Study of magnetic shielding for superconducting cavities

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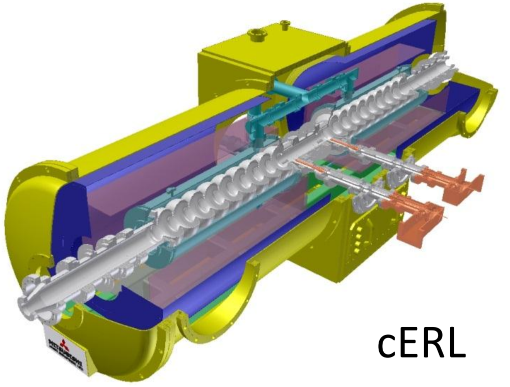

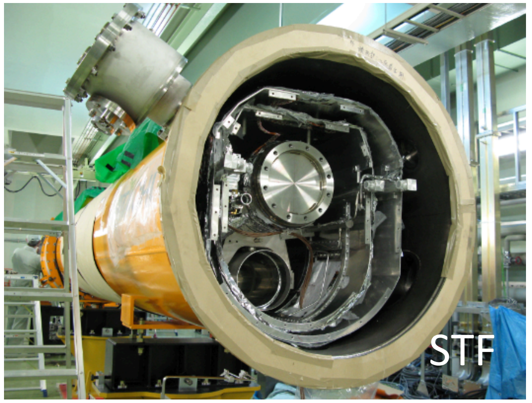

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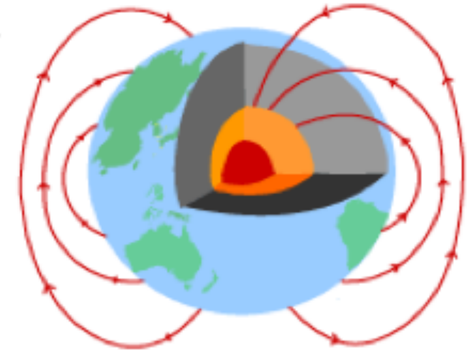
Contents

- Introduction
  - What we need
  - What we learned
- Permeability measurement 2012
  - Evaluation of the variation in permeability among samples from the same material.
  - Permeability dependence on heat-treatment temperature.
- Application to cERL (KEK) and XFEL (CEA)
- Proposal for 2013-2014

Introduction



- Magnetic shielding is a key technology for superconducting RF cavities.
- The acceptable level of ambient magnetic field depends on factors such as operating RF frequency and acceleration gradient, but it can be as low as a few mG.
- Shielding of the earth's magnetic field (~500 mG, depending on the environment).
- ~10 % of the cost of an SC cavity system comes from magnetic shielding (private communication with S. Yamaguchi, head of the KEK LC division).

A factor of 100 reduction,
from ~500 mG down to ~5 mG, is needed.

Finding a good enough material and establishing a good and solid technology are important.

What we learned

From permeability measurements of various Ni-content alloys materials

- Permeability depends on material and manufacturer
- Permeability decreases at cryogenic temperature

Effects of the heat-treatment and mechanical strain

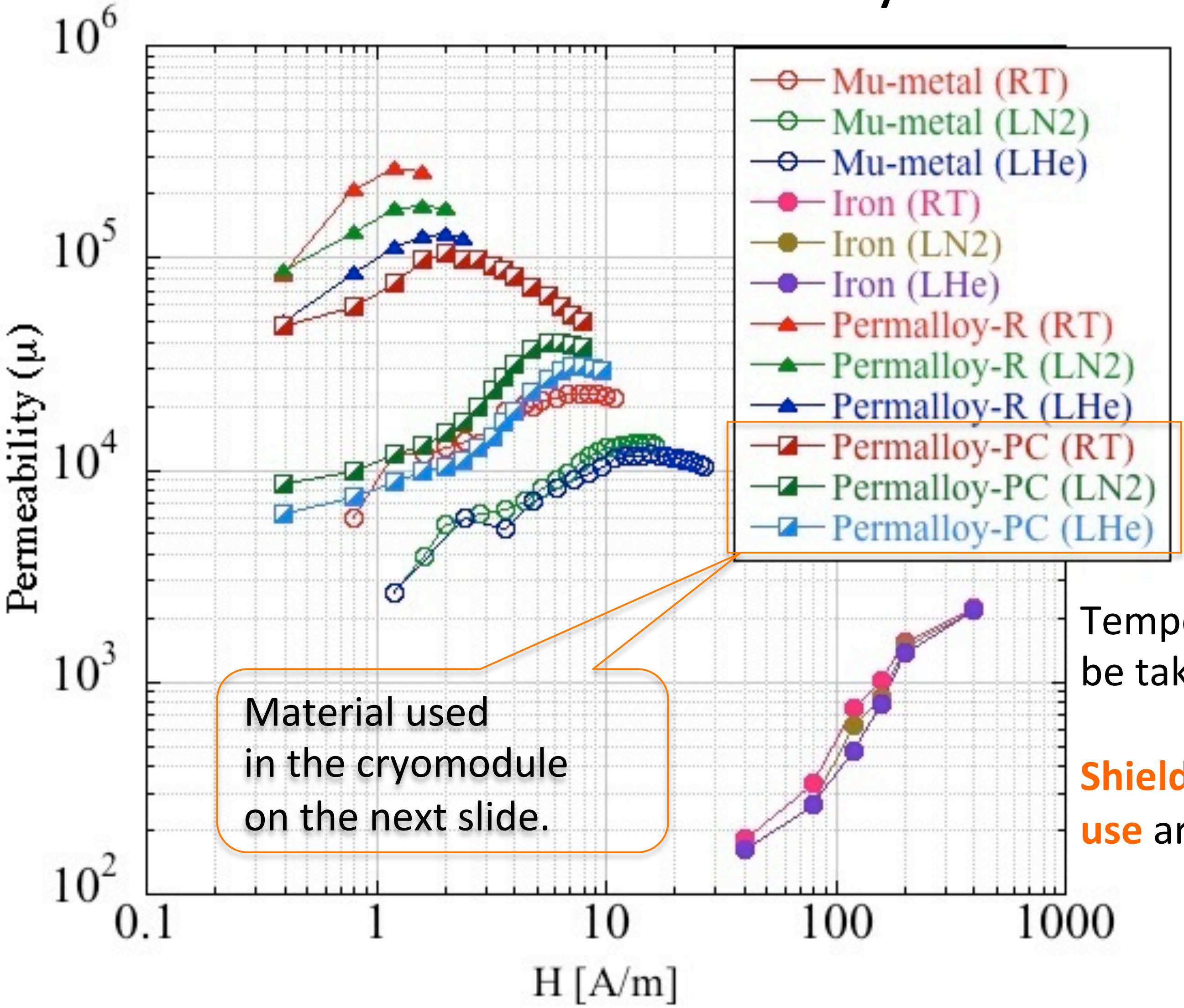
- Cooling rate is important.
- Significant decrease in permeability due to deformation is observed.

Choosing proper shielding material is necessary though not sufficient.

- It is important to understand the conditions needed to reproduce the “good” permeabilities, especially in the case of a large-scale production.

Standard shielding materials:
Permeability decreases at cryogenic temperatures

Permeability dependence on temperature is confirmed by measurements

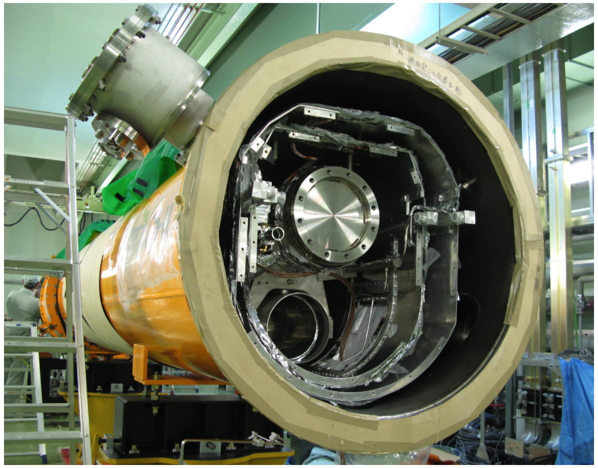


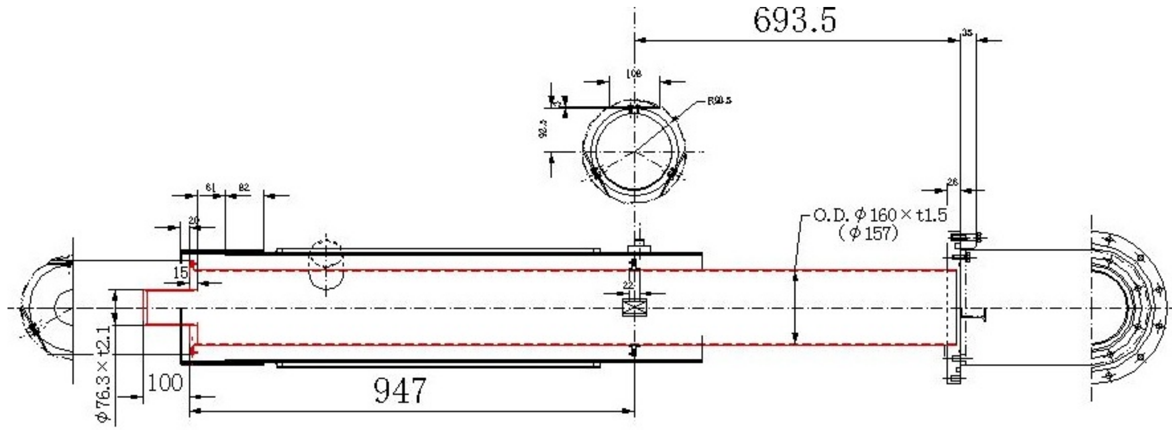
Temperature dependence should be taken into account.

Shielding materials for cryogenic use are commercially available.

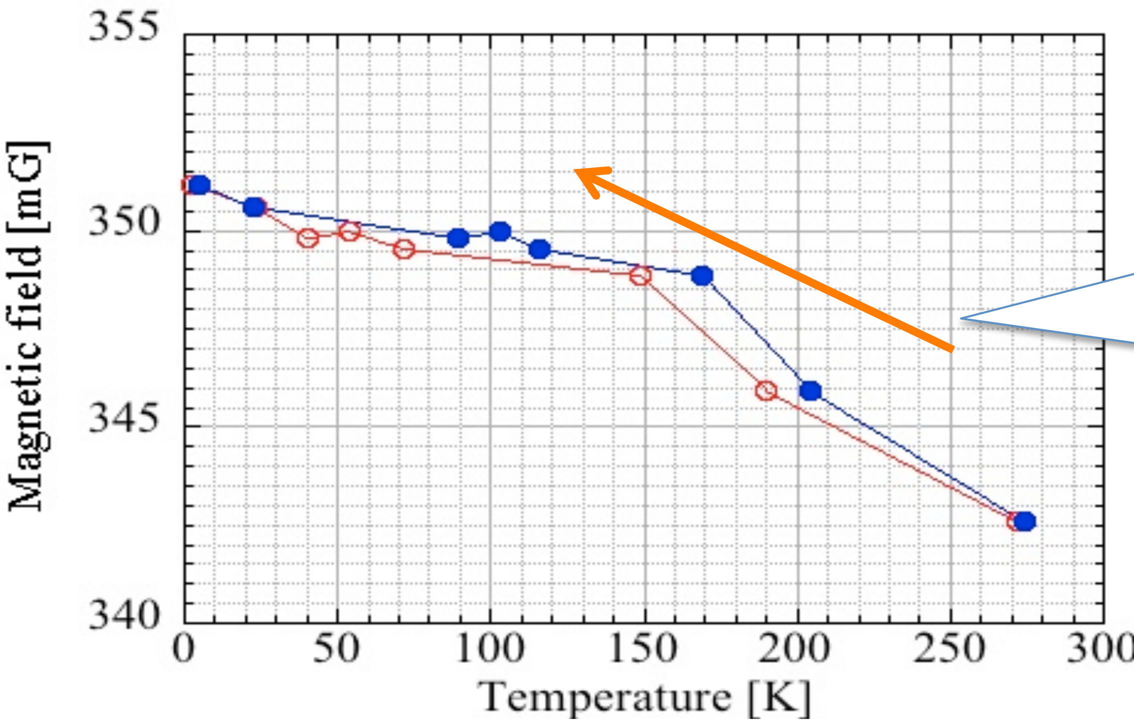
K. Tsuchiya, et.al., "Cryomodule development for superconducting RF Test Facility (STF) at KEK," Proc. of the 2006 European Particle Accelerator Conference, Edinburgh, Scotland, 26-30 June 2006, pp.505-507.

Standard shielding materials:
Permeability decreases at cryogenic temperatures
and the shielding effect also decreases.





Ambient magnetic field measured at a fixed point during the warm-up process of the cryomodule.

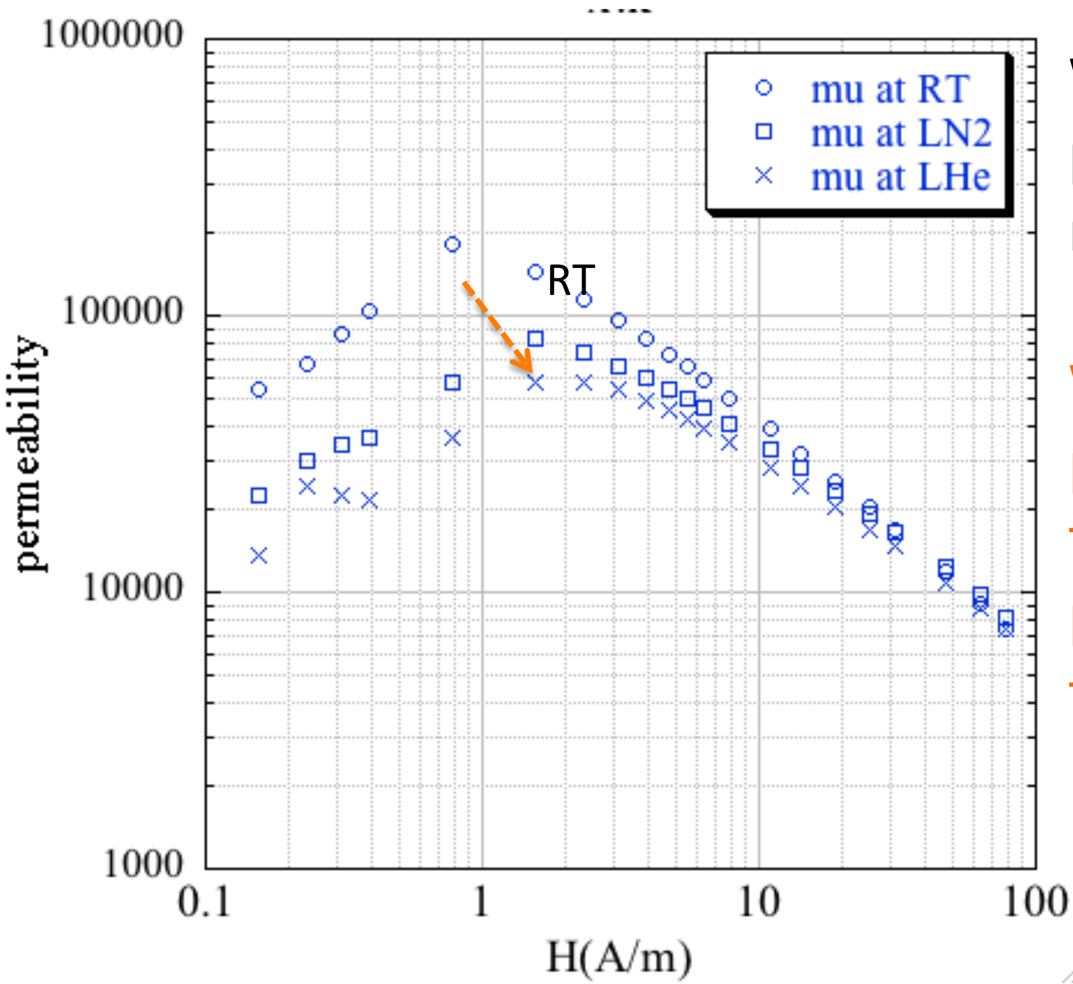


Shielding effect reduced at lower temperature, due to degradation of permeability of the shielding material.

The magnetic field is plotted against both the temperature of the helium vessel (open circles) and that of the 5 K radiation shield (solid circles). A clear correlation between the shielding effect and the temperature is seen.

What about
Shielding materials for cryogenic use?
More expensive than mu-metal, for example.

Shielding materials for cryogenic use



We measured the permeability of shielding material for cryogenic use.

We still see degradation in performance at cryogenic temperature, with measured permeability being lower than the "catalog" value.

What we learned

From permeability measurements of various Ni-content alloys materials

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Effects of the heat-treatment and mechanical strain

- Cooling rate is important.
- Significant decrease in permeability due to deformation is observed.

Choosing proper shielding material is necessary though not sufficient.

- It is important to understand the conditions needed to reproduce the "good" permeabilities, especially in the case of a large-scale production.

Study of materials for magnetic shields in the framework of the FJPPL collaboration

Progress in 2012

- Evaluation of the stability of the measurement

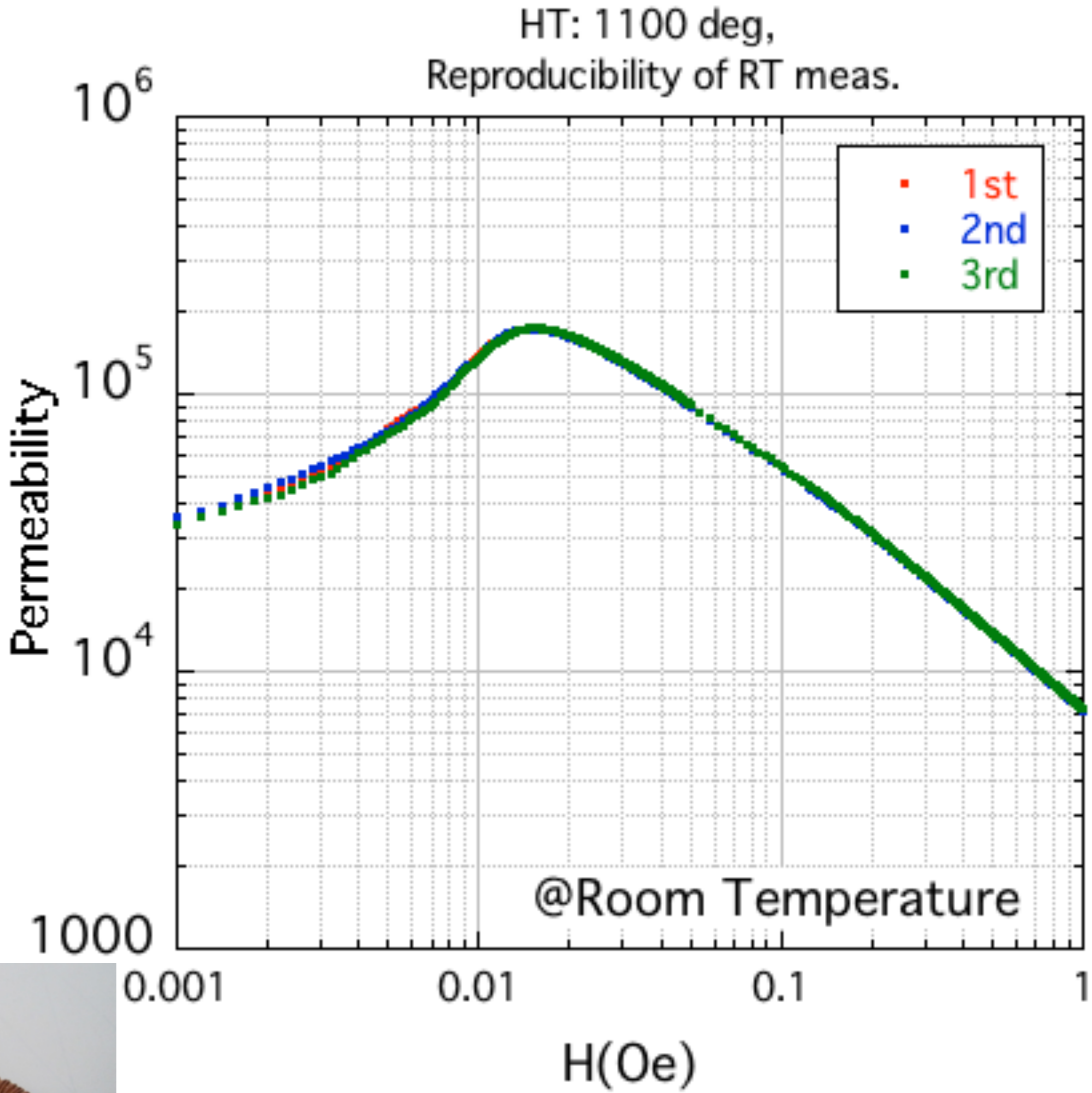
We made repeated measurements at both room temperature and liquid helium temperature using the same sample. Good measurement reproducibility was obtained at both temperatures.

- Evaluation of variation among samples from the same material

The variation was examined using 20 ring samples cut out from the same sheet of Cryophy and heat-treated in the same oven. The permeability measurements were then carried out for the 20 samples at both room temperature and liquid helium temperature.
The variation in the permeability among the 20 samples is about 5% at each temperature.

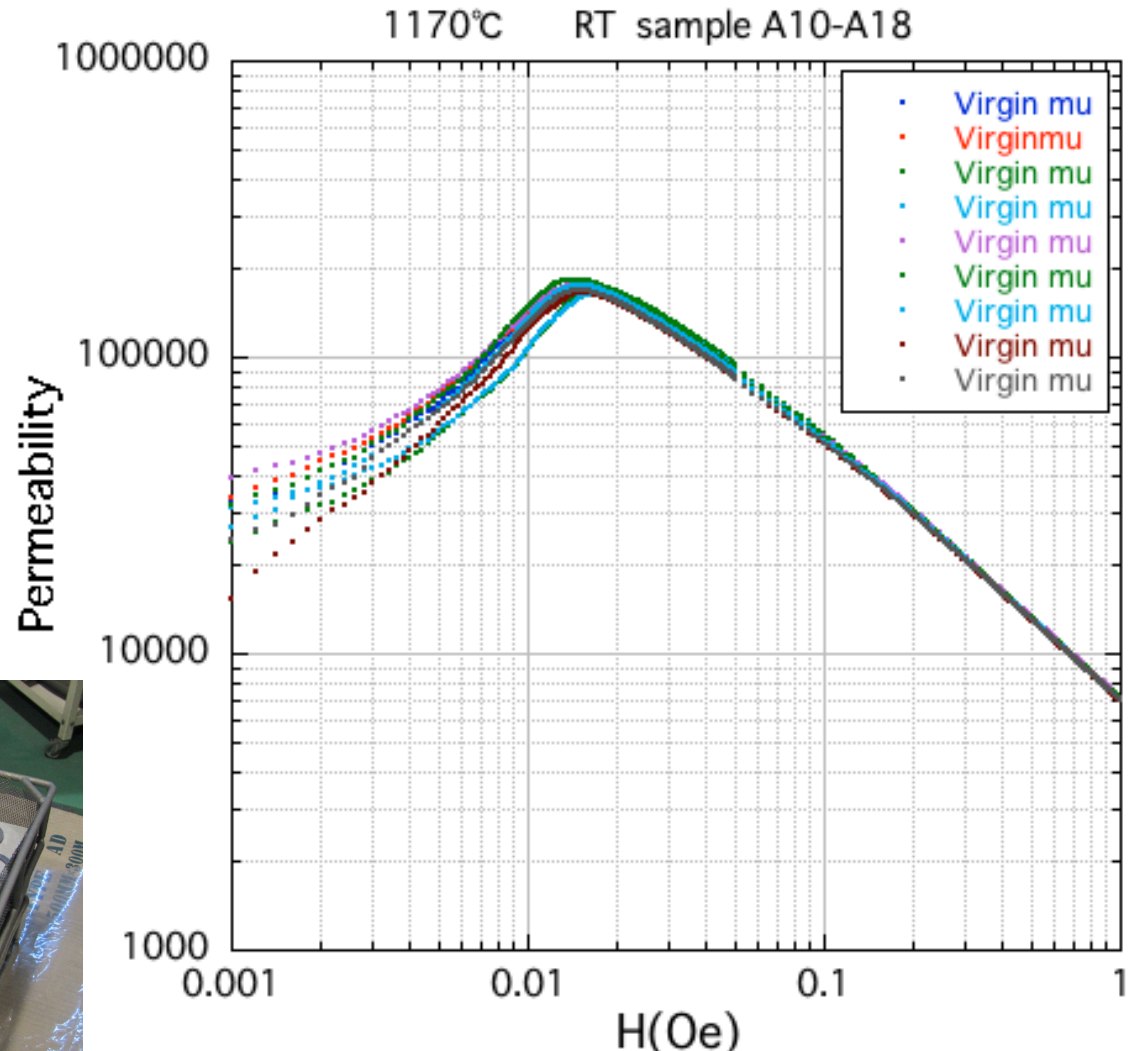
High permeability material for cryogenic applications

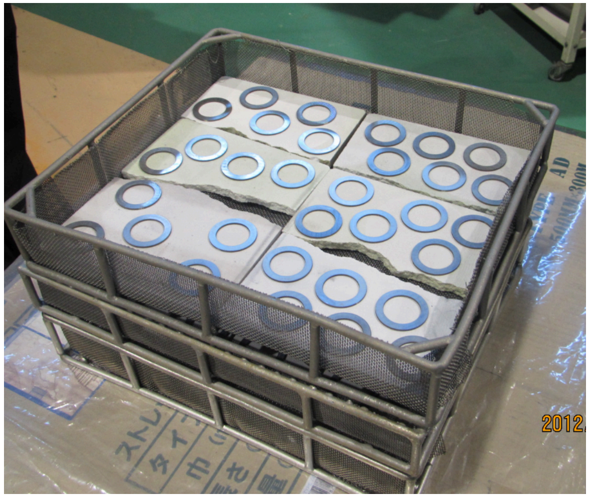
Stability of the measurement



Good reproducibility

Variation among samples

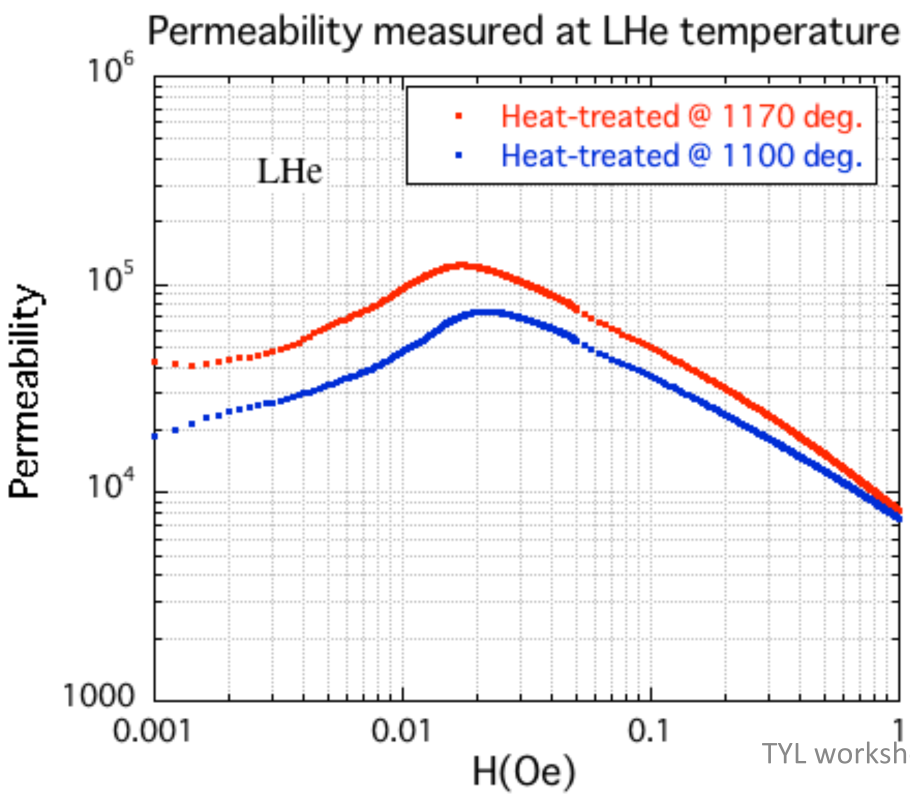




Study of materials for magnetic shields in the framework of the FJPPL collaboration

Progress in 2012

- Permeability dependence on the heat-treatment temperature was examined using Cryophy. A factor of about two difference in maximum permeability is seen between the Cryophy samples heat-treated at 1170 degrees and those heat-treated at 1100 degrees.

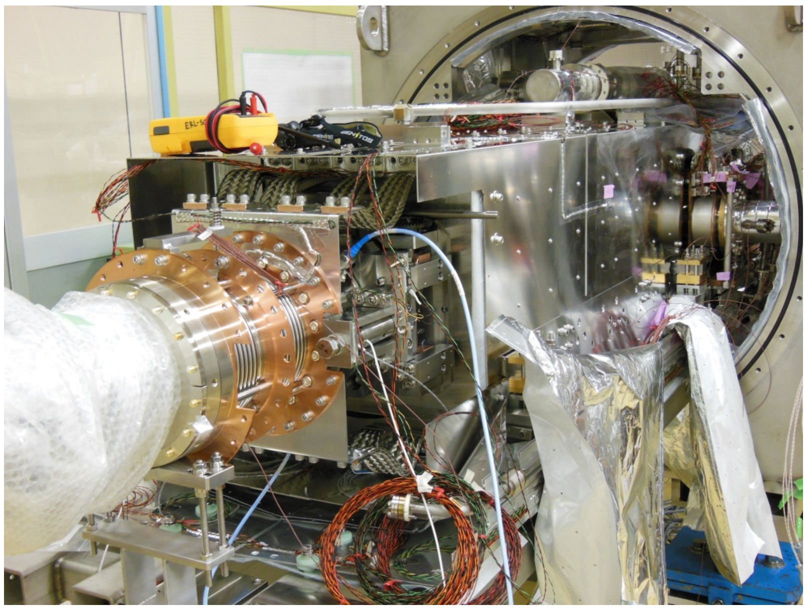


Oven used for 1170 degree
Heat treating for moisture-free hydrogen atmosphere.

Application to XFEL and cERL

Progress in 2012

- Information was exchanged between CEA and KEK.
- We both chose Cryophy for the X-FEL (CEA) and cERL (KEK)



cERL (KEK) Main Linac Cavities
A Q-value of 10^{10} was achieved in the high power test in December 2012, indicating that the remnant magnetic field is less than 10 mG.

[1] Mika Masuzawa, et al. "Magnetic Properties of Shielding Materials for Superconducting Cavities" *IEEE Transactions on Applied Superconductivity*, 2012. Volume: 22, Issue: 3 Page(s): 3500104.

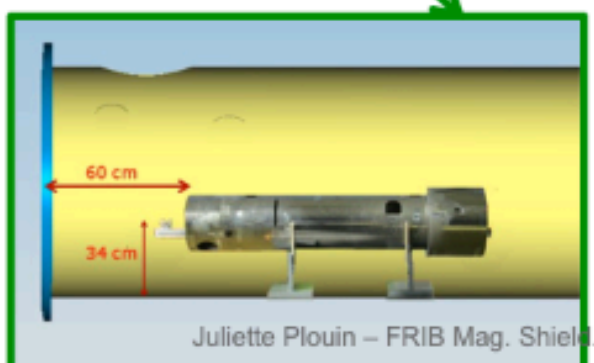
[2] Juliette Plouin, "Magnetic Shielding Activities for IFMIF/CEA and Study on the Magnetic Shielding in the FJPPL Collaboration", presented at "MSU FRIB Workshop on Magnetic Shielding for Cryomodules" Feb.4-6, 2013.

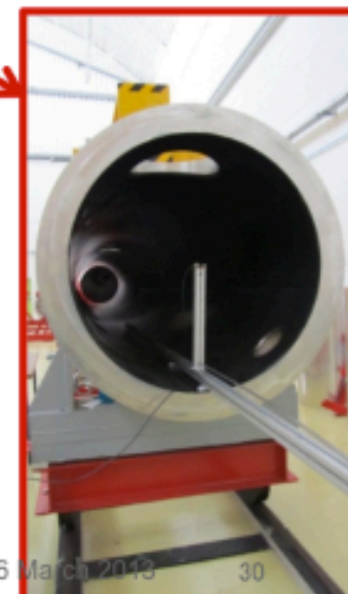
MAGNETIC SHIELD MEASUREMENTS @ CEA

B field measurement with a Gaussmeter

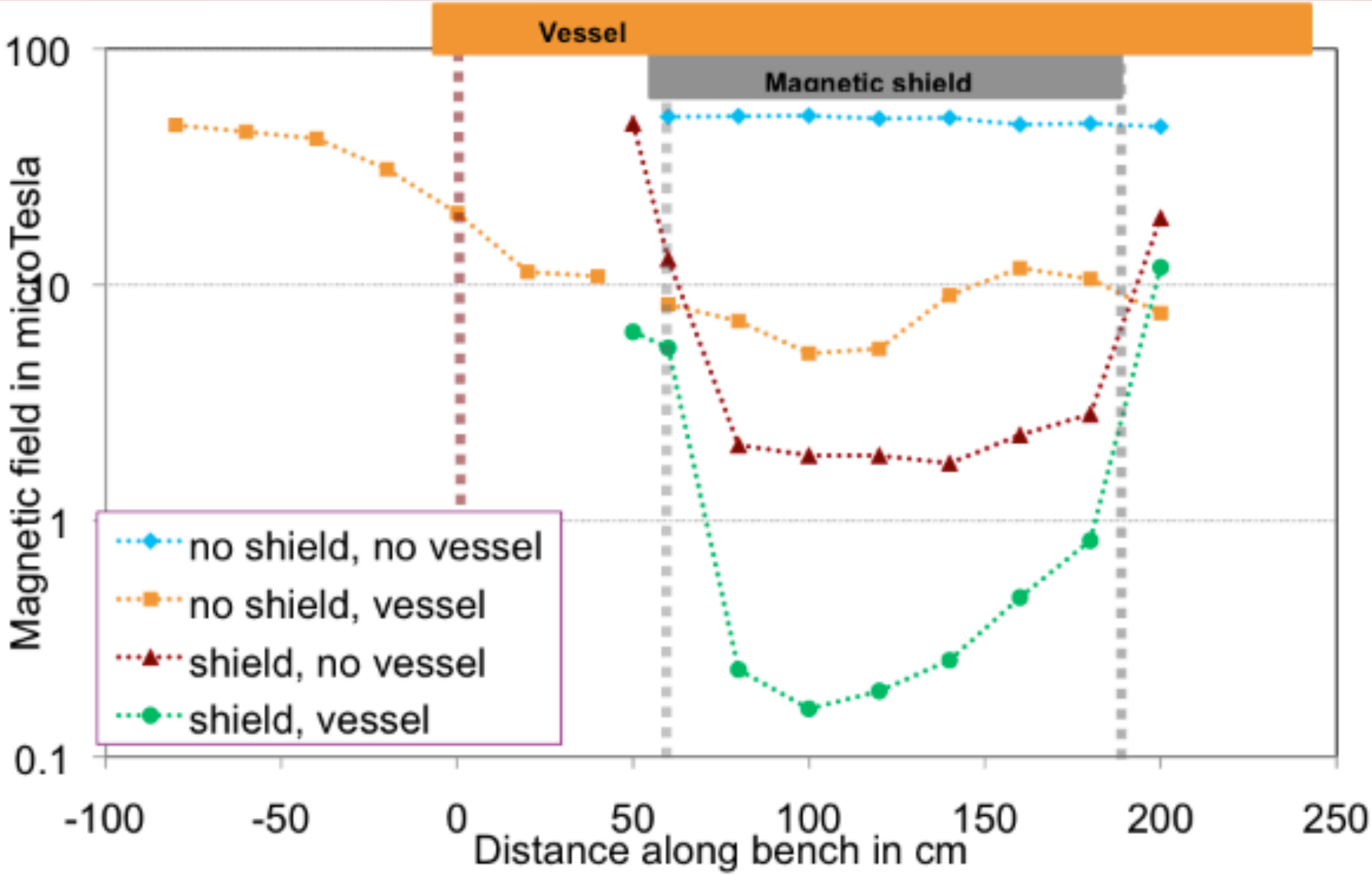
Measurements performed at room temperature

- In free air
- Inside a XFEL vacuum vessel (w/o shield)
- Inside two different shields (w/o vessel)
  - Cryoperm
  - Cryophy
- Inside a shield placed inside the vessel





MAGNETIC FIELD MEAS.@CEA: RESULTS SUMMARY



- ✓ B is reduced by the steel vessel alone
- ✓ B is reduced to ~ 2μT with shield alone
- ✓ B is reduced to less than 0,5 μT with shield and module
- ✓ Total shielding efficiency (module+magnetic shield) is more than 100

Proposals for 2013-2014

- Continue measurement of permeability of many samples, measuring statistical fluctuations from the same lot at various temperatures, in order to evaluate measurement errors.
- Continue evaluation of samples from different suppliers/lots.
- Measure permeability of the same sample at CEA and KEK at room temperature and cryogenic temperature and make a comparison and evaluate possible systematic errors between the two groups.
- CEAs collaboration with CERN may give more data to be compared.

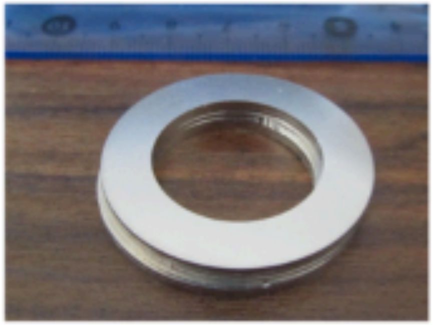
→ Contribute to a shielding material/technology database that the community can share.

- Continue to investigate possible causes for the performance degradation of the shielding material at cryogenic temperatures.
- Develop a quality control method, suitable for use in mass production.
- CEA Collaboration with a French supplier (APERAM)
- Relate ambient magnetic field to the cavity performance (Q-value).

Extending our network, for more through examination

NEXT AT CEA: CARACTERIZATION OF SAMPLES

Same material, different methods
Aperam will provide Cryophy samples (material choosen for XFEL magnetic shields)
All from same batch, with same heat treatment



1 set measured by APERAM

1 set to CERN with special permeameter

1 set measured by french metrology company

Planed at room temperature, at 70 K and 4 K

Same method, different materials
Measurements by APERAM

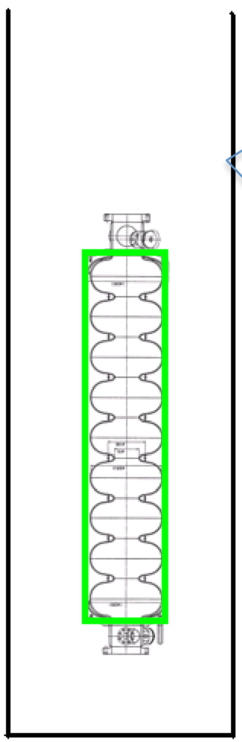
Cryophy from Aperam

Cryoperm for VAC (sheets provided by Desy)

… from KEK

The supply of material and measurement by APERAM has just been launched

What we really want to know is the relation between ambient magnetic field and cavity performance (Q-value)



Measure ambient magnetic field in the cavity shield made of different materials in a vertical cryostat. Evaluate cavity performance (Q-value measurement)

Create a low magnetic field environment by placing a shield on the cryostat (red). Generate ambient magnetic field using solenoid coil wound around the cavities, and measure Q-value.