NEUTRONS FOR SOCIETY

Annual Report 2025

Institut Laue Langevin

The world's leading facility in neutron science and technology

Ipoustéguy's sculpture at the Institut Laue Langevin (ILL) in Grenoble is a monumental work that seamlessly integrates with its surroundings. It depicts an evocative sequence of human history and its challenges, from humorous beginnings to darker representations of the consequences of the discovery of atomic fire. The artwork also expresses hope through symbols of maternity and the continuity of life. The depiction of man, portrayed vividly, embodies the duality of his existence, illustrated by symbolic forms and a door evoking uncertainty about the future. This captivating sculpture invites deep reflection on the journey of humanity.

annual **report** 2025

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FOREWORD

As you read through our annual report for 2025, I am sure you will be struck by the breadth and quality of the science highlights. ILL continues to deliver unique and important scientific insights, and in doing so reinforces its position as the leading facility in the world for research using neutrons. But our impact is much broader than fundamental science. Many of the research areas you will read about serve as illustrations of the importance of neutron scattering in delivering solutions to societal challenges. Thanks to the unique sensitivity of neutrons to hydrogen and other light elements, we can study materials and operating devices needed for the large-scale electrification which will reduce our reliance on fossil fuels, while this same sensitivity is also used to better understand key biological systems which improve human health. The ability of neutrons to deliver quantitative information on magnetic systems continues to drive our fundamental understanding of the quantum materials which will form the basis of the quantum computers of the future.

ILL is particularly well-placed to deliver on these inherent strengths of neutron scattering because of the breadth and technical quality of our instrument suite. After a two-decades-long continual programme of technical developments and instrument upgrades, the ILL instrument suite is at the peak of its performance. It is the largest and most capable it has ever been. It is also the largest and most capable instrument suite anywhere in the world.

This is evident in our operational record for 2025 in which we delivered two long (63-day) cycles. The first cycle was the most scientifically productive on record, beating all previous records on the number of experiments performed and users on site. The second cycle beat that record, delivering even more experiments than the first.

The ILL Science Strategy which was published in 2025, outlines how we will leverage this position of strength to deliver scientific and societal impact, via three parallel approaches. Firstly, we will consolidate the strengths which have brought us to where we are today: the scientific user programme which forms the backbone of our operational model and allows us to respond to the evolving needs of European scientists. Our PhD and postdoc programmes will continue to support early-career researchers and strengthen the connections with our user community. In nuclear and particle physics, we will focus on flagship experiments addressing new physics on the precision frontier and nuclear forces in neutron-rich nuclei.

The second element of our Science Strategy arises from identifying and prioritising a number of emerging scientific areas of important societal impact. This includes nuclear medicine for cancer treatment, in which we are expanding our delivery of radionuclides which already allows for the treatment of many thousands of patients each year, and which we will continue to support through the development of new diagnostic and therapeutic tools using radionuclides.

We are in the process of setting up two new mechanisms to promote internal collaboration and facilitate external outreach: Science Hubs and Showcase Experiments. The four Science Hubs which we are setting up this year have themes of Batteries, Advanced Manufacturing, Quantum Materials, and Liquid-Liquid Phase Separation. Each Hub will serve as a network of scientific excellence and a pole of attraction in its scientific area, coordinated by a high-profile scientist. It will have a well-defined set of research objectives and will be structured and evaluated as limited-term research project. So far, a coordinator has been appointed for the Battery hub, and we expect to appoint coordinators for the remaining three Science Hubs in 2026. Showcase Experiments are intended to open up new fields of research to expand our range and impact and will start up in 2026.

The third element of the Science Strategy is a series of cross-cutting implementation mechanisms that increase the impact and visibility of our efforts in all the other aspects of the Science Strategy. Our capacity and capabilities within Neutron Imaging will be expanded to address more fields of science and increase throughput. The expanded imaging suite will be housed within a new instrument group for Applied Science which will also include strain-scanning and irradiation, and which will have as a key objective to strengthen collaborations with industry. A new data science strategy will improve and broaden our data reduction software suite for real-time experiment planning and execution, while establishing an integrated platform for data analysis, interpretation and simulation, and harnessing the latest AI and ML tools for improved performance.

Finally, an enhanced emphasis on communication and partnerships will allow us to attract more external funding while more effectively communicating the ILL value proposition: that our impact on science and society remains both important and strategic and that we are drivers for increasing economic growth in Europe. The continuing role of the ILL in the future development of the neutron landscape will depend on the effective communication of our scientific achievements.

A crucial decision was made in 2025 to continue ILL operations until the end of our Sixth Protocol Period in 2033. The scientific and societal impact which will be demonstrated by the success of the Science Strategy will be key to securing a positive decision to continue operating beyond 2033.

Ken Andersen
ILL Director

WHAT IS THE ILL?

The Institut Laue-Langevin (ILL) is an international research centre providing world-leading facilities in neutron science and technology. As a service institute, the ILL makes its facilities and expertise available to visiting scientists. It has a truly global user community: about 1800 researchers from 43 different countries came to work at the ILL in 2025. The 1393 experiments they performed were pre-selected by a scientific review committee. During 2025, some 512 scientific papers were published based on data obtained from the use of our facilities. 205 of these articles appeared in high-impact journals.

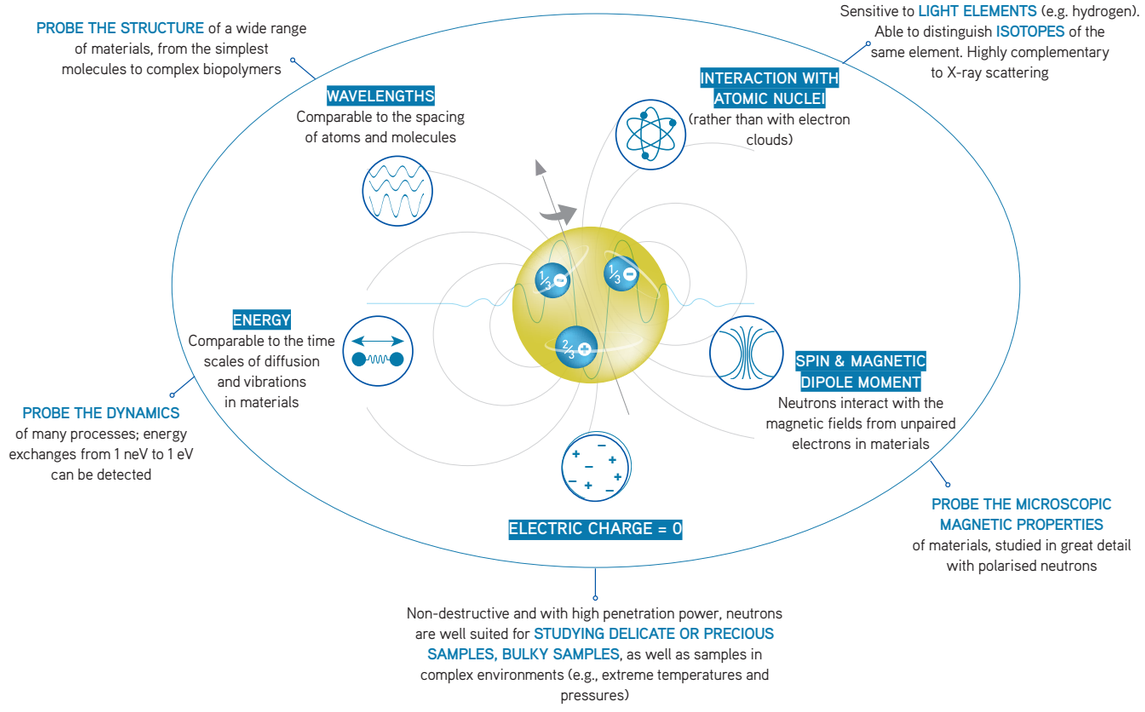
Neutrons are used at the ILL to probe the microscopic structure and dynamics of a broad range of materials at molecular, atomic and nuclear level. Thanks to its 54.8-MW nuclear reactor, which is specifically designed for high brightness, the ILL delivers the most intense continuous neutron beams in the world. In 2025, the reactor operated round-the-clock for two cycles, each lasting 50 to 60 days.

The reactor supplies neutrons to a suite of over 40 continuously upgraded, state of the art instruments.

The ILL is owned by its three founding countries - France, Germany and the United Kingdom. These three Associate countries contributed some 71 M€ to the Institute in 2025, with the ILL's Scientific Member countries - Austria, the Czech Republic, Denmark, Italy, Poland, Slovakia, Slovenia, Spain, Sweden and Switzerland – contributing a further 25 M€. The ILL's overall budget in 2025 amounted to around 104 M€.

The impact of the neutron science carried out at the ILL ranges from scientific discovery and excellence to addressing societal challenges in the fields of health, energy, the environment and quantum materials. While applied research can help provide answers to the societal challenges of today, exploring the mysteries of the Universe - through innovative discoveries and the production of new knowledge - are key to addressing the challenges of tomorrow and transforming society in the future.

Why neutrons are useful

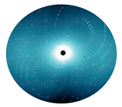


Neutron techniques, science and impact

Neutron techniques are vital research tools in science and innovation. They help us to understand and develop a huge variety of materials and processes in a host of societally relevant areas, including the environment, energy, health, and quantum and information technologies. The range of scientific fields covered by neutron-based research is truly vast: nuclear, particle and condensed matter physics, chemistry, biology, materials science, engineering and more. Over the years, advances in instrumentation have continuously improved signal quality and reduced sample requirements (size and composition), opening up fundamentally new research opportunities. A detailed view of the 2025 ILL instrument suite can be found on page 40.

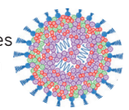
DIFFRACTION

Neutron diffraction is a powerful, very precise and often unique tool for measuring the structure of materials, providing detailed insights into the arrangement of atoms. Diffraction is used to study the structure of a wide range of materials, ordered and disordered, in powder, single crystal and amorphous or liquid form, ranging from the simplest to the most complex, on the sub-nanometre length scale.



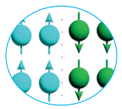
SMALL ANGLE SCATTERING

Small-angle neutron scattering (SANS) is used to study the organisation of macromolecular complexes on length scales from of 1 to hundreds of nanometres. As the scattering elements are large (polymers, micelles, foams, etc.), diffraction occurs at very small angles.



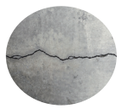
REFLECTOMETRY

Neutron reflectometry gives information on the structure of thin films (depth-dependent composition and in-plane information) and of surfaces. It is also a powerful technique for studying interfaces (solid/solid, solid/liquid, liquid/liquid) that may be buried in multi-layer systems.



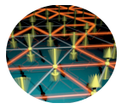
IMAGING

Neutron imaging is a non-destructive technique, highly complementary to X-ray imaging, can 'see' inside materials, with a spatial resolution as good as several microns, and examine processes therein, with a time resolution down to milliseconds. White beam imaging is based on the attenuation of the neutron beam. Tomography is performed by rotating the sample and reconstructing the 3-dimensional volume from a series of images.



SPECTROSCOPY

Neutron spectroscopy includes quasielastic and inelastic neutron scattering (QENS and INS) and measures energy and momentum exchanges between the sample and the neutron beam. QENS is used to study diffusion and relaxation processes of atoms, ions, molecules and magnetism in a range of materials. INS is used to study excitations with distinct energies in materials including lattice phonons, molecular vibrations, magnetic excitations and even electronic transitions.



NUCLEAR & PARTICLE PHYSICS

A unique set of instruments is used to examine key questions in nuclear and particle physics. They explore the structure, dynamics, lifetime and decay of atomic nuclei and use the neutron as a unique probe to address key questions in fundamental particle physics.

Societal impact of neutrons

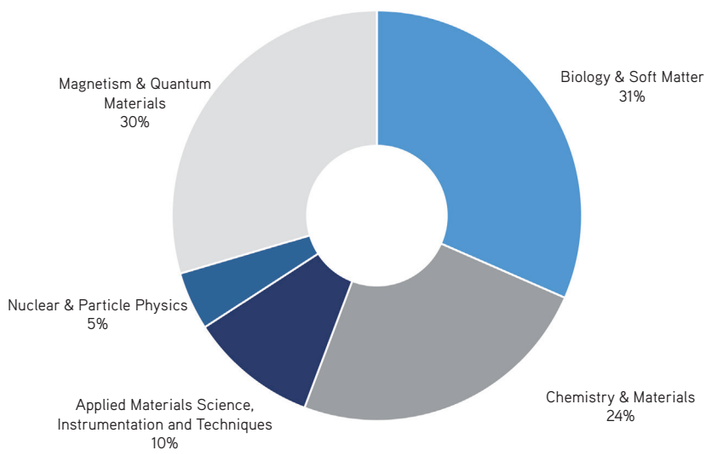
ILL SCIENCE IN NUMBERS

1 393
SCHEDULED EXPERIMENTS
Corresponding to **1119** proposals

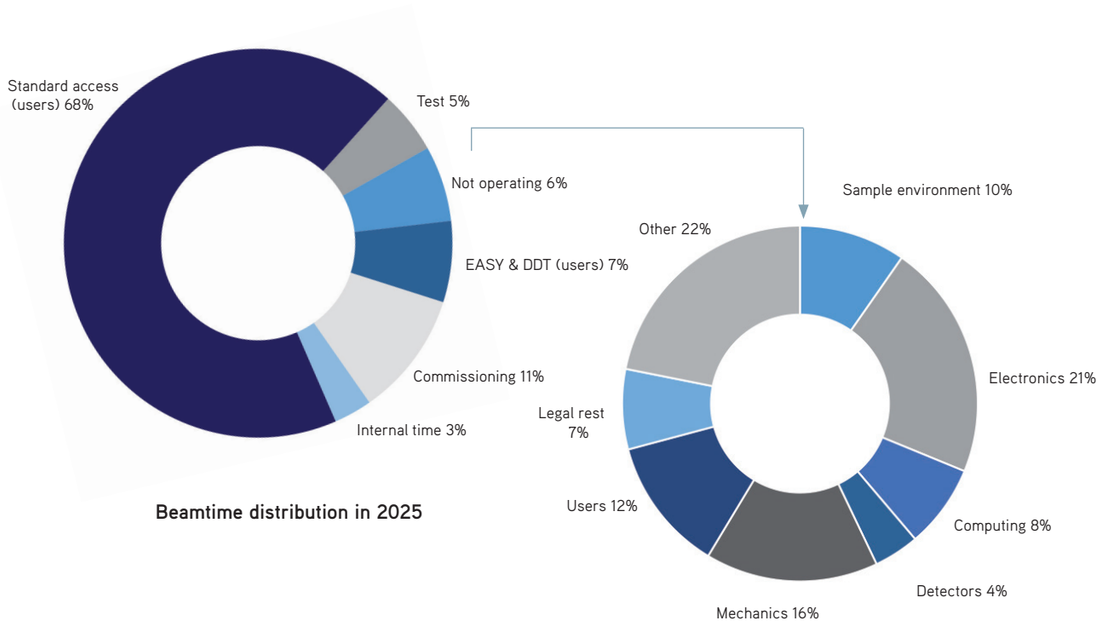
126 DAYS OF NEUTRONS

3749 DAYS FOR SCIENCE *

* Taking into account the number of days of neutrons and the number of available instruments.



Distribution by field of research
Accepted proposals



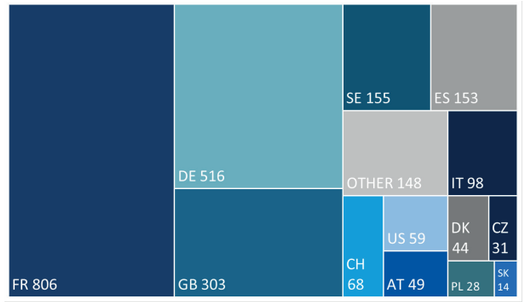
Beamtime distribution in 2025

Not operating beamtime distribution in 2025

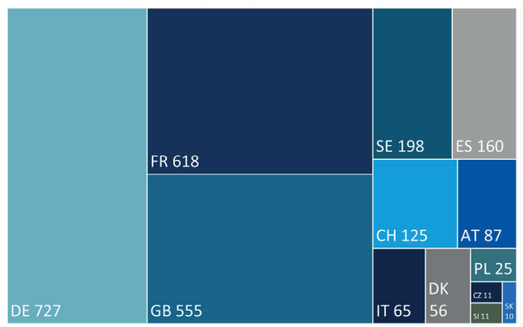
1 811
INDIVIDUAL USERS

2 472
USER VISITS
FROM **43** COUNTRIES

National affiliation of ILL users in 2025
Total number of user visits - 2472

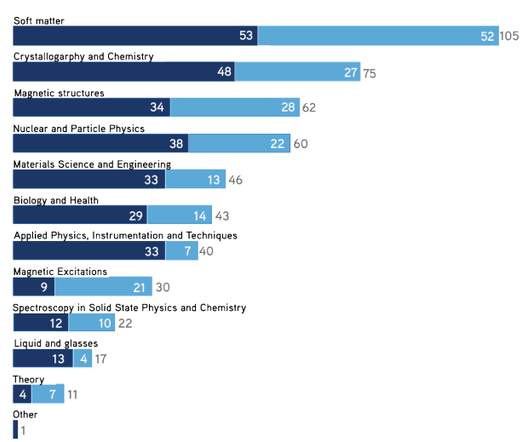


Number of days allocated
(April 2025 + Novembre 2025)



512
ILL publications
recorded in 2025 of which **205** published in **high-impact journals***

* This set of journals is identified by ILL as being of high impact (IF ≥ 7) or particular relevance to the neutron scientific programme.



TRAINING

GRADUATE School

29 full-time-equivalent ILL PhD students
56 PhD students working on ILL PhD projects
17 successfully defended ILL PhD theses

HERCULES School

94 participants of
28 different nationalities
working in **18** different countries

FROM STRATEGY TO REALITY

Implementing the ILL Science Strategy

2025 was a landmark year for the ILL. After an extensive period of scientific consultation and strategic reflection, our Science Strategy, which provides a detailed roadmap for the next decade, moved from vision to implementation. Adopted by the Steering Committee in June and presented to the international neutron community at the ICNS conference in Copenhagen shortly after, it sets a clear direction for where we are heading and how we intend to get there.

The Science Strategy is built around a clear objective: to consolidate the ILL's existing strengths while creating new structures to support emerging scientific areas of real societal importance. At its heart, our peer-reviewed user programme remains the foundation of everything we do and delivered outstanding results in 2025. The spring cycle saw a record 665 experiments performed, with nearly 1 000 user visits on site (which is almost twice as many user visits as 25 years ago). The autumn cycle, which finished at the end of October, then beat that record, delivering some 726 experiments. User demand remains consistently high, with an oversubscription factor of around 2, reflecting the central position the ILL continues to occupy in the European neutron landscape.

Science Hubs: New centres of expertise

One of the most significant steps forward has been the creation of Science Hubs. These are dedicated centres of expertise designed to support and expand our user base, foster internal collaboration, and strengthen connections with industry. Four Hubs have been identified, each targeting a scientific area where neutrons can make a real difference:

- Quantum Materials
- Liquid-liquid Phase Separation
- Li-ion Batteries
- Advanced Manufacturing

Each Hub will be led by a prominent scientist who will define and coordinate a five-year research project, selected through a competitive, peer-reviewed proposal process to ensure the highest scientific standards. We have already recruited two expert Hub Coordinators for the Battery Hub, and the response and interest so far has been very encouraging.

Showcase Experiments: Opening new scientific frontiers

Alongside the Science Hubs, we have introduced a new mechanism for performing *Showcase Experiments*. These are ambitious, high-resource experiments designed to open up entirely new fields of activity, attract new user communities, and deliver results with genuine societal visibility. Three initial topics have been identified:

- Superconducting wires
- Cell structure with high-resolution bio-imaging
- Water membranes for a sustainable future

Though requiring more resources and longer timescales than regular user experiments, Showcase Experiments have the potential for exceptional impact in both science and in terms of how we communicate the relevance of neutron science to a wider world.

Nuclear medicine: Innovation for future therapies

Our nuclear medicine programme is another area where the Science Strategy sets out a clear and ambitious direction. We are expanding our capacity to produce radioisotopes for cancer treatment and continuing to invest in the development of isotopes for future diagnostics and therapies. It is a programme with a direct, tangible benefit to patients and one that sits at the heart of our commitment to science in the service of society.

Investing in people, infrastructure and innovation

None of this is possible without the right people. The ILL's PhD programme is being enhanced and refocused around the priorities of the Science Strategy. In 2025, we selected seven new ILL PhD projects, nine projects through the NEXTSTEP programme in partnership with ESRF, and three IRGA projects co-funded with the Université Grenoble Alpes. We have taken particular care to ensure good geographical balance, giving priority to projects from Associate countries.

On the infrastructure side, a new Applied Science instrument group has been created, bringing together Neutron Imaging, Strain Scanning and Irradiation instruments within a single structure with stronger links to industry. The portable cold-neutron tomograph PorTo, which was installed at the PF1B position this year, is a tangible example of our push towards more flexible high-resolution imaging to meet growing user demand. We are also making meaningful investments in computing and data analysis tools, including AI and machine learning, and the PUMA platform, developed jointly with ESRF, is already giving us much better insight into the reach and impact of our scientific output.

Actively managing our instrument suite

The Science Strategy also provides a clear framework for managing our instrument suite in a more active and focused fashion. It reflects a genuine commitment to ensuring that our resources are always deployed where they will have the greatest scientific impact, and that the ILL remains well positioned and complementary to other European facilities as the landscape evolves, in particular with the ramp-up of ESS and the anticipated restart of FRM II. We are working closely with the ILL Scientific Council to think through these decisions carefully, transparently and in line with the priorities of the Science Strategy.

A strong foundation for the years ahead

Implementation of the Science Strategy is well underway, and 2025 gave us a great deal to build on. There is still much to do, but already the right structures are taking shape, the right people are joining us, and the scientific community is responding with enthusiasm. We are looking forward to what comes next.

Jacques Jestin
Associate Director
Head of the Science Division

SCIENTIFIC HIGHLIGHTS

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I'm a Senior Research Scientist at the Jülich Centre for Neutron Science and Privatdozent in Physical Chemistry at RWTH Aachen University. My research focuses on neutron and X-ray scattering studies of biomolecules and biologically inspired soft-matter systems.

Cedric J. Gommes
FNRS & University of Liège, Belgium
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I'm a Research Associate of the Belgian Funds for Scientific Research (FNRS) based at the University of Liège. My general research interests are in the physical chemistry of nanostructures, with a focus on X-ray and neutron scattering and mathematical modelling.

Model for small-angle scattering analysis of membranes with protein-like inclusions

Biological membranes are complex, dynamic systems whose structure and fluctuations are essential for cellular function. Although neutron and X-ray scattering techniques can probe membranes under near-physiological conditions, quantitative interpretation becomes challenging when large fractions of membrane proteins are present. We present a general modeling framework that explicitly incorporates protein inclusions into membrane scattering models. This enables a unified analysis of elastic and inelastic neutron and X-ray scattering data.

Original publication: JAC (2025) - 10.1107/S1600576725007277
ILL contact: O. Czakkel, czakkel@ill.fr
Instrument: Large dynamic range small-angle diffractometer **D22**

Cell membranes are far from being homogeneous lipid bilayers. Instead, they contain a variety of embedded membrane proteins that play crucial and active roles in transport, signaling, and mechanical stability. From a scattering perspective, these proteins strongly affect contrast, correlations, and dynamics, complicating data interpretation. This is particularly evident in red blood cell (RBC) membranes, where transmembrane proteins constitute approximately one-quarter of the membrane volume.

In this work, we developed a general mathematical framework that allows protein-like inclusions to be added to any pre-existing membrane model. The approach is conceptually simple: First, an independent two-dimensional model describes the spatial distribution of proteins in the membrane plane. Then, a three-dimensional membrane model is combined with this model by representing proteins as cylinders that intersect the membrane. Assigning appropriate scattering length densities along the cylinder axis enables the method to describe proteins that span the membrane fully, partially, or that also can protrude into the surrounding solvent.

We applied this approach to a joint analysis of SAXS, SANS, and NSE data from liposomes consisting of RBC membranes, see Figure 1. First, we analyzed elastic SAXS/ SANS data using a slab membrane model with embedded protein cylinders representing the dominant band-3 transmembrane protein. The combined SAXS/ SANS analysis yielded a RBC membrane thickness of approximately 42 Å, which is in excellent agreement with previous studies. Importantly, the model shows that, while protein contributions are quasi negligible for neutron contrast, they dominate key features of the SAXS signal. This underscores the strong complementarity of the two techniques. Next, we analyzed the same SAXS/ SANS data using a Gaussian membrane model that explicitly accounts for thermal membrane fluctuations (Figure 1a). This model equally well reproduces the elastic scattering while providing direct access to membrane roughness and deformation length scales (see Figure 1b for an illustration).

Finally, NSE measurements were used to probe membrane dynamics. Since protein contrast is weak for neutrons, the NSE signal is dominated by collective membrane fluctuations rather than lateral protein diffusion. Fixing all structural parameters from the SAXS/SANS analysis allowed the NSE data to be described by a single dynamic parameter: a diffusion coefficient that governs the relaxation of RBC membrane bending modes (Figure 1c).

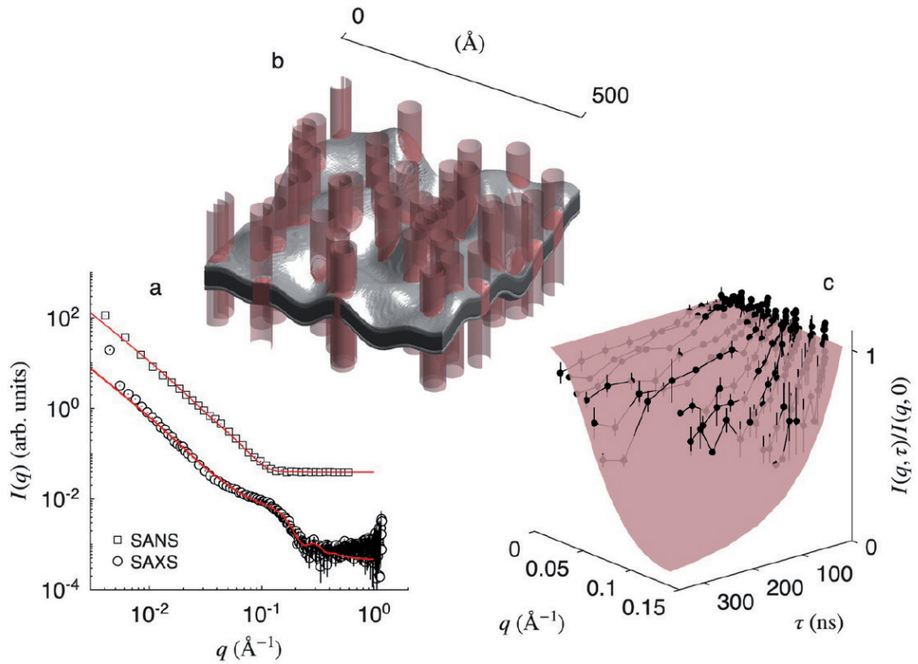

Figure 1: (a) SANS and SAXS data of RBC liposomes with the fitted Gaussian random membrane model with included band-3 protein. (b) Particular realization of the model with the protein-defining cylinders shown in red. (c) One-parameter fit of the NSE data with the Gaussian membrane model.

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I have just obtained my PhD as a biophysicist investigating the structure and the mechanisms of pulmonary surfactant by advanced techniques such as neutron reflectometry, in the research group BIOMIL that has spent more than 30 years dedicated to the study of this important system.

Original publication: J. Colloid & Interface Science (2026) - 110.1016/j.jcis.2025.138769
ILL contact: J. Carrascosa-Tejedor, carrascosa-tejedor@ill.fr
Instrument: Fluid Interfaces Grazing Angles ReflectOmeter **FIGARO**

ESCAPING FROM FLATLAND

Mammalian lungs are coated by pulmonary surfactant, a lipid/protein complex essential for breathing. Thanks to its optimized composition, this complex forms a thin film at the alveolar air-liquid interface that reduces surface tension to minimal values preventing alveolar collapse. Given its crucial role, any disruption or malfunction of this system can lead to respiratory pathologies, some of which still lack effective treatments. Understanding how pulmonary surfactant works at a molecular level is therefore essential for improving current therapies and developing new ones.

Pulmonary surfactant is composed of lipids and specific proteins. Its major lipid component is DPPC, a disaturated phospholipid that is able to pack very efficiently at the interface, thus reducing the surface tension to minimal values when required. Other unsaturated and neutral lipids provide fluidity to its membranes. Surfactant proteins SP-A and SP-D are hydrophilic and play a role in lung defense, while SP-B and SP-C are extremely hydrophobic proteins responsible for the biophysical function of the surfactant. During inspiration, the respiratory surface increases, and SP-B and SP-C facilitate the adsorption of lipids into the interface. During expiration, when the respiratory surface decreases, excess material must be removed from the interface. It is believed that SP-B and SP-C play a key role by promoting the ejection of non-packable unsaturated lipids from the interface to three-dimensional reservoirs that remain connected to the interface, allowing rapid readsorption during subsequent inspirations. However, the complexity of this biological system, combined with the difficulty to work with the small hydrophobic proteins poses a challenge even for experts. As a result, their mechanisms of action are still not fully understood.

To gain insight into the structural rearrangements taking place in pulmonary surfactant films and the specific role of the hydrophobic proteins, we used the FIGARO reflectometer at the ILL. The strength of neutron reflectometry lies in the sensitivity of neutrons to hydrogen and deuterium, which enables the resolution of three-dimensional structures formed at the interface, beneath the monolayer, owing to the large difference in scattering length density between the lipid molecules and the buffer under the investigated conditions shown in Figure 1. In this way, we can accurately determine under which conditions during interfacial compression, three-dimensional structures form and which components of the system are responsible for their formation.

In this study, films were formed by spreading lipid mixtures onto a Langmuir trough filled with buffered solution and set properly under the neutron beam. To identify the role of each surfactant protein individually, we used lipid model systems mimicking the main compositional features of pulmonary surfactant, incorporating either SP-B or SP-C. The films were then compressed, and neutron reflectivity profiles were collected at different compression stages using different isotopic contrasts. By co-refining the different contrasts, we were able to determine the structural and compositional changes taking place during compression.

Our results provide direct evidence of the nucleation of three-dimensional reservoirs at surface pressures of around 45 mN/m only when the protein SP-B is present. No formation of these structures was observed with the system containing only lipids or lipids plus only SP-C. Thus, neutron reflectometry has been fundamental in demonstrating for the first time that SP-B is the key protein that drives the formation of lipid reservoirs, supporting previous knowledge indicating that SP-B is critical for sustaining life, while SP-C plays an auxiliary role. The findings were further corroborated by epifluorescence microscopy.

Overall, this work, carried out within a fruitful and ongoing multidisciplinary collaboration represents a step forward in understanding how pulmonary surfactant reorganizes during breathing dynamics. This valuable information should be taken into consideration to optimize therapeutic preparations, i.e. by including an operative analog of the key surfactant protein SP-B, for the treatment of still unresolved surfactant-related pathologies.

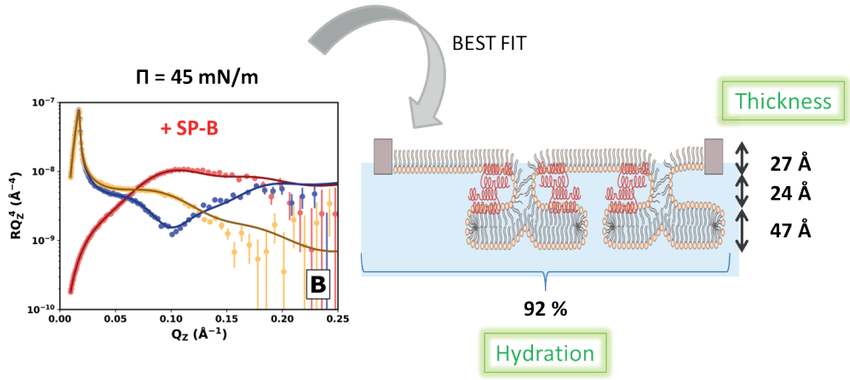

Figure 1: Neutron reflectivity profiles obtained for hydrogenous lipids + SP-B in D_2O (yellow), deuterated lipids + SP-B in D_2O (blue) and deuterated lipids in ACMW (red) at 45 mN/m. The lines show the fits to a model that describes the structure of the interfacial film as a 27 Å monolayer, a 24 Å hydrated gap attributed to the presence of SP-B, and a 47 Å bilayer connected to the interface thanks to the protein.

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I'm the head of Institute for Electrochemical Energy Storage at Helmholtz-Zentrum Berlin für Materialien and Energie, and full professor at Friedrich Schiller University Jena. My research focuses on developing colloidal nanoparticles for energy storage, catalysts, and sensors.

Original publication: Advanced Energy Materials (2025)
10.1002/aenm.202501324
ILL contact: L. Helfen, helfen@ill.fr - A. Tengattini, tengattini@ill.fr
Instrument: Neutron and X-ray tomography **NeXT**

Visualizing the Dynamic Wetting and Redistribution of Electrolyte in Lean-Electrolyte Lithium-Sulfur Pouch Cells via Operando Neutron Imaging

In lithium-sulfur (Li-S) batteries, lean electrolyte often causes inhomogeneous wetting and uneven electrochemical reactions, leading to performance loss. Here, operando neutron tomography is used to non-destructively visualize electrolyte distribution in lean-electrolyte Li-S pouch cells. Rest and cycling influence electrolyte redistribution, with slow cycling enhancing wetting and sulfur activation. Periodic "breath-in/out" behavior is linked to polysulfide dynamics. These insights guide electrolyte management and cell design in Li–S and other metal–sulfur batteries.

Lithium–sulfur (Li–S) batteries promise exceptionally high gravimetric energy density (>700 Wh kg-¹, compared with ~250 Wh kg-¹ for state-of-the-art lithium-ion batteries) while relying on abundant, low-cost sulfur. However, their practical deployment is limited under lean-electrolyte conditions required for high energy density. Incomplete electrolyte wetting disrupts electrochemical processes, accelerates degradation, and can lead to failure. Yet direct, non-destructive observation of electrolyte wetting and distribution in closed Li–S pouch cells remain highly challenging.

In this work, operando neutron imaging was for the first time performed at the NeXT instrument at the ILL, making it possible to directly visualize electrolyte wetting and redistribution in realistic Li–S pouch cells, offering unprecedented insight into how liquid electrolyte dynamics evolve during battery operation. Owing to the strong neutron sensitivity to hydrogen-containing species and lithium from electrolyte, the liquid electrolyte can be visualized even within thick, commercially relevant cell architectures. This enables direct observation of electrolyte wetting from different stacking layers non-destructively.

The pronounced inhomogeneity of electrolyte distribution under lean-electrolyte conditions in Li-S pouch cells is first visualized. Shortly after cell assembly, large regions of the cathode stack remain insufficiently wetted, particularly in the central regions of the pouch cell. These unwetted or partially wetted regions change slightly over time and correlate with electrochemically inactive zones, highlighting electrolyte access as a key limitation to sulfur utilization in practical Li–S cells.

Significantly, the discharge/charge processes improve the homogeneity of the electrolyte and can therefore promote the electrochemical activation of sulfur. For the first time, this study unveils the unique "breath-in" and "breath-out" wetting behaviours (as shown in Figure 1), the periodic processes in the electrolyte wetting that correlate with the dissolution and precipitation of sulfur compounds. This dynamic electrolyte wetting behaviour differs significantly from that of conventional Li-ion batteries due to the distinct chemistry of Li-S systems.

The study establishes the relationship between macroscopic electrolyte redistribution to electrochemical processes and battery performance. Regions with delayed or incomplete wetting exhibit reduced reaction activity, contributing to non-uniform reaction interfaces and capacity losses. These findings help explain why lean-electrolyte Li–S cells often show poor rate capability and incomplete sulfur utilization, even when electrode materials are well optimized.

Beyond fundamental insight, the work provides practical guidance for Li–S battery development. The results emphasize the importance of electrolyte formulation, cell assembly protocols, and stack pressure in promoting rapid and uniform wetting. Moreover, the neutron-imaging methodology established here offers a valuable diagnostic tool for evaluating future electrolyte systems, additives, and cell designs under realistic operating conditions.

This study establishes *operando* neutron imaging as a uniquely powerful approach to uncovering electrolyte wetting and redistribution phenomena in lean-electrolyte Li–S pouch cells. By directly linking dynamic electrolyte transport to electrochemical activity and performance limitations, the work identifies electrolyte accessibility as a critical bottleneck for practical Li–S batteries. These insights provide a strong foundation for rational cell engineering toward high-energy and durable Li–S technologies.

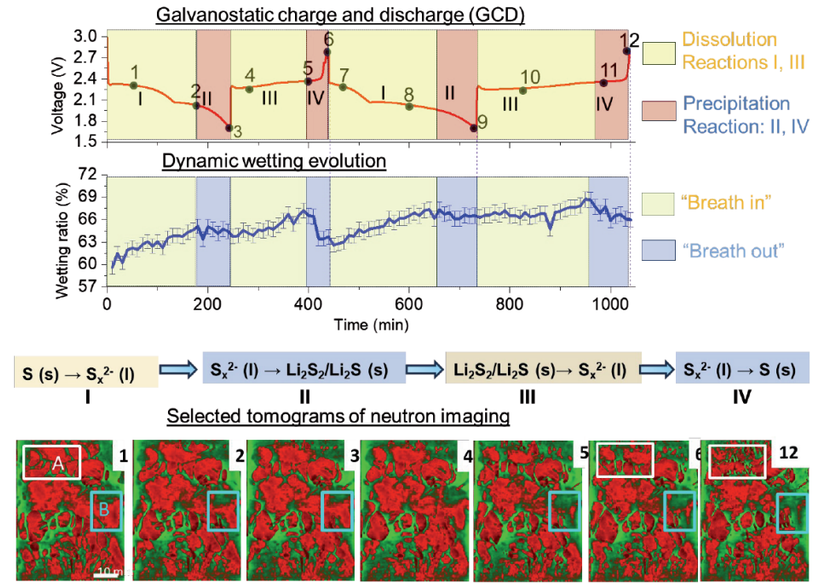

Figure 1: The dynamic electrolyte wetting is correlated to the discharge/ charge processes of the Li-S pouch cell. The selected tomograms demonstrate the wetting evolution in local areas (e.g. the area marked A and B).

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I am a computational and solid-state chemist based in the UK, working on defect chemistry and disorder in functional materials for energy applications. My theoretical research into defects and disorder relies on specialist experimental techniques such as neutron diffraction for validation.

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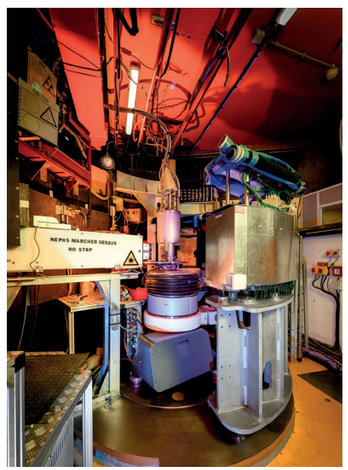
ILL contact: E. Suard, suard@ill.fr
Instrument: High-resolution two-axis diffractometer **D2B**

Watching Disorder in Action: Neutron Diffraction Reveals How Solid Electrolytes Really Form

Solid-state batteries promise safer, higher-energy storage than today's lithium-ion technology, but their performance depends critically on how lithium moves through solid materials. This case study describes how neutron diffraction at the Institut Laue-Langevin (ILL) was used to directly observe atomic-scale disorder forming in a promising class of solid electrolytes, the lithium argyrodites. By revealing how synthesis conditions control this disorder, the work provides practical guidance for designing the next generation of battery materials.

Lithium argyrodites are among the most promising solid electrolytes for next-generation batteries, with ionic conductivities approaching those required for commercial devices. A key reason for their high performance is anion site disorder: a subtle mixing of sulfur and halide ions within the crystal structure. This disorder reshapes the pathways available for lithium ions, enabling faster transport through the material. Despite its importance, anion disorder is usually treated as a static property determined only by chemical composition. In practice, it forms dynamically at high temperature during synthesis, and until now this process has remained poorly understood.

Neutron diffraction is uniquely suited to addressing this challenge. Neutrons can clearly distinguish sulfur from halogen anions occupying closely related crystallographic sites. High-resolution neutron powder diffraction measurements were carried out on the D2B beamline at ILL, whose combination of resolution and intensity allowed anion site disorder to be quantified with exceptional accuracy. Measurements on quenched samples provided precise structural snapshots, while high-temperature neutron diffraction enabled direct observation of how disorder develops at elevated temperature.



The two-axis diffractometer instrument D2B.

The experiments revealed that anion disorder is governed by kinetics as much as by thermodynamics. Materials with very similar compositions can exhibit markedly different levels of disorder depending on the temperature from which they are quenched. Chemical substitution was also shown to influence the rate at which disorder develops. Introducing silicon into the structure and altering the lithium content slows the exchange of anions between crystallographic sites, even at high temperature, meaning that synthesis protocols must be adjusted alongside compositional changes. Crucially, the neutron data coupled with simulations demonstrate that anions are mobile at synthesis temperatures, challenging the common assumption that the anion framework remains static.

These insights have clear applied relevance for solid-state battery development. Because anion disorder strongly affects lithium mobility, understanding how it forms provides a route to tuning ionic conductivity through synthesis control rather than chemistry alone. Parameters such as annealing temperature and cooling rate, which are straightforward to adjust in industrial processing, can be used deliberately to optimise performance. The work also provides a more realistic foundation for modelling solid electrolytes by showing that framework species cannot always be treated as immobile. In all cases, access to the high-resolution capabilities of the D2B instrument at ILL was essential for resolving these effects directly.

This study demonstrates how neutron scattering at ILL complemented with simulation can uncover kinetic processes that govern the real-world performance of energy materials. By directly observing how anion disorder forms and evolves in lithium argyrodites, the work bridges fundamental understanding and practical battery design, highlighting the critical role of neutron science in the development of future solid-state energy technologies.

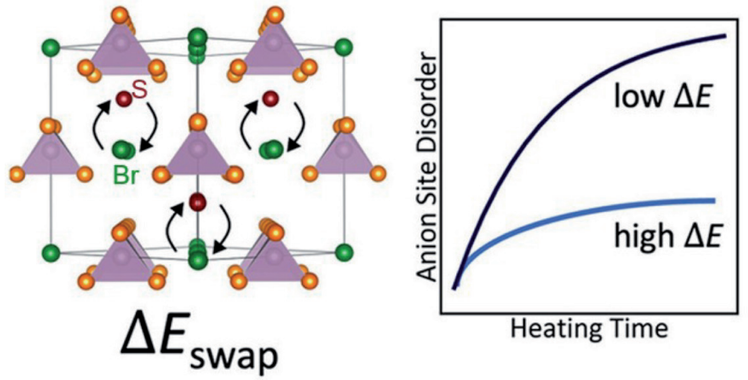


Figure 1: Schematic illustration of anion site swapping in lithium argyrodites and its kinetic consequences. The left panel shows sulfur and bromine exchanging between crystallographic sites, characterised by an anion swap energy barrier, ΔE_{swap}. The right panel illustrates how this barrier controls the rate at which anion disorder develops during heating: low ΔE leads to rapid disordering, while high ΔE results in slower, incomplete disorder frozen into the final structure.

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I'm a CNRS Research Director at Sorbonne University and Associate Professor at Sapienza University working on the structure and dynamics of molecular systems under extreme conditions. My research combines neutron scattering, synchrotron radiation and simulations to explore exotic phases of water and other planetary materials.

Original publication: Nature 2025 - 10.1038/s41586-025-08750-4
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Instruments: Time-of-flight spectrometers **IN5** & **SHARPER**

Plastic ice VII: a new exotic state of water blending together solid and liquid behaviour

Water is one of the most familiar substances on Earth, yet under extreme pressure and temperature it displays an extraordinary variety of solid phases. These conditions prevail inside icy moons and water-rich planets, where exotic forms of ice are expected to dominate. Using quasi-elastic neutron scattering we have experimentally observed a long-predicted hybrid phase of water: plastic ice VII, in which crystalline order coexists with liquid-like fast molecular re-orientational motions.

At high pressures, above two gigapascals, ordinary liquid water crystallises into ice VII, a dense cubic phase, to be widespread in icy moons and planets of our Solar System. More than fifteen years ago, molecular-dynamics simulations predicted that, close to its melting line, ice VII should transform into an unusual intermediate state known as plastic ice VII. In this phase, water molecules remain fixed on a rigid crystalline lattice, as in a solid, while simultaneously rotating on picosecond time scales, resembling the dynamics of a liquid. Despite its fundamental importance, this phase had never been observed experimentally, as the transition primarily involves changes in hydrogen dynamics rather than major structural rearrangements.

To address this challenge, we exploited the unique capabilities of neutron scattering at the ILL. Quasi-elastic neutron scattering (QENS) experiments were performed on the IN5 and IN6-SHARPER time-of-flight spectrometers, combined with a Paris–Edinburgh press allowing pressures up to 10 GPa and temperatures approaching 600 K. Neutrons are extremely sensitive to hydrogen thanks to its exceptionally large incoherent scattering cross-section, enabling direct access to molecular motion on picosecond time scales. This makes QENS particularly well suited to distinguishing between translational diffusion and localized rotational dynamics in hydrogen-rich materials.

By following controlled pressure–temperature paths across the ice VII melting curve (Figure 1), three distinct regimes were clearly identified. In the liquid phase, both translational and rotational motions contribute to the neutron scattering signal. In ordinary ice VII, all molecular dynamics are frozen on the experimental time scale. Between these two extremes, we observed an intermediate crystalline phase in which translational motion is arrested while rotational dynamics persist — the defining signature of plastic ice VII.

A detailed analysis of the QENS spectra, supported by molecular-dynamics simulations and Markov-chain modelling, revealed that the molecular motions in plastic ice VII do not correspond to free isotropic rotations. Instead, water molecules undergo rapid orientational jumps between preferential directions imposed by the crystalline environment. The dominant mechanism corresponds to a fourfold jump rotation, typical of a jump-rotor in plastic crystals, reflecting the delicate interplay between hydrogen bonding, molecular symmetry and lattice constraints in dense water.

The identification of plastic ice VII fills a long-standing gap in the high-pressure phase diagram of water. It also provides important insight into the nature of phase transitions in water under extreme conditions, governed primarily by hydrogen dynamics. Plastic ice VII is considered a potential precursor to the superionic state of water, in which protons become mobile within a fixed oxygen lattice — a phase thought to exist deep inside icy planets.

Beyond its fundamental significance, this discovery has important implications for planetary science. Plastic phases exhibit mechanical and thermal properties markedly different from those of conventional crystalline solids, potentially influencing heat transport, plasticity and differentiation processes inside icy bodies. The presence or absence of such a phase may help explain the contrasting internal evolution of Jupiter's moons Ganymede and Callisto, as well as the complex interiors of Uranus- and Neptune-like planets and water-rich exoplanets.

This work highlights the unique role of neutron spectroscopy at the ILL in exploring hydrogen-bearing materials under extreme conditions. By directly probing molecular dynamics at pressures comparable to those found in planetary interiors, neutron scattering continues to reveal unexpected states of matter — even for a molecule as familiar as water.

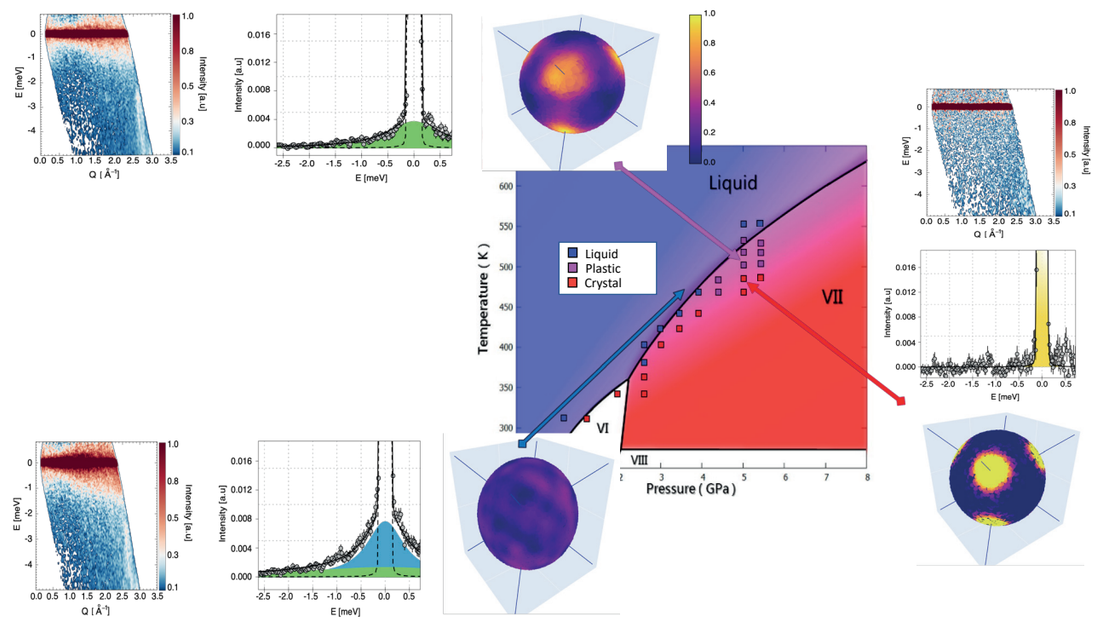

Figure: Pressure–temperature phase diagram of water in the investigated region, highlighting the stability fields of the liquid (blue), plastic crystal (purple), and ordinary ice VII (red). Symbols indicate the thermodynamic points explored by quasi-elastic neutron scattering. Representative measurements of the dynamical structure factor S(Q,ω) and their energy projections are shown for the three phases. In the liquid phase (bottom), both translational and rotational contributions are observed. In the plastic phase (top), translational diffusion is arrested while fast rotational dynamics persist on the picosecond timescale. In ordinary ice VII (right), no quasi-elastic broadening is detected within the instrumental resolution. The three-dimensional maps illustrate the orientational probability distribution of hydrogen atoms as calculated by Molecular Dynamics simulations, highlighting the dynamically disordered nature of the plastic phase despite the preservation of an average orientation along the cubic lattice diagonals.

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I am a postdoctoral researcher at the University of Cambridge in Materials Science and Metallurgy. I received my PhD in Nanoscience and Nanotechnology from ICMol, University of Valencia, in 2024, with Guillermo Mínguez Espallargas, focusing on nanoscale magnetic materials using neutron-based techniques.

Original publication: Nature Communications (2025) - s41467-025-63837-w
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Instrument: High-intensity two-axis diffractometer **D20**

Direct synthesis of an iron metal-organic framework antiferromagnetic glass

Glasses are familiar materials, yet their atomic-scale organisation and physical properties remain difficult to understand. This challenge is particularly acute for magnetic glasses, where structural disorder strongly affects collective magnetic behaviour. In this work, we introduce a new way to prepare metal–organic framework (MOF) glasses that enables, for the first time, a clean investigation of magnetism in a fully amorphous molecular material using neutron scattering.

Most conventional glasses are inorganic and chemically simple, which limits the range of properties they can display. Metal–organic frameworks (MOFs), by contrast, are built from metal ions and organic linkers, offering exceptional chemical flexibility. Recently, some MOFs were converted into glasses by melting a crystalline precursor and rapidly cooling it. While effective in some cases, this melt-quenching process often introduces impurities and partial chemical degradation, especially when paramagnetic transition metals such as iron are involved.

These impurities are a serious limitation for magnetic studies. Even small amounts of metallic iron or iron oxides can dominate bulk magnetic signals, making it impossible to access the intrinsic magnetism of the glass itself. This problem has so far prevented a reliable neutron-based investigation of magnetic correlations in MOF glasses.

Here, we present a direct-glass synthetic route that avoids melting entirely. Instead, the organic linker acts as both reactant and reaction medium under an inert atmosphere. This one-step method produces transparent, free-standing iron(II) MOF glasses of composition $Fe(im)_{2-x}(bim)_x$, which we name **dg-MUV-29**. Crucially, the process suppresses oxidation and decomposition, yielding glasses that are effectively free of magnetic impurities.

This high purity is the key enabling factor for neutron studies. Using powder neutron diffraction on the D20 diffractometer at the Institut Laue-Langevin (ILL), we directly probed magnetic correlations in **dg-MUV-29** over a wide temperature range. Because neutrons are sensitive to both atomic structure and magnetic moments, they are uniquely suited to studying disordered magnetic systems such as glasses.

The neutron data reveal clear short-range antiferromagnetic correlations, visible as a broad magnetic scattering feature at low momentum transfer. The position of this feature corresponds closely to the iron–iron distances within the amorphous network, showing that magnetic interactions are governed by the same local geometry throughout the material. Importantly, no magnetic Bragg peaks are observed, confirming the absence of long-range magnetic order and demonstrating that the material is truly amorphous.

Complementary magnetometry measurements support this picture. The glass exhibits strong antiferromagnetic interactions, but without the sharp ordering transition typically seen in crystalline materials. Instead, a low-temperature cusp in the susceptibility indicates cooperative magnetic behaviour driven by local correlations rather than periodic order.

Together, these results establish **dg-MUV-29** as a rare example of a topologically disordered antiferromagnet. Unlike amorphous metallic magnets, where disorder arises from random site occupancy and fluctuating interactions, the MOF glass retains a well-defined local environment around each iron ion. This makes it an unusually clean model system in which topological disorder alone controls the magnetic behaviour.

Beyond fundamental science, the direct-glass approach offers practical advantages. The method allows different organic linkers and functional groups to be incorporated, enabling systematic tuning of structure and properties. The glasses can also be processed into free-standing films, which we demonstrate by integrating **dg-MUV-29** into an optoelectronic device. This combination of processability, chemical flexibility and well-defined magnetism is highly unusual for amorphous materials.

In summary, direct synthesis of MOF glasses opens a new pathway to study magnetism in fully amorphous, yet chemically well-defined systems. By enabling impurity-free neutron measurements, this work demonstrates the potential of MOF glasses as model antiferromagnets and highlights their relevance for neutron science, disordered magnetism, and future functional devices.

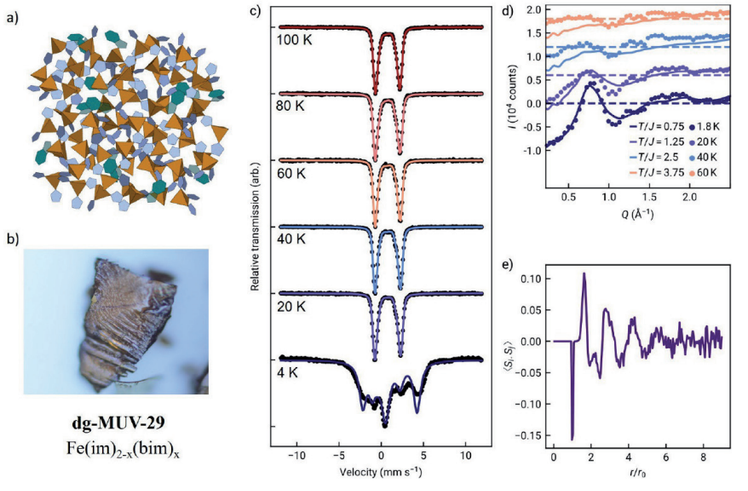

Figure 1: a) Schematic representation of **dg-MUV-29**. b) Optical image of **dg-MUV-29**. c) Mössbauer spectra of **dg-MUV-29** at different temperatures. d) Neutron scattering data compared with Monte Carlo simulations. e) Simulated spin correlations showing short-range antiferromagnetic order.

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My research focuses on the synthesis and crystal growth of emergent quantum materials based on oxides and fluorides. I investigate compounds containing unstable cations such as Ag^{2+} and employ neutron scattering techniques to determine their atomic and magnetic structures.

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ILL contact: T. Hansen, hansen@ill.fr
Instrument: High-intensity two-axis diffractometer with variable resolution **D20**

Mechanochemical Synthesis and Magnetic Properties of the Mixed-Valent Binary Silver(I,II) Fluorides, $Ag^{I}_2Ag^{II}F_4$ and $Ag^{I}Ag^{II}F_3$

Silver(II) compounds represent a promising platform for exploring exotic magnetism and cuprate-like superconductivity, yet their synthesis is challenging as the Ag^{2+} cation is an unstable and very reactive species. We recently introduced mechanochemistry as a novel and facile approach to access new Ag^{2+} compounds. Using this method, we obtained the highly sougth-after mixed-valent silver(I,II) phases, $Ag^{I}_2Ag^{II}F_4$ (Ag_3F_4) and $Ag^{I}Ag^{II}F_3$ (Ag_2F_3). These compounds represent the first successful examples of binary silver(I,II) mixed-valence systems, providing a way to study strong electron doping in AgF_2, a structural analogue of cuprate superconductors. Expanding the underexplored chemistry of silver(II) compounds, this method could accelerate the search for silver-based superconductors.

Compounds containing silver in the +2 oxidation state are highly promising analogues to cuprate superconductors. However, unlike the relatively stable Cu^{2+} cation, Ag^{2+} is highly reactive and unstable, and is stabilised almost exclusively in highly electronegative environments such as fluorine. Consequently, synthesizing and handling these phases becomes extremely challenging. Moreover, the primary Ag^{2+} precursor, AgF_2, is insoluble in anhydrous HF and thermally unstable. A new synthetic approach that could overcome the disadvantages of conventional methods is highly desired to realise the full potential of Ag^{2+}.

We recently introduced mechanochemistry as a novel route for the synthesis of Ag^{2+} compounds. This method enables room-temperature reaction conditions, enhanced kinetics, and solvent-free synthesis. Moreover, mechanochemistry can stabilise metastable phases that are otherwise inaccessible through conventional methods. Using this approach, we were able to synthesize the first binary, mixed-valent Ag(I,II) compounds $Ag^{I}_2Ag^{II}F_4$ (Ag_3F_4) and $Ag^{I}Ag^{II}F_3$ (Ag_2F_3). These compounds were highly sought-after as they are considered the charge-doped analogues of cuprates. The Ag_3F_4 compound was obtained at room temperature, whereas the Ag_2F_3 is metastable and required milling under cryogenic conditions.

The obtained polycrystalline phases were characterized using synchrotron X-ray and neutron powder diffraction complemented by Raman spectroscopy. Neutron powder diffraction patterns were collected at the D20 beamline at ILL from room temperature down to 1.7 K. No magnetic Bragg reflections were observed, but the data enabled precise refinement of the fluoride positions within the structures (Figure 1a).

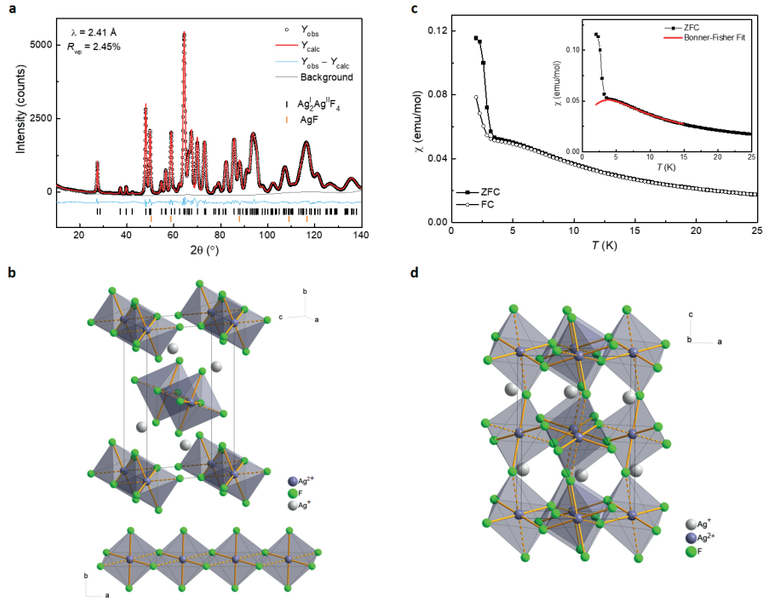

Figure 1: (a) The 5 K neutron powder diffraction pattern of the $Ag^{I}_2Ag^{II}F_4$ sample collected on D20 beamline at ILL. (b) Magnetic susceptibility data of $Ag^{I}_2Ag^{II}F_4$ in the 2–25 K temperature range; an upturn in the magnetic susceptibility characteristic of AFM ordering can be seen, with a Bonner–Fisher fit of the 2–15 K region shown in the inset. (c) Unit cell of the $Ag^{I}_2Ag^{II}F_4$ and a chain of edge-sharing $[Ag^{II}F_2F_{4/2}]^{2-}$ distorted octahedral units which extends parallel to *a*-crystallographic axis. (d) Unit cell of the $Ag^{I}Ag^{II}F_3$ phase with apex-sharing $[Ag^{II}F_{6/2}]^{-}$ distorted octahedral units resulting in a 1D, chain-like structure.

Structural analysis revealed that Ag_3F_4 crystallizes in the $P2_1/c$ space group (Figure 1b) and is isostructural to β-K_2AgF_4. In this crystal structure $[Ag^{2+}F_{4/2}]^{2-}$ distorted octahedral units extend parallel to the *a*-crystallographic axis, giving rise to a quasi-one-dimensional canted antiferromagnetic character, as evidenced by magnetic susceptibility (Figure 1c).

On the other hand, the Ag_2F_3 phase adopts the *P*–1 space group (Figure 1d), is isostructural to $AgCuF_3$, and exhibits features of a one-dimensional antiferromagnet, analogous to $KAgF_3$. In this structure, chains of edge-sharing $[Ag^{2+}F_6]$ octahedra alternate with Ag^{+} ions along one direction, which supports antiferromagnetic interactions along the chain. These findings show that mechanochemistry can be successfully applied to synthesize compounds containing the unstable Ag^{2+} cation. It could facilitate the discovery of new magnetic materials with properties approaching those of cuprates, while also opening opportunities to explore compounds containing other cations in unusual oxidation states.

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Instrument: IN1-Lagrange

Amino acid-decorated MOFs for greenhouse gas separation

The removal of CO_2 from methane-rich (CH_4) gas streams is key in the purification of varied biogas sources, an alternative to fossil-derived natural gas that can play an important role in the energy transition. Biogas can be obtained from the valorisation of different types of waste but it has a significant percentage of carbon dioxide (CO_2) as a secondary component. Indeed, the removal of CO_2 from methane-rich (CH_4) gas streams is key to enhance their quality and energy density. This is particularly important in the context of biogas production and conditioning prior to injection into natural gas distribution pipelines.

Thanks to recent advances, so-called mixed-matrix membranes (MMMs) based on polymer composites are steadily approaching practical application. Nevertheless, permeability and selectivity remain two of the most critical factors limiting technology scale-up under real operating conditions. This is where porous materials—and more specifically, metal–organic frameworks (MOFs) as microporous sorbents—can make a decisive difference by enhancing these properties. MOFs, composed of metal ions or clusters interconnected by organic linkers, are considered a highly promising emerging solution for environmental remediation. They offer exceptional porosity and, more importantly, outstanding chemical versatility, which enables pore functionalization with basic amino acids such as lysine or arginine, promoting selective interactions with CO_2 molecules. These essential building blocks of life enable modulating the gas-adsorption capacity and affinity of the parent mesoporous MOF-808 employed in this work, and hence, adapting their properties to enhance the baseline performance of gas-separation membrane technologies based on polymers of intrinsic microporosity (Figure 1).

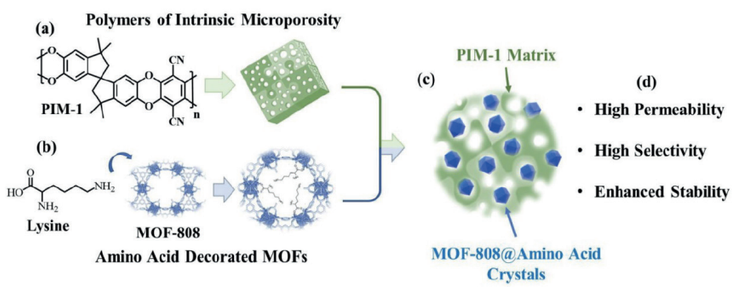

Figure 1: General strategy to combine (a) polymers of intrinsic microporosity and (b) amino acid functionalized MOF-808 to (c) develop mixed matrix membranes with (d) enhanced properties.

Following established protocols, MOF-808 scaffold was synthesized and post-synthetically functionalized with the amino acids lysine and arginine, and subsequently incorporated as a nanoporous filler into the polymeric scaffold of PIM-1 membranes. Both the MOF materials and the MOF-based mixed-matrix membranes were characterized by X-ray diffraction (XRD), infrared (IR) spectroscopy, scanning electron microscopy (SEM), thermogravimetric analysis (TGA), and N_2 adsorption measurements, among other conventional laboratory techniques. This initial characterization strategy enabled us to correlate the structure and chemistry of the studied systems with the observed improvements in permeability and, in particular, selectivity in CO_2/CH_4 gas separation experiments. The permeation results, which rival the best MOF-based mixed-matrix membrane technologies reported to date for CO_2/CH_4 separation, were published in *Journal of Materials Chemistry A* in 2025.

Despite providing insight into the general physicochemical and functional properties of the system, the laboratory techniques employed were insufficient to elucidate the mechanisms governing CO_2/CH_4 separation in these materials. Unravelling how CO_2 and CH_4 interact with the different amino-acid-functionalized MOF variants can open the way to the identification of the most promising MOF-808@amino-acid systems, while also guiding future modifications and performance improvements. Here is where the laboratory-based characterization protocols were combined with advanced inelastic neutron spectroscopy (INS) data acquired at ILL's IN1-Lagrange neutron spectrometer (Figure 2) and Density Functional Theory (DFT) calculations based on selected molecular models of the MOF-808@amino acid structure. The exceptionally high flux, energy range and energy resolution offered by IN1-Lagrange is ideal to identify the intramolecular vibrations affected by the gas molecules loaded into the MOF-808@amino acid structures.

Among the INS bands affected by gas adsorption (Figure 2), a clear shift is observed for band A, located at 740 cm^{-1}, along with the appearance of a new signal at approximately 1170 cm^{-1} upon gas loading. Both spectral changes are closely linked to the formation of carbamic acid, arising from the reaction of CO_2 with the pendant amino groups of the amino-acid moieties, as confirmed by the Density Functional Theory (DFT) calculations.

Overall, the immobilization of amino-acid functionalities within the pore space of MOF-808 endows the material with CO_2-selective adsorption, which is subsequently reflected in the enhanced selectivity and permeability performance of the resulting mixed-matrix membrane systems. We foresee that the incorporation of amino acids, especially through multivariate functionalization of MOFs with diverse residues, will emerge as a key approach for designing highly selective gas-separation materials, with applications far beyond biogas upgrading.

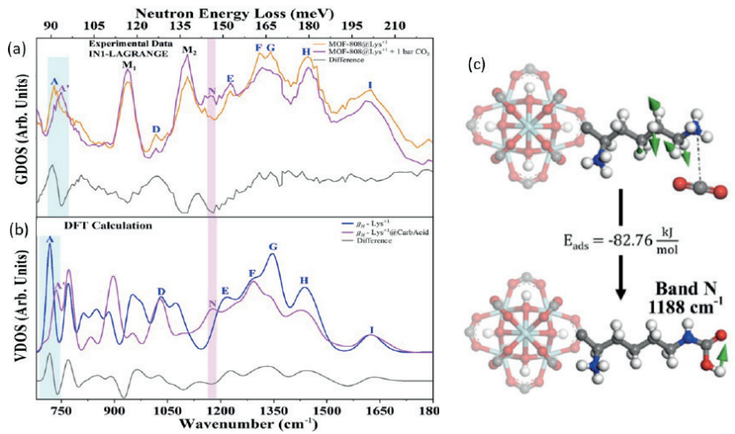

Figure 2: (a) INS spectra measured by means of IN1-LAGRANGE for MOF-808@Lys and MOF-808@Lys@CO_2. (b) INS spectra calculated from the Lys and Lys-carbamic acid models. (c) Proposed CO_2 adsorption mechanisms highlighting the vibrational modes most affected by the process.

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My research focuses on quantum materials at extreme conditions where novel quantum many-body effects emerge. I am based at the high-pressure beamlines ID27 and ID15B at the ESRF.

Original publication: Nature Communications (2025) - 10.1038/s41467-025-58380-7
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Instruments: ThALES, ILL and LET, ISIS

Supersymmetry in Quantum Magnets

Supersymmetric quantum mechanics suggests a fundamental symmetry between bosonic and fermionic particles and may underpin physics beyond the Standard Model. In condensed matter, the concept that strong, many-body correlations can produce fractional bosonic and fermionic collective states is well established but possible supersymmetries between these states are rarely invoked. In this work we use neutron spectroscopy to probe fundamental excitations in a quantum magnet and demonstrate observable fingerprints of supersymmetry in condensed matter.

Despite decades of research at large colliders no direct evidence of supersymmetry has been found at high energies where new particles are created. However, supersymmetry also applies to bosonic and fermionic quasiparticles in condensed matter physics. To probe fingerprints of supersymmetry we investigate the spin and charge dynamics in the quantum spin ladder materials $(C_5D_{12}N)_2CuBr_4$ (BPCB) and $(C_5D_{12}N)_2CuCl_4$ (BPCC) by neutron spectroscopy and model the excitations using matrix-product-state calculations. Our quantum spin ladders are magnetic insulators where spin-1/2 magnetic moments are arranged in pairs of coupled chains. The crystal structure of BPCB and BPCC imposes quasi-one-dimensional magnetic interactions in ladder geometry. In the ladder, charge appears as a hole in the magnetic environment, with its properties intrinsically connected to the spins of the electrons. The physics of the magnetic excitations at applied magnetic field is captured by the t-J model, a paradigm for describing charged particles interacting strongly with an environment of correlated quantum spins. For $2t = J$, where t is the hopping integral and J the antiferromagnetic exchange coupling, the model becomes supersymmetric: The two fermions representing the spin sector and the boson representing the charge sector are superpartners. This situation is realised in our spin ladder materials at half magnetisation.

To establish the baseline of our investigation we have measured the magnetic excitations of BPCB at various magnetic fields using ThALES at ILL, see Figure 1. The applied magnetic field of $B = 6$ T (Figure 1a) causes the three gapped magnon modes (t^+, t^0 and t^-) to split in energy. The neutron scattering intensities calculated by matrix product state calculations are in excellent agreement with experiment (Figure 1e), where the t^0 mode represents the spin-charge excitation in the t-J model (Figure 1i). At higher magnetic fields the t^+ gap closes and the excitations become gapless spinons with fractionalized continuum spectra (Figure 1 b-d). At $B = 10.4$ T (Figure 1c) the system is at half magnetisation and supersymmetry comes into play.

To investigate how supersymmetry affects the fundamental excitations we focus on the t^0 excitation at $\boldsymbol{Q} = 0$ (Figure 2) using LET at ISIS. Thanks to an elegant parity selectivity of the ladder geometry, singlet-triplet excitations appear in the antisymmetric rung sector ($q_\perp = \pi$) whereas triplet-triplet excitations show up in the symmetric sector ($q_\perp = 0$). These excitations have an exact correspondence to spin-charge excitations in the t-J model where the antisymmetric sector represents spin-down – hole interaction and the symmetric sector spin-up – hole interaction. Careful theoretical considerations yield that the ladder-derived t-J model preserves one supersymmetry which is the duality between the up-spin fermion and the bosonic holon. The consequence of this leaves its fingerprint in the magnetic excitation spectra shown in Figure 2: The t^0 spectral functions of the non-supersymmetric $q_\perp = \pi$ sector (Figure 2a,b) broadens with temperature and loses intensity whereas the t^0 spectral function in the supersymmetric $q_\perp = 0$ sector (Figure 2c,d) is resolution limited and temperature-independent.

To conclude, we have shown that supersymmetry leaves its fingerprints in the magnetic excitations of a quantum spin ladder. This opens the opportunity to study supersymmetric holon-spinon fractionalization dynamics in experiment. Interestingly, we find that supersymmetry protects quantum states against thermal decay, a property that is extremely sought after in quantum information processing.

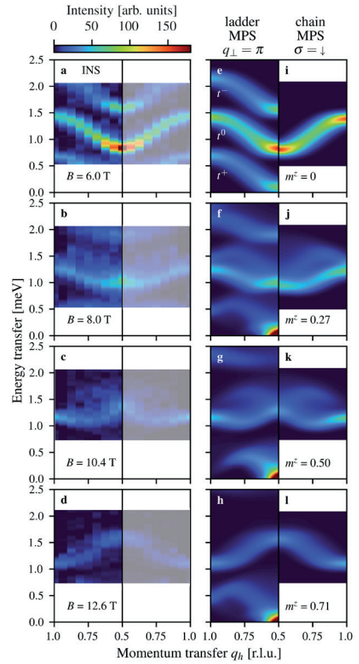

Figure 1: Neutron scattering intensities of BPCB at $T = 50$ mK (a-d). Calculated spectral functions for the spin ladder (e-h) and the equivalent t-J model (i-l).

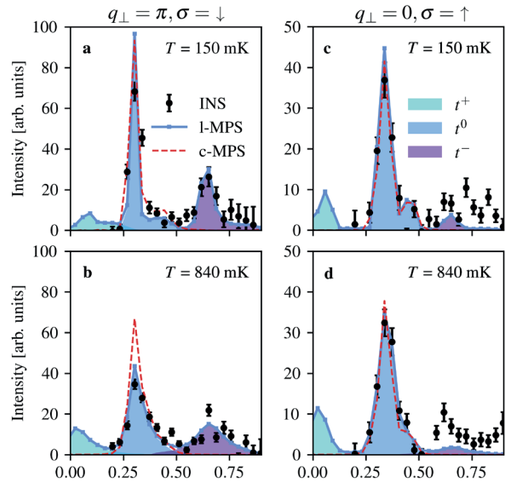

Figure 2: Fundamental excitations in BPCC at half magnetisation. The t^0 excitations are protected by supersymmetry in the $q_\perp = 0$ sector (c, d).

Romain Sibille

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My research focuses on magnetism in condensed matter – I study materials where local constraints promote emergent quantum states or unusual magnetic structures. I am responsible for the thermal neutron single-crystal diffractometer Zebra at the Swiss Spallation Neutron Source SINQ.

Original publication: Nature Physics (2025) -10.1038/s41567-024-02711-w
ILL contact: M. Appel, appel@ill.fr - J. Ollivier, ollivier@ill.fr
Instrument: Time-of-flight spectrometer **IN5**, backscattering spectrometer **IN16B**

Neutron spectroscopy unveils fractional quasiparticles in three dimensions

Certain phases of condensed matter are predicted to be 'quantum orders' where electronic correlations are described using a long-range entangled wavefunction instead of a symmetry-breaking order parameter. However, finding experimental evidence of this organisation is extremely challenging.

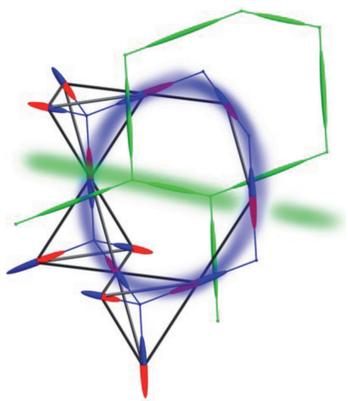

Figure 1: Magnetic moments (blue/red ellipses) on a pyrochlore lattice (in black) constrained by a local '2-in-2-out' rule, defining flux sources that form a diamond lattice (in blue). Quantum dynamics on rings create emergent flux variables (in green) living on a second diamond lattice.

In spin ices the atoms are arranged on a lattice of corner-sharing tetrahedra resembling that of frozen water — hence the 'ice' in their name. The specific local order of their electronic spins prevents the formation of a single state of minimal energy and provides a fertile ground for a type of exotic order known as 'quantum spin ice'. This quantum spin liquid is well understood from a theoretical point of view: the long-range quantum entangled nature is here described by an emergent dynamical 'gauge field' (Figure 1). Finding experimental signatures of this quantum organization is, however, very difficult.

Neutrons are expected to create spin-flip excitations leading to integer changes of the total spin. In a quantum spin liquid, this is expected to generate pairs of fractional excitations each carrying spin ½ and known as 'spinons'. These quasiparticles deconfine: they separate and execute quantum motion, but this occurs under the constraints of the emergent gauge field. Their dynamics is therefore highly nontrivial, and theorists have long struggled to predict their experimental spectrum in detail. This work presents strong evidence, through spectroscopic features, of fractional spinon excitations in a cerium pyrochlore oxide ($Ce_2Sn_2O_7$).

First indications for the existence of fractional excitations in this material were obtained in the past by measuring a continuum of excitations on the IN5 time-of flight neutron spectrometer. Although this experiment already pointed towards the general shape expected for fractional excitations – a continuum, the experimental resolution made it impossible to demonstrate detailed features like the gapped nature of the continuum. This is because magnetic interactions in rare-earth pyrochlore oxides are characterized by small energy scales, typically of the order of 0.01 to 0.1 meV.

Thanks to instrumental developments on the backscattering neutron spectrometer IN16B, follow-up experiments could achieve much higher resolution data over an extended window of energy transfers. Two complementary IN16B experiments using the 'high-resolution' configuration, and 'time-of-flight' option, finally provided a detailed view of the time-dependent magnetic response. The first achievement realized by the backscattering data (Figure 2) is to demonstrate the gapped nature of the continuum, consistent with expectations for spinons in a quantum spin ice. But this is not the only finding.

The fine resolution of the data over an extended range of energy transfers was instrumental in revealing an additional feature: the main peak centered on the energy of the dominant interaction in this material is accompagnied by additional, weaker peaks at higher energy transfers. This assymetry of the time-dependent magnetic response was anticipated by theory works showing that the spectrum is expected to have three peaks of decreasing intensities. Remarkably, their energy positions directly relate to the ratio of exchange interactions that, on one hand, stabilize a spin ice manifold and, on the other, hand induce quantum fluctuations between these configurations.

Fractionalization – the phenomenon whereby quasiparticles cannot be constructed as combinations of the elementary constituents of a system, is known as a beautiful manifestation of quantum mechanics, for which this work identified specific signatures in a three-dimensional system.

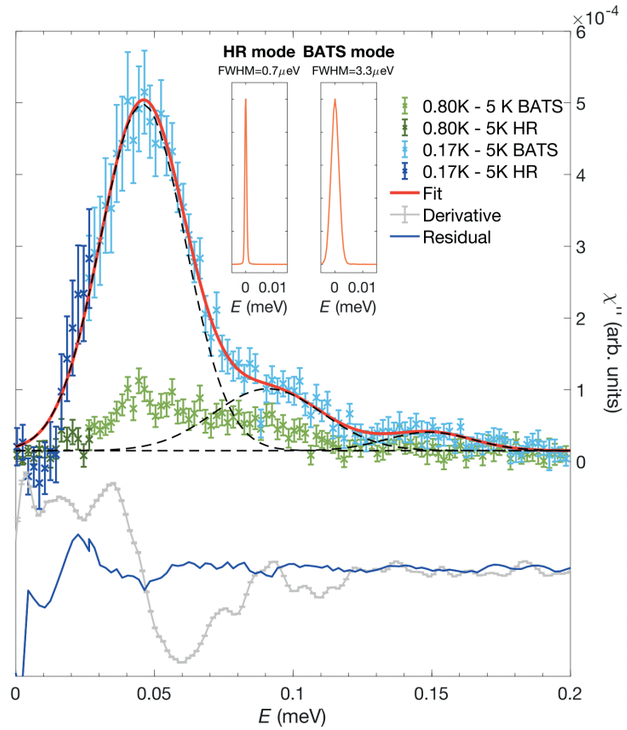

Figure 2: Imaginary part of the dynamical spin susceptibility from experiments on IN16B. The continuous red line is a fit using a constant background and three Gaussian peaks. The insets show the energy resolution provided by each instrument configuration.

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I am a condensed-matter physicist at Lund University. I earned my PhD from Lund University in 2024. My research focuses on superconductivity and quantum materials using neutron scattering, X-ray scattering and muon spectroscopy, with particular interest in multiband superconductors and vortex matter.

Original publication: Phys. Rev. Lett. 2025 - 10.1103/PhysRevLett.134.116001
ILL contact: R. Cubitt, cubitt@ill.fr
Instrument: Massive dynamic q-range small-angle diffractometer **D33**

Mapping multiple superconducting responses using neutron scattering

Superconductivity is a quantum property of materials that emerges at low temperatures, where electrical resistance disappears and magnetic fields are expelled or reorganized into quantized vortices. In some materials, multiple electronic bands contribute to this state, leading to more than one superconducting energy gap - a phenomenon known as multiband superconductivity.
For decades, researchers have debated whether the superconductivity of 2H-$NbSe_2$ arises from a single anisotropic electronic state or from multiple superconducting bands. In this work, we address this question using neutron scattering at the Institut Laue-Langevin (ILL). By directly measuring the magnetic vortex lattice, we identify distinct superconducting contributions and demonstrate the unique capability of neutron techniques to resolve fundamental questions in quantum materials.

When a magnetic field is applied to a type-II superconductor, magnetic flux penetrates the material in the form of quantized vortices arranged in an ordered vortex lattice. The structure and strength of this lattice provide direct information about the superconducting state. Small-angle neutron scattering (SANS) is uniquely suited to study vortex lattices because neutrons are sensitive to magnetic fields inside materials and can probe bulk properties under realistic conditions.

Using the D33 instrument at the ILL, complemented by measurements at the SANS-I instrument at Paul Scherrer Institute (PSI), we investigated the vortex lattice in the layered superconductor 2H-$NbSe_2$ over a wide range of magnetic fields and temperatures. This material has long been suspected to host more than one superconducting electronic band, but experimental signatures have been difficult to disentangle from strong anisotropy effects.

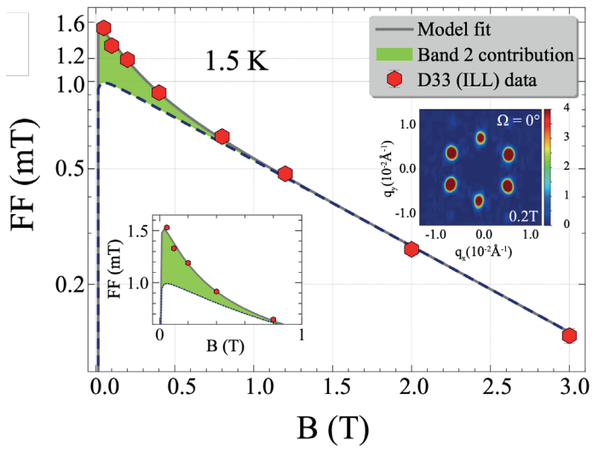

Figure 1: Magnetic field dependence of the measured quantity FF (first-order vortex lattice form factor), highlighting the contribution of a second band. The inset on the left shows the data with a linear vertical scale, focusing on the low-field region. The inset on the right shows an example of diffraction patterns measured at the instrument.

Our measurements focused on the intensity of neutron scattering from the vortex lattice, shown in Figure 1. This intensity is used to extract the vortex-lattice form factor, which is proportional to the density of electrons participating in superconductivity. In this way, the vortex lattice acts as a bulk probe of how different electronic components contribute to the superconducting state. At low magnetic fields, the inferred density of superconducting electrons is significantly larger than expected for a conventional single-band superconductor. As the magnetic field increases, however, one contribution is rapidly suppressed well below the upper critical field where superconductivity vanishes completely.

This behavior provides clear evidence that two distinct superconducting components contribute to the vortex lattice. One component dominates at all magnetic fields, while the second contribution disappears already around 0.8 Tesla. This suppression cannot be explained by a simple anisotropic superconducting gap. Instead, it reflects the presence of two superconducting bands with different characteristic length scales and energy gaps.

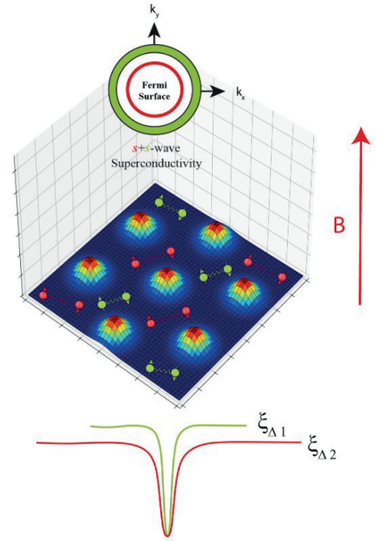

Figure 2: Schematic illustration of two-band superconductivity in 2H-$NbSe_2$, highlighting the coexistence of two distinct superconducting gaps, each associated with its own characteristic length scale Cooper pair size. *Credit: Ahmed Alshemi, Postdoctoral Fellow-Lund University, Sweden.*

By combining field-dependent and temperature-dependent measurements, we could quantify how much each band contributes to the superconducting response. At low fields, the second band accounts for a substantial fraction of the superfluid density, but its contribution fades as vortices begin to overlap. This field-selective sensitivity is a key strength of vortex lattice studies and allows neutron scattering to distinguish between competing superconducting scenarios.

A schematic summary of the two-band superconducting state is shown in Figure 2. Together, these results resolve long-standing doubts about whether 2H-$NbSe_2$ should be described as an anisotropic single-band superconductor or a genuine multiband system. Our findings clearly support the multiband picture, with moderate coupling between the bands. Importantly, this approach is not limited to this material. The same methodology can be applied to other candidate multiband superconductors, providing a powerful benchmark for theoretical models.

Beyond fundamental insight, understanding multiband superconductivity has practical implications. Different superconducting bands respond differently to magnetic fields, temperature, and disorder. Controlling these responses is essential for designing superconductors for high-field magnets, energy-efficient power transmission, and emerging quantum technologies. Neutron scattering at the ILL plays a crucial role in this effort by offering a direct, microscopic view of superconducting states that cannot be accessed by surface-sensitive probes alone.

This study demonstrates how neutron scattering at the ILL can decisively resolve complex superconducting behavior. By directly visualizing the vortex lattice in 2H-$NbSe_2$, we uncovered two distinct superconducting contributions and showed how one is suppressed at moderate magnetic fields. These results settle a long-standing debate and highlight neutron scattering as a key tool for understanding and designing advanced superconducting materials.

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My research interests span a broad range of astroparticle physics, covering direct neutrino mass measurements, neutrino oscillations and the detection of high-frequency gravitational waves. My experimental activity primarily involves cryogenic techniques and superconducting quantum technologies.

Original publication: APS (2025) - doi.org/10.1103/s9vl-7n24
ILL contact: Ulli Köster, koester@ill.fr
Instrument: Ultracold neutron facility, **PF2**

Most Stringent Bound on Electron Neutrino Mass Obtained with a Scalable Low-Temperature Microcalorimeter Array

Determining the absolute mass scale of neutrinos remains one of the central open questions in contemporary particle physics, with far-reaching implications for the Standard Model and cosmology. In this context, the HOLMES experiment has achieved a major milestone by delivering a stringent and model-independent new limit on the electron-neutrino mass using an array of superconducting low-temperature detectors. Beyond this result, the experiment establishes a scalable experimental framework with the potential to pin down the neutrino mass in future measurements.

The HOLMES experiment is based on the calorimetric study of the electron-capture decay of holmium-163, an isotope with a very low decay energy of about 2863 eV. Indeed, the high-energy region of the decay spectrum is distorted in proportion to the value of the electron-neutrino mass, as shown in Figure 1. Isotopes with a low decay endpoint energy and a sufficiently short half-life, such as holmium-163, rhenium-187 and tritium, are therefore particularly well suited for neutrino mass investigations, as they allow sufficient statistics to be collected to detect such a small effect.

At the core of HOLMES is an array of low-temperature microcalorimeters based on transition-edge sensors (TES), operated at temperatures around 100 mK, strongly coupled to gold absorbers. The holmium-163 source is ion-implanted directly into the absorbers of the detectors, ensuring nearly 100% detection efficiency. In this calorimetric approach, the total energy released in the decay is measured, with the exception of that carried away by the neutrino, thereby eliminating uncertainties associated with atomic and molecular final states. The detectors are read out using a scalable multiplexing scheme based on microwave signal modulation, a key technique that enables the operation of large detector arrays in a cryogenic environment without compromising the excellent energy resolution of the devices.

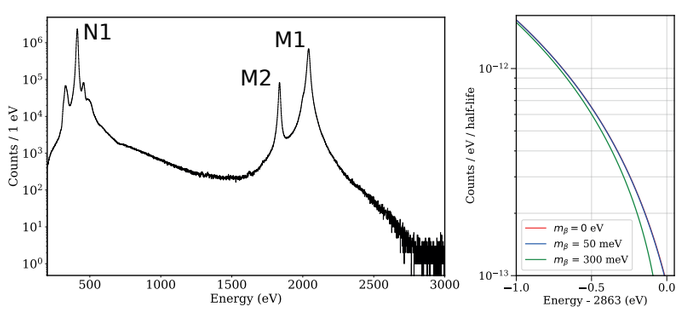


Figure 1: Left: The total holmium-163 calorimetric spectrum measured with the HOLMES microcalorimeters. Right: Example of the expected spectral distortion due to different neutrino mass value.

The first HOLMES physics result was obtained after two months of data taking using an array of 64 detectors, depicted in Figure 2, with a mean activity per detector of 0.6 Bq, during which approximately 7×10^7 decay events were recorded. The detectors achieved an average energy resolution of about 6 eV (FWHM) and demonstrated stable operation over extended periods (with a duty cycle of about 82%), a performance level that validates the maturity of TES for precision neutrino physics. A Bayesian analysis of the high-statistics spectrum near the decay endpoint yielded an upper limit on the effective electron-neutrino mass (mβ) of $m\beta < 27$ eV/c² (90% credibility).

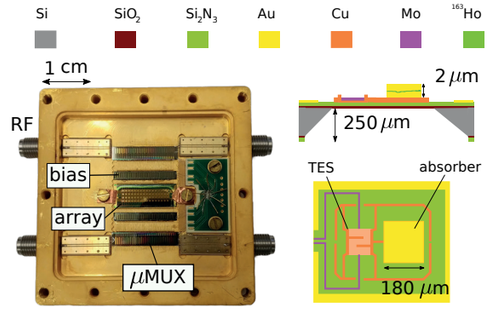


Figure 2: Left: Copper box containing the 64 TES array in the middle. The two chips on either side of the array are the bias network and the microwave multiplexer (μMUX, developed by the National Institute of Standards and Technology, Boulder, USA), respectively.
Right: Schematic, not to scale, representation of the HOLMES TES microcalorimeter used in the experiment.

The production and purification of the holmium isotope relied critically on high-fluence neutron irradiations in the V4 irradiation position of the ILL's high-flux reactor. For this purpose, several batches of enriched erbium-162 were irradiated, ultimately producing more than 100 MBq of the desired ^{163}Ho isotope. The Er/Ho mixture was then subjected to radiochemical separations at Paul Scherrer Institut, Villigen, Switzerland, using ion-exchange chromatography to isolate the holmium product from the erbium target material. To selectively implant holmium-163 while rejecting spurious isotopes, isotope selection and ion implantation were performed using a dedicated ion implanter composed of a sputter ion source coupled to a magnetic dipole.

HOLMES is conceived as a stepping stone toward next-generation experiments aiming at sub-electronvolt sensitivity. Achieving this goal will require a substantial increase in statistics, made possible by larger detector arrays, higher source activities, and longer measurement times. The technologies validated in the current phase of the experiment -TES microcalorimeters, microwave multiplexing, and integrated radioactive sources- form the essential building blocks for such an upgrade path.

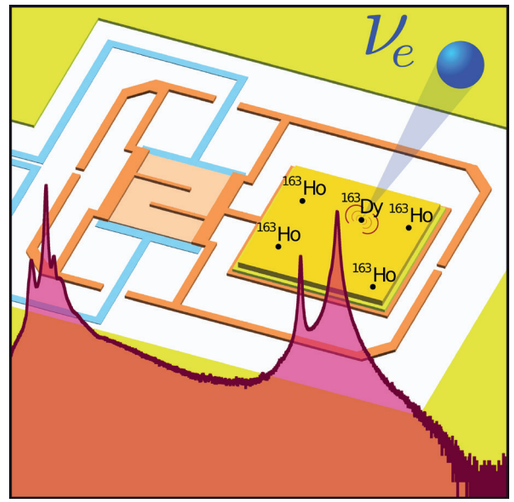


Figure 3: Scheme combining detector layout and measured spectrum.

A UNIQUE FACILITY

REACTOR OPERATIONS

The reactor schedule for the period 2024–2027 is organised around continuing with the implementation of safety commitments from the last ten-year safety review requiring long reactor shutdowns, and delivering reactor operating periods for the ILL's scientific programme.

Within this framework, the ILL has planned four major long shutdowns for this work, whilst ensuring that a maximum number of beam days are delivered for science and for the production of radioisotopes, in particular lutetium-177, which is highly effective in treating certain forms of cancer.

After completion of the second of the long shutdowns, which began on 9 July 2024 to carry out a series of safety-related upgrades, including refurbishment of the polar crane on Level D of the reactor building, installation of a fire-suppressing sprinkler system on Level C, and reinforcement of the casemate for the H1-H2 guide system, the reactor delivered two cycles in 2025 with a high level of availability (>96%), allowing the scientific programme to be successfully carried out.

The first cycle began with the start-up of the reactor on 5 May and was completed on 7 July. The second cycle started as planned on 26 August, and the reactor has been shut down since 28 October for the third long shutdown. The work to be carried out during this shutdown includes the reinforcement of canal n° 3, the replacement of the B27 heat exchanger, the start of the refurbishment of the overhead crane on level C, the reinforcement of the H5 casemate, the painting of the reactor dome, the replacement of two new beam tubes, and the reinforcement of the support structure of the emergency fuel element drop system (PUC).

As has been the case for the last few years, the ILL's relations with the French nuclear safety authority (ASNR) continue to be good, as shown by the confidence expressed by the ASNR at the annual review in March 2025.

Concerning the RPP project to reinforce the physical protection of the installations, which is being conducted under the supervision of France's security authority, the HFDS (*Haut Fonctionnaire de Défense et de Sécurité*), a new strategy has been defined by the ILL which includes the deployment of armed guards. This project will be finalised in 2026.

The main operations carried out by the Reactor Division during the shutdowns in 2025 were as follows:

- Maintenance work and periodic testing.
- Completion of the reinforcement of the polar crane on Level D and the replacement of its trolley.
- Completion of the clean-up of the detritiation facility with the removal of certain components/equipment and the installation of a recombiner unit. The purpose of this recombiner unit is to recombine tritium and deuterium with oxygen at very low concentration, in order to produce heavy water for the primary circuit.
- Completion of the installation of a fire suppression system (installation of fire sprinklers on Level C and construction and commissioning of a water tank in building ILL52).
- Reinforcement of the pipe support structures located at the bottom of the transfer canals n° 1 and n° 2.
- Reinforcement of the casemate H5 to protect the reactor building penetrations.

Concerning the fuel cycle, taking into account the scenario based on the end of reactor operation in 2033, the fuel conversion programme foresees the irradiation of the First-Of-A-Kind (FOAK) element in 2029 and conversion of the reactor to LEU by the end of 2032. In this framework, the ILL is continuing its participation in the HERACLES programme and in the new European project "LEU conversion". The ILL has optimised the scope of the conversion programme by focusing on the performance of the neutron flux delivered to experiments and maximising the number of days per cycle.

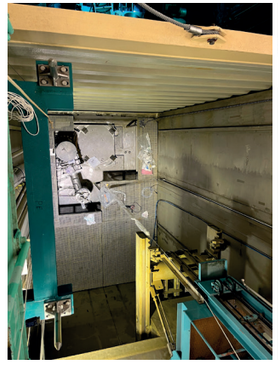
Jérôme Estrade
Head of the Reactor Division

TWO CYCLES AND **126 DAYS** OF **OPERATION** IN **2025**

~50.0 MW

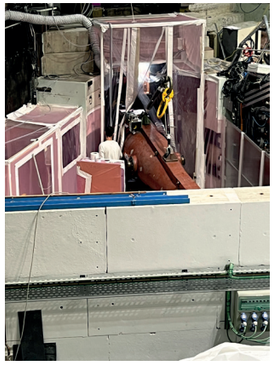
1.5 x 10^{15} n/s cm^2

A SINGLE HIGHLY ENRICHED URANIUM FUEL ELEMENT

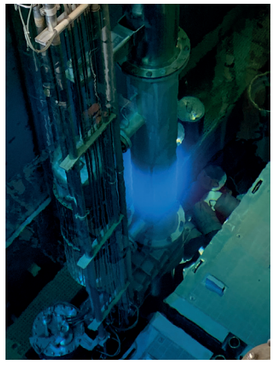


Canal n°3.

Replacement of B27 heat exchanger.



Work on beam tube H13.



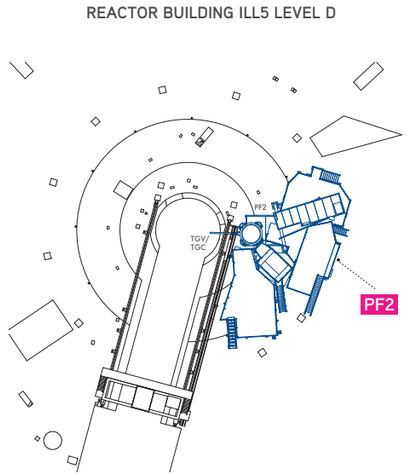
Unloading of fuel element.

B27 heat exchanger.

Crane on Level C.

Painting of the reactor dome.

ILL INSTRUMENT LAYOUT

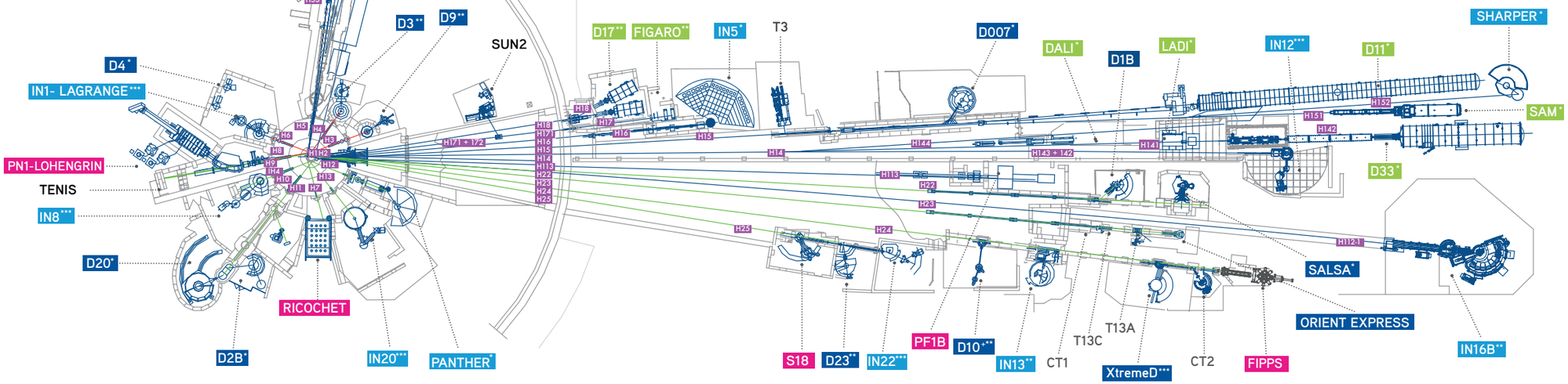


Instruments groups

- Diffraction
  - (*) Powder diffractometers
  - (**) Single crystal diffractometers
  - (***) Powder & Single crystal diffractometers
- Large Scale Structures
  - (*) Large-scale structure diffractometers
  - (**) Reflectometers
  - (***) Imaging
- Nuclear & Particle Physics
- Spectroscopy
  - (*) Time of light
  - (**) High Resolution
  - (***) Three-axis
- Test instruments

Guides

- Hot neutrons
- Thermal neutrons
- Cold neutrons



SUPPORT LABORATORIES

The ILL is firmly committed not only to building high-performance instruments, but also to offering the best possible scientific environment for its user community. On-site sample preparation laboratories provide scientists with space and equipment to prepare and characterise samples before, during and after neutron experiments. They are available to the user community and help to fuel in-house research. The laboratories operated by the Biology, Deuteration, Chemistry and Soft Matter (BDCS) group include the Deuteration (D) Lab and Lipid (L) Lab, providing the ILL user community with a variety of deuterated biological molecules.

Evolution of the BDCS group and new science projects

Since its creation in 2023, the BDCS group has grown from a team of 10 to a team of 20. Most of its new members are Master's or PhD students or postdoctoral researchers and are involved in multiple projects. Current projects include developing novel deuteration protocols (in particular amino acid-specific and segmental labelling), exploring the complexity of lipid compositions in cellular membranes, and devising a joint neutron/X-ray contrast approach for membrane proteins. In 2025, the group was further strengthened by the recruitment of a technician to take charge of the maintenance of the scientific equipment in the various labs.

New synergies between the D- and L-Labs

The integration of the D- and L-Labs into the BDCS group has led to the proposal to create a new joint D/L-Lab to simplify user requests for samples that require collaboration between the two labs. Typical examples are lipids (including phospholipid mixtures of different classes) and sterols (both hydrogenated and deuterated), which are extracted and purified in the L-Lab from cell paste prepared in the D-Lab.

Vibrant user activity in the chemistry and PSCM labs

In 2025, the chemistry and soft matter support laboratories remained indispensable to the ILL neutron scattering user community, providing vital expertise, infrastructure, and instrumentation. In the past few years, the number of user access requests per reactor cycle has almost doubled. In 2025, approximately 350 experiments benefited from the chemistry laboratories, while 51 studies utilised at least one of the ~30 instruments available in the laboratories of the Partnership for Soft Condensed Matter (PSCM), underscoring their crucial role in supporting cutting-edge research at the ILL.

Scientific outreach and training

The BDCS group was also involved in the organisation of several scientific events in 2025 and regularly participates in teaching and training activities, including the European HERCULES school, EMBO SAXS/SANS practical courses, the ILL/ESRF International Student Summer Programme on X-Ray and Neutron Science, and university courses at UGA Grenoble.

Further information and contact details

Deuteration laboratory - www.ill.eu/d-lab
Deuterated lipids laboratory - www.ill.eu/l-lab
Chemistry laboratories - www.ill.eu/chem-lab
Partnership for soft condensed matter - pscm-grenoble.eu
Partnership for Structural Biology - www.psb-grenoble.eu

Giacomo Corrucci
Imperial College, London, UK
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I'm a postdoctoral researcher at Imperial College London, working under the supervision of Professors Francesco Aprile and Annalisa Pastore. My research focuses on protein-lipid interactions studied by neutron and X-ray scattering, with applications to neurodegenerative diseases.

Membrane charge drives the aggregation of TDP-43 pathological fragments

TDP-43 is an RNA-binding protein linked to neurodegenerative diseases and has recently been shown to interact with lipid membranes. To characterise this interaction, we carried out a systematic biophysical study using a TDP-43 fragment called M85. Our results show that lipid charge affects the modality by which M85 interacts with membranes: a higher negative charge promotes protein binding to the bilayer surface, leading to increased protein aggregation and reduced lipid bilayer damage.

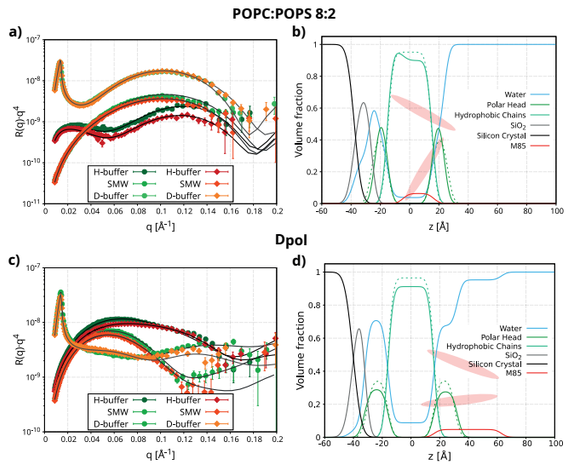


Figure 1: Two examples of neutron reflectivity static measurements: Measurements before (green colors) and after (red colors) M85 injection and incubation with POPC: POPS 8:2 (20% negative charges) and Pichia pastoris Dpol (around 25% negative charges).

Original publication: JACS (2025) - 10.1021/jacs.5c00594
ILL contact: K. Batchu, batchu@ill.fr

Lipids play a dominant role in the aggregation of several proteins associated with neurodegeneration, either by inducing or modulating their aggregation rates or through more subtle means. Extracellular vesicles are an important medium for cell–cell communication that allow for the transfer of material between cells but can also facilitate the spread of misfolded proteins that could "infect" other cells. The TDP-43 protein is linked to the neurodegenerative diseases amyotrophic lateral sclerosis, frontotemporal dementia and Alzheimer's disease. To assess whether it interacts with lipid membranes and to understand the physical determinants required for this interaction, we carried out a systematic biophysical study using a TDP-43 fragment lacking the first 84 N-terminal residues, called M85. This fragment was of particular interest because proteolysis appears to be a common post-translational modification in several neurodegenerative diseases, especially in TDP-43 pathologies. We examined how M85 interacts with lipids using large unilamellar vesicles (LUVs), supported lipid bilayers (SLBs), and lipid monolayers at the air/water interface. We employed state-of-the-art biophysical techniques, including fluorescence microscopy, alongside advanced neutron-based methods such as neutron reflectivity, which are particularly effective for studying protein–lipid interactions. In our experiments, we systematically varied the lipid composition of synthetic membranes to probe how lipid charge and charge density affect M85-membrane interactions, as well as the conformation and stability of both the protein and the lipid bilayer. Our results confirmed interactions in all cases and showed that lipid charge affects the modality by which M85 interacts with the membrane. Higher negative charge induces the protein to bind to the bilayer surface, enhancing protein aggregation while reducing lipid bilayer damage (which is higher with more neutral lipid membranes) (Figure 1). To our knowledge, this is the first comprehensive study to examine the atomic determinants and molecular consequences of such interactions using a highly aggregation-prone TDP-43 fragment. These interactions may influence how TDP-43 and its fragments form aggregates, damage membranes, or transfer between cells: key steps in their pathogenic role. Our findings underscore the importance of the relative charges of both proteins and lipids. This work was also supported by the D-Lab and L-Lab, which provided deuterated natural lipids for neutron reflectivity measurements.

TECHNOLOGICAL INNOVATION AT THE ILL

At the Institut Laue-Langevin, scientific excellence is inseparable from technological innovation. The performance of our instruments - and the discoveries they enable - are build on decades of in-house development in neutron optics, detection systems, sample environments, electronics, and scientific computing.

The completion of the Endurance programme marked a major milestone in the modernisation of our instrument suite. Throughout this ambitious upgrade effort, technologies developed within our technical services have played a central role. Examples include advanced monochromators and supermirrors, ^{3}He-based polarisation systems, next-generation detectors, high-performance sample environments, precision electronics, and integrated instrument-control solutions. These capabilities now form the backbone of post-Endurance maintenance and future upgrades, ensuring that the ILL remains at the forefront of neutron science.

The highlights presented in this report illustrate how this technological expertise continues to evolve.

The MARMOT analyser system represents a breakthrough in diffractive neutron optics. By exploiting permanently bent silicon crystals assembled with exceptional precision, it enables continuous high-resolution energy analysis on the thermal imaging instrument ThALES across a wide angular range. This achievement demonstrates not only scientific creativity, but also mastery of crystal processing, high-temperature deformation, and precision alignment techniques.

Detector development remains a cornerstone of instrument performance. The installation of the new Trench Multi-Wire Proportional Chamber on D20 ensures the long-term reliability of one of our highest-intensity diffractometers, while maintaining demanding counting-rate and angular-coverage specifications. This upgrade reflects our continued commitment to in-house detector expertise and sustainable technological independence.

Our capability to probe matter under extreme conditions is also of central importance. The successful neutron diffraction study of ε-iron at 20 GPa and 160 mK highlights the strength of our internally developed high-pressure and ultra-low-temperature sample environments. Such experiments push the limits of mechanical design, cryogenics, and magnetic compatibility, and demonstrate the unique experimental space available at the ILL.

Beyond neutron scattering in condensed matter, the commissioning of the RICOCHET experiment underscores the ILL's contribution to fundamental physics. Supporting coherent elastic neutrino–nucleus scattering detection requires advanced cryogenic engineering, custom electronics and radiation shielding design, and high-throughput data acquisition systems – once again illustrating the breadth of our technical expertise.

Finally, the commissioning of PorTo expands our cold-neutron imaging capabilities, enabling more high-resolution three-dimensional studies of complex materials and dynamic processes.

Together, these developments demonstrate that the ILL's strength lies not only in the intensity of its neutron beams, but in the depth of its technological expertise. Our integrated approach—from neutron optics to sample environment, detectors, and digital infrastructure—continues to provide our scientific community with world-leading tools to explore matter in increasingly complex experiments.

The achievements presented here are the result of the dedication and creativity of our scientific, engineering, and technical teams. Their work ensures that the ILL remains a reference facility for advanced neutron instrumentation and a driver of innovation across disciplines.

Andreas Meyer
Associate Director
Head of the Projects & Techniques Division

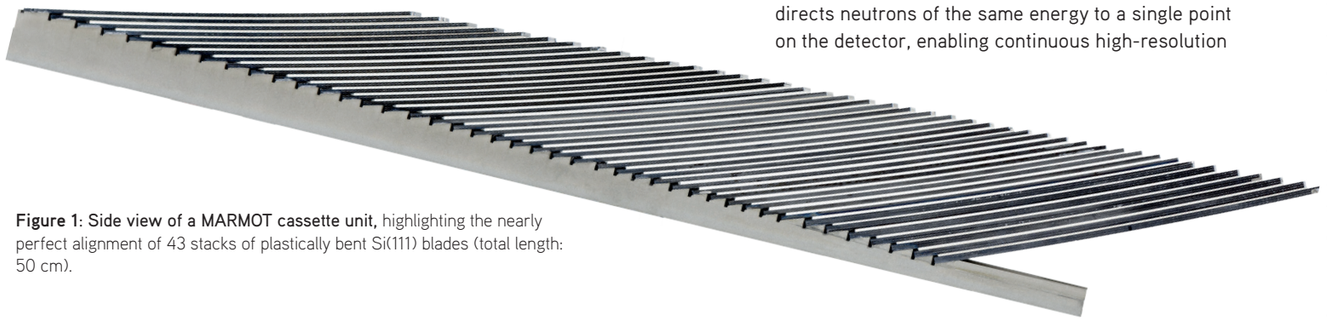


Figure 1: Side view of a MARMOT cassette unit, highlighting the nearly perfect alignment of 43 stacks of plastically bent Si(111) blades (total length: 50 cm).

NEUTRON TECHNOLOGY HIGHLIGHTS

Pierre Courtois and Paul Steffens

MARMOT is the result of combining a brilliant scientific idea with innovative technological developments. It is a highly complex system that pushes the limits of what is currently possible in diffractive neutron optics.

New bent silicon crystal technology: shaping the future of neutron spectroscopy with MARMOT

Recently validated on ThALES at the ILL, the MARMOT device is redefining neutron spectroscopy. At its core are bent silicon crystals, exploiting Si's ideal properties to deliver unprecedented energy resolution and efficiency. Developed at the ILL, this advanced Si-based technology represents a real breakthrough in neutron instrumentation.

MARMOT (Multiplexed Array for Mapping on ThALES) aims to provide continuous energy analysis across the 4–7 meV range for the triple-axis spectrometer ThALES, while covering a wide analysis angle of 75°. The central component of the system is an assembly of 2790 bent silicon crystals, organised into 30 cassette units.

A cassette unit consists of 43 stacks, each composed of two or three 1-mm-thick Si(111) blades, permanently bent to a fixed curvature (Figure 1). The blades, produced in five different length and width configurations, are approximately 200 mm long and 20 mm wide. Their curvature radii range from 2.4 to 2.8 meters. The design ensures that each crystal diffracts neutrons within a specific energy range, while the focusing geometry directs neutrons of the same energy to a single point on the detector, enabling continuous high-resolution energy analysis. Such a concept overcomes the limitations of a conventional Si analyser, which suffers from restricted angular and energy coverage.

The production of bent Si crystals with a fixed curvature involved high-temperature deformation using precision anvils with controlled curvature in a dedicated hot-press furnace. Preserving crystal quality throughout the bending processes was vital, as structural defects could significantly reduce neutron reflectivity and compromise performance. To this end, the process was meticulously optimised to avoid damaging the crystals. Continuous quality control was performed using hard X-ray diffraction, a method that provided direct imaging of structural defects. Comparison of diffraction images

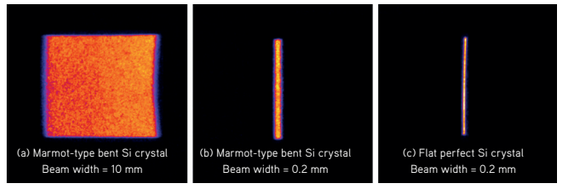


Figure 2: Hard X-ray diffraction images of a Marmot-type Si crystal (R = 2.6 m). (a) Uniform curvature observed using a large beam width (10 mm). (b) Preserved structural quality with a small beam width 0.2 mm. (c) Diffraction image of a perfect flat Si crystal with a small beam (0.2 mm) for comparison.

with a perfect flat Si crystal confirmed that the bent crystal maintained uniform curvature and excellent structural integrity after deformation (Figure 2).

The neutron performance of the crystals was evaluated using neutron diffraction on the high-resolution diffractometer T13C. Comparative neutron tests between elastic and Marmot-type Si crystals demonstrated nearly identical peak reflectivity of approximately 70%, a value estimated from theoretical calculations for elastically bent silicon crystals. This performance is comparable to that of graphite (HOPG), underscoring the exceptional quality of Marmot-type crystals.

The final, non-trivial step involved the careful assembly of the cassette unit, a process that required high precision. The gluing of each Si crystal onto a dedicated aluminium support was monitored using hard X-ray diffraction, providing almost immediate feedback on its alignment, ensuring an alignment accuracy better than 0.02° (Figure 1).

Seven cassettes were produced for tests on ThALES during the last cycle in 2025. The full-scale prototype demonstrated excellent energy resolution combined with high neutron intensity, confirming the high performance of the system. However, work is not yet finished! Production is still ongoing, with the aim of completing all 30 cassettes by mid-2027.

Bruno Guerard

The Neutron Detector Service (SDN) team comprises three detector scientists (W. Saenz, J. Marchal, B. Guérard), one mechanical engineer (J.C. Buffet), one machinist (S. Cuccaro), and two assembly technicians (N. Sartor and J. Pentenero). Together, they provide extensive expertise in the design, manufacturing, assembly, and testing of detector systems and their associated gas-handling equipment. Strongly oriented toward the development of innovative solutions, the team works closely with instrument scientists to address specific performance requirements. Specialised in ³He-based detectors, SDN designs, manufactures, and maintains a wide range of detector systems meeting most of the Institute's needs. Several detector systems have also been delivered to other research centers.

A new detector for D20

The D20 instrument is a high-intensity neutron powder diffractometer designed for structural studies requiring high counting rates and large angular coverage. Its performance critically depends on the reliability and efficiency of its detector system.

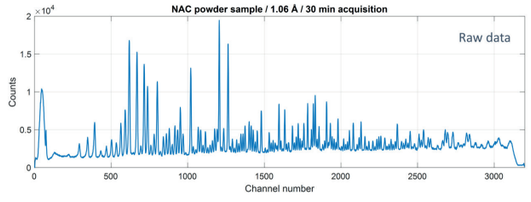
From 2000 to 2024, the D20 instrument was equipped with a large-area curved position-sensitive detector based on Micro-Strip Gas Counter (MSGC) technology, introduced at the ILL by A. Oed in 1988. After almost two decades of reliable operation, the detector began to show signs of ageing, notably an increasing number of non-functional readout channels. In 2018, it was decided to replace it to ensure continued reliable operation and to anticipate a potential major failure.

The development of the new detector was initiated based on the Trench Multi-Wire Proportional Chamber (Trench-MWPC) technology, which was then under development for XtremeD. The Trench-MWPC provides detection performance comparable to MSGCs, most notably a high counting-rate capability, while avoiding their main limitations. In particular, it eliminates the dependence on a single supplier of MSGC plates, whose production quality had become increasingly uncertain.

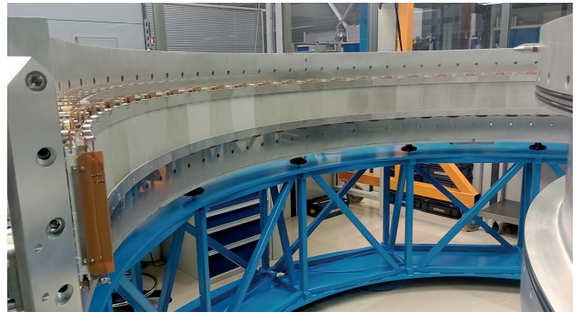
The new D20 Trench-MWPC was designed to retain the main characteristics of the previous detector. It comprises 1600 electronic channels covering an angular range of 160°, corresponding to a readout pitch of 0.1°. The dimensions of the aluminium pressure vessel, as well as the detector curvature radius of 1.5 m, were kept unchanged to ensure full interchangeability with the previous detector.

The aluminium pressure vessel was manufactured by Mecanicas Bolea S.A. (Spain), while most internal components, particularly the 25 aluminium trench blocks, each comprising 64 channels, were produced at the ILL using wire-cut EDM. The 1600 gold-plated tungsten anode wires, 20 µm in diameter, were individually soldered by hand onto the contact pads of flexible polyimide circuits connected to 50 custom-designed high-voltage 32-pin feedthroughs integrated into the vessel. Precise anode positioning, essential for detector response uniformity, is ensured using MACOR combs. Signal readout is performed using 32-channel electronics boards developed by the ILL Instrument Control Service (SCI).

The new Trench-MWPC detector has been in operation on the D20 instrument since May 2025.



Diffraction line-profile from a NaCaAlF powder sample acquired with the new Trench-MWPC detector on the D20 instrument.



Inside view of the D20 trench-MWPC detector. The 25 trench modules are mounted side by side without any dead zone to ensure a continuous 160° angular coverage.

Stefan Klotz

IMPMC, Sorbonne Université– CNRS - Paris - France
Stefan.Klotz@upmc.fr

Research Director at the Sorbonne University in Paris, Stefan Klotz has dedicated his career to studying condensed matter under extreme conditions. He is particularly known for developing methods to perform high-pressure neutron scattering to beyond 20 GPa.

No long-range magnetic order in ε-iron down to 160 mK

The magnetic properties of ε-iron — the high-pressure phase of iron found in the Earth's core — have long been debated, with theories suggesting residual magnetic moments which might order at ultra-low temperatures. In this study, we applied a pressure of 20 GPa at 160 mK with a new piece of equipment developed internally to probe ε-iron's magnetism. The findings reveal no long-range magnetic order, challenging existing models and showcasing the cutting-edge experimental techniques in extreme-condition physics, developped the ILL's Advanced Neutron Environment Service (SANE).

The magnetic state of ε-iron has long been controversial due to conflicting theoretical and experimental evidence. While early Mössbauer studies suggested ε-iron is non-magnetic, recent theories and indirect experiments proposed residual magnetic moments and potential ordering at low temperatures. To address this, with the SANE team, S. Klotz *et al.* employed neutron diffraction using a Triton DR-200 dilution cryostat, which enables cooling to 70 mK in a closed-cycle system, and a Paris-Edinburgh press for high-pressure conditions. The setup included double-toroidal diamond anvils and copper-beryllium gaskets, ensuring mechanical stability and minimal magnetic interference.

Neutron diffraction patterns were collected at the XtremeD instrument using a wavelength of 2.4446 Å. The results showed no evidence of long-range magnetic order or diffuse scattering in ε-iron at 160 mK and 20 GPa. The absence of magnetic Bragg reflections or intensity changes in nuclear peaks suggests any magnetic moment must be below 0.2 µB, significantly lower than theoretical predictions of 0.5–1 µB.

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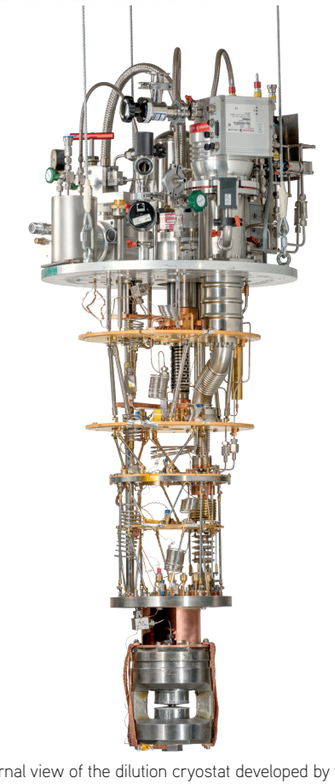
10.1103/PhysRevLett.134.116001
ILL contact: E. Lelièvre-Berna, lelievre@ill.eu

The study also considered short-range magnetic correlations or rapid spin fluctuations, which could remain undetected if occurring on timescales faster than 10–100 femtoseconds. These findings constrain theoretical models and highlight the need for further investigation using techniques like muon spin spectroscopy. This work demonstrates the capability of high-pressure neutron diffraction at ultra-low temperatures to explore quantum and magnetic phenomena under extreme conditions.



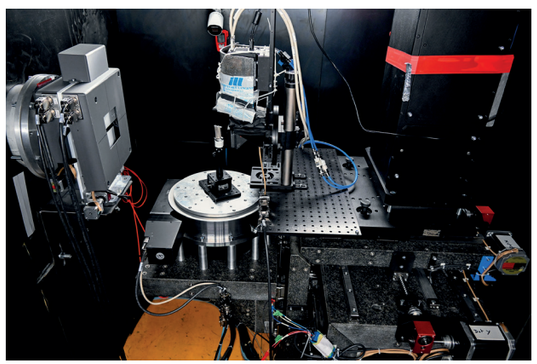
Internal view of the dilution cryostat developed by the ILL team. The VX5 Paris-Edinburgh press is suspended from or attached to the stage of the mixing chamber with a support made from OFHC copper.

Bratislav Lukić

I'm a scientist working in high-speed and high-resolution imaging of materials and multi-phase systems. My work focuses on neutron and synchrotron X-ray imaging methods to investigate materials and fluids under extreme conditions. I joined the vibrant imaging team at the ILL in August 2025.

PorTo: New high-resolution neutron tomograph for micro-imaging

With PorTo, the ILL expands its imaging capabilities and makes neutron microtomography readily accessible to the user community, enabling highest 3D detail, enhanced multi-material sensitivity, and practical operando experiments using cold neutron radiation. As its high-resolution capabilities continue to consolidate, PorTo is set to become a particularly well-adapted instrument for revealing internal microstructures and accessing micro-scale detail and material dynamics in complex materials and systems.



PorTo, the ILL's new cold-neutron microtomography instrument, was commissioned in September 2025 with the objective of making neutron imaging at the micrometre scale readily available to the user community. During its commissioning cycle, nine friendly-user experiments were successfully performed, validating both the instrument's performance and its suitability for a variety of scientific use cases. By combining a compact design with a high-flux cold-neutron spectrum and dedicated high-resolution detectors, PorTo delivers detailed 3D(+t) observation of complex, multi-material samples—expanding the possibilities for *operando* and *in-situ* lab-scale experiments in energy research, materials science, materials engineering, and life sciences at the microscale.

PorTo is built to complement the ILL's established imaging suite (notably NeXT and MoTo) and to serve experiments where fine microstructure and/or subtle internal contrast require imaging at high spatial resolution. Example applications range from tracking hydrate formation in metallic materials and visualising local in-situ dynamics in fuel cells, to following liquid electrolyte (re)distribution in compact battery concepts, locating micro-defects in additively manufactured materials, and micro-imaging cultural heritage objects and small biological specimens.

The first commissioning results highlighted both resolution and adaptability. PorTo produced detailed 3D tomography images of porous phantoms mimicking cancellous bone microstructure—demonstrating the ability to distinguish multiple materials within a single dataset and confirming full operation with dedicated high-resolution detectors. Early applied investigations further included imaging of additively manufactured auxetic steel foams engineered for improved impact performance, as well as (phase-) contrast-enhanced micro-imaging of small specimens such as insects, where non-destructive access to internal 3D structure is particularly valuable.

Installed on the H113 neutron guide, PorTo is currently operating every three reactor cycles. Its design provides high spatial resolution and supports long-duration operando measurements, with imaging setups conceived to minimise experimental logistics and set-up time.

Torsten Soldner

Instrument responsible for PF1B and RICOCHET with main research interest in precision tests of the Standard Model of particle physics.

Installation and commissioning of the RICOCHET instrument for CENNS detection

RICOCHET, an experiment aiming to explore coherent elastic neutrino-nucleus scattering with reactor antineutrinos, completed commissioning and entered its scientific phase in 2025.

Figure 1: Heart of the cryostat: 18 copper-encased cryogenic calorimeters are installed on the 10 mK stage below the inner shielding of HDPE, copper and lead at the 1 K stage. The inner veto is installed on the 4 K stage. The outer shielding is visible in the background.

Neutrinos only interact with matter via the weak force, making their detection challenging. Coherent elastic neutrino-nucleus scattering (CENNS) – where a neutrino scatters off an entire nucleus – enhances the cross-section by orders of magnitude. In 1 kg germanium exposed to ILL's neutrino flux of $10^{12}/(cm^2\ s)$ at 8.8 m from the core, this yields about 10 nuclear recoils/day above 50 eV. Predicted in 1974 by Freedman and first observed by the COHERENT experiment at the Spallation Neutron Source (SNS) in 2017, CENNS becomes fully coherent for reactor antineutrinos (<10 MeV), providing a unique probe of the Standard Model's weak mixing angle at low energy and of new physics. Yet, nuclear recoils from reactor antineutrinos deposit less than 1 keV in germanium, with only ~20% visible as ionization due to quenching. Even optimised high-purity germanium detectors struggle to resolve these low-energy events and cannot distinguish them from electronic recoils, though hints for observation have been reported recently by Dresden-II and CONUS+.

Original publication: Phys. Rev. D (2025) - 10.1103/7xy6-jq3c
https://ricochet-exp.org/
ILL contact: T. Soldner, soldner@ill.eu

The RICOCHET collaboration addresses these challenges by using cryogenic calorimeters designed and fabricated by IP2I Lyon and IJCLab: 42 g germanium crystals operated at ~15 mK. The ratio of simultaneously measured ionization to heat discriminates nuclear recoils (from CENNS or fast neutrons) from electronic recoils (from gamma rays).

The instrument is installed in a shielded casemate, below the reactor's transfer channel providing 15 m water-equivalent overburden against cosmic radiation. The low-vibration dilution cryostat sits in a radiation and magnetic shielding of 23 t of borated HDPE, lead and soft iron designed and installed by LPSC Grenoble. Cosmic muons, which generate fast neutrons in lead, are tagged by a veto detector covering the shielding. Undetected cosmic background and natural radioactivity are subtracted using measurements during reactor shutdowns. ^{41}Ar present in air during reactor cycles is suppressed by the casemate and sealed shielding. Fire-retardant wall insulation and a retention system mitigate the calorific load from the HDPE and plastic scintillators. Noisy infrastructure is enclosed in a soundproof cabin.

Custom electronics developed by IP2I Lyon and Institut Néel samples heat and ionization signals at 100 kS/s. Unlike traditional triggered systems, which risk missing low-energy events due to predefined thresholds, RICOCHET stores all samples for offline analysis, where signals are converted to frequency space for optimum filter analysis. This technique maximizes the signal-to-noise ratio and enables event reconstruction down to the noise floor, which is critical for CENNS detection. About 1 TB/day of raw data are transferred to IN2P3's computing centre in Lyon for analysis by collaboration members in France, Canada, and the US.

The cryostat was installed in winter 2023/24. Commissioning with three detectors started in February 2024. The detector payload was incrementally increased, reaching full capacity of 18 detectors in summer 2025. Parallel improvements included detector and electronics upgrades, mechanical decoupling of the cryostat, and adding an inner shielding and an inner veto. First commissioning results are detailed in *Phys. Rev. D* (2025).

This setup positions RICOCHET as a leading experiment for CENNS with reactor antineutrinos. While a 5-sigma significant CENNS detection will require years of data, first physics results are expected in 2026.

INDUSTRY AND IMPACT

At research infrastructures like the ILL, there is a growing awareness of the broader impact of our organisations, extending from the traditional focus on scientific impact to cover, for example, training, innovation and socio-economic impacs. While fundamental science and knowledge generation underpin future innovation and socio-economic impacts, industry research and development (R&D) is particularly relevant in this context since it operates at higher technology readiness levels (TRLs), developing materials, products and processes closer to market.

A particularly striking example of research at the ILL leading to significant socio-economic impact is the production of radio-isotopes for medical applications. The nuclear physics research programme at the ILL over many years has identified key isotopes and determined how to produce them, in particular with the very high flux of the ILL reactor. In 2025, working with the radiopharmaceutical industry, the ILL continued to deliver isotopes like Lu-177 and Tb-161, which are used in clinics for cancer therapy. Each week of reactor operation sees several thousand doses provided to patients, generating significant revenue for the ILL.

When most people think about industry beam time use of ILL, they tend to think about proprietary access i.e. paid access by industry for confidential work, which is managed by the Industrial Liaison Unit (ILU). This R&D is at the upper end of the TRL scale (typically 5-8) and, in 2025, it generated a record level of revenue per cycle of operation through 20 paid beam times. Almost 10 feasibility studies were also performed to prepare new paid services. Imaging and SANS were the main techniques used in 2025 for proprietary access.

Obviously, confidential R&D cannot be publicised, in which case it is insightful to turn to industry R&D in the user programme, which is at lower TRL and can, indeed must be published. In reality, more companies access the ILL free of charge through the ILL user programme than pay for confidential access and they use most of the instrument suite. The companies participating in user experiments in 2025 included AstraZeneca, Tetra Pak, Sanofi and ArcelorMittal. Almost 10% of ILL publications in 2025 featured authors from industry, including L'Oreal, BASF, Umicore, Seagate and Rolls Royce. Many of the companies participating in the user programme do so in collaboration with academic partners -the ILL plays a crucial role in enabling these collaborations between European universities and industry.

Whilst it's clear how the ILL supports industry through research and scientific discovery, there are also other ways through which ILL boosts innovation. One is via a culture of open innovation with ILL suppliers. Another is via direct knowledge transfer to industry in the form of human capital. For instance, many former ILL PhD students and staff now work in industry, with many of those being in R&D roles. Those companies benefit from the unique skills and experience brought by staff who have worked at the world's leading neutron source.

Recognising the importance of impact, two impact pre-studies were completed in 2025 and subsequently a full, lifetime impact study was launched last autumn. This work on impact will be essential to support stakeholder engagement at the ILL, for example, the extension of Scientific Member contracts until the end of the current, 6th protocol in 2033.

48 Experiments involving industry

86 Experiments with industrial relevance

44 Publications with industry

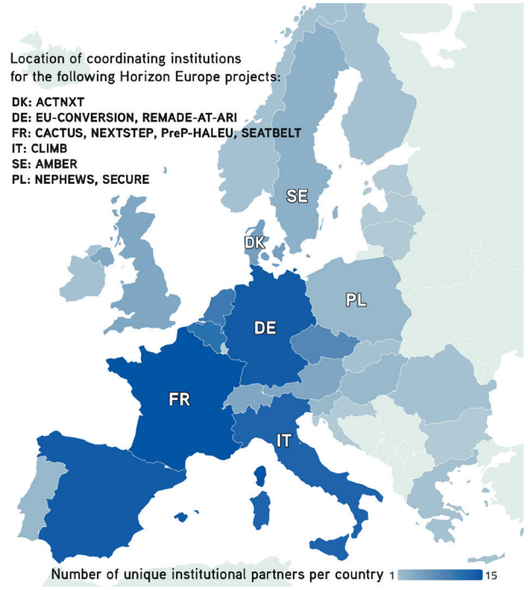
EUROPEAN COLLABORATIONS

The ILL has a central and long-standing commitment to research collaboration, actively participating in national- and EU-supported research initiatives that span a broad spectrum of science, innovation, technology and training priorities. Involvement in European projects cultivates strategic partnerships with leading European research organisations, higher education institutions, and large-scale research infrastructures, as demonstrated by the current network of over 130 unique partners across Europe and beyond.

The EU Office at the ILL focuses mainly on European projects which tend to fall under Pillar 1 - Excellent Science – of Horizon Europe. This covers funding for research infrastructures (INFRA), Marie Skłodowska-Curie Actions (MSCA) for training and European Research Council (ERC) grants. As the ILL Science Strategy gains momentum, new opportunities are sought in Pillar 2 – Global challenges and European Industrial Competitiveness – and in Pillar 3 – Innovative Europe – to support innovation and work with industry. The Widening Programme also offers opportunities to develop collaboration with existing and potential new Scientific Member countries.

Throughout 2025,the ILL continued to develop its European research presence through a diverse portfolio of 18 ongoing EU-funded projects, generating approximately €700k in annual revenue, and securing €6.4M in EU funding since the start of the Horizon Europe Framework Programme in 2021. The ILL currently participates in projects covering topics ranging from recyclable materials (REMADE@ ARI - INFRASERV) to medical radionuclides (PRISMAP - INFRASERV, SECURE - EURATOM), battery degradation (SEATBELT - Pillar 2), fuel cells (ACTNXT - INFRATECH), photovoltaics (CACTUS - INFRADEV), radiation testing (RADNEXT - INFRASERV), and the European Open Science Cloud (OSCARS - INFRAEOSC). 2025 marked the successful completion of 4 projects (ATTRACT-2, CACTUS, EURIZON, PRISMAP) and the launch of 2 new projects (ACTNXT, CLIMB).

In total, 12 PhD students and postdoctoral researchers were fully funded in 2025 by CLIMB (lipid-based nanomaterials) and AMBER (biological imaging) MSCA projects, with the biggest being NEXTSTEP: 9 projects were selected on topics including battery materials synthesis, mRNA delivery systems, magnetic phenomena, RNA helicase mechanisms, cryogenic materials testing, crystallisation dynamics, hydrogen storage, antimicrobial delivery, and CO_2 capture technologies.



European project partner network

Distribution of unique partners across on-going Horizon Europe funded projects at ILL

Non-European partners not shown: Israel (2), United States (1), Chile (1), Colombia (1), Jordan (1)

15 proposals were submitted to Horizon Europe calls in 2025, including one to the European Innovation Council and, at the time of writing, we are delighted to learn that 6 out of 7 'infrastructure' proposals will be funded. Some of these follow on from recent projects (PRISMAP+, RADNEXT 2030, READY-PV, ATTRACT-EXPAND), focus on training of Research Infrastructure staff (PRIME-ARI) and will help to shape the next Framework Programme (COORDINAINNOV for a future, high-tech – RI ecosystem).

The European Office team, as part of the Partnership and Communication Services (PACS), provides staff with expertise and guidance in the European and international funding landscape, support and tools to develop and manage research projects, from funding acquisition through successful implementation to completion.

If you would like to develop projects involving the ILL in any part of Horizon Europe as outlined above, or apply for an individual award, such as an MSCA postdoctoral fellowship, please contact the EU Office at europe@ill.eu or contact ILL staff directly.

VISITS & EVENTS

30 January

Visit by the delegation from GANIL (Grand Accélérateur National d'Ions Lourds)

5-6 February

Participation in the the innovation festival Tech&Fest

11 February

Visit by the General Consul Jessica Engel, German Consulate in Lyon

8-11 April

Subcommittee and ILL Scientific Council meetings

13-14 May

Meeting of the Subcommittee on Administrative Questions (SAQ)

19-20 June

Associates and Steering Committee meetings (Meudon)

17 September

Visit of Hiroshima International University

10 October

Visit by the Annual Monitoring Committee of the Auvergne-Rhône-Alpes Region Directorate for EU Funding

Visit at ILL by the German Consulate in Lyon.

11 October

Participation in the science festival 'Fête de la science' as part of the EPN Campus

14-15 October

Meeting of the Subcommittee on Administrative Questions (SAQ)

4-7 November

Subcommittee and ILL Scientific Council meetings

20 November

Visit of RePSO@UGA - Research Project Support Office

20-21 November

Visit by Deputy Director-General for Research and Innovation DG (RTD), M. C. Russo and of a delegation of French European Deputies

27 November

Associates and Steering Committee meetings (Grenoble)

The ILL received visits from ASNR inspectors throughout the year in the framework of periodic inspections and the annual review.

Visit by the Annual Monitoring Committee of the Auvergne-Rhône-Alpes Region Directorate for EU Funding.

Visit of Hiroshima International University.

SCIENTIFIC EVENTS

In 2025, the ILL organised (or co-organised) 23 scientific events (workshops, conferences and schools). In addition, a total of 75 general seminars were organised.

Workshops

11-16 January
ADD2026 | Analysis of Diffraction Data in Real-Space

20 February
Small-angle scattering data analysis course @ EPN Campus

20-21 March
Neutron Scattering Support Laboratories Symposium

5-7 May
7th International Symposium on Diffraction Structural Biology

3 June
PSB (Partnership for Structural Biology) & GRAL (Grenoble Alliance for Integrated Structural & Cell Biology) Student Day

2-5 June
JDN 2025 - Journées de la diffusion neutronique, Annecy

26-27 June
5th PSB biennial Symposium - Machine Learning in Cellular Structural Biology

6-10 July
International Conference on Neutron Scattering (ICNS) 2025

20-24 October
DENIM XIV - Design and Engineering of Neutron Instruments Meeting

11 December
CARAC 2025 - Characterization techniques for the electronics domain and beyond

16-17 December
SAXS, SANS workshop - A stereo approach to elucidating complex fluids at the nanoscale with neutrons and X-rays

Schools

24–28 February
ENGINE (grEnoble eNerGy conversIoN & storagE) school

10 March-11 April
HERCULES European School

16-21 March
JDA - School on the Physics and Chemistry of the Actinides

24-27 March
IRT Nanoelec Doctoral Days

31 March-4 April
Fullprof - School on Neutron Diffraction Data Treatment

24-26 June
FANs - Neutron training school

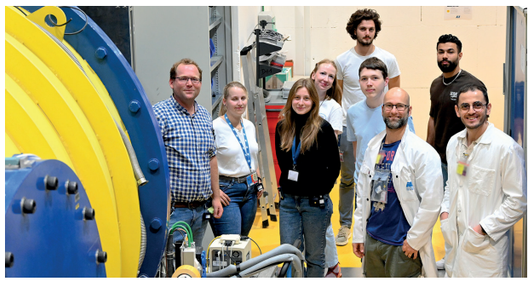
1-3 July
Soft Matter Summer School 2025

1-5 September
JCNS Laboratory Course - 27th edition of the Laboratory Course on Neutron Scattering

2-30 September
International Student Summer Programme on X-Ray and Neutron Science

27-31 October
FullProf Suite - Second 2025 edition

Soft Matter Summer School.



JCNS Laboratory Course.

ILL ORGANISATION

The main governing body of the ILL is the Steering Committee, which represents the Associate Countries, establishes the general operational and investment strategies and takes the important policy decisions concerning the future of the facility. The Subcommittee of the Steering Committee on Administrative Questions (SAQ) monitors the administrative operations and makes recommendations to the Steering Committee. The Scientific Council advises the ILL Management Board on scientific matters, in particular in what concerns scientific priorities and the development of the infrastructure in the interest of the user programme. It also assesses the scientific output of the facility. The Scientific Council is composed of representatives of the Associate and the Scientific Member countries.

The ILL scientific life is organised in 'Colleges', each College dealing with a particular field of research. Each college is animated by a College Secretary elected amongst its members. For each college there is a corresponding review panel that assesses the proposals in that field of research. These review panels, known as 'Subcommittees' (of the Scientific Council), meet twice a year (in Spring and Autumn) to evaluate the proposals submitted to the ILL and issue recommendations on beamtime allocation. Subcommittee panel members are selected from the academia. The panel also comprises the elected ILL College Secretary.

Associates

France
Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)
Centre National de la Recherche Scientifique (CNRS)
Germany
Forschungszentrum Jülich (FZJ)
United Kingdom
United Kingdom Research & Innovation (UKRI)

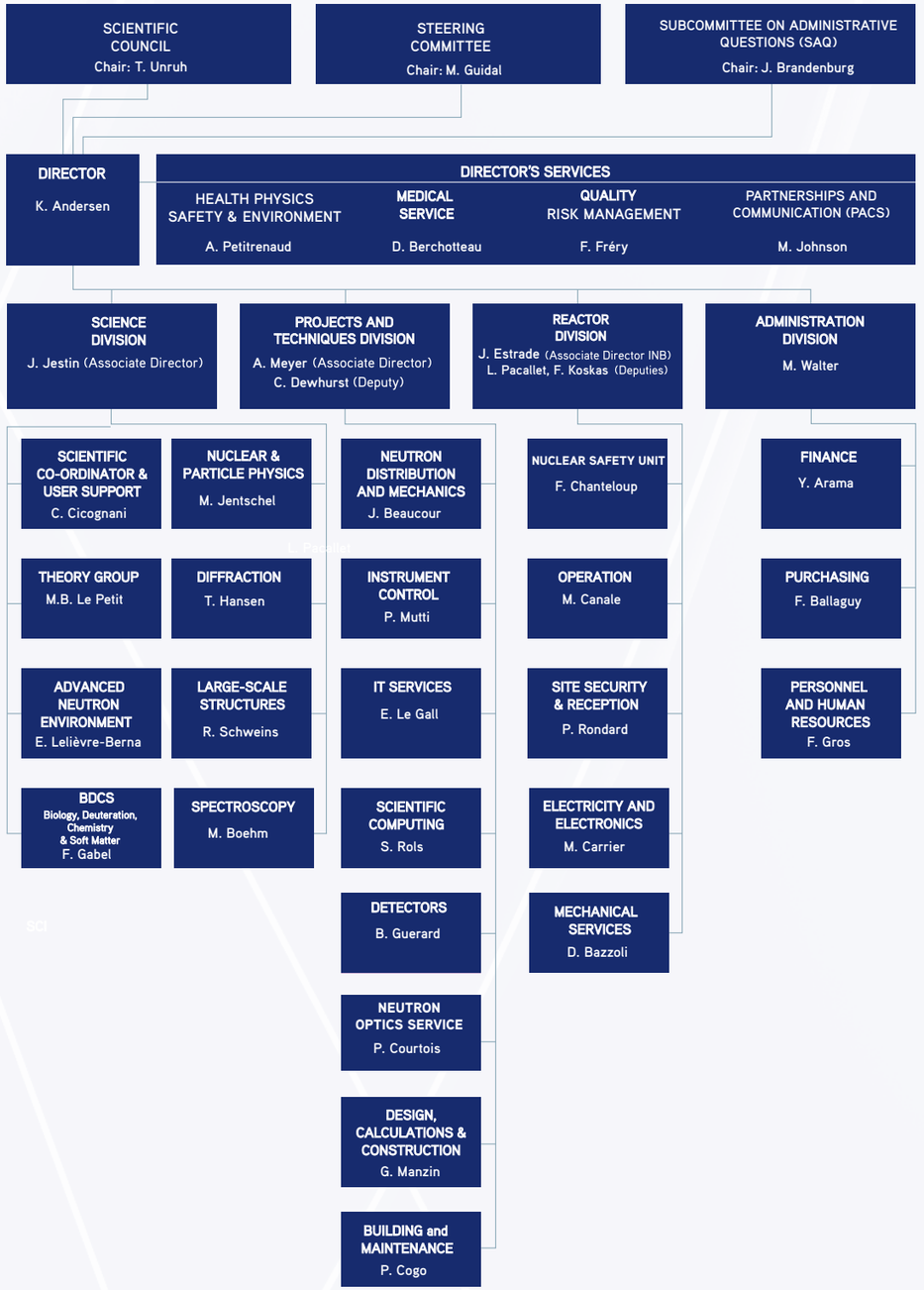
Countries with Scientific Membership

Austria: Österreichische Akademie der Wissenschaften
Czech Republic: Charles University, Prague
Denmark: Danish Agency for Science, Technology and Innovation
Italy: Consiglio Nazionale delle Ricerche (CNR)
Poland: Consortium of Polish Scientific and Research Institutions (NDPN)
Slovakia: Comenius University, Bratislava
Slovenia: The National Institute of Chemistry
Spain: MCIN Ministerio de Ciencia e Innovación
Sweden: Swedish Research Council (VR)
Switzerland: Staatssekretariat für Bildung, Forschung und Innovation (SBFI)

Review panels

Key **Chair**
College secretary

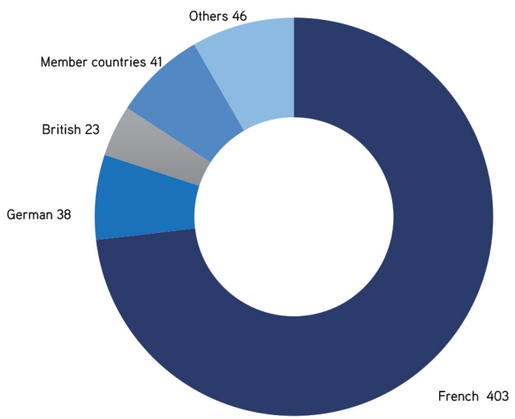
Applied materials science, instrumentation and techniques
Monica Ceretti (University of Montpellier, FR)
Anna Fedrigo
Nuclear and particle physics
Martin Fertl (Johannes Gutenberg university Mainz, DE)
Hanno Filter
Magnetic excitations
Rasmus Toft Petersen (Technical University of Denmark, DK)
Arno Hiess
Crystallography
Nicolas Barrier (CRISMAT/ENSI Caen, FR)
Nebil Ayape Katcho
Magnetic structures
Fabio Orlandi (ISIS, UK)
Jose Alberto Rodriguez Velamanzan
Nanoscale magnetism and superconductivity
Jonathan White (PSI, CH)
Thomas Saerbeck
Structure and dynamics of disordered systems
Fabrizia Foglia (University college London, UK)
Gabriel Cuello
Spectroscopy in solid state physics and chemistry
Wiebke Lohstroh (TUM, FRM II, DE)
Mohamed Zbiri
Structure and dynamics of biological systems
Andreas Stadler (Forschungszentrum Jülich, DE)
Anne Martel
Structure and dynamics of soft condensed matter
Natalie Malikova (CNRS/Sorbonne university (PHENIX), FR)
Orsolya Czakkel
Structure and dynamics of soft condensed matter - focus group
Olaf Soltwedel (Technische Universität Darmstadt, DE)
Ben Humphreys



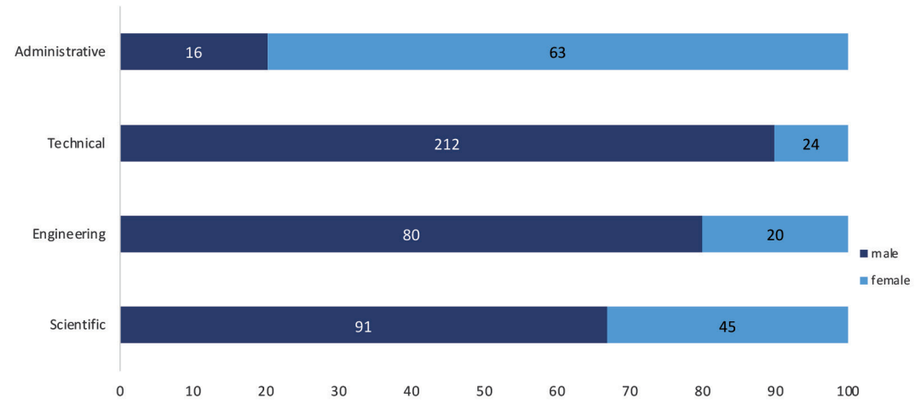
STAFF & BUDGET

551 members of staff
of **29** different nationalities

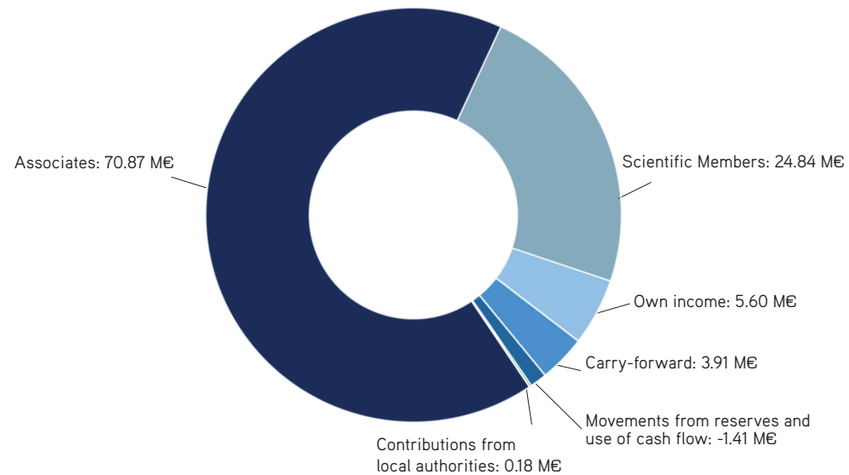
Distribution of staff by nationality - 31 December 2025



2025 gender balance per area of activity
Total share of women: 28%



Operating budget 2025: 104.004 M€ (excluding taxes)
The ILL's Associate countries contributed some 71 M€ to the Institute in 2025, a sum enhanced by significant contributions from the ILL's Scientific Member countries.

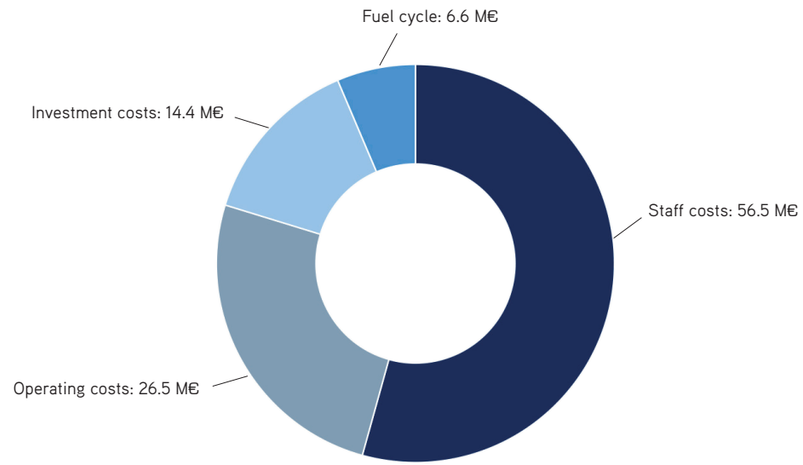


104 M€

Annual budget

68% from the Associates

24% from the Scientific Member countries



2025 Expenditure

USER PROGRAMME STATISTICS

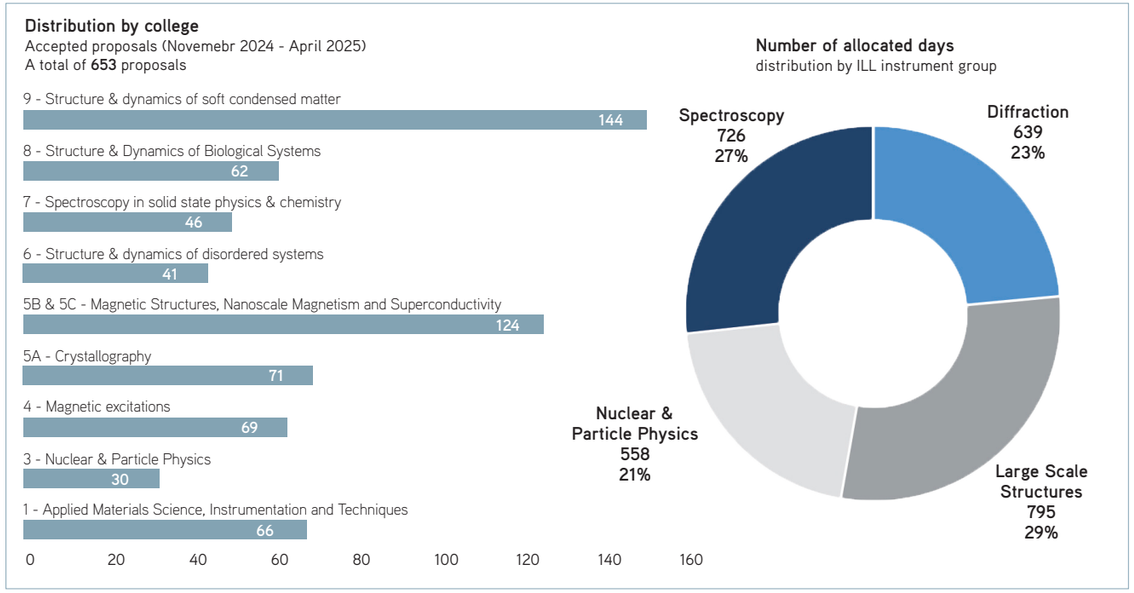
In this section we give the key numbers from the November 2024 and April 2025 proposal rounds, which corresponds to the experiments scheduled in 2025.

ILL INSTRUMENTS		DAYS REQUESTED	DAYS ALLOCATED	NUMBER OF ACCEPTED EXPERIMENTS
D007	diffuse-scattering spectrometer	95	22	7
D10*	single crystal diffractometer	145	95	18
D11	small-angle scattering diffractometer	92	53	31
D16	small momentum-transfer diffractometer	84	71	14
D17	vertical reflectometer	127	43	14
D20	powder diffractometer	257	90	42
D22	small-angle scattering diffractometer	203	89	60
D2B	powder diffractometer	151	91	52
D3	single crystal diffractometer	173	59	12
D33	small-angle scattering diffractometer	149	92	40
D4 (50% with IN1-LAGRANGE)	liquid diffractometer	132	42	11
D9	single crystal diffractometer	150	49	13
DALI	quasi-laue diffractometer for biological macromolecules	96	51	5
FIGARO	horizontal reflectometer	162	92	39
FIPPS	fission product prompt gamma-ray spectrometer	231	126	7
IN15	spin-echo spectrometer	137	83	18
IN16B	backscattering spectrometer	286	109	31
IN20	three-axis spectrometer	102	66	10
IN5	time-of-flight spectrometer	274	100	36
IN8	three-axis spectrometer	135	44	6
LADI	Laue diffractometer	91	80	7
Lagrange (50% WITH D4)	neutron vibrational spectrometer	70	24	8
MoTo	monochromatic tomography	54	35	6
PANTHER	time-of-flight spectrometer	147	82	33
PF1B	neutron beam for fundamental physics	56	56	5
PF2	ultracold neutron source for fundamental physics	79	62	3
PN1	fission product mass-spectrometer	188	103	8
PORTO	cold neutron tomography	27	27	8
SALSA	strain analyser for engineering application	196	68	17
SUPERSUN	ultracold neutron source	154	75	1
ThALES	three-axis spectrometer	138	93	17
WASP	wide-angle spin-echo spectrometer	155	88	21

Note: PF2 consists of different set-ups where several experiments are running simultaneously.

CRG INSTRUMENTS (ILL TIME)		DAYS REQUESTED	DAYS ALLOCATED	NUMBER OF ACCEPTED EXPERIMENTS
D1B - CRG-A	powder diffractometer	72	48	20
D23 - CRG-B	single crystal diffractometer	63	29	6
IN12 - CRG-B	three-axis spectrometer	85	32	5
IN13* - CRG-A	backscattering spectrometer	107	47	8
IN22 - CRG-B	three-axis spectrometer	92	18	3
SHARPER- CRG-A	time-of-flight spectrometer	49	23	8
JOINTLY FUNDED INSTRUMENTS				
NeXT 75%	imaging instrument operated with Ni-Matters composed of HZB, UGA and ILL	216	84	37
S18 - CRG-B	interferometer	70	53	4
SAM	small-angle neutron scattering	32	43	21
SuperADAM - CRG-B	reflectometer	56	35	8
XtremeD - CRG-B	powder diffractometer	76	46	15
TOTAL ALL INSTRUMENTS		**5454**	**2718**	**735**

Collaborating Research Group (CRG) instruments are built and operated at the ILL by CRGs, for the purpose of carrying out their own research programmes. They provide additional capacity (typically 50% of their beam time) and, in many cases, unique capability fto the ILL instrument suite. Details in https://www.ill.eu/users/instruments/crgs



Scientific life at the ILL is organised in **colleges**, each dealing with a particular field of research and the associated neutron methods and instrumentation. ILL scientists organise in **groups** according to the techniques and instruments they work with.

NEUTRONS
FOR SOCIETY

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Photos: ILL's staff members and L. Thion.