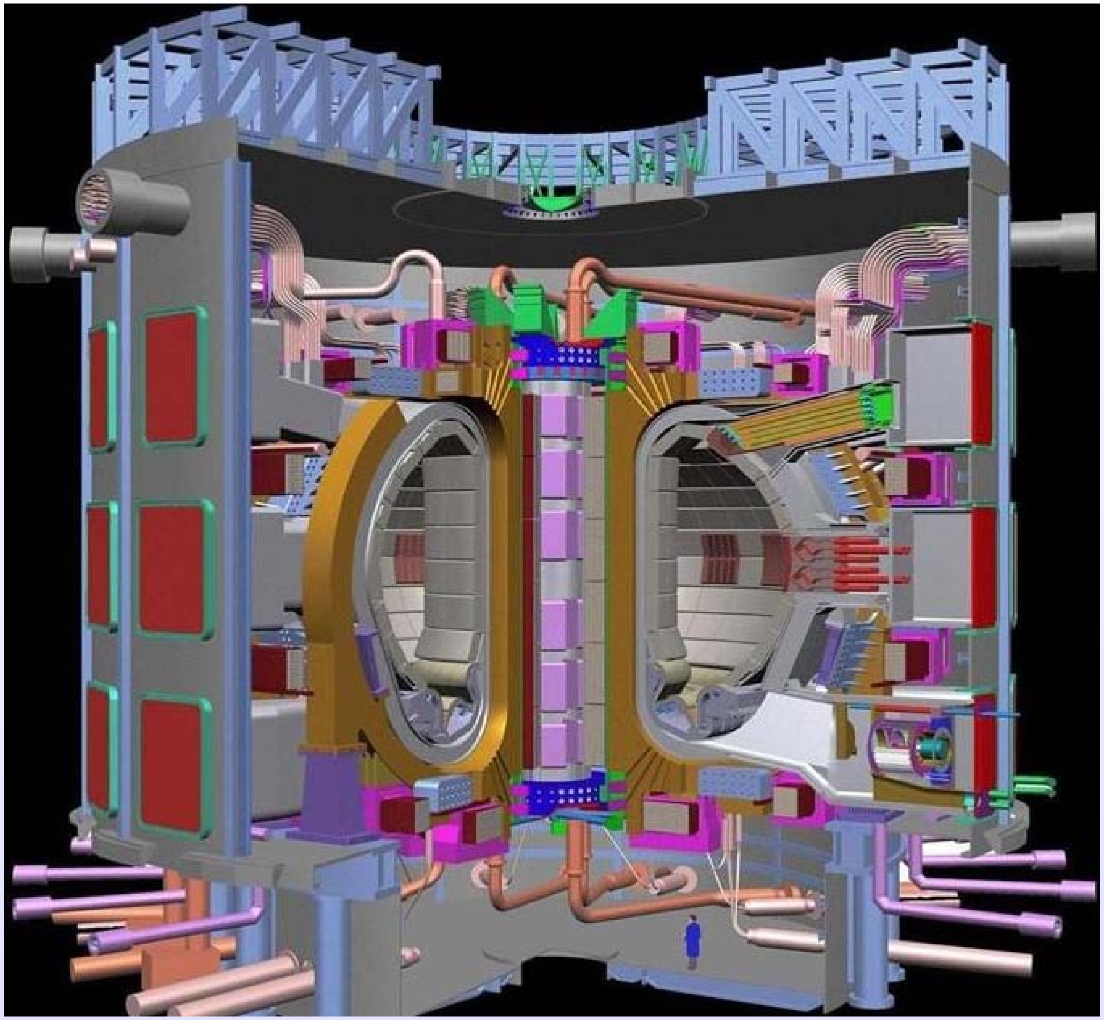
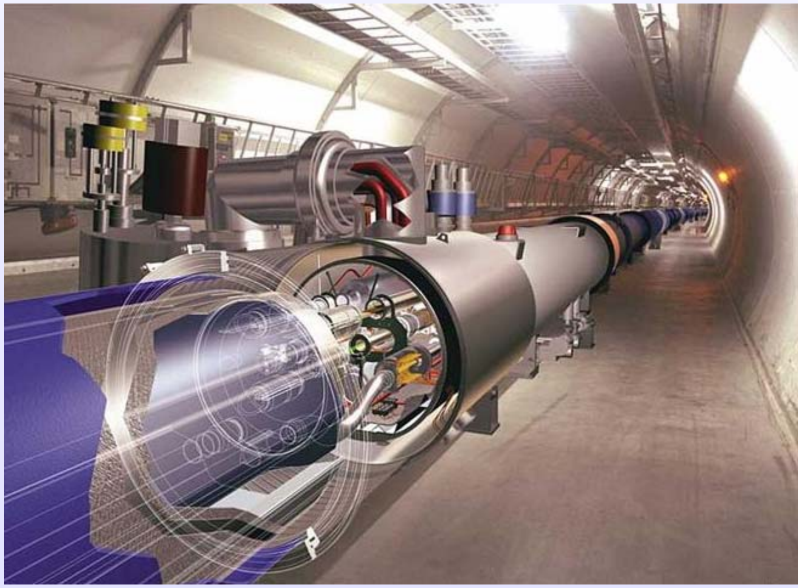


Radiation Studies for HTS Magnets

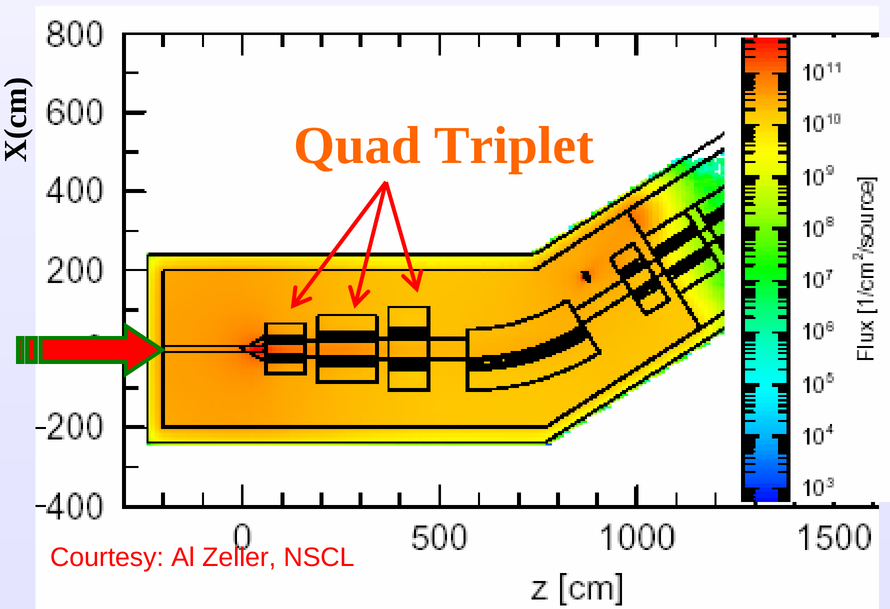
Ramesh Gupta
BNL

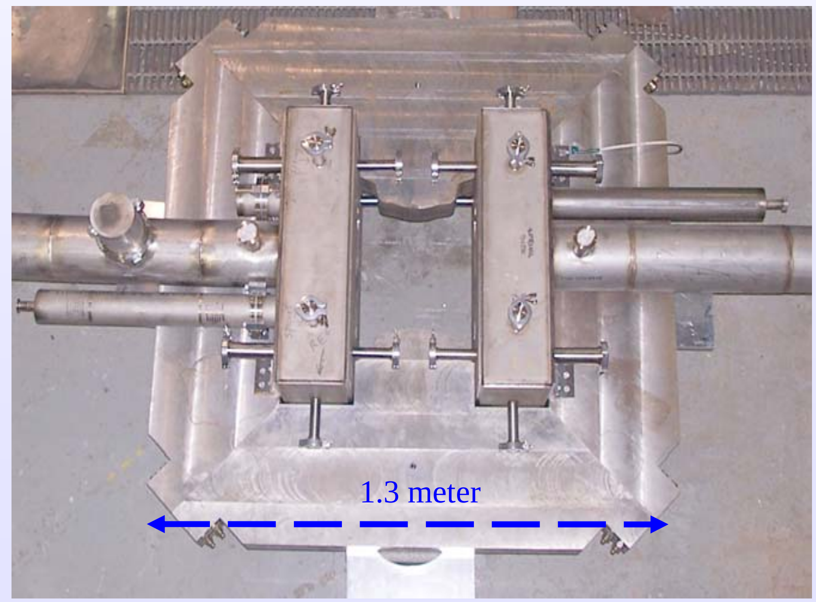


Motivation

- Radiation damaged studies are being carried for the proposed RIA (Rare Isotope Accelerator), now morphed to FRIB (Facility for Rare Isotope Beams).
- Critical quadrupoles in Fragment Separator region are exposed to unprecedented level of radiation (~20 MGy/year) and heat loads (~10 kW/m, 15 kW in first quad itself).
- **CLAIM:** HTS magnets can withstand and remove these radiation and heat loads economically.
- A comprehensive conductor and magnet R&D program was carried out to demonstrate above.
- The results of this successful program may have far reaching impact on many future proposals.

400 kW beam from LINAC (to Fragment Separator)

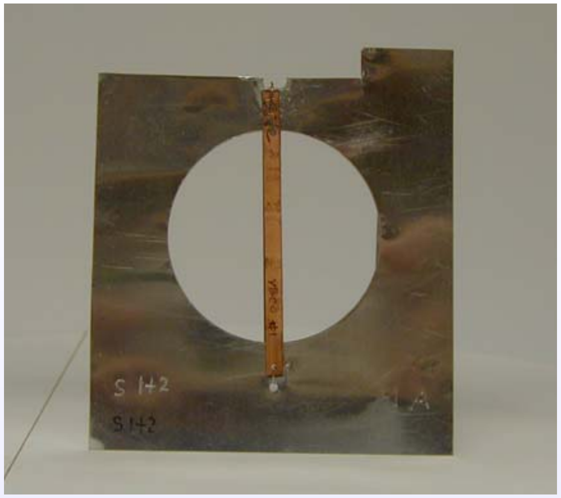


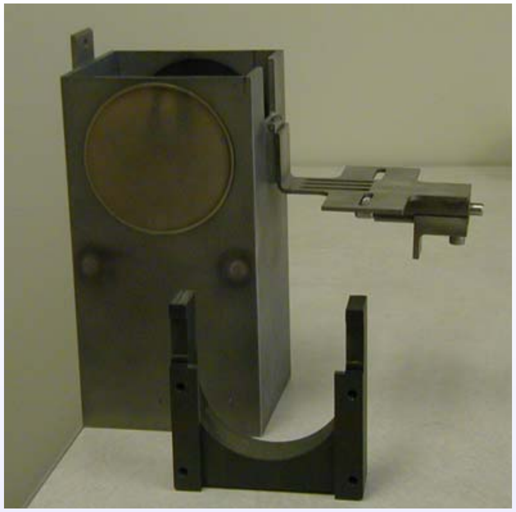


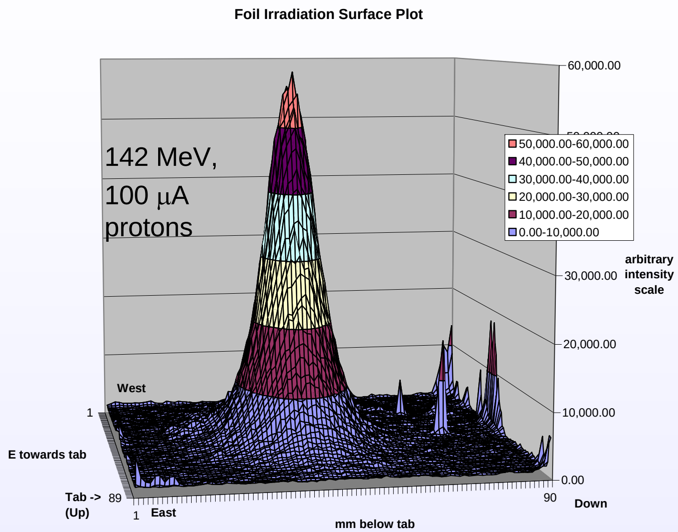
Radiation Damage Studies of HTS (YBCO, Bi2223 and Bi2212)

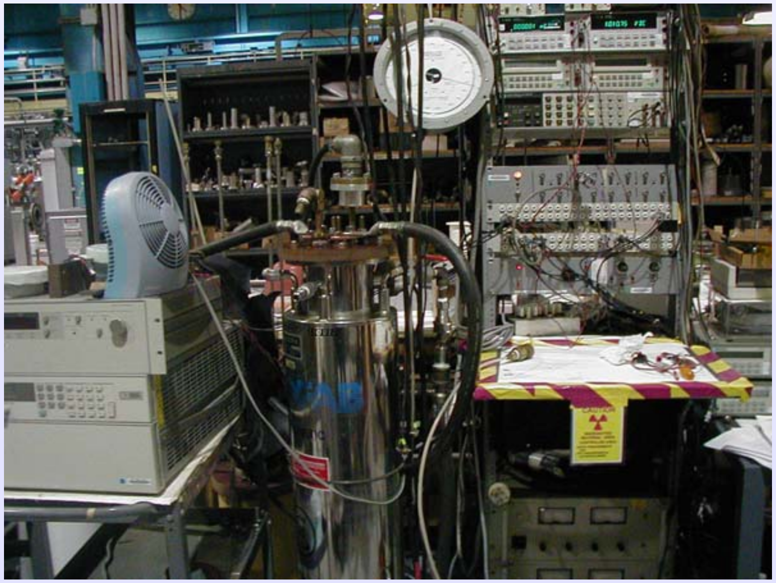
- BNL and NSCL (Zeller) are collaborating in radiation damage studies on HTS and on determining the impact of it in the performance of actual magnets.
- First set of radiation damage studies on Bi2223 was carried out by Al Zeller at LBL Cyclotron (paper published).
- More recent studies on YBCO, Bi2223 and Bi2212 are being carried out by George Greene and Bill Sampson at BLIP.
- Test results and analysis of radiation damage on YBCO will be briefly presented. YBCO samples were provided by SuperPower and American Superconductor Corporation.

Key Steps of Radiation Damage Experiment (Courtesy George Greene and Bill Sampson)









Radiation Damage Studies at BLIP

Figure 2. The BLIP facility.

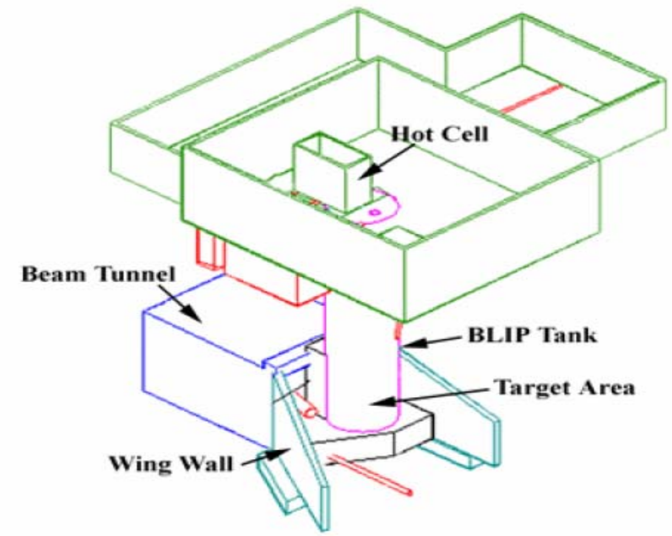


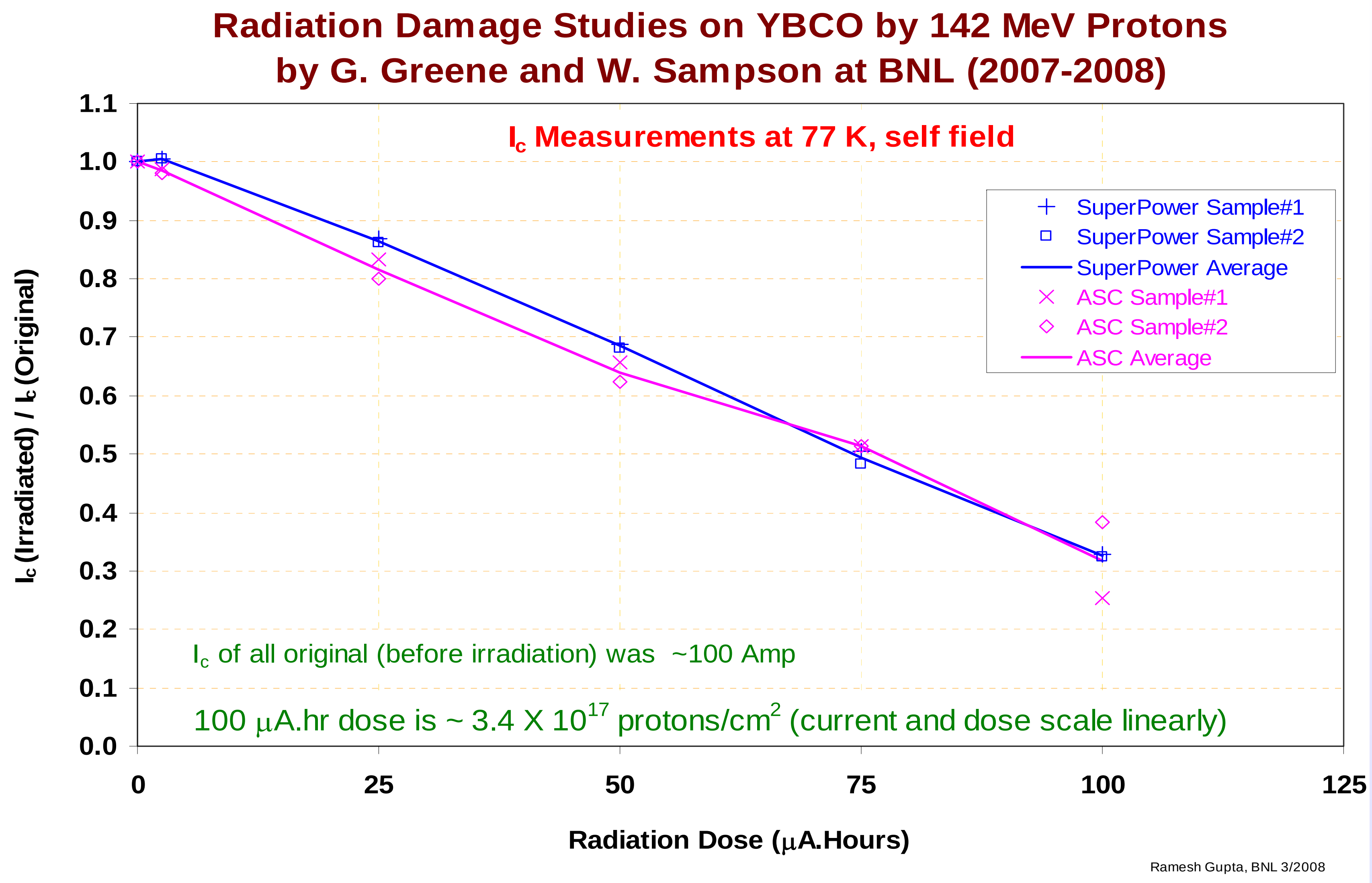
Figure 3. BLIP Beam Tunnel and Target Schematic

From a BNL Report (11/14/01)

The Brookhaven Linac Isotope Producer (BLIP) consists of a linear accelerator, beam line and target area to deliver protons up to 200 MeV energy and 145 µA intensity for isotope production. It generally operates parasitically with the BNL high energy and nuclear physics programs.

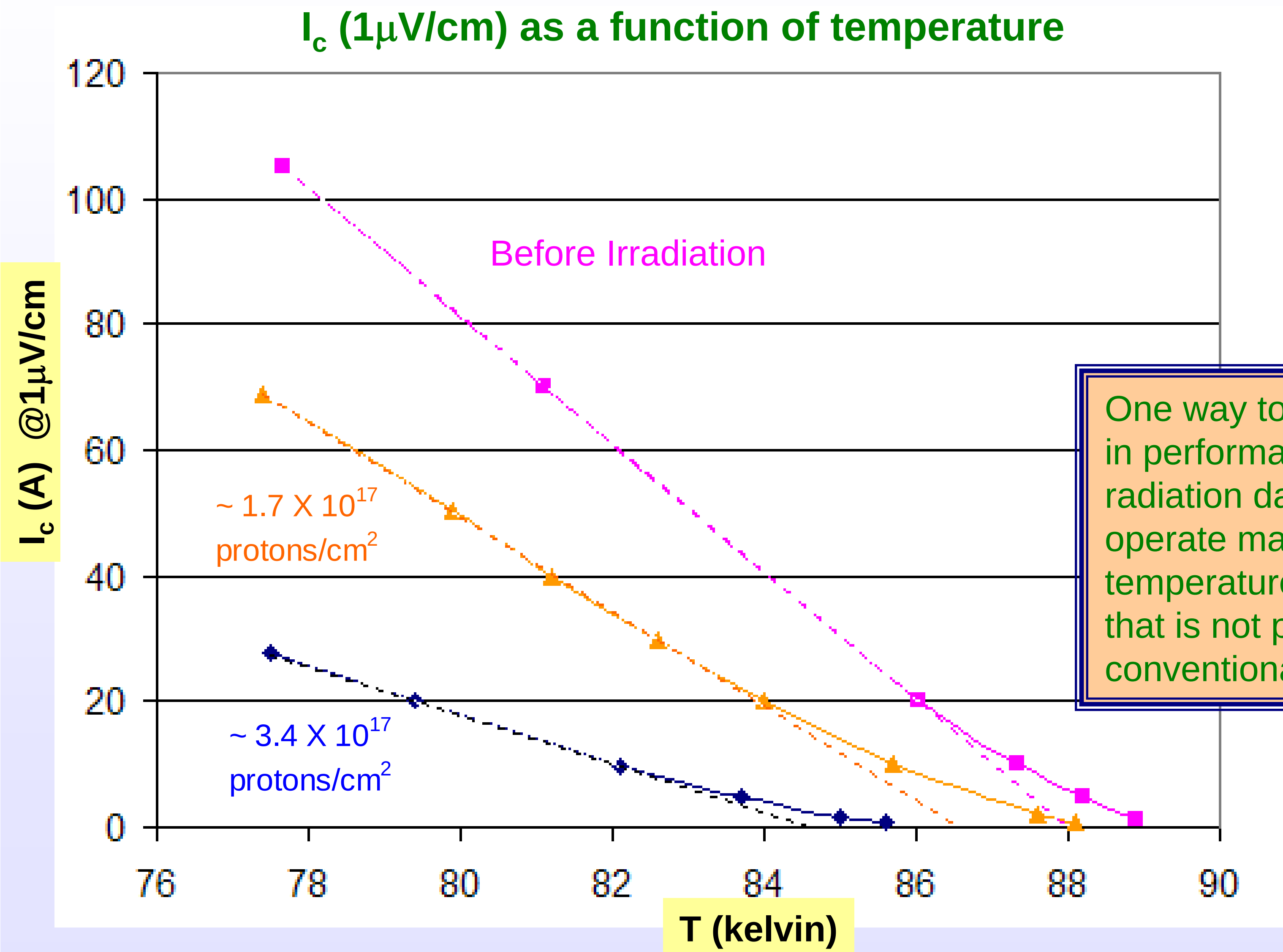
Superconducting
Magnet Division

Change in Critical Current (I_c) of YBCO Due to a Large Irradiation



Brookhaven National Laboratory
Superconducting Magnet Division

Change in Critical Temperature (T_c) of YBCO Due to a Large Irradiation



Note:
Radiation damage has impact on T_c, in addition to that on I_c.

One way to recover the loss in performance due to radiation damage is to operate magnet at a lower temperature – something that is not possible in conventional LTS magnets.

Results will be formally presented at ASC2008.

Impact of Irradiation on Magnet

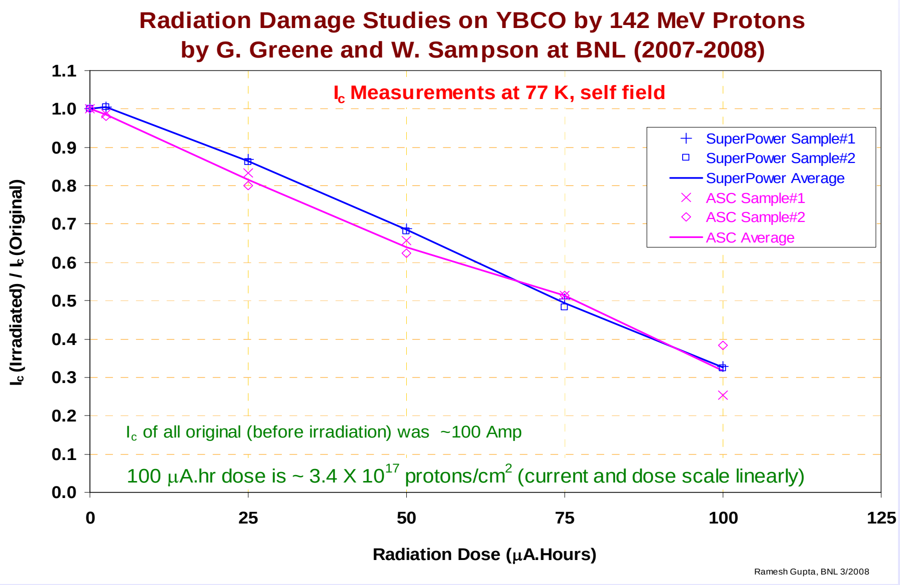
- The maximum dose was 3.4 X 10^{17} proton per sec 100 μA.hr.
- As per Al Zeller, displacement per atom (dpa) per proton is ~9.6 X 10^{-20}.

This gives ~0.033 dpa at 100 μA.hr.

Bottom line:

- **I_c performance of YBCO will drop ~10% after 30 years operation.**
- **This is pretty acceptable !!!**

- **It appears that YBCO is at least as much radiation tolerant as Nb_3Sn is (Al Zeller).**



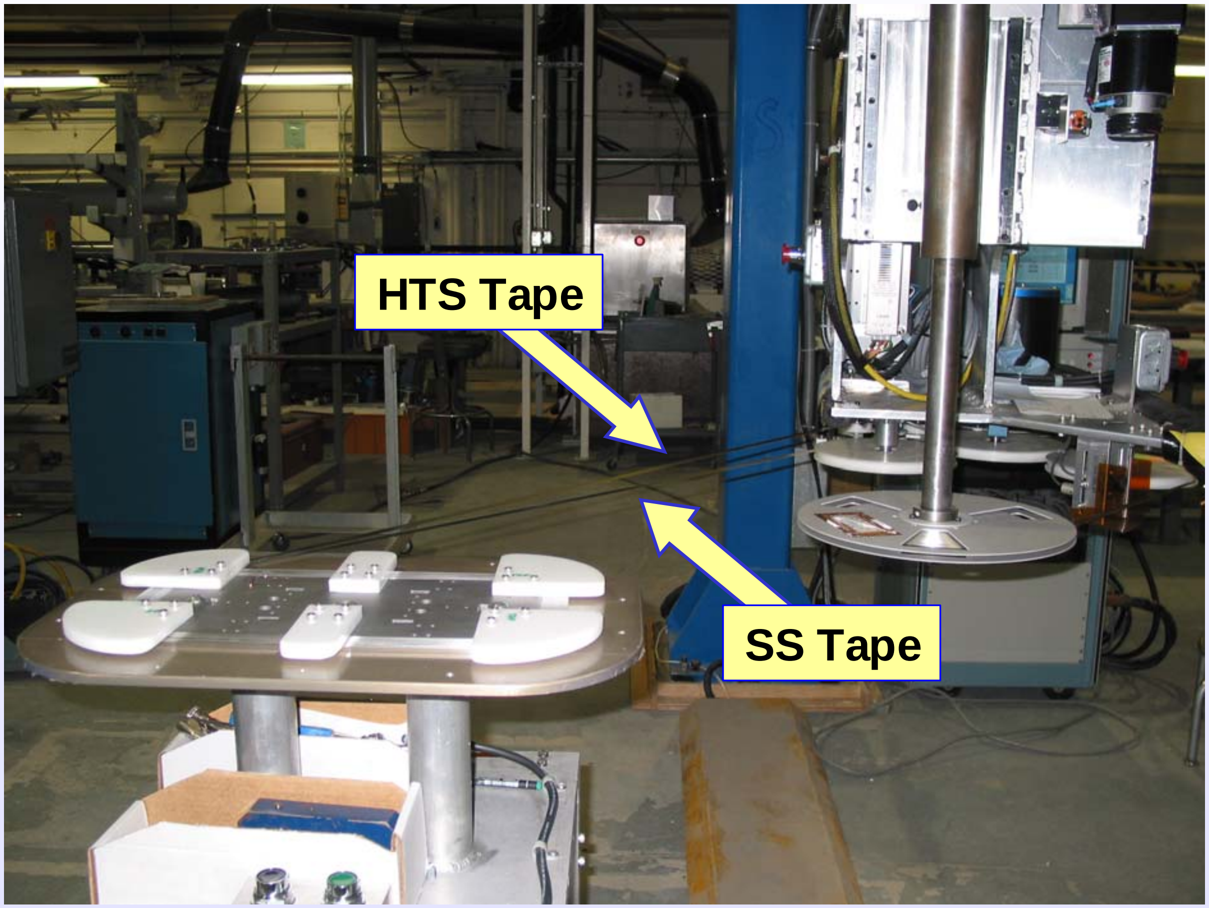
Caveat:

Above is based on 77 K, no applied field.

To be completely sure, examine it at 50 K and 3 T (or whatever the operating parameters may be).

Stainless Steel Insulation in HTS Coils

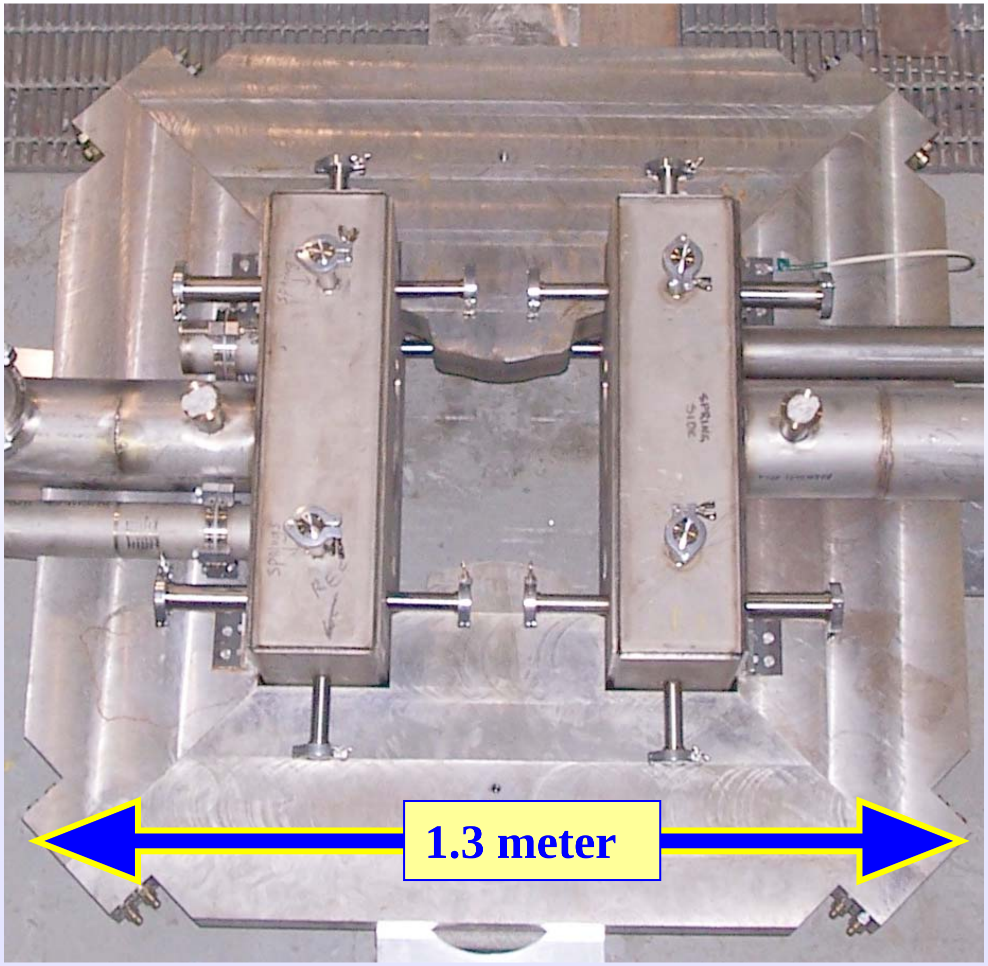
Radiation damage to insulation is another major issue for magnets in high radiation area.



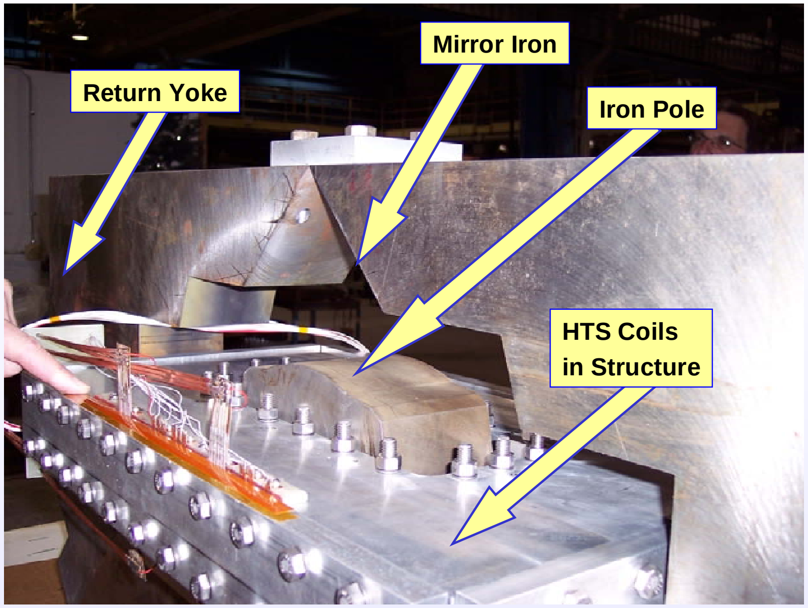
RIA/FRIB coil being wound with HTS and stainless steel

- In FRIB/RIA magnets SS tape, rather than the kapton tape, is used as insulator.
- Relatively to superconductor, stainless steel is a good insulator.
- The major advantage of stainless steel is that being metal, it is highly radiation resistant.

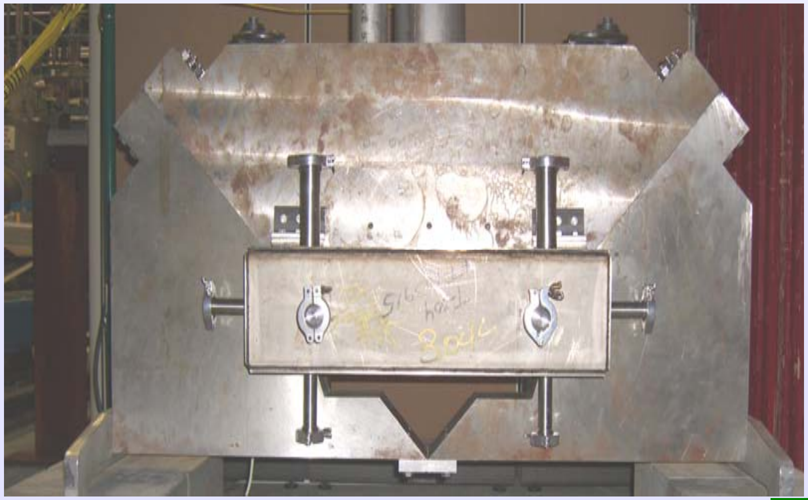
RIA/FRIB HTS Quad Models for High Radiation, High Energy Deposition (~15 kW) Magnets



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



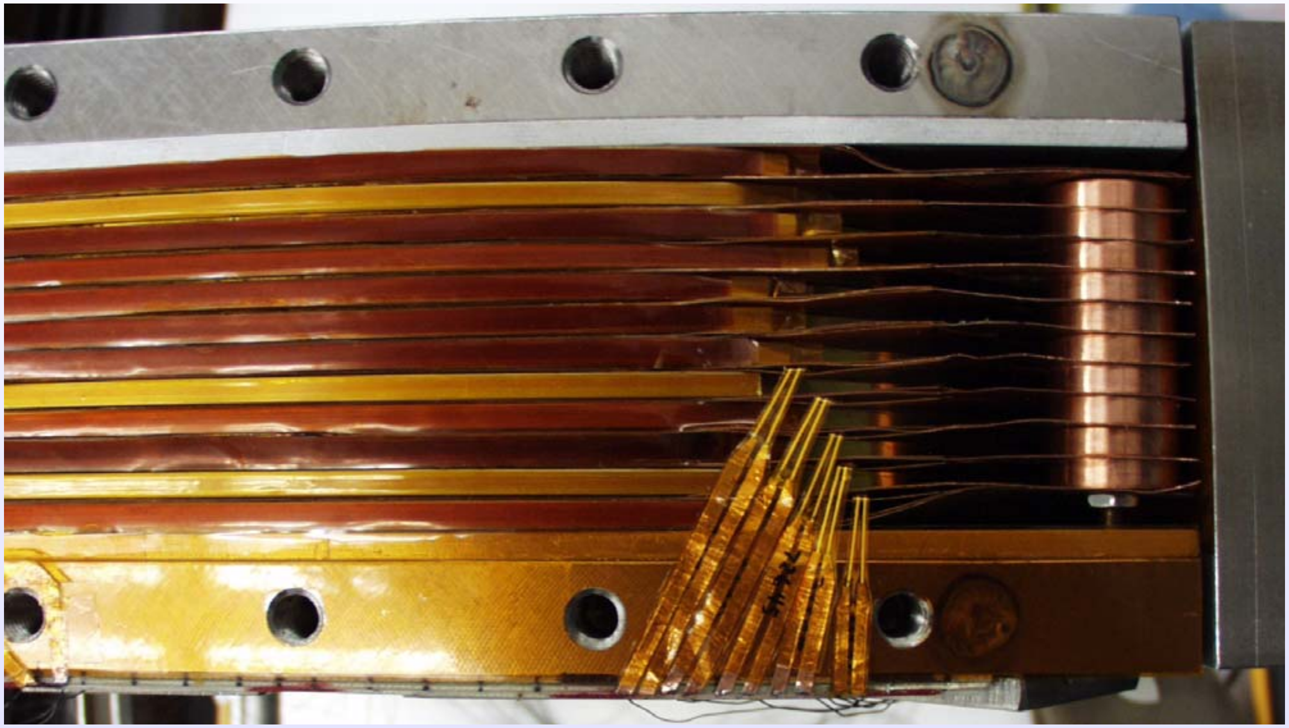
Cold iron mirror model



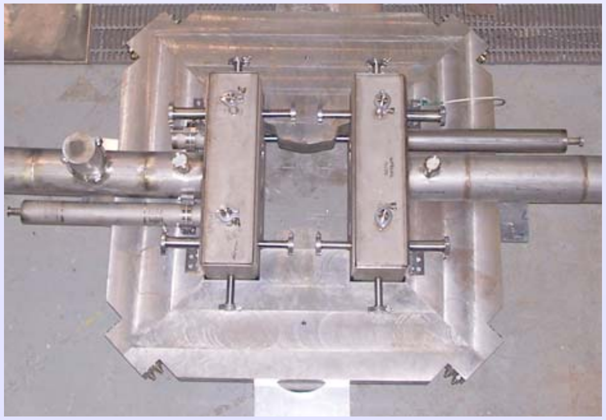
Warm iron mirror

Setup for Energy Deposition Experiments

Tests must demonstrate an stable operation of HTS magnet at 30 Kelvin with a huge 25 W ($5mW/cm^3$ or $5kW/m^3$) heat load on coils.



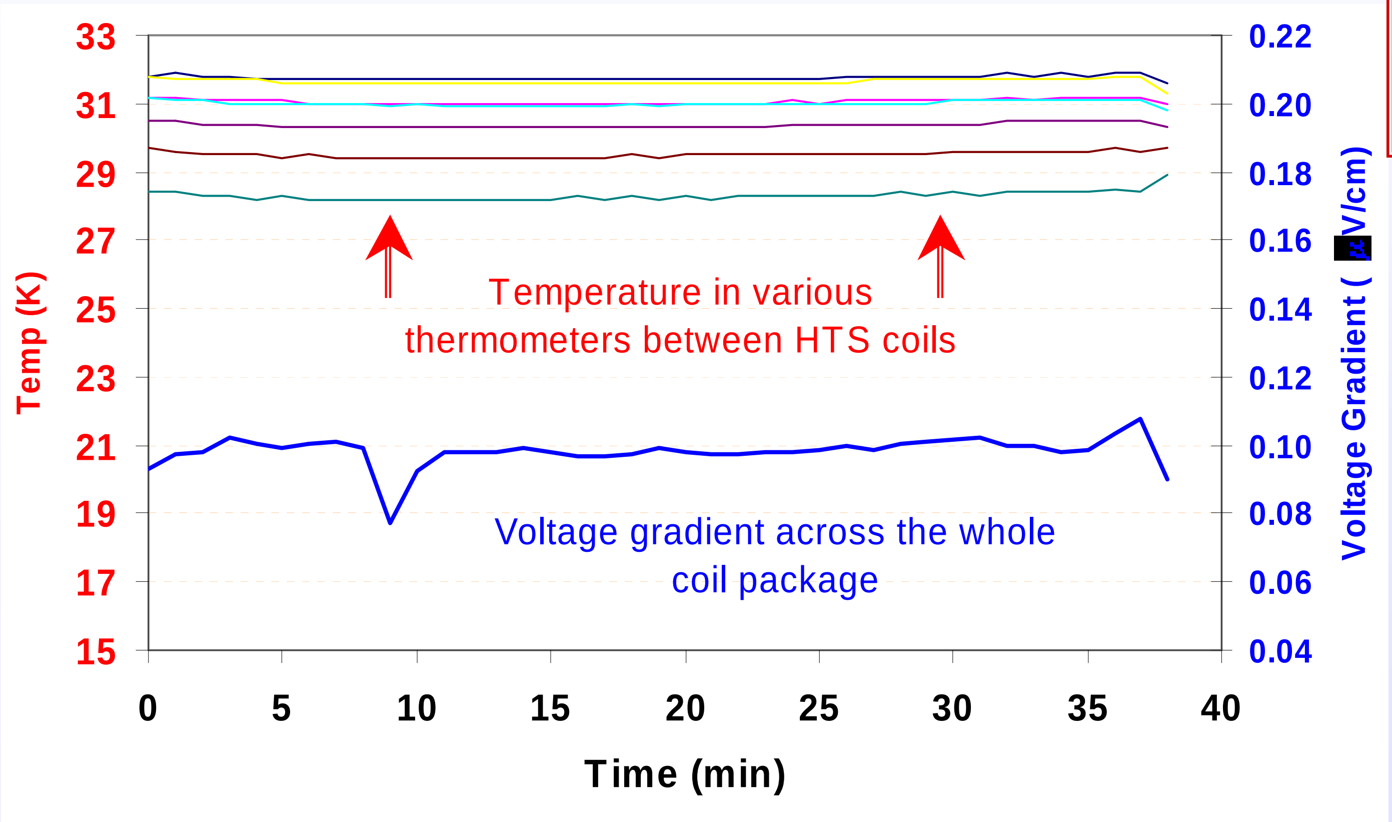
Stainless steel tape heaters between coils for energy deposition experiments



Copper sheets, etc. between HTS coils for other conduction cooling experiments

Simulated Energy Deposition Experiment at the Operating Condition (Environment)

Goal is to demonstrate that the magnet can operate in a stable fashion at the expected heat loads (5mW/cm^3 or 5kW/m^3 or 25 W on 12 short HTS coils) at the design temperature (~30 K) with some margin on current (@140 A, design current is 125 A).



Voltage spikes are related to the noise

Stable operation for ~40 minutes

- **We use 0.1 μV/cm as the definition of I_c.**
- **Temperature differences may be partly real and partly calibration mis-match.**
- **As such HTS can tolerate such temp variations with small margin.**

SUMMARY

• Useful, systematic, high dose, radiation damage experiments have been performed at BLIP. The setup is available for other future studies.

• Based on 77 K, zero field measurements, it has been demonstrated that HTS can survive high radiation doses as present in FRIB (or RIA).

• It has been also been shown that HTS can remove very high heat loads at elevated temperature and can operate in an stable fashion.

• Surprisingly, it was also found that in this application, the proposed HTS magnet option was cheaper (Zeller, PAC'05) than the radiation resistant water-cooled copper design (which was giving a lower performance).