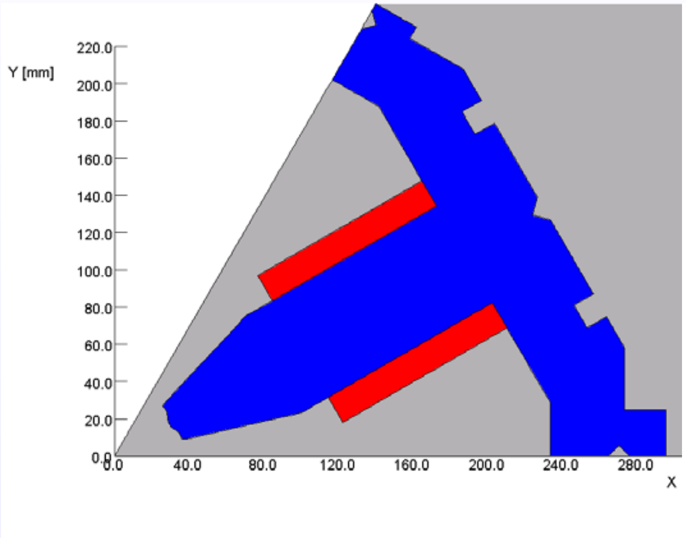
Recent Progress in Magnetic Analysis

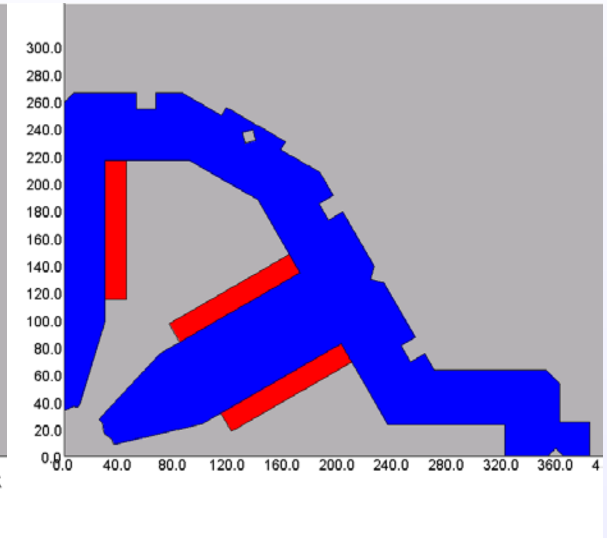
Ramesh Gupta

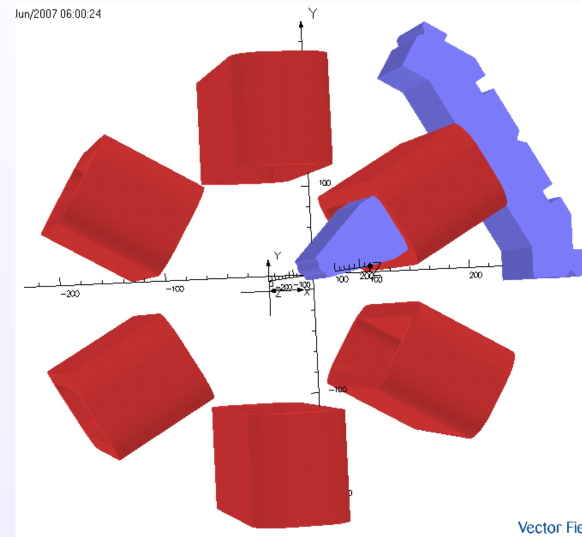
BROOKHAVEN NATIONAL LABORATORY

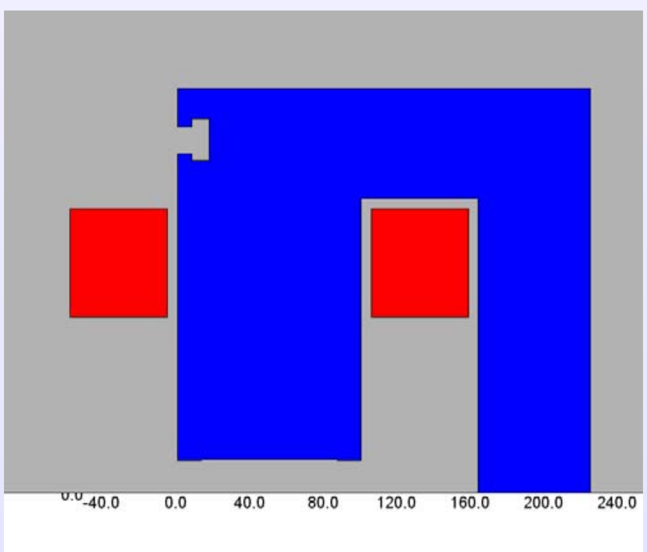
Superconducting
Magnet Division

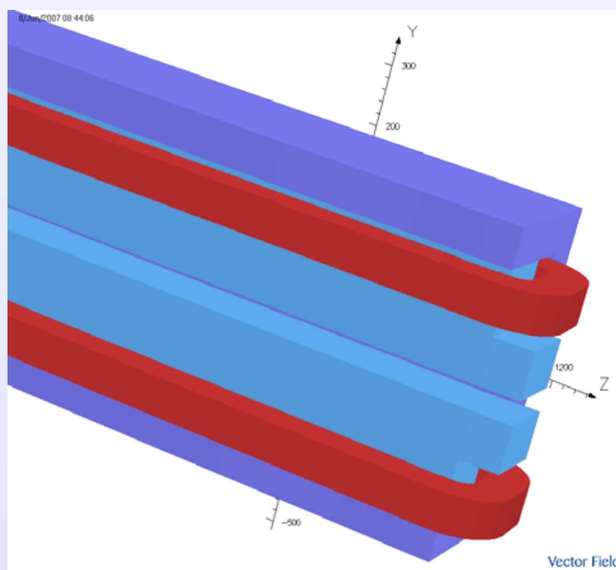
Recent Magnetic Models

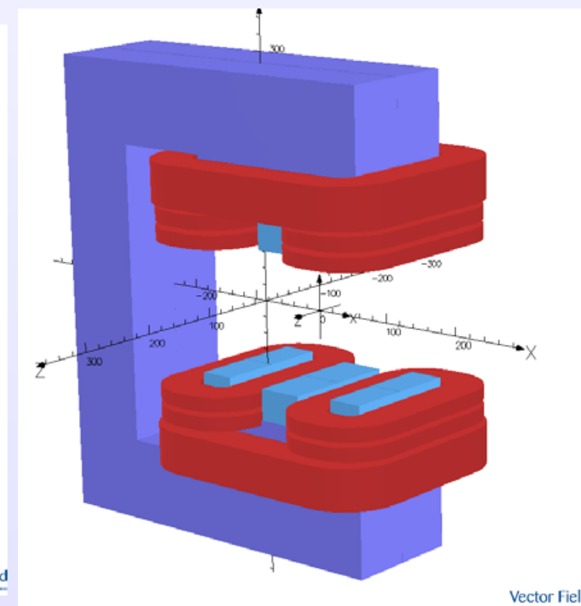












SLS Sextupole

Preliminary results of modeling and analysis

(sorry if I am not up-to-date, as I was not involved in this or any other LS2 sextupole work before this week)

Caution:

Beware of the computer models with dimensions based on tape measure

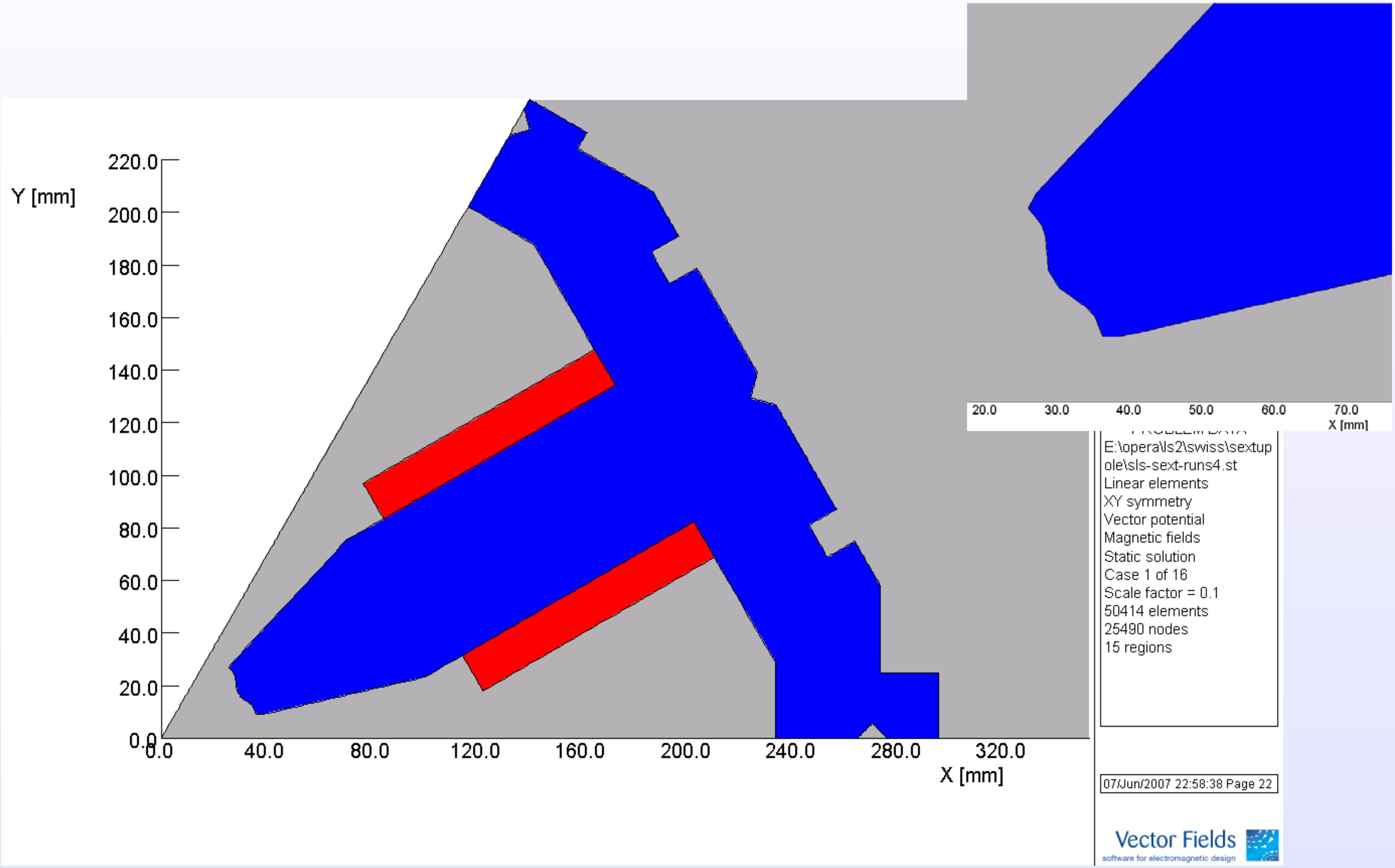
✓ **An easy and sure way to get an "F", if you come to my class.**

Models will be presented that are based on drawing.

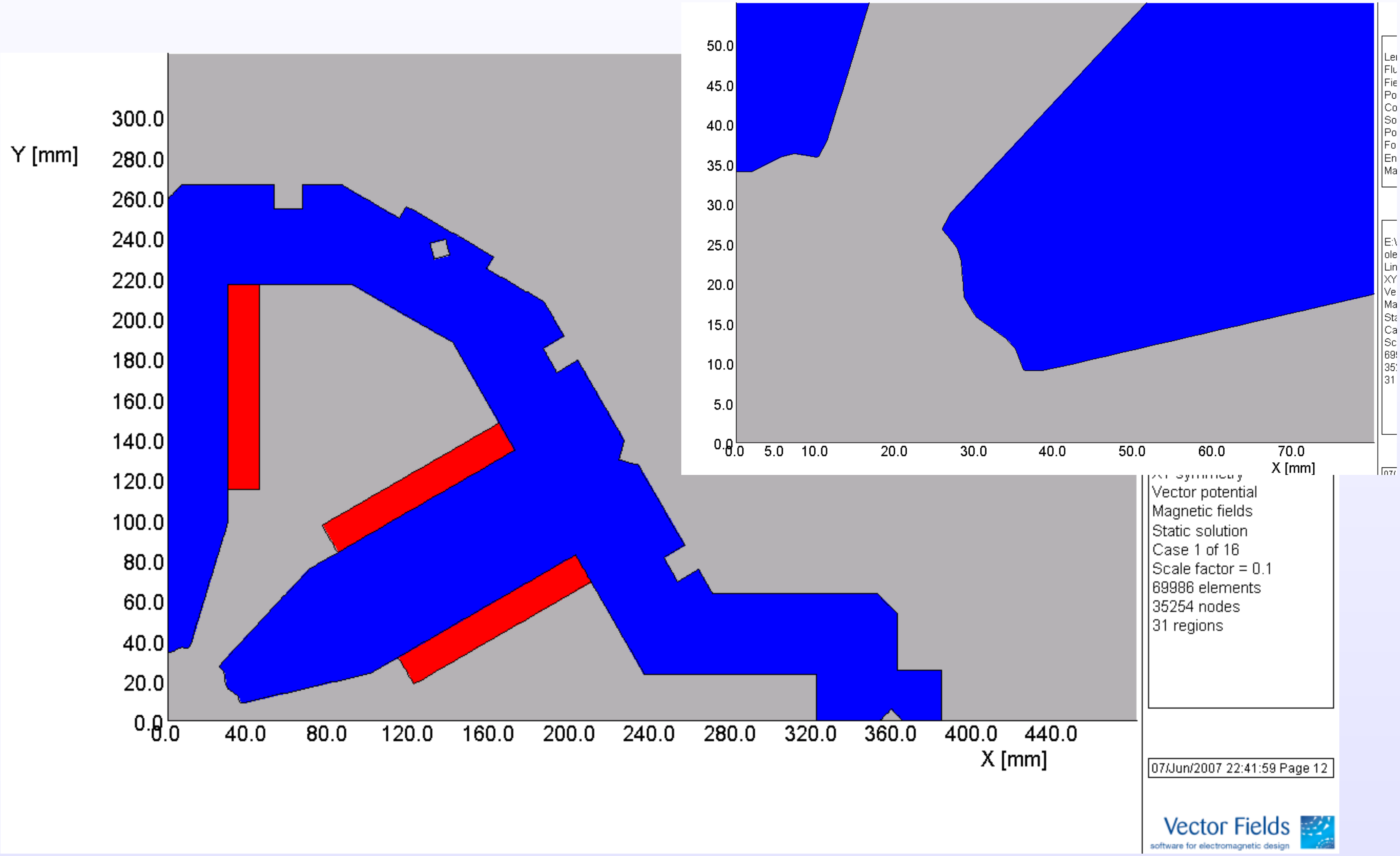
But beware, true magnet experts don't held the quality of their magnet hostage to the drawings. They would make adjustments in magnets whether the adjustments in drawings are made or not (story based on true experience in RHIC magnets).

Specifically, in this case, end profile shaping is not indicated in drawings.

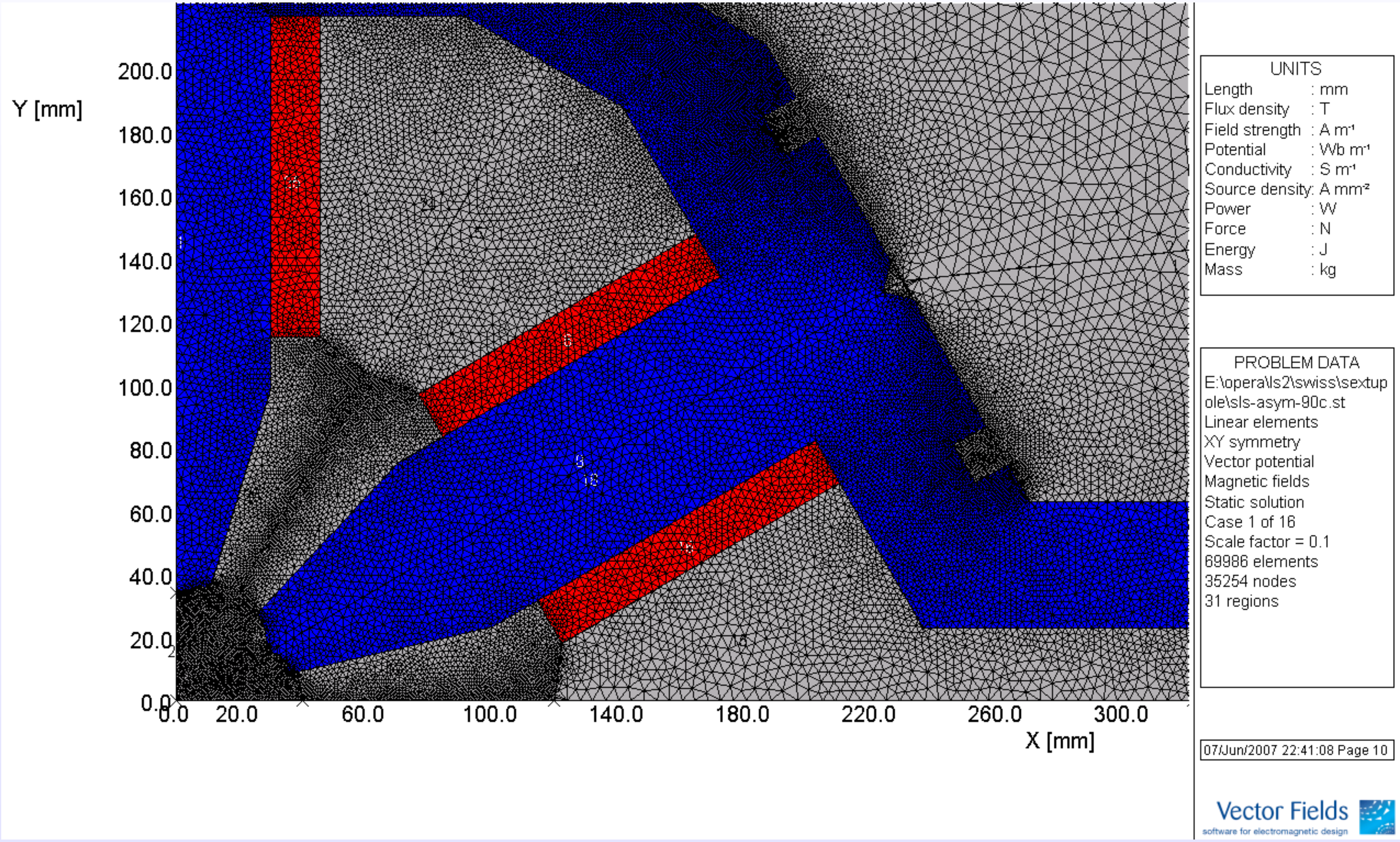
SLS Symmetric 2-d Model



SLS Sextupole with Broken Symmetry



Mesh to Obtain Good Results

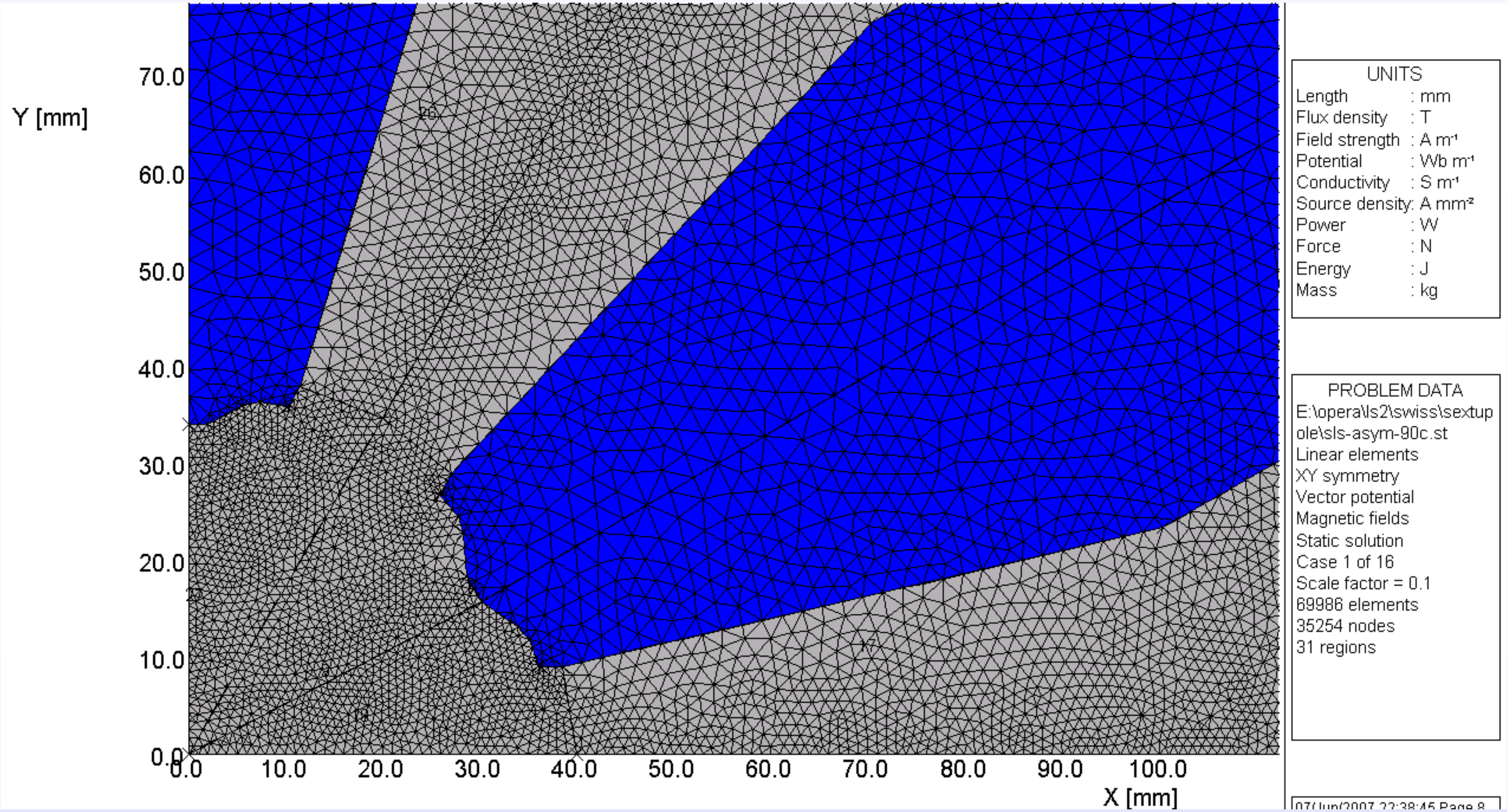


Mesh For Good Harmonic Analysis

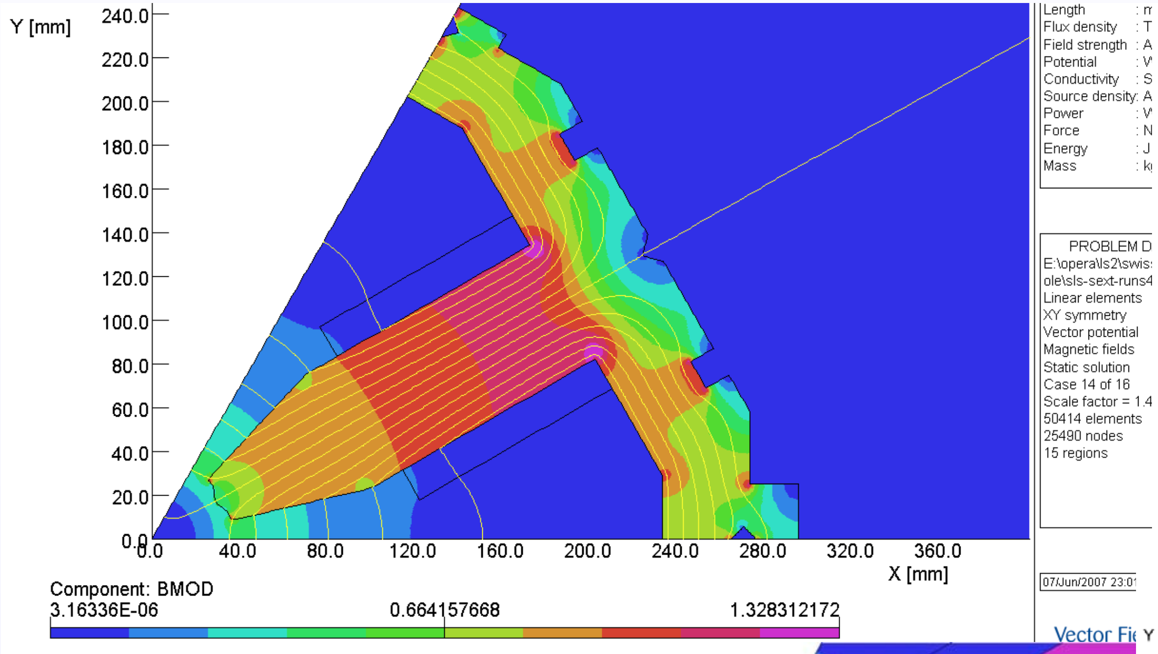
Make denser mesh in the region where harmonic analysis is performed

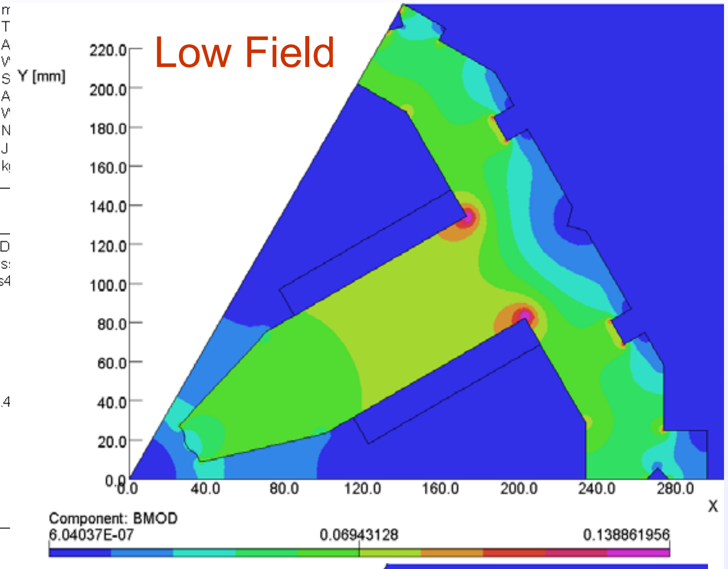
- 30 mm is field integration radius and 25 mm is reference radius.

It should be as large as possible but should be several mesh point away from source terms



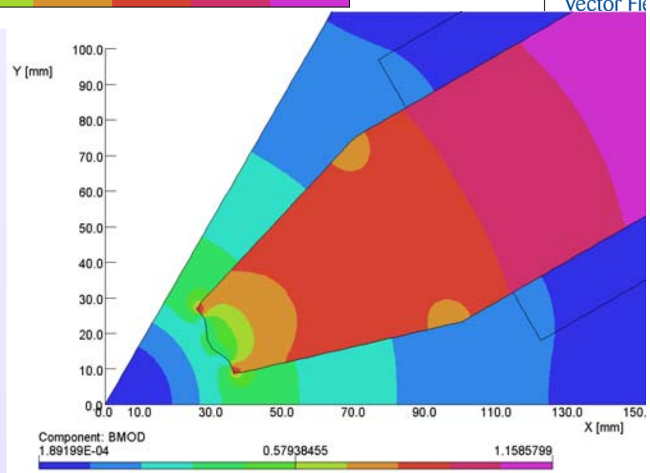
Magnetic Analysis of Symmetric Case

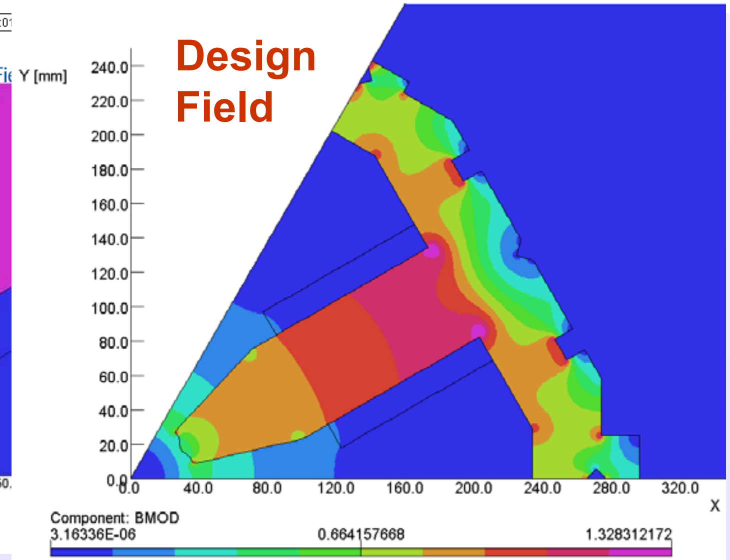




Note:

Allowed harmonic should not change too much between symmetric case and in the model that is being measured (if the real pole profile is similar to that in drawing).





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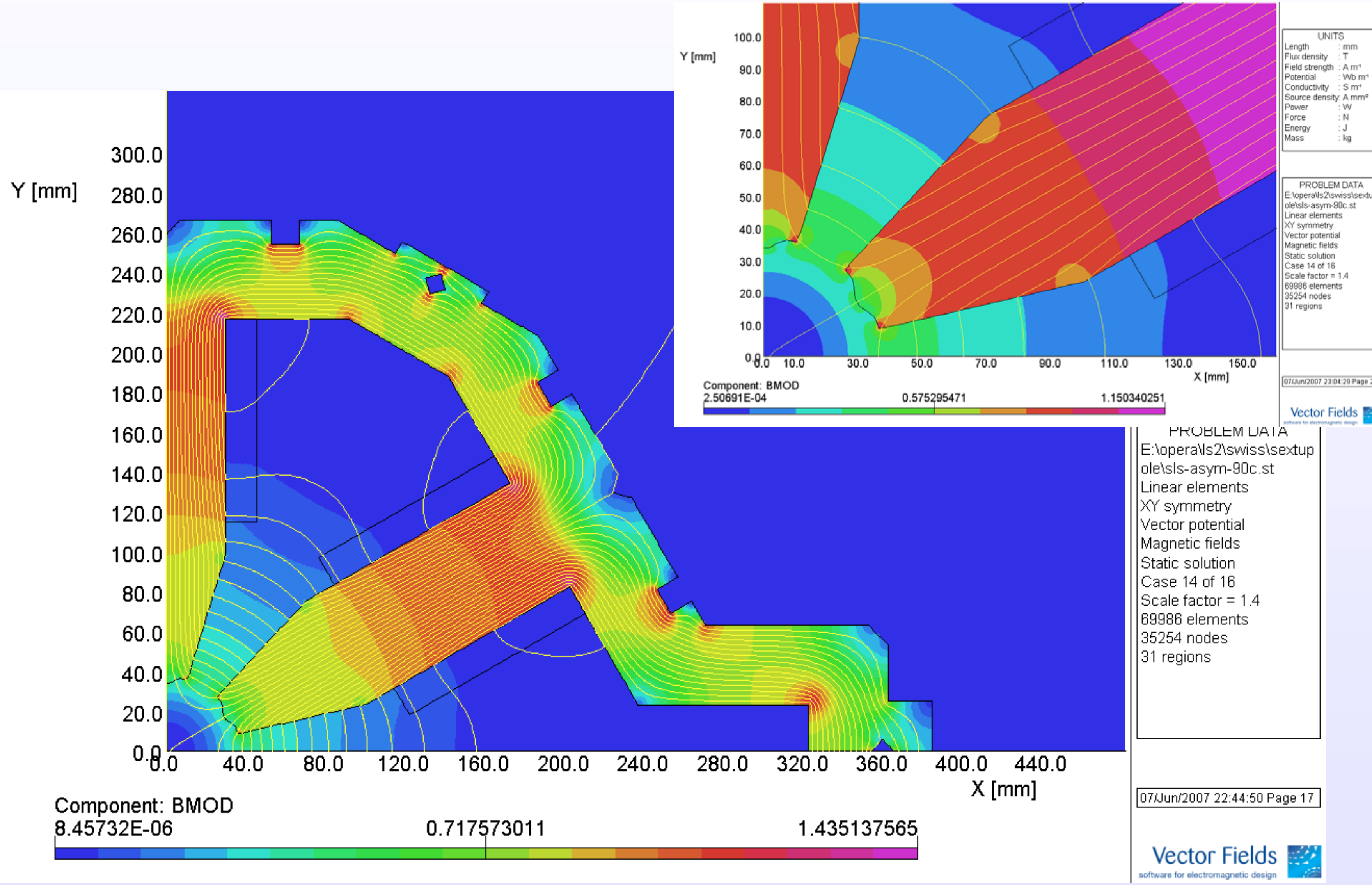
Results of Harmonic Analysis

Case	Scale	C3(Fundamental),T	C3/A (T/kA)*X	b3	b9	b15	b21
1	0.1	0.01452	1.4525	10000	-1.36	7.74	-3.57
2	0.2	0.02905	1.4525	10000	-1.36	7.74	-3.57
3	0.3	0.04357	1.4525	10000	-1.36	7.74	-3.57
4	0.4	0.05810	1.4525	10000	-1.36	7.74	-3.57
5	0.5	0.07262	1.4525	10000	-1.36	7.74	-3.57
6	0.6	0.08715	1.4525	10000	-1.36	7.74	-3.57
7	0.7	0.10167	1.4524	10000	-1.36	7.74	-3.57
8	0.8	0.11619	1.4524	10000	-1.36	7.74	-3.57
9	0.9	0.13070	1.4522	10000	-1.36	7.74	-3.57
10	1	0.14519	1.4519	10000	-1.36	7.74	-3.57
11	1.1	0.15966	1.4514	10000	-1.36	7.74	-3.57
12	1.2	0.17411	1.4509	10000	-1.37	7.74	-3.57
13	1.3	0.18853	1.4503	10000	-1.37	7.74	-3.57
14	1.4	0.20292	1.4494	10000	-1.38	7.74	-3.57
15	1.5	0.21726	1.4484	10000	-1.38	7.74	-3.57
16	1.6	0.23153	1.4470	10000	-1.38	7.74	-3.57

- A very good agreement between calculations and measurements is accidental (don’t get too spoiled) as many things are not included.
- Note harmonics are given at 25 mm reference radius.
  - The magnitude of higher order harmonics is very sensitive to that **(r^n)**

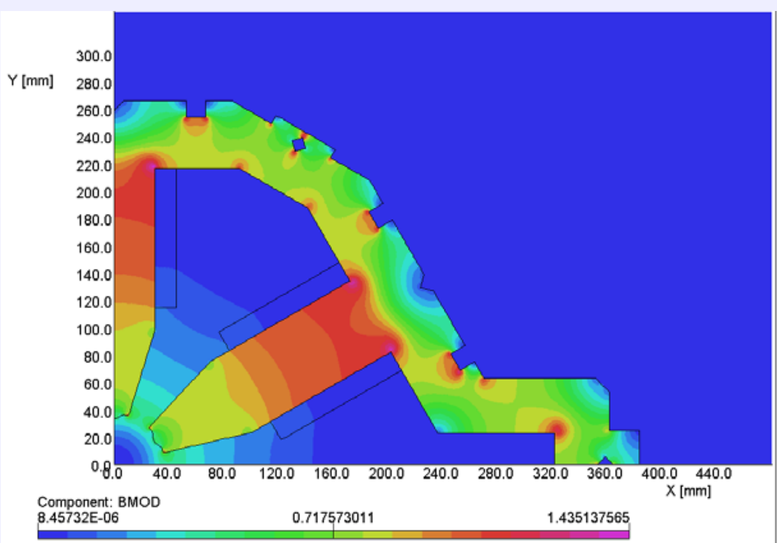
Broken Symmetry Model



Asymmetric SLS Sextupole

Don't even try to read these numbers.

Case	Scale	C3(Fundamental),T	C3/A (T/kA)	1	3	5	7	9	11	13	15	17	19	21
1	0.1	0.01	1.45	-28.07	10000.00	-14.45	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
2	0.2	0.03	1.45	-28.07	10000.00	-14.45	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
3	0.3	0.04	1.45	-28.07	10000.00	-14.45	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
4	0.4	0.06	1.45	-28.07	10000.00	-14.45	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
5	0.5	0.07	1.45	-28.09	10000.00	-14.46	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
6	0.6	0.09	1.45	-28.11	10000.00	-14.46	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
7	0.7	0.10	1.45	-28.16	10000.00	-14.47	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
8	0.8	0.12	1.45	-28.24	10000.00	-14.49	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
9	0.9	0.13	1.45	-28.36	10000.00	-14.51	5.99	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
10	1	0.15	1.45	-28.53	10000.00	-14.55	5.98	-5.11	1.98	0.23	7.64	0.11	0.14	-3.70
11	1.1	0.16	1.45	-28.71	10000.00	-14.59	5.98	-5.11	1.99	0.23	7.64	0.11	0.14	-3.70
12	1.2	0.17	1.45	-29.00	10000.00	-14.64	5.97	-5.11	1.99	0.23	7.64	0.11	0.14	-3.70
13	1.3	0.19	1.45	-29.43	10000.00	-14.73	5.97	-5.11	1.99	0.23	7.64	0.11	0.14	-3.70
14	1.4	0.20	1.45	-29.94	10000.00	-14.84	5.96	-5.12	1.99	0.23	7.64	0.11	0.14	-3.70
15	1.5	0.22	1.45	-30.49	10000.00	-14.95	5.94	-5.12	1.99	0.23	7.64	0.11	0.14	-3.70
16	1.6	0.23	1.45	-31.03	10000.00	-15.07	5.93	-5.13	2.00	0.23	7.64	0.11	0.14	-3.70



Note:

Some non-allowed harmonics are present.

b_9 changes (but we still don't have right iron).

Higher order harmonics do not change much.

Note: Comparison with measurements requires 3-d model (particularly with correct end pole shaping and cutout in cross-section).

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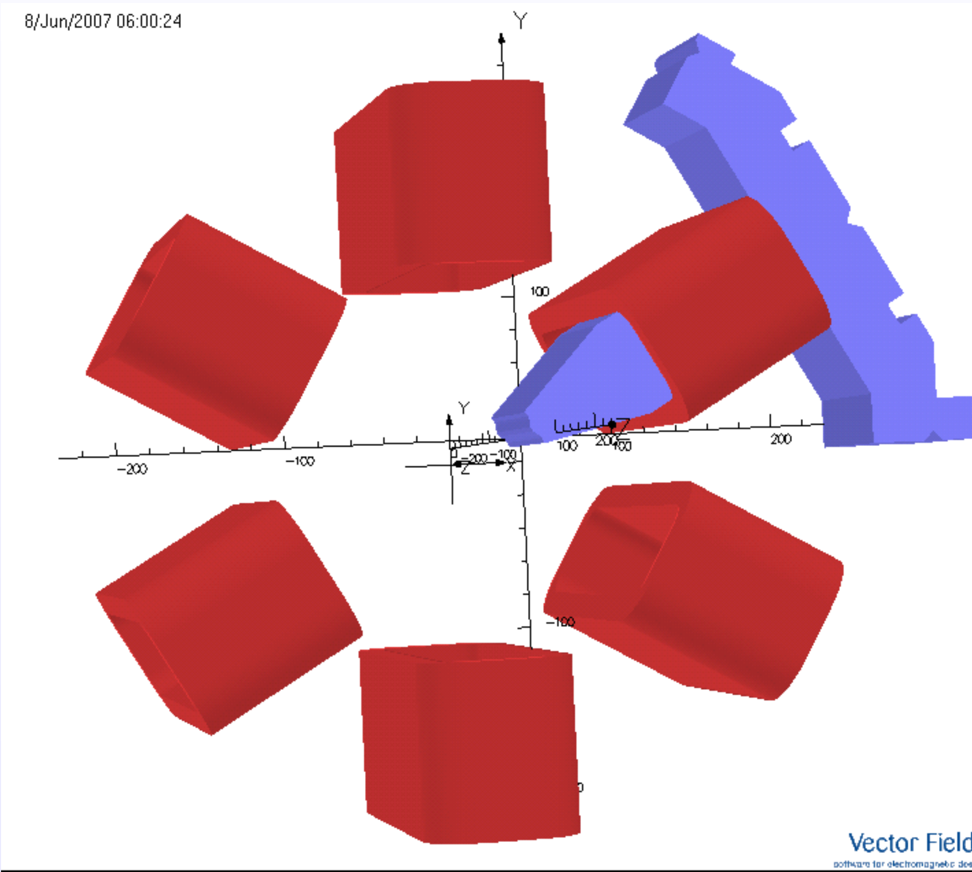
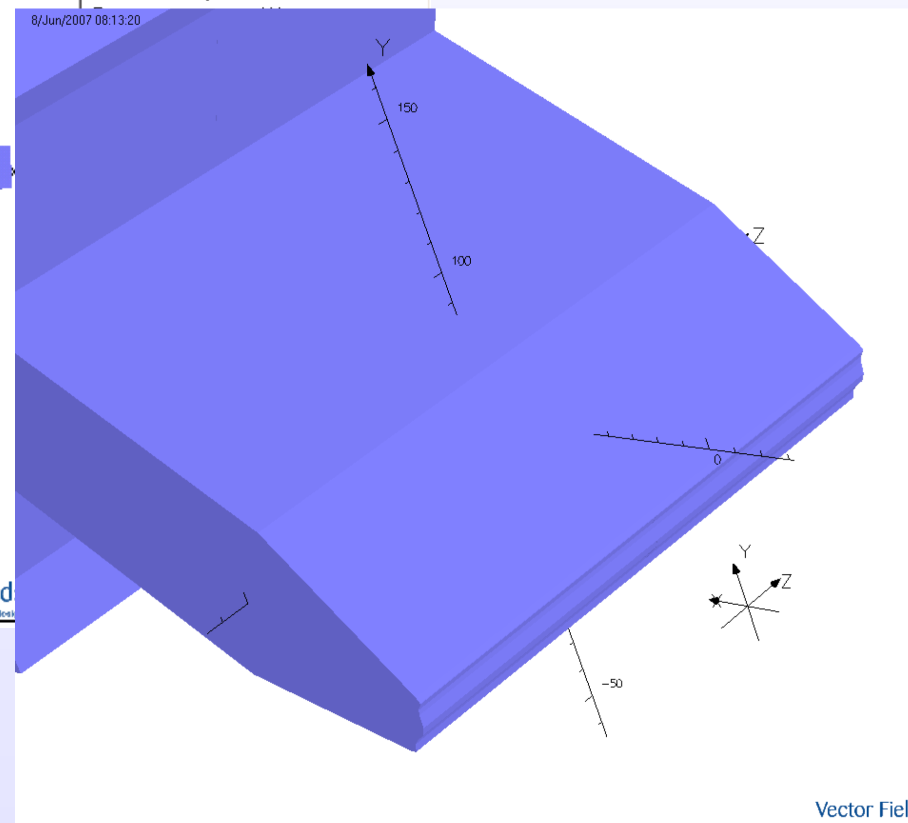
3-d Model of Symmetric SLS Sextupole

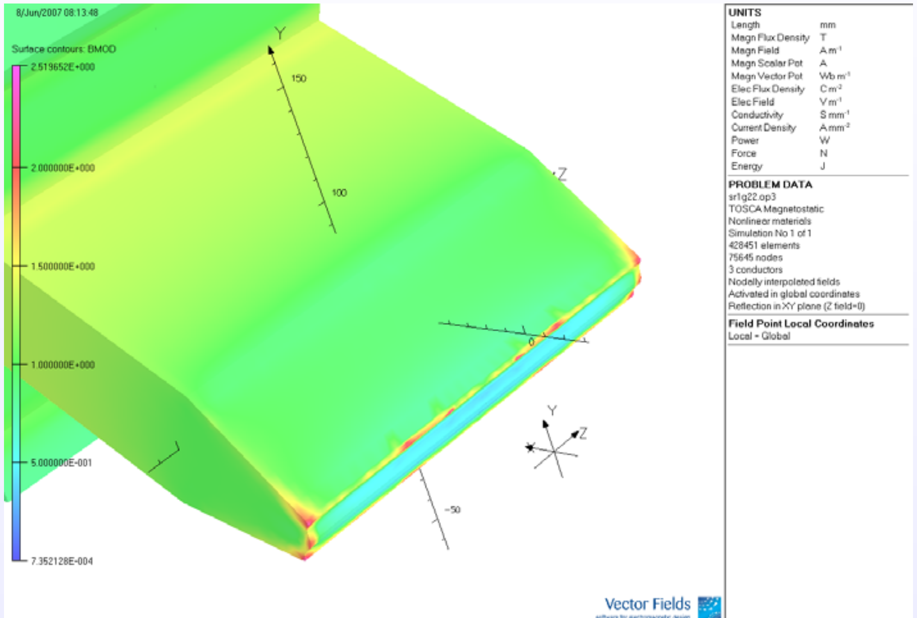


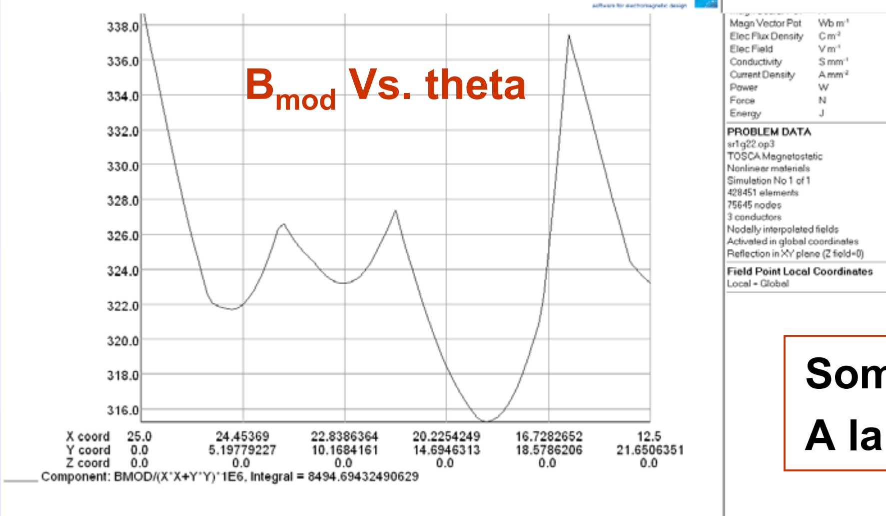
UNITS	
Length	mm
Magn Flux Density	T
Magn Field	$A\,m^{-1}$
Magn Scalar Pot	A
Magn Vector Pot	$Wb\,m^{-1}$
Elec Flux Density	$C\,m^{-2}$
Elec Field	$V\,m^{-1}$
Conductivity	$S\,mm^{-1}$
Current Density	$A\,mm^{-2}$

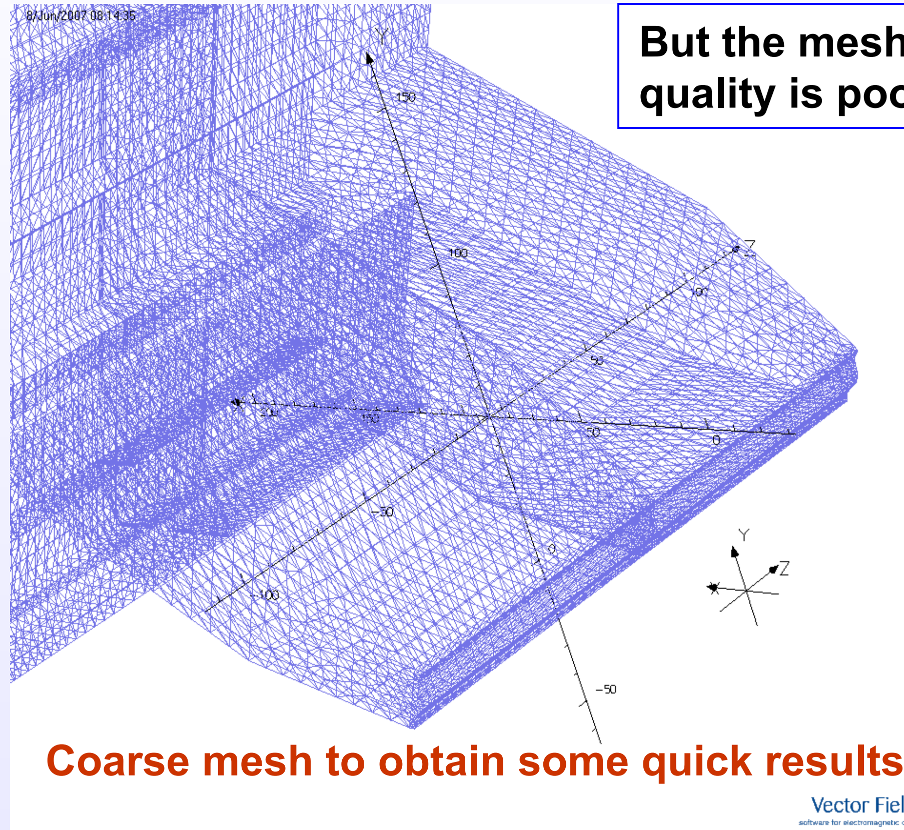
Pole profile properly modeled for obtaining a reasonable solution of field quality.



3-d Mesh is Not Sufficient for Reliable Results







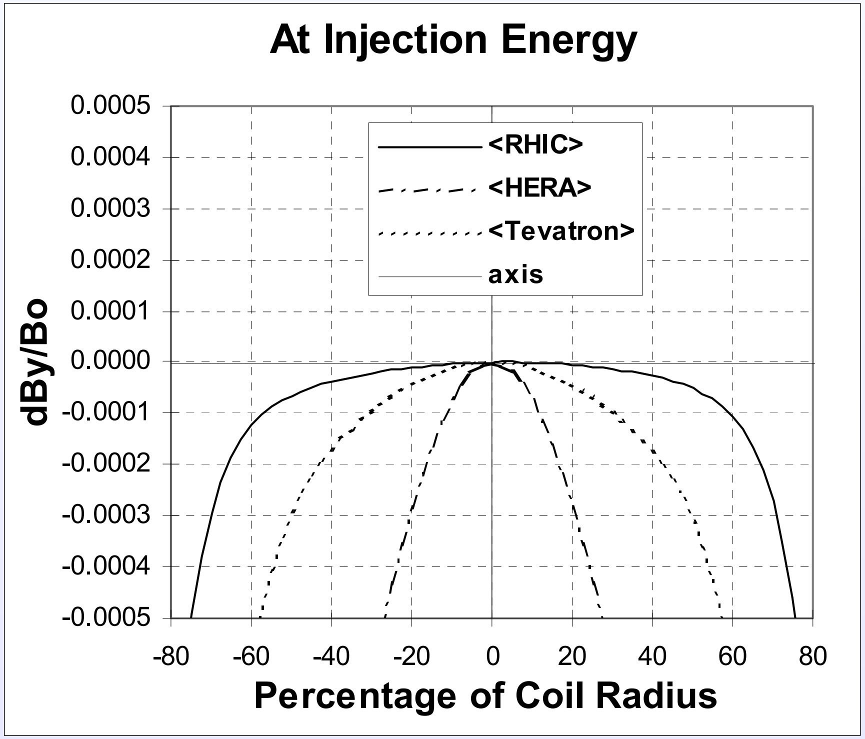
But the mesh quality is poor.

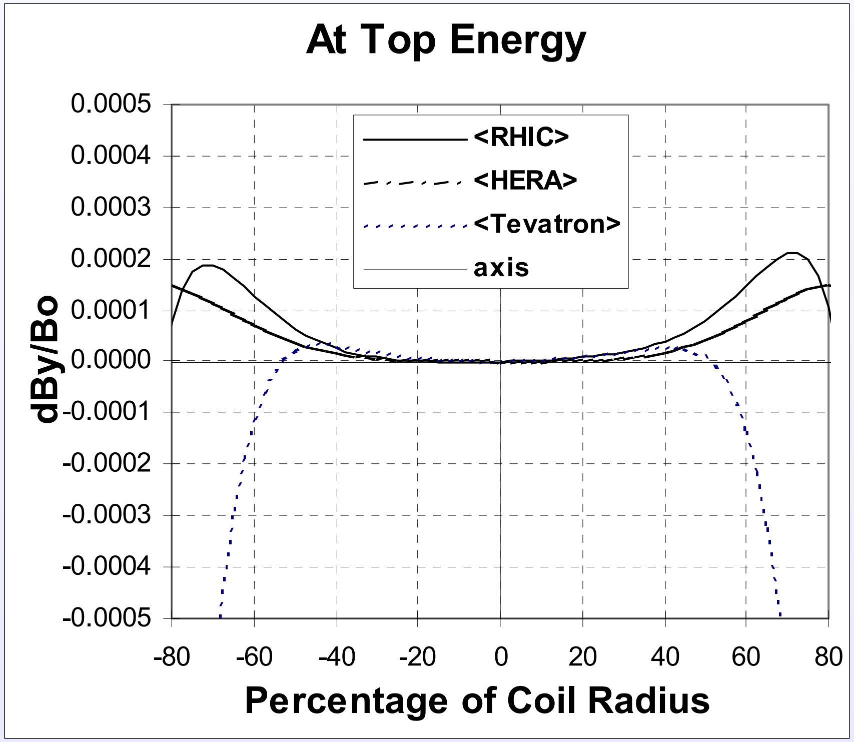
Coarse mesh to obtain some quick results

Some saturation real, some because of poor mesh.
A larger variation in field is due to poor meshing.

Average Field Errors on X-axis

COIL ID : RHIC 80 mm, HERA 75 mm, Tevatron 76.2 mm





- Warm-Cold correlation have been used in estimating cold harmonics in RHIC dipoles (~20% measured cold and rest warm).
- Harmonics b_1-b_{10} have been used in computing above curves.
- In Tevatron higher order harmonics dominate, in HERA persistent currents at injection. RHIC dipoles have small errors over entire range.

Saturation in RHIC Arc Dipoles

In RHIC dipoles, iron is closer to coil and contributes ~ 50% of the coil field:

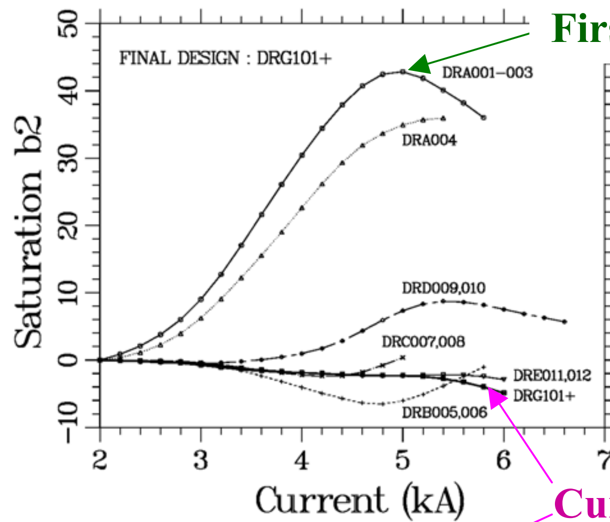
3.45 T (Total) ~ 2.3 T (Coil) + 1.15 (Iron)

That's good.

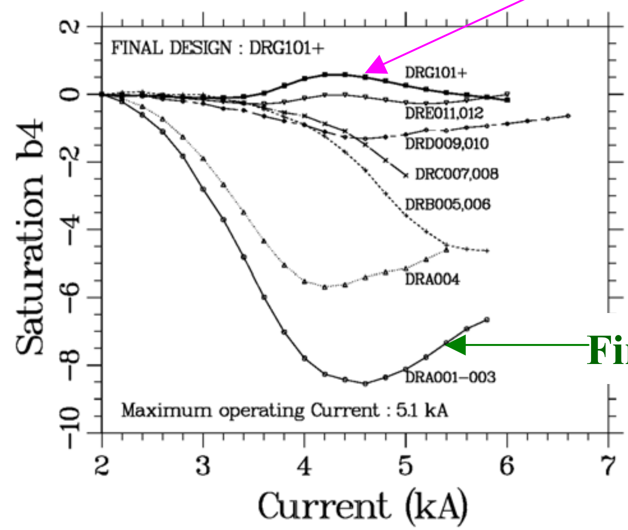
But the initial designs had bad saturation, as conventionally expected when iron yoke is so close to the coils and contributes such a large fraction of coil field.

This course will teach you several techniques to reduce the current-dependence of field harmonics.

First Design

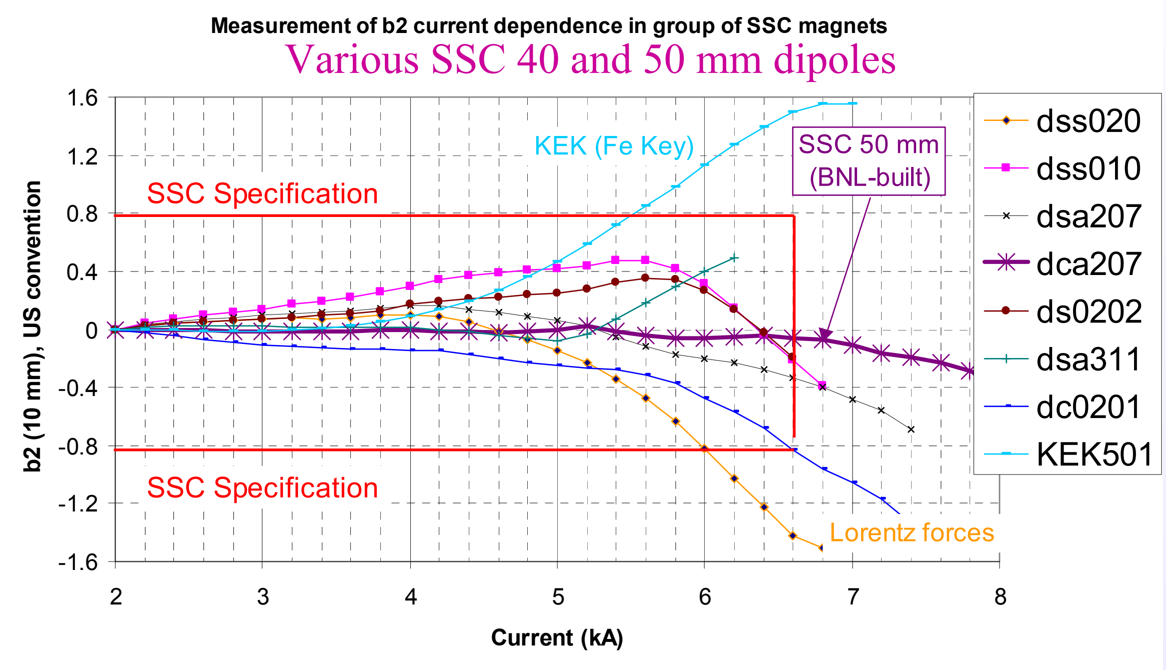


Current Design



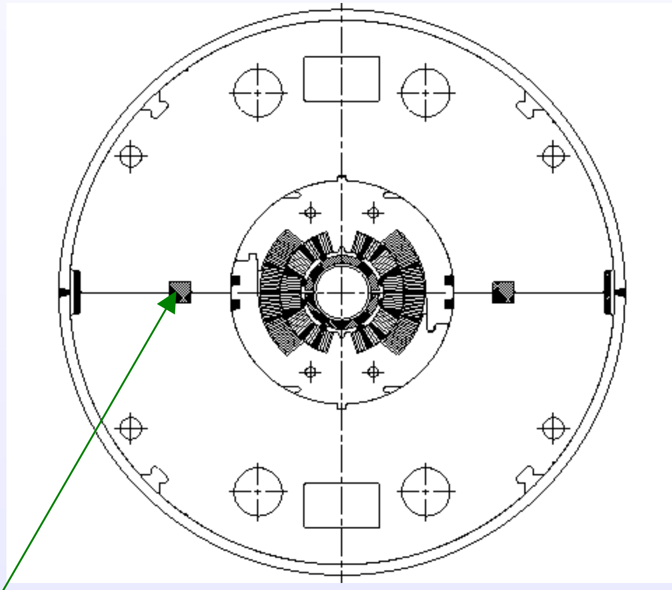
First Design

Measured Current Dependence in Sextupole Harmonic in Various Full-length SSC Magnets



Cross section of SSC 50 mm Dipole

Yoke optimized for low saturation



Non-magnetic key to force uniform saturation

Could also have been used to adjust current dependence after design, as in RHIC magnets.

Near zero current dependence in b_2 variation in the very first design of BNL built SSC 50 mm long magnets.

Specifications was 0.8 unit.

A much larger value in earlier SSC 40 mm design.

b_2 change from yoke magnetization & Lorentz forces.

Major progress in reducing the saturation-induced harmonics.

Conclusions

Make your own, please!

http://www.bnl.gov/magnets/Staff/Gupta/Talks/field-quality-talks.htm

http://www.bnl.gov/magnets/Staff/Gupta/Publications/fq-papers.htm