Brookhaven National Laboratory

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U.S. DEPARTMENT OF ENERGY

B2pF Q3 Superconducting Package

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June 10, 2026

Electron-Ion Collider

OVERVIEW

Magnetic requirements of SC 3pF Package:

- ❑ 0.1 T-m horizontal corrector
- ❑ 0.1 T-m vertical corrector
- ❑ 3 T skew quadrupole corrector
- ❑ 8.4 T normal quad (NOT a corrector, field quality must be good)

Inner diameter of the 1st winding: 137.4 mm

Coil length : 400 mm (B2pF: coil i.d. =120 mm, length > 3400 mm)

Q3 package has a very small length/aperture ratio (<3)

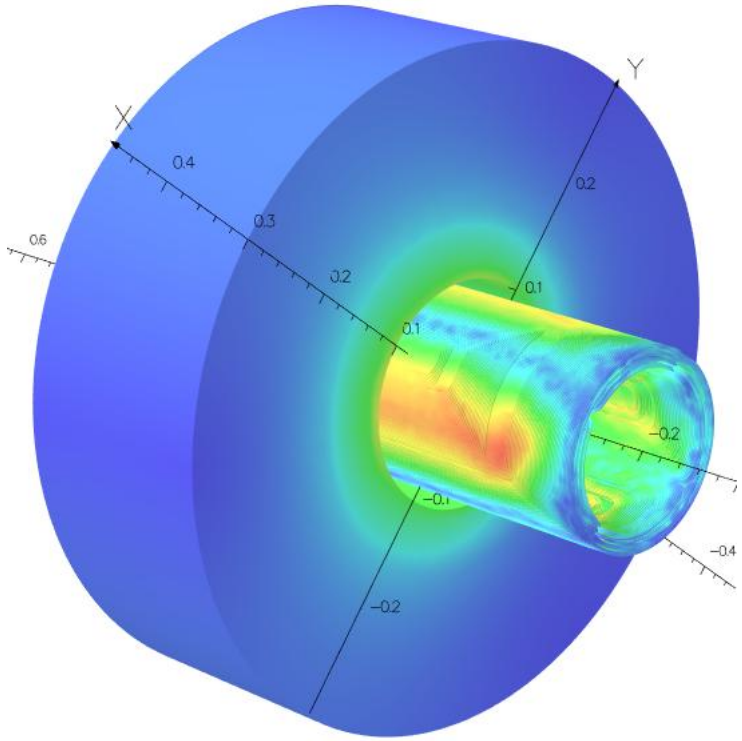
✓ **Optimum Integral Design (OID) makes a big difference such cases.**

Initial feasibility of OID for Q3 package was been presented earlier.

➢ **This iteration is for (a) complying with the latest parameters and (b) minimizing the number of layers for reducing cost.**

Basic Parameters of the Iterated Design

- Coil i.d.: ~134.4 mm, coil length: 400 mm, space in cryostat ~500 mm
- Optimum Integral Design (OID) maximizes field integral for small length/aperture ratio
- Summary of the iterated design:
  - ➢Normal Quad: two coil sets (4 layers, reduced from 6)
    - ❖Two coil sets allow iteration in field harmonics based on the measurements in the first coil set
  - ➢Skew Quad corrector: one coil set (2 layers)
  - ➢Horizontal dipole corrector: one layer **(OID allows it)**
  - ➢Vertical dipole corrector: one layer (gap at midplane to avoid interference in coil winding)
- Meets operating margin and field quality requirements
  - Margins are computed for all are powered at maximum and then all have a load line fraction margin of ~65% together (overkill?)



All quad layers are inside
All dipole layers are outside

Computed Optimized Harmonics @33 mm in Three Coil Sets of Quad

Two coil sets for normal quad and one coil set for skew quad
(in principle, they can be in any order – either normal in or skew in)

Coil set #1

INTEGRATED FIELD HARMONICS :

No.	Bn(T.m)	bn*10^4(units)
1	0.14984E+00	10000.0000
5	0.21611E-07	0.0014
9	0.45762E-07	0.0031
13	0.89712E-06	0.0599
17	-0.27749E-07	-0.0019
21	0.65381E-10	0.0000
25	-0.14494E-09	-0.0000
29	0.41595E-11	0.0000

Coil set #2

INTEGRATED FIELD HARMONICS :

No.	Bn(T.m)	bn*10^4(units)
1	0.14866E+00	10000.0000
5	0.21583E-07	0.0015
9	-0.10802E-07	-0.0007
13	0.56309E-06	0.0379
17	-0.19014E-07	-0.0013
21	-0.30955E-09	-0.0000
25	-0.55936E-11	-0.0000
29	0.54869E-12	0.0000

Coil set #3

INTEGRATED FIELD HARMONICS :

No.	Bn(T.m)	bn*10^4(units)
1	0.15032E+00	10000.0000
5	-0.20352E-07	-0.0014
9	-0.20705E-08	-0.0001
13	0.10312E-06	0.0069
17	-0.15113E-08	-0.0001
21	-0.72268E-10	-0.0000
25	-0.13961E-11	-0.0000
29	0.16690E-12	0.0000

Very low computed design harmonics in all cases

- Old US definitions, b_2 is sextupole

Spec <1 units for normal Quad; <10 units for skew quad (?check?)

Computed Optimized Harmonics @33 mm in 2 Coil Sets of Dipole

Low design harmonics for correctors

Coil layer #1

INTEGRATED FIELD HARMONICS :

No.	Bn(T.m)	bn*10^4(units)
0	0.21753E+00	10000.0000
2	0.83591E-05	0.3843
4	0.17421E-04	0.8009
6	0.22942E-04	1.0547
8	-0.30589E-05	-0.1406
10	0.28072E-06	0.0129
12	-0.12634E-07	-0.0006
14	-0.38119E-08	-0.0002
16	0.79735E-09	0.0000
18	-0.13164E-09	-0.0000
20	0.93845E-11	0.0000
22	0.26488E-12	0.0000
24	-0.26125E-12	-0.0000
26	0.56983E-13	0.0000
28	-0.57724E-14	-0.0000
30	0.35600E-15	0.0000

Coil layer #2

INTEGRATED FIELD HARMONICS :

No.	Bn(T.m)	bn*10^4(units)
0	0.20631E+00	10000.0000
2	0.75612E-06	0.0366
4	0.43698E-06	0.0212
6	-0.25212E-04	-1.2221
8	-0.32163E-05	-0.1559
10	-0.26696E-06	-0.0129
12	-0.60366E-07	-0.0029
14	-0.41239E-08	-0.0002
16	-0.13309E-08	-0.0001
18	-0.17356E-09	-0.0000
20	-0.27502E-10	-0.0000
22	-0.20295E-11	-0.0000
24	-0.26014E-12	-0.0000
26	-0.77201E-13	-0.0000
28	-0.13794E-13	-0.0000
30	-0.13916E-14	-0.0000

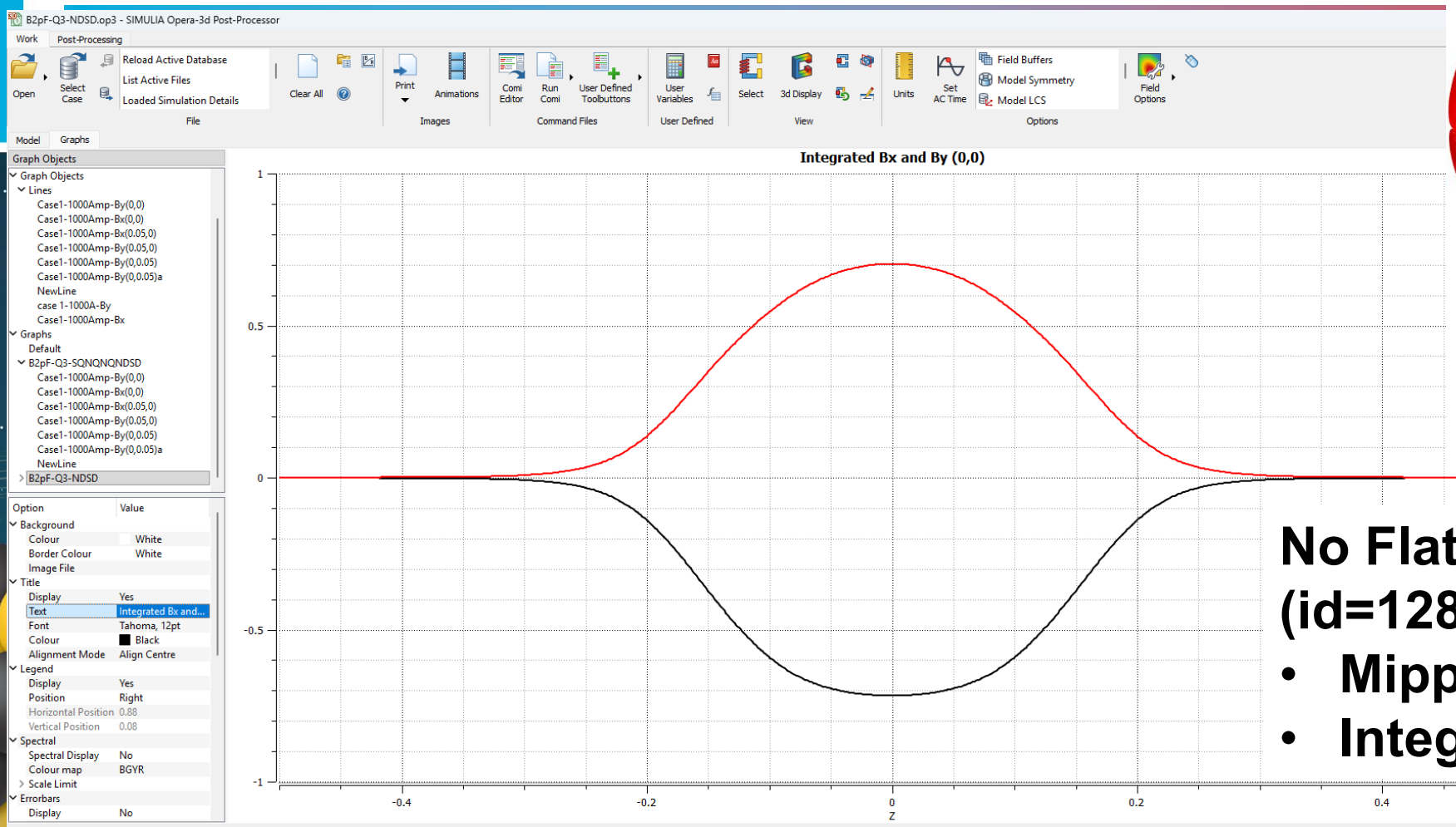
Spec <10 units

One coil layer for vertical corrector, one for horizontal (they can be in any order)

Optimum integral design allows a single layer coil

Old US definitions, b2 is sextupole

Axial Field Profiles of Horizontal and Vertical Dipole correctors



No Flat-top (short coil length (id=128.8, L=400mm; L/d<2.4)

- **Mipplane turn is full length**
- **Integral cos theta modulated**

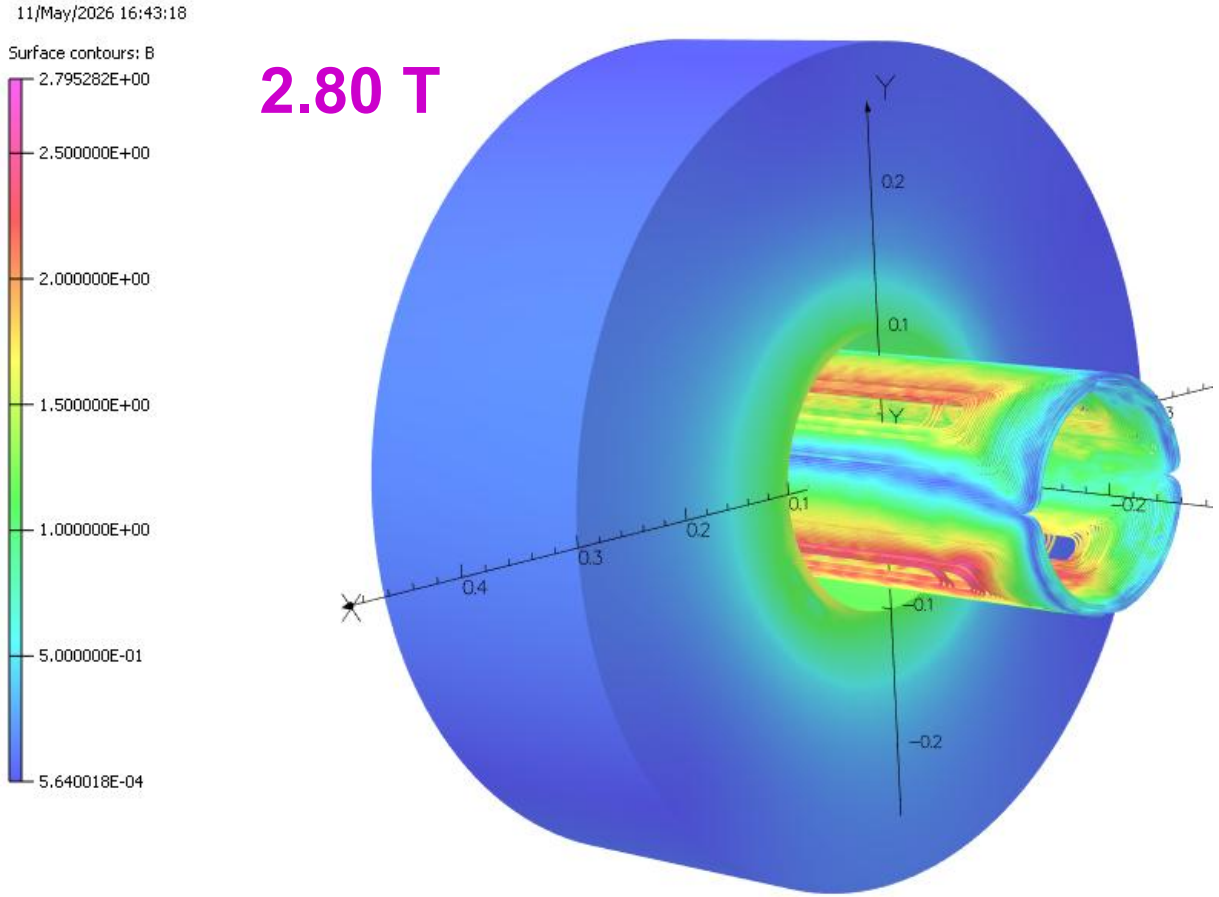
Quad layers inside; dipole layers outside

Field on the Normal Quad at the design field (all other coils also powered at the design field)

Normal Quad inside
(other coils hidden)

I(NQ) = ~910 A for 8.4 T, 4 layers
I(SQ)= ~700 A for 3 T, 2 layers
I(H,V)= ~500A for 0.1 T.m, 1 layer, each

Skew Quad inside
(other coils hidden)



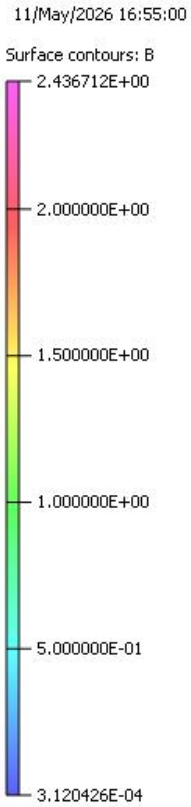
Preferred combination

Field on the Skew Quad at the design field (all other coils also powered at the design field)

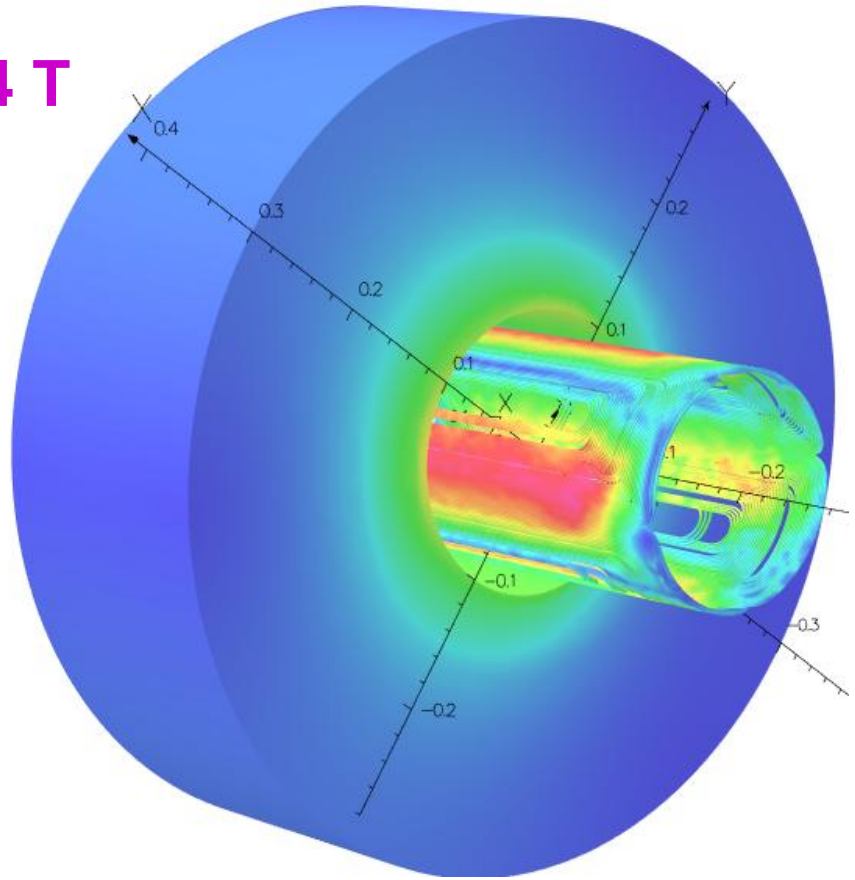
Normal Quad inside
(other coils hidden)

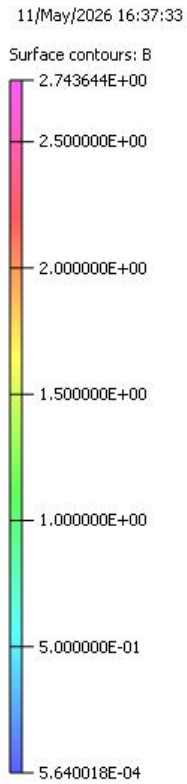
I(NQ) = ~910 A for 8.4 T, 4 layers
I(SQ)= ~700 A for 3 T, 2 layers
I(H,V)= ~500A for 0.1 T.m, 1 layer, each

Skew Quad inside
(other coils hidden)

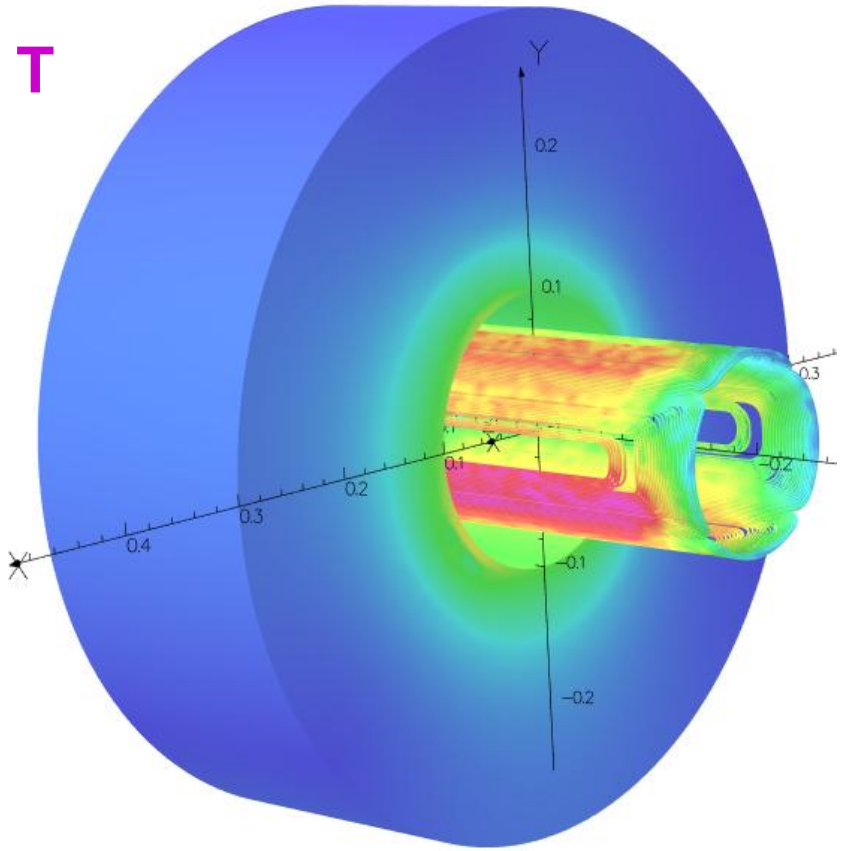


2.44 T





2.75 T



Field on the Vertical and Horizontal Dipoles at design field (all other coils also powered at the design field)

Vertical Dipole

(other coils hidden)

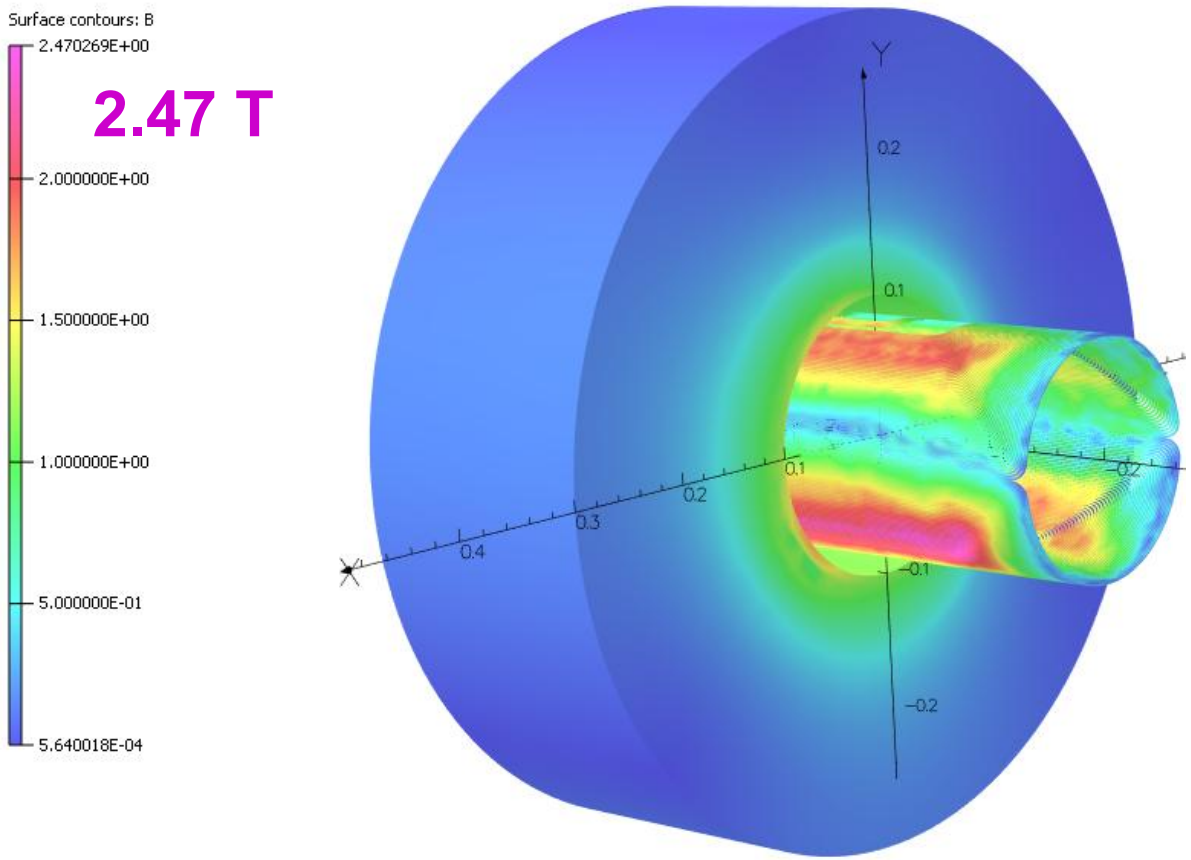
Skew Quad inside

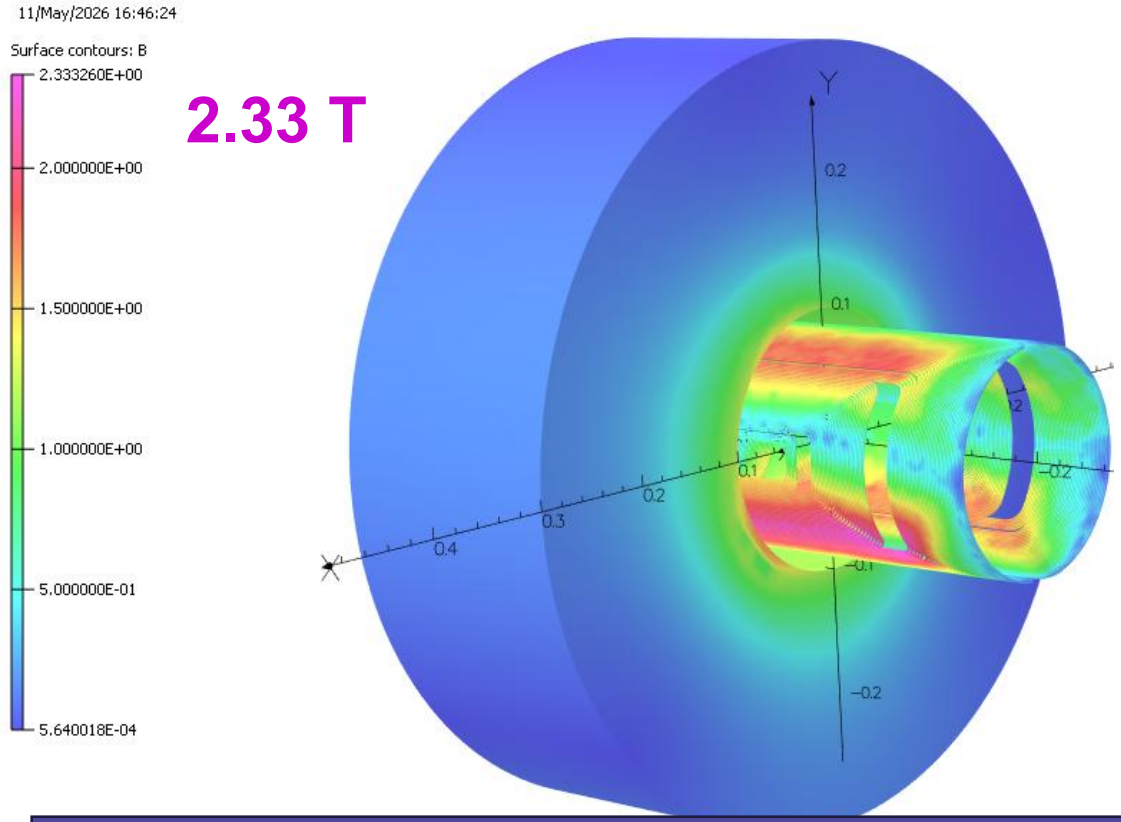
I(NQ) = ~910 A for 8.4 T, 4 layers
I(SQ)= ~700 A for 3 T, 2 layers
I(H,V)= ~500A for 0.1 T.m, 1 layer, each

Horizontal Dipole

(other coils hidden)

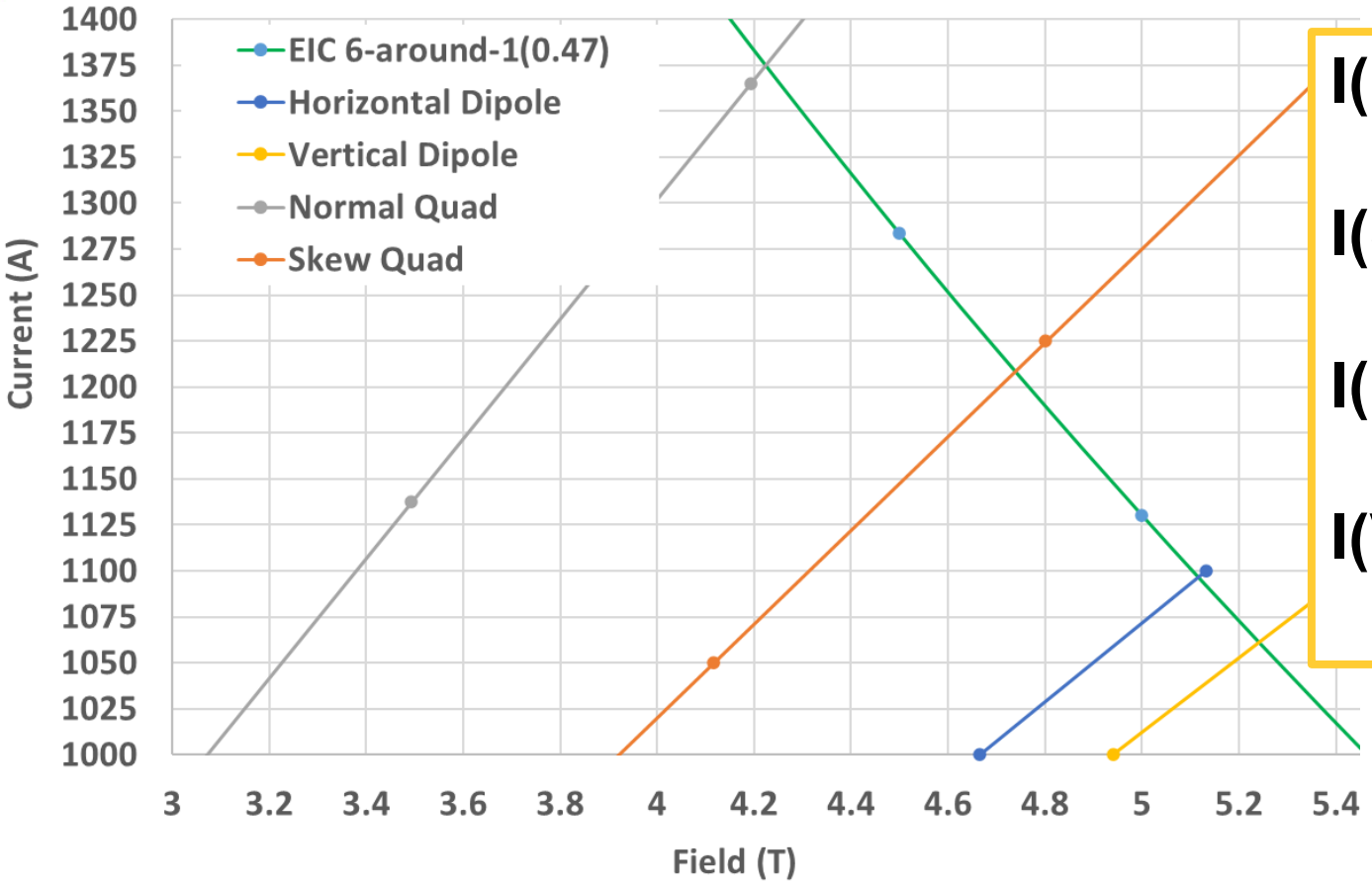
Skew Quad inside





Significant field from the quads inside

Computed Quench Performance
(with field from all coils changing together)



I(NQ) = ~910 A for 8.4 T, Iss = 1375A
- **Load line fraction*: 66%**

I(SQ) = ~700 A for 3 T, Iss = 1210 A
- **Load line fraction*: 58%**

I(H) = ~500A for 0.1 T.m, Iss = 1100 A
- **Load line fraction*: 45%**

I(V) = ~500 A for 0.1 T.m, Iss =1060 A
- **Load line fraction*: 47%**

Latest standard Ic(B) curve used for the cable

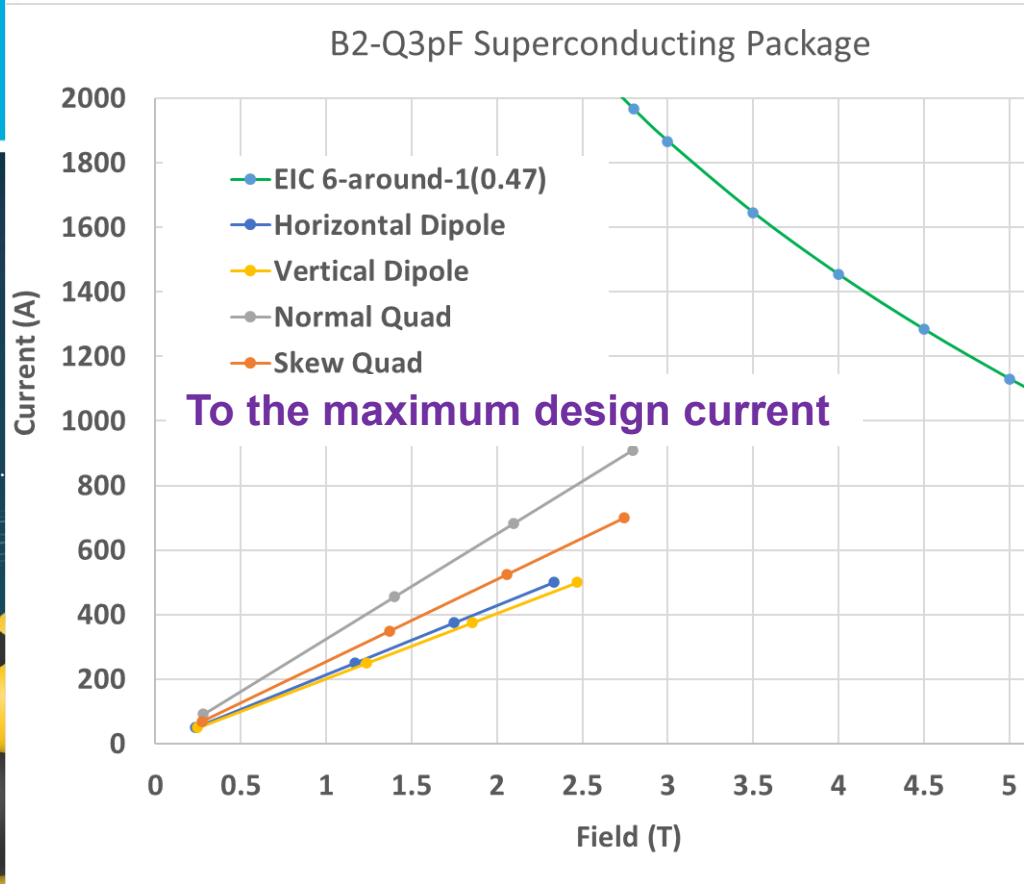
***Margins are computed for all are powered at maximum and then all together operate at a load line fraction of ~65%. Individual set will have higher margin.**

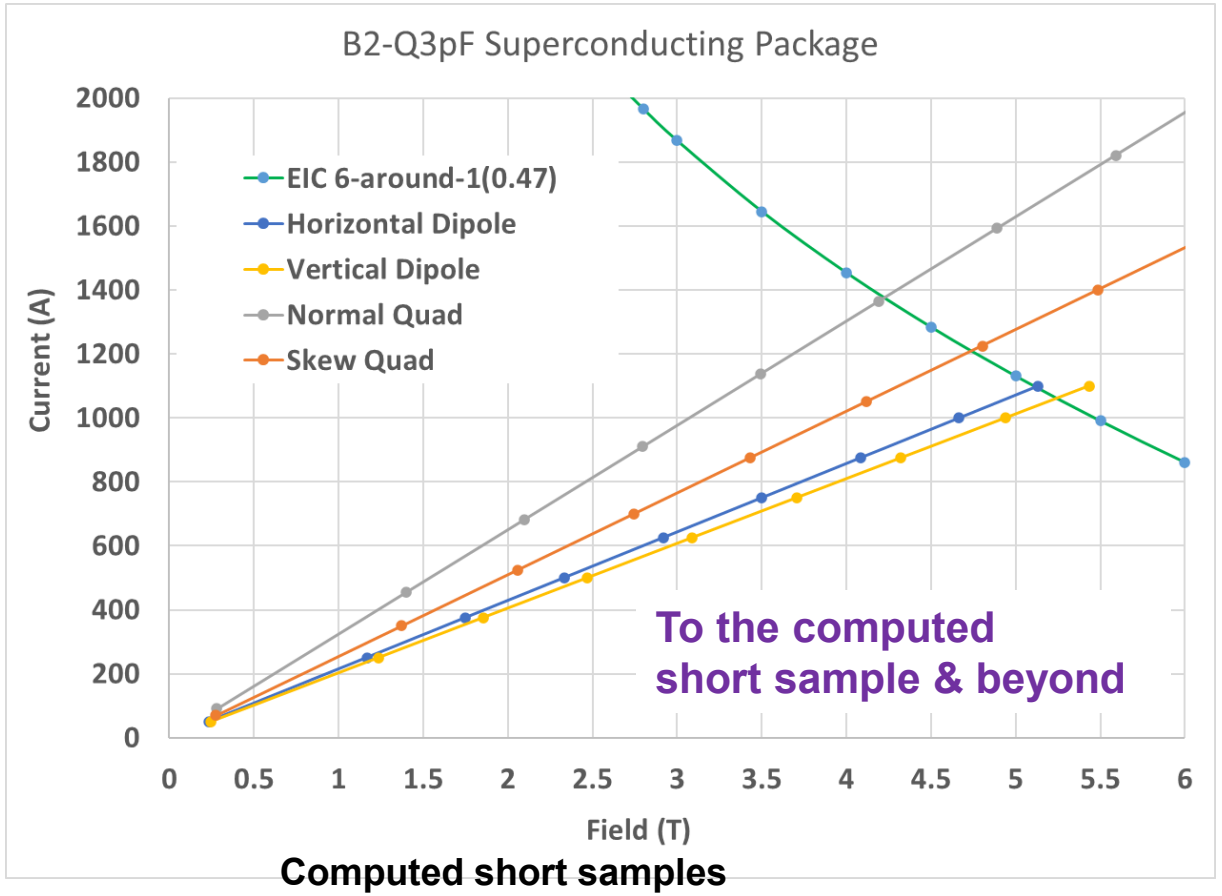
SUMMARY

- Iterated design calculations confirm that the specified performance of superconducting Q3 package, placed in the same cryostat as the B2pF, can be obtained with a 400 mm long multilayer-direct wind coils based on the optimum integral design. Maximum space to be used ~500 mm.
- Design of the Q3 package is optimized to meet the requirements with a minimum number of layers. It requires only 4 layers (2 coil sets) for the normal quad, 2 layers (1 coil set) for the skew quad and single layer each (OID allows that) winding for the vertical and horizontal dipole correctors.
- Additional windings can be added if performance of any is not as desired. This can be left as an option (not a baseline) to balance cost and risk.
- The design, as such, is ready to go. Minor iterations in the actual winding file can still be carried out without impacting the overall design.
- Not examined yet – cross talk for the ESR line.

Extra Slides

Computed Quench Performance
(with field from all coils changing together)

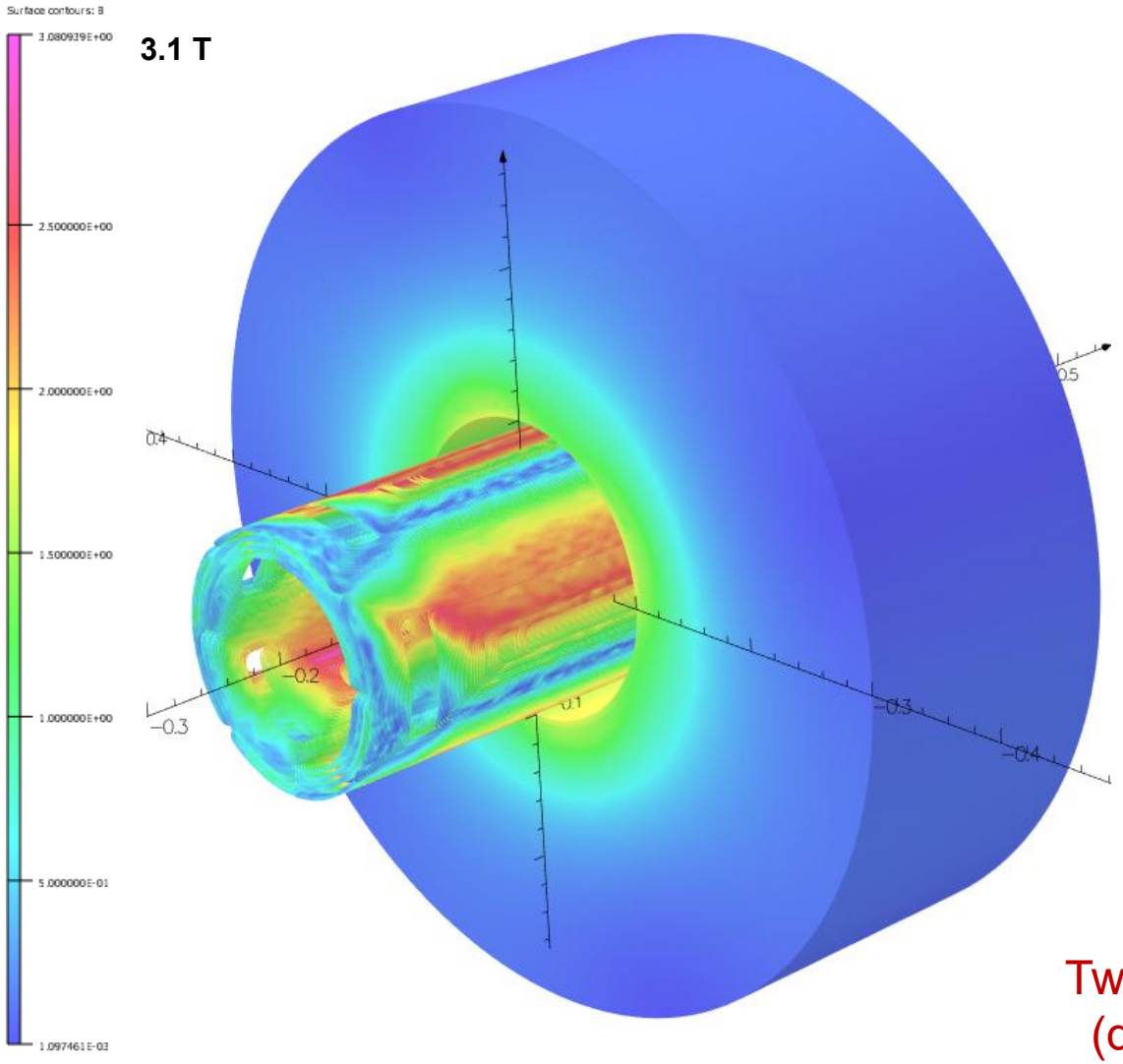




Margins are computed for all are powered at maximum and then all have a load line fraction margin of ~65% over that (overkill?)

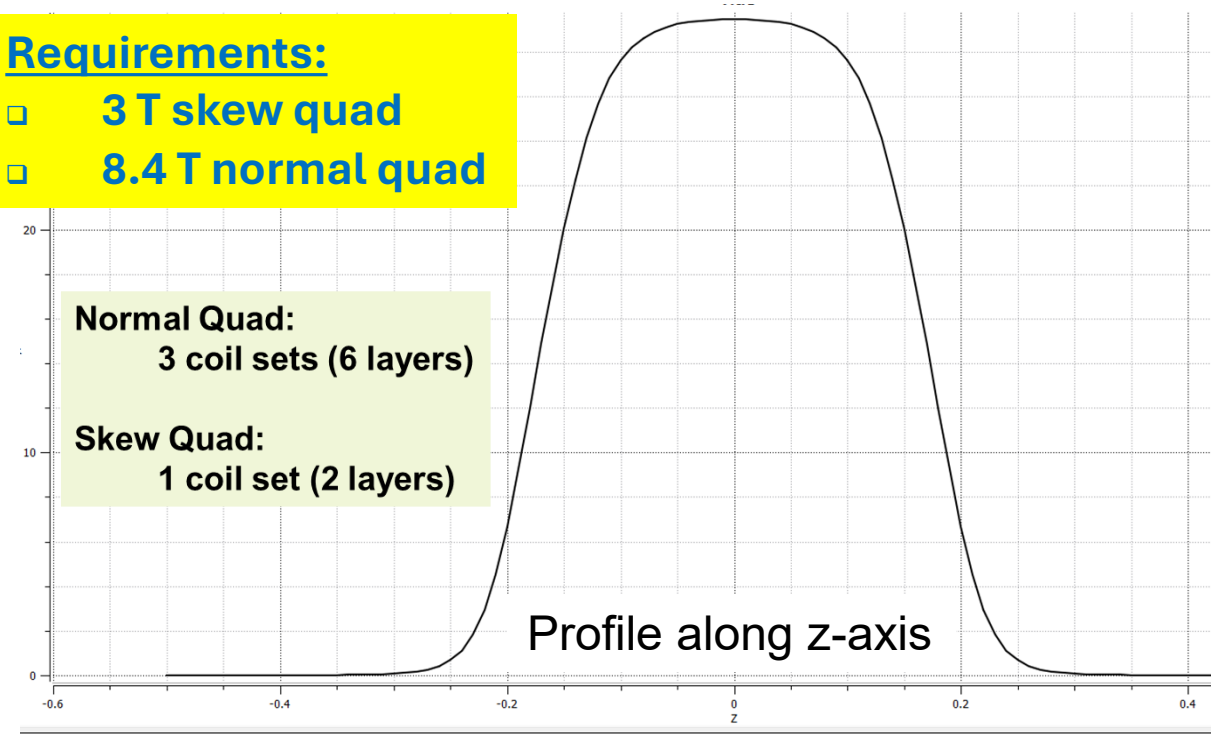
Computed short samples
Normal Quad 1375 A
Skew Quad 1210A
Horizontal Dipole 1100 A
Vertical Dipole 1060 A

Field contour with normal and skew quads @500 A (presented last time)



Requirements:

- 3 T skew quad
- 8.4 T normal quad



Iterated design

- Normal quad: 2 coil sets @ ~900 A
- Skew quad: 1 coil set @~700 A

Two options examined: skew quad inside or normal quad inside
(dipole correctors are always outermost layers in both cases)