Common Coil Dipole for EDM Proposal

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Background

- The proposed experiment to measure Electric Dipole Moment (EDM) of Deuteron to an unprecedented sensitivity of 10^{-27} e.cm requires coupled electric and magnetic in perpendicular direction for two counter rotating beams.
- In the original EDM proposal of 2004, this was proposed through 2-in-1 side-by-side magnet (a BNL invention, currently used in LHC).
- It was recently pointed out (see current EDM proposal) that the time dependence of electric fields in the two rings can be better cancelled through a single pair of electrical plates in an over-under 2-in-1 magnet geometry (common coil magnet design, another BNL invention).

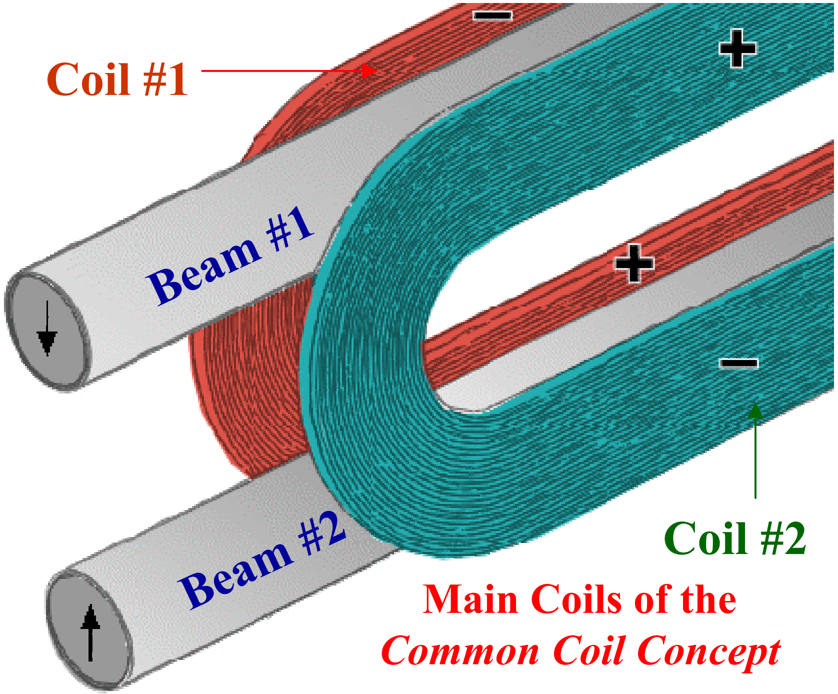
Overview of the Presentation

- Introduction to Common Coil Design
- Field Quality in Common Coil Design
- Magnets built with Common Coil Design
- Initial Magnet Design for EDM Proposal
- Summary

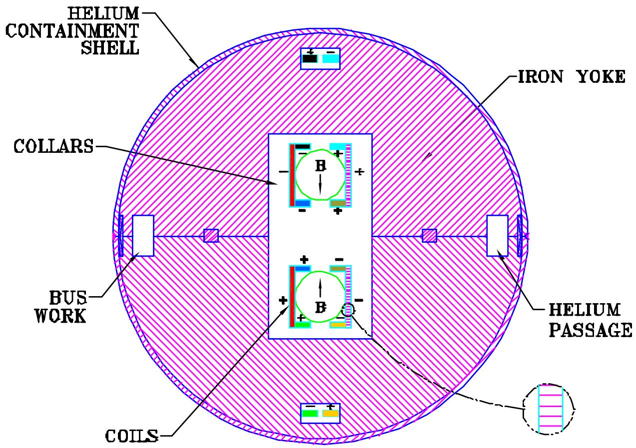
Common Coil Design Concept

A 2-in-1 dipole design with coils common to two apertures

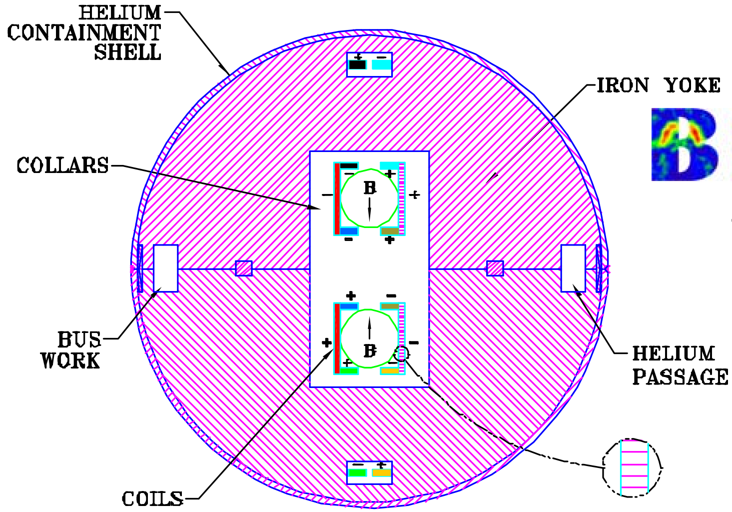
- In a typical magnet, the coils from left side of the aperture returns on the right side.
- In a typical 2-in-1 magnet design the yoke is common between the two apertures but the pairs of coils in two apertures are still separate.
- In the common coil 2-in-1 design, the coils are also common between the two apertures.
- This geometry has been found to offer some crucial advantages in some applications.



Main Coils of the *Common Coil Concept*

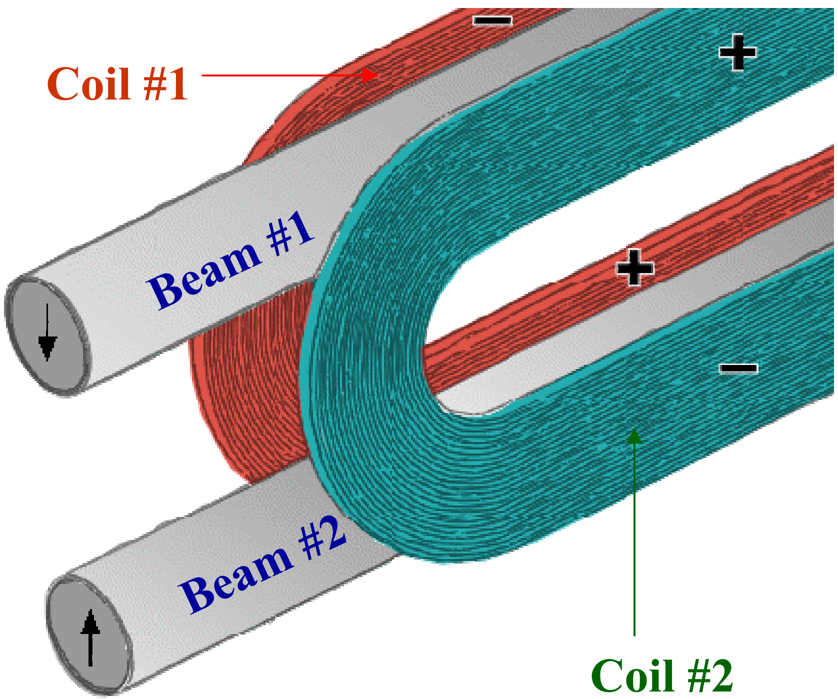


A complete cross-section of a common coil dipole.



Some Advantages of Common Coil Design

- **Simple 2-d geometry with large bend radius** (determined by spacing between two apertures, rather than aperture itself)
- **Conductor friendly (no complex 3-d ends, suitable for brittle high field superconductors - Nb_3Sn and HTS)**
- **Compact (quadrupole type cross-section, field falls more rapidly)**
- **Block design (for handling large Lorentz forces at high fields)**
- **Combined function magnets possible**
- **Minimum requirements on big expensive tooling and labor**
- **Lower cost magnets expected**
- **Efficient and methodical R&D due to simple & modular design**

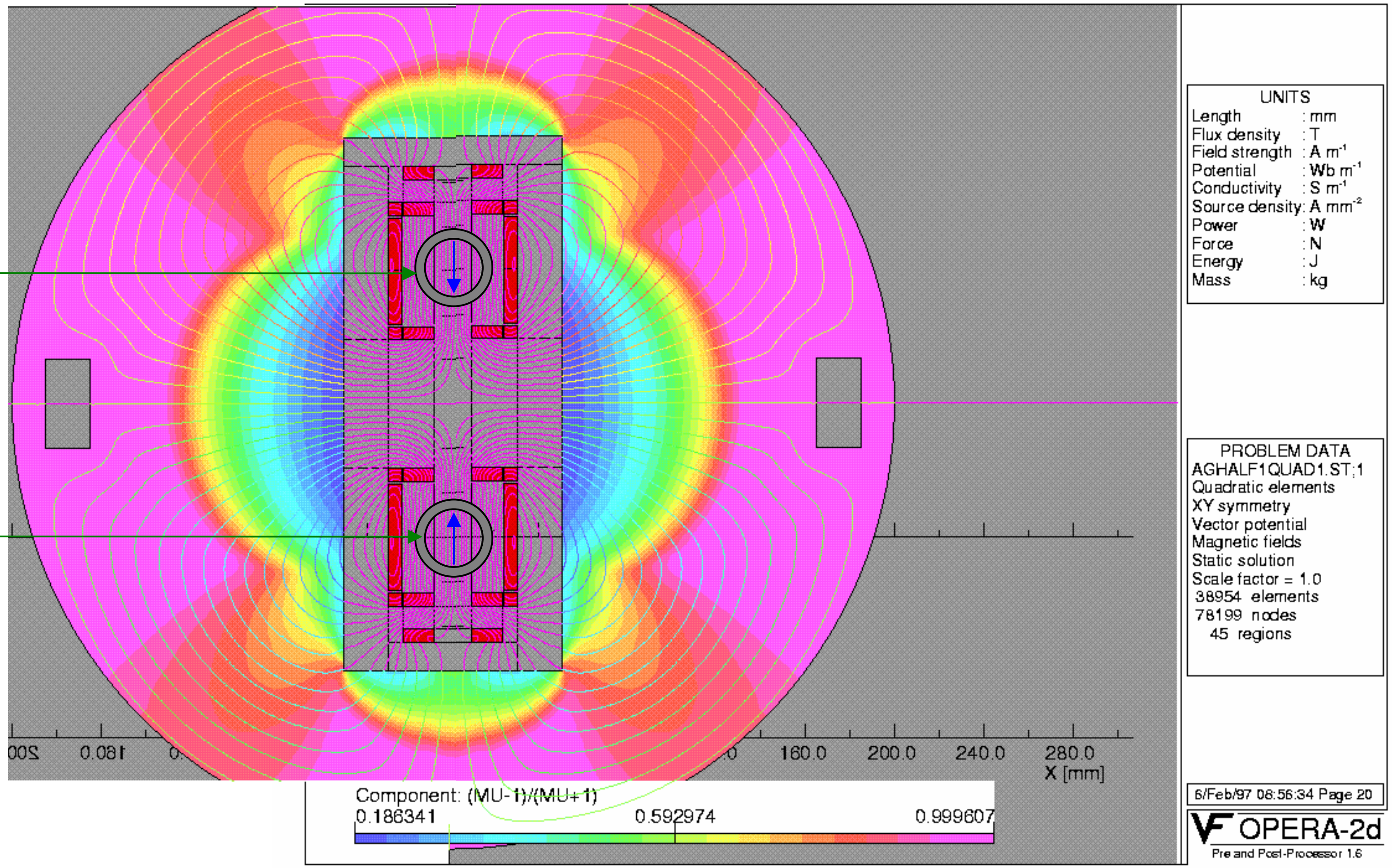


Main Coils of the *Common Coil Design*

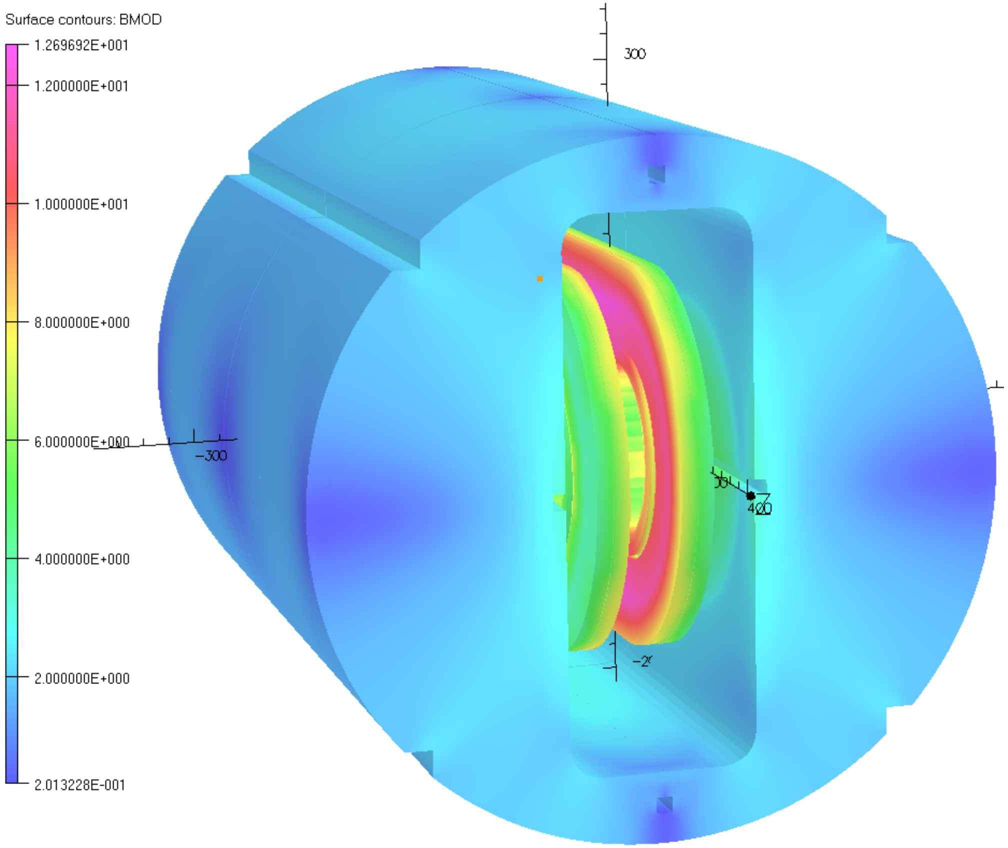
Field Lines at 15 T in a Common Coil Magnet Design

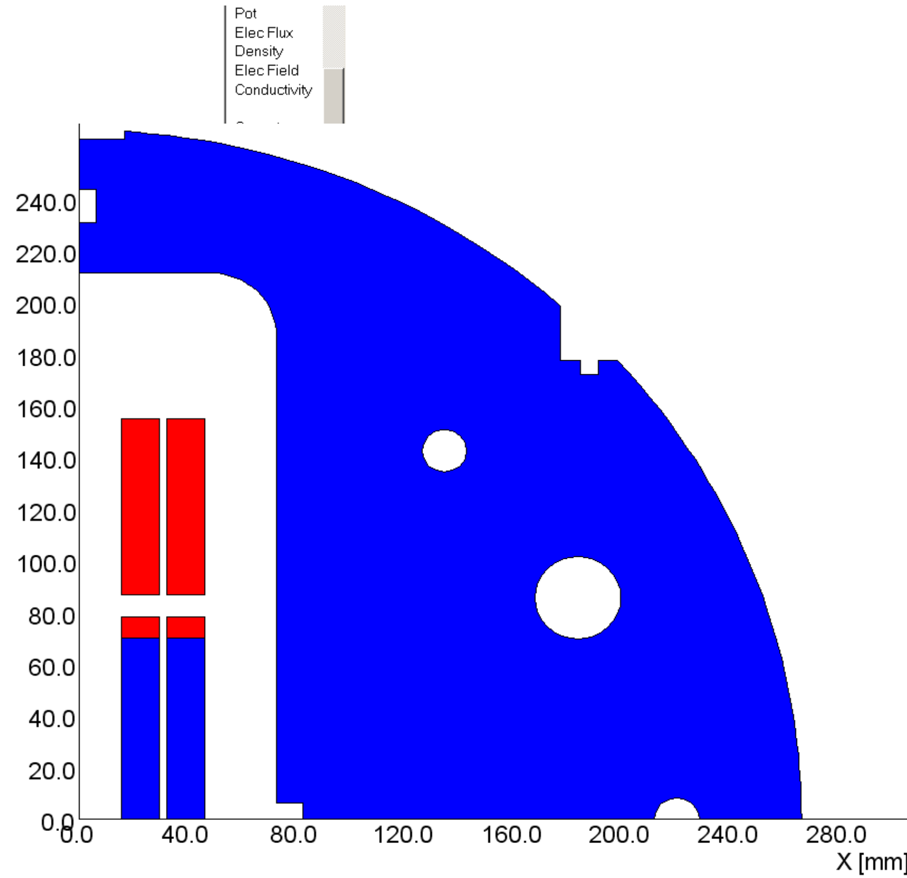
Aperture #1

Aperture #2



Magnetic Design 3-d and 2-d Models



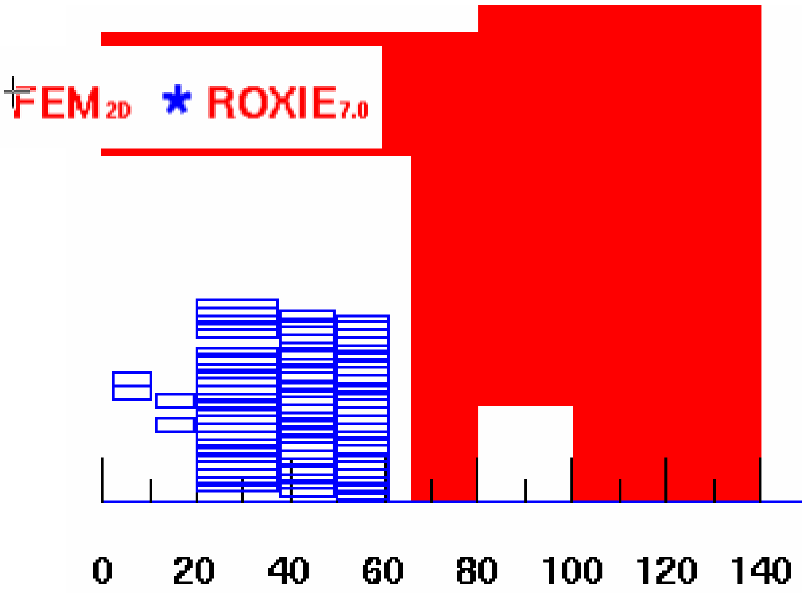


Field Quality in Common Coil Design

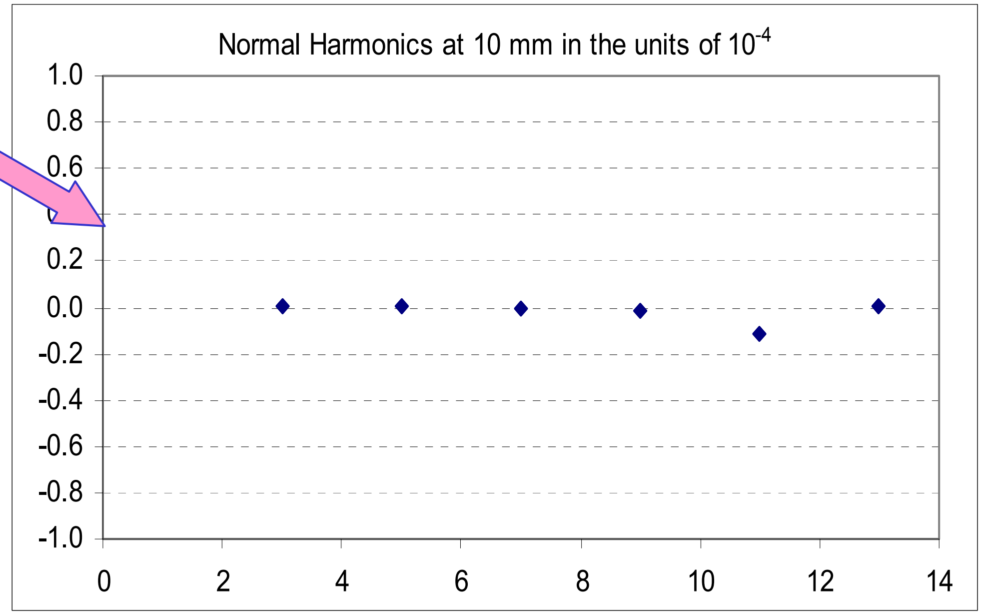
Question: Can such a geometry produce designs with low field harmonics?

The answer is yes! And the proof for 2-d design is here:

Typical Requirements:
~ part in 10^4, we have part in 10^5



The above model uses all flat coils.



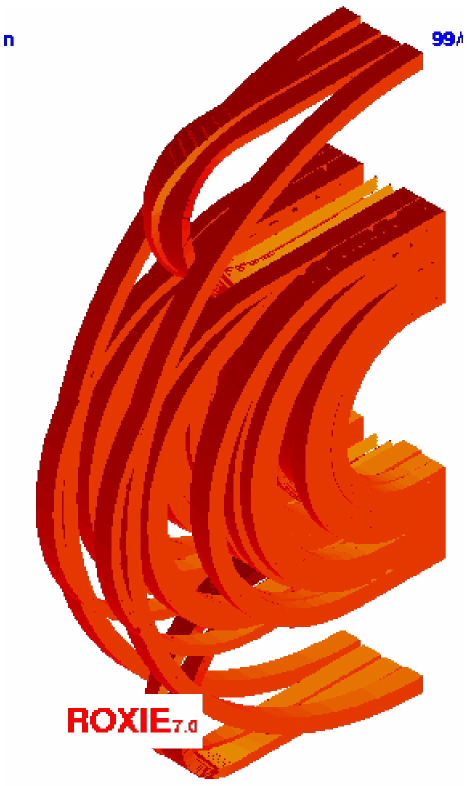
(from 1/4 model)

MAIN FIELD: -1.86463 (IRON AND AIR):

b 1:	10000.000	b 2:	0.00000	b 3:	0.00308
b 4:	0.00000	b 5:	0.00075	b 6:	0.00000
b 7:	-0.00099	b 8:	0.00000	b 9:	-0.01684
b10:	0.00000	b11:	-0.11428	b12:	0.00000
b13:	0.00932	b14:	0.00000	b15:	0.00140
b16:	0.00000	b17:	-0.00049	b18:	0.00000

Optimization of 3-d Magnetic Design of Common Coil Geometry

End harmonics can be made small in a common coil design.

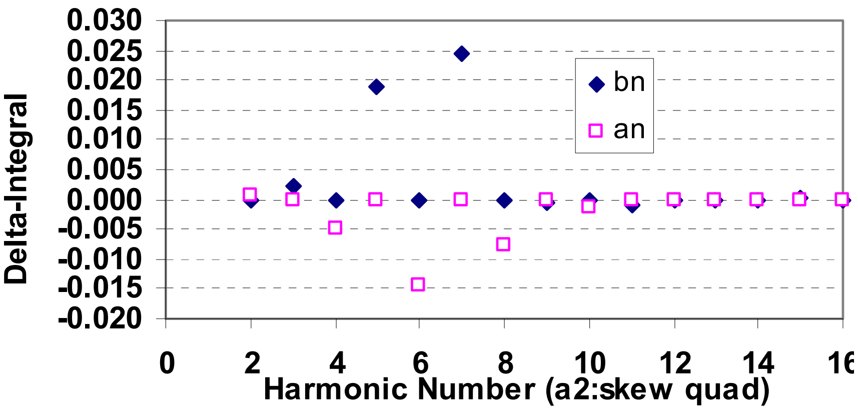


End harmonics in Unit-m

n	Bn	An
2	0.00	0.00
3	0.01	0.00
4	0.00	-0.03
5	0.13	0.00
6	0.00	-0.10
7	0.17	0.00
8	0.00	-0.05
9	0.00	0.00
10	0.00	-0.01
11	-0.01	0.00
12	0.00	0.00
13	0.00	0.00
14	0.00	0.00
15	0.00	0.00
16	0.00	0.00
17	0.00	0.00
18	0.00	0.00

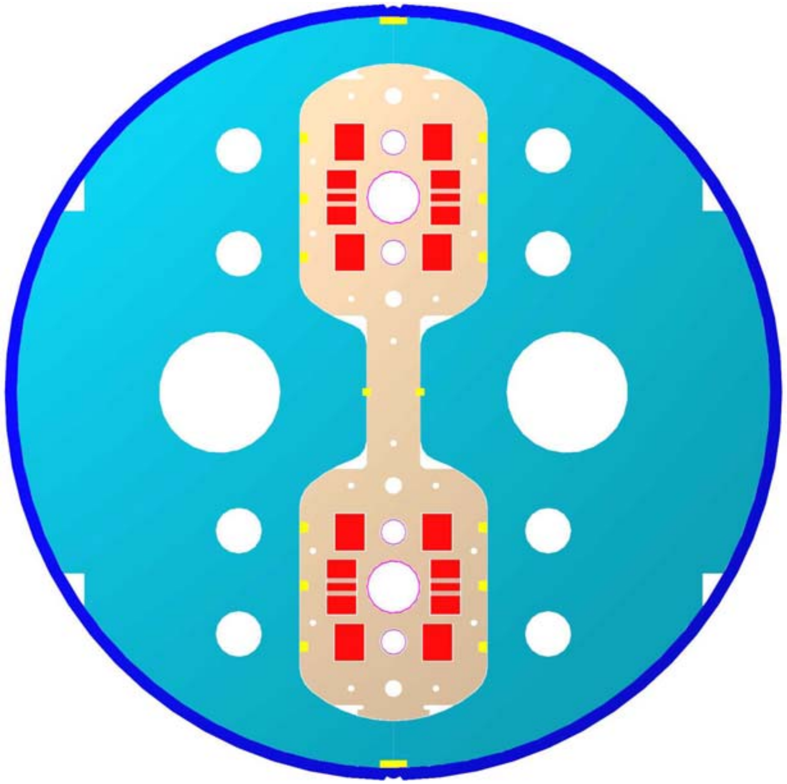
Contribution to integral (a_n,b_n) in a 14 m long dipole ($<10^{-6}$)

n	bn	an
2	0.000	0.001
3	0.002	0.000
4	0.000	-0.005
5	0.019	0.000
6	0.000	-0.014
7	0.025	0.000
8	0.000	-0.008
9	-0.001	0.000
10	0.000	-0.001
11	-0.001	0.000
12	0.000	0.000



Generally speaking, integral end harmonics less than 0.1 unit-meter are considered to be "good".

Status of R&D on Common Coil Magnets



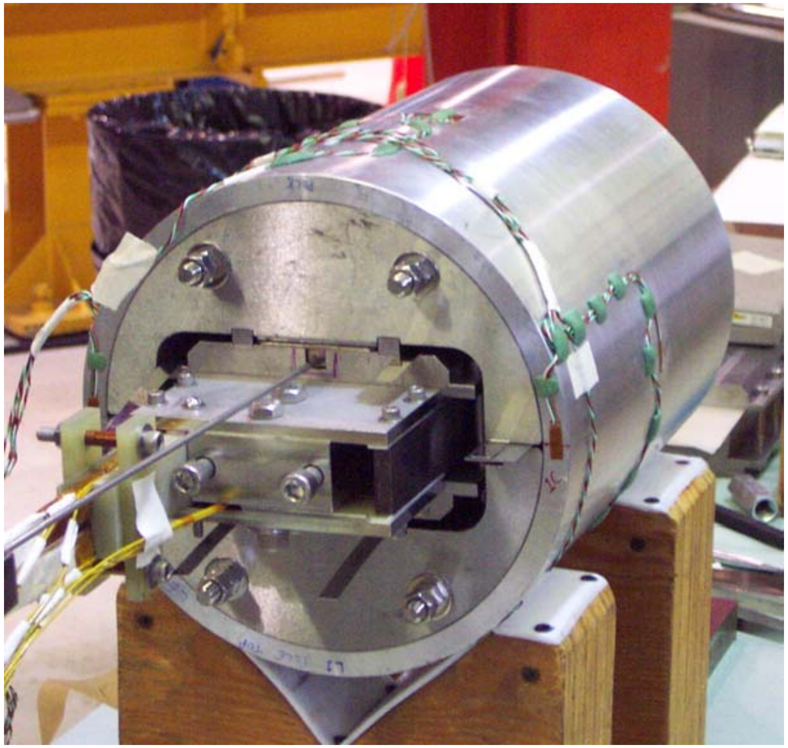
Fermilab Design of Common Coil Magnet for VLHC-2

- A large number of papers (~50) written (a number of designs with good field quality magnets have been presented)
- A significant number (30+) of R&D test magnets built in last few years
- Magnets with both “React & Wind” and “Wind & React” approaches are built
- New superconductors (HTS) have been introduced in accelerator magnets
- All three major US labs (BNL, LBL, FNAL) have built magnets based on this design

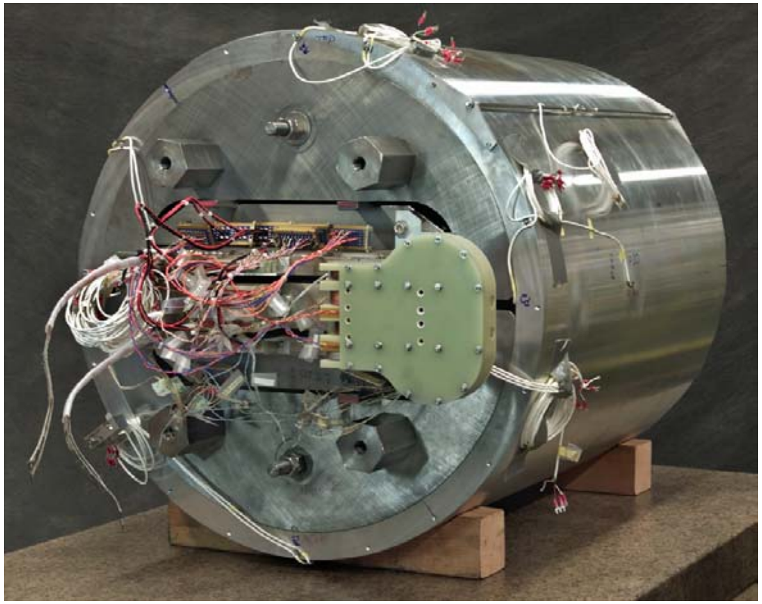
Common Coil Magnets Built at BNL, FNAL, LBNL

BNL

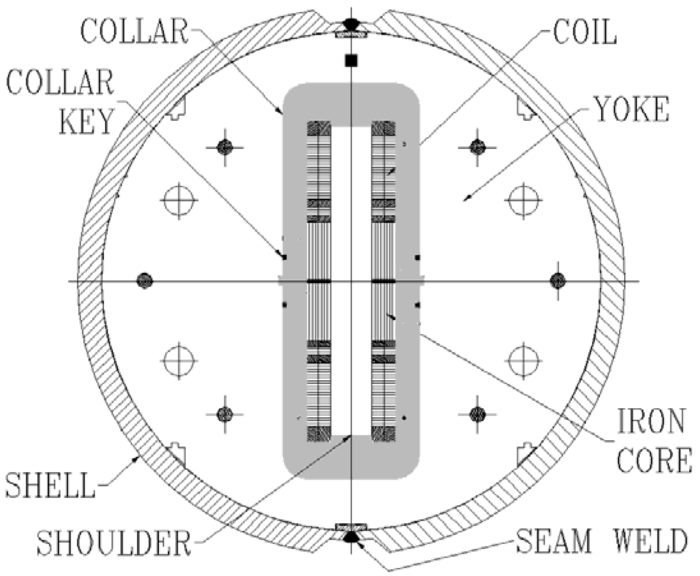
FNAL

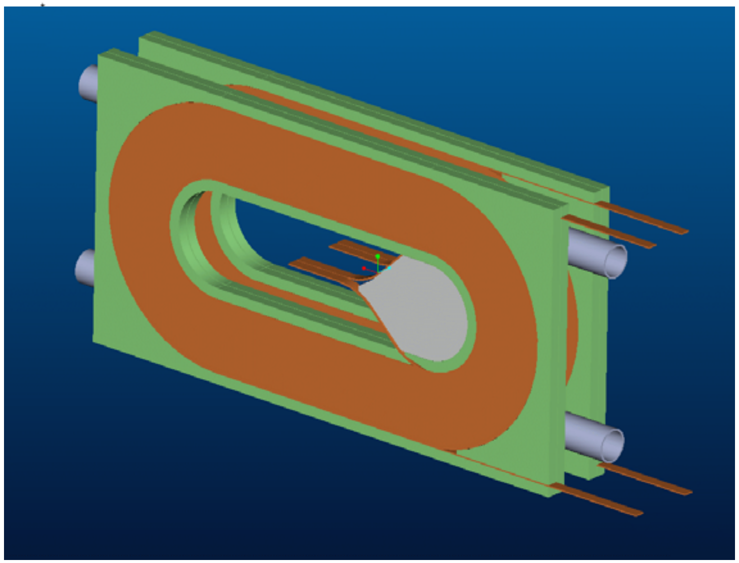


LBNL



Basic Features of BNL Nb_3Sn 10^+ T React & Wind Common Coil Dipole





- Two layer, 2-in-1 common coil design
- 10.2 T bore field, 10.7 T peak field at 10.8 kA short sample current
- 31 mm horizontal aperture
- Large (338 mm) vertical aperture
  - » A unique feature of BNL design
- Dynamic grading by electrical shunt
- 0.8 mm, 30 strand Rutherford cable
- 70 mm minimum bend radius
- 620 mm overall coil length
- Coil wound on magnetic steel bobbin
- One spacer in body and one in ends
- Iron over ends
- Iron bobbin
- Stored Energy@Quench ~0.2 MJ

BNL Nb_3Sn React & Wind Common Coil Dipole DCC017 During Final Assembly

BNL Nb_3Sn Common Coil Dipole at Vertical Test Facility

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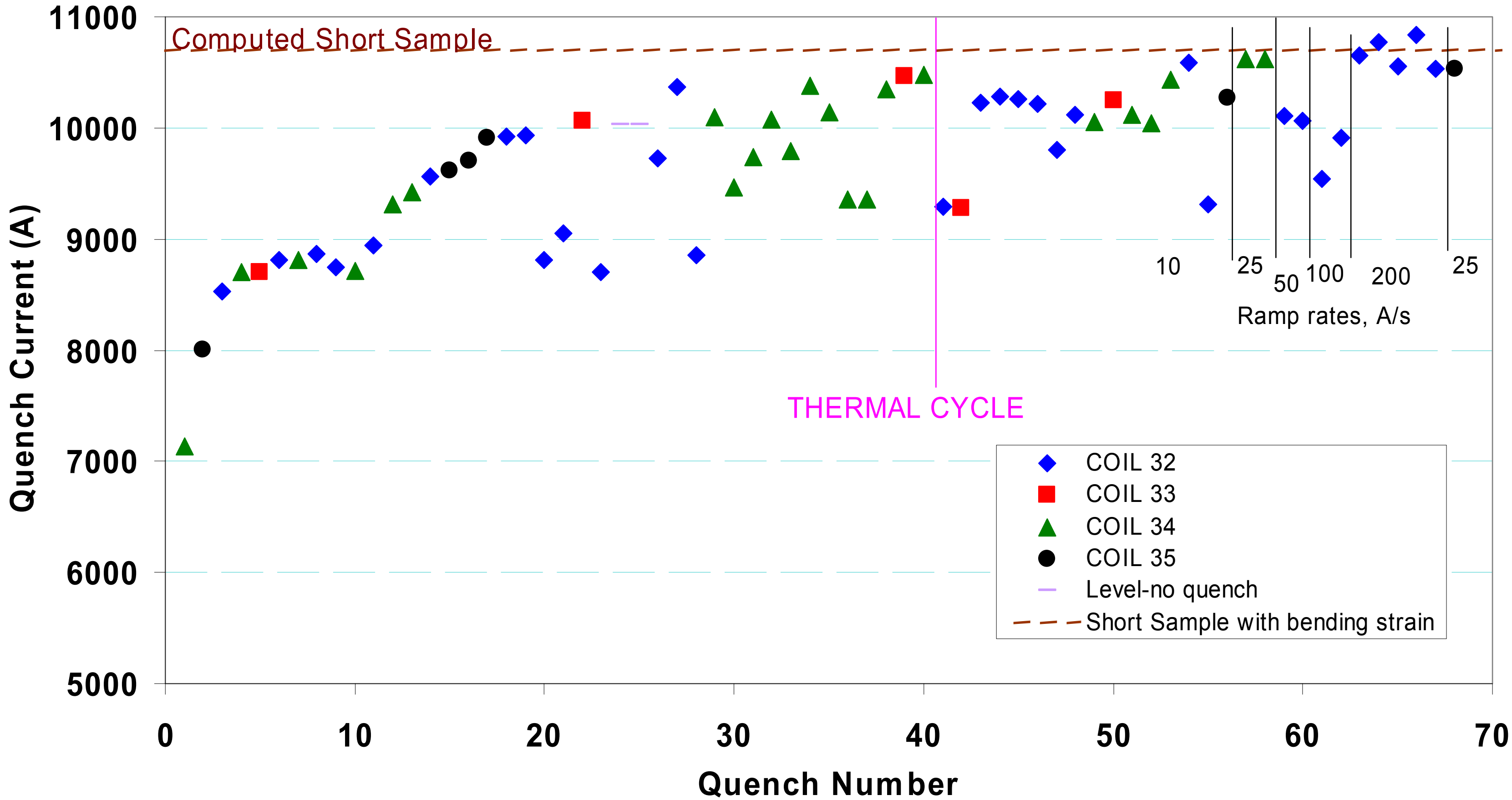
Quench Plot of BNL React & Wind Common Coil Dipole DCC017



- **Magnet reached short sample after a number of quenches**
  - √ **Reasonable for the first technology magnet**

I_c=10.8 kA

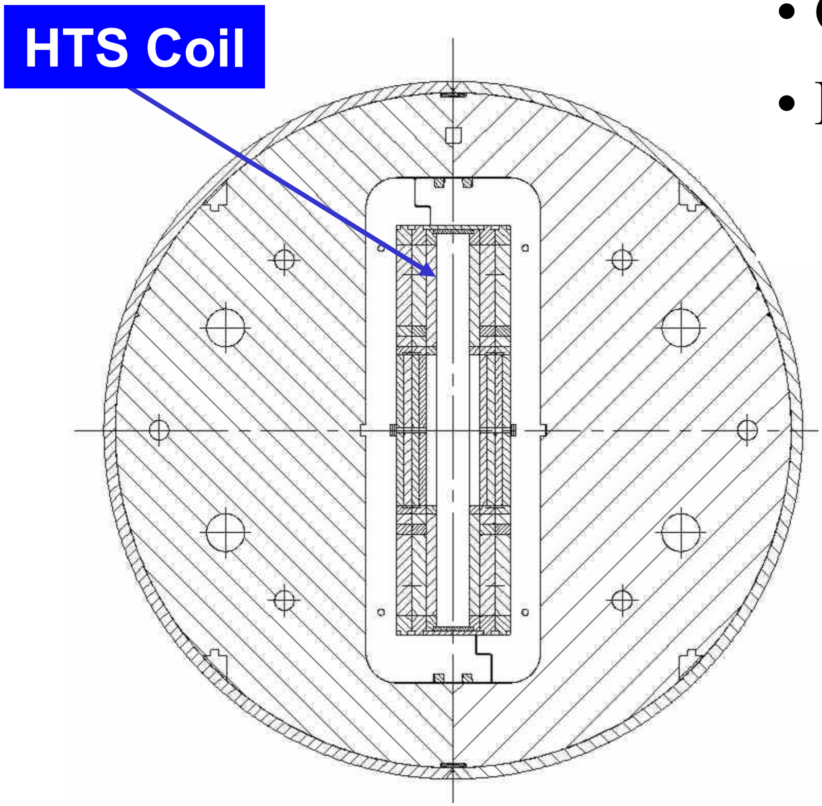
B_{pk}=10.7 T

B_{ss}=10.2 T

A Unique Feature of BNL Common Coil Design

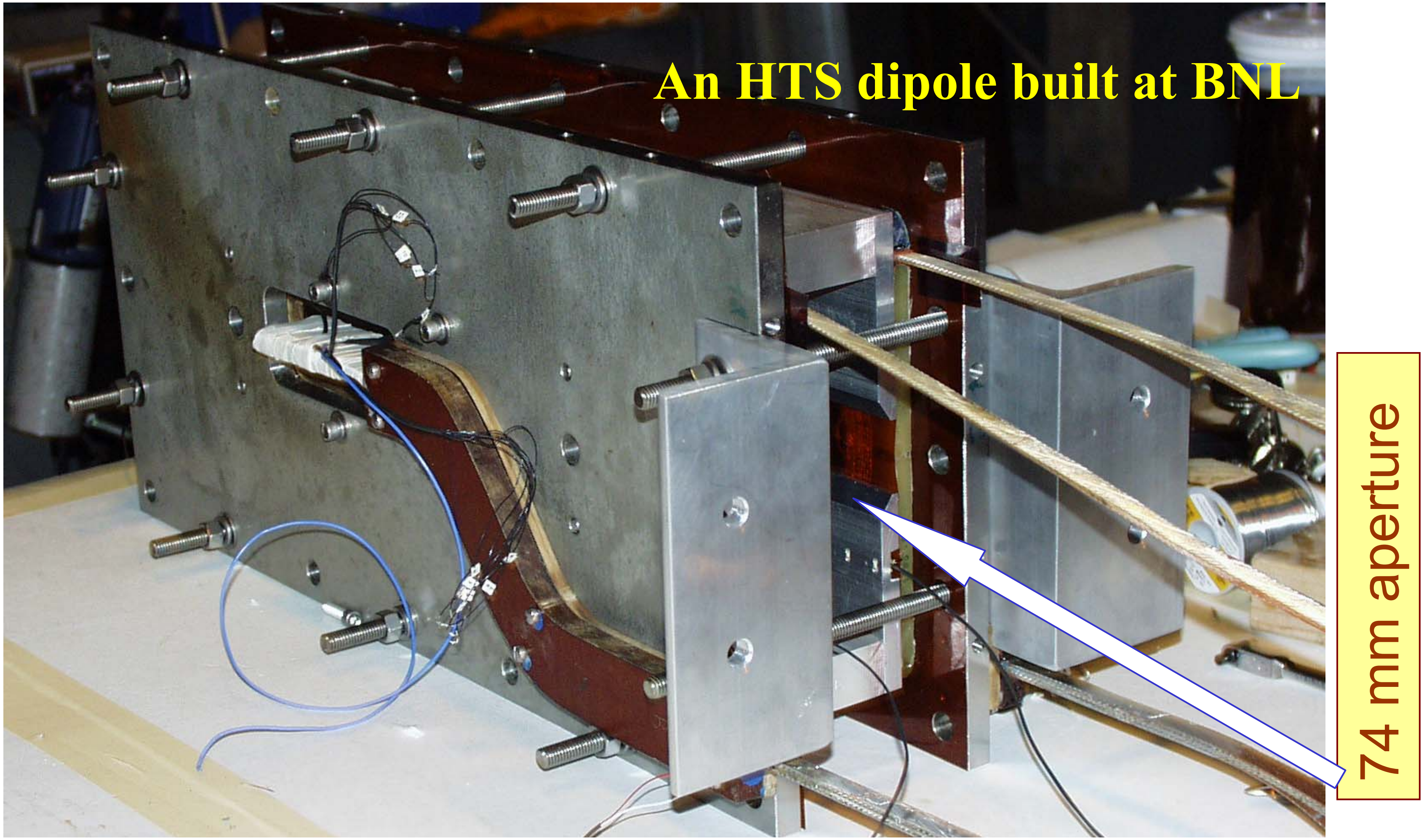
A unique feature of BNL design is a large vertical open space between the two coils.

- Can be used for insert HTS coil testing.
- For EDM proposal, it is ideally suited for electric plates inside the coils!



HTS insert coil test configuration (HTS/Nb_3Sn Hybrid magnet)

HTS 74 mm Aperture Common Coil Dipole
(Space for electric plates for EDM type magnet)



Depending on the details of how the design evolves, High Temperature Superconductors (HTS) may offer some advantages

Iron Dominated Common Coil Design

A figure from the 1997 Particle Accelerator Conference Paper

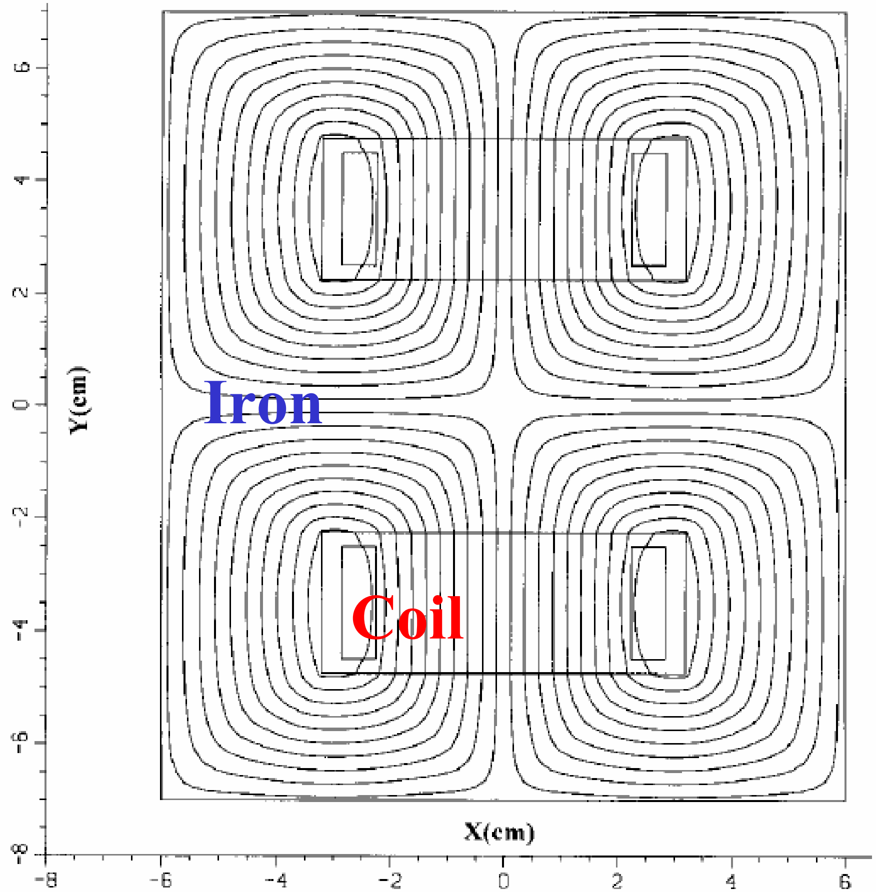


Fig. 5: A proposed low field iron dominated 45 mm x 25 mm aperture 2-in-1 magnet based on the common coil design. The coldmass is shown ~½ scale here.

Common Coil Design for EDM Proposal

- Sketch on the side from Yannis Semertzidis shows the initial dimensions of electrical plates, etc. inside the vacuum chamber.

- The coils and iron producing ~0.52 T magnetic field must be placed around it.

- A preliminary magnetic design with water-cooled copper coils and iron shield has been developed.

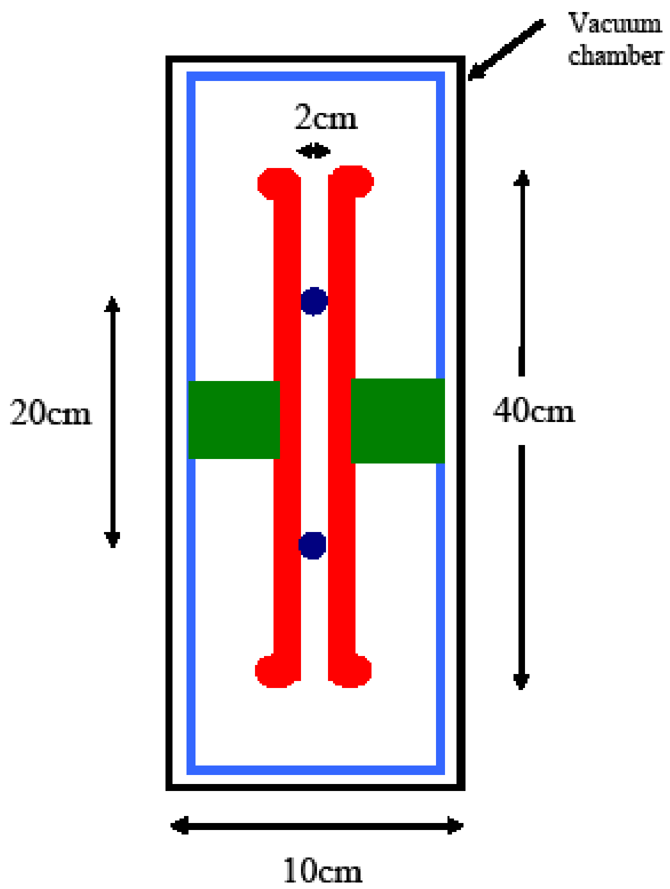
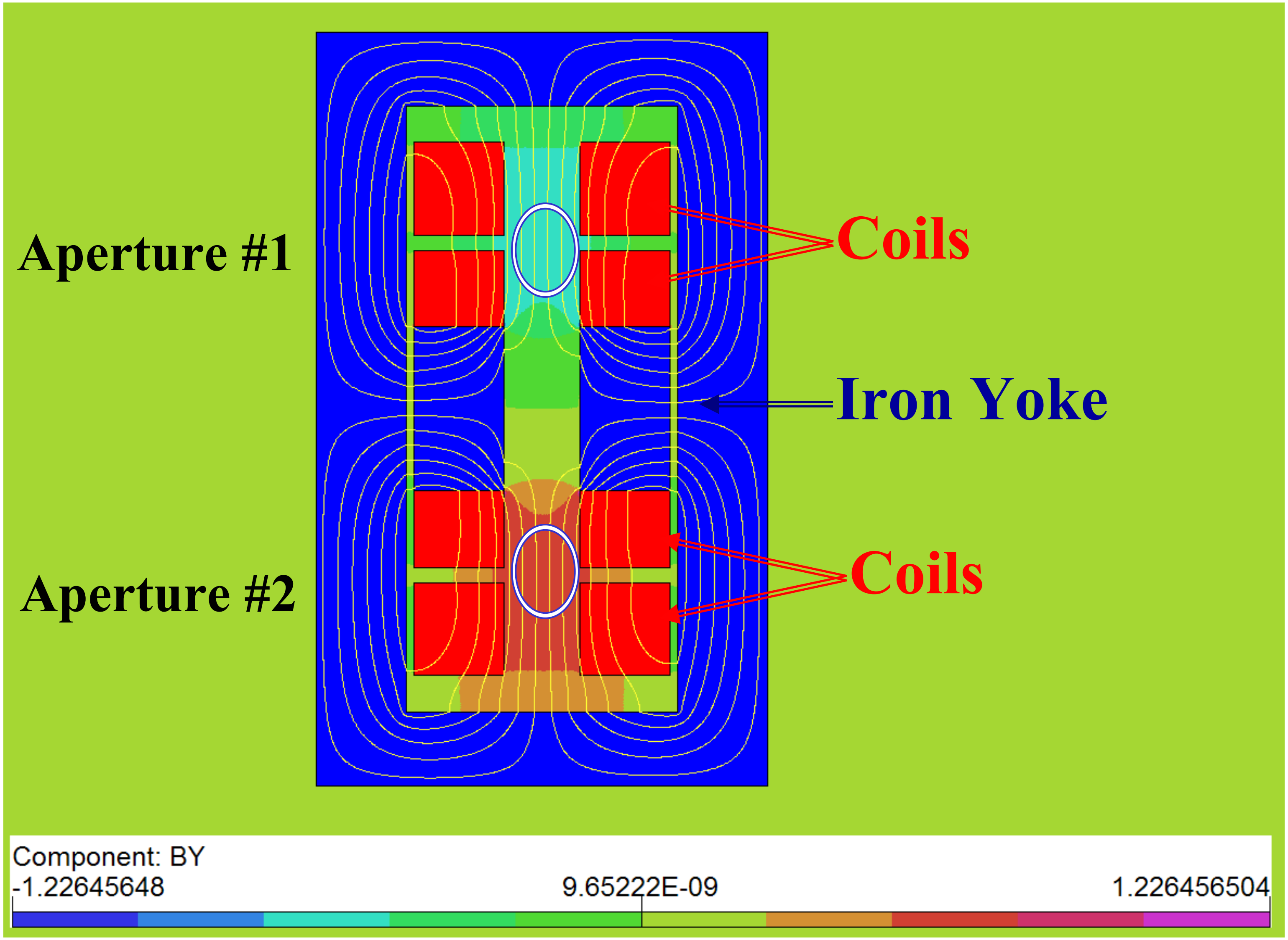
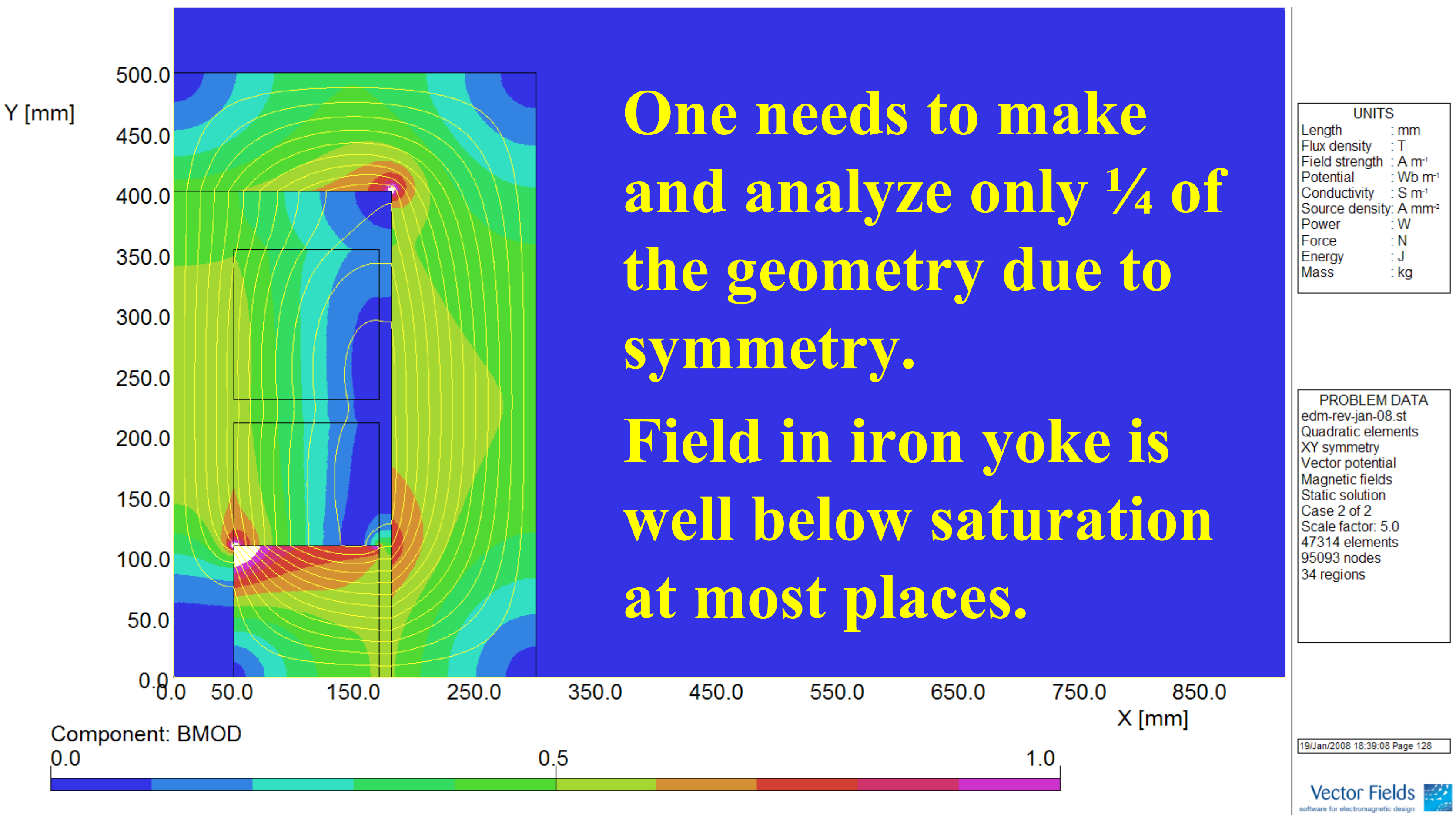


Figure 1. The electrostatic plates (red) are 40cm high separated by 2cm and are supported by the structure support shown in light blue, with high voltage insulators shown in green. This structure is enclosed in the vacuum chamber. The storage beam regions are shown in dark blue, 20 cm apart vertically.

Common Coil Design for EDM



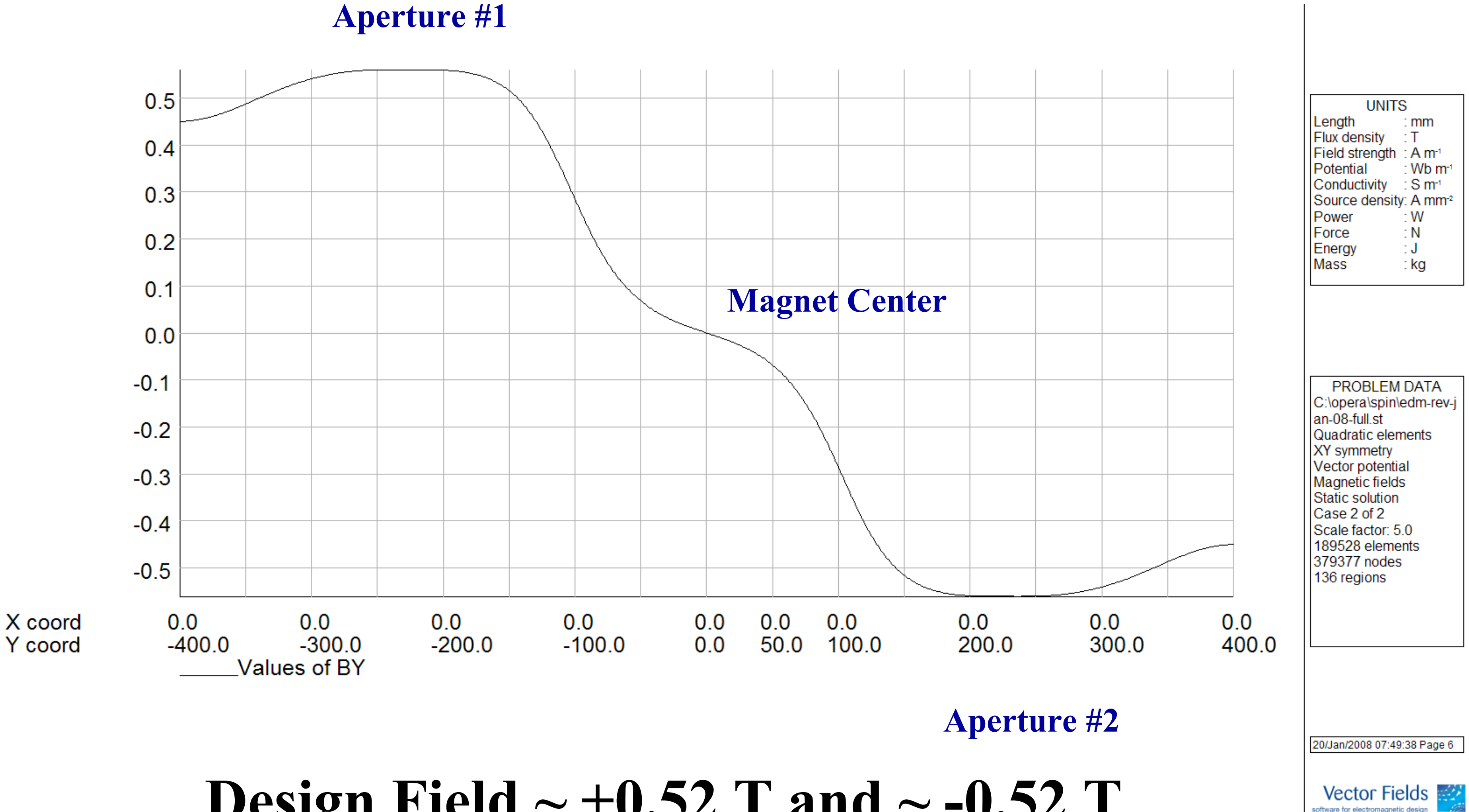
Field Lines and Field Contous



One needs to make and analyze only ¼ of the geometry due to symmetry.

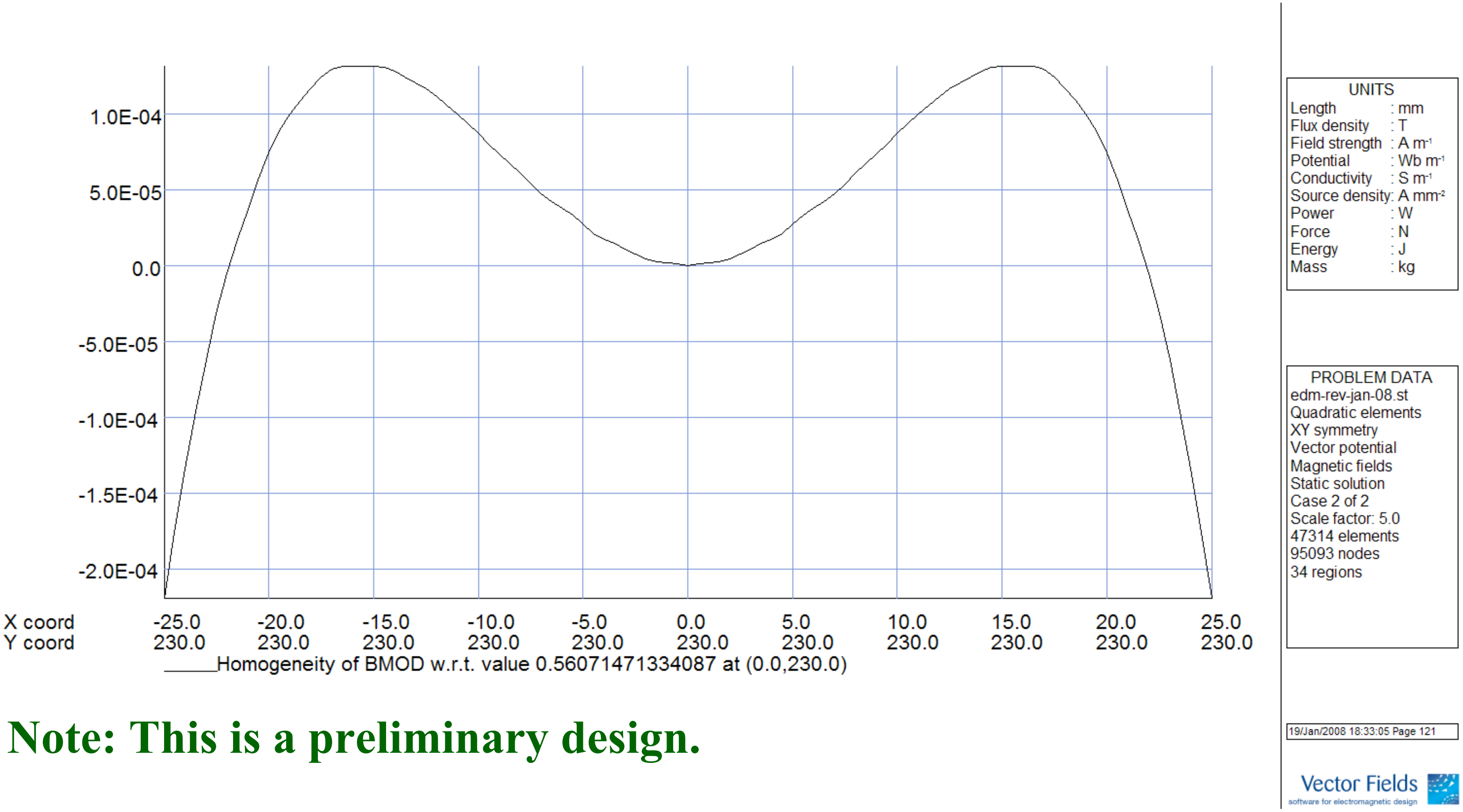
Field in iron yoke is well below saturation at most places.

Vertical Field along Y-axis



Design Field ~ +0.52 T and ~ -0.52 T

Relative Field Errors on the Horizontal Axis in One Aperture



Note: This is a preliminary design.

Field errors are displayed for +/- 25 mm. Actual beam size may be smaller.

Also, this is an easy way to evaluate overall field quality, but in a more detailed design and analysis, we would examine field harmonics, etc.

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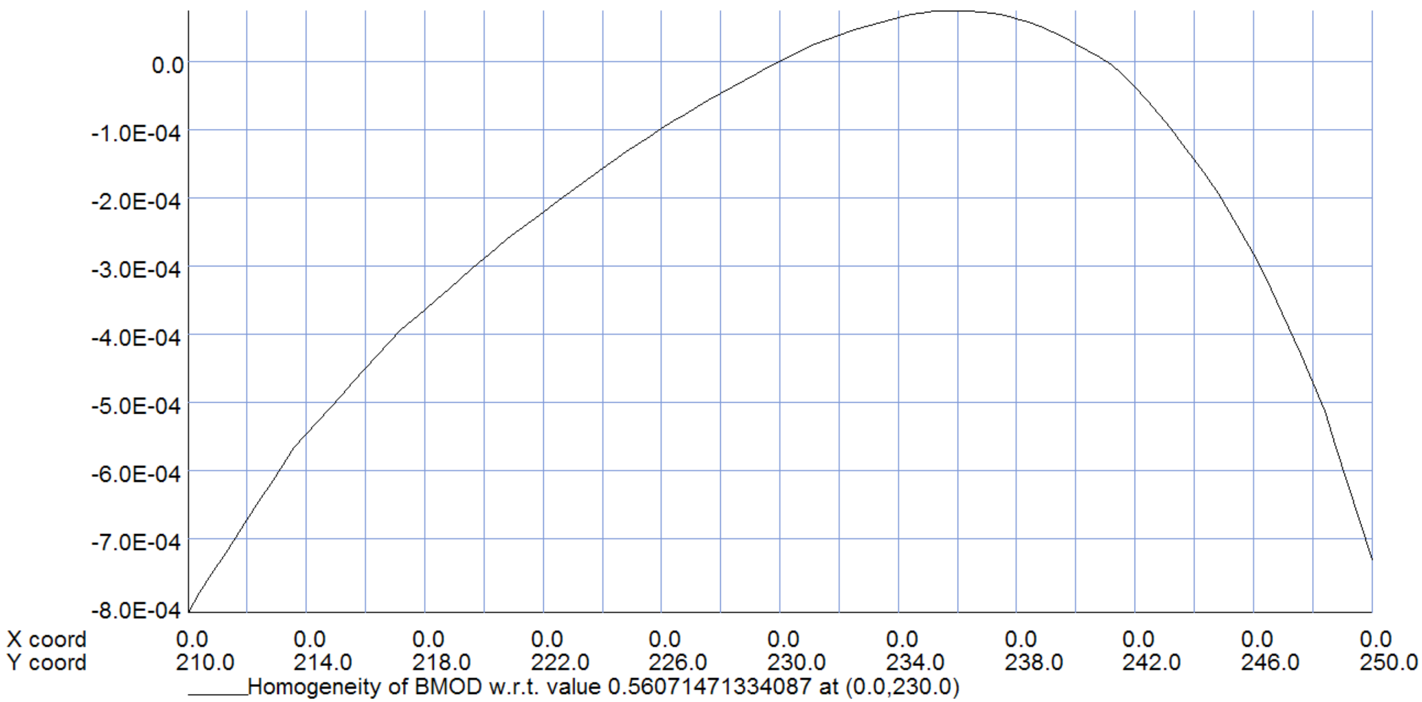
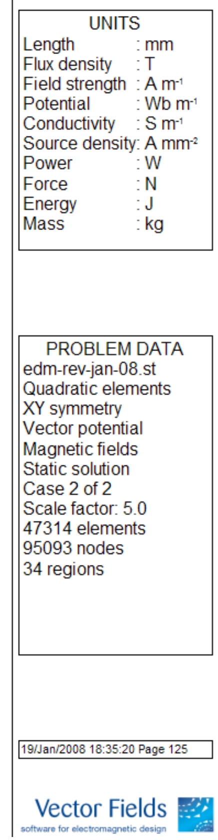
Relative Field Errors on the Vertical Axis in One Aperture





Note: This is a preliminary design.

Field errors are displayed for +/- 20 mm. Actual beam size may be smaller.

Also, this is an easy way to evaluate overall field quality, but in a more detailed design and analysis, we would examine field harmonics, etc.

SUMMARY

- **Common Coil Dipole Design offers a valuable option for EDM proposal. Because of the common vertical electrical plates for two beams, it offers better time dependent E-field cancellation (as pointed out in the proposal).**

- **The results of the preliminary design are encouraging.**

- **However, details are yet to be examined. As we go along there may be some interesting options/possibilities.**