Q1ApF and Q1BpF Design for 4K Operation

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BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

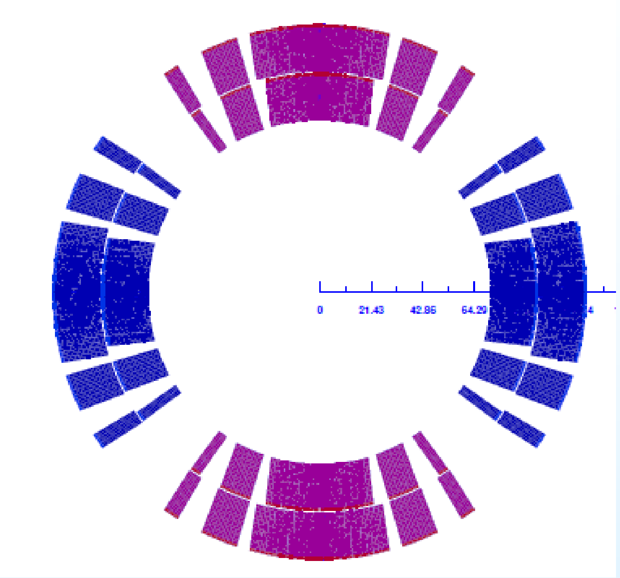
Overview

- **Goal: Optimize the design of Q2B, Q1BpF and Q1Apf to allow 4K operation**
- **In all cases, peak field (margin), field quality and field in the electron beam region are being optimized together**
- **Q1BpF symmetric yoke design**
- **Q1ApF yoke optimization to reduce field in electron beam region**
- **Several cases examined; only one each of above will be presented**
- **Q1Apf & Q1BpF system optimization – tweak combination to balance margin**
- **Next task?**

Field Harmonics in Q1BpF

A reasonably good field quality is obtained with a good mechanical design (coil radius 71 mm)

(all harmonics <1 unit)



Gradient 72.6 T/m at ~9.3 kA

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REFERENCE RADIUS (mm) ........   36.0

MAGNET STRENGTH (T/(m^(n-1)) ......................     72.6821

NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:     -0.77119  b 2:  10000.00000  b 3:     -0.17439
b 4:     -0.03551  b 5:     -0.01107  b 6:     -0.18329
b 7:     -0.00119  b 8:     -0.00028  b 9:     -0.00008
b10:      0.17361  b11:     -0.00001  b12:     -0.00000
b13:     -0.00000  b14:      0.04157  b15:     -0.00000
b16:     -0.00000  b17:      0.00000  b18:     -0.00097
b19:     -0.00000  b20:     -0.00000  b
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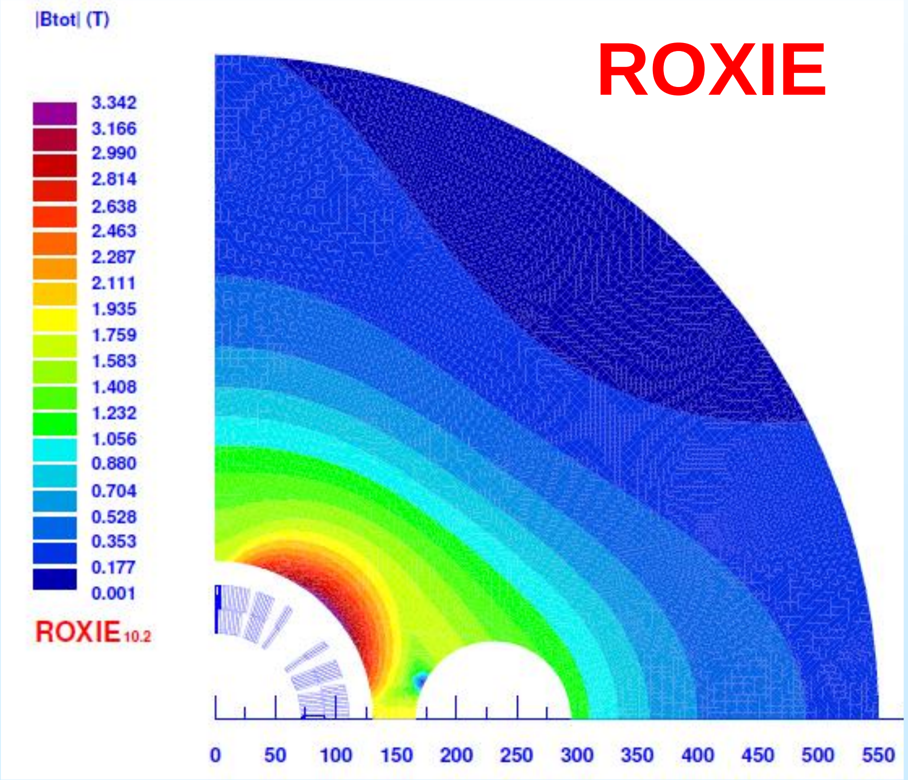
Q1A Yoke (shown last time)

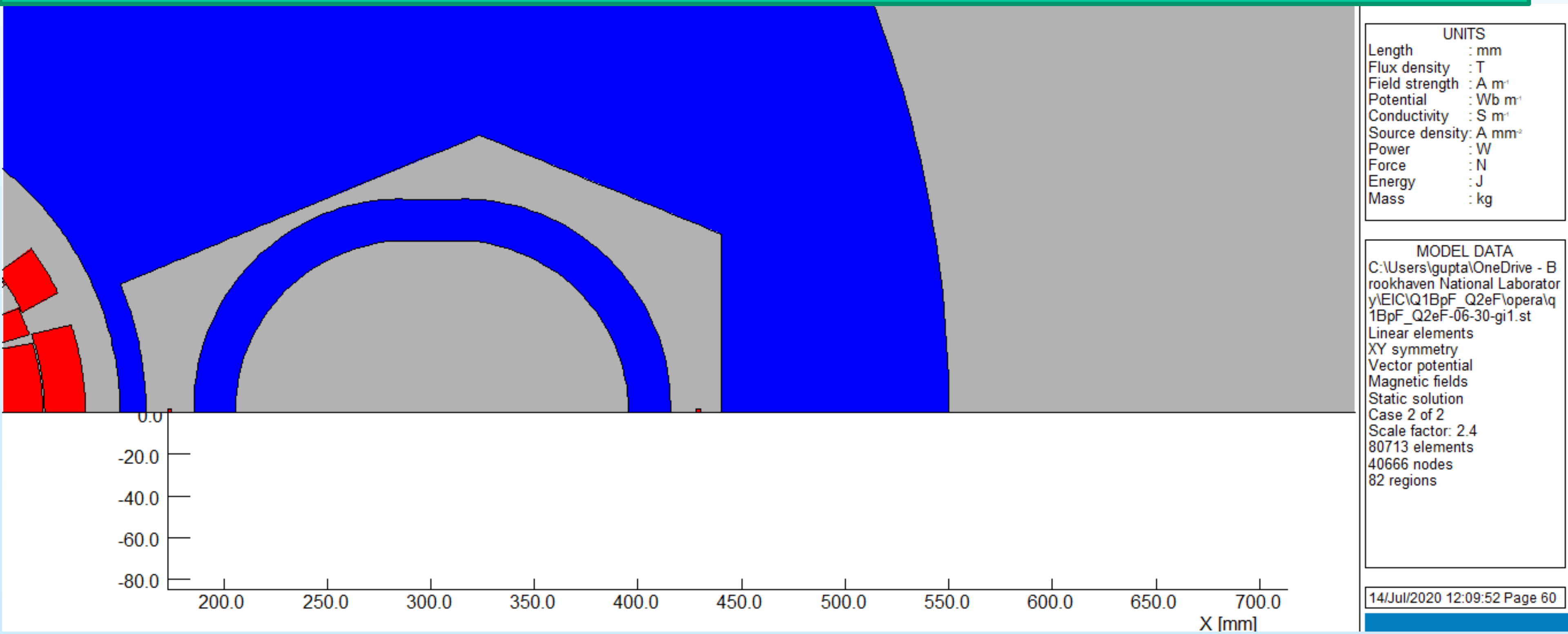
Yoke: ir = ~131 mm; or = 550 mm (or 500 mm)
Hole@ x = 230.5 mm to 259 mm
Radius of hole = 44.6 & 58.4 mm (+20 mm for electron beam)
Collar width = ~20 mm



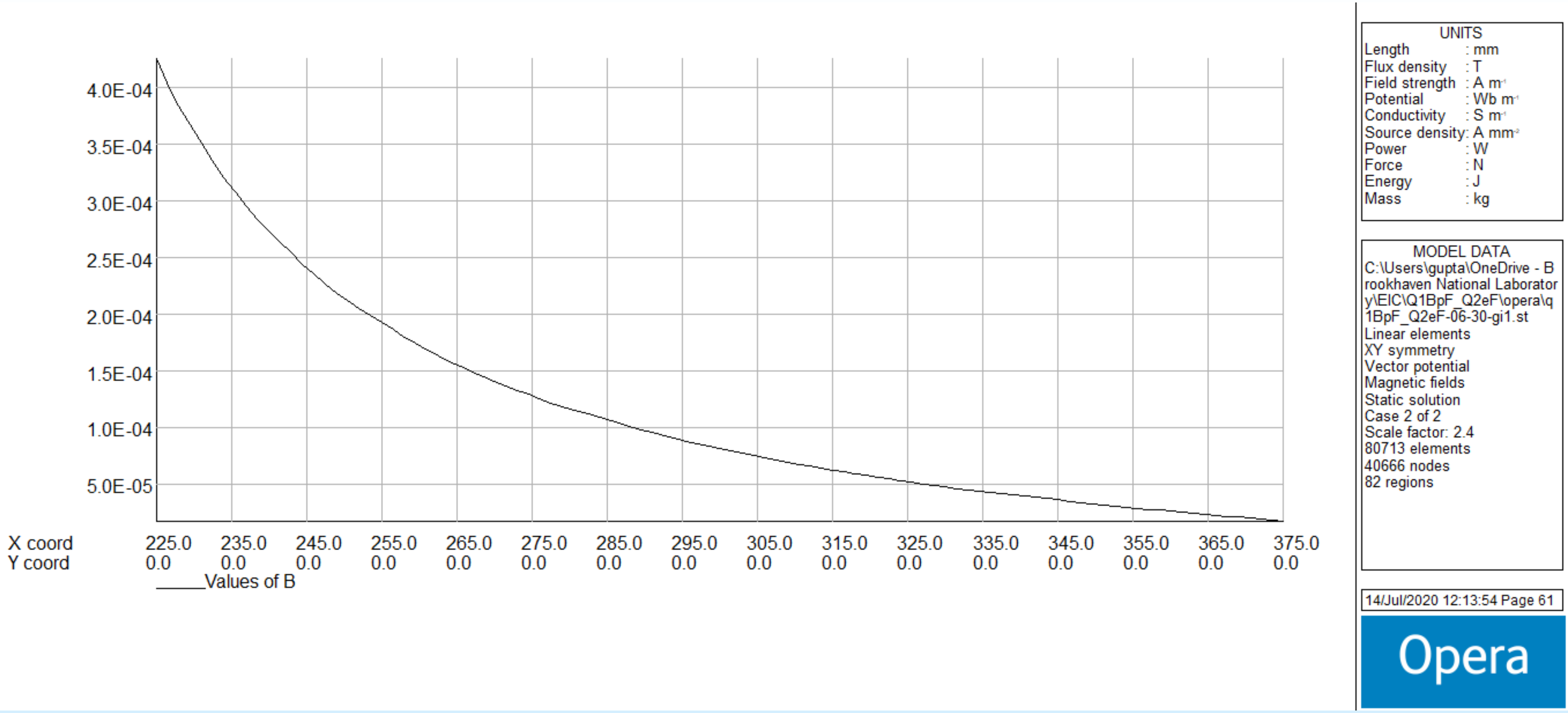
Today's presentation
Reduce field in the electron beam region

Shielding Solution that Worked in Q1B

Path of flux lines navigated with cutout in yoke and small coils on the two side of yoke over e-beam region added to further navigate flux lines (and reduce saturation) to significantly reduce field in the e-beam region



Two order of magnitude reduction in field in e-beam region of Q1B

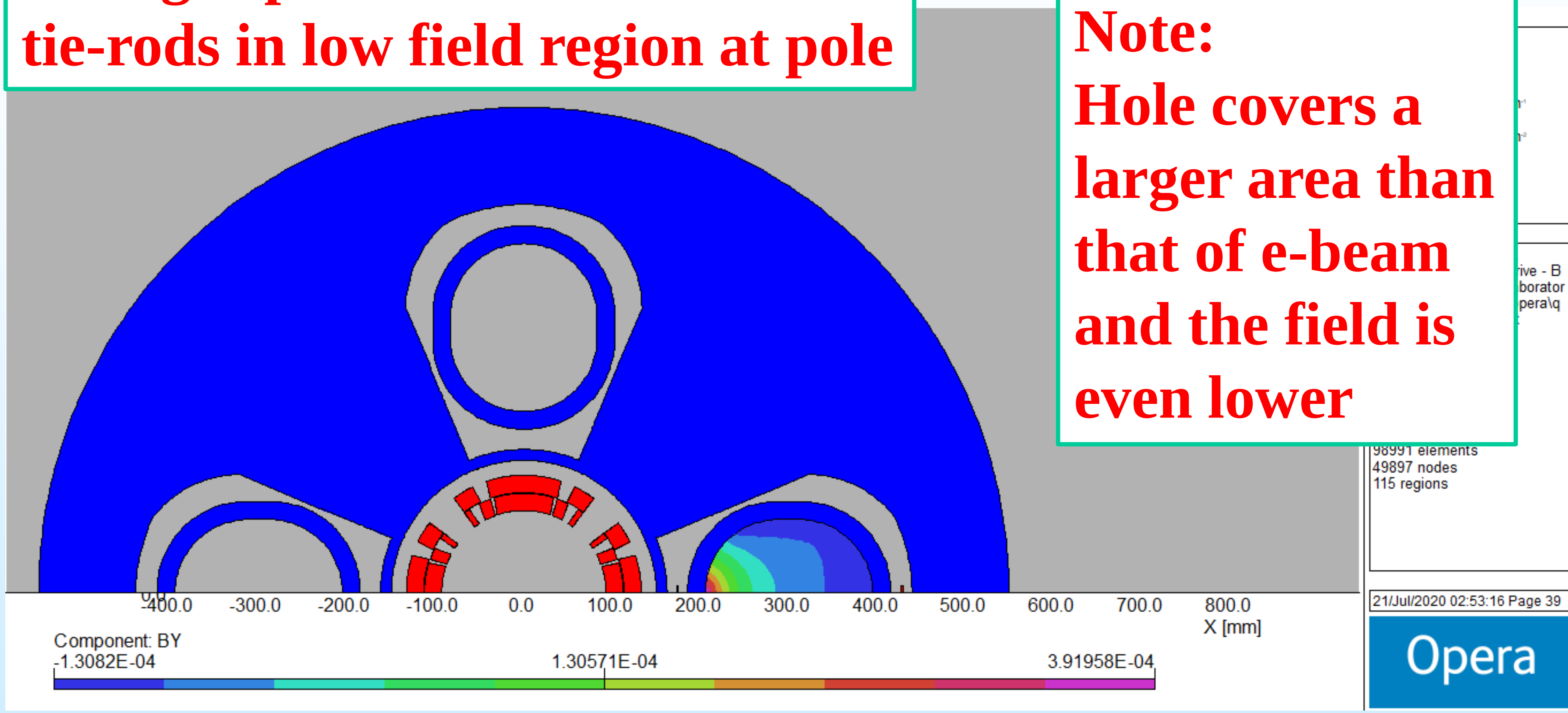


Such fields can be shield with mu-metal, etc.

Quadrupole Symmetric Yoke of Q1B

Enough space for holes for tie-rods in low field region at pole

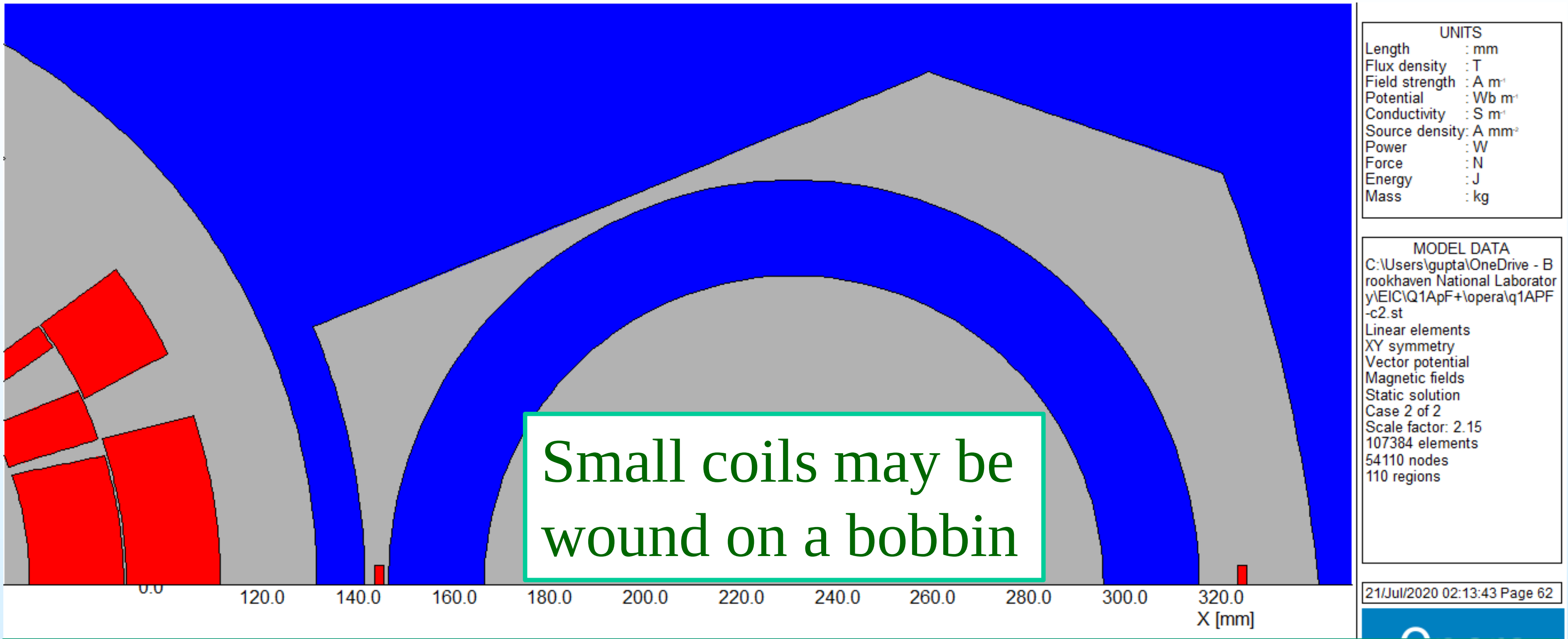
Note: Hole covers a larger area than that of e-beam and the field is even lower



- It works. Field in the e-beam region ~10^{-4}
- But it may or may not be the best solution

Yoke Design of Q1A for a low field e-beam region

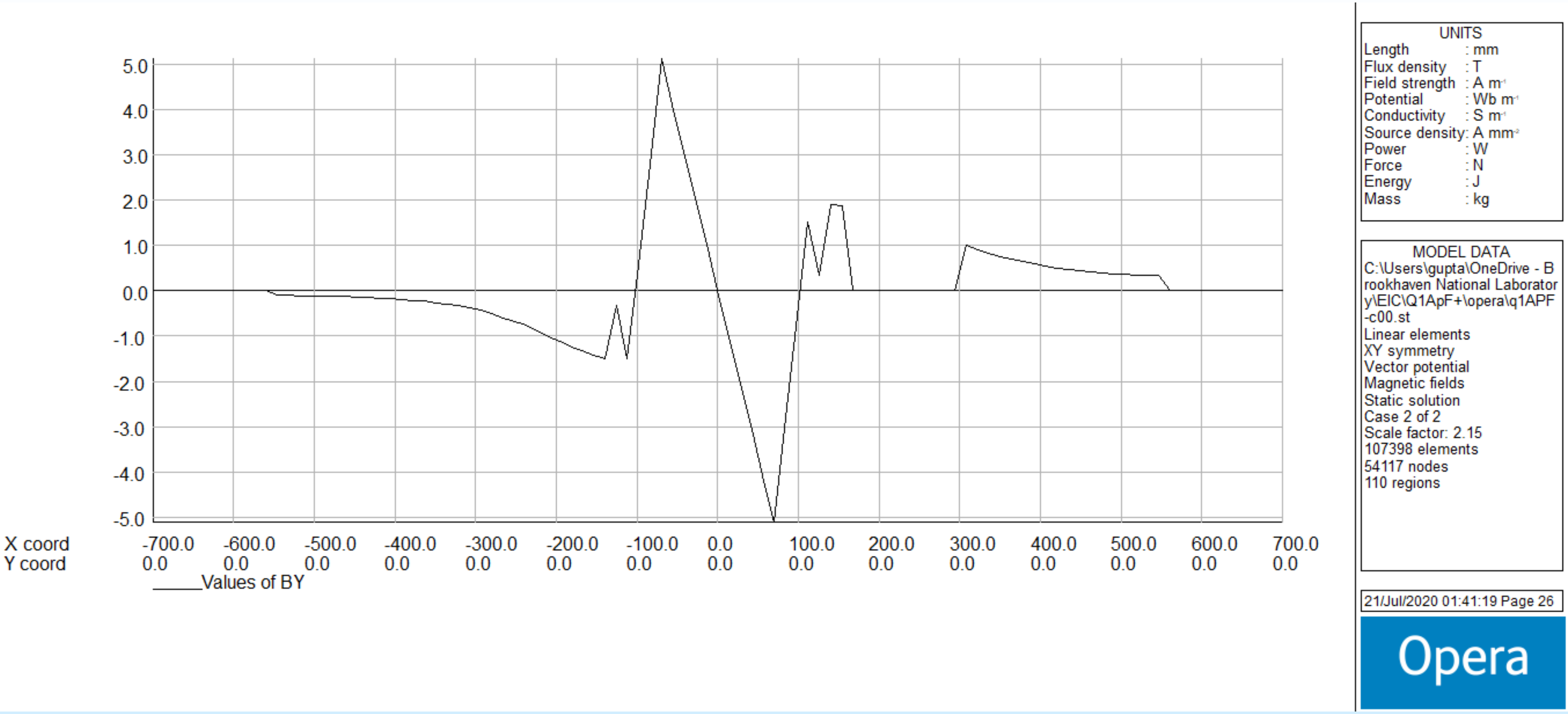
Optimized Q1A Yoke with Small Coil (same technique that worked in Q1B)



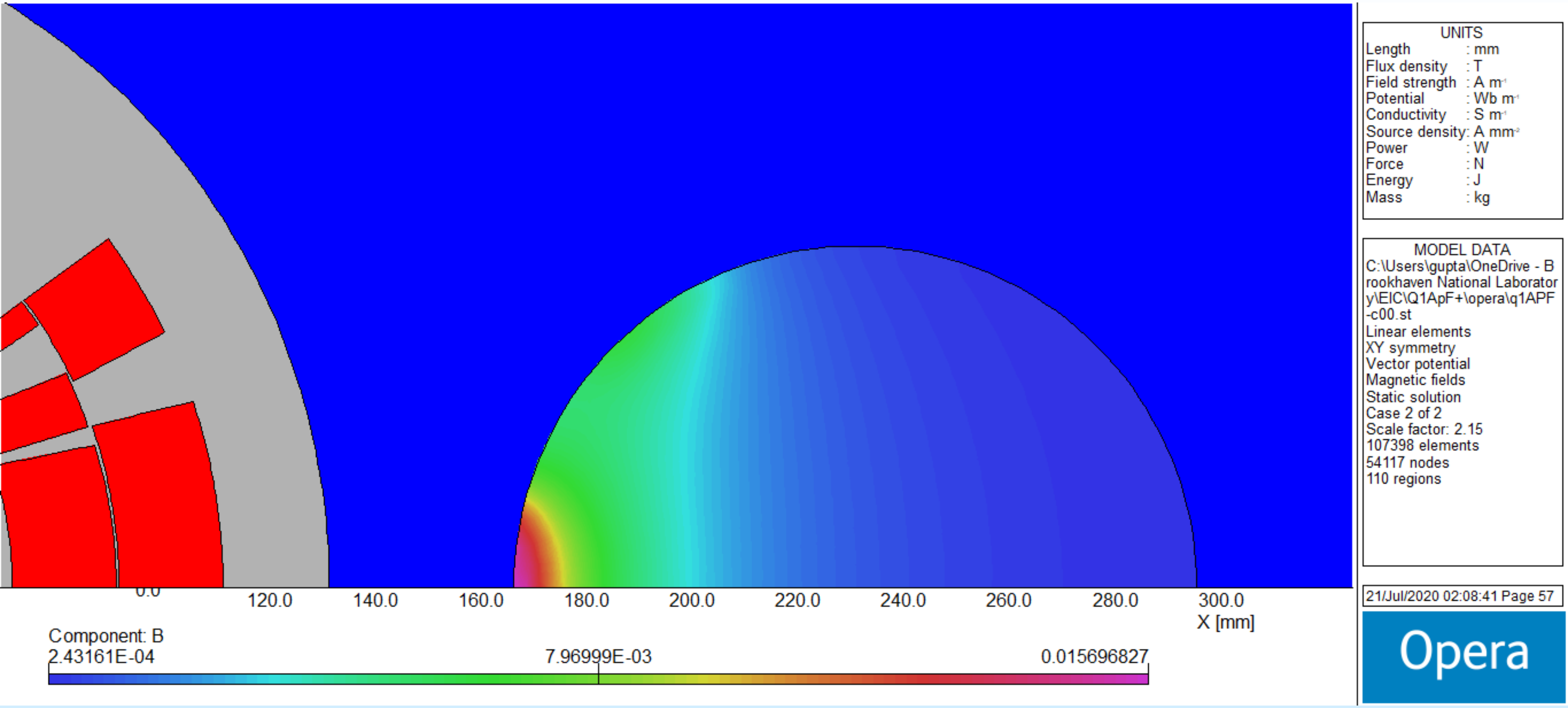
Small coils may be wound on a bobbin

Path of flux lines navigated with cutout in yoke and small coils on the two side of yoke over e-beam region added to further navigate flux lines (and reduce saturation) to significantly reduce field in the e-beam region

Original Case (nothing done)

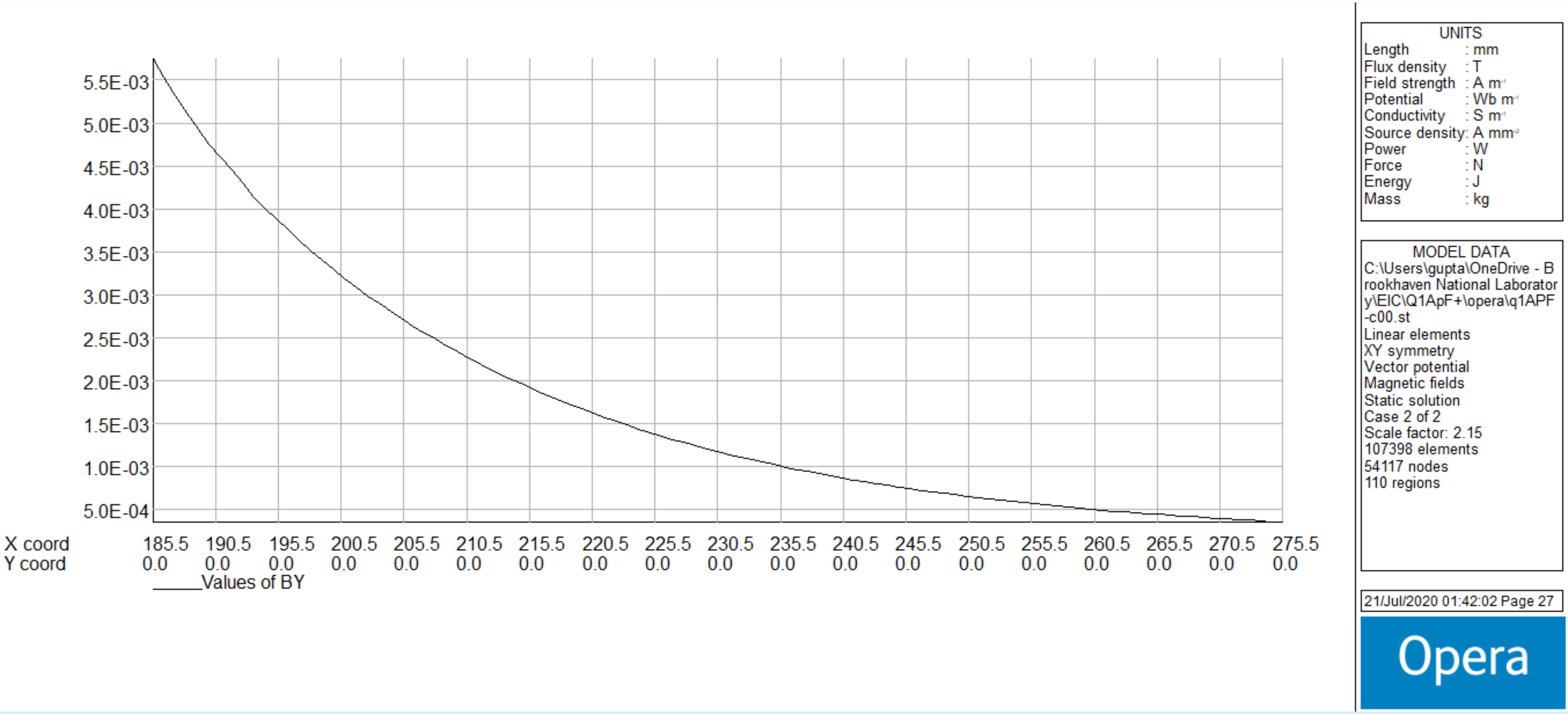


Original Case (nothing done)



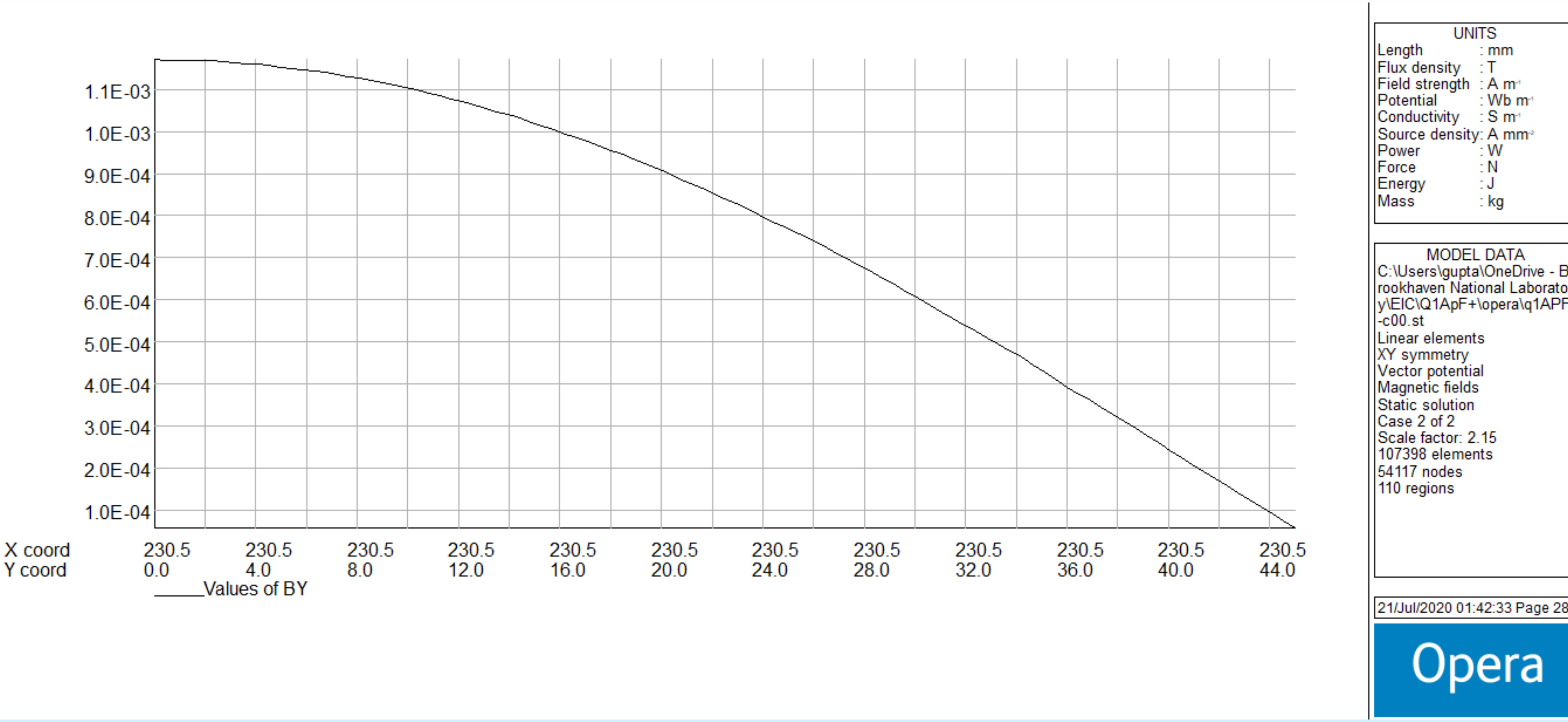
Very high field in electron beam region

Original Case (nothing done)



Very high field in electron beam region

Original Case (nothing done)



Very high field in electron beam region

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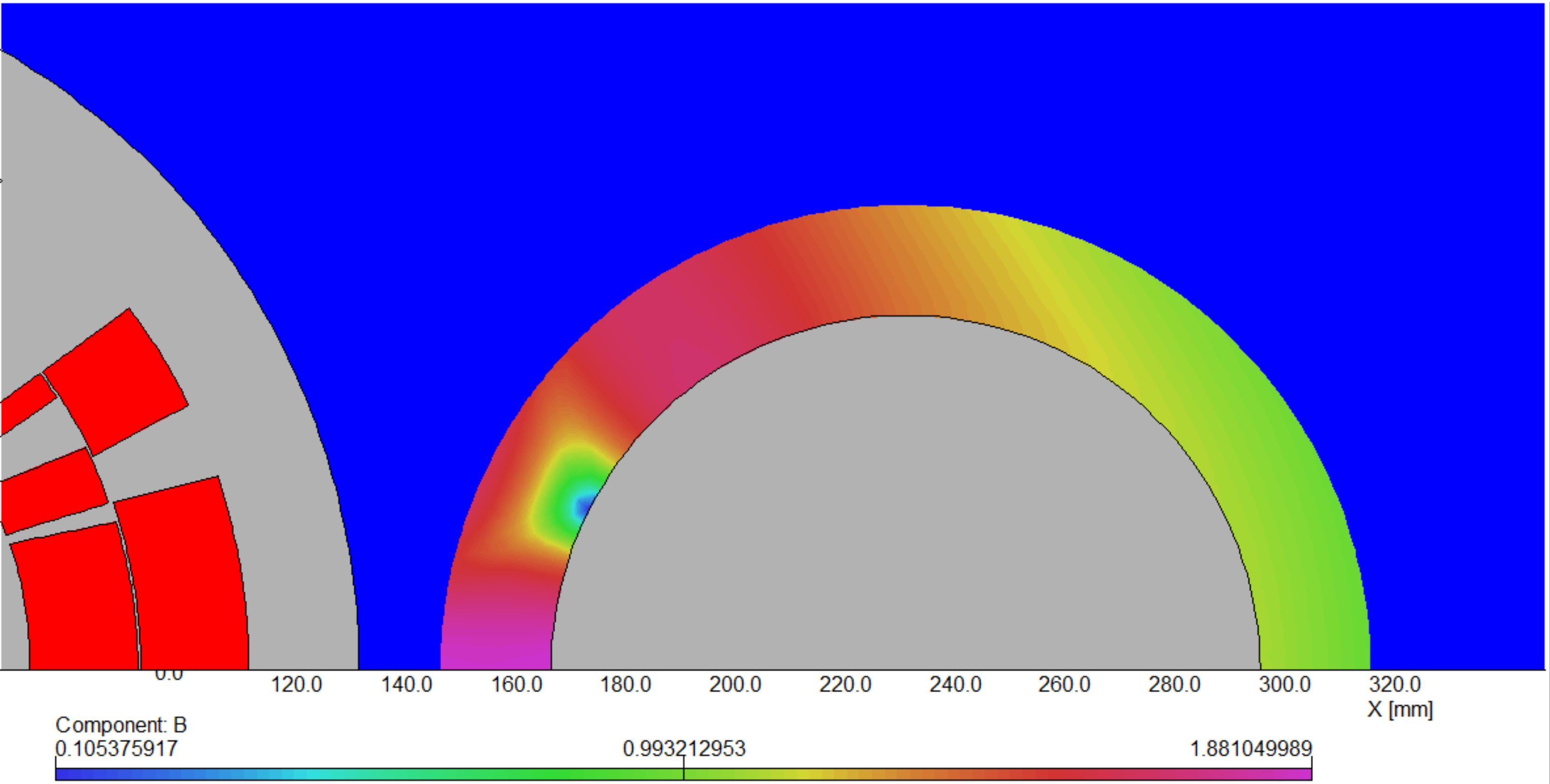

UNITS
Length : mm
Flux density : T
Field strength : A m⁻¹
Potential : Wb m⁻¹
Conductivity : S m⁻¹
Source density: A mm⁻²
Power : W
Force : N
Energy : J
Mass : kg

MODEL DATA
C:\Users\gupta\OneDrive - Brookhaven National Laboratory\EIC\Q1ApF+\opera\q1APF-c00.st
Linear elements
XY symmetry
Vector potential
Magnetic fields
Static solution
Case 2 of 2
Scale factor: 2.15
107398 elements
54117 nodes
110 regions

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Opera

Yoke around electron beam region highly saturated

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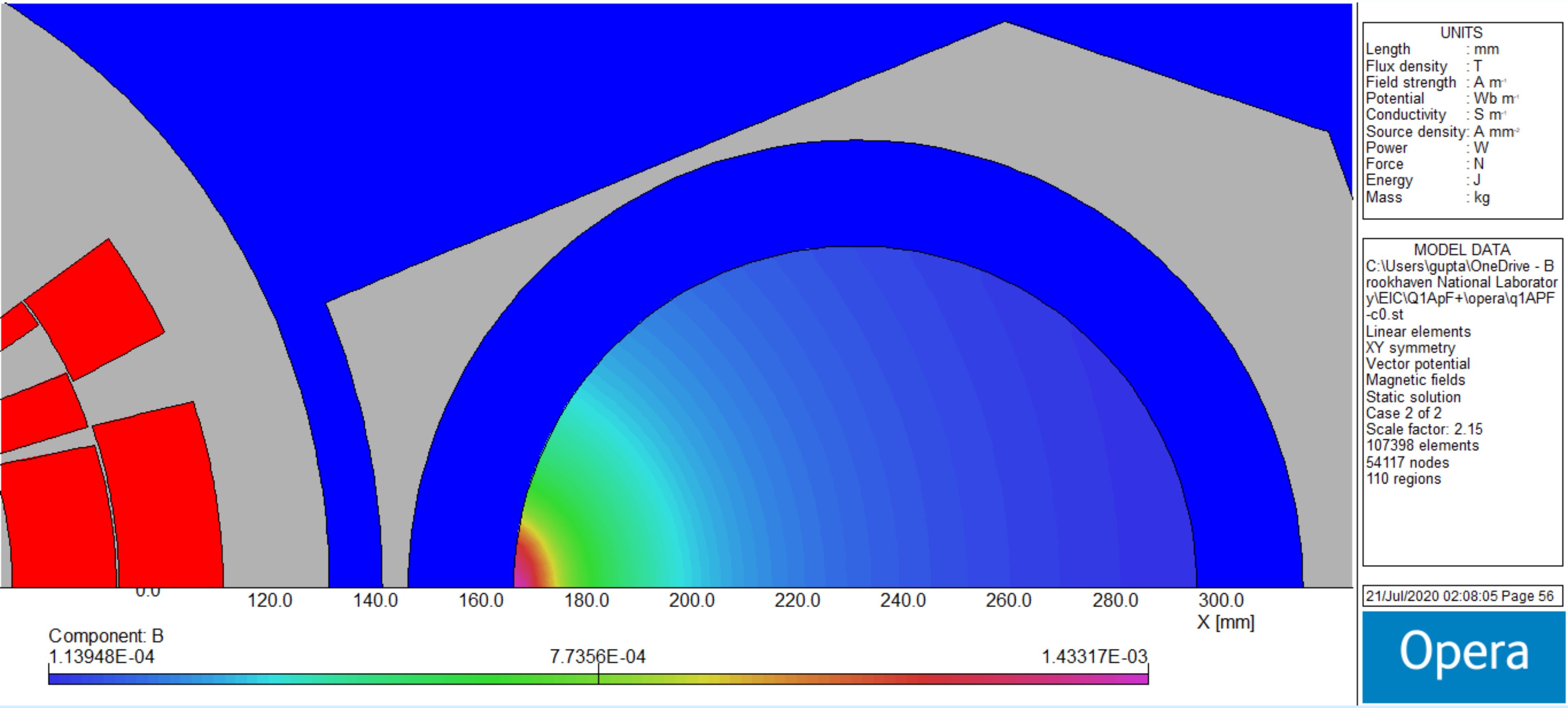
Cutout in the Yoke of Q1A



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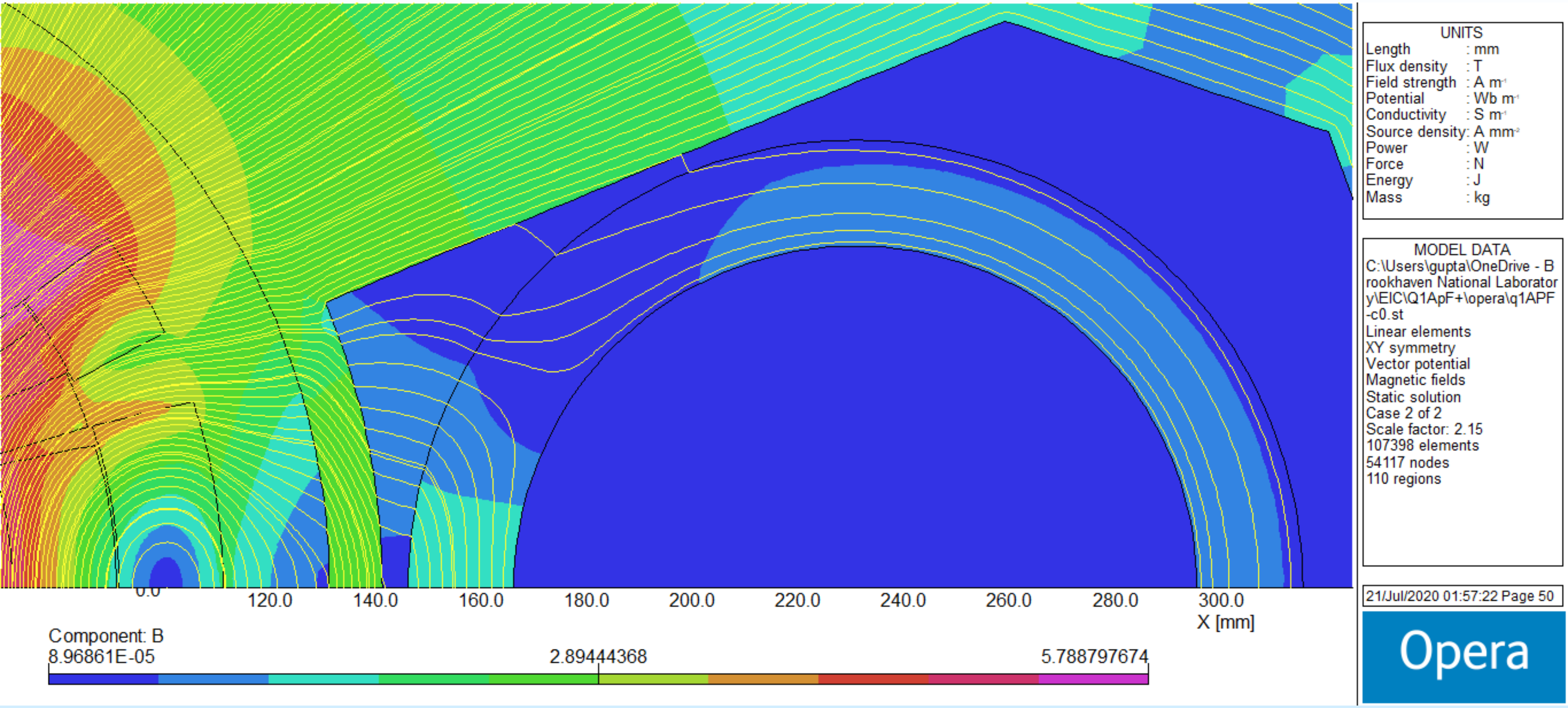

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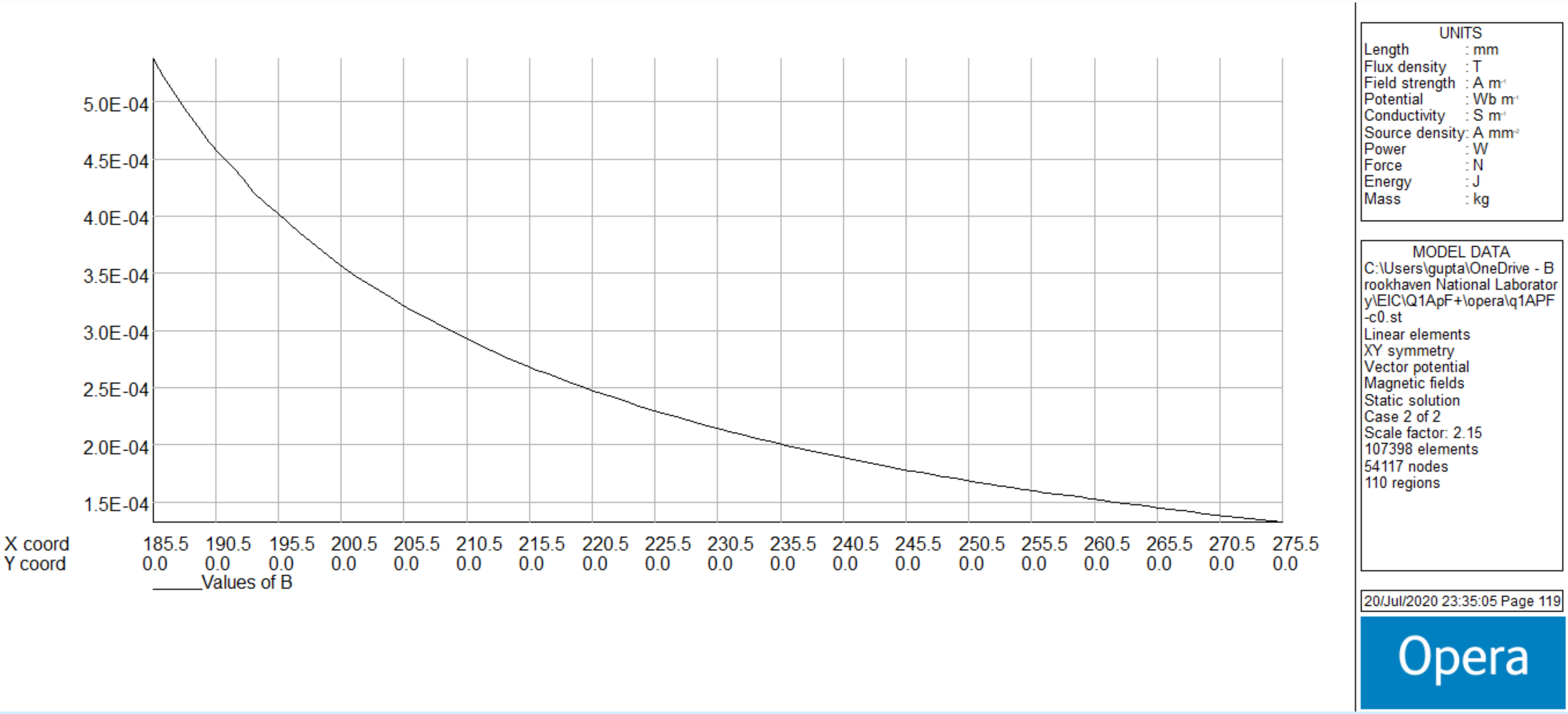

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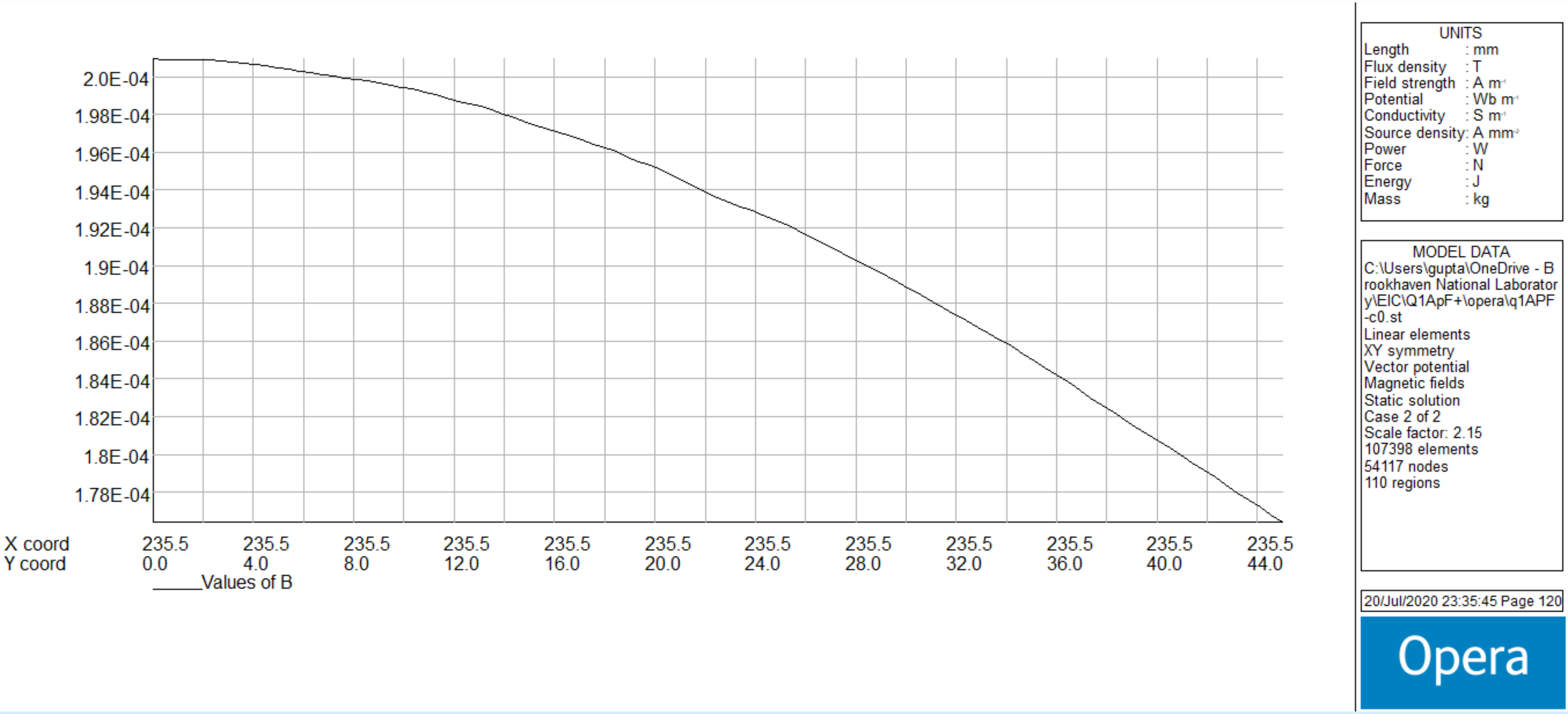

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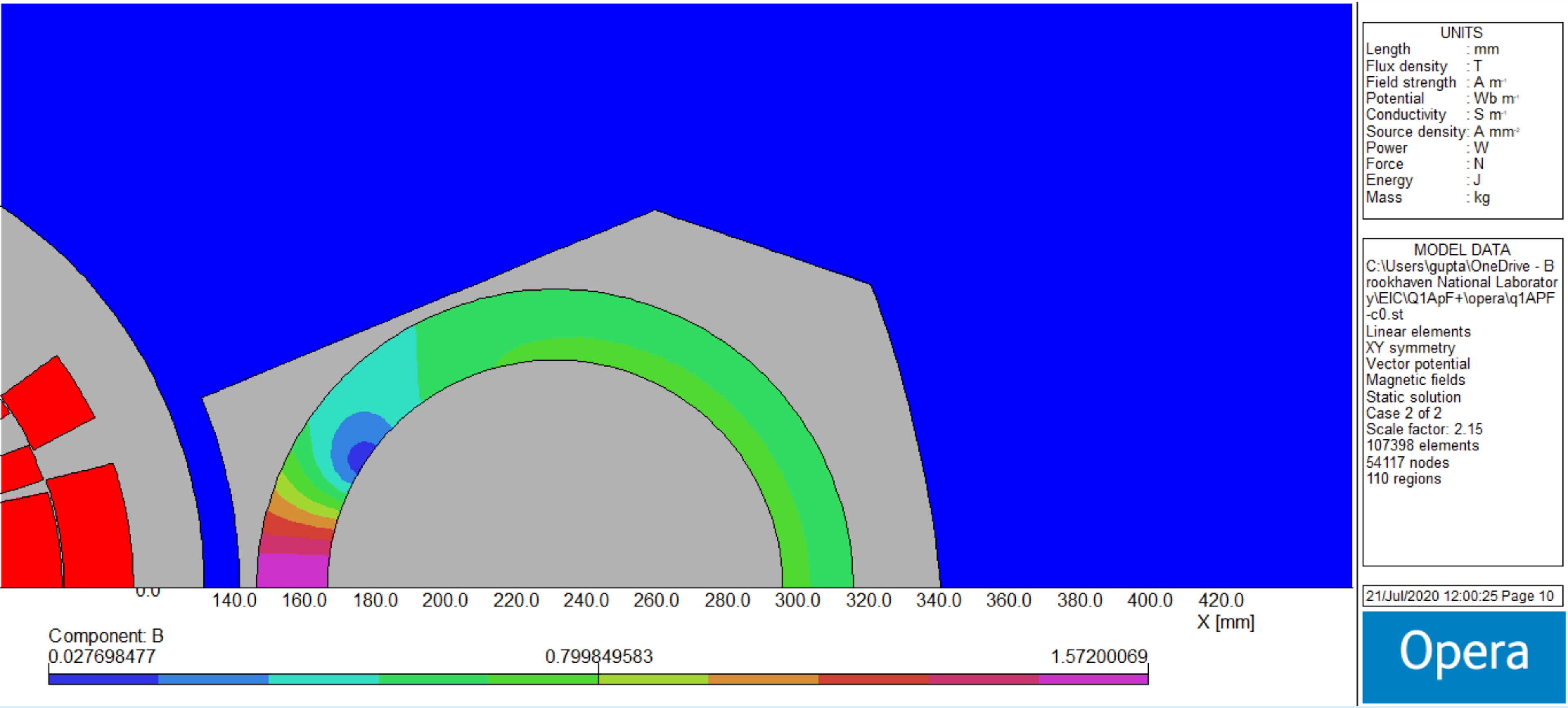

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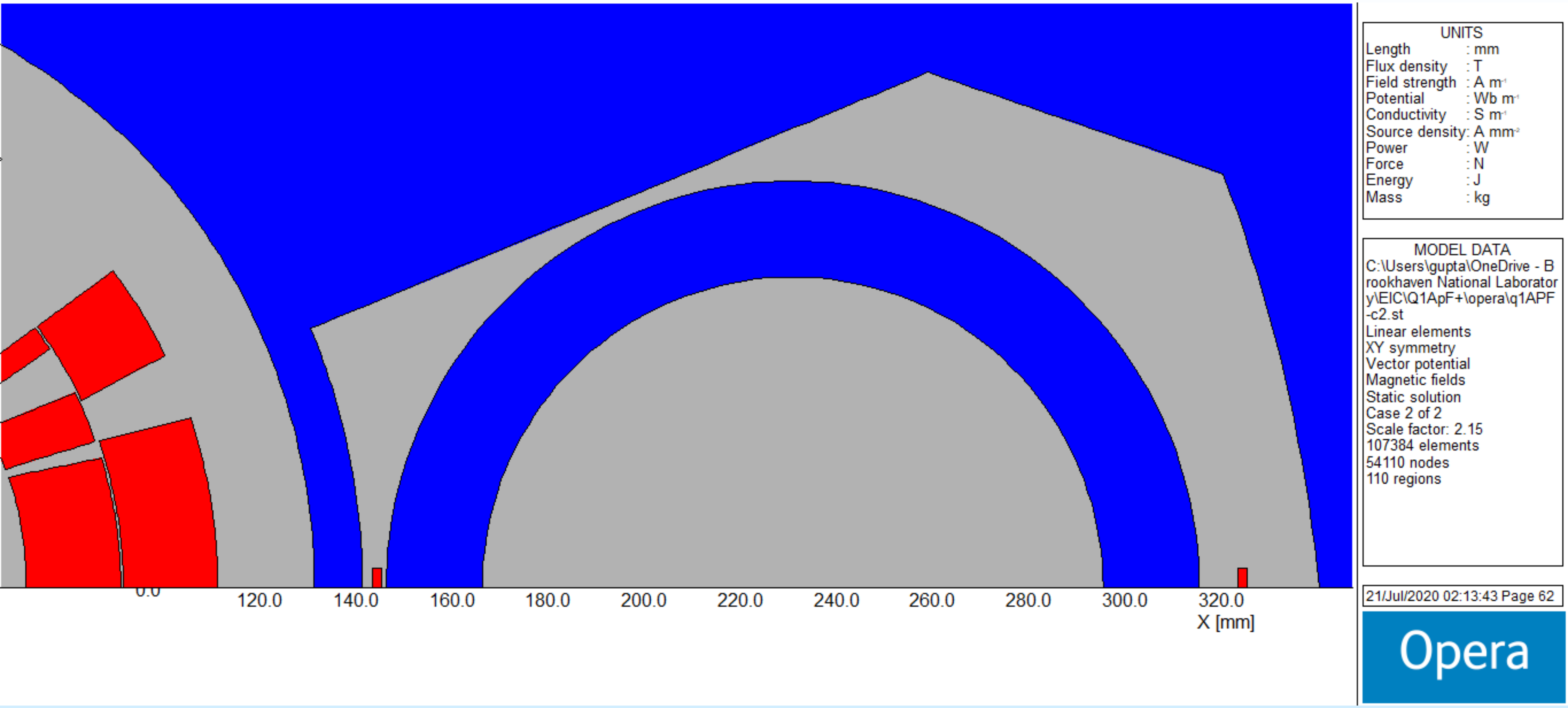
Cutout and Small Coil in Q1A



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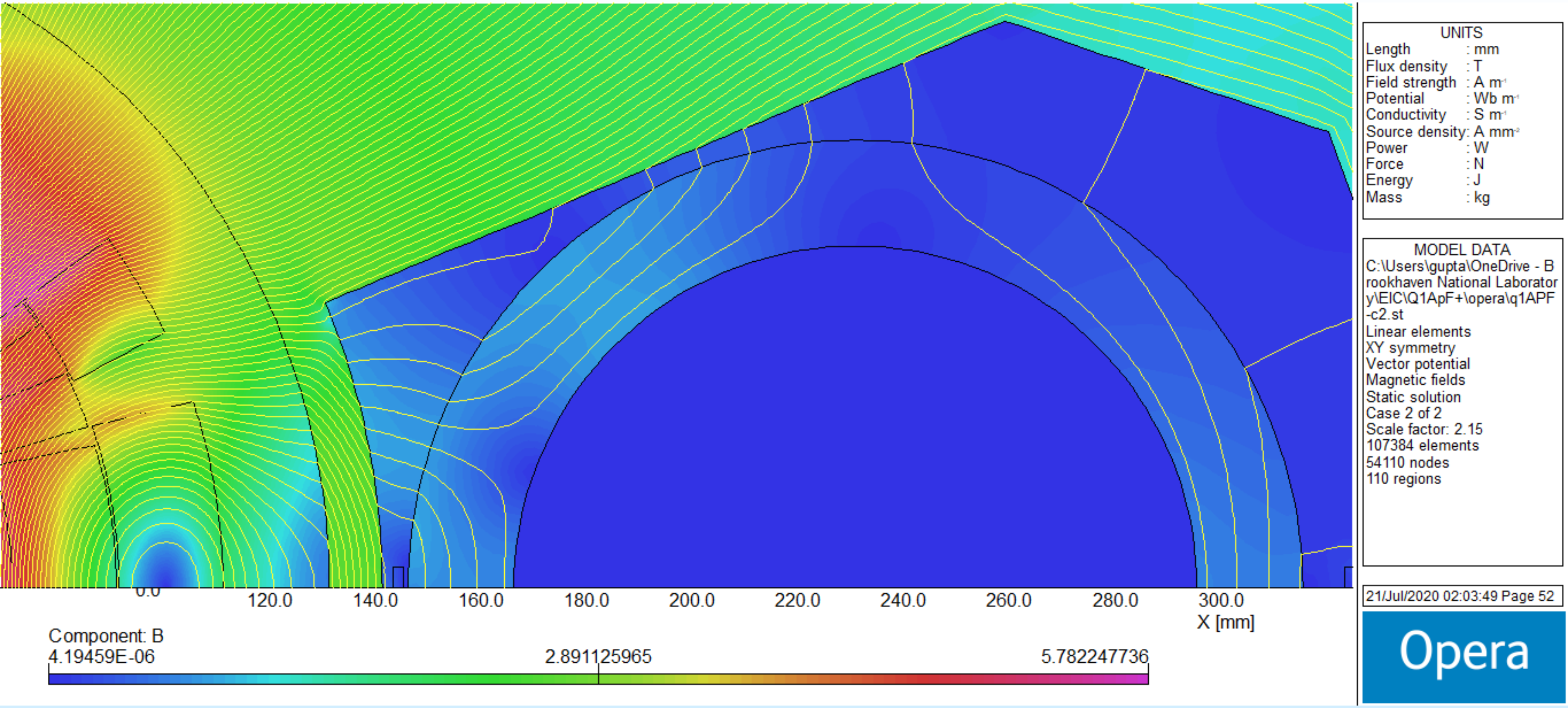

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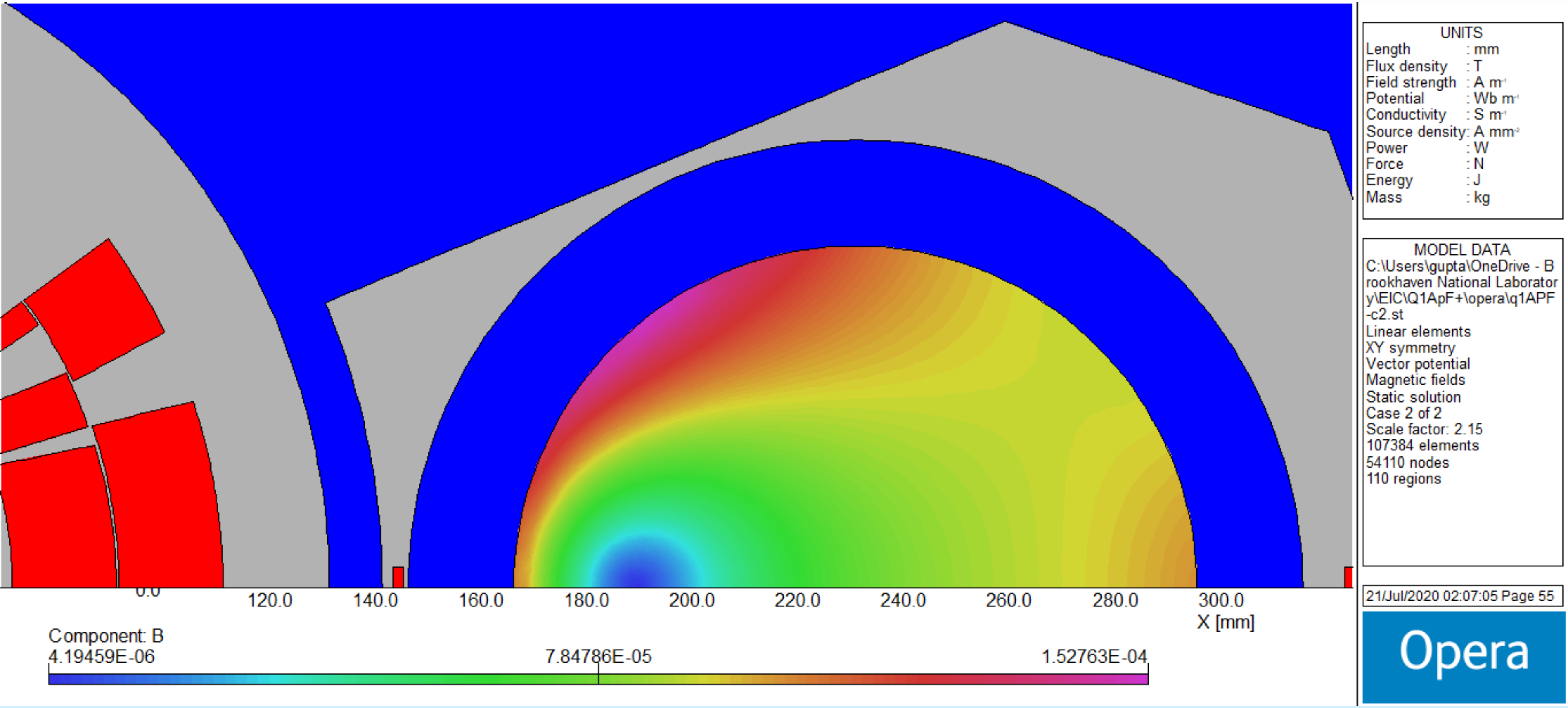
Cutout and Small Coil in Q1A



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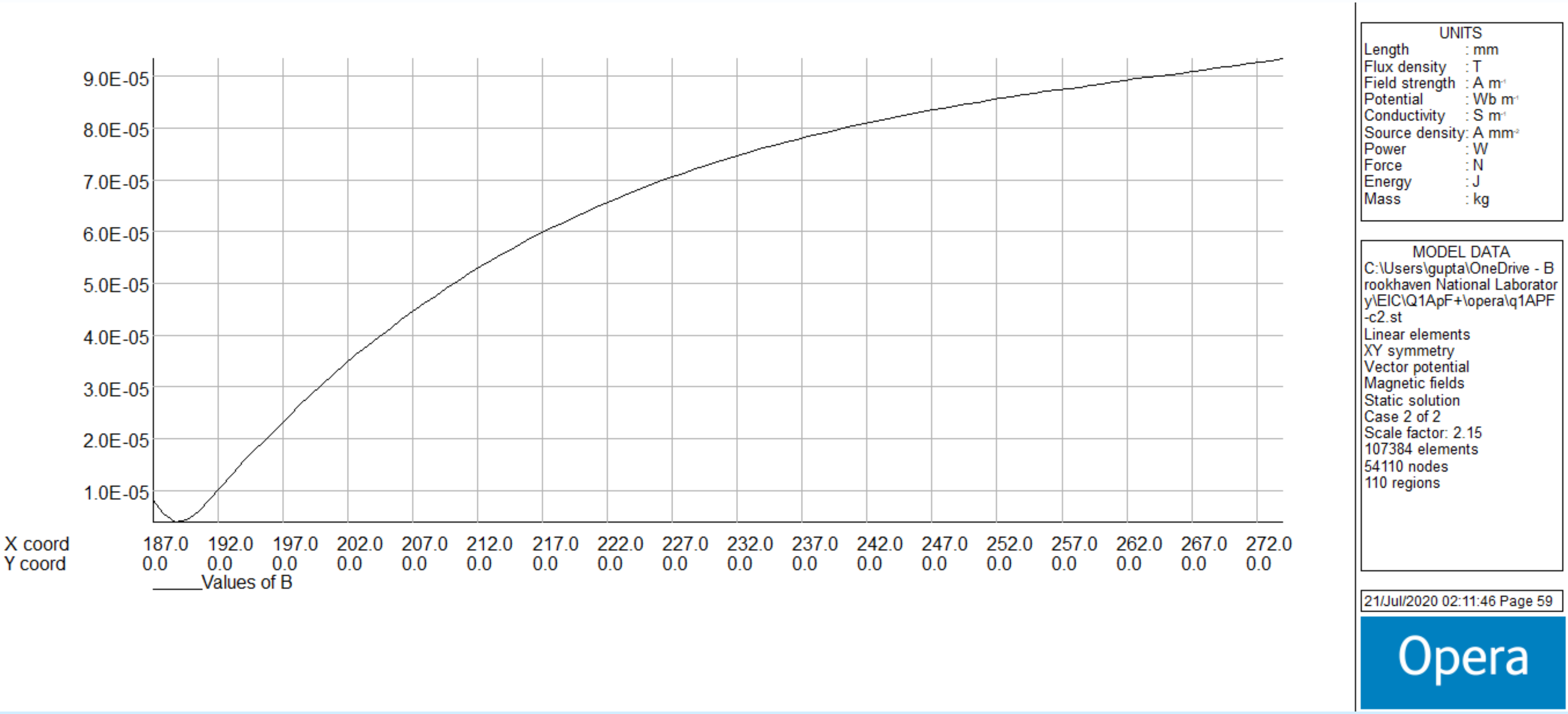

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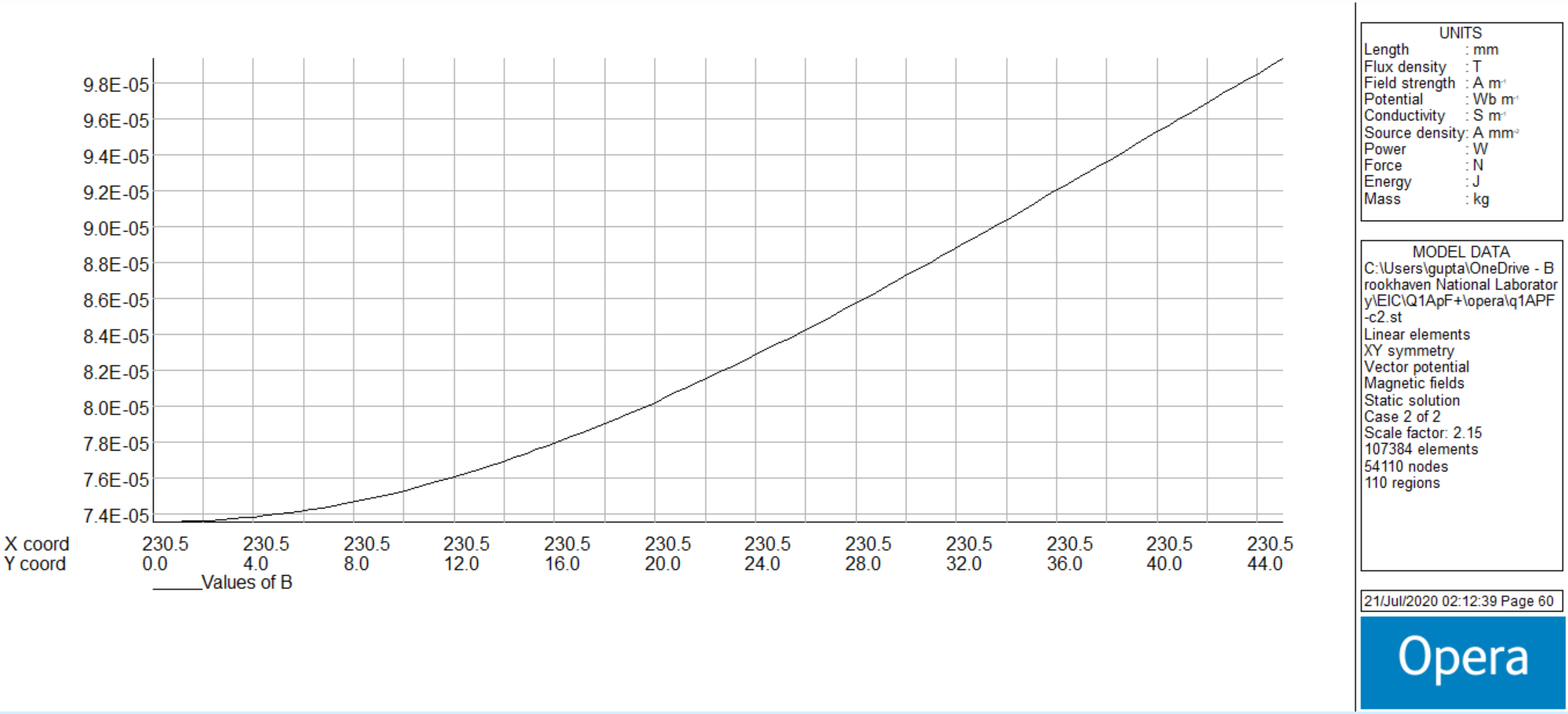

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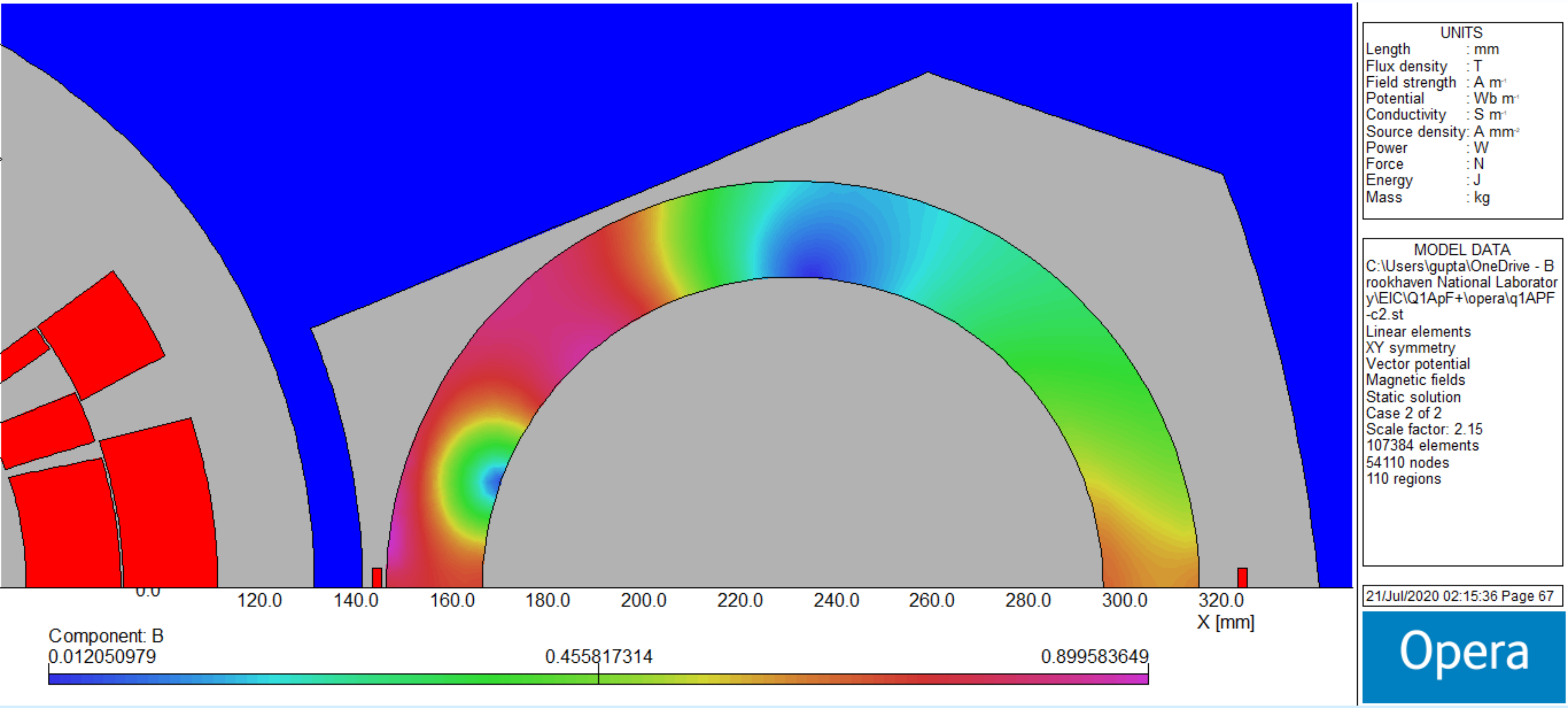

MOU Deliverables
Magnetic Design Tasks

Two type of tasks:

- **The first one refers to the major task on 4 K optimization**
- **The second task is to evaluate all magnets**

Summary of MOU Deliverables required by 09/30/20:

Optimization of the Interaction Region's Forward direction hadron magnets starting with the magnets Q2pF, and Q1BpF and Q1ApF. A goal of this work shall be to optimize the IR's present two 2K magnets, Q1ApF and Q2pF, to run at 4.2K.

An evaluation of the viability of the present lattice in the EIC Interaction Region - with the magnet designs and space allocations as they are presently shown. This is to start with magnets in the rear/forward direction close to the IP (forward: B0ApF, Q1ApF, Q1BpF, …; rear: Q1ApR/Q1eR, ….), as changes here will likely have a larger impact on the lattice. The evaluation shall also identify anything that shall cause major magnet and lattice redesign. If a problem is found it shall be discussed immediately with the 6.06 WBS level 2 and 3 managers to determine a path forward.

The viability of 4 K operation is demonstrated. The coil cross-section is made with the desired cable. It is good for winding and collaring. Moreover, field in electron beam region is also low.

Discussion

- **Good results for 4.2 K option for all magnets**
- **Q1A/Q1B adjust gradient for balanced margin**
  - **Q1A has much bigger margin than Q1B (though new Q1B is in acceptable range). Both have the same polarity**
  - **Re-optimize optics for increasing design gradient of Q1A (say 5%) and reducing gradient of Q1B**

- **Next task?**
- **3d-design of above magnets?**
- **Examine other magnets?**
- **Insert electron quad coils and other features that Brett gave**