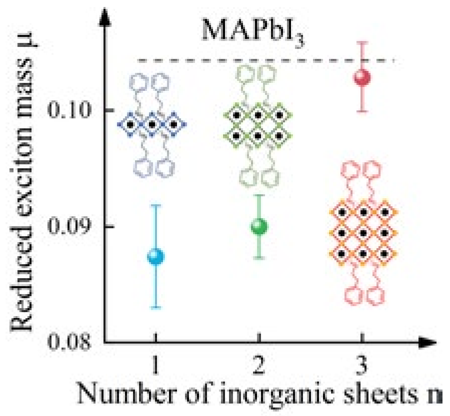
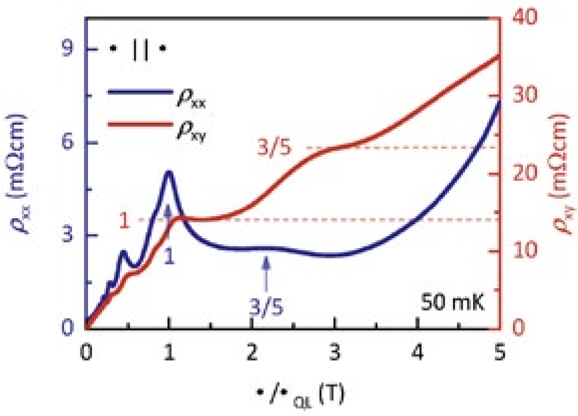
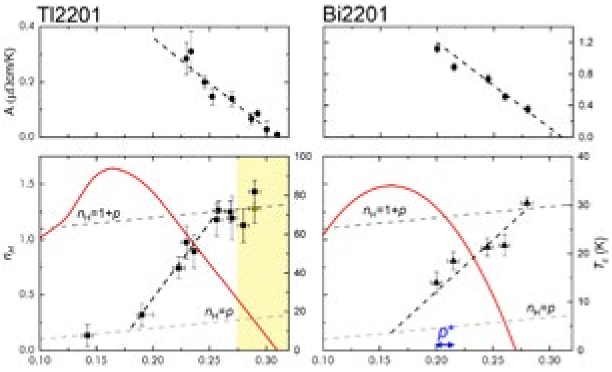
EMFL
European Magnetic Field Laboratory

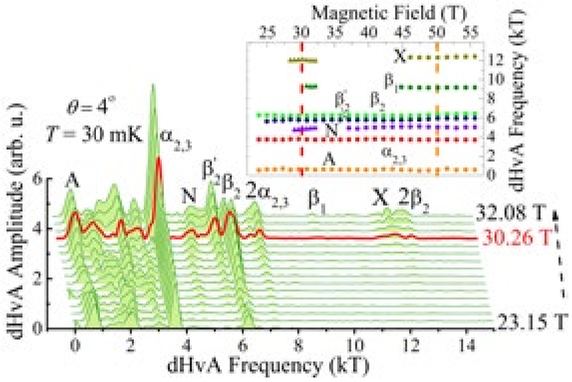
EMFLNEWS

N°4 2020









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DEAR READER

First of all, on behalf of the whole EMFL staff, let me wish you a prosperous and healthy New Year. I do this as the new chair of the EMFL Board of Directors, succeeding Geert Rikken who has stepped down as director of LNCMI and as EMFL BoD chair. I would like to take this opportunity to thank Geert; not only for his excellent chairmanship during the last two years, but also for his great work, during a large number of years, constructing the European network of the high magnetic field facilities and being one of the founders of the EMFL. Clearly, without Geert EMFL would not be in the excellent position it is in now. I wish Charles Simon all the best as the new director of LNCMI and I welcome him in the EMFL BoD.

Unfortunately, we still suffer from the consequences of the Corona pandemic and we still have to deal with restrictions for operation and traveling. This makes it difficult to schedule all projects approved in the last call for proposals. We are working very hard to execute as many projects as we can, for instance via mail-in samples, but we fear that in several cases it will not be possible to realize your project at the desired moment. We ask for your understanding that these exceptional circumstances do not leave us much choice.

Fortunately, there is also good news to share. The ISABEL project has started and we have had a successful kick-off meeting on November 20th. Together with many partners, both from academia and industry, we are working on improving the long-term sustainability of the EMFL. Moreover, on January 1st the SuperEMFL project has started, which will focus on the development of high-T_c superconducting user magnets. Last but not least, the highlights in this EMFL News show that the good work continues at our facilities, even in these most difficult times. I wish you happy reading and please take good care of yourself and your loved ones.

Peter Christianen
Director HFML
Chairman EMFL

MEET OUR PEOPLE

Eva Bezgousko, LNCMI Toulouse

After a bachelor degree in literature, I decided to continue my scientific career aiming at a master degree at Aix-Marseille University, a master of European and International Relations studies with a specialization in European project management and European programs. During these studies, I discovered my interest for European research and innovation programs. Therefore, after a traineeship at the University Lyon 2 as an assistant of project management, I finished my master with a dissertation on Horizon 2020 and France's position on calls for projects.

Then, I had the opportunity to join the LNCMI team in Toulouse for the project ISABEL, as European Project Manager. I am interested in the goals that EMFL wants to achieve through the ISABEL project. I am also attracted by its commitment to bring the importance of research infrastructures and their development, through various types of collaboration, to the intention of the general public and policymakers. Indeed, since my traineeship in a research environment, I want to help to reinforce European research networks and actions.

To be a project manager is to act on various levels (administrative, financial, legal, communication…), to collaborate with international partners, and to find effective and efficient ways to implement the project altogether. I really appreciate the multi-tasking aspect of my job and the multicultural aspect of the teams I am working with. For example, the project ISABEL gathers 9 countries all around Europe and we all come from different professional backgrounds. I find this really enriching on both professional and personal levels.
Now, I am looking forward to working together!

Eva Bezgousko, LNCMI Toulouse

ROBUST FERMI-SURFACE TOPOLOGY OF $CeRhIn_5$ IN HIGH MAGNETIC FIELDS

Sanu Mishra and Ilya Sheikin, LNCMI Grenoble, Tobias Förster, HLD Dresden, and Alix McCollam, HFML Nijmegen

Rare-earth-based materials are now widely recognized as an ideal playground for exploration of the fascinating physics that develops around a quantum critical point (QCP). In Ce-based compounds, such a QCP typically separates an antiferromagnetic (AFM) state from a nonmagnetic ground state. In spite of numerous experimental investigations of such systems near a QCP, the details of what drives the QCP remain the subject of much theoretical debate.

$CeRhIn_5$ is one of the best-studied heavy-fermion materials. This AFM compound with $T_N = 3.8$ K can be tuned to a QCP by pressure, chemical substitution, and magnetic field. Several de Haas–van Alphen (dHvA) experiments evidence localized f electrons of $CeRhIn_5$ at ambient pressure. As the critical pressure for the suppression of antiferromagnetism, $P_c = 2.3$ GPa, is reached, all dHvA frequencies observed below this pressure change discontinuously, signaling an abrupt Fermi-surface (FS) reconstruction as a consequence of f-electron delocalization. Recent results obtained at high magnetic fields suggested a unique behavior in $CeRhIn_5$. A field-induced QCP was reported to occur at the critical field $B_c \approx 50$ T. An electronic-nematic phase transition was observed at $B^* \approx 30$ T and attributed to an in-plane symmetry breaking. Finally, the emergence of additional dHvA frequencies was observed at B* and interpreted as a field-induced FS reconstruction associated with f-electron delocalization. This result is surprising given that magnetic fields are generally expected to localize the f electrons.

To resolve this controversial issue, researchers from the EMFL laboratories in Grenoble, Dresden, and Nijmegen, together with their Japanese colleagues, performed a comprehensive dHvA study of $CeRhIn_5$ using both static (up to 36 T) and pulsed (up to 70 T) magnetic fields. Several dHvA frequencies were found to gradually emerge at high fields as a result of magnetic breakdown (Figure). Among them is the theoretically predicted β_1 branch, not observed so far. Comparison of the angle-dependent dHvA spectra with those of the non-4f compound $LaRhIn_5$ and with band-structure calculations evidence that the Ce 4f electrons in $CeRhIn_5$ remain localized up to 70 T. This rules out any FS reconstruction, either at the suggested nematic phase transition at B* or at the putative QCP at B_c. These results demonstrate the robustness of the FS and the localized nature of the 4f electrons inside and outside of the AFM phase.

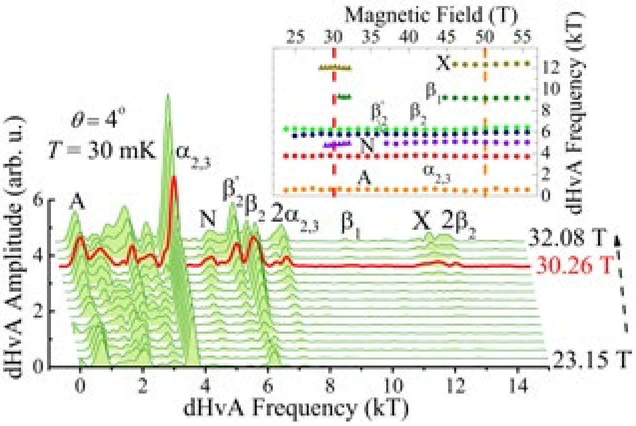

Figure: FFT spectra of the static-field dHvA oscillations in $CeRhIn_5$. The inset shows the evolution of the dHvA frequencies with field obtained from pulsed (circles) and static (triangles) field measurements.

Robust Fermi-Surface Morphology of $CeRhIn_5$ across the Putative Field-Induced Quantum Critical Point, S. Mishra, J. Hornung, M. Raba, J. Klotz, T. Förster, H. Harima, D. Aoki, J. Wosnitza, A. McCollam, and I. Sheikin, Phys. Rev. Lett. **126**, 016403 (2021).

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REDUCED HALL CARRIER DENSITY ACROSS THE STRANGE METAL PHASE OF CUPRATES

Nigel Hussey, HFML and Anthony Carrington, University of Bristol

Researchers from the UK and Japan, together with scientists from three of the EMFL laboratories, have uncovered a striking crossover in the Hall resistivity across the so-called strange-metal phase of overdoped cuprate superconductors [1]. The work builds on a seminal work carried out at LNCMI-Toulouse back in 2016 [2] and sheds important new light on the nature of the strange-metal phase out of which high-temperature superconductivity emerges.

The phase diagram of high-temperature superconductors has intrigued condensed-matter physicists around the globe for well over three decades but many outstanding questions remain, including: (i) Is there a quantum critical point at some location in the phase diagram? (ii) If so, are quantum fluctuations associated with the quantum critical point responsible for the anomalous properties of the normal state and the occurrence of superconducting? (iii) Is the pseudogap the ordered phase which is responsible for the quantum criticality? (iv) What is the origin of the pseudogap?

In this investigation, the research team headed by Tony Carrington from University of Bristol performed measurements of the in-plane Hall resistivity $\rho_{xy}(H)$ of two cuprate families, $Tl_2Ba_2CuO_{6+d}$ (Tl2201) and $Bi_2Sr_2CuO_{6+d}$ (Bi2201), concentrating on the limiting behavior that can only be reached at low temperature and high magnetic fields. Their measurements and subsequent analysis established, for the first time, that the low-temperature Hall number transitions from p to 1 + p (where p is the number of doped holes) smoothly across the strange metal regime that spans the region of the phase diagram from the point where the strength of superconductivity is maximized to the edge of the superconducting dome. Significantly, the study reveals that this transitioning is not simply related to the closing of the normal-state pseudogap since reduction in Hall number occurs before the pseudogap opens. Rather, the reduction in carrier density is seen to be correlated with the increase in the strength of the linear-in-temperature component to the resistivity found throughout the strange-metal regime. This finding thus suggests an entirely new feature of the cuprate strange metal, one that links the nature of the strange-metal phase to a gradual decoherence of the quasiparticle states as the pseudogap and ultimately, the Mott insulating state, is approached.

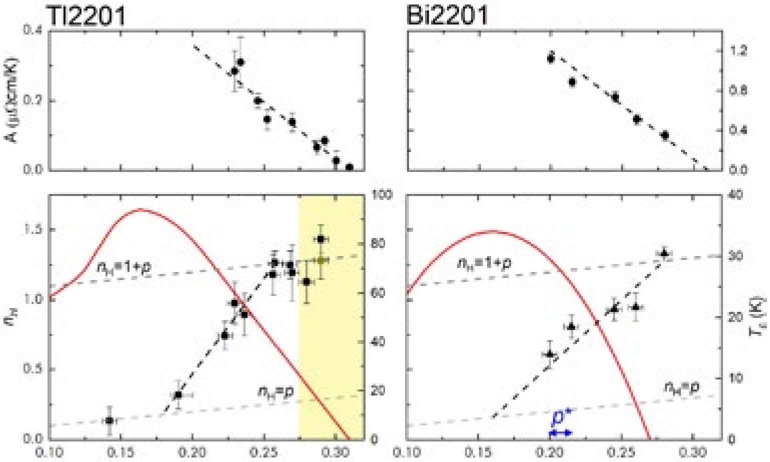

Figure: Bottom panels: Evolution of the low-T, high-field Hall number $n_H(0)$ across the strange-metal regime in Tl2201 and Bi2201 [1]. The solid lines show the evolution of T_c with doping. For Bi2201, p* shows the location of the end point of the pseudogap regime as determined by transport measurements on the same samples (for Tl2201, NMR measurements suggest the pseudogap closes at p*=0.19). The top panels show the evolution of the linear-in-T coefficient of the in-plane resistivity with doping.

[1] Reduced Hall carrier density in the overdoped strange metal regime of cuprate superconductors, C. Putzke, S. Benhabib, W. Tabis, J. Ayres, Z. Wang, L. Malone, S. Licciardello, J. Lu, T. Kondo, T. Takeuchi, N. E. Hussey, J. R. Cooper, and A. Carrington, arXiv:1909.08102 Nat. Phys., in press

[2] Change of carrier density at the pseudogap critical point of a cuprate superconductor, S. Badoux, W. Tabis, F. Laliberté, G. Grissonnanche, B. Vignolle, D. Vignolles, J. Béard, D. A. Bonn, W. N. Hardy, R. Liang, N. Doiron-Leyraud, L. Taillefer, and C. Proust, Nature **531**, 210 (2016).

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TUNING THE EXCITONIC PROPERTIES OF A TWO-DIMENSIONAL PEROVSKITE FAMILY VIA QUANTUM CONFINEMENT

Mateusz Dyksik, Wrocław University of Science and Technology and Paulina Plochocka, LNCMI Toulouse

Two-dimensional (2D) metal-halide perovskites constitute an important step in the evolution of low-cost organic-inorganic hybrid light absorbers and emitters. Similar to their 3D counterparts, layered perovskites show promising performance in photovoltaic and light emitting devices while preserving high environmental stability. The latter is of paramount importance for the industrialization of perovskite technology. In 2D perovskites the improved stability stems from the large hydrophobic organic cations L separating inorganic octahedral sheets. The general formula describing Ruddlesden-Popper (RP) 2D layered perovskites is $L_2A_{n-1}M_nX_{3n+1}$, where A is a small monovalent cation, M is a metal atom, X is a halide atom, and n denotes the number of octahedral layers.

Despite their popularity and successfully deployment in various opto-electronic devices, some questions about their fundamental opto-electronic properties remain unanswered. For example, determining the effective mass of charge carriers in 2D perovskites is challenging, with most attempts so far limited to density functional theory (DFT) calculations. In principle, it is interesting to understand how the charge-carrier effective mass changes with increasing n, as the crystal structure evolves from that imposed by the large organic spacer L, to the crystal structure determined mostly by methylammonium (MA), i.e., in the bulk limit. Currently, the only report addressing this problem is limited to the case of butylamine (BA) [Blancon et al., Nat. Commun. **9**, 2254 (2018)]. It was shown that the charge-carrier effective mass is enhanced in this 2D perovskite with respect to 3D $MAPbI_3$, and with an increasing number of inorganic sheets n, the effective mass μ decreases, reaching the bulk limit for high n values.

We demonstrate that such an observation does not necessarily apply to all 2D perovskites. With the use of optical spectroscopy in high magnetic fields, we observe interband Landau-level transitions which provide direct access to the reduced effective mass μ of the charge carriers in 2D $(PEA)_2MA_{n-1}Pb_nI_{3n+1}$ perovskites, where n = 1, 2, 3 (see Figure for structure schematics). We demonstrate that μ increases with the number of inorganic layers n, reaching the same value as 3D $MAPbI_3$ already for n = 3. Our observations prove that an appropriate choice of organic spacer and inorganic layer thickness provide efficient methods to engineering the charge-carrier effective mass in 2D perovskites, which can be either lower or higher than in their 3D analogues. Having precisely determined μ, we also report on all important exciton parameters, such as binding energy, in-plane radius, and how these parameters evolve with increasing n. Our experimentally determined parameters can serve as a benchmark for first-principles calculations and exciton models.

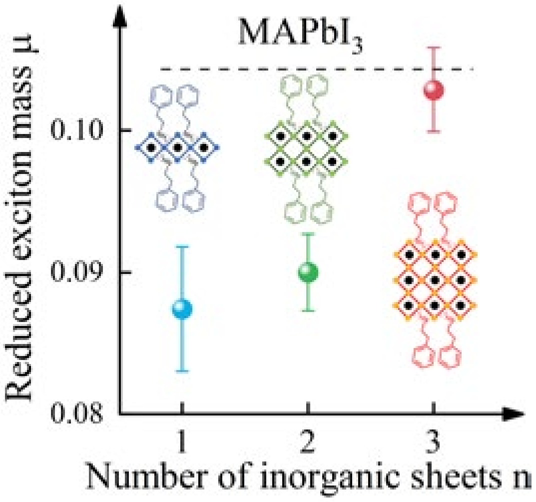

Figure: Evolution of the reduced effective mass μ with increasing number of inorganic sheets. Insets show the schematics of each sample (c axis pointing upwards): Black and open spheres stand for Pb and I atoms and build the inorganic framework; phenyl rings with attached ethylammonium groups form large organic spacers L (PEA, $C_6H_5C_2H_4NH_3^+$). For clarity, the small organic cation (MA, methylammonium) filling the octahedral voids is omitted.

Tuning the Excitonic Properties of 2D $(PEA)_2(MA)_{n-1}Pb_nI_{3n+1}$ Perovskite Family via Quantum Confinement, M. Dyksik, S. Wang, W. Paritmongkol, D. K. Maude, W. A. Tisdale, M. Baranowski, and P. Plochocka, J. Phys. Chem. Lett., in press; https://dx.doi.org/10.1021/acs.jpclett.0c03731

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UNCONVENTIONAL HALL RESPONSE IN THE QUANTUM LIMIT OF HfTe$_5$

S. Galeski, J. Gooth, MPI CPfS and T. Förster, HLD Dresden

The quantum Hall effect is a prominent example of a quantum phenomenon that is of great importance for research in solid-state physics and the application of electronic devices. Since 1990, it defines the standard used in resistance calibrations. It is and was used to probe numerous topological states of matter and helped significantly to understand these systems.

The quantum Hall effect is usually observed in two-dimensional metals, but now quantized Hall states appeared in high-quality crystals of HfTe$_5$. A team from the Max Planck Institute for Chemical Physics of Solids (MPI CPfS) in Dresden, the Technische Universität Dresden, the Brookhaven National Laboratory, the Chinese Academy of Sciences, and HLD at the Helmholtz-Zentrum Dresden-Rossendorf discovered a new strongly correlated electronic state in this three-dimensional metal that is a close relative of the two-dimensional quantum Hall state.

Our measurements reveal an unconventional correlated electron state manifested in the Hall conductivity of the bulk semimetal HfTe$_5$ in the quantum limit, adjacent to the 3D integer quantum Hall effect at lower magnetic fields. The observed plateau-like feature is accompanied by a Shubnikov-de Haas minimum in the longitudinal electrical resistivity and its magnitude is approximately given by $3/5(e^2/h)k_{F,z}/\pi$, where $k_{F,z}$ is the relevant Fermi wave vector (Figure, left panel).

To exclude that these features are caused by the presence of a second pocket at the Fermi energy, we have performed pulsed-field magneto-transport measurements up to 70 T. These high-field measurements show no evidence for a second Fermi-surface sheet (Figure, right panel)

Analysis of derivative relations and estimation of the gap energies suggest that this feature is related to quantum Hall physics. The absence of this unconventional feature in the quantum limit of isostructural single-band ZrTe$_5$ samples with similar electron mobility and Fermi wave vector indicates the presence of a correlated state that may be stabilized by spin–orbit coupling.

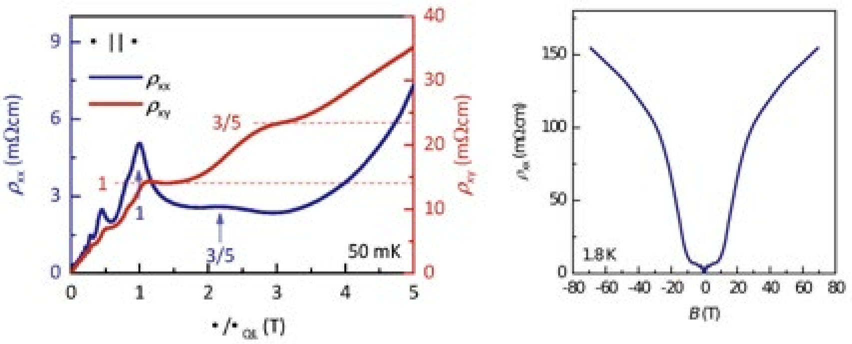

Figure: Left panel: Longitudinal electrical resistivity ρ_{xx} (blue, left axis) and Hall resistivity ρ_{xy} (red, right axis) of HfTe$_5$ as a function of B/B_{QL} at T = 50 mK with the magnetic field B applied along the z direction for $0 T \leq B \leq 9 T$. The blue arrows mark the onset of the Landau levels. B_{QL} = 1.8 T denotes the magnetic field of the onset of the N = 1 Landau level. The blue numbers label the index N of the Landau level and the red numbers label the corresponding value of ρ_{xy} with respect to $(h/e^2)\pi/k_{F,z}$. Right panel: Longitudinal electrical resistivity ρ_{xx} of HfTe$_5$ at 1.8 K as a function of magnetic field up to ±70 T

Unconventional Hall response in the quantum limit of HfTe$_5$, S. Galeski, X. Zhao, R. Wawrzyńczak, T. Meng, T. Förster, P. M. Lozano, S. Honnali, N. Lamba, T. Ehmcke, A. Markou, Q. Li, G. Gu, W. Zhu, J. Wosnitza, C. Felser, G. F. Chen, and J. Gooth, Nat. Commun. **11**, 5926 (2020).

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RESULTS OF THE TWENTY-FOURTH CALL FOR ACCESS

On November 15th, 2020, the 24th call for access ended. Proposals for research activities requiring access to the large-scale high magnetic field facilities collaborating within EMFL were submitted to be ranked on a competitive basis.

Our four facilities

- LNCMI - Grenoble - France: Static magnetic fields to 36 T
- HFML - Nijmegen - the Netherlands: Static magnetic fields to 38 T
- HLD - Dresden - Germany: Pulsed magnetic fields to beyond 95 T
- LNCMI - Toulouse - France: Pulsed magnetic fields of long duration to over 90 T, and on the microsecond scale to beyond 180 T

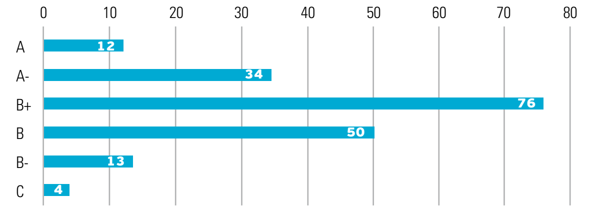
are open to users worldwide. EMFL operates a joint transnational access program, which grants full access to these installations and all associated scientific infrastructure to qualified external users, together with the necessary support from the scientific and technical staff on site.

For this 24th call, 189 applications were submitted, even more than the number we regularly received in pre-COVID-19 times. The proposals came from 18 different countries and were evaluated by the EMFL selection committee until December 15th, 2020. The Selection Committee consists of 18 specialists covering the following five scientific topics:

- Metals and Superconductors (53 applications),
- Magnetism (72 applications),
- Semiconductors (53 applications),
- Soft Matter and Magnetoscience (5 applications),
- Applied Superconductivity (6 applications).

Besides of ranking the proposals, the committee decides on the number of accepted magnet hours and number of pulses.

NEXT CALL :
Launch: April 15th, 2021
Deadline: May 15th, 2021



Evaluation of applications

The proposals are ranked in three classes:

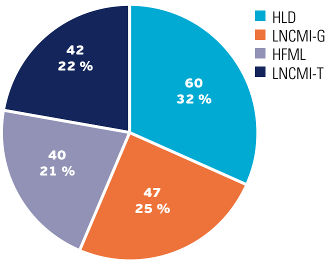
A (excellent proposal to be carried out),

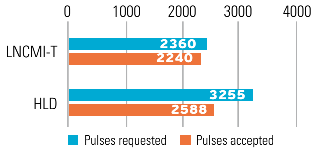
B (should be performed but each facility has some freedom considering other constraints),

C (poorly crafted proposal, or one that does not need any of the four unique high-magnetic-field laboratories).

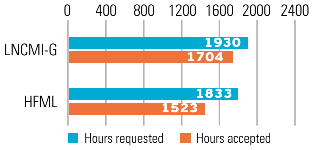
In the B category, the ranking + or - serves as a recommendation to the facility. This degree of freedom is necessary to allow the facilities to consider other aspects such as available capacity and equipment necessary for the successful outcome of a project.

Distribution by facilities
Number of applications

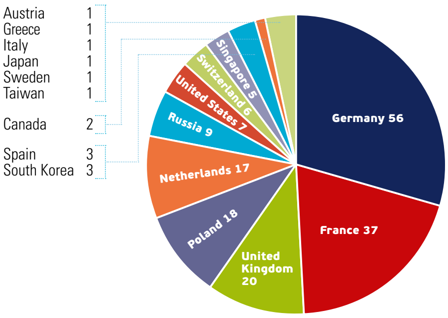




LNCMI-T mobile: no limitation to pulse number



Distribution by country of PI affiliation



CHANGES IN THE EMFL BOARD OF DIRECTORS – GEERT RIKKEN STEPS DOWN AS LNCMI DIRECTOR

Since January 1, 2021, there have been some changes in the composition of the EMFL Board of Directors (BoD). Geert Rikken has stepped down as director of LNCMI and is succeeded by Charles Simon, who will join the EMFL BoD. Peter Christianen, director of HFML, fills the BoD chair position. Changes in the EMFL board do occur more regularly, as the chair position rotates every 2 years, but with Geert Rikken stepping down, a period ends. Geert is one of the founders of EMFL and has been involved in the European collaboration of the high magnetic field facilities from the early start.

The first collaboration was the Integrated Infrastructure Initiative (I3) project EuroMagnet I (2004-2008), which was continued by EuroMagnet II (2009-2013, coordinated by Geert). The great success of these projects resulted in the EMFL –project (2011-2014), finally culminating in the foundation of the legal entity EMFL-AISBL on January 27, 2015. All that time, Geert has been present at the board meetings, the user meeting and schools and supported, wrote and coordinated many European projects. EMFL is in an excellent position and welcomed 3 external members, the University of Nottingham, representing the UK user community (2015), the University of Warsaw, representing the Polish user community (2019) and CEA-IRFU (2019) strengthening the collaboration on magnet technology. The EMFL-AISBL is also participating as partner in 2 European projects ISABEL and SuperEMFL.

The new EMFL Board of Directors

Peter Christianen (Chair)
– Director HFML – Nijmegen

Jochen Wosnitza
– Director HLD – Dresden

Charles Simon
– Director LNCMI – Grenoble & Toulouse

Geert has actively managed many of those activities, being chair of the EMFL BoD for 2 periods and successfully paved the way for the expansion of EMFL. As Geert is the coordinator of the H2020 ISABEL project that stands for 'Improving the Sustainability of the European Magnetic Field Laboratory', he will be closely involved in the further development of EMFL. Fortunately, EMFL can continue profiting from his knowledge, new ideas, and determination to further advance the high magnetic field community.

THANK YOU, GEERT!

SUPEREMFL: TOWARDS ALL-SUPERCONDUCTING USER MAGNETS BEYOND 40 TESLA

The primary objective of the EU funded design study SuperEMFL is to add an entirely new dimension to the EMFL through the development of all-superconducting user magnets at unprecedented field strengths of 40 T and beyond, granting the European high-field user community access to such high superconducting magnetic fields, more magnet time, and novel low-noise high-sensitivity capabilities, whilst at the same time reducing operating costs and the EMFL environmental impact.

SuperEMFL aims to develop a conceptual design report addressing all key questions concerning the technical and conceptual feasibility as well as the maturity of a major upgrade of the EMFL facilities based on the development of the high-temperature superconductor (HTS) technology. In this manner, SuperEMFL addresses both the scientific, organizational, and technical work to provide data, drafts, and plans for the construction, efficient implementation, and the conceptual work to fund and coherently integrate such magnets in the existing facilities.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HTS insert magnet with its instrumentation wiring before mounting on the characterization probe.

The 48-months SuperEMFL design-study project contains several specific components:

- Define appropriate specifications such as homogeneity, stability and bore size according to the users' requirements with two targets: a 32+ as well as a 40+ T all-superconducting user magnet.
- Produce a complete design including a failure-mode analysis and a risk assessment of these all-superconducting user magnets.
- Develop the complete characterization and electrical, thermal and mechanical qualification of the HTS conductors and test coils. SuperEMFL will include characterizing industrial HTS conductors in an extensive manner giving a decisive advantage to the European companies involved in SuperEMFL.
- Demonstrate the feasibility concerning technological challenges through modeling and tests.
- Develop requirements for fabrication in an industrial environment.
- Prepare a funding roadmap to implement the magnets.

The EU Horizon 2020 program INFRADEV aims to support the development of world-class research infrastructures which will help Europe to tackle grand challenges in science, industry, and society. It facilitates and supports the implementation and long-term sustainability of the research infrastructures identified by the European Strategy Forum on Research Infrastructures (ESFRI) and of other world-class research infrastructures. In the SuperEMFL project, the following partners are involved:

- Centre National de la Recherche Scientifique (FR)
- Helmholtz-Zentrum Dresden-Rossendorf e.V. (DE)
- Radboud University (NL)
- Commissariat à l'Énergie Atomique et aux Énergies Alternatives (FR)
- European Magnetic Field Laboratory AISBL (BE)
- Université de Genève (CH)
- Universiteit Twente (NL)
- Institute of Electrical Engineering, Slovak Academy of Sciences (SK)
- Theva Dünnschichttechnik GmbH (DE)
- Oxford Instruments Nanotechnology Tools Limited (UK)
- Bilfinger Noell GmbH (DE)

The kick-off meeting was held on January 25th, 2021.

UPCOMING EVENTS

1. APS March Meeting, March 15-19, 2021.
   https://march.aps.org/
   VIRTUAL

2. The International Magnetics Conference (INTERMAG), Lyon, France, April 26-30, 2021.
   https://intermag.org/
   VIRTUAL

3. CM&LTP 2021, Condensed Matter and Low Temperature Physics 2021, Kharkiv, Ukraine, June 6-12, 2021.
   http://ilt.kharkov.ua/cmltp2021/index.html

4. DPG Meeting of the Condensed Matter Section, Berlin, Germany, **probably** September 26-October 1, 2021.
   https://www.dpg-physik.de/aktivitaeten-und-programme/tagungen/fruehjahrstagungen/herbst_2021

5. MT27, International Conference on Magnet Technology, Fukuoka, Japan, November 15-19, 2021.
   http://csj.or.jp/conference/MT27/

6. International Conference on Magnetism (ICM), Shanghai, China, July 3-8, 2022.
   http://www.icm2021.com/
   SHIFTED

7. International Conference on the Physics of Semiconductors (ICPS), Sydney, Australia, June 26- July 1, 2022.
   https://www.icps2022.org/

8. 29th International Conference on Low Temperature Physics (LT29), Sapporo, Japan, August 2022.
   http://www.lt29.jp
   SHIFTED


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