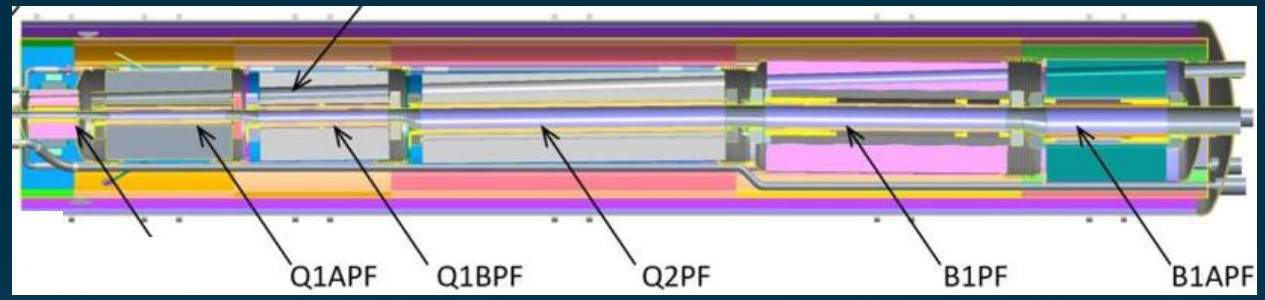



Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

# EIC Cable Magnets


## Ramesh Gupta

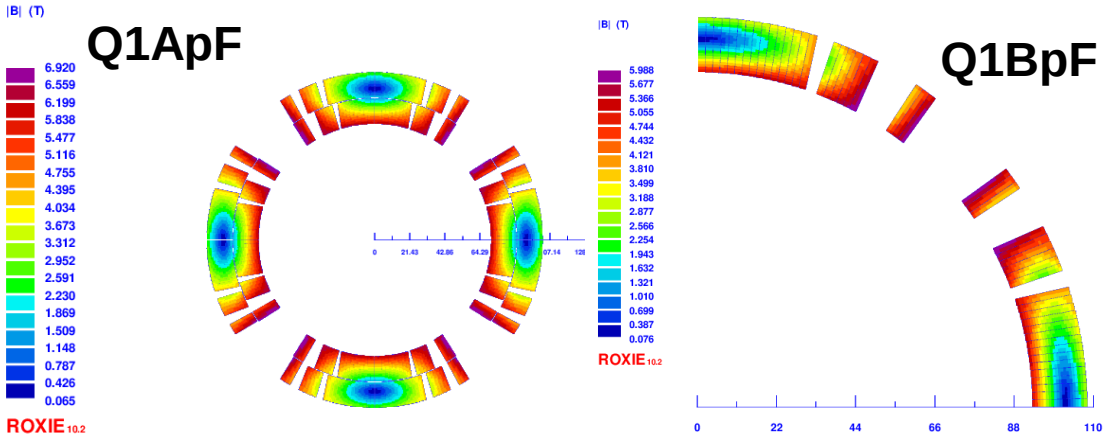
(on behalf of many scientists, engineers and technicians of magnet division)


@BrookhavenLab

October 18, 2024

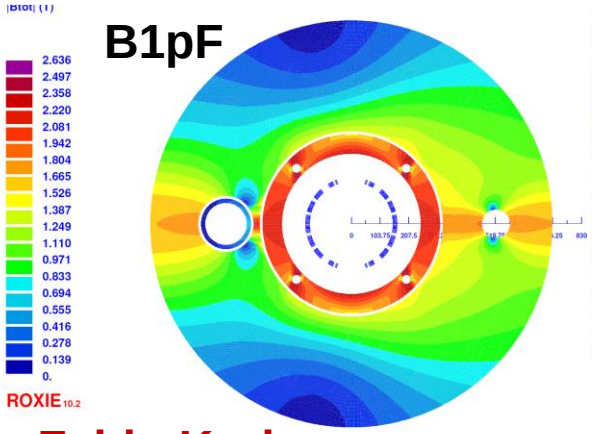
# EIC Cable Magnets Designed at Magnet Division

- Five EIC IR cable magnets have been designed at Magnet Division.
- This presentation summarizes the magnetic design work of many scientists & engineers.
- Having designed and built several RHIC and other accelerator magnets, magnet division is in a unique position to help EIC.
- That practical knowledge which advanced the state-of-the-art, is being transferred to the next generation. Highlights in next few slides.

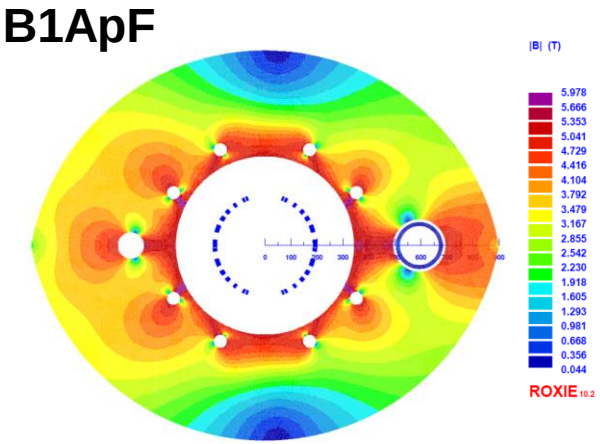



Anis Ben Yahia and Julien Avronsart

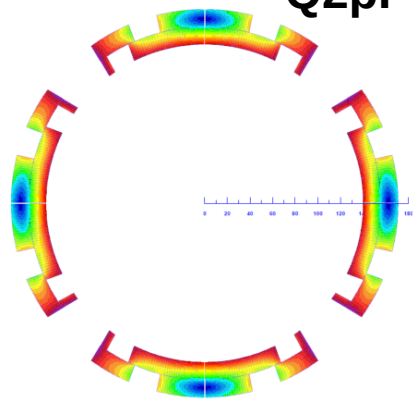
B1pF has advanced the most, and will be used as the example




Febin Kurian



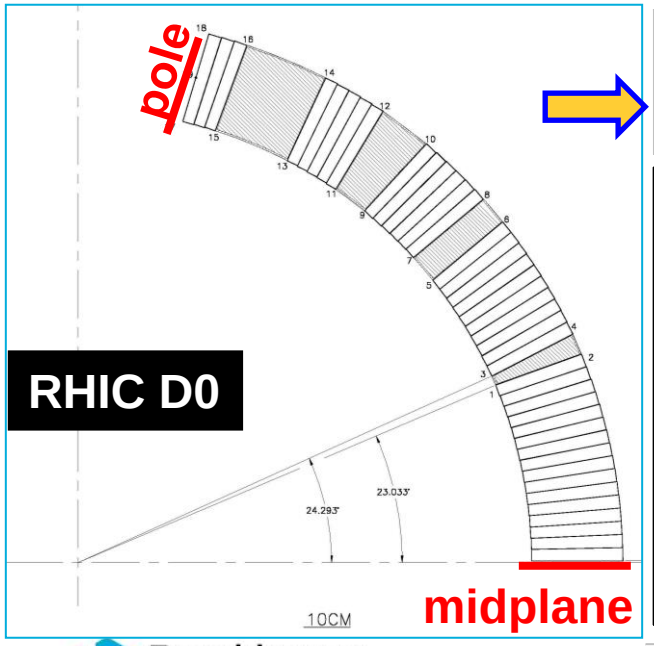

Mithlesh Kumar




Ramesh Gupta

# Obtaining Good Field Quality in Accelerator Magnets

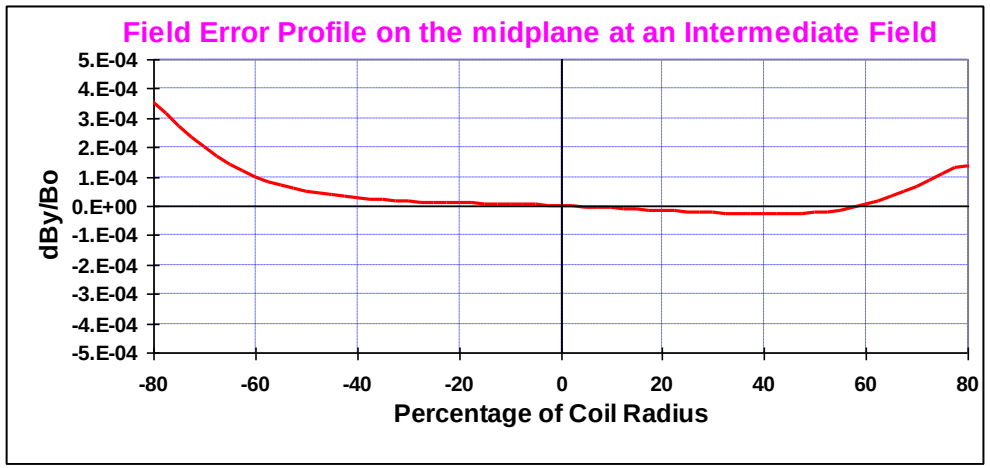
- Accelerator magnets require a very good field quality, with errors < a few parts in $10^4$.
- This puts tight requirements on the design, tolerances in parts, and on construction.
- Despite the best efforts, cumulative errors become large, more so in the 1st magnet.
- Iterations are expensive and take time. They used to be part of building magnets.
- BNL Magnet Division developed a flexible design approach during the RHIC magnet program, which assured a good field quality despite some errors in parts.
- This approach has been fully adopted in the EIC cable magnet designs.



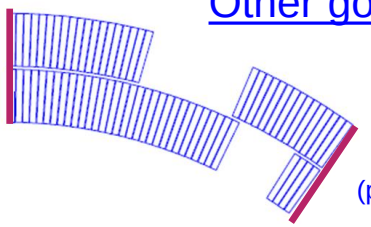

**Geometric Field Errors on the X-axis of DRZ101 Body**

**First magnet and first attempt in RHIC 100 mm aperture insertion dipole**

**A number of things were done in the test assembly to get pre-stress & harmonics right**



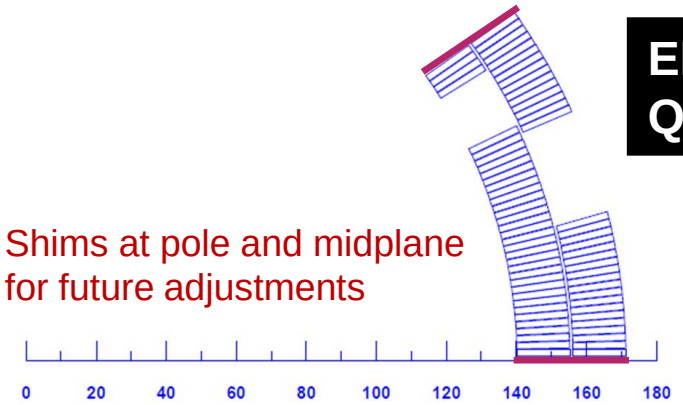

**Field errors are within $10^{-4}$ at 60% of coil radius and ~$4*10^{-4}$ at 80% radius.**



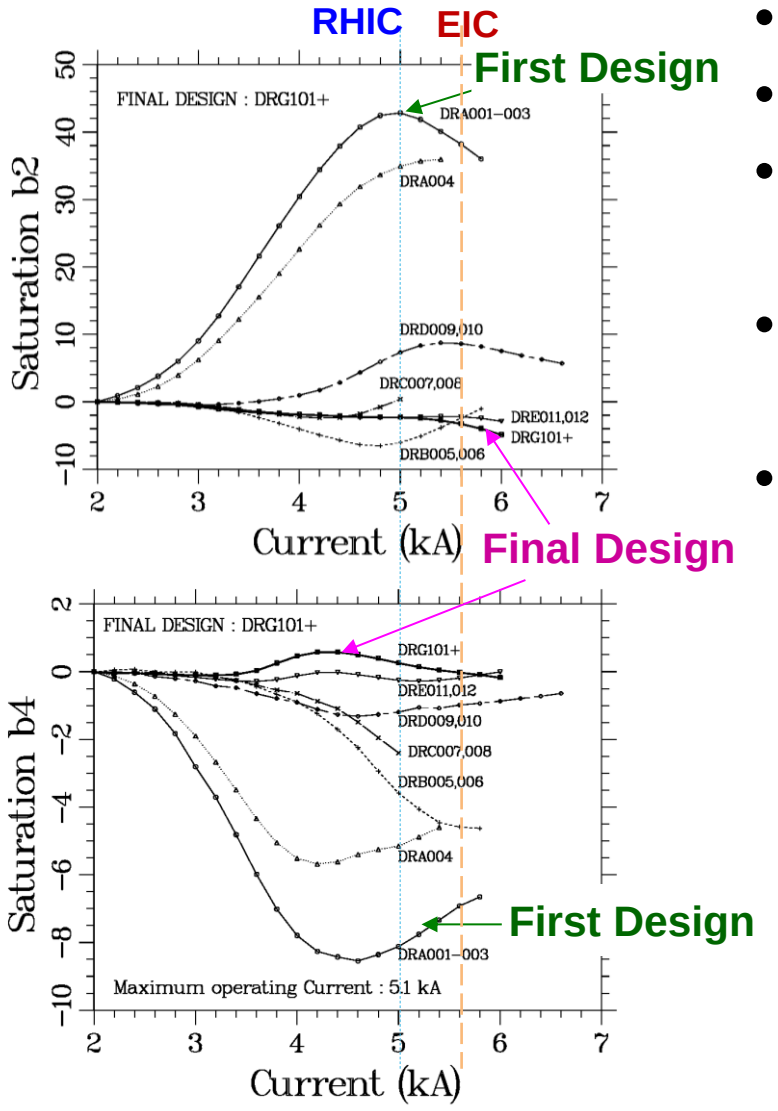
Other good design practices:

- Mechanically sound
- Symmetric wedges
- Aligned poles

(paying attention to details matters)

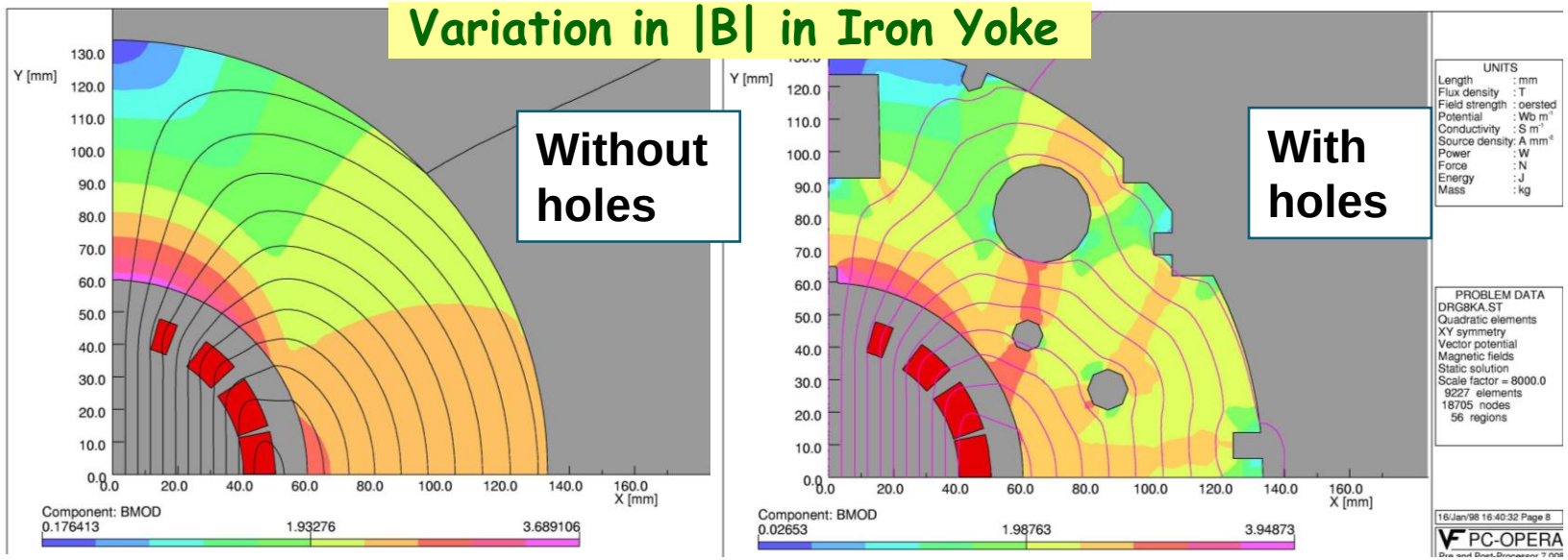


# Field Quality as a Function of Field (RHIC dipoles to be used in EIC)




**(as measured in long RHIC dipoles)**

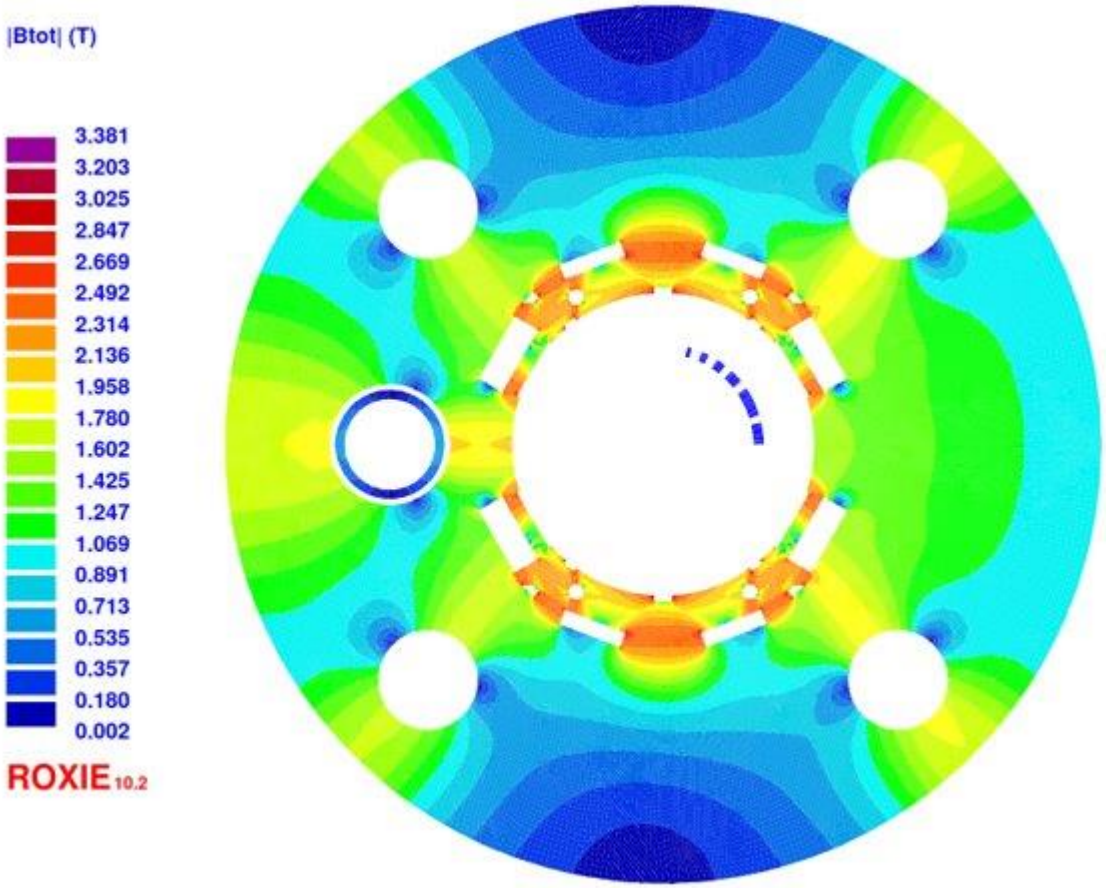
- A good field quality must be maintained at all fields.
- Non-linear properties of yoke iron creates field errors.
- A change in design approach brought large reduction in change in field harmonics in RHIC (and SSC) magnets.
- Rather than removing the saturating iron, we forced the iron to saturation more uniformly with holes and cutouts.
- EIC needs RHIC magnets (arc and IR dipoles and quads) to operate ~10% above the RHIC design field. This approach assured field quality for all RHIC magnets in EIC.

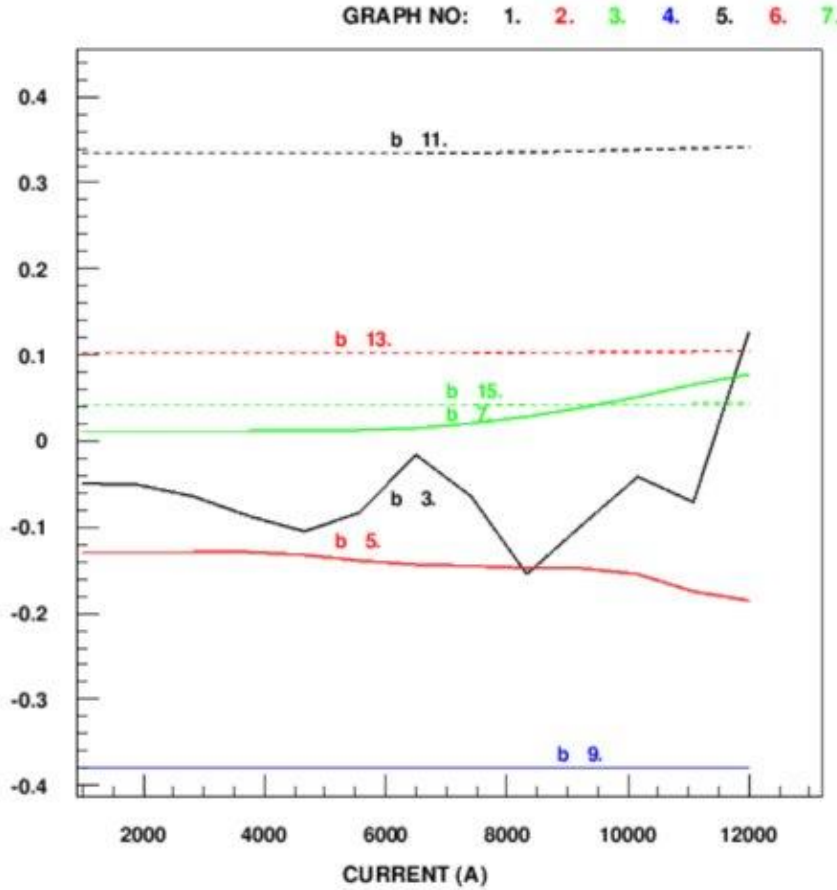


# Field Quality as a function of Current in EIC IR Dipole B1pF

(particularly challenging in B1pF due to so many, and so large cutouts near the yoke inner surface)

- Experience and techniques developed during RHIC are getting applied to EIC IR magnets now.




All harmonics within +/-1 unit

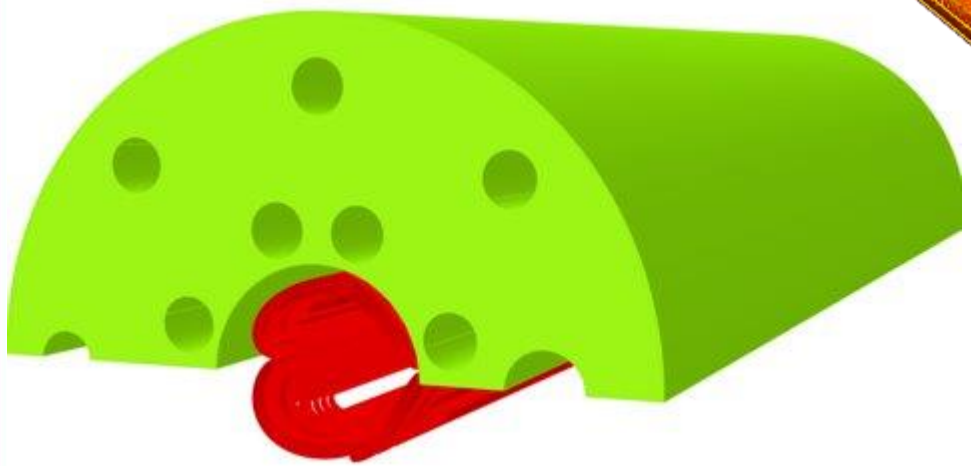
Courtesy Febin Kurian

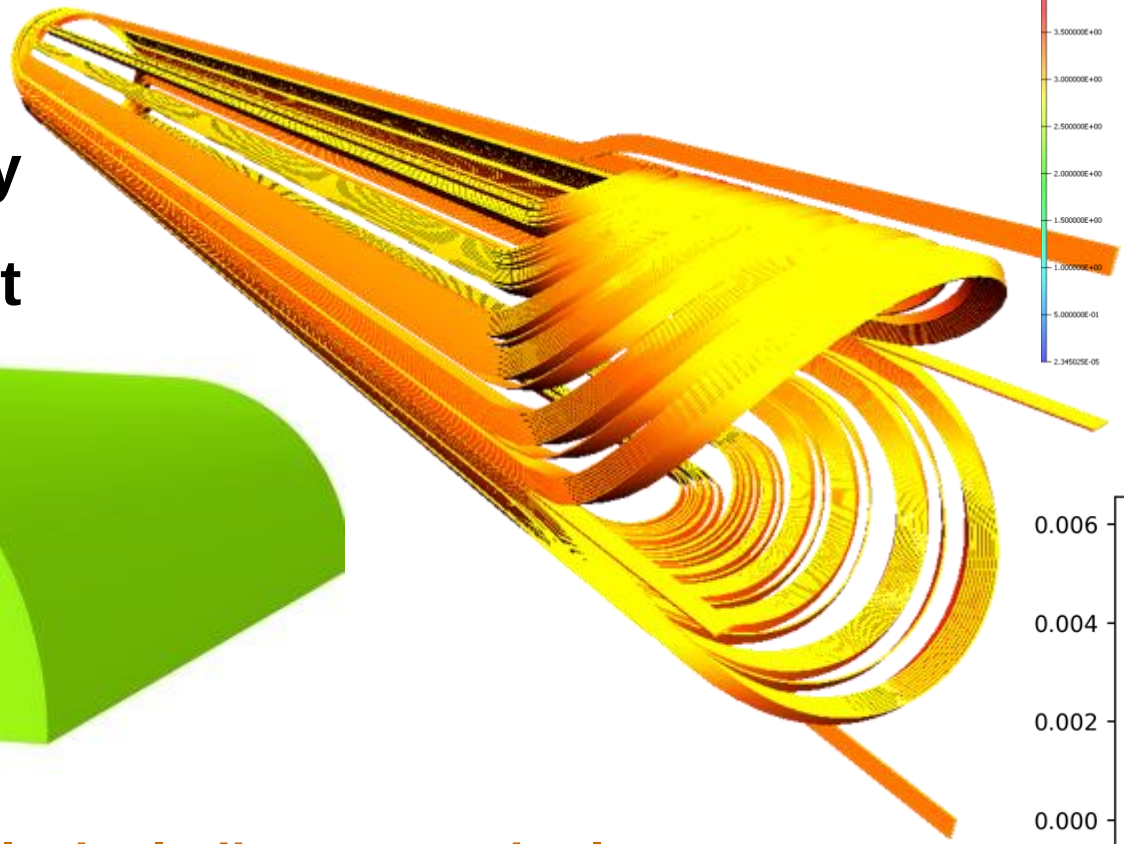
- **Large cutouts near the yoke inner surface cause extensive iron saturation (non-linear). We force it to become uniform to make impact on error harmonics lower.**

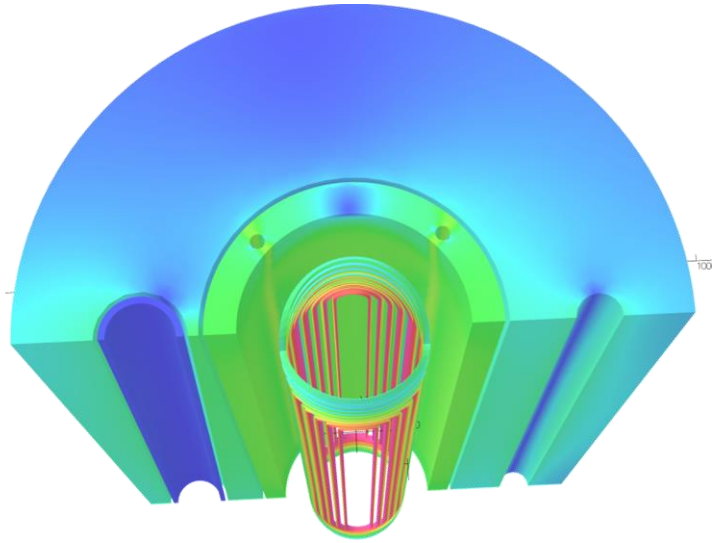
# End Design: Example EIC IR B1pF (most advanced)

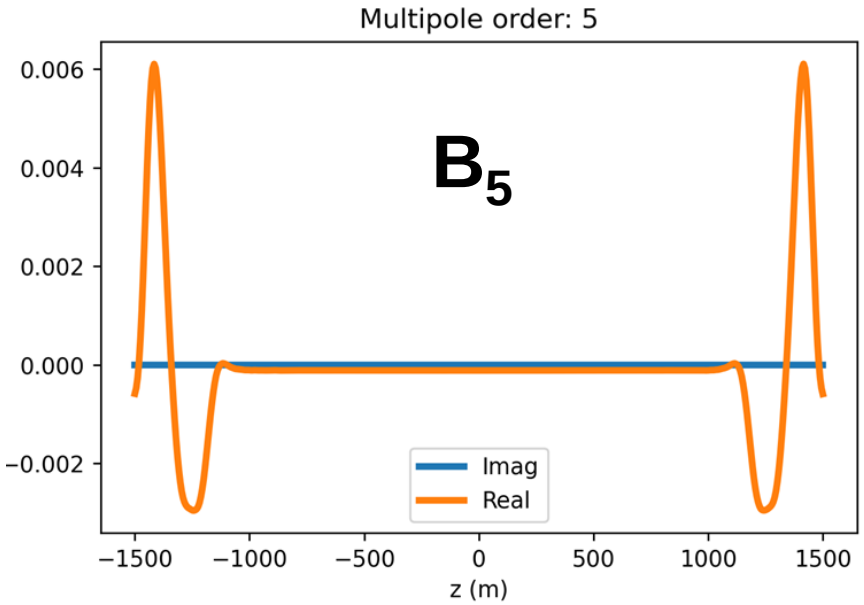
**Goals and criteria of a good end design:**

- **Low peak fields**
- **Good field Quality**
- **Mechanical layout**





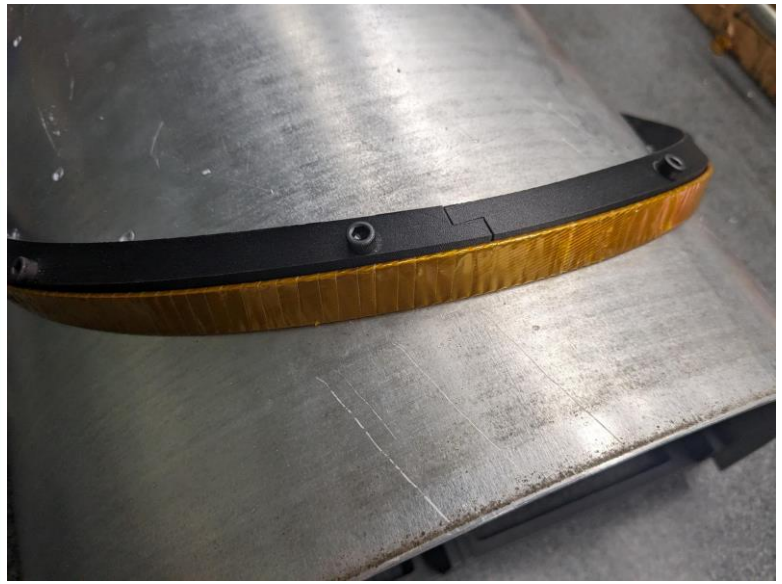


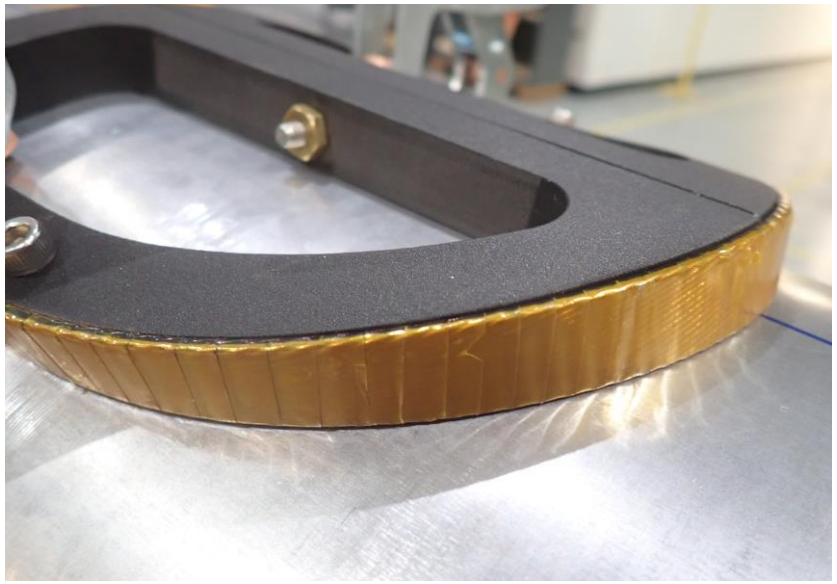


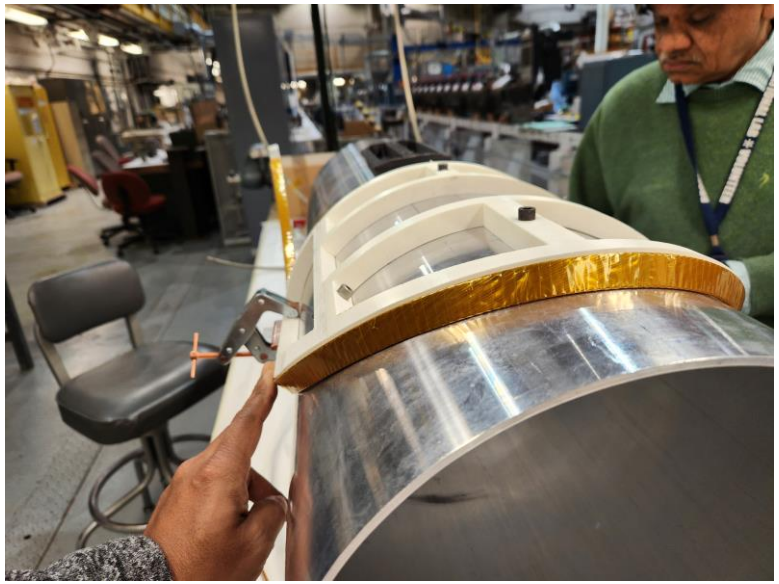

**Extensive winding trials, including many single turn winding tests, were very important (next slide)**

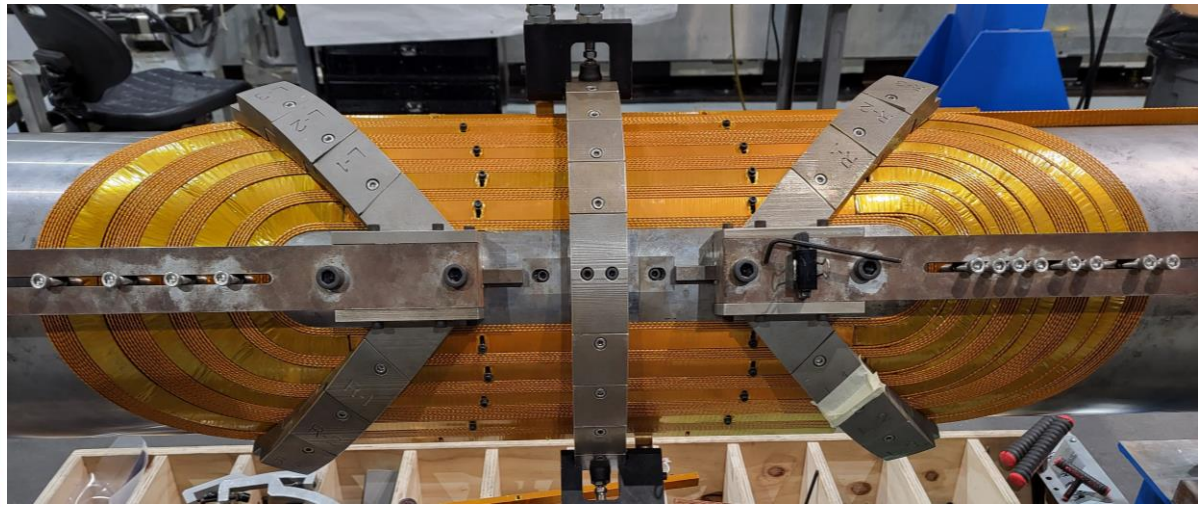
**Courtesy: Febin Kurian**

# Winding with Extensive Trial Runs (including single turn)





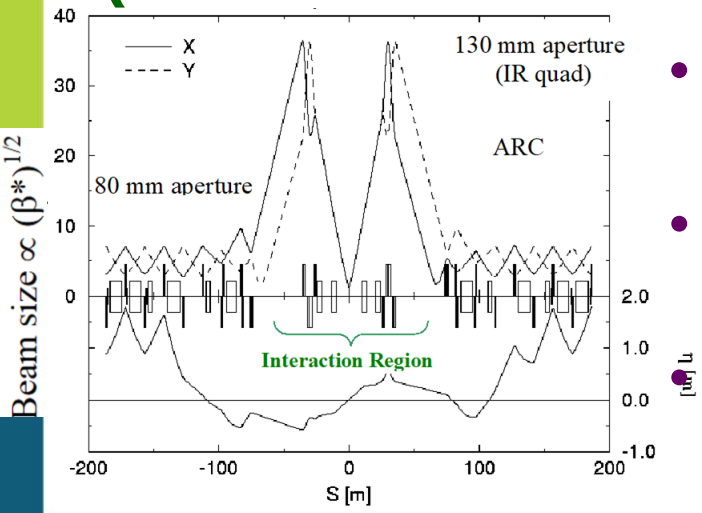


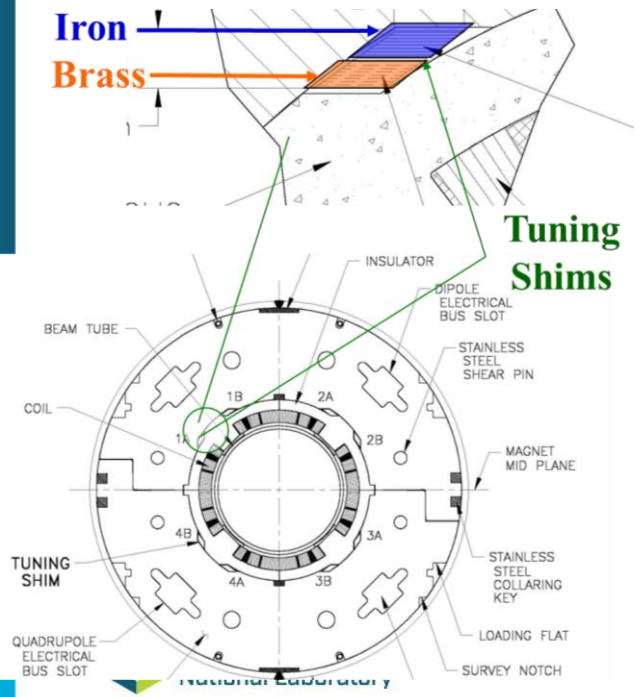


- **Clamps play important role**

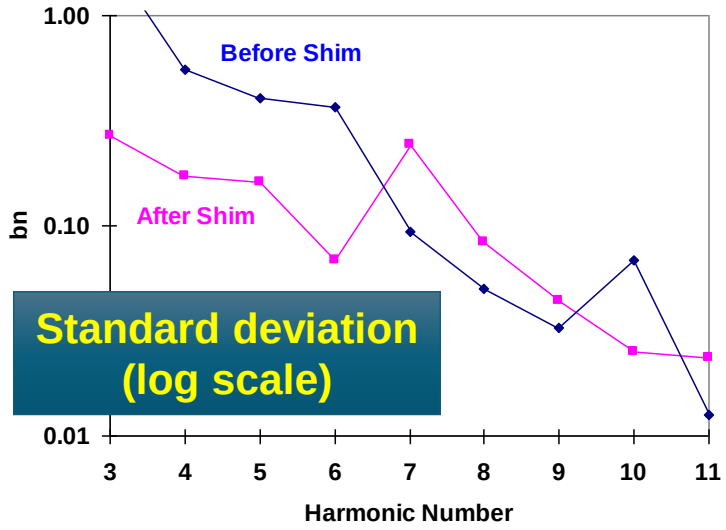
# Tuning Shims for Ultimate Field Quality in RHIC IR Quads

## (to be used in EIC for avoiding expensive and time-consuming iterations)

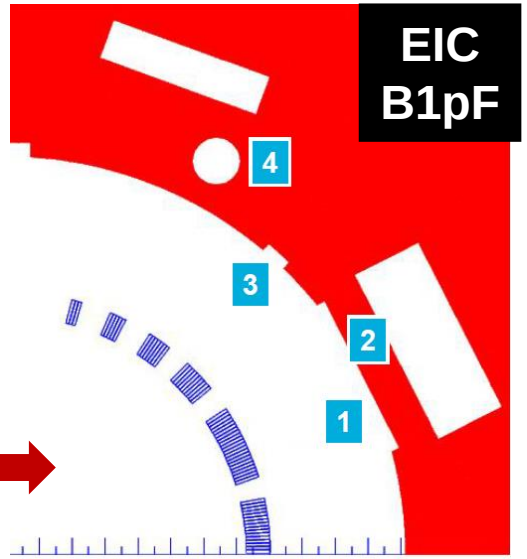



- Whereas the ratio of the beam size between arc magnets and IR quads is ~7, the ratio between the bores is only ~1.6.
- The ultimate luminosity of RHIC depends on the field quality of "IR Quads"; entire bore, not the typical 2/3 must be good.
- Tuning shim method was invented and utilized to cancel out the errors from the construction; just as in MRI magnets.
- Ultimate field quality obtained since the harmonic changes from the quench/thermal cycle are larger than the residual.



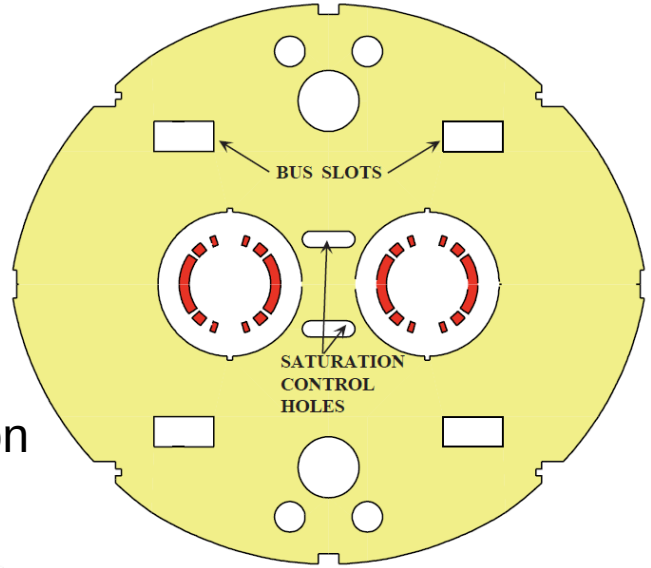

**Tuning shim technique is planned to be implemented in EIC B1pF and other magnets**



# SUMMARY

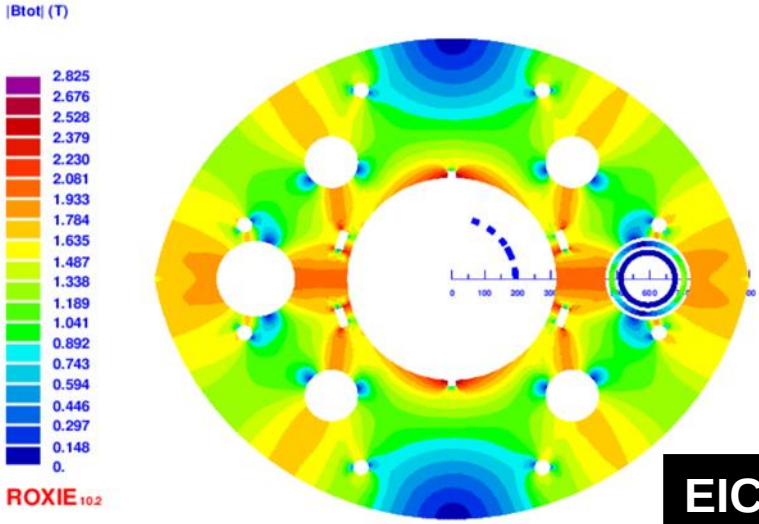
- **This presentation highlighted the advanced aspects of the magnet designs and technology developed during RHIC, SSC, LHC and other accelerator magnet programs that are being applied to EIC (not all presented, e.g., see one below).**
- **In addition, success of any superconducting magnet depends on paying attention to details, even to the routine aspects of the design and construction.**
- **The value of magnet division to EIC is the unique experience of working with superconducting magnets and passing that knowledge to the next generation.**

2-in-1 dipole
- a BNL invention
(Bob Palmer)




**LHC IR Dipole from BNL**

LHC IR oblate yoke
design to EIC IR oblate




**Courtesy: Mithlesh Kumar**

**EIC B1ApF**