Measurements of the transverse magnetization of a bulk MgB_2 cylinder

Marco Statera
on behalf of the
INFN and Ferrara University team

SPIN2018
Ferrara September 11th 2018

SUMMARY

- brief introduction
- a bulk transverse magnet
- test bench in Ferrara
- transverse measurements
- next steps
- conclusion

A HD-ICE TRANSVERSE TARGET FOR CLAS12?

Jlab – Hall B - CLAS12

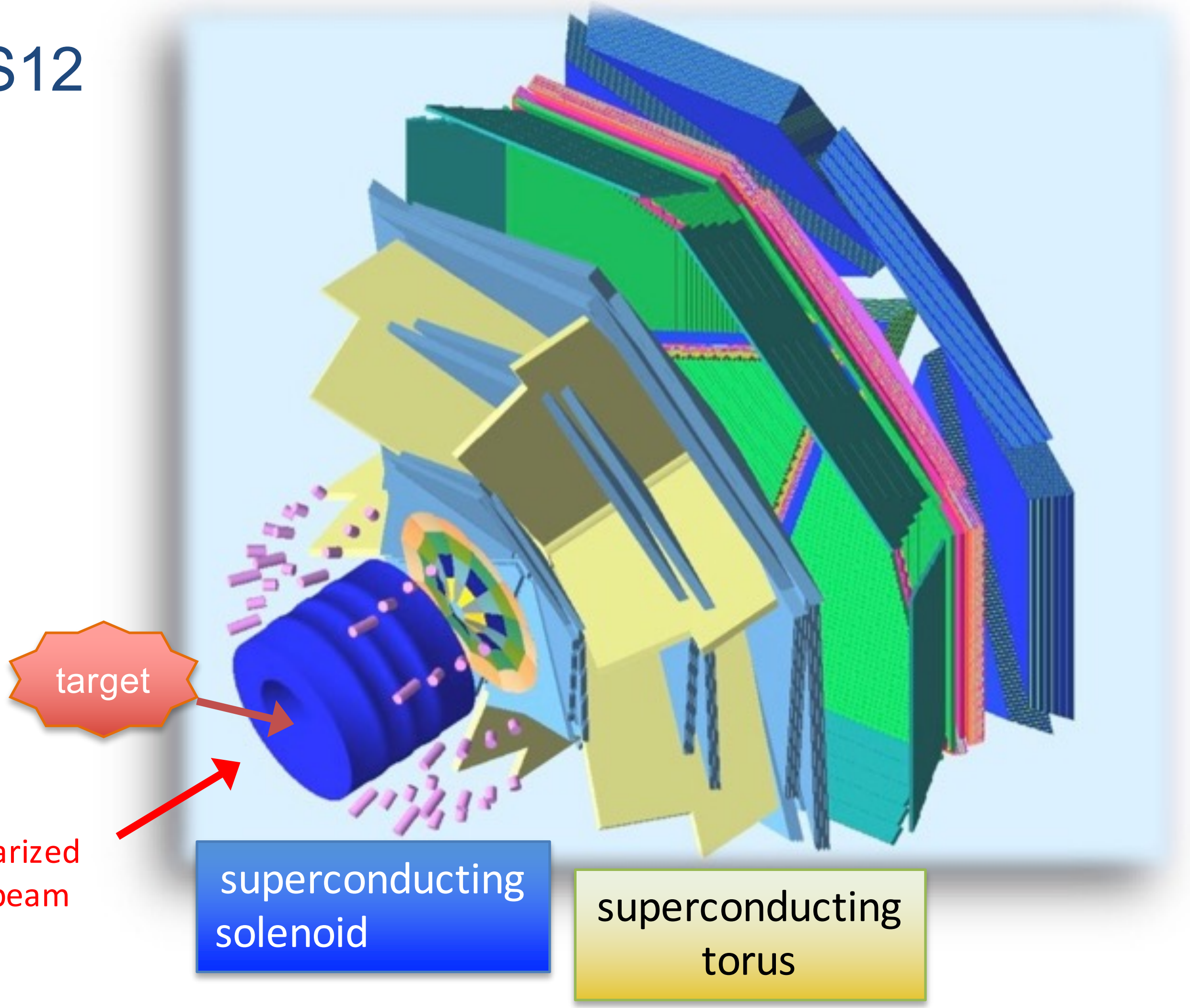
- HD-ice
- polarized

tracking solenoid

- design field 5 T longitudinal
- HD-ice target working field 2 T
- 4 K L-He cryostat
- diameter 440 to 942 mm
- length 1500 mm

HDice Transverse Target:

- high polarization
- ϕ 25 mm – Length 25 mm
- transverse field 0.5-1.25 T

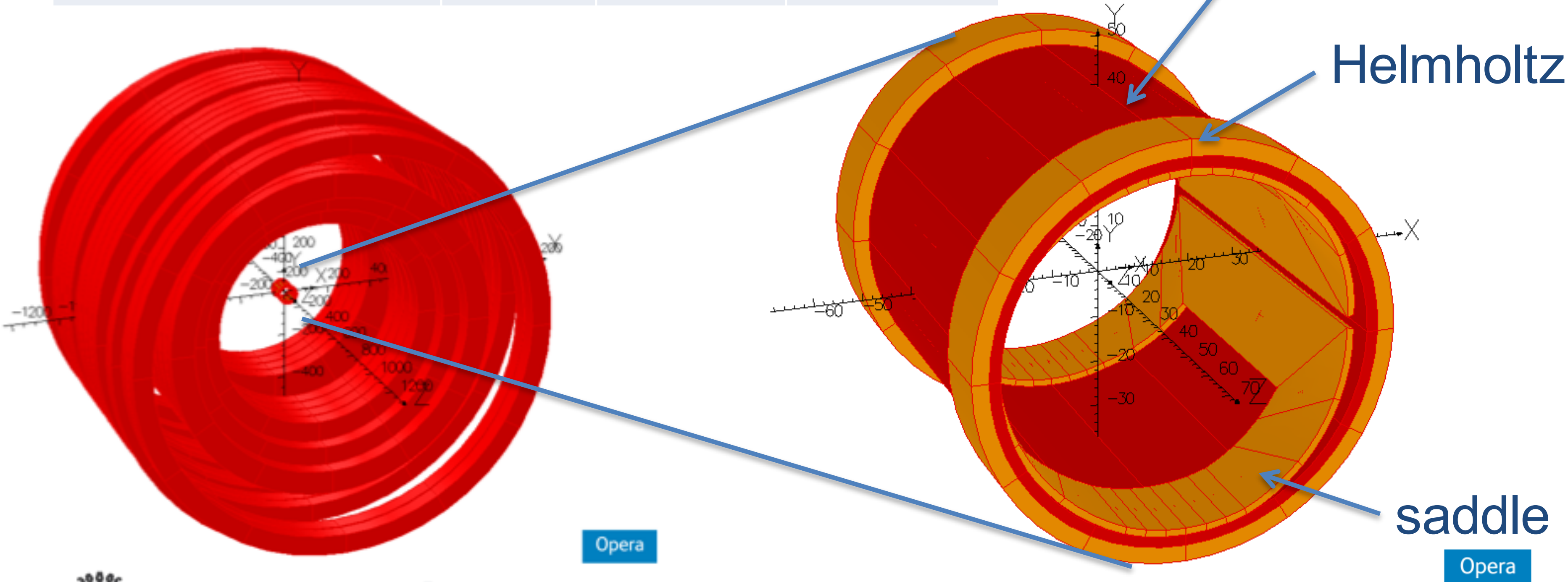


A STANDARD SOLUTION

PARAMETER	saddle	solenoid	Helmoltz
inner radius [mm]	35.7	37.2	39.4
outer radius [mm]	37.2	39.4	42.8
length [mm]	100	100	15 each
J_e [A/mm^2]	730	730	730

3 NbTi MAGNETS

$B_y = 0.5$ T



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

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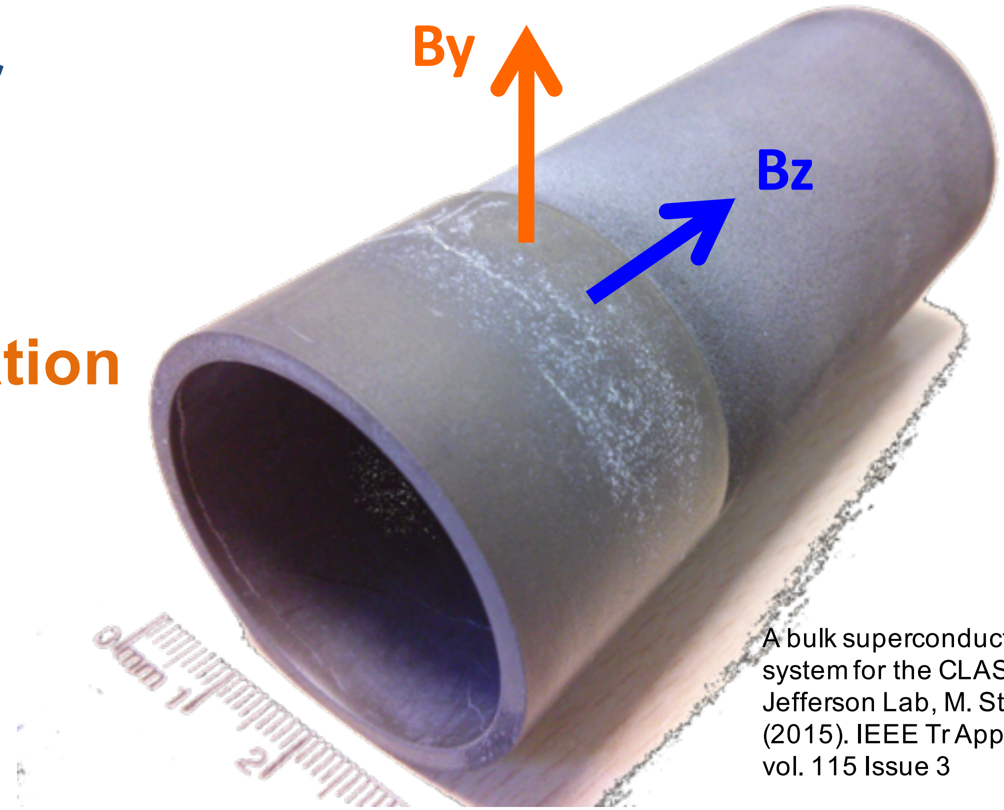
A BULK TRANSVERSE MAGNET?

bulk cylinder

- **MgB_2**
- **longitudinal shield**
- **transverse magnetization**

features

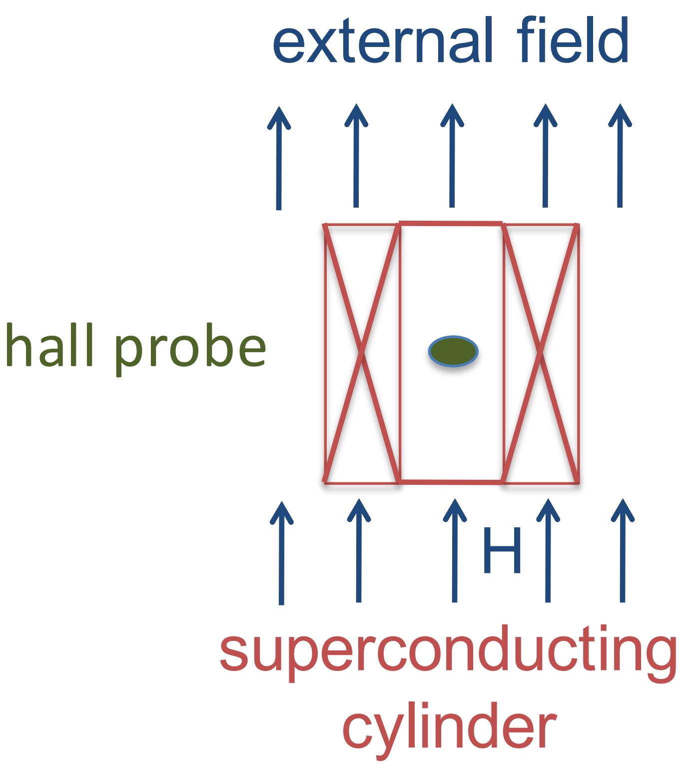
- no current leads
- Cu free
- self tuning
- simple
- low making cost
- few mm thickness
- external magnet (magnetization)

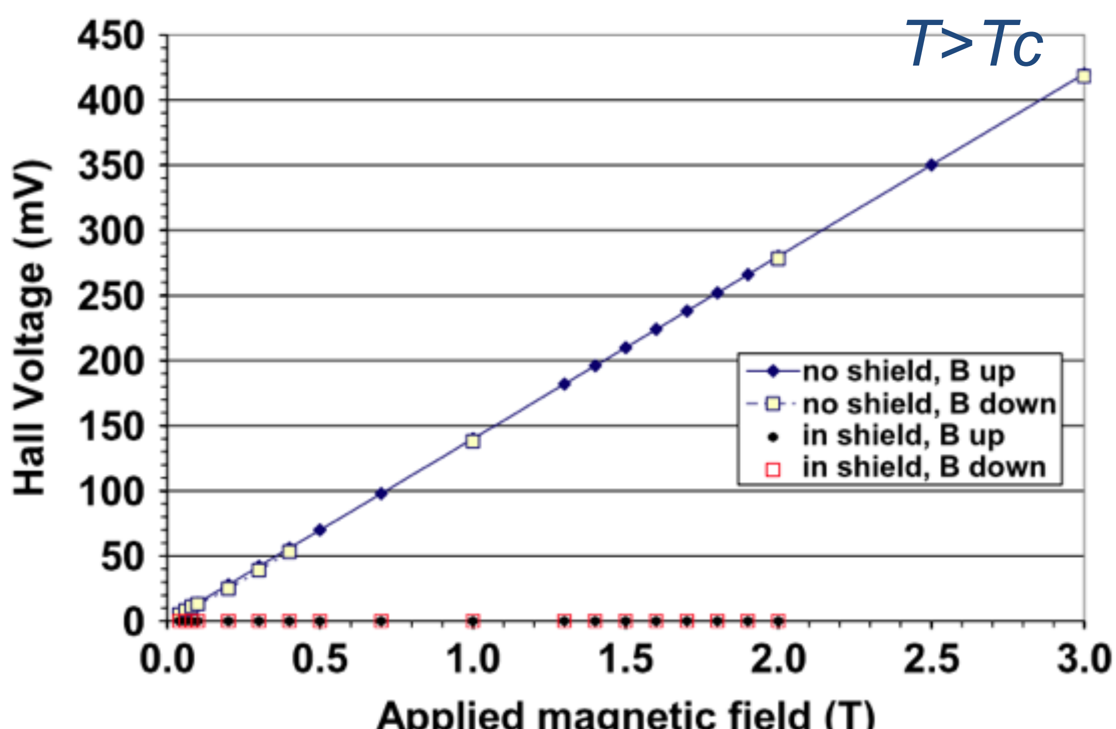


A bulk superconducting magnetic system for the CLAS12 target at Jefferson Lab, M. Statera et al. (2015). IEEE Tr Appl. Supercon., vol. 115 Issue 3

existing sample (courtesy of G. Giunchi)
diameter 39 mm - length 90 mm
thickness ~1 mm

SUPERCONDUCTING CYLINDER COOLING

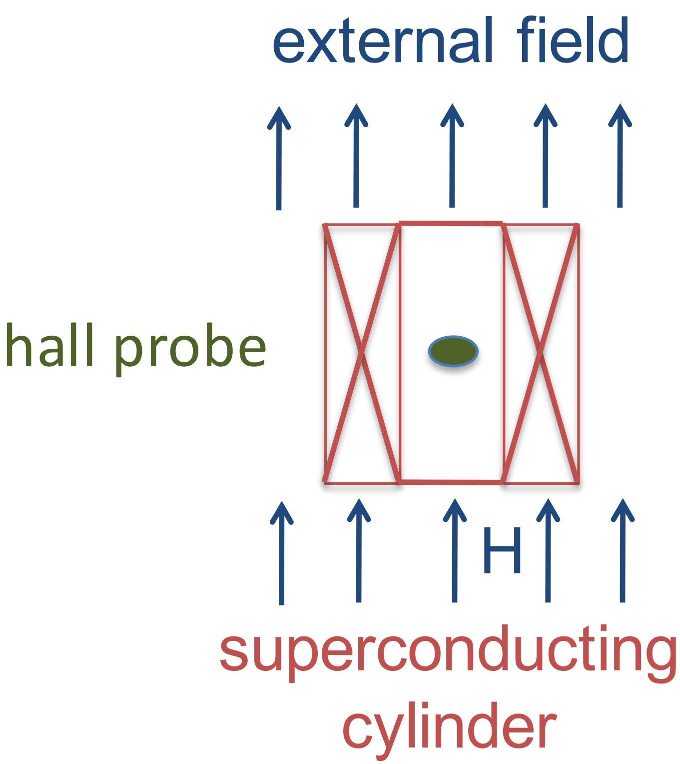


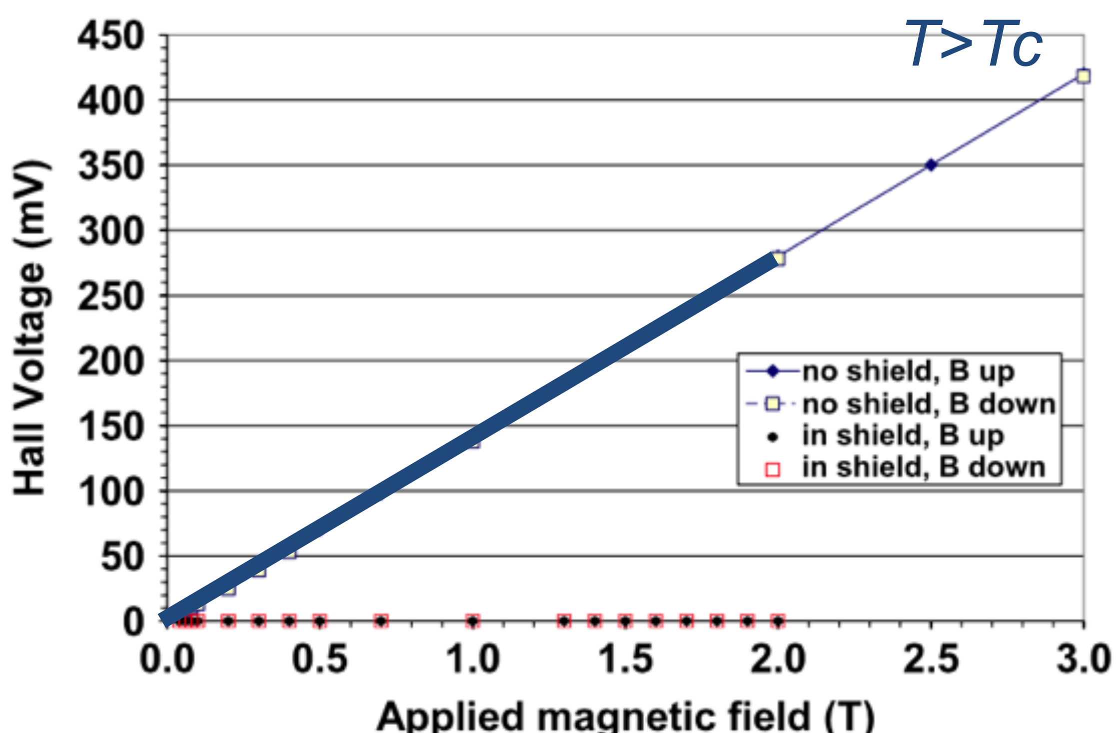


J. J. Rabbers et al. “Magnetic shielding capability of MgB2 cylinders” Supercond. Sci. Technol. Vol. **23**, 2010

SUPERCONDUCTING CYLINDER COOLING

- cylinder not superconducting (*T>Tc*)



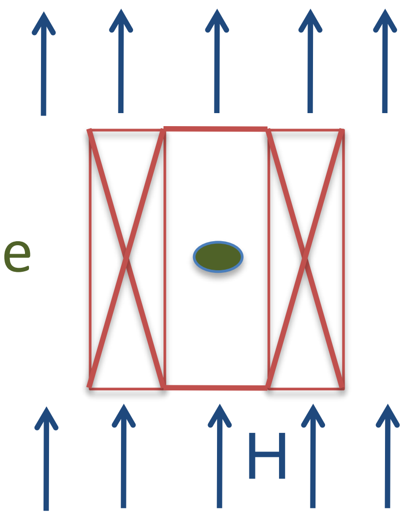


J. J. Rabbers et al. "Magnetic shielding capability of MgB2 cylinders" Supercond. Sci. Technol. Vol. **23**, 2010

SUPERCONDUCTING CYLINDER COOLING

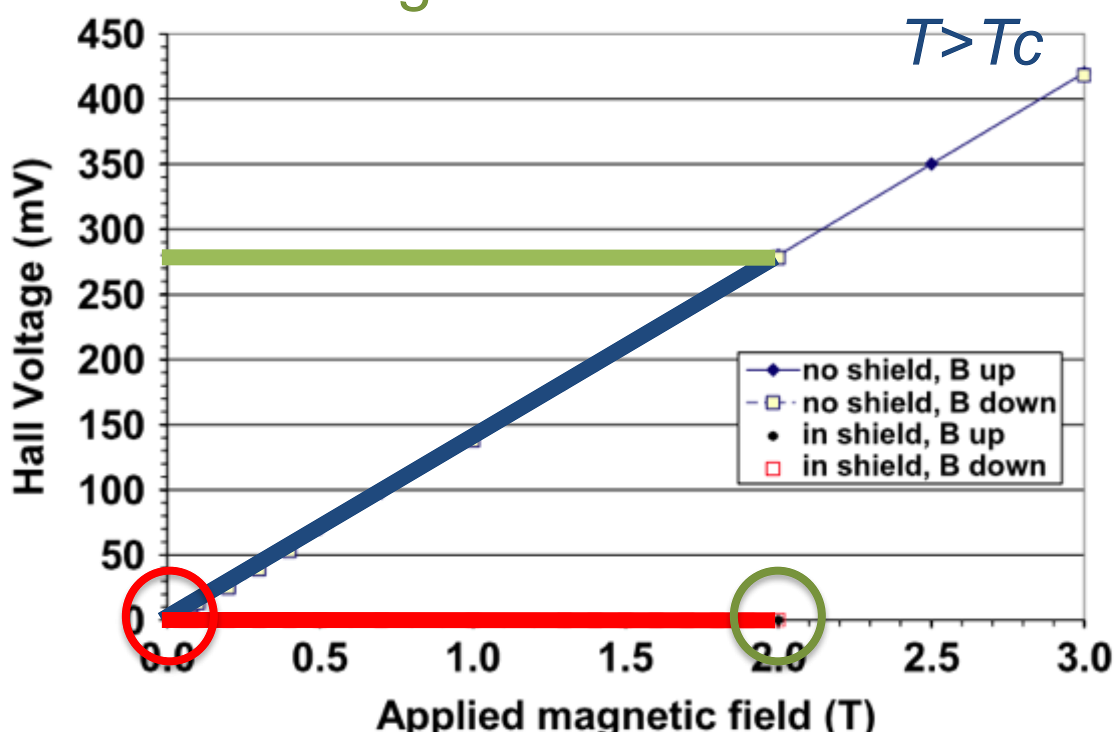
- cylinder not superconducting (*T>Tc*)
- Zero Field Cooling
- Field Cooling

external field



hall probe

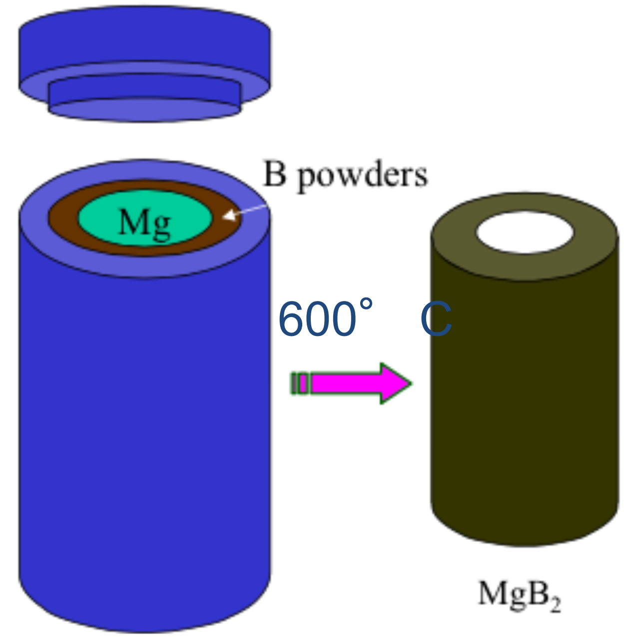
superconducting cylinder

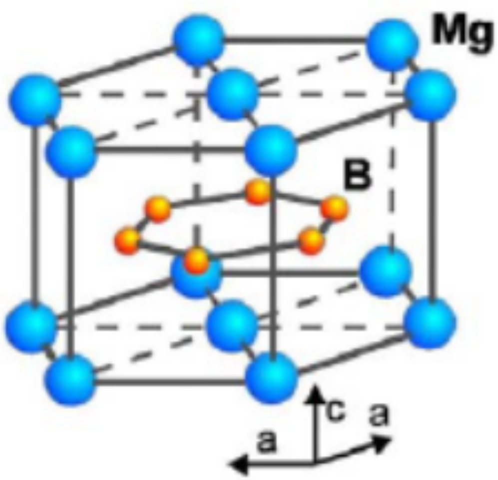


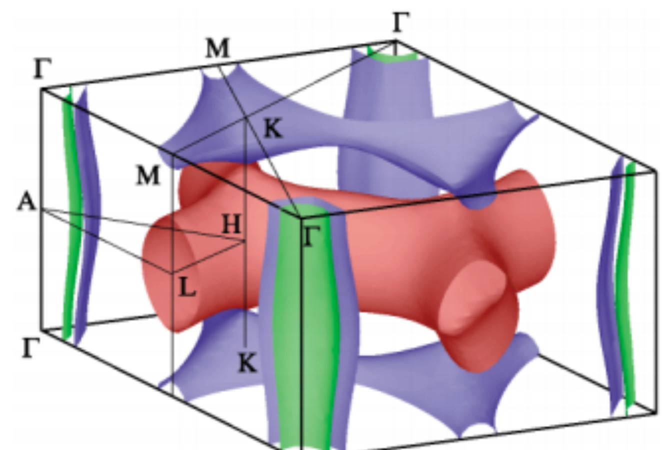
J. J. Rabbers et al. "Magnetic shielding capability of MgB2 cylinders" Supercond. Sci. Technol. Vol. **23**, 2010

BULK MAGNESIUM DIBORIDE

- critical temperature 39.5 K
- discovered in 2001 (Akimitzu et al.)
- production method (sinterization): Reactive Liquid Infiltration
  (Edison Spa pat., G. Giunchi, S.Ceresara 2001)
- density 2.4 g/cm^3
- low Z



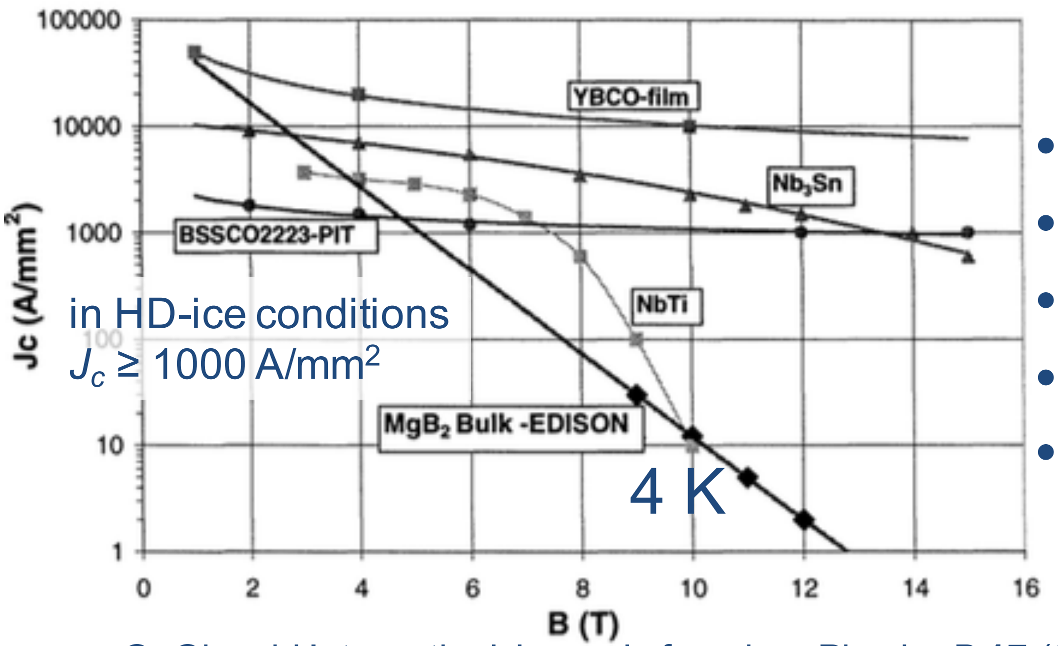




J. Kortus et al, Phys. Rev. Lett. 86, 2001

CRITICAL CURRENT

- bulk superconductors $J_e = J_c$
- standard coiled magnets $J_e \leq 0.5\ J_c$



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

WHY Mg diboride?

- low Z
- cheaper than LTS and HTS
- machinable
- operating point at low field
- may operate up to 25 K

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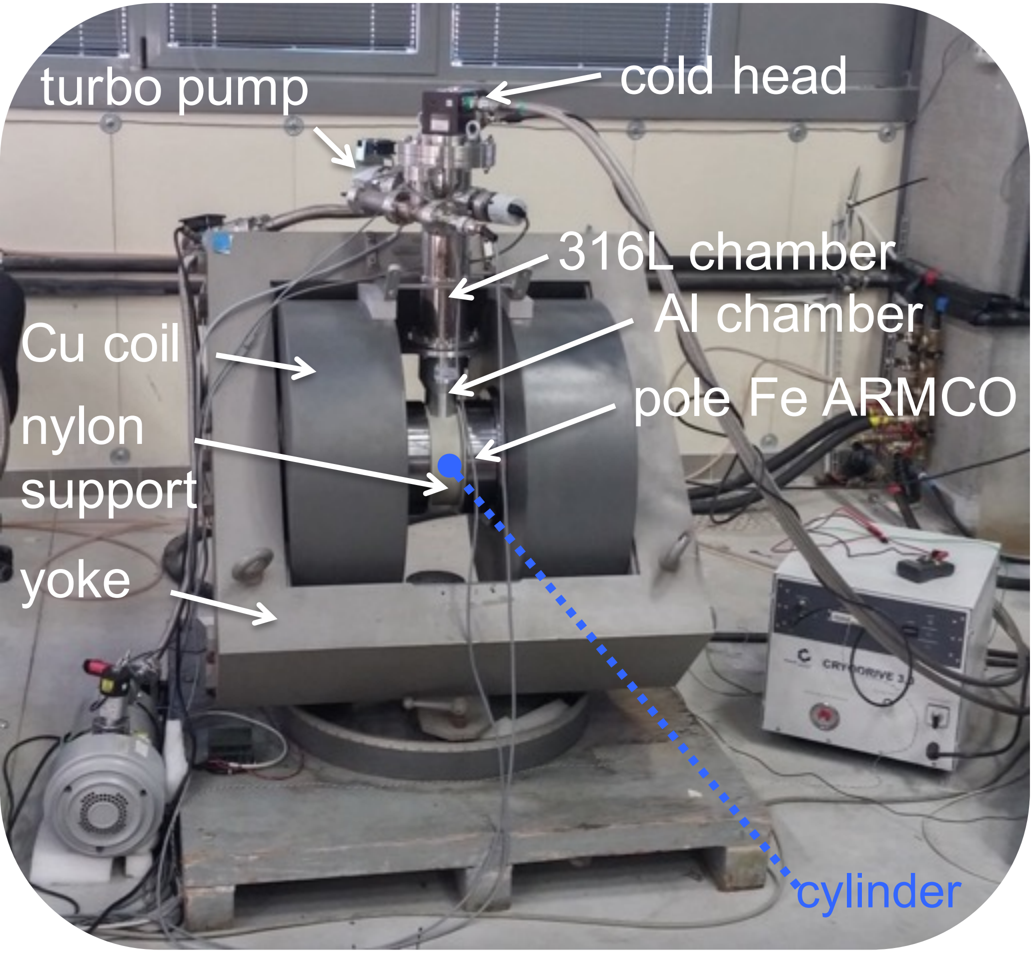
FEASIBILITY STUDY

is a double effect bulk magnet feasible?

- longitudinal shielding
  - current decay t > 2 h
  - 50 h ÷ 170 h for an experiment
- transverse magnetization
  - test experimentally
  - probe modelling
  - measure current decay

FERRARA SETUP

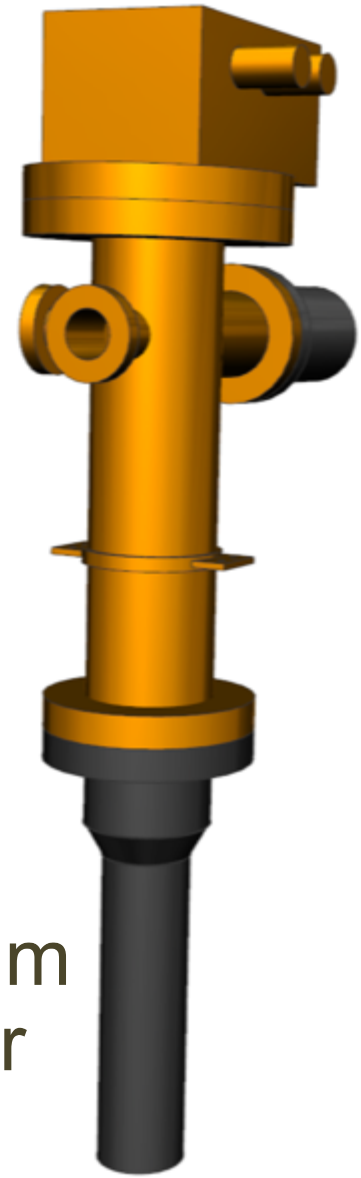


- resistive magnet
- transverse field
- custom poles
- max field about 1 T
- vacuum chamber (316L and Al)
- liquid free cryostat
- controlled cylinder temperature
- minimum temperature ≈13 K
- $\Delta B/B < 2\ 10^{-3}$ (on cylinder volume)

further details in M. Statera, M. Contalbrigo, G. Ciullo, P. Lenisa, M. Lowry, A. Sandorfi, "A Bulk Superconducting Magnetic 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

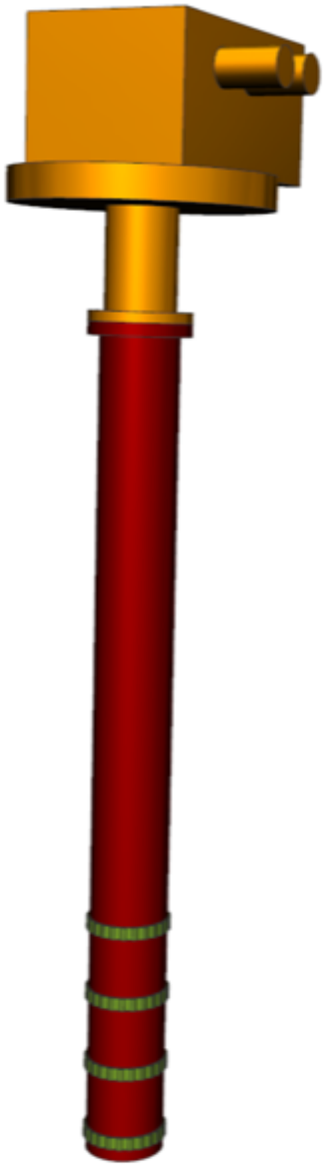
- cold head
  Edwards 6/30



Aluminum
chamber

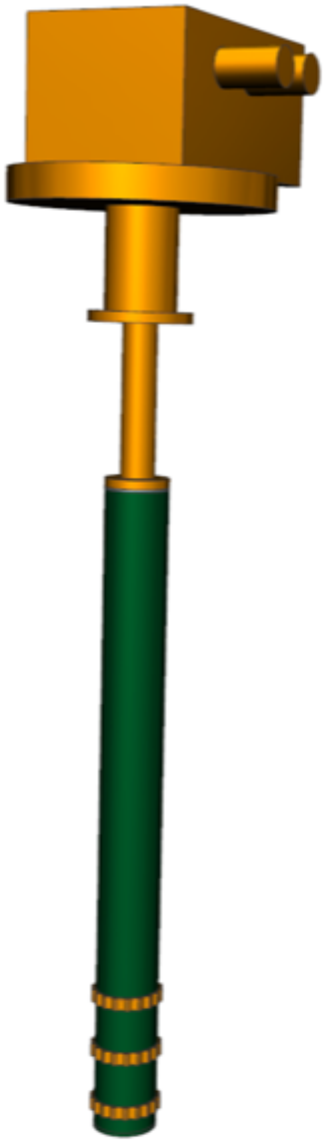
COOLING

- cold head Edwards 6/30
- thermal screen
  - copper
  - 25 W



COOLING

- cold head
  Edwards 6/30
- thermal screen
  - copper
  - 25 W
- cylinder cooling
  - copper
  - heater
  - 2 W
- epoxy spacers
  + myoflex



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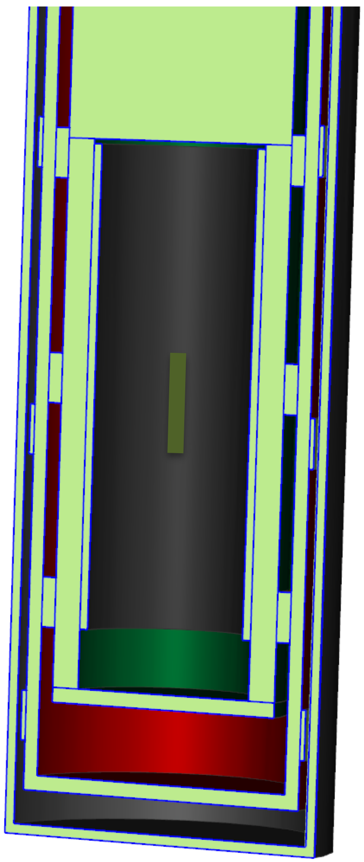
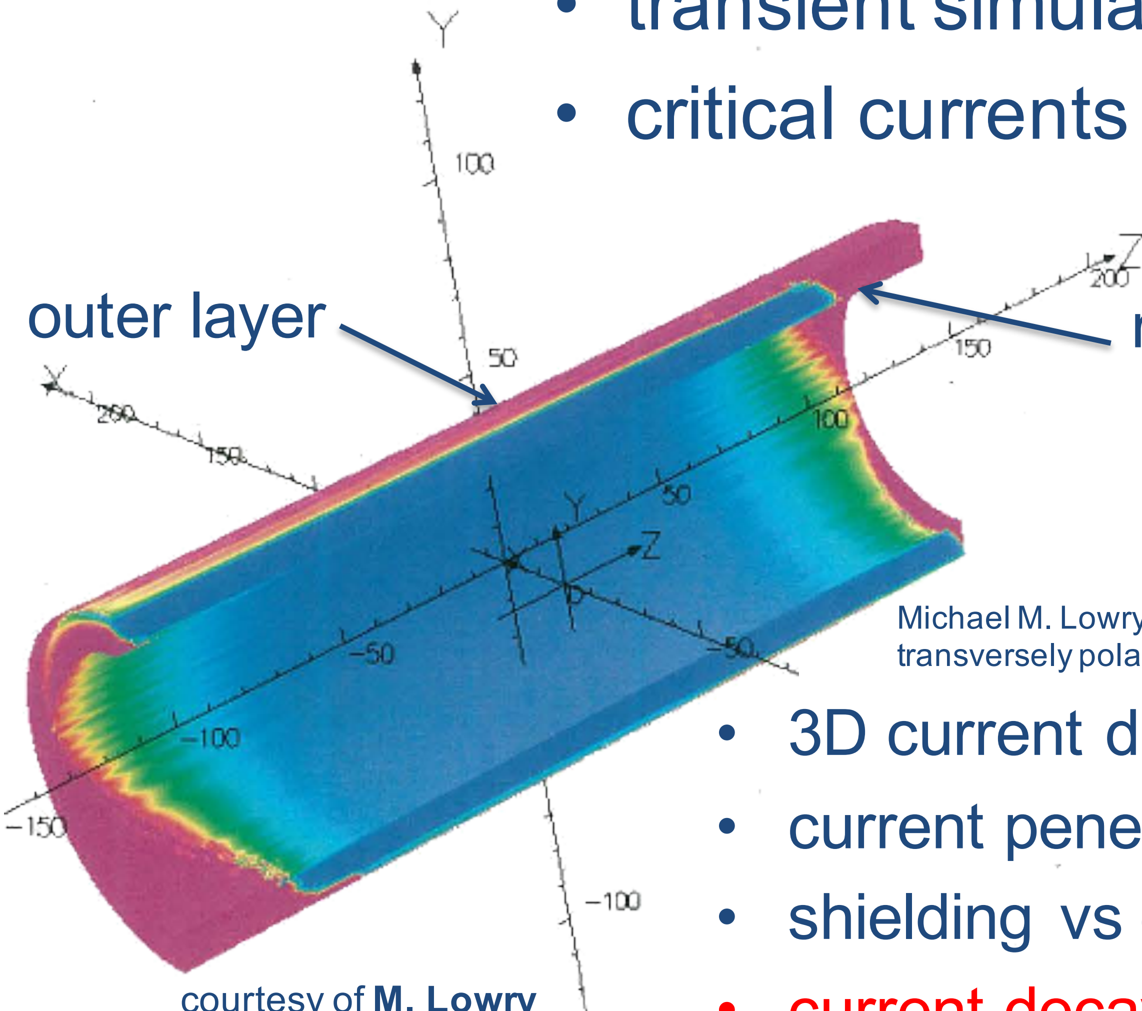


SHIELDING SIMULATIONS

- transient simulation
- critical currents from literature

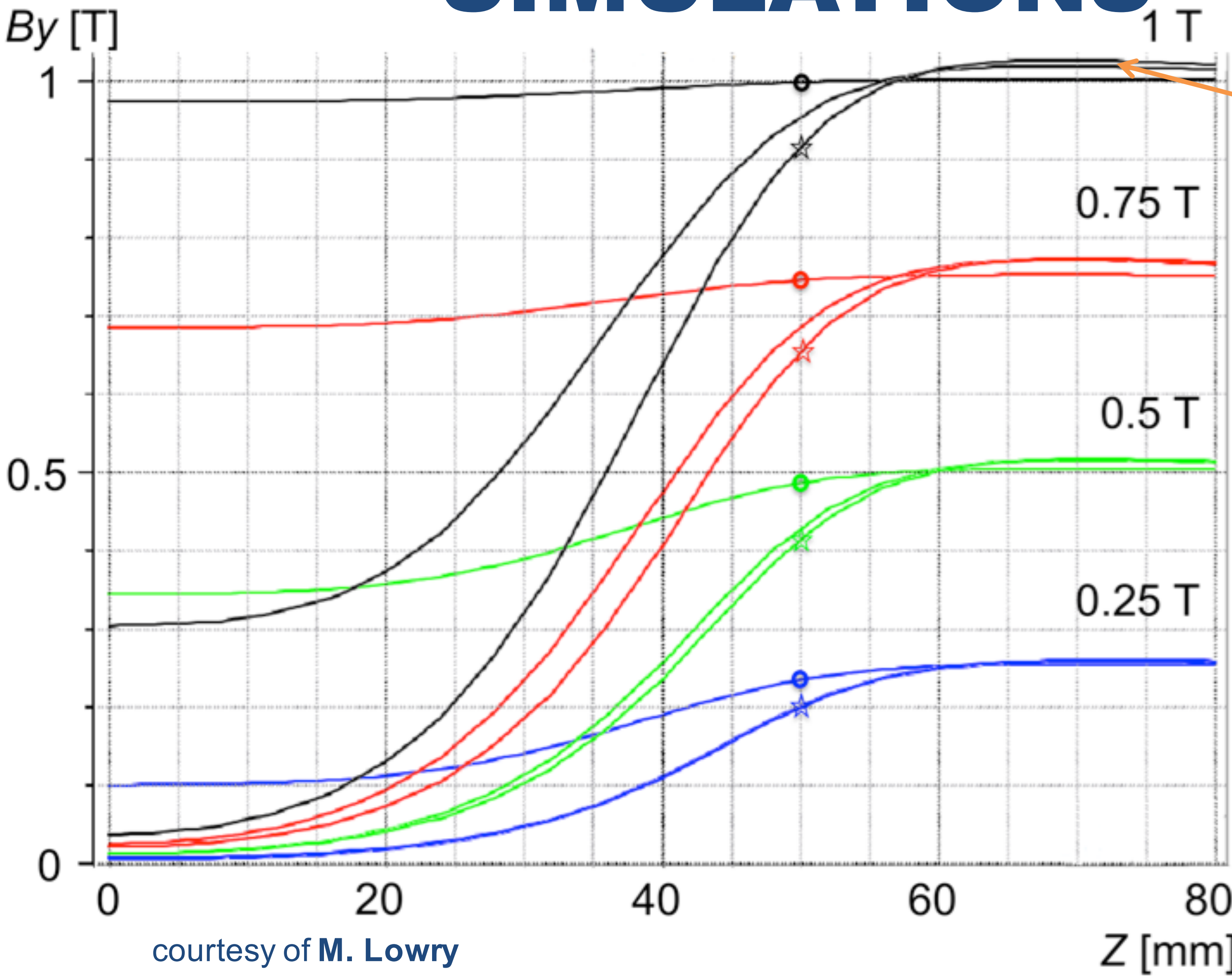


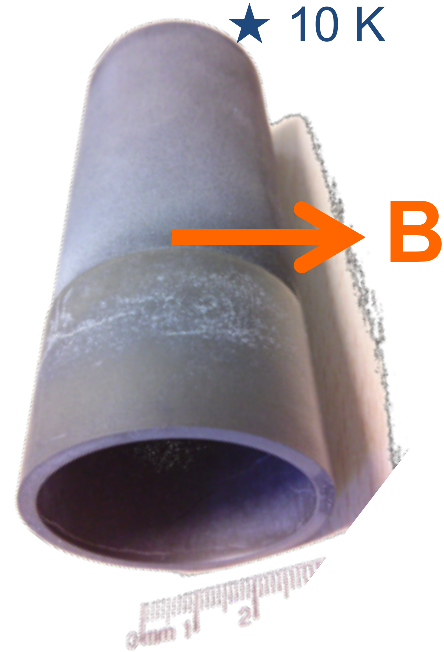
Michael M. Lowry "Magnesium di-Boride: A novel solution for a transversely polarized target holding field in CLAS12 ", SPIN2016

courtesy of **M. Lowry**

- 3D current distribution
- current penetration vs external field
- shielding vs external field
- current decay

SIMULATIONS





courtesy of **M. Lowry**

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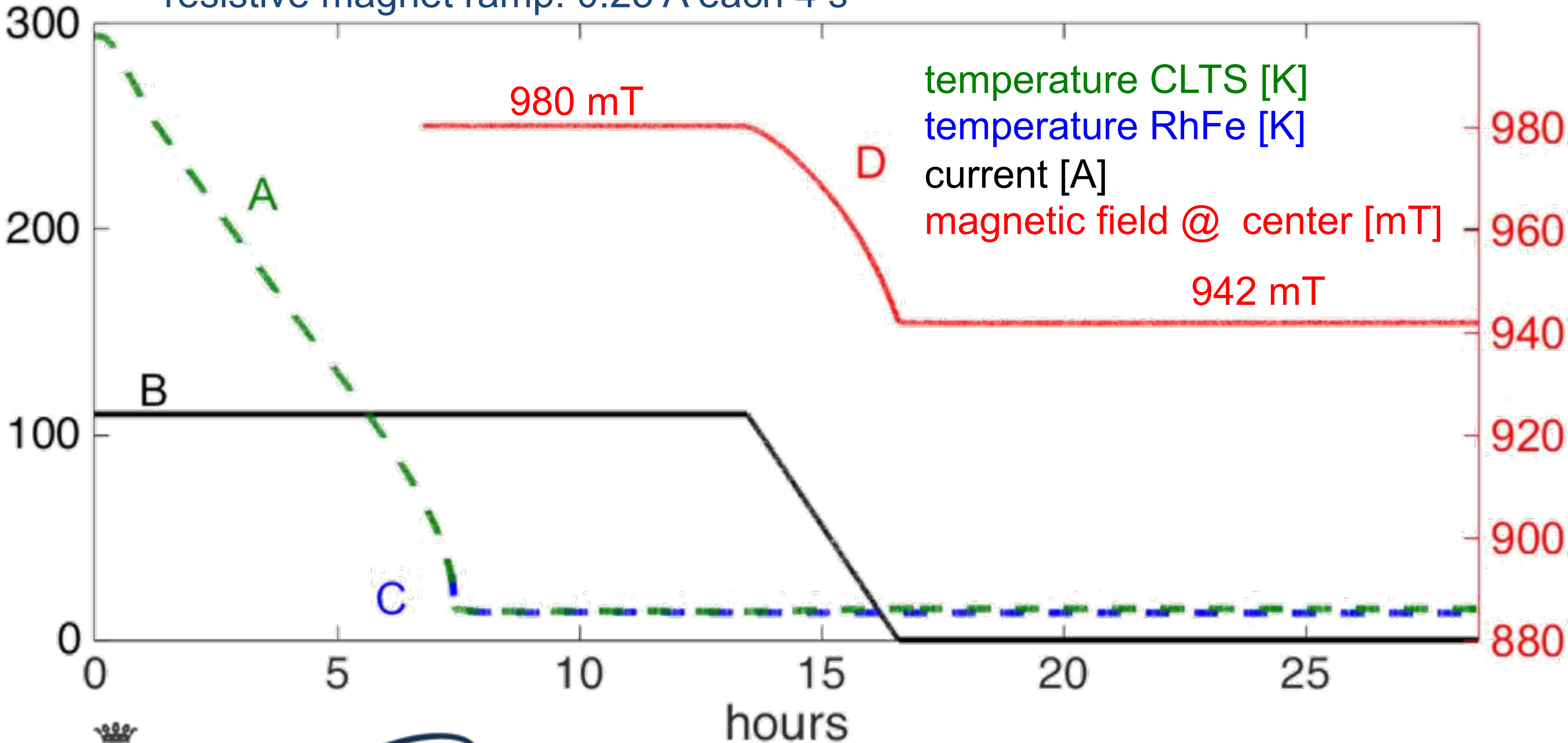
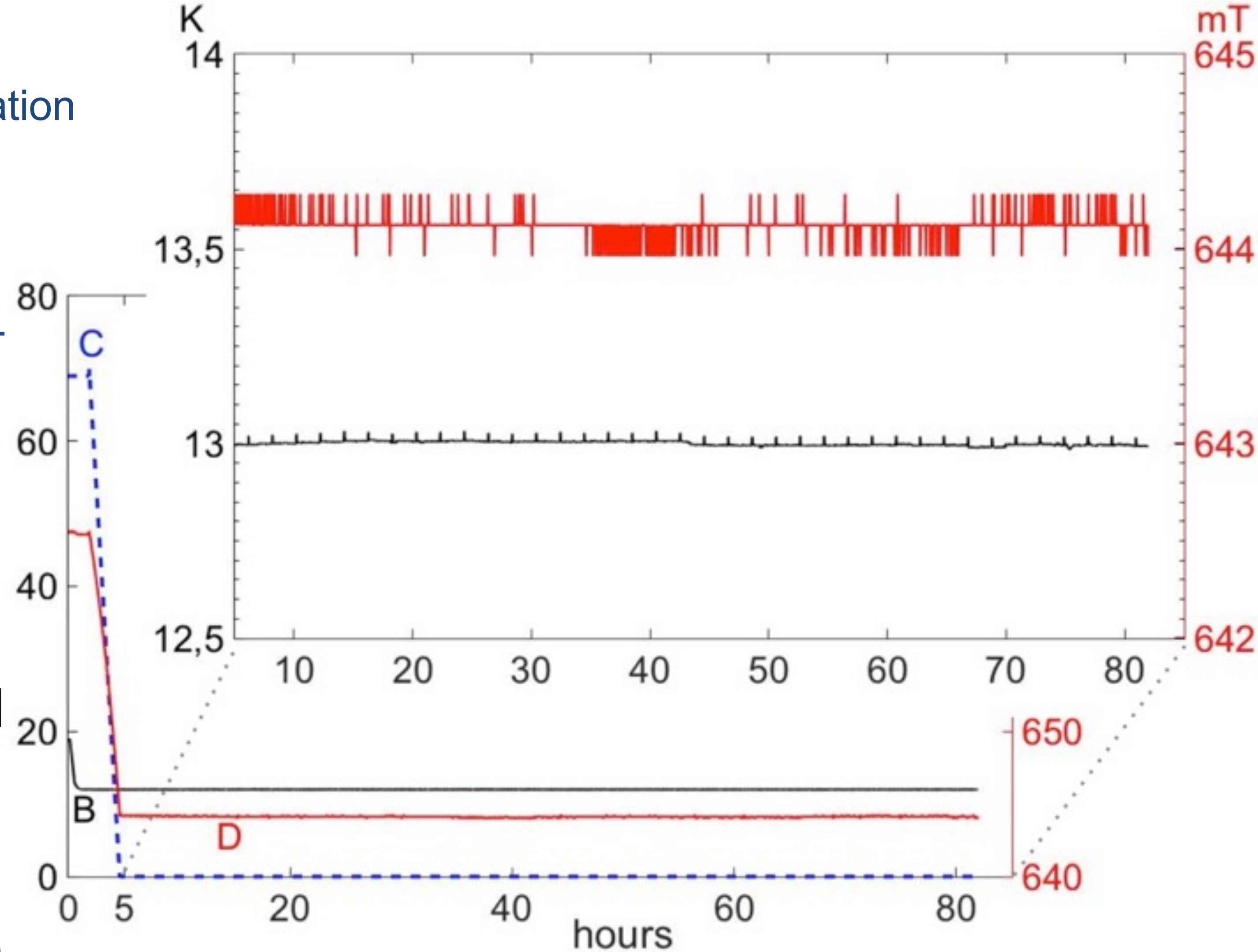
MAGNETIZATION @13 K

Field Cooling -> Field Trapping
cool down about 7.5 hours
temperature 13 K
resistive magnet ramp: 0.25 A each 4 s



LONG TERM MAGNETIZATION I

- low field magnetization
- 80 hours
- temperature 13 K
- field 644 mT
- simulation: 637 mT

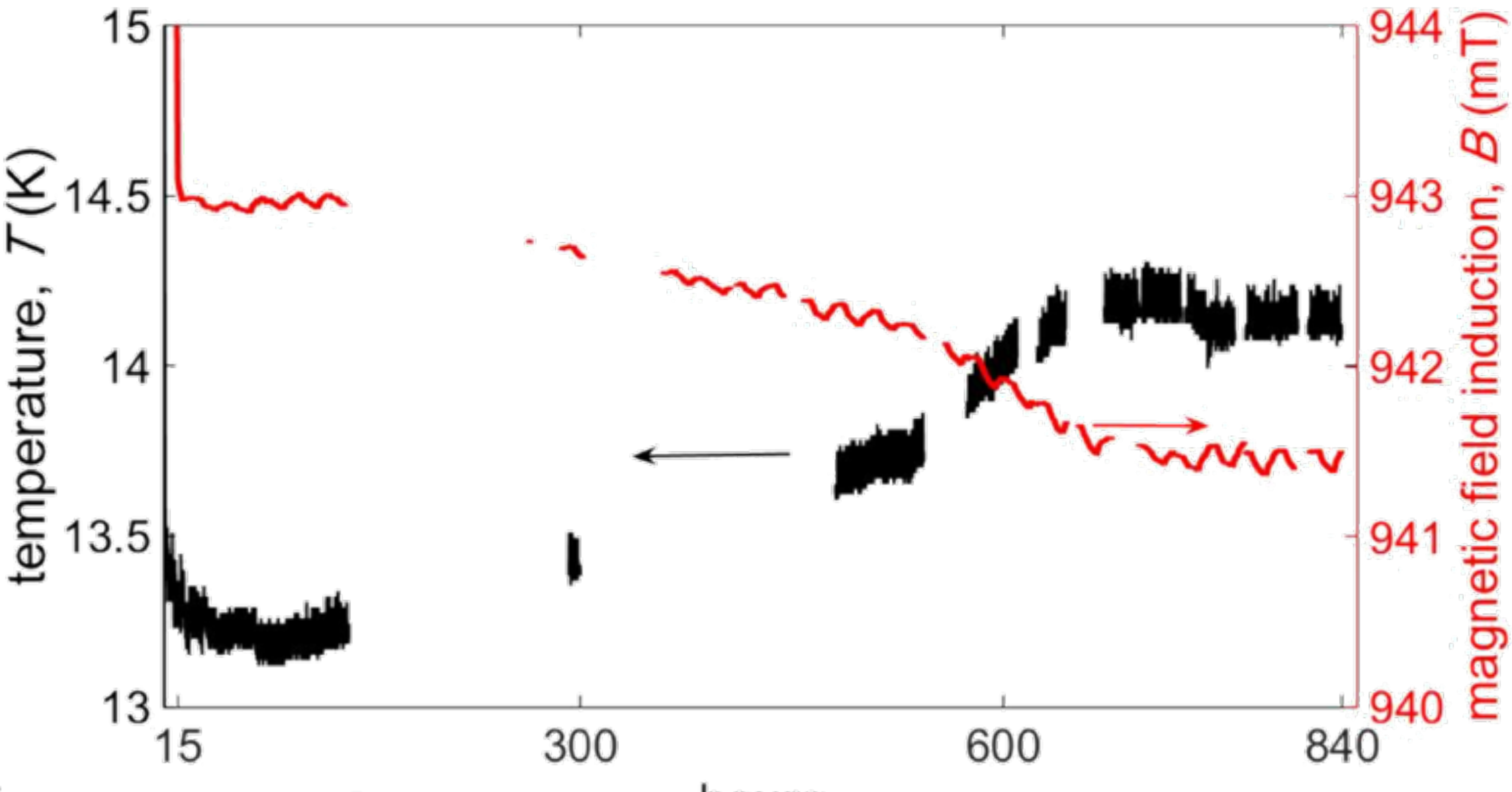


temperature RhFe [K]
current [A]
magnetic field [mT]

LONG TERM MAGNETIZATION II

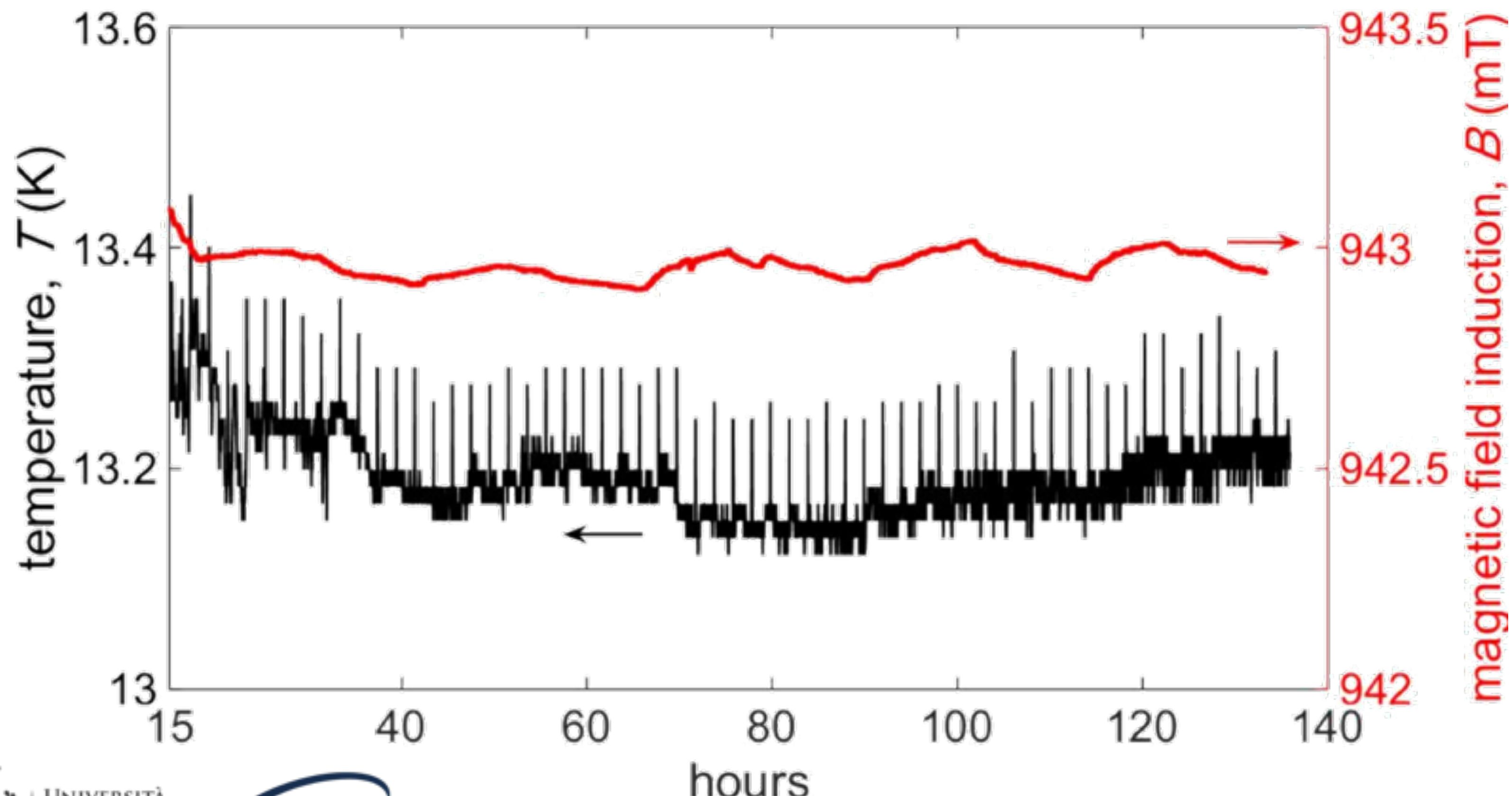
- 800 hours
- temperature stability issue
- temperature 13.2 K - 14.3 K

- maximum current on resistive magnet
- field 943 mT - 941 mT
- simulation 938 mT



LONG TERM MAGNETIZATION III

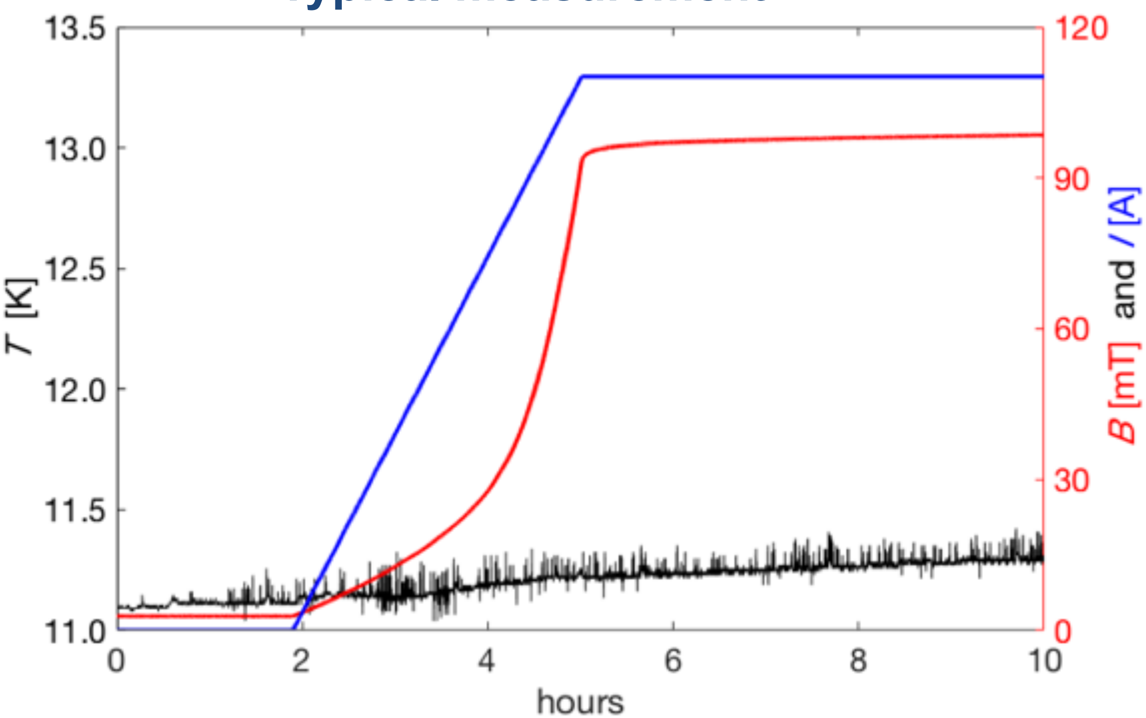
first 140 hours
temperature and field are stable



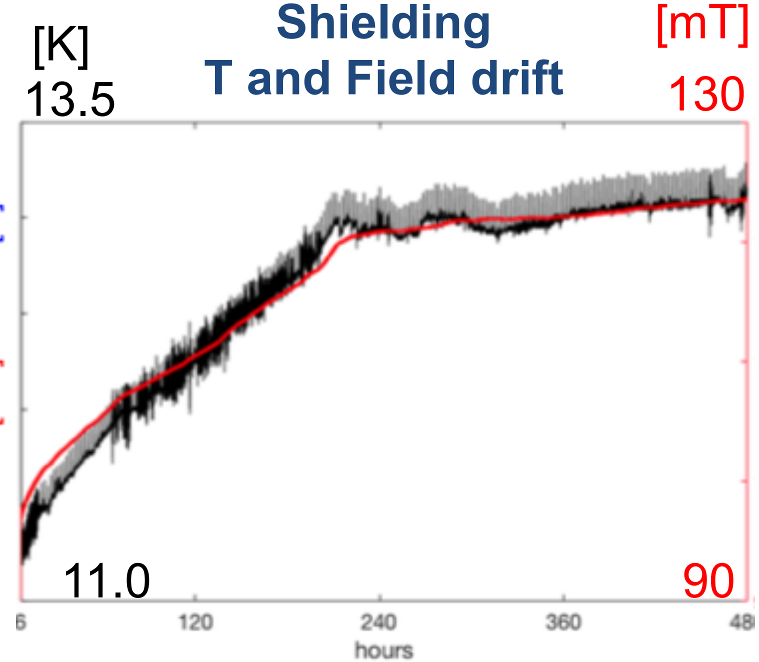
MAGNETIC SHIELDING

- Zero Field Cooling
- magnetic shielding @13K
- max shielded current 110 A

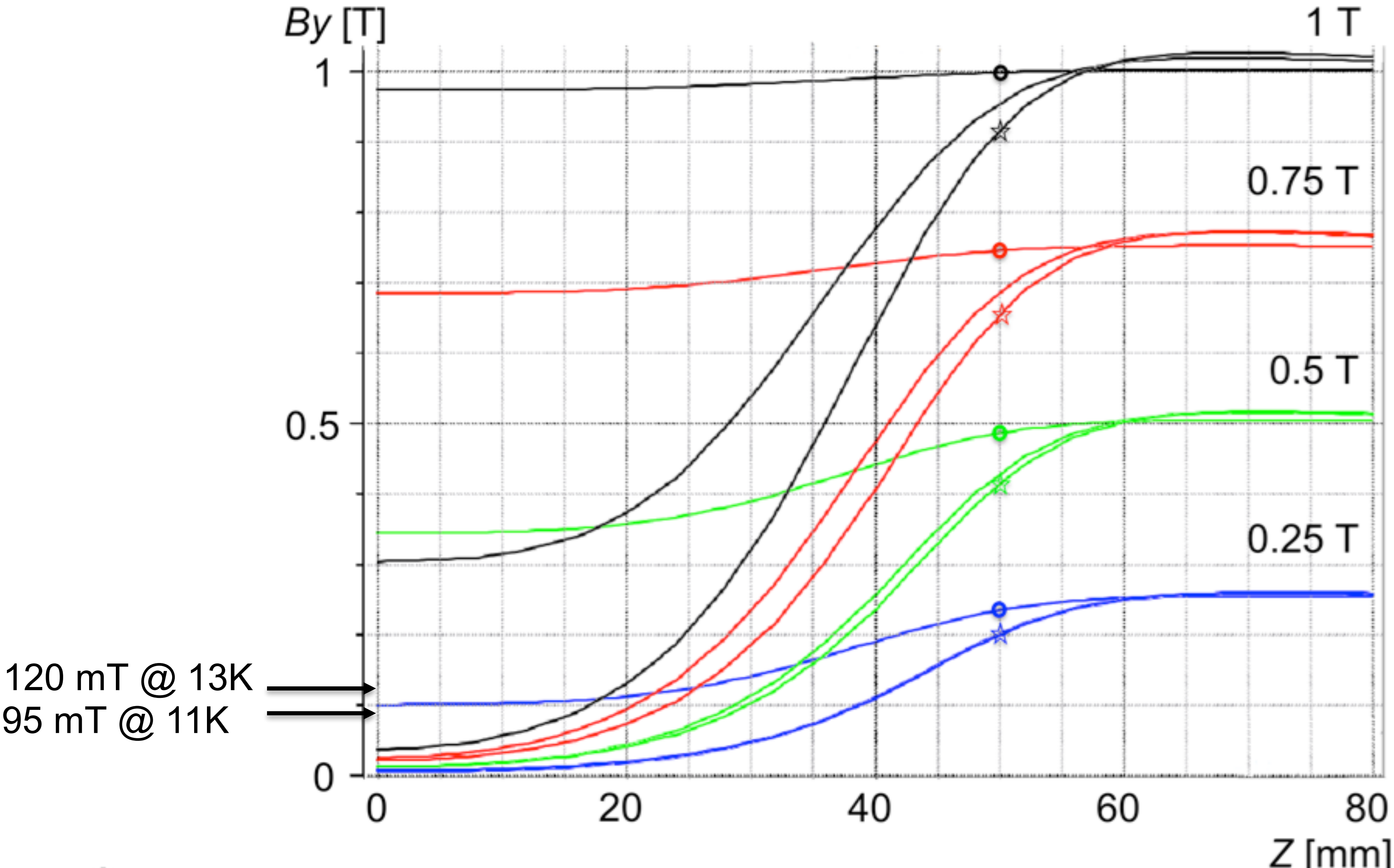
Typical measurement



Shielding T and Field drift



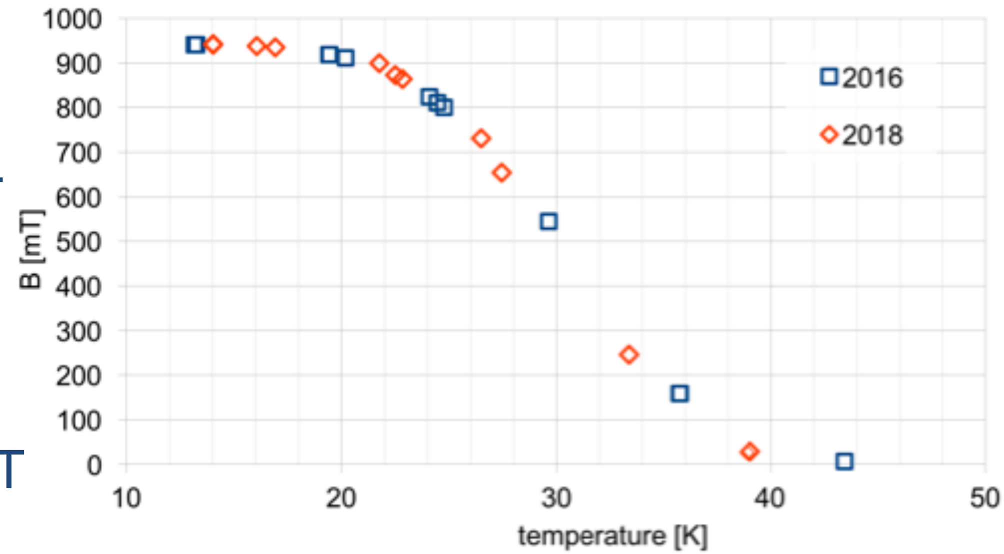
RESULTS



TEMPERATURE DEPENDENCE

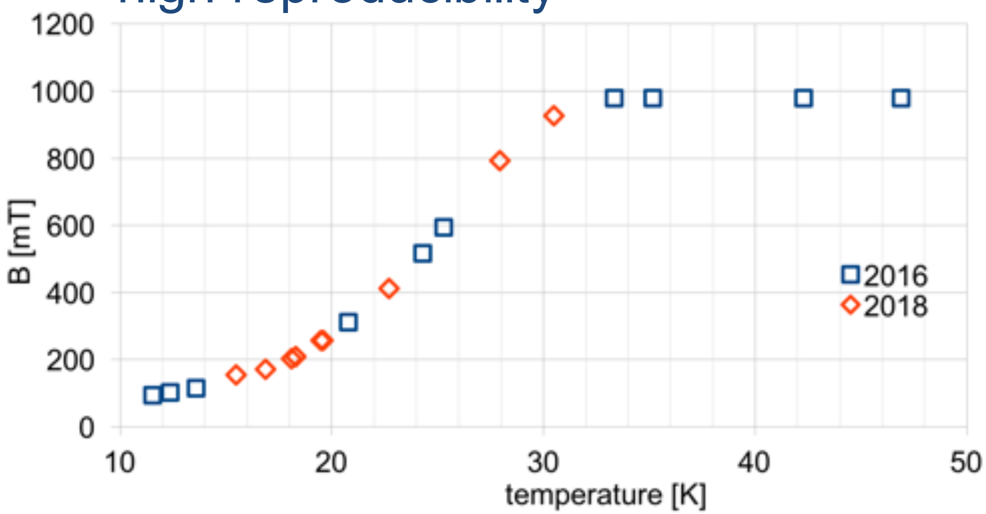
FIELD TRAPPING

- clear indication of Tc
- field trapping saturation @ low T
- high reproducibility



SHIELDING

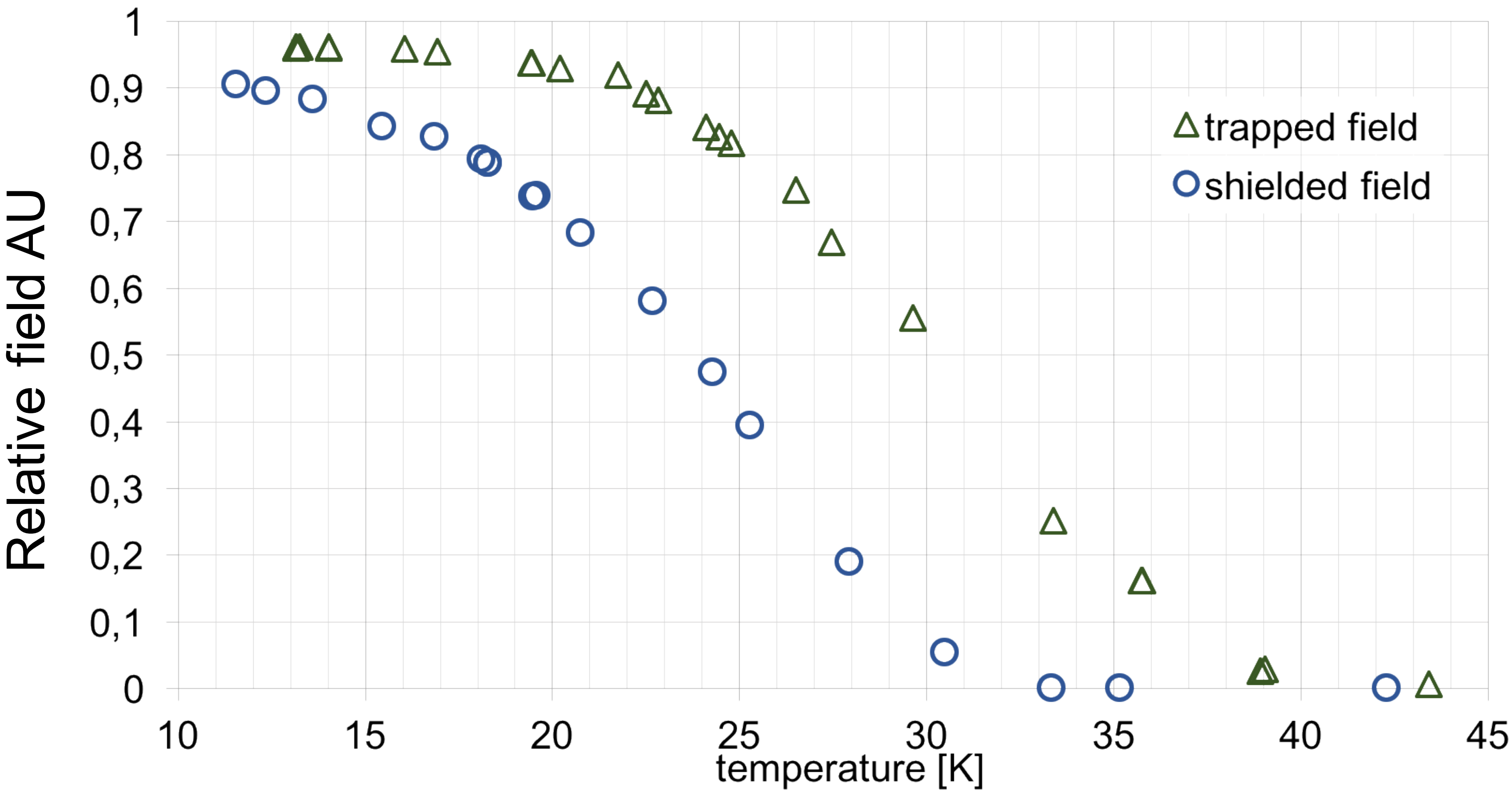
- field trapping saturation @ high T
- high reproducibility



High reproducibility of the SC material and apparatus after

- several thermal cycles
- several quenches
- two assemblies

SHIELDING VS TRAPPED FIELD

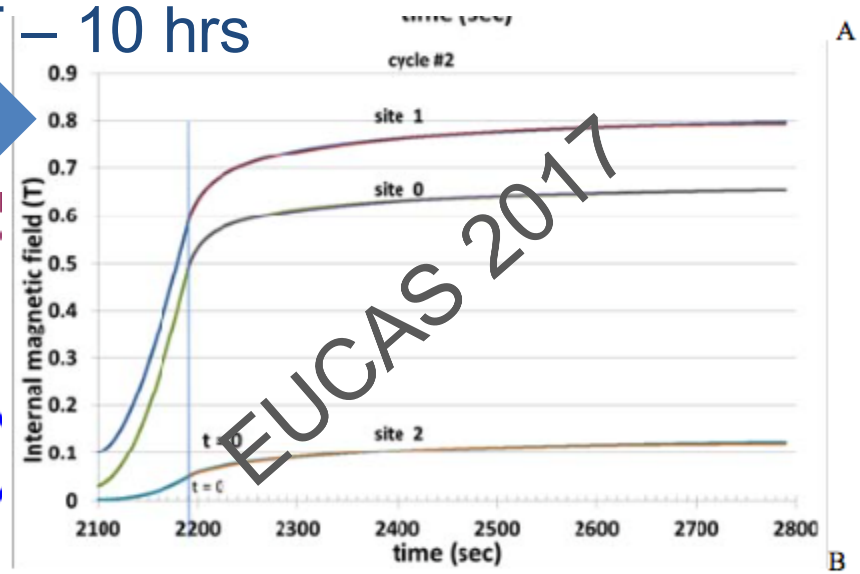


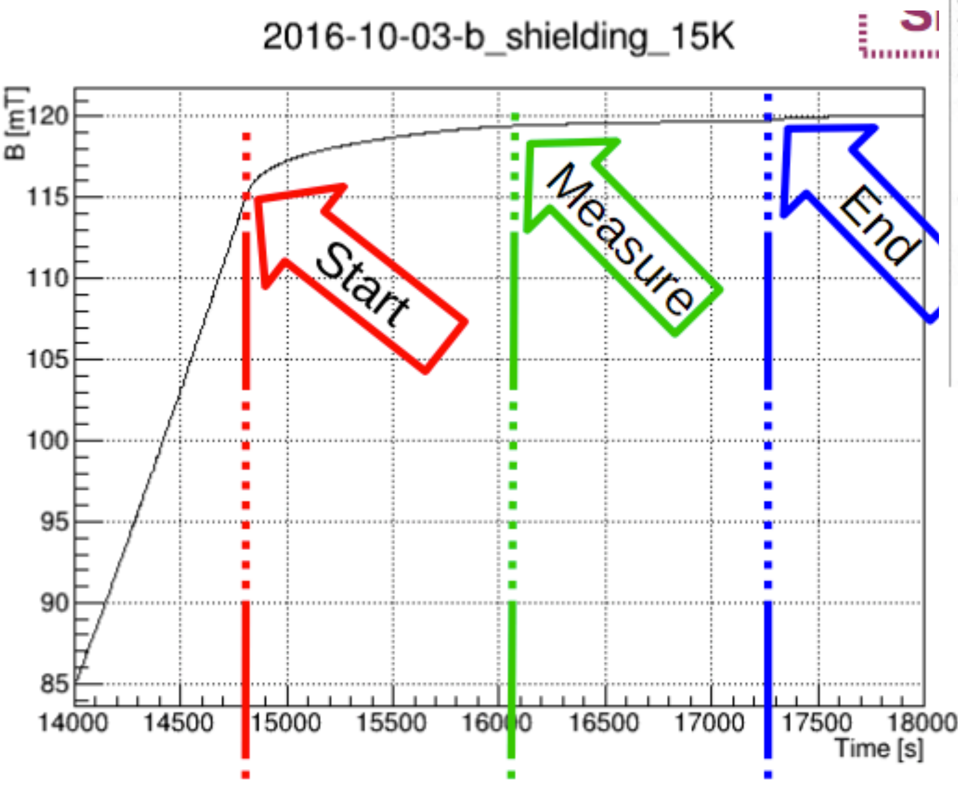
- field trapping: residual field
- shielding: shielded field

CURRENT CREEP

creep measurement @4.2 K 3T – 10 hrs

G. Giunchi et al (CERN) FCC





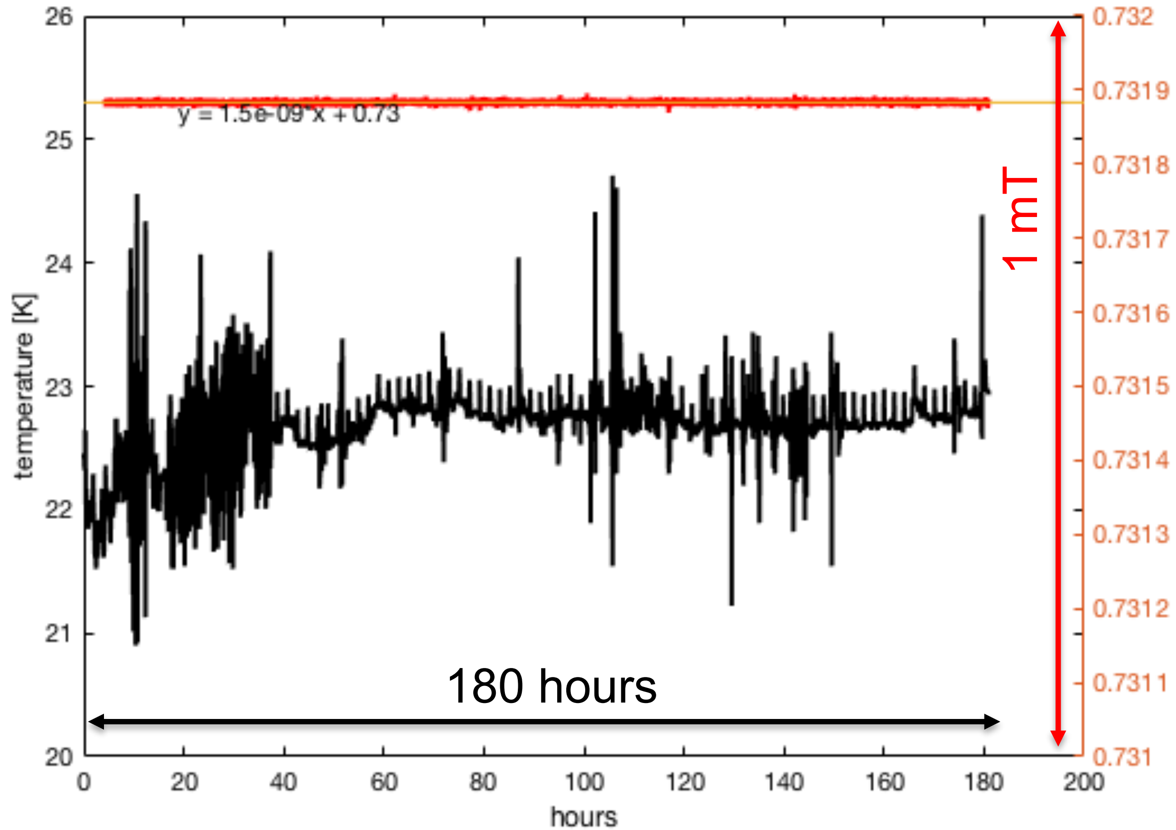
we measured a similar behaviour for shielding data have to be analyzed

CURRENT DECAY

What about field trapping?

No long term creep measured

we measured:
630 mT 4.2 E-6 mT/h
730 mT 1.5 E-6 mT/h
940 mT 2.6 E-7 mT/h

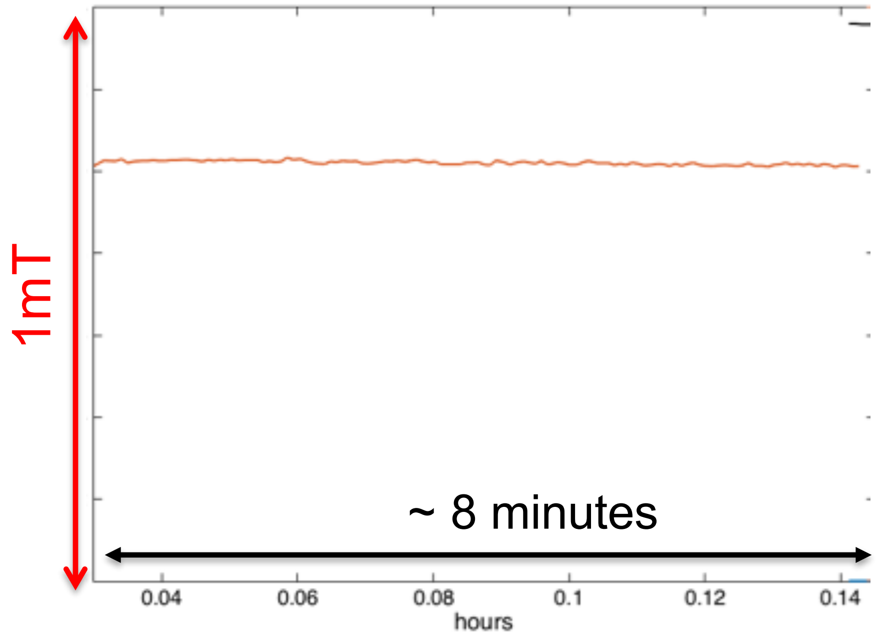


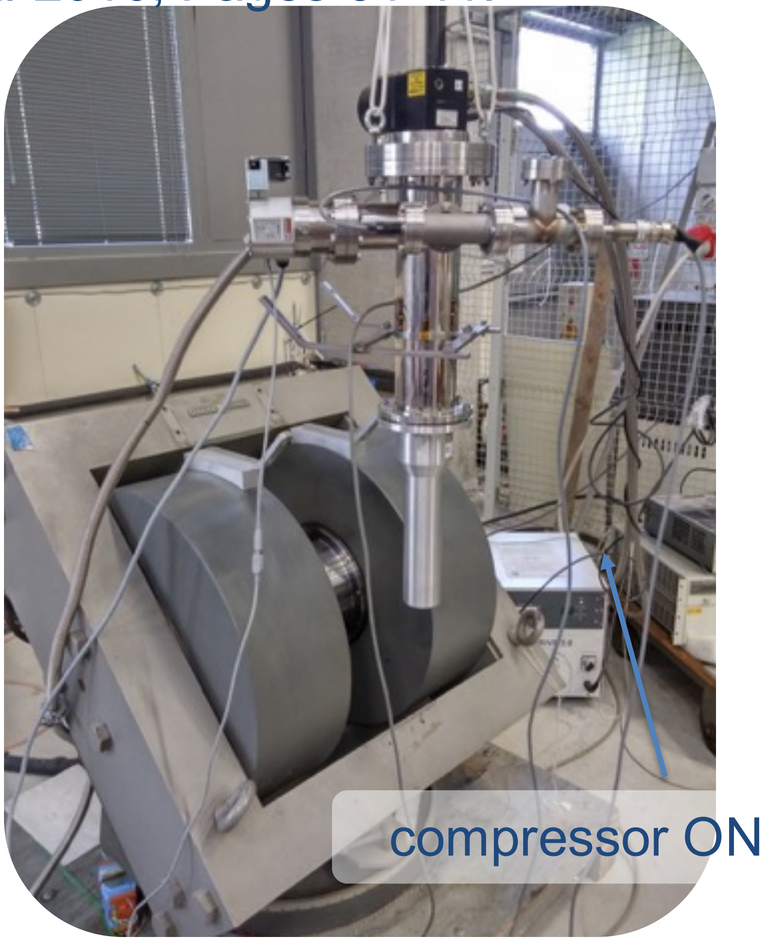
MOVING

The CLAS12 target has to be moved to the operation position.

See M. Lowry et al. "A cryostat to hold frozen-spin polarized HD targets in CLAS: HDice-II" NIM A, Volume 815, 11 April 2016, Pages 31-41.

- temperature 13.6 K
- field 565 mT

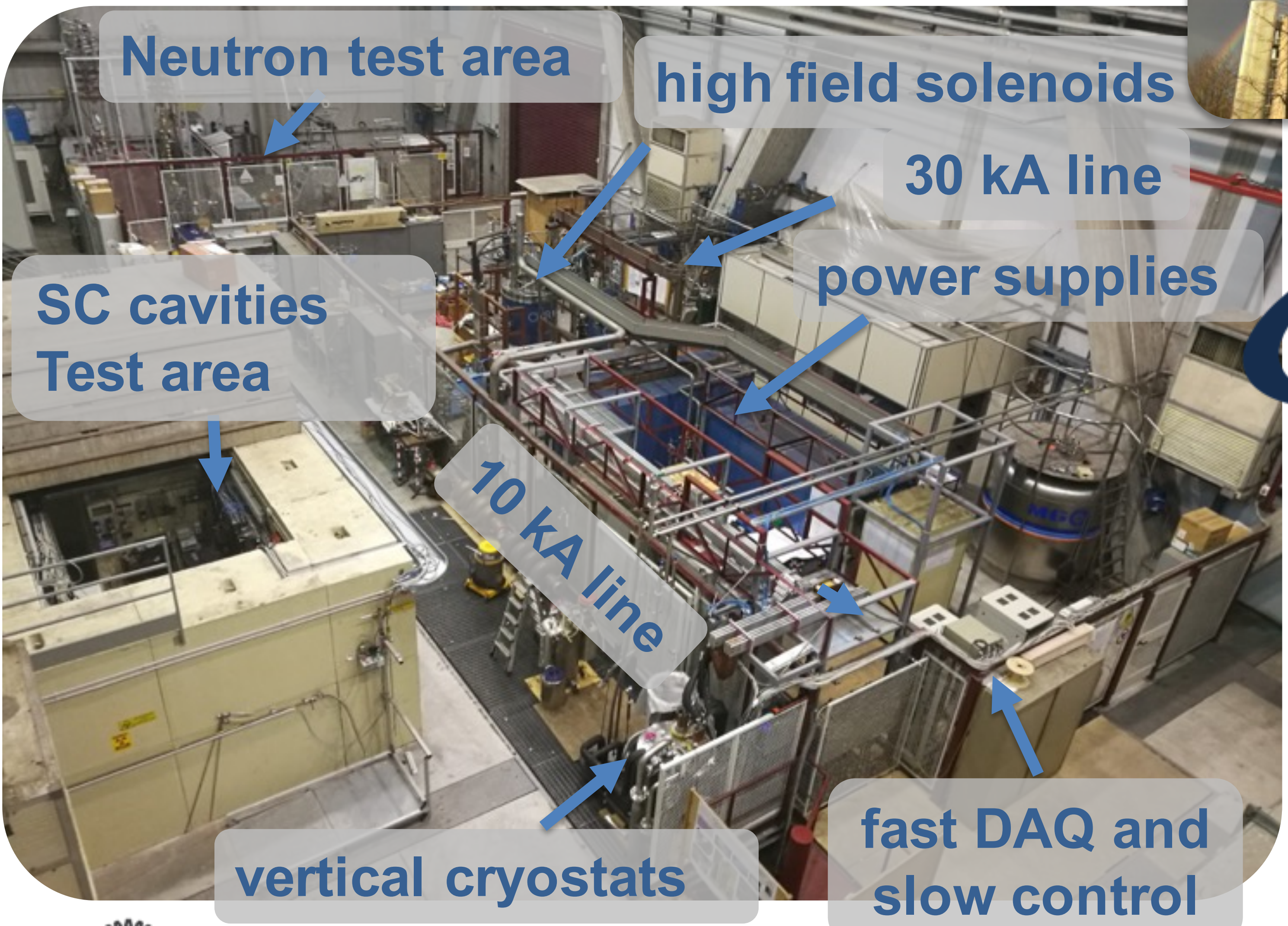




NEXT STEPS

- further measurements (gradients, longitudinal and transverse field)
- test new cylinders
- cylinder transversely magnetized + solenoidal field
- real dimension prototype

WHERE?



INFN LASA

MILANO (I)

SOLEMI 1
8 T x D535 mm
warm bore

SOLEMI 2-3
15 T xD100 mm
cold bore

CONCLUSION

- a bulk SC magnet for HD-ice in CLAS12?
- transverse field test bench: commissioned
  - 0.94 T transverse magnetic field
  - magnetization (field trapping)
  - shielding
  - temperature control
  - the magnetized cylinder can be moved
- More measurements
  - Field quality
  - Dual operation
- working for a final size prototype

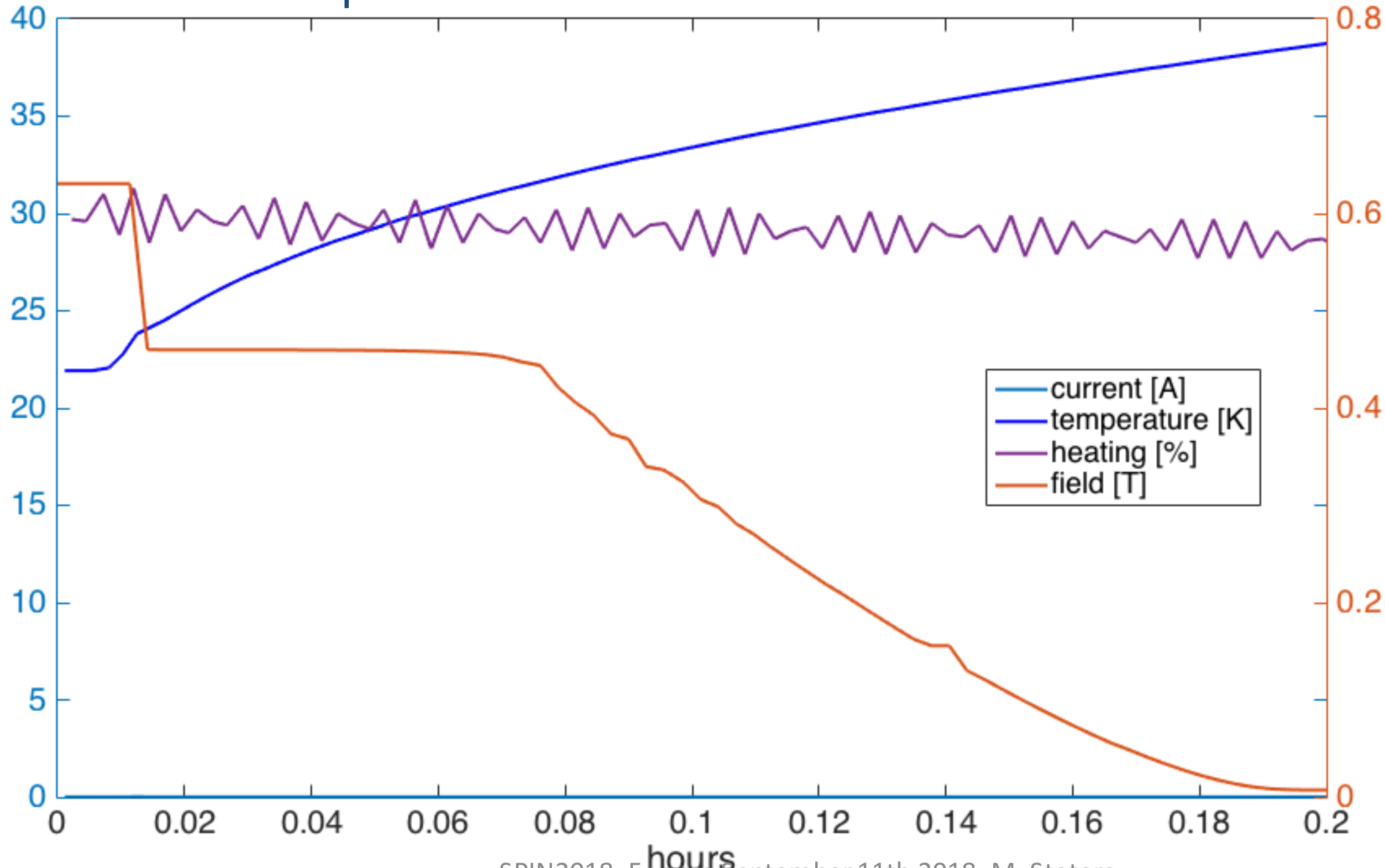
THANK YOU

I. Balossino, L. Barion, G. Ciullo, M. Contalbrigo, P. Lenisa, M. Statera, G. tagliente, M. Lowry, A. Sandorfi

backup

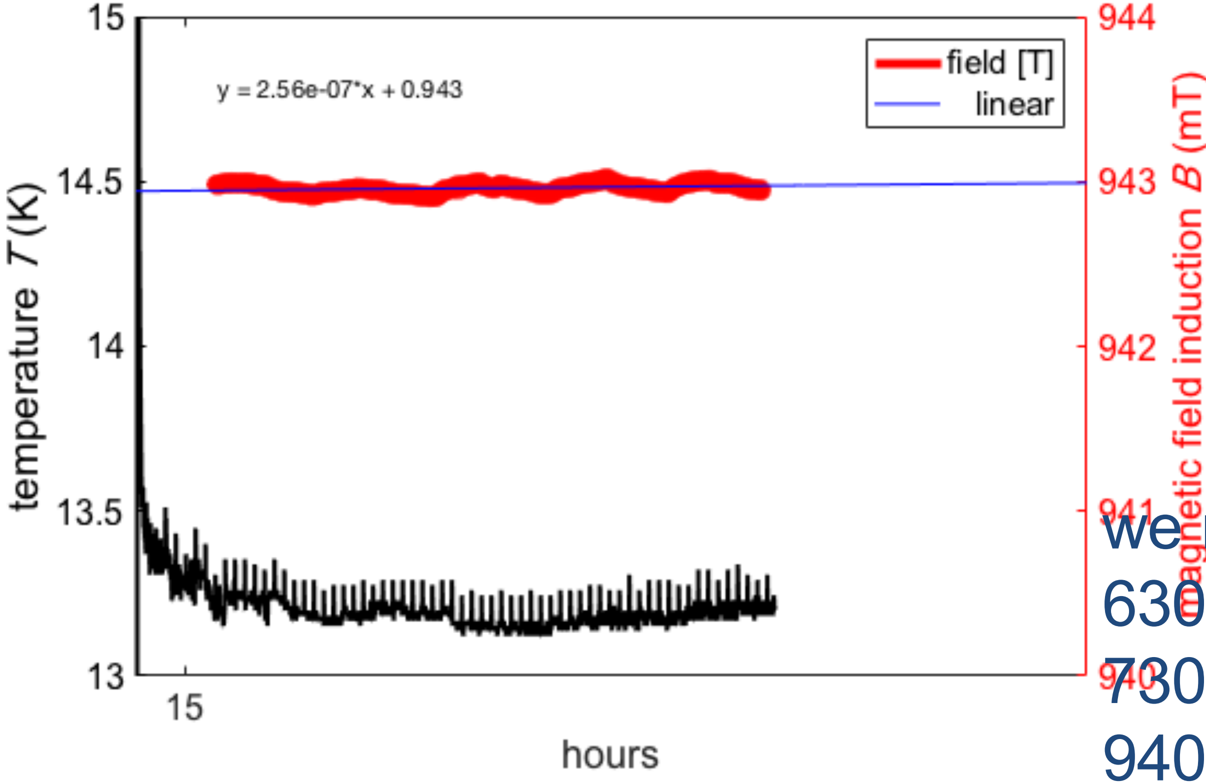
HEATING

- temperature masured at the bottom of the cold mass
- heating up to 70 K : 2 hours
- field drops at about 39 K



CURRENT DECAY

what about field trapping?



we measured:

630 mT 4.2 E-6 mT/h

730 mT 1.5 E-6 mT/h

940 mT 2.6 E-7 mT/h

no long term creep measured

CURRENT DECAY

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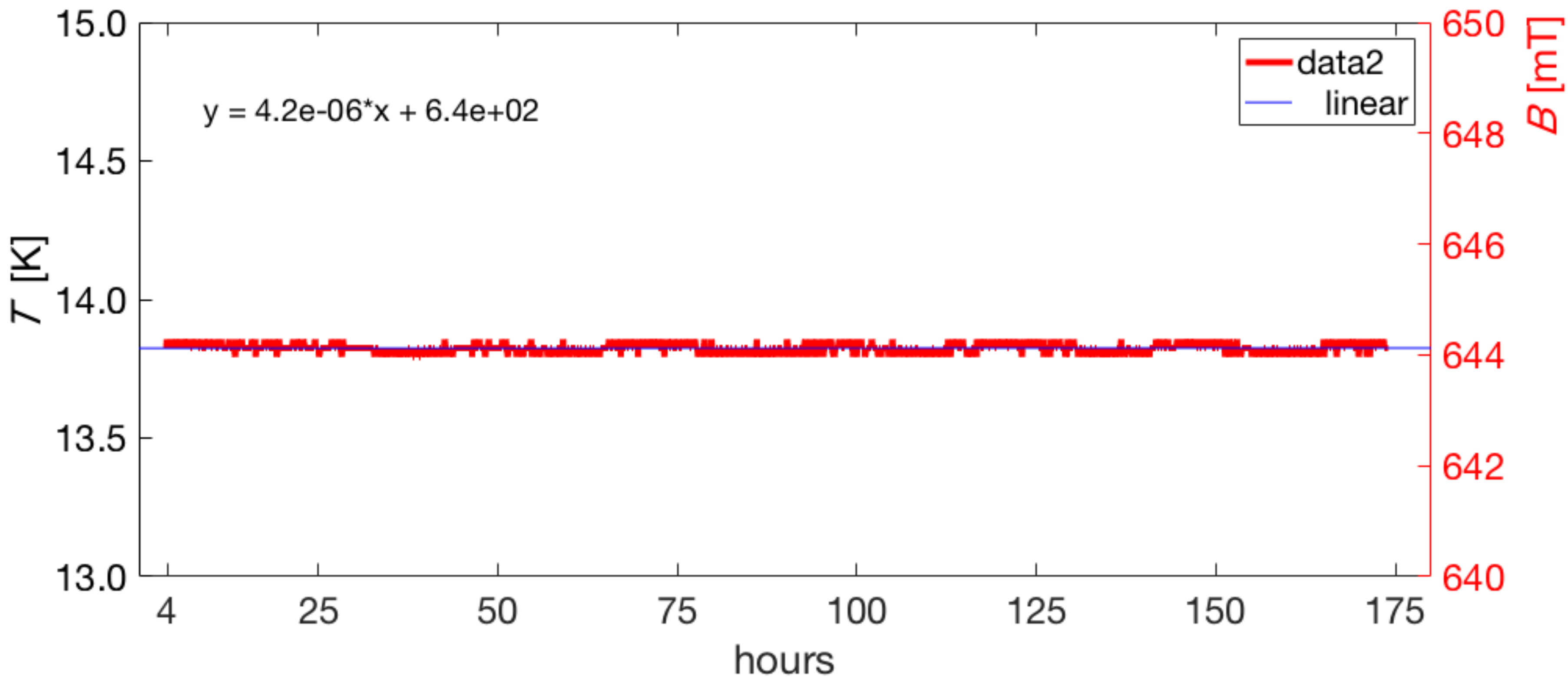

CURRENT DECAY

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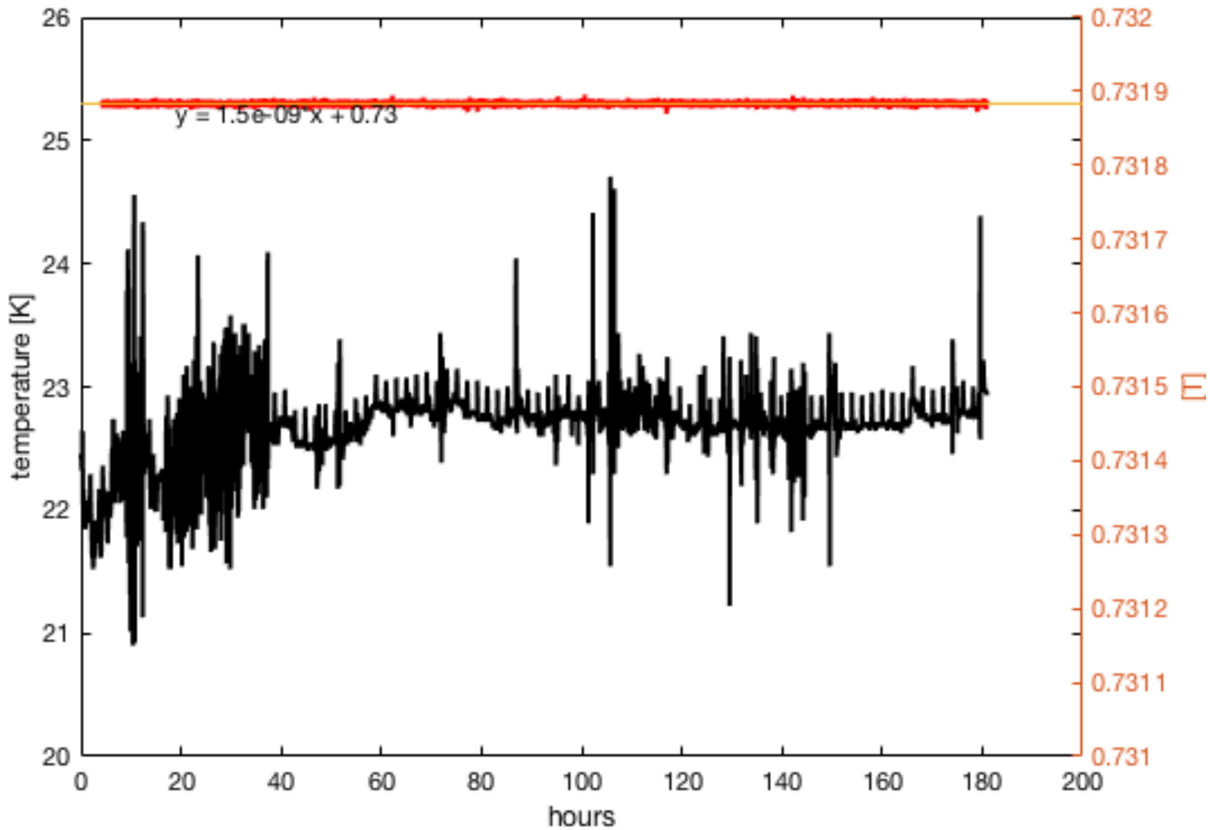
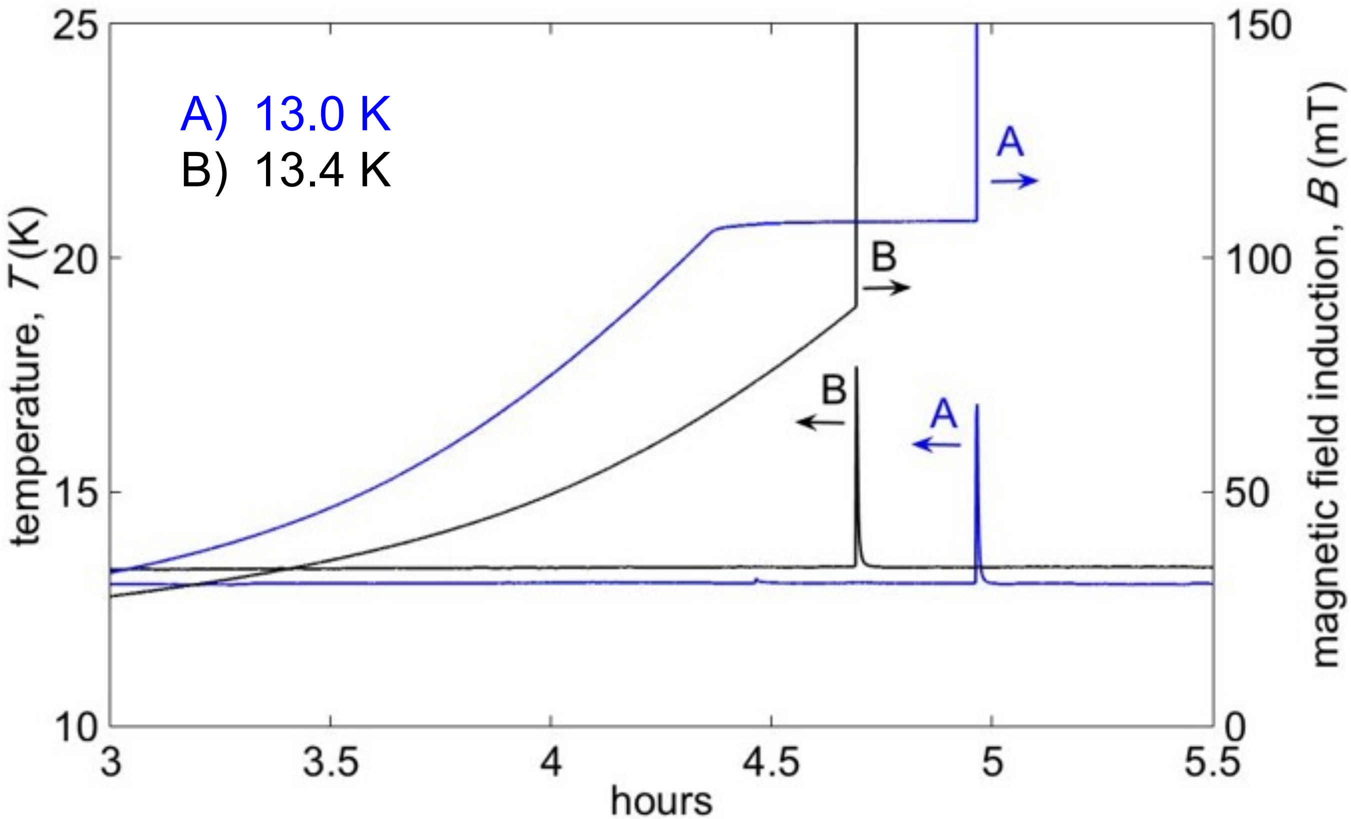
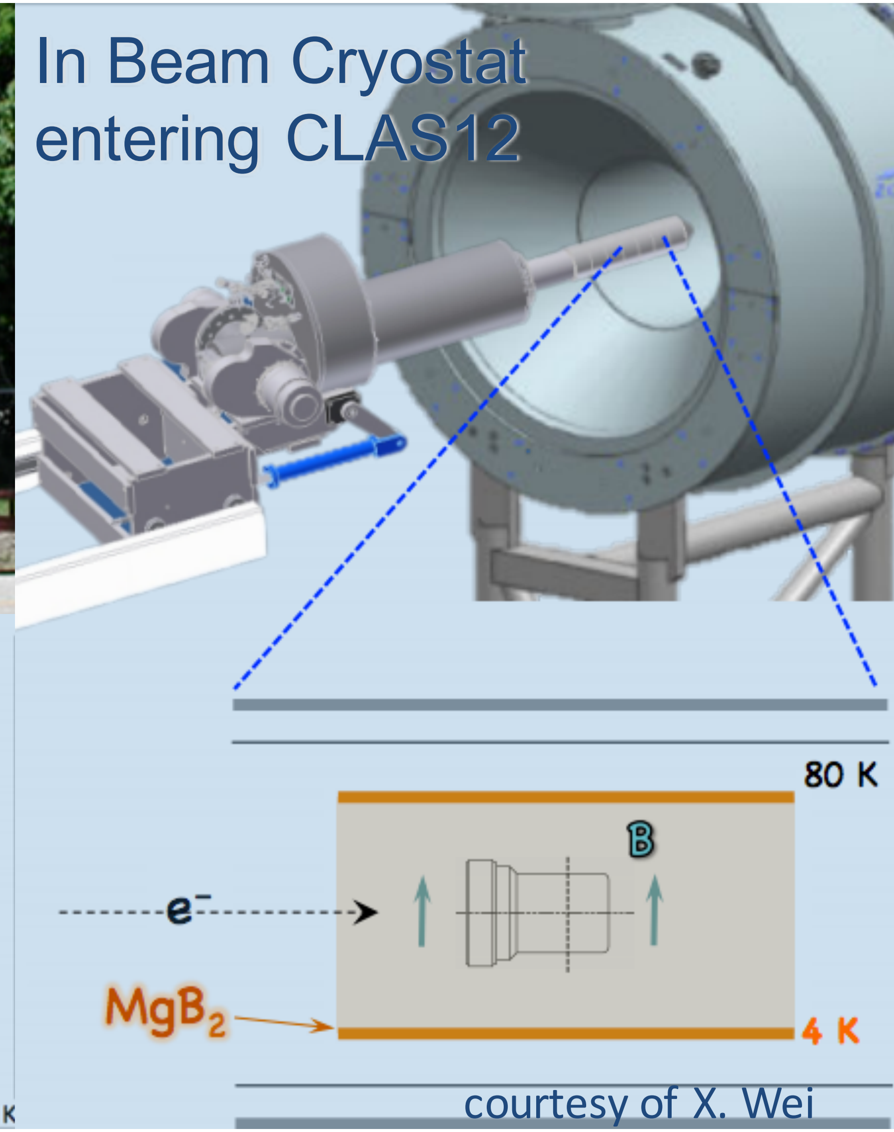


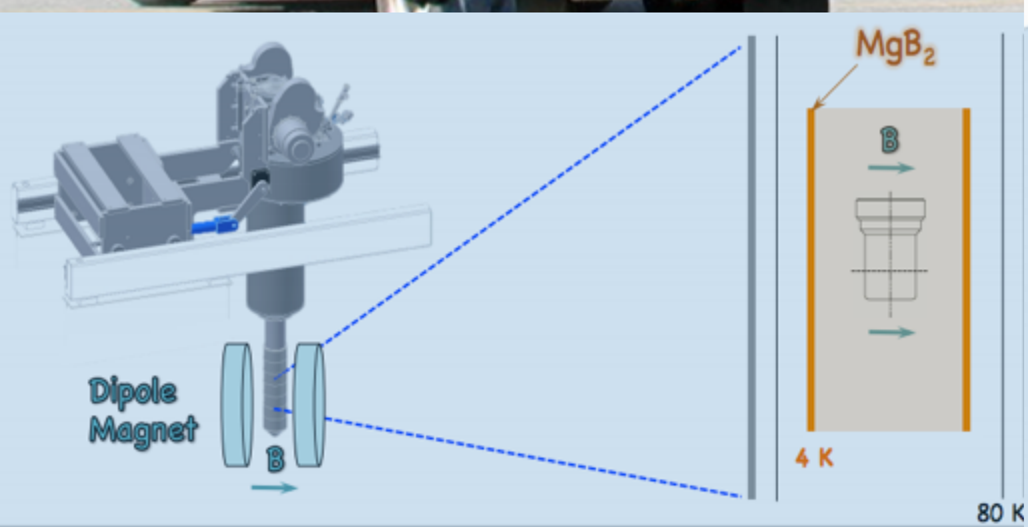
QUENCH

Quenches induced by cryocooler spikes

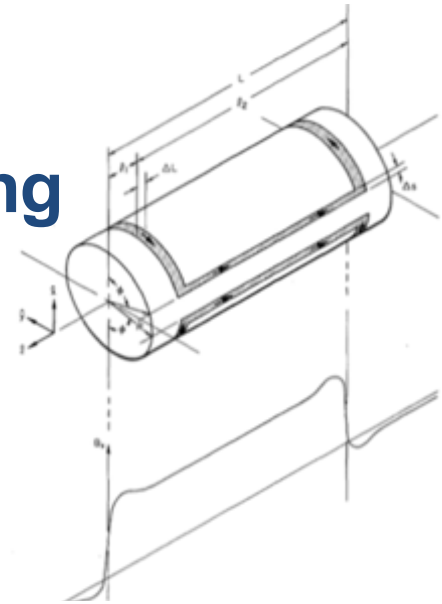


CLAS12 INTEGRATION





BULK SC FOR ACCELERATORS AND DETECTORS?



transverse shielding and field trapping

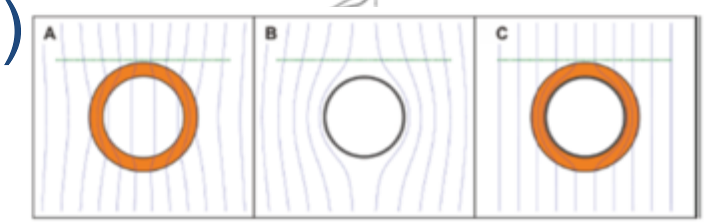
- 1979 NbTi D. J. Frankel

longitudinal shielding

- Giunchi et al, EDISON
- Maing F. Maas et al PANDA

magnetic shielding (**field cloak**)

- main field not affected
- SC+ferromagnetic
- E. Barzi et al (FNAL) muon g-2 inflector
- Capobianco-Hogan et al- Electron Ion Collider



[ref] F. Gomory et al. "Experimental Realization of a Magnetic Cloak" Science 335, 1466 (2012)

FOR DISCUSSION

SC materials

- NbTi – 4.2 K
- MgB_2 – sinterized RLI –induction heating UNIGE (CH)
- YBCO – deposition vs sinterized

	SC long	SC transv	ferromagnetic
longitudinal shielding	shielding		
transverse shielding		shielding	
field cloak		shielding	yes
Dual operation bulk	shielding	field trap	