# Brookhaven Magnet Division - Nuclear Physics Program Support Activities

Spin Program support - AGS Cold Siberian Snake

RHIC Operations Support

E-Cooling R&D

RIA R&D

Future plans

Non - NP work

Summary

# AGS Cold Siberian Snake

- The AGS Cold Snake was the major RHIC program element during FY05
  - Augment the existing partial snake with a more powerful one. Polarisation 50% -> 70%
  - Issues

    Complex geometry (variable pitch helix)

    Complex correction coils

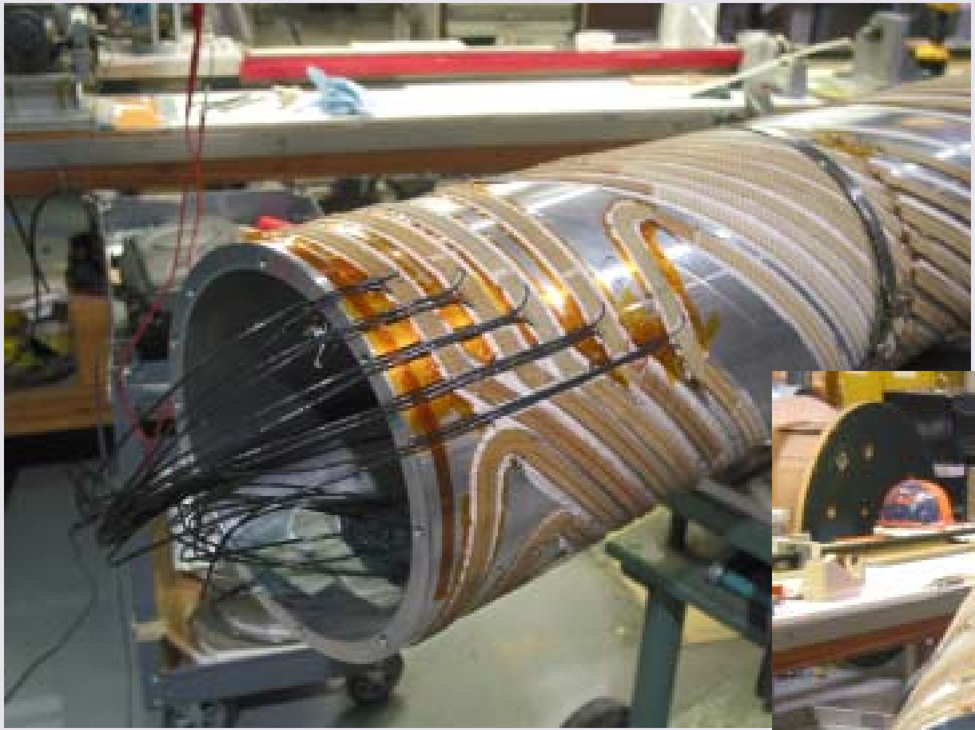
    Large aperture, high field (20cm, 3T)

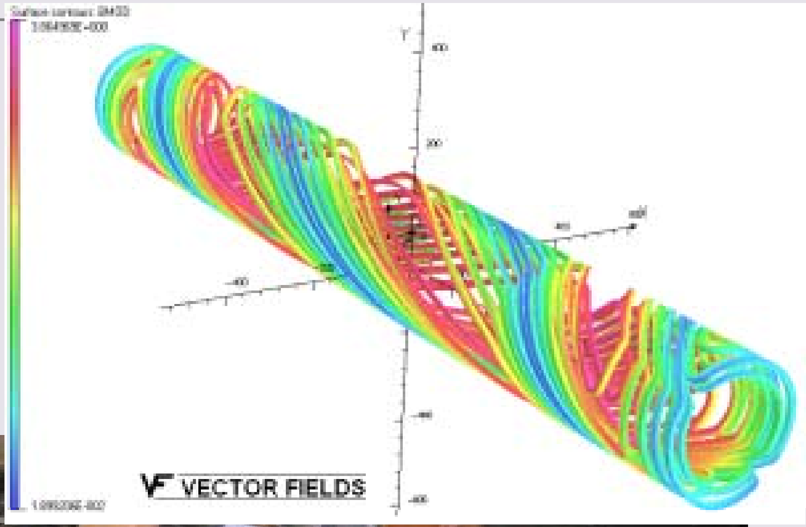
    No cryogenic infrastructure - low heat leak, cryo-coolers
      - Cooldown -helium back-up from remote dewar
      - Cooling from cryo-coolers for DC operation, 2W heat load max

    AGS beam loss induced quenching
      - energy removal

# AGS Snake - Coil Geometry



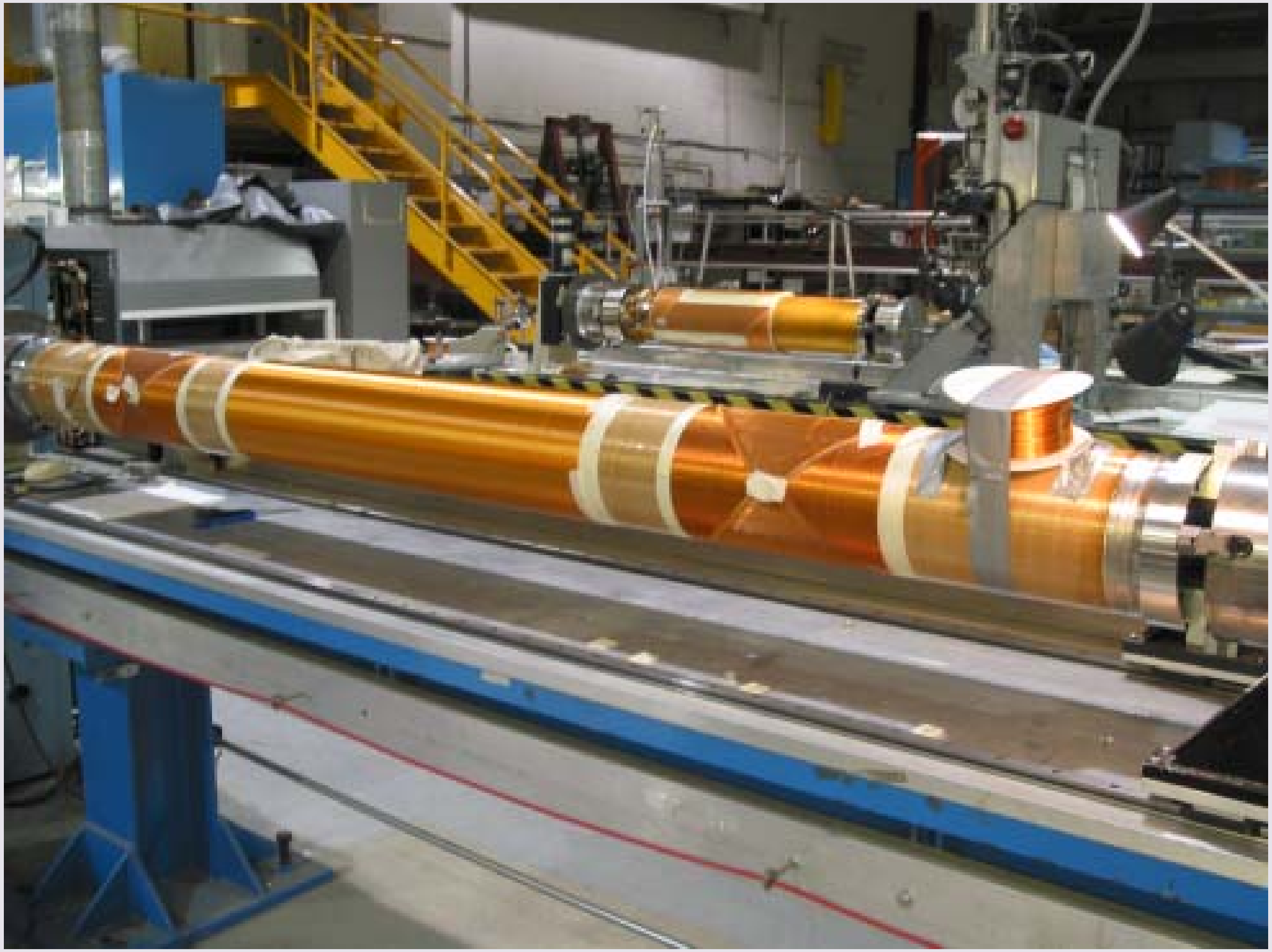





Inner and outer coils

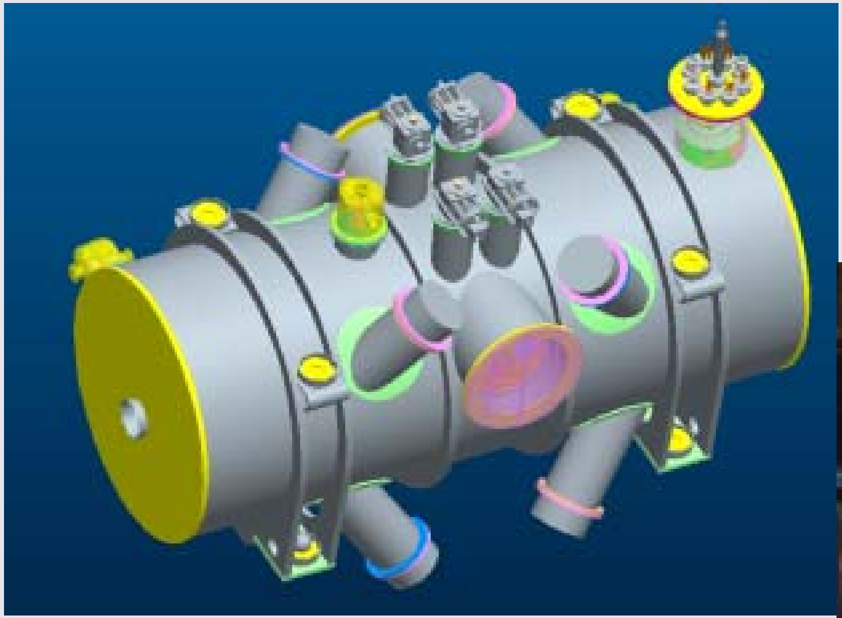
# AGS Snake Bore Tube Correctors





Bore tube wound corrections elements: H&V dipoles + solenoid

# AGS Cold Snake Production

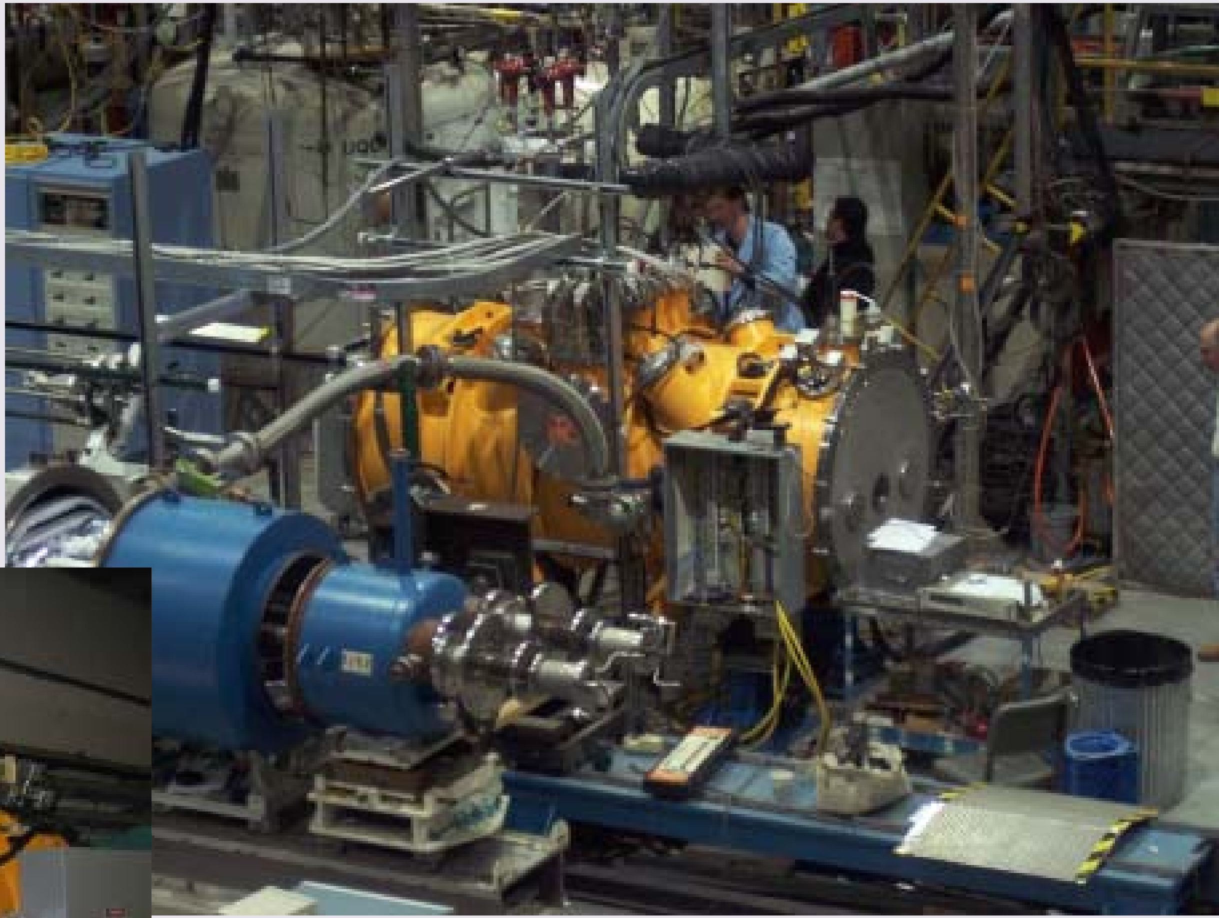


Cold Snake cryostat on the production floor

# AGS Cold Snake Production



In the AGS tunnel - delivered in March 05



Preparing for cold testing

# RHIC Magnet Systems Scope

A large superconducting inventory of magnets:

- ~ 300 8cm dipoles
- ~ 400 8cm quadrupole/sextupole/corrector units
- 96 13cm IR quadrupoles
- 24 10cm IR dipoles
- 12 18cm IR dipoles
- 12 siberian snakes/spin rotators (48 helical dipole units)

# RHIC Magnet Repair

To date we have experienced failures in:

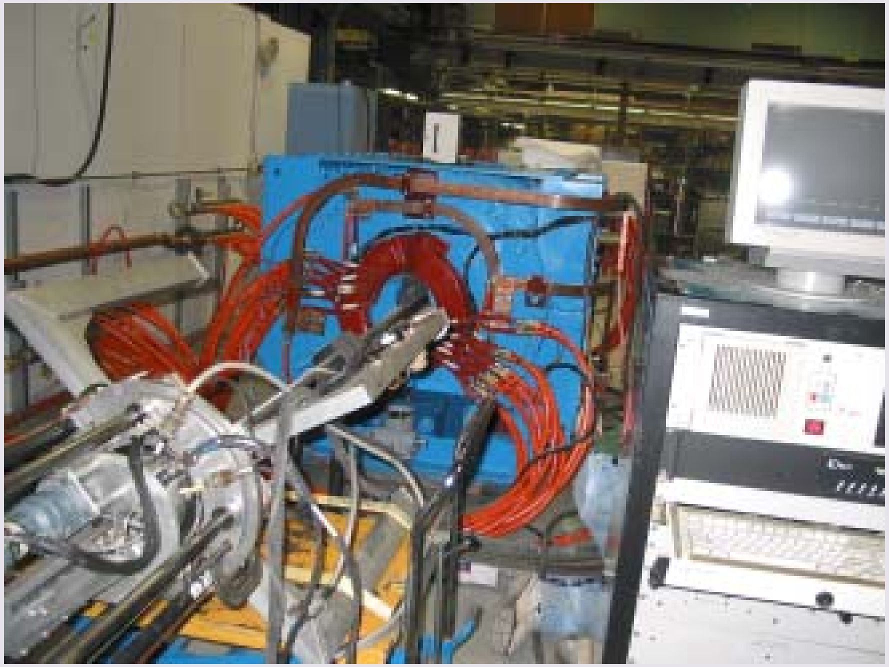
- A RHIC helical dipole cold mass
  - A great deal of testing time in the magnet division was expended to track down the root cause of this failure. We suspected the quench detection algorithm was incorrect. Tests proved inconclusive, changes to the quench detection were made none the less
- A CQS correction element package
  - A dipole layer
- A trim quadrupole in a CQS unit (in progress)
  - The problem is believed to be the wiring card

Less than 1 failure per run

# RHIC Program Support



- Quench protection/magnet power supply system integration and fault diagnosis
- Quench protection system development
- AGS rapid cycling field measurements
- General magnetic measurements
- Shutdown manpower



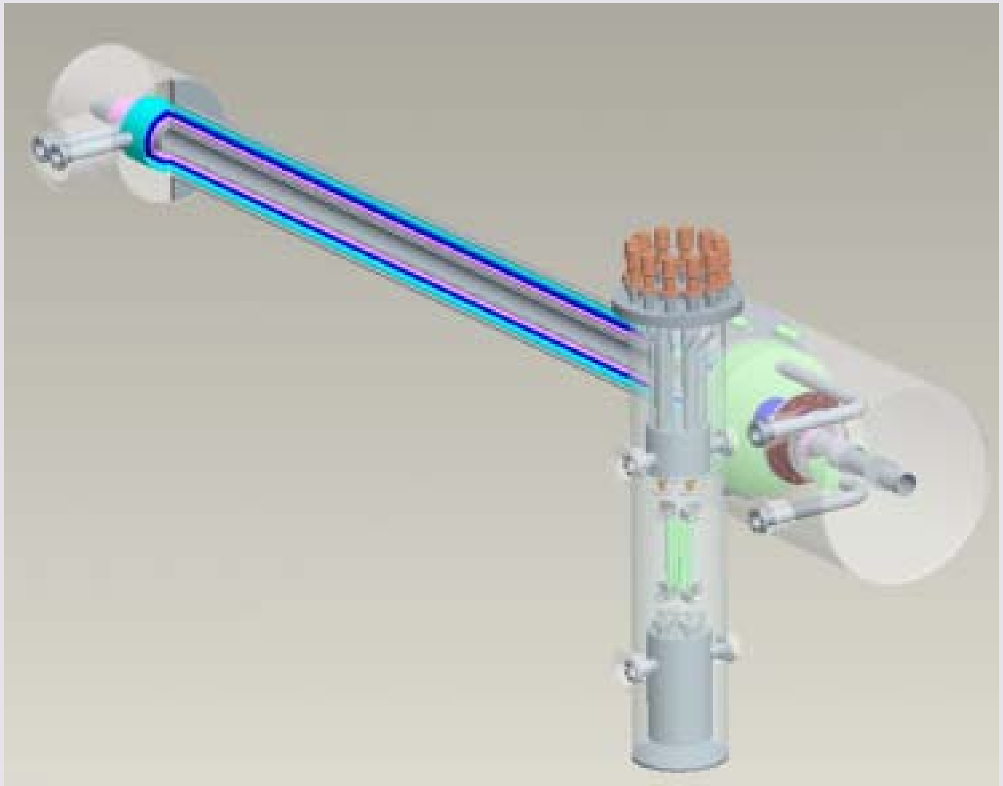
# RHIC II e-Cooling R&D: Solenoid development

## Solenoid Requirements

- $B_t / B_{axial} < 10^{-5}$
  - on-axis $\Rightarrow$ straightness
  - How about off-axis? At least ~5 mm radius zone is needed just to make measurements.
- Up to 30-meter total length (in two or more sections)
- 100 mm coil ID (gives approx. 89 mm cold bore diameter; warm bore needed?)
- Exact field requirements not specified yet but solenoidal field will lie in the range of 2T -> 5T

# E-Cooling Conceptual design





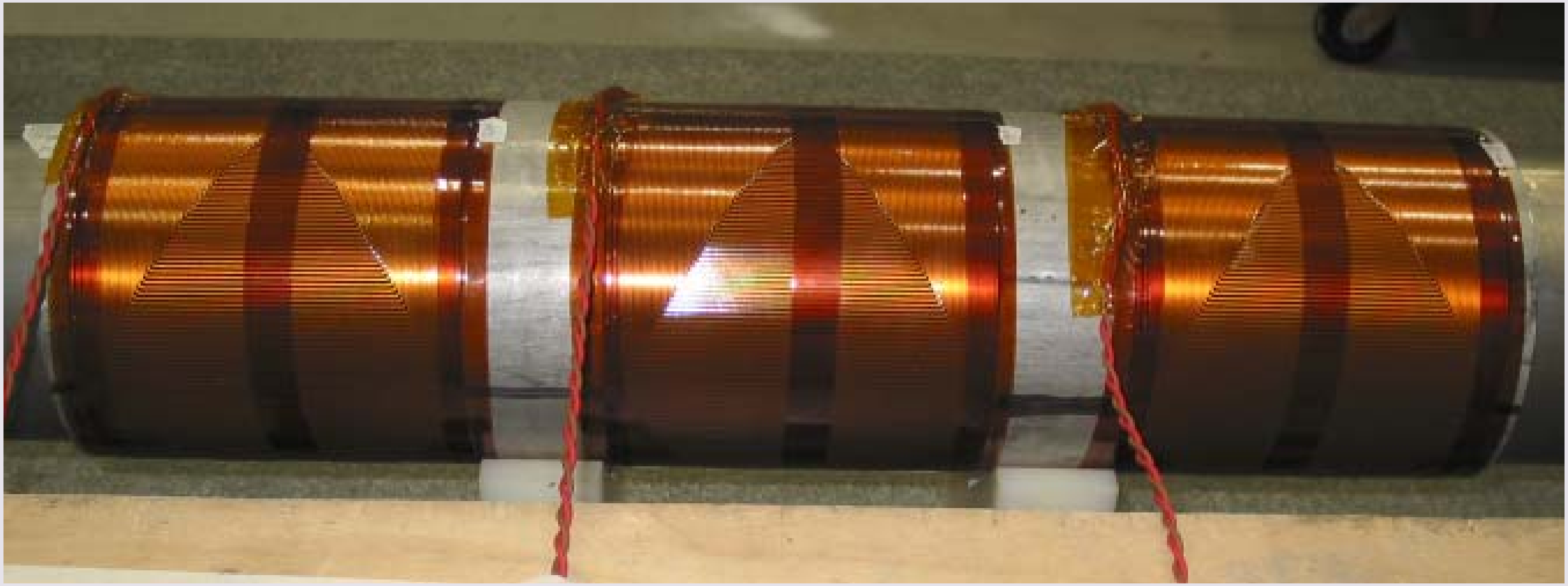
The magnetic ends are not finalized yet but a basic concept exists. The gap between sections is also under analysis

# Achieving the field quality specifications

- $B_\perp / B_z \sim 10^{-5}$ implies a straightness of 10 μm over 1 meter length. This may not be achieved with mechanical alignment alone.
- Winding imperfections are also likely to produce transverse fields on-axis.
- Goal is to achieve as close to $1\times10^{-5}$ as possible with construction tolerances and mechanical adjustment (expect ~ a few $\times 10^{-4}$)
- Correct the remaining errors with an array of ~ 150 mm long, printed circuit dipole correctors.
- **Two sets of correctors *per axis* are required.**

# Printed Circuit Dipole Correctors





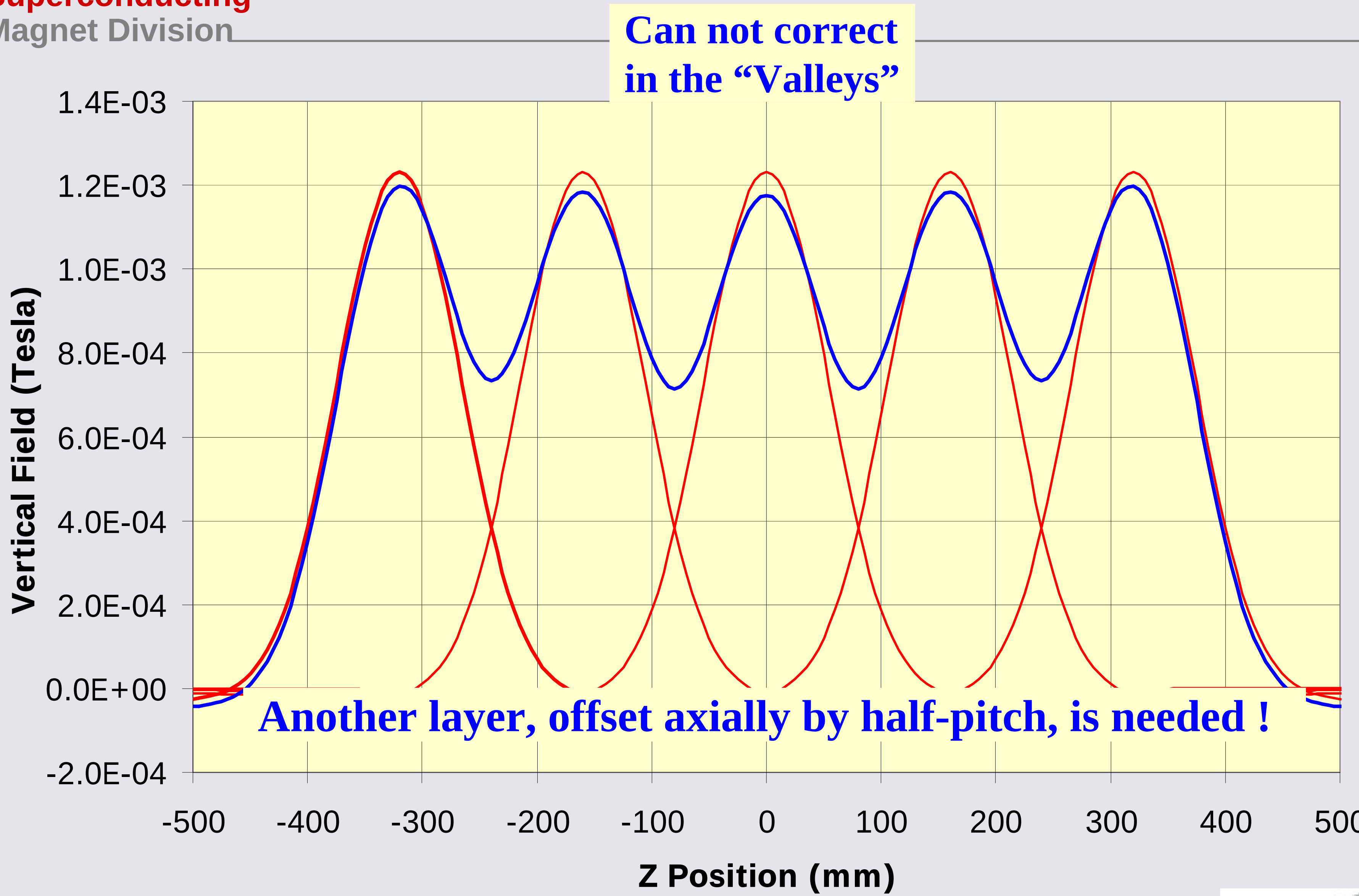
2 Layers of 4 oz Copper patterns; 159 mm ID, 150 mm long

1.25 x 10–3 Tesla central field at 2 A; DB/B ~ 10–3 at 50 mm

Mounted on cryogenic heat shield to minimize dissipated power (approx. 190 W/m expected at full power).

# Array of 150 mm long Correctors, 160 mm apart

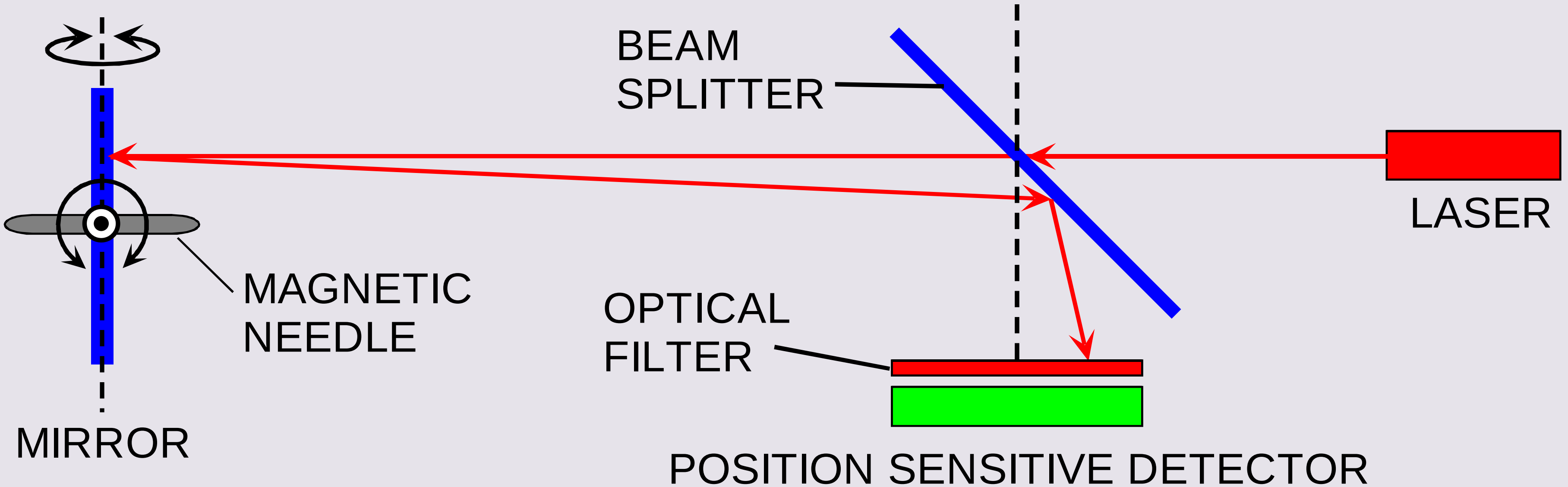




# e-Cooler Solenoid Measurement System

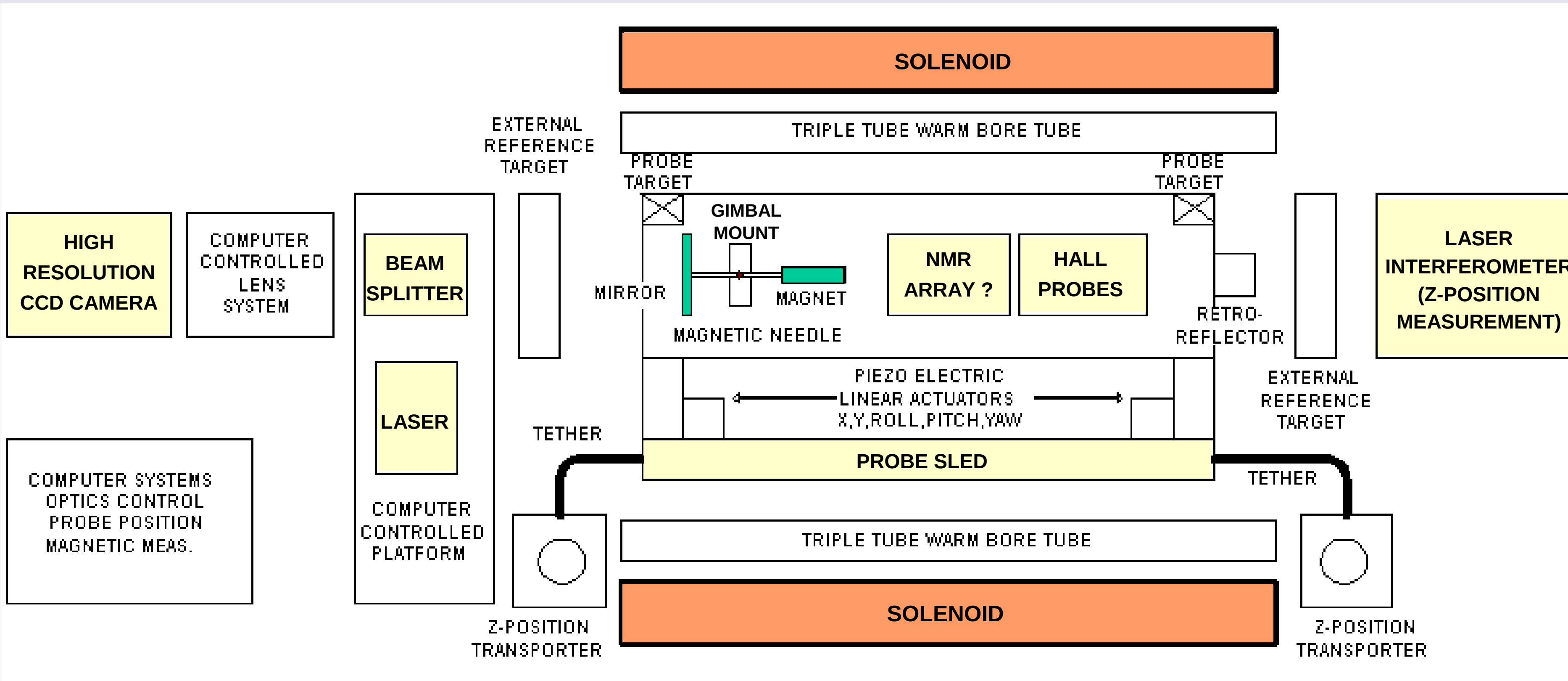
3-D Hall probe system (expected resolution of ~10–3 radian)

Magnetic needle and mirror system (expected resolution of ~10–5 radian; used at BINP, IUCF, Fermilab)

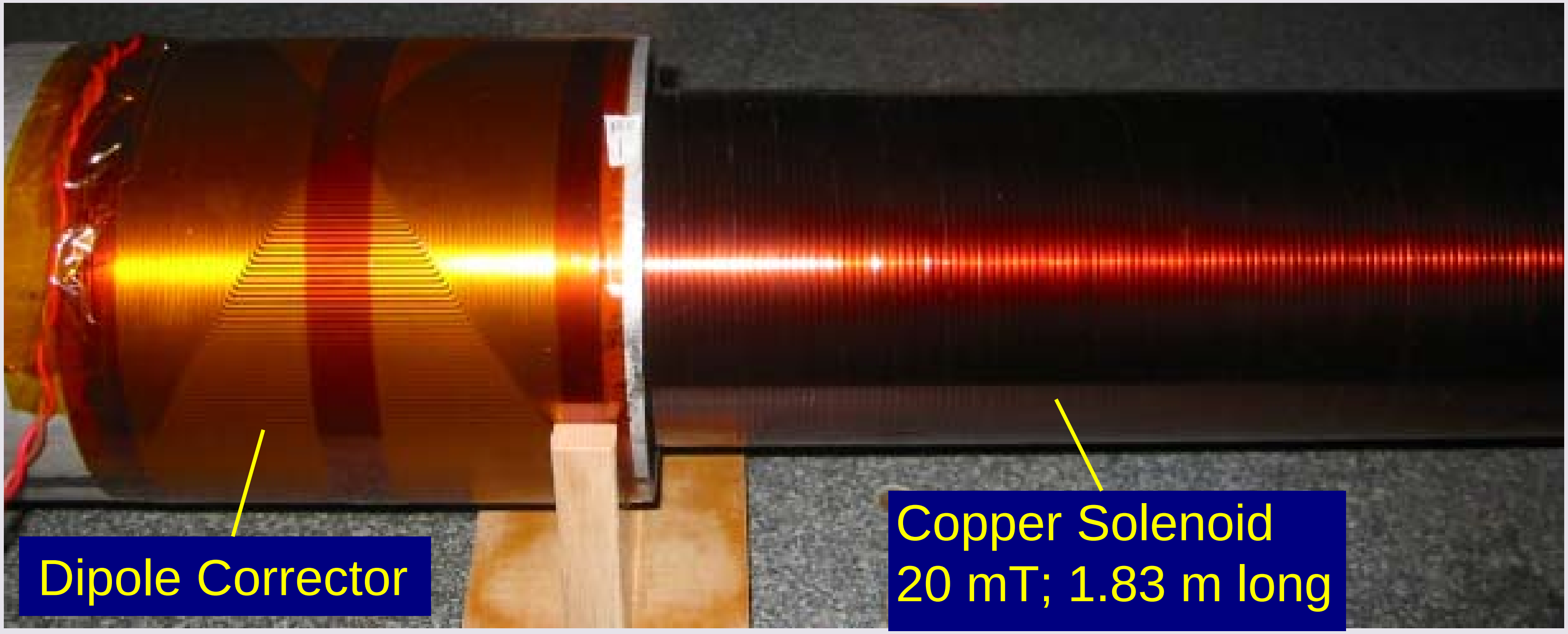


# Measurement System Schematic

**Superconducting**
**Magnet Division**



# Setup for testing the measurement system

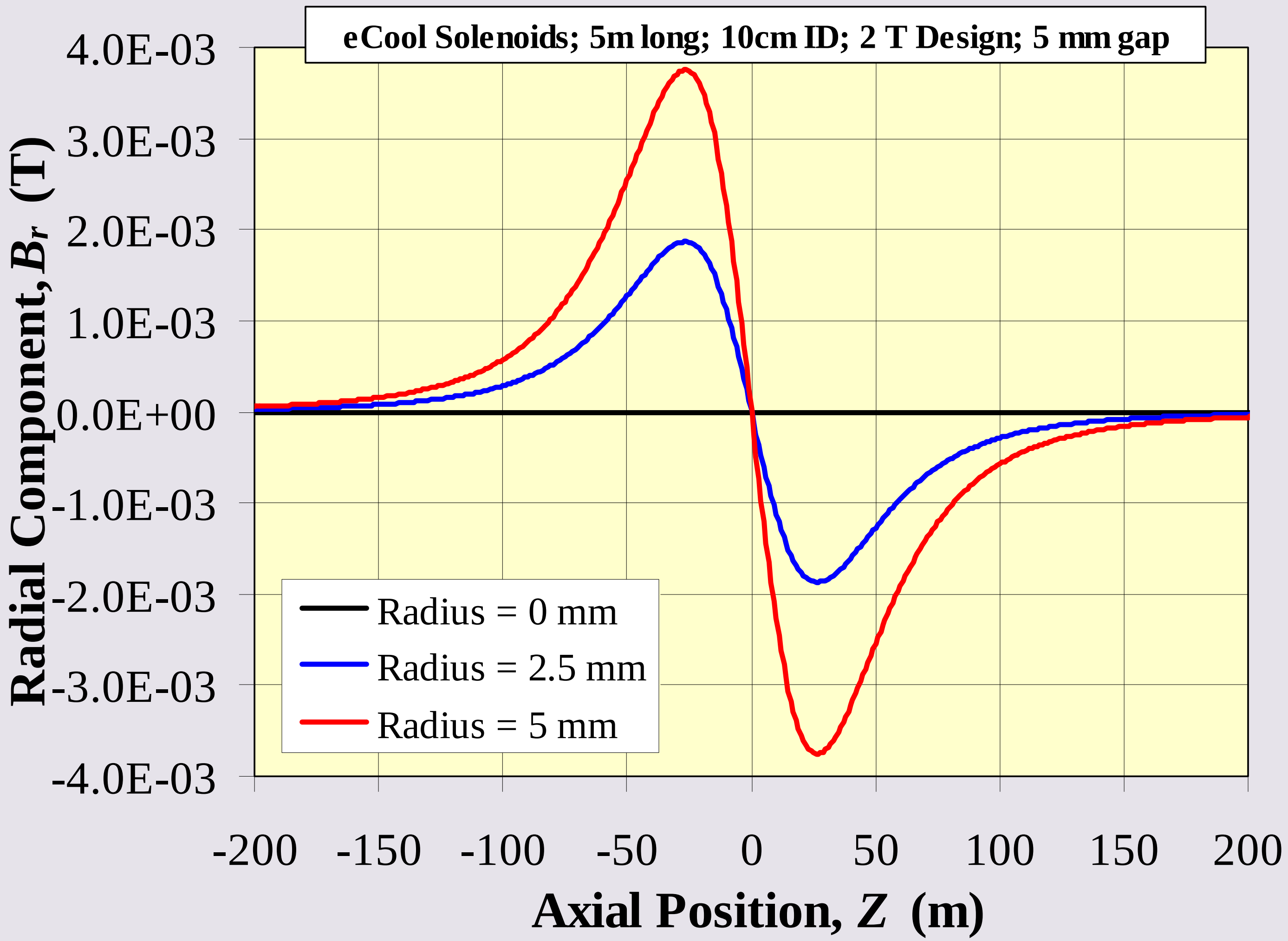



By exciting the dipole correctors at a known strength, the deflection of laser spot can be compared with the expected change in the solenoidal field direction.

The complete measurement system is currently under development.

# Radial Field with 5 mm Gap

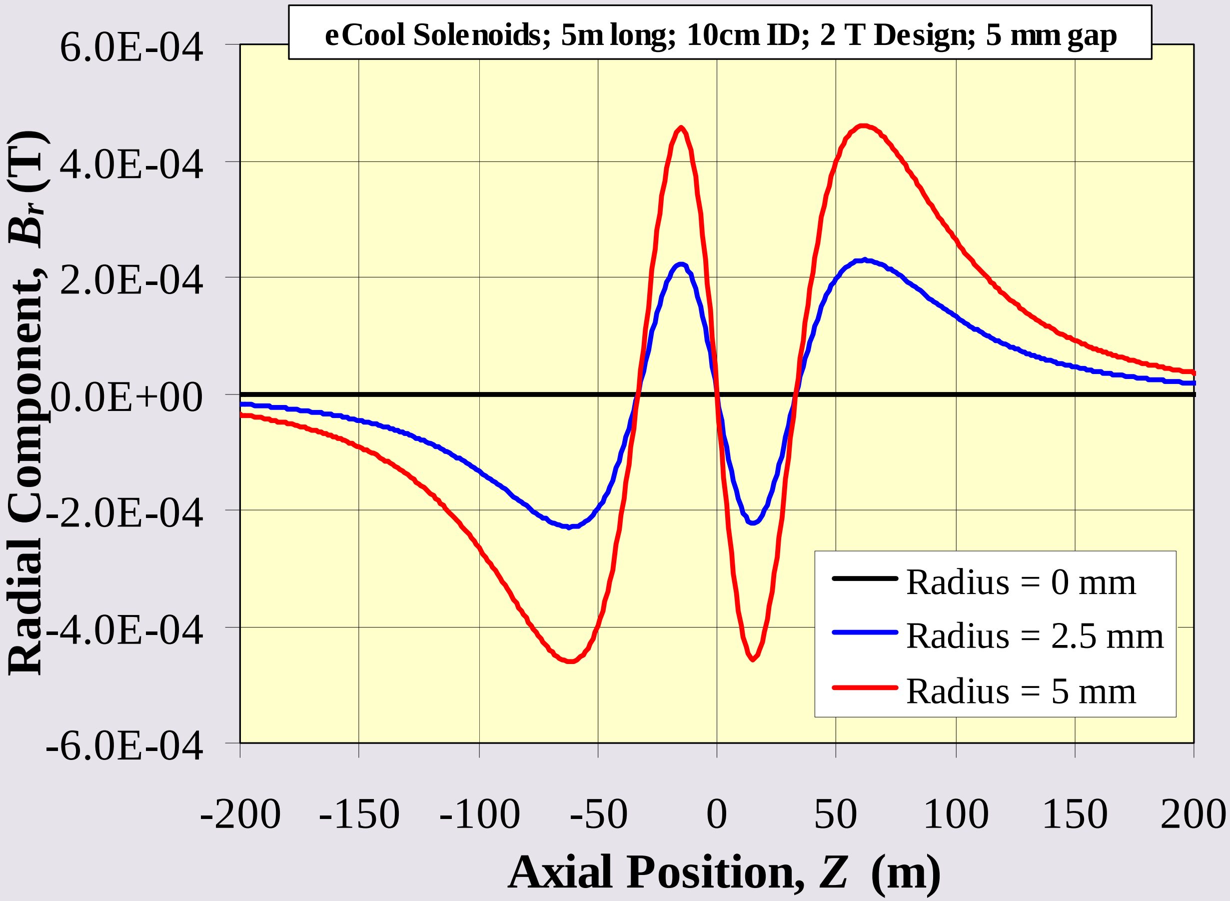




# E_Cooling Solenoid: Radial Field with 5 mm Gap & Corrector

**Superconducting**
**Magnet Division**

Simple, short solenoid corrector.
NOT OPTIMIZED.



# FY06 Plans for measuring system

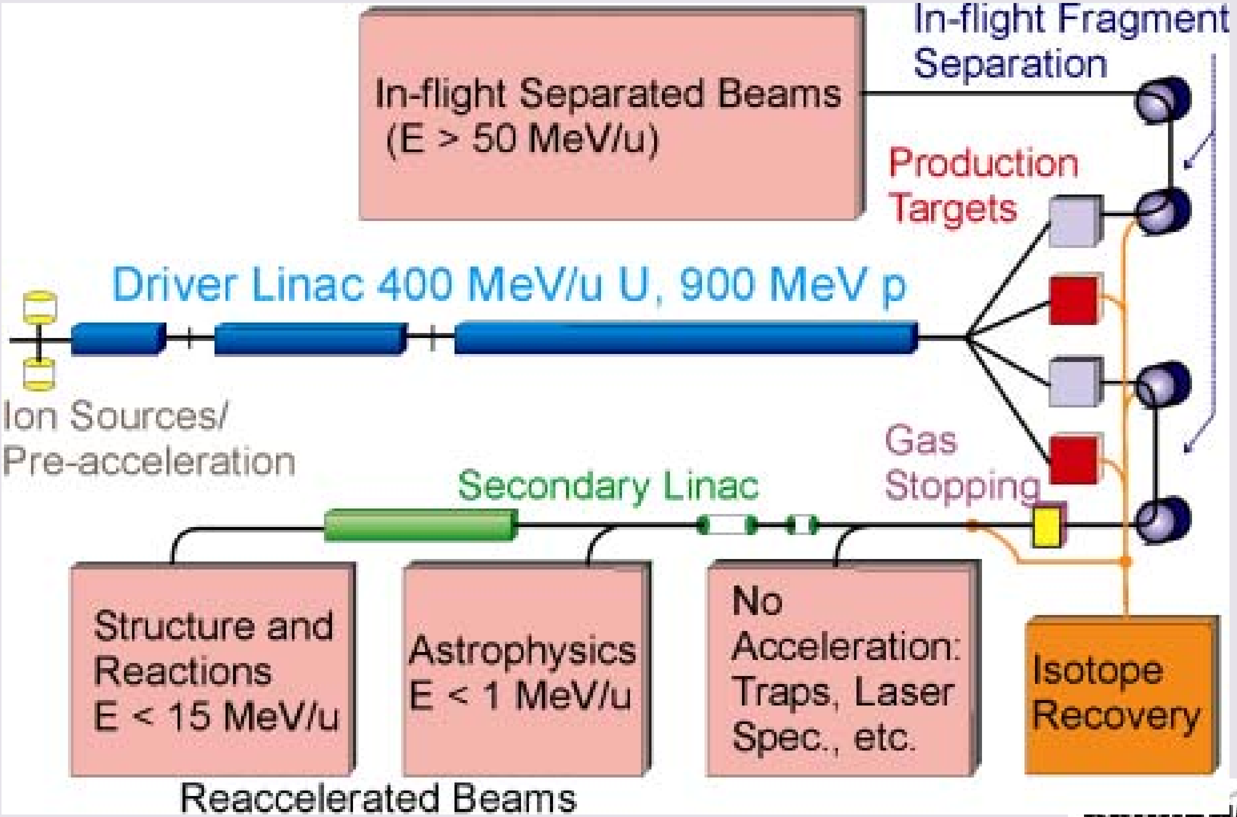
- Calibrate scale and sensitivity of field measuring system with resolution ~ $10^{-3}$ resolution. Have most components:
  - Solenoid + dipole correctors (room temp.)
  - Mirror/magnetic needle + Hall probes
  - Laser
  - CCD camera + pattern recognition software
- Map magnetic field of solenoid along its axis.
  - Build sled to hold mirror/magnetic needle and Hall probes

# Rare Isotope Accelerator - RIA

## Intense source of rare isotopes

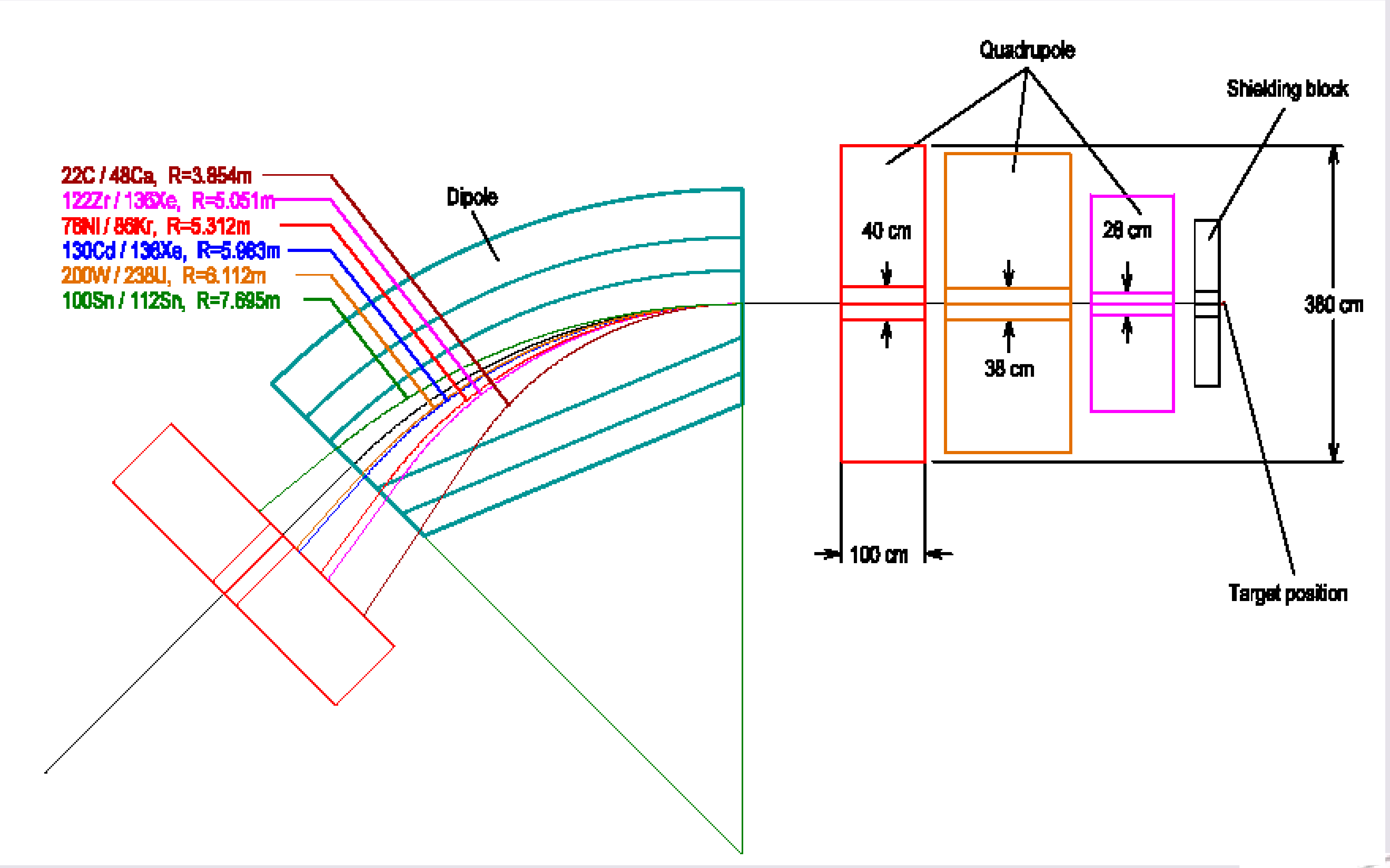
- High power primary beams elements up to uranium at $6x10^{12}$/s and E > 400 MeV/nucleon.
- Possibility to optimize the production method for a given nuclide.

Schematic of the RIA Concept →



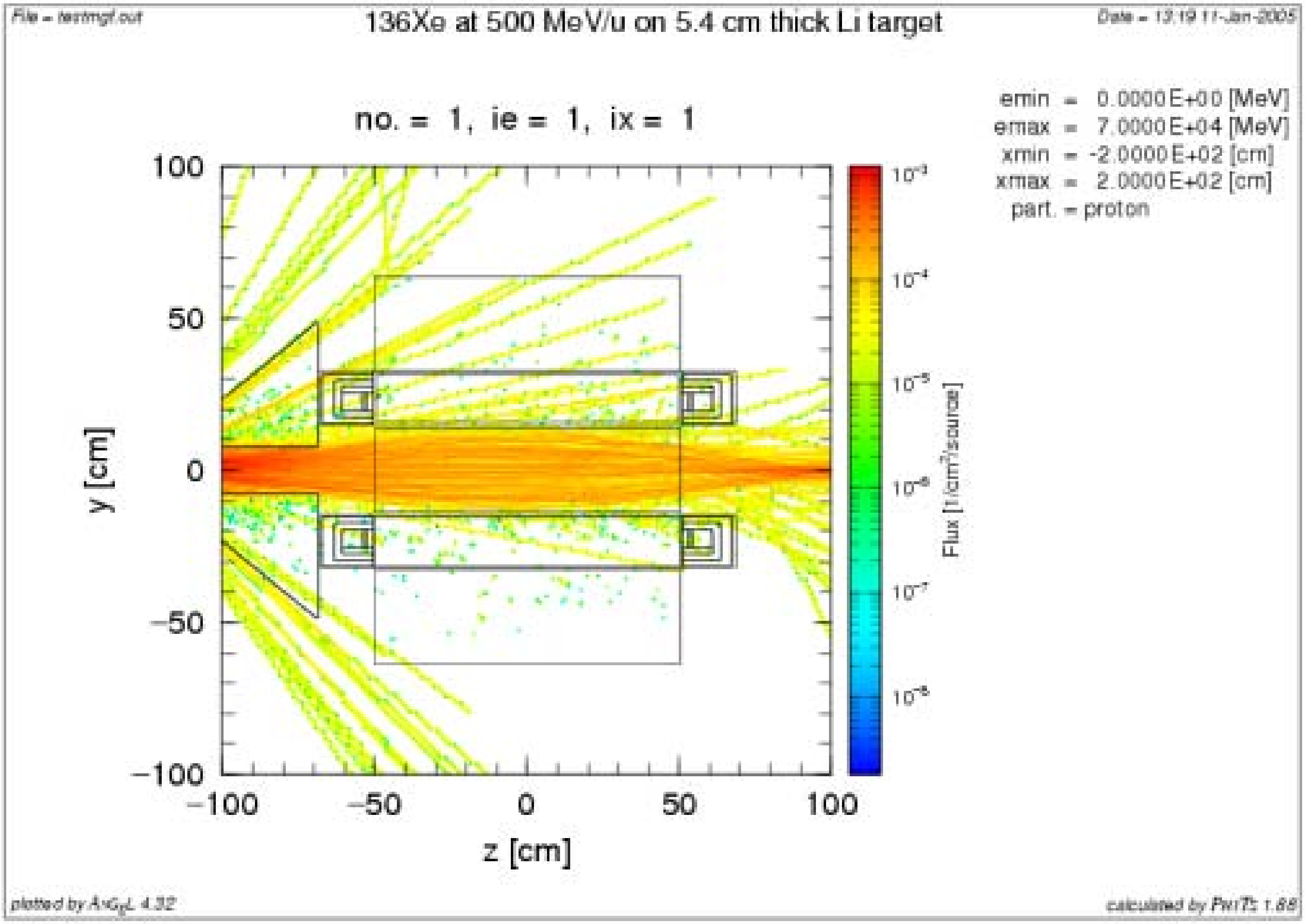
# Beam-Fragment Locations





# Protons – magnetic field





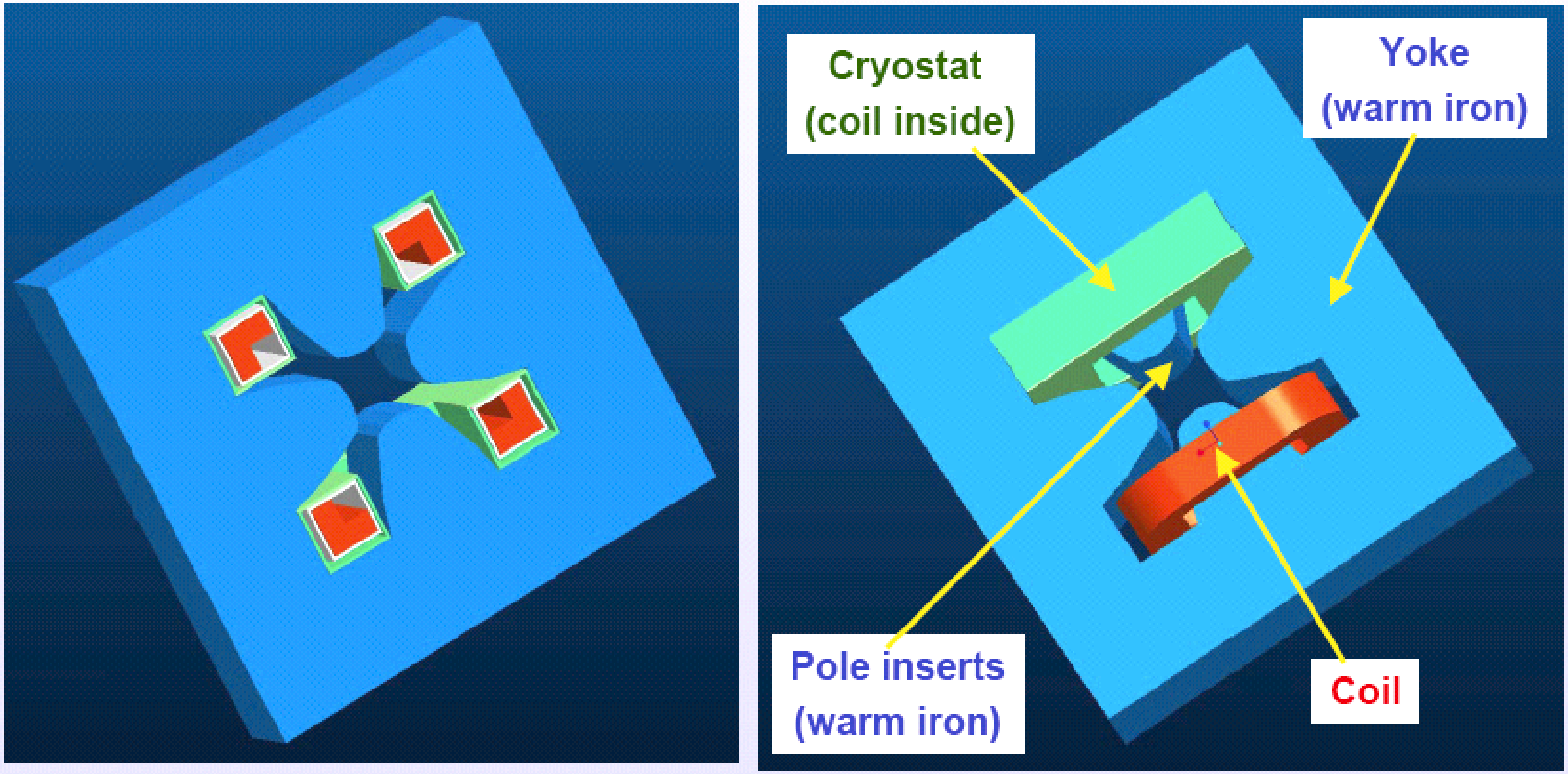
# RIA R&D - why HTS ?

- HTS critical current falls slowly as a function of temperature
- Can operate at 20-40 K while giving twice the gradient of conventional magnets
- Operation at 20-40 K gives a much simplified cryogenic system
- Precise temperature control not necessary
- Radiation resistant design using stainless steel as an insulator

# RIA R&D

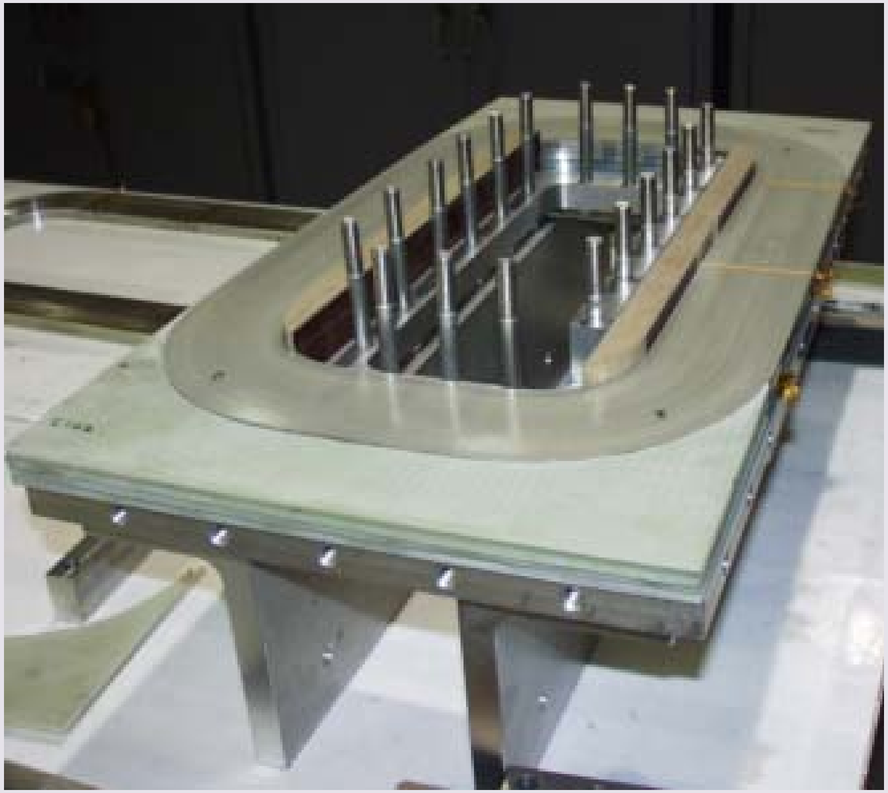
## A simple warm iron super-ferric quad design with two racetrack HTS coils

Note that only a small fraction of mass is cold (see green portion), and also that it is at a large solid angle from the target



# HTS Coils

A coil being wound on the new computer controlled winding machine.



Three pairs of coils during their assembly in a support structure.

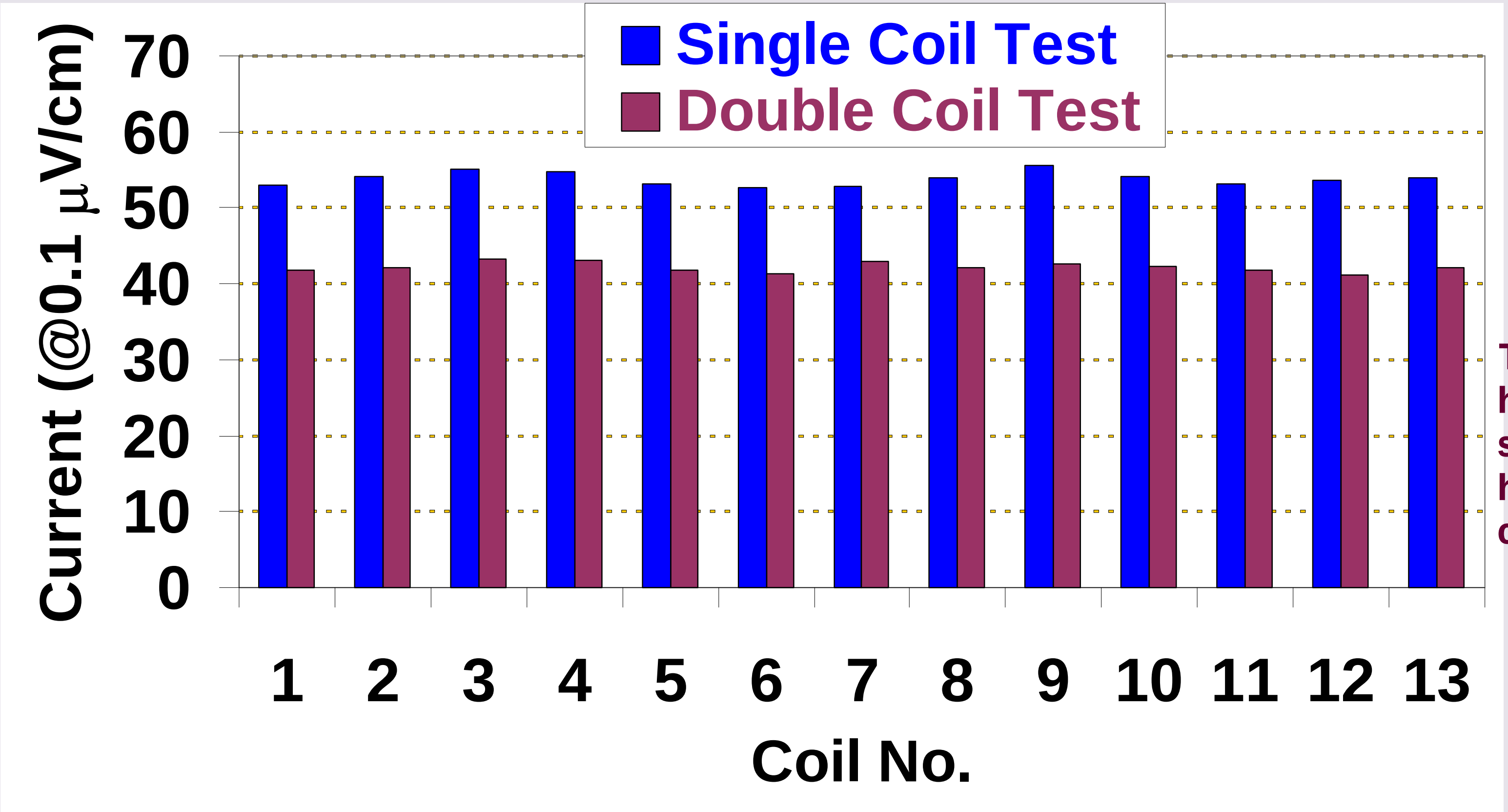
# Magnetic Mirror HTS Model Magnet for RIA

**Coils in a bolted support structure for magnetic mirror model magnet test.**

**Magnetic mirror model ready for test in a temp. range of 4.2K to 80K. A higher operating temperature translates to a lower operating cost.**

# Performance of 13 HTS Coils

Critical current of the coils at 77 K (0.1 μV/cm over the coil length).



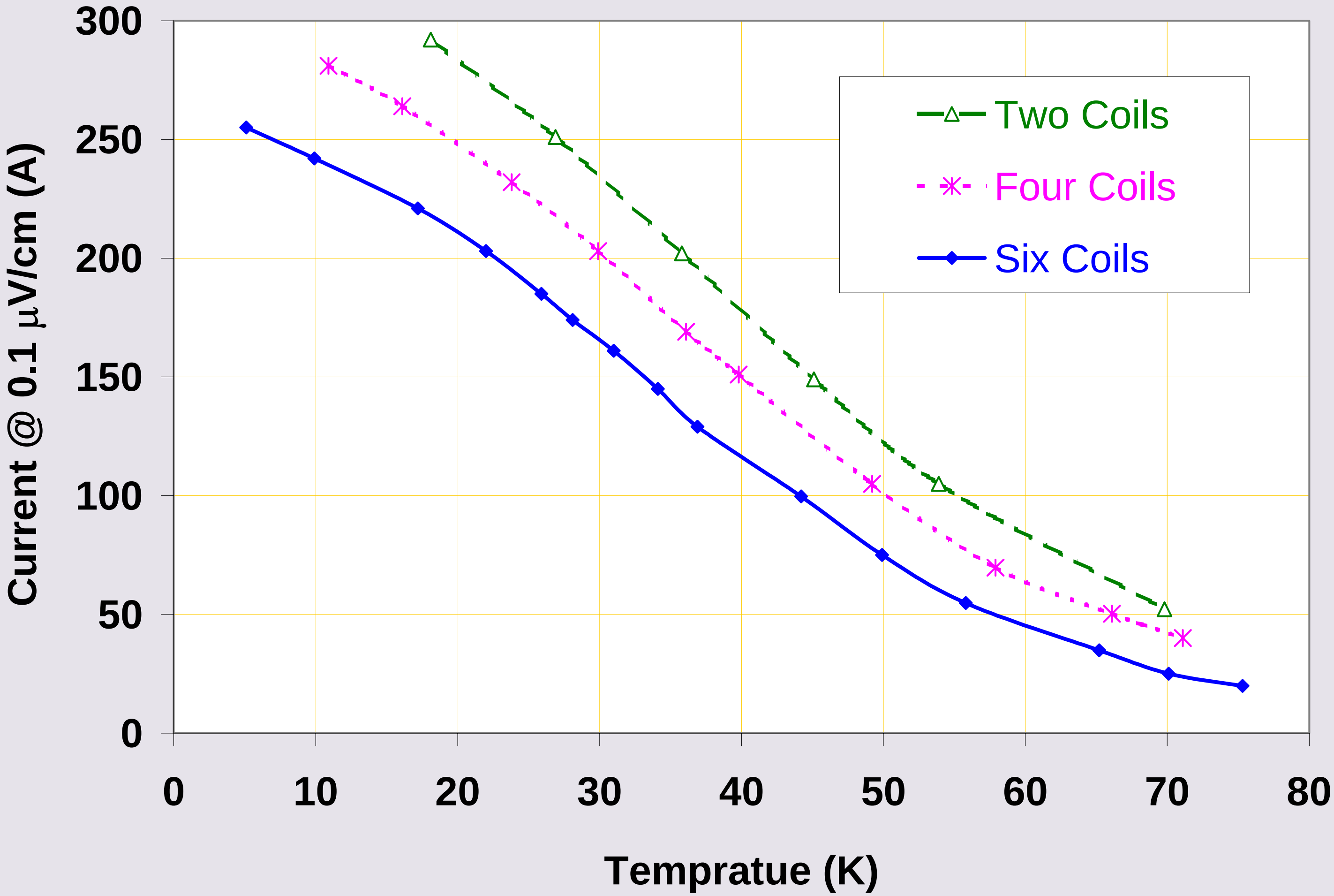

Two coils have larger self field and hence lower current

HTS coil performance matches the conductor performance.

A uniform performance of all coils implies a dependable technology.

# Temperature Dependence of the Current Carrying Capacity of HTS Coils

**Temperature dependence of the critical current in two, four and six coils in the magnetic mirror model.**




**More coils means higher self field and hence lower current**

**HTS coils can operate at a wide range of operating temperature**

# HTS Magnets - Cost Effective ?

**A. Zeller's Paper at PAC 2005 comparing various options for RIA quad**

Table 3. Comparison for several construction methods for the radiation resistant first quad in the FS. Warm iron. 8 T/m gradient.

| Case | Current density ($A/mm^2$) | Power (kW) | Iron (ton) | Coil (ton) | Coil cost (M$) |
|---|---|---|---|---|---|
| Resistive | 2 | 160 | 38 | 7 | 1 |
| HTS | 50 | - | 10 | 0.25 | 0.3 |
| CICC | 20 | - | 20 | ? | ? |
| Cold iron | 35 | - | 2.5 | 0.25 | 0.1 |

**We see a possibility that HTS magnet technology can be developed to a level where it can compete with 1.5+ T room magnet technology in overall system cost. In addition, it brings significant savings in operating cost.**

# Future Developments - eRHIC



# Future Developments - eRHIC

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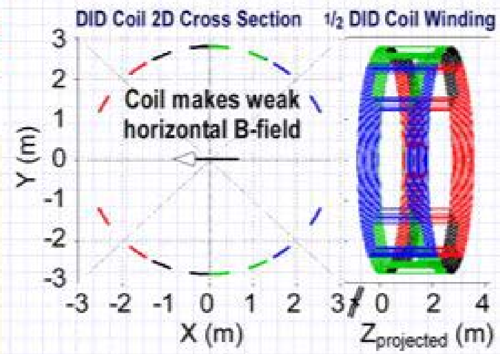
Superconducting Magnet Division

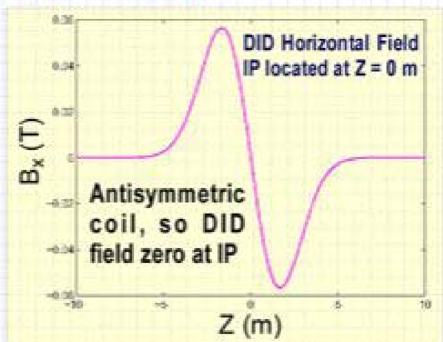
## Limited Synrad Effects by "Pointing" Solenoid Field Lines to Incoming Beams.

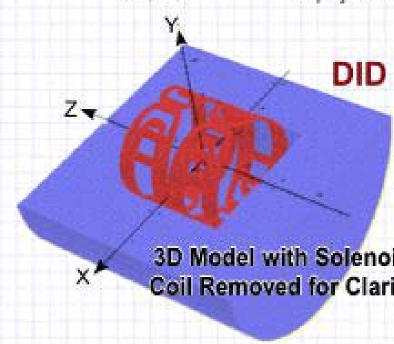
### Recent Invention: Detector Integrated Dipole (DID).

For a weak enough field, not much penalty (magnetic stored energy) in filling detector with dipole field. So integrate dipole coil within detector solenoid cold mass.




Local correction inside detector done without adding extra material near the IP.




**In effect can align incoming beams with solenoidal field to reduce synrad and preserve polarization, whether colliding e-e+ or e-e-, and independent of the incident energy.**

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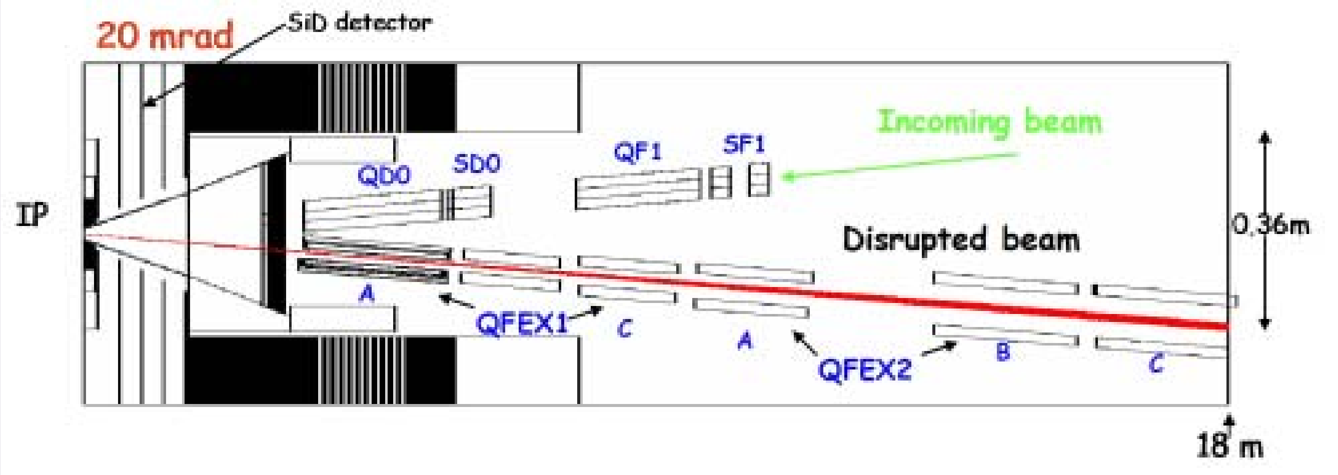
# Non NP Projects

## ILC final focus quadrupole development - highly compact elements




**LHC Nb3Sn quadrupole development - the LARP Program in collaboration with Fermilab and LBL**

**Final focus quads for BEPC II Project at IHEP, Beijing**

# Magnet Division Logistics

| Nuclear Physics | FY 2001 | FY 2002 | FY 2003 | FY 2004 | FY 2005 | FY 2006 |
|---|---|---|---|---|---|---|
| NP program magnet support | $4,786 | $4,740 | $5,350 | $5,874 | $5,805 | $5,300 |
| FTE's | 25.5 | 26.5 | 28.5 | 29.0 | 29.0 | ~25 |
| RIA R&D | | | | $290 | $400 | $400 |
| FTE's | | | | 2.0 | 2.5 | 2.5 |
| High Energy Physics | | | | | | |
| LHC/LARP | | $9,707 | $4,307 | $2,302 | $1,280 | $2,000 |
| Base program | | $1,063 | $990 | $1,000 | $1,250 | $1,000 |
| ILC | | | | $250 | $500 | ? |
| | | 44.0 | 30.6 | 18.8 | 12 | 12+ |
| Other | | | | | | |
| | | | $2,600 | $3,840 | $2,095 | small |
| | | | 16.3 | 26.8 | 15 | |

We assume that the RHIC support program will remain at this level of effort for the foreseeable future.

This represents ~50% of the Magnet Division's total activity.

Obvious problem in FY05/06 from HEP

# Summary

The RHIC program support requirements are maturing (as is the machine):

- Magnetic measurements are becoming more subtle
- Magnet technology is becoming more complex

No major production tasks anticipated in the near future. We are moving into a low volume, R&D, environment (spin, e-cooling, e-RHIC, RIA). The most immediate being RHIC II and e-cooling solenoids.

The RHIC magnets appear to be very reliable no major repair role to date.

Planning on a constant level of effort for NP programs.

HTS magnets for RIA looking 'interesting'