Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Status of Q2pF End Design

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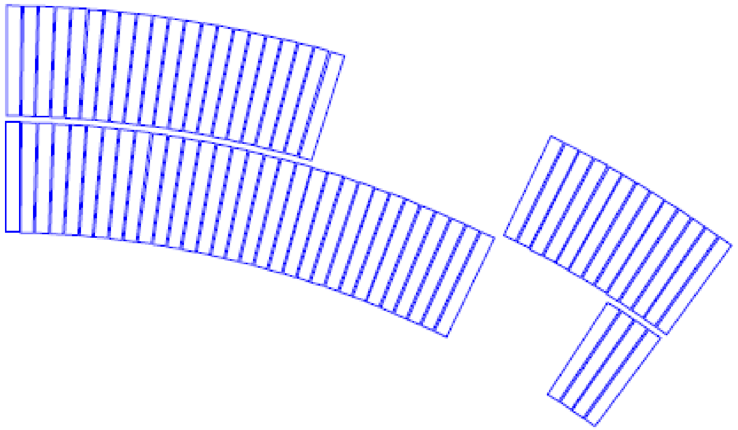
Cross-section with Symmetric Wedges (with EIC "Q" cable)



38% margin on load-line (2-d)

Looks good mechanically

2-d Field Harmonics

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HARMONIC ANALYSIS NUMBER .........................                 1
MAIN HARMONIC ....................................                 2
REFERENCE RADIUS (mm) ............................           83.0000
X-POSITION OF THE HARMONIC COIL (mm) .............            0.0000
Y-POSITION OF THE HARMONIC COIL (mm) .............            0.0000
MEASUREMENT TYPE ...................... ALL FIELD CONTRIBUTIONS
ERROR OF HARMONIC ANALYSIS OF Br .................        0.6776E-04
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

MAIN FIELD (T) ...................................          3.147502
MAGNET STRENGTH (T/(m^(n-1)) .....................           37.9217

NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:     -0.14254  b 2:  10000.00000  b 3:       0.00250
b 4:     -0.01577  b 5:      0.02641  b 6:      -0.10295
b 7:     -0.00201  b 8:     -0.00094  b 9:       0.00065
b10:     -0.40774  b11:     -0.00011  b12:       0.00000
b13:     -0.00002  b14:     -0.46484  b15:       0.00000
b16:     -0.00000  b17:     -0.00000  b18:       0.00550
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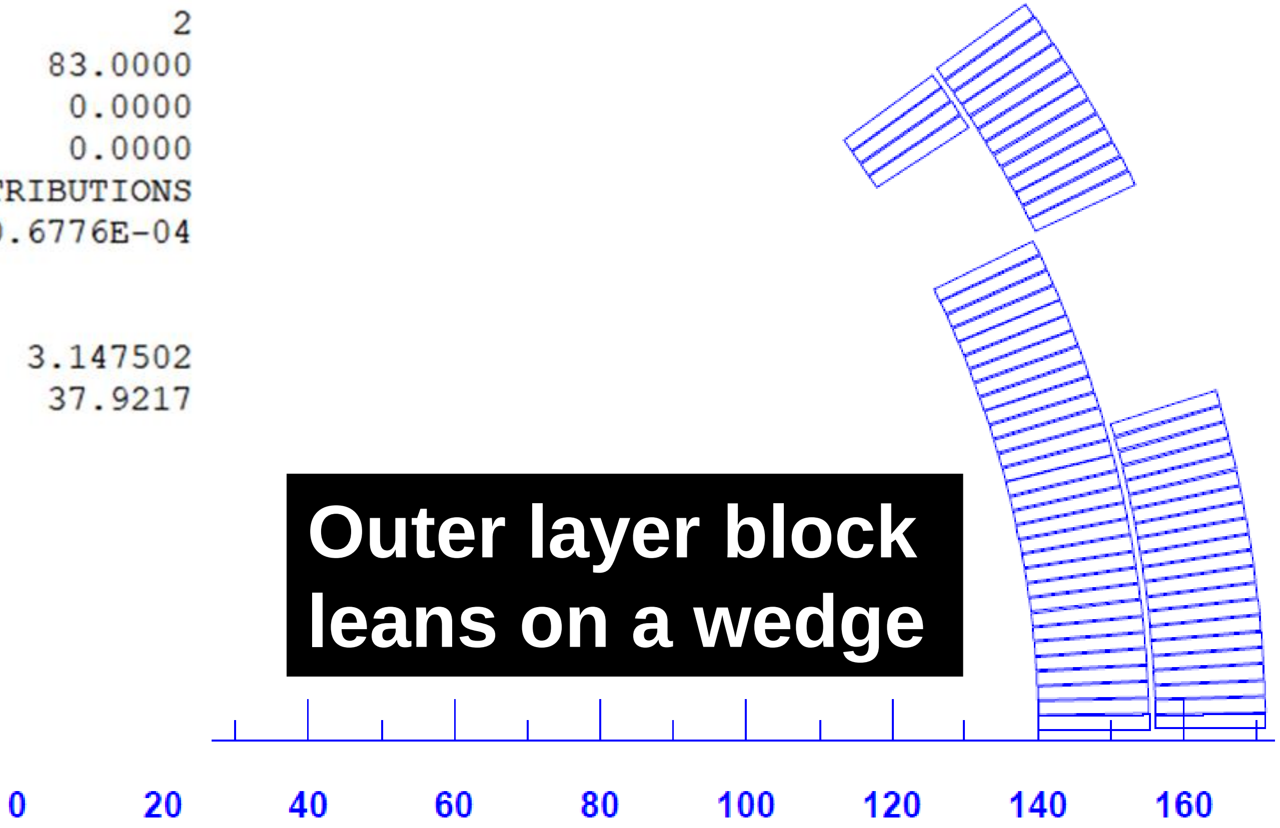
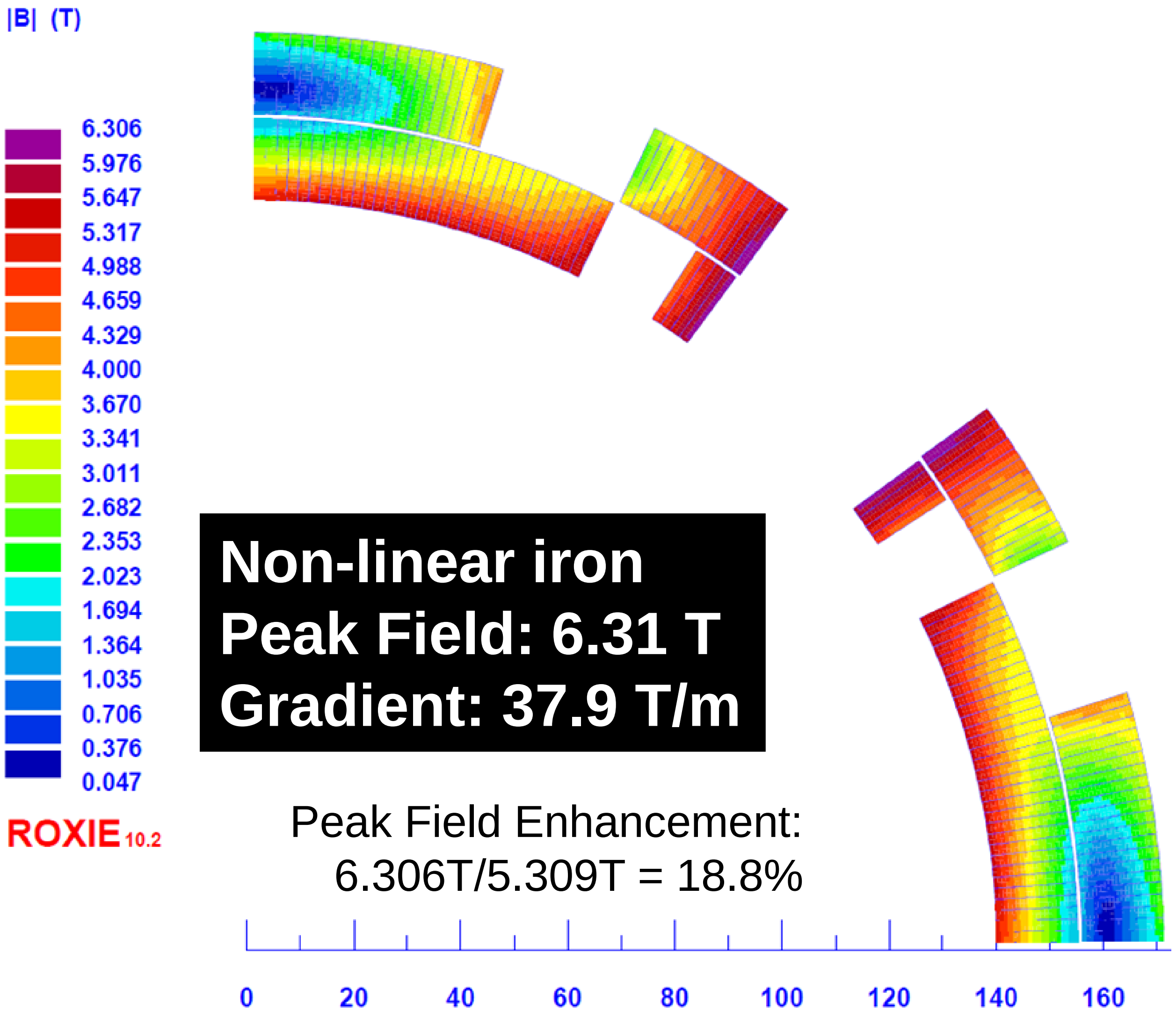


Outer layer block leans on a wedge

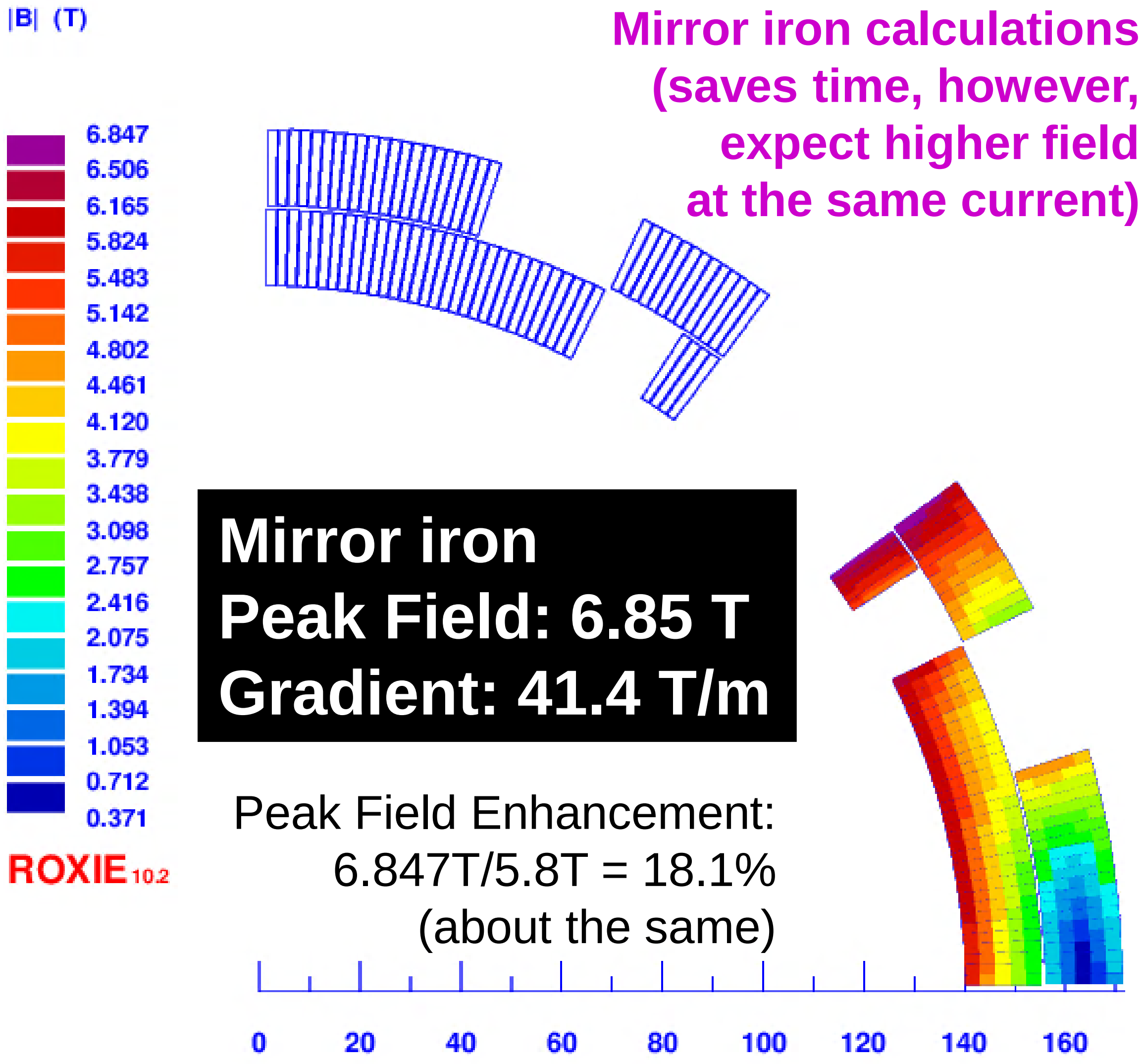
Peak Field Calculations in Q2pF Cross-section



Non-linear iron
Peak Field: 6.31 T
Gradient: 37.9 T/m

Peak Field Enhancement:
6.306T/5.309T = 18.8%

Mirror iron calculations
(saves time, however,
expect higher field
at the same current)



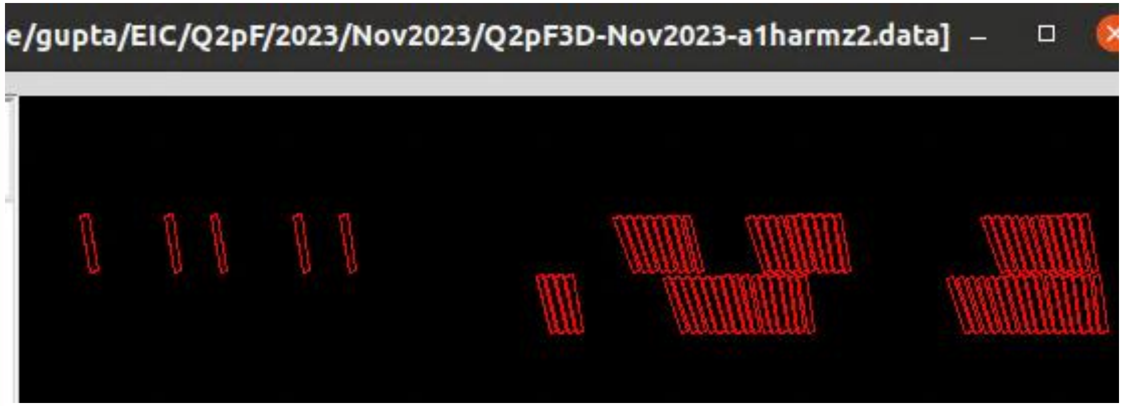
Mirror iron
Peak Field: 6.85 T
Gradient: 41.4 T/m

Peak Field Enhancement:
6.847T/5.8T = 18.1%
(about the same)

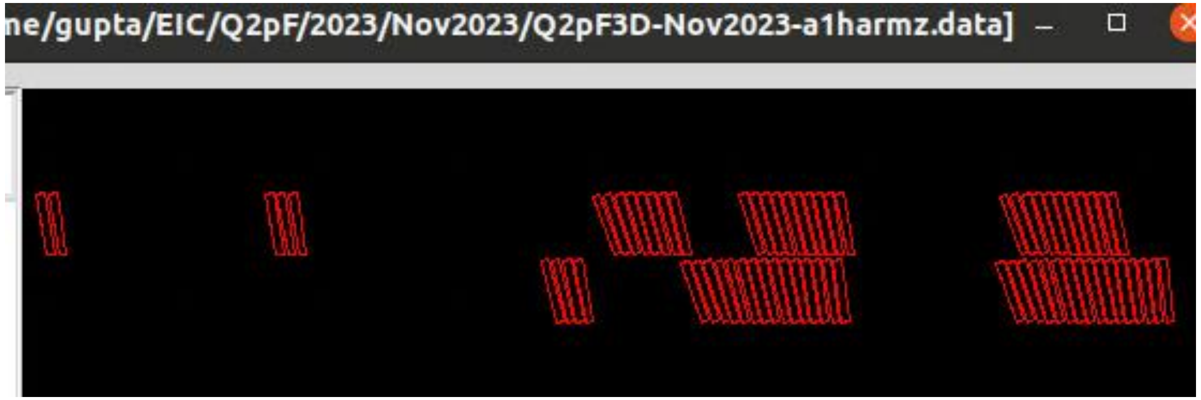
- Mirror iron calculations takes significantly less time
  Important in 3-d calculations; to be used during optimization

Initial Investigation of Q2pF End Designs (presented earlier)

End Design v1



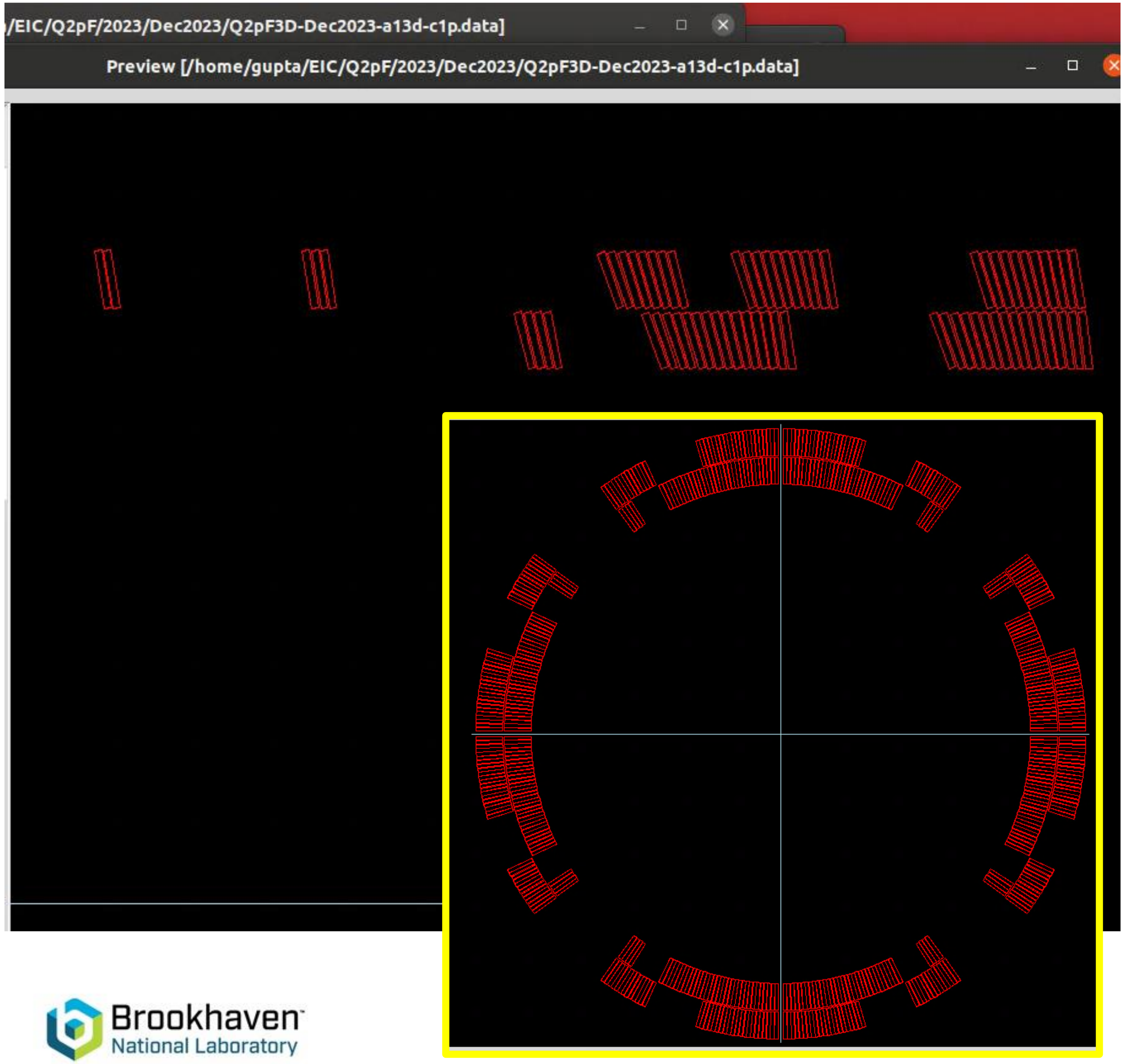
End Design v3



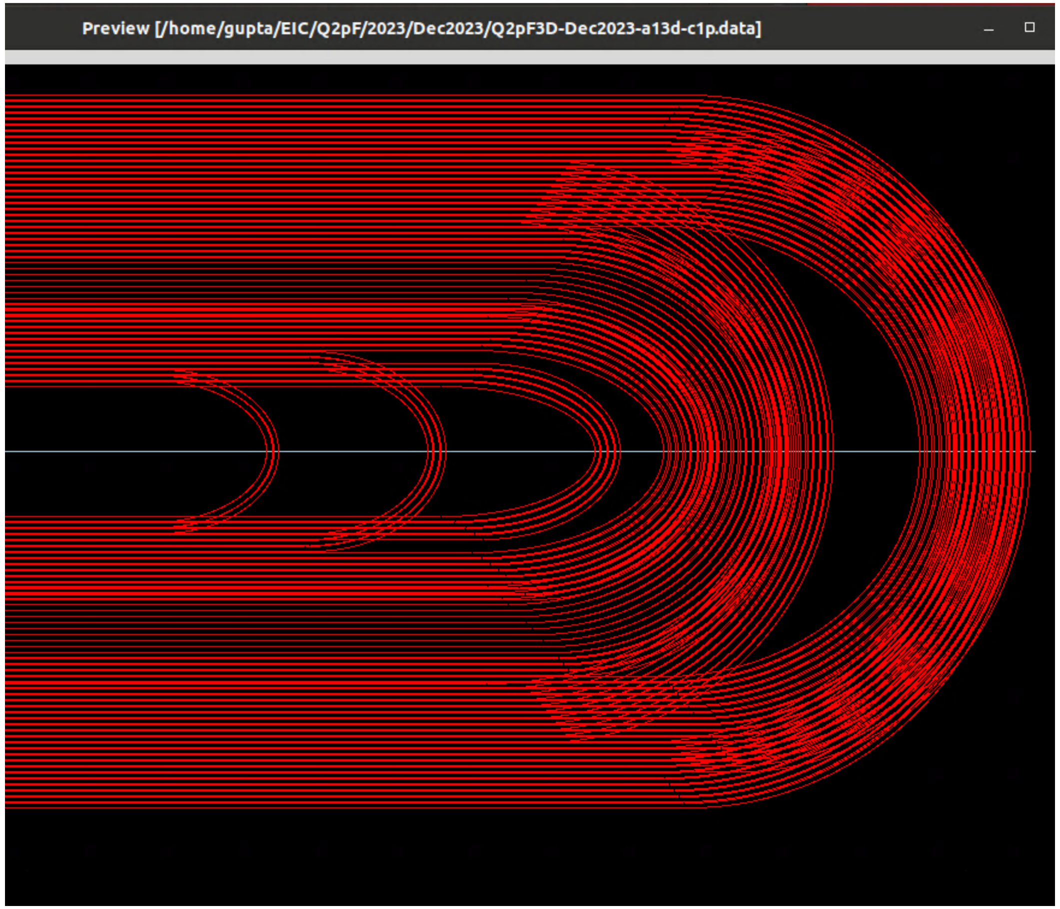
End Design v2

- Minimum tilt angle in all cases: 70 degrees
- Peak field in the ends is within ~2% of the peak field in the body (cross-section)
- Last turns of inner and outer layer turns are aligned together in v1 and v2, but not in v3
- In going from v1 to v3, see pole turns of outer layer (scattered earlier to minimize peak field), v3 is preferred for fewer spacers

Current Version (tilt angle 70º)



- Fewer spacer in the outer layer
- End turns of the outer and the inner layers aligned



Peak field & harmonics

Reasonable start:

- **Field harmonics (3-d): seems ok**
- **Peak field: 6.98 T (Vs 6.85 T in 2-d)**

Only about ~1.9% higher peak field than that in x-section

(calculation errors?)

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MARGIN CALC (USING JC-FIT):
BLOCK NUMBER ..........................................        11
PEAK FIELD IN CONDUCTOR    69 (T) ...................      6.9820
CURRENT IN CONDUCTOR  69 (A) ........................  -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ............   -886.0233
PERCENTAGE ON THE LOAD LINE ........................     66.3112
QUENCHFIELD (T) ....................................     10.5291
TEMPERATURE MARGIN TO QUENCH (K) ...................      3.1222
PERCENTAGE OF SHORT SAMPLE CURRENT .................     27.0201

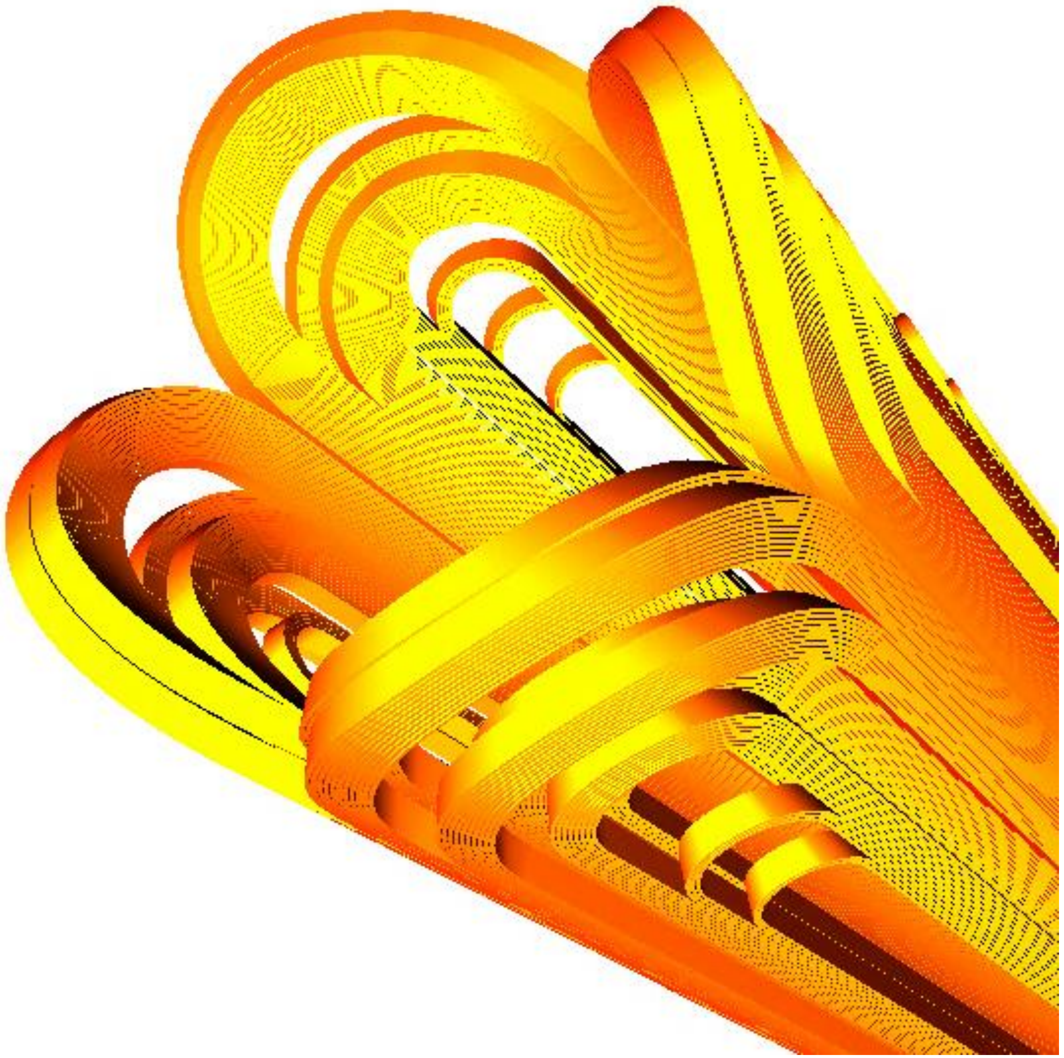
FORCES (N) IN COIL ENDS
CONDUCTOR  FX           FY           FZ          FPAR        FPER
  69    49855.837   -69011.412    1403.623    105.388    85879.574
SUMM    49855.837   -69011.412    1403.623    105.388    85879.574

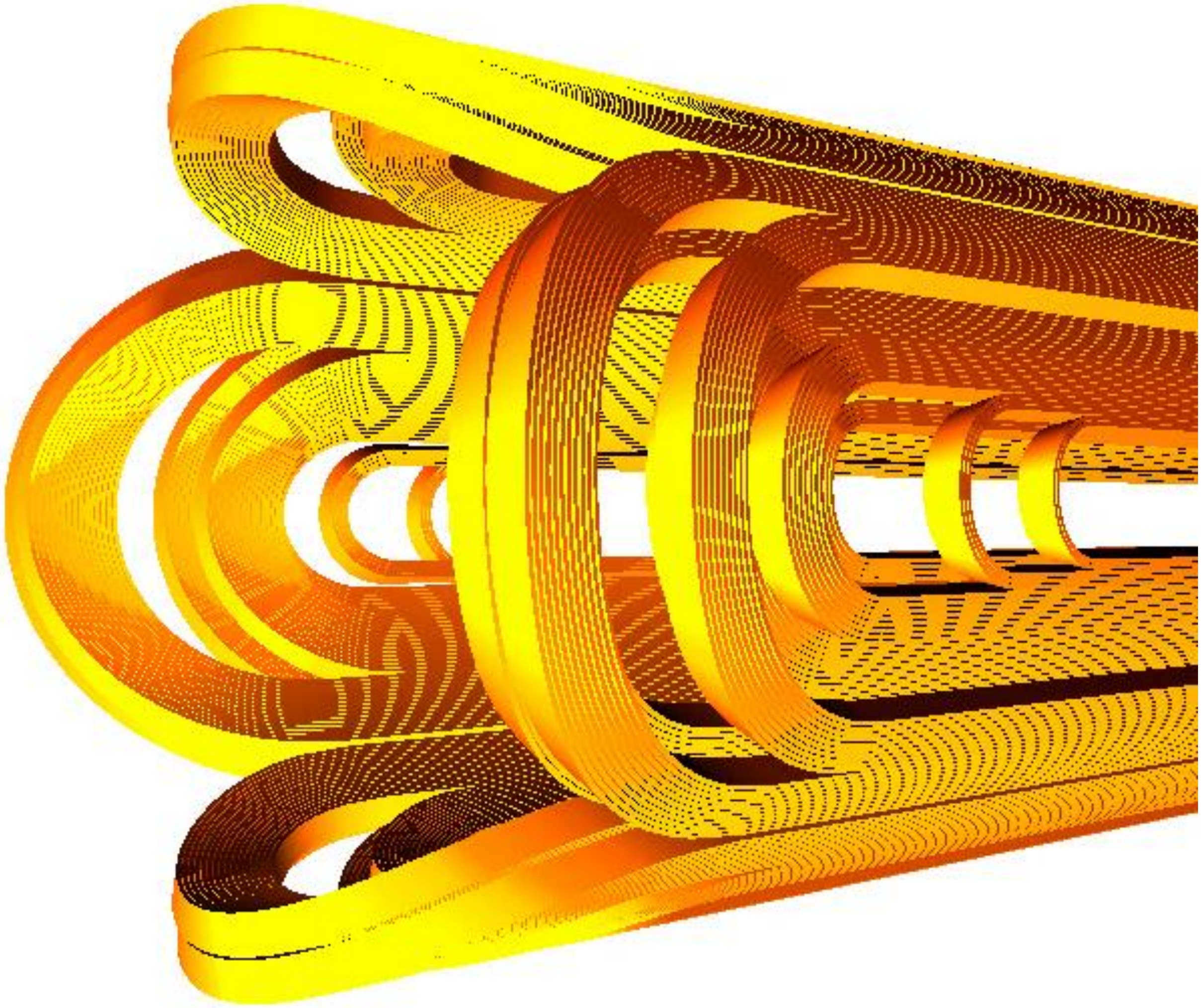

HARMONIC ANALYSIS NUMBER ...........................           1
MAIN HARMONIC ......................................           2
REFERENCE RADIUS (mm) ..............................     83.0000
X-POSITION OF THE HARMONIC COIL (mm) ...............      0.0000
Y-POSITION OF THE HARMONIC COIL (mm) ...............      0.0000
NUMBER OF ANALYSES ALONG Z .........................         100
LENGTH OF VIRTUAL COIL (mm) ........................    200.0000
REFERENCE POSITION NUMBER ..........................          10
MEASUREMENT TYPE ........................ ALL FIELD CONTRIBUTIONS
ERROR OF HARMONIC ANALYSIS OF Br ...................  0.6826E-04
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

3D REFERENCE MAIN FIELD (T) ........................      3.4386
REFERENCE MAGNET STRENGTH (T/(m^(n-1)) ............     41.4295
MAGNETIC LENGTH (mm) ...............................    200.0006

NORMAL 3D INTEGRAL RELATIVE MULTIPOLES (1.D-4):
b 1:      0.00000  b 2:  10000.00000  b 3:      0.00000
b 4:     -0.00000  b 5:      0.00000  b 6:      0.13027
b 7:     -0.00000  b 8:      0.00000  b 9:     -0.00000
b10:     -0.40171  b11:      0.00000  b12:      0.00000
b13:     -0.00000  b14:     -0.43070  b15:     -0.00000
b16:     -0.00000  b17:      0.00000  b18:      0.00484
```

More Renderings of the Current End Design





Looks reasonable ok; to be examined more carefully

Next Step: Things to be done prior to further optimization of the end design

- It is shown that reasonable ends are possible with (a) minimum tilt angle in the end 70 degree with reasonable geometric layout, (b) peak field in ends with 2% of peak field in the body, and (c) low end harmonics.
- However, before going for finer optimization, a few things need to be done in the body which would require an update in the ends as well.
- We need to incorporate the tuning shims to correct harmonics measured warm and cold (low-current). This will require a change in the yoke inner surface and hence in the coil to compensate the harmonics generated.
- We should also try to make outer yoke diameter same in all quads, if possible (MA).

Extra slides

Background

Attempt will be to satisfy the same goals as in the earlier designs:

- Peak field in Ends remain close to the 2-d peak field in the X-section.
- Small integrated harmonics.
- End turn layout should be as vertical as possible at pole (kept 70^{o} in all cases) and layout looking visually reasonable before printing 3-d parts to try different variations. We will follow the useful experience from the single turn winding test of B1pF.

LHC Style Cable used in Quad & Dipole (based on full keystone for Q2pF and B1ApF)

EIC

LHC

Cable Geometry

No	Name	height	width_i	width_o	ns	transp.	degrd	Comment
1	EICLHCB	15.1	1.816	1.984	28	115	5	LHC IN KEYSTOE FOR EIC DIPOLE
1	EICLHCQ	15.1	1.79	2.01	28	115	5	LHC IN KEYSTONE FOR EICIR QUAD
1	EICLHC01	15.1	1.786	2.014	28	115	5	LHC CABLE KEYSTOR FOR EIC 4.2K
2	EIC3642	19.4	1.773	2.027	36	115	3	EIC 36 STRAND 04.2K
3	EIC3618	19.4	1.773	2.027	36	115	3	EIC 36 STRAND 01.8K
4	EIC3642A	19.4	1.788	2.012	36	115	3	EIC 36 STRAND 04.2K 2 Layers
5	CABLE01	15.1	1.736	2.064	28	115	5	MB INNER LAYER,STR01
6	CABLE02	15.1	1.362	1.598	36	100	5	MB OUTER LAYER,STR01
7	SINGLE	0.94	0.94	0.94	1	0	0	SINGLE STRAND
8	GSI1CAB	9.74	1.061	1.271	30	74	0	GSI001 (RHIC) CABLE
9	GSI001	9.73	1.111	1.321	30	74	0	GSI001 following Wanderer
10	20MMCABLE	20	1.736	2.172	37	0	0	20mm cable
11	20MMCBNOK	20	13.8	13.8	280	0	0	7x20mm cable, no keystone
12	20MMCAB2	20	1.8	2	37	0	0	20 mm cable 2

EIC

LHC

Cable Definition

No	Name	Cable Geom.	Strand	Filament	Insul	Trans	Quench Mat.	T_o	Comment
1	EICLHCB2K	EICLHCB	STREIC1	NBTII	ALLPOLYIL	TRANS1	NONE	2	LHC INNER FOR EIC IR QUAD 02K
2	EICLHCQ2K	EICLHCQ	STREIC1	NBTII	ALLPOLYIL	TRANS1	NONE	2	LHC INNER FOR EIC IR DIPOLE 0
3	LHCIN42K	EICLHC01	STREIC1	NBTII	ALLPOLYIL	TRANS1	NONE	4.2	LHC INNER FOR EIC 04.2K
[illegible]	YELLONIN	CABLE01	STR01	NBTII	ALLPOLYIL	TRANS1	NONE	1.9	V6-1 DESIGN DIPOLE INNER
[illegible]	YELLONOU	CABLE02	STR02	NBTIO	ALLPOLYOL	TRANS1	NONE	1.9	V6-1 DESIGN DIPOLE OUTER

Keystone angle for cable width << coil readius

	Q2pF	B1ApF
Cable height	15.1	15.1
Cable mid-thickness	1.9	1.9
Insul (one side)	0.12	0.12
Coil i.r.	140	185
Avg Rad	147.55	192.55
dt	0.2190	0.1678
Width_i	1.790	1.816
width_o	2.010	1.984

Note: Keystones are reduced for EIC

Cables considered for EIC: "EICLHCB2K" and "EICLHCQ2K" (EICLHCB and EICLHCQ)
Similar to LHC inner: "YELLONIN" (CABLE01)

Brookhaven National Laboratory
Magnet Division

Ramesh Gupta   Cable Parameters of the EIC IR Cable Magnets   March 22, 2022   3

Updated (current) Design Uses "Q" cable, instead of "B" cable