# Q1ApF Cross-section for 2K Operation (one design study)

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# Basic Parameters of the current Q1ApF Design

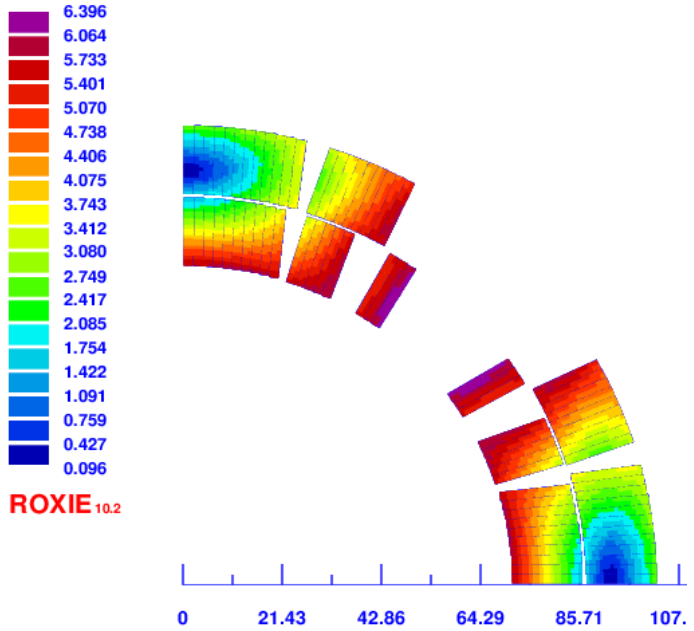
## Parameters from pCDR:

**Table 6.2:** Parameters of the Q1ApF magnet.

| Parameter | Value |
|---|---|
| Magnetic length [m] | 1.46 |
| Maximum gradient [T/m] | 72.6 |
| Aperture diameter [m] | 0.1120 |
| Required field quality | $1 \times 10^{-4}$ |
| Physical length [m] | 1.48 |
| Physical width [m] | 0.182 |
| Physical height [m] | 0.182 |
| Superconductor type | NbTi |
| Conductor | Cable $20 \times 2\,mm^2$ |
| Current density [A/mm] $^2$ | 512 |
| Cu:Sc ratio | 1.3 |
| Temperature [K] | 1.8 |
| Peak field wire [T] | 6.85 |
| Magnetic energy [J] | 360000 |
| Ampere turns [kA·t] | 360 |
| Number of turns | 18 |
| Current [kA] | 20 |
| Inductance [mH] | 1.8 |
| Margin loadline [%] | 32 |

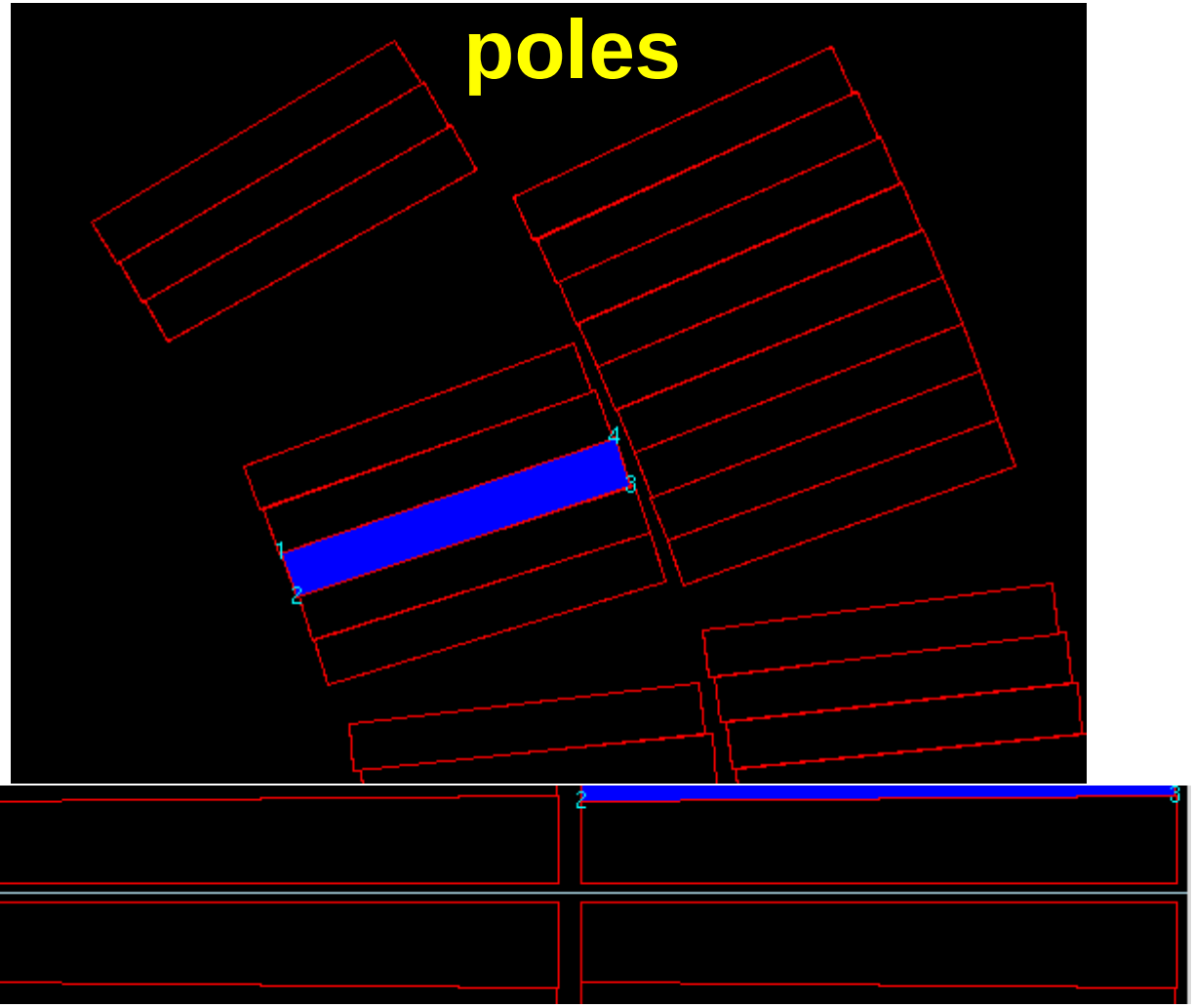
## Parameters used in the current design:

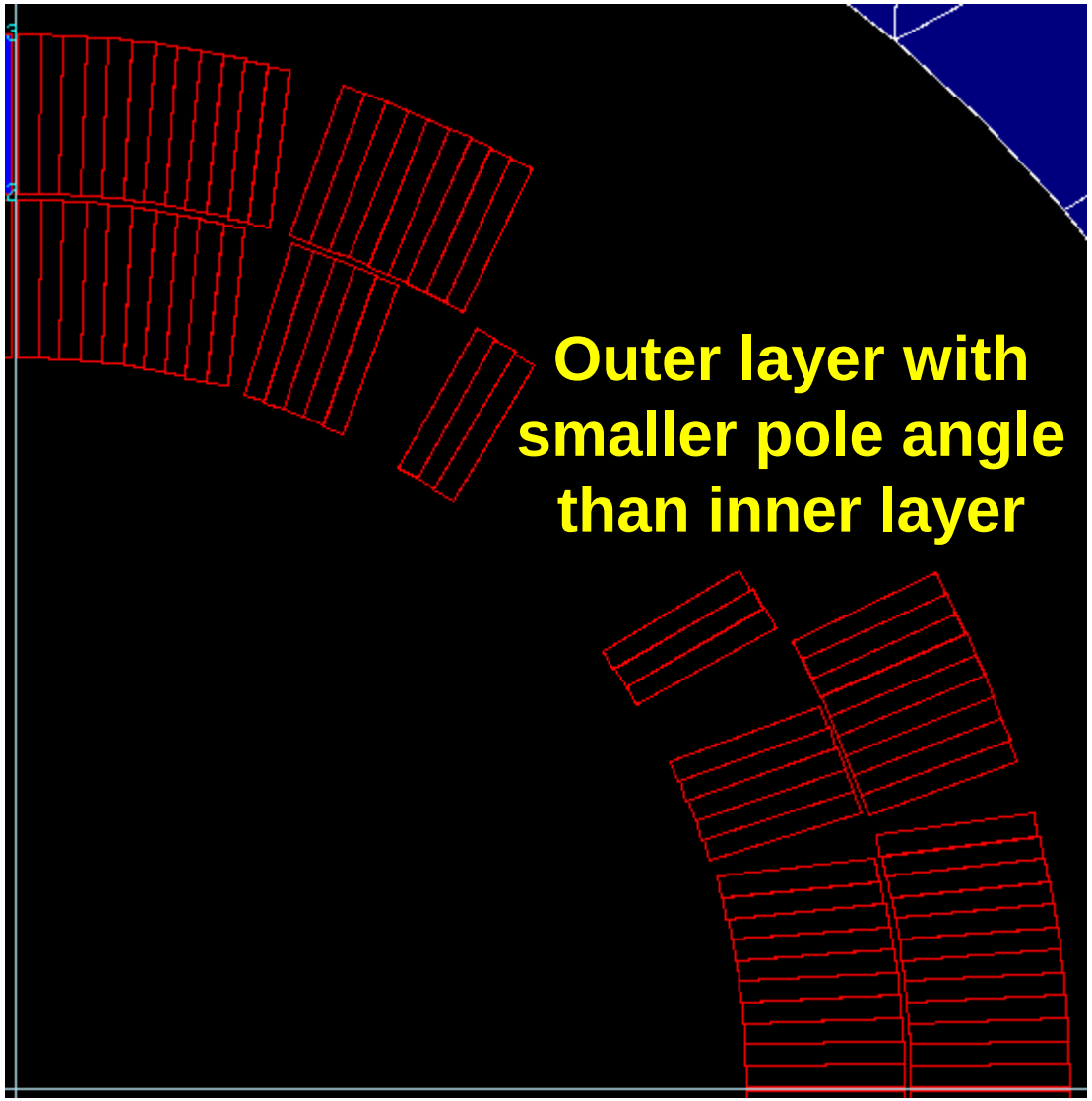
- Gradient: 72.6 T/m (revised from pCDR, current ~75 T/m)
- Physical Length: 1.48 m (not fixed, depends on Q1BpF)
- Coil inner radius: 71 mm
- Estimated effective length: 1.48 - 0.071 = ~1.4 m
- Estimated gradient in body: 75*1.48/1.4 = ~79.3 T/m
- Cable: 15 mm
  - ➢ LHC inner type
  - ➢ Also used in B1pF/B1ApF
- Cu/SC: 1.6
- Temperature: 2 K



# Optimization of Coil Geometry (pictorial)

- Angle for poles for collars, two layers, wedges, gap at midplane (+/- 0.25 mm)



# Optimization of Coil Geometry – ROXIE Input

## Input to coil geometry

Xroxie [/home/gupta/EIC/cable15mm/Q1ApF/05r-Q1APF-b1b-NON-IP10kA.data]

File Edit Display Run

Comment : Q1APF 15mm EIC-LHC-B cable@2K, 30 mm collar RG

Main Options

- 3D geometry (LEND)
- Endspacers (LWEDG)
- Time transient (LPERS)
- Quench simulation (LQUENCH)
- Optimization (LALGO)

Cable data path : /home/gupta/EIC/cable15mm/Q1ApF/roxie-eic.cadata  Browse  View file

2D Options

- Fields & forces in coil (LPEAK)
- Margin to linear Jc-approx. (LINMARG)
- Margin to Jc-fit (LMARG)
- Self field in strands (LSELF)
- Enthalpy margins (LMQE)
- Inductance and energy (LINDU)
- Cable eddy currents (LEDDY)
- Axi-symmetry (for solenoids) (LSOLE)

Block Data 2D

| No | Type | NCab | R | φ | α | Current | Cable name |
|---|---|---|---|---|---|---|---|
| 1 | Cos | 10 | 71 | 0.2017 | 0 | 10000 | EICLHCB2K |
| 2 | Cos | 5 | 71 | 17.518 | 20 | 10000 | EICLHCB2K |
| 3 | Cos | 3 | 71 | 30.897 | 32 | 10000 | EICLHCB2K |
| 4 | Cos | 12 | 87 | 0.1646 | 0 | 10000 | EICLHCB2K |
| 5 | Cos | 9 | 87 | 17.518 | 25 | 10000 | EICLHCB2K |

Midplane half-gap = 0.25 mm (both layers)

Design Variables

Optimization algorithm : 1 Extrem ?

| No | Xl | Xu | Xs | String | Act | N/a |
|---|---|---|---|---|---|---|
| 1 | 1 | 5 | 1.43 | PHIR | 2 | 2 |
| 2 | 10 | 14 | 10.7145 | ALPHR | 2 | 2 |
| 3 | 1 | 9 | 5.0778 | PHIR | 2 | 3 |
| 4 | 6 | 9 | 8.8244 | ALPHR | 2 | 3 |
| 5 | 1 | 7 | 1.3611 | PHIR | 2 | 5 |
| 6 | 12 | 12 | 12 | ALPHR | 2 | 5 |

Edit Cable Data [/home/gupta/EIC/cable15mm/Q1ApF/roxie-eic.cadata]

File Display

**Cable parameters**

Insulation

| No | Name | Radial | Azimut | Comment |
|---|---|---|---|---|
| 1 | BARE | 0 | 0 | BARE |
| 2 | ALLPOLYIL | 0.15 | 0.12 | POLYIMID MB INNER |
| 3 | ALLPOLYOL | 0.15 | 0.13 | POLYIMID MB OUTER |
| 4 | ALLPOLMQY | 0.08 | 0.08 | POLYIMID MQY,MQM |
| 5 | ALLPOLMQ | 0.13 | 0.11 | POLYIMID MQ |

Jc-Fit

| No | Name | Type | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FIT1 | 1 | 3E+09 | 9.2 | 0.57 | 0.9 | 2.32 | 27.04 | 14.5 | 0 |
| 2 | TES1 | 1 | 3E+09 | 9.2 | 0.57 | 0.9 | 2.32 | 27.04 | 14.5 | 0 |
| 3 | GSIFIT | 1 | 3E+09 | 9.2 | 0.7 | 1.57 | 1 | 25 | 14.5 | 0 |
| 4 | SISFIT | 1 | 3E+09 | 9.33517 | 0.68 | 0.8477 | 2.23234 | 25 | 14.5 | 0 |

Filament

| No | Name | fildiao | fildiai | Jc-Fit | Comment |
|---|---|---|---|---|---|
| 1 | TESTI1 | 6 | 0 | TES1 | NBTI INNER CABLES |
| 2 | TESTO1 | 5 | 0 | TES1 | NBTI INNER CABLES |
| 3 | NBTII | 7 | 0 | FIT1 | NBTI INNER CABLES |
| 4 | NBTIO | 6 | 0 | FIT1 | NBTI OUTER CABLES |
| 5 | NB3SN | 22 | 12 | FIT1 | NB2SN TWENTE |

Strand

| No | Name | diam. | cu/sc | RRR | Tref | Bref | Jc@BrTr | dJc/dB | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | STREIC1 | 1.065 | 1.6 | 70 | 1.9 | 10 | 1591 | 500.34 | EIC BRUKER-CERN SCALED,7%DEGRA |
| 2 | STR01 | 1.065 | 1.6 | 70 | 1.9 | 10 | 1433.3 | 500.34 | MB INNER |
| 3 | STR02 | 0.825 | 1.9 | 80 | 1.9 | 9 | 1953 | 550.03 | MB OUTER, MQ |
| 4 | WIRE3 | 0.93683 | 1.6 | 70 | 4.222 | 5 | 2640 | 606.8 | MCS,MCD,MQT? |
| 5 | GSI1STRA | 0.648 | 2.21 | 187 | 4.2 | 5.5 | 2495.24 | 583.898 | GSI001 (RHIC) STRANDS |

Transient

Quench Material Properties

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 @4.2K |
| 3 | EIC3618 | 19.4 | 1.773 | 2.027 | 36 | 115 | 3 | EIC 36 STRAND @1.8K |

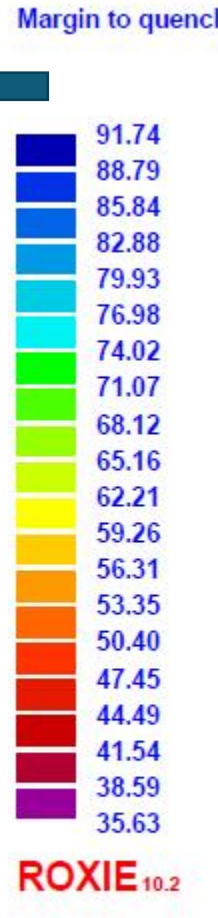
Cable Definition

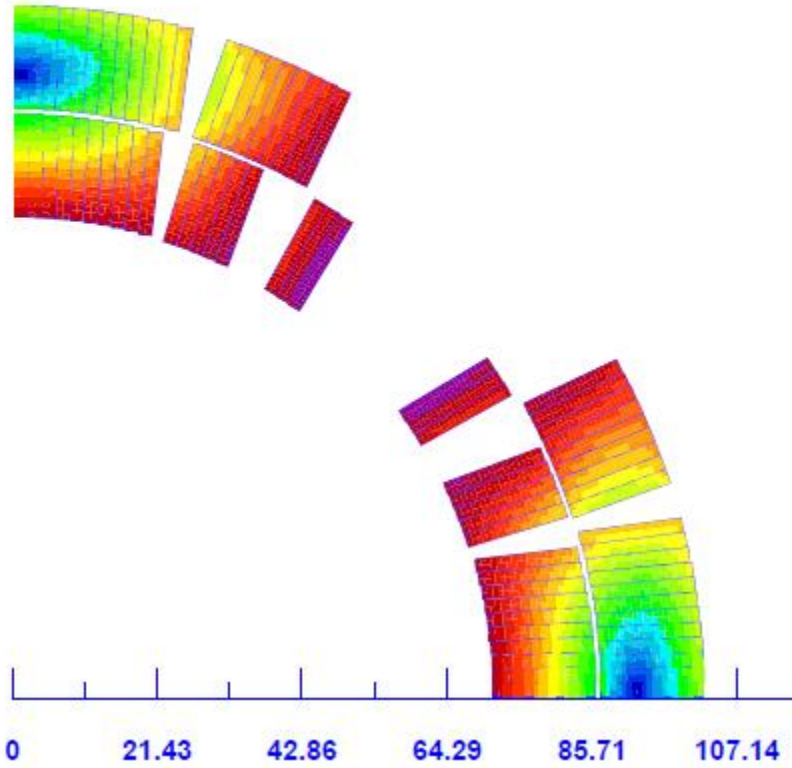
| No | Name | Cable Geom. | Strand | Filament | Insul | Trans | Quench Mat. | T_o | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | EICLHCB2K | EICLHCB | STREIC1 | NBTII | ALLPOLYIL | TRANS1 | NONE | 2 | LHC INNER FOR EIC IR Dipole@2K |
| 2 | EICLHCQ2K | EICLHCQ | STREIC1 | NBTII | ALLPOLYIL | TRANS1 | NONE | 2 | LHC INNER FOR EIC IR Quad @2K |
| 3 | LHCIN42K | EICLHC01 | STREIC1 | NBTII | ALLPOLYIL | TRANS1 | NONE | 4.2 | LHC INNER FOR EIC @4.2K |
| 4 | YELLONIN | CABLE01 | STR01 | NBTII | ALLPOLYIL | TRANS1 | NONE | 1.9 | V6-1 DESIGN DIPOLE INNER |
| 5 | YELLONOU | CABLE02 | STR02 | NBTIO | ALLPOLYOL | TRANS1 | NONE | 1.9 | V6-1 DESIGN DIPOLE OUTER |

# Quench Margin in the X-section of the Q2pF @2K

```
MAIN FIELD (T) ..........................................    -3.384763
MAGNET STRENGTH (T/(m^(n-1)) ............................     -79.8293


BLOCK NUMBER ..............................................          23
PEAK FIELD IN CONDUCTOR  156 (T) ..........................      6.3964
CURRENT IN CONDUCTOR 156 (A) ..............................  10000.0000
LOWEST FIELD IN CONDUCTOR  154 (T) ........................      5.0786
SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ....................   1042.3804
COPPER CURRENT DENSITY (A/MM2) ............................    651.4877
PERCENTAGE ON THE LOAD LINE ...............................     64.3614
QUENCHFIELD (T) ...........................................      9.9383
TEMPERATURE MARGIN TO QUENCH (K) ..........................      3.2390
PERCENTAGE OF SHORT SAMPLE CURRENT ........................     28.3054
```




- Operational margin = 100/64.4 = >55%

Recall 75 T/m meant and estimated integral of 79.3 T/m. We have a healthy margin

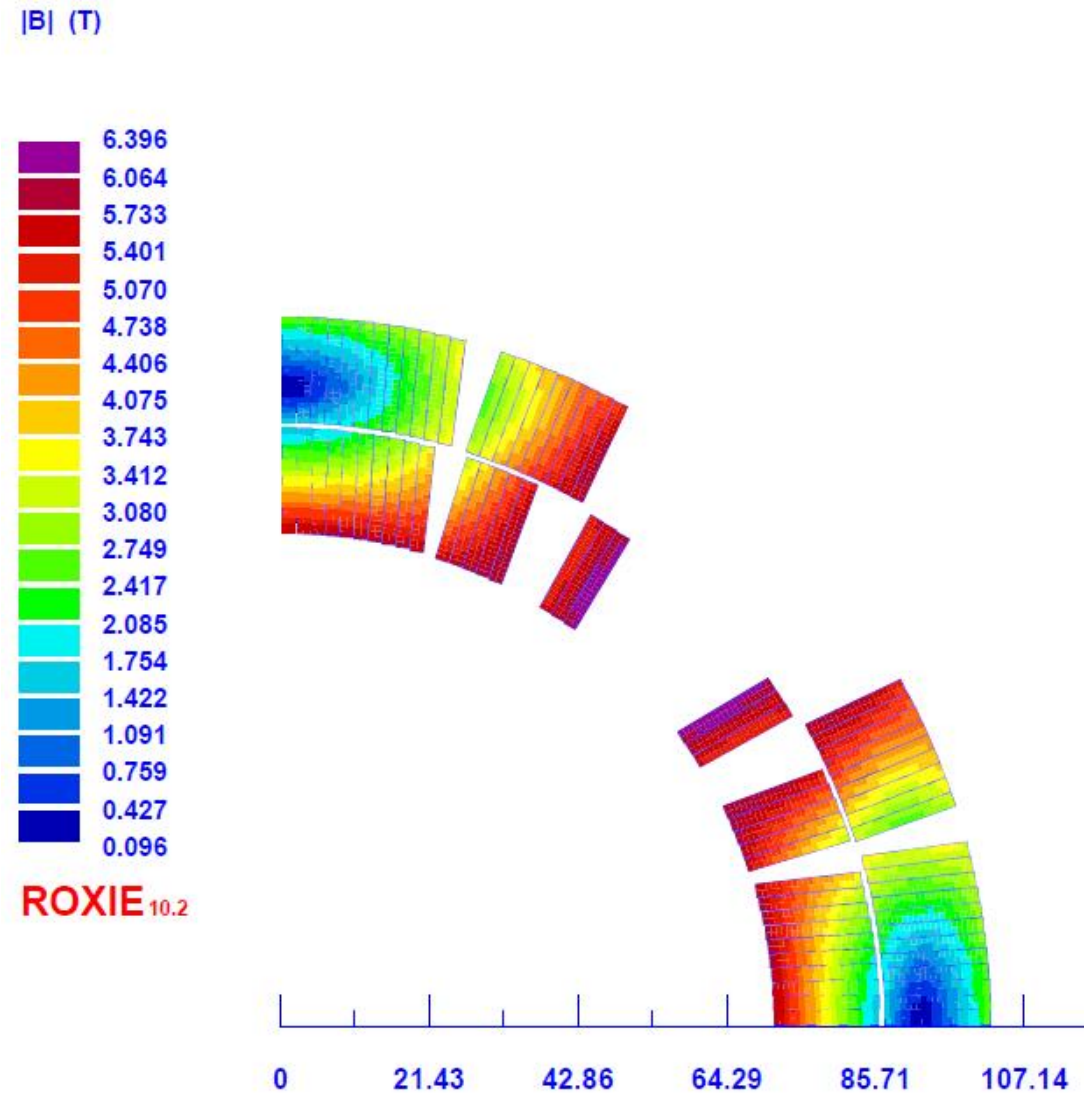
**Should be able to operate @80 T/m (~84.6 T/m in body), with a good margin**

# Quench Margin in the Current X-section of the Q1ApF

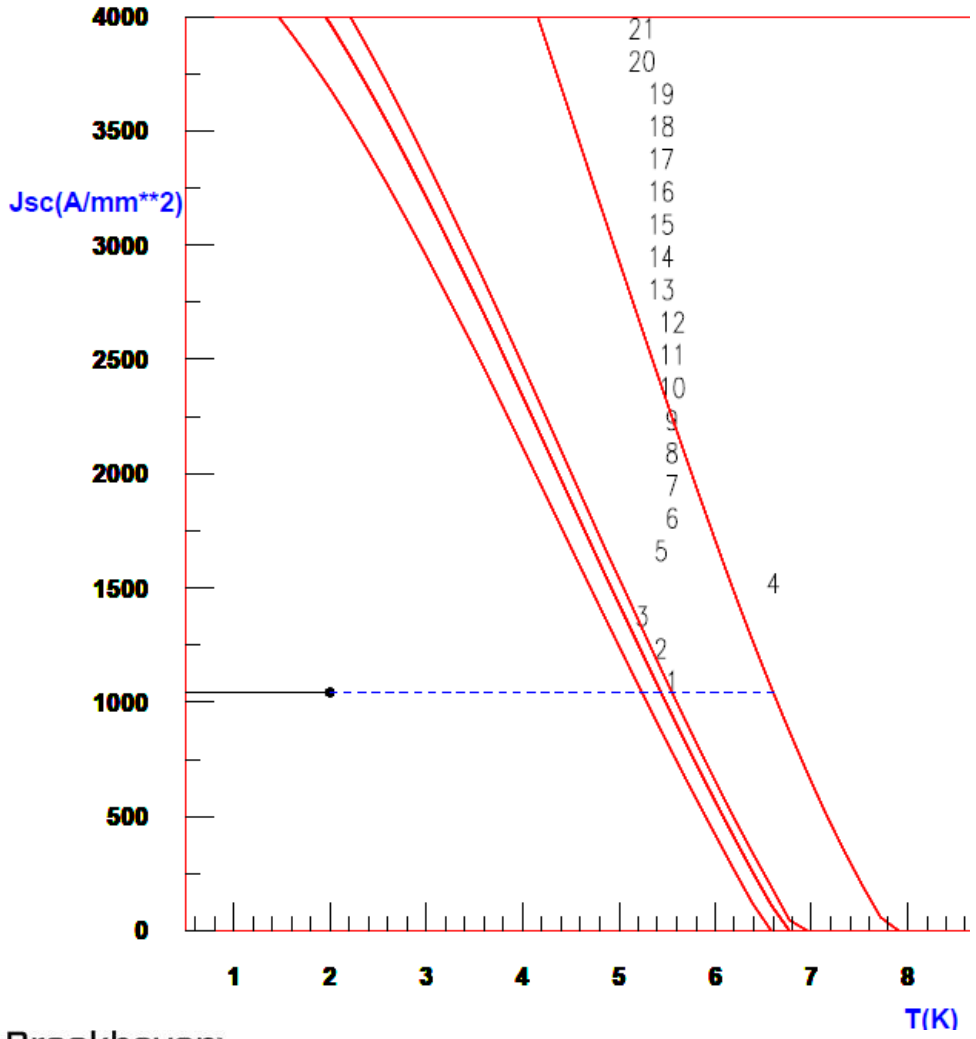
## Peak Field Enhancement

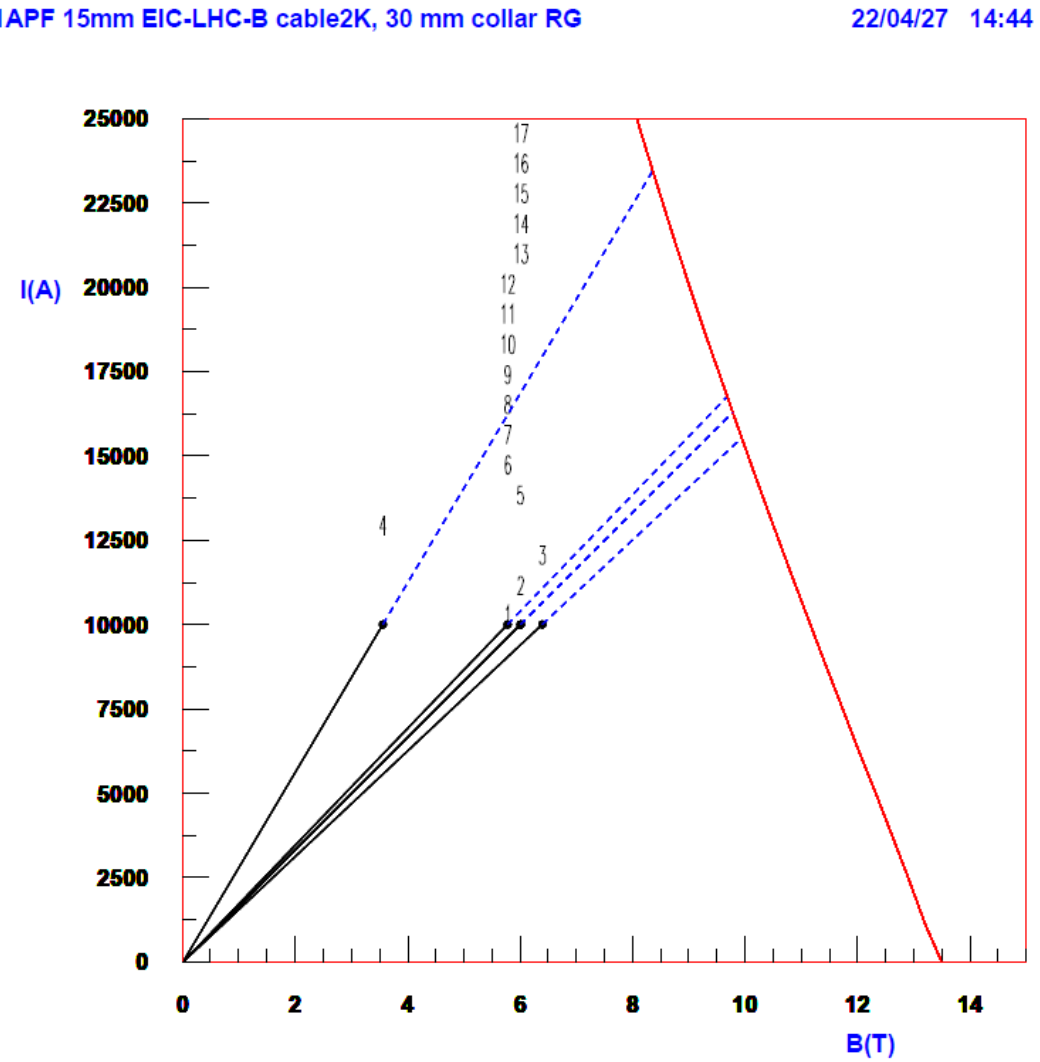
- Field gradient = 79.8 T/m (@10kA)
- Coil Radius = 71 mm
- Computed midplane field at coil radius = 0.071 * 79.83 = 5.668 T
- Peak field enhancement = 6.396/5.668 = 12.8%

**Making outer layer smaller than inner layer reduces peak field significantly**



# Quench Margin in the Current X-section of the Q1ApF at 2 K

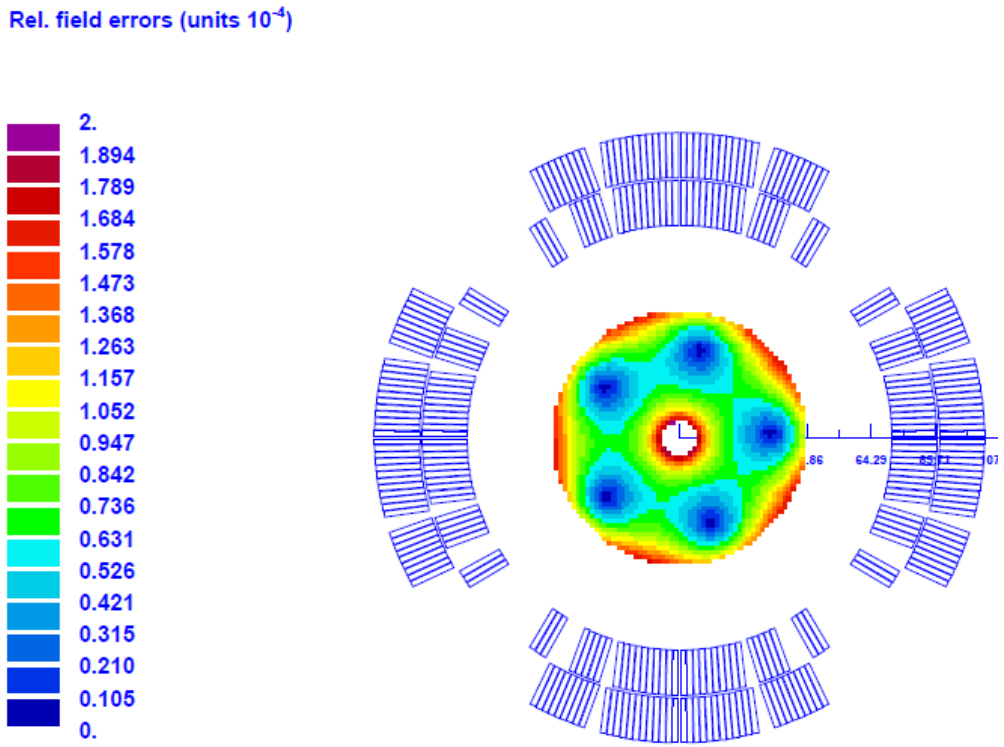


# Field Quality (Geometric Harmonics @2kA)

**GOAL: Obtain low field harmonics in a geometry which is good mechanically**

**Field quality at 2kA**




```
HARMONIC ANALYSIS NUMBER ..............................          1
MAIN HARMONIC ..........................................          2
REFERENCE RADIUS (mm) ..................................      42.4000
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 .....................   0.6637E-05
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

MAIN FIELD (T) .........................................    -0.684996
MAGNET STRENGTH (T/(m^(n-1)) ...........................     -16.1556

NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:     -0.08823  b 2:  10000.00000  b 3:     -0.00288
b 4:     -0.00176  b 5:     -0.00101  b 6:     -0.00053
b 7:     -0.00004  b 8:     -0.00001  b 9:     -0.00000
b10:      0.00002  b11:     -0.00000  b12:      0.00000
b13:     -0.00000  b14:     -0.02185  b15:     -0.00000
b16:     -0.00000  b17:      0.00000  b18:      0.00290
b19:      0.00000  b20:     -0.00000  b
```

Note: Above plot is at 10 kA

➢ **All geometric harmonics are small**

# Saturation-induced Harmonics

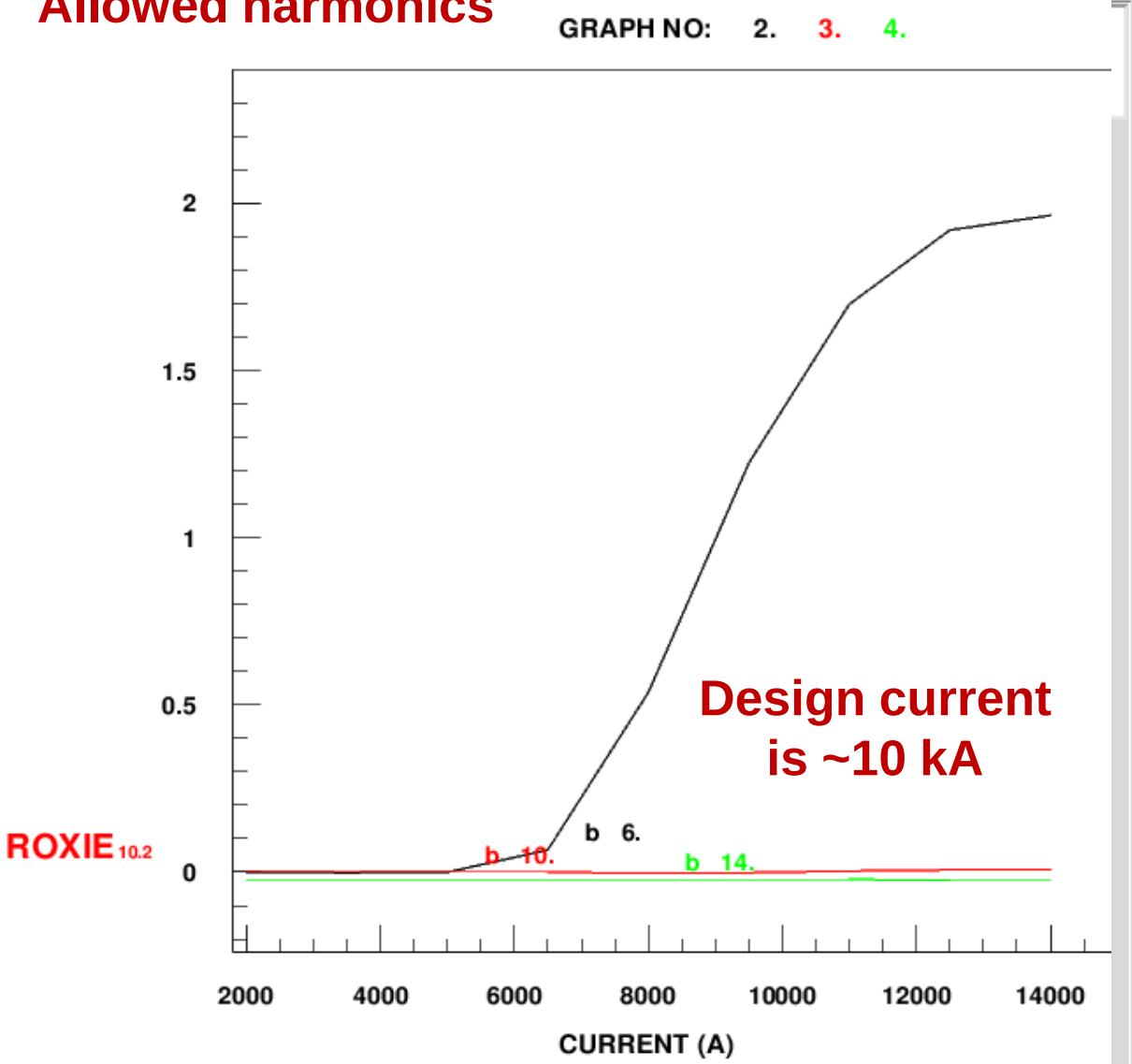
**(examine the impact of non-liner properties of iron at high fields)**

**Current nominal operating range of EIC (Holger Witte): 41 GeV to 275 GeV**
**Minimum to Maximum Ratio: 1 to 6.7; Maximum current: ~10 kA**

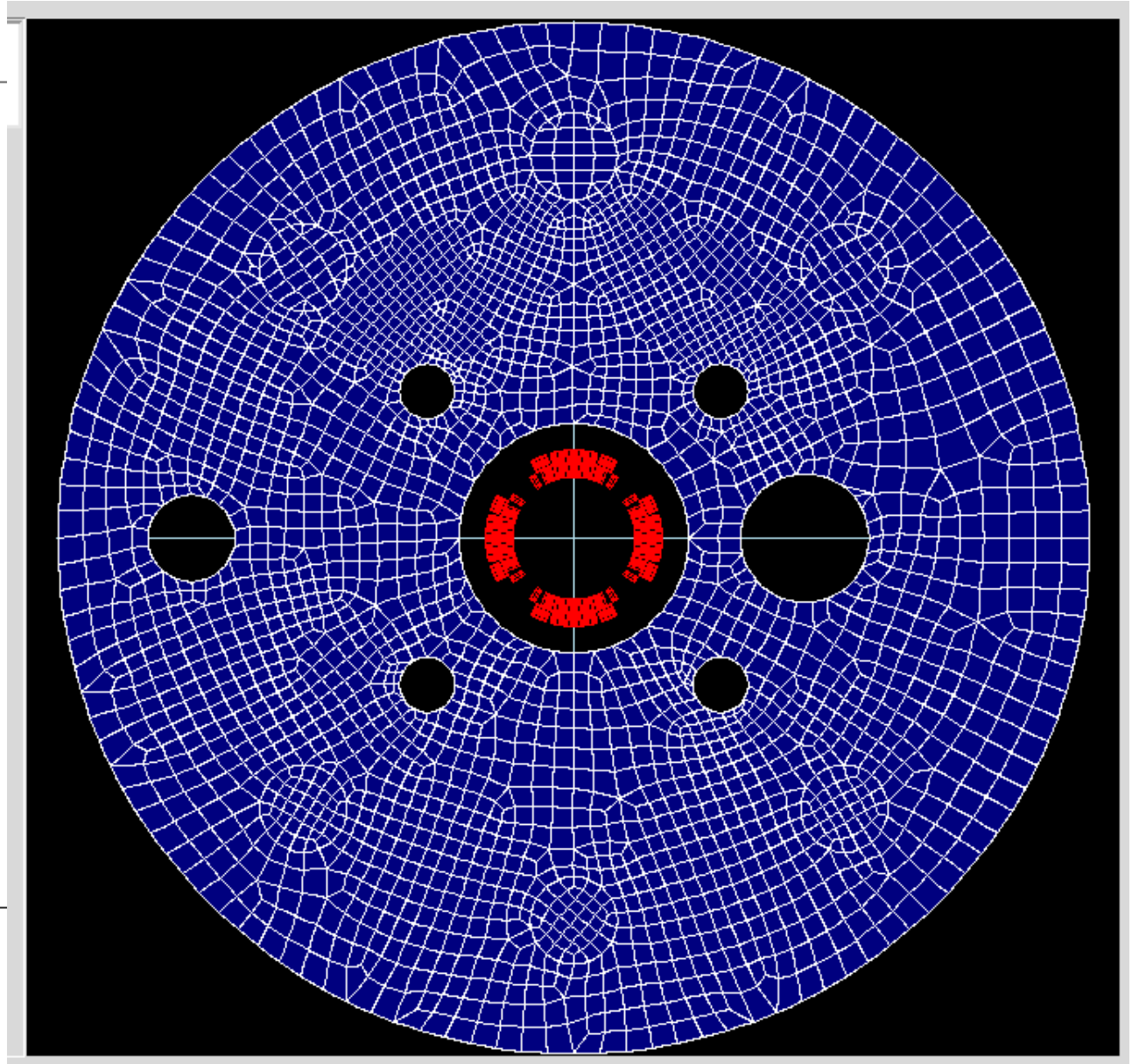
**(Note: Optimization of yoke with holes, and onion ring, etc. not done yet)**

# Field quality in operating range (saturation-induced harmonics)

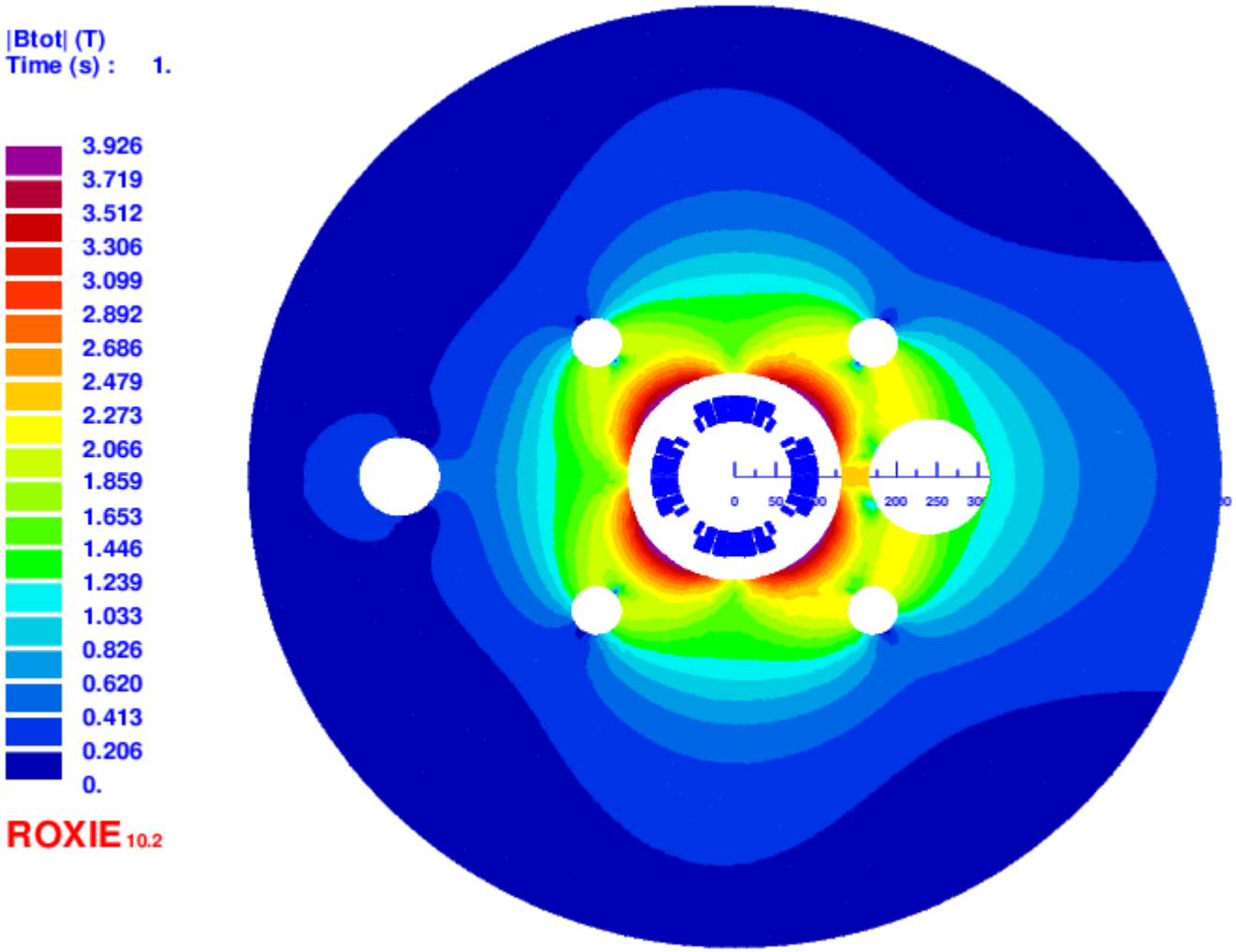
## Allowed harmonics



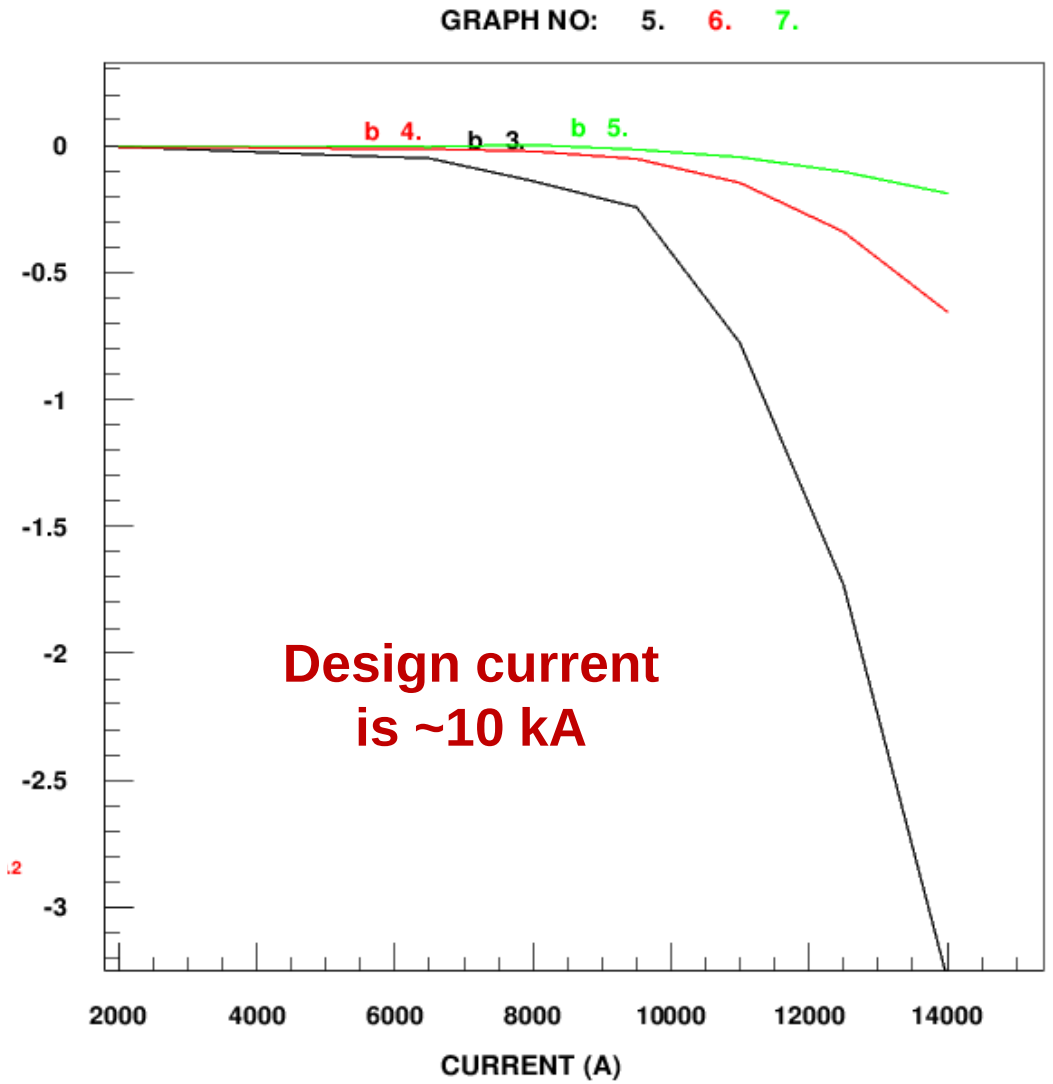

**Design current is ~10 kA**



# Field quality in operating range (saturation-induced harmonics)




**Non-allowed harmonics**




**Design current is ~10 kA**

Note: difference in field between left and right at the midplane of yoke