MAGNETIC DESIGN OF E-LENS SOLENOID AND CORRECTOR SYSTEM FOR RHIC*

BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division
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Demanding Magnet System with Unique Challenges

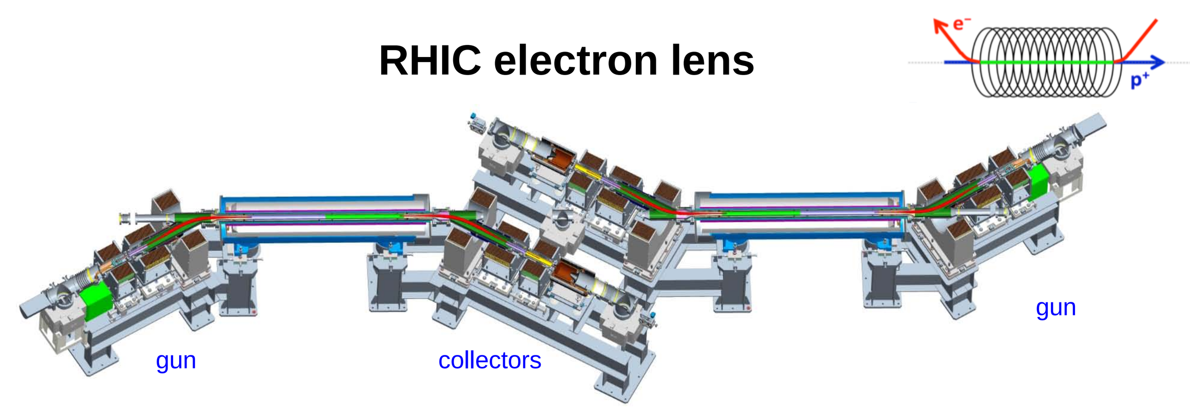
- Large aperture (200mm), high field (6T), long magnet (2.5m) with high stored energy and large Lorentz forces
- Field straightness: ±50 μm in z = ±-1050 mm
- Low field errors, -1050 <z <1050 mm, 1-6 T : <6 x 10-3
- Novel corrector system
- Require large fringe field outside the magnet
- Use existing parts to keep cost low and schedule fast

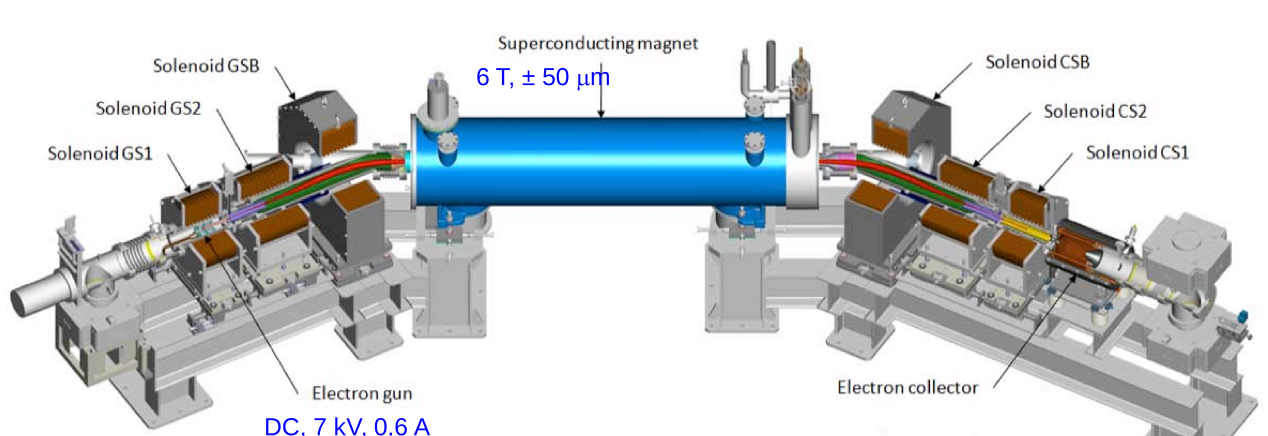
Field Straightness (50 μm) Requirement

The most critical and demanding requirement

- guides and determines the overall design
  - too risky for industry to take this job
- well beyond the normal construction errors
  - corrector magnets an integral part of the design
- yoke shielding to limit the influence of surrounding

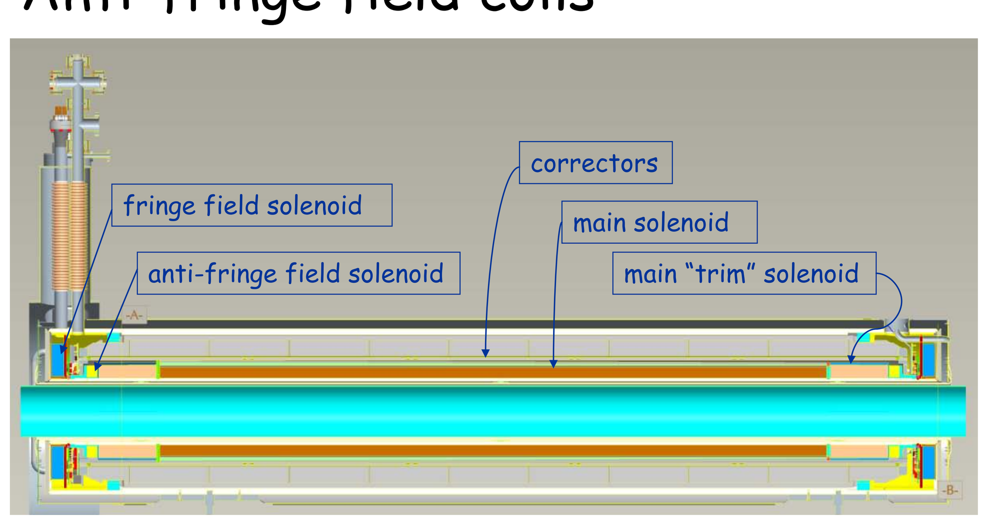
RHIC electron lens





Superconducting Magnetic System

- Main solenoid
  - including trim sections
- Correction coils
  - long and short
  - horizontal and vertical
- Fringe field coils
- Anti-fringe field coils



Major Design Parameters of the Main Solenoid

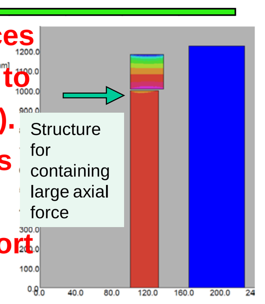
Parameters	Value
Wire, bare	1.78 mm X 1.14 mm
Wire, insulated	1.91 mm X 1.27 mm
Wire I_c specification (4.2 K, 7 T)	>700 A
Turn-to-turn spacing (axial)	1.98 mm
Turn-to-turn spacing (radial)	1.42 mm
Number of layers (main coil)	22 (11 double layers)
Additional trim layers in ends	4 (2 double layer)
Length of additional trim layers	173 mm on each end
Coil inner diameter	200 mm
Coil outer diameter	274 mm
Coil length	2360 mm
Yoke length	2450 mm
Maximum design field	6 T
Current for 6 T	~440 A
Peak Field on the conductor @ 6 T	~6.5 T
Computed Short Sample @4.2 K	~7.0 T
Stored energy @ 6 T	~1.4 MJ
Inductance	~14 Henry
Yoke inner diameter	330 mm
Yoke outer diameter	454 mm
Operating field (on the axis)	1 T to 6 T
Relative field errors on axis	$<6 \times 10^{-3}$

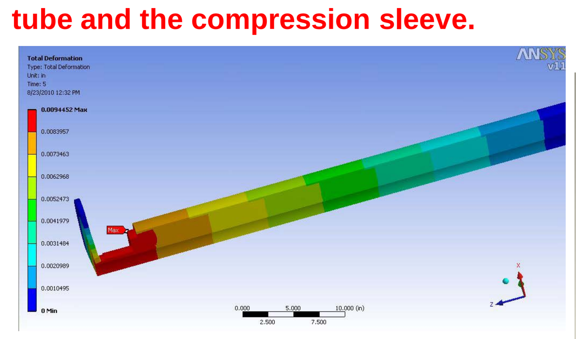
Major Design Parameters of the Fringe Field and Anti-fringe Field Coils

Parameters	Fringe field coil	Anti-fringe coil
Coil inner diameter	206.4 mm	206.4 mm
Coil outer diameter	404.0 mm	274.0 mm
Coil length	37 mm	30 mm
Number of layers	70 layers	24 layers
Maximum design current	~470 A	~330 A

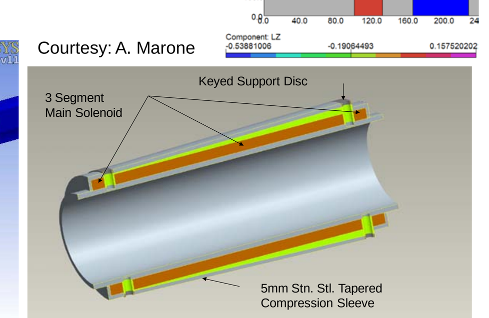
Axial force containment

- Insert structure near the end of the coil to contain forces.
- Coil is wound continuously through the end structure to keep axial forces contained throughout (during quench).
- The axial forces exerted by the outer solenoid sections are transferred around the center section.
- The keyed support discs transfer the load to the support tube and the compression sleeve.



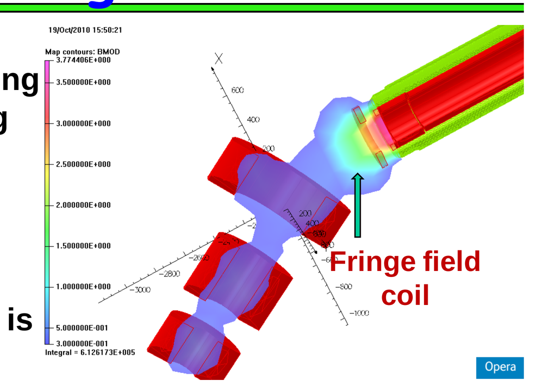


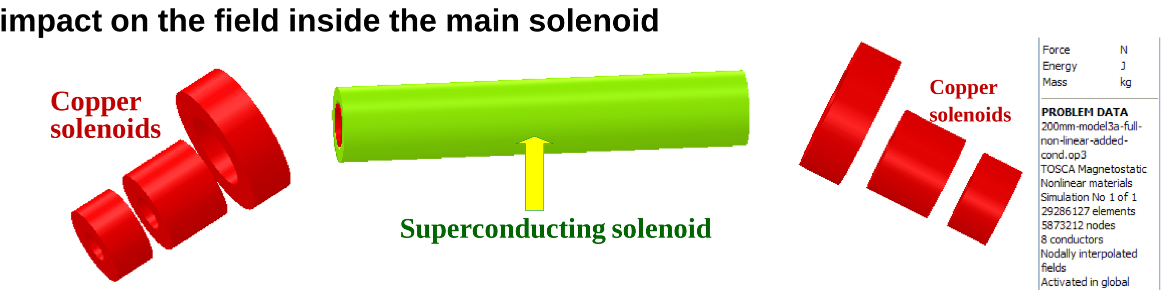
Courtesy: A. Marone



Field between superconducting and copper solenoid with superconducting solenoid at 6T

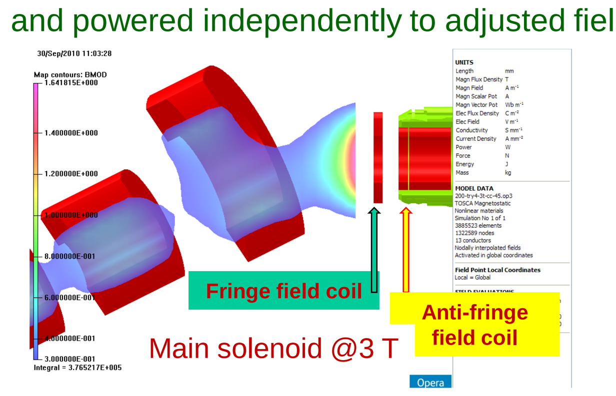
- The desired field (>0.3 T between copper solenoids and superconducting solenoid along the electron beam path) with desired spacing is not possible with copper solenoid alone.
- This requirement is satisfied by inserting superconducting coils inside the cryostat of the main superconducting solenoid.
- The size and location of the fringe field coil is optimized to minimize space usage
- Strong fringe field coils have a significant impact on the field inside the main solenoid

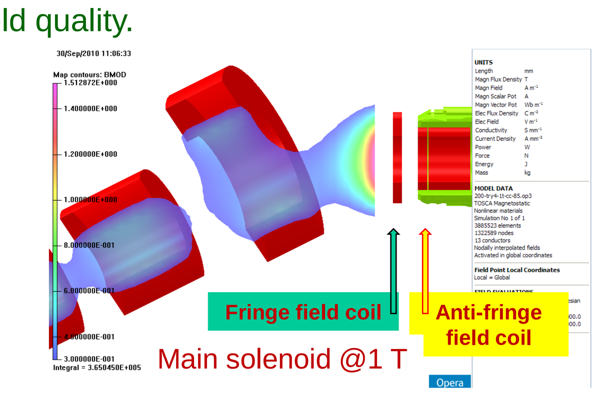




Field between superconducting and copper solenoid with superconducting solenoid <6 T

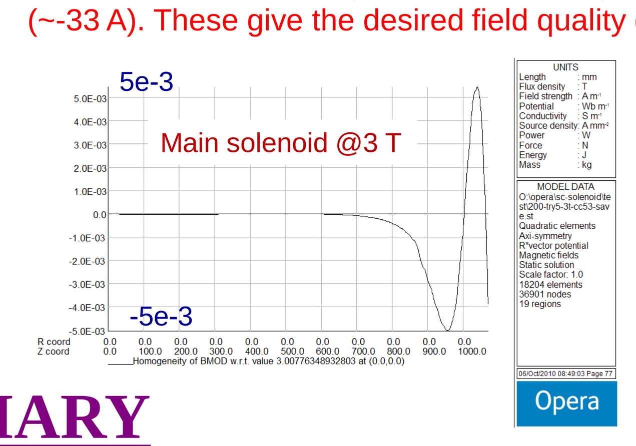
- However, the situation becomes complicated when the main solenoid is operated at a field lower than 6 T – the desired range is field as low as 1 T.
- In this case the outside field becomes significantly smaller because (a) the leakage field from the main solenoid becomes lower and (b) exterior field from the fringe field coil also becomes lower if it scales with the main solenoid to maintain field quality.
- To obtain desired the desired (>0.3 T) field between copper solenoids and the superconducting solenoid, the fringe field must run at full power.
- To obtain the required field quality, an additional coil (anti-fringe field coil) is added and powered independently to adjusted field quality.

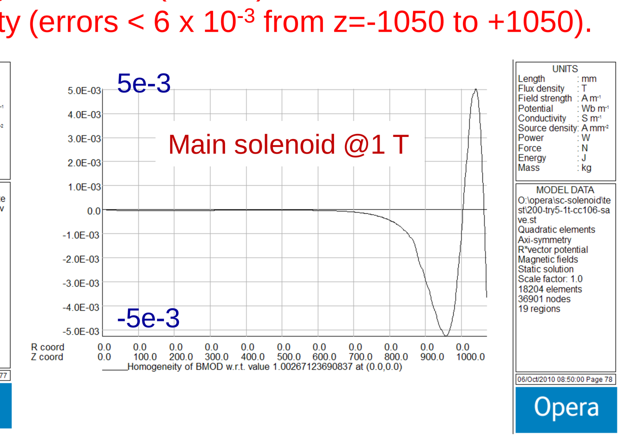




Field Quality in Main Solenoid at 1T and 3T with the desired fringe field (>0.3 T)

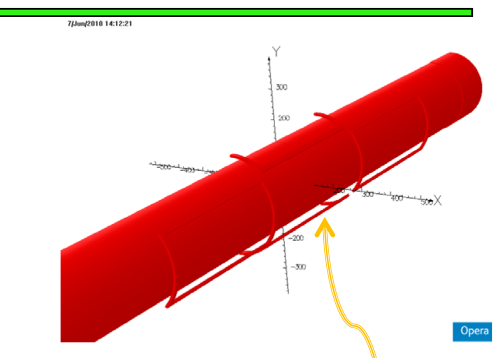
- To obtain the desired (>0.3 T) field between copper solenoids and the superconducting solenoid, the fringe field must run at full power.
- To obtain the required field quality, the current in the anti-fringe field coil is adjusted.
- To minimize the amp-turn requirements, anti-fringe field coils have a nominal zero current when the main solenoid is at 6 T.
- The current in anti-fringe coil must be negative at 3T (~-16 A) and even more at 1T (~-33 A). These give the desired field quality (errors < 6 x 10^{-3} from z=-1050 to +1050).

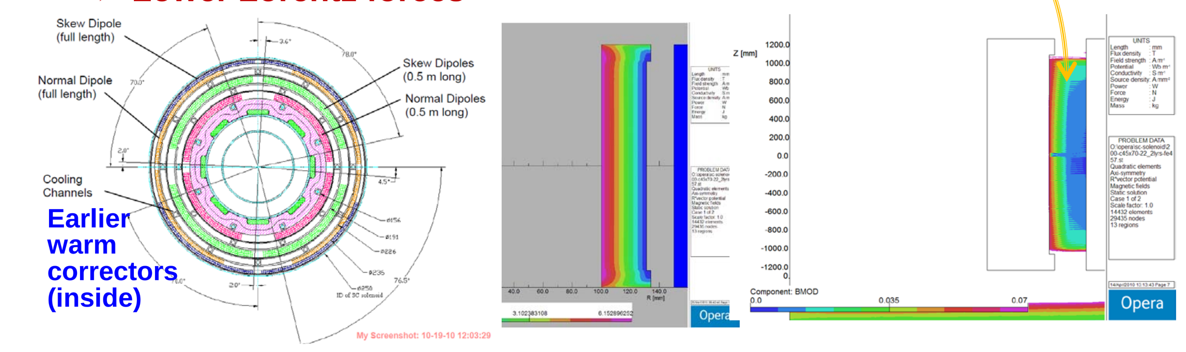




Corrector Design

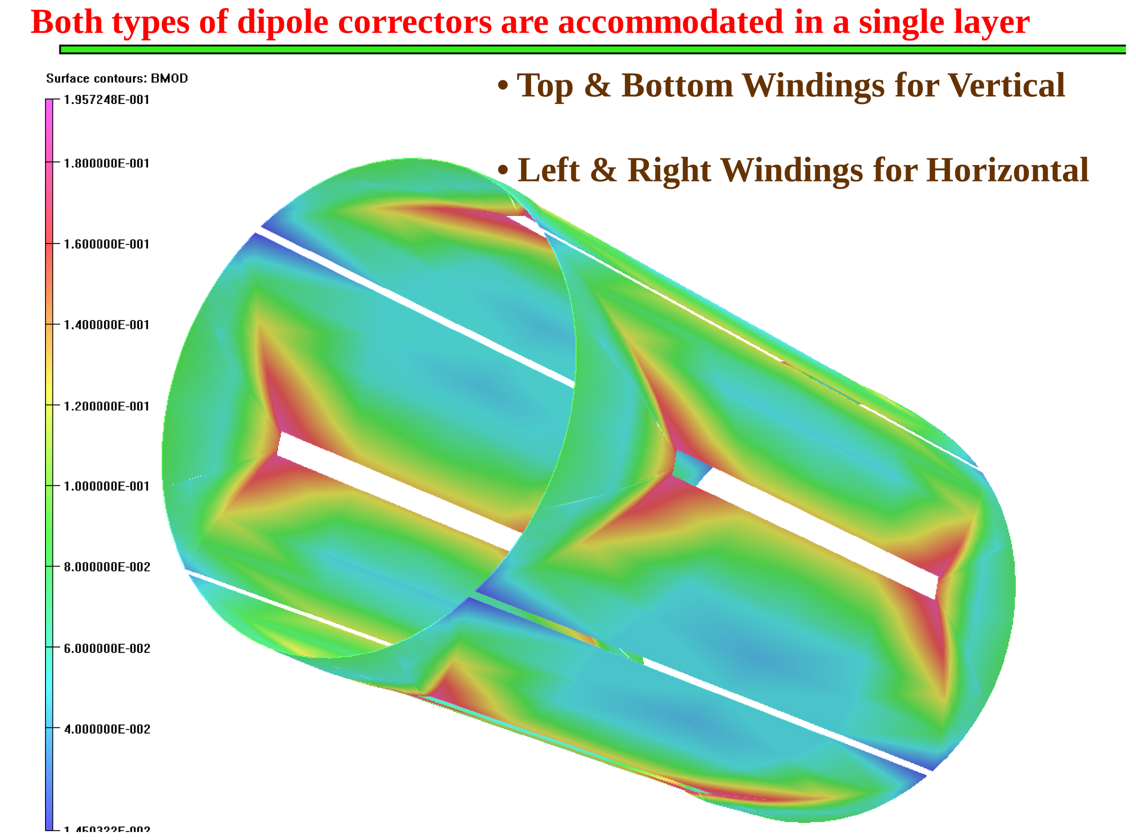
- Correctors are made superconducting
  - Reduces the size of sc solenoid
- Also placed outside the solenoid
- Reside in a low field region (<1% of 6T)
- This helps significantly:
  - Large margin
  - Lower Lorentz forces





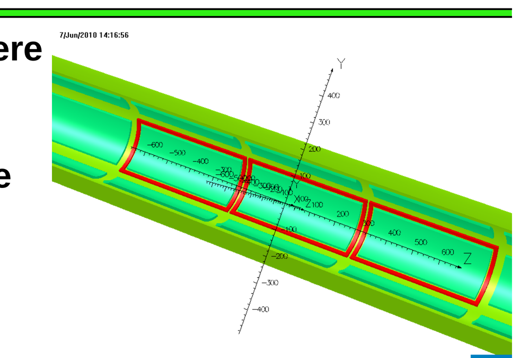
Combined Horizontal and Vertical Corrector Design

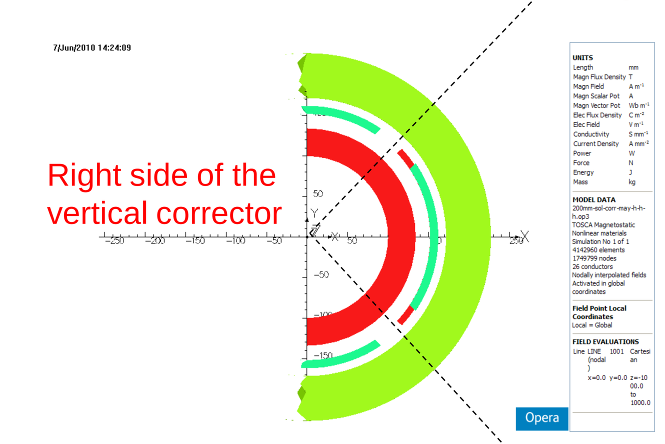
Both types of dipole correctors are accommodated in a single layer

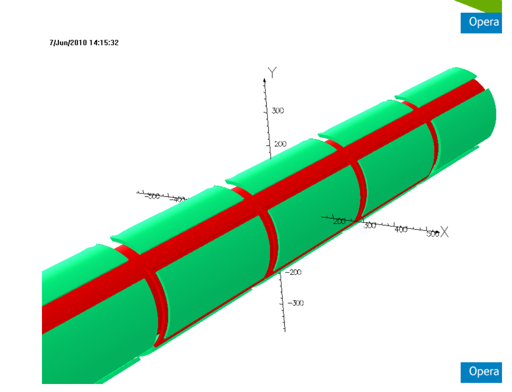


Slotted Dipole Corrector Design

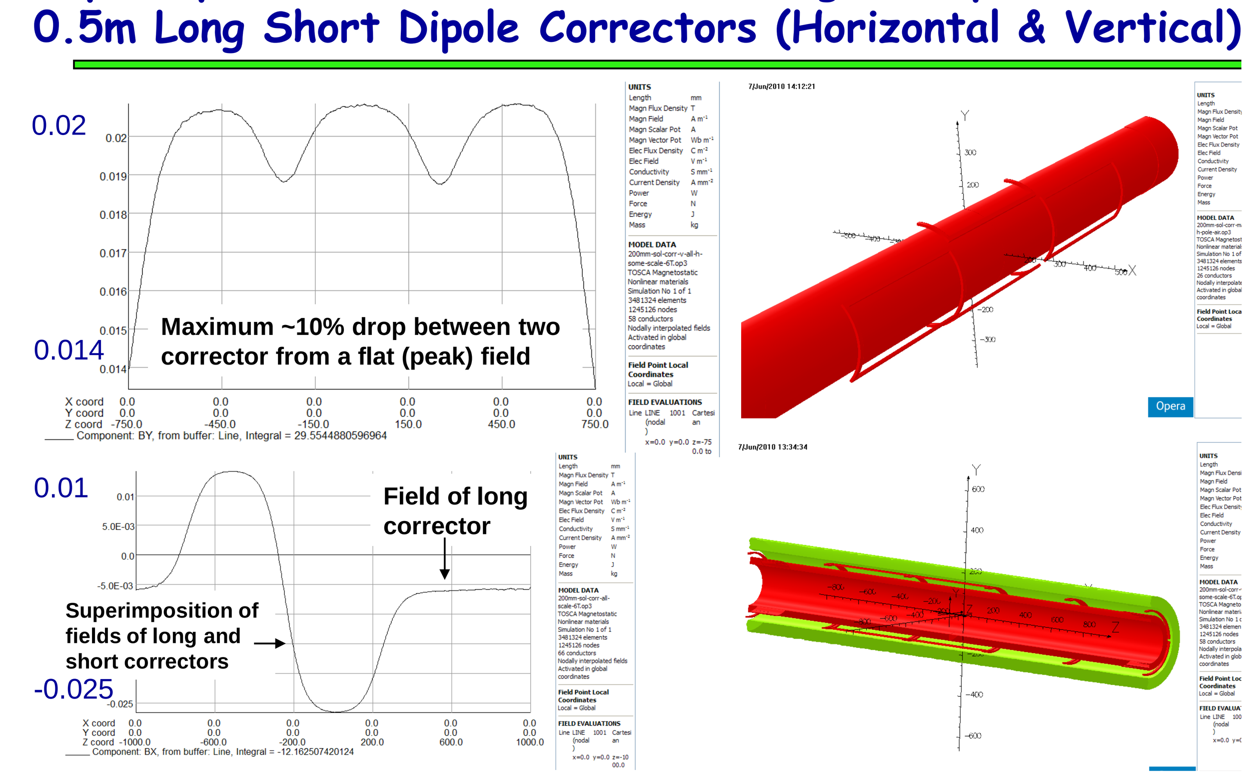
- Slots are machined in an Al tube where superconducting wires are placed.
- Horizontal and vertical correctors are placed in the same radial location.







Superimposition of Fields of 2.5m Long and up to Five 0.5m Long Short Dipole Correctors (Horizontal & Vertical)



SUMMARY

As a part of the proposed electron lens system for the Relativistic Heavy Ion Collider (RHIC), two 6 T, 200 mm aperture, 2.5 meter long superconducting solenoids are being designed and built. Because of several demanding and unique requirements, this has become a very involved and technologically advanced magnet system. To deal with the large axial forces in the ends and large hoop stress along the length of the solenoid, a new structure has been developed. A new type of dipole corrector has been developed to satisfy the demanding requirements of field straightness inside the solenoid. To facilitate the unusual requirement of significant field outside the coldmass, fringe field coils have been added at the two ends. Moreover, anti-fringe field coils are also incorporated to maintain good field quality inside the main solenoid while the ratio of the fields between the main solenoid and the fringe field coils changes. This paper summarizes the development and optimization of the entire e-lens superconducting magnet system consisting of the main, the fringe field and the anti-fringe field solenoids together with the nested corrector package consisting of short and long horizontal and vertical dipoles.

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