NEUTRONS
FOR SOCIETY

Annual Report 2024

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
2024

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FOREWORD

We can look back at 2024 as a year which was both remarkable and routine. Remarkable because of what we achieved in completing major projects, most notably Endurance. Routine because we are now back to our core business of operating the reactor, performing experiments and delivering science. This is where we belong: at the heart of the European science landscape, and the recognised worldwide reference for neutron science.

The formal completion of the Endurance Programme is a major milestone. It represents the latest in a continuous series of ambitious upgrade projects, starting with the Millennium modernisation programme in 2000. In that 25-year period, not a single instrument at the ILL has been left untouched. The improvements have been as varied as the science that we perform: increases in flux thanks to new guides and monochromators, improved resolution thanks to better crystals, detectors and choppers, lower backgrounds thanks to better shielding, choppers and collimators, increased solid-angle coverage thanks to larger detectors, increases in dynamic range, enhanced capability and capacity in sample environment, better instrument control, data reduction and data analysis, not to mention the delivery of scientific capabilities which were simply not available before. The list seems endless. Attempting to quantify such a vast range of improvements is a project in itself, but if we simply tabulate the increases in counting rate (i.e. flux on sample multiplied by solid angle of detection) as a gain factor across the instrument suite, we get a flavour of the magnitude of what has been accomplished. Since the start of the Millennium Programme, the gain factor has reached more than 300. Across the instrument suite, we are counting at least 300 times more neutrons than we did in 2000!

Most of this huge improvement has gone into supporting the continuing trend to investigate more complex problems, opening up new areas of science amenable to neutron scattering. However, some of it has also gone into increasing our experiment throughput. Although the number of instruments and operating days today is very similar to what we delivered 25 years ago, the average experiment time has almost halved, reflecting a gradual but systematically increasing throughput, and allowing us to expand and strengthen our user community.

The completion of Endurance affords us the opportunity to step back and take stock of what we have achieved. It also moves us into a transition phase, shifting our focus from carrying out large-scale projects to delivering scientific and societal impact. This is of course an oversimplification. Instrument upgrades, the construction of new instruments, and improvements to instrument technologies will continue. Doing so is essential for our health and our culture as a scientific and technical organisation. They are also an efficient way of leveraging the experience and technical expertise we have accumulated as a result of Endurance. At the same time, we have always sought to deliver scientific and societal impact through our user programme. 2024 has been no exception to that track record, as I hope you will see when you read through the many stunning examples of scientific excellence in this year's report.

The change is one of emphasis. The Endurance programme places the ILL in its strongest position ever in terms of technical capability and capacity. The 43-instrument suite is the largest, most diverse and most capable ever seen at the ILL, or indeed anywhere else in the world. Our task now is to use this instrument suite to continue to deliver science and societal impact and build up evidence of our importance to European science and competitiveness. We have drafted a Science Strategy which outlines how this will be achieved. This document will serve as a guide to ILL Management on resource allocation, strengthening and demonstrating ILL's importance to European science and innovation, and supporting political decisions on the future European neutron landscape.

We serve to deliver knowledge for its own sake: the awe and wonder of the universe, the mysteries of the existence of matter, and the origins of dark matter and dark energy. However, we also – and increasingly – serve to develop the materials and boost the innovation which are needed to strengthen European economic competitiveness and improve our society in general. Hence the change of tagline a few years ago from Neutrons for Science to Neutrons for Society. The Science Strategy reflects this evolving balance between consolidating existing strengths and creating new structures and mechanisms to support emerging scientific areas of societal importance. Expect to hear more as we move ahead and start implementing the strategy!

Ken Andersen
ILL Director

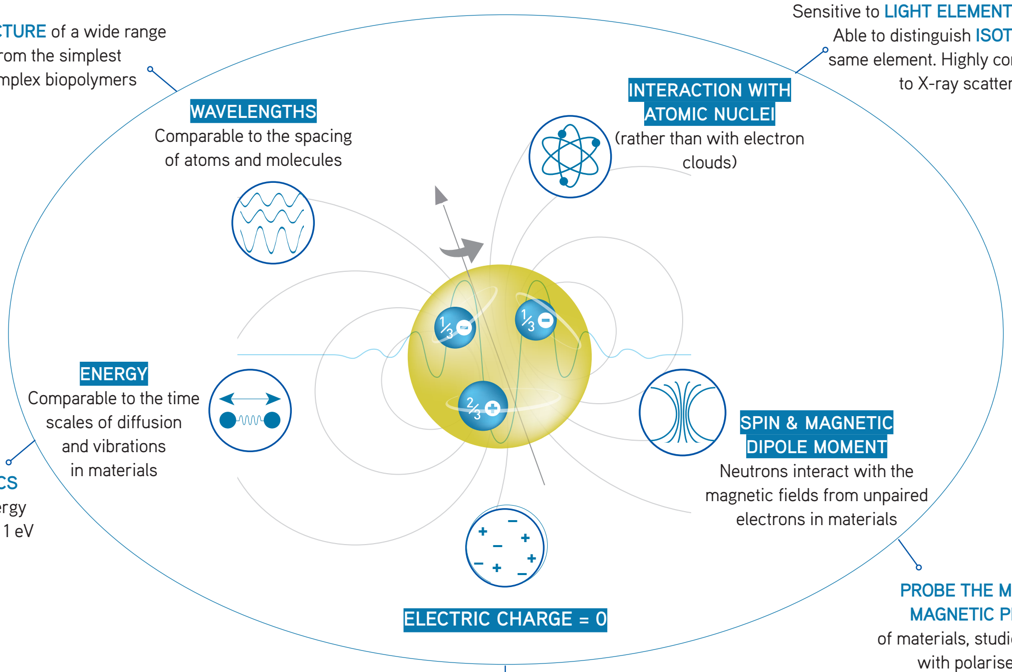
WHAT IS THE ILL?

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 1600 researchers from 41 different countries came to work at the ILL in 2024. The 1094 experiments they performed were pre-selected by a scientific review committee. During 2024, some 465 scientific papers were published based on data obtained from the use of our facilities. 116 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 2024, 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 72 M€ to the Institute in 2024, with the ILL's Scientific Member countries - Austria, the Czech Republic, Denmark, Italy, Poland, Spain, Slovakia, Slovenia, Sweden and Switzerland – contributing a further 23 M€. The ILL's overall budget in 2024 amounted to around 106 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



PROBE THE STRUCTURE of a wide range of materials, from the simplest molecules to complex biopolymers

Sensitive to LIGHT ELEMENTS (e.g. hydrogen). Able to distinguish ISOTOPES of the same element. Highly complementary to X-ray scattering

WAVELENGTHS
Comparable to the spacing of atoms and molecules

INTERACTION WITH ATOMIC NUCLEI
(rather than with electron clouds)

ENERGY
Comparable to the time scales of diffusion and vibrations in materials

SPIN & MAGNETIC DIPOLE MOMENT
Neutrons interact with the magnetic fields from unpaired electrons in materials

PROBE THE DYNAMICS of many processes; energy exchanges from 1 neV to 1 eV can be detected

ELECTRIC CHARGE = 0

PROBE THE MICROSCOPIC MAGNETIC PROPERTIES of materials, studied in great detail with polarised neutrons

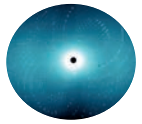
Non-destructive and with high penetration power, neutrons are well suited for STUDYING DELICATE OR PRECIOUS SAMPLES, BULKY SAMPLES, as well as samples in complex environments (e.g., extreme temperatures and pressures)

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.

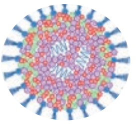
DIFFRACTION

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.



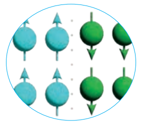
SMALL ANGLE SCATTERING

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.



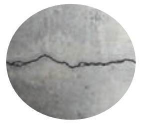
REFLECTOMETRY

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

HEALTH

ENERGY

ENVIRONMENT

QUANTUM MATERIALS

UNIVERSE

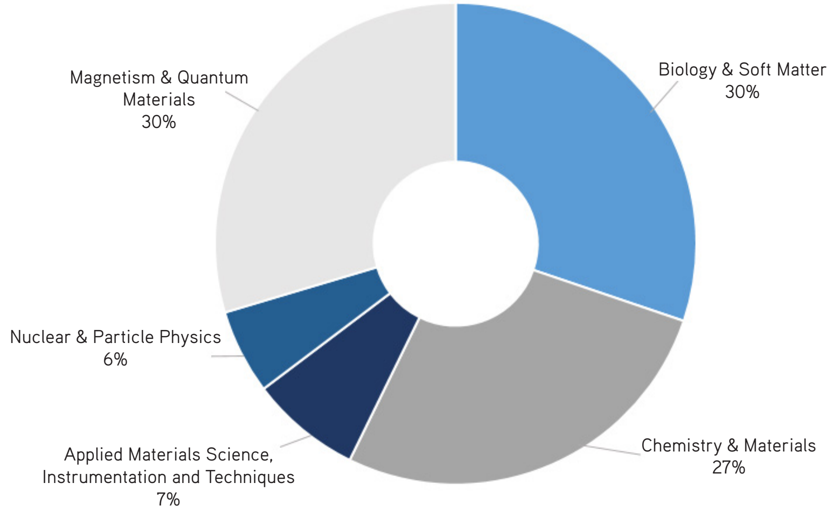
SCIENCE AT THE ILL

ILL SCIENCE IN NUMBERS

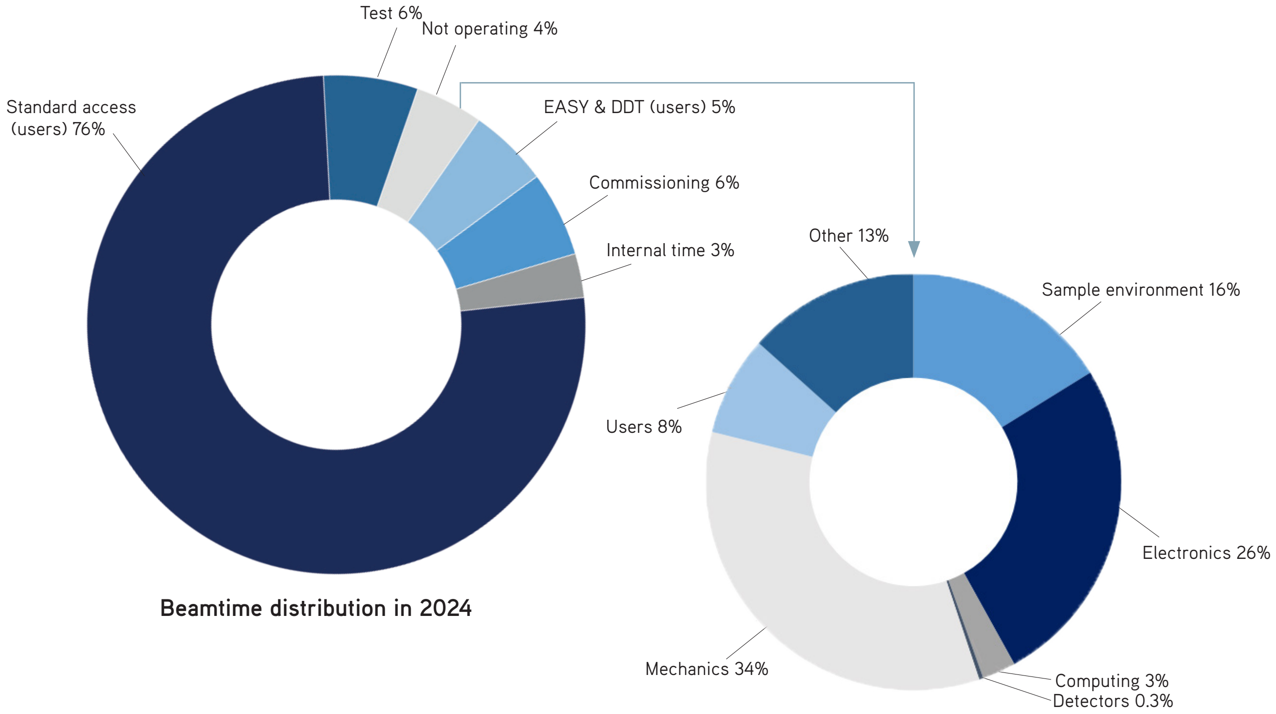
1 094
SCHEDULED
EXPERIMENTS
Corresponding to
923 proposals

105 DAYS OF NEUTRONS

3000 DAYS FOR SCIENCE



Distribution by field of research
Accepted proposals



Beamtime distribution in 2024

Not operating beamtime distribution in 2024

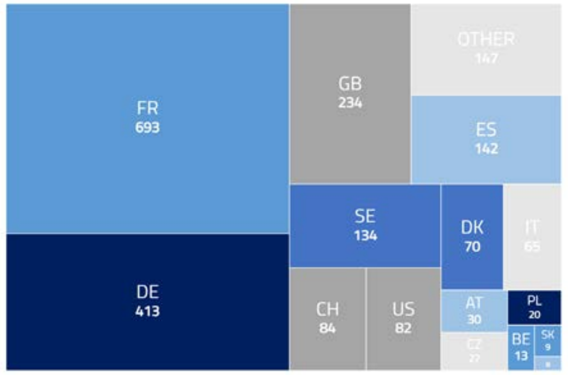
1 582
INDIVIDUAL USERS

2 167
USER VISITS
FROM **41** COUNTRIES

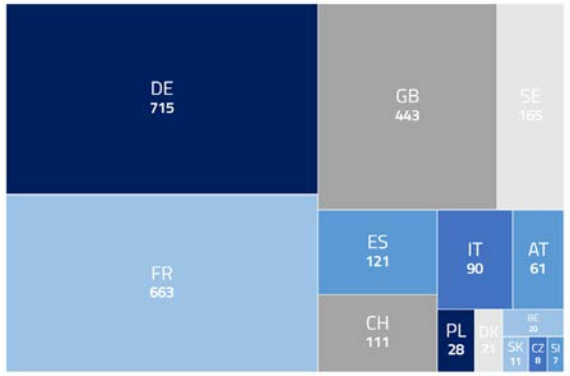
465
ILL publications
recorded in 2024 of
which **116** published
in high-impact journals*

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

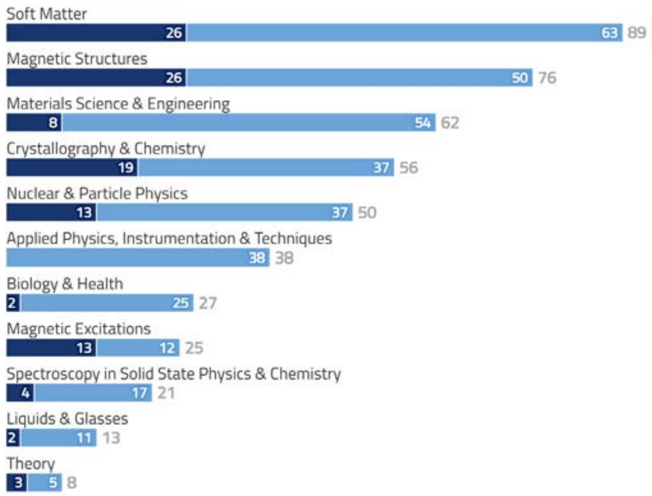
National affiliation of ILL users in 2024
Total number of user visits - 2167



Number of days allocated
(April 2024 + Novembre 2024)



465 publications in 2024
of which 116 published in high-impact journals



TRAINING

GRADUATE School

28 full-time-equivalent ILL PhD students
46 PhD students working on ILL PhD projects
10 successfully defended ILL PhD theses

HERCULES School

105 participants of
35 different nationalities
working in **27** different countries

SCIENCE STRATEGY

The ILL has been the world's leading facility for neutron science for almost 60 years, making essential contributions to many areas of science for the benefit of society and setting the gold standard as a user facility for the benefit of the scientific community. With the imminent completion of the ambitious instrument and guide upgrade programme Endurance and the ongoing renewal of the neutron source in line with the highest safety and security standards, the ILL now operates the largest and most versatile instrument suite of any neutron facility and is ready to deliver unparalleled ground-breaking science over the coming decade.

The next step is to develop a strategy that capitalises on this strong position in order to maximise the impact the ILL has on science and society, particularly in addressing major societal challenges such as climate change, food security, an aging population, the need for sustainability, digitalization.

The Science Strategy will allow the ILL to demonstrate its importance to European science and innovation within our operating horizon. As such, it will help support political decisions on the future European neutron landscape. The Science Strategy will also guide ILL Management when making decisions on resource allocation. The document itself will serve as a communication tool for strengthening and disseminating the ILL value proposition. It will also help to reinforce recruitment and retention by strengthening our scientific culture. The strategy must reflect a balance between consolidating our strengths and identifying emerging areas where we can maximise our impact. The goals that it outlines must be achievable within a few years, and its content and implementation will be reviewed and updated on a regular basis.

The Science Strategy identifies:

- The ILL's existing strengths, which will be continued and enhanced
- Scientific priorities in both new and emerging fields and in existing areas that can be consolidated and reinforced.
- New implementation mechanisms and structures to be put in place to achieve the aims of the Science Strategy.
- An outline of the resources and infrastructure needed to implement the Science Strategy.
- An integrative approach for communication, external funding opportunities and closer ties with industry.

The process of preparing the Science Strategy began in early 2024 with the appointment of a Science Strategy Working Group composed of 26 members (13 ILL scientists and 13 external scientists). The external members were selected from a list of eminent scientists from both academia and industry, drawn up with considerable input from the ILL Scientific Council. A deliberate effort was made to include external non-neutron experts in the Working Group to ensure a fresh perspective, with specialised neutron expertise provided by the ILL scientists.

The Working Group met several times over a five-month period starting in March 2024 and was subdivided into five focus groups:

- Digitalization / Quantum Materials
- Universe Essentials and Cultural Heritage
- Health and Life Sciences
- Energy
- Environment and Sustainability

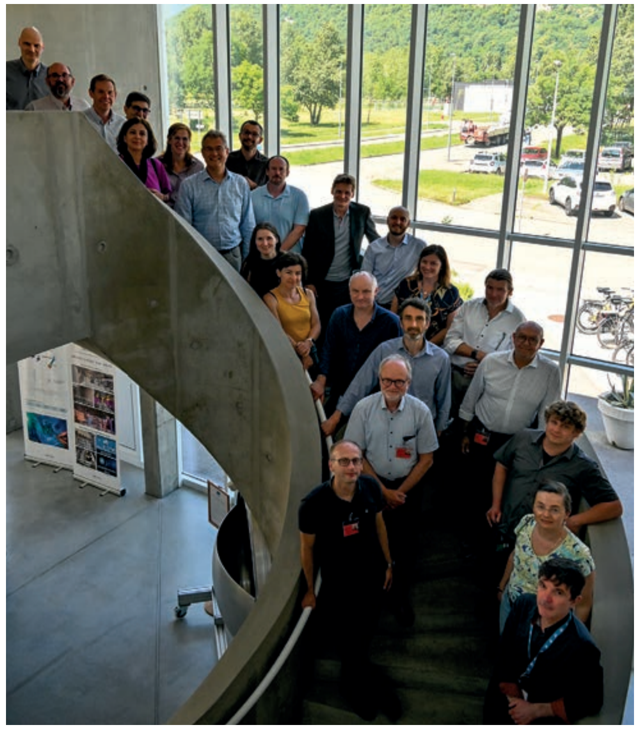
The focus groups identified emerging scientific areas and areas of exisiting strenghts, suggested implementaton resources and mechanisms, and proposed metrics for scientific output and impact. Their findings were complied into a recommendation report, which was submitted to ILL Management on 26 July 2024. Following a careful assessment, a certain number of recommendations were selected from the report for incorporation into the Science Strategy.

The Science Strategy in short:

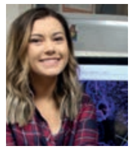
- The scientific excellence delivered by our peer-reviewed user programme will continue to provide the foundation of the ILL's work
- In Nuclear and Particle Physics, we will focus our attention on Flagship Experiments involving long-term collaborations with external users.
- We will create new structures, known as Science Hubs, bringing together internal and external scientists, whose aim will be to support and expand the user base, promote internal collaboration, enhance partnerships and relevance with industry, and deliver high-profile science. The Science Hubs will cover the following four areas:
    - Magneto-structural quantum coupling
    - Liquid-liquid phase separation
    - Li-ion batteries
    - Advanced manufacturing
- A new mechanism will be introduced for designing and performing important Showcase Experiments with the aim of opening up a new field of activity, attracting new users, and providing high-visibility societal impact. Three initial topics have been identified:
    - Superconducting wires
    - Cell structure with high-resolution bio-imaging
    - Water membranes for a sustainable future
- We will consolidate and expand our programme in nuclear medicine, increasing our production capacity for radioisotopes for cancer treatment and continuing to invest in the development of isotopes for future diagnostics and therapies.
- Other clear scientific needs identified include increasing the capacity for neutron imaging experiments and enhancing IT support for experiment planning and execution and for data analysis, including the use of enhanced AI and ML tools.
- ILL's PhD programme will be enhanced and partially redirected to the scientific priorities identified in the Science Strategy.
- Effective communication of ILL's impact is key to its success. Communication and outreach will therefore be consolidated for the benefit of all aspects of the Science Strategy.

All the activities and mechanisms outlined in the Science Strategy will be reviewed on a regular basis and adapted where necessary. As always, scientific excellence will remain our key driver.

Jacques Jestin
Associate Director
Head of Science Division



From left to right: Frank Schreiber, Arno Hiess, Paul Shiering, Margarida Costa Gomes, Didier Gigmes (in background), Caterina Michelagnoli, Ken Andersen, Tobias Jenke, Elisa Rebolini, Catrin Davies (behind), Frank Gabel (in background), Andreas Meyer, Andrew Wildes, Andrea Taroni (foreground), Robert Feidenhans'l (chair), Alessandro Tengattini, Howard Jones, Orsolya Czakkel, Thomas Hansen, Philippe Miele, Thomas Saerbeck, Silvia Leoni, Jacques Jestin.



Victoria Drago
Neutron Scattering Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee USA - dragovn@ornl.gov

After successfully completing my PhD in 2022 from the University of Toledo, entitled 'Microgravity crystallization and neutron diffraction of PLP-dependent enzymes' I have expanded my research on these important family of enzymes working as a Postdoctoral researcher in the Neutron Scattering division of Oak Ridge National Laboratory.

Perdeuterated protein crystals grown on the International Space Station facilitate all-atom crystal structure of tryptophan synthase

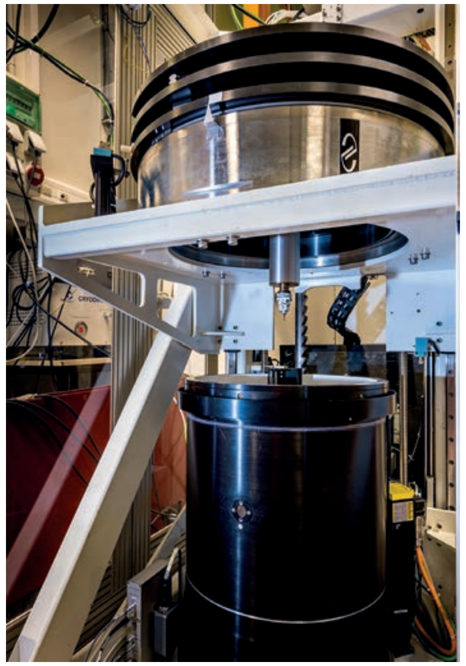
Single-crystal neutron diffraction is a powerful technique in structural biology that can accurately visualize the hydrogen atom positions in biomacromolecules. Since hydrogen atoms determine protonation states and facilitate enzyme function, pinpointing their locations contributes to an atomic-level understanding of proteins and invaluable information for structure-based drug design. Tryptophan synthase (TS) is a pyridoxal 5'-phosphate (PLP, vitamin B6 derivative) dependent enzyme found in plants, fungi and bacteria, but not in humans. As such, TS is an attractive target for the design of inhibitors against pathogenic organisms such as *Staphylococcus aureus* and *Mycobacterium tuberculosis*. The goal of this study was to use neutron diffraction data to shed new light on the TS catalytic mechanism by determining protonation states.

SCIENTIFIC HIGHLIGHTS

Original publication: Cell Rep. Phys. Sci. (2024) — 10.1016/j.xcrp.2024.101827
ILL contact: M. Blakeley, blakeleym@ill.fr
Instrument: Quasi-Laue diffractometer **LADI**

TS is an αββα heterotetramer with active sites catalyzing two individual reactions. In the α-active site, indole 3-glycerol-phosphate is cleaved into indole and glyceraldehyde-3-phosphate. Indole travels through an internal hydrophobic channel to the β-active site, where it reacts with a PLP-L-serine external aldimine to produce L-tryptophan. Perhaps the most intriguing part of the mechanism involves a communication domain (β-comm) which senses indole in the channel to activate serine in the β-site.

To increase the neutron scattering power of the crystals, TS was first produced in perdeuterated form at the Deuteration Laboratory (D-Lab) in the Life Sciences Group at Institut Laue-Langevin (ILL). Then, in order to grow very large crystals of perdeuterated TS, we conducted crystallization experiments on the International Space Station (ISS) using our Toledo Crystallization Box flight hardware. Microgravity lacks the gravity-driven convection currents that may lead to irregular crystal feeding and depletion zones that cause defects and hinder crystal growth. Perdeuterated TS solutions arrived at the ISS via a Space-X resupply mission for a six-month journey. Unaffected by gravity, several very large and well-ordered crystals of TS grew, which travelled for more than 50 million miles before returning to earth for neutron diffraction data collection using the quasi-Laue diffractometer LADI-III at the ILL. Data were obtained to 2.1 Å resolution resulting in an all-atom structure of the TS holoenzyme, with a substrate-free α-subunit and a covalently bound PLP internal aldimine state in the β-subunit.



The quasi-Laue diffractometer LADI.

Direct visualization of hydrogen atoms allowed protonation states to be assigned to the active site amino acid residues and the PLP cofactor. Structural analysis of the α-active site, assisted by pK_a predictions, revealed how the catalytic glutamate residue may adopt two conformations with disparate pK_a's to obtain and donate a proton in the α-subunit reaction (**Figure 1**). This proton is involved in the cleavage of indole glycerol-3-phosphate, releasing indole whose presence in the channel leads to a conformational change in the α-subunit that relocates the β-comm domain signalling for the activation of serine by the β-subunit – a series of events initiated by a single proton.

In the β-active site, we found the Schiff base nitrogen atom in the PLP internal aldimine was protonated, while the pyridine nitrogen and phenolic oxygen were both deprotonated (**Figure 2**). The observed protonation states depict how the protonation profile of PLP contributes to the reaction specificity and promotes β-elimination of the PLP-serine hydroxyl group to generate L-tryptophan. The knowledge gained from the neutron crystal structure of TS provides insight into the selective protonation of the PLP cofactor and electrostatic environments of the active sites that govern the enzyme's catalytic function and helps inform future efforts to target TS for antibacterial therapeutics.

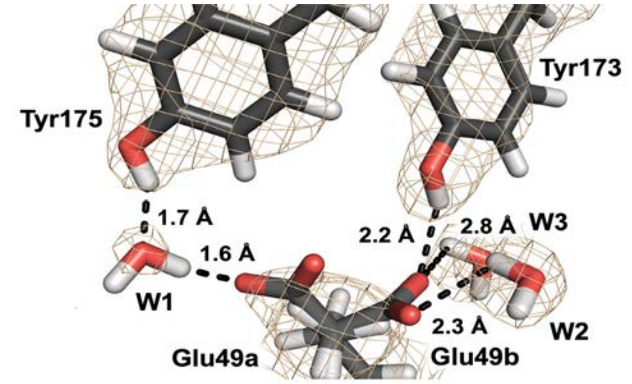


Figure 1: Dual conformations of α-active site residue Glu49.
$2F_o$-F_c neutron map (at 1 σ, colour wheat). Hydrogen bond distances are given between the heteroatom and hydrogen atom. In the active position (Glu49a), Glu49 can donate a proton to indole 3-glycerol phosphate in the α-subunit reaction. Glu49 is oriented to receive a proton through a hydrogen bonding network in the Glu49b conformation.

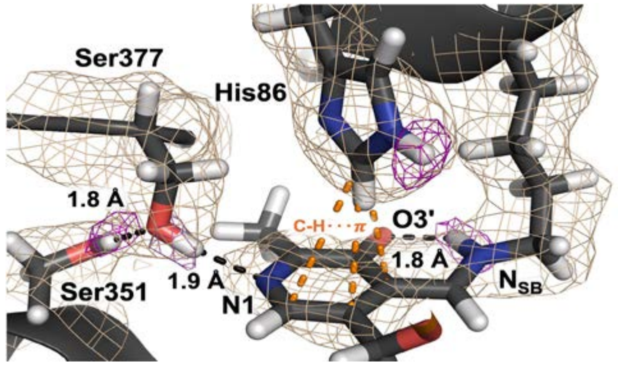


Figure 2: Protonation states of β-subunit active site and PLP.
$2F_o$-F_c neutron map (at 1 σ, colour wheat) and the omit $2F_o$-F_c neutron map (at 2.2 σ, colour purple). The Schiff base nitrogen, N_{SB}, is protonated and makes an intramolecular hydrogen bond with the phenolic oxygen, O3'. Protonation of pyridine nitrogen, N1, is prevented by Ser377, which is stabilized by a hydrogen bond with Ser351. His86, positioned above the cofactor, is neutral and monoprotonated on the ε-nitrogen.

Garry Laverty
School of Pharmacy, Queen's University Belfast, N. Ireland - garry.laverty@qub.ac.uk

My research studies peptide-like hydrogels for drug delivery and biomaterial applications, including as long-acting injectable platforms to improve patient adherence to medicines. I also use neutron methods to study the fundamental characteristics of these gels and to tailor their properties for sustained delivery.

Original publication: JACS 2024 — 10.1021/jacs.4c03751
ILL contact: R. Schweins, schweins@ill.fr
Instrument: Small-angle neutron scattering instrument **D11**

In situ forming, enzyme-responsive peptoid-peptide hydrogels: An advanced long-acting injectable drug delivery system

Patients often encounter difficulties adhering to their medicines. This is especially problematic for diseases such as HIV whereby medicines have complicated dosage regimens; need to be taken at specific times daily for the rest of the patient's lifetime and a missed dose increases the risk of antimicrobial resistance. Long-acting injectables are being explored as alternatives to typical oral e.g., tablet formulations, to alleviate this burden.

Here, we discovered an advanced long-acting drug delivery system composed of a peptoid-peptide that forms a sustained release hydrogel depot in response to phosphatase enzymes. The use of peptide-based systems offer several advantages within this field. They are more amenable to manipulation at the molecular scale compared to synthetic polymers, offering the ability to tune properties, e.g., drug release, by altering their constituent monomers e.g., amino acids, and the nature of the covalent peptide-drug linker. Unlike existing long-acting formulations, for example suspensions, they form aqueous solutions with enhanced pharmaceutical stability, improving ease of transport and distribution to areas of greatest need e.g., Low-to-Middle Income Countries. Natural peptides are limited by a lack of biological stability, being degraded rapidly, within hours, by protease enzymes. This is detrimental to their use as a long-acting drug delivery platforms. The focus of this work was to improve biological stability by focusing on peptide-like molecules termed peptoids.

Peptoids are molecules that mimic natural L-α-peptides but with enhanced biostability against peptide-targeting protease enzymes, due to a switch of their constituent R-functional group from the α-carbon of each amino acid to the nitrogen. Peptoids, like proteins/peptides, are highly tuneable but with the additional benefit of enhanced biological stability. This platform forms a drug-releasing hydrogel depot *in situ*, in response to enzymes (phosphatases) present in the subcutaneous skin space.

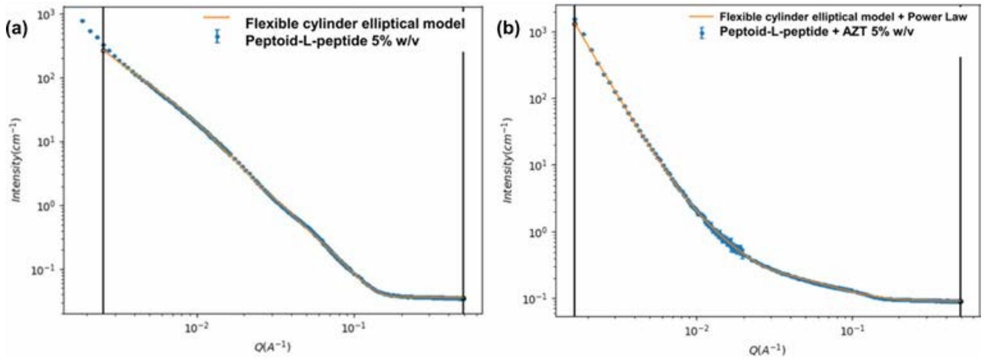


Figure 1: SANS data. **(a)** (*N*Phe)$_4$GGGGKY-OH; **(b)** (*N*Phe)$_4$GGGGK(AZT)Y-OH (dotted). Solid line = flexible cylinder elliptical model (a) and with power law applied (b).

SANS measurements, performed using the D11 instrument, were important to elucidate the properties of this new material including hydrogel fibre properties at the macroscopic scale and understanding how molecular packing and long-range networks are influenced by covalent attachment of the model HIV drug zidovudine (AZT). These influence our ability to understand and optimise the structure of peptoid-peptides and their pharmaceutical formulation for long-acting delivery.

SANS is advantageous, providing information at a 1–100 nm scale without the need for drying or the formation of artifacts. **Figure 1a** demonstrates that a 5% w/v peptoid-peptide hydrogel fits the flexible cylinder elliptical model with a fibre radius of 1.825 nm. **Figure 1b** shows that covalent attachment of zidovudine to form a 5% w/v hydrogel also closely fits the flexible cylinder elliptical model with the power law applied with a narrower fibre radius of 0.781 nm. The large lengths of these fibres are also evidence of entangled fibres. From this model, differences in rheological properties observed between peptoid-peptide ± drug are likely due to changes in how these fibres entangle rather than by changes in their composition or underlying molecular arrangement. For example, the covalent attachment of zidovudine significantly reduced the peptoid-peptide's gel stiffness (**Figure 2a**) and extended gelation time (**Figure 2b–c**).

These results suggest that the formulation and the gelation process of peptoid-peptide should have a significant impact on the nature of fibre entanglement and the resulting mechanical and functional properties. Peptoid-peptides hydrogels may be of benefit to diseases were patient adherence to medicines are low or where drugs are difficult to deliver locally e.g., ocular, spinal.

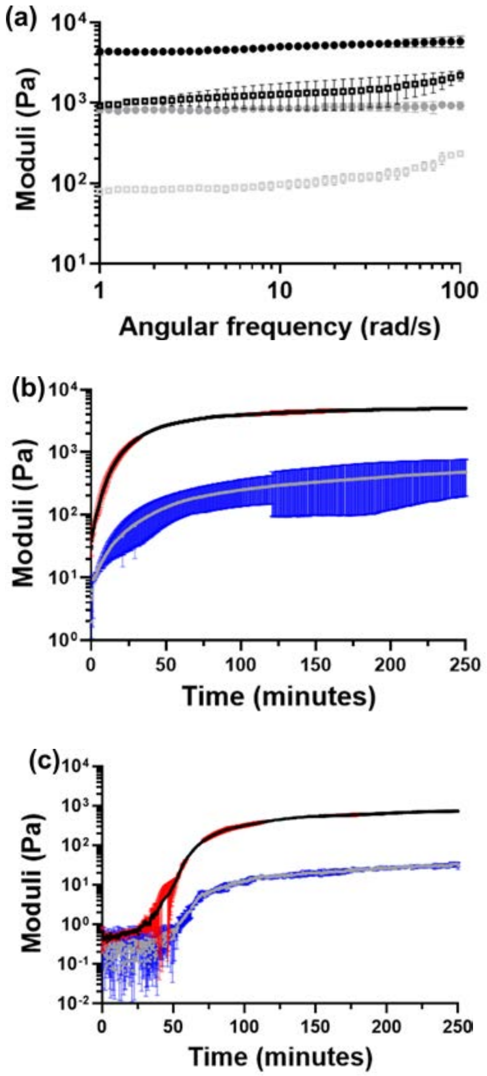


Figure 2: Rheological data. **(a)** Frequency sweeps: (*N*Phe)$_4$G-GGGKY-OH (black), (*N*Phe)$_4$GGGGK(AZT)Y-OH (grey). Filled circles = the storage modulus (G'), open squares = loss modulus (G"). Time sweeps for **(b)** (*N*Phe)$_4$GGGGKY(p)-OH, **(c)** (*N*Phe)$_4$GGGGK(AZT)Y(p)-OH. Black lines = storage modulus (G'), grey lines = loss modulus (G"), red and blue areas donate standard deviations for G' and G".

Jennifer Johnstone-Hack

School of Chemical, Materials and Biological Engineering, University of Sheffield, UK - j.johnstone-hack@sheffield.ac.uk

I am a Royal Academy of Engineering Research Fellow, and my research aims to utilise the complementary nature of neutron and X-ray imaging to visualise how and why the materials in electrolysers and batteries fail.

Understanding water dynamics in operating fuel cells with different flow field designs

Water management plays a crucial role in fuel cell performance. Too much water and the cell floods and blocks reactant gas access, but too little leads to dehydration and poor ionic conduction. Studying the relationship between flow field design (the component responsible for delivering gas to and removing water from the cell) and water accumulation can, therefore, give important insight into the optimal management of water and, hence, improve performance in these technologies that are critical for achieving net zero carbon emissions.

Original publication: JPhys Energy 2024 — 10.1088/2515-7655/ad3984
ILL contact: L. Helfen, helfen@ill.fr
Instrument: Neutron and X-ray tomography **NeXT**

There has been significant research focus on optimising the ~1 mm-wide flow field designs in polymer electrolyte fuel cells (PEFCs). Patterns can vary from 'serpentine' single or multi-channel designs to parallel, pin-type or even fractal designs. A good flow field is critical for effective water management to avoid cell flooding/drying and ultimately failure.

In this work, we utilised the high-flux and high-resolution capabilities of ILL's NeXT instrument to conduct operando studies on three flow field designs: single serpentine (SS), double serpentine (DS) and parallel (PAR) (**Figure 1a**), aiming to gain a deeper insight into the effect of flow field design on performance and flooding. As shown in these representative water-filled tomograms, the designs have various features, like bends, straights and number of channels, which all influence the water management within the cell.

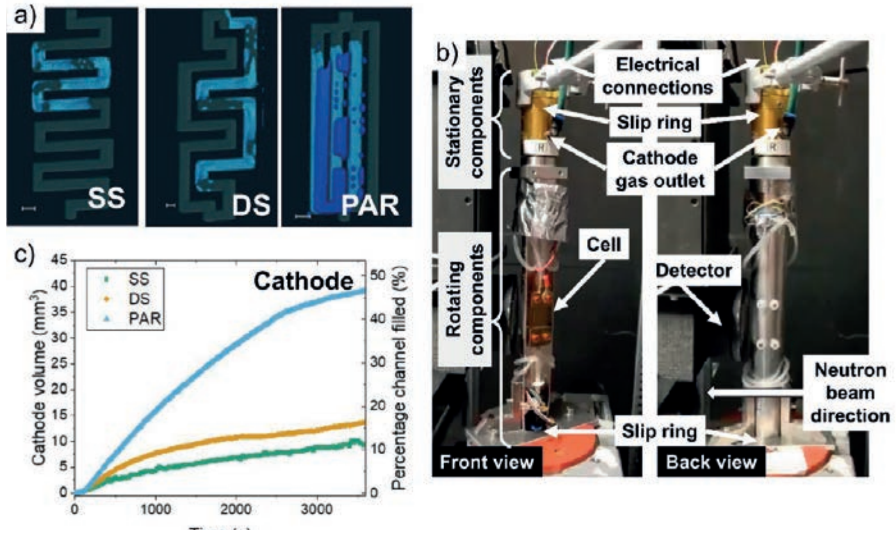


Figure 1: **a)** Tomograms of the partially water-filled channels SS>DS>PAR flow-fields. Light and dark blue show water in cathode and anode, respectively; **b)** photographs of the cell on the beam; **c)** evolution of the water volume in the cathode flow fields.

Advances in the operando fuel cell setup for imaging included the incorporation of slip rings (**Figure 1b**). This allowed for continuous sample rotation in one direction, enabling uninterrupted imaging, whilst electrochemically operating the cell. The slip-ring system also enabled reconstruction of the datasets with 180° steps between tomograms, which corresponds to 18 s per tomogram: a new important achievement for neutron tomography studies of fuel cells, obtained at 64 µm voxel size.

Alongside allowing high-speed data collection, the ability to conduct tomography (over the more commonly employed radiography) enables individual water droplets in the cathode and anode flow fields to be studied in isolation. Thus, we could quantify the volume of water in each channel over the course of the galvanostatic (constant current) holds, and spatially resolve the distribution and evolution of water within these.

Analysis of both electrochemical and imaging data revealed some interesting trends in the relationship between flow field design and cell performance. Overall, it was found that the effectiveness of water management was in the order SS>DS>PAR (**Figure 1a, c**). At the end of the 1 h galvanostatic hold at 400 mA cm^{-2}, the percentage of the cathode flow field filled with water was 11%, 16% and 47% for SS, DS and PAR, respectively (**Figure 1c**).

Visual analysis of the tomography datasets confirmed this trend, with the SS design effectively removing 'slugs' from the flow channel to retain an unimpeded gas flow (**Figure 2a**). Interestingly, in the multi-channel designs one or more of the channels were completely blocked and filled with water, leaving only one free unimpeded channel actually delivering the gas flow (**Figure 2b**). This would be expected to lead to unfavourable inhomogeneous degradation rates arising from the non-uniform distribution of reactants.

This work represents an important step forward in neutron imaging of fuel cell flow fields, particularly enabling high-speed operando tomography with continuous rotation. As novel flow field designs emerge, it is expected that these methods will provide valuable insights into water management in the next generation of designs.

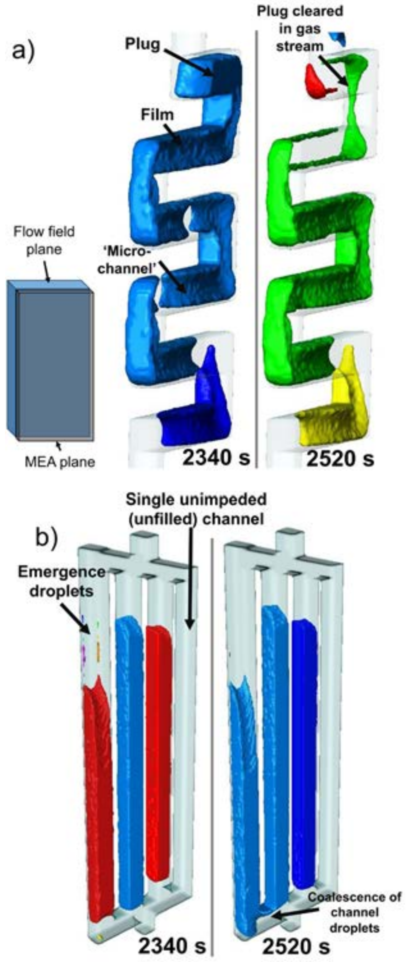


Figure 2: Schematic of flow fields at two time-stamps, showing **a)** effective 'plug' removal in the SS cell, and **b)** inhomogeneous water filling in the PAR cell.

Adrien Perrichon
European Spallation Source, Sweden - adrien.perrichon@ess.eu

I work as instrument scientist for VESPA at the ESS. My activities include the development of instrumentation and methods for neutron spectroscopy (NVS, QENS), and my scientific focus is on energy materials and non-stoichiometric oxides.

Original publication: Chemistry of Materials — 10.1021/acs.chemmater.3c00754
ILL contact: M.M. Koza, koza@ill.fr
Instrument: Cold-neutrons backscattering spectrometer **IN16B**, time-of-flight spectrometer **IN6** and spin-echo spectrometer **IN11C**

Proton Diffusion Mechanism in Hydrated Barium Indate Oxides

Proton-conducting oxides are currently receiving considerable attention, because of their promise as electrolytes in future environmentally friendly proton-conducting fuel cells (PCFC). However, the lack of materials with sufficiently high proton conductivity hampers the development and, ultimately, commercialization of this technology. The development of new, better performing materials depends, in part, on a better understanding of the proton conductivity mechanism in the most promising proton-conducting oxides. Here, in a combined quasielastic neutron scattering (QENS) and ab initio molecular dynamics (AIMD) simulation study, we elucidated the proton conduction mechanism in hydrated barium indate oxides $Ba_2In_2O_5(H_2O)_x$ $(0 < x \leq 1)$, which is the ideal model system for brownmillerite-based proton-conducting oxides.

Structurally, $Ba_2In_2O_5(H_2O)_x$ type proton conductors are derived from the more familiar brownmillerite-structured barium indate oxide $Ba_2In_2O_5$, which is featured by an intergrowth of alternating InO_6 octahedral layers and InO_4 tetrahedral layers (**Figure 1a**) and which, when subjected to a humid atmosphere, transforms into the hydrogenated, proton-conducting material $Ba_2In_2O_5(H_2O)_x$. In this latter material, hydroxyl groups (OH^-) occupy the formerly tetrahedral layers to create a structurally distorted "pseudo-cubic" layer, whereas protons (H^+) are delocalized over the formerly relatively undistorted "cubic" layer. In effect, two distinct types of proton sites, H(1) and H(2), are present (**Figure 1b**).

With respect to its proton-conducting properties, our combined analyses of variable temperature QENS and AIMD data showed that the proton-conduction mechanism involves localized motions of the protons, distinguished as rotational diffusion of the O-H(1) species and H(2) proton transfers between neighboring oxygens (**Figure 2a**). In particular, by investigating two samples, with different levels of hydration (x = 0.30 and 0.92), we also revealed, in the nearly fully hydrated material (x = 0.92) the presence of a third proton site, H(3), which is found to become occupied upon increasing the temperature and that serves as a saddle state for the inter-exchange between H(1) and H(2) protons (**Figure 2b**). Crucially, the occupation of the H(3) site enables long-range diffusion of protons, which is highly anisotropic in nature and occurs through a two-dimensional pathway (**Figure 3**). For the partially hydrated material (x = 0.30), however, the occupation of the H(3) site and subsequent long-range diffusion are not observed, which is rationalized by hindered dynamics of H(2) protons in the vicinity of oxygen vacancies.

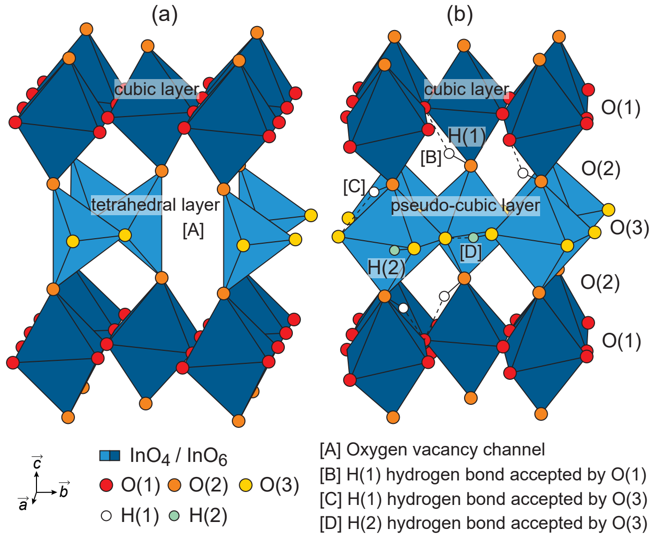


Figure 1: Schematic structure of **(a)** $Ba_2In_2O_5$ and **(b)** $Ba_2In_2O_5(H_2O)$. Dashed lines refer to hydrogen bonds.

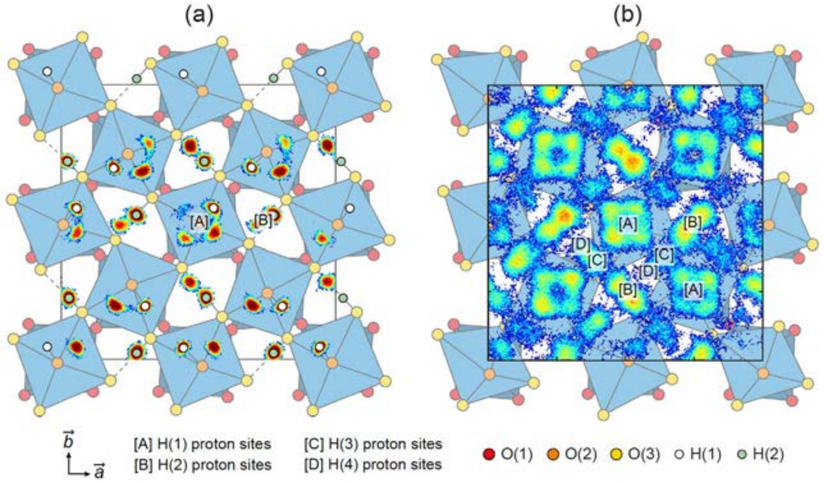


Figure 2: Structural model of $Ba_2In_2O_5(H_2O)$ projected in the (a,b) plane. Superimposed are the histogram of the proton nuclear densities calculated by AIMD at (a) 300 K and (b) 1200 K.

To conclude, we established the nature of the proton-conduction mechanism in $Ba_2In_2O_5(H_2O)_x$ (x = 0.30 and 0.92). A comparison to other proton-conducting oxides, such as barium zirconate-based compounds, suggests that the generally lower proton conductivity in $Ba_2In_2O_5(H_2O)_x$ is due to a large occupation of the H(1) and H(2) sites, which, in turn, means that there are few sites available for proton diffusion. This new insight suggests that the chemical substitution of indium by cations with higher oxidation states offers a novel route toward higher proton conductivity because it reduces the proton site occupancy while preserving an oxygen-vacancy-free structure.

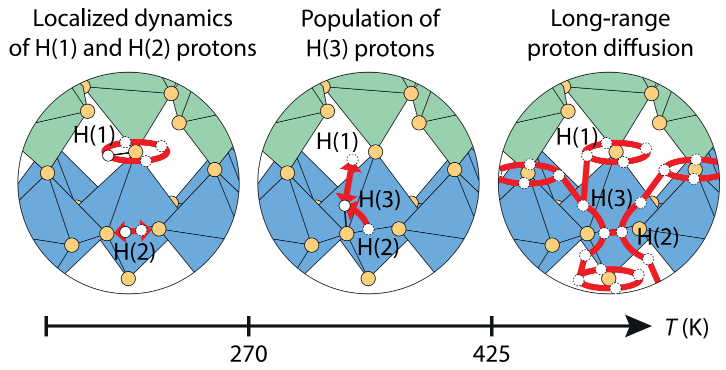


Figure 3: Schematic illustration of the relevant proton dynamic processes in $Ba_2In_2O_5(H_2O)_x$ (x = 0.92), as determined using QENS and AIMD.

Laura Cañadillas-Delgado

Institut Laue Langevin, Grenoble, France – lcd@ill.fr

My research focuses on the characterization of multifunctional metal-organic materials, with special emphasis on modulated structures, trying to obtain structure-properties relationship to get the clue for the design of new materials with desired assets.

Tuning Structural Modulation and Magnetic Properties in Metal-Organic Coordination Polymers

The development and characterization of new materials are key challenges in condensed matter, chemistry and physics. The ability of hybrid coordination polymers (CPs) to combine within the same framework different physical properties have attracted a huge interest in last years. The study of modulated structures constitutes an important step in the better understanding of the structure-property relationship of CPs, since the intrinsic properties of the material are likely to be different from those of periodic materials.

Original publication: IUCrJ 2024— 10.1107/S2052252524008583
ILL contact: L. Cañadillas-Delgado, canadillas-delgado@ill.fr
Instruments: Thermal neutron four-circle diffractometer **D19**,
Laue thermal neutron diffractometer **CYCLOPS** and hot neutron four-circle diffractometer **D9**

$[CH_3NH_3]M(HCOO)_3$ M = Co and Ni compounds undergo phase transitions from unmodulated (*Pnma*) to modulated (*Pnma*(00γ)0*s*0) structures upon cooling **(Figure 1)**. Although isomorphous at ambient temperature, the series of temperature-induced phase transitions exhibited by the two compounds are not equivalent. They present a perovskite-like ABX_3 structure with the metal at the B-site, methylammonium at the A-site, and formate as the linker. The nickel compound remains in a modulated phase until the onset of long-range magnetic ordering at 34 K. Here, the phase is described as a proper incommensurate magnetic structure, with modulation of the magnetic moments due to the occurrence of incommensurate magnetic modes.

These studies motivated us to investigate the feasibility of combining Ni and Co in the perovskite B-site to explore the sensitivity of the modulated phase transitions and magnetic characteristics of the formate compounds.

The present work is focused on the analysis of three solid solutions of $[CH_3NH_3]Co^xNi_1{}^{-x}(HCOO)_3$, *x* = 0.25 (**1**), 0.50 (**2**) and 0.75 (**3**). At room temperature, they crystallize in the *Pnma* orthorhombic space group, akin to the cobalt and nickel end series members. Upon cooling, each compound undergoes distinct series of structural transitions to modulated structures (**Figure 2**).

1 and **3** exhibit phase transitions similar to the pure nickel and cobalt compounds, respectively. However, neutron diffraction measurements (D19 and CYCLOPS) showed that the structural evolution of **2** diverges from that of either parent compound, with the competing hydrogen bond interactions which drive the modulation throughout the series producing a unique sequence of phases. This is likely as a result of the differing M–O bond lengths which dictate the limits of the atom amplitude displacement modulations. It involves two modulated phases, with different **q**-wavevector, maintaining the modulated phase below magnetic order, resulting in an improper modulated magnetic structure. Despite these large scale structural changes, magnetometry data reveal that the bulk magnetic properties of these solid solutions form a linear continuum between the end members.

Neutron diffraction has been crucial not only to analyse magnetic structures, but also because the number of satellite reflections needed to refine a modulated structure is high, including high-**q** reflections, which are difficult to obtain using X-rays.

In conclusion, the magnetic properties and nature of the nuclear phase transitions of $[CH_3NH_3]Co^xNi_1{}^{-x}(HCOO)_3$ can be tuned through the metal ratios. Our results advocate that doping the samples increases frustration in the structure, leading to the stabilization of modulated structures over a broader temperature range, and that the energy barrier separating distinct structural phases is minimal, implying the feasibility of transitioning between them via external stimuli, such as pressure.

The study of modulated structures constitutes an important step in the better understanding of the structure-property relationship of CPs. Despite the sparsity of reported aperiodic molecular frameworks, this study presents the opportunity to consciously design molecular compounds with the propensity for modulated phases and finer control of their properties.

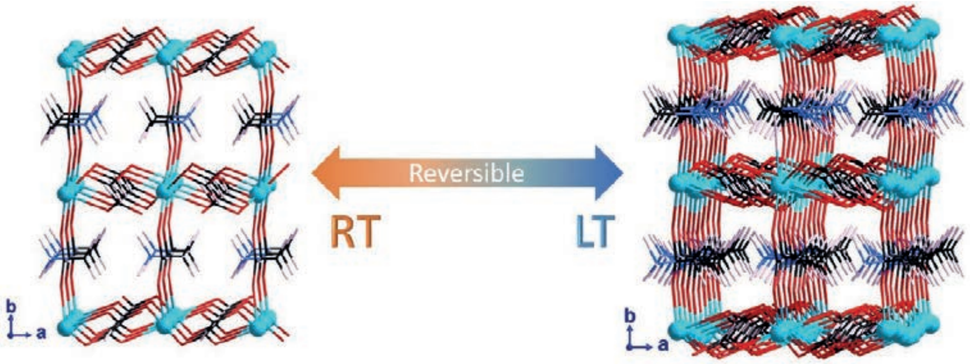


Figure 1: View of the *Pnma* and *Pnma*(00γ)0*s*0 structures along the *c* axis.

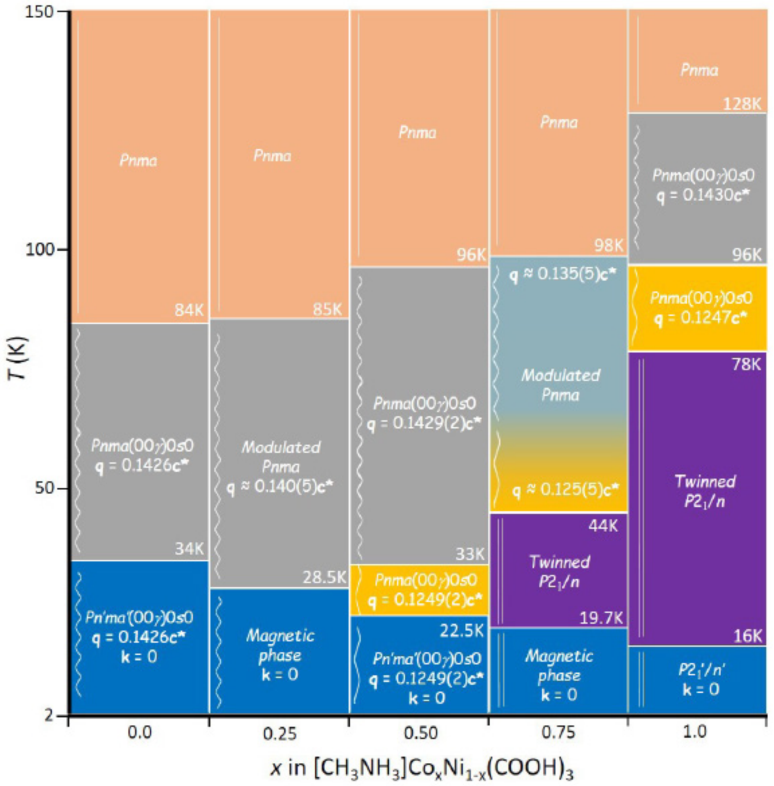


Figure 2: Graphical representation of the different transition undergone by the $[CH_3NH_3]M(HCOO)_3$ family of compounds.

Leonardo Chiappisi

Institut Laue Langevin, Grenoble, France – chiappisi@ill.fr

Scientific Coordinator of the Partnership for Soft Condensed Matter at the ILL.

My research spans the diverse field of soft condensed matter, from studying the assembly of colloidal building blocks into responsive materials to exploring the complexities of foams. Advanced scattering experiments, have been central to uncovering the underlying mechanisms in these systems

Tuning Structural Modulation and Magnetic Properties in Metal-Organic Coordination Polymers

Understanding the self-assembly of supramolecular systems is essential for advancing soft-matter science and developing functional materials. Leveraging the unique high-pressure capabilities of the ILL, a recent study provides a groundbreaking perspective on the effect of hydrostatic pressure on cyclodextrin-surfactant inclusion complexes. This investigation represents a significant step in elucidating how external stimuli influence complex soft-matter systems.

Original publication: PCCP 2024— 10.1039/D4CP02043J
Instrument: Massive dynamic q-range small-angle diffractometer **D33**

Understanding and controlling supramolecular assembly processes can shed light into the organisation of proteins in viruses, the controlled production of certain polymers, or the design of molecular machines and nanomaterials with advanced functionalities.

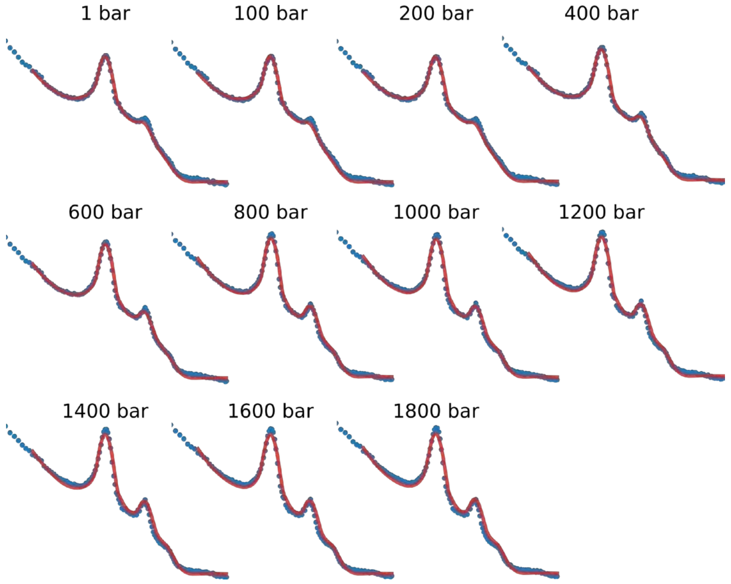
Cyclodextrin-surfactant inclusion complexes are versatile supramolecular assemblies with potential applications ranging from targeted drug delivery systems, such as encapsulating hydrophobic pharmaceuticals for improved solubility, to nanotechnology applications like designing responsive nanosensors. These systems exhibit a planar lattice structure arising from host-guest complexation. Their assembly behavior is influenced by both non-specific long-range interactions, such as dispersion forces, and specific forces, including water-mediated hydrogen bonds. High-pressure experiments provide an unparalleled opportunity to investigate the role of hydration in these assemblies. Hydration balances host-guest interactions and stabilizes the planar lattice structure, with water-mediated hydrogen bonds playing a key role. Under high pressure, changes in hydration shells can modulate system flexibility and rigidity, revealing how environmental conditions control molecular dynamics and supramolecular organization.

The study explored these interactions under pressures up to 1800 bar, nearly twice the highest pressure found at the ocean's deepest point. The findings revealed that the overall architecture of the assemblies remains stable under increasing pressure, underscoring the robustness of their host-guest binding. However, a closer examination of the planar lattice showed a fourfold increase in stiffness between 250 and 1000 bar, highlighting the role of pressure in enhancing lateral cohesion within the lattice.

Neutron scattering experiments at ILL provided critical insights into these structural changes, offering unparalleled resolution into nanoscale alterations under high-pressure conditions. The combination of small-angle neutron scattering (SANS) and the unique high-pressure sample environments at ILL was pivotal in uncovering these effects. These findings emphasize the transformative role of neutron techniques in advancing soft-matter research, particularly under challenging conditions.

From a broader perspective, this study sheds light on the principles governing supramolecular assembly under external stimuli, with implications extending beyond the system studied. The pressure-induced modulation of stiffness suggests new strategies for designing adaptive materials that respond predictably to environmental changes. This discovery also opens avenues for exploring other systems, such as micelles, gels, and vesicles, under non-ambient conditions.

This work demonstrates the potential of high-pressure neutron experiments as a powerful tool for investigating supramolecular assemblies. By exploring how hydration influences these systems under varying pressures, the study highlights a methodology that could be extended to other complex materials. We hope that this example inspires further research groups to employ high-pressure techniques to deepen the understanding of their own systems and enhance insights into supramolecular science.



SANS data shows that as pressure increases, the scattering curve shape remains consistent, but peak intensity rises. This indicates that while the overall structure of the aggregates stays stable, high pressure enhances rigidity and order within the supramolecular architecture.

Schematic of the basic building block of the supramolecular assembly: a red ring represents a cyclodextrin (a circular sugar molecule) that captures a surfactant molecule. (**Right**) Schematic of a macromolecular assembly constructed from these inclusion complexes.

Abbie Mclaughlin
University of Aberdeen, UK -
a.c.mclaughlin@abdn.ac.uk

I'm a Professor of materials chemistry at the University of Aberdeen. I'm an expert in Rietveld refinement using both neutron diffraction and X-ray diffraction data to elucidate structure property relationships of exotic electronic and magnetic phases and energy materials.

Observation of an exotic insulator to insulator transition upon electron doping the Mott insulator CeMnAsO

A promising route to discover exotic electronic states in correlated electron systems is to vary the hole or electron doping away from a Mott insulating state. We have recently shown that upon electron doping the Mott insulator CeMnAsO, a novel quantum insulating state emerges below a distinct critical transition temperature, T_{II}. The insulator-insulator transition is accompanied by a significant reduction in electron mobility as well as a colossal Seebeck effect and slow dynamics, highlighting very unusual and novel physics.

Original publication: Nature Communications — 10.1038/s41467-023-42858
ILL contact: C. Ritter, ritter@ill.fr
Instrument: Two-axis diffractometer **D2B**

In stark contrast to the *Ln*FeAsO oxypnictides, which have a metallic ground state, *Ln*MnPnO (*Ln* = lanthanide; *Pn* = As, P) are Mott insulators. To further investigate the electronic properties of Mn oxypnictides, we synthesised and investigated $CeMnAsO_{1-x}F_x$ (x = 0 – 0.075). Surprisingly, upon cooling, an insulator-insulator transition is observed for $x > 0.03$ where the resistivity increases by more than two orders of magnitude over a narrow temperature interval below a distinct temperature, T_{II} (**Figure 1**). The transition temperature from the Mott insulator to the quantum insulating phase can be tuned by varying x with T_{II} increasing from 18 K to 82 K as x increases from 0.035 – 0.075 or by the presence of a small amount of Ce non-stoichiometry (T_{II} for $Ce_{0.96}MnAsO_{0.95}F_{0.05}$ = 104 K). The insulator-insulator transition is also apparent from Hall resistivity measurements, where a sharp and significant drop in the Hall mobility occurs at T_{II}. This significant reduction in electron mobility further triggers a colossal Seebeck effect at T_{II}. A novel quantum insulating phase emerging from a Mott insulator is surprising. Such resistivity changes of several orders of magnitude, within a narrow temperature range, have also previously attracted technological interest for a range of practical applications in functional devices.

In order to investigate the origin of the transition, variable temperature neutron diffraction data were recorded between 3.5 K and 290 K on the high-resolution neutron diffractometer D2B on a sample of $Ce_{0.96}MnAsO_{0.95}F_{0.05}$ with T_{II} = 104 K. The results show that surprisingly, there is no change in the crystal symmetry or magnetic structure at T_{II} and there are no significant anomalies in the Ce-O/F or Mn-As bond lengths or angles.

These results rule out possible mechanisms for the insulator-insulator transition such as charge ordering, a spin state transition, a magnetic or structural transition, or orbital ordering, all of which would present a signature in the neutron diffraction data. The insulator-insulator transition observed in $Ce_yMnAsO_{1-x}F_x$ phases with no change in the crystal or magnetic structure is highly unusual and suggests a more exotic phenomenon drives the significant increase in resistivity at T_{II}.

In summary we have reported an unusual transition from a Mott insulator to a novel quantum insulator upon electron doping $Ce_yMnAsO_{1-x}F_x$. The origin of this exotic transition could be a result of many-body localization or an interlayer excitonic insulator phase, both of which have yet to be reported in the bulk. Further research is warranted to elucidate the mechanism of the insulator-insulator transition.

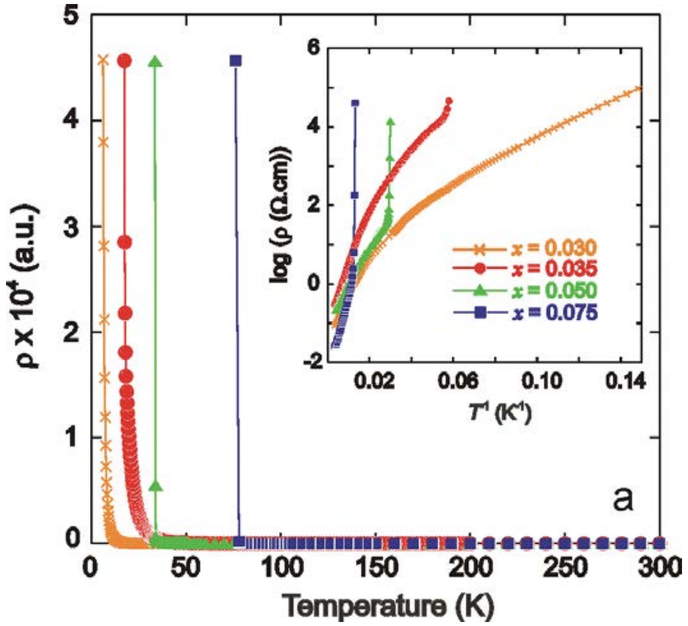
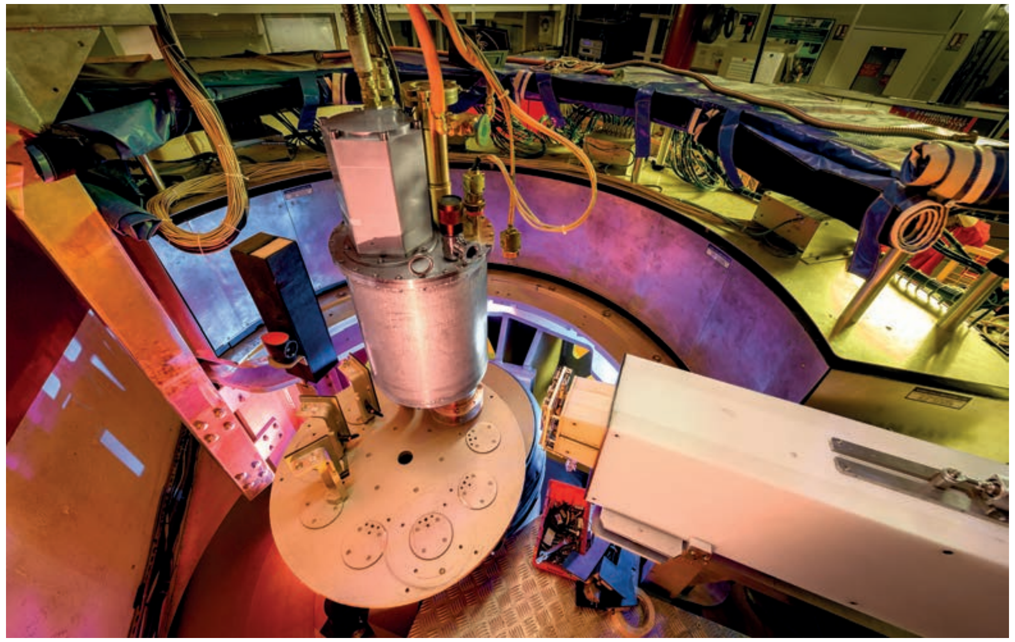


Figure 1: The temperature-dependent resistivity of $CeMnAsO_{1-x}F_x$, showing an insulator-insulator transition for $x > 0.03$. The inset shows the variation of log(resistivity) versus inverse temperature where the insulator-insulator transition is observed for x = 0.035, 0.050 and 0.075.



The two-axis diffractometer instrument D2B.

Hazuki Furukawa
RIKEN Institute and Ochanomizu University, Japan
furukawa.hazuki@ocha.ac.jp

I am currently working as a team leader of the Strongly Correlated Spin Research Team at RIKEN CEMS and as a professor in the Department of Physics at Ochanomizu University. I am deeply grateful for the opportunity to use the distinctive instruments at neutron research facilities around the world to prove the fundamental insights I am striving for.

Experimental Proof of the Asymmetric Dispersion of Phason Excitations in Skyrmion Lattices

Recent global deterioration in power supply rates, driven by the rapid development of the AI industry, has further heightened the demand for energy-efficient devices. A magnetic skyrmion, which has attracted attention in the field of spintronics, is a magnetically ordered state with a period ranging from a few nanometers to several hundred nanometers. It consists of hundreds to thousands of spins, collectively forming with a continuous phase change under a finite magnetic field and is a topologically stable magnetic quasi-particle with a winding number. In this study, we conducted experiments to observe the anisotropic oscillations predicted for skyrmion crystals.

Original publication: Nature Physics (2023) —10.1038/s41567-023-02120-5
ILL contact: I. Hoffman, hoffmann@ill.fr
Instrument: Spin-echo spectrometer **IN15**

It is known that the energy required to drive the motion of skyrmions is several orders of magnitude smaller than that needed to drive magnetic domains in ferromagnetic materials. This suggests that skyrmion materials hold promise for applications in low-power, high-density non-volatile memory, and are thus expected to develop as next-generation materials for spintronics. Moreover, regarding skyrmion crystals, theorists have pointed out the possibility of generating waves with different energies under parallel and antiparallel magnetic fields. This phenomenon originates from the intrinsic "chirality" of skyrmions, which resembles that of a screw, leading to asymmetric behavior in the +z and -z directions—just like a right-handed screw advances in a specific direction.

We have been actively advancing research on strongly correlated electron systems, such as magnetic and superconducting materials, using neutron scattering. Since the phason excitations of skyrmion crystals lie in the very low energy range of a few μeV, experiments using conventional three-axis spectrometers are not possible. Therefore, we focused on the possibility of studying the dynamics of magnetic skyrmions using the spin-echo method, which involves a complex experimental process of labeling incident and scattered neutrons according to their spin directions and manipulating those spin directions to detect small energy changes. For a series of experiments, researchers from institutions in Japan, the UK, Sweden, and the Czech Republic gathered at one of the world's top spin echo facilities ILL-IN15, and, in collaboration, investigated the low-energy excitations of skyrmion crystals in the promising spintronic material, MnSi.

The first experiment was conducted in the skyrmion phase, and the results indicated the presence of asymmetric slow dynamics in the skyrmion lattice of MnSi (**Figure 1**). However, we wanted these results to be fully verified. Therefore, we planned experiments to confirm that the anisotropic dynamics is **only** observed in the skyrmion phase. Due to the COVID-19 pandemic, these experiments were postponed and became remote experiments, but they proceeded smoothly, and our assumptions were validated. The findings were then published in *Nature Physics*.

The spin-echo method is the only technique capable of observing magnetic fluctuations on the micro-electronvolt scale with small wave vectors, thus it was the sole approach to demonstrate the asymmetry of the excitations. In the future, this research could pave the way for further discoveries regarding the dynamics of magnetic skyrmions and potentially open up new possibilities for the development of spintronic devices.

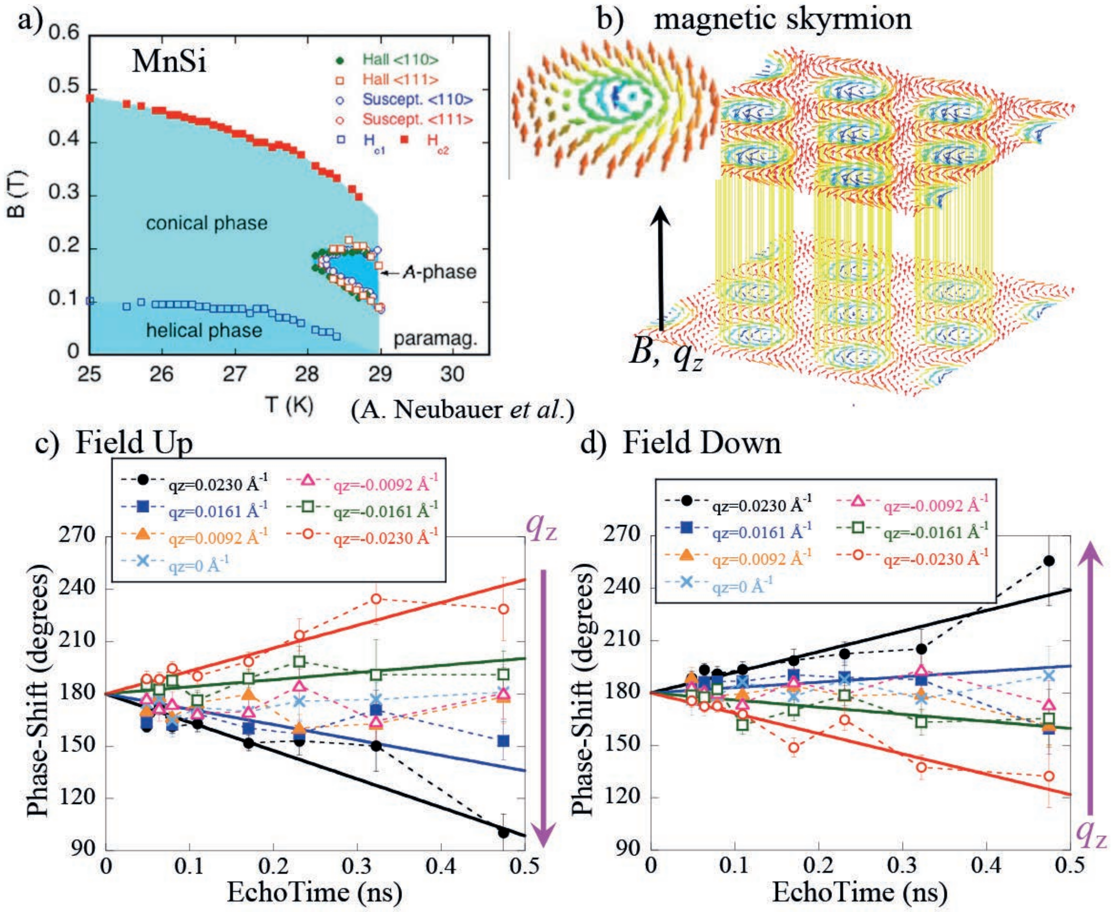


Figure 1: **a)** Phase diagram of MnSi, reported by A. Neubauer *et al.* **b)** Schematic views of skyrmion lattice. **c), d)** Experimental data, Phase shift of spin echo versus Fourier time. The slope gives the average energy of the excitations. The results clearly show that this depends on q_z and the direction of the field, which is in the + or - z-direction.

Wentao Jin
School of Physics, Beihang University - wtjin@buaa.edu.cn

I obtained my PhD from Peking University in 2012, followed by postdoctoral research at Juelich Center for Neutron Science and University of Toronto. In 2019, I joined Beihang University as an associate professor. My research focuses on neutron scattering studies of quantum magnets and unconventional superconductors.

Original publication: Nature 2024— 10.1038/s41586-023-06885-w
ILL contact: W. Schmidt, schmidt@ill.fr; K. Schmalzl, schmalzl@ill.fr
Instrument: Thermal-neutron two-axis diffractometer **D23**

Giant magnetocaloric effect in spin supersolid candidate $Na_2BaCo(PO_4)_2$

Triangular lattice antiferromagnets (TLAFs) are highly frustrated quantum spin systems and promising hosts for exotic quantum spin states, including the quantum magnetic analogue of the long-sought supersolid state, namely, spin supersolid, in which both the lattice translational and spin rotational symmetries are broken simultaneously. We performed single-crystal neutron diffraction experiments on $Na_2BaCo(PO_4)_2$ (NBCP), a spin supersolid candidate, using the thermal-neutron two-axis diffractometer D23, to provide microscopic evidences for the coexistence of solid and superfluid spin orderings.

NBCP, a novel TLAF with $T_N \sim 150$ mK, is an ideal material realization of the spin-1/2 easy-axis XXZ model, for which two spin supersolid states are expected in a magnetic field applied along the c axis. Using high-quality single crystals of NBCP, we measured the temperature variation upon changing magnetic field in an adiabatic demagnetization process, which reveals a giant magnetocaloric effect with the lowest cooling temperature of 94 mK. Two low-temperature valley-like regimes with pronounced spin fluctuations are revealed (**Figure 1**), which agrees well with the theoretically calculated two spin supersolid phases for $B<B_{c1}$ and $B_{c2}<B<B_{c3}$.

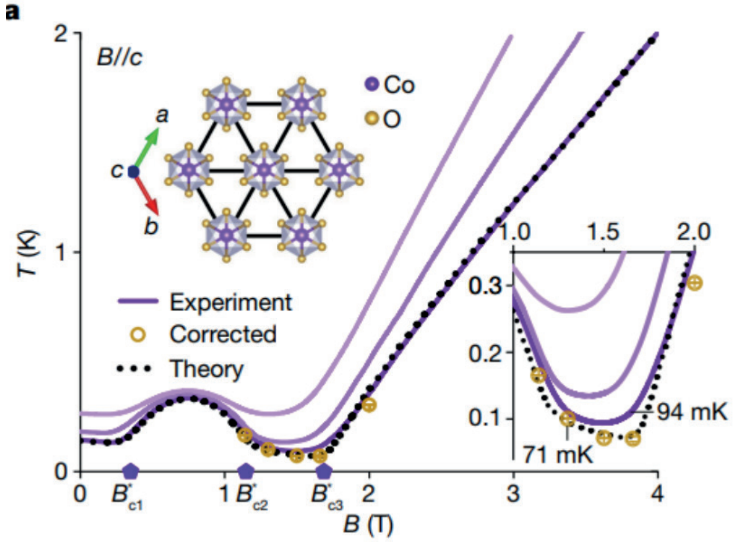


Figure 1: Measured and calculated adiabatic cooling curves of NBCP from an initial temperature $T_0 = 2$ K and various initial fields $B_0 = 3$, 3.5 and 4 T.

To search for microscopic evidences for the spin supersolid states in NBCP, we further conducted single-crystal neutron diffraction measurements at D23. Reciprocal-space scans at 95 mK under applied fields along the *c* axis are presented in **Figure 2a**, which shows a significant change in the ordering vector at the transition fields. In the regime $B<B_{c1}$ and $B_{c2}<B<B_{c3}$, the ordering vector locates at (1/3, 1/3, q_c) with an incommensurate out-of-plane q_c, whereas the system shows commensurate ordering for $B_{c1}<B<B_{c2}$. **Figure 2b** shows the diffraction intensities at (1/3, 1/3, 0.836), (1/3, 1/3, 1) and (1/3, 1/3, 0.664) as functions of the applied field, which show great similarities with the density matrix renormalization group (DMRG) calculations shown in **Figure 2d**. In the supersolid phases, intertwined spin solid and superfluid orders coexist, while in the UUD phase, only a solid order is present. By comparing experiments with DMRG calculations, we identify that (1/3, 1/3, 0.836) and (1/3, 1/3, 0.664) correspond to the Y and V spin supersolid states (the observed incommensurate q_c can be attributed to the sensitivity of spin supersolid states to weak interlayer couplings), respectively, whereas the (1/3, 1/3, 1) reflection corresponds to the gapped UUD solid order. **Figure 2c** shows the temperature dependences of the representative magnetic reflections. A maximal moment is estimated to be roughly 0.59 and 1.74 μ_B at 95 mK for B = 0 and 0.8 T, respectively. These findings support the coexistence of magnetic ordering and strong fluctuations in the spin supersolid phases.

These results indicate that a spin supersolid state has been identified in a real-world quantum magnet for the first time. In addition, the giant magnetocaloric effect of NBCP associated with the strong quantum spin fluctuations in the spin supersolid states makes it a very promising quantum material coolant for sub-Kelvin refrigeration.

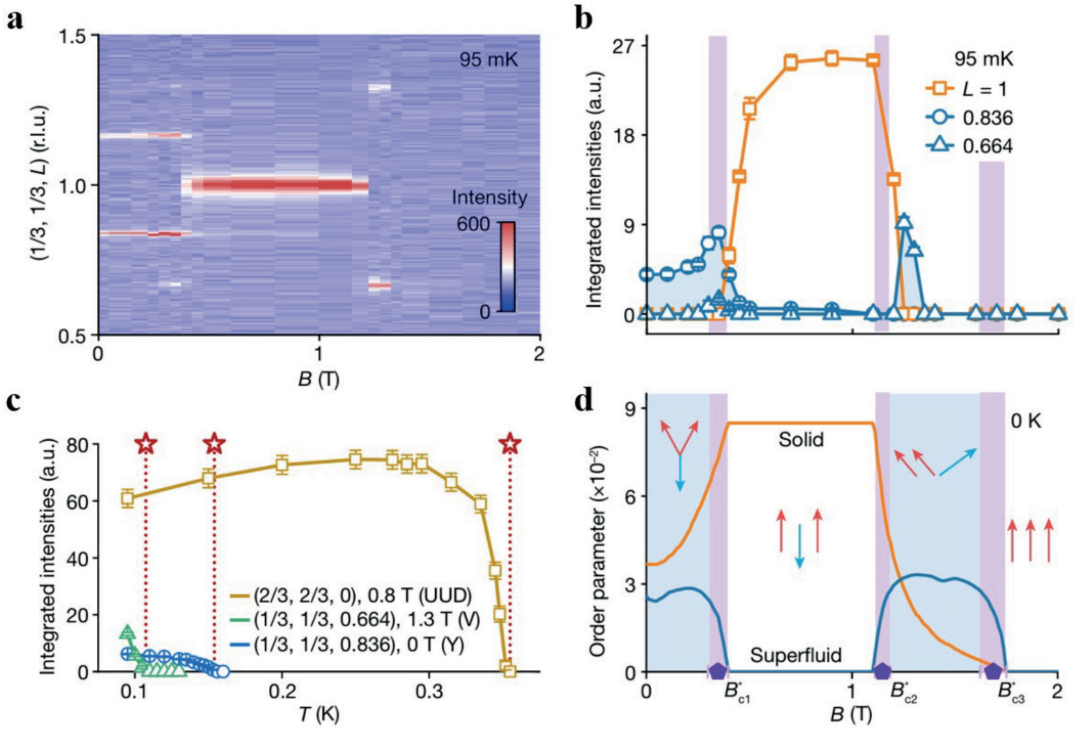


Figure 2: Neutron diffraction data collected at D23 including the reciprocal-space scans at 95 mK under different fields applied along the *c* axis **(a)**, field and temperature dependences of representative magnetic reflections **(b, c)**, and the comparison with ground-state DMRG calculations **(d)**.

Victor Ukleev
Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, DE
victor.ukleev@helmholtz-berlin.de

A neutron reflectometry expert, I earned my Ph.D. from the Petersburg Nuclear Physics Institute in 2016. I have since held postdoctoral positions at RIKEN and Paul Scherrer Institut, studying topological magnetic materials with neutron and x-ray scattering.

Original publication: Science and Technology 2024 —
10.1080/14686996.2024.2315015
ILL contact: N.-J. Steinke, steinkenj@ill.fr; R. Cubitt, cubitt@ill.fr
Instrument: Massive dynamic q-range small-angle diffractometer **D33**

Unlocking Peculiarities of Skyrmions in Magnetic Multilayers by Means of Polarized Small-Angle Neutron Scattering and Polarized Neutron Reflectometry

Understanding the magnetic textures in periodic multilayers is crucial for advancing spintronic devices. This study focuses on [Pt(1 nm)/(CoFeB(0.8 nm)/Ru(1.4 nm)]^{10} multilayers, investigating their magnetic properties using polarized neutron reflectometry (PNR) and small-angle neutron scattering (SANS). These techniques provide valuable insights into the behavior of skyrmions, which are stabilized by Dzyaloshinskii-Moriya interactions at asymmetric interfaces.

PNR measurements at SuperADAM reveal well-defined structural features and layer-resolved magnetization profiles. The in-plane magnetization of CoFeB layers aligns well with magnetometry data and confirms the excellent structural quality of the sample.

SANS measurements performed at D33, as a bulk probe, detect long-period magnetic stripe domains and skyrmion ensembles at room temperature. Skyrmion stability is observed to decrease below 250 K due to increased magnetic anisotropy in CoFeB layers. Magnetic Modulation: Polarized SANS confirms the existence of pure Néel-type windings in both stripe domain and skyrmion regimes, with no Bloch-type winding admixture, matching micromagnetic modeling predictions.

The ILL instrument D33.

The findings provide crucial microscopic insights that can enhance the development of skyrmion-based spintronic devices, which promise lower energy consumption and higher data storage efficiency. The study's methodologies can be applied to other magnetic materials, aiding in the discovery of new phenomena and the development of advanced magnetic materials.

This research offers a comprehensive understanding of the magnetic order in [Pt(1 nm)/(CoFeB(0.8 nm)/Ru(1.4 nm)]^{10} multilayers, highlighting the intricate interplay between structural and magnetic properties. The suppression of skyrmions below 250 K and the identification of Néel-type domain walls provide a pathway for further exploration and application in future spintronic devices.

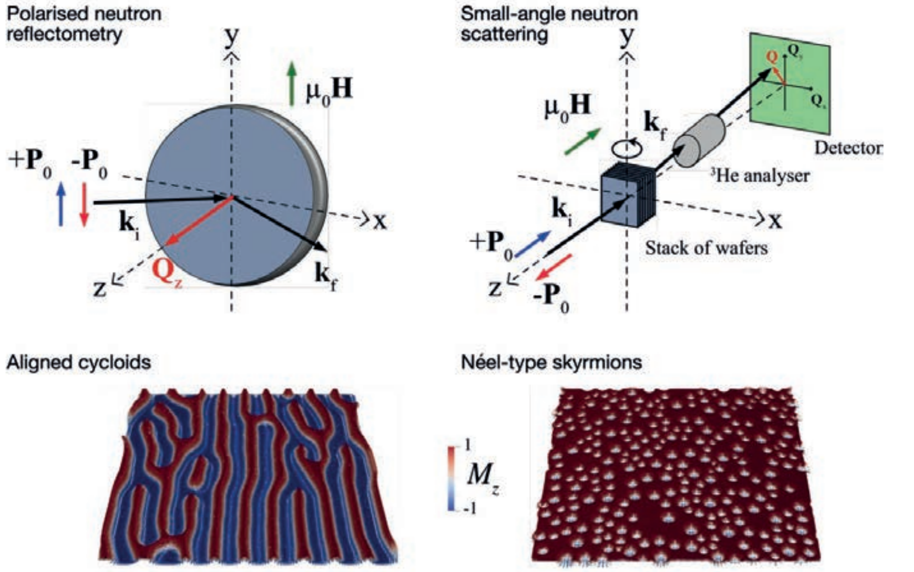


Figure 1: Top panel schematics of PNR and SANS experiments. **Bottom panel** micromagnetic simulations of field-aligned cycloids and Néel-type skyrmions in a magnetic multilayer.

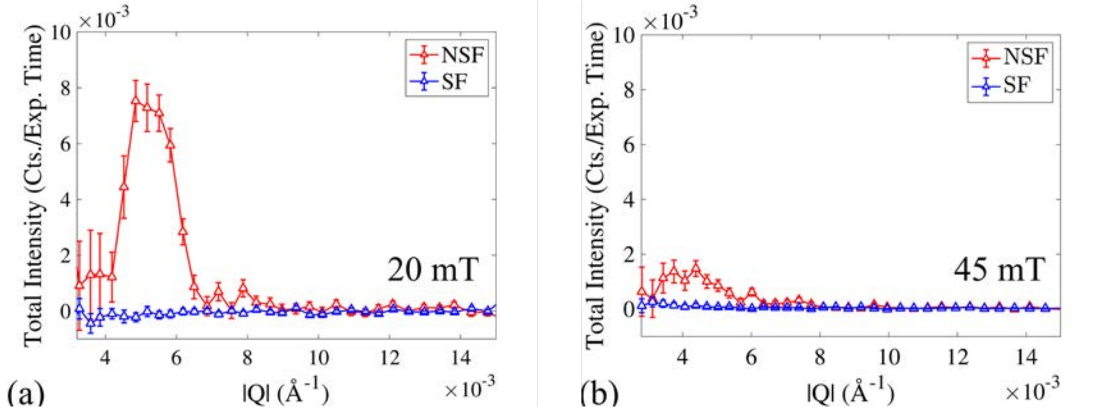


Figure 2: Polarised SANS intensity for non-spin flipped (NSF) and spin flipped (SF) neutrons in the (a) cycloidal phase at 20 mT and (b) skyrmion phase at 45 mT. Suppressed intensity in the SF channel indicates the Néel-type character of both textures.

Jérémie Dudouet
Institut de Physique des 2 infinis (IP2I), Lyon, France
j.dudouet@ip2i.in2p3.fr

I am a CNRS researcher at IP2I Lyon. My main interest is the investigation of the structure of exotic nuclei by means of high-resolution gamma spectroscopy. My main research focuses on nuclei produced in the fission process. I'm one of the main developers of analysis codes for the Advanced-Gamma-Tracking Array (AGATA), a new generation spectrometer developed within an international collaboration.

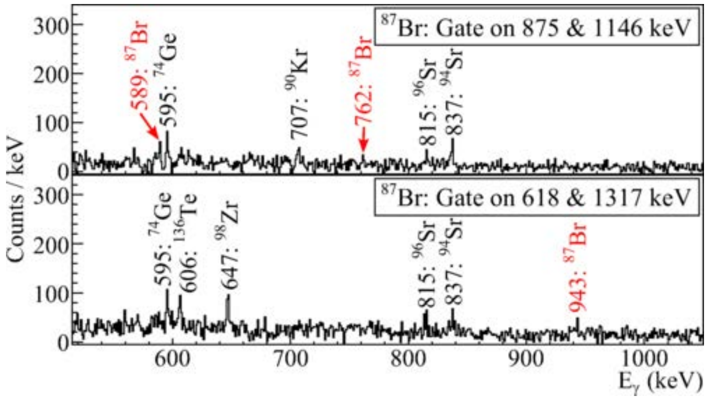
Nuclear shape transitions in exotic nuclei

The nuclear many-body system is so complex that it requires various international facilities and multiple approaches to obtain a better understanding and predictability. The intense neutron flux combined with the high sensitivity gamma array of the FIPPS instrument at ILL have been used to investigate the structure of neutron-rich Br nuclei produced in the fission process. The data have been analyzed in combination with those obtained at the GANIL facility and new theoretical calculations have been employed to identify the signature of a prolate-to-oblate shape transition for nuclei with number of neutrons N=56.

Original publication: Phys. Rev. C (2024) — 10.1103/PhysRevC.110.034304
ILL contact: Caterina Michelagnoli, michelagnolic@ill.fr
Instrument: FIssion Product Prompt gamma–ray Spectrometer, **FIPPS**

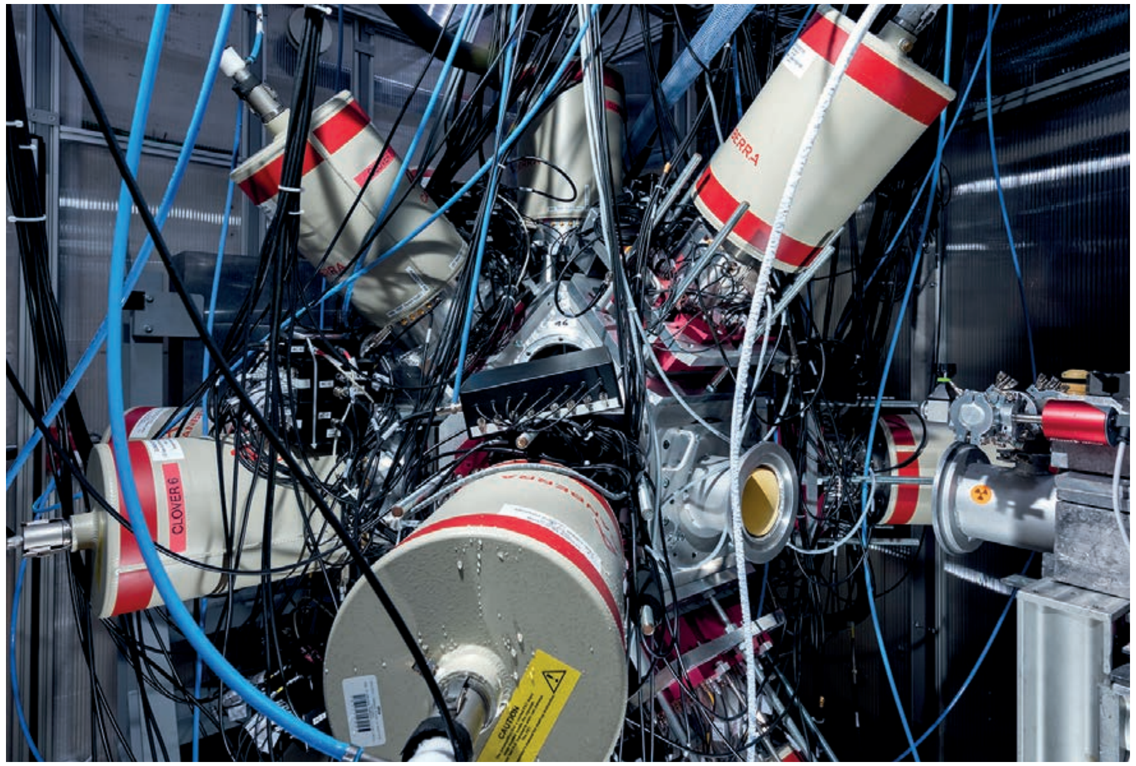
More than 100 years from its discovery, the atomic nucleus is still source of unresolved questions. A model describing all the nuclear chart is not existing, a brain teaser for nuclear theories with huge impact on nuclear astrophysics and applications. The complexity relies mainly in the lack of knowledge of the nuclear forces among protons and neutrons in the atomic nucleus. The systematic study of the structure of nuclei along different isotopic or isotonic chains is very important in order to gain in insight into this matter. With 35 protons Br nuclei are an ideal testing ground for the proton-neutron interaction between the shell model orbitals of interest in the mass region.

The behavior of these nuclei far from stability is of particular interest, given the asymmetry between the numbers of protons and neutrons. Those exotic isotopes are very challenging to be produced and studied. Nuclear fission is the key mechanism for experimental access to their spectroscopic observables.



Example of g – g – g coincidence spectra obtained with FIPPS confirming the placement of newly observed transitions in the ^{87}Br level scheme.

An experiment has been recently performed at the GANIL accelerator facility to produce these nuclei via fission in inverse kinematics. The identification of the fission fragments with the VAMOS magnetic spectrometer and the detection of the gamma rays with the Advanced-Gamma-Tracking-Array has allowed the study of exotic nuclear species. These data have allowed to identify, for the first time, gamma rays in the very exotic ^{93}Br. The identification of the fission fragments with a magnetic spectrometer is very powerful, but the gamma detection capabilities are often compromised because of the solid angle occupied by the spectrometer. The almost 4π high-efficiency geometry of the FIPPS spectrometer and its intense neutron flux have been used as a complementary approach to identify higher-lying gamma rays in the level schemes of $^{87\text{-}89}$Br. The use of an active fission target has allowed for high sensitivity data, excluding the gamma-ray background coming from beta decay. The newly obtained systematics have been used to challenge state-of-the-art shell model calculations. Those have been combined with deformation calculations via mean-field approaches, in order to search for signatures of different nuclear shapes. Evidence for a prolate to oblate nuclear shape transition have been found for the first time in those nuclei. This opens a way to further nuclear physics investigations at FIPPS, GANIL and many other laboratories to understand the nuclear forces behind this behavior.



The FIPPS instrument at the ILL.

William Saenz-Arevalo
Laboratoire de Physique Nucléaire et des Hautes Energies, Paris, France - william.saenz@lpnhe.in2p3.fr

I am currently enrolled as a Post-Doctoral Researcher at LPNHE, working on the T2K experiment. My PhD studies focused on UCN physics, particularly on the search for hidden neutron oscillations.

Original publication: PRL (2023) — 10.1103/PhysRevLett.131.191801
ILL contact: Tobias Jenke, jenke@ill.fr
Instrument: Ultracold neutron facility, **PF2**

Search for Neutron-to-Hidden-Neutron-Oscillations in an Ultra-Cold Neutron Beam

Hidden particles forming extra sectors of the universe are among the multiple candidates for dark matter. Free neutrons are ideal probes for studying these hidden sector theories, as they predict oscillations between ordinary and hidden universes for neutral particles. We conducted the first search for such oscillations directly on a beam of ultra-cold neutrons (UCN). The experiment benefited from the world's most intense UCN beam at the PF2 instrument at ILL and the high counting rate gaseous detector GADGET.

In the hidden sectors scenario, all known particles and interactions of the Standard Model would have twin counterparts. These counterparts could interact with our ordinary particles via gravitational interaction and potentially through exotic new interactions. To test these additional interactions in neutrons, we installed a six-meter-long UCN guide followed by the newly developed detector GADGET. The neutron guide was surrounded by a five-meter-long solenoid and mu-metal-based magnetic shielding (**Figure 1**).

The hidden sector theory predicts that during their flight time in the instrument, neutrons could oscillate into their twin counterparts. These twins cannot be detected by GADGET, resulting in a drop in the count rate. The probability of this effect depends on two model parameters: the neutron-hidden neutron mass splitting (δm) and the characteristic oscillation time ($\tau_{nn'}$). While the former, representing the energy difference between the neutron and hidden neutron, can be accessed by tuning the applied magnetic field, the latter is fixed and determines the amplitude of the expected signals. The shorter the $\tau_{nn'}$, the greater the decrease in UCN detected rate. During the main measurements, we scanned the magnetic field strength and carefully monitored for missing neutron signals.

The stability of the incoming neutron flux is crucial. A drop in the incoming flux could mimic a false positive effect. We did not use a beam monitor, as it would have significantly reduced the high flux of PF2 and could also have introduced new systematic effects. Instead, we applied a self-normalization algorithm by dividing each data cycle of 200 seconds into sub-cycles and applying three different magnetic field amplitudes. By taking ratios of the neutron counts from different sub-cycles, all linear instabilities were canceled, while maintaining the full beam statistics.

After several months of careful data analysis, we gained valuable insights into the stability of the PF2 instrument on short- and medium-term time scales. However, the UCN rates were found to be consistent with the predictions of standard physics. We exclude that neutrons oscillate into their hypothetical twin copies of a hidden world in the range $|\delta m| \in [2\text{–}69]\times 10^{-12}$ eV (95% C.L.) for $\tau_{nn'}$ as short as 1 second (**Figure 2**). Although this study covers a considerable part of the parameter space for such theories, the existence of the hidden world is not yet completely excluded.

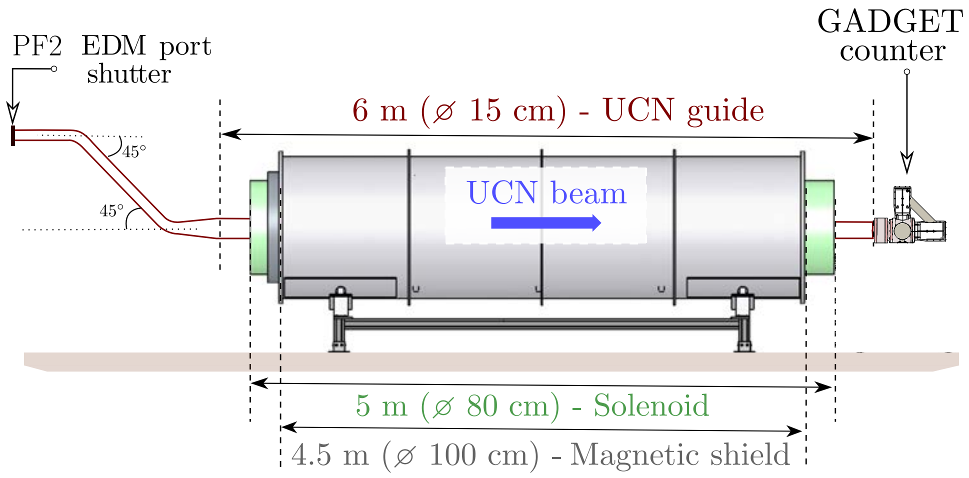


Figure 1: Schematic side view of the experimental setup.

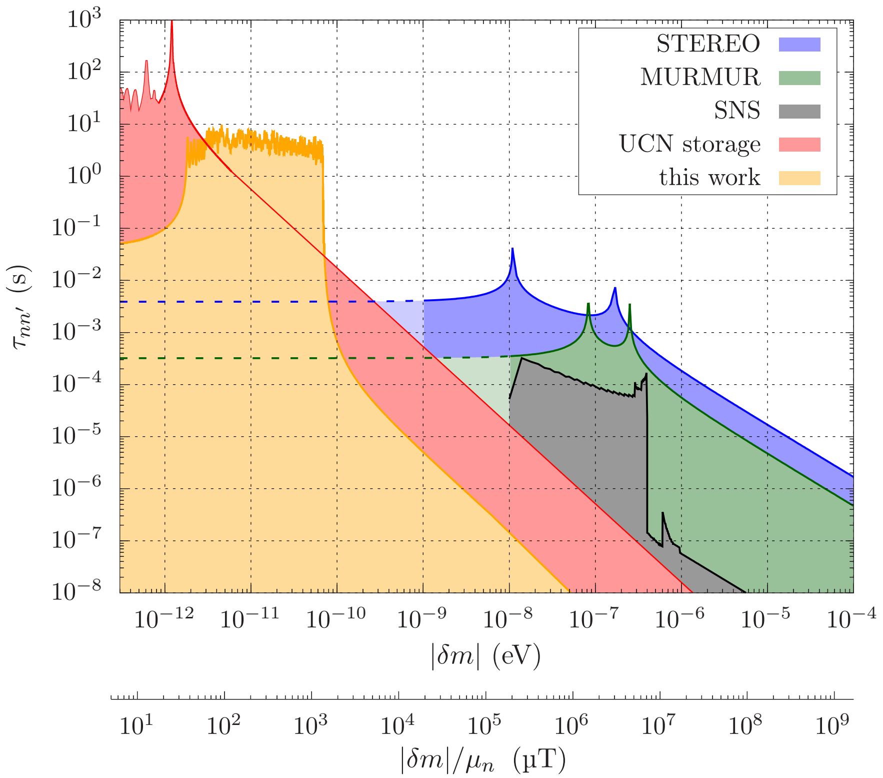
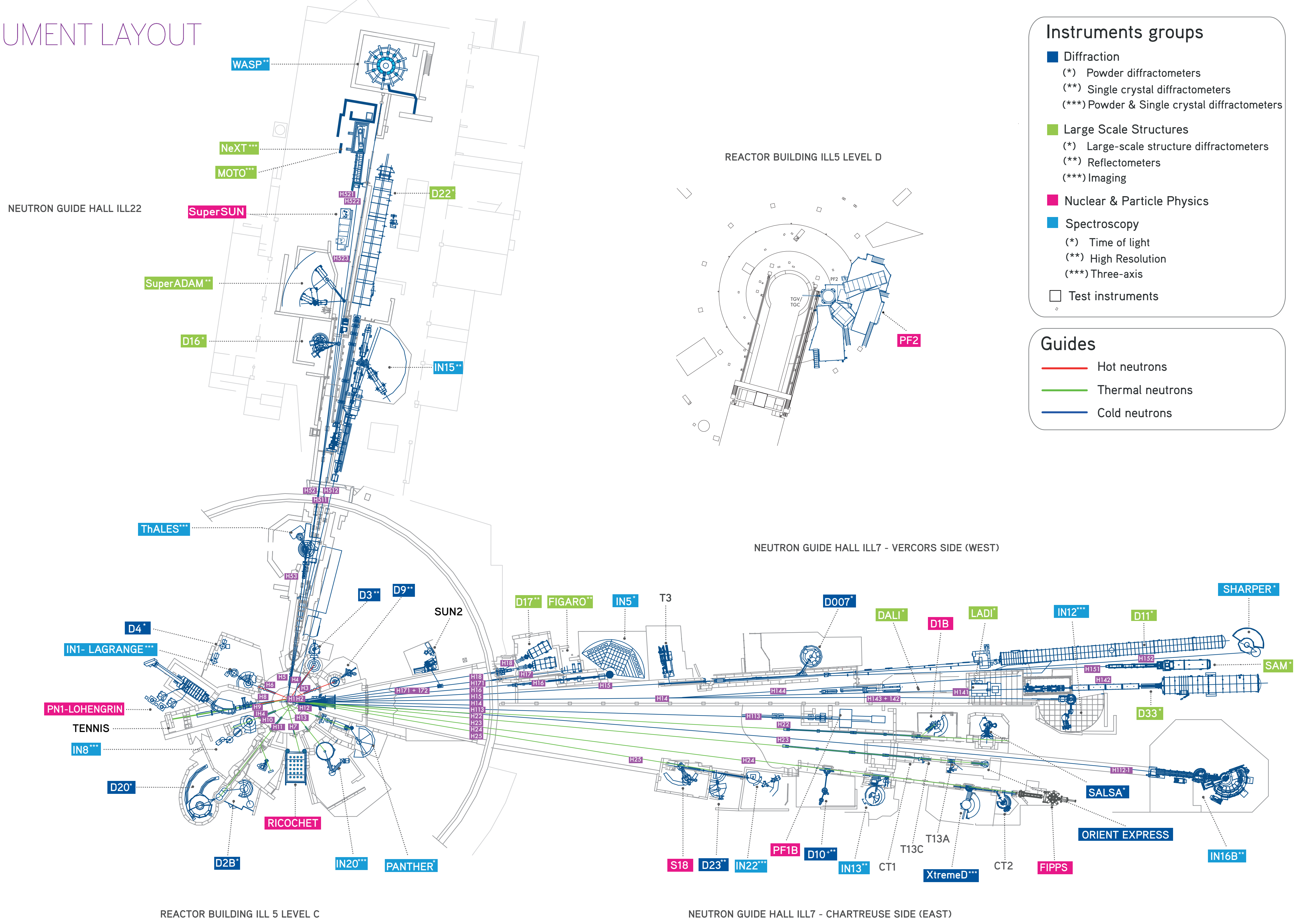


Figure 2: Exclusion of the neutron-to-hidden-neutron-oscillations parameter space including all experimental results up to August 2022.

A UNIQUE FACILITY

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

COMPLETION OF ENDURANCE

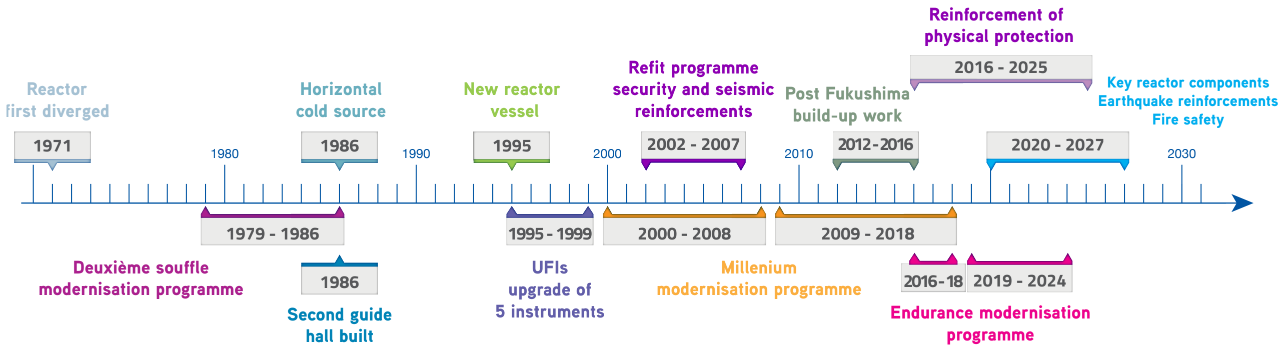
From a programmatic perspective the Endurance programme (2016–2024) is now complete. A few small adjustments, alignments, installations and commissioning measures remain to be completed in 2025. Endurance has seen the upgrade, modernisation or complete renewal of more than 30 instrument and infrastructure projects, almost all of which are available to users in the science programme. The H15 project was the last of the major packages to be deployed with installation beginning during the H1-H2 shutdown (Oct. 2021 – Feb. 2023), continued though reactor operation in 2023 and was completed during the winter shutdown 2023/2024. The H15 instrument suite, D007, D11, SHARPER, SAM, with the exception of T3, was completed during the first half of 2024, and saw their first neutrons to begin radioprotection measurements and commissioning. The gains in instrument performance for all Endurance projects are in line with expectations, of particular note, the performance gains for the H24 and H15 instrumentation. The new D20c detector is in the process of installation along with the MoTo imaging side-station to NeXT. The Endurance programme is effectively complete and ILL has a fully modernised suite of world-class instruments. In-house developed technologies have been key to successful and efficient instrument upgrades. The overall result of 25 years of continuous instrument and infrastructure upgrades through the Millennium and Endurance programmes is a staggering gain average in performance over the entire instrument suite of more than x300 compared to the instrument suite at the turn of the millennium and with a total cost of about 130 M€ - about one years running budget of the ILL – a 4% investment.

60 M€
ENDURANCE
9 YEARS (2016-2024)

more than **30** instrument and infrastructure projects

H15 GUIDE
& INSTRUMENT SUITE
COMMISSIONED IN 2024

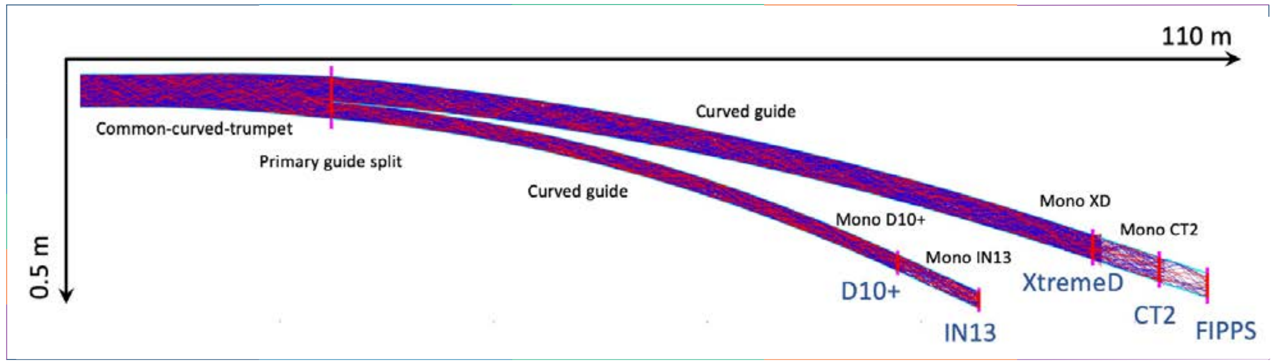
D007
D11
SHARPER
SAM
T3



Timeline of major ILL modernisation programmes for the reactor (top) and instrument suite (bottom). The ILL instrument suite has undergone almost continuous and uninterrupted modernisation for nearly 25 years since the year 2000.

Endurance Phase I: (2016 – 2018)

The 'backbone' of Endurance 1 was the Chartreuse project involving the renewal of the H24 thermal neutron guide and associated suite of upgraded instruments. The new guide has a high critical angle coating (m=3) and exploits the two radii of curvature of the H241 (R=14000m) and H242 (R=8000m) down-stream sub-branches to naturally curve and expand the guide over a distance of 22 m. Dedicated end-of-guide positions allow for optimised beam-shaping and monochromator optics for the upgraded D10$^+$, IN13 (CRG) and the new extreme conditions powder and single-crystal diffractometer XtremeD (CRG) as well as providing neutrons to the renewed test instrument CT2 and a repositioned FIPPS. We have measured a total gain in count rate of 11 times on the new D10$^+$ single crystal diffractometer (Cu monochromator at 1.26 Å) with respect to the old D10 instrument due to the efficiency of the new detector (x1.6) and neutron flux (x6.6) due to the increased divergence, guide and monochromator size. Similar gains in intensity have been measured on IN13, primarily due to the performance of the new H24 guide coupled with a new temperature-gradient monochromator which is in the process of being optimised. New capabilities and capacity are available with the new CRG powder and single crystal diffractometer XtremeD having an intensity to rival that of D20c.



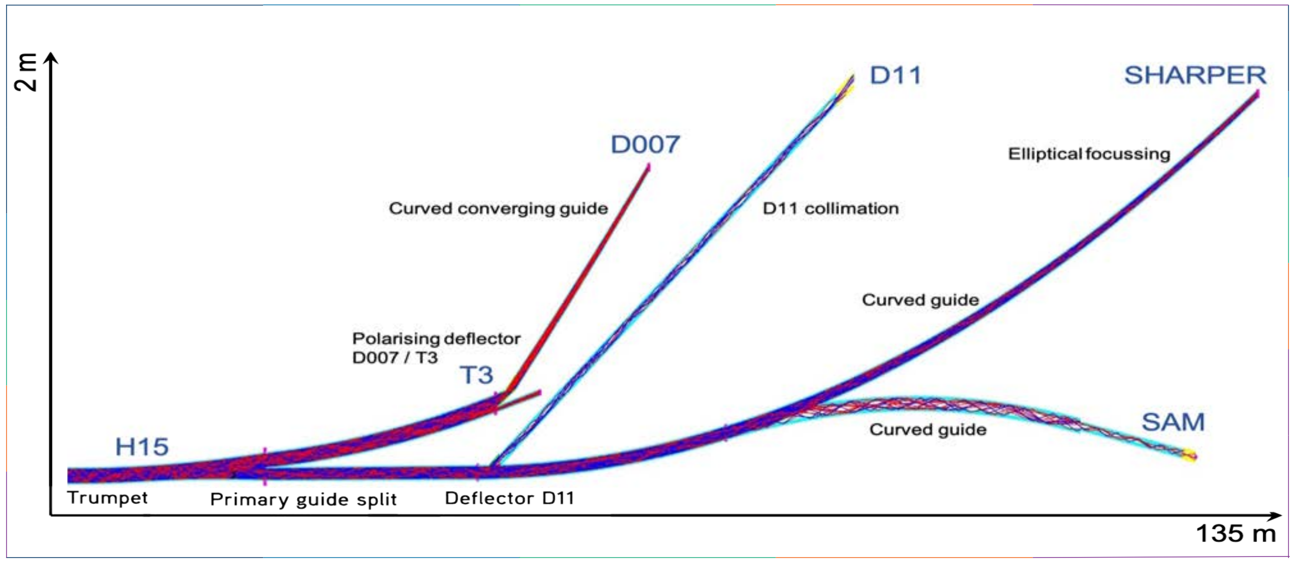
Simulation trace showing the plan view geometry of the new H24 thermal-neutron guide and instrument end-of-guide positions.

We also delivered a number of independent instrument projects during the first phase of Endurance such as the new fission-fragment gamma ray spectrometer FIPPS, the upgraded IN5 cold time-of-flight (TOF) spectrometer, upgraded IN20 thermal triple-axis spectrometer (TAS), new thermal TOF spectrometer PANTHER and an upgraded D3 hot-neutron diffractometer to allow for efficient measurement of hydrogen-containing liquid samples. Meanwhile, after a long and complex cryogenic project the SuperSUN source of ultra-cold-neutrons has begun commissioning with the aim to produce the highest densities of UCN's and allow science to begin on the PanEDM experiment. The BASTILLE and NESSE infrastructure projects have continuously delivered software for data treatment and analysis and new sample environment capabilities throughout Endurance.

Endurance Phase II: (2019 – 2024)

In a first round of funding for Endurance 2 we were able to rapidly construct detectors for the SANS instruments D22 and D11. A second protein crystallography station, DALI, was installed on a modified H141 guide (ex IN11) while the secondary spectrometer of the D16 cold-neutron diffractometer has also been upgraded including a new wide-angle detector. The neutron imaging facility, NeXT, was fully rebuilt allowing for state-of-the-art imaging and a second (monochromatic) imaging station, MoTo to be operational in 2025.

The 'lion's share' of Endurance 2 was the Vercors project involving the renewal of the H15 cold-neutron guide and associated suite of upgraded instruments. The H15 guide has a rather complex opposing-curved expanding section, referred to as 'the trumpet' which allows to spatially expand the neutron guide and allows guide branches to be more widely separated in angle, therefore allowing space for substantially more instrumentation downstream. Vast in terms of the scope as well as the engineering and optical complexity the new H15 guide began installation during the H1-H2 shutdown, continued though reactor operation in 2023 and was completed during the winter shutdown 2023/2024. SAM was the first of the new H15 instruments to begin commissioning demonstrating excellent performance with a neutron brightness equivalent to that of D22 and D33, beam cleanliness and polarisation capabilities. The 3-disc chopper and Fermi chopper system for SHARPER were the last components to be received and installed before the second cycle in May 2024 allowing commissioning to begin during the second cycle demonstrating an impressive performance with a gain in intensity of at least x10 compared its predecessor IN6. D007 received its first neutrons at the beginning of the second cycle with initial data showing the intensity gain on D007 to be more than x10 compared to D7. Flipping-ratio measurements also show the quality of the polarisation and analysis to be as good as, or better than D7. Both the flux and polarisation data therefore indicate that the H15-D007 polarising deflector is performing as expected. This order-of-magnitude increase in flux will make spectroscopic



Simulation trace showing the plan view geometry of the new H15 cold-neutron guide and instrument end-of-guide positions.

polarisation and analysis measurements realistic upon receipt of the new D007 chopper system in May 2025, as well as provide massive gains for the more usual diffuse scattering measurements. A new suite of position-sensitive detectors is currently under installation and will be available on the new instrument in 2025. D11 was completed towards the end of the second cycle and due to technical issues was only able to receive neutrons for several hours but enough to perform initial radioprotection tests and confirm instrument performance. The measured beam intensity on D11 is improved by approximately a factor of x1.5 compared to the old instrument with a brightness comparable to the other three SANS instruments. The detector trolley upgrade allows smooth and rapid change in detector position taking only 6 minutes for the detector to travel the 40 m length of the D11 detector tube. T3 is under installation during the current shutdown to be ready to begin commissioning with the first cycle of 2025. Completion of H15 marks the end of the second, largest and most complex of the Endurance packages. All new or upgraded H15 instruments will be available to users in 2025.

Endurance Impact

We have attempted to formulate a simple metric indicating the impact of the Endurance programme on the performance of the ILL instrument suite. A similar evaluation was performed at the end of the Millennium programme. The metric involves estimating the effective increase in capacity to the ILL overall instrument suite as contributed by the individual gains in performance for instruments.

For example, in replacing the thermal TOF spectrometer IN4 by PANTHER we gained a factor of x2 in neutron flux from the larger double focussing monochromator and x3 in solid angle coverage of the detector. The instrument count rate on PANTHER is therefore increased by a factor x6 compared to the old IN4 instrument. This is equivalent to having 6 instruments of the intensity of the old IN4 and means that, upon delivery in 2019, PANTHER gave an effective gain of +5 (6-1) to the instrument suite as a result of this upgrade. Note, here we are only considering gains in counted neutrons and are ignoring other sources of instrument improvement such as a substantial reduction in background and additional capabilities such as the position sensitive nature of the detector. If we consider all projects delivered in 2019, we have gains of:

- **PANTHER**: Instrument gain x6. Effective 'addition' to the total instrument suite +5
- **D17**: Instrument gain x10. Effective 'addition' to the total instrument suite +9
- **IN5**: Instrument gain x4. Effective 'addition' to the total instrument suite +3

The total effective 'addition' to the instrument suite in 2019 is +17 out of a base of 40 instruments. The yearly gain factor is then 40 + 17 / 40 = 1.425. If we do this for all years through the programme, we can then calculate a cumulative multiplicative gain though the years reaching a gain of 14 in 2025.
The cumulative gain factor in the instrument suite performance for both the Millennium (gain x23) and Endurance (x14) rises to an impressive overall gain factor of more than x300 compared to the instrument suite at the turn of the millennium.

Completed Endurance projects

We have delivered almost all new or upgraded instruments and infrastructure packages that are now in user operation. These are:

- **FIPPS**: Fission-fragment gamma ray spectrometer giving new capabilities in the identification of prompt short-lived fission products and entirely complimentary to the existing Lohengrin mass spectrometer. (2016)
- **RAINBOWS**: A re-scoped project to upgrade the D17 reflectometer with a new focussing guide and chopper system to pursue an alternative high-flux mode of operation using the so-called 'coherent summing' method. (2018)
- **IN5 / H16**: Cold-neutron TOF spectrometer. The new elliptically focussing H16 guide boasts huge gains in intensity, in particular at shorter wavelengths while focussing onto much smaller samples. Access to shorter wavelengths on IN5 improves the overlap with the new thermal-neutron TOF spectrometer PANTHER. (2019)
- **NESSE 1 & 2**: Stimulus in sample environment capabilities covering all scientific domains such as low- and high-temperatures, high pressure, magnetic fields, humidity environments, and equipment for soft-matter and biological sciences. (2019, 2023)
- **BASTILLE 1 & 2**: Stimulus in scientific computing - Modern data reduction and analysis software tools via the Mantid project. Mantid is now well developed and fully deployed over our suite of TOF spectrometers and begins adoption on our powder diffraction, reflectometry and SANS instruments (solution scattering). (2019), (2023)
- **PANTHER**: New thermal-neutron TOF spectrometer replacing IN4 and with performance (signal/noise) approximately 60 times that of its predecessor. (2020). A cascade of five background choppers have been installed during the H1-H2 shutdown to further improve the performance of PANTHER. (2022)
- **IN20**: Upgraded thermal triple-axis spectrometer. A velocity selector for wavelength filtering and allowing much greater flexibility in instrument use and accessible energies. (2020). New graphite monochromator and analyser and a new Heussler monochromator. (2023).
- **Orient Express**: Strategic move of instrument to H23 to allow uninterrupted access for sample alignment during the H24 works and to free up end-of-guide position for the relocation of FIPPS. (2020)
- **DALI**: Second protein crystallography instrument. Doubles the capacity and throughput of protein crystallography measurements with an increased neutron flux and flexibility due to the use of a velocity selector. (2020)
- **D3 Liquids**: Hot-neutron diffractometer with a new position-sensitive area detector and polarisation components, allowing for efficient measurement of hydrogen-containing liquid samples with precise discrimination of incoherent scattering. (2021)
- **D11 Detector**: Replaced the aging multidetector with a modern, increased area, efficiency and count-rate detector. (2021)
- **D22 Detector**: An additional high-angle detector, massively extending the instrument's dynamic q-range and making for more rapid measurements with a reduced number of instrument configurations. (2021)
- **D16**: New secondary spectrometer, including a new wide-angle detector bank with approximately four times the angular coverage (85o) of the previous detector. (2023)
- **NeXT**: A full re-build of the neutron imaging instrument allowing for state-of-the-art imaging with advanced contrast techniques, high spatial resolution, intense neutron flux and combined X-ray imaging. (2023). A second (monochromatic) imaging station, MOTO, for measurements such as Bragg-edge and dark-field imaging as well as technique development is under installation. (2024)
- **H24 guide**: New thermal neutron guide providing dedicated end-of-guide positions to D10^{+}, IN13^{+} and the new XtremeD (CRG) powder and single-crystal diffractometer as well as providing neutrons to the test instrument CT2 and a relocated FIPPS. (2023)
- **D10^{+}**: Renewed thermal single-crystal diffractometer with count-rates more than ten times that of the previous D10 instrument due to the new H24 guide, new and larger focussing monochromators and improved efficiency detector. (2023)
- **IN13**: New primary spectrometer, including new temperature gradient monochromator, optimised for the dedicated end-of-guide position on the new H24 guide. (2023)
- **XtremeD**: New CRG thermal neutron powder and single crystal diffractometer with performance to rival that of D20. (2023)
- **CT2**: Renewed test instrument for the characterisation of neutron detectors. (2023)
- **SuperSUN**: The new ultra-cold neutron (UCN) source SuperSUN is in the commissioning phase with the successful fabrication and installation of the converter guide and cool-down of the superfluid He converter volume. SuperSUN will begin to produce high densities of UCNs and will allow science to begin on the PanEDM experiment. (2023)
- **Move FIPPS**: Relocation of the fission fragment gamma ray spectrometer onto the new H24 guide for increased intensity, beam stability and instrument space. (2024).
- **H15 guide**: New cold neutron guides to upgrade D007, T3, D11, SHARPER (CRG) and SAM (CRG). (2024).
- **D11**: SANS instrument relocated onto the new H15 guide. A new optically 'clean' collimation and renewed H15 guide, combined with the new detector, will bring D11 to a performance comparable with D22 and D33. (2024)

- SAM: New SANS CRG instrument with MIEZE option. (March 2024)
- SHARPER: Relocation of the SHARP (CRG) spectrometer (previously IN6) onto the new H15 guide and upgrade of the primary spectrometer with focussing guide, monochromator and chopper cascade. (2024)
- D20c Detector: Replace the aging microstrip detector with a new banana detector of TMWPC technology. (2024)
- SALSA: Additional (Cu 200) monochromator. Up to x5 increased flux and instrument capabilities at longer wavelengths (e.g. access to titanium-based materials and carbides) (spring 2024).

Ongoing Endurance projects

A number of Endurance projects remain in execution. These are:

- D007: Upgraded diffuse scattering diffractometer and spectrometer with gains in flux of more than one order of magnitude due to the new primary spectrometer and dedicated H15 end-of-guide position. While commissioning has begun in 2024, new position-sensitive detectors are being installed during the current long shutdown ready to continue commissioning next cycle. The chopper system for the spectroscopy option will be received and installed in summer 2025. (2025)
- MARMOT: Multiplexed energy and angle analysis on the cold-neutron TAS instrument Thales. Detector elements and bent silicon analyser crystals for the spectrometer use in-house technologies and fabrication. (2025)
- WASP: The wide-angle spin-echo instrument will receive its additional detector bank due in 2025. (2025)
- SuperSUN (phase2): Ultra-cold neutron (UCN) source SuperSUN phase 2 will see the installation and commissioning of the superconducting magnetic trap. (2026)

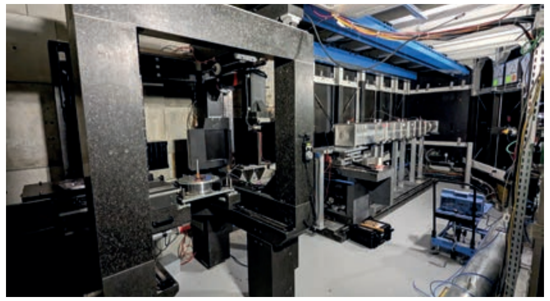
Andreas Meyer
Associate Director
Head of Projects & Techniques division (DPT)

Charles Dewhurst
Deputy Head of DPT

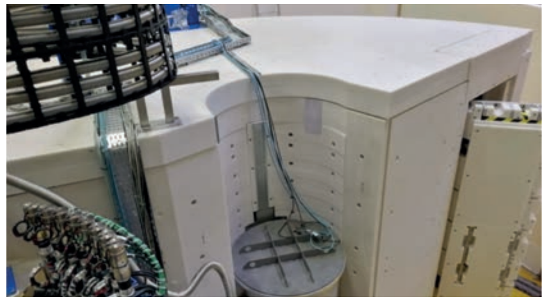
Examples of new and upgraded instruments at the ILL.

D10$^+$

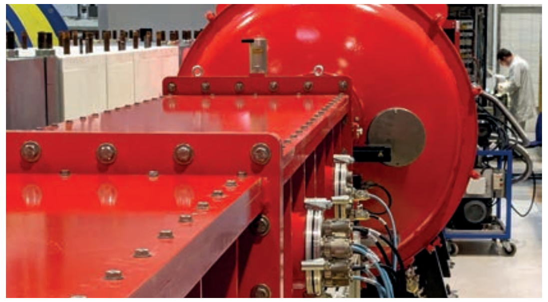
SHARPER



NeXT



PANTHER

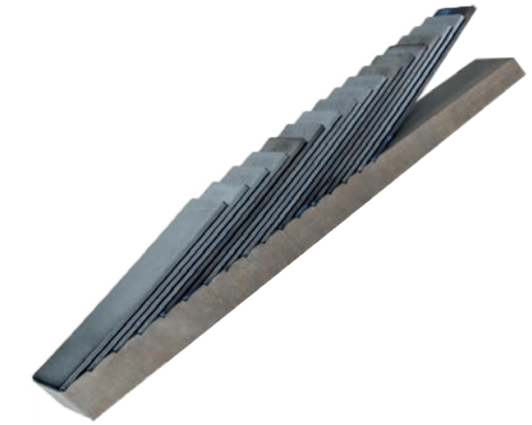


SAM

NEUTRON TECHNOLOGY HIGHLIGHTS

Throughout Endurance, technologies developed in-house have been key to successful and efficient instrument upgrades involving all of our technical services. These include the production of monochromators, supermirrors, ^{3}He technologies for neutron polarisation, detectors, sample environment, neutron infrastructure installation and maintenance, electronics, instrument control and data treatment. In-house developed technologies and capabilities will continue to form the backbone of post-Endurance maintenance and upgrades ensuring the ILL instrument suite remains world leading.

Installation of the new Trench Multi-Wire Proportional Counter (TMWPC) detector on D20c.



Mosaic bent silicon crystals to form assemblies for the MARMOT analysers.

As world leader in neutron technologies, the ILL supports the other neutron centres in Europe, in particular the European Spallation Source (ESS). Early in 2024, a collaboration agreement was signed between the ILL and the ESS for the supply of a TYREX station for the production of polarised Helium-3.

In July 2024, another agreement was signed between the ILL and the ESS for ILL to manufacture the detector for the CSPEC instrument at the ESS. The kick off meeting was held on 16-17 October at the ESS, and nine people from the ILL Detectors R&D service staff travelled to Lund to meet with the local team in charge of the CSPEC. The group photo was taken during the visit to the experimental hall at ESS.

Similar to those of the ILL instruments IN5 and PANTHER but slightly bigger, this Helium-3 detector will be made up of 12 multitube modules, plus a spare module, each comprising 32 tubes at a length of 3.5 m long. Each module will be tested and manufactured at the ILL, delivered to the ESS by the end of 2027, and then filled with the detection gas before installation on the instrument. The agreement includes also the training of ESS staff.

SUPPORT LABORATORIES

In order to maintain their ranking at an international level, European research infrastructures must optimise their resources and develop synergies at every level. 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 space and equipment to prepare and characterise samples before, during and after neutron experiments. They are available to the user community and empower in-house research. Over the years, we have established close collaborations with neighbouring institutes and launched a number of successful scientific and support partnerships, such as the Partnerships for Soft Condensed Matter (PSCM) since 2012, and for Structural Biology (PSB) since 2002. Within these partnerships, dedicated platforms and laboratories: the Deuteration (D)-Lab and Lipid (L)-Labs provide the ILL user community with a variety of deuterated biological molecules, including proteins and lipids. These activities are now grouped together in the BDCS (Biology, Deuteration, Chemistry and Soft Matter) group, headed by Frank Gabel.

The year 2024 has seen a rich variety of activities in the BDCS group:

Move of the D-Lab

Several lab spaces and multiple equipment were transferred from the EMBL to the CIBB building, regrouping now a total lab surface of 300 m^2, dedicated to the production of tailor-made deuterated samples for the neutron user community, and for the development of new protocols via scientific collaborations. The group's crystallography room has been completely refurbished. Specialized equipment in the D-Lab includes fermentors, HPTLC, photobioreactors, and a peptide synthesizer.

New synergies between the D- and L-Labs

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

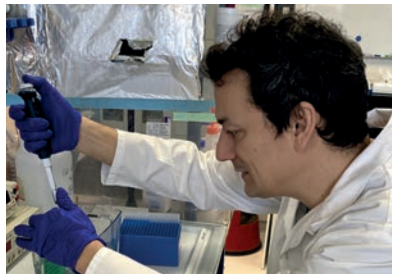
Further, the L-Lab has been working on developing novel chromatographic approaches for the separation of a wide range of neutral lipids, glycosylated lipids and lipopolysaccharides. In this way the L-Lab will be in a position to continuously offer its services through providing users with novel labeled biomolecules for their neutron experiments.

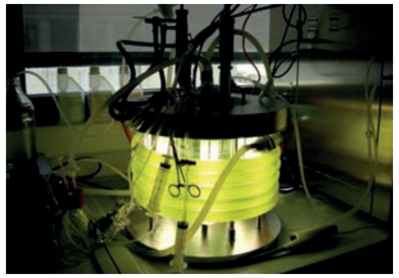
A vibrant user activity in the chemistry and PSCM-Labs

In 2024, the chemistry and soft matter support laboratories remained indispensable to the ILL neutron scattering user community, providing vital expertise, infrastructure, and instrumentation. Approximately 250 experiments benefited from the chemistry laboratories, while 55 studies utilized at least one of the ~30 instruments available at the PSCM—underscoring the laboratories' crucial role in supporting cutting-edge research at the ILL.

Scientific collaborations, outreach and training

Apart from the user support, BDCS staff are equally involved in multiple scientific collaborations and in the supervision of PhD projects, including the development of novel deuteration protocols at the D-Lab, and exploring the complexity of lipid compositions in cellular membranes at the L-Lab (Horizon EU CLIMB Grant).



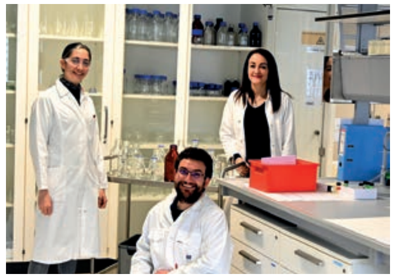
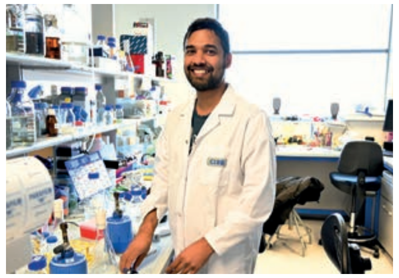


The BDCS group was also involved in the organization of a number of scientific events in 2024: the PSCM User Meeting (March 4-6), a PSB Spotlight on Neutrons in Biology (June 28), and an EMBO practical course on SAXS/SANS on biomacromolecules in solution (September 16-20).

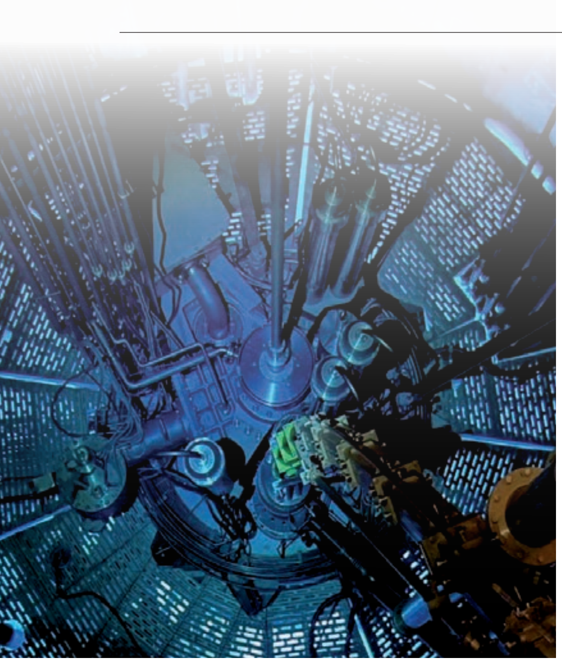
Finally, the BDCS staff is regularly participating in teaching and training activities, including the European HERCULES school, the Advanced Isotope Labeling Methods (AILM) symposium, and university courses at Grenoble Alpes University (UGA).

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


REACTOR



TWO
CYCLES AND
105
DAYS OF
OPERATION
IN **2024**

~50.0 MW

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

A SINGLE
HIGHLY
ENRICHED
URANIUM
FUEL ELEMENT

REACTOR OPERATIONS

The reactor delivered two cycles during the first half of the year with a high level of availability (98%), allowing the scientific programme to be carried out as planned. The first cycle began as scheduled with the start-up of the reactor on 27 February 2024, which was completed on 16 April. The second cycle started as planned on 14 May, and the reactor has been shut down since 9 July to carry out long shutdown work, mainly involving the refurbishment of the polar crane, reinforcement of the H1-H2 casemate and installation of fire protection sprinklers.

Following the H1-H2 long shutdown in 2021/2022, the reactor schedule for the period 2024–2026 has been organised around continuing implementation of safety commitments from the last ten-year safety review, requiring long shutdowns in order to do so, and delivering reactor operating periods for the ILL's scientific programme.

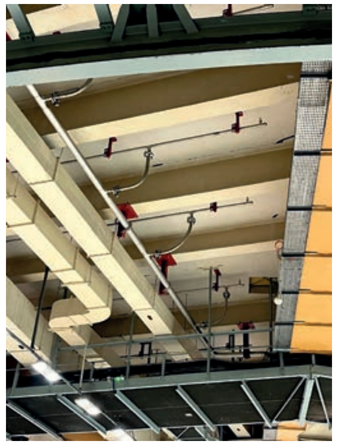
Within this framework, the ILL has planned two major long shutdowns for this work, whilst ensuring that a maximum number of beam days are delivered for science. Over the past few years, the ILL has been producing radioisotopes, in particular lutetium-177, which is highly effective in treating certain types of cancer.

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 January 2024.

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 2025.

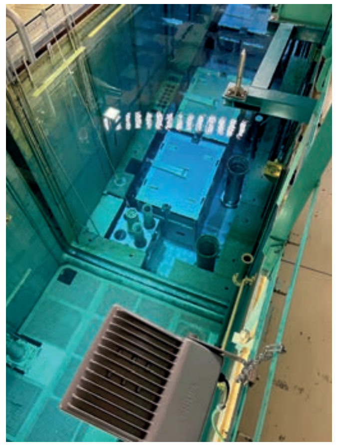
The main activities carried out by the Reactor Division during the inter-cycle shutdowns in 2024–2025 were as follows:

- Maintenance work and periodic testing
- Reinforcement of the polar crane on Level D and preparation for the replacement of the trolley
- Continued work on the clean-up of the detritiation facility by removing certain components/equipment in order to prepare the facility for the installation of a recombiner unit. The purpose of this unit will be to recombine the tritium and deuterium with oxygen at very low concentration to produce heavy water for the primary circuit.

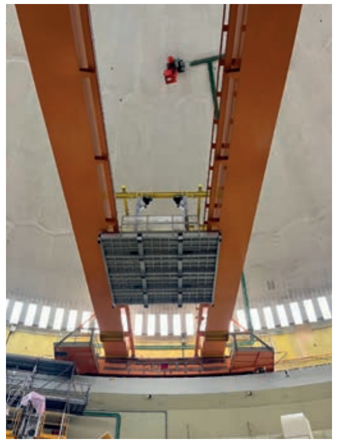


Sprinklers on Level C.

Reinforcement of the H1-H2 casemate on Level C.



Preparatory work for the reinforcement of the pipe support structures in transfer canal no. 2.



Refurbishment of the polar crane on Level D and replacement of the trolley.

- Continued work on the fire sprinkler system (installation of the fire sprinklers on Level C and the water tank in building ILL52)
- Preparation for the reinforcement of pipe support structures located at the bottom of transfer canal no. 2 by divers.
- Reinforcement of the H1-H2 casemates to protect the reactor building penetrations.

Concerning the fuel cycle for the scenario based on the end of reactor operation in 2033, the Associates recently approved a commitment to the fuel conversion programme with the irradiation of the First-Of-A-Kind (FOAK) element in 2029 and conversion of the reactor to LEU by the end of 2032. Within this framework, the ILL is continuing its participation in the HERACLES programme and in the new European "EU-CONVERSION" project. The ILL has optimised the scope of the conversion programme by focusing on the performance of the neutron flux supplying the experiments and maximising the number of beam days per cycle.

Moreover, as part of preparations for the upcoming long reactor shutdowns in 2025 and 2026, the Reactor Division has:

- finalised the work on the clean-up of the detritiation facility by removing certain components/equipment in order to prepare the facility for the installation of a recombiner unit. The purpose of this unit will be to recombine the tritium and deuterium with oxygen at very low concentration, in order to produce heavy water for the primary circuit.
- prepared the reinforcement of the crane on Level C
- replaced the H13 beam tube and reinforced its casemate
- installed supports for the fuel cask temporary storage and PUC "fuel element emergency drop" system, in transfer canal no. 2
- reinforced the pipe support in transfer canals nos. 1 and 3
- prepared the reinforcement of the H5 casemate to protect the reactor building penetrations.

Jérôme Estrade
Head of the Reactor Division

RADIONUCLIDES: FROM ZERO TO HUNDRED FOR MEDICINE AND RESEARCH

Nature provides us with about 250 stable nuclides that are belonging to 80 different chemical elements ranging from hydrogen (proton number Z=1) to lead (Z=82). In addition, over 3000 radioactive nuclides are known so far. Most of the latter are not naturally available, but have to be produced artificially in nuclear reactions, a process called transmutation.

For this purpose, target nuclides are bombarded with neutral or charged particles. When an incident particle is absorbed, the nucleus may emit other particles or radiation and form a new product nuclide. Thermal neutrons are particularly efficient for this process and high activities can be produced by thermal neutron capture in a high flux reactor. This technique is regularly applied in ILL's V4 high flux position, that provides by far the highest neutron flux among all reactors in Europe.

Today, the dominant application is large-scale production of lutetium-177, ^{177}Lu, the "gold standard" in targeted radionuclide therapy, where this radionuclide is coupled to a biomolecule capable of seeking specifically certain species of cancer cells. After administration to the patient, the radioactive compound will be internalised by a cancer cell or bind to its surface. Electrons emitted by decaying ^{177}Lu can destroy this and adjacent cancer cells.

In the very lively field of targeted radionuclide therapies, new molecules are regularly coming into clinical use. In 2024, the company *Curium* reported successful results of their *ECLIPSE* trial treating metastasized prostate cancer with the compound ^{177}Lu-PSMA-I&T. To ramp up production of this new radiopharmaceutical, *Curium* signed a partnership agreement with ILL to perform irradiations of stable ^{176}Yb generating ^{177}Lu.

While certain radionuclides are already in clinical routine, other "emerging" radionuclides produced at ILL are used for fundamental or applied research in medicine, radiobiology, radiochemistry, nuclear physics or atomic physics. After irradiation, the produced radionuclides need to be separated from remaining target material and other co-produced radionuclides by radiochemical separation and/or electromagnetic mass separation. Such processing is not performed at ILL, but at collaborating laboratories in ILL's member states.

Emerging radionuclides for medical research are made available to the user community via the EU project *PRISMAP** (http://prismap.eu), while R&D towards upscaling the production of certain emerging medical radionuclides is being performed in the frame of the EU project *SECURE***.

SEVERAL

1 000

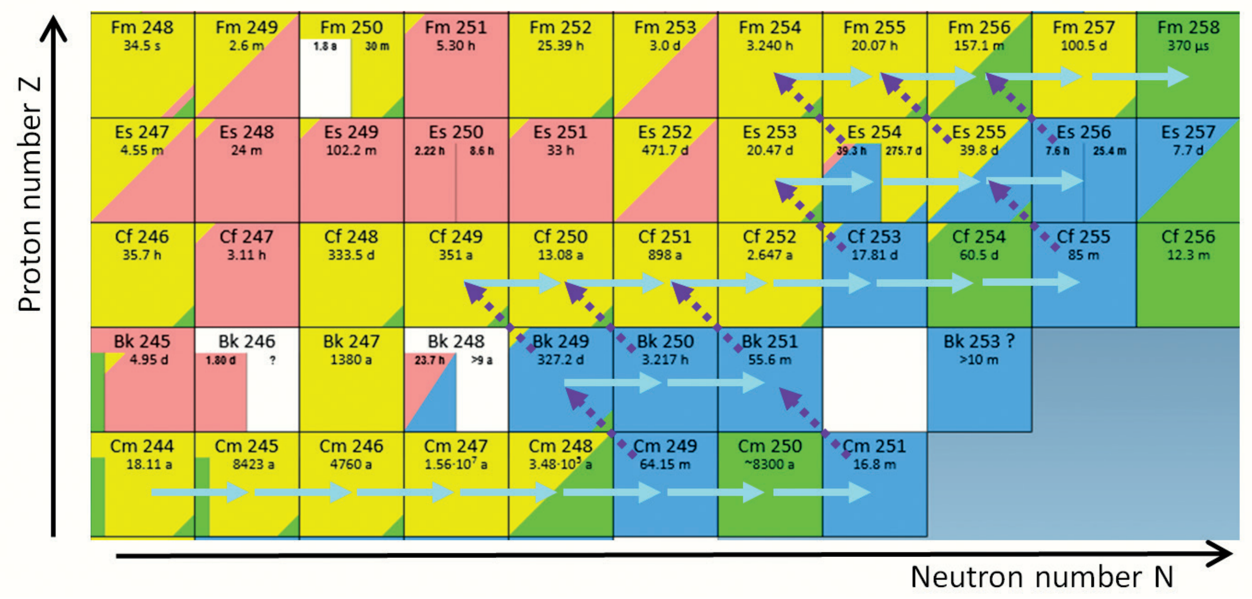
radiotherapy cancer treatment

doses delivered per week

during reactor cycles

While nuclear transmutation may transform stable targets into radioactive products, also radioactive targets can undergo further transmutations. The production of fermium may serve as textbook example: curium (Z=96) isotopes retrieved from spent fuel elements of power reactors had been irradiated in the HFIR (High Flux Isotope Reactor) at Oak Ridge National Laboratory, TN, USA. During long irradiations, a chain of neutron captures and beta decays lead to heavier nuclides and heavier elements (higher Z), namely berkelium, californium, einsteinium and fermium. From this mixture of produced elements, radiochemists at Mainz University extracted the einsteinium (Z=99) fraction, mainly consisting of the isotope ^{254}Es, that was then irradiated at ILL to produce ^{255}Es, with 40 days half-life. This keeps decaying to ^{255}Fm, with only 20-hours half-life. The latter was repeatedly radio-chemically extracted at Mainz University, radiochemists call this process "milking" a fermium cow. The so-produced ^{255}Fm served for high-resolution laser spectroscopy, enabling to extract trends of atomic radii of fermium isotopes [*Jessica Warbinek et al., Nature 634 (2024) 1075. https://doi.org/10.1038/s41586-024-08062-z*].

Interestingly these elements' names are well-deserved eponyms for the production process: the famous $E=mc^2$ relation by Albert Einstein is the foundation of energy generation in nuclear reactors; Enrico Fermi is the creator of the first human-made nuclear reactor, and the heaviest element directly reachable by thermal neutron (Z=0) capture in nuclear reactors is fermium (Z=100).



Excerpt from the Karlsruhe Chart of Nuclides. Thermal neutron captures (blue arrows to the right) form heavier isotopes of the same element. Beta-minus decays (violet arrows upwards to the left) transform a neutron into a proton, leading to a nuclide of a heavier element. Combination of both processes can form heavier nuclides of heavier elements. Alpha decays (yellow) and spontaneous fission (green) generate products with lower mass, i.e. are counter-productive to reach heavier masses. Therefore the heaviest element that can be generated by neutron (Z=0) captures is fermium (Z=100).

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* This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008571.

** Funded by the European Union under grant agreement 101061230.

MORE THAN SIMPLY NEUTRONS

INDUSTRY

2024 saw the Industrial Liaison Unit (ILU) prepare its new strategy. The strategy was developed over a period of six months and was presented to the ILL's Management Board in early September and since then, it has been shared more broadly, including with ILL scientists. The ILU strategy is fully aligned with and supports the ILL's Science Strategy, which provides focal points in thematic areas, like clean energy, and techniques, like neutron imaging for developing industry involvement.

The strategy is described in detail in a 26-page document, presenting a coherent vision for how the ILU will increase industry use of ILL via all access routes. It builds upon successful activities that have been developed over the years, combining these with new actions to drive efforts in specific areas. At the heart of the new strategy is impact, and the clear link between industry use of ILL and impact generation. It recognises that research with industry has the potential to generate scientific, innovation and socio-economic impact that is associated with technology development and product development at higher Technology Readiness Levels (TRLs).

The new strategy is data driven and combines data from a variety of different sources. The data reveals exactly how industry benefits from ILL whilst helping to identify the obstacles preventing access. Four new Key Performance Indicators (KPIs) have been established alongside an array of other metrics to measure the success of new outreach activities and track progress towards the ILU's strategic objectives: promote direct industry use via all access routes; promote collaborations between academic users and industry; and communicate the value of working with industry.

This data-driven approach has already revealed some interesting insights, such as the important role that our academic partners play in supporting industry access through the user programme and how, by extension, Research Infrastructures can add value in collaborations between universities and industry. Meanwhile, viewing industry use of ILL through the lens of impact generation shows that, whilst the majority of ILL experiments involving industry have taken place on SANS instruments, nearly all ILL instruments play a role. This challenges the conventional view that activities with industry tend to be confined to just a handful of instruments and demonstrates the potential for growing industry access across the entire instrument suite.

As a final note, developing the new strategy has required the ILU to build up a breadth of knowledge around the impact of Research Infrastructures. This knowledge, and the associated data on industry use of ILL, will put the ILL in a stronger position to articulate its value to society.

38 Experiments involving industry

77 Experiments with industrial relevance

40 Publications with industrial co-authors

EUROPEAN COLLABORATIONS

ILL has a long-standing history of involvement in EU-funded research projects, having participated in 35 projects in the previous H2020 and the current Horizon Europe Framework Programmes for research and innovation, with EU contributions of 21.4 M€ since 2014.

While strengthening its strategic position in the European research landscape throughout 2024, the Institute has maintained a dynamic project portfolio with 21 ongoing EU-funded projects, with annual revenue of about 800 k€. 2024 saw the successful completion of 4 projects, the start of 5 new projects and the submission of 11 new project proposals, demonstrating ILL's continuous engagement in cutting-edge research and innovation.

The Institute maintains strong connections with other European large-scale research infrastructures through EU-funded projects, with numerous ongoing collaborations with CERN, ESRF, ESS, ISIS (UKRI), and PSI. Its networking and collaborative capacity is demonstrated by partnerships across Europe, including projects coordinated by institutes in France (7), Germany (3), Denmark (2), Poland (2), Belgium (1), Greece (1), and Sweden (1), as well as 4 projects coordinated by CERN. The networks of projects span EU Member States, countries associated with Horizon Europe, and non-EU nations. For example, the CACTUS project fosters collaboration between European and South American research infrastructures.

Projects encompassed diverse research domains such as materials science (EASI-STRESS, CACTUS), the circular economy (REMADE@ARI), radioisotopes for health (PRISMAP, SECURE), batteries for clean energy (BIG-MAP, SEATBELT), as well as conversion of European research reactors to low-enriched uranium fuels (EU-CONVERSION).

Several Marie Skłodowska-Curie Actions (MSCA) COFUND projects contributed to funding PhD and postdoctoral positions. Through INNOVAXN and DESTINY, ILL supported 14 early-career researchers in 2024. Looking ahead, the AMBER and NEXTSTEP programmes will enable ILL to welcome 12 additional researchers in 2025.

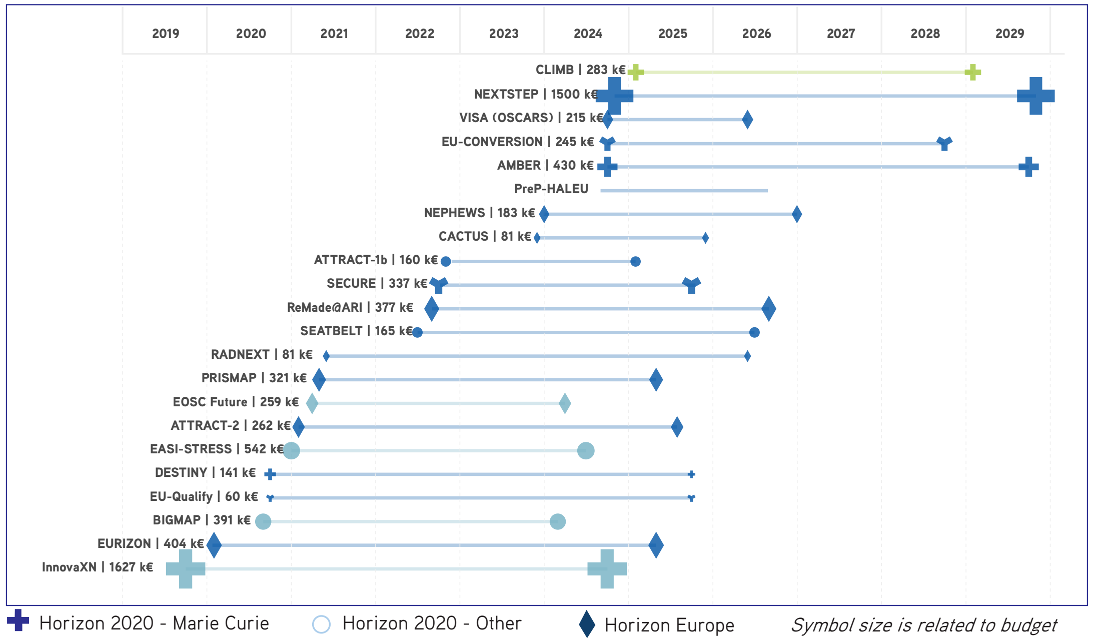
The Institute's commitment to expanding research accessibility was exemplified through participation in several Trans-National Access initiatives:

- PRISMAP enhances access to radionuclide production facilities
- RADNEXT provides opportunities for electronics components and system irradiation
- NEPHEWS focuses on engaging new user communities
- OSCARS improves VISA's functionality, enhancing the virtual scientific analysis infrastructure

Concerning the prestigious ERC grants, ILL has identified 42 projects using the ILL since 2007, with most projects falling in three domains: fundamental constituents of matter, condensed matter physics, and synthetic chemistry and materials. ILL staff will submit three (consolidator, advanced and synergy) ERC projects this year.

Throughout the year, the European Office, operating under the umbrella of the Partnerships and Communication Service (PACS), supported these proposals and project administration, ensuring alignment with the Institute's strategic objectives.

For inquiries about EU projects at ILL or future collaboration opportunities, please contact europe@ill.eu.



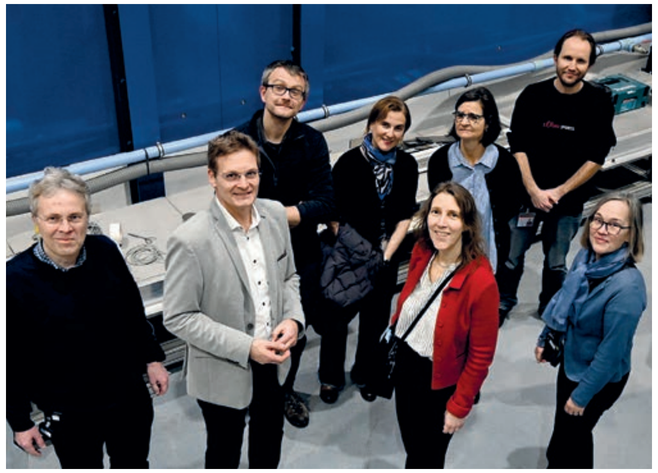
WORKSHOPS & EVENTS

The ILL-ESS User Meeting 2024 brought together experts, researchers, and users from across the globe to celebrate collaboration and scientific progress.

Celebrating the completion of Endurance on 27 November 2024 in the presence of representatives of the ILL Associate Countries – France, Germany and the United Kingdom – and of several ILL Scientific Member Countries, European neutron facilities and key partner institutions.

On the occasion of the meeting in Grenoble of the users of the two largest European research infrastructures dedicated to neutrons, the ILL invited the general public to attend a conference in French at Minatec, entitled "La science des neutrons au service de notre avenir" (Neutron science supporting our future).

Prof. Martina Hirayama, Swiss State Secretary for Education, Research and Innovation during the signing of the agreement to renew Switzerland's Scientific Membership of the ILL. During 2024, 10 countries signed similar agreements.



On 11 February 2025, the ILL was honoured to welcome the highest representatives of Germany in France from the General Consulate of Germany in Lyon, General Consul Jessica Engel and Consul Ulrike Johag. The visitors were hosted by ILL's German Associate Director Andreas Meyer.

HERCULES school practicals.

PhD clip session.

ILL - ESRF Summer school.

EUCYS student visit.

33 **SCIENTIFIC EVENTS** AND **VIP** VISITS

45 GENERAL SEMINARS

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)

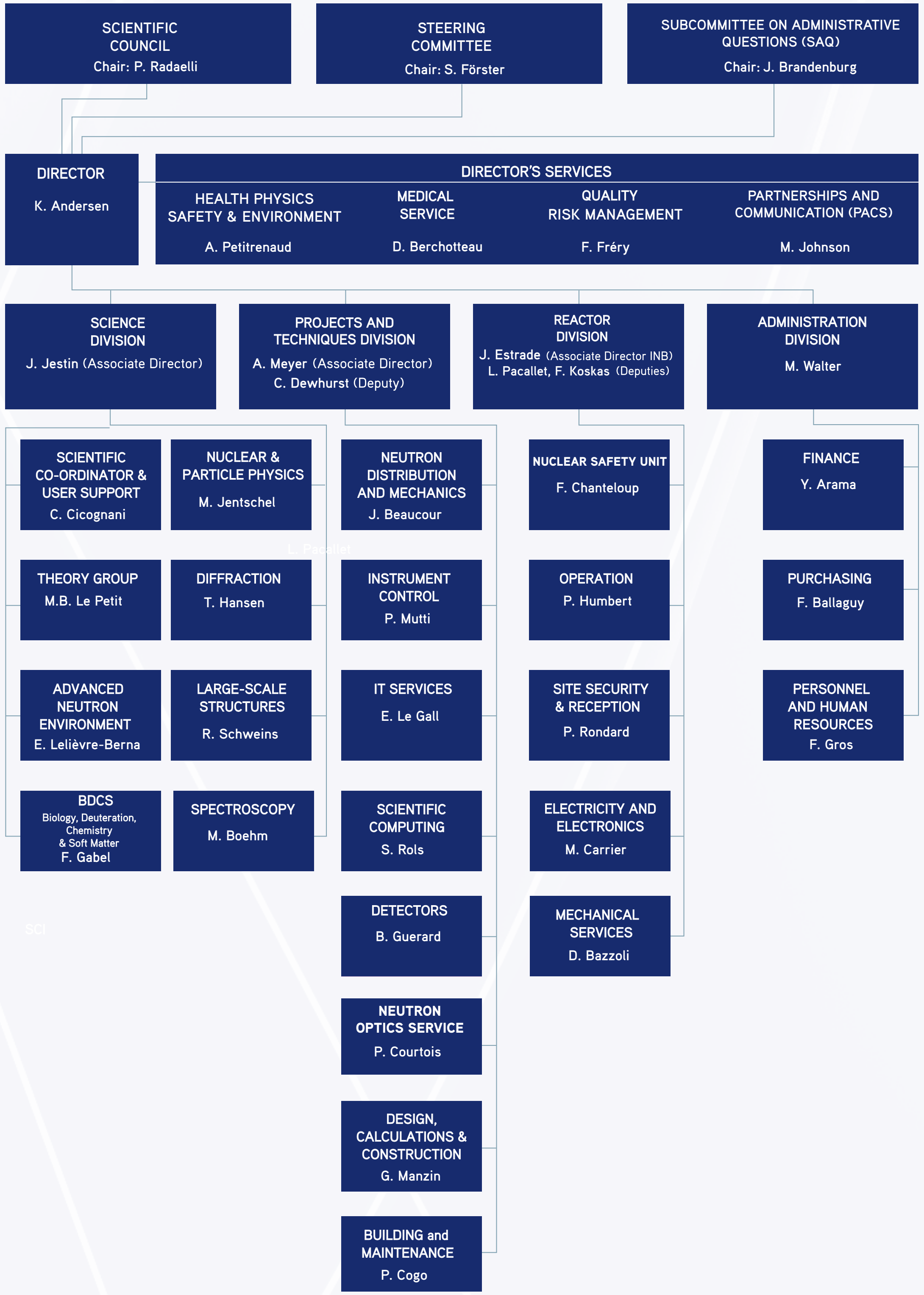
Countries with Scientific Membership

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

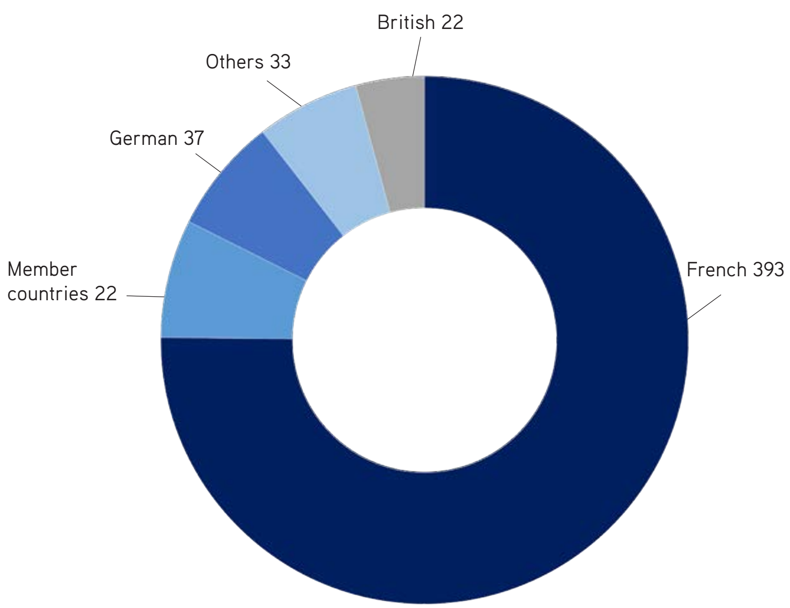
Applied materials science, instrumentation and techniques
Monica Ceretti (University of Montpellier, FR)
Anna Fedrigo
Nuclear and particle physics
Martin Fertl (Johannes Gutenberg universty Mainz, DE)
Hanno Filter
Magnetic excitations
Rasmus Toft Petersen (Technical University of Denmark, DK)
Lucile Mangin-Thro
Crystallography
Nicolas Barrier (CRISMAT/ENSI Caen, FR)
Nebil Ayape Katcho
Magnetic structures
Fabio Orlandi (ISIS, UK)
Iurii Kibalin
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)
Monica Jimenez Ruiz
Structure and dynamics of biological systems
Jian Ren Lu (University of Manchester, UK)
Lukas Gajdos
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



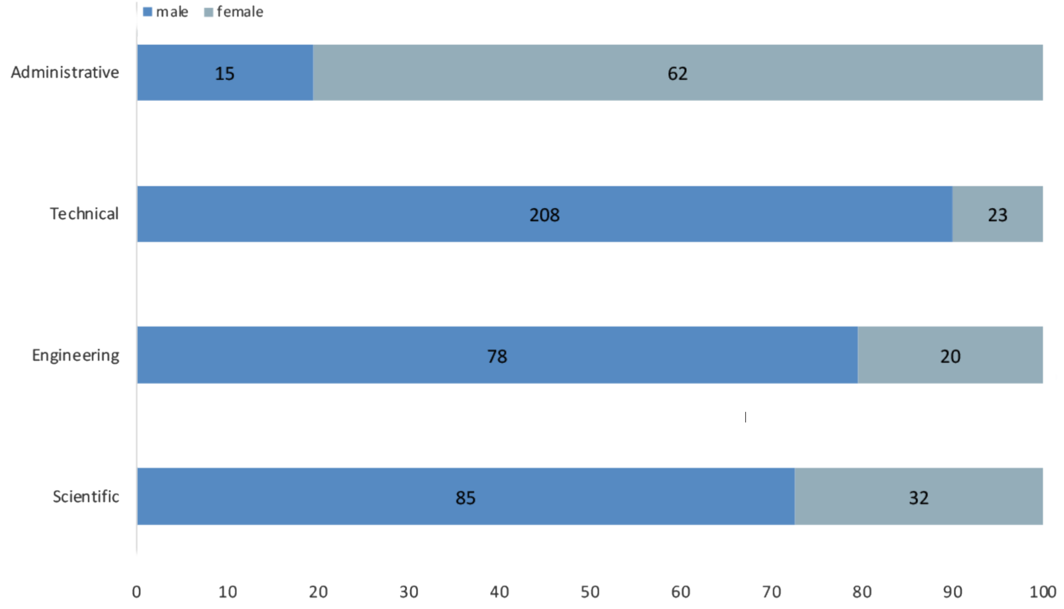
STAFF & BUDGET

523 members of staff
of **25** different nationalities

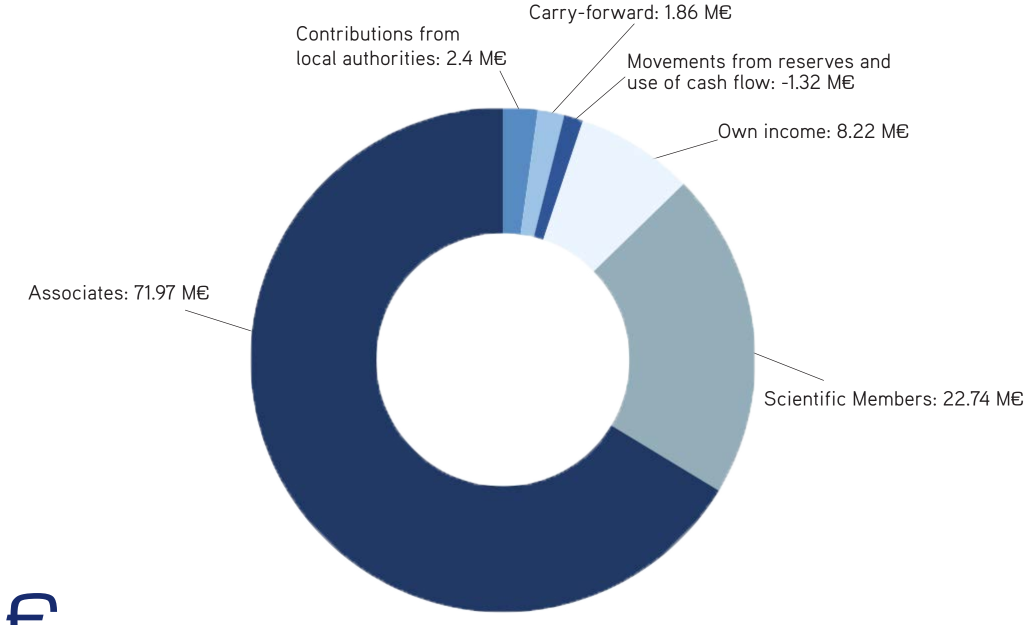
Distribution of staff by nationality - 31 December 2024



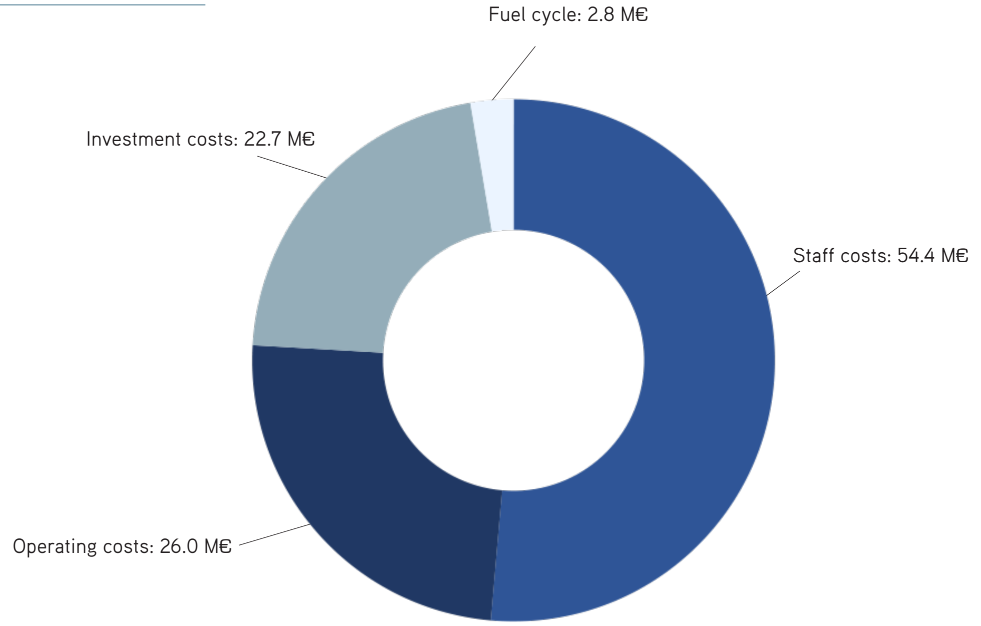
2024 gender balance per area of activity
Total share of women: 26%



Operating budget 2024: 105.858 M€ (excluding taxes)
The ILL's Associate countries contributed some 72 M€ to the Institute in 2024, a sum enhanced by significant contributions from the ILL's Scientific Member countries.



106 M€
Annual income
70% from the Associates
22% from the Scientific Member countries



2024 Expenditure

USER PROGRAMME STATISTICS

In this section we give the key numbers from the November 2023 and April 2024 proposal rounds, which corresponds to the experiments scheduled in 2024.

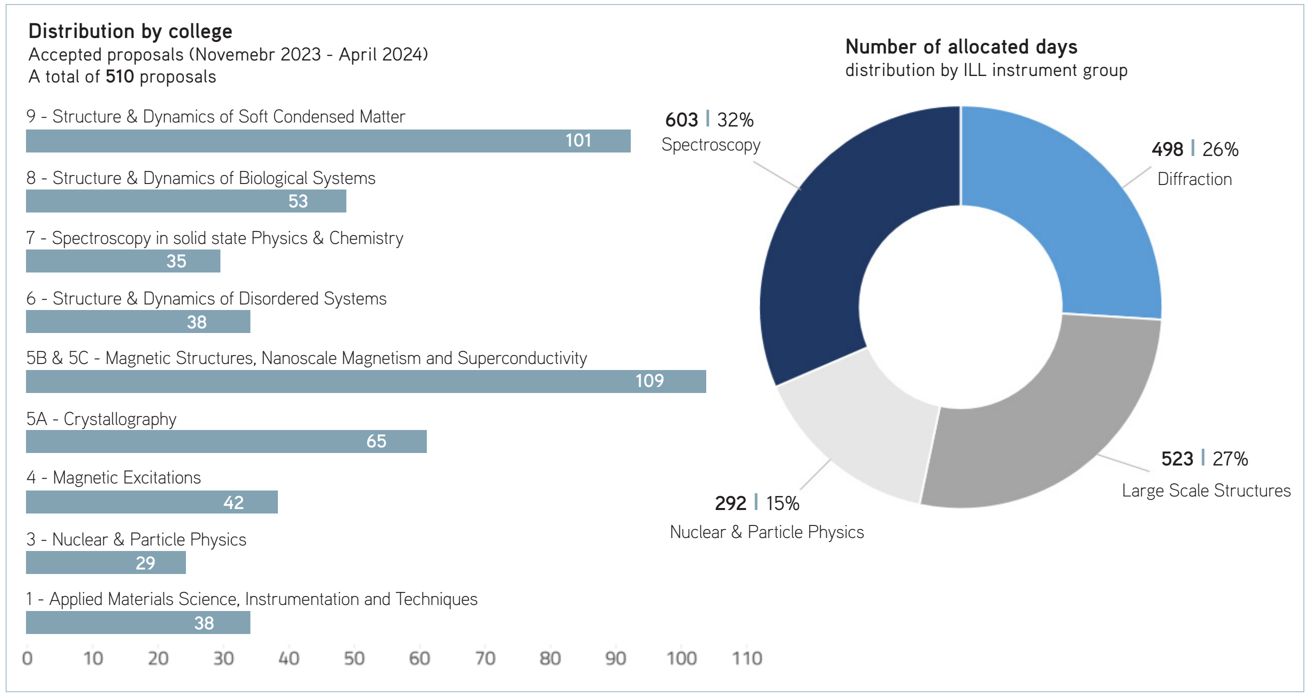
ILL INSTRUMENTS		DAYS REQUESTED	DAYS ALLOCATED	NUMBER OF ACCEPTED EXPERIMENTS
D2B	powder diffractometer	124	77	47
D3	single crystal diffractometer	168	37	8
D4 (50% with IN1-LAGRANGE)	liquid diffractometer	96	34	12
D007*	diffuse-scattering spectrometer			
D9	single crystal diffractometer	174	38	7
D10^{+}	single crystal diffractometer	195	81	15
D11*	small-angle scattering diffractometer	18	16	11
D16	small momentum-transfer diffractometer	105	65	16
D17	vertical reflectometer	187	62	20
D20	powder diffractometer	260	85	43
D22	small-angle scattering diffractometer	235	67	46
D33	small-angle scattering diffractometer	177	75	30
DALI	quasi-laue diffractometer for biological macromolecules	49	35	3
FIGARO	horizontal reflectometer	169	71	29
FIPPS	fission product prompt gamma-ray spectrometer	188	45	5
IN5	time-of-flight spectrometer	324	74	27
IN8	three-axis spectrometer	205	41	9
IN15	spin-echo spectrometer	161	73	13
IN16B	backscattering spectrometer	234	81	27
IN20	three-axis spectrometer	133	61	9
LADI	Laue diffractometer	89	55	5
Lagrange (50% WITH D4)	neutron vibrational spectrometer	121	29	11
PANTHER*	time-of-flight spectrometer			
PF1B	neutron beam for fundamental physics	92	64	5
PF2	ultracold neutron source for fundamental physics	73	62	9
PN1	fission product mass-spectrometer	176	96	8
SALSA	strain analyser for engineering application	143	41	11
ThALES	three-axis spectrometer	204	93	17
WASP	wide-angle spin-echo spectrometer	140	68	16

* under commissioning

Note: D3, D9 and IN8 operated for 50% of the time from 2024.
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	62	40	21
D23 - CRG-B	single crystal diffractometer	69	27	7
IN12 - CRG-B	three-axis spectrometer	69	30	6
IN13^{+} - CRG-A	backscattering spectrometer	65	29	6
IN22 - CRG-B	three-axis spectrometer	105	24	3
SAM - CRG-B *	small-angle scattering diffractometer			
SHARPER- CRG-A *	time-of-flight spectrometer			
SuperADAM - CRG-B	reflectometer	92	33	6
S18 - CRG-B	interferometer	66	25	3
XtremeD - CRG-B	powder diffractometer	104	38	12
JOINTLY FUNDED INSTRUMENTS				
NeXT 75%	imaging instrument operated with Ni-Matters composed of HZB, UGA and ILL	263	44	19
TOTAL ALL INSTRUMENTS		**5135**	**1916**	**542**

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

Institut Laue Langevin
71 avenue des Martyrs, CS 20156
F-38042 Grenoble Cedex 09

communication@ill.eu
www.ill.eu

design: Virginie Guerard
Photos: ILL's staff members and L. Thion.