Magnesium di-Boride:

A novel solution for a transversely polarized target holding field in CLAS12

Michael M. Lowry
Presented by Charles Hanretty

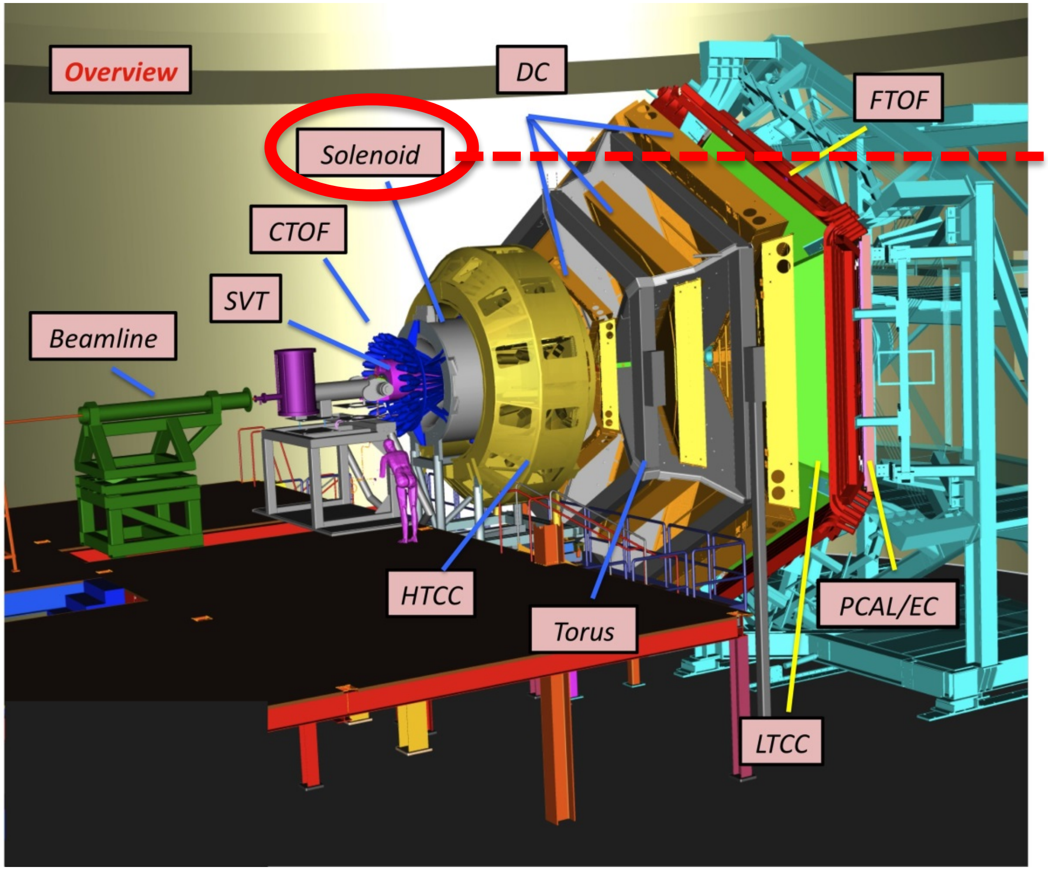
Magnesium di-Boride Group

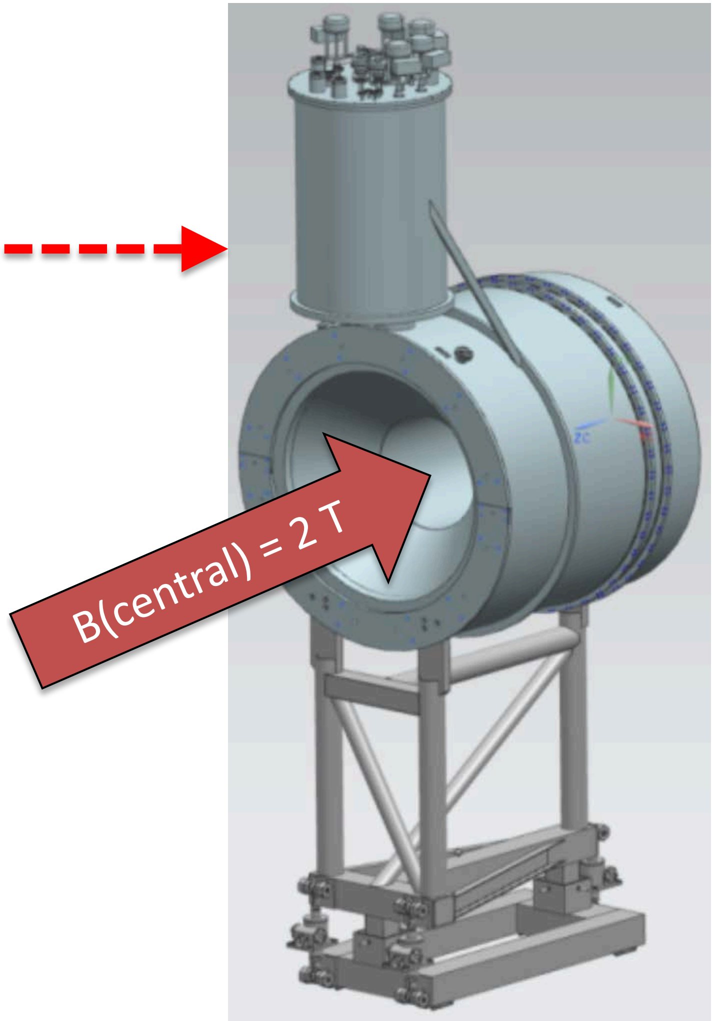
- Effort is a collaboration between:
  - Università di Ferrara and INFN-Sezione di Ferrara
    - M. Contalbrigo, M. Statera, L. Barion, G. Ciullo, and P. Lenisa
  - HDice Group, Jefferson Lab
    - M. M. Lowry, and A. M. Sandorfi,

MgB2 Motivation

- 3 A-rated experiments for CLAS12 that require a transverse polarized target (see previous talk).
  - C12-11-111 SIDIS on transverse polarized target
  - C12-12-009 Transversity w/ di-hadron on transverse polarized target
  - C12-12-010 DVCS with transverse polarized target in CLAS12
- But a transverse polarization means a transverse holding field.
  - Requires short length to minimize beam deflection.
  - Requires canceling solenoid field of CLAS12.

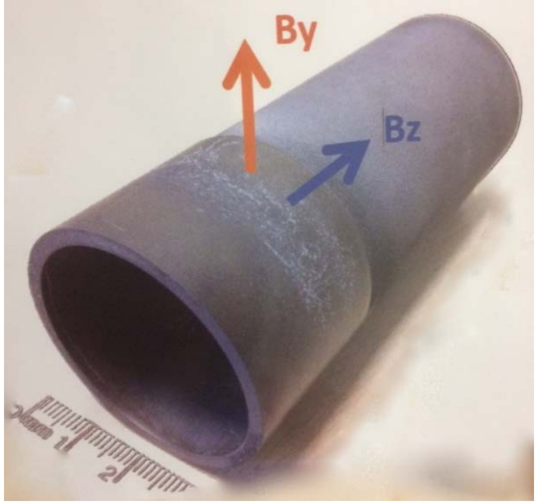
Maintaining Transverse Holding Field Within CLAS-12 Solenoid





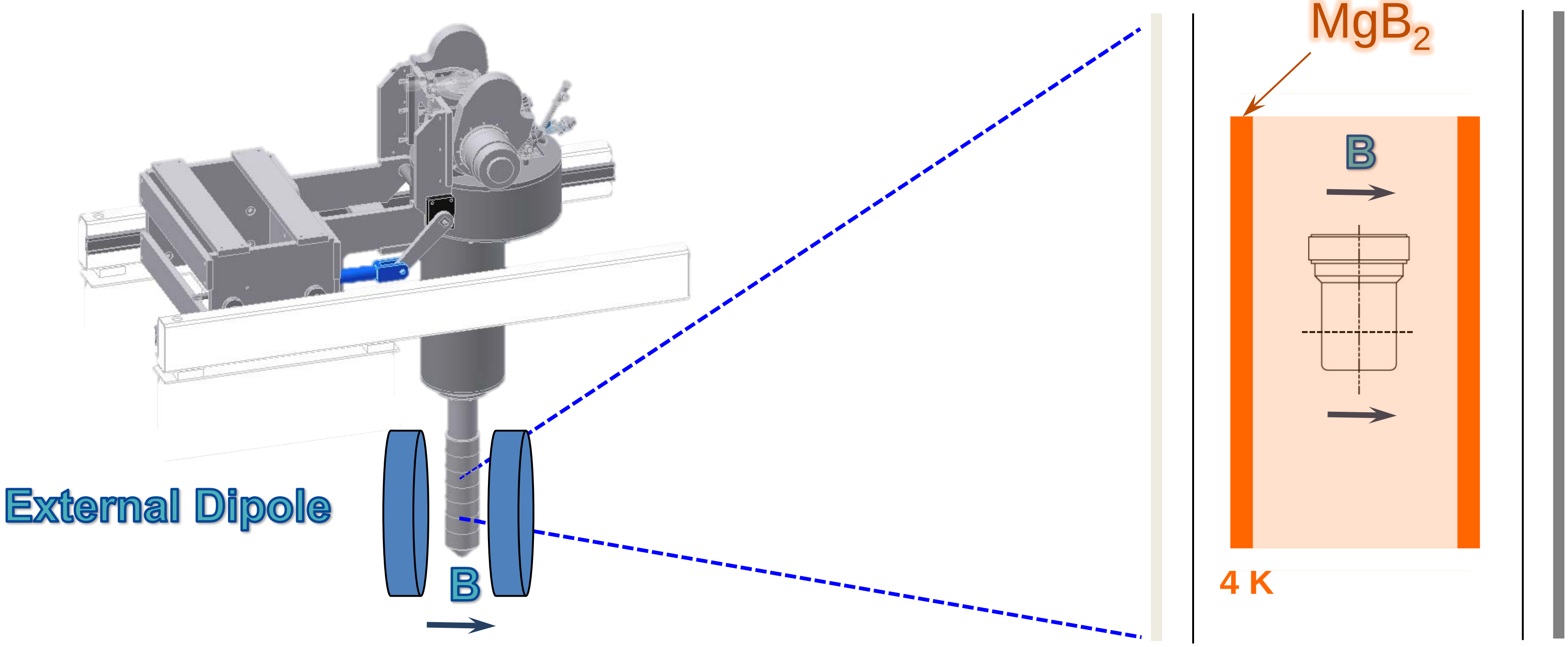
MgB2 – Elegant Solution

- Magnesium diBoride (MgB_2)
  - – High T_c , superconducting material ($T_c = 39$ K)
  - – Bulk Type 2 traps external field when transitioning
  - – Once superconducting, shields additional field
  - – Can be fabricated into a shell around HD
  - – $\langle Z \rangle \approx 7$ (minimal dE/dx)



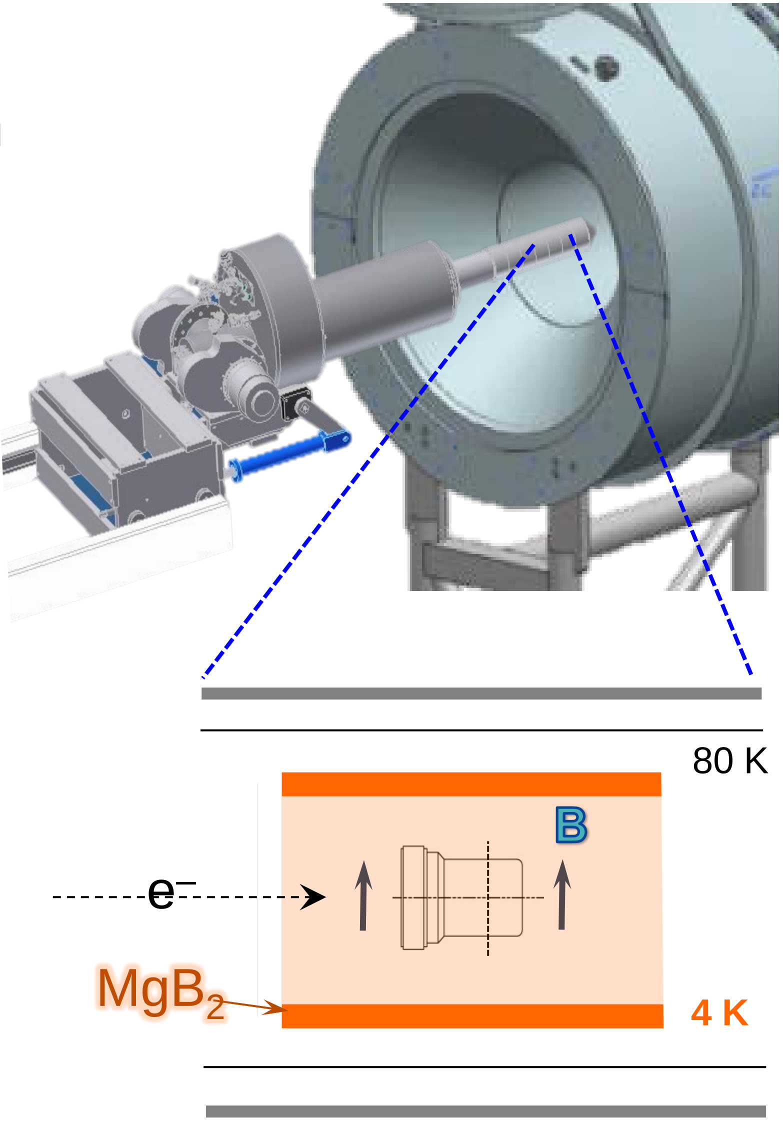
How would MgB_2 be used? - Trapping a Transverse Field

- Ramp up 1.25 T external magnet (transverse field) around nose of IBC
- Cool MgB_2 inside of IBC to 4 K (T_c = 39 K)
- Load polarized HD cell into IBC
- Lower external field
- The perfect diamagnetism of MgB_2 allows for the spontaneous generation of currents, maintaining the original internal field



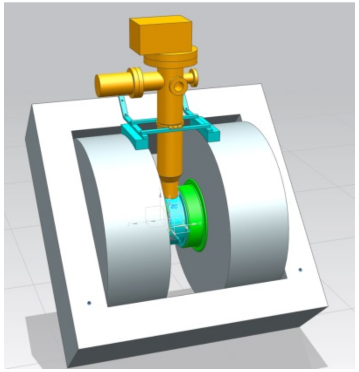
How would MgB_2 be used? - Shielding CLAS-12 Solenoid Field

- IBC rotated into horizontal position and moved into CLAS-12
- CLAS-12 Solenoid ramped up ➔ additional currents arise in MgB_2, maintaining original (transverse) field
- These complex currents can/will be much more intricate than could be achieved with an electromagnet



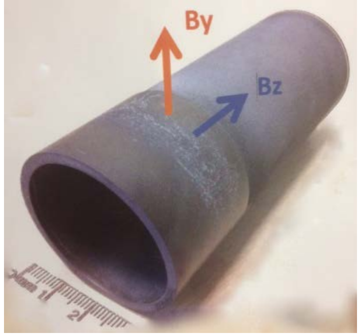
Prototype Tests in Ferrara

- Repeatable results indicate that MgB_2 shell can trap a transverse field of ≈1 Tesla.
- MgB_2 can maintain this internal field for weeks with negligible droop (0.0015 T over 1 month)
- MgB_2 shell can survive magnet quenches
  - Subjected to several quenches (flux jumps)
  - MgB_2 survived with no change in performance



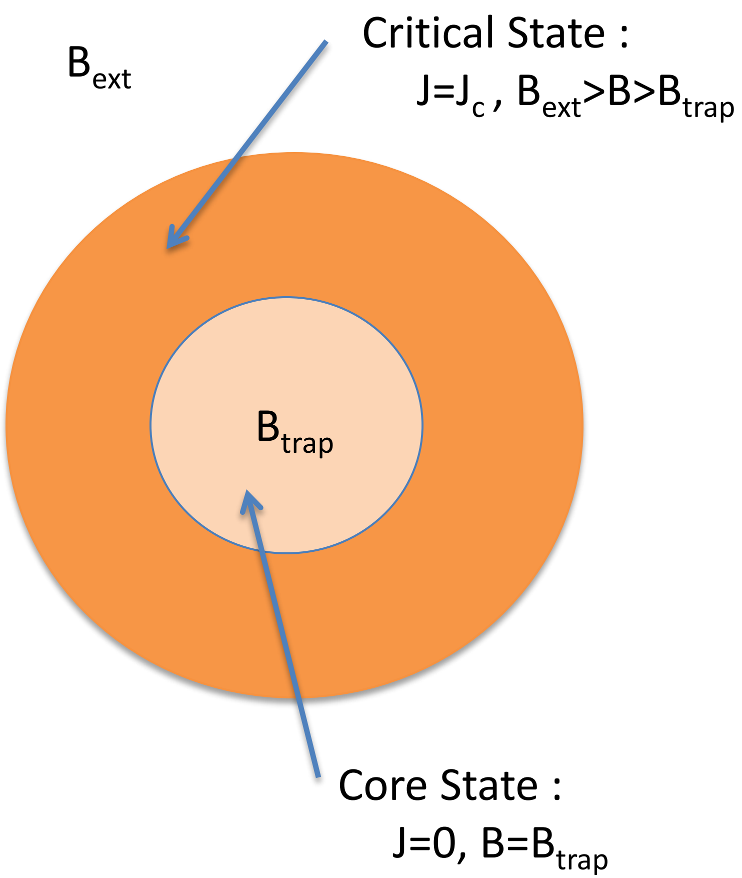
MgB_2 shell held in 14K cryocooler between poles of a 1 tesla dipole

MgB_2 prototype:
39 mm Ø
86 mm long
1 mm wall



M. Statera, et al, IEEE Trans Appl. Supercond., 25 (2015) 4501004.

Bean Critical State



B_{ext}

Critical State :

$J=J_c$, $B_{ext}>B>B_{trap}$

B_{trap}

Core State :

$J=0$, $B=B_{trap}$

- Super-Current Distribution in Type 2 Superconductors governed by Bean Model. (C.P. Beam Rev Mod Phys 36 (1964) 31)
- Currents confined to shell of varying thickness such that always just under critical current density.
- Not aware of any general geometry numerical solution software.

Opera/Elektra/TR Emulation

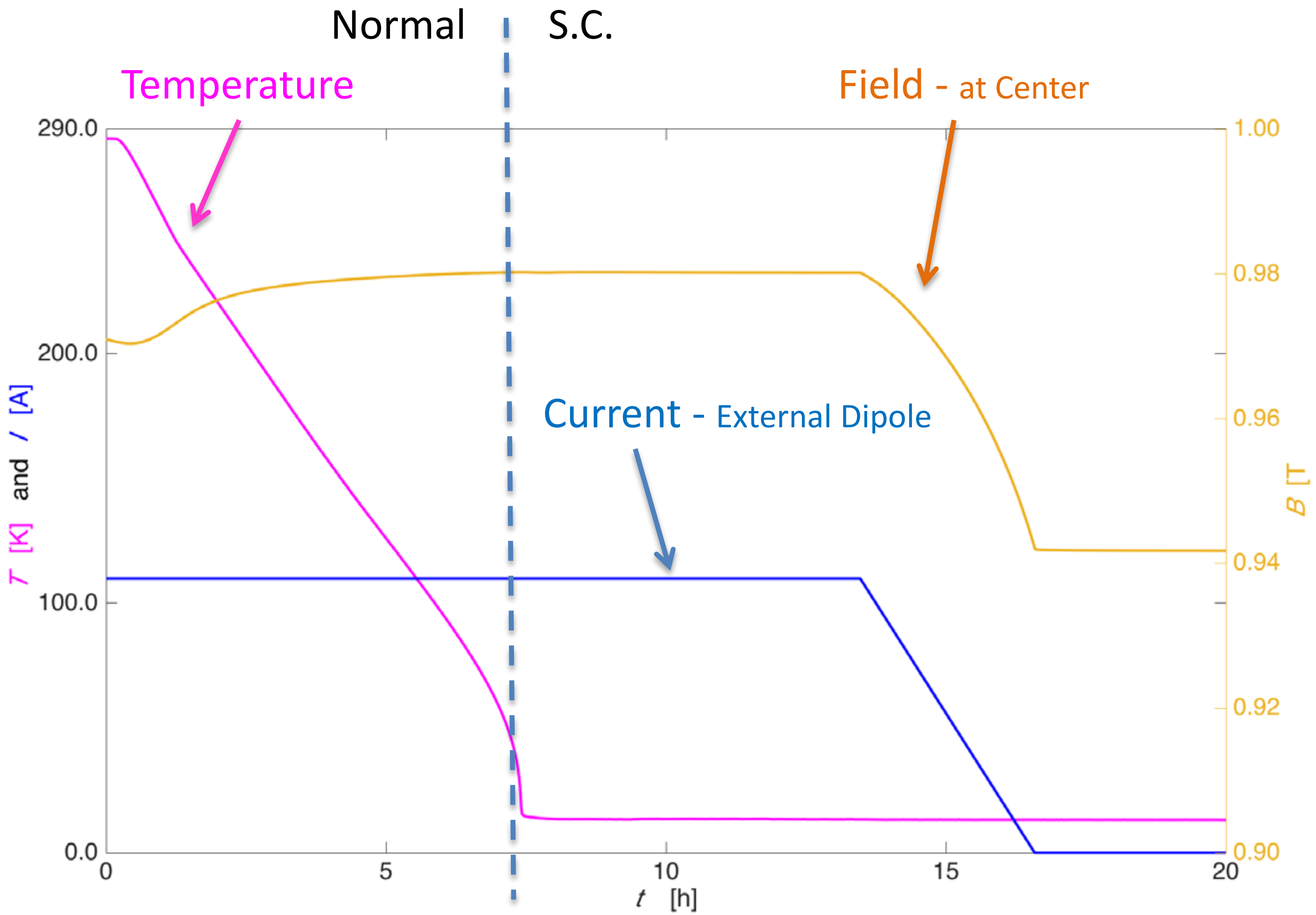
- Finite-element electro-magnetic transient analysis program suite. (OperaFEA, Cobham Technical Services, Vector Fields Software, UK)
- Iterative solution at each time step.
  - $\nabla \times B \leftarrow \mu_0 J$ Ampere’s Law
  - $\nabla \times E \leftarrow -\partial B / \partial t$ Faraday’s Law
  - $J \leftarrow \sigma E$ Ohm’s Law

    user defined!

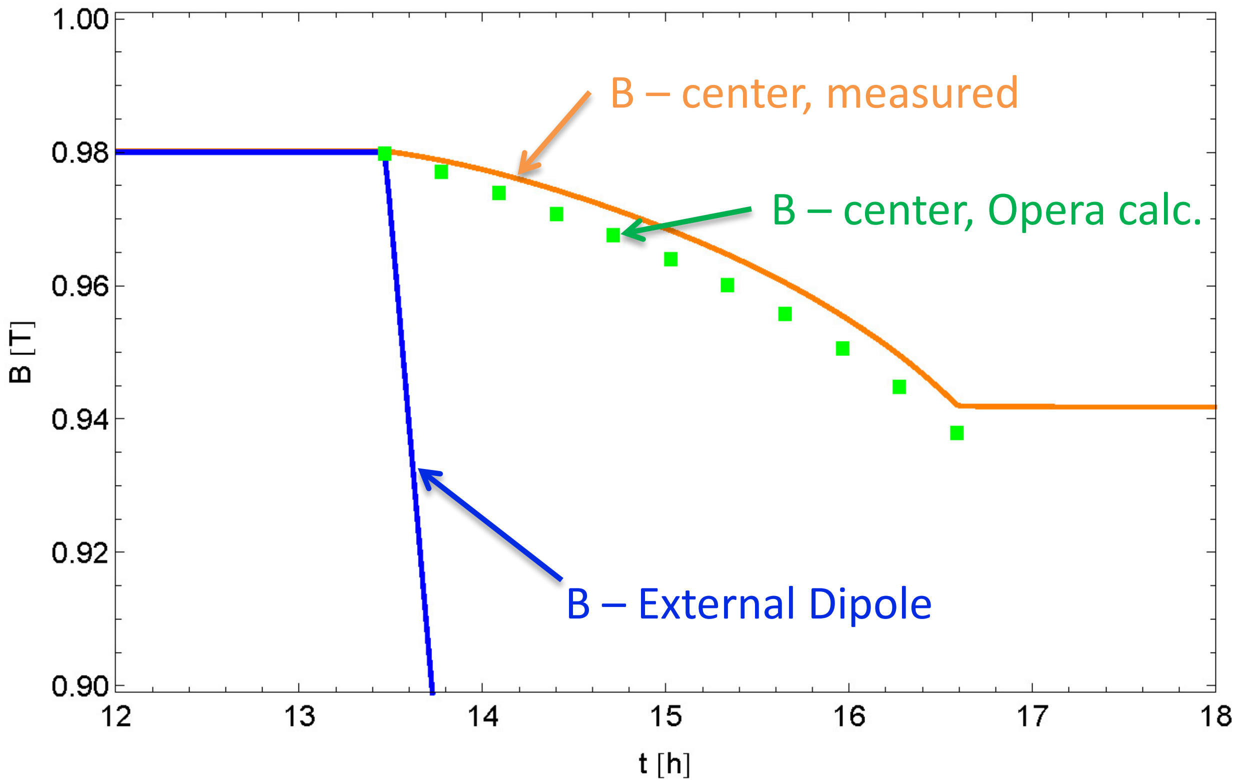
Implement Bean Model

- Conductivity $\sigma = MIN(\sigma_{max}, \frac{J_{critical}}{E})$
- $J_{critical}$(B,T) from measurement.
  - (J. J. Rabbers, et al, Supercond. Sci. Technol. 23 (2010) 125003).
- σ_{max} is parameter determining electrical field too small to completely transform Finite Element into critical state.
- Results insensitive to choice within factor of 10. (too big - slow convergence, too small - numerically unstable)

Ferrara Magnetization Results

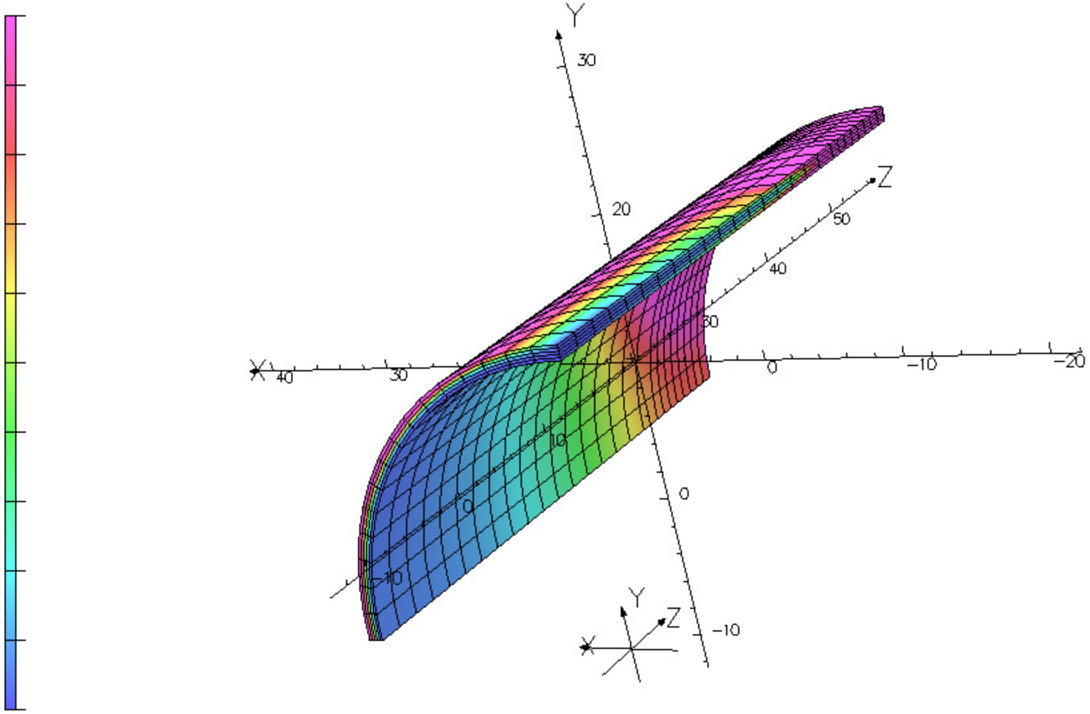


Opera Result



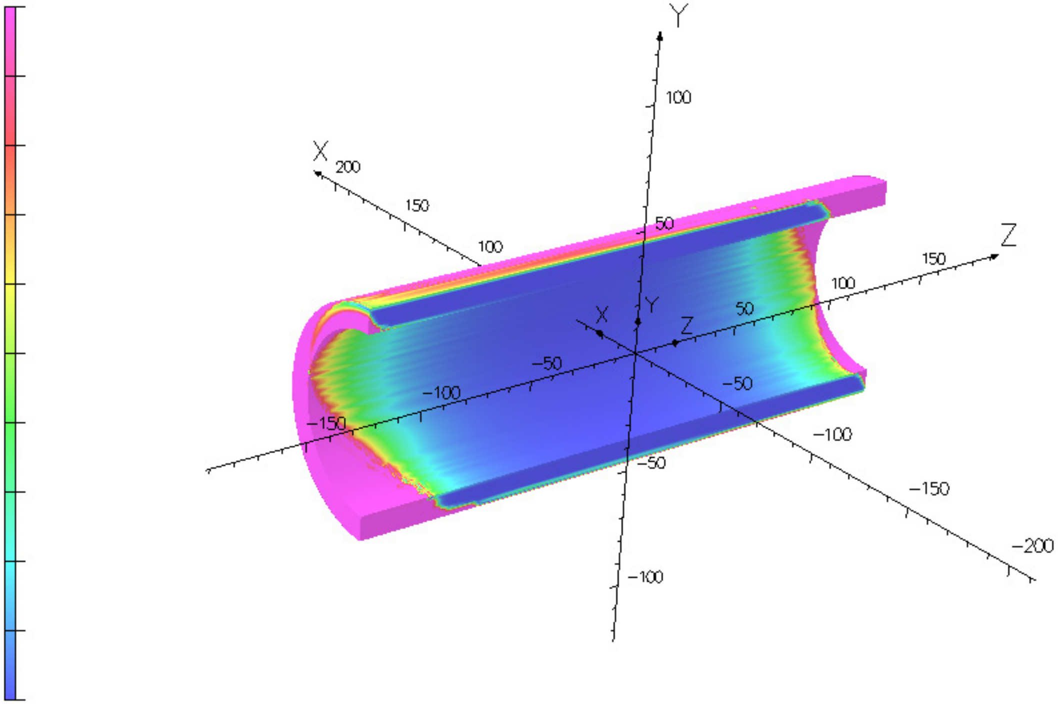
- Good agreement, ≈ 0.5%.
- Droop is from open geometry.
- Curvature of droop from saturation.
- Validates Opera simulation method.

Opera: Current Distribution



- Symmetries on all 3 axes so only 1/8 cylinder needed.
- Contours are relativity to $J_{critical}$(B,T) .
- Dipole field is along Y-axis.
- Center cut shows not fully saturated. ≈ 50% in Bean Critical state.

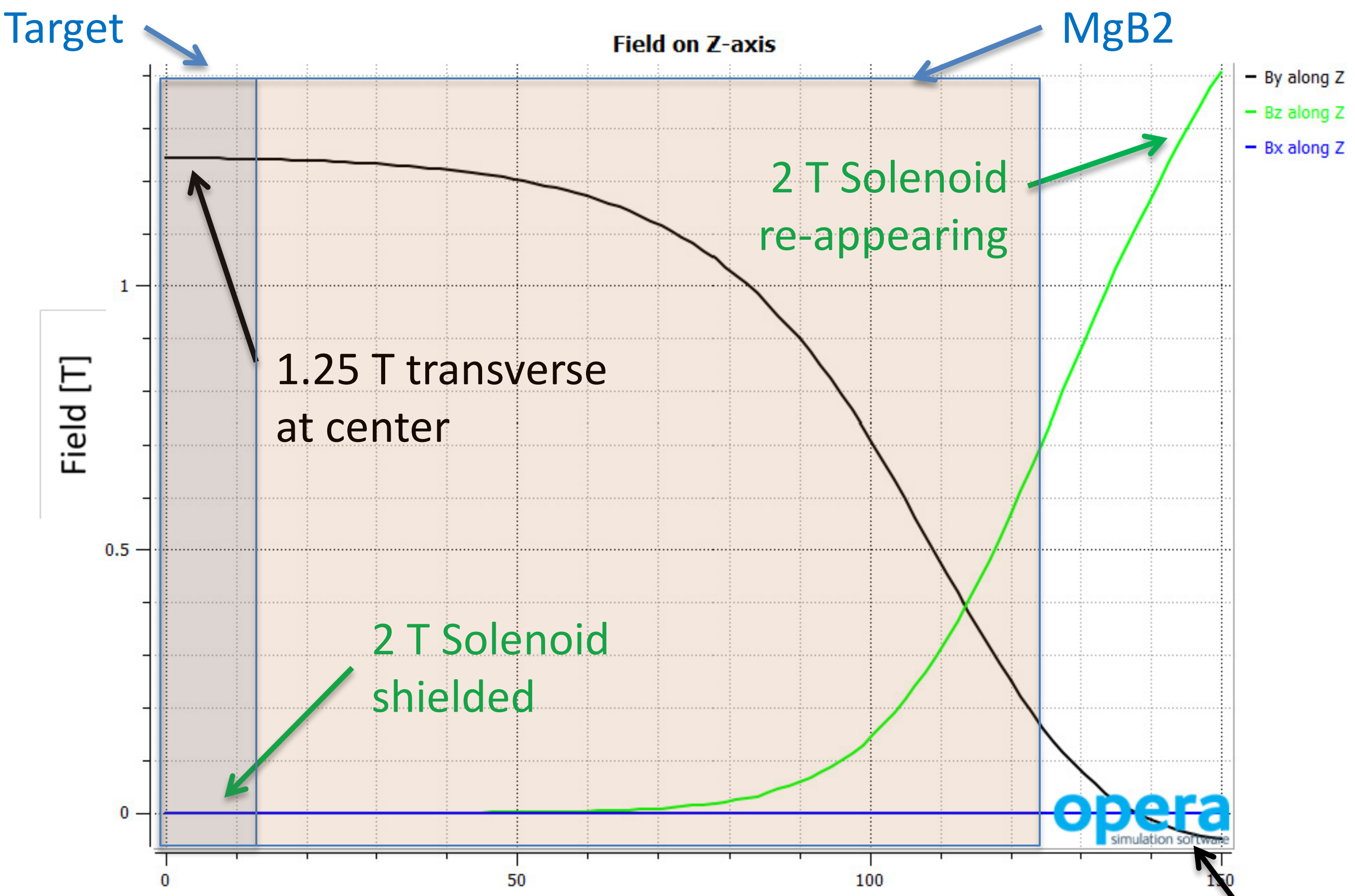
Preliminary CLAS12 Design



MgB2 cylinder:
86 mm Ø
250 mm long
7 mm wall

1.25 T transverse magnetization
2.0 T axial shield
5x10-3 uniformity (Y_{20}/Y_{00})
over 20 mm radius sphere

Field along Cylinder Axis



Target

MgB2

2 T Solenoid re-appearing

1.25 T transverse at center

2 T Solenoid shielded

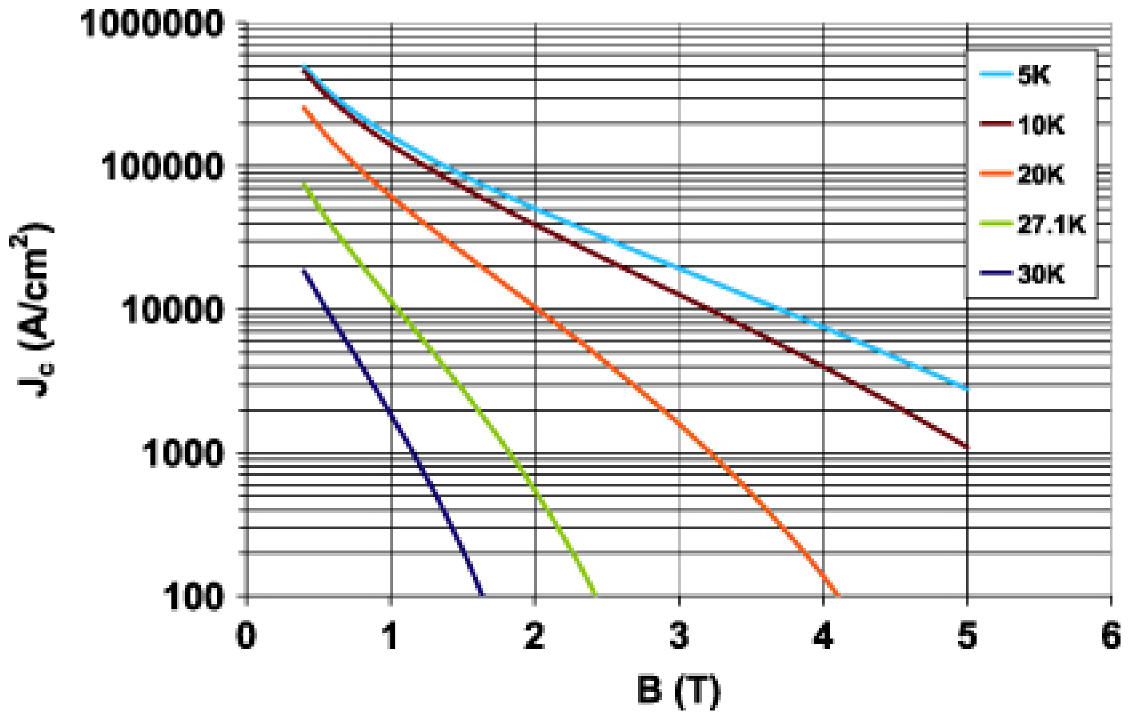
Transverse dipole return

Summary

- Simultaneous magnetization and shielding is elegant and novel solution to difficult magnetic field problem.
- Ferrara tests demonstrate good material properties of MgB2.
- Ferrara tests validate non-obvious Opera calculation strategy.
- Promising design for CLAS12 exists.

Backups

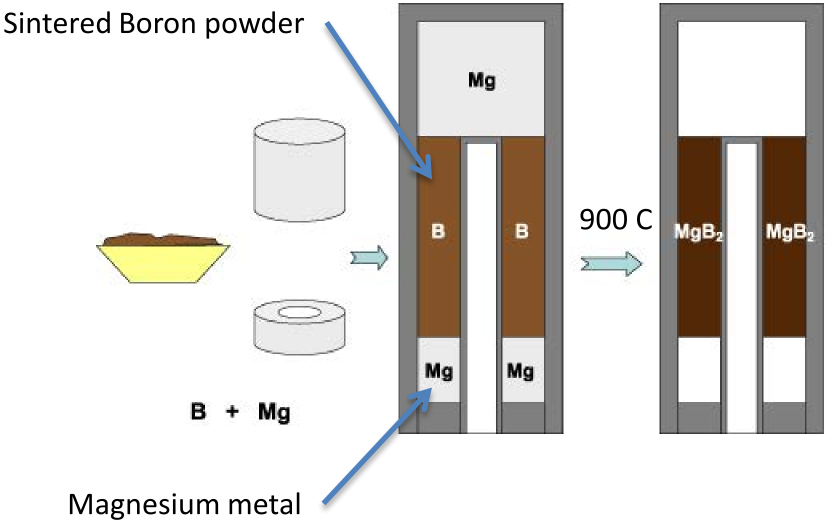
Critical Current Density vs B & T



J. J. Rabbers, et al, Supercond. Sci. Technol. 23 (2010) 125003

MgB2 Material Properties

- Density 2.4 g/cc, <Z> = 7.3 (by atom, 8.7 by wt.).
- Created with Mg-Reactive Liquid Infiltration (Edison SpA, Milan, Italy).
- Machine-able (diamond tools), stabile in air.



J. J. Rabbers, et al, Supercond. Sci. Technol. 23 (2010) 125003