BNL/PBL HTS Solenoid

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Background Information

- BNL magnet division is a partner in a just funded Phase II SBIR (check is almost in the mail) with Particle Beam Lasers (PBL). BNL is responsible for the construction and test of the HTS solenoid.
- BNL has built and tested an FRIB/RIA R&D quadrupole with 24 HTS coils using ~ 5 km of conductor. It has also built and tested several HTS solenoids.
- Accumulated and local stress (strain) on this solenoid are well below the limit of YBCO and are in the ballpark of the SuperPower HTS solenoid tested in the background field of NHFML solenoid.
- We are in early stage of the program. This presentation will give over-all outline, NOT detailed design or calculations. However, based on previous experience and material limits, we are expecting a positive outcome.

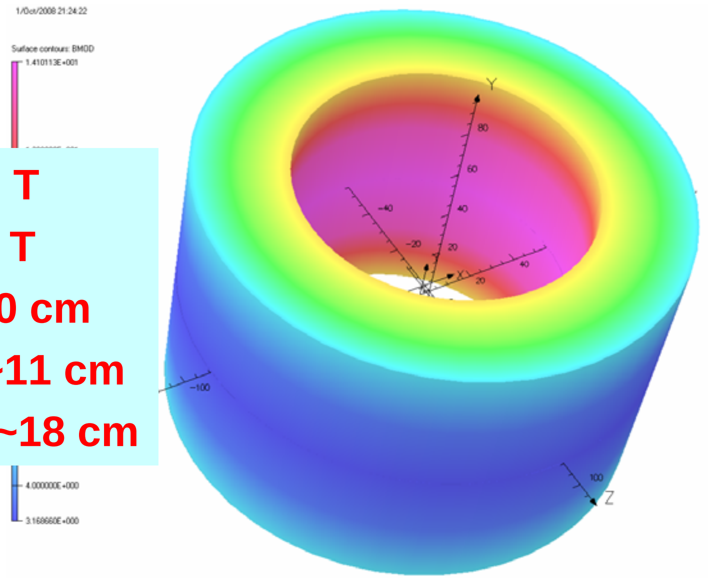
Other participants in this SBIR are:

- *A. Garren, S. Berg, D. Cline, H. Kirk, J. Kolonko and* ***B. Weggel (magnet)***

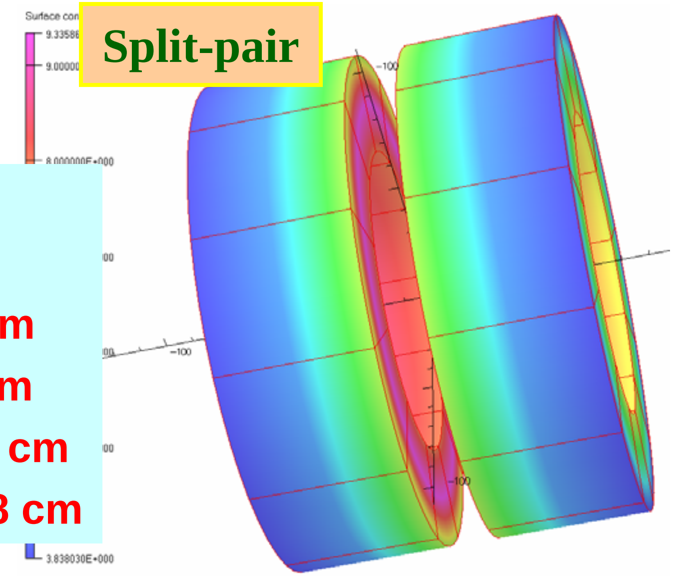
HTS Solenoid (Part of PBL SBIR)
Goals and Opportunities

- **SBIR magnet deliverable (along with other AP components)**
  - 10 T @4 K (~5 T @35 K), 100 mm bore HTS solenoid (coil i.d. 110 mm)
  - Measure performance as a function of temperature to help design future high field solenoids operating at higher temperature
- **Other goals and opportunities**
  - Build and test ~***22-25 T***, ~29 mm BNL/PBL/SuperPower ***all HTS solenoid***
  - Develop technology for 10 T, 100 mm HTS solenoid operating at 35 K
  - Develop a test facility with a reasonable *"turn around"* to measure HTS Ic as a function of the field and field angle in a temperature range of 4 K to 80 K
  - Carry out this R&D as a step towards developing very high field (30-40 T) HTS solenoids (in a smaller bore)
  - Develop HTS technology for other accelerator magnets that reside in high energy deposition, high radiation environment

HTS Solenoid Designs (in collaboration with SuperPower)

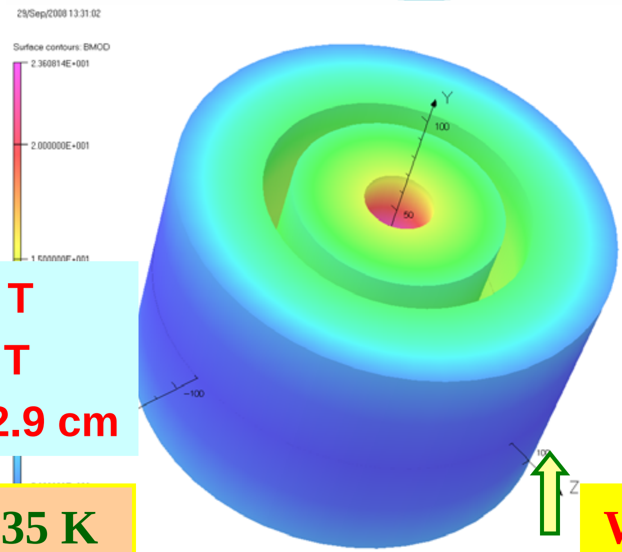


Bo ~ 12 T
B_{pk} ~ 14 T
Bore ~10 cm
Coil id ~11 cm
Coil od ~18 cm



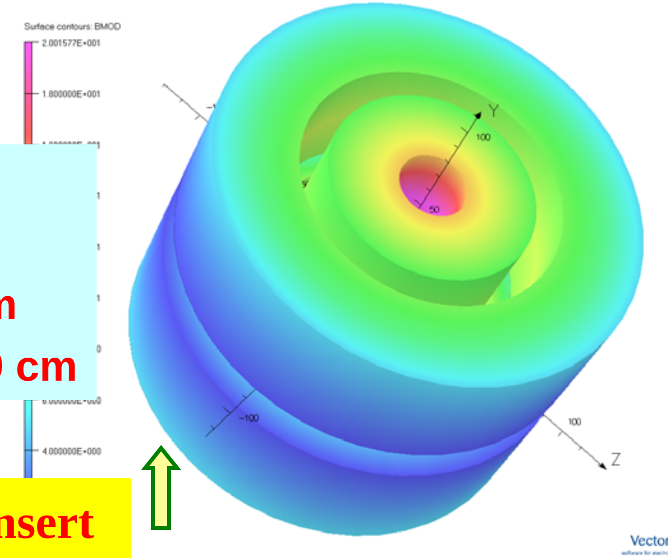
Split-pair

Bo ~ 10 T
B_{pk} ~ 12 T
Bore ~10 cm
Gap ~1.8 cm
Coil id ~11 cm
Coil od ~18 cm



Bo ~ 23 T
B_{pk} ~ 24 T
Coil id~2.9 cm

~10T@35 K

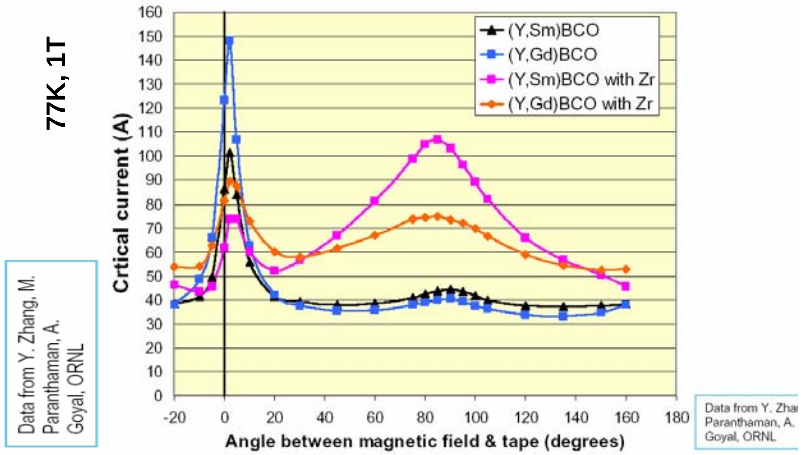


Bo ~ 18 T
B_{pk} ~ 20 T
Gap ~1.8 cm
Coil id ~ 2.9 cm

With SuperPower Insert

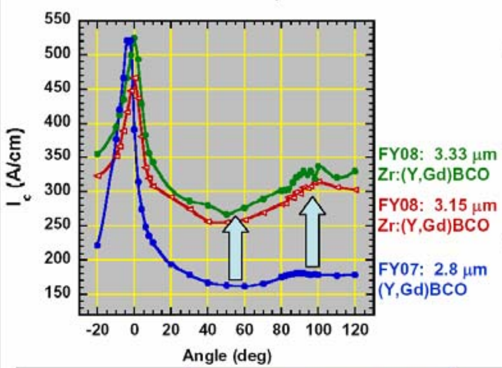
Large Improvements in I_c by Doping

Zr-doped chemistry has been successfully transferred from Research system to Pilot MOCVD



SuperPower

Excellent in-field performance at 65 K, 3 T



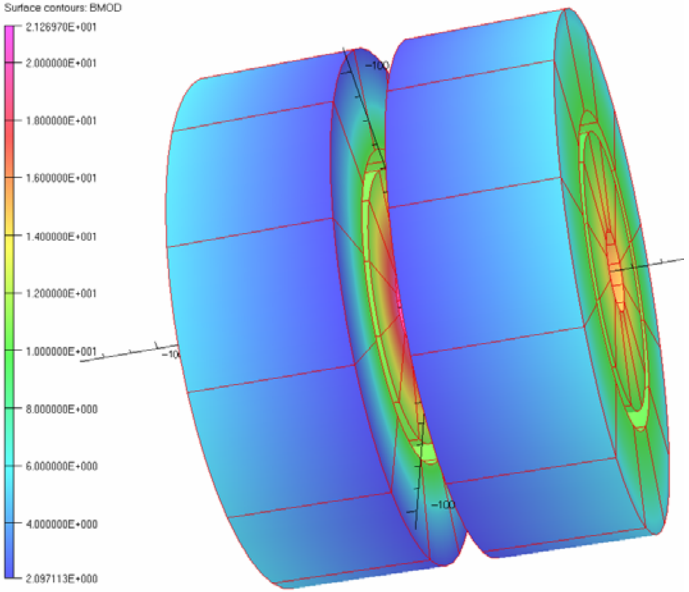
- Title III Phase 3 program goal is Je without stabilizer of 15,000 A/cm² at 65 K, 3 T
- Minimum Ic = 267 A/cm corresponds to Je of 41,000 A/cm² at 65 K, 3 T
- Ic perpendicular to tape = 340 A/cm corresponds to Je of 52,300 A/cm²

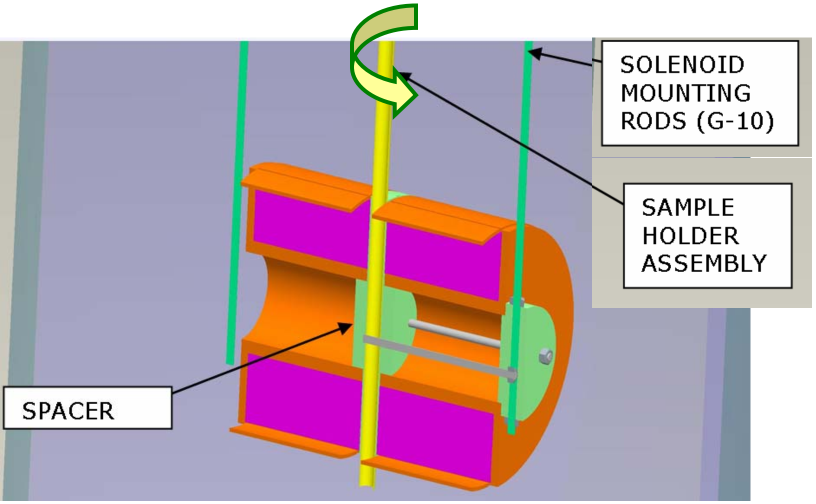
Ic (77 K, 1 T)	FY08 Zr-doped (Gd,Y)BCO	FY07 (Gd,Y)BCO	Improvement
B // c	340 A/cm	181 A/cm	88%
Minimum Ic	267 A/cm	160 A/cm	67%

Data from Y. Zhang, M. Paranthaman, A. Goyal, ORNL

- Doping or nano-dots have brought major improvements in in-field I_{c}. The type of doping (or nano-dots) used has a major influence on the angular dependence of I_{c}.
- One can consider using conductors with different dopings (or nano-dots) in different parts of the coil (different field angle) as it could offer large benefits.
- For example, as a part of FRIB R&D, we are purchasing four 100 meter pieces of YBCO with three different dopings from SuperPower and two 100 meter pieces of YBCO with nano-dots from ASC.
- In-field improvement in I_c could have a significant impact on the future high field magnet program and therefore, HEP community should strongly support this specialized development.
- We also need a simple low temperature test facility where we can measure I_c as a function of field and field angle (finer steps) in a day or so to support optimization of dopings (or nano-dots) at high fields.

Converting HTS Solenoid to a Unique and Useful Conductor Test Facility

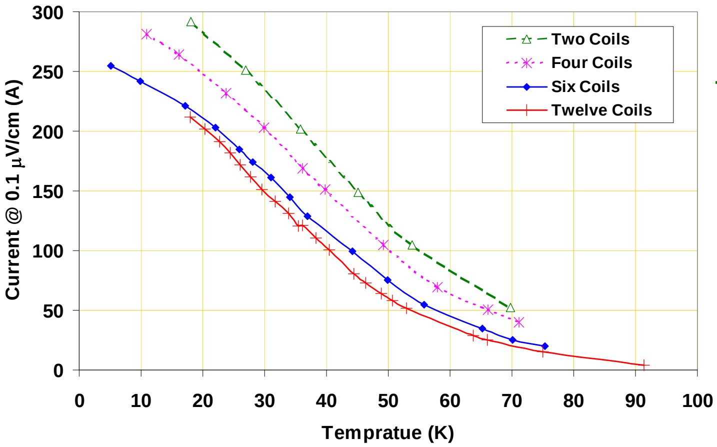




- A split-pair solenoid using these coils, can create a unique test facility for measurement of field and field angle in small steps.
- We are planning ~18 mm gap between the coils to accommodate a solid disc with ~13 mm hole for sample holder. A rotation controlled from outside the cryostat will vary the relative direction of field on the sample.
- We will have ~10 T field in 10 cm space and ~18 T field in 2 cm thanks to the expected contributions of HTS insert coils by SuperPower.
- In addition, the temperature on the sample can be varied with the on-board heaters in the sample holder.

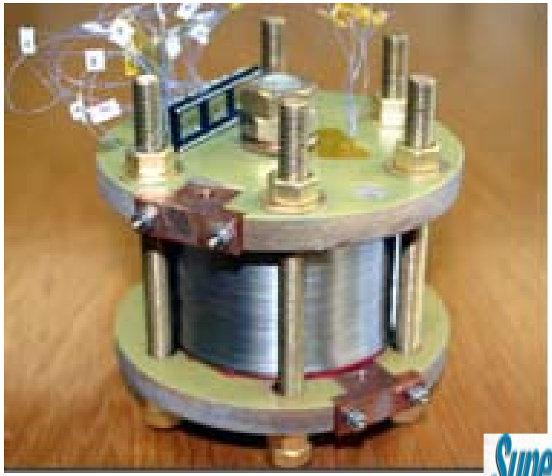
Construction Plan and Schedule

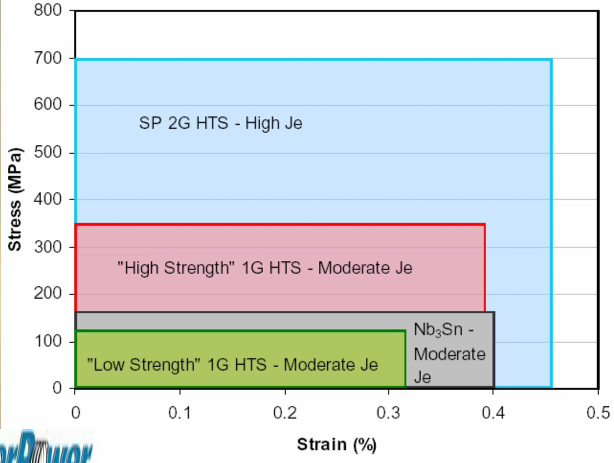
FRIB/RIA coils - S.S. tape over HTS



Measured Ic as a function of temperature in FRIB/RIA quadrupole. Similar measurements will be performed in this solenoid.

- As in FRIB, we will wind coils with stainless steel tape. Stainless steel tape gives extra strength which is useful in very high field magnets (in addition to high strength of 2G).
- As in SuperPower/NHFML solenoid, stainless steel over-bend will be used.
- During the first year we will make half solenoid with 12 coils. It will generate B_o ~7 T (B_{peak} ~10 T) by itself and B_o ~16 T (B_{peak} ~16.6 T) with SuperPower insert. We will measure field as a function of temperature in 4K-80K range.
- We will soon be testing new SuperPower coil (4K-80K).
- During the second year we will build and test full solenoid (~12 T) and with SuperPower insert (~23 T) and measure field as a function of the temperature.





BNL/PBL HTS Solenoid

Summary

- This proposal is built upon the successful demonstration of the 2G HTS in high field (27 T) SuperPower/NHFML solenoid thru HTS insert coil.
- This will demonstrate (a) large aperture medium field (10+ cm, 10+ T) and (b) small aperture high field (2.9 cm, 20+ T) *all HTS solenoid*.
- This may be considered as a step towards high field, small aperture (~2 cm, ~40 T) solenoids as needed for muon collider (it's OK to make progress in small steps – this approach may in fact be desirable here).
- As a part of this SBIR, we will also study the performance of this solenoid as a function of temperature over a wide range (4 K – 80 K).
- The experience of this R&D should be helpful in the developing various HTS high field dipoles and quads for muon collider and LHC IR upgrade.
- We also hope to create an additional test facility for measuring I_c as a function of the magnitude of the field, field angle and the temperature over a wide range in small increments.