Updated Design of the EIC IR Dipole Magnet B0ApF

R. Gupta[1], M. Anerella[1], Y. Bai[2], J. Becker[1], J.S. Berg[2], A Drees[1], T.J. Hollis[2], P. Joshi[1], M. Kumar[1], A. Marone[1], J. McNaughton[1], B. Parker[1], C. Runyan[1], V. Teotia[1], P. Xu[2], P. Ferracin[3], E. Ravaioli[3]

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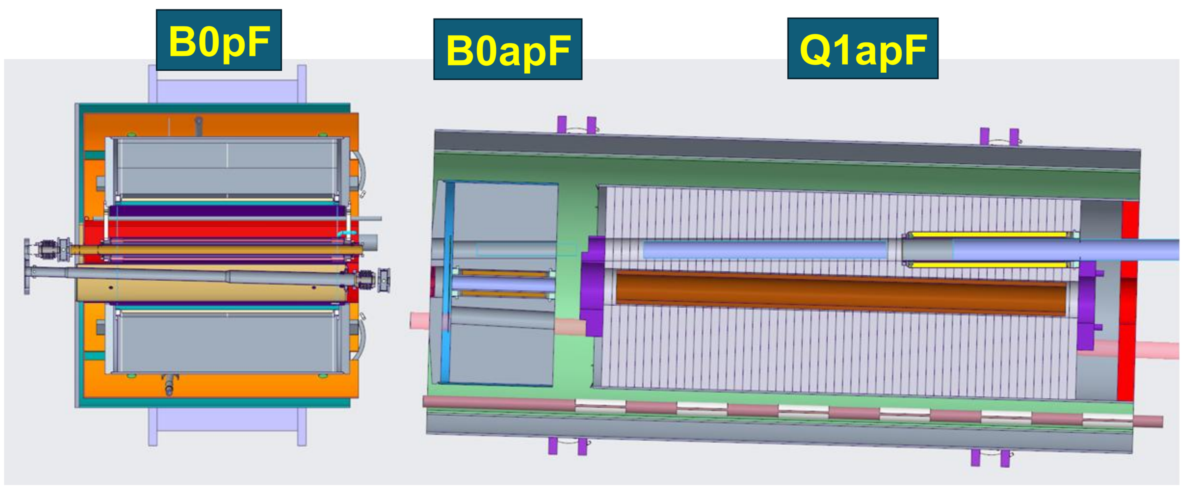
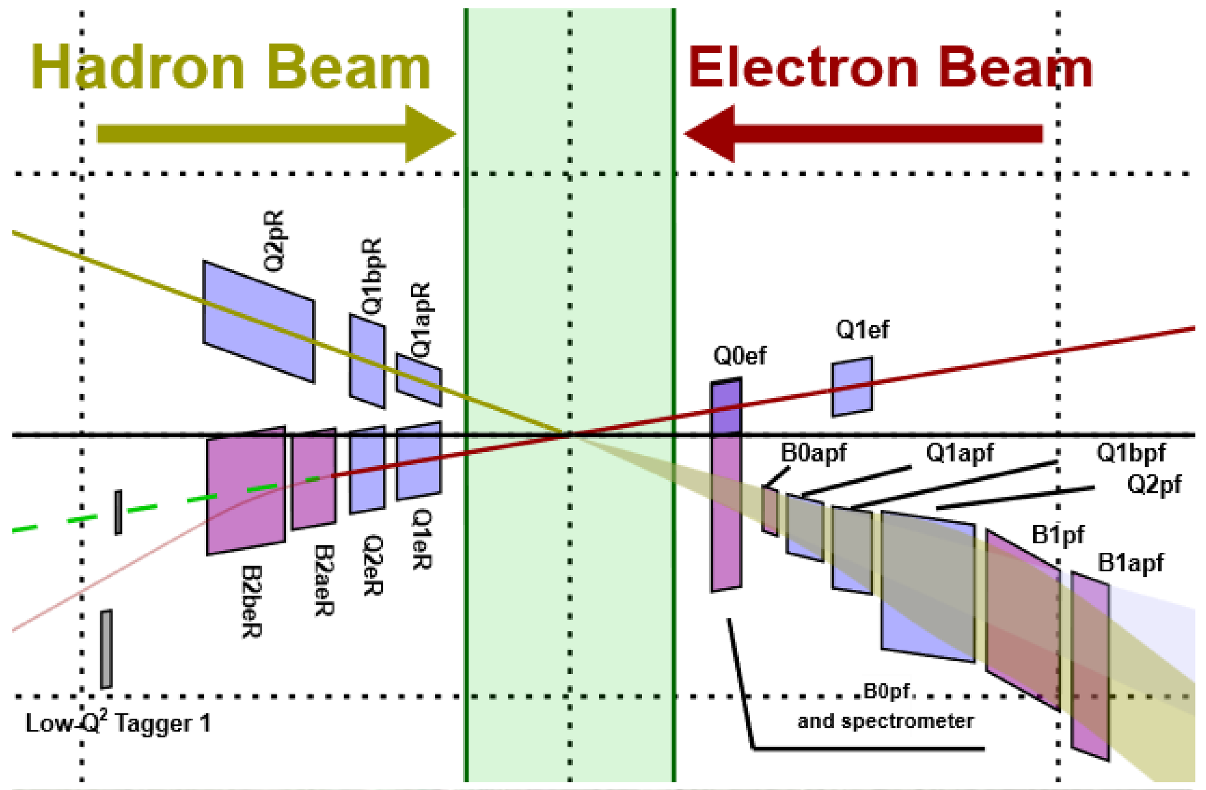
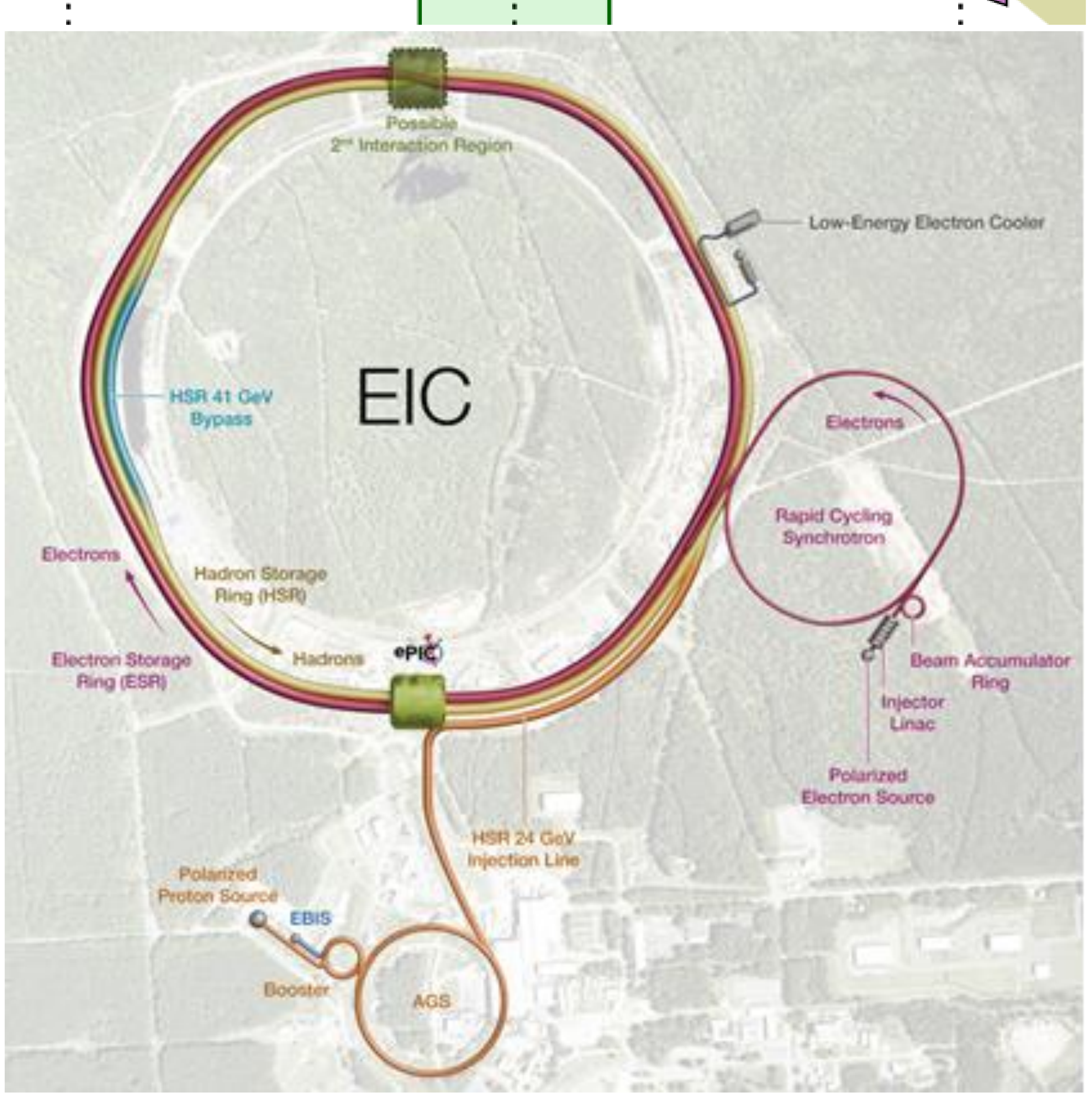
INTRODUCTION

- B0ApF is the first dipole on forward side after the large spectrometer dipole B0pF
- It helps keep different energy beams on track despite a constant field in B0pF
- Initial parameters have been updated and skew dipole and skew quad added.
- A smaller length allows more space for other magnets in the interaction region.







OPTIMUM INTEGRAL DESIGN (OID)

Midplane turns extended to full coil length

Optimize cross-section and ends together for an overall cosine theta distribution to obtain an *Optimum Integral Design (OID):*

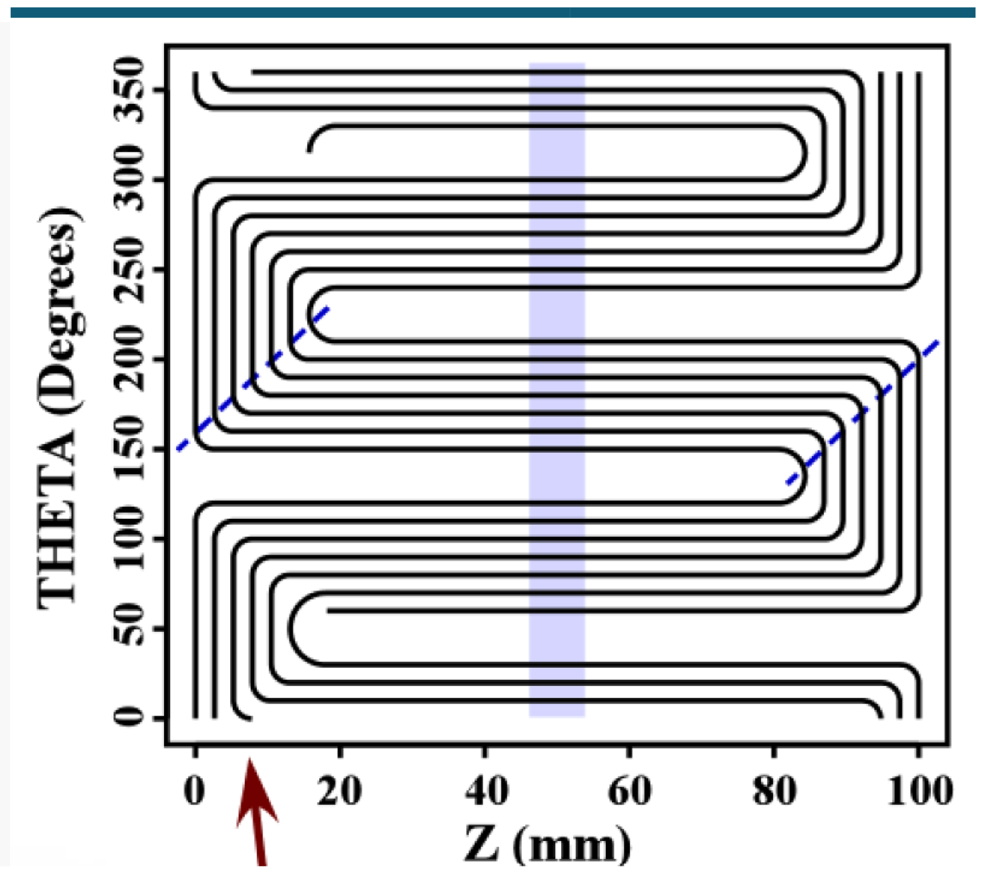
$$I(\theta) \cdot L(\theta) = I_o \cdot L_i(\theta) \propto I_o \cdot L_o \cdot \cos(n\theta)$$

Reduction in length of the turns in going from midplane to pole helps optimization

✓ Loss due to ends essentially eliminated

➢ *OID is thus preferred in short magnets*

SEPENTINE DESIGN



- Continuous winding: no leads & splices between poles in any n–pole magnet
- Design optimized for 2-d is good for 3-d also since all turns have the same length
- Preferred in long magnets where a loss in integral field due to ends is small

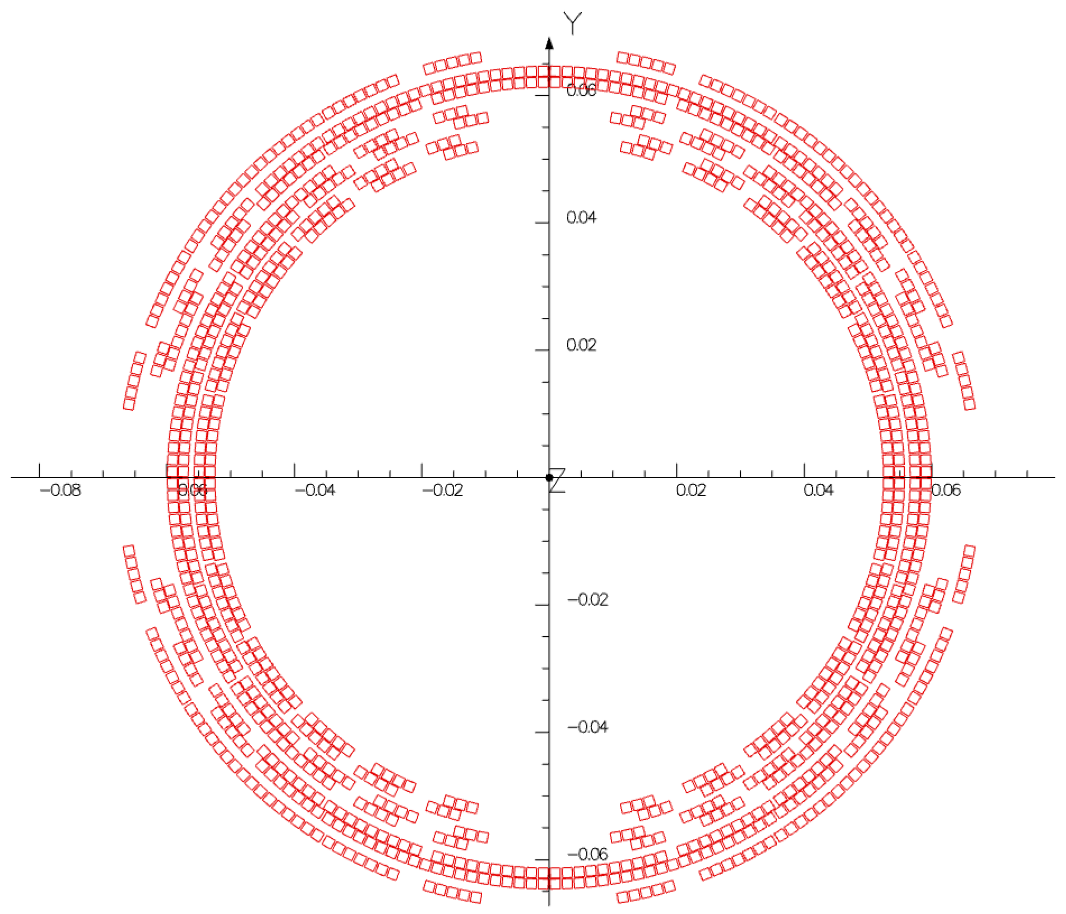
DESIGN PARAMETERS

- Coil length 500 mm (also examined cases for 400 mm, 600 mm, and 765 mm)
- Coil inner diameter: 105.33 mm
- (Coil length) / (Coil i.d.) ratio: 4.7
- Wire/cable diameter: 0.47mm/1.7 mm
- Yoke length: 0.62 m
- B0apF dipole integral field: 1.05 T.m
- Skew dipole integral field: 0.6 T.m
- Skew quadrupole integral gradient: 3 T
- Field homogeneity (harmonics @26 mm)
  - ❑ B0ApF dipole: -2 to +2 units
  - ❑ Skew dipole: -10 to +10 units
  - ❑ Skew quadrupole: -10 to +10 units
- Crosstalk (harmonics in ESR@26 mm)
  - ❑ Linear integral: <6.2 μT.m
  - ❑ Non-linear integral: <6.2 μT.m

DESIGN OVERVIEW

- Direct Wind (DW) technology with multi-layer coils is used to reduce cost.
- Co-centric coils for three: B0ApF Dipole, Skew Dipole, and Skew Quadrupole.
- A set of design options examined for a range of integral fields and coil lengths.
- In conventional designs, ends dilute the integral field in short coils. In B0ApF coil id/length ratio <5; some options had <4).
- Optimum Integral Design (OID) preferred for its efficiency in such short magnets.
- Required load-line margin 65% for each magnet, when powered together to max.
- Cross-talk (field errors in close-by electron beam line) must be kept small.
- Structure must handle the overall and intra-coil Lorentz forces between layers.

CURRENT DESIGN (coil length 500 mm)



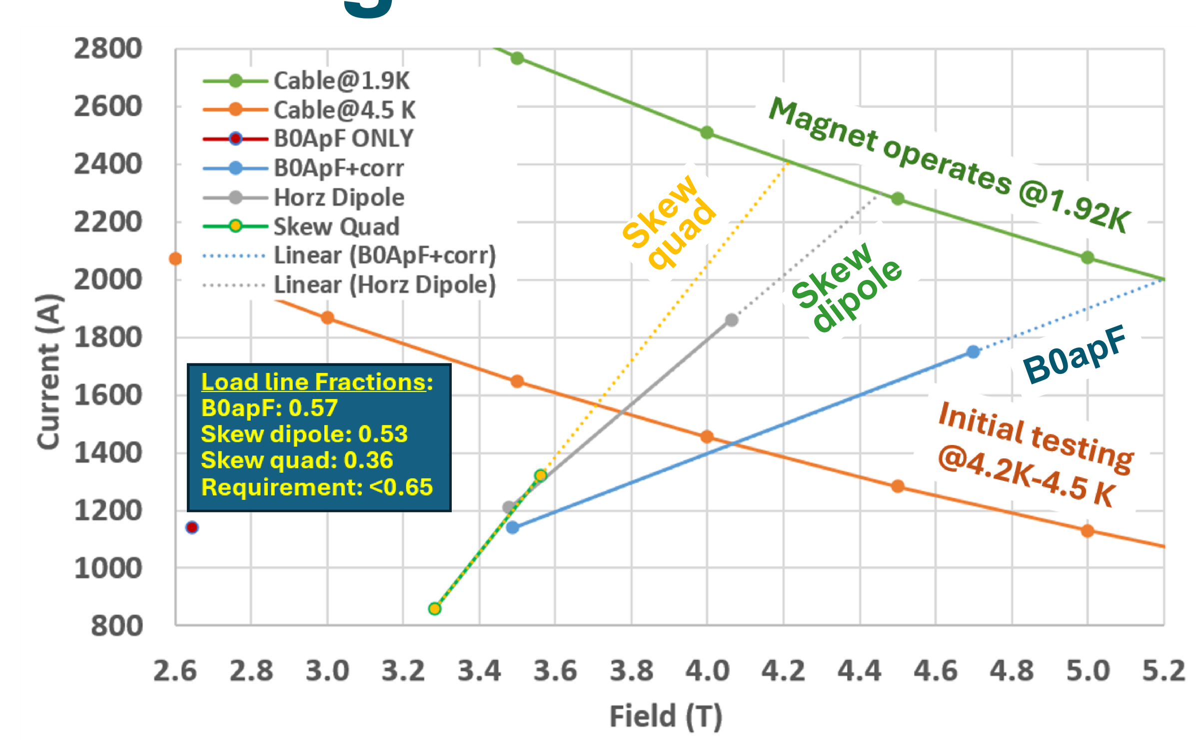
B0ApF package (with number of layers):

➢ B0ApF dipole (four): 1.05 T.m @1140 A

➢ Skew dipole (two): 0.6 T.m @1210 A

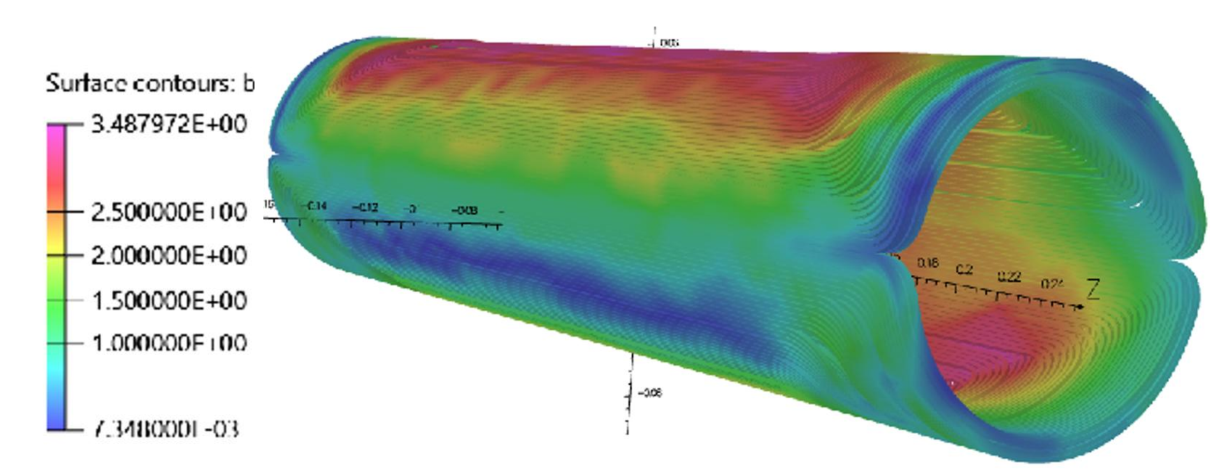
➢ Skew quadrupole (single): 3 T@860 A

Margin Calculations



Field contour superimposed on B0ApF coil

(other coils powered at the nominal current but hidden)



Electron-Ion Collider

Brookhaven National Laboratory

Jefferson Lab

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https://wpw.bnl.gov/rgupta/eic-work-in-progress/

*This work is supported by Brookhaven Science Associates, LLC under contract No. DE-SC0012704, with the U.S. Department of Energy.

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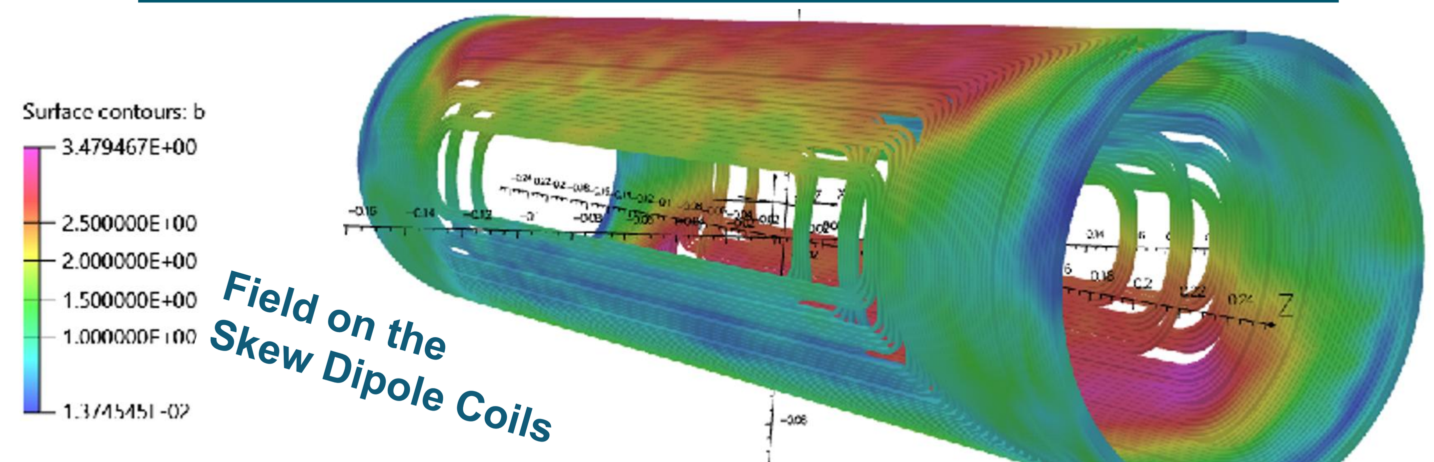
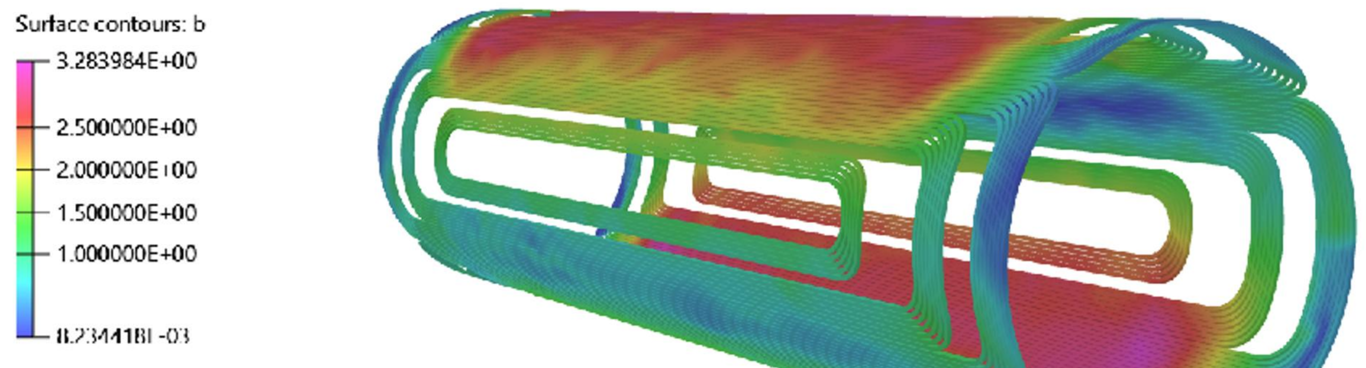
MAGNETIC ANALYSIS





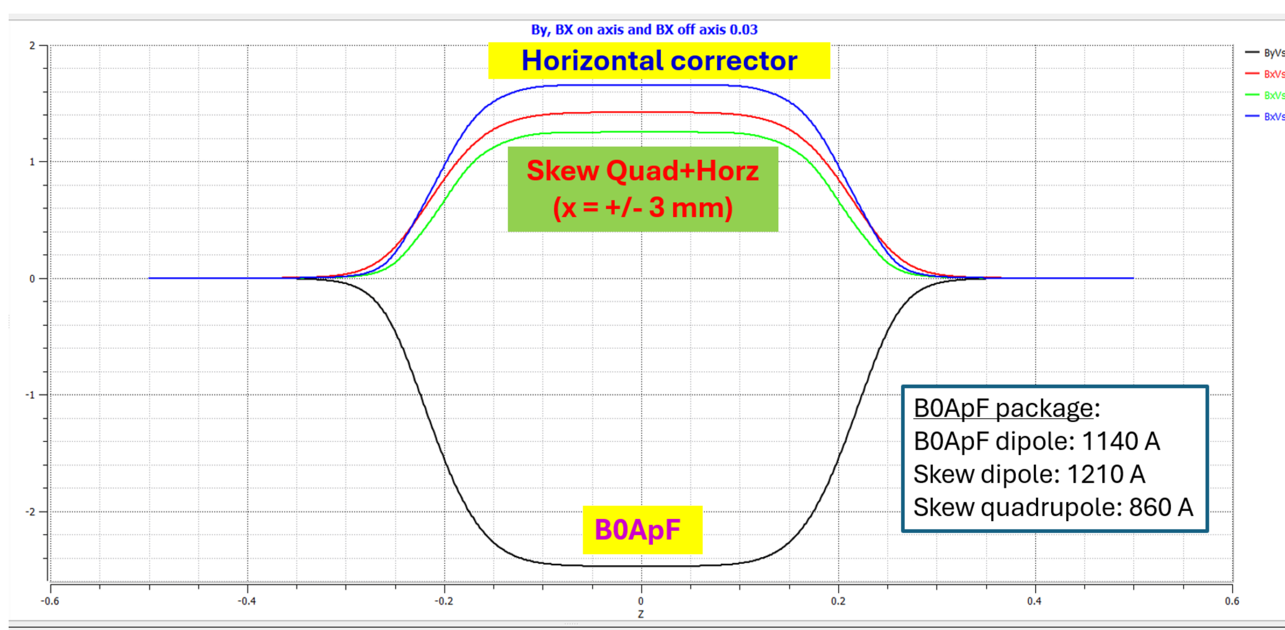
Field on the Skew Quad Corrector Coil
(all coils powered at nominal current but hidden)

Harmonics are optimized in each layer.

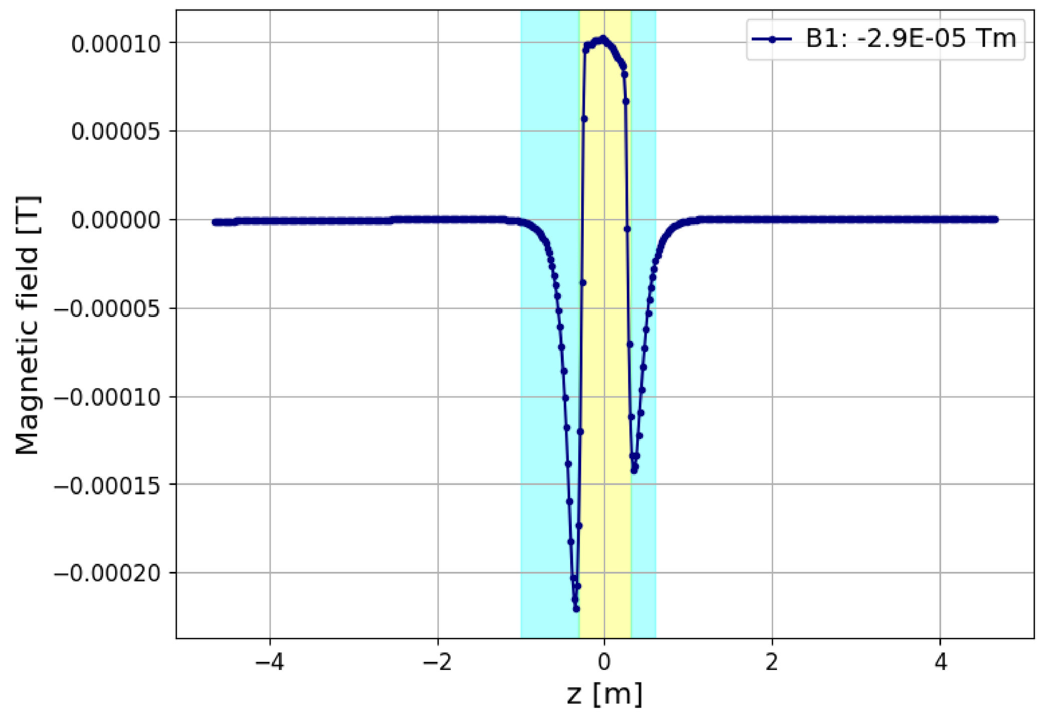
b_n/a_n @25 mm in 1st layer of each multipole:

B0apF Dipole		Skew Dipole		Skew Quad	
n	bn	n	an	n	an
3	0.00	3	0.00	6	0.00
5	0.01	5	0.00	10	0.00
7	0.05	7	0.00	14	0.00
9	0.35	9	0.04	18	0.00
11	0.03	11	0.06	22	0.00
13	-0.02	13	0.00	26	0.00
15	0.00	15	0.00	30	0.00

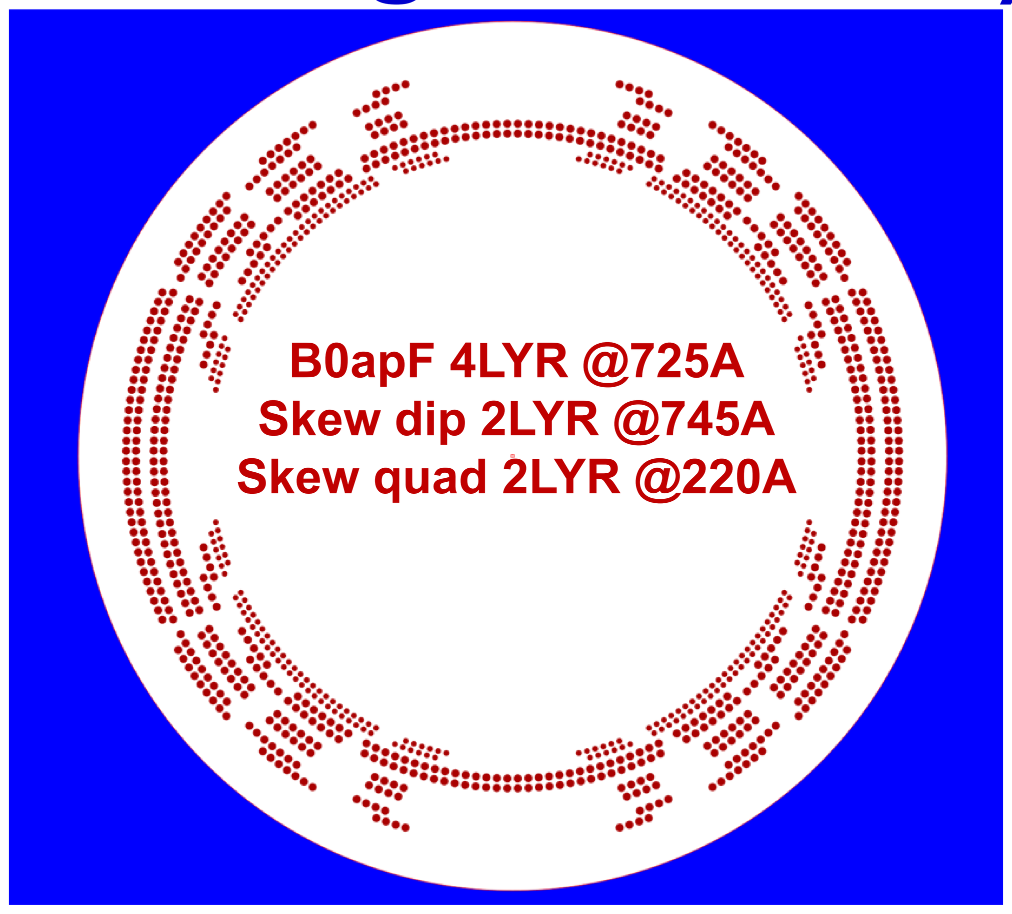
Field along the hadron path with B0apF & correctors at full strength



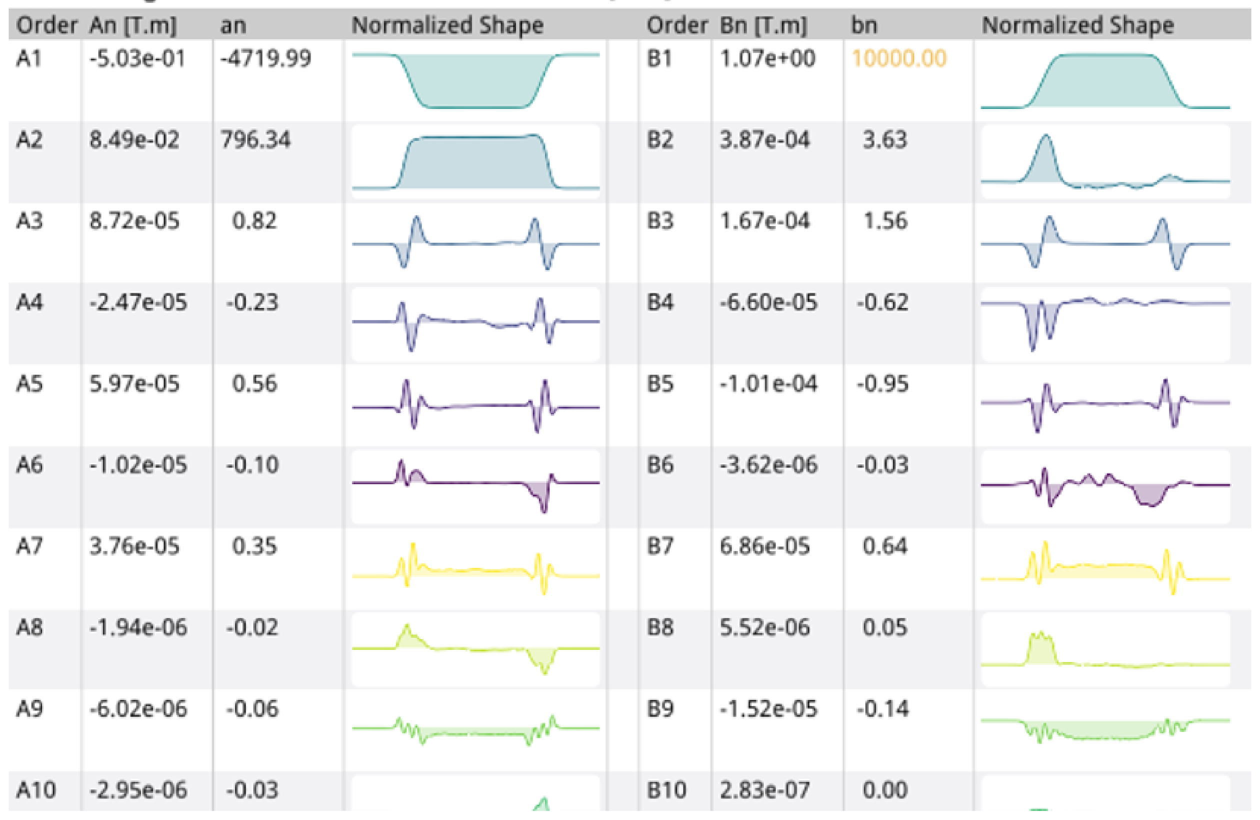
Field along the electron path



SERPENTINE DESIGN (coil length 745 mm)



B0ApF Combined Harmonics Analysis

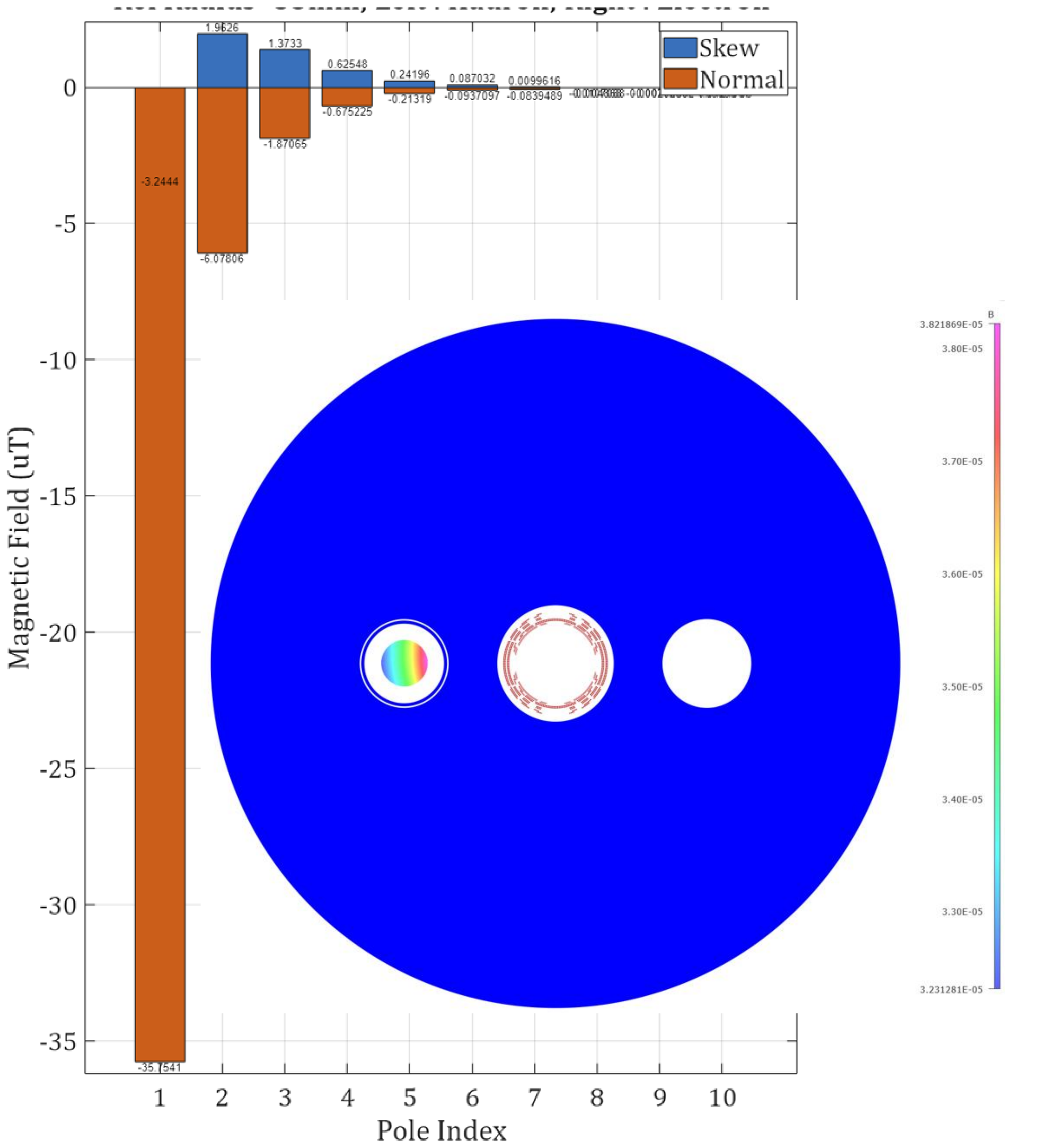


Harmonics Table | Main Harmonics | Skew harmonics | Axial Field

harmonics given at a reference radius of: 28.000 [mm]

Order	An [T.m]	an	Normalized Shape	Order	Bn [T.m]	bn	Normalized Shape
A1	-5.03e-01	-4719.99		B1	1.07e+00	10000.00	
A2	8.49e-02	796.34		B2	3.87e-04	3.63	
A3	8.72e-05	0.82		B3	1.67e-04	1.56	
A4	-2.47e-05	-0.23		B4	-6.60e-05	-0.62	
A5	5.97e-05	0.56		B5	-1.01e-04	-0.95	
A6	-1.02e-05	-0.10		B6	-3.62e-06	-0.03	
A7	3.76e-05	0.35		B7	6.86e-05	0.64	
A8	-1.94e-06	-0.02		B8	5.52e-06	0.05	
A9	-6.02e-06	-0.06		B9	-1.52e-05	-0.14	
A10	-2.95e-06	-0.03		B10	2.83e-07	0.00	

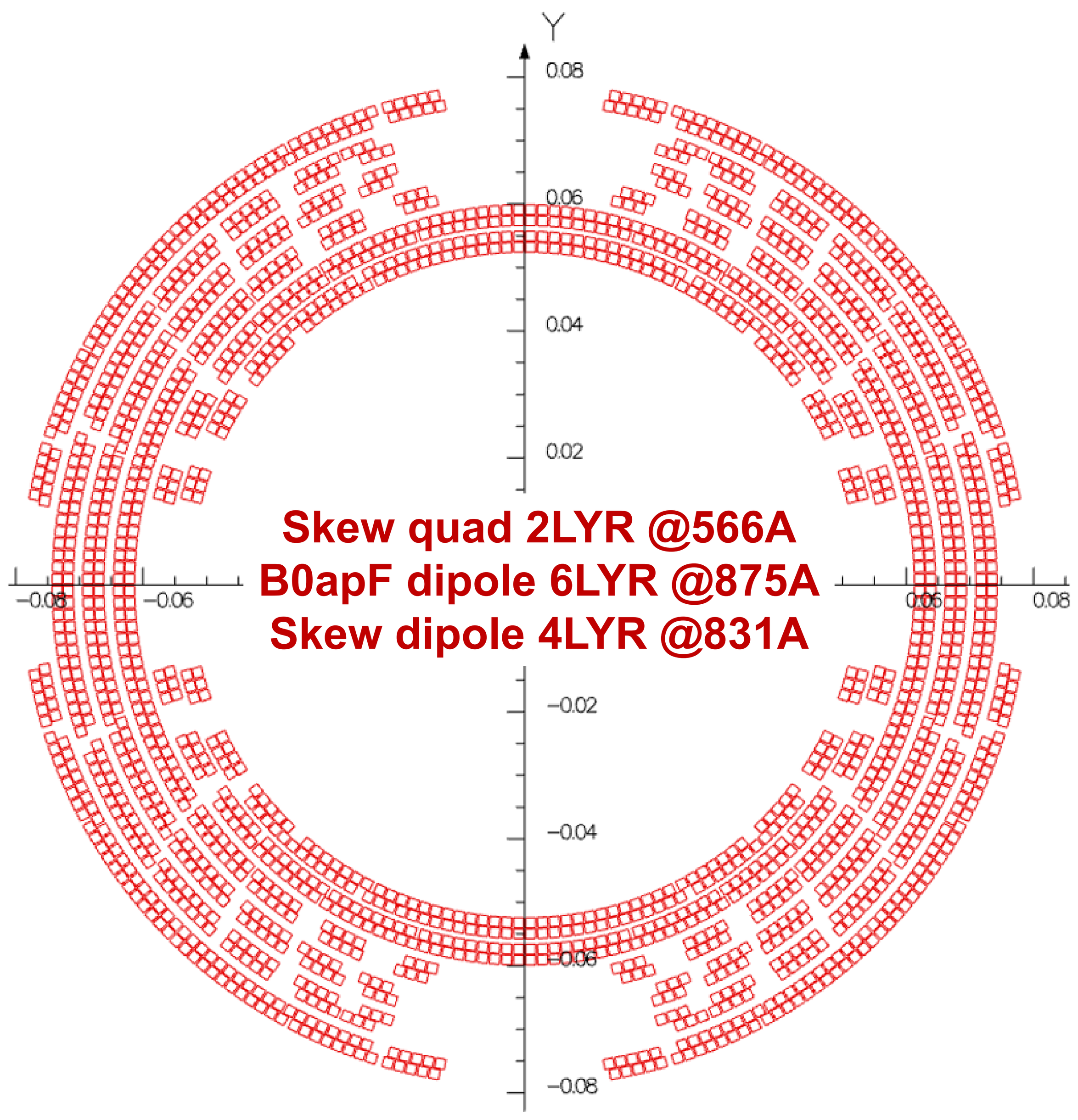
B0ApF Cross-talk Mitigated



SHORT OID PACKAGE (coil length only 400 mm)

Optimum Integral Design (OID) allows very short magnets (coil length to coil diameter ratio <4 or smaller) with a good field quality.

Number of layers, however, must increase to provide the required field integral.



NEXT STEP

With the basic coil design developed, the next step is to perform detailed magnetic, mechanical and quench analysis and to develop detailed engineering design of the cold mass and cryostat (EIC IR magnets Q1A and Q1B will be in the same cryostat).

SUMMARY

Updated design has a coil length of 500 mm which is even smaller than that in the previous design (600 mm). The optimum integral dipole design has already been demonstrated in a B0ApF R&D dipole built and tested at a higher field.

Reduction in the length of B0ApF allows more space for other magnets in the crowded region of the EIC IR.