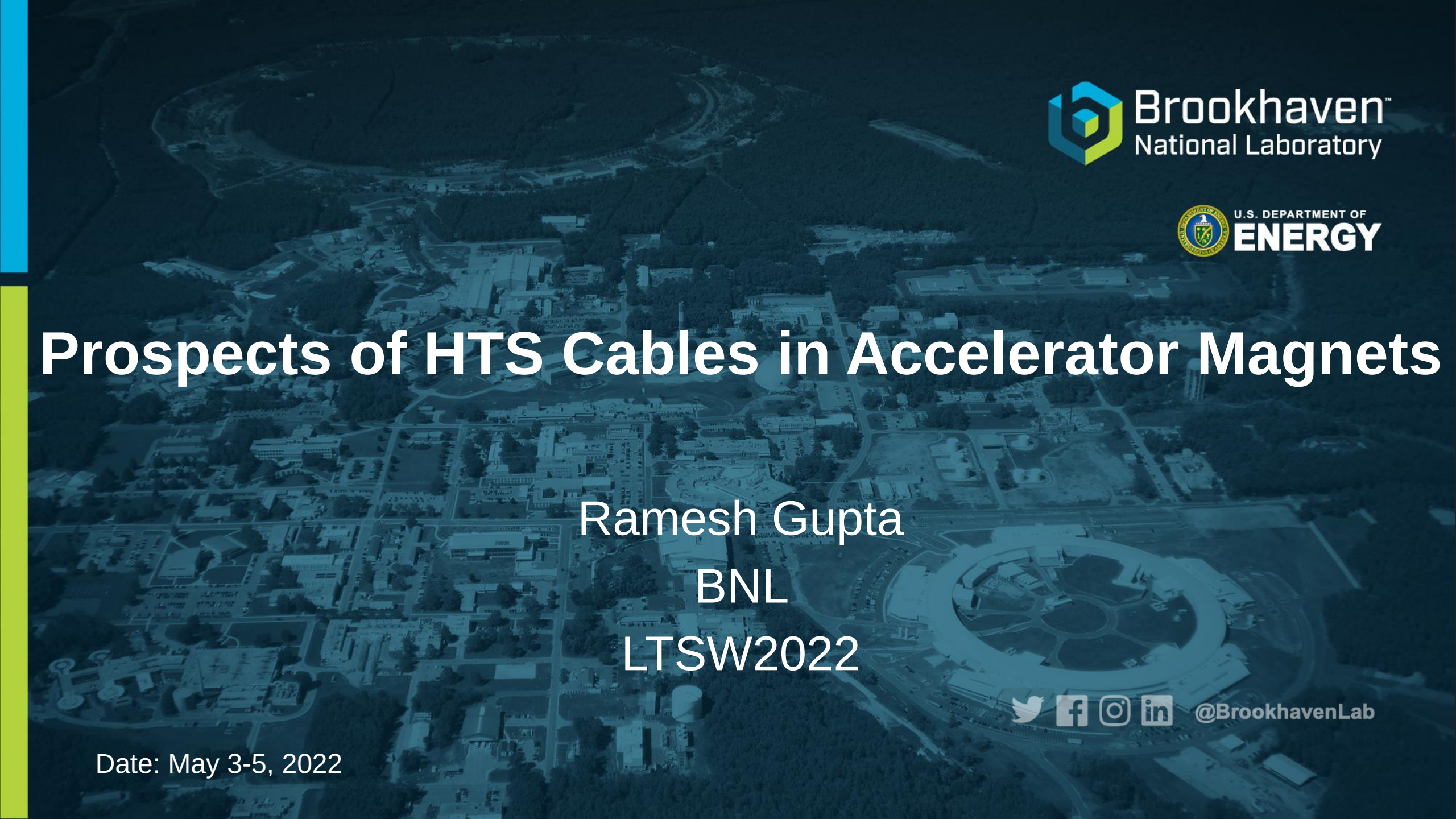


Prospects of HTS Cables in Accelerator Magnets

Ramesh Gupta
BNL

LTSW2022

Date: May 3-5, 2022

Overview/Summary

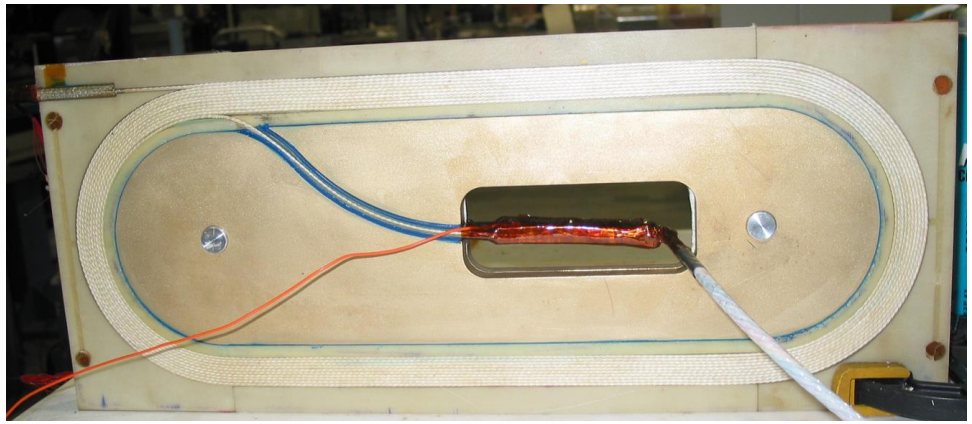
- Most HTS magnets built so far have been made with HTS tapes/wires. However, future magnets with large stored energies will benefit from the use of HTS cables.
- HTS cables offer new opportunities. They also offer new challenges, as well.
- This presentation will *(a) share BNL past and ongoing programs with HTS cables*.
- Current HTS cable market (and hence development of most HTS cables) is primarily driven by fusion applications; and is likely to remain so for a foreseeable future.
- Can HEP community learn to use the HTS fusion cables in designing accelerator magnets? If we can, both fusion and HEP communities will directly benefit.
- This presentation will *(b) summarize accelerator magnet designs with fusion cables.*
- There is a need for testing high current HTS cables and HTS coils in conditions as close to that in actual applications. That should minimize surprises and/or setbacks and speed-up the progress. This presentation will *(c) discuss low-cost, fast turn-around R&D program for HEP and FES with ongoing upgrades for testing long-length HTS cables and HTS insert coils in dipole field at various temperatures.*

A Major Gap in the Past and Current Magnet R&D Programs

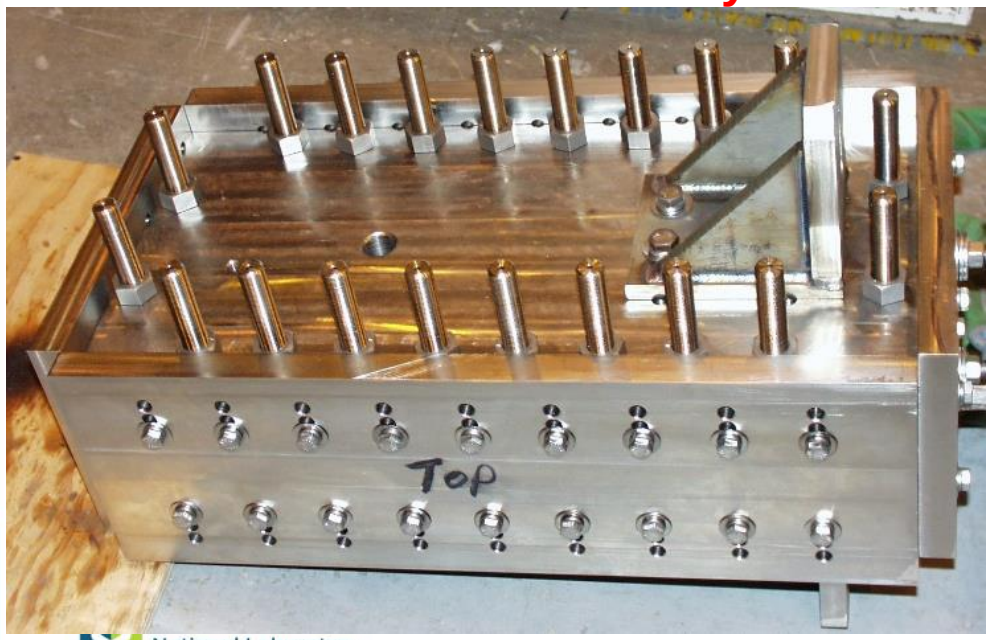
- It is often said that "the magnet can only be as good as the conductor". Therefore, we invest significant resources in "*testing*" and "*understanding*" of the superconducting wires and cables.
- How about, "the magnet can only be as good as the coil". Why not test the coils in an environment as close to the operating condition as practical to find out how good the coil is before we build a magnet.
- Going directly from testing the conductor to testing the magnet is a big step. It inserts many unknowns because of many steps and material are involved (design, wind, react, impregnate, assemble). This also leaves the inherent design and manufacturing flaws undetected. Has it happened with you?
- Building magnets take a lot of time and resources and becomes a major milestone. It limits what we can do. We move away from objective and systematic understanding to the managerial decisions.
- Above has been a major gap in the magnet R&D program. We can't afford that anymore due to budget limitations. To add, the conductor and stresses have changed a lot due to higher fields.
- Why shouldn't we have coil test as a significant part of the R&D program as we do for the conductor.
- Why not do a major reconfiguration of the R&D program NOW and invest significant more resources in building and testing coils in an environment as close to the operating condition as practical.
- Making magnet demonstration a major milestone of the R&D program is a dangerous shortcut. It may be limiting the progress in the magnet technology and the science these magnets are intended to do.

HTS Cables, HTS Coils and HTS/LTS Hybrid Dipoles (2001-03)

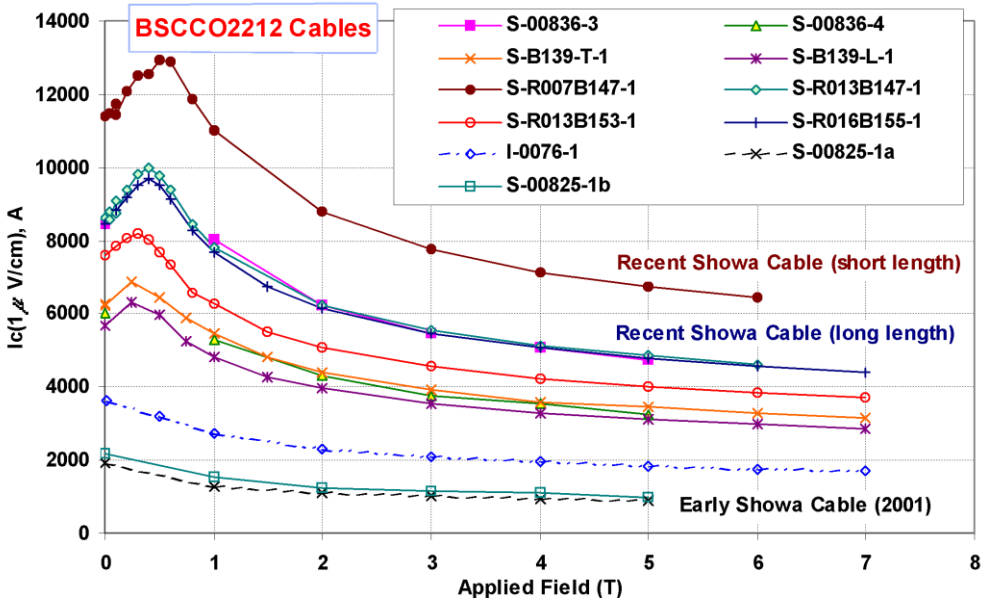
Bi2212 Rutherford Cable Coils (R&W)



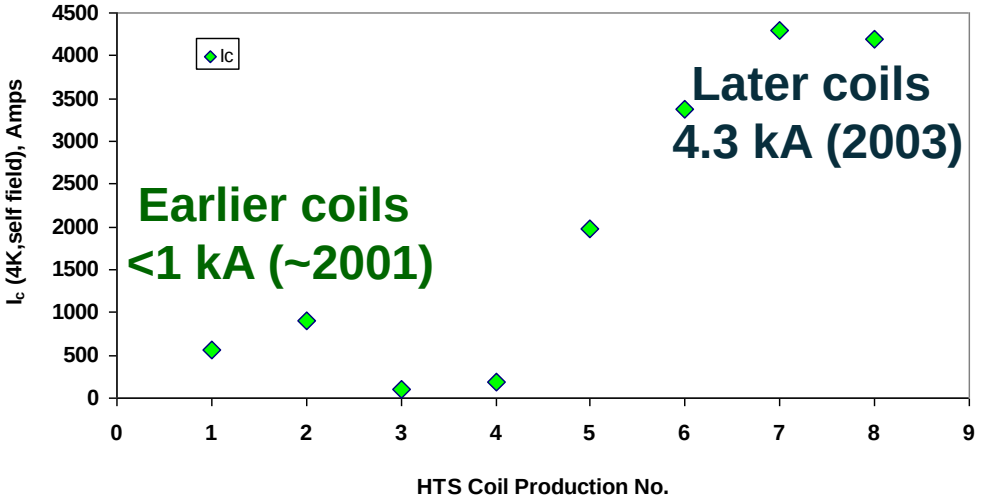
Structure for 2 to 6 HTS/LTS Hybrid Coils



Bi2212 Rutherford Cable Tests at BNL



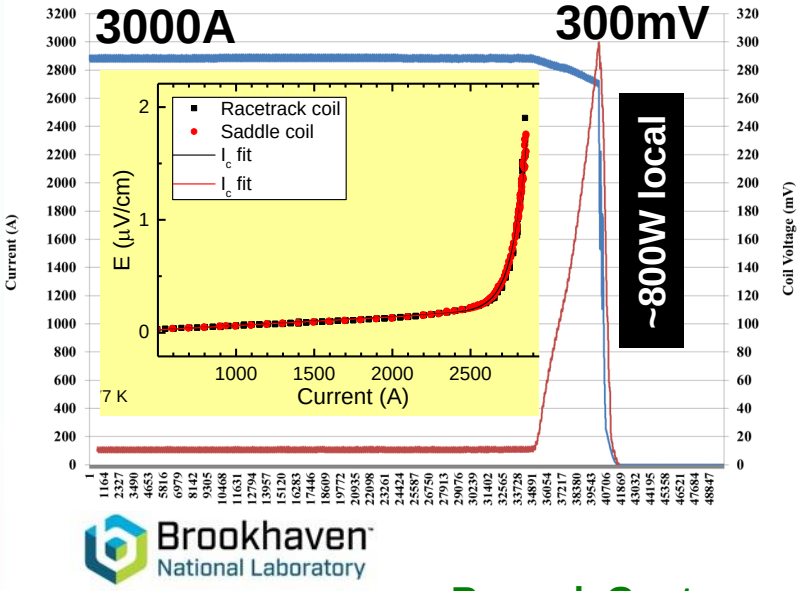
Bi2212 Rutherford Coil Tests at BNL



- An international collaboration - BNL, LBNL and Showa (Japan)
- BNL got free HTS cables for making 8 coils, in return for testing HTS cables in field
- Such across the platform collaborations are mutually beneficial to help understand and grow together

Lessons Learned (to learn, sometimes one has to push to get burned)

- With increasing current and stored energy, HTS coils started getting burned, primarily because of the slow quench propagation velocities (right a Bi2212 Rutherford cable coil in 2003)
- Since then, quench detection and protection has significantly advanced. Test below is an example of CORC cable test at BNL, where the high current cable remained protected (but low energy)
- However, large temperature margins in HTS only helps in transient and buys extra time. Be prepared for real operating conditions – noisy environment, coil voltage running away, decay determined by L/R and low quench propagation velocities in HTS.

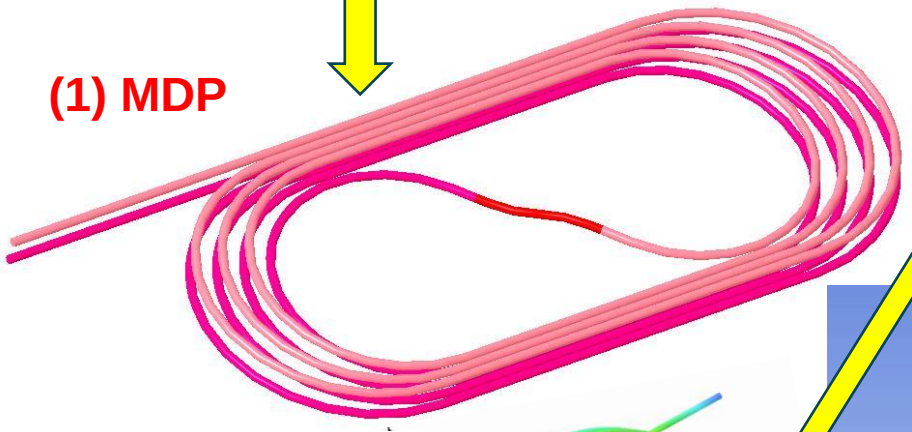


HTS Cable Magnet R&D Programs for HEP

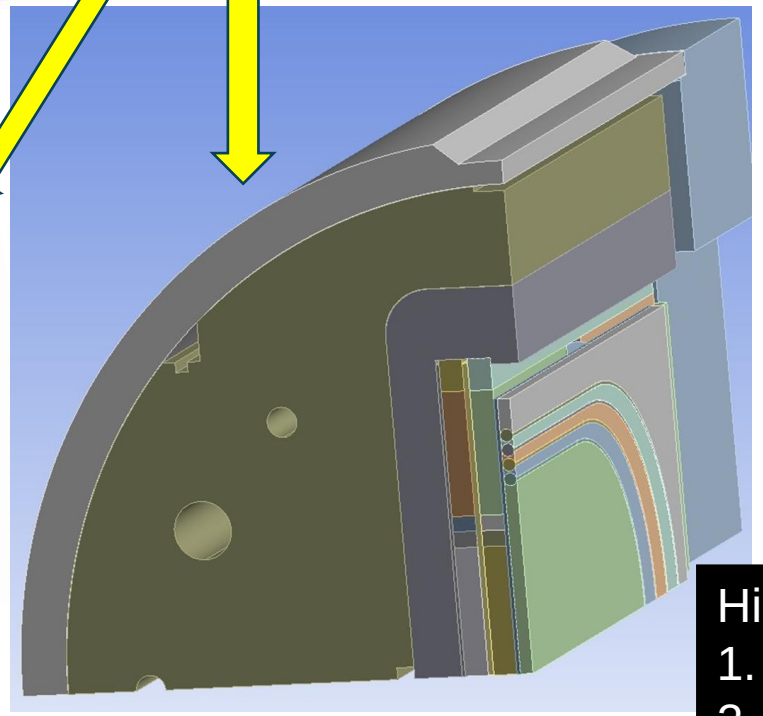
- Two high current (~10 kA) CORC cable coil programs

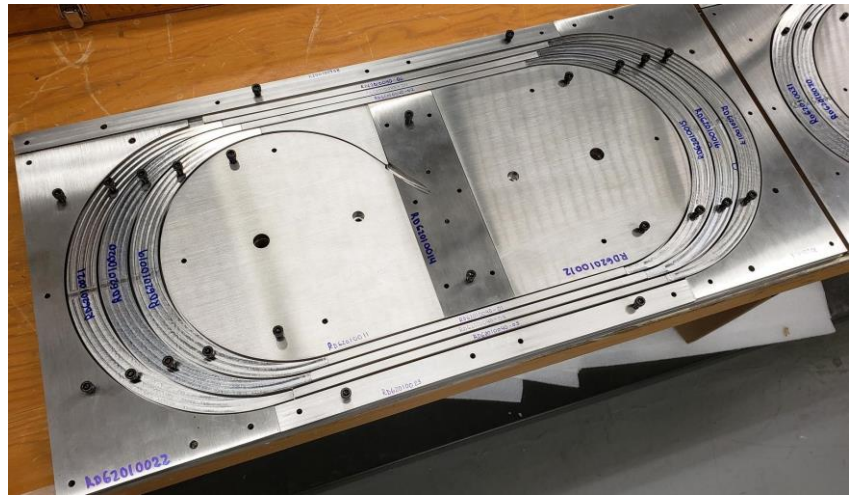
1. Quench studies in long length HTS/LTS hybrid dipole (0-10T)

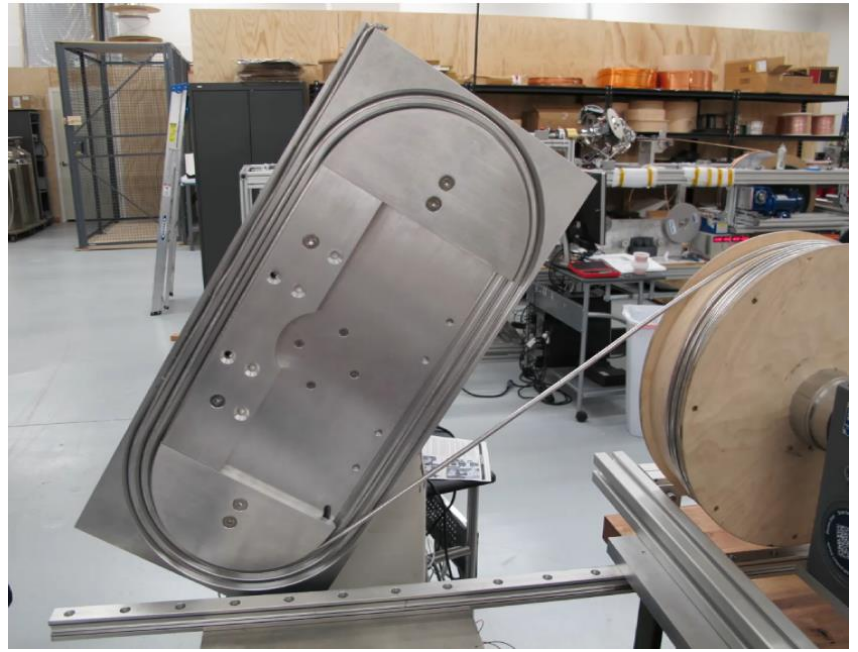
(1) MDP



2. STTR: HTS/LTS coils in series for high field hybrid R&D dipole (13-14 T)

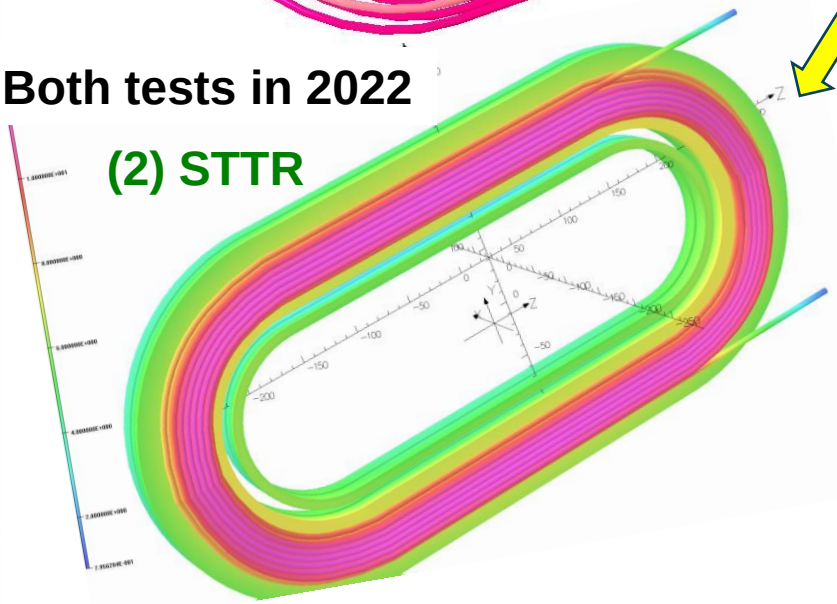






Both tests in 2022

(2) STTR



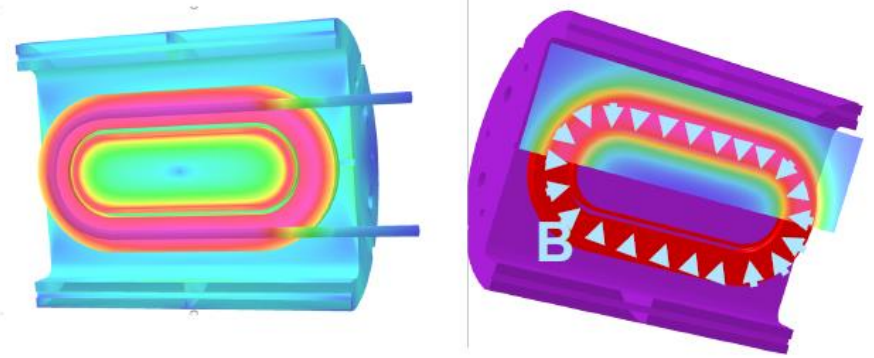
High current cable SBIR proposals (2022):
1. STAR cable coil for ~14 T hybrid dipole
2. Magnum-NX cable coil for hybrid dipole

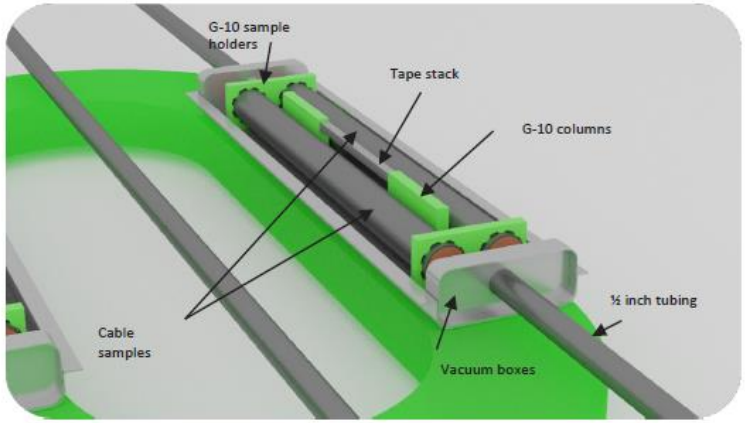
HTS Cable R&D program at BNL for Fusion

ASTI Seminar Series - CFS and the new public-private fusion energy landscape

BNL and CFS

- CFS and BNL have won INFUSE, ARPA-E programs together
  - AC loss testing on HTS cables
  - Demonstrated significant performance improvement in support of Central Solenoid Model coil
  - Thank you to Kathleen Amm, Rajesh Gupta and their team
- We're pursuing an expanded relationship
  - BNL has relevant core competencies in materials, magnets, manufacturing, instrumentation, modeling, computing, etc.
  - Fusion is moving from a science problem to an engineering problem



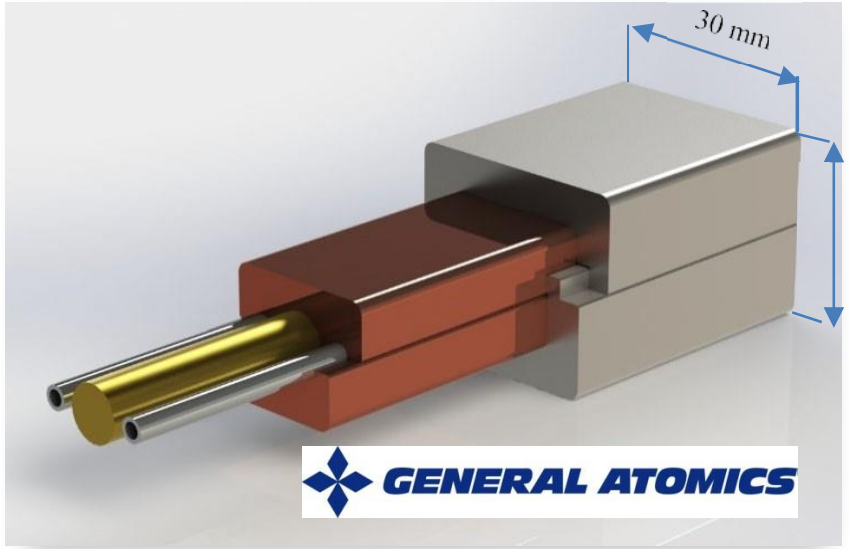


5/3/22

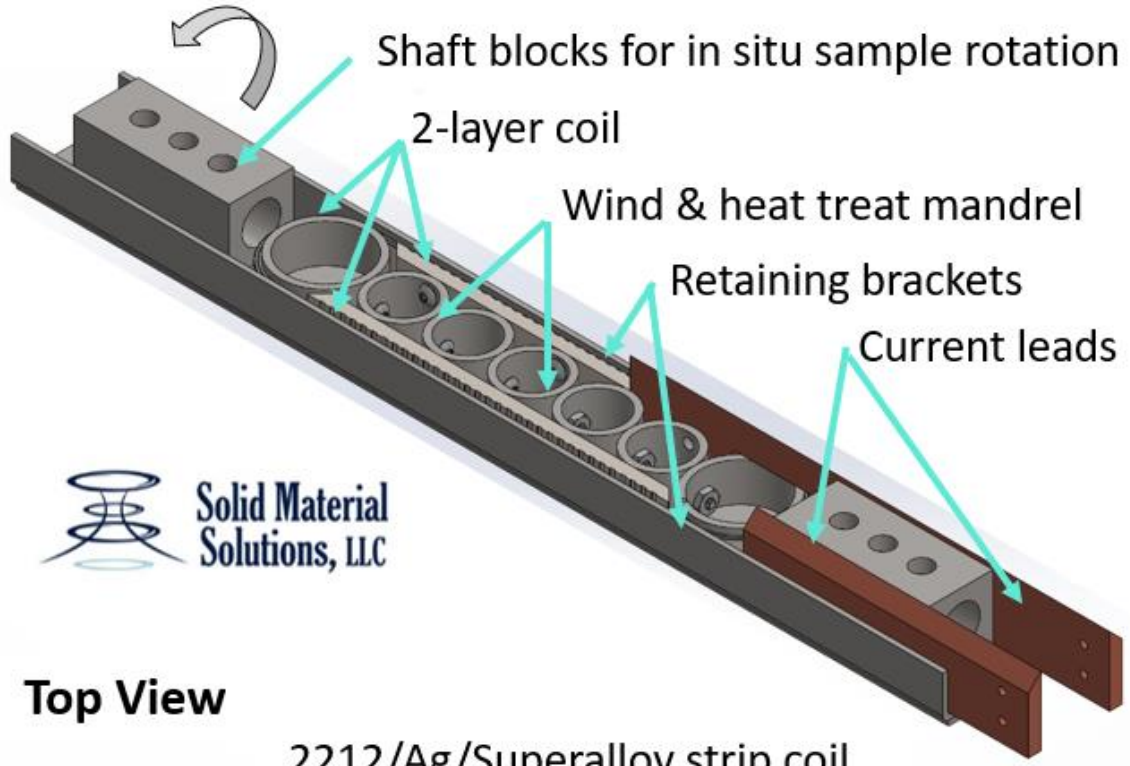
2

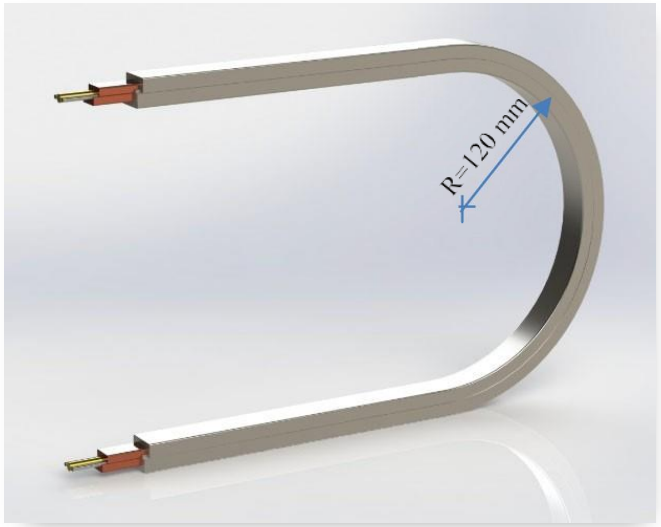
HTS Cable and Coil R&D for Fusion

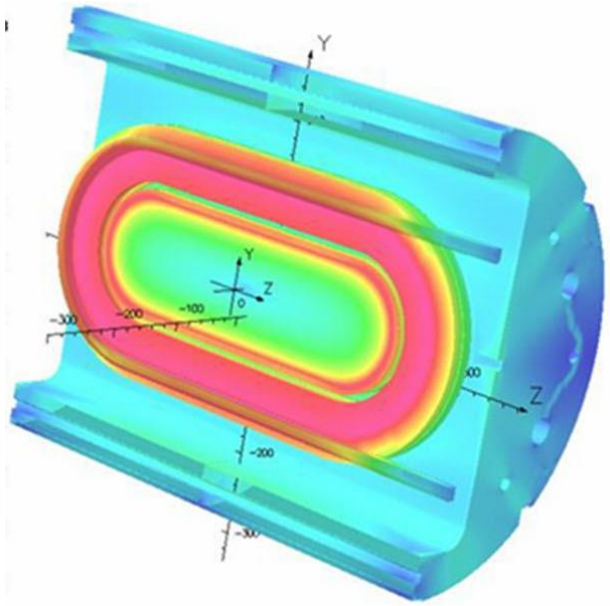
CORC
CICC



Rotation of HTS Coil in dipole field

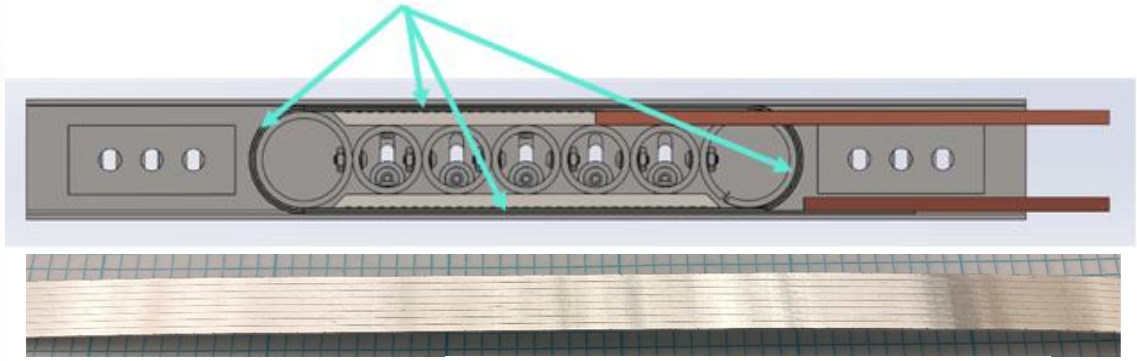






Top View

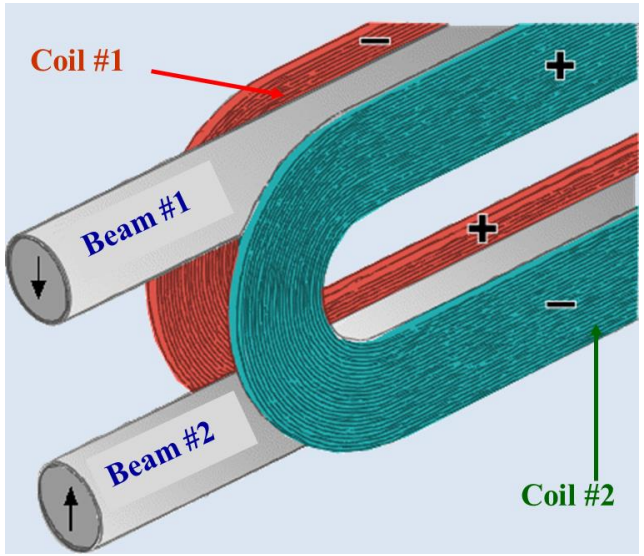
2212/Ag/Superalloy strip coil

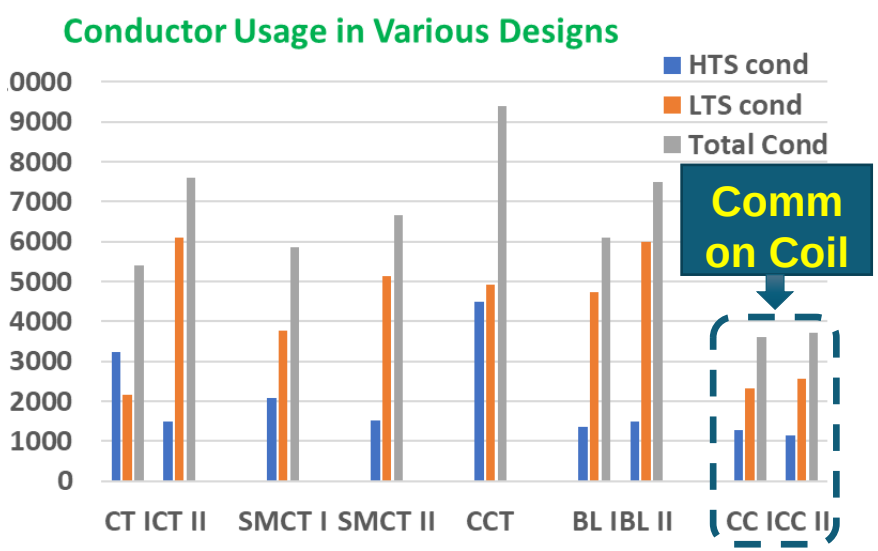


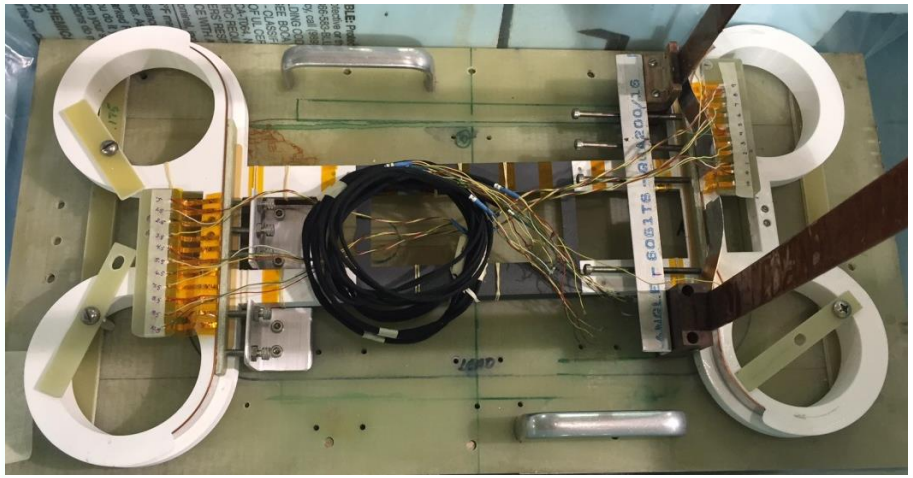
8.5 mm x 0.55 mm wire

On Using Fusion Cable for Accelerator Magnets

- Most high current fusion cables require large bending radii.
- If accelerator magnet designers can use these types of cables, then both FES and HEP can benefit from this major undertaking.
- Promising magnet designs exist, however, yet to be demonstrated

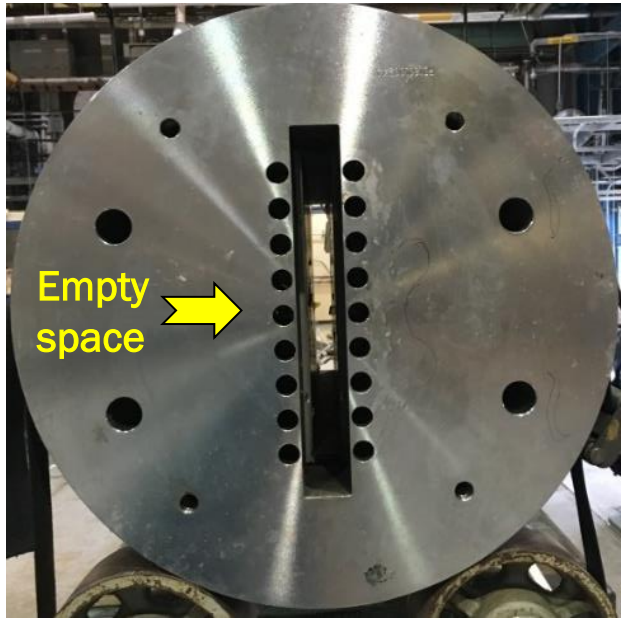




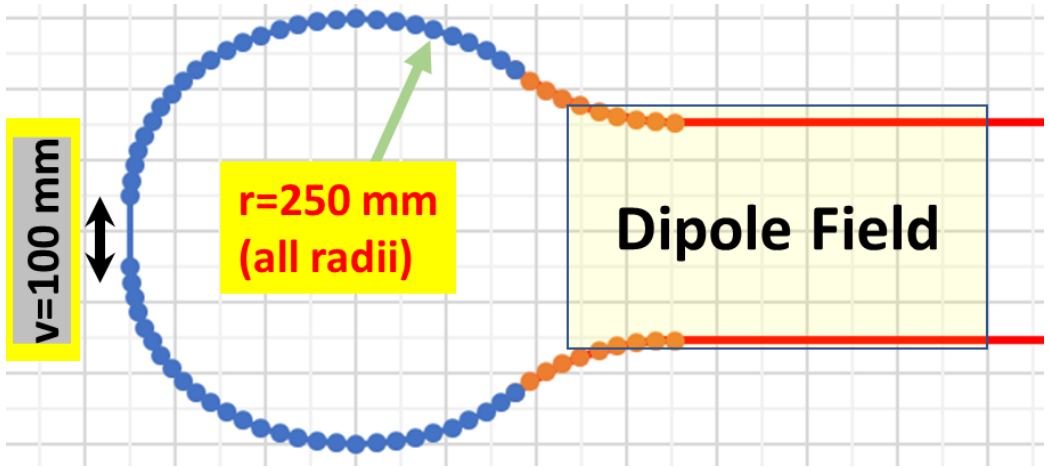


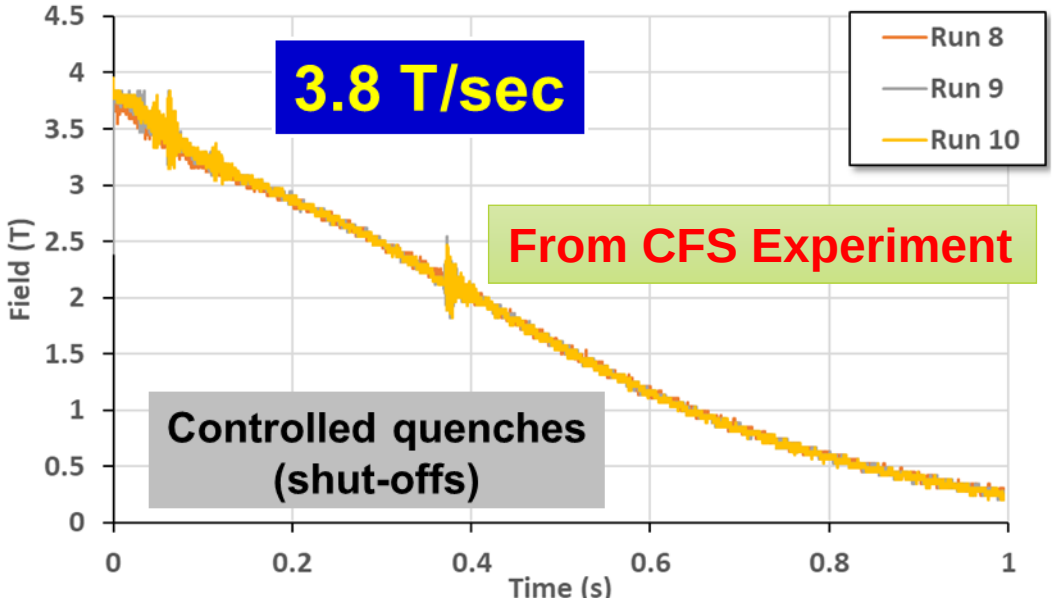
SBIR with e2P

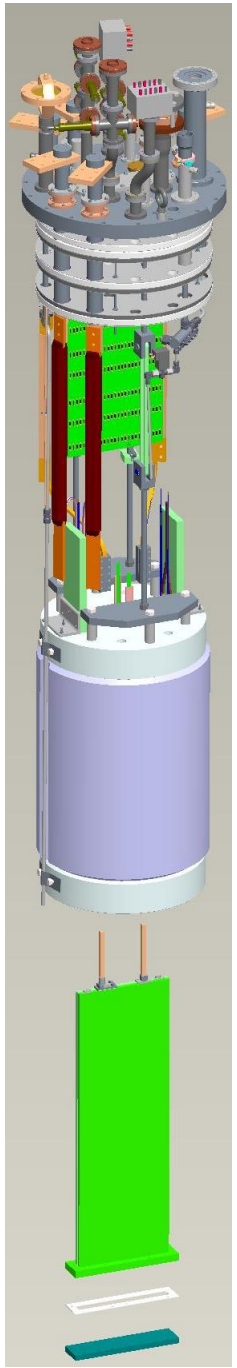
Facility for Testing HTS Cables and Insert Coils in 10 T Dipole



- A unique facility for testing high current cables with large bend radii with bending part in dipole field.
- Fast ramp rate (up to ~4 T/s possible).
- A unique facility for testing coils where insert coil become an integral part of the magnet (low cost, fast turn-around).
- Facility is getting upgraded for variable temperature and high current (20-25 KA from power supply and 100 kA from superconducting transformer).
- Several possible use, some thought not to be possible before.







CAD model of 20 K Insert ready for installation in the magnet

Cable with large bend radius

Summary/Overview

- Most HTS magnets built so far have been made with HTS tapes/wires. However, future magnets with large stored energies will benefit from the use of HTS cables.
- HTS cables offer new opportunities. They also offer new challenges, as well.
- This presentation will *(a) share BNL past and ongoing programs with HTS cables*.
- Current HTS cable market (and hence development of most HTS cables) is primarily driven by fusion applications; and is likely to remain so for a foreseeable future.
- Can HEP community learn to use the HTS fusion cables in designing accelerator magnets? If we can, both fusion and HEP communities will directly benefit.
- This presentation will *(b) summarize accelerator magnet designs with fusion cables.*
- There is a need for testing high current HTS cables and HTS coils in conditions as close to that in actual applications. That should minimize surprises and/or setbacks and speed-up the progress. This presentation will *(c) discuss low-cost, fast turn-around R&D program for HEP and FES with ongoing upgrades for testing long-length HTS cables and HTS insert coils in dipole field at various temperatures.*