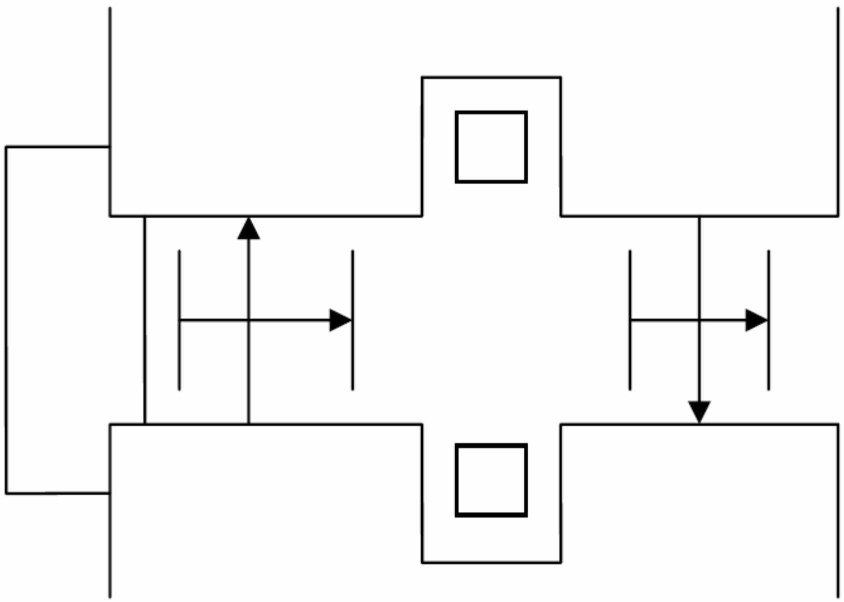
Common Coil Dipole Magnet Design Status for the dEDM

Ramesh Gupta
Magnet Division
Brookhaven National Laboratory

EDM Collaboration Meeting
March 10, 2008

Electric and Magnetic Fields in the Original Proposal

The direction of dipole field alternates but electric field does not



Bill Morse original proposal (2004) was based on 2-in-1 dipole magnet (Palmer's design)

Fig. 1. Two in one magnet showing the CW and CC channels. Only the inner coils are shown for clarity. The direction of the current is reversed every fill. Only one stainless steel support is shown. This drawing is not to scale.

Electric and Magnetic Fields in the Current Proposal

• It has been pointed out that the time dependent errors can be cancelled much better if the electric fields in the two apertures is provided by a set of common plates (Yannis Semertzidis, Bill Morse, et. al).

• Magnetic field should be perpendicular to electric field and should alternate sign.

• The resulting configuration should look something like the one shown in the right.

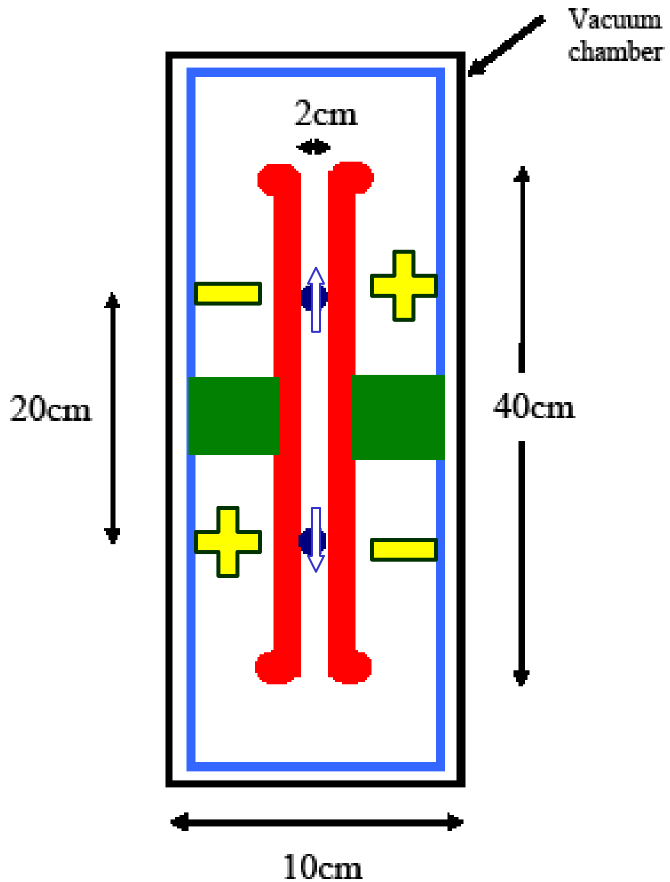
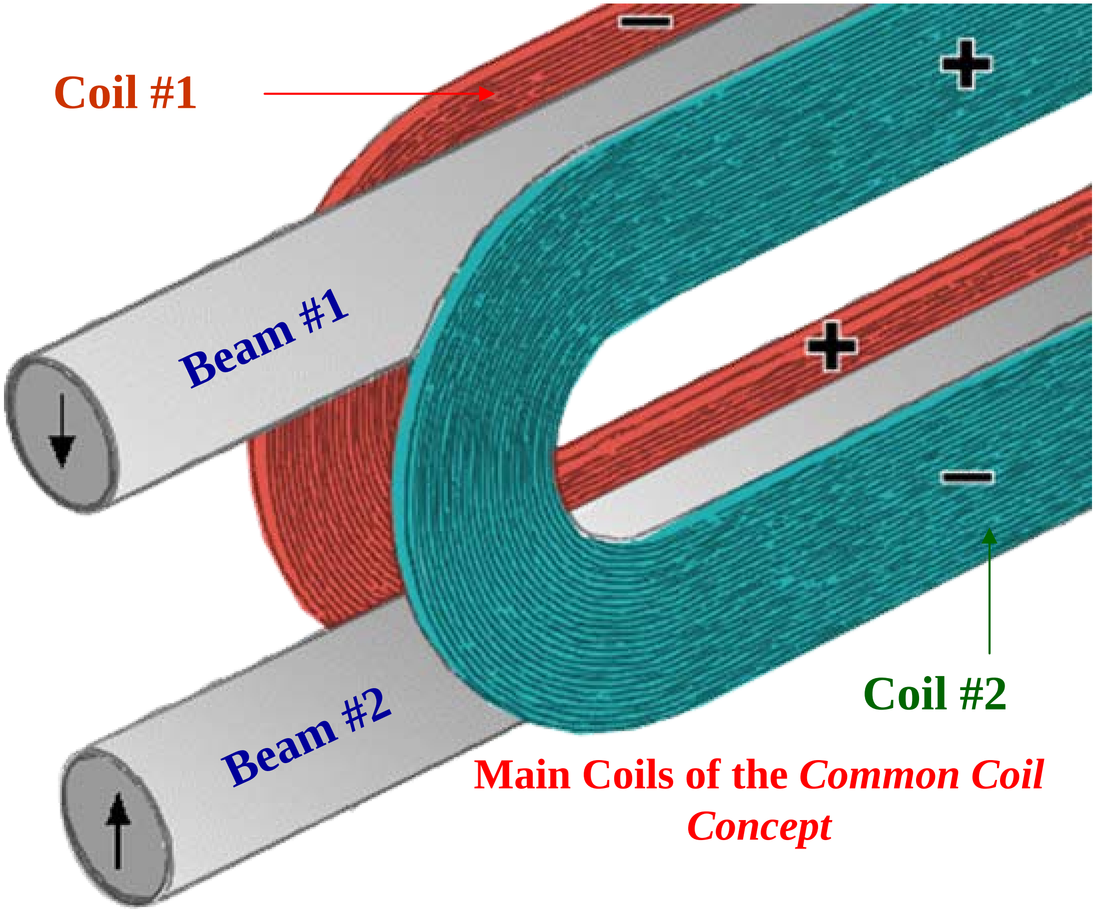


Figure 1. The electrostatic plates (red) are 40cm high separated by 2cm and are supported by the structure support shown in light blue, with high voltage insulators shown in green. This structure is enclosed in the vacuum chamber. The storage beam regions are shown in dark blue, 20 cm apart vertically.

Question: Is there a magnet design with such a configuration?

Aren't We Lucky



Main Coils of the *Common Coil Concept*

- Yes, there is a magnet design twith desired configuration.
- It is called common coil design - another BNL invention.
- In fact, many magnets have been built in last decade based on this common coil geometry.
- Since left and right coils are separate, a combined function magnet (dipole + quadrupole) is possible.

Overview of the Presentation

- **Introduction to the Common Coil Design**
- **Magnets Built with the Common Coil Design**
- **Common Coil Design for dEDM Proposal**
- **Progress Since the Last Meeting**
- **A Few Comments on the Cost**
- **Summary**

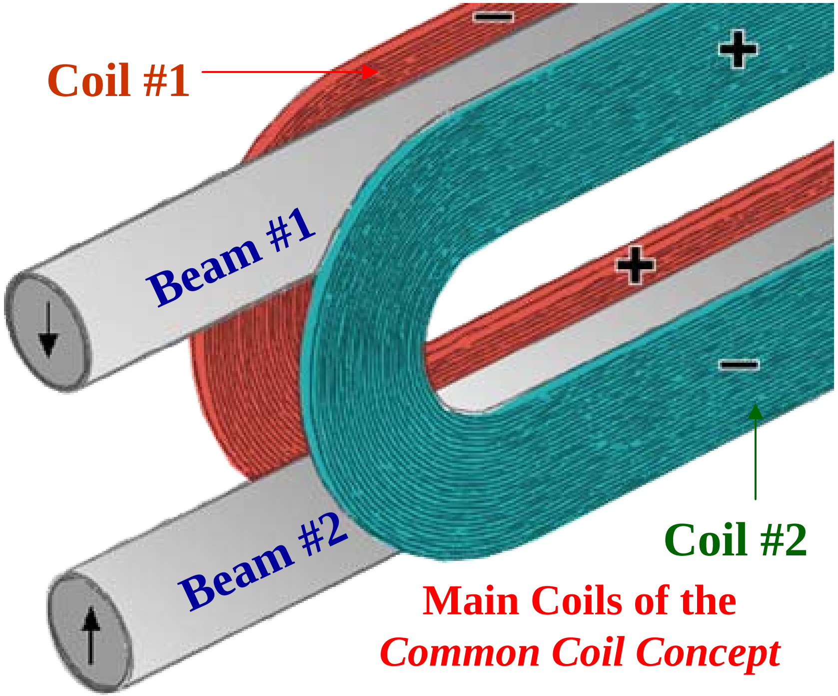
Brookhaven National Laboratory

Superconducting Magnet Division

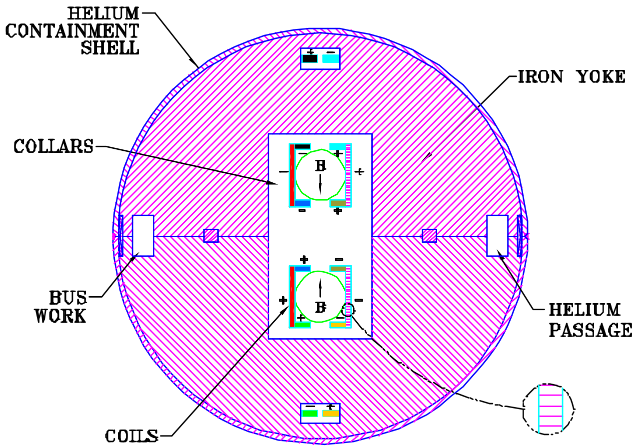
Common Coil Design Concept

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.

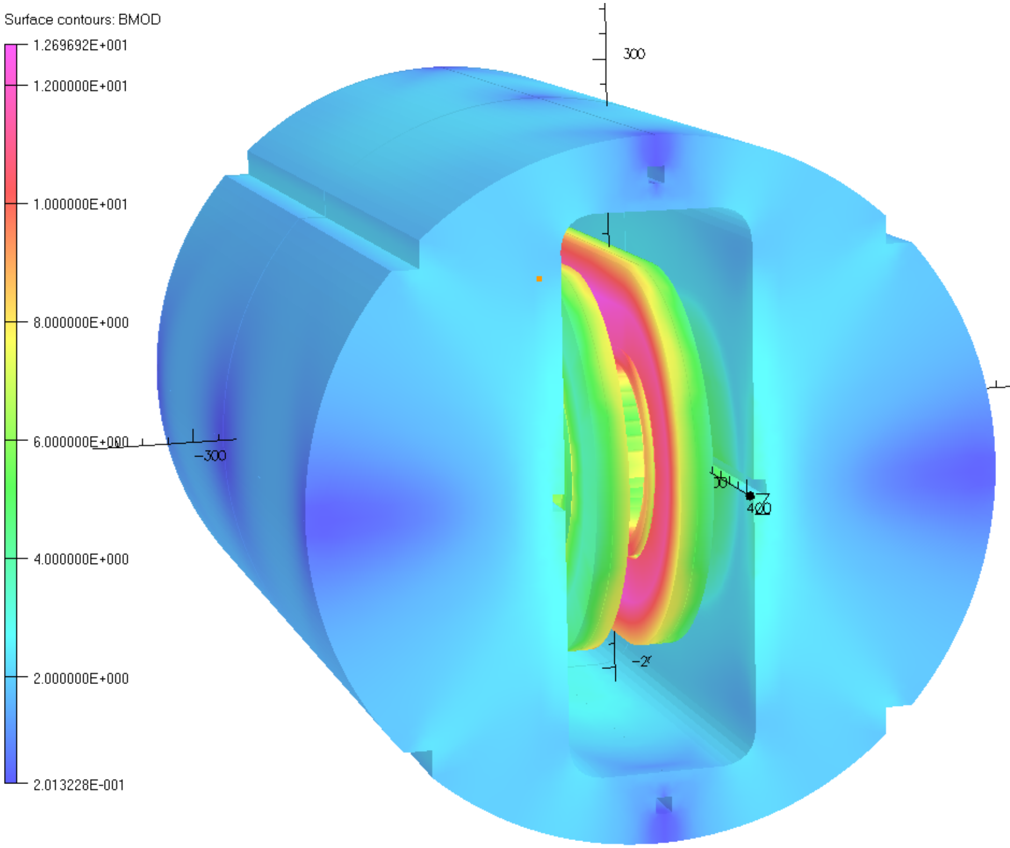


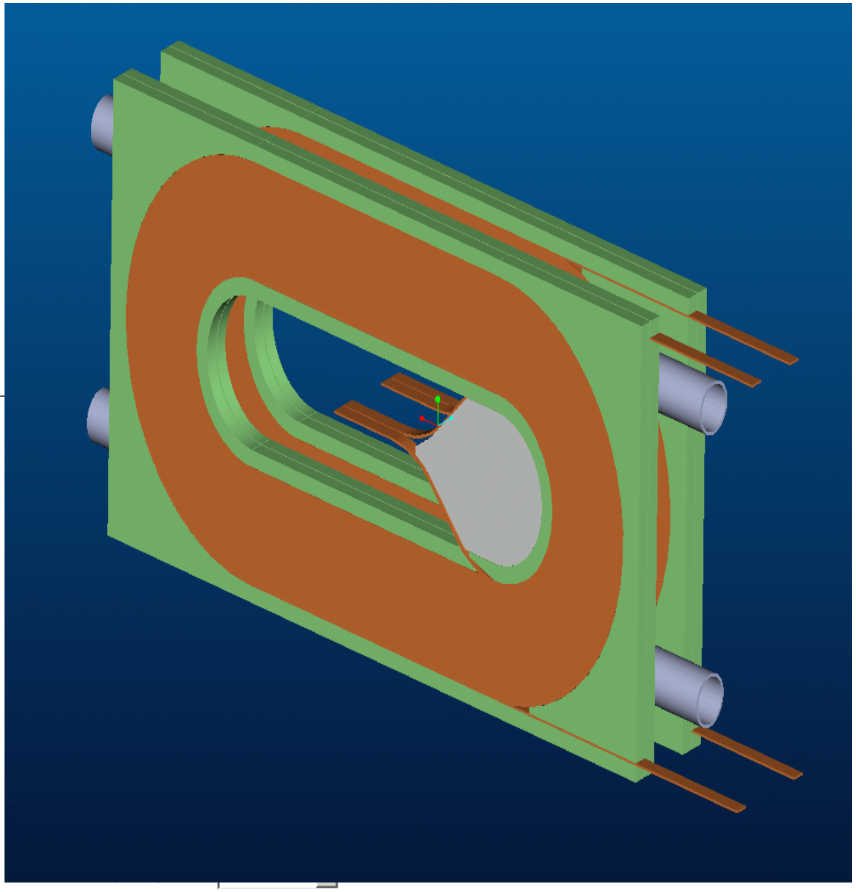
Main Coils of the
Common Coil Concept



A complete cross-section of a common coil dipole.

3-d Model of Common Coil Design





3-d model of simple common coil design

2-in-1 over and under geometry with coil common to two aperture

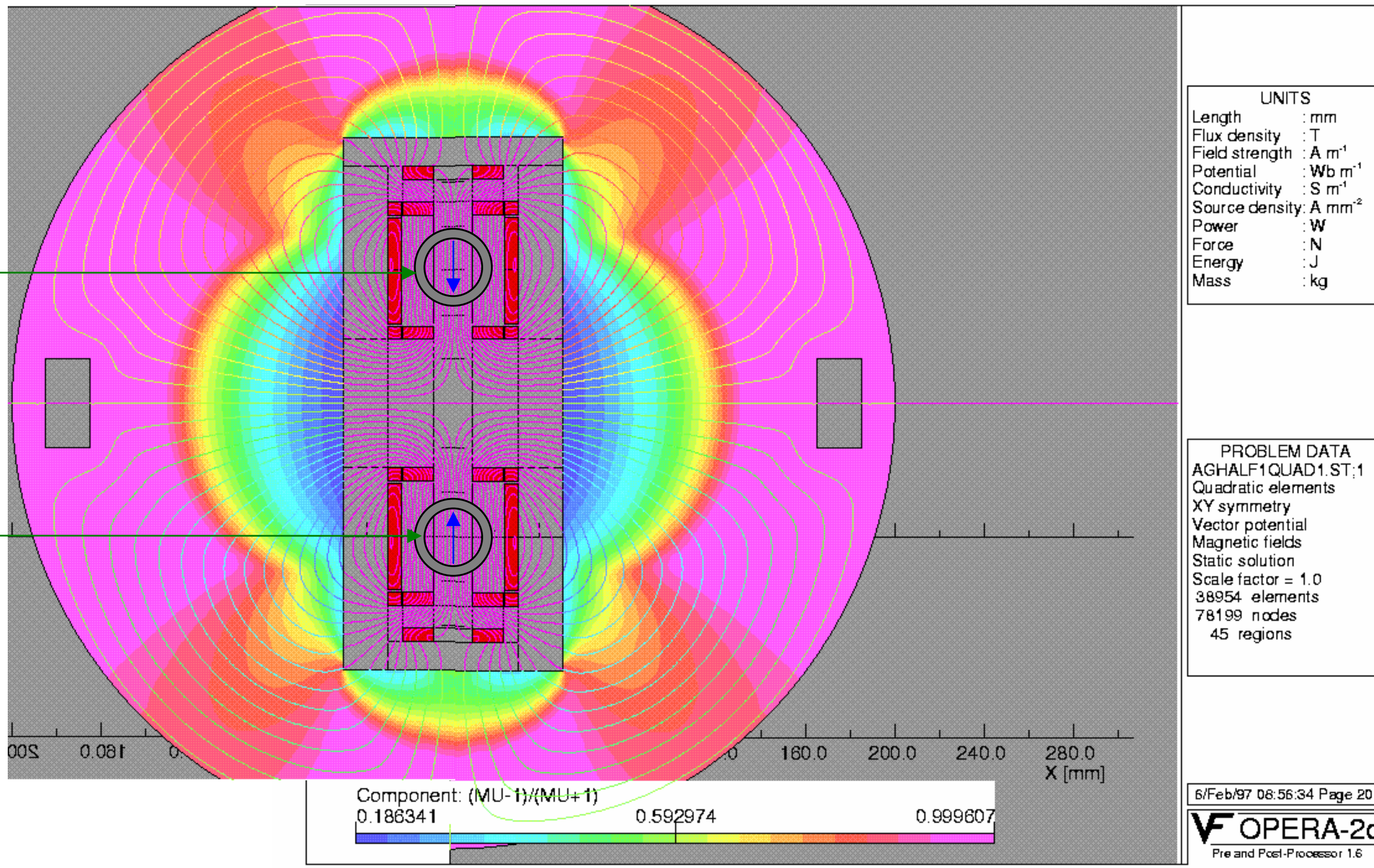
BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

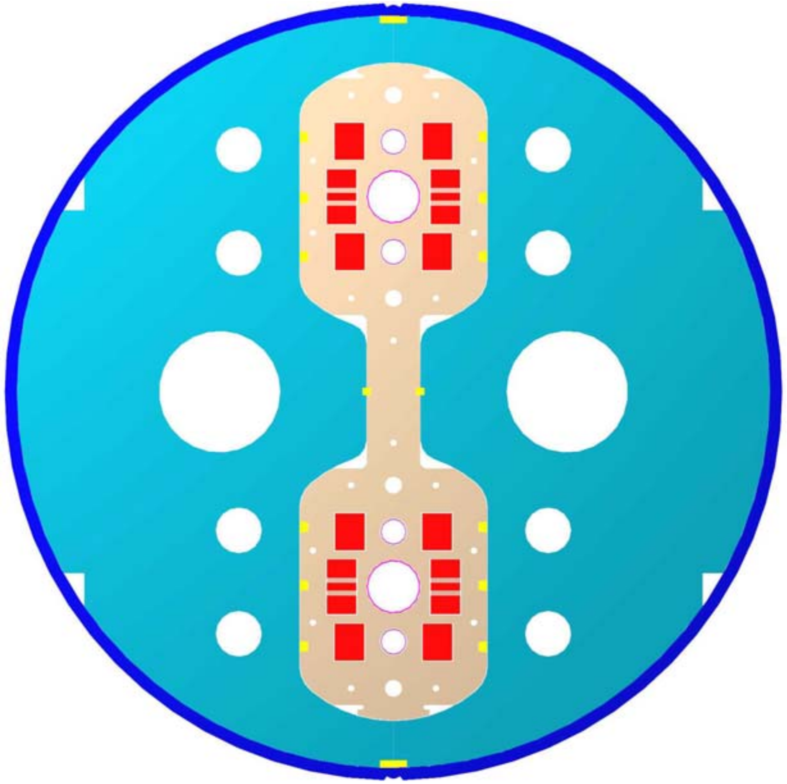
Field Lines at 15 T in a Common Coil Magnet Design

Aperture #1

Aperture #2



Status of R&D on Common Coil Magnets



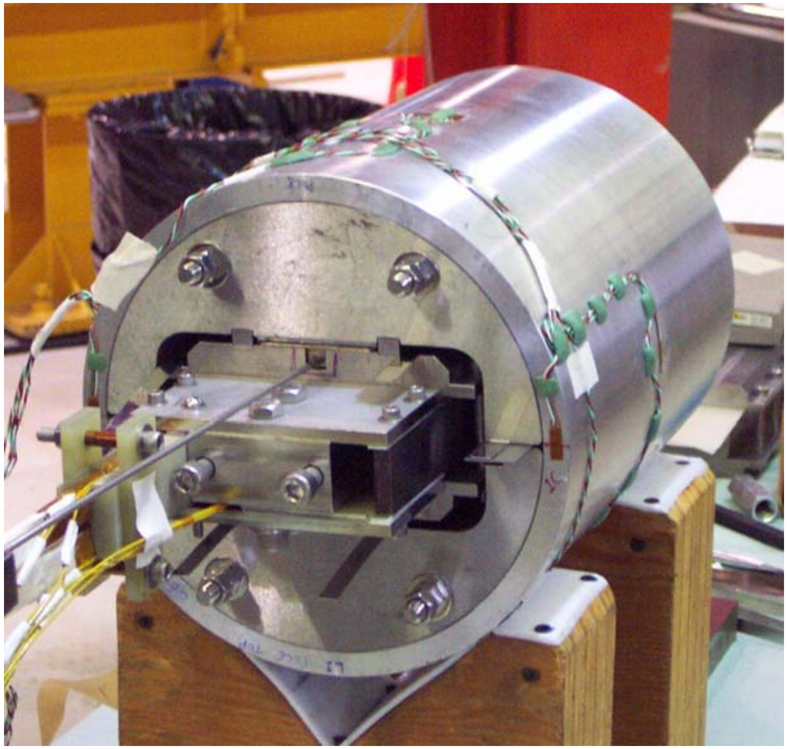
Fermilab Design of Common Coil Magnet for VLHC-2

- 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
- New superconductors (HTS) have been introduced in accelerator magnets
- All three major US labs (BNL, LBL, FNAL) have built magnets based on this design

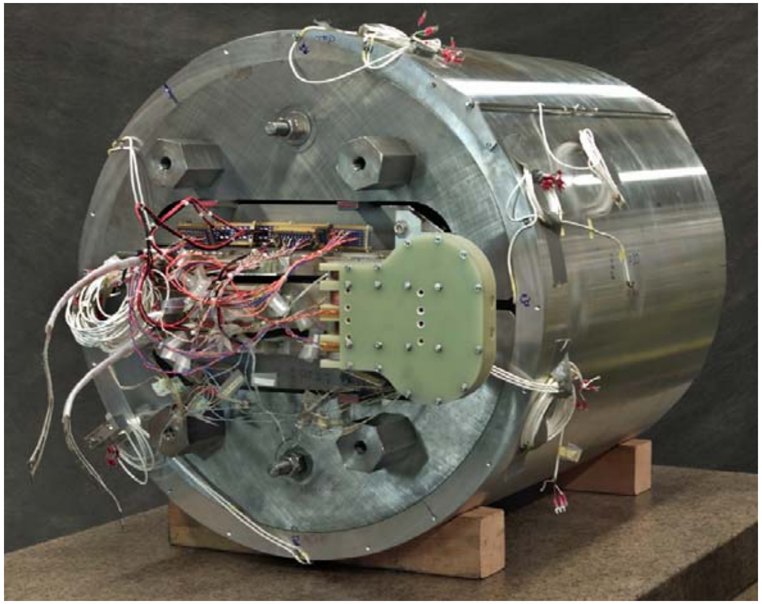
Common Coil Magnets Built at BNL, FNAL, LBNL

BNL

FNAL



LBNL

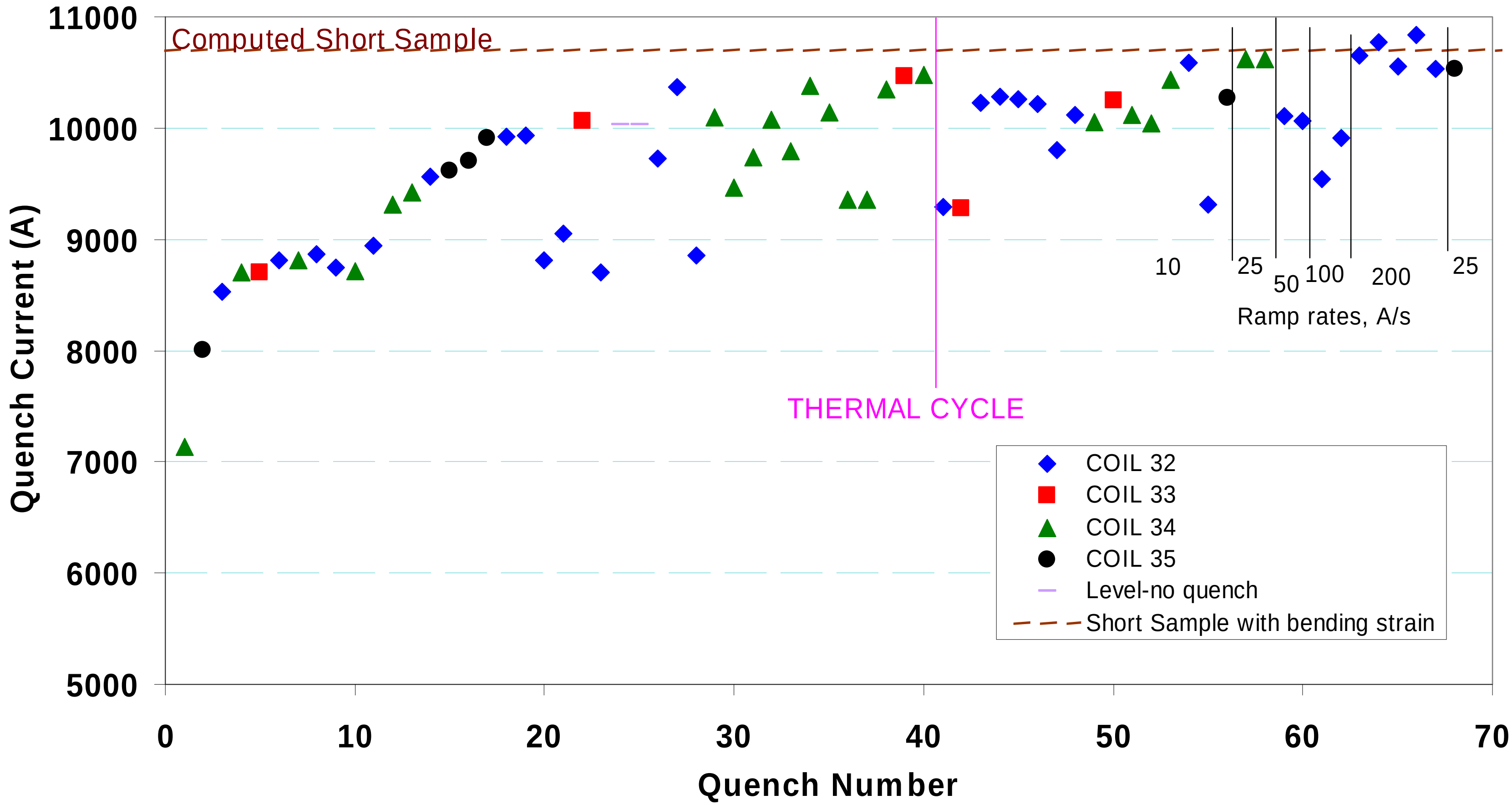


BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

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

Quench Plot of BNL React & Wind Common Coil Dipole DCC017



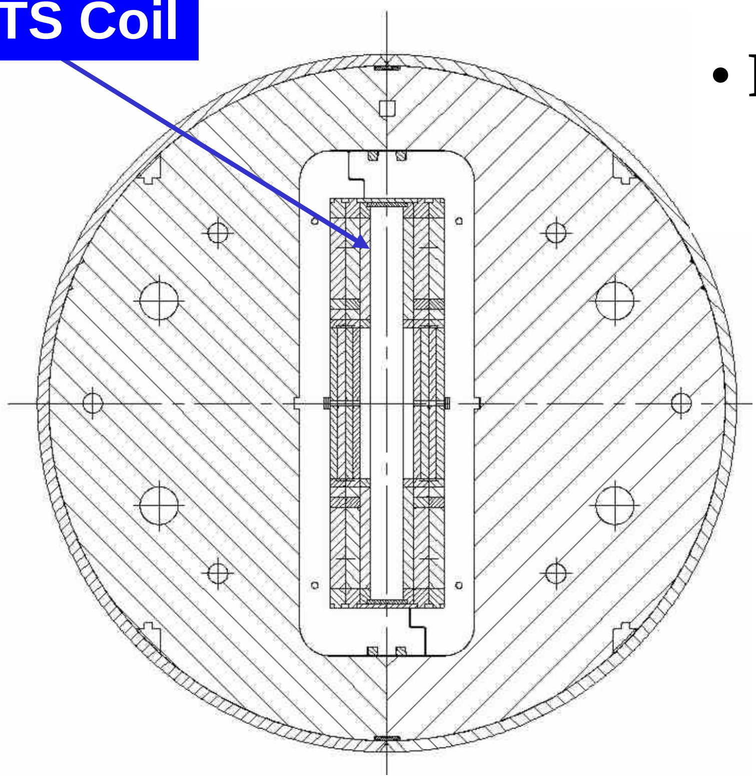
- **Magnet reached short sample after a number of quenches**
  - √ **Reasonable for the first technology magnet**

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.

HTS Coil



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

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

Iron Dominated Common Coil Design

A figure from the 1997 Particle Accelerator Conference Paper

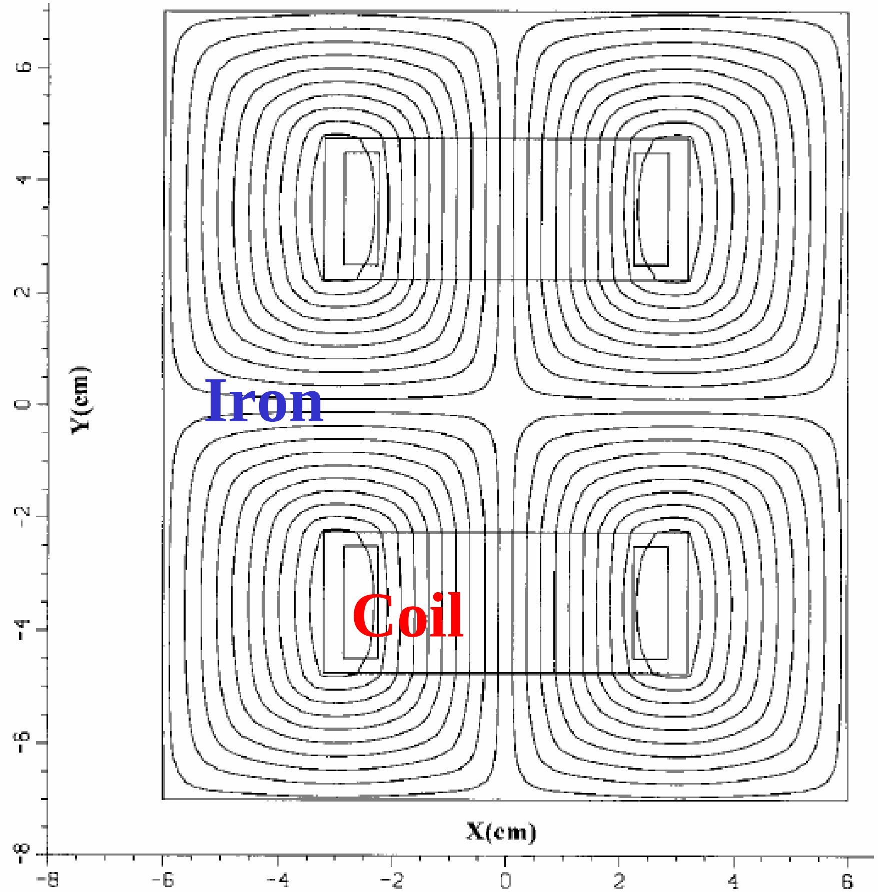


Fig. 5: A proposed low field iron dominated 45 mm x 25 mm aperture 2-in-1 magnet based on the common coil design. The coldmass is shown ~½ scale here.

Common Coil Design for EDM Proposal

In the common coil design for EDM proposal, not only the coils but the electric plates are also common to two apertures.

- **Sketch on the right side from Yannis Semertzidis shows the initial dimensions of electrical plates, etc. inside the vacuum chamber.**
- **The coils and iron must be placed around it to produce ~0.52 T magnetic field.**
- **An initial magnetic design with water-cooled copper coils and iron shield has been developed.**

Warning: Yannis gave me liberty to make vertical spacing larger and I used it. We need to be consistent.

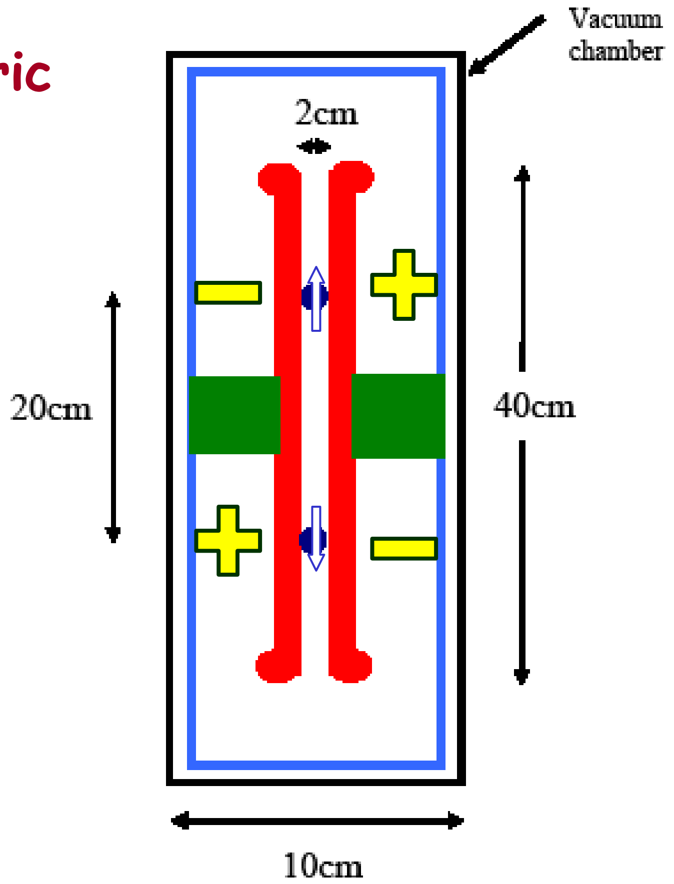
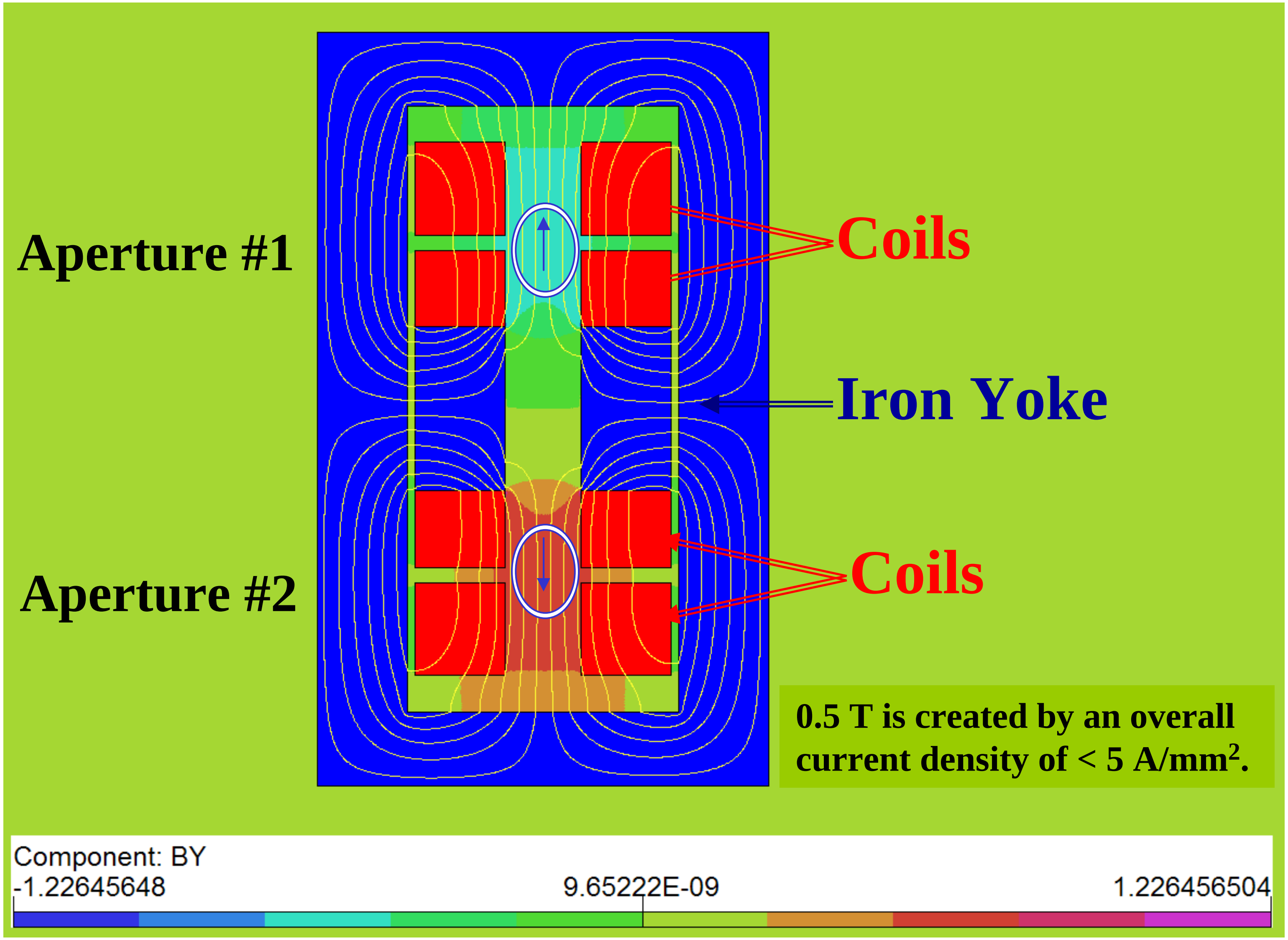
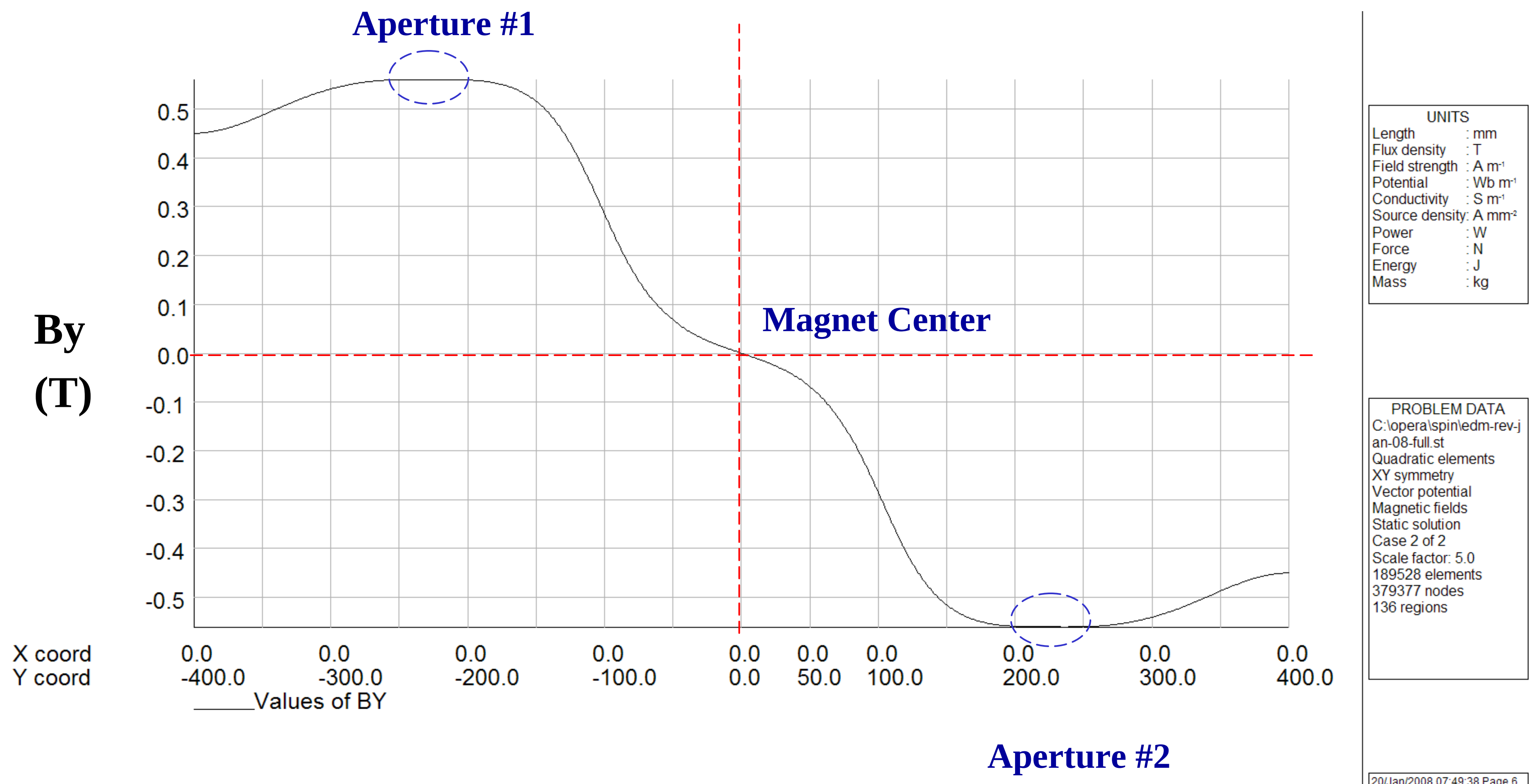


Figure 1. The electrostatic plates (red) are 40cm high separated by 2cm and are supported by the structure support shown in light blue, with high voltage insulators shown in green. This structure is enclosed in the vacuum chamber. The storage beam regions are shown in dark blue, 20 cm apart vertically.

Common Coil Design for EDM



Vertical Field Along the Y-axis



Design Field ~ +0.52 T and ~ -0.52 T

Obtaining Good Field Quality in Common Coil Design for dEDM Proposal

- Strategy for obtaining a good field quality in a common coil magnet is somewhat different from that used either in iron dominated magnets or in conductor dominated magnets.
- In iron dominated magnets, we rely on field perpendicular boundary at the upper and the lower poles to get vertically homogeneous field. We don't have that case here.
- In conductor dominated magnets, we have cosine theta current distribution in a circular coil or use elliptical coils to get ideal vertical field. We don't have that case either.
- In this case, we rely on sort of field parallel boundary to conductor. We use some spacers within the coil to keep the coil height small.

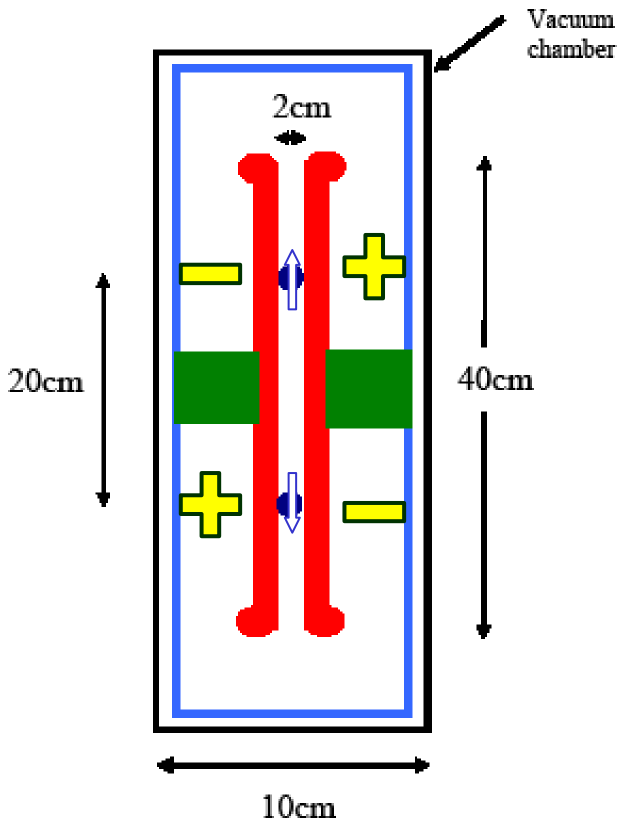
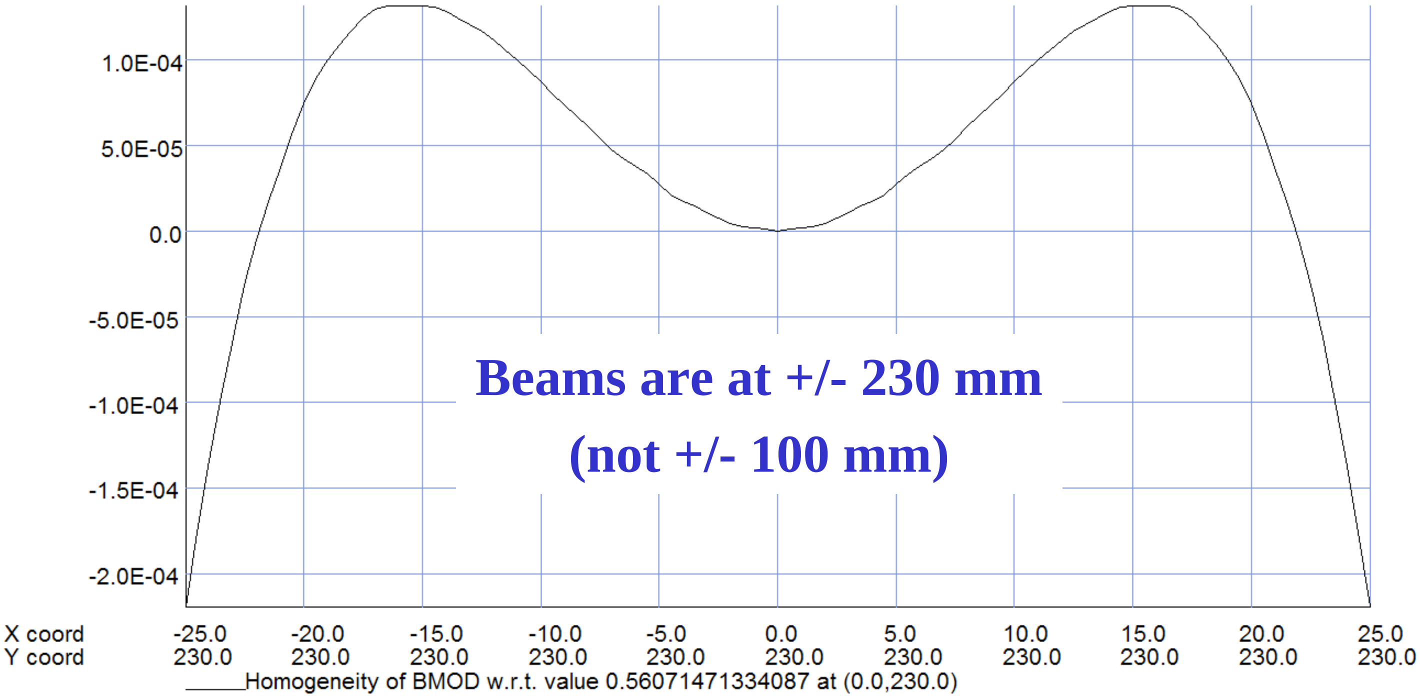


Figure 1. The electrostatic plates (red) are 40cm high separated by 2cm and are supported by the structure support shown in light blue, with high voltage insulators shown in green. This structure is enclosed in the vacuum chamber. The storage beam regions are shown in dark blue, 20 cm apart vertically.

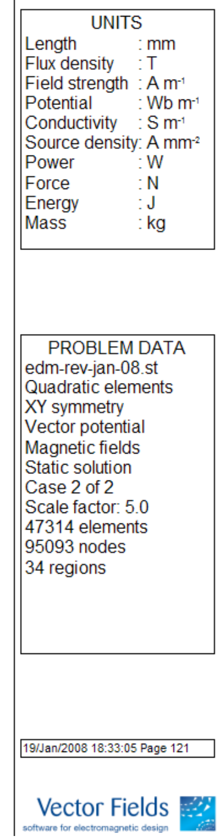
Relative Field Errors on the Horizontal Axis in One Aperture

Proof that a good field quality can be obtained.



Beams are at +/- 230 mm

(not +/- 100 mm)



This preliminary design was presented in the last meeting.

Field errors are displayed for +/- 25 mm. Actual beam size is much smaller.

Also, this is an easy way to evaluate overall field quality, but in a more detailed design and analysis, field errors in terms of harmonics are examined.

Field Harmonics at 10 mm Radius (harmonics are in units of 10^{-4})

- The following is for the design presented in the last meeting.
- Field errors are given in terms of harmonic at 10 mm radius (20 mm aperture).
- Note: Harmonics are in the units of 10^{-4} (means the field errors are part in 10^4).

BY 0.11212 TF 0.33300

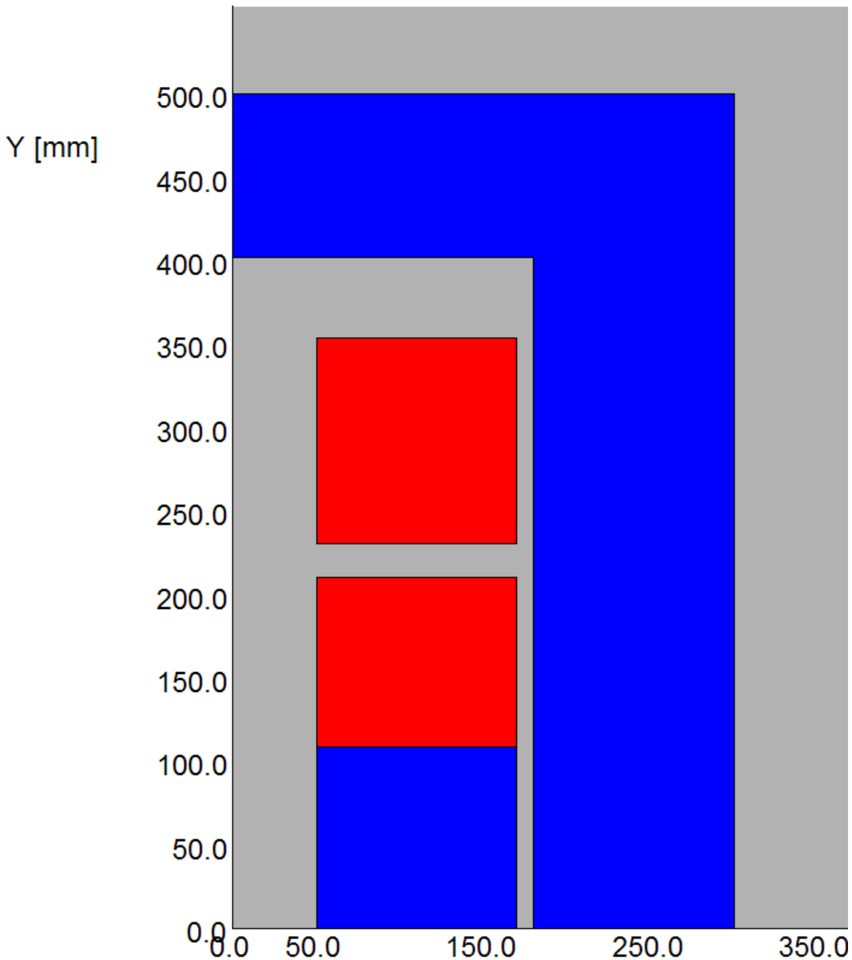
N	SKEW(an)	NORMAL(bn)
1	-3.397	0.000
2	0.000	0.841
3	0.502	0.000
4	0.000	-0.310
5	-0.004	0.000
6	0.000	-0.005
7	0.000	0.000
8	0.000	0.000
9	0.000	0.000
10	0.000	0.000
11	0.000	0.000
12	0.000	0.000
13	0.000	0.000
14	0.000	0.000

Except for skew quad, all harmonics are less than one part in 10^4.

BY 0.56055 TF 0.33296

N	SKEW(an)	NORMAL(bn)
1	-3.524	0.000
2	0.000	0.850
3	0.503	0.000
4	0.000	-0.310
5	-0.004	0.000
6	0.000	-0.005
7	0.000	0.000
8	0.000	0.000
9	0.000	0.000
10	0.000	0.000
11	0.000	0.000
12	0.000	0.000
13	0.000	0.000
14	0.000	0.000

Design to Reduce Field Harmonics



- Several design iterations were carried out since the last meeting.
- The beams are at +/- 220 mm.
- The design on left produces all harmonics (including the skew quadrupole harmonic, which is the reflection of broken top-bottom symmetry) below 1 part in 10^4.
- Interestingly, we are trying to eliminate skew quad harmonic from a magnet which is basically a skew quadrupole magnet.

Field Harmonics at 10 mm Radius (harmonics are in units of 10^{-4})

- The following is for the new iterated design.
- Field errors are given in terms of harmonic at 10 mm radius (20 mm aperture)
- Note: Harmonics are in the units of 10^{-4} (means the field errors are part in 10^{4})

BY	TF
0.11102	0.33178

N	SKEW(an)	NORMAL(bn)
1	-0.09	0.00
2	0.00	0.32
3	-0.66	0.00
4	0.00	-0.23
5	-0.03	0.00
6	0.00	0.00
7	0.00	0.00
8	0.00	0.00
9	0.00	0.00
10	0.00	0.00
11	0.00	0.00
12	0.00	0.00
13	0.00	0.00
14	0.00	0.00

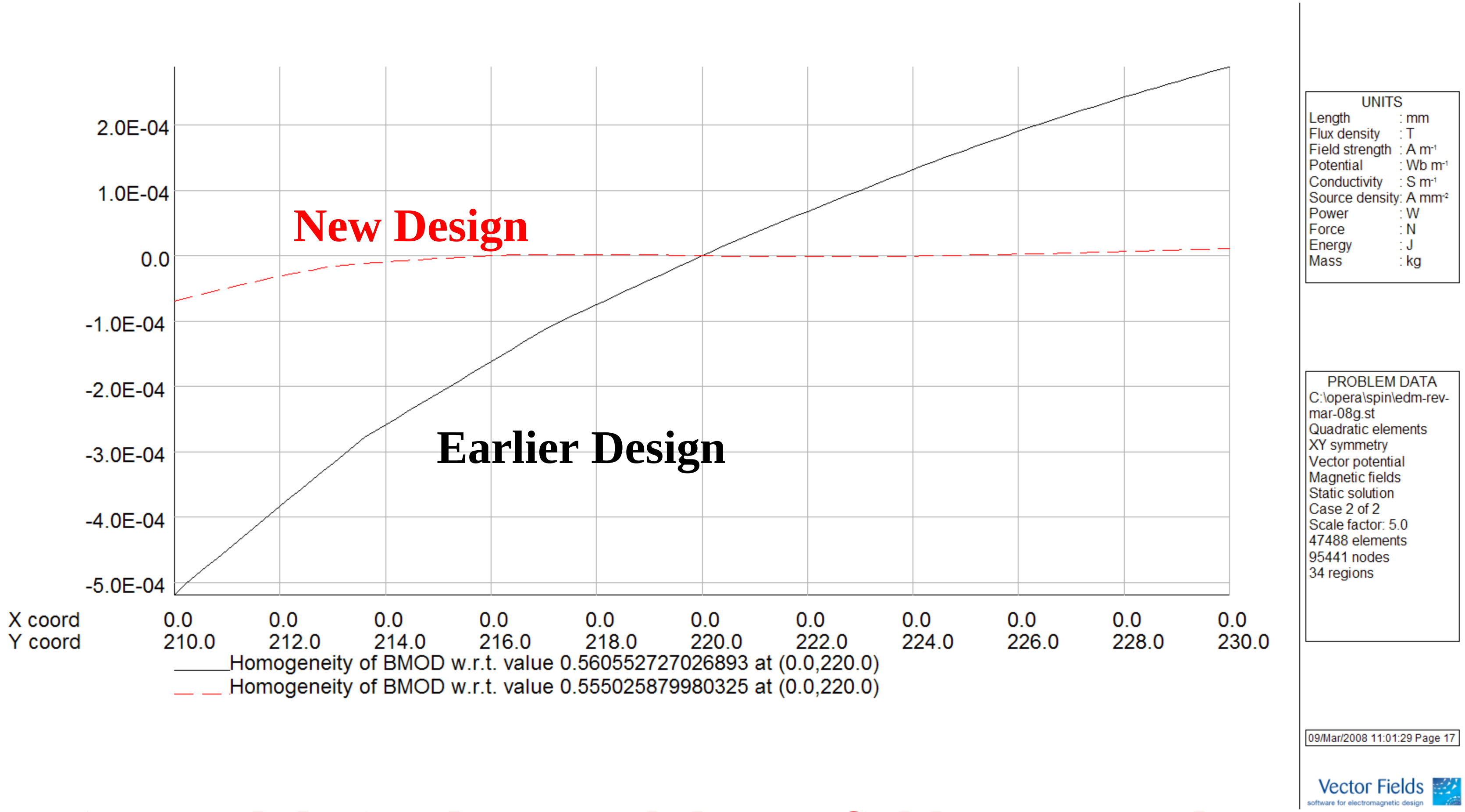
All harmonics, including skew quad, are less than 1 part in 10^{4}.

May be field quality is too good. May be we can tolerate larger errors and make magnets smaller and cheaper.

BY	TF
0.55503	0.33175

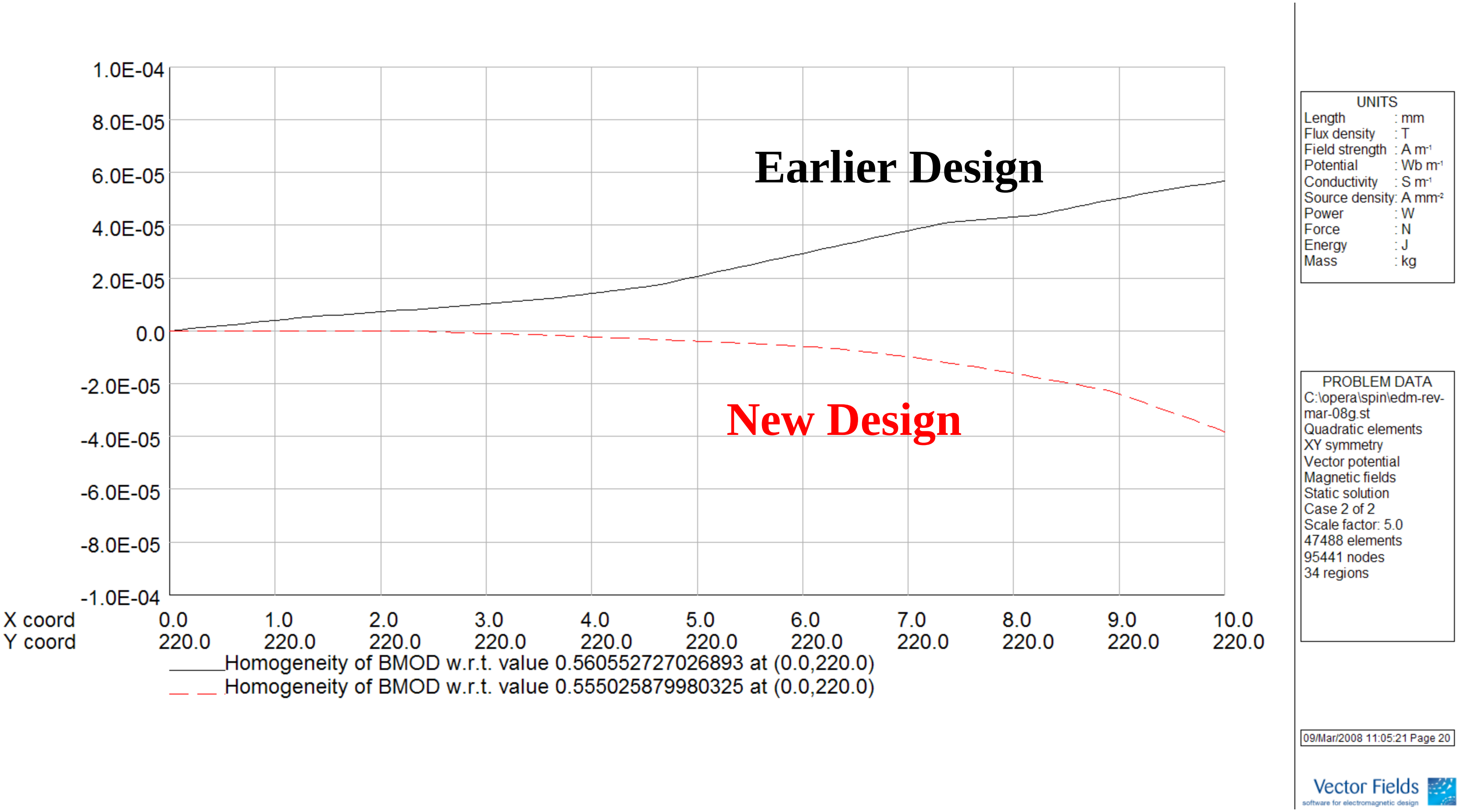
N	SKEW(an)	NORMAL(bn)
1	-0.19	0.00
2	0.00	0.33
3	-0.66	0.00
4	0.00	-0.23
5	-0.03	0.00
6	0.00	0.00
7	0.00	0.00
8	0.00	0.00
9	0.00	0.00
10	0.00	0.00
11	0.00	0.00
12	0.00	0.00
13	0.00	0.00
14	0.00	0.00

Relative Field Error on the Vertical axis of the Aperture



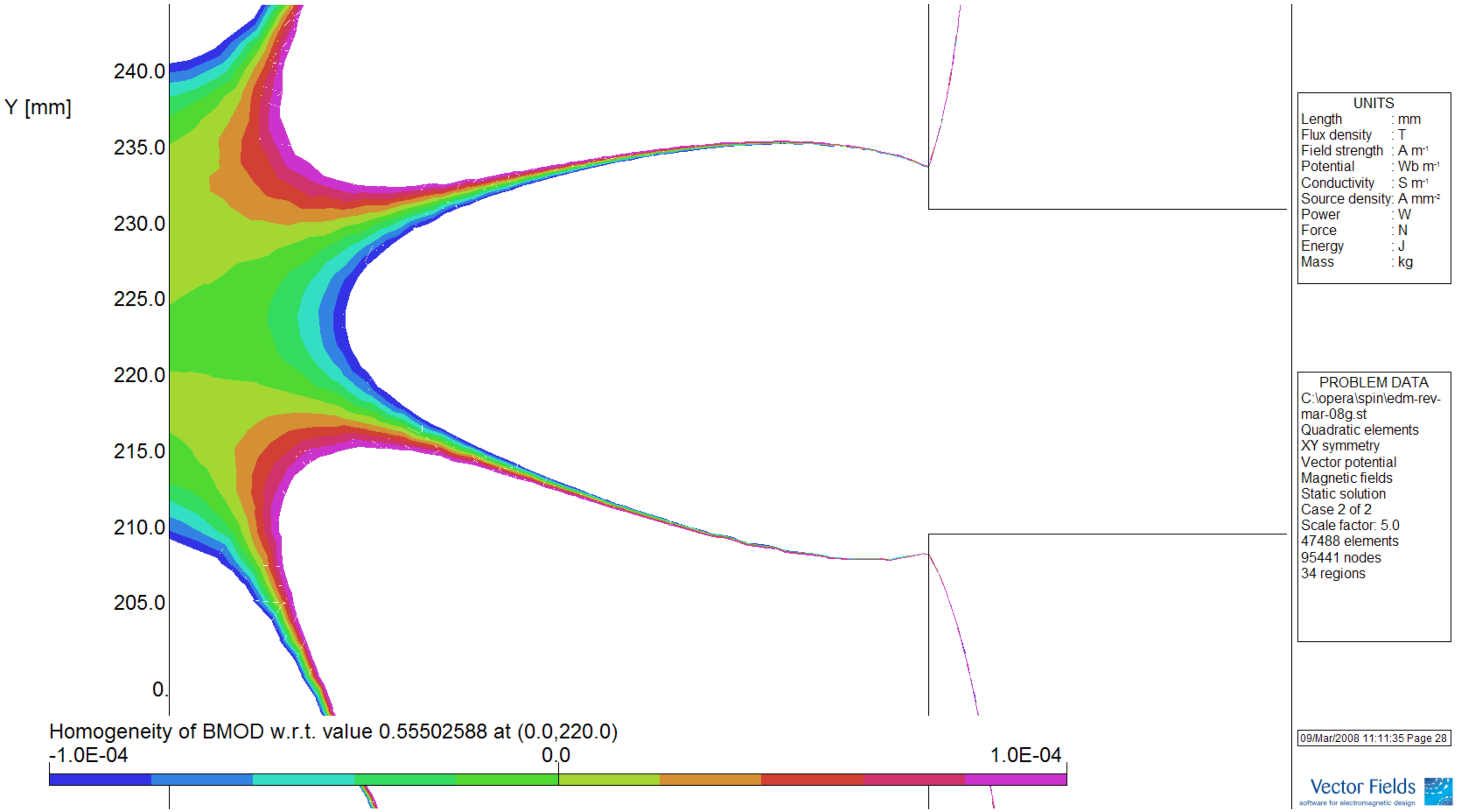
New iterated design has much lower field error on the vertical axis – a reflection of lower skew harmonic.

Relative Field Error on the Horizontal axis of the Aperture

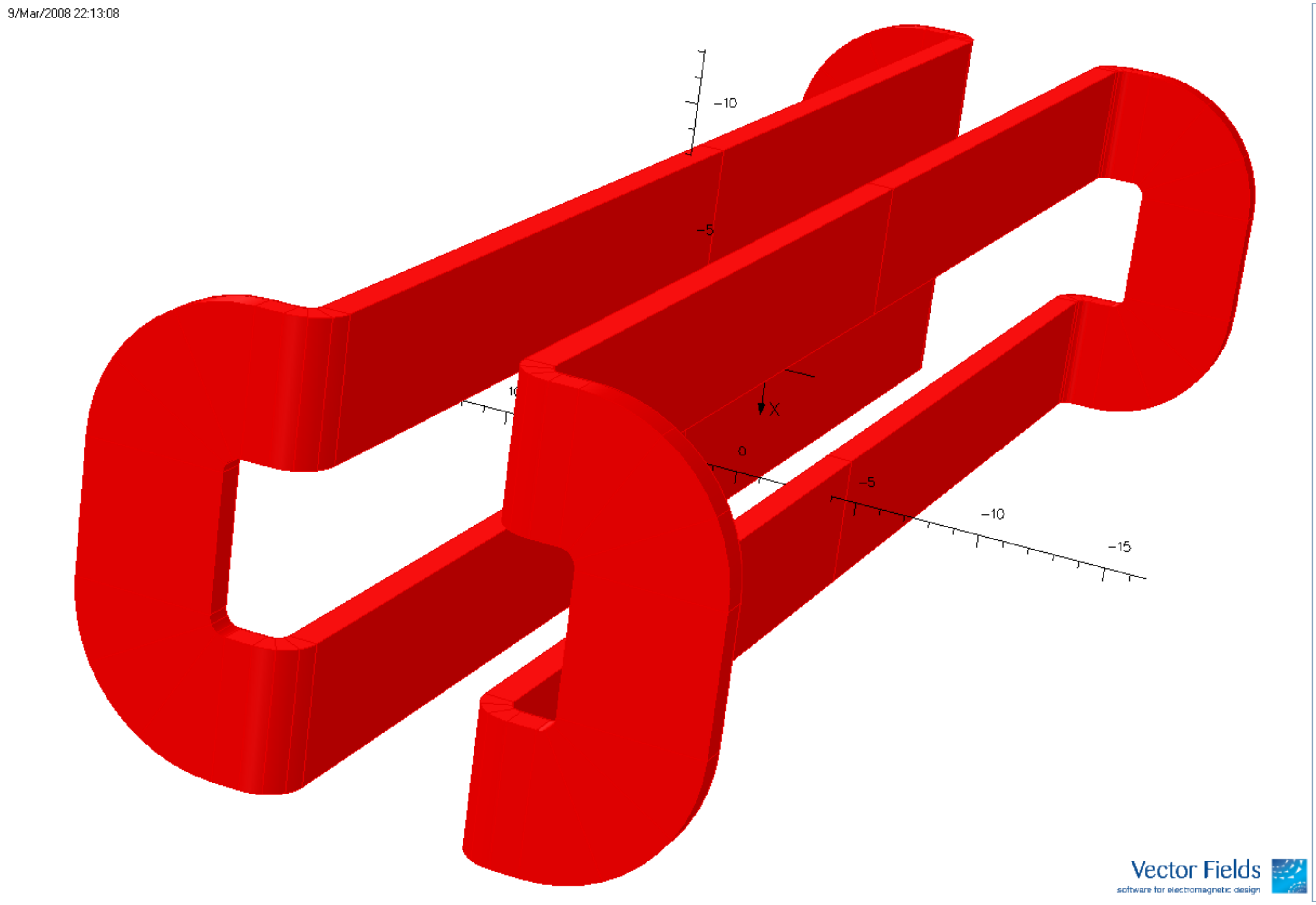


Both designs have small field errors on the horizontal axis – a reflection of low normal harmonics in both cases.

Relative Field Error in the Right-half of the Upper Aperture



Possible Use of Saddle Coil for Efficient Use of Space



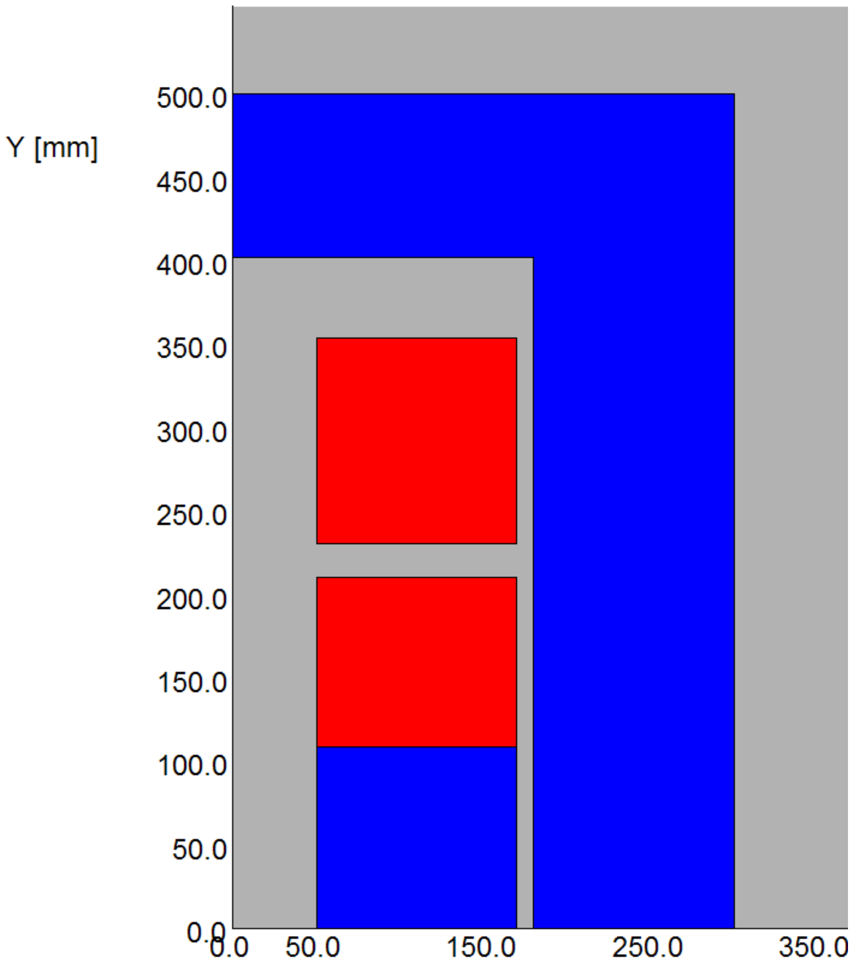
UNITS	
Length	cm
Magn Flux Density	gauss
Magn Field	oersted
Magn Scalar Pot	oersted cm
Magn Vector Pot	gauss cm
Elec Flux Density	C cm^{-2}
Elec Field	V cm^{-1}
Conductivity	S cm^{-1}
Current Density	A cm^{-2}
Power	W
Force	N
Energy	J
Mass	g

PROBLEM DATA
1 conductor

Field Point Local Coordinates
Local = Global

Note: In reality, the coils will be curved to match the saggitta of the yoke.

Some Thoughts on Magnet (and system) Size



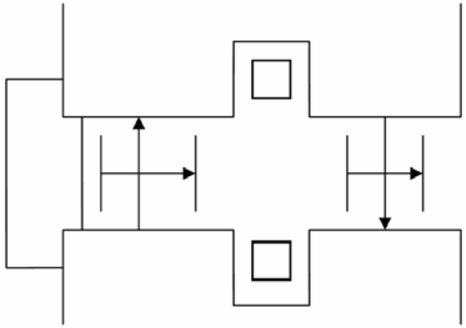
- Magnet size is determined by the coil.
- We need certain coil volume (height and width) to generate certain field. As compared to 2004 proposal, this magnet has higher field (but less total length).
- Taller coils keep field straight (field parallel condition) and hence make field uniform.
- Larger beam separation reduces cross talk (broken top-bottom symmetry).
- I doubt if the beam separation can be smaller than 30 cm. It is more likely closer to be 35-40 cm.

Magnet Costs (crude estimates)

Storage Ring

Costs from 2004 proposal

16 dipole magnets @ $50 K each	$800 K
48 quadrupole magnets @ $25 K each	1,200 K
32 sextupole magnets @ $15 K each	480 K
Dipole power supply	250 K
Quadrupole magnet power suppply	250 K
RF cavity & associated equipment	75 K
Vacuum & vacuum instrumentation	1,100 K
16 electric field regions with power supplies	1,500 K
Controls	240 K
Beam Instrumentation	500 K
Sub-Total	**$6,395 K**
Including Burdens	**$18,800 K**



Bo = 0.21 T

- **Magnet cost in 2004 proposal was $50 k each.**
- **Based on quotes for NSLS2 from different vendors (which varies as much as a factor of three), and a guess on what above magnet was, this seems reasonable.**
- **Present magnet is larger than the 2004 magnet. The cost should be about 2 times.**
- **However, we still have to work on the details. There seems to be way to make the magnet smaller to reduce cost. But the first magnet cost more.**
- **The bottom line is that we are in the ball park for magnet #2 onward.**

SUMMARY

- **Common Coil Dipole Design offers a valuable option for EDM proposal.**

- **Common vertical electrical plates offer better time dependent E-field cancellation (as pointed out in the proposal).**

- **A reasonable 2-d design has been developed. It meets the stated field quality requirements. But the beam spacing is about 2X (40+ cm instead of 20 cm).**

- **Detailed design work is yet to be carried out. That may result in a more optimized design. The beam spacing can be reduced to reduce the system cost.**