

Medium Field HTS Magnets

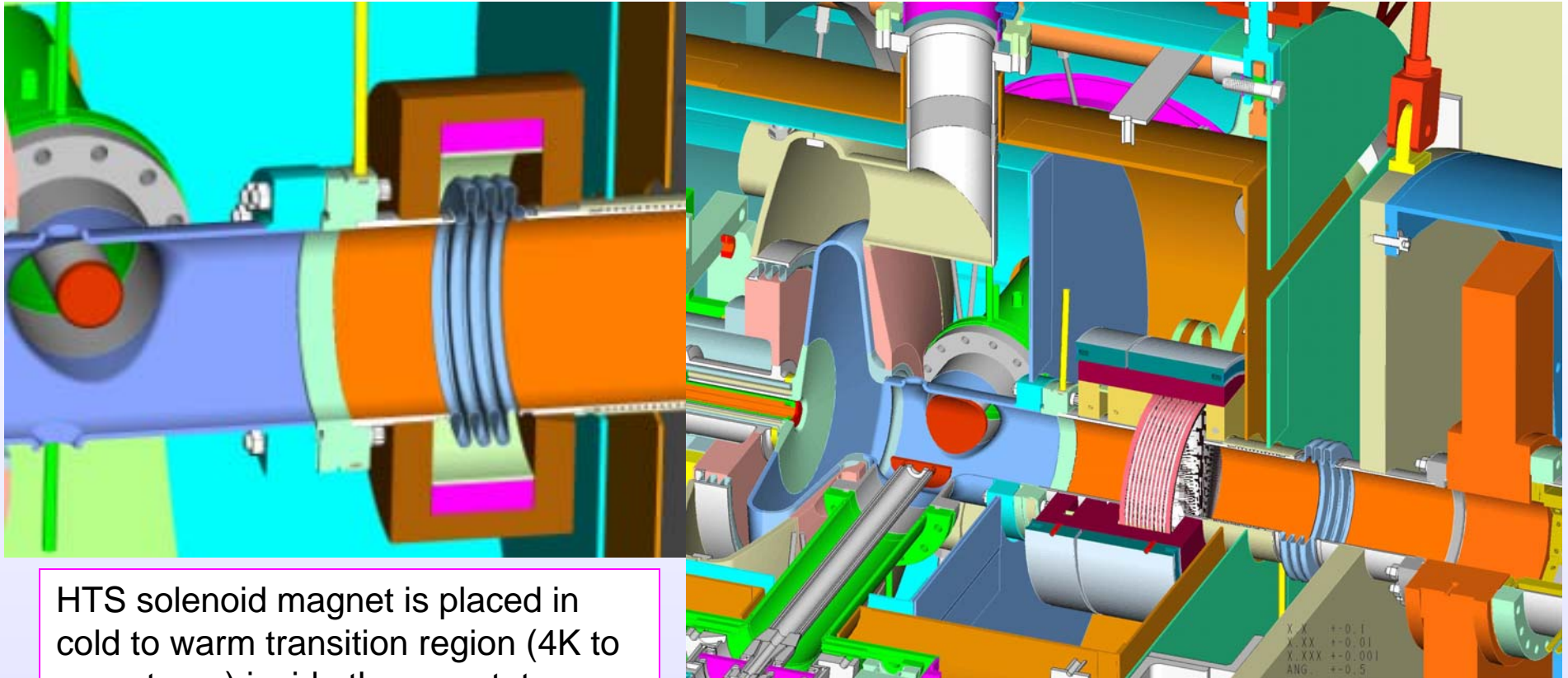
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Overview

- In addition to high field applications, HTS may offer some unique advantages in specific low to medium field magnet applications.
- A number of R&D HTS coils (over 50) and low to medium field HTS R&D magnets (over 10) have been built and tested.
- Some of them are already part of R&D systems, providing unique solutions.
- HTS medium field magnet designs have been studied for a number applications. In some cases they could provide a *“lower cost of ownership (capital + operation)”*.
- A very brief summary and outlook is presented. HTS super-ferric option for PS2 can be examined with latest conductors and magnet design studies.
- Presentation will start with “real R&D devices”, not just R&D studies.

HTS Solenoid for the Proposed ERL (Electron Recovery Linac) at BNL

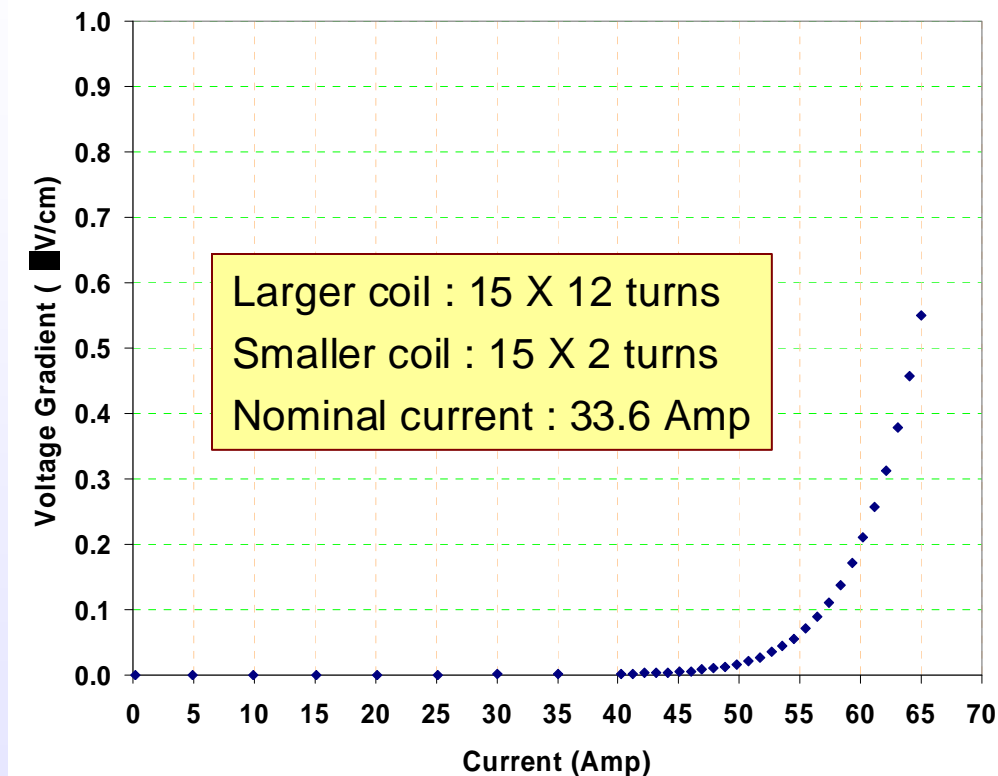


HTS solenoid magnet is placed in cold to warm transition region (4K to room temp) inside the cryostat.

- This close proximity of focusing to cavity significantly improved the system performance. There was no equivalent NbTi or copper magnet solution.
- Solenoid was designed to give required performance at 77 K. Rest is for margin. Savings in the cost LN2 test over the cost of 4 K helium test was much more than the cost of HTS.

77 K Test of Solenoid Coils for ERL

Test results of larger coil

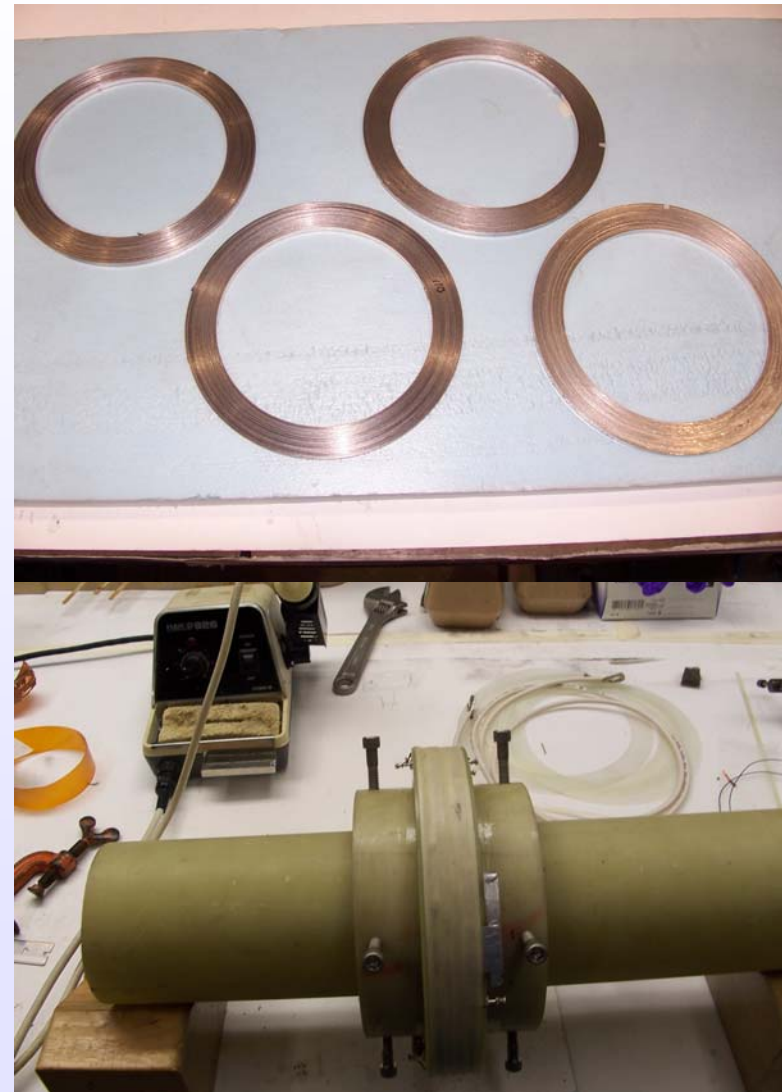


- Coils were successfully operated well above the design current (~34 Amps) even at 77 K (much higher value expected at 10-20 K).

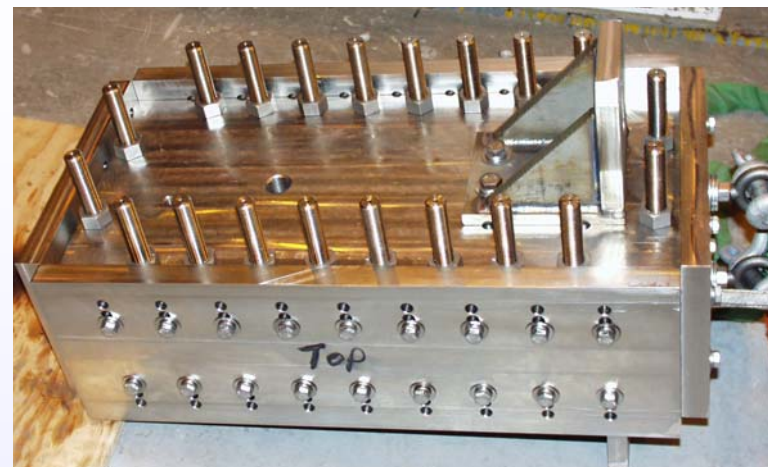
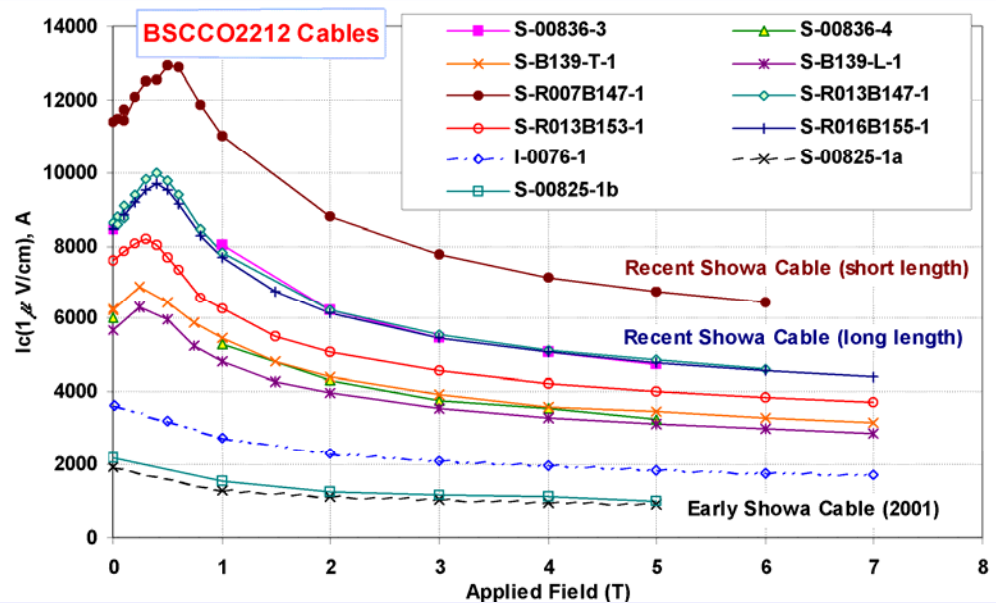


HTS Solenoid for an LDRD @ BNL

- A solenoid was needed to focus the electron beam after superconducting cavity.
- Permanent magnet and copper solenoid did not provide the required solution.
- Estimated temperature in the area was ~20 K. HTS solenoid provided a unique solution with about an order of magnitude current margin.
- Simple, inexpensive QA 77 K sub-system test.

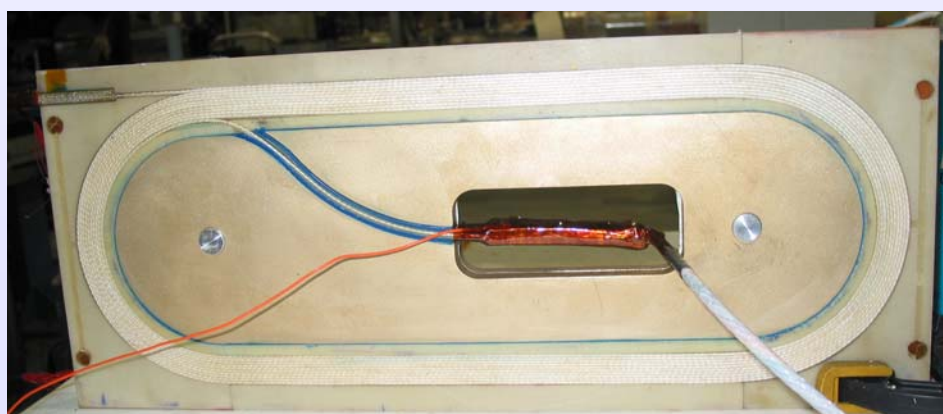


HTS for High Field Magnets with Rutherford Cable

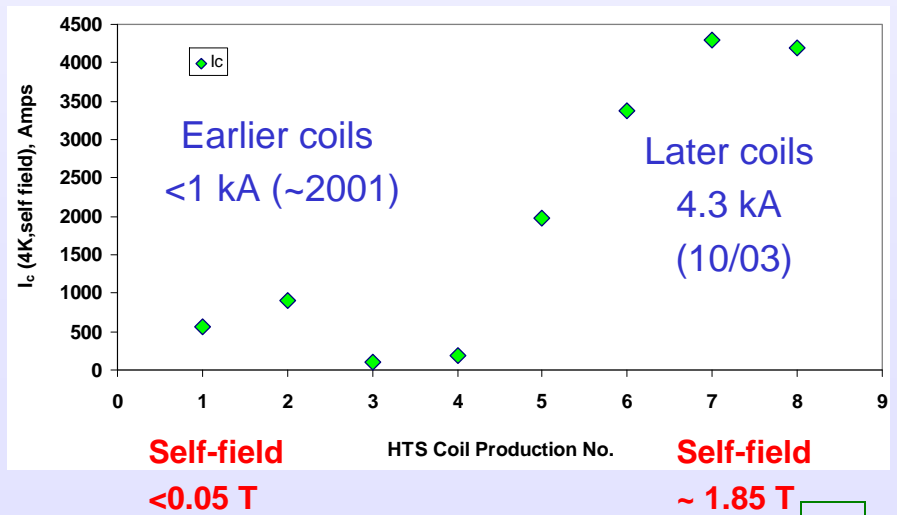


**HTS cables, coils & magnets
can carry a significant current.**

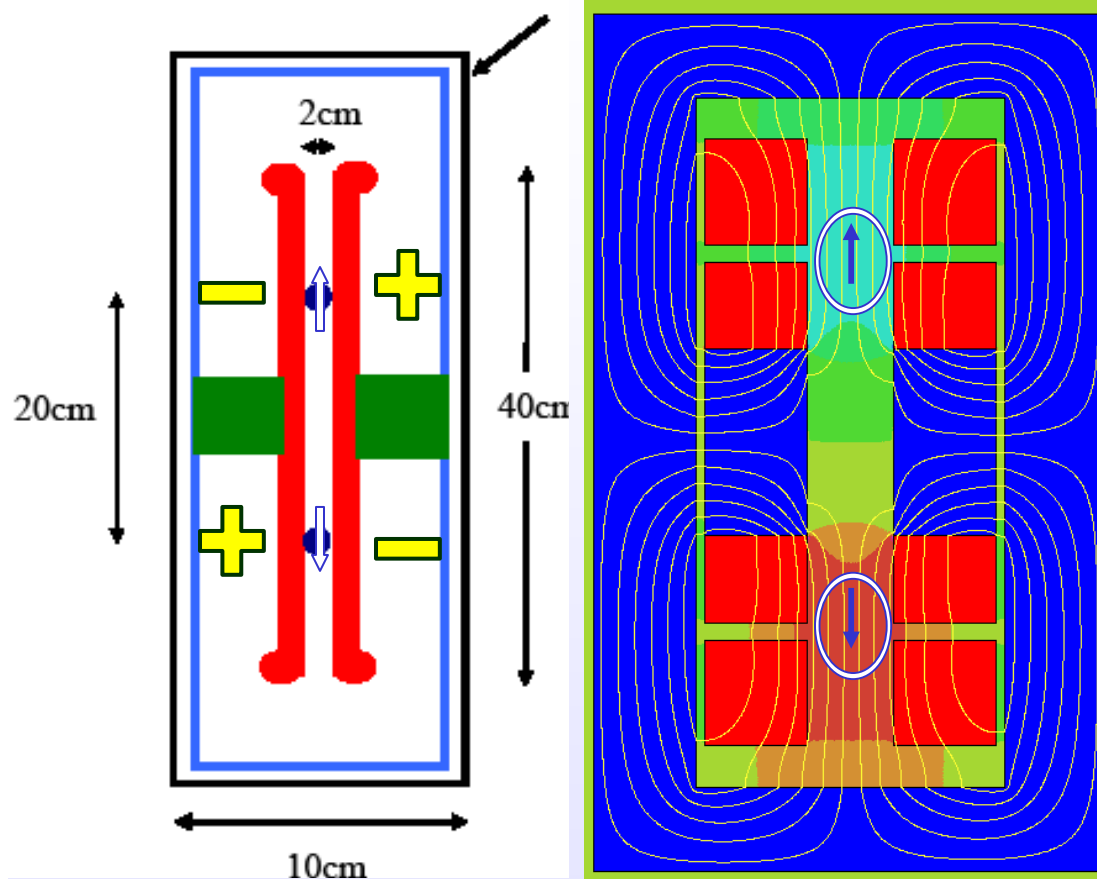
Cable made at LBL, reacted at Showa, tested at BNL



HTS coil wound & tested in a common coil magnet at BNL



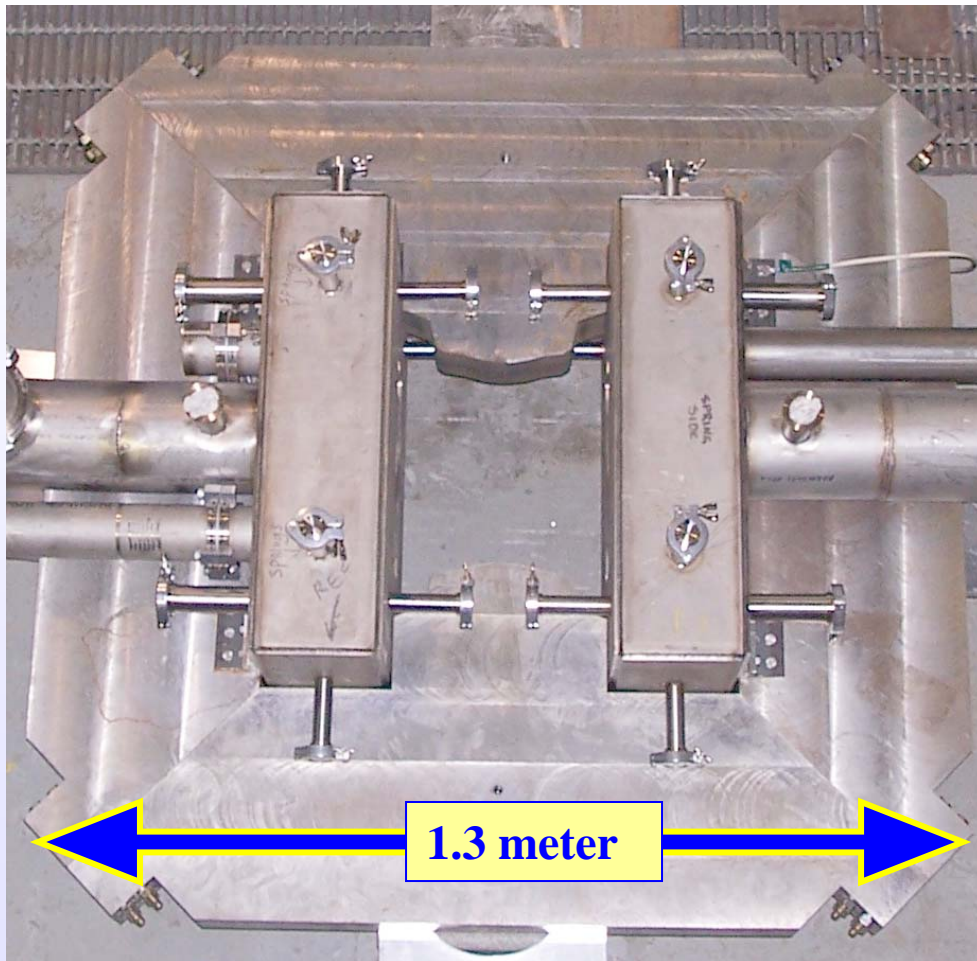
HTS Common Coil Design for the Proposed dEDM Experiment at AGS



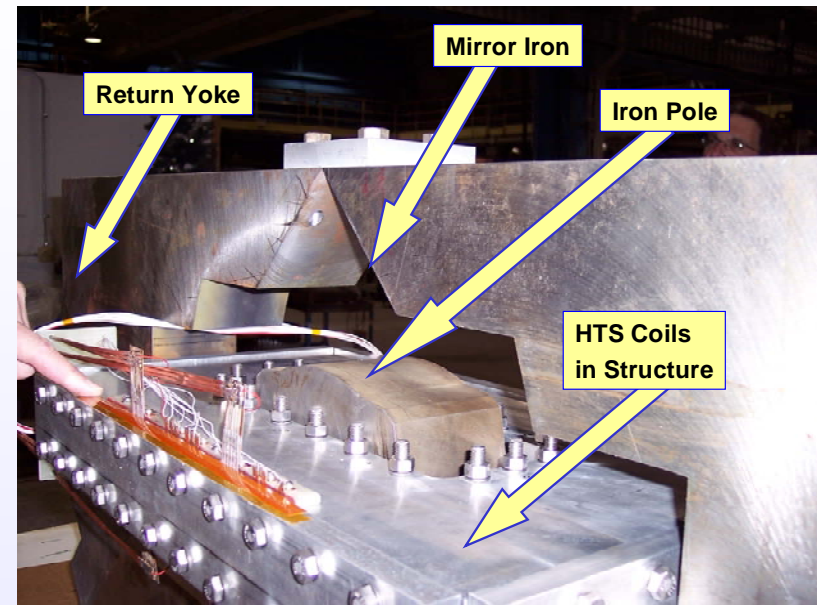
- A very high precision measurements of deuteron electric dipole moment can be made if electric field and magnetic field are coupled in certain way so that time dependent error cancel (Semertzidis, Morse, et. al).
- This happens naturally in common coil design.
- Field requirements are low (0.5 T) but power requirements are high as it is a large aperture conductor dominated design.
- HTS can save on power costs.

HTS Common coil design with **Bi2212 round wire** provides an ideal solution as bending is required in both hard and easy direction due to large saggitta.

RIA HTS Model Quadrupoles



Warm iron R&D quadrupole with twenty four coils in two cryostats



Cold iron mirror model



Warm iron mirror

HTS Coils for RIA/FRIB Magnet Models

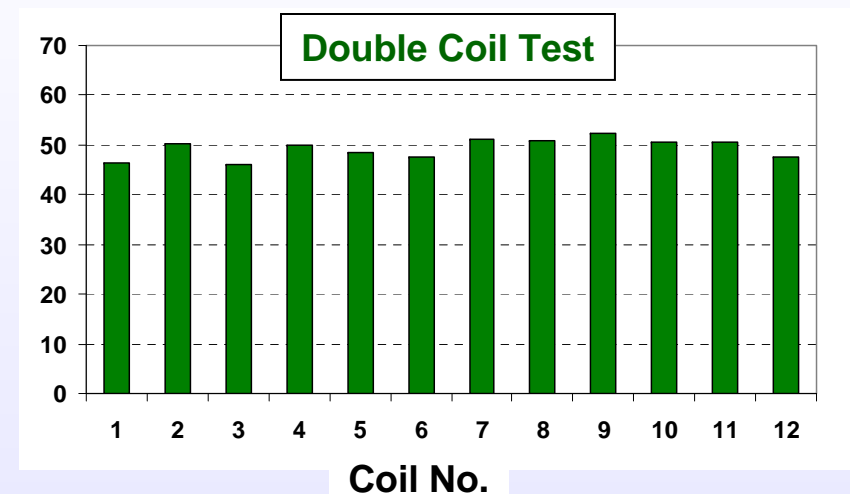
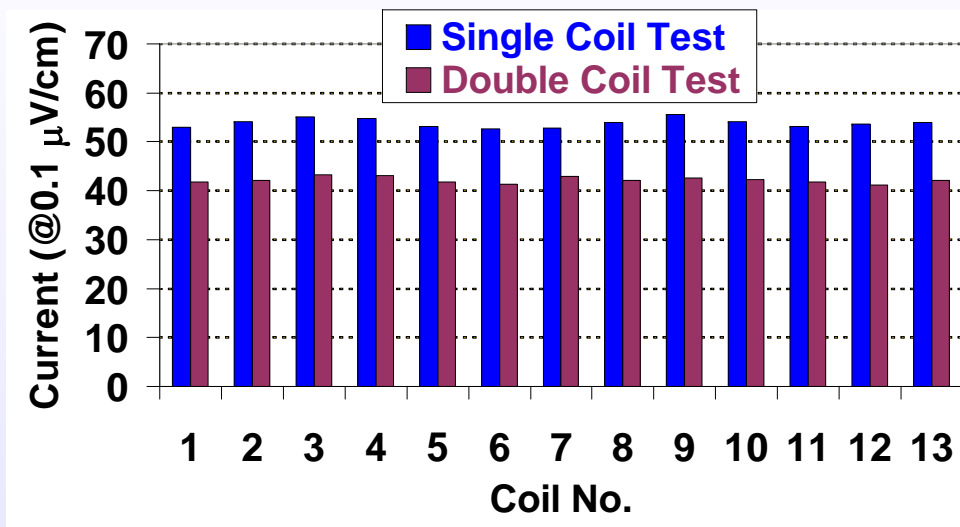


- RIA quad is made with 24 coils, each using ~200 meter of commercially available HTS.
- This gives a good opportunity to examine the reproducibility and reliability in performance of number of coils (number grows every year).

LN₂ (77 K) Test of 25 BSCCO 2223 Coils

13 Coils made earlier tape
(Nominal 175 turns with 220 meters)

12 Coils made with newer tape
(150 turns with 180 meters)

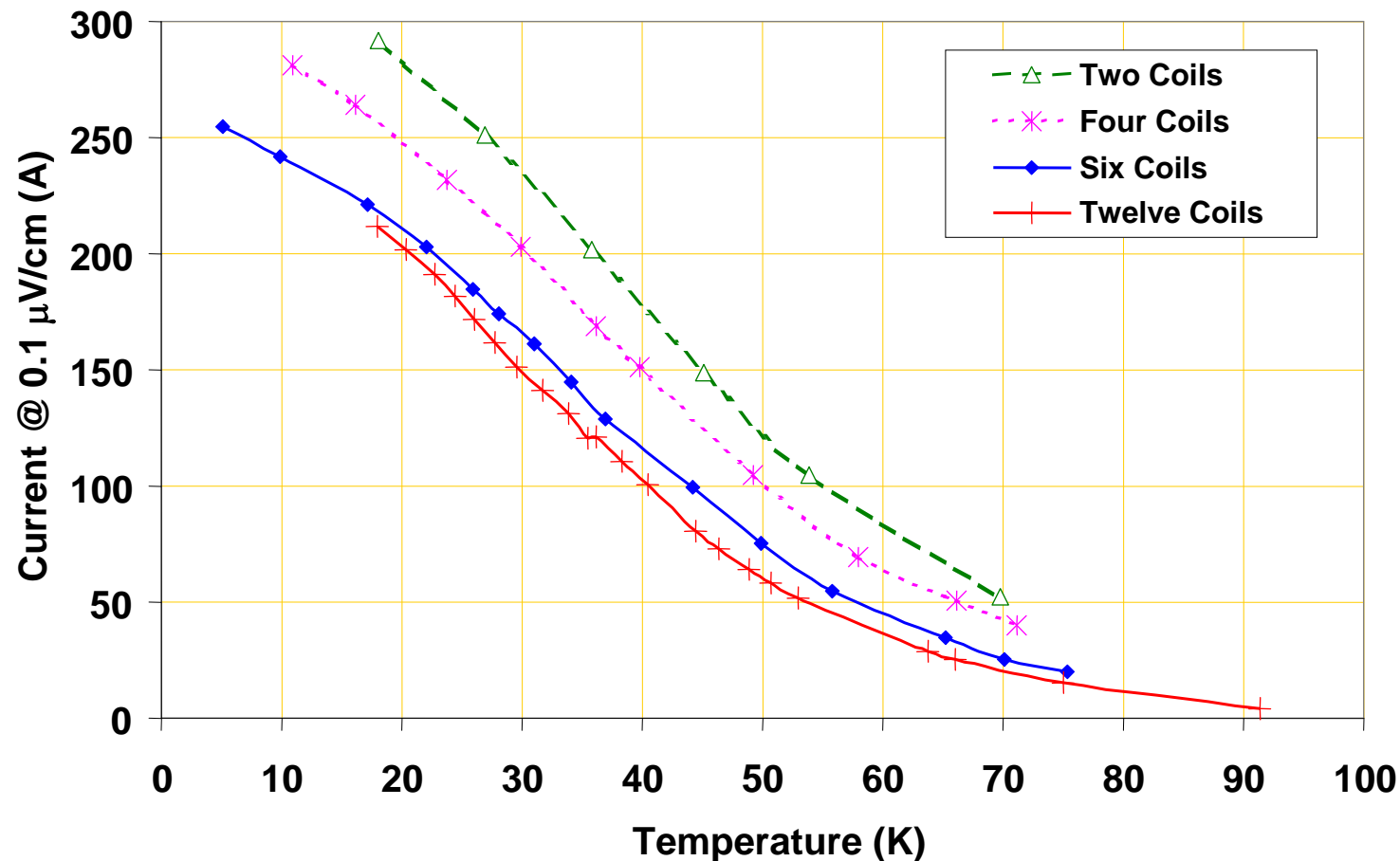


Coil performance generally tracked the conductor performance very well.

Note: A uniformity in performance of a large number of HTS coils made with commercially available superconductor (ASC).

It shows that the HTS technology is now maturing !

RIA HTS Mirror Model Test Results (operation over a large temperature range)

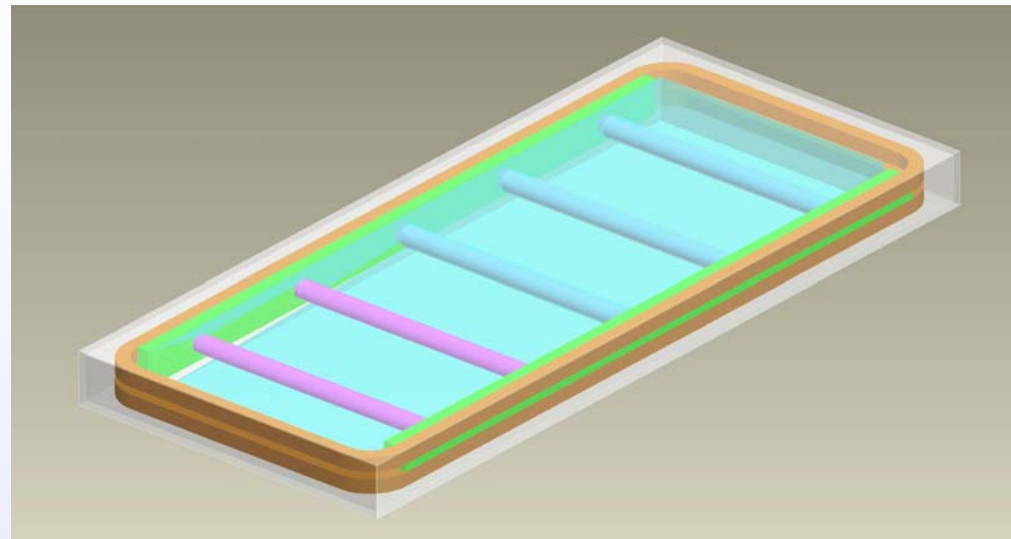
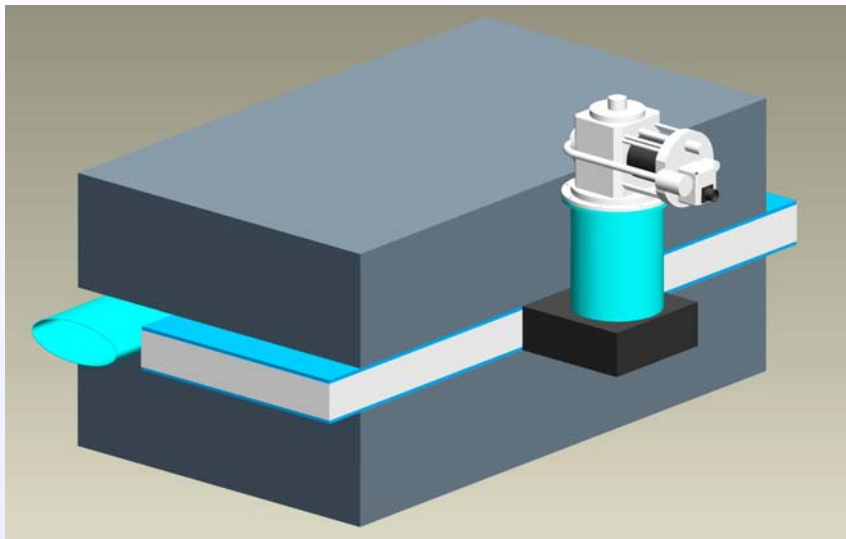


More coils create more field and hence would have lower current carrying capacity

A summary of the temperature dependence of the current in two, four, six and twelve coils in the magnetic mirror model. In each case voltage first appears on the coil that is closest to the pole tip. Magnetic field is approximately three times as great for six coils as it is for two coils.

Medium field (1.5 T-3 T) Energy Efficient HTS Magnets

HTS dipole conceptual design for Super-neutrino beam line magnet proposal



- **Successful construction and test of RIA R&D magnets makes us more positive for future medium field super-ferric HTS magnets.**
- **Consider the cost of ownership – capital cost of magnets plus operating cost for a number of years.**
- **With the cost of electricity increasing and the cost of second generation HTS decreasing, we may now have a good shot at arguing the case of energy efficient, cryo-cooled HTS magnets in 1.5 T to 3 T magnetic field range.**

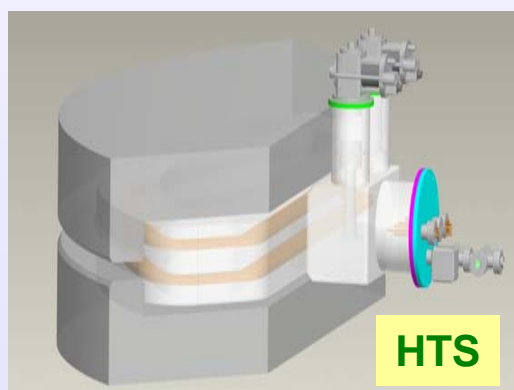
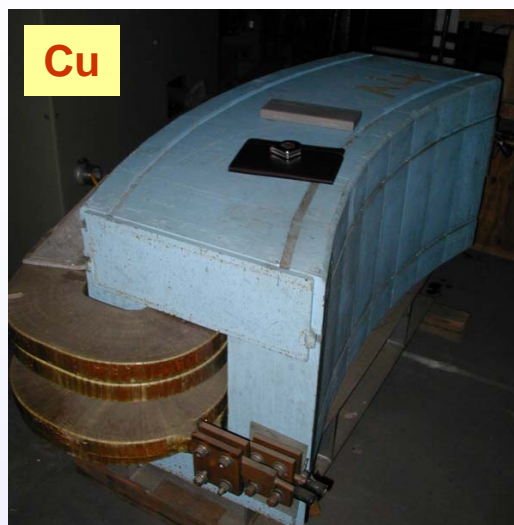
A Case Study for Cost Comparison of Copper and HTS Dipole for Neutrino Facility

Design Parameters:

- $B = 1.55 \text{ T}$
- $L = 3.73 \text{ m}$
- Pole width = 153 mm
- Pole gap = 76 mm

Copper Magnets:

- Better known costs (estimated : ~150k\$ each for this magnet)
- Cost of individual components like coil, yoke, etc., is well understood
- High operating costs (estimated ~3 MW total)
- Need low thermal conductivity water cooling plan
- Higher current (a few kA) power supply (higher cost)
- Maintenance issues (cost, downtime): water leak etc.



Desired cost of support structure and cryostat in this HTS magnet: < 20 K\$

HTS Magnets:

- Develop designs to reduce cost (goal : ~150k\$/magnet for equivalent integral field)
- Cost of HTS as per present price: ~35 k\$ (only ~1/4, lower in future)
- Need to include cost of other components like iron (low and well understood), support structure, cryostat (major driver unless better designs developed)
- Lower operating costs (wall power of cryo-cooler?)
- Cost of cryo-coolers (compare with infrastructure cost of Low Thermal Conductivity Power Plant)
- Lower current (a few hundred Amp) power supply (cheaper)
- Maintenance issues (cost, downtime): cryo-coolers

Summary and Outlook

- HTS magnets have been shown to be attractive in a number of research applications. It is already part of certain subsystem due to its higher performance and lower overall cost.
- RIA/FRIB R&D has demonstrated that HTS magnets can be designed, built and operated in high energy deposition and radiation environment.
- HTS is an enabling technology in niche applications such as high field magnets, magnets that must deal with large energy deposition, etc.
- However, a larger scale application may lie in the HTS super-ferric magnets for beam-lines, lower energy machines (such as **PS2** injector, neutrino factories and synchrotron radiation sources to save operating costs – electricity) and magnets for a number of medical applications.
- Second generation conductor should make HTS magnets much more attractive (higher J_e , lower cost and higher temperature operation).