Testing of magnets and components at cryogenic temperatures, report from TNA WP9

Marta Bajko CERN

For the ARIES ANNUAL MEETING 2022

ARIES is co-funded by the European Commission Grant Agreement number 73087

WP9 TNA : tasks 9.1 and 9.2.

WP9 (Magnet Testing) offered Transnational Access (TA) to the magnet testing Magnets or instrumentation at CERN (MagNet) and University of Uppsala (Gersemi).

The activity of the MagNet Transnational access has been set up within a Superconducting(Sc) Magnet Test Facility at CERN. This test facility composed by a high number of vertical cryostats and feed boxes, is essentially dedicated to the CERN projects and within those activities is allowing to perform Sc magnet test and qualifications.

The FREIA Laboratory host the "Gersemi" vertical cryostat test facility allowing to test Sc magnets and radio frequency cavities.

ARIES TNA

(https://aries.web.cern.ch/application-and-follow-procedures)

User Selection Pannel and Evaluation Criteria

WP9 has a common Selection Panel for both tasks 9.1 and 9.2. The entire panel has expertise in superconducting magnets. The selection panel is made of experts coming from 4 different worldwide laboratories:

- **Roger Ruber FREIA (DWPL TNA, Gersemi)**
- **Marta Bajko CERN (WPL TNA, MagNet)**
- **GianLuca Sabbi LBNL**
- **Tatsu Nakamoto KEK**

Evaluation criteria

a. Scientific interest for our community or more specifically for our test stands
b. Coming from universities or Institutes not having easy access to our facility
c. Coming from small countries not yet well represented in big EU projects
d. Young researchers, students. Equal opportunities and diversity.
e. Collaboration of different countries or different institutes
f. Potential to make a patent or export its know how towards industry

Total score

Average score

The engagement evolution of the TNA

Intial engagement

Number of projects, users and access units for the magnet testing facilities

Facility	Total no. of projects	Total no. of users	Total no. of access units
MagNet	8	40	1920
Gersemi	8	56	2880

These engagements has been based on the experience of MagNet within the EUCARD2 TNA project that has been successfully completed.

Reviewed engagement (from 2020)

Number of projects, users and access units for the magnet testing facilities

Facility	Total no. of projects	Total no. of users	Total no. of access units
MagNet	5	30	1300
Gersemi	3	15	1800

These engagements has been reviewed to insure at MagNet higher priority CERN projects (HL-LHC) and to cope with the delayed start of the installation recently built in FREIA.

Summary Status of WP9

The TNA is composed by two laboratories: CERN and FREIA.

- MagNet (@CERN)
- GERSEMI (@FREIA)**

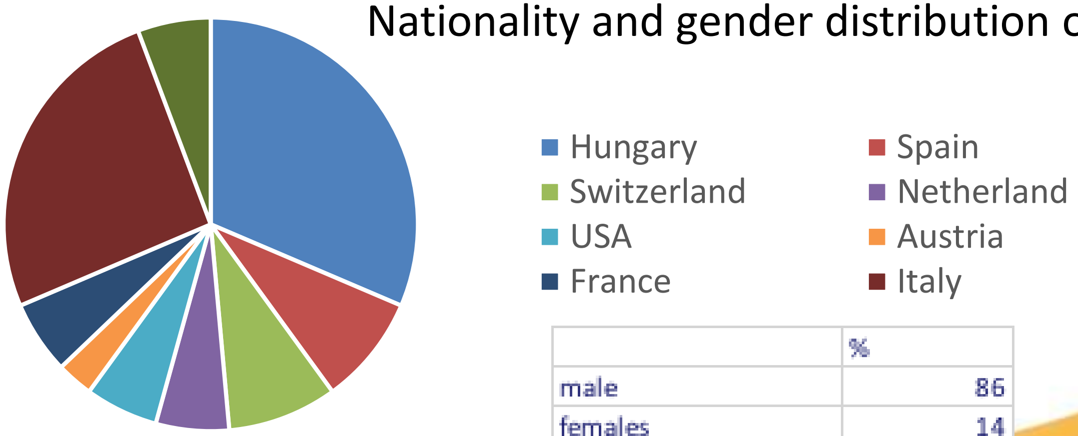
Number of projects, users and access units for the magnet testing facilities

Facility	No. of projects P3	Total P1+P2+ P3	Total no. of projects Annex 1*	No. of users P3	Total P1+P2+ P3	Total no. of users Annex 1*	No. of access units P3	Total P1+P2+ P3	Total no. of access units Annex 1*
MagNet	1	6	5	12	40	30	788	1932	1300
Gersemi	0	0	3	0	0	15	0	0	1,800

* *Updated according 2020 amendment.*

*** Gersemi started late as the test stand construction was longer than expected*

Nationality and gender distribution of users @ MagNet



	%
male	86
females	14

Summary of PROJECT in ARIES TNA WP9 Task 9.1.MagNet

Sushi

To demonstrate the capability of shielding a NbTi/Nb/Cu for a massless septum magnet.

NbTi/Nb/Cu multilayer shield for the superconducting shield (SuShi) septum

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arXiv:1809.04330v1 [physics.acc-ph] 12 Sep 2018

***Abstract*—A passive superconducting shield was proposed earlier to realize a high-field (3-4 T) septum magnet for the Future Circular Collider. This paper presents the experimental results of a potential shield material, a NbTi/Nb/Cu multilayer sheet. A cylindrical shield was constructed from two halves, each consisting of 4 layers with a total thickness of 3.2 mm, and inserted into the bore of a spare LHC dipole corrector magnet (MCBY). At 4.2 K, up to about 3.1 T at the shield's surface only a leakage field of 12.5 mT was measured inside the shield. This can be attributed to the mis-alignment of the two half cylinders, as confirmed by finite element simulations. With a better configuration we estimate the shield's attenuation to be better than 4×10^{-5}, acceptable for the intended application. Above 3.1 T the field penetrated smoothly. Below that limit no flux jumps were observed even at the highest achievable ramp rate of more than 50 mT/s at the shield's surface. A 'degaussing' cycle was used to eliminate the effects of the field trapped in the thick wall of the shield, which could otherwise distort the homogeneous field pattern at the extracted beam's position. At 1.9 K the shield's performance was superior to that at 4.2 K, but it suffered from flux jumps.**

***Index Terms*—superconducting shield, NbTi, septum magnet, Future Circular Collider, accelerator**

I. INTRODUCTION

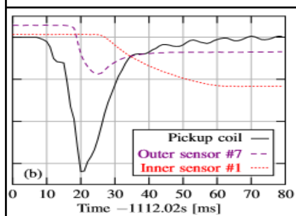
The Future Circular Collider (FCC) study was launched in 2014 to identify the key challenges of the next-generation particle collider of the post-LHC era, propose technical solutions and establish a baseline design. In its early phase the parameters are subject to frequent changes. The current values of the relevant parameters are shown in Table I. One of the key problems of the proton-proton ring is the high beam rigidity and the very strong magnetic fields required to manipulate this beam. A new generation of superconducting dipole magnets using Nb_3Sn conductors is being developed to produce the 16 T field necessary to keep the beam on orbit. The beam extraction system uses so-called septum magnets, which create

TABLE I
RELEVANT PARAMETERS OF THE FUTURE CIRCULAR COLLIDER

Parameter	Symbol	Value	Unit
Circumference		80-100	km
Collision energy		50+50	TeV
Injection energy		1.3/3.3	TeV
Septum field homogeneity		±1.5	%
Septum integrated field	$\int B\,dl$	190	Tm
Deflection by the septa	α_s	1.14	mrad
Deflection by the kickers	α_k	0.13	mrad
Maximum apparent septum thickness		25	mm

materials, including beam pipes and beam screens between the two regions) needs to be minimized in order to relax the requirements on the kicker magnets' strength. The target value is 25 mm, which corresponds to a thickness of 17-18 mm of the shield itself, without beam pipes and beam screens. These lead to a very sharp transition between the high-field and no-field regions of the septa. These requirements are even more important for the high-energy LHC (HE-LHC) option (an alternative to the FCC), which would use FCC technology in the LHC tunnel, where space is very limited.

In a recent proposal [1] this field configuration would be realized by the combination of a superconducting magnet and a passive superconducting shield, referred to as a superconducting shield (SuShi) septum in the following. The geometry of the shield and the magnet winding need to be optimized simultaneously to give the required field homogeneity outside the shield. While a complete demonstrator prototype creating this homogeneous field pattern would be a major project including the design and construction of a special superconducting magnet, different superconducting shield materials can be easily tested in simpler setups and existing magnets. These tests can study the performance of the shield materials in general, with



Even though the shield's performance was better at 1.9 K in terms of shielding efficiency and relaxation rates, frequently occurring flux jumps make this temperature inapplicable. The observed properties of the material make it an ideal candidate for the realization of a SuShi septum magnet. Unfortunately the material is a discontinued product of Nippon Steel Ltd., and its availability is not clear even on the short term. The material for the reported tests was purchased from a small remaining stock of semi-finished products of the company, post-processed to the final thickness and specifications by a private company in Japan. If the material can be produced in larger quantities, the unit cost is expected to be reduced.

MgB_2, another candidate material, also demonstrated an excellent shielding performance in a similar test. It supported 3 T on its surface with a wall thickness of 8.5 mm, perfectly shielding its interior [12]. However, it suffered from flux jumps when the external field was ramped down to zero. This material is relatively cheap and easy to produce, and if the

2020 research and innovation programme under grant agreement No 730871 (ARIES), and from the Hungarian National Research, Development and Innovation Office under grant #K124945.

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[1] D. Barna, "High field septum magnet using a superconducting shield for the Future Circular Collider," Phys. Rev. Accel. Beams, vol. 20, no. 4, p. 041002, 2017. [Online]. Available: http://link.aps.org/doi/10.1103/PhysRevAccelBeams.20.041002
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[3] I. Itoh, K. Fujisawa, and H. Otsuka, "NbTi/Nb/Cu Multilayer Composite Materials for Superconducting Magnetic Shielding," Nippon Steel Tech. Rep., vol. 85, p. 118, 2002. [Online]. Available: http://www.nssmc.com/en/tech/report/nsc/pdf/8522.pdf
[4] A. Yamamoto, Y. Makida, K. Tanaka, F. Krienen, B. Roberts, H. Brown, G. Bunce, G. Danby, M. G-Perdekamp, H. Hseuh, L. Jia, Y. Lee, M. Mapes, W. Meng, W. Morse, C. Pai,

Barna, is involving now eastern European and Japanese industry to a larger project: building the septa and the shield itself.

They uses a vertical cryostat and a magnet.
440 Accesses

The ***difficulties*** for the Sushi team is […] to protect the superconductor and even before to detect and distinguish between a ***quench and a flux jump.***

Automated HV Testing of Sc Coils

To automat High Voltage Testing of Superconducting Coils

Varadine is proud of ***his students*** having developed a system that turned to be efficient in the test and found users at bug laboratories

- New release has been tested in November
- Hardware and software renewed
- New functionalities (safety & HV feature) implemented

This equipment, developed by MSc students found users:@ GSI for SFRS magnets and @ CERN SM18 for HL-LHC magnets!!

They uses any cryostat (horizontal or vertical) with any magnet.
288 Accesses

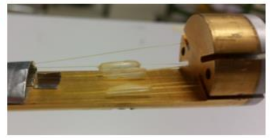
Test @ MagNet

Monitoring by distributed optical fibre sensors

To demonstrate the feasibility of the quench monitoring in a SC link and and HTS magnet.

CHARACTERIZATION OF SENSORS

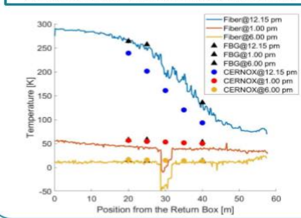
Calibration bare sensors → Coating → Calibration coated sensors



Polymers, like PMMA or epoxy, result to be the best candidates to improve the FBG temperature sensitivity. They also respond to requirements of coating uniformity and adhesion to the interface fiber-material.

Challenge: MATERIAL

SENSORING TRANSMISSION LINES

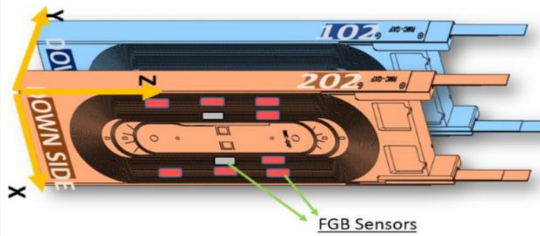


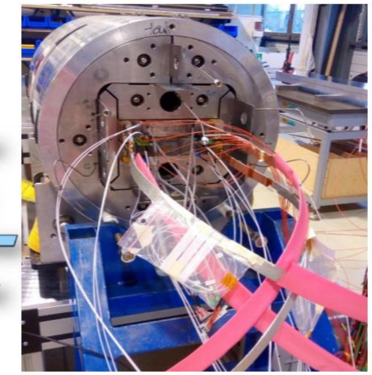
The goal is to monitor the temperature of the He gas along the line. For their validation, the FBG based sensors have been compared during the test to the CERNOX commonly used in the test station.

Challenge: INSTALLATION

SENSORING MAGNETS

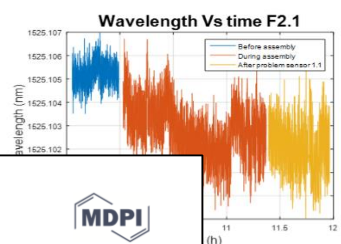
Installation of the fibers during the integration steps. Environment: High Magnetic Field, High Current, High Voltage, Low Temperature.

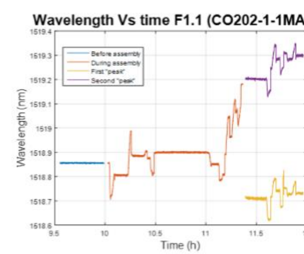




Monitoring during the impregnation and assembly procedures. Validating the mechanical model and understanding where the forces become larger, FBG sensors are able to measure the strain distribution in the coils during the powering or on quench detection.

The installation of the sensors is very important because the impact of the strain could damage them. Below, the plot shows how a temperature sensor changes its behavior to a strain sensor, and then it gets double signal.





...ting to validate the mechanical stress inside and how it affects to the coils and the sensors. It is needed ... strain discriminating the temperatu...

A challe... transmis...

L. Palmieri is willing to take

Article

Distributed cryogenic temperatures monitoring by mean of OFDR

Leonardo Marcon[1,2,*], Antonella Chiuchiolo[3], Bernardo Castaldo[2], Hugues Bajas[2], Andrea Galtarossa[1], Marta Bajko[2], and Luca Palmieri[1]

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2 CERN - European Organization for Nuclear Research, Espl. des Particules 1, 1211 Meyrin, Switzerland.
3 GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany.
* Correspondence: leonardo.marcon@cern.ch

Abstract: The properties of optical fiber sensors makes them ideal candidates for applications at cryogenic temperatures, like the monitoring of superconducting devices. The implementation of such systems however is not straightforward as the fiber thermal response is non-linear and

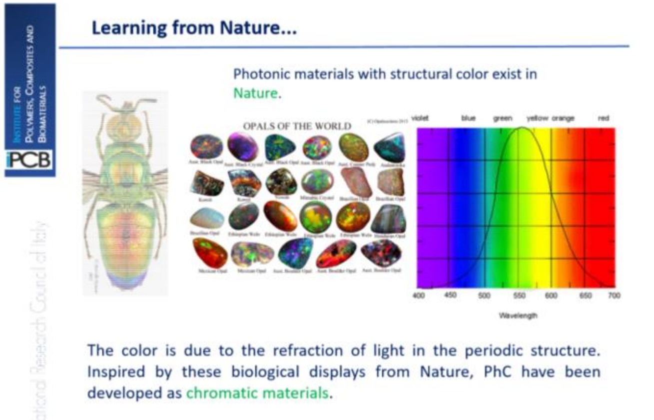
They uses a magnets and transmission lines in development at CERN
192 Accesses

...ia, Virginia.

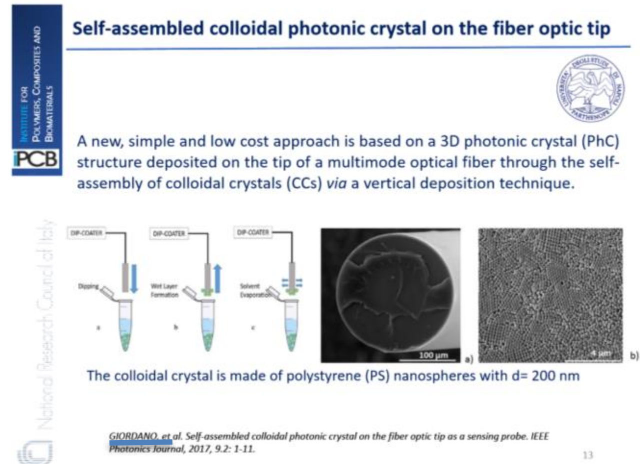
Test @ MagNet

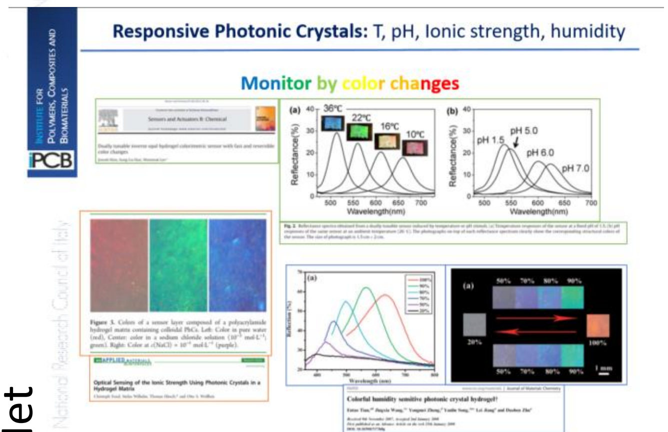
CRYOPAL

To find new materials usable for the temperature monitoring at cryogenic conditions.



Inspired by nature :
Giordano et all,
our old users of the facility, proposed to create and TEST in MagNet new sensors





They uses the cryo cooler
24 Accesses

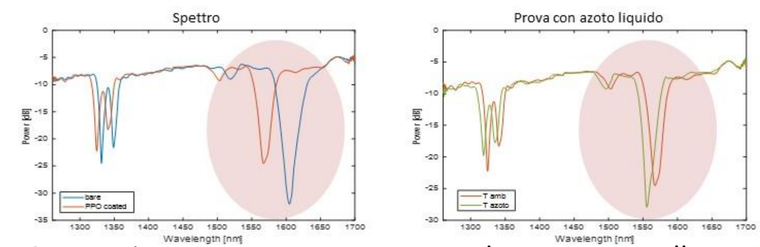
First test during the first discussions on the installations

LPG_PPO_400_2016_05_20_03

Tipo: LPG coating PPO
Modo: LP07

Giorno 23
Connettore 14

Shift deposizione = -39 nm
Shift azoto = -12 nm



Thermal Response Characterization of Different Optical Fibers Samples at Cryogenic Temperatures by Leonardo Marcon et all , [27th International Conference on Optical Fiber Sensors .]

Cryogenic test facility instrumentation with fiber optic and fiber optic sensors for testing superconducting accelerator magnets" (December 2017, IOP Conference Series Materials Science and Engineering 278(1):012082. DOI: 10.1088/1757-899X/278/1/012082)

Test @ MagNet

ReBCO –CORC-CIC

ReBCO CORC-CIC

For the purpose of future superconducting detector magnets and busbars for accelerator application, a development is on-going of ReBCO-based Conductor-On-Round-Core Cable-In-Conduit (ReBCO-CORC-CIC) conductors. This activity has already been on- going for some five years, and in the coming months it is foreseen to test a prototype conductor in the SULTAN test facility at EPFL, location PSI, in a 12 T magnetic field back-ground and at variable temperature.

Before shipping the conductor to EPFL/PSI for test at 4.3 K, the test of the conductor at 77 K (in liquid nitrogen) is foreseen and without back-ground field, which involves running some 20 kA current through the sample, measuring the voltage taps on the conductor, and checking the sensors.

Expert in the Sc magnet domains: **<u>Ten Kate et all</u>**, applied for a test at 77 K and high current

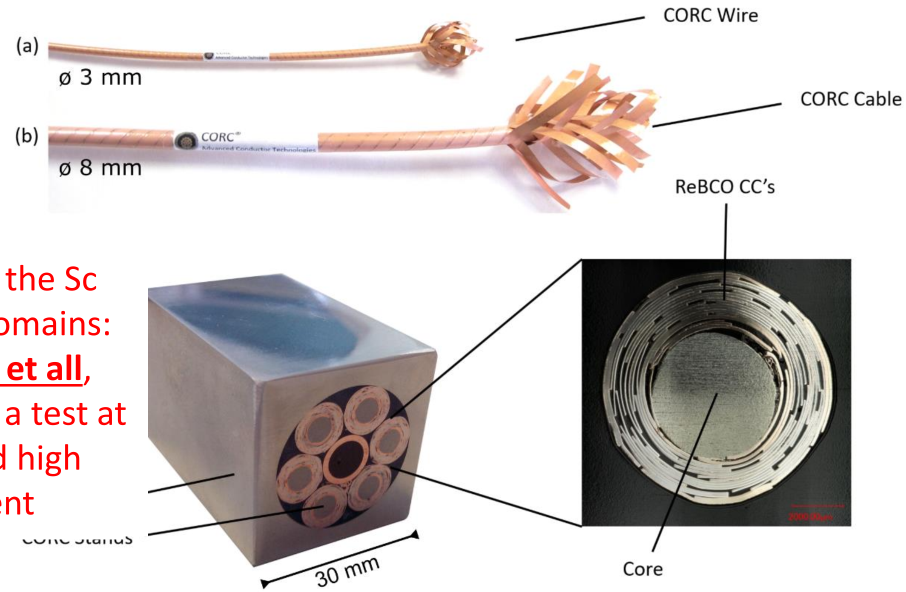


Figure 1.4: Picture of a thin flexible CORC wire and a thicker CORC cable/strand (courtesy of D. van der Laan) and of a multi-strand Cable-In-Conduit Conductor.

https://ris.utwente.nl/ws/portalfiles/portal/63693761/thesis_final_Tim_Mulder.pdf

The 5 users used 24 access to a high current power converter

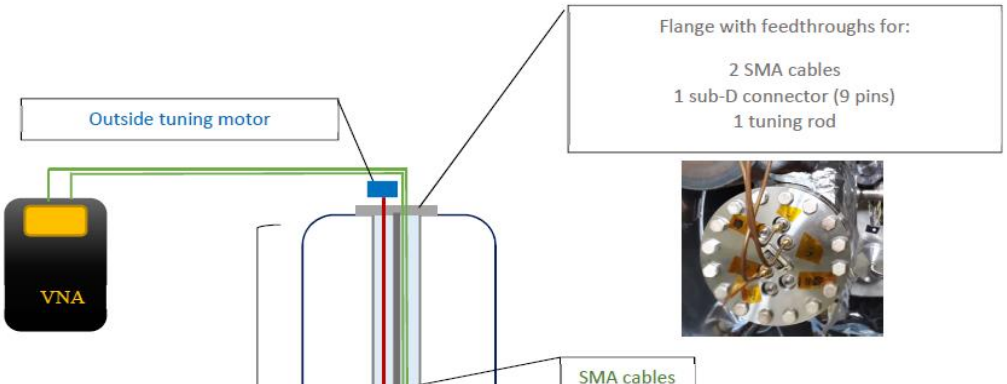
RADES

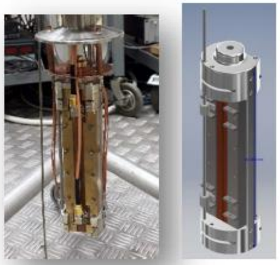
RADES

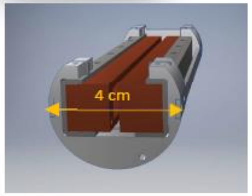
(Relic Axion Detector Exploratory Setup)
is a project with the goal of directly searching for axion dark matter employing custom-made microwave filters in magnetic dipole fields.

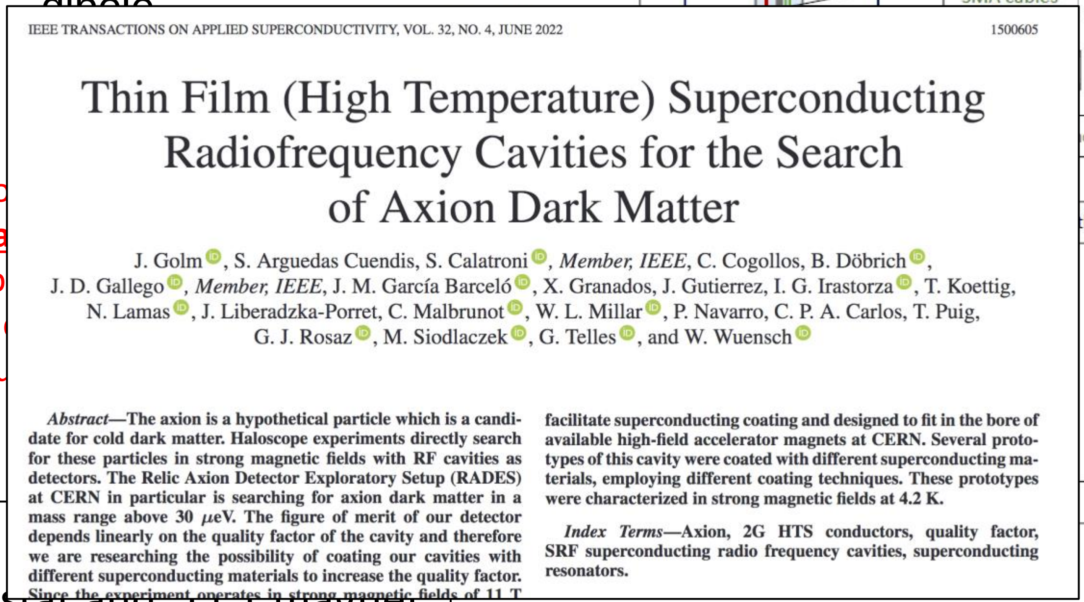
With a final goal to
Axions: **Irastorza**
asked for equip
qualification for a
at low temperatu
high magnetic

The 8 users
vertical cryostat and 11 T magnet









IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 32, NO. 4, JUNE 2022 1500605

Thin Film (High Temperature) Superconducting Radiofrequency Cavities for the Search of Axion Dark Matter

J. Golm, S. Arguedas Cuendis, S. Calatroni, *Member, IEEE*, C. Cogollos, B. Döbrich, J. D. Gallego, *Member, IEEE*, J. M. García Barceló, X. Granados, J. Gutierrez, I. G. Irastorza, T. Koettig, N. Lamas, J. Liberadzka-Porret, C. Malbrunot, W. L. Millar, P. Navarro, C. P. A. Carlos, T. Puig, G. J. Rosaz, M. Siodlaczek, G. Telles, and W. Wuensch

Abstract—The axion is a hypothetical particle which is a candidate for cold dark matter. Haloscope experiments directly search for these particles in strong magnetic fields with RF cavities as detectors. The Relic Axion Detector Exploratory Setup (RADES) at CERN in particular is searching for axion dark matter in a mass range above 30 μeV. The figure of merit of our detector depends linearly on the quality factor of the cavity and therefore we are researching the possibility of coating our cavities with different superconducting materials to increase the quality factor. Since the experiment operates in strong magnetic fields of 11 T facilitate superconducting coating and designed to fit in the bore of available high-field accelerator magnets at CERN. Several prototypes of this cavity were coated with different superconducting materials, employing different coating techniques. These prototypes were characterized in strong magnetic fields at 4.2 K.

Index Terms—Axion, 2G HTS conductors, quality factor, SRF superconducting radio frequency cavities, superconducting resonators.

https://arxiv.org/pdf/2110.01296.pdf

Summary of PROJECT in ARIES TNA WP9 Task 9.2.GERSEMI

Star up of "Gersemi" Facility at FREIA, Uppsala University

- The FREIA Laboratory started preparation of the "Gersemi" vertical cryostat test facility in 2014 within a collaboration agreement between CERN and Sweden. After a one year design phase, a public tender was published in 2015. The commercial contract for the manufacturing and installation of the vertical cryostat system was signed in April 2016.
- The delivery of the vertical cryostat system was delayed due to technical difficulties during manufacturing. The vertical cryostat, liquid bath insert, valve box, and transfer lines were finally completed during January 2018. Factory tests followed and the complete system was transported to Uppsala in several *parts between March and May 2018*. Installation work was completed during June, and a first commissioning phase started end June with some minor equipment missing from the manufacturers delivery scope. *This revealed some minor bugs* in the control software which were quickly fixed. During August a second commissioning phase was started continuing into September. *This revealed a cold lea*k in the liquid helium circuit. After extensive testing the so-called valve box cryostat was opened and the leak could be located at one cold valve. The valve was dismounted by FREIA personnel and shipped back to the sub-contractor of the manufacturer.
- At present the test stand is completed and operational

Users event @ GERSEMI

3rd International Workshop of the Superconducting Magnets Test Stands

11-12 June 2019
Ångström laboratory
Europe/Stockholm timezone

With 45 participants and 35 talks

Overview

- Industrial Exhibition
- Timetable
- Contribution List

UPPSALA UNIVERSITET

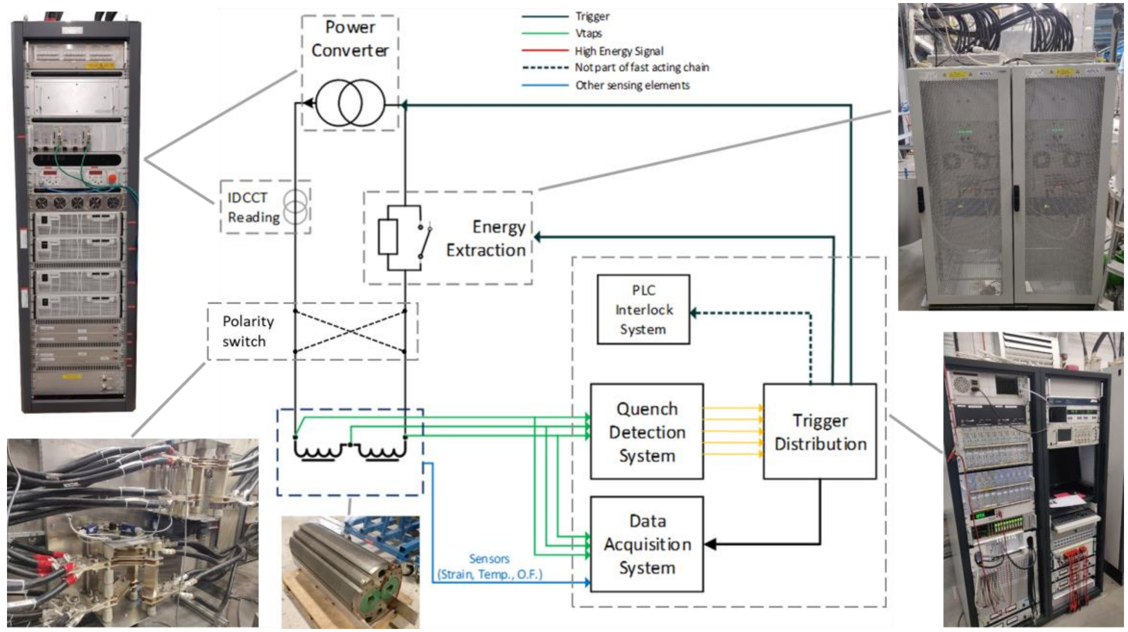
HiLumi HL-LHC PROJECT

ARIES

FREIA

Ångström Laboratory, Lägerhydddsvägen 1, Uppsala

WP9.2 The *Gersemi* TNA



2x 2 kA power supplies
2x energy extraction

Polarity reversing switch

Safety PLC and control system

Test of SC magnets (<350kJ)

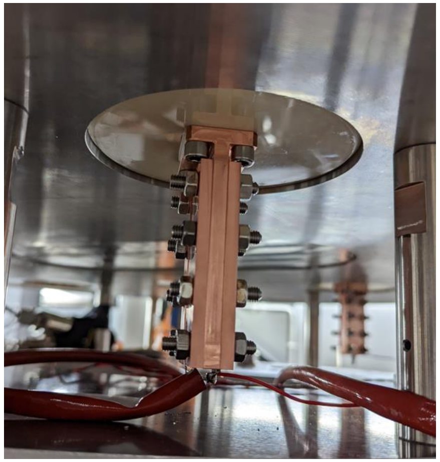
- 3.2m x ø1.1m total volume
- 2.65m x ø1.1m below lambda plate

48 HF acquisition channels
72 LF acquisition channels
1 uQDS (to detect symmetric quenches)

Gersemi is a facility to test superconducting magnets at 4.3 K and 1.9 K

Recent Improvements@ GERSEMI

Fully instrumented insert with new copper clamps for the magnet's leads

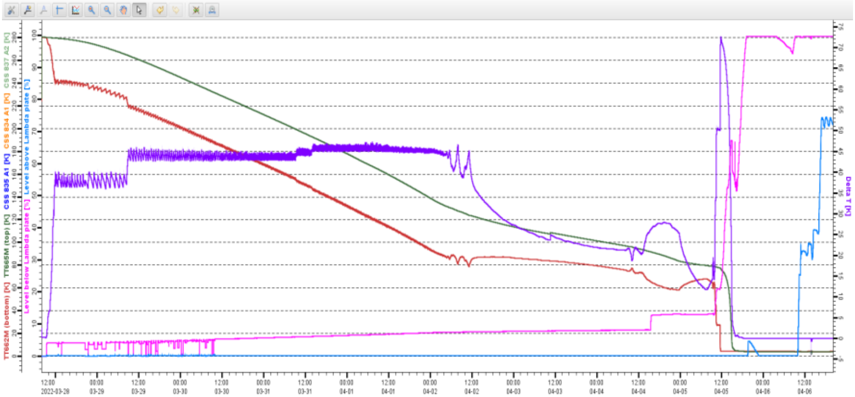


Copper clamps below the lambda plate to attach the magnet's leads to the insert's leads (above the lambda plate)

Rotating sleigh

Platform to rotate magnets – tested up to 5 t

Controlled cooldown of long magnet from 300K to 4.3K (in 10 days of 2.2 m long magnet)



Future tests and improvements @ GERSEMI

- Improve the HV breakdowns on the insert, which is currently limited by some connectors on the top flange

- Test the SuShi CCT magnet at 450 A and 4.3 K

This test will consist of the first powering of the CCT (canted cosine theta) SuShi (Superconducting Shield) magnet. This magnet uses a CCT like magnet with a superconducting shield installed in its aperture to create a field-free channel

Summary

- ARIES TNA within WP9 gave the great opportunity of a high number of users from 9 different countries to the the unique infrastructure as is the MagNet to perform important measurements and qualifications of Sc magnets, Sc conductors or instrumentations of 6 different scientific projects.
- In all cases the test infrastructure needed was a key point as their needs were in a specified domain where low temperature, high current and high magnetic fields were crucial.
- The Gersemi test facility , once set up within a collaboration agreement between CERN and Sweden, could made this new facility known by the community and start their "new carrier" in this domain complementing its " big sister" the MagNet for the next decades.
- As an image of the CERN international collaboration tradition, the ARIES project founded by the EU, could once again bring together the scientific community of a precise domain, sharing infrastructures and services now together with a Swedish University.
- I close here this chapter within ARIES TNA WP9 and hope that even without a formal project, the tradition of the TNA will be encored at CERN and in the EU institutions and will continued in a way or other in the next coming years at the service of science.