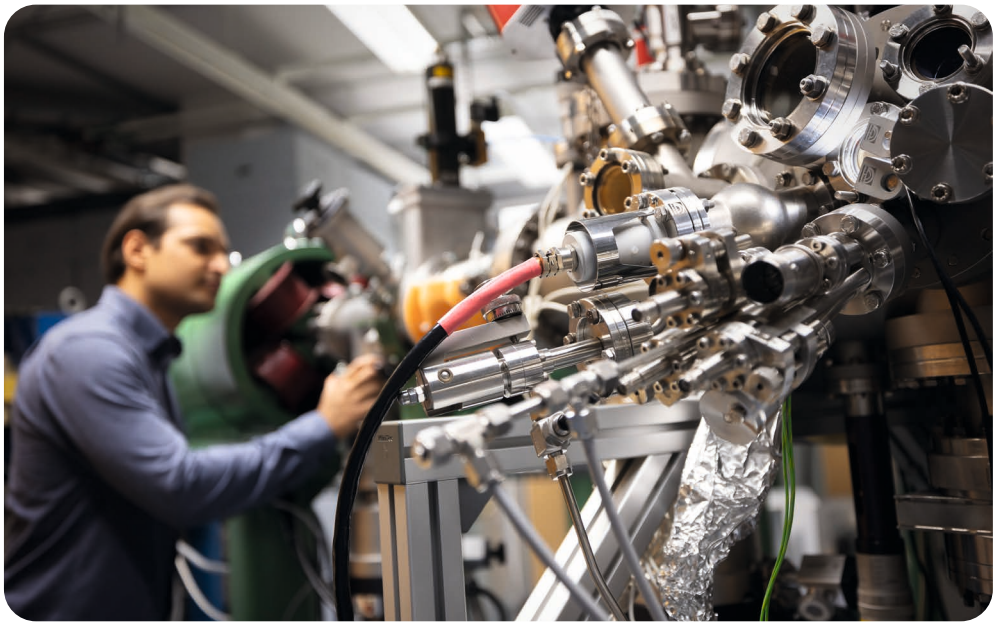
Tandem Laboratory

A National Research Infrastructure

Highlights 2025



UPPSALA
UNIVERSITET

The Tandem Lab in Numbers

4 **Accelerators at the Tandem Laboratory**

- The 5 MV Tandem Pelletron for a plethora of techniques and applications.
- The 350 kV implanter for implantations and high-resolution materials analysis.
- The MICADAS – a compact Tandem accelerator dedicated to radiocarbon dating.
- The time-of-flight low-energy ion scattering (LEIS) system.

11 **Beamlines in total** are connected to the accelerators providing many analytical techniques within ion beam analysis (IBA), ion-beam induced materials modification (IBMM), and accelerator mass spectrometry (AMS).

~300 **Electronvolt** is the lowest energy available at our accelerators – enabling materials analysis with extreme surface sensitivity.

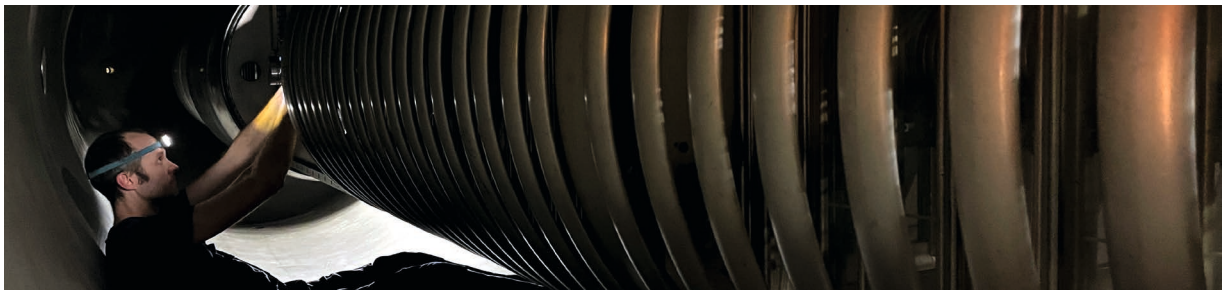
~50 **Mega-Electronvolt** is the highest ion energy available – achievable by accelerating for example gold ions with charge state 11+ in the Tandem Pelletron.

2746 **Hours of beamtime** were provided at the Tandem Pelletron in 2025.

1883 **Hours of beamtime** were provided at the implanter in 2025. Of these, 924 hours were used for implantations and 959 for medium-energy ion scattering and low-energy IBA.

5493 **Samples dated** in 2025 using AMS at MICADAS.

>550 **Individual users** accessed our infrastructure in 2025; using our services in either IBA, IBMM or AMS.



Funding acknowledgements

The Tandem Laboratory is supported by the Swedish Research Council, the Swedish Energy Agency, the Wallenberg Initiative Materials Science for Sustainability (WISE) and EUROfusion. We are part of the infrastructure networks ReMade@ARI and RIANA funded by the European Commission as well as the Swedish archaeology infrastructures Swedigarch and ArchLab.

2025 in Review

LEIS workshop

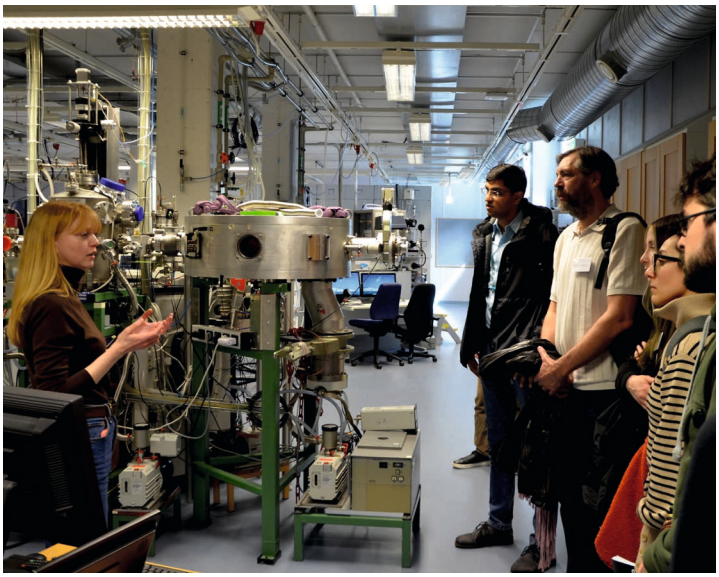
The Division of Materials Physics and the Tandem Laboratory hosted a workshop in June 2025 that brought together 20 researchers working with low-energy ion scattering (LEIS). LEIS uses low-energy ion beams to enable high-resolution measurements of the surface composition of materials.

The workshop covered challenges and shared expertise related to the use of LEIS over two days in Uppsala. Partici-pants presented their research on topics such as thin-film production, carbon quantification, and silicide formation.

WISE study visit

A group of PhD students and postdocs funded by the Wallenberg Initiative Materials Science for Sustainability (WISE) visited us in May. They were introduced to the WISE infrastructure **LigHt** at the Tandem Laboratory. LigHt is an interdisciplinary user platform for materials science with a specific focus on energy materials and sustainability that is currently being built at the Tandem Lab.

We are always happy to offer study visits upon request, both for researchers, students and the general public.



Harriet Åhlgren joined

In September, Harriet Åhlgren joined the Materials Physics division as Associate Professor. Her research focuses on the modification of 2D materials using ion beams. She develops ultra-low energy techniques for high-precision modifications and defect engineering. Besides a range of experimental characterisation methods, she also uses atomistic simulations to study dynamic ion-solid interactions.

Previously, she worked as an Academy Research Fellow at the University of Helsinki, where she developed functional nanomaterials, including defect-engineered graphene and 2D metals.

Research Highlights 2025

AMS Radiocarbon dating gives insight into runic traditions

The discovery of several inscribed sandstone fragments at the grave field at Svingerud, Norway, provides the earliest known dated context for a runestone. Radiocarbon dating using AMS was provided by the Tandem Lab.

The development of runic writing and the practice of inscribing runes on stone are difficult to trace because runestone inscriptions are rarely found in original or datable contexts. The Svingerud stone fragments are a rare find since samples from the grave could be used for radiocarbon dating.

One single standing stone

The Museum of Cultural History, University of Oslo, excavated the grave field Svingerud in 2021-2023. In a flat grave beneath one of the grave mounds, a large sandstone with runes from the older futhark, the oldest runic alphabet, was uncovered. Together with a large sandstone slab from a different grave as well as several fragments it once formed one single standing stone.

Grave samples for radiocarbon dating

29 samples of charcoal and cremated human bones from the graves were radiocarbon dated by the Tandem Laboratory. The authors of the study used these data to construct a chronological model using Bayesian statistics. The placement of the different graves provided additional information on their relative age.

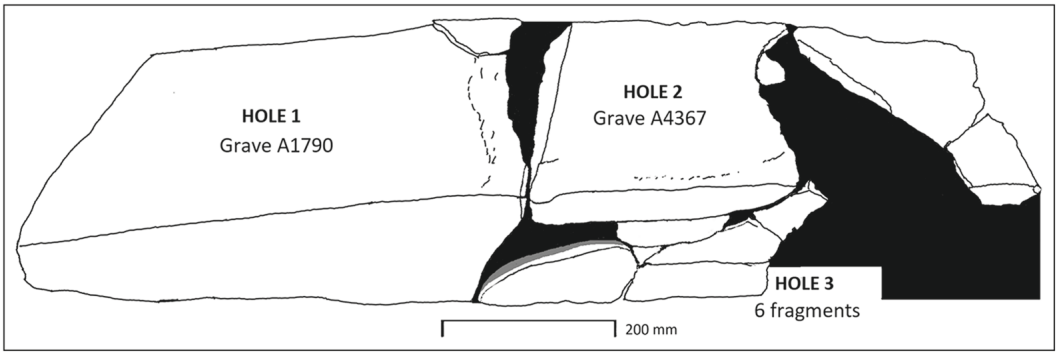
All this information suggests that the grave containing the large, inscribed sandstone dates to the Roman Iron Age, between 50 BC and AD 275. Even though this is a wide time span, it makes the Svingerud stone the oldest dated runestone.

Multiple runic inscriptions

The runestone features multiple runic sequences and other visual elements. It is not always obvious, which elements are purely ornamental, and which are a form of early writing. The position on a grave field and the original raised stone suggest a commemorative or dedicatory intention. On the large stone fragment eight runes are more distinct than the rest. They face right and read idiberug (marked by a "1" in the image). Idiberug might be a female name referring to a person buried in the grave, the person who raised the stone or someone/something else.

Runic inscriptions on the large sandstone piece from the Svingerud grave field. Reproduced from reference below.

The early date and unusual mixture of runes raise new questions on the meaning and function of early Scandinavian runestones. The discovery might also shed new lights on the development of early runic writing.



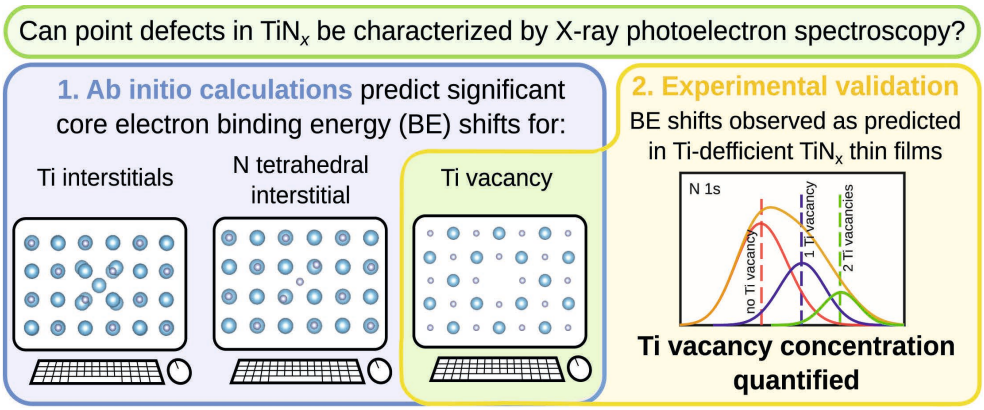
The assembled sandstone fragments weigh 107 kg. Once upon a time they formed one single raised stone. Reproduced from reference below.

Inscribed sandstone fragments of Hole, Norway: radiocarbon dates provide insight into rune-stone traditions

S. Solheim et al.
Antiquity 99 (2025) 404

IBA Is it possible to identify point defects in TiN_x with X-ray photoelectron spectroscopy?

A combination of ab-initio calculations, X-ray photoelectron spectroscopy and IBA could determine that the nitrogen excess in TiN_x films is caused by Ti vacancies. The Ti vacancy concentration in TiN films with 54 to 58 atomic per cent N was quantified.



The combination of DFT and XPS could successfully identify and quantify point defects in titanium nitride samples. Reproduced from reference below.

Titanium nitride (TiN) is a hard and non-toxic material, making it widely used as a decorative layer for cutting and other tools as well as a structural and functional coating on medical implants. It also has potential to be applied in other technologies such as solar cells and plasmonics.

Point defects influence materials properties

The properties of TiN_x are greatly influenced by the stoichiometry, i.e. the ratio of Ti to N atoms, the value of x in this notation. The stoichiometry in turn is governed mainly by different point defects. The study, which is a collaboration between Masaryk University (Czech Republic), RWTH Aachen University (Germany), Uppsala University and Montanuniversität Leoben (Austria), investigates how a combination of X-ray photoelectron spectroscopy (XPS) and ab-initio calculations based on density functional theory (DFT) can detect and predict these defects.

XPS can determine how an atom is bound in a solid. Point defects therefore lead to small shifts in the measured electron binding energy, but it remained to be seen if those are big enough to be detected with a tabletop instrument. The researchers analysed four samples with different stoichiometries with XPS and could indeed see shifts in the binding energy. The causal relationship between stoichiometry and these shifts was based on IBA done at the Tandem Laboratory to accurately determine the samples' compositions. All samples had been coated with a thin layer of aluminium to exclude any influence from oxidation.

DFT predicts shifts in binding energy

The researchers used DFT to calculate the expected shifts of the binding energy and compared the results to the experiments: they got a match for Ti vacancies (= missing Ti atoms in the crystal lattice), N tetrahedral interstitials (= additional N atoms in the crystal structure), and two types of Ti interstitials (= additional Ti atoms in the crystal structure). The IBA results showed that for all samples the ratio of N to Ti atoms was greater than one, excluding the case of Ti interstitials.

Observed shifts are caused by Ti vacancies

The two remaining options: N interstitials and Ti vacancies are hard to distinguish with XPS. However, N interstitials are unlikely to stay at the tetrahedral site but move to different positions in the crystal lattice that are energetically more favourable. Interstitials at this site do not cause a chemical shift according to the DFT calculations and are consequently invisible with XPS.

Ti vacancies are therefore the only remaining explanation for the chemical shifts measured with XPS. With this knowledge it was even possible to fit the spectra and quantify the amount of Ti vacancies. The researchers point out that the method can also be applied to other nitrides of the NaCl prototype crystal structure.

Prediction and identification of point defect fingerprints in X-ray photoelectron spectra of TiN_x with 1.18<= x <= 1.37

P. Ondračka et al.
Materials & Design 259 (2025) 114752

IBA

New insights into erosion of Moon's surface

The erosion caused by the bombardment with solar wind ions has been greatly overestimated. This was revealed by a study combining experiments using real Moon rocks and 3D simulations.

Astronaut Charles M. Duke Jr., lunar module pilot, is photographed collecting lunar samples during the Apollo 16 mission. Photo: NASA

While the Moon has no real atmosphere, it has a thin exosphere containing individual atoms and molecules. The origin of this exosphere is an important open research question, and several mechanisms are thought to be possible. The study at hand looked at one of them, sputtering caused by light solar wind ions, and found that it contributes much less than previously thought. The researchers believe that this difference results from accounting for the roughness and porosity of the Moon rock regolith.

The study was done by an international collaboration coordinated by TU Wien. The Tandem Lab contributed with high-resolution IBA to determine the Moon rock's composition with high accuracy.

Solar wind erosion of lunar regolith is suppressed by surface morphology and regolith properties

J. Brötzner et al.
Communications Earth & Environment 6 (2025) 560

IBMM

Defects in graphene can migrate at room temperature

Irradiation through a mask provided direct evidence that defects in self-supporting graphene are mobile at room temperature.

Defects and strain can be unwanted imperfections in a material, but they can also be used to tailor desired properties. The controlled introduction of defects into graphene can for example enhance chemical reactivity or change the bandgap for semiconductor applications.

Tuan Tran, researcher at Uppsala University, is loading graphene samples into the irradiation chamber of the Tandem Lab's ion implanter.

The Tandem Lab's implanter was used to irradiate self-supporting graphene samples with 20 keV argon ions. The irradiation induced a strain up to 0.8%. The effect reversed at even higher irradiation doses indicating that the accumulation of defects leads to strain relaxation.

In a second part of the study the graphene was irradiated through a nanopore mask. Single-vacancy-defects were found even in the areas shaded by the mask, which can be explained by them migrating from irradiated to non-irradiated areas – even at room temperature!

Mobility of Single Vacancies and Adatoms in Graphene at Room Temperature

T. T. Tran et al.
Small 21 (2025) 2504370

IBA

Titanium particles common around dental implants

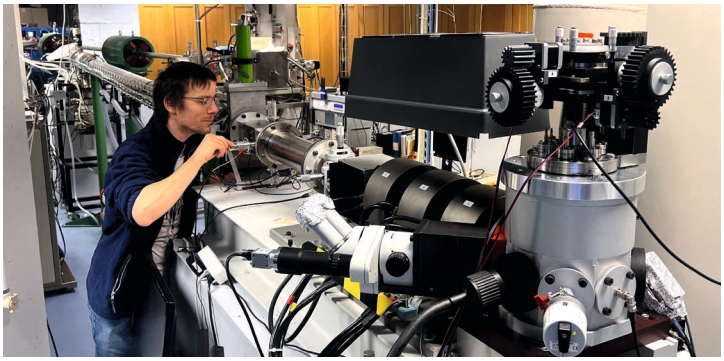
Titanium micro-particles in the oral mucosa around dental implants are common. This was shown in a study from the University of Gothenburg and Uppsala University using the Tandem Laboratory's microprobe.

Dental implants are common and are secured with biocompatible titanium screws. Previous research has shown that titanium particles may occur in inflamed tissues around dental implants. The study demonstrated that titanium micro-particles were consistently found at all examined implants – even those without signs of inflammation.

Accelerator-based microscopy, μ-PIXE

The microprobe was combined with particle-induced X-ray emission (μ-PIXE) to map the distribution of titanium particles in tissue samples. μ-PIXE is a non-destructive microscopy method providing information on the elemental composition of samples. Its high sensitivity and spatial resolution enabled the efficient detection of the microscopic particles.

In Sweden, only the Tandem Laboratory offers μ-PIXE measurements. To make this type of study possible the researchers had to develop the existing μ-PIXE system further. Now much larger sample areas can be scanned and microparticles can be identified automatically. This high throughput ensured that data from a sufficiently large population could be collected.



Gyula Nagy at the beamline at the Tandem Laboratory where the μ-PIXE measurements were done.

21 patients serving as their own control

The study included tissue samples from 21 patients with multiple adjacent implants. Samples were taken both at healthy implants and at implants affected by peri-implantitis, an inflammatory disease in the tissue around the implant. Each patient thus served as their own control. The density of particles varied between patients, but not between sites with and without peri-implantitis within the same patient.

The researchers also observed that tissue samples with higher concentrations of titanium particles had an altered gene expression, especially genes related to inflammation and wound healing. 14 such genes were identified, but it is unclear whether the particles influence the local immune response or if the difference in gene expression reflects inter-individual variability in inflammatory conditions.

The researchers suspect that titanium particles are released during the surgical installation procedure. In this context, the observation on differences in micro-particle densities between various implant systems deserves attention, since the surface structure of the implant may influence the deposition of micro-particles.

Titanium micro-particles are commonly found in soft tissues surrounding dental implants

C. Dionigi, G. Nagy et al.
Communications Medicine 5 (2025) 78

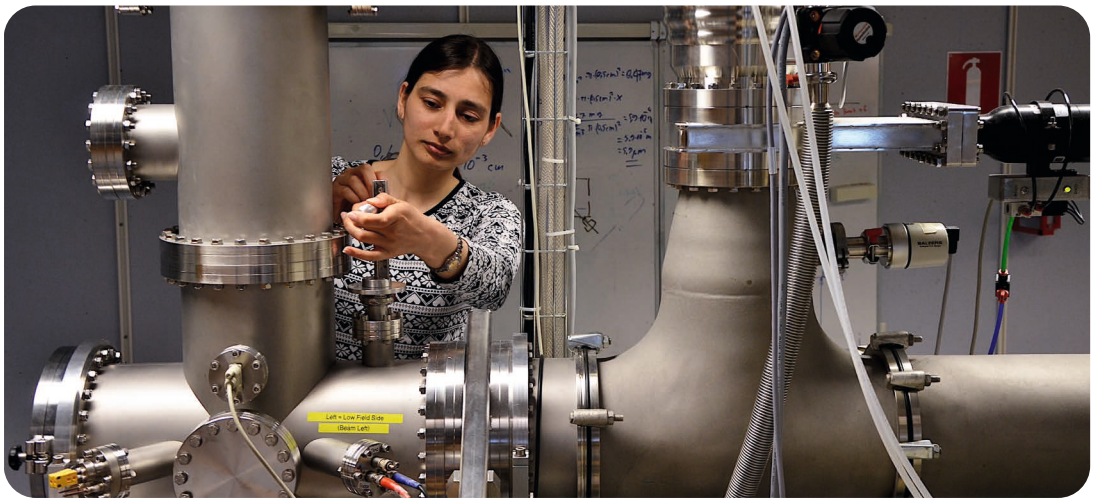
Infrastructure update: Microprobe autofocussing system

The software-based autofocussing system focusses the beam down to 3 μm, independent of the user's level of experience.

Previously, the user had to observe the ion beam spot on a fluorescence screen and manually adjust the currents to the focussing magnets to decrease the beam size. This procedure could prove difficult – especially for inexperienced users and at small beam spot sizes. Now, a software processes images of the beam spot in real time providing feedback to a minimisation algorithm that controls the magnet currents. This way, a focussed beam spot of 3 μm is achieved in only 3 minutes – independent of the user's experience. The software can be adapted to other microprobe systems, and is also available on GitHub.

An autofocusing system for nuclear microprobes—based on real-time image processing and numerical optimization

D. Papaioannou et al.
The European Physical Journal Plus 140 (2025) 585



Contact

The Tandem Laboratory is a user facility and provides services within radiocarbon dating, ion-beam induced modifications of materials including implantations as well as analysis of materials composition and structure on the nanoscale. Check our website on how to gain access.

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