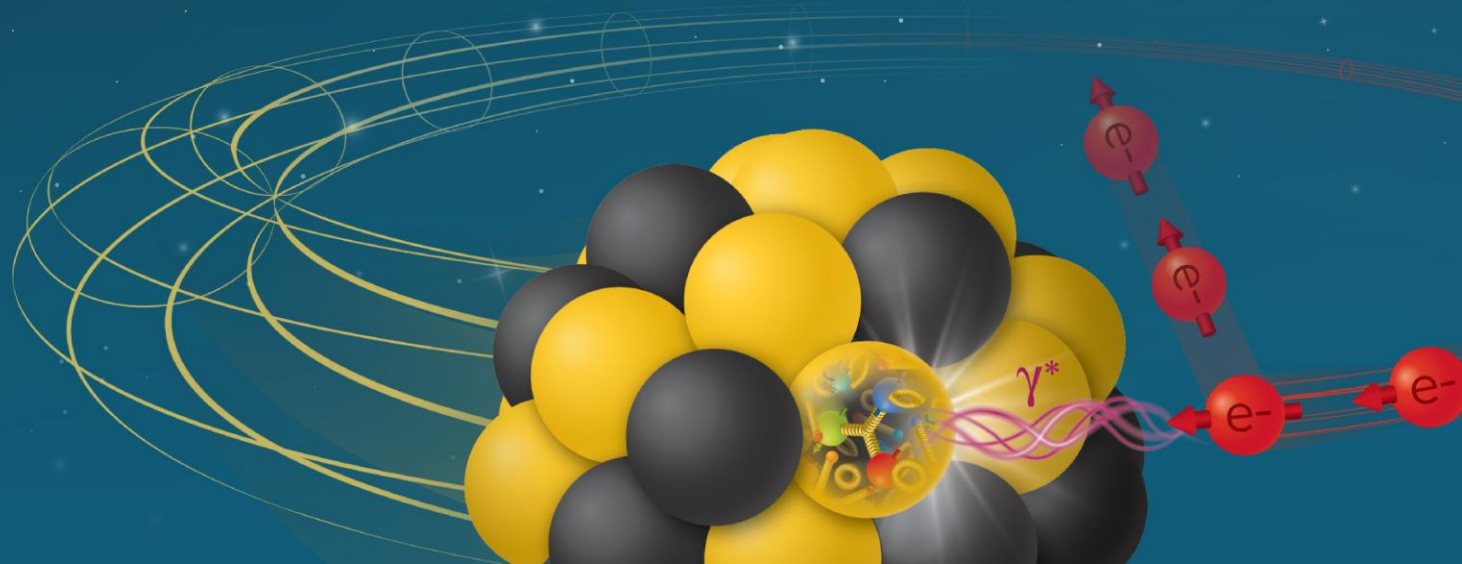
Brookhaven National Laboratory | Jefferson Lab | U.S. DEPARTMENT of ENERGY | Office of Science

# B0ApF with correctors: 400mm and 500mm options based on the Optimum Integral Design

Ramesh Gupta
Superconducting Magnet Division




FC1 Tracking Meeting
June 26, 2026

Electron-Ion Collider

# OVERVIEW

**Magnetic design requirements of B0ApF with the Corrector Package:**

- ❑ 1.05 T.m for B0ApF
- ❑ 0.6 T.m vertical corrector (includes 20% margin)
- ❑ 3 T skew quadrupole corrector (includes 20% margin)

**Inner diameter of the 1st winding: ~105.4 mm**
**Coil length Options: (a) 400 mm and (b) 500 mm**

**A small length/aperture ratio (<4 for the 400 mm case)**

- ✓ **Optimum Integral Design (OID) makes a big difference such cases.**

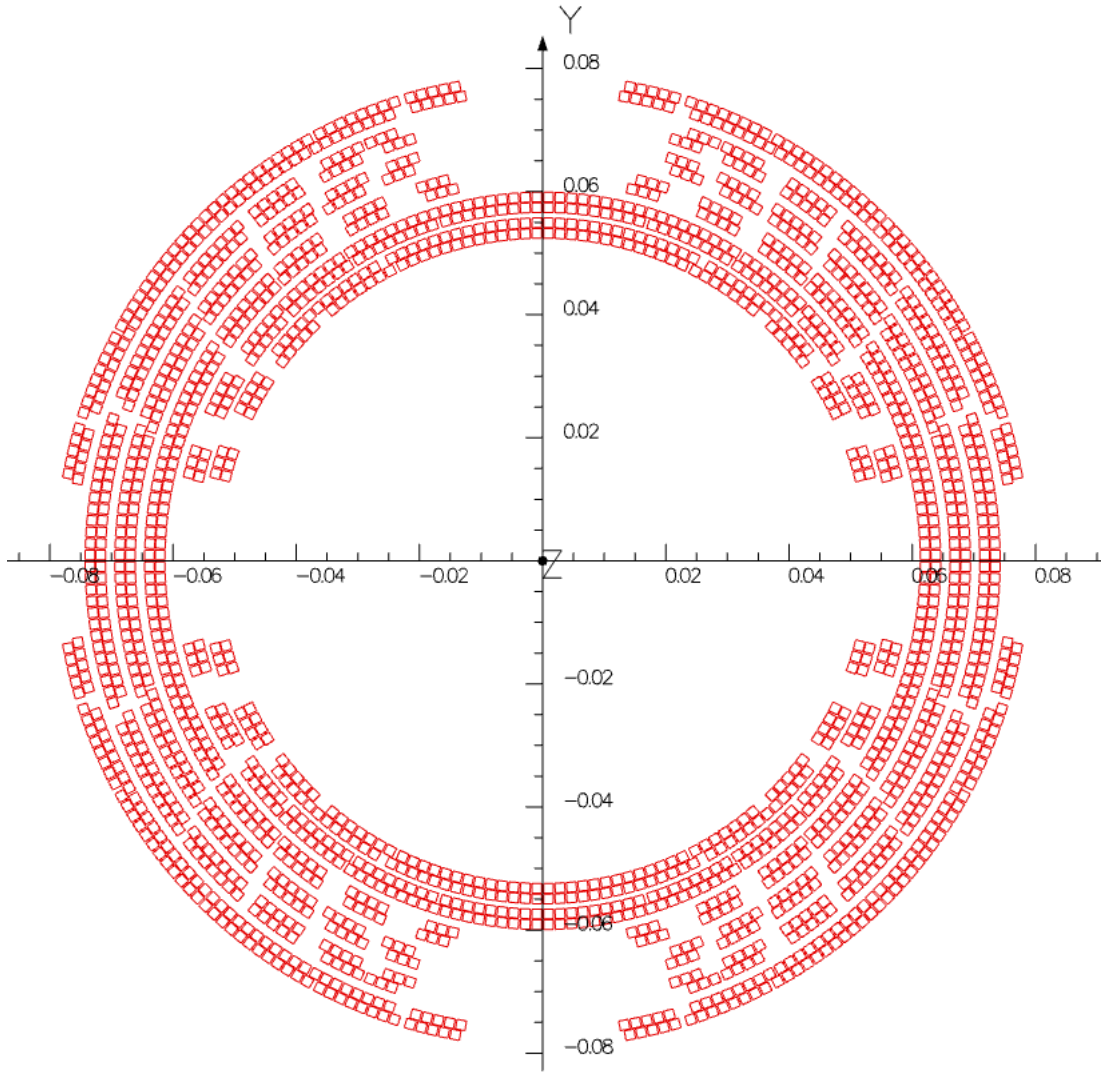
**A working design for both cases. The difference is in the number of winding layers needed.**
**Compare: "Increased cost of B0ApF" Vs "Benefits of longer Q1A/BpF"**

# 400 mm long B0ApF
# Twelve layer design
# (same coil id as in the serpentine)

- **4 layers (2 coil sets) creating 0.6 T.m Horizontal Dipole**
- **6 layers (3 coil sets) creating 1.05 T.m Vertical Dipole**
- **2 layers (1 coil set) creating 3 T Skew Quadrupole**

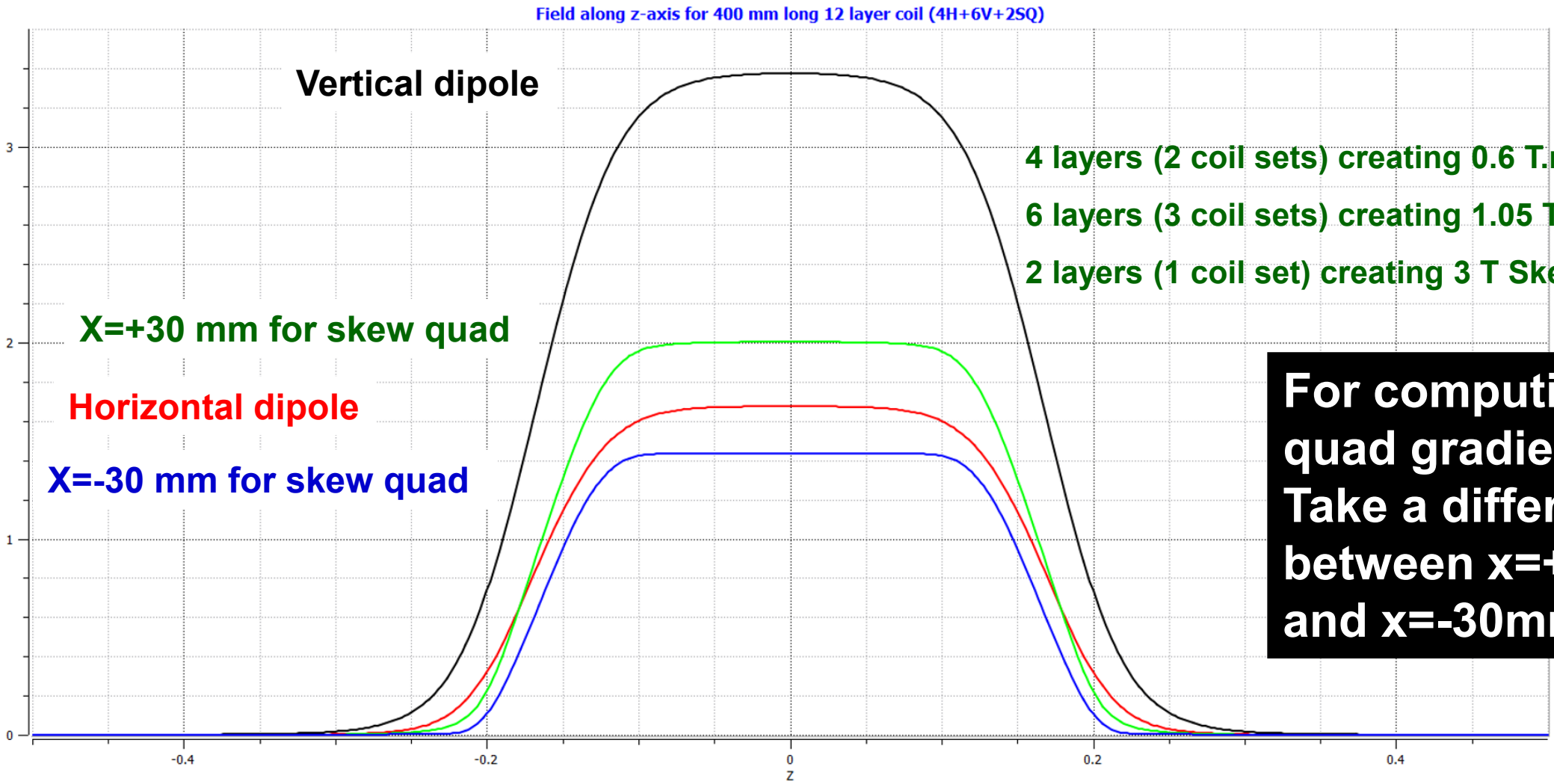
- The order of placement is chosen to balance out (maximize the minimum) margins in all magnets
- For margin calculations, all magnets are set at the maximum field, and margin is computed over that (same as in the Q3package with B2pF)

# Basic Model of the 12-layer design for 400 mm-long B0ApF




- 4 layers (2 coil sets)
  - ➢ creating 0.6 T.m Horizontal Dipole
- 6 layers (3 coil sets)
  - ➢ creating 1.05 T.m Vertical Dipole
- 2 layers (1 coil set)
  - ➢ creating 3 T Skew Quadrupole

# Field Profile on the z-axis at the design field (all powered)




Vertical dipole

X=+30 mm for skew quad

Horizontal dipole

X=-30 mm for skew quad

4 layers (2 coil sets) creating 0.6 T.m Horizontal Dipole

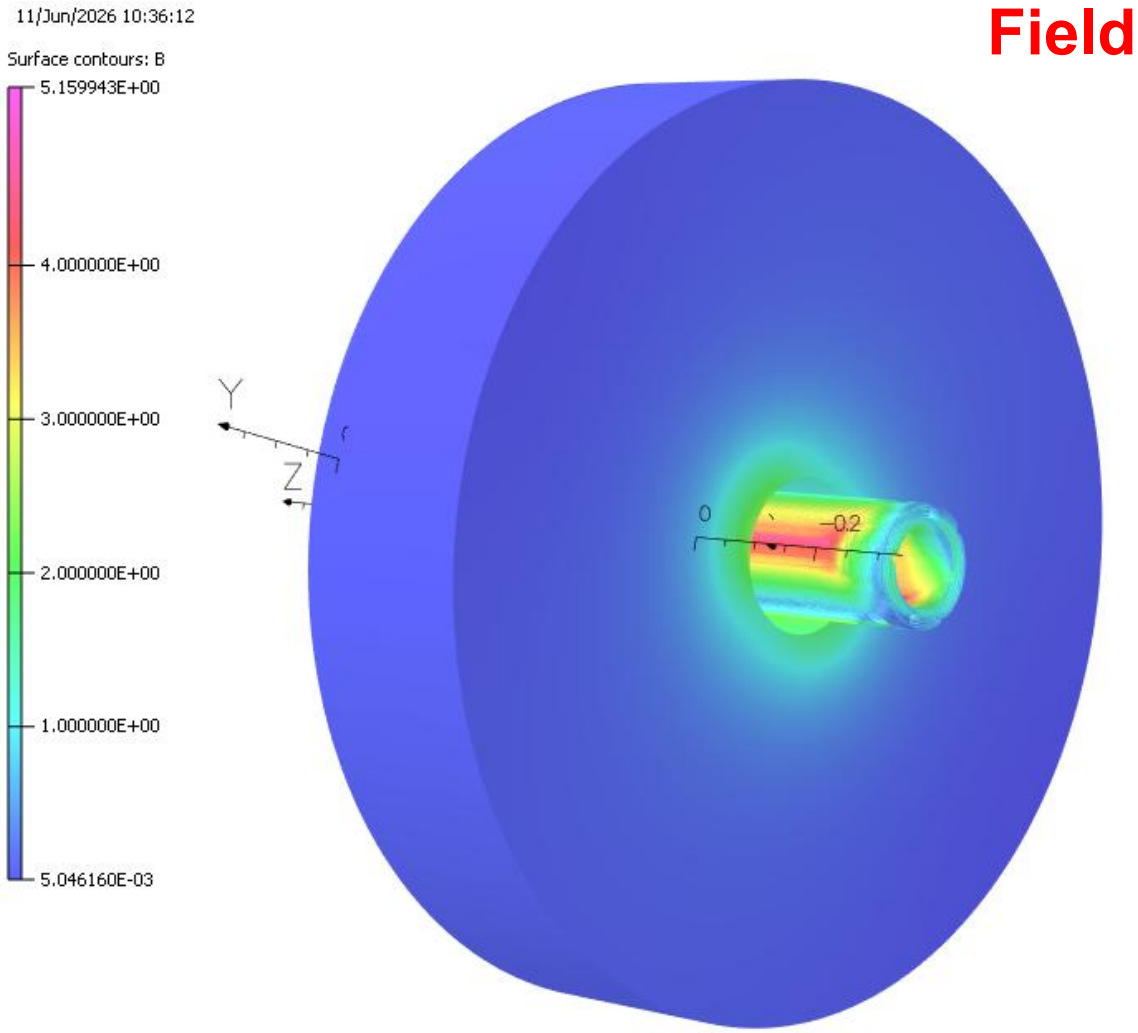
6 layers (3 coil sets) creating 1.05 T.m Vertical Dipole

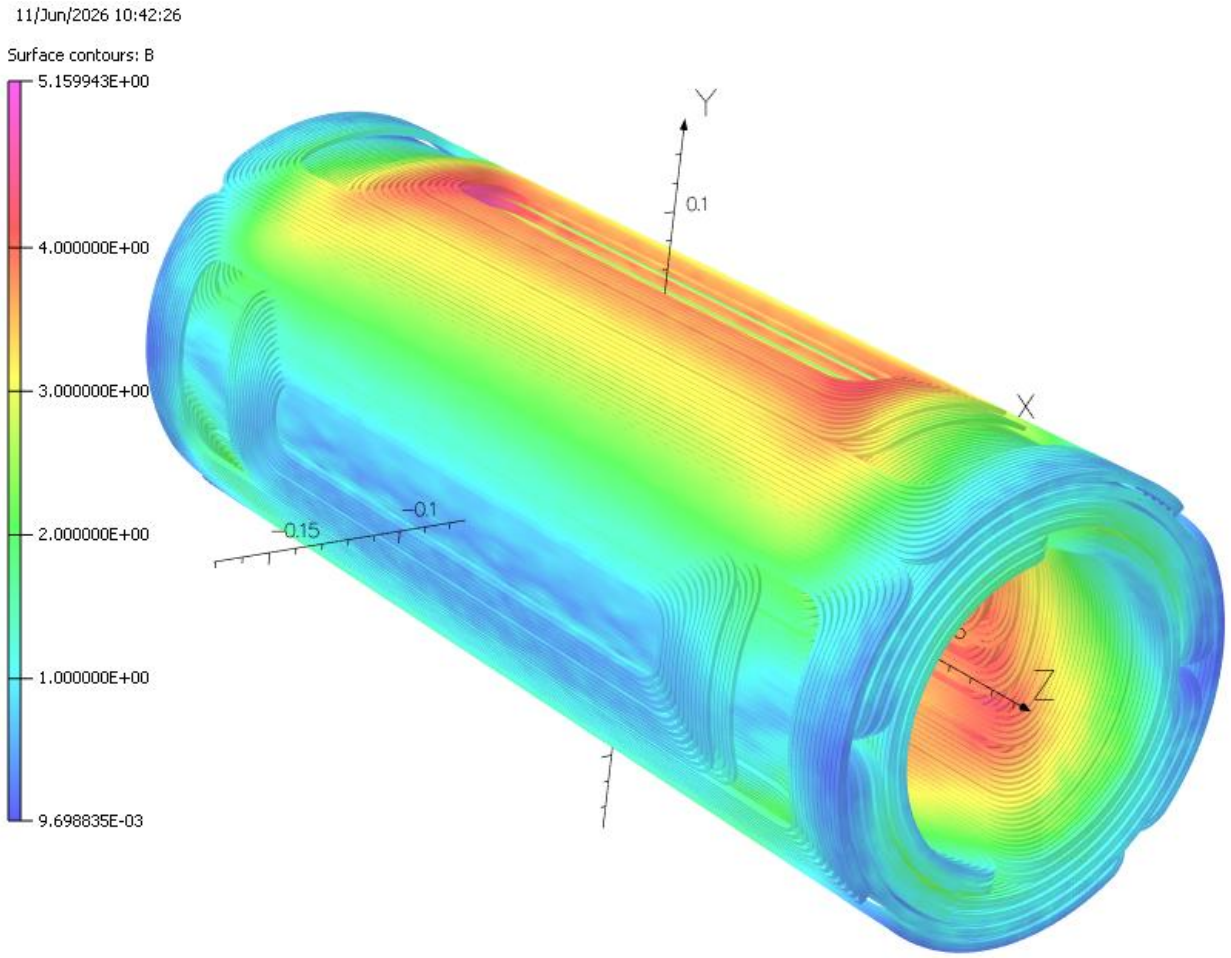
2 layers (1 coil set) creating 3 T Skew Quadrupole

**For computing skew quad gradient, Take a difference between x=+30 mm and x=-30mm**

# 12-layer Optimum Integral Design for B0ApF

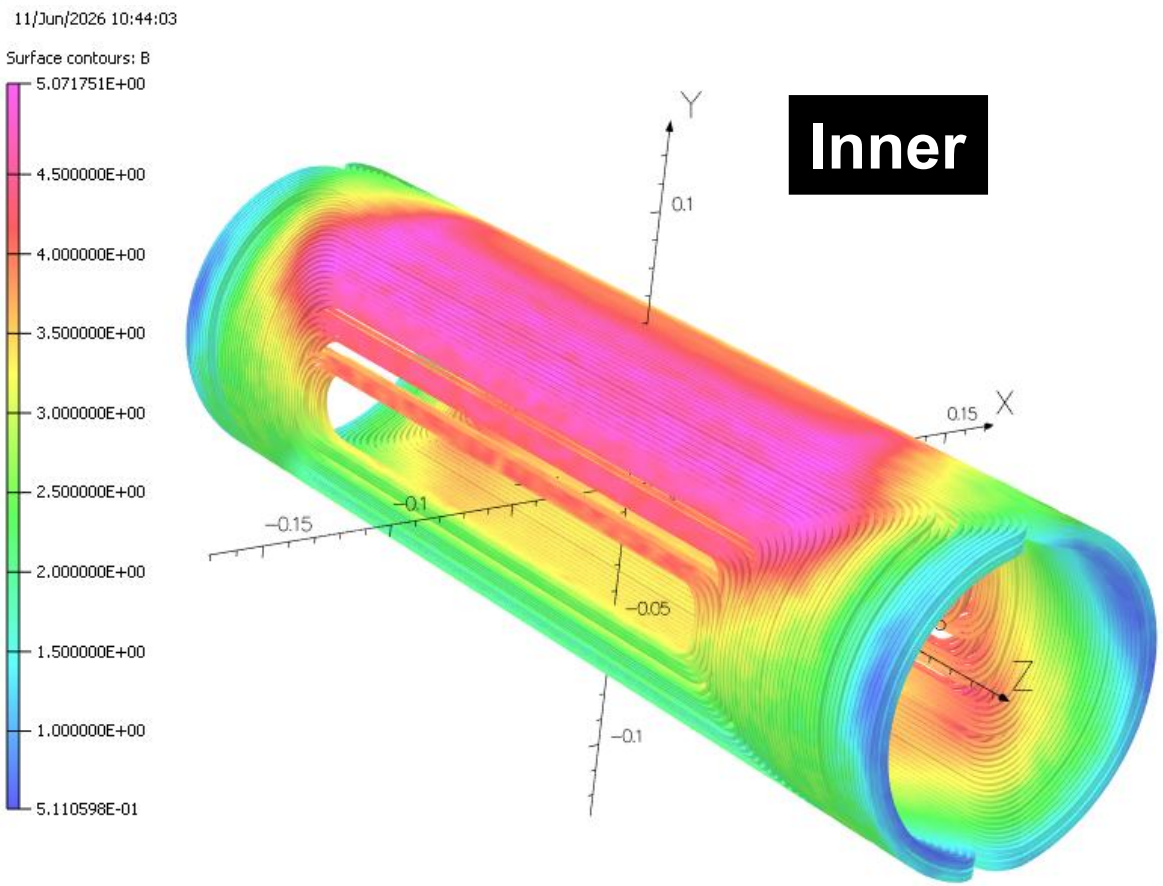
## Field contours at the design field in all layers



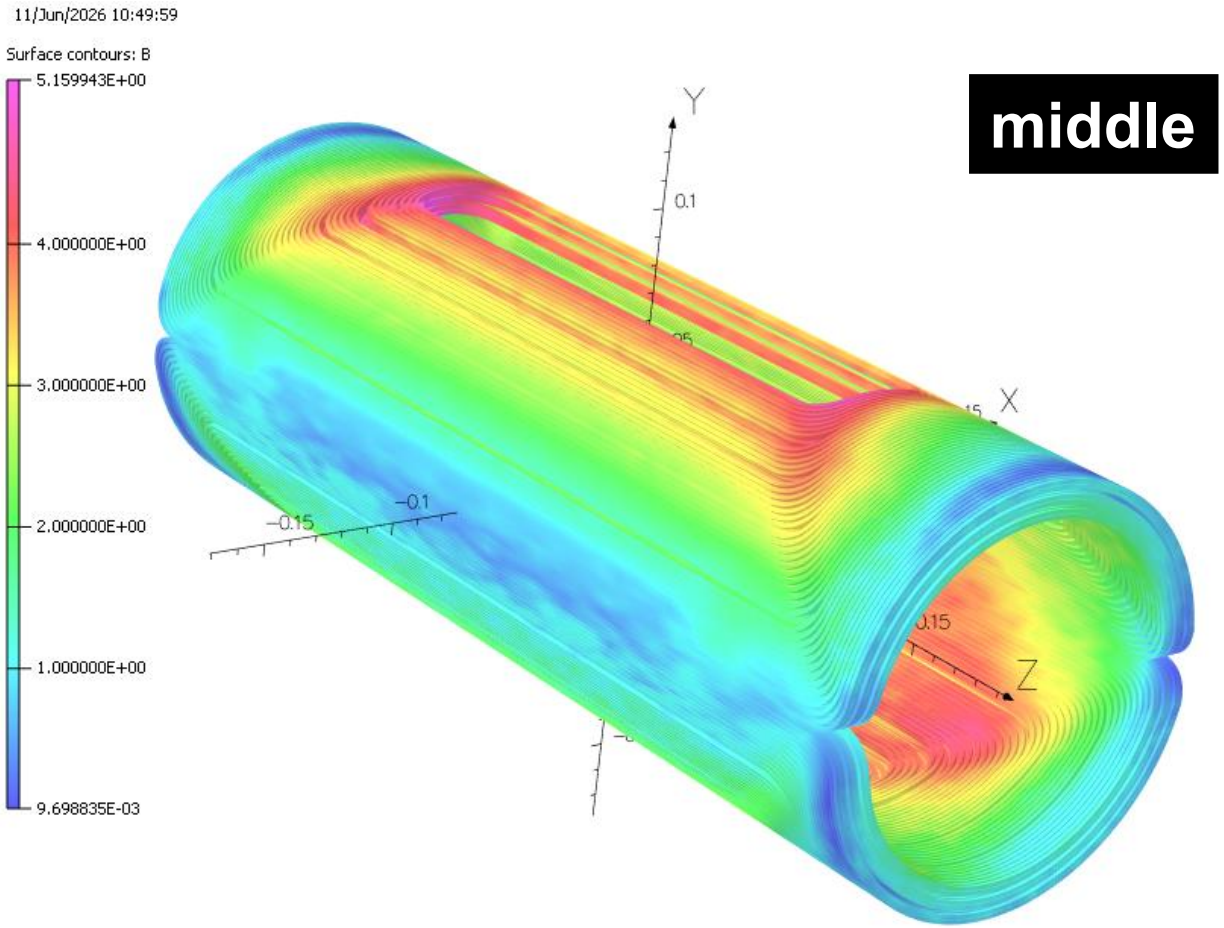



# 12-layer Optimum Integral Design for B0ApF

**Field contours in the horizontal dipole coils while all coils powered at the design field**

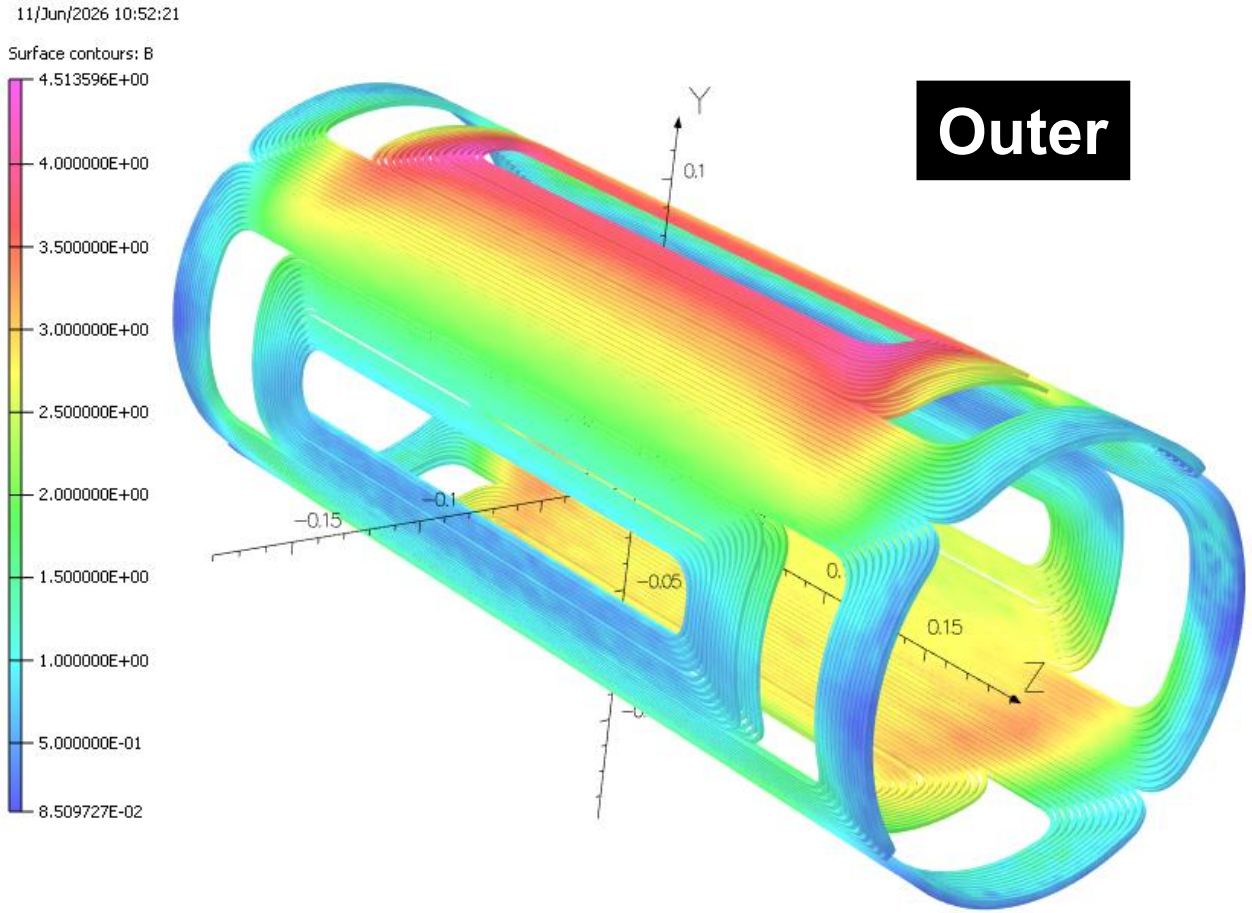



**Field contours in the vertical dipole coils while all coils powered at the design field**

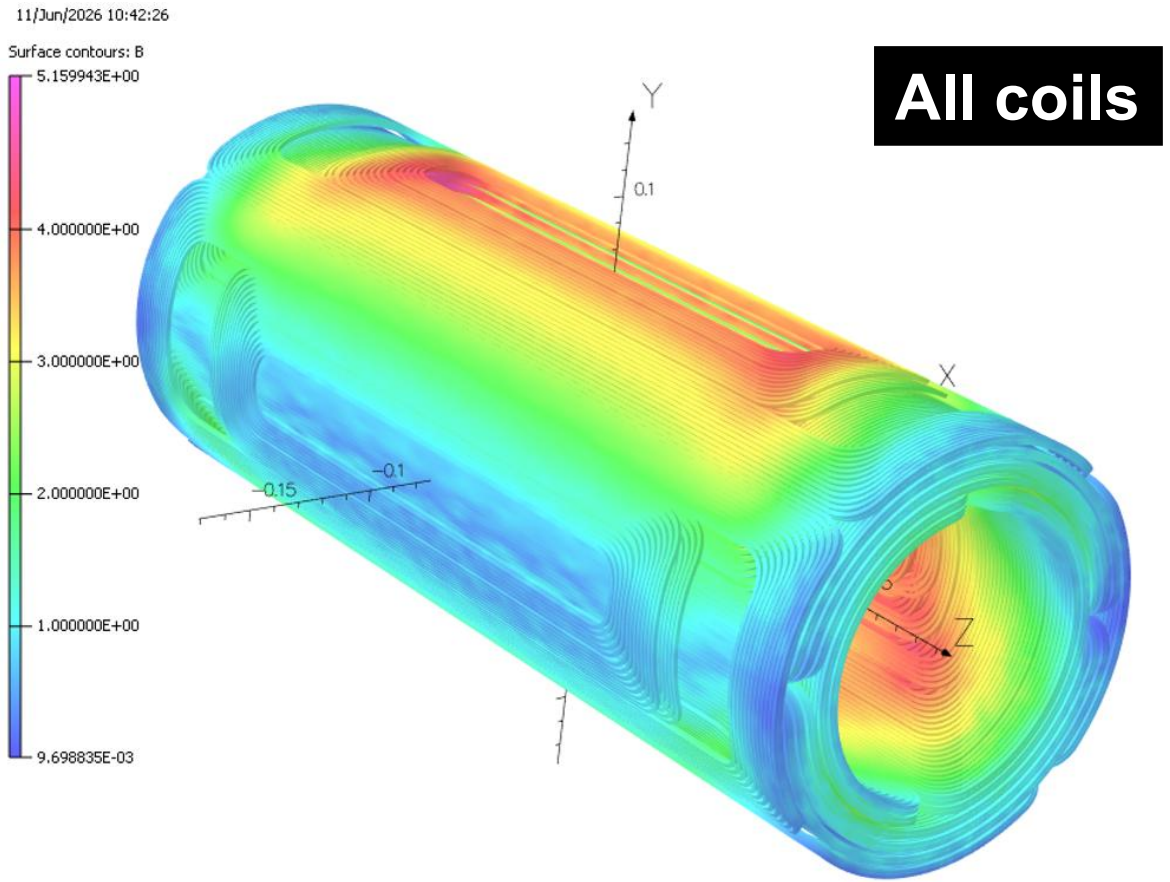


# 12-layer Optimum Integral Design for B0ApF

**Field contours in the skew quadrupole coils while all coils powered at the design field**




**Field contours in all coils when all powered to the design field**



# Computed harmonics in the 4 layers of horizontal dipole

**Harmonics at r=25 mm (spec for corrector magnet ~10 units?)**

**Layer #1**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.18176E+00 | 10000.0000 |
| 2 | 0.87115E-06 | 0.0479 |
| 4 | 0.47826E-05 | 0.2631 |
| 6 | 0.48165E-05 | 0.2650 |
| 8 | -0.81335E-05 | -0.4475 |
| 10 | 0.42777E-06 | 0.0235 |
| 12 | 0.12776E-06 | 0.0070 |
| 14 | 0.57418E-07 | 0.0032 |
| 16 | -0.40936E-07 | -0.0023 |
| 18 | 0.47968E-08 | 0.0003 |
| 20 | 0.12072E-10 | 0.0000 |
| 22 | 0.36863E-09 | 0.0000 |
| 24 | 0.17770E-10 | 0.0000 |
| 26 | -0.55355E-10 | -0.0000 |
| 28 | 0.10607E-10 | 0.0000 |
| 30 | 0.46587E-12 | 0.0000 |

**Layer #2**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.18234E+00 | 10000.0000 |
| 2 | -0.70121E-06 | -0.0385 |
| 4 | -0.17585E-05 | -0.0964 |
| 6 | 0.12326E-04 | 0.6760 |
| 8 | 0.64118E-05 | 0.3516 |
| 10 | -0.11468E-06 | -0.0063 |
| 12 | -0.67509E-06 | -0.0370 |
| 14 | 0.31161E-07 | 0.0017 |
| 16 | 0.24615E-08 | 0.0001 |
| 18 | 0.49508E-08 | 0.0003 |
| 20 | -0.93985E-09 | -0.0001 |
| 22 | 0.12578E-09 | 0.0000 |
| 24 | 0.32230E-10 | 0.0000 |
| 26 | -0.25796E-10 | -0.0000 |
| 28 | 0.37334E-11 | 0.0000 |
| 30 | 0.20620E-12 | 0.0000 |

**Layer #3**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.18864E+00 | 10000.0000 |
| 2 | -0.63228E-08 | -0.0003 |
| 4 | 0.63656E-08 | 0.0003 |
| 6 | 0.59424E-09 | 0.0000 |
| 8 | 0.11331E-06 | 0.0060 |
| 10 | 0.15914E-06 | 0.0084 |
| 12 | -0.27785E-07 | -0.0015 |
| 14 | 0.19375E-07 | 0.0010 |
| 16 | -0.52368E-08 | -0.0003 |
| 18 | 0.12416E-08 | 0.0001 |
| 20 | -0.31315E-09 | -0.0000 |
| 22 | 0.26767E-10 | 0.0000 |
| 24 | -0.48352E-11 | -0.0000 |
| 26 | -0.10736E-11 | -0.0000 |
| 28 | 0.11133E-11 | 0.0000 |
| 30 | -0.19574E-12 | -0.0000 |

**Layer #4**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.19159E+00 | 10000.0000 |
| 2 | 0.42012E-06 | 0.0219 |
| 4 | -0.34542E-06 | -0.0180 |
| 6 | 0.22186E-05 | 0.1158 |
| 8 | 0.31445E-05 | 0.1641 |
| 10 | -0.89502E-07 | -0.0047 |
| 12 | -0.16952E-06 | -0.0088 |
| 14 | 0.27273E-07 | 0.0014 |
| 16 | -0.12744E-08 | -0.0001 |
| 18 | 0.22163E-10 | 0.0000 |
| 20 | -0.14593E-09 | -0.0000 |
| 22 | 0.40274E-10 | 0.0000 |
| 24 | -0.37999E-11 | -0.0000 |
| 26 | -0.97644E-12 | -0.0000 |
| 28 | 0.54506E-12 | 0.0000 |
| 30 | -0.81229E-13 | -0.0000 |

**Easily met in the computer models.**

- Old US definition: b2 is sextupole

# Computed harmonics in the 6 layers of Vertical dipole

**Harmonics at r=25 mm (spec for magnet 1 units?). Easily met in the computer models.**

- **In direct wind coils harmonics can be easily corrected during the subsequent layers**

**Layer #1**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.20043E+00 | 10000.0000 |
| 2 | 0.25702E-08 | 0.0001 |
| 4 | 0.16443E-06 | 0.0082 |
| 6 | 0.53291E-05 | 0.2659 |
| 8 | 0.10329E-05 | 0.0515 |
| 10 | -0.45818E-06 | -0.0229 |
| 12 | -0.73576E-07 | -0.0037 |
| 14 | 0.17512E-07 | 0.0009 |
| 16 | 0.27714E-09 | 0.0000 |
| 18 | 0.88602E-10 | 0.0000 |
| 20 | -0.89696E-10 | -0.0000 |
| 22 | 0.12689E-10 | 0.0000 |
| 24 | -0.12234E-11 | -0.0000 |
| 26 | -0.78057E-13 | -0.0000 |
| 28 | 0.13983E-12 | 0.0000 |
| 30 | -0.24221E-13 | -0.0000 |

**Layer #2**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.20518E+00 | 10000.0000 |
| 2 | 0.31254E-07 | 0.0015 |
| 4 | 0.33639E-07 | 0.0016 |
| 6 | 0.19854E-06 | 0.0097 |
| 8 | 0.20846E-06 | 0.0102 |
| 10 | -0.30471E-07 | -0.0015 |
| 12 | -0.65164E-07 | -0.0032 |
| 14 | 0.11852E-07 | 0.0006 |
| 16 | -0.36282E-09 | -0.0000 |
| 18 | 0.12600E-10 | 0.0000 |
| 20 | -0.21661E-10 | -0.0000 |
| 22 | 0.30610E-11 | 0.0000 |
| 24 | -0.37303E-12 | -0.0000 |
| 26 | -0.21334E-13 | -0.0000 |
| 28 | 0.53527E-13 | 0.0000 |
| 30 | -0.10100E-13 | -0.0000 |

**Layer #3**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.20944E+00 | 10000.0000 |
| 2 | 0.13121E-05 | 0.0627 |
| 4 | 0.24514E-05 | 0.1170 |
| 6 | 0.15999E-04 | 0.7639 |
| 8 | -0.28987E-05 | -0.1384 |
| 10 | 0.29579E-06 | 0.0141 |
| 12 | -0.16662E-07 | -0.0008 |
| 14 | 0.68988E-09 | 0.0000 |
| 16 | 0.17006E-09 | 0.0000 |
| 18 | -0.23132E-10 | -0.0000 |
| 20 | -0.18556E-11 | -0.0000 |
| 22 | -0.25791E-11 | -0.0000 |
| 24 | 0.24331E-12 | 0.0000 |
| 26 | 0.40827E-13 | 0.0000 |
| 28 | -0.13151E-14 | -0.0000 |
| 30 | -0.24040E-15 | -0.0000 |

**Layer #4**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.21153E+00 | 10000.0000 |
| 2 | 0.47958E-06 | 0.0227 |
| 4 | 0.14770E-05 | 0.0698 |
| 6 | 0.10250E-04 | 0.4846 |
| 8 | -0.10114E-05 | -0.0478 |
| 10 | 0.31667E-06 | 0.0150 |
| 12 | -0.20129E-07 | -0.0010 |
| 14 | 0.47771E-09 | 0.0000 |
| 16 | -0.16760E-09 | -0.0000 |
| 18 | -0.34103E-10 | -0.0000 |
| 20 | -0.83131E-12 | -0.0000 |
| 22 | -0.10698E-11 | -0.0000 |
| 24 | 0.14622E-12 | 0.0000 |
| 26 | 0.18848E-13 | 0.0000 |
| 28 | 0.92047E-15 | 0.0000 |
| 30 | -0.22995E-15 | -0.0000 |

**Layer #5**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.21445E+00 | 10000.0000 |
| 2 | 0.66011E-06 | 0.0308 |
| 4 | 0.98145E-06 | 0.04 |
| 6 | 0.10476E-04 | 0.48 |
| 8 | -0.77568E-07 | -0.00 |
| 10 | 0.25164E-06 | 0.01 |
| 12 | -0.89369E-08 | -0.00 |
| 14 | 0.52365E-09 | 0.00 |
| 16 | -0.17041E-09 | -0.00 |
| 18 | -0.31021E-10 | -0.00 |
| 20 | -0.19357E-11 | -0.00 |
| 22 | -0.38656E-12 | -0.00 |
| 24 | 0.60578E-13 | 0.00 |
| 26 | 0.66441E-14 | 0.00 |
| 28 | 0.39628E-15 | 0.00 |
| 30 | -0.29498E-16 | -0.00 |

**Layer #6**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.21845E+00 | 10000.0000 |
| 2 | 0.46191E-06 | 0.0211 |
| 4 | 0.16742E-05 | 0.0766 |
| 6 | 0.13055E-04 | 0.5976 |
| 8 | -0.15755E-06 | -0.0072 |
| 10 | 0.23911E-06 | 0.0109 |
| 12 | -0.16060E-07 | -0.0007 |
| 14 | 0.39833E-09 | 0.0000 |
| 16 | -0.63183E-10 | -0.0000 |
| 18 | -0.47475E-10 | -0.0000 |
| 20 | 0.16338E-11 | 0.0000 |
| 22 | -0.51843E-13 | -0.0000 |
| 24 | 0.93010E-14 | 0.0000 |
| 26 | 0.83644E-14 | 0.0000 |
| 28 | -0.22277E-15 | -0.0000 |
| 30 | -0.23910E-16 | -0.0000 |

- Old US definition: b2 is sextupole

# Computed harmonics in the 2 layers of Skew Quad

**Harmonics at r=25 mm (spec for corrector magnet ~10 units?)**

**Layer #1**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.76422E-01 | 10000.0000 |
| 5 | -0.87141E-10 | -0.0000 |
| 9 | 0.39115E-07 | 0.0051 |
| 13 | -0.29598E-09 | -0.0000 |
| 17 | -0.51681E-10 | -0.0000 |
| 21 | 0.58453E-12 | 0.0000 |
| 25 | -0.60423E-14 | -0.0000 |
| 29 | 0.26028E-16 | 0.0000 |

**Layer #2**

INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.77764E-01 | 10000.0000 |
| 5 | -0.55379E-08 | -0.0007 |
| 9 | 0.55103E-08 | 0.0007 |
| 13 | 0.17536E-08 | 0.0002 |
| 17 | -0.62913E-10 | -0.0000 |
| 21 | 0.28961E-12 | 0.0000 |
| 25 | -0.54065E-15 | -0.0000 |
| 29 | 0.67806E-17 | 0.0000 |

**Easily met in the computer models.**

- Old US definition: b2 is sextupole

# 500 mm long B0ApF

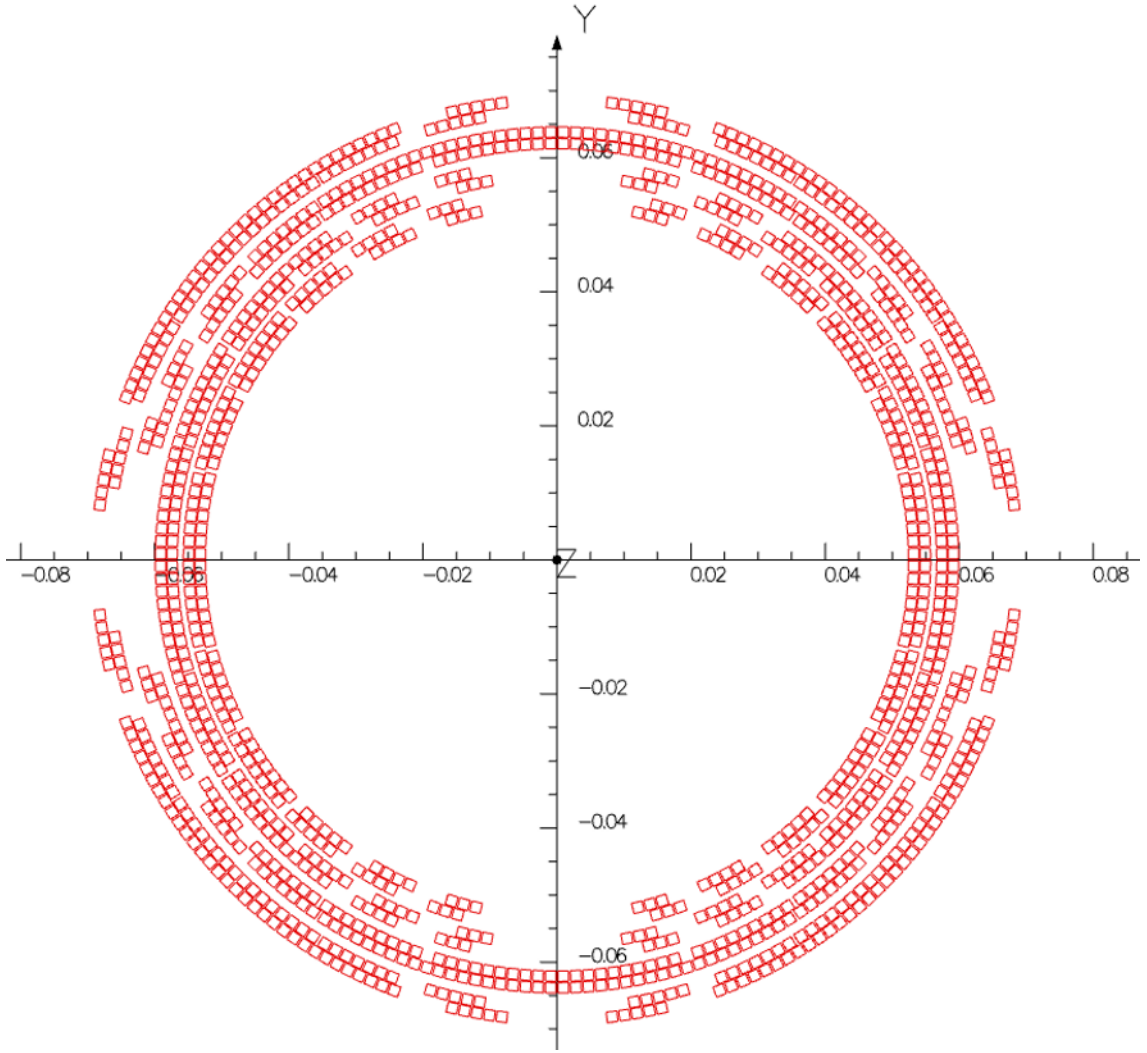
## Eight layer design
## (same coil id as in the serpentine)

- **4 layers (2 coil sets) creating 1.05 T.m Vertical Dipole**
- **2 layers (1 coil set) creating 0.6 T.m Horizontal Dipole**
- **2 layers (1 coil set) creating 3 T Skew Quadrupole**

- The order of placement is chosen to balance out (maximize the minimum) margins in all magnets
- For margin calculations, all magnets are set at the maximum field, and margin is computed over that

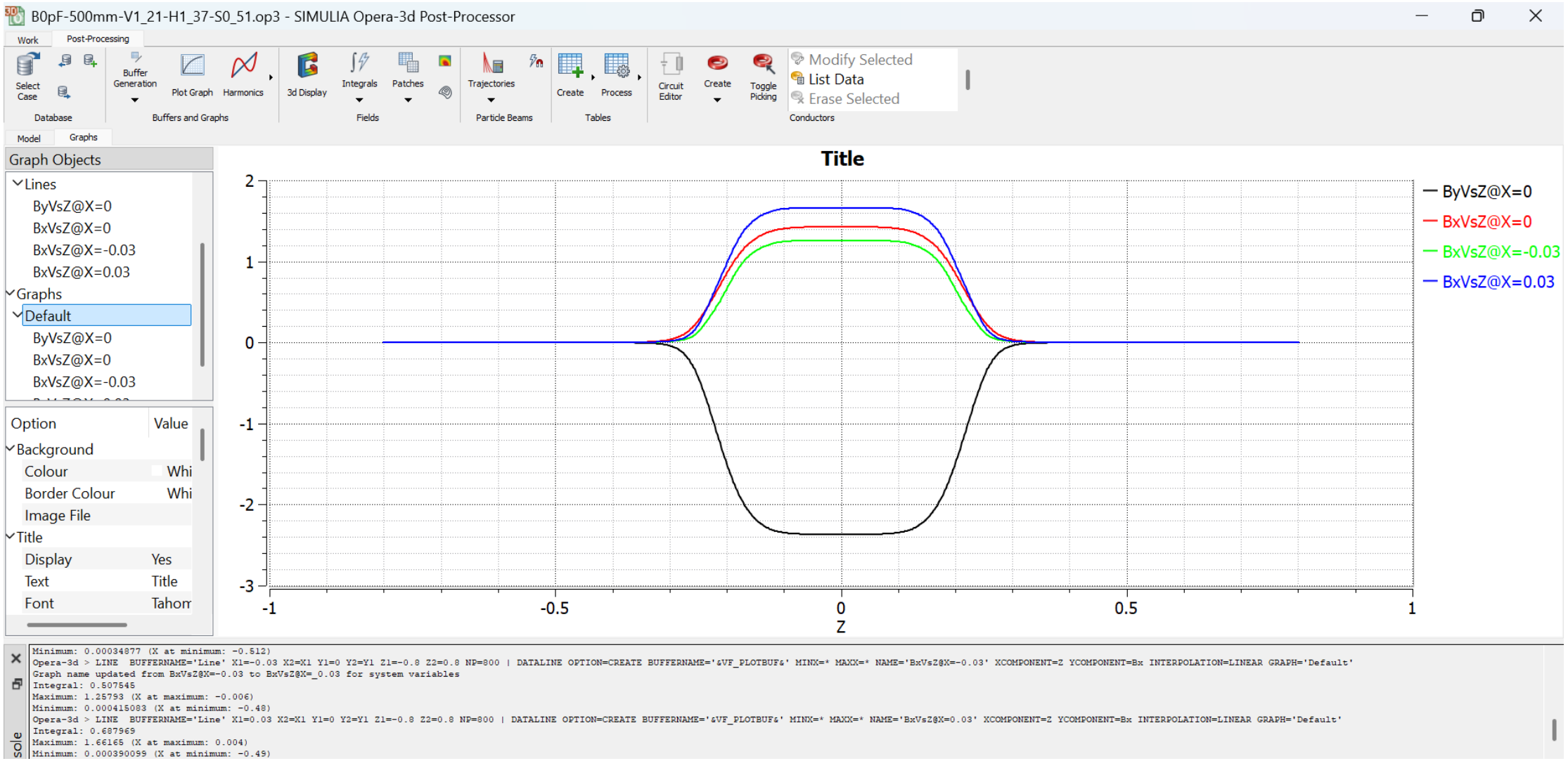
(for reference, in the 400 mm long design, it was 6 layers for vertical dipole, 4 layers for horizontal and 2 layer for skew quad)

# Basic Model of the 8-layer design for 500 mm-long B0ApF

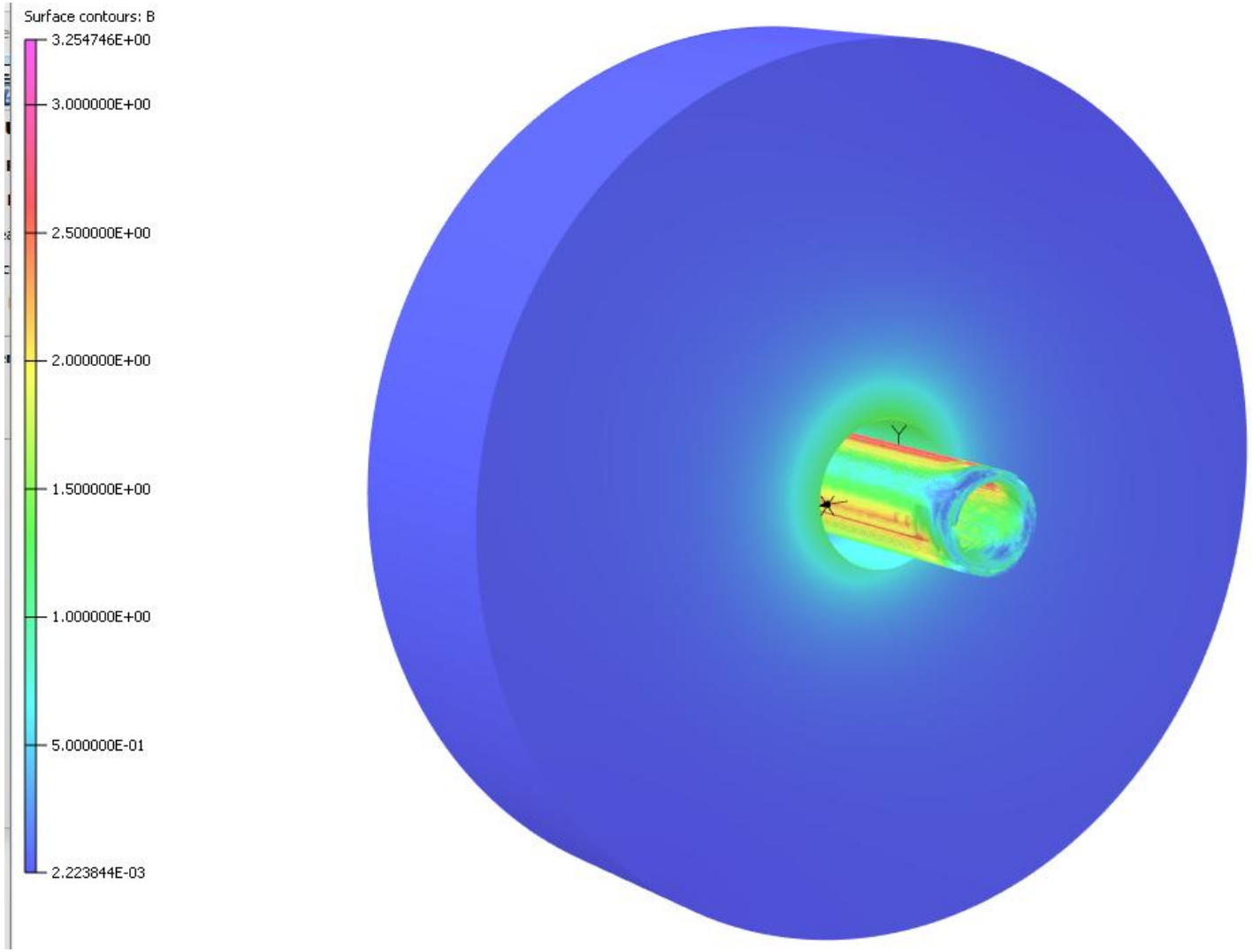



- 4 layers (2 coil sets)
  - ➢ creating 1.05 T.m Vertical Dipole
- 2 layers (1 coil set)
  - ➢ 0.6 T.m Horizontal Dipole
- 2 layers (1 coil set)
  - ➢ creating 3 T Skew Quadrupole

# Field Profile on the axis at the design field

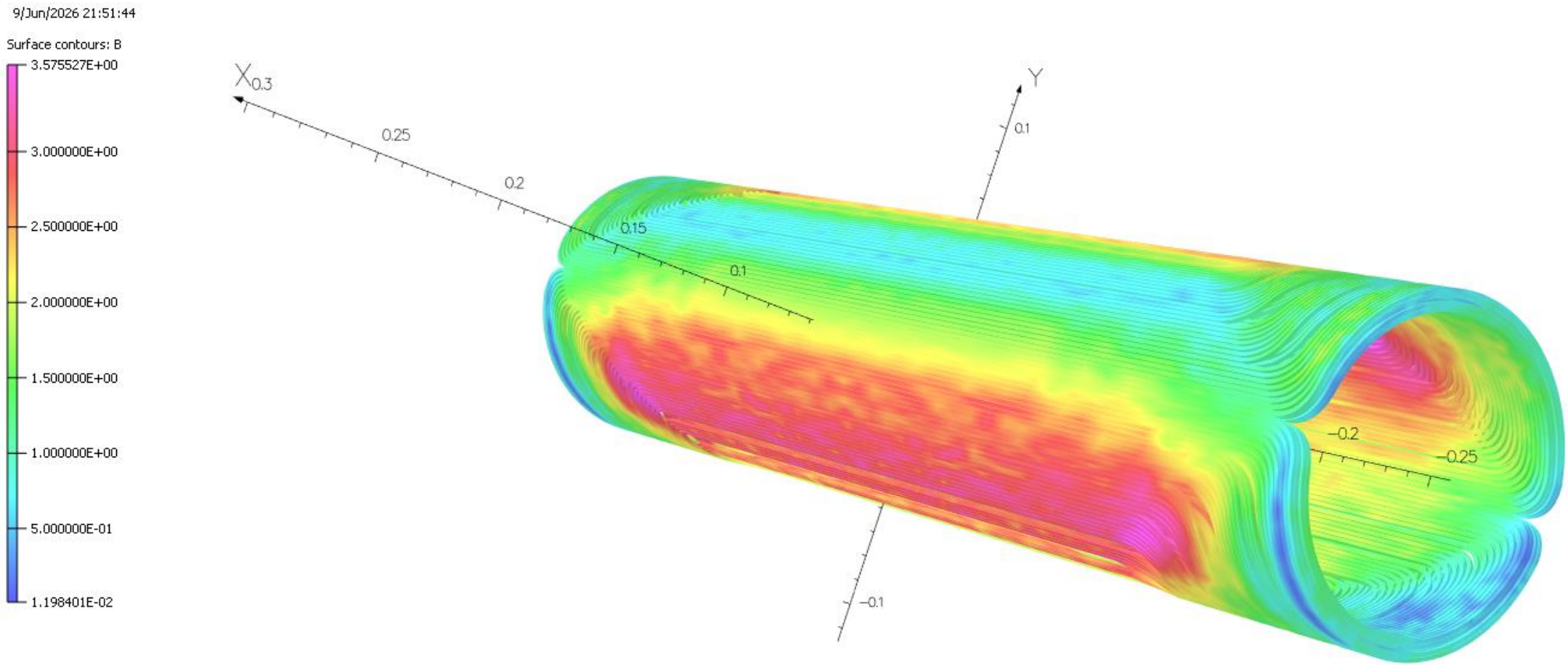


# 8-layer Optimum Integral Design for B0ApF

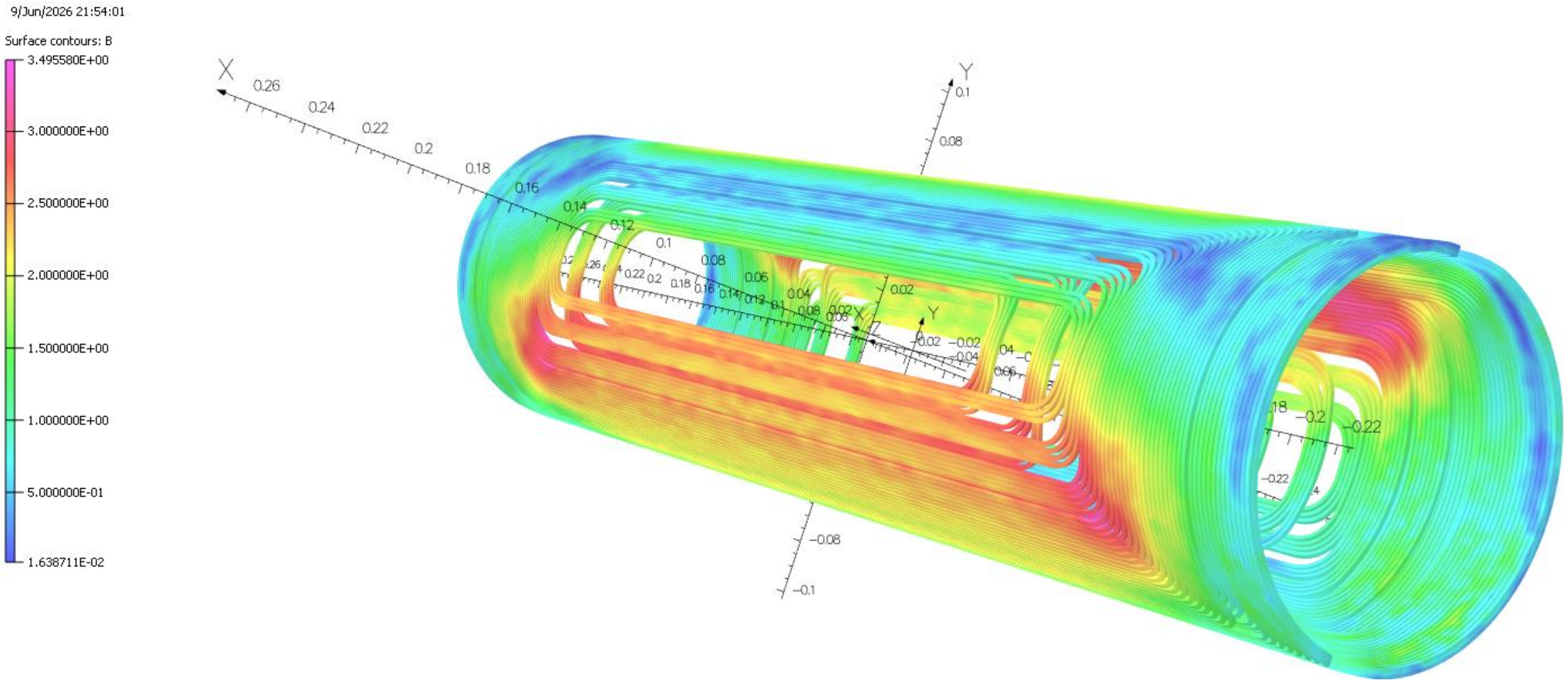



**Field contours at the design field in all layers**

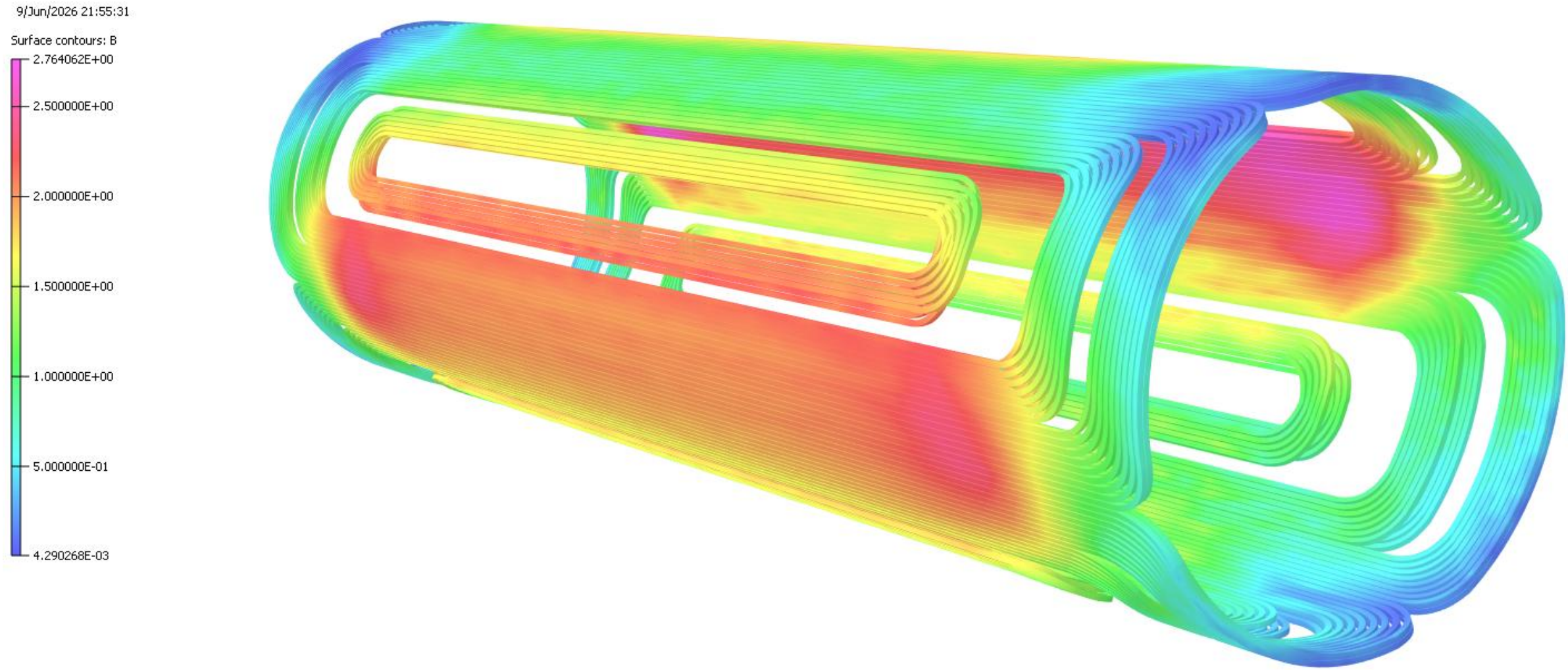
# Vertical Dipole



# Horizontal Dipole



# Skew Quad


9/Jun/2026 21:55:31
Surface contours: B
2.764062E+00
2.500000E+00
2.000000E+00
1.500000E+00
1.000000E+00
5.000000E-01
4.290268E-03

# Summary (to be done)

- Remaining work (short term) : Add more details of 500 mm long design
- Add load line margin calculation
- Compare 400 mm and 500 mm designs side by side

- Remaining to be done in longer term– realistic iron, field quality as a function of current (including cross-talk)