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# Updated Design of B0pF

## (with separate quadrupole and dipole windings)

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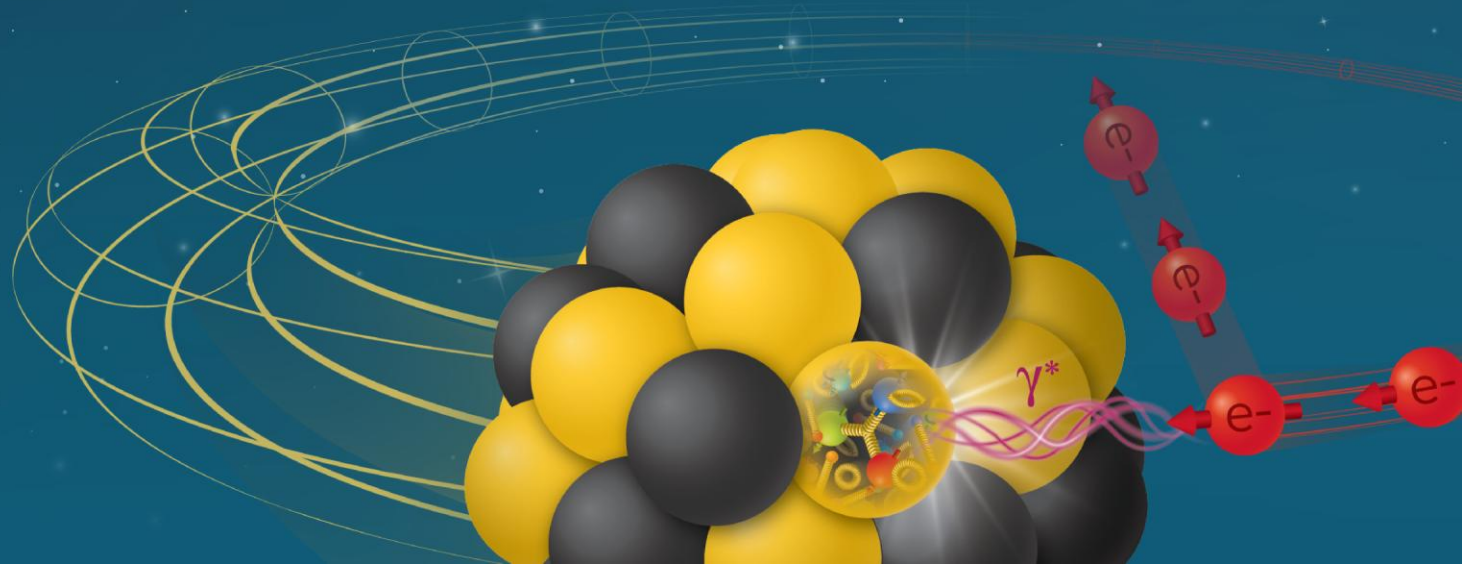
Electron-Ion Collider



# Summary and Major Goals of the Iteration (1)

This iteration addresses the technical requirements/guidance mentioned by Brett.

Assure good field quality while allowing the use of the standard codes (including legacy programs) to cross-check and iterate the design, as necessary.

- Field quality is easier to optimize in a separated function design rather than in a combined function
  - Symmetry helps - 3 out of 4 in quad and 1 out 2 in dipole harmonics are zero
- The nominal design has six quad layers and one dipole layer. Dipole layer will have its own (or a trim) power supply to provide better flexibility in matching quad to dipole ratio in various cases, such as if two more quad layers are to be added/replaced later, or if we go from cold iron to warm iron design.

# Summary and Major Goals of the Iteration (2)

- Each quadrupole and dipole layer is optimized so that each has <1 unit of field harmonic at a reference radius of 220 mm (~2/3 of coil radius).
- Two quadrupole layers will be wound as a one coil set with no splice in between. Each coil set can be divided between upper and lower halves for quench protection, if desired.
- Electron and hadron beams will have an angle of 25 milli-radian between them. Center of hadron beam is at -126 mm and electron beam at +34 mm.
- Integral field for the hadron beam is 1.56 T.m and electron beam is zero (there are correction coils for fine tuning).
- Variation in the field along the electron beam is less than 0.02 T.
- Design has a good load line margin at 1.92 K and a respectable margin at 4.2 K.
- Design is almost ready for checking with other persons and by other codes, etc. (always desirable before winding a coil for a potential machine magnet) and for mechanical and quench protection analysis.

# Optimized Harmonics by the OID code at 220 mm Radius (<1 unit in each layer)

## Quad Layer 1

TOTAL NUMBER OF TURNS = 108
CHI SQUARE = 4.9496169826745984E-
INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.42503E+00 | 10000.0000 |
| 5 | 0.50745E-08 | 0.0001 |
| 9 | 0.40715E-07 | 0.0010 |
| 13 | -0.89046E-07 | -0.0021 |
| 17 | 0.33983E-06 | 0.0080 |
| 21 | 0.14450E-05 | 0.0340 |
| 25 | -0.69550E-06 | -0.0164 |
| 29 | -0.76843E-07 | -0.0018 |

## Quad Layer 2

TOTAL NUMBER OF TURNS = 107
CHI SQUARE = 0.20215782364584811
INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.42560E+00 | 10000.0000 |
| 5 | 0.10593E-06 | 0.0025 |
| 9 | 0.11908E-05 | 0.0280 |
| 13 | 0.40257E-05 | 0.0946 |
| 17 | 0.22374E-04 | 0.5257 |
| 21 | -0.63780E-06 | -0.0150 |
| 25 | -0.95453E-08 | -0.0002 |
| 29 | -0.55015E-07 | -0.0013 |

## Quad Layer 3

TOTAL NUMBER OF TURNS = 110
CHI SQUARE = 0.14807616989128292
INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.42775E+00 | 10000.0000 |
| 5 | -0.15695E-05 | -0.0367 |
| 9 | -0.64879E-05 | -0.1517 |
| 13 | -0.14212E-04 | -0.3322 |
| 17 | 0.11769E-04 | 0.2751 |
| 21 | -0.11994E-05 | -0.0280 |
| 25 | -0.77247E-07 | -0.0018 |
| 29 | -0.36137E-07 | -0.0008 |

## Quad Layer 4

TOTAL NUMBER OF TURNS = 109
CHI SQUARE = 4.5360278986208868E-
INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.43550E+00 | 10000.0000 |
| 5 | 0.13028E-06 | 0.0030 |
| 9 | 0.70204E-06 | 0.0161 |
| 13 | 0.25090E-05 | 0.0576 |
| 17 | 0.10696E-04 | 0.2456 |
| 21 | -0.57733E-06 | -0.0133 |
| 25 | 0.16169E-07 | 0.0004 |
| 29 | -0.62011E-08 | -0.0001 |

**Guidance from Brett:**
**$b_3(b_{2us})$ <3, $b_4(b_{3us})$ <5, $b_5(b_{4us})$ <10, higher <25 @218 mm radius.**

TOTAL NUMBER OF TURNS = 118
CHI SQUARE = 0.49143448653194355
INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 0 | 0.41104E+00 | 10000.0000 |
| 2 | -0.24181E-06 | -0.0059 |
| 4 | 0.16764E-05 | 0.0408 |
| 6 | 0.81339E-06 | 0.0198 |
| 8 | -0.90486E-05 | -0.2201 |
| 10 | -0.11065E-05 | -0.0269 |
| 12 | 0.32800E-04 | 0.7980 |
| 14 | 0.76289E-05 | 0.1856 |
| 16 | -0.19487E-04 | -0.4741 |
| 18 | -0.87178E-05 | -0.2121 |
| 20 | -0.90354E-05 | -0.2198 |
| 22 | -0.23606E-05 | -0.0574 |
| 24 | -0.27120E-05 | -0.0660 |
| 26 | -0.84490E-06 | -0.0206 |
| 28 | 0.34291E-06 | 0.0083 |
| 30 | 0.49103E-07 | 0.0012 |

## Quad Layer 6

TOTAL NUMBER OF TURNS = 108
CHI SQUARE = 1.0923326022350466E-
INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.41343E+00 | 10000.0000 |
| 5 | 0.23922E-07 | 0.0006 |
| 9 | -0.15362E-06 | -0.0037 |
| 13 | -0.10027E-05 | -0.0243 |
| 17 | -0.50164E-05 | -0.1213 |
| 21 | -0.82271E-06 | -0.0199 |
| 25 | -0.41240E-07 | -0.0010 |
| 29 | -0.65076E-07 | -0.0016 |

## Quad Layer 7

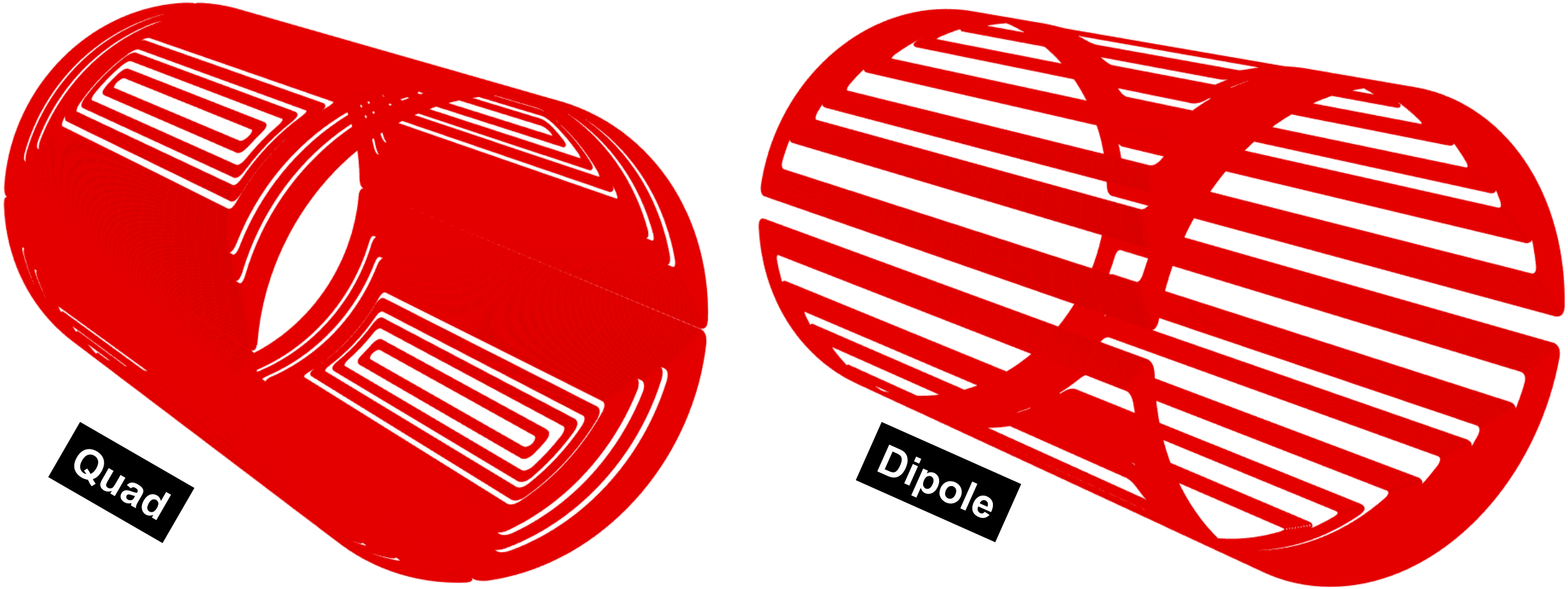
TOTAL NUMBER OF TURNS = 109
CHI SQUARE = 1.3931129233185402E-
INTEGRATED FIELD HARMONICS :

| No. | Bn(T.m) | bn*10^4(units) |
|---|---|---|
| 1 | 0.42888E+00 | 10000.0000 |
| 5 | 0.46304E-07 | 0.0011 |
| 9 | 0.10484E-06 | 0.0024 |
| 13 | 0.53551E-06 | 0.0125 |
| 17 | 0.34295E-05 | 0.0800 |
| 21 | -0.10977E-05 | -0.0256 |
| 25 | -0.27148E-07 | -0.0006 |
| 29 | -0.22039E-07 | -0.0005 |

**Techniques used in the optimum integral design code do rapid calculations and optimization.**
Takes ~1 minute for creating a 3-d optimized design, along with creating many files (including OPERA 3d input).

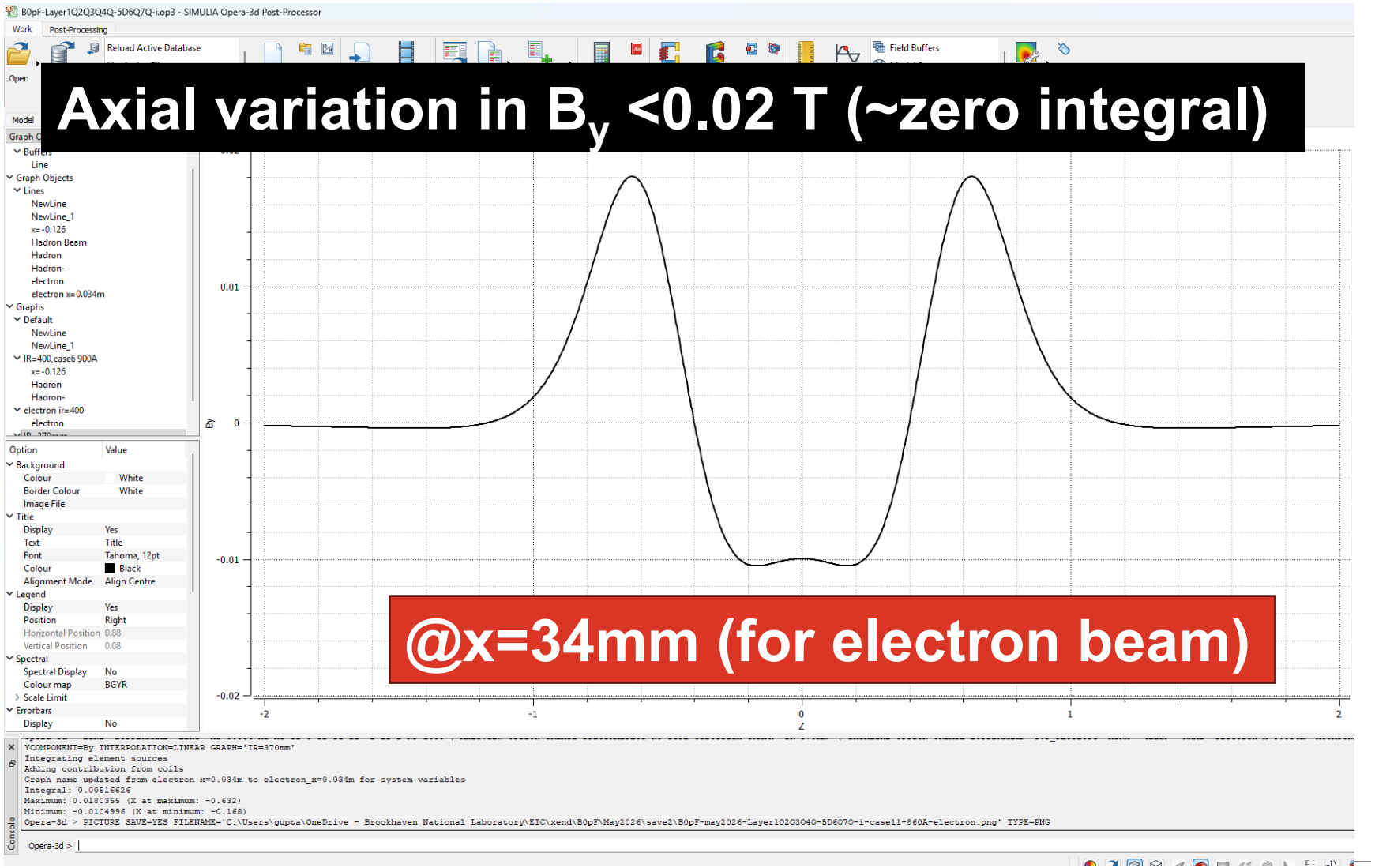
# Quad and Dipole Layer Designs for Matching of Axial Profile

**Generally, fields falls slower axially in dipole ends than in the quad ends.**
**Approach to overcome: Make ends compact for dipole and spread out for quad.**



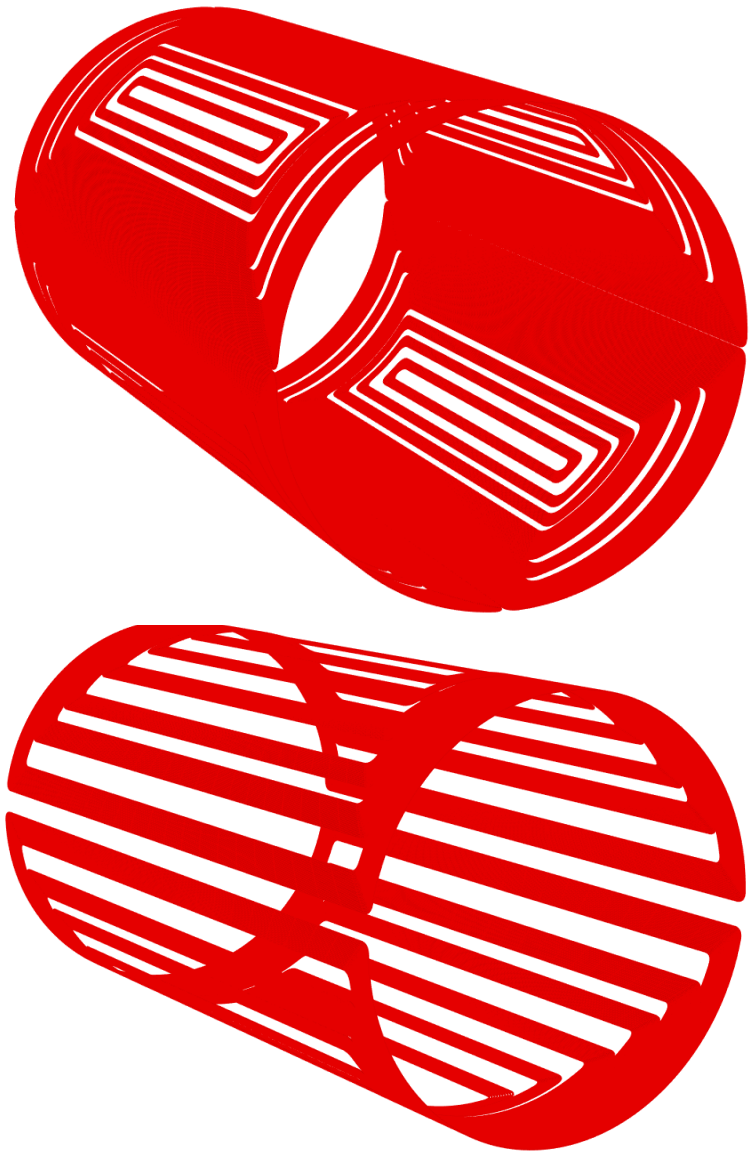

➢ **Note the difference in distribution of turns between body and end**

# Quad and Dipole Layer Designs for Matching of Axial Profile

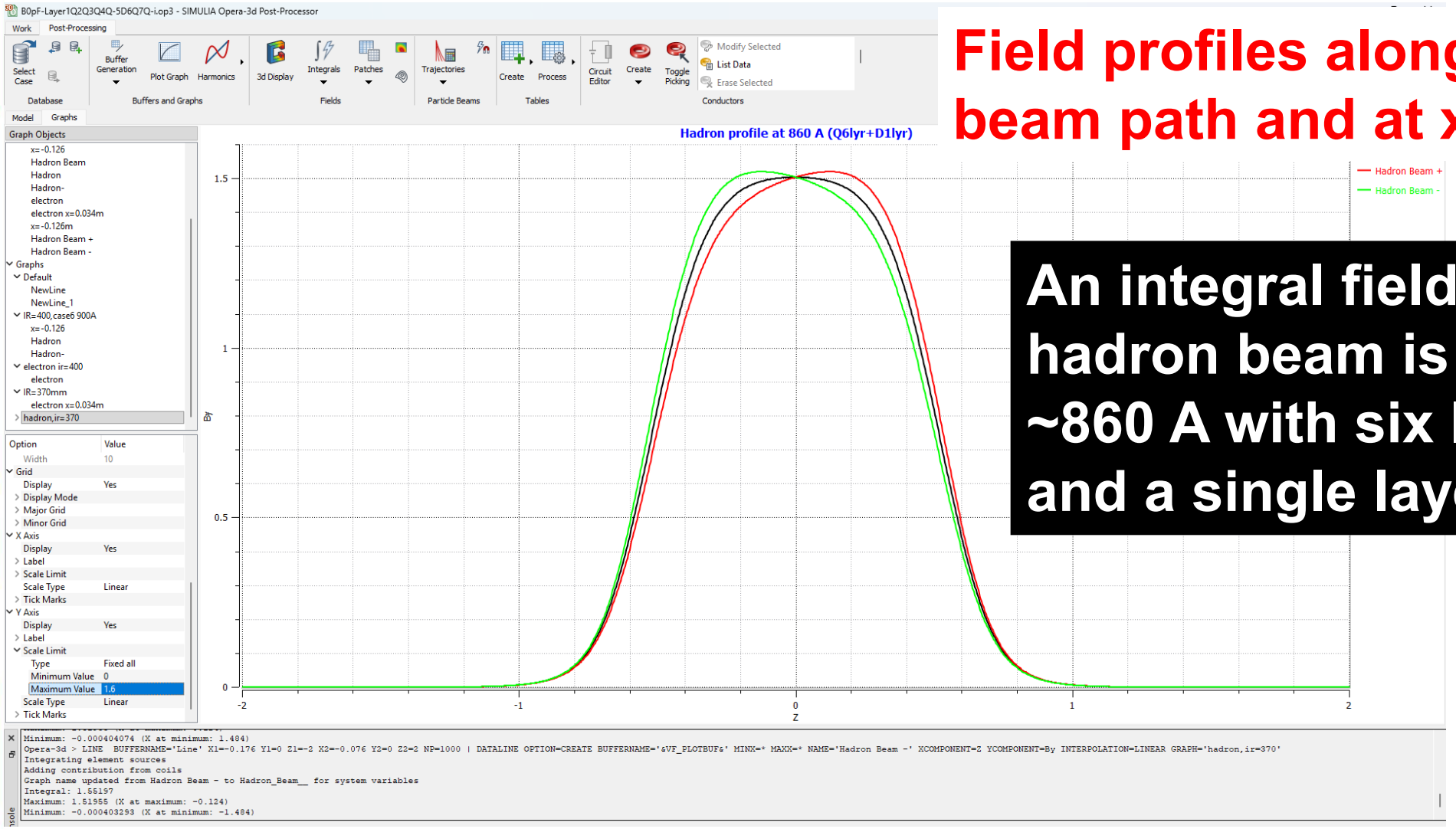



**Axial variation in $B_y$ <0.02 T (~zero integral)**

**@x=34mm (for electron beam)**



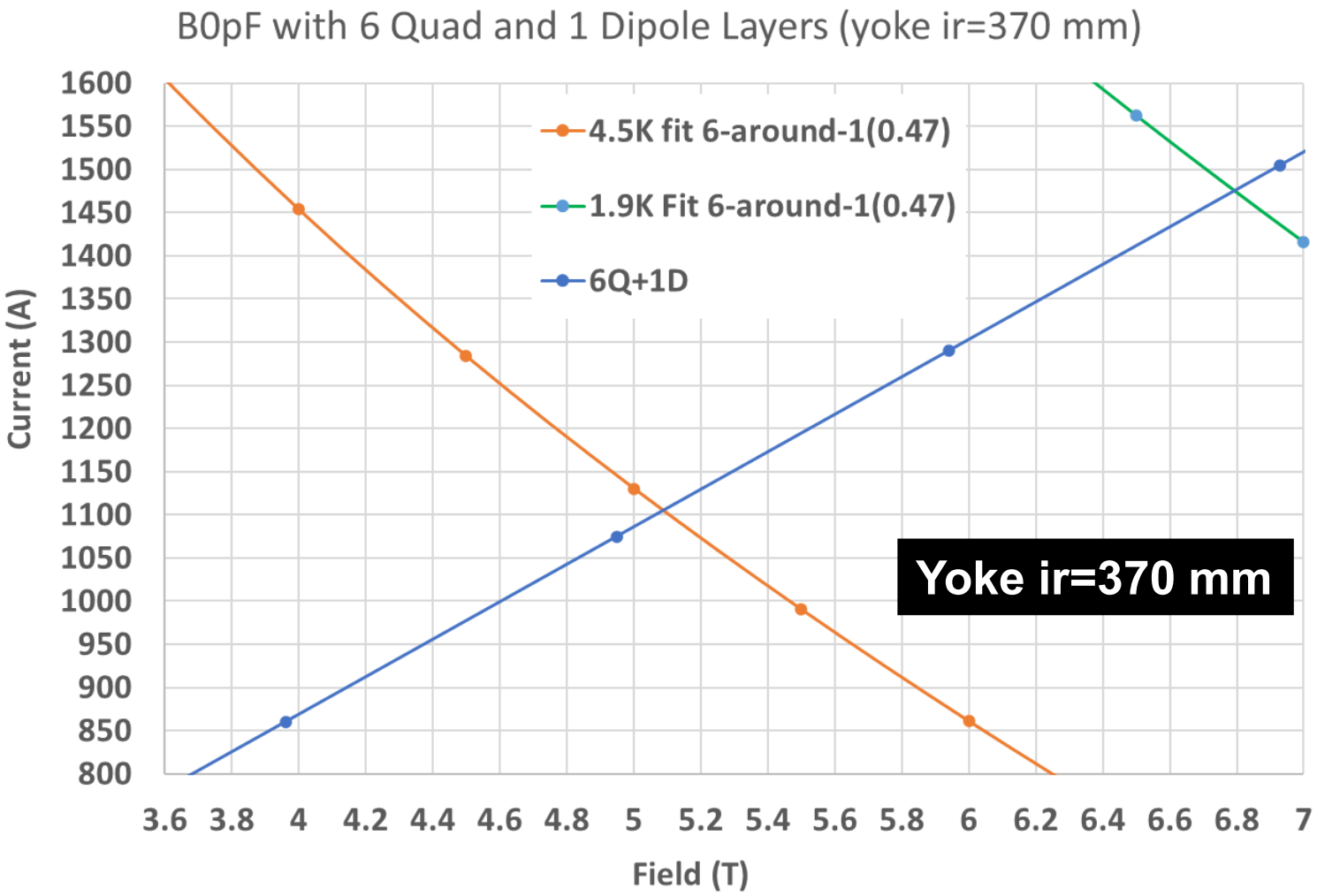
# Axial Profile and Integral Field for Hadron Beam at 860 A




**Field profiles along the hadron beam path and at x=-126 mm**

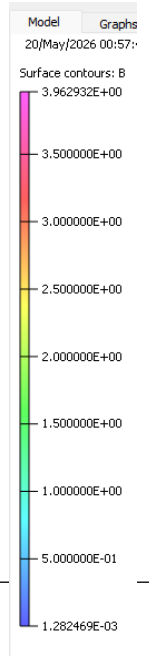
**An integral field of 1.56 T.m for hadron beam is achieved at ~860 A with six layers of Quad and a single layer of dipole**

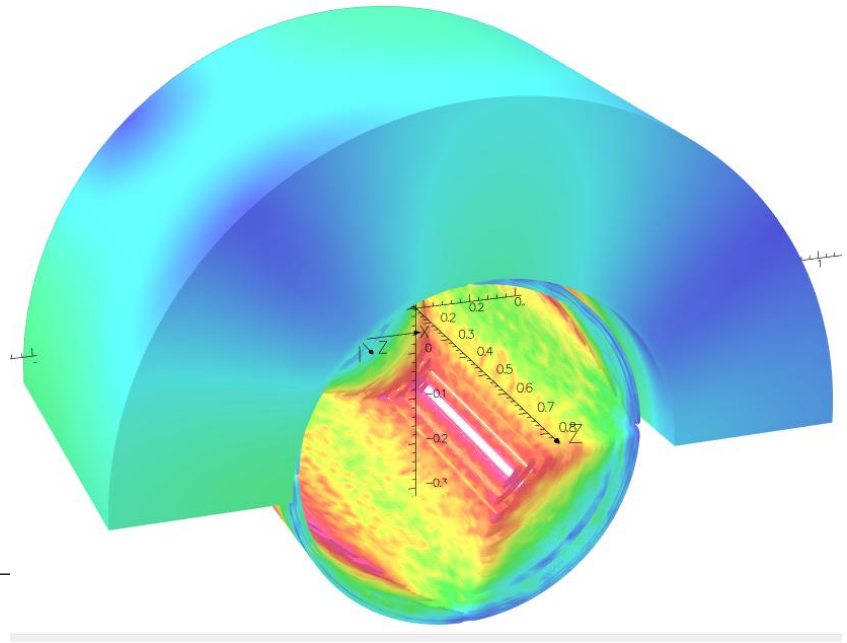
# Expected Performance of 6 Quad + 1 Dipole Layer Design




**Design currrent: 860 A**
**Iss(1.9K): 1480 A**
- **58% on load line**

Iss(4.5K):1100 A
- 78% on load line

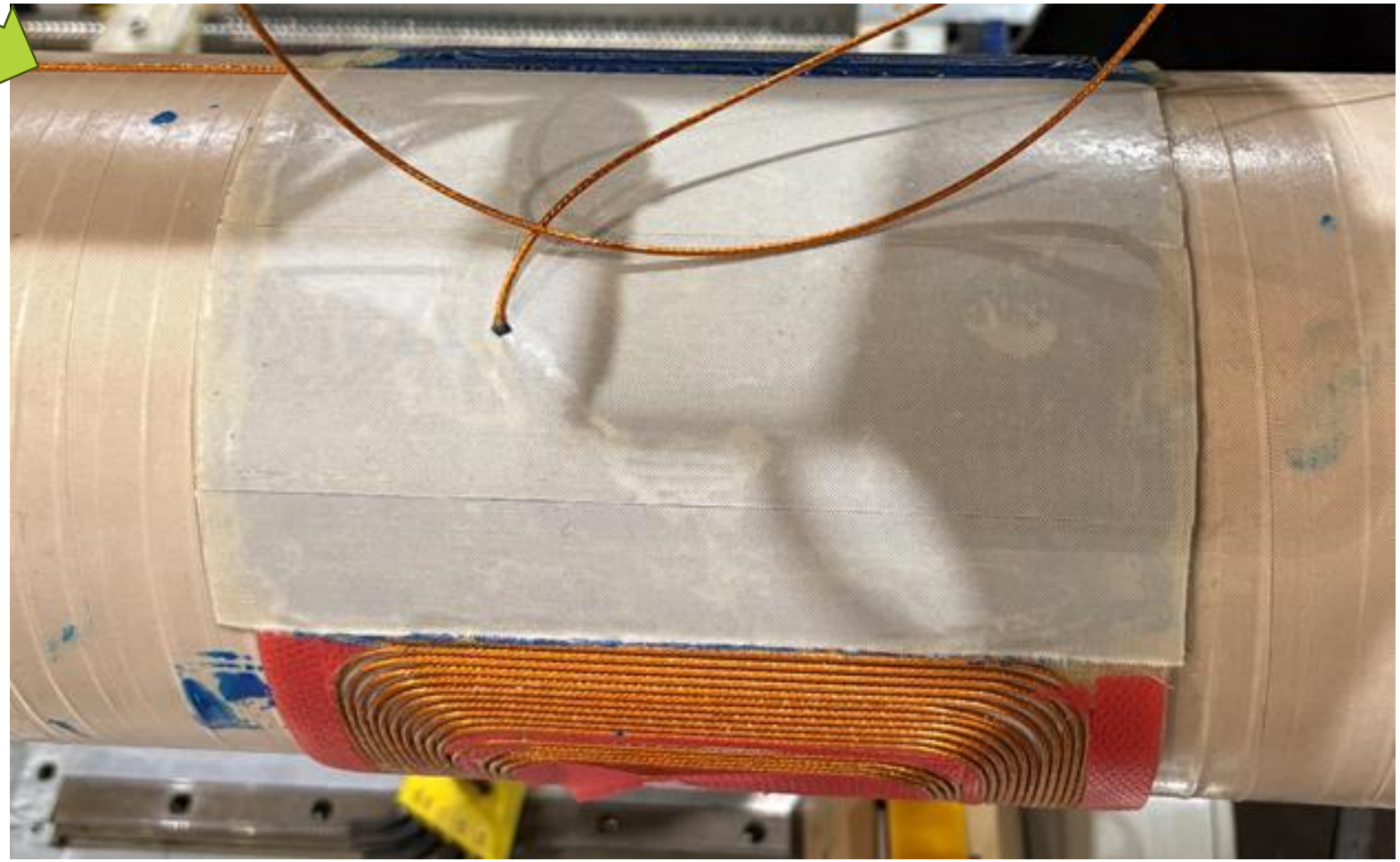


# No-splice OID Winding Experience

**Incoming lead**
**Outgoing lead will be next to it**

Ready to wind the second layer of the 4th quadrant

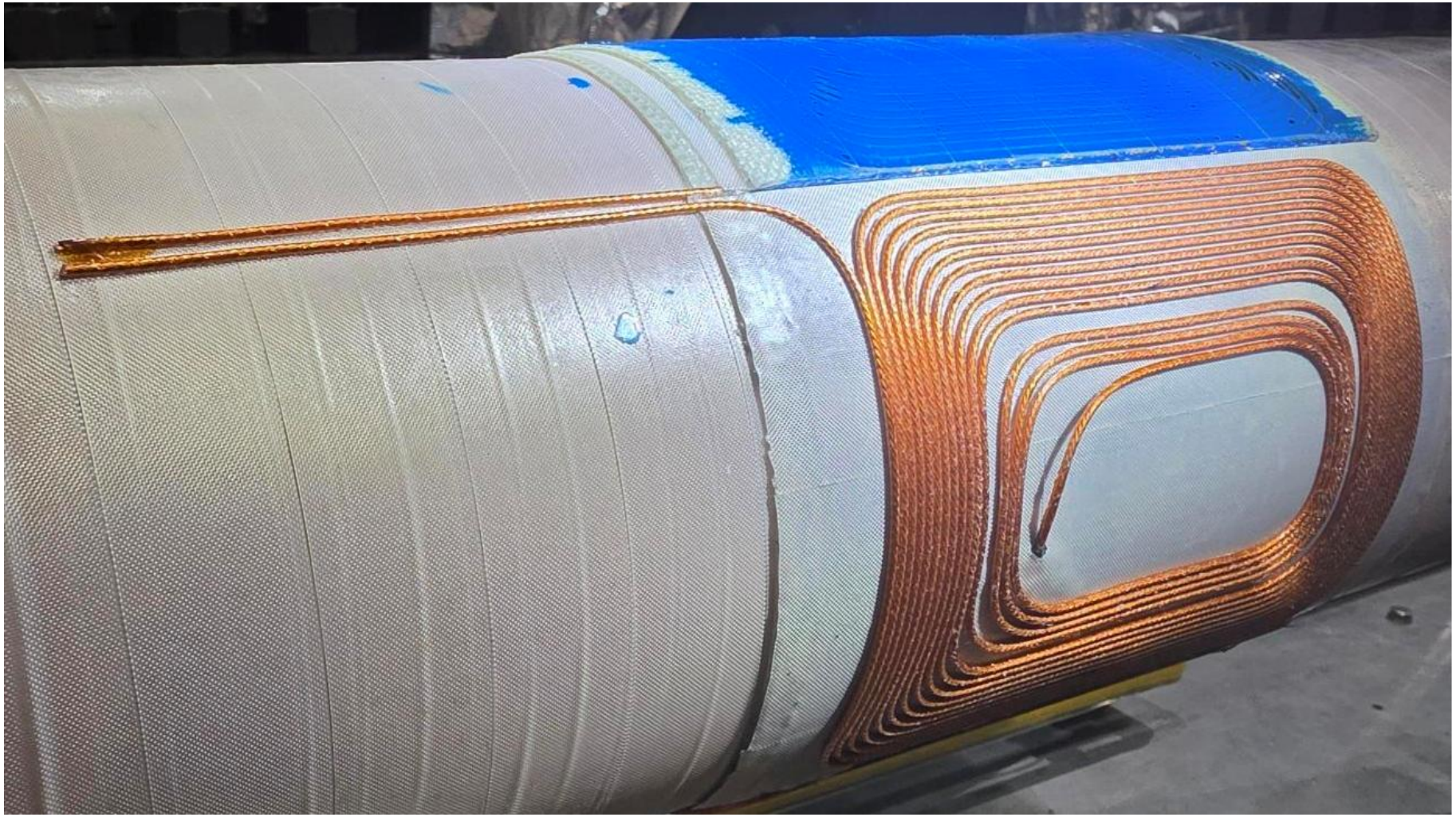


Leave 1 turn gap (1/2 turn per quadrant) at the midplane (1 out of ~200) of 1st layer.

Leave 1 turn gap at the two ends of the second layer (~4 mm out of ~1200 mm) for winding over the 1st.

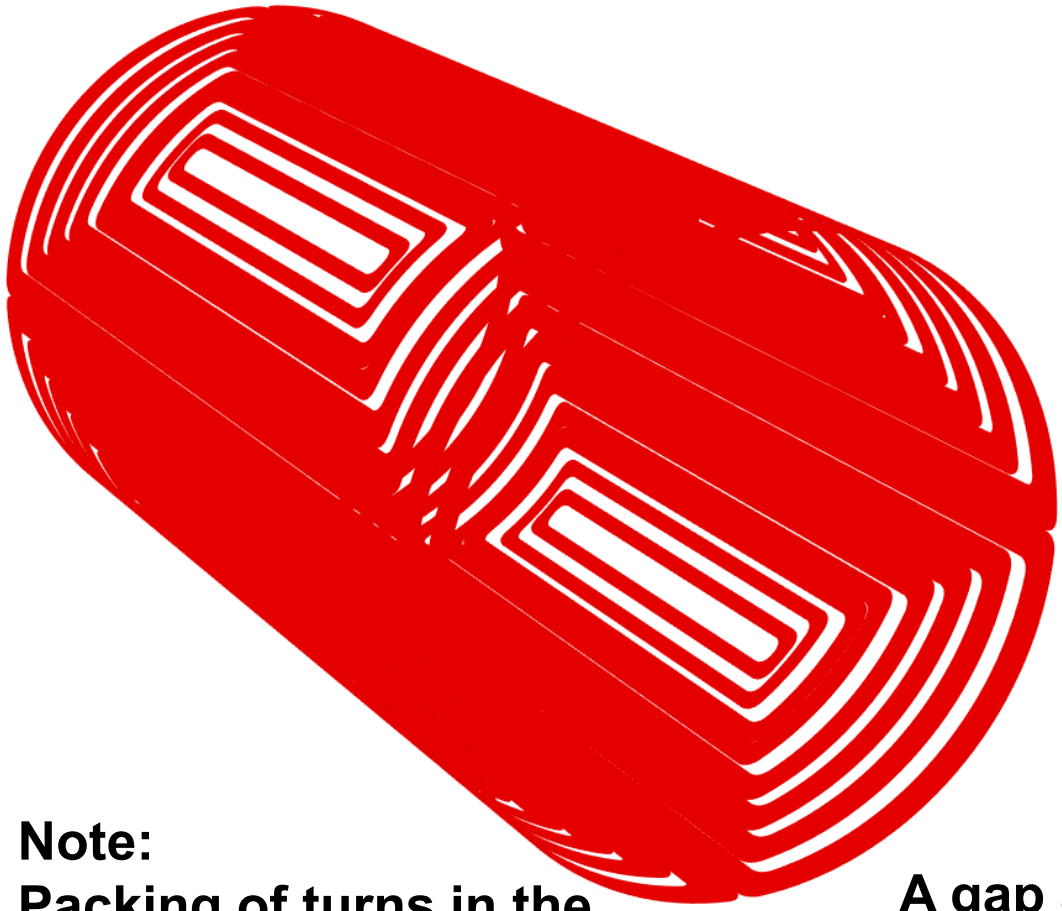
Iterated design includes above and a small adjustment for approximating the round section of the bend.

# No-splice OID Winding Just Completed



**A positive experience**

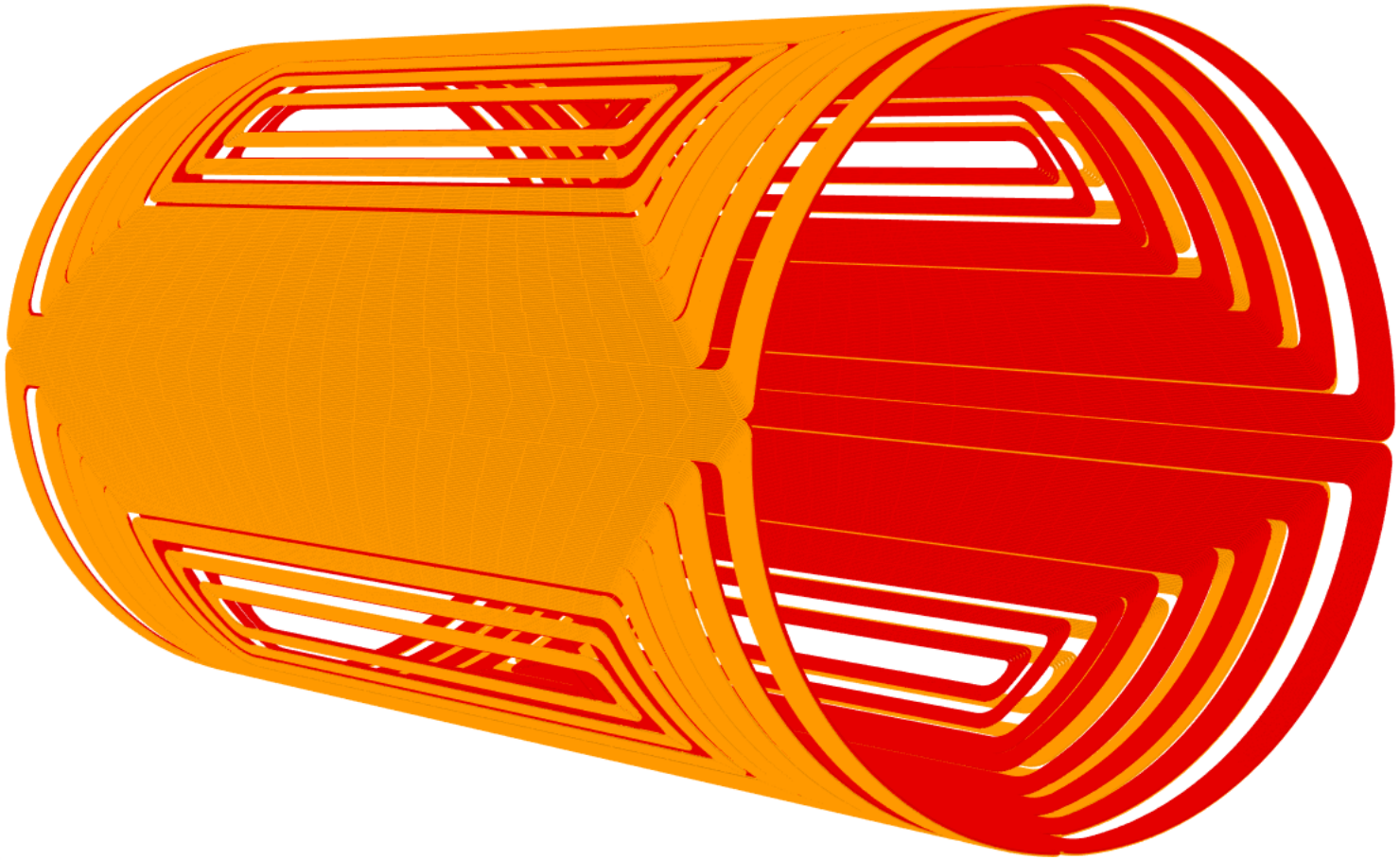
# Iterated Design of the First Layer

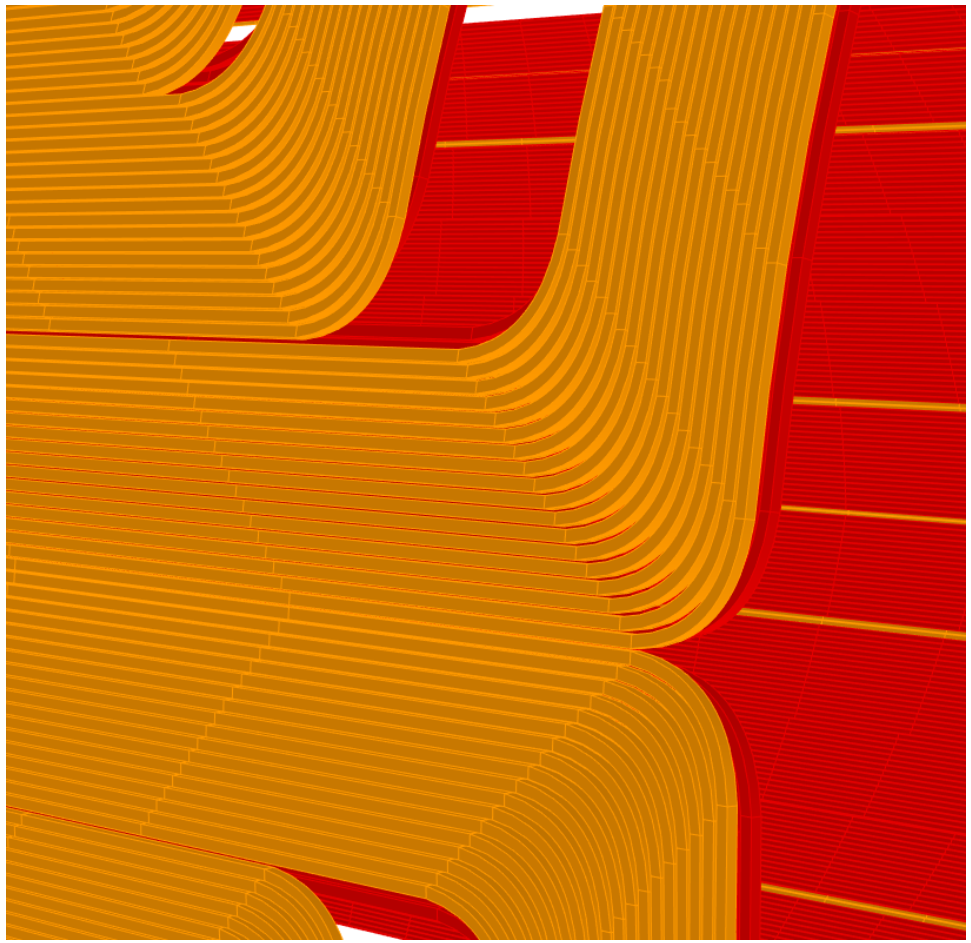



**Note:**
**Packing of turns in the body of the magnet and spread out at ends**

**A gap at midplane for a better allowance of transition from the 1st quadrant of the 2nd layer to the 2nd quadrant of the 1st layer**

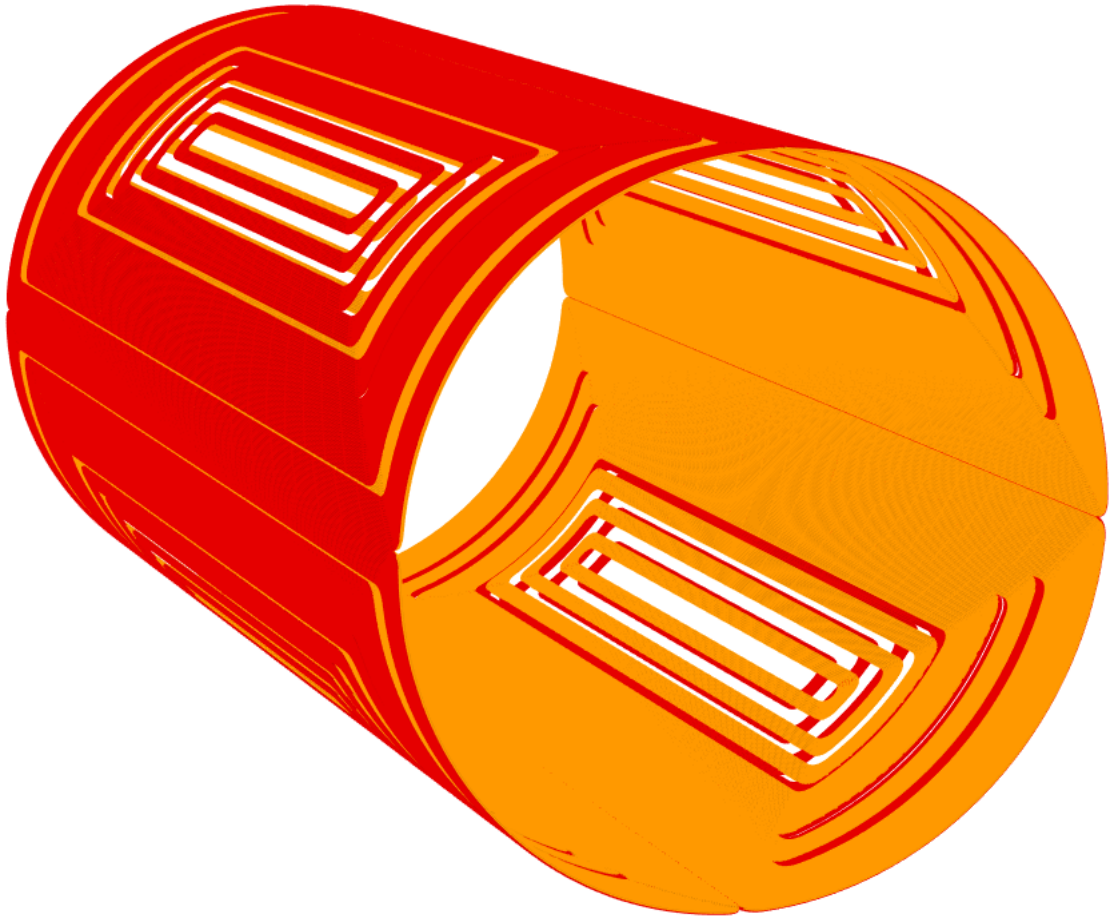
# Iterated Design of the 2nd Layer (on the top of the 1st)

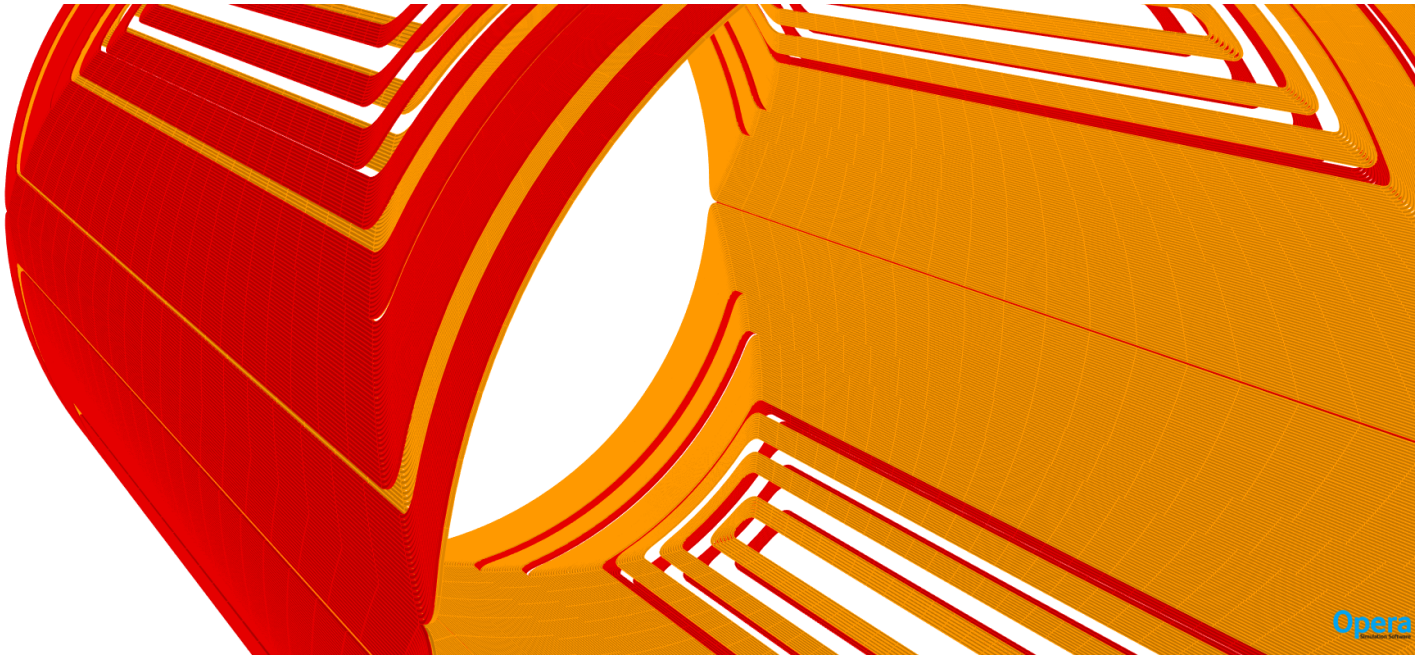




**2nd layer made one turn shorter in the end to allow better support for winding**

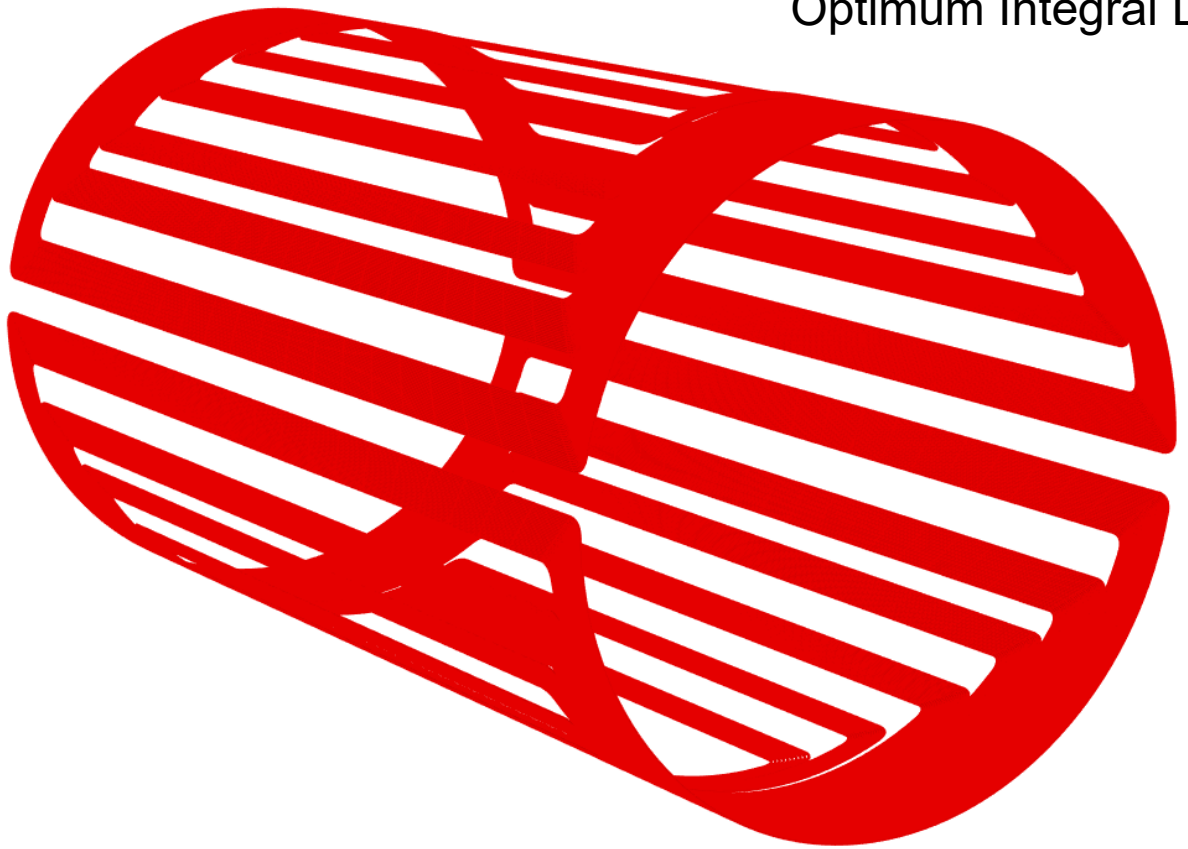
# Design of Quad layers 3 & 4 (like layers 1 & 2)

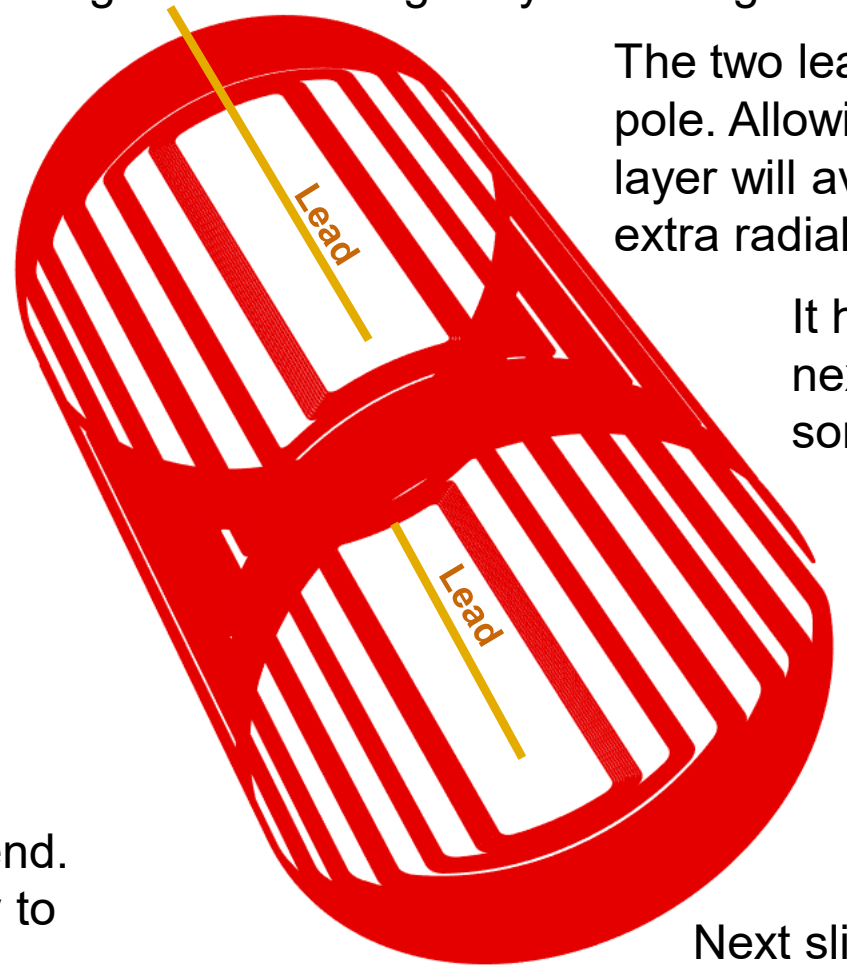




# Design of the 5th Layer (Dipole)

Optimum Integral Design allows a single layer winding.





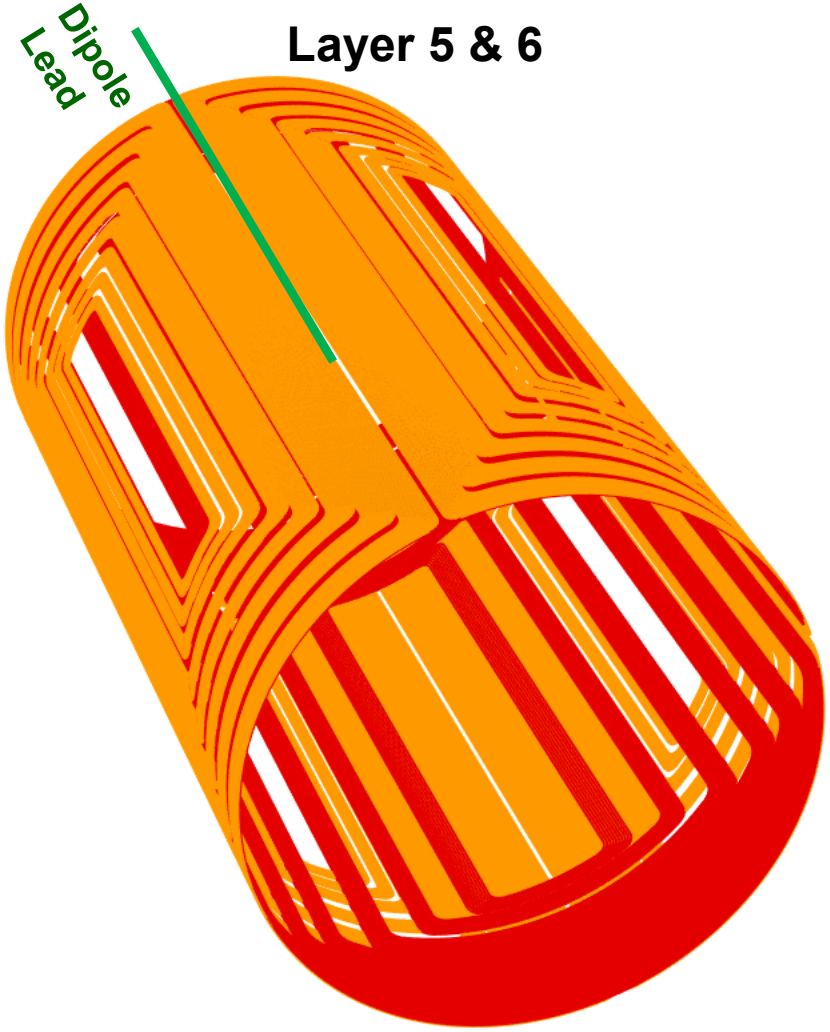

The two leads come out at the pole. Allowing gap in the next layer will avoid leads taking extra radial space.

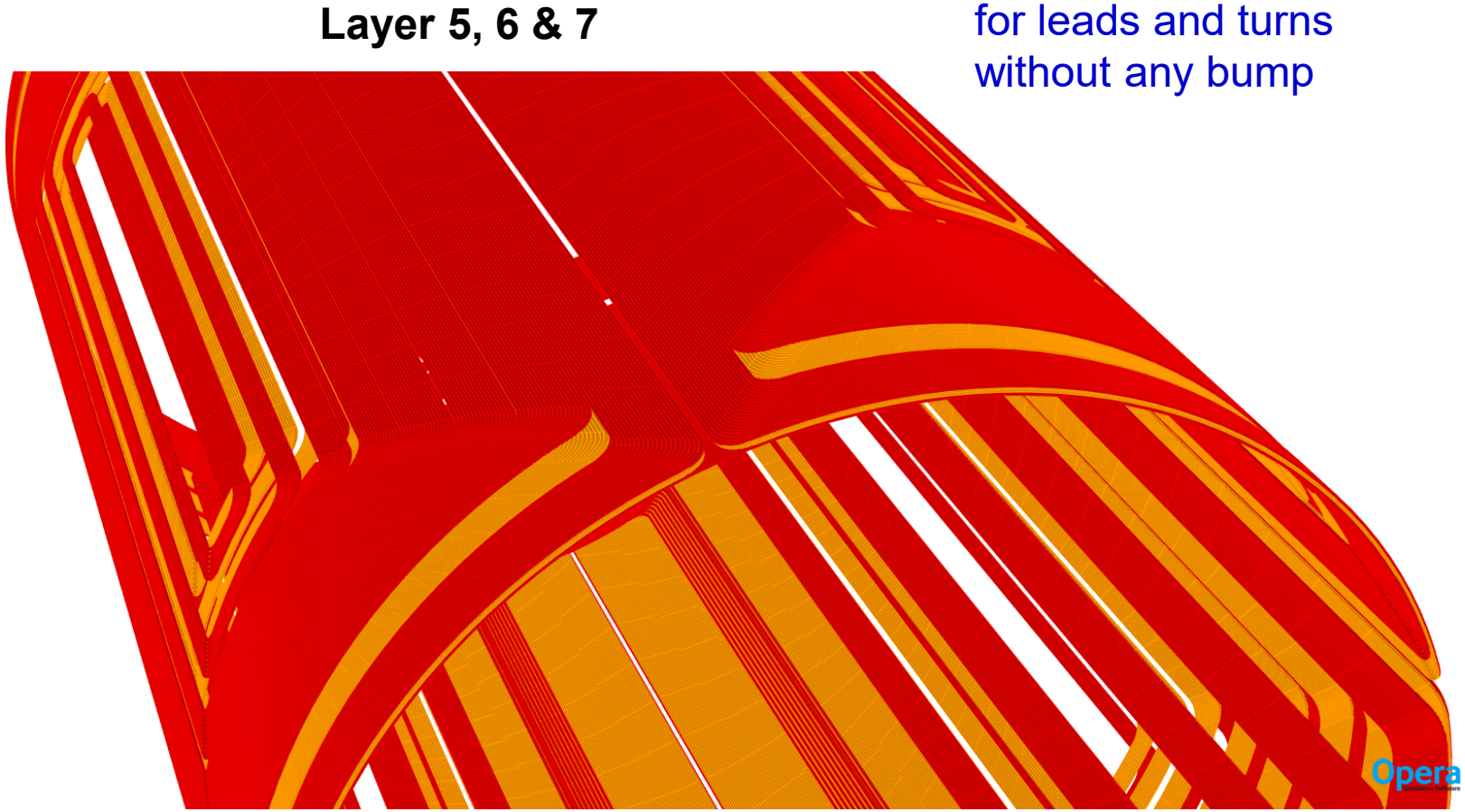
It happens naturally if the next layer is quad with some midplane gap.

Turns are distributed in the body and compact in the end.
Turns are distributed in blocks, rather than individually to minimize filling gaps by either spacers or blue epoxy.
Should also create a relatively more robust winding pack.

Next slide:
How to do it in a robust way.

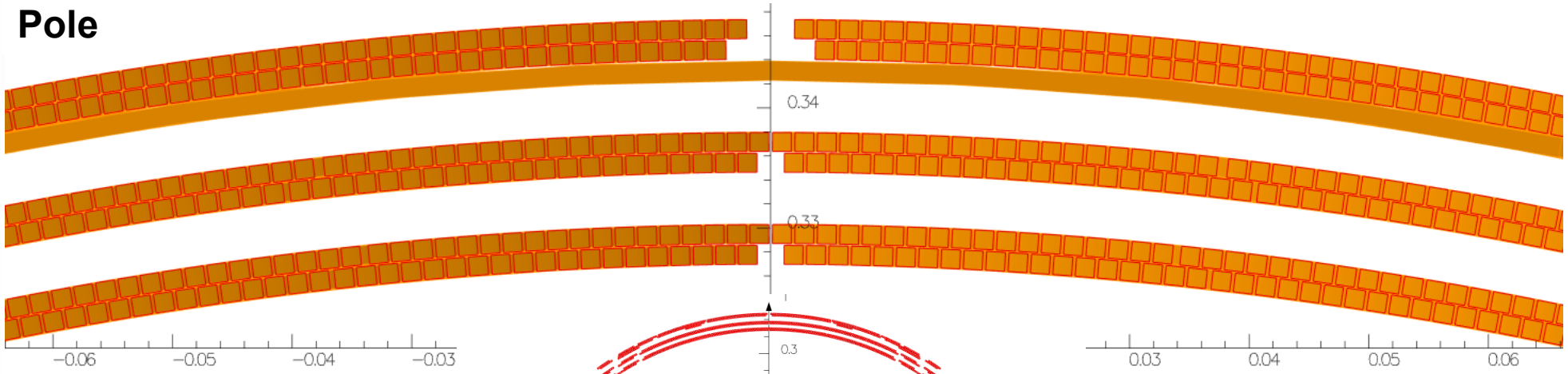
# Layer 5 (dipole), Layer 6 & 7 (quadrupole)

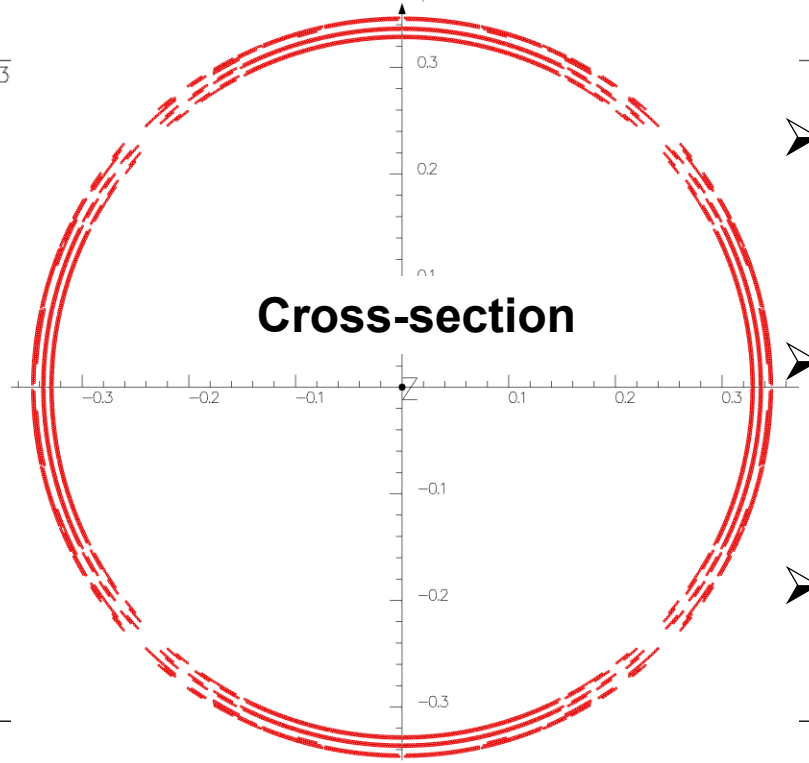



More on next slide for assuring a good support for leads and turns without any bump

# All Seven Layers Together with Strategically Included Gaps




- **Midplane gaps in layer 1, 3 and 6 for double layer winding.**
- **Pole gap in layer 6 for bringing out lead with splice.**
- **Pole gap in layer 7 to avoid bump.**