ecaart15

Conference Program & Abstracts

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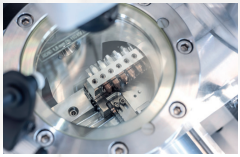
ionplus

Scientific Instruments for Radiocarbon Dating
and Accelerator Mass Spectrometry



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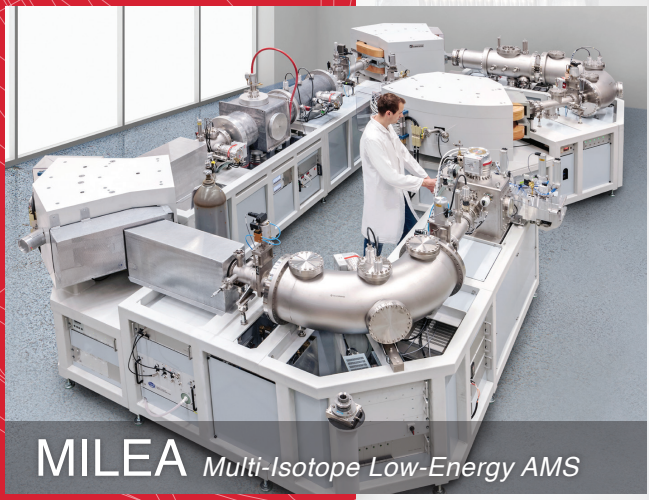

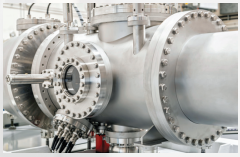

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A Word of Welcome

It is our pleasure to welcome you to the **15th European Conference on Accelerators in Applied Research and Technology (ECAART 15),** which is being held in Zurich again, 30 years after ECAART 4. The conference is organized by the Laboratory of Ion Beam Physics and takes place at the campus Hönggerberg of the Swiss Federal Institute of Technology (ETHZ). The campus offers an excellent environment for scientific exchange only 20 min away from Zurich city center.

The organizers are happy to welcome all participants on Sunday 7th September starting at 16:00 for the ice breaker in the **Laboratory of Ion Beam Physics**, where food and drinks are served to create a pleasant atmosphere to start scientific discussion and the possibility to visit the LIP instrumentation.

A variety of social activities are offered as part of the official conference program. We believe that such events will foster personal contacts, exchange of ideas among the participants, and will help to integrate younger scientists into the international accelerator community. One of these visits is to Ionplus AG where participants will have the opportunity to see first-hand the production of state-of-the-art AMS instruments.

A half-day trip with the opportunity to explore the picturesque village Einsiedeln, where guided tours will give an insight to the famous baroque church and the historic library of Einsiedeln Abbey. Afterwards, we will enjoy dinner on the Au Peninsula, taking in the charming lakeside scenery of Lake Zurich.

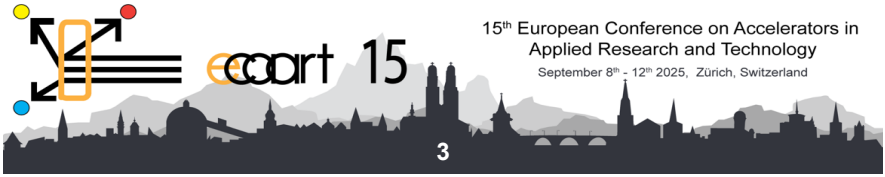
In the supporting program after the official end of the conference, there is the chance to visit the Paul Scherrer Institute (PSI) and see for example the recently upgraded Swiss Light Source (SLS 2.0), the worldwide unique continuous spallation neutron source SINQ or the experimental infrastructure of the PSI magnet section.

The conference organization team is excited to welcome you all to Zurich. We hope you'll enjoy your stay and engage in valuable scientific discussions, and more importantly, experience a bit the unique spirit of Zurich and Switzerland.

Yours Sincerely,

Arnold Müller *Marcus Christl* *Christof Vockenhuber*

Zürich, Switzerland.



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Switzerland

Christof Vockenhuber
ETH Zurich
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Marcus Christl
ETH Zurich
Switzerland

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General Information and Logistics

Conference Badges

Conferences badges include important information for the conference and should be worn when attending the conference.

Conference Office

The conference office is open during the conference week from 8:00 till 12:00 in room **HPH entrance**. Registration is also possible on Sunday 16:00 till 19:00 at the Welcome Reception at the Laboratory of Ion Beam Physics.

Coffee Breaks

Coffee, tea and drinks are offered together with snacks in the coffee breaks between the sessions in the **HPH entrance hall**.

Lunches

Tickets for **lunches** (Monday-Thursday) are included in the registration and are valid in the **ETH Foodmarket (HPR)**.

Public Transportation

The participants receive a **ZVV ticket** printed on the conference badge valid in fare zone 110 (city of Zurich) from Sunday September 7th to Friday September 12th. Please note, transport to the airport requires a ticket for an additional zone (Anschlussbillet 1-2 Zonen).

WiFi

Wi-Fi is available within ETH buildings by the following SSIDs:

eduroam-5 / eduroam – for members of universities from around the world.

public / public-5 – ETH guests can register on the landing page ETH Zurich with their mobile-number; the access code will be sent in a text message.

Industry Exhibition

Please visit the exhibition booths of our sponsors which are located on the **HPH entrance hall** near the poster and catering area from Monday to Friday.

Emergency

In case of an emergency within the ETH buildings please contact the **conference office** directly or **call 888** from internal connections or **+41 44 342 11 88**.
Outside the ETH buildings you can call the **European emergency number 112**.

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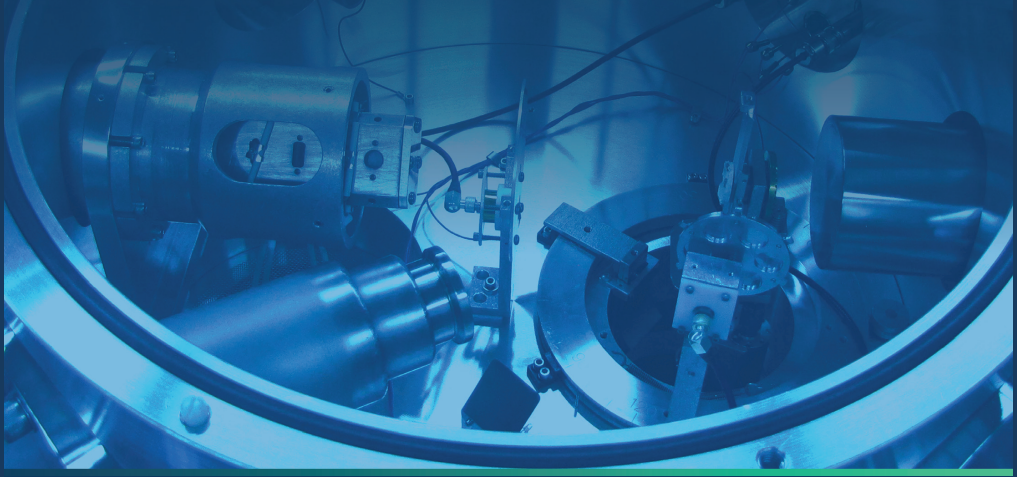

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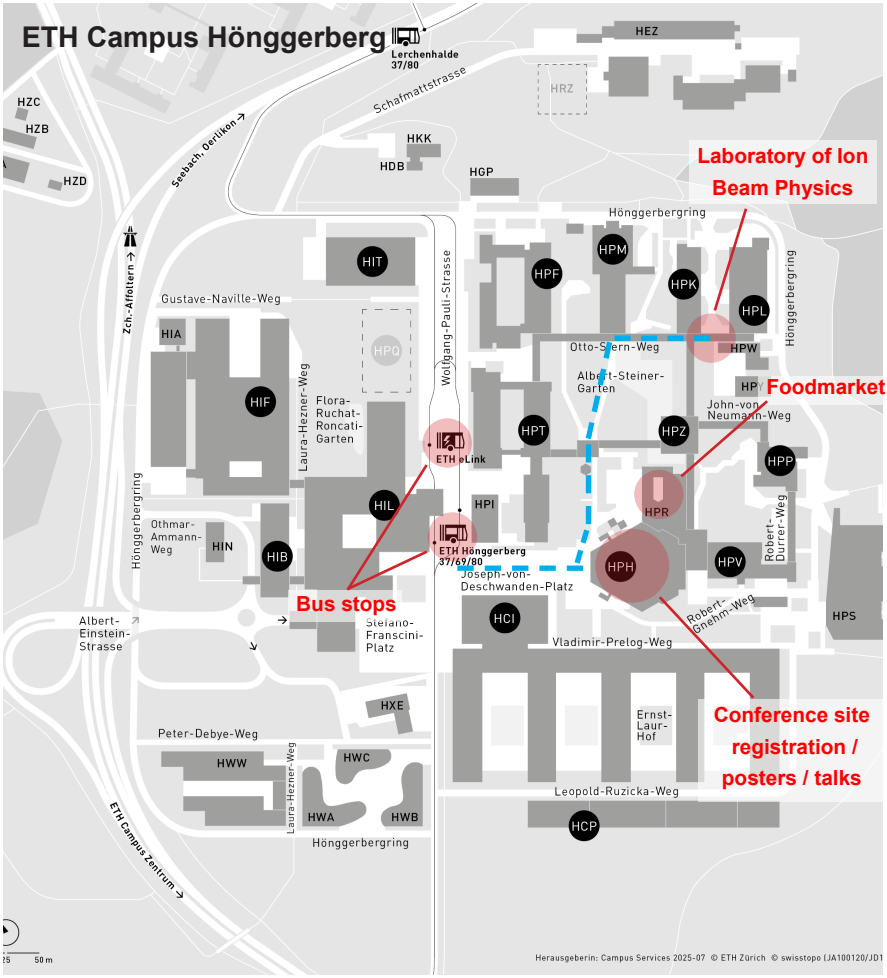
Conference Venue - ETH Hönggerberg



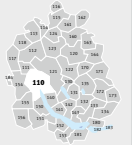
Registration and the Welcome Reception at the **Laboratory of Ion Beam Physics**.
Monday - Friday, registration is possible from 8:00 to 12:00 in the **HPH entrance**.
The **talks** will held **lecture room G2** in the HPH building, upper floor.
The **posters** will be presented in the **HPH entrance hall**.

ZVV Stadt Zürich | Zurich City

ZVV CONTACT
0800 988 988
www.zvv.ch

Conference site
ETH Hönggerberg

Tarifzone 110
Fare zone 110



Public Transportation / Site Visits

How to get to ETH Campus Hönggerberg (conference site):

- From Zurich main station:
  - by **tram 11** to «Bucheggplatz» – change – **bus 69** to «ETH Hönggerberg»
  - by **tram 14 or 7** to «Milchbuck» – change – **bus 69** to «ETH Hönggerberg»
- from train station «Oerlikon-Nord» by **bus 80** to «ETH Hönggerberg»
- from train station «Altstetten» by **bus 80** to «ETH Hönggerberg»
- from train station «Zürich Affoltern» by **bus 37** to «ETH Hönggerberg»

Conference trip to Einsiedeln and Dinner at Halbinsel Au (included):

Busses will be available for the afternoon trip to Einsiedeln (**Thursday September 11th**) and the confernce dinner at Halbinsel Au.

How to get to Ionplus AG (optional):

A visit to the Ionplus production site will take place on **Tuesday afternoon** (**September 9th**), and will give participants an opportunity to learn more about their instrumentation. Busses will pick up registered participants in groups after the afternoon session on September 9th at roughly **16:00** and provide direct transportation to Ionplus AG. A shuttle service will take you back to Zurich's city center after the event. In case of earlier return public transport (S8 to Zurich HB) is possible.

How to get to Paul Scherrer Institute (optional):

Visit to Paul Scherrer Institute (PSI), central location for Switzerland's large research facilities will take place on **Friday** (**September 12th**), following the conclusion of the official program. PSI has the world's most powerful muon source, a unique proton and neutron source, a synchrotron and one of only five X-ray free-electron lasers with hard X-rays. Bus services to PSI and back will be provided. A lunch package will be available.

Check the ZVV timetable here:

Upload of the Oral Presentations

Please upload the talks to server directly (see below) or bring a USB-stick to the conference office for upload at least half a day in advance.

In order to assign your presentations to the correct session please rename your presentation as Microsoft Powerpoint or PDF files as follows:

'program presentation code'_'name of the presenter'

Example: IBA1-ID-1_Mustermann

The presentation code can be found of the upperleft corner of the abstract page.

The presentations can be **uploaded** here:

https://ecaart15.ethz.ch/upload

Proceedings Instructions

Authors of accepted contributions will be invited to submit their research manuscripts to the **conference proceedings**, which will be published in a special issue of **Nuclear Instruments and Methods in Physics Research Section B**.

Manuscript submissions will be opened on **September 7, 2025**, with a planned submission deadline on **February 1, 2026**.

Instructions for the proceedings will be availabe here:

https://ecaart15.ethz.ch/conference-proceedings/

Social programme, Thursday, September 11th

Trip to Einsiedeln Abbey

A half-day trip will be organised, giving the participants an opportunity to explore **Einsiedeln Abbey**, one of Switzerland's most significant religious and historical landmarks. Located approximately 30 km southeast of Zurich in the picturesque village of Einsiedeln, this Benedictine monastery has been a centre of pilgrimage and monastic life for over a thousand years.The **guided tour** will include visits to the abbey church and the historic library, which houses a vast collection of rare manuscripts.
Optionnally, a visit to the **Rosengarten Brewery** will be offered. In this family-owned brewery, located in the heart of Einsiedeln, guests will have the opportunity to sample a selection of locally crafted beers and get a taste of Swiss brewing heritage.

Conference Dinner

After the trip to Einsiedeln we are delighted to invite you to the conference dinner at **Landgasthof Halbinsel Au**, a historic country inn established in 1865, nestled on the hilltop of the scenic Au Peninsula along the western shore of Lake Zurich. This charming venue offers a unique setting with panoramic views of the lake and the Alps.

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- Archeology
- Oceanography
- Geosciences
- Material sciences
- Biomedicine
- Etc.

Ion Microbeam Systems

- Tandetron and Singletron based Systems

Neutron Generator Systems

- Air-insulated, Tandetron and Singletron based DC and Pulsed-beam Systems

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Programm Overview

	Monday 08.09.2025	Tuesday 09.09.2025	Wednesday 10.09.2025	Thursday 11.09.2025	Friday 12.09.2025	
09:00	ETH Welcome Günther Dissertori	IBA1: Lars Jeurgens – ID 59	AMS1: Nikolas Brehm - ID 104	ALS: Alessandra Gianoncelli - ID 55	ACH: Anita Quiles - ID 11	09:00
09:30	ATD 1: Romain Ganter – ID 25	Mathew Sharpe – ID 54	Johannes Lachner - ID49	Mikko Laitinen – ID 22	D. Jembrih-Simborger – ID 67	09:30
10:00	Serge Mathodt – ID 15	Iva Bogdanović Radović – ID 29	Martin Martschini - ID35	Ren Minquin – ID 26	Lucile Beck - ID 69	10:00
10:30	Break	Michael Kokkoris – ID 12	Carlos Vivo-Vilches - ID 40	Marco Michel – ID 31	A. Gillon - ID 90	10:30
11:00	ATD2: Stephané Sanfilippo – ID 14	Break	Break	Adrien Sari – ID 95	Break	11:00
11:30	Ion Burdecea – ID 86	DNT: Victoria Vojtech – ID 46	AMS 2: Stephanie Adler – ID 106		AQNT: Shengqiang Zhou - ID 20	11:30
12:00	Rong Xiang – ID 89	Ziga Brencic – ID 45	Miriam Mindova – ID 10		Emilio Corte – ID 42	12:00
12:30	Edoardo Renaldin – ID 27	Corline Czelusniak – ID 74	Alexander Redl – ID 41		Nitipon Puttaraksa – ID 72	12:30
14:00	Lunch	Stuart Warren – ID 7	IBA2: Tieshan Wang - ID 92		Closing	14:00
14:30	IBMM: Susie Speller - ID13	Lunch	Guesmia Abdelkader – ID 75	Excursion and Dinner	Visit PSI	14:30
15:00	E. Punzón-Quijorna – ID 96	ANPP: Anton Wallner – ID 112	Lunch			15:00
15:30	Gihan Velisa – ID 58	Eric Strub – ID 38	IBA3: Stiepko Fazinic - ID 32			15:30
16:00	Zoran Jovanocovic – ID 47	Sihem Foul – ID 83	Frans Munnik - ID 68			16:00
18:00	Ruslan Rymzhanov – ID 9	Evangelia Taimpiri – ID 66	Anastasia Ziagkova - ID 82			18:00
	Poster Session A	Ionplus Visit	Carmen Torres Munoz – ID 57			
			Antonius Armonius – ID 51			
			Poster Session B			

ATD	Accelerator technology and development
DNT	Development of novel technologies
SFAT	Simulation and fundamentals related to accel. tech.
IBMM	Ion beam modification of materials
IBA	Ion beam analysis and applications
AMS	Accelerator Mass Spectrometry
ANPP	Application to nuclear and particle physics
AQNT	Applications to quantum and nano technology
ALS	Application to life science
ACH	Applications to Cultural Heritage

SLS 2.0 Storage ring upgrade overview

Romain Ganter, Masamitsu Aiba, Alun Ashton, Felix Armborst, Michael Boege, Hans-Heinrich Braun, Alessandro Citterio, Ciro Calzolaio, Micha Dehler, Haimo Jöhri, Markus Joerg, Boris Keil, Natalia Kirchgeorg, Giuseppe Montenero, Cigdem Ozkan Loch, Martin Paraliev, Marco Pedrozzi, Joerg Raabe, Beat Ronner, Stephane Sanfilippo, Volker Schlott, David Stephan, Lukas Stingelin, Johan Wickström, Philip Willmott, Maximilian Wurm

Paul Scherrer Institut, 111 Forschungsstrasse, Villigen, 5232 Switzerland.

romain.ganter@psi.ch

The Swiss Light Source (SLS) storage ring has been re-built as SLS 2.0, improving radiation brightness by approximately two orders of magnitude and increasing the photon energy range by about 50%. All components of the storage ring lattice and its supporting infrastructure were newly constructed and installed during a 15-month shutdown that began in October 2023. The linac and booster synchrotron received only minor modifications, with the exception of a new power supply for the main magnet circuit.

The new seven-bend achromat arcs had to fit within the existing tunnel footprint and maintain alignment with the beamline exit ports, resulting in very small distances between magnets. Additionally, all bending (and reverse bending) magnets are based on permanent magnets, necessitating thorough cross-talk studies due to significant stray magnetic field effects. The high magnet density prevented the installation of vacuum bellows required for in-situ bake-out. Consequently, the twelve vacuum arc strings, each 17 meters long, were installed in the ring after activation and pumping to a pressure of approximately 1×10^{-11} mbar. Four HOM-damped RF cavities operating at 500 MHz are installed in a row and powered by four 150 kW solid-state amplifiers. Two beamlines are dedicated to beam diagnostics, and newly developed BPM and feedback systems continuously monitor and stabilize the beam.

This presentation outlines the key components of the new storage ring, details their installation, and provides an overview of the performance achieved to date.

[1] H.-H. Braun et al., "SLS 2.0 storage ring. Technical design report.," Paul Scherrer Institut, 2021. [Online]. Available: https://www.dora.lib4ri.ch/psi/islandora/object/psi:39635

The authors would like to thank all PSI colleagues who contributed to the realization of SLS 2.0.

storage ring a successful project

Figure 1. *Snapshot of arc 09 area between October 2023 and August 2024*

The CERN ELISA project

S. Mathot, S. Atieh, F. Di Lorenzo, J. Dumerger, B. Fernandez, J. Fernandez, P. Geeraert, F. Killing, J.B Lallement, A. Lombardi, I. Neuhold, E. Pasino, M. Widorski

CERN–European Organization for Nuclear Research, CH-1211 Geneva 23, Switzerland

serge.mathot@cern.ch

This paper presents ELISA (Experimental LInac for Surface Analysis), the first proton accelerator at CERN designed for both education and precision surface analysis freely accessible in a public exhibition. ELISA uses the same RFQ (Radio Frequency Quadrupole) accelerating cavity as the MACHINA (Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis) project, a joint development by CERN and INFN and presented at ECAART13.

The proton beam energy remains at 2 MeV, but the average current has increased to 40 nA. This enables visitors to the Science Gateway exhibition at CERN to witness an extracted proton beam in low-light condition just a few centimetres from their eyes. The setup has been carefully designed and shielded to ensure it is entirely safe for the public.

Demonstrations are organised to show the public different physical phenomena, such as light production in gases and beam deflection with dipoles or quadrupoles. The PIXE analysis method is also demonstrated.

ELISA is also a research-grade accelerator used periodically for precision surface analysis within the framework of scientific collaborations. The first measurements concern the cultural heritage field, but the system is adaptable for broader applications in material science and applied physics.

In this paper, we describe the accelerator in detail, as well as our first ion beam analysis performed in public.

Accelerator Magnet Technologies at the Paul Scherrer Institute: Recent Development and Perspectives

Stephane Sanfilippo, Bernhard Auchmann, André Brem, Ciro Calzolaio, Douglas Martins, Giuseppe Montenero, Jaap Kosse and Rebecca Riccioli

Center for Accelerator Science and Engineering, Paul Scherrer Institute
Forschungsstrasse 111 5232 Villigen PSI Switzerland

Stephane.sanfilippo@psi.ch

In recent years, the Paul Scherrer Institute (PSI) has significantly advanced its capabilities in the design, fabrication, and qualification of state-of-the-art magnet technologies for particle accelerators. These developments are rooted in major initiatives such as the Swiss Light Source upgrade (SLS 2.0) and the Swiss Accelerator Research and Technology (CHART) program, which have fostered core competencies in magnet design, dedicated infrastructure, and high-precision magnetic qualification. A flagship achievement is SLS 2.0, which integrates a unique mix of technologies: NdFeB-based permanent magnets, compact combined-function electromagnets, and in a second phase two NbTi superconducting dipoles with longitudinal field gradients. All magnets are fully designed and magnetically qualified in-house to meet demanding field quality and alignment criteria. Beyond light sources, PSI develops radiation-resistant electromagnets for high-intensity beam applications, such as the IMPACT project at the High-Intensity Proton Accelerator (HIPA). Within the CHART initiative, PSI advances R&D for the Future Circular Collider (FCC). In the PSI Positron Production experiment for FCC-ee, a 15-T wide-bore REBCO solenoid is under development. PSI is also designing a highly efficient nested sextupole/quadrupole/dipole magnet using REBCO technology, aiming to cut FCC-ee power consumption by 20–30%. For FCC-hh, PSI follows an extensive roadmap for material development and magnet design. A Nb_3Sn canted-cosine-theta dipole has achieved 10 T, a subscale common coil magnet reached 5.2 T, and an insert coil attained 12.3 T. A high-field common coil magnet, targeting 12–14 T, is scheduled for testing in early 2026. In parallel, PSI is developing REBCO technology for high-field accelerator magnets, with ongoing AC-loss characterization. A subscale common coil REBCO magnet will be tested later this year. This presentation provides an overview of PSI's recent progress in magnet R&D and outlines upcoming directions, including the SMILE initiative (Superconducting Magnets to Improve Large research facility Efficiency), which targets energy savings and sustainable accelerator infrastructure. These efforts support both PSI's internal programs and external collaborations, including partnerships with ETH Zurich and other leading research institutions.

The CHART research activities are conducted under the auspices of the Swiss Accelerator Research and Technology (CHART) Collaboration (www.chart.ch), in close collaboration with CERN's FCC Design Study and High Field Magnet (HFM) Program.

A novel radiation hardness testing facility at the 3 MV Tandetron from IFIN-HH- Status report

I. Burducea[1], *M. Petruneac*[1], *M. Focșăneanu*[1], *R.F. Andrei*[1], *A.T. Hotnog*[1], *M. Lechințan*[1], *D.A. Iancu*[1], *D.G. Ghiță*[1], *G. Velișa*[1], *M. Straticiuc*[1], *A. Totu*[2], *C. Gogu*[2], *M.I. Lazăr*[2]

[1]Applied Nuclear Physics Department, Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering IFIN-HH, 30 Reactorului Street, Măgurele, Romania.

[2]MAZAROM IMPEX SRL, 20-22 Mușetești Street, Bucharest, Romania

bion@nipne.ro

An experimental platform for radiation hardness testing of electronic devices is currently being integrated at the 3 MV Tandetron™ multipurpose facility of IFIN-HH. Following successful installation, the system will be commissioned by real-time monitoring of CARD-SAT nano-satellite components exposed to different extreme conditions (i.e., high dose and flux). It is well known that solar radiation can have a deleterious impact on electronic devices, especially during episodes of high solar activity. The platform employs proton ion beams with controlled energies to simulate space radiation. FLUKA simulations were performed to model proton interactions in silicon, providing key physical parameters for correlation with experimental data. The input proton energy has been varied between 3 and 6 MeV to assess penetration depth and irradiation volume. Fluence distributions were obtained while total ionizing dose (TID) and displacement per atom (dpa) quantify cumulative damage effects. Linear energy transfer (LET) profiles and energy deposition per interaction offer key input for assessing devices sensitivity to single event effects (SEEs). The platform could contribute to the development of radiation-hardened technologies while supporting innovation in space electronics.

[1] I. Burducea, M. Straticiuc, D. G. Ghiță,…, et al.; *A new ion beam facility based on a 3 MV Tandetron™ at IFIN-HH, Romania*; Nuclear Instruments and Methods in Physics Research B 359 (2015) 12–19
[2] G. Hugo, C. Ahdida, D. Bozzato,…, et al.; *Latest FLUKA developments*; EPJ Nuclear Sciences & Technologies 10 (2024). https://fluka.cern

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CCCDI-UEFISCDI, project number PN-IV-P7-7.1-PED-2024-2029, 53PED, within PNCDI IV. The National Research Program “Nucleu”, Project code PN 23210201/2023 is also acknowledged.

CW e- beam from SC RF gun for Multifunctional Accelerator Facility ELBE

Rong Xiang, Andre Arnold, Andreas Wagner and ELBE team

Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany.

r.xiang@hzdr.de

The ELBE user facility [1] is a compact, accelerator-based research center that produces a wide range of radiation types—including gamma rays [2], IR- Free-Electron Lasers (FELs) [3], THz radiation [4], neutrons [5], positrons [6] and electron beams [7]—for applications in materials science, medicine, and nuclear physics. Its FELs provide tunable, high-repetition-rate radiation ideal for time-resolved and nonlinear spectroscopy. ELBE supports advanced experiments like pump-probe spectroscopy and delivers precisely timed electron and Bremsstrahlung beams for detector testing, biological research and nuclear physics. The TELBE facility offers intense THz pulses for ultrafast studies of matter under strong electromagnetic fields.

ELBE SRF gun represents a new step in the improving ELBE performance. By merging the well-established NCRF technology and superconductivity, the dissipated RF power is reduced by several orders of magnitude and the CW operation for high average currents can be realized. Starting from 2019, SRF gun II is routinely used for TELBE users with high bunch charge (200 pC @ 100 kHz) and high stability [8].

[1] https://www.hzdr.de/db/Cms?pNid=145&pOid=10242
[2] R. Schwengner, et al., Photoexcitation of 59Co, Physical Review C 111(2025), 014312-1-014312-12. DOI: 10.1103/PhysRevC.111.014312
[3] M. Helm, et al., The ELBE infrared and THz facility at Helmholtz-Zentrum Dresden Rossendorf, European Physical Journal Plus 138(2023), 158. DOI: 10.1140/epjp/s13360-023-03720-z
[4] J.-C. Deinert, et al., Grating-graphene metamaterial as a platform for terahertz nonlinear photonics, ACS Nano 15(2021), 1145-1154, DOI: 10.1021/acsnano.0c08106
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This research was supported by the German Federal Ministry of Education and Research (BMBF). We would like to gratefully acknowledge the whole team of the ELBE facility.

Performance investigation of a thermocouple-based beam position monitor for PSI's IP2 beamline for radionuclide production

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At the Paul Scherrer Institute (PSI), medically relevant radionuclides are produced using the 72 MeV proton beam accelerated by the Injector II cyclotron to the IP2 irradiation station [1]. The IP2 beam line lacks beam diagnostics near the target station. The last beam position monitors are located approximately 1 meter upstream from the vacuum window. To address this issue, a thermocouple-based beam position monitor ring was developed for installation directly in front of the vacuum window, inspired by a similar system used at the SINQ spallation source [2].

This study focuses on testing the performance of this new diagnostic ring to ensure accurate beam position feedback for improved radionuclide production efficiency and safety. The diagnostic ring consists of four pairs of thermocouples (TCs), arranged along perpendicular axes. Preliminary simulations were performed to optimize TC placement. Several test irradiations with dummy targets were conducted to investigate operation conditions. Beam sweeps were performed to evaluate TCs' sensitivity to beam shifts. Autoradiography of target lids provided surface activity distributions, reflecting transverse beam distribution. A new beam window and target chamber design enabled irradiation at higher energies compared to the previous design. Titanium foils were also irradiated to validate beam currents on target ranging between 2 µA and 27 µA at a maximum beam energy of 66.7 MeV. Activities of ^{46}Sc ($t_{1/2}$=83.8 d) and ^{48}V ($t_{1/2}$=16.0 d), produced from irradiating said foil, were measured via gamma-ray spectrometry, which enabled a comparison against monitor cross sections.

Preliminary irradiations demonstrated optimum TC position to ensure safe operation, even during beam loss events. Beam sweeps revealed asymmetries in beam shape, with higher temperatures and steeper gradients horizontally. These findings were supported by autoradiography results. Additionally, results obtained from Ti foil irradiations highlight the need for more accurate experimental assessment of beam current and energy, which will be pursued using a stacked foil technique combined with monitor reaction cross sections.

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Radiation damage of high temperature superconductors

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High temperature superconductors (HTS) in the form of coated conductors are an enabling technology for the next generation of compact nuclear fusion reactors and accelerators that require higher magnetic fields than Nb_3Sn can provide. However, in operation, the superconducting magnet windings will be exposed to a flux of particles which will introduce structural damage at cryogenic temperatures. Many previous studies using both fission spectrum neutrons and ions at room temperature (or slightly elevated temperatures) have shown that an initial increase in the superconducting current carrying performance upon irradiation is followed at higher fluences by a severe degradation of the properties and eventually complete loss of superconductivity. The superconducting transition temperature is found to decrease monotonically with fluence, strongly suggesting that radiation-induced defects occur throughout the entire crystal lattice, even at relatively low fluence. This talk will outline the research being carried out to improve understanding of radiation damage in HTS materials. This includes innovative in situ ion irradiation experiments to assess radiation damage of HTS at cryogenic temperatures, superconducting property measurements at ultra-high magnetic fields, and studies aimed at elucidating the nature of irradiation induced lattice defects using state-of-the-art microscopy and spectroscopy techniques.

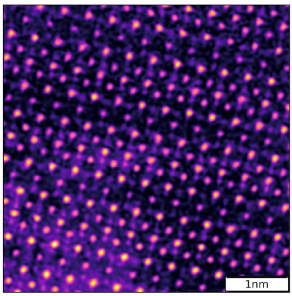

Figure 1. *Electron ptychography reconstruction of He^+ irradiated REBCO coated conductor*

Characterization of Radiation-Induced Defects and Deuterium Trapping in Tungsten using Ion Beam Channeling Techniques

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Tungsten (W) is a prime candidate for plasma-facing components in fusion reactors due to its excellent thermal and mechanical properties and low hydrogen retention. However, exposure to 14 MeV neutrons from the D-T fusion reaction induces significant lattice damage, which affects key physical properties such as thermal conductivity and hydrogen isotope retention. To investigate irradiation-induced damage and deuterium (D) trapping, W(111) and W(100) single crystals were irradiated with 10.8 MeV W ions at doses of 0.02 and 0.2 dpa and temperatures of 300 K and 800 K to introduce single vacancies, vacancy clusters, and dislocation structures [1]. Rutherford Backscattering Spectrometry in channeling configuration (RBS-C) and Nuclear Reaction Analysis in channeling mode (NRA-C), using the $D(^3He,p)^4He$ reaction, were employed to quantify the lattice disorder and determine the location of trapped D. Multi-energy RBS-C along <111> revealed yield variations corresponding to different defect types and irradiation conditions. These findings were supported by Transmission Electron Microscopy (TEM) observations, used to identify dislocation lines and loops, and by Positron Annihilation Spectroscopy (PAS), which revealed open-volume defects. Molecular Dynamics (MD) simulations of overlapping cascades were used as input for the RBSADEC code to model RBS-C spectra [3]. Good agreement was found for low-dose samples, while discrepancies at higher doses were attributed to limitations in MD cell size for capturing extended defects. New simulations using improved potentials and larger cells showed better agreement. In W(100) crystals exposed to low-energy D plasma, simultaneous RBS-C and NRA-C with a 0.8 MeV ^3He beam revealed preferential D trapping along <100> axial and (110) planar channels [4]. These findings were interpreted using the upgraded RBSADEC code, now supporting NRA-C simulations.

This study confirms RBS-C and NRA-C as valuable tools for characterization of irradiation-induced defects and hydrogen isotope behaviour in W, providing experimental validation for defect models and contributing to material development for ITER and DEMO.

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Athermal recovery of defects in Ge using ionization irradiation: Myth or Reality?

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Ionization-induced athermal annealing of pre-existing defects in semiconductors, which can promote complete restoration of structural order in semiconductors, may be a valuable alternative to thermally activated annealing that has difficulties to overcome the drawback of dopant diffusion. Through the fusion of experimental and theoretical results, this study demonstrates that the energy transfer of only 2.4 keV nm-1 from ions to electrons can annihilate quite effectively the pre-existing defects and restore the pristine Ge crystal structure at room-temperature. This study further demonstrates that the irradiation-induced crystalline-to-amorphous (c/a) transformation in Ge is reversible, although previously considered unattainable without additional thermal energy imposed during irradiation. For partially damaged (defective) Ge, the overall damage fraction decreases with increasing fluence and approaches zero. In contrast for the pre-amorphized sample, the annealing process starts with defect recovery outside the amorphous layer and shrinkage of the amorphous thickness; after which, the remaining Gaussian damage profile decreases slowly with fluence without fully recovering to the pristine state. These effects are discussed in the framework of the differences in the structure of the initial defective layers that affect the annealing kinetics. This study suggests a pathway for low-temperature crystallization of pre-amorphized Ge using ion irradiation, having broad implications across condensed matter physics and materials science, as well as for Ge-based-device fabrication.

Swift heavy ion irradiated thin films of bismuth vanadate for oxygen evolution reaction: Impact of defect engineering and opening of ion tracks

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Swift heavy ion (SHI) irradiation using 150 MeV Xe ions (fluence: 5×10^9–5×10^{11} ions cm^{-2}) was employed for defect engineering in hydrothermally synthesized $BiVO_4$ (BVO) thin films in order to investigate their impact on photoelectrochemical (PEC) performance toward the oxygen evolution reaction (OER). SHI treatment induces residual stress and amorphization, along with the formation of bismuth-rich hillocks above oxygen-deficient ion tracks. At high fluence (5×10^{11} ions cm^{-2}), excessive defect accumulation and ion track overlap result in irreversible degradation of PEC activity. In contrast, lower fluences (5×10^9 and 1×10^{10} ions cm^{-2}) generate a moderate defect density that initially traps charge carriers but show photocurrent density improvements of 58.6% and 25.2% with time, respectively. Post-PEC analysis reveals that latent ion tracks are transformed into nanoscale holes up to 30 nm in diameter and 200 nm in depth. The sample irradiated at 1×10^{10} ions cm^{-2} exhibits particularly well-defined holes, indicating an optimal balance between defect formation and mechanical stress. A comprehensive set of structural, electronic, and morphological analyses was employed to correlate defect evolution with PEC behaviour. The obtained results demonstrate the potential of SHI irradiation as a precise tool for nanoscale morpho-structural engineering. The controlled formation of nanoscale holes enables the integration of cocatalysts or plasmonic structures, offering a promising route to enhance PEC efficiency and broaden the material's applicability in energy-related technologies.

Acknowledgment: This research was supported by the Science Fund of the Republic of Serbia, grant No. 6706, "Low-dimensional nanomaterials for energy storage and sensing applications: Innovation through synergy of action"- ASPIRE.

Exploring structural alterations in dielectrics exposed to high-energy heavy ion beams

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Accelerated heavy ions, when passing through matter, lose most of their energy through ionization of the medium. The extremely high level of excitation of the electronic subsystem generated during this process is accompanied by relaxation of the electronic ensemble and the transfer of part of the energy to the target lattice, leading to the formation of a damaged area – the ion track. Such unique characteristics of high-energy heavy ions allow their use in three main areas: simulating the effects of fission fragments on structural materials in nuclear energy, studying the radiation resistance of electronic components to cosmic ray radiation, as well as nanoscale modification of material properties and nanostructuring.

The report demonstrates the most relevant research results on the morphology of radiation damage in materials for nuclear energy and electronics applications, depending on the irradiation conditions: ion mass and energy, radiation dose, temperature, etc. Structural response of functional materials to swift heavy ion irradiation was studied using transmission electron microscopy complemented with numerical methods combining the Monte Carlo code TREKIS [1] and molecular dynamics simulations [2,3]. We discuss here the different stages of the kinetics and the mechanisms of individual track formation, tracks overlap and surface modifications in some amorphizable and non-amorphizable solids irradiated with SHIs.

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The work was funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP23484126).

Chemical Interaction of Hydrogen with Functional Oxides by Combining Ion-Beam Analytical and Spectroscopic Techniques

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The interaction of H with functional oxides are known to affect their mechanical, chemical, and electronic properties, for example, in oxide electronics, oxide membranes for H-purification and water splitting, and barrier oxide films for corrosion protection. The ongoing energy transition of our society towards a H-based economy requires improved understanding of the interaction of H with such functional oxides. However, experimental quantification of impurity concentrations and chemical bonding states of H in oxide films remains very challenging, especially for an amorphous state of the oxide and for film thicknesses in the nanometre range. Generally, only ion beam techniques, such as elastic recoil detection analysis (ERDA), offer the required mass and depth resolution to quantify H impurity concentrations in very thin, amorphous oxide films. Proton concentrations in oxides can also be derived indirectly by e.g. conductivity measurements and/or H-induced chemical shifts, vibrational states and/or defect levels measured by XPS or Raman. This talk will present an overview of recent and ongoing studies of Empa and LIP on the interaction of H with functional oxide films by combining ion-beam analytical and spectroscopic techniques, in particular, ERDA, LIP, and XPS/HAXPES [1-3]. The quantification of H impurity concentrations, densities and H-induced chemical bond states in amorphous Al_2O_3 barrier oxide films grown by anodic polarization [1] and atomic layer deposition (ALD) [2,3] will be discussed. Furthermore, ongoing studies on the interaction of H with passive oxide films on steel upon in-situ H-charging by combining XPS/HAXPES and ERDA/RBS will be highlighted.

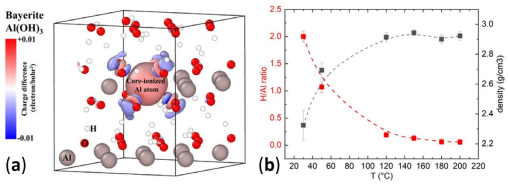

Figure 1. (**a**) Visualization of electronic screening of core-ionized Al atoms by OH ligands as probed by HAXPES. (**b**) Experimentally determined relationships between H content and oxide density in amorphous Al_2O_3 barrier films grown by ALD at various temperatures.

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Time-of-Flight Elastic Recoil Detection Analysis for Simulated Radiation Induced Effects on Li containing Nuclear Waste Glasses

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Borosilicate glasses, such as Calcium Zinc (CaZn) [1] and Mixed Windscale (MW) [2] are of interest for nuclear waste glass due to low processing temperatures and durability, with the capability to incorporate a wide range of radionuclides. With a high capacity of waste loading into the glass structure, the glasses can retain radionuclides for thousands of years. The radiation produced by the nuclear waste does affect the glass structure causing defects, which may impact its suitability.

To mimic the effect of the nuclear waste, the various glass samples were irradiated with 8 MeV Au^{3+} for a total fluence of 1×10^{16} cm^{-2}. The Au simulates the effect of damage on the glasses caused by the alpha decay process where an actinide, for example ^{239}Pu, converts to ^{235}U by releasing an α particle and acting as an energetic recoil causing displacements and damage within the glass. Various CaZn and MW glasses with a differing amount of Li present were studied to determine which were most stable to damage caused by the Au irradiation.

To analyse the displacements and measure the compositions with respect to depth, time-of-flight elastic recoil detection analysis (ToF-ERDA) was used [3, 4]. For the ToF-ERDA measurements 16 MeV $^{127}I^{8+}$ ions were used to enable detection and quantitation of the various elements present within the glasses. ToF-ERDA compositional depth profiles were compared for the pristine and Au irradiated regions in the glasses. With the lighter elements present within the glasses, especially Li and B showing the larger degree of radiation induced diffusion, with MW glasses showing greater displacement compared to the CaZn glasses. As shown in Figure 1, the comparison for the Li depth profiles before and after irradiation will be discussed.

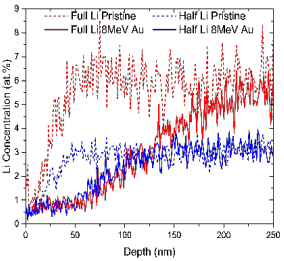

***Figure 2**: Li depth profile comparisons for MW glass*

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Damage Cross Section Measurements of Organic Materials Using MeV SIMS

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Secondary Ion Mass Spectrometry with MeV energy ion beams (MeV SIMS) is a well-established technique for the characterization of organic materials. It has been routinely employed for over a decade at the Laboratory for Ion Beam Interaction. MeV SIMS enables molecular identification of organic compounds up to approximately 1000 Da and, when combined with a focused ion beam, allows for two-dimensional mapping of molecular distributions with lateral resolution down to a few hundred nanometers.

In addition to molecular information, the elemental composition of organic samples is often of great interest. Since MeV SIMS alone cannot provide elemental data, it is typically complemented by other Ion Beam Analysis techniques—most notably, Particle Induced X-ray Emission (PIXE)—through sequential measurements. This integrated approach offers a more comprehensive characterization of organic materials.

However, combining these techniques presents a challenge due to the significant difference in their ion beam requirements: while MeV SIMS operates at much lower beam currents and fluences, PIXE requires ion fluences that are approximately six orders of magnitude higher. Despite the widespread use of sequential measurements, relatively little is known about how high-current ion irradiation may affect the integrity of organic samples prior to MeV SIMS analysis.

In this work, we investigate the effect of ion fluence on molecular yield by measuring the secondary ion signal as a function of incident heavy ion fluence. The goal is to determine the damage cross sections and identify the static limit—i.e., the maximum fluence at which the sample remains analytically unchanged.

Damage cross-section measurements were conducted on leucine, cholesterol, phthalocyanine, and a real paint sample using two ion species commonly employed in MeV SIMS: 5 MeV Si^{4+} and 9 MeV O^{4+}. Targets were prepared by depositing a few hundred nanometers of material on either a thin Si_3N_4 membrane with a 10 nm Ag coating or a thick Si wafer; the paint sample was cast on the Si wafer. Initial MeV SIMS measurements were performed in pulsed mode over an area of approximately 400 × 400 μm² to assess the secondary ion yield from a pristine surface. The scan area was then doubled, and the sample was irradiated in high-current mode at fluences of 10^8–10^9 ions/cm² for a short duration. Beam currents were monitored before and after each irradiation using a PIN diode positioned in front of the scattering chamber. This process was repeated up to ten times to track changes in the yield of intact molecular and fragment ions as a function of ion fluence.

Damage cross sections were determined for all samples and ion species investigated, and the implications of these results are discussed.

Determination of fundamental channeling parameters in single-crystal diamond wafers using deuterons and α-particles in the backscattering geometry

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Diamond is an allotropic form of carbon, renowned for its exceptional hardness, highest atomic density among solids, and outstanding heat conductivity, despite being an insulator. Artificial diamonds are extensively utilized in the development of advanced radiation detectors and the RBS/C approach has already been extensively utilized to investigate the diamond amorphization caused by ion implantation. Thus, a thorough investigation of the fundamental channeling parameters as studied in the backscattering geometry, namely, the average stopping power ratio of axially channeled ions with respect to the randomly oriented ones, along with the characteristics of the dechanneling function relative to the penetration depth, is deemed necessary. Nonetheless, apart from a study with protons [1], there is a notable deficiency in the literature regarding backscattering investigations of MeV deuterons and α-particles impinging on diamond crystals and the present work aims at contributing in this field, combining EBS/C and NRA/C data for the first time.

The studies were conducted at two locations: (a) NCSR 'Demokritos' utilizing deuterons within the energy range of 1.2 to 1.5 MeV, and (b) RBI, Zagreb, Croatia employing α-particles between 2 and 3 MeV. In both instances, the beam energy was varied in ~100 keV increments, with a maximum beam spot dimension of approximately 1x1 mm². The current on target did not exceed ~20 nA to prevent potential overheating of the samples. The targets were two single-crystal diamond wafers with [100] axial orientation, suitable for detector fabrication, obtained from Ningbo Cornerstone Semiconductor Co., Ltd (Ningbo, China), which were mounted in the sophisticated, high-precision channeling goniometers at both locations. The analysis of the obtained EBS/C and NRA/C spectra has been conducted using innovative, specific software designed for the backscattering geometry [1], and an effort is made to elucidate the observed similarities and differences in comparison to the proton case.

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Collisions of highly charged ions with surfaces: Does electron emission occur above the surface or below?

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Just as fast-moving particles lose kinetic energy through interactions with electrons in matter, slow highly charged ions dissipate their *potential* energy via electronic interactions. As the ion captures and stabilizes electrons from the target, its potential energy excites the target electronic system or is released through the emission of numerous low-energy electrons [1]. These processes occur on ultrafast timescales (femtoseconds) and are confined to the topmost atomic layers [2], making them difficult to study directly.

Two-dimensional materials offer a unique opportunity to study these interactions and spatially resolve where electron emission originates. In this contribution, we present preliminary results on electron yields measured separately on both sides of a freestanding single layer of graphene (SLG) irradiated with highly charged xenon ions. By detecting the transmitted ion in coincidence with emitted electrons, we correlate electron emission with the kinetic and potential energy loss of the ion and the local surface cleanliness at the impact point. As shown in Fig. 1, we observe remarkably high electron yields of up to ~60 electrons per ion on each side. Comparing electron yields with the degree of neutralization of the ion reveals different trends on entrance and exit side, suggesting distinct emission mechanisms above and below the surface.

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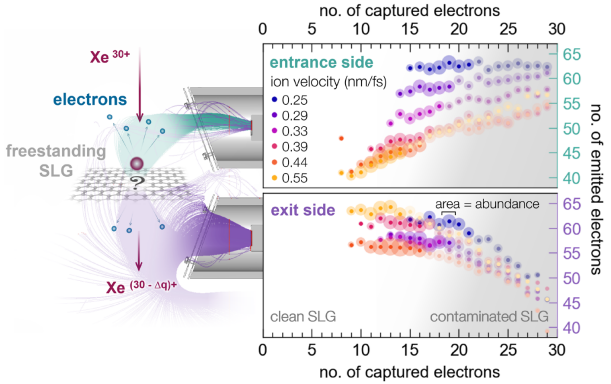

Figure 1. *Preliminary results on the measured electron emission from both sides of a freestanding SLG sample irradiated with Xe^{30+} ions of different velocities.*

Development of the low energy ion implanter at the Micro Analytical Center

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An emerging promising technique for creating qubits is the creation of ion-vacancy (I-V) centers in crystal-like structures. In such a structure, the (nuclear) spins of implanted ions combined with vacancies in the crystal lattice create a bound state which behaves like a quantum qubit. The easiest way to create I-V centers in a crystal is by ion implantation at various ion energies.
Once ion-vacancy centers are implanted into the lattice, the sample has to be annealed, and then the I-V centers have to be characterized via the optical response. Currently, the creation of I-V centers is performed in separate setups with implanted samples being removed from the vacuum several times, introducing surface impurities and degrading sample performance. The implantation of ions into sample sub-surface to create I-V centers has been attempted before [1], but not combined with in-situ annealing and in-situ optical verification.
For the purpose of the high-precision sub-surface ion implantation described above, we are currently commissioning the Low Energy Branch (LEB) [2], located at the Micro Analytical Center (MIC) [3]. The branch operates in a versatile regime of high current (up to 50 μA) ion beams spanning the entire periodic table. Ranging from light (e.g. H, He, C, B, ^{15}N), mid-mass (e.g. Si) to heavy (Ag, W, Pb, Bi) ion beams in the energy range of 1 keV up to 30 keV.
The LEB consists of electrostatic steerers to correct for misalignment of the beam in the x-y plane and move the beam to the desired location on the target, the dipole magnet to select the desired ratio m/q, and the Einzel lens to focus the beam. To verify ion transport, three Faraday Cup (FC) detectors are used. At the end of the beamline, an in-situ ion implantation chamber is located.
In this contribution, we will discuss the status of the LEB system and the in-situ implantation chamber.

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Characterization of the proton beam produced by MACHINA, the Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis

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MACHINA was built within a collaboration between INFN and CERN [1]. It is a movable accelerator completely dedicated to Cultural Heritage studies, to be placed inside the Opificio delle Pietre Dure of Florence, a renowned center for art conservation in Italy. The main goal of the project was to build a compact, low power consumption instrument with an open-source control system. Based on CERN's patented 750 MHz HF-RFQ cavities, MACHINA produces a 2 MeV pulsed proton beam, with a repetition rate of 200 Hz, and a pulse length of 125 μs. It can be powered on and ready for use in less than 1 hour, and its radioprotection system allows the instrumentation to be placed inside museums for campaign measurements even when there are visitors nearby. Being the first of its kind, MACHINA's proton beam has been under an experimental characterization process. This characterization is mandatory because: it ensures the safety of the measurements in terms of damages to artworks; it enables the possibility of quantitative measurements; it might reveal new applications prospects. In an initial study, MACHINA's proton beam has been characterized in terms of current and energy, with a focus on their dependence on HF-RFQ power. Experimental results are being compared with simulation data, underscoring the critical role of beam diagnostics in defining accurate measurement protocols.

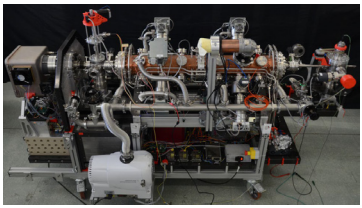

Figure 1: Side view of MACHINA. As a total, the system weights less than 900 kg, has a footprint of 3.5 m × 1 m and a power consumption of about 14 kW.

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The TATTOOS Facility

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TATTOOS (Targeted Alpha Tumour Therapy and Other Oncological Solutions) is the next major installation at the Paul Scherrer Institute as part of the IMPACT project [1]. It envisages the use of the high intensity high energy proton beam from the ring cyclotron (HIPA, 590MeV @ 2.2mA) to impinge on high z targets for spallation produced radionuclides.

The facility is, by design, a high throughput machine, with expected 100 uA proton beams impacting the target, producing a high yield of isotopes (>GBq Tb149) via spallation, online mass separation and laser ionization with less than 2% neighbouring mass contamination.

Here, we present the current designs and layout for the core features of the facility, the high throughput electromagnetic separator with the moderate resolution of 3000 for 20 um ion beams, the Ta target, the ion beamlines and collections, and proposed layout in the confined space of the site.

The facility aims to be the silver bullet in the production bottleneck of radionuclides for oncological solutions, bridging the gap between the technology and the clinical trial solution with medically relevant quantities of radionuclides.

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Direct detection of interstellar radionuclides – messengers of heavy element nucleosynthesis and recent nearby cosmic explosions

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Earth is exposed to nearby cosmic events. Freshly produced radionuclides in the interstellar medium contain information about how and where the heavy elements are made in nature. The solar system moves through the interstellar medium (ISM) and collects interstellar dust particles that contain fresh nucleosynthetic signatures, including the radionuclides Fe-60 ($t_{1/2}$=2.6 Myr) and Pu-244 ($t_{1/2}$=81 Myr) or Cm-247 ($t_{1/2}$=15.7 Myr). These nuclides are incorporated into terrestrial archives over millions of years.

Detection of interstellar nuclides remains extremely challenging and so far was successful only with Accelerator Mass Spectrometry (AMS). Recent technical developments have seen an exceptional gain in measurement efficiency and sensitivity for smaller AMS systems, in particular for actinides, including Pu-244 and Cm-247; and more recently for Hf-182 ($t_{1/2}$=9 Myr). On the other hand, very large accelerators with >10 million volts terminal voltage are required for the identification of small traces of interstellar Fe-60.

Recent data demonstrate a global Fe-60 influx and is evidence for exposure of Earth to recent (<10 Myr) supernova explosions. In addition, search in deep-sea archives and in lunar soil samples provides the first clear detection of interstellar Pu-244, an actinide nuclide exclusively produced by rapid-neutron capture (r-process), supporting the hypothesis that the dominant heavy element r-process nucleosynthesis is a rare process.

Besides new data for the direct search for interstellar signatures I will also present preliminary results of recent laboratory measurements using AMS for understanding Fe-60 and Hf-182 production in massive stars - predominantly produced via double neutron capture reactions.

Cross-section measurements of the $^{nat}Zr(\alpha,x)^{93m/99}Mo$ reactions up to 30 MeV

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The radionuclide ^{99}Mo, the parent of the world´s most widely used medical radionuclide ^{99m}Tc, is almost exclusively produced in nuclear research reactors by the fission of highly enriched ^{235}U, which poses a proliferation risk. Moreover, the supply of ^{99}Mo has been repeatedly disrupted in the past due to maintenance of aging reactors and unexpected shutdowns. To address these problems, alternative production routes for ^{99}Mo using accelerator-based technologies need to be developed. A precise understanding of the relevant excitation functions is essential for this purpose. In this work, we investigated the excitation functions for the alpha induced reaction on ^{nat}Zr to produce ^{93m}Mo and ^{99}Mo up to alpha particle energies of 30 MeV. Irradiations were performed at the IBA Cyclone 30 XP at the INM-5, Forschungszentrum Jülich, employing the stacked foil target technique. The foil arrangement in each stack was optimized based on calculated energy loss profiles. The $^{nat}Cu(\alpha,x)^{66/67}Ga$ reactions were used to determine the alpha particle energy and flux. High-resolution gamma-ray spectrometry was used to identify the reaction products and quantify their activities. Reaction cross-sections were calculated using the standard activation equation and compared with values reported in the literature [1-5].

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This work was supported by the German Federal Ministry for Research, Technology and Space (BMFTR) under grant No. 02NUK080A.

Proton and alpha particle parameterizations for stopping power calculation of light and heavy ions in monoatomic and polymer foils, extending the energy range up to 120 MeV/n

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In the present work, we have proposed two parameterizations for the calculation of the stopping power for charged particles deduced from the modified Bethe-Bloch formula. These expressions are based mainly on accurate experimental data of the stopping power for protons as well as α particles and are independent of the shell correction, the mean ionization potential and the density effect correction. We have calculated the stopping power of ^{1}H, ^{4}He, ^{7}Li, ^{12}C, ^{16}O ions in ^{27}Al, ^{63}Cu, ^{107}Ag, ^{197}Au, polypropylene, mylar and polycarbonate targets, for energies ranging from 1 to 14 MeV/n (Bethe region).

The calculated values using these two expressions were compared with those obtained using the modified Bethe-Bloch formula, obtained experimentally [1] and generated by SRIM-2013 [2], PSTAR- ASTAR [3] and MSTAR [4] calculation codes.

Good agreement was found, particularly between our values and those determined using the modified Bethe-Bloch formula, obtained experimentally [1] and compiled by SRIM-2013 [2] calculation code.

A comparison was made between the present calculated stopping power of ^{7}Li ion through ^{27}Al, ^{63}Cu, ^{107}Ag, ^{197}Au and polycarbonate targets, obtained using these two expressions in the energy range 1 to 14 MeV/n. It was noted that the majority of the points coincide with those generated by SRIM-2013 calculation code.

Finally, we have extended the energy range from 1 to 120 MeV/n using the proton's stopping power values in ^{27}Al and ^{107}Ag targets compiled by SRIM-2013 [2] and PSTAR [3] codes, applying the first expression based on proton's stopping power. We have calculated the stopping power of ^{4}He and ^{16}O ions in ^{27}Al, ^{107}Ag targets, respectively. A remarkable agreement is found between our values and those generated by SRIM-2013 [2], ASTAR [3] and MSTAR [4] codes. For energies $E \geq 3$ MeV/n; the deviations are found to be less than 3%.

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Study of the elastic scattering of low energy protons on ^{13}C and ^{19}F, suitable for Ion Beam Analysis purposes

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Fluorine and carbon constitute two of the lightest elements in nature. Fluorine is a monoisotopic chemically reactive element often found in batteries, polymers, metals, biological and geological samples. Carbon has two naturally occurring stable isotopes (^{12}C: 98.93%, ^{13}C: 1.07%). As it exists everywhere in nature, mainly in the form of ^{12}C, ^{13}C-enriched samples can be employed for stable isotopic tracing when studying dynamic systems (e.g. CO_2 uptake in plants, diffusion, polymer aging). All these properties render both elements particularly important for detection and depth profile determination via Ion Beam Analysis (IBA) techniques.

The proton-induced Elastic Backscattering Spectroscopy (p-EBS) technique is widely used for the detection of most light elements, since protons reach greater depths than other ion beams for the same energy/nucleon values. When p-EBS is performed at $E_{p,lab}$=100-300 keV (Medium Energy Ion Scattering – MEIS), enhanced sensitivity to the surface layers of a sample is achieved, with depth resolutions of a few nm, due to the increase of the corresponding stopping power values. Moreover, the cross sections of the elastic scattering of protons in ^{13}C and ^{19}F, present several resonances even well below 1 MeV, further enhancing the detection limits of these light isotopes and the accuracy of their corresponding concentration depth profiling. Consequently, reliable differential cross-section data are required in order to apply p-EBS, in the medium energy range, and to extend the theoretically evaluated datasets well below 0.5 MeV.

The experiments were conducted at the 4 MV Dynamitron Tandem Laboratory of the Central Unit for Ion and Radionuclides (RUBION) of the Ruhr University Bochum in Germany, in two different accelerators. A 500 kV single-stage accelerator providing protons from 140 keV to 340 keV, and a 4 MV Dynamitron Tandem accelerator which provided protons in the energy range of 300 keV to 1 MeV. The elastic scattering cross sections were studied at six backward detection angles. The obtained results are discussed and compared to the existing datasets.

Millennia of Solar Cycles and Extreme Solar Events from Tree-Ring ^{14}C Records

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The Sun serves as the primary energy source for Earth's system, and fluctuations in solar activity can have a significant impact on climate. Although direct records of solar activity, such as sunspot observations, date back only about 400 years, cosmic ray-induced radionuclides preserved in tree rings and ice cores provide valuable proxies, allowing scientists to reconstruct solar activity patterns over thousands of years [1].

However, the low temporal resolution of most existing long, precisely dated cosmogenic nuclide records poses challenges for studies of short-term solar variability, such as the 11-year Schwabe cycle and solar energetic particle events. Here we present several continuous, annually resolved records of atmospheric ^{14}C concentration from tree rings covering most of the past 6000 years.

The records are extensively analyzed to identify the 11-year Schwabe cycle and potential solar energetic particle events. Evidence suggests that the 11-year solar cycle has persisted for thousands of years, at least during grand solar maxima.

[1] E. Bard, G. Raisbeck, F. Yiou,& J. Jouzel, *Solar irradiance during the last 1200 years based on cosmogenic nuclides*. Tellus *B* 52, 2000

The new ion cooler for isobar suppression ILTIS

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The AMS system HAMSTER (Helmholtz Accelerator Mass Spectrometer Tracing Environmental Radionuclides) will be installed at HZDR in 2025. While the conventional part of the AMS system is inspired by the VEGA facility with its 1 MV Accelerator [1] it also includes an additional injection line for the purpose of isobar suppression with an ion cooler, the so-called Ion Linear Trap for Isobar Suppression (ILTIS). This injector beamline started operation in 2024. The design of the ion cooler follows the setup of the Ion-Laser InterAction Mass Spectrometer (ILIAMS) at the University of Vienna [2,3]. HAMSTER will thus be the first smaller AMS system allowing for isobar suppression by means of collisional and laser photodetachment of anions.

A number of modifications were made compared to the original ILIAMS setup. The radiofrequency quadrupole (RFQ) has the same overall length, but is slightly larger diameter and divided into four equal sections, each 237 mm long. More control of the ion energy during their passage through the cooler is achieved by adapting a small DC guiding field individually to each of the four sections.

A chopper system for beam attenuation and dynode detectors for low-intensity beam measurements enable characterization of the RFQ down to pA currents, which are realistic conditions for AMS measurements.

The presentation will cover the description of the new injection line. First experiments with cooled ions, e.g. Cl^- and Cu^-, document ion residence times in the range of several ms to a few 10 ms, as well as suppression factors of 6 orders of magnitude by laser photodetachment.

[1] K. Wilcken et al.; *From carbon to actinides: A new universal 1MV accelerator mass spectrometer at ANSTO*; Nucl. Instrum. Methods B, 2015

[2] M. Martschini et al.; *The ILIAMS project—An RFQ ion beam cooler for selective laser photodetachment at VERA*; Nucl. Instrum. Methods B, 2019

[3] M. Martschini et al.; *5 years of Ion-Laser Interaction Mass Spectrometry – status and prospects of isobar suppression in AMS by lasers*; Radiocarbon, 2021

Ion-Laser interaction isobar suppression for Accelerator Mass Spectrometry of ^{44}Ti, ^{59}Ni and ^{107}Pd

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The Ion-Laser InterAction Mass Spectrometry Setup (ILIAMS) at the Vienna Environmental Research Accelerator (VERA) offers unique opportunities for atomic isobar suppression in Accelerator Mass Spectrometry (AMS) via element-selective laser photodetachment [1]. Over the past years, several studies on the ILIAMS performance for the rather exotic AMS isotopes ^{44}Ti ($T_{1/2}$ = 59 y), ^{59}Ni ($T_{1/2} = 7.6\times10^4$ y), and ^{107}Pd ($T_{1/2} = 6.5\times10^6$ y) were carried out, fueled by interest in these isotopes from nuclear astrophysics, cosmochemistry and environmental sciences. In classical AMS, sensitivities for these isotopes are typically hindered by the strong interference from highly abundant stable atomic isobars.

First, screening campaigns of oxide and fluoride molecular anions to identify systems suited for ILIAMS-suppression of Ca, Co, and Ag, respectively, were conducted using our fixed-frequency lasers of typically 10-20 W output power. Subsequently, negative ion yields of several of these anions in a Cs-sputter ion source were investigated. Furthermore, two measurement campaigns with tunable Ti:Sa and OPO lasers allowed to pin down unknown detachment energies of promising systems.

Recently, test samples of TiO_2 and NiO chemically prepared from roughly known amounts of ^{44}Ti (solution from the Paul Scherrer Institute; based on γ-activity) and of ^{59}Ni (foil irradiated in the TRIGA reactor at TU Wien; based on thermal neutron capture cross section and neutron fluence), were employed to benchmark the isobar suppression capabilities. Extracting TiO^- from the sputter ion source, the isobar CaO^- is suppressed by $>10^6$, allowing for measurements of ^{44}Ti/^{48}Ti around 5×10^{-14}, which will enable future studies related to the cross section of the reaction ^{40}Ca(α,γ)^{44}Ti. Photons from a 532 nm laser neutralize CoF_2^- by ~10^8, while leaving NiF_2^- largely unaffected, resulting in a background level of ^{59}Ni/^{58}Ni around 5×10^{-13}.This is sensitive enough for cosmogenic abundances of ^{59}Ni in meteorites to determine their long terrestrial ages.

[1] M. Martschini et al., *5 years of Ion-Laser InterAction Mass Spectrometry – status and prospects of isobar suppression in AMS by lasers*, Radiocarbon 64 (2022) 555.

This work was partly supported by ChETEC-INFRA (EU H2020 #101008324).

Ion-Laser InterAction Mass Spectrometry for the measurement of long-lived radionuclides produced in fusion environments

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Radionuclide inventories of future nuclear fusion reactors, such as ITER or DEMO, are assessed based on simulation codes. To validate these codes, foils of different materials were irradiated with neutrons from the deuterium-tritium (D-T) fusion at the Joint European Torus (JET) reactor, followed by γ-spectrometry measurements of short-lived radionuclides [1]. Nevertheless, the expected activities of long-lived radionuclides in those materials are too low to be measured by radiometric techniques. At the Vienna Environmental Research Accelerator (VERA) we are studying the use of accelerator mass spectrometry (AMS) for the measurement of ^{93}Mo, ^{91}Nb and ^{94}Nb, which are produced by the reactions of the D-T neutrons with different isotopes of molybdenum. This element is present in different structural materials to be used at ITER, such as stainless steel SS316. The measurement of these radionuclides by AMS requires the suppression of their respective stable isobars: ^{93}Nb, ^{91}Zr, and ^{94}Zr + ^{94}Mo. We investigated their suppression using the Ion-Laser InterAction Mass Spectrometry (ILIAMS) setup for laser photodetachment [2]. In the case of ^{93}Mo, the selection of MoO_2^- allows the suppression of $^{93}NbO_2^-$ by a factor >10^6 using photons with a wavelength of 637 nm. The capabilities of VERA for ^{93}Mo have been assayed with MoO_3 samples prepared from a Mo thin foil irradiated in the TRIGA Mark-II reactor at TU Wien to reach ^{93}Mo/^{nat}Mo ratio of 10^{-9}, and isotopic dilutions with stable ^{nat}Mo to reach ^{93}Mo/^{nat}Mo ratios between 10^{-12} and 10^{-10}. The blank ^{93}Mo/^{nat}Mo ratio was in the 1-5 × 10^{-13} range, both in targets from commercial MoO_3 and our processing blank. This blank ^{93}Mo/^{nat}Mo ratio is three orders of magnitude lower than the ^{93}Mo/^{nat}Mo ratio expected in the samples of interest. The ^{93}Mo specific activity of an aliquot of the irradiated foil will be measured by liquid scintillation counting at the Technical University of Denmark. For ^{91,94}Nb, the selection of NbO_3^- allows the suppression of $^{91,94}ZrO_3^-$ by collisions with the He buffer gas in the ion cooler. This suppression is further enhanced by photons with a wavelength of 355 nm, which also suppress the other isobaric interference, $^{94}MoO_3^-$.

[1] Packer et al., *ITER materials irradiation within the D-T neutron environment at JET: post-irradiation radioactivity analysis following the DTE2 experimental campaign*, Nuclear Fusion 64 (2024) 106059

[2] Martschini et al., *5 years of Ion-Laser InterAction Mass Spectrometry – status and prospects of isobar suppression in AMS by lasers*, Radiocarbon 64 (2022) 555-568

Technetium-99 Detection at the Limits of AMS Sensitivity

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Accelerator Mass Spectrometry (AMS) enables ultra-sensitive quantification of long-lived radionuclides in environmental samples. Determination of absolute concentrations of the anthropogenic radionuclide ^{99}Tc ($t_{1/2}$ = 2.1× 10^5 yrs) in environmental samples using AMS requires the suppression of the isobaric background of stable ^{99}Ru and a reliable normalization method. The latter is particularly challenging due to the absence of a stable Tc-isotope.

At the Vienna Environmental Research Accelerator (VERA), we are investigating an approach that uses a 3 MV tandem accelerator coupled with an Ion-Laser InterAction MS (ILIAMS) setup. It has been demonstrated that, due to different detachment energies, $^{99}RuF_5^-$ can be suppressed by up to factor of 10^5 using a 532 nm-laser, making extraction of $^{99}TcF_5^-$ a viable option for ILIAMS [1]. When normalizing the ^{99}Tc-counts in the detector to $^{93}NbF_5^-$ extracted from the same sample, the reproducibility of the method was significantly improved from 50% to 15% through the systematic optimization of ion source parameters.

In parallel, high-energy AMS of the Australian National University has been further optimized. Using the 15 MV tandem accelerator, ^{99}Tc is separated from ^{99}Ru by their energy loss characteristics in an 8-anode gas ionization chamber [2] together with TcO^- extraction from the ion source. Normalization to $^{93}NbO^-$ current extracted from the sputter matrix [3] achieved a precision of 10%. This method facilitated precise analysis of environmental samples including 1 g peat and 10 L water samples from marine and freshwater sources.

The feasibility of normalization using a ^{97}Tc spike, produced by irradiating a Niobium foil with a 32 MeV $^7Li^{3+}$ beam at the University of Cologne, is being investigated. These collaborative developments advance the applicability of AMS for mapping ^{99}Tc in remote and diverse environmental reservoirs, providing new insights into its global distribution and behavior.

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[3] Koll et al.; *Recent developments for AMS at the Munich tandem accelerator,* Nucl Instr Meth Phys Res B 438, 2019

Iodine isotope analysis of the nuclear industry emissions in Czechia

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The combination of nuclear forensics and the analytical determination of radionuclides in the environment has led to the development of a distinct discipline: environmental nuclear forensics. This discipline utilizes knowledge of the (radio)nuclide concentrations and ratios to stable isotope in various environmental matrices, along with region-specific isotope background values, to identify and track new sources of contamination. In our case, the ^{129}I as very mobile nuclide with origin mainly from human nuclear activities was selected. However, the utilization of iodine isotopes in these applications is hindered by the complexity inherent to their variable speciation and chemical properties. In this study, a leaching method using tetramethylammonium hydroxide solution was optimized and applied to the determination of iodine in sediments and soils, followed by liquid-liquid extraction, which was also applied to water samples. Subsequent to the separation process, the samples were subjected to analysis using a MILEA-type accelerator mass spectrometry method. This particular method is regarded as the most appropriate for the measurement of the background value of the isotope ^{129}I. Samples were obtained in cooperation with external institutions involved in monitoring radionuclides in the environment, as well as by personal sample collection in the Czech Republic. The results indicate elevated concentrations of ^{129}I in the vicinity of nuclear power plant Temelín, with one of the samples exhibiting concentrations that are almost three orders of magnitude higher than the other samples from this region, still well below clearance levels. The correlation of the isotopes ^{129}I and ^{137}Cs indicates a shared origin for the contamination of the Vltava and Otava rivers. Elevated concentrations of ^{129}I have also been detected in archive-samples affected by Chernobyl fallout. When combined with the ^{137}Cs data, this finding is consistent with the occurrence of the Chernobyl incident. These results suggest the potential value of integrating iodine analysis and nuclear forensics in the identification of sources of contamination. Furthermore, they highlight the significance of AMS technology in the advancement of environmental nuclear forensics.

The research is co-financed with the state support of the Technology Agency of the Czech Republic as part of the SARA project (SQ01010334), Environment for Life 2 Program. The infrastructure of the AMS laboratory built as part of the OP VVV RAMSES project was used during the implementation of the research.

Generation and Control of Picosecond Ion Pulses via Laser-Stimulated Desorption from a Tungsten Nanotip

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We present a novel approach for generating and manipulating ultrashort ion pulses with durations of less than 100 ps, using a compact laser-stimulated desorption ion source. The setup utilizes an electrochemically etched tungsten nanotip with 150 nm apex radius, which is biased at high voltage and irradiated with femtosecond ultraviolet (259 nm) laser pulses. Surface-adsorbed species are ionized and desorbed from the tip, producing keV-energy ion pulses that are intrinsically synchronized with the laser.

We systematically explore the dependence of ion pulse width and yield on laser pulse energy, repetition rate, polarization, working gas species, and extraction voltages. Time-of-flight (TOF) spectroscopy reveals tunable picosecond ion pulses for various adsorbate-capable species, including hydrogen, deuterium, nitrogen (shown in *Figure 1*). The source operates at moderate optical fluence (~10^{11} W/cm^2) and achieves a full width at half maximum (FWHM) of 84 ps for hydrogen ions.

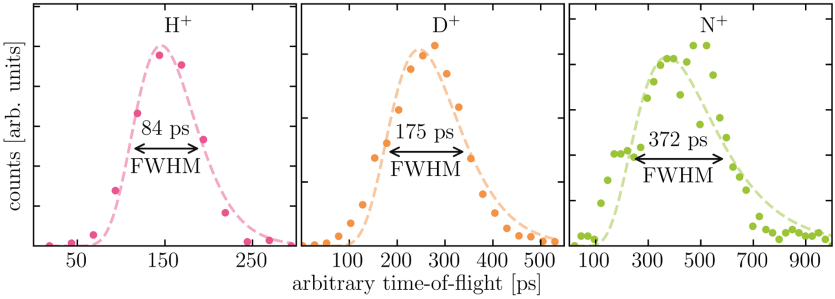

Figure 1: *Ion pulses for different species*

Our results build upon the work of Mihaila *et al.* [1], extending their concept by enabling precise control over both temporal and compositional characteristics of ion pulses. This allows for implementation in pump-probe experiments with picosecond resolution, establishing the nanotip source as a versatile tool for ultrafast materials research.

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In-situ study of the evolution of zirconium deuteride under deuterium ion beam bombardment by dual-beam experiments

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Zirconium-deuteride/tritide (ZrD_x/ZrT_x, x is the atomic ratio) are used as targets in fast neutron generators which are widely applied in scientific research and industry. The stability of neutron intensity depends on deuterium(D)/tritium(T) concentration and distribution in targets during the deuterium ion beams (D_n^+, n=1,2,3) bombardment. In this work, the ZrD_x film in ~3 μm was prepared as target by magnetron sputtering on a silicon substrate at Lanzhou University. The roughness of ZrD_x targets is less than 5 nm. In-situ dual-beam experiments were carried out at the Laboratory of Accelerator and Radiation Technology, University of Lisbon. The D_n^+ beam with 20 keV/D from the 210 kV ion implanter was used to bombard the ZrD_x target in a fluence of 2.39×10^{15}-4.00×10^{17} D/cm^2, and $^3He^+$ ion beam from 2.5MV Van de Graaff accelerator was used to analyze the D concentration and distribution by Nuclear Reaction Analysis (NRA). The D_n^+ implantation and ^{3}He-NRA were conducted alternatively at certain implantation fluence in-situ. The x in virgin sample is about 1.6. Following the D_n^+ implantation, the x increased rapidly at the beginning and then reached to a dynamic saturation at the fluence of 1.0×10^{17} D/cm^2. The D-distribution in the near surface region changed significantly versus the implantation. The out-diffusion of D was also observed while the sample was stored in vacuum for hours. After the experiment, the D-depth profiles in implanted area and virgin area is measured by Time of Flight Elastic Recoil Detection Analysis (ToF-ERDA) ex-situ. The main value of x in implanted area is much larger than 1.6. At the same time, some surface contaminations of carbon (C) and oxygen (O) have been found in the beam spot, which affect to the surface D-distribution and the out diffusion. The carbide and oxide layer is characterized by X-ray Photoelectron Spectrometer (XPS). The topographies at beam spot and virgin region are also observed by Scanning Electron Microscopy (SEM). The roughness at the beam spot is significantly larger. Some surface damages have been also observed.

Energy loss straggling of ^{16}O, ^{19}F, ^{48}Ti and ^{63}Cu ions in Molybdenum from 0.08 to 0.6 MeV/n using Time-of-Flight spectrometry

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In this work, Time-of-Flight spectrometry was used to measure the energy loss straggling of ^{16}O, ^{19}F, ^{48}Ti and ^{63}Cu partially stripped heavy ions traversing a molybdenum target in the energy range of 0.08–0.6 MeV/nucleon. The measured straggling values were systematically compared with theoretical predictions from widely used formulations, including Bohr's classical theory, the Bethe-Livingston model, and Yang's semi-empirical approach. This comparative analysis was performed to assess the validity and limitations of existing straggling theories in describing energy loss fluctuations for light to medium-mass ions in solid targets. A significant discrepancy was observed between the experimental data and theoretical predictions, with the measured straggling values consistently exceeding those calculated by all three models (up to 50%). The observed straggling excess can be attributed to charge-exchange processes, fluctuations of the ion charge state as the beam traverses the target material. This effect, often neglected in standard straggling theories, plays a non-negligible role in the energy loss distribution and must be incorporated to achieve quantitative agreement between experiment and theory.

Development and applications of the new Ion Beam Analysis setup with the wavelength and energy dispersive X-ray spectrometers installed at the ion microprobe

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Tandem Accelerator Facility at the Ruđer Bošković Institute has been equipped with two electrostatic accelerators and nine beam lines, including two ion microprobes. We have developed a new modular experimental vacuum chamber for installation at ion microprobes that is designed to enable simultaneous ion beam analysis of micro-samples using wavelength and energy dispersive X-ray spectrometers (for high-resolution and standard Particle Induced X-ray Emission spectroscopies) together with the solid-state particle detector for elastic backscattering spectroscopies (EBS and RBS) and/or nuclear reaction analysis (NRA). It is equipped with piezoelectric stage for precise sample positioning. Here we describe this new setup [1] and demonstrate its usefulness in the ion microprobe analysis of micro-samples that exhibit complex energy dispersive X-ray spectra [1,2] as well as in studying the influence of chemical effects [3] and multiple inner-shell ionization [4,5] on X-ray spectra.

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Analysis of compositional changes in MoS_2 coatings after friction experiments in different atmospheres

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Historically, molybdenum disulfide (MoS_2) has been employed as an efficient dry lubricant in space due to its low coefficient of friction in vacuum. In contrast, the performance of MoS_2 breaks down in the presence of oxygen and water, due to oxidation to MoO_3 and disruption of the van der Waals sliding mechanism. Still, no clear evidence of the structural evolution of the material during friction experiments in different atmospheres has been reported.
MoS_2 coatings of 2 µm thickness were deposited by the filtered Laser-Arc on 100Cr6 substrates with a Cr adhesion layer and exposed to friction tests in vacuum, dry and humid air in a ball-on-disc configuration. Microbeam Rutherford backscattering spectrometry (µ-RBS), was used together with other techniques to investigate the element distribution and structural changes in the wear tracks as well as the wear scars of the 100Cr6 counterbodies. After the friction experiment in dry air, µ-RBS demonstrates the absence of oxygen in the MoS_2 coating, suggesting it does not oxidize. However, in the wear scar of the counterbody, molybdenum, sulfur, and other elements are distributed heterogeneously in different areas, indicating a complex tribochemistry. The results show that µ-RBS can give a valuable contribution to the study of changes in the composition of dry lubricants like MoS_2 in friction experiments.

Financial support by the DFG, grant No. 415726702, project TRIGUS, is gratefully acknowledged.

Development of a Gas Ionisation Detector for IBA purposes

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Charged particle detection is conventionally achieved using Silicon based detectors (SSB, PIPS, e.t.c.). Therefore, their low depth and mass resolution capabilities can affect the quality of the measurement, especially in the case of the Time of Flight – Elastic Recoil Detection Analysis (ToF – ERDA) technique [1][2]. Heavy particle detection in the specific technique requires high energy, depth, and mass resolution, as well as endurance against radiation damage. Therefore, replacing the silicon energy detector with a new Gas Ionisation Detector (GID) is mandatory for the ToF – ERDA spectrometer at N.C.S.R. "Demokritos".

The new GID detector is an exclusively built in-house assembly. The characteristics of the detector are compatible with the needs of the ToF – ERDA technique regarding the kind of ion and energy ranges expected to be recorded. Two parallel copper plates constitute the anode and cathode electrodes, while a Frisch grid between them shields the anode from the drift region (active volume) of the detector. Related simulations were completed, for the estimation of the electric fields between the various components, while different profiles of the anode electrode were constructed and tested in order to achieve lower capacity of the detector. Dedicated measurements using various configurations and settings were conducted, aiming at the determination of the properties and the quality of the detector performance. The effect of using different types of gas in different pressure conditions was also tested. The corresponding results of the above mentioned evaluation tests will be presented and discussed.

Replacement of the Frisch grid by a Gas Electron Multiplier (GEM) was tested out in order to evaluate the performance and the anticipated enhancement of the energy resolution.

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Characterization of 4H-SiC p-n Junction Detectors for Alpha Particle Detection in Plasma Diagnostics

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In future nuclear fusion reactors, diagnosing escaping suprathermal ions, such as the 3.5 MeV alpha particles produced in D-T reactions, is essential to optimize plasma performance and ensure reactor integrity. Silicon carbide (SiC) emerges as a promising candidate for fast ion detection due to its wide bandgap, high radiation tolerance, and thermal stability. In this work, we study 4H-SiC p-n junction detectors fabricated by the Institute of Microelectronics of Barcelona (IMB-CNM). These detectors have a non-metalized surface, with only a guard ring structure, making them suitable not only for charged particle detection but also as potential diagnostic tools for X-ray detection in fusion environments. To enable this study, we upgraded the nuclear microprobe at the National Center of Accelerators (CNA) by installing a temperature-controlled heating system, allowing in situ irradiation of samples at temperatures up to 1200 °C.

The detectors were irradiated with 3.5 MeV alpha particles at fluences ranging from 10^{11} to 10^{13} ions/cm^2 at three different temperatures: room temperature (RT), 200°C, and 400°C. The irradiation process was monitored in real time using Proton-Induced X-ray Emission (PIXE) to ensure precise fluence control. The spectroscopic response of the devices was assessed through Charge Collection Efficiency (CCE) measurements using Ion Beam Induced Charge (IBIC).

These results provide valuable insight into the suitability of SiC-based detectors for use in extreme environments, such as nuclear fusion reactors, where high temperatures and radiation levels challenge conventional diagnostic systems.

In-depth charecterization of Silicon Nitride membranes using ERDA, RBS, XRR and Ellipsometry

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Silicon nitride membranes exhibit exceptionally high mechanical quality factors (Q), reaching values in the hundreds of millions [1]. These high Q-factors are largely attributed to the intrinsic tensile stress in the membranes, which increases their resonance frequency without proportionally increasing energy dissipation—a mechanism known as dissipation dilution [2,3]. To further enhance Q, reducing intrinsic dissipation is crucial. However, doing so first requires a detailed understanding of the origins of this dissipation and how it relates to the material and surface properties of the membranes. Given their nanoscale thickness, many of these properties are difficult to access or are characterized with significant uncertainty.

In this work, we demonstrate how ion beam analysis techniques—particularly Elastic Recoil Detection Analysis (ERDA) and Rutherford Backscattering Spectroscopy (RBS)—can contribute to high-precision characterisation of ultra-thin Silicon Nitride membranes (20–100 nm thick). When combined with X-ray Reflectivity (XRR) and Ellipsometry, these accelerator-based methods can be used to determine membrane thicknesses with better than 1% accuracy, measure the material density with comparable precision, and reconstruct detailed profiles of elemental composition, electron density, and refractive index with nanometer-scale resolution.

To broaden the material picture, we also integrate insights from complementary techniques such as X-ray Photoelectron Spectroscopy (XPS), Fourier Transform Infrared Spectroscopy (FTIR), and Electron Paramagnetic Resonance (EPR). Together, these methods allow us to probe both bulk and surface, correlating them with mechanical performance in terms of Q.

This work highlights the critical role of accelerator-based techniques in uncovering the microscopic factors governing energy loss in high-Q nanomechanical resonators—advancing their development for applications at the quantum frontier.

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Soft X-ray Microscopy Multimodal Imaging for Life Sciences Applications at TwinMic – Elettra

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Scanning Transmission Soft X-ray Microscopy (STXM) combined with Low Energy X-ray Fluorescence (LEXRF) mapping has become a well-established technique for investigating the spatial distribution of light elements in biological tissues and cells at submicron resolution [1–3]. The TwinMic beamline at the Elettra Synchrotron (Trieste, Italy) has played a pioneering role in integrating these modalities [4].

Scanning microscopy is particularly well-suited for multimodal imaging, as it enables the simultaneous acquisition of diverse signal types—each arising from distinct physical interactions—as the sample is raster-scanned across the focused beam. This capability allows for the generation of rich, complementary datasets, providing deeper insights into the structural and chemical characteristics of biological specimens.

In this talk, we will present recent advancements in Life Science applications achieved at the TwinMic beamline [5], with an emphasis on instrumental developments and intelligent imaging strategies. Highlights include the integration of a newly developed in-vacuum X-ray Atomic Force Microscopy (X-AFM) system, enabling concurrent acquisition of topographical, STXM, and low-energy XRF data [6]. We will also discuss the advantages of implementing a novel Compressive Sensing approach to enhance acquisition efficiency and data quality [7].

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New neutron facility for preclinical BNCT research

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Boron Neutron Capture Therapy (BNCT) is a promising approach in cancer treatment, offering precise targeting of malignant cells with minimal damage to healthy tissues [1]. Despite its potential, the adoption of clinical BNCT and especially the preclinical research has been constrained by the availability of suitable neutron sources [2]. Finland has been at the forefront of BNCT research, contributing to significant advancements in therapy optimization at the FIR1 reactor . However, the number of reactor-based neutron facilities is declining and current accelerator-based neutron sources (ABNS) are largely designed for full-scale clinical applications. The full-scale clinical push of the BNCT and ABNS has however one significant drawback at the moment: dedicated patient systems are unsuitable or unavailable for preclinical research and technology development. Currently there is no ABNS dedicated for preclinical BNCT research in Finland, even the first patient with ABNS system in Finland has been already treated in May 2025. This work proposes a new facility in Jyväskylä which will bridge the gap to clinical technologies by developing a compact neutron source optimized for preclinical BNCT research. With an output aperture of approximately 1 cm, the moderator will maximize epithermal neutron yield while catering to small targets, such as mice or high flux neutron detectors. In this presentation we will introduce the plans, including laboratory layout, predicted beam intensities, as well as collaborational aspects for the new low energy neutron beam facility in Finland.

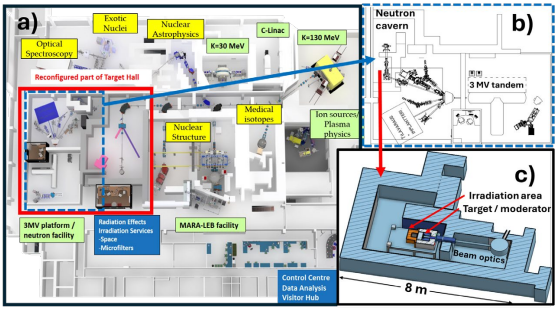

Figure 1. *Design of the new neutron beam facility to the JYFL-ACCLAB. a) Layout plan for 2026-spring of the JYFL-ACCLAB with Radiation Effects Facility moved to make room for the new 3MV tandem, b) 3MV facility layout with some existing beamlines and ion sources and c) Model of the neutron production area for radiation simulations (Geant4* [4]*) with the target-moderator and preclinical animal(murine)/detector irradiation bunker.*

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The accurate proton dose delivery system for proton therapy research based on accelerator techniques in the Centre for Ion Beam Applications in the National University of Singapore

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The Centre for Ion Beam Applications (CIBA) is a multidisciplinary research center based in the Dept of Physics, NUS, specializing in the development of nuclear particle technology and subsequent applications of MeV ions (proton, helium nuclei etc).
One of the unique capabilities developed by CIBA is the ability to focus and target protons down to 10nm spot sizes [1]. This unique performance characteristic of our system has been applied in the following research program: 1) Investigation into the targeted damage response mechanisms of single cells, 2) Low dose radiation research on multicellular cultures, 3) Comparison between targeted low dose ion radiation and photon radiation.

In order to deliver accurate proton doses [2] to various samples for the above mentioned research programs, proton dose calibration is the utmost important step. Two Ion Beam Analysis techniques namely Rutherford Backscattering spectrometry (RBS) and Scanning Transmission Ion Microscopy (STIM) have been used. Due to the rare events of back scattered particle when ions are interacting with matter, the current of incoming proton beam is controlled to be less than 0.01pA for precise calibration. Then RBS and STIM are carried out simultaneously for the dose calibration prior to the delivery of the required doses to the samples.

This presentation will focus on the accurate dose calibration method for proton therapy research of various cancer cells, this dose calibration method has been used to govern that the right doses are delivered to the right samples.

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Accelerator produced ^{99m}Tc for medical applications: Technical and chemical optimizations

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The generation of ^{99m}Tc and its parent nuclide ^{99}Mo by means of various accelerator reactions has been heavily investigated in the last 10-20 years to find alternative production methods of ^{99}Mo for the medical application of ^{99m}Tc.[1,2] A key challenge for building Mo/Tc generators is the lower specific activity (LSA) of accelerator-generated ^{99}Mo compared to ^{99}Mo generated from fission of highly-enriched ^{235}U. We report here on investigations to increase the low specific activity with the planned 'High Brilliance Source System' (HBS) accelerator at the Forschungszentrum Jülich in Germany.[3] Different factors are considered to optimize the specific activity of ^{99}Mo and to maximize output of ^{99m}Tc. This includes calculations to improve production and increase of ^{99}Mo activity [4], as well as the adaptations of the existing nuclide generator system, e.g. increased amount of Al_2O_3, higher Mo adsorption, optimization of the elution scheme, or modifications of the separation columns. First results of the modified system so far indicate that the applicability as a clinically used Mo/Tc nuclide generator might be reached.[5] Building on these results, we expect additional improvements adapting the irradiation scheme, as well as the chemical processing scheme. We will also discuss whether and how clinical practice might be adapted.

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This work is part of the 99MoBest joint project and was funded by the Federal Ministry of Education and Research (BMBF) under funding number 02NUK080A.

Benchmarking Monte Carlo codes for the characterization of photoneutron fields from VHEE accelerators in FLASH radiotherapy

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Recent advances in FLASH radiotherapy, combined with Very High-Energy Electron (VHEE) accelerators, have sparked growing interest in photoneutron production within the quasi-deuteron and photopion energy regimes—areas that remain relatively unexplored [1–3]. The FRATHEA project, a large-scale initiative led by *Institut Curie* in collaboration with CEA, aims to establish a FLASH-VHEE radiotherapy platform at the Orsay hospital site (France). This project seeks to demonstrate both the safety and therapeutic potential of such an emerging treatment modality. These developments critically rely on Monte Carlo simulation tools, which must undergo rigorous evaluation and validation. In this study, four Monte Carlo particle transport codes—MCNP6, PHITS, FLUKA, and Geant4—are benchmarked using various nuclear data libraries and physics models. Heavy targets (tantalum, tungsten, gold, and lead) as well as light targets (water, concrete, and aluminum) are irradiated with photons in the 30–300 MeV energy range. The resulting photoneutron fields are characterized through three key physical observables: particle current, energy spectrum, and angular distribution. By enhancing the predictive accuracy of Monte Carlo simulations for secondary photoneutron emissions from VHEE accelerators, this work supports the design and optimization of next-generation FLASH radiotherapy platforms.

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This research was funded by the FRATHEA project.

Applying AMS techniques (^{26}Al, ^{10}Be, ^{14}C) to preserve and restore the past: Chuchuwayha, people and nature in the Similkameen (British Columbia, Canada)

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Chuchuwayha rockshelter is a sacred place within the territories of the Upper Similkameen Indian Band. People have left evidence of their presence in archaeological deposits and through the over 70 pictographs. The study is developed in a multiscalar approach, both spatially and temporally, and aims to restore the temporalities of the major events that have shaped the life of the site, whether natural or anthropogenic, and to frame the realization of the preserved rock art, by implementing AMS technics.

Cosmogenic dating (^{10}Be, ^{26}Al) is used to determine the age of the main morphological events of the site that have constrained human occupation. Its application is based on the morphogenic evolution of the site and the different identified collapses phases, using the 3D model. ^{14}C determinations on organic materials collected during the excavation enable modeling the time depth of human occupation. A homogeneous compact ash level marks the major ancient catastrophic event of Mt St Helens Yn that occurred more than 3200 years ago. The time frame within which people could reoccupy the region after it is being modeled. Also, pictographs made by ochre material can't be dated directly, but they are covered by silico-calcic crusts. Analytical investigations are being processed to carry out ^{14}C/U-Th cross-dating of wall crusts in order to pinpoint the morphological variations in the decorated walls and thus set *termini* for the art realisation.

The multitechnical chronological Bayesian model aims at restoring the story of the Chuchuwayha site's life, both from human and natural points of views.

Probing Writing Ink Dyes Mixtures in Literary Works with MeV SIMS and Raman: A Combined Analytical Approach

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Synthetic dyes are used in various writing inks applied to cultural heritage objects e.g. literary/artistic works from 20th/21st century. Depending on quality, modern inks contain mixtures of different dyes, e.g. cationic (basic) and anionic (acid, solvent and direct) dyes, and/or synthetic organic pigments. Due to the low lightfastness of everyday ballpoint pen and felt-tip inks, dye identification is therefore crucial for preventive conservation and determining appropriate (lighting) conditions during exhibitions. To explore the potential of accelerator-based MeV SIMS (secondary ion mass spectrometry) in combination with Raman spectroscopy (both used in forensic ink analysis but with different aims) we applied these methods to the same ink samples for identification of dyes on literary works. Previous Raman analyses with different laser excitations failed to detect some of the dyes present in the samples (indicated by ink color). The same occurred for MeV SIMS, but for another class of dyes. This complementarity of MeV SIMS and Raman suggests a synergetic benefit when both methods are combined. Minute ink on paper samples (six ballpoint and six felt-tip) from authors' notes on literary works (dated between 1960 and 2004, the Literary Archive at the Austrian National Library) were analysed. As found in our previous research, MeV SIMS enables identification of colorants in complex mixtures through the soft desorption of molecular ions and larger fragments from the uppermost paint/ink layers [1]. Analyses of ink samples were performed using a linear ToF-SIMS setup with 8 MeV Si^{4+} primary ions in both positive and negative ion modes. Dispersive μ-Raman measurements were performed with 532 and 785 nm laser excitation. Results show that MeV SIMS is suitable for identifying cationic (basic) dyes (e.g. Basic Blue 7, Basic Green 1, Basic Violet 1 and 3) and aryl guanidines—markers for anionic dyes—in positive ion-mode. Anionic dyes could not be detected, most probably due to insufficient ionisation in the negative-ion mode. Raman additionally identified Solvent Blue 37 and 38, which were not detected with MeV SIMS in ballpoint pen inks. The identification of aryl guanidines with MeV SIMS is very important due to their ability to form salts with sulphonated solvent or acid dyes, influencing their stability and thus the stability of the inks.

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This research was supported by Federal Ministry of Education, Science and Research Austria, project no. HR13/2024, via "Scientific & Technological Cooperation", OeAD GmbH. We thank C. Hofmann, Austrian National Library for providing real samples within the project.

AMS ^{14}C dating in the scientific renovation project of the Notre-Dame cathedral of Paris

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Following the fire at Notre-Dame cathedral of Paris in 2019, the national research community implemented a vast scientific effort to support the restoration. One of the project's aims was to study the materials uncovered by the disaster. Remains of framework beams, iron armatures, stained glass, stone, mortar and sculpted decorations were collected during an extensive campaign dedicated to sorting the debris, as well as during subsequent excavations or surveys on the building. Accelerator Mass Spectrometry ^{14}C dating has been involved in various aspects of the project [1-3]. First, the iron structure was deeply investigated. At Notre-Dame, the use of iron reinforcements was long considered as a feature of late restoration (19th c.). However, the destruction of the roof revealed an unprecedented number of iron cramps as well as other armatures used in several parts of the building (with an estimated total of approx. 2000 cramps). 81 iron armatures (mainly cramps) were observed by metallography and chemical analysis and 32 of which were dated by ^{14}C. The results show that iron armatures were present from the beginning of the construction, revealing that Notre-Dame de Paris was the first known Gothic cathedral where iron was used on a large scale to bind stones throughout its entire construction [2]. The scientific project also presented an opportunity to study the remaining traces of medieval polychromy on Notre-Dame's stone façades. Small paint samples were taken from various portals. Microscale observations and chemical analyses showed that the coloured layers were applied on a preparatory layer made of lead white containing hydrocerussite ($2PbCO_3 \cdot Pb(OH)_2$) and cerussite ($PbCO_3$) [3]. The ^{14}C results obtained on lead white indicated dates in the 11th - 12th centuries, which correspond to the synthesis of the pigment, just before the beginning of the cathedral construction. In 2022, a lead coffin was discovered in the cathedral's basement during excavations at the transept crossing. Lead corrosion products were identified as lead carbonates. ^{14}C dating of the samples showed that their formation resulted from body decomposition, thus giving access to the burial date.

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Non-destructive fast ion beam and portable X-ray fluorescence analysis of heritage objects: case study of a 12th - century fire-gilded brass crucifix

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This work focuses on the study of a 12th-century crucifix composed of an applique figure, a Christ in brass, mounted on its original plate, a copper cross [1]. The fire-gilding, revealed during the restoration of the object, is very incomplete despite the generally good state of conservation of the two elements. The use of mercury to gild copper alloys can be challenging due to the physico-chemical properties of the amalgam formed with the alloying elements (Pb, Sn, Zn). According to ancient texts [2], the surface of the object had to be pre-treated to be enriched with copper or gilded by multiple layers. The main question was to assess whether the gilding process could have been adapted to the nature of the substrate in our case. Analysis was performed by high-energy PIXE (HE-PIXE) using a 68 MeV alpha beam, and with a p-XRF (40 kV, Rh).

The HE-PIXE [3] non-destructive method detects high-energy X-rays $K\alpha Au\ at$ 68,8 keV which are less surface sensitive than low-energy X-rays ($L\alpha$, $L\beta\ et\ L\gamma Au$). The intensity of $K\alpha Au$ line gives the average thickness of the gilding under the millimetric beam spot. A standard copper matrix covered with gold leaf of known thicknesses was irradiated under the same conditions as the crucifix to calibrate our measurements. p-XRF measurements were realized on the majority of the gold areas of interest, identified by the restorer, in order to gain access to information on the object as a whole and not just on the few HE-PIXE reference points. In addition, the ratios of gold L X-ray lines as well as copper K X-ray lines were used to characterize the degree of homogeneity of the gilded areas compared with the case of a flat surface of homogeneous thickness.

The average thickness of the gilding measured on the crucifix as a whole is fairly regular and varies between 2 µm and 5 µm, which is consistent with the literature. Characterization of the surface condition of the irradiated areas reveals a high degree of local heterogeneity, with some areas showing gaps. Despite a more complex morphology than on the cross, the gilding on the revers of Christ's hand is flat and even, with a measured thickness of 2.4 µm. According to the restorer, this is its original state, which is surprising for brass. The hypothesis that the surface of Christ's hand has been enriched with copper cannot be dismissed. These results provide the restorer with information about the quality of the gilding on the crucifix and offer an analytical approach that can be applied to other rare examples of similar works.

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Ion beams for optoelectronics and quantum technologies

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Ion beams are an indispensable tool in semiconductor technology. On one hand, implanted ions—often substituting host atoms—can introduce free charge carriers. This enables doping of semiconductors and their nanostructures well beyond the solubility limit. Heavily doped semiconductors such as GaAs, Ge, and Si are particularly attractive for near- and mid-infrared plasmonics, where the plasma frequency is governed by the carrier concentration. On the other hand, energetic ions interact with materials through ionization and nuclear collisions, leading to the formation of electronic defects and atomic displacements. The concentration and distribution of these defects can be precisely controlled by adjusting the ion fluence and energy [1]. As such, ion beams offer a powerful method for defect engineering. As a national lab in Germany, our center is running an Ion Beam Center for materials research [2]. It is open free to the international community for fundamental research based on a proposal system. With the research department “Semiconductor Materials”, we are running unique annealing methods, including millisecond flash lamp annealing and nanosecond pulsed laser melting, to repair the ion beam induced damage and to activate the dopants [3, 4]. I will show the applications of ion beams for optoelectronics and quantum technologies by still using Si, the workhorse of semiconductor industry. They include doping with exotic ions for infrared optoelectronics [5, 6] and creating color centers for quantum technologies [7].

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Writing of SnV colour centres in diamond via Focussed Ion Beam

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Colour centres in diamond are appealing solid-state systems for single photon sources development. Group-IV lattice impurities has recently emerged [1, 2, 4] as promising alternative to the Nitrogen Vacancy colour centres, evidencing intriguing properties such as narrow emission bandwidth and controllable spin states [3]. Particularly, the tin-vacancy centre (SnV) has attracted the interest of the scientific community due to its high saturation intensity (>10^6 photons/s at room temperature [2]) and its near-transform-limited emission in cryogeny [5]. Despite these premises, a full understanding of the SnV centre formation upon ion implantation and annealing has yet to be achieved, multiple emission lines at single emitter level (namely 620 nm, 630 nm and 647 nm) have been reported in Sn-implanted diamond samples [2, 4].
The work is based on the use of a Focused Ion Beam (FIB) setups available at the University of Surrey, which offer high spatial resolution (< 40 nm) and ion detection efficiency above 80%. This experiment explores scalable, high-resolution techniques for the controlled fabrication of SnV colour centres in diamond through focused ion beam (FIB) implantation. The primary objective is to assess the single-emitter creation yield and its potential for quantum information processing with improved accuracy, as compared to traditional implantation methods using collimated beams, which result in stochastic defect placement at low fluences (10^9-10^{13} cm^{-2}). Implantation energy of 70 keV is used to examine the variation of creation yield of Sn varying the number of implanted Sn ion per spot (from 500 to 20) for a total of 9 regions. The samples are subsequently annealed at various temperatures, between 500 °C and 1200 °C, in a low-pressure environment (10^{-6} mbar) to investigate the temperature-dependent optical activation of SnV centres. Single-photon sensitive photoluminescence confocal microscopy is employed to assess the quantum-optical properties of the fabricated defects, focusing on spectral inhomogeneity and single-photon emitter creation yield as a function of processing parameters.

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Microstructure-assisted microscopy and photonic nanojets by SU-8 microstructures made by proton beam writing

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Proton beam writing (PBW) has been recognized as a direct writing tool for making micro- and nanostructures. Our PBW system can produce a proton microbeam (a typical energy of 1 MeV) with a beam size of ~1 μm × ~1 μm, which can be employed to create microstructures in poly(methyl methacrylate) (PMMA) [1,2] and epoxy-based polymer (SU-8) [3,4]. Our previous studies have demonstrated that PMMA microstructures could be applied to form photonic nanojets (PNJs) with a high-intensity and narrow focusing beam behind the microstructures [1]. In addition, the PMMA microstructures could assist in the nanoimaging of commercial Blu-ray discs as microstructure-assisted microscopy [2]. In this work, we examine microstructure-assisted microscopy and the PNJ formation from the SU-8 microstructures. Accordingly, SU-8 microstructures with different diameters were fabricated using the PBW method on commercial Blu-ray discs, which were cut to ~1 cm × ~1 cm in size. Subsequently, imaging of nanopatterns on Blu-ray discs with the help of SU-8 microstructures was achieved by using an Olympus LEXT OLS 4000 laser confocal microscope at a wavelength of 405 nm. For the PNJ characterization, SU-8 microstructures were made on silica glass substrates. The PNJs were then measured using a confocal microscope at Mie University with an incident wavelength of 532 nm. In this meeting, we will present and discuss the results of the performance of SU-8 microstructures in microstructure-assisted microscopy and the generation of PNJs.

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This work was supported by JSPS KAKENHI Grant No. JP23K04558.

Poster Session A - Monday, 08.09.2025

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X-band Electron Linac for High-Energy X-ray Computed Tomography

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X-ray Computed Tomography (CT) is a non-destructive testing technique capable of producing three-dimensional images of internal structures, and its industrial applications have continued to expand in recent years. In recent years, specimen geometries have become larger and more complex due to the adoption of advanced manufacturing techniques such as metal additive manufacturing. Consequently, X-ray CT systems are required to offer higher transmission capabilities, enhanced resolution, and the capacity to image large specimens.

A high-energy X-ray CT system has been developed in collaboration with Saitama University and Metal Technology Co., Ltd. The system comprises two X-ray CT units operating at 0.95 MeV and 9 MeV, respectively. X-rays are generated by irradiating a tungsten target with electron beams at these energies. These high-energy electron beams are produced using X-band side-coupled electron linacs. To ensure a long target lifetime, a high-toughness tungsten compound [1] has been employed as the target material. The dual-energy X-rays enable high-resolution imaging of both the surface and interior regions of specimens. In this contribution, the X-ray CT system and recent experimental results are presented.

[1] H. Kurishita *et al.*, “Development of Nanostructured Tungsten-Based Materials Resistant to Recrystallization and/or Radiation-Induced Embrittlement,” *Materials Transactions*, vol. 54, pp. 456–465, 2013.

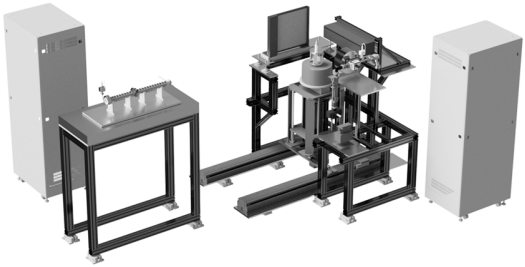

Figure 1. *Schematic view of the high-energy X-ray CT system.*

Beam Design of TE_{211}-Mode Single Hybrid Cavity Linac

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A TE_{211}-mode Single Hybrid Cavity linear accelerator (TE_{211}-SHC linac) is an ion linac with 4-vane RFQ and double IH-DTL structures in a single cavity. A double IH-DTL incorporates drift-tubes inside from alternating horizontal and vertical direction and excites TE_{211}-mode and provide gap voltage. This linac operated using the TE_{211}-mode accelerates ion beams in the low energy region (several tens of keV to about 3 MeV) with high efficiency. In this study, a TE_{211}-SHC linac proof-of-principle machine was designed and the cell parameters of RFQ and DTL sections were evaluated using a beam simulation code. In particular, to obtain high acceleration efficiency, the compound zero-order structure (KONUS[1]) was introduced as the acceleration method in the DTL section. Furthermore, end-to-end beam simulations in the TE_{211}-SHC linac were carried out to evaluate beam acceleration characteristics. The basic structure of the TE_{211}-SHC and the results of analysis using the beam simulation code are reported.

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This work was supported by JSPS KAKENHI Grant Number JP23H03668.

Development of a fast electrostatic chopper for short pulse beam generation using a compact proton accelerator neutron source

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Active neutron method, a type of neutron time-of-flight technique, is used for the non-destructive analysis of nuclear fuel materials. For practical on-site applications, the portability of the neutron source and the ability to perform fast analysis using high-intensity neutron beams are critical. The RIKEN Accelerator-driven Compact Neutron System-II (RANS-II), based on a proton linear accelerator, addresses these needs by enabling on-site installation and achieving a neutron yield of 10^{11} s^{-1} at a beam current of 100 μA [1].
To demonstrate the active neutron method using RANS-II, we have initiated the development of a fast electrostatic chopper designed to shorten the proton pulse width to a few microseconds. This chopper will be integrated into the Low Energy Beam Transport (LEBT) line of RANS-II. The beamline and chopper electrodes have been designed using a beam simulation code and 3-D electromagnetic simulation software. To evaluate the chopper's performance, we conduct beam chopping experiments using an ECR ion source and measure the chopped ion beam.
This presentation will detail the design and configuration of the electrostatic chopper and beamline, as well as report on the current status and progress of the chopper development.

[1] Kobayashi, T., Ikeda, S., Otake, Y., Ikeda, Y., & Hayashizaki, N. (2021). Completion of a new accelerator-driven compact neutron source prototype RANS-II for on-site use. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 994, 165091

This work was supported by JAEA Nuclear Energy S&T and Human Resource Development Project Grant Number JPJA24H24020125.

Development of a 200-kilovolt ion implanter setup at Ruđer Bošković Institute's accelerator facility

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Research interest on color centers in materials such as diamond, silicon, and silicon carbide has grown rapidly in recent years due to their vast potential for applications in quantum computing and quantum sensing [1]. To fabricate color centers, defects need to be introduced in the material so that they form various complexes with lattice atoms or lattice vacancies. There are two main ways of introducing defects into a diamond lattice: during growth and by ion implantation in a high-purity crystal. Ion implantation is a very mature material modification technique in the semiconductor industry where it is used to introduce dopants into semiconductors [2]. This technique offers several key advantages over incorporation of defects during growth. Specifically, ion beams can be focused to tens of nanometers [3], allowing for laterally well-resolved positioning of defects in the diamond lattice. Furthermore, by selecting the ion energy, implantation depth can be defined. Also, most ion sources used in accelerators allow for a wide range of elements from the periodic table to be accelerated. Finally, using low-noise systems for detecting incident ions [4], it is possible to very accurately determine the implanted fluence. For example, by implanting ions such as nitrogen optically active color centers (NV^- and NV^0) have been created and studied in detail [5].

The ongoing development of a low-energy ion implantation system (< 200 keV) at the Ruđer Bošković Institute's (RBI's) accelerator facility is presented. This system will enable the RBI accelerator group to expand its research into fabrication of color centers using keV-energy ions for use in quantum sensing applications.

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Experimental characterization of configurable electron beam parameters for multidisciplinary applications at the REX facility

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The REX (Removable Electron to X-ray) irradiation facility, based on a 5 MeV S-band standing wave electron linear accelerator, supports flexible beam configurations tailored to different irradiation setups [1]. This radiofrequency pulsed linac, developed at ENEA Frascati Research Centre, operates with a typical peak current of 120 mA and an adjustable pulse repetition frequency up to a maximum of 20 Hz. It enables a wide range of experimental activities, including studies on radiation damage in materials, testing of space components (as part of the ASIF program supported by the Italian Space Agency [2]), and cultural heritage restoration. A critical aspect underpinning these applications is the accurate and systematic characterization of the electron beam parameters, which vary depending on the irradiation configuration.

This work presents an overview of the REX facility's operating conditions and experimental techniques employed to qualify the electron beam at defined source-to-target distances and extraction energies. Multiple irradiation positions, each characterized by a distinct two-dimensional Gaussian transverse beam profile, when combined with adjustable machine settings, enable fine control over key beam properties, including transverse uniformity on the target surface, particle flux, energy, and energy spectrum [3]. Such versatility makes the facility suitable for a growing portfolio of multidisciplinary research activities. To qualify the beam, a comprehensive set of diagnostic tools is employed along the beamline. These include AC current transformers and Faraday collectors, which provide real-time beam current monitoring integrated with a pulse-by-pulse signal acquisition system. Dosimetric techniques involve the use of radiochromic films, which allow for detailed mapping of the transverse dose distribution as well as percentage depth-dose (PDD) profiles, and alanine pellets, which offer accurate absolute dose measurements. The combination of data from these independent monitoring systems enables the construction of inter-calibration curves and accurate dose maps, enhancing the facility's operational flexibility.

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Development of the RANS-III on-board Neutron Source System for the non-destructive Visualization of Bridge Decks Deterioration

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The 500 MHz RFQ 2.5 MeV proton accelerator, Li neutron generation target and other equipment were installed on a 40-foot size custom-built trailer. This system is the third accelerator neutron source in the RANS (RIKEN Accelerator-driven compact neutron systems) project and we call it RANS-III. The system is currently being developed to visualize deterioration of bridge decks due to water and salt by imaging using back scattered neutron and prompt gamma-ray measurement.

The floor of the trailer is reinforced with 22 mm thick steel plates and seven steel gates are installed to ensure rigidity. Protons accelerated horizontally toward the rear of the vehicle are deflected vertically by electromagnets and injected to Li target installed in the center of the elevating shielding under the floor through an approximately 80 cm square through-hole in the floor. The Li target is 40 mm in diameter, and the irradiated proton beam diameter is designed to be about the same size to disperse the heat load on the target surface. The shield, which prevents neutrons from being emitted except downward, is installed at the rear of the vehicle and can be raised upward during driving and lowered close to the road surface during measurement. The shielding was made as lightweight as possible, and Monte Carlo neutron scattering simulations were performed.

We have been developing RANS since 2011. Two accelerator-based neutron systems and an RI-based neutron salt meter are already being used for daily neutron scattering measurement experiments. RANS-I consists of 7 MeV proton LINAC (425MHz RFQ+DTL coupled) and a Be target with moderators of polyethylene at RT and mesitylene at 20 K. For the RANS-II (200MHz RFQ with Li target), the proton energy was lowered to 2.5 MeV to reduce the weight of the accelerator and the shielding. At the same time, we have developed a method to make measurements with a smaller number of neutrons. RANS-II is currently used as a stationary compact neutron source. Based on the measurement techniques, accelerator technology, and shielding parameters obtained in RANS and RANS-II, the RANS-III project is currently underway. In 2025, with the trailer stored in the newly constructed building, we prepare neutron generation tests, environmental radiation level measurements, and actual sample measurements.

Advances in Cs-Ion Source Technology for AMS

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Recent developments in Cs-ion source technology have led to significant improvements in efficiency, stability, and ease of maintenance, making it a new standard for MICADAS, MILEA, and LEA accelerator mass spectrometers. A newly designed Cs-nozzle offers a compact and modular construction, allowing for efficient manufacturing and simplified maintenance. This optimized design enhances Cs vapor output, enabling a reduction in Cs reservoir temperature while maintaining high ionization efficiency. Additionally, a newly developed ionizer, fabricated in house, provides improved longevity and operational stability. A dedicated mounting platform ensures reproducible assembly and disassembly, streamlining maintenance and replacement procedures.

A key innovation is the integration of a precise target positioner, enabling real-time x-, y-, and z-axis adjustments during measurements. This allows for external manipulation of the target position within the ion source chamber, optimizing the ion beam without interrupting data acquisition. These enhancements collectively contribute to a more robust and efficient Cs-ion source, advancing the capabilities of accelerator mass spectrometry.

Modular and Scalable LLRF Control System for RFQ Testing in MicroTCA Architecture

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In this contribution, the development of a Low-Level Radio Frequency (LLRF) acquisition and control system for high-gradient RF accelerator cavities is presented. This system leverages open-standard architectures for hardware and software, facilitating equipment reuse and reducing operational costs for testing RFQ (Radio Frequency Quadrupole) structures around 750 MHz. The approach overcomes proprietary limitations by adopting MicroTCA (uTCA), renowned for modularity, versatility, and scalability [1].

The system, presently under testing, adopts specialized Advanced Mezzanine Cards (AMC) for RF signal generation, conditioning and digitization, interlock handling, and triggering. I/Q modulation/demodulation enables precise analog-to-digital conversion and signal reconstruction. Similar MicroTCA-based LLRF implementations have been successfully demonstrated in high-gradient cavity tests [2], [3]. Parallel digital I/Q demodulators are implemented in FPGAs to efficiently manage multiple high-speed RF channels. Test results confirm high stability and highlight benefits in processing speed, flexibility, and multi-channel handling.

The software stack is built on open-source real-time operating systems. Tools like Yocto/Petalinux create custom embedded Linux distributions hosting real-time multithreaded control processes, including PID controllers for power control and critical operational threshold monitoring.

Control and supervision are provided by a SCADA system based on the TANGO Controls framework—an open-source, object-oriented, distributed-controls toolkit widely used at synchrotron and accelerator facilities. TANGO device servers abstract physical/logical components, enabling real-time monitoring, data archiving, alarm/event management, and graphical operator interfaces.

In conclusion, this work demonstrates a flexible and stable LLRF system architecture tailored for high-gradient RF accelerator cavity testing, promoting innovation in particle accelerator technology.

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Development of a C-band dielectric assist accelerating structure using high-permittivity ceramics

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A dielectric assist accelerating (DAA) structure [1], which is a type of dielectric-loaded accelerating structure, offers significantly higher power efficiency than conventional disk-loaded copper structures. The DAA structure is a higher-order TM-mode standing-wave accelerating structure, composed of low-loss dielectric cylinders and disks with irises, all periodically arranged inside a metallic enclosure. One key advantage of the DAA structure is its extremely high unloaded quality factor (Q_0) and high shunt impedance (Z_{sh}) at room temperature. This is achieved by tailoring the geometry of the structure to control the electromagnetic field distribution of the accelerating mode and reduce wall losses on the metallic surfaces [1,2]. Thanks to its high acceleration efficiency, the DAA structure can contribute directly to power savings and the miniaturization of industrial electron accelerator systems. However, while the DAA structure achieves high shunt impedance, its accelerating gradient is limited by the onset of multipactor discharges [3]. To address this limitation, we have developed a new DAA structure that employs high-permittivity ceramic materials, and we are currently evaluating its accelerator performance. In this conference, we will present the latest results from both simulation studies and experimental investigations of the improved DAA structure.

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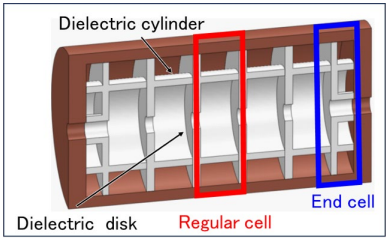

Figure 1. *Dielectric assist accelerating structure*

Development and Application of Three-Layer Structure RFQ Linac

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A radio frequency quadrupole linear accelerator (RFQ linac) is suitable for accelerating protons and heavy ions in the low energy region because it accepts a DC beam extracted from a proton or ion source and accelerates effectively up to the design energy with bunching and focusing using the RFQ electric fields. Depending on the quadrupole electrodes configuration, the RFQ linac can be classified into several types such as four-vane and four-rod. The four-vane RFQ linac, which accelerates beams with an electric field excited by the TE211 mode, has been mainly used for proton and heavy ion acceleration at high operating frequencies above 100MHz. Typically, in order to fabricate an RFQ cavity the necessary components are formed in advance and are then joined together to assemble the acceleration cavity by welding or brazing. However, the three-layer structure RFQ fabrication method, which was pioneered by our group at the Institute of Science Tokyo and TIME Co., can assemble the acceleration cavity by bolting together three pieces seamlessly, including RFQ electrodes from the same materials. The positional relationship between the tubular part and the electrodes can be maintained precisely at the time of machining. Therefore, the dimensional precision is increased and it is possible to manufacture a RFQ cavity with enhanced beam acceleration characteristics.
TIME Co. has been supplying three-layered structure RFQ linacs for heavy-ion therapy injectors and accelerator-driven compact neutron sources [1-5]. We are also developing an energy-tunable cavity. These results will be presented at this conference.

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Intense emission of secondary ions from energetic large cluster-ion impacts and its application to highly sensitive imaging mass spectrometry

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Primary ion impact on a solid target induces the emission of secondary ions (SIs) originating from atoms and/or molecules at or near the surface of the target. SI mass spectrometry (SIMS) is based on the fact that mass-spectroscopic analyses of the emitted SIs sensitively provide information on the chemical structure and elemental composition of the near-surface region of the target. SI emissions occur as a result of the deposition of the energy of primary ions on the target surface, and consequently, emission characteristics of the SIs strongly depend on the energy deposition processes. Cluster ion impacts are unique in that the constituent atoms of a primary cluster ion simultaneously impact a very small (nanoscale) area of the surface, giving different energy deposition processes and SI emission characteristics from monoatomic ion impacts. One of the SI emission characteristics of cluster ion impacts is that the number of emitted SIs per incident atom for a cluster ion impact is larger than that for the corresponding monoatomic ion of the same element with the same velocity and is generally enhanced with increasing the number of the constituent atoms of the primary cluster [1]. Therefore, the larger the primary cluster ion is, the larger the expected enhancement effect is on the SI yield. In addition, for the same cluster species, the number of emitted SIs becomes larger with increasing the impact energy [2]. We developed accelerator-based SIMS systems using energetic sub-MeV – MeV ion impacts of large clusters including C_{60} [3,4] and demonstrated their advantages for highly sensitive surface-analysis [5,6]. The enhancement effect of the energetic impacts of large clusters on SI emission yields is also advantages for highly sensitive imaging mass spectrometry [2]. Here we will present recent progress toward highly sensitive imaging mass spectrometry with energetic large cluster ion impact ionization.

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The performance of the Ljubljana nanobeam with sub-micrometre ion beams

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We constructed a new high energy focused ion beam setup. In order to be able to focus heavy ions to beam diameters well below one micrometre, we incorporated knowledge accumulated during the 25 year-long operation of the Ljubljana microbeam [1], as well as novel approaches, which include utilization of quadruplet of thin magnetic quadrupole lenses, active anti-vibration dumping system and a mu-metal shielding of the beamline. The process of ion optics optimisation and geometrical alignment was long but nevertheless converging and rewarding. By combining the four thin quadrupole lenses into an easy-to-operate focusing system, we created a setup that can focus ion beams with magnetic rigidities of up to 45 MeV amu.

The achieved beam sizes are strongly dependent on the injected ion beam brightness. As we rely on a high-brightness H^- multicusp injector for creation of the proton beams [2], we managed to form a 3 MeV proton beam with the size of 300 x 300 nm^2 at ion current of 5 pA, as well as 80 x 120 nm^2 at proton flux of 10000 ions/sec, where we measured the beam profile by means of an off-axis Scanning Transmission Ion Microscopy (STIM).

Our sputter heavy ion source produces ion beams with the beam brightness values typically two orders of magnitude lower than the multicusp, which reflects in the achievable minimal beam sizes. Among the heavy ion beams used for nanoimplantation, we managed to form e.g. 3.85 MeV $^{15}N^{2+}$ ion beam at ion current of 5 pA with a size of 600 x 600 nm^2, as well as 3 MeV $^{28}Si^{2+}$ beam with dimension of 700 x 700 nm^2.

We are currently looking for suitable nanopatterned structures in order to test and optimize the operation in low-current mode at ion fluxes of 1000 ions/sec, with a definite goal to form a 3 MeV proton beam with a size of 60 nanometers, measured by an on-axis STIM.

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CMAM for combined access to multiple facilities through EU project “ReMade@ARI” and “RIANA”

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The Centre for Micro Analysis of Materials (CMAM) is a research center belonging to the Universidad Autónoma de Madrid (UAM). Whose main experimental tool is an electrostatic ion accelerator with a maximum terminal voltage of 5 MV, devoted to the analysis and modification of materials. The accelerator is exploited through a set of beamlines, complemented by several ancillary scientific tools and lab support spaces. CMAM is a distributed Singular Scientific-Technical Infrastructure (ICTS) called Accelerator-Based Application Infrastructure (IABA) and formed by two nodes, the National Accelerator Center (CNA) and the CMAM. CMAM, in collaboration with ReMade@ARI, opens the door to over 50 premier European analytical infrastructures, empowering groundbreaking research in the circular economy for both academia and industry. We invite you to submit proposals that utilize at least two techniques from these state-of-the-art facilities, with the added bonus of generous funding for travel and accommodation. Take advantage of our biannual calls for proposals, where you'll benefit from the support of seasoned experts in various analytical methods alongside a vibrant network of dedicated junior scientists. Our newly created selection committee ensures a thorough and equitable evaluation of all submissions, making this an exceptional opportunity for innovative research. Further information can be found on the ReMade@ARI website (https://remade-project.eu/).

CMAM is also involved in RIANA (https://riana-project.eu/), an innovative project funded by Horizon Europe focused on nanoscience. The ARIE network (Analytical Research Infrastructures in Europe) plays a crucial role in the RIANA consortium, bringing together premier European networks dedicated to large-scale research infrastructures. Coordinated by DESY, RIANA comprises seven elite networks that offer advanced techniques in nanofabrication, processing, characterization, analysis, and simulation. RIANA provides streamlined access to 69 specialized infrastructures through a single-entrypoint, supported by a team of senior scientists, facility experts, and trained junior scientists. By integrating both curiosity-driven and challenge-driven approaches, RIANA aims to make a significant impact in nanotechnology, driving meaningful advancements for the future.

Characterisation of Zirconolites for Geological Disposal of Nuclear Waste Using Time-of-Flight Elastic Recoil Detection Analysis

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The safe storage of high-level nuclear waste is a global concern, with no unanimous method for long-term disposal. In recent years, the UK alone has reported an inventory exceeding 350,000 tonnes of waste containing significant quantities of radioisotopes such as U and Pu [1]. As such, it is paramount that storage materials are capable to withstand radiation damage, while still retaining the ability to immobilise radioactive nuclei. The current standard method of storage processing waste involves a vitrification process, whereby waste is incorporated into borosilicate glasses matrices [2]. Ceramics, such as zirconolites, are a promising alternative storage material, especially for transuranic elements, demonstrating both improved chemical durability and loading capabilities [3]. Understanding irradiation induced changes and the behaviour of He, i.e. α-particles, in such materials is essential in assessing their long-term stability.

To study the impact of radiation damage and helium accumulation in zirconolites, samples were irradiated with 30 keV α-particles at various fluences between the range of 4×10^{15} to 3×10^{16} ions/cm^2 to simulate the effects α-decay and internal helium accumulation. The diffusion behaviour of He was also investigated by annealing the implanted zirconolite at several temperatures between 450˚C to 650˚C. Characterisation and quantification of the implanted zirconolites was undertaken using time-of-flight elastic recoil detection analysis (ToF-ERDA) [4]. ToF-ERDA measurements were conducted using 16 MeV $^{127}I^{8+}$, with the simultaneous measurement of velocity and energy of recoiled atoms enabling an enhanced mass separation, alongside independent analysis of each element present. An example time-of-flight-energy histogram is shown in Figure 1, illustrating the elemental separation and distribution of He. ToF-ERDA was used to depth profile each zirconolite sample, allowing for determination of the He retention and diffusion characteristics. An increased annealing temperature was found to cause a reduction in the He content of the zirconolites, which was consist across all fluences.

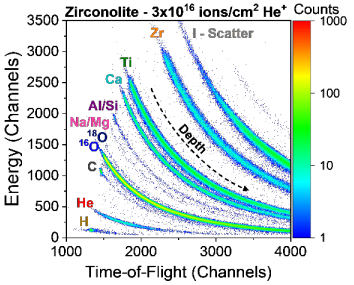

Figure 1: ToF-E histogram for a zirconolite implanted with 30 keV 3×10^{16} He$^+$/cm^2

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[3] D. Errandonea et al., Results Phys., 61, 107703, (2024)
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The study of chemical effects on high-resolution proton and alpha PIXE spectra of Al, Mg and Na

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The Kα Particle Induced X-ray Emission (PIXE) spectra of Al [1], Mg, Na, and their different compounds, excited by 2 MeV H and 3 MeV He ions, were measured with a recently developed wavelength-dispersive (WD) spectrometer with a flat diffraction crystal [2]. This setup enables energy resolution on the order of the natural linewidth of the measured Kα lines, allowing us to explore the fine structure of both X-ray diagram lines and multiple ionization satellite lines, which are unresolvable with energy-dispersive (ED) spectrometers typically used in PIXE experiments. Measurements were performed at the ion microprobe of the Tandem Accelerator Facility at the Ruđer Bošković Institute. From the recorded spectra, the energy shifts and relative intensities of different components of the emission spectral lines were extracted, with the aim of determining their dependence on the chemical environment of the measured atoms.
In this contribution, the experimental procedure will be briefly described, and the results of the experiments will be presented in detail.

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[2] I. Božičević Mihalić, A. Mioković, M. Rodriguez Ramos, D. Cosic, D. Mudronja, M. Tkalčeić, S. Fazinić; *Upgrade of the Ion Beam Analysis End-Station with the wavelength dispersive X-ray spectrometer for use with the focused MeV ion beams*, Measurement, 238 (2024), 115325.

Nanolaminate HfO_2/Al_2O_3 Films Studied by Combining MEIS and ERDA Techniques

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High-depth resolution analysis methods are increasingly essential to the characterization of modern nano-materials. Ion beam analysis methods, medium energy ion scattering (MEIS), particularly, are especially suited for nano-layer characterization. MEIS, however, has limitations, most notably analysis of hydrogen. In this study, we present a comprehensive analysis of HfO_2/Al_2O_3 nanolaminate structures using Medium Energy Ion Scattering (MEIS), performed with a toroidal electrostatic analyzer (ESA) based setup, combined with Time-of-Flight Elastic Recoil Detection Analysis (ToF-ERDA). These techniques provide complementary insights into the depth-resolved composition, interface quality, and dynamic processes occurring within the nanolaminates. Specifically, this combination enables accurate identification of interfacial impurities and defects, significantly contributing to the overall understanding of layer quality and stability.

Results show that MEIS, with its high-depth resolution, is well-suited to probe interfacial mixing, while ToF-ERDA offers unique capabilities for detecting light elements and quantifying stoichiometric variations. Combining these methods provides excellent depth resolution together with full elemental analysis. Additionally, the study evaluates the impact of deposition parameters on the nanolaminate structure, providing insights into optimal fabrication conditions.

Quantitative analysis of the samples was obtained by fitting simulations to experimental MEIS data. Simulations were done using the powerMEIS software [1] combined with elemental composition obtained from ToF-ERDA measurements. Layer thickness and elemental composition of the simulated spectrum were fitted using our own fitting code. The aim of this is to improve the accuracy of MEIS data analysis. The results underscore the potential of MEIS in the development of the deposition of thin films and nanolaminate materials for next-generation electronic and optoelectronic applications.

[1] http://tars.if.ufrgs.br/

Stopping power measurement of ^{7}Li, ^{16}O, ^{48}Ti and ^{63}Cu ions in platinum by time of flight spectrometry

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Accurate data on electronic stopping powers i.e., the specific energy loss of ions as they traverse matter are crucial across numerous fields of both fundamental and applied science [1]. However, due to the vast number of possible projectile-target combinations and the wide energy range over which stopping power data are required, it is impractical to experimentally determine all such values. This limitation underscores the importance of reliable theoretical models. While ab initio approaches have significantly advanced our understanding of ion–matter interactions, the most accurate predictions currently come from semi-empirical computer codes, which are based on optimized fits to existing experimental data. To enhance the predictive power and reliability of these models, extensive experimental data covering a broad range of ion-target pairs and projectile energies are still needed. In this study, we investigate the stopping power of carbon ^{7}Li, ^{16}O, ^{48}Ti and ^{63}Cu ions in platinum foil. The measurements were performed using a Time-of-Flight Elastic Recoil Detection Analysis (ToF-ERDA) system, as depicted in Fig. 1. A 30 MeV $^{197}Au^{7+}$ primary beam was used to induce recoil of ^{7}Li, ^{16}O, ^{48}Ti and ^{63}Cu ions from thick Lithium, silicon dioxide, Titanium and copper targets, respectively, toward a platinum stopper foil. The ions' energy loss through the Pt foil was determined by comparing their measured time-of-flight over a fixed path length, with and without the foil. Stopping forces were then calculated using the known foil thickness. The thickness of the used target was measured using 3.6 MeV Li^{3+} Rutherford Backscattering Spectrometry (RBS). The results provide valuable data for improving theoretical models, and observed deviations suggest possible charge exchange effects.

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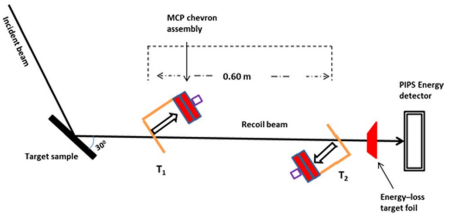

Figure 1. *Basic set up of the Time of Flight (ToF) ERDA spectrometer for stopping force measurements*

High Energy Particles Induced X-ray Emission (HE-PIXE) set-up optimization to detect trace elements in silver coins

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Previous research [1] has traced the provenance of silver extracted from mines in South America (Mexico and Potosi) via trade between Spain and France during the 16th century. A new numismatic approach focusing on a corpus of silver coins minted in Nantes enables them to be selected for chemical composition analysis, enabling trace elements such as gold, mercury, and indium to be quantified. This presentation will show the progress of the experimental work carried out at ARRONAX cyclotron and will focus particularly on high-energy PIXE [2] to detect traces of indium in silver-copper matrix probed with 68 MeV alphas beam. Setup was optimized to improve the detection limit down to few ppm and reach the average indium concentration in Potosi silver ore of 6.9±2.6 ppm.

HE-PIXE non-destructive analyses were done with high energy HPGe X-ray detector. Experimental parameters like resolution, shielding, X-ray filters, geometry (distances, angles) and electronic settings were explored to find the best configuration for indium detection. As a result, the count rate, signal-to-noise ratio and detection limit were improved using reference materials. The aim was to distinguished natural indium from activation products.

High count rates in the Ag Kα main pic about 2000 cps reduce irradiation time and provide enough statistic in In Kα line at 24.2 keV (Figure 1) with a dead time < 10% and good peak resolution. Also, first results show that irradiation time impact the production of Cd (Z+1) but not In (Z+2). Background noise was reduced using PMMA filter placed in front of the detector window to reduced low energy sum peaks in the area, improving S/N ratio. Assuming that indium nuclear production should be proportional to the silver content of the target, we found a difference between two Ag-Cu targets with 37 ppm and 65 ppm In. Meaning that natural in was detected within a few ppm. This result shows that high energy PIXE can be used to quantify traces elements in silver coins.

[1] E. Le Roy Ladurie, D. Richet, A. Gordus, J. Gords, et E. Le Roy Ladurie, « Le Potosi et la Physique nucléaire », Annales. Histoire, Sciences Sociales, vol. 27, no 6, p. 1235-1256, 1972.

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Elemental analysis upgrades at In-Air External Beamline

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Elemental quantification and localization with Ion Beam Analysis (IBA) methods and techniques utilizing accelerated ion beams at Jožef Stefan Institute (JSI) in Ljubljana, Slovenia, is frequently used for specific material research on various experimental beamlines.
In the last years, the In-Air External Beamline has undergone several upgrades including beam focusing system, PB-WDS (Parallel Beam - Wavelength Dispersive) X-ray spectrometer setup for improved fluorescence detection in the low energy range [1] and the end station was upgraded with improved capability for elemental mapping in the XY plane.
Typical experiments with standard PIXE (Proton Induced X-ray Emission) at the external beamline, can now be expanded with elemental mapping that include PIGE (Proton Induced Gamma-ray Emission) detection of lighter elements as well.
The latest experiments to test the overall capabilities of the developed setup were conducted on biological samples of tea leaves (*Camellia sinensis*) where elemental mapping of Fluorine and Aluminium was conducted on the large area of tea leaf samples [2].
For elemental quantification the software code XANTHO was developed to report concentration of detected elements for standard configuration setup [3].

[1] Kavčič, Matjaž, Rajh, Ava. *In-Air Micro-PIXE Mapping with Chemical Contrast,* Anal. Chem. (2025), 97, 11636-11642
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Ion Beam techniques for Space TPS material characterizations

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Re-entry into Earth's atmosphere, whether from low Earth orbit or an interplanetary trajectory, represents one of the most critical phases for spacecraft materials, particularly those comprising the Thermal Protection System (TPS). During this phase, vehicle surfaces are subjected to extremely high thermal loads and heat fluxes, primarily due to the formation of hot plasma downstream of the shock wave at the vehicle's leading edges. Accurate simulation of these conditions on the ground is essential for the characterization and qualification of TPS materials and is typically carried out in Plasma Wind Tunnel (PWT) facilities [1].

A major challenge during such test campaigns is not only the precise measurement of thermal fluxes but also the assessment of correlated surface degradation phenomena - most notably oxidation - that can critically affect the performance and lifespan of TPS materials [1,2].

Current methodologies used in aerospace material testing often fall short in providing sensitive and non-intrusive measurements of these degradation effects. To address these limitations, a collaborative research effort involving CIRA, the University of Campania, and ETH Zurich is investigating the use of Ion Beam Analysis (IBA) techniques [3]. These methods offer high sensitivity and are inherently non-destructive, making them suitable for characterizing the oxidation state of Ceramic Matrix Composites (CMCs) applied to TPS materials.

The current study focuses on ISiComp®, a carbon fiber-reinforced silicon carbide (SiC) composite produced via the Liquid Silicon Infiltration (LSI) process. This material has been developed by CIRA and Petroceramics and is employed in the TPS of ESA's Space Rider reusable re-entry module. The preliminary results of the IBA methodologies used to quantitatively determine the oxidation state and its possible correlation with the depth profile will be presented and discussed.

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[2] M. De Cesare et al., *Gamma and infrared novel methodologies in Aerospace re-entry: γ-rays crystal efficiency by GEANT4 for TPS material recession assessment and simultaneous dual color infrared temperature determination*, NIM B, 479 (2020) 264-271

[3] D. Rapagnani at al., *Ion Beam Analysis for recession determination and composition estimate of Aerospace Thermal Protection System materials*, NIM B, 467 (2020) 53-57

Stopping of He in Au and Ni with 1.7% accuracy

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Rutherford backscattering spectrometry (RBS) yields the elemental depth profile near the surface with a very good accuracy [1]. The accuracy is limited by the uncertainty on the energy loss of the ions, described in terms of the stopping cross-section (ε). Therefore, the stopping cross sections have been measured extensively [2] and the experimental data have been consolidated in semi-empirical models such as SRIM [3]. The spread in the data generally indicates a 5% uncertainty [3]. In this work, we critically analyze the available experimental data for He ions in Ni and Au, and we introduce a method to reduce the uncertainty to 1.7%.

Firstly, we review the literature stopping cross section for He in Ni and Au, ε_{Ni} and ε_{Au}, [2] following an approach akin to [4], which yields an uncertainty around 3%. Secondly, we use RBS spectra recorded at He energies between 0.9 and 2.5 MeV on samples consisting of ~100 nm thick Au and Ni layers, and the ratio, $r = \varepsilon_{Ni}/\varepsilon_{Au}$ is obtained with a high accuracy from the analyses [5]. By combining stopping cross sections from the literature and the ratio, new stopping cross section values are obtained for which the uncertainties are much reduced. Fig. 1 shows the stopping factors for He in Au and the associated uncertainties obtained in this work.

The new experimental values allowed us to construct a new curve for the stopping cross section. The correction to the stopping cross section for He in Au compared to SRIM-2003 and the associated uncertainties are shown in the lower part of Fig. 1. The accurate stopping cross sections can be used to reduce the uncertainty on the stopping cross section in other materials through relative measurements. This is essential to further improve the accuracy of RBS.

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[4] H. Paul *et al.*, Nucl. Instrum. and Methods B 61 (1991) 261-281.
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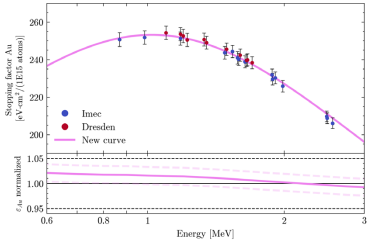

Figure 1. Stopping cross section for He in Au.

Free access to large-scale facilities through ReMade@ARI

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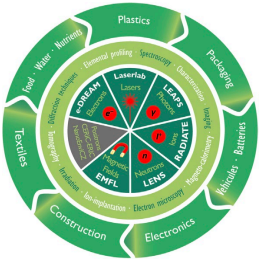

ReMade@ARI includes more than 50 infrastructures from 6 networks with corresponding analytical probes: RADIATE for ion beams, e-DREAM for electron microscopes, Laserlab-Europe for laser light sources, LEAPS for synchrotron radiation and free electron lasers, LENS for neutron sources, and EMFL for high magnetic fields as well as various other probes including positrons. After 5 periodic calls, ReMade@ARI opens in September 2025 a running call for proposals for users from the entire world (not limited to Europe). The evaluation criteria of proposals include (1) scientific excellence and methodology, (2) circular economy relevance, (3) novelty and interdisciplinary, (4) commercial impact. Proposals requesting simultaneously multiple techniques are given priority. The proposals are handled by a dedicated ReMade@ARI user office, and a single proposal for multiple techniques replaces the traditional facility-specific proposals. Beyond instrument access, ReMade@ARI offers extensive scientific support through the Smart Science Cluster: a team of 18 Junior Scientists offers one-to-one support to users from writing proposals to conducting experiments and analyzing data. This tailored scientific support enables researchers that may be new to large-scale facilities to concentrate on the science rather than the measurement techniques.

Funded by the European Union as part of the Horizon Europe call HORIZON-INFRA-2021-SERV-01 under grant agreement number 101058414 and co-funded by UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee (grant number 10039728) and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 22.00187.

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the UK Science and Technology Facilities Council or the Swiss State Secretariat for Education, Research and Innovation (SERI). Neither the European Union nor the granting authorities can be held responsible for them."

Optimization of the operating principle of a gas ionization detector for ion implantation

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The structural simplicity of gas ionization detectors makes them popular in particle physics experiments. In this work, the operational parameters of a novel gas-based system devised to register MeV ions were studied and optimized.
The detector is designed around the idea of the minimal interaction principle - traversing ions should only deposit a minimal proportion of their initial energy in the detector. This hinders ion detection due to few ionization events in the detection region, but enables transmission-style use in ion implantation experiments. The implementation of said principle involves removing the vacuum-to-gas barrier at the detector entrance in order to minimize straggling. The resulting pressure difference leads to a considerable outflow of gas. 2 MeV protons and a silicon-based reference detector were used to measure the detection efficiency as a function of the detector geometry, the electric field strength and the gas pressure. SRIM simulations estimate that these protons lose only 0.043% of their initial energy in the detection region, creating approximately 37 electron-ion pairs. To still ensure good ion counting efficiency, the detector operates in proportional mode such that the signal is enlarged through charge multiplication by avalanche formation. Efficiencies close to 90% were achieved for two different detector geometries, implying that the specific geometry is secondary as long as the electric field in the detection region is sufficiently strong. Switching to heavier ions allows for measuring the ion trajectory scattering in gas because of stronger interactions compared to protons. The measured values for 1.5 MeV silicon ions do not match with SRIM simulations, which can be explained by an off-axis or tilted active area of the reference detector.
Overall, the results are interpreted as a proof of concept for the chosen detector design. The bold removal of the vacuum-to-gas barrier did not negatively impact the detection efficiency, and the current design can serve as a basis for future iterations.

Investigation of Helium Ion Sources for a Compact High-Intensity Linear Accelerator System to Enable Large-Scale Astatine-211 Production

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At Institute of Science Tokyo, formerly Tokyo Institute of Technology, a high-intensity linear accelerator system is being investigated specifically to enable the large-scale production of astatine-211 (^{211}At) used in targeted alpha therapy (TAT) [1]. In this system, the ion source that provides the helium-ion beam plays a critical role for ensuring sufficient ^{211}At production and achieving system compactness.

In order to fully exploit the advantages of a high-intensity linear accelerator, the ion source must produce He^{2+} ions, which are more favorable for acceleration, beam current on the order of milliamperes. Therefore, we aim to develop a type of ion source based on plasma generation mechanisms that include microwave discharge (MD) and electron cyclotron resonance (ECR).

Previously, assuming He^{2+} ions as multiply charged species we proposed the design of a 10 GHz ECR ion source introducing a high magnetic confinement scheme [2]. This approach tries to solve the requirements by increasing the ratio of He^{2+} ions. As a different strategy we are investigating to enhance the total beam current including He^{2+} ions by using a mono-charged ion source powered by the microwave of 2.45 GHz widely used in commercial applications. Depending on the beam current obtained, this approach could offer a more economical solution.

In this presentation, we explore ion sources appropriate for this objective, based on various analyses, including magnetic-field distribution calculations and plasma simulations.

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Defect engineering and strain doping for oxide thin films by ion irradiation

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Complex oxides host a multitude of novel phenomena in condensed matter physics, such as various forms of multiferroicity, colossal magnetoresistance, quantum magnetism, and superconductivity. This is largely due to the strong correlation between charge, spin, orbital, and lattice parameters. Specifically, tilting the delicate energy balance in lattice interactions and kinetics, achieved by temperature, strain, or chemical doping, can result in significant modifications in these materials [1]. In this context, defect engineering by ion irradiation, which can introduce strain and electronic disorder, has emerged as a powerful technique to fine-tune complex phases of oxide thin films. The induced uniaxial strain, manifested as the elongation of the out-of-plane lattice spacing, is not limited to available substrates, the conventional and well-known strain engineering approach. In this contribution, we will introduce the tailoring of oxide thin films by ion irradiation, with examples including the modification of magnetic and magneto-transport properties of SrRuO3 [2, 3], and ferroelectric properties of BiFeO3 [4, 5]. The irradiated SrRuO3 films exhibit a pronounced topological Hall effect in a wide temperature range from 5 to 80 K, which can be attributed to the emergence of Dzyaloshinskii–Moriya interaction resulting from artificial inversion symmetry breaking associated with lattice defect engineering. In BiFeO3, we have obtained a super-tetragonal phase with the largest c/a ratio (~1.3) ever experimentally achieved. By controlling the ion energy, we can create a continuous in-plane charged antiphase boundaries around the implanted depth. The antiphase interface reveals a variety of atomic bonding configurations, showing the atomically sharp 180° polarization reversal across the boundary. We show that ion irradiation is a very versatile pathway for tailoring oxide functionalities, analogous to ion-implantation doping for conventional semiconductors. It is worth noting that ion beam technology has been well-developed for microelectronics. Once the principle of concept is approved, the approach can be easily scaled up and integrated into the industry production line.

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Grazing incidence high-energy heavy ions as a tool for production of nanoscale ripples

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High-energy heavy ion beam irradiation is a well-known tool for nanoscale modification of materials. Permanent damage formed along ion trajectory, known as an ion track, can be observed by different experimental techniques, such as TEM, RBS/c and AFM. Recently, it was noticed that grazing incidence irradiation can make ion tracks on the surface of the material much more easily than normal incidence irradiation can make ion tracks in the bulk [1]. Additionally, relatively large ion fluxes available at RBI accelerator facility, makes surfaces nanopatterning via multiple ion track overlap much easier [2].

In this work, thin oxide films (a-SiO_2, a-Al_2O_3 and a-MgO) prepared by magnetron sputtering deposition were irradiated by high-energy heavy ions (23 MeV I, 18 MeV Cu and 2.5 MeV Cu) at grazing incidence. After irradiation, these thin films were investigated by atomic force microscopy (AFM) and grazing incidence small angle X-ray scattering (GISAXS). Here we present results obtained by these investigations, and report optimal irradiation conditions under which nanoscale ripples appear.

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Metal/graphene oxide micro-structures for sensory application

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Graphene oxide based solids are excellent candidates for the sensory applications due to ability to detect at room temperature, excellent sensitivity, short reaction time, low cost, easy processing and mechanical stability. Furthermore, their doping by metals leads to an improvement of its sensory and electrical properties. Ion-beam lithography is a highly localized precise technique for doping and modifying properties, with several advantages, such as the absence of chemical agents, absence of unwanted oxide formation, less of residual impurities, and cost-competitive production. Unfortunately, direct ion-beam lithography with heavy metal ions remains a challenge due to the difficulty of focusing a heavy ion beam into a micrometer-size spot. This promotes the dominance of mask-based ion beam lithography to micro-pattern the material with heavy ions.

For this reason, we prepared polymeric masks on GO and PI substrates by ion beam lithography and subsequently the micro-scale sensors by ion implantation. The polymeric mask was prepared directly on the surface of the substrates by spin coating of PMMA, followed by proton beam writing and development in isopropyl alcohol. After the ion beam implantation, the mask was removed using acetone. The ion implantation was performed using 2.5 MeV Cu, Ag and Au ion beams with an ion fluence of 3.75×10^{13} and 3.75×10^{14} cm^{-2}. Subsequently, the shape of the created micro-structures and compositional changes of the irradiated materials were studied using Scanning Electron Microscopy/Energy-Dispersive X-ray spectroscopy methods, respectively. Complementary structure and compositional changes in the irradiated area were characterized by micro-Raman spectroscopy, X-ray Photoelectron Spectroscopy and Ion Beam analysis. The irradiation of non-conductive materials leads to de-oxygenation, carbonization, and creation of new carbon bonds, resulting in increased electrical conductivity. The electrical and humidity sensing properties of the prepared micro-structures were also tested and compared to the commercial sensor and to each other.

Investigation into the Response of Binary Semiconductors to Energetic Ions

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Utilizing the versatility of ion beam applications require a thorough understanding of the response of materials to ion irradiation. Incident energetic ions interact with materials, causing energy deposition in both electronic and atomic subsystems, and subsequent energy dissipation. Despite advances in a variety of ion beam applications, the role of energy deposition/dissipation processes in defect generation and annihilation is still not well understood. The present work studies the ion-irradiation effects on two binary semiconductor materials, namely GaAs and 4H-SiC. Both of these materials have attracted a lot of attention as suitable semiconductors with excellent radiation hardness. Thus, comprehensive studies are performed on the roles of the energy dissipation processes and irradiation temperature on the structural evolution of these materials after ion irradiation. More research has been devoted to determining the optical and electrical characteristics of 4H-SiC following various intense ion bombardments, oxidation, and post-irradiation thermal annealing. The findings of this work provide the foundation for comprehending the effects of the energetic ion-induced response of 4H-SiC and GaAs.

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Investigating the effect of ion beam irradiation on silica-embedded AuAg and AgPt bimetallic nanoparticles

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Nanocomposites (NCs) containing bimetallic nanoparticles (NPs) within a silica matrix demonstrate better optical properties and enhanced thermal and structural stability compared to their monometallic counterparts [1], making them adaptable for applications in plasmonics, photonics, and catalysis [2-3]. However, the utility of these NCs relies heavily on the morphological (size and shape) and physical characteristics (nanoalloy phase and segregation) of the NPs [4].

In this study, we explore the influence of low-energy ions (2.1 MeV Xe^{7+}) and swift heavy ions (100 MeV Au) on the growth kinetics, NP morphology, and stability of the nanoalloy phase in two bimetallic NCs: AuAg/SiO_2 and AgPt/SiO_2, across various ion fluences. The results are further compared with their monometallic counterparts (Au/SiO_2, Ag/SiO_2, Pt/SiO_2) [1, 5]. We extensively utilized the JEOL-F200 Transmission Electron Microscope in HRTEM, SAED, STEM, and EDS modes, along with UV-Visible absorption spectroscopy for the samples irradiated at different ion fluences and energies.

Under low-energy ion irradiation, we observe the dissolution of larger NPs with increasing ion fluences in both NC systems, leading to a uniform size distribution of embedded NPs while preserving the nanoalloy phase. For swift heavy ions irradiation, our results reveal a slight increase in NP size up to the ion fluence of $1x10^{13}$ ions/cm^2, due to SHI-induced thermal spike annealing. Beyond this ion fluence, the embedded bimetallic NPs elongate (into nanorods) in the direction of ion beam irradiation as a linear function of ion fluence applied. Notably, both AuAg and AgPt NPs maintain their alloy phase even at the highest ion fluence of $1x10^{13}$ ions/cm^2, unlike steady-state annealing where dealloying of AgPt NPs occurs after an annealing temperature of 500 °C. Finally, the possible reasons for elongation kinetics and significant nanoalloy phase stability are discussed.

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From recrystallization to electronic sputtering: Electron-phonon coupling strength-dependent structural evolution of Ge using SHI

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The effect of swift heavy ions (SHI) on single crystal Ge wafer is studied and detailed comparison with pre-damaged Ge single crystal wafer on further irradiation with SHI are reported. The irradiation by 100 MeV Ag was performed at room temperature with ion fluence ranging from 10^{12} to 10^{14} ions cm^{-2} using beam current of 1-2 pA. Electronic energy loss (S_e) of 100 MeV Ag in Ge is ~16 keV/nm and nuclear energy loss (S_n) is approximately 0.1% of S_e. We observed negligible damage formation in single crystal Ge. Three sets of Ge samples with sub-threshold, threshold and above threshold fluences of amorphization, were prepared by Ar irradiation. After SHI irradiation of these samples, it is observed that the first set of samples (sub-threshold amorphization) has undergone substantial recrystallization whereas in the second set of samples recrystallization is restricted to the region close to amorphous-to-crystalline boundary. Apart from results of c-RBS, Raman spectroscopy, high resolution transmission electron microscopy (HRTEM) and associated Fast Fourier transform (FFT) pattern studies confirm recrystallization [1, 2, 3]. In the case of heavily damaged samples no change in amorphous phase is recorded, instead swelling of the sample is observed after Ag irradiation. The relative swelling is found to increase steadily with increasing ion fluence up to 3×10^{13} ions cm^{-2} and then to saturate at a maximum value of 20% at highest fluence of 1×10^{14} ions cm^{-2} [4]. An unusual high sputtering of the porous structure opens up the sub-surface voids to show the surface pattern [5]. The results are explained on the basis of the thermal spike model [6].

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Use of JSI nano-probe for depth resolved implantation of ^{15}N ions for the formation of NV colour centers in a diamond

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Nitrogen–vacancy (NV) centres are a type of point defects in a diamond lattice where a carbon atom is replaced by a nitrogen atom, which is then coupled to a vacancy at one of the neighboring sites. These pairs form quantum systems that exhibit specific optical properties, such as photon absorption and emission, which can be exploited in a variety of applications in nanotechnology-related fields (e.g., nanosensors) [1]. For an NV centre to be used as a quantum sensor, it is important to know its precise depth in the diamond lattice. To achieve this, we employed ion implantation of ^{15}N ions at various energies. The main advantage of this technique is the control it offers over the amount of N atoms embedded in the diamond lattice and their precise depth.

By impinging ^{15}N into electronic-grade diamond substrates in an energy range from 0.485 MeV to 5.35 MeV, we created areas with ion doses ranging from 10^{11} up to 10^{14} N-atoms/cm² in predetermined patterns. The implantation was carried out at the Jožef Stefan Nano-Beamline, which is coupled with a 2 MV tandem accelerator. With the current set-up we are able to focus the 3.85 MeV ^{15}N beam to dimensions of 600 X 600 nm². However, for the purpose of implantation, the beam was defocused to a range of 3–6 μm, to ensure more homogenous implantation over the areas of 100 X 100 μm^2 or bigger. Ion currents were kept at a few pA to minimize the potential heating of the samples during implantation.

After vacuum annealing, NV centres were created, as confirmed by examining the samples using a confocal fluorescence microscope. With this we confirm the implantation of correct ions and activation of NV centers and indication of their depth in the prepared sample. Further characterization of NV properties, such as their luminescence relaxation time and other light response measurements, is ongoing to determine the effects of depth and NV centers density on their use as quantum sensors.

With nano-probe capabilities of focusing the ion beam with magnetic rigidities of up to 45 MeV amu, we are exploring the creation of ion-vacancies colour centers in diamond with other ion species.

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Investigation of Structural and Optical Properties of CZTS Thin Films sulphurized at varying times using Ion Beam Techniques

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In this study Copper Zinc Tin Sulphide (CZTS) thin films of 44 nm thickness were implanted with 150 keV Vanadium ions at fluence $3x10^{16}$ ions/cm^2. The CZTS thin films were synthesized utilizing a two-stage process, i.e., electron beam deposition of metal precursors on glass substrate in the order Zn\Sn\Cu followed by sulphurization in a quanta tube at 500°C under controlled nitrogen gas environment for durations of 30 and 60 minutes. The thicknesses of the thin films were determined by fitting the Rutherford backscattering spectrometry (RBS) spectra using the SIMNRA software. The range of the implanted ions was predicted using the Stopping and Range of Ions in Matter coupled with the Transport of Ions in Matter (SRIM/TRIM) software. The interest of this study is to investigate the effects of V^+ ion implantation on structural, optical and electrical properties of CZTS thin films sulphurized for durations of 30 and 60 minutes. X-ray diffraction (XRD) analysis identified CZTS with PDF 00-026-0575 as the main phase. Lattice parameters increased upon implantation, and that contributed to the large volume of the unit cell which confirmed the replacement of Zn^{2+} of small radius with V^+ of large atomic radius at the lattice site. Raman Spectroscopy confirmed the presence of intense peaks at wavenumbers 332 cm^{-1} – 337 cm^{-1}, corresponding to the primary vibrational A1 symmetry mode of single-phase Cu_2ZnSnS_4 with a kesterite structure [1]. Atomic Force Microscopy (AFM) reported roughness in the 30 nm – 68.47 nm range, associated with nucleation of grains that occurred after ion implantation. Ultraviolet-visible (UV-Vis) spectroscopy showed improvement in the optical properties after ion implantation with band gap in the 1.45 – 1.6 eV range. This energy band gap range is suitable for absorbing sunlight in the UV region for photovoltaic applications [2]. Improvement in conductivity upon ion implantation was confirmed from I-V measurements. Our findings show that V^+ ion implantation can be used to tune the properties of Cu_2ZnSnS_4 thin films into desirable properties for photovoltaic applications.

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Enhancement in NO_2 gas-sensing properties by low energy (keV) ion beam engineering of WO_3-SnO_2 nanocomposite thin films

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The various nanostructured materials have attracted significant attention in the domain of gas sensing on account of various active sites on the surface, high specific surface area, and also exhibit crystal facets with significant surface reactivity. The present investigation emphasizes the effect of low-energy ion beam irradiation on the structural, optical, morphological, and gas-sensing characteristics of WO3-SnO2 nanocomposite thin films.WO3-SnO2 nanocomposite thin films were grown by RF sputtering and irradiated with He ion beam with an energy of 125 keV at various fluences 1×1015, 5×1015, and 1×1016ion/cm2. The electronic energy loss and nuclear energy loss were confirmed by SRIM/TRIM simulation. The gas-sensing response measurements of pristine and 125 keV He ion irradiated thin films have been performed with the oxidizing gas NO2 (10 ppm) at varying temperatures. The morphological, optical and crystal structure of pristine and ion beam implanted thin films were studied by various characterization techniques like X-ray diffraction (XRD), UV-Visible, PL spectroscopy, X- Ray photoelectron spectroscopy (XPS), Raman spectroscopy, Atomic force microscopy (AFM). The results will be discussed during the presentation.

100 MeV Titanium Ion Beam-Induced Modifications in PTFE Thin Films: Structural, Optical, and Chemical Perspectives

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Polytetrafluoroethylene (PTFE) polymers are very adaptable in a variety of applications due to their distinctive qualities, which include low friction, great chemical resistance, exceptional heat stability, and non-stick qualities. PTFE's dielectric strength, thermal stability, and chemical inertness make it ideal for insulation in ion beam sources, ion implantation masks, and sample holder coatings. The structural and chemical properties of this polymer can be altered by high energy ion beam irradiation. The durability, accuracy, and effectiveness of the ion beam equipment are enhanced by PTFE through component protection, enhanced material selectivity, and reliable operation in high-energy and high-radiation environments. Under regulated energy and scan rate settings, several PTFE sheets were subjected to 100 MeV titanium ions in an ion fluence range of 10^{11} to 10^{12} ions/cm^2. Multiple characterization techniques were then used to analyze the irradiated materials such as X-ray diffraction (XRD), UV- visible, Fourier transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM) and atomic force spectroscopy (AFM). The detailed results will be addressed during the presentation.

Defect Engineering in SiC: Using Pre-Existing Damage to Prevent Helium-Induced Degradation

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Designing radiation-tolerant ceramics requires controlling how implanted gases interact with irradiation-generated defects. Here, we demonstrate that the concentration of pre-existing voids in sintered 6H-SiC directly influences the size and shape of helium-induced defects. Bulk samples were pre-damaged with self-ion carbon irradiation to 0.25 dpa and 0.5 dpa, creating two distinct populations of vacancy clusters. Subsequent 300 keV He implantation at 750 °C was analyzed using ERDA, TEM, nano-beam precession electron diffraction (N-PED), depth-resolved Doppler broadening spectroscopy, and supported by DFT/MD simulations. In pristine SiC, He agglomerates into extended platelets and nanocracks. Conversely, increasing the pre-damage level systematically reduces He-induced defects: at 0.25 dpa, discrete bubbles and bubble arrays form instead of platelets, while at 0.5 dpa, only sub-nanometer He–vacancy clusters are observed. Atomistic simulations show that higher void densities serve as efficient interstitial sinks during collision cascades, shrinking voids and encouraging the formation of many small vacancy clusters with high He binding energies. These findings establish "void-concentration engineering" as a practical method for reducing helium-driven degradation in SiC and other structural ceramics used in advanced nuclear systems.

PhD project: Ion implantation analysed with X-ray microscopy

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Understanding the effects of impurity incorporation at the few- to single-atom level is essential for scaling up deterministic doping strategies in quantum and classical nanoelectronics as well as to mitigate defects. In my PhD project, I investigate implanted atoms in silicon using synchrotron-based X-ray microscopy techniques. The project is two-fold, focusing both on the sensitivity and detection limits of scanning X-ray fluorescence (XRF) and X-ray beam-induced current (XBIC) [2] for analyzing low-dose implants with nanoscale spatial resolution.

In prior work [1], Masteghin et al. demonstrated detection of down to 650 Ga atoms in crystalline silicon via XRF using the Hard X-ray Nanoprobe (HXN) at NSLS-II. The sample was manufactured at the University of Surrey. Elaborating on this work we seek to set new benchmarks in sensitivity and detection limits. Our ongoing efforts aim to improve detection limits by employing different optical setups, reducing the noise level, and pushing towards experimentation at the newest 4th generation synchrotron storage rings, where an expected improvement of photon flux and a smaller spot size may enable the detection of single impurities in future. In parallel, we seek to investigate the complementary sensitivity of XBIC for electrically active dopants using crystalline Si samples prepared at Arizona State University with impurities implanted at the laboratory of Ion Beam Physics at ETH Zürich. These samples will be processed further to solar cells, which will allow the quantification of the effect of impurities on the local charge collection efficiency. This is critical to promote recycling of Si for solar cell applications (part of a ReMade@ARI-funded project). This combined approach tackling the quantification of both impurity concentration in semiconductors and their impact on electrical device performance aims to establish a metrology standard for few-ion implantation.

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[2] C. Ossig et al.; *X-ray Beam Induced Current Measurements for Multi-Modal X-ray Microscopy of Solar Cells*; Journal of visualized Experiments, no. 150, 2019

Dr. Giovanni Fevola and Dr. Svenja Patjens (DESY) are greatly acknowledged for supporting the experiment design and the team of Arnold Müller (ETHZ) for supporting the ion implantation.

Funded by the European Union as part of the Horizon Europe call HORIZON-INFRA-2021-SERV-01 under grant agreement number 101058414 and co-funded by UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee (grant number 10039728) and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 22.00187.

Accelerator production of theranostic radioisotopes

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Theranostic isotopes are pairs, sets of, or single radionuclides used in theranostic treatments as a combination of therapy and diagnostics simultaneously. This method allows the medical staff to diagnose and treat diseases simultaneously, i.e., cancers, using radioactive isotopes with similar chemical and biological behaviors that use the same biological pathways.

Although nowadays the diagnostics by using radioactive isotopes is much more widely used than the therapy with them, recent studies have proved the important role of therapeutical role of radioisotopes. The most common diagnostic radioisotopes are mainly used in PET/SPECT studies to characterize tumors and other diseases, and they are mainly gamma- and positron emitters (e.g., ^{18}F, ^{11}C, ^{67}Ga, ^{68}Ga, ^{64}Cu, ^{124}I, ^{44}Sc, ^{99m}Tc). The therapeutic radioisotopes provide lethal radiation of different types to the malignant cells. They are α–, β^-- and/or Auger-electron emitters (e.g., ^{177}Lu, ^{225}Ac, ^{90}Y, ^{131}I, ^{212}Pb/^{212}Bi). The most common theranostic pairs are: ^{68}Ga (PET) - ^{177}Lu (β^-) for nervous tumors and prostate cancer, ^{64}Cu (PET) - ^{67}Cu (β^-) for cancer treatment; ^{123}I (SPECT) - ^{131}I (β^-) for thyroid cancer treatment; ^{44}Sc (PET) - ^{47}Sc (β^-) for treatment of various cancers; ^{86}Y (PET) - ^{90}Y (β^-) for lymphoma and liver tumor treatment and ^{212}Pb (γ) - ^{212}Bi/^{212}Pb (α) for targeted therapy. There are also emerging multi-modal isotopes, where the diagnostic and therapeutic properties can be provided by a single radioisotope, such as ^{161}Tb and ^{117m}Sn (diagnostic: γ-emission; therapeutic: β^-/Auger-electron)[1,2]. The advantages of theranostic treatments are the tailored personal treatment, better positioning of the target cells and reduced damage in the healthy cells.

The production of these radioisotopes is mainly possible by using small and medium energy compact cyclotrons. In this presentation cross cross-section measurements and yield calculations will be provided to see the possibility of mass production of these radio medicines.

Our group has been performing experiments for decades to investigate production parameters of different radioisotopes (cross-section, yield, …), both on our compact multi-particle cyclotron and in cooperation with higher energy accelerators, among others, for the production of theranostic radioisotopes. Some of these results will be presented at the conference.

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[2] F. Ditrói, S. Takács, H. Haba, Y. Komori, M. Aikawa, Z. Szűcs, M. Saito, *Excitation function of the alpha particle induced nuclear reactions on enriched ^{116}Cd, production of the ^{117m}Sn theranostic isotope*, Nuclear Instruments & Methods in Physics Research B, 385 (2016) 1-8

Proton irradiation of Antarctic cryptoendolithic communities for the CRYPTOMARS project

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The CRYTPOMARS project [1], funded by the Italian Space Agency (ASI) and led by the department of Ecological and Biological Sciences of University of Tuscia, is a multidisciplinary research project aimed at investigating, with a multi-omic approach, the mechanisms of resistance developed by microbial communities living in the interstices of the porous rocks of Continental Antarctica. These communities, exploiting the refuge provided by the rock, survive in an environment referred to as "Martian analogue on Earth".
Investigation of their metabolic properties is conducted once colonized samples of Antarctic rocks are exposed, separately, to different stress factors representative of the Martian environment, such as thermal and hydration/dehydration cycles, UVs and ionizing radiation. The dose levels and dose rates for the different stress factors were selected with the aim of mimicking, as closely as possible, the chronic exposure conditions on the planet Mars, based on literature evidence.
In this contribution, we report the experimental set-up design, the dosimetric characterization and beam monitoring result of the irradiation campaign with 70 MeV proton beam provided by the TOP-IMPLART pulsed RF linear accelerator at ENEA Frascati Research Centre [2,3].
Challenges of this experiment lie mainly in the realization of a tailored accelerator set-up, allowing a reproducible and controlled delivery of very low doses (down to 50 mGy in irradiation times of at least half an hour) to over 80 samples. This was achieved by combining a machine setup characterized by an extremely low current (< 1 μA in a 3 μsec pulse) with a specifically designed sample-support.

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[2] P. Nenzi, et al., *Status of the TOP-IMPLART Proton Linac*, Proceedings of the 31st Int. Linear Accel. Conf., 28/08 - 2/09 2022, Liverpool (UK)
[3] V. Surrenti et al. *The new proton beam delivery line of the TOP-IMPLART accelerator*, Proceedings of the 14th International Particle Accelerator Conference, Venice (Italy) p.2423

This research has been carried out within the CRYPTOMARS project funded by the Italian Space Agency (ASI) under the contract n. 2023-12-U.0.

Investigating how COVID-19 may alter sodium distribution in lung: micro-LEXRF analyses in human tissues

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SARS-CoV-2 infection commonly presents with respiratory symptoms, which in severe cases can progress to pneumonia, acute respiratory distress syndrome and even death. Recent findings [1] indicate that the human epithelial sodium channel (ENaC), expressed in respiratory system, shares an identical Furin-sensitive cleavage sequence with the Spike viral protein. This may disrupt sodium (Na) homeostasis in the lung alveoli.

Scanning Transmission Soft X-ray Microscopy (STXM) combined with Low Energy X-ray Fluorescence (LEXRF) mapping is an established technique for analyzing the distribution of light elements in biological tissues and cells at submicron resolution [2–3]. The TwinMic beamline at the Elettra Synchrotron (Trieste, Italy) is particularly well-suited for detecting sodium in biological specimens [4].

Here, autoptic lung samples from COVID-19 affected patients were obtained by the Hospital of Trieste, chemically fixed and paraffin-embedded for safety reasons, and sectioned into 10 µm-thick slices. STXM imaging was performed on unstained slices deposited on ultralene film, using 1.5 keV photon energy to optimize the excitation of both Mg and Na. The regions of interest were selected in the consequent slices properly stained for histology recognition.

Initial analyses involved standard TwinMic STXM surveys across 80 × 80 µm² regions at submicrometric resolution. Subsequently, a novel Compressive Imaging method [5] was applied to XRF microscopy. This technique enables the mapping of millimeter-scale areas at high resolution, surpassing the limits of traditional methods by acquiring sparse data and adaptively selecting regions of interest in real-time.

The resulting elemental maps revealed intriguing patterns of sodium distribution. Notably, certain cartilage structures exhibited altered accumulations of Na, suggesting possible tissue-specific ion dysregulation associated with SARS-CoV-2 infection.

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Morphological characterization of neocortical lamination

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The neocortex has a cytoarchitecture structure composed of six layers of neurons with intrinsic connections and function. Attempts have been made to precisely define the cytoarchitecture of the cortical areas by establishing their spatial limits and the types of cells. Histological techniques that are traditionally used for this purpose have limitations and none in isolation provides the unequivocal and non-subjective definition of the different cortical layers. It is important to determine additional criteria for the clear establishment of cortical lamination to understand the diseases that affect such tissue. Then, the main aim of this work was to distinguish the cortical layers based on the elemental and areal density distribution of the neocortex tissue, using good resolution ion beam and synchrotron radiation facilities. To do that, brain samples from two male donors, who died of non-violent causes and without acute or chronic neurological diseases, were studied. Cerebral neocortex samples were irradiated with a 3 MeV proton beam for elemental and areal density measurements, through PIXE and STIM, respectively. Additional measurements using STXM were performed for morphological purposes. PIXE results showed increased peaks of Zn in two of the cortical layers. Moreover, the results demonstrated that the cortical layers have different densities. Density decreases drastically with the tendency of the neurons to be in greater number, especially in regions with higher concentration of pyramidal neurons.

Preliminary PIXE imaging tests carried out by MACHINA (Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis)

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Diagnostics for material analysis, in general, and for Cultural Heritage (CH), in particular, is a well-established research field [1]. Artworks being precious, and sometimes fragile objects, cannot always be moved, due to obvious logistic, economical and safety reasons. Therefore in-situ analyses are increasingly required, in order to respect the physical integrity of the object under investigation, avoiding damages. Among all the nuclear physics techniques applied for CH diagnostics, the IBA technique is one of the most used, as it allows for high sensitivity, multi-elemental, non-invasive and non-destructive analyses. However, this kind of techniques have remained a laboratory based technique because particle accelerators usually cannot be moved and just a few museums worldwide possess an accelerator laboratory. A step towards finding an answer to these difficulties is building smaller, lighter, less power-consuming particle accelerators, such as MACHINA. The accelerator was built within a collaboration between INFN and CERN to be completely dedicated to CH studies [2]. The main goal of MACHINA is to carry out imaging PIXE analyses, which are powerful above all in the CH field where often the sample has heterogeneous, layered and complex structure, such as in the case of paintings. MACHINA control and data acquisition systems were completely designed and implemented in laboratory by using open-source software. Being a new instrumentation, its complete characterization is mandatory, specially concerning the proton beam characteristics, in particular its effect on different materials, and the acquisition system protocol. Macro-areas (in order of cm^2) PIXE imaging tests were obtained by moving the sample in front of the fixed beam; analyses were carried out both on mock-up/all-purpose made sample and on real CH samples. For example, one of the former is a replica of a fresco's artwork and one of the latter is an ancient nautical chart by Jaume Bertran (1489), made accessible thanks to the collaboration with the Marucelliana Library of Florence. First tests of PIXE imaging showed no deformation or artefacts in the elemental distribution maps, and above all no material damage was revealed.

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On-line monitoring of H_2 release during external beam analysis of heritage pictorial materials

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The preservation of heritage materials during ion beam analysis (IBA) requires a thorough understanding of beam-induced effects and the implementation of exposure limits to prevent irreversible damage [1]. Pictorial materials are particularly sensitive to energetic ions beams, in which they can induce chemical modifications including gas emission [2]. In this study, we present a real-time method to monitor hydrogen (H_2) released during proton irradiation of paint layers using a fast-responsive, compact, and sensitive solid-state chemiresistor designed to detect trace amounts of H_2 in air. Experiments were performed on synthetic paint mock-ups —comprising white lead pigments (cerussite $PbCO_3$ and hydrocerussite $2(PbCO_3)\cdot Pb(OH)_2$) mixed with linseed oil (triglycerids) or egg yolk (lipids and proteins) — and a sample from an 18th-century painting [3]. Irradiations were carried out in a sealed chamber of 0.3 L volume filled with ambient air mounted on the external microprobe beamline of the AGLAE accelerator. The beam conditions were standard for PIXE analysis (3 MeV protons, 1.6 µC total dose, few nA intensity, 4 x 4 mm² area). The developed set-up enabled following and quantifying the H_2 microvolumes released every second (ca. 0.1 mL total, concentration up to several 100 ppm v/v) and differentiating between hydrogen released by the sample and originating from the ionization of water vapor along the beam path in atmosphere. These results provide a basis for developing integrated monitoring solutions to ensure the safe analysis of large cultural artifacts with the PIXXL beamline under construction at the AGLAE facility.

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This work was developed in the project *MONitoring fragile pictorial material during analysis by IONS beams*, in the frame of CNRS UAR 3506 Lab-BC and the ESPADON Equipex+ program (ANR-21-ESRE-0050), funded by the Agence Nationale de la Recherche and the Fondation des Sciences du Patrimoine.

Investigating Lanthanide Accelerator Mass Spectrometry for its use in Nuclear Data Production

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Accelerator Mass Spectrometry (AMS) is traditionally applied to radiocarbon dating and cosmogenic nuclides, but has the capability of analyzing heavier elements [1,2]. This study aims to create a sensitive technique for measuring lanthanides and select transition metals to measure cross sections and obtain other nuclear data that are helpful in filling gaps in the data base. The initial exploration determined baseline mass scans for yttrium, lanthanum, neodymium, samarium, europium, gadolinium, terbium, dysprosium and holmium. The optimal starting material was determined by collecting mass scans of lanthanide oxides, oxide mixed with calcium fluoride or lanthanide fluorides, along with testing silver and niobium mixtures with the lanthanide oxides. Aluminum and copper cathodes were used to determine whether this had an impact on the lanthanide ion current. The results showed that lanthanide fluorides produced more current than any of the chemicals without metal binders. Niobium mixed with an oxide in a 1:2 or 2:1 ratio performed better than a pure oxide and the silver ratios. The copper cathode also improved the beam current compared to the aluminum cathodes.

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Improved ^{36}Cl and ^{32}Si AMS Measurements at the 6 MV Tandem accelerator at ETH Zurich

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The 6 MV Tandem accelerator at ETH Zurich has a long history in Accelerator Mass Spectrometry (AMS). After more than 60 years of operation and almost 40 years of experience in AMS as one of the first AMS facilities in Europe this instrument is still in operation.
However, it underwent several modifications and upgrades during its lifetime. More recently, in 2012 the charging system was changed to a NEC Pelletron system. In 2023/24 the entire low-energy side was upgraded with the installation of a MICADAS-type ion source and an achromatic injector, and corresponding diagnostics elements.
The system is nowadays primarily used for AMS measurements that still require high energy for isobar separation, namely ^{36}Cl and ^{32}Si. For these lighter radionuclides the 6 MV tandem accelerator provides sufficient energy (around 40 MeV) for efficient suppression in the Gas-filled Magnet (GFM).
The performance of the upgraded system is described and discussed for ^{36}Cl measurements. The new ion source together with newly designed sputter targets for volatile Cl samples is the basis for high and stable source output and low cross-talk (factor 1:5000 to succeeding samples). Transmission is high (>20% for 7+) with thin 2 μg/cm^2 carbon stripper foils. Thin and large silicon nitride windows at the GFM entrance (50 nm, 10x10mm^2) and gas ionization detector (500 nm, 30x40 mm^2) results in high efficiency (>65%) while ^{36}S is effectively suppressed with an additional aperture inside the GFM at point with largest separation of ^{36}S from ^{36}Cl, resulting in measurements down to the 10^{-16} range.
In this contribution we report from our experience of the first two years of operation with samples measured for geological applications and larger ice core studies. We discuss in particular efficiency and cross-talk in the ion source, stability of the measurement and background suppression. Additionally, the experience for absolute measurements of ^{32}Si will be reported.

Recent developments in MILEA measurements at the CTU in Prague

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The Joint Accelerator Mass Spectrometry Laboratory of the Nuclear Physics Institute of the Czech Academy of Sciences (NPI CAS), Czech Technical University in Prague (CTU), and Archaeological Institute Prague of the Czech Academy of Sciences (AIP CAS) in Řež, Czechia, has operated the MILEA (Multi-Isotope Low-Energy AMS, Ionplus AG) system since 2021 [1]. While radiocarbon traditionally remains the primary focus, MILEA provides also versatile measurement options including following radionuclides – ^{10}Be, ^{26}Al, ^{41}Ca, ^{129}I, ^{236}U and other actinides. Within this list, CTU is responsible for measurement and development of methodologies for nuclides heavier than ^{26}Al – specifically their tuning, target matrix development, sample treatment, and analytical applications.
This contribution lists the laboratory's current sample portfolio, including analytical strategies for diverse matrices and contaminants, measurement parameters and limits achieved with MILEA. A brief overview of the ^{129}I, ^{236}U, ^{233}U, ^{239}Pu measurements, our first attempts at ^{41}Ca analysis, future plans, including a selection of previously unmeasured radionuclides, as well as problems encountered during the implementation and operation of MILEA will be presented. By sharing these insights, the authors intend to discuss AMS facility workflows, advance the measurement of target radionuclides, and expand their applications.

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The research is co-financed with the state support of the Technology Agency of the Czech Republic as part of the SARA project (SQ01010334), Environment for Life 2 Program. The infrastructure of the AMS laboratory built as part of the OP VVV RAMSES project was used during the implementation of the research.

Determination of ^{236}U in aqueous and other environmental samples from the area of the Czech Republic

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The anthropogenic uranium isotope ^{236}U is a highly relevant analytical tool used for both qualitative and quantitative analysis of the environmental impact of nuclear activities, allowing characterization of both associated emissions and nuclear materials, while at the same time, due to the chemically conservative behaviour of uranium, it can be applied as a tracer of a number of natural processes. However, due to the trace concentrations in environmental samples, the analysis places considerable demands on the sensitivity of the instrumental method used, which for most applications is met only by accelerator mass spectrometry (AMS), also operated in Řež u Prahy since 2022 as a joint facility of the Institute of Nuclear Physics and the Archeological institute of the CAS and the FNSPE, CTU. The ^{236}U levels were not previously mapped on the territory of the Czech Republic in connection with these facts, but recently, in cooperation with the Department of Nuclear Chemistry of the FNSPE, CTU and the TGM WRI, initial sampling and analysis of environmental samples from selected sites, including subsurface water from boreholes, surface water samples and sediment samples, especially from the Vltava River basin and the vicinity of the Temelín NPP, have been carried out. Besides these, various other samples including uranium ore, iron and demi-water from different sources were also analysed. Related ongoing project research includes mapping of ^{236}U and ^{129}I abundance in selected locations in the Czech Republic in the context of historical and present potential emission sources along with the preparation of a complete validated methodology to enable reliable monitoring of these anthropogenic radionuclides.

This research is co-funded with state support from the Czech Technology Agency under the SARA project (SQ01010334), Environment for Life 2 Programme. The infrastructure of the AMS laboratory built under the RAMSES project was used in the research realization.

A compact AMS laser photo-detachment system for isobar suppression

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Understanding Earth's past climate variability is essential for interpreting the mechanisms that drive natural fluctuations and for distinguishing them from anthropogenic influences. Long-lived cosmogenic radionuclides offer powerful records of past environmental conditions. Among these, ^{36}Cl is particularly suited to reconstructing solar proton events due to its enhanced low-energy production [1] and direct deposition in ice cores [2]. Surface-produced radionuclides like ^{10}Be and ^{26}Al are also widely used to date geological processes through measured nuclide ratios [3]. Accelerator mass spectrometry (AMS) enables detection of these radionuclides at extremely low concentrations by eliminating interfering isobars. At the Laboratory of Ion Beam Physics at ETH Zürich, the development of compact AMS systems has improved efficiency, precision, and throughput while reducing system complexity and cost.

Nevertheless, the ultra-low concentrations of ^{36}Cl and ^{26}Al still challenge the detection limits of compact AMS. In order to break new ground in measurements of these radionuclides with compact AMS, we turn to laser photo-detachment as a novel isobar suppression method [4], where interfering anions are neutralised via photon energies just above their electron affinity, leaving the radionuclide of interest unaffected. Realising this technique requires decelerating the ion beam to ensure sufficient laser-ion interaction time, typically achieved using a radiofrequency quadrupole (RFQ) cooler filled with a light cooling gas. Optimising such a system requires precise control of the deceleration and reacceleration regions surrounding the gas cell, as ion cooling in helium demands sub-eV energies to avoid neutralisation. This work presents our initial focus on two critical aspects: delivering the lowest energy beam possible from the ion source and controlling the deceleration into the RFQ. The former is addressed through beam energy and emittance measurements at low extraction voltages, while the latter is guided by ion-optical calculations and gas flow simulations to model conditions at the RFQ entrance.

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