A versatile bulk superconducting MgB_2 cylinder for polarized fuel and target

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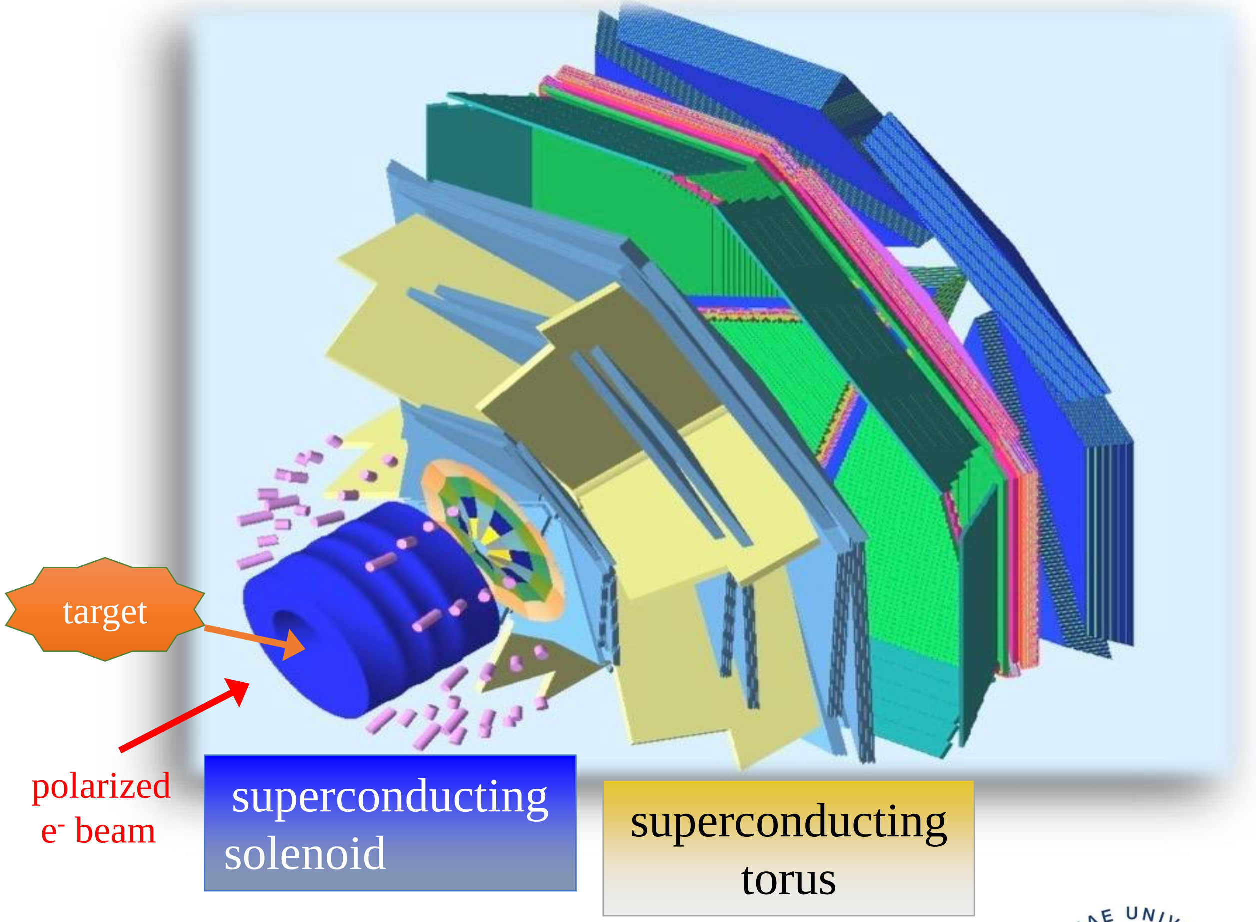
On behalf of INFN and Ferrara’s University team

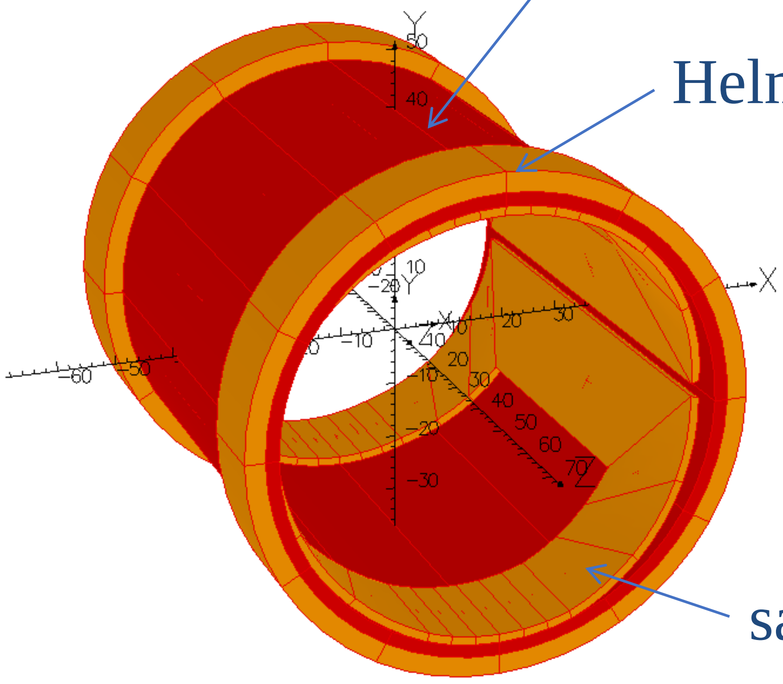
HD-Ice transverse target for CLAS12

- It’s an experiment located in JLab-Hall B
- The requirement of CLAS12 is a solid polarized target composed of protons and neutrons
- The targets also requires a transverse magnetic field with a range of 0.5-1.25 T in order to shield the magnetic field from the superconducting solenoid (2 T)



The standard solution

- Possible solution:
  - Solenoid + dipole
- Issues:
  - Due to cables needed to give power to the coils, the cryogenics of the system gets influenced.
  - This configuration is not self tuning with respect to the external field.



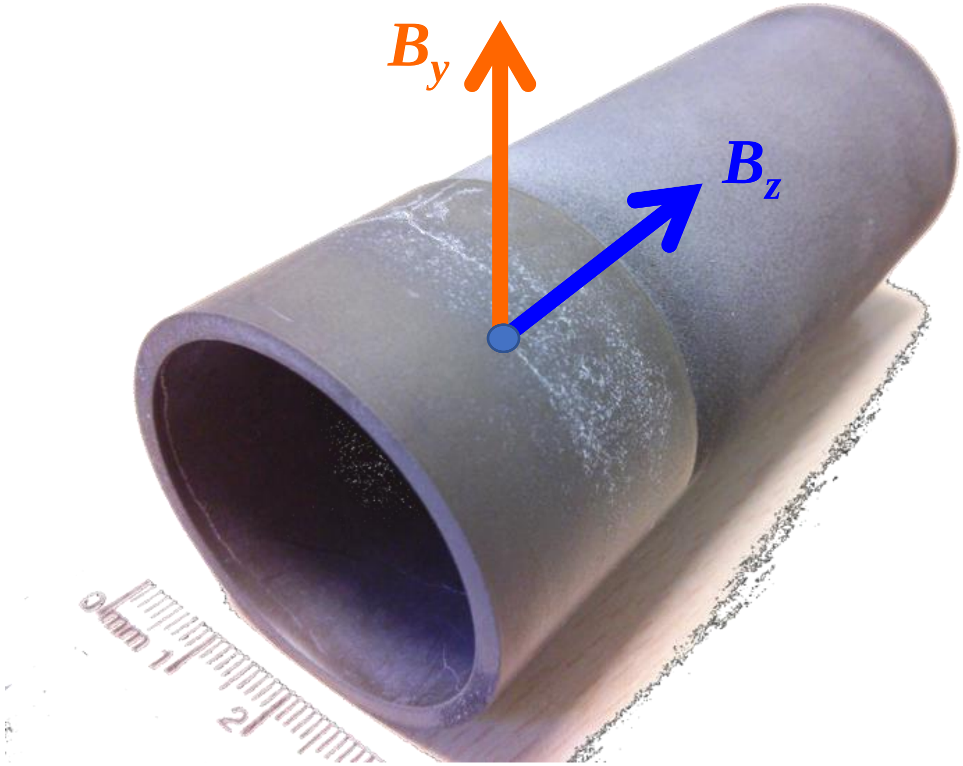
A magnetic system for the CLAS12 proposal, M. Statera et al (2013), IEEE Tr. Appl, Superc., vol. 22

Alternative solution: a bulk transverse magnet

It is a bulk cylinder composed of MgB_2

The main advantages are:

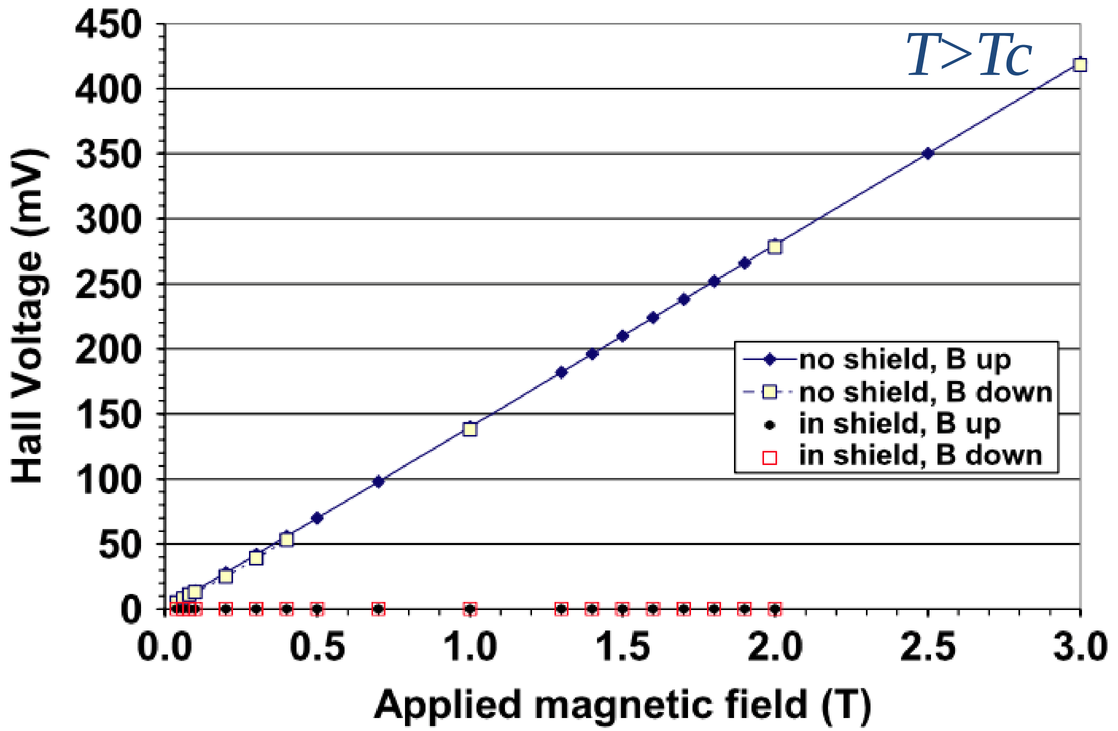
- No current leads
- Affordable and simple
- The magnetization is imposed externally and it is self tuning
- Self protective against quenching



A bulk superconducting magnetic system for the CLAS12 target at Jefferson Lab, M. Statera et al. (2015). IEEE Tr Appl. Supercon., vol. 115 Issue 3

Superconducting cylinder cooling

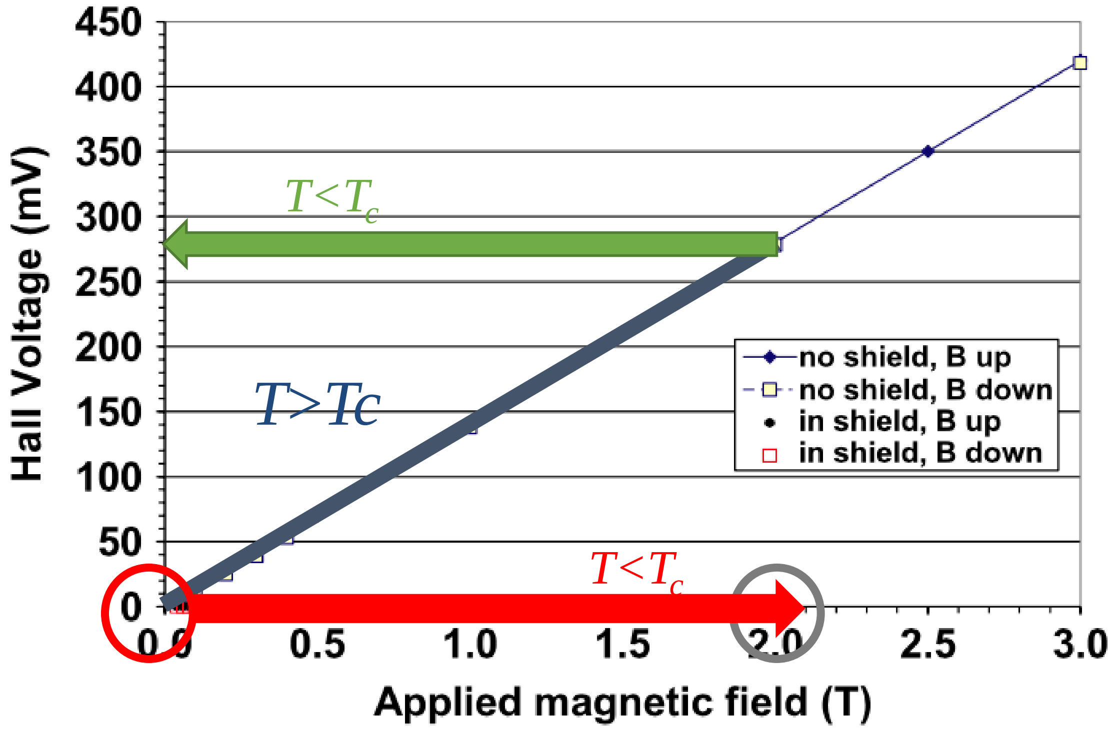
- A superconductive cylinder can be utilised in 2 configurations:
  - Zero Field Cooling:
    - The cylinder is cooled below the critical temperature without an external magnet field applied
  - Field Cooling
    - The cylinder is cooled below the critical temperature while immerged in an external magnetic field



J. J. Rabbers et al. “Magnetic shielding capability of MgB2 cylinders” Supercond. Sci. Technol. Vol. **23**, 2010

- Zero Field Cooling
  - Used to shield an external field keeping the superconductive cylinder below the critical temperature.

- Field Cooling
  - Used to keep a magnetic field trapped inside the cylinder
  - Is obtained by applying an external magnetic field while the cylinder is cooled below the critical temperature.



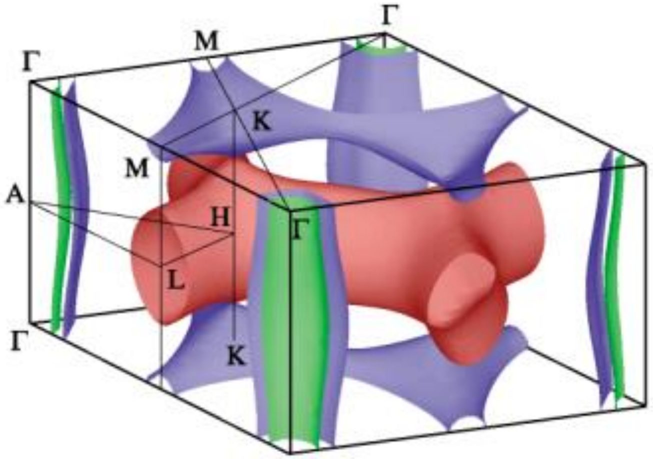
J. J. Rabbers et al. "Magnetic shielding capability of MgB2 cylinders" Supercond. Sci. Technol. Vol. **23**, 2010

Bulk Magnesium Diboride

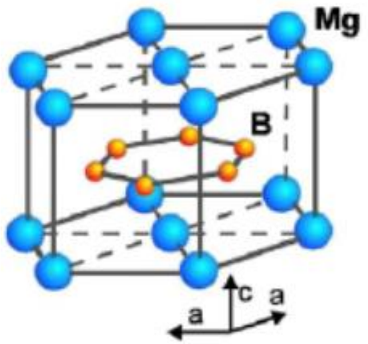
- Discovered in 2001 by Akimitzu et al.

- Its critical temperature is 39.5 K

- Our cylinders are produced with the Reactive Liquid Infiltration Method (Edison Spa pat., G. Giunchi, S. Ceresara 2001)
- Its density is: 2.4 g/cm^3
- It is machinable (Rare for a SC)

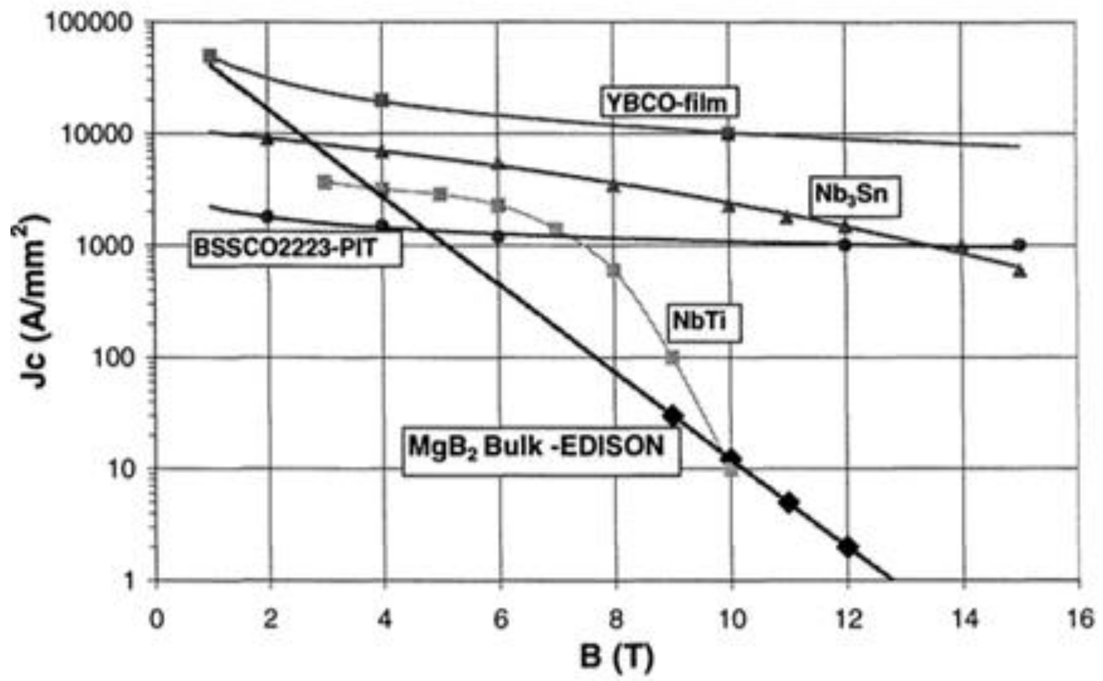


J. Kortus et al, Phys. Rev. Lett. 86, 2001



Critical Current

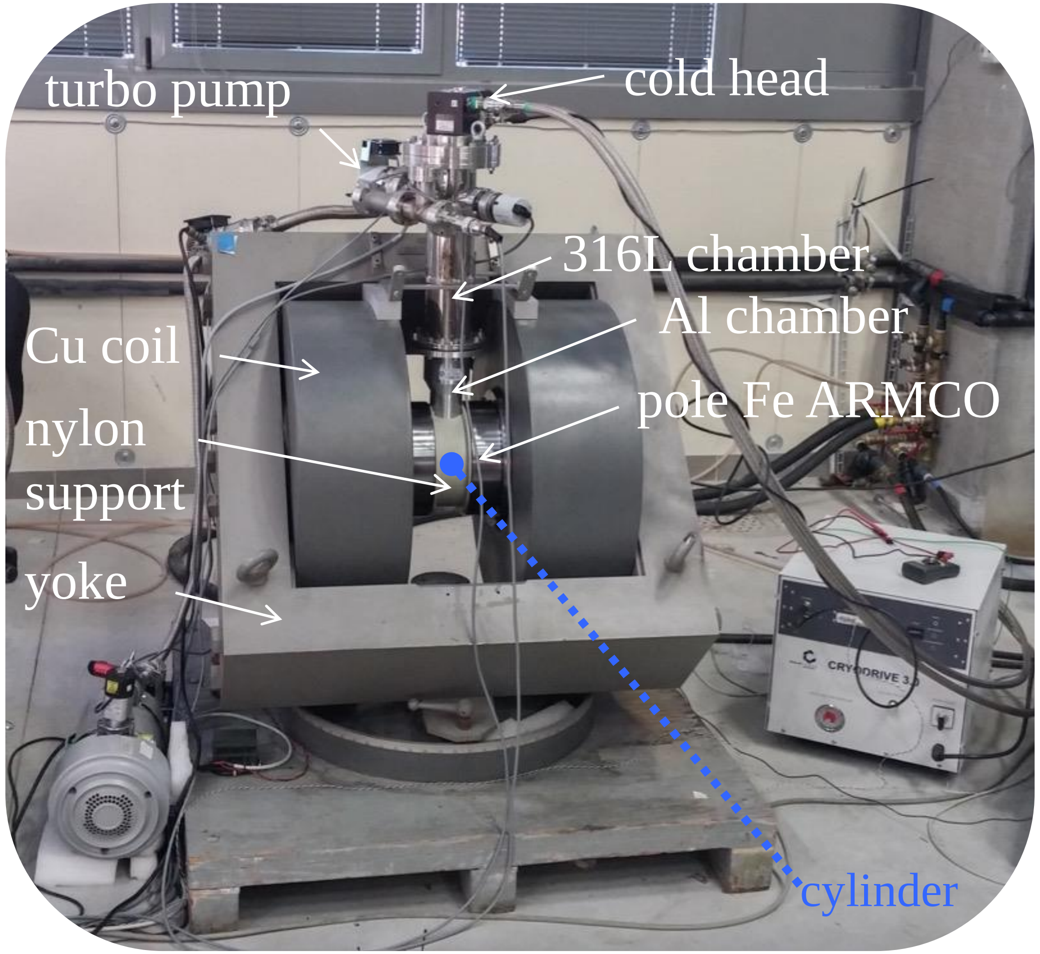
- For a bulk superconductor J_e=J_c while for a standard coiled magnet $J_e \leq 0.5\ J_c$
- MgB_2 at low field can work at temperatures up to 25 K



G. Giunchi Internationl Journal of modern Physics B **17** (2003)

Ferrara’s setup

- The longitudinal field (maximum field about 1.3 T and a $\Delta B/B = 2\ 10^{-3}$) is produced by coils with custom poles made of Fe ARMCO.
- The superconducting cylinder is placed in a vacuum chamber (composed of 316L and Al) cooled by a liquid free cryostat, that ensures a minimum temperature of $T_{min} \approx 13$ K

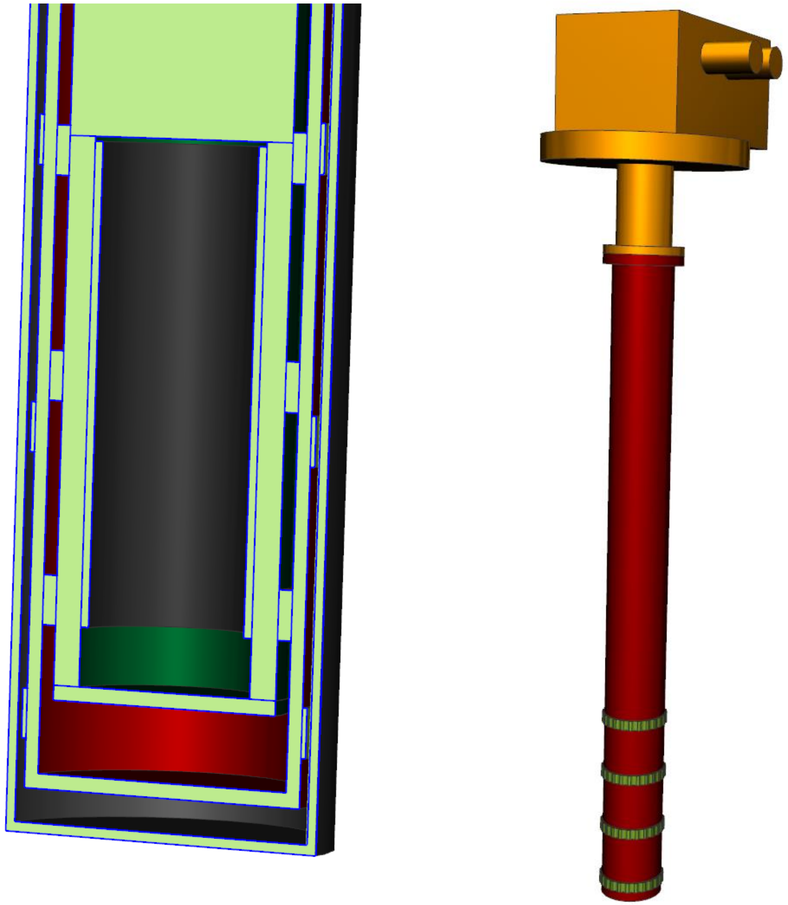


further details in M. Statera, M. Contalbrigo, G. Ciullo, P. Lenisa, M. Lowry, A. Sandorfi, “A Bulk SuperconductingMagnetic System fot the CLAS12 Target at Jefferson Lab”, IEEE Trans. On Applied Superconductivity, Issue 99 (2015)
M. Statera, et al., A bulk superconducting MgB2 cylinder for holding transversely polarized targets, NIM-A 882, Pages 17-21 (2018)

Cooling

The cooling setup is composed (from outside to inside shell) by:

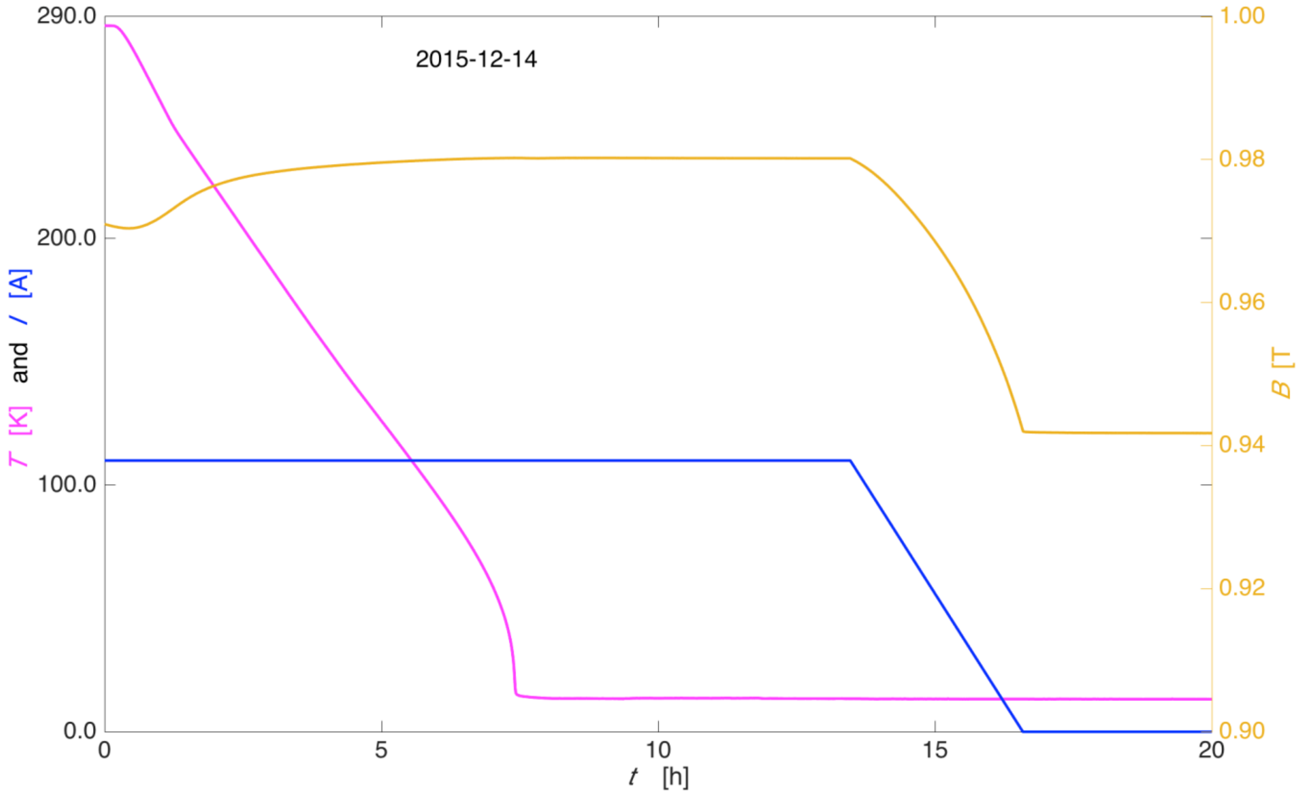
- A cold head Edwards 6/30 with a copper thermal shield capable of 25 W shielding
- The SC cylinder is cooled by a cylindric copper block attached to the cold head. Here is also placed a heater with a 80 W heating capacity; used to control temperature.
- In between the shells there are epoxy spacers and myoflex.



On the left: section of the part containing the superconducting cylinder

On the right: the cooling setup inside the vacuum chamber

Magnetization at 13 *K*



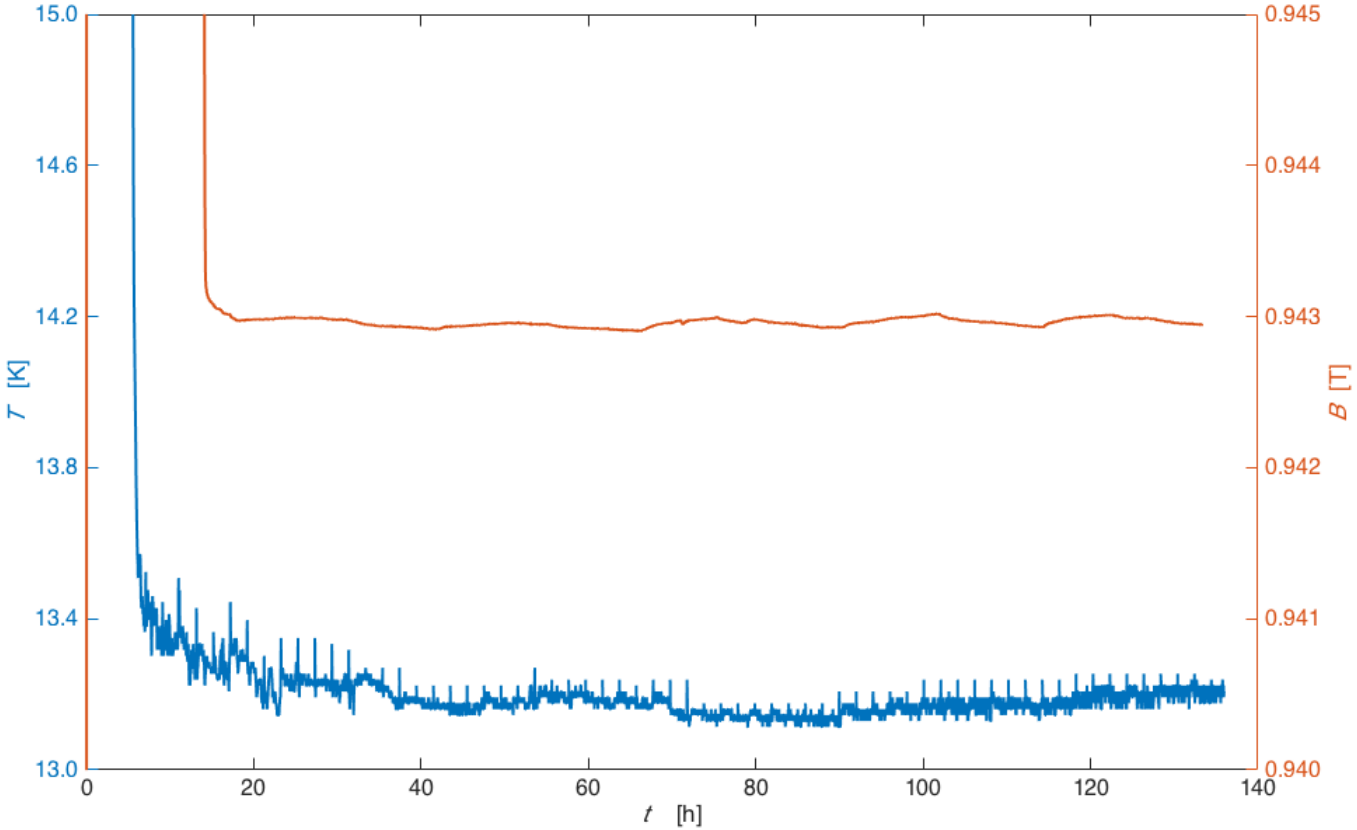
Field Cooling test:

- Cool down of about 7.5 h
- Final temperature 13 K
- Current ramp given to the coils: 0.25 A each 4 s

Long term magnetization I

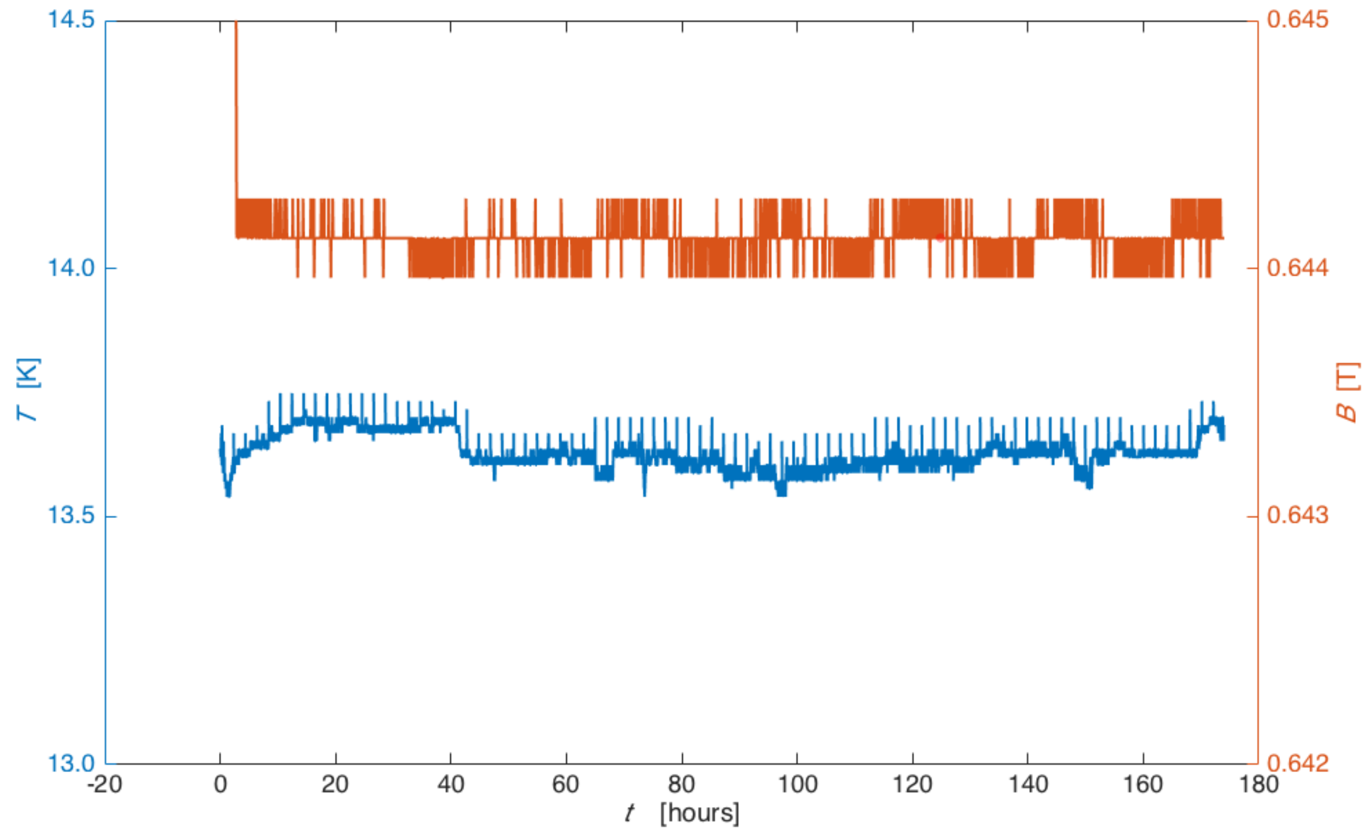
- For the first 140 hours temperature and field are stable

- In the longer term (up until 800 hours) the magnetization stays almost stable



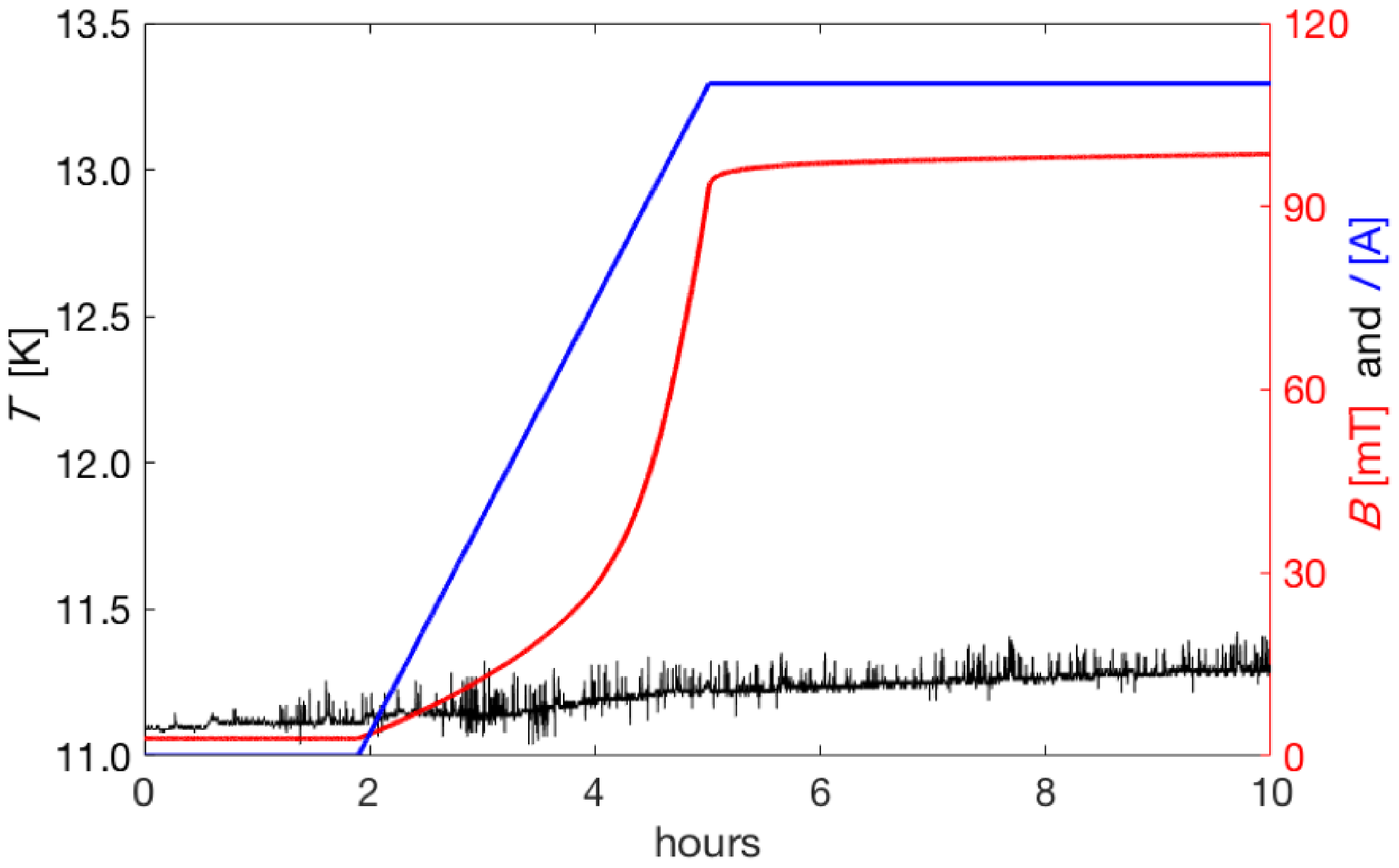
Long term magnetization II

- Low field magnetization (644 mT)
- Temperature: 13 K
- Duration: 180 h



Magnetic shielding test (zero field cooling)

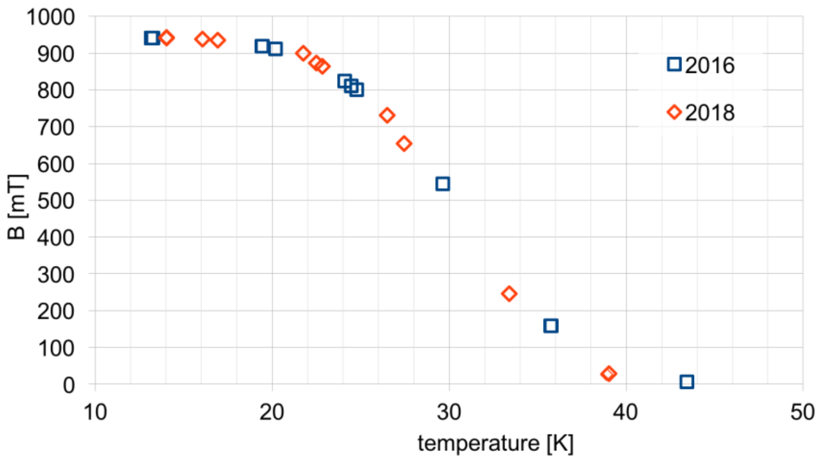
- Performed at 13 K
- Maximum shielded field: 980 mT (due to power supply)

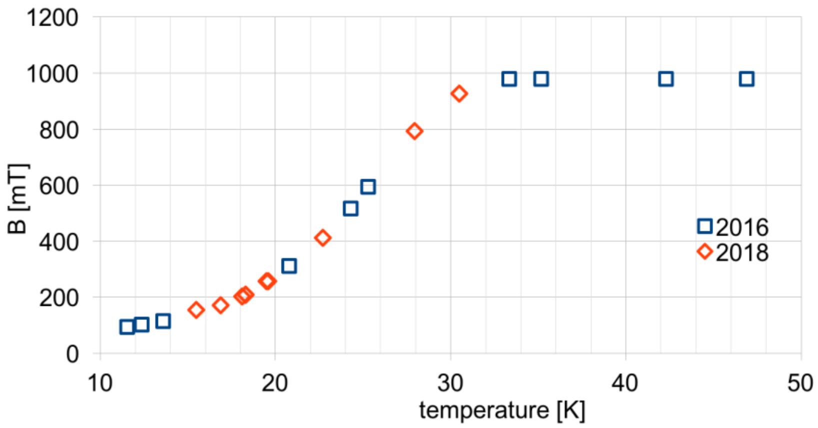


Temperature dependence

- Both process shows high reproducibility even after several thermal cycles, various quenches and two assemblies.

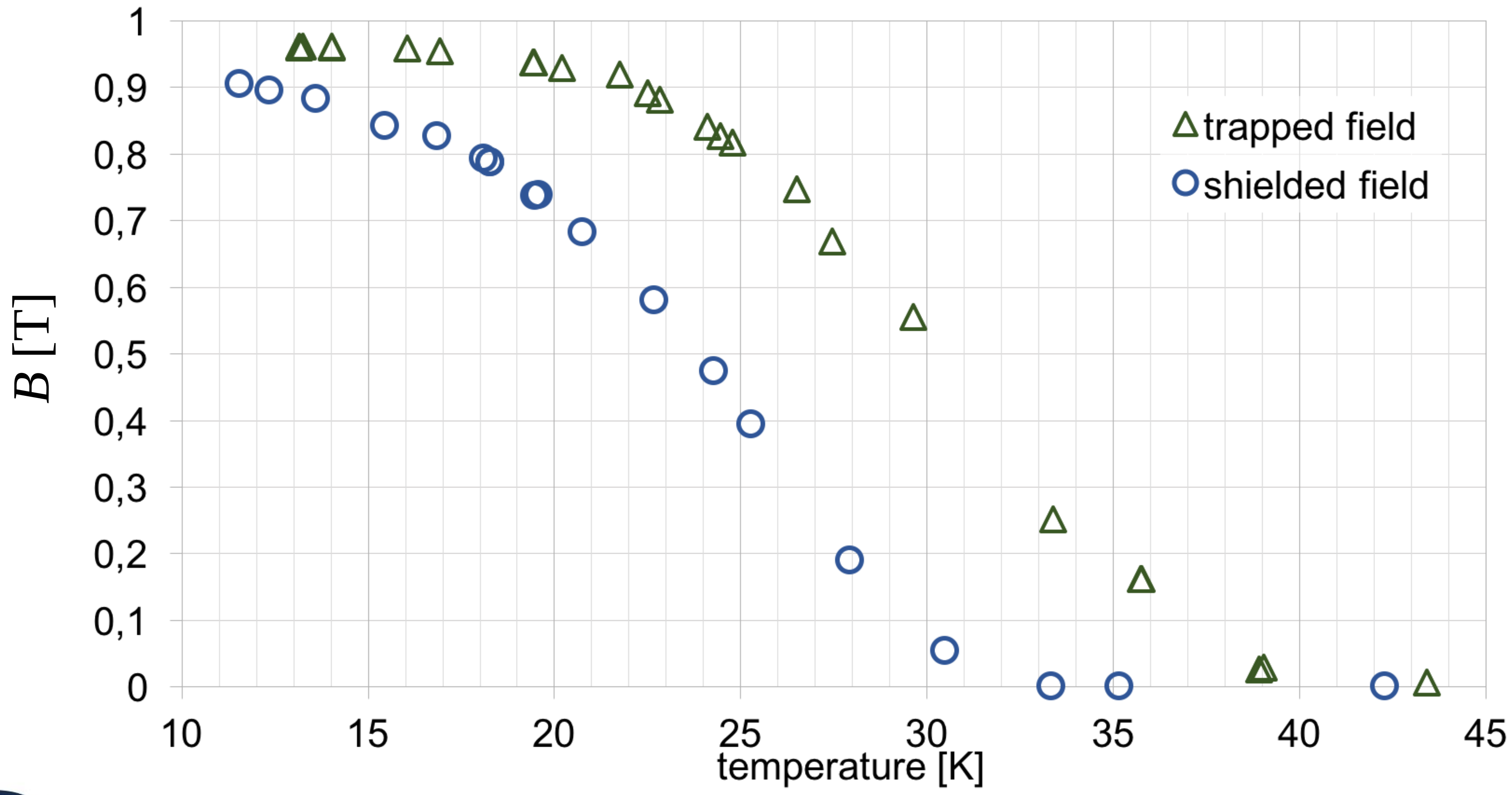
- Field trapping demonstrate a better performance at higher temperature with respect to magnetic shielding





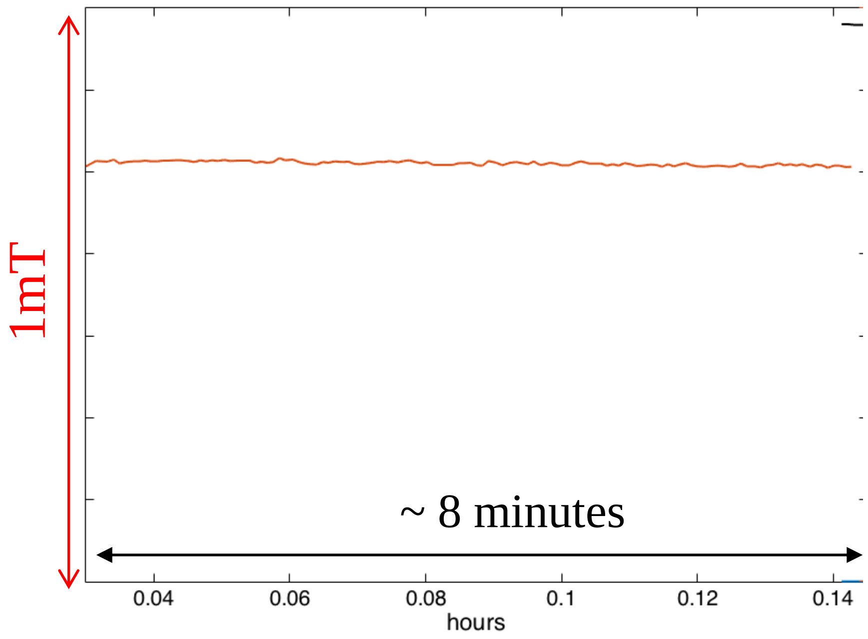
Upper graph: Field Trapping vs Temperature
Lower graph: Magnetic shielding vs Temperature

Shielded vs trapped field (detail)



Movement test

- This test comes from the request that the CLAS12 target needs be moved to the operating position
- It has been performed with:
  - Temperature 13.6 K
  - Field 565 mT



compressor ON

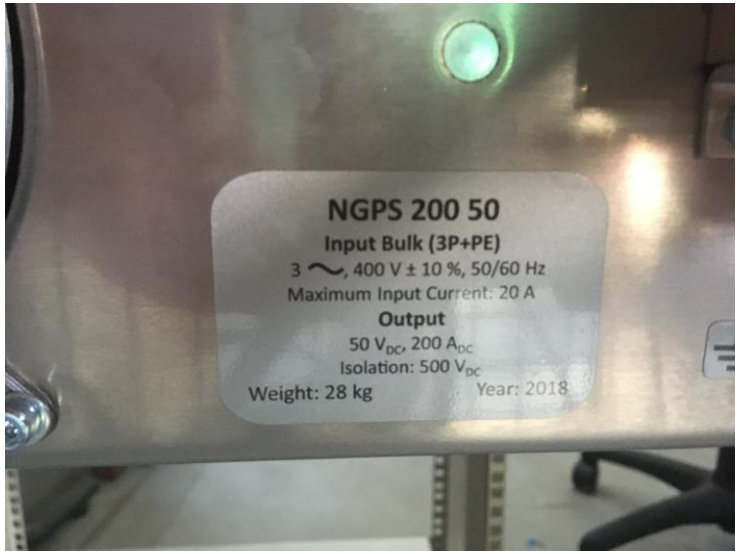
Further steps

- Additional measurements with a higher amperage (hence higher external magnetic field) power supply
- Test with new SC cylinders (different granularity, thickness)
- Cylinder transversly magnetized and a solenoidal field
- Real dimension prototype

New power supply

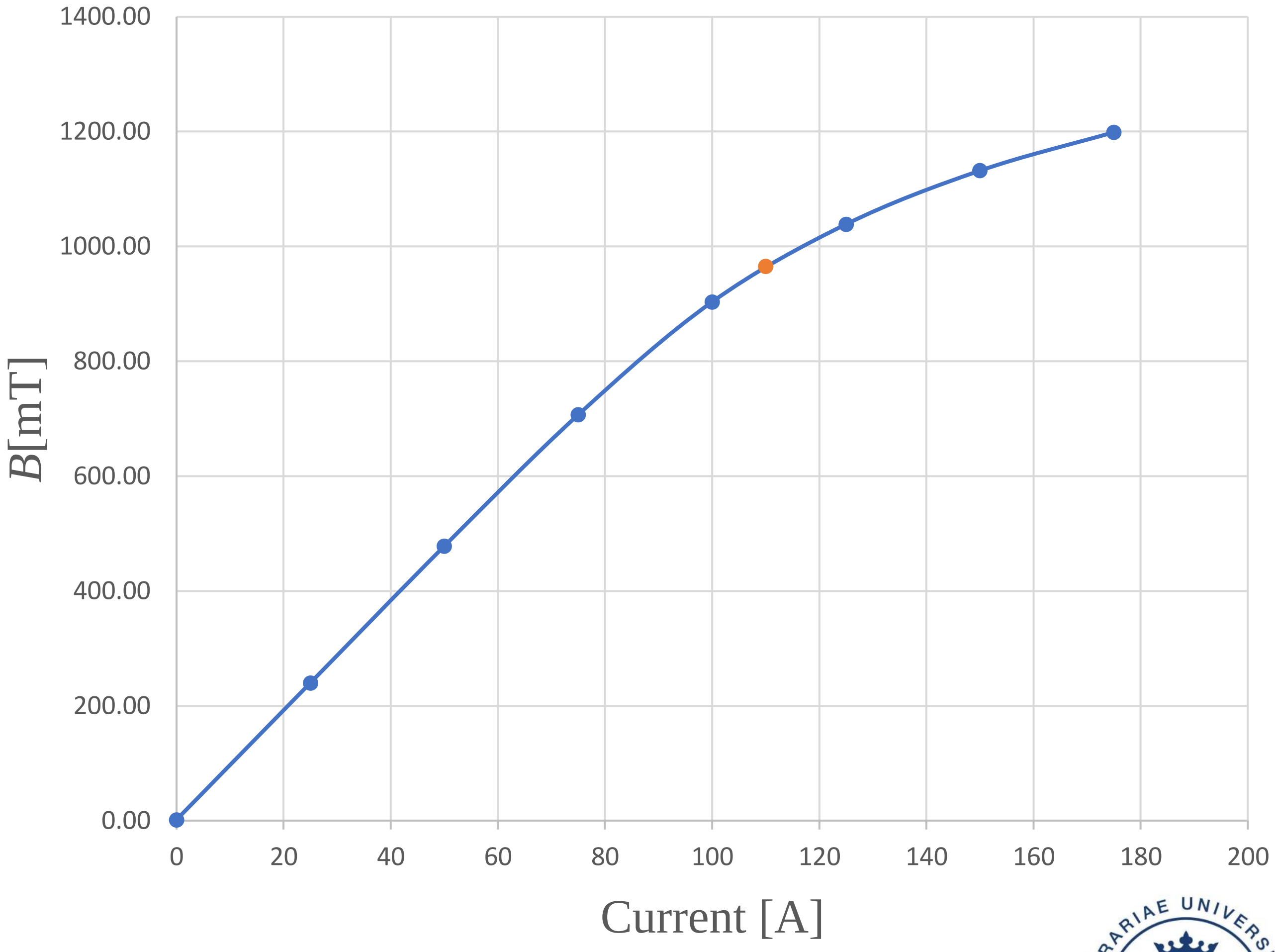
- The new power supply is a NGPS 200 50:

- The maximum ampere output is 200 A_{DC} at 50 V



Magnetic saturation of the system

- With the new power supply, we saw the beginning of magnetic saturation of the system.
- Above 1 T all the iron components of the system (yoke and the iron components inside the coils) start to saturate.
- A possible solution could be the substitution of all these iron components with *FeCo* with a 2.4 T magnetic saturation.

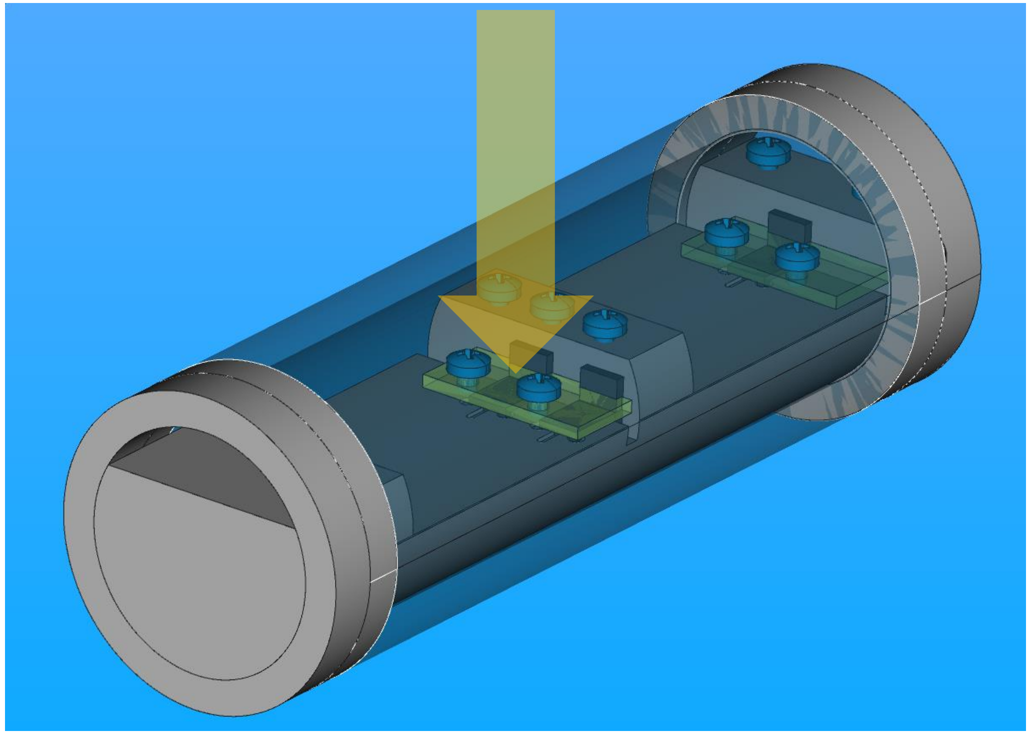


New sensors' arrangement

In the previous measurements was used one Hall probe placed inside the superconducting cylinder (yellow arrow)

To obtain further data, in the next set of measurement, will be used a set of 6 Hall probes (as shown in the image on the right).

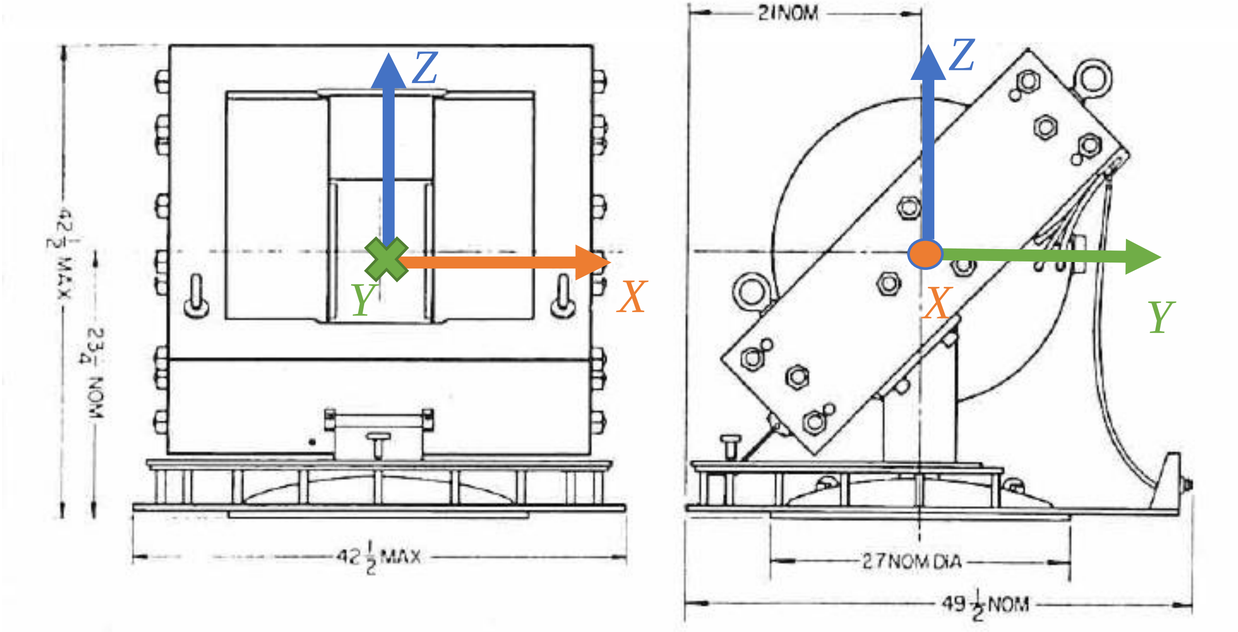
The new sensor configuration will give data of both the transverse and the longitudinal field in different positions inside the SC cylinder.



Characterizing the external magnetic field

In order to better characterize the magnetic field shielded or trapped inside the superconducting cylinder, we have first to measure the magnetic field produced by the coils.

Setting a reference system in the center of the nylon support, we will follow 2 different methods to scan the magnetic Field in the *X* and *Y* direction both based on 3D printed models.

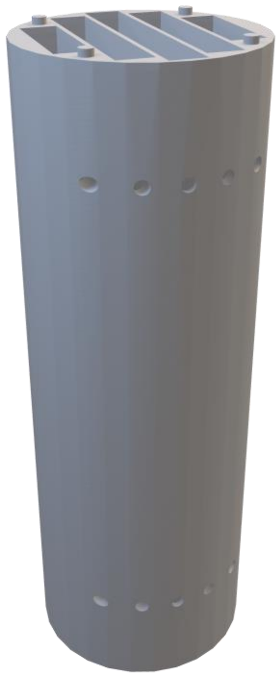


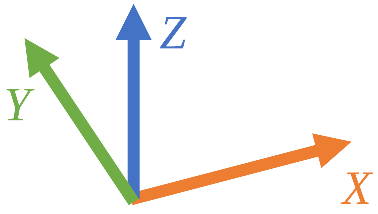
The Hall probe for external field mapping

The sensor is placed inside a rectangular shaped aluminum laminate and settled through a 3D printed support.

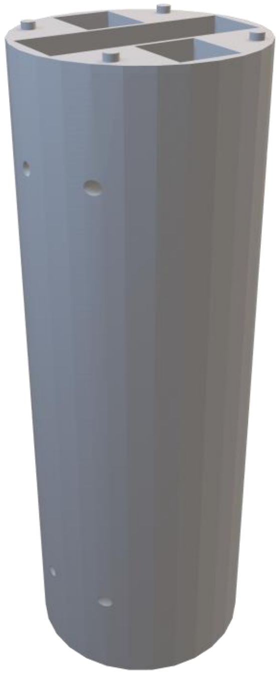
The 2 models

For the *Y* direction

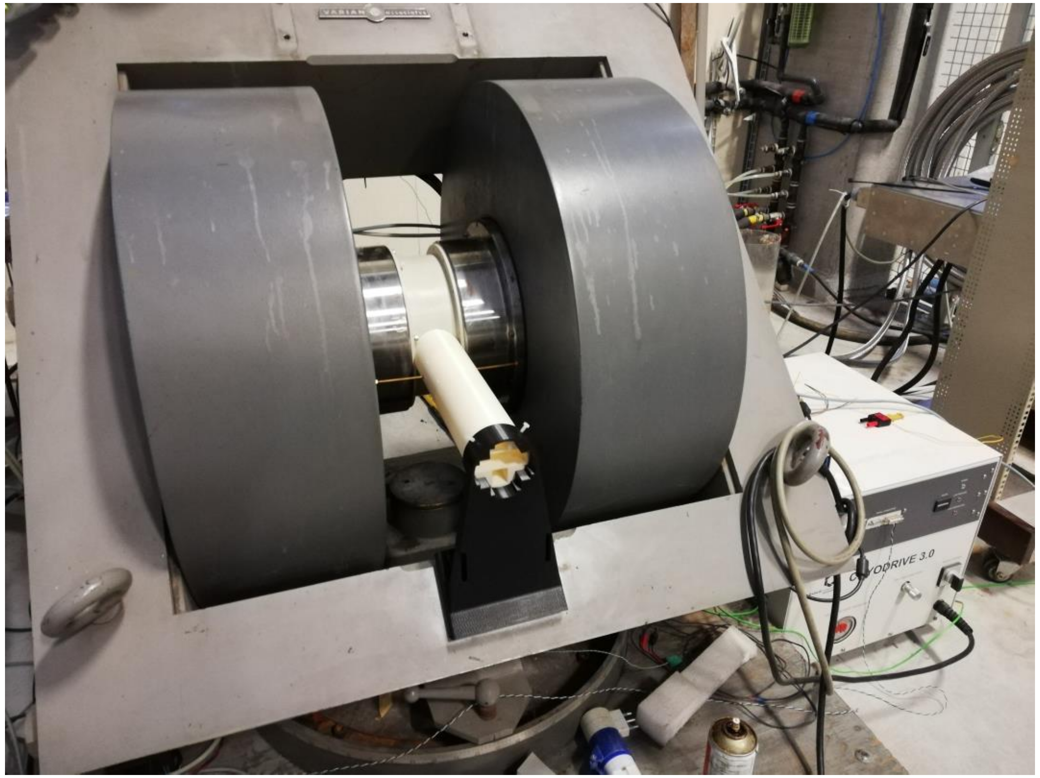




For the *X* direction



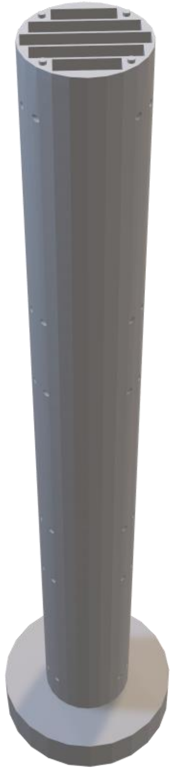
The *X*-direction Scan



The scan along the *X*-direction will be performed with the nylon support rotated of 90° with respect to the typical allignment.

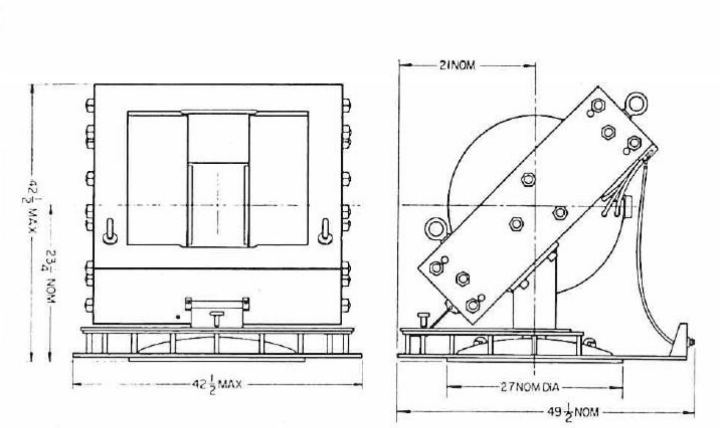
Placing the sensor in the middle of the rod, we will increase its stability and we will be able to scan both along the *X* and *Y* direction.

The *Y*-direction Scan



The scan along the *Y*-direction will be performed with the nylon support in the typical (vertical) position. With this configuration, we will be able to scan the *Y* and *Z* directions simultaneously.

The 3D printed guide for the rod, which contains the sensor, will be laid on the pin at the base of the magnet used to rotate it.



Conclusions

- Preliminary observation using a 0.94 T magnetic field:
  - >90% Field trapping or magnetic shielding of up to 90% at ~ 13 K
  - Temperature dependence of both configurations
  - The magnetized cylinder can sustain transportation from the polarization site to the experiment site
- More measurements are needed:
  - Field mapping
  - Dual field configuration (trapping and shielding)
- Working on a realistic demonstrator

Thank You

L. Barion; G. Ciullo; M. Contalbrigo; L. Del Bianco; F. Lanaro; P. Lenisa; F. Spizzo; M. Statera; G. Tagliente.