Implications on the necessary developments / upgrades of technical platforms:

Test stations for mechanical manufacturing and test (at warm and cryogenic temperatures)

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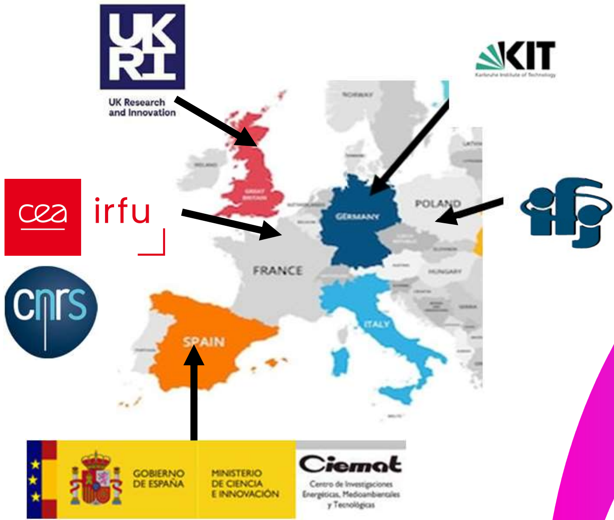
The recent development of High-Temperature Superconductors (HTS), the challenge of the future generation of particle accelerators and the new design of compact magnetic fusion power plants require the exploration of new materials, techniques and technologies to take a step forward compared to the current state of the art.
R&D and developments in platforms would make possible to operate at higher temperatures of 20 K and to reach high magnetic fields of up to:

16 T for Nb_3Sn
20 T for HTS.

Group E. - Laboratories :
CEA
CIEMAT
CNRS
KIT
STFC
IFJ-PAN



Summary

- State of the art on:
  - ✓ Mechanical testing machines
  - ✓ Cryogenic test stations
- Some achievements
  - ✓ HTS R&D
  - ✓ Nb_3Sn R&D
- Future needs
  - ✓ Mechanical tests at variable cryogenic temperatures (77K, 20 K, 4.2 K)
  - ✓ Platform for studying the of influence of strong magnetic fields (>20 T) on LHe cooling

State of the art on mechanical tests

❑ Mechanical test Laboratory

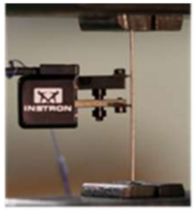
Determination of the mechanical characteristics (elasticity modulus, elastic limit, breaking load and stretch, fragility) of metal and composite materials, study of assembly behavior (bending, traction, compression and slippage).

- ➢ Testing machines
  - ✓ Two electro-mechanical machines of 150 and 300 kN
  - ✓ One hydraulic machine of 1600 kN
- ➢ Load cells plugged on the machine (300, 150, 10 and 2 kN)
- ➢ Cryogenic inserts (on the 150 kN machine)

  - ✓ “Small” insert (300 K, 77 K, 4.2 K)
    Usable volume: Φ 50 mm x 200 mm
    45 kN in traction or flexion

  - ✓ “Big” insert (300 K, 77 K, 4.2 K)
    Usable volume: Φ 150 mm x 140 mm
    80 kN in traction
    150 kN in compression

Tensile test on Rutheford cable



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State of the art on mechanical tests

- Tensil test

The typical tensile test uses samples extracted from raw material or directly the component to test until rupture.

- Shear test (orientable support)

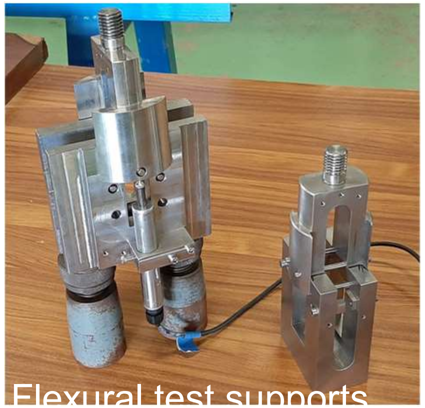
It is possible to adapt the sample support of the sample itself to perform a shear test with a tensile solicitation.

- Flexural test

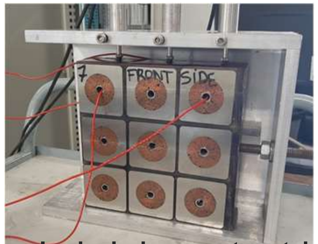
In some case (impossibility to attach the sample), it is possible to obtain some material characteristics with a flexural test instead of a tensile one. The small insert can be equipped with flexural test support in three of four points

- Compressive test
- Thermal shrinkage measurement

The thermal shrinkage is measure by a compressive test with a reference test at constant loading force or by direct Measurement of the sample expansion



The platform is being used for Nb3Sn and HTS R&D (FRESCA2, R2D2) and is sought for material testing for 20K (hydrogen activities) and 100-150K (insulators) applications



Thermal shrinkage test bench

State of the art on mechanical characterization

Description: Laboratory for Mechanical Properties of Structural Materials is a facility with specialized instruments and devices to perform tests and measurements on various types of materials in order to obtain information about their mechanical parameters such as strength,stiffness, fatigue,toughness, among others for various fields of engineering and materials science. This facility is composed by the following infrastructures:

1. Creep test performed using a tensile specimen to which a constant stress and temperature are applied.
2. Tensile test, toughness, fatigue crack growth… 2 MTS-810 servo-hydraulic machines
3. Two Small punch test: (T range from -180°C to 500°C) and (T up to 900°C) – EN10371:2021
4. Impact test**:** Two pendulums (Wolpert Impact test 300 J and 25 J) for carrying out impact tests with a standard specimen and an undersized specimen (KLST).
5. Durometer: Hardness machine (Akashi Seisakusho AVK-AII) is used to perform Vickers hardness test according with the standard ASTM E-92.
6. Nanoindentation test: MTS XP Nanoindenter is an accurate instrument for nanomechanical testing.
7. Radiactive facility: Mechanical characterization of irradiated steels (tensile, toughness, impact tests, etc.).
9. Metrology laboratory

Unique features: Facility for mechanical properties testing in radioactive installation.
Activities: Mechanical characterization of materials through testing, which can be carried out with irradiated materials. Innovative Structural Materials For Fission And Fusion - INNUMAT; European Database For Multiscale Modelling Of Radiation Damage (ENTENTE)
Future plans: In operation for several years. No large change presently planned.
Web: http://rdgroups.ciemat.es/web/materiales/mechanical-properties-laboratory
Contact person: Marta Serrano, Head of Material for Energy Interest Division, marta.serrano.ciemat.es

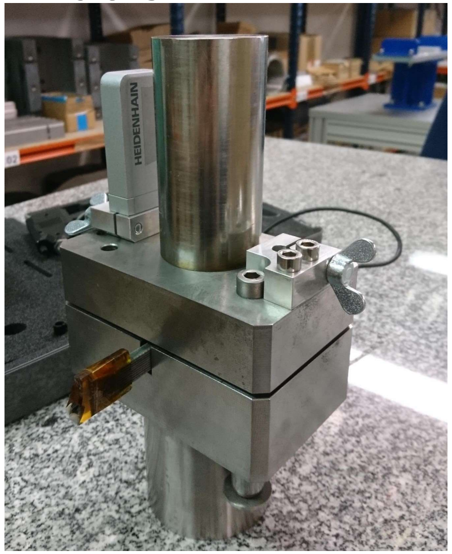
State of the art on mechanical characterization

Some illustrations on characterization tests

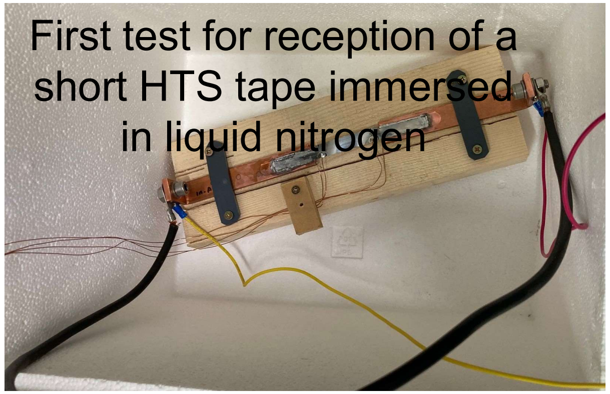
CIEMAT Cryostat and cryocooler for simple measurements or processes like sensor calibration, thermal conductivity

Magnets and other Accelerator components are assembled and tested at the Julian Camarillo Laboratory. It includes:

- 2 Cryostats
- Power supplies up to 2000 A
- 2 Cryocoolers
- 2 Winding machines
- Impregnation tooling
- Instrumentation



Preparation of the assembly for the mechanical measurements of the Young modulus of a stack of impregnated cable



First test for reception of a short HTS tape immersed in liquid nitrogen

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State of the art on mechanical characterization

Some achievements

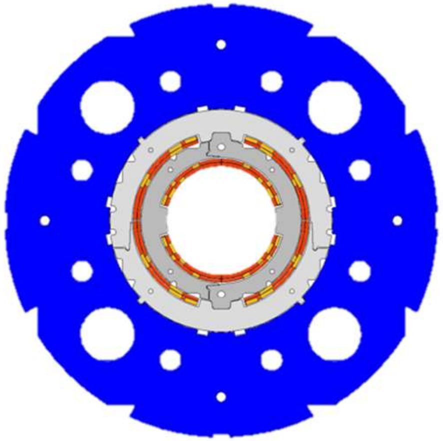
At this moment in the framework of the PRISMAC project, one of the most relevant activity in CIEMAT concerns the fabrication, in collaboration with industry, of the so called MCBXFA & MCBXFB magnets for the HI_LUMI project. Non-superconducting components for accelerators like resistive magnets or RF cavities, have also been developed by the group

Main objectives *of PRISMAC project:*

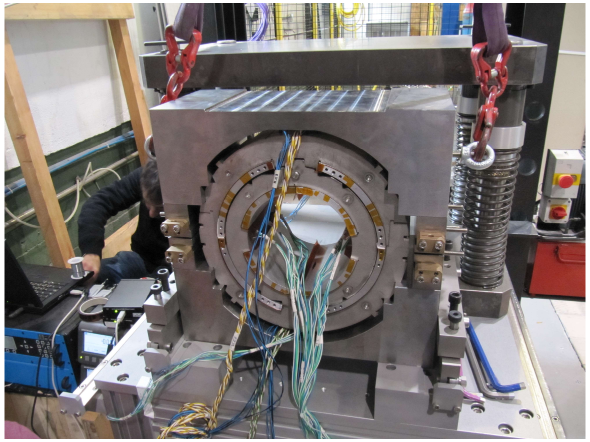
a) Developing MCBXF magnets

b) Starting a Laboratory for High Field Magnet (HFM) Prototypes

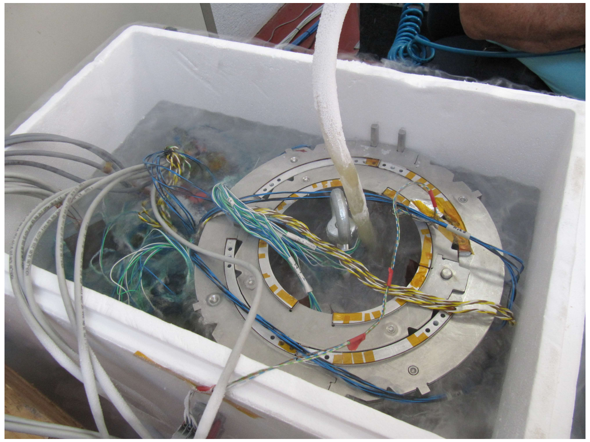
c) Participating in the High Field Magnet Program making Nb_3Sn prototypes and eventually HTS magnets for future accelerators.



The MCBXF is a 2 nested dipoles magnet orbit corrector and is the Spanish contribution to HL-LHC



MCBXF Short model
with strain gauges at press at 300 K



MCBXF Short model
with strain gauges at press at 77K

Cryogenic thermometers calibration facility

Description:

The cryogenic thermometers calibration facility was designed and constructed in the framework of LHC. More than 5000 thermometers were calibrated with this facility. These sensors (1800 sensors for the magnets and the 3200 for the cryogenic lines and equipment) are used for cryogenics and operation process of the LHC

The main features are:

- Calibration is performed by comparison to reference sensors: the thermometers to be calibrated are mounted on the same thermostatic copper block as the 4 reference thermometers (4 RhFe working temperature references)
- Temperature range: 1.6 K-300 K
- Absolute accuracy of ± 5 mK from 1.6 K to 4.2 K, Relative accuracy: 1 % of temperature T in the range 4.2 K -300K.
- Capability: up to 90 thermometers
- Automatic data acquisition and analysis (fit of experimental data), calibration data saving in a dedicated database

Activities:

The facility is used for the calibration of cryogenic thermometers for two main applications,

- SRF based cryomodules development and/or construction (SPIRAL2, ESS, MYRRHA) by IJCLab or by other institute
- Cryogenic industrial applications. The facility will be upgraded in order to extend the temperature range down

to ~100 mK in the framework of NGCRYO project (R&D program supported by IN2P3)

Superconductor characterization test stand

Description: The platform is based on 16 T superconducting magnet with a Variable temperature Insert (VTI). The temperature inside the VTI is controlled by a calibrated Cernox sensor and can be regulated between 1.8 K and 200 K. The current of up to 1000 kA can be delivered to the sample from external power converter using two current leads.

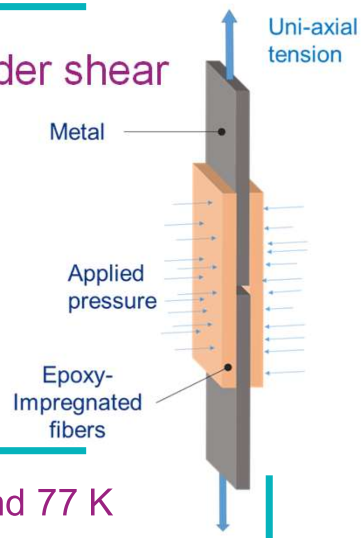
Activities: The platform is currently in the hardware commissioning phase

Futur plans : The platform can be used to characterize critical current of superconducting wire strands of various materials. Additionally it will be possible to perform resistance and RRR measurement. The capability of the test station could be further improved by the acquisition of the sample holder which enables applying variable mechanical stress to the sample.

Some achievements on mechanical tests

✓ Behavior of metal/insulation interface under shear

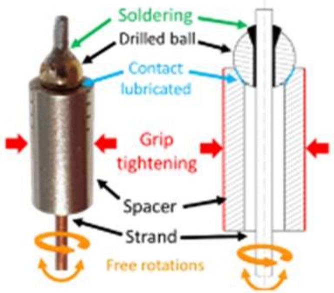
Goal: Reproduce the behavior of the interface between metal components and insulated cables
Mean: shear test under compression

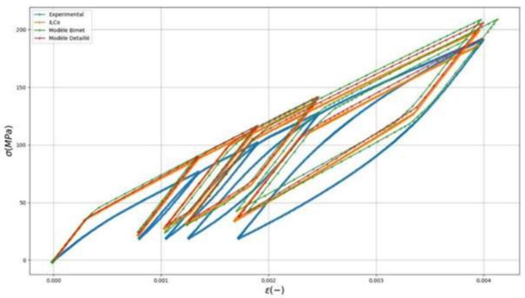


Material samples towards 16 T Nb_3Sn Dipoles

✓ Tensile tests of strands in small insert at 300 and 77 K

Goal: Characterize the mechanical behavior of Nb3Sn strands





Loading cycles

✓ Compression tests into big insert at 300 and 77 K

Goal: Characterize the mechanical behavior of Nb3Sn strands

Loading cycles

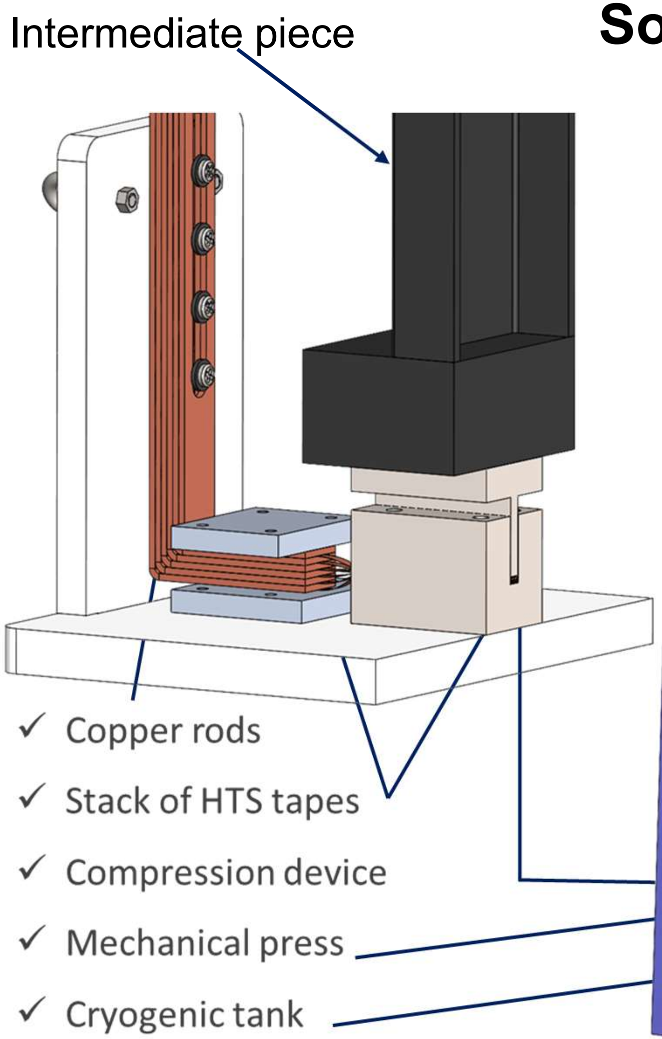
10-stack of Nb_3Sn cables

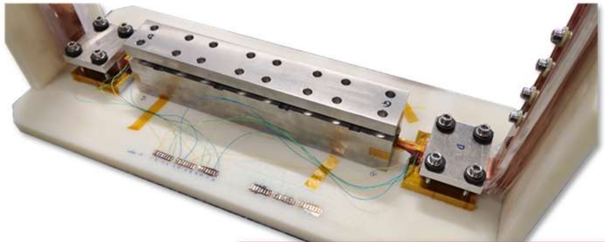
Courtesy E. Rochepault

Some achievements on mechanical tests

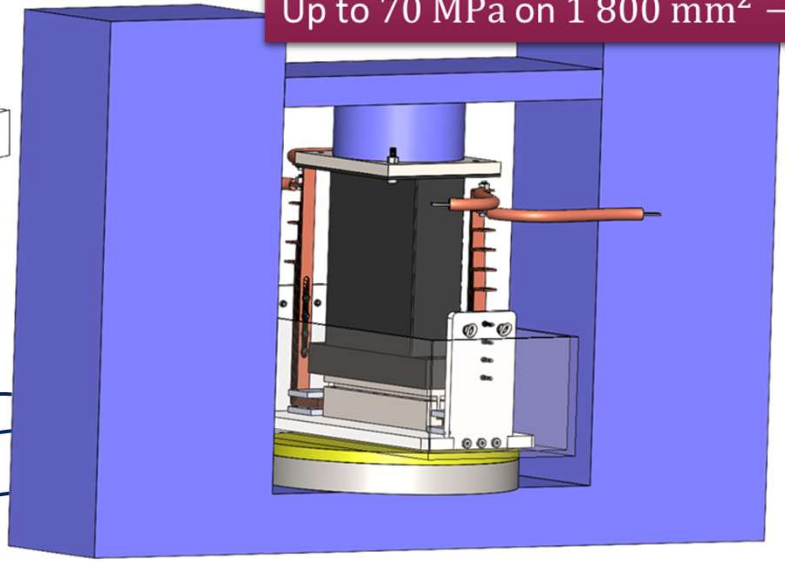
Towards HTS Magnets

In order to protect the HTS magnet as well as possible, the value of the contact resistivity between turns (Rct) must be controlled in several insulation conditions: No-Insulation (NI) or Metal-Insulation (MI) coil.





@ 77 K (liquid nitrogen)
Up to 70 MPa on 1 800 mm^2 → 12,6 t



The experimental setup allows to measure the contact resistivity between No-Insulation 6 mm HTS superconducting tapes cooled at 77 K in a liquid nitrogen bath, as a function of the mechanical stress

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Courtesy C. Genot

Future needs on mechanical tests

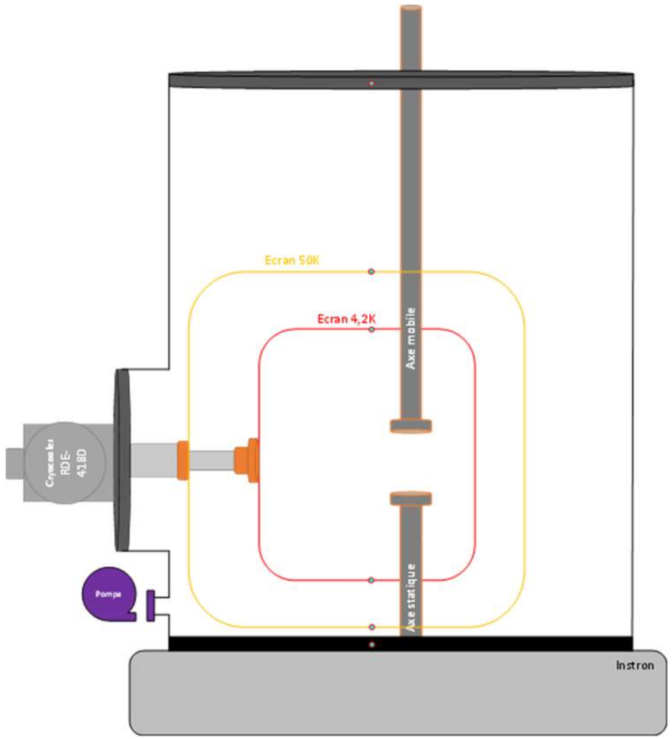
Mechanical Test Bench at variable cryogenic temperatures (from 150 to 4.2 K)

(Currently under development)

Design of cryostat devoted to mechanical test on samples at high stress level

Why?

The increasing use of superconductors HTS will require their mechanical characterization at a temperature not accessible in current stations.
The mechanical characterization should extend to composite blocks comprising the superconductor and its insulation at a controlled temperature between 4.2 K and 150 K, or even more if possible using the 300 kN electromechanical traction machine that the laboratory already has.



Sketch of the platform

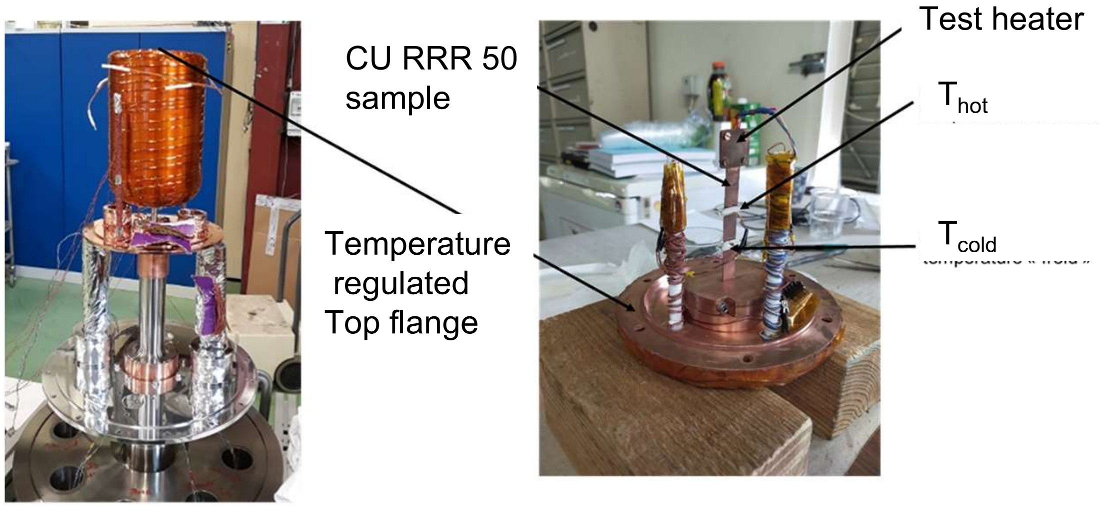
New requirements for hydrogen transport → materials test at 20 K

State of the art on cryogenic test stations

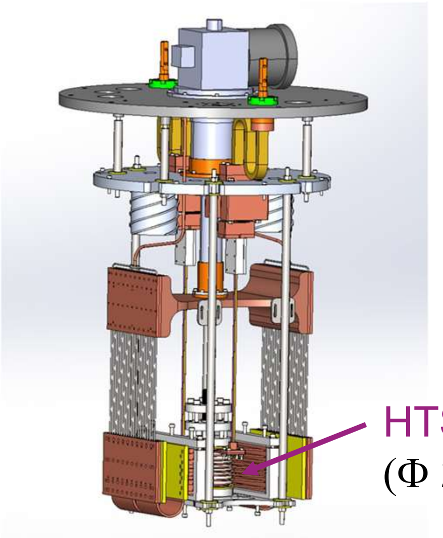
MectiX – Thermal measurement facility

cryogenerator-cooled variable temperature measurement cell for carrying out thermal conductivity measurements using either the differential or the integral method on samples of around 10 cm in length in a temperature range from 4.2 K to 300 K.

cell is isothermal within 50 mK over the entire temperature range (4 K to 50 K)



Towards a new method for cooling by means of PHP



HTS magnet ~10 T
(Φ 25 mm, L ~ 60 mm)

Future needs on cryogenic test stations

Cryogeny on Cooling Disturbance in Liquid Helium for magnets beyond >20 T

(Currently under development)

One of the major challenges for the development of muon colliders is to manufacture and operate superconducting magnets reaching magnetic inductions up to 20 T

In the past, influence of magnetic fields (~17 T) on critical heat flux decrease in liquid helium* was demonstrated

Goal: To better characterize and quantify disturbances induced by high magnetic fields on liquid helium

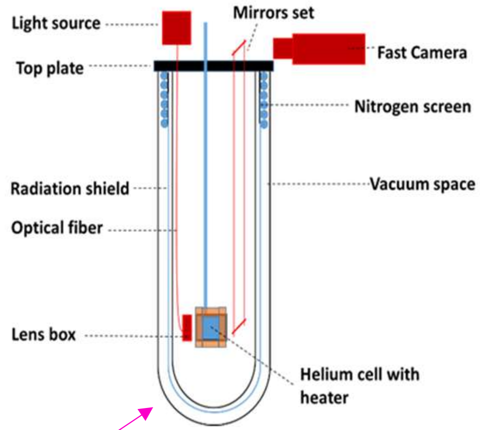
(a) Past
-> 17 T

(b) Present**
-> 30 T

**Full characterization of the critical heat flux from 0g to 2g (PhD thesis: S. Bagnis)

- Future steps: Development of a modular test station allowing to carry out various cryo-magnetic studies with a vizualisation system

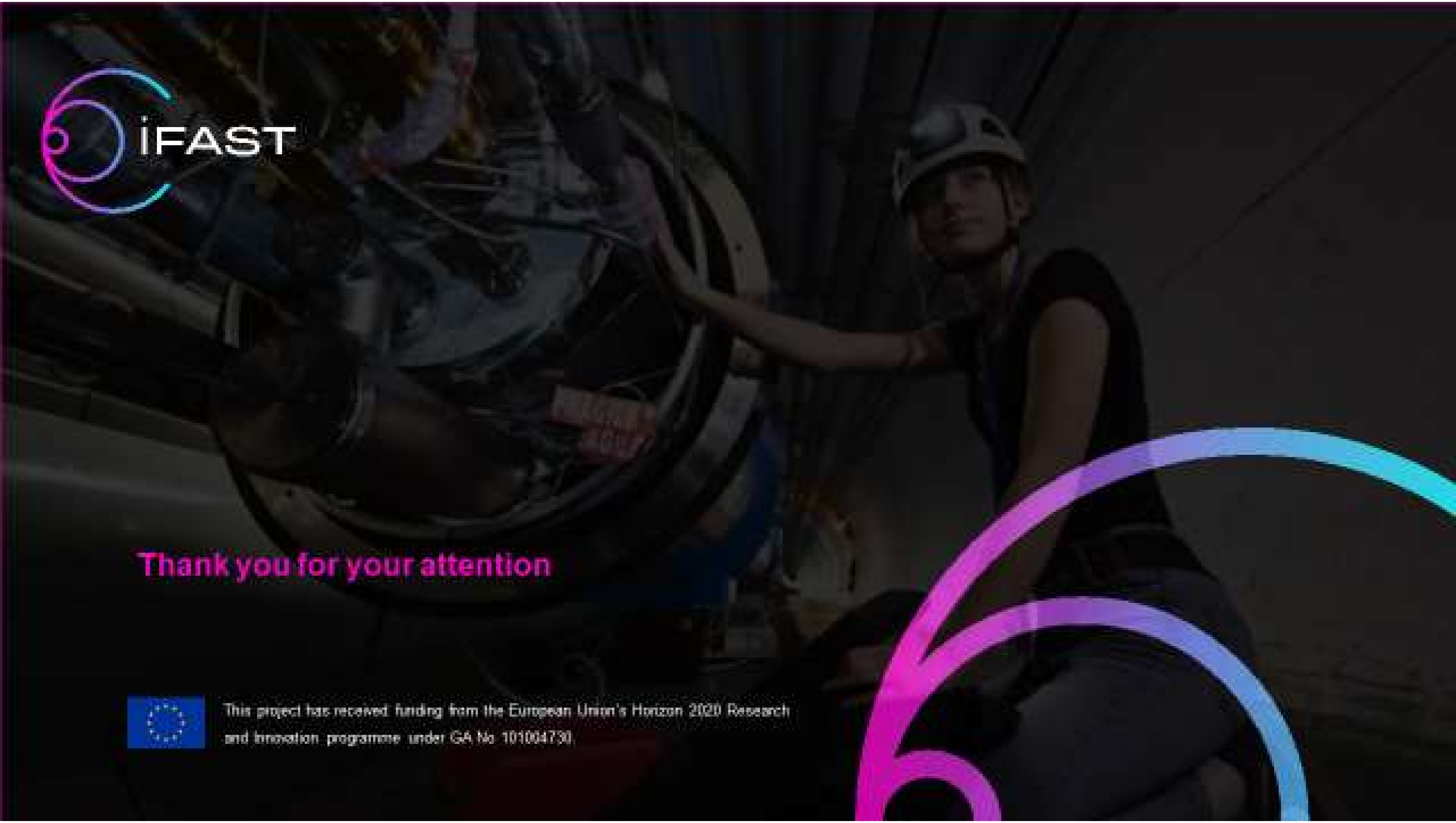
✓ Study of single-phase natural convection regimes as well as boiling convective regimes with different configurations reproducing the cooling channel orientation in the magnets with respect to the residual forces



Sketch of the CroCoDILHe test station

*L.Quettier and B. Baudouy, A magnet system design for reduced gravity environment, Cryogenics 2010

**S. Bagnis et al, Helium pool boiling critical heat flux under various magnetically controlled gravity levels, Int. J.. Heat and Mass Transf., revised version under review.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