BNL LARP Dipole R&D

Ramesh Gupta
Superconducting Magnet Division
Brookhaven National Laboratory
Upton, NY 11973 USA

Contents

High Field Magnet R&D at BNL

- Update on the Conceptual Design of the LHC IR Upgrade Dipole
  - Open midplane dipole concept looks more promising now.
- React & Wind Program at BNL
  - Mixed results from Nb_3Sn and HTS cable and test coils.

Some Special Considerations for LHC Upgrade Magnet Designs

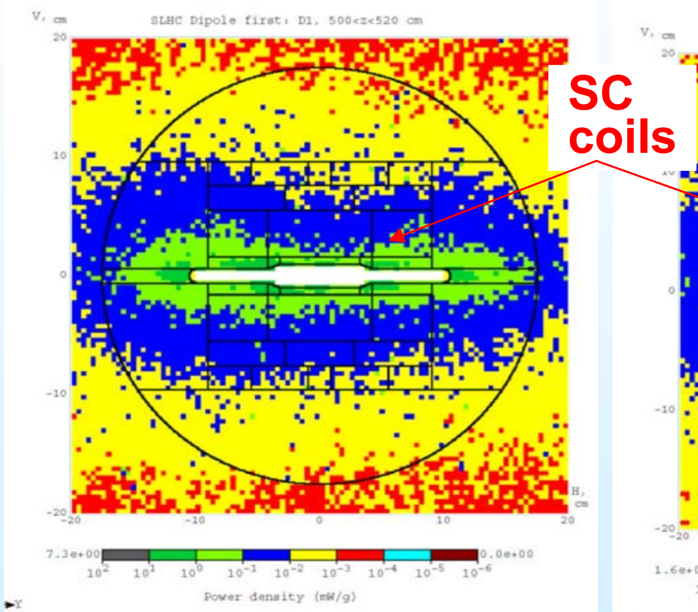
High luminosity Interaction Regions (IR) present a hostile environment for superconducting magnets due to large amount of particle spray from Interaction Point:

- ~9 kW of power from each beam for 10^{35} luminosity.
- Several hundred W/m of energy deposition in first dipole (D1).
- Energy deposition raises overall and local coil temperature. This brings a reduction in operating margin or may even cause a pre-mature quench. Radiation damage issues should also be examined.
- Heat removal poses a significant challenge, both in terms of technical performance and in terms of economical operation of IR magnets.
- Energy deposition is anisotropic with a large peak at the midplane.

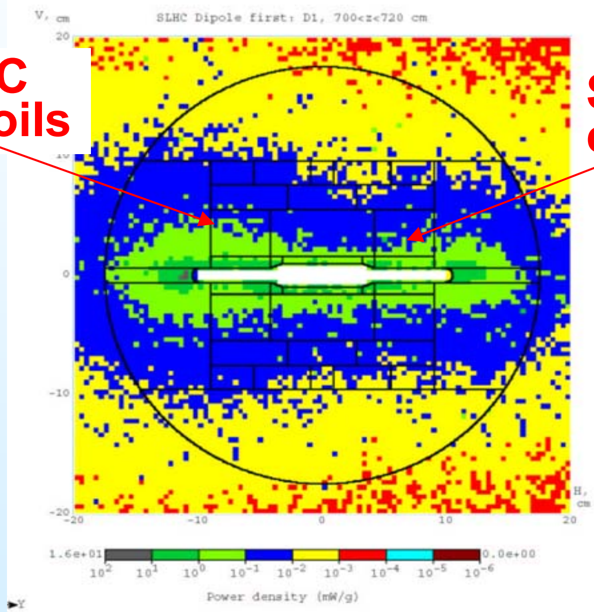
Energy Deposition Calculations (As Presented at Archamps, 03/03)

Energy deposition at various axial position along the axis

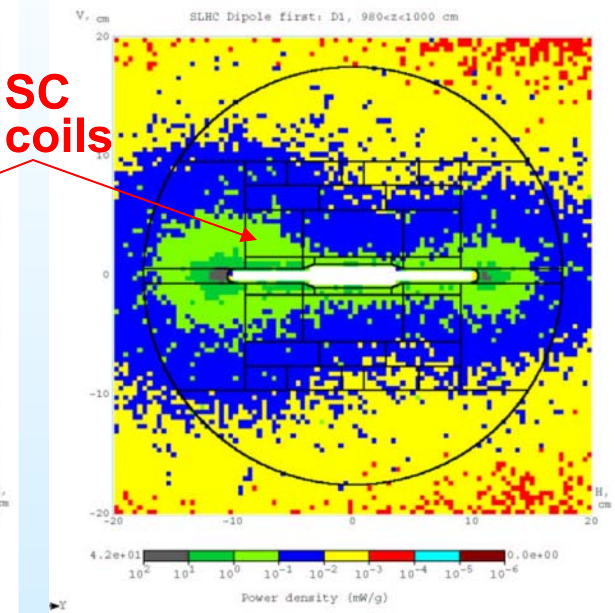
Computed by Nikolai for a Luminosity of 10^{35} (10X over present design)



@Middle (z=>5m-5.2m)



@70% (z=>7m-7.2m)



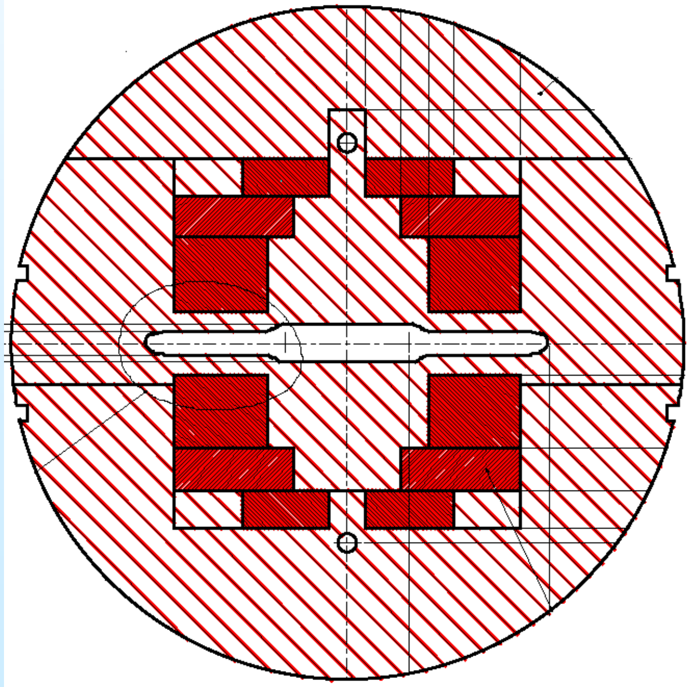
@End (z=>9.8m-10m)

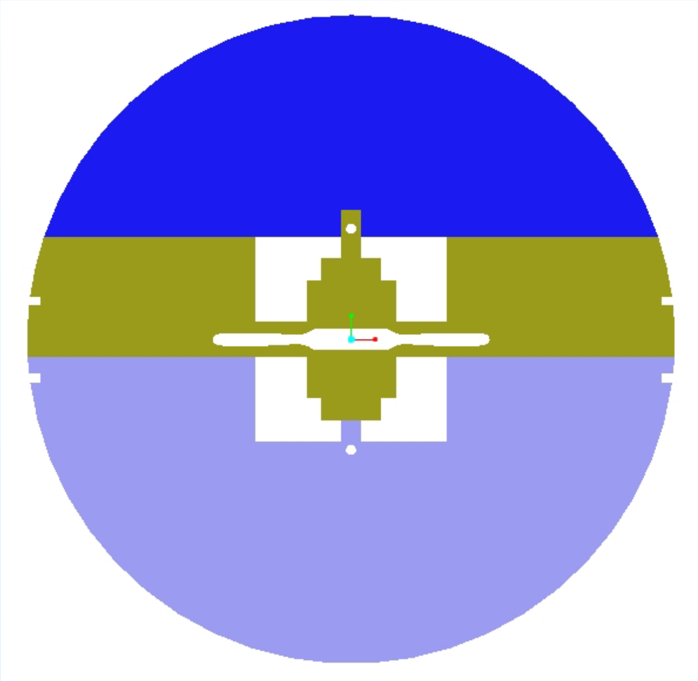
Peak power density in the superconducting coils is only 1-1.3 mW/g, i.e., below our current quench limit of 1.6 mW/g even at 10^35 luminosity!!!

Total power dissipation: TAS: 3.17 kW, D1: 0.90 kW, TAN: 2.45 kW.

Support Structure for Cold Iron Concept (As Presented at Archamps)

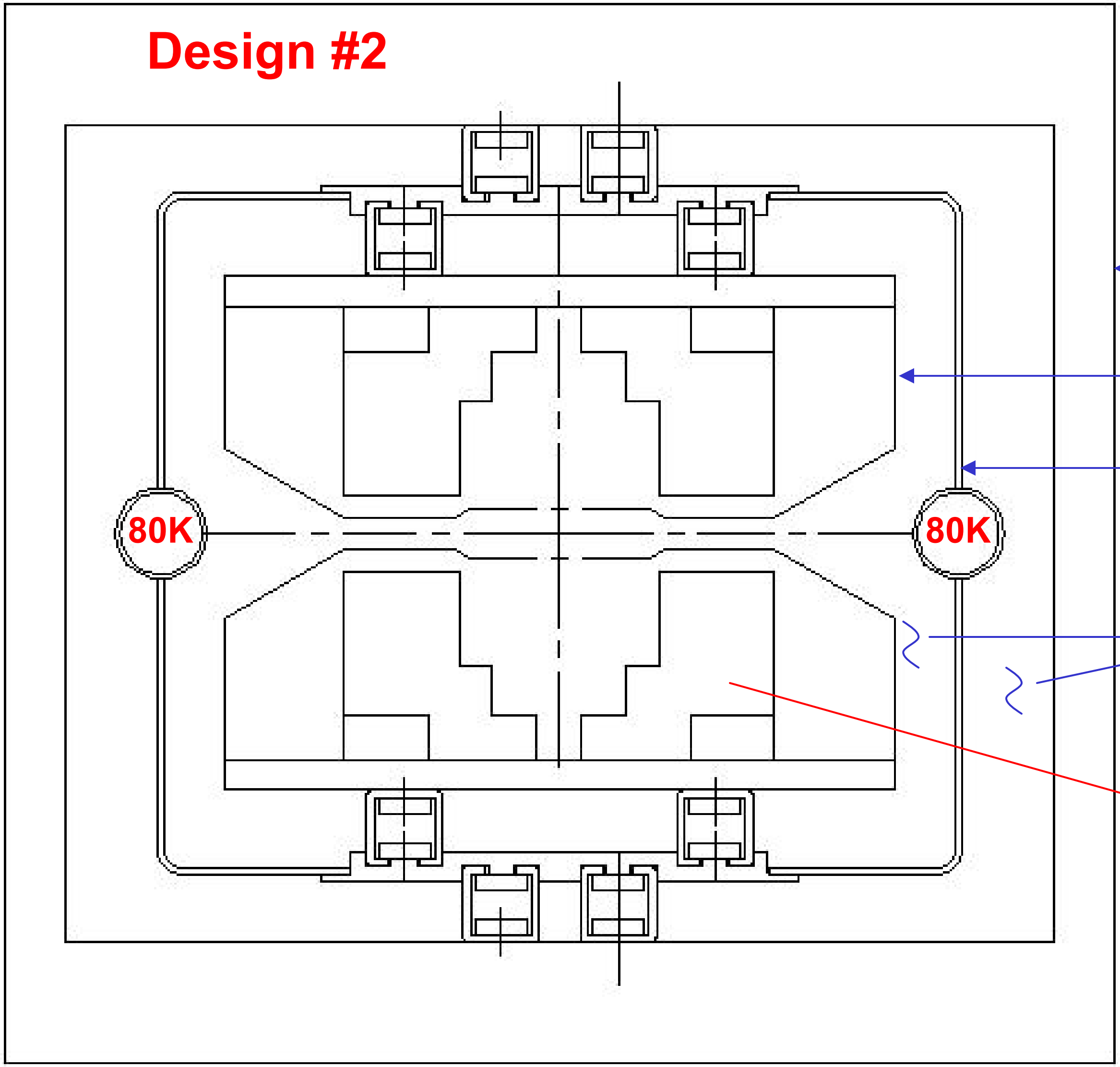
By open midplane, we mean really open midplane; particle spray from IP that is mostly at midplane, pass through the open region to outside the coil without hitting anything. In earlier designs, although there was no conductor at the midplane, but the other structure was. The secondary shower were created when that other structure was hit. The energy deposited on the coils by the secondary shower became a serious problem and, therefore, the earlier open midplane designs were not all that attractive.





Design #1:
Decay products hit the external structure at 4K.

Support Structure for Warm Iron Concept (As Presented at Archamps)



Dump energy in a relatively warmer structure

(more efficient heat removal)

Cryostat (300K)

Coldmass (4K)

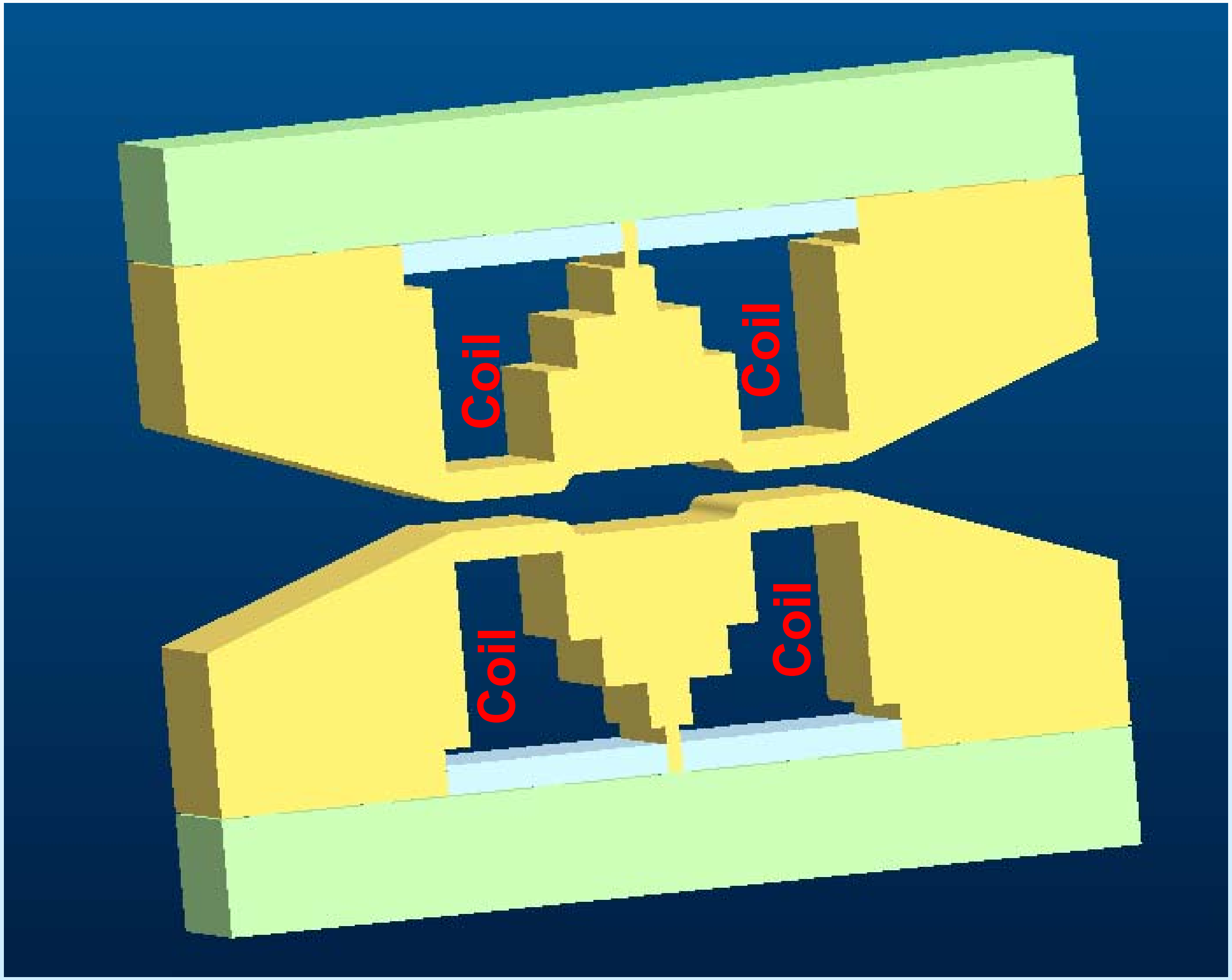
Heat Shield (80K)

Vacuum Space

Superconducting coils

Warm Iron Design

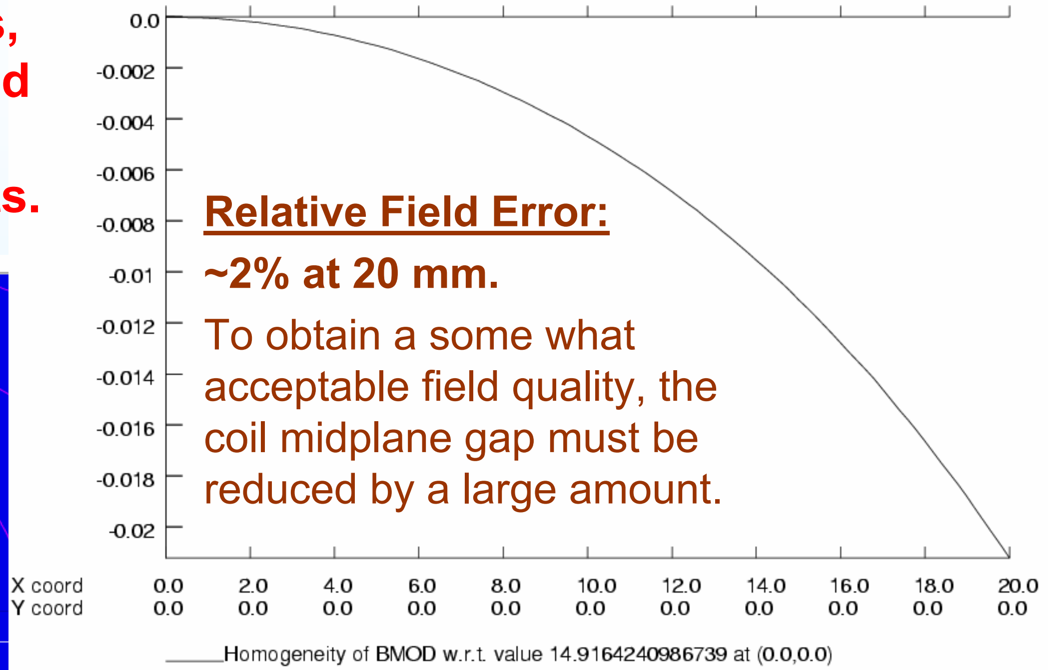
Update on the Mechanical Design



Mike Anerella's presentation for more details and updates on the mechanical design and analysis of the support structure.

Field Quality in the Design Presented at Archamps

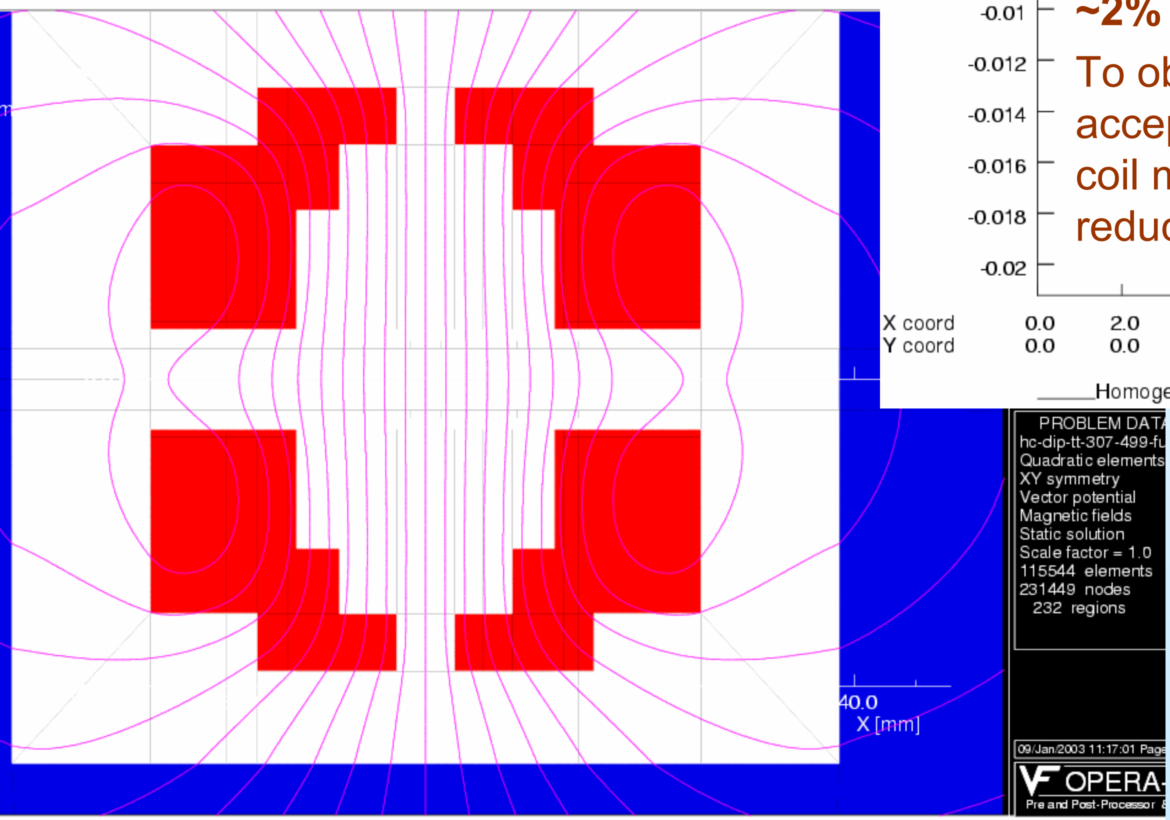
In the design presented at Archamps, the coil midplane gap was determined by the heat deposition, support structure and cryogenic requirements.



Relative Field Error:

~2% at 20 mm.

To obtain a some what acceptable field quality, the coil midplane gap must be reduced by a large amount.

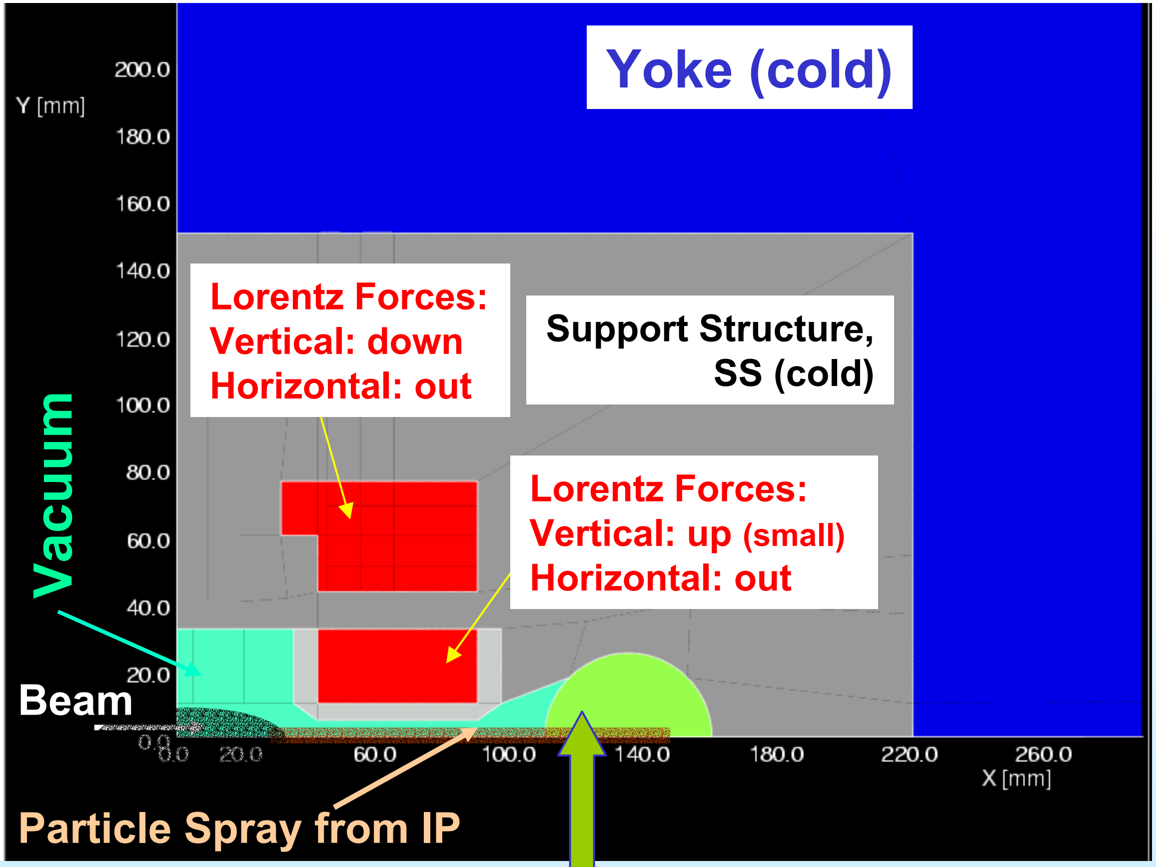


Large Gap at midplane => field lines bulges out;

Field errors are ~ 2 order of magnitude too much!

How to satisfy these conflicting requirements?

Open Midplane Dipole Concept Updated



A large amount of particles coming from high luminosity IP deposit energy in a warm (or 80 K) absorber, that is inside the cryostat. Heat is removed efficiently at higher temperature.

- Particle spray from IP go through the open midplane and dump most of their energy in a cryo-insulated warm absorber.
- The lower coil block has small upward force and upper coil has large downward force. The large downward force is taken out in a segmented support structure.
- The lower coil block is now brought closer to midplane to produce a good field quality design.

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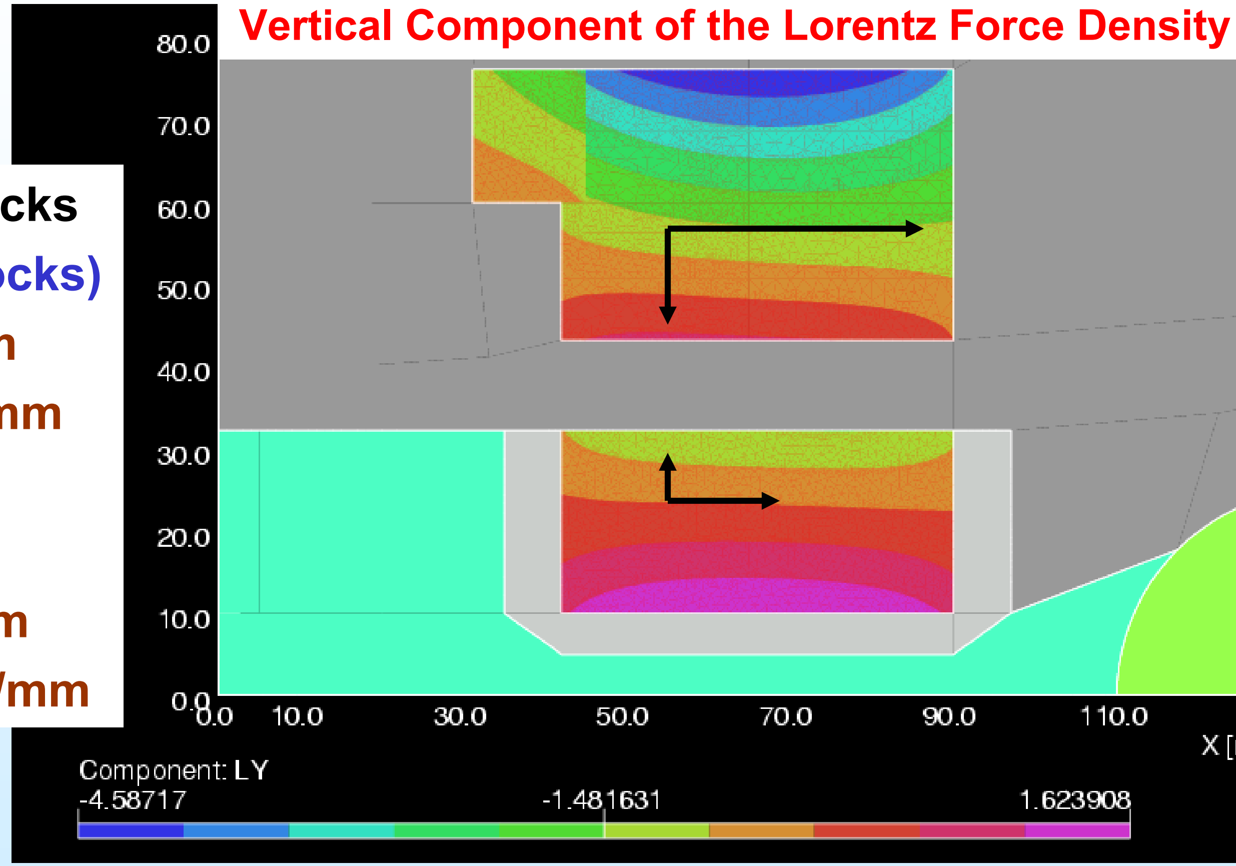
Vertical Force Containment

Upper-right quadrant

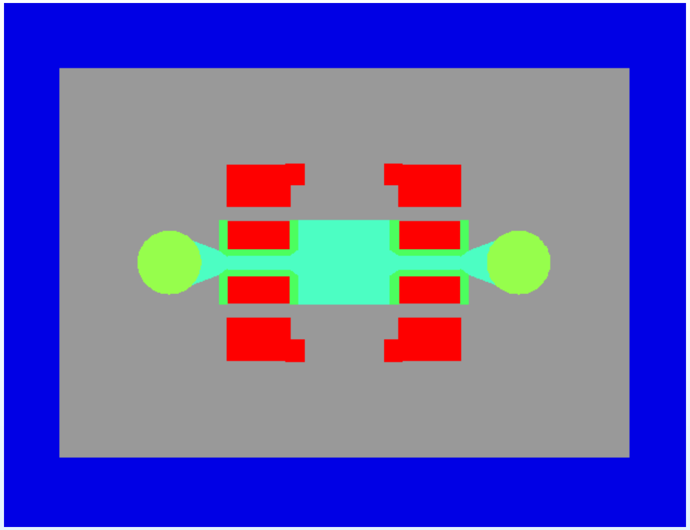


Lorentz Forces on the Blocks

- **Total (Upper + Lower Blocks)**
  - **Vertical: -3 kN/mm**
  - **Horizontal: 7 kN/mm**
- **Lower Coil Block Only**
  - **Vertical: +0 kN/mm**
  - **Horizontal: ~3 kN/mm**

Since there is no downward force on the lower block (there is slight upward force), we do not need much support below it, if the structure is segmented. The support structure can be designed to deal with the downward force on the upper block using the space between the upper and the lower blocks.

Vertical Force Transfer Columns (Think outside the magnetic box)

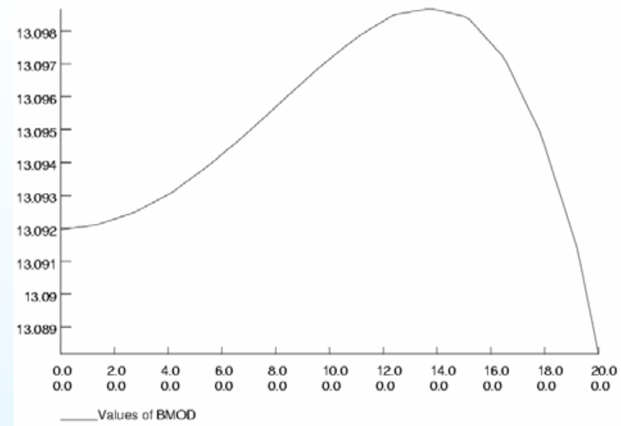


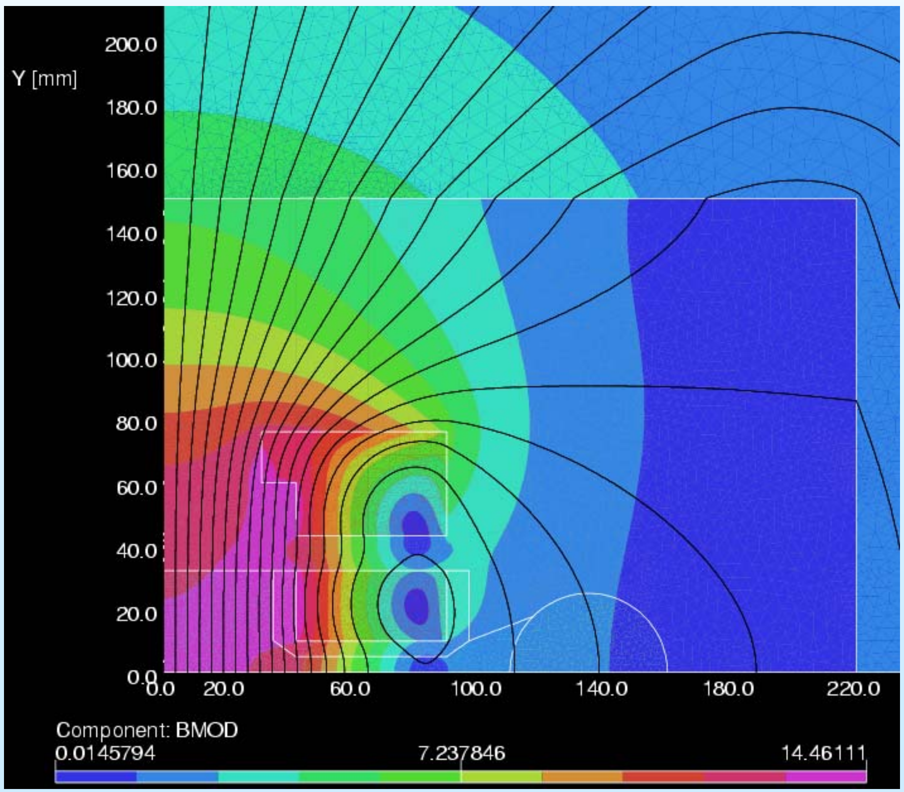
- We are used to having a solid base under the coil midplane for dealing with vertical forces.
- However, the forces can be transferred to the outside columns, as done in the bridges.
- Coil geometry is optimized such that the lower block has small upward force. The lower block can now be brought closer to the midplane to improve field quality.
- The space between the two vertical blocks is determined by structure and magnetic requirements.
- More than minimizing overall deflection, minimize the relative deflection. Experience from the common coil design indicates that the coil can move as a whole (~mm), without causing a quench. Small change in field harmonics due to Lorentz forces should be optimized, together with the saturation induced harmonics.

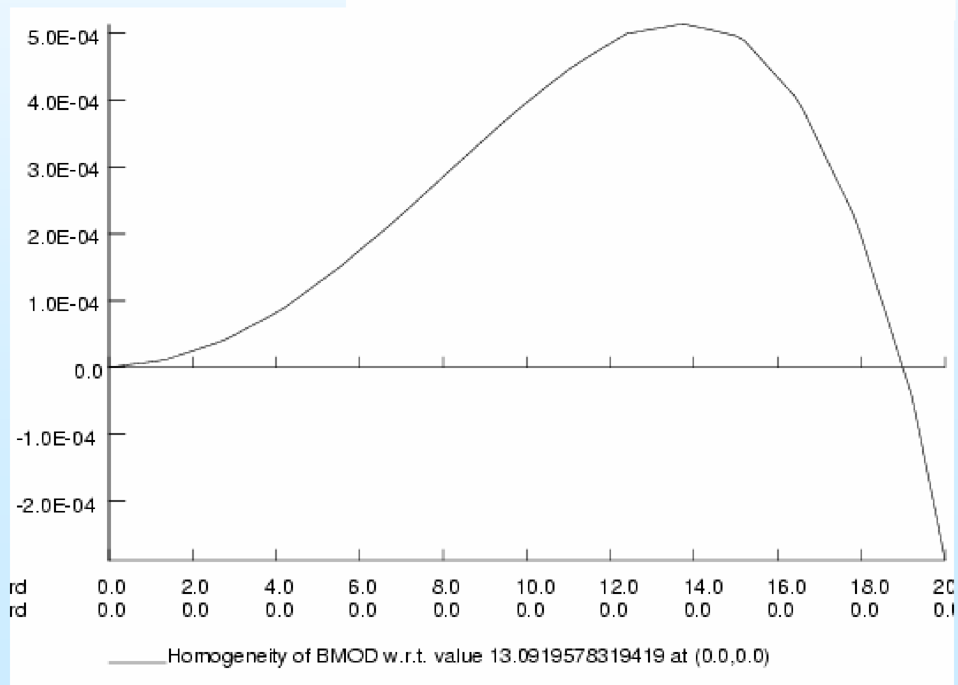
Improvement in Field Quality

A reduction in midplane gap, straightens the field lines at midplane and improves the field quality.

The actual field quality optimization will be done with the coil optimization programs. But 10^{-4} relative error implies that a magnetic design with low harmonics is possible.

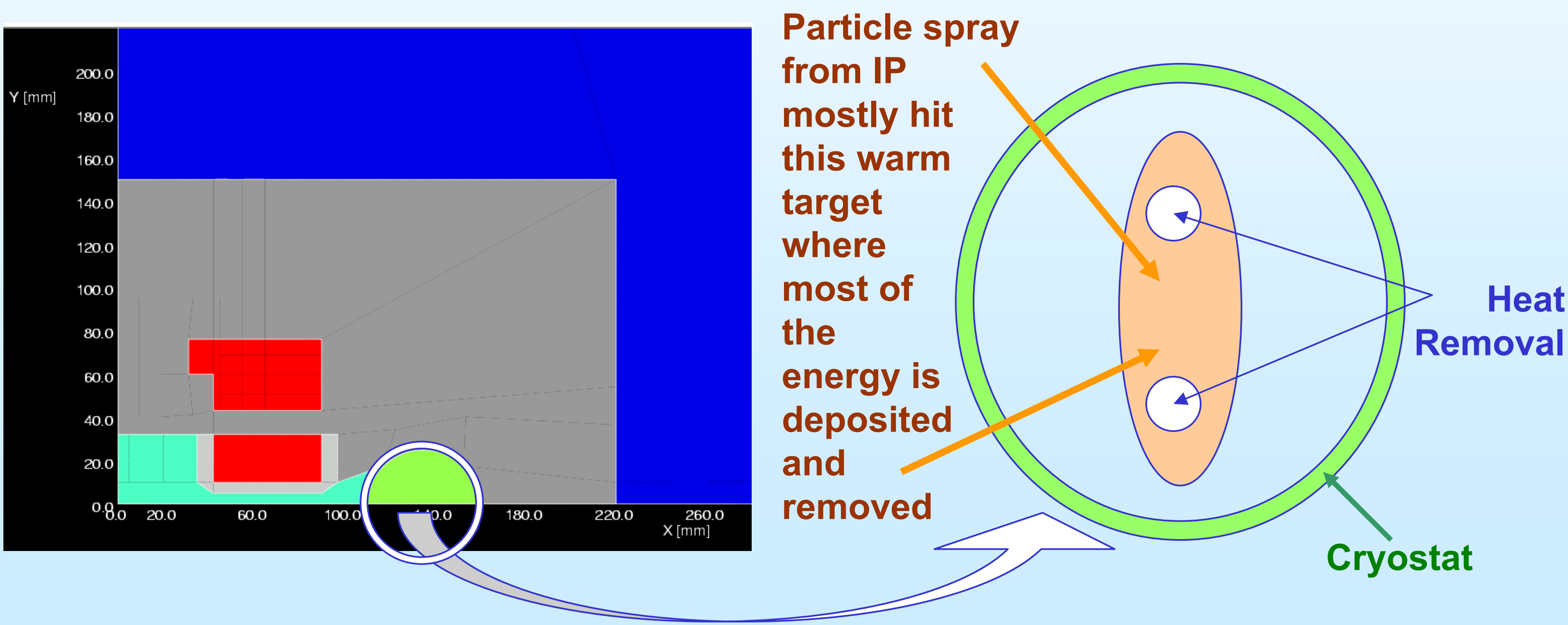




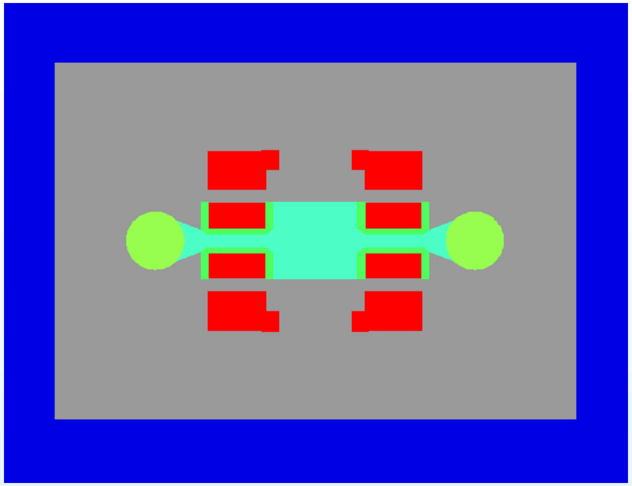


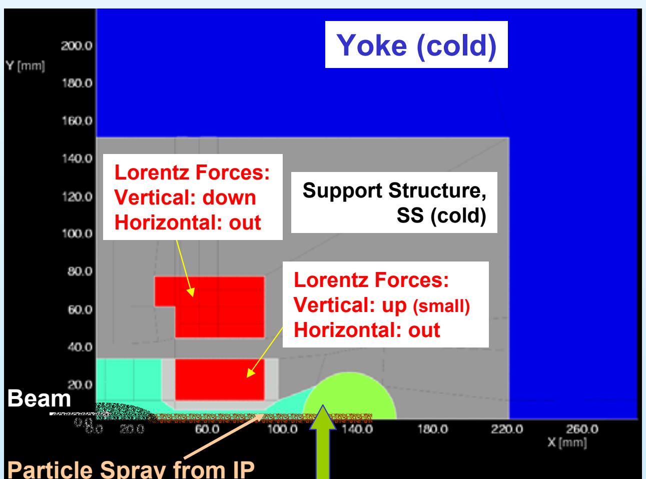
Energy/Heat Removal

The design philosophy is that a warm island is created inside the support structure (cold) but outside the coils. Most of the energy will be deposited in this warm island from where it can be removed efficiently. The warm island is placed inside a separate cryostat.



Future Work on the Open Midplane Dipole Design





A large amount of particles coming from high luminosity IP deposit energy in a warm (or 80 K) absorber, that is inside the cryostat. Heat is removed efficiently at higher temperature.

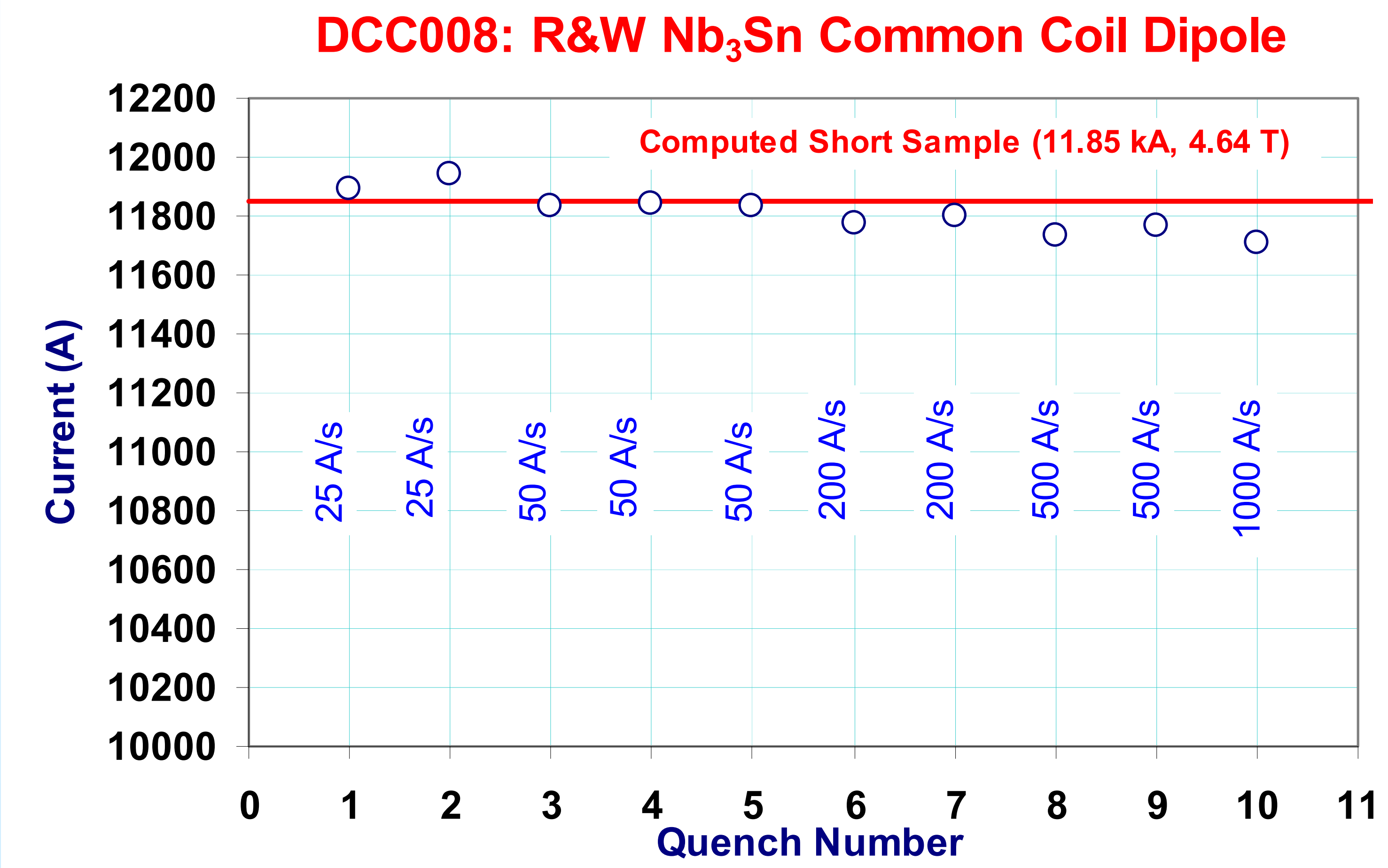
The development of the overall magnet design is expected to be an iterative process. For an optimum design it requires input from:

- –The beam optics.
- –The minimum free space at midplane we can get away with
  - ➢Feedback from Nikolai Mokhov on the minimum clear space required.
  - ➢What is the minimum structure required below the lower coil?
- –Development of an overall structure.
- –Development of the warm target and heat removal system which includes developing a compact cryostat design around the warm target.
- –A good magnetic design with an acceptable field quality.

Test Results of Mini R&D Program for React & Wind Nb_3Sn and HTS Technology

- **Nb_3Sn React & Wind Program**
  - Mixed results.
  - Aggressive; e.g., as compared to that in Fermilab program, the wire diameter is larger and coil bending radius is smaller => computed strain is 60% higher.
  - Are we being too aggressive or we both are facing some fundamental problems?
- **HTS Cable and Test Coil Program**
  - It has been an encouraging experience so far.
  - Test results of longer length cable and HTS coils in background field continue to show progress.
  - We still need higher current densities, and there seems to be some room for improvements.

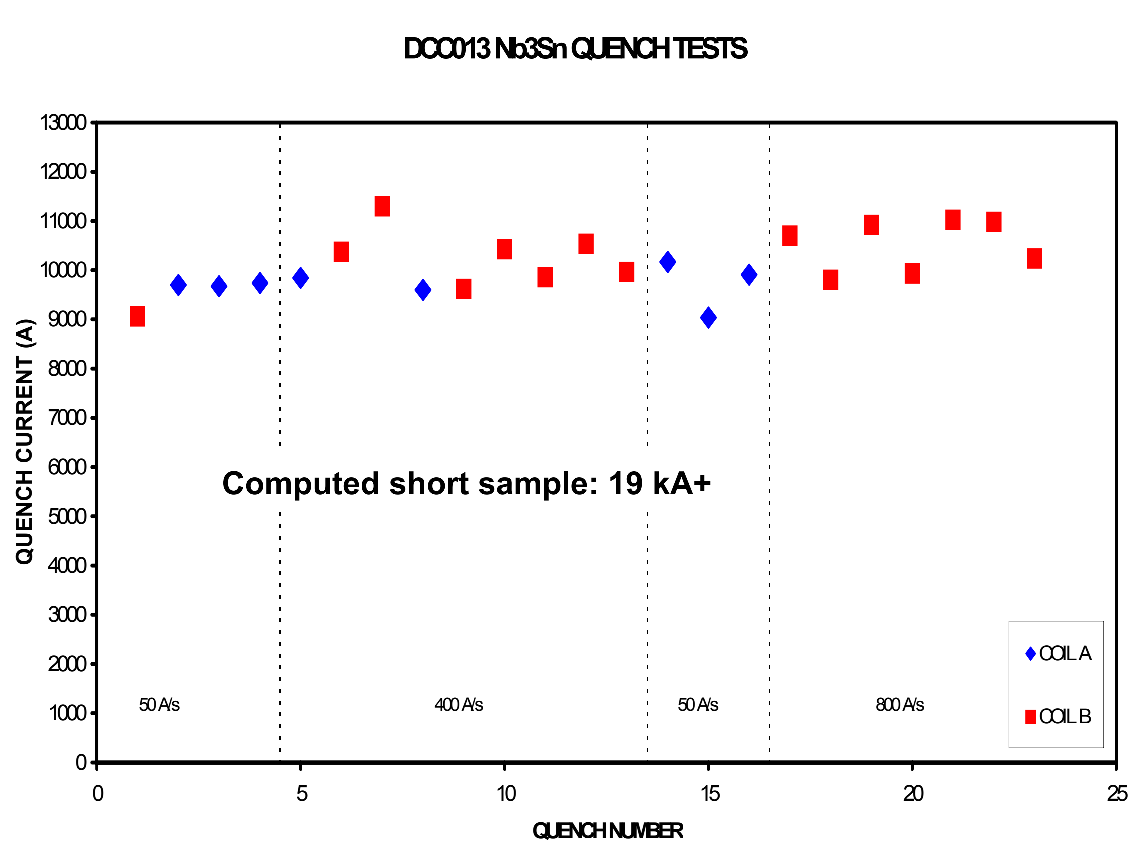
Initial Experience with React & Wind Nb_3Sn Technology Magnet



- Good test result from the R&W common coil dipole magnet made with ITER cable.
- Perhaps too good and we got carried away with such a nice performance.

Current Status

Test Results of the Last Magnet Tested



Both coils quenched but all quenches were in the first turn.

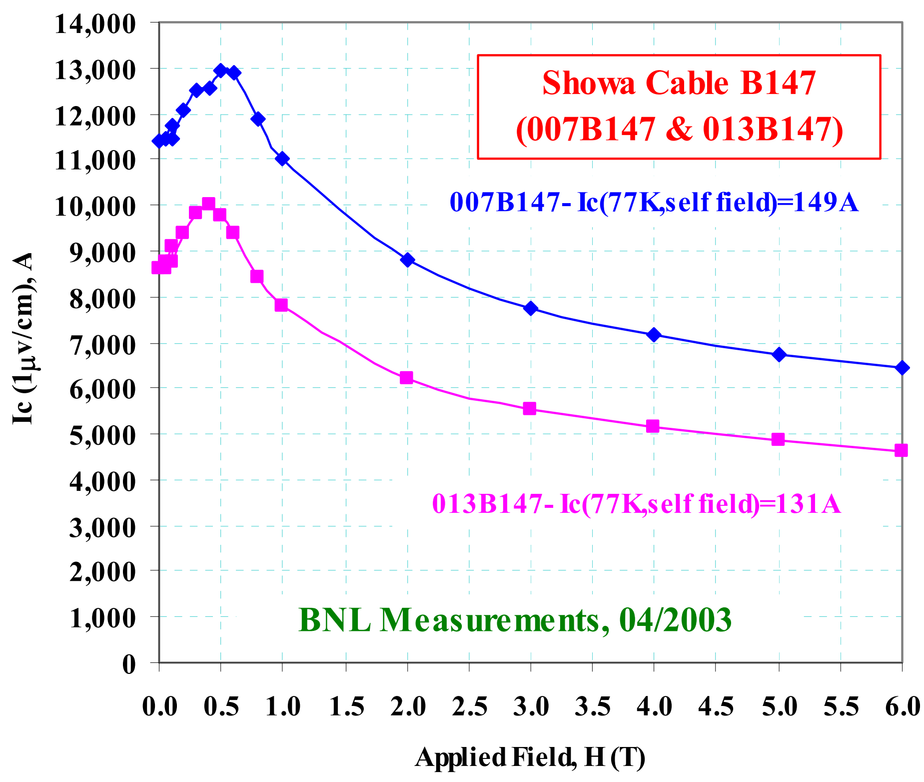
Possible causes:

- **Bending degradation**
- **Special issues related to first turn (geometry, splice, etc.)**
- **Kevlar string causing large local strain on the cable**
- **Bonding between Nomex insulation and turns**
- **Mechanical (zero pre-stress)**
- **Practical issues (technicians keep changing)**
- **Other fundamental issues: conductor stability, etc.**

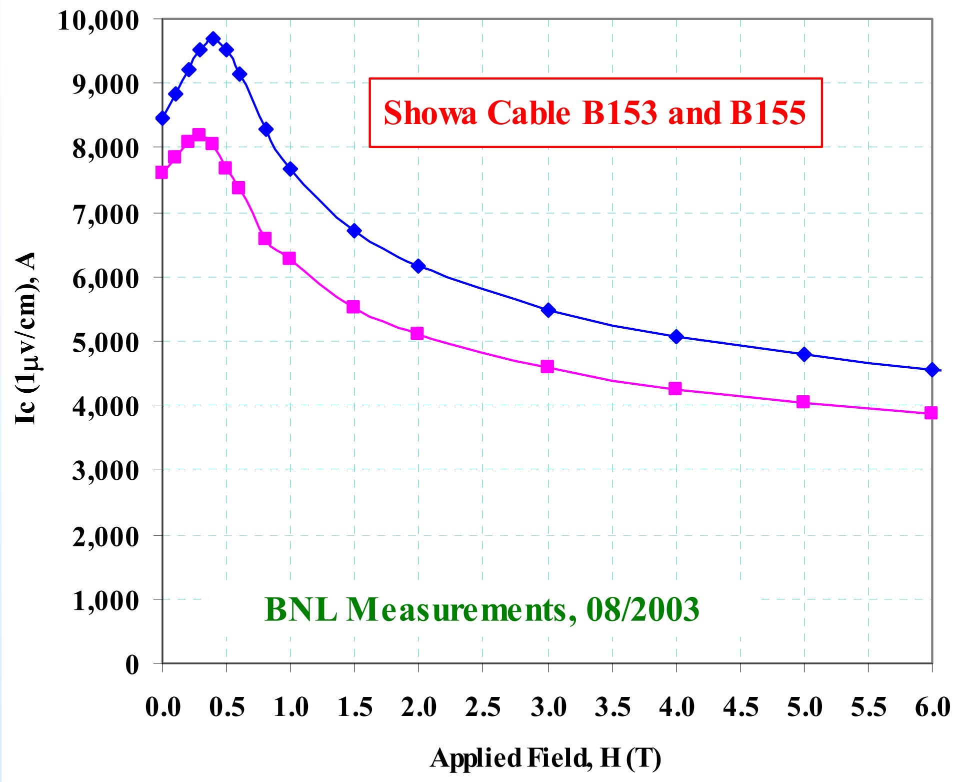
Is the performance limited by (a) mechanical and/or handling issues or (b) some thing more fundamental like conductor stability, bending strain, etc.
Personal opinion: We have not reached a stage yet to conclude either way.

HTS Cable Test Results
(BSCCO 2212 from Showa: 30 strand 0.8 mm dia)

Measurements in short (2 m long) cable



Measurements in longer (10-100 m) cable



- HTS cables continue to show improvements. However, note a lower performance in longer cables.
- Two coils have been just wound with the two cables plotted on the right and they will be tested soon.

HTS cables now carry a respectable current, but we still need more!

Performance of HTS Coils in the Background Field of Nb_3SN Coils

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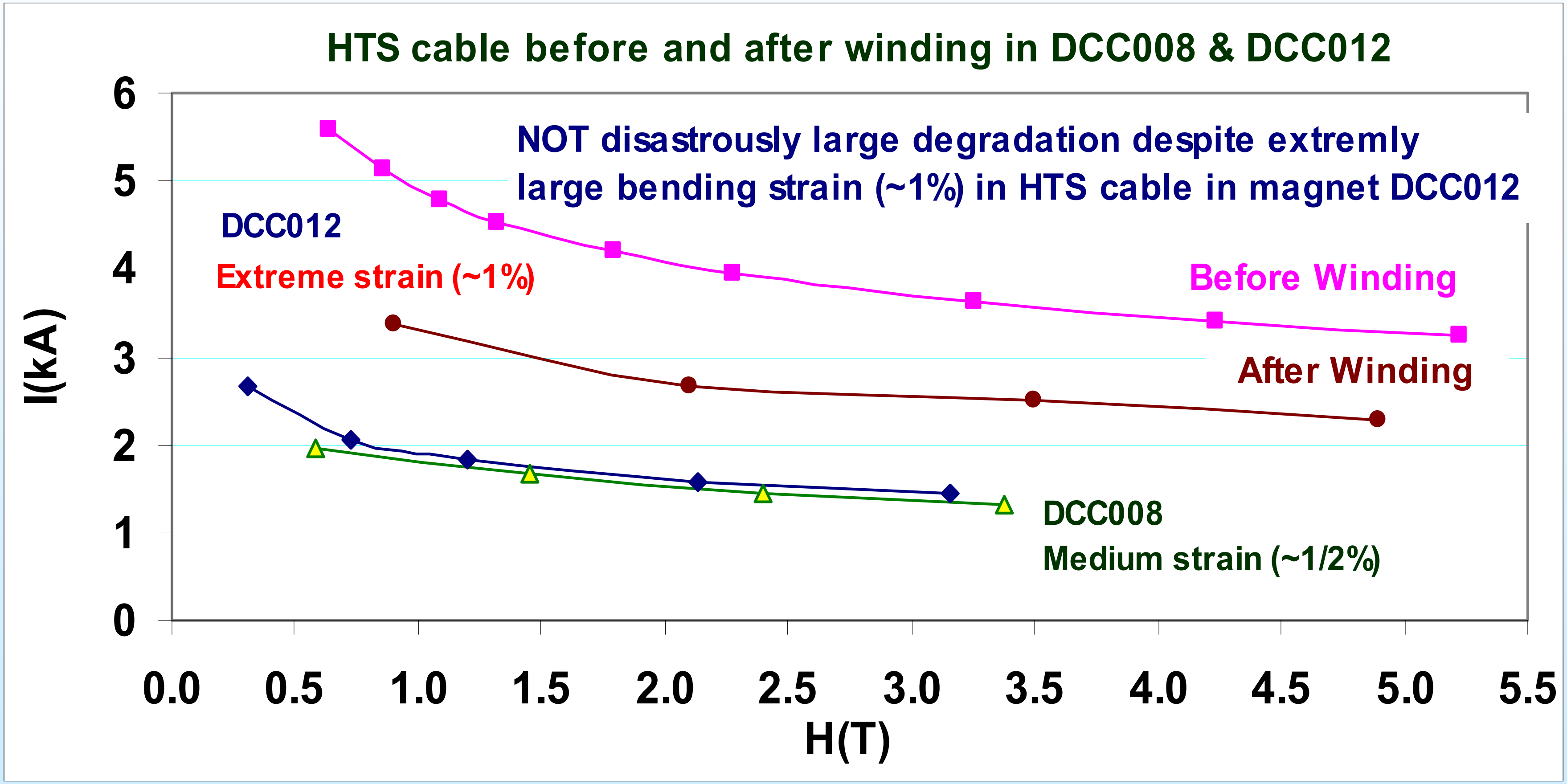
Test results show that coils can be made with HTS Rutherford cable.

DCC008 (cable with 0.8 mm wire) and DCC012 (cable with 1 mm wire, ~1% bending strain).



Recently two coils have been wound with the cable having a lower bending strain. They are expected to carry 4^+ kA at high fields (expect test results in MT18).

Summary

- "Open Midplane Dipole Design" seems to offer a good technical and an economical option for LHC luminosity upgrade in dealing with the challenges associated with such a large increase in luminosity.
- The concept is exciting and is still evolving; it's a fun thing to work on. The overall design is yet to be optimized, however, it looks more and more promising with the preliminary calculations indicating that:
  - ➢ The energy deposition in superconducting coils can be made small so that it remains below the nominal quench limit.
  - ➢ It may be possible to remove energy at a higher temperature and therefore, bring a significant reduction in the operating cost.
- At this stage, one must explore various options and look for new possibilities. This should be supported by a minimum R&D to develop the base technology. This will assure that when it comes time to make a choice, we have the necessary and complete technical input.