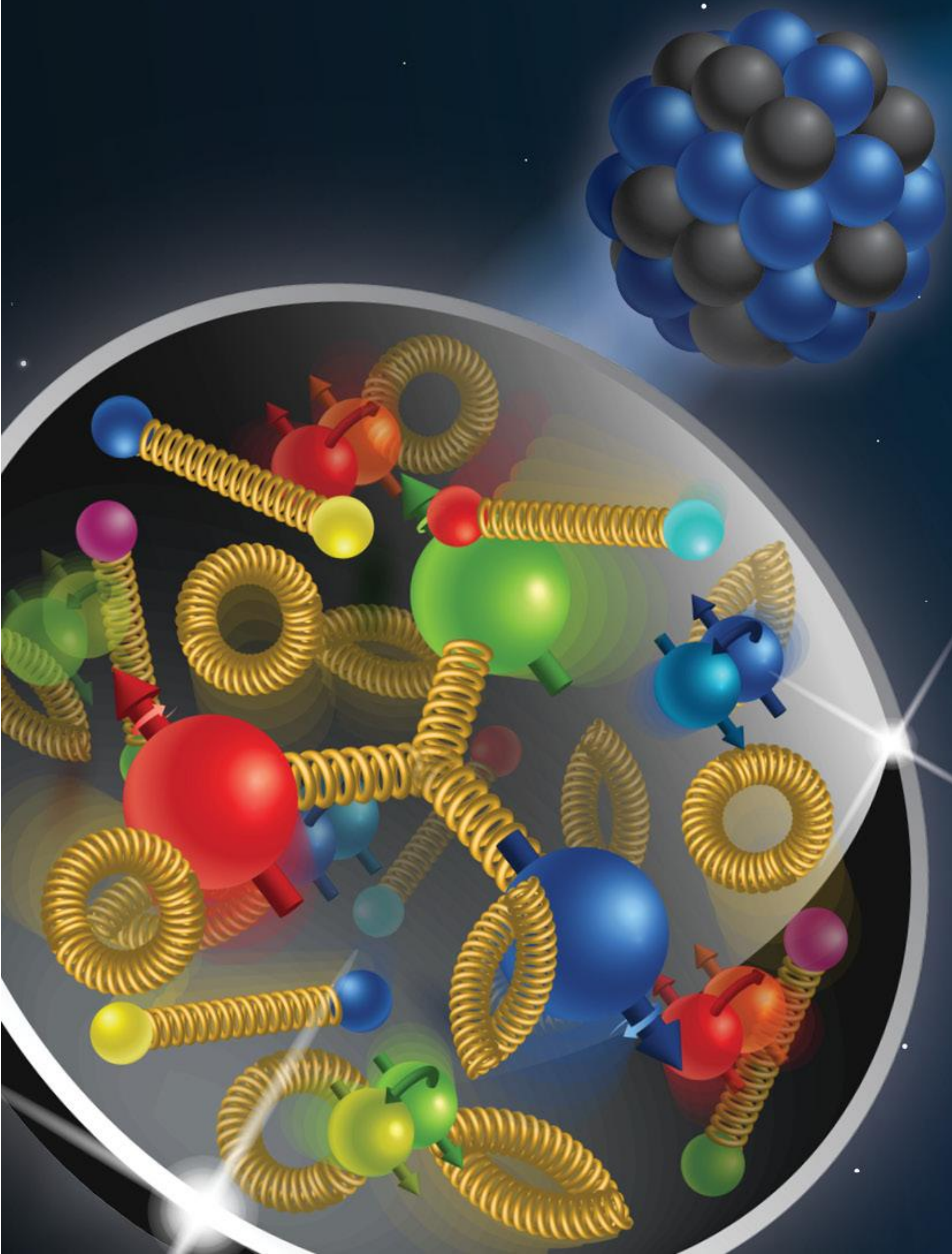

Update on the Optimum Integral Design for B0pF

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Electron-Ion Collider

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Jefferson Lab
U.S. DEPARTMENT OF ENERGY | Office of Science

Major Goals of the 1st Update

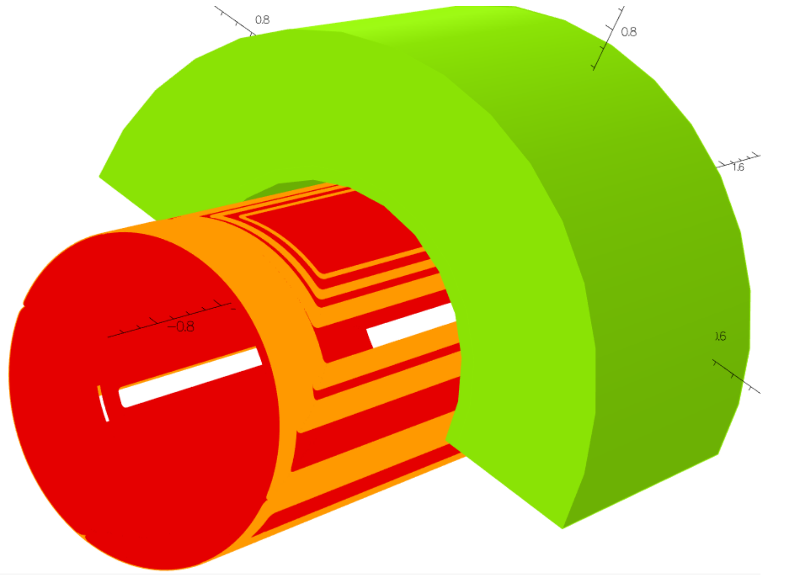
- Add dipole on the preferred 6-layer (three coil sets) design to make the field on the electron beam path (x=-34 mm) zero and make oscillation (up-down variation in the vertical field) <1 kG (present serpentine design has ~100 G).

- Compute new margin for the integral field on the integral path of the center of proton beam is ~1.56 T.m at x=126 mm and 25 mRad angle.

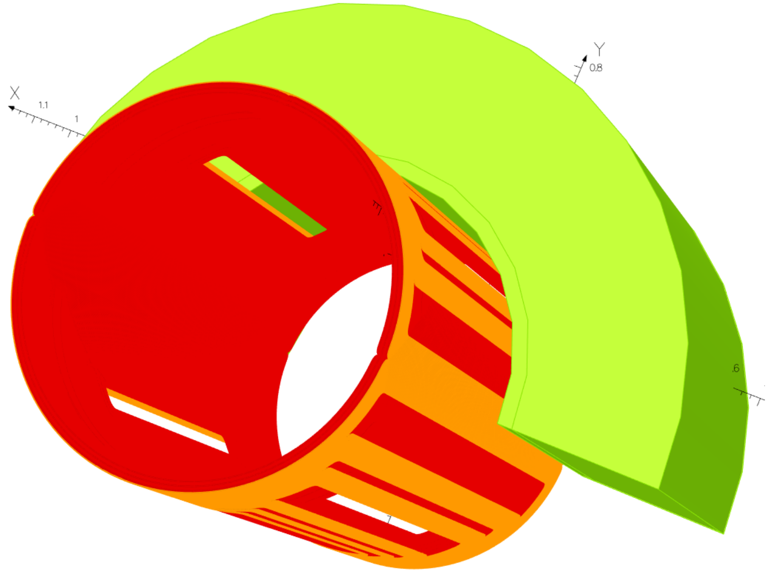
- Perform the margin calculations for the most ambitious case of the optimum integral design with 6 superconductors around 1 copper and do it for both1.92 K and 4.2 K.

Dipole Coil Added to the Quad in B0PF

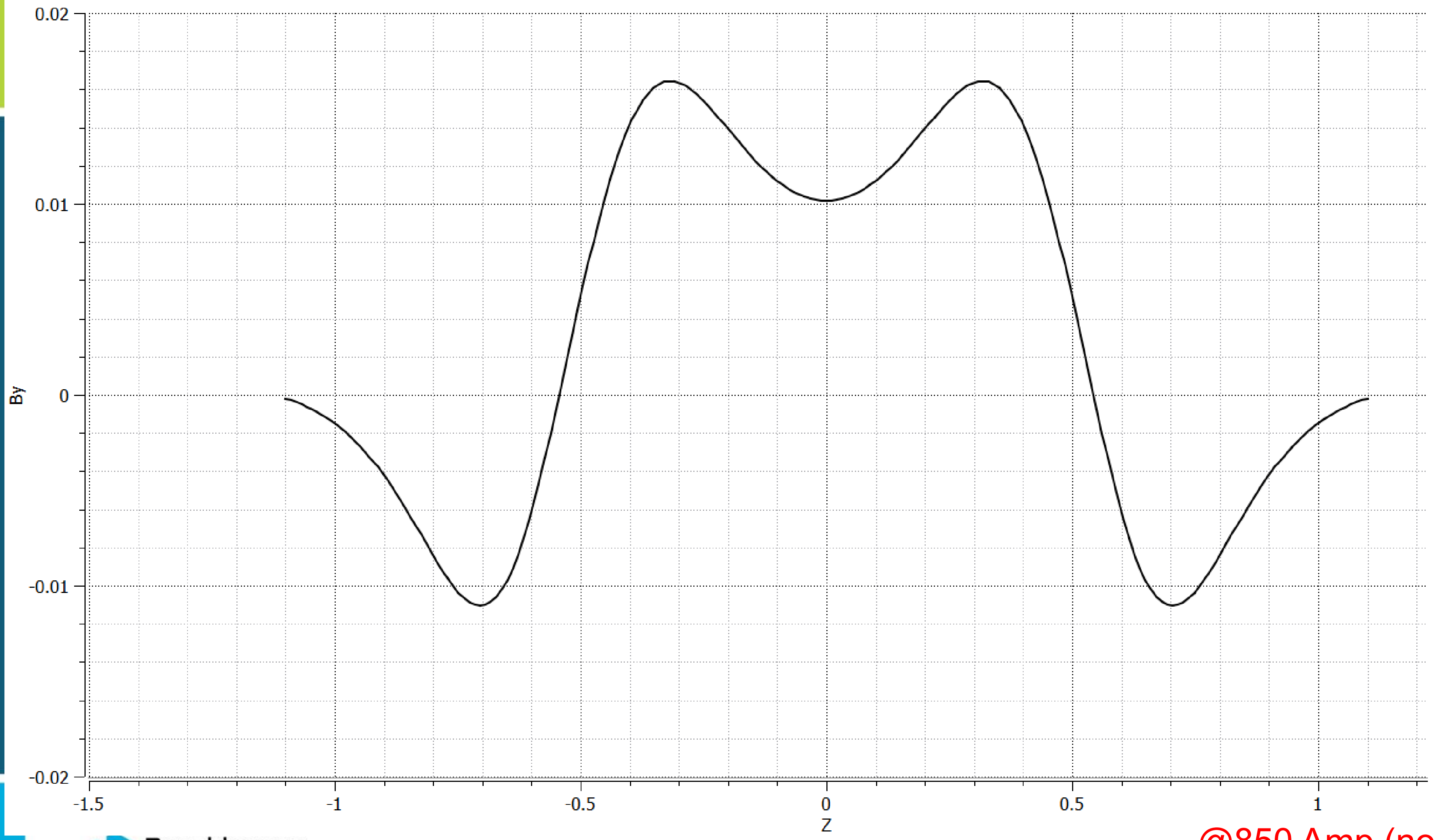
- Dipole coil runs in series with the quad and is made with the same cable as the quad coil.
- A single layer is enough (optimum integral design can have a single layer, as in the optimum integral corrector in the AGS tunnel)
- Even a single layer design creates too much field, and therefore more than ½ of the turns are removed to avoid over-correction.
- Turns are clubbed together in a few blocks (rather than evenly distributing the gaps between them) to save the construction time.



Dipole coil highlighted



Field along the electron path (X=-34 mm)

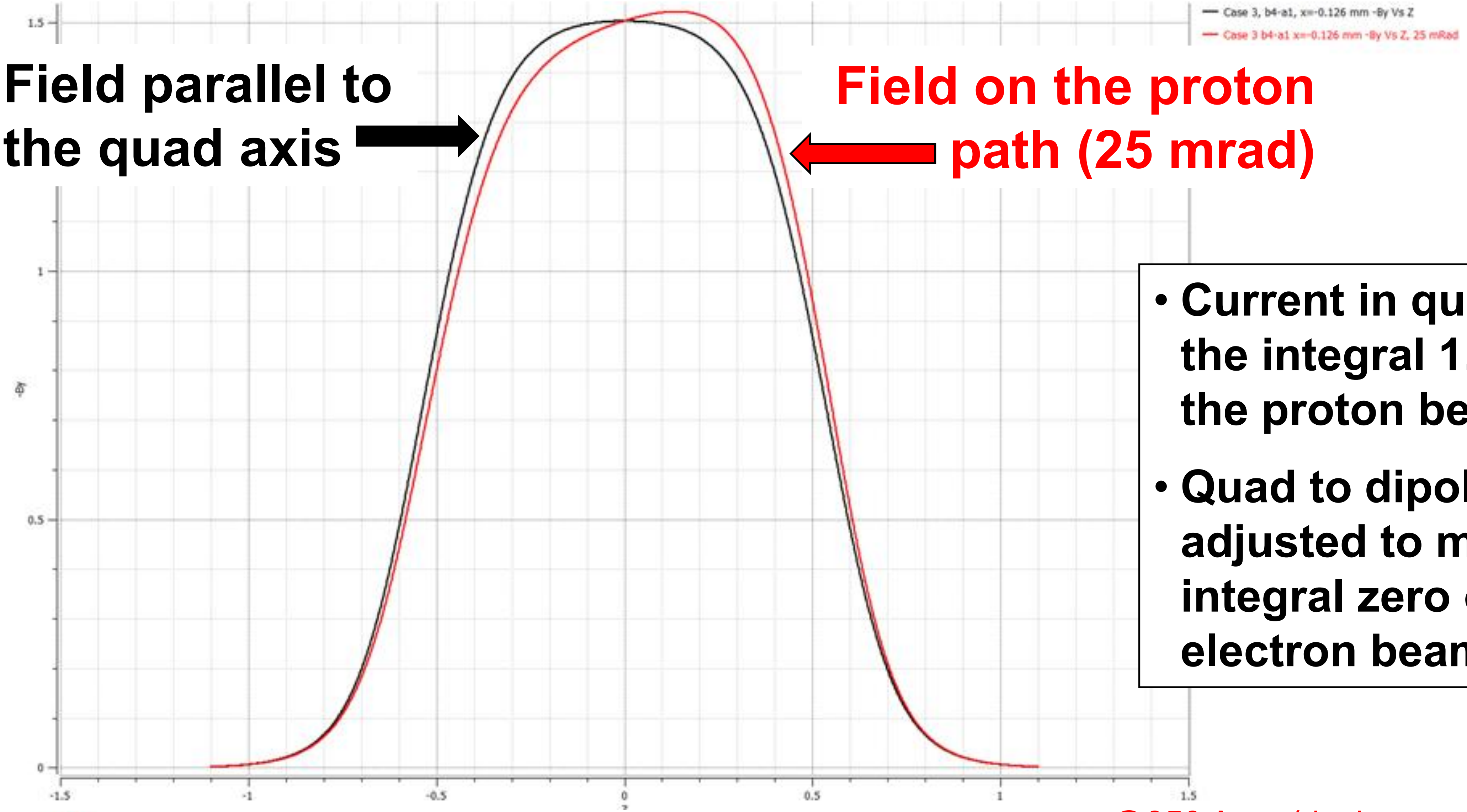


- Integral field is nearly zero (can be fine tuned to make it exactly 0)
- Oscillation in By is naturally <1 kG or 0.1 T (may be further reduced if necessary).

✓ Good enough for the initial investigation

@850 Amp (nominal 835A)

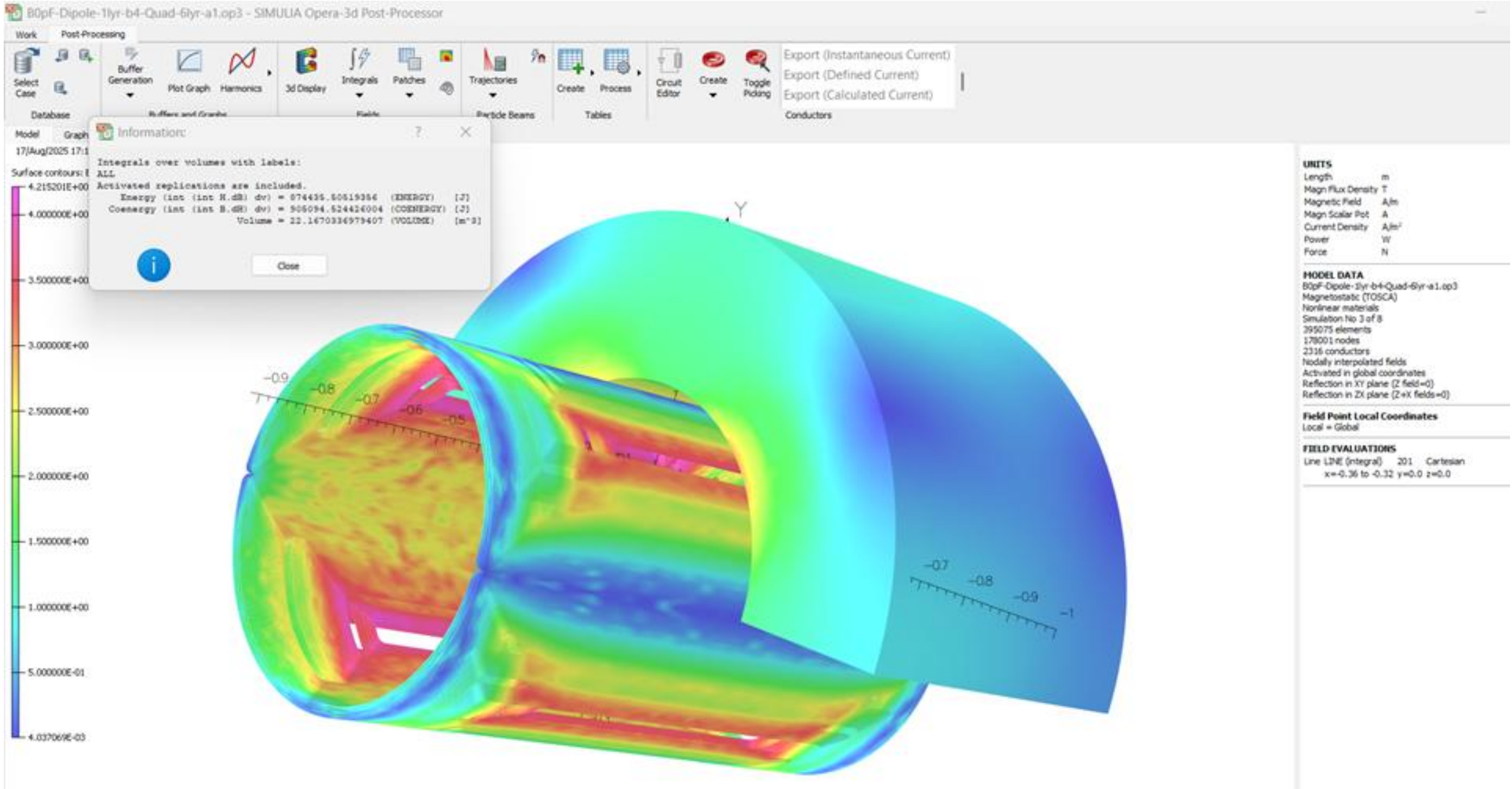
Field along the proton path (X=126 mm)



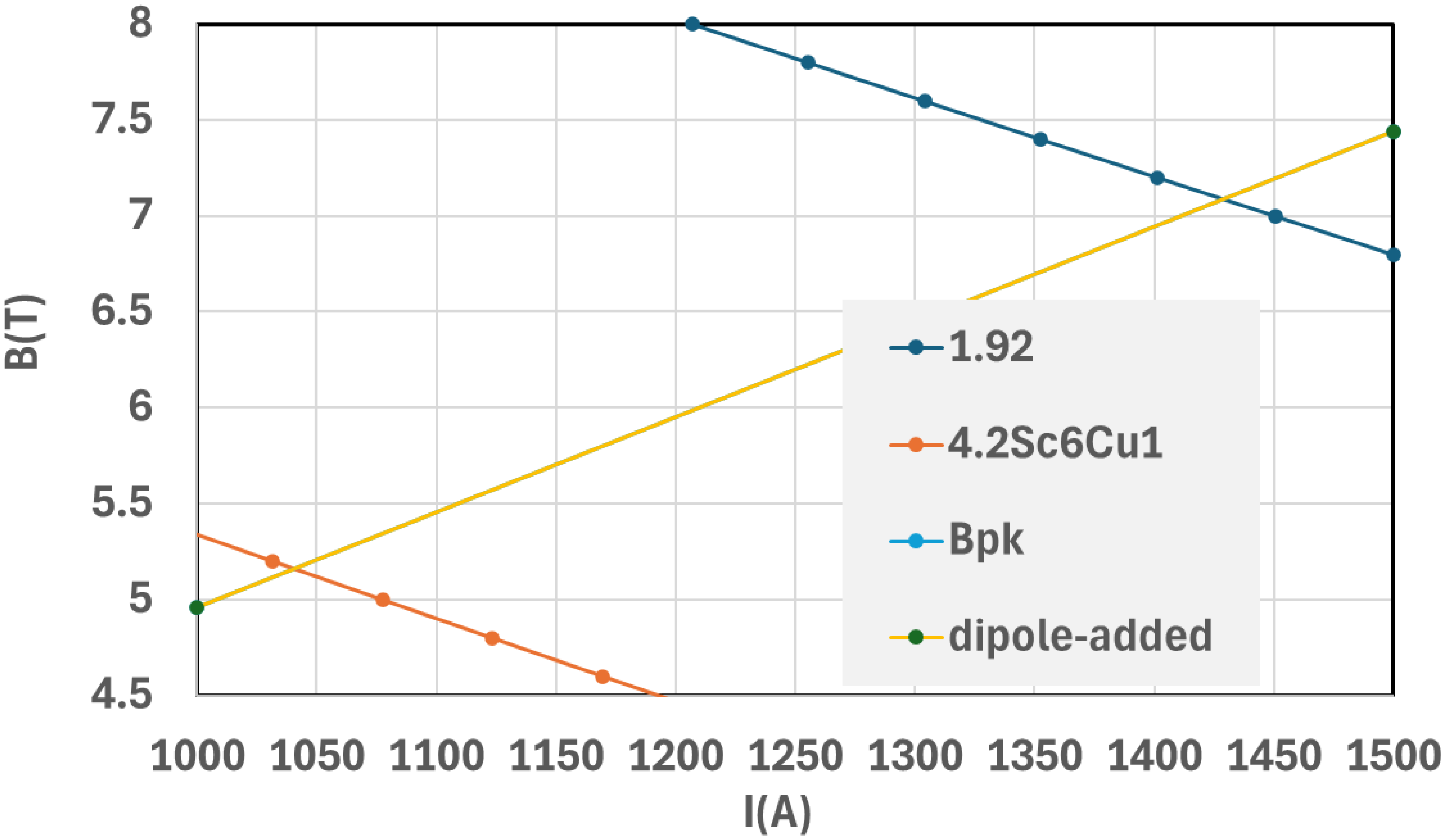
- **Current in quad to make the integral 1.56 T.m for the proton beam.**
- **Quad to dipole ratio is adjusted to make field integral zero on the electron beam path**

@850 Amp (design current 835 A)

Model with field Superimposed at 850 A
(nominal current for desired integral is 835 A)



6-Layer Optimum Integral Design B0pF Quad Performance
(with 1-layer optimum integral dipole for electron beam)



Nominal Current for design integral: 830 A

SS@1.92K, all SC 1460 Amp (margin = 75%)

SS@4.2K, 6SC on 1Cu : 1040 Amp (margin = 25%)

Summary

- **A sparsely packed single-layer optimum integral dipole was sufficient to obtain zero integral field on the path of electron beam in 6-layer B0PF Quad.**
- **The first design itself produced a peak-to-peak variation of ¼ kG or 0.025 T (goal was to make it 1 kG or 0.1 T).**
- **All essential advantages that were presented in the 1st quick design last week, are still retained in the same optimum integral 6-layer quad. These include: (a) possibility of testing it to the design performance at 4.2 K with a respectable 25% margin, (b) allowing central wire to become copper for better quench protection, in addition to reducing current to ~835 Amp from the 1146 A.**
- **Next step: try to make it a combined function design 6-layer design which creates both dipole and quadrupole.**
- **Further steps: A quick quench analysis and winding of short ¼ coil.**

Extra slides

(selected slides from the presentation on 8/14)

Background

The inset slide must force one to at least have a quick look at the optimum integral design for B0pF (reference for length to id ratio: <4 in quad; it's 1.8 here). However, to change from the serpentine design to anything else at this stage, the benefits must be significant, such as (at least one or two from the list below):

Loss in Integral Field Due to Ends and Some Short EIC Magnets

- Relative loss starts becoming important when the length of magnet is so small that the straight becomes comparable to the ends.
- Typical mechanical length of end: ~ 2 coil diameter each in dipole. Total ends in dipole: ~four diameter (~2 coil diameter in quad).
- Compare coil length (L) to coil i.d. (id) ratios. Relative loss will be significant when the ratio is <8 in dipoles and <4 in quadrupoles.

Coil length to coil diameter ratios in some EIC magnets:

- B0ApF (*L* = 600 mm, *id* = 114 mm): ~5.3
- B1ApF (*L* = 1600 mm, *id* = 370 mm): ~4.3
- B1pF/B1ApF (L = 2500 mm, id = 363 mm): ~6.9
- B0pF/Q0eF (L=1200 mm, id = 656 mm): ~1.8 (refer to quad)

Reference guide
~8 in dipole
~4 in quads

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- ***6 layers instead of 8 layers so that it can be tested in our Dewar at 4K (beside cutting cost and schedule).***
- ***The magnet achieves the design field integral at 4.2 K (with a good margin) to demonstrate the design.***
- ***Quench protection becomes significantly less challenging.***
- ***Max. field gradient (Lorentz forces) gets reduced significantly.***

Following slides are from <2 days of work using the same cable as in serpentine. First look is promising!

Six superconductor around one copper in 6-around-1 cable (instead of all super)

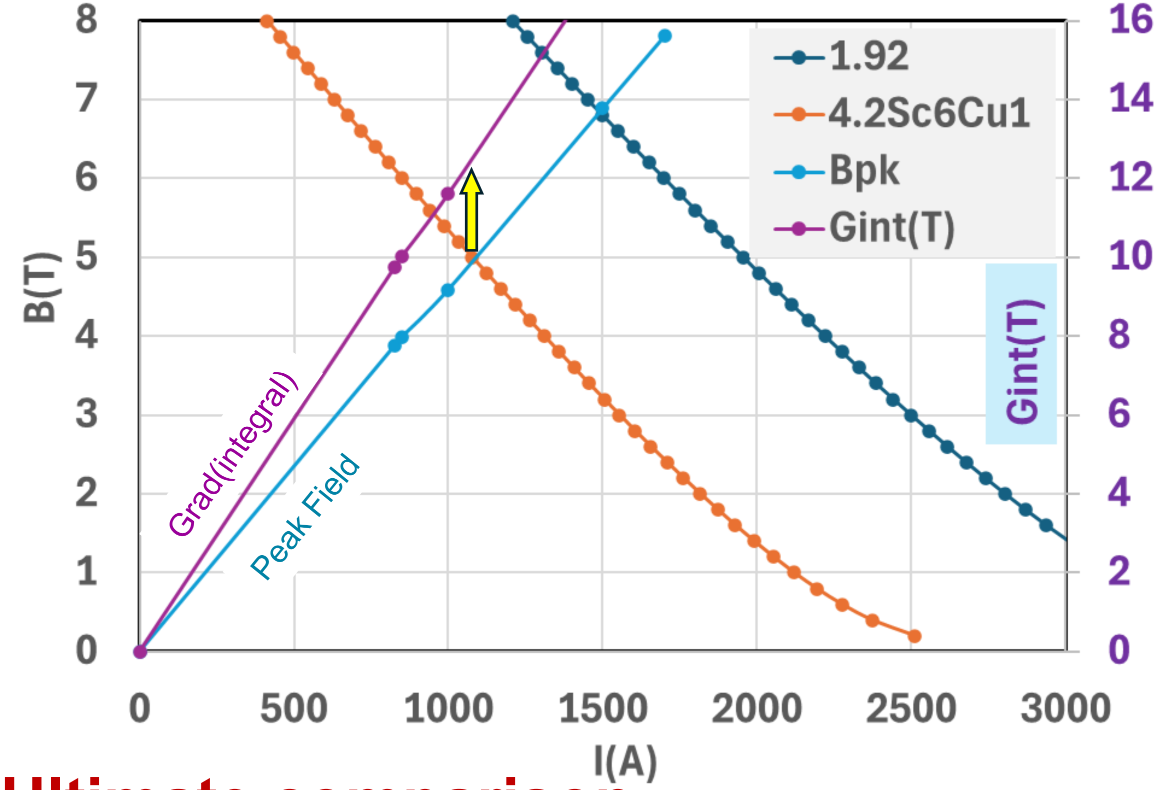
- **Center wire in 6-around-1 cable is not transposed.**
- **This creates issues at high ramp rates as the center wire tries to resist the change. At very high ramp rates, the current can even be in a direction opposite to the transport current. That will reduce the quench current of the magnet.**
- **It, however, should also help in quench protection due to the "quench back" effect. The center wire can be copper.**
- **Making the center wire Cu effectively increases the copper to superconductor ratio. That will not only help in quench protection but may even prevent a quench.**
- **The penalty to pay is in reduction in the critical current of the cable which becomes 6/7 of that in all super wire case.**

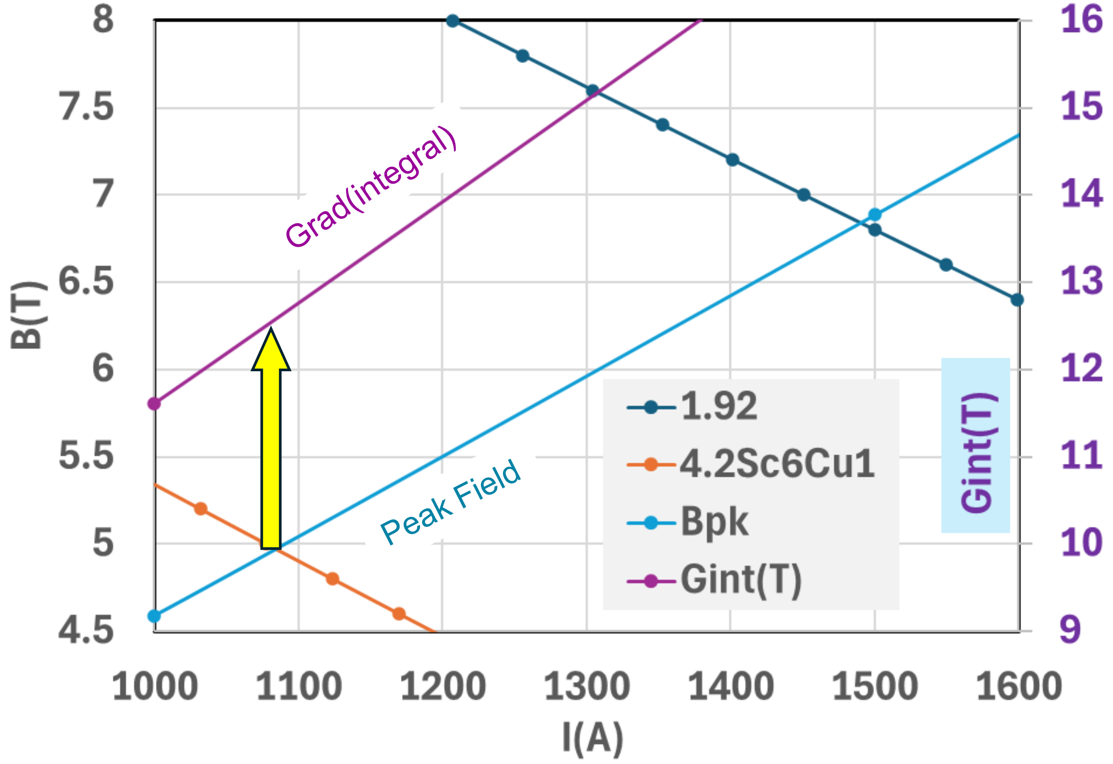
Effective Copper to Superconductor ratio in 6-around-1 copper

Cu/Sc from Brucker		
Original	Cu/Sc	**1.75**
Cu wires	**1**	
SC Wires	**6**	
Wire dia	0.473	mm
Wire area	0.176	mm^2
Super in wire	0.064	mm^2
Cu in Wire	0.112	mm^2
Cable Area	1.230	mm^2
Cu in Cable	0.847	mm^2
Super in cable	0.383	mm^2
Effective	**Cu/Sc**	**2.21**
Iquench	**1080**	Amp
Jcu@Qnch	**1276**	A/mm^2
Idesign	**827**	Amp
Jcu@design	**977**	A/mm^2

6-layer Optimum Integral Design for B0PF

(all seven super at 1.92 K Vs six super and one cu at 4.2 K)





Ultimate comparison

(for reference present serpentine design has 8 layers, 1143 A and 43% margin at 1.92 K for all seven super)

- **Design current 827 A**

	Iss(A)	Margin(%)
All SC @1.92K	1490	80%
SC6Cu1 @4.2K	1090	32%

Still heathy margins despite granting all wishes!

Summary and the Next Step (1)

- Let us compare the two options. The current serpentine design has eight quad and two dipole layers. Even quad doesn't fit in the Dewar.
- It has a nominal operating current of 1143 A. It has a margin of 43% at 1.92 K when all wires in 6-around-1 are superconducting wire, same as always.
- A quench protection solution has been found for the serpentine design with ten sets of leads and dump registers. It, however, is in challenging territory.
- Initial optimum integral design has 6 layers in quad. It can fit in our Dewar for 4.2 K testing for a computed short sample that has a comfortable 32% margin.
- Moreover, the center wire is made of copper to help quench protection by taking advantage of the quench back. This also increases Cu/Sc ratio to 2.2 to reduce current density in copper after quench at the design current, which was already smaller in this optimum integral design (827 A instead of 1143 A).

Summary and the Next Step (2)

- Lower maximum gradient means lower Lorentz forces, which should make the design less challenging. We may be able to reduce the thickness of inner tube.
- Initial outcome looks very promising. However, the electro-magnetic design, etc., must be analyzed independently (e.g. Vikas with RAT). In parallel a more optimized version can be found. This should be a few days activity only.
- Then a quick 1st order quench analysis of this design should be performed.
- Optimum integral design can conveniently allow a combined function design (rather than quad and dipole in series) – hopefully still in a 6-layer design.
- As attractive as that option maybe, evaluation of that may wait a bit for now. However, if that works, we will need only 6 sets of leads and dump resistors (instead of 10) and should offer a better technical and strategic option, in addition to all above.