A Proposed Plan to Optimize and Communicate Field Quality in 35 mm Dipole

(similar approach could be used in some other magnets)

Ramesh Gupta

Overview

We have today:

- A prototype magnet delivered
- Measuring equipments (rotating coils) +
- Magnet design with some special features

The question is how to obtain a good (acceptable) field quality and *how to communicate* that. Challenges are:

  - Curved magnet
  - Rectangular aperture
  - Available hardware (straight rotating coil of certain size)
  - Accuracy in 3-d calculations

- Goal is to develop a plan that delivers a good field quality despite these limitations or challenges.
- Similar things have been done before to some level. We should develop a plan for our case to the level required for this machine.
- New particle tracking tools in magnet models that may be useful.

Model Magnet as Delivered

Back of the magnet

Front of the magnet

Design Parameters for model magnet (also for full length magnet):

- Magnetic length = ~0.9 meter (design length for full length 2.62 meter)
- Bend angle = ~2.06 degree (full magnet 6 degree)
- Design field = 0.4 T at ~360 A (field quality, etc. good to 0.48 T and above)

Initially we considered 1.31 m long dipole with 3 degree bend so that one side represents sector bend and other side two faces parallel. Above parameters were chosen for practical reasons.

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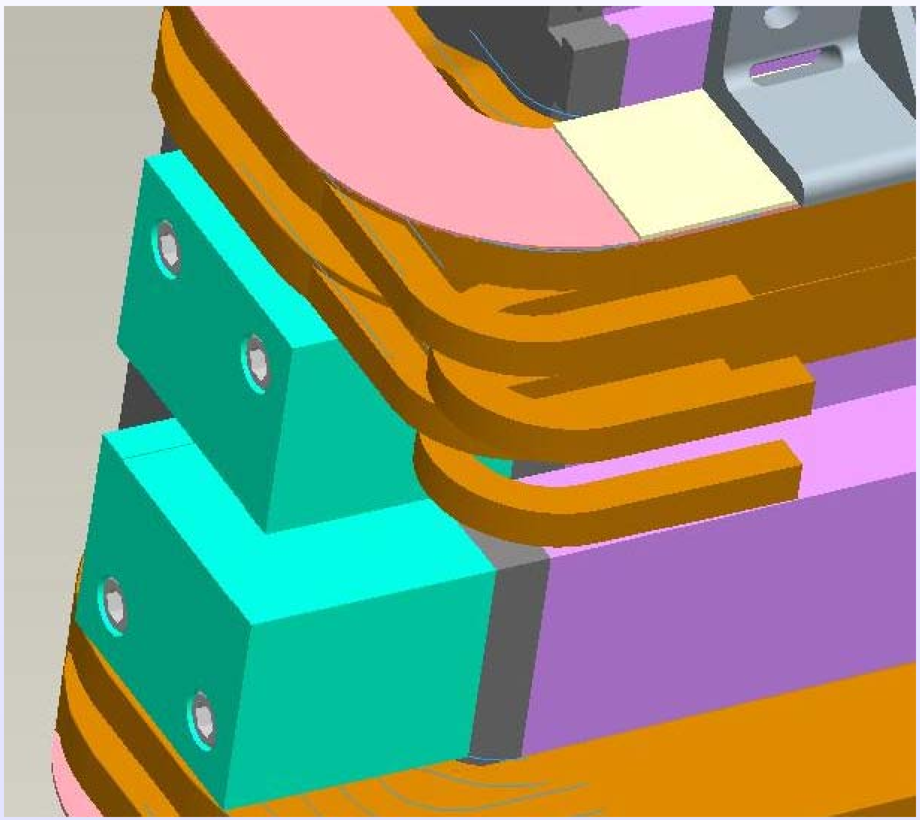
Unique Feature : Extended Pole (Nose)

We take advantage of the low field requirements (0.4 T)

Magnetic length > Mechanical length

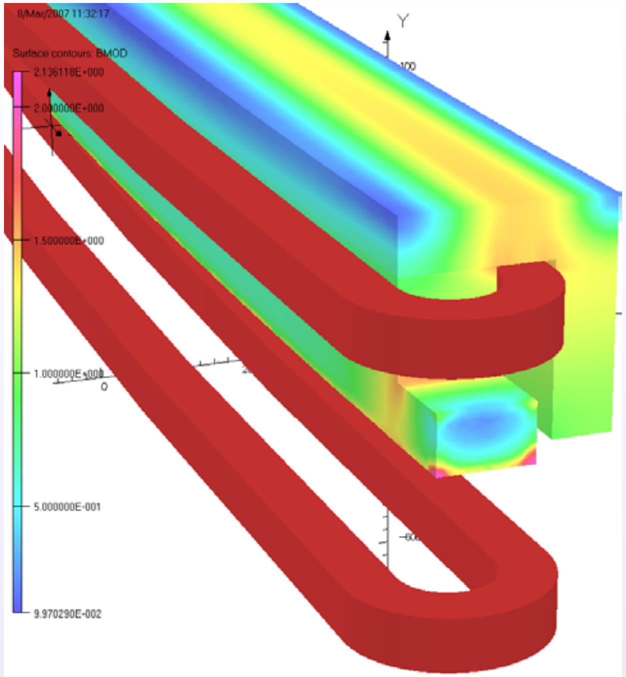


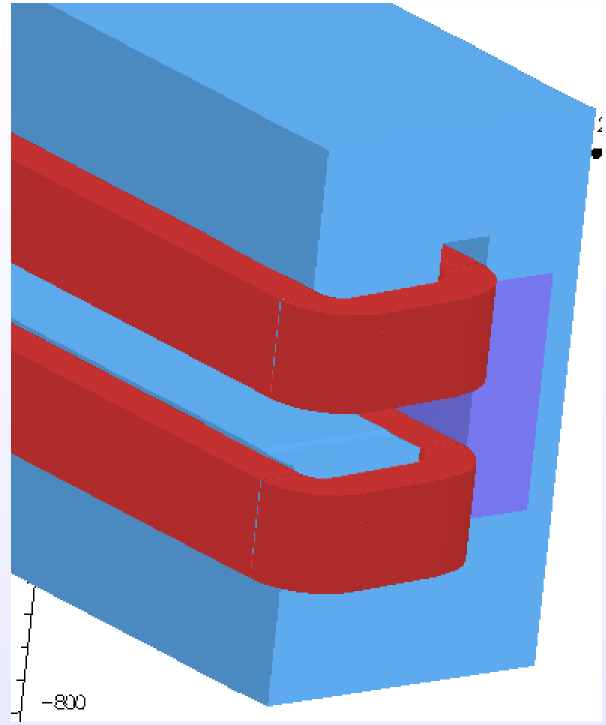
Additional plans to take advantage of this unique feature in this magnet:

- Measure field harmonics without chamfering.
- Compute required chamfering of the nose piece and do measurements again after the chamfering
    - Do iterations, if necessary.
- Above is similar to what has been done in magnets for other projects, except that they had to do it in the end laminations and we can do it in a separate nose piece. This has many benefits.
- The design gives an opportunity to shape the nose piece to create sector bends with end fields perpendicular to the trajectory.
- 1 degree bend for 100 mm aperture requires only ~1.7 mm; +/- 3 degree requires ~5.2 mm. This can be accommodated in the present nose.
- In the present short magnet, we need ~1.7 mm.
- We are making two sides of end pieces to simulate both designs – you decide later.

Fine Tuning of Transfer Function Matching
(between 35 mm and 90 mm aperture dipoles)

Ends of 35 mm Dipole





Ends of 90 mm Dipole

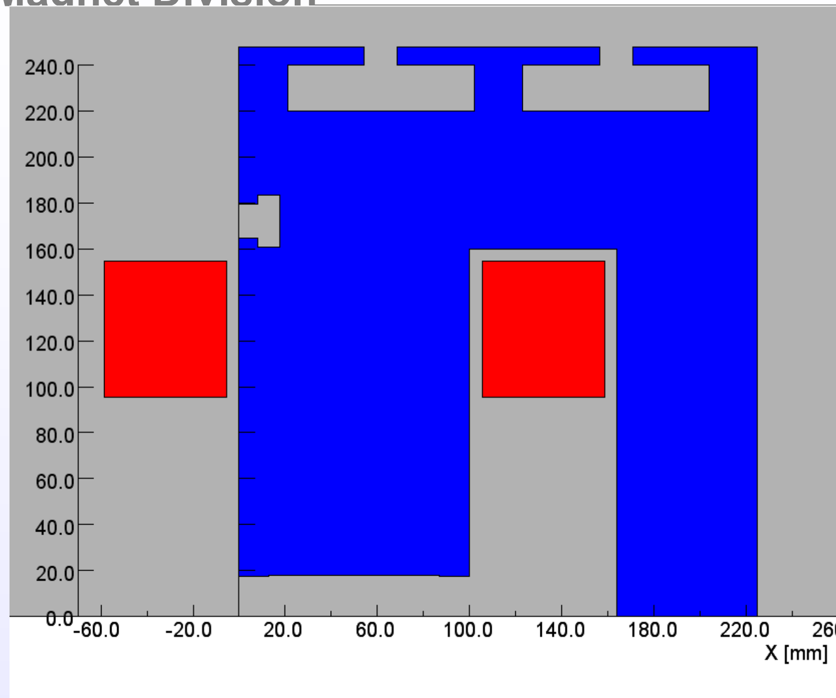
The integral transfer function between above two magnets should match

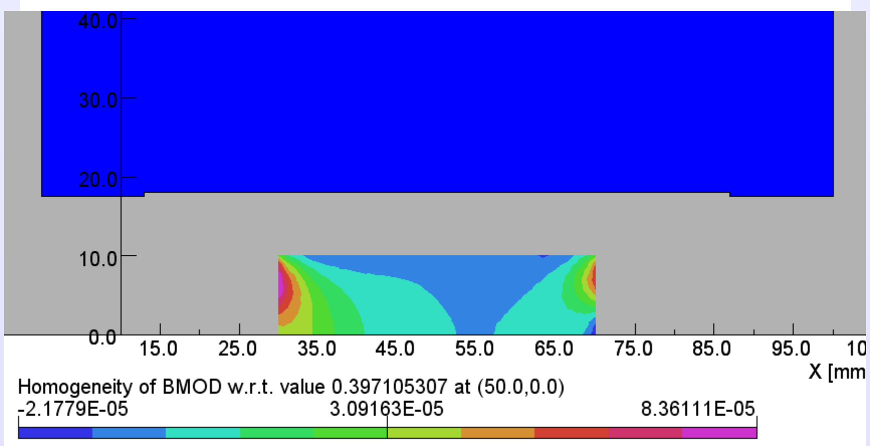
- Fine tuning of the integral field may be done by adjusting **the length of the nose piece** of the 35 mm dipole after the field measurements of both 35 mm and 90 mm dipoles.
- We could do some measurements in the present model to observe sensitivity, etc.

Discrepancies in the Nose Piece

- Nose piece should have extended to the coil ends
  - ➢ it did not.
- Mounting bolts should not have extended beyond the end of the nose
  - ➢ they did.

2-d Magnetic Model of 35 mm Aperture Baseline Dipole Design





Coil Parameters:

- 16 turns, 13 mm X 13 mm each.
- Overall current density for 0.4 T ~ 1.8 A/mm^2.
- Space is left above the main coil for installing trim coil cable for doing 3% field adjustment.

Pole Parameters:

Minimum pole half gap is 17.5 mm (18 mm at the center)

- To optimize field quality, 13 mm wide and 0.5 mm high pole bumps are used on either side.
- Since coils are sufficiently above the midplane, asymmetric pole bumps were not required for removing quadrupole-type terms despite the yoke having a C-shape.

Note: Field quality is optimized to satisfy both harmonics and the field deviation requirements.

Question: How to communicate this between measurements, calculations and AP use?

Computed 2-d Harmonics in 35 mm Dipole

Harmonics at 10 mm reference radius

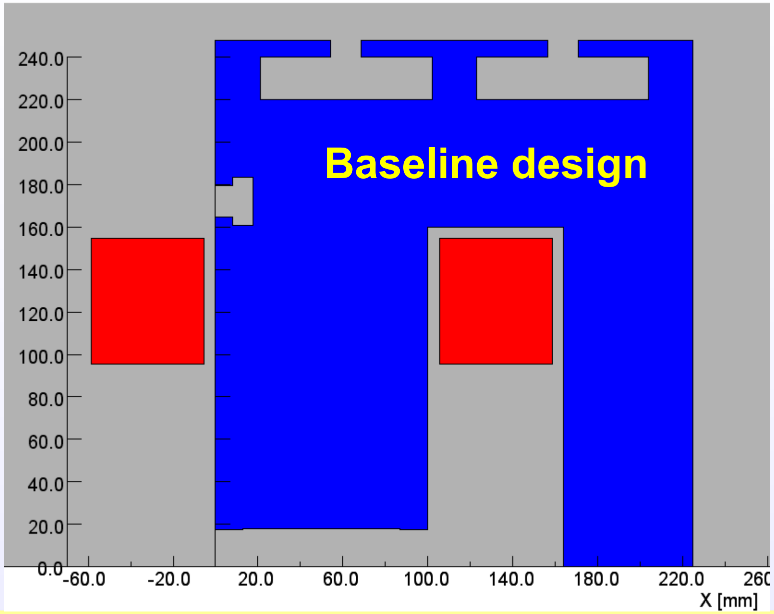
(Note: Harmonics are given as parts in 10^4; b2 is quadrupole)

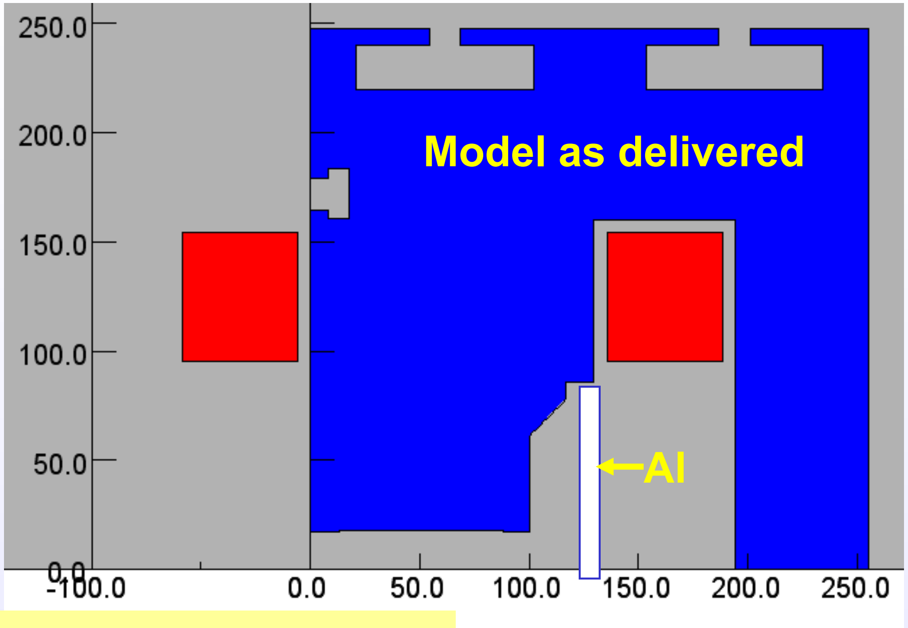
Case#	I(Amp)	Bo(T)	TF(T/kA)	dTF(%)	b2	b3	b4	b5	b6	b7	b8
1	10	0.01107	1.107	0	-0.03	0.04	-0.01	0.02	0.00	0.00	0.00
2	50	0.05535	1.107	0.00	-0.03	0.04	-0.01	0.02	0.00	0.00	0.00
3	100	0.11069	1.107	-0.01	-0.03	0.04	-0.01	0.02	0.00	0.00	0.00
4	150	0.16603	1.107	-0.01	-0.03	0.04	-0.01	0.02	0.00	0.00	0.00
5	200	0.22133	1.107	-0.03	-0.03	0.04	-0.01	0.02	0.00	0.00	0.00
6	250	0.27649	1.106	-0.09	-0.03	0.04	-0.01	0.02	0.00	0.00	0.00
7	300	0.33151	1.105	-0.18	-0.03	0.04	-0.01	0.02	0.00	0.00	0.00
8	350	0.38623	1.104	-0.31	-0.04	0.04	-0.01	0.02	0.00	0.00	0.00
9	**360**	**0.39711**	**1.103**	**-0.35**	**-0.04**	**0.04**	**-0.01**	**0.02**	**0.00**	**0.00**	**0.00**
10	370	0.40795	1.103	-0.40	-0.04	0.04	-0.01	0.02	0.00	0.00	0.00
11	380	0.41875	1.102	-0.45	-0.04	0.04	-0.01	0.02	0.00	0.00	0.00
12	390	0.42951	1.101	-0.51	-0.04	0.04	-0.01	0.02	0.00	0.00	0.00
13	400	0.44021	1.101	-0.58	-0.04	0.04	-0.01	0.02	0.00	0.00	0.00
14	450	0.49191	1.093	-1.25	-0.05	0.04	-0.01	0.02	0.00	0.00	0.00
15	500	0.53723	1.074	-2.94	-0.05	0.03	-0.01	0.02	0.00	0.00	0.00
16	550	0.57142	1.039	-6.15	-0.05	0.03	-0.01	0.02	0.00	0.00	0.00
17	600	0.60008	1.000	-9.65	-0.05	0.02	-0.01	0.02	0.00	0.00	0.00

Small values of field harmonics (only a few parts in 10^5 even at 20 mm radius).

Remember: These are for an ideal design and do not include harmonics from construction errors.

35 mm Dipole as Delivered (dimensions from John Skaritka)





35 mm Aperture Dipole for NSLS2 (design: 35mm-07-aug-js1)
Harmonics at 10 mm reference radius

Case#	I(Amp)	Bo(T)	TF(T/kA)	dTF(%)	b2	b3	b4	b5	b6	b7	b8
1	10	0.01107	1.107	0	0.00	-0.04	-0.06	0.00	-0.01	0.00	0.00
2	50	0.05536	1.107	0.02	0.00	-0.04	-0.06	0.00	-0.01	0.00	0.00
3	100	0.11071	1.107	0.01	0.00	-0.04	-0.06	0.00	-0.01	0.00	0.00
4	150	0.16606	1.107	0.01	0.00	-0.04	-0.06	0.00	-0.01	0.00	0.00
5	200	0.22138	1.107	-0.01	0.00	-0.04	-0.06	0.00	-0.01	0.00	0.00
6	250	0.27656	1.106	-0.07	0.00	-0.04	-0.06	0.00	-0.01	0.00	0.00
7	300	0.33162	1.105	-0.14	0.00	-0.04	-0.06	0.00	-0.01	0.00	0.00
8	350	0.3864	1.104	-0.27	-0.01	-0.04	-0.06	0.00	-0.01	0.00	0.00
9	360	0.39729	1.104	-0.31	-0.01	-0.04	-0.06	0.00	-0.01	0.00	0.00
10	370	0.40816	1.103	-0.35	-0.01	-0.04	-0.06	0.00	-0.01	0.00	0.00
11	380	0.41899	1.103	-0.40	-0.02	-0.04	-0.06	0.00	-0.01	0.00	0.00
12	390	0.42977	1.102	-0.45	-0.02	-0.04	-0.06	0.00	-0.01	0.00	0.00
13	400	0.4405	1.101	-0.52	-0.02	-0.04	-0.06	0.00	-0.01	0.00	0.00
14	450	0.49249	1.094	-1.14	-0.03	-0.05	-0.06	0.00	-0.01	0.00	0.00
15	500	0.53845	1.077	-2.72	-0.03	-0.05	-0.06	0.00	-0.01	0.00	0.00
16	550	0.57362	1.043	-5.79	-0.03	-0.06	-0.06	0.00	-0.01	0.00	0.00
17	600	0.6029	1.005	-9.23	-0.03	-0.06	-0.06	0.00	-0.01	0.00	0.00

Width of one the pole bump (closer to the added yoke) is reduced by 1 mm to keep quad term low.

Above mechanical structure with Al plate is not needed.

- **Go back to the baseline design.**

- With this summary of the current status, let's plan what do we do and how we communicate.

- One question is whether the field harmonic description is the right approach to communicate.

- However, the present discussion is how to use upcoming harmonic measurements to calculate, optimize and communicate field quality that can be used in beam physics calculations.

Communication on End Harmonics (1)

- Let's make sure that we all are on the same page and communicating with the same definitions and understanding of what end harmonics represent.
- Points of communications:
  - Calculations, measurements and beam dynamic calculations.
- Let's first consider straight magnets where the calculations and measurements can be easily compared. One can devise a variety of strategies in calculations for representing field harmonics in curved magnets but the rotating coils for measuring field harmonics are straight.
- As such, end regions have 3-d fields where the standard 2-d harmonic definitions are not valid.
- However, the standard harmonic definitions are valid for the 3-d fields if integrated over the entire magnet length (extended to include all fringe fields).
- This allows a way to lump end fields (next slide).

Communication on End Harmonics (2)

The following method has been used to communicate the end fields in long straight magnets (more discussion on calculations and measurements later):

1. Compute and measure 2-d harmonics in the magnet body
2. Compute and measure integral harmonics
3. Multiply 2-d harmonics by the magnetic length and take difference between (1) and (2) to get integrated end harmonics.
4. Divide the end harmonics in two parts. And describe the magnet as 3 elements:
   - **END/2 + BODY + END/2**

In this case, body represents an element having a magnet length with 2-d fields and end represent two local kicks of zero length multi-poles.

Situation gets complicated for curved magnets. Harmonic measurements are not possible, as such. In calculations, we follow a curved path for magnetic length and straight on either side. Then we would do a similar simulation.

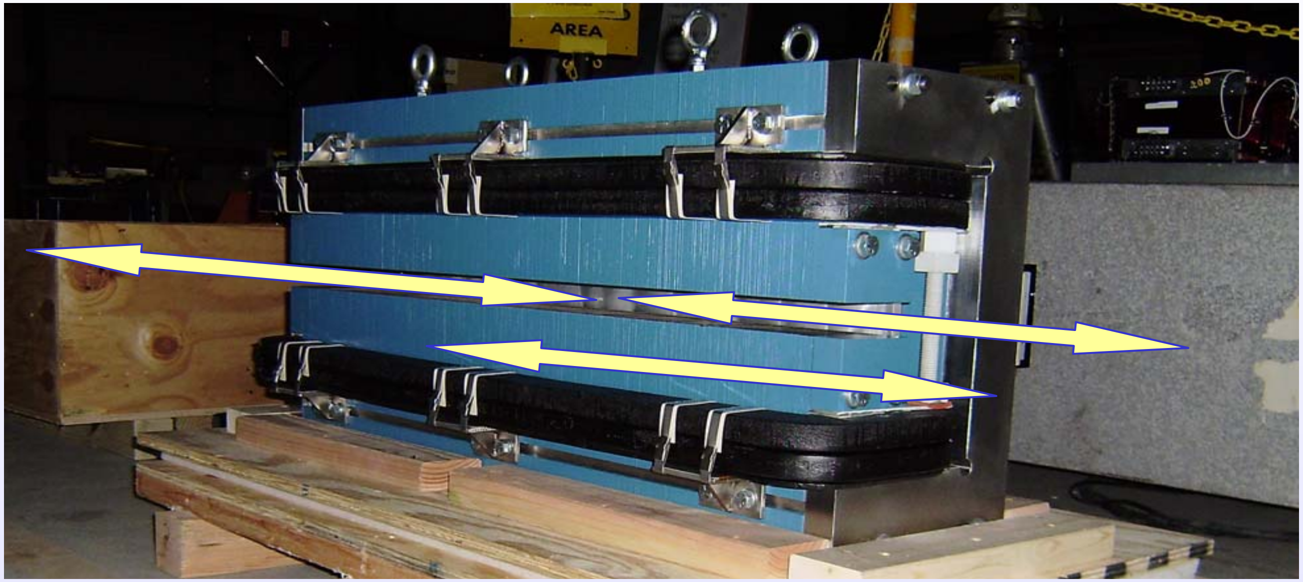
Is this OK? If not then we need to develop alternate method.

Proposed Plan for Measurements

The magnet is slightly curved but the measuring coil is not.

We would measure harmonics on straight path and do the field computation on about the same path.

By comparing calculations and measurements, we would try to optimize field quality on curved path.



To get the maximum information to help minimize and define end harmonics, we would do measurements with 1 meter long coil at several axial locations. It will be a little bit tricky to match these measurements but we would try to make the best use of them in calculations.

- We would try to study and optimize two ends separately for two designs.
- One side would represent sector bend ends and the other parallel ends.
- The optimized cuts for (trapezoidal and rectangular) chamfers are expected to be similar.

Proposed Plan for Calculations and Magnet Optimization

Integrated harmonics can be computed using the following two methods:

- Consider a cylinder (in calculations it could be either a straight cylinder or curved cylinder). Then compute axially integrated field over several azimuthal angle. This integrated field can be analysed with harmonic description.
- Compute 2-d field harmonic analysis along the axis of the magnet (it could be either straight or curved). Then compute integrated harmonics with proper weighing for local fields.

•One can do a reliability check by comparing the two calculations.

•One can also do reliability check of each method by changing parameters like radius for field calculations, etc.

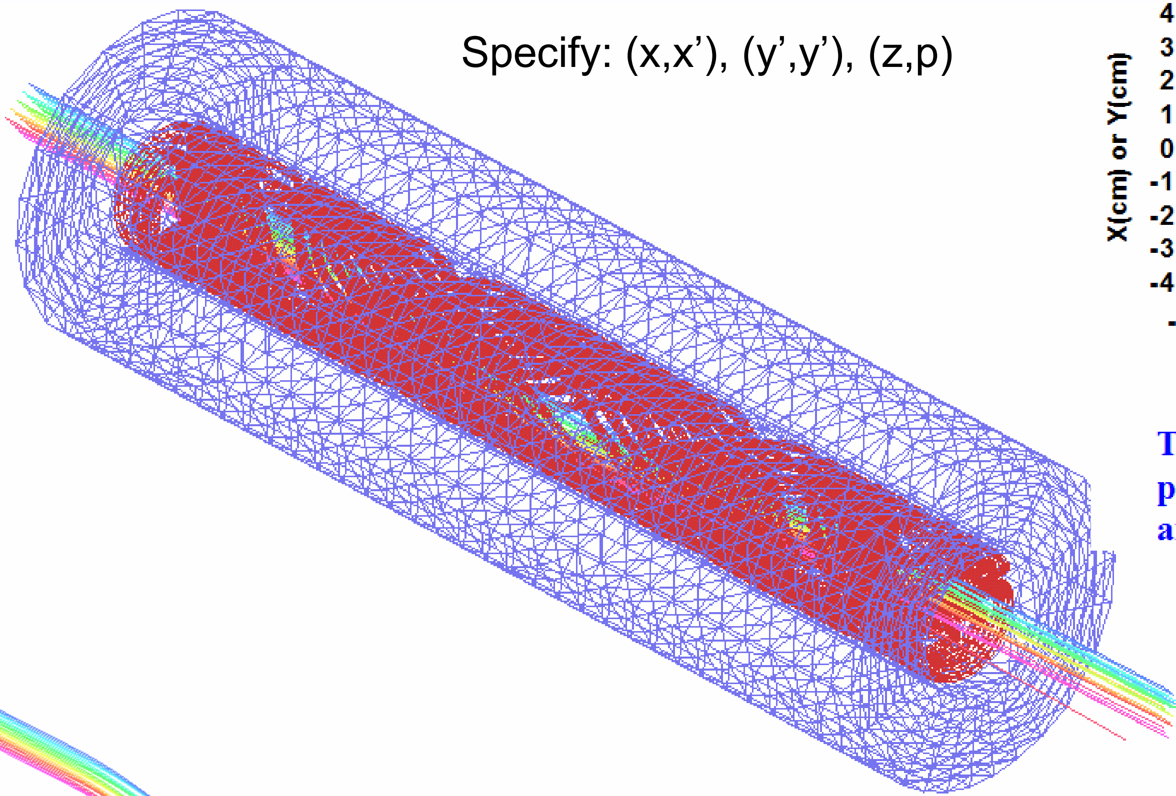
•To optimize the chamfer design which minimizes the impact of calculation errors and measurement errors in the given situation, we would make computer models such that a particular chamfer is created by just changing the material.

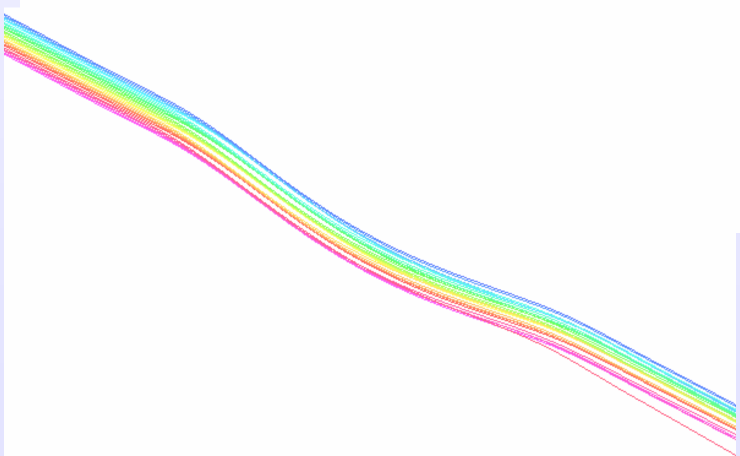
•Since the mesh, etc. does not change, it minimizes the computational errors and gives the most reliable calculations.

•We will iterate the chamfer design, if necessary.

OPERA3d Allows Direct Particle Tracking in 3-d Field of the Model

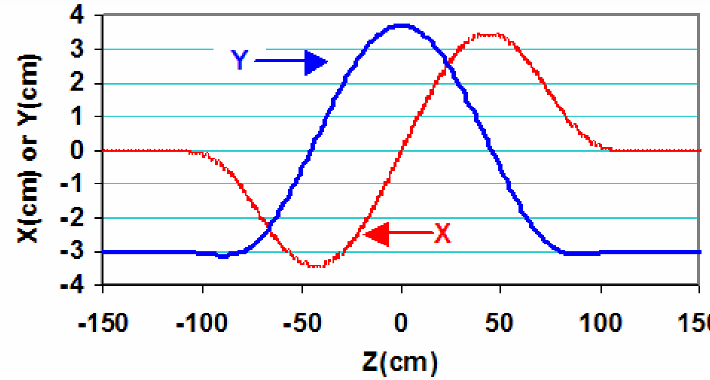
Specify: (x,x'), (y',y'), (z,p)





VECTOR FIELDS

OPERA3d model with coil and iron yoke with the particle tracking superimposed.



The nominal horizontal and vertical position of the beam as function of axial position inside the helical magnet.

- The magnetic design of the AGS helical magnet was optimized with the help of the particle tracking.
- (X, X') and (Y, Y') should match between the entry and the exit of the magnet.
- One can also obtain 3-d field map on the specified grid.