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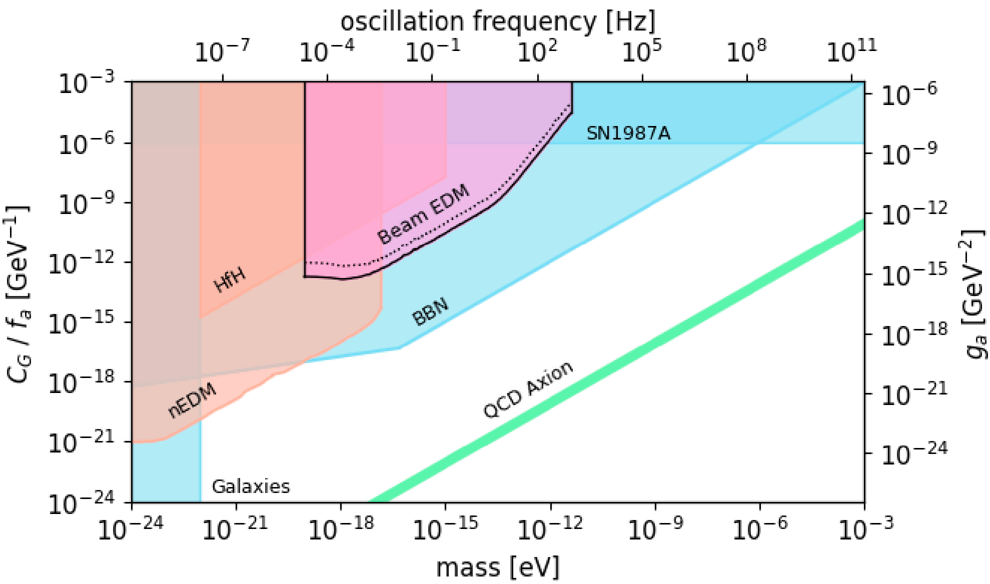

Schweizerische Gesellschaft für Neutronenforschung
Société Suisse de la Science Neutronique
Swiss Neutron Science Society

On the cover

The existence of axion-like particles (ALP) was investigated with a cold neutron beam at the EDM apparatus. The limits on the ALP-gluon coupling are shown as a function of the mass and frequency. The shaded areas are exclusion regions from cosmology and astrophysical observations (blue) and laboratory experiments (orange). The black outlines with the pink area mark the exclusion region obtained from the discussed work (labelled Beam EDM). The green line indicates the region where the axion would solve the unsolved "strong CP problem" of quantum chromodynamics (QCD) in particle physics.

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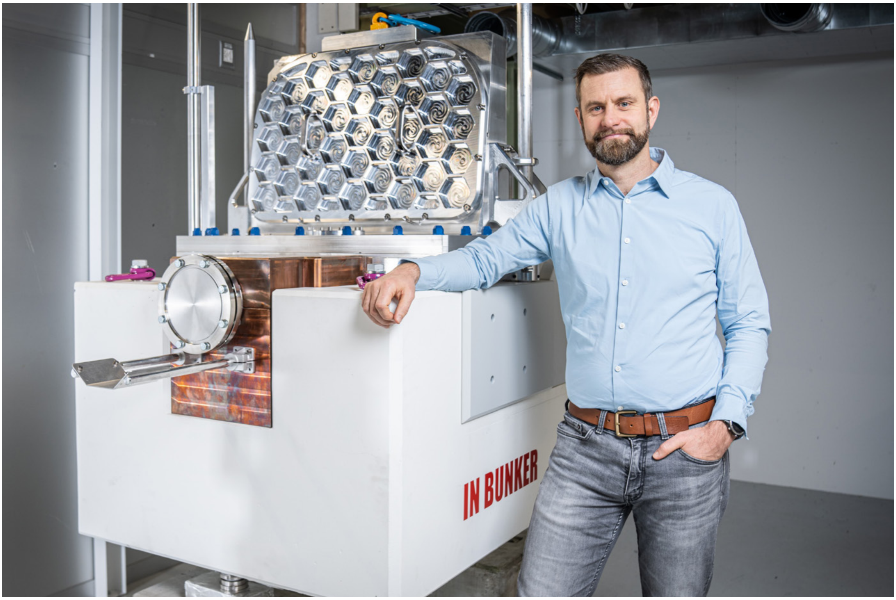


Dear fellow neutron scientists,

I want to start by expressing my extreme gratitude to three board members that have left the executive board of our society at the end of last year. Urs Gasser (PSI), Karl Krämer (University of Bern) and Henrik Ronnow (EPFL) are looking back on very long periods of service to the Swiss neutron science community. Urs has served as the secretary since 2009 and additionally oversaw editing and publishing the Swiss Neutron News for an extended period. Karl has served as auditor from 2004 to 2018 and has been on the board since 2019. Henrik has been a board member from 2009 to 2023 and was our president from 2009 to 2021. Taken together, they have formed the backbone supporting our society's progress over a period extending well beyond a decade. Please join me in thanking them for their monumental efforts. At the last general assembly on November 23, 2023, we confirmed two new colleagues to join the executive board: Fanni Juranyi and Romain Sibille (both from PSI). They are introduced with brief bios on page 6. Please note that currently, we have one vacant seat on the executive board and are looking for additional members willing to lead the society. Please contact me if you are interested in this opportunity.

I would also like to inform you that our society has been tasked by the Swiss Academy of Sciences (SCNAT) to provide an update of the Neutron Science Roadmap that was published 2021. SCNAT has received a formal mandate from the State Secretariat for Education, Research and Innovation (SERI) to work with all stakeholders to update existing scientific community roadmaps. Naturally this update of our roadmap is a crucial activity for SNSS as SERI, for example, funds the Swiss membership at the Institute Laue Langevin and at the European Spallation Source, and therefore guarantees access of Swiss neutron scientist to these European flagship facilities. The executive board has already started working on this update, which will need to be finalized in December of this year. It is important that all of us engage in this process, and we invite you to read and review the existing roadmap (https://dx.doi.org/10.5281/zenodo.4637660) and send us your feedback including your needs towards facilities and projects that will allow you to continue to do state-of-the-art research with neutrons. Your feedback can be sent to sgn@psi.ch (Please include the subject "Roadmap Update"). At our next general assembly which will take place on May 27 at 15:00 in the auditorium of PSI, we will provide some more information on the timeline of the roadmap.

This also brings me to highlighting some changes that we are enacting this year. Typically, our general assembly took place towards the end of the year. As you noticed, the general assembly this year takes place much earlier. The executive board decided to move the general assembly out of the busy end-of-year period and hopefully allow more members to join. An additional benefit is that the general assembly will now take place while the Swiss neutron sources SINQ and UCN are not running, which should allow the instrument scientist to join the assembly more easily. In addition, we decided at our last general assembly to modernize and update our webpage and logo. This project is making good progress, and we hope that we will be to go live with both soon.

Finally, you will find two articles describing recent breakthroughs of Swiss neutron science in this issue of Swiss Neutron News. Elisabetta Nocerino's article reports on using neutrons to study multifunctional quantum materials and Ivo Schulthess describes his search for dark matter. Both shared last year's SNSS Young Scientist price for their PhD work. In this context, I would like to highlight that the winner of the 2024 edition of the Young Scientist price that is kindly supported by SwissNeutronics will be announced at the general assembly and May. The winner will also be invited to give an award lecture at the award session of the annual meeting of the Swiss Physical Society, which takes place at ETH Zurich from September 9-13, 2024. At the same meeting, we have also organized the traditional Neutron Science session.

I hope to see many of you either at the next general assembly in May at PSI or at the Neutron Science Session in September at Zurich!

Marc Janoschek

New board Members

Fanni Juranyi

Fanni Juranyi studied physics at the Eötvös Loránd University (Hungary) and received her doctorates by the TU Chemnitz (Germany). Since 2001, she works as instrument scientist at PSI. First at the time-of-flight spectrometer FOCUS as a PostDoc, employed by the Saarland University (Germany), followed by a PSI PostDoc at the backscattering spectrometer MARS, and later as tenured instrument scientist back at FOCUS.

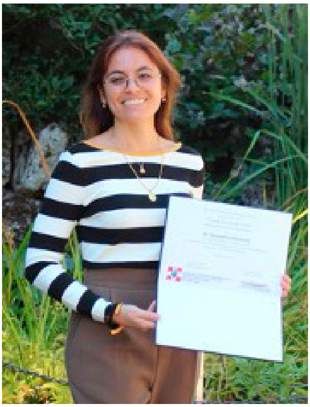
Romain Sibille

Romain Sibille studied matter sciences at the University Paris Diderot (2009) and received a doctorate from the University of Lorraine (2012) for his work on magnetic metal-organic frameworks performed at the Institut Jean Lamour. Following subsequent positions as postdoctoral researcher at the Paul Scherrer Institute (2012-2016), he is a tenured scientist at the Laboratory for Neutron Scattering & Imaging and co-responsible for the single-crystal diffractometer Zebra. He runs a research program on frustrated quantum magnets with a team of junior researchers and collaborators at PSI and abroad.

Young Scientist Prize of the Swiss Neutron Science Society (2023)

The Young Scientist Prize is awarded every year to young scientists in recognition of the impactful use of neutrons during their PhD thesis. The prize amounts to a gratification of 1000 CHF and is sponsored by SwissNeutronics.

In 2023, the prize was awarded to Dr. Elisabetta Nocerino and Dr. Ivo Schulthess.



Dr. Elisabetta Nocerino

Dr. Elisabetta Nocerino received the prize for her thesis work on "A Comprehensive Experimental Approach to Multifunctional Quantum Materials & their Physical Properties".

BIO

Elisabetta Nocerino is an Italian physicist who is currently managing her own postdoctoral project as a junior Principal Investigator at Stockholm University, Sweden. She secured funding for this collaborative research project, which is carried out between Stockholm University and PSI in Switzerland, through a competitive grant. Her work focuses on the development of new materials technologies for climate change mitigation. Elisabetta earned her PhD from the KTH-Royal Institute of Technology (Sweden), where she specialized in the advanced characterization of exotic physical properties of crystalline materials using large-scale experimental techniques. Her PhD thesis was distinguished with the Young Scientist Prize by the Swiss Neutron Science Society, recognizing her outstanding achievements in the field. Holding a Master of Science in Physics from the University of Naples Federico II (Italy), her earlier academic work focused on semiconductors physics and electronics for the development of astroparticle detectors. Before delving into the realm of physics, Elisabetta completed her education at a Liceo Classico in Italy, providing her with a strong foundation in humanities and classical studies.

Dr. Ivo Schulthess

Dr. Ivo Schulthess receives the prize for his thesis work on "Search for Axion-Like Dark Matter and Exotic Yukawa-Like Interaction".

BIO

Ivo Schulthess studied physics at the ETH Zurich and received his doctorate from the University of Bern in 2022. He worked in the "Fundamental Neutron and Precision Physics Group" led by Prof. Florian Piegsa, where he investigated the existence of axion-like dark matter using a cold neutron beam and developed a tabletop experiment that aims to measure a new exotic Yukawa-like interaction with protons in water. For this work, he received the Young Scientist price in 2023 from the Swiss Neutron Science Society, sponsored by SwissNeutronics. With his Postdoc.Mobility fellowship that he received from the SNSF, he moved to the Deutsche Elektronen-Synchrotron DESY in 2023 to work on the LUXE experiment, where he is developing new detectors to investigate QED in the strong-field regime.

How a Dark Matter Search Led to an Unexpected Discovery

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(Dated: April 18, 2024)

Abstract

New particles and gauge bosons are required to solve puzzles that the standard model of particle physics so far fails to explain. We present two searches performed in the Fundamental Neutron and Precision Physics Group of the University of Bern. Using the Beam EDM apparatus, we investigated the existence of axion-like dark matter with a cold neutron beam. Further, we built a tabletop experiment that applies nuclear magnetic resonance techniques to protons in water. We can use it to probe for a new long-range interaction between protons and neutrons.

INTRODUCTION

Despite the undoubted success of the standard model of particle physics, it fails to answer longstanding questions, such as the strong CP problem, the observed effects of dark matter, and the baryon asymmetry in our universe. Many theoretical models that try to answer those questions require new particles and gauge bosons, which must be verified or excluded experimentally. We present two low-energy particle physics experiments to search for such particles.

The first candidate is called an axion or axion-like particle (ALP). It is an ultralight pseudo-scalar particle, i.e., it has zero spin and changes the sign under parity transformation. Our experiment used Ramsey's method of separated oscillatory fields applied to a beam of cold neutrons [1, 2]. In this technique, neutrons act as a spin clock precessing with their Larmor frequency in superimposed magnetic and electric fields. We precisely measured this frequency and examined it for the slightest periodic fluctuations that the interaction with the ALPs could cause. We did not find a significant oscillating signal, but using present dark-matter models allows for constraining the existence of ALPs.

The second candidate is an axial-vector gauge boson, meaning it is a spin-1 particle and does not change the sign under parity transformation. This boson could mediate a Yukawa-like interaction in the millimeter range between standard model fermions [3]. Such interactions appear, for example, in string theory models [4]. We developed and built a dedicated tabletop experiment that also employs Ramsey's method. However, this time, the method was applied to proton spins in flowing water.

AXION-LIKE DARK MATTER

Dark matter is a postulated form of matter that is not visible but interacts via gravity. For example, its effects can be seen in the measurements of rotation curves of galaxies or the cosmic microwave background. It makes up roughly 84% of the matter content in our Universe. So far, no dark-matter model like, for instance, WIMPs or primordial black holes has been experimentally verified. Another possibility are axions and a more general class of axion-like particles that remain promising candidates. Besides being an explanation for dark matter [5, 6], they could also resolve the strong CP problem of quantum chromodynamics [7–10] and in addition serve as an explanation for the matter-antimatter asymmetry in the universe [11, 12].

The coupling of axions and ALPs to gluons is common in many theories beyond the standard model of particle physics. One consequence of this coupling is that an oscillating ALP field induces a proportionally oscillating electric dipole moment (EDM) of the neutron [13]. The parameter space of the ALP-gluon coupling is defined by their mass and their coupling constant. It is restricted by various astrophysical and cosmological constraints and has been scrutinized in three recent laboratory experiments. The CASPEr experiment is dedicated to searching for axion signals using nuclear magnetic resonance technique [14, 15]. Two other experiments search for a permanent EDM of the electron, using trapped molecular ions, and the neutron, using ultracold neutrons in a storage experiment. Both experiments found no significant oscillating signal from the nHz region up to 0.4 Hz [16, 17].

We present the results of the Beam EDM experiment, which employs a continuous cold neutron beam with intrinsic sub-ms time resolution. The experiment is ultimately intended to measure the neutron EDM in a fundamental physics experiment at the European Spallation Source ESS in Lund, Sweden [18–20]. The Beam EDM apparatus [21]

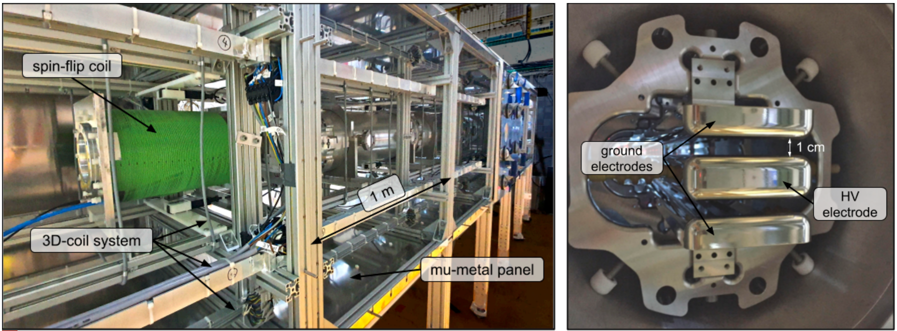


Figure 1
(left) Photo of the experimental Ramsey apparatus with the 3D-coil system to set and stabilize the magnetic field. The coils are mounted to the aluminum frame of the experiment. The mu-metal panels are mounted on top, below, and on the back side of the experiment. The panels on the front side are not mounted to access the interior. One of the two neutron spin-flip coils is visible in green on the left side. (right) Photo with the view into the vacuum beam pipe. A holding-ring structure holds the electrodes. The high-voltage electrode is in the center, and the ground electrodes are on top and bottom. The electrode separation is 1 cm.

employs two parallel beams of polarized cold neutrons, which enter a homogeneous and stabilized vertical 220 μT magnetic field. Passive magnetic shielding surrounds the entire setup. Two radio frequency spin-flip coils, one before and one after the electric field region of 3 meters in length, cause resonant 90° flips of the neutron spins. In the electric field region (35 kV/cm), the interaction of the neutrons with the ALP field would induce an oscillating EDM signal. Downstream of the setup, a neutron spin analyzer spatially separates the two spin states of each beam before they are counted in a 2D-pixel detector. Photos of the apparatus and the interior of the vacuum beam pipes with the electrodes, producing the electric field, are shown in Fig. 1.

The data we are presenting are based on a measurement performed at the Institut Laue-Langevin ILL in September 2020 [22], but the experiment was developed, commissioned, and tested at multiple beamtimes at the BOA and Narziss beamlines at the Paul Scherrer Institut. With the aforementioned precision apparatus, we continuously measured the neutron EDM over 24 hours with a sampling rate of 4 kHz, i.e., one EDM value every 0.25 ms. Besides having a significant amplitude over the background noise level, an oscillating EDM signal induced by ALPs must disappear if no electric field is present. This way, noise or spurious signals from external sources can be excluded.

To search for periodic signals induced by the ALPs, we analyzed a frequency range from 23 μHz to 1 kHz. No significant oscillating signal was found. Present dark-matter models allow for constraining the coupling of ALPs to gluons in the mass range from 10–19 to 4 × 10–12 eV, covering a mass region of almost eight orders of magnitude. Figure 2 shows our obtained exclusion graph of the coupling as a function of ALP mass and frequency, respectively [23]. The best limit of $C_G/(f_a m_a) = 2.7 \times 10^{13}\,\mathrm{GeV}^{-2}$ (95% C.L.) is reached in the mass range from 2×10^{-17} to 2×10^{-14} eV. Our experiment substantially extends the exclusion region accessible by laboratory experiments to higher frequencies. Altogether, a large part of the ALP-dark-matter parameter space could be excluded, and future EDM searches may extend this even further.

AN UNEXPECTED DISCOVERY IN THE FIRST DATA

In 2018, while performing a proof-of-principle search for axion-like dark matter at the BOA beamline at PSI, we found significantly oscillating signals in our datasets. Surprised, we set out to find the cause, which was quickly found. For our search, we required continuous data of the neutron counts and a dedicated algorithm to perform the spectral analysis. The system was optimized to be highly sensitive to periodic changes in the neutron EDM. However, as a byproduct, it was also sensitive to periodic fluctuations of the neutron flux. The discovered signal showed a clear oscillation of the neutron

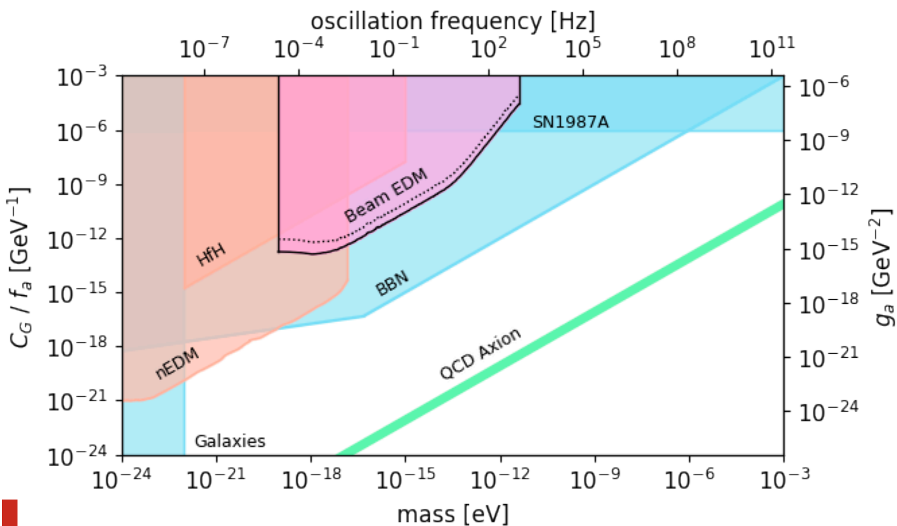


Figure 2
Limits on the ALP-gluon coupling are shown as a function of the mass or frequency as published in PRL [23]. The shaded areas are exclusion regions from cosmology and astrophysical observations (blue) and laboratory experiments (orange). The black outlines with the pink area mark the exclusion region of our work (labeled Beam EDM). The green line indicates where the axion would solve the strong CP problem of quantum chromodynamics (QCD).

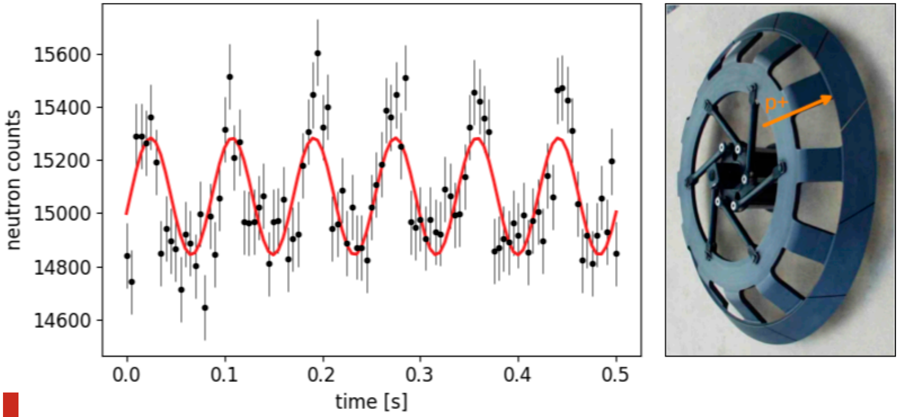
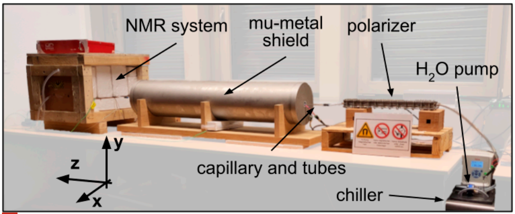


Figure 3
(left) Neutron counts at BOA for a short snippet of half a second with a sampling period of 5 ms. The red line corresponds to a sinusoidal least-squares fit, yielding a frequency of (12.01 ± 0.08) Hz. (right) Image of PSI's target E from reference [24], where the 12 diagonal slits are visible. The target is rotating with a frequency of 1 Hz. The protons pass the target as indicated by the orange arrow.

intensity at PSI's BOA beamline at roughly 1 Hz and 12 Hz. After further testing at the Narziss beamline, we confirmed that this oscillation is an actual characteristic of the PSI facility: After the acceleration in the high-intensity proton accelerator (HIPA), the protons hit the two graphite targets of the Swiss Muon Source (SμS) for muon and pion production. The second one, called target E, has 12 diagonal slits in the version that was mounted in 2018 [24]. The slits are designed to compensate for the thermal expansion due to the energy deposit of the proton beam. However, they also modulate the intensity of the remaining proton beam after the target. This beam is guided to the SINQ target, where the neutrons are produced in the spallation process. This in turn leads to a modulation of an absolute neutron intensity by approximately 1.5%. The 1 Hz signal in the intensity corresponds to a full rotation of target E, but this effect is much smaller. An example measurement of the neutron counts at BOA and a photo of target E are presented in Fig. 3.

EXOTIC YUKAWA-LIKE INTERACTION

As introduced before, we also built a dedicated tabletop experiment to search for a new axial-vector gauge boson. We again apply Ramsey's technique, but this time to the proton spins of hydrogen in water [25, 26]. The measurement principle is analogous to the one of Beam EDM. Figure 4 shows a photo of the experimental setup and the interior of the magnetically shielded interaction region. The water is circulated through the system using a gear pump. First, the water passes through a polarizer to create a sizable spin polarization of the protons. It then flows



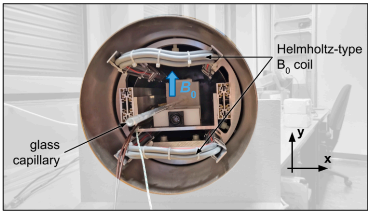
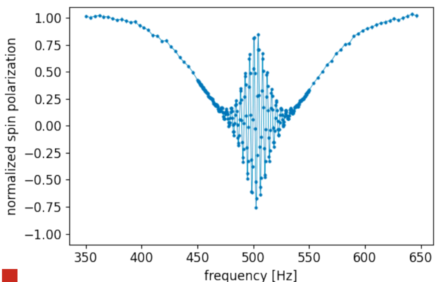


Figure 4
(left) Photo of the experimental setup with an overall length of roughly 2 meters. (right) Photo of the view into the mu-metal. The water flows through the glass capillary in the center. The rectangular-shaped Helmholtz coil that creates the magnetic field is also visible.

through the interaction region in a glass capillary, which is magnetically isolated by a double-layer mu-metal shield. The spins interact with the magnetic field in that region and can be manipulated with spin-flip coils. If the setup is used to search for new interactions, a sample that serves as a source can be placed here. Finally, the spin polarization is measured and analyzed employing nuclear magnetic resonance (NMR) techniques.

We performed a proof-of-principle search for the exotic Yukawa-like interaction between fermions, i.e., protons and neutrons. For the first time, protons were used as probe particles. A block of copper served as the source. If this interaction exists, the presence of the copper will lead to a tiny shift in the Ramsey resonance pattern as the one shown in Fig. 5. We could not yet detect or constrain the existence of such an interaction due to the mechanical problems of the apparatus. Developments are underway that will allow this to be done soon.



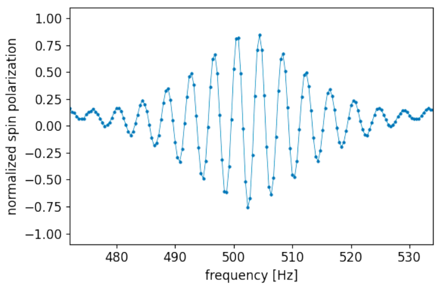


Figure 5
(left) Typical resonance pattern obtained with Ramsey's method of separated oscillatory fields at a magnetic field of B0 ≈ 12 μT as published in JMR [25]. (right) Zoom in the central frequency range of the full resonance. The total measurement time was roughly 1.5 hours. The solid lines serve only as a guide for the eyes.

CONCLUSION

In this article we presented two ways how neutrons and protons can be used to search for new fundamental interactions beyond the standard model of particle physics. In the first experiment, we used a cold neutron beam to search for axion-like dark matter. Even though we did not find a significant signal, we could test its existence over a mass range spanning almost eight orders of magnitude. Additionally, our sensitive apparatus revealed the characteristic periodic intensity modulation of the SINQ spallation source at PSI. In a second experiment, we built an apparatus that applies magnetic resonance techniques to the nuclear spin of hydrogen protons in water. We showed how it can be used to search for new exotic interactions in the millimeter range.

ACKNOWLEDGMENTS

This report was presented on behalf of all actual and former members of the Fundamental Neutron and Precision Physics Group of F. M. Piegsa at the University of Bern. It is largely based on the doctoral thesis by I. Schulthess, where more details can be found [27]. It is an overview article about the winning research topic of the Young Scientist Prize 2023 of the Swiss Neutron Science Society. We gratefully acknowledge the excellent contributions of S. Bosco, J. Christen, R. Hänni, and L. Meier from the University of Bern, D. Berruyer, T. Soldner, and O. Zimmer from the Institute Laue-Langevin, and P. Hautle, U. Filges and C. Klauser from the Paul Scherrer Institute. The experiments were performed at the Institute Laue-Langevin in Grenoble, France, and the Swiss Spallation Neutron Source SINQ at the Paul Scherrer Institute in Villigen, Switzerland. They were supported by the European Research Council under ERC Grant Agreement No. 715031 (BEAM-EDM) and the Swiss National Science Foundation under Grants No. 163663, No. 181996, and No. 215185.

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A Comprehensive Experimental Approach to Multifunctional Quantum Materials and their Physical Properties: Geometry and Physics in Condensed matter

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Multifunctional quantum materials, characterized by their complex physical properties, stand at the forefront of condensed matter physics, holding promise for groundbreaking applications in technology and energy. This PhD thesis, through a comprehensive experimental approach employing neutron scattering, X-ray diffraction, and muon spin rotation, reveals novel insights into the structure and emergent physical properties of these systems. In particular, we uncovered complex magnetic ground states in newly synthesized materials, including the low-dimensional compound $NaCr_2O_4$ with colossal magnetoresistance, and the triangular lattice antiferromagnets $LiCrSe_2$ and $LiCrTe_2$. Furthermore, we provided insights into non-conventional symmetry breaking phenomena within widely debated systems, such as the superconductor $LiTi_2O_4$, the charge density wave system $LaPt_2Si_2$, and the topological insulator $ZrTe_5$. A comprehensive understanding of the physics gover-

ning these materials was attainable solely through the elucidation of the details, and temperature dependent evolution, of their structures. This study enhances our fundamental understanding of quantum materials by integrating advanced experimental techniques with theoretical insights, demonstrating the critical importance of neutron scattering in interdisciplinary scientific research.

INTRODUCTION

"[Natural] Philosophy is written in this great book, that is continuously open before our eyes (I say the Universe) but it cannot be understood until its language is understood, and the characters in which it is written are known. It [the book of Nature] is written in the language of mathematics, and the characters are triangles, circles, and other Geometric figures, without which it is impossible to humanly understand a word of it; without these, humanity vainly wanders through a dark maze."

This is how Galileo Galiei, in his treaty "Il Saggiatore" (1623) [1], defined the relevance of Geometry in the human effort towards understanding Nature's working principles. The concept of Geometry as the language of Nature found a more complex declination later on, when Felix Klein, within his Erlangen Program [2], introduced the revolutionary idea that every geometry can be described as the study of an ensemble of properties that are invariant with respect to a particular group of transformations (i.e., symmetries). In this regard, symmetry and geometry can be considered interchangeable concepts since symmetry essentially defines geometry. The need to bind to the geometric principle of symmetry (i.e., invariance), assumed fundamental importance in the general physics approach. In fact, the search for transformations under which the system does not change simplifies greatly, but still on rigorous grounds, problems that would not be solvable otherwise. Outstanding milestones in modern physics can be indeed seen as direct consequence of the Klein's revolution. From the formulation of Albert Einstein's Special and General Relativity [3, 4], to Emmy Noether's settlement "symmetries-conservation laws" [5, 6] which, together with the geometric approach of the Hamiltionian mechanics, constitute the very foundation of the formalism of Quantum Mechanics. From Hermann Weyl's attempt to unify Electromagnetism and General Relativity [7], to the formulation of deeply geometry-based gauge theories which led to the conception of the Standard Model of Particle Physics [8, 9]. In contemporary physics, geometry dictates the structure and dynamics of the space-time itself and generates the interactions, forces and forms of energy which build the very physical reality around us. The title PhD thesis [10] ranges within the vast framework of experimental solid condensed matter physics. Here, the structural symmetries of a system and its physics are also intimately intertwined and the crystal structure of a material determines most of its physical properties, as first showed by Hans Albrecht Bethe with his crystal field theory [11]. Therefore, it could be said that the physics of solids stems from the symmetry of their lattices, where the collective nature of the strong interactions between the closely packed electrons and nuclei eventually results in the emergent physical properties we can observe, in a so-called phase. A transformation that changes the state of a physical system, bringing it from one phase to another, is called a Phase Transition, and it involves a variation in the physical properties of the system such as crystal structure, density, magnetization, and electrical conductivity. It is said that a system that exhibits a continuous phase transition has a spontaneous symmetry breaking when its ground state has a lower symmetry with respect to the symmetry of its Hamiltonian. Meaning that the global symmetry of the underlying physical laws of a system (i.e., the invariance of its Hamiltonian with respect to its transformations) is conserved, while the possible ground states of the system experience a symmetry loss. The symmetry breaking can be referred to a discrete symmetry (such as symmetry by reflection) or a continuous symmetry (such as translational or rotational). It can be demonstrated that, in transitions that break symmetries of the latter type (continuously moving from one state to another at zero energy cost), the creation of a new scalar particle, with zero mass, can occur in the excitations spectrum of the system for each symmetry generator that breaks. Here the system chooses spontaneously its ground state, after the phase transition, breaking the degeneration among all the possible ground states. Symmetry-breaking phenomena underpin various intriguing physical properties in condensed matter such as magnetism and superconductivity. Understanding such fundamental properties holds significant importance for the development of cuttingedge technologies, including spintronics, quantum computing, and advanced magnetic materials, as well as foster innovation in energy-related applications. In this work several types of symmetry breaking phenomena were explored in different crystalline systems, superconductors and magnets. Specifically, systems with complex crystal-field symmetries resulting in mixed valence states of their transition metal ions: the unconventional colossal magnetoresistive $NaCr_2O_4$ and its solid solution with calcium $Ca_{1-x}Na_x Cr_2O_4$ [12–14], the antiferromagnetic insulators $NaMn_2O_4$ and $Li_{0.92}Mn_2O_4$ [15], and the unconventional superconductor $LiTi_2O_4$ [16]. Geometrically frustrated antiferromagnets with unconventional magnetic behavior arising from competing magnetic interactions: $MgReO_4$ with a putative wolframite structure [17], and the triangular lattice antiferromagnets $LiCrSe_2$, $LiCrTe_2$ and $NaCrTe_2$ [18–20]. Systems with competing instabilities of the electron spectrum, which can lead to changes in their crystal structures: the charge density wave superconductor $LaPt_2Si_2$ [21, 22] and the topological semimetal $ZrTe_5$ [23].

DISCUSSION

Due to the well-defined arrangement of atoms in crystalline lattices, and the presence of boundary conditions at their surface, translational symmetry breaking occurs in crystals. The consequence of this is the genesis of phonons. Quanta of vibrations of the atoms, that undergo displacements equal to u(x) along a certain direction around their equilibrium position. Additionally, charge density waves (CDW), arising from electronlattice interactions and leading to a spontaneous additional modulation of the original crystal structure (which is often incommensurate), breaks the $U(1)$ unitary symmetry group [21]. This group, constituted by the set of complex numbers with norm equal to 1 (i.e., the unit circle $U(1) = e^{i\theta}$), governs the symmetry of the electromagnetic field (i.e., Maxwell's equations are invariant under the action of elements of $U(1)$). Since the underlying lattice and the CDW induced incommensurate lattice distortion are arbitrarily "out of phase" with respect to each other, we say that the $U(1)$ symmetry is broken. As a result, a phason excitation occurs together with a renormalization of the phonon frequencies in the vibrational excitation spectrum of the system. In this thesis, structural instabilities and phonon spectra were investigated to clarify the unconventional nature of the charge density wave in the superconductor $LaPt_2Si_2$ [22]. The relationship between CDW and superconductivity (SC) has been a central topic of scientific debate in contemporary physics for decades, and clarifying the underlying superconducting mechanism of materials having competing orders, may be ground-breaking for understanding and engineering room temperature SC. $LaPt_2Si_2$ displays strong interplay between CDW and SC and it is characterized by a $CaBe_2Ge_2$-type structure, which is similar to the one commonly found in pnictide SC, while being a much less complex system, not hosting the additional competing orders typical of Fe-based SC (e.g., magnetism, spin density wave, nematicity). These features make $LaPt_2Si_2$ the ideal study case for a clear understanding of the CDW-SC relationships in unconventional superconductors and, for this reason, it is surrounded by a lively interest in the condensed matter community. However, due to misinterpretations of previously reported X-ray and in-house bulk characterization measurements, the high-temperature physics of this compound (and the very existence of the CDW state) is debated and the low temperature superconducting mechanism is not yet understood. Indeed, the published literature around $LaPt_2Si_2$ is unable to provide a clear picture of the nature of its CDW and SC phases. One of the results of this thesis was to provide the first experimental observation of the theoretically predicted CDW-driven phonon softening in $LaPt_2Si_2$ via an inelastic neutron scattering experiment [22]. We identified a non-conventional critical behavior for the CDW phase transition in $LaPt_2Si_2$, compatible with a scenario of CDW discommensuration (DC). The DC would be caused by the existence of two CDWs in this material, propagating separately in two non equivalent Si-Pt layers with two distinct transition temperatures. A strong q-dependence of the electron-phonon coupling has been identified as the driving mechanism for the first CDW transition while a CDW with 3-dimensional character, and Fermi surface quasi-nesting as a driving mechanism, is suggested for the second transition. Our investigation solved the debate around the nature of this CDW phase, hereby opening the way for more meaningful theoretical and experimental studies on the superconducting state in this material. Here the use of neutron scattering as investigation technique was highly beneficial for the unambiguous interpretation of the observed behavior. Indeed, since neutrons scatter with the atomic nuclei rather than with the surrounding electronic clouds, it was possible to investigate the system without charge ordering contributions to the signal.

In the case of superconductors, the $U(1)$ local gauge symmetry is also broken on lowering temperature since the superconducting state is marked by a phase coherence. Unlike other types of continuous symmetry breaking phenomena, superconductivity is rather special because there is no excitation associated to it. So here we investigated the unconventional mechanism of superconductivity in the thin film $LiTi_2O_4$ by direct observation of its order parameter. The mechanism underlying superconductivity in this system is highly debated and a large number of interpretations have been given over the years to try to explain its behavior. In this thesis we propose that the observed behavior is compatible with a superconductivity of BCS type (i.e., conventional), with disturbance by Ti^{3+} spin fluctuations, which introduce a time reversal symmetry breaking perturbation in the system. This measurement gives a robust indication that LTO is a non-conventional SC and sets an important step forward in understanding the controversial nature of superconductivity in this material [16].

In the case of magnets, a spontaneous rotational symmetry breaking occurs together with a translational symmetry breaking due to alterations of the spatial periodicity of the magnetic cell with respect to the nuclear cell. The breaking of the continuous rotational symmetry implies the emergence of spin waves magnetic excitations, and the appearance of a spontaneous magnetization (i.e., the orientation of the electronic moments of the atoms in the ordered state). The latter, chooses to orient itself along a certain direction on lowering temperature, leading the system to an ordered ground state. In this thesis we investigated several unconventional and low dimensional magnets, but the most striking representative case is provided by $LiCrSe_2$, which we found to undergo a drastic structural transition to accommodate a very complex magnetic structure [19]. In this material unprecedented conditions are realized between structural degrees of freedom and competing magnetic couplings, leading to a restructuring of the crystal lattice accompanied by the formation of a complex incommensurate up-up-down-down magnetic structure, with itinerant frustration of the Cr moment and periodic reorientation of the Cr spin axial vector. This is unique among 2-dimensional triangular lattice antiferromagnets and consistent with the remarkable presence of tunable field-free topological spin textures in $LiCrSe_2$, which make this material appealing for applications in spintronics circuitry [24, 25]. The crystalline solid $NaCr_2O_4$ also represents a remarkable example among the magnetism-related systems investigated in this thesis. Indeed it exhibits fascinating low temperature electronic properties (i.e., dual itinerant and localized electronic nature, anomalous colossal magnetoresistance, exceptional coexistence of positive and negative charge transfer states, coexistence of antiferromagnetic (AFM) and ferromagnetic (FM) correlations in its magnetic ground state), but it also lends itself well as a study model for the development of Na-ion battery materials in a high temperature regime [13]. Therefore, $NaCr_2O_4$ is suitable for the realization of magnetoelectronic devices for data storage, magnetic sensors, as well as solid oxide fuel cells, and clarifying its magnetic structure and magnetic coupling mechanisms is the first step towards the optimization and employment of this material for such applications. Neutron diffraction is the only method that allows for direct determination of the spatial arrangement of magnetic moments and their orientations in the crystal lattice and, in this work, this technique has been employed to solve the complex magnetic structure of $NaCr_2O_4$ [12]. We identified a commensurate canted magnetic cell with unusually large value of the Cr moment, suggested to be originated by itinerant electrons, coexisting with an incommensurate cycloidal magnetic supercell, which would be instead originated by localized electrons. Indications of unconventional critical behavior for the commensurate magnetic phase transition in $NaCr_2O_4$ were also found. In particular, we suggest that the magnetic transition might be at the edge of a tricritical point with possible formation of a metamagnetic hidden phase.

In all these works the crystal structure and the physical phenomena occurring in the material of interest were proven to be in constant communication and codetermination. In examining the intricate dance between crystal structure and the physical phenomena within specific materials, we find a vivid illustration of Galileo's assertion that geometry, and therefore symmetry, forms the fundamental language of the natural world.

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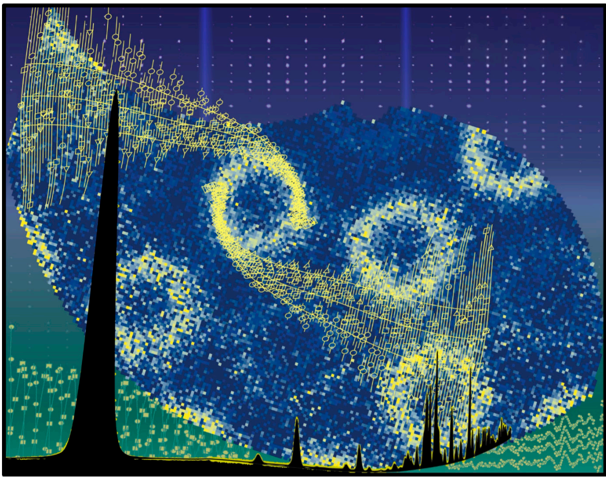

Reproduction of Vincent van Gogh's painting "The Starry Night" realized by using diverse data from the doctoral thesis presented in this article. The figure includes: neutron powder diffraction and bulk m^+SR data from $NaCr_2O_4$, collected at the diffractometer iMATERIA (J-PARC) and at the multipurpose muon instrument Dolly (PSI) respectively [12]; longitudinal field m^+SR data from $NaCr_2O_4$, collected at the muon instrument EMU (ISIS) [13]; low energy m^+SR data from $LiTi_2O_4$, collected at the LEM spectrometer (PSI) [16]; synchrotron X-ray single crystal diffraction data from $LaPt_2Si_2$, collected at the P21.1 diffractometer (DESY-Petra III) [21]; inelastic neutron scattering data from $YbBr_3$, collected during the commissioning of the multiplexing neutron spectrometer CAMEA (PSI). As this thesis encompasses diverse physical systems and experimental techniques, this figure constitutes a powerful visual summary of the presented work.

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Announcements

General Assembly 2024

The General Assembly 2024 of the Swiss Neutron Science Society will take place on **May 27 at 15:00**, at the Paul Scherrer Institut, in the auditorium WHGA/001. We will also send a link for those who need to join online. The tentative Agenda is the following:

1. Welcome
2. Minutes of the General Assembly 2023
3. Annual Report of the Chairman
4. Annual Report of the Treasurer
5. Report of the Auditors
6. Budget 2025
7. SGN Board: open board seat (interested members should contact the president)
8. News from UCN / SINQ / ENSA / ILL / ESS
9. 2024 Update of the Swiss Neutron Science Roadmap
10. Progress on New Webpage and Logo
11. Varia

After the meeting, all will be invited for a nice spring Apéro.

SGN/SNSS Board

SGN/SNSS Members

Presently the SGN/SNSS has 195 members. New members can register online on the SGN/SNSS website: http://sgn.web.psi.ch

SGN/SSSN Annual Member Fee

The SGN/SNSS members are kindly asked to pay their annual member fees. At the general assembly 2013 of the society, the fee has been increased from CHF 10 to **CHF 20**. It can be paid either by bank transfer, twint or in cash during your next visit at PSI. The bank account of the society is accessible for both Swiss national and international bank transfers: Postfinance: 50-70723-6 (BIC: POFICHBE), IBAN: CH39 0900 0000 5007 0723 6.

The SGN/SSSN is an organisation with tax charitable status. All fees and donations paid to the SGN/SSSN are **tax deductible**.

PSI Facility News

Recent news and scientific highlights of the three major PSI user facilities SLS, SINQ and SμS can be found in the **quarterly electronic newsletter** available online under:
https://www.psi.ch/science/facility-newsletter

News from SINQ

Please visit the page https://www.psi.ch/sinq/call-for-proposals to obtain the latest information about beam cycles and the availability of the neutron instruments.

Registration of publications

Please remember to **register all publications either based on data taken at SINQ, SLS, SμS or having a PSI co-author** to the Digital Object Repository at PSI (DORA):
www.dora.lib4ri.ch/psi/
Follow the link 'Add Publication'.

Open Positions at SINQ and ILL

Open positions at SINQ or ILL are advertised on the following webpages:
https://www.psi.ch/pa/stellenangebote
https://www.ill.eu/careers/all-our-vacancies/?L=0

PhD positions at ILL

The PhD program of the Institut Laue-Langevin, ILL, is open to researchers in Switzerland. Consult the page:
https://www.ill.eu/careers/all-our-vacancies/phd-recruitment.

For information on the PhD program of ILL or get in contact with the managers of the program using the email address phd@ill.fr.

The Swiss agreement with the ILL includes that ILL funds and hosts one PhD student from Switzerland.

Conferences and Workshops May 2024 and beyond

An updated list with online links can be found here: http://www.psi.ch/useroffice/conference-calendar

May 2024

Mini-symposium on neutron diffraction in drug discovery, design and formulation
May 7-8, 2024, Lund, Sweden and online

Heritage Science Sverige forum 2024
May 13-14, 2024, Stockholm, Sweden

Helios Graduate School
May 13-17, 2024, Lund, Sweden

Advanced optics for neutron beams
May 17, 2024, online

Exploring Dynamic Properties of Earth and Planetary Materials Using Neutron and X-Ray Methods
May 21-23, 2024, Grenoble, France

Active Training Course Advanced Deep Learning
May 21-24, 2024, Filderstadt, Germany

WaterX: exotic properties of water under extreme conditions
May 25-30, 2024, La Maddalena (Sardinia Island), Italy

Northern Lights on Food Conference V - Boosting structural food science
May 27-29, 2024, Lund, Sweden

Swedish Neutron Week 2024
May 29-31, 2024, Lund, Sweden

3D biomedical imaging with synchrotron radiation: State-of-the-art & future possibilities
May 30, 2024, Lund, Sweden

Chemistry of Life: Young Researchers' Symposium
May 30-31, 2024, Lund, Sweden

Danscatt Annual Meeting 2024
May 30-31, 2024, Aarhus University

June 2024

12th World Conference on Neutron Radiography
June 2-7, 2024, Idaho Falls, ID, USA

4th ISIS inelastic neutron data analysis course
June 3-7, 2024, Didcot, UK

MLZ Conference 2024: Neutrons for Energy Storage
June 4-7, 2024, Munich, Germany

16th Bombannes Summer School: Scattering Methods Applied to Soft Condensed Matter
June 4-11, 2024, Bombannes/Carcans-Maubuisson, France

TEMM2024: Theoretical and Experimental Magnetism Meeting
June 10-11, 2024, Abingdon, UK

Neutrons in Structural Biology – Challenges & Opportunities
June 10-12, 2024, Arlington, VA, USA

QENS/WINS 2024
June 10-14, 2024, Manchester, UK

Neutrons and Food 7
June 10-14, 2024, Newark, DE, USA

Trends in Magnetism 2024
June 10-14, 2024, Lund, Sweden

SWEPROT 2024: 27th Swedish Conference on Macromolecular Structure & Function
June 14-17, 2024, Tällberg, Sweden

Coherence 2024: 11th International Conference on Phase Retrieval and Coherent Scattering
June 16-20, 2024, Helsingborg, Sweden

812th WE-Heraeus Seminar: Bridging Length Scales in Magnetism – Diffuse Scattering from the Atomic to the Mesoscale
June 16-20, 2024, Bad Honnef, Germany

TNT: Training on Neutron Techniques: Small Angle Scattering and Reflectometry
June 16-21, 2024, Valle Aurina, Italy

Bridging Length Scales in Magnetism – Diffuse Scattering from the Atomic to the Mesoscale
June 17-20, 2024, Bad Honnef, Germany

5th European Conference on Hydrogen & P2X 2024
June 19-20, 2024, Copenhagen, Denmark

ACNS 2024: American Conference on Neutron Scattering
June 23-27, 2024, Knoxville, TN, USA

5th Summer School on Neutron Detectors and Related Applications
June 23-27, 2024, Riva del Garda, Italy

9th European Crystallographic School
June 24-30, 2024, Nancy, France

July 2024

ICTMS 2024: International Conference on Tomography of Materials and Structures
July 1-5, 2024, Stellenbosch, South Africa

SXNS17: International Surface X-ray and Neutron Scattering Conference
July 15-18, 2024, Grenoble, France

Symposium in honour of John White
July 18-19, 2024, Grenoble, France

6th Open Reflectometry Standards Organisation annual meeting
July 19, 2024, Grenoble, France

30th CHRNS School on Methods and Applications of Small Angle Neutron Scattering and Neutron Reflectometry
July 22-26, 2024, NIS, Gaithersburg, MD, USA

August 2024

Summer School on Biomedical Image Analysis
August 12-16, 2024, Svendborg, Denmark

16th International Conference on X-Ray Microscopy
August 12-16, 2024, Lund, Sweden

Fast and Efficient Python Computing School
August 19-23, 2024, Aachen, Germany

Workshop on 'Tips and tricks for the crystal growth of inorganic materials'
August 26-27, 2024, Villigen, Switzerland

Developers Workshop PyHEP.dev
August 26-30, 2024, Aachen, Germany

SRI2024: 15th International Conference on Synchrotron Radiation Instrumentation
August 26-30, 2024, Hamburg, Germany

September 2024

NEUWAVE-12: 12th Workshop on NEUtron WAVElength-dependent Imaging
September 1-4, 2024, Lund, Sweden

38th Conference of the European Colloid & Interface Society
September 1-6, 2024, Copenhagen, Denmark

MATRAC 2 School: Application of Neutrons and Synchrotron Radiation in Materials Science with Special Focus on Fundamental Aspects of Materials
September 1-6, 2024, Herrsching and Garching, Germany

RÅC Summer School 2024
September 1-8, 2024, tbd, Poland

ILL and ESRF International Summer Programme on Neutron and X-Ray Science for undergraduate students 2024
September 1-8, 2024, Grenoble, France

XI AUSE conference and VI ALBA Users Meeting
September 2-5, 2024, Oviedo, Spain

26th Laboratory Course - Neutron Scattering 2024
September 2-13, 2024, Jülich and Garching, Germany

18th Oxford School on Neutron Scattering
September 3-13, 2024, Oxford, UK

Annual Meeting of the Swiss Physical Society SPS 2024
September 9-13, 2024, Zurich, Switzerland

DN2024: Deutsche Neutronenstreutagung 2024
September 16-18, 2024, Aachen, Germany

MSE 2024: Materials Science and Engineering (MSE) Congress 2024
September 24-26, 2024, Darmstadt, Germany

2024 Workshop of the International Union of Crystallography (IUCr) Commission on High Pressure
September 25-28, 2024, Lund, Sweden

October 2024

JCNS Workshop 2024: Trends and Perspectives in Neutron Scattering: Functional Interfaces
October 8-11, 2024, Tutzing, Germany

J-PARC2024: 4th J-PARC Symposium
October 14-18, 2024, Mito, Japan

IMoH 2024: 2nd International Meeting on Opportunities and Challenges for High Current Accelerator-driven Neutron Sources
October 15-17, 2024, Leioa (Basque Country), Spain

ANSTO-HZB Neutron Training Course
October 27 – November 1, 2024, Sydney, Australia

November 2024

SAS2024: XIX edition of the International Small-Angle Scattering Conference
November 3-8, 2024, Taipei, Taiwan

MDANSE School 2024: Mastering Materials through DFT & MD
November 5-7, 2024, Grenoble, France

December 2024

2024 ILL ESS User Meeting
December 10-11, 2024, Grenoble, France

BESSY@HZB User Meeting 2024
December 11-12, 2024, Berlin, Germany

Editorial

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