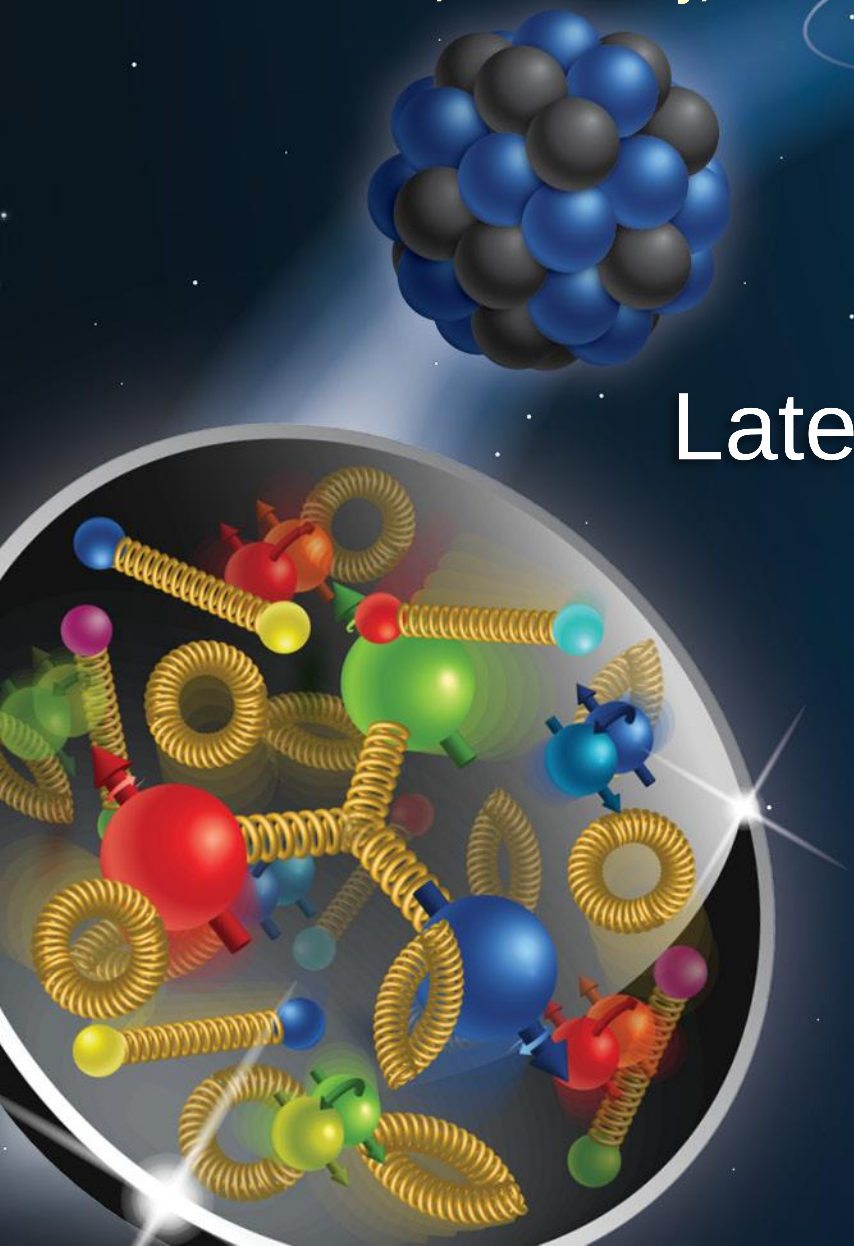
Electrons for the LHC - LHeC/FCCeh and Perle Workshop
27 – 29 June 2018, LAL Orsay, France.



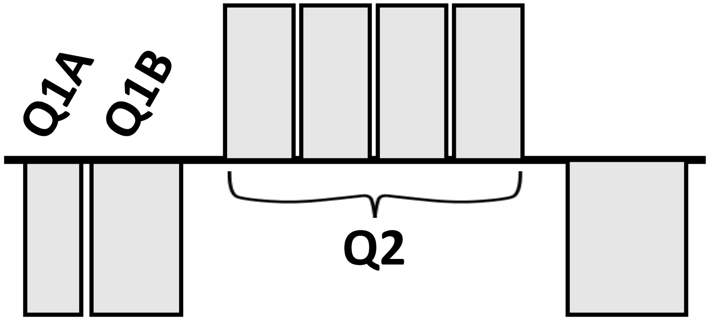
Latest Developments and Progress on the IR Magnet Design

Brett Parker, BNL / SMD

Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

Presentation Outline



- Summarize the need for a baseline change; introduce superconducting self-contained coil concept.
- For Q1A / Q1B achieve minimum d_{min} using a slotted quadrupole symmetric yoke (control field outside coil).
- For Q2 maximize external, field-free region by using an active shield coil (i.e. brute force kill field outside coil).
- Briefly report on high field (Nb_3Sn) R&D on an actively shielded coil structure for an EIC quad (Fast Track Test).

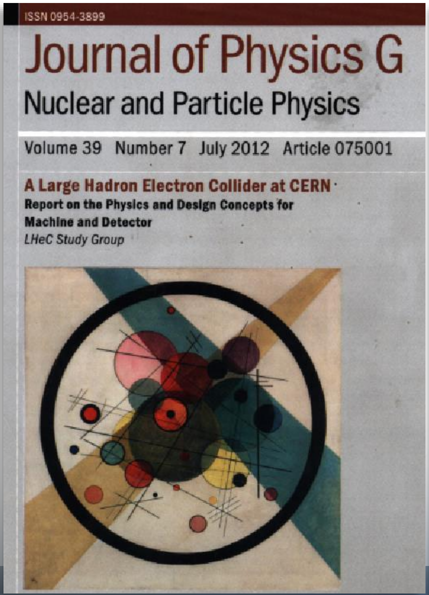
Recent Progress on IR Magnets

In preparation for the present meeting we revisited the design concepts for the first few LHeC IR quads during a two week period at CERN, May 2018. See:

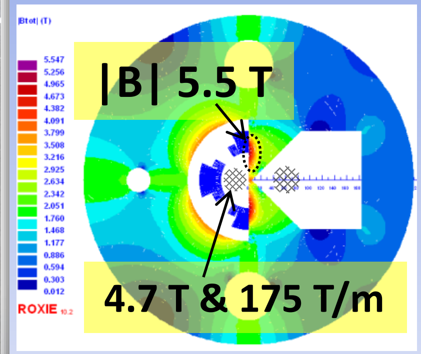
https://indico.cern.ch/event/727278/

https://indico.cern.ch/event/731311/

- The mirror quadrupole concept shown to the right (from the 2012 design report) is not viable.
- Large-angle synchrotron radiation (synrad) from separation dipole should pass further from IP in order to minimize synrad albedo background; i.e. introduce yoke “slots” not “round holes.”
- Here we report on two magnet design concepts that use self contained superconducting coils to deal with IR design optimization challenges.

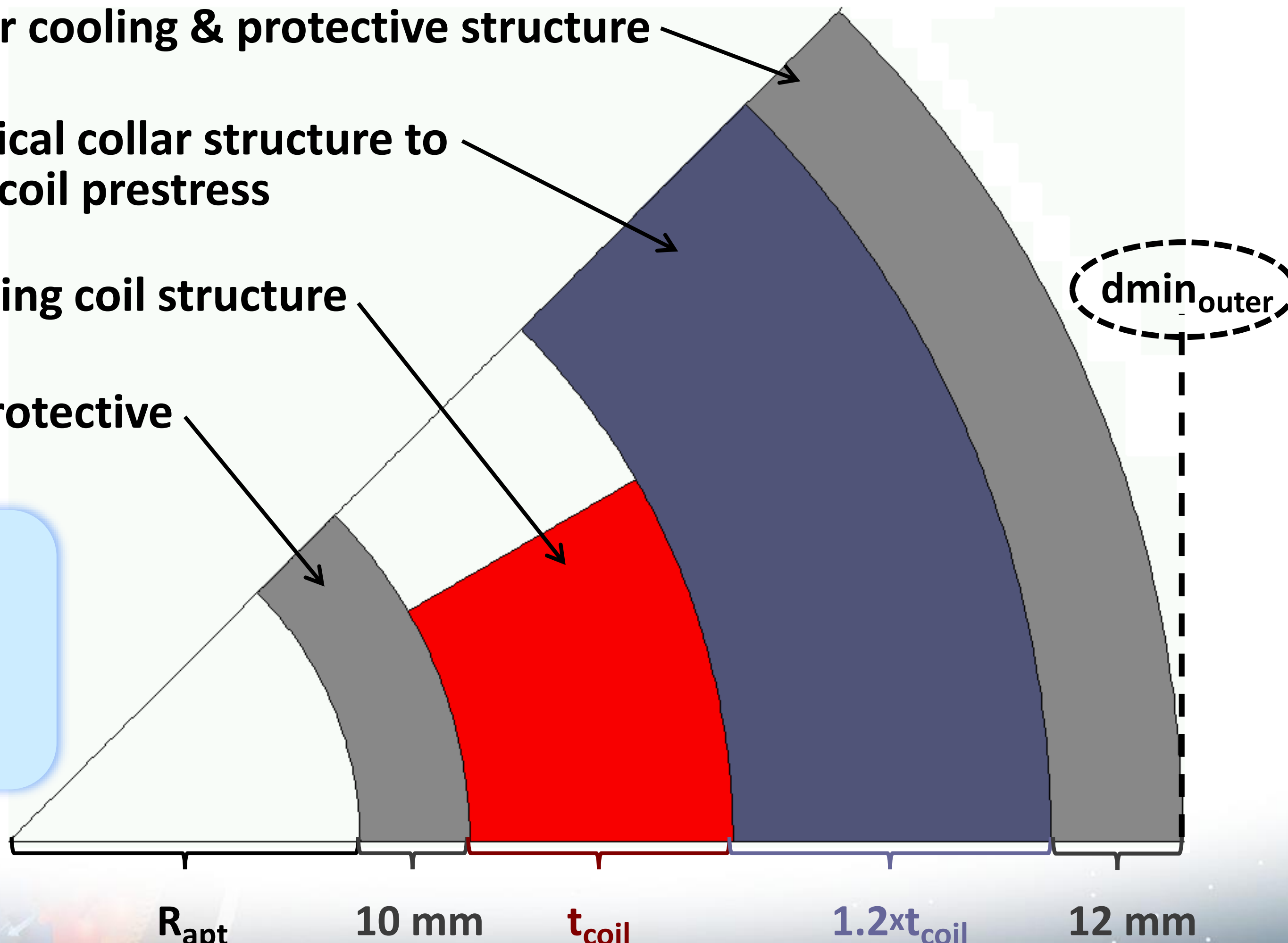

ISSN 0954-3899
Journal of Physics G
Nuclear and Particle Physics
Volume 39 Number 7 July 2012 Article 075001
A Large Hadron Electron Collider at CERN
Report on the Physics and Design Concepts for Machine and Detector
LHeC Study Group

Previous Mirror Quad Baseline



Large harmonic errors.
Large leakage field.

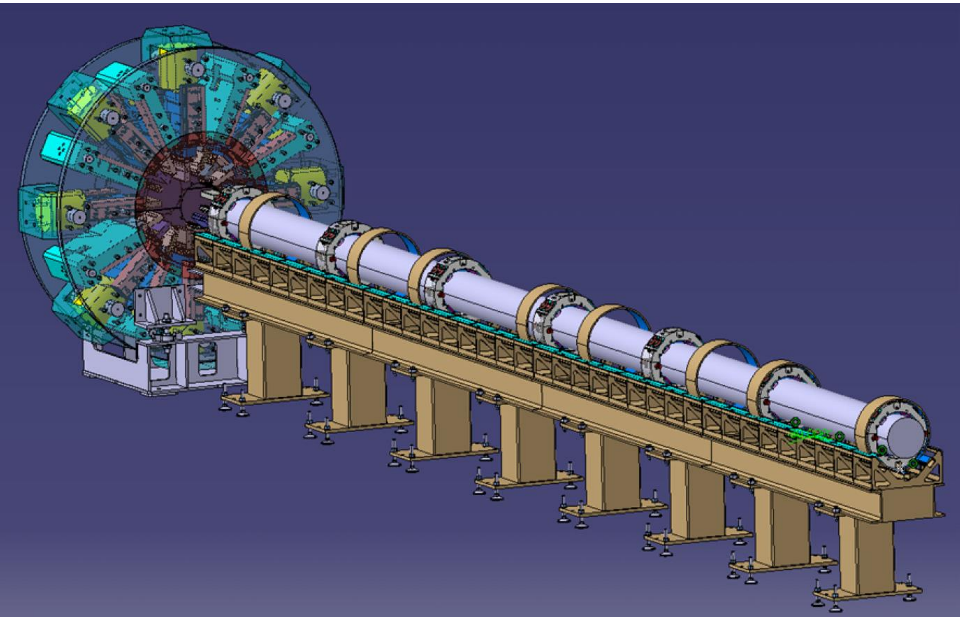
Self-Contained Coil Assumptions*.



R_apt from optics
t_inner by assumption
R_coil from R_apt + t_inner
gradient from optics
t_coil from gradient and R_coil
t_collar from 1.2 x t_coil
t_outer by assumption
d_outer is the net buildup

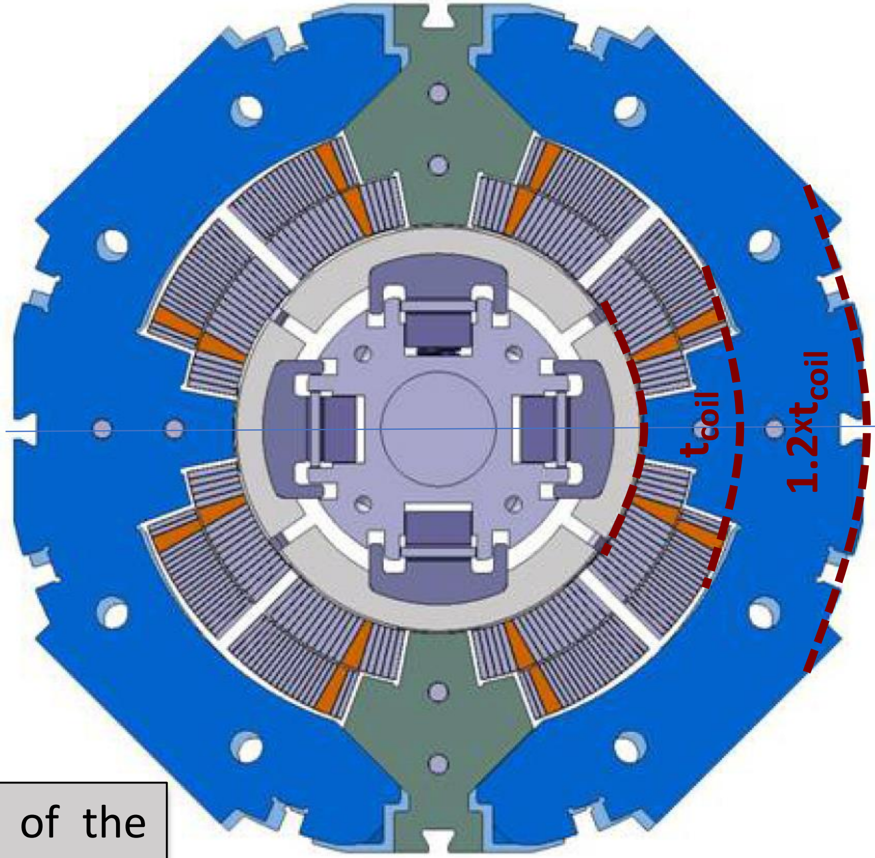
***Assumptions for minimum practical thickness.**

How to Make a Self-Contained Coil.



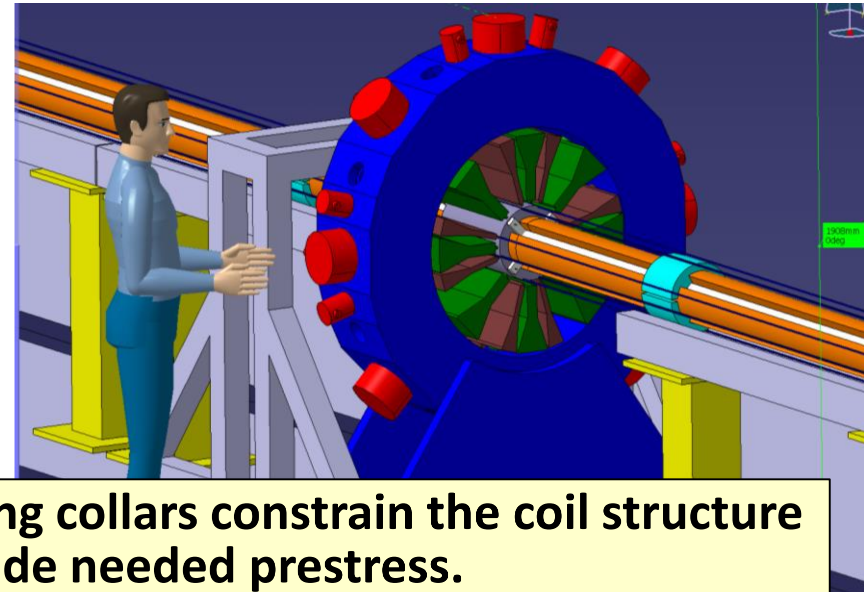
Artist's view of the horizontal collaring press with a coil-support bench.

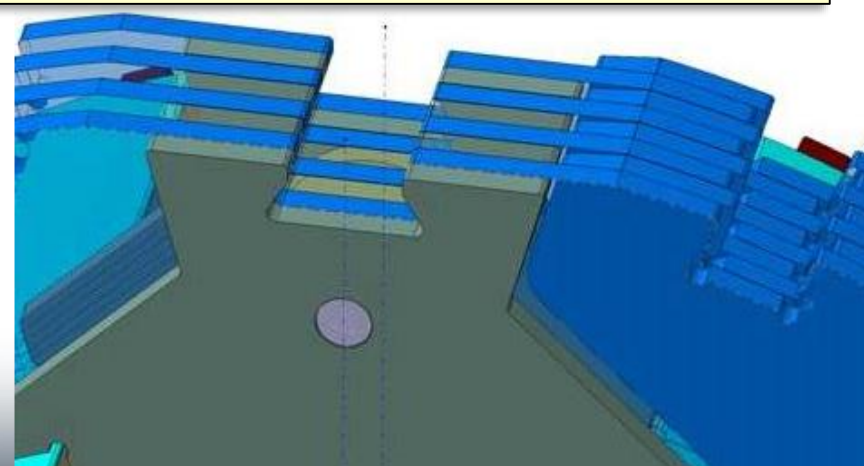
Spring-loaded, collapsible assembly mandrel with collar pack position prior to collaring.



S. Russenschuck, for WP-6 project team, "Design of the Inner Triplet Magnets for a Luminosity Upgrade of the LHC."

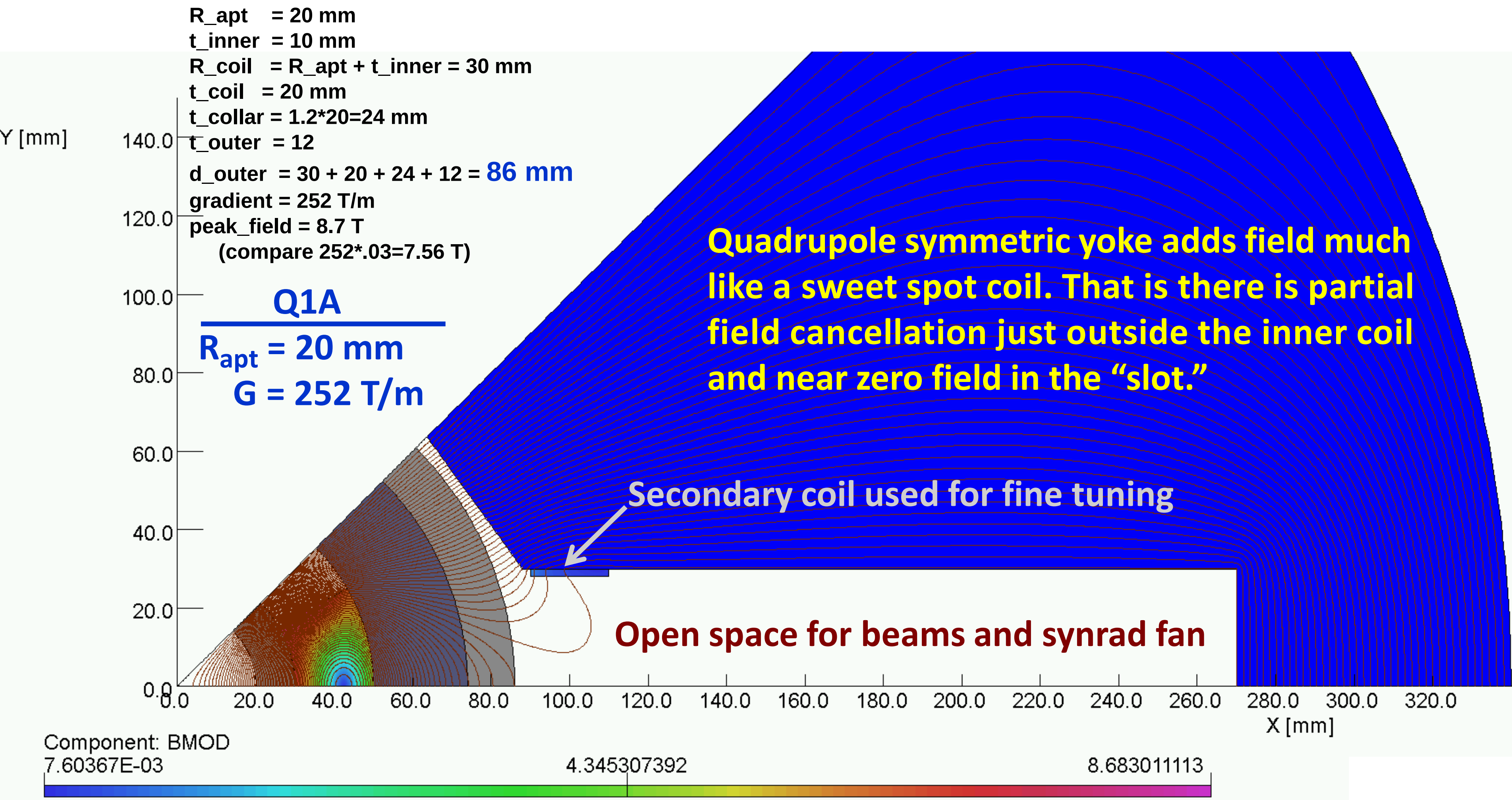
How to Make a Self-Contained Coil.





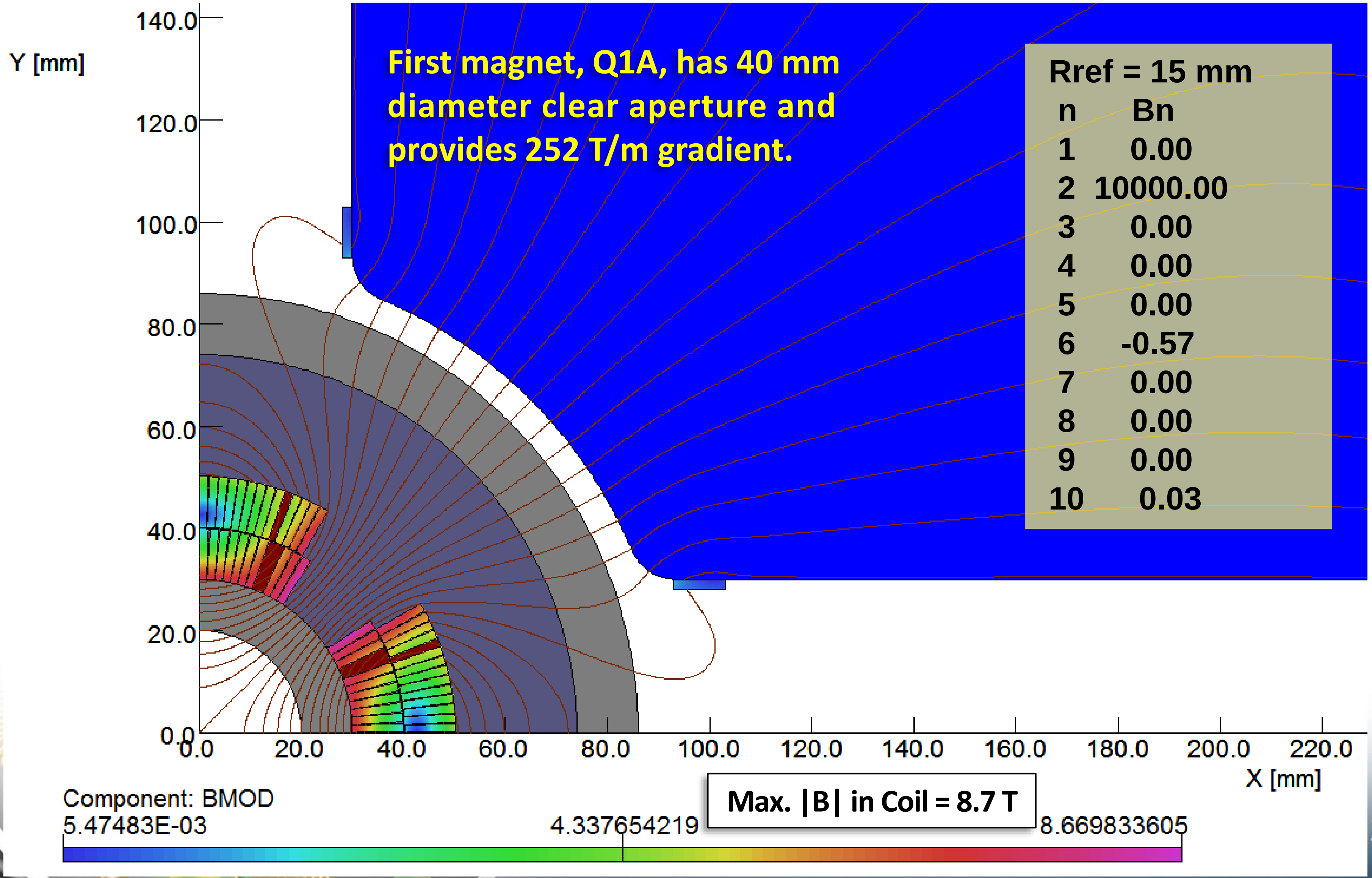
Self locking collars constrain the coil structure and provide needed prestress.

Self-Contained Coil Plus Quad Yoke*.

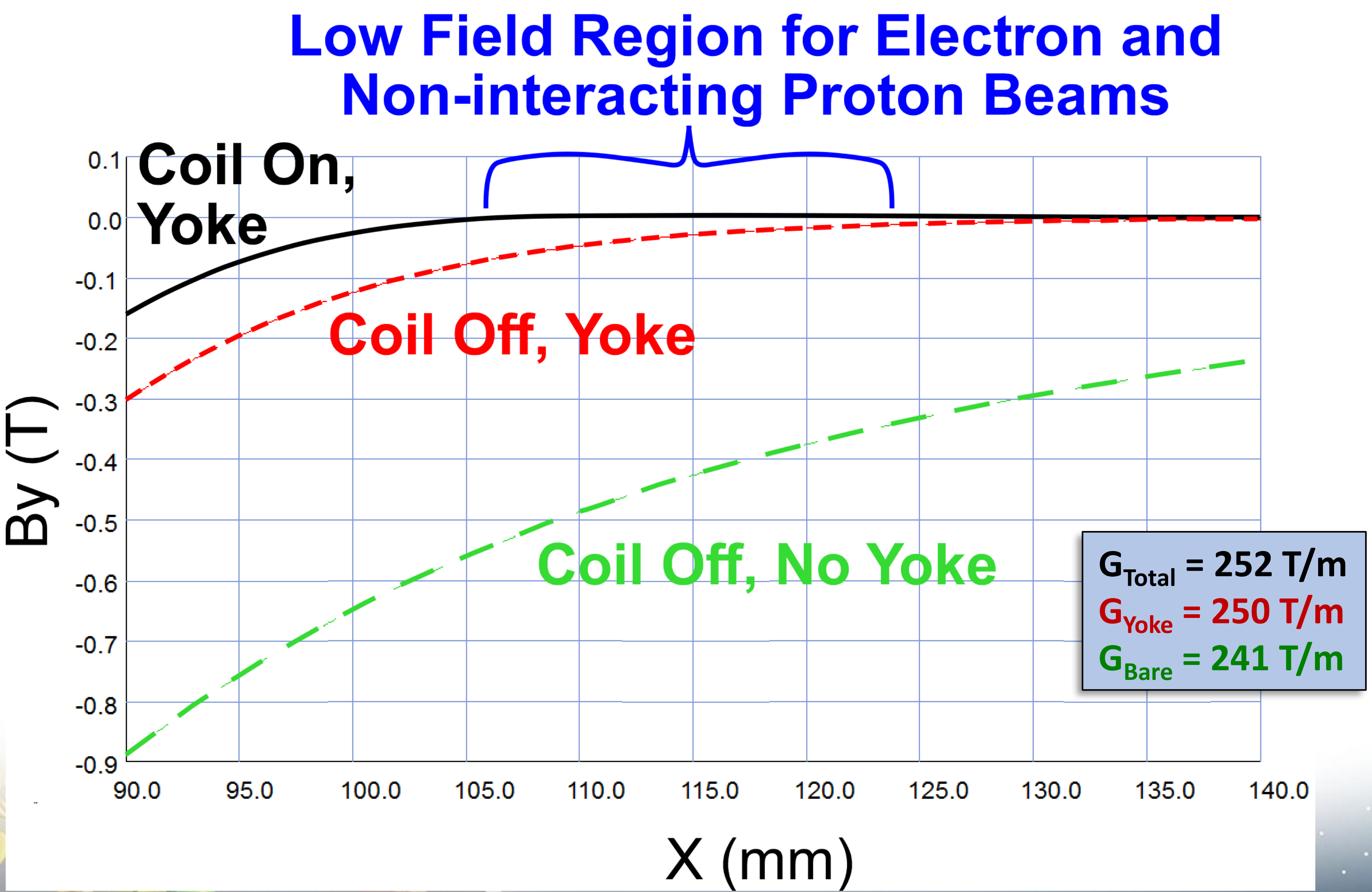


*Concept discussed at May 2018 CERN meeting.

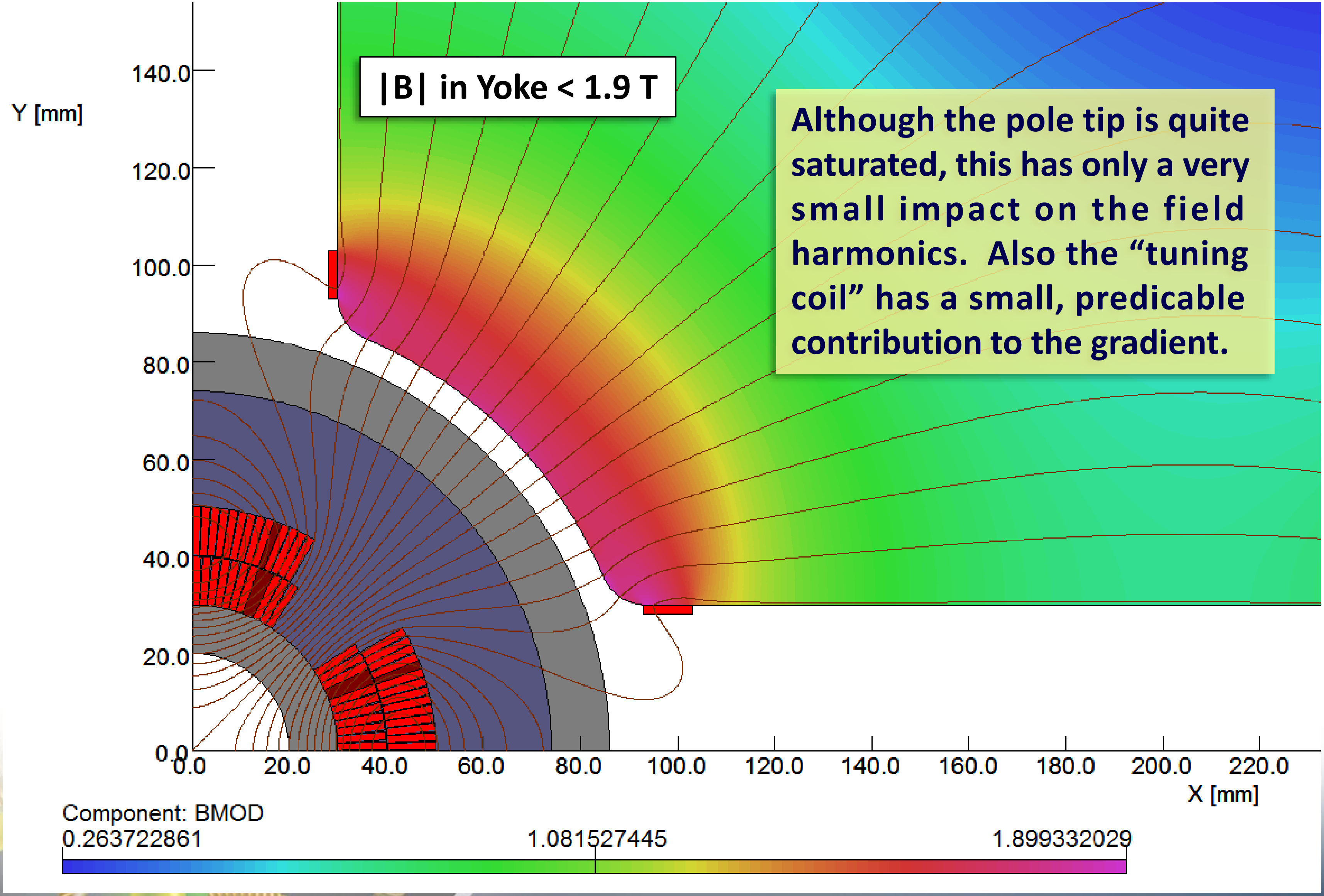
Self-Contained Coil Plus Quad Yoke.



40 mm Bore, Slotted Yoke Field Profile.



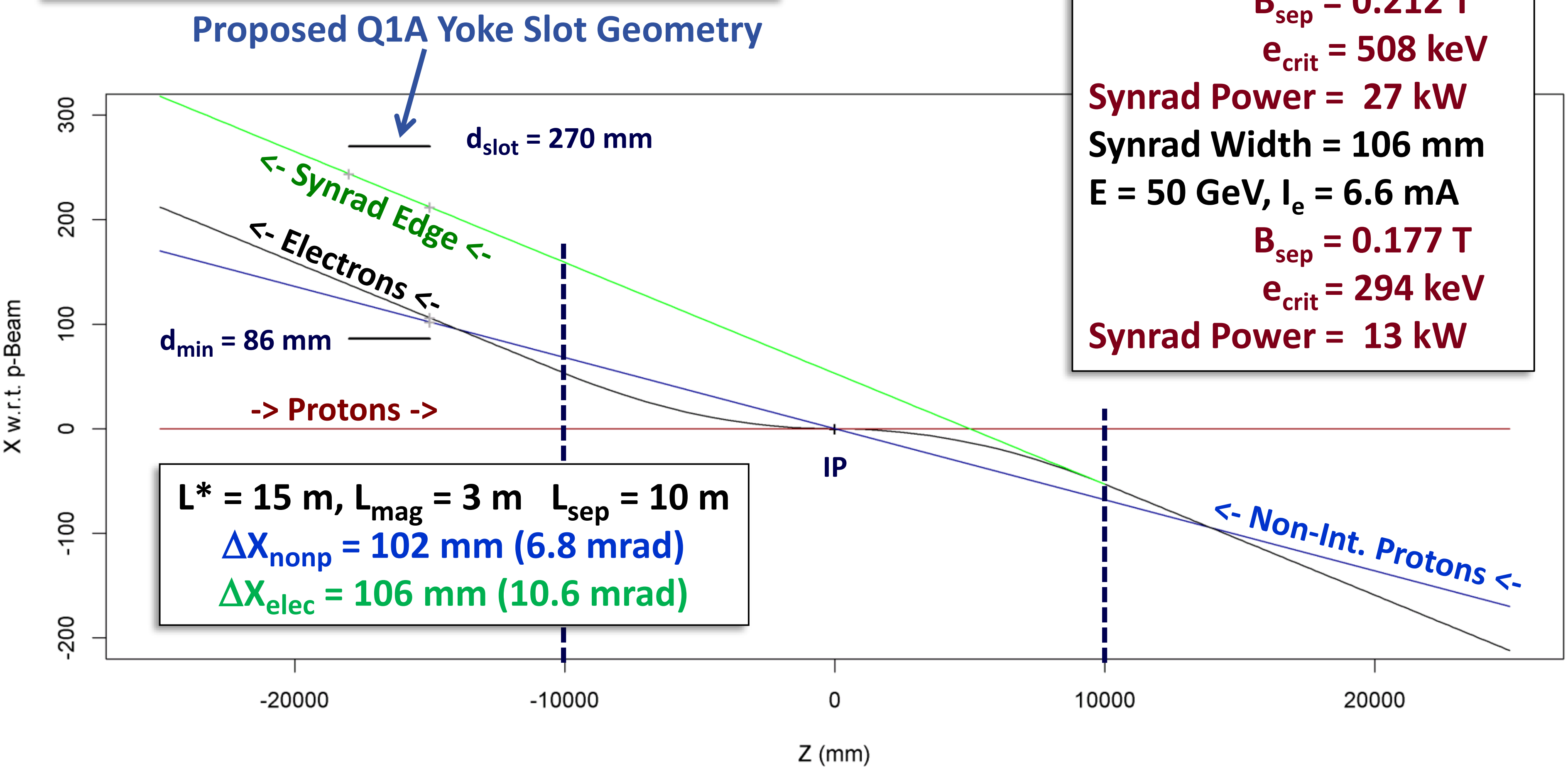
40 mm Bore, Slotted Yoke Saturation.



Zeroth Iteration LHeC IR Geometry*.

Note: Synrad edge is // to outgoing e-beam

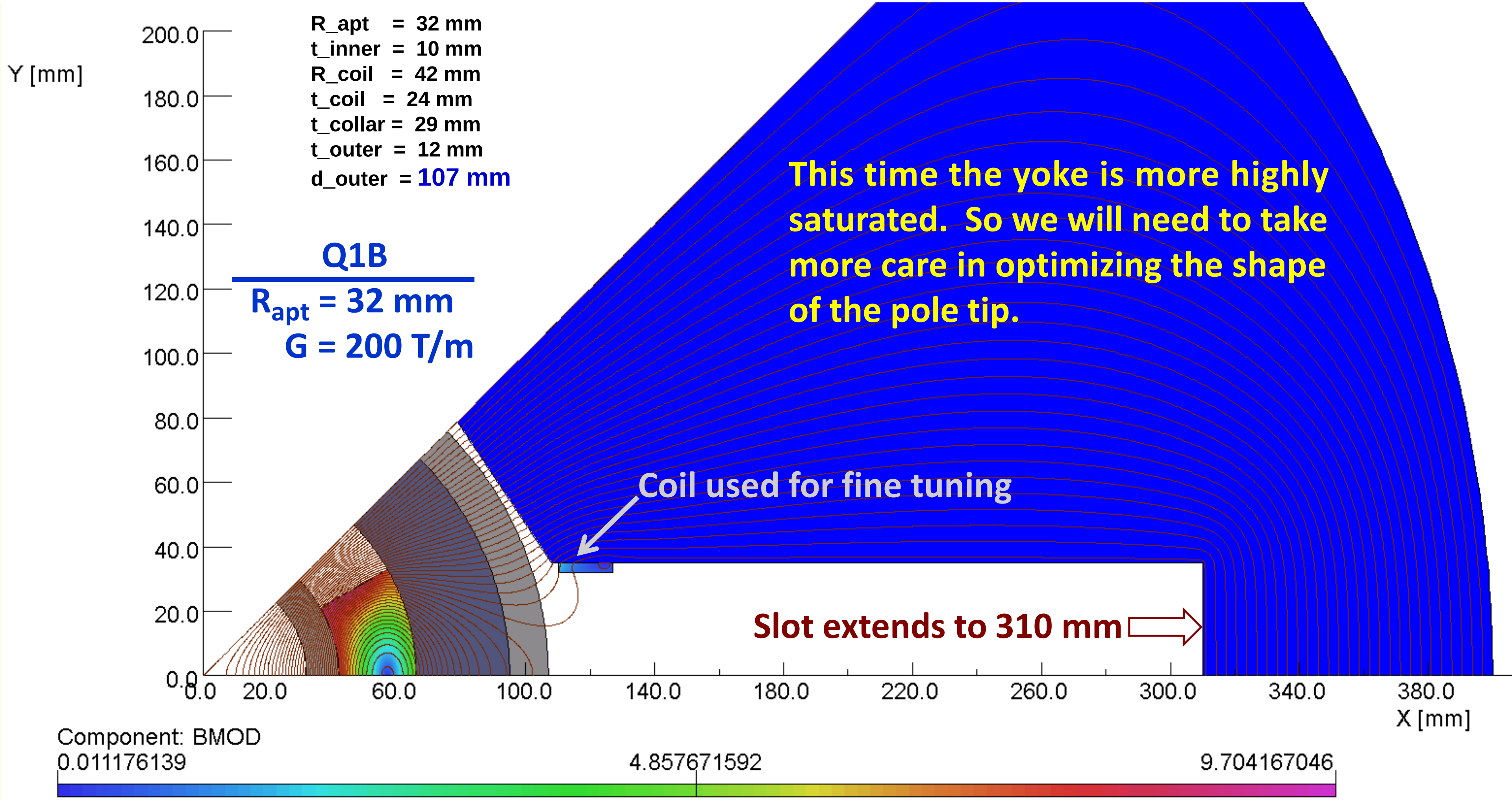
E = 60 GeV, I_e = 6.6 mA
B_{sep} = 0.212 T
e_{crit} = 508 keV
Synrad Power = 27 kW
Synrad Width = 106 mm
E = 50 GeV, I_e = 6.6 mA
B_{sep} = 0.177 T
e_{crit} = 294 keV
Synrad Power = 13 kW



L* = 15 m, L_{mag} = 3 m L_{sep} = 10 m
ΔX_{nonp} = 102 mm (6.8 mrad)
ΔX_{elec} = 106 mm (10.6 mrad)

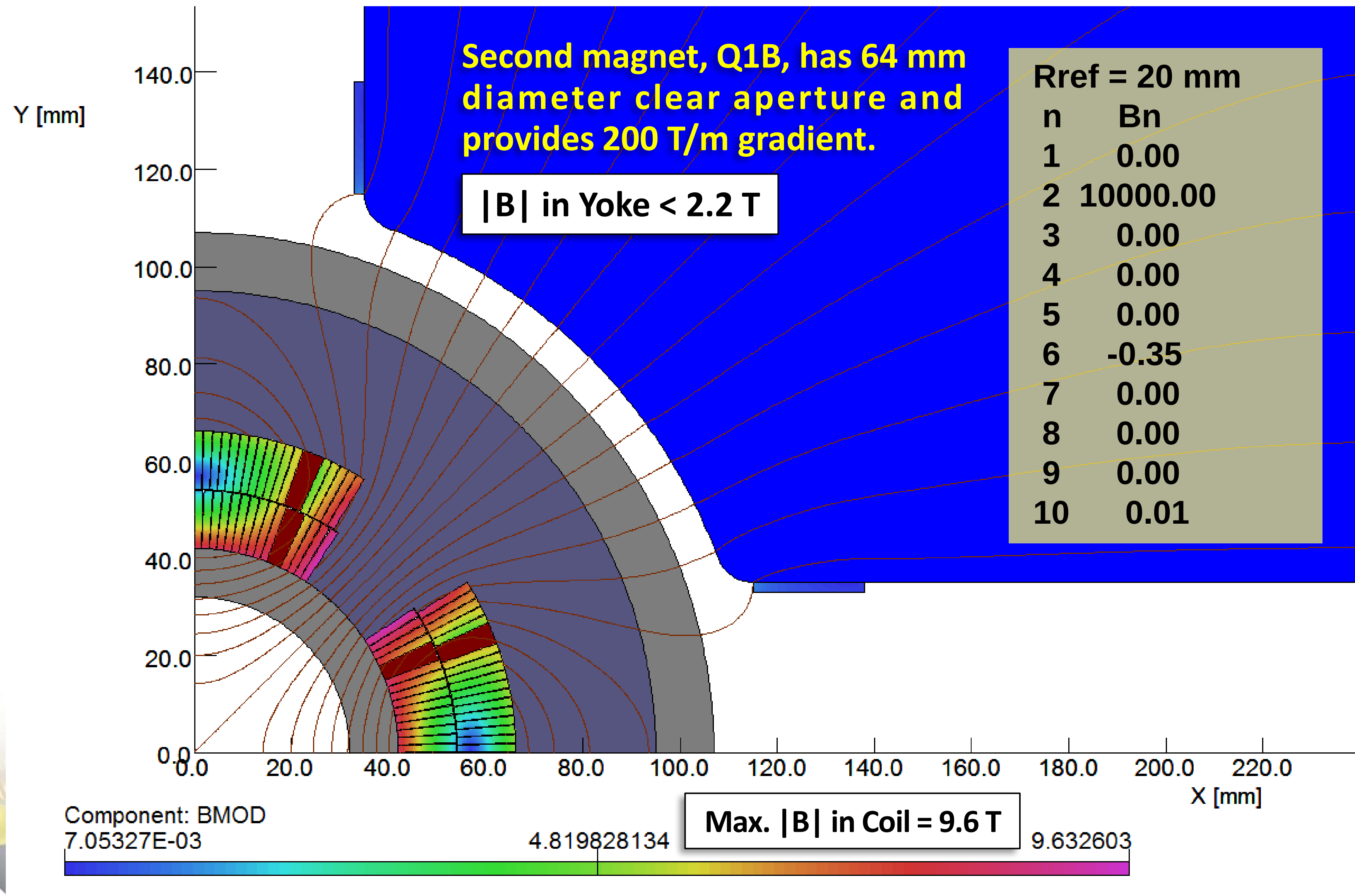
*Concept discussed at May 2018 CERN meeting.

Proposed Q1B Quadrupole Parameters*.

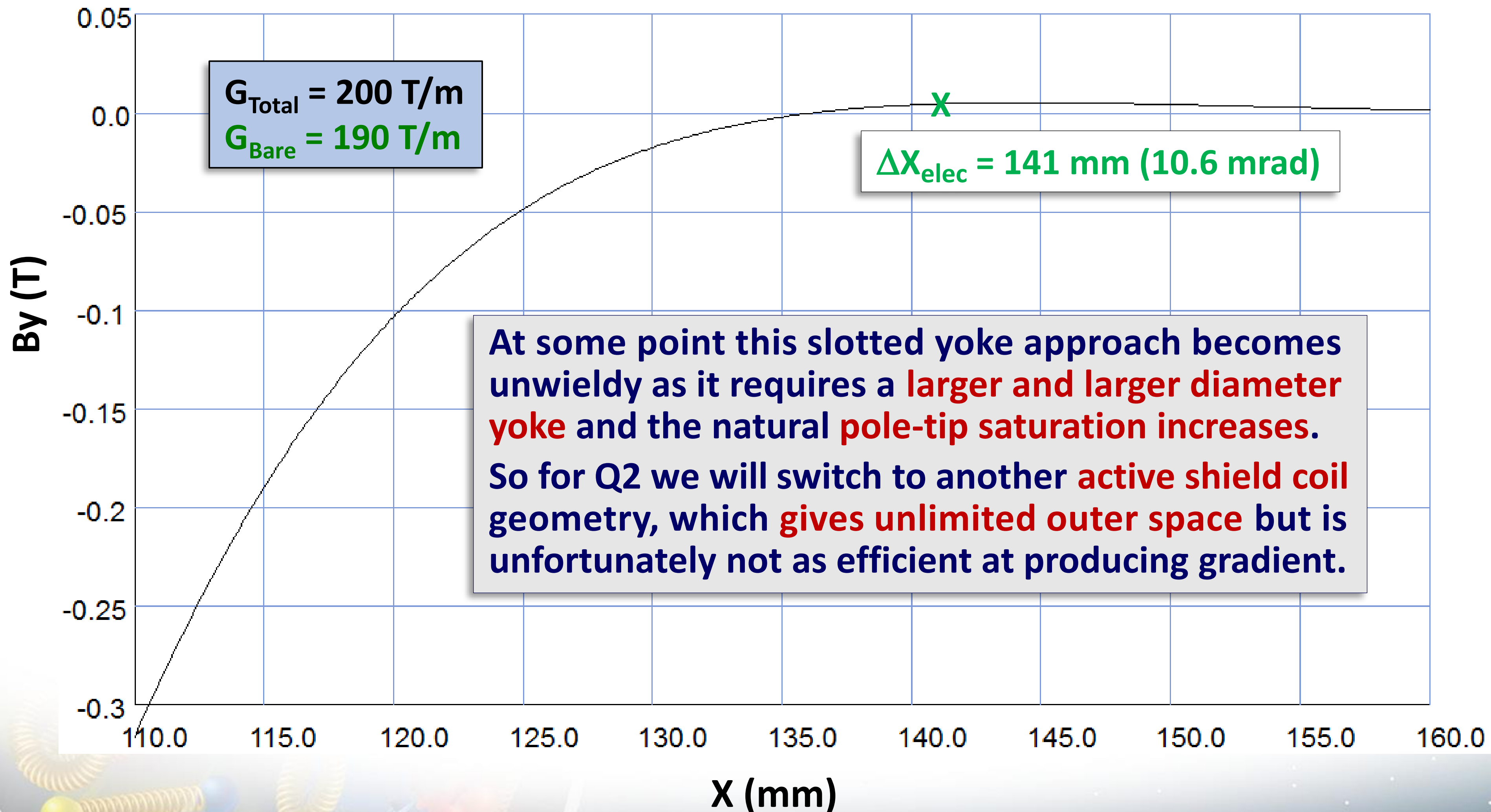


*Concept discussed at May 2018 CERN meeting.

64 mm Bore, Slotted Yoke Q1B Design.



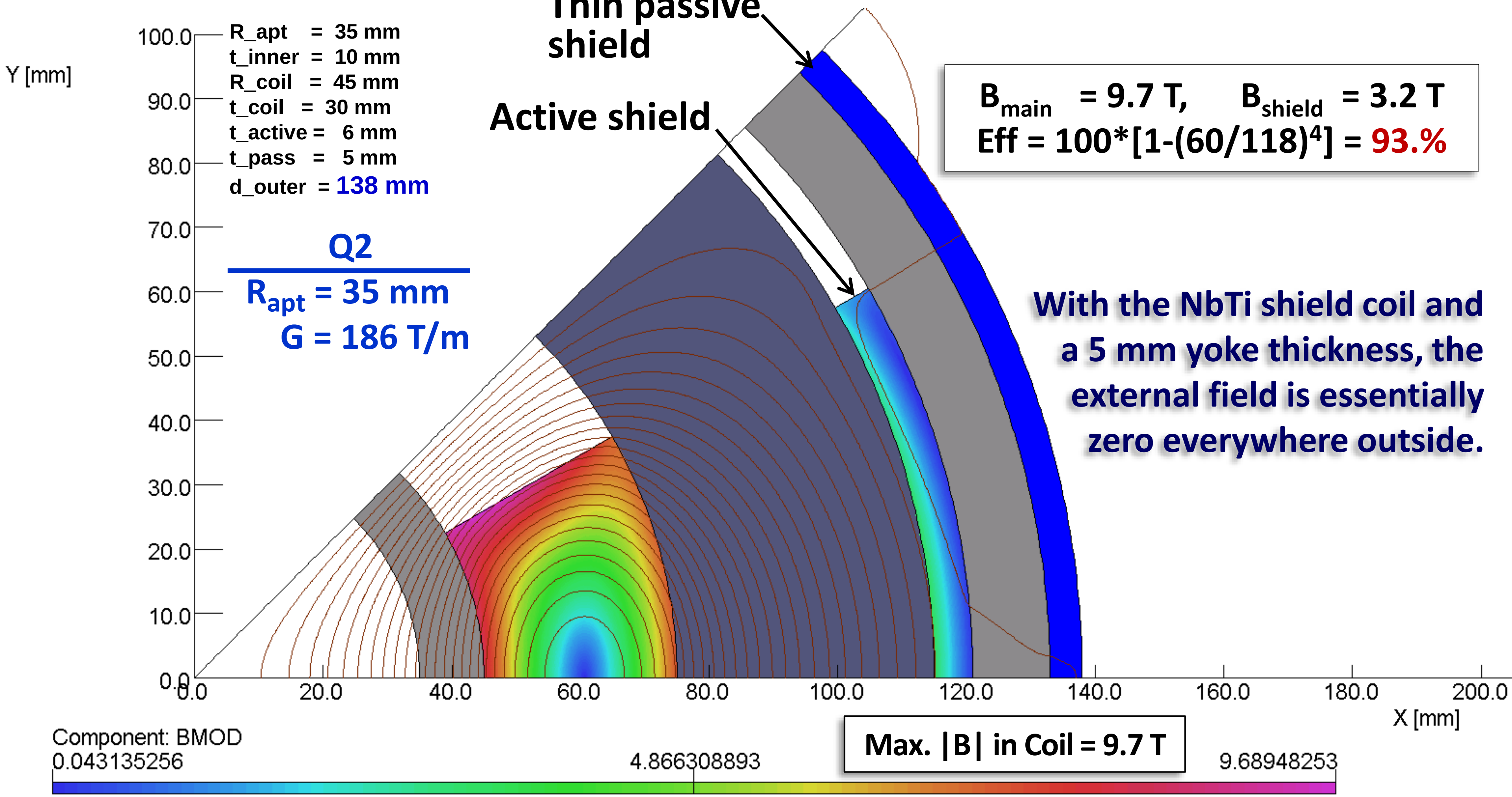
64 mm Bore, Q1B Slotted Yoke Field Profile.



At some point this slotted yoke approach becomes unwieldy as it requires a larger and larger diameter yoke and the natural pole-tip saturation increases.

So for Q2 we will switch to another active shield coil geometry, which gives unlimited outer space but is unfortunately not as efficient at producing gradient.

70 mm Bore, Q2 Actively Shielded Quad*.



B_{main} = 9.7 T, B_{shield} = 3.2 T

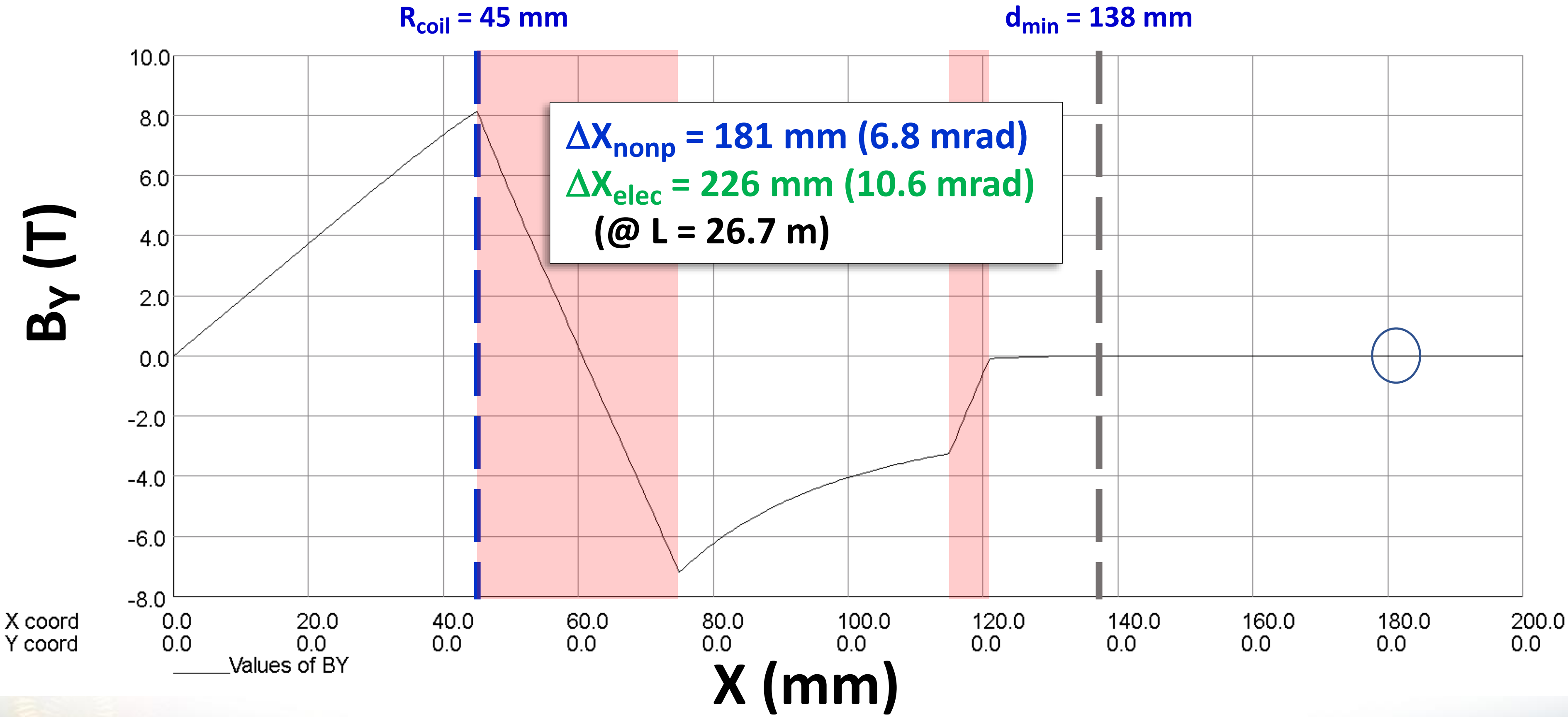
Eff = $100*[1-(60/118)^4]$ = 93.%

With the NbTi shield coil and a 5 mm yoke thickness, the external field is essentially zero everywhere outside.

***Concept discussed at May 2018 CERN meeting.**

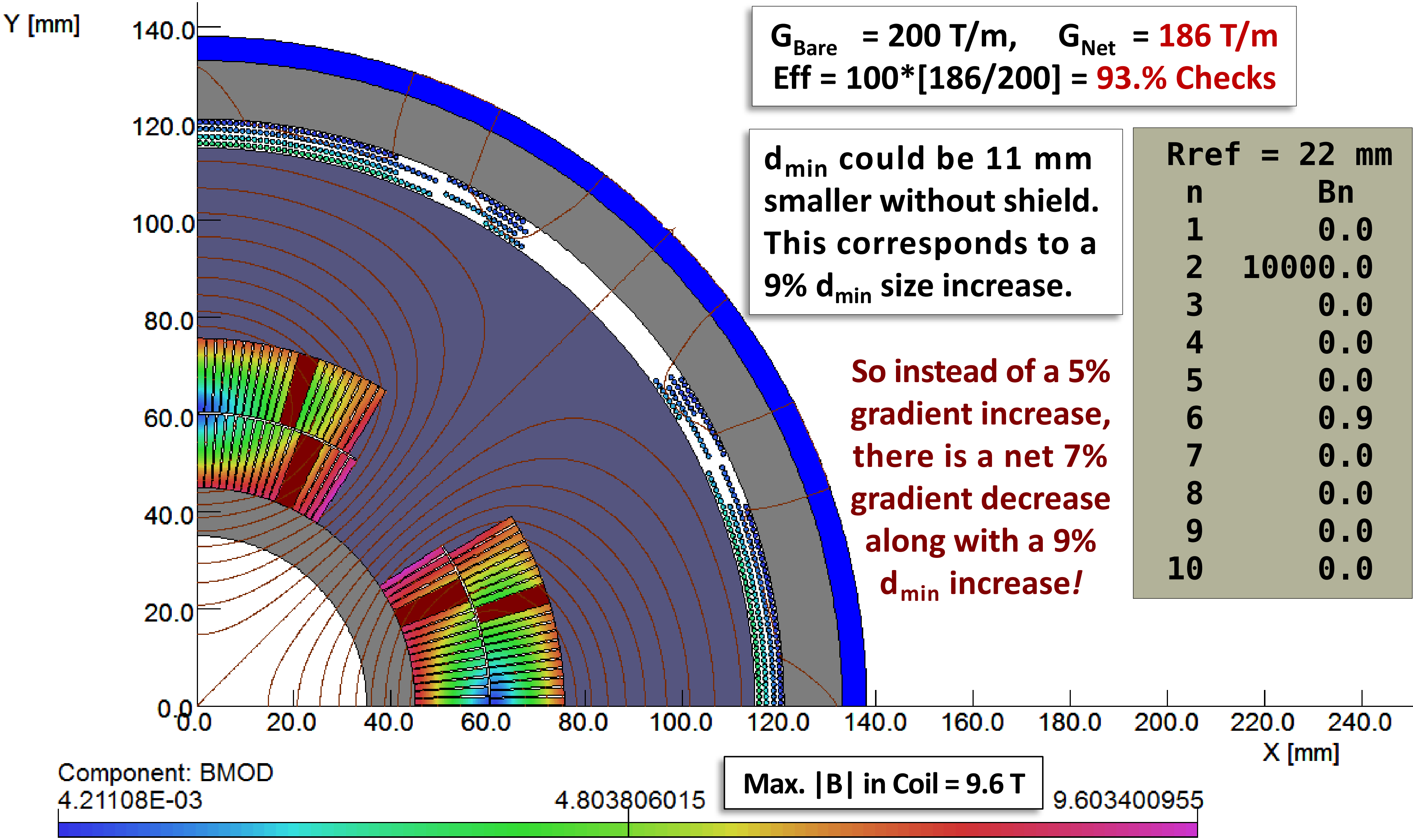
70 mm Bore, Q2 Actively Shielded Quad*.

Note: Early LARP coil prototypes had 45 mm coil radius.



***Concept discussed at May 2018 CERN meeting.**

70 mm Bore, Q2 Actively Shielded Quad*.



G_{Bare} = 200 T/m, G_{Net} = 186 T/m
Eff = 100*[186/200] = 93.% Checks

d_{min} could be 11 mm smaller without shield. This corresponds to a 9% d_{min} size increase.

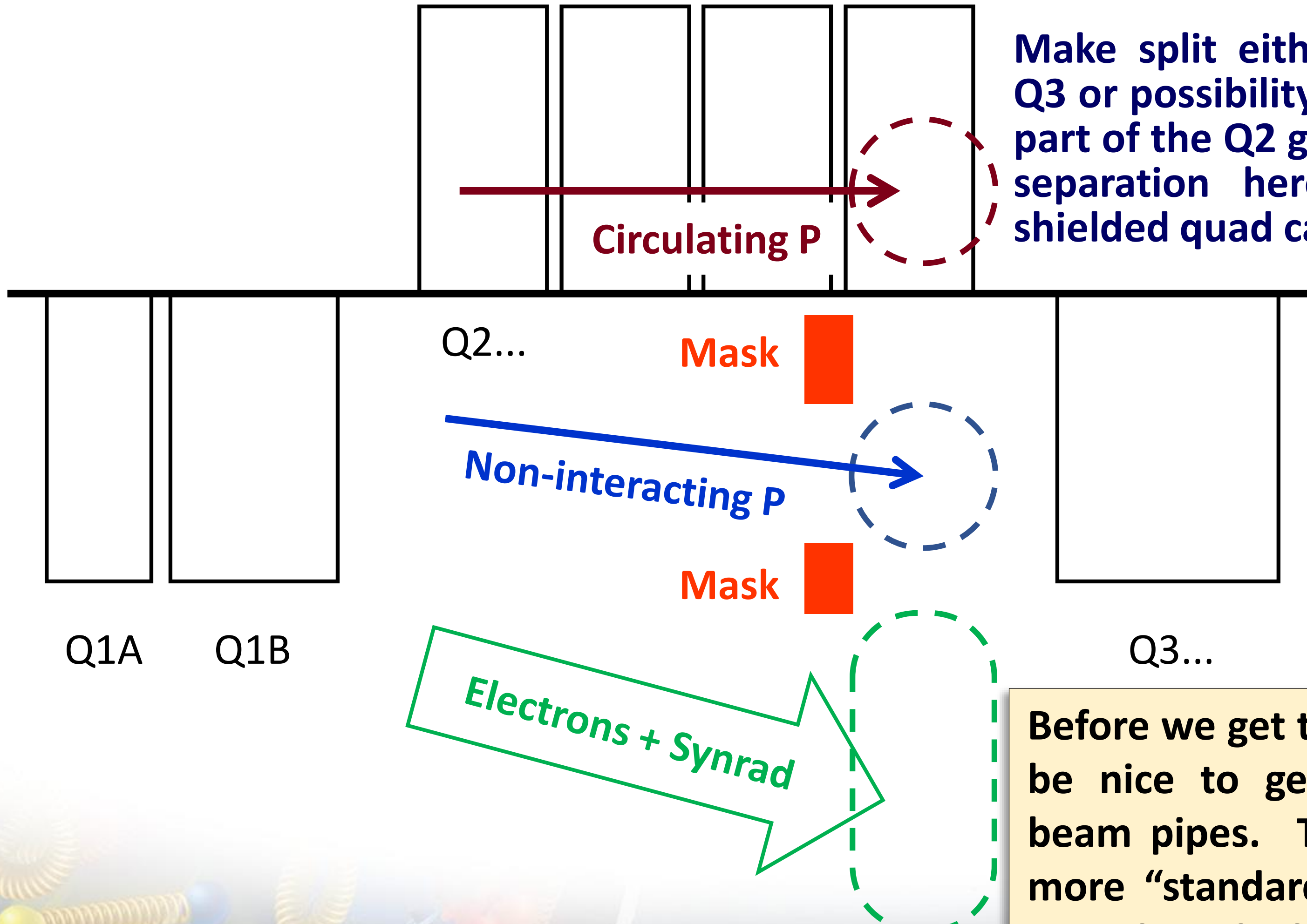
Rref = 22 mm	
n	Bn
1	0.0
2	10000.0
3	0.0
4	0.0
5	0.0
6	0.9
7	0.0
8	0.0
9	0.0
10	0.0

So instead of a 5% gradient increase, there is a net 7% gradient decrease along with a 9% d_{min} increase!

Max. |B| in Coil = 9.6 T

Why not use active shielding for all IR quadrupoles?
Answer: The slotted yoke is more efficient.

Some Further Layout Thoughts*.

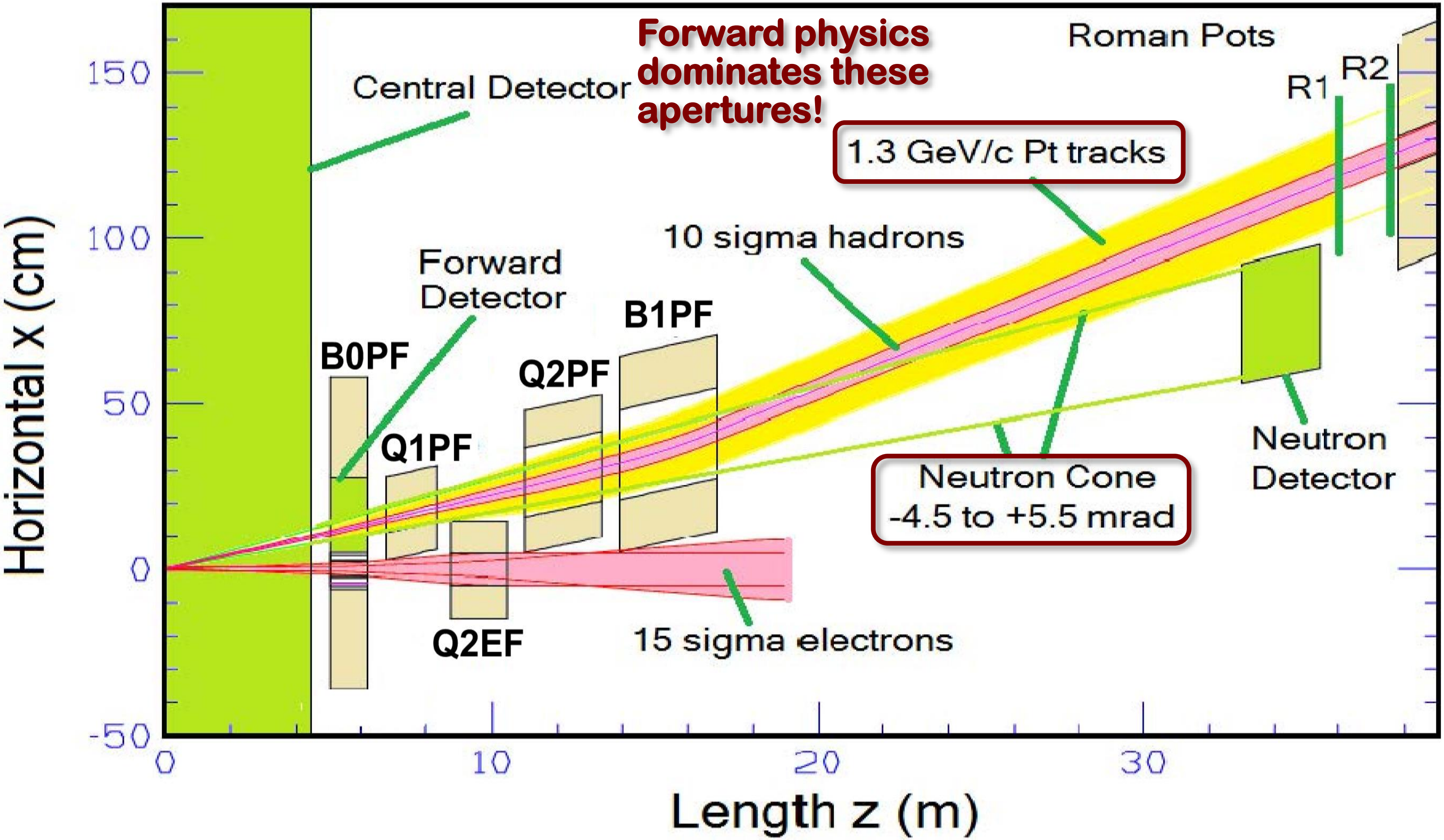


Make split either between Q2 and Q3 or possibility overlapping the last part of the Q2 group. There is a large separation here and the actively shielded quad can be well protected.

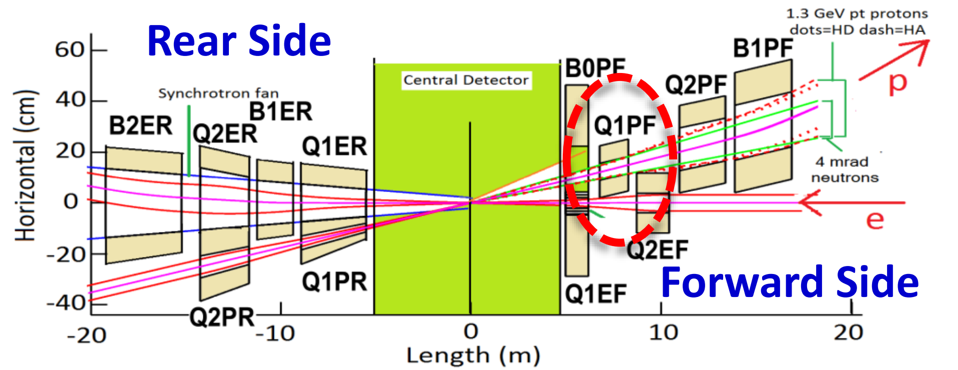
Before we get to Q3 group it would be nice to get into independent beam pipes. Then Q3 could be a more "standard" quad design and again have higher gradient.

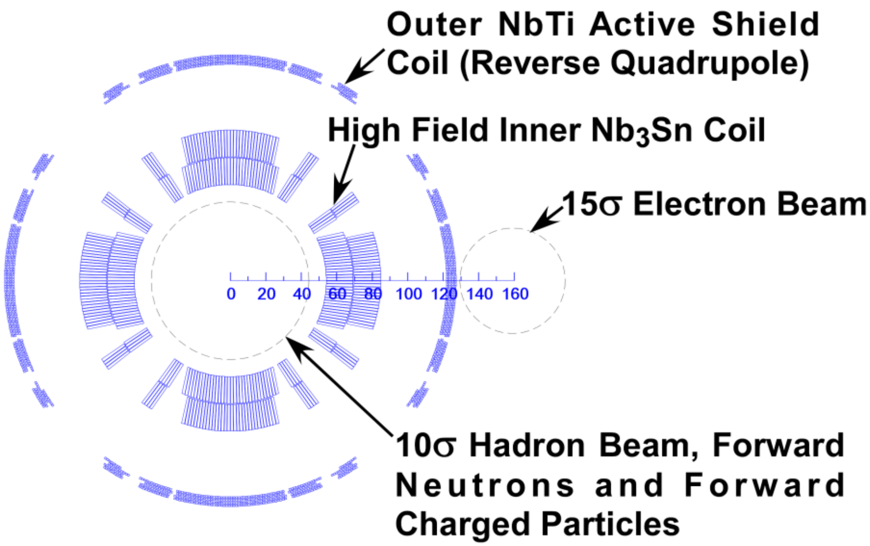
***Concept discussed at May 2018 CERN meeting.**

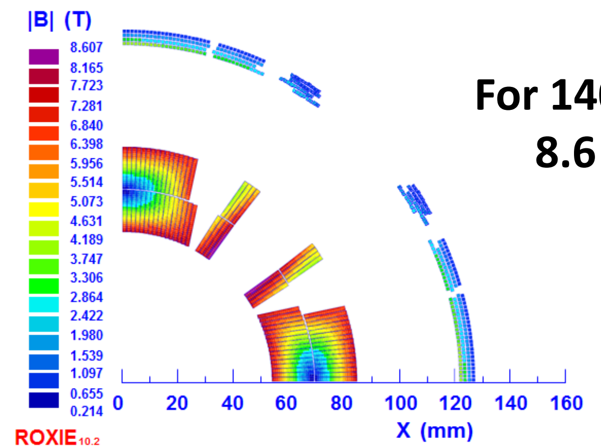
eRHIC IR Magnet Forward Layout



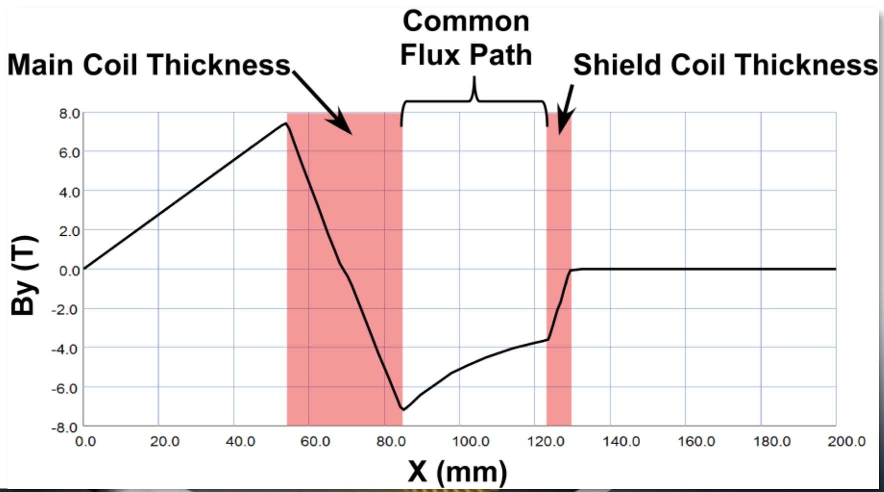
eRHIC Q1PF Design



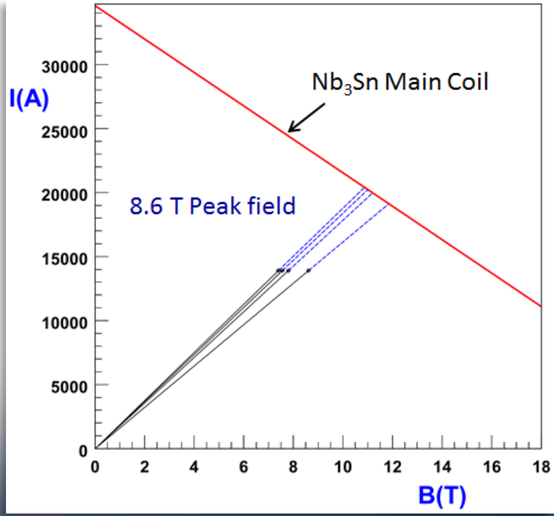




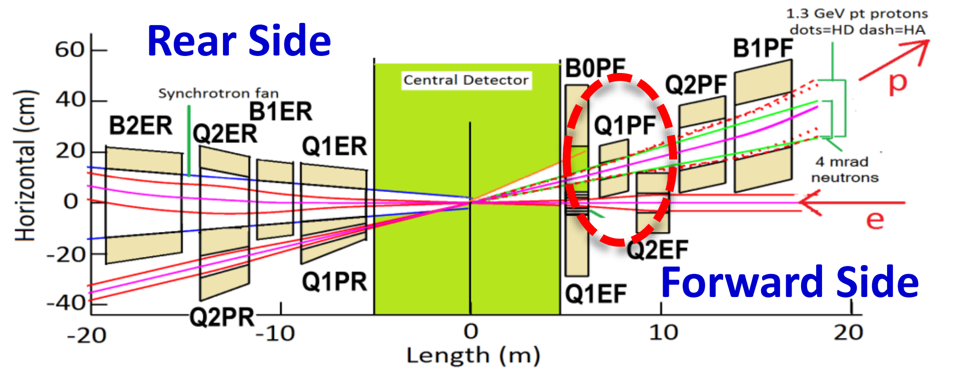
For 140 T/m Gradient
8.6 T peak field



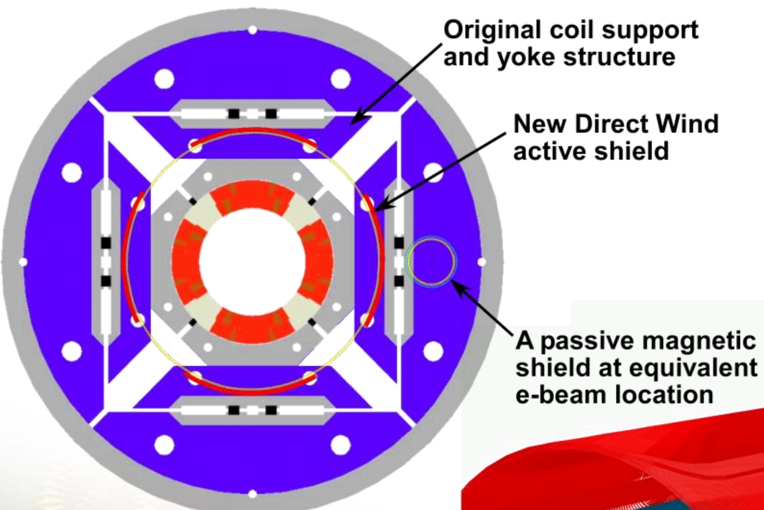
Active shield kills the external field outside the coils then also reduces gradient inside the main aperture.



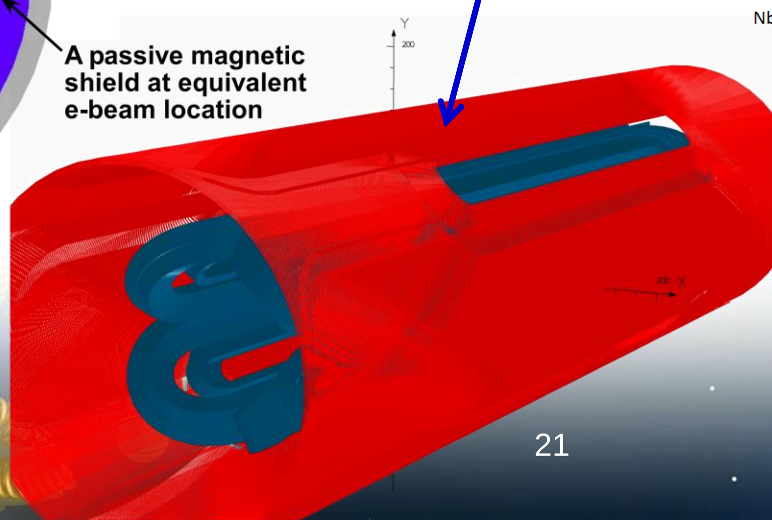
Fast Track R&D



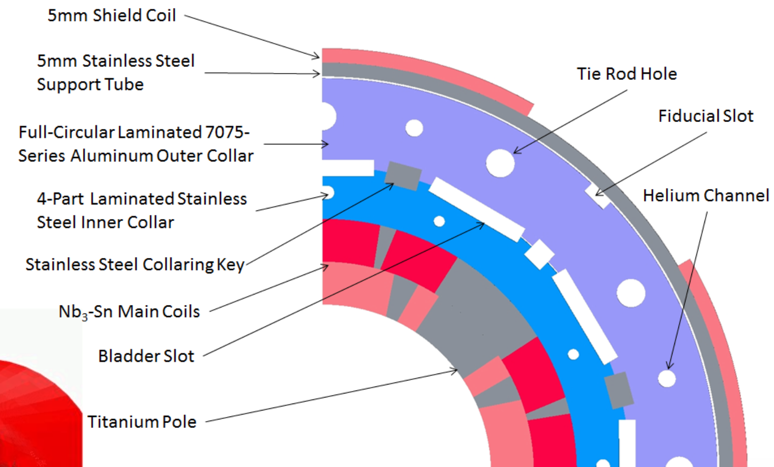
- Use existing Nb_3Sn coils (from LARP work) with a new active shield to prove out Q1PF concept.
- Main challenge is limited space for mechanical structure.



LARP mechanical structure comparison

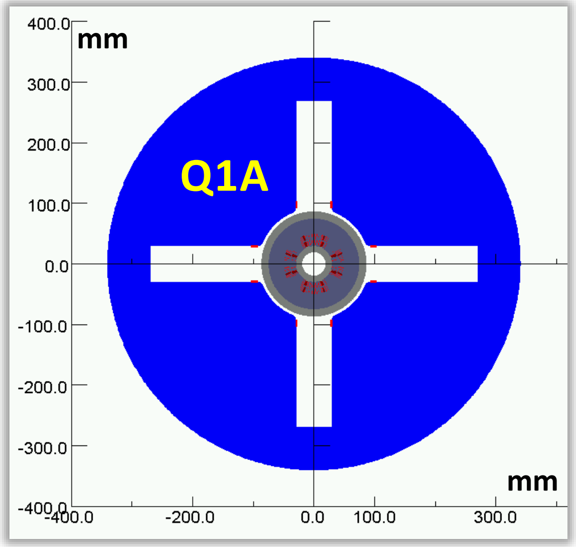


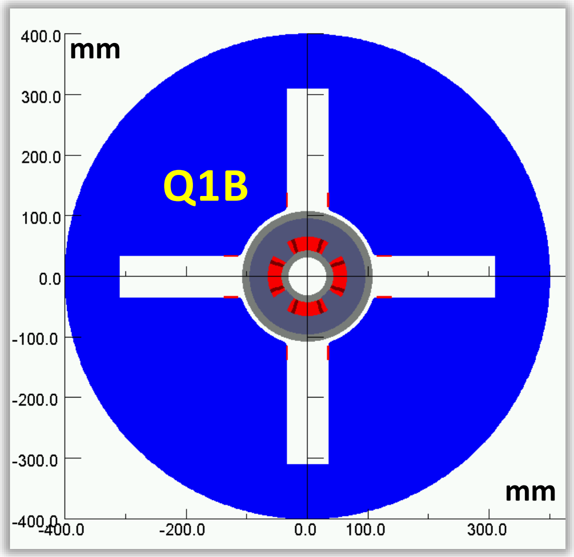
NbTi active shield coil around an Nb_3Sn inner coil

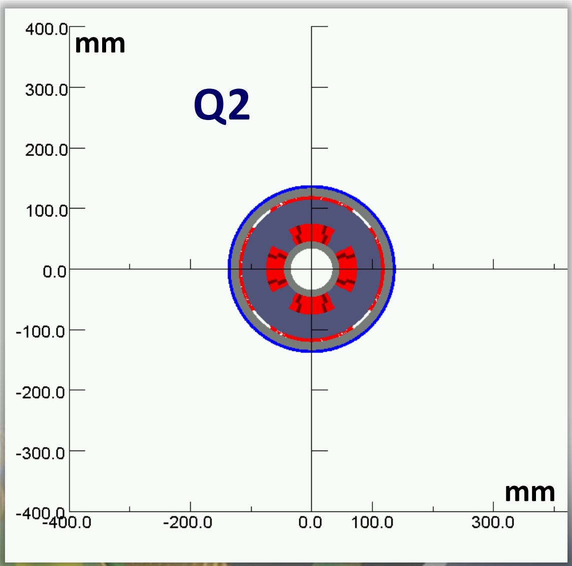


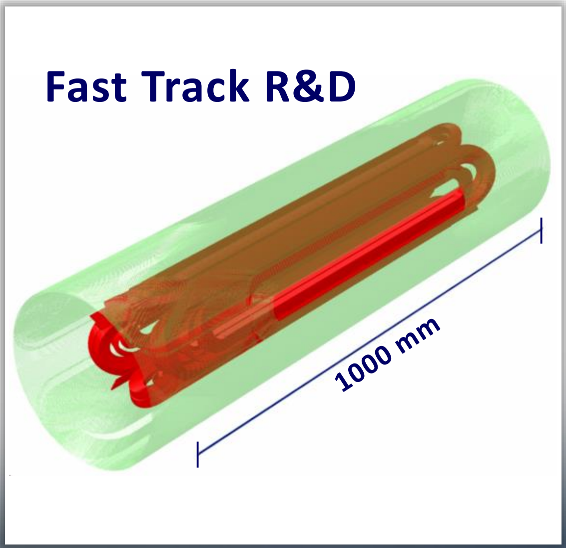
New proposed compact mechanical structure

Recent Progress on IR Magnets Summary







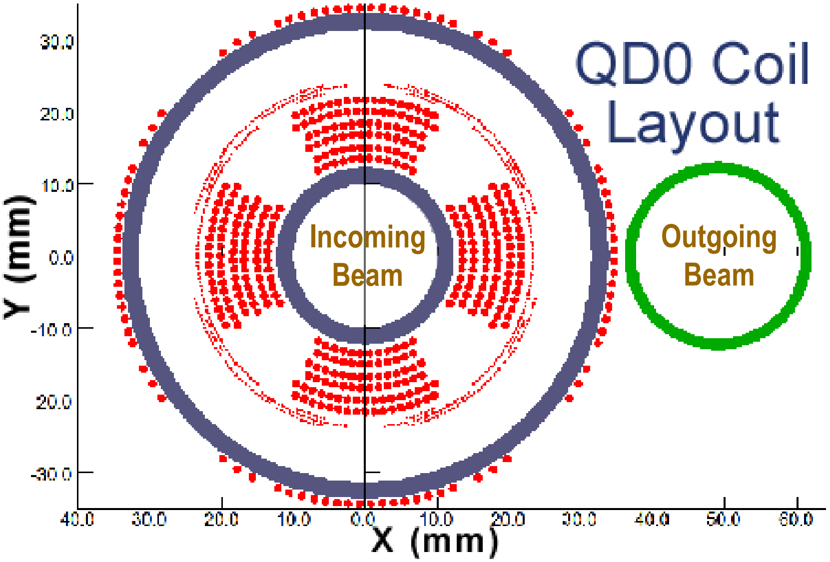


Backup Materials (2 Slides)

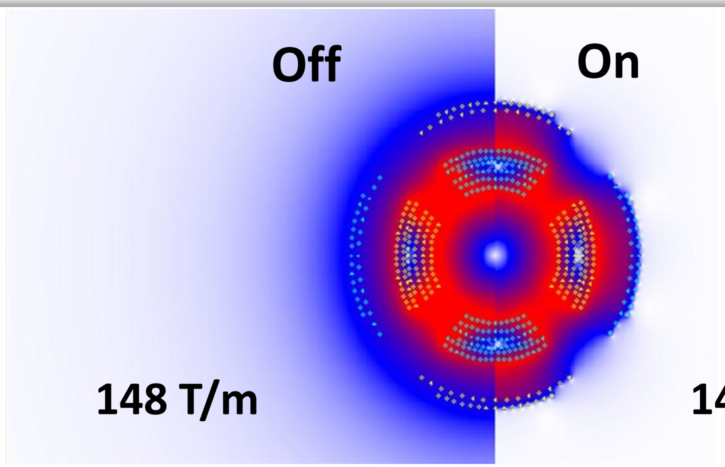
- Active Shielding for the ILC QD0 Final Focus Magnet.
- Active Shielding for EIC IR Quadrupoles (Fast Track).

Thank you for your attention.

Design for Compact Superconducting Magnet Used in the ILC 14 mr Layout.

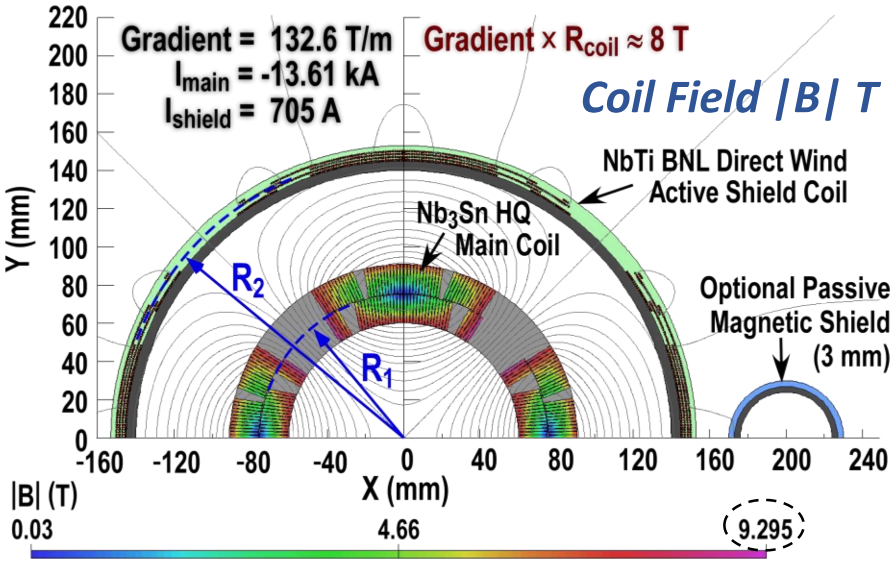


- 14 mr crossing angle via compact self-shielded QD0 coil windings.
- Extracted beam passes just outside coil into separate focusing channel.
- Cryostat to fit within limited space inside detector at L* = 4.1 m.

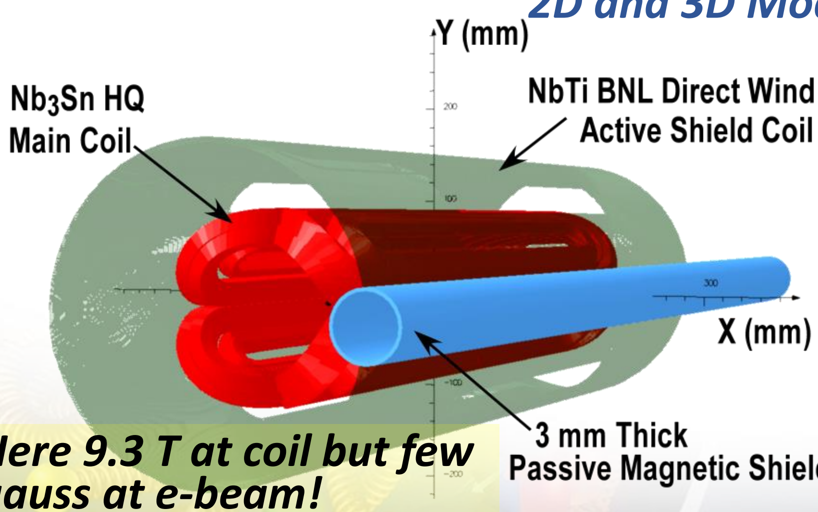


QD0 with active shield off/on

Active Shielding for EIC IR Quadrupoles



2D and 3D Models



Here 9.3 T at coil but few gauss at e-beam!

Actively Shielded Coil Designs

- As with the ILC QD0 we can use an Active Shield (here an anti-quad) to eliminate the external field.
- An Active Shield is useful for large crossing angles, since one can null the external field over a large region.
- Field cancellation leads to gradient loss

$$G_{Final} = [1 - (R_1/R_2)^4]\, G_{Main}$$

- Active Shield magnets are of interest for both the BNL and JLAB EIC IR designs and thus represent an area of common R&D interest.

Models correspond to the "Fast Track" R&D quad described in this presentation.