A TRANSVERSE SUPERCONDUCTING BULK MAGNET

Marco Statera
on behalf of the INFN Ferrara team

Polarized Fuel for Fusion
Ferrara October 3rd 2017

SUMMARY

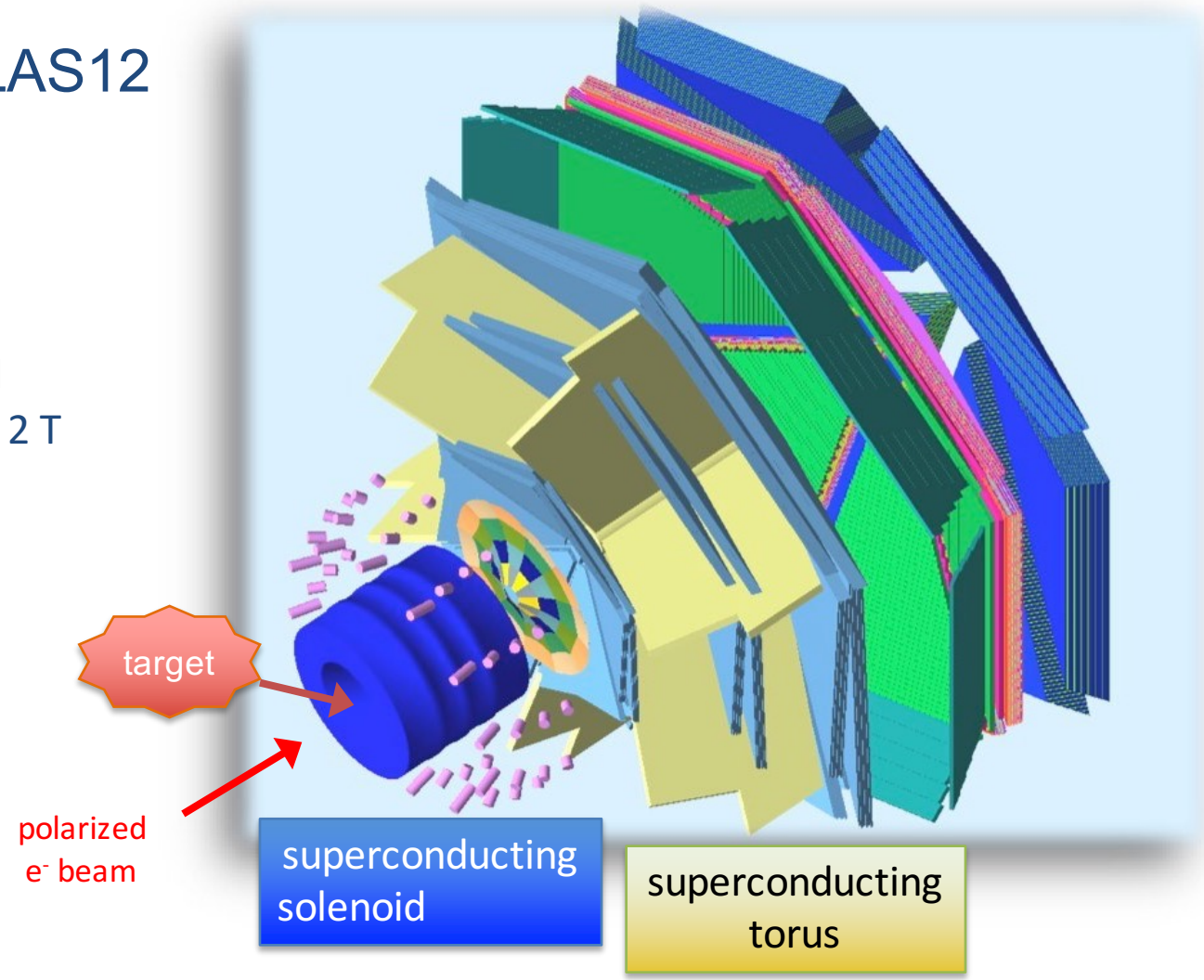
- brief introduction
- a bulk transverse magnet
- test bench in Ferrara
- transverse measurements
- next steps
- bulk materials
- conclusion

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

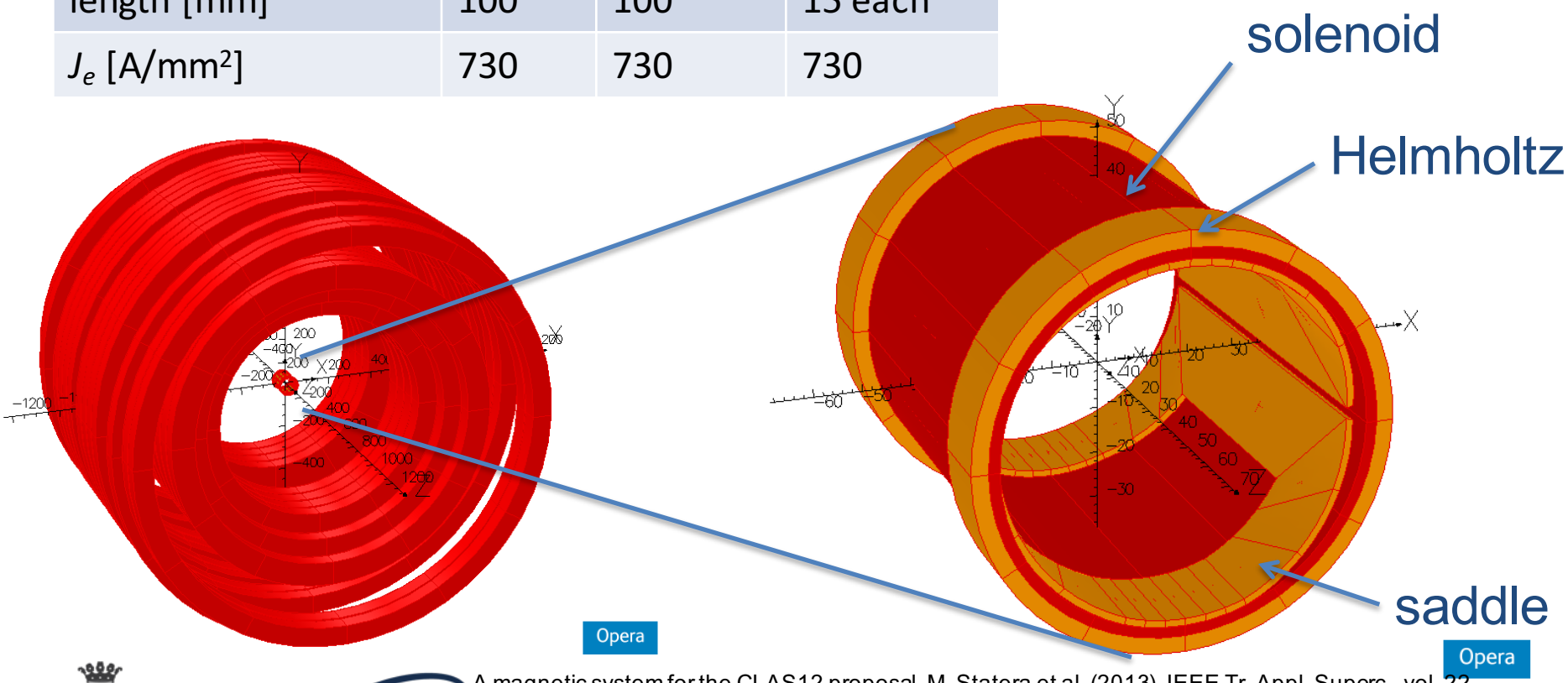


A STANDARD SOLUTION

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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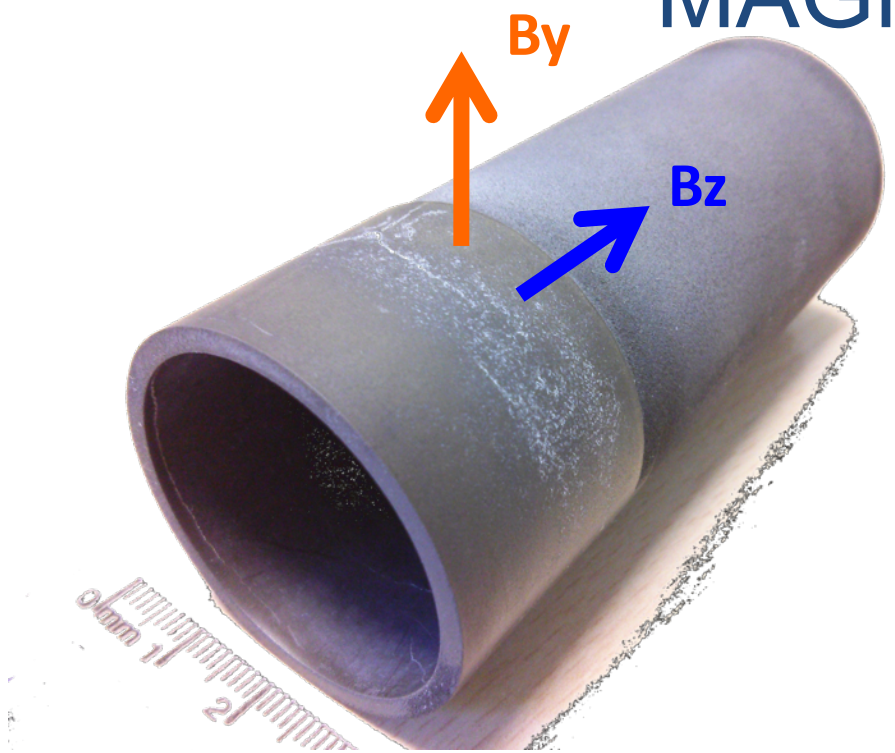
A BULK TRANSVERSE MAGNET?



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

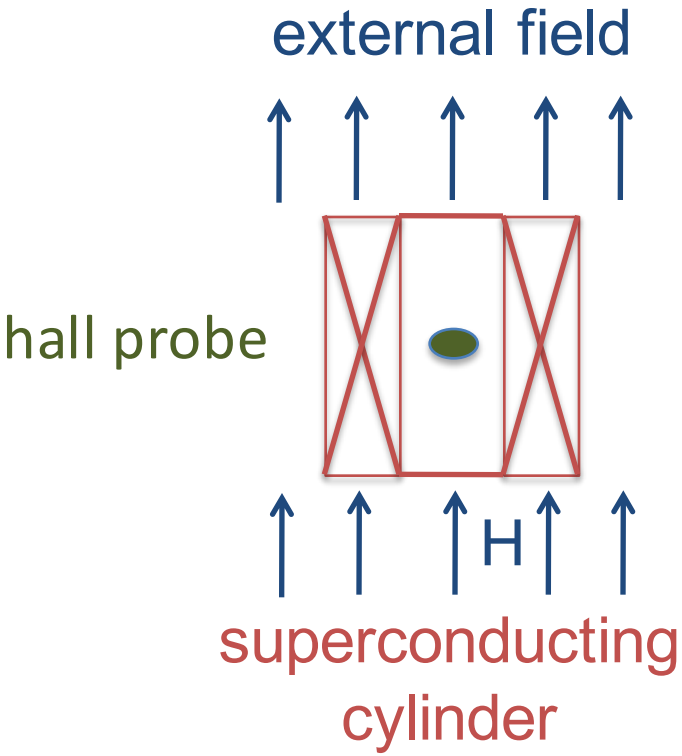
bulk cylinder

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

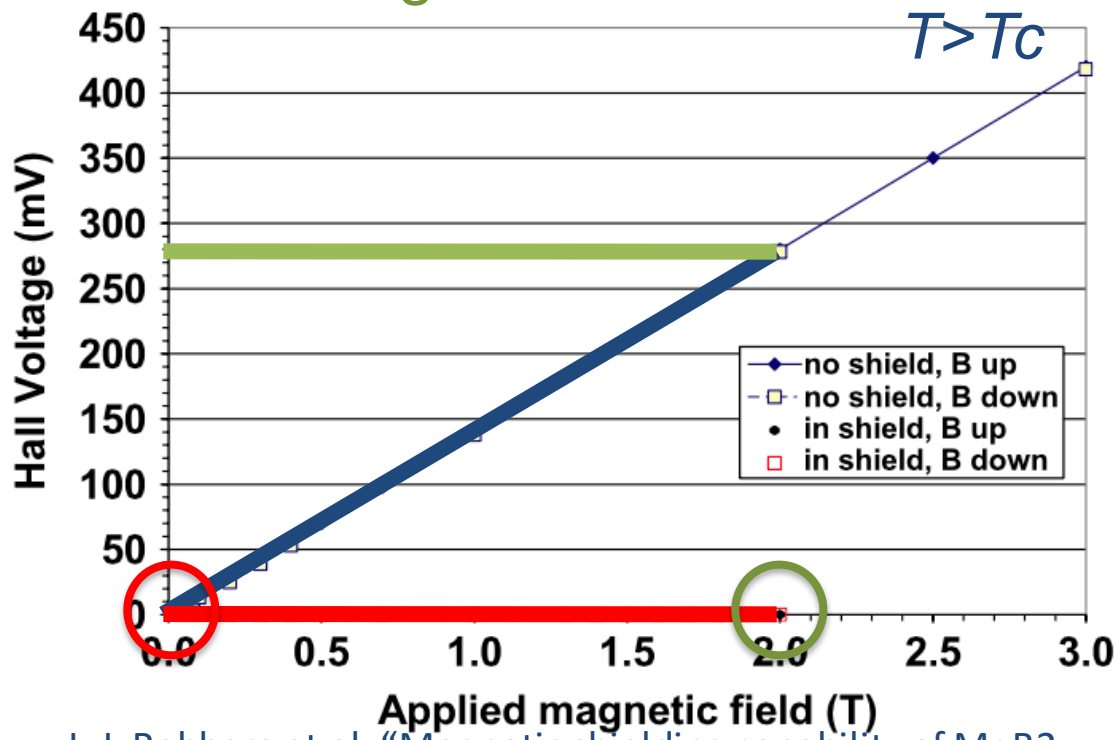
features

- no current leads
- Cu free
- self tuning
- few mm thickness
- external magnet for magnetization

SUPERCONDUCTING CYLINDER COOLING



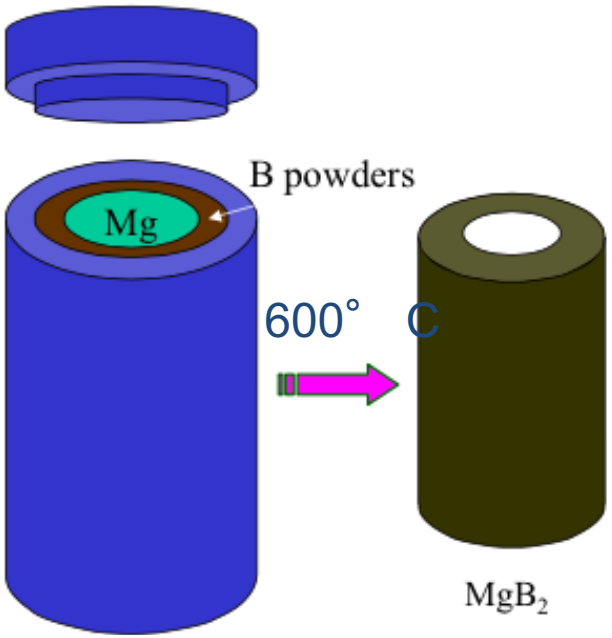
- cylinder not superconducting ($T>Tc$)
- Zero Field Cooling
- Field Cooling

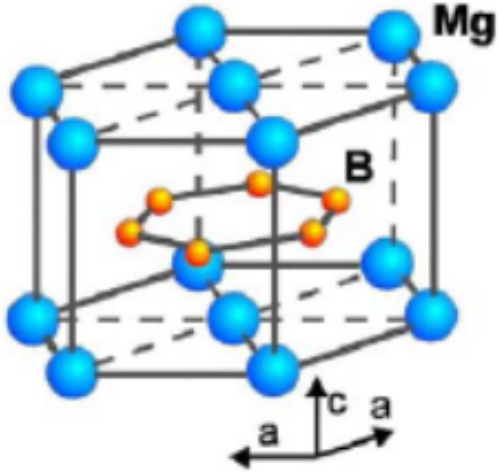


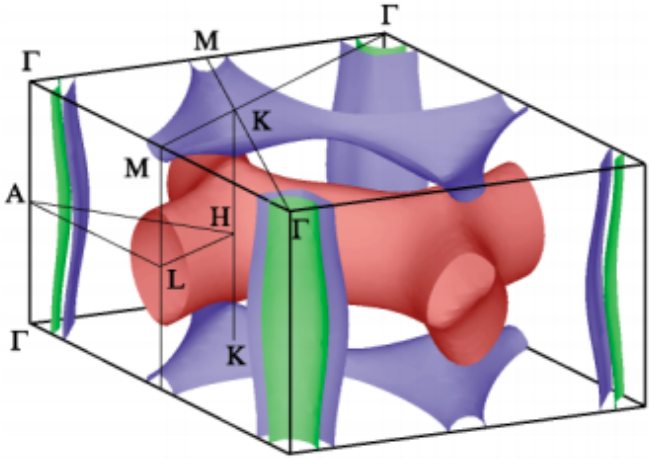
J. J. Rabbers et al. "Magnetic shielding capability of MgB2 cylinders" Supercond. Sci. Technol. Vol. **23**, 2010

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



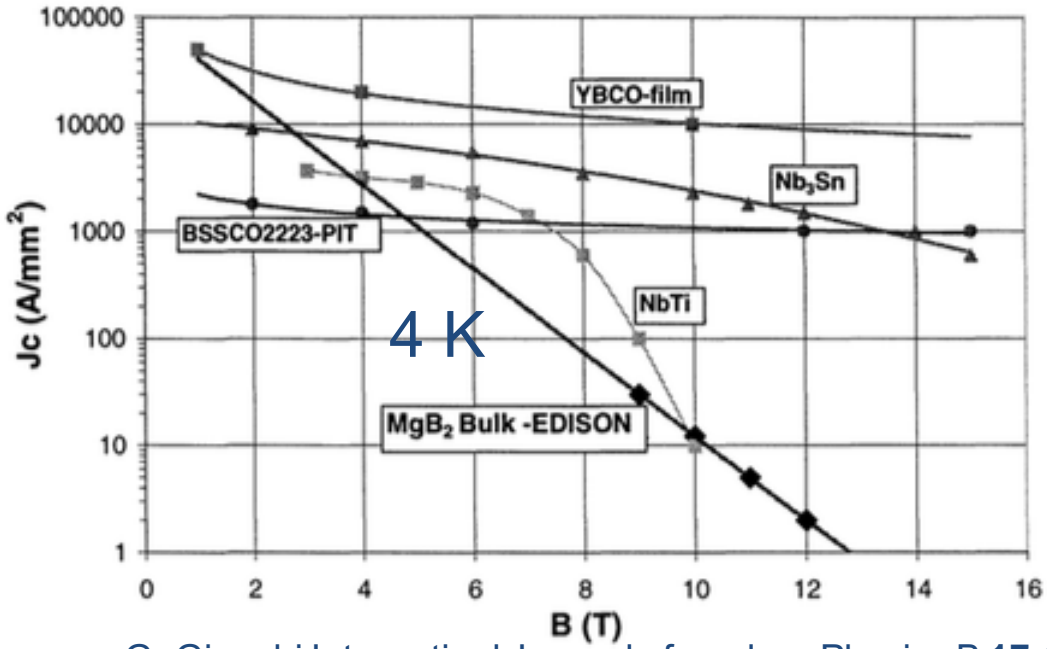




J. Kortus et al, Phys. Rev. Lett. 86, 2001

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)

in HD-ice conditions
$J_c \geq 1000\ A/mm^2$

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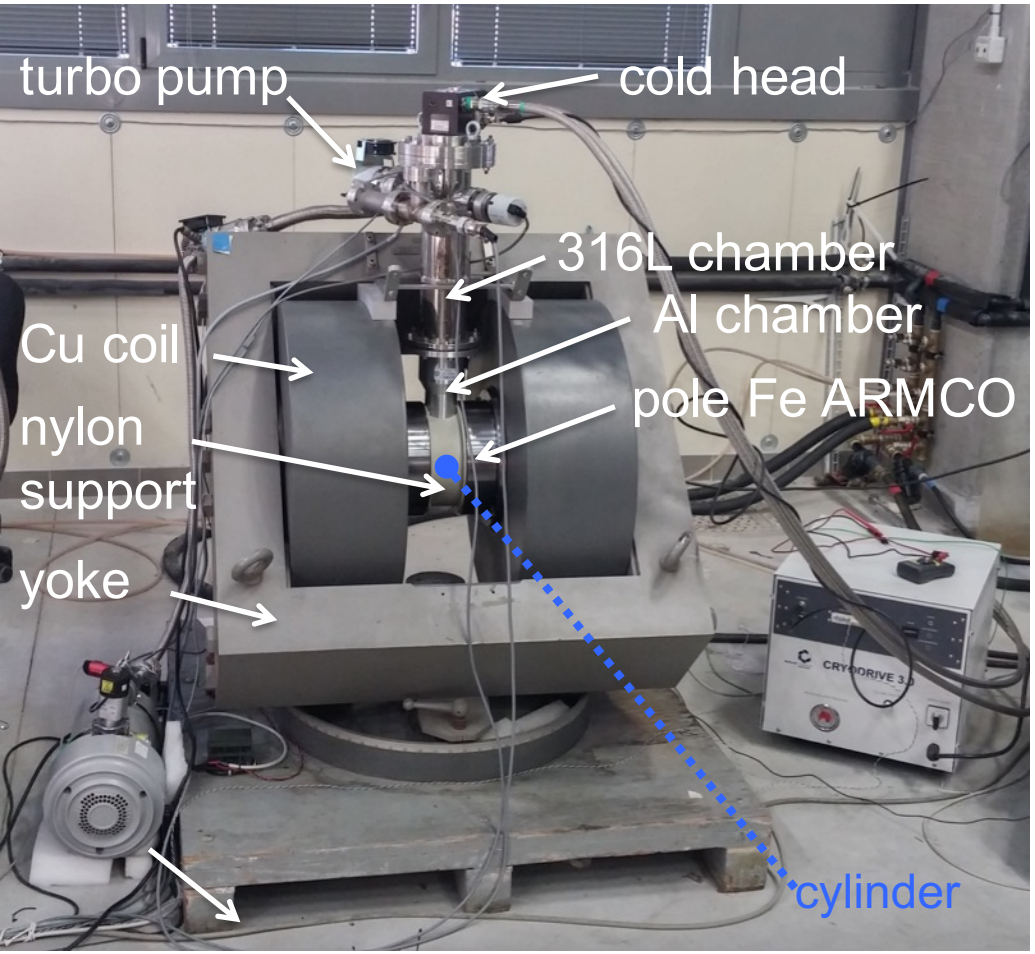
FEASIBILITY STUDY

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



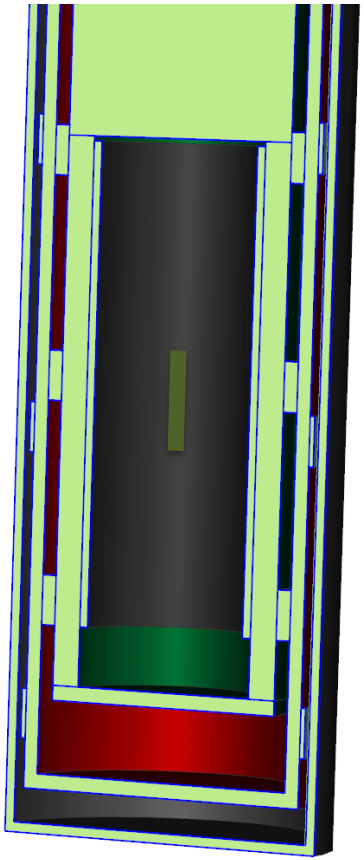
- **resistive magnet**
- **transverse field**
- **custom poles**
- **max field about 1 T**
- **vacuum chamber (316L and Al)**
- **liquid free cryostat**
- **controlled cylinder temperature**
- **minimum temperature ≈13 K**
- **$\Delta B/B < 2\ 10^{-3}$**

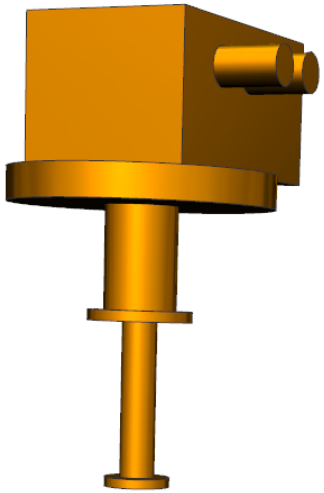
  (on cylinder volume)

further details in M. Statera, M. Contalbrigo, G. Ciullo, P. Lenisa, M. Lowry, A. Sandorfi, "A Bulk SuperconductingMagnetic System fot the CLAS12 Target at Jefferson Lab", IEEE Trans. On Applied Superconductivity, Issue 99 (2015)

COOLING

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





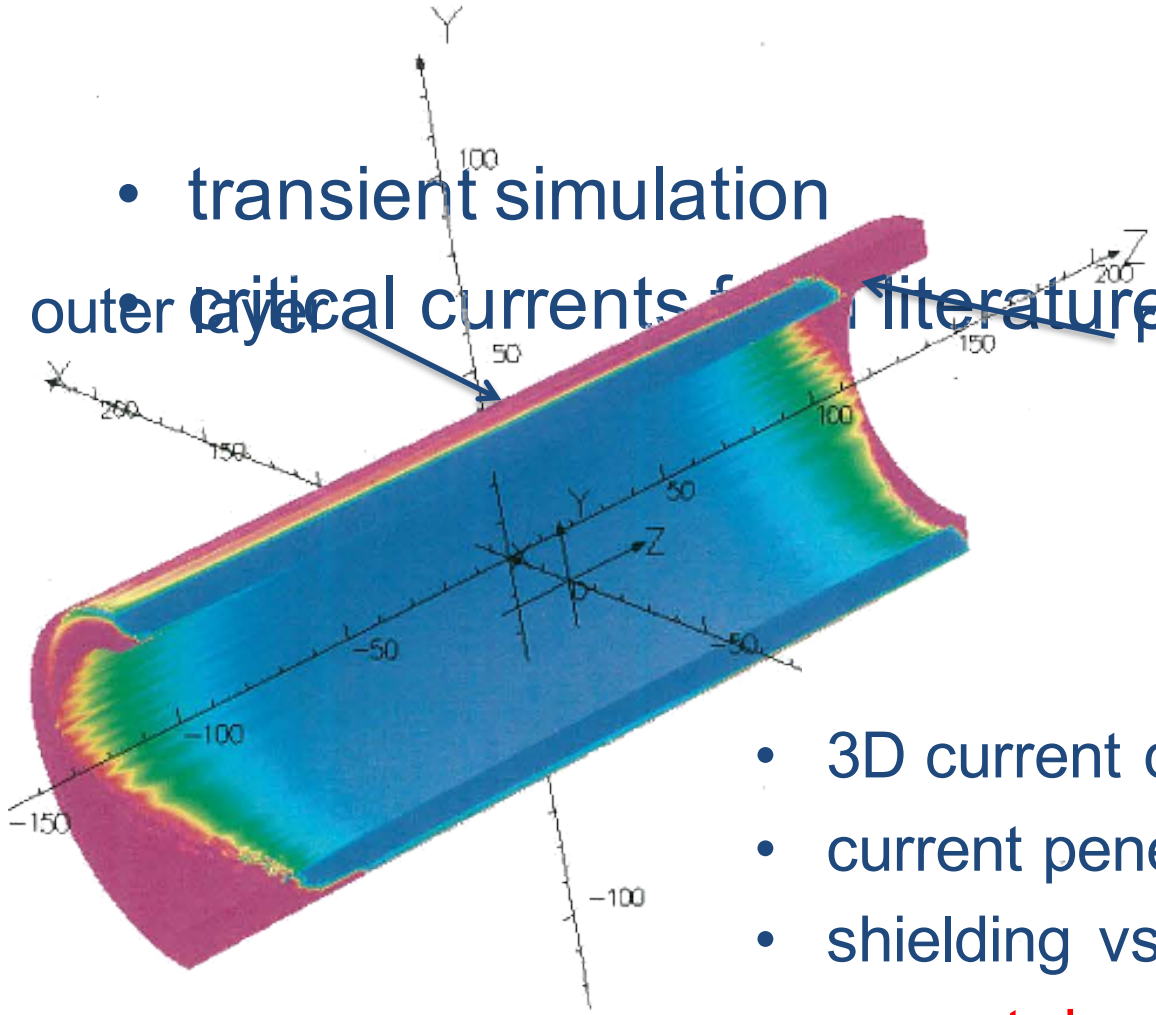
SHIELDING SIMULATIONS

detailed results
by M. Lowry (JLab)
at SPIN2016

- transient simulation
- critical currents from literature

outer layer

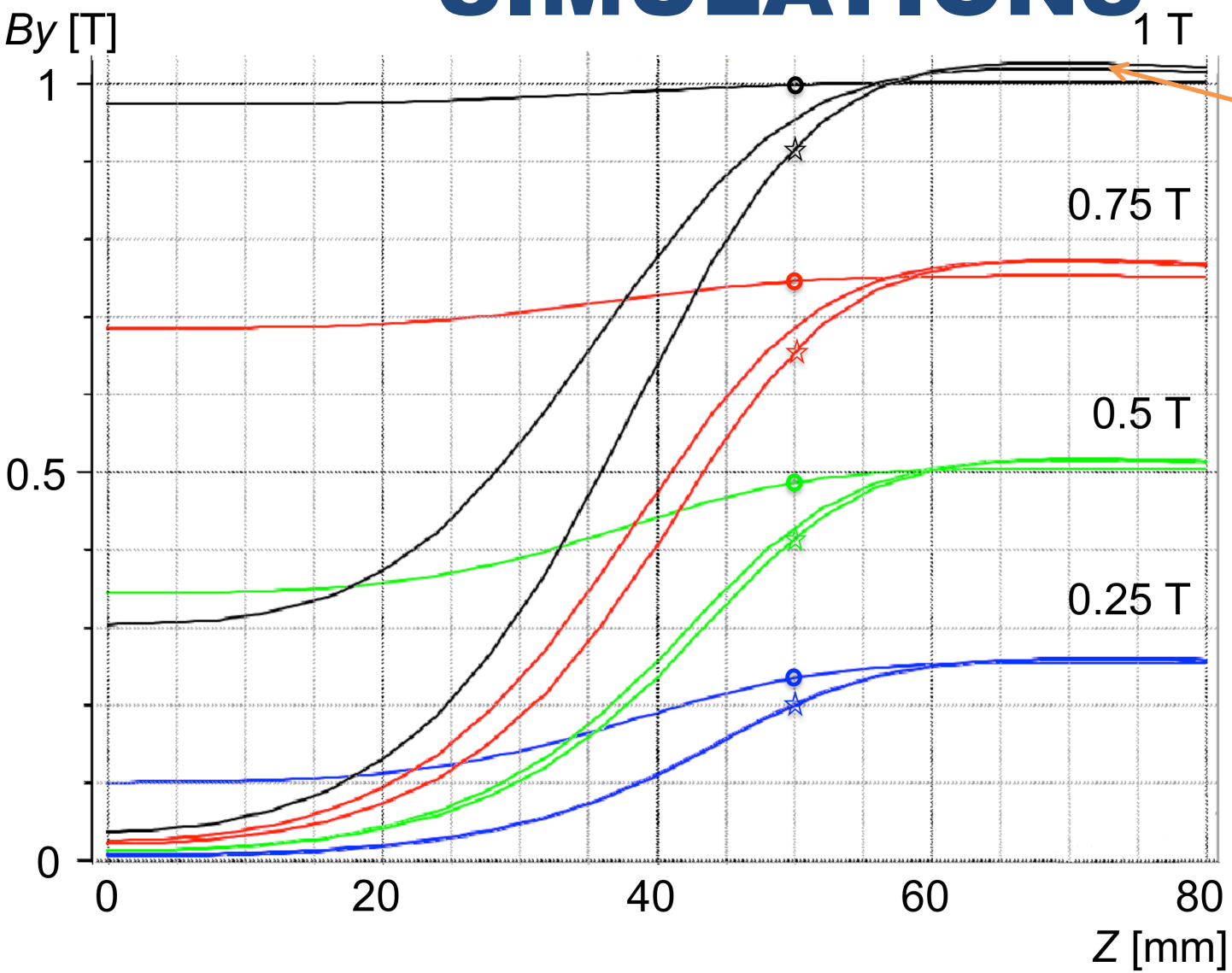
radial penetration

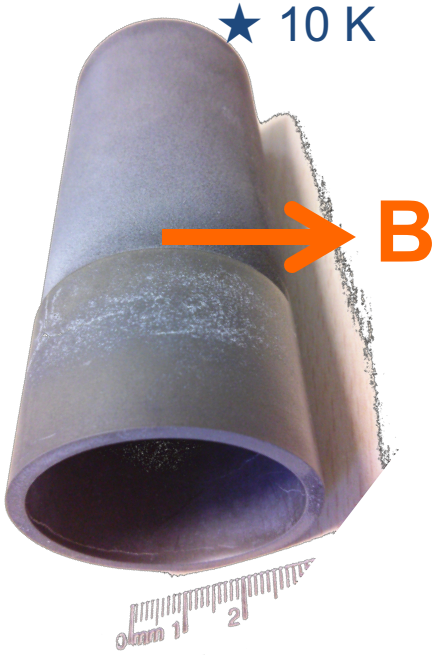


- 3D current distribution
- current penetration vs external field
- shielding vs external field
- current decay

courtesy of M. Lowry

SIMULATIONS





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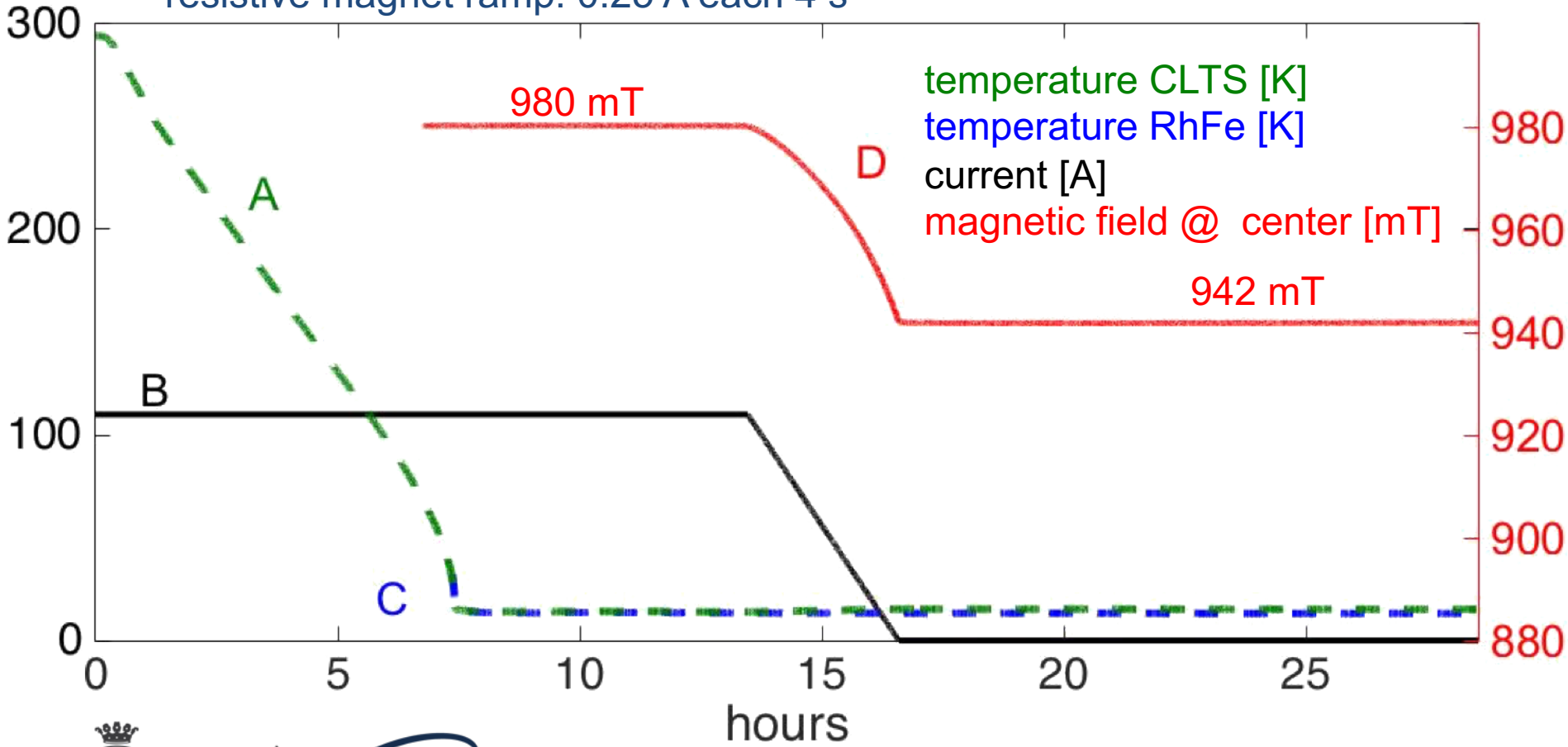
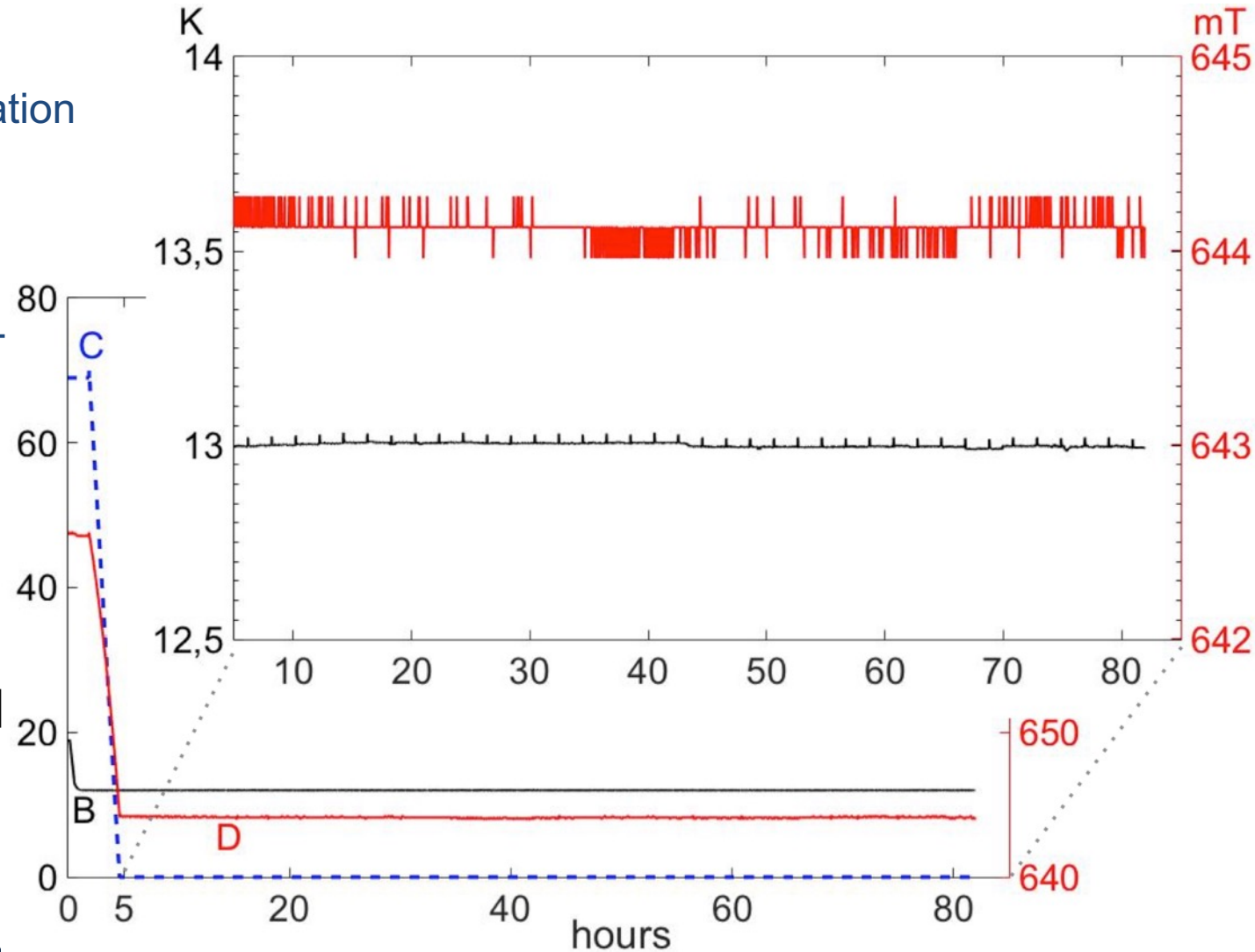
MAGNETIZATION @13 K

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

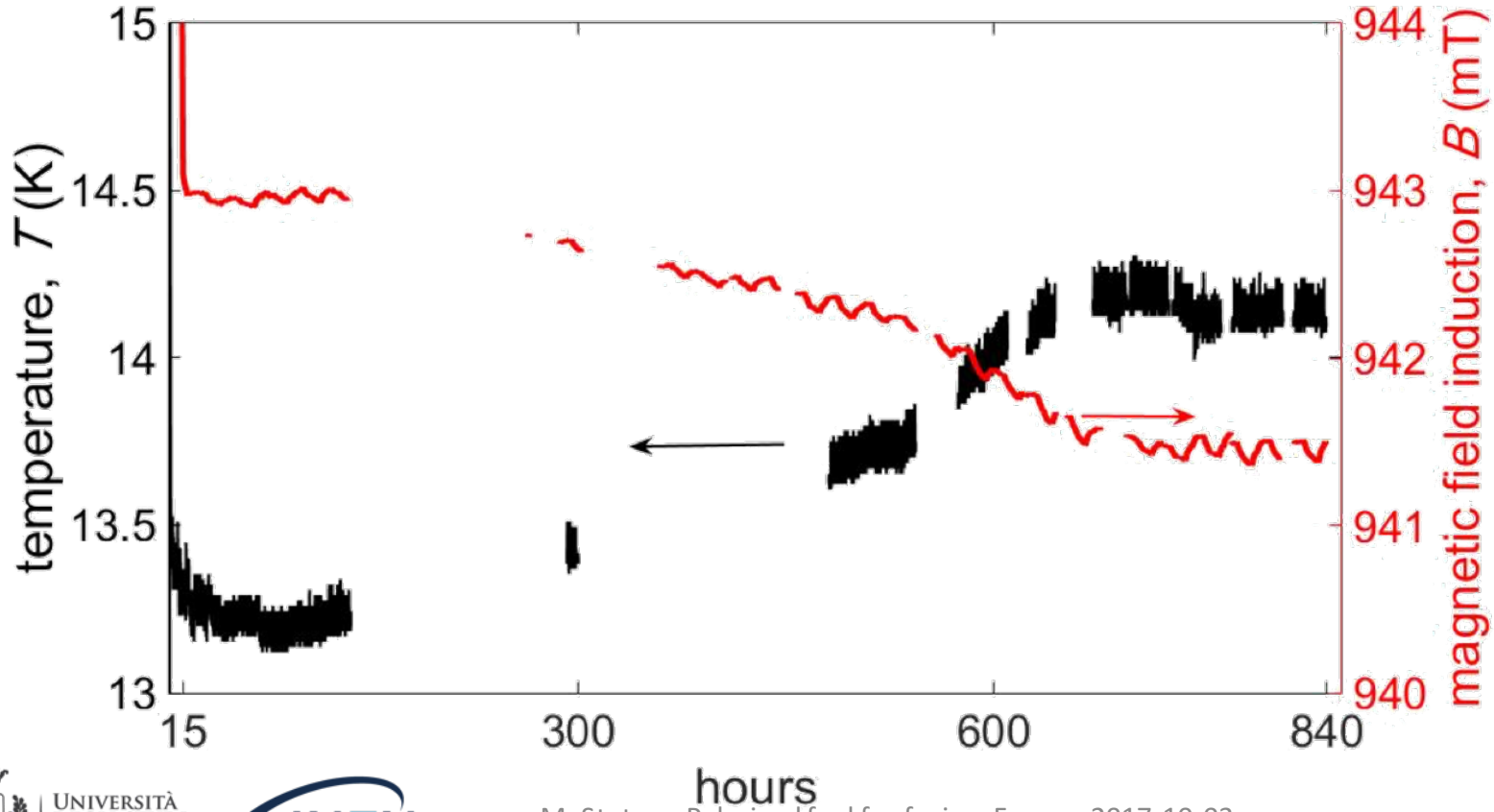


temperature RhFe [K]
current [A]
magnetic field [mT]

LONG TERM MAGNETIZATION II

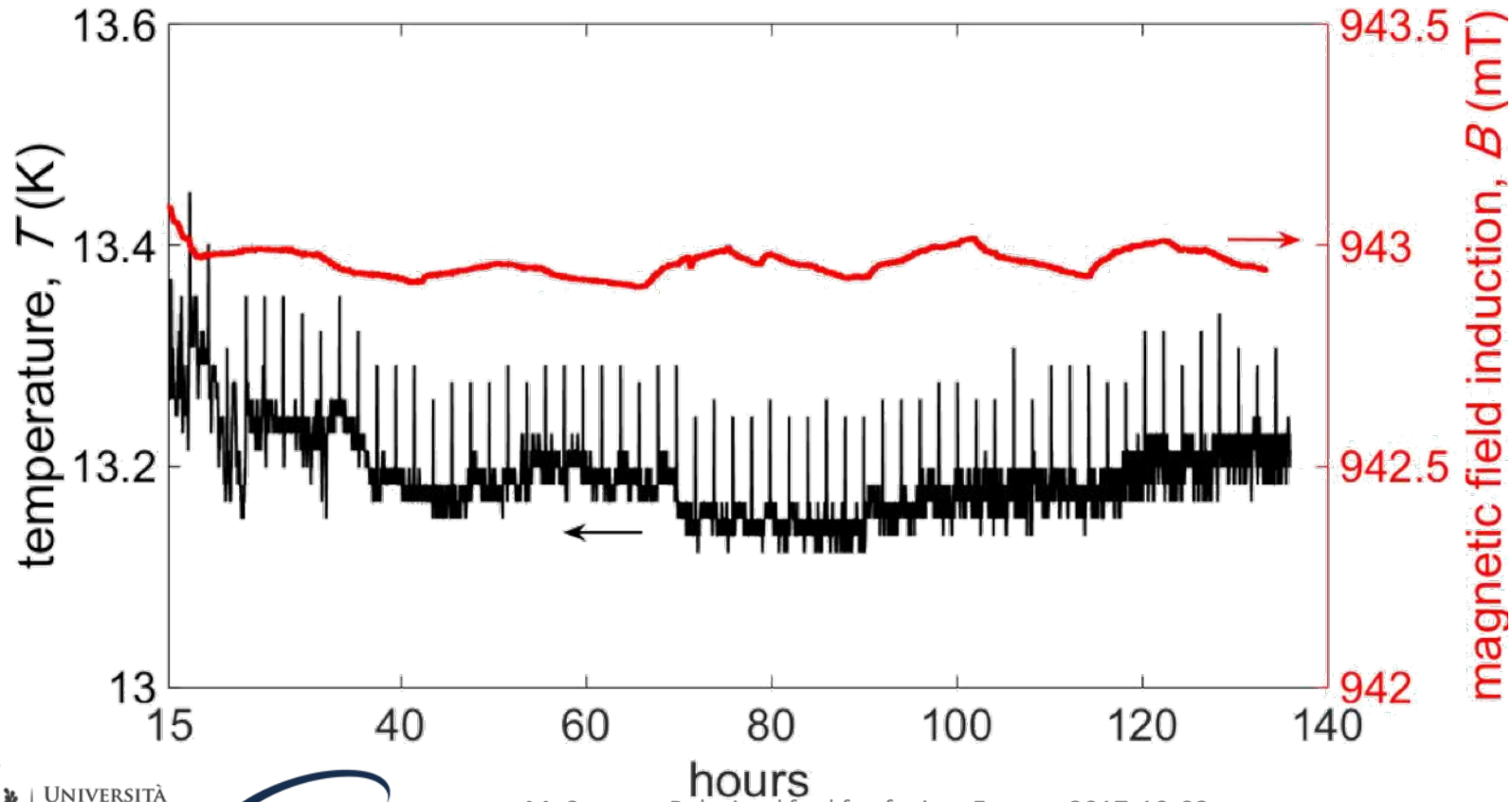
- 800 hours
- temperature stability issue
- temperature 13.2 K - 14.3 K

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



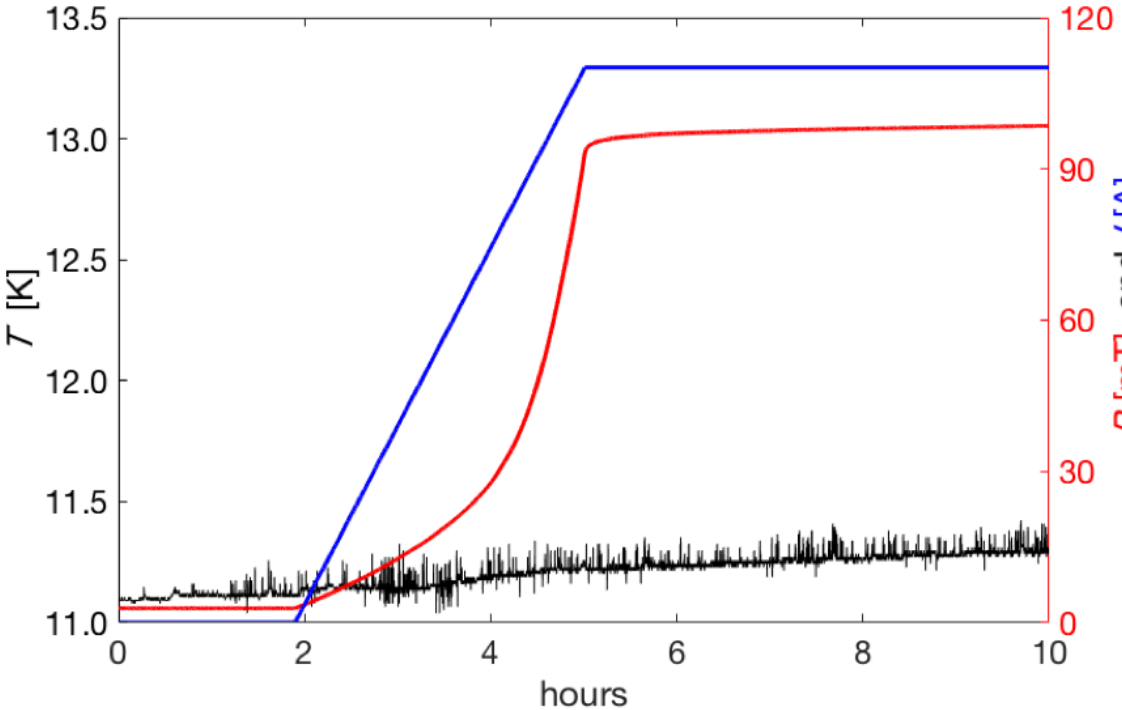
LONG TERM MAGNETIZATION III

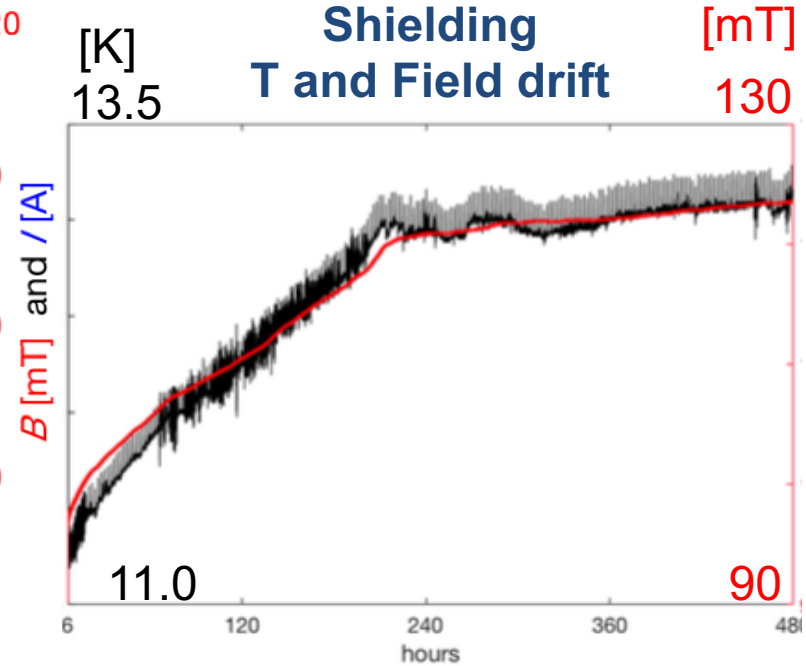
first 140 hours
temperature and field are stable



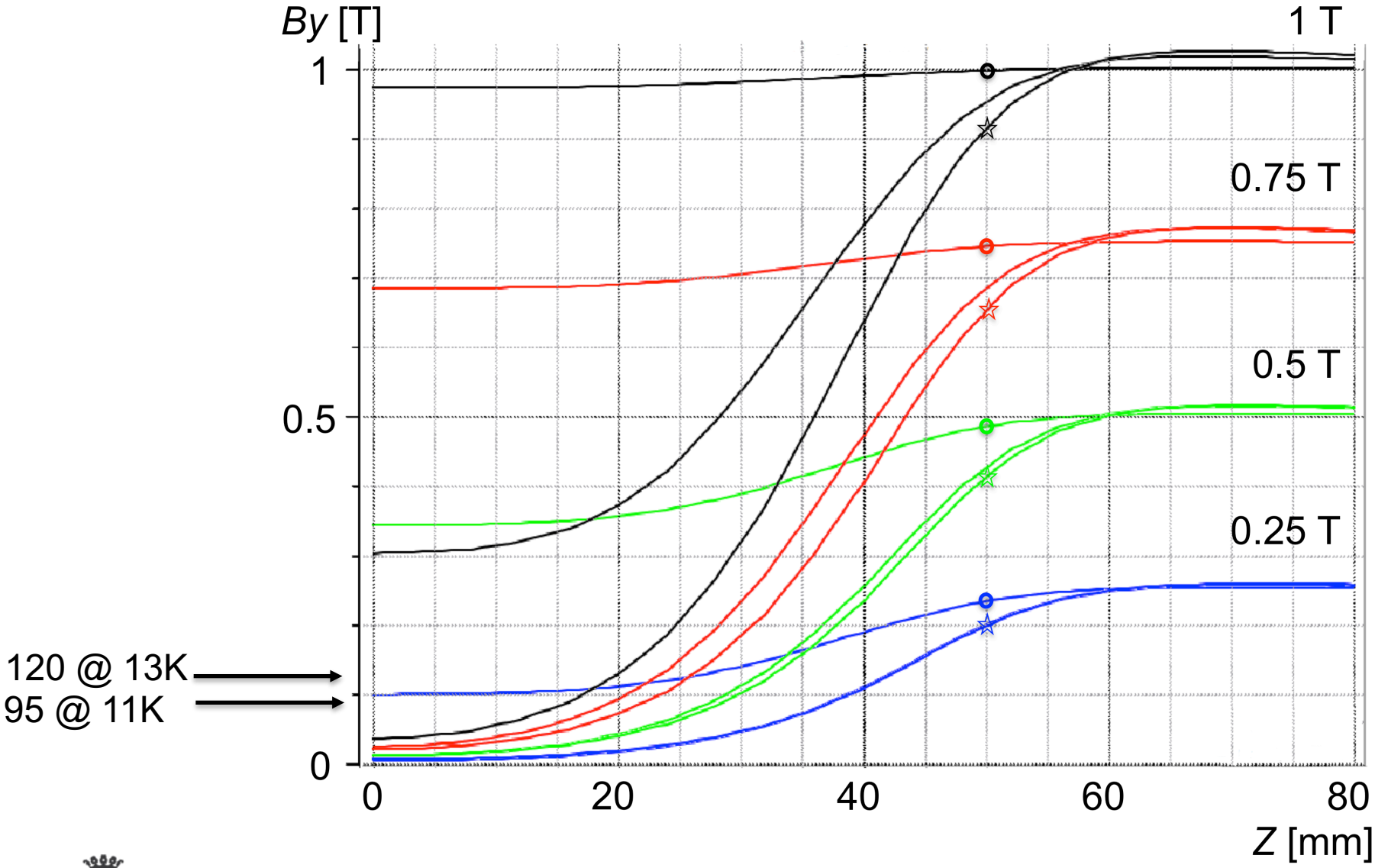
MAGNETIC SHIELDING

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

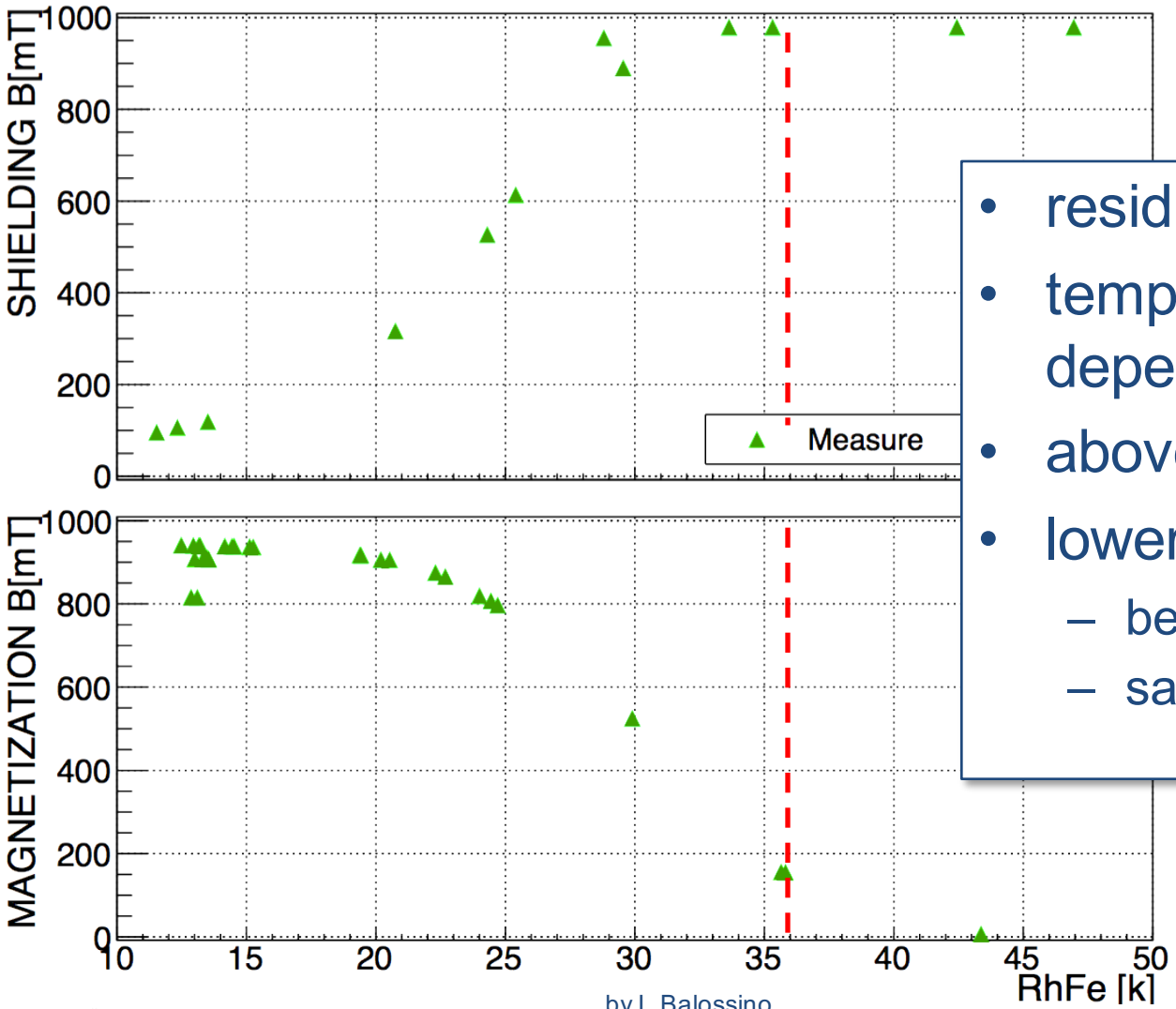




RESULTS



TEMPERATURE DEPENDENCE

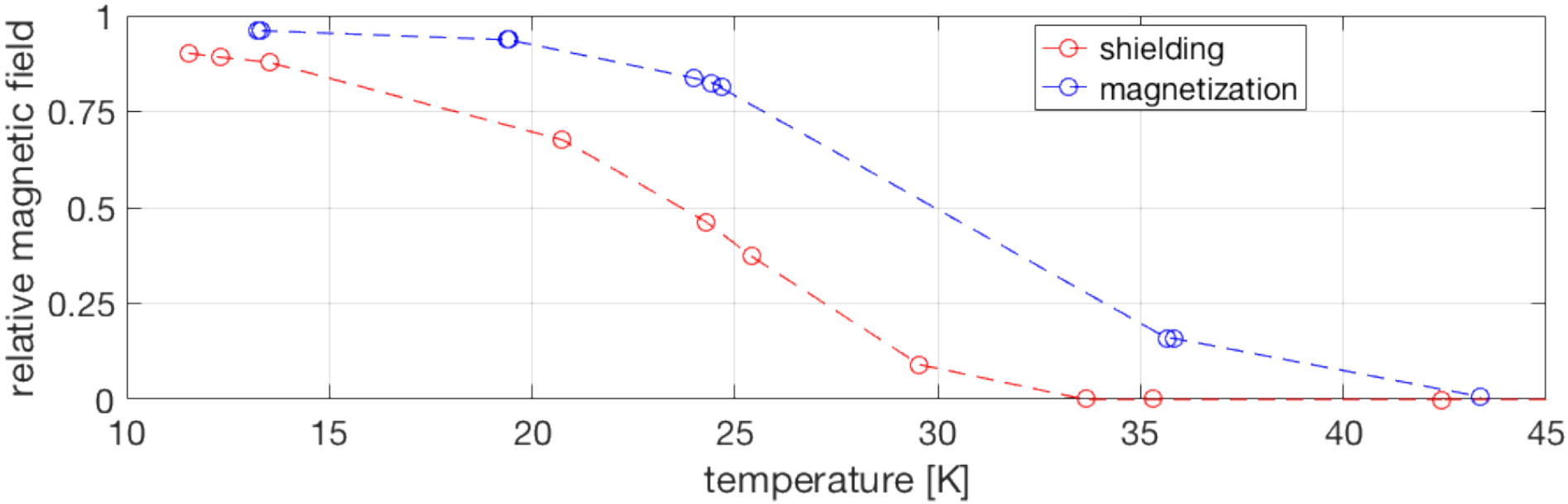


- residual field
- temperature dependence
- above Tc
- lower temperature
  - better shielding
  - saturate magnetization

by I. Balossino

SHIELDING VS TRAPPED FIELD

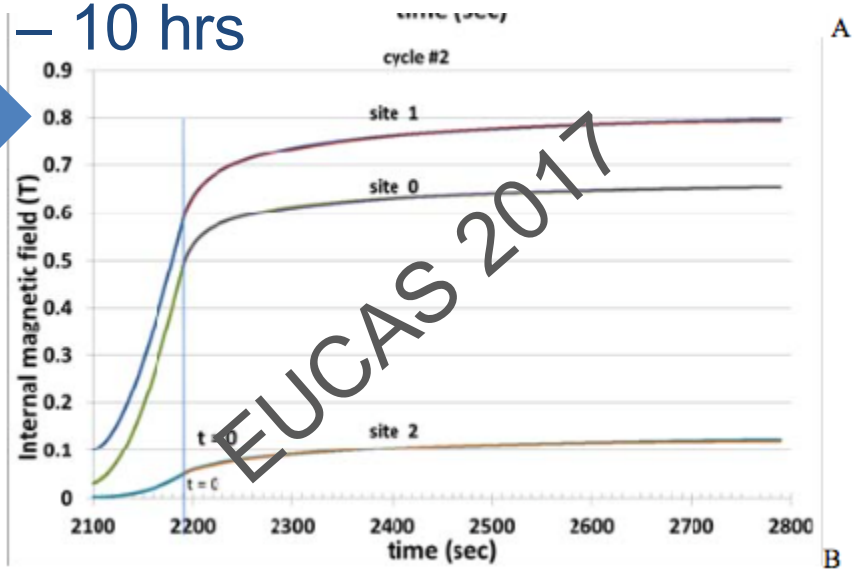
- field trapping: residual field
- shielding: shielded field

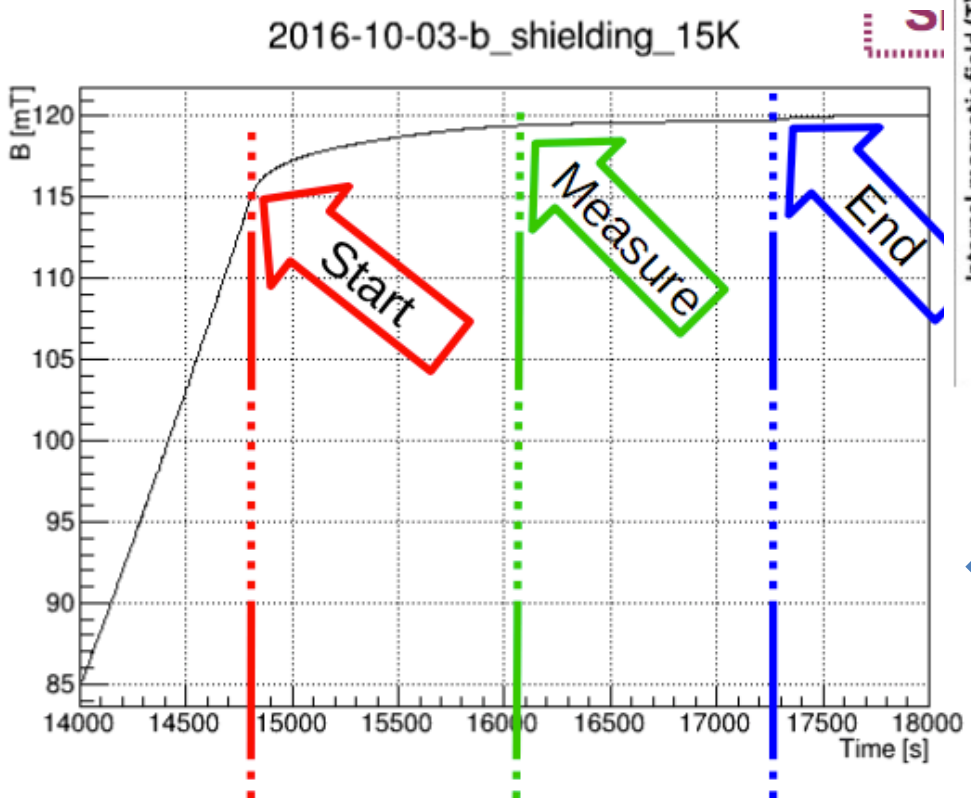


CURRENT CREEP

creep measurement @4.2 K 3T – 10 hrs

G. Giunchi et al (CERN) FCC

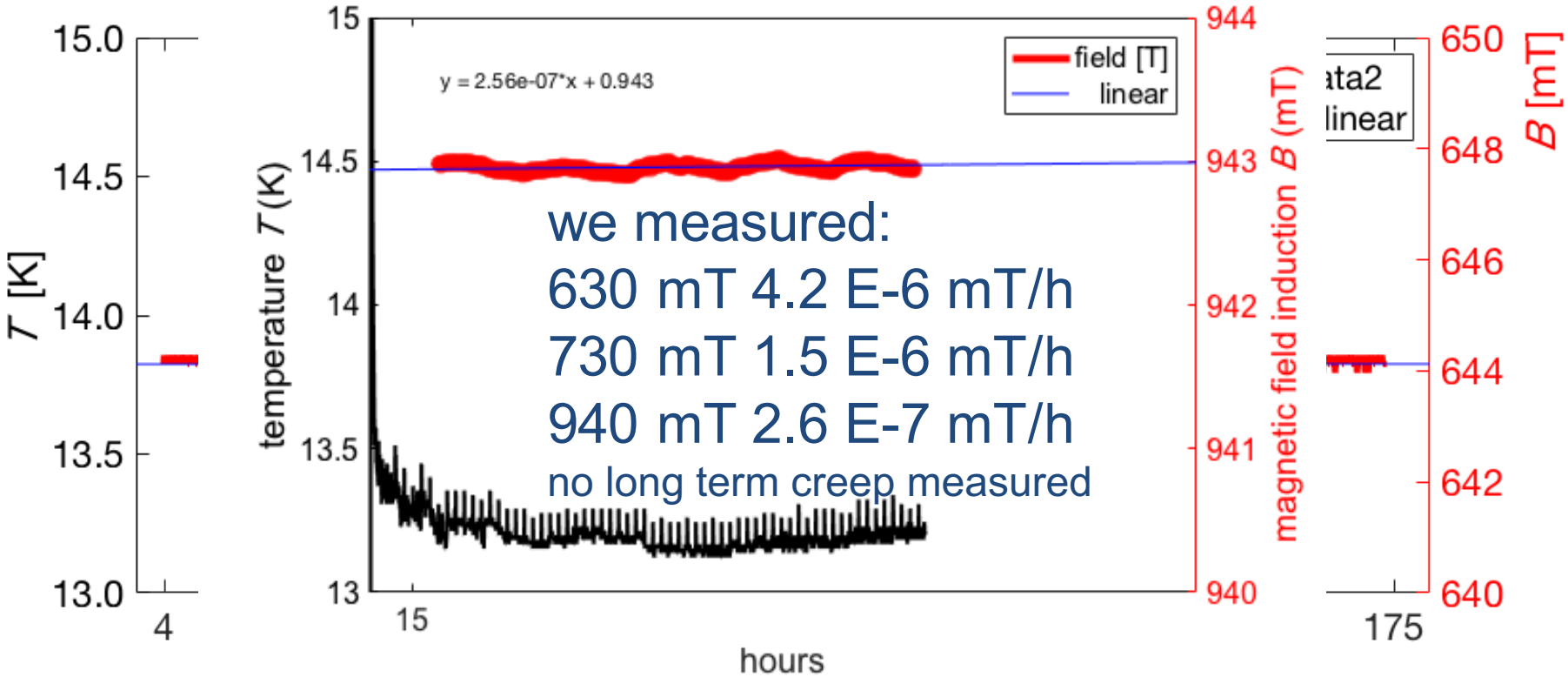




we measured a similar behaviour for shielding data have to be analyzed

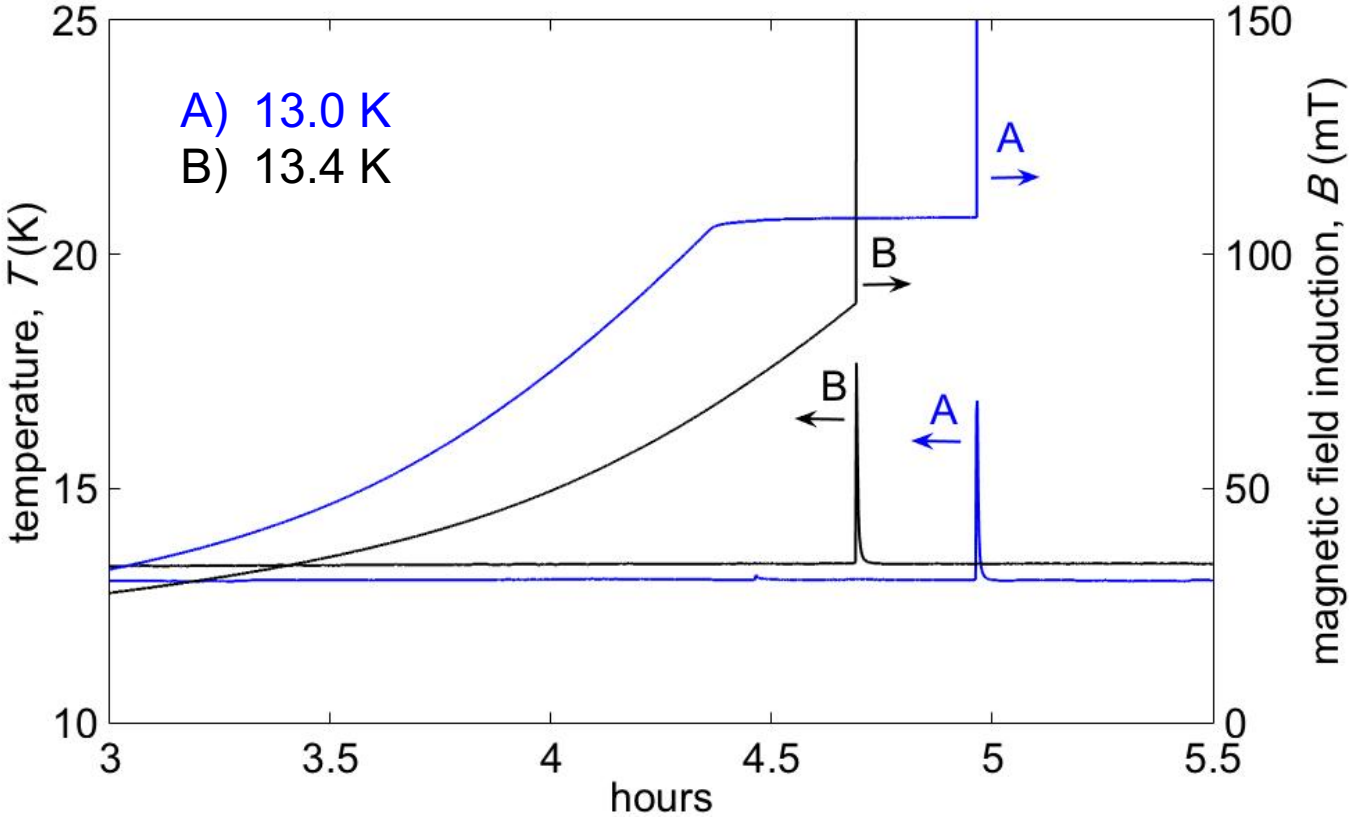
CURRENT DECAY

what about field trapping?



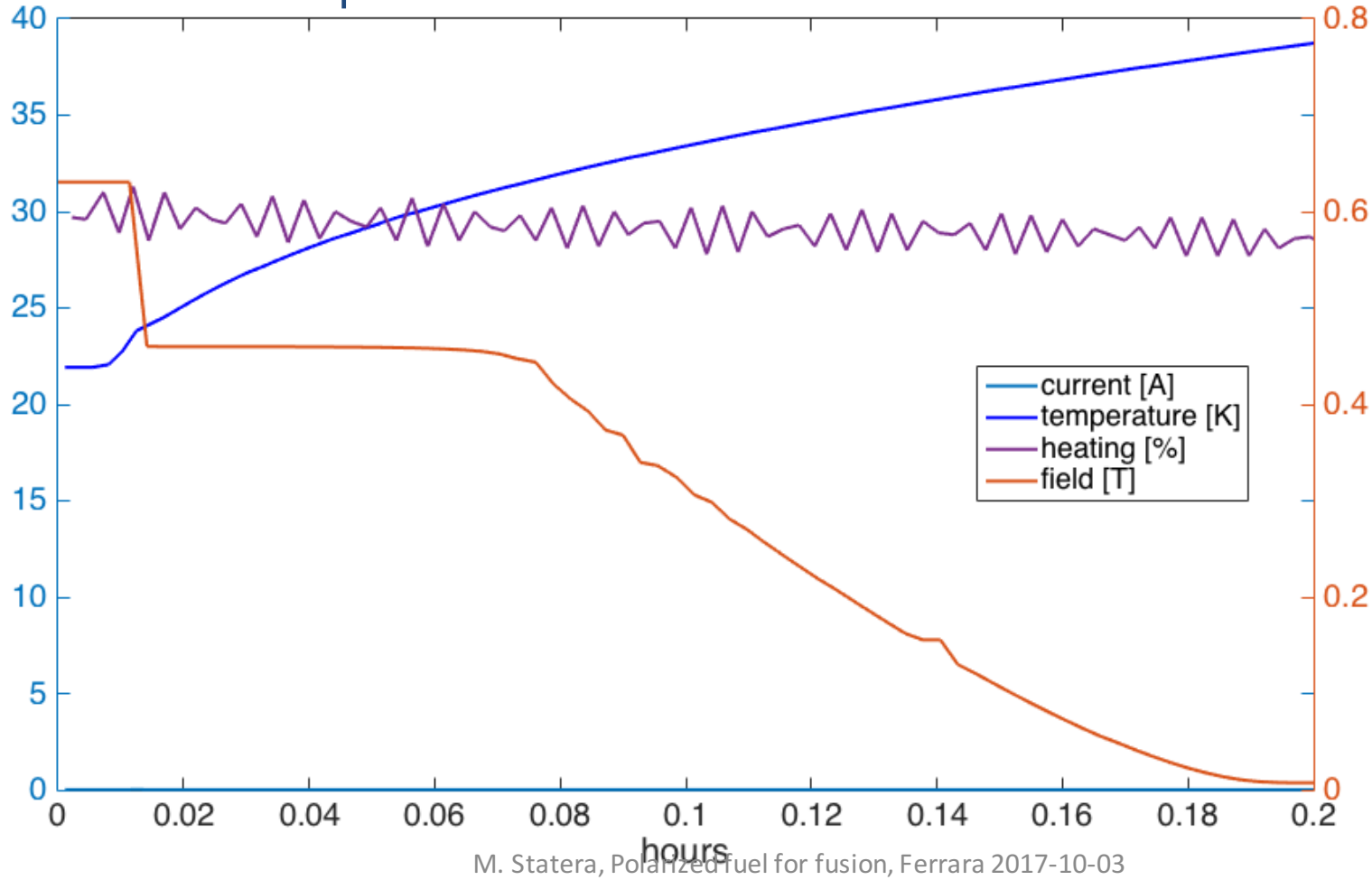
we measured:
630 mT 4.2 E-6 mT/h
730 mT 1.5 E-6 mT/h
940 mT 2.6 E-7 mT/h
no long term creep measured

PROBLEMS?


A) 13.0 K
B) 13.4 K
A
B
B
A
temperature, T (K)
magnetic field induction, B (mT)
hours
25
20
15
10
150
100
50
0
3
3.5
4
4.5
5
5.5

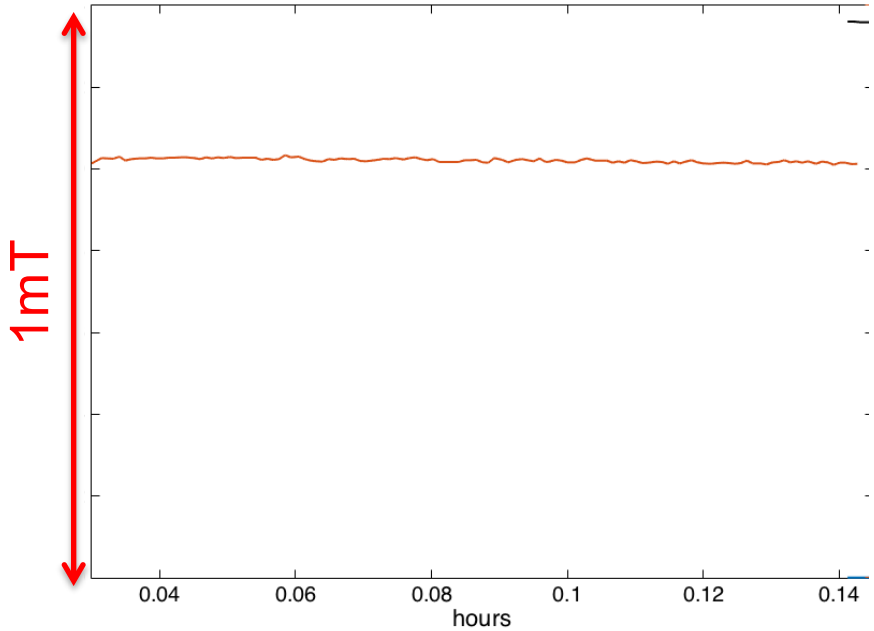
HEATING

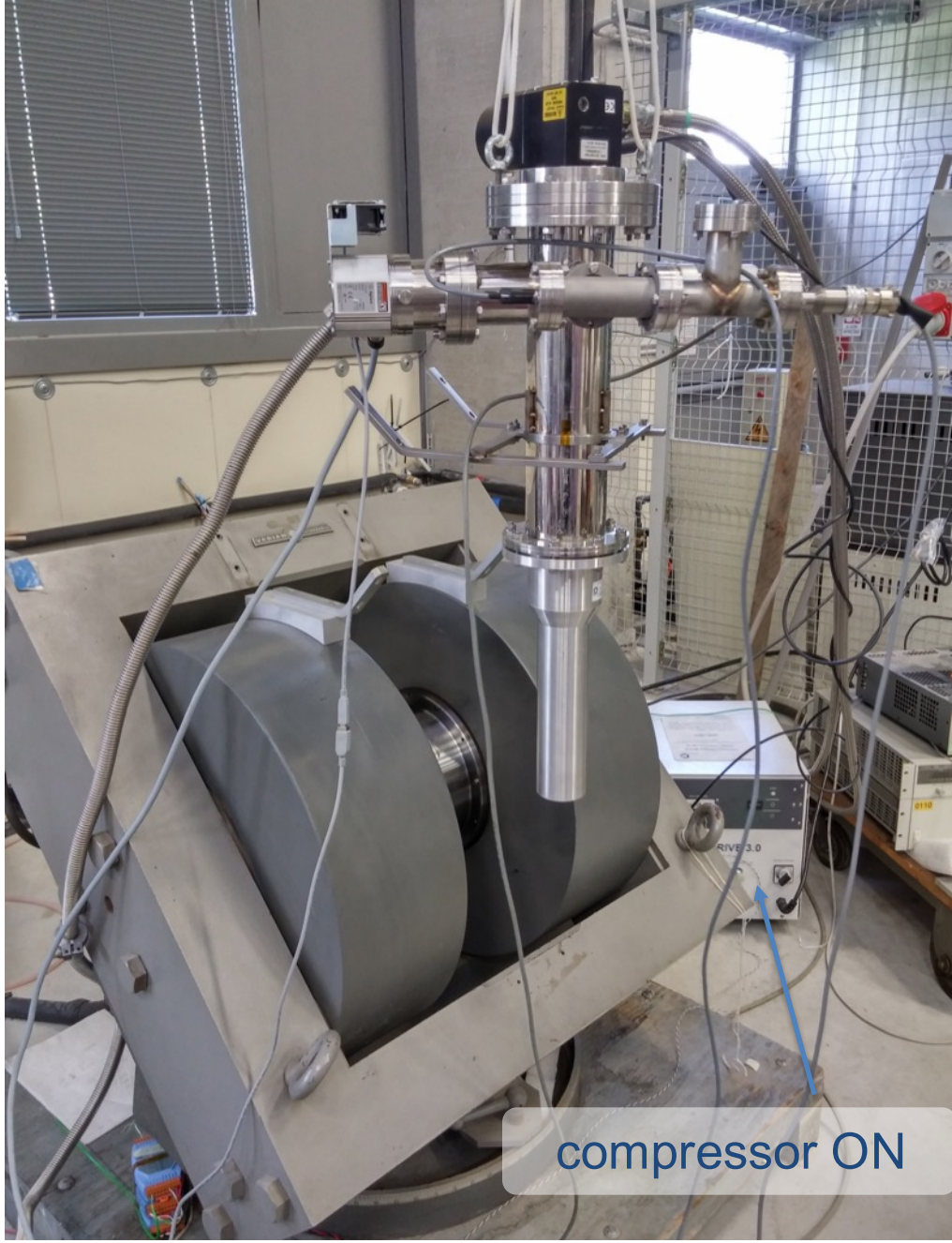
- temperature masured at the bottom of the cold mass
- heating up to 70 K : 2 hours
- field drops at about 39 K



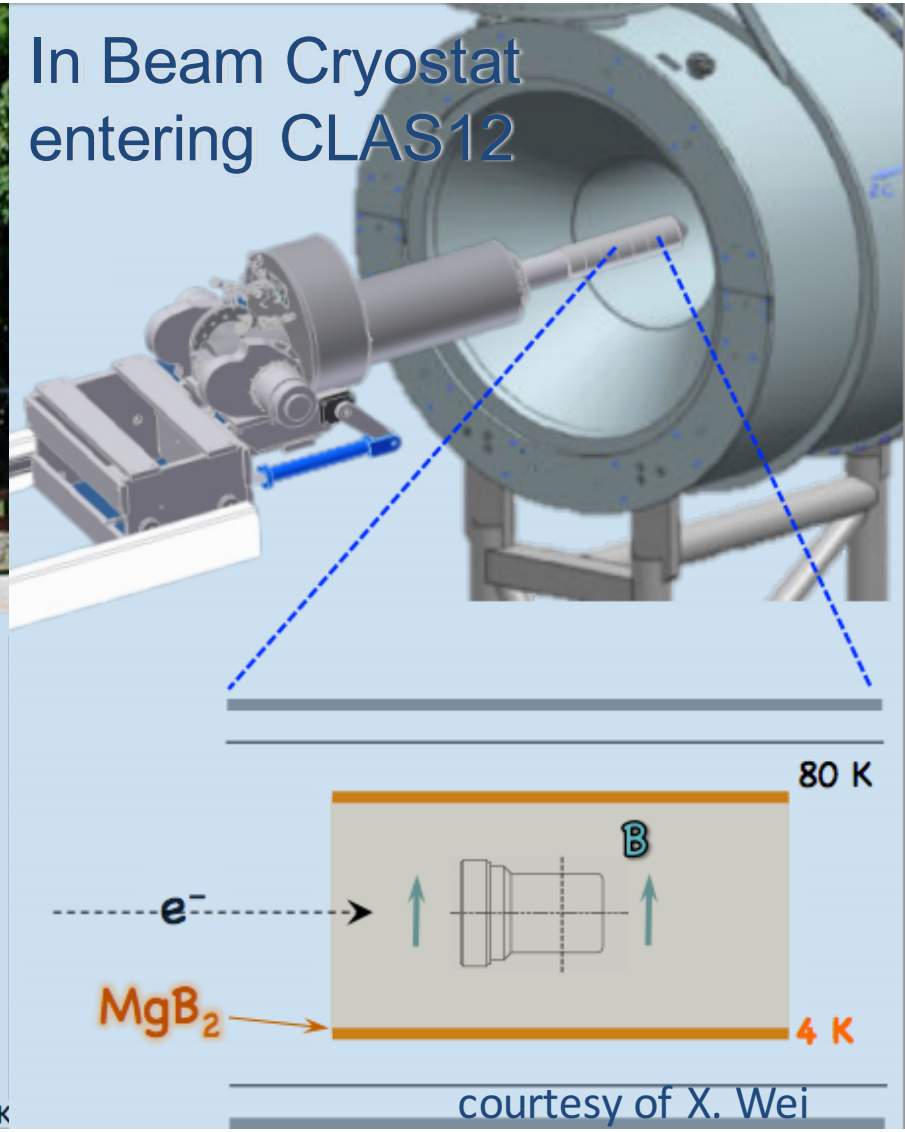
MOVING

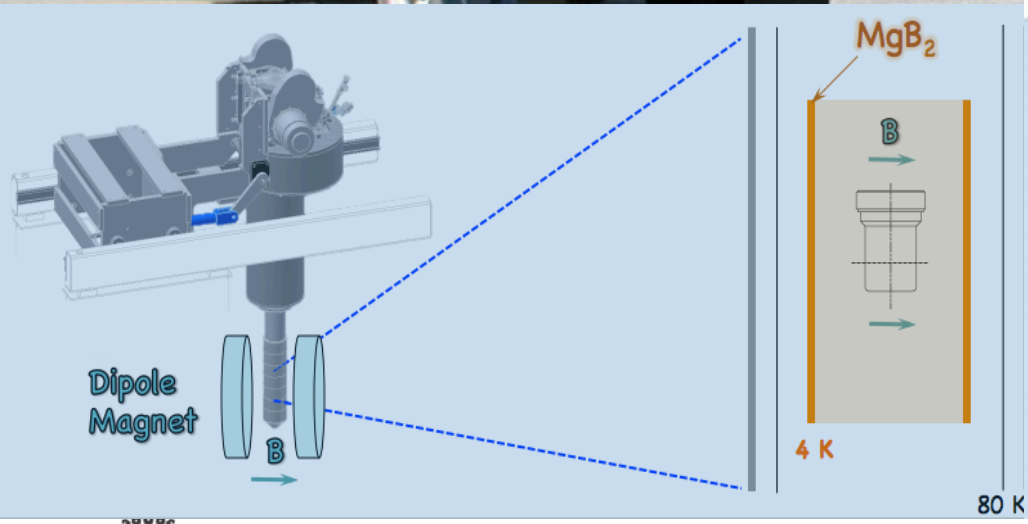
- temperature 13.6 K
- field 565 mT





CLAS12 INTEGRATION





NEXT STEPS

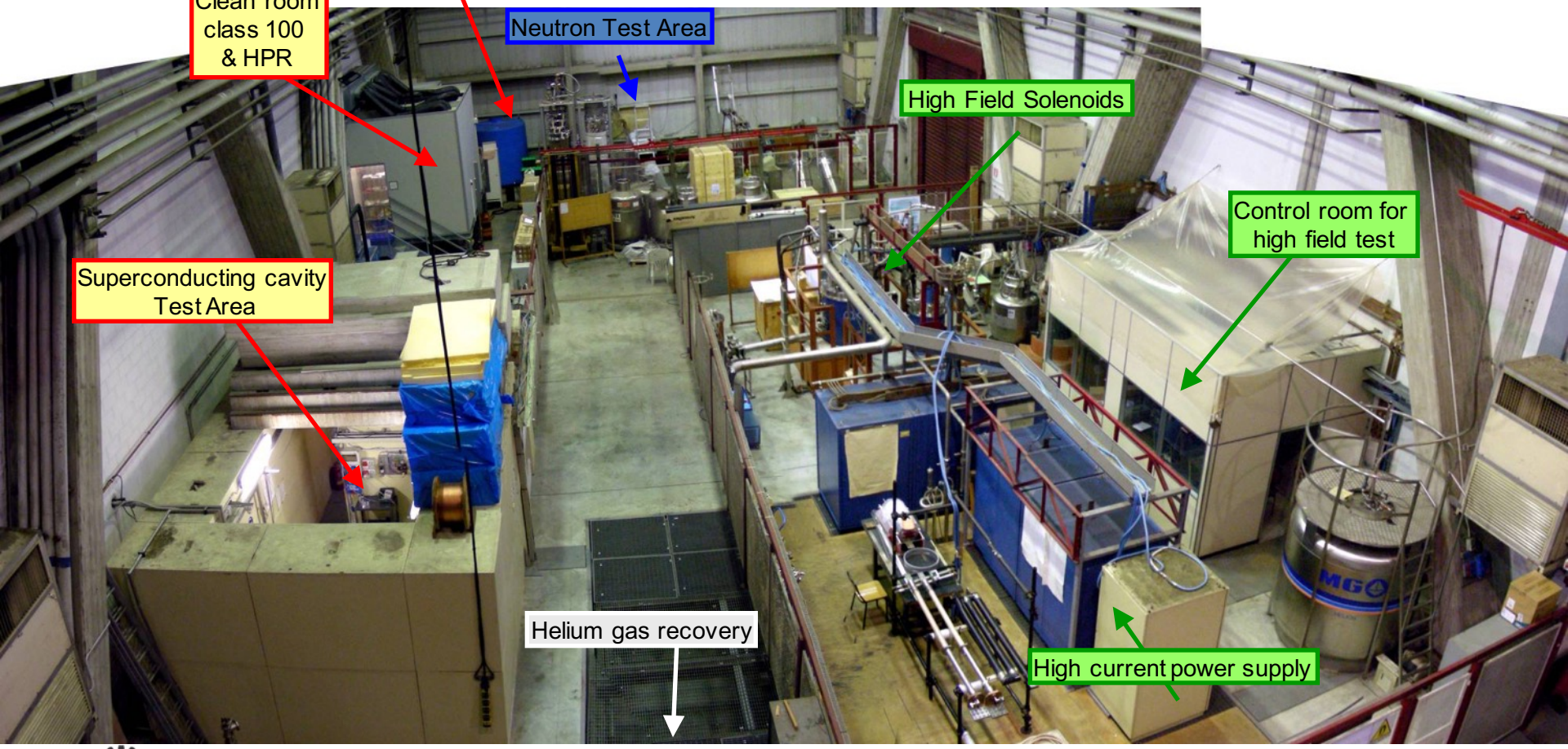
- further measurements
- test new cylinders
- cylinder transversely magnetized + solenoidal field
- real dimension prototype

WHERE?

INFN LASA Milano

SOLEMI-1 8 T x D535 mm warm bore

SOLEMI 2-3 15 T x D100 mm cold bore



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BULK SC FOR ACCELERATORS AND DETECTORS?

transverse shielding and field trapping

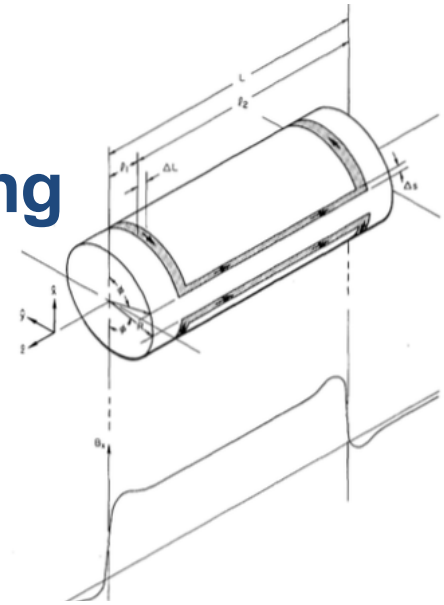
- 1979 NbTi D. J. Frankel

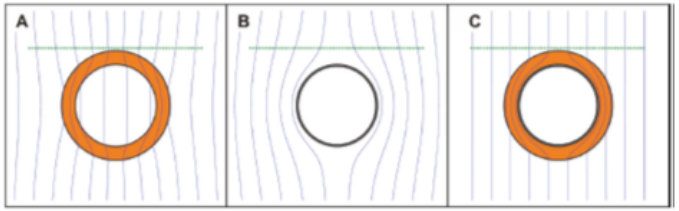
longitudinal shielding

- 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	

CONCLUSION

- a bulk magnet for HD-ice in CLAS12?
- transverse field test bench: commisioned
  - 0.94 T transverse magnetic field
  - magnetization (field trapping)
  - shielding
  - temperature control
  - the magnetized cylinder can be moved
- working for a final size prototype
- bulk superconductors for accelerators and detectors