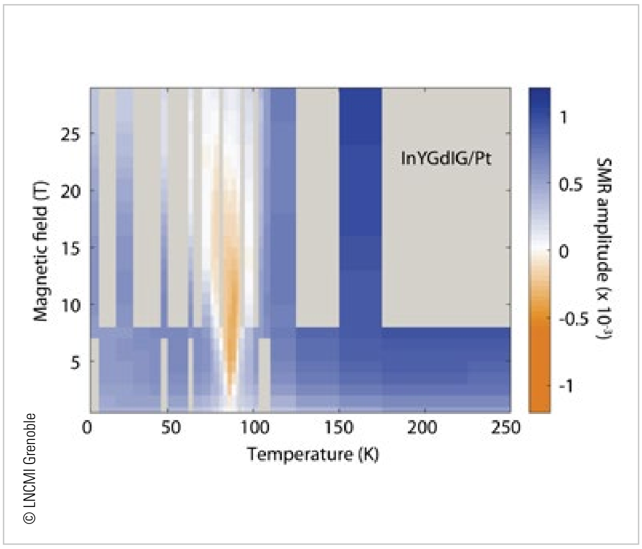
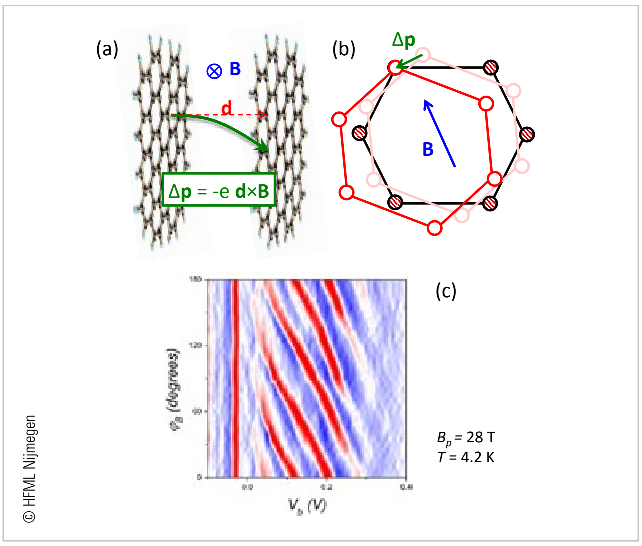
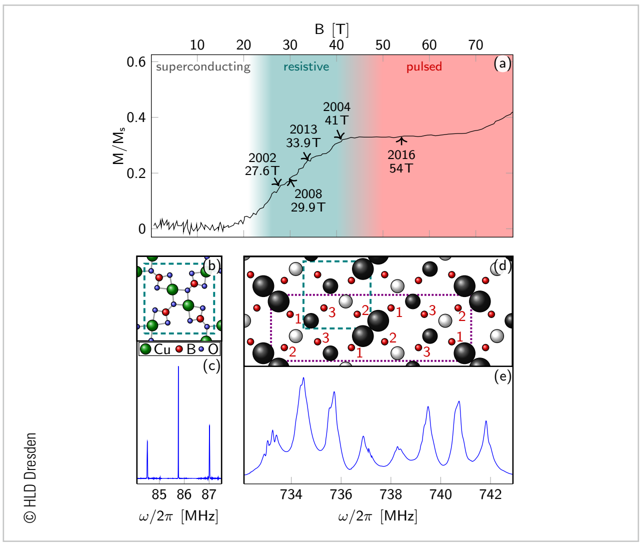
European Magnetic Field Laboratory

EMFLNEWS

N°3 2016







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DEAR READER

The EMFL staff has just returned from a joint meeting in Königstein (near Frankfurt/Main), where all aspects of the EMFL operation were discussed, with the ultimate aim to provide a better service to our users. Some concrete outcomes from these discussions will become evident in the coming months.

We have already informed you about the creation of the Global High Magnetic Field Forum, which unites all major high field facilities worldwide, in order to coordinate and lobby for high-field research. You can now follow the activities of this group online: http://globalhiff.org/

I profit from the occasion to invite you to the next EMFL User Meeting, taking place in Nottingham on June 23rd 2017, where you will be informed of the latest developments and plans of the EMFL facilities, and where you can exchange with facility staff and other users on high-field science and instrumentation. You will receive more information on this meeting in the coming issues of our newsletter.

And of course exciting new scientific results keep on pouring out of the EMFL facilities, as you will see further on in this issue.

Geert Rikken
Director LNCMI
Chairman EMFL

MEET OUR PEOPLE

Daryna Dmytriieva, HLD Dresden

I am a second-year PhD student at the Dresden High Magnetic Field Laboratory (HLD). During my time as a Master student at the Taras Shevchenko National University of Kiev, I had the opportunity to perform some key experiments at the University of Konstanz, where I was impressed by the excellent scientific environment.

Being given the opportunity to pursue my PhD research at the HLD, I honestly can say that I loved it from the first glance. Having always felt myself as an experimental physicist, I was and still am very excited about the superb instrumental infrastructure that allows to perform experiments on tiny samples at extremely low temperatures and in very strong fields, generated by superconducting magnets and the pulsed-field installations of the HLD.

My research is focused on low-dimensional quantum spin systems with strong magnetic frustration, yielding new and exciting ground states in high magnetic fields. The exploration of these new states of quantum matter is very important not only for fundamental research (as acknowledged by the 2016 Nobel Price in Physics), but also for the understanding of several topical phenomena, such as unconventional high-temperature superconductivity, that emerge from complex electronic interactions. As an experimental technique, I mostly use nuclear magnetic resonance (NMR). NMR is a powerful probe to get microscopic insight into magnetic and electrical material properties. With our instrumental setups, we can cover a wide range of temperatures, down to less than one degree above absolute zero, and magnetic fields up to beyond 90 Tesla.

Our NMR team is multinational and very amicable, and we often pursue a coordinated approach to reach our goals in the experiments. Also, I get in regular contact with external users of the HLD, which stimulates a lot of fruitful discussions, often helping to generate new ideas for my own research.

› Members of the NMR group in Dresden: Daryna Dmytriieva, Dr. Hannes Kühne, Dr. Zhitao Zhang, Sebastian Molatta (from left to right)

ELECTRICAL DETECTION OF MAGNETIZATION CANTING IN A MAGNETIC INSULATOR

Kathrin Ganzhorn and Sebastian T. B. Goennenwein, Walther-Meißner-Institut, Garching
Benjamin Piot, LNCMI-Grenoble

In addition to collinear magnetic order, magnetic materials can exhibit a large variety of other types of order, such as canted, spiral, frustrated or even topological states. However, unravelling these different magnetic structures usually requires sophisticated methods, e.g., spin-polarized neutron scattering, x-ray magnetic circular dichroism, or Lorentz transmission electron microscopy. Here, we present a method for the electrical detection of magnetic phases based on the spin Hall magnetoresistance effect (SMR). The SMR has been extensively studied in heterostructures consisting of a collinear ferrimagnetic insulator (MI) with net magnetization M and a normal metal (NM) with large spin-orbit coupling such as Pt. Owing to the spin Hall effect, a charge current driven through the Pt is accompanied by a spin current with a spin polarization s, which is either transmitted into or reflected at the interface of the magnetic system, depending on the orientation of M. This leads to a magnetization orientation dependent modulation of the resistance in the metal – the so-called spin Hall magnetoresistance effect.

We have measured the SMR in a MI/Pt bilayer based on the compensated ferrimagnet (In,Y)-doped $Gd_3Fe_5O_{12}$ (InYGdIG) as the MI. InYGdIG assumes a canted phase around its compensation temperature T_{comp} = 85 K, whereas it exhibits collinear ferrimagnetism both well above and well below T_{comp}. We extract the amplitude of the SMR effect from measurements at the LNCMI-Grenoble in magnetic fields up to 29 T in the collinear as well as in the canted phase, and observe a sign change (red pocket in the Figure) around T_{comp}. The latter can be understood in terms of canted magnetic sublattices, as confirmed by atomistic spin calculations. Our analysis furthermore suggests that the SMR response in $Gd_3Fe_5O_{12}$ is dominated by the iron sublattice magnetizations. Taken together, our results clearly show that the SMR is not governed by the net magnetization, but by the orientation of magnetic moments on different sublattices. This suggests that SMR experiments can be used to map out different magnetic phases in magnetic insulators.

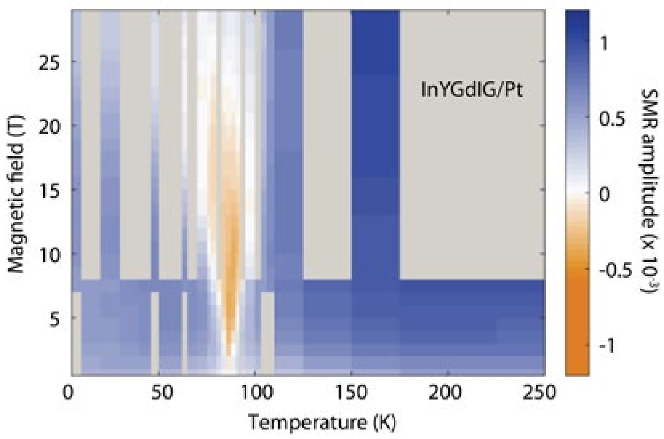

Figure: False-color plot of the SMR amplitude in (In,Y)-doped $Gd_3Fe_5O_{12}$/Pt measured as a function of temperature and magnetic field. A sign change of the SMR is evident as the red pocket around 85 K, where the Fe and Gd sublattice magnetizations are canted.

Spin Hall magnetoresistance in a canted ferrimagnet, K. Ganzhorn, J. Barker, R. Schlitz, B. A. Piot, K. Ollefs, F. Guillou, F. Wilhelm, A. Rogalev, M. Opel, M. Althammer, S. Geprägs, H. Huebl, R. Gross, G. Bauer and S. T. B. Goennenwein, Phys. Rev. B **94**, 094401 (2016).

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CHIRALITY OF GRAPHENE ELECTRONS MANIPULATED IN HIGH MAGNETIC FIELDS

Sergio Pezzini, Steffen Wiedmann, Uli Zeitler, HFML Nijmegen; Benjamin Piot, Marek Potemski, LNCMI Grenoble

Apart from the conventional properties charge and spin, electrons in graphene possess an additional degree of freedom: pseudospin which quantifies the contributions to the electronic wave functions from the two sublattices. Such electrons can then be described as chiral particles with their pseudospin locked to the direction of their momentum in a parallel or antiparallel fashion for electrons belonging to the K or K' valley, respectively. This makes them promising candidates to perform new types of experiments as a basis of novel quantum-information devices. However, in general electrons with different chirality and pseudospin contribute to the transport phenomena in standard experiments on graphene, and it is not straightforward to observe and manipulate them individually in real devices.

Scientists from Manchester and Nottingham (United Kingdom), Chernogolovka (Russia) and the two EMFL Labs LNCMI-CNRS in Grenoble and HFML-RU/FOM in Nijmegen have now achieved both: Using vertical tunneling between two nearly aligned graphene sheets in strong magnetic fields they succeeded in observing and manipulating the chirality and pseudospin polarization.

The devices used are van der Waals heterostructures consisting of two stacked graphene (Gr) layers with 3-5 monolayers of hexagonal boron nitride (hBN) acting as a tunneling barrier in between. Due to a slight misalignment (~1 degree) resonantly tunneling electrons between the two graphene layers can only originate from specific regions of momentum space although contributions from different chiral states remain indistinguishable. However, when applying a large magnetic field of up to 30 T perpendicular to the tunneling direction, the Lorentz force leads to an additional momentum acquired by the tunneling electrons parallel to the graphene layers and perpendicular to the applied magnetic field. This so-called Lorentz boost Δp is defined by the thickness of the hBN, the tunneling direction, and the magnetic field.

In particular, this makes it possible to overcome the momentum mismatch between the two slightly misaligned graphene layers, thereby enhancing the tunneling probability from a specific valley in one graphene layer to the same valley in the adjacent layer. Depending on the angle of the magnetic field, one specific chirality can tunnel easily thought the boron nitride whereas the other one is suppressed yielding a significant chiral selection of the tunneling electrons.

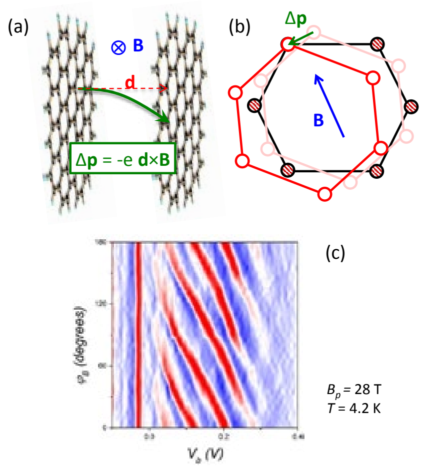

Figure: (a) Schematics of the Lorentz boost for electrons tunneling between two graphene layers.
(b) Momentum-space representation of the two slightly misaligned graphene layers. Due to the in-plane magnetic field the Brillouin zone of the second layer is shifted by Δp, thereby bringing its top left valley in resonance with a valley in the adjacent layer.
(c) Differential conductance map of a Gr-hBN-Gr tunneling device as a function of bias voltage and angle of the in-plane magnetic field. The 60°-periodic pattern originates from resonances with one of the six K-valleys in the corners of the first Brillouin zone and the asymmetry in the pattern reflects the chiral selection.

Tuning the valley and chiral quantum state of Dirac electrons in van der Waals heterostructures, J. R. Wallbank, D. Ghazaryan, A. Misra, Y. Cao, J. S. Tu, B. A. Piot, M. Potemski, S. Pezzini, S. Wiedmann, U. Zeitler, T. L. M. Lane, S. V. Morozov, M. T. Greenaway, L. Eaves, A. K. Geim, V. I. Fal'ko, K. S. Novoselov and A. Mishchenko, Science **355**, 575 (2016).

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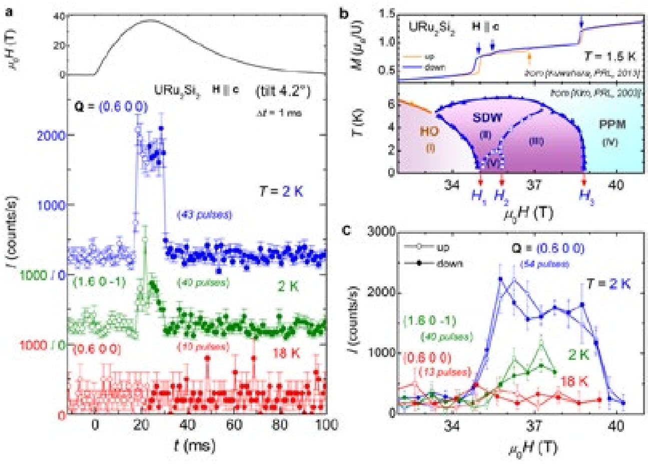
FIELD-INDUCED SPIN-DENSITY WAVE BEYOND HIDDEN ORDER IN URu_2Si_2

William Knafo and Fabienne Duc, LNCMI-Toulouse

URu_2Si_2 is one of the most enigmatic strongly correlated electron systems and offers a fertile test ground for new concepts in condensed-matter science. In spite of more than thirty years of intense research, no consensus on the order parameter of its low-temperature hidden-order phase exists. Under a high magnetic field applied along c, a cascade of first-order phase transitions leads to a polarized paramagnetic regime above the c direction. Here, thanks to a new cryomagnet (developed by the LNCMI-Toulouse, the CEA-Grenoble, and the ILL-Grenoble) allowing neutron diffraction up to 40 T, we have determined that URu_2Si_2 enters in a spin-density wave state in fields between 35 and 39 T. The transition to the spin-density wave represents a unique touchstone for understanding the hidden-order phase.

The Figure shows the diffracted neutron intensities recorded in magnetic fields up to 40 T at the momentum transfers $\mathbf{Q}$ = (0.6 0 0) and (1.6 0 -1), which are satellites of wavevector $\mathbf{k}_1 = \mathbf{Q} - \boldsymbol{\tau}$ = (0.6 0 0) around the structural Bragg positions $\boldsymbol{\tau}$ = (0 0 0) and (1 0 -1), respectively. The enhancement of the intensity at 2 K, absent at 18 K, shows that the spin-density wave with wavevector $\mathbf{k}_1$ is established at high field and low temperature. In an itinerant picture of magnetism, a spin-density wave can be related to a partial or complete nesting of two parts of the Fermi surface. In URu_2Si_2, our observation of a spin-density wave in magnetic fields between 35 and 39 T will certainly push to develop models incorporating on equal basis the Fermi-surface topology and the magnetic interactions. To describe competing quantum instabilities between the hidden-order and long-range-ordered phases, such models will be a basis to solve the hidden-order puzzle.



› Figure: (a) Time profile of a magnetic field pulsed up to 38 T, and corresponding time-dependence of the neutron-diffracted intensity at $\mathbf{Q}$ = (0.6 0 0) and $\mathbf{Q}$ = (1.6 0 -1). (b) Magnetization versus magnetic field at T = 1.5 K and magnetic-field-temperature phase diagram of URu_2Si_2. (c) Field dependence of the neutron-diffracted intensities in fields up to 40.5 T.

Field-induced spin-density wave beyond hidden order in URu_2Si_2, W. Knafo, F. Duc, F. Bourdarot, K. Kuwahara, H. Nojiri, D. Aoki, J. Billette, P. Frings, X. Tonon, E. Lelièvre-Berna, J. Flouquet, and L.-P. Regnault, Nat. Commun. **7**, 13075 (2016).

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PULSED-FIELD BROADBAND NMR OF $SrCu_2(BO_3)_2$

Jonas Kohlrautz, University of Leipzig, and Hannes Kühne, HLD Dresden

The spin-dimer antiferromagnet $SrCu_2(BO_3)_2$ was investigated in great detail over the past two decades, as it represents the most prominent realization of the Shastry-Sutherland lattice model. In this material, electronic spins of Cu^{2+} ions within the $Cu_2(BO_3)_2$ layers form a lattice of mutually orthogonal spin-singlet dimers with significant interdimer interaction, giving rise to pronounced magnetic frustration.

At high magnetic fields, triplet states with reduced kinetic energy condense, resulting in a field-driven sequence of magnetic superlattices with corresponding plateaus in the macroscopic magnetization. The microscopic detection of these superlattice structures by means of NMR as a local probe is of great interest. To study all magnetization plateaus up to half of the saturation value, pulsed magnetic fields up to the regime of 100 T are required. A team of Estonian, Canadian, and German scientists from Leipzig University, the NICPB (Tallinn), McMaster University (Hamilton), and the HLD has performed NMR measurements on $SrCu_2(BO_3)_2$ in pulsed magnetic fields. The results are in very good agreement with a transition from a high-temperature, paramagnetic state to a low-temperature, commensurate superstructure of field-induced spin-dimer triplets in the 1/3 magnetization plateau. Moreover, the technical approach to measure broadband NMR in pulsed fields, that was developed in the course of this work, opens the door not only to the exploration of the higher-field ground states of $SrCu_2(BO_3)_2$, but also to studies of many other quantum magnets with complex interactions that stabilize new phases of matter in very strong magnetic fields.

Field-stepped broadband NMR in pulsed magnets and application to $SrCu_2(BO_3)_2$ at 54 T, J. Kohlrautz, J, Haase, E.L. Green, Z. T. Zhang, J. Wosnitza, T. Herrmannsdörfer, H. A. Dabkowska, B. D. Gaulin, R. Stern, and H. Kühne, J. Magn. Reson. **271**, 52 (2016).

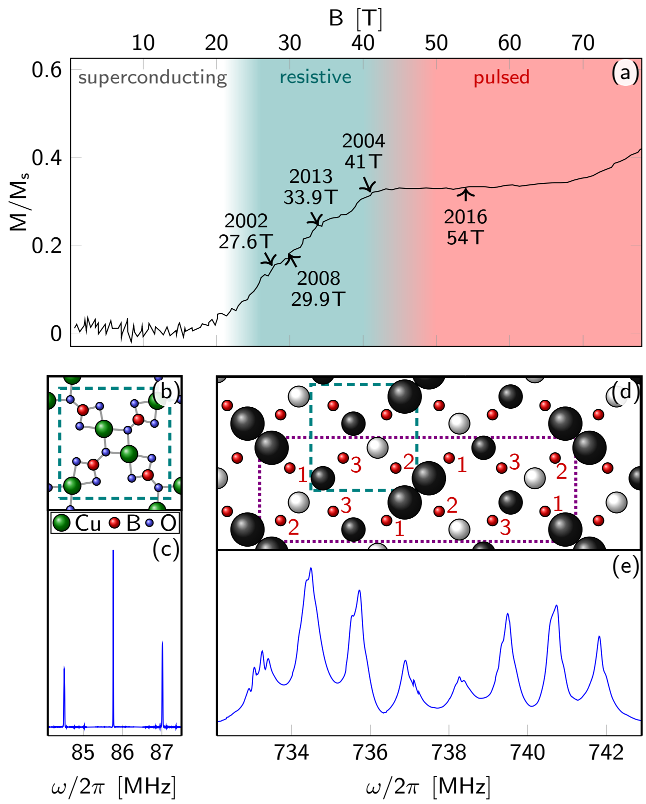

Figure: (a) Macroscopic magnetization of $SrCu_2(BO_3)_2$ at 2 K (from Matsuda et al.). (b) Unit cell of the $Cu_2(BO_3)_2$ plane and (c) the corresponding ^{11}B NMR spectrum at 6 T and 5 K. (d) Magnetic superlattice in the 1/3 magnetization plateau with three different ^{11}B sites (red spheres). White and black spheres represent negative and positive spin polarization, their size the magnitude. (e) ^{11}B NMR spectrum at 54 T and 2 K.

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OPENING OF THE SIXTEENTH CALL FOR ACCESS

The 16th call for proposals has been launched in October, 2016 inviting researchers worldwide to apply for access to one of the large installations for high magnetic fields collaborating within EMFL.

The four facilities

- LNCMI - Grenoble - France: Static magnetic fields up to 36 T
- HFML - Nijmegen - the Netherlands: Static magnetic fields up to 37,5 T
- HLD - Dresden - Germany: Pulsed magnetic fields to beyond 90 T
- LNCMI - Toulouse - France: Pulsed magnetic fields of long duration to beyond 80 T and on the microsecond scale to beyond 180 T

run a joint proposal program, which allows full access to their installations and all accompanying scientific infrastructure to qualified external users, together with the necessary support from their scientific and technical staff.

Users may submit proposals for access to any of these installations by a unified procedure. The online form for these proposals can be found on the EMFL website.
www.emfl.eu/user

The next deadline for proposals for magnet time is November 15, 2016.

The proposals will be evaluated by a Selection Committee. Selection criteria are scientific quality (originality and soundness), justification of the need for high fields (are there good reasons to expect new results) and feasibility of the project (is it technically possible and are the necessary preparations done). It is strongly recommended to contact the local staff at the facilities to prepare a sound proposal and ideally indicate a local contact. There is no support from the EU available anymore. Therefore, only occasional travel and subsistence support may be provided for users. If such a support is necessary, users are requested to contact the facility.

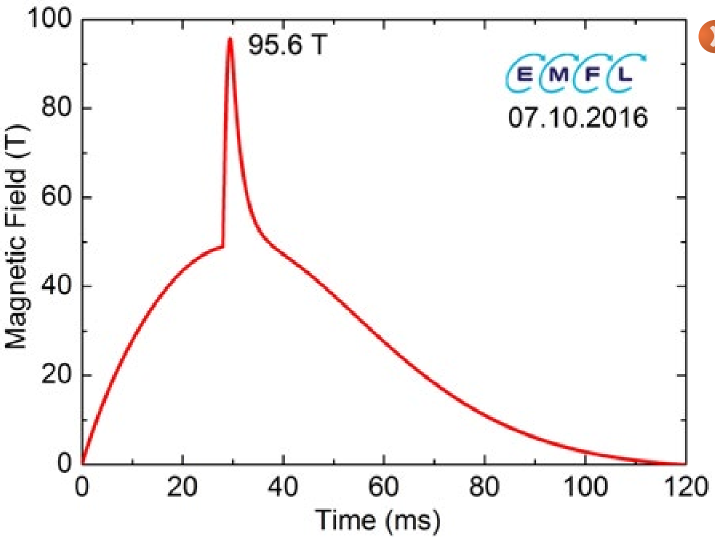
- You may find more information on the available infrastructures for user experiments on the facility websites.

www.hzdr.de/hld
www.lncmi.cnrs.fr
www.ru.nl/hfml

EMFL
European Magnetic Field Laboratory

The EMFL develops and operates world class high magnetic field facilities, to use them for excellent research by in-house and external users.

NEW EMFL 95 T NON-DESTRUCTIVE MAGNET

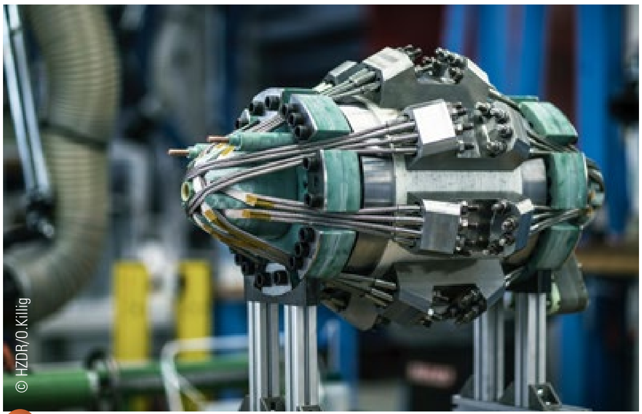


Magnetic field versus time in the new HLD 95 T dual-coil magnet.

Recently, the HLD team has managed to successfully reach 95.6 T (see figure) using a new, non-destructive dual-coil 9.5 MJ magnet with 12 mm bore. Currently, this is the highest magnetic field obtained in Europe non-destructively.

Now, this magnet combined with various experimental techniques is available for users that can prove the necessity for such a high field. This will ultimately be decided on-site by the staff of the HLD in Dresden. Another dual-coil magnet providing up to 85 T in a 16 mm bore is available at the HLD as well.

Scientific proposals for using these very high fields are very welcome.



Dual-coil magnet

WINTER SCHOOL: NEW FRONTIERS IN 2D MATERIALS – APPROACHES & APPLICATIONS

From 15 to 20 January 2017, the winter school „New Frontiers in 2D Materials: Approaches & Applications" will be held in Villard-de-Lans, a small ski resort near Grenoble, France.

The winter school will cover theoretical, experimental, and also technological aspects of current research on novel 2D materials (graphene, silicene, transition-metal dichalcogenides, topological insulators & semiconductor nanostructures) and other emerging systems (multiferroics, materials for spintronics, semiconductor quantum dots, and quantum fluids in polariton structures). It will bring together young researchers – master and doctoral students as well as postdocs – interested in the field of novel 2D materials. The talks by selected renowned invited speakers will introduce the participants to the specific areas of this field and provide them with an overview of recent progress. At the same time, all the participants are strongly encouraged to present the results of their own research during a dedicated poster session.

The winter school is organized within the scope and with the support of the TWINFUSYON project (EC, No. 692034), but is open to all young researchers.

Registration deadline: October 31, 2016

Participation fee:

Double room (per person): 600 EUR ; single room: 800 EUR
This fee comprises accommodation, full board meals, and conference materials

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www.ceitec.eu/winter-school-new-frontiers-in-2d-materials

› The city center of Villard-de-Lans

EMFL DAYS IN KÖNIGSTEIN

At the beautiful site of Königstein im Taunus the third gathering of the EMFL members took place. From 14th to 16th of September 2016 more than 130 people shared their scientific and engineering interests, discussed activities in managing and data-base issues, identified possibilities for future collaborations, had fun visiting Frankfurt am Main, and enjoyed delicious food and sport activities.

For almost two years now, the three laboratories at the four sites in Grenoble, Nijmegen, Toulouse, and Dresden are officially united as EMFL in an international non-profit organization. Last year, the British partner EPSRC (Engineering and Physical Sciences Research Council) joined the EMFL. In the German city of Königstein, we continued to learn more about each other's work and tried to identify routes to further improve. This includes engineering and scientific activities, but as well our work on technological and administrative aspects. Besides this formal program, there also was time for sight-seeing during an informal visit to nearby Frankfurt am Main. In that way, the EMFL members not only had a chance to acquire new information on the EMFL activities, but also to get to know each other better on a personal level. The EMFL members definitely had a great time in the mountainous region of the Taunus.

› More than 130 people attended the three EMFL days in September 2016

Welcome talk by Geert Rikken

Magnet-technology session

Administration session

Session on experimental techniques

KTC Königstein at night

Excursion to Frankfurt/Main

European Magnetic Field Laboratory

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The Netherlands
www.ru.nl/hfml

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LNCMI Toulouse
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France

LNCMI Grenoble
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