This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

Deliverable Number: 7.2	**Due date: 11.30.2021**
Deliverable Title: Second Proceedings Workshops &Conference Sessions **WP number: 7** **Leader Beneficiary: RU** **Deliverable type: Report, Presentations** **Dissemination level: Confidential**	**Reporting period: RP3** **Issue date: 07.11.2024** **Authors: Peter Christianen** **Reviewers: ISABEL Coordination Board**

ISABEL

Improving the sustainability of the European Magnetic Field Laboratory

Second Proceedings Workshops and Conference Sessions

Start date of the project: 1st November 2020

Duration: 60 months

Project Coordinator: Geert Rikken – CNRS LNCMI (P1 - CNRS)

Contact:

Version	Modifications	Date	Author
1.0	First draft	07.11.2024	Peter Christianen
1.1	Comments from Charles Simon &, Jochen Wosnitza	11.11.2024	Peter Christianen

1.2	Comments from Geert Rikken	20.11.2024	Peter Christianen
Final version	Last correction	10/12/2024	Coordination Board

DOCUMENT ABSTRACT

The aim of task 7.2 is to create a global network of parties interested in the development of the next generation of high-field magnets and to stimulate stronger interaction between facilities and other large-scale research infrastructures on the one hand, and industrial companies on the other. This should lead to the definition of a Global Roadmap for future high-field developments.

Starting point of the network is the existing global high-field forum (HiFF), formed by the directors of the individual high magnetic field facilities in the USA, Europe and East Asia, combined with the partners of the ISABEL project. The aim is to identify other partners that are active in high field technology and connect to them. One vehicle to advertise the activities of EMFL to external partners is the participation to conferences and workshops on high field technology.

This document summarizes the list of high-field conferences and workshops attended and an overview of presentations given, specifically to advertise the activities of EMFL to external partners.

Table of contents

1. Identification of partners in high magnetic field research

In the task 7.2 creation of a global network in high-field technology, first the most prominent actors in high-field technology have been identified.

- The partners of the global high-field forum (HiFF)
- The partners within the ISABEL project
- The partners in the SuperEMFL project
- The other large-scale infrastructures in Europe, organized in ARIE, the Analytical Research Infrastructures in Europe
- The partners of FuSuMaTech (Future Superconducting Magnet Technology)
- The High-Field Magnet Network of CERN

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

- The High-Field Magnet Network of ILL
- The partners of the Superconductivity Global Alliance
- The European High Field MRI community, organized in The European Society for Magnetic Resonance in Medicine and Biology (ESMRMB)

2. High Field Meetings and Presentations 2022-2024

The table below shows an overview of the conferences and workshops related to research in high magnetic fields, which took place in the period of 2022-2024.

Conference	Date	Place	Link	Sponsored by EMFL or ISABEL
EMFL user meeting 2022	June 15, 2022	Grenoble (Hybrid)	https://emfl.eu/events/	X
24th Int. Conf. on High Magnetic Fields in Semiconductor Physics HMF-24	July 3 - 8, 2022	On-line Hong Kong	https://hmf24.ust.hk	
7th Superconductivity Summer School	July 7 – 8, 2022	Oxford, UK	https://iop.eventsair.com/sup2022/	X
Pre-meeting Superconductivity Summit Initiative	July 11 – 12, 2022	Oxford, UK	Upon invitation	
EMFL Summer School 2022	Sept. 21 – 25, 2022	Kerkrade, NL	https://www.hfml.ru.nl/emflschool2022/	X
Applied Superconductivity Conference	Oct 23 – 28, 2022	Honolulu, HI, USA	https://ascinc.org/	
Symposium SF02-Materials for Extreme Conditions @ MRS	Nov. 27 – Dec. 2, 2022	Boston, USA	https://tinyurl.com/yc5npdy6	
HiFF meeting	March 8th, 2023	Las Vegas, USA	Upon invitation	
Workshop "Magnetic Fields in **Materials Research**"	May 22 – 24, 2023	Wroclaw, Poland	https://emfl.eu/9603-2/	
EMFL user meeting 2023	June 13 – 14, 2023	Nijmegen, NL	https://emfl.eu/events/	X
Condensed Matter and Quantum Materials (CMQM 2023)	June 28 – 30, 2023	Birmingham, UK	https://www.iop.org/events/condensed-matter-and-quantum-materials-cmqm-2023	
25th EP2DS and 21st MSS	July 9 - 13, 2023	Grenoble, France	https://ep2ds25mss21.sciencesconf.org/	X

16th EUCAS (2023)	Sept. 3 – 7, 2023	Bologna, Italy	https://eucas2023.esas.org/	
Joint annual meeting of the **Swiss Physical Society and Austrian Physics Society 2023**	Sept. 4 - 8, 2023	Basel, Switzerland	https://indico.cern.ch/event/1252545/	X
Regional Meeting on Research in High Magnetic Field	Sept. 6 - 8, 2023	Prague, Czech Republic	https://magnet2023.kfkl.cz	X
28th International Conference on Magnet Technology (MT-28)	Sept. 10 – 15, 2023	Aix-en-Provence, France	www.mt28.aoscongres.com	
UK Magnetic Society Meeting	Nov. 29, 2023	Birmingham, UK	https://ukmagsoc.org/events/ewing23/	X
Science & Technologies in High magnetic Fields	Dec. 6, 2023	Oxford, UK	https://sthmf.web.ox.ac.uk/	X
MAGNET2024 – 8th Italian Conf. on Magnetism	Febr. 7 – 9, 2024	Milano, Italy	https://magnet.aimagn.org/	
EMFL Summer School 2024	April 15 – 19, 2024	Dresden, Germany	https://emfl.eu/emfl-school-2024-dresden/	X
EMFL user meeting 2024	June 11, 2024	Nottingham, UK	https://emfl.eu/emfl-user-meeting-11-june-2024-in-nottingham/	X
International Conference on Magnetism ICM 2024	June 30 – July 5, 2024	Bologna, Italy	www.icm2024.org/	
HiFF meeting	July 7, 2024	Nijmegen, NL	Upon invitation	
Research in High Magnetic Fields (RHMF2024)	July 8 – 11, 2024	Nijmegen, NL	www.hfml.ru.nl/RHMF2024/	X
8th School on Superconductivity	July 9 – 12, 2024	Oxford, UK	https://www.iop.org/events/8th-superconductivity-summer-school	X
EMFL/Japanese collaboration: Megagauss workshop	July 12 – 15, 2024	Toulouse, France	Upon invitation	X
25th Int. Conf. on High Magnetic Fields in Semiconductor Physics (HMF-25)	Sept 16 – 20, 2024	Warsaw, Poland	https://hmf25.fuw.edu.pl/	X
SUPERMAX - International Workshop on Superconductivity & Magnetism in f-Electron Quantum Materials under Extreme Conditions	Oct 14 – 18, 2024	Toulouse, France	https://supermax.sciencesconf.org/	X

Many employees and partners of EMFL participated to these events. Many of these events have been sponsored by EMFL or the ISABEL project, as indicated on the table.

In several cases, a special presentation was given to advertise the activities of EMFL and the ISABEL project:

1) Introduction EMFL, Peter Christianen, EMFL User meeting, June 15, 2022;
2) Introduction EMFL & ISABEL, Amalia Patanè, 7th UK School on Superconductivity, July 7 – 8, 2022;
3) Status EMFL, Jochen Wosnitza, HiFF meeting, March 8, 2023;
4) Introduction EMFL, Charles Simon, EMFL User meeting, June 13 – 14, 2023;
5) Introduction EMFL & ISABEL, Amalia Patanè, CMQM, June 30, 2023;
6) Introduction EMFL & ISABEL, Charles Simon, Joint annual meeting of SPS and APS, Sept. 7th (2023);
7) Introduction EMFL & ISABEL, Jochen Wosnitza, Regional Meeting on Research in High Magnetic Field, Sept. 6th (2023);
8) Introduction EMFL, Amalia Patanè, UK Magnetic Society Meeting, November 29, 2023;
9) Introduction EMFL, Amalia Patanè, UK Science & Technology meeting in High Magnetic Fields, December 6, 2023;
10) Welcome User meeting, Amalia Patanè, EMFL User meeting, June 11, 2024;
11) Introduction EMFL, Charles Simon, EMFL User meeting, June 11, 2024;
12) Poster EMFL & ISABEL, Giuseppe Maruccio, ICM 2024, June 30 – July 5, 2024;
13) Status EMFL, Jochen Wosnitza, HiFF meeting, July 7th, 2024;
14) Introduction EMFL & ISABEL, Amalia Coldea, 8th UK School on Superconductivity, July 9 – 12, 2024.

On behalf of
the EMFL user committee &
the EMFL Board of Directors

Welcome to the EMFL user meeting

June 15th, 2022

Current status & developments

- Operation of the facilities & Output
- Infrastructure developments
- EU projects ISABEL and SuperEMFL

Programme of today

Operation of the facilities & Output

Proposals	2019	2020	2021
User proposals received	367	273	323
User projects executed	257	185	194
Proposals executed mail-in	3	50	76

- Facilities have resumed “regular” operation, still backlog of projects
- Regular calls continued
- Mail-in sample & staff-support procedures in place

Publications	2019	2020	2021
Peer reviewed publications	177	199	189
Of which high impact (5 < IF < 15)	34	46	50
Of which very high impact (IF > 15)	13	13	15
PhD thesis defended	8	7	9

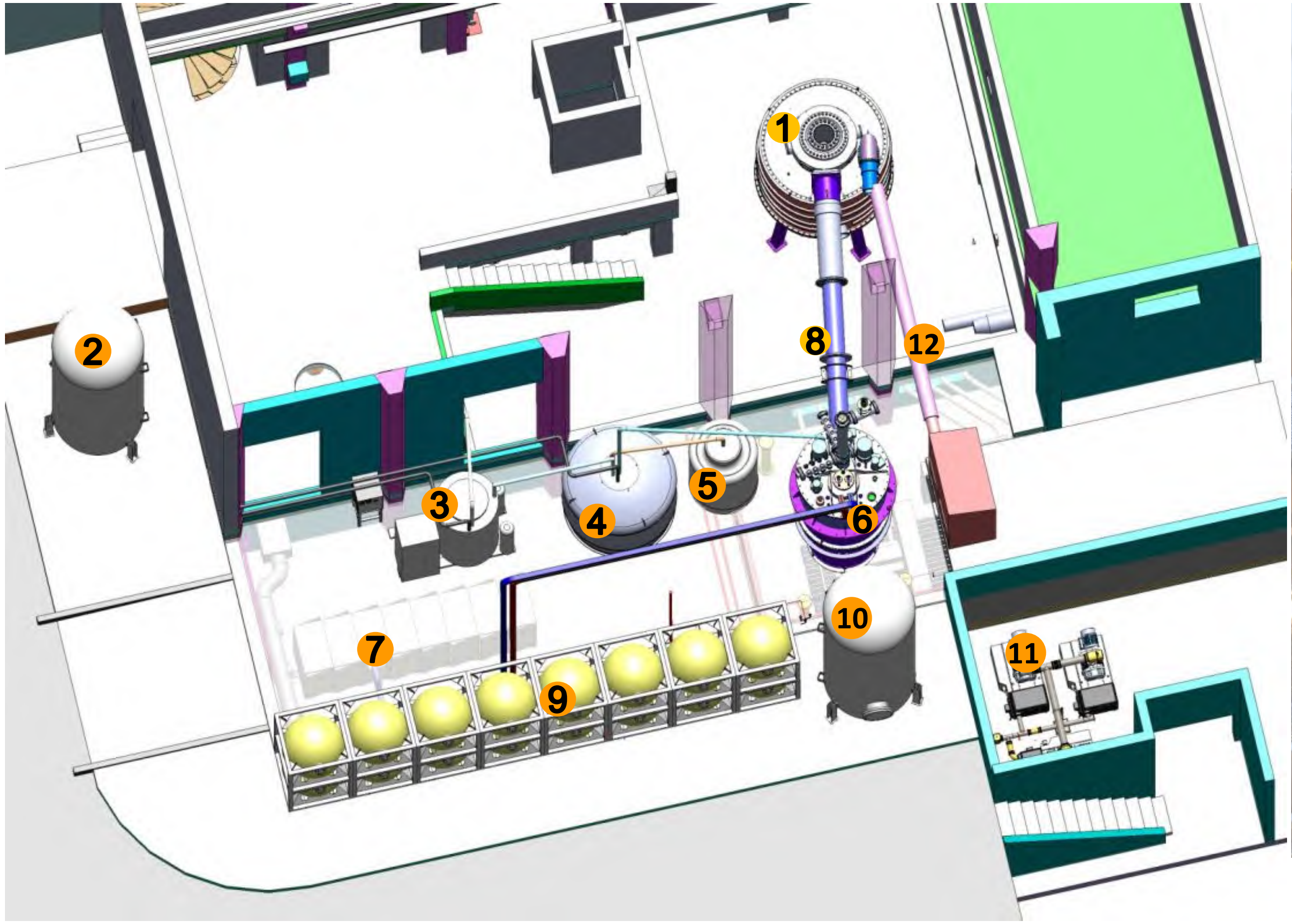
EMFL
European Magnetic Field Laboratory

Infrastructure developments

EMFL-G: 43 T Hybrid system

1. Superconducting Magnet
2. LN_2 tank 27 000 litres.
3. He liquefier coldbox
   150 l/h @ 4.5 K , 1.3 bar
4. Main LHe Dewar 4500 litres
5. Secondary LHe Dewar 1700 litres
6. Cryogenic satellite to produce the 1.8 K LHe bath
7. DC power converter
   7500 A , 30 V (underground)
8. Cryoline with busbars @ 1,8 K
9. High pressure gaseous He tanks
   16 x 1 m^3 @ 200 bars
10. Liquefier pure He buffer tank
    15 m^3 @ 20 bars
11. Helium pumping system
    6000 m^3/h @ 10 mbar, 20 °C
12. Quench line

Already installed (orange)
Installation on going (yellow)

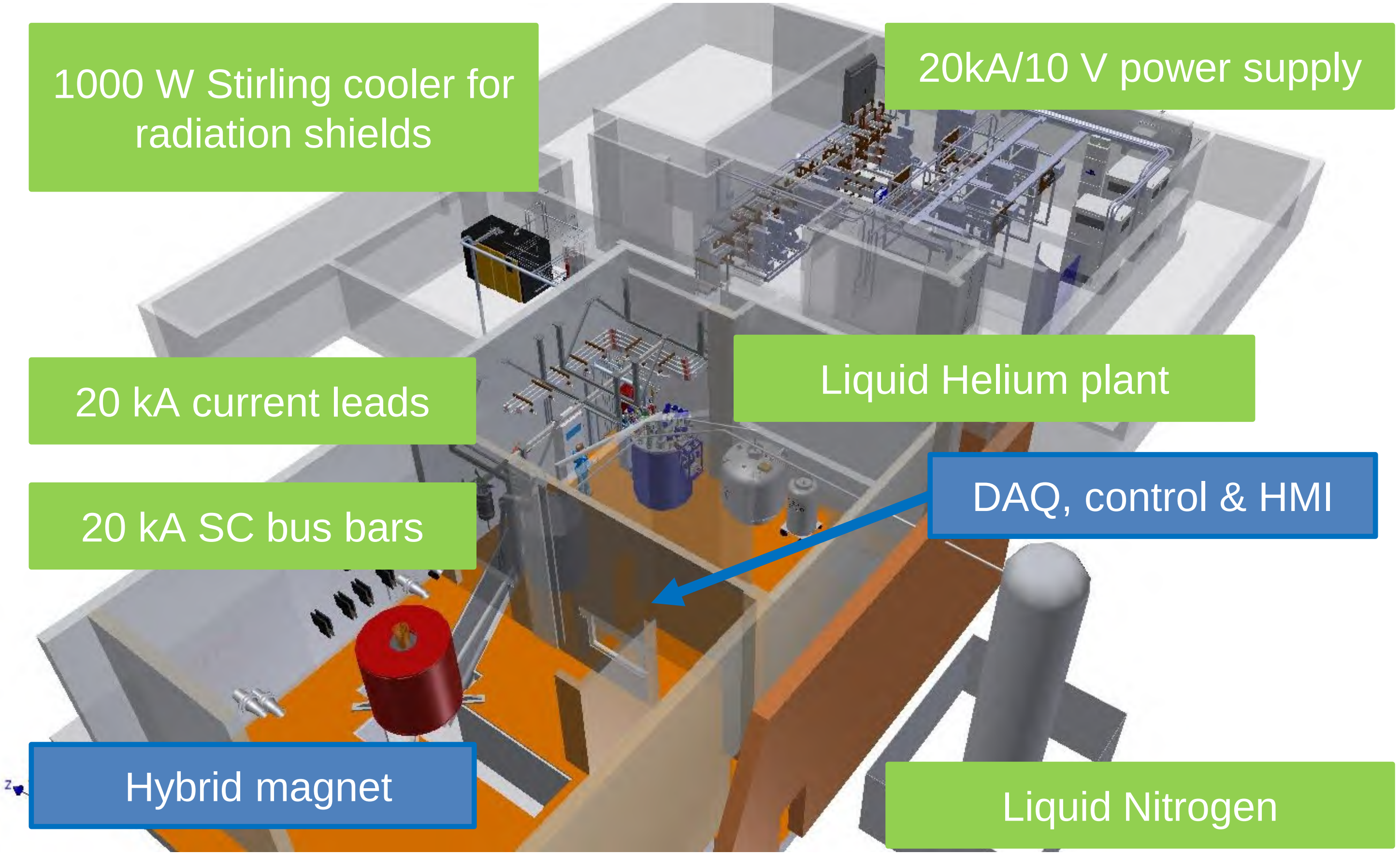


Expected magnet cool-down June 2022

European Magnetic Field Laboratory

Infrastructure developments

EMFL-N: 45 T Hybrid system

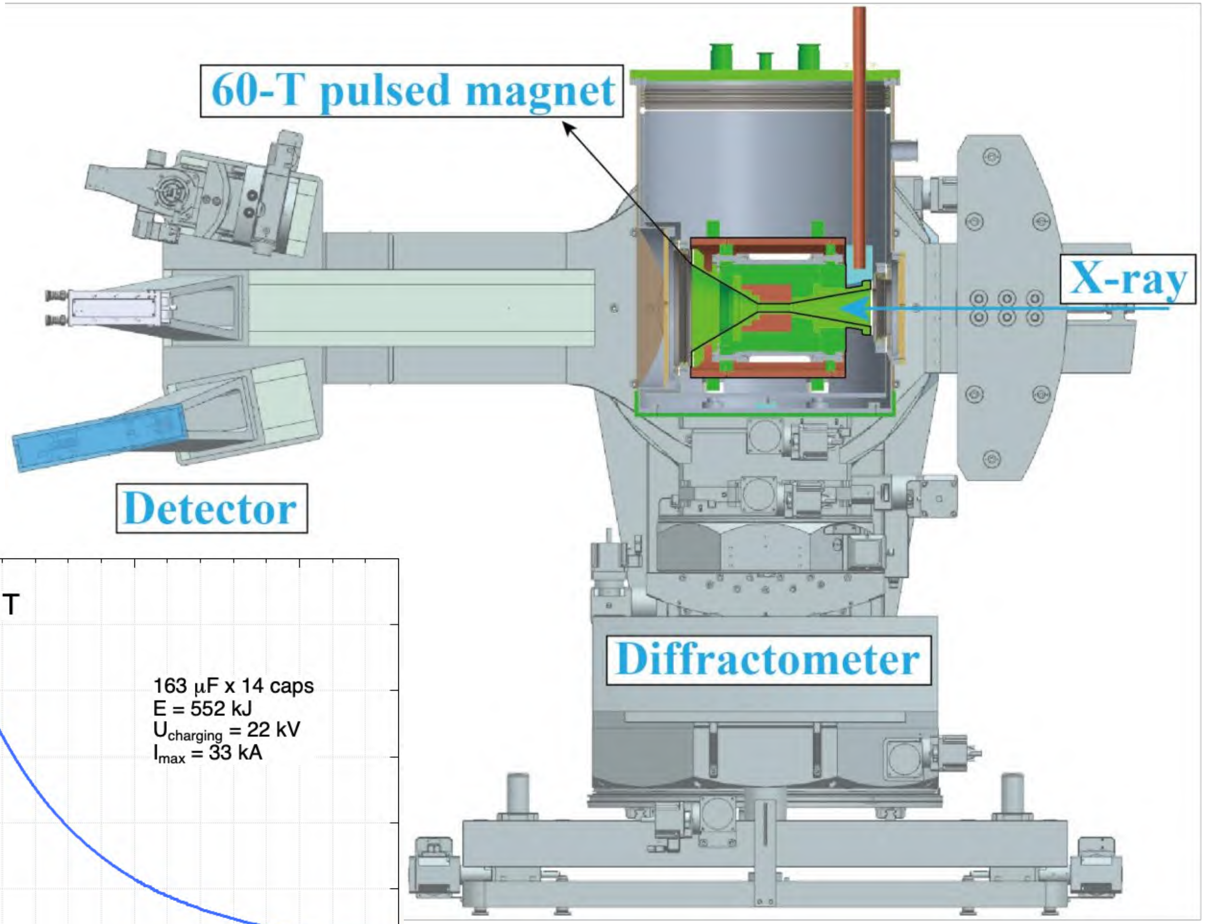


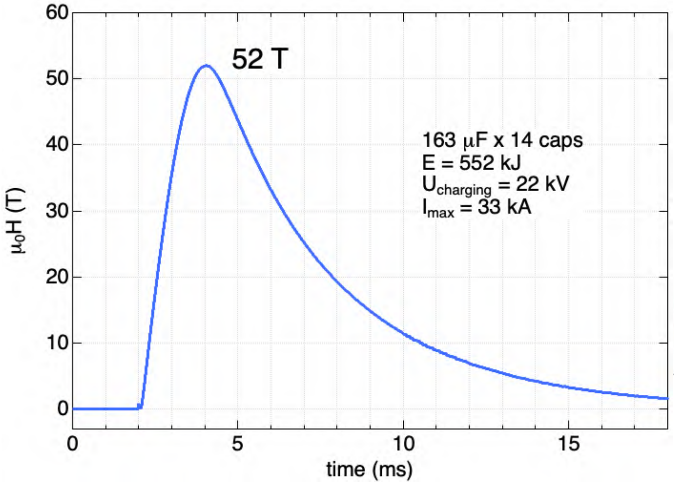
Final test cryostat planned summer 2022
Magnet cool-down planned end of 2022

European Magnetic Field Laboratory

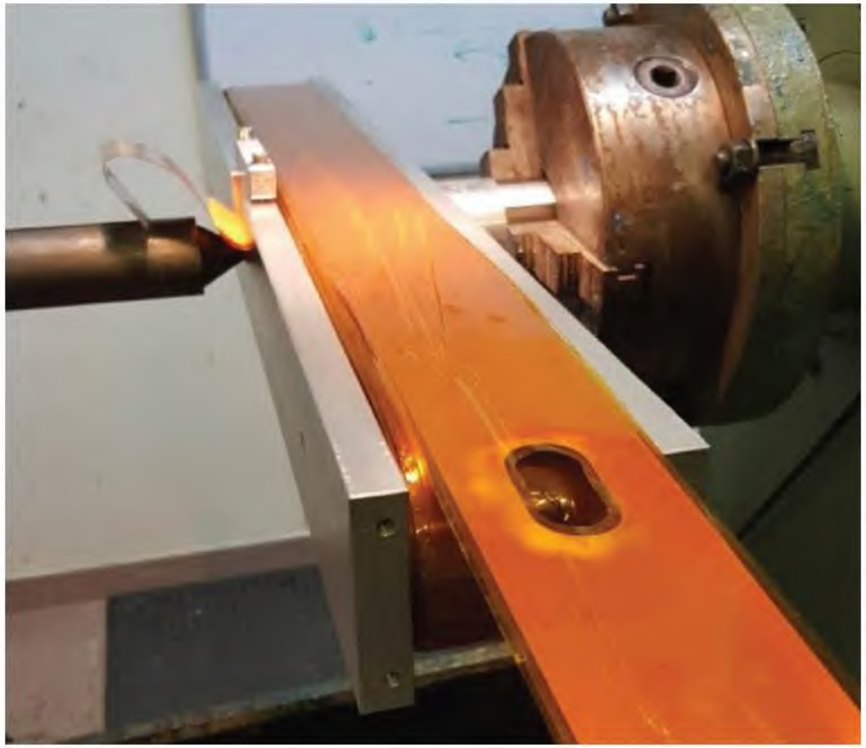
Infrastructure developments

Dresden
Pulsed magnetic fields at XFEL





Toulouse: Design pulsed magnetic dipole for magnetic birefringence measurements



European Magnetic Field Laboratory

ISABEL – Overview

ISABEL – Coordinator: Geert Rikken

Improving the Sustainability of the European Magnet Field Laboratory

2020-2023, 18 partners, of which 5 industrial, budget 4,9 M€, started 1 November 2020

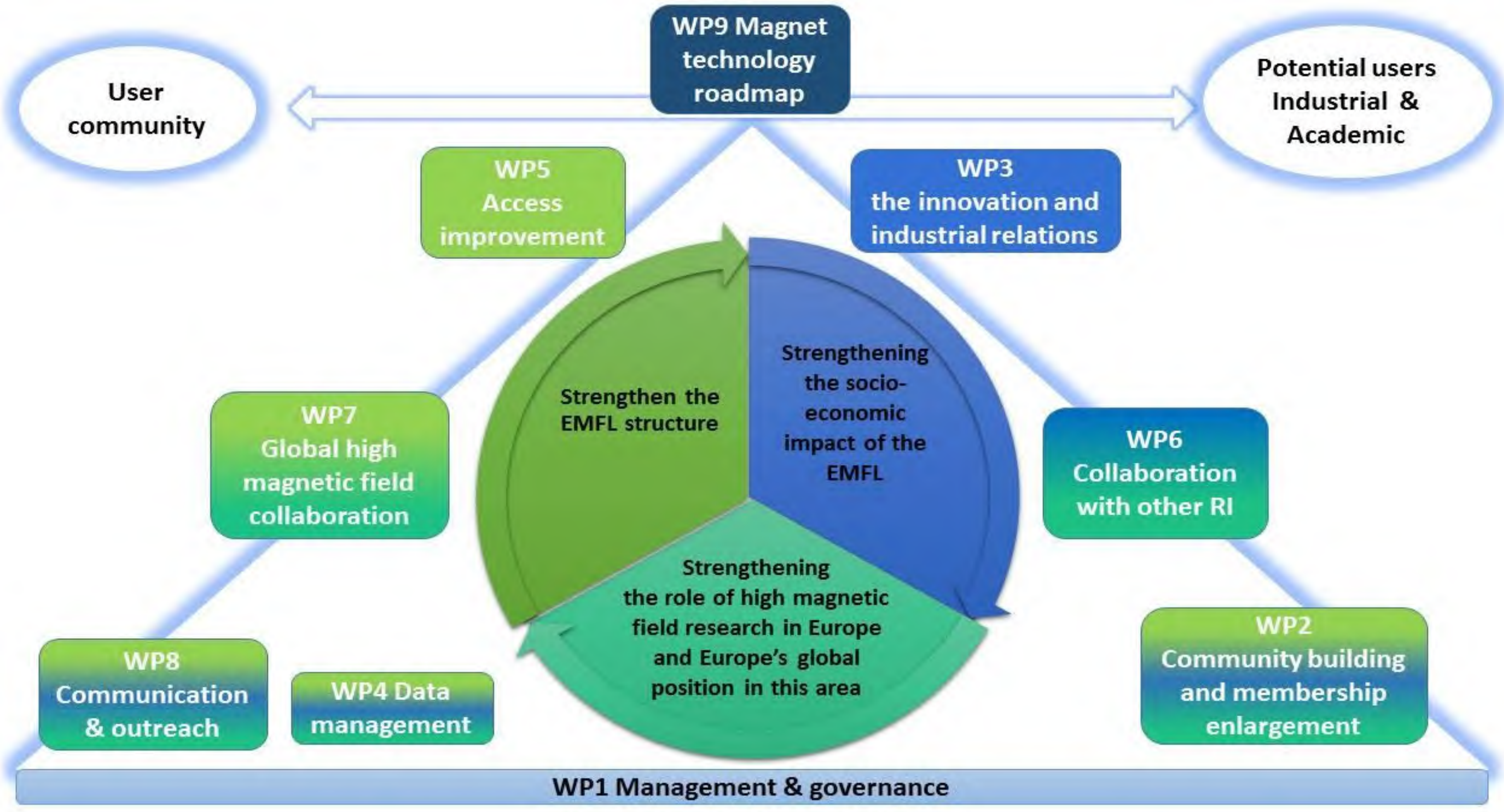
- Strengthen the EMFL structure
- Strengthening role high magnetic field research in Europe and Europe's global position in this area
- Strengthening the socio-economic impact of the EMFL

Report 1st period (till 30-4-22) in preparation

The ISABEL-project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 871106.

European Magnetic Field Laboratory

ISABEL – Overview



European Magnetic Field Laboratory

Regional Partners

UK
University of Nottingham (R. Hill/A. Patanè)
University of Oxford (A. Coldea/S. Blundell)

Poland
University of Warsaw (A. Babinski)

Spain
UAM Madrid (H. Suderow)

Estonia
NICPB, National Institute of Chemical Physics and Biophysics (R. Stern and T. Rõõm)

Czech Republic
Charles University (P. Javorsky)

Italy
University of Salento (G. Maruccio)

Switzerland
University of Geneva (S. Gariglio/C. Senatore)

- Promote EMFL activities & provide information
- Workshops, trainings
- Explore opportunities to secure membership of EMFL
- Dual access mode (10 proposals so far): https://emfl.eu/dual-access/

European Magnetic Field Laboratory

ISABEL – Developments

Development of new access modes (https://emfl.eu/apply-for-magnet-time/)

- User Survey executed and published
- **Dual access** (since call in April 2021): 10 project proposals so far
- **First-time** access (since call in April 2022): 9 project proposals so far
- **Long-term** access: in preparation
- **Industrial** access: in preparation
- **Fast-track** access: in preparation
- **Technical development** access: in preparation
- Evaluation of remote access and mail-in sample access

Secondments

- Call open July 2021/deadline Sept. 2021
- 12 proposals received (37.1 k€)
- 10 proposals granted (22.4 k€)
- New call this year

European Magnetic Field Laboratory

ISABEL – Developments

Innovation

- Industrial Liaison officer: Aimee Savourey
- IPR & Technology transfer trainings for EMFL employees
- Innovation call (deadline Dec. 2021): 3 proposals received, 2 granted (50 k€); Next call in 2023
- Skill map nearly completed
- 5 Exhibition visits planned in 2022
- Industrial Partner Club to be launched in Nov. 2022

Collaboration with other Research Infrastructures

- Development of Scientific cases
- Workshops with other RIs
  - Neutrons (2-4 Nov. 2022), Lasers (2022)
  - FELs (2023), Xrays (2023)
- Evaluation of the access procedures
- Definition of Roadmap for High fields and other RIs

EMFL European Magnetic Field Laboratory

ISABEL – Developments

Magnet technology

- Goal: Magnet technology Roadmap
- User Survey in preparation
- Material developments
- New design tools
- Sustainability (energy efficiency, recycling)

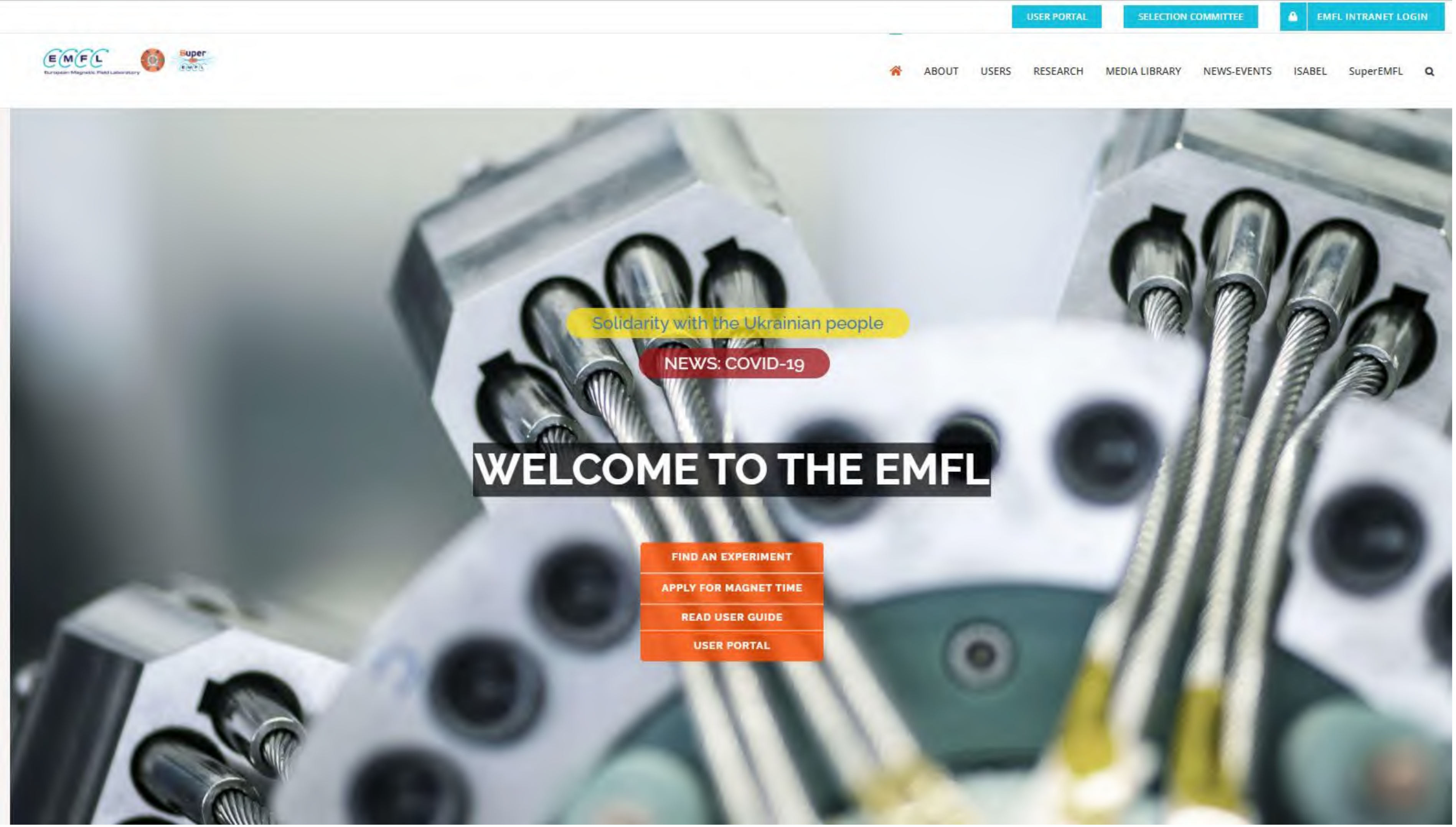
Strategical External connections

- HiFF
- Other European Large Scale Infrastructures
- CERN: Magnets for Accelerators & Muon Colliders
- FuSuMaTech: Shaping the Future of Superconductive Magnets
- European MRI community

European Magnetic Field Laboratory

Communication

Renewed website, LinkedIn, Twitter, Folders, Flyers, Exhibitions…



European Magnetic Field Laboratory

EMFL School – September 2022

21 – 25 September 2022

Abdij Hotel Rolduc Kerkrade, the Netherlands

- Lectures by renowned scientists
- Open for young scientists, PhDs and postdoctoral researchers
- Pitch sessions

Application deadline: June 30th 2022

www.hfml.ru.nl/emflschool2022

Organisation:
Steffen Wiedmann (steffen.wiedmann@ru.nl)

EMFL
European Magnetic Field Laboratory

SuperEMFL – Overview

SuperEMFL – Coordinator: Xavier Chaud

All superconducting magnets for the European Magnet Field Laboratory

2021-2024, 11 partners, of which 3 industrial, budget 2,9 M€, started January 2021

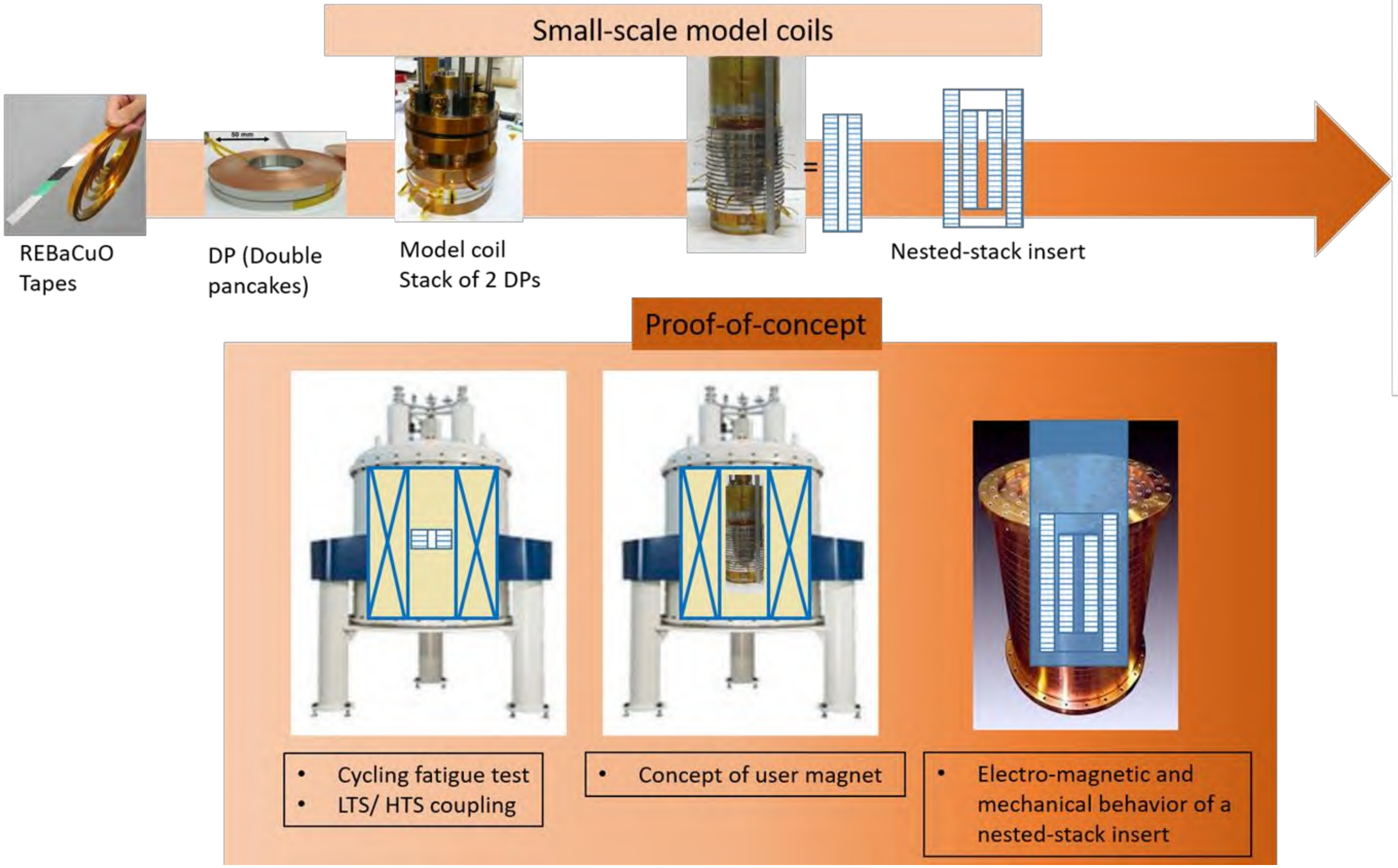
Superconductors for high magnetic field
- A change of paradigm -

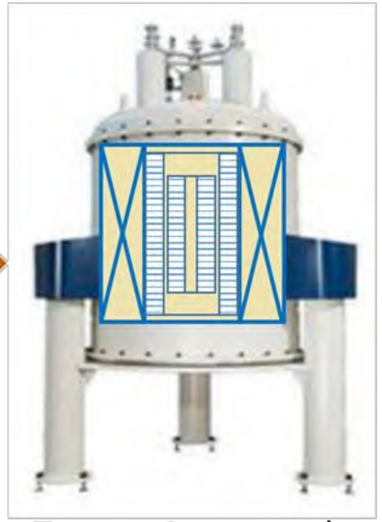
- Energy reduction to generate high fields
- More user access
- Allowing long duration / low noise experiments
- Enabling new experimental possibilities

1st period (till 30-06-22) almost finished

SuperEMFL – HTS Roadmap

From tapes to a 40+ T all-superconducting magnet chart





Target : Conceptual design of a 40+ T all-SC user magnet

Byproducts : Dedicated intermediate field magnets of which a 32+ T all-SC user magnet

European Magnetic Field Laboratory

SuperEMFL – Status 1

- March 2022: Critical current measurements of Theva's tape at LNCMI-Grenoble
- June 2022: Complementary critical current measurements at HFML Nijmegen
- End of 2022: Test measurements of 2 double pancake coil configuration at LNCMI-Grenoble
- A set of insert designs computed by WP4 partners according to the existing tape data

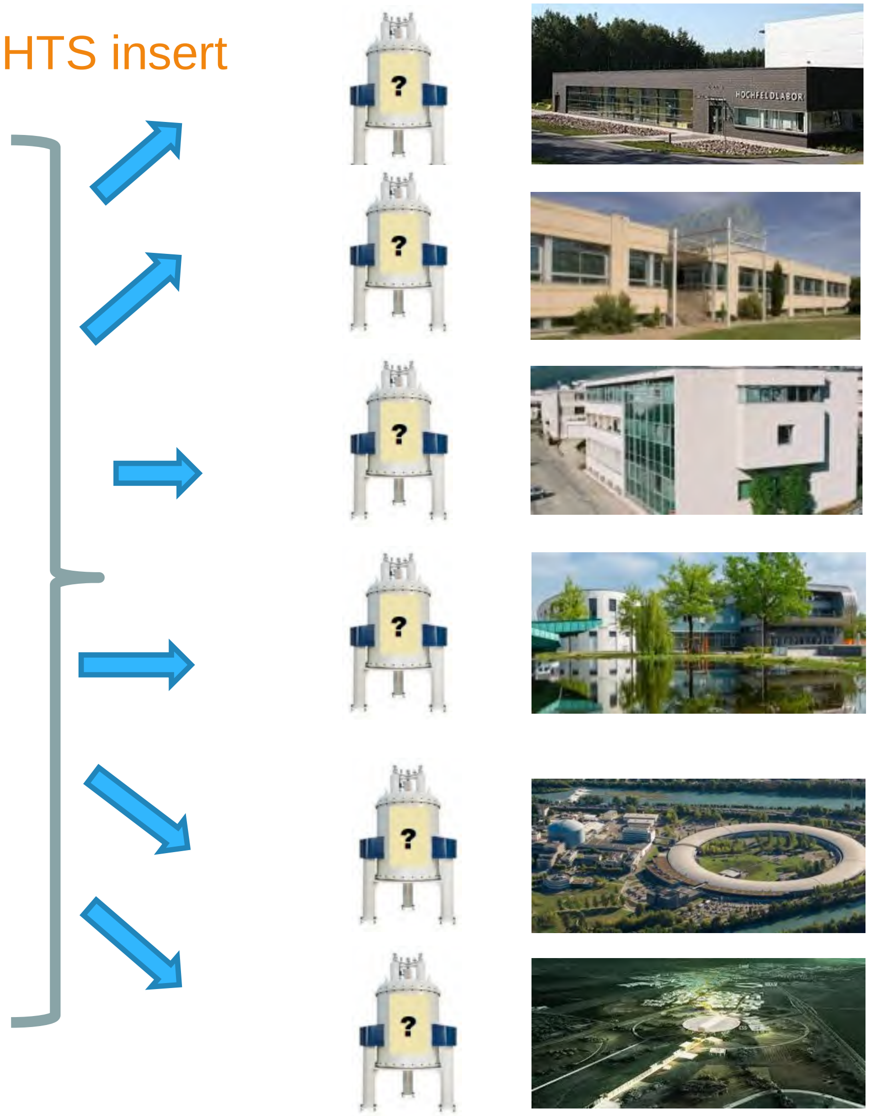
European Magnetic Field Laboratory

SuperEMFL – SC Magnet System

Combination of a LTS outsert and a HTS insert

32+ T tests
40+ T design

Conceptual design for a suite of beyond-state-of-the-art SC magnets to be deployed at the EMFL facilities or at other RI



Max field
Bore size

Geometry
Homogeneity

Compatibility with local instruments
- DC 50 mm
- Pulse 25 mm
- Beam line

Opportunities with local equipment
- Helium recovery
- Helium liquefier

European Magnetic Field Laboratory

SuperEMFL – Status 2

- LTS magnet being prepared at HLD Dresden to welcome an HTS insert,

  2 Double Pancake coil provided by LNCMI
- In April 2022, new tests of the NOUGAT insert showed that

  levitation of helium bubbles reduces the cooling efficiency

  Achievable field under good cooling conditions is limited to about 28 T
- Next SuperEMFL general meeting June 16th in Grenoble
- User Questionnaire ready to be launched (June 2022)

European Magnetic Field Laboratory

EMFLs Executive Manager leaves

EMFL User meeting 2013
Nijmegen

EMFL Kick-off 2014
Brussel

EMFL Days 2013
Egmond aan Zee

EMFL Signing 2015

Thank you Martin

Programme of Today

Time	What	Presenter(s)	Chair
09:15	Welcome	Peter Christianen	
09:35	Announcement & talk EMFL Price Winner	Price Winner	Jochen Wosnitza
10:10	Presentations by EMFL users (part 1)	Stanislaw Galeski, Charis Quay	
10:50	Coffee Break		
11:20	Presentations by EMFL users (part 2)	Shravani Chillal, Marco Bonura	
12:00	Lunch Break		
13:30	Presentations by EMFL users (part 3)	Elena Blundo, Maciej Molas, Julien Fuchs, Michael Schmitz	
14:50	Coffee Break		
15:20	User Committee Meeting		Raivo Stern
16:20	Report User Committee Meeting		Raivo Stern

European Magnetic Field Laboratory

European Magnetic Field Laboratory

Science and Technologies

Professor Amalia Patanè
Member of the EMFL Council
School of Physics and Astronomy
University of Nottingham, UK

https://m.facebook.com/studentmusicorganizer/photos/a.239301002775069/3240781299293676/

Outline

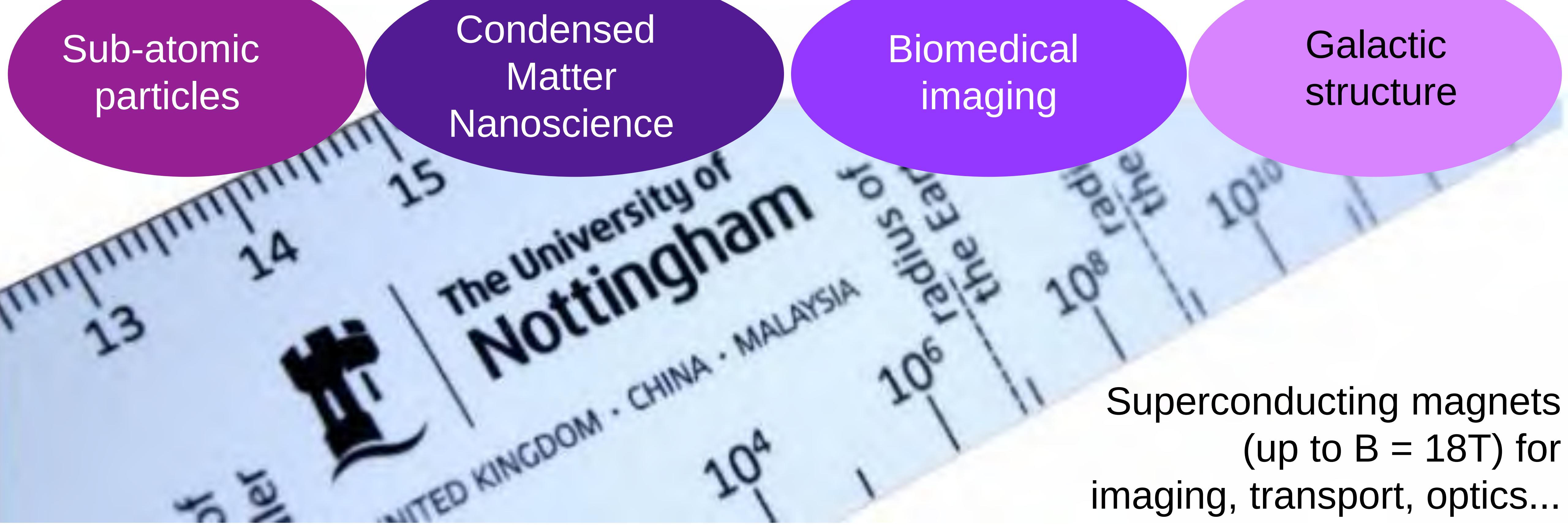
- ❖ Research in High Magnetic Fields
- ❖ European Magnetic Field Laboratory, EMFL
- ❖ Opportunities within the EMFL

High Magnetic Fields at the University of Nottingham

School of Physics and Astronomy

Research spanning several spatial and energy scales

- Sub-atomic particles
- Condensed Matter Nanoscience
- Biomedical imaging
- Galactic structure



Superconducting magnets (up to B = 18T) for imaging, transport, optics...

High Magnetic Fields at the University of Nottingham

Magnetic Resonance Imaging (MRI)

2003 Nobel Prize in Physiology and Medicine

Imaging in magnetic field has impacted on
> 500M people who had MRI scans

Sir Peter Mansfield Imaging Centre

An interdisciplinary centre for imaging in experimental and translational medicine, bringing together clinicians and scientists

2022 Announcement of UK National MRI Facility

£29 million to establish in 2025
the UK’s most powerful MRI scanner
(B = 11.7T and 83-cm bore)

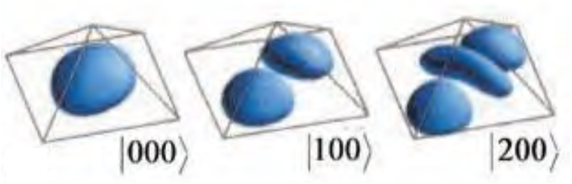
High Magnetic Fields at the University of Nottingham

Condensed Matter Physics

Magnetic fields used to probe/manipulate condensed matter systems

Imaging Quantum States

Quantum systems probed/manipulated at the nanoscale.



Magneto-tunnelling for k-space imaging of electron wavefunctions

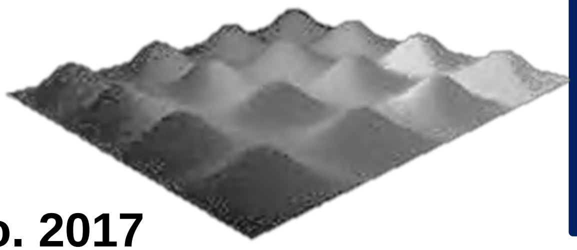
Vdovin et al. **Science 2000**

Patanè et al. **PRL 2010**

My research on quantum systems

Quantum Devices

"Giant" quantum Hall effect, spin valves, quantum tunnelling...



2-dimensional materials

Kudryinskiy et al. **PRL 2017**

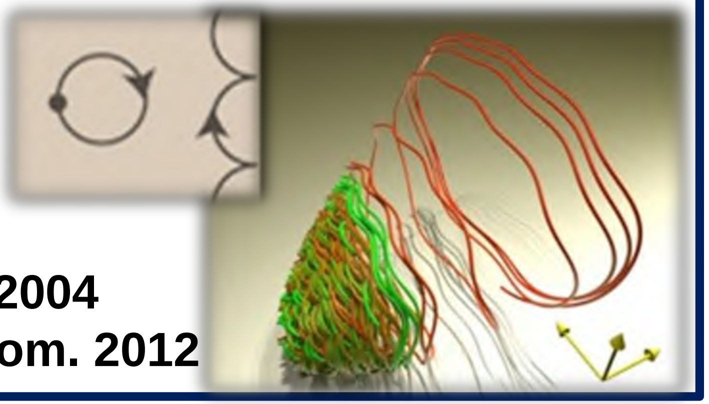
Bandurin et al. **Nature Nano. 2017**

Zhu et al. **Adv. Materials 2021**

Non-linear dynamics

Non-KAM chaos, linear magnetoresistance...

Modify electron orbital motion to tailor conductivity

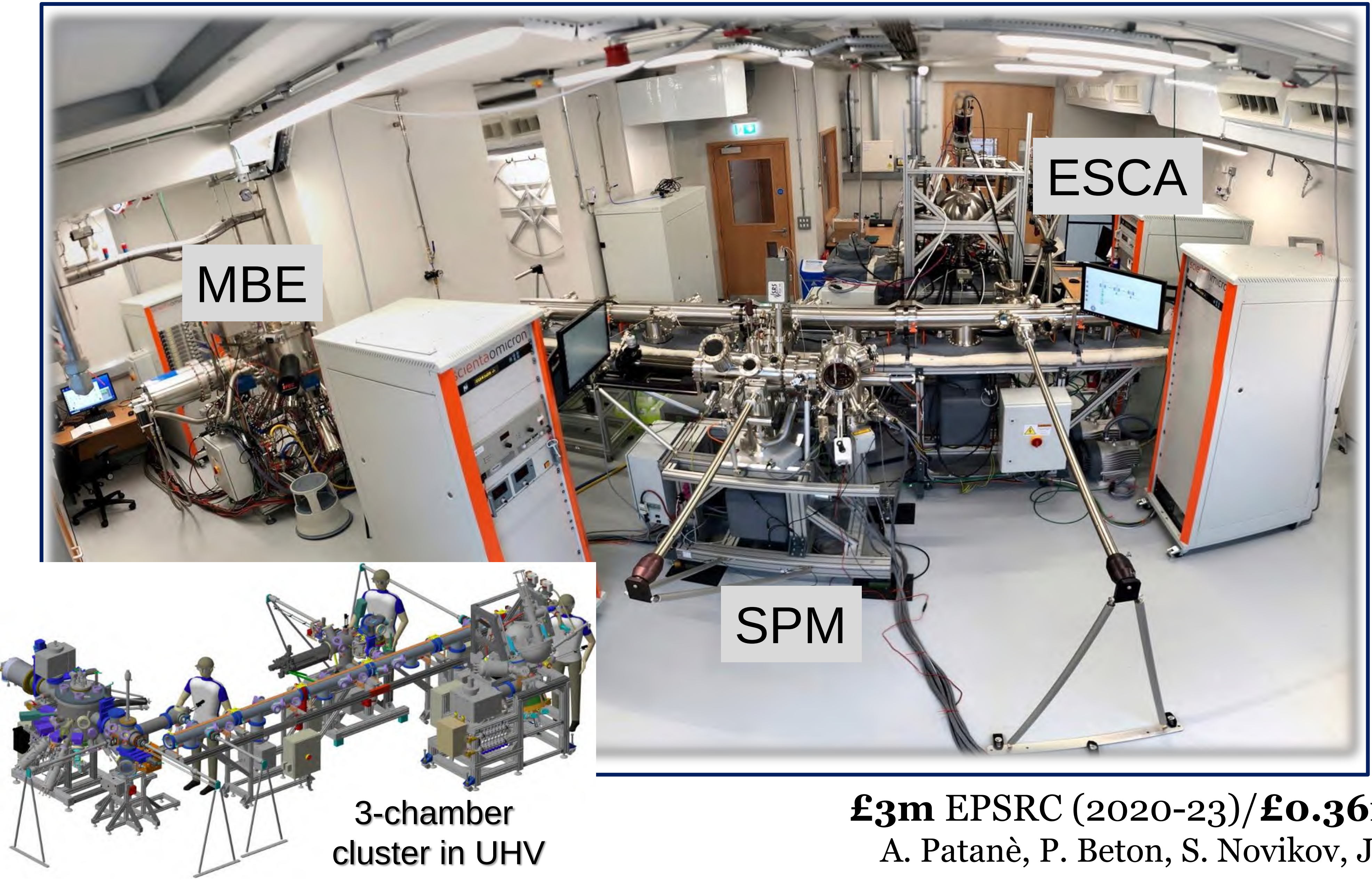


Patanè et al. **PRL 2004**

Fromhold et al. **Nature 2004**

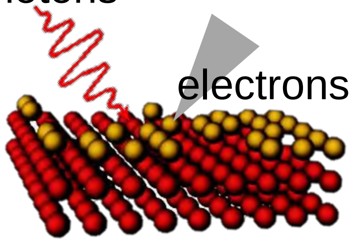
Kozlova et al. **Nature Com. 2012**

EPI2SEM EPitaxial growth and In situ analysis of 2-dimensional SEMiconductors

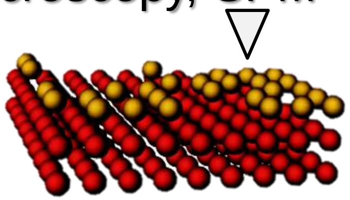


3-chamber cluster in UHV

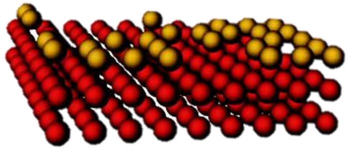
Electron Spectroscopy for Chemical Analysis ESCA



Scanning Probe Microscopy, SPM



Molecular Beam Epitaxy, MBE



£3m EPSRC (2020-23)/**£0.36m** Un. of Nottingham

A. Patanè, P. Beton, S. Novikov, J. O’Shea, A. Khlobystov

High Magnetic Field Research in the UK

Academia
Coventry University
Durham University
Imperial College London
ISIS, Rutherford Appleton Lab
Keele University
Royal Holloway London
University of Bath
University of Bristol
University of Cambridge
University College London
University of Edinburgh
University of Exeter
University of Liverpool
University of Manchester
University of Nottingham
University of Oxford
University of Strathclyde
University of Surrey
University of Warwick

Industry
AstraZeneca, Cryogenic Limited, Oxford Instruments, Paragraf Limited, Siemens Magnet Technology, Hitachi, Toshiba

Large community working on
strongly correlated metals,
superconductors,
molecular magnets,
quantum materials,
semiconductors,
graphene and 2D materials,
pharmaceutical compounds,
geophysics,
metallurgical processes...

Wide range of techniques
High spatial and energy resolution
Wide T-range down to the mK
High-pressure
Large instruments: neutron sources, synchrotrons, free electron lasers...

High Magnetic Field Research in the UK

Academia
Coventry University
Durham University
Imperial College London
ISIS, Rutherford Appleton Lab
Keele University
Royal Holloway London
University of Bath
University of Bristol
University of Cambridge
University College London
University of Edinburgh
University of Exeter
University of Liverpool
University of Manchester
University of Nottingham
University of Oxford
University of Strathclyde
University of Surrey
University of Warwick

Industry
AstraZeneca, Cryogenic Limited, Oxford Instruments, Paragraf Limited, Siemens Magnet Technology, Hitachi, Toshiba

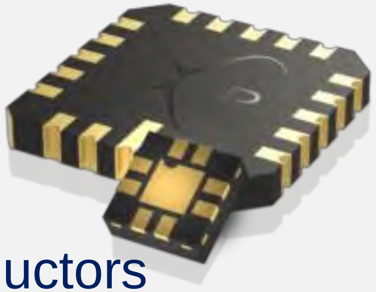
UK Membership of the EMFL

for high magnetic field (> 20 Tesla) science and technologies

UKRI-EPSRC 9 M€, 2015 – 2027

Recent highlights

Paragraph graphene Hall sensors
for high-accuracy operation in B > 30 T and cryogenics temperatures



Research on high-T_c superconductors
Signature of coherent and incoherent transport in the strange-metal regime of high-T_c cuprates
Nature 595, 661-666 (2021)

High Magnetic Field Research in the UK

Academia
Coventry University
Durham University
Imperial College London
ISIS, Rutherford Appleton Lab
Keele University
Royal Holloway London
University of Bath
University of Bristol
University of Cambridge
University College London
University of Edinburgh
University of Exeter
University of Liverpool
University of Manchester
University of Nottingham
University of Oxford
University of Strathclyde
University of Surrey
University of Warwick

Industry
AstraZeneca, Cryogenic Limited, Oxford Instruments, Paragraf Limited, Siemens Magnet Technology, Hitachi, Toshiba

UK Membership of the EMFL

for high magnetic field (> 20 Tesla) science and technologies

UKRI-EPSRC 9 M€, 2015 – 2027

ISABEL

Improving the **S**ust**A**ina**B**ility of the **E**uropean Magnet Field **L**aboratory

Horizon 2020 4.9 M€, 2020 – 2024

18 partners (5 industrial)

SuperEMFL

Horizon 2020 2.9 M€, 2021 – 2024

11 partners (3 industrial)

European Magnetic Field Laboratory, EMFL

World class high magnetic field facilities for research across different disciplines and by users from all over the world

https://emfl.eu/

High magnetic field installations are expensive to built and run. They require operational expertise. Thus, they are generally rare.

European Magnetic Field Laboratory, EMFL

World class high magnetic field facilities for research across different disciplines and by users from all over the world

https://emfl.eu/

Links

- Other European Large Scale Infrastructures
- CERN: Magnets for Accelerators & Muon Colliders
- FuSuMaTech: Shaping the Future of Superconductive Magnets
- European MRI community

EMFL State-Of-The-Art Magnet Technology

How to generate high magnetic fields?

A current I flowing in a coil generates a magnetic field **$B \propto I$**

Limitation: heating (Joule effect) **$P \propto RxI^2 \propto$** B^2

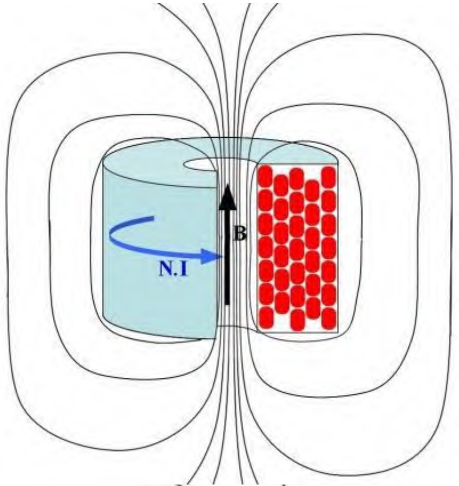
Solutions: - superconductors $R = 0$ ($B < B_{crit}$)

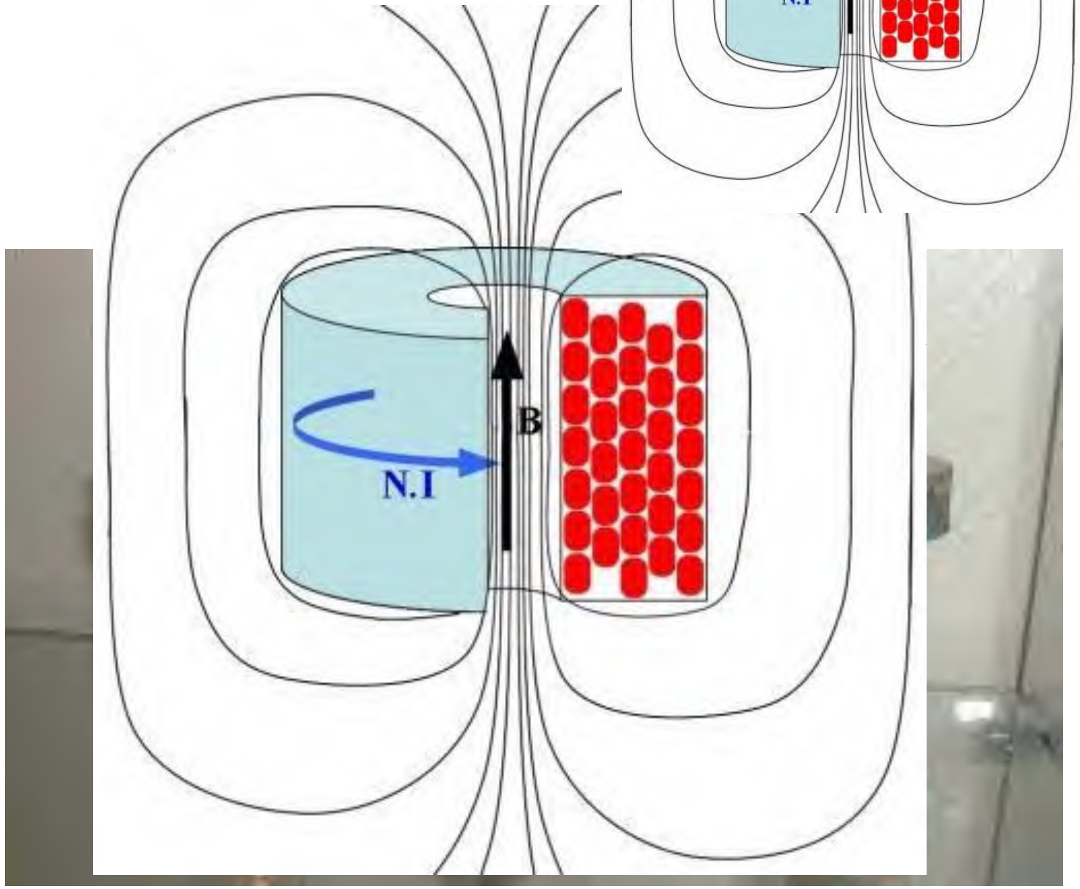
- cooling: static fields
- pulsed current (< 1 s)

Limitation: Lorentz force on the coil $\propto$ **BxI** $\propto$ B^2

Solutions: - strong conductor

- mechanical reinforcement
- sacrifice the coil

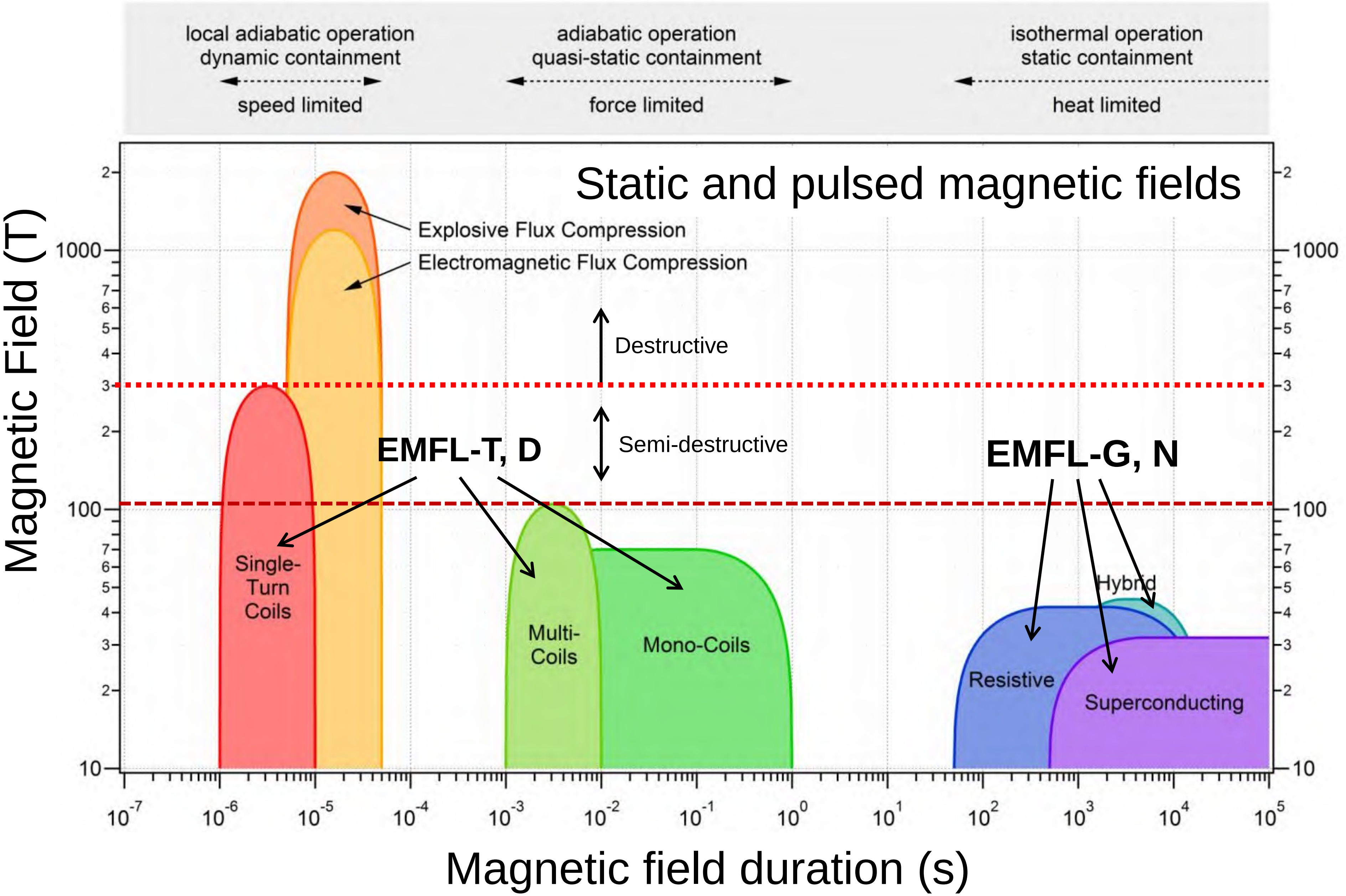




Magnetic field: strength and duration

EMFL-T, Toulouse

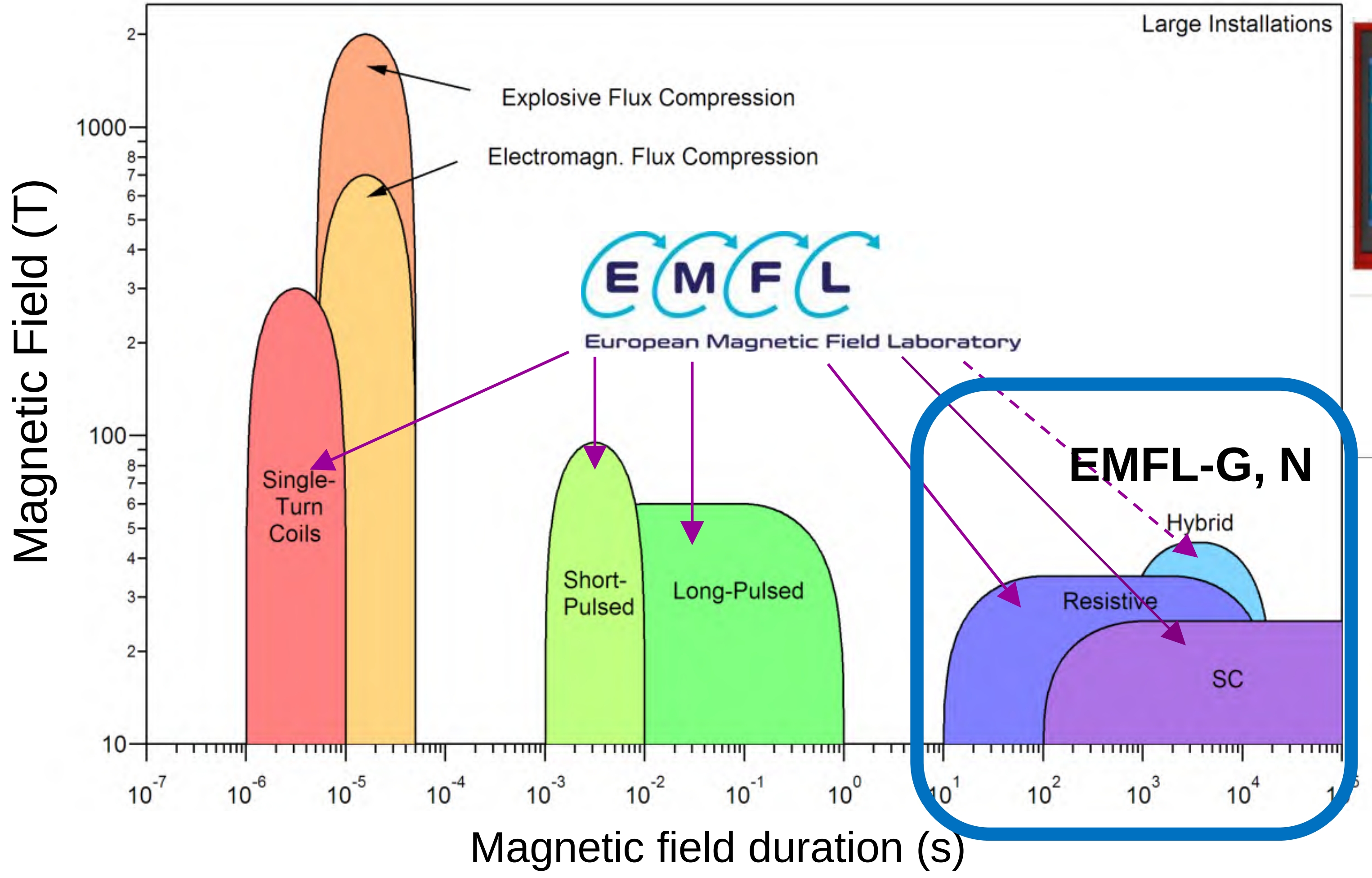
EMFL-D, Dresden



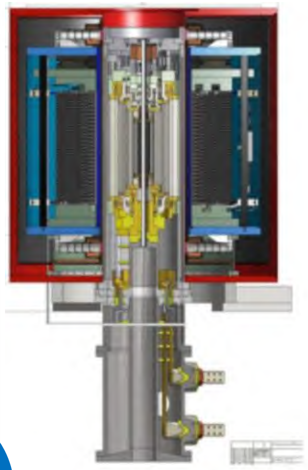
EMFL-G, Grenoble

EMFL-N, Nijmegen

EMFL State-Of-The-Art Magnet Technology



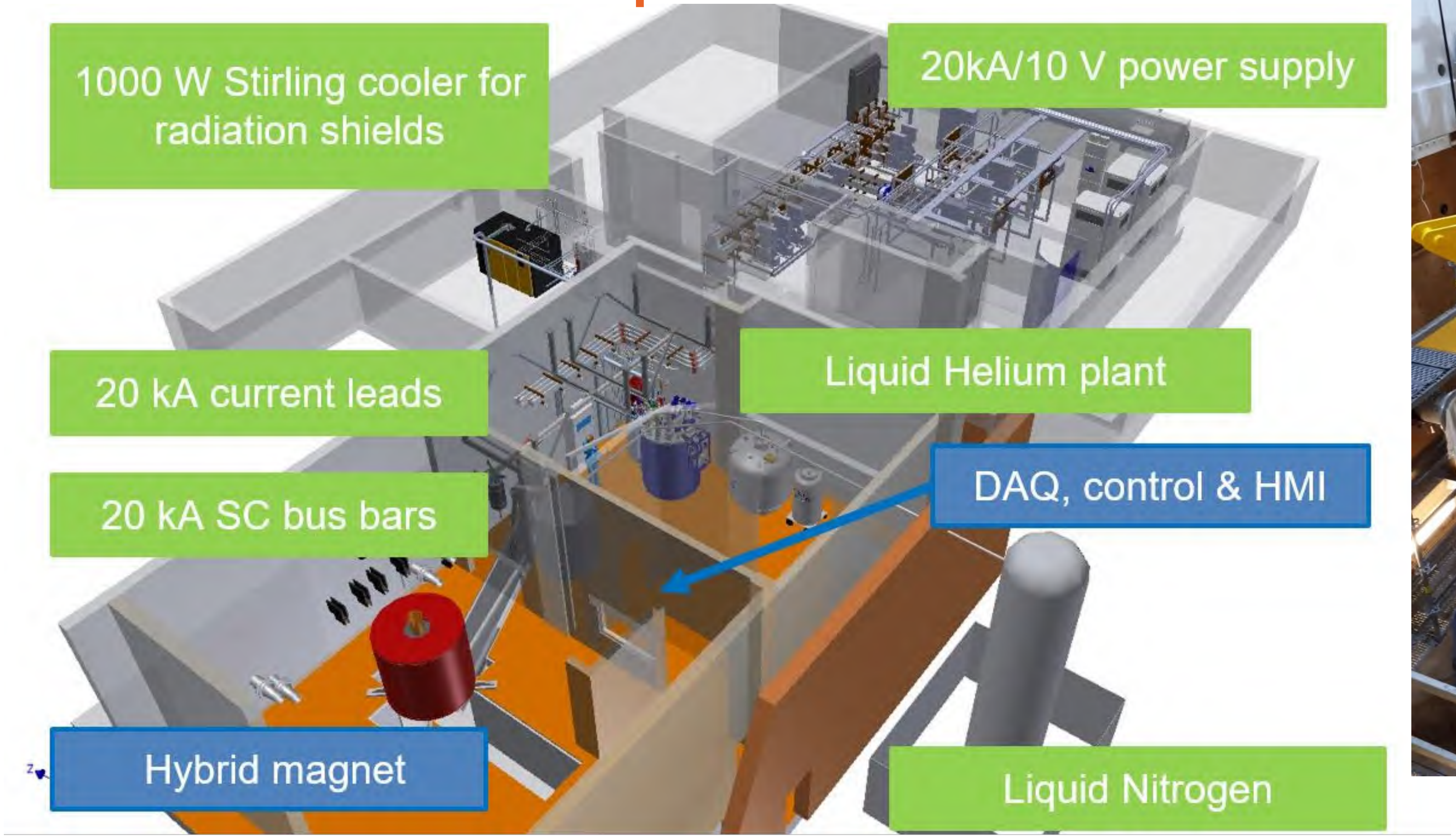
Static magnetic fields



Magnet cool-down
Summer 2022

EMFL State-Of-The-Art Magnet Technology

Infrastructure development



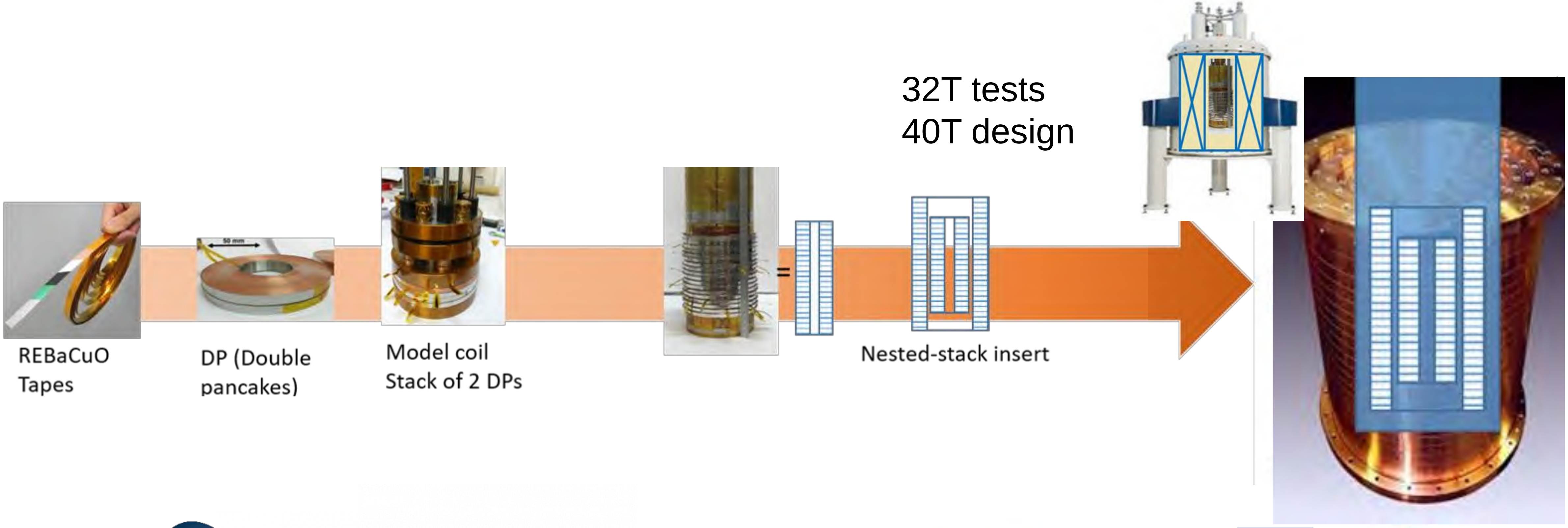
EMFL-G: Hybrid magnet

Magnet cool-down
Summer 2022

H2020 SuperEMFL

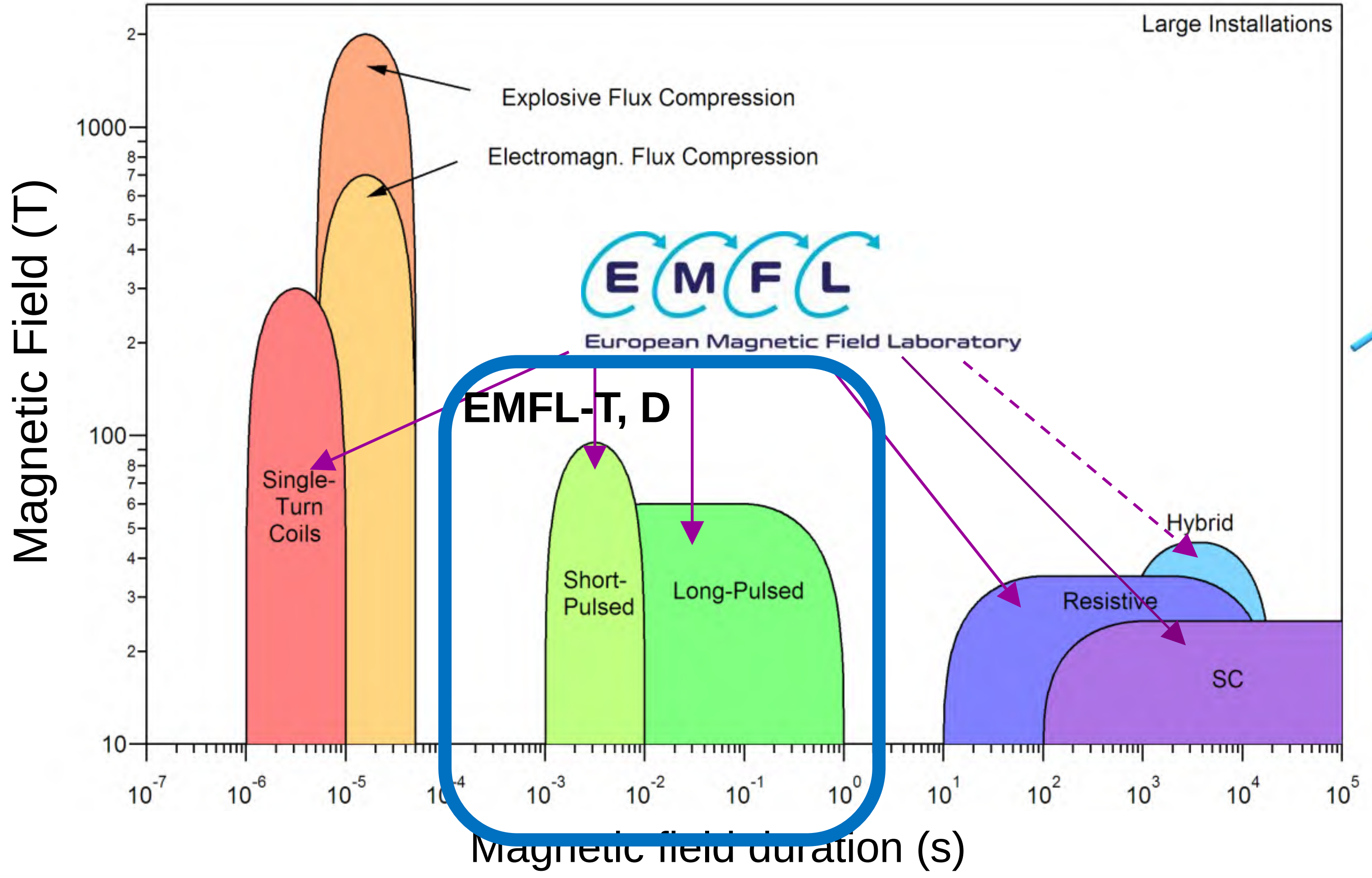
2021-2024, 11 partners (3 industrial), 2.9M€

Design of all-superconducting magnets (**32T** and **40T**) through the development of high-T superconductor technology and its combination with low-T superconductors.



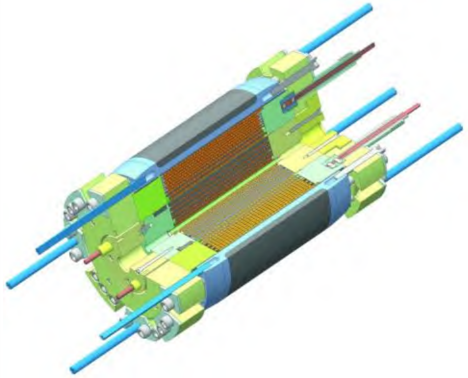
EMFL European Magnetic Field Laboratory · cnrs · HLD. HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF · Radboud University · cea · OXFORD INSTRUMENTS · THEVA · UNIVERSITÉ DE GENÈVE · ELÚ · BILFINGER · UNIVERSITY OF TWENTE.

EMFL State-Of-The-Art Magnet Technology



Pulsed magnetic fields

❖ Non-destructive pulsed fields: 100 T



The construction of coils for B up to 100 T is technologically challenging due to enormous electrical, magnetic, thermal, and mechanical stresses on the coils. The forces and pressure on the wire inside a coil is given by $p = B^2 / 2\mu$. For 100T, this corresponds to a pressure 4 GP (40000 atmospheres).

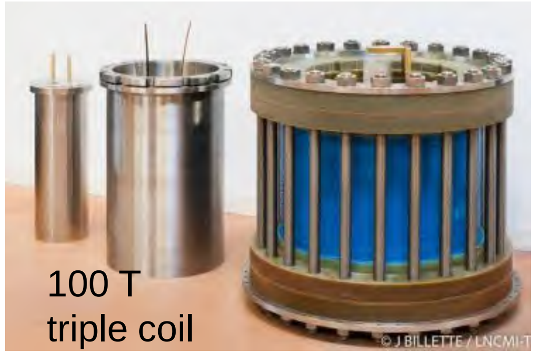
EMFL State-Of-The-Art Magnet Technology

Progress over one century

From 1924 to 1990 the field increased from 50 T to 70 T by improving the same technique: The conductor is reinforced by the outside with a high strength metallic cylinder

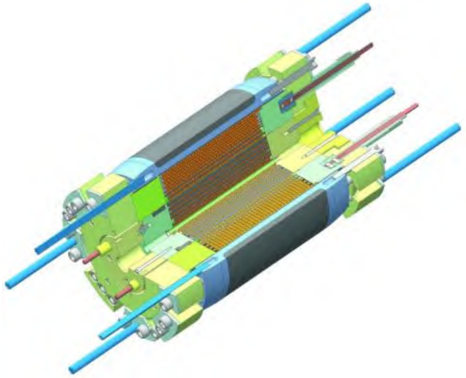
1990s Field increases from 70 T to 80 T with single coil by using an optimized reinforcement technique

After 2000, the field increases from 80 T to 100 T with dual coil systems powered by 2 different generators. The next step is the use of 3 or 4 concentric coils to take advantages of existing materials properties.



Pulsed magnetic fields

- Non-destructive pulsed fields: 100 T



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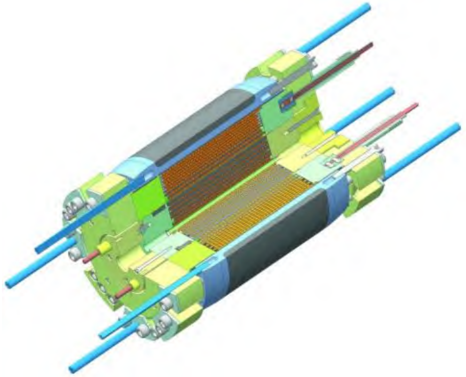
EMFL State-Of-The-Art Magnet Technology

High-energy capacitor bank

Example in Dresden: High-energy capacitor banks to provide the current (>100kA) for the coils within a short time. 500 capacitors with a capacity of 350 µF each can store a total energy of 50 MJ. Prior to a B pulse, the required capacitors are charged from the mains. The required energy is then supplied to the coil systems via electronic switches (thyristors).

Pulsed magnetic fields

- Non-destructive pulsed fields: 100 T



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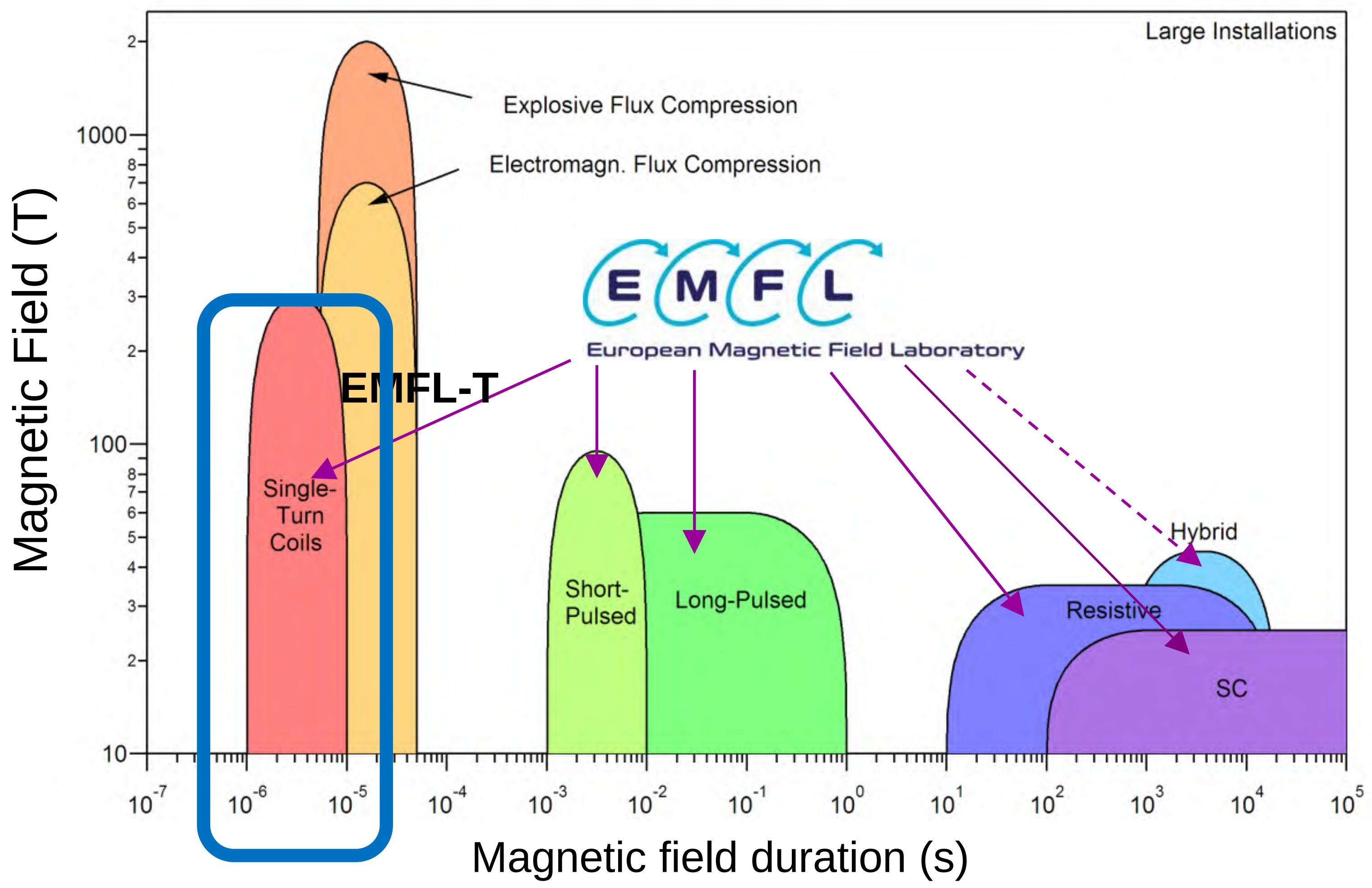
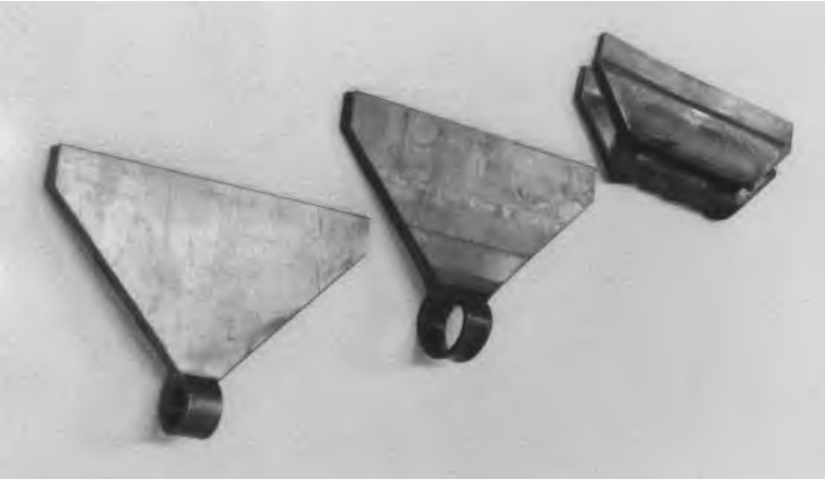
EMFL State-Of-The-Art Magnet Technology



Pulsed magnetic fields

- Semi-destructive pulsed fields

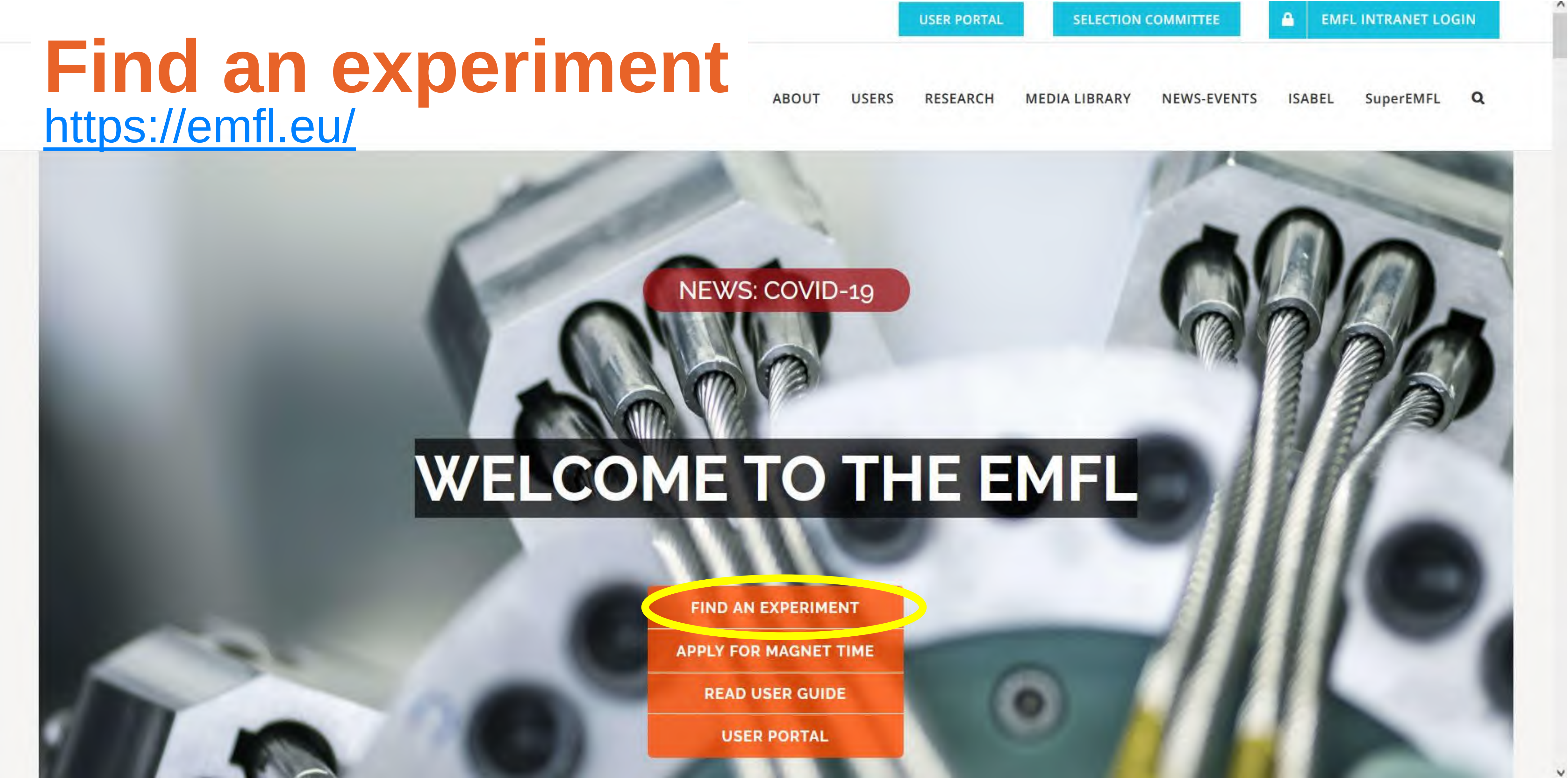


12 mm × 12 mm × 3 mm single-turn coils before the pulse (bottom), after a 10 kV, 6 kJ discharge with 37 T peak field and after a 55 kV, 189 kJ discharge with 188T peak field (top).

After the 55 kV discharge, the coil is destroyed and the triangular feed flanges are ripped off by the extreme current density.

Find an experiment

https://emfl.eu/



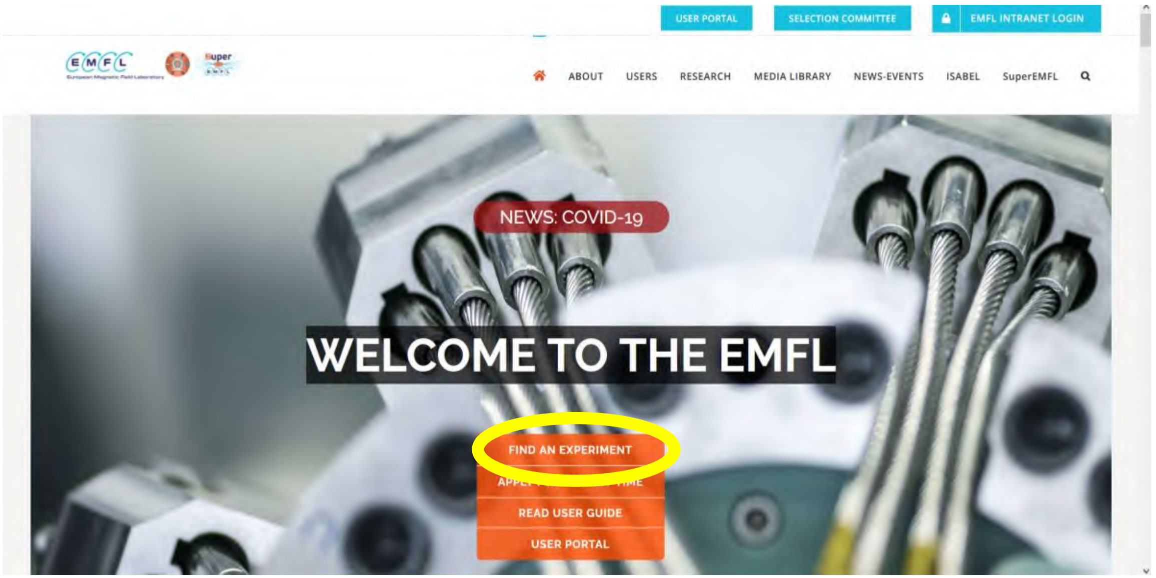
Find an experiment

MAGNETO-OPTICS

- OPTICAL MICROSCOPE IMAGING
- BIREFRINGENCE, DICHROISM AND FARADAY ROTATION
- PHOTOLUMINESCENCE AND RAMAN SPECTROSCOPY
- INFRARED SPECTROSCOPY
- ULTRAFAST DYNAMICS
- SCANNING TUNNELLING MICROSCOPY

THERMODYNAMIC PROPERTIES

- SPECIFIC HEAT
- THERMOPOWER AND NERNST-ETTINGHAUSEN
- MAGNETOSTRICTION
- SOUND VELOCITY AND ATTENUATION
- MAGNETOCALORIC EFFECT
- ...



MAGNETOMETRY

- COMPENSATED-COIL MAGNETOMETRY
- FARADAY BALANCE
- VSM VIBRATING-SAMPLE MAGNETOMETER
- TORQUE MAGNETOMETRY

MAGNETOTRANSPORT

- RF CONTACTLESS TRANSPORT
- CRITICAL CURRENT SUPERCONDUCTORS
- MAGNETOTRANSPORT (IN-SITU SAMPLE ROTATION)
- LOW NOISE&LOW RESISTANCE

MAGNETIC RESONANCE

- ELECTRON SPIN RESONANCE
- NUCLEAR MAGNETIC RESONANCE

ADVANCED SOURCES

- X-RAY
- NEUTRONS

ELECTRIC POLARIZATION

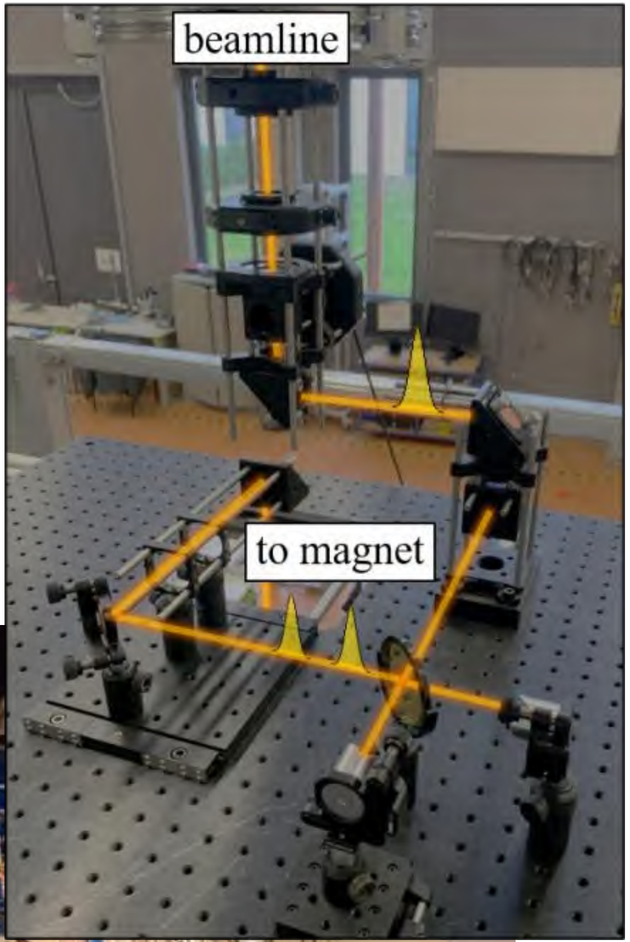
- ELECTRIC POLARIZATION

FURTHER INFORMATION FROM THE USER ACCESS MANAGER OF THE 4 LABS OF THE EMFL

Find an experiment

Advanced Sources and Magnetic Fields

FELIX-EMFL Nijmegen
Free-**E**lectron **L**asers for **I**nfrared e**X**periments



FELIX generates and uses very intense radiation in the (far)infrared region of the radiation spectrum.

The four lasers **FELIX-1**, **FELIX-2**, **FELICE** and **FLARE** each produce their own range of wavelengths and together, they provide a tuning range between **3 µm** and **1500 µm**.

aboratory

Apply for magnet time

https://emfl.eu/

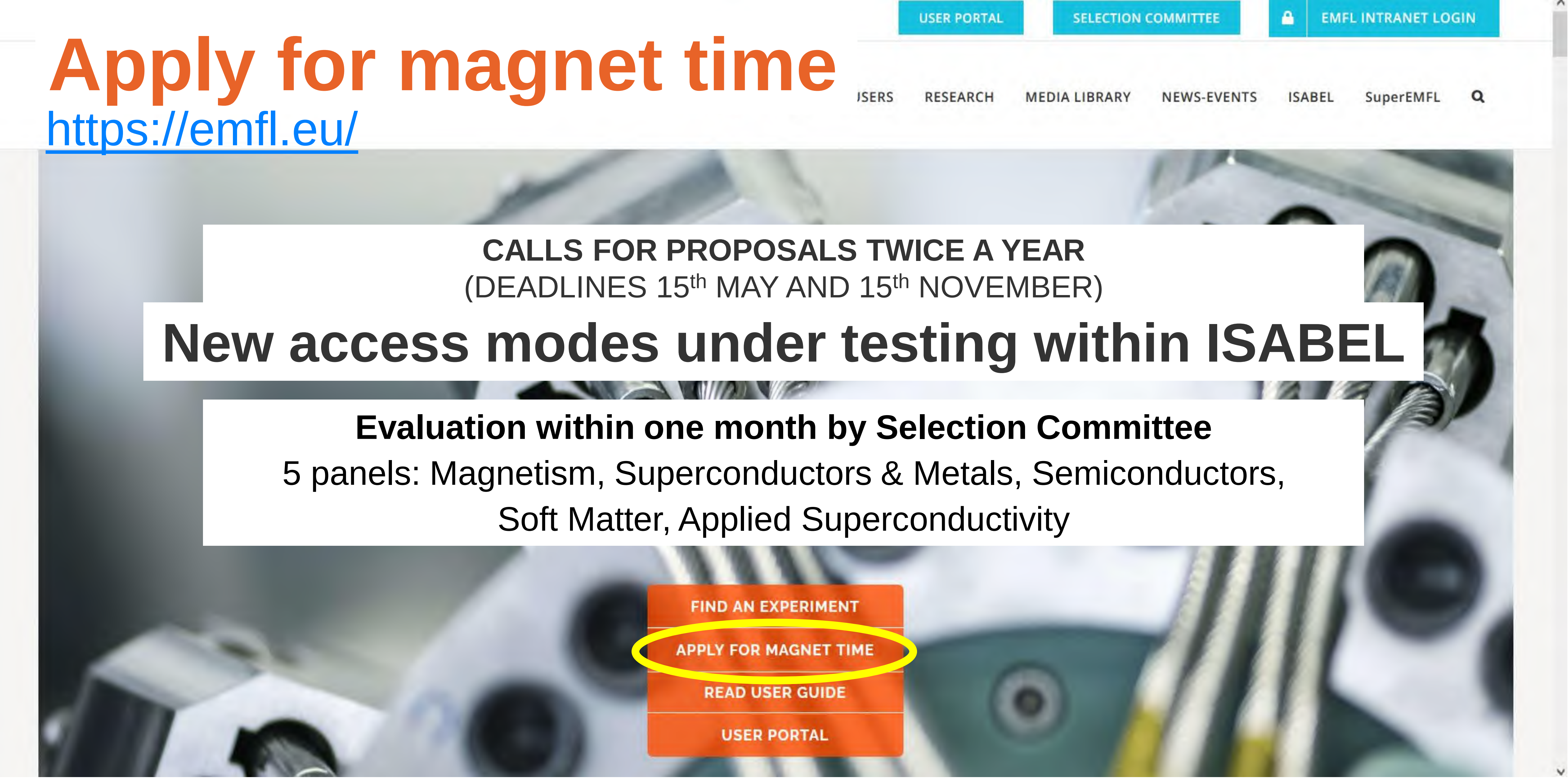
CALLS FOR PROPOSALS TWICE A YEAR

(DEADLINES 15th MAY AND 15th NOVEMBER)

New access modes under testing within ISABEL

Evaluation within one month by Selection Committee

5 panels: Magnetism, Superconductors & Metals, Semiconductors, Soft Matter, Applied Superconductivity



ISABEL

Coordinator: Geert Rikken, CNRS

Improving the Sustainability of the European Magnet Field Laboratory

2020-2024 4.9 M€ 18 partners (5 industrial)

Dual access

EMFL and ISABEL partners are developing **dual access procedures** for :

- Fast track access
- Long-term access
- Industrial access
- First-time access

INTRODUCING OUR REGIONAL PARTNER FACILITIES

University of Nottingham Magnetic Levitation Laboratory

The Nottingham magnetic levitation laboratory is a relatively small facility hosted by the School of Physics and Astronomy at the University of Nottingham, UK.

The lab houses two superconducting magnets, reaching fields of up to 18.3 Tesla. Both magnets have been custom-built to perform experiments using the technique of diamagnetic levitation to mimic weightlessness and novel 'differential gravity' environments.

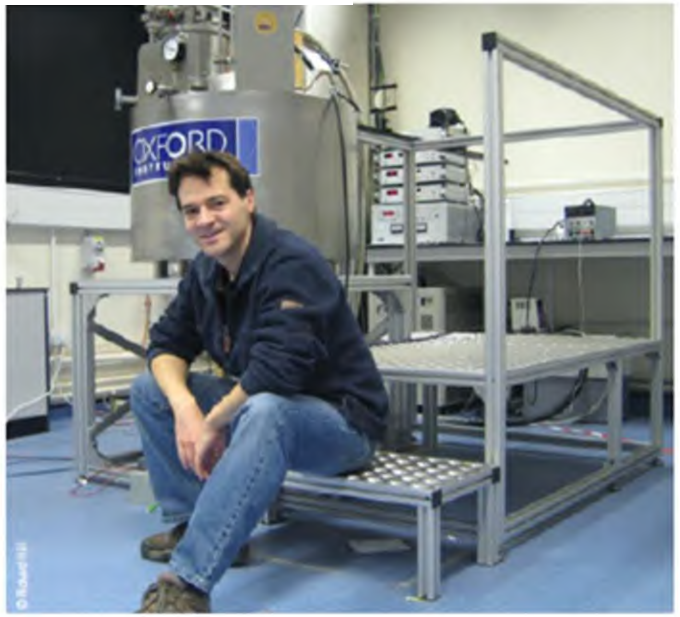
These magnets can be run for extended periods at maximum magnetic field, allowing long-duration (up to several days) 'microgravity' experiments to be performed, an expensive and often impossible feat using comparable alternatives: space and parabolic flights and drop towers.

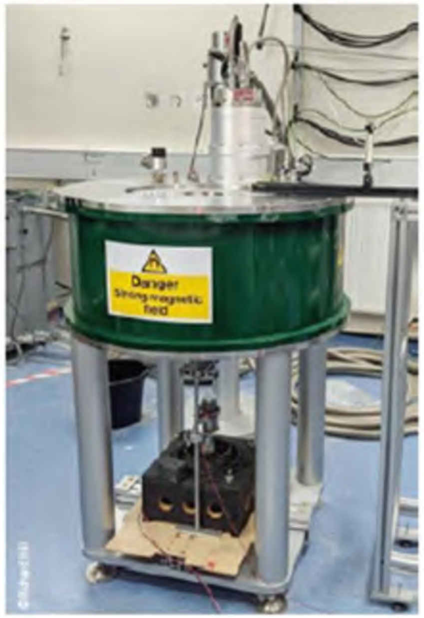
The continuous running mode allows experimental methods to be improved and expanded iteratively, and extensive testing, before translating to the shorter duration experiments typically undertaken

Univ. of Nottingham

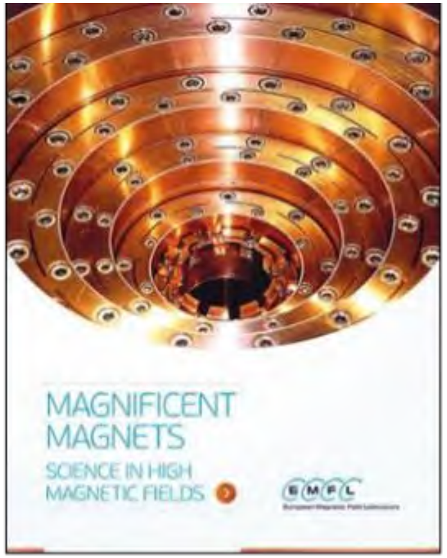
Using diamagnetic levitation to mimic the absence of gravity

Dr. Richard Hill





EMFL: Dissemination and Training



Website https://emfl.eu/
EMFLNews https://emfl.eu/emfl-news/

YouTube https://www.youtube.com/watch?v=4dM07vic150

Virtual tour https://virtualtours.360totaal.nl/tour/hfml-felix
An overview of the high field installation and instrumentation with the latest updates
Provides first-time users with a realistic view of what they can expect when arriving at the facility to perform their experiment.

Thank you!

European Magnetic Field Laboratory

Global High Magnetic Field Forum

Status EMFL

Uli Zeitler, Charles Simon, Jochen Wosnitza

Global HiFF meeting Las Vegas

March 8, 2023

Situation COVID-19 & Ukraine War

Technical developments

Scientific outcome

Strategic developments,

Future plans

COVID-19 situation

Operation

- Facilities have resumed “regular” operation
- Still backlog of projects
- Mail-in sample & staff-support procedures if they will remain: extra staff required

	2019	2020	2021	2022
Proposals received	363	270	318	304
Proposals performed	257	185	194	228
Thereof mail-in	3	50	76	37

Technical developments

- Infrastructure and instrumentation developments continued, but delayed

Networking activities

- Many meetings occur(ed) on-line. Transition to hybrid & in-person meetings
- EMFL User meeting June 16, 2022 in Grenoble: hybrid
- EMFL User meeting June 13 -14, 2023 in Nijmegen: hybrid
- High-field conferences: Finally in person RHMF2024
- After virtual HiFF meeting 2022, finally in-person now

Consequences Ukraine War

Response

- Statements of the partner institutions on their websites
- Statement on the EMFL website

Strong condemnation of the Russian invasion of Ukraine

Support for Ukrainian, Russian, and Belarusian students and staff

Suspension of partnerships with Russia and Belarus

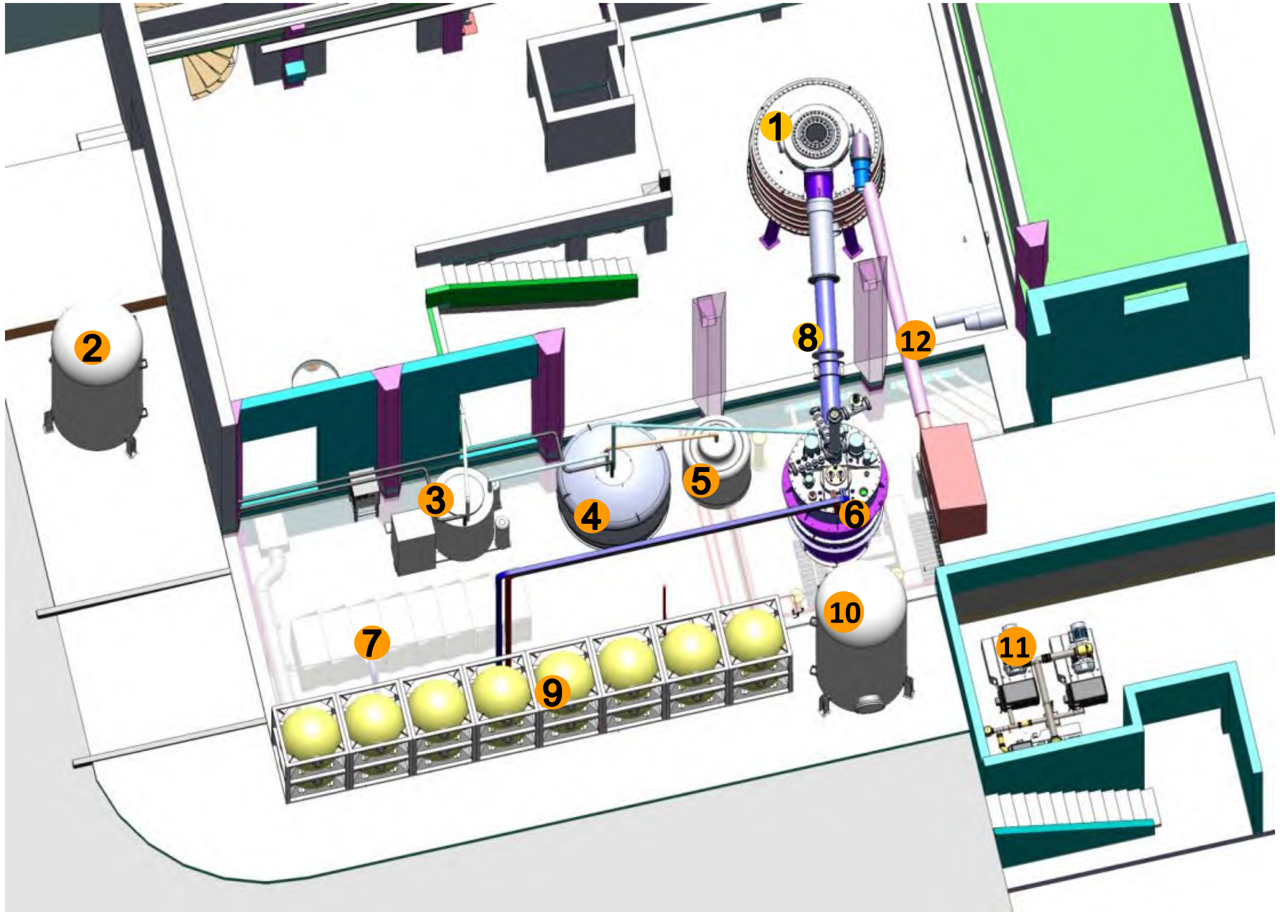
Consequences for EMFL

- No users from Russian or Belarussian institutions
- No participation to EMFL events of researchers with Russian or Belarussian affiliations
- No secondments of researchers with Russian or Belarussian affiliations

Technical developments: infrastructure

EMFL-G: Hybrid magnet in Grenoble

1. Superconducting Magnet
2. LN_2 tank 27 000 liter
3. He liquefier coldbox
   150 l/h @ 4.5 K , 1.3 bar
4. Main LHe Dewar 4500 litres
5. Secondary LHe Dewar 1700 litres
6. Cryogenic satellite to produce the 1.8 K LHe bath
7. DC power converter
   7500 A , 30 V (underground)
8. Cryoline with busbars @ 1.8 K
9. High pressure gaseous He tanks
   16 x 1 m^3 @ 200 bars
10. Liquefier - He buffer tank
    15 m^3 @ 20 bars
11. Helium pumping system
    6000 m^3/h @ 10 mbar, 20 °C
12. Quench line

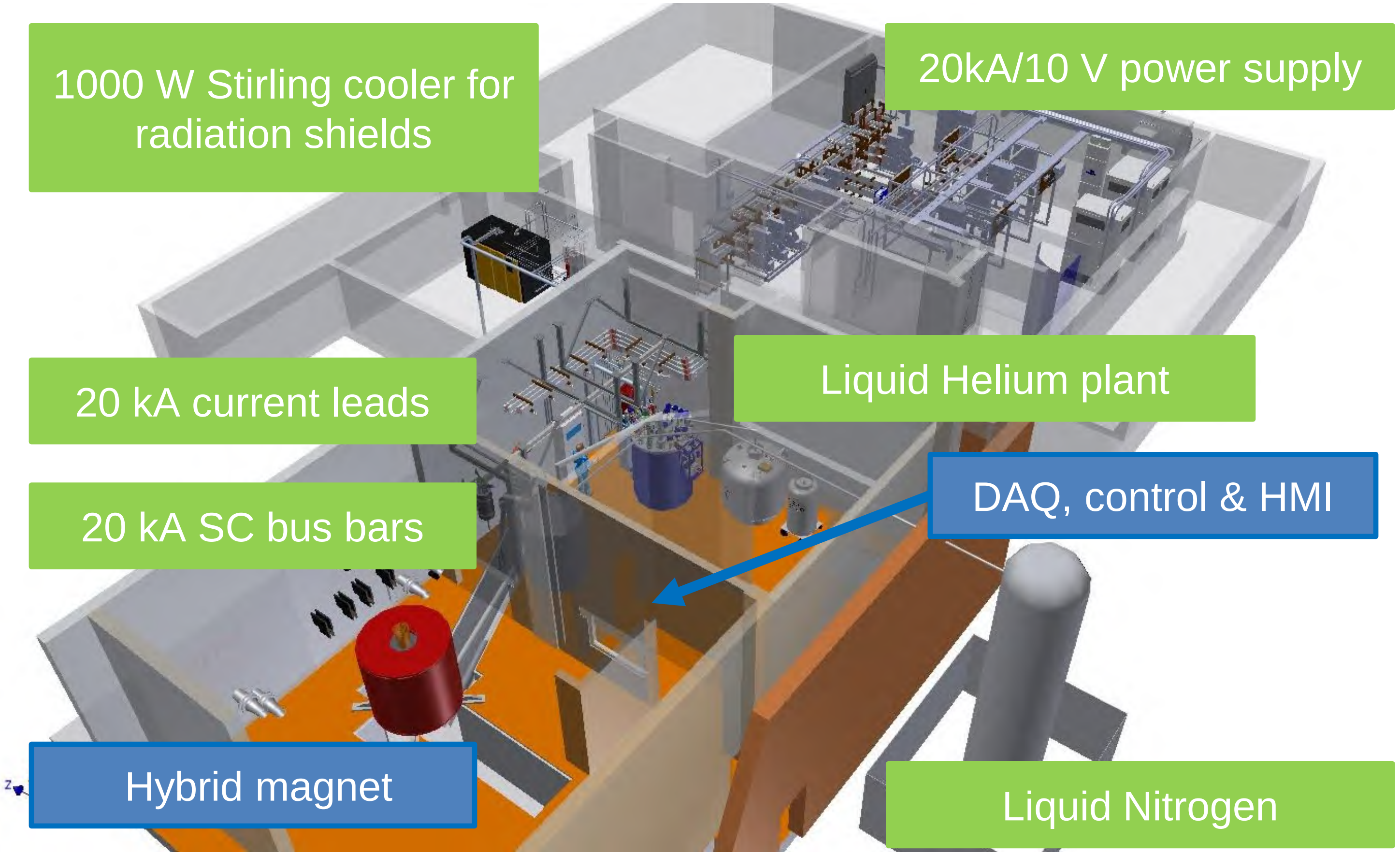


- Construction finished in 2022 (Cost: 18 M€)
- Superconducting magnet at 1.6 K
- NMR measurements at 2 T resistive and 2 T superconducting (center the magnets) (Dec 2022)
- First measurements towards 43 T in 2023

Not shown (located in other areas)
- Liquefier cycle compressor @ 14.5 bars
- He recovery compressor @ 200 bars
- Magnet Safety and Magnet Control Systems
- He recovery balloon : 30 m^3 @ Patm
- 32 x 0.5 m^3 high pressure gaseous He tanks @ 200 bars

Technical developments: infrastructure

EMFL-N: 45 T Hybrid system



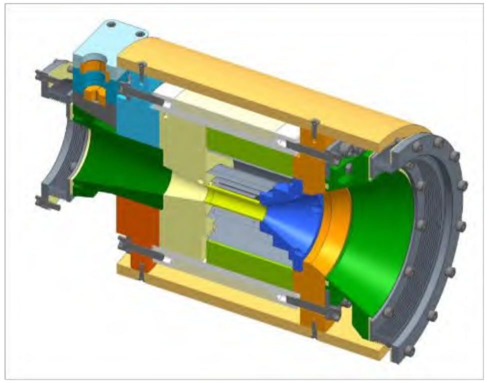
Final test cryostat expected summer 2023
Magnet cool-down expected end of 2023

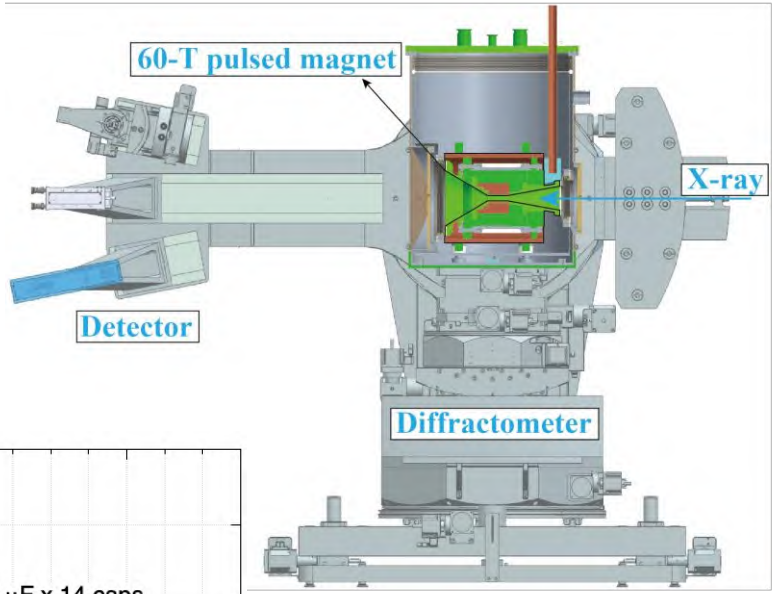
EMFL European Magnetic Field Laboratory

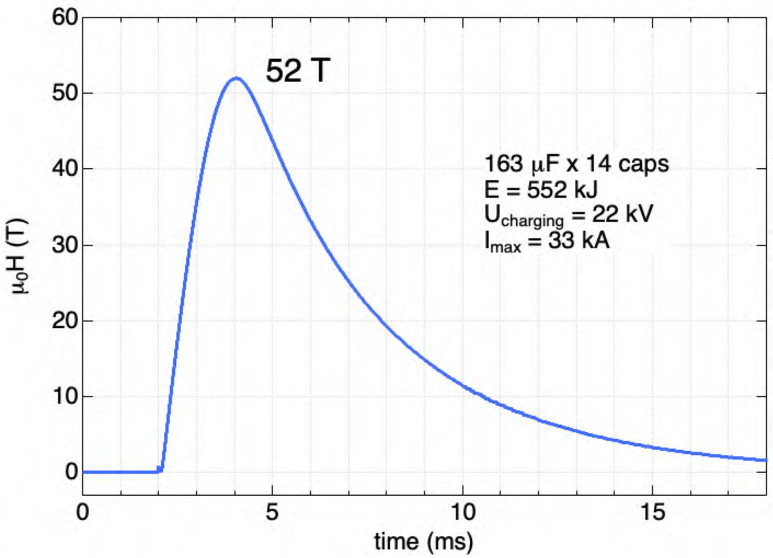
Technical developments: infrastructure

EMFL-D: Development of pulsed-field magnet for external infrastructure (Eu XFEL)

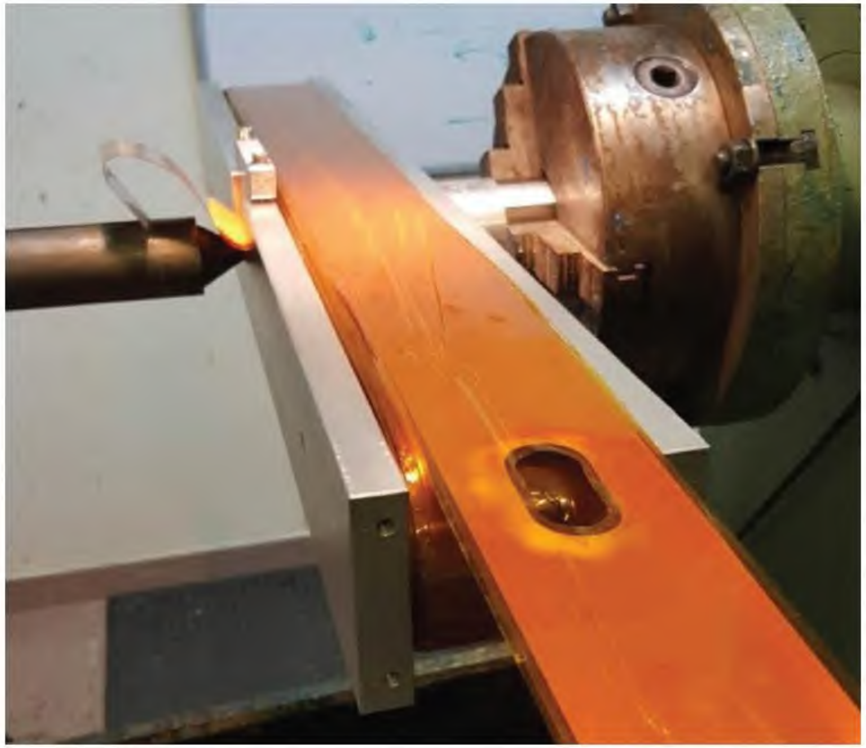
EMFL-T: Design pulsed magnetic dipole for magnetic birefringence measurements







BMBF project:
Pulsed-field magnet at ESRF (soft x-rays)

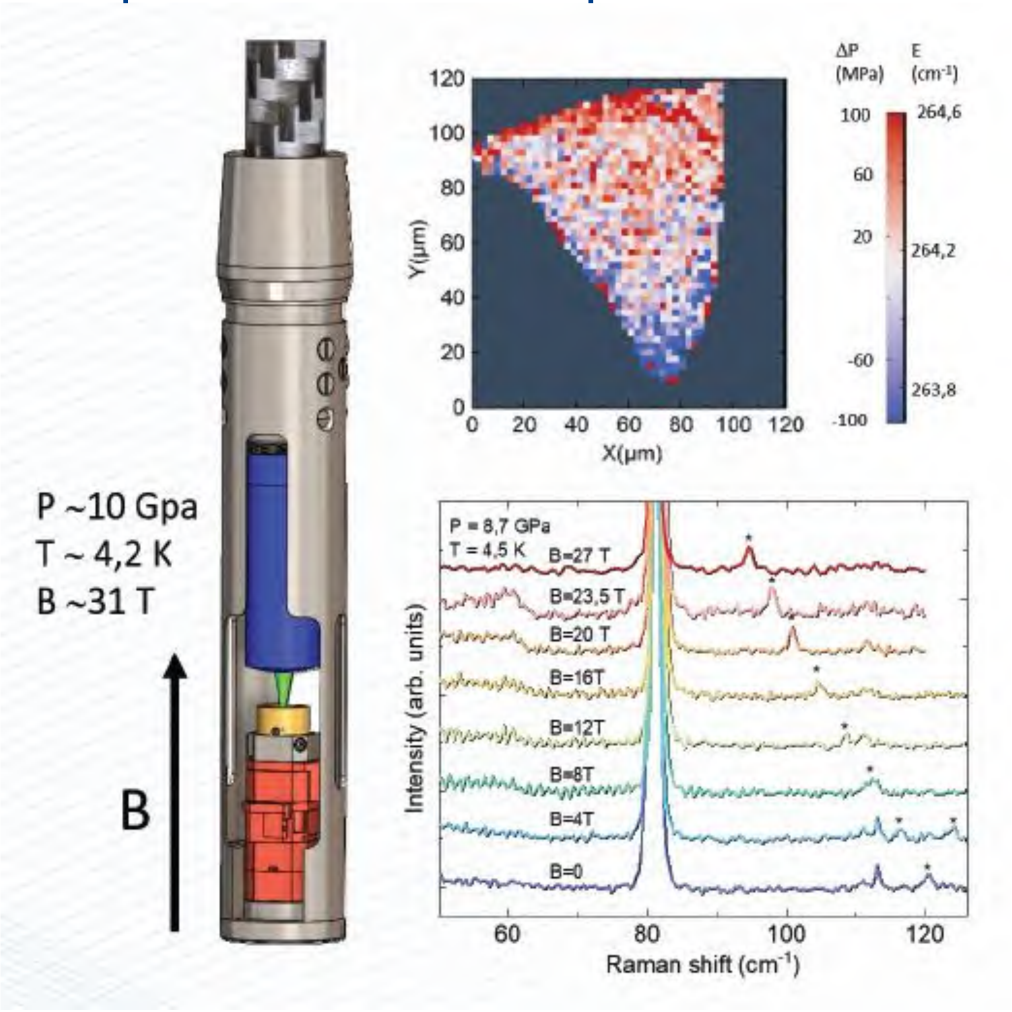


J. Beard et al. Rev. Sci. Instruments **92,** 104710 (2021)

EMFL
European Magnetic Field Laboratory

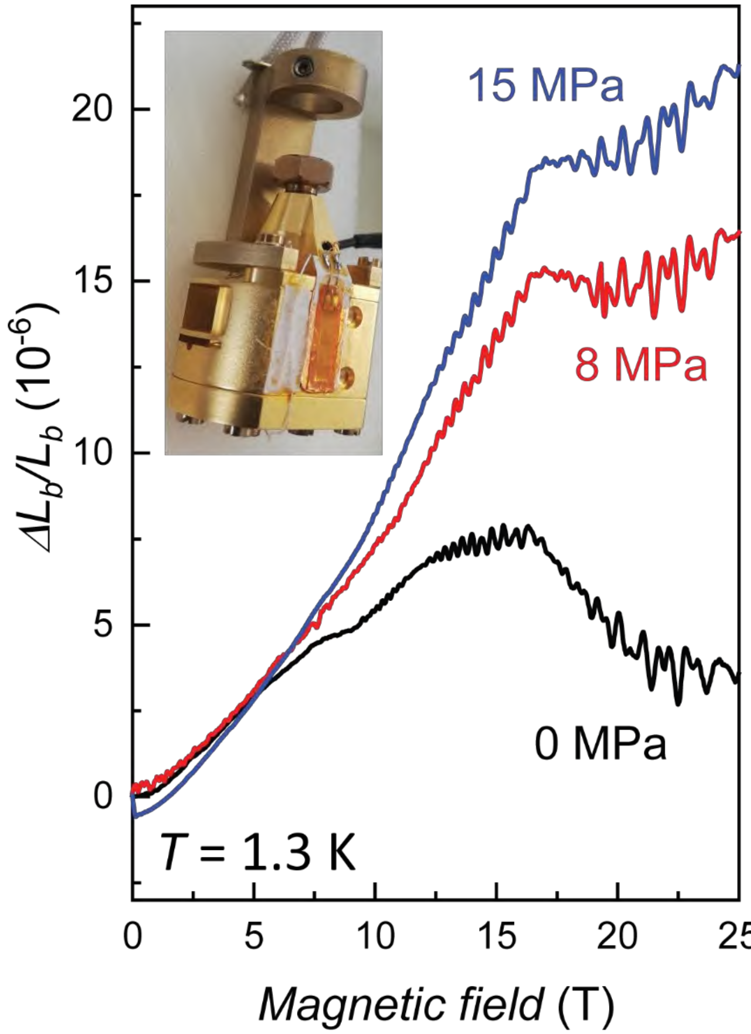
Technical developments: instrumentation

EMFL-G: High-field high-pressure Raman experiments



I. Breslavetz et al. Rev. Sci. Instruments **92,** 121909 (2021)

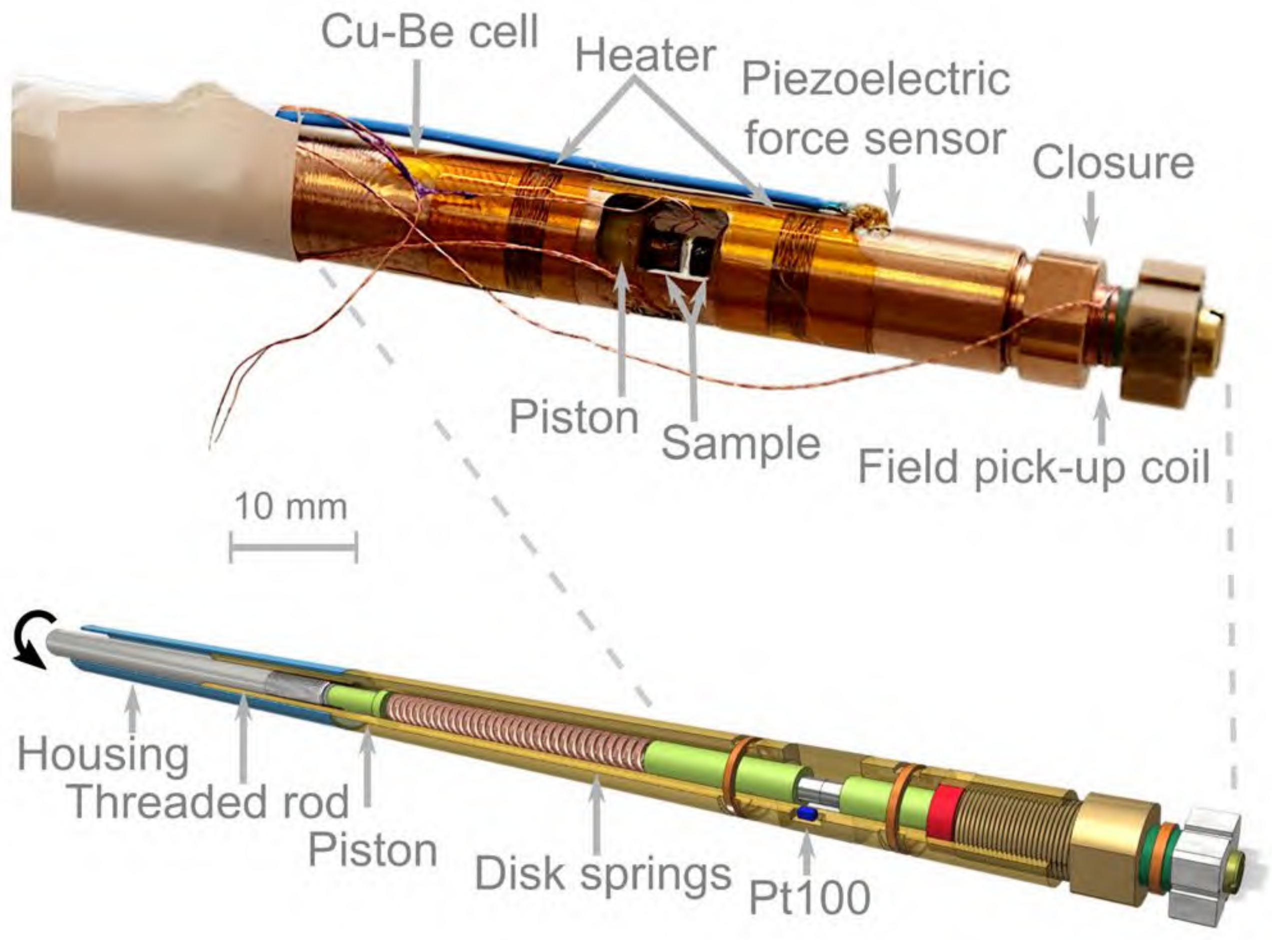
EMFL-N: Strain dilatometer

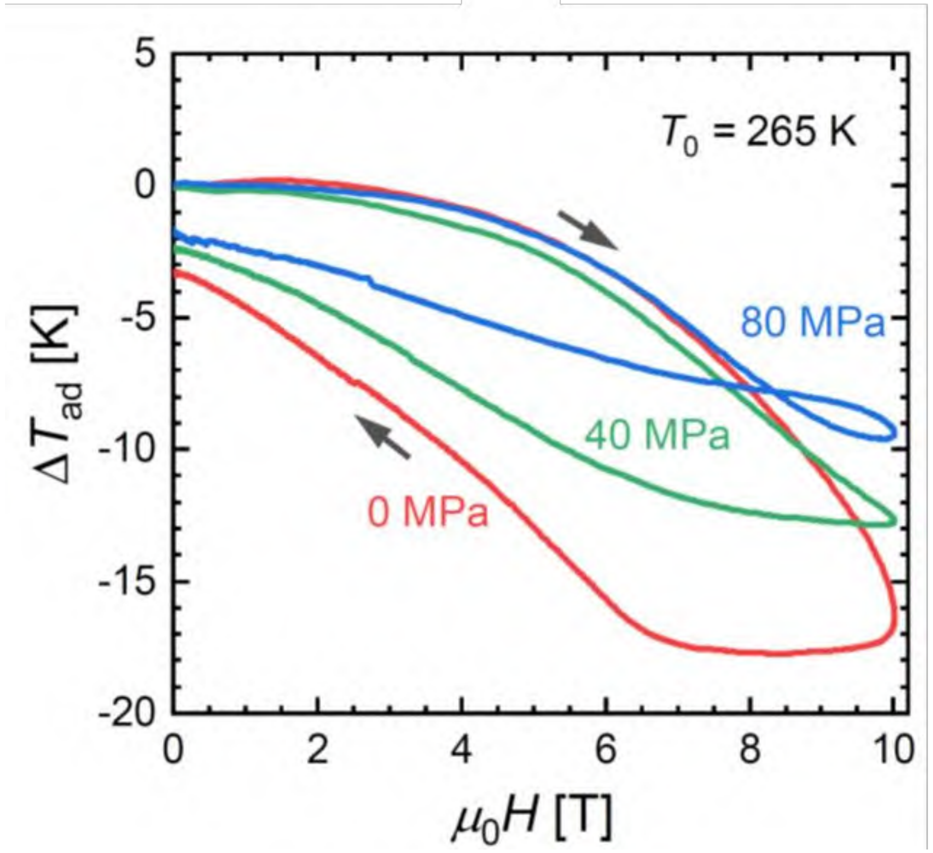


European Magnetic Field Laboratory

Technical developments: instrumentation

EMFL-D: Characterization of multicaloric materials under uniaxial pressure





European Magnetic Field Laboratory

EMFL Scientific Activity 2021

Proposals & Publications	2019	2020	2021	2022
User proposals received	363	270	318	304
User projects performed	257	185	194	228
Peer reviewed publications	177	199	189	148
Of which high impact (5 < IF < 15)	34	46	50	49
Of which very high impact (IF > 15)	13	13	15	19
PhD thesis defended	8	7	9	7

EMFL Strategic goals

- Scientific excellence for the in-house and user research programs in a maximum number of research areas
- Stakeholder support and membership expansion
- Improving the high-field infrastructure and instrumentation, incl. superconducting magnet technology
- Combination with other large-scale research infrastructures
- Strengthening the socio-economic impact of the EMFL
- Improve communication and outreach to enhance the awareness among scientists and the general public on the excellent science, technology, and education done at the EMFL facilities

EU projects ISABEL & SuperEMFL

Improving the Sustainability of the European Magnet Field Laboratory
2020-2024, 18 partners, of which 5 industrial, budget 4,9 M€, started 1 November 2020

- Strengthen the EMFL structure
- Strengthening role high magnetic field research in Europe
- Strengthening the socio-economic impact of the EMFL

New access modes

- Dual access
- Long-term access
- Industrial access
- First-time access
- Fast-track access
- Mail-in / remote access

SuperEMFL

2021-2024, 11 partners, of which 3 industrial, budget 2,9 M€, started January 2021

Design study all-SC magnets for the European Magnet Field Laboratory

32 T & 40 T all-SC user magnet concepts

European Magnetic Field Laboratory

Regional partners

UK
University of Nottingham (R. Hill/A. Patanè)
University of Oxford (A. Coldea/S. Blundell)

Poland
University of Warsaw (A. Babinski)

Spain
UAM Madrid (H. Suderow)

Estonia
NICPB, National Institute of Chemical Physics and Biophysics (R. Stern and T. Rõõm)

Czech Republic
Charles University (P. Javorsky)

Italy
University of Salento (G. Maruccio)

Switzerland
University of Geneva (S. Gariglio/C. Senatore)

- Promote EMFL activities & provide information
- Workshops, trainings
- Dual access mode
- Explore opportunities to secure membership of EMFL

ARIE

- Analytical Research Infrastructures in Europe (ARIE) represents the main centres of scientific and technological excellence in Europe, including EMFL
- EMFL (JW) spokesperson of network in 2022
- 3 EU running projects with ARIE contribution:
  - *ReMade@ARI [HZDR] (Circular Economy)*
    14 Mio €, 4 years, 46 beneficiaries
  - *CANServ [INSPIRE] (Precision Medicine)*
    15 Mio €; only small part to INSPIRE
  - *eRImote [DESY] (remote/digital access)*
    1.5 Mio €, 30 months, 8 beneficiaries
- ARIE lobbying RIs at EU level – visibility of RIs

European Magnetic Field Laboratory

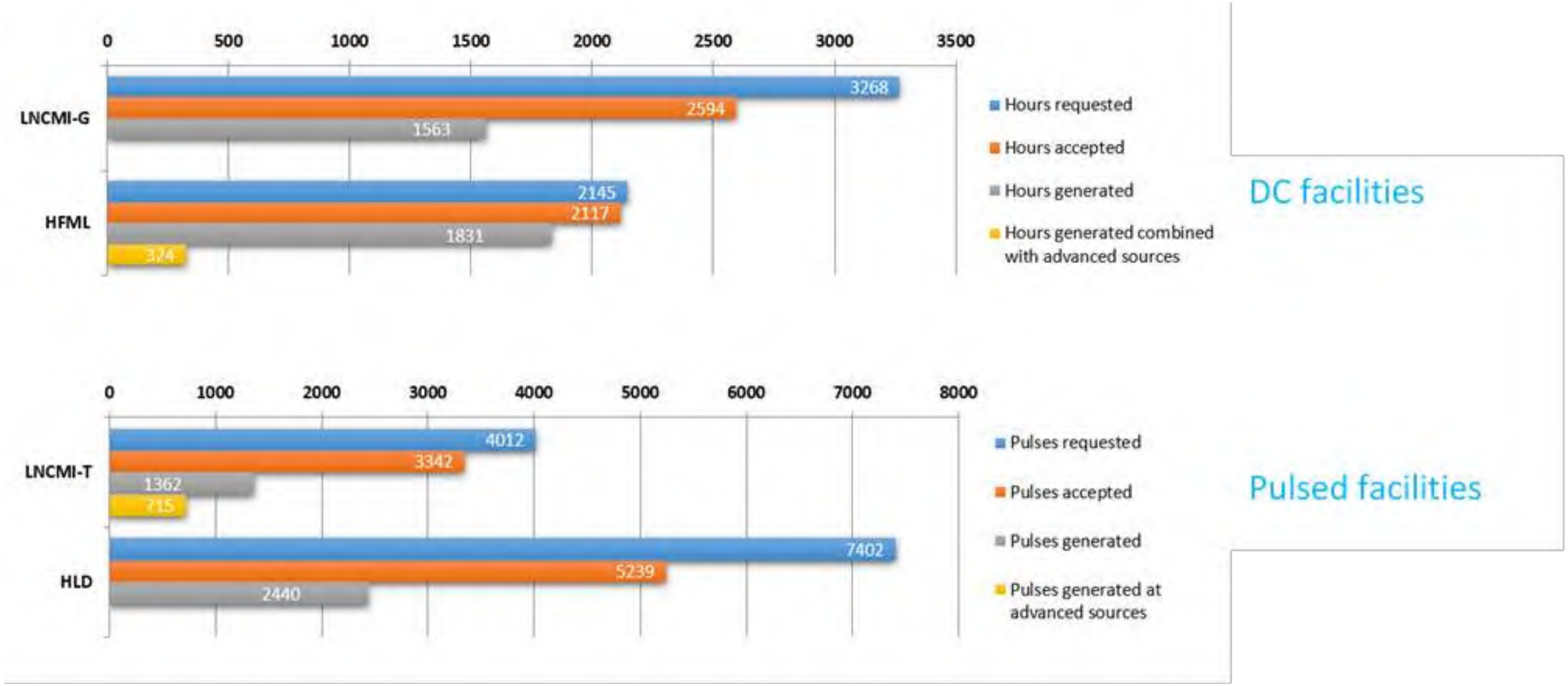
Introduction to the user meeting

Charles Simon,

EMFL User meeting

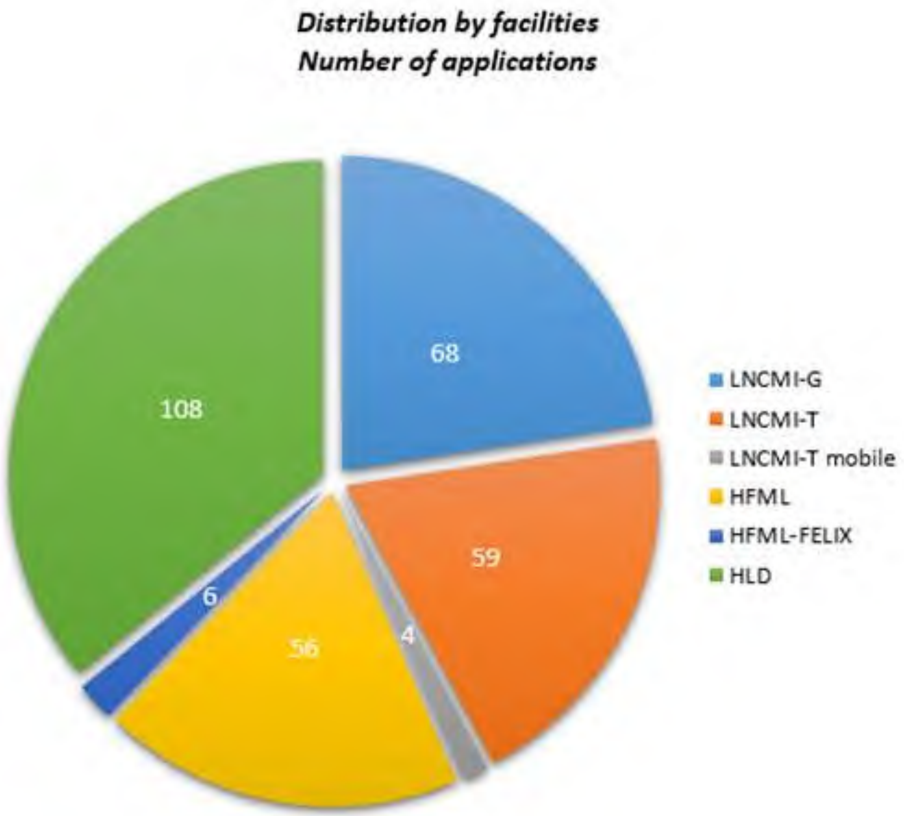
June 13^{th}, 2023

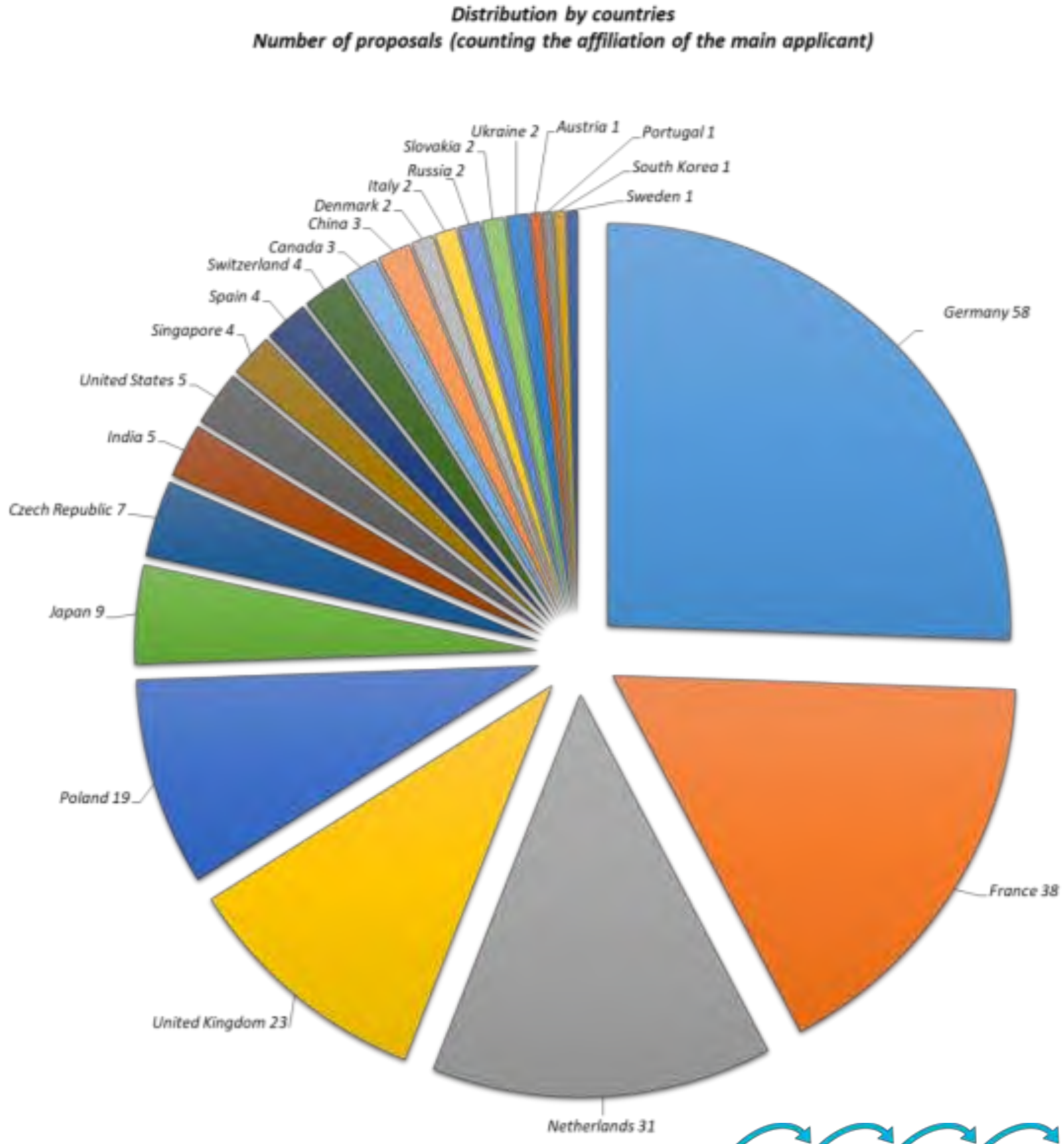
Summary of the use in 2022



European Magnetic Field Laboratory

2022





European Magnetic Field Laboratory

Happy users

European Magnetic Field Laboratory

Each year : user meeting and price

Grenoble, June 2022

Mateusz Dyksik, Wroclaw Univ.

European Magnetic Field Laboratory

EMFL school
Kerkrade, Netherland

European Magnetic Field Laboratory

EMFL Scientific Activity 2022

	2019	2020	2021	2022
Peer reviewed publications	177	199	189	150
Executed proposals	257	185	194	189
Requested proposals	367	273	323	301
PhD thesis defended	8	7	9	7

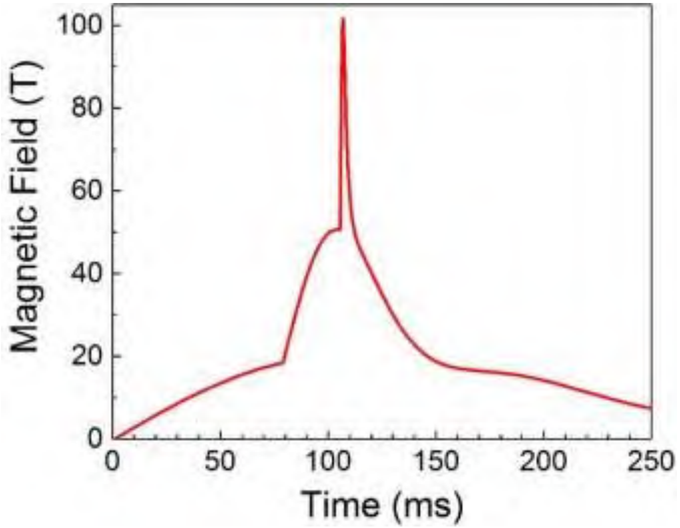
EMFL
European Magnetic Field Laboratory

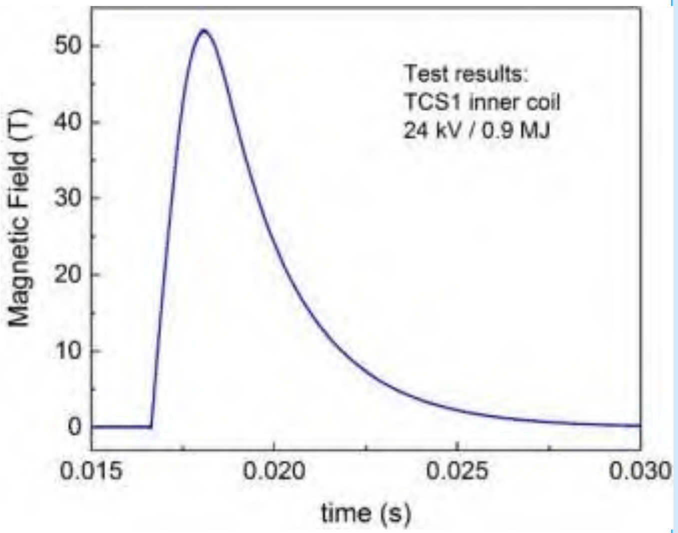
Technical developments: new magnets in Dresden

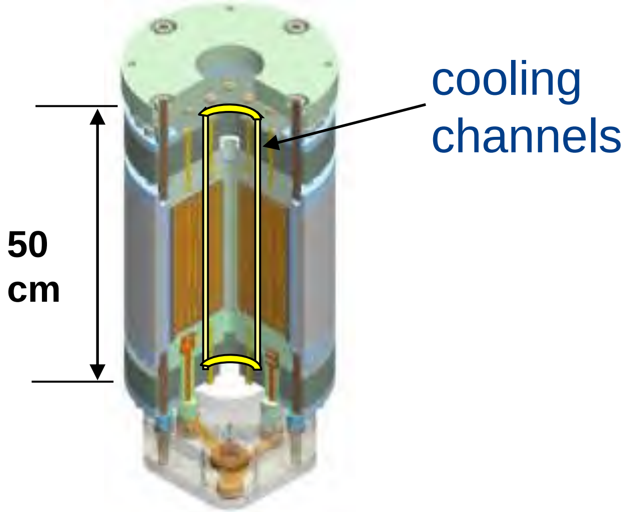
- Triple-coil magnet
  100 T / 10 ms / 12 mm bore
  (inner and middle coil wound,
  outer coil in production)

User-demand magnets

- 55 T / 150 ms / 20 mm
  (magnetocaloric effect)
- 65 T / 25 ms / 16 mm
  (magnetization)
- 70 T / 150 ms / 20 mm
  (with cooling channels)







HLD. EMFL European Magnetic Field Laboratory

Technical developments: Hybrid in Grenoble

1 Superconducting Magnet

2 LN_2 tank 27 000 litres.

3 He liquefier coldbox
150 l/h @ 4.5 K , 1.3 bar

4 Main LHe Dewar 4500 litres

5 Secondary LHe Dewar 1700 litres

6 Cryogenic satellite to produce
the 1.8 K LHe bath

7 DC power converter
7500 A , 30 V (underground)

8 Cryoline with busbars @ 1,8 K

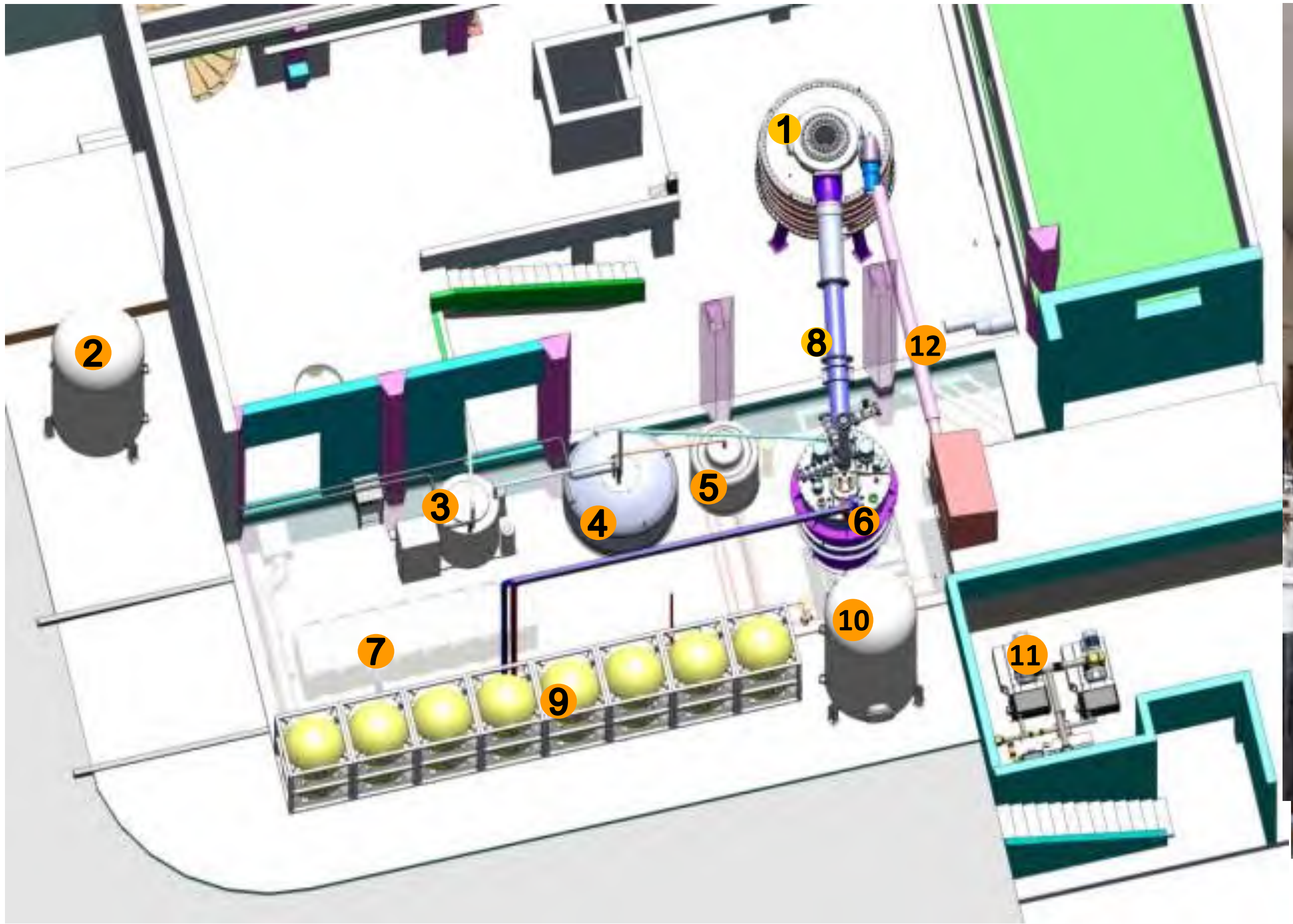
9 High pressure gaseous He tanks
16 x 1 m^3 @ 200 bars

10 Liquefier pure He buffer tank
15 m^3 @ 20 bars

11 Helium pumping system
6000 m^3/h @ 10 mbar, 20 °C

12 Quench line

Already installed



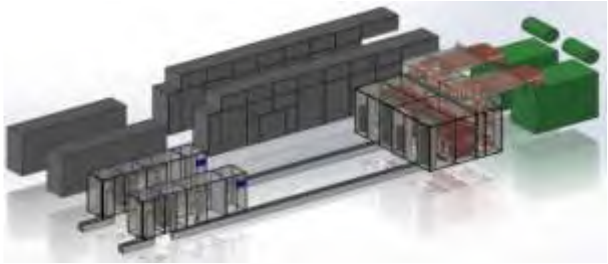
Expected magnet at 43T October 2023

EMFL
European Magnetic Field Laboratory

Technical developments: Hybrid in Grenoble UPALIM : upgrade to 30 MW

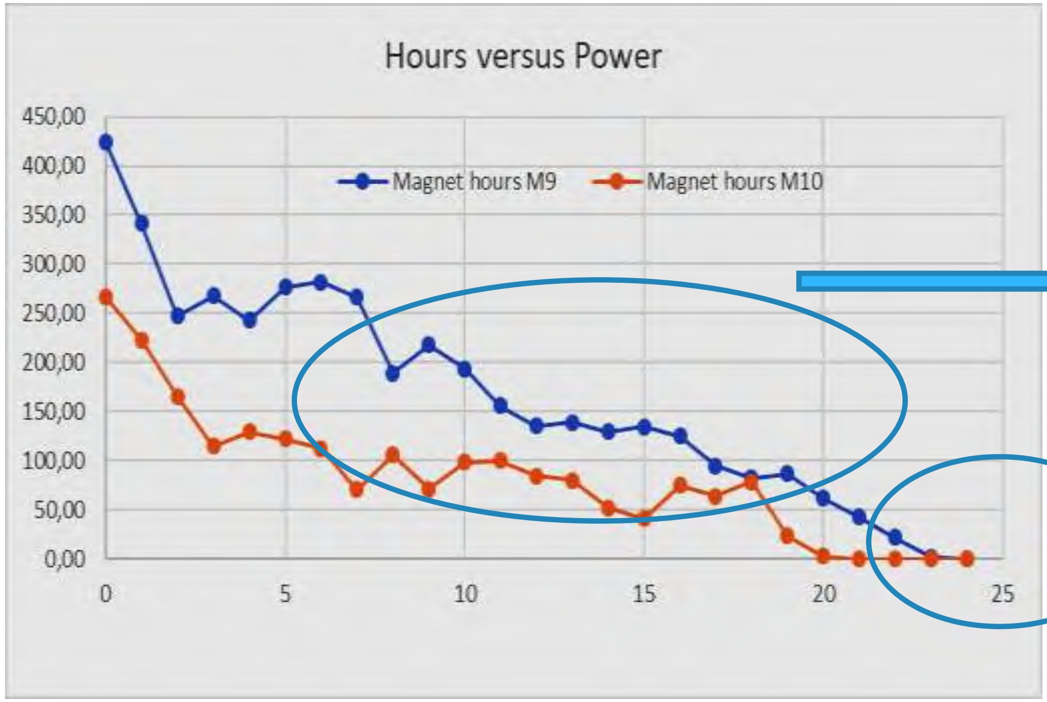
Today: 24 MW ➔ 36 T

From 2024: 30 MW ➔ Towards 40 T



30 MW converters
(operational)
+
225 to 15 KV Transformer
(to be delivered end 2023)

➔ Aim acces to higher magnetic fields and decrease of the energy consumption

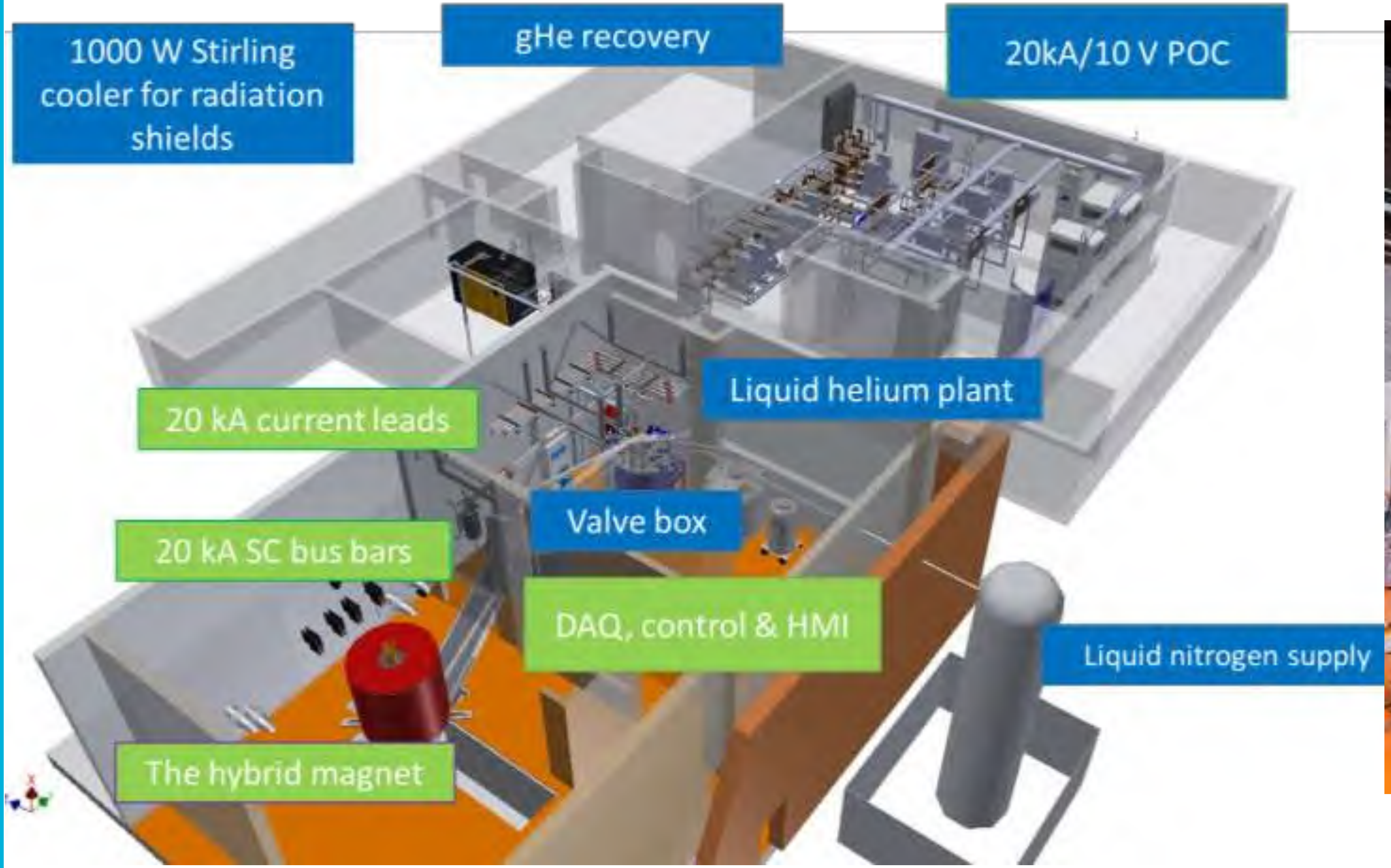


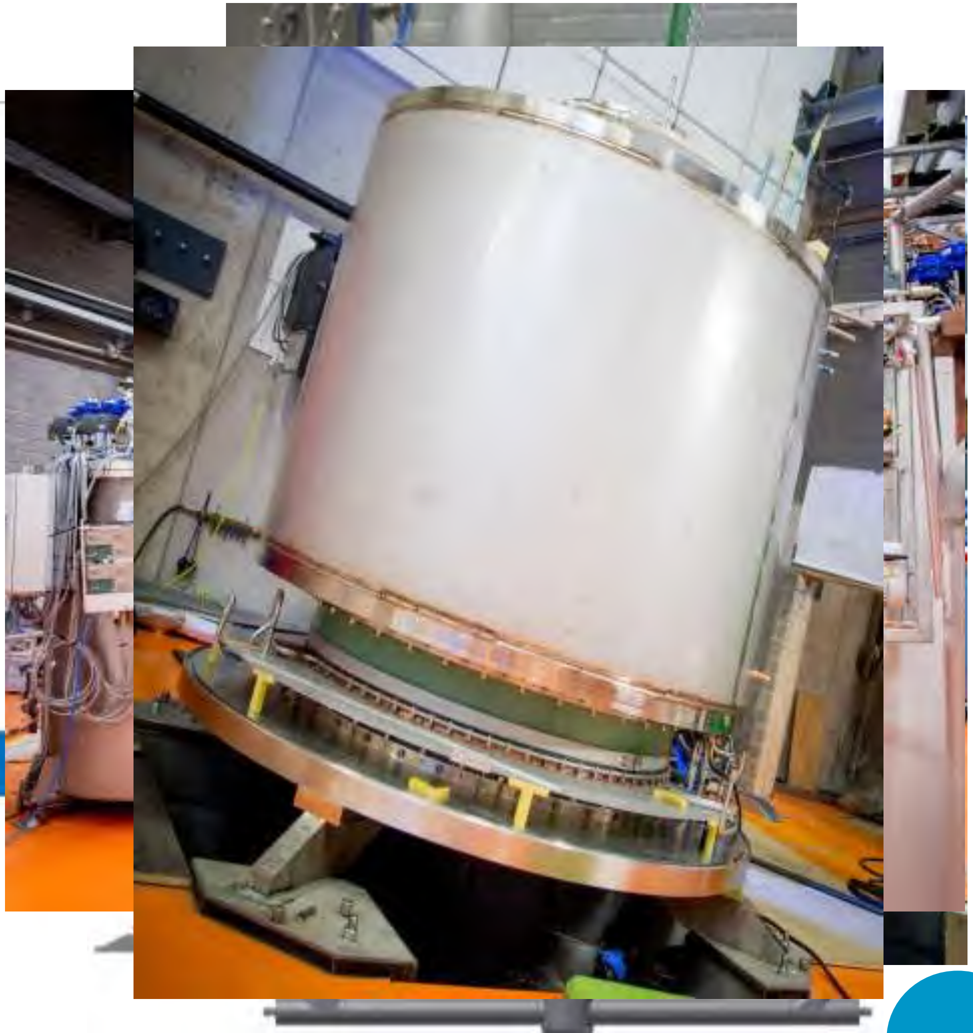
INCREASE EFFICIENCY:
Decrease the consumption on a large range of Power
- Eco-mode V2 (differentiate piloting of the sub magnets)
- Material progress (Cold Spray)
- Heat Transfer Enhancement (geometry + surface treatment)
- Use electricity when there is too much

INCREASE B :
Push the power to 30 MW for a limited number of hours

EMFL
European Magnetic Field Laboratory

Technical developments: Hybrid in Nijmegen





Magnet cool-down expected end of 2023

EMFL European Magnetic Field Laboratory

EMFL Strategic goals

- Scientific excellence for the in-house and user research programs in a maximum number of research areas
- Stakeholder support and membership expansion
- Improving the high-field infrastructure and instrumentation, incl. superconducting magnet technology and the combination with other large scale research infrastructures
- Prepare response to the energy crisis and CO_2 issues.
- Strengthening the socio-economic impact of the EMFL
- Improve communication and outreach to enhance the awareness among scientists and the general public on the excellent science, technology, and education done at the EMFL facilities

European Magnetic Field Laboratory

EMFL is on the ESFRI list

- ESFRI Landmark
- Two European programmes
  - ISABEL (to strengthen the EMFL, new types of call : fast track, new users, …) end 2024
  - SuperEMFL (superconducting 40T magnet, design study) end 2024

European Magnetic Field Laboratory

EU projects ISABEL& SuperEMFL

Improving the Sustainability of the European Magnet Field Laboratory
2020-2023, 18 partners, of which 5 industrial, budget 4,9 M€, started 1 November 2020

- Strengthen the EMFL structure
- Strengthening role high magnetic field research in Europe and Europe's global position in this area
- Strengthening the socio-economic impact of the EMFL

SuperEMFL

2021-2024, 11 partners, of which 3 industrial, budget 2,9 M€, started January 2021

Design study all-SC magnets for the European Magnet Field Laboratory

32 T & 40 T all-SC user magnets

Regional partners

UK
University of Nottingham (R. Hill/A. Patanè)
University of Oxford (A. Coldea/S. Blundell)

Poland
University of Warsaw (A. Babinski)

Spain
UAM Madrid (H. Suderow)

Estonia
NICPB, National Institute of Chemical Physics and Biophysics (R. Stern and T. Rõõm)

Czech Republic
Charles University (P. Javorsky)

Italy
University of Salento (G. Maruccio)

Switzerland
University of Geneva (S. Gariglio/C. Senatore)

- Promote EMFL activities & provide information
- Workshops, trainings
- Dual access mode
- Explore opportunities to secure membership of EMFL

EMFL European Magnetic Field Laboratory

Industrial partner club

European Magnetic Field Laboratory

7th workshop on Magnetic Fields in Laboratory High Energy Density Plasmas

- "Perspectives with High Magnetic Fields at Neutron Sources

European Magnetic Field Laboratory

ISABEL developments

Development of new access modes

- Dual access (since call in May 2021)
- Long-term access
- Industrial access
- First time access

User Survey executed

Secondments

- Call every 6 months since 2021

Innovation

- Industrial Liaison officer
- IPR & Technology transfer training for EMFL employees
- Innovation call/deadline Dec. 2021
- 3 proposals received, 2 granted (50 k€)

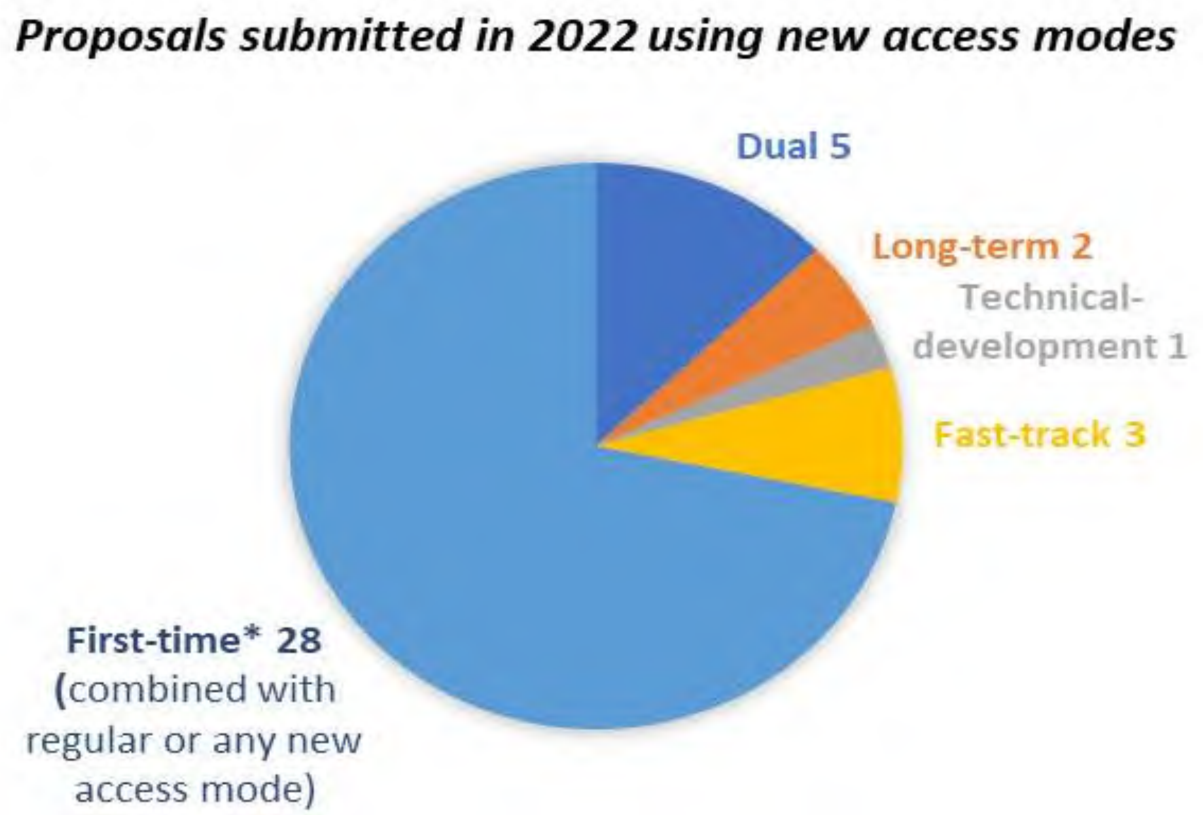
Magnet technology

- Goal: Magnet technology Roadmap
- User Survey in preparation
- Material developments
- New design tools
- Sustainability (energy efficiency, recycling)

Strategical External connections

- HiFF
- Other European Large Scale Infrastructures
- CERN: Magnets for Accelerators & Muon Colliders
- FuSuMaTech: Shaping the Future of Superconductive Magnets
- European MRI community

European Magnetic Field Laboratory

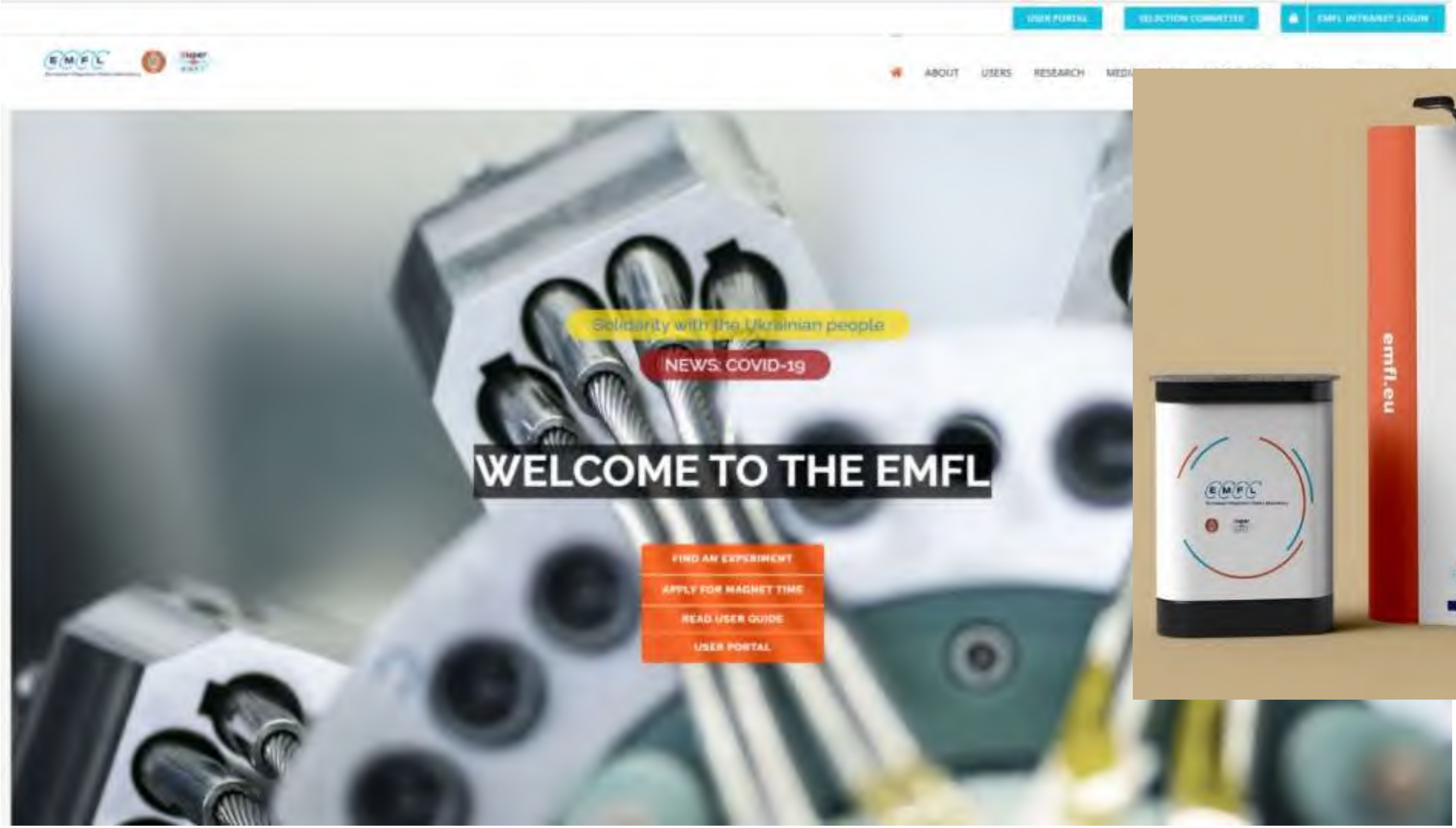


European Magnetic Field Laboratory

Communication

JOINS US !

Renewed website, LinkedIn, Twitter, Folders, Flyers, Exhibitions…



European Magnetic Field Laboratory

Update ARIE

- Analytical Research Infrastructures in Europe (ARIE) represents the main centres of scientific and technological excellence in Europe, including EMFL.
- EMFL chairs the coordination board in 2022
- 3 EU proposals with ARIE contribution in negotiation:
  - *ReMade@ARI [HZDR] (Circular Economy)*
    14 Mio €, 4 years, 46 beneficiaries
  - *CANServ [INSPIRE] (Precision Medicine)*
    15 Mio €; only small part to INSPIRE
  - *eRImote [DESY] (remote/digital access)*
    1.5 Mio €, 30 months, 8 beneficiaries
- ARIE in contact with ERA (Andrew Harrison)
  lobbying RIs at EU level – visibility of RIs

European Magnetic Field Laboratory

FLEXibility in Research Infrastructures: Towards Carbon Neutral (FLEXRICAN)

INFRATECH	1 topic	25 million
Proposals now under evaluation	Reducing the environmental footprint of research infrastructures	Indicative budget for this call

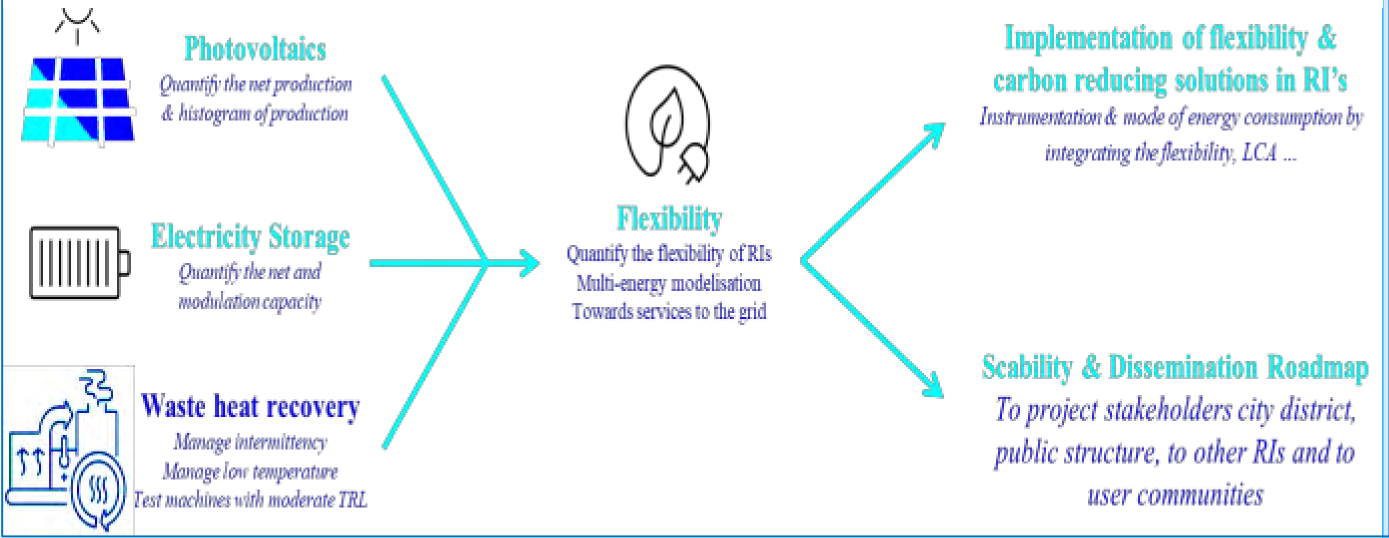
5 proposals received for this destination by call deadline
Now under evaluation by independent experts
Answer in July-August

Proposal submitted the 9th of March 2023 for a 3 year project (2024-2026)
- 3 RI : The European Spallation Source (**ESS**) (coordinator), **EMFL** & The Extreme Light Infrastructure (**ELI**)
- 2 industrial partners : Energy Pool and Alfa Laval

A variety of energy usages: a strength for FlexRICAN

- a quite uniform consumption along the year at **ELI** facilities (CZ and HU), with the highest priority set on regulation and securing the availability of electricity,
- a hyper-variability of electrical consumption with peaks up to 30 MW at the two **EMFL** DC facilities (FR and NL),
- 3 levels of consumption at the **ESS** facility (SE) comprising a full operation mode during 240 days a year up to 35 MW.

FlexRICAN concept : from intermittency to flexibility & services to networks



➔ Increase the long-term sustainability of European Research Infrastructures,
➔ Contribute to the resilience of the energetical European system.

European Magnetic Field Laboratory

Thank you

- Please participate to the user feedback today and to the user feedback for future developments tomorrow

European Magnetic Field Laboratory

Prof. Amalia Patanè
Director of the UK partnership/Member of EMFL Council
School of Physics and Astronomy, University of Nottingham, UK

European Magnetic Field Laboratory

Science and Technologies

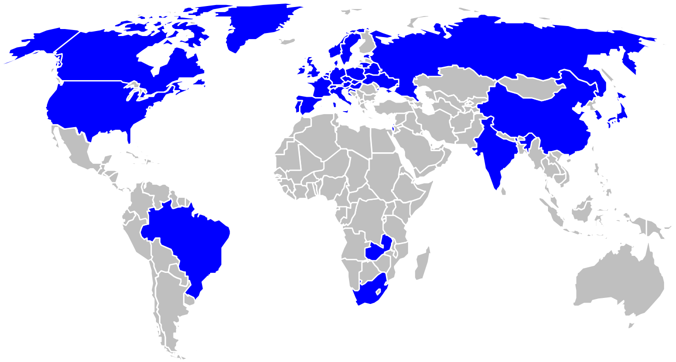
Outline

- Introduction to the EMFL
- Research in high magnetic field
- Opportunities

European Magnetic Field Laboratory, EMFL

World class high magnetic field facility for research by users from all over the world

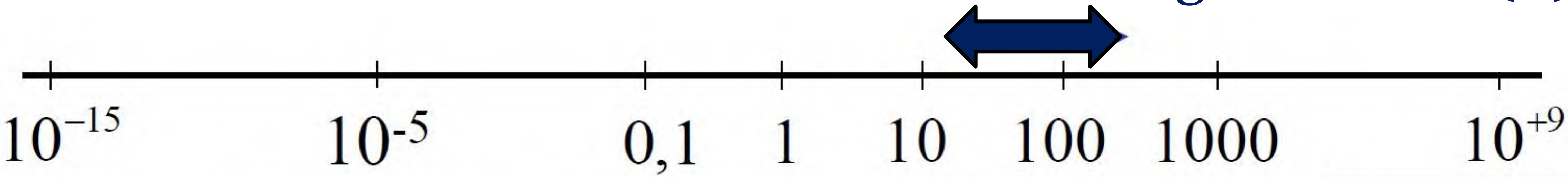
- 4 sites in the EU
- Users from
  > 30 countries

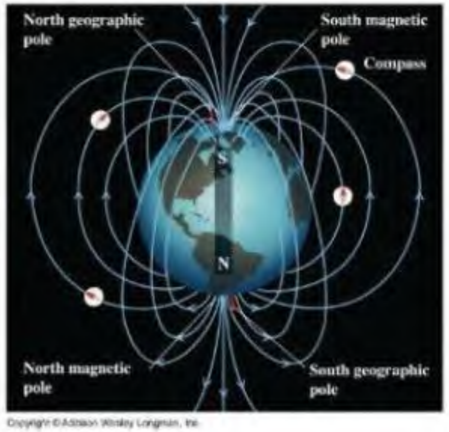


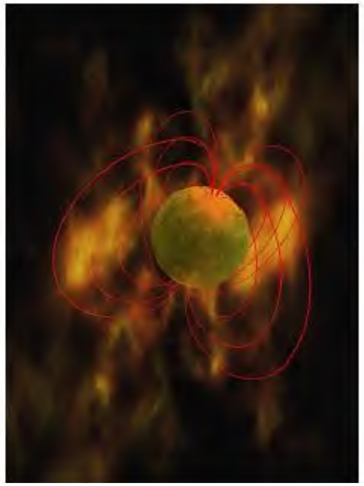
- UK Partnership funded by the UKRI (2015-27, 9 M€)

EMFL State-Of-The-Art Magnet Technology

Magnetic Field (T)

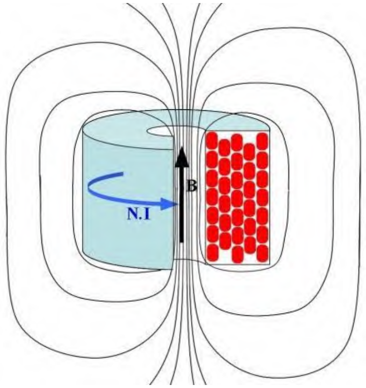






EMFL

Static magnetic fields up to 38T
Pulsed magnetic fields up to 98.8T (non destructive)
up to 209T (destructive)



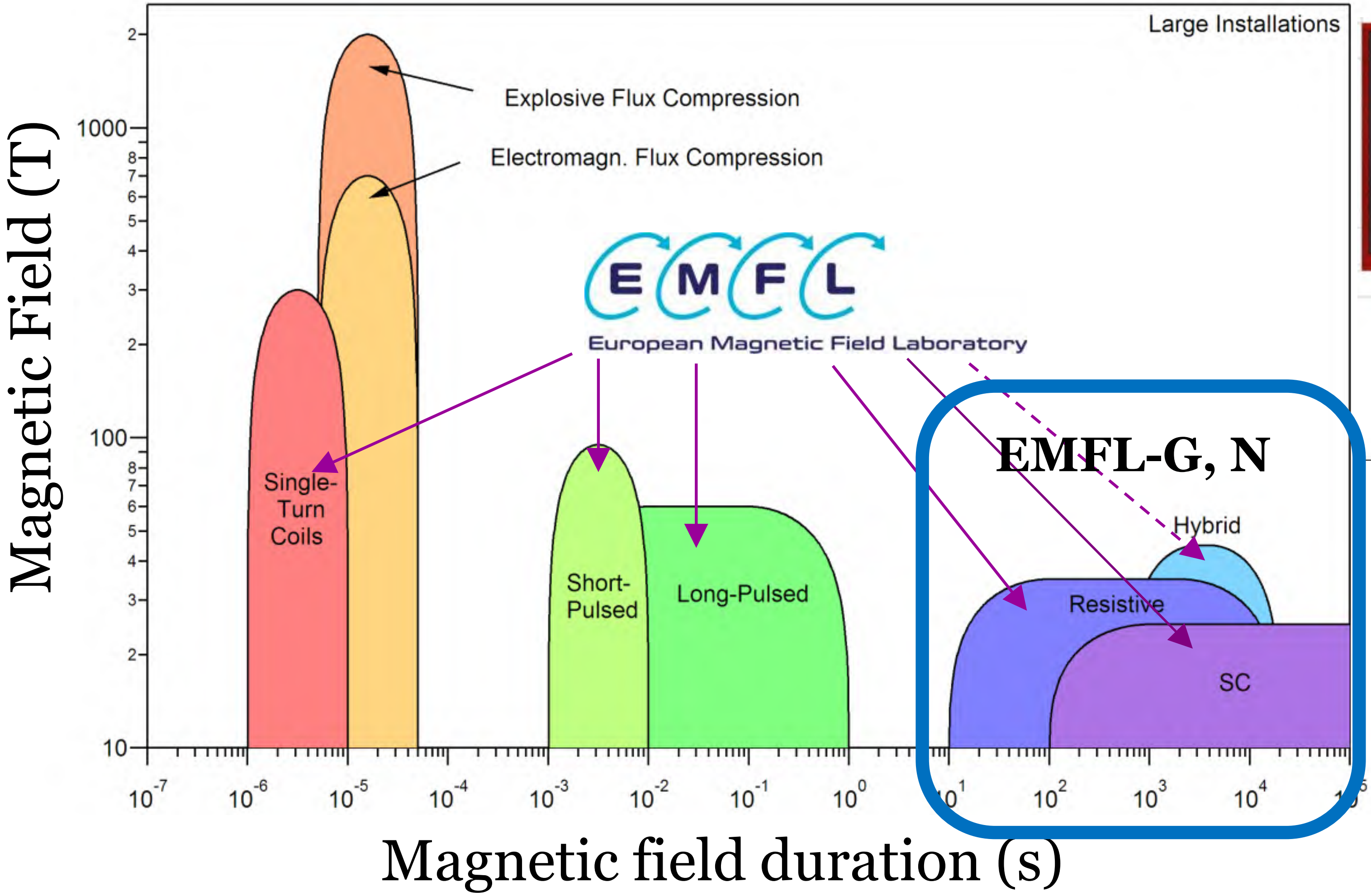
A current I flowing in a coil generates a magnetic field $B \propto I$

Limitations

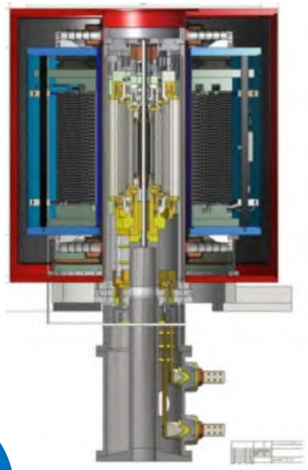
Heating $P \propto RI^2 \propto B^2$

Lorentz force $\propto BI \propto B^2$

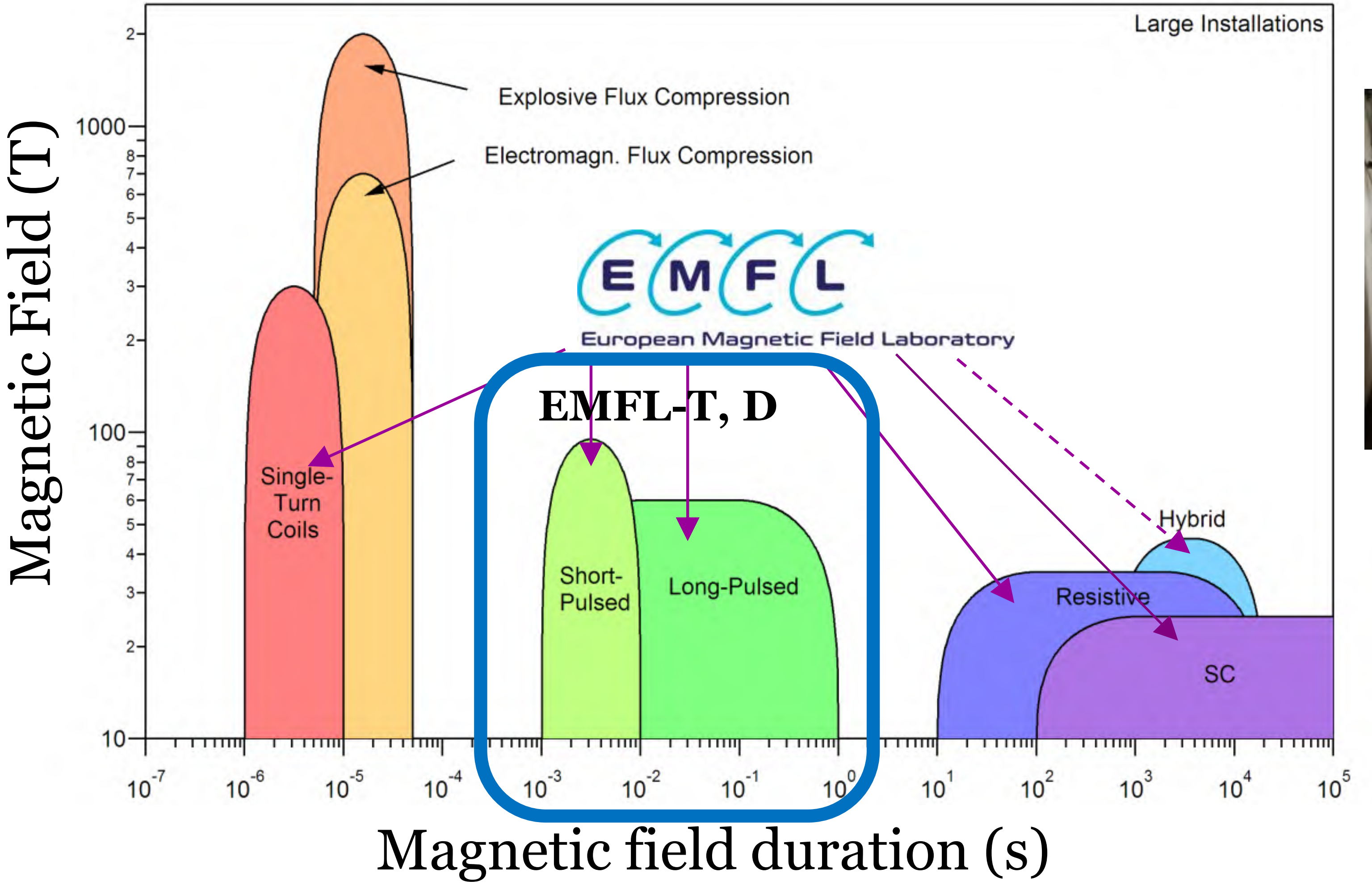
EMFL State-Of-The-Art Magnet Technology



Static magnetic fields



EMFL State-Of-The-Art Magnet Technology

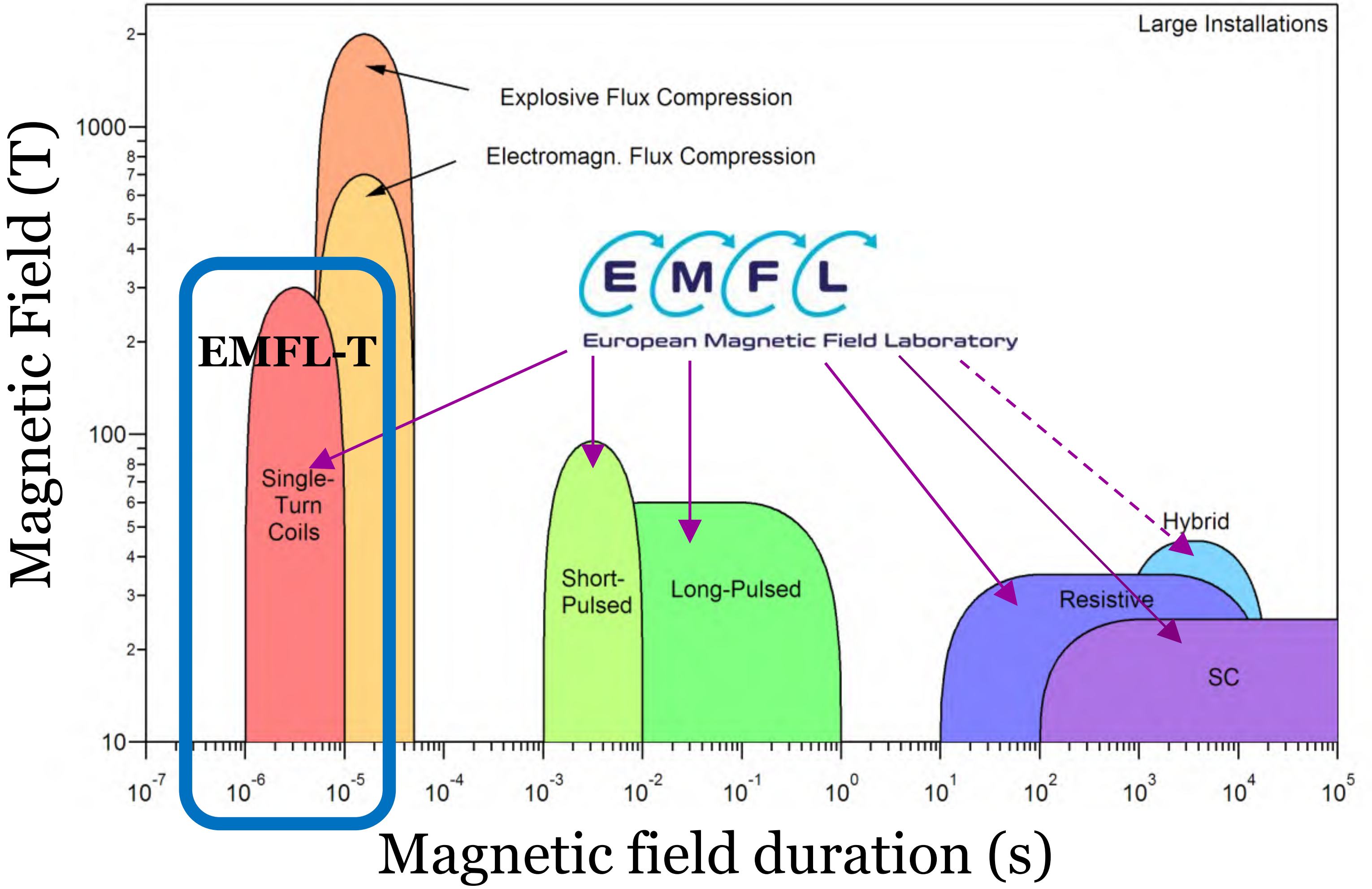


Pulsed magnetic fields

- Non-destructive pulsed fields: 100 T

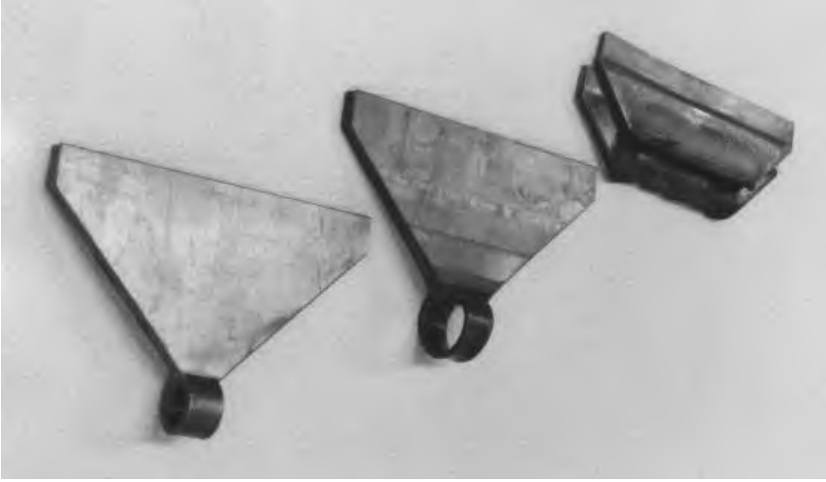
Technologically challenging due to enormous electrical, magnetic, thermal, and mechanical stresses on the coils. The forces and pressure on the wire inside a coil is given by $p = B^2/2\mu$. For 100T, p ~ 4 GP (40000 atmospheres).

EMFL State-Of-The-Art Magnet Technology



Pulsed magnetic fields

❖ Semi-destructive pulsed fields



12 mm × 12 mm × 3 mm single-turn coils before the pulse (bottom), after a 10 kV, 6 kJ discharge with 37 T peak field and after a 55 kV, 189 kJ discharge with 188T peak field (top). After the high field pulse, the coil is destroyed.

EMFL State-Of-The-Art Magnet Technology

H2020 ISABEL

2020-24, 4,9 M€

18 partners, 5 industrial

H2020 SuperEMFL

2021-2024, 2.9M€

11 partners, 3 industrial

Design of all-superconducting magnets (32T/40T) through high-T and low-T superconductors.

From the development of all-superconducting magnets to the integration of different techniques and international partnerships

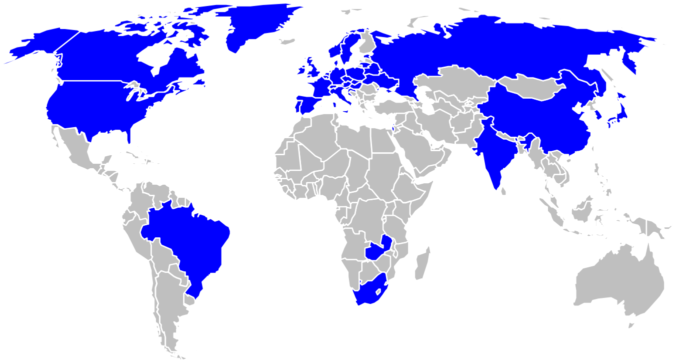
Integration with Large Scale Infrastructure

Transportable pulsed magnets allow fields of up to 40T to be combined with neutron, X-ray, or laser sources

European Magnetic Field Laboratory, EMFL

World class high magnetic field facility for research by users from all over the world

- 4 sites in the EU
- Users from
  > 30 countries



- UK Partnership funded by the UKRI (2015-27, 9 M€)

UK Community

Academia
Coventry University
Durham University
Imperial College London
ISIS, Rutherford Appleton Lab
Keele University
Royal Holloway London
University of Bath
University of Bristol
University of Cambridge
University College London
University of Edinburgh
University of Exeter
University of Liverpool
University of Manchester
University of Nottingham
University of Oxford
University of Strathclyde
University of Surrey
University of Warwick

Industry
AstraZeneca, Cryogenic Limited, Oxford Instruments, Paragraf Limited, Siemens Magnet Technology, Hitachi, Toshiba

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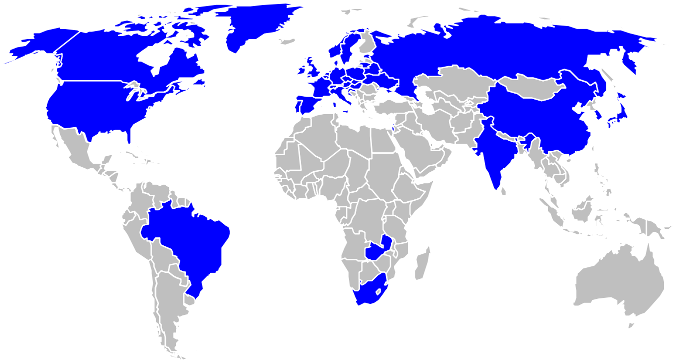
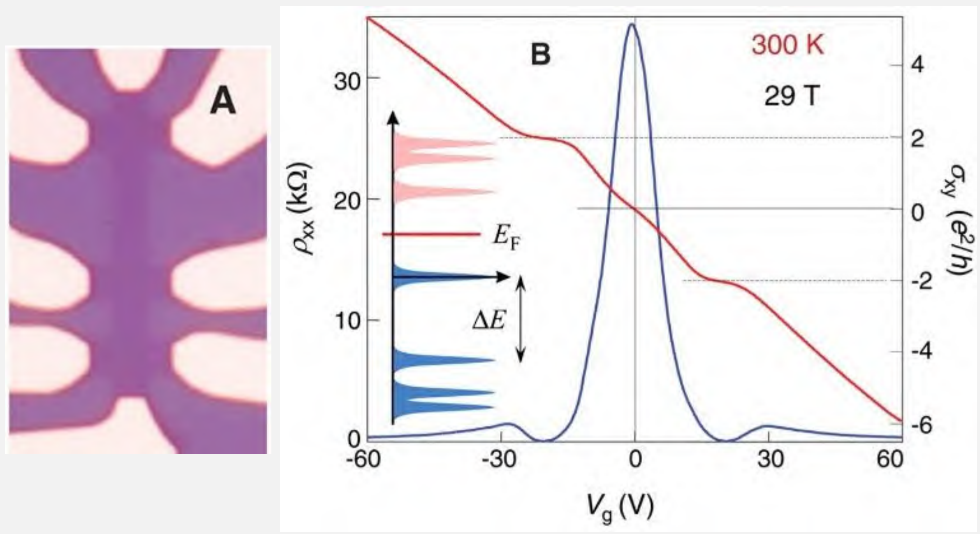


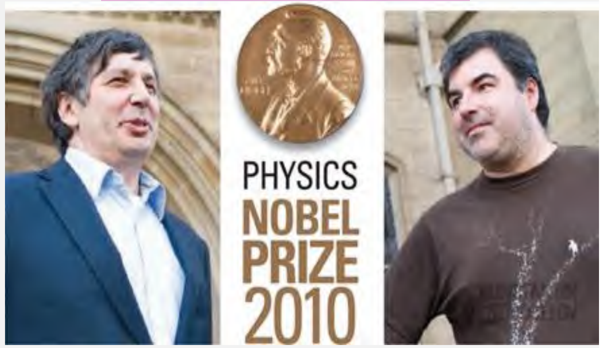
- UK Partnership funded by the UKRI (2015-27, 9 M€)

Graphene: Science and Technology

Graphene: RT Quantum Hall effect

Science 315, 5817, 2007





A. Geim and K. Novoselov

A. Geim
IG Nobel Prize 2000

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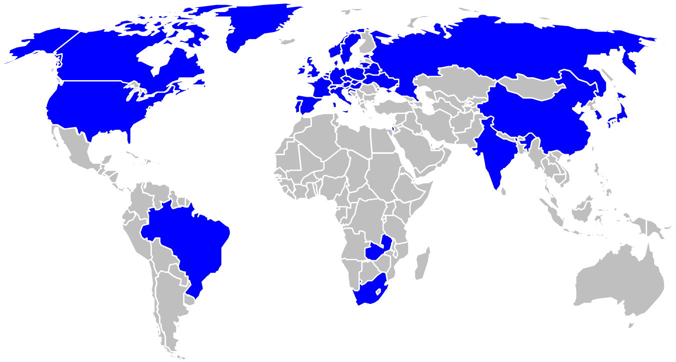
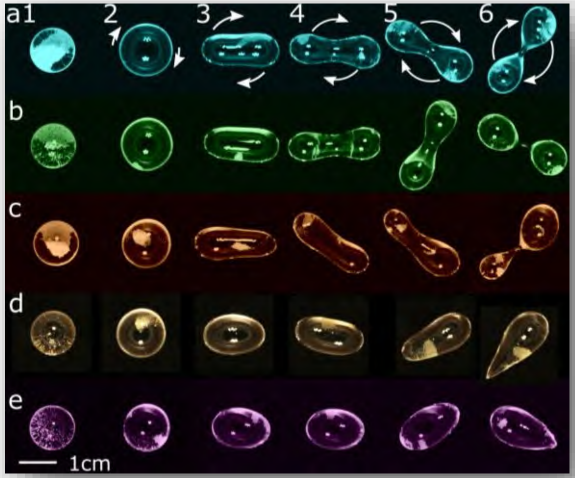


- UK Partnership funded by the UKRI (2015-27, 9 M€)

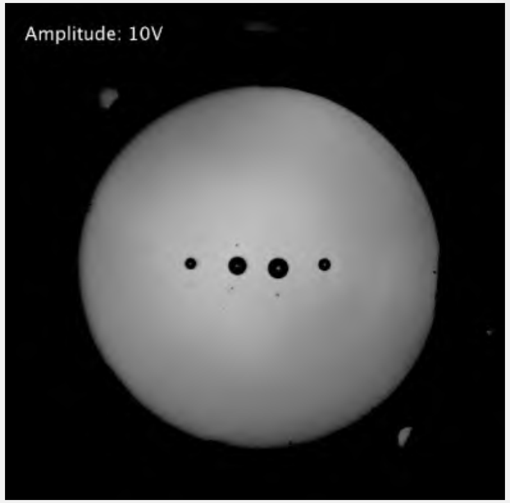
Magnetic levitation

Spinning liquid droplets

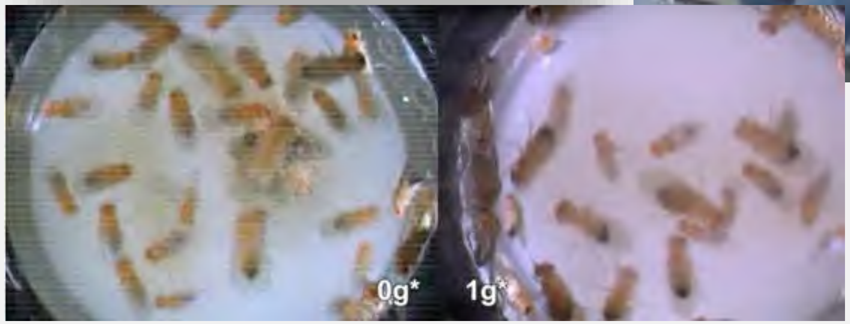


University of Nottingham UK | CHINA | MALAYSIA

R. Hill



Acoustic manipulation of liquid droplets



Fruit flies in weightless conditions

Phys. Rev. Lett. 119, 114501 (2017)
Appl. Phys. Lett. 122, 014103 (2023)

European Magnetic Field Laboratory, EMFL

World class high magnetic field facility for research by users from all over the world

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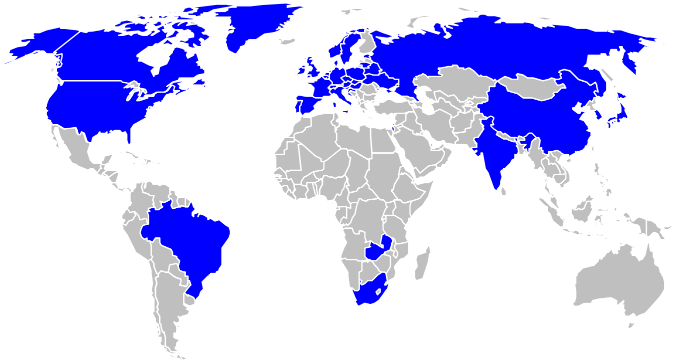
- ❖ Users from > 30 countries

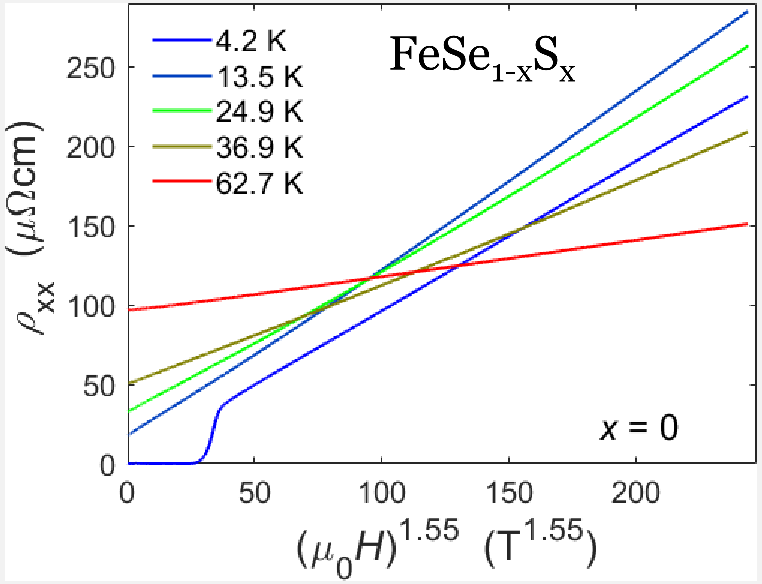


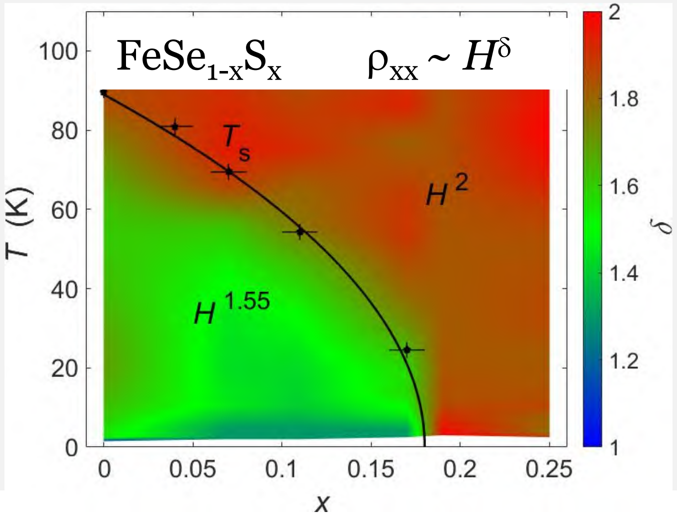
- ❖ UK Partnership funded by the UKRI (2015-27, 9 M€)

High-T_c Superconductors

A.I. Coldea — University of Oxford

Iron-based superconductors and new topological materials





Phys. Rev. Res. 2, 013309 (2020)
PNAS 119 e220040511 (2022)

European Magnetic Field Laboratory, EMFL

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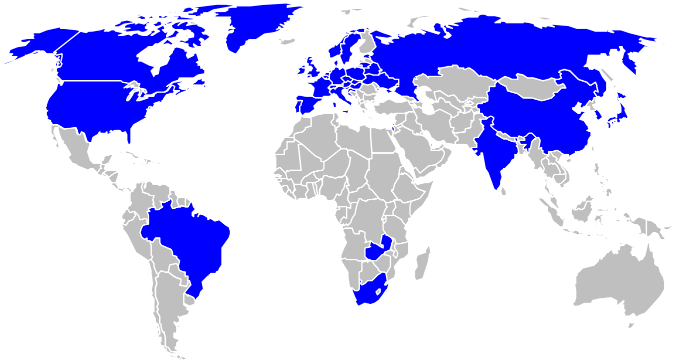
  > 30 countries

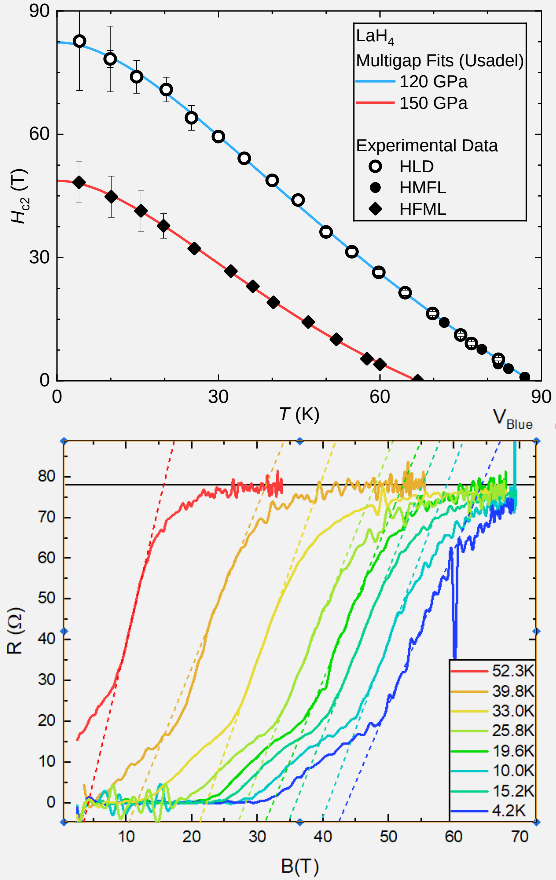


- ❖ UK Partnership funded by the UKRI (2015-27, 9 M€)

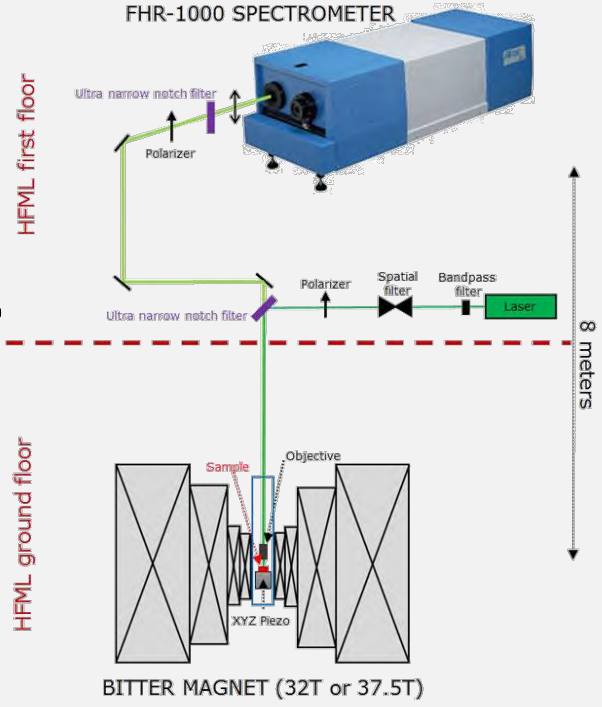
High-T_c Superconductors Under Pressure

Hydride LaH_4: Critical field and two-band superconductivity

S. Friedemann
University of BRISTOL



Raman spectroscopy



Superconductivity Talk at 3:30 - 4:00 pm

European Magnetic Field Laboratory, EMFL

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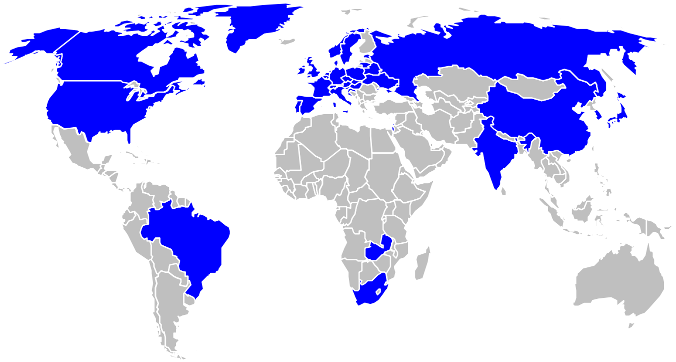
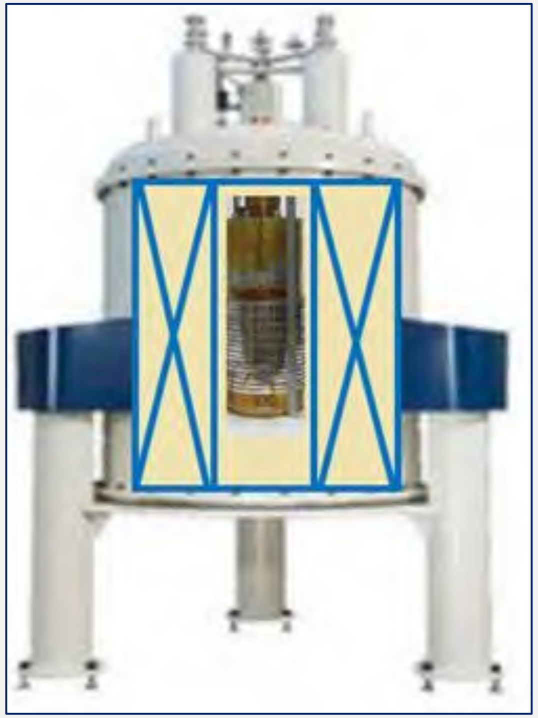
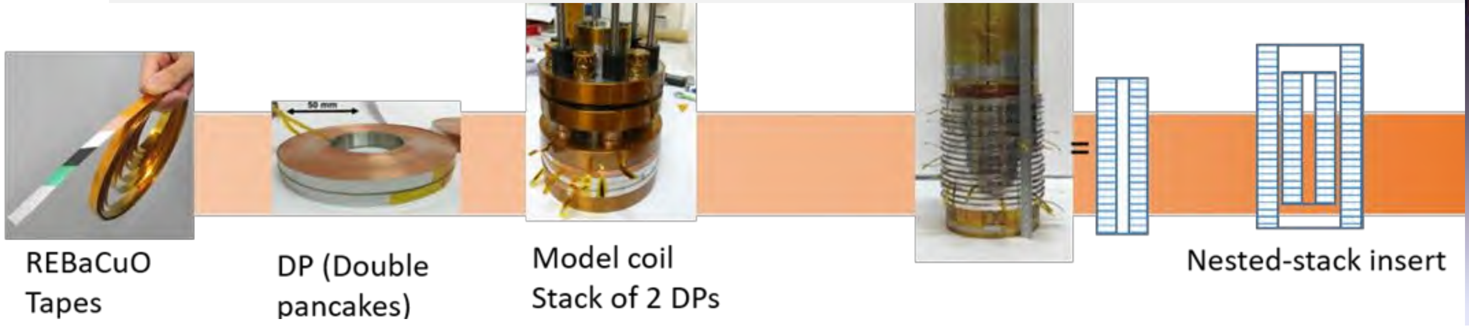


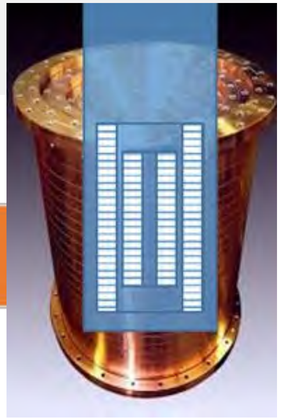
- UK Partnership funded by the UKRI (2015-27, 9 M€)

Beyond-state-of-the-art magnets

Design of all-superconducting magnet (32T/40T) through high-T and low-T superconductors.







EMFL: Dissemination, Training and Prizes

Prizes

Dr Jake D S Ayres
Univ. of Bristol

University of BRISTOL

Awarded the EMFL Prize in 2023

EPSRC Doctoral Prize Fellow
Awarded an Early Career Fellowship (2022-25) by the Leverhulme Trust to undertake research into the "strange metal" regimes of inorganic and organic high-T superconductors

International Schools

Science in High Magnetic Fields in Kerkrade, The Netherlands (Sept. 21-25 2022)
https://www.hfml.ru.nl/emflschool2022/
School free of charge for all its participants. Participants selected primarily among young scientists (doctoral students and postdoctoral researchers) and given an opportunity to present their research in pitch sessions.

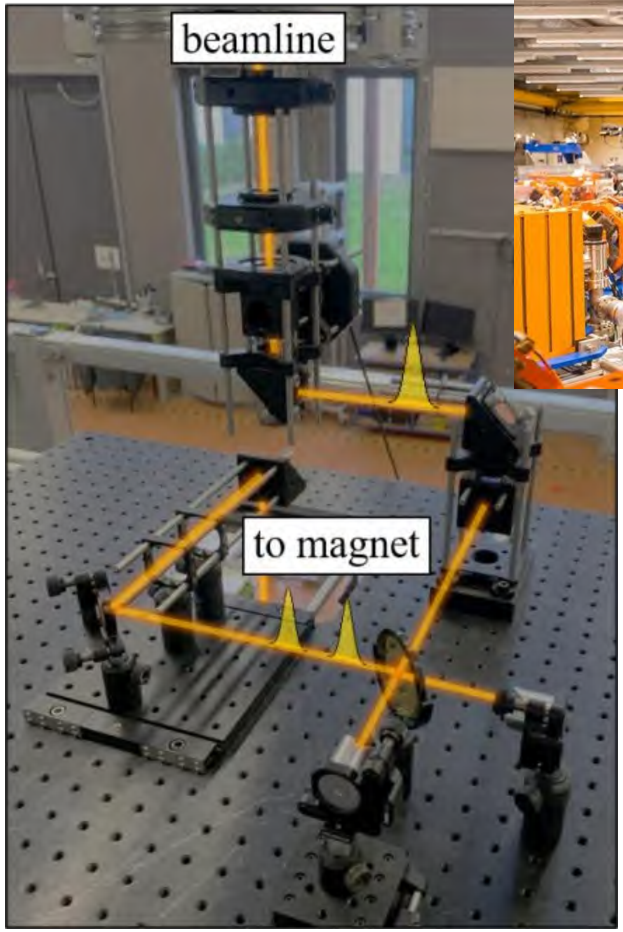
User Meeting

Nijmegen, Radboud University (June 13-14 2023)
https://emfl.eu/emfl-user-meeting-2023/

EMFL: Dissemination, Training and Prizes

Workshops

Joint workshop on “the combination of High Magnetic Fields and Free Electron Lasers”
Nijmegen, Radboud University (June 14-15 2023)



FELIX
Free-**E**lectron
Lasers
for **I**nfrared
e**X**periments
(3-1500 μm)

International Schools

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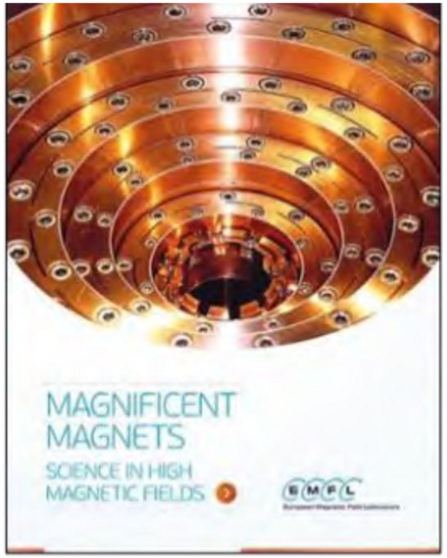
https://emfl.eu/emfl-user-meeting-2023/

EMFL: Dissemination



Website https://emfl.eu/
EMFLNews https://emfl.eu/emfl-news/

YouTube https://www.youtube.com/watch?v=4dM07vic150

Virtual tour https://virtualtours.360totaal.nl/tour/hfml-felix
An overview of the high field installation and instrumentation with the latest updates
Provides first-time users with a realistic view of what they can expect when arriving at the facility to perform their experiment.

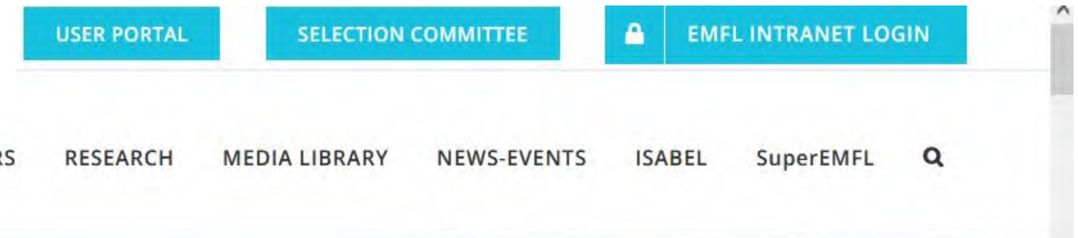
Find an experiment

https://emfl.eu/

CONTACT ACCESS MANAGERS

Apply for magnet time

https://emfl.eu/



CALLS FOR PROPOSALS

DEADLINES 15th MAY AND 15th NOVEMBER

Evaluation within one month by Selection Committee

5 panels: Magnetism, Superconductors & Metals, Semiconductors, Soft Matter, Applied Superconductivity

Thank you!

https://emfl.eu/

AVAILABLE EXPERIMENTS

Experimental techniques	Nijmegen	Grenoble	Dresden	Toulouse
Optical spectroscopy and magneto-optics				
Optical microscope imaging	✓	✓		
Birefringence, Dichroism and Faraday rotation	✓	✓		✓
(Micro-) photoluminescence spectroscopy	✓	✓	✓	✓
(Micro-) Raman scattering	✓	✓		
(Far) infrared spectroscopy	✓	✓	✓	✓
Ultrafast dynamics	✓			
Thermodynamic properties				
Dilatometry	✓			
Magnetocaloric effect			✓	
Specific heat	✓	✓		
Thermopower and Nernst-Ettingshausen	✓	✓		✓
DC/AC susceptibility	✓	✓		
Compensated-coil magnetometry	✓		✓	✓
Torque magnetometry	✓	✓	✓	✓
Magnetostriction and thermal expansion (under uniaxial strain)	✓		✓	
Ultrasonic measurements (sound velocity and attenuation)		✓	✓	✓
Magnetotransport				
Magnetotransport with in-situ sample rotation	✓	✓	✓	✓
Critical current of superconductors (wires, tapes and coils)		✓		
'Contactless' transport (TDO, PDO)	✓		✓	✓
Magnetic resonance				
Electron spin resonance		✓	✓	
Nuclear magnetic resonance		✓	✓	✓
Advanced sources				
Free electron laser	✓		✓	
X-Ray Spectroscopies				✓
Environments				
³He cryostats (1.5 - 300 K)	✓	✓	✓	✓
⁴He cryostats (down to 300 mK)	✓	✓	✓	✓
Dilution refrigerators (down to 30 - 100 mK)	✓	✓	✓	✓
Thermostats up to 300°C	✓	✓		
High pressure	✓	✓	✓	✓
Uniaxial strain	✓			
Other				
Megagauss facility (semi-destructive fields > 170 T)				✓
Mobile 1 MJ installation allowing X-rays, laser and neutron scattering under pulsed magnetic fields				✓
Levitation	✓	✓		
Thermometry	✓	✓	✓	

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Super EMFL

HOW TO OBTAIN ACCESS

Twice a year (deadlines May and November 15) a call for proposals is launched. Access to one or more of the infrastructures will be given for research in high magnetic fields, provided that the research proposal is positively rated by a Selection Committee based on:

- **scientific quality and originality of the proposal;**
- **necessity for the use of the infrastructure;**
- **past performance of the applicants.**

Users are strongly advised to contact the facility in order to prepare a better proposal or to investigate the feasibility of the work and possibly identify your local contact. Access implies the use of the installation, the use of all available auxiliary equipment and (if necessary) support by local staff.

Here you will find the online proposal form:
www.emfl.eu/apply-for-magnet-time

NETWORKING ACTIVITIES

- **Schools**
- **Exchange Programmes**
- **User Committee**
- **User Meeting**
- **EMFL NEWS**
- **EMFL prizes**
- **Workshops**
- **and many more**

CONTACT

- **HFML Nijmegen**
  www.ru.nl/hfml
- **LNCMI Toulouse and Grenoble**
  www.lncmi.cnrs.fr
- **HLD Dresden**
  www.hzdr.de/hld

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FIELDS FOR SCIENCE

IN THE EUROPEAN MAGNETIC FIELD LABORATORY

WWW.EMFL.EU

EMFL European Magnetic Field Laboratory

Login | Royal Society W. Improving the susta... My Awards | Resear... ScholarOne Manus... Web of Science [v.5... Application form -... Launch Meeting - Z... Log in to Je-S

Event Time - (UTC+00:00) Dublin, Edinburgh, Lisbon,...

Wednesday, June 28, 2023 | Thursday, June 29, 2023 | Friday, June 30, 2023

	Room: Theatre 1 (Upper Ground Floor)	Room: Theatre 2 (First Floor)	Room: 118/119 (First Floor)	Room: 109 (First Floor)
8:30 AM - 9:00 AM	**Arrival Refreshments**			
9:00 AM - 9:30 AM	**Plenary Session 2**			
9:30 AM - 10:30 AM	**Magnetism 2**	**Atomic, Molecular and Optical Physics**	**Facilities 1**	**Metals and Correlated Electron Systems 3**
10:30 AM - 11:00 AM	**Morning Break. Sponsored by Oxford Instruments NanoScience**			
11:00 AM - 1:00 PM	**Magnetism 3**	**Topological Materials 2**	**Facilities 2**	**Surfaces, Interfaces and Thin Films**
1:00 PM - 3:00 PM	**Lunch, Poster Session 2 and Exhibition**			
3:00 PM - 5:00 PM	**Magnetism 4**	**Superconductivity 3**	**Metals and Correlated Electron Systems 4**	**1. Nonequilibrium Physics 2. Instruments and Applications**
5:00 PM - 5:10 PM	**Depart**			

Tell us what you think

FUTURE SCIENTIFIC OPPORTUNITIES IN EMFL

Charles Simon,

Joint annual meeting of SPS and OPG

Sept 7th, 2023

Support of “ISABEL”, supported by EU

EMFL
EUROPEAN MAGNETIC FIELD LABORATORY

An European laboratory on 4 sites (Grenoble, Toulouse, Dresden, Nijmegen

Common selection committee

2 partners : UK and Poland

What is the benefit for the partners ?

Participation to the steering committee
Possibility to nominate selection committee members
Participation to the scientific council
Financial support for visitors

As a result : increase of the number of users
and common publications

European Magnetic Field Laboratory

- UK new contract for 5 years (2022-2027)
- Poland, new contract for 5 years (2024-2029)
- Italy, new contract for 5 years (2023-2028)

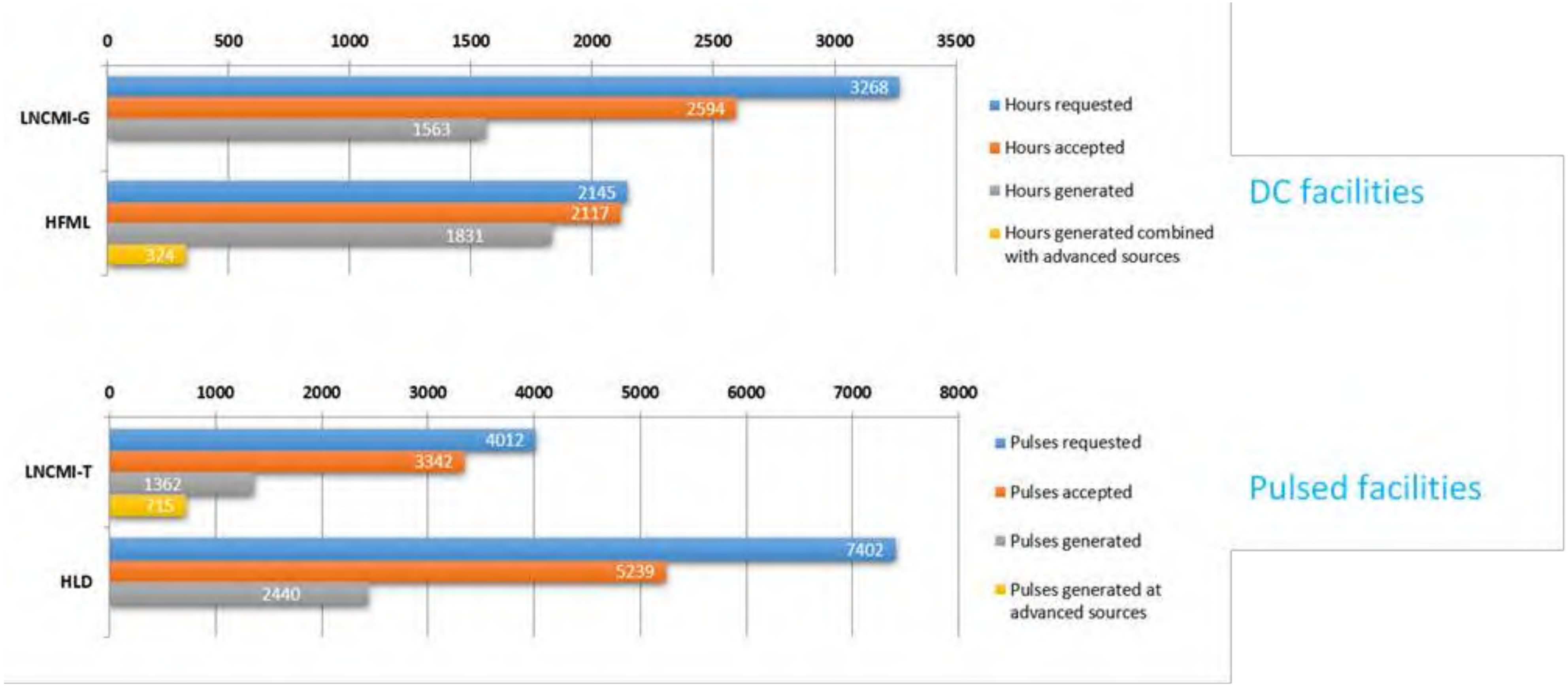
Benefit for the EMFL : increase the sustainibility

European Magnetic Field Laboratory

EMFL is on the ESFRI list

- ESFRI Landmark
- Two European programmes
  - ISABEL (to strengthen the EMFL, new types of call : fast track, new users, …) end 2024
  - SuperEMFL (superconducting 40T magnet, design study) end 2025
  - FLEXRICAN : to increase the energetic sustainibility

Use in 2022



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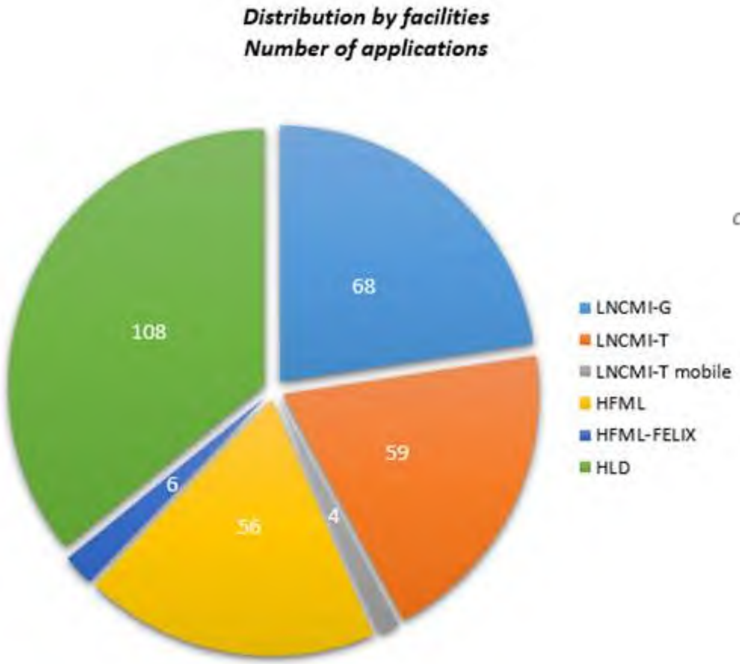
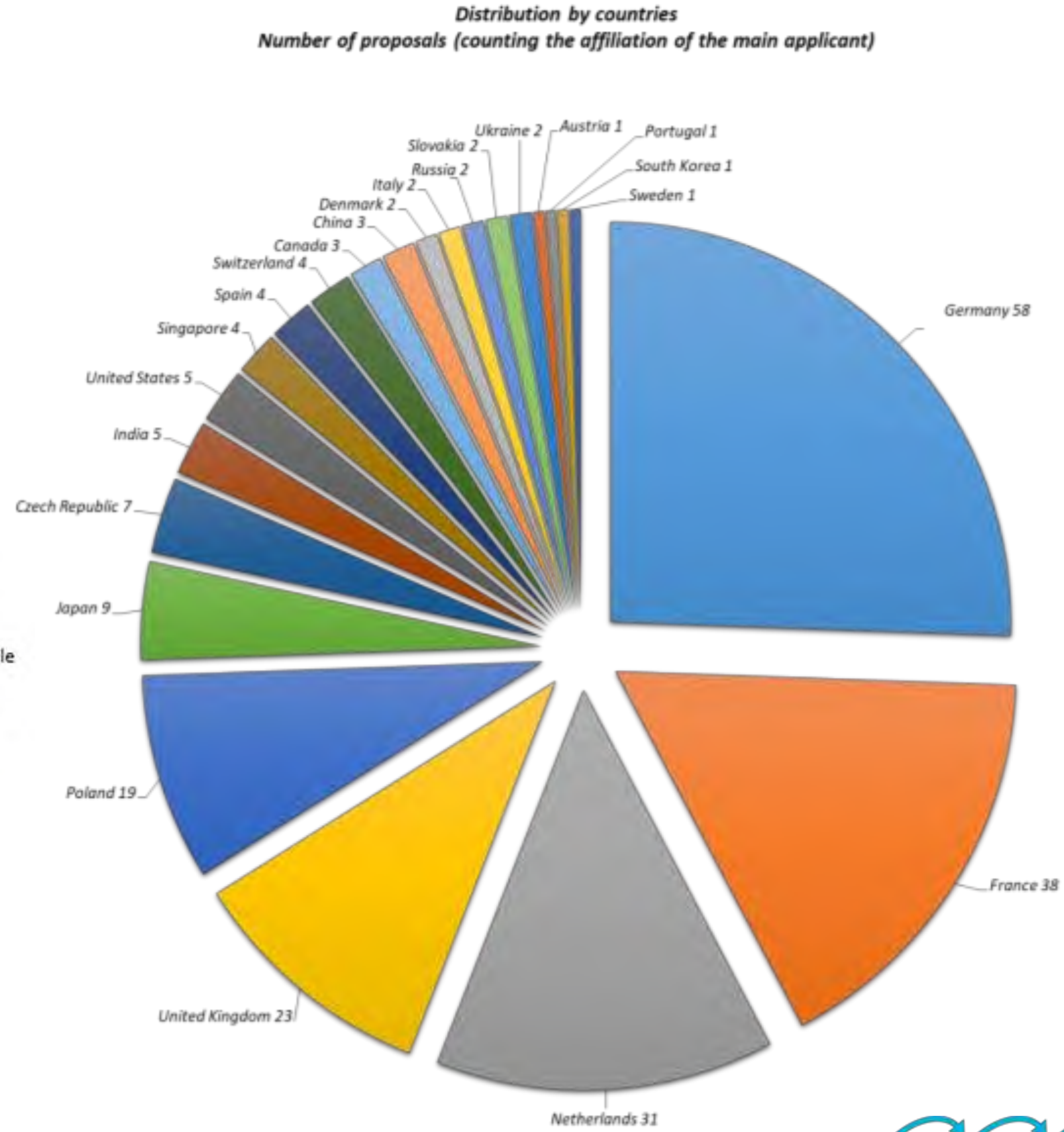
2022


Distribution by facilities
Number of applications
68
59
4
56
6
108
LNCMI-G
LNCMI-T
LNCMI-T mobile
HFML
HFML-FELIX
HLD


Distribution by countries
Number of proposals (counting the affiliation of the main applicant)
Germany 58
France 38
Netherlands 31
United Kingdom 23
Poland 19
Japan 9
Czech Republic 7
India 5
United States 5
Singapore 4
Spain 4
Switzerland 4
Canada 3
China 3
Denmark 2
Italy 2
Russia 2
Slovakia 2
Ukraine 2
Austria 1
Portugal 1
South Korea 1
Sweden 1

Happy users

European Magnetic Field Laboratory

Each year : user meeting and price

Grenoble, June 2022

Mateusz Dyksik, Wroclaw Univ.

European Magnetic Field Laboratory

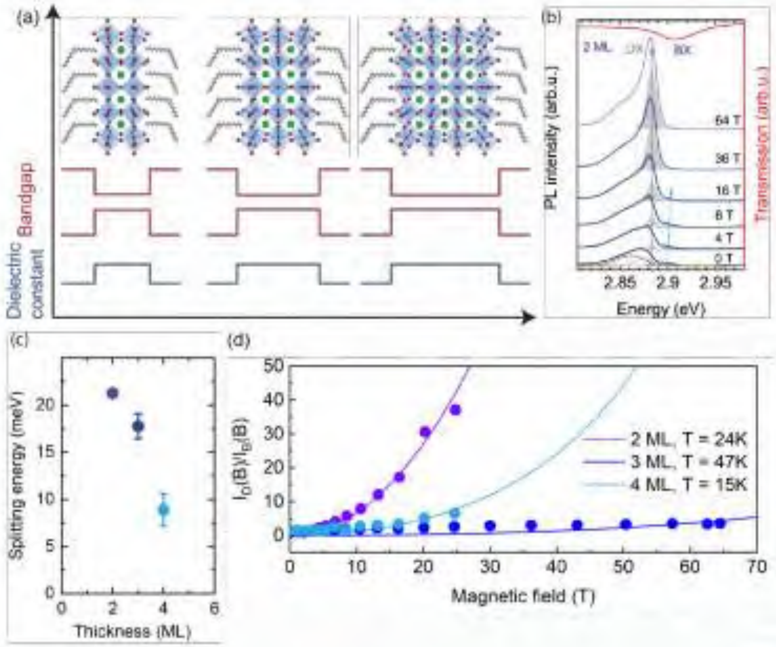
EMFL school
Kerkrade, Netherland

European Magnetic Field Laboratory

Science (highligths 2022)

MAGNETCALLY BRIGHTENED DARK EXCITONS IN TWO-DIMENSIONAL METAL-HALIDE PEROVSKITES

Figure: (a) Top: schematic of the crystal structure of lead-halide perovskite nanoplatelet. Bottom: spatial dependence of the band gap and the dielectric constant. (b) Magneto-PL spectra of nanoplatelets. BX: bright exciton. DX: dark exciton. (c) Measured bright-dark splitting as a function of nanoplatelet thickness. (d) PL intensity ratio between dark and bright exciton states for the three nanoplatelet thicknesses investigated as a function of the applied magnetic field. Full circles represent experimental points. The curves are calculated using the temperature indicated in the legend..

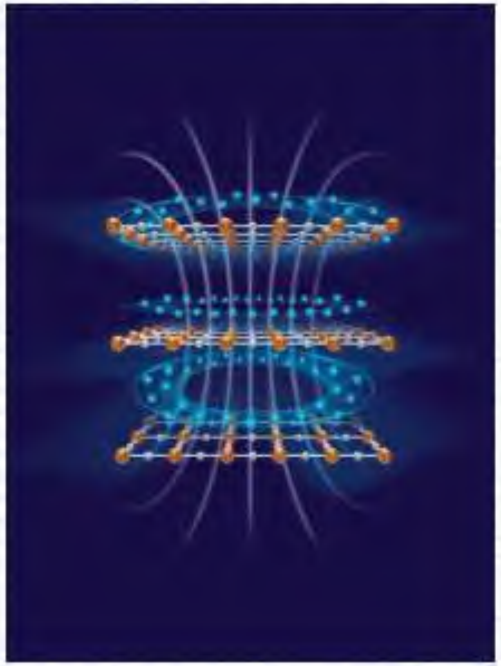


Reference

Thickness-dependent dark-bright exciton splitting and phonon bottleneck in CsPbBr3-based nanoplatelets revealed via magneto-optical spectroscopy, S. Wang, M. Dyksik, C. Lampe, M. Gramlich, D. K. Maude, M. Baranowski, A. S Urban, P. Plochocka, and A. Surrente, Nano Letters 22, 7011 (2022).

netic Field Laboratory

INFLUENCE OF HIGH MAGNETIC FIELDS ON ELECTRONS UNDERGOING PLANCKIAN DISSIPATION



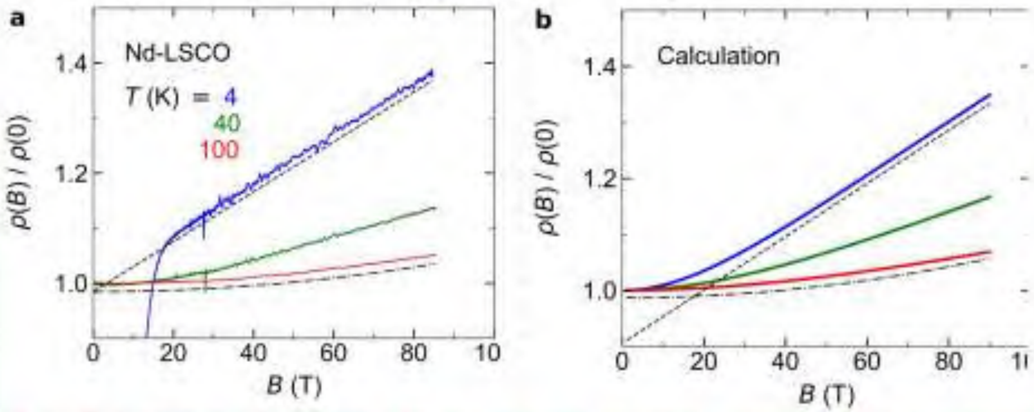


Figure 1: Sketch of electrons (cyan) moving in orbits within the copper-oxide planes of a cuprate material (Cu atoms in bronze, O atoms in silver) when a magnetic field is applied normal to the planes. Credit: Impakt Scientifik

Figure 2: Measured and calculated magnetoresistance (MR) in the cuprate superconductor Nd-LSCO at a hole doping p = 0.24, plotted as ρ(B)/ρ(0) vs B, for J || a and B || c, at various fixed temperatures, as indicated. (a) Isotherms measured up to 85 T, for T = 4 K (blue), 40 K (green), and 100 K (red). The MR at 4 K is seen to be linear in field above ~about 40 T, whereas the MR at 100 K is quadratic, as emphasized by the linear (dashed) and quadratic (dashed dotted) lines. (b) Calculated MR using the parameters for Nd-LSCO extracted from a prior ADMR study (Grissonnanche et al., Nature 595, 667 [2021]), for the same three temperatures.

Reference

Electrons with Planckian scattering obey standard orbital motion in a magnetic field, A. Ataei, A. Gourgout, G. Grissonnanche, L. Chen, J. Baglo, M-E. Boulanger, F. Laliberté, S. Badoux, N. Doiron-Leyraud, V. Oliviero, S. Benhabib, D. Vignolles, J.-S. Zhou, S. Ono, H. Takagi, C. Proust, and L. Taillefer, Nat. Phys. 18, 1420 (2022).

etic Field Laboratory

EVIDENCE FOR A SQUARE-SQUARE VORTEX-LATTICE TRANSITION IN A HIGH-Tc CUPRATE SUPERCONDUCTOR

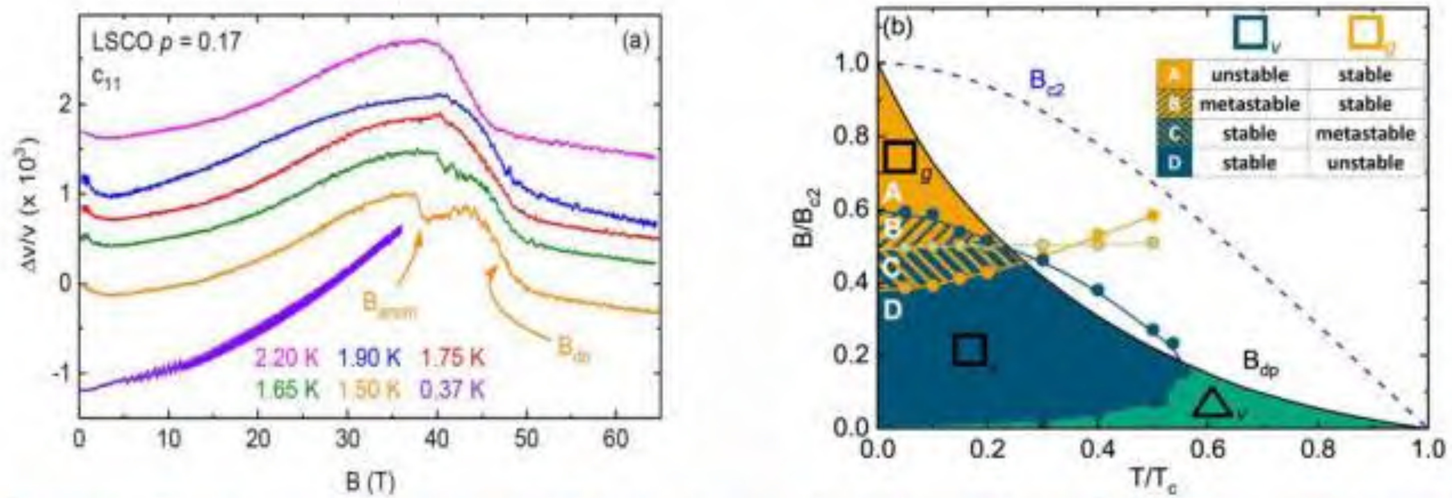
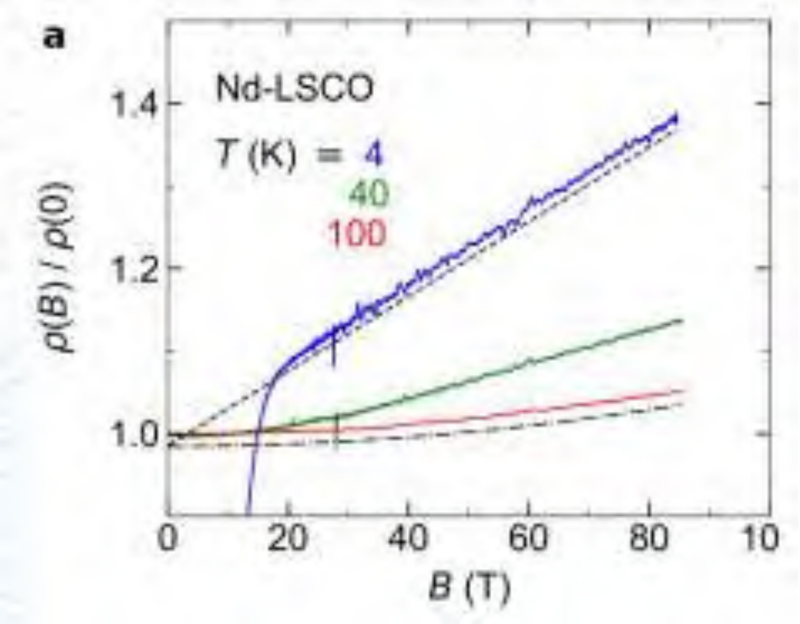


Figure: (a) The change in sound velocity of the in-plane longitudinal mode (c11) of an LSCO crystal with x = 0.17 at different temperatures, as a function of magnetic field. The arrow marks the field of the anomaly, Banom. (b) Theoretical phase diagram showing the different vortex-lattice configurations as a function of T and B. The hexagonal phase is stable in the green-colored area. In regions A and D, two different square vortex lattices are stabilized with a range of metastability emerging in rapidly varying magnetic field shown in regions B and C.

Reference

Evidence for a Square-Square Vortex Lattice Transition in a High-Tc Cuprate Superconductor, D.J. Campbell, M. Frachet, S. Benhabib, I. Gilmutdinov, C. Proust, T. Kurosawa, N. Momono, M. Oda, M. Horio, K. Kramer, J. Chang, M. Ichioka, and D. LeBoeuf, Phys. Rev. Lett. 129, 067001 (2022).

Future scientific opportunities in Toulouse



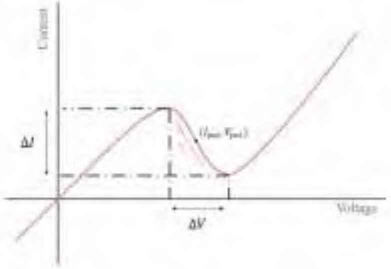
90T Tesla magnets in routine

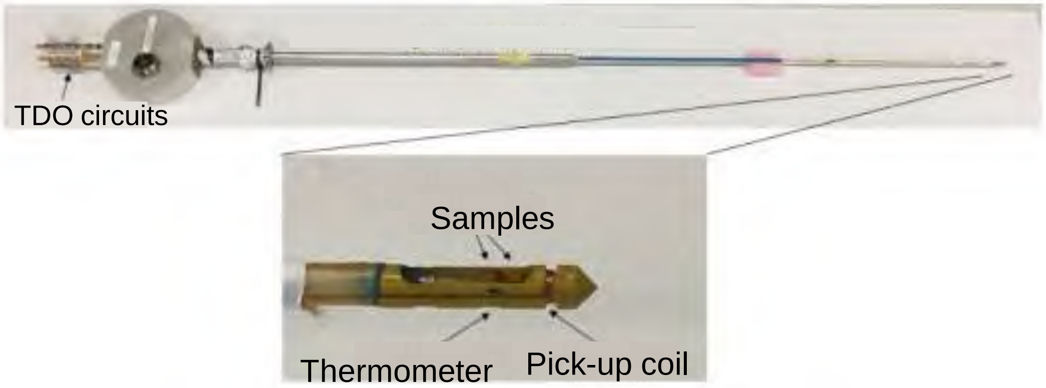
98T Toulouse record 2018
103T in future

European Magnetic Field Laboratory

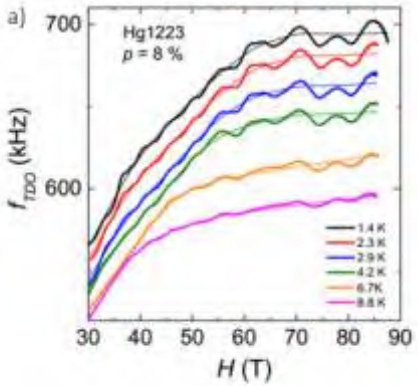
Contactless measurement in pulsed magnetic field : TDO technique (up to 90 T down to 600 mK)

Self resonating circuit based on a tunneling diode oscillator

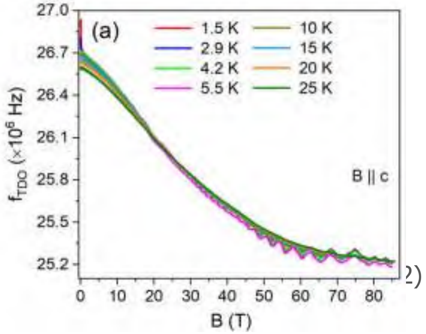


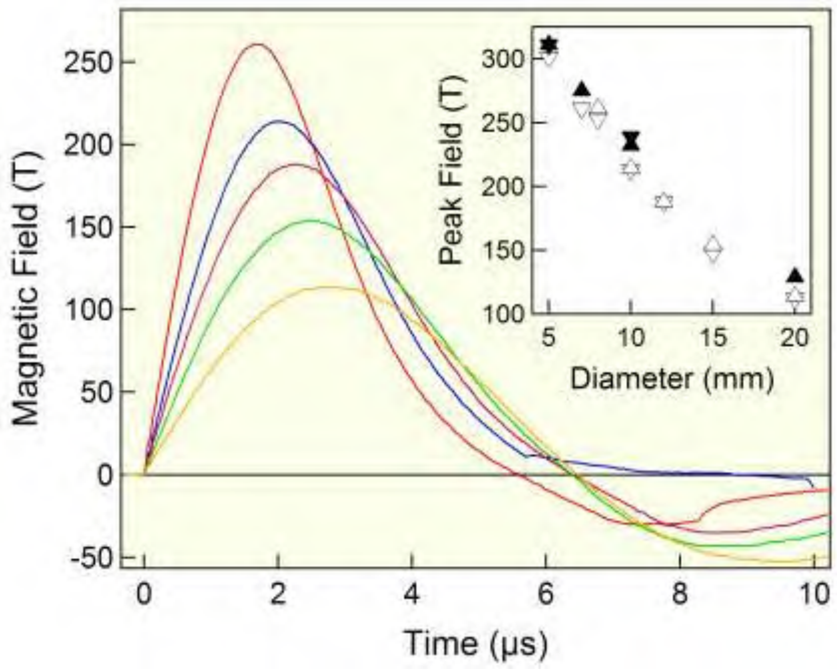


Mercury based cuprates superconductors



Kagome superconductor CsV_3Sb_5





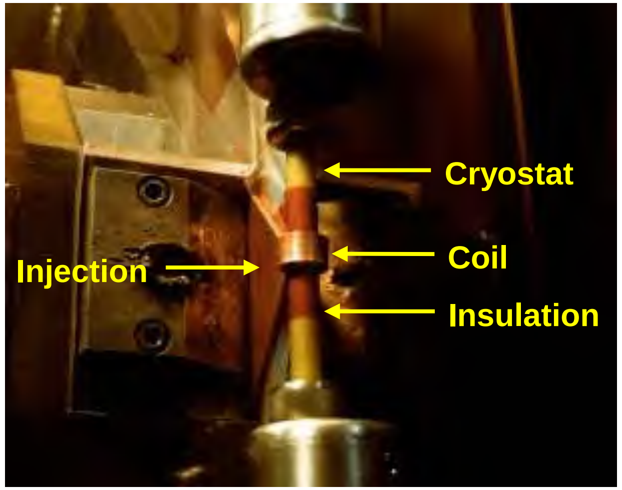
Fields beyond 100 T in single-turn coils

Principle: fast capacitor discharge into single-turn coil; inertia delays coil expansion up to peak field.

Performance: 150-200 T in 10 mm (for experiments); μs-duration; ~5 shots/day.

Applications: VIS-MIR spectroscopy at 5.0-300 K and magnetization at 2.5-300 K.

Developments: THz spectroscopy, spectrally resolved measurements and magneto-transport.



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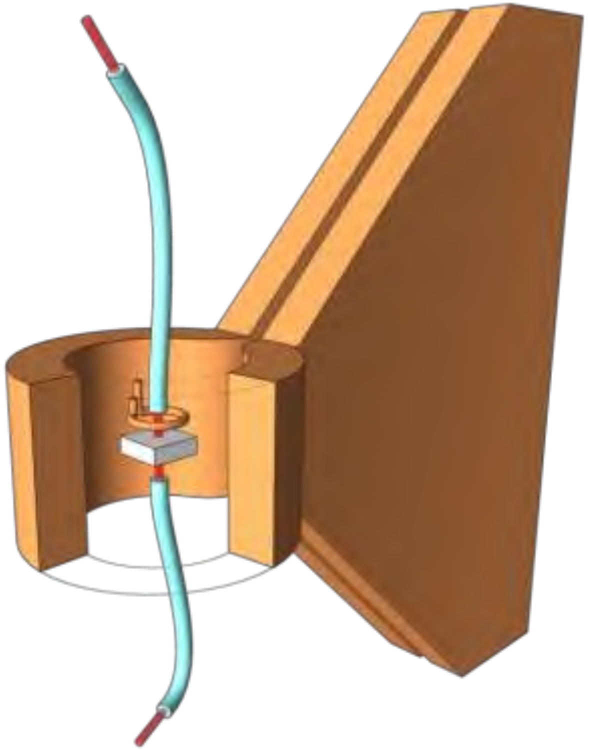
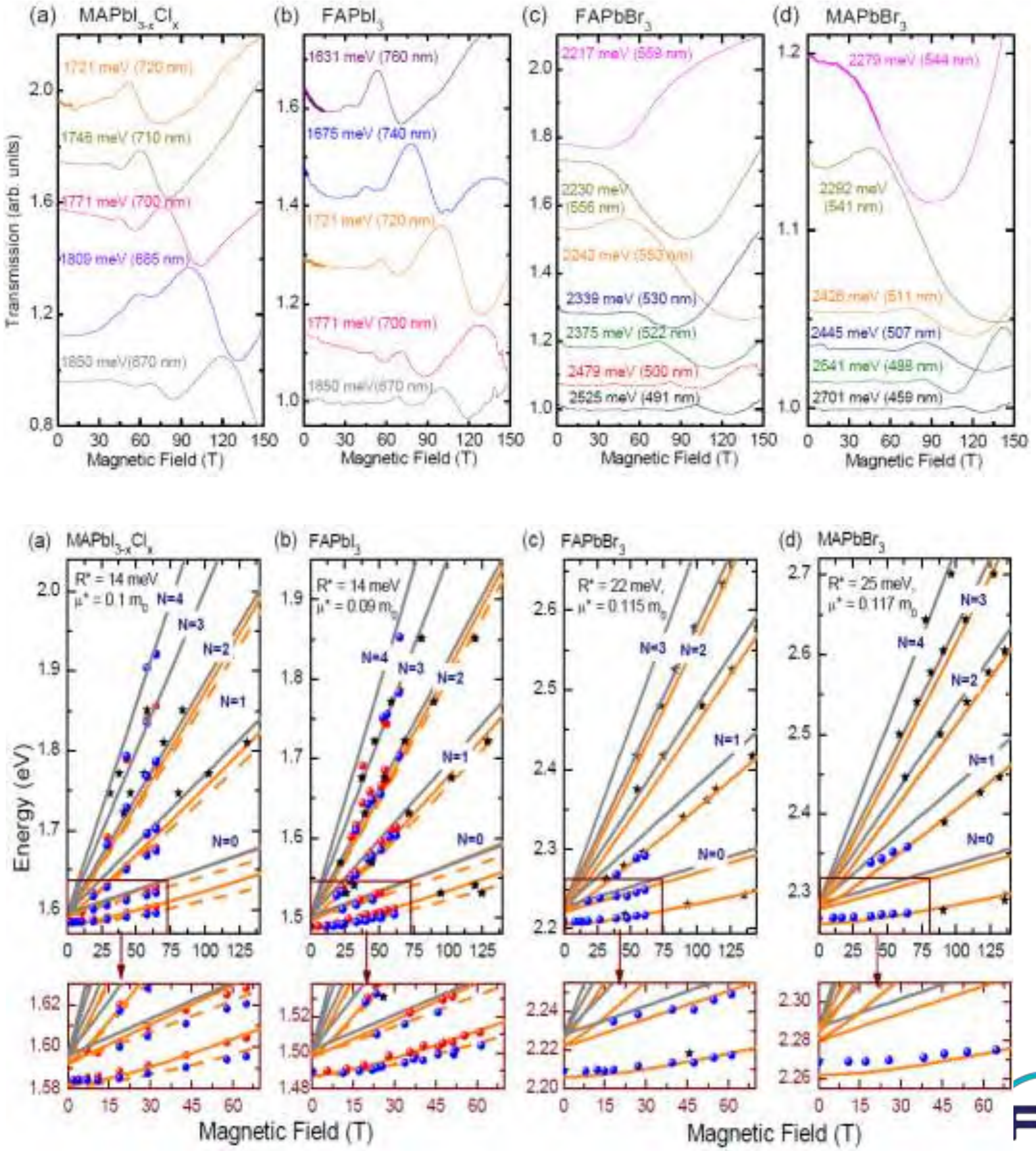
VIS-NIR spectroscopy: fibre-based magneto-transmission measurements with monochromatic sources.

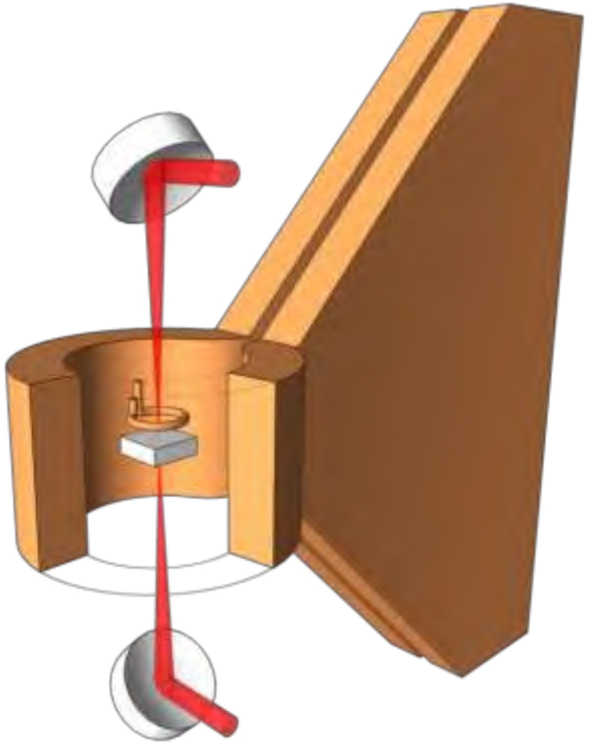




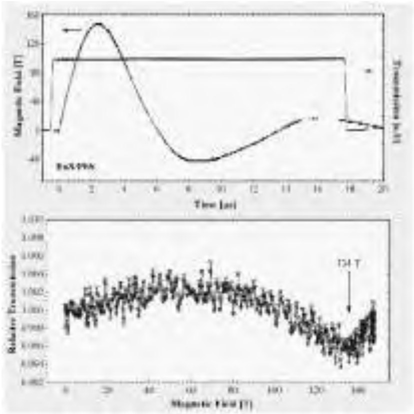
K. Galkowski et al,

Energy Environ. Sci. ***9*** *(2016)*

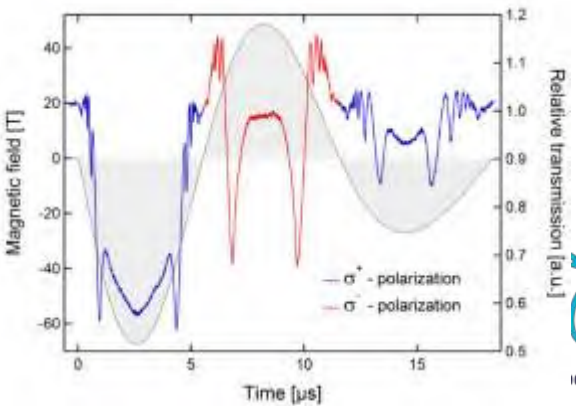
MIR spectroscopy: free-beam optics with high-power MIR-lasers (CO, CO_2) and fast MCT detectors.



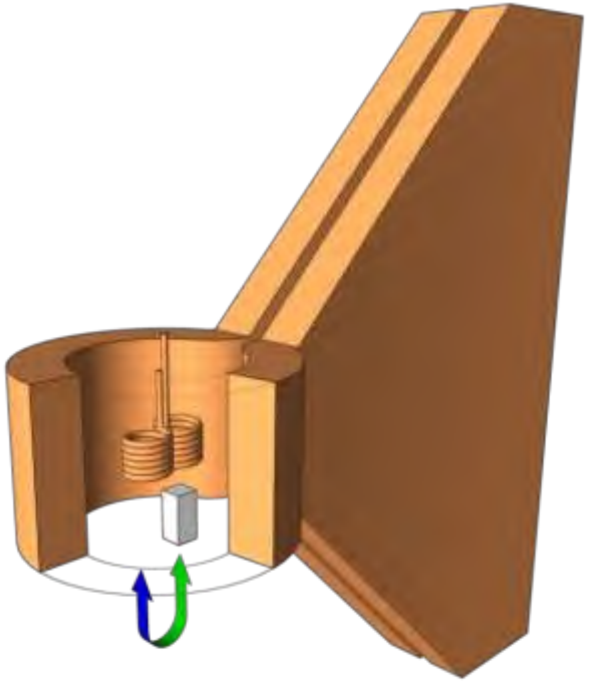
Transmission of EuS/PbS MQW at 10.6 µm, 150 K
I. Stolpe Ph.D. 2000, PRB 62 2000

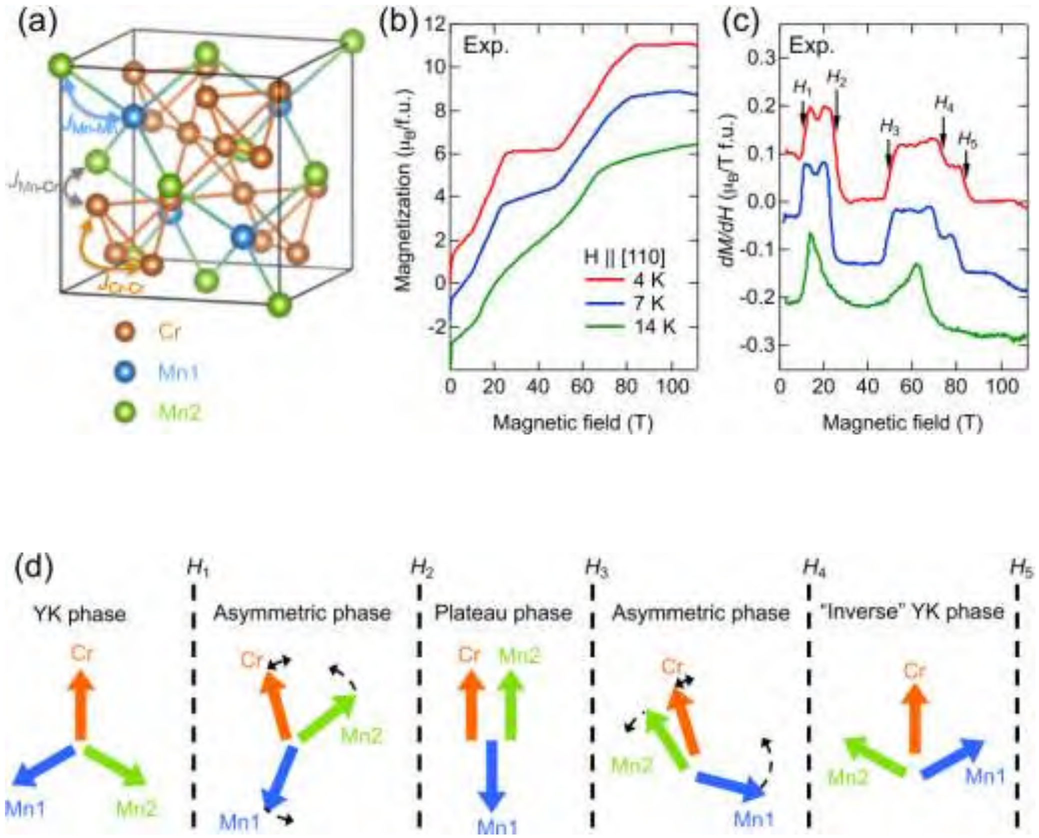


Transmission of exfoliated graphite at 5.2 µm, 300 K,
P.Y. Solane Ph.D. 2012, PRB 85 2012



Magnetization: dM/dt with compensated pick-up coils and background elimination by averaging alternate measurements





Magnetization changes in the ferrimagnetic spinel MnCr2S4
A. Miyate et al, PRB 101 (2020)

European Magnetic Field Laboratory

The Modular Grenoble Hybrid Magnet User Platform

LNCMI

Objectives for the Highest Magnetic Field configuration

- **Baseline @ 24 MW*/2022 : 43 T in 34 mm dia.**
  SC + poly-Bitter + poly-helices = 8.5 + 9 + 25.5 = 43 T

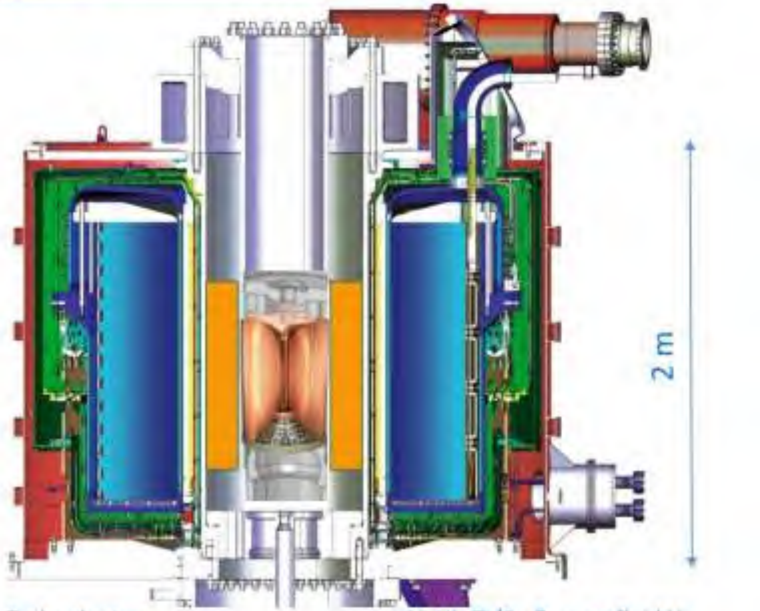
PROJET LaSUP
Equipex

But also various high magnetic Flux configurations

Field	Warm dia.	Configuration	Electric Power*
43 T	34 mm	14 helices + 2 Bitter + SC	24 + 1 + 0.4 MW
40 T	50 mm	12 helices + 2 Bitter + SC	24 + 1 + 0.4 MW
35 T	34 mm	14 helices + SC	12 + 0.5 + 0.4 MW
27 T	170 mm	6 helices + 2 Bitter + SC	18 + 0.75 + 0.4 MW
17.5 T	375 mm	2 Bitter + SC	12 + 0.5 + 0.4 MW
9.5 T	812 mm	SC	0.4 MW**

Eco-mode (35 T configuration)

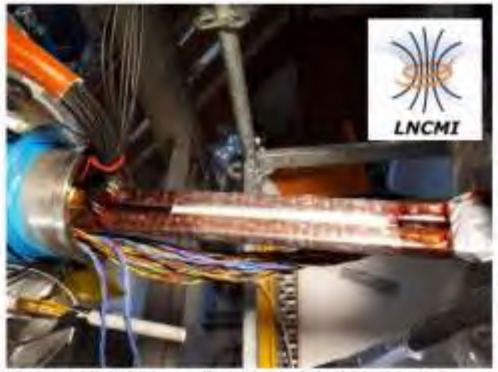
* Magnet powering + water cooling pumps + cryogenics
** He liquefier + 1.8 K pumps + cryoplant ancillaries



Technologies	*SC Nb-Ti/Cu & superfluid He*
Hydraulics for resistive inserts	*300 l/s*
Total stored energy @ 43 T	*108 MJ (~ 26 kg of TNT explosive)*

P. Pugnat, R. Pfister, L. Ronayette *et al.*, *IEEE Trans. Appl. Supercond.* 28, 4300907 (2018) ; *IEEE Trans. Appl. Supercond.* 32, 4300607 (2022)

Final assembly of the Cu/Nb-Ti superconducting bus bars on their support prior to their insertion inside the cold mass of the cryoline.



Insulated bus bars at the level of the connections & instrumentation wires in the magnet side on the left & in the cryogenic satellite in the right (14 Feb. 2022)

Reception & assembly of the magnet protection system (MSS) developed by CEA-Saclay (March 2022), which is now operational.

Welding of the cold mass of the cryogenic line to the magnet one

Mounting superinsulation layers on the magnet side (12 & 13 April)

European Magnetic Field Laboratory

Mounting of the mezzanine for users (May 2022)

European Magnetic Field Laboratory

State of the art

- November 2022 : 1.8K superfluid operation
- December 2022 : 2T superconducting and 2T resistive (NMR for centering)
- June 2023 : test at 8.5T superconducting 1.8K
- October 2023 : 43T hybrid
- 2024 : internal measurements (commissionning)

European Magnetic Field Laboratory

Upalim in Grenoble

- November 2023 : deconnexion of existing power supply (24MW) (36T resistive magnet in 34 mm)
- February 2024 : end of the tests of the new 32MW power supply (40 T resistive magnet in 34mm)
- In parallel, save electricity power with eco mode (intermediate fields), shorter measurements, etc…
- **New proposals in 2025 for larger fields in Grenoble (resistive and hybrid)**

In summary

- Toulouse and Dresden today
  - 150T magnetization, optics
  - 90T routine 0.6K, dilution fridge
- Grenoble and Nijmegen in 2025
  - Upalim 40T resistive less electricity, less CO_2
  - 43T Hybrid / 45T hybrid

  - Existing set up to be used in future

EMFL European Magnetic Field Laboratory

Thank you

European Magnetic Field Laboratory

European Magnetic Field Laboratory

DRESDEN HIGH MAGNETIC FIELD LABORATORY

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

EMFL – a Distributed User Facility

Jochen Wosnitza, Dresden High Magnetic Field Laboratory

Regional Meeting on Research in High Magnetic Field

September 6-8, 2023

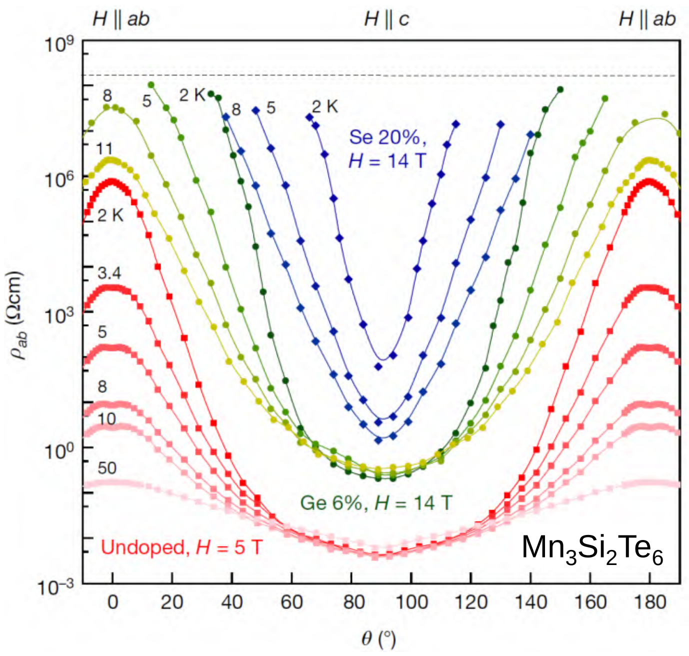
Prague

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

Research in high magnetic fields

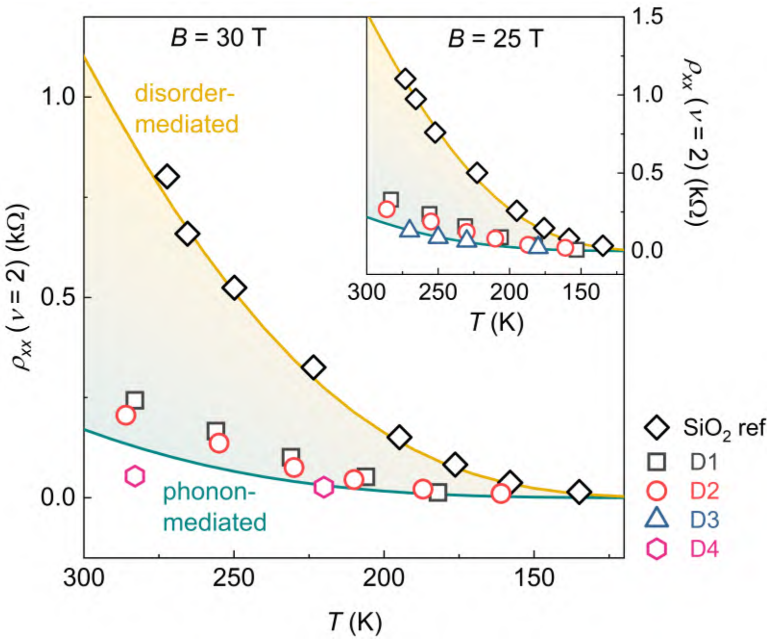
"Everything is magnetic"

Strongly correlated electron physics



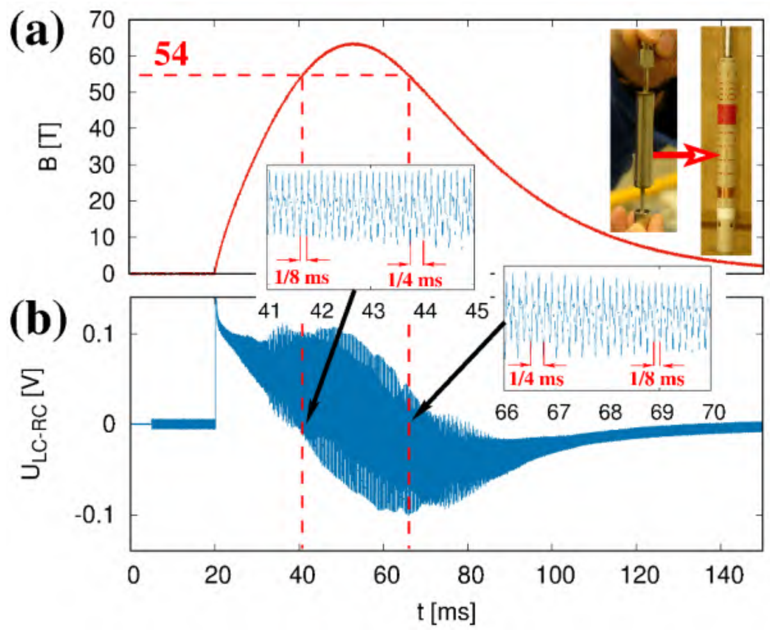
Colossal angular magnetoresistance in ferromagnetic nodal-line semiconductors
J. Seo et al.,
Nature 599, 576 (2021)

Low-dimensional semiconductors



Phonon-mediated room-temperature quantum Hall transport in graphene
D. Vaquero et al.,
Nat. Commun. 14, 318 (2023)

Soft matter Magnetoscience



Liquid-rubidium Alfvén-waves in pulsed magnetic fields
F. Stefani et al.,
Phys. Rev. Lett. 127, 275001 (2021)

DRESDEN concept
HZDR
EMFL
European Magnetic Field Laboratory

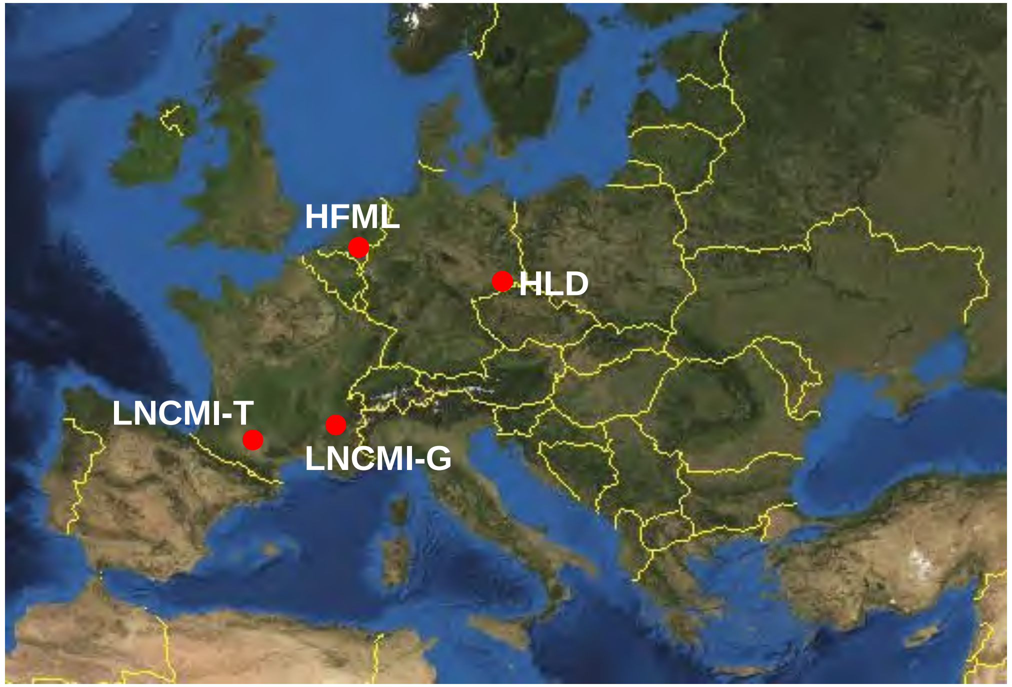
Shaping the high-field-lab landscape

EuroMagNET I and II
2005 – 2013

On ESFRI roadmap 2008
EMFL-P3 2011 – 2014
AISBL established 2015

ESFRI
Projects Landmarks
ROADMAP 2016

European Magnetic Field Laboratory



- Acts as a single laboratory
- Represents Europe in HMF
- Coordinates magnet technologies
- Coordinates new experiments
- Common committees and networking

EuroMagNET → EuroMagNET II → EMFL-P3 →

Four EMFL sites – Three labs

HFML – Nijmegen

HLD - Dresden

LNCMI - Toulouse

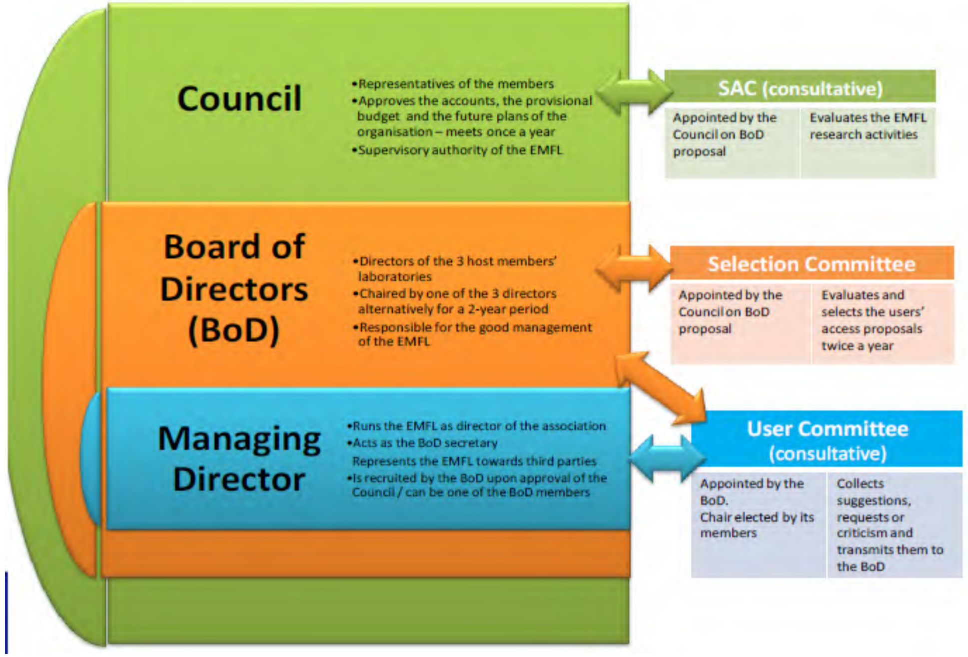
LNCMI - Grenoble

The mission

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

Governance bodies of European high-field labs:

France: CNRS (LNCMI-G and LNCMI-T)
Netherlands: Radboud University / NWO (HFML)
Germany: Helmholtz-Zentrum Dresden-Rossendorf (HLD)



EMFL-AISBL

- 3 founding members + UK + Poland + CEA + Italy(soon) ⇒ representatives in Council
- BoD responsibly for daily running, assisted by managing director (secretary)
- Membership fee 20 kEuro / year

DRESDEN concept HZDR EMFL European Magnetic Field Laboratory

Regional partners

UK
University of Nottingham (R. Hill/A. Patanè)
University of Oxford (A. Coldea/S. Blundell)

Poland
University of Warsaw (A. Babinski)

Spain
UAM Madrid (H. Suderow)

Estonia
NICPB, National Institute of Chemical Physics and Biophysics (R. Stern and T. Rõõm)

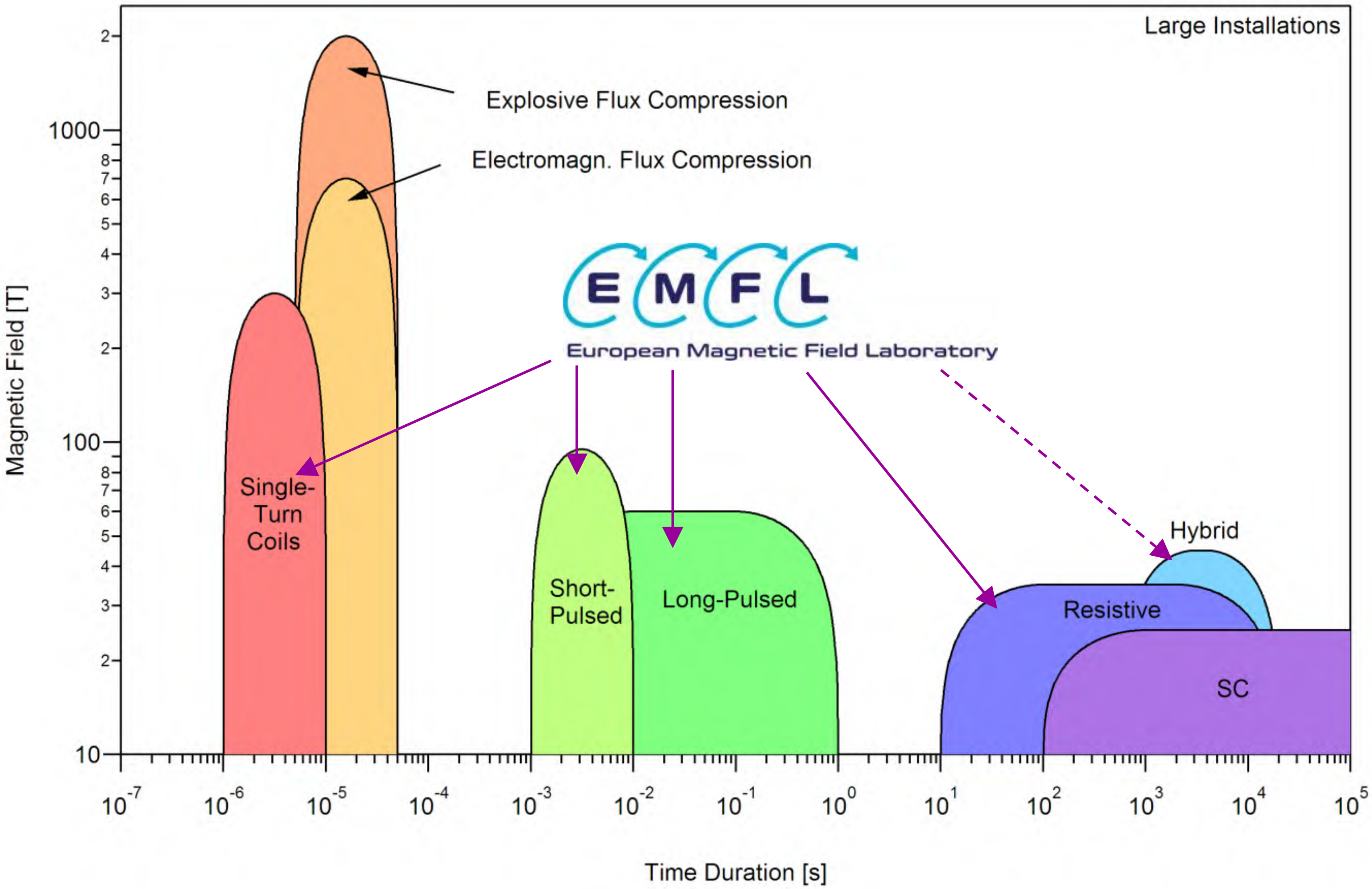
Czech Republic
Charles University (P. Javorsky)

Italy
University of Salento (G. Maruccio)

Switzerland
University of Geneva (S. Gariglio/C. Senatore)

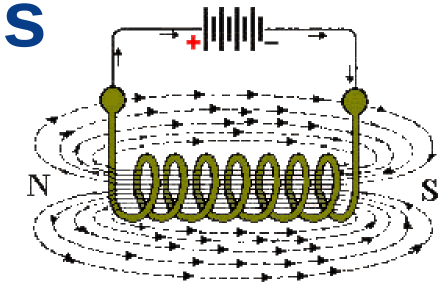
- Promote EMFL activities & provide information
- Workshops, trainings
- Dual access mode
- Explore opportunities to secure membership of EMFL

Magnetic fields for science

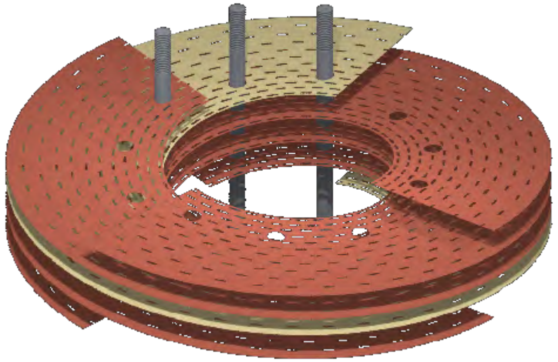


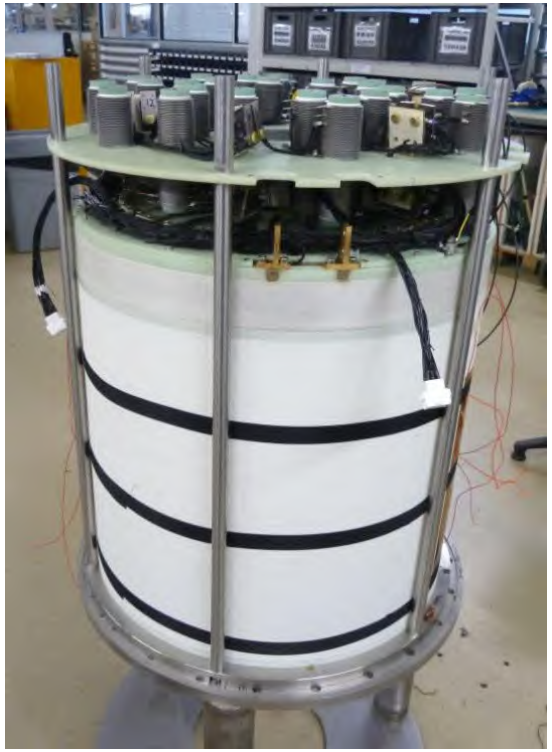
EMFL European Magnetic Field Laboratory

Generation of magnetic fields



- Superconductors up to about 22 T
- Resistive coils up to about 38 T
  (22 MW power supply)





- Hybrid coils up to about 45 T

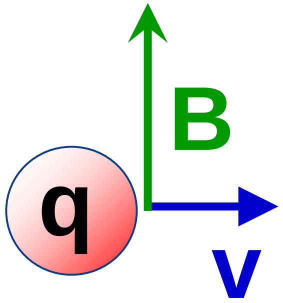
Grenoble 2023

Nijmegen 2024

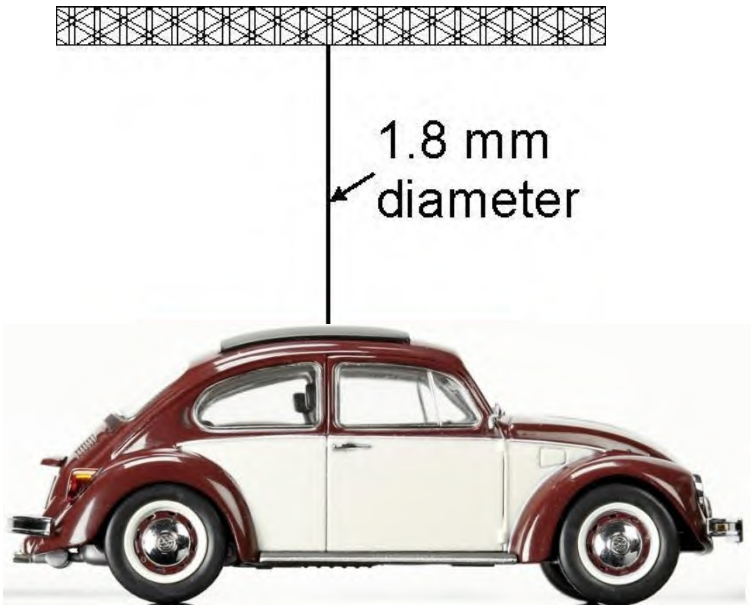
⇒ Higher fields
pulsed

Technological challenge

Lorentz force:

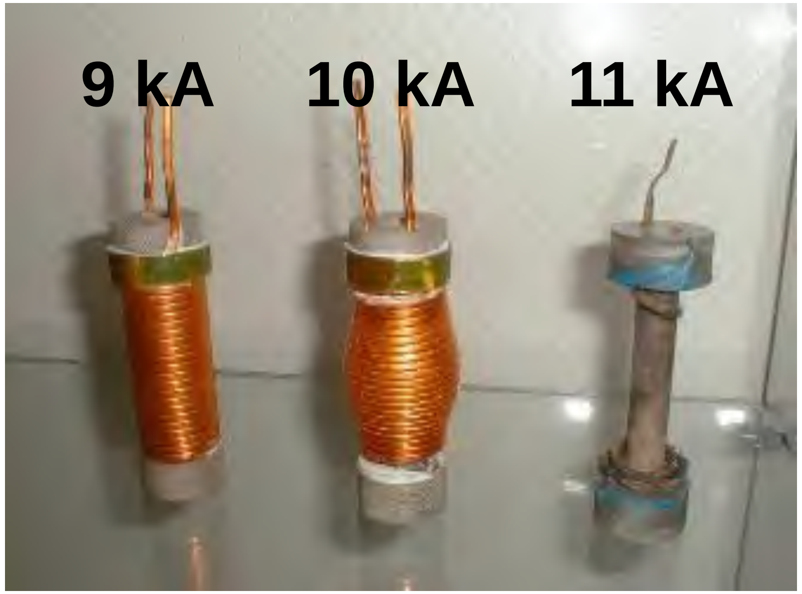


$$\vec{F} = q\,\vec{v} \times \vec{B}$$



Magnetic pressure:

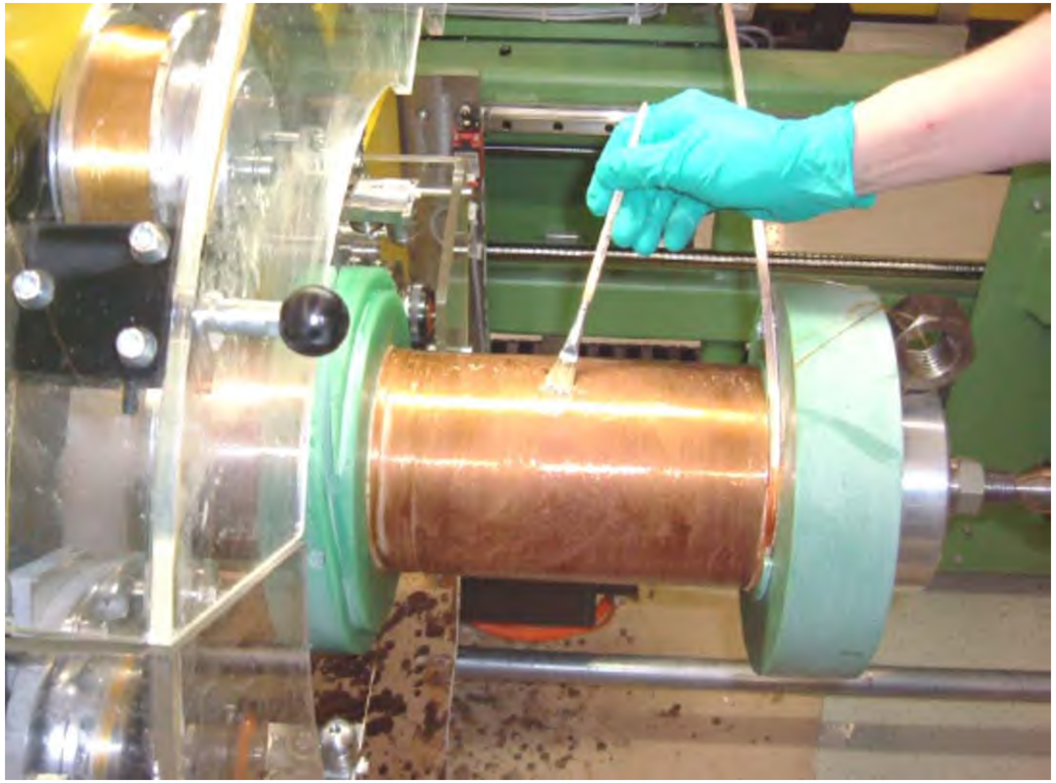
$$P = \frac{B^2}{2\mu_0}$$



4 GPa at 100 T!

Tame the forces

Best high-strength wires
rip apart at about
1 GigaPascal (10 000 bar)



Reinforce every conducting
layer by insulating fiber:
Zylon® withstands ~ 5.5 GPa

Power supply for pulsed fields

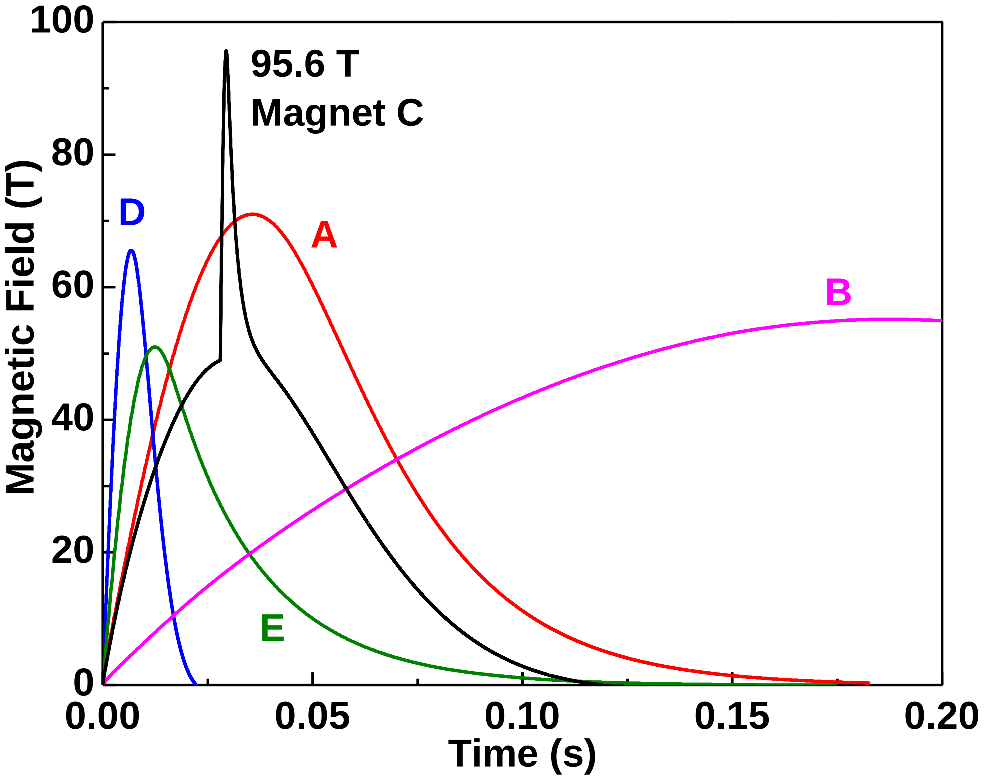
Capacitor banks

50 MJ in Dresden

14 MJ in Toulouse

Generation of pulsed magnetic fields

- Nondestructive pulsed-field coils
  (typical HLD examples)
  - 60 T / 20 ms / 20 mm bore
  - 50 T / 100 ms / 20 mm
  - 70 T / 150 ms / 24 mm
  - 60 T / 1500 ms / 40 mm
  - 85 – 95 T / 10 ms / 12-16 mm
- Semidestructive pulsed-field coils
  (available at LNCMI-Toulouse)
  - 120 – 200 T / 5 µs / 10 mm
- Destructive pulsed fields
  (only available at ISSP, Tokyo)
  - 300 – 1000 T / 5 µs / 10 mm



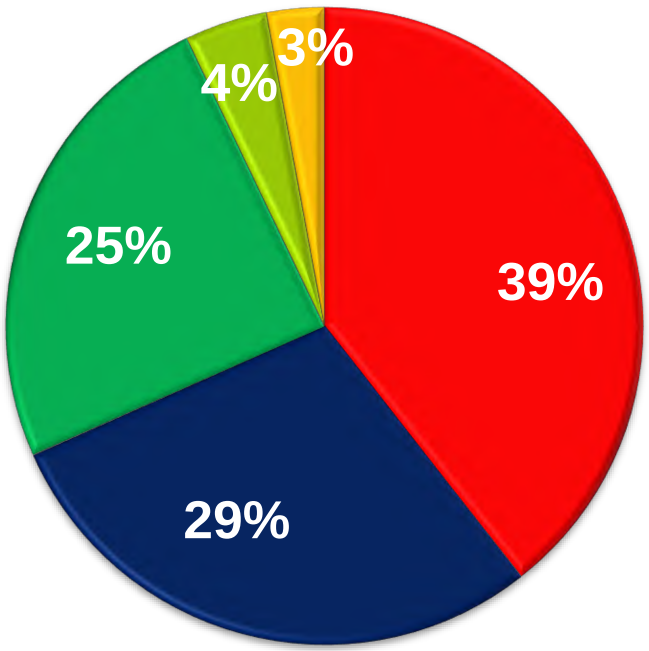
European Magnetic Field Laboratory

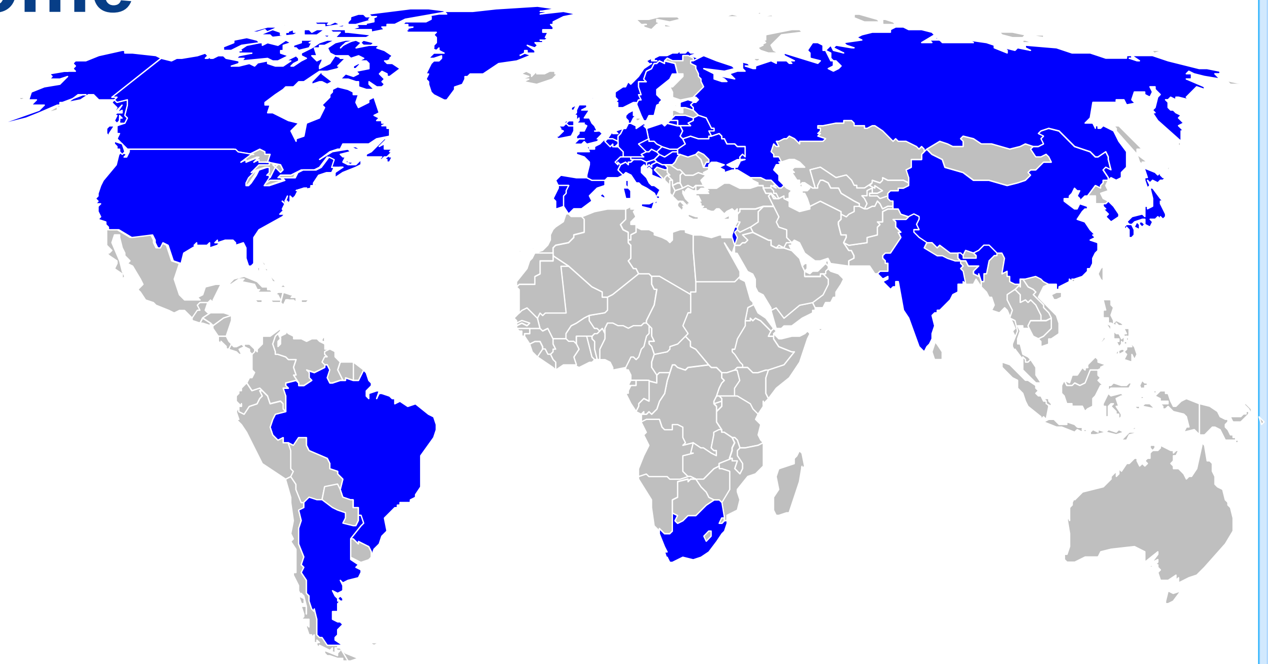
Scientific request and outcome

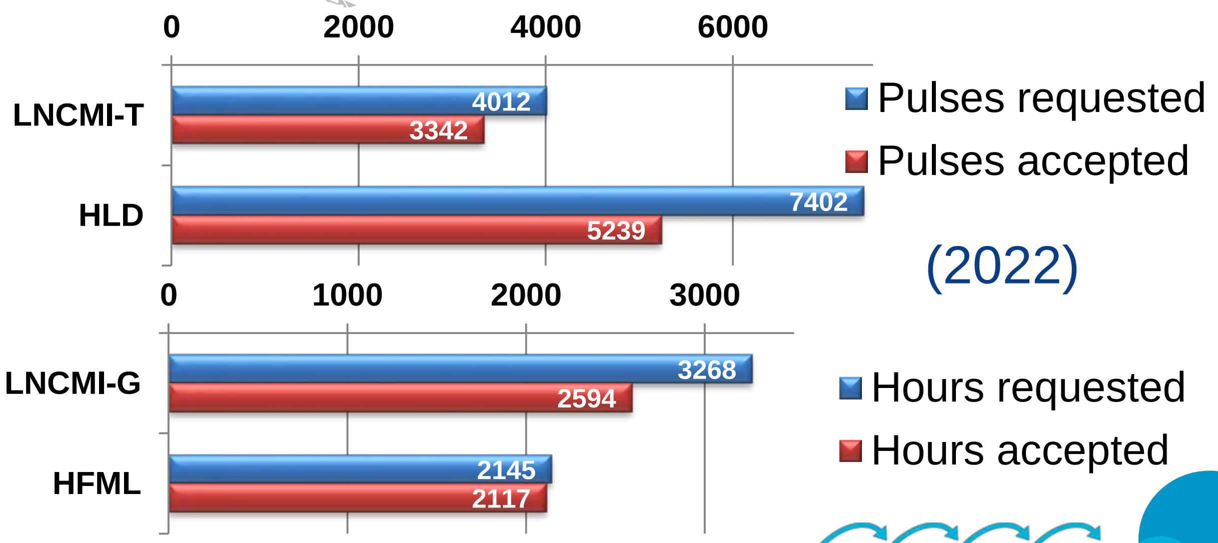
Two calls per year (April & October)

Submitted proposals last 5 years

(1574 total)







Scientific output:

887 publications

~200 (5 < IF < 15)

~65 (IF > 15)

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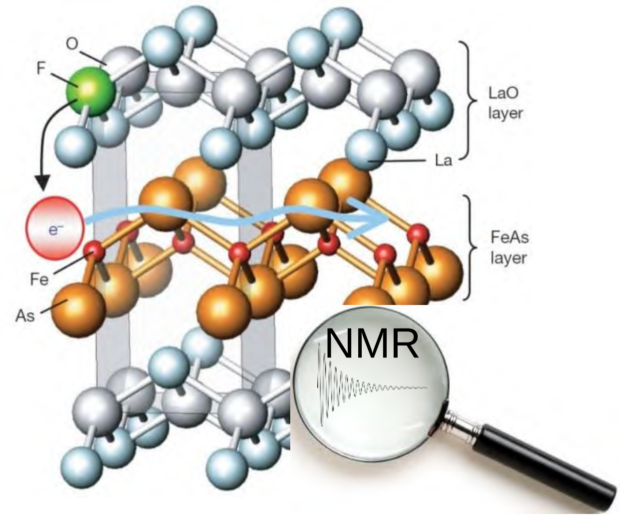
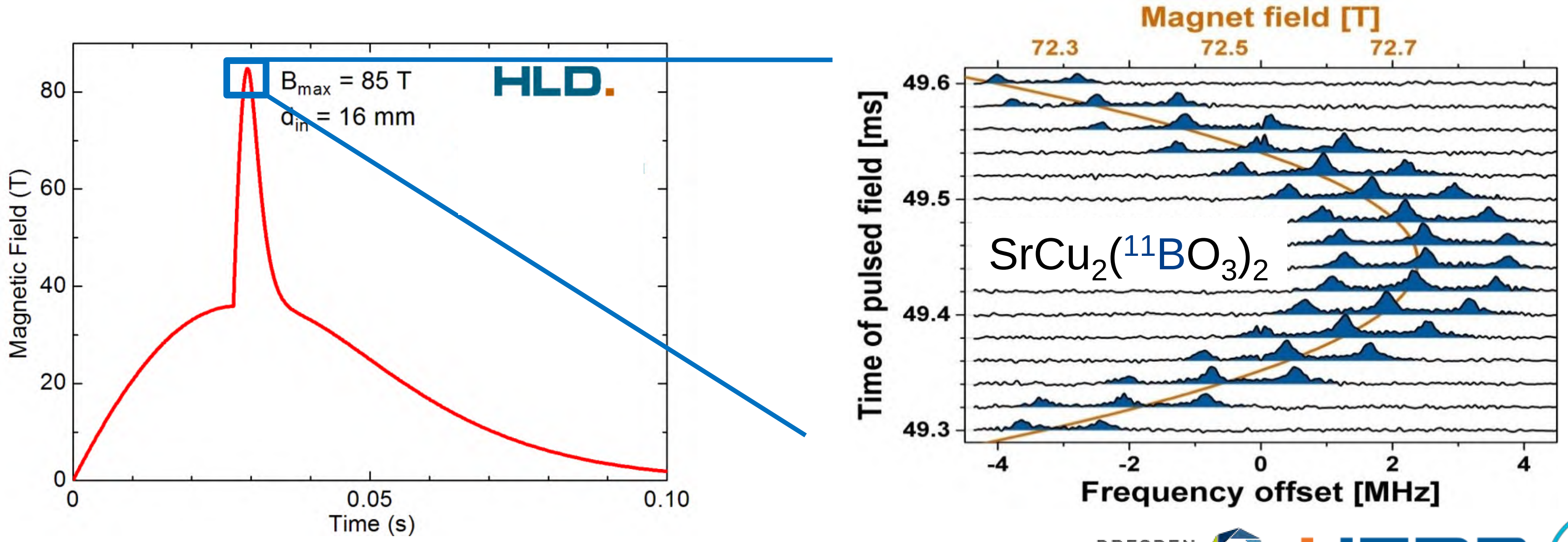
Techniques: NMR

High-resolution NMR in pulsed fields

- Hannes Kühne with J. Haase, Uni Leipzig
- Up to 30 spectra per ms
- ^{11}B NMR of $SrCu_2(BO_3)_2 \Rightarrow$ magnetic order
  (Scientific cooperation with R. Stern, Tallinn)

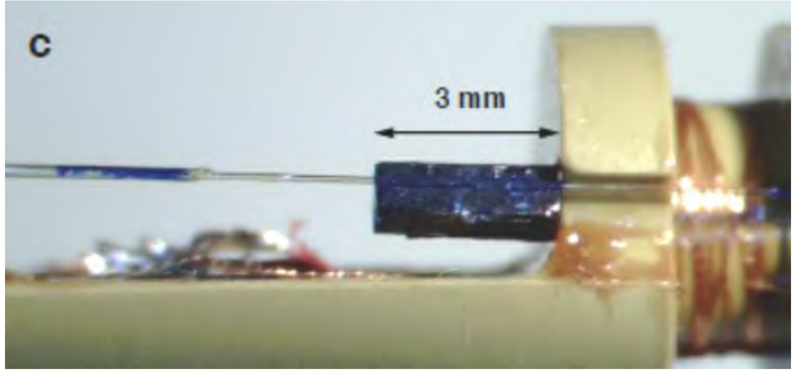


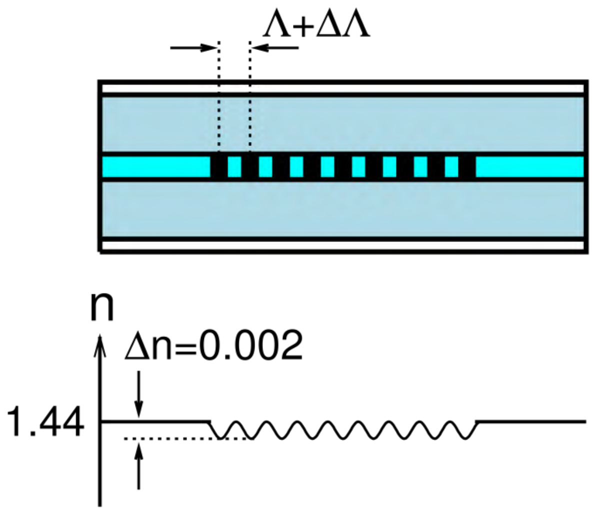


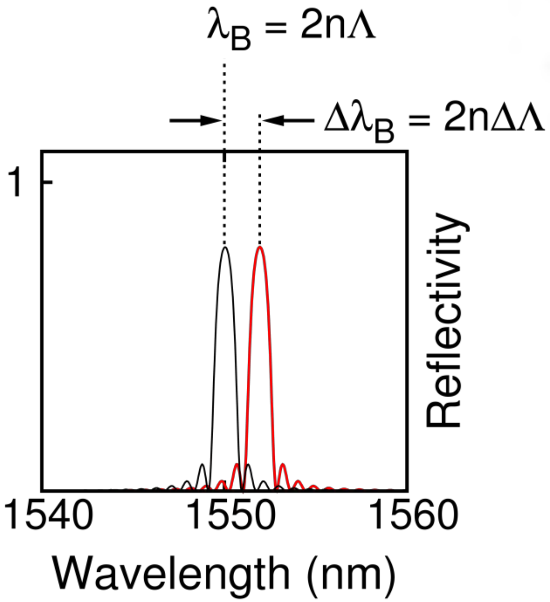
World-record field
for NMR experiment

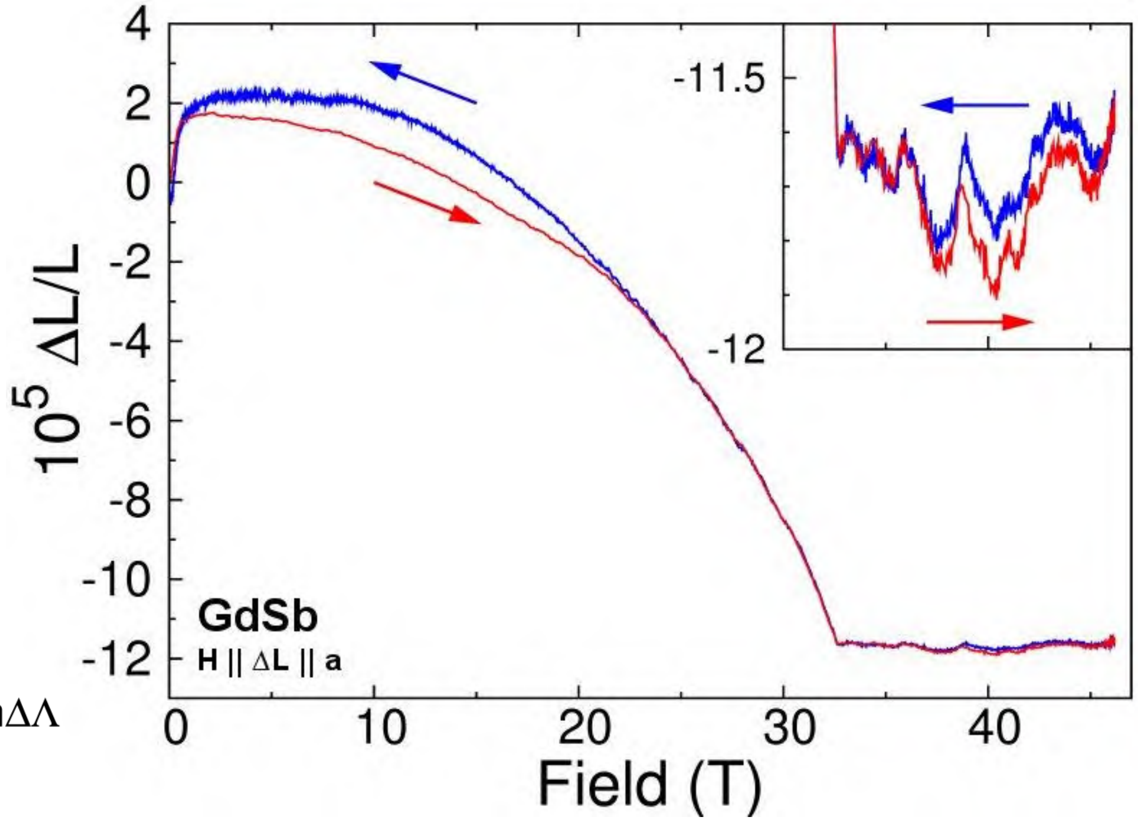
Techniques: Magnetostriction

- Fiber Bragg grating
  noise level below 2×10^{-7}



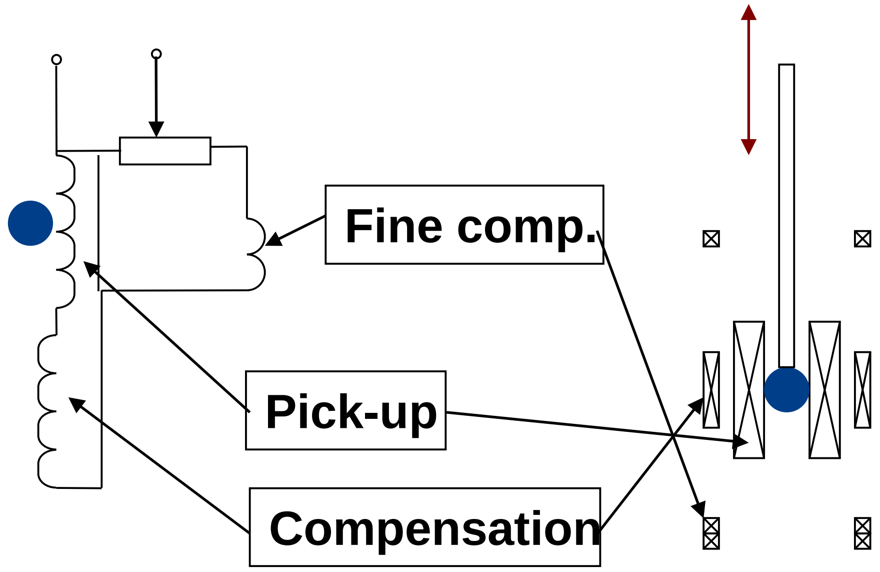


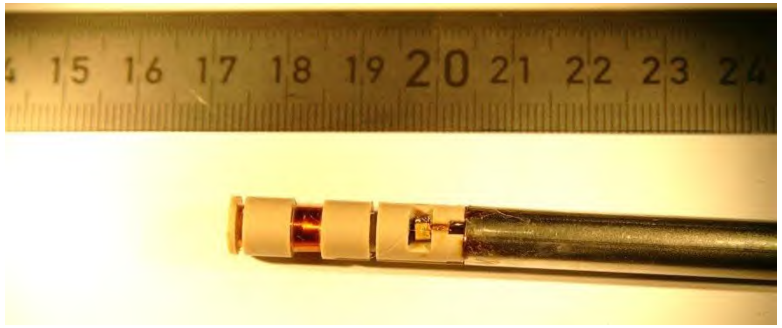


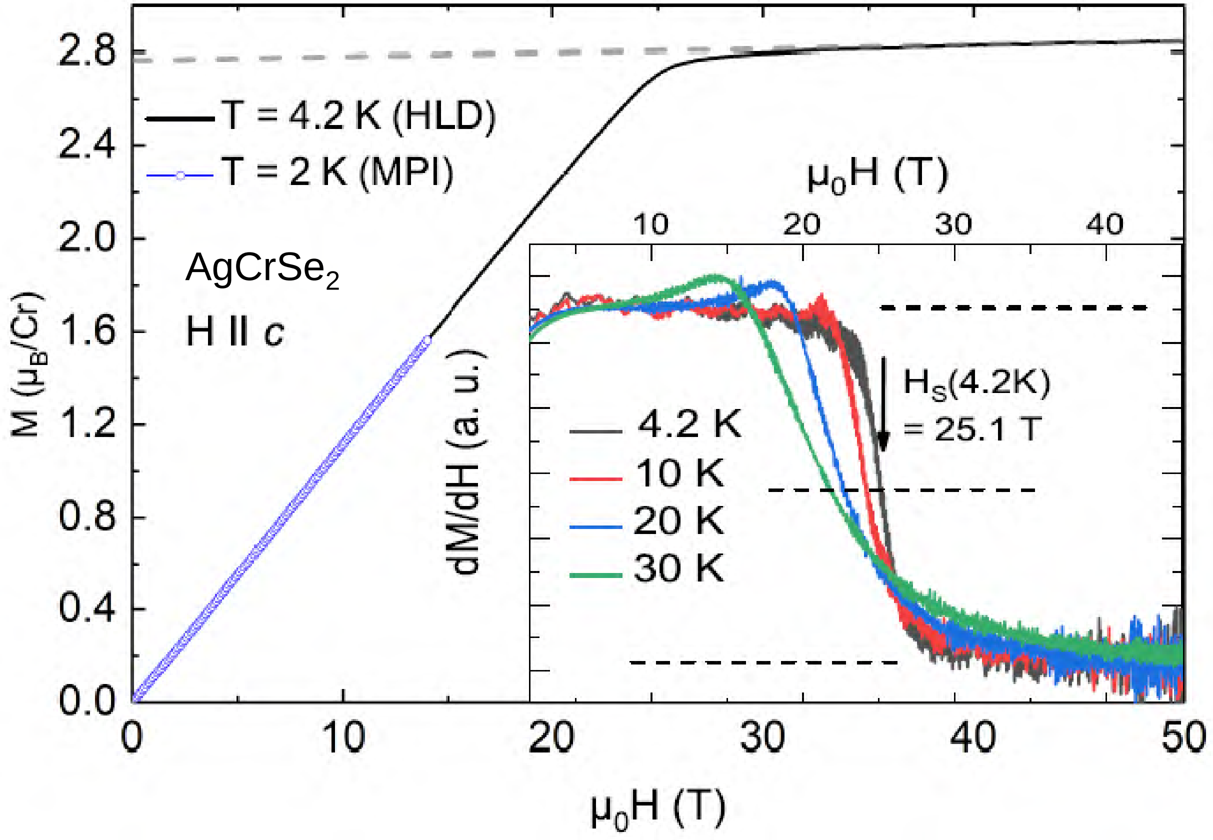


R. Daou et al.,
Rev. Sci. Instr. 81,
033909 (2010)

Techniques: Magnetization







M. Baenitz et al., Phys. Rev. B 104, 134421 (2021)

Integrating pick-up signal in compensated coils ⇒ Magnetization

Y. Skourski et al., Phys. Rev. B 83, 214420 (2011)

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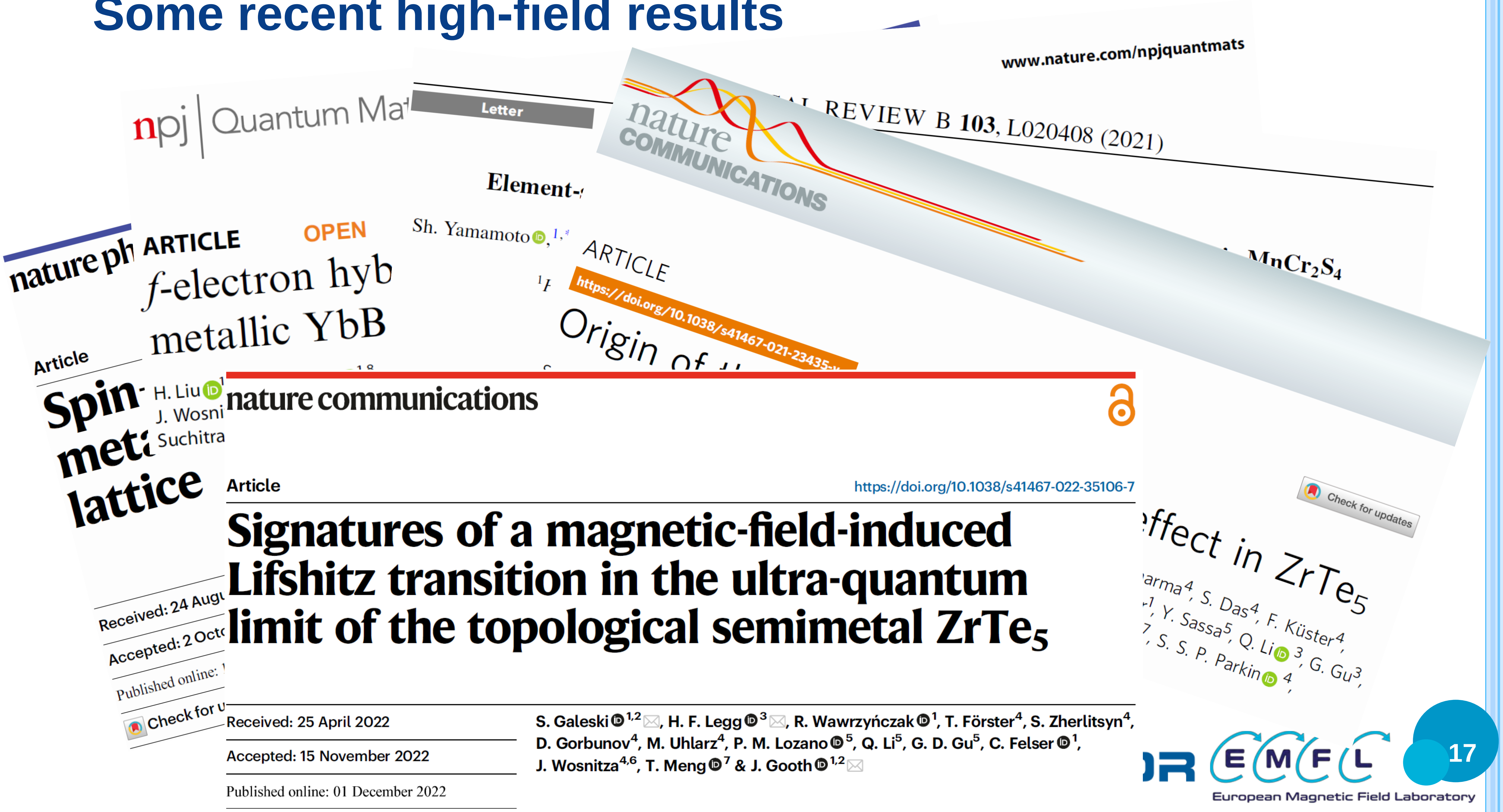
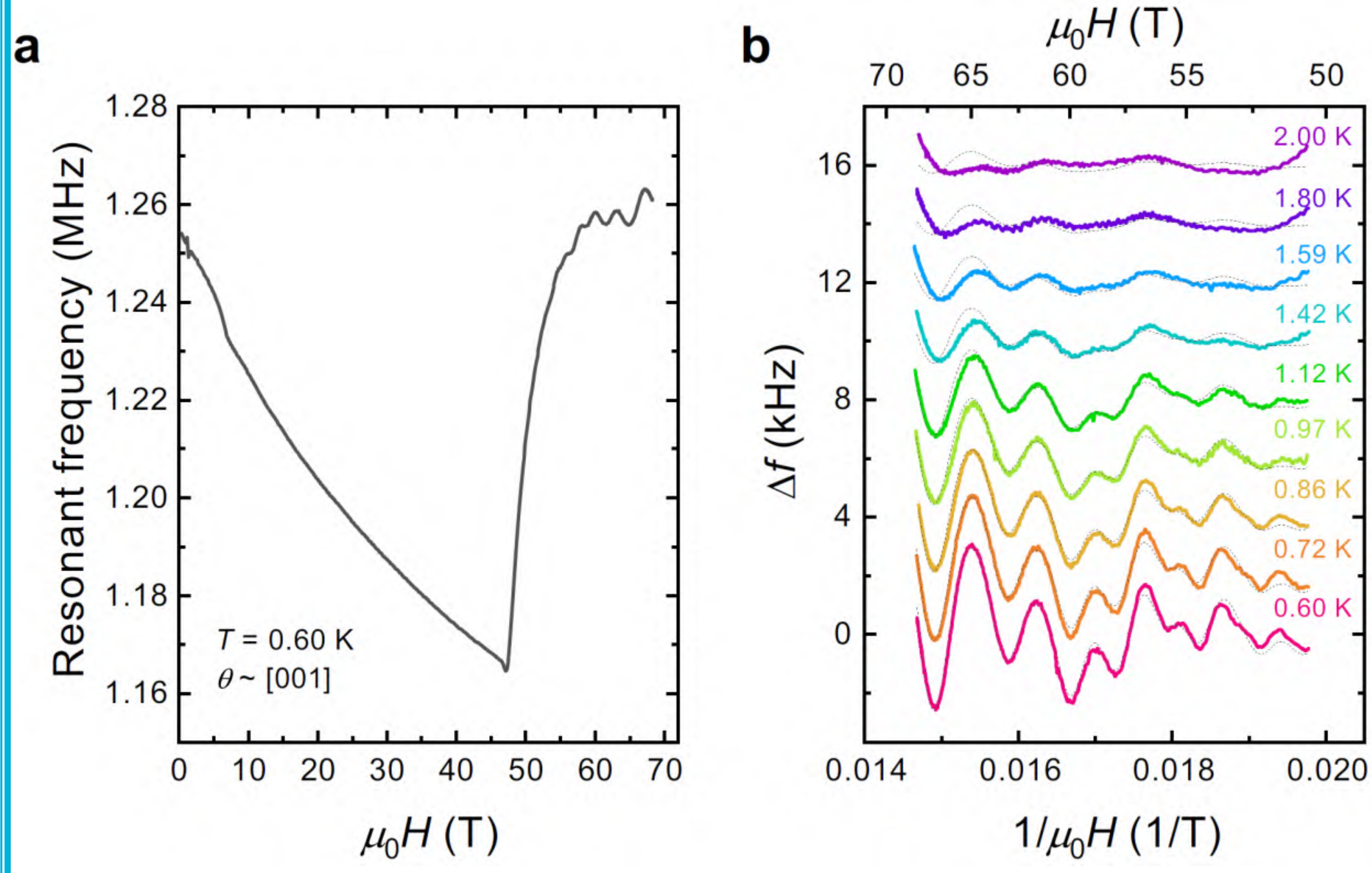
Some recent high-field results



European Magnetic Field Laboratory

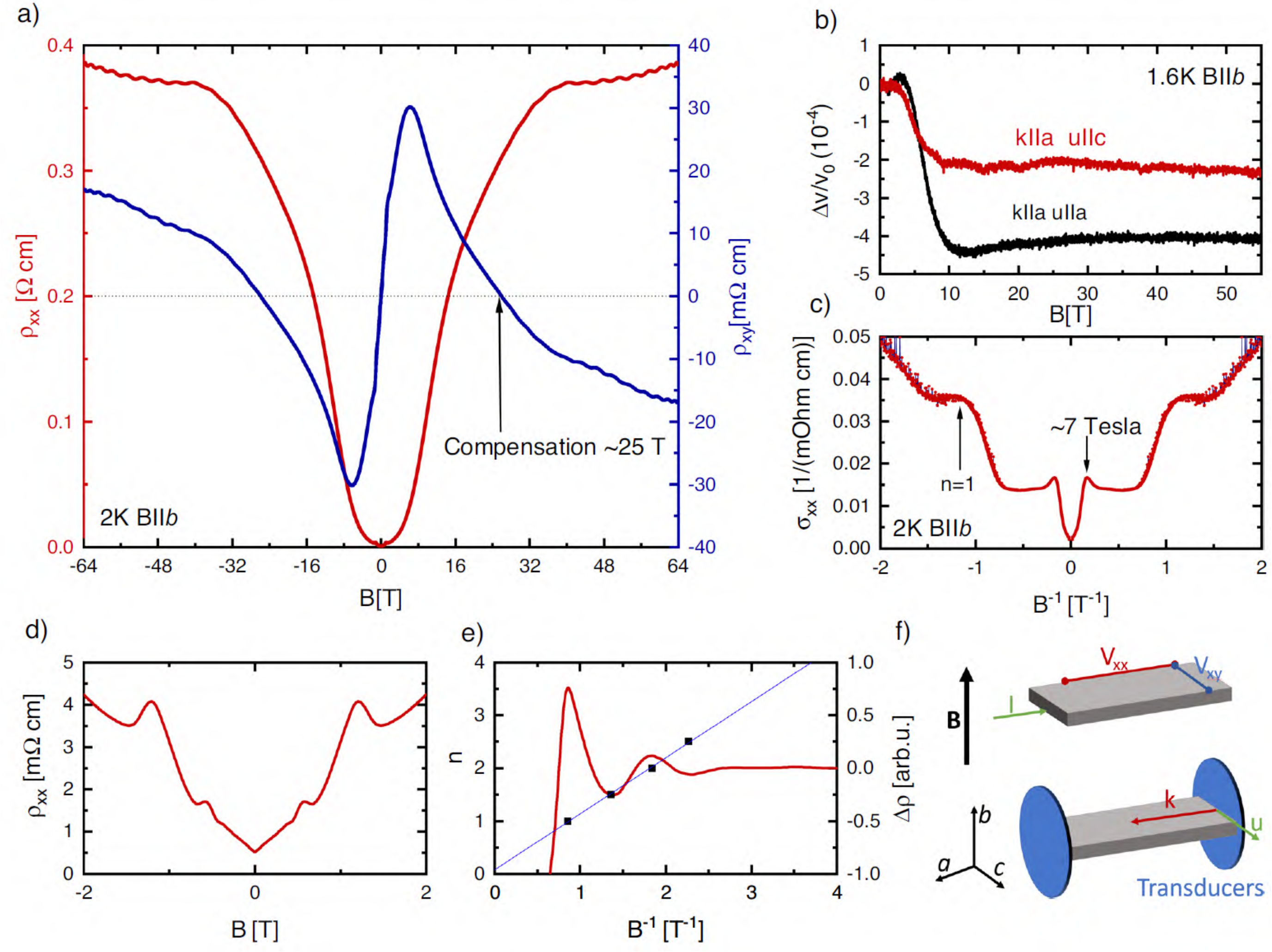
Field-induced metallic state in insulator



- YbB_{12}: unconventional Kondo insulator
- Field-induced metallic state above 47 T
- Quantum oscillations allow comparison with band-structure calculations
- Important for understanding appearance of quantum oscillations in insulating state

H. Liu et al., npj Quantum Materials **7**, 12 (2022)

Ultra-quantum limit in topological semimetal



- $ZrTe_5$: semimetal with very small Fermi surfaces → Quantum limit at a few tesla
- Zeeman effect enables tuning of 1D Landau band structure
- Lifshitz transition to a 1D Weyl regime
- $ZrTe_5$ as platform for exotic interaction-driven phases in the ultra-quantum limit

S. Galeski et al., Nat. Commun. **13**, 7418 (2022)

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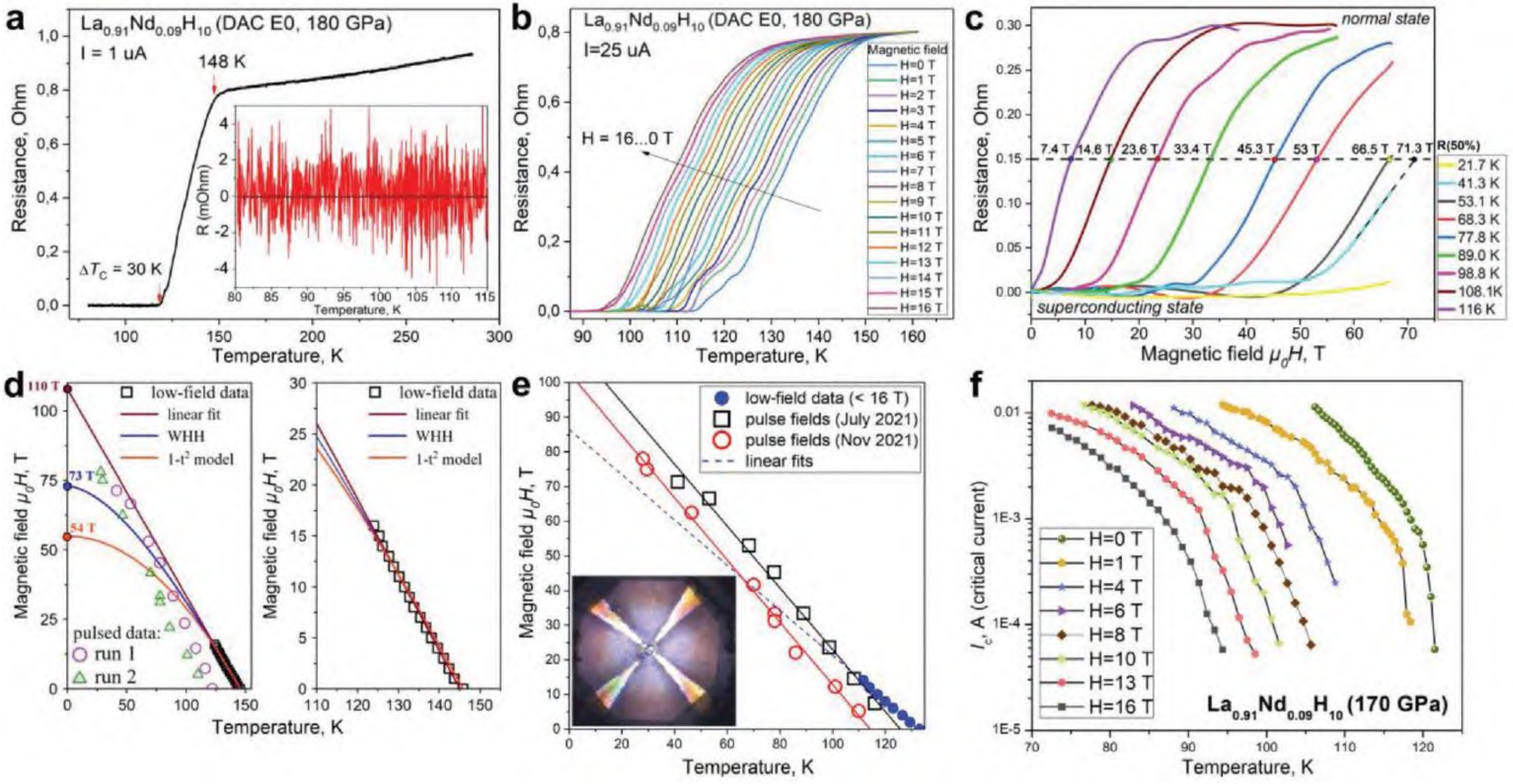
Superconductivity in LaH_{10} – effect of impurities



- (La,Nd)H_{10}
- T_c = 148 K
- 100 K lower than pure LaH_{10}
- 170 - 180 GPa
- H_{c2} linear in T
- BCS s-wave

D. V. Semenok et al., Adv. Mater. **34**, 2204038 (2022)

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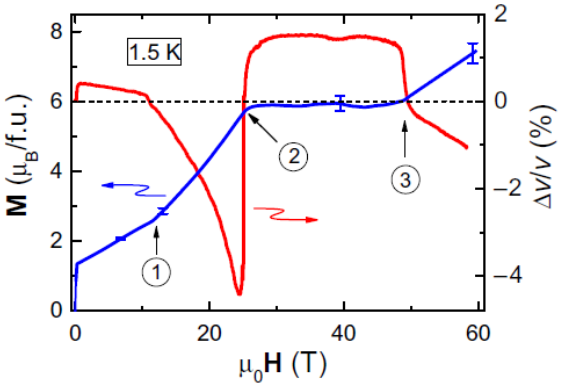
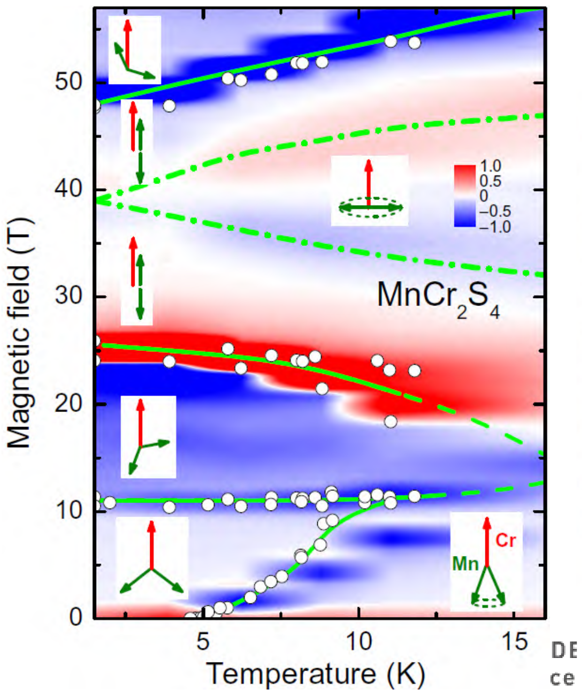
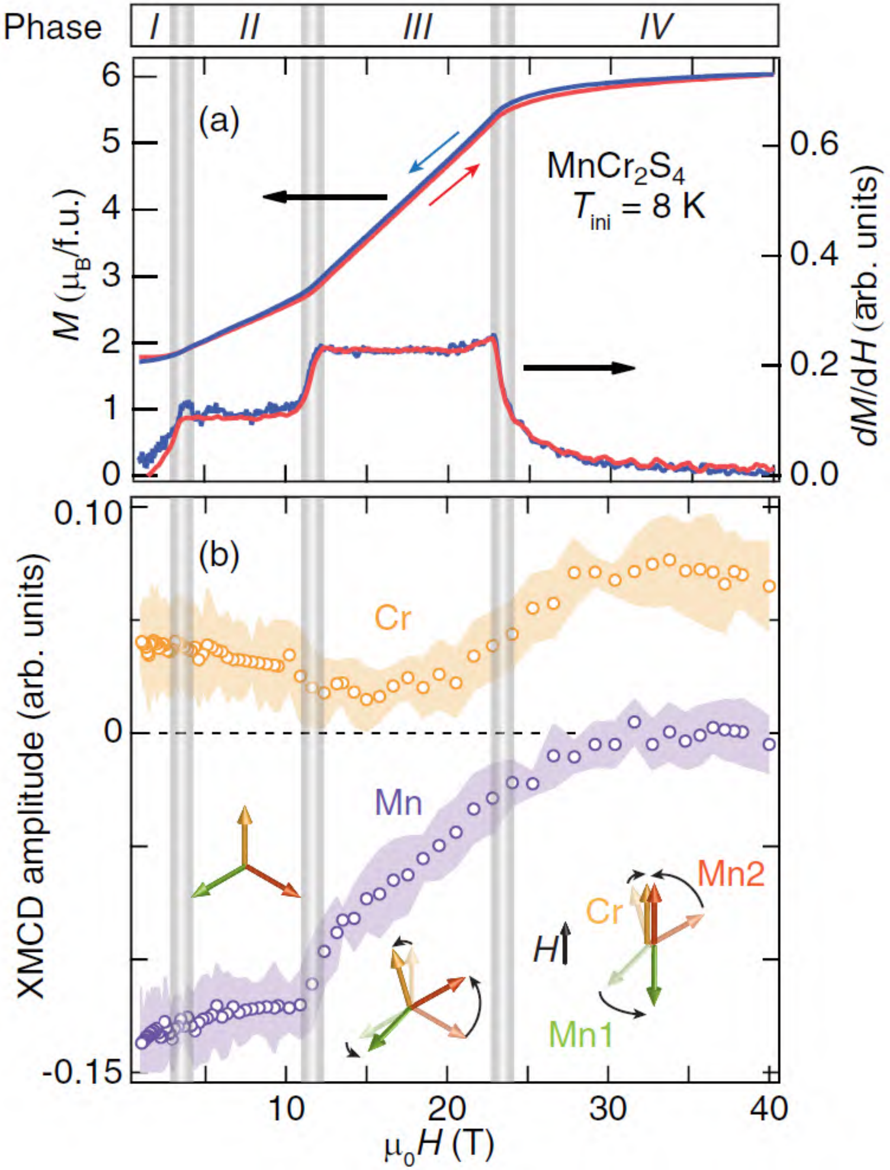
Using x-rays in pulsed fields

Element-specific field-induced spin orientation

- Understand microscopic nature of phase diagram
- Use XMCD to follow rotations of individual magnetic moments in pulsed magnetic fields up to 40 T
- HIBEF benchmark experiments (pulsed fields at EuXFEL)



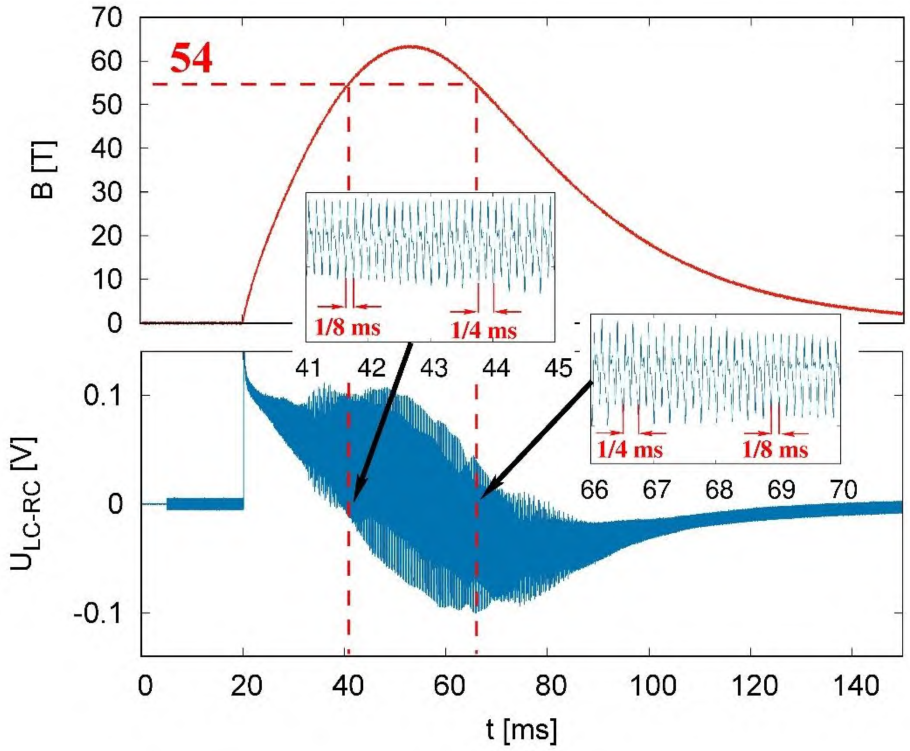




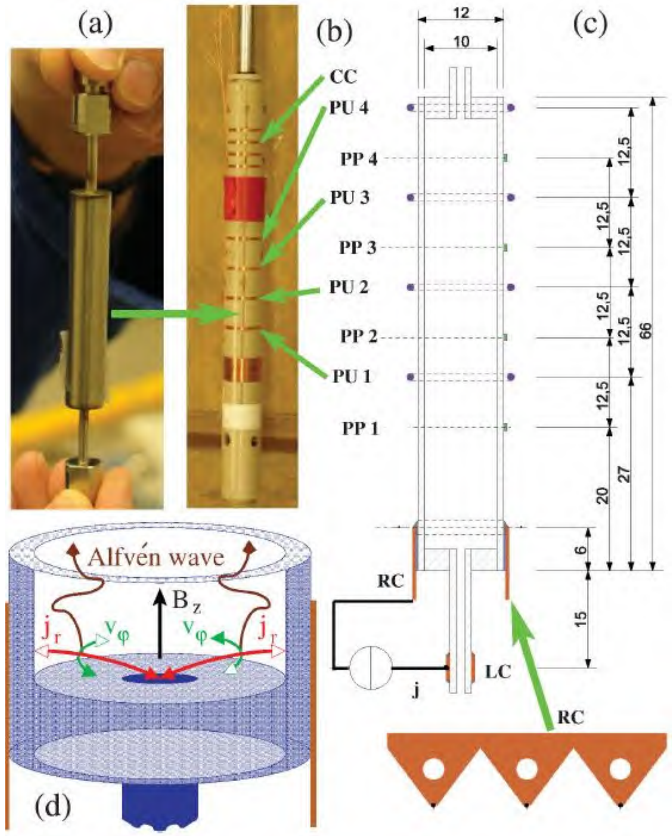
V. Tsurkan et al., Sci. Adv. **3,** e1601982 (2017)
A. Miyata et al., PRB **101**, 054432 (2020)
S. Yamamoto et al., PRB **103**, L020408 (2021)
D. Gorbunov et al., PRL **122**, 127205 (2019)

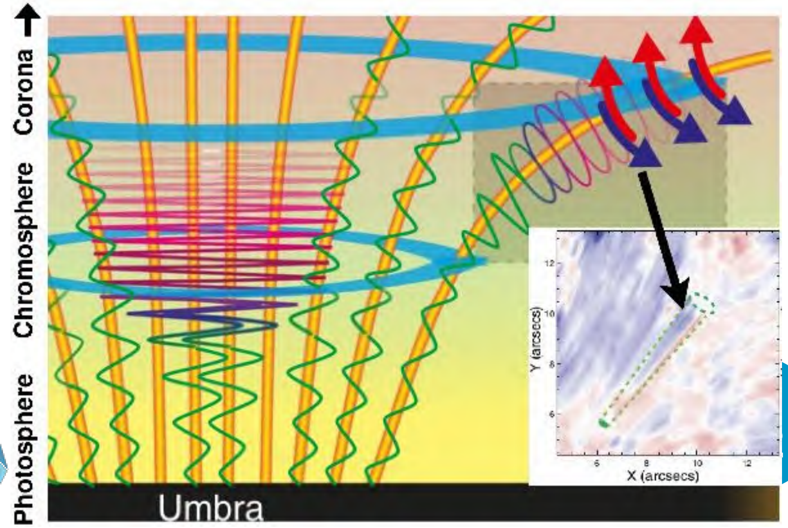
Bringing the sun into the lab

Why is the solar corona hotter than the sun's surface?
Expertise of two institutes needed:
- liquid metal (rubidium): Institute of Fluid Dynamics
- pulsed magnetic fields above 54 T: HLD



F. Stefani et al.,
PRL **127**, 275001 (2021)





DRESDEN
concept

Thanks for your attention

University of Nottingham

UK China Malaysia

Generating and using high magnetic fields

Prof. Amalia Patanè
UK Director of the EMFL
School of Physics and Astronomy
University of Nottingham

EMFL European Magnetic Field Laboratory

UKRI

University of Nottingham

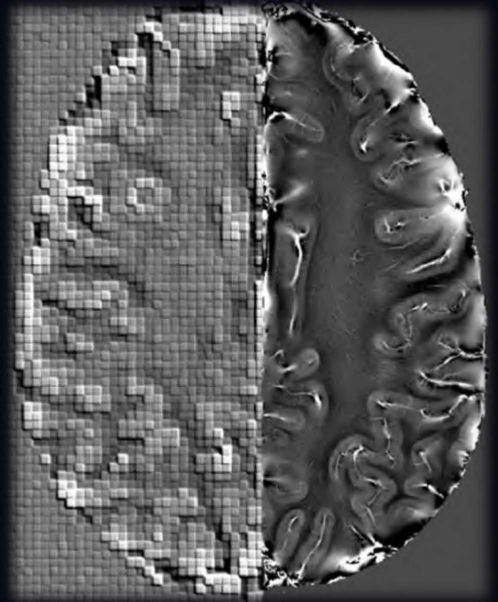
UK China Malaysia

Founded in 1881
4 campuses in the UK

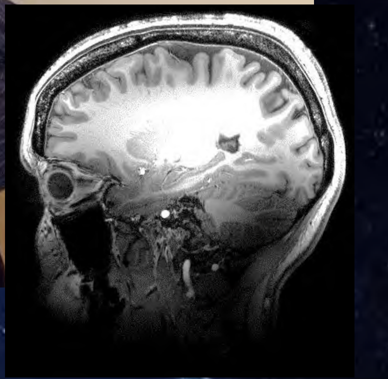
45,500 students
7,000 staff

2023 Announcement of UK National MRI Facility

£29 million to establish in 2025 the UK's most powerful MRI scanner (11.7T and 83-cm bore)

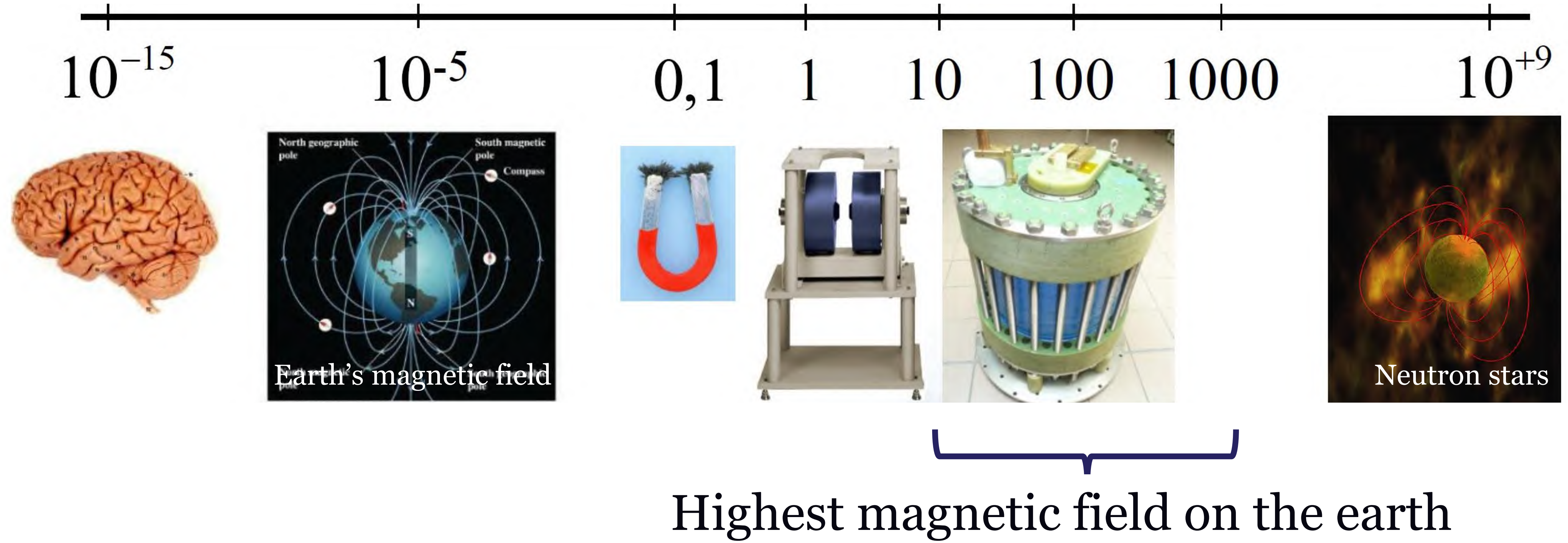


2003 **Sir Peter Mansfield**
Nobel Prize, MRI
Magnetic Resonance Imaging



Magnetic fields: Order of magnitudes

Magnetic B-field (units of tesla, T)

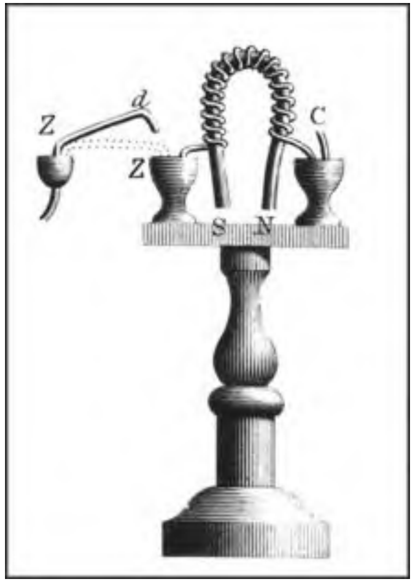


Tesla (T) is the SI unit of measurement to define the **magnetic flux density** (or Wb/m^2 or 10,000 gauss).
This is a unit of measurement on the International System of Units, which is the metric system.

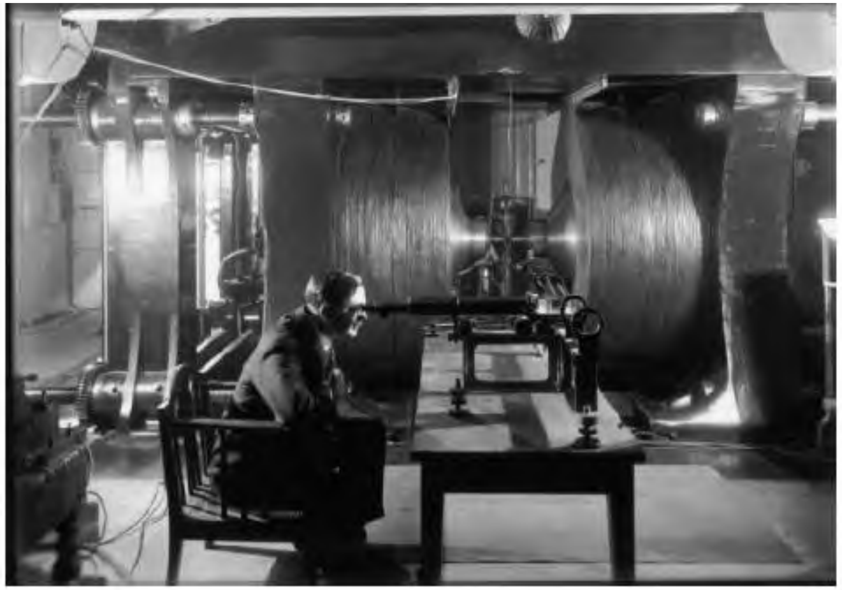
How to generate high magnetic fields?

A current I in a coil generates a magnetic field $B \propto I$

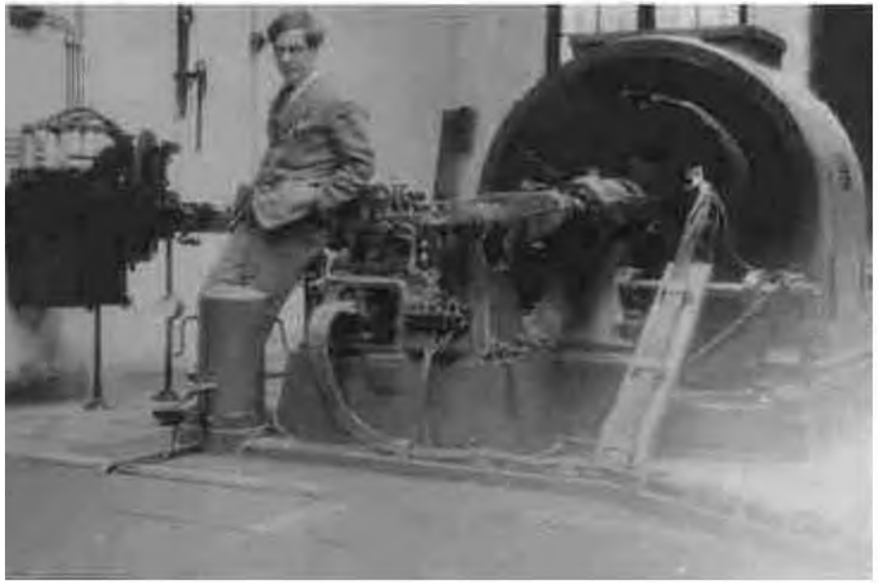
William Sturgeon 1824
First electromagnet



Aimè Cotton 1920
6-7 T iron-core electromagnet



Piotr Kapitza 1924
30-50 T pulse electromagnet



How to generate high magnetic fields?

A current I in a coil generates a magnetic field $B \propto I$

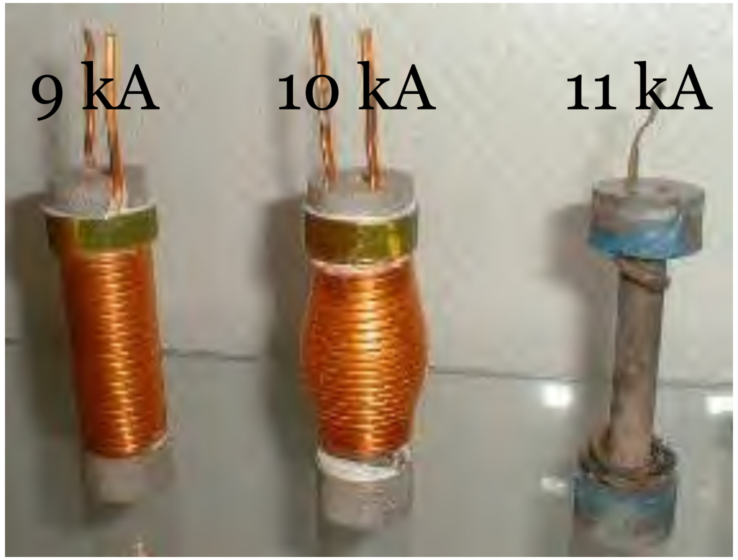
Limitation: heating (Joule effect) $P \propto R \times I^2 \propto B^2$

Solutions:
- superconductors $R = 0$ ($B < B_{crit}$)
- cooling conductor
- pulsed current (< 1 s)

Limitation: Lorentz force on the coil $F \propto B \times I \propto B^2$

Solutions:
- strong conductor
- mechanical reinforcement
- sacrifice the coil

The generation of high magnetic fields poses scientific and technical challenges!



European Magnetic Field Laboratory

World class high magnetic field facility https://emfl.eu/

Users from > 30 countries

UK partnership funded by the UKRI for free access of facility and development of techniques/magnets

4 sites in the EU

European Magnetic Field Laboratory

HFML Nijmegen

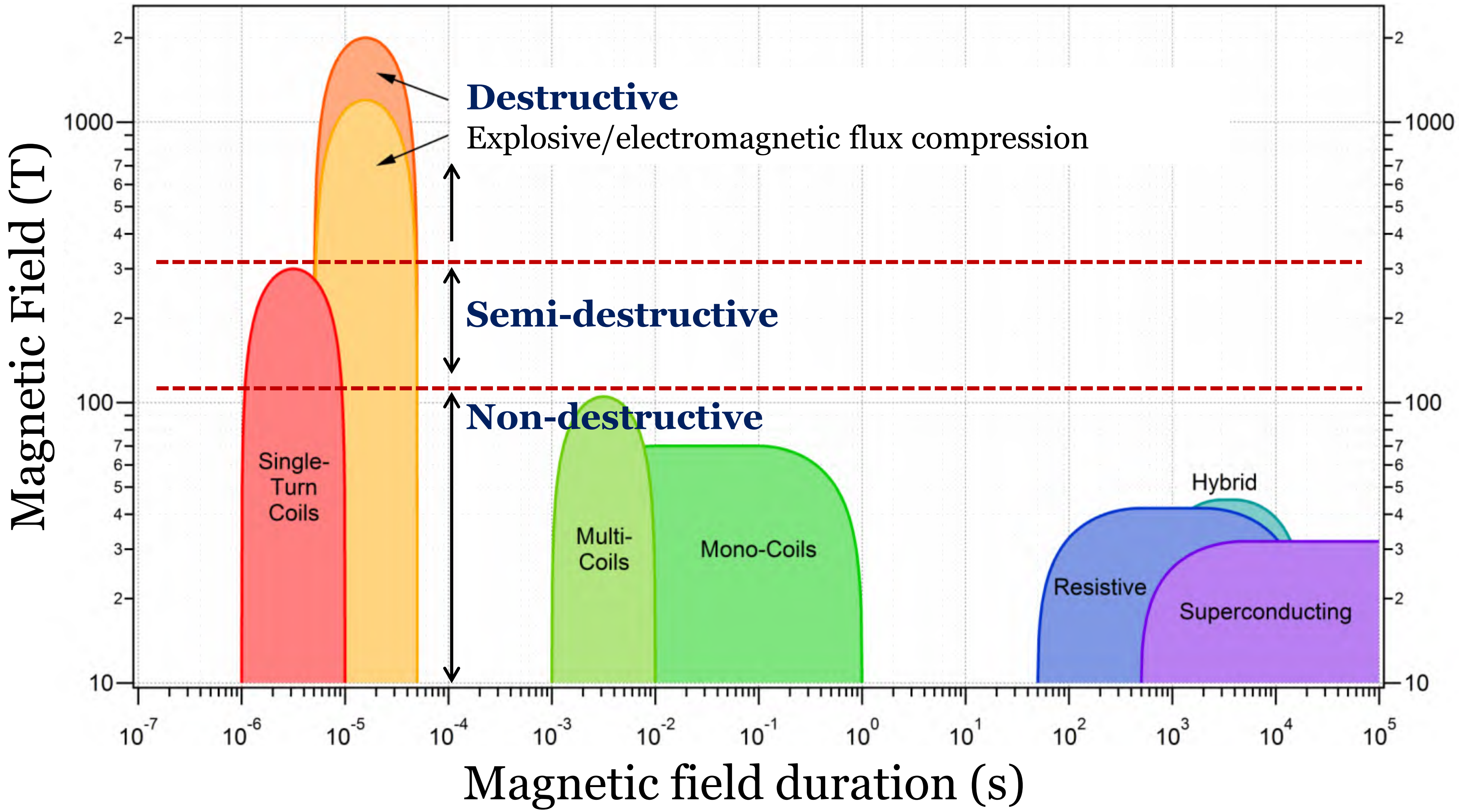
HLD Dresden

LNCMI Toulouse

LNCMI Grenoble

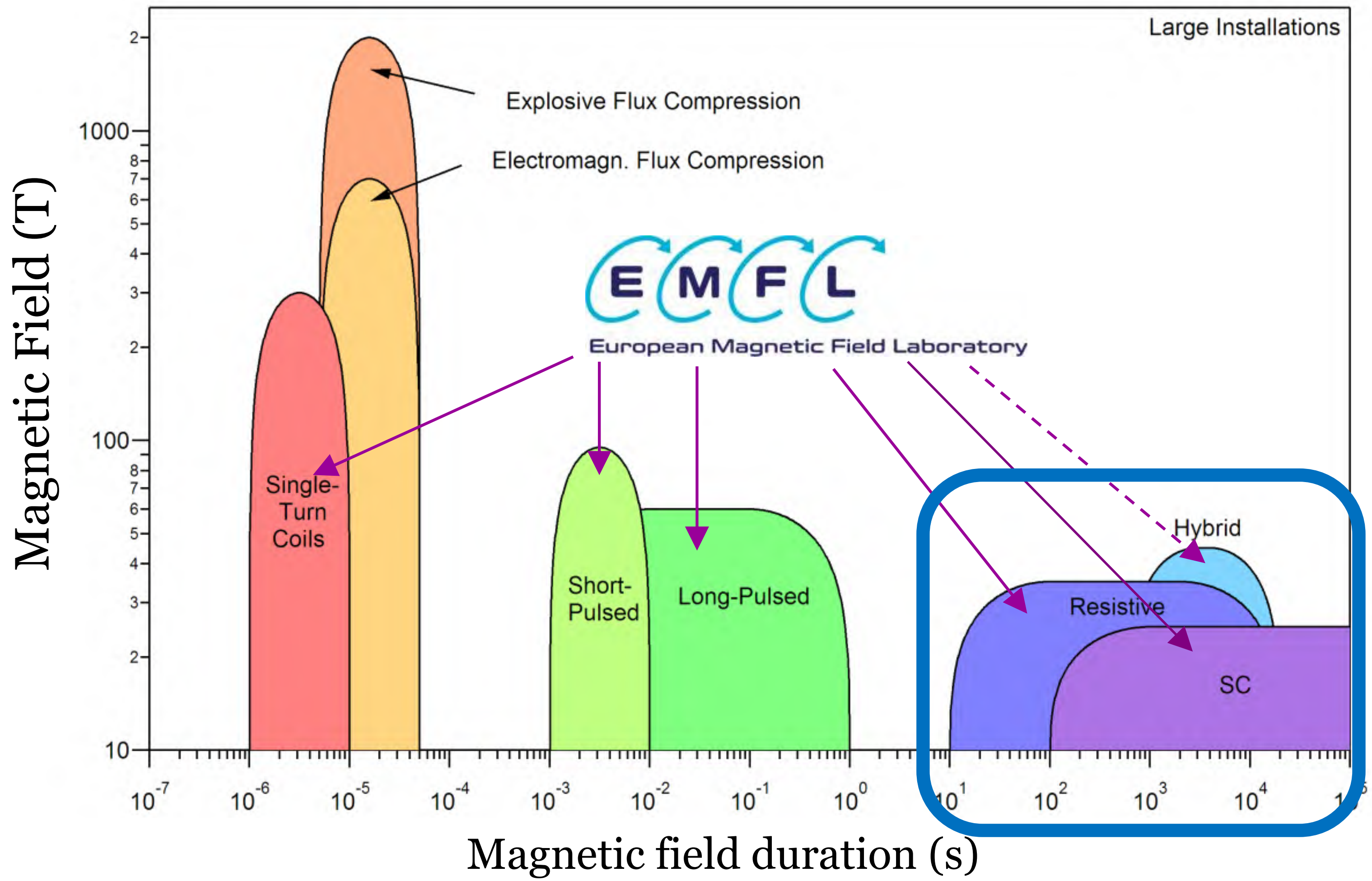
Magnetic field strength

Static and **pulsed** magnetic fields

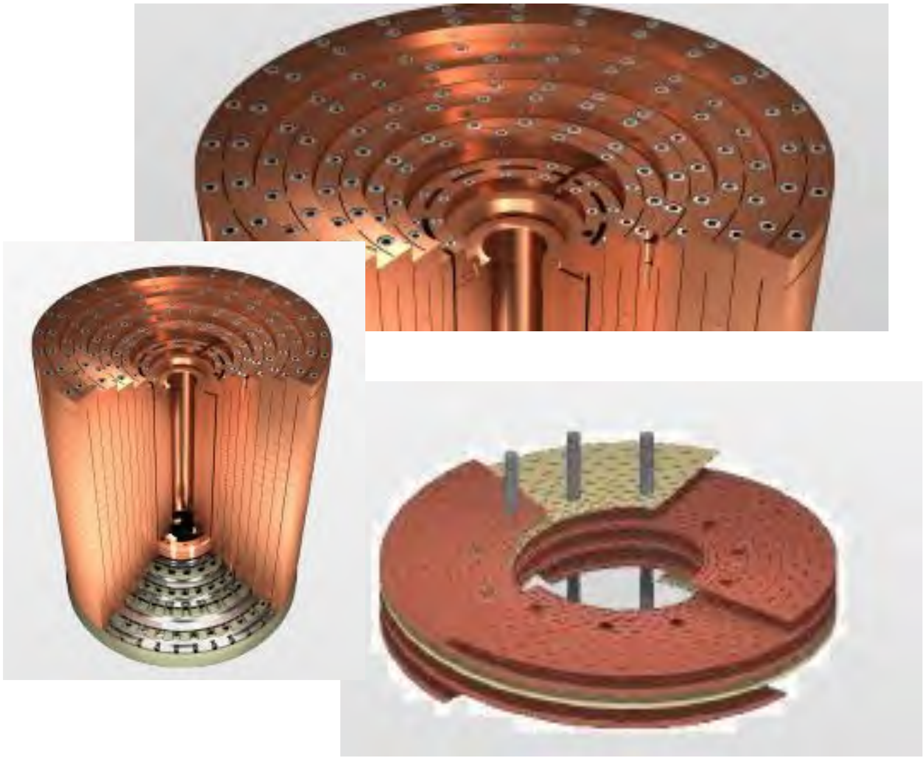


Static Magnetic Fields

Superconducting, resistive and hybrid magnets

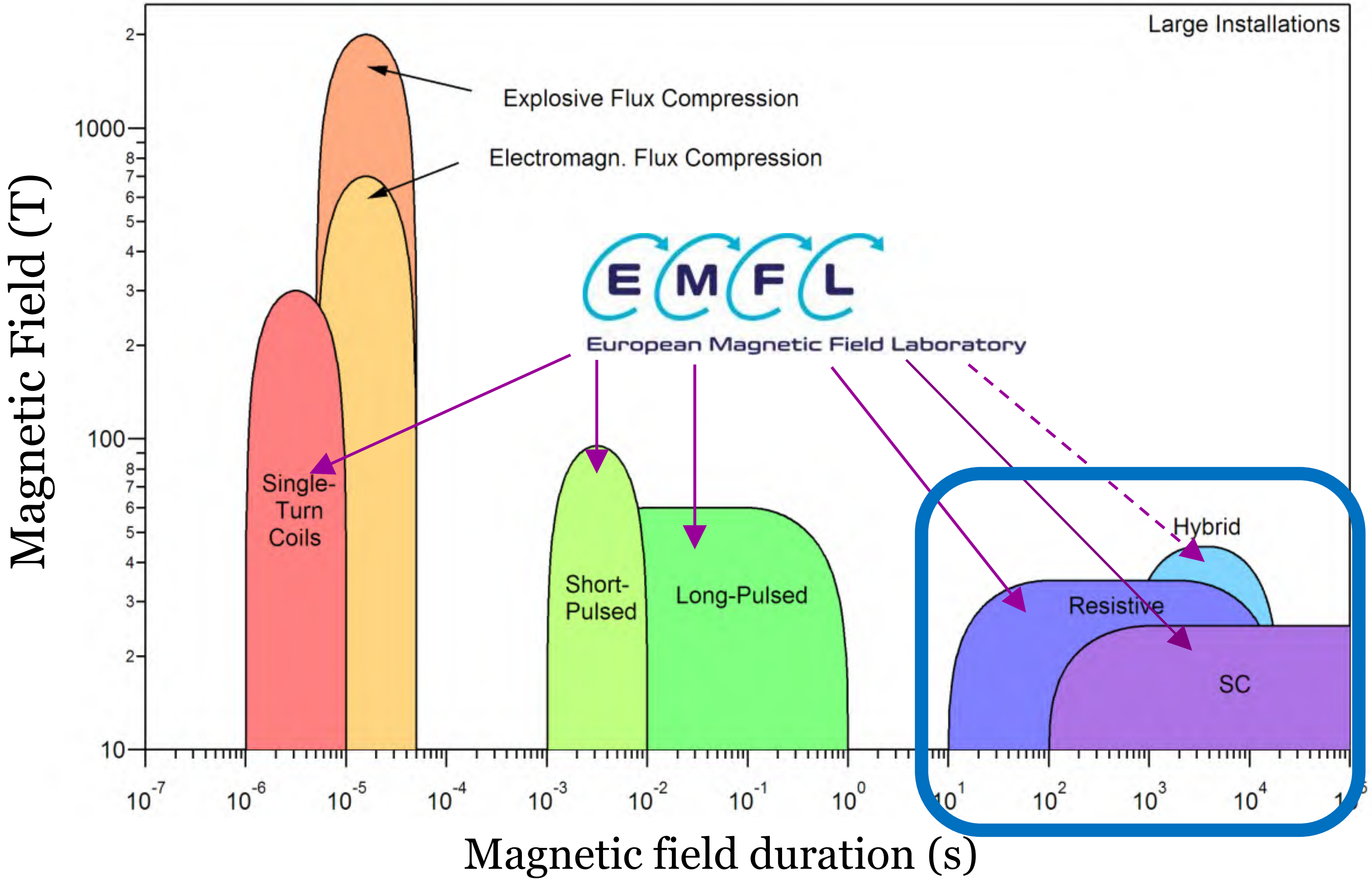


- **Resistive magnets:** 38 T
  DC current (~30 kA), > 20 MW
  300 L/s of cold water



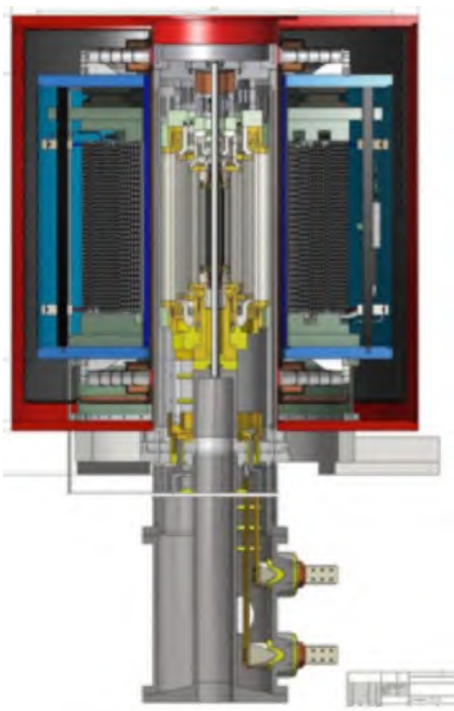
Static Magnetic Fields

Superconducting, resistive and hybrid magnets



- ❖ **Hybrid magnet**: 45 T

The hybrid magnet combines a **resistive insert** with a large-bore **superconducting outsert** (Nb_3Sn) to create an overall continuous magnetic field of 45T in a bore size of 32 mm.



Static Magnetic Fields

Hybrid magnets

Infrastructure for magnet cooling

1 Superconducting Magnet

2 LN_2 tank 27 000 litres.

3 He liquefier coldbox
150 l/h @ 4.5 K , 1.3 bar

4 Main LHe Dewar 4500 litres

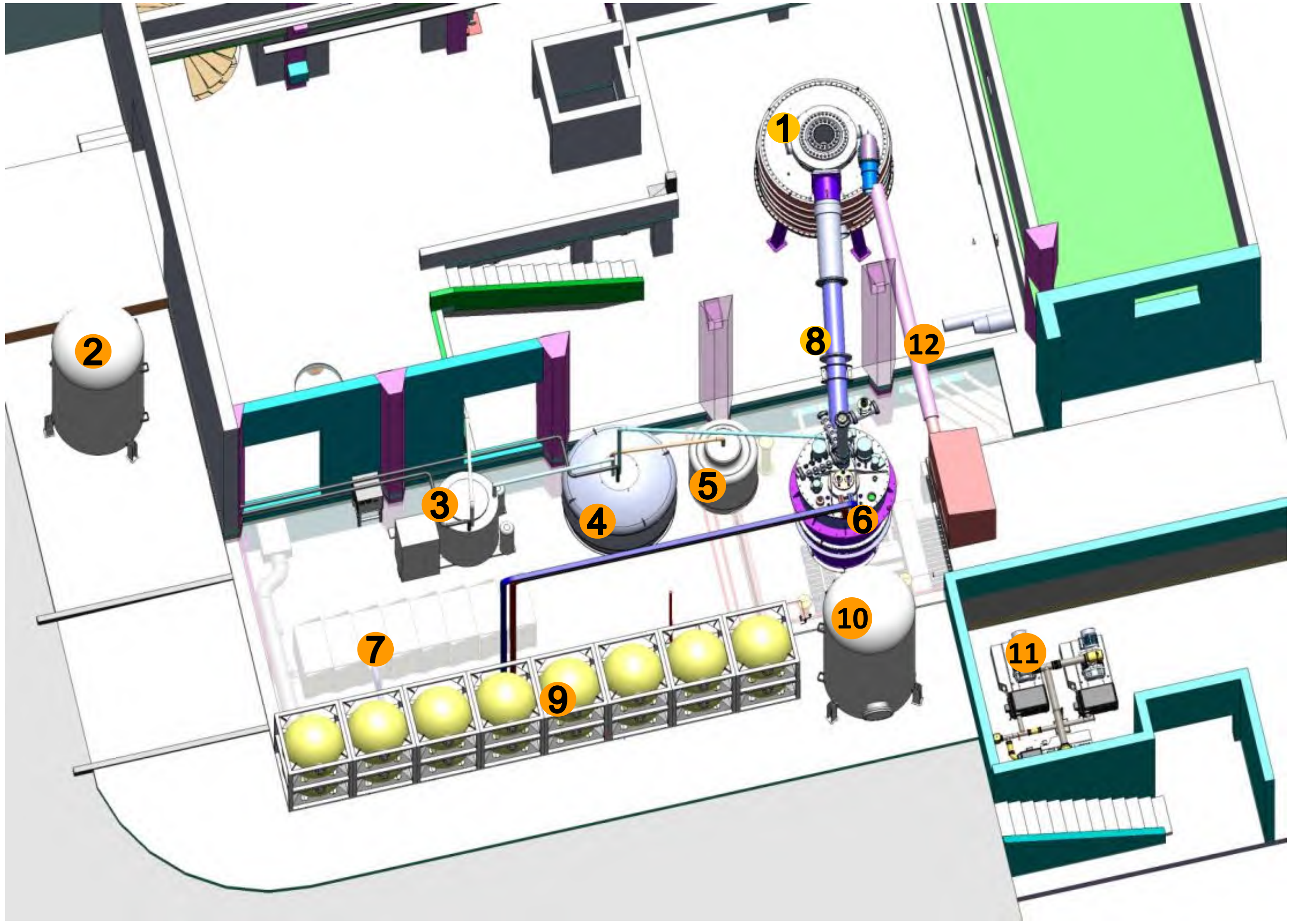
5 Secondary LHe Dewar 1700 litres

6 Cryogenic satellite to produce
the 1.8 K LHe bath

7 DC power converter
7500 A , 30 V (underground)

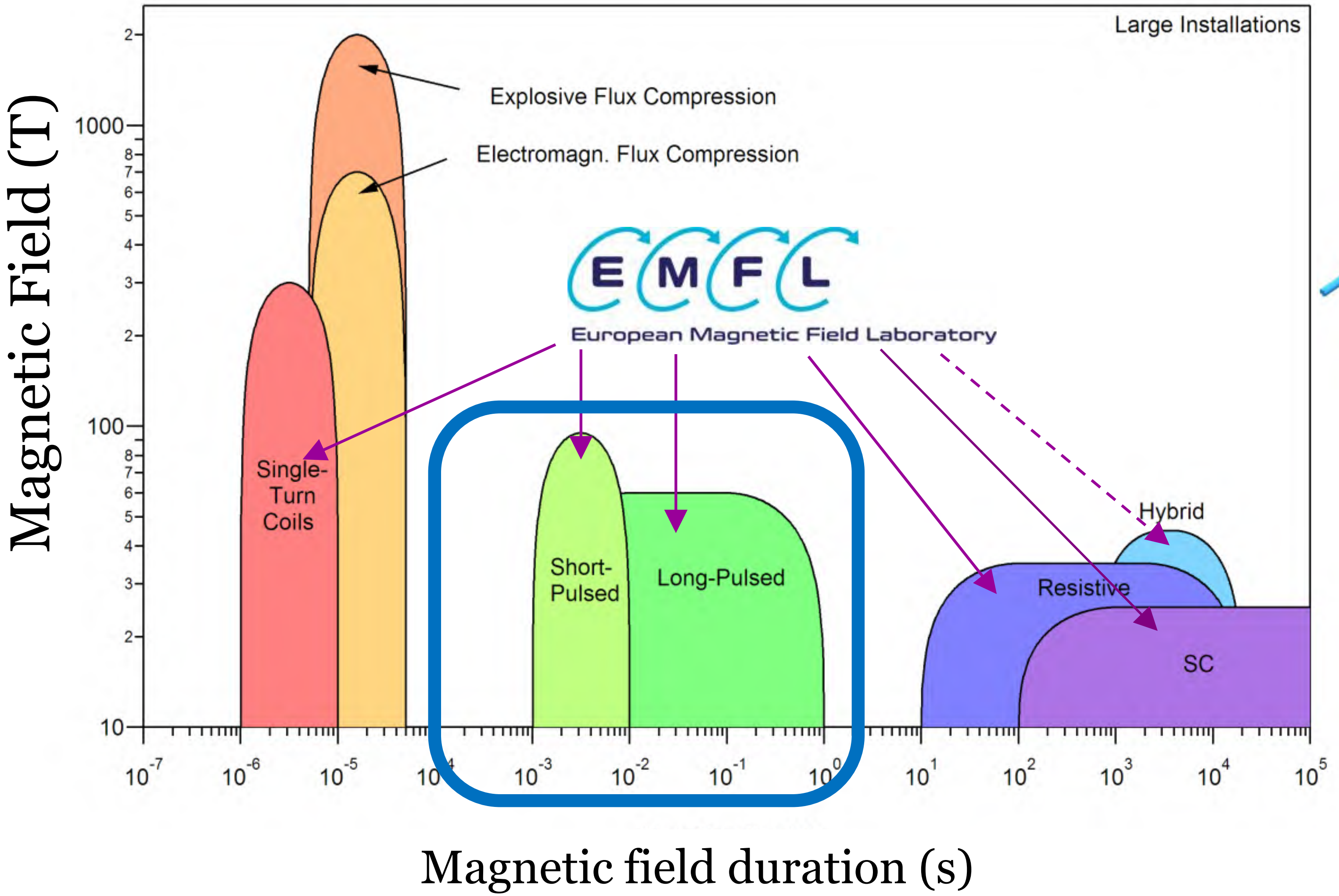
Cryoline with busbars @ 1,8 K

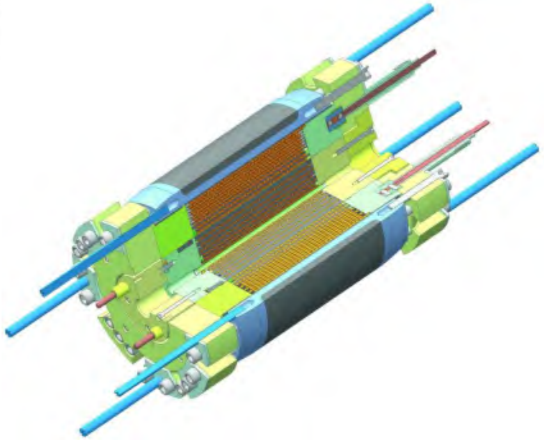
9 High pressure gaseous He tanks
16 x 1 m^3 @ 200 bars



Pulsed Magnetic Fields

Non destructive fields (up to 100T)





The construction of coils for B up to 100 T is challenging due to enormous electrical, magnetic, thermal, and mechanical stresses on the coils.

The pressure on the wire inside a coil is $p = B^2/2\mu$. For $B = 100$T, $p = 4$ GP (40000 atm)

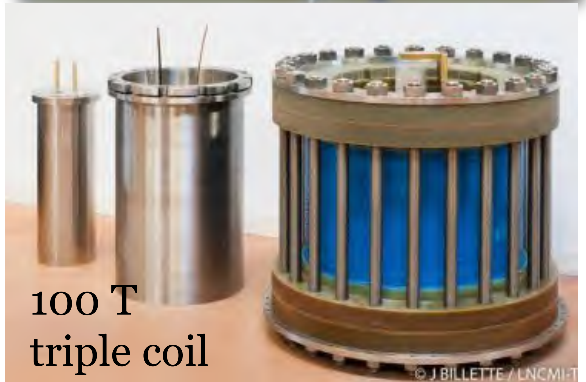
Pulsed Magnetic Fields

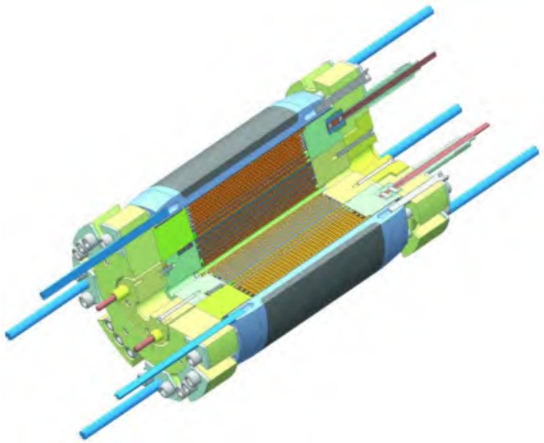
Non destructive fields (up to 100T)

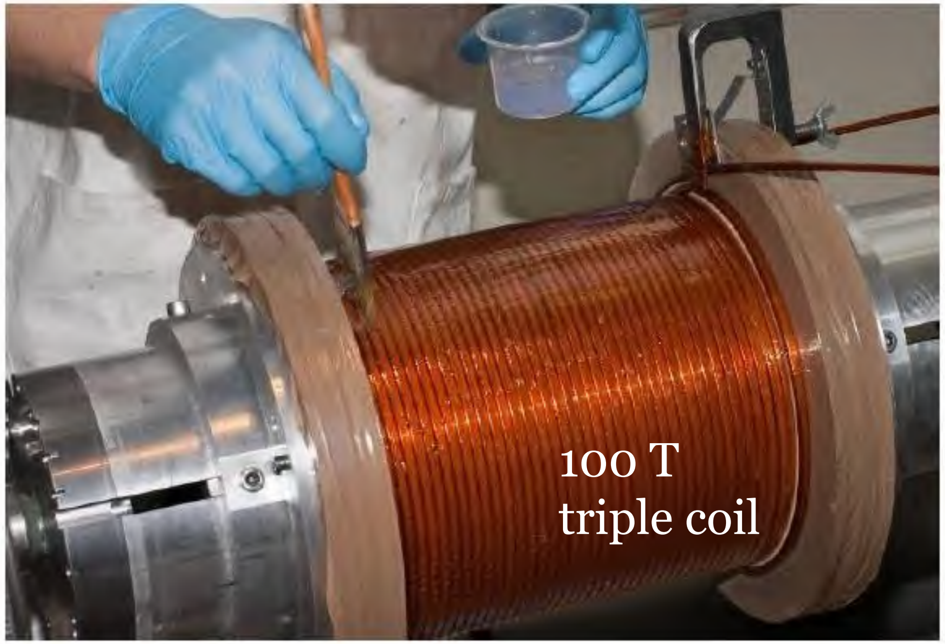
1924 - 1990
from 50 T to 70 T by reinforcing the conductor by the outside with a high strength metallic cylinder

1990s
from 70 T to 80 T with single coil by using an optimized reinforcement technique

> 2000
from 80 T to 100 T with dual coil systems powered by 2 generators. The next step is the use of 3 or 4 concentric coils





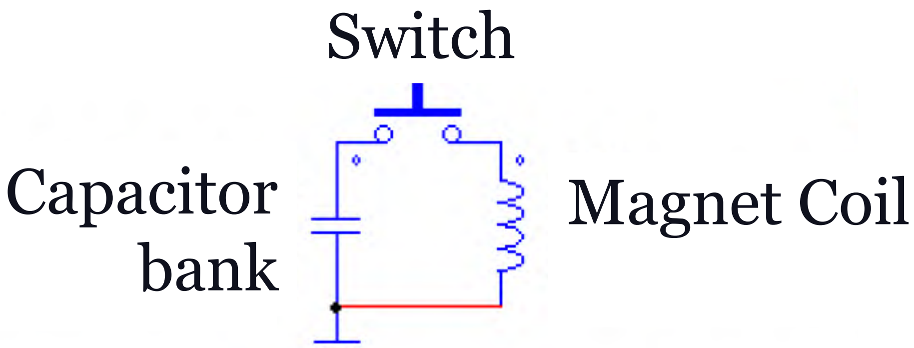


Pulsed Magnetic Fields

Non destructive fields (up to 100T)

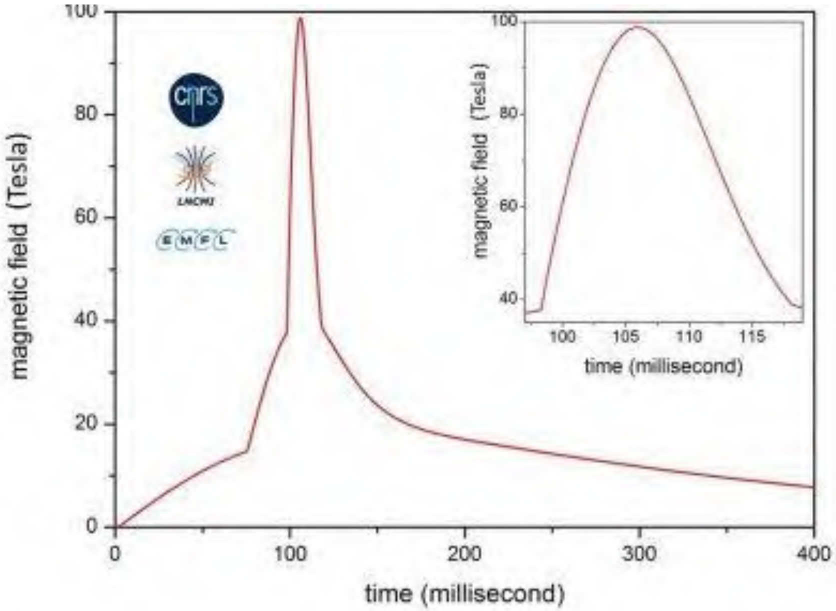
High-energy capacitor bank

High-energy capacitor bank to provide the current (> 10 kA) for the coils. Prior to a *B* pulse, the required capacitors are charged from the mains. The required energy is then supplied to the coil systems via electronic switches.



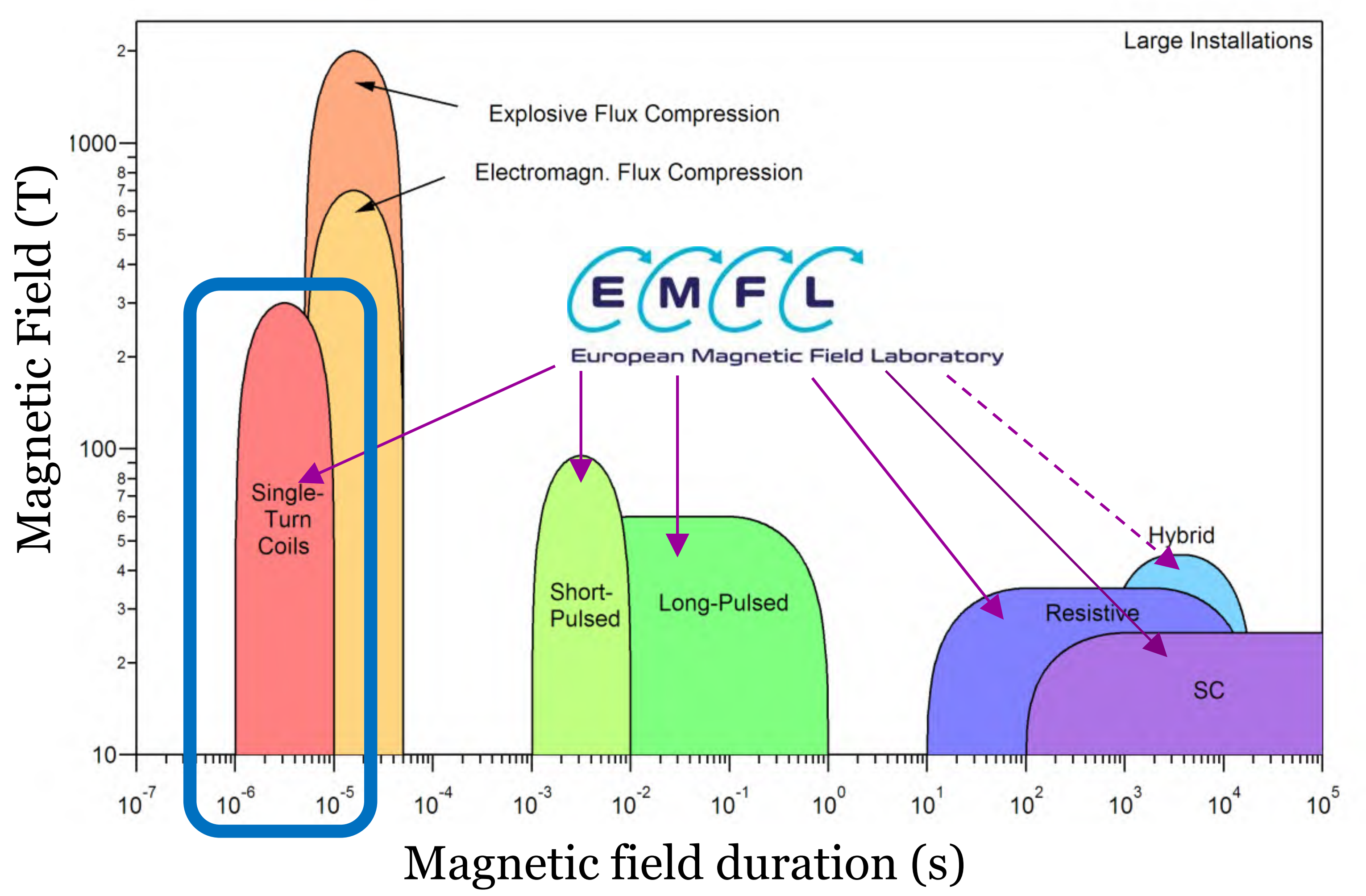
Stored energy $E = CV^2/2 \sim 10MJ$

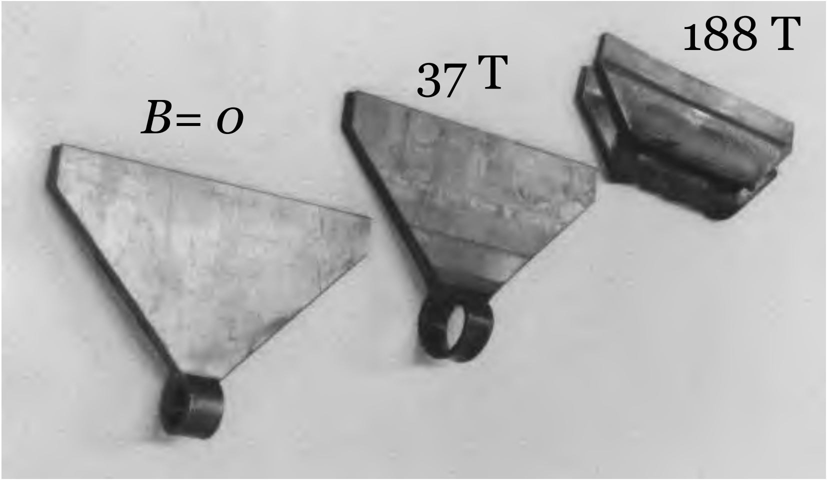
Typical current $I \sim 10\text{-}30$ kA



Pulsed Magnetic Fields

Semi-destructive fields (> 100T)





Single-turn coils before the pulse, after a 10 kV, 6 kJ discharge with B_{max} = 37 T and after a 55 kV, 189 kJ discharge with B_{max} = 188 T.

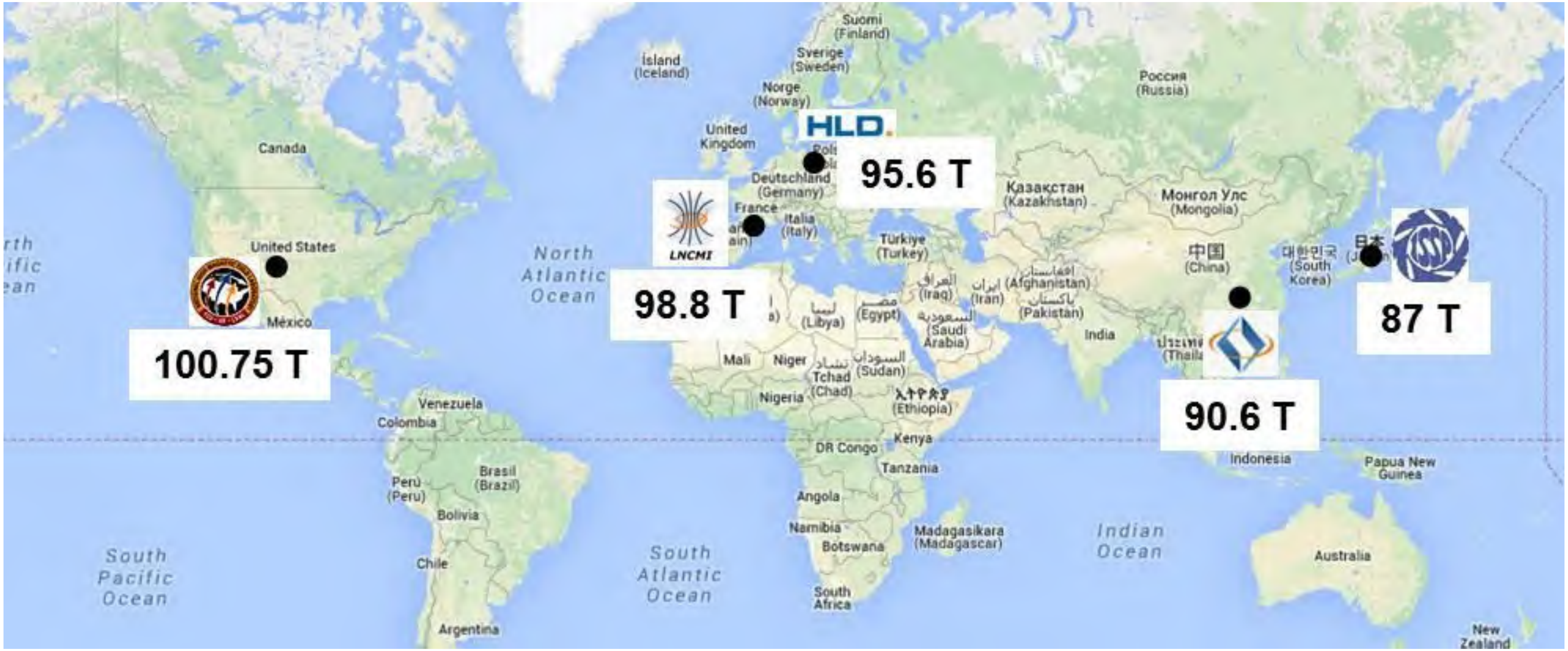
After the 55 kV discharge, the coil is destroyed and the triangular feed flanges are ripped off by the extreme current density.

Magnetic Fields Worldwide

Only a few labs in the world with $B > 80$ T

High magnetic field installations are expensive to built and run!

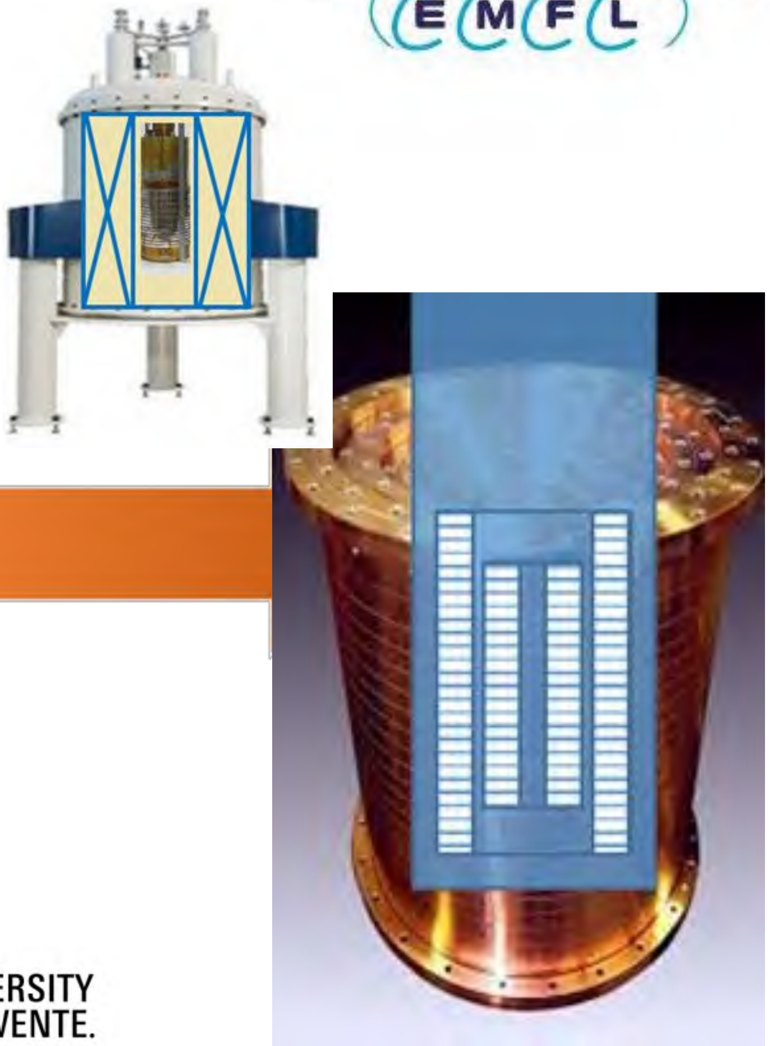
20 MJ equivalent to the kinetic energy of 100 running elephants!



All superconducting magnet

Design of all-superconducting magnet (**32T** and **40T**) through the development of high-T superconductor technology and its combination with low-T superconductors.

2021-2024, 11 partners (3 industrial), 2.9M€



HLD. Radboud University THEVA

cnrs HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF cea OXFORD INSTRUMENTS UNIVERSITÉ DE GENÈVE ELÚ BILFINGER UNIVERSITY OF TWENTE.

Using high magnetic fields

Probing and discovering matter

NMR, cyclotron resonance, EPR, Hall effect…

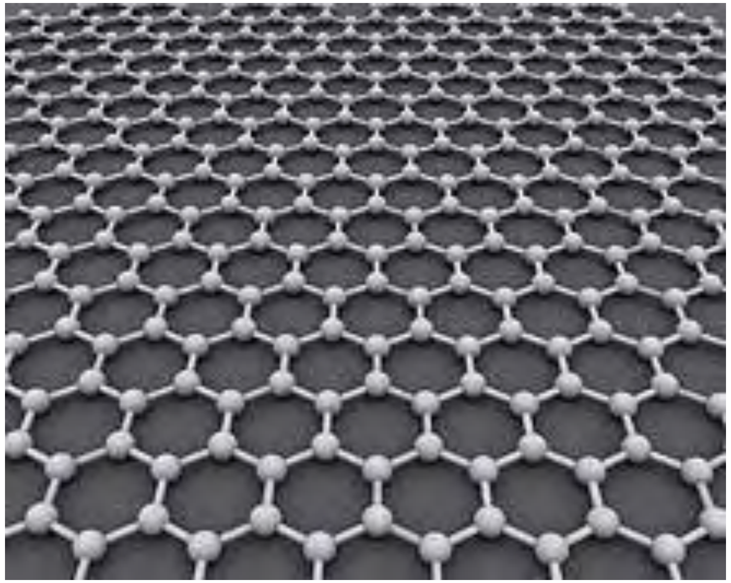
Creating new states of matter

Normal state of superconductors,
magnetic states, quantum critical points…

Manipulating matter

Deflection, levitation, separation, alignment…

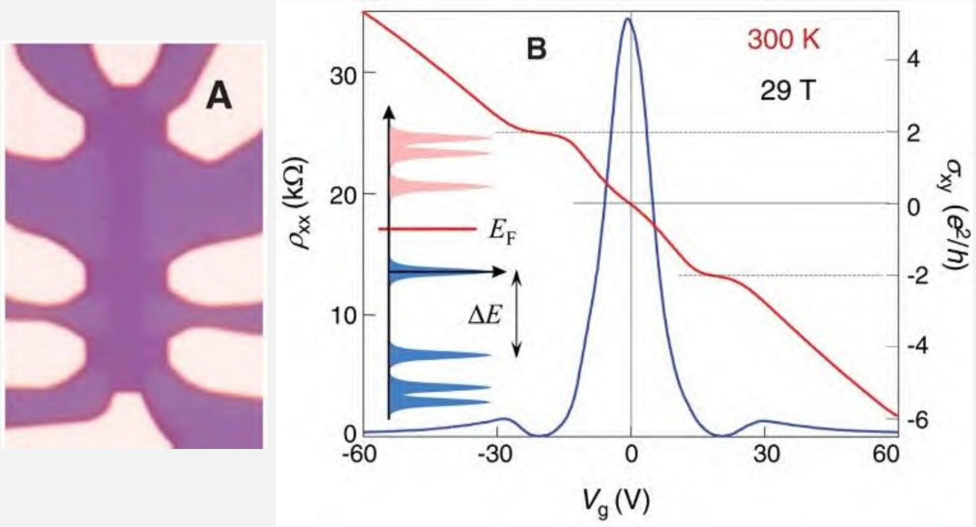
Graphene: The wonder Material

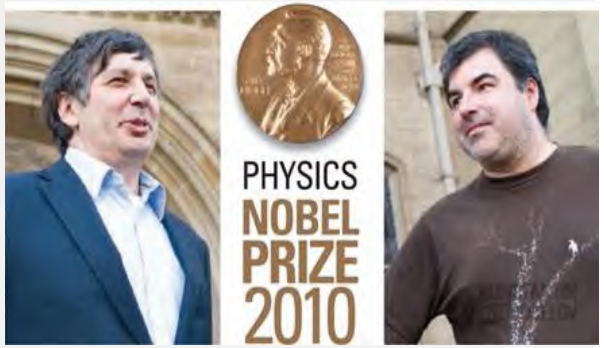


Using high magnetic field to reveal the conductivity properties of two-dimensional systems

Quantum Hall effect

Science 315, 5817, 2007



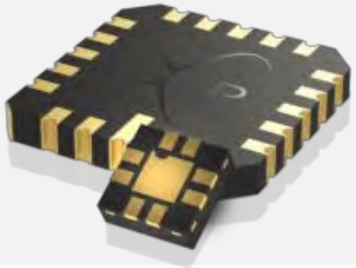


A. Geim and K. Novoselov

MANCHESTER
1824

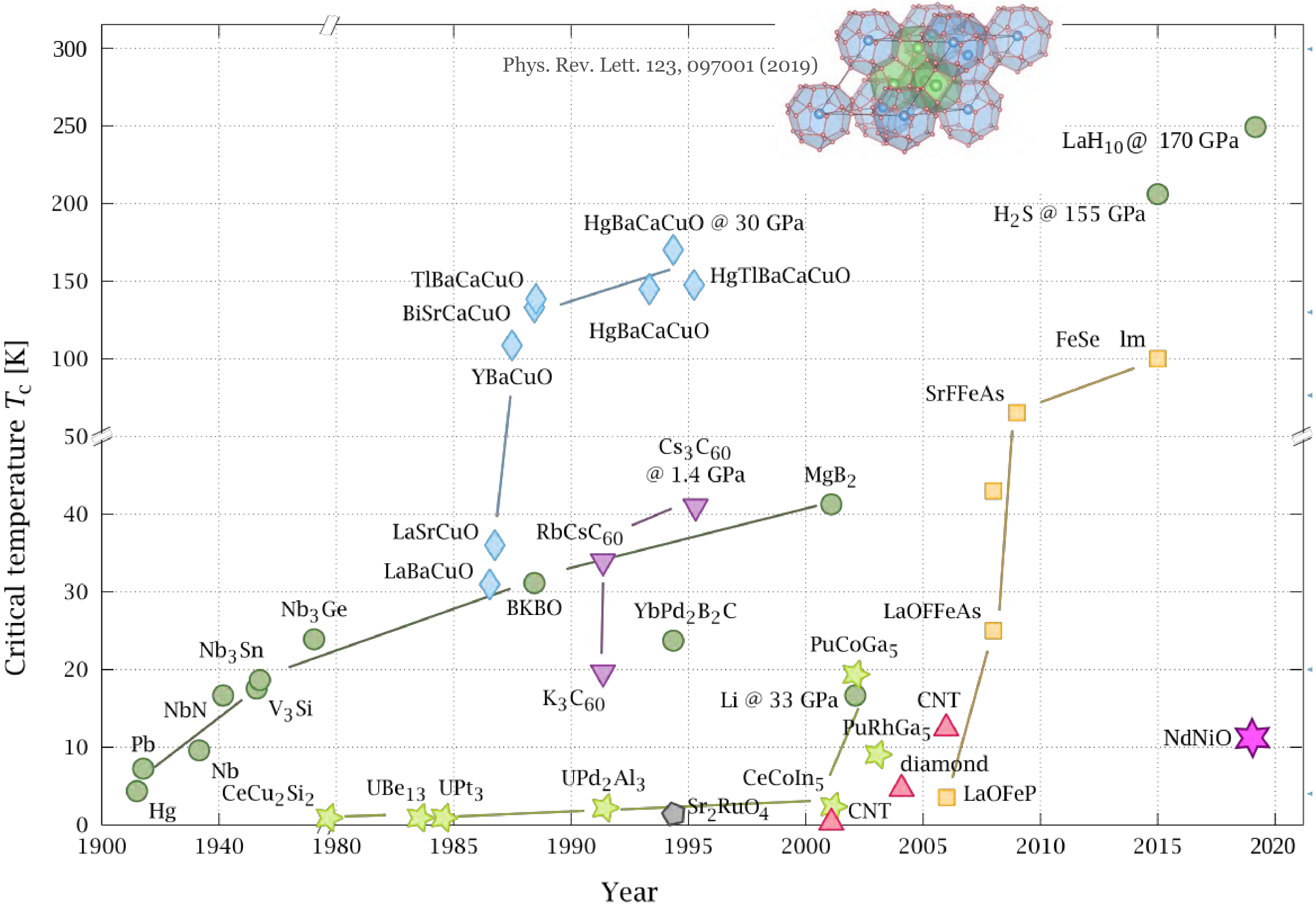
PARAGRAF

https://paragraf.com/



Produce graphene-based electronic devices (magnetic sensors) using standard semiconductor processes.

High-Temperature Superconductors



A wide range of materials, from low T_c superconductors to high T_c superconductors: **cuprates**, **iron-based superconductors**, and **hydrite superconductors**

Magnetic Levitation

Almost everything can levitate

It is possible to levitate magnetically
every material on earth.
We call them ‘diamagnetic’.

The force, called the diamagnetic force, can be strong enough to compensate the force of gravity that also acts on every single atom of the material, mimicking the absence of gravity.

Several applications

growing crystals,
body tissue without a scaffold,
cosmology…

Berry and Geim, Eur. J. Phys. 18, 307 (1997)

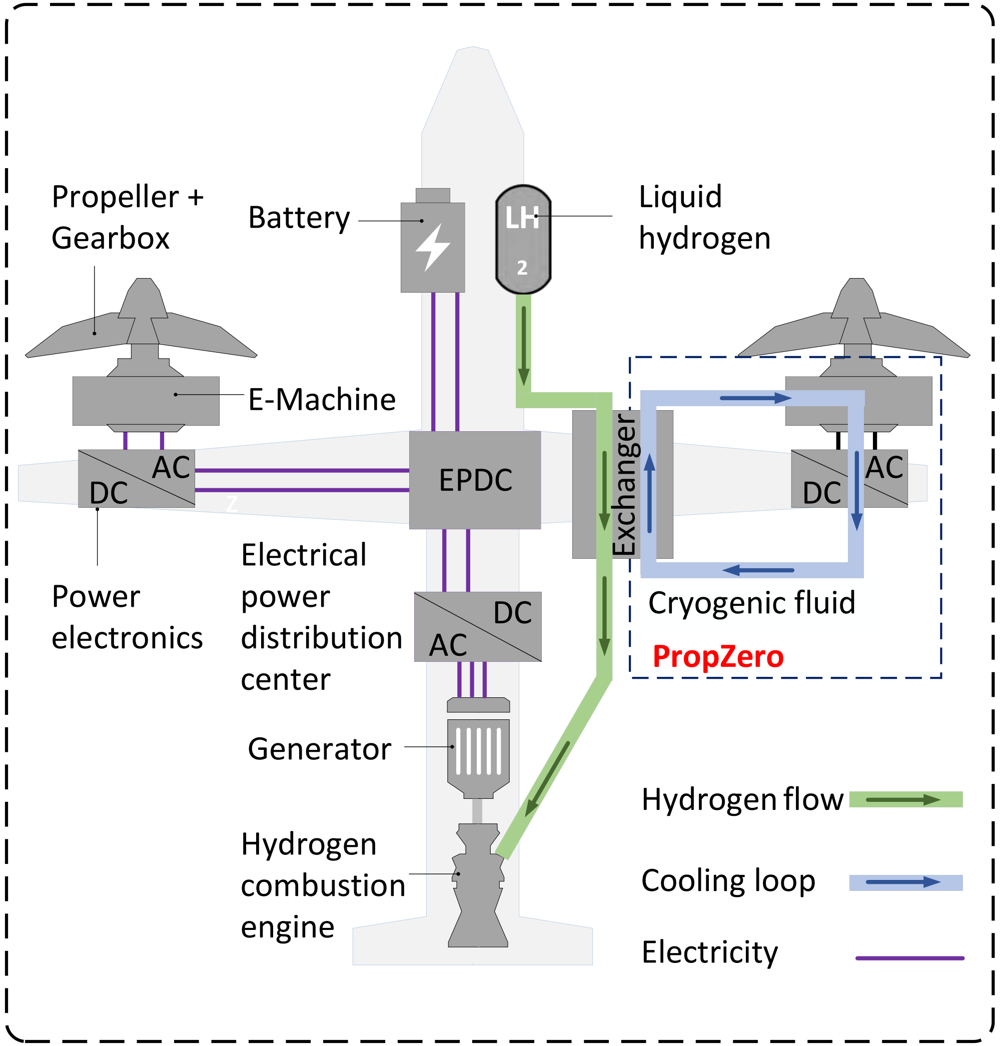
Cryogenically-cooled Electrical Propulsion System with Rotating Magnetic Field

PropZero

Cryogenically-cooled Electrical Propulsion System (EPS) for Future Hydrogen Net-Zero Aircraft is an ongoing fellowship of Dr Fengyu Zhang (Un. of Nottingham) to achieve ultra-high power density compact electric propulsion system for electrify future aircraft towards 2050 net-zero target.

New electric propulsion system topology.

Design and operate an electric power and cryogenic hydrogen system.



Find an experiment

https://emfl.eu/

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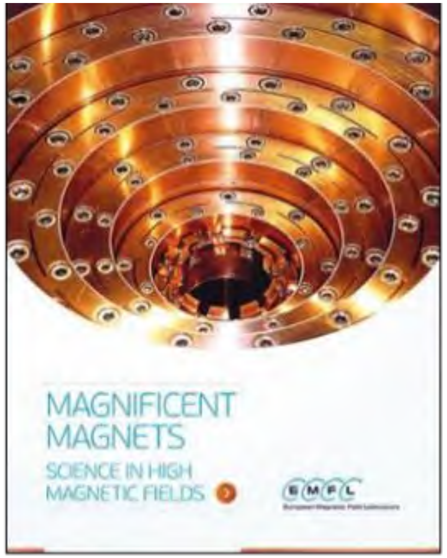
CALLS FOR PROPOSALS

DEADLINES

15th MAY AND **15th NOV**

EMFL: Dissemination



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EMFL: Annual User Meeting

User Meeting

Nijmegen, Radboud University (June 13-14 2023)

https://emfl.eu/emfl-user-meeting-2023/

2024 User Meeting
At the University of Nottingham

Thank you!

https://emfl.eu/

University of Nottingham
UK China Malaysia

Science and Technologies in High Magnetic Fields

Amalia Patanè
UK Director of the EMFL
School of Physics and Astronomy
University of Nottingham

Amalia Coldea
University of Oxford

John Burgoyne
Oxford Instruments

EMFL
European Magnetic Field Laboratory

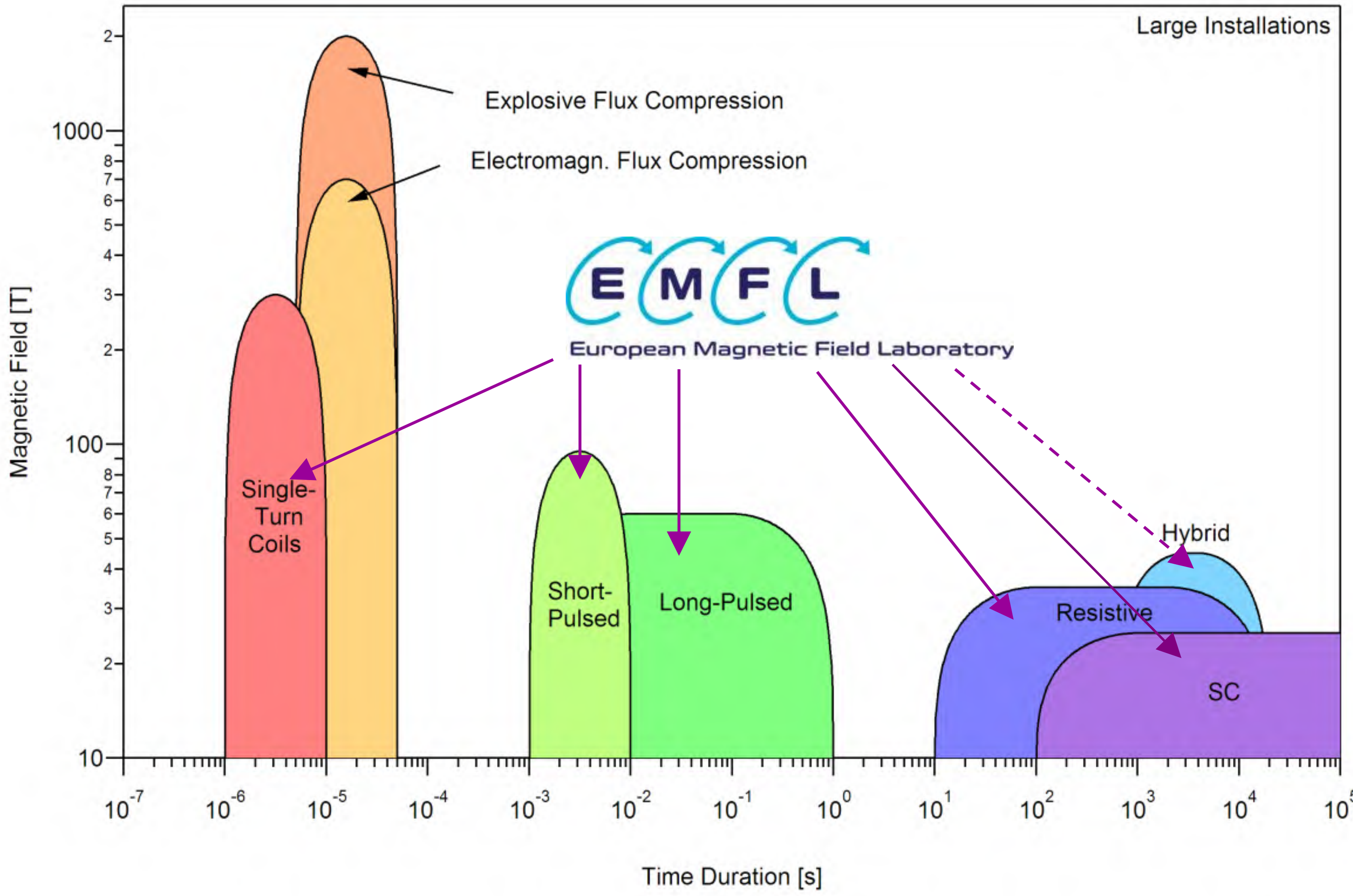
European Magnetic Field Laboratory

World class high magnetic field facility https://emfl.eu/

UK partnership funded by the UKRI for free access of facility/network activities/training **2015-2027**

After Germany and France, the UK has the largest user community (>100 users)

4 sites in the EU



European Magnetic Field Laboratory

World class high magnetic field facility https://emfl.eu/

Horizon 2020 (**2020- 2025**)
Supporting community building &
membership enlargement

*"**I**mproving the **S**ust**A**ina**B**ility of the*
***E**uropean Magnetic Field **L**aboratory"*

S A B E L I

10-11 June 2024

EMFL User Meeting

Programme

Part I: Science in high magnetic fields

09.40 - 10.00	**Prof Antony Carrington**, University of Bristol - *High-magnetic fields for fundamental Science*
10.00 - 10.20	**Dr Richard Hill**, University of Nottingham - *Diamagnetic levitation and related techniques in fluid and granular dynamics*
10.20 - 10.40	**Dr Shuqiu Wang**, University of Oxford/Bristol - *STM Visualisation of unconventional superconductors at high-magnetic fields*
10.40 - 11.10	Coffee break and poster session (Buttery)
11.10 - 11.30	**Prof Steven P. Brown**, University of Warwick, EPSRC solid-state NMR National Research Facility - *Solid-State NMR at High Magnetic Fields*
11.30 - 11.50	**Prof David Collison**, University of Manchester, EPSRC EPR National Research Facility- *Electron Paramagnetic Resonance (EPR) Spectroscopy at High-Fields and High-Frequencies*

Programme

Part I: Science in high magnetic fields

11.50 - 12.20	**Flash Talks**
12.20 - 13.00	**Discussion on Science in High Magnetic Fields**
13.00 - 14.00	Lunch and poster session (Buttery)

Slido

Q&A and polling platform
for live discussion

Programme

Part II: Technologies in high magnetic fields

14.00 - 14.20 **Dr Xavier Chaud**, European Magnetic Field Laboratory, CNRS/LNCMI - *Towards High field magnets using HTS inserts at EMFL*

14.20 - 14.40 **Dr Oleg Kirichek**, ISIS Neutron and Muon Source, Rutherford Appleton Laboratory - *High-Magnetic Field Sample Environment at ISIS Neutron and Muon Source*

14:40 - 15.00 **Prof Steven Blundell**, University of Oxford - *High-magnetic fields and muons*

15.00 - 15.30 Coffee break and poster session (Buttery)

15.30 - 15.50 **Dr John Burgoyne,** Oxford Instruments - *State of the art in commercial superconducting magnets for high field*

15.50 - 16.10 **Sir Colin John Humphreys**, Paragraf /Queen Mary University of London- *Measuring High Magnetic Fields using a Graphene Hall-effect Sensor*

16.10 - 16.30 **Dr Roland Gyuraki**, Tokamak Energy - *HTS magnet technology applications beyond fusion at Tokamak Energy*

Programme

Part II: Technologies in high magnetic fields

16.30 - 17.00	**Discussion on Technologies in High Magnetic Fields**
17.00	Closing down of the meeting

Slido

Q&A and polling platform for live discussion

Videos

What are magnetic fields:
https://alexwilkinsonmedia.post.pro/review/8100c6c0a620dcf4a1d81ff3d894d7ad/version/3

What is EMFL:
https://alexwilkinsonmedia.post.pro/review/05ec97f74b7b5a507883939d32e434d1/version/3

What research is done
https://alexwilkinsonmedia.post.pro/review/3059cdfe7f01fd873d7b95fb10479097/version/3

How to get involved
https://alexwilkinsonmedia.post.pro/review/ffaeff16d51e2049981aba6df8826e0f/version/3

Who can be involved:
https://alexwilkinsonmedia.post.pro/review/3786d6407827f7634031fe1b06efb964/version/3

Future:
https://alexwilkinsonmedia.post.pro/review/74bfe5004f14e43c27b3814cc62dc486/version/3

Posters

1.	**Ioana Paulescu** University of Oxford	*Quantum Oscillations of a candidate bulk Dirac system*
2.	**Weixin Song** University of Oxford	*Atomic-scale structure characterisation of battery materials*
3.	**James Tufnail** University of Oxford	*Understanding Irradiation Damage Mechanisms in High Temperature Superconductors for Fusion*
4.	**William Iliffe** UK Atomic Energy Agency (UKAEA)	*STEP's plan for understanding REBCO coated conductors in the Fusion Environment*
5.	**John Pearce** University of Oxford	*Torque Magnetometry in a Stripe-Ordered Triangular Antiferromagnet*
6.	**Shroya Vaidya** University of Warwick,	*Uncovering magnetic and electronic properties in two-dimensional van der Waals magnet Fe3GeTe2 using high magnetic fields*
7.	**Andrew Varney** Oxford Instruments NanoScience	*Quench modelling of high field magnets*
8.	**Petr Zagura** University of Oxford	*Ultra-low resistance joints in high temperature superconductors*
9.	**Kirk Adams** University of Oxford	*In situ measurements of REBCO coated conductor performance under ion irradiation*
10.	**Muslum Guven** University of Oxford	*Persistent MgB2 Joints for React and Wind Magnet*
11.	**Jan Plechacek** CAN Superconductors	*New Generation of HTS Bulks for High-Field Applications*
12.	**Dirk Honecker** ISIS Pulsed Neutron and Muon Source	*Investigating mesoscopic vortex matter with neutrons*

Flash Talks

1.	**Fengyu Zhang** University of Nottingham	*Advancements in Cryogenic Technologies: Harnessing Magnetic Fields for Transportation Innovation*
2.	**Jan Knapp** University of Oxford	*High Magnetic Fields for Quantum Gravity*
3.	**Nathan Cottam** University of Nottingham	*Functionalised graphene in high magnetic fields*
4.	**Yannik Dieudonne** UK Atomic Energy Agency (UKAEA)	*Ultrasonic Additive Manufacturing for REBCO Tape Assemblies*
5.	**Jeremy Good** Cryogenic Ltd.	*NMR at high field without liquid helium*

Find an experiment

https://emfl.eu/

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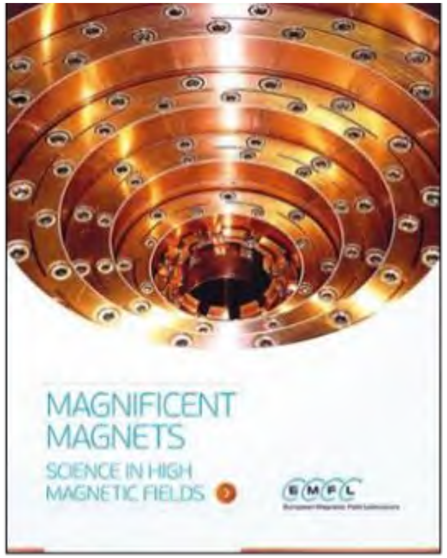

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University of Nottingham
UK China Malaysia

User Meeting of the EMFL

Amalia Patanè
UK Director of the EMFL Partnership
School of Physics and Astronomy
University of Nottingham

EMFL
European Magnetic Field Laboratory

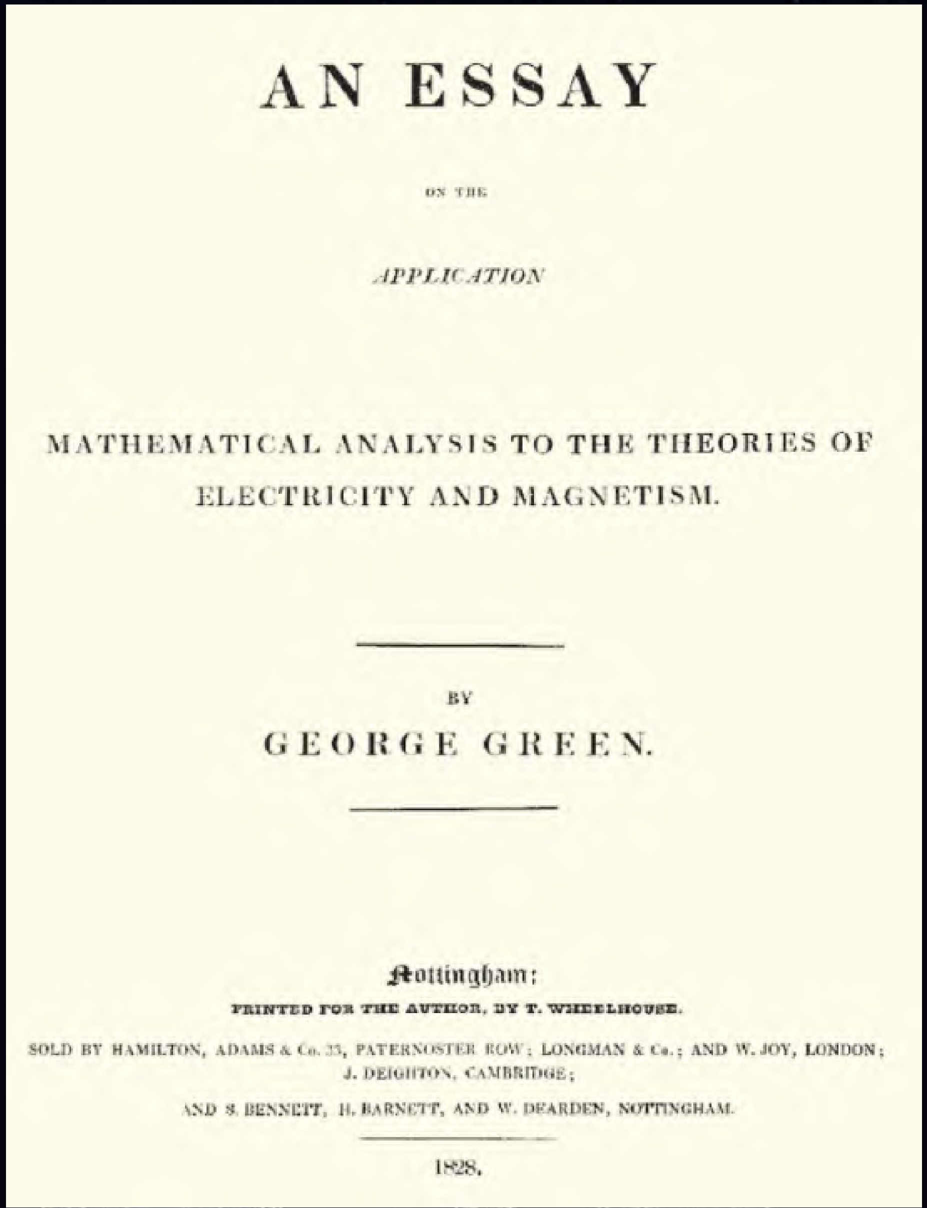
UKRI

SABLEMI

University of Nottingham

UK China Malaysia

George Green 1793-1841



AN ESSAY

ON THE

APPLICATION

OF

MATHEMATICAL ANALYSIS TO THE THEORIES OF ELECTRICITY AND MAGNETISM.

BY

GEORGE GREEN.

Nottingham:

PRINTED FOR THE AUTHOR, BY T. WHEELHOUSE.

SOLD BY HAMILTON, ADAMS & Co. 33, PATERNOSTER ROW; LONGMAN & Co.; AND W. JOY, LONDON; J. DEIGHTON, CAMBRIDGE;

AND S. BENNETT, H. BARNETT, AND W. DEARDEN, NOTTINGHAM.

1828.

1828 Essay on the **mathematical theory of electricity and magnetism**

The essay introduced the idea of potential and the **Green function** and **Green theorem**.

$$L \circ u(x) = f(x)$$

$$L \circ G(x,s) = \delta(x-s)$$

$$u(x) = \int G(x,s) f(s) ds$$

University of Nottingham
UK China Malaysia

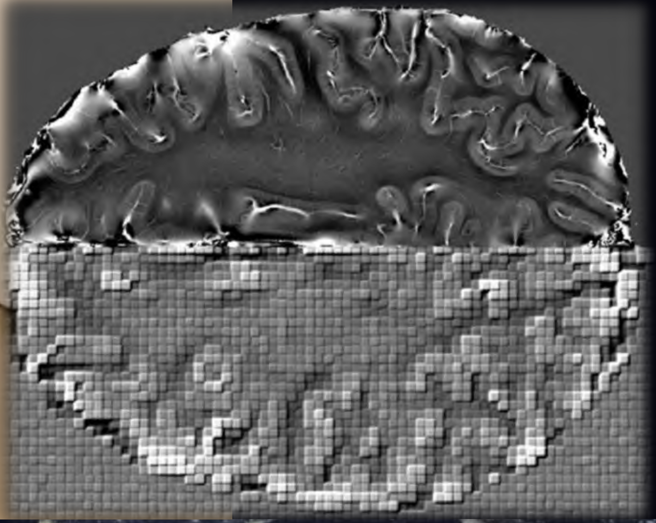
Sir Peter Mansfield 1933-2017

2003 Nobel Prize for **Magnetic Resonance Imaging**

Sir Peter Mansfield
Magnetic Imaging Centre

Focussed on magnetic resonance techniques

UK's most powerful MRI scanner
11.7 T and 83-cm bore
to be established in 2025



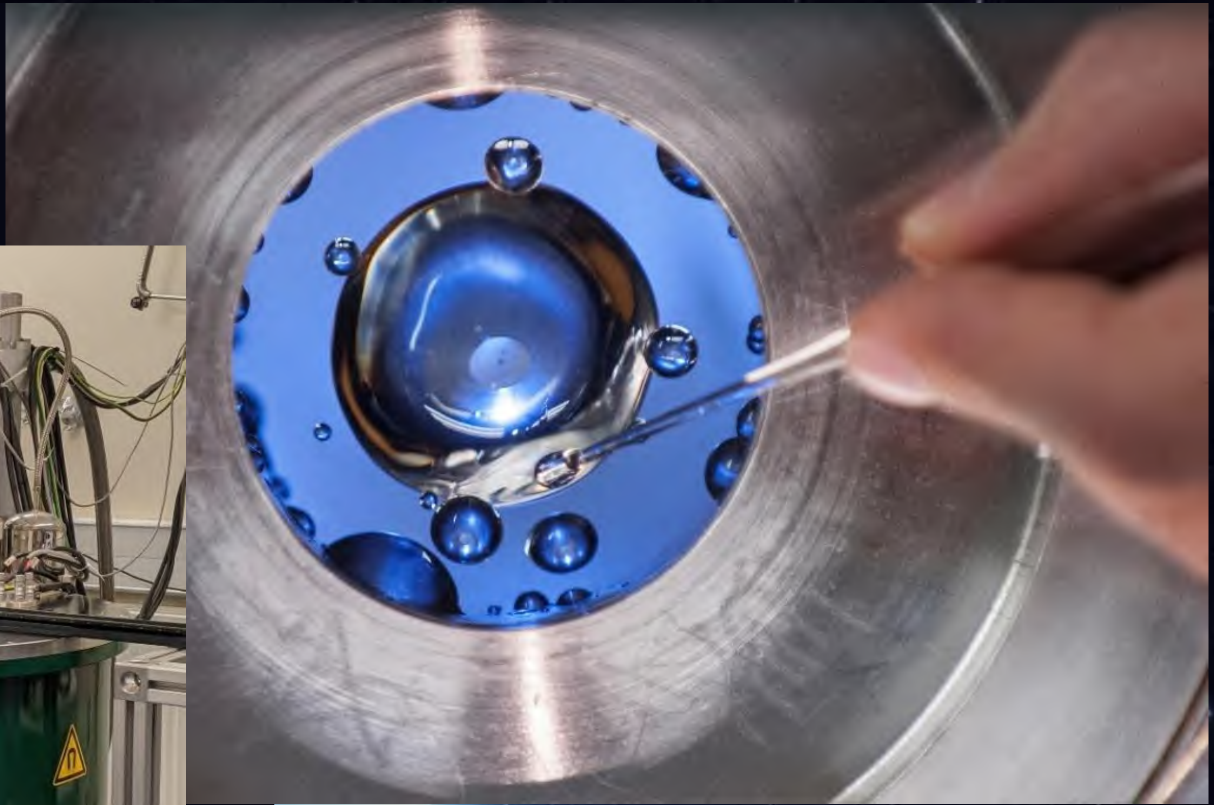
Nottingham Maglev Lab

University of Nottingham
UK China Malaysia

- **18.3 T** magnet, 60 mm room temperature bore

- Custom-built for experiments using diamagnetic levitation

Research areas :
- fluid physics
- granular physics
- biological responses to microgravity
- solid state physics



Contact: Richard.Hill@nottingham.ac.uk

EMFL and Partnerships

University of Nottingham
UK China Malaysia

ISABEL 2020-25

"Improving the SustAinaBility of the European Magnetic Field Laboratory"

Dual Access Scheme

lowering the barrier to EMFL access for users who do not have access to magnets.

Financial support for experiments at regional partners: Warsaw, Madrid, Prague, Oxford, Lecce, Tallinn, Nottingham

EMFL and Partnerships

ISABEL 2020-25

"Improving the SustAinaBility of the European Magnetic Field Laboratory"

Funded initiatives

Secondments
Workshops
Schools
Technical developments

Programme

Part I

10:10	10:30	***Introduction to the EMFL*** Charles Simon, EMFL-CNRS, France
10:30	11:00	***EMFL Prize and Lecture*** Jochen Wosnitza, EMFL-HLD, Germany

Part II

11:00	11:20	***Magneto-hydrodynamics in stars*** Susanne Horn, Coventry, UK
11:20	11:40	***Quantum nature of charge transport in inkjet-printed graphene….*** Oleg Makarovskiy, Un. of Nottingham, UK
11:40	12:00	***Distinct switching of chiral transport in kagome metals*** Chunyu Guo, Max Planck Inst. for the Structure & Dynamics of Matter, Germany
12:00	12:20	***Optical spectroscopy of new two-dimensional materials - experimental opportunities at the University of Warsaw*** Adam Babinski, Un. of Warsaw, Poland

12:20	**14:00**	**Buffet lunch and Poster session**	**B23**

University of Nottingham
UK China Malaysia

EMFL and Partnerships

UK Partnership 2015-27

Free
Access Scheme
for the UK community
by 5-year subscription

Funded initiatives
Secondments
Workshops
Schools
Technical developments

Programme

Part III

13:20	14:00	***User Committee and Survey*** Raivo Stern, Nat. Inst. of Chem. Physics & Biophysics, Estonia
14:00	14:20	***Feedback session with Directors of the EMFL*** Raivo Stern, Nat. Inst. of Chem. Physics & Biophysics, Estonia

Part IV

14:20	14:40	***Evidence for spin-mediated superconductivity in n-doped cuprates*** Caitlin Duffy, LNCMI Toulouse, France	
14:40	15:00	***Unconventional Supercondutivity in UTe2 in extreme conditions*** Georg Knebel, CEA Grenoble, France	
15:00	15:20	***Studies of hydride superconductors in pulsed magnetic fields up to 80 T using special high-pressure DACs*** Dmitrii Semenok, HPSTAR, Beijing, China	
15:20	15:40	***Superconductivity: enabling transformative technologies*** Antony Carrington, Un. of Bristol	
15:40	**16:10**	**Coffee Break and Poster session**	**B23**

Programme

Part V

16:10	16:30	***Magnetic field technologies*** John Burgoyne, Oxford Instruments plc
16:30	16:50	***Magnetic field technologies*** M'hamed Lakrimi, Siemens Magnet Technology
16:50	17:00	***Final remarks on funding opportunities and closure*** Amalia Patanè, Un. of Nottingham

Find an experiment

https://emfl.eu/

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CALLS FOR PROPOSALS

DEADLINES

15th MAY AND **15th NOV**

Novel access modes

https://emfl.eu/

“Improving the SustAinaBility of the European Magnetic Field Laboratory”
2020-25

DUAL ACCESS MODE

FIRST-TIME ACCESS MODE

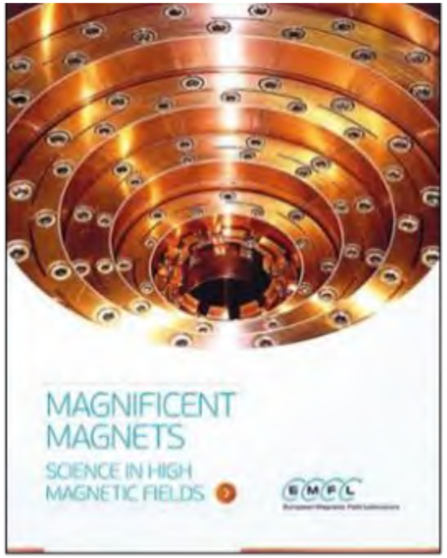
LONG-TERM ACCESS MODE

TECHNICAL DEVELOPMENT ACCESS

FAST-TRACK ACCESS MODE

INDUSTRIAL ACCESS MODE

Information about the EMFL



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User Community and Feedback

Online User Feedback

If you are a user of the EMFL, we invite you to send your feedback on your experience during your last visit at one of the facilities of the EMFL to the User Committee.

An online user feedback form is available at

https://emfl-users.lncmi.cnrs.fr/SelCom/UserCommittee/feedbackform.php

User Committee

You may also want to contact directly the User Committee via e-mail at

UserCommittee@gmail.com

EMFL
European Magnetic Field Laboratory

Introduction to the user meeting

Charles Simon, Chair of the board of directors of EMFL

EMFL User meeting

June 11th, 2024

EMFL

- The goal of EMFL is to provide access to high magnetic field facilities to researchers
- Four sites : three laboratories (Dresden, Nijmegen, Toulouse and Grenoble
- Members (UK, Italy, Poland)

European Magnetic Field Laboratory

EMFL organisation

- Council

Prof. José M. Sanders (RU/NWO)
Dr. Sylvain Ravy (CNRS)
Prof. Sebastian M. Schmidt (HZDR) President of the EMFL Council
Prof. Amalia Patanè (University of Nottingham)
Prof. Adam Babiński (University of Warsaw)
Dr. Pierre Védrine (CEA-IRFU)
Prof. Giuseppe Maruccio (University of Salento).

- Board of Directors

Dr. Charles Simon (LNCMI, Chair)
Prof. Jochen Wosnitza (HLD)
Prof. Britta Redlich (HFML)

- Executive Manager Prof. Peter C.M. Christianen

European Magnetic Field Laboratory

Summary of the use of EMFL in 2020-2023

	2020	2021	2022	2023
Executed proposals	185	194	189	152
Requested proposals	273	323	301	267

User meeting and EMFL price 2023

WORKSHOP “COMBINATION OF HIGH MAGNETIC FIELDS AND FREE ELECTRON LASERS”

Nijmegen, June 2023

Jake Ayres, Bristol, UK

Scientific Highlights

Please visit our web site and the scientific highlights

https://emfl.eu/

European Magnetic Field Laboratory

Infrastructure developments

- Grenoble : 225kV power supply up to 30MW (previously 24MW)

September 2023 to February 2024

European Magnetic Field Laboratory

Upalim in Grenoble

- November 2023 : deconnexion of existing power supply (24MW) (36T resistive magnet in 34 mm)
- February 2024 : end of the tests of the new 32MW power supply (40 T resistive magnet in 34mm)
- In parallel, save electricity power with eco mode (intermediate fields), shorter measurements, etc…
- **New proposals in 2025 for larger fields in Grenoble (resistive and hybrid)**

Hybrids magnets in Nijmegen and Grenoble

- Under commissionning
- Next year for proposals

Infrastructure developments

Pulsed fields at lasers, neutrons and x-ray sources

- LNCMI/CNRS Toulouse

Running magnet in ILL (new capacitor bank and new magnet in 2023)

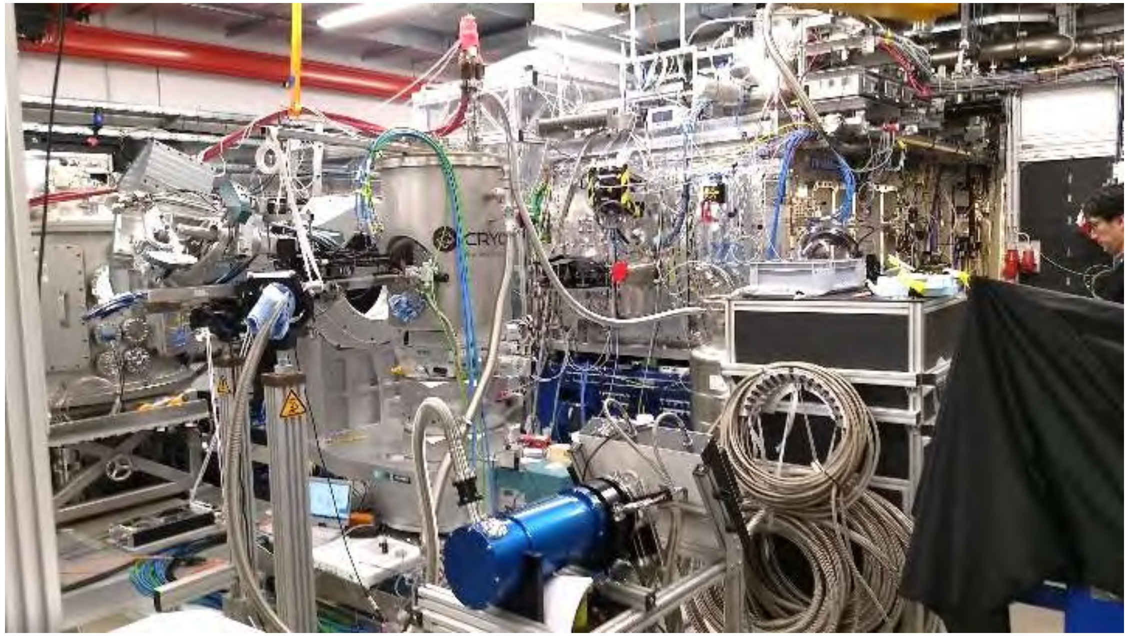
Running Magnet in ESRF

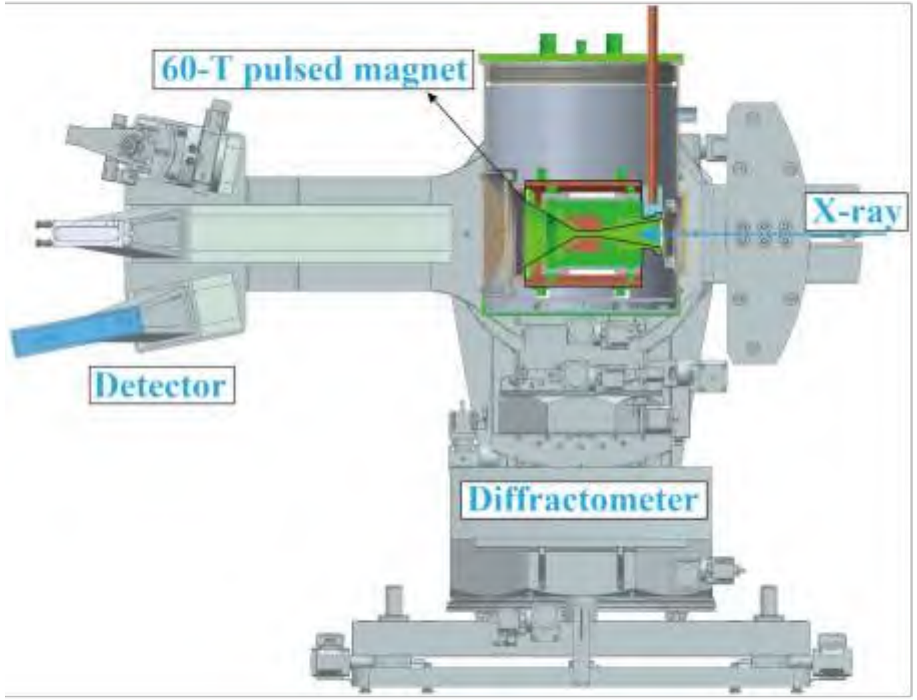
Running Magnet in LULI (Fr), EU XFEL (G), RAL (UK), OMEGA, NIF (USA)

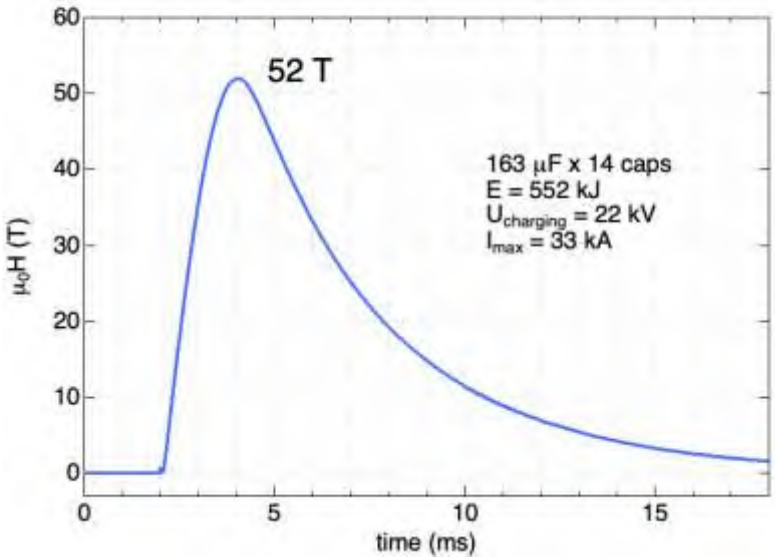
Infrastructure developments

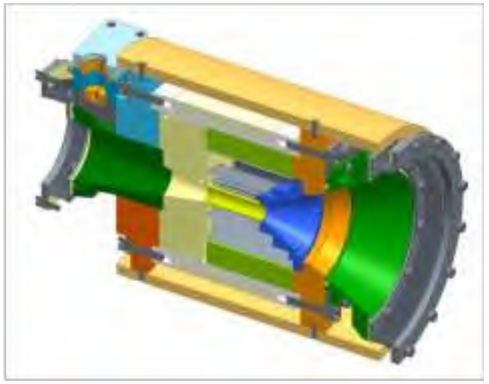
Pulsed fields at x-ray sources

- HIBEF at Eu XFEL
  Commissioning 02/2024
- PUMA at ESRF
  Construction started









European Magnetic Field Laboratory

European Magnetic Field Laboratory

Strategic Developments

EMFL Strategic goals

- Strengthening the socio-economic impact of the EMFL
- Scientific excellence for the in-house and user research programs in a maximum number of research areas
- Stakeholder support and membership expansion
- Improving the high-field infrastructure and instrumentation, incl. superconducting magnet technology and the combination with other large scale research infrastructures
- Prepare response to the energy crisis and CO_2 issues.
- Improve communication and outreach to enhance the awareness among scientists and the general public on the excellent science, technology, and education done at the EMFL facilities

European Magnetic Field Laboratory

EMFL Highlights

- ESFRI Landmark
- Three European programmes and two projects
  - ISABEL (to strengthen the EMFL, new types of call : fast track, new users, …) end 10/2025
  - SuperEMFL (superconducting 40T magnet, design study) end 2024
  - FlexRICAN (flexibility to reduce environmental impact) end 2027 5M€ ESS (+ELI)

EU projects ISABEL& SuperEMFL

Improving the Sustainability of the European Magnet Field Laboratory
2020-2023, 18 partners, of which 5 industrial, budget 4,9 M€, started 1 November 2020, end October 2025

- Strengthen the EMFL structure
- Strengthening role high magnetic field research in Europe and Europe's global position in this area
- Strengthening the socio-economic impact of the EMFL

SuperEMFL

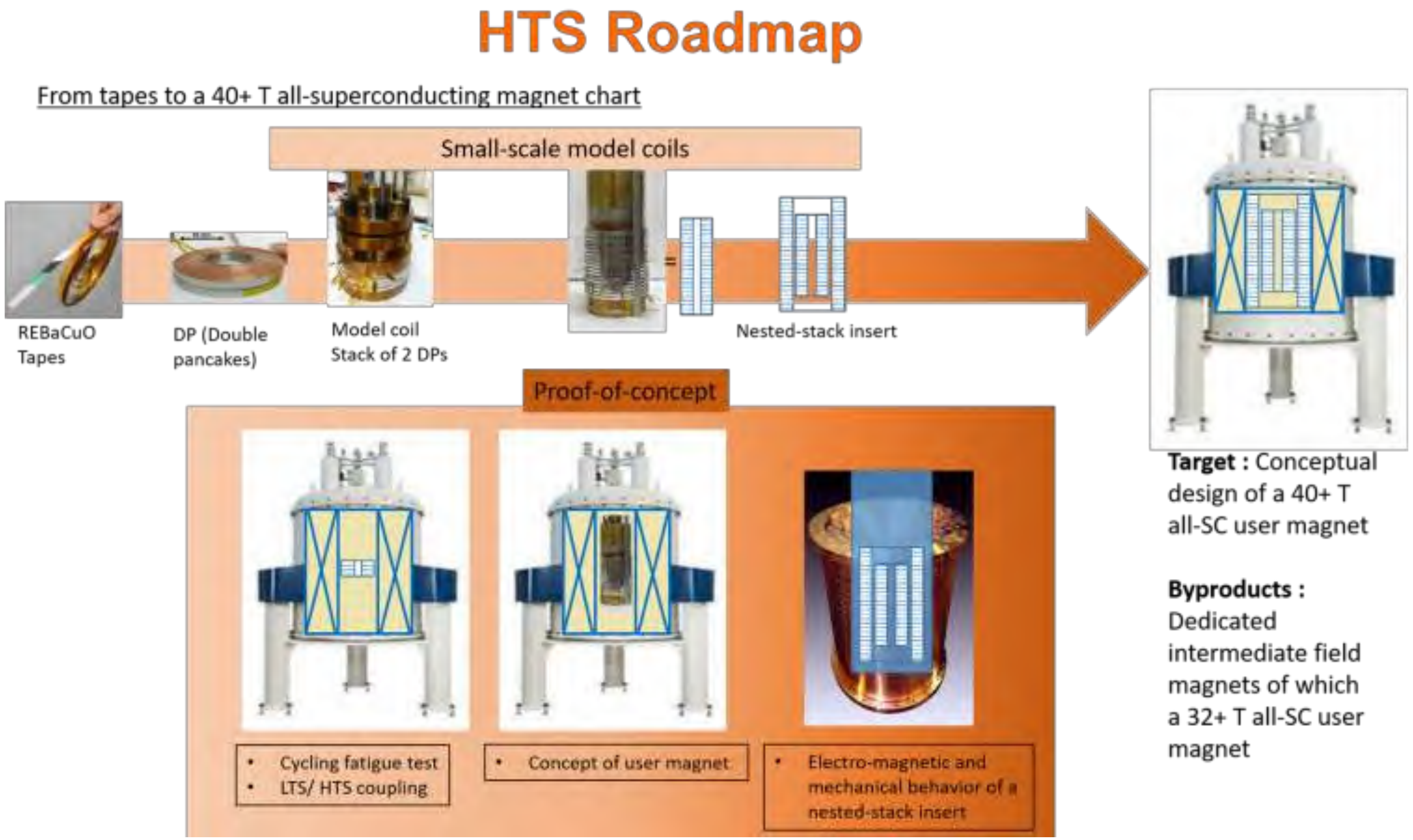
2021-2024, 11 partners, of which 3 industrial, budget 2,9 M€, started January 2021, end December 2024

Design study all-SC magnets for the European Magnet Field Laboratory

32 T & 40 T all-SC user magnets

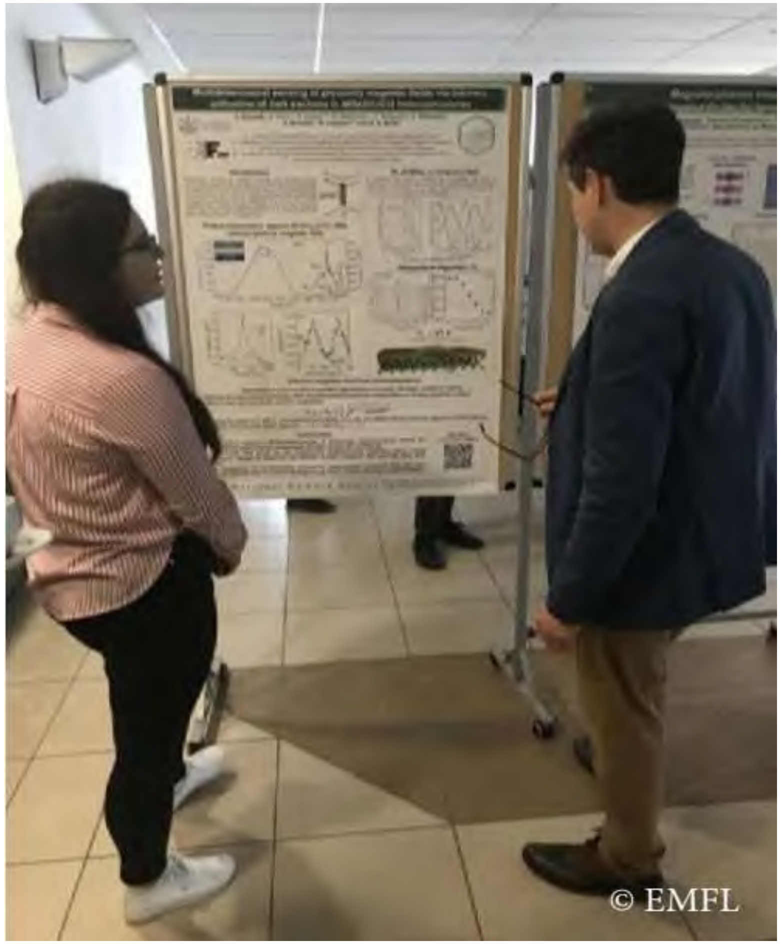
European Magnetic Field Laboratory

Update SuperEMFL



- Choice of the TEVA tape
- Design study to be validated
- Test of prototypes to be done

Regional meetings in Wroclaw May 2023 and Prague September 2023



European Magnetic Field Laboratory

Regional meeting Basel September 2023 (Swiss, Austria, Slovenia and Croatia)

European Magnetic Field Laboratory

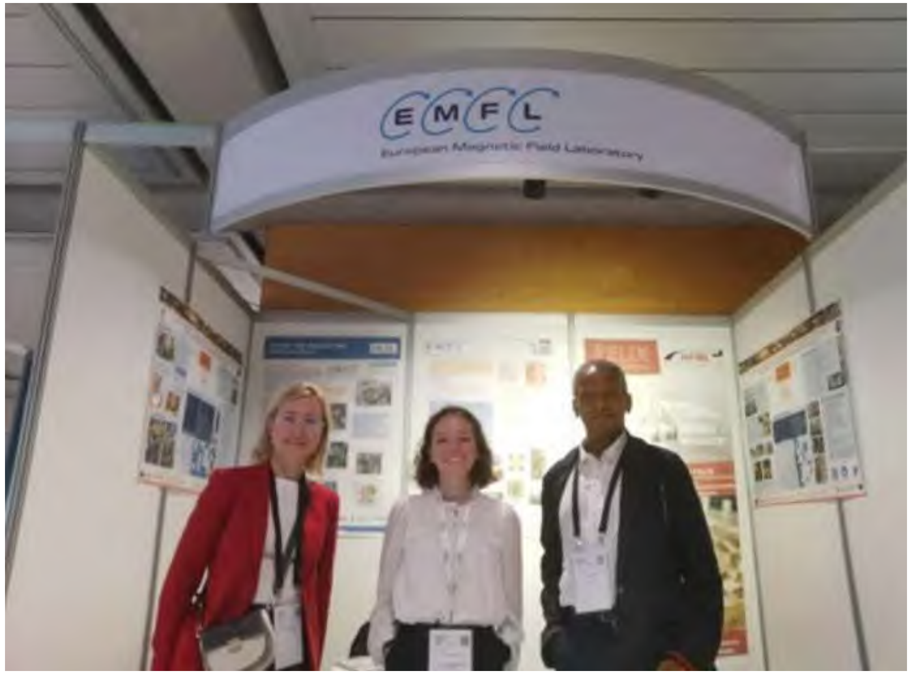
FRONTIERS OF SYNCHROTRON AND XFEL RESEARCH AT HIGH MAGNETIC FIELDS

DRESDEN, October 2023

EMFL
European Magnetic Field Laboratory

Industrial partner club

EMFL participation to industrial exhibitions



Lyon, Hanover, Paris, Düsseldorf, Granada

European Magnetic Field Laboratory

ISABEL developments

Development of new access modes

- Dual access (since call in May 2021)
- Long-term access
- Industrial access
- First time access

User Survey executed

Secondments

- Call every 6 months since 2021

Innovation

- Industrial Liaison officer
- IPR & Technology transfer training for EMFL employees
- Innovation call/deadline

Magnet technology

- Goal: Magnet technology Roadmap
- User Survey in preparation
- Material developments
- New design tools
- Sustainability (energy efficiency, recycling)

Strategical External connections

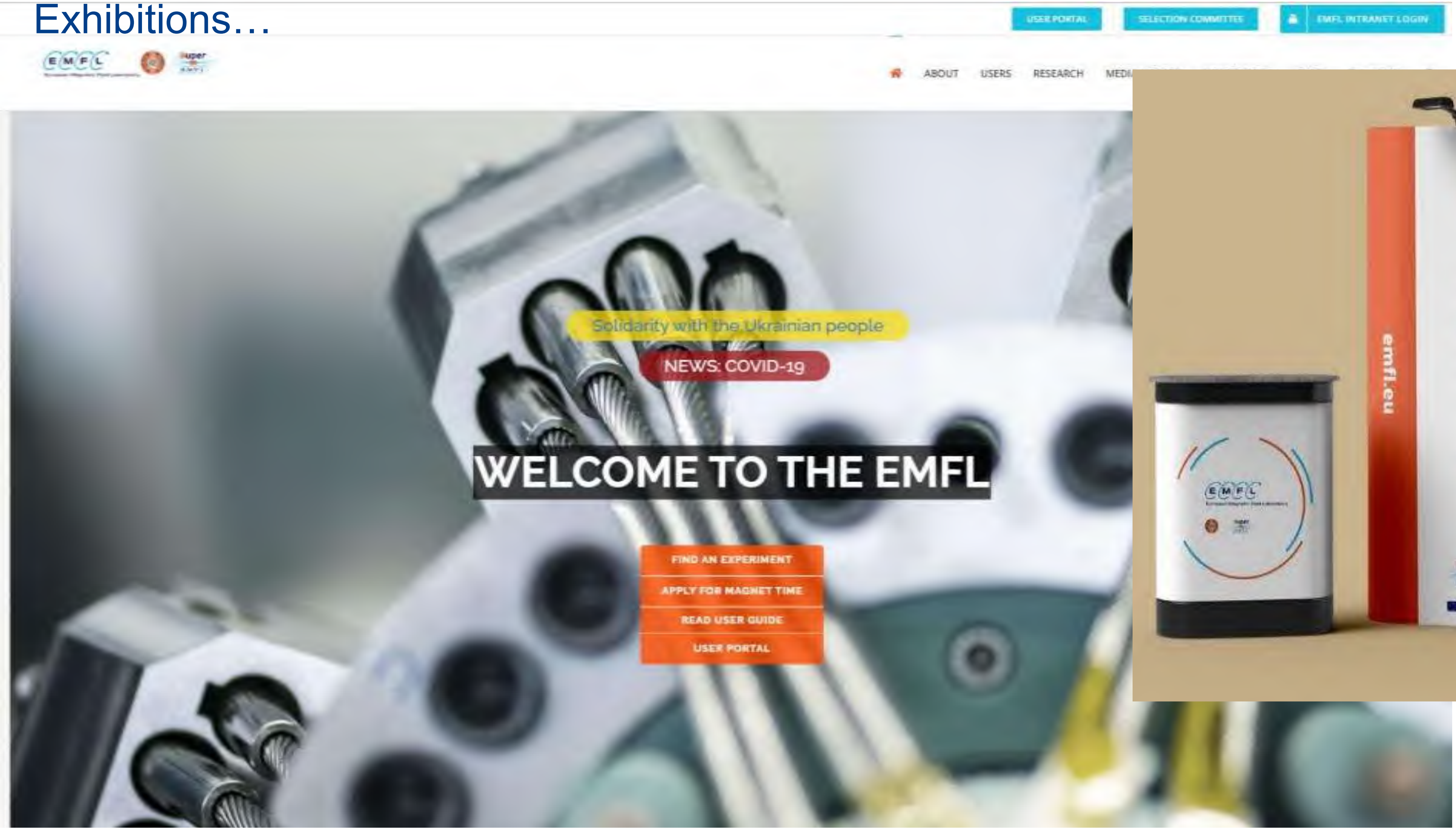
- HiFF
- Other European Large Scale Infrastructures
- CERN: Magnets for Accelerators & Muon Colliders
- FuSuMaTech: Shaping the Future of Superconductive Magnets
- European MRI community

European Magnetic Field Laboratory

JOINS US !

Communication

Renewed website, virtual tour, LinkedIn, Twitter, Folders, Flyers, Exhibitions…



EMFL
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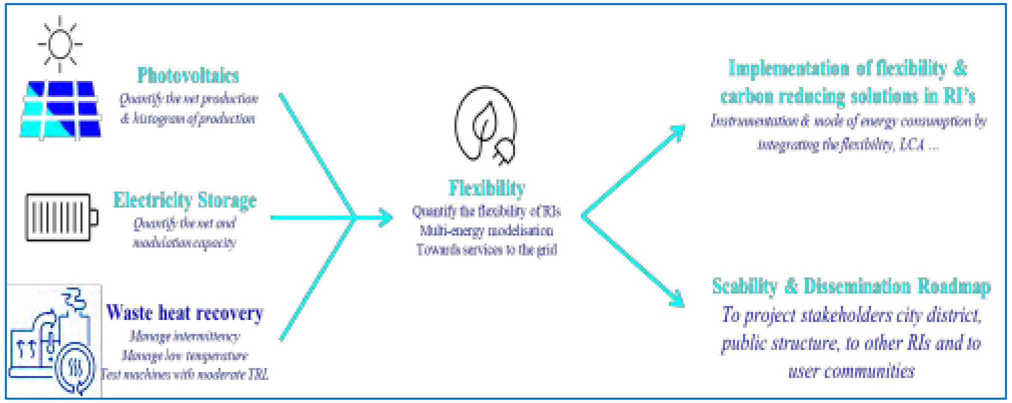
FLEXibility in Research Infrastructures: Towards Carbon Neutral (FLEXRICAN)

INFRATECH

Reducing the environmental footprint of research infrastructures

Proposal Accepted in 2023 for a 3 year project (2024-2026)
- **3 RI :** The European Spallation Source (**ESS**) (coordinator), **EMFL** & The Extreme Light Infrastructure (**ELI**)
- **2 industrial partners** : Energy Pool and Alfa Laval

FlexRICAN concept : from intermittency to flexibility & services to networks



➔ Increase the long-term sustainability of European Research Infrastructures,
➔ Contribute to the resilience of the energetical European system.

European Magnetic Field Laboratory

- Thank you

European Magnetic Field Laboratory

ISABEL
Improving the sustainability of the EMFL

Follow us

SCAN ME

SCIENCE IN HIGH MAGNETIC FIELDS

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

EMFL HIGHLIGHTS

- **up to 38 T** continuous fields with resistive magnets
- **up to 100 T** pulsed fields
- **up to 209 T** semi-destructive pulsed fields (MEGAGAUSS)
- **up to 32.5 T** with a high-temperature superconducting magnet

APPLY FOR MAGNET TIME

- 2 calls for proposals per year:
  deadlines May 15th & November 15th
- Selection Committee judges the proposed experiments on scientific excellence
- Categories: correlated electrons, magnetism, semiconductors, applied superconductivity, magnetoscience & soft matter

NOVEL ACCES MODES

- **Dual** for initial intermediate field experiments
- **First-time** for first time users
- **Fast-track** for urgent projects
- **Long-term** for long-term projects
- **Industrial** for industrial projects
- **Technical** for technical development projects

DUAL ACCES MODE

The Dual Access Scheme lowers the barrier to access EMFL for users who do not have inhouse access to magnets.

1st step : measure at a regional partner facility (intermediate field)

2nd step : Measure at an EMFL facility (high magnetic field)

Regional partners:
University of Salento
University of Warsaw
University of Nottingham
University of Oxford
Charles University
NICPB Tallinn
University of Geneva
University Autonoma Madrid

THE HIGH FIELD FACILITIES IN EUROPE

- **HFML (Nijmegen, NL)**
  High Field Magnet Laboratory
- **HLD (Dresden, DE)**
  Hochfeld-Magnetlabor Dresden
- **LNCMI - Grenoble (FR)**
- **LNCMI -Toulouse (FR)**
  Laboratoire National des Champs Magnétiques Intenses

EXPERIMENTAL TECHNIQUES

- MAGNETIZATION & MAGNETIC TORQUE
- MAGNETO-TRANSPORT
- CONTACTLESS RESISTIVITY
- ULTRASOUND VELOCITY & THERMOELECTRICITY
- PHOTOLUMINESCENCE & RAMAN
- VIS-IR-THZ SPECTROSCOPY
- POLARIMETRY
- EPR & NMR
- X-RAY AND NEUTRON SCATTERING
- MAGNETIC MODELLING
- VERY LOW TEMPERATURE (mK)
- HIGH PRESSURE (GPa)

ITALIAN NODE: UNIVERSITY OF SALENTO

The **EMFL/Isabel Italian node** is located **in Lecce** at University of Salento which represents a national network of research laboratories active on magnetism and superconductivity and operates in synergy with **AIMagn** (Associazione Italiana di Magnetismo), a scientific organization which joins together Italian researchers working in the field. Thanks to (NextGenerationEU) PNNR funds within the **Italian Infrastructure for Innovative Research on Applied Superconductivity** (IRIS, Prot. IR0000003), the node is renovating its labs and expanding the set of available instrumentation and experimental techniques:

- Magnetic Fields up to 10 T
  & Vector magnetic fields 6T, 1T, 1T
- Temperature ranges from 10 mK to 400 K
- Electrical measurements from DC to 67 GHz
- Experimental techniques: magneto-transport, magnetization, FMR, MFM/PFM, magneto-optical measurements
- Sample preparation facilities: sputtering and PLD/PED deposition

Contact : info@emfl.eu
More details: www.emfl.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

EMFL
European Magnetic Field Laboratory

Global High Magnetic Field Forum

Status EMFL

Britta Redlich, Charles Simon, Jochen Wosnitza

Global HiFF meeting Nijmegen
July 7, 2024

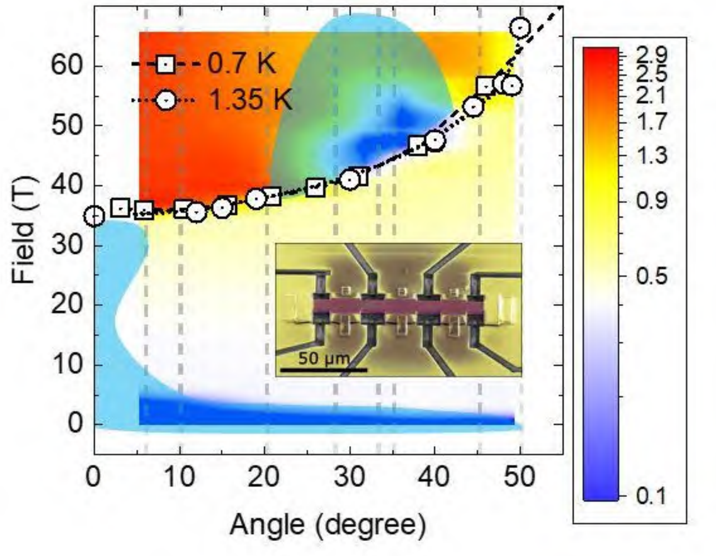
User operation
Infrastructure developments
Strategic developments

User operation

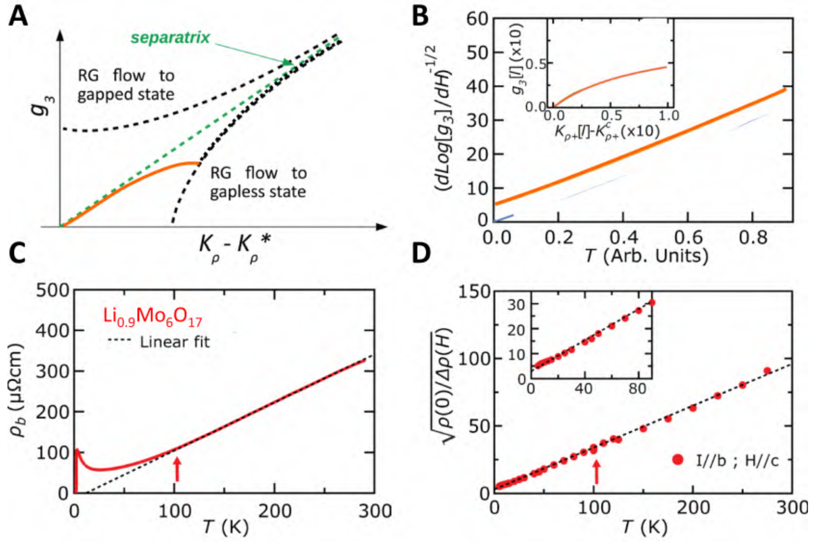
Facilities have resumed “regular” operation

Still no proposals for users with Russion and Belarus affiliation

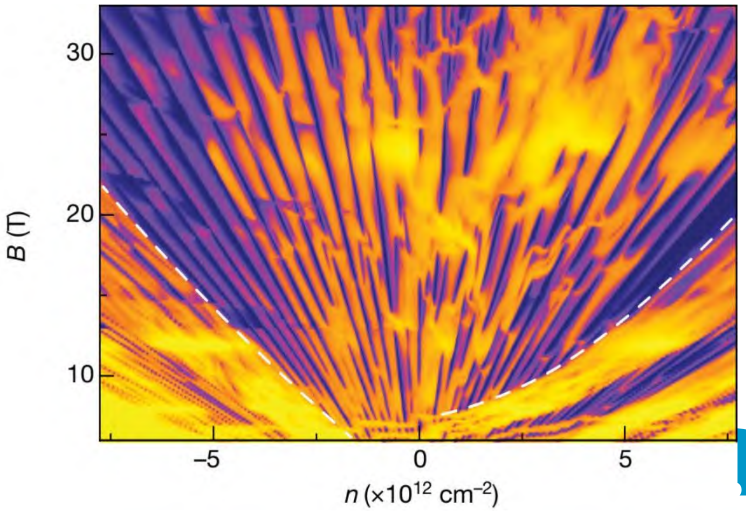
	2019	2020	2021	2022	2023
Proposals received	362	279	287	298	268
Proposals executed total	210	185	194	189	152
PhD theses defended	8	7	9	7	13



T. Helm et al., Nat. Commun. **15**, 37 (2024)



P. Chudzinski et al., Science **382**, 792 (2023)



C. Mullan et al., Nature **620**, 756 (2023)

Infrastructure developments

EMFL-G: • Final tests of hybrid magnet in Grenoble
• 225 kV power supply up to 30 MW (previously 24 MW)

EMFL-N: • First tests of hybrid in Nijmegen

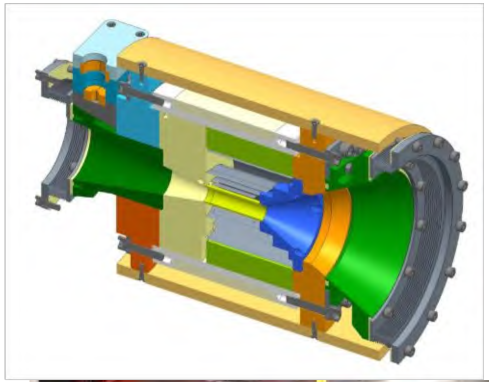
Sep 2023 – Feb 2024

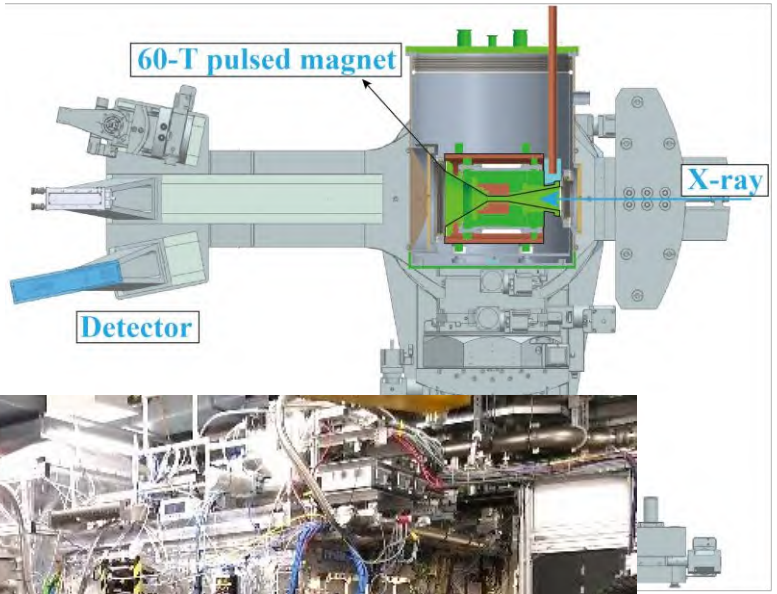
43 T hybrid

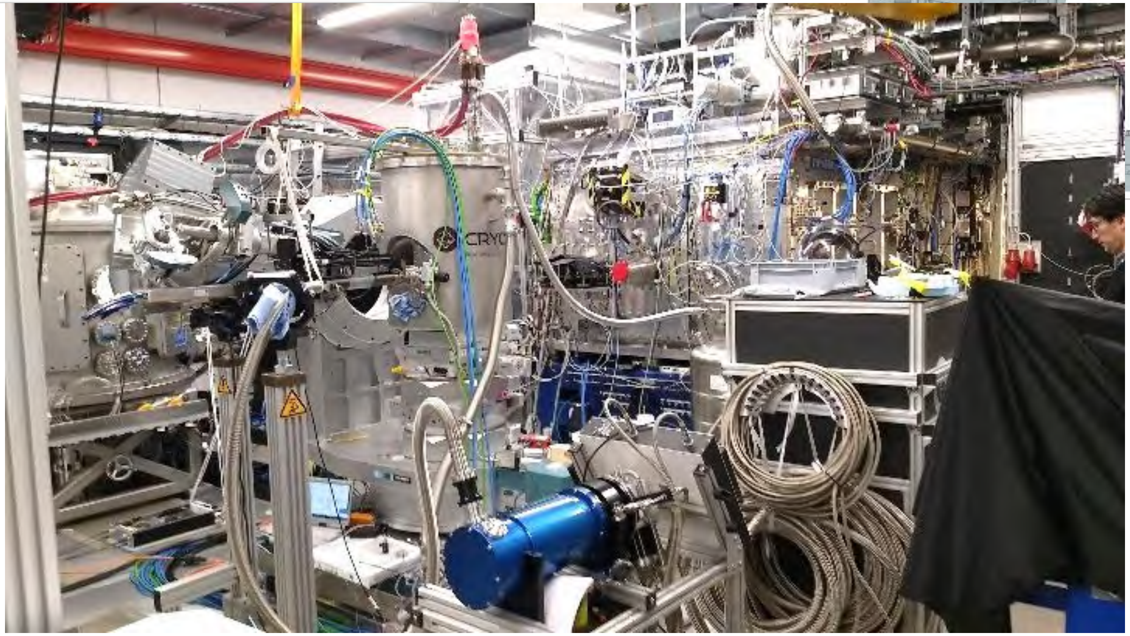
Infrastructure developments

Pulsed magnetic fields at external large-scale infrastructures

EMFL-D: HIBEF at Eu XFEL; PUMA at ESRF







EMFL-T:
Running magnets at
- ILL
- ESRF
- LULI, ...

European Magnetic Field Laboratory

Strategic developments

- Italy new member of EMFL since 2024
- Workshops, trainings

Regional partners

UK
University of Nottingham (R. Hill/A. Patanè)
University of Oxford (A. Coldea/S. Blundell)

Poland
University of Warsaw (A. Babinski)

Spain
UAM Madrid (H. Suderow)

Estonia
NICPB, National Institute of Chemical Physics and Biophysics (R. Stern and T. Rõõm)

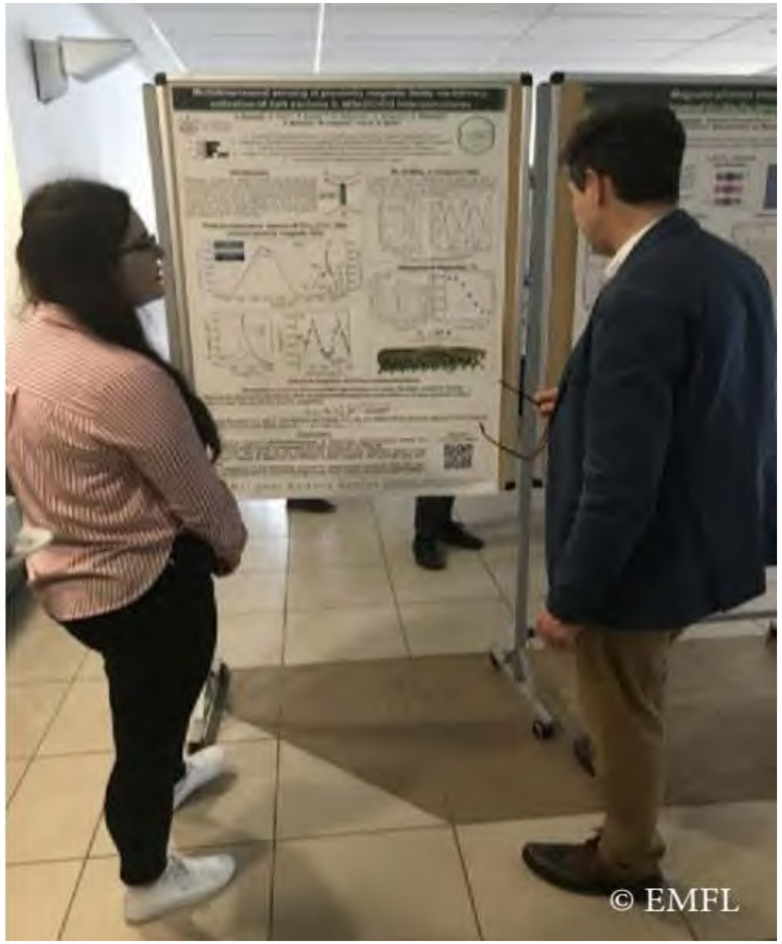
Czech Republic
Charles University (P. Javorsky)

Italy
University of Salento (G. Maruccio)

Switzerland
University of Geneva (S. Gariglio/C. Senatore)

European Magnetic Field Laboratory

Strategic developments: workshops



Wroclaw, May 2023

Prague, Sep 2023

Basel, Sep 2023

European Magnetic Field Laboratory

Strategic developments: workshops

FRONTIERS OF SYNCHROTRON AND
XFEL RESEARCH AT HIGH MAGNETIC FIELDS

Dresden, Oct 2023

Virtual tours (see websites):

European Magnetic Field Laboratory

EU projects ISABEL & SuperEMFL

Improving the Sustainability of the European Magnet Field Laboratory
2020-2025, 18 partners, of which 5 industrial, budget 4,9 M€, started 1 November 2020

- Strengthen the EMFL structure
- Strengthening role high magnetic field research in Europe
- Strengthening the socio-economic impact of the EMFL

SuperEMFL

2021-2024, 11 partners, of which 3 industrial, budget 2,9 M€, started January 2021

Design study all-SC magnets for the European Magnet Field Laboratory

32 T & 40 T all-SC user magnet concepts

New access modes

- Dual access
- Long-term access
- Industrial access
- First-time access
- Fast-track access

Thanks for your attention

European Magnetic Field Laboratory

EMFL

European Magnetic Field Laboratory

High Magnetic Field Research in the UK

European Magnetic Field Laboratory

Professor Amalia Patanè
Member of the EMFL Council
School of Physics and Astronomy
University of Nottingham, UK

High Magnetic Field Research in the UK

Academia
Coventry University
Durham University
Imperial College London
ISIS, Rutherford Appleton Lab
Keele University
Royal Holloway London
University of Bath
University of Bristol
University of Cambridge
University College London
University of Edinburgh
University of Exeter
University of Liverpool
University of Manchester
University of Nottingham
University of Oxford
University of Strathclyde
University of Surrey
University of Warwick

Industry
AstraZeneca, Cryogenic Limited, Oxford Instruments, Paragraf Limited, Siemens Magnet Technology, Hitachi, Toshiba, Tokomak Energy

Large community working on
strongly correlated metals,
superconductors,
molecular magnets,
quantum materials,
semiconductors,
graphene and 2D materials,
pharmaceutical compounds,
geophysics,
metallurgical processes...

Wide range of techniques
High spatial and energy resolution
Wide T-range down to the mK
High-pressure
Large instruments: neutron sources, synchrotrons, etc.

High Magnetic Field Research in the UK

Academia
Coventry University
Durham University
Imperial College London
ISIS, Rutherford Appleton Lab
Keele University
Royal Holloway London
University of Bath
University of Bristol
University of Cambridge
University College London
University of Edinburgh
University of Exeter
University of Liverpool
University of Manchester
University of Nottingham
University of Oxford
University of Strathclyde
University of Surrey
University of Warwick

Industry
AstraZeneca, Cryogenic Limited, Oxford Instruments, Paragraf Limited, Siemens Magnet Technology, Hitachi, Toshiba

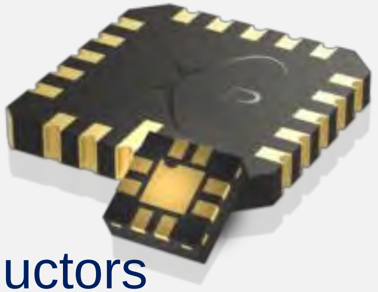
UK Membership of the EMFL

for high magnetic field (> 20 Tesla) science and technologies

UKRI-EPSRC 9 M€, 2015 – 2027

Recent highlights

Paragraph graphene Hall sensors
for high-accuracy operation in B > 30 T and cryogenics temperatures



Research on high-T_c superconductors
Signature of coherent and incoherent transport in the strange-metal regime of high-T_c cuprates
Nature 595, 661-666 (2021)

High Magnetic Field Research in the UK

Academia
Coventry University
Durham University
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ISABEL

Improving the **S**ust**A**ina**B**ility of the **E**uropean Magnet Field **L**aboratory

Horizon 2020 4.9 M€, 2020 – 2024

18 partners (5 industrial)

SuperEMFL

Horizon 2020 2.9 M€, 2021 – 2024

11 partners (3 industrial)

European Magnetic Field Laboratory, EMFL (2015)

World class high magnetic field facilities for research across different disciplines and by users from all over the world

https://emfl.eu/

High magnetic field installations are expensive to built and run. They require operational expertise. Thus, they are generally rare.

European Magnetic Field Laboratory, EMFL

World class high magnetic field facilities for research across different disciplines and by users from all over the world

https://emfl.eu/

Links

- Other European Large Scale Infrastructures
- CERN: Magnets for Accelerators & Muon Colliders
- FuSuMaTech: Shaping the Future of Superconductive Magnets
- European MRI community

EMFL State-Of-The-Art Magnet Technology

How to generate high magnetic fields?

A current I flowing in a coil generates a magnetic field **$B \propto I$**

Limitation: heating (Joule effect) **$P \propto R x I^2$** $\propto B^2$

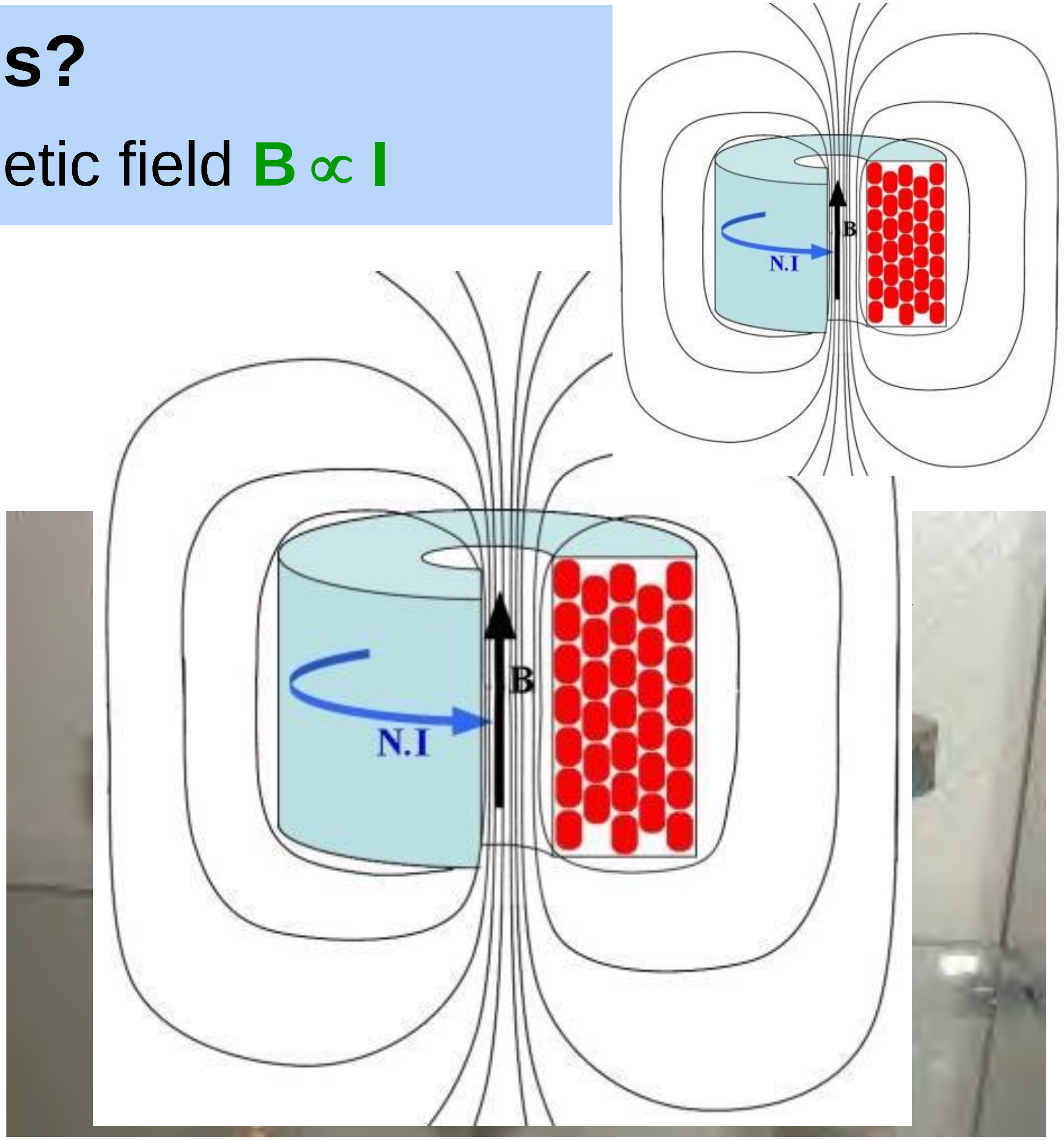
Solutions: - superconductors $R = 0$ ($B < B_{crit}$)

- cooling: static fields
- pulsed current (< 1 s)

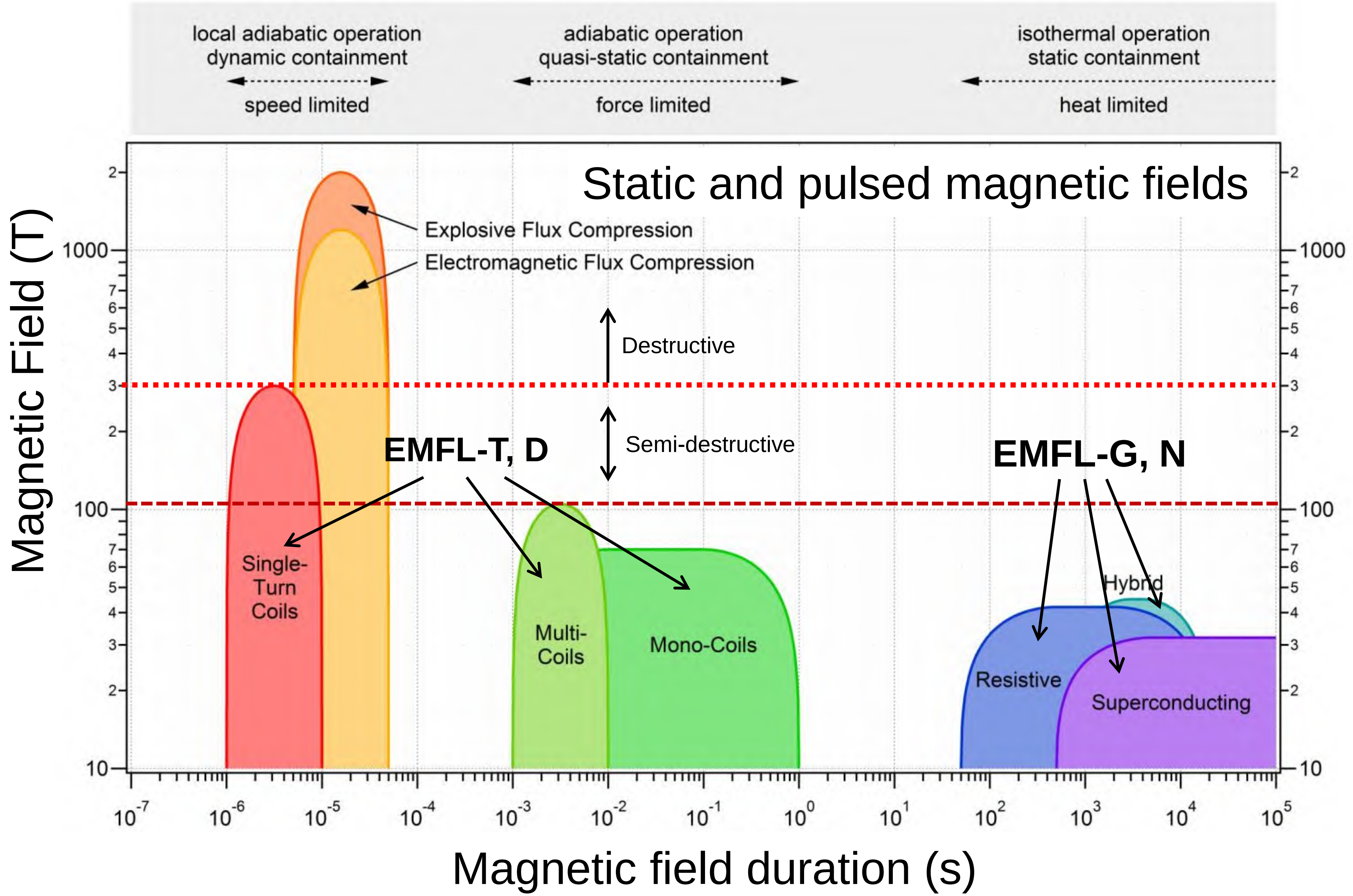
Limitation: Lorentz force on the coil $\propto$ **$B x I$** $\propto B^2$

Solutions: - strong conductor

- mechanical reinforcement
- sacrifice the coil



Magnetic field: strength and duration



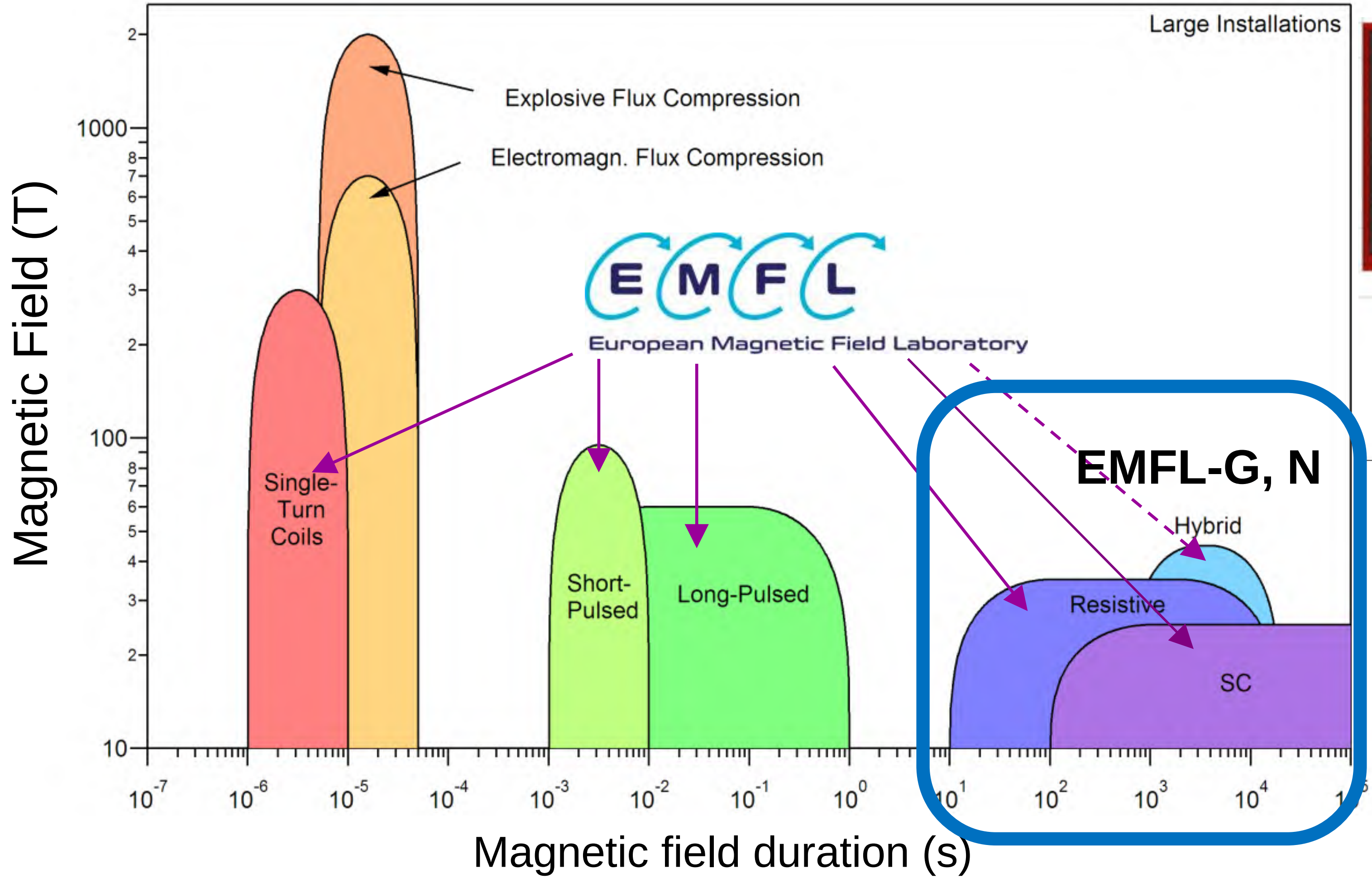
EMFL-T, Toulouse

EMFL-D, Dresden

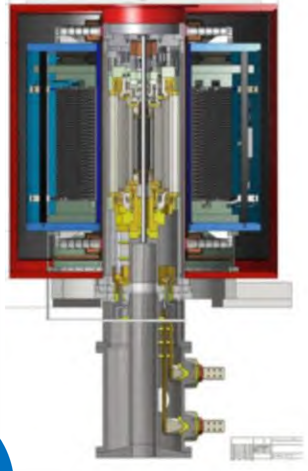
EMFL-G, Grenoble

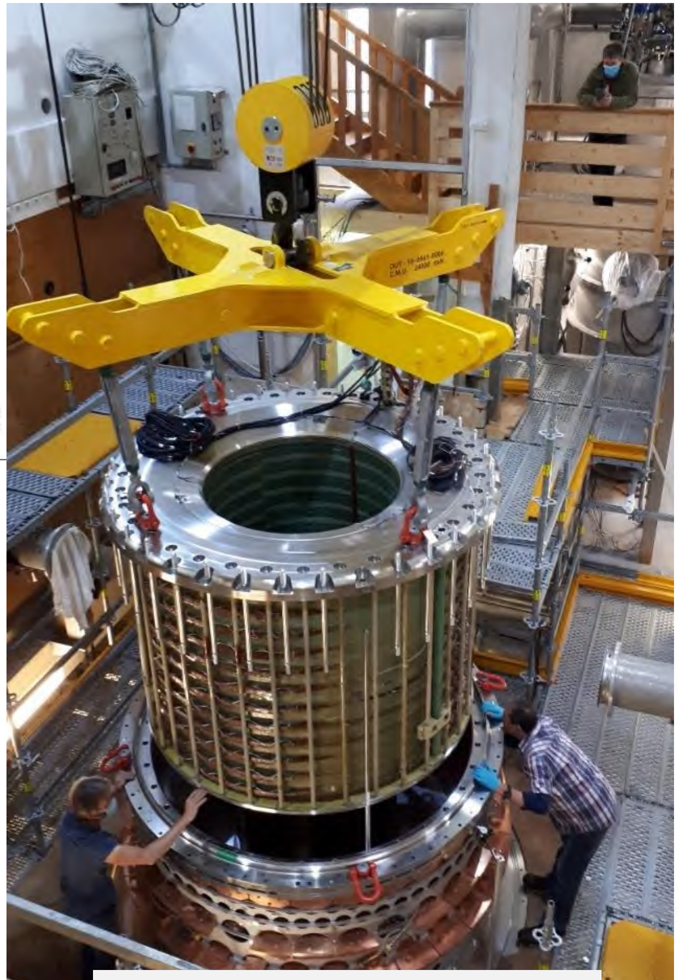
EMFL-N, Nijmegen

EMFL State-Of-The-Art Magnet Technology



Static magnetic fields

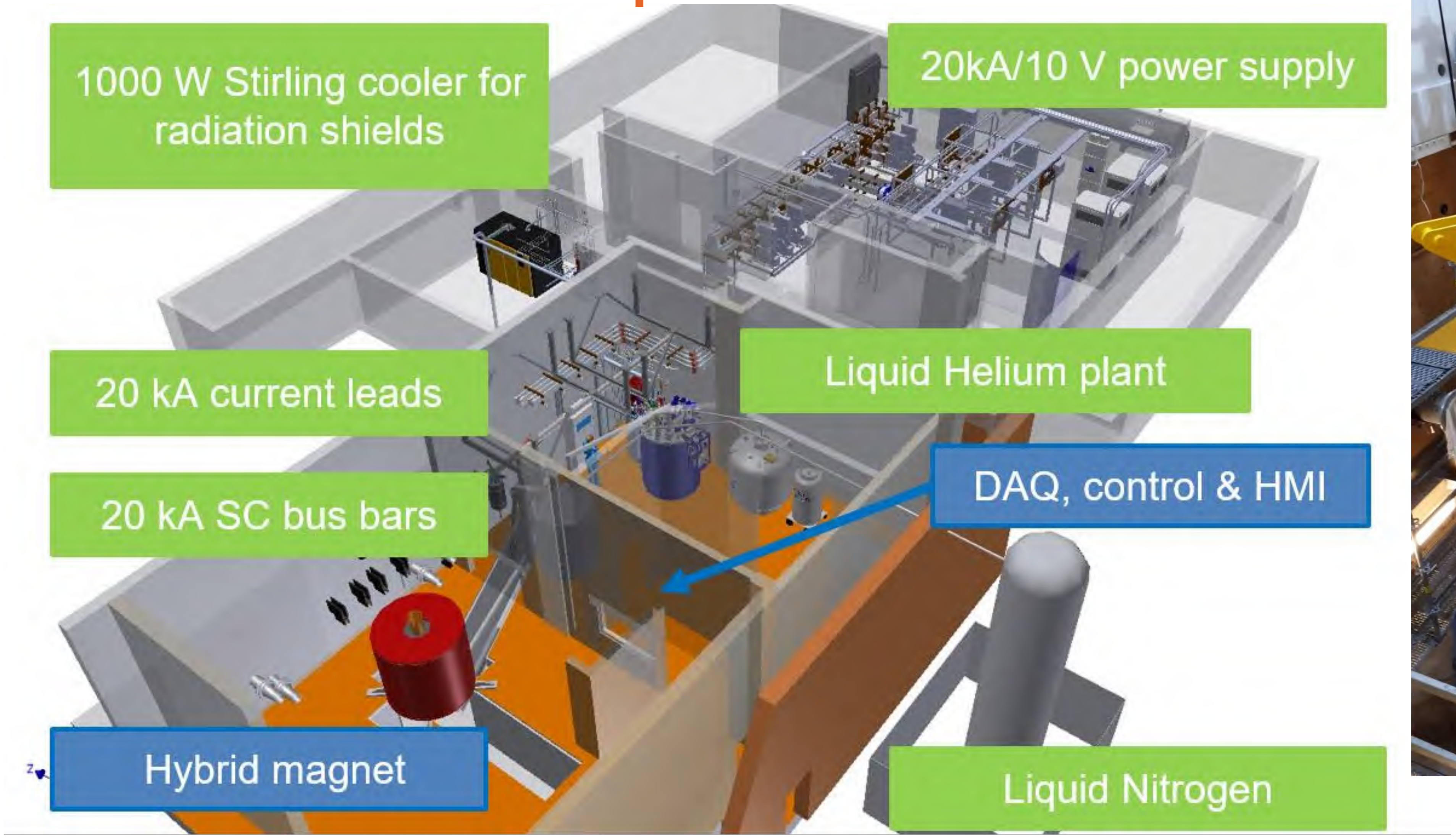




Magnet cool-down
Summer 2022

EMFL State-Of-The-Art Magnet Technology

Infrastructure development



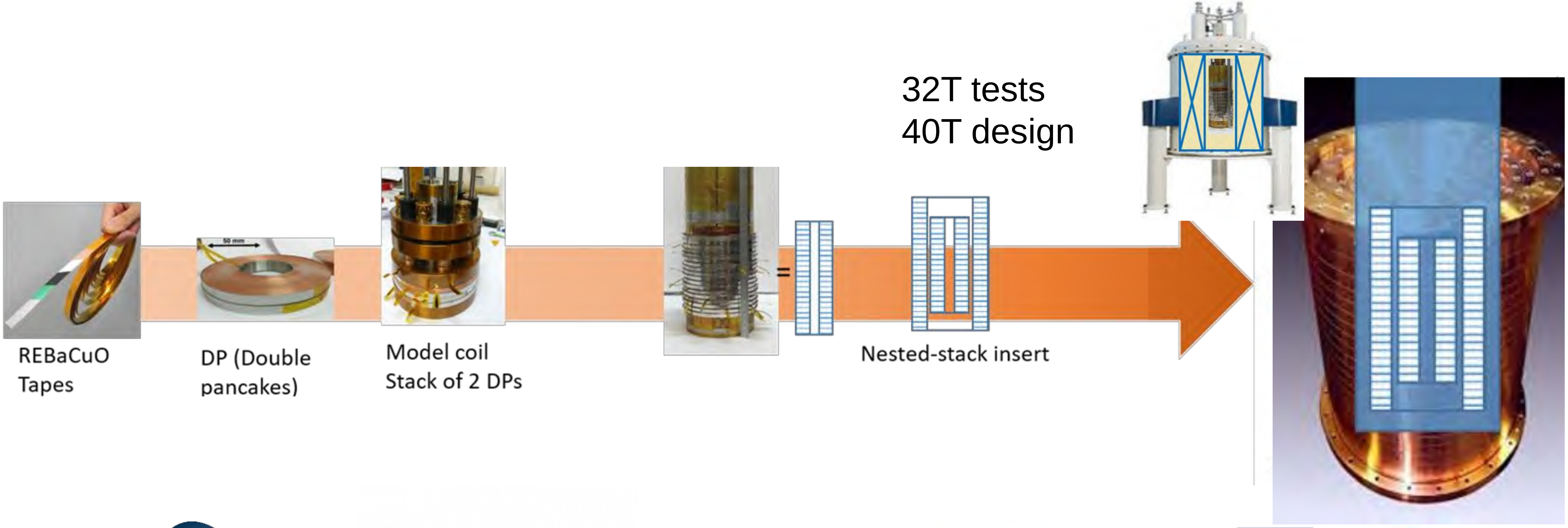
EMFL-G: Hybrid magnet

Magnet cool-down
Summer 2022

H2020 SuperEMFL

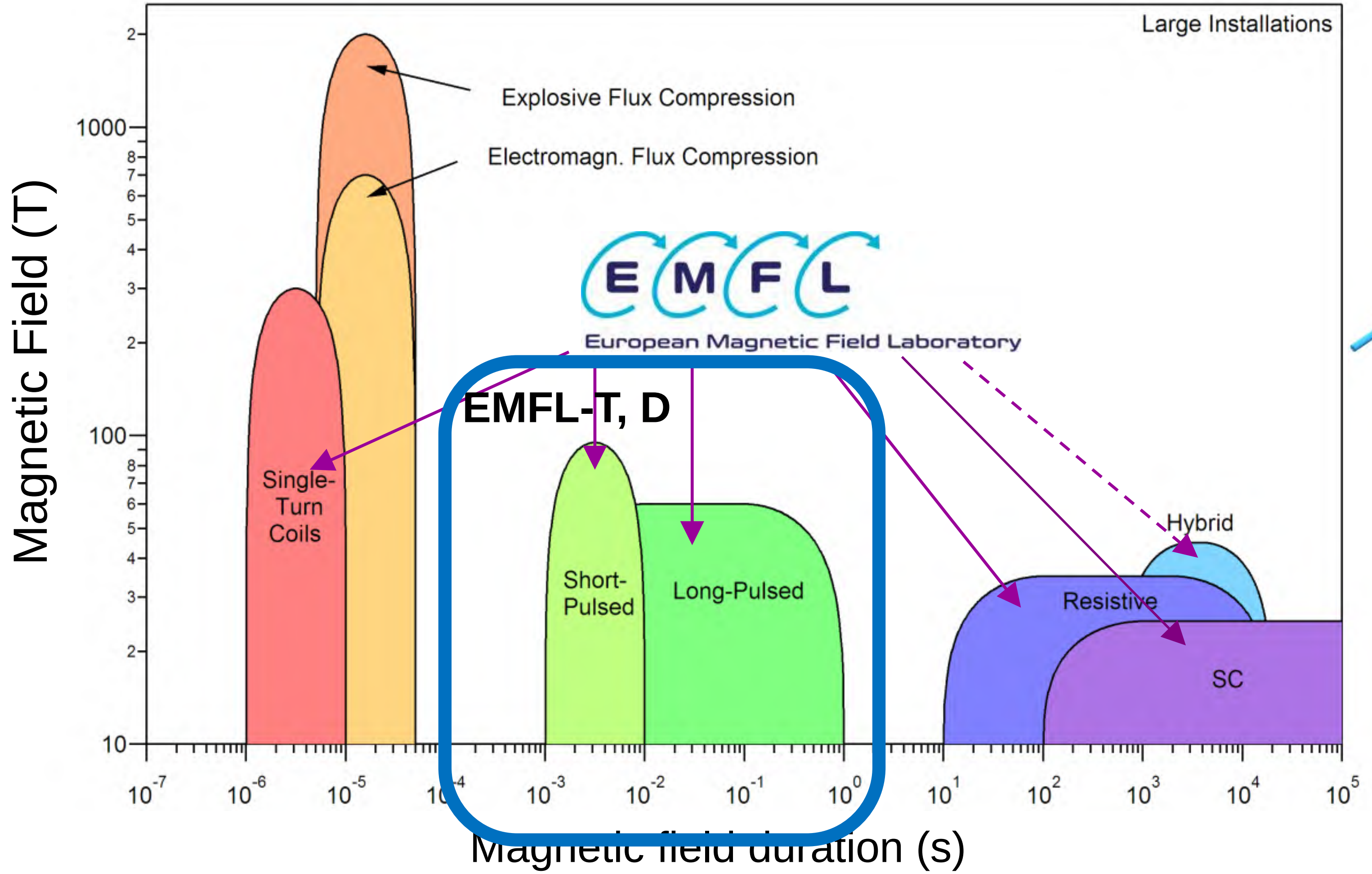
2021-2024, 11 partners (3 industrial), 2.9M€

Design of all-superconducting magnets (**32T** and **40T**) through the development of high-T superconductor technology and its combination with low-T superconductors.



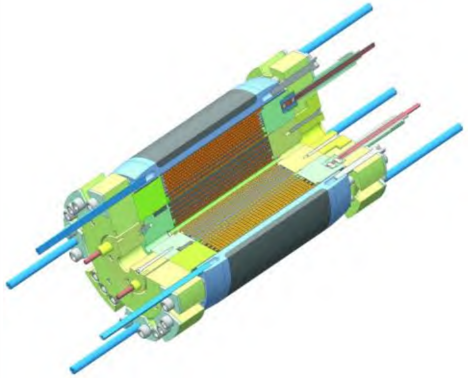
EMFL European Magnetic Field Laboratory · cnrs · HLD. HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF · Radboud University · cea · OXFORD INSTRUMENTS · THEVA · UNIVERSITÉ DE GENÈVE · ELÚ · BILFINGER · UNIVERSITY OF TWENTE.

EMFL State-Of-The-Art Magnet Technology



Pulsed magnetic fields

- Non-destructive pulsed fields: 100 T



The construction of coils for B up to 100 T is technologically challenging due to enormous electrical, magnetic, thermal, and mechanical stresses on the coils. The forces and pressure on the wire inside a coil is given by $p = B^2 / 2\mu$. For 100T, this corresponds to a pressure 4 GP (40000 atmospheres).

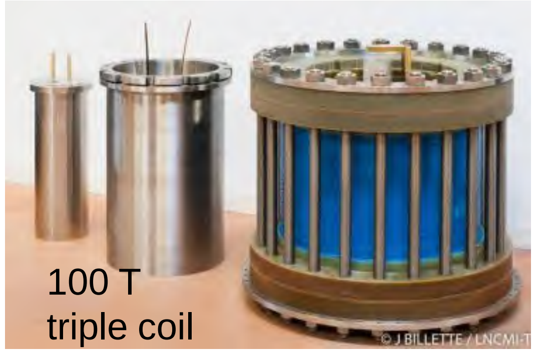
EMFL State-Of-The-Art Magnet Technology

Progress over one century

From 1924 to 1990 the field increased from 50 T to 70 T by improving the same technique: The conductor is reinforced by the outside with a high strength metallic cylinder

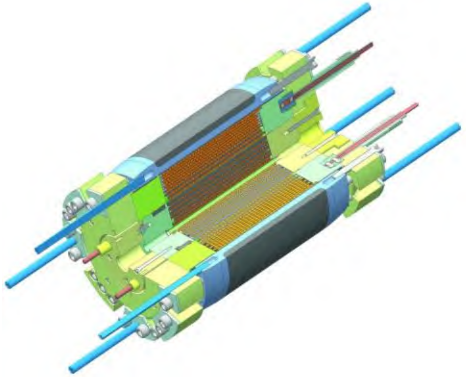
1990s Field increases from 70 T to 80 T with single coil by using an optimized reinforcement technique

After 2000, the field increases from 80 T to 100 T with dual coil systems powered by 2 different generators. The next step is the use of 3 or 4 concentric coils to take advantages of existing materials properties.



Pulsed magnetic fields

- ❖ Non-destructive pulsed fields: 100 T



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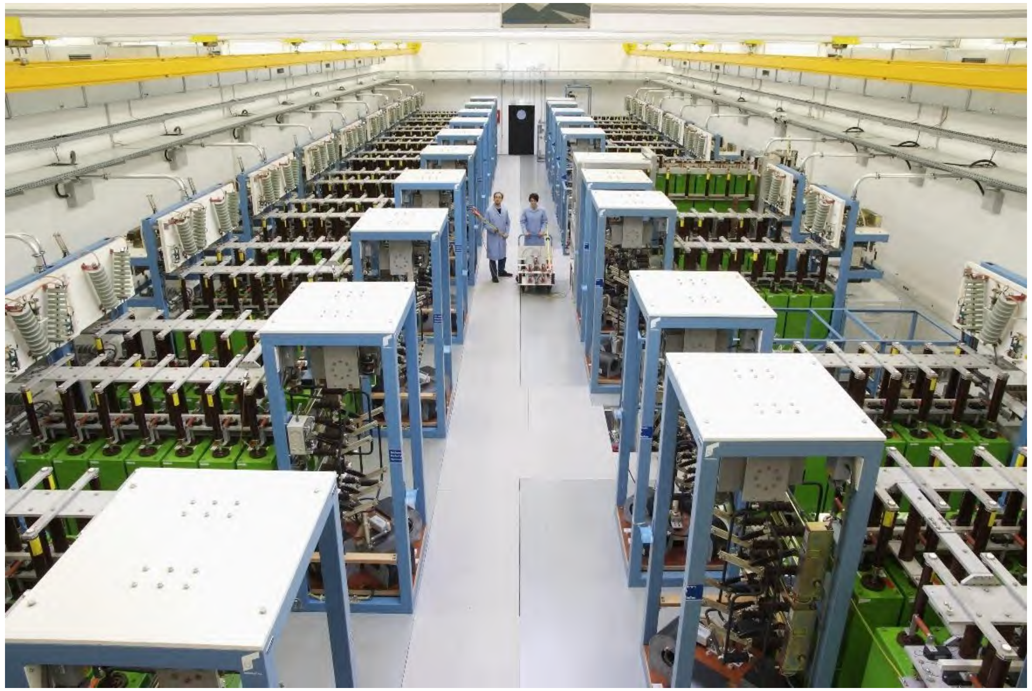
EMFL State-Of-The-Art Magnet Technology

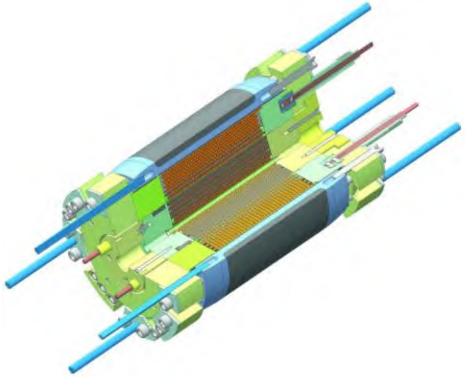
High-energy capacitor bank



Example in Dresden: High-energy capacitor banks to provide the current (>100kA) for the coils within a short time. 500 capacitors with a capacity of 350 µF each can store a total energy of 50 MJ. Prior to a B pulse, the required capacitors are charged from the mains. The required energy is then supplied to the coil systems via electronic switches (thyristors).

Pulsed magnetic fields

- Non-destructive pulsed fields: 100 T



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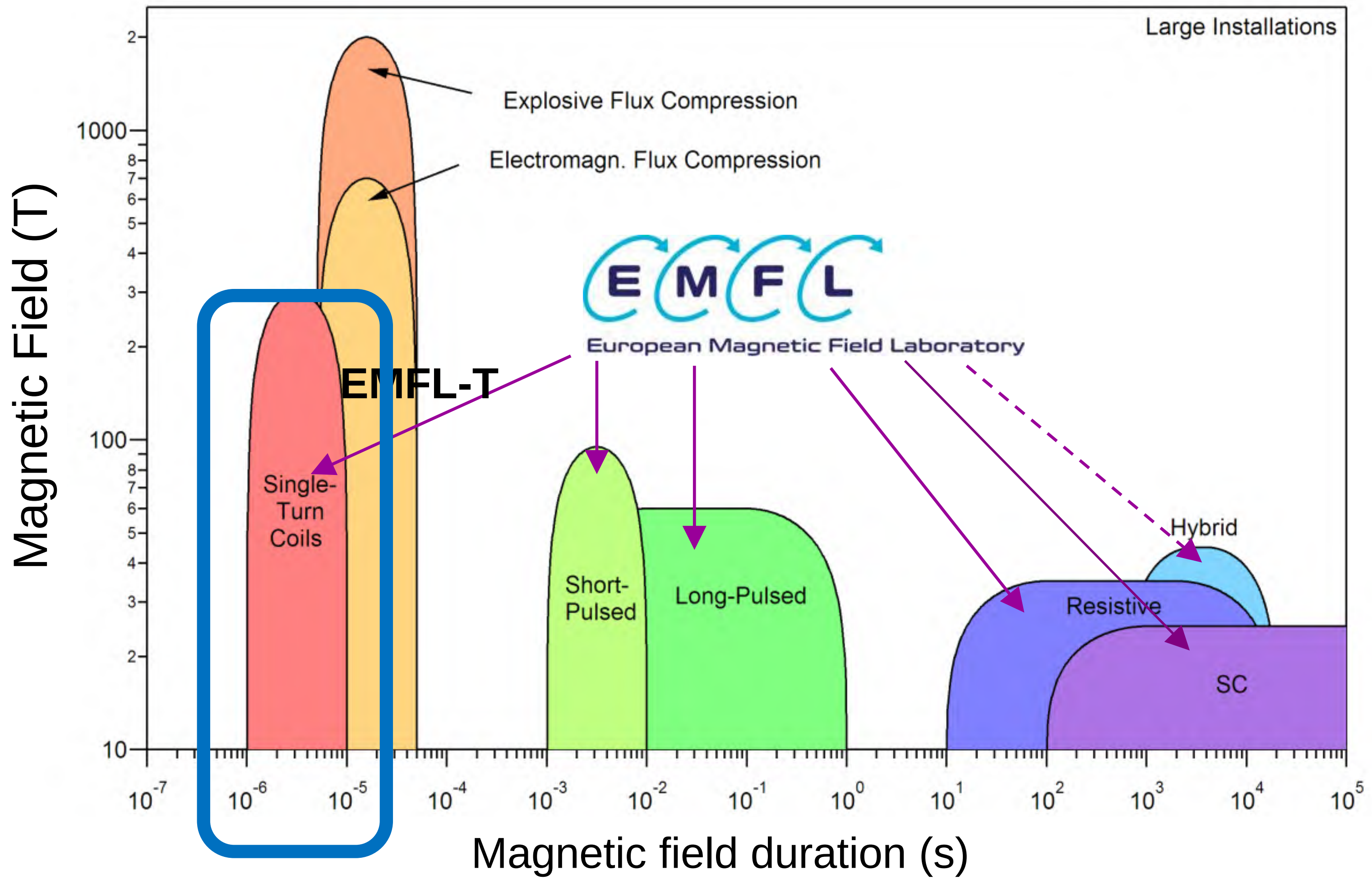
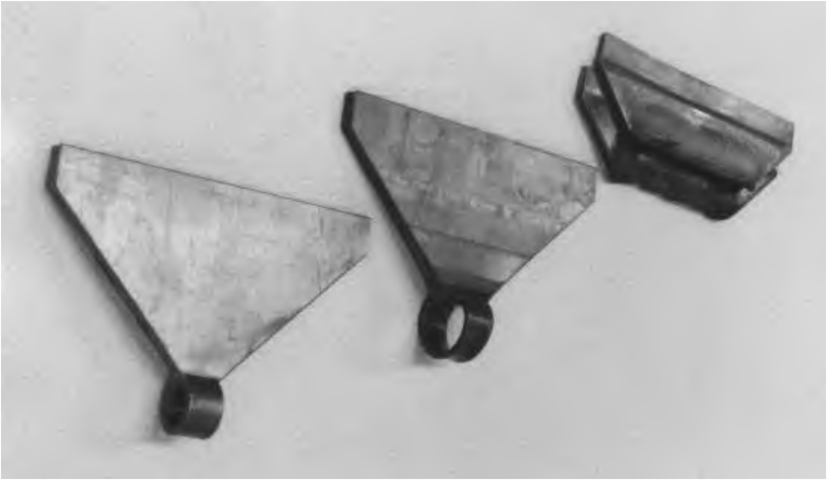
EMFL State-Of-The-Art Magnet Technology



Pulsed magnetic fields

❖ Semi-destructive pulsed fields

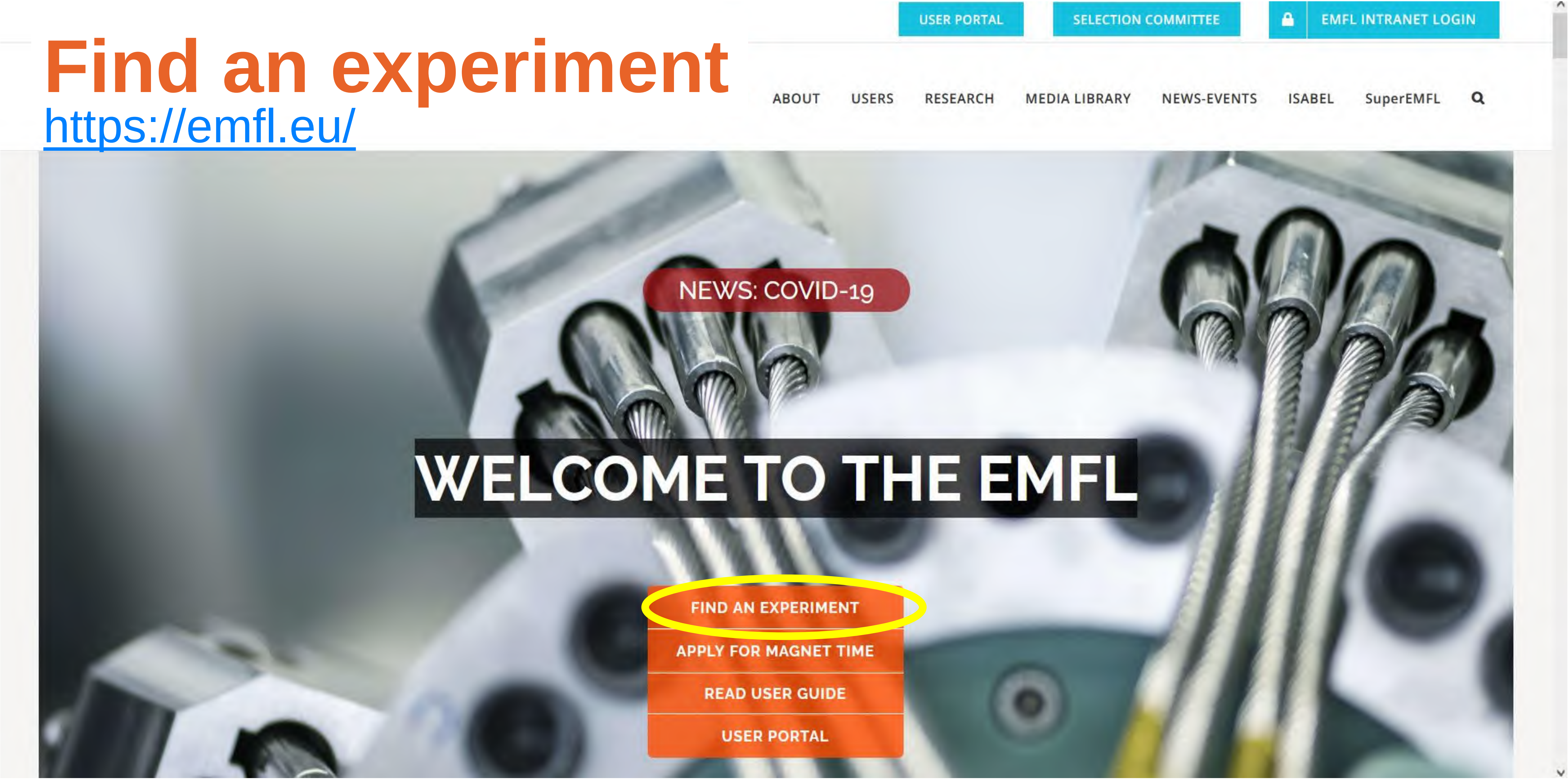


12 mm × 12 mm × 3 mm single-turn coils before the pulse (bottom), after a 10 kV, 6 kJ discharge with 37 T peak field and after a 55 kV, 189 kJ discharge with 188T peak field (top).

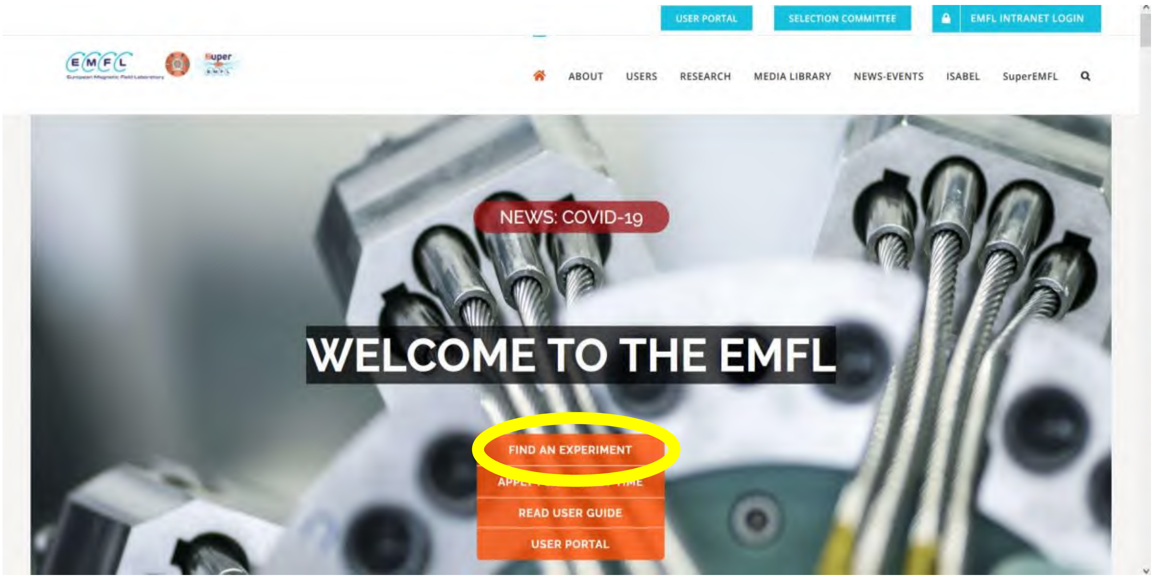
After the 55 kV discharge, the coil is destroyed and the triangular feed flanges are ripped off by the extreme current density.

Find an experiment

https://emfl.eu/



Find an experiment



MAGNETO-OPTICS

- OPTICAL MICROSCOPE IMAGING
- BIREFRINGENCE, DICHROISM AND FARADAY ROTATION
- PHOTOLUMINESCENCE AND RAMAN SPECTROSCOPY
- INFRARED SPECTROSCOPY
- ULTRAFAST DYNAMICS
- SCANNING TUNNELLING MICROSCOPY

THERMODYNAMIC PROPERTIES

- SPECIFIC HEAT
- THERMOPOWER AND NERNST-ETTINGHAUSEN
- MAGNETOSTRICTION
- SOUND VELOCITY AND ATTENUATION
- MAGNETOCALORIC EFFECT
- ...

MAGNETOMETRY

- COMPENSATED-COIL MAGNETOMETRY
- FARADAY BALANCE
- VSM VIBRATING-SAMPLE MAGNETOMETER
- TORQUE MAGNETOMETRY

MAGNETOTRANSPORT

- RF CONTACTLESS TRANSPORT
- CRITICAL CURRENT SUPERCONDUCTORS
- MAGNETOTRANSPORT (IN-SITU SAMPLE ROTATION)
- LOW NOISE&LOW RESISTANCE

MAGNETIC RESONANCE

- ELECTRON SPIN RESONANCE
- NUCLEAR MAGNETIC RESONANCE

ELECTRIC POLARIZATION

- ELECTRIC POLARIZATION

ADVANCED SOURCES

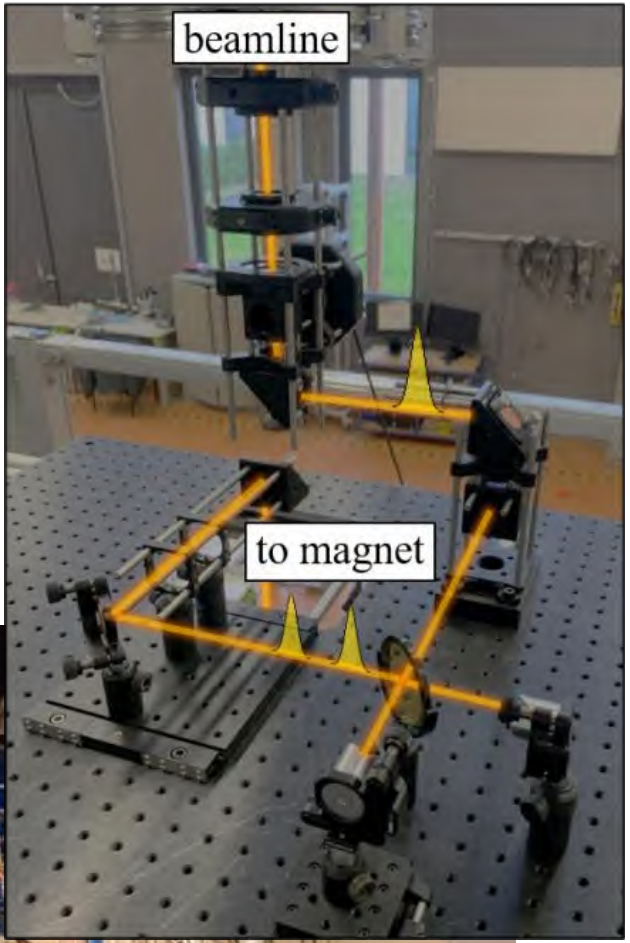
- X-RAY
- NEUTRONS

FURTHER INFORMATION FROM THE USER ACCESS MANAGER OF THE 4 LABS OF THE EMFL

Find an experiment

Advanced Sources and Magnetic Fields

FELIX-EMFL Nijmegen
Free-**E**lectron **L**asers for **I**nfrared e**X**periments



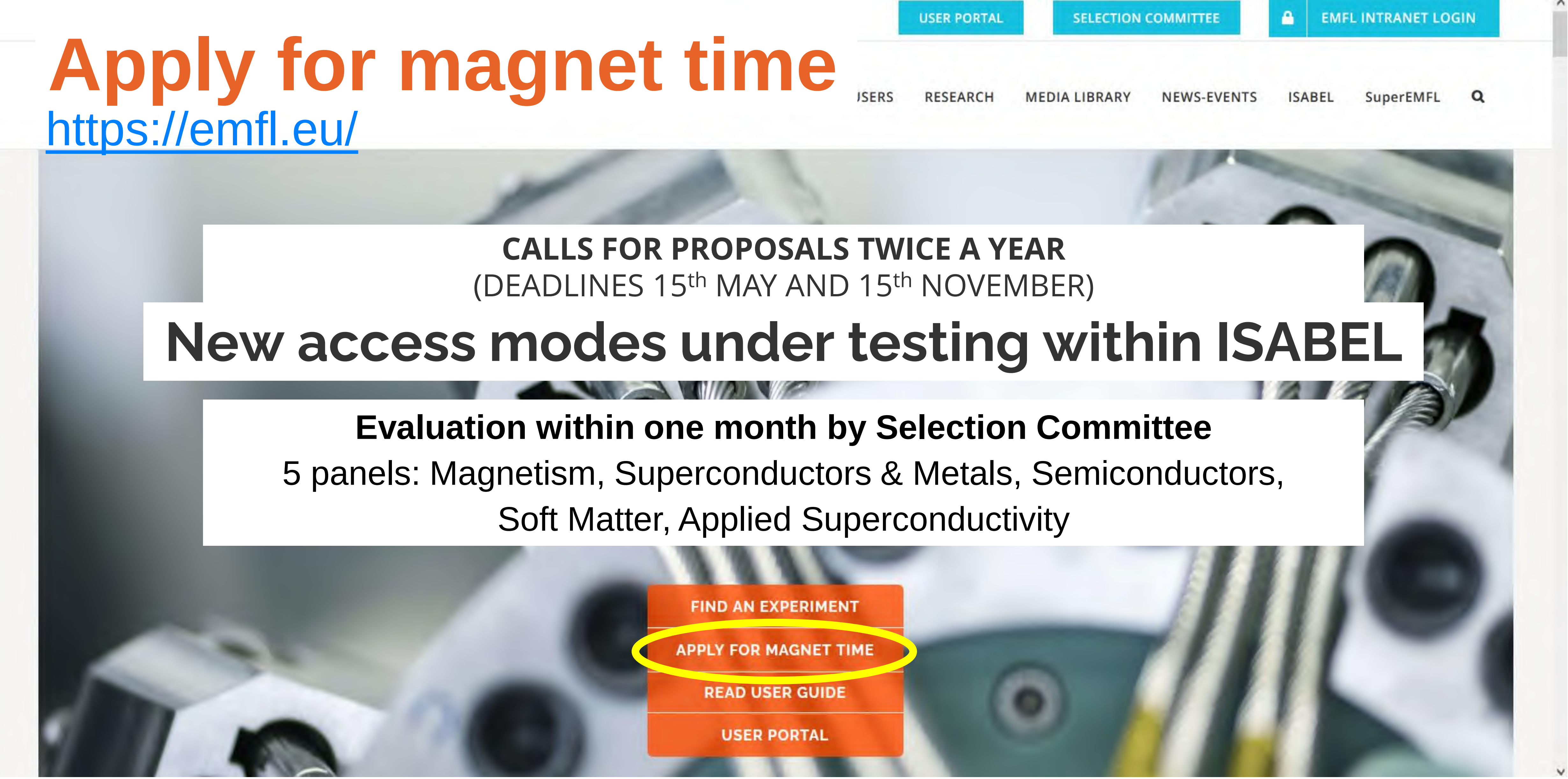
FELIX generates and uses very intense radiation in the (far)infrared region of the radiation spectrum.

The four lasers **FELIX-1**, **FELIX-2**, **FELICE** and **FLARE** each produce their own range of wavelengths and together, they provide a tuning range between **3 µm** and **1500 µm**.

aboratory

Apply for magnet time

https://emfl.eu/



CALLS FOR PROPOSALS TWICE A YEAR

(DEADLINES 15th MAY AND 15th NOVEMBER)

New access modes under testing within ISABEL

Evaluation within one month by Selection Committee

5 panels: Magnetism, Superconductors & Metals, Semiconductors, Soft Matter, Applied Superconductivity

ISABEL

Coordinator: Geert Rikken, CNRS

Improving the Sustainability of the European Magnet Field Laboratory

2020-2024 4.9 M€ 18 partners (5 industrial)

Dual access

EMFL and ISABEL partners are developing **dual access procedures** for :

- Fast track access
- Long-term access
- Industrial access
- First-time access

INTRODUCING OUR REGIONAL PARTNER FACILITIES

University of Nottingham Magnetic Levitation Laboratory

The Nottingham magnetic levitation laboratory is a relatively small facility hosted by the School of Physics and Astronomy at the University of Nottingham, UK.

The lab houses two superconducting magnets, reaching fields of up to 18.3 Tesla. Both magnets have been custom-built to perform experiments using the technique of diamagnetic levitation to mimic weightlessness and novel 'differential gravity' environments.

The areas of research normally pursued in this laboratory include studies of fluid and granular physics in pseudo-weightless condi-

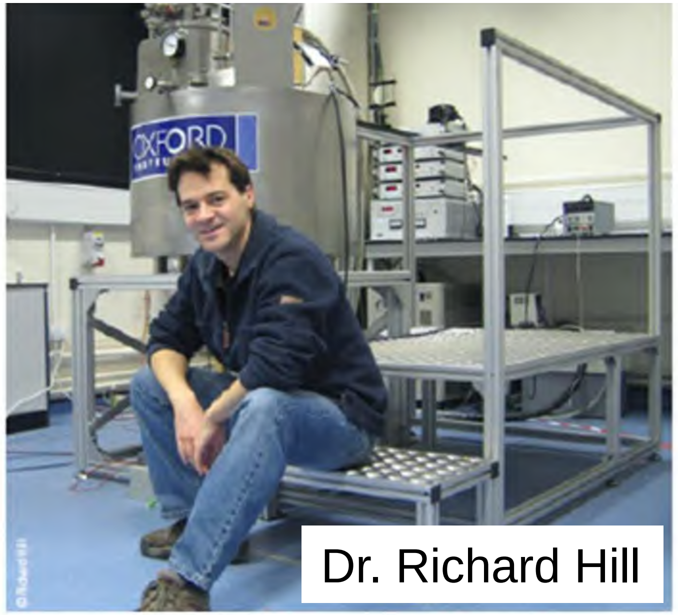
These magnets can be run for extended periods at maximum magnetic field, allowing long-duration (up to several days) 'microgravity' experiments to be performed, an expensive and often impossible feat using comparable alternatives: space and parabolic flights and drop towers.

The continuous running mode allows experimental methods to be improved and expanded iteratively, and extensive testing, before translating to the shorter duration experiments typically undertaken in the high-field facilities of EMFL.

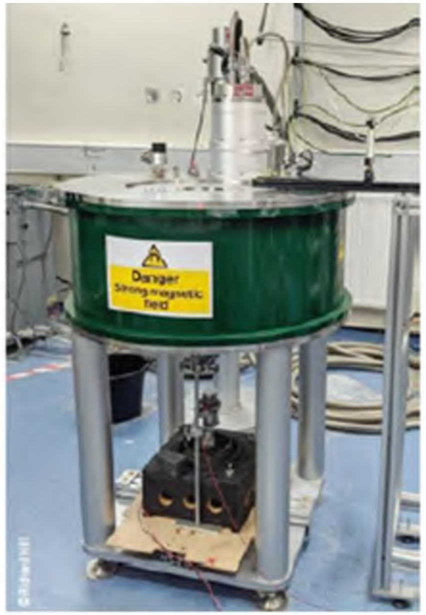
Researchers interested in undertaking experiments at this labo-

Univ. of Nottingham

Using diamagnetic levitation to mimic the absence of gravity



Dr. Richard Hill



ISABEL and DUAL ACCESS

Oxford Centre for Applied Superconductivity


JC STUDIES (500 A and 4.2 K) for tapes and wires

Oxford Centre for Applied Superconductivity

CONTACT: Amalia Coldea

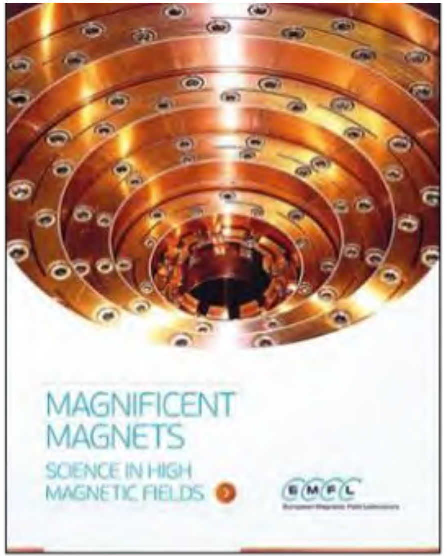
Nicholas Kurti Pulsed Field Facility (Station 1)

Maximum charge voltage 15kV
Energy stored per section: 495kJ

WINDING MACHINE

CONTACT: Stephen Blundell

EMFL: Dissemination and Training



Website https://emfl.eu/
EMFLNews https://emfl.eu/emfl-news/

YouTube https://www.youtube.com/watch?v=4dM07vic150

Virtual tour https://virtualtours.360totaal.nl/tour/hfml-felix
An overview of the high field installation and instrumentation with the latest updates
Provides first-time users with a realistic view of what they can expect when arriving at the facility to perform their experiment.

Engineering and Physical Sciences Research Council

EPSRC Centre for Doctoral Training in Superconductivity: Enabling Transformative Technologies

University of Bristol | University of Oxford | University of Cambridge

Students start in October 2025 – students apply from October 2024

History of EPSRC CDTs in UK

Started in 2009. Repeated in 2014, 2018, 2023

This time….EPSRC CDTs

- Approx 350 Outline proposals (number of applications per institution capped)
- 120 proposals invited to full application
- 65 CDTs funded (including 5 AI CDTs)
- £479 million total budget (£7.3m/CDT)
- Results announced March 2024

Subject areas of the 65 funded CDTs

- **Advanced materials and physical sciences**
- AI, robotics, digital security and resilience
- Energy and decarbonisation
- Engineering
- Health technologies
- Information and communication technologies
- Manufacturing and the circular economy
- Mathematical sciences
- Quantum technologies

Superconductivity CDT

- First students will start October 2025
- 4 yearly intakes, CDT ends in 2032 (up for refunding in 2028)
- Budget £6.1M EPSRC, £4M Partners: Total £10M
- Total ~ 60 students

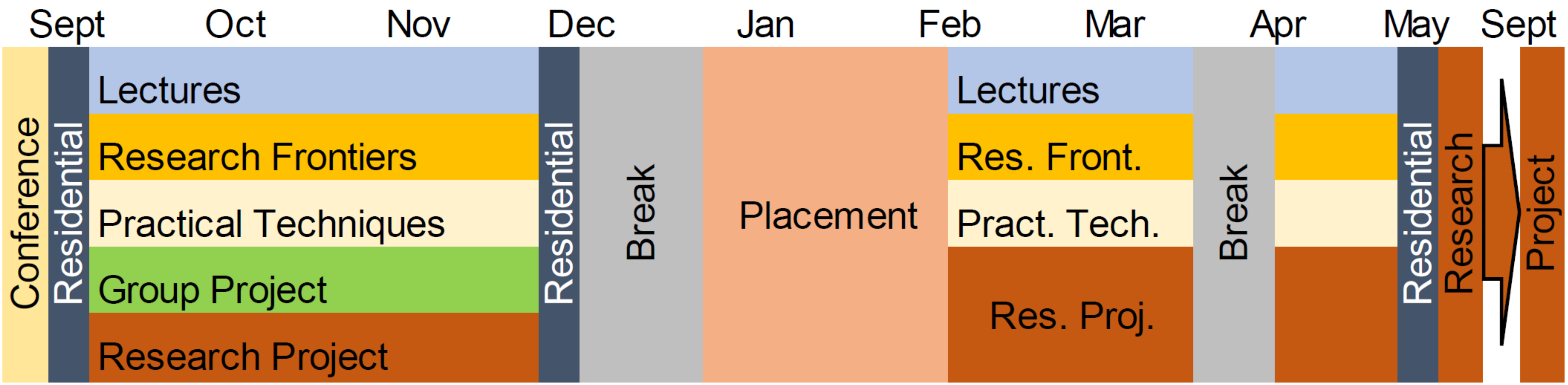
- **Materials**
- **Applications and devices,**
- **Fundamental Science (experiment and theory)**

Aims of the Superconductivity CDT

The aim of this Centre for Doctoral Training (CDT) is **to equip students with essential interdisciplinary skills needed by industry and to deliver cutting edge research in the area of superconductivity**. The unique properties of superconducting materials mean that they can deliver revolutionary technologies which will help to decarbonize our energy production and improve healthcare. Superconductors are also an essential component in many quantum devices such as those used for quantum computing.

Training of the Superconductivity CDT

Schematic 1st year timetable showing how training is spread across the year.



PhD level training for 4 cohorts of 10 – 20 students on a specific topic from October 2025

6-12 months ‘intense training’, followed by 3 to 3.5 years research for PhD (4 year total)

Advantages / Features of CDT approach to PhD training

- Students form community: sharing experience and peer-to-peer learning (Cohort Effe
- Forms HUB for subject area. Workshops, conferences, shared training course
- Concentrates training resources allowing more extensive courses
- Strong interaction with INDUSTRY and Research FACILITIES
- Encourages collaboration between academics
- Delivery of Impact through OUTREACH

CDT Management Board

Antony Carrington
CDT Director

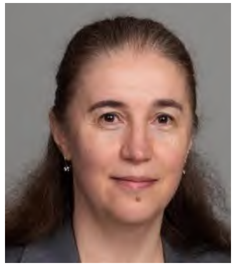
Stephen Hayden

University of BRISTOL

John Durrell

Malte Grosche

UNIVERSITY OF CAMBRIDGE



Amalia Coldea

Susie Speller

UNIVERSITY OF OXFORD

EPSRC Centre for Doctoral Training in **Superconductivity**

Engineering and Physical Sciences Research Council

University of BRISTOL · UNIVERSITY OF OXFORD · UNIVERSITY OF CAMBRIDGE

42 CDT Supervising Academics

Materials and Chemistry
Christopher Grovenor
Rebecca Nicholls
Susie Speller
Judith Driscoll
Bartomeu Monserrat
Sian Dutton
Tomas Martin

Simon Clarke
Michael Hayward
Charl Faul
Simon Hall

Applications and Devices
John Durrell
David Cardwell
Tim Coombes
Jun Ma
Chris Bell
Jason Robinson
Peter Leek

Fundamental Science: Theory
Claudio Castelnovo
Stephen Clark
Nigel Cooper
Felix Flicker
Sean Hartnoll
Steven Simon
Siddharth Parameswaran
Chris Pickard

Fundamental Science: Experimental
Arzhang Ardavan
Stephen Blundell
Andrew Boothroyd
Antony Carrington
Amalia Coldea
Seamus Davis
Stephen Dugdale
Sven Friedemann
Malte Grosche
Stephen Hayden
Nigel Hussey
Paolo Radaelli
Siddharth Saxena
Suchitra Sebastian
Michael Sutherland
Shuqiu Wang

Industrial Partners

Low carbon energy production / transmission

Tokamak Energy

UK Atomic Energy Authority

Magnets for nuclear fusion

VEIR

nationalgrid

HTSC conductors for electrical power transmission

SIEMENS Healthineers

Magnets for MRI

Advanced Healthcare

Industrial Partners

OXFORD INSTRUMENTS

CRYOGENIC
CRYOGENIC LIMITED

ICE

RAZORBILL INSTRUMENTS

Superconducting magnet systems, cryogenic systems, and instruments for research and industry

can superconductors

Bulk Superconducting materials

Research Institute Partners

CERN (magnet technology)

Diamond Light Source

ISIS Neutron and Muon Source

Karlsruhe Institute of Technology - KIT

High Magnetic Fields Research centre partners

European Magnetic Fields Laboratory

HFML-Felix : Nijmegen

LNCMI: Toulouse / Grenoble

HLD Dresden

NHMFL : Tallahassee

HENRY ROYCE INSTITUTE — UK national institute for advanced materials research and innovation

CONECTUS — Consortium of European Industrial Superconductivity companies

OQS Oxford Quantum Solutions — Oxford Quantum Solutions

Partners for Outreach

Cambridge Academy for Science and Technology — CAST - Cambridge

Clevedon School — Clevedon School (near Bristol)

Bartholomew School Oxford

How the Partners Contribute to the CDT

- Funding and co-supervising PhD studentships
- Hosting 6-week project placements
- Delivering lectures on specialised subjects
- Co-delivering group projects
- Giving careers advice to students
- Contributing equipment and/or materials
- Co-organising workshops and conferences
- Steering the direction of the CDT through Partnership Board
- Hosting and mentoring Outreach activities

ACTION:
Project proposals:
July- Sep 2024

EPSRC Centre for Doctoral Training in **Superconductivity**

Engineering and Physical Sciences Research Council

Year 1

Placement Projects → Group Projects → Guest Lectures

Years 2-4

Business Training → Site Visits → Careers → Outreach

Partner Board

Conferences & Workshops

PhD Project Supervision

https://superconductivity-cdt.ac.uk

Launching event: 18 Sep 2024- Oxford Physics