MOLLER Spectrometer Update

Juliette M. Mammei

University of Manitoba

Outline

- Previous recommendations
- Sensitivity study results
- Magnetic force results – failure scenario
- Power deposited on coils
- Upstream Torus
- Collimators
- Shielding

Recommendations from last meeting

Liked the larger conductor size, water-cooling hole, and simpler design (fewer out of plane bends)

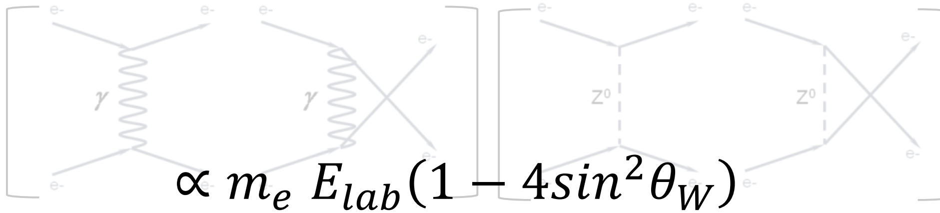
- Water cooling needs to be addressed (extra chiller, more LCW)
- Power supply – think about how the will hybrid be powered (we have)
- Coil construction
  - No splicing
  - Deep pockets for brazing water connections
  - Support it to be moved easily (assumed in the design)
  - Will be labor intensive and time consuming (we assume this)
  - Multiple magnets (not enough space for separate supports and water/electrical connections)
- Optics
  - Target windows (part of background, will be included in final optimization)
  - Optimized (not 100% yet)
- Forces
  - Iron may reduce the forces (not high priority right now – not a huge win)
  - Coil failure scenarios (provided to Jason)
- Cost analysis
  - Design all parameters of magnet system
  - Compare costs for long coils vs. multiple short coils (including tooling). Consider capital costs and operating expenses.

- The Physics
  - Search for ***physics beyond the Standard Model***
  - Interference of Z boson with single photon in Møller scattering
  - Measure the weak charge of the electron and $sin^2\theta_W$
  - Sensitivity comparable to the two high energy collider measurements

- The Experiment
  - High rate, small backgrounds – 150 GHz, 8% backgrounds
  - Novel toroid design, with multiple current returns
  - Full azimuthal acceptance, scattering angles from 5.5-19 mrads, 2.5-8.5 GeV
  - 150cm (5 kW) target, detectors 28m downstream

The Physics

$$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx$$



$$\propto m_e\, E_{lab}(1 - 4sin^2\theta_W)$$

$$= 35.6 \pm 0.73\, ppb$$

$\delta Q_W^e = 2.3\%, \sim 5 \times smaller$

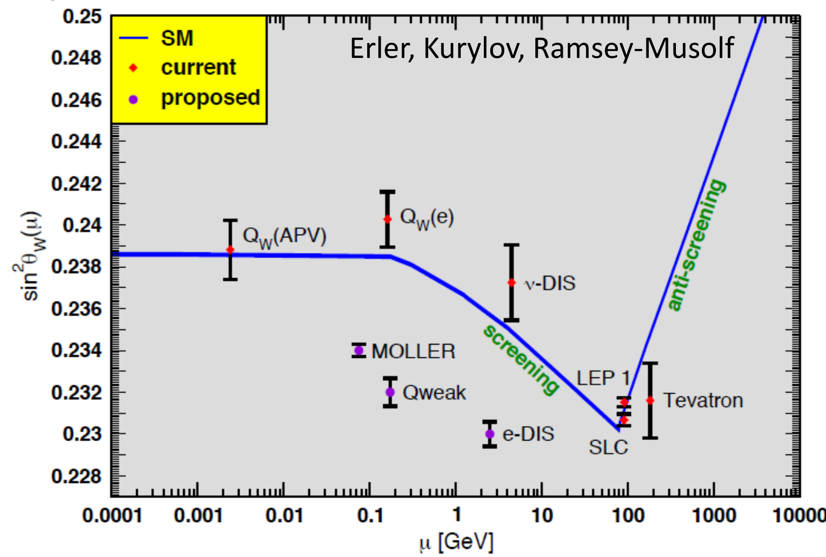
$than\ E158\ (\delta Q_W^e = 10.9\%)$

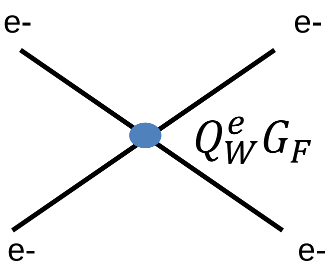
$$\boldsymbol{\mathcal{L}_{e_1e_2}^{PV} = \mathcal{L}_{SM}^{PV} + \mathcal{L}_{NEW}^{PV}}$$

Coupling constants

$$\mathcal{L}_{NEW}^{PV} = \sum_{i,j=L,R} \frac{g_{ij}^2}{2\Lambda_{ij}^2} \bar{e}_i\gamma_i e_i \bar{e}_j \gamma^j e_j$$

Mass scale



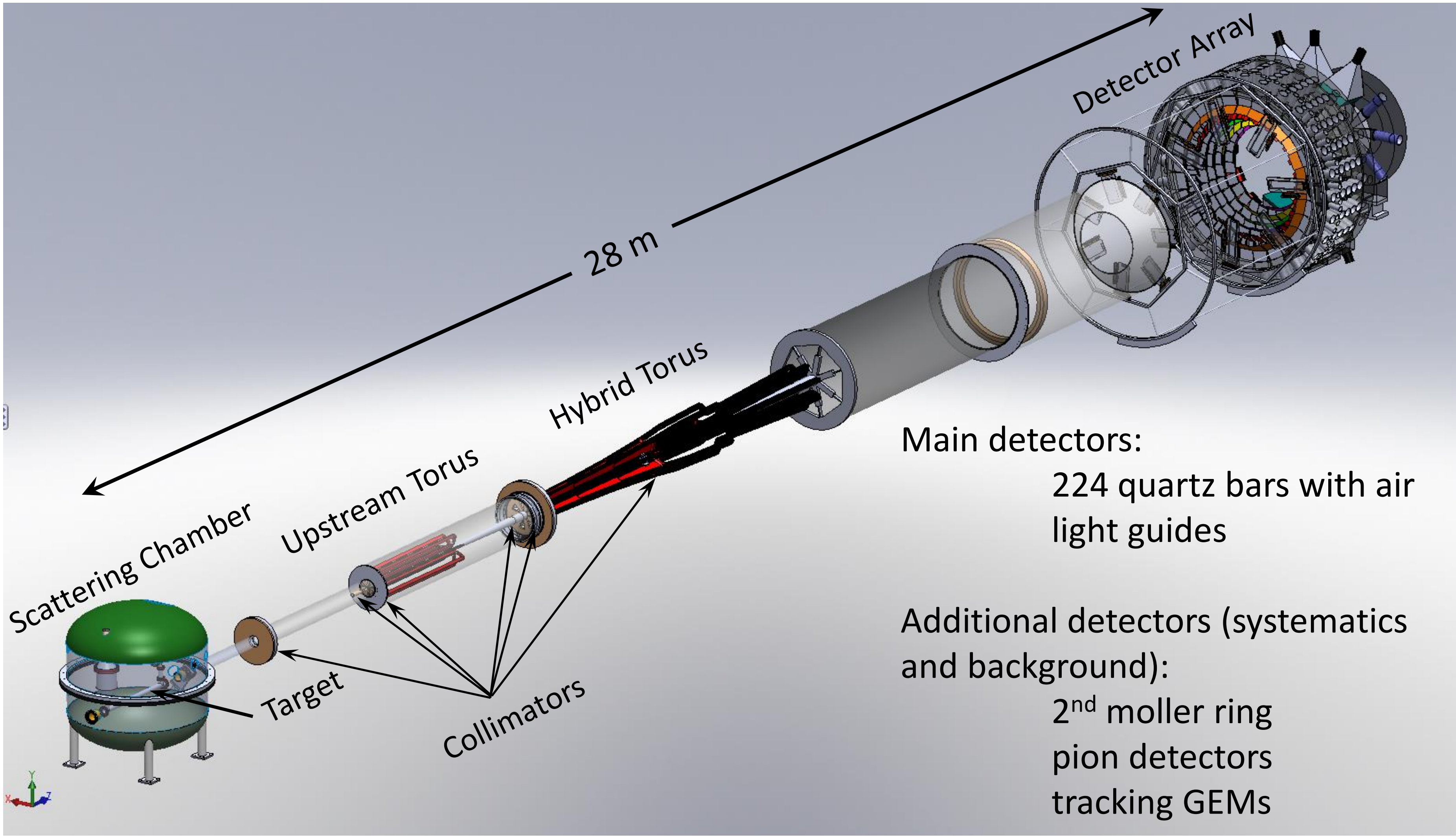


$$\frac{\Lambda}{\sqrt{|g_{LL}^2 - g_{RR}^2|}} = \frac{\Lambda}{\sqrt{\sqrt{2}G_F|\Delta Q_W^e|}}$$

2.3% MOLLER uncertainty

$$\rightarrow \boldsymbol{7.5\ TeV}$$

The Experiment



Main detectors:

224 quartz bars with air light guides

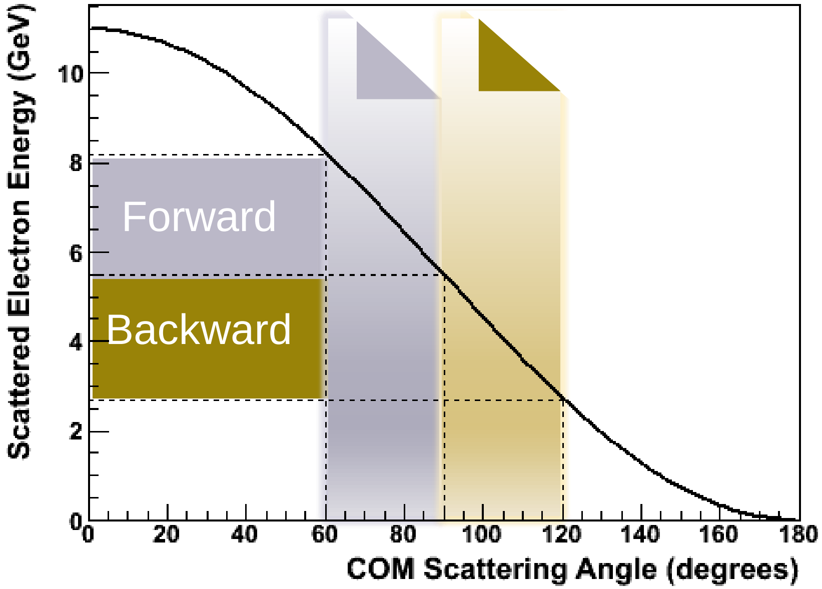
Additional detectors (systematics and background):

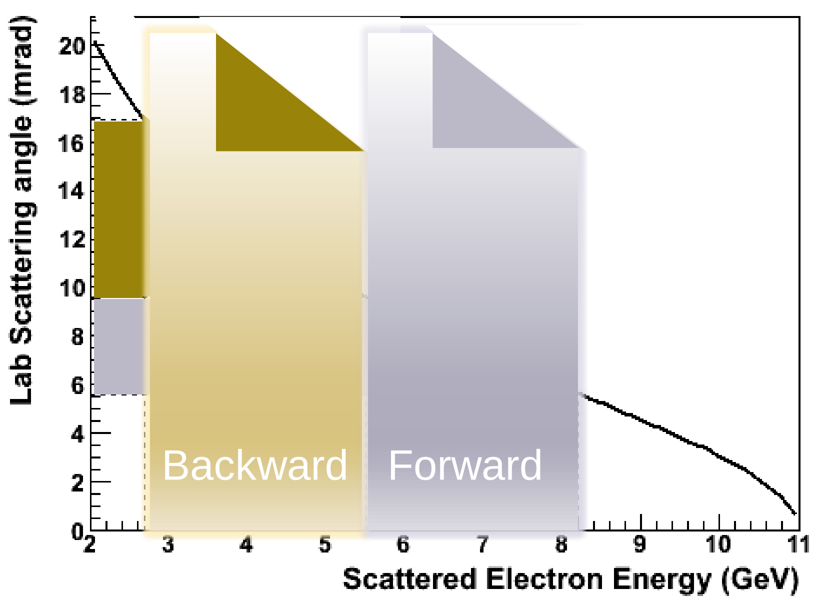
2^{nd} moller ring
pion detectors
tracking GEMs

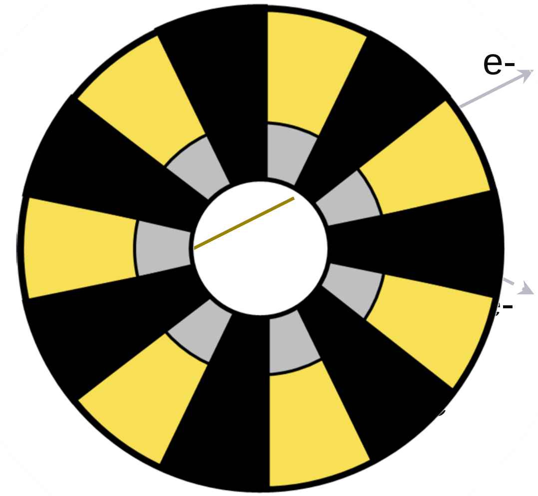
Spectrometer Meetings

- Director's Review – *January 2010*
- **Advisory Group Meeting – *August 2010***
- Collaboration Meeting – *December 2010*
- Supergroup Meeting – *June 2012*
- Collaboration Meeting – *September 2012*
- Collaboration Meeting – *June 2013*
- **Advisory Group Meeting – *October 2013***
- Collaboration Meeting – *May 2014*
- DOE Science Review – *September 2014*
- Collaboration Meeting – *January 2015*
- **Advisory Group Meeting – *July 2015***
- JLAB Technical Review – *September 2015??*

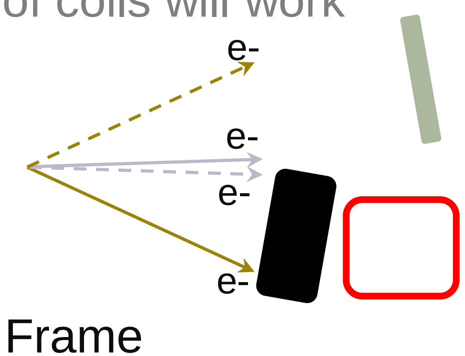
100% Azimuthal Acceptance





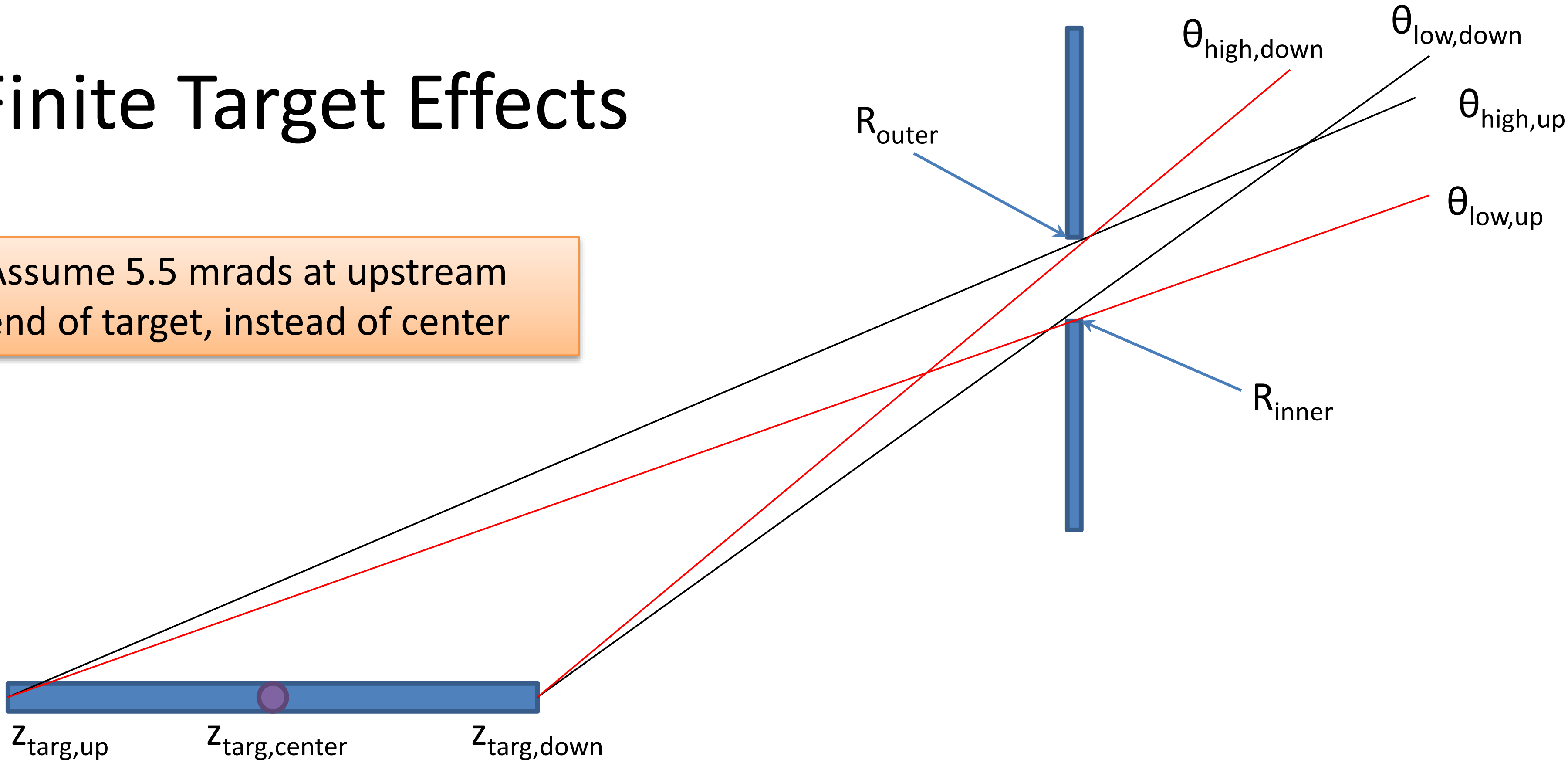


Any odd number of coils will work



Finite Target Effects

Assume 5.5 mrads at upstream end of target, instead of center



z_{coll} = 590 cm

$z_{targ,up}$ = -75 cm
$z_{targ,center}$ = 0 cm
$z_{targ,down}$ = 75 cm

θ_{low} = 5.5 mrad
θ_{high} = 17 mrad

R_{inner} = 3.658 cm
R_{outer} = 11.306 cm

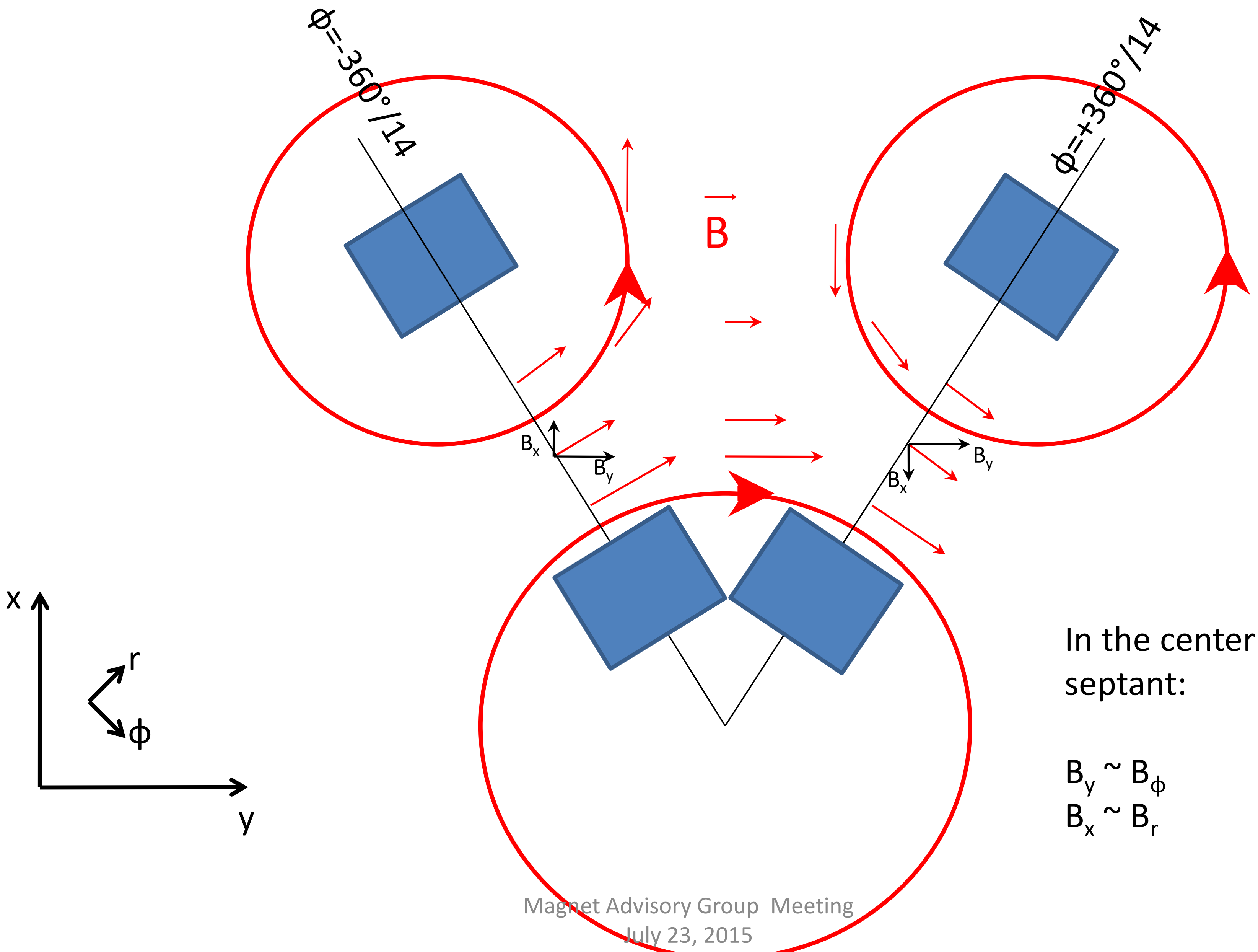
From center:

$\theta_{low,cen}$ = 6.200 mrads
$\theta_{high,cen}$ = 19.161 mrads

From downstream:

$\theta_{low,down}$ = 7.102 mrads
$\theta_{high,down}$ = 21.950 mrads

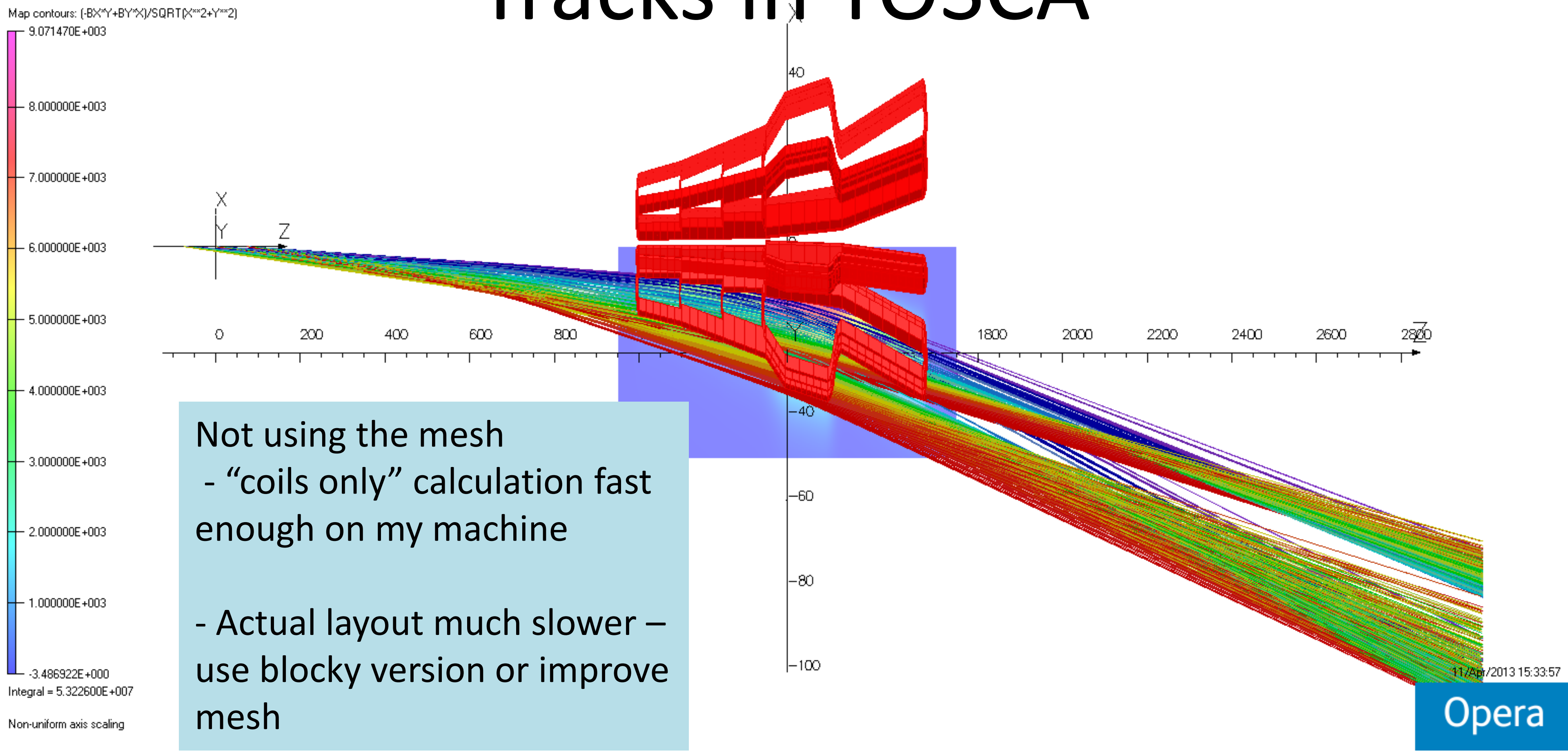
Looking downstream



In the center of this septant:

$B_y \sim B_\phi$
$B_x \sim B_r$

Tracks in TOSCA



Not using the mesh
- "coils only" calculation fast enough on my machine

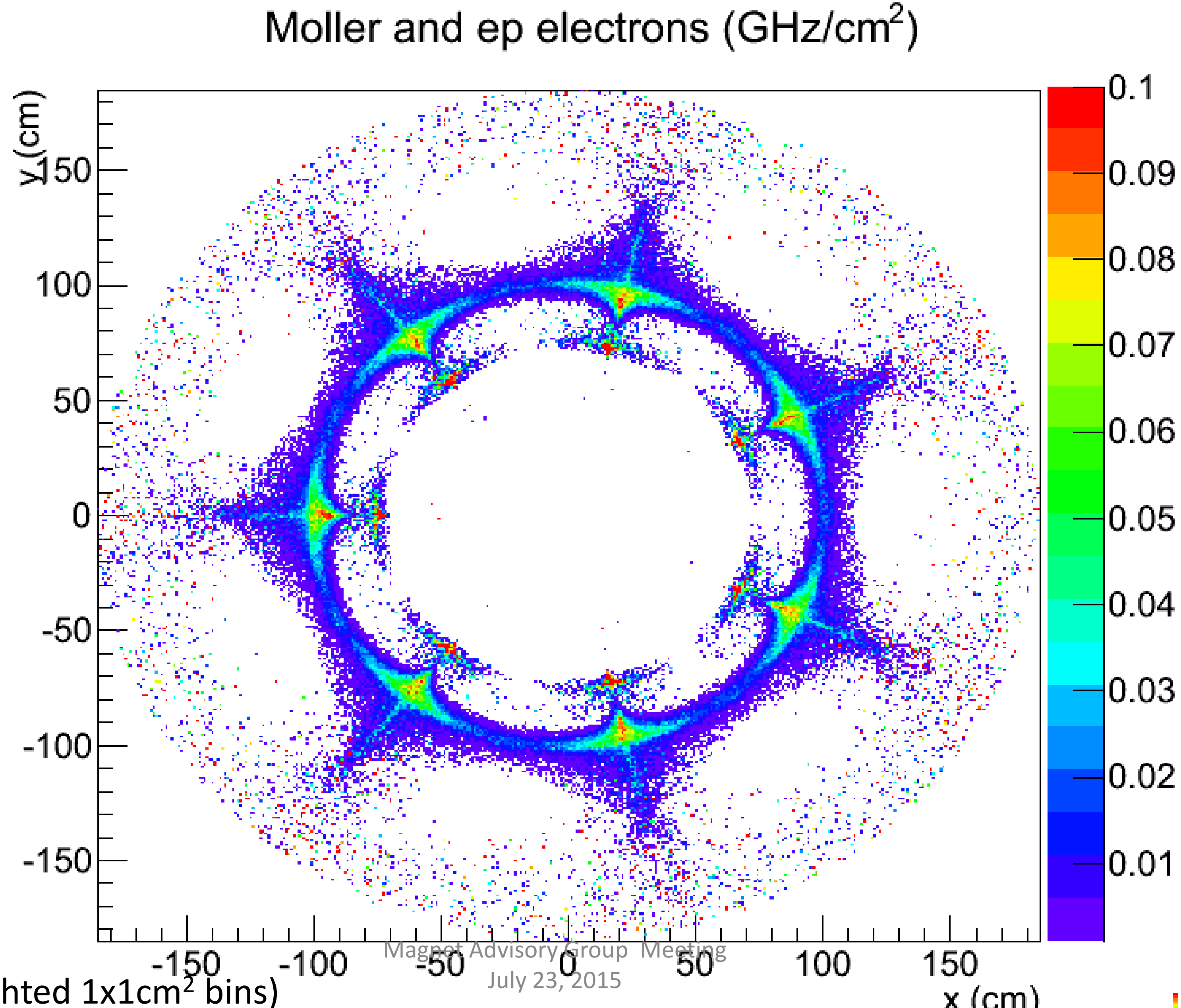
- Actual layout much slower – use blocky version or improve mesh

up	(z0 =-75 cm)	5.5 to 15 mrads
middle	(z0 =0 cm)	6.0 to 17 mrads
down	(z0 =75 cm)	6.5 to 19 mrads

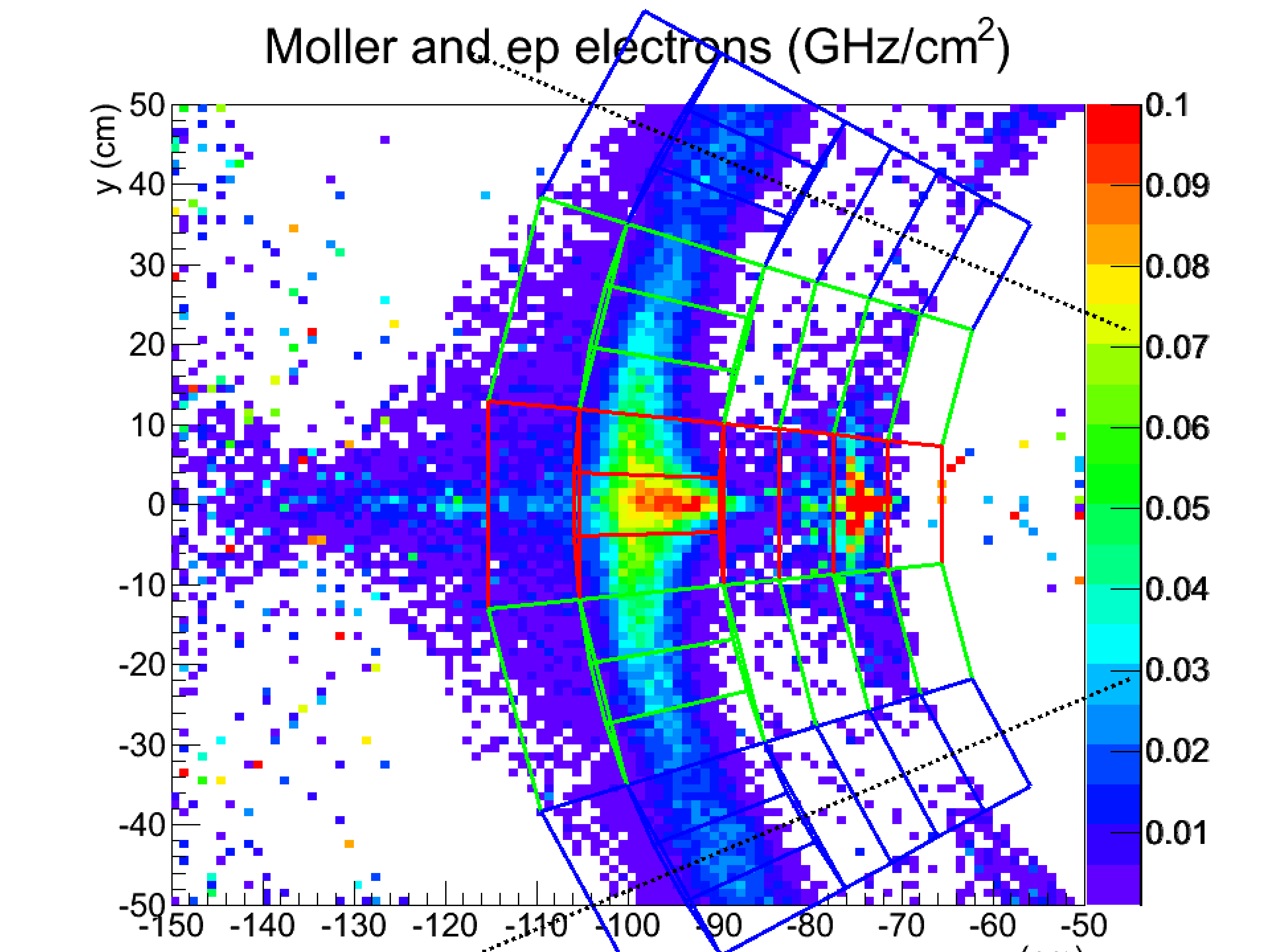
Tracks colored by theta from purple to red (low to high)

Range of phi values

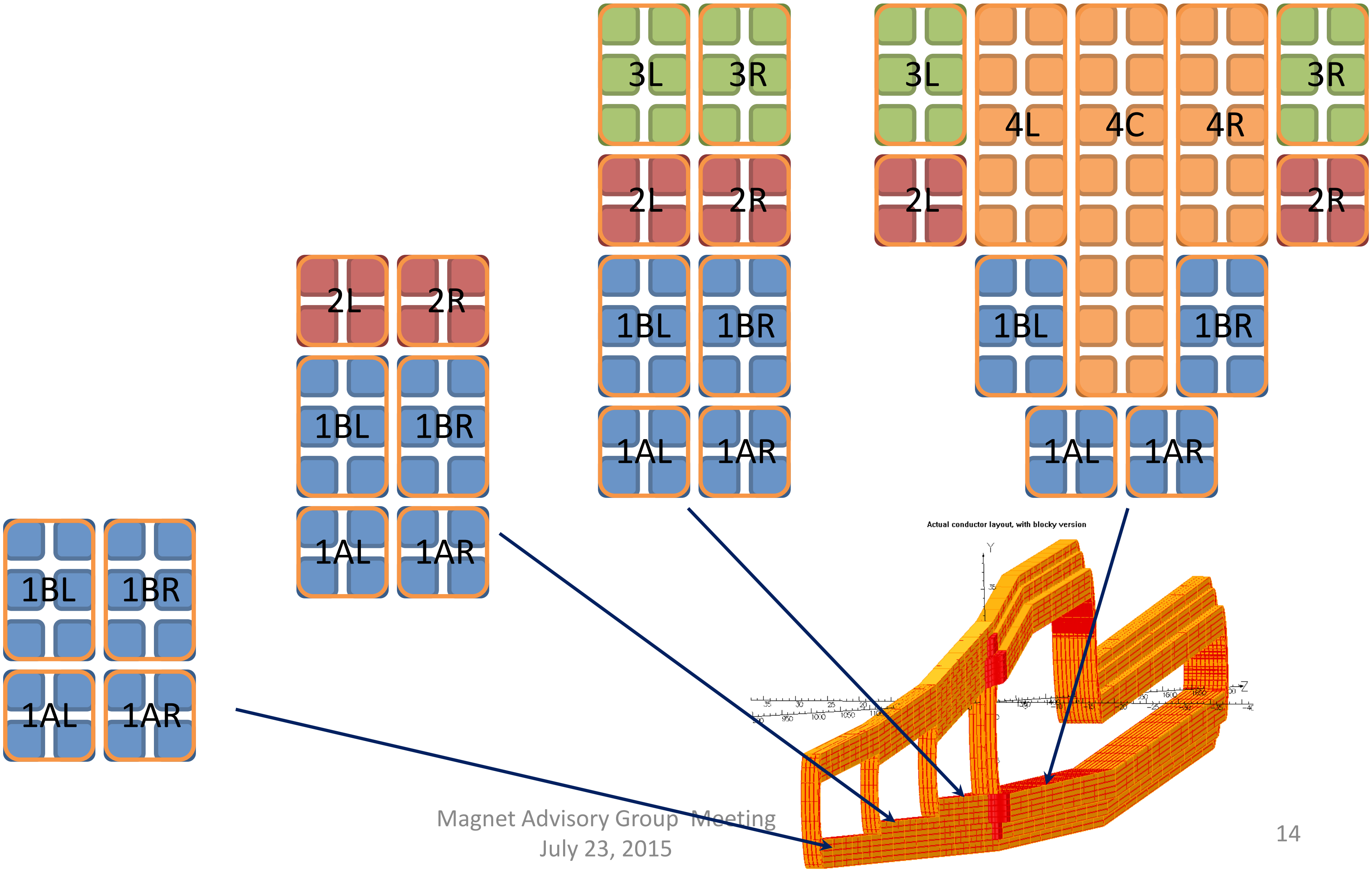
Tracks in GEANT4

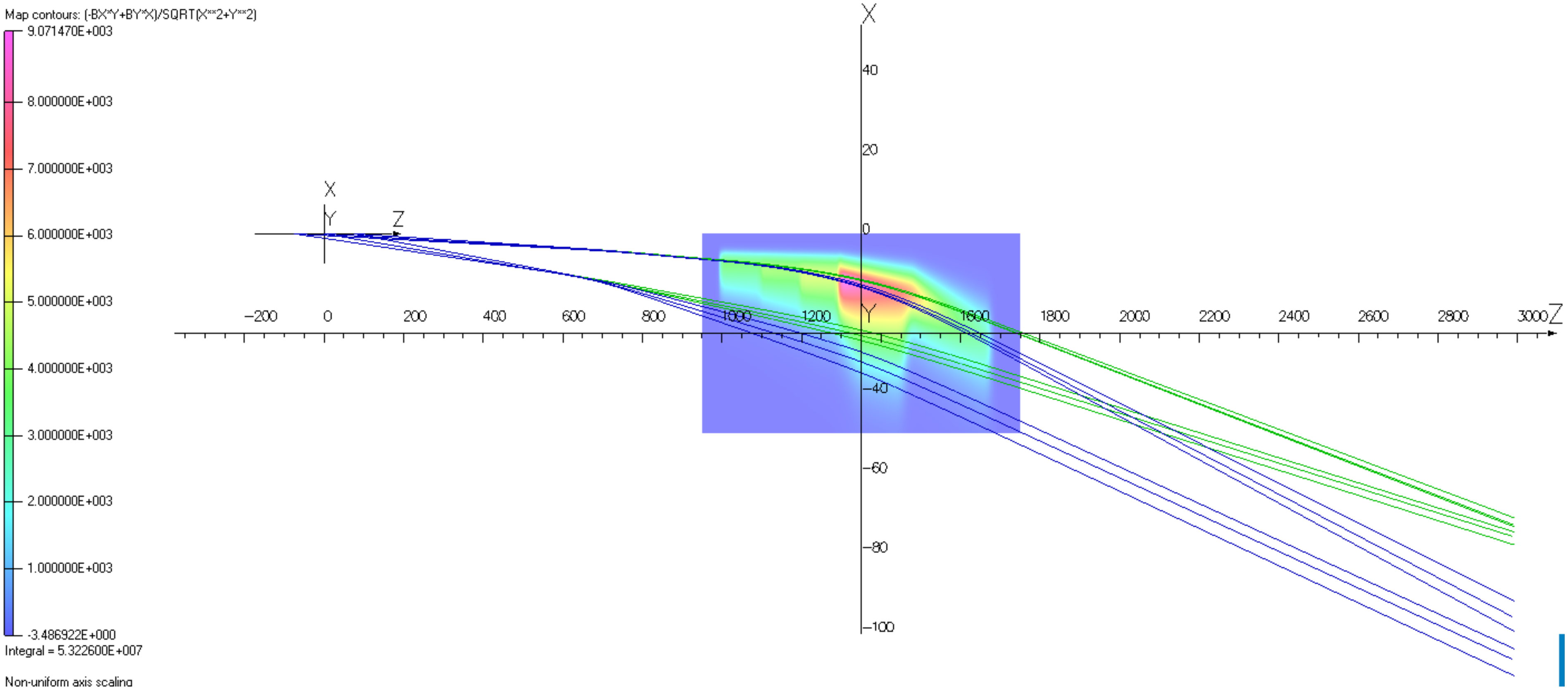


(Rate weighted 1x1cm^2 bins)


Moller and ep electrons (GHz/cm^2)
y (cm)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01

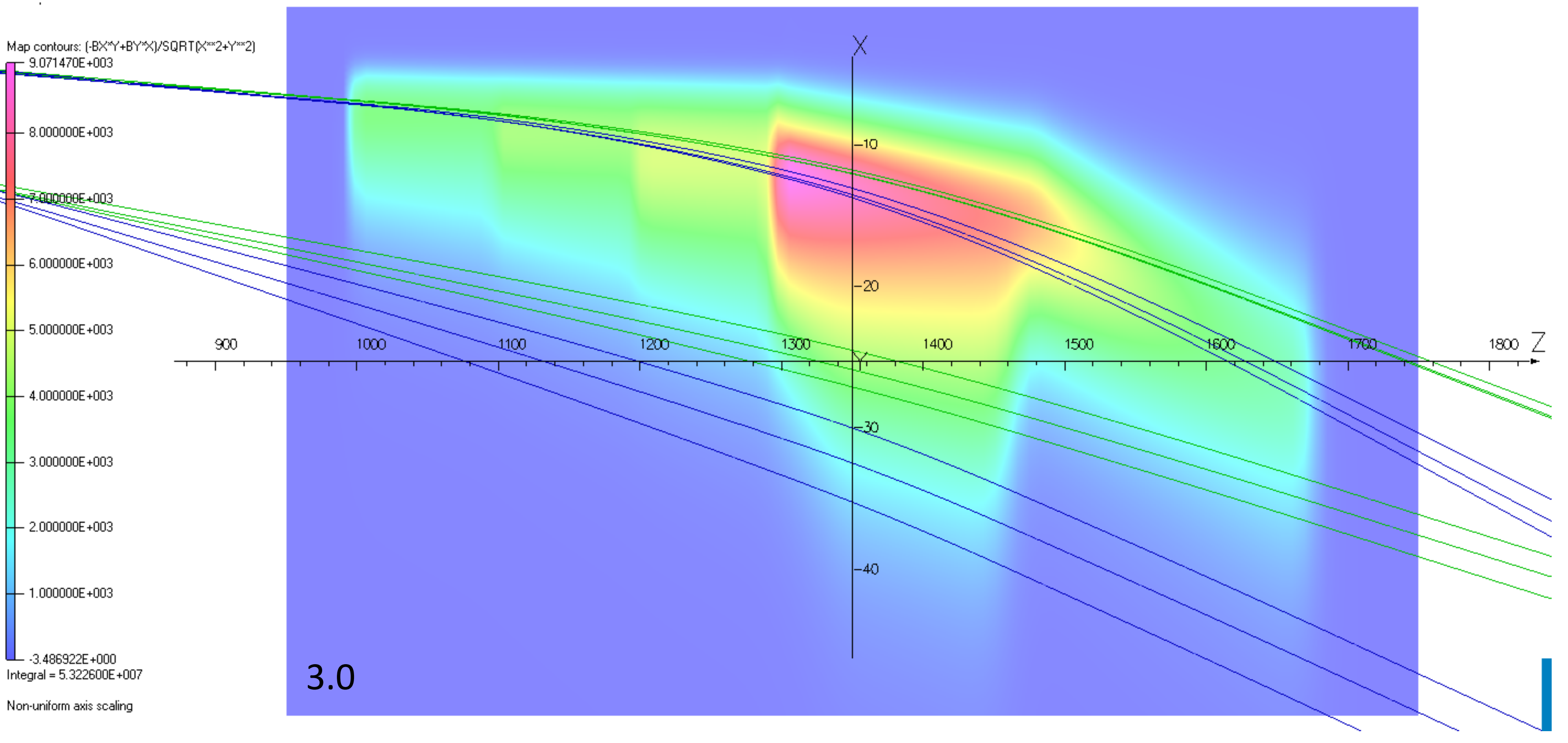
Layout


1BL
1BR
1AL
1AR
2L
2R
1BL
1BR
1AL
1AR
3L
3R
2L
2R
1BL
1BR
1AL
1AR
3L
4L
4C
4R
3R
2L
2R
1BL
1BR
1AL
1AR
Actual conductor layout, with blocky version



up (z0 =-75 cm) 5.5 and 15 mrads
middle (z0 =0 cm) 6.0 and 17 mrads
down (z0 =75 cm) 6.5 and 19 mrads
phi=0 only

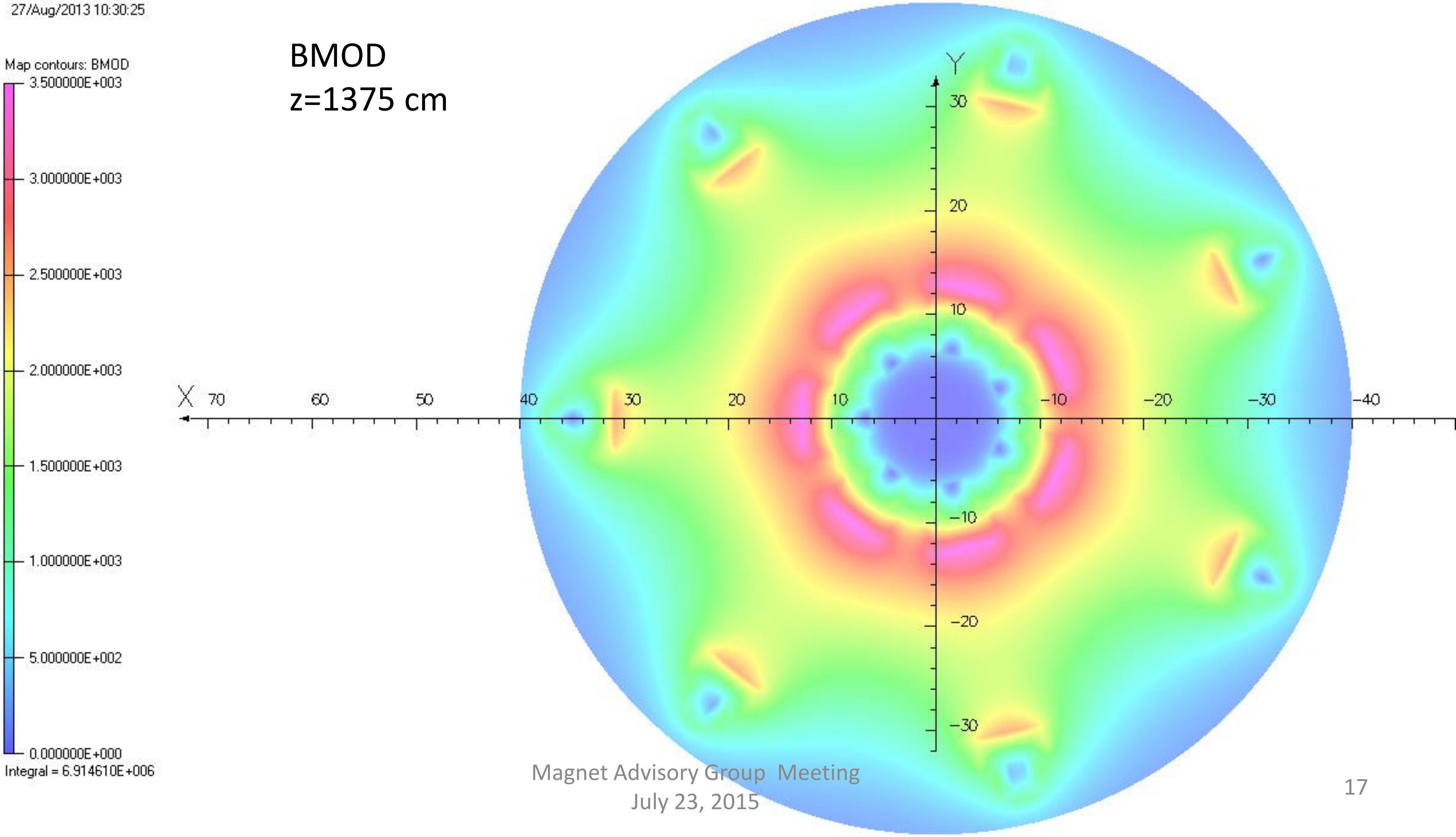
green – eps
blue - mollers



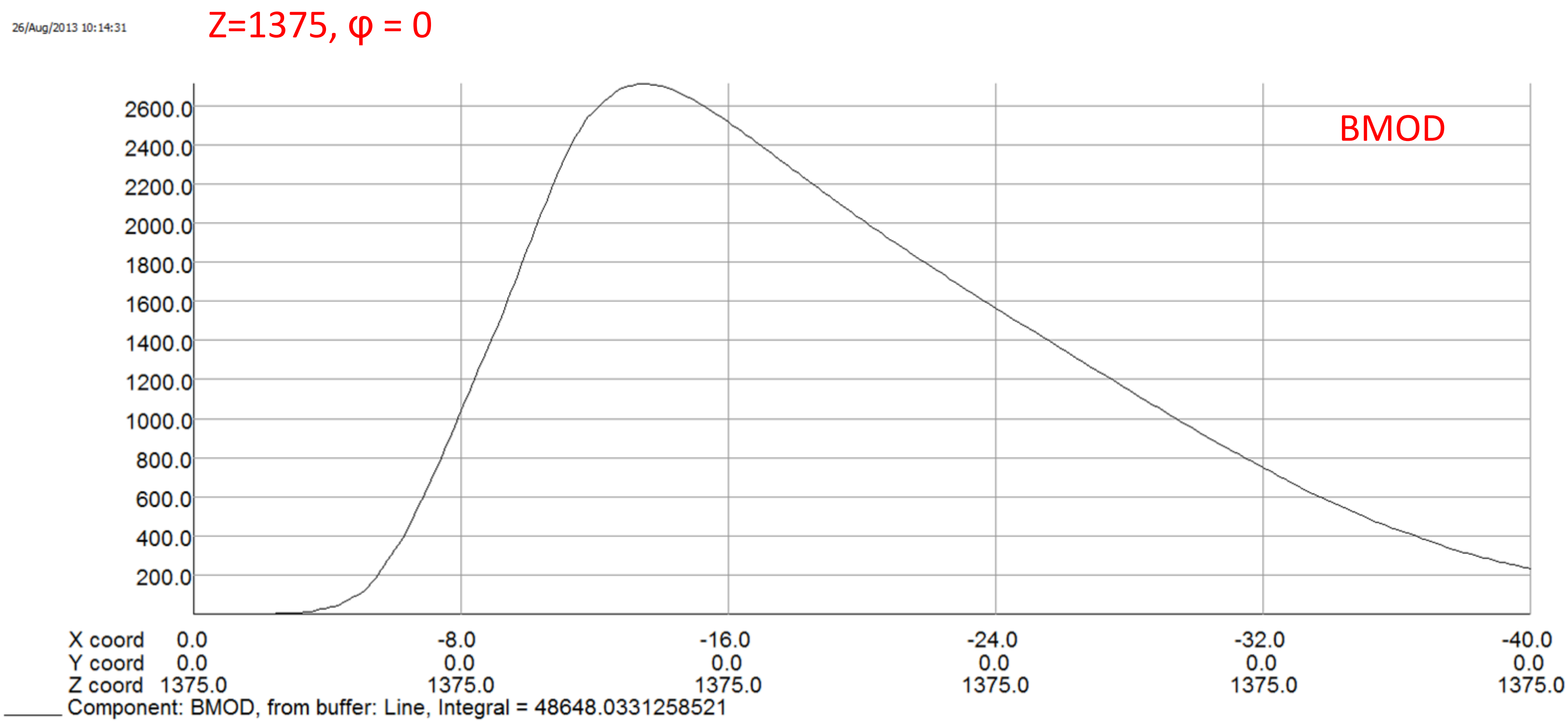
up (z0 =-75 cm) 5.5 and 15 mrads
middle (z0 =0 cm) 6.0 and 17 mrads
down (z0 =75 cm) 6.5 and 19 mrads
phi=0 only, near magnet

green – eps
blue - mollers

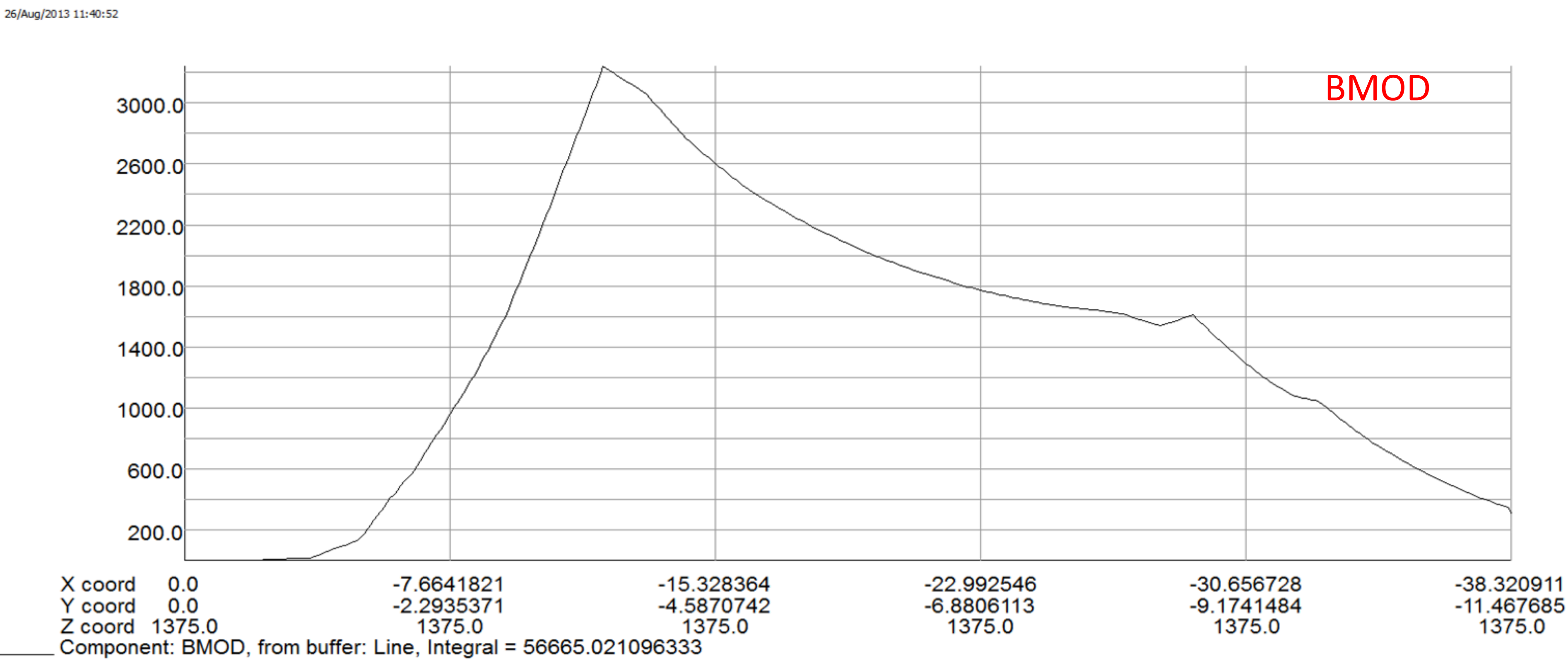
Field representations



Radial plot, middle of open sector

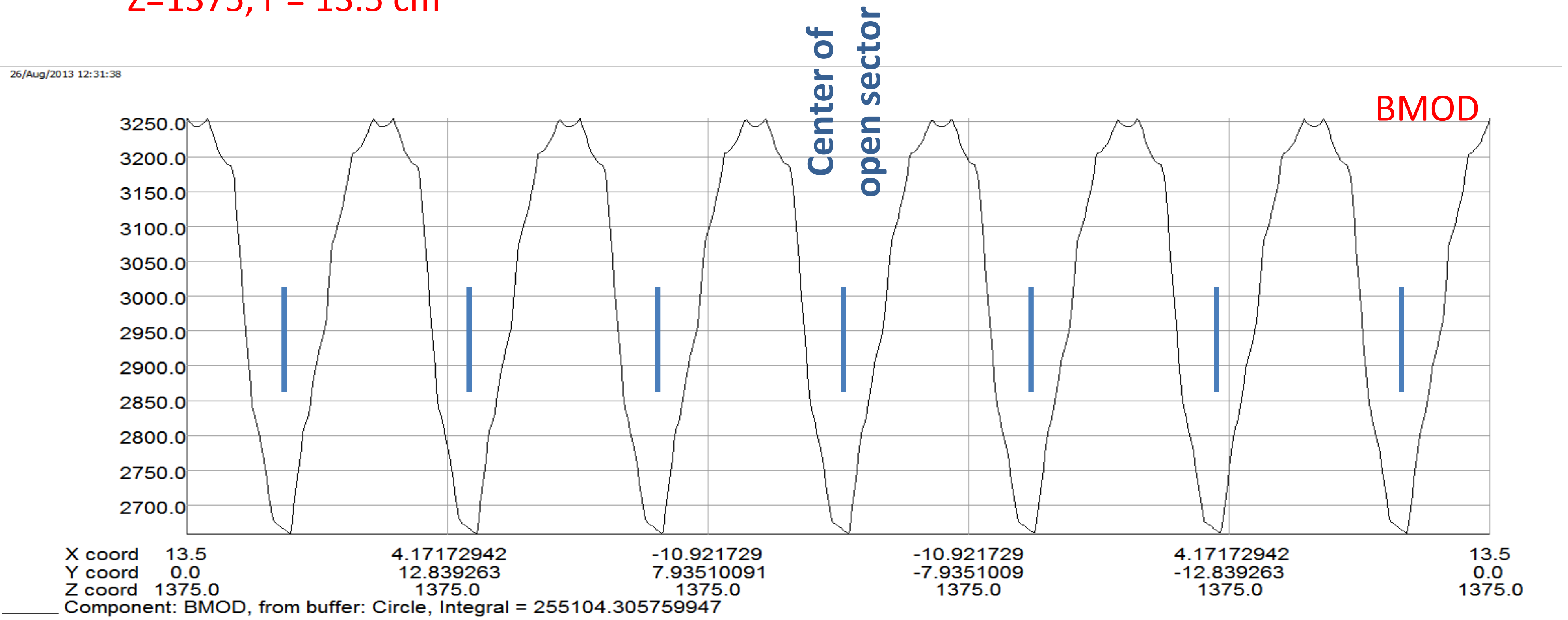


Radial plot, edge of open sector



Around Azimuth

Z=1375, r = 13.5 cm



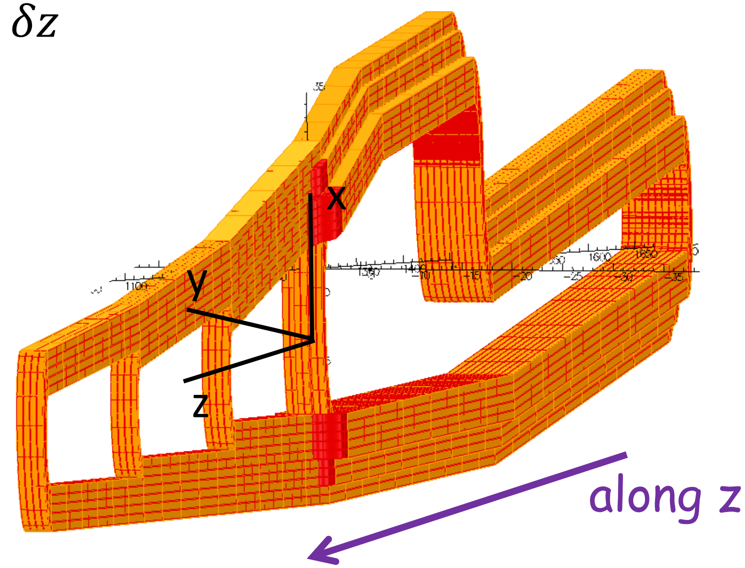
Sensitivity Studies

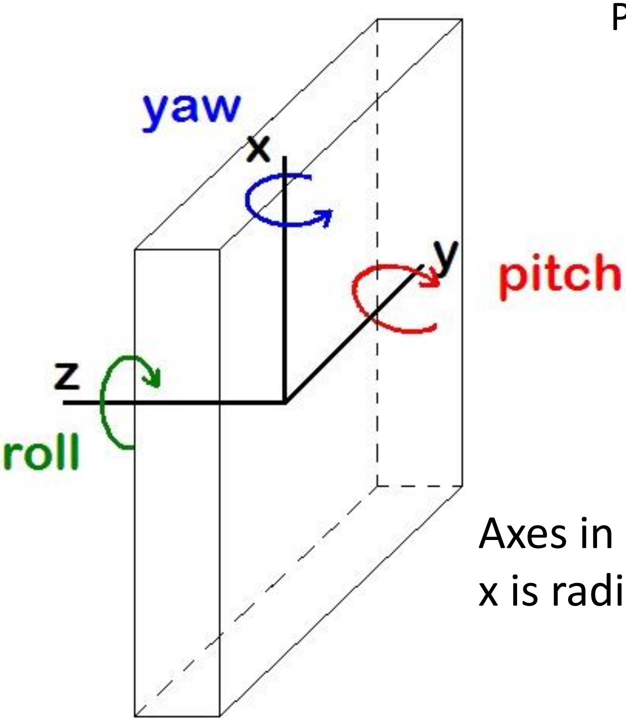
field maps for a **single coil** misplaced by 10 (5) steps

$$\delta A_{raw}\left(\frac{\Delta\langle A_{raw}\rangle}{\Delta z}\right)^{-1} = \delta z$$

$$\delta A_{raw} = 0.1\ ppb$$

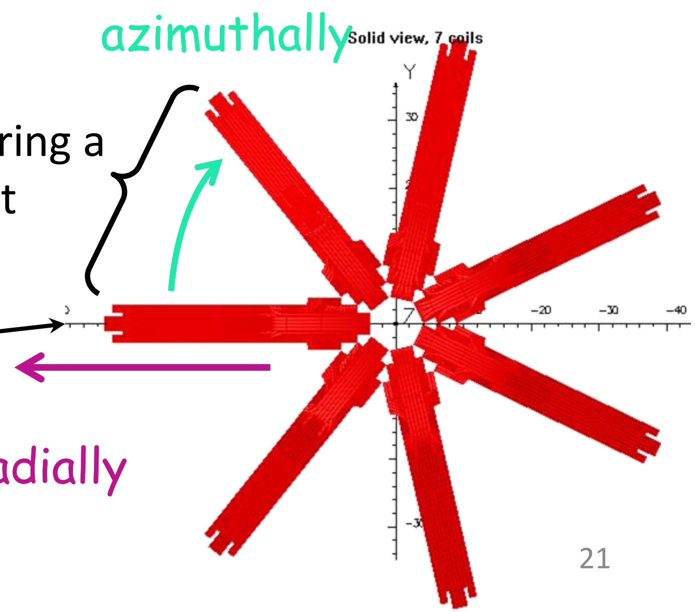
Along beam, Z –	± 0.5 cm	(±10 cm)
Radially, R –	± 0.5 cm	(±2 cm)
Azimuthally, T –	± 0.05°	(±5°)
Roll –	±0.05°	(±4°)
Pitch –	±0.05°	(±1°)
Yaw –	±0.05°	(±1°)



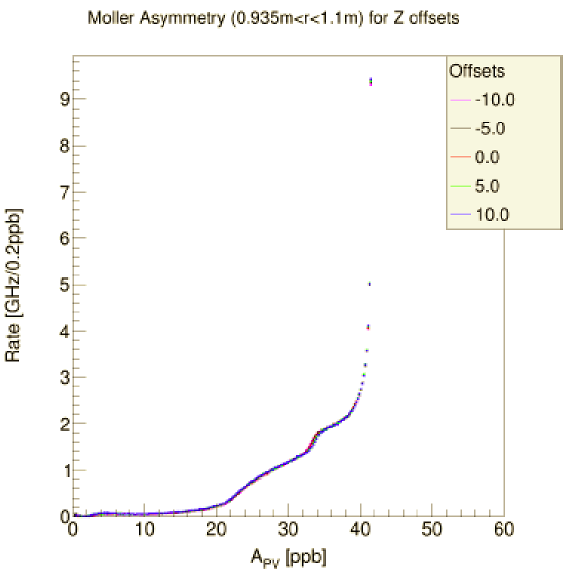


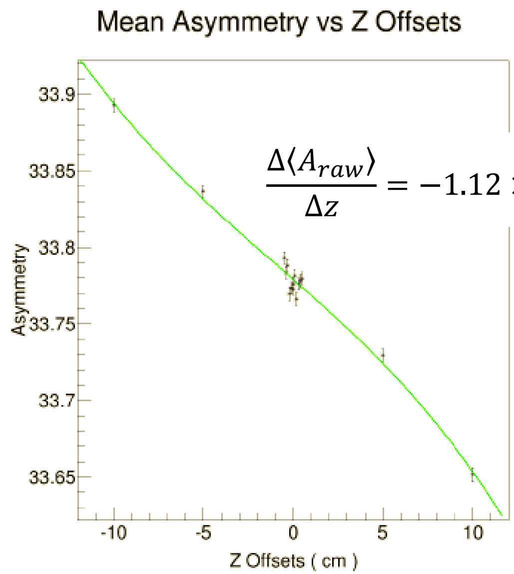
Only considering a single septant

Axes in frame of single coil, x is radial direction



Rate vs. Radial Offsets

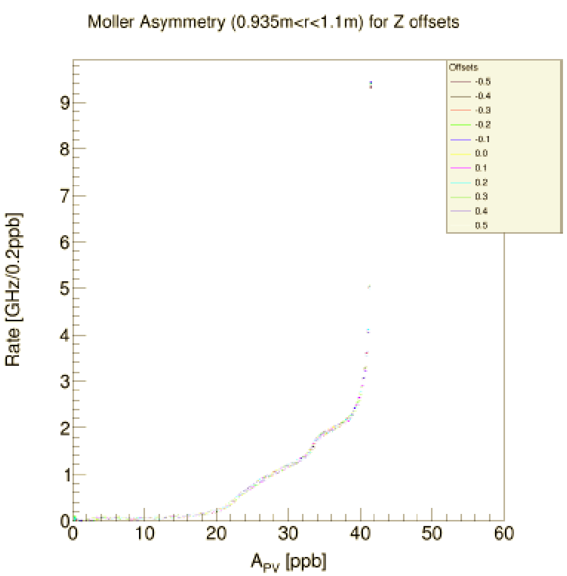


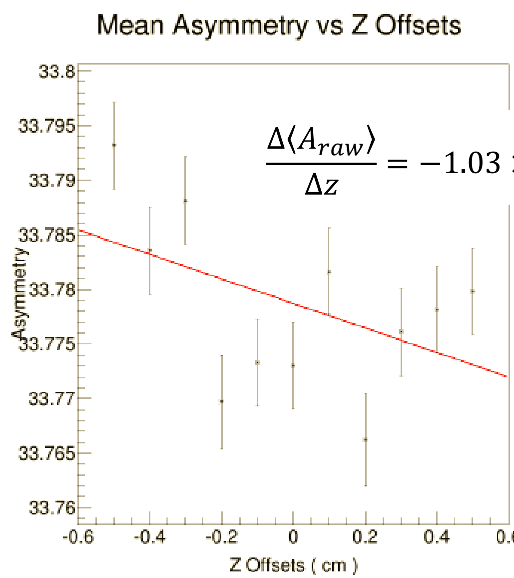


$$\frac{\Delta\langle A_{raw}\rangle}{\Delta z} = -1.12 \times 10^{-2}\ ppb/cm$$

field maps for a **single coil** misplaced by 10 (5) steps

$$\delta A_{raw}\left(\frac{\Delta\langle A_{raw}\rangle}{\Delta z}\right)^{-1} = \delta z$$





$$\frac{\Delta\langle A_{raw}\rangle}{\Delta z} = -1.03 \times 10^{-2}\ ppb/cm$$

$$\delta A_{raw} = 0.1\ ppb$$

$$\delta z \approx 8.9\ -\ 9.7cm$$

Preliminary Results

Position sensitivity in cm

	Asymmetry (δA = 0.1 ppb)		
	Large Range (higher order fit)	Small Range (linear fit)	Old (over linear range)
Z (cm)	-9.73	-8.89	-9.24
R (cm)	0.28	0.29	0.29
T (cm)	-6.37	19.11	-12.89
Roll (cm)	0.62	-1.37	1.59
Yaw (cm)	9.73	2.90	9.72
Pitch (cm)	-4.46	-3.29	-4.58

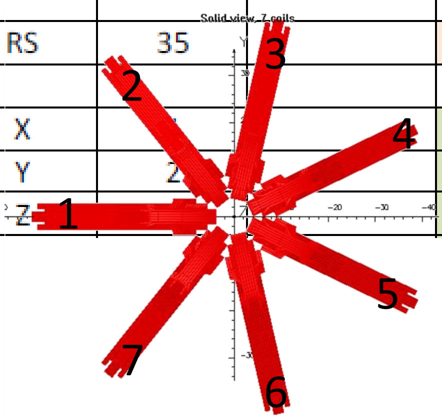
over (half) radius

over half-length

- Need to look at the effect of tracking algorithm with incorrect maps
- Need to consider the effect of multiple types of offsets in one coil, and multiple coils having offsets

Forces

New CURD2 = 0 Force on horizontal coil (lbs)					
Segment	Cond. #	Length (cm)	F_x	F_y	F_z
A	4, 5, 6		-1575.89	-427.59	27.04
B	7, 8, 9		-1120.77	-122.59	69.43
C	10, 11, 12		-0.96	-5.33	65.79
D	13, 14, 15		912.52	-72.03	-58.37
E	16, 17, 18		87.05	-13.57	31.72
F	19, 20, 21		60.35	-12.61	23.20
G	22, 23, 24		370.23	-82.52	-12.93
H	25, 26, 27		200.05	-42.92	-34.45
IJ	28, 29		-13.54	-11.31	-84.93
K	30		153.81	-29.25	-6.51
LM	31		-1.07	-0.75	-11.76
N	32		87.13	-16.77	-3.69
O	33		-0.60	-0.42	-6.03
Q	34		51.79	-10.17	-1.51
RS	35		-1.43	-2.19	-8.24
X	[illegible]		-106.67	-28.75	0.27
Y	2		-181.23	-48.18	0.47
Z	[illegible]		-319.04	-83.80	0.82



Old

	F_x (lbs)	F_y (lbs)	F_z (lbs)
Total	-2941.75	0.00	36.88
Inner	-5434.03	-7.24E-08	1.05E+02
Outer	2636.429	-2.80E-08	-84.7468
returns	-144.153	1.71E-10	16.45164
	-2941.75	0.00	36.88

New

	F_x (lbs)	F_y (lbs)	F_z (lbs)
Total	-1883.92	0.00	-9.34
Inner	-4111.14	0.00	119.65
Outer	2013.15	0.00	-30.87
returns	214.07	0.00	-98.13
	-1883.92	0.00	-9.34

Coil off

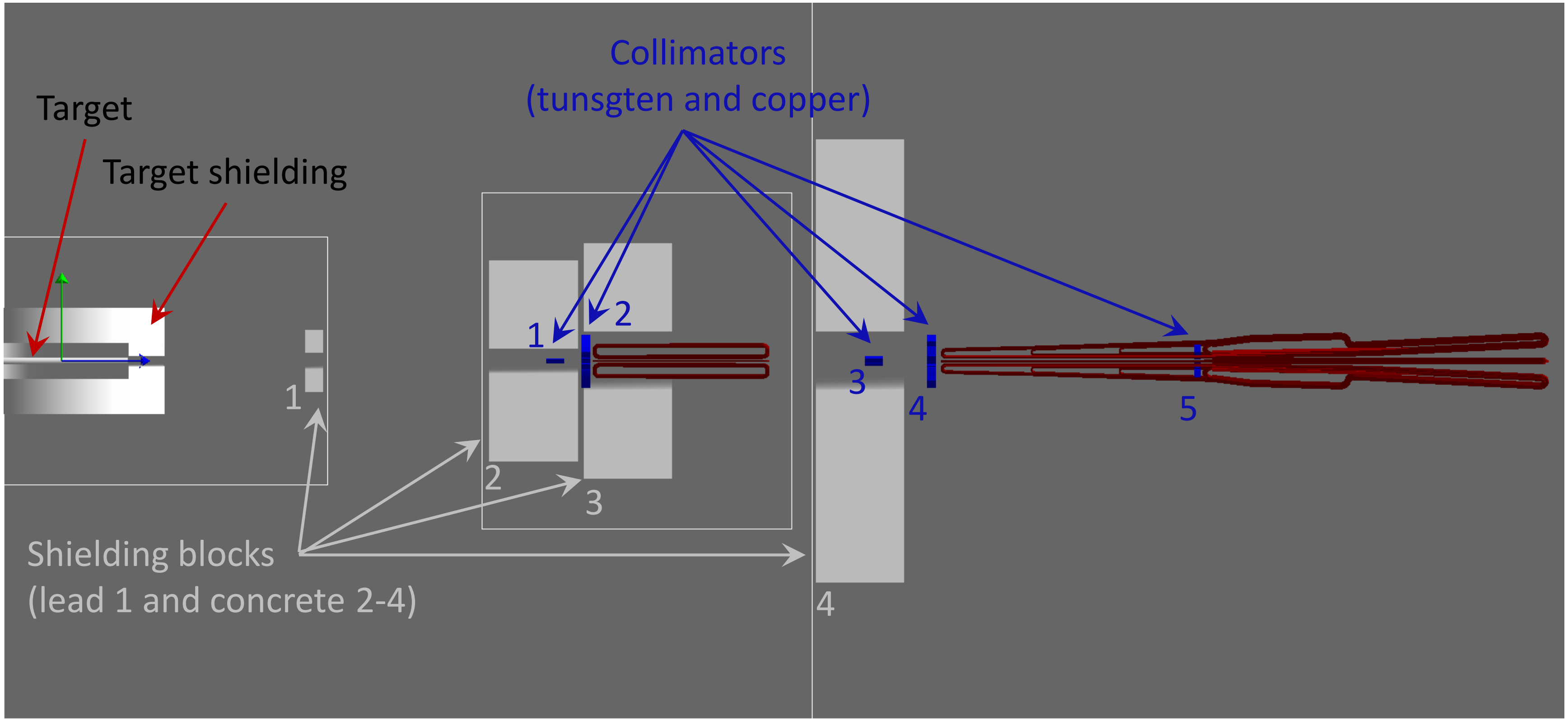
	F_x (lbs)	F_y (lbs)	F_z (lbs)
Total	-1398.25	-1010.75	-9.66
Inner	-3303.59	-710.91	98.03
Outer	1722.88	-236.92	-28.08
returns	182.45	-62.92	-79.61
	-1398.25	-1010.75	-9.66

Spectrometer and shielding

Collimators are designed to provide a 2-bounce system for photons to detectors

Some will be moveable, all must be precisely aligned; some will be water-cooled

We will require local shielding (mostly due to neutron production) and radiation monitoring



Simulations

- Optimize collimator acceptances
- Design local shielding
- Reduce radiative power deposited on collimators and coils to acceptable levels

(for 85 μA)

Collimator	Total Incident (W)	Only e- (W)	Only e+ (W)	Only γ (W)
1	3238.5	2141.5	996.7	97.8
2	1757.5	1195.3	501.9	58.5
3	1985.4	1331.7	588.4	63.5
4	229.0	156.1	65.1	7.7
5	34.7	23.0	10.5	1.1

Dominated by electrons

US Magnet

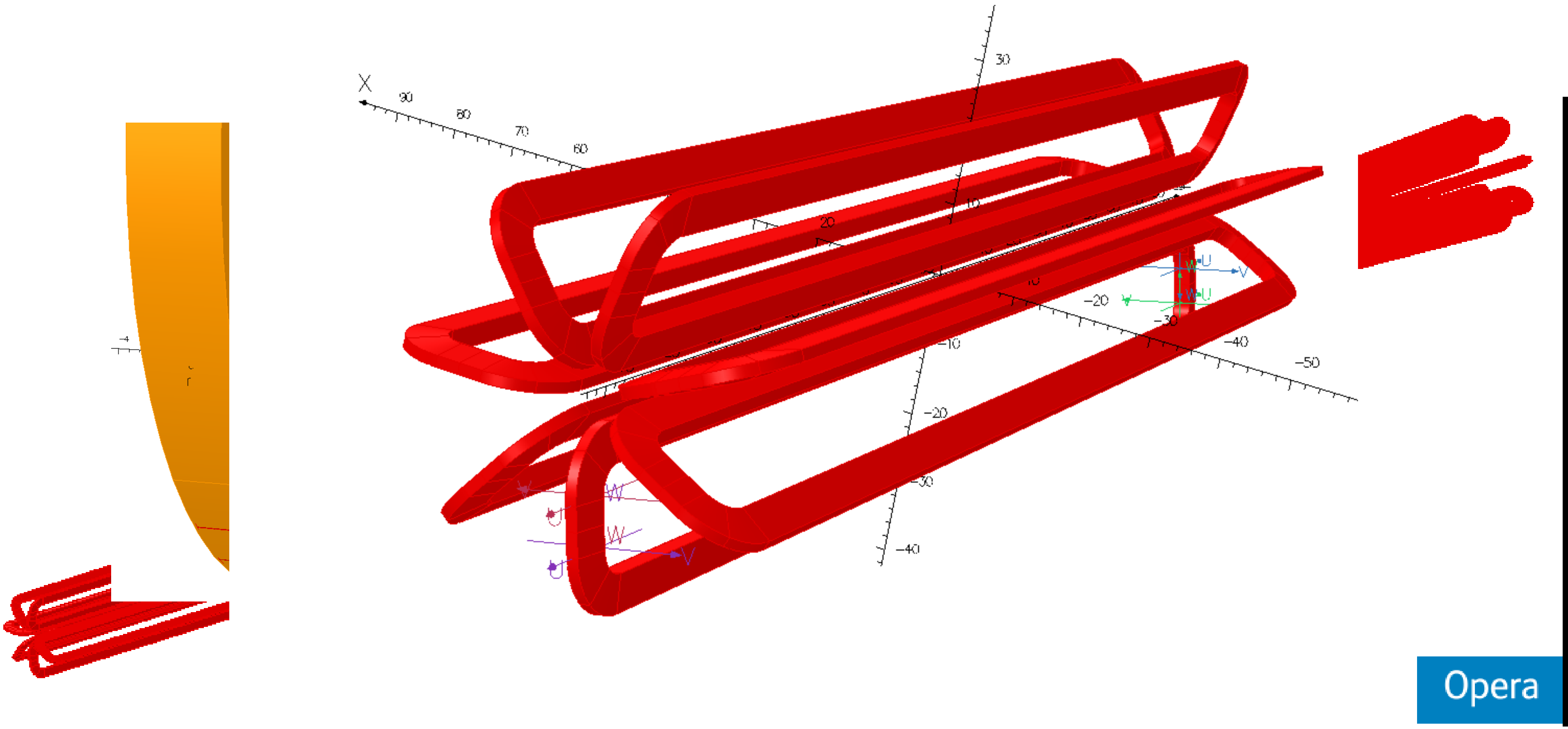
Type	E Rnge	Total Power	Total Flux
	(MeV)	(W/uA)	(per uA)
Total	E<10	0.116	3.22E+11
	0<E<100	0.373	7.56E+10
	100<E	1.534	3.07E+10

Dominated by photons

DS Magnet

Type	E Rnge	Total Power	Total Flux
	(MeV)	(W/uA)	(per uA)
Total	E<10	0.034	7.34E+10
	0<E<100	0.173	3.22E+10
	100<E	0.501	1.03E+10

Upstream Torus



Upstream torus studies

- Physics
  - Included in optics studies
  - Radiative power deposited (mostly upstream end)
  - Sensitivity studies
  - Effect of fringe fields in beampipe

- Engineering
  - Water cooling and power connections
  - Manufacturing procedure
  - Support structure

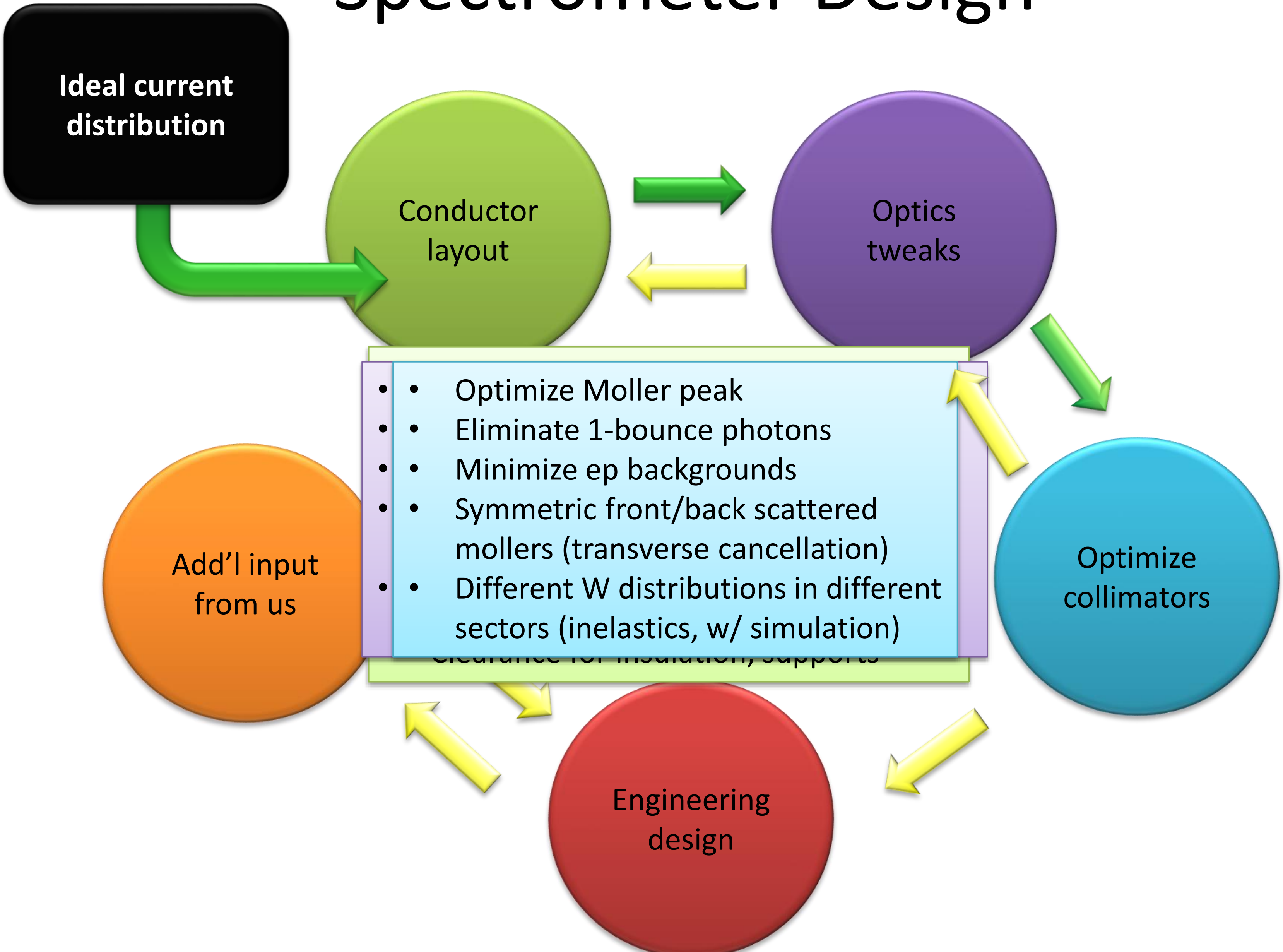
Extra Slides

Large Phase Space for Design

I. Large phase space of possible changes
   A. Field (strength, coil position and profile)
   B. Collimator location, orientation, size
   C. Choice of Primary collimator
   D. Detector location, orientation, size

II. Large phase space of relevant properties
   A. Moller rate and asymmetry
   B. Elastic ep rate and asymmetry
   C. Inelastic rate and asymmetry
   D. Transverse asymmetry
   E. Neutral/other background rates/asymmetries
   F. Ability to measure backgrounds (the uncertainty is what's important)
      1. Separation between Moller and ep peaks
      2. Profile of inelastics in the various regions
      3. Degree of cancellation of transverse (F/B rate, detector symmetry)
      4. Time to measure asymmetry of backgrounds (not just rate)
   G. Beam Properties (location of primary collimator)

Spectrometer Design



Work since original proposal

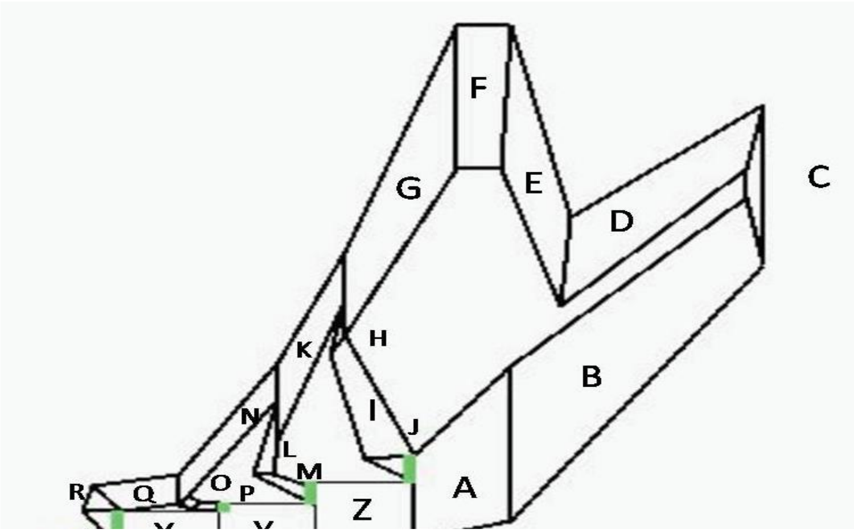
- First Engineering Review
  - Verified the proposal map in TOSCA
  - Created an actual conductor layout with acceptable optics

- Since the engineering review
  - New conductor layout, take into account keep-out zones
  - Water cooling more feasible
  - Preliminary look at the magnetic forces

Purchase of a new machine and TOSCA license for use at University of Manitoba

- Interfacing with engineers
  - JLab engineers estimate that pressure head is not an issue
  - New conductor layout with larger water cooling hole
  - Coil carrier and support structure design
  - Working toward a “cost-able” design for DOE review soon

Proposal Model to TOSCA model

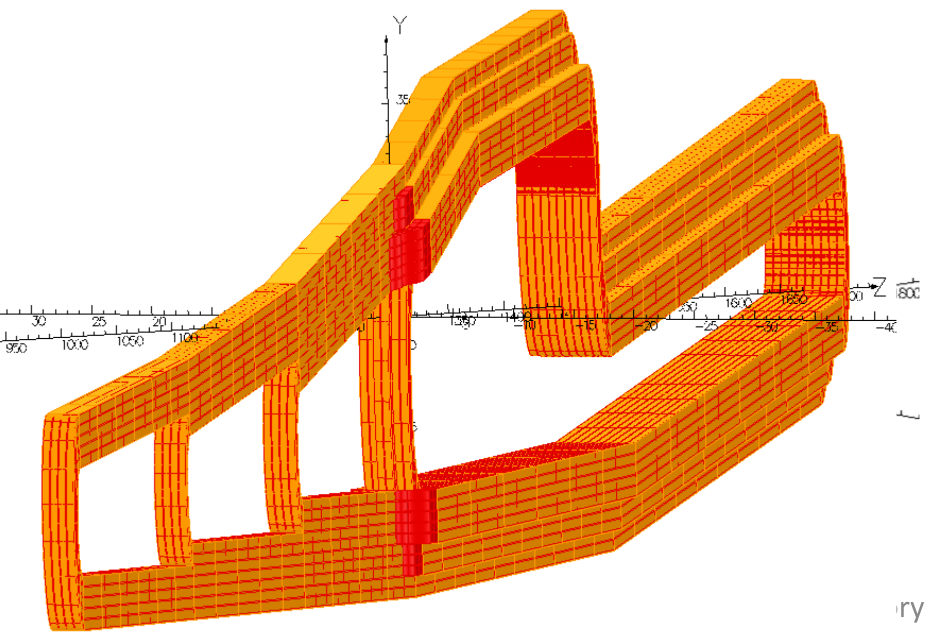


Actual conductor layout, with blocky version

Home built code using a Biot-Savart calculation

Optimized the amount of current in various segments (final design had 4 current returns)

Integrated along lines of current, without taking into account finite conductor size



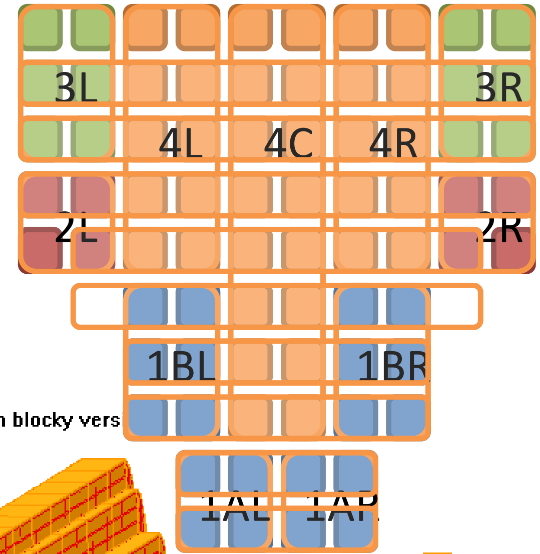
"Coils-only" Biot-Savart calculation

Verified proposal model

Created a first version with actual coil layout

Created second version with larger water cooling hole and nicer profile; obeyed keep-out zones

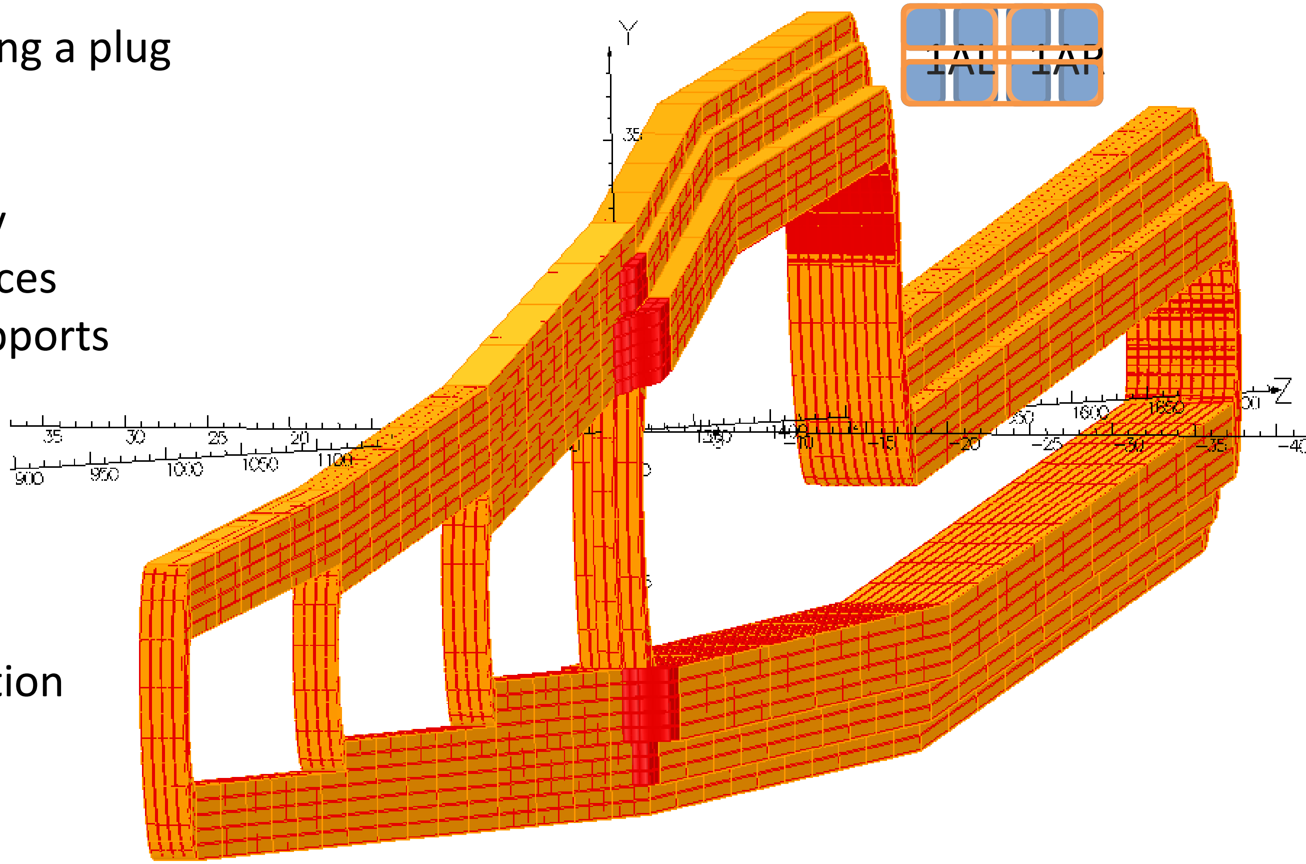
Concept 2 – Post-review

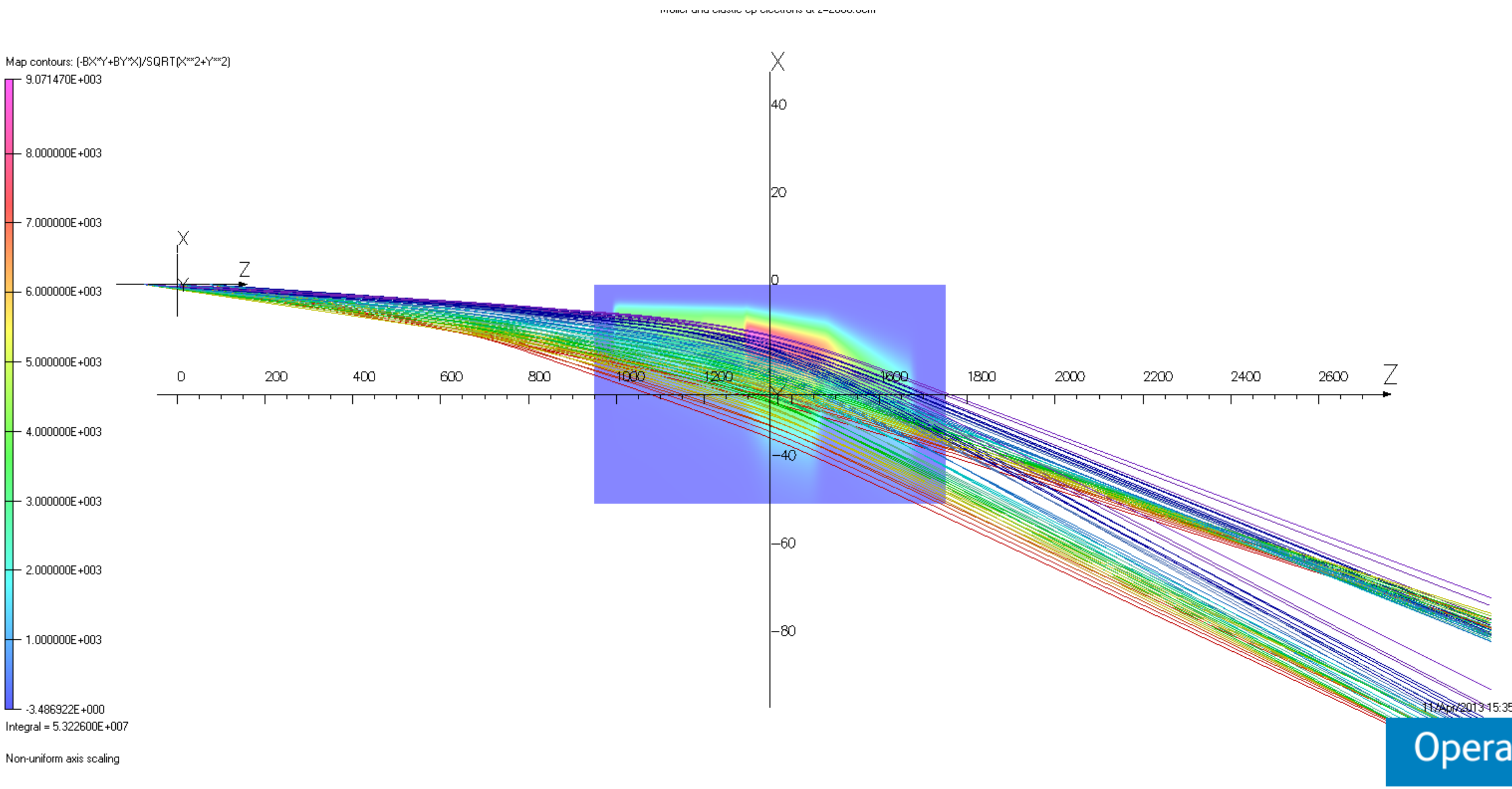


Current density not an issue, but affects cooling

- Larger conductor
  - Larger water-cooling hole
  - Fewer connections
  - Less chance of developing a plug
- New layout
  - Use single power supply
  - Keep-out zones/tolerances
  - Need to think about supports
  - Study magnetic forces
- Continued simulation effort
  - Consider sensitivities
  - Re-design collimation
  - Power of incident radiation

Actual conductor layout, with blocky versi

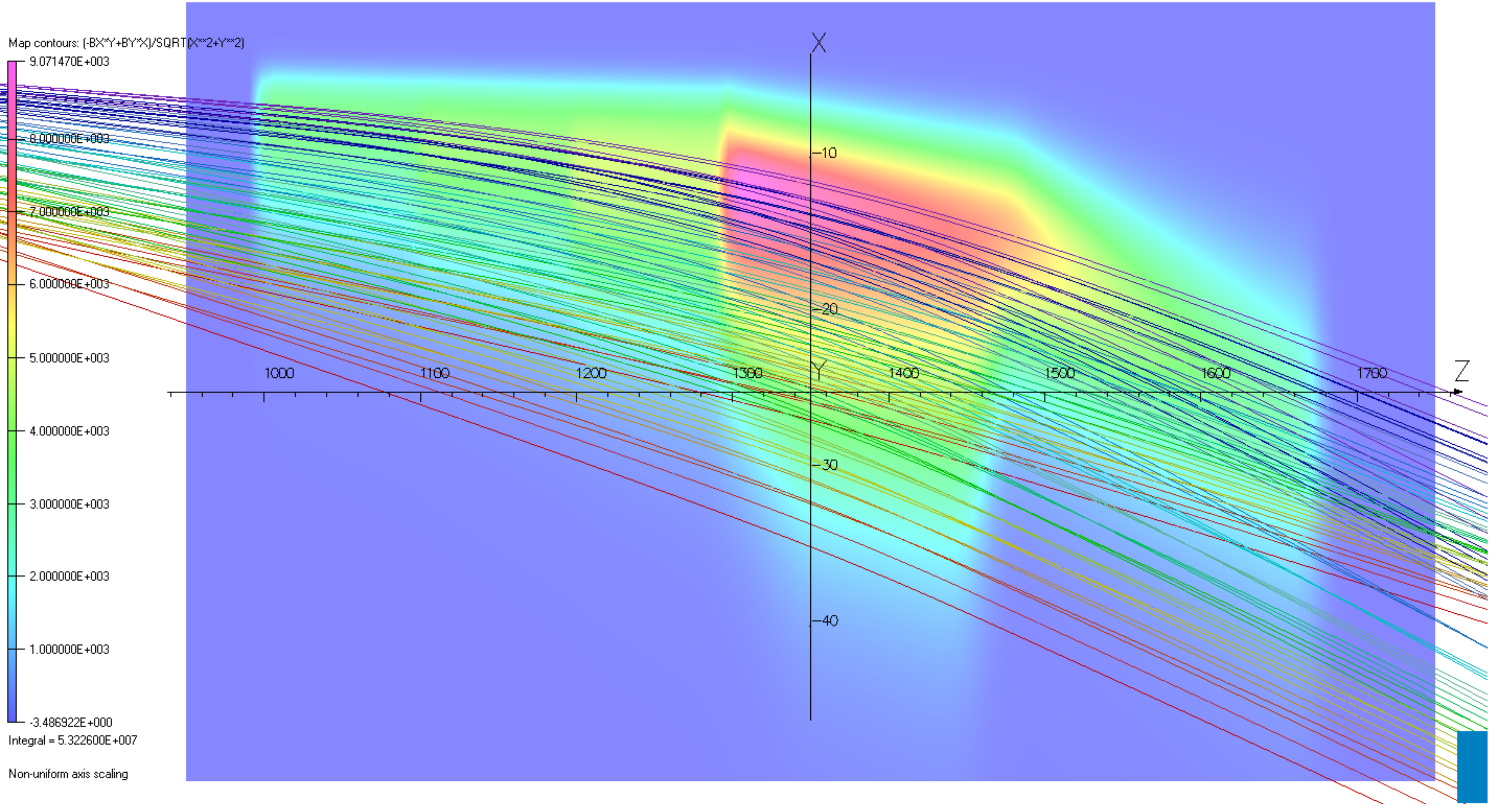




up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

Tracks colored by theta from purple to red (low to high)

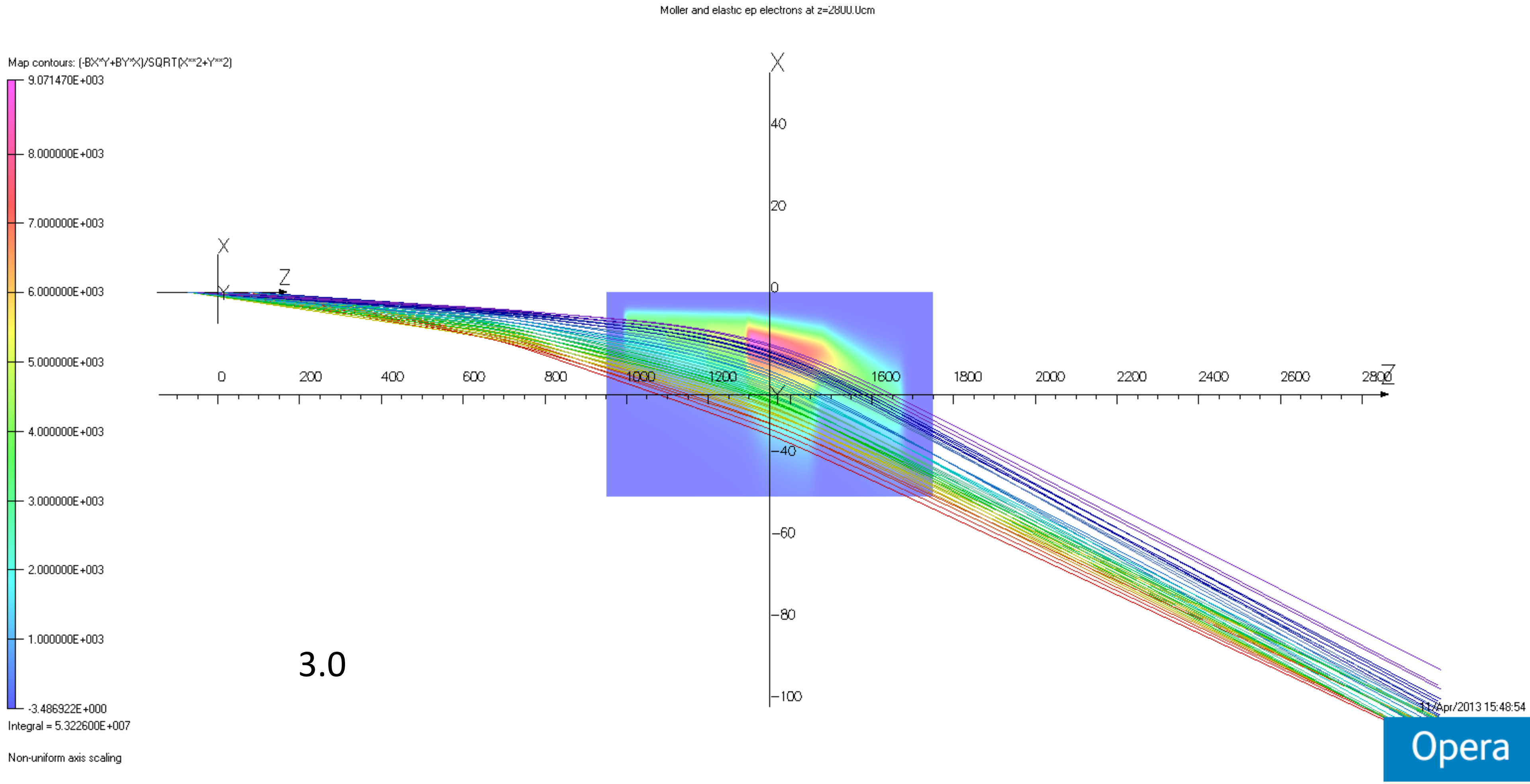
phi=0 only



up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

Tracks colored by theta from purple to red (low to high)

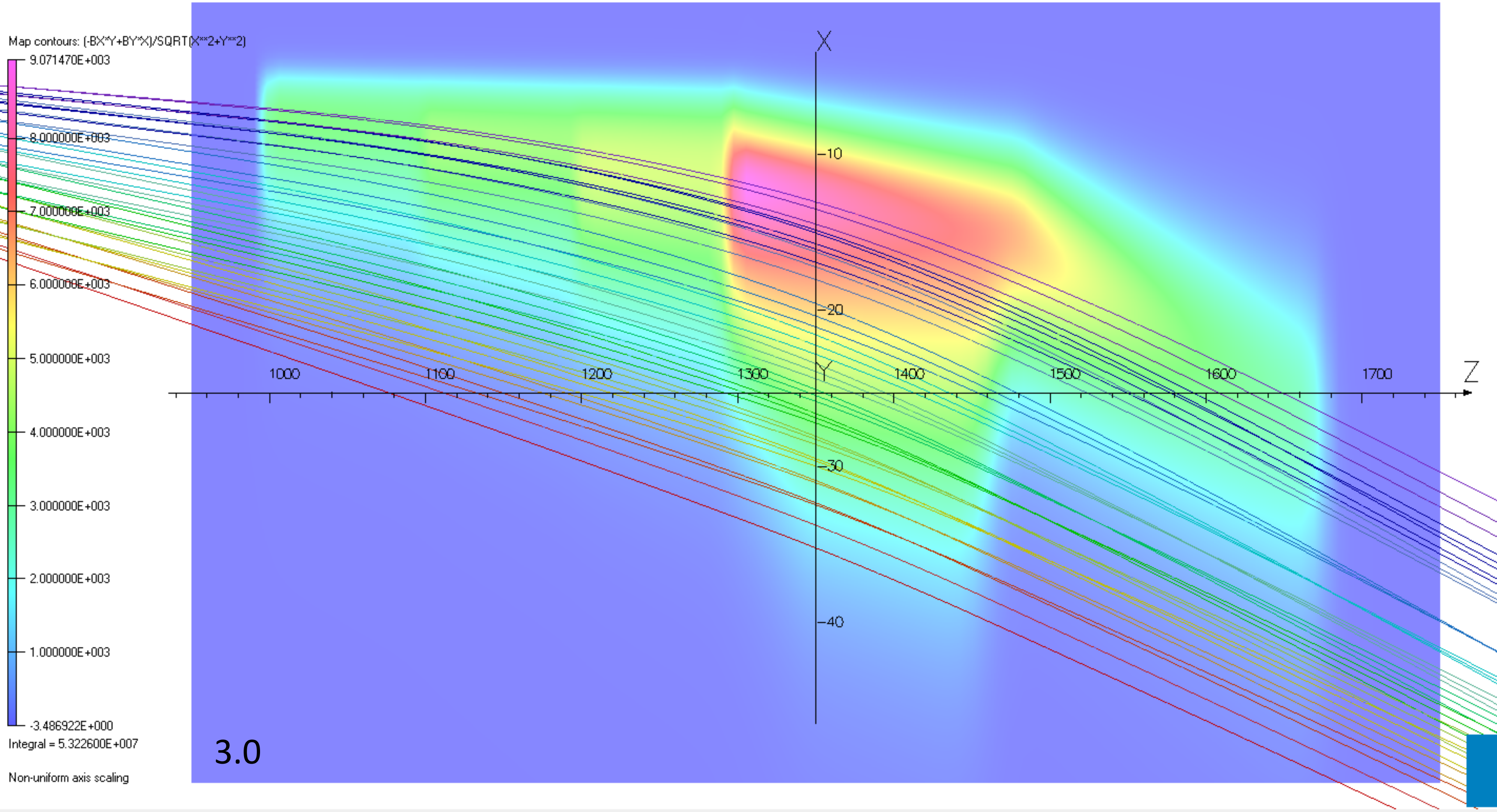
phi=0 only, near magnet



up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

phi = 0 , Mollers only

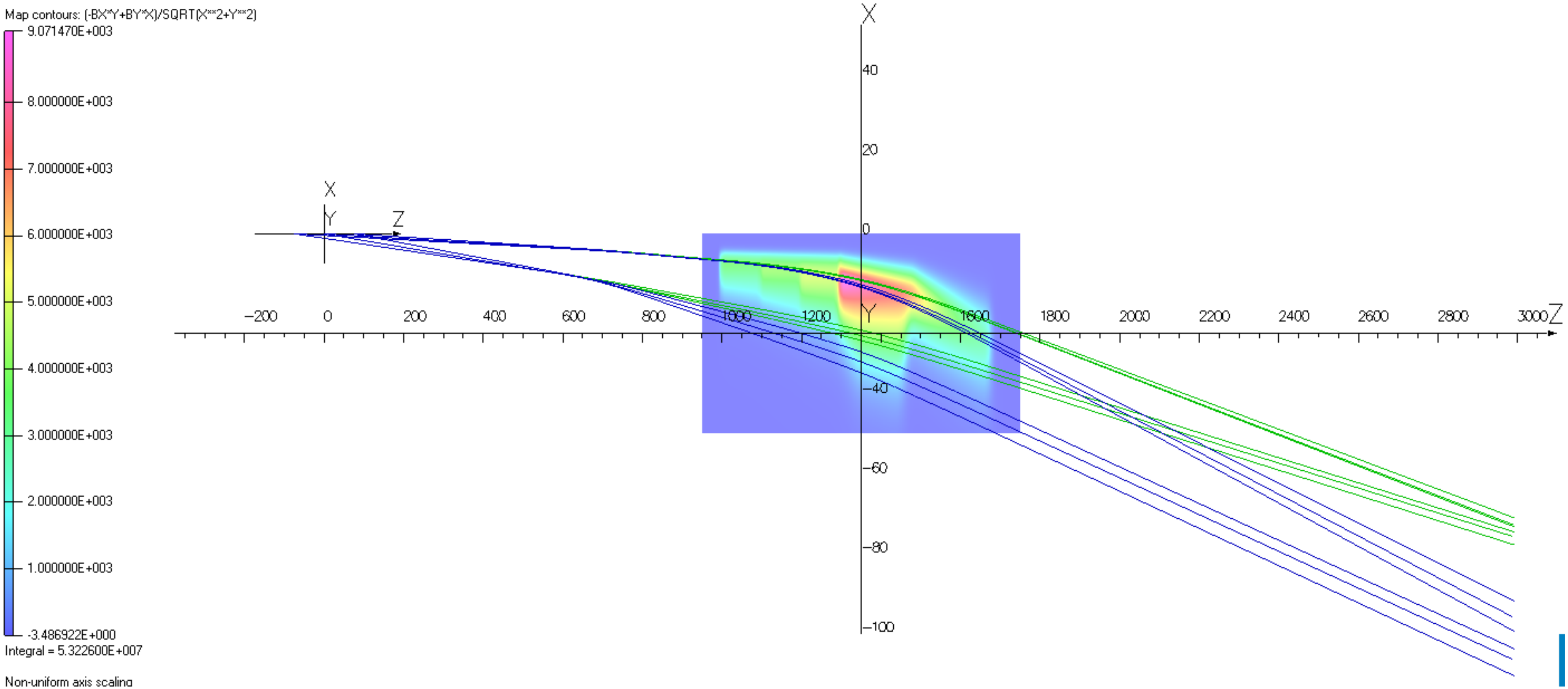
Tracks colored by theta from purple to red (low to high)



up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

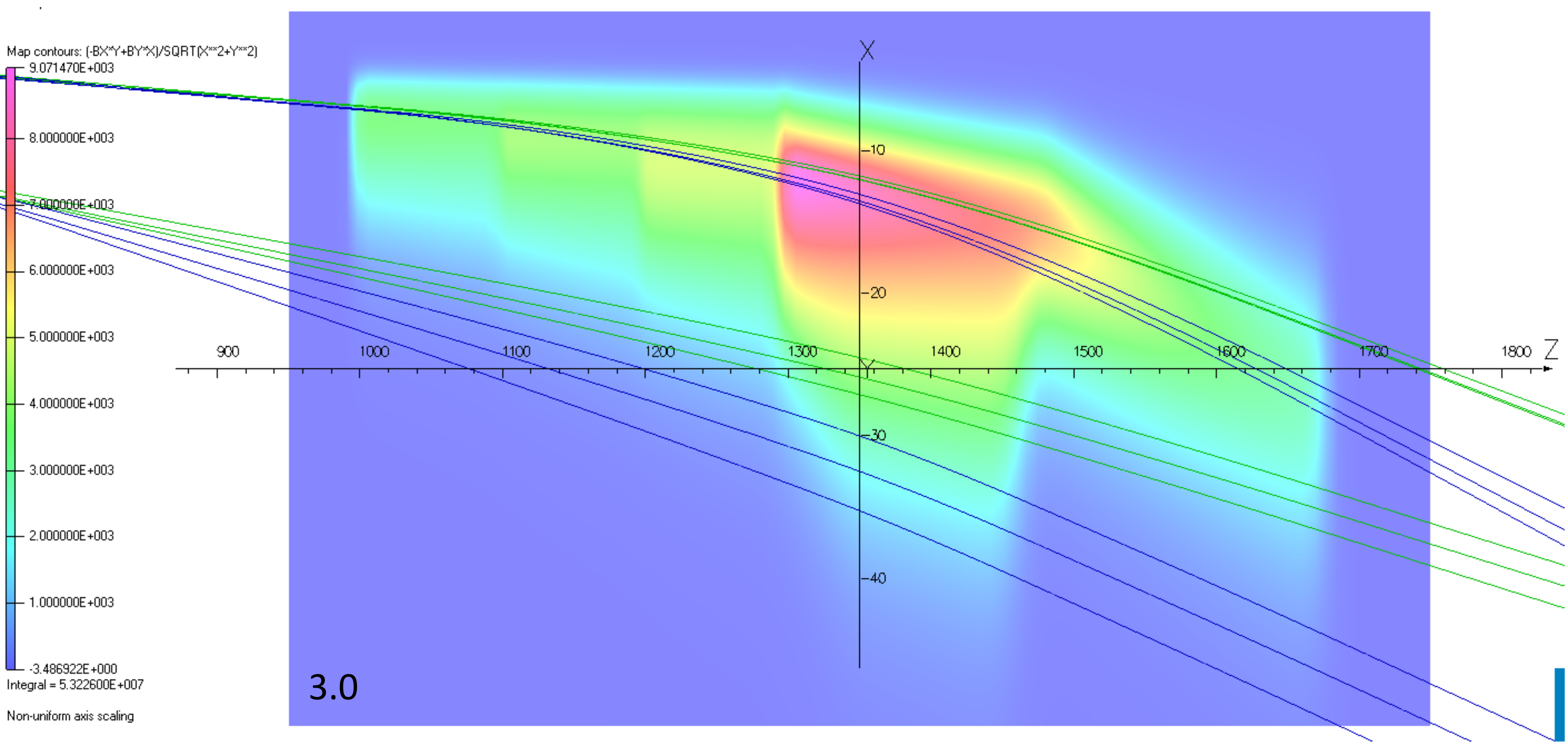
phi=0 only, near magnet, mollers only

Tracks colored by theta from purple to red (low to high)



up (z0 =-75 cm) 5.5 and 15 mrads
middle (z0 =0 cm) 6.0 and 17 mrads
down (z0 =75 cm) 6.5 and 19 mrads
phi=0 only

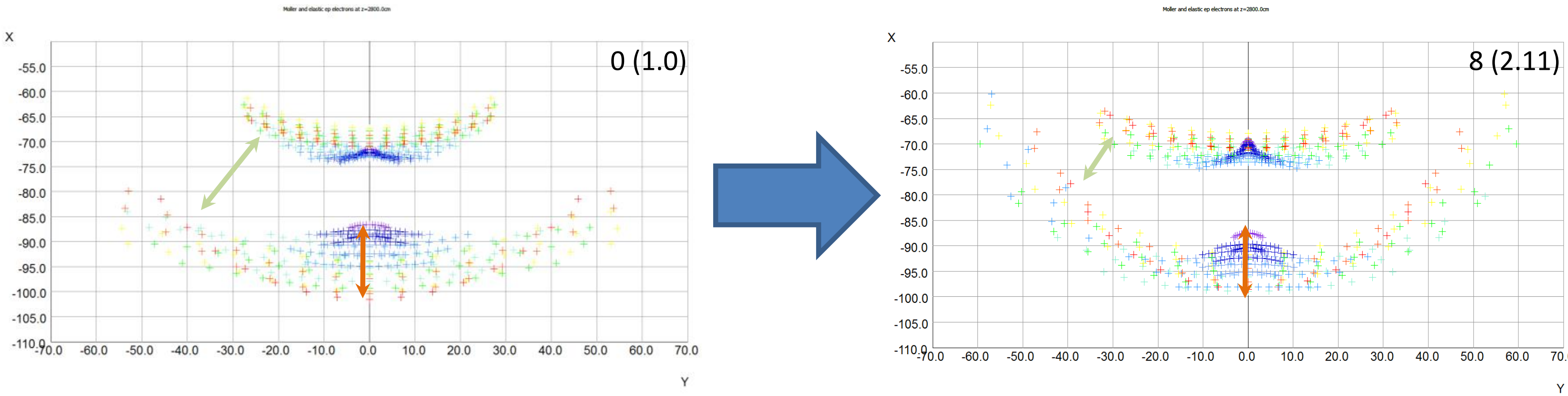
green – eps
blue - mollers

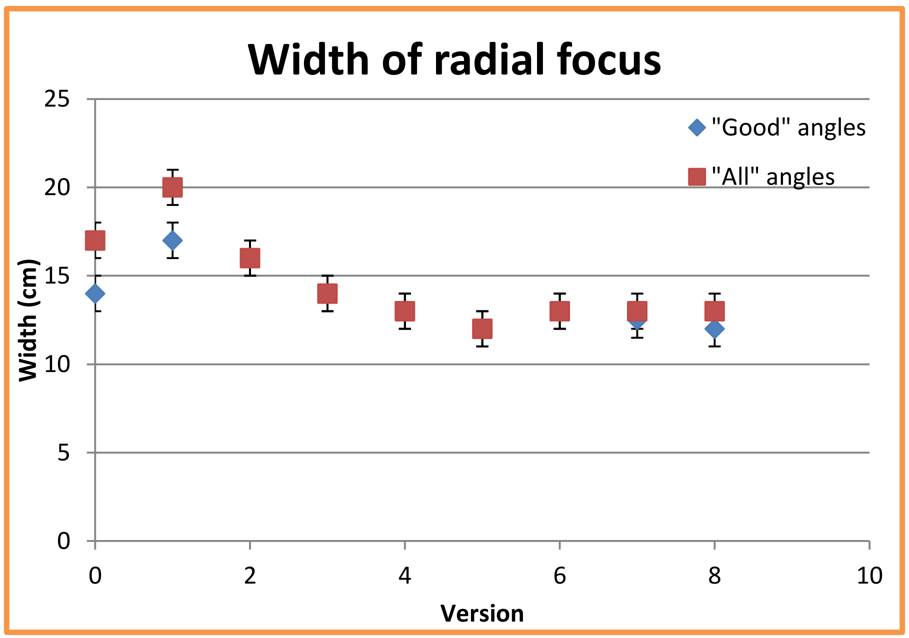


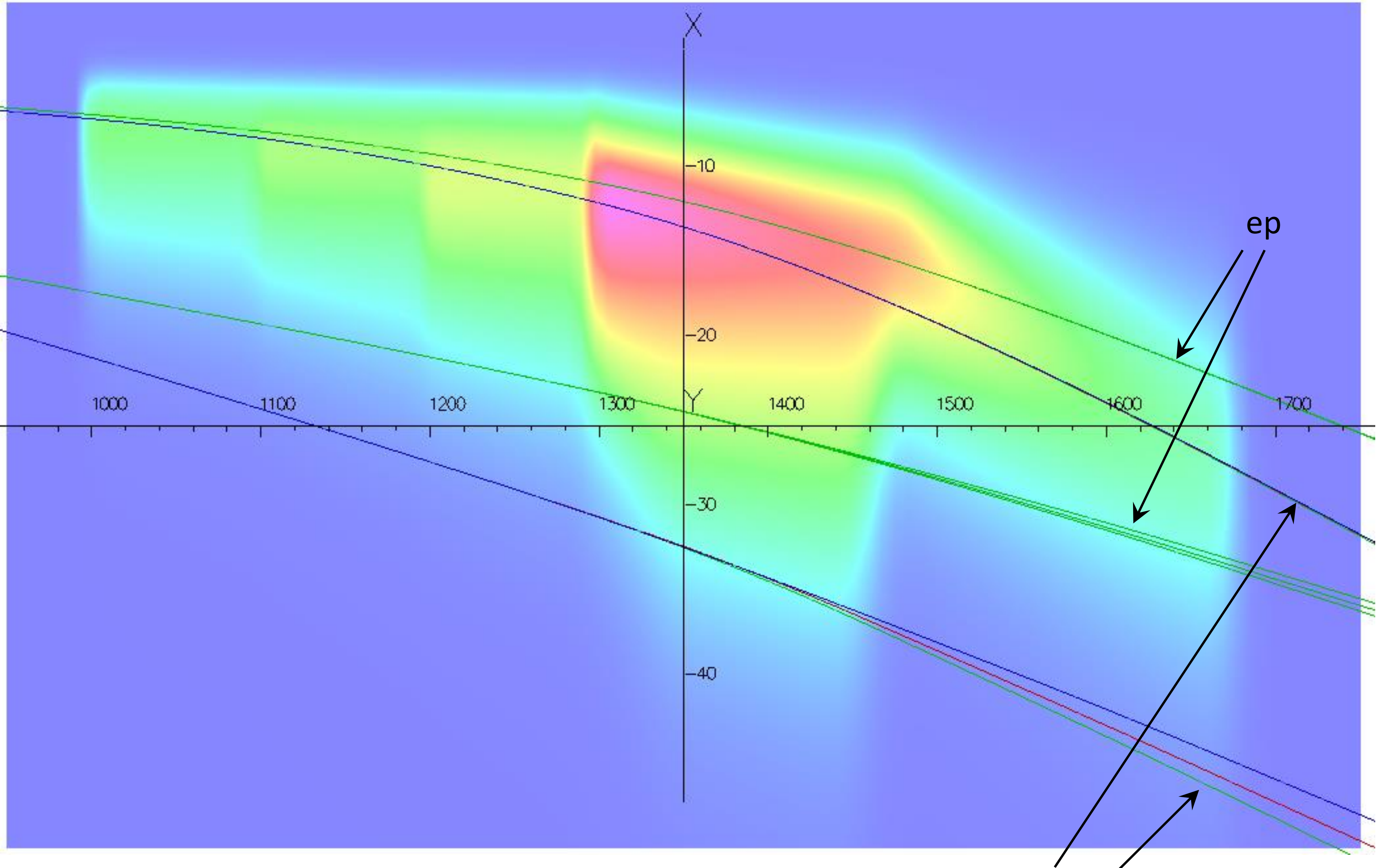
up (z0 =-75 cm) 5.5 and 15 mrads
middle (z0 =0 cm) 6.0 and 17 mrads
down (z0 =75 cm) 6.5 and 19 mrads
phi=0 only, near magnet

green – eps
blue - mollers

Tweaking the Optics

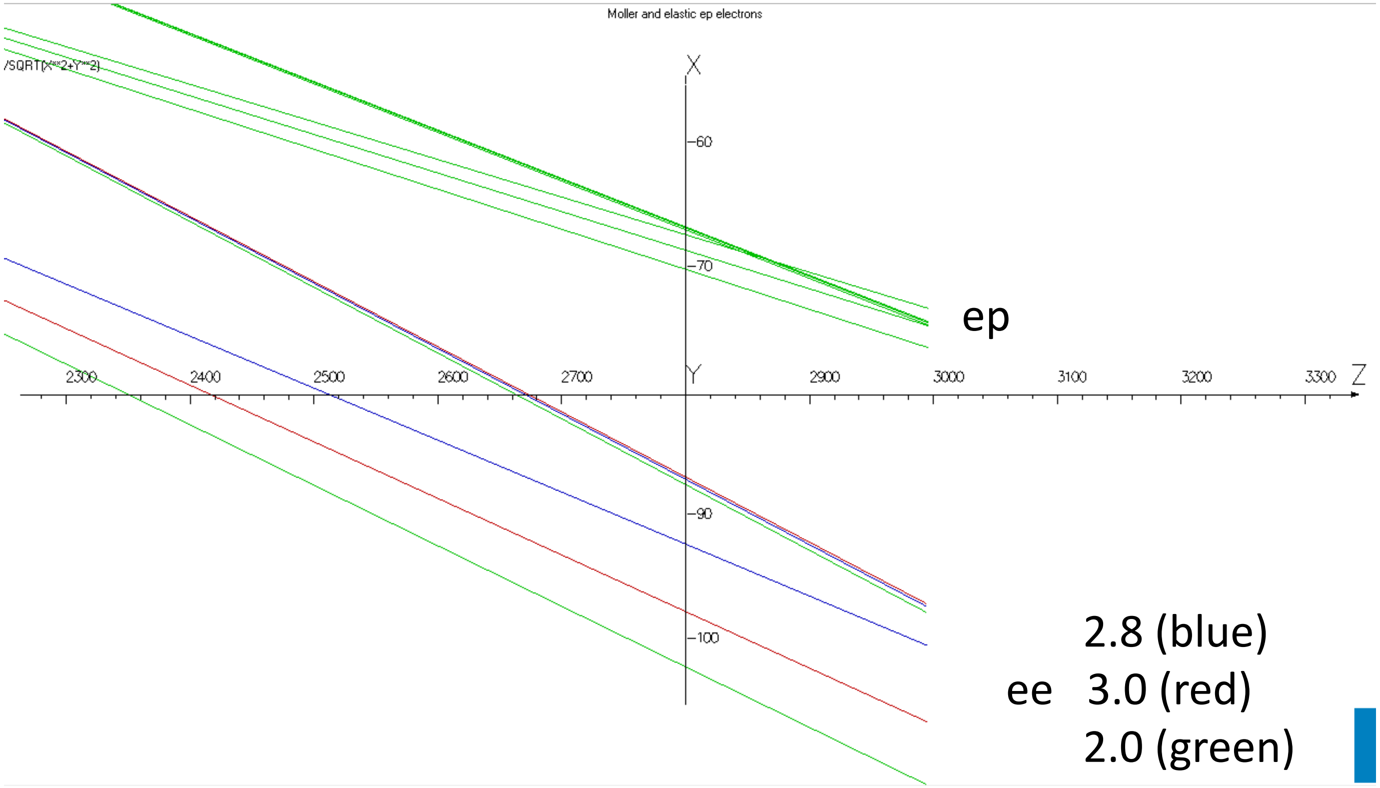






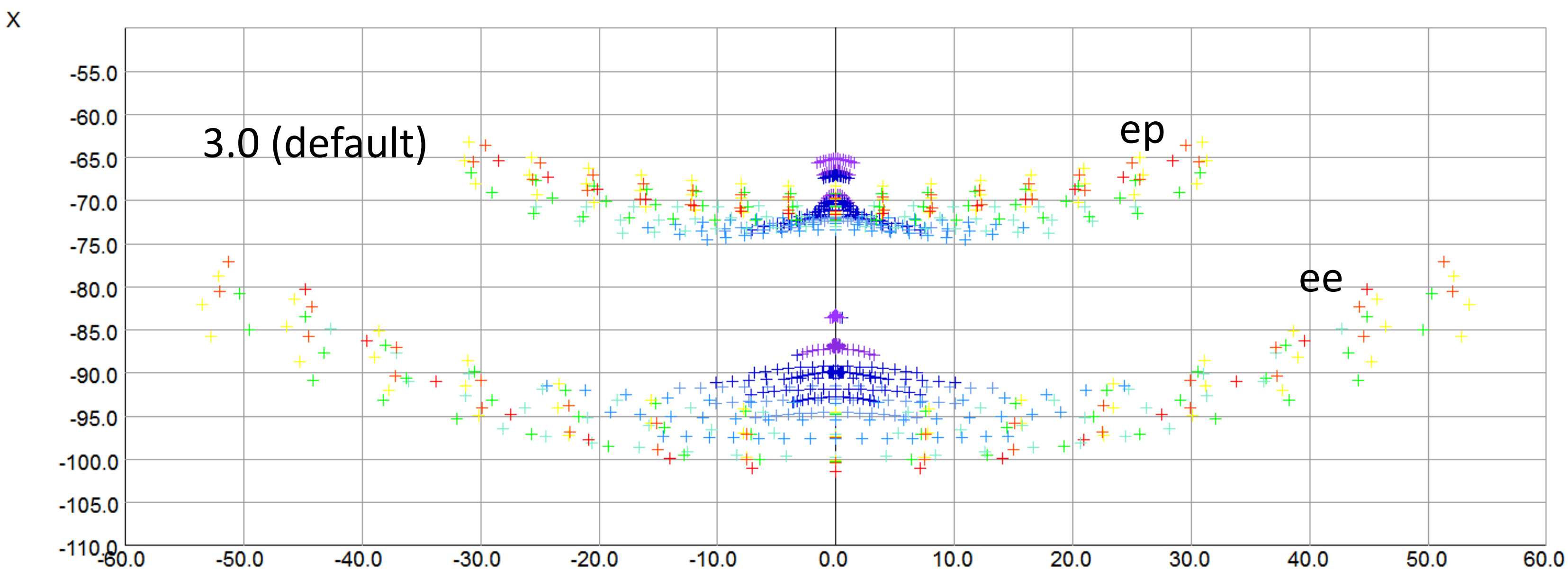
Tracks from middle of target (z=0), phi =0 only
6.0 and 17 mrads

2.8 (blue)
ee 3.0 (red)
2.0 (green)



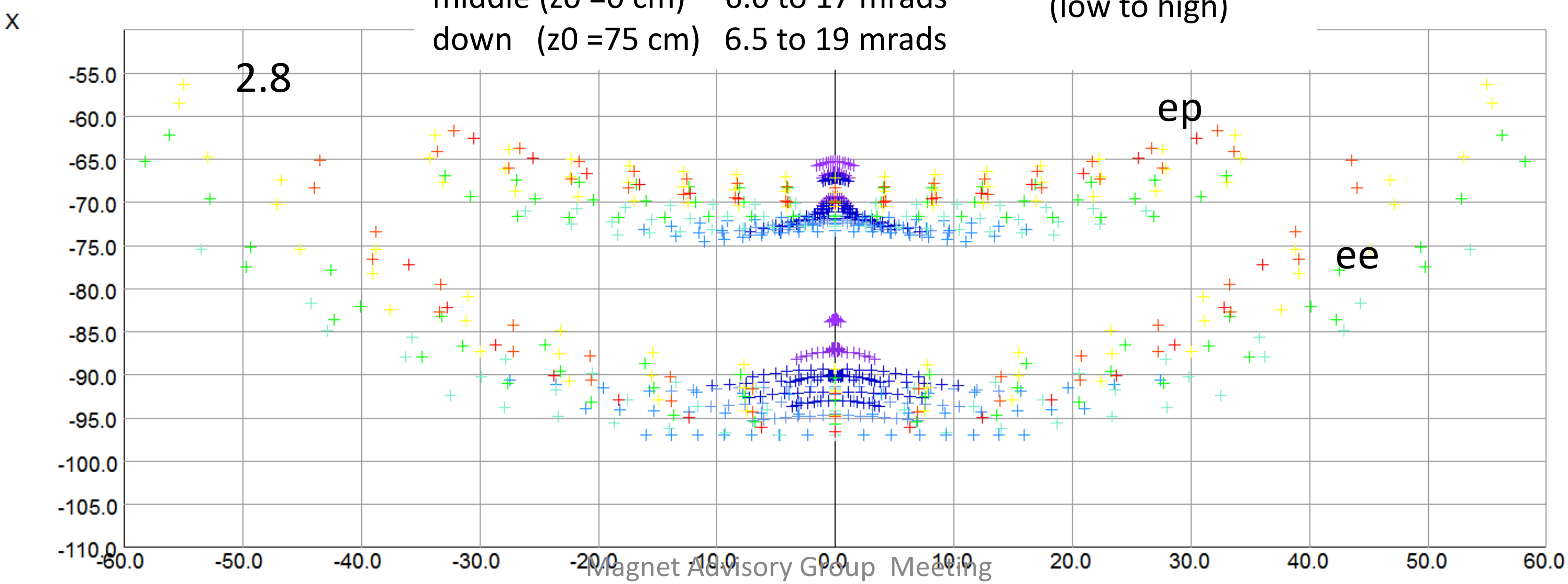
Tracks from center of target, phi =0 only
6.0 and 17 mrads

Moller and elastic ep electrons at z=2800.0cm

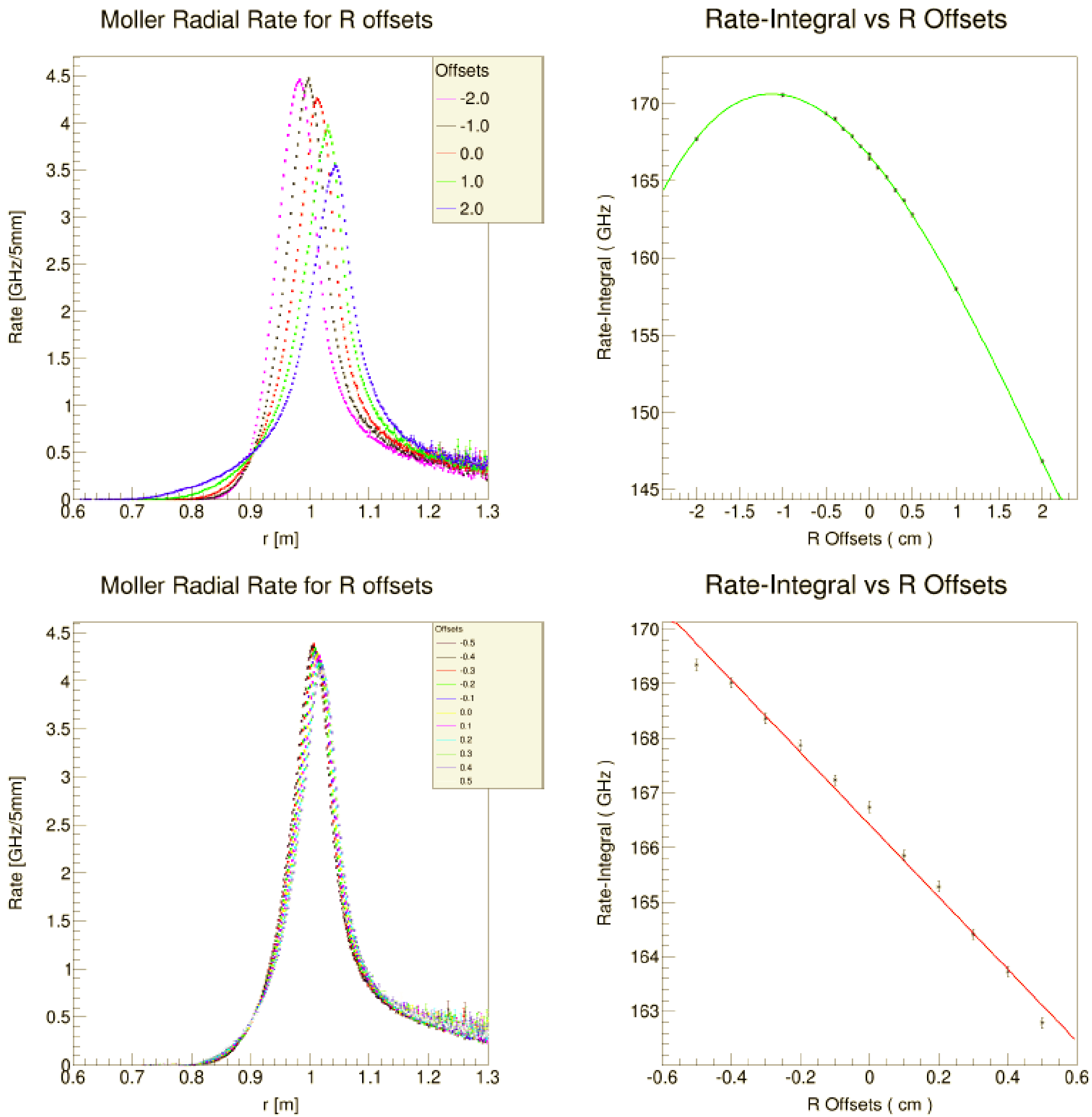


up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

Tracks colored by theta from purple to red (low to high)



Rate vs. Radial Offsets



field maps for a **single coil** misplaced by 10 (5) steps

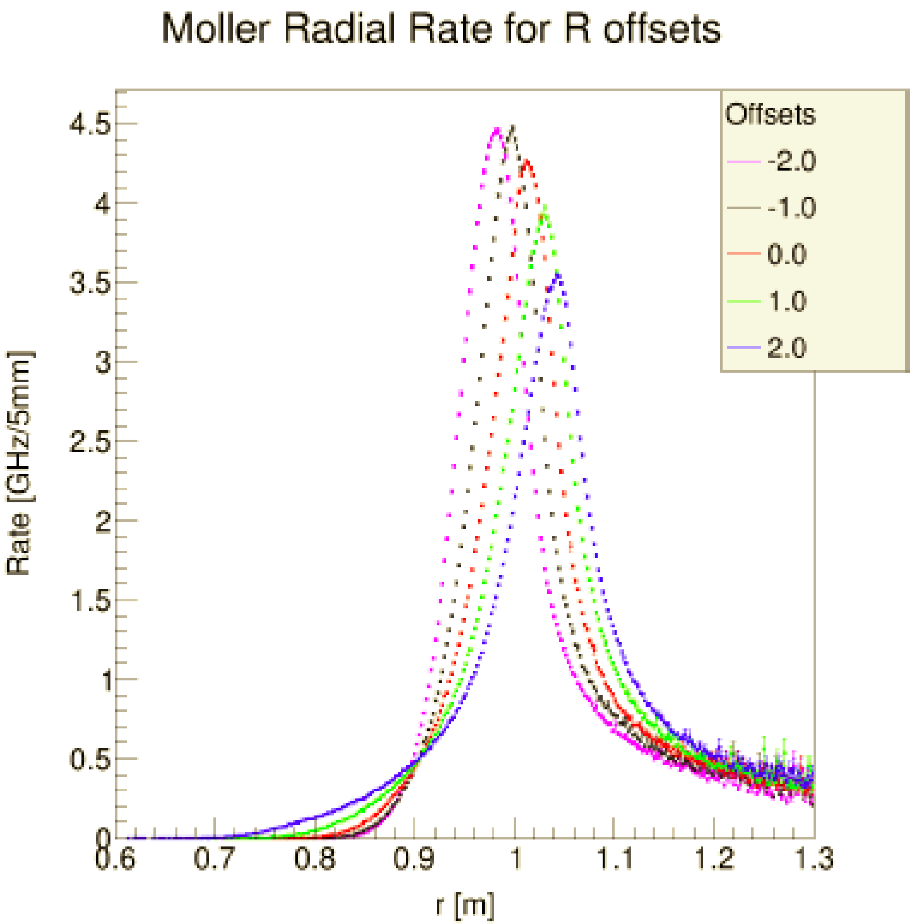
$$\delta A_{raw}\left(\frac{\Delta\langle A_{raw}\rangle}{\Delta R}\right)^{-1} = \delta R$$

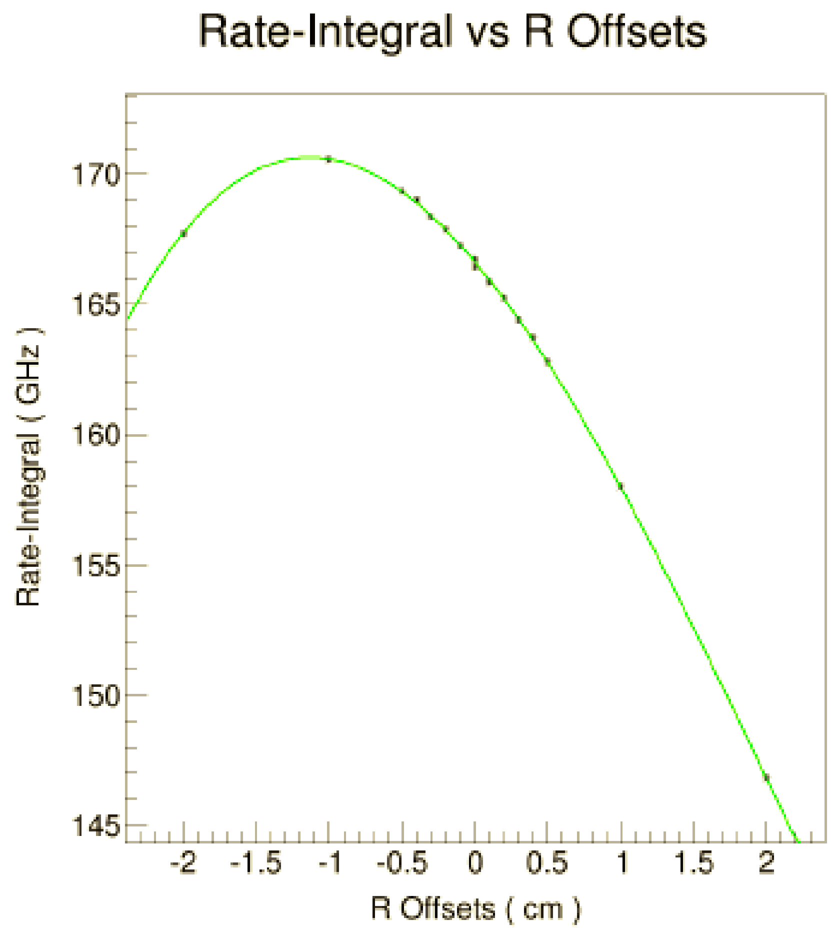
$$\delta A_{raw} = 0.1\ ppb$$

$$\frac{\Delta\langle A_{raw}\rangle}{\Delta R} = 0.36 ppb/cm$$

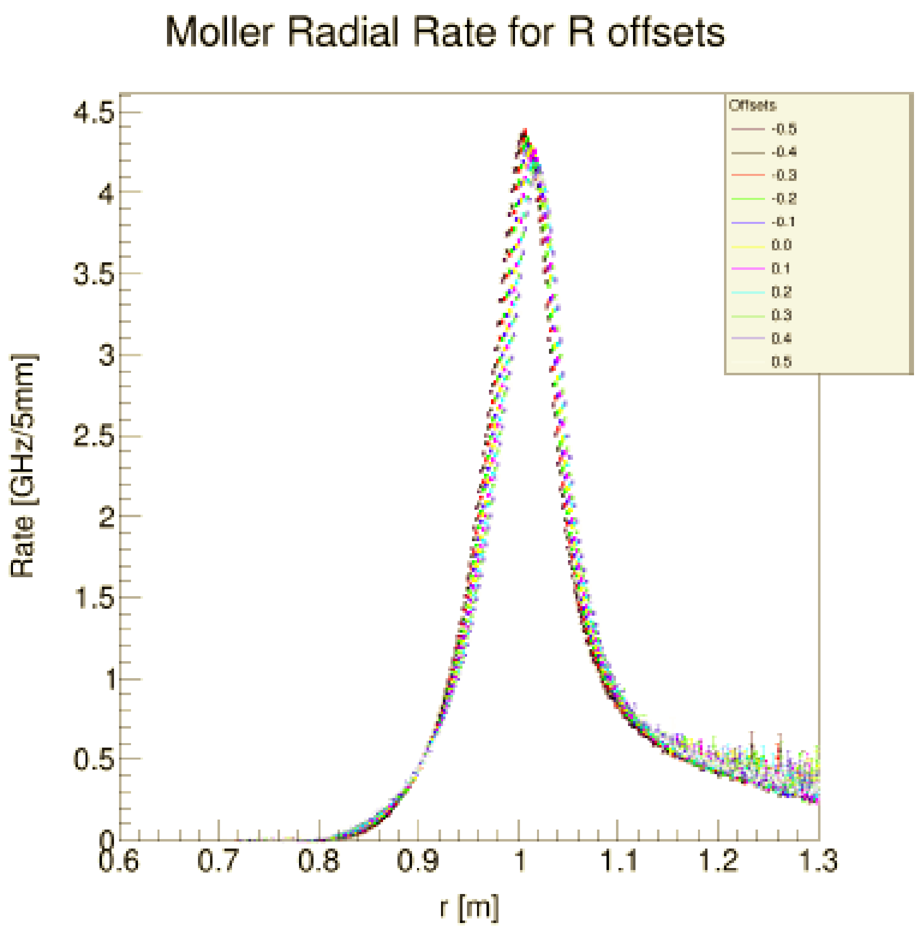
$$\frac{\Delta\langle A_{raw}\rangle}{\Delta R} = 0.29 ppb/cm$$

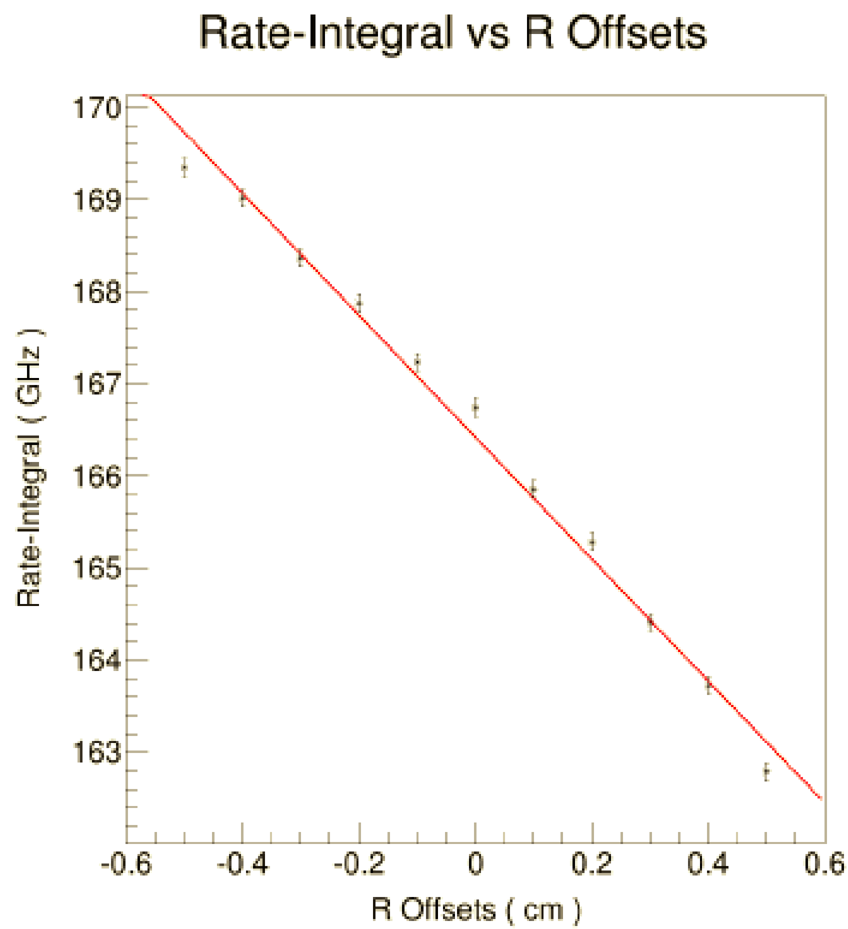
Rate vs. Radial Offsets

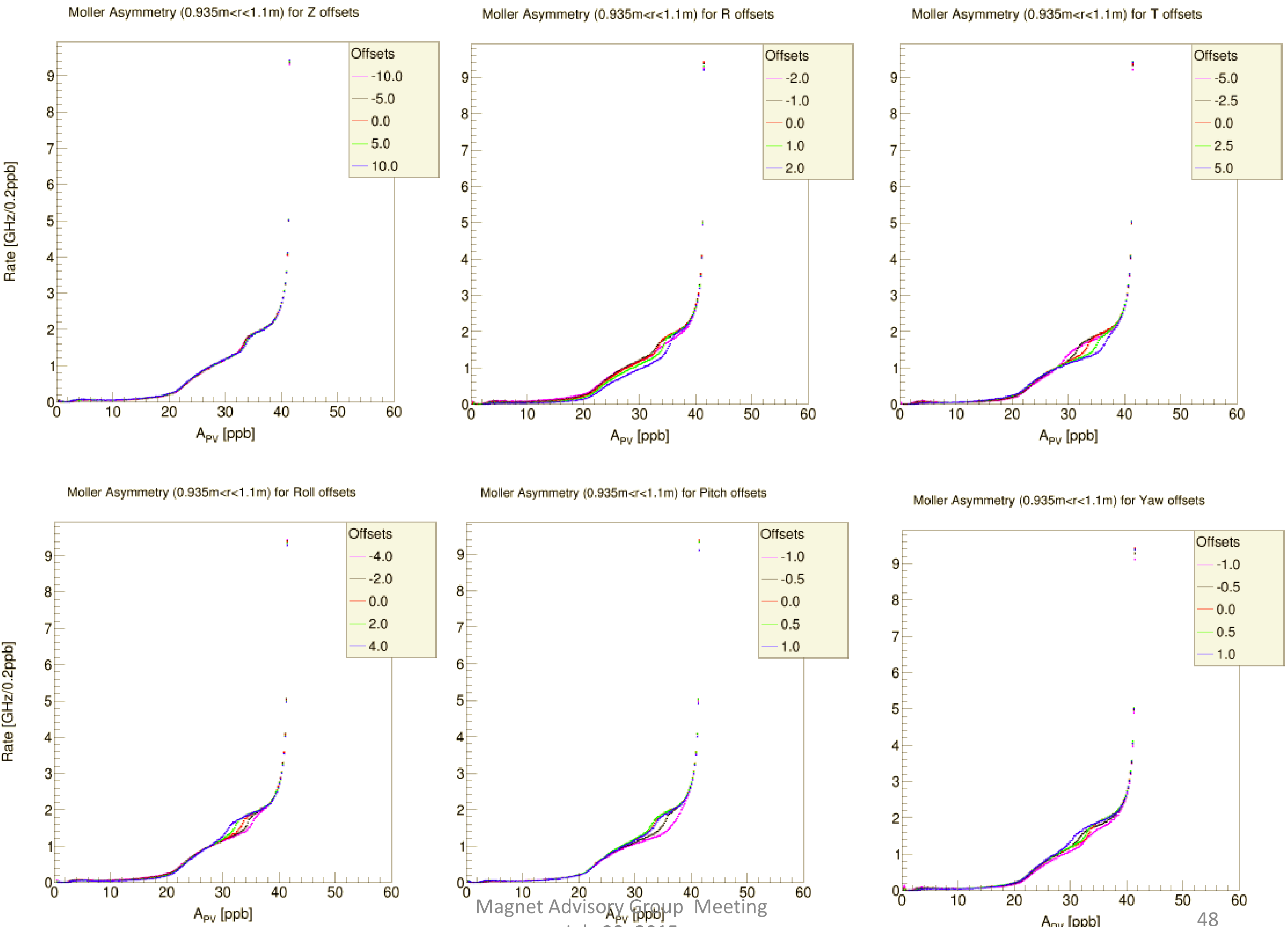


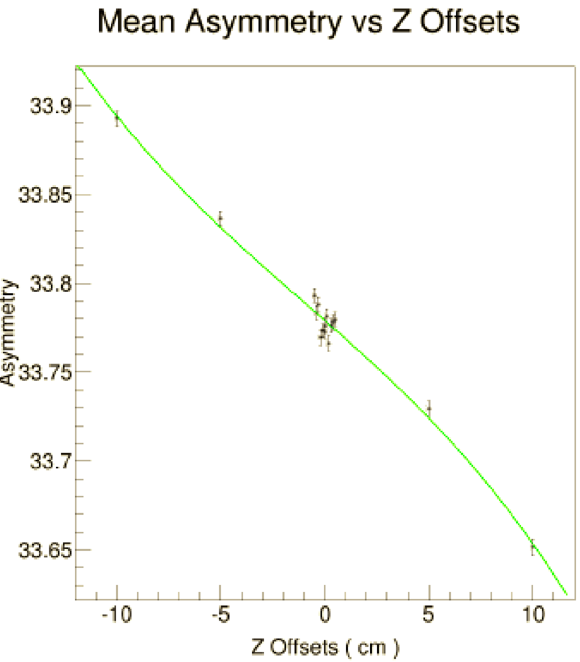


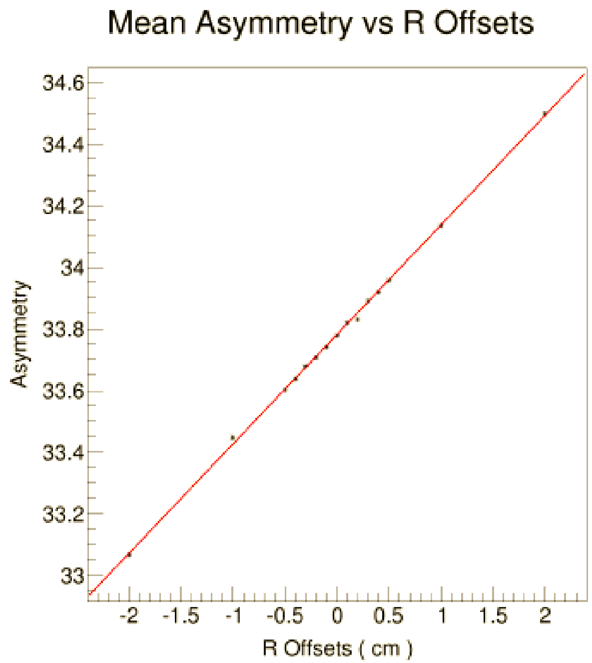
Rate vs. Radial Offsets

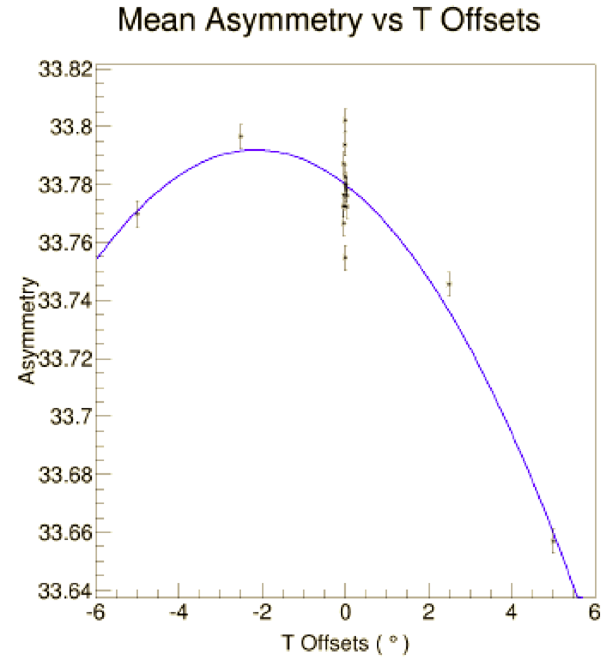


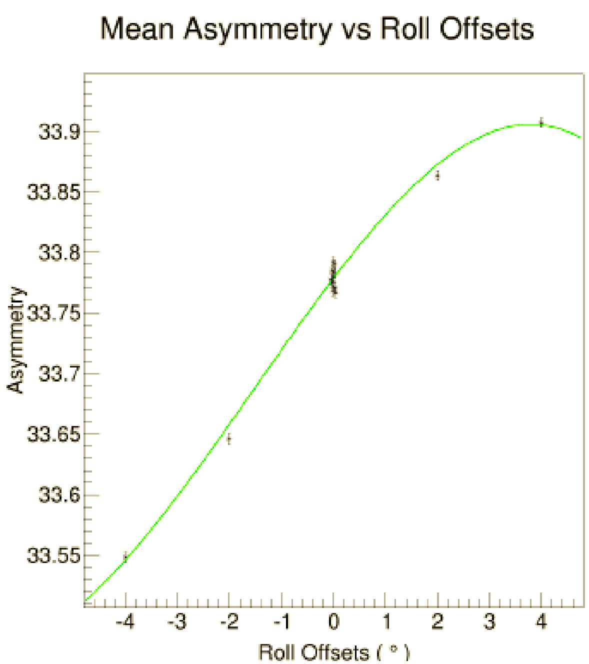


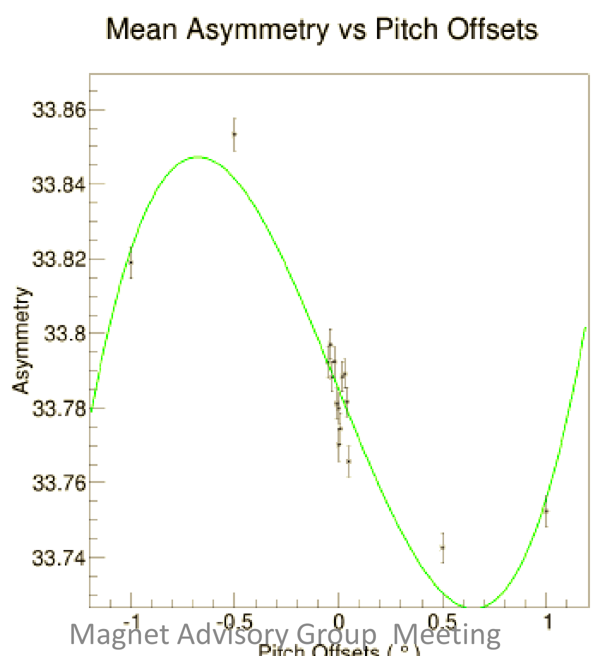

Moller Asymmetry (0.935m<r<1.1m) for Z offsets
Offsets
-10.0
-5.0
0.0
5.0
10.0
Moller Asymmetry (0.935m<r<1.1m) for R offsets
Offsets
-2.0
-1.0
0.0
1.0
2.0
Moller Asymmetry (0.935m<r<1.1m) for T offsets
Offsets
-5.0
-2.5
0.0
2.5
5.0
Moller Asymmetry (0.935m<r<1.1m) for Roll offsets
Offsets
-4.0
-2.0
0.0
2.0
4.0
Moller Asymmetry (0.935m<r<1.1m) for Pitch offsets
Offsets
-1.0
-0.5
0.0
0.5
1.0
Moller Asymmetry (0.935m<r<1.1m) for Yaw offsets
Offsets
-1.0
-0.5
0.0
0.5
1.0
Rate [GHz/0.2ppb]
A_{PV} [ppb]

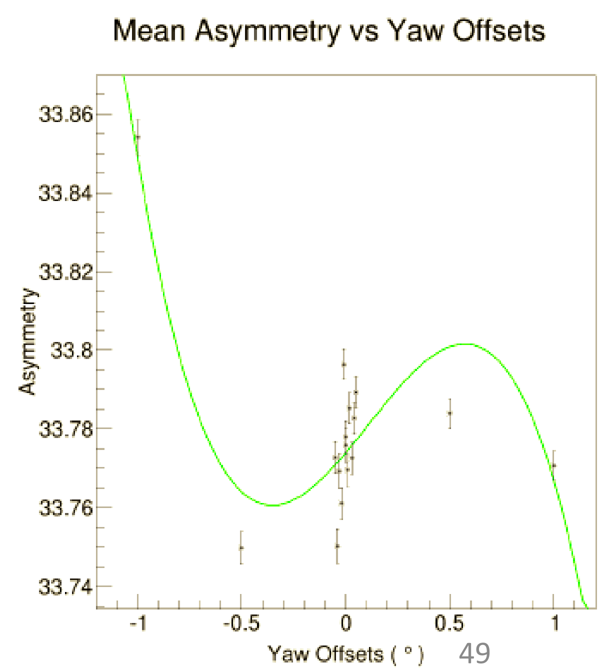

Mean Asymmetry vs Z Offsets
Asymmetry
Z Offsets (cm)

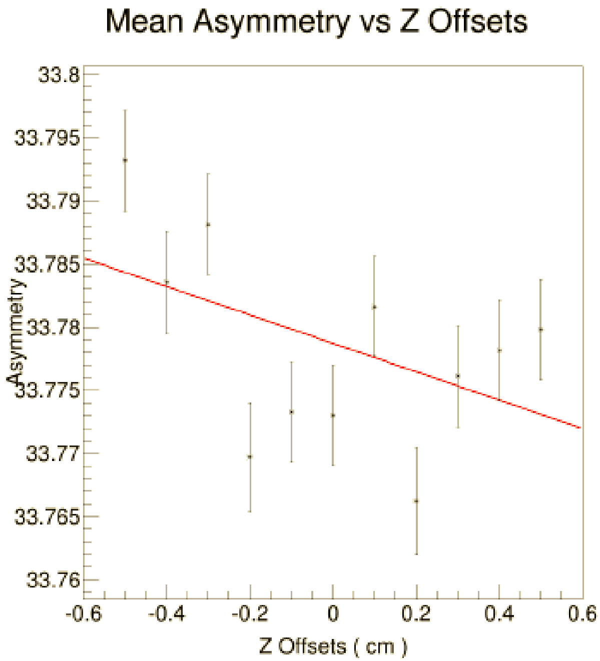

Mean Asymmetry vs R Offsets
Asymmetry
R Offsets (cm)

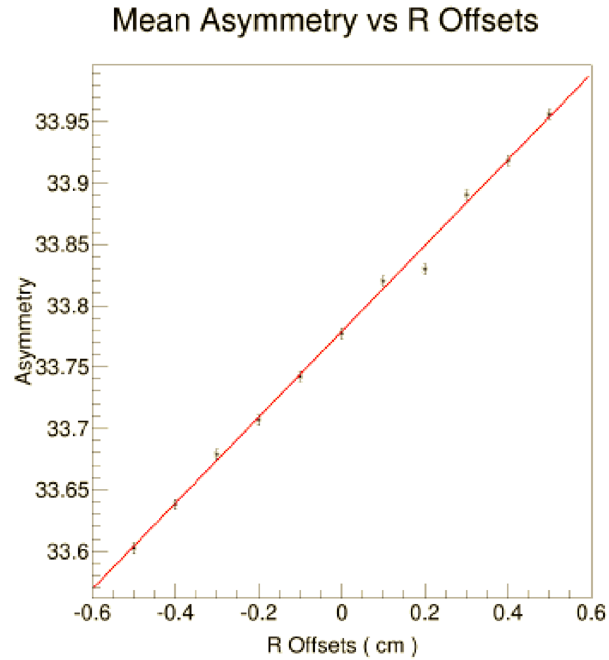

Mean Asymmetry vs T Offsets
Asymmetry
T Offsets (°)

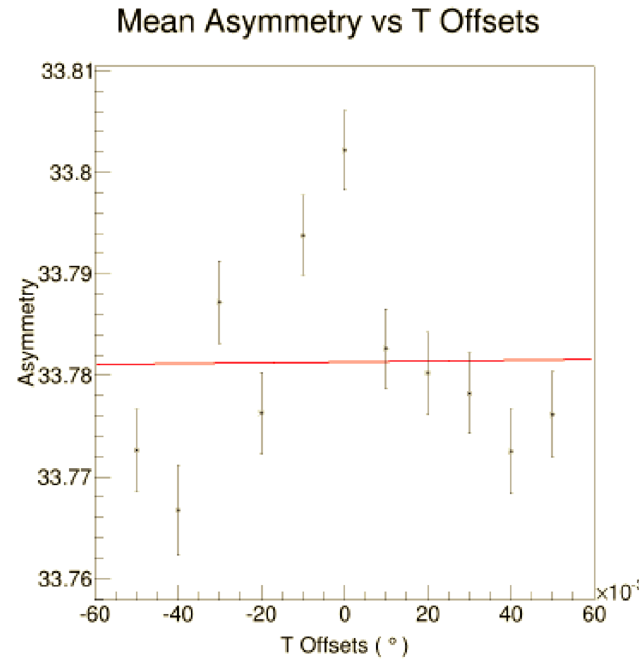

Mean Asymmetry vs Roll Offsets
Asymmetry
Roll Offsets (°)

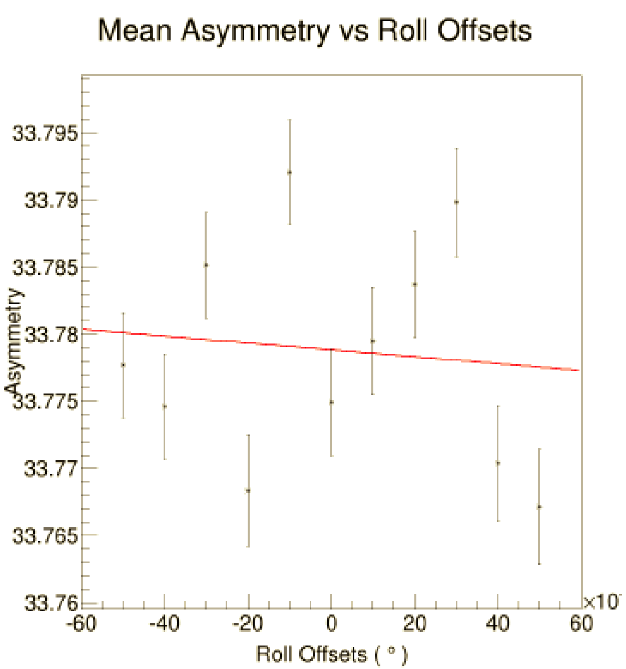

Mean Asymmetry vs Pitch Offsets
Asymmetry
Pitch Offsets (°)

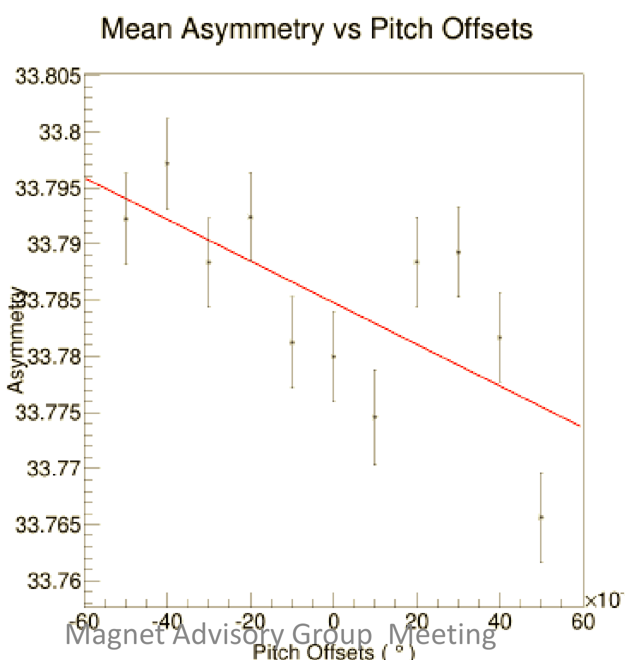

Mean Asymmetry vs Yaw Offsets
Asymmetry
Yaw Offsets (°)

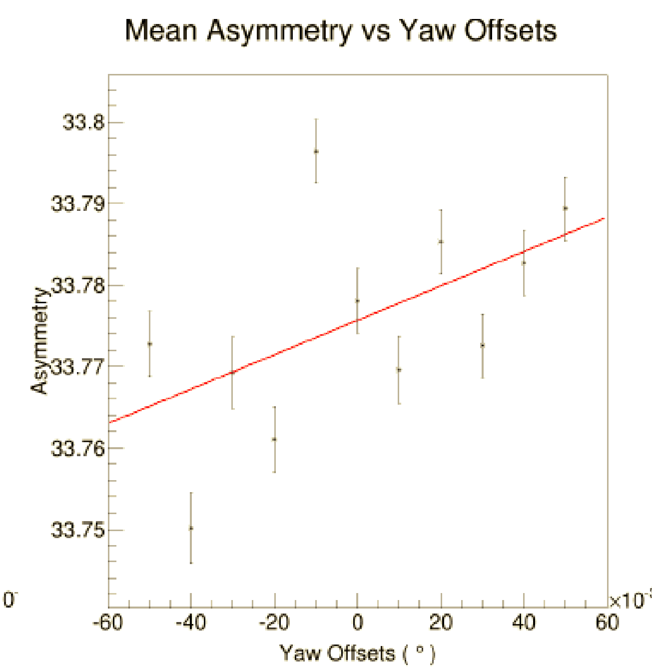

Mean Asymmetry vs Z Offsets
Asymmetry
Z Offsets (cm)
33.8
33.795
33.79
33.785
33.78
33.775
33.77
33.765
33.76
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


Mean Asymmetry vs R Offsets
Asymmetry
R Offsets (cm)
33.95
33.9
33.85
33.8
33.75
33.7
33.65
33.6
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

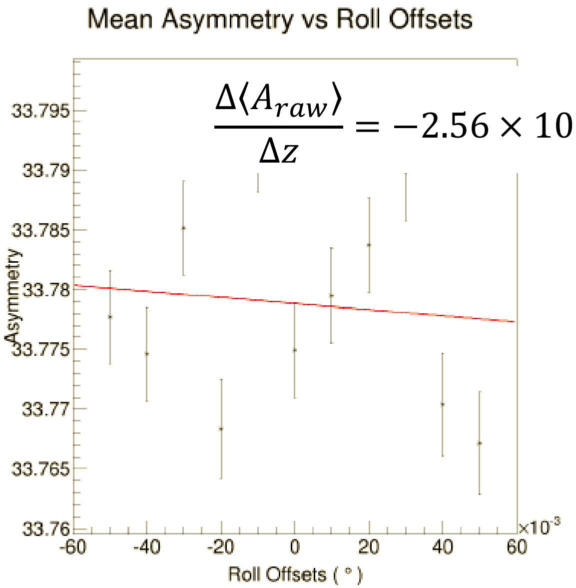

Mean Asymmetry vs T Offsets
Asymmetry
T Offsets (°)
33.81
33.8
33.79
33.78
33.77
33.76
×10-3
-60
-40
-20
0
20
40
60


Mean Asymmetry vs Roll Offsets
Asymmetry
Roll Offsets (°)
33.795
33.79
33.785
33.78
33.775
33.77
33.765
33.76
×10
-60
-40
-20
0
20
40
60

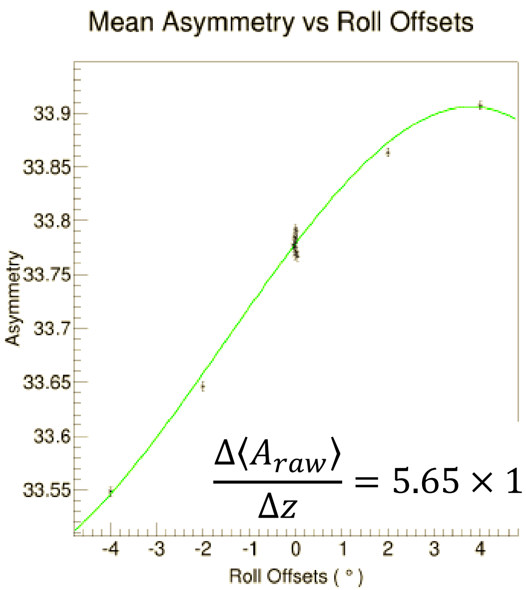

Mean Asymmetry vs Pitch Offsets
Asymmetry
Pitch Offsets (°)
33.805
33.8
33.795
33.79
33.785
33.78
33.775
33.77
33.765
33.76
×10
-60
-40
-20
0
20
40
60


Mean Asymmetry vs Yaw Offsets
Asymmetry
Yaw Offsets (°)
33.8
33.79
33.78
33.77
33.76
33.75
×10-3
-60
-40
-20
0
20
40
60

Determining the slope



$$\frac{\Delta\langle A_{raw}\rangle}{\Delta z} = -2.56 \times 10^{-2}\ ppb/degree$$



$$\frac{\Delta\langle A_{raw}\rangle}{\Delta z} = 5.65 \times 10^{-2}\ ppb/degree$$

Smaller range only may give misleading sensitivity…

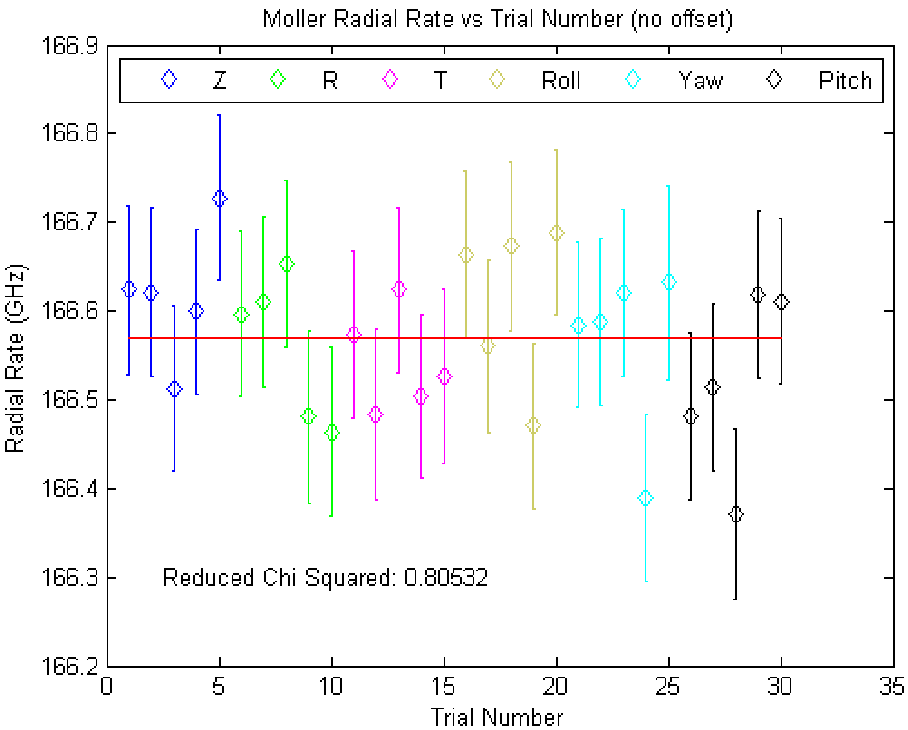
Need more statistics with smaller range?
Zero-offset study

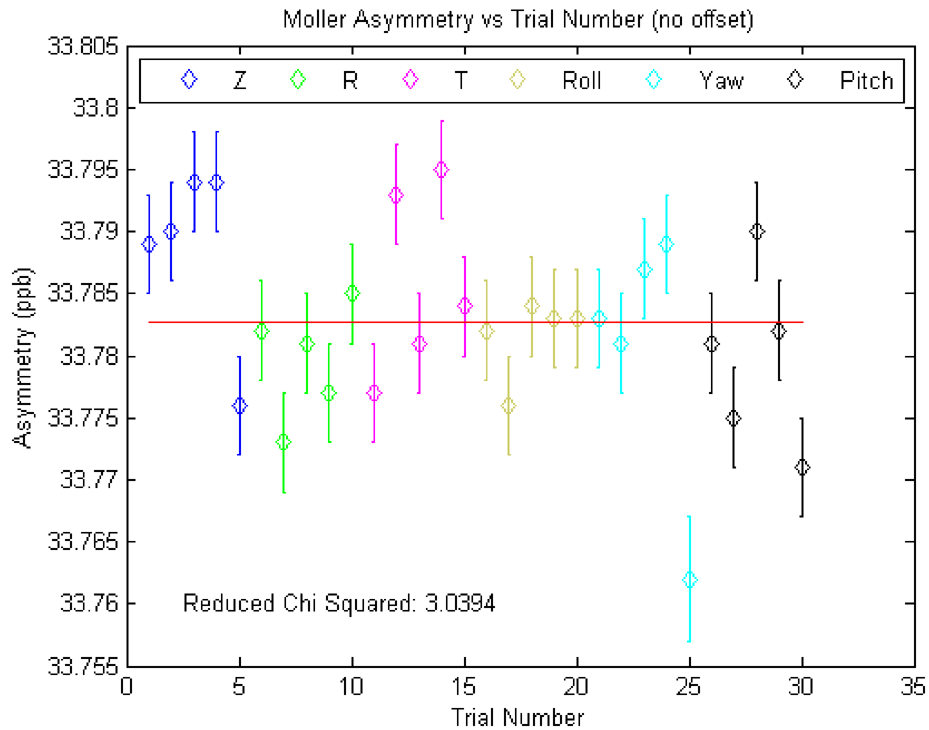
“Systematic” from TOSCA maps or GEANT4 simulation?

“Zero Offset” Study

- Check that the statistical uncertainties we are calculating are correct
- Estimate a “simulation systematic” uncertainty
  - Add that in quadrature to the slope plots
- Extract an uncertainty on the sensitivity

“Zero Offset” Study





Summary

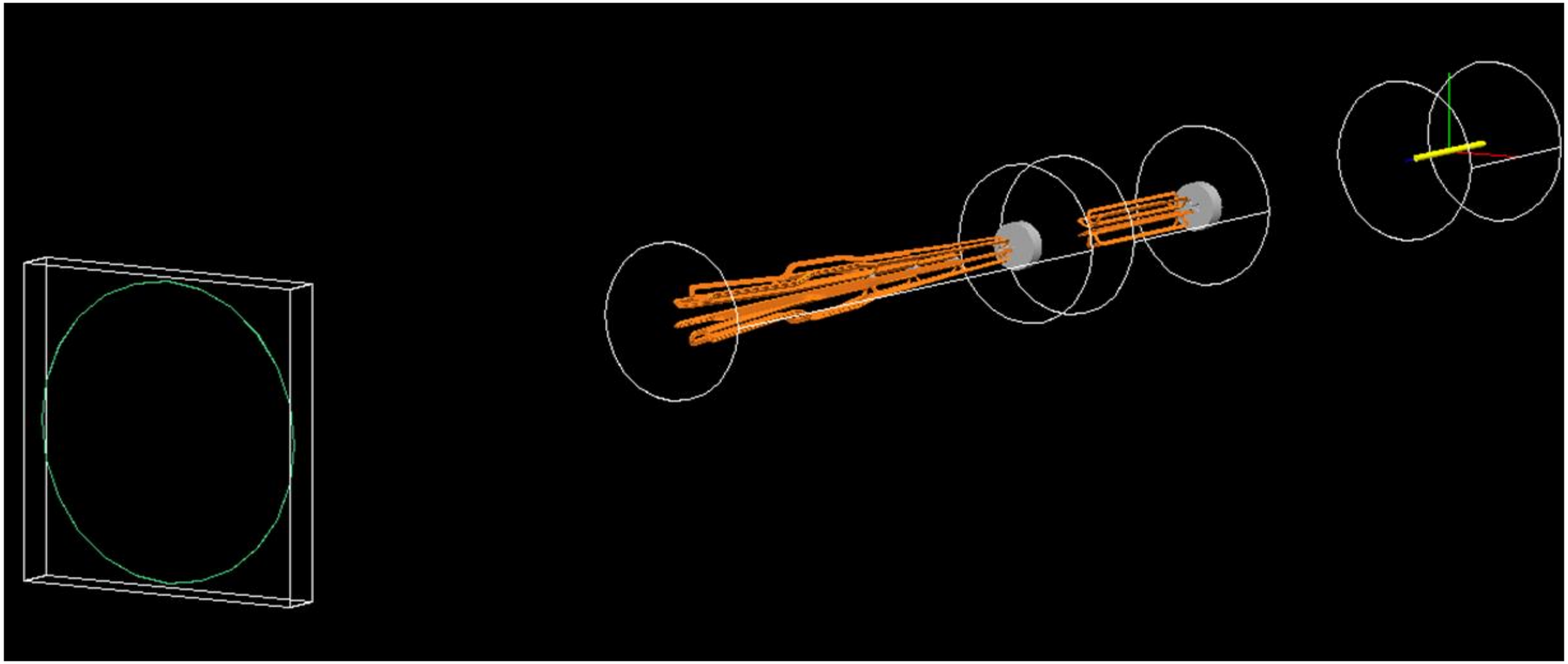
- Results show order ~3 mm sensitivities (not sub-mm)

- Need to look at the effect of tracking algorithm with incorrect maps
- Need to consider the effect of multiple types of offsets in one coil, and multiple coils having offsets

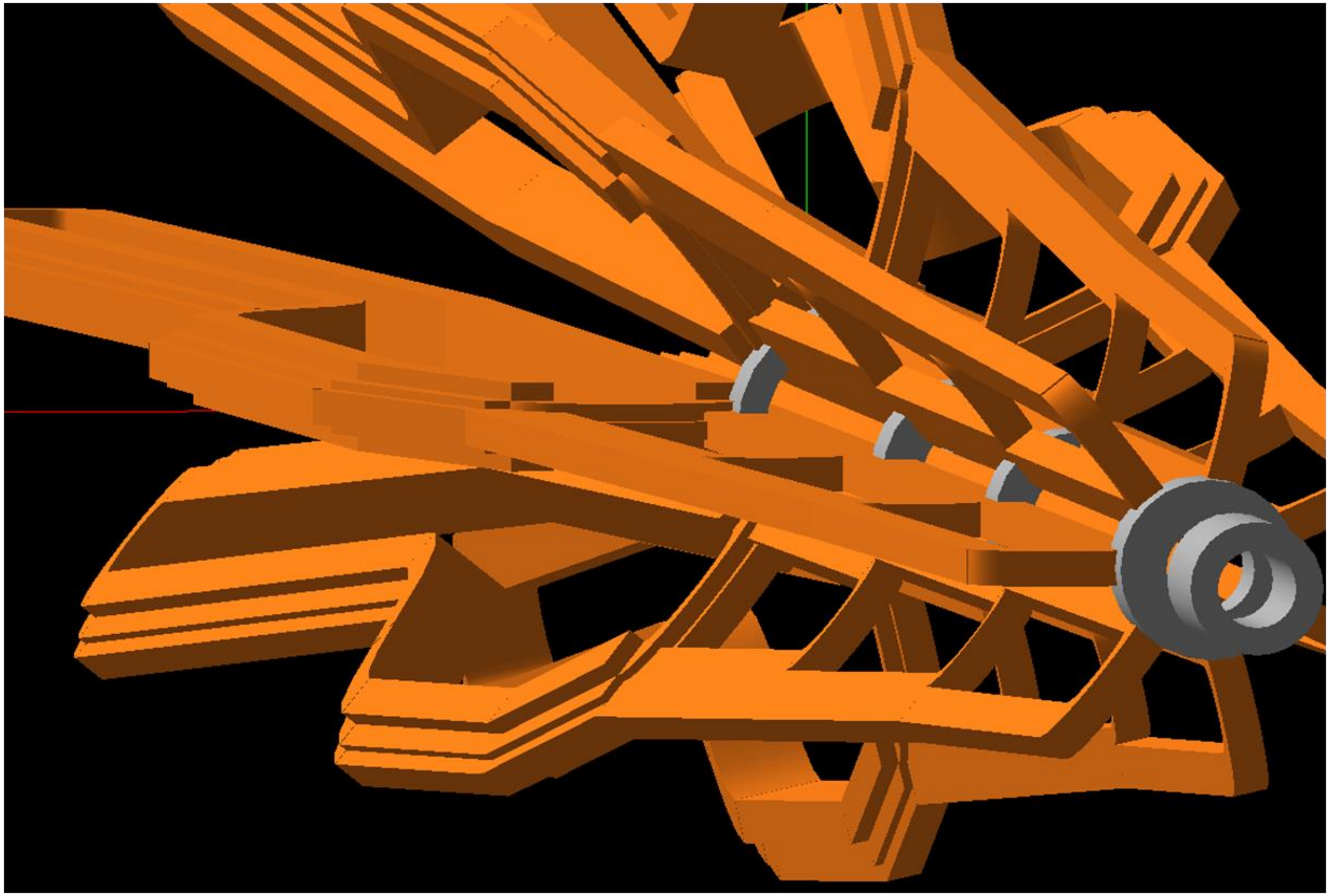
- What is the most important parameter – what is it that will determine the sensitivity
  - A background correction done incorrectly?
  - The mean asymmetry, as I've assumed here?
  - The mean θ_{lab}, which will go into the extraction of $\sin^2\theta_W$?
  - A physical interference with the scattered electron envelope?

GEANT4

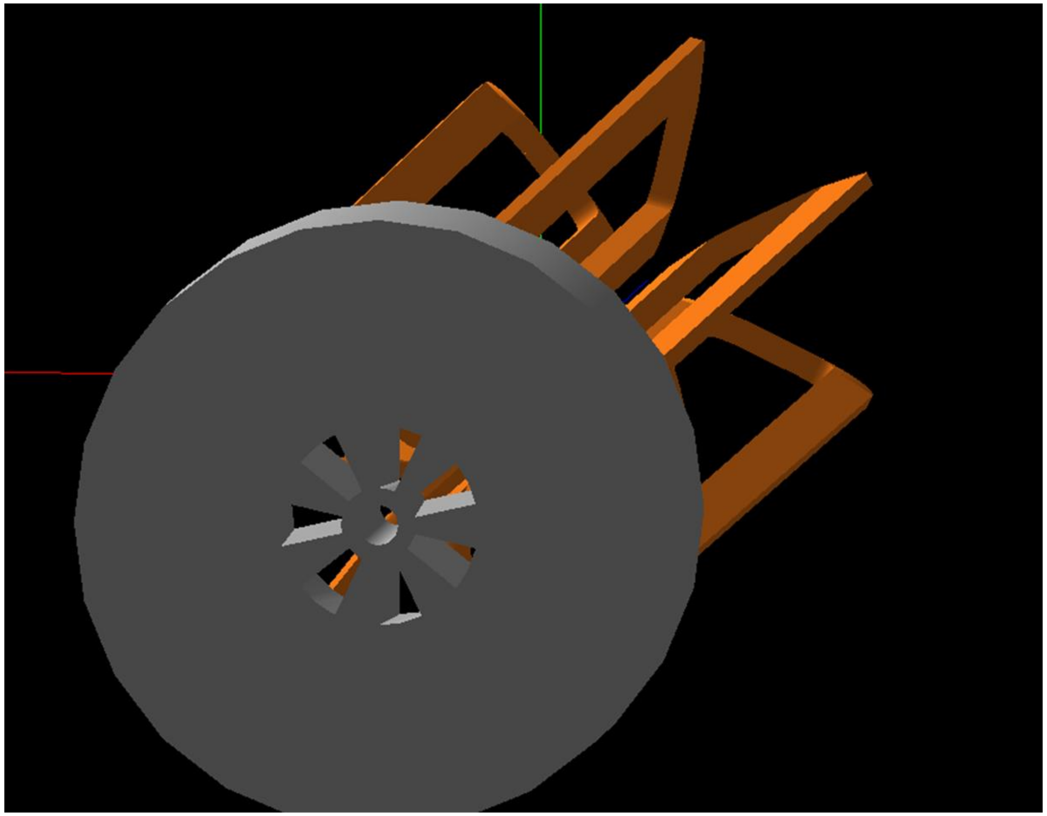
- Moved to GDML geometry description
- Defined hybrid and upstream toroids
  - Parameterized in same way as the TOSCA models



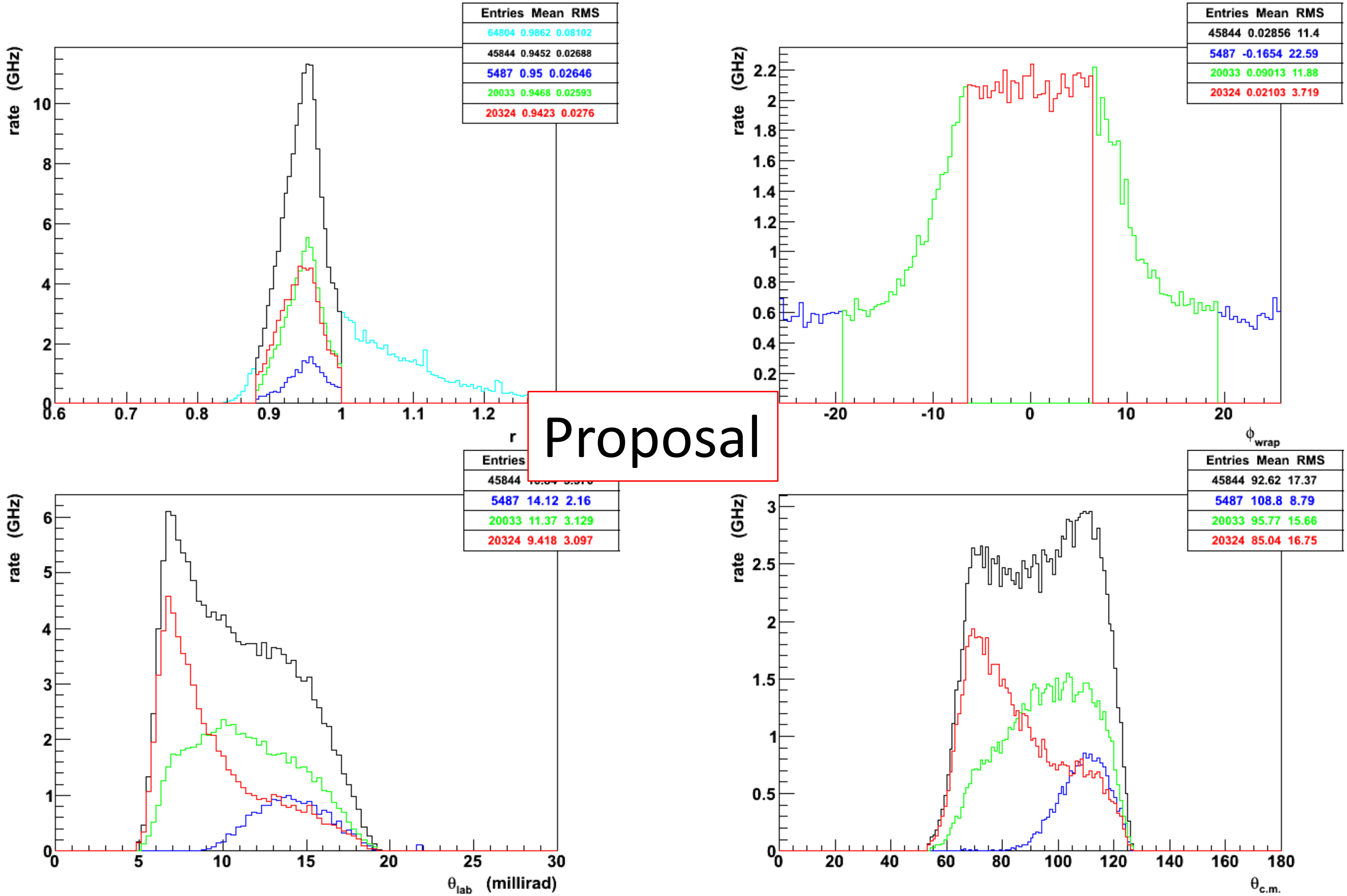
GEANT4 - Collimators



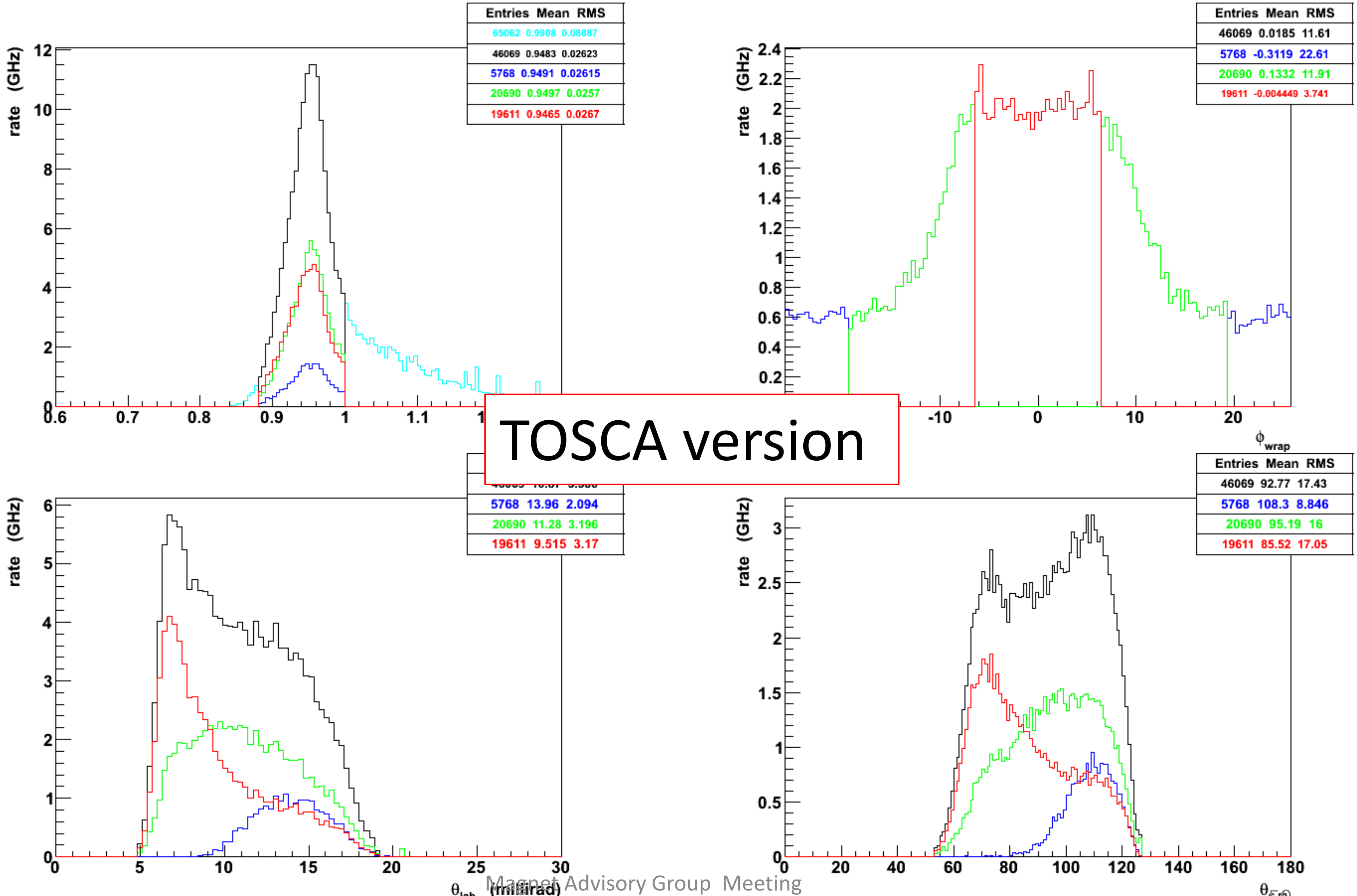
GEANT4 – Acceptance definition



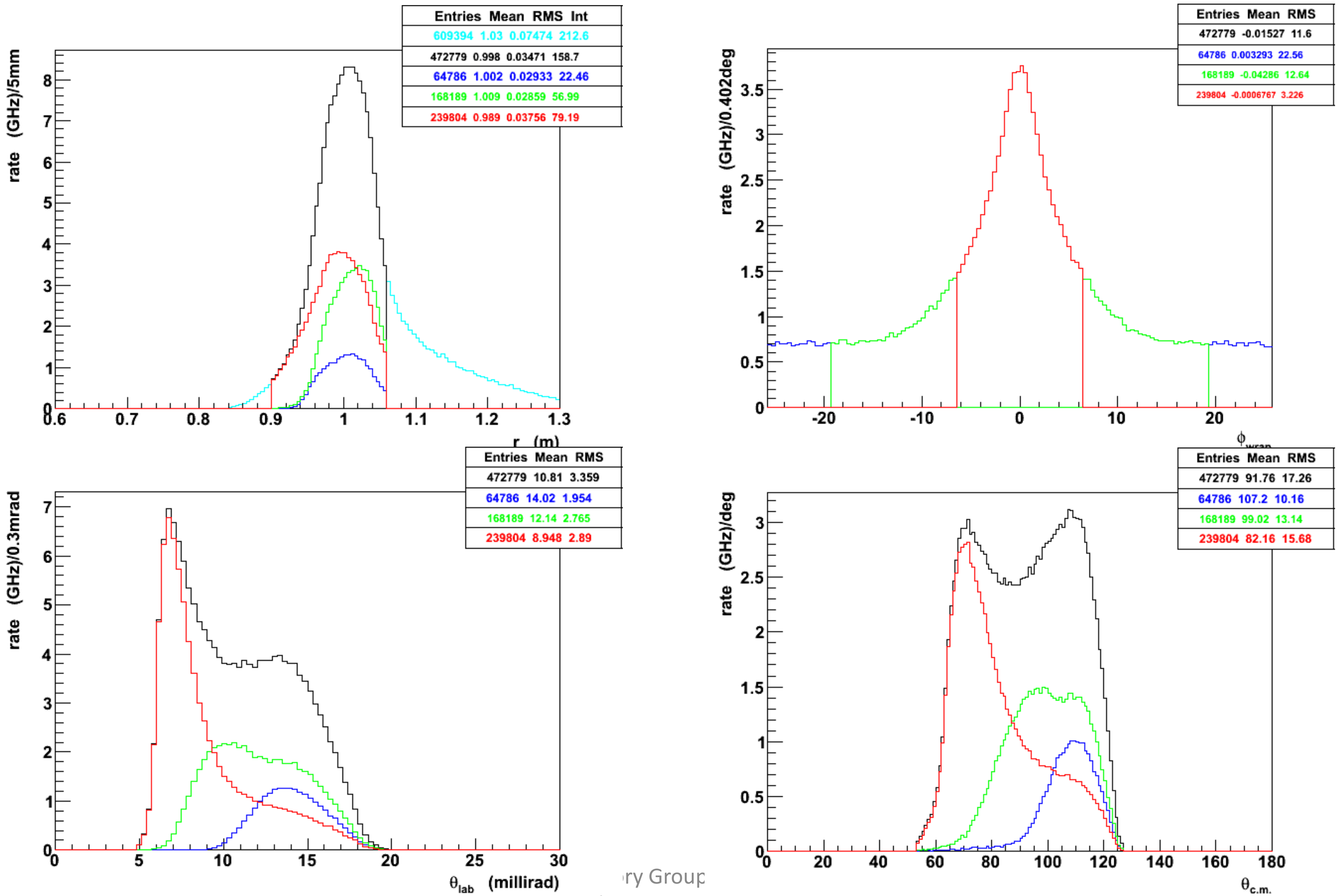
Comparison of GEANT4 Simulations



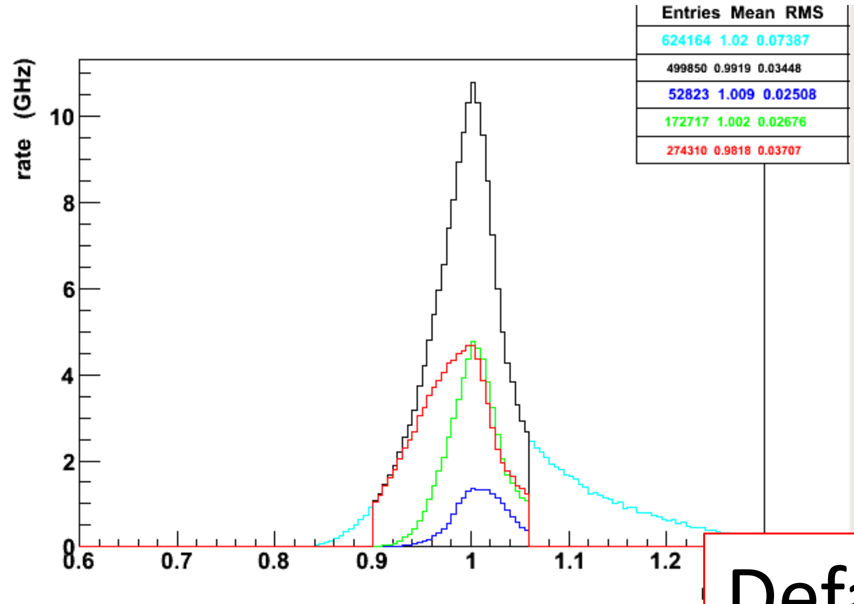
Comparison of GEANT4 Simulations

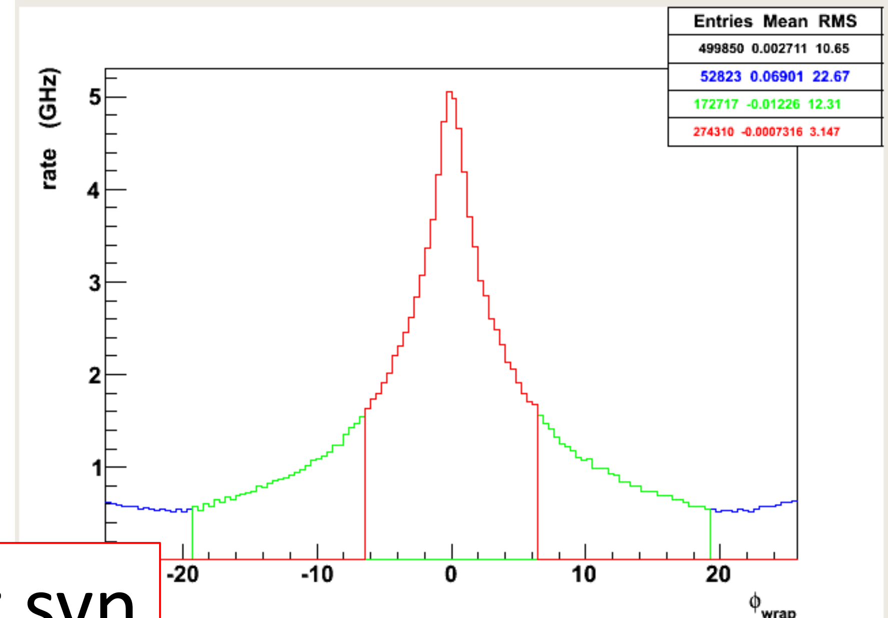


2.6

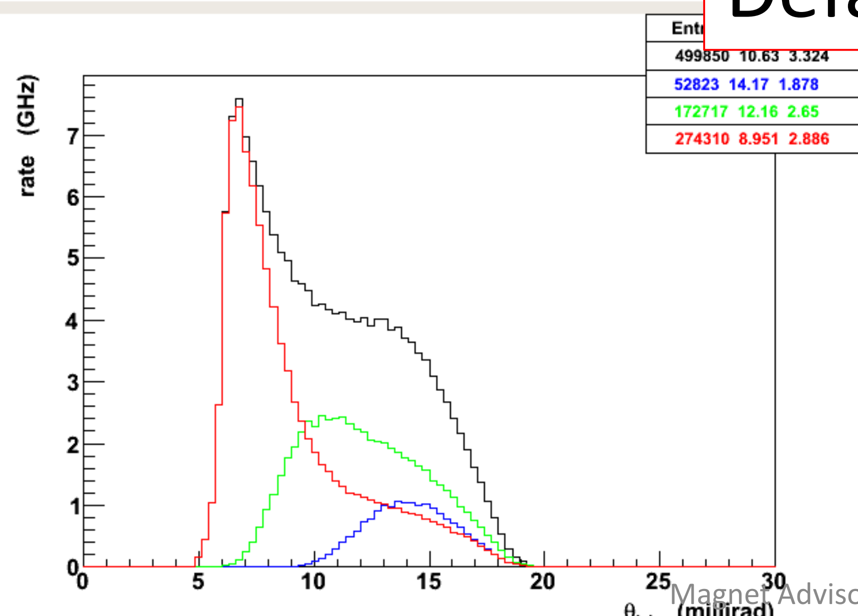

Entries Mean RMS Int
609394 1.03 0.07474 212.6
472779 0.998 0.03471 158.7
64786 1.002 0.02933 22.46
168189 1.009 0.02859 56.99
239804 0.989 0.03756 79.19
rate (GHz)/5mm
r (m)
Entries Mean RMS
472779 -0.01527 11.6
64786 0.003293 22.56
168189 -0.04286 12.64
239804 -0.0006767 3.226
rate (GHz)/0.402deg
Entries Mean RMS
472779 10.81 3.359
64786 14.02 1.954
168189 12.14 2.765
239804 8.948 2.89
rate (GHz)/0.3mrad
θ_{lab} (millirad)
Entries Mean RMS
472779 91.76 17.26
64786 107.2 10.16
168189 99.02 13.14
239804 82.16 15.68
rate (GHz)/deg
$\theta_{c.m.}$

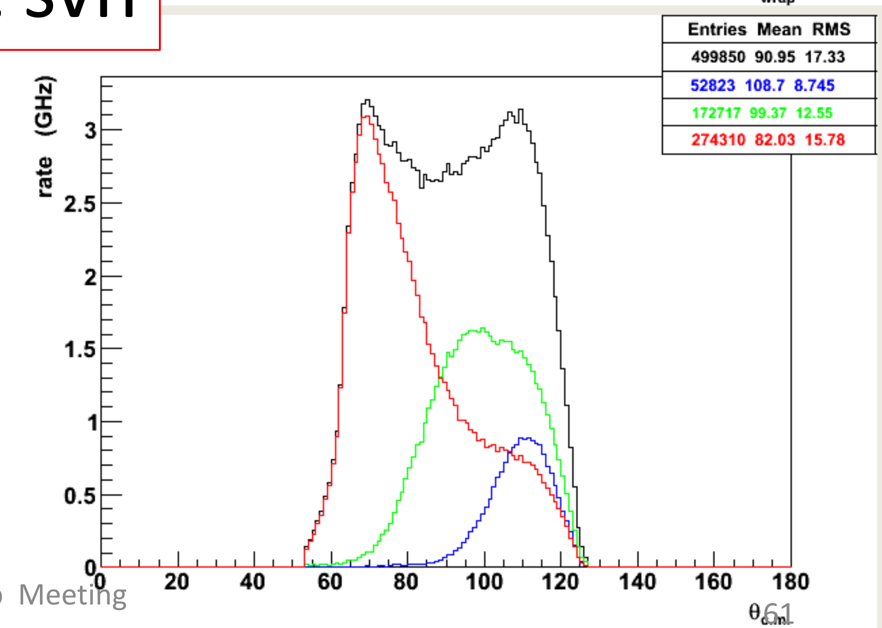
Current Version of the Hybrid and Upstream





Default svn

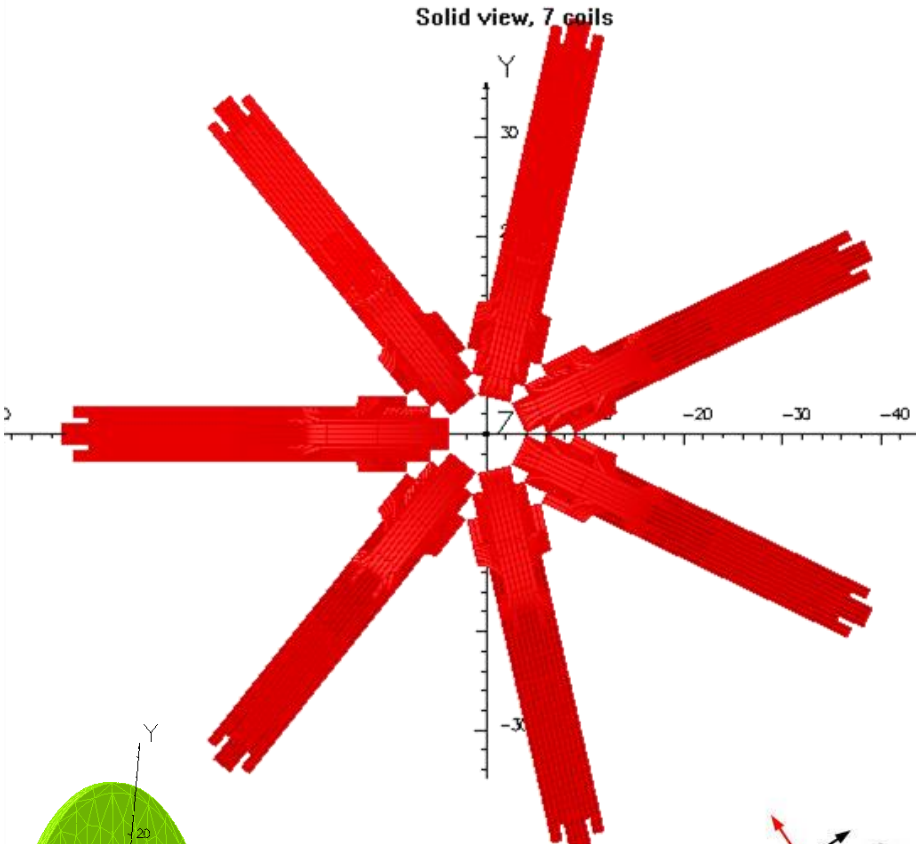


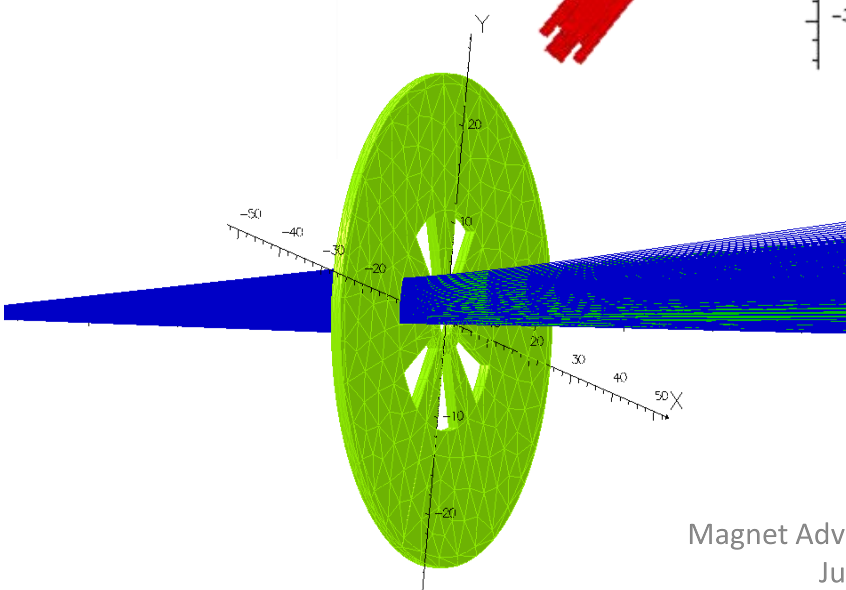


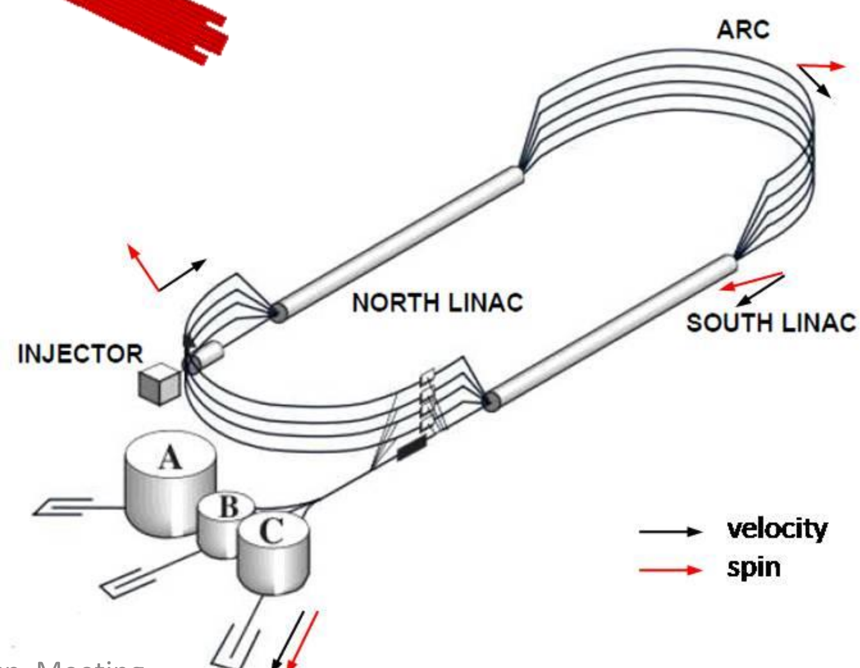
Ongoing/Future Work

- Ongoing/Future work
  - Optimization of the optics
  - Magnetic force studies
  - Sensitivity studies
  - Collimator optimization
  - Design of the water-cooling and supports
  - Design of electrical connections
  - Look at optics for 3 coils

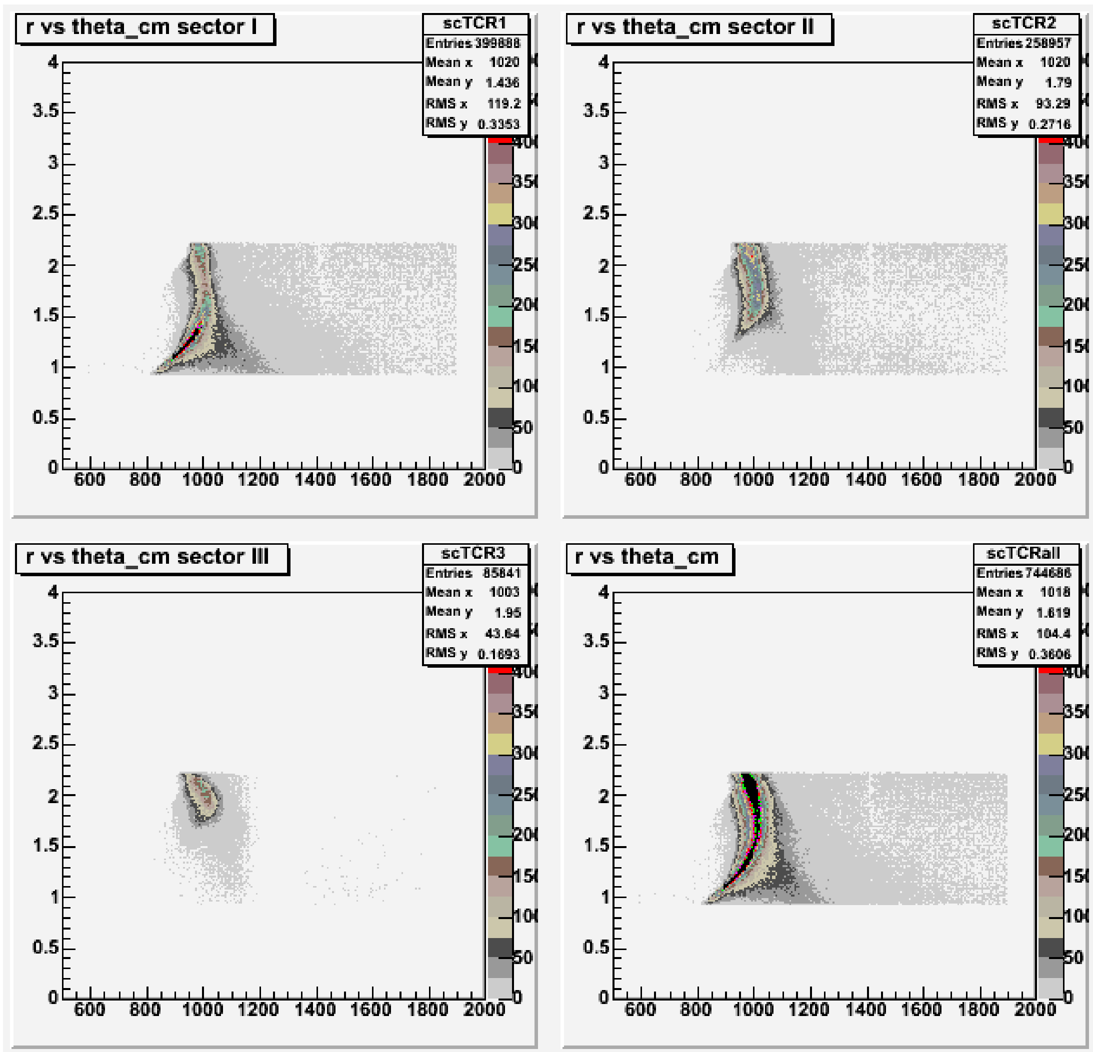
Sector Orientation







Collimator Study



Look at focus for different

- Sectors
- Parts of target

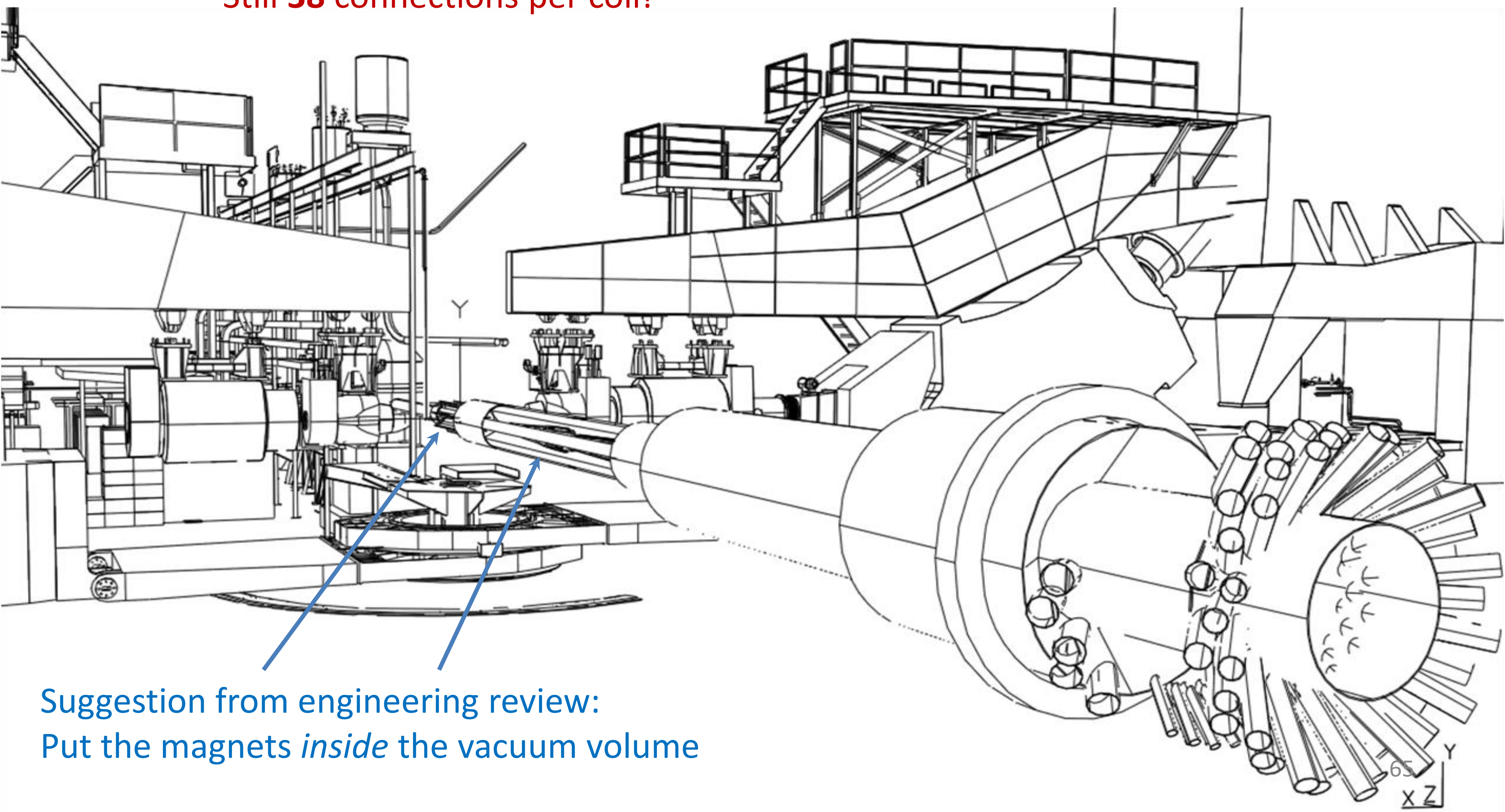
Useful for optics tweaks and collimator optimization

Ideally the strips would be vertical in these (actually theta vs. radius) plots

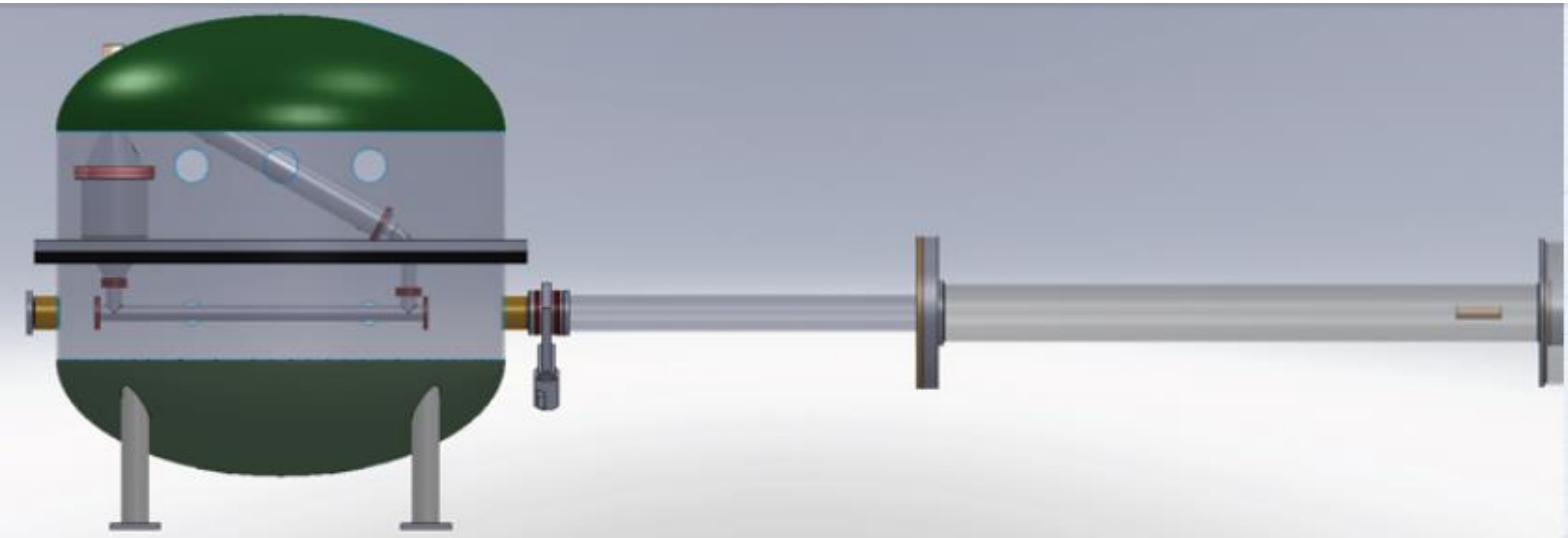
see elog 200

Water-cooling and supports

Verified by MIT engineers
– cooling could be accomplished in concept 2 with 4 turns per loop
Still **38** connections per coil!



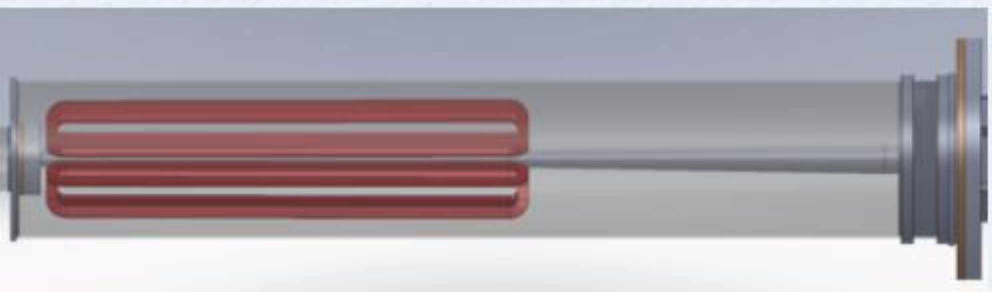
Suggestion from engineering review:
Put the magnets *inside* the vacuum volume



F

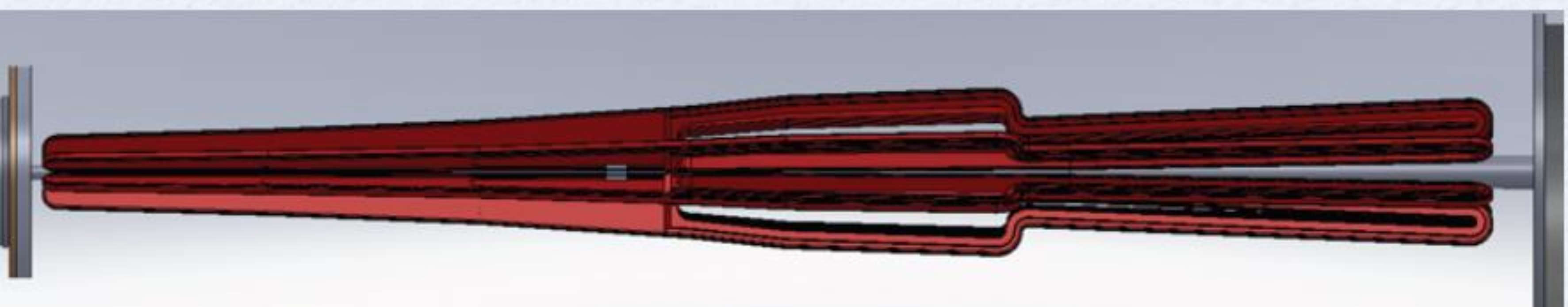
z = 0 (cer

z =

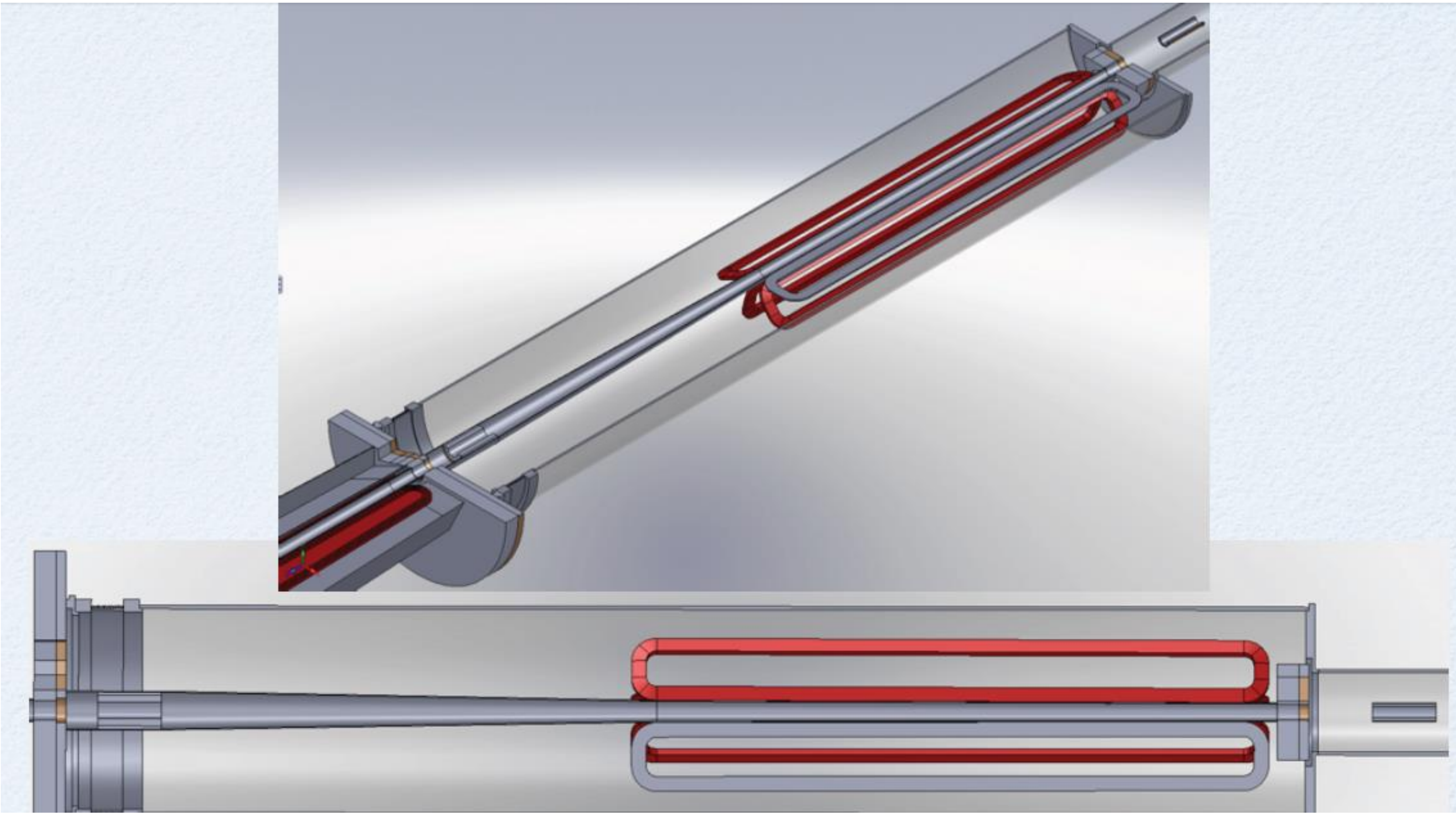


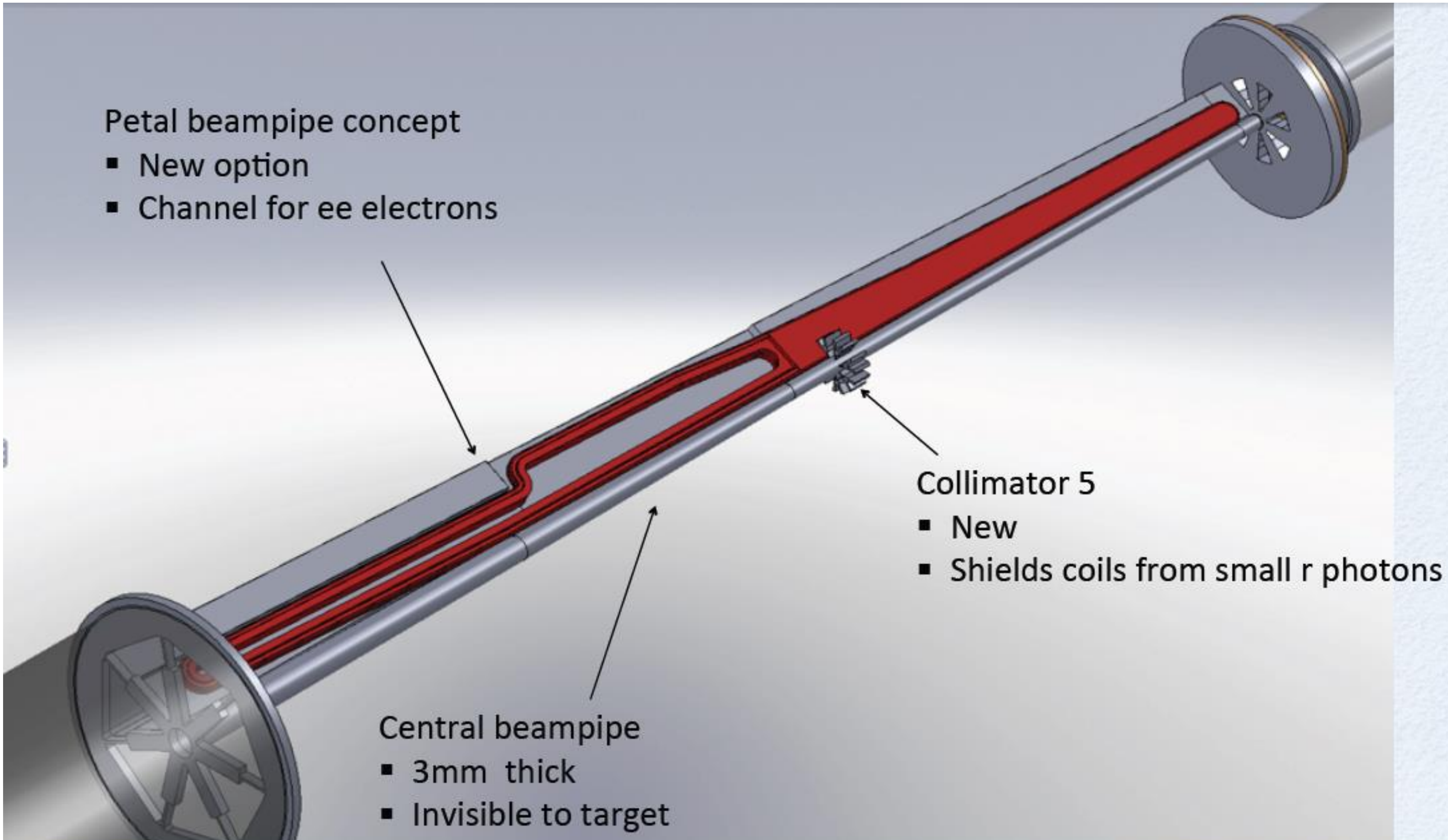
z =

z =

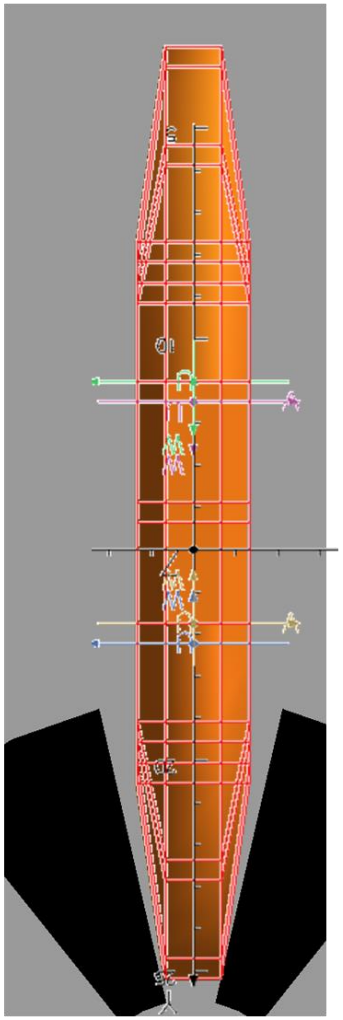


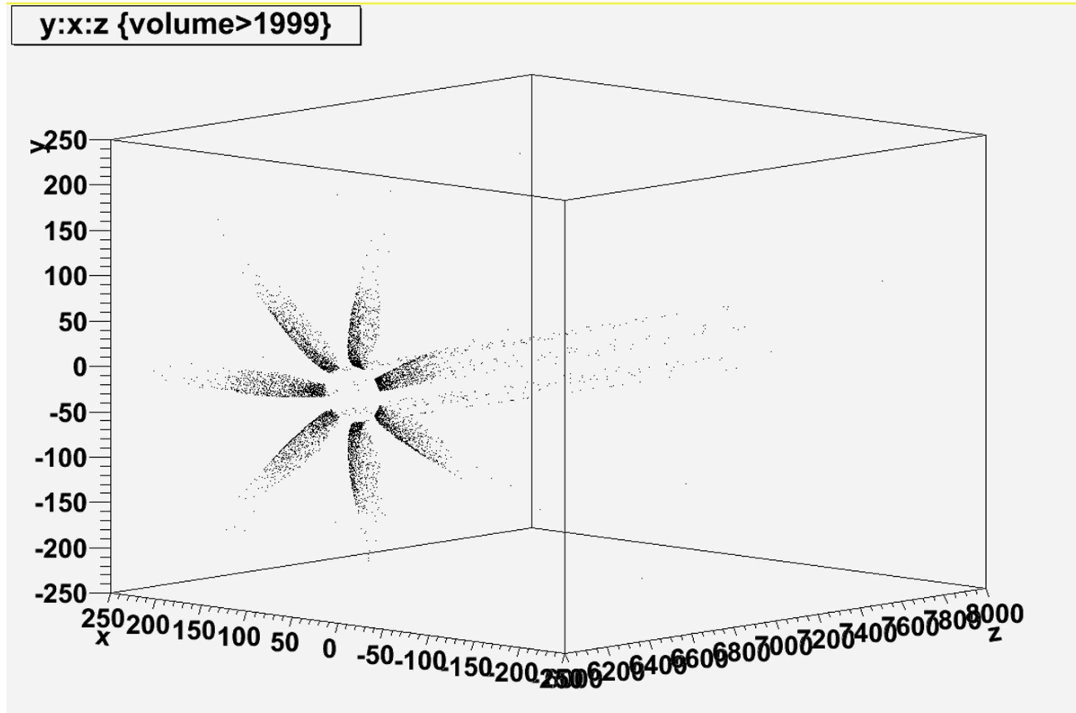
z

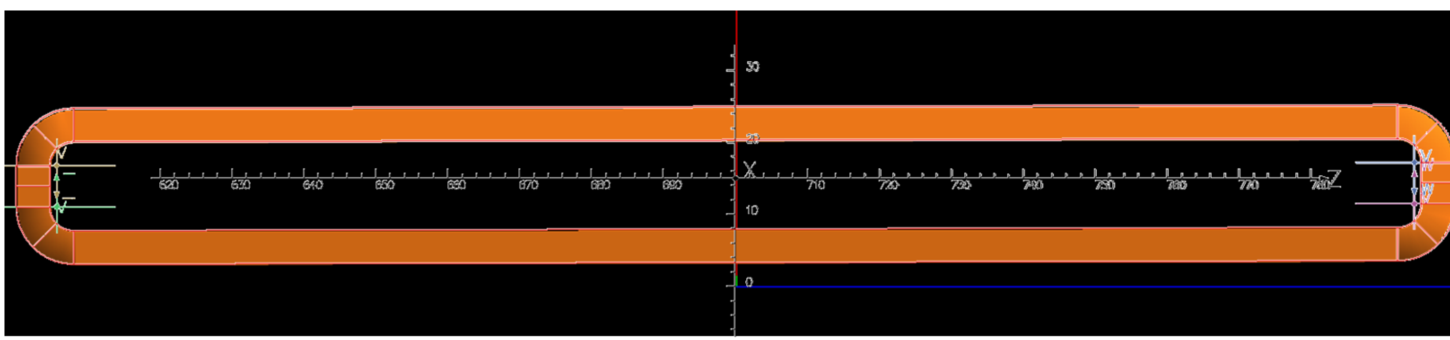



Petal beampipe concept
▪ New option
▪ Channel for ee electrons
Collimator 5
▪ New
▪ Shields coils from small r photons
Central beampipe
▪ 3mm thick
▪ Invisible to target

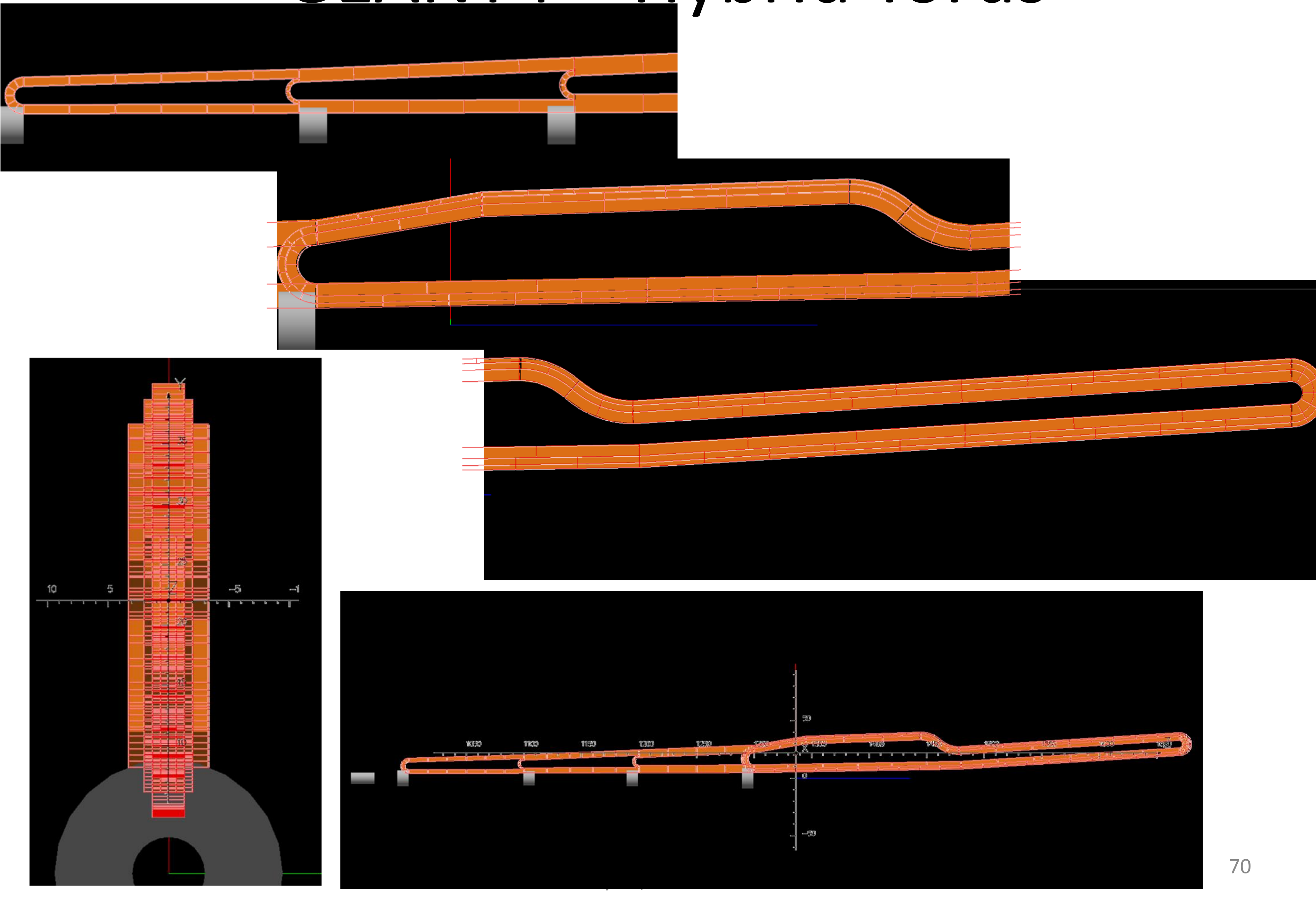
GEANT4 – Upstream Torus







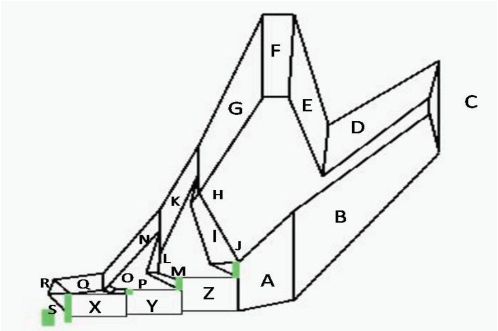
GEANT4 – Hybrid Torus

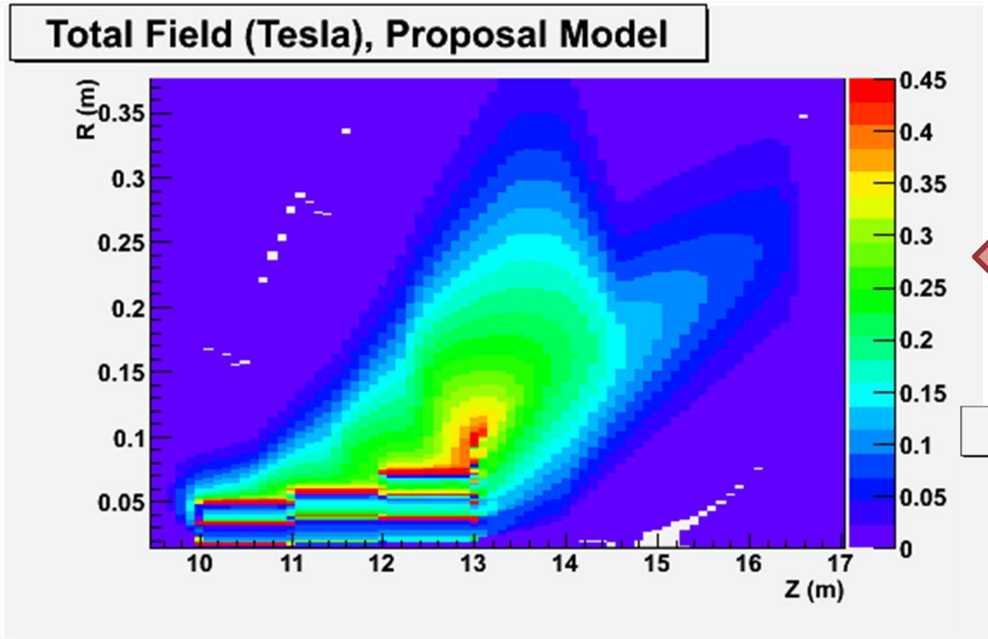


GEANT4

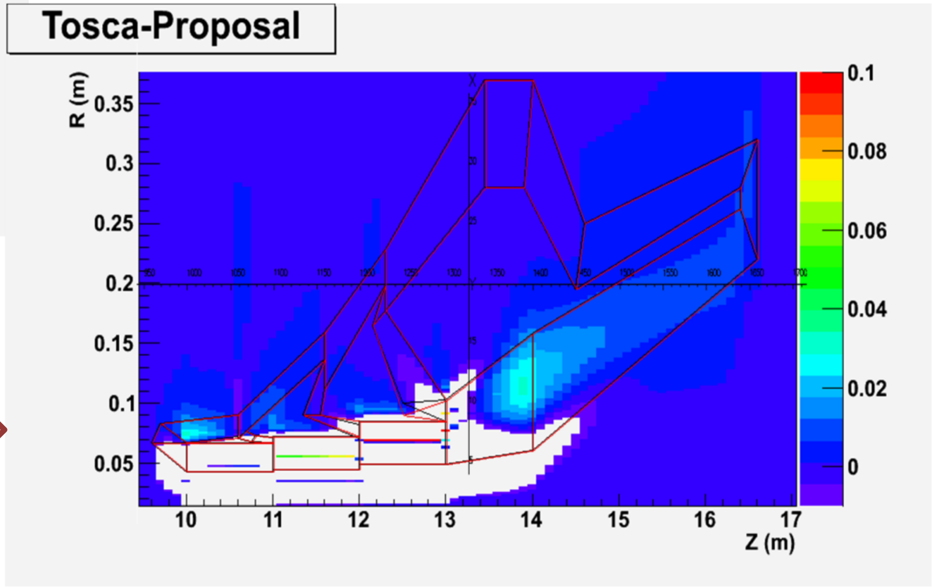
Direct Comparison of Fields

Complicated field because of multiple current returns





The average total field in a sector in bins of R vs. z



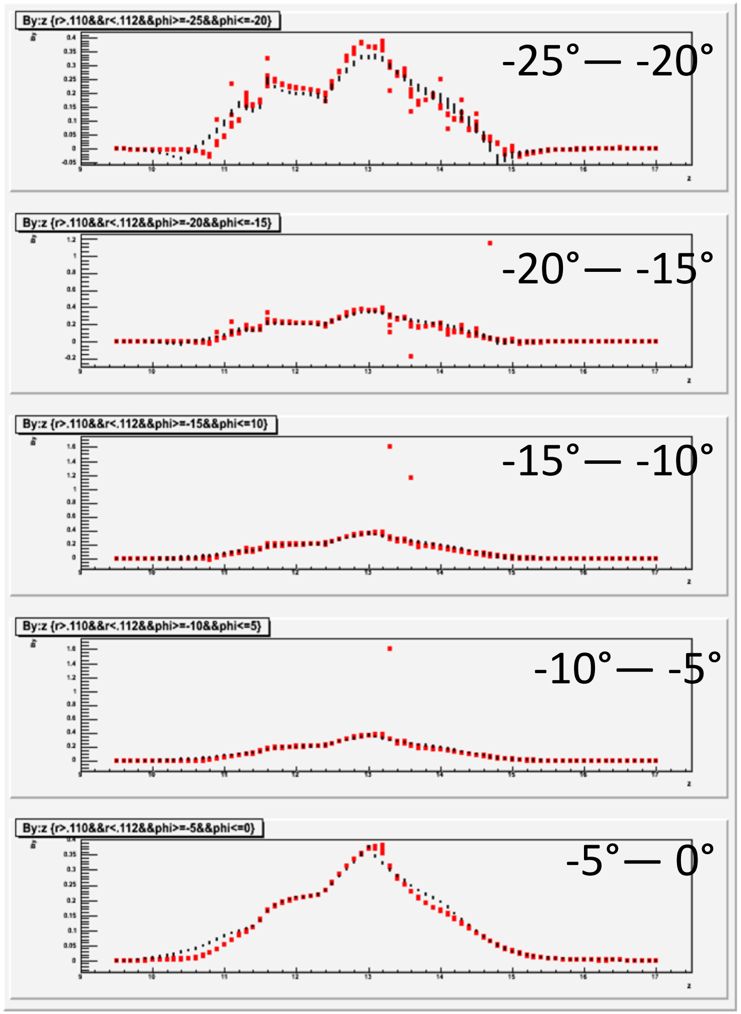
The difference of the total field in a sector in bins of R vs. z for the TOSCA version of the proposal and the original proposal model

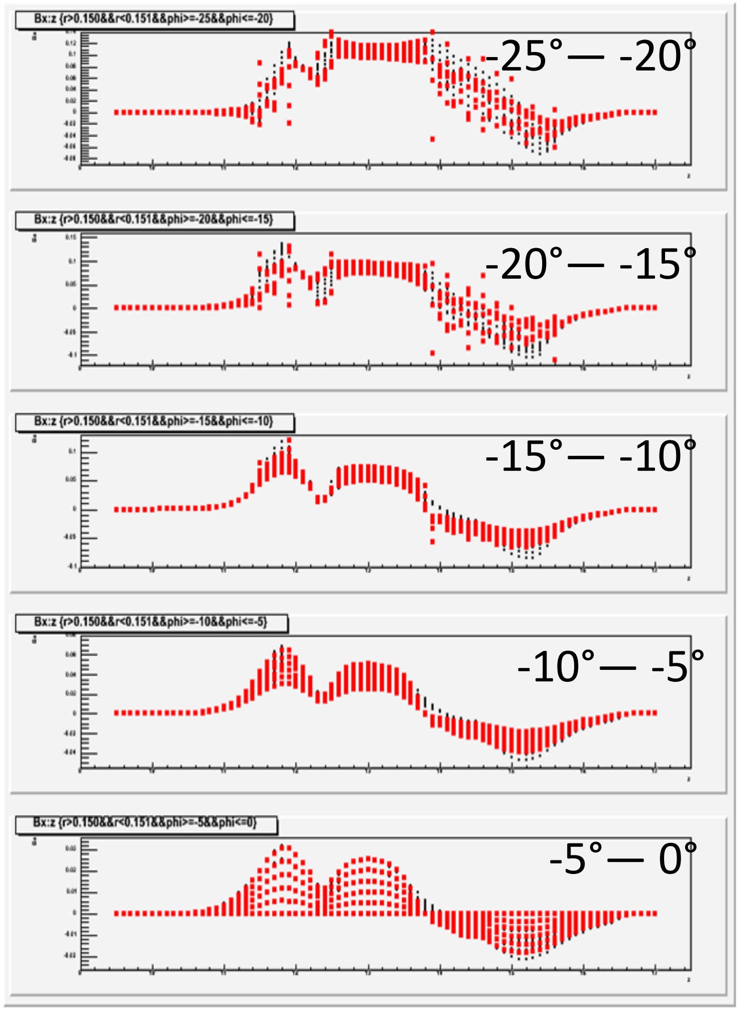
Comparison of field values

Red – proposal model

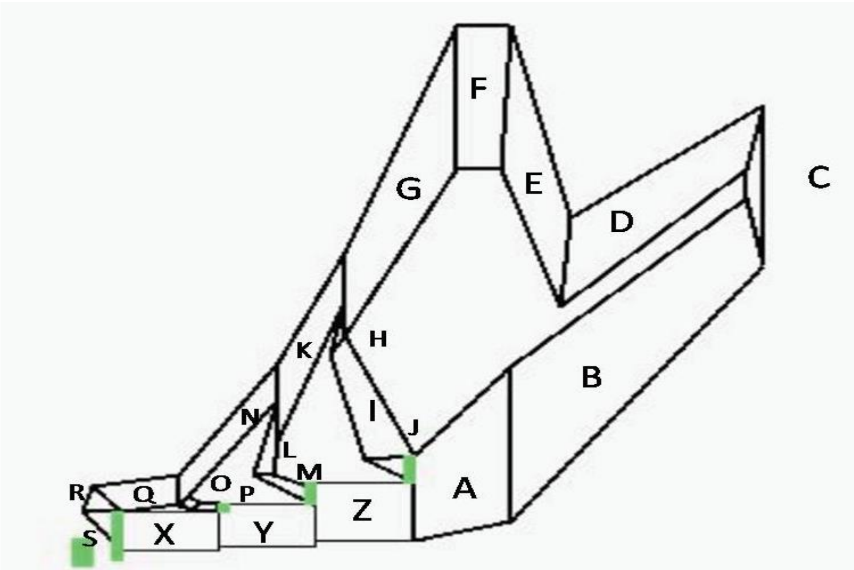
Black – TOSCA model

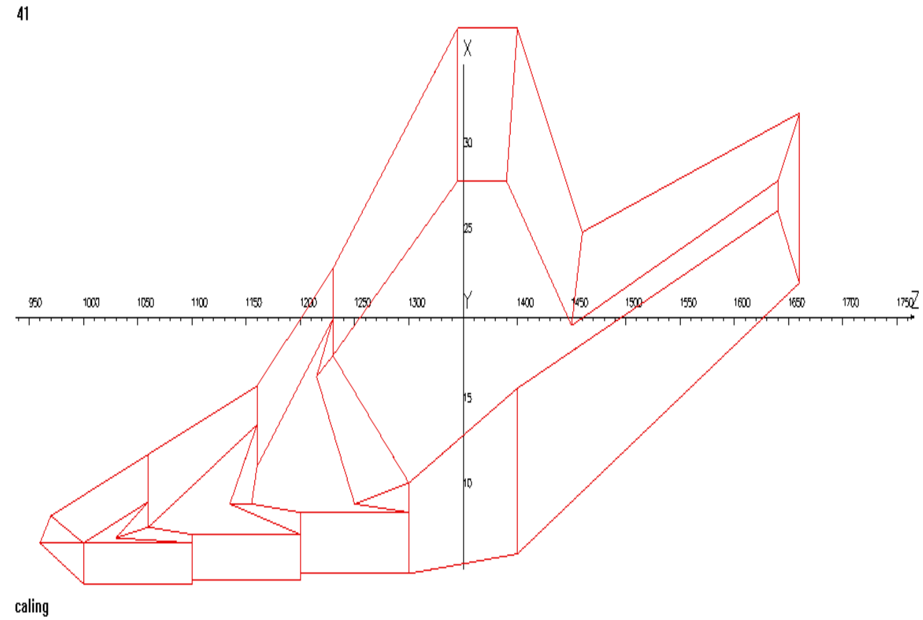
By (left) or Bx (right) vs. z in 5° bins in phi





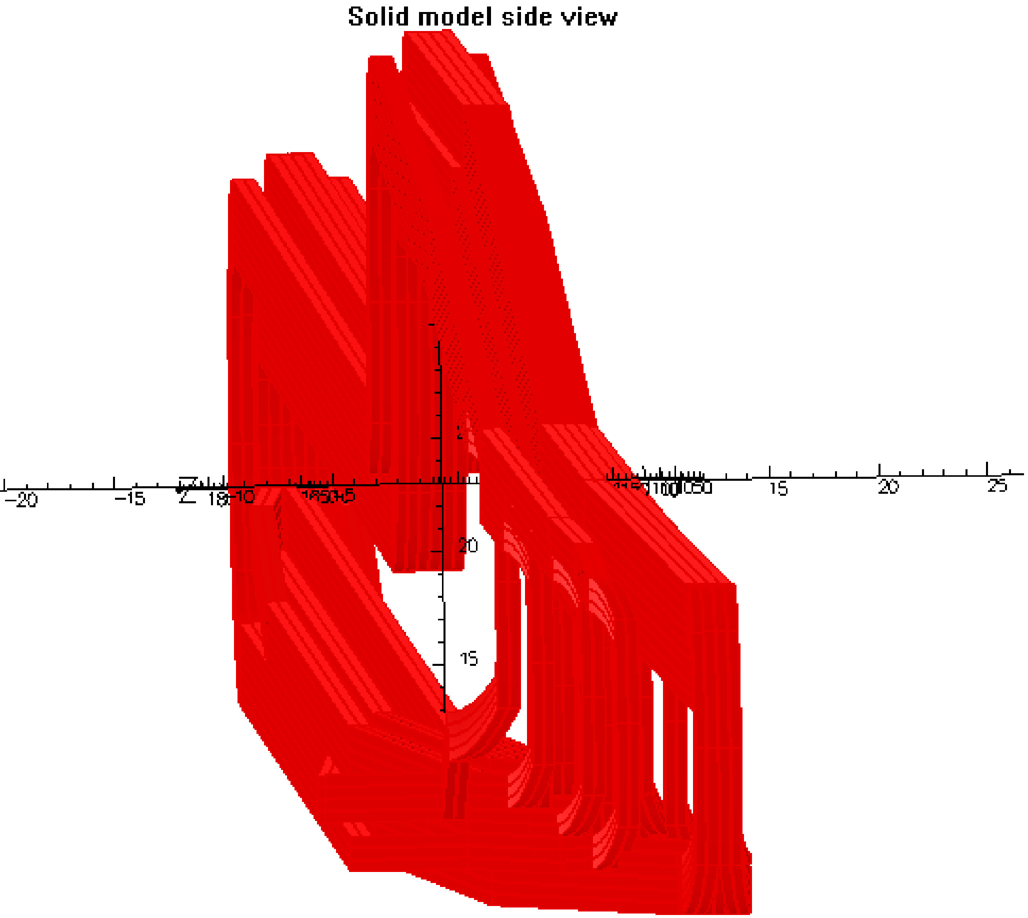
Proposal Model

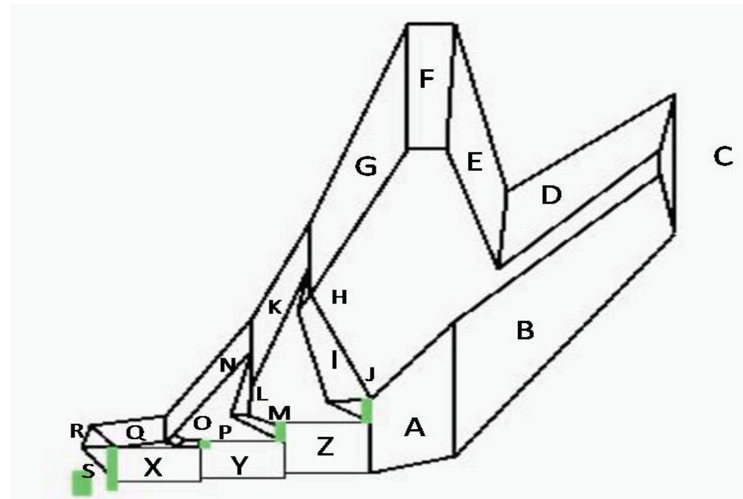


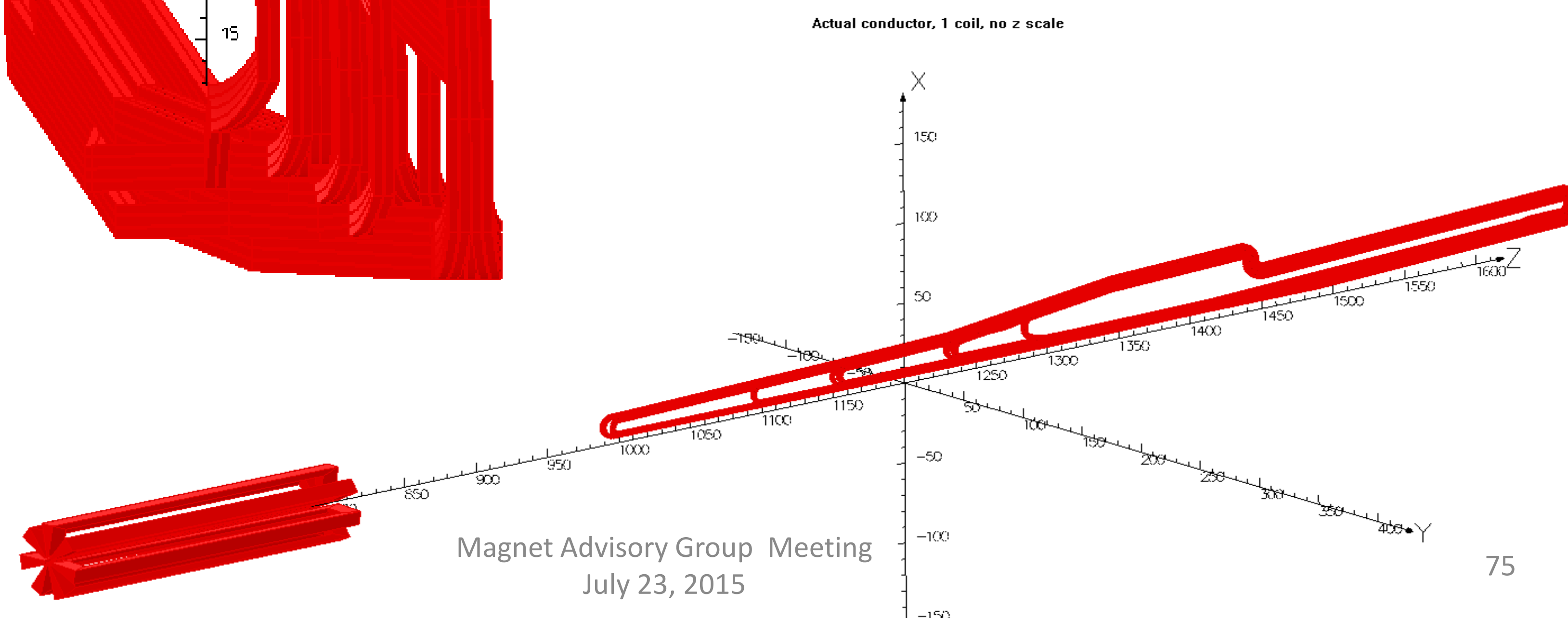


OD (cm)	A_{cond} (cm^2)	Total # Wires				Current (A)				Current per wire	J (A/cm^2)
		X	Y	Z	A	X	Y	Z	A		
Proposal		---	---	---	---	7748	10627	16859	29160	---	1100
0.4115	0.1248	40	54	86	146	7989	10785	17176	29160	200	1600
0.4620	0.1568	32	44	70	120	7776	10692	17010	29160	243	1550
0.5189	0.1978	26	36	56	94	8066	11168	17372	29160	310	1568
0.5827	0.2476	20	28	40	76	7680	10752	15360	29184	384	1551

Actual Conductor Layout







Choose constraints

- Choose (standard) conductor size/layout minimizes current density
- Try to use “double pancakes”; as flat as possible
- Minimum bend radius 5x conductor OD
- Fit within radial, angular acceptances (360°/7 and <360°/14 at larger radius)
- Total current in each inner “cylinder” same as proposal model
- Take into account water cooling hole, insulation
- Need to consider epoxy backfill and aluminum plates/ other supports?

➢ Radial extent depends on upstream torus and upstream parts of hybrid!!

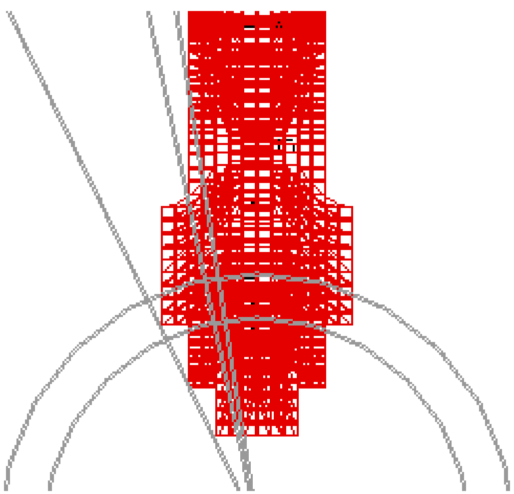
Conductor Size

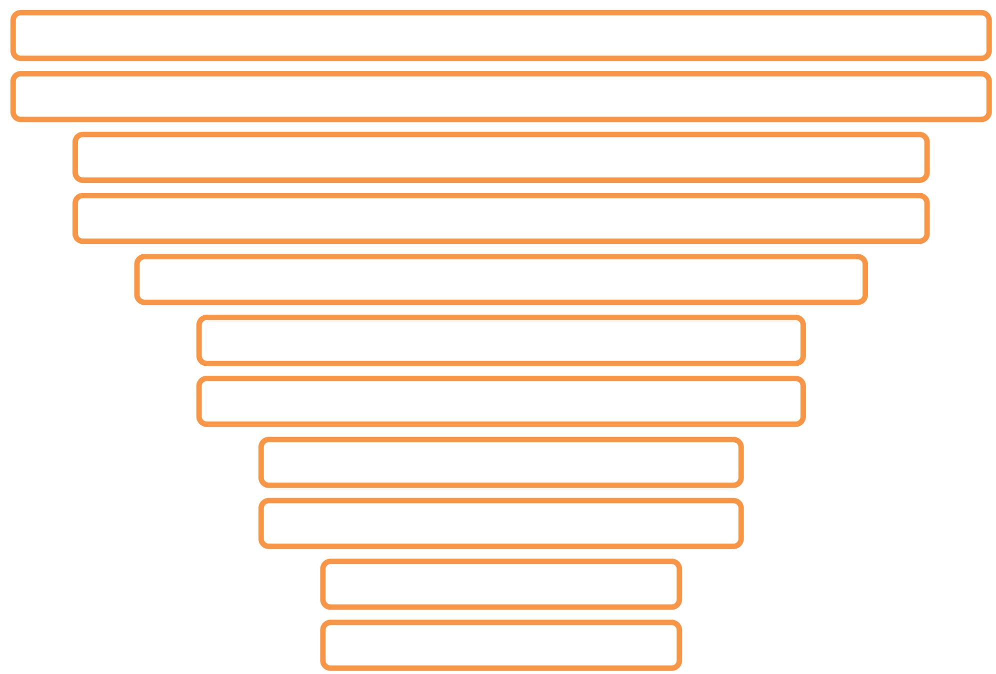
Need to “fill” the available space at low radius

Trade-off between more insulation for smaller conductor and losing space at the “edges” with larger conductor

Also need to fit all the conductor in a particular radius at a given z location

- Much bigger conductors have even higher current densities because of “edge” effects





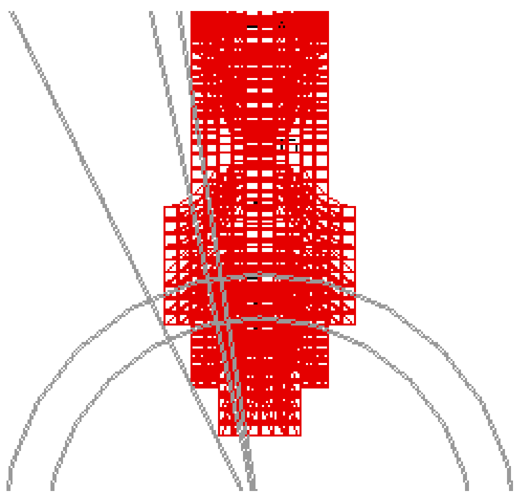
Conductor Size

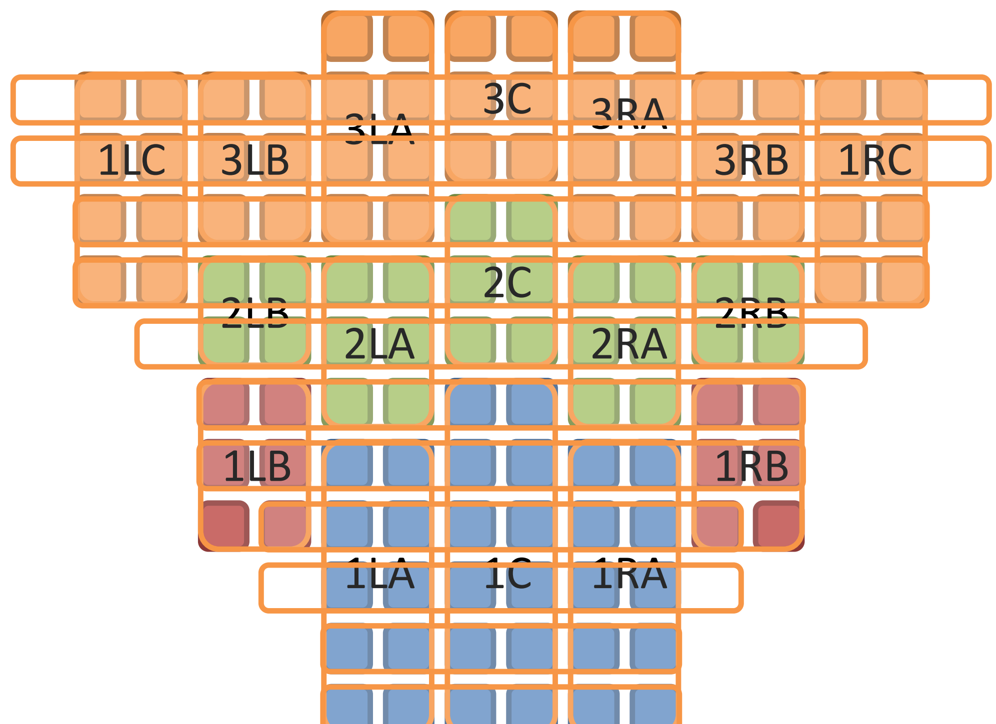
Need to "fill" the available space at low radius

Trade-off between more insulation for smaller conductor and losing space at the "edges" with larger conductor

Also need to fit all the conductor in a particular radius at a given z location

- Much bigger conductors have even higher current densities because of "edge" effects





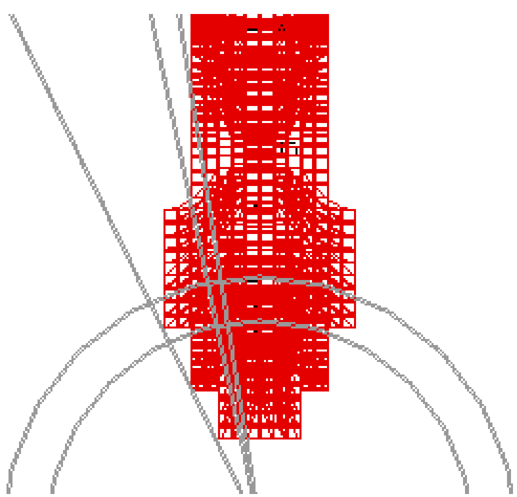
Conductor Size

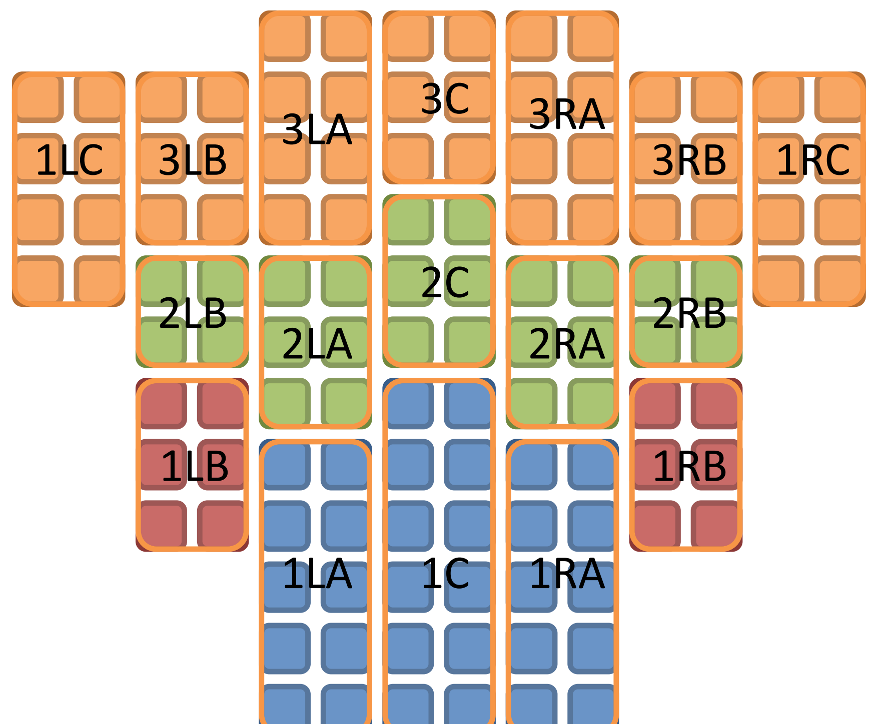
Need to "fill" the available space at low radius

Trade-off between more insulation for smaller conductor and losing space at the "edges" with larger conductor

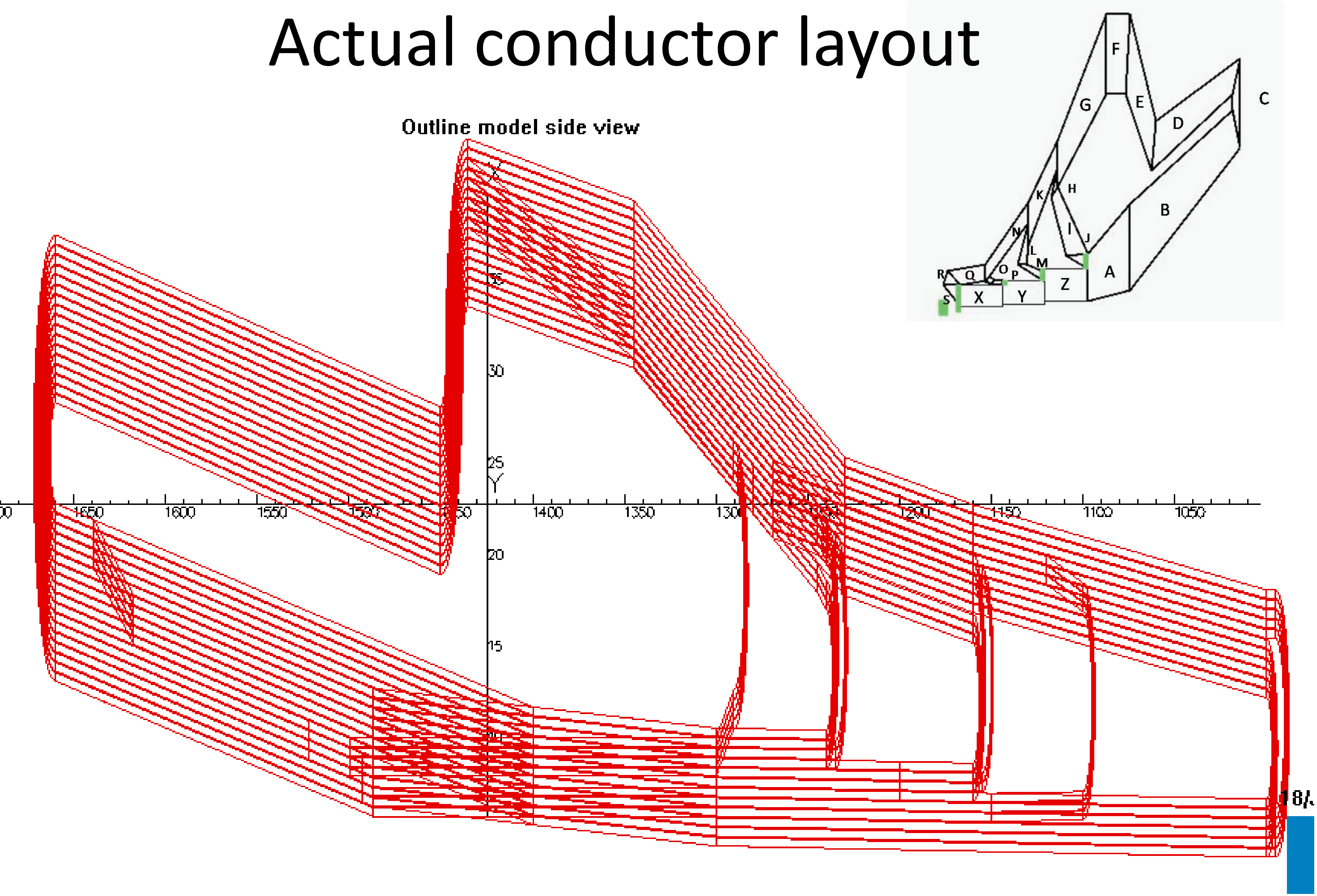
Also need to fit all the conductor in a particular radius at a given z location

- Much bigger conductors have even higher current densities because of "edge" effects

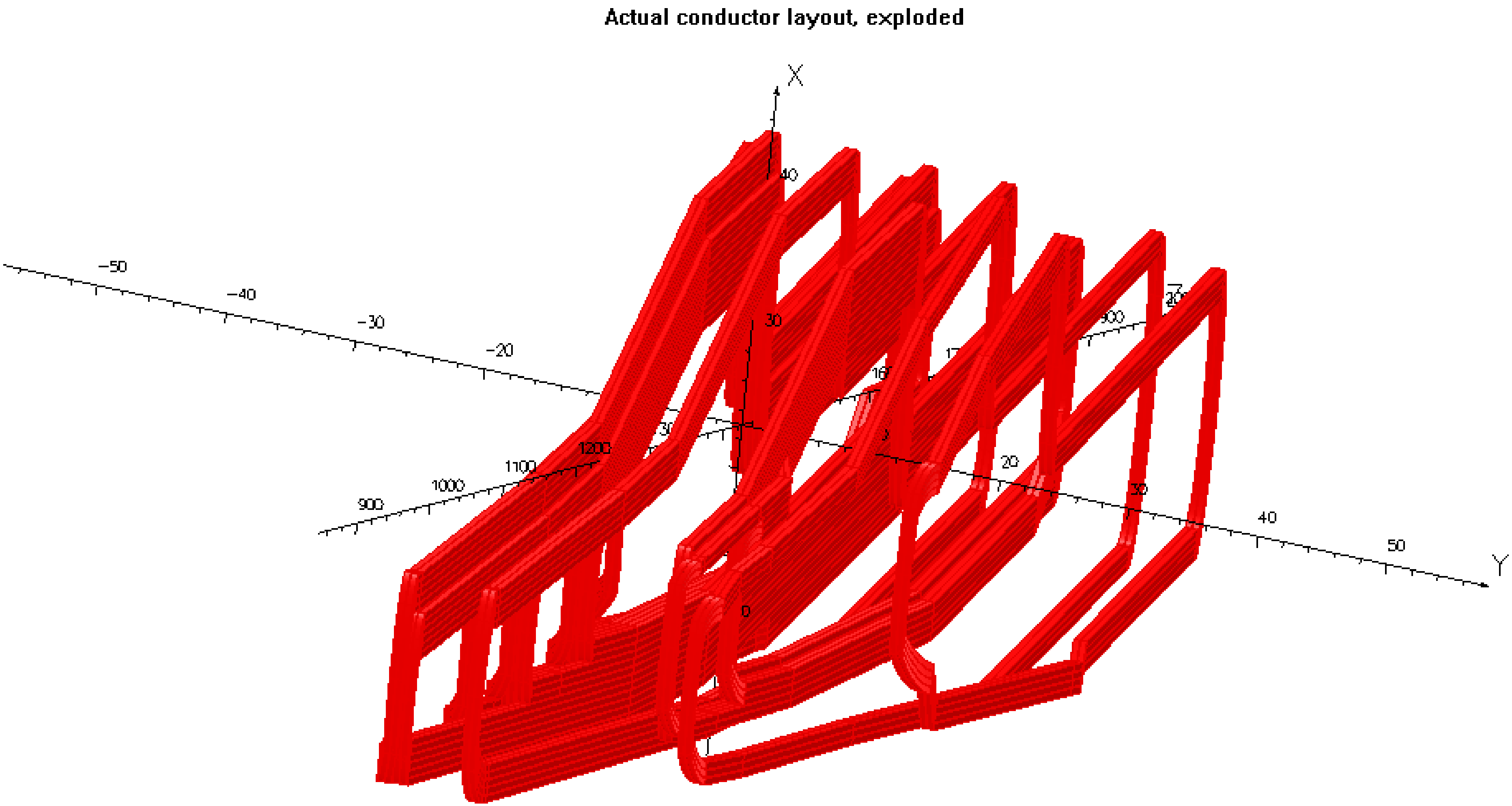




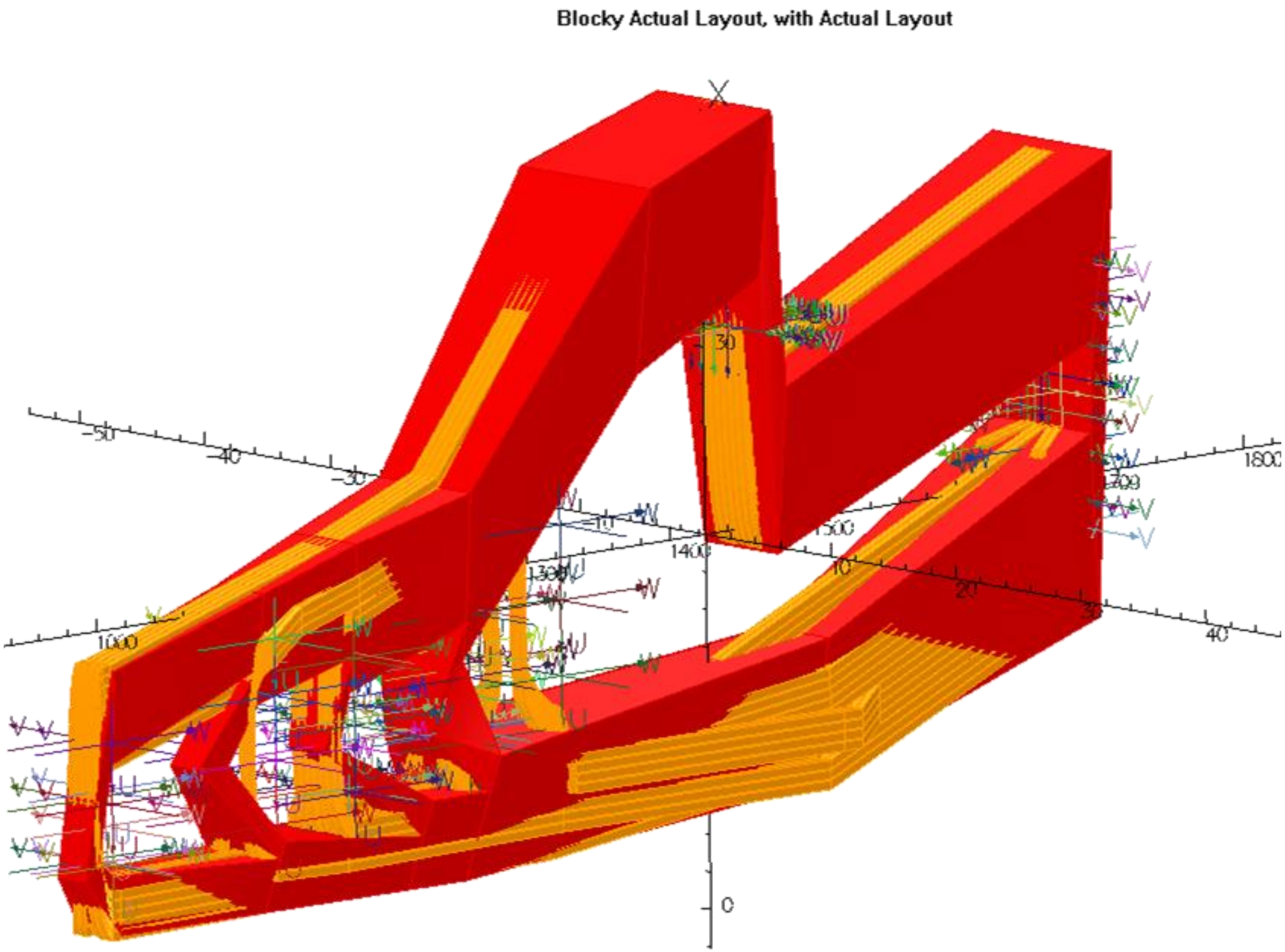
Actual conductor layout



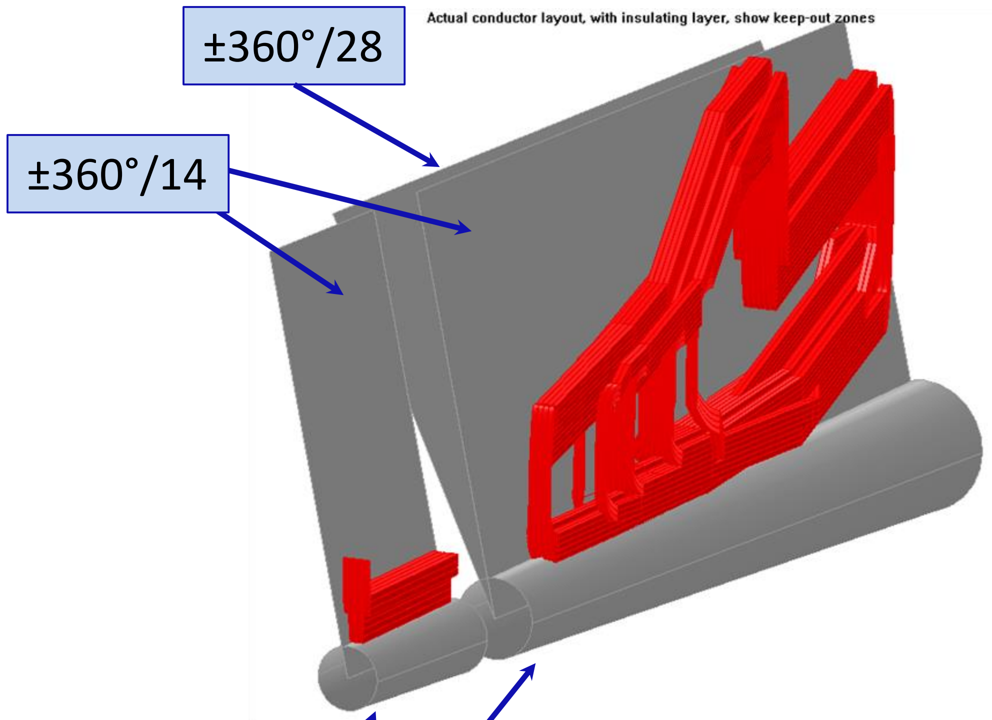
Actual conductor layout



Blocky Model superimposed



Keep Out Zones



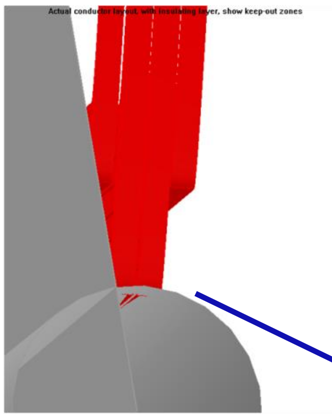
cones are defined using:

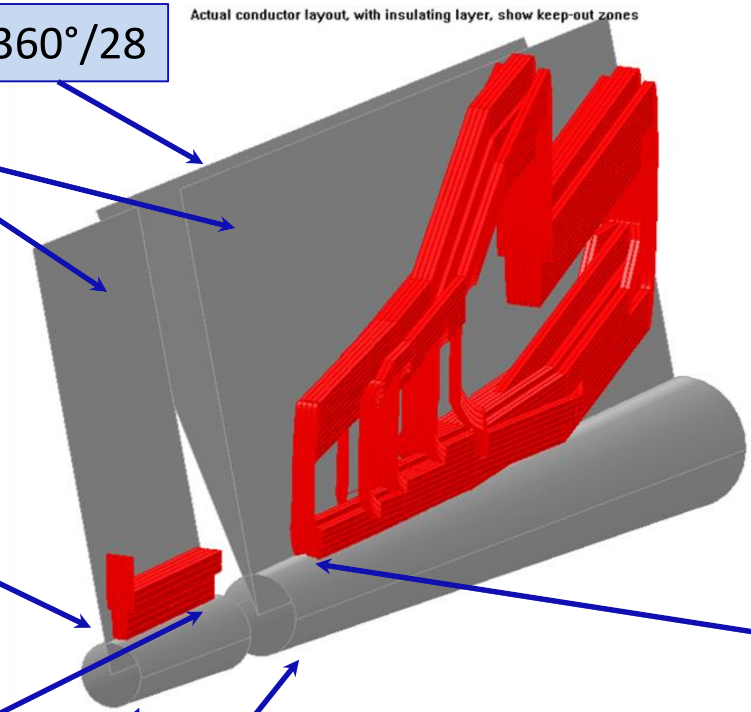
- nothing w/in 5σ of the multiple scattering radius
- + 1/4" each for Al support and W shielding

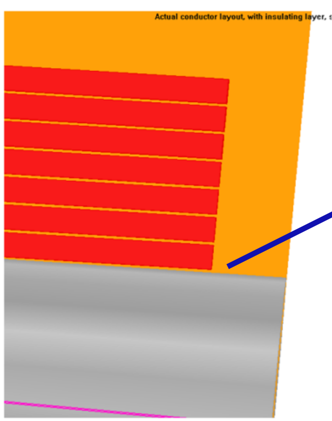
Keep Out Zones

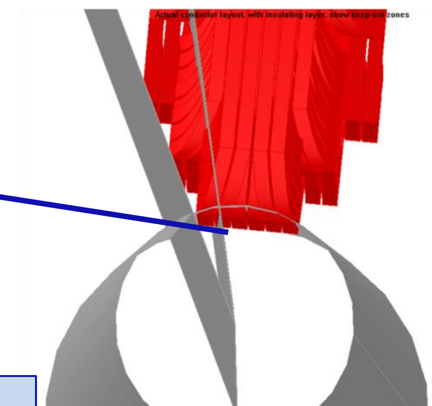
±360°/28

±360°/14









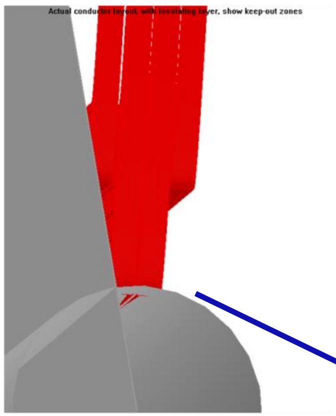
cones are defined using:

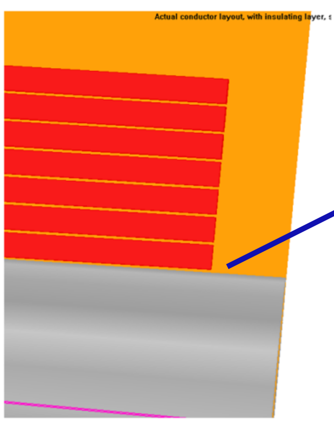
- nothing w/in 5σ of the multiple scattering radius
- + 1/4" each for Al support and W shielding

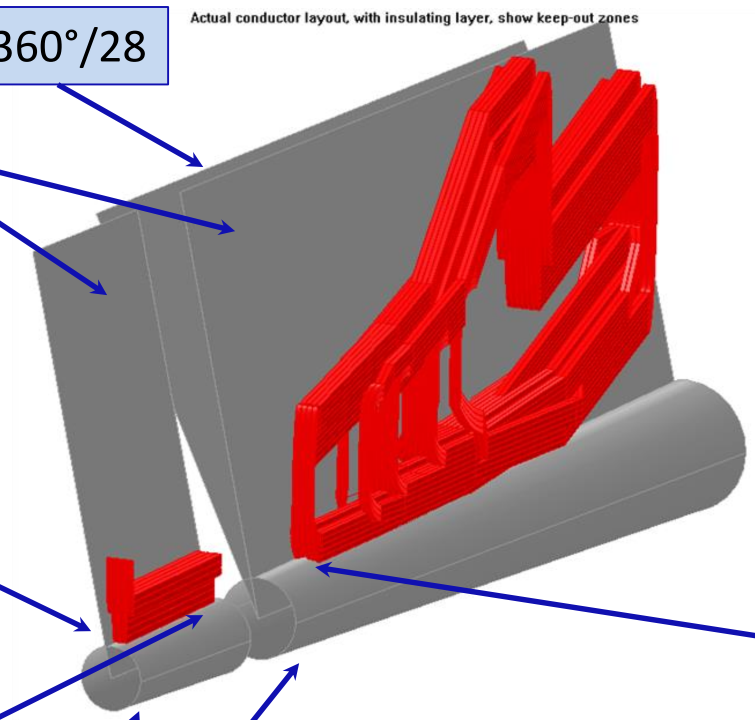
Keep Out Zones

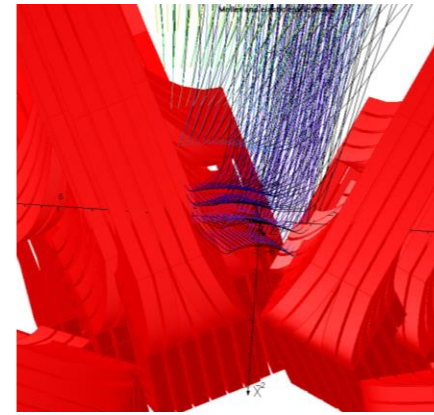
±360°/28

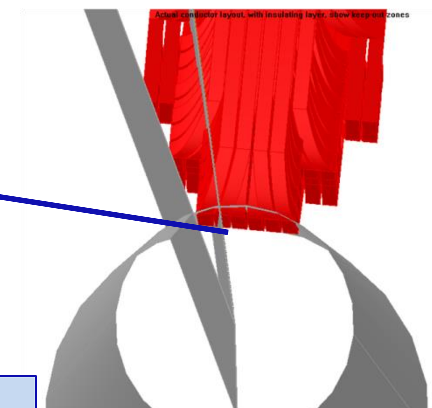
±360°/14







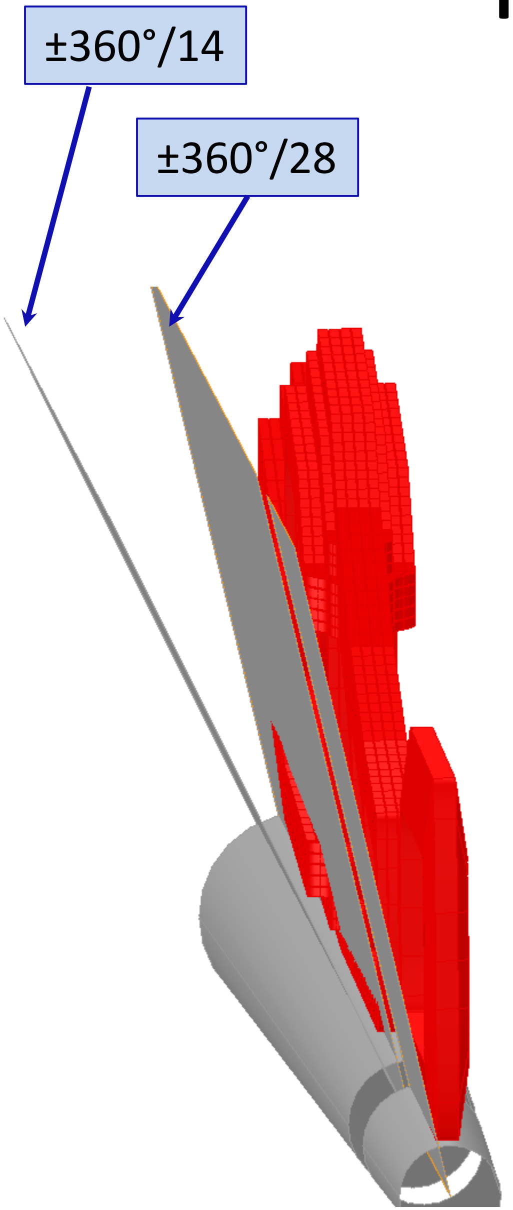


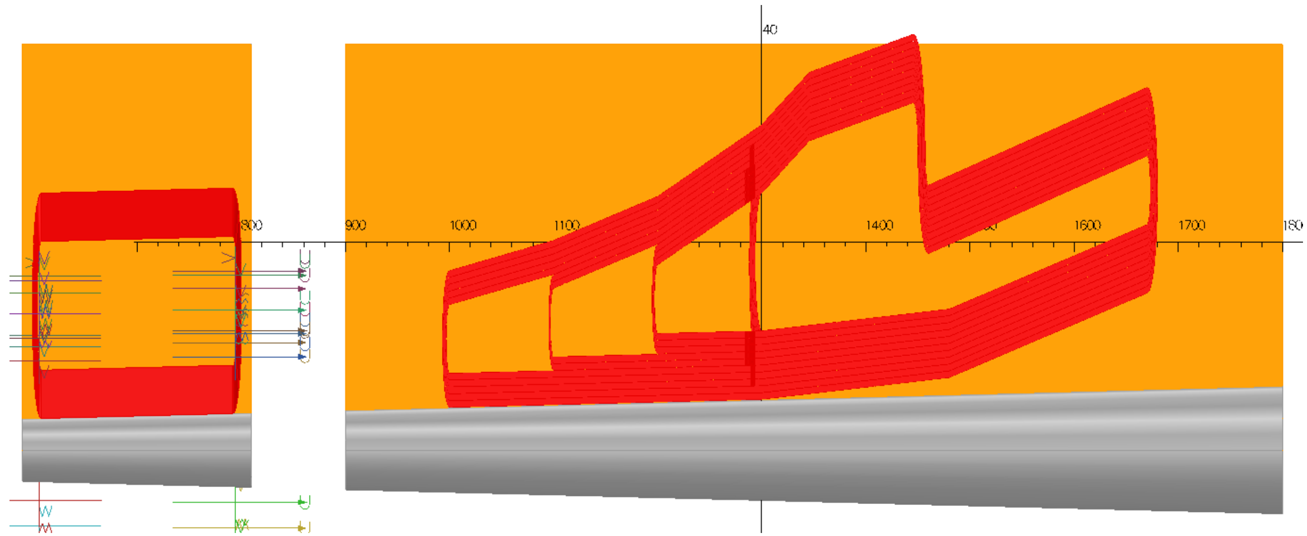


cones are defined using:

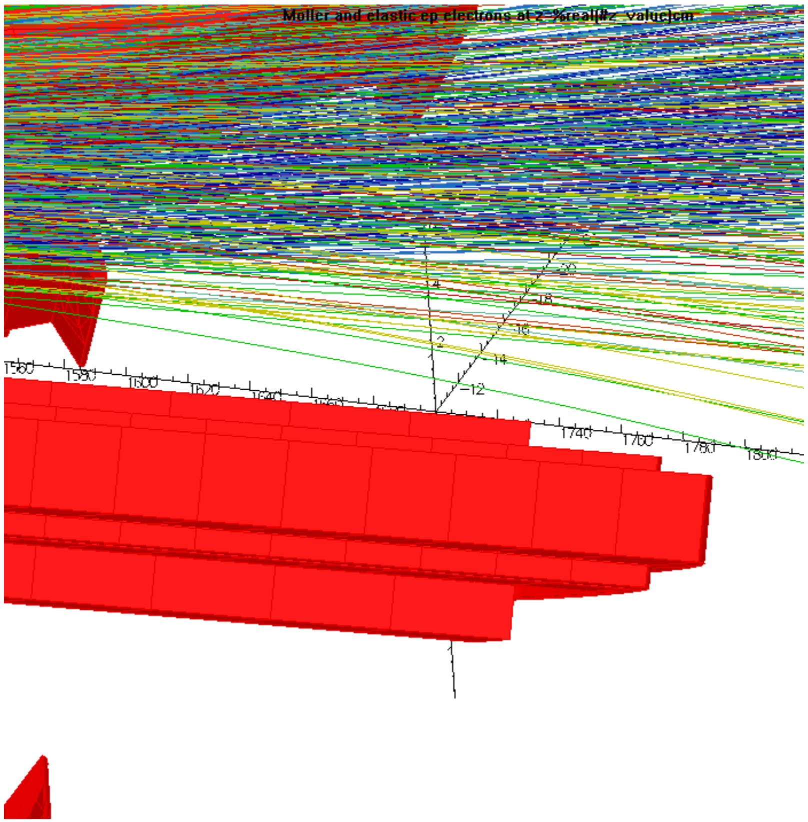
- nothing w/in 5σ of the multiple scattering radius
- + 1/4" each for Al support and W shielding

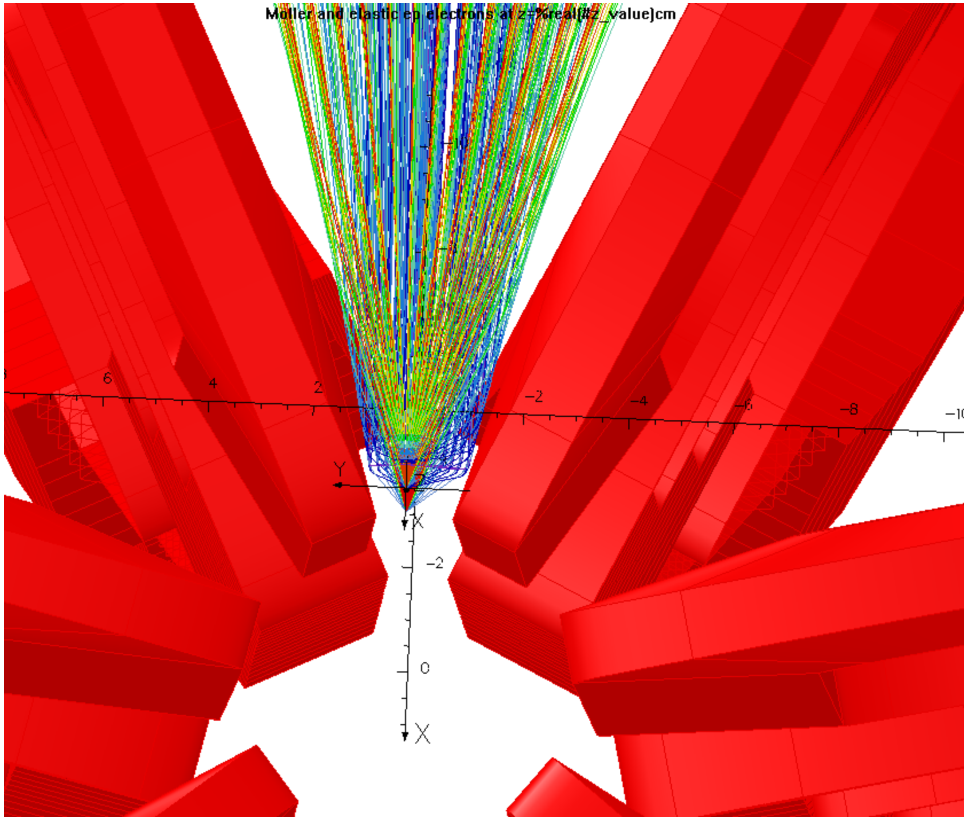
Keep Out Zones/Concept 2



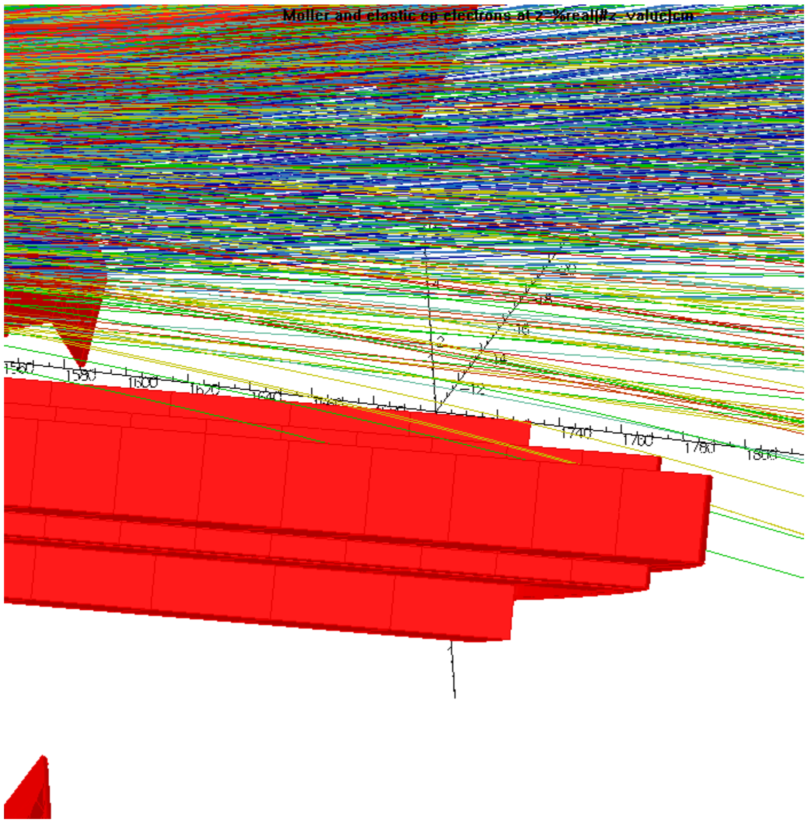


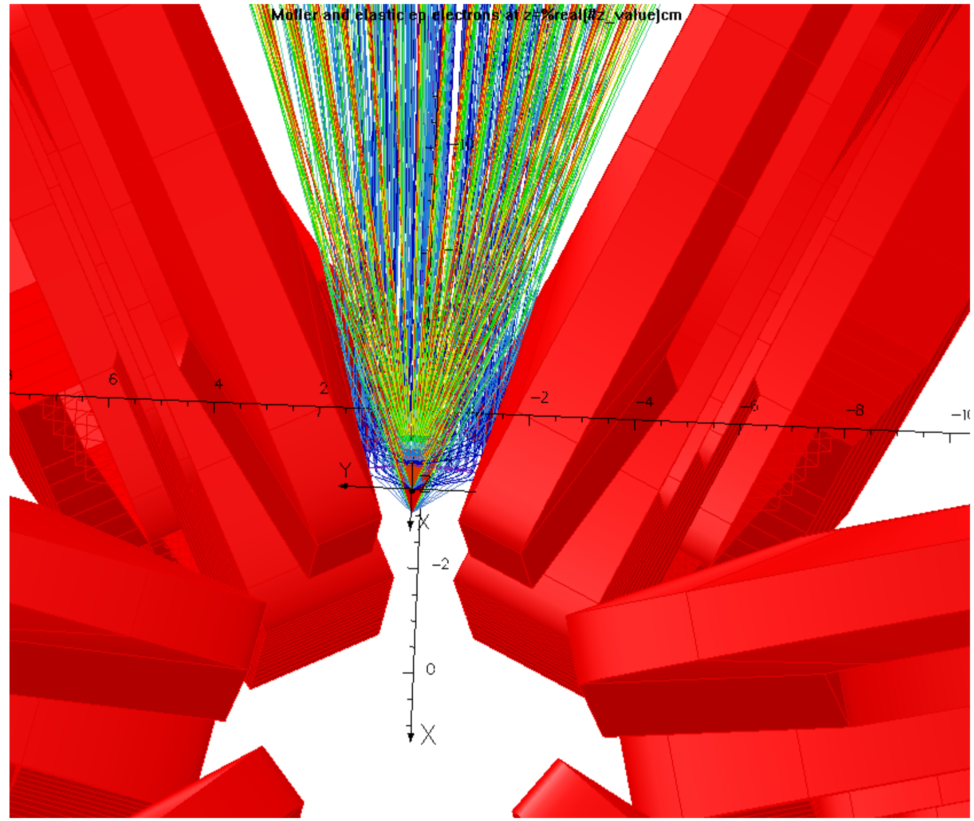
Interferences



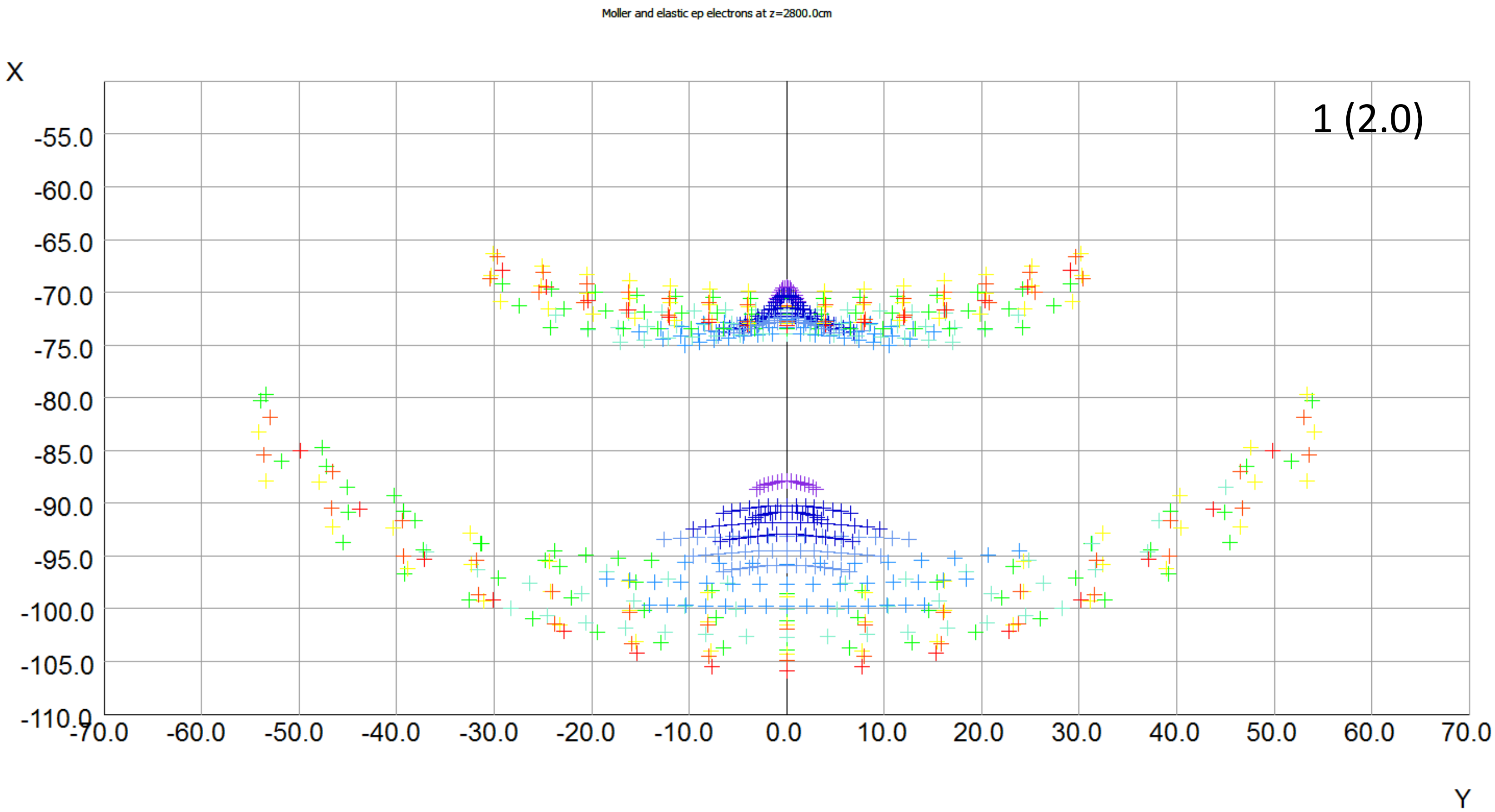


Interferences

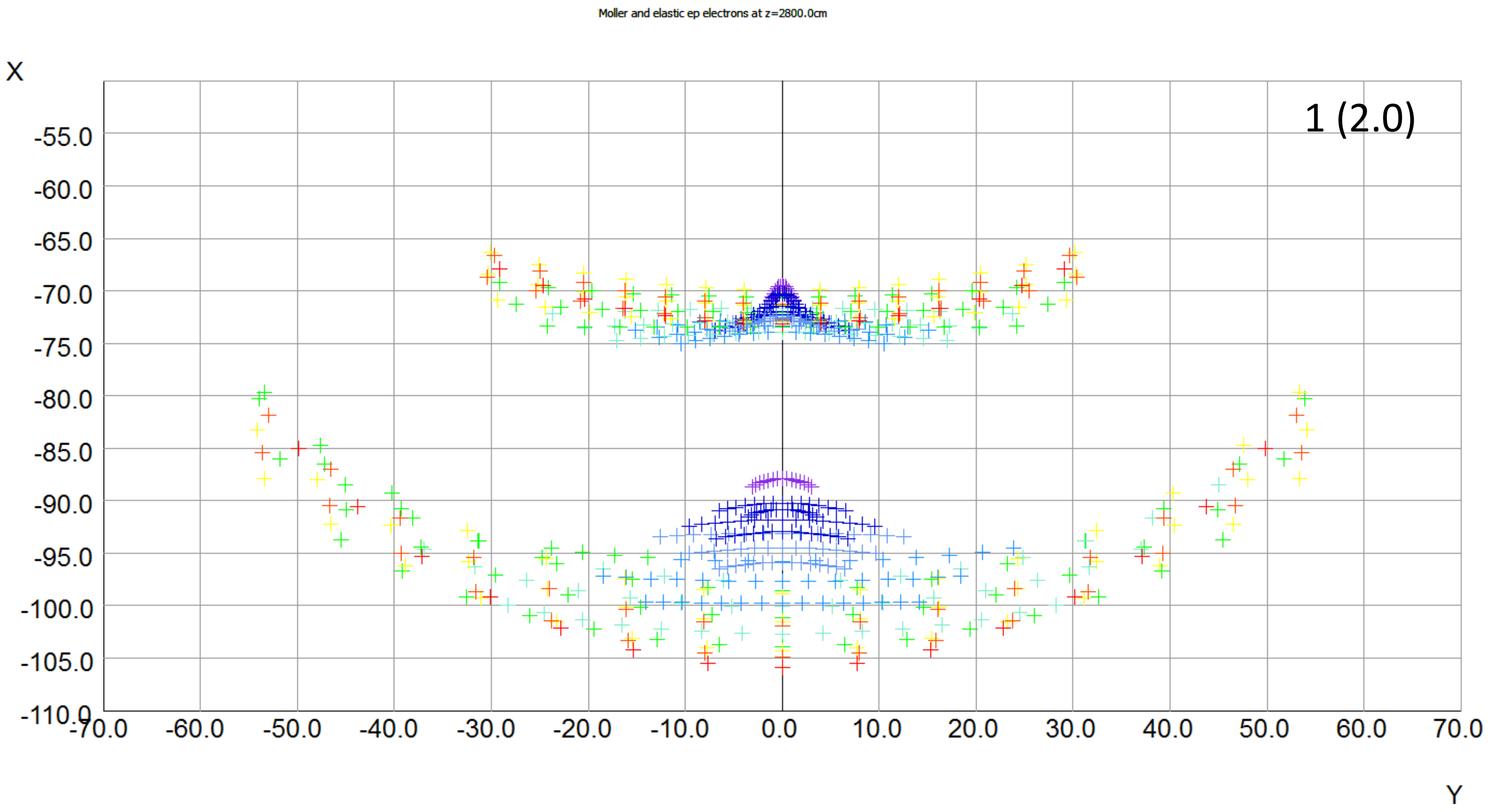




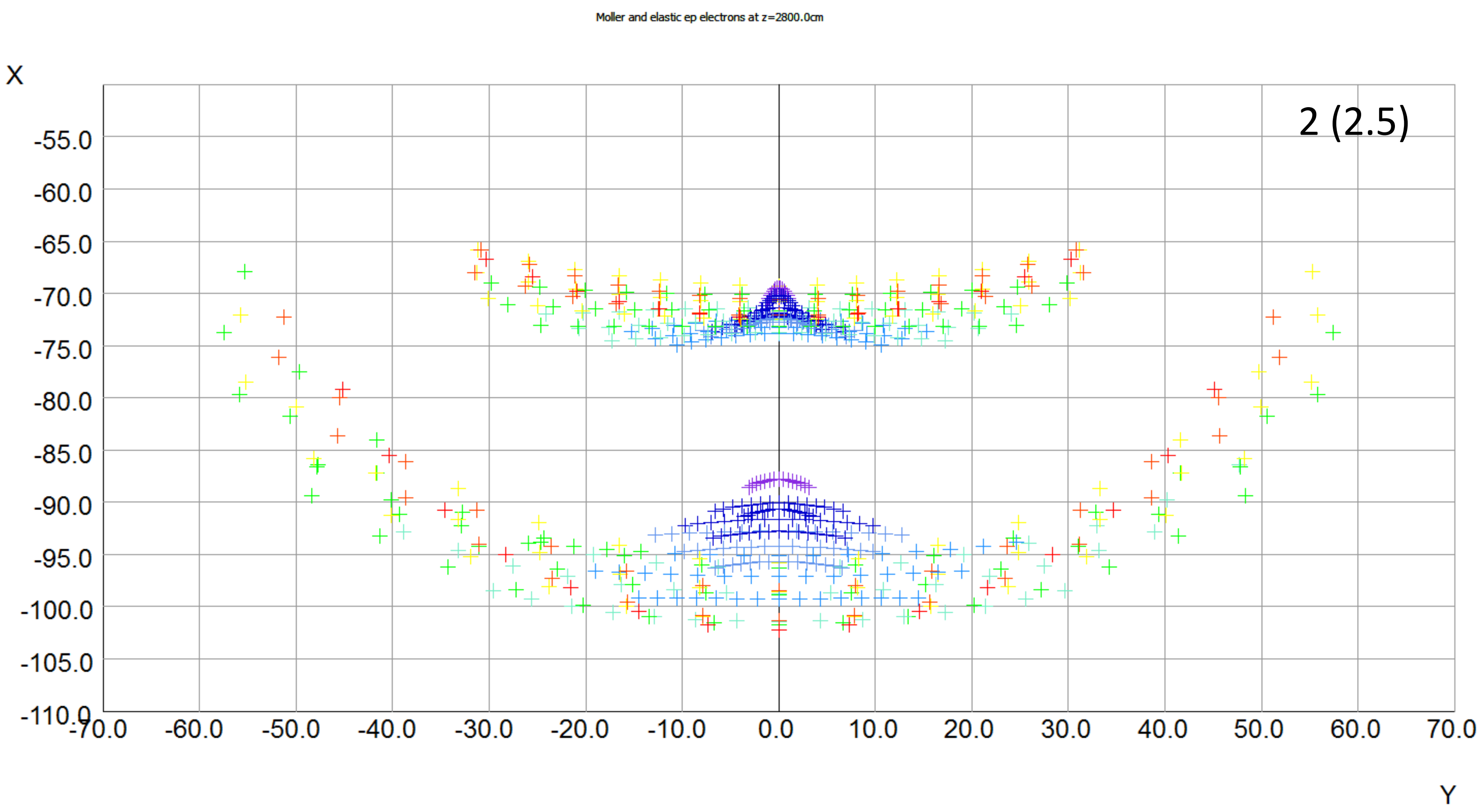
Tweaking the Optics



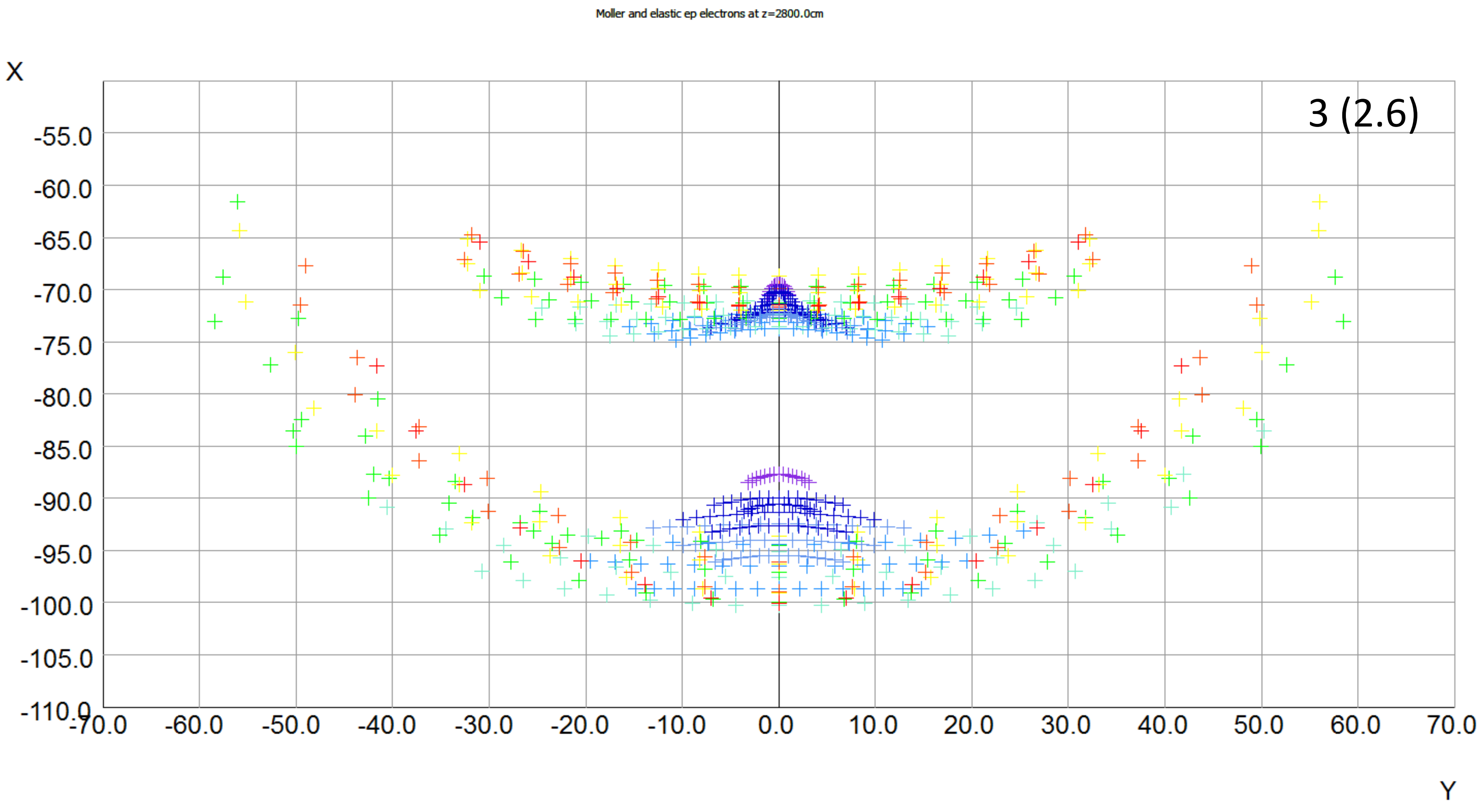
Tweaking the Optics



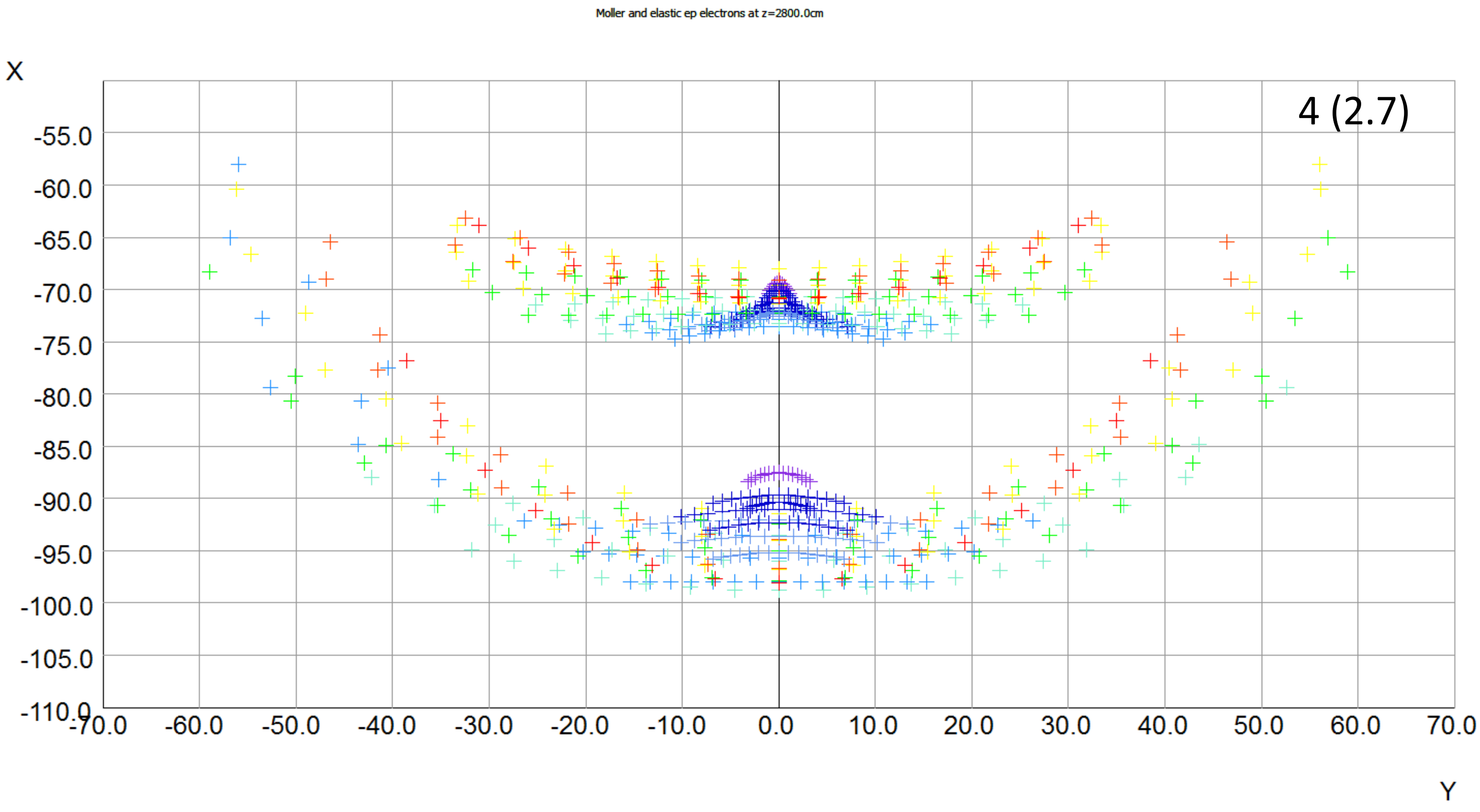
Tweaking the Optics



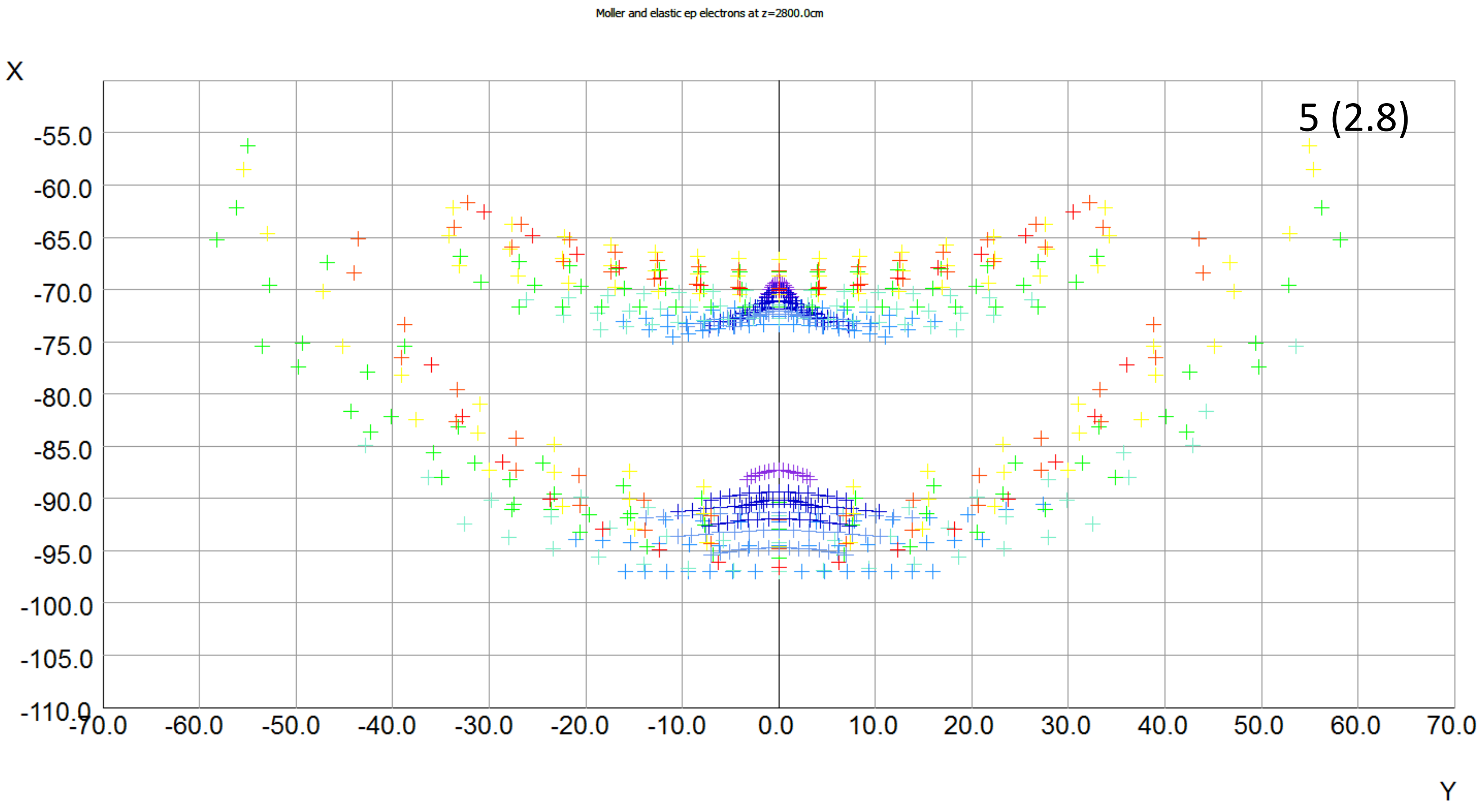
Tweaking the Optics



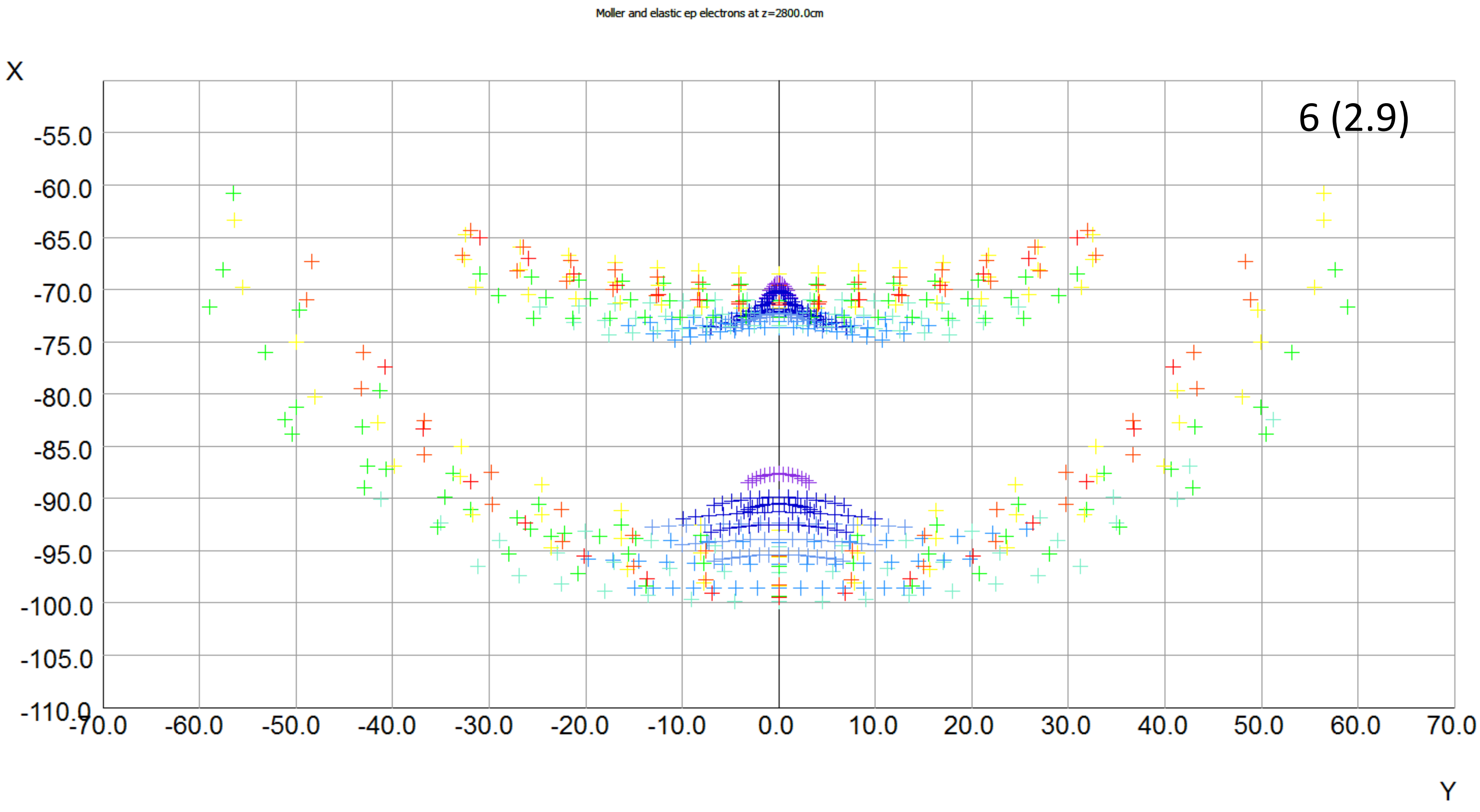
Tweaking the Optics



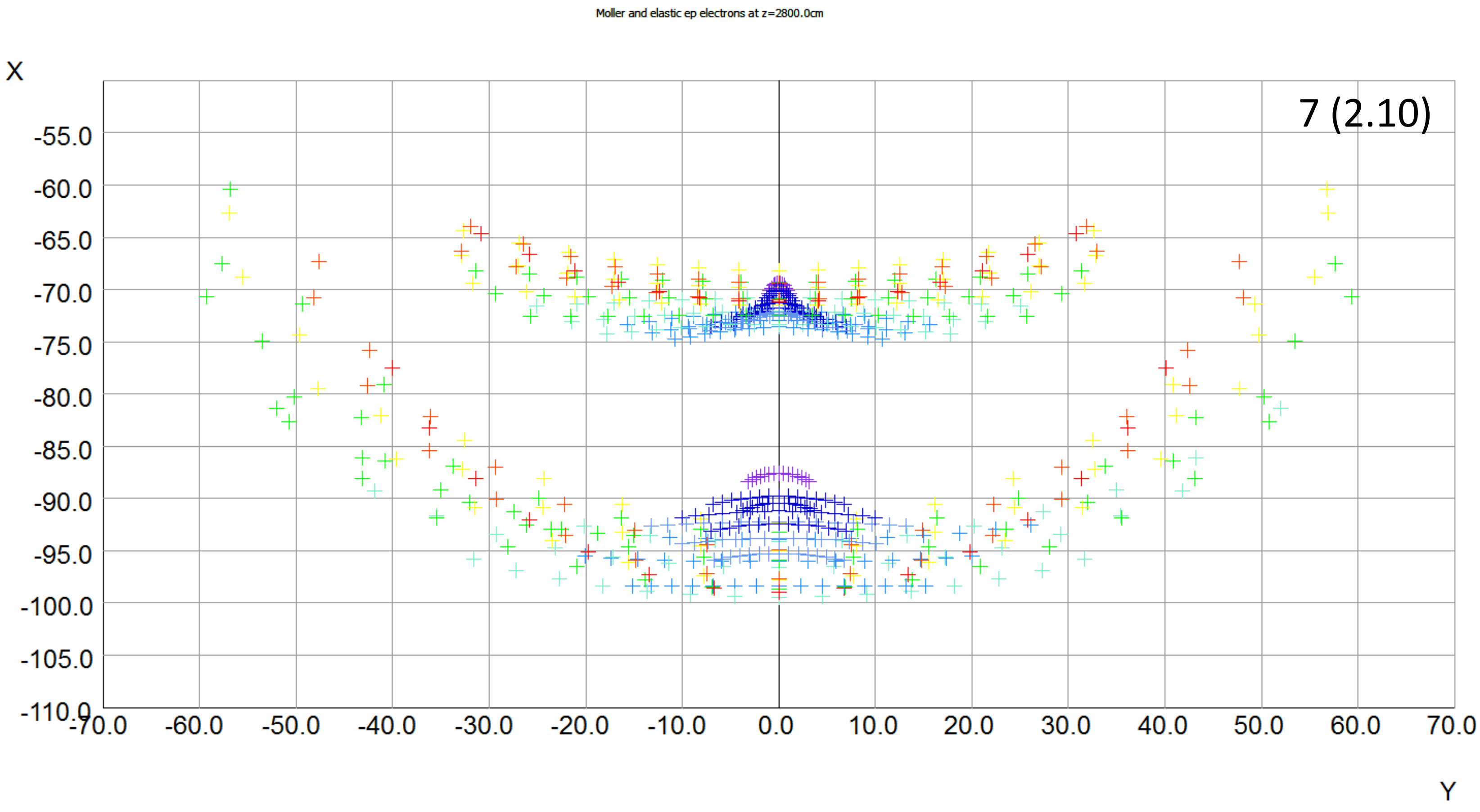
Tweaking the Optics



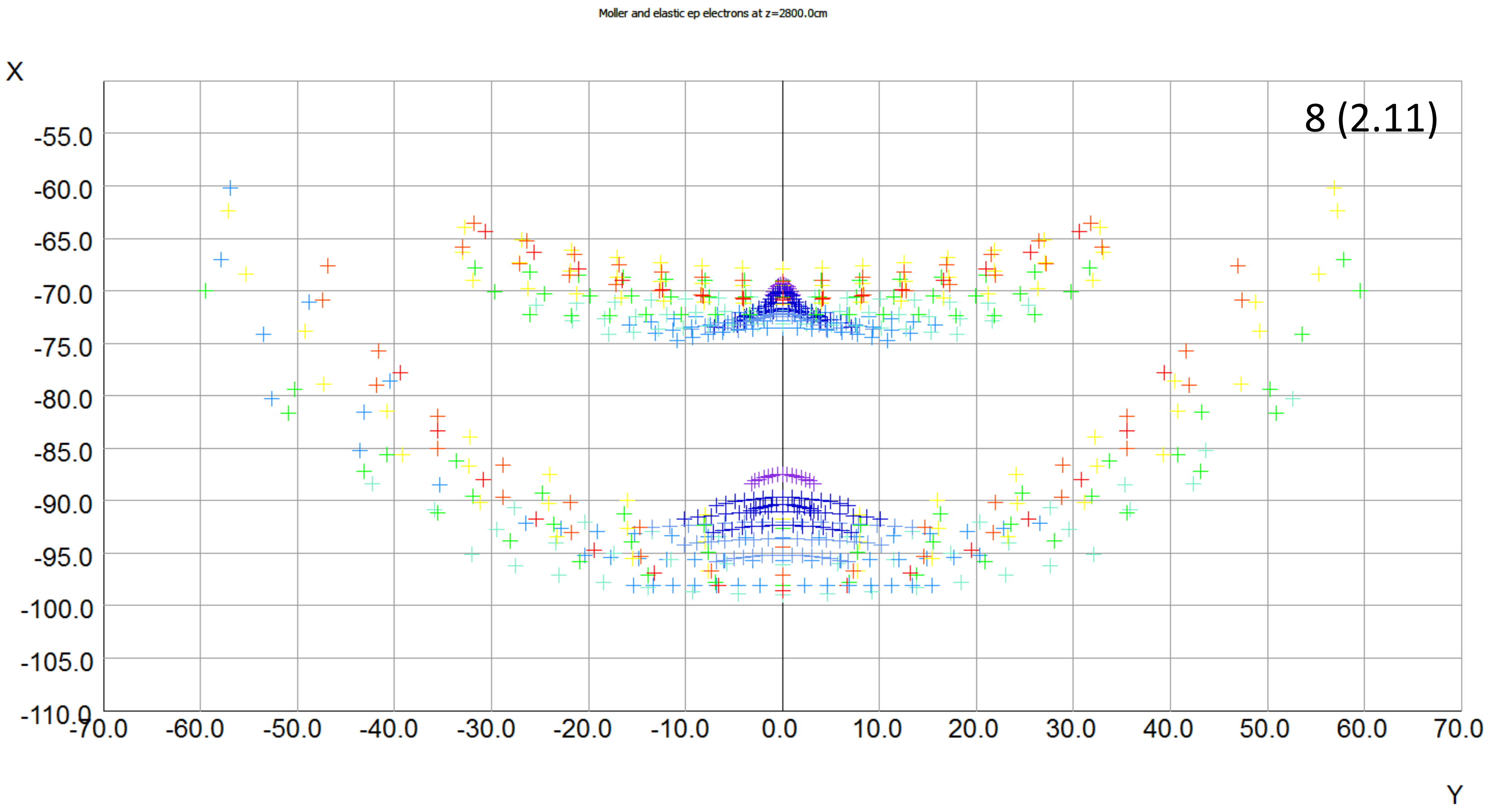
Tweaking the Optics



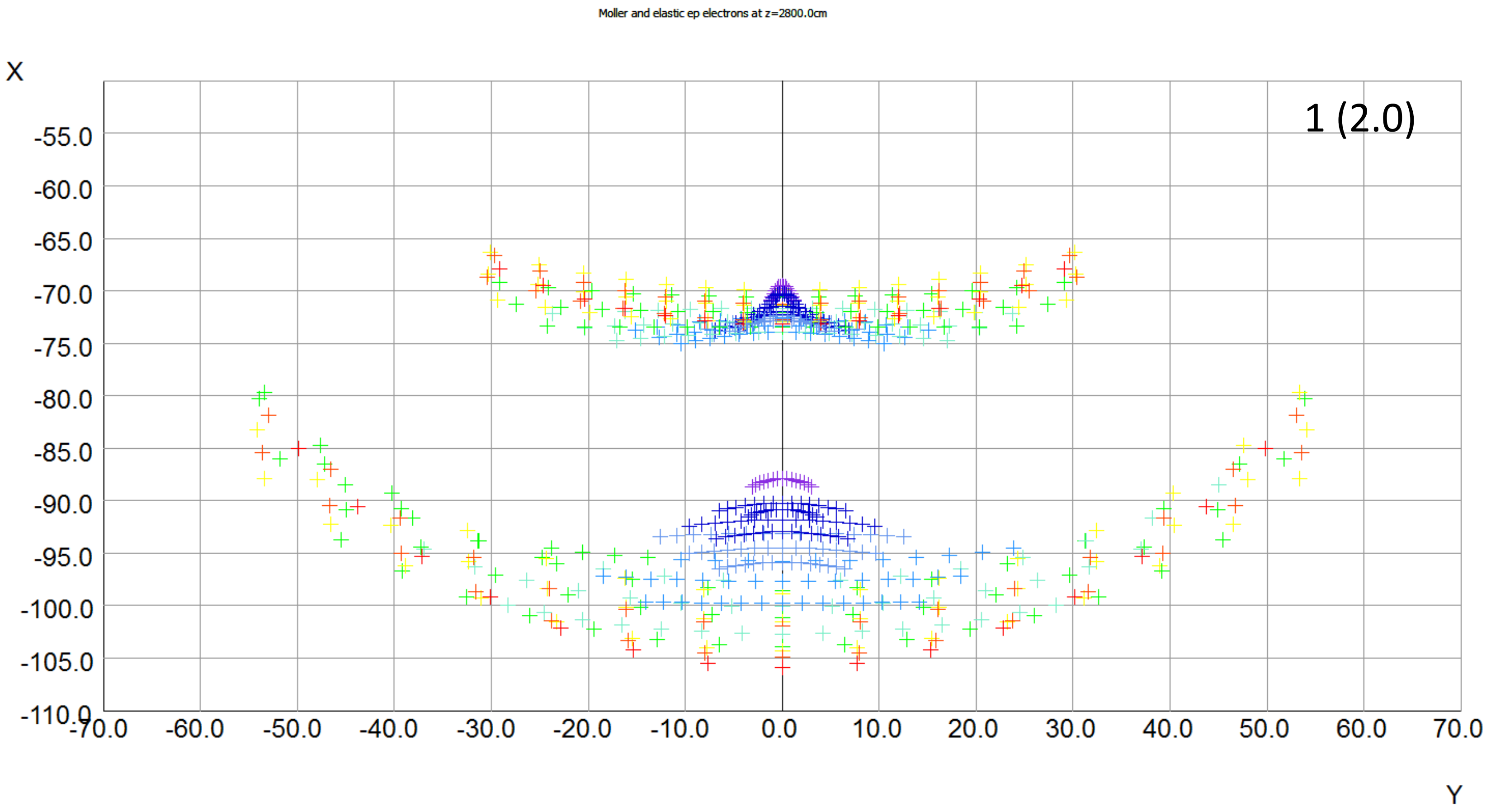
Tweaking the Optics

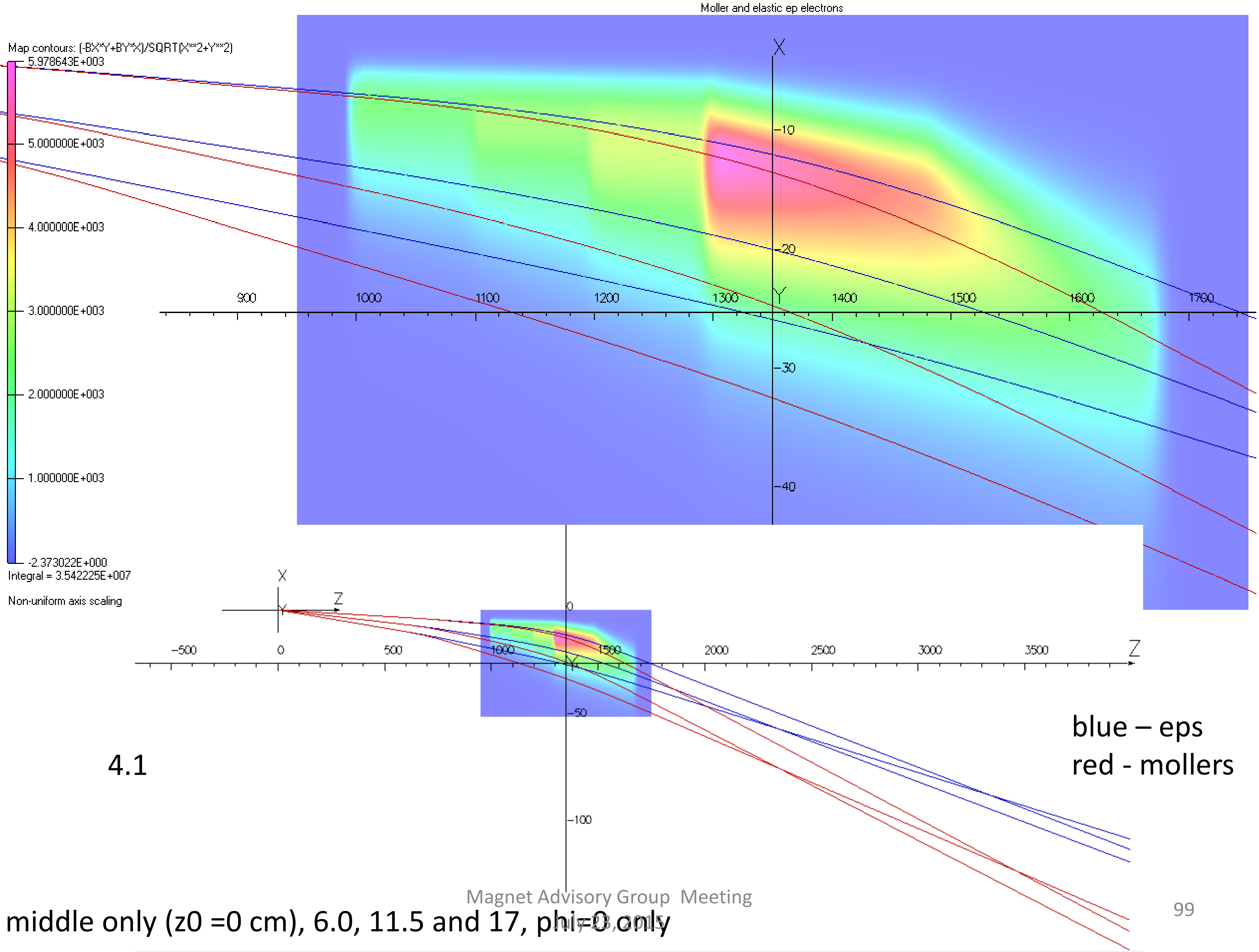


Tweaking the Optics

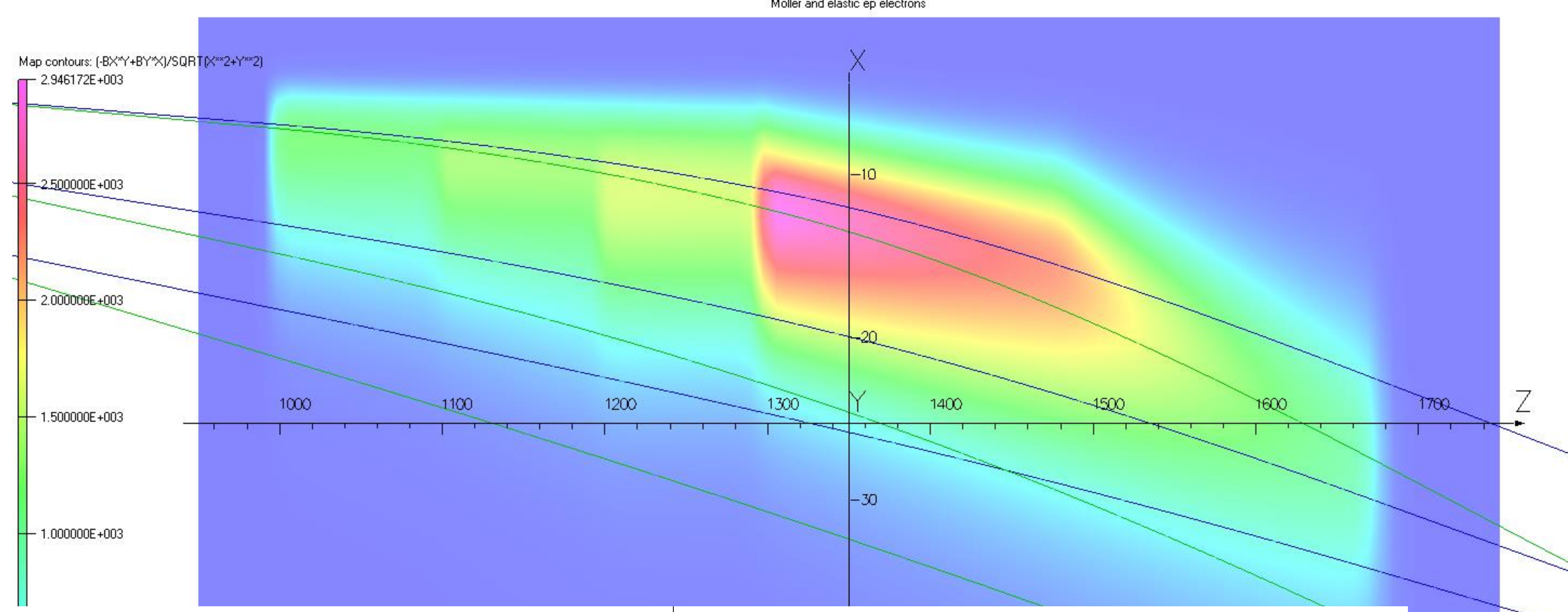


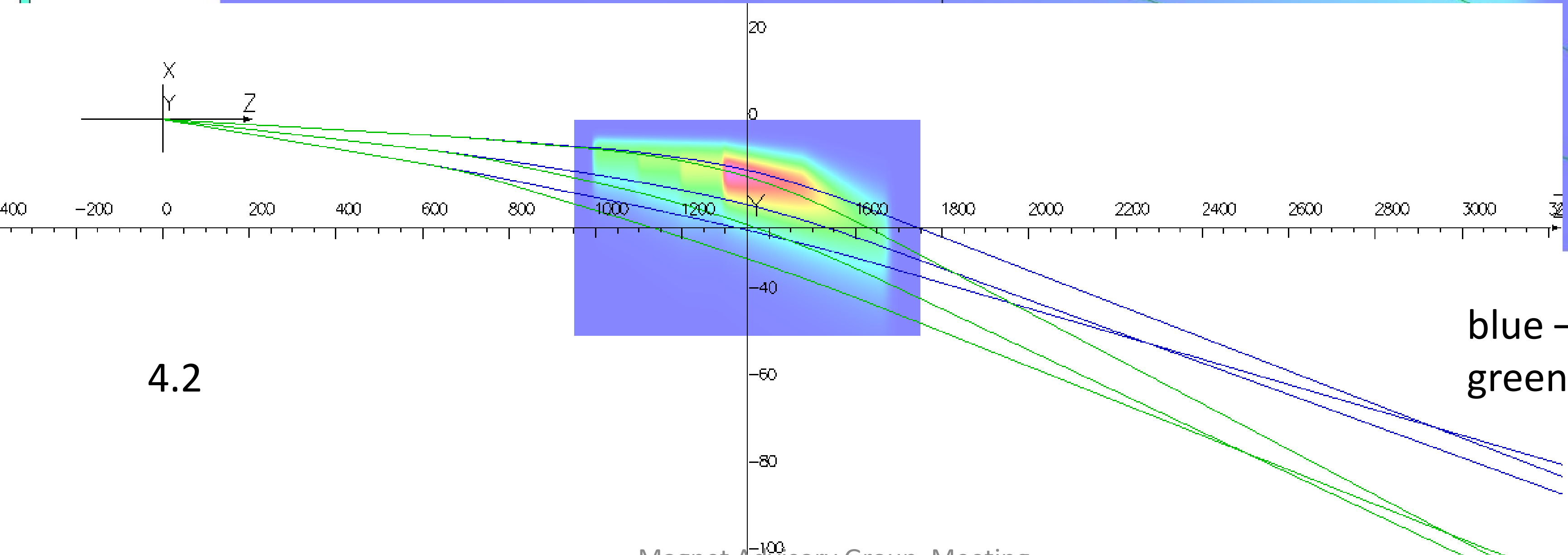
Tweaking the Optics





middle only (z0 =0 cm), 6.0, 11.5 and 17, phi=0 only

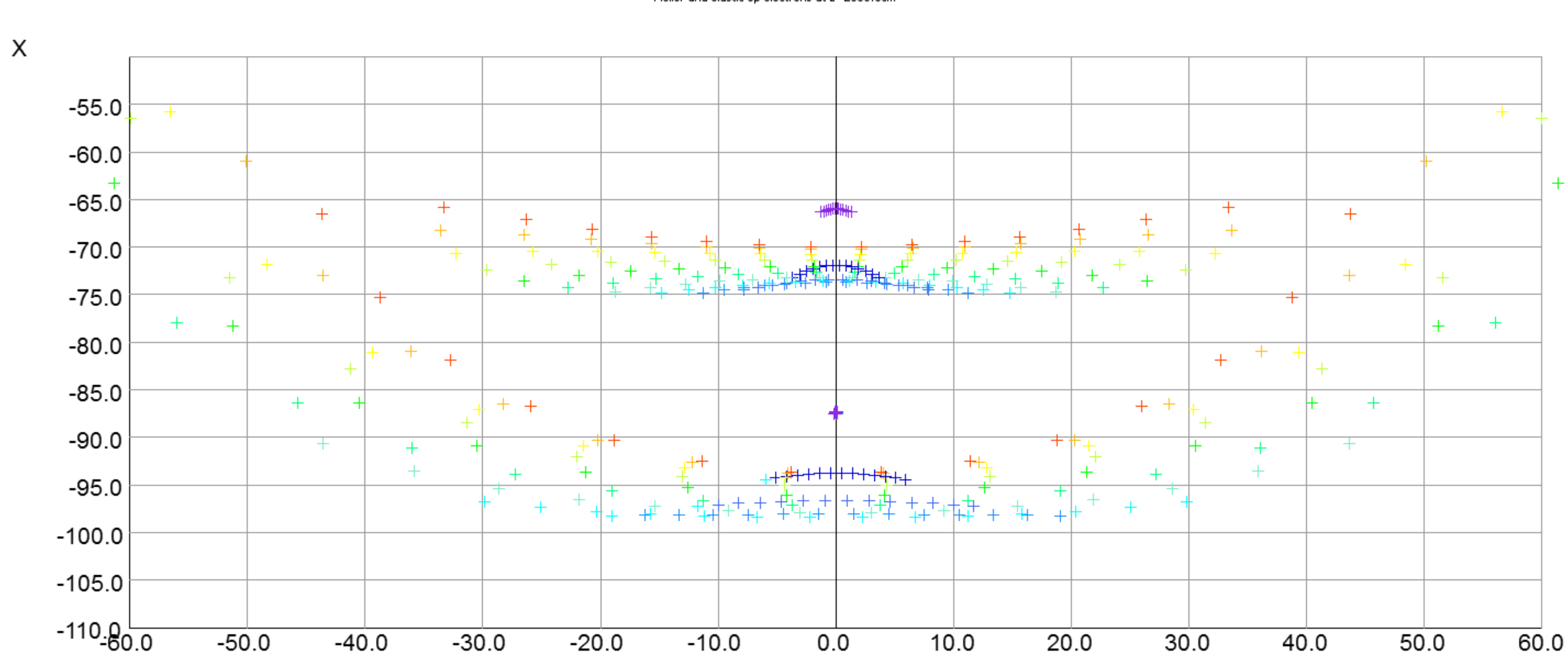




blue – eps
green - mollers

4.2

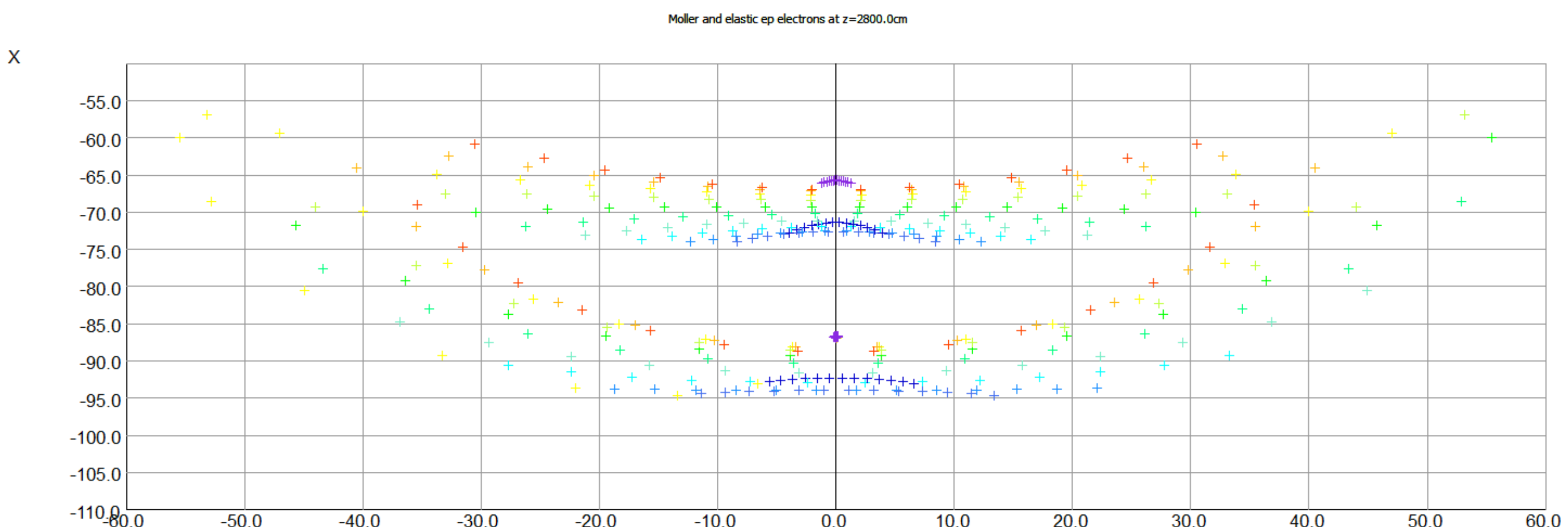
middle only (z0 =0 cm), 6.0, 11.5 and 17, phi=0 only



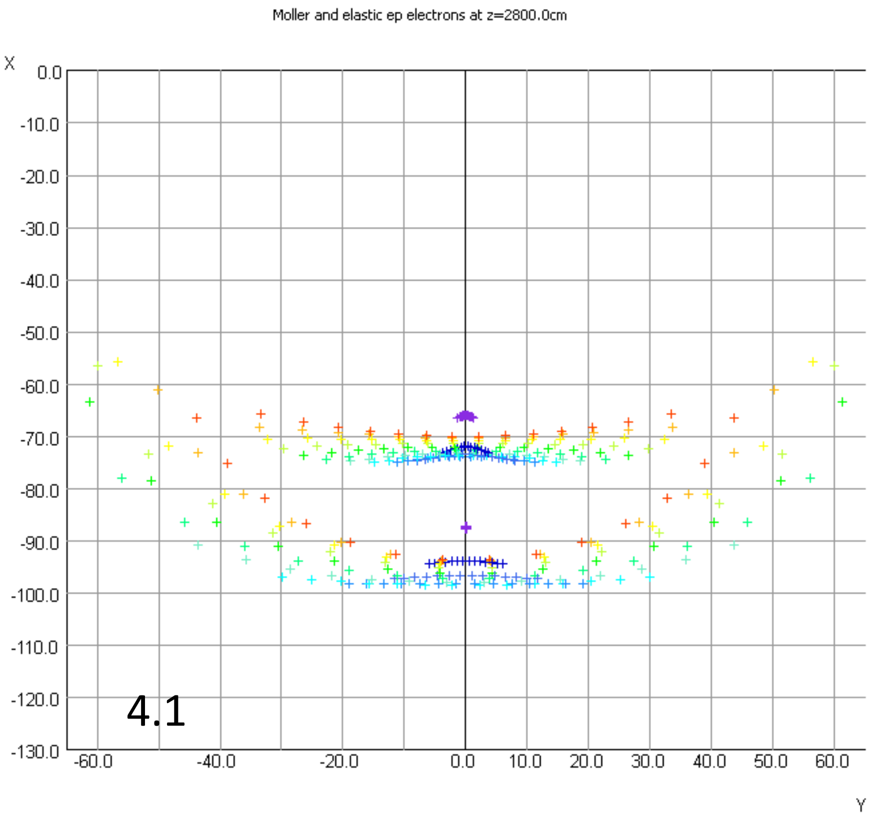
4.1

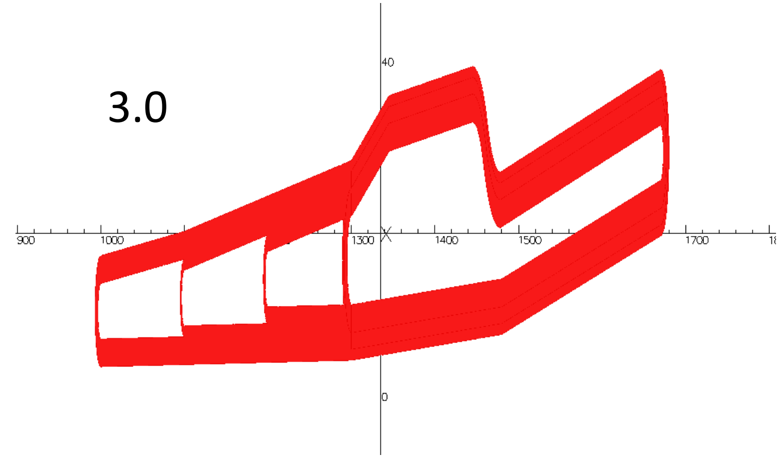
middle (z0 =0 cm)   6.0 to 17 mrads

Tracks colored by theta from purple to red (low to high)



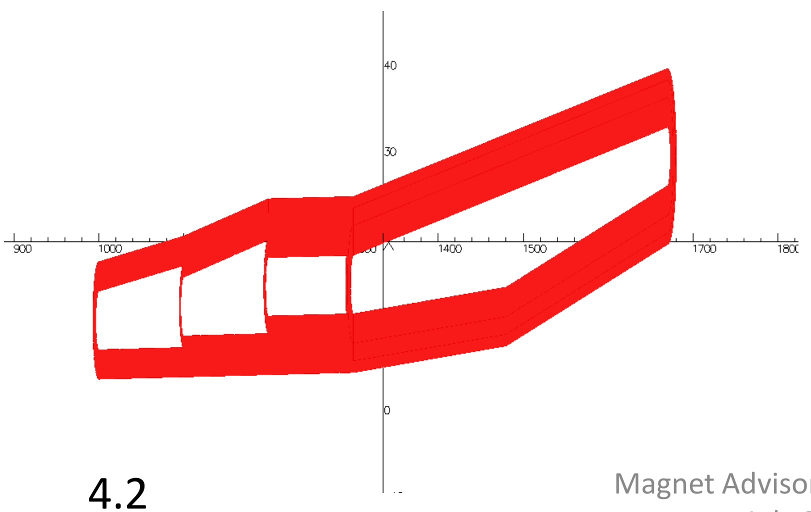
4.2

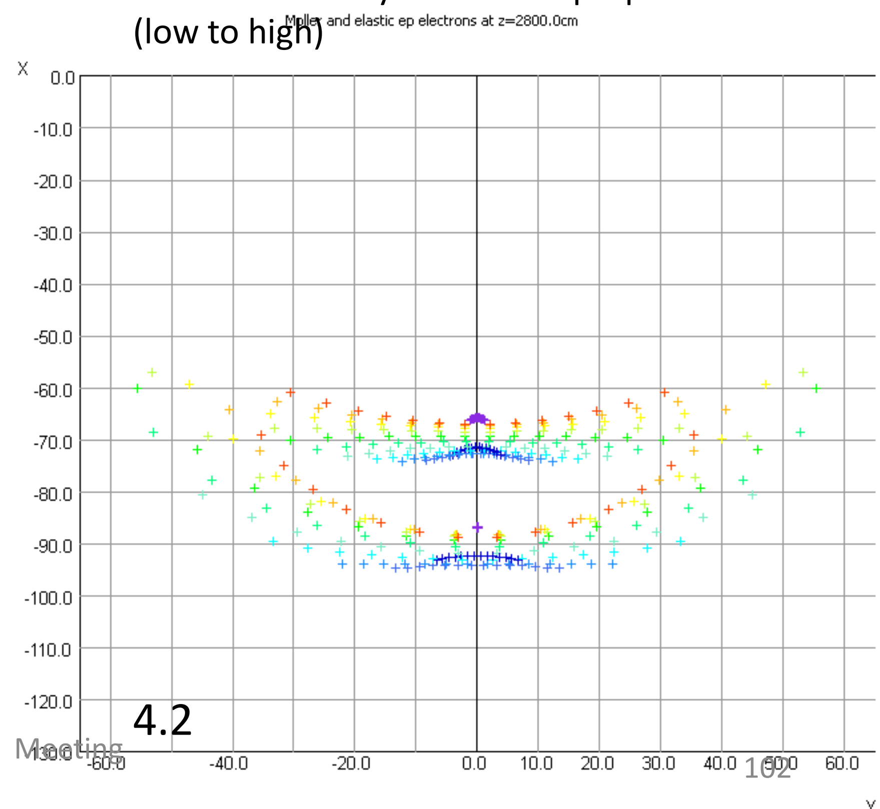


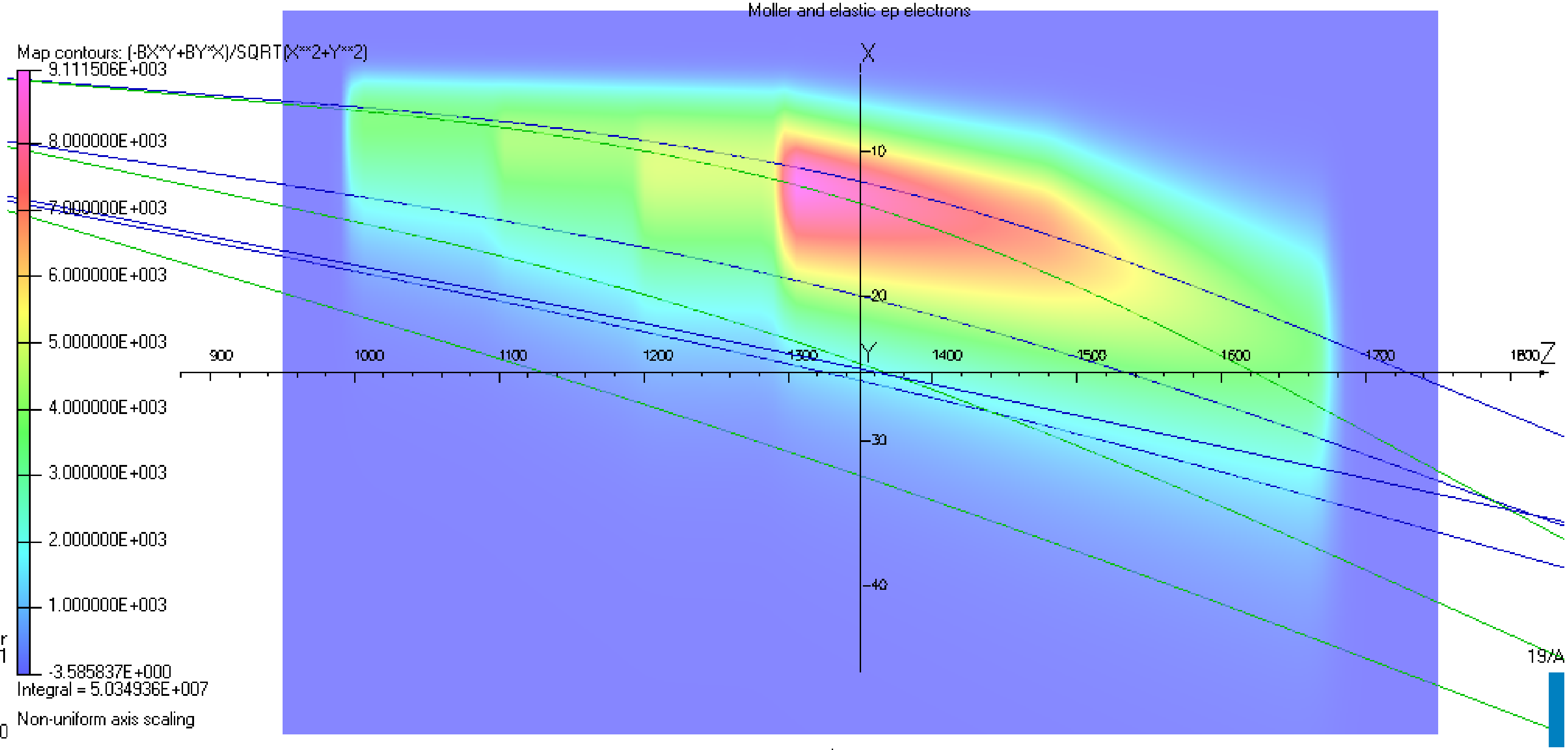


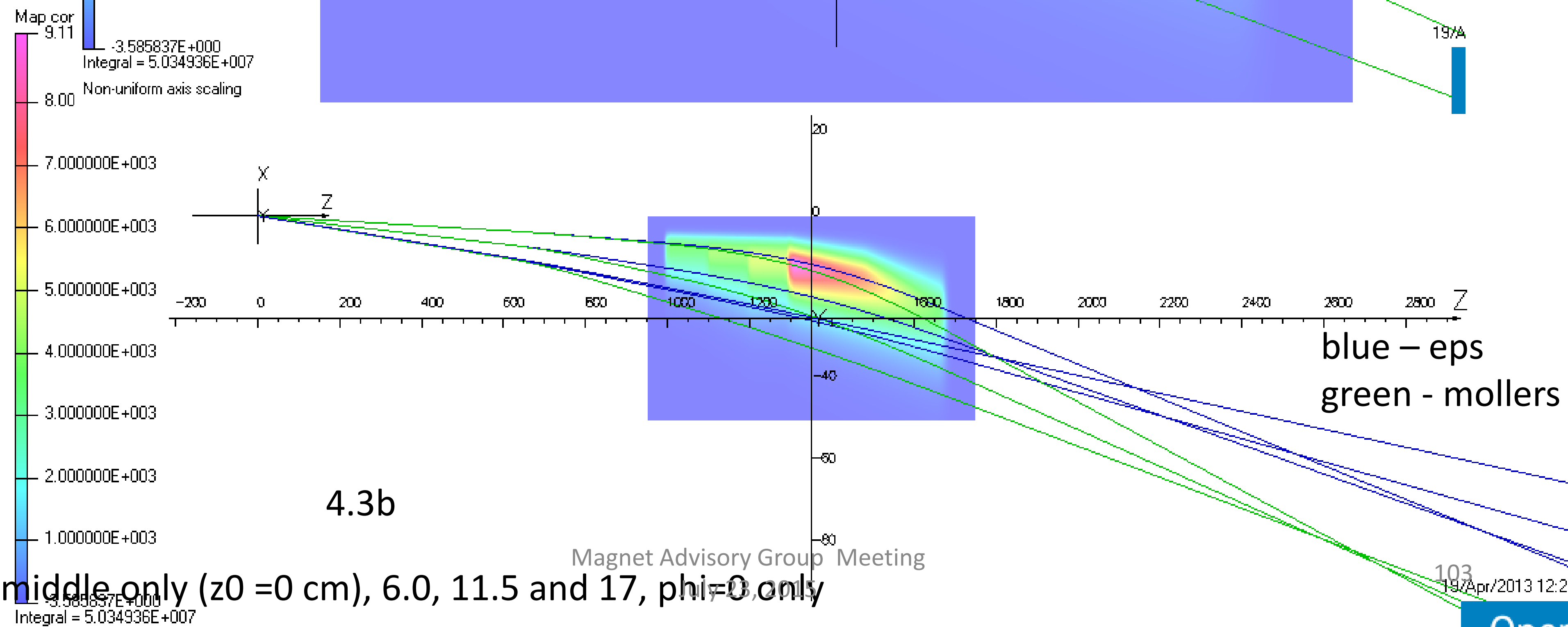
middle (z0 =0 cm)   6.0 to 17 mrads

Tracks colored by theta from purple to red (low to high)





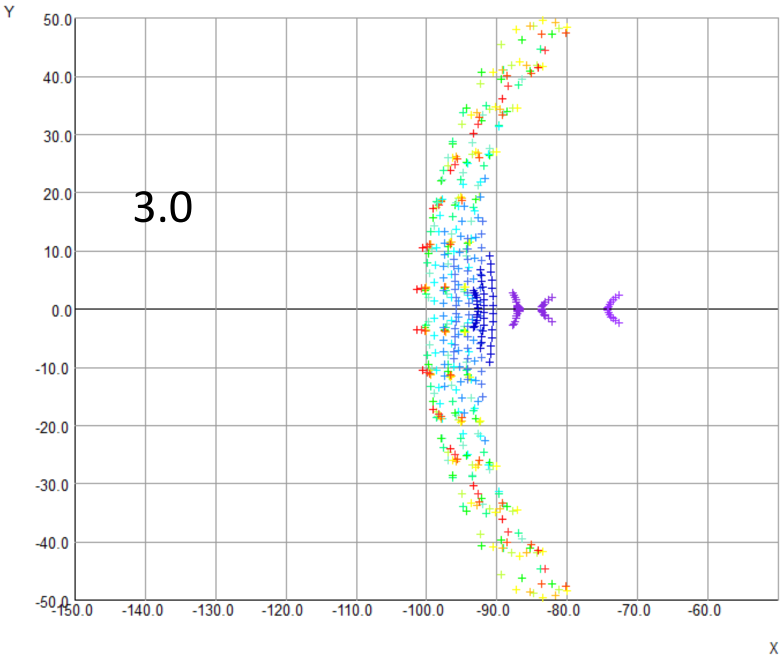


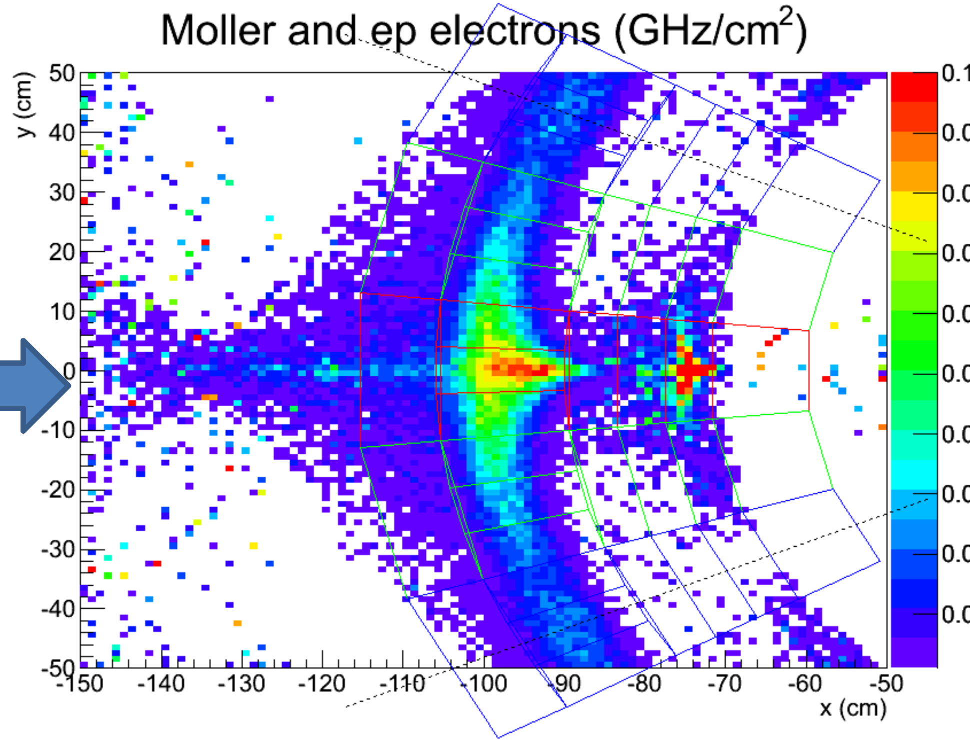


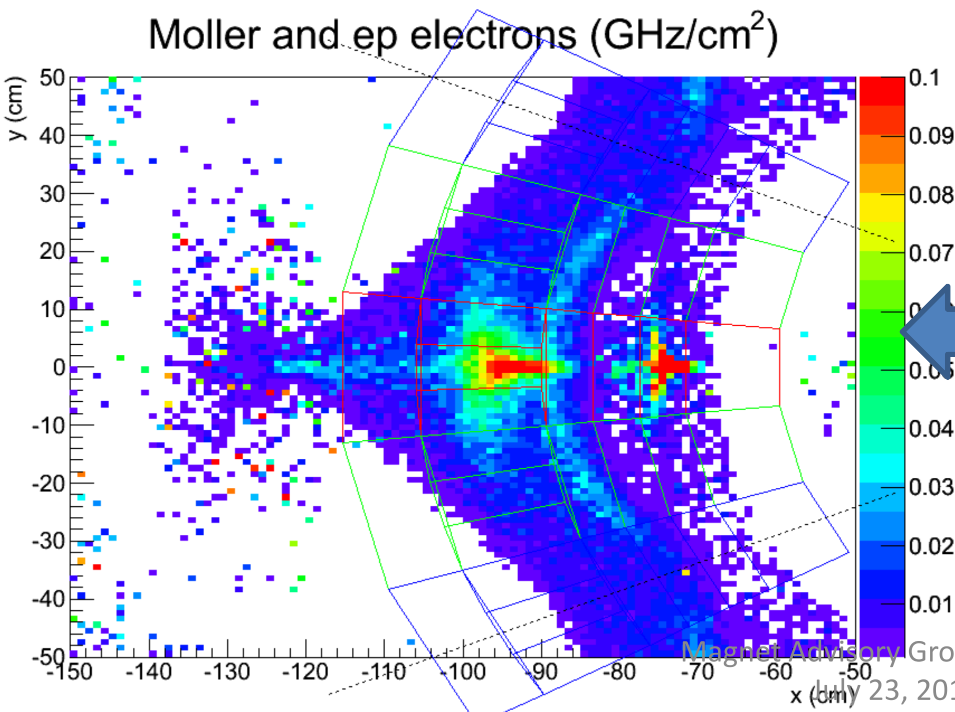
blue – eps
green - mollers

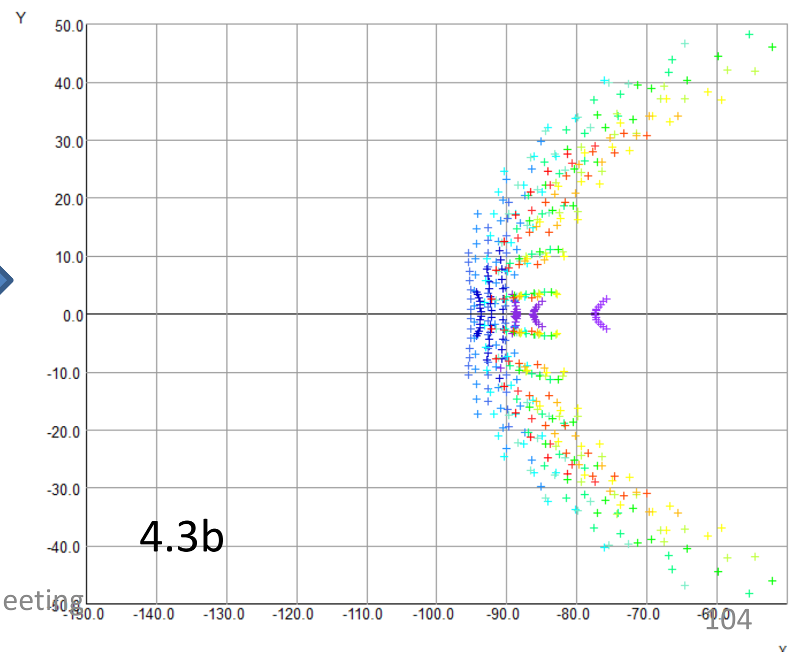
4.3b

middle only (z0 =0 cm), 6.0, 11.5 and 17, phi=0 only


3.0
Y
X


Moller and ep electrons (GHz/cm^2)
y (cm)
x (cm)


Moller and ep electrons (GHz/cm^2)
y (cm)
x (cm)

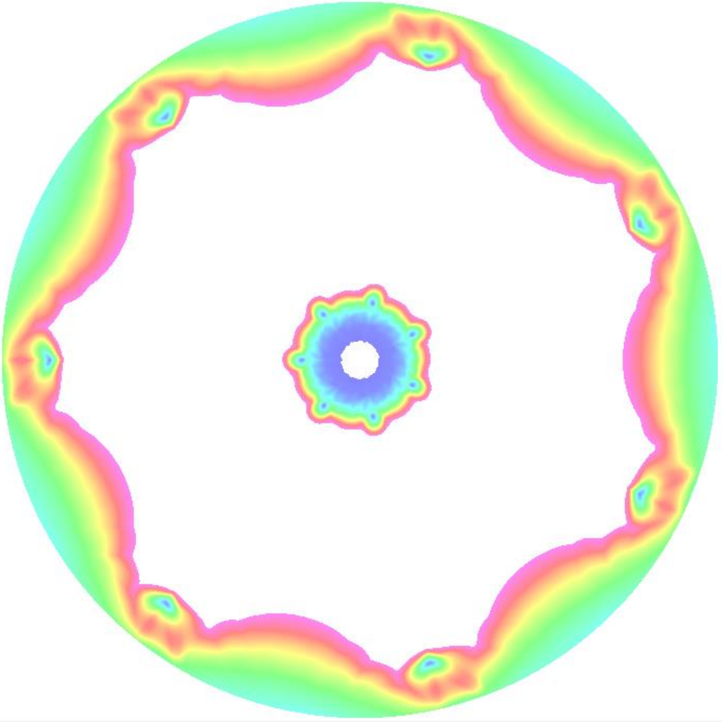

4.3b
Y
X

Outline

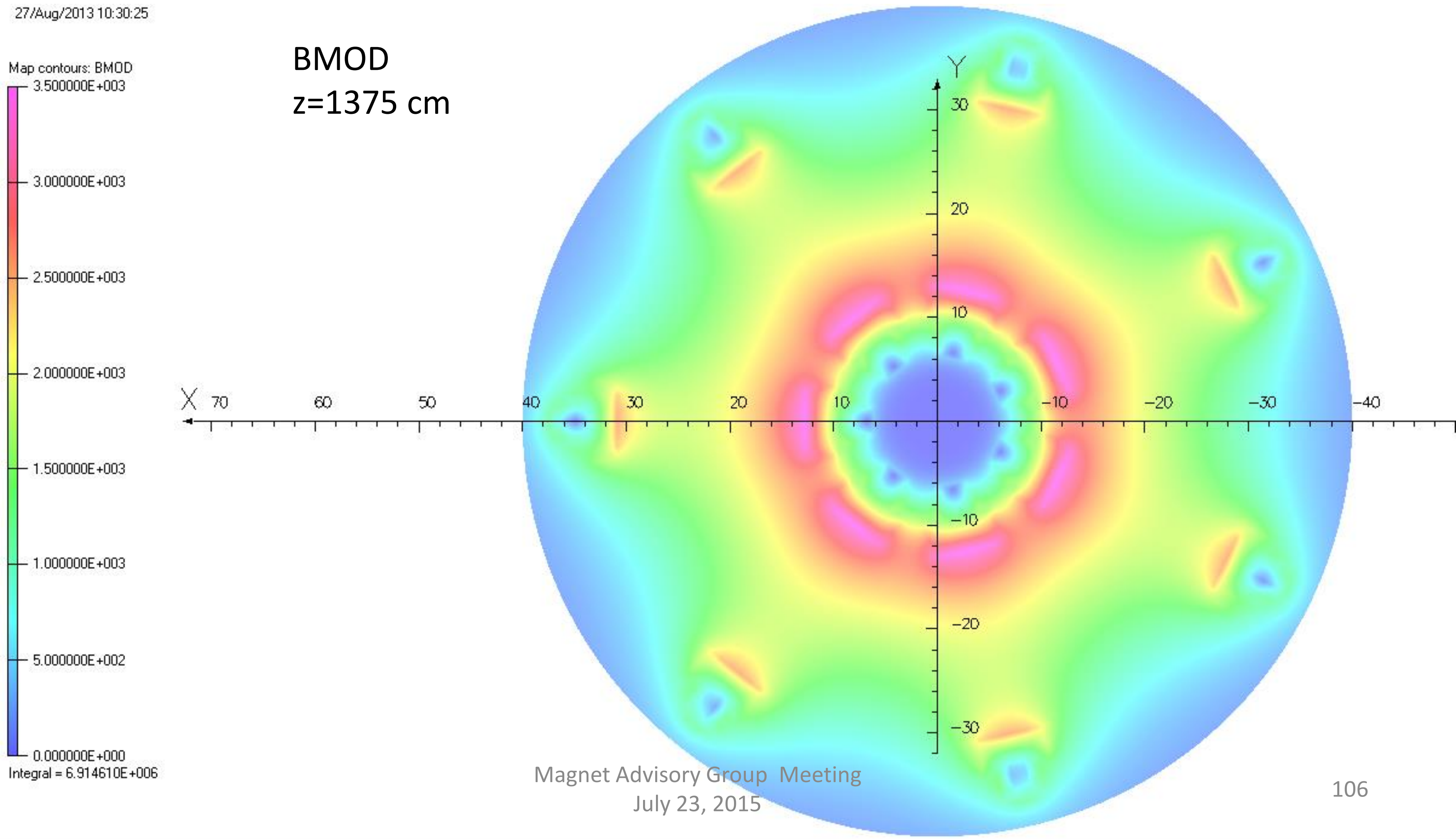
- Meshed with no iron for comparison
- Used Willy's conceptual design for iron pieces
  - Not optimized in any way
  - Used thin and thick pieces
- Compared fields (BMOD and BR)
- Compared tracks for no iron and thick iron

Note: op3 file names are:

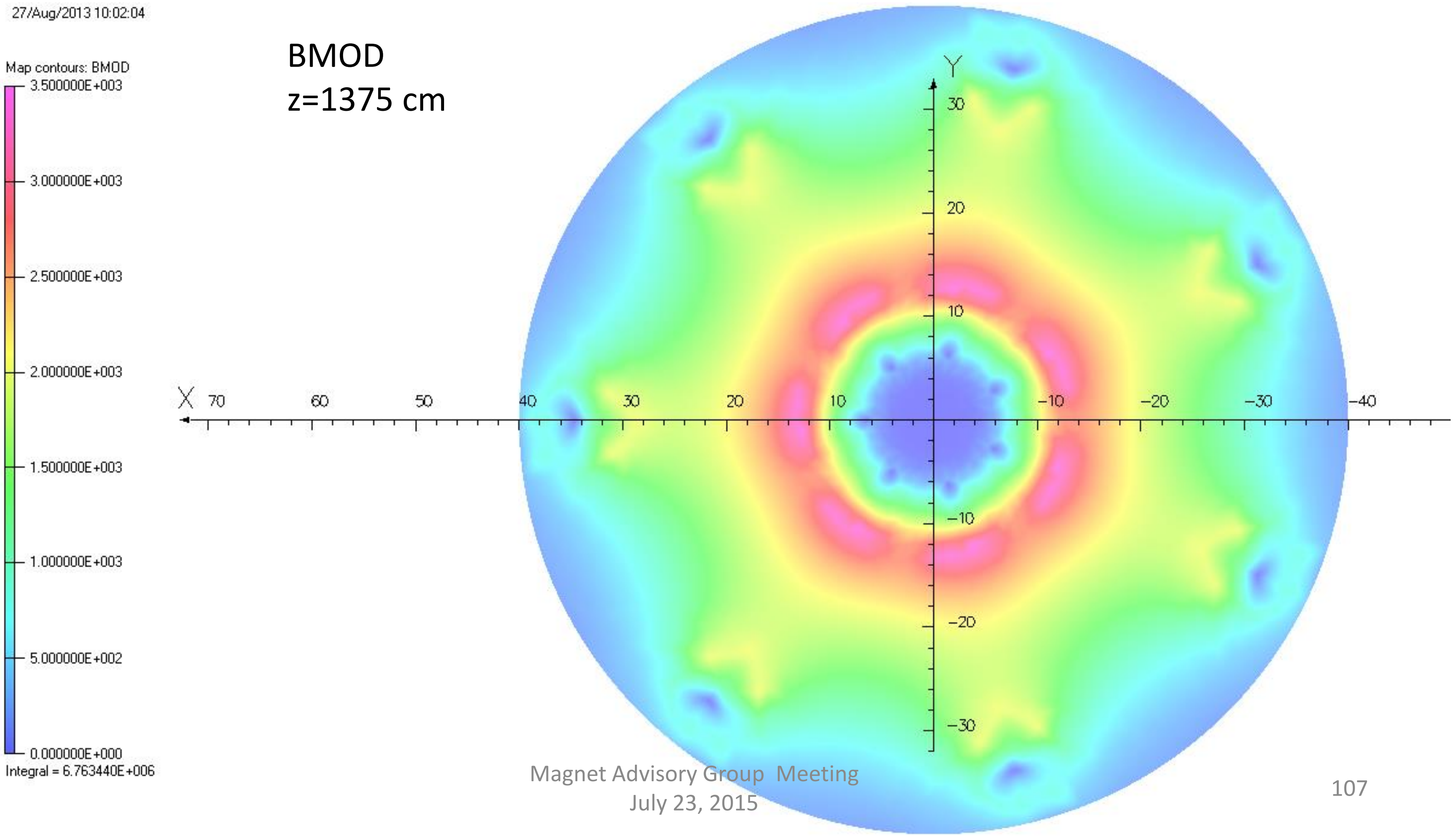
no_iron_in_coils_test_ver2.op3 (smaller mesh size)
iron_in_coils_ver3.op3 (thin)
iron_in_coils_ver4.op3 (thick)



No iron, coils only



No iron w/ mesh



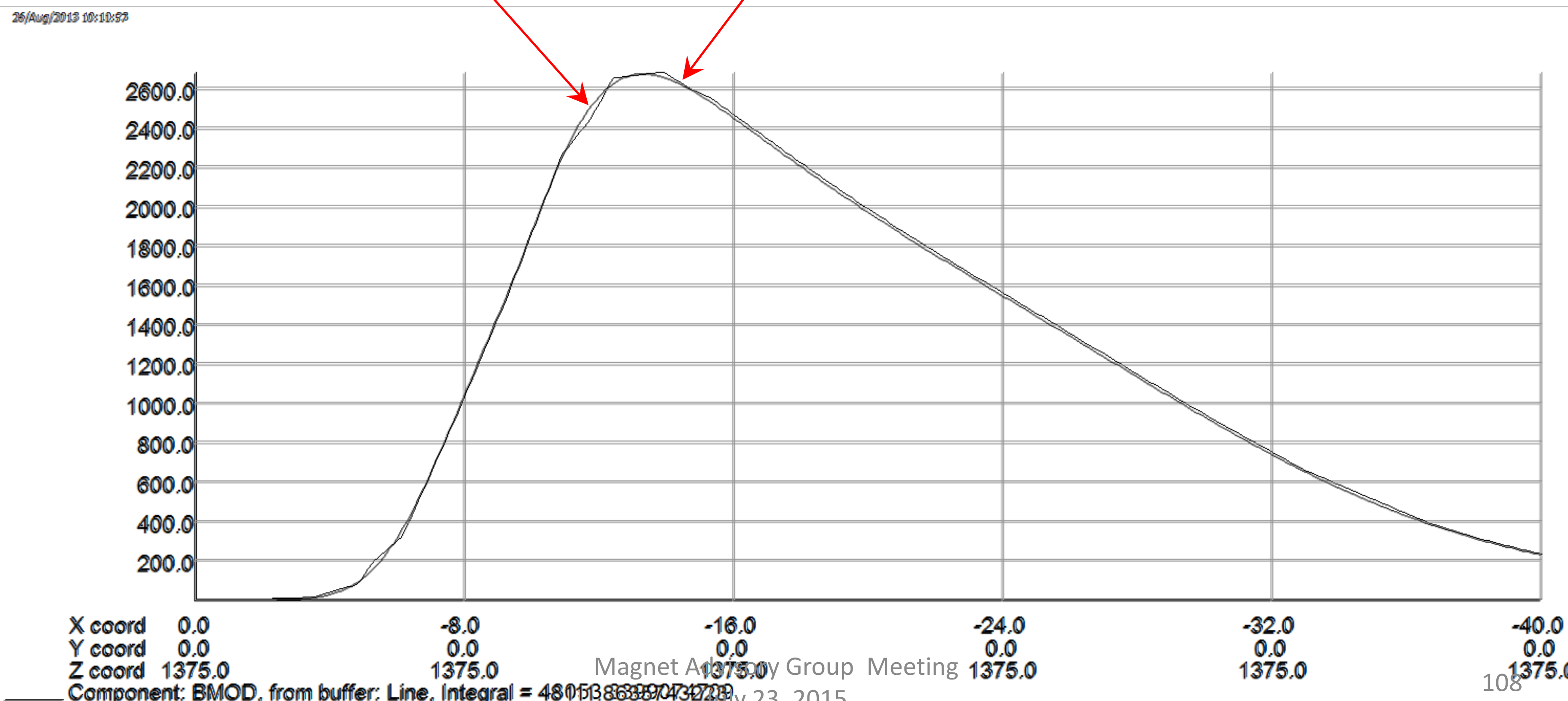
Field on a line, middle of open sector

BMOD
z=1375 cm, y= 0 cm , 0 < x < -40 cm

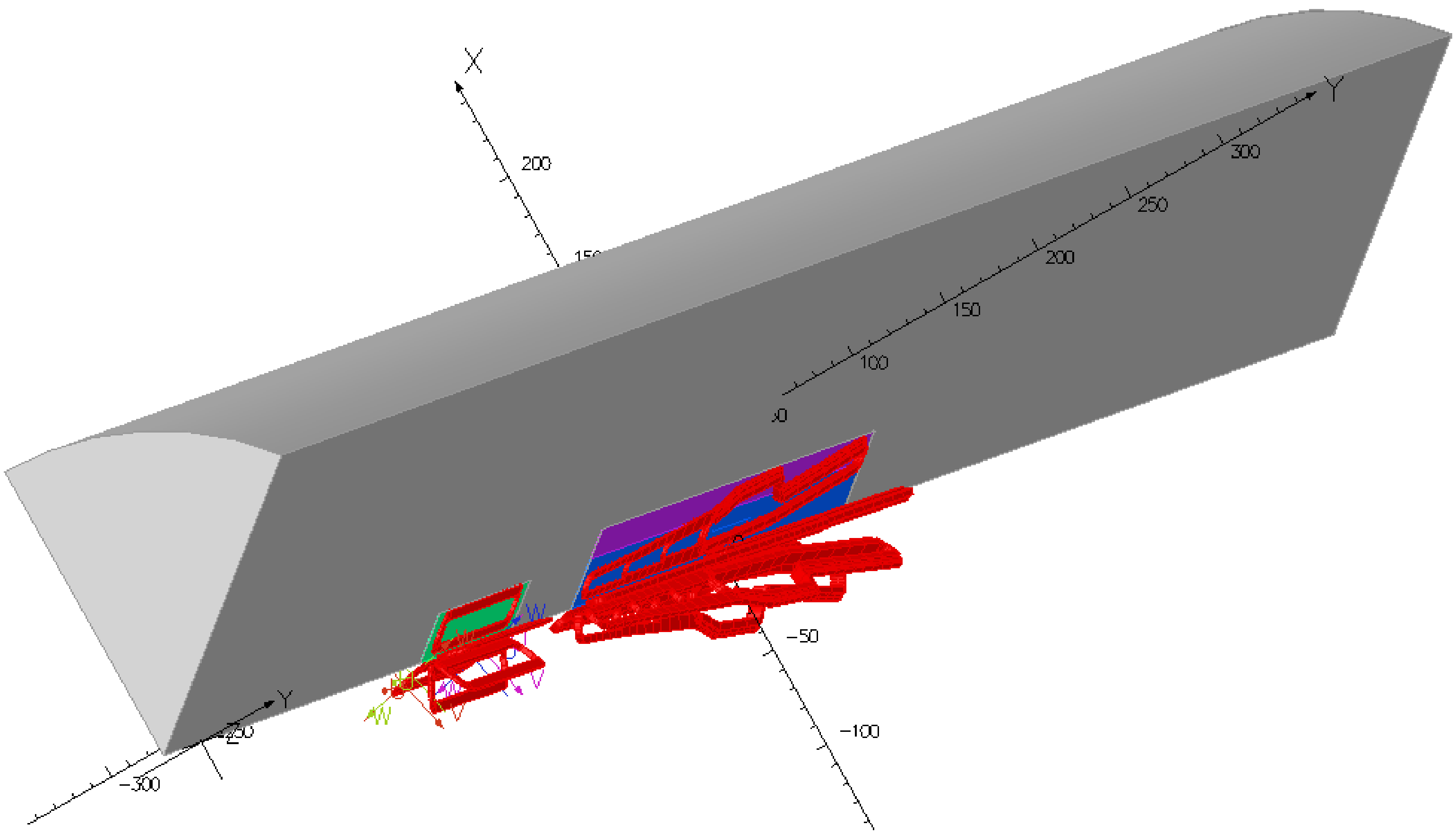
BMOD

With coils only

With mesh

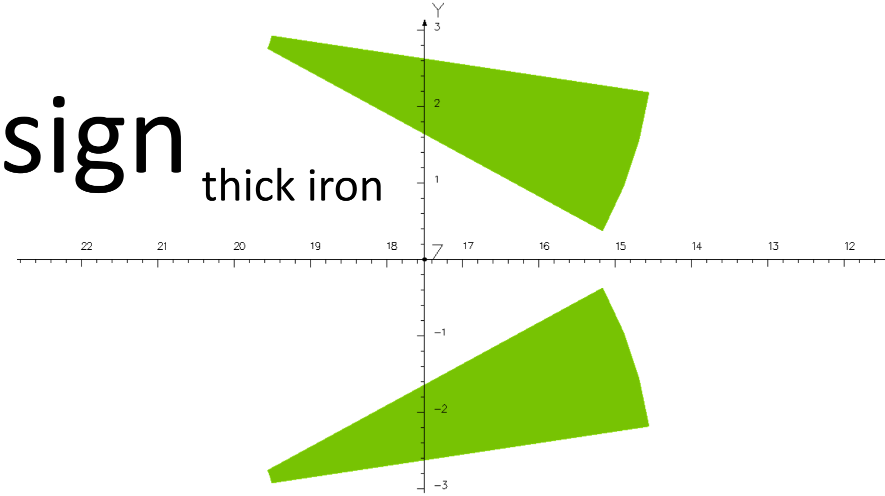


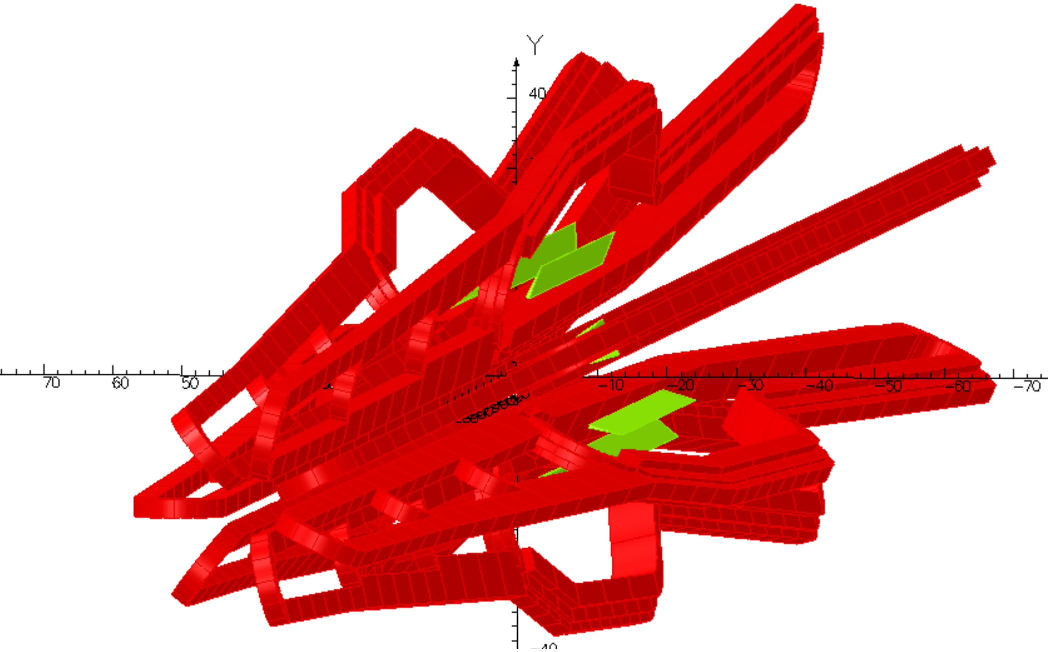
Model body in mesh



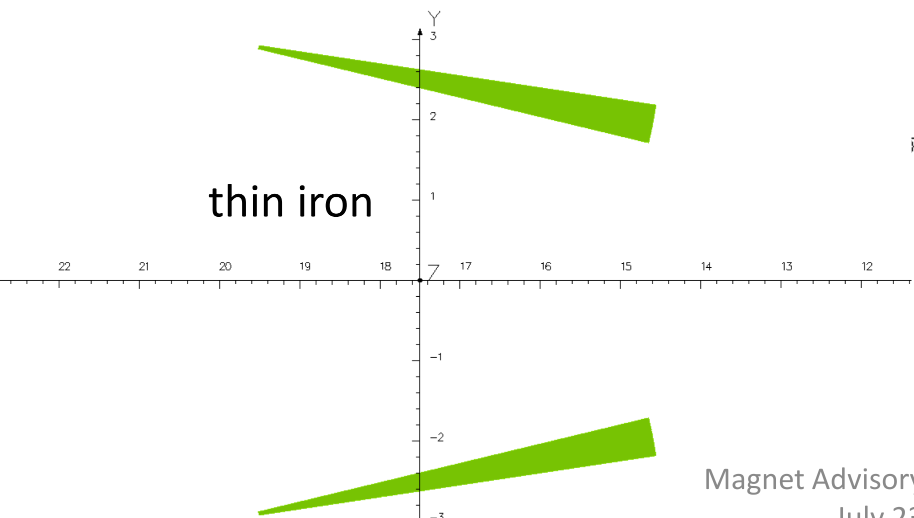
Iron design

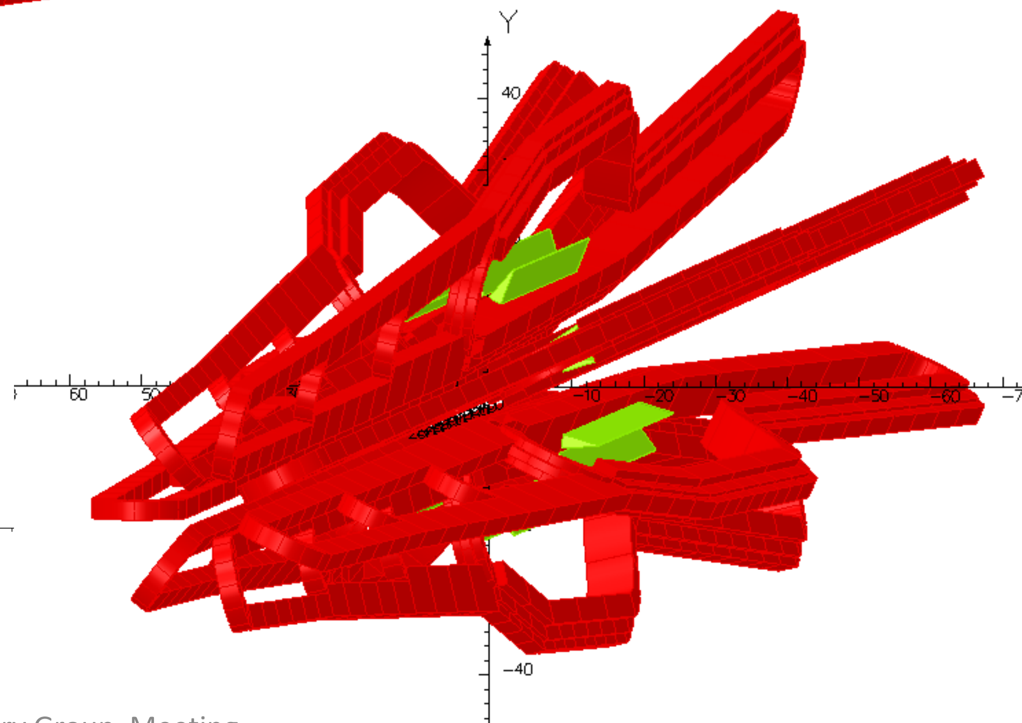
thick iron





thin iron

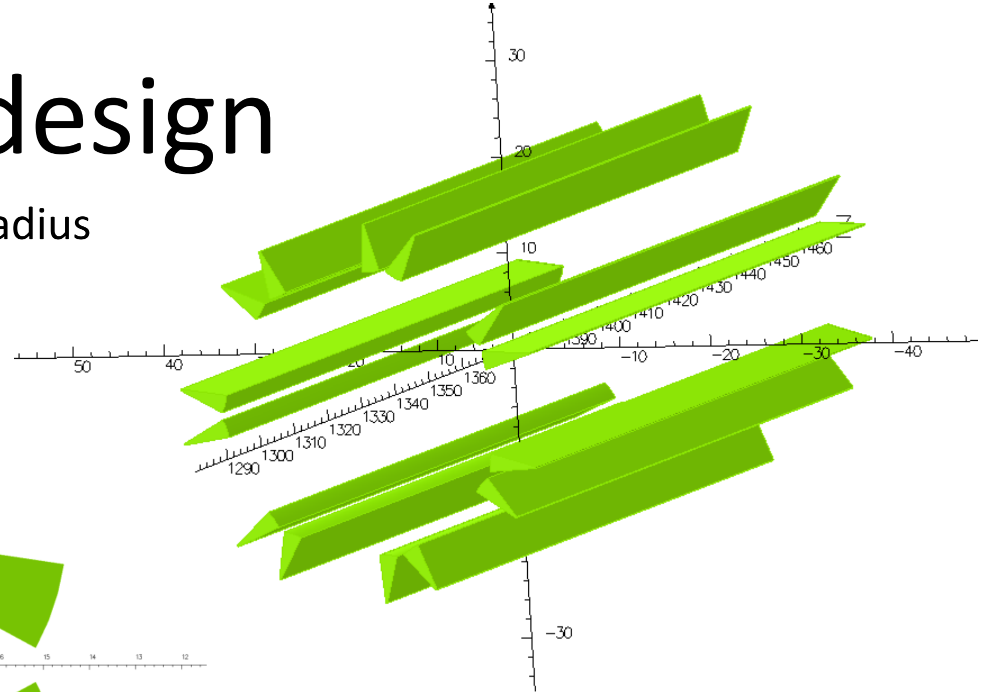


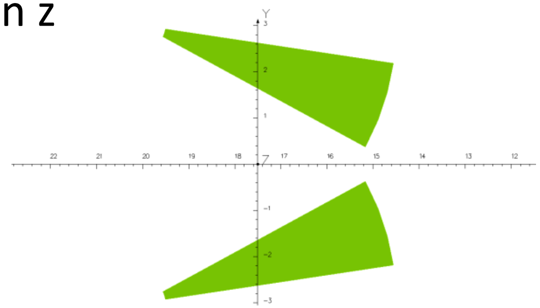


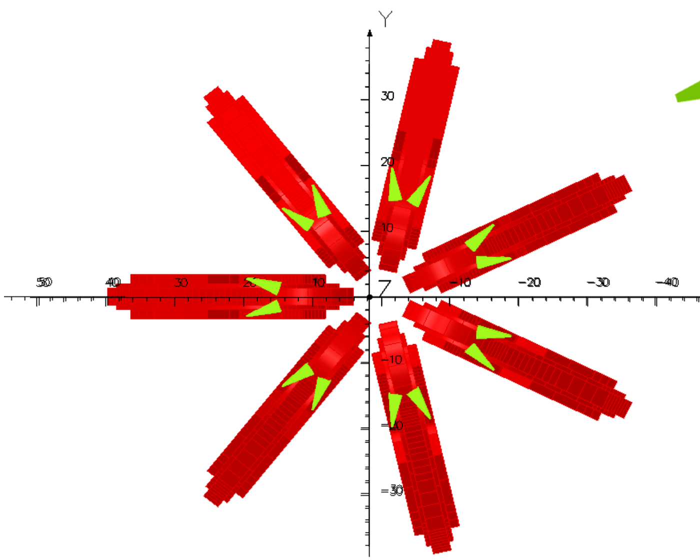
Iron design

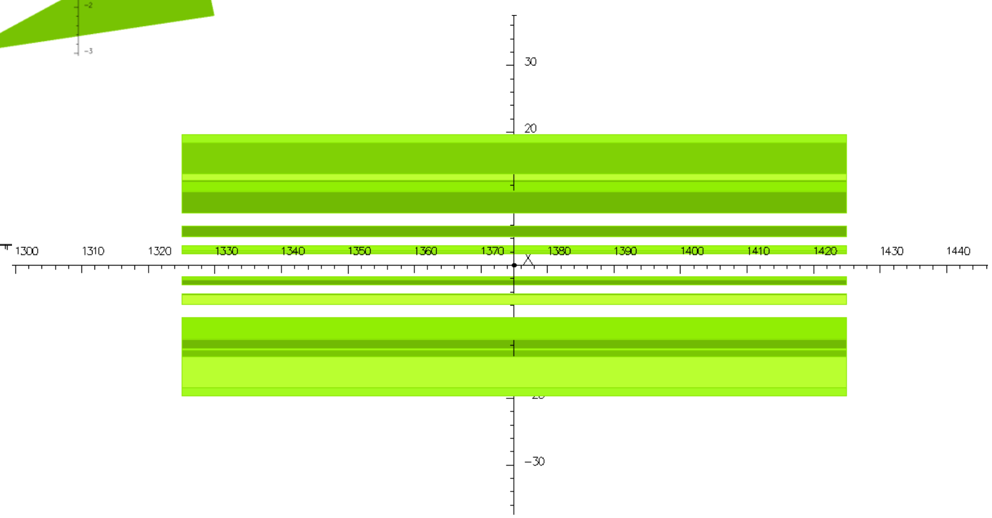
1 m long, section of tube from 0.5 to 5.5 cm radius
Opening angle, thin: 5 degrees
Opening angle, thick: 20 degrees

Placed radially from 5 – 20 cm
between 1325 and 1425 cm in z

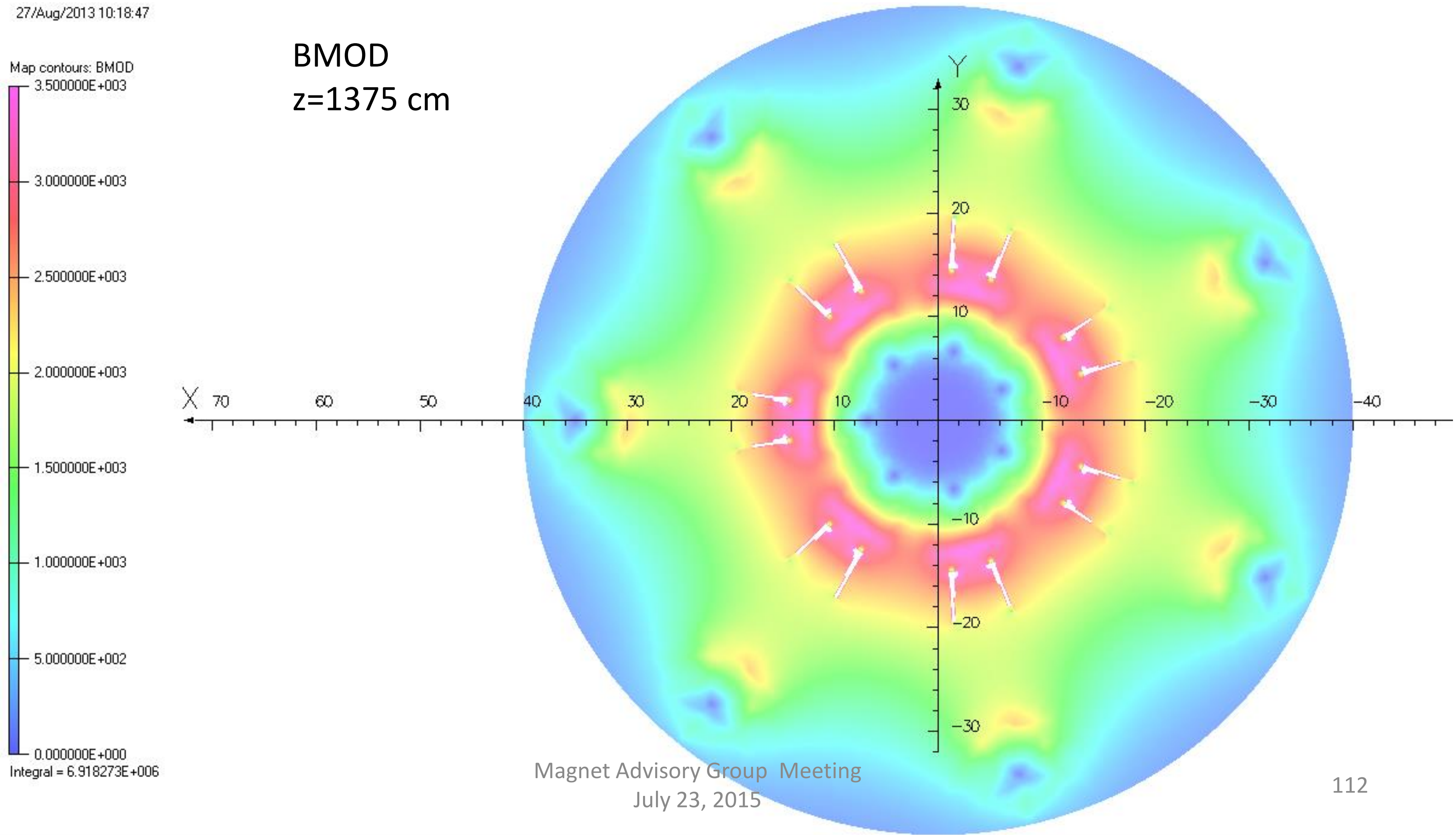




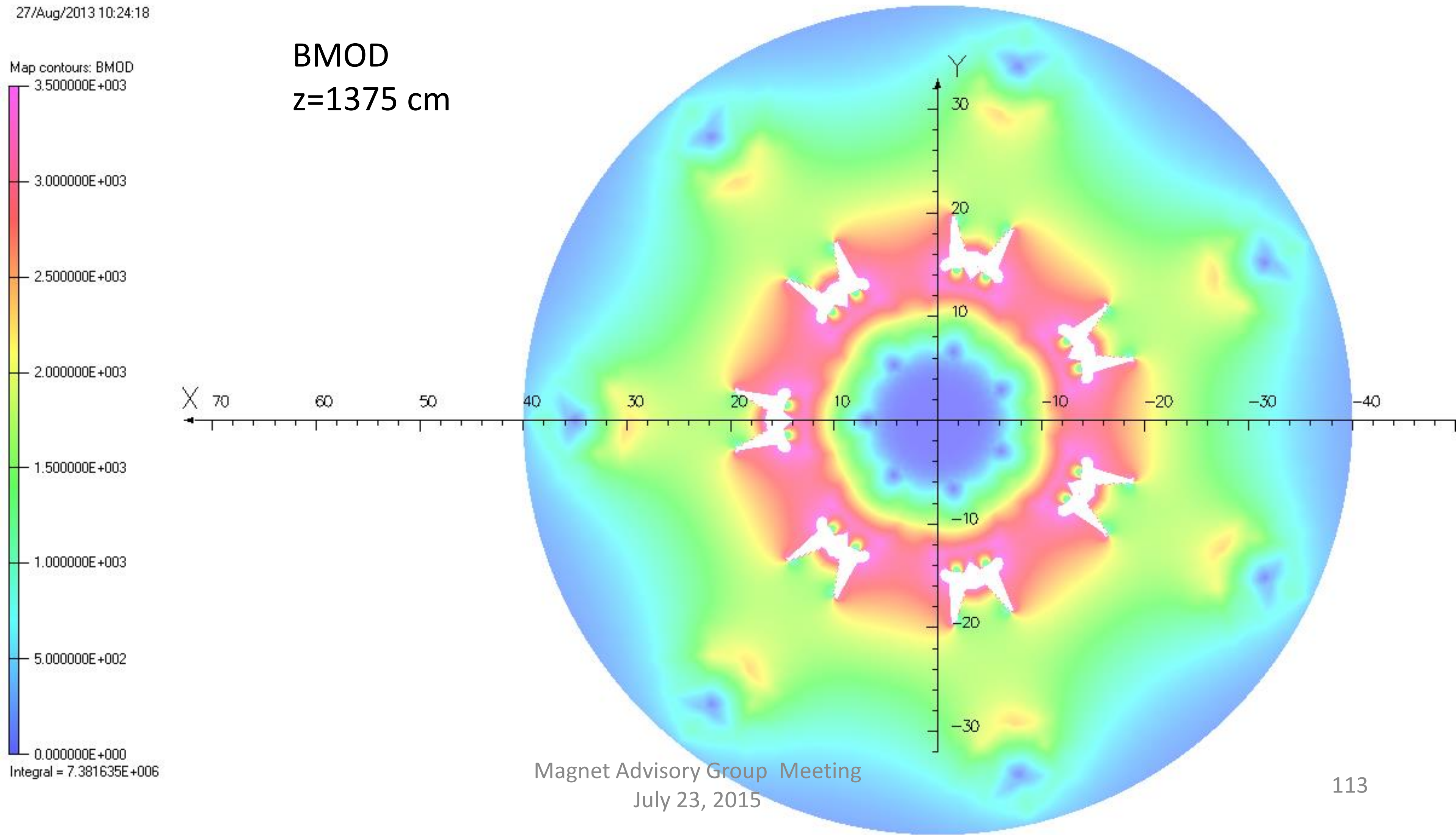




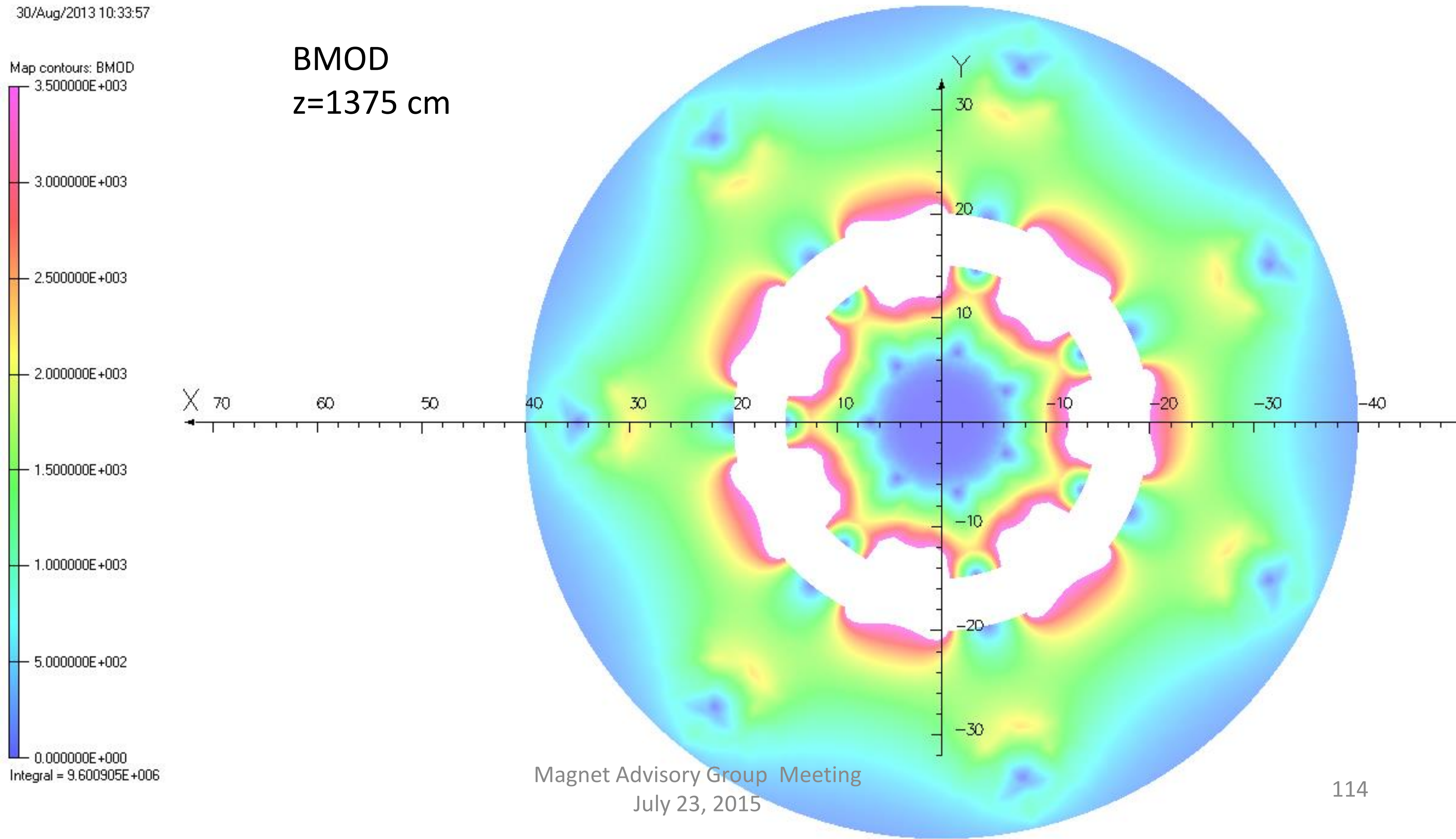
Thin Iron w/ mesh



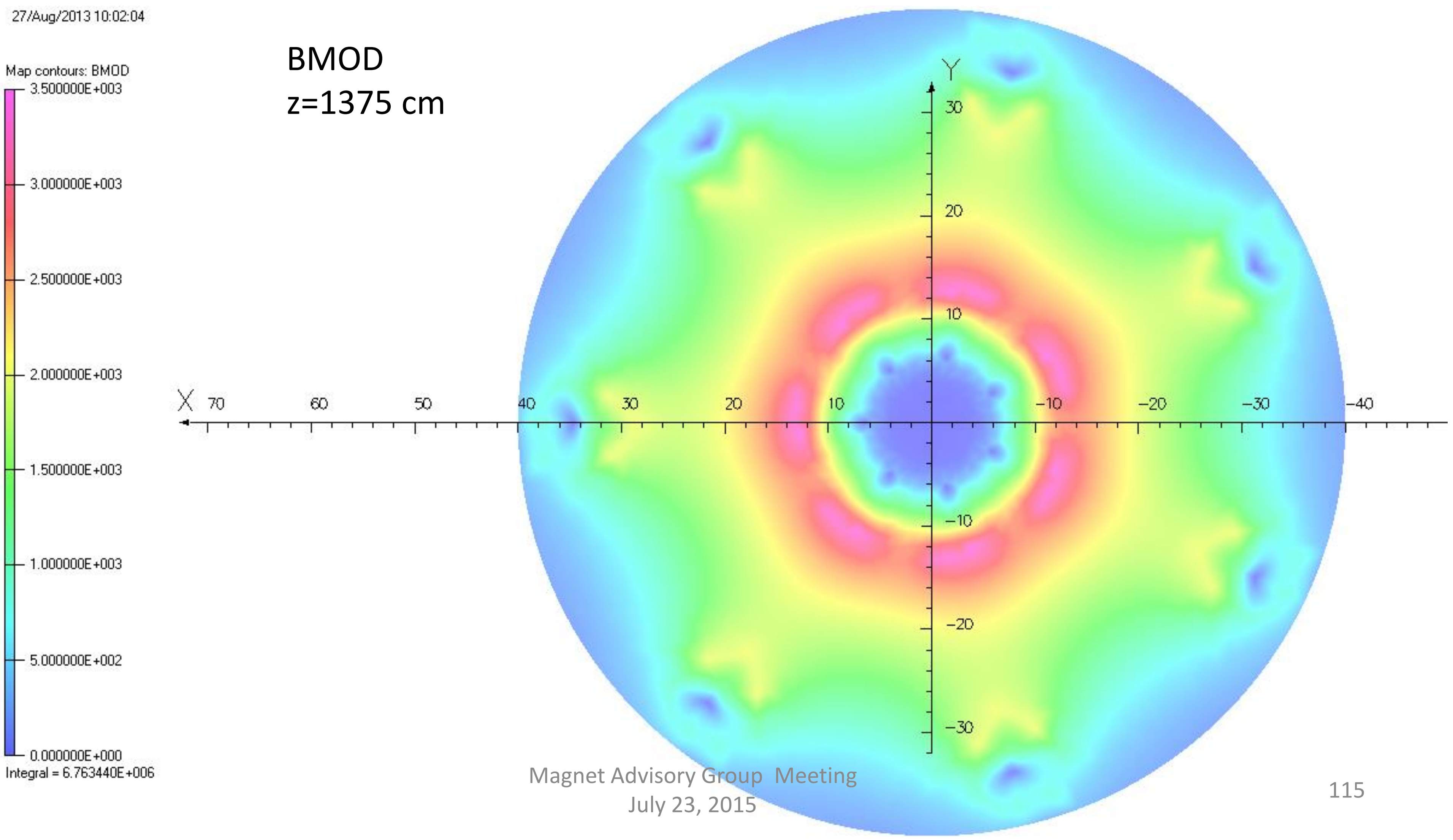
Thick Iron w/ mesh



Giant blocks of iron

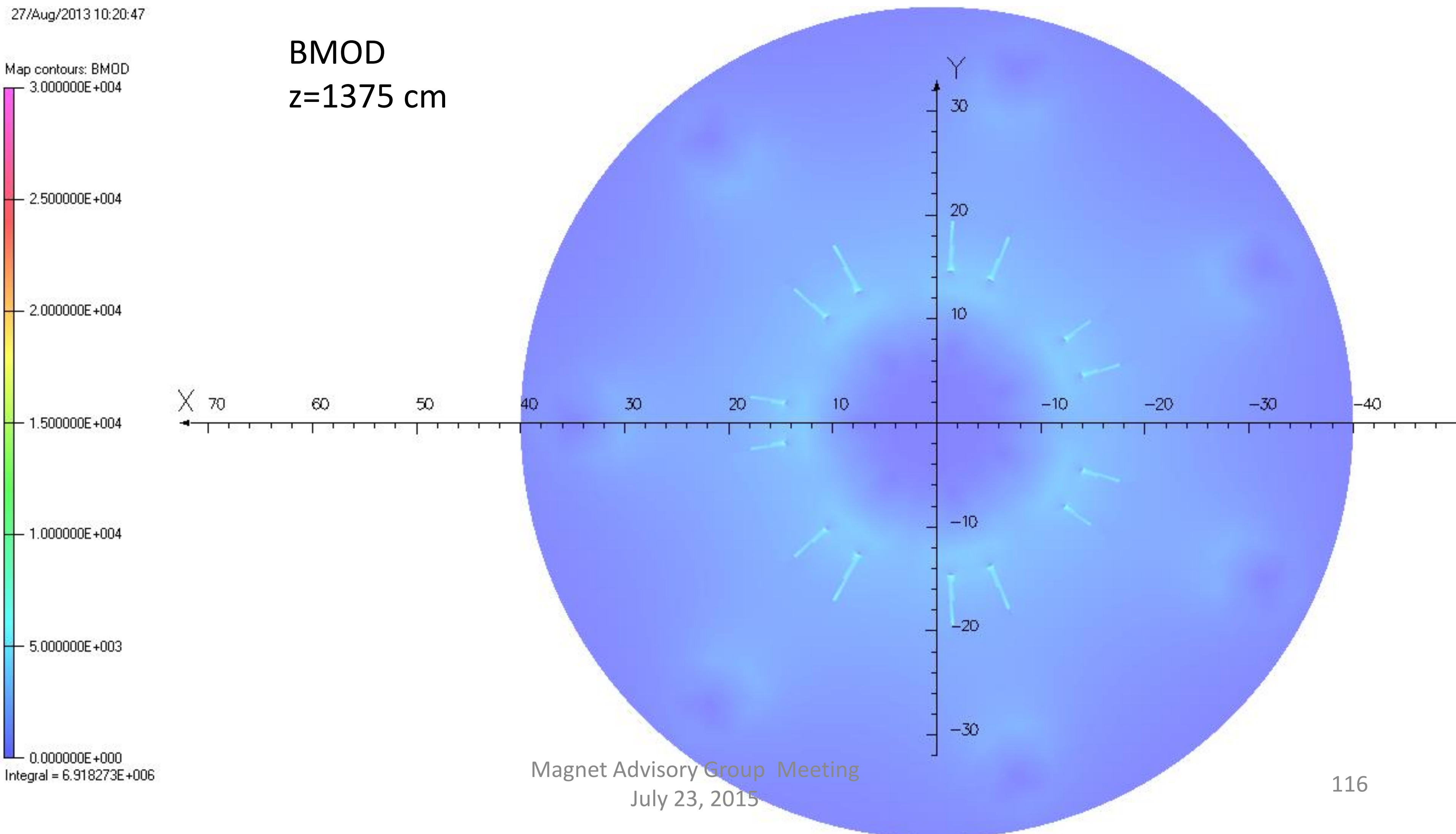


No iron w/ mesh

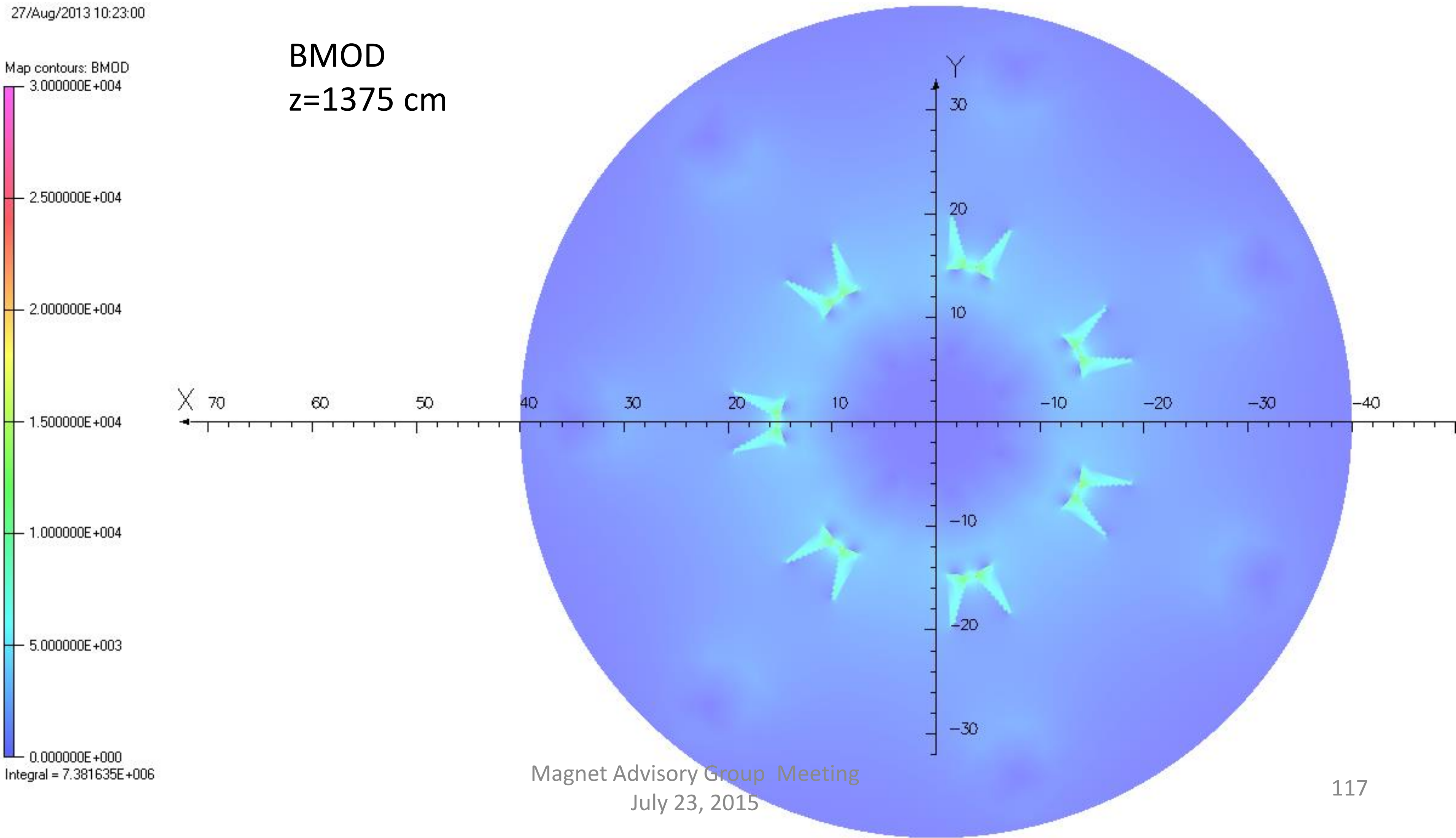


Thin Iron w/ mesh

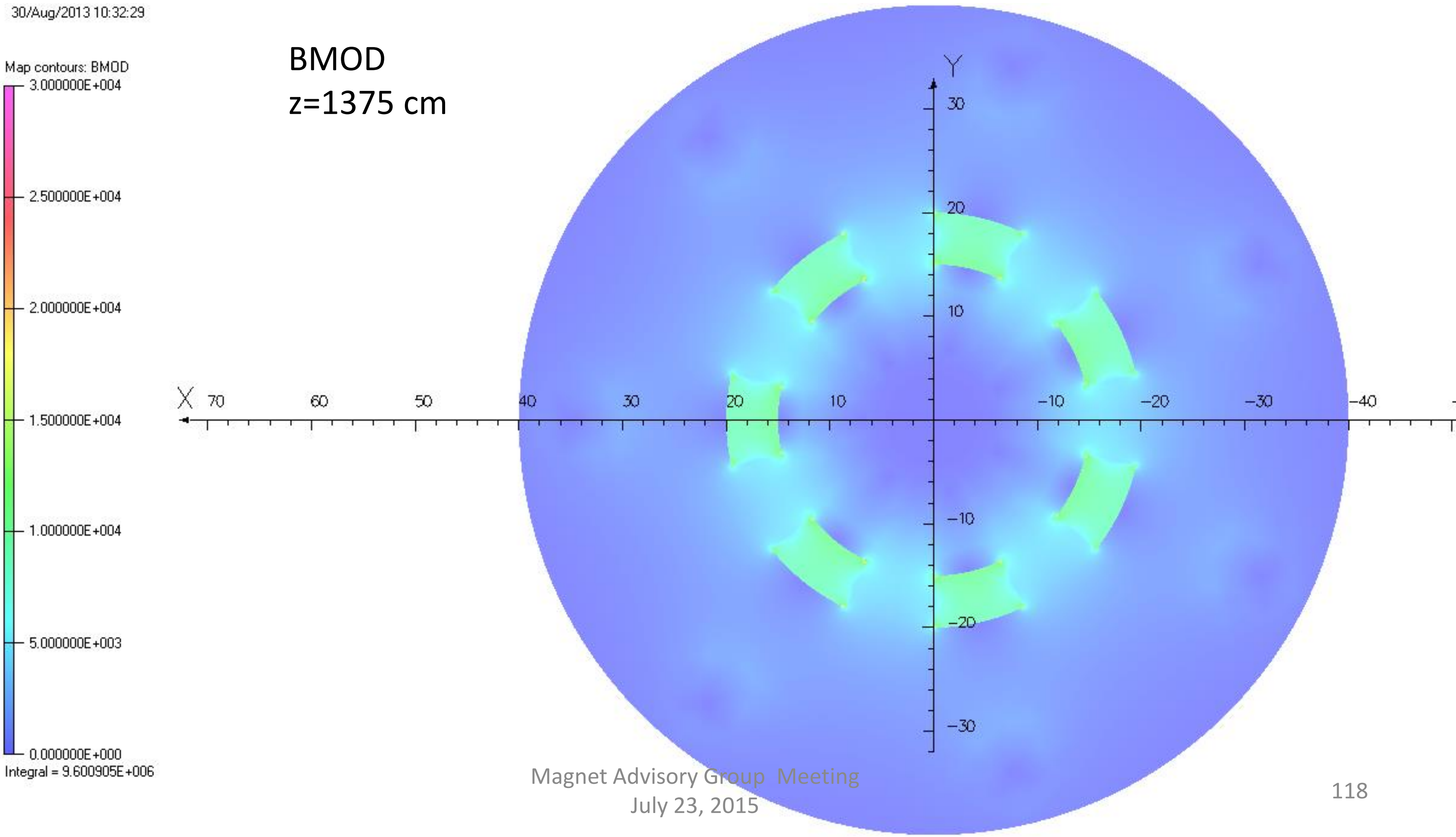
BMOD
z=1375 cm



Thick Iron w/ mesh

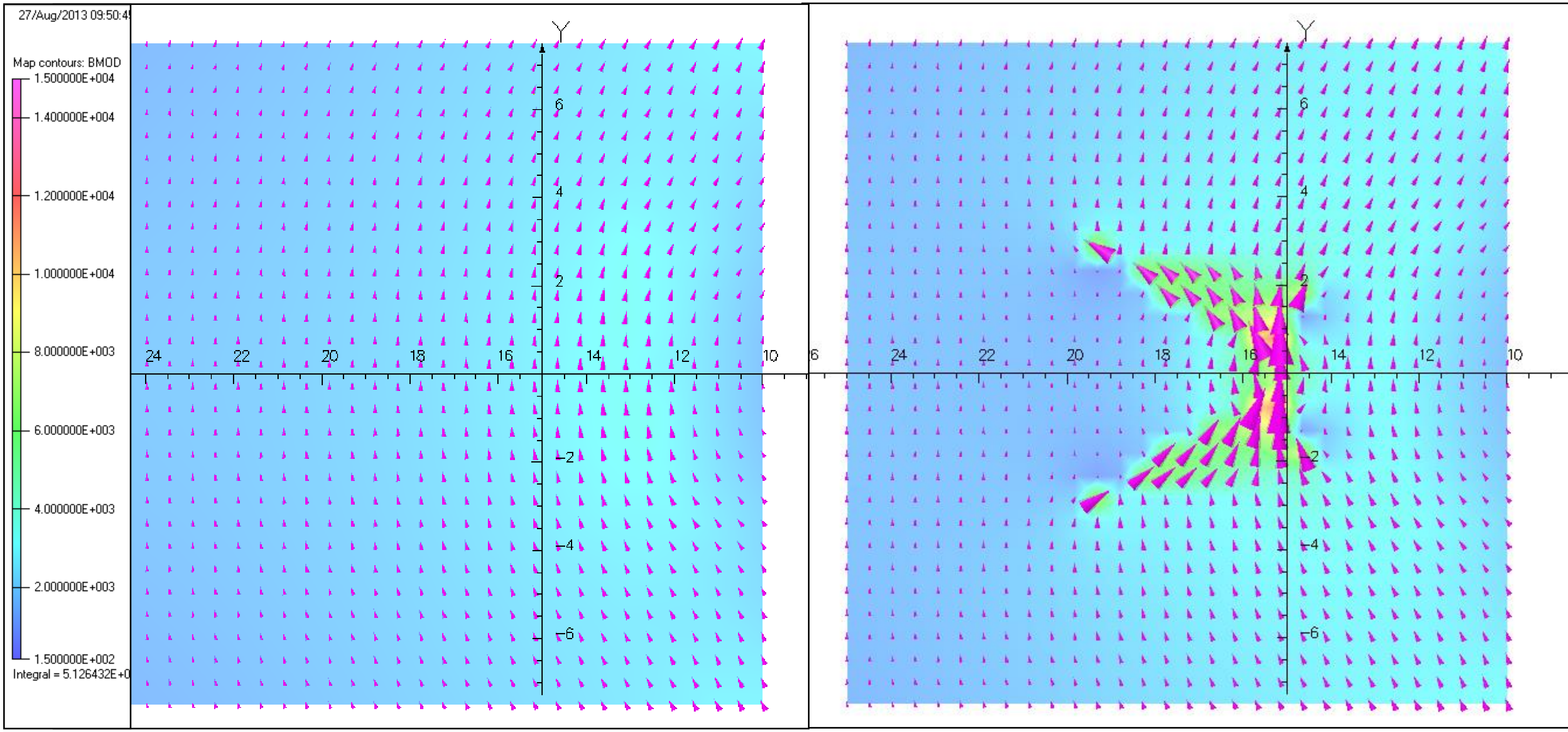


Giant blocks of iron

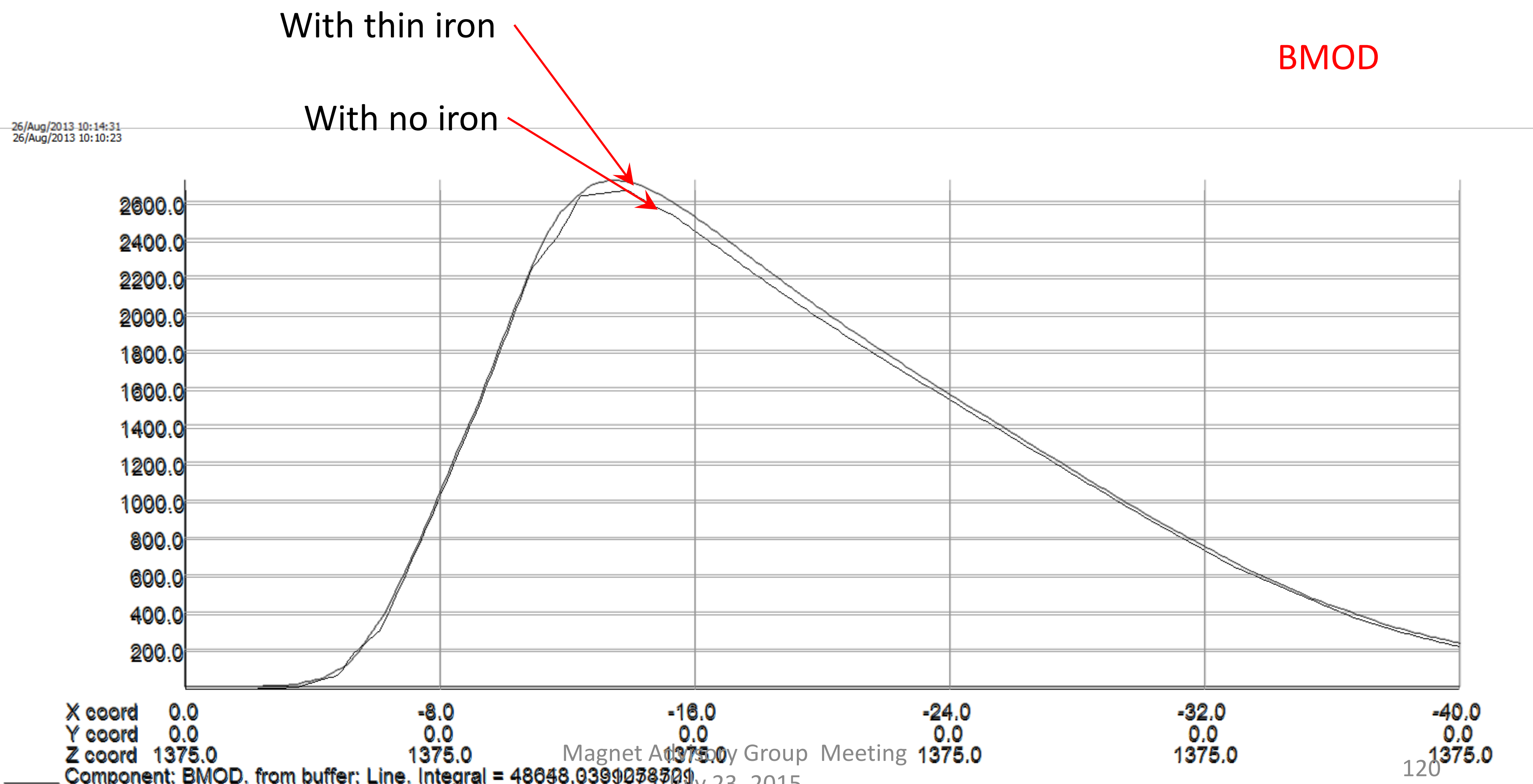


Vector plots

BMOD

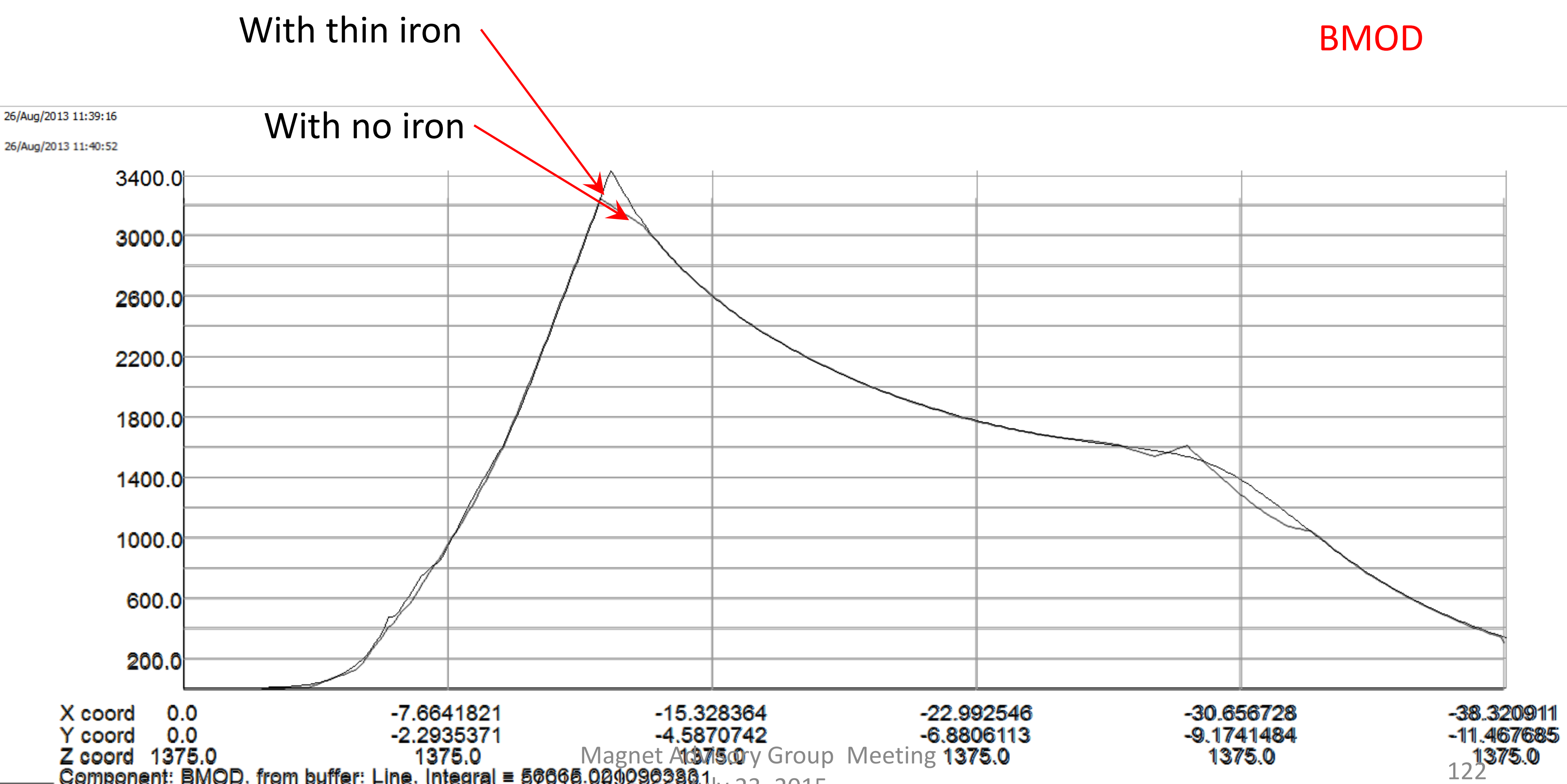


Middle of open sector

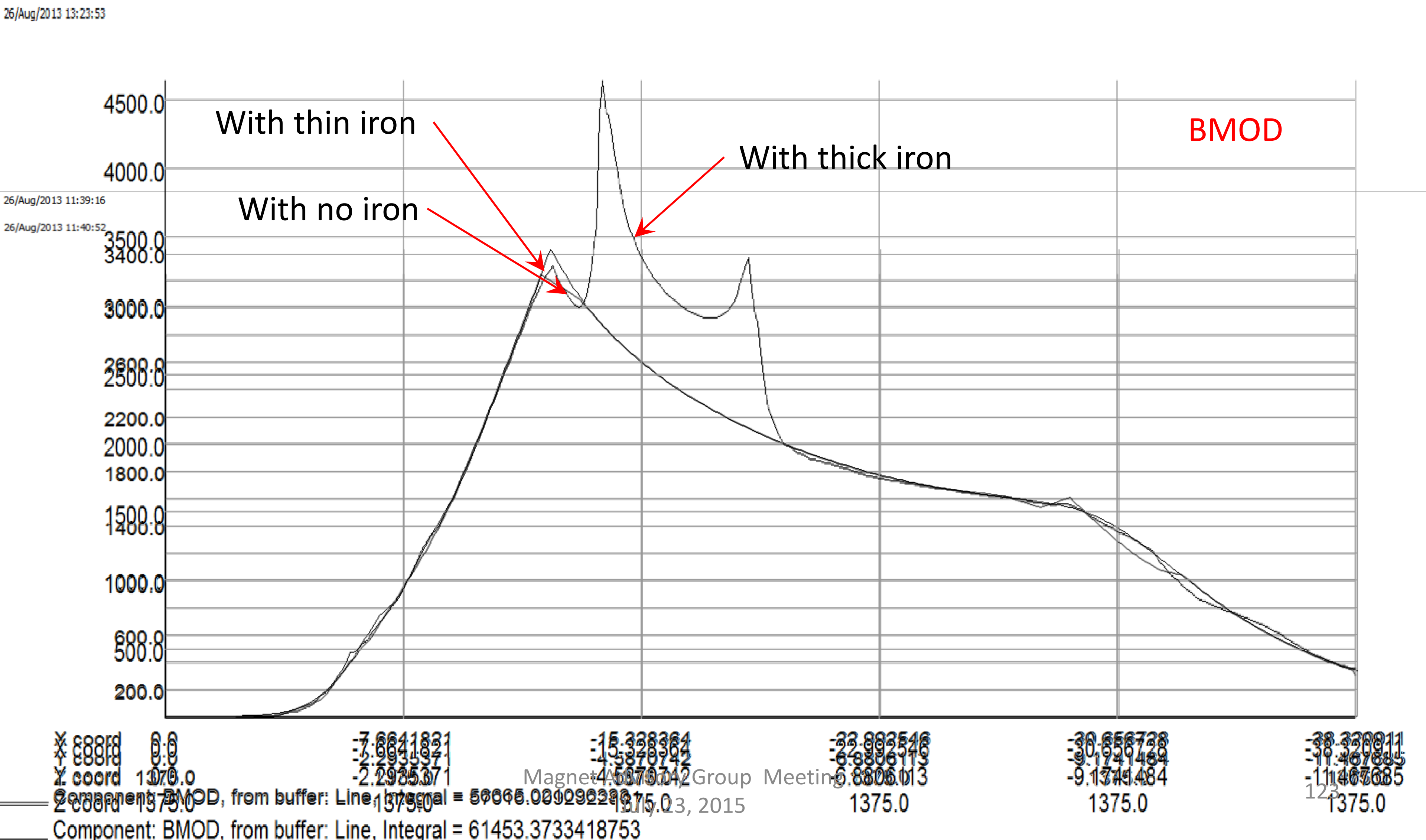


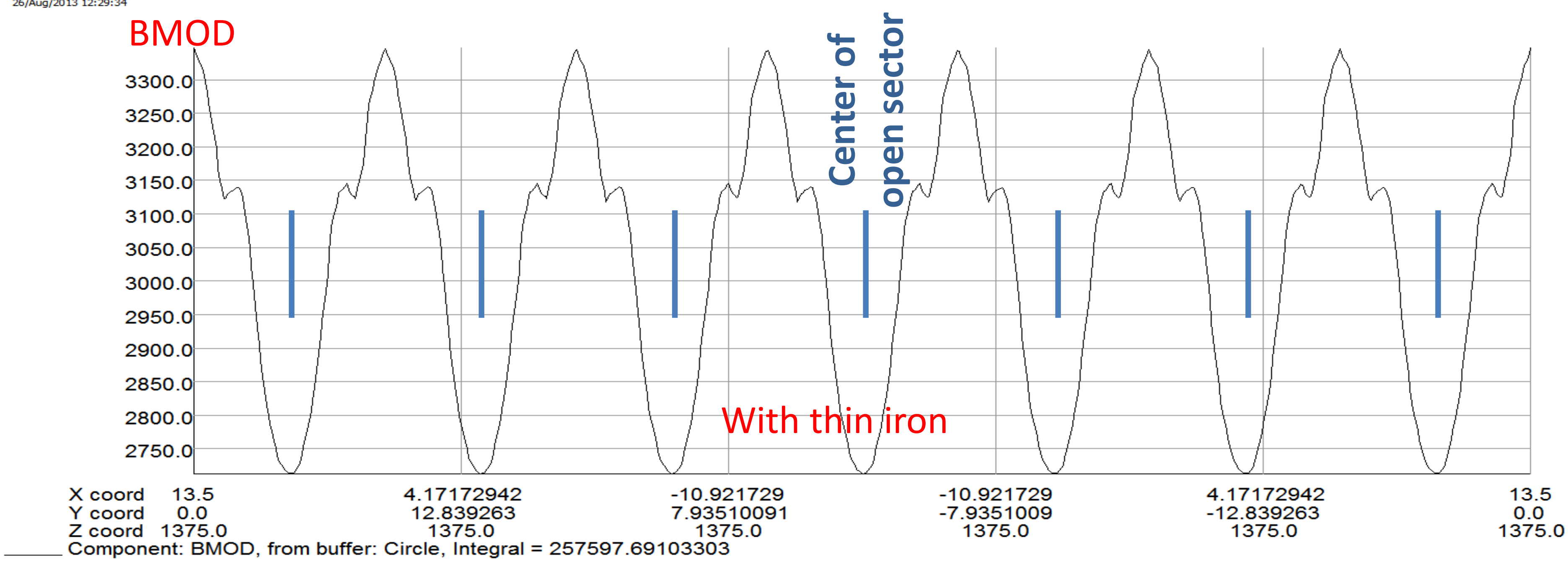
Middle of open sector

Edge of open sector

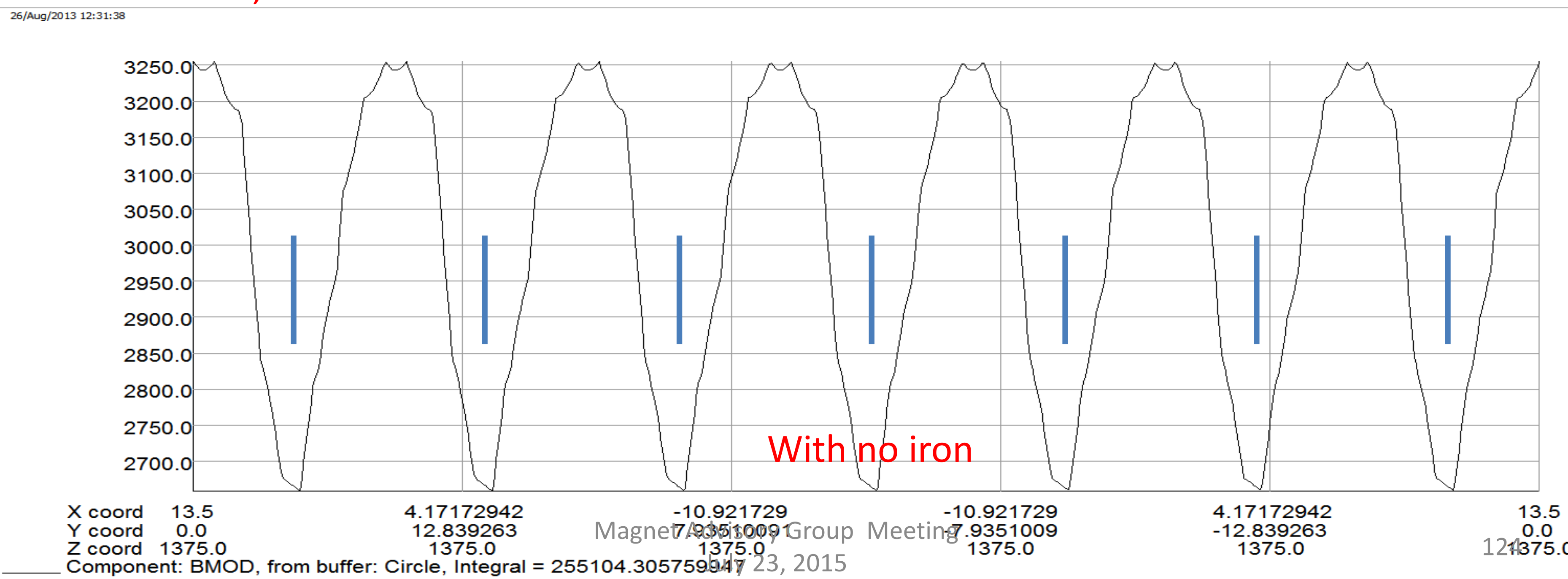


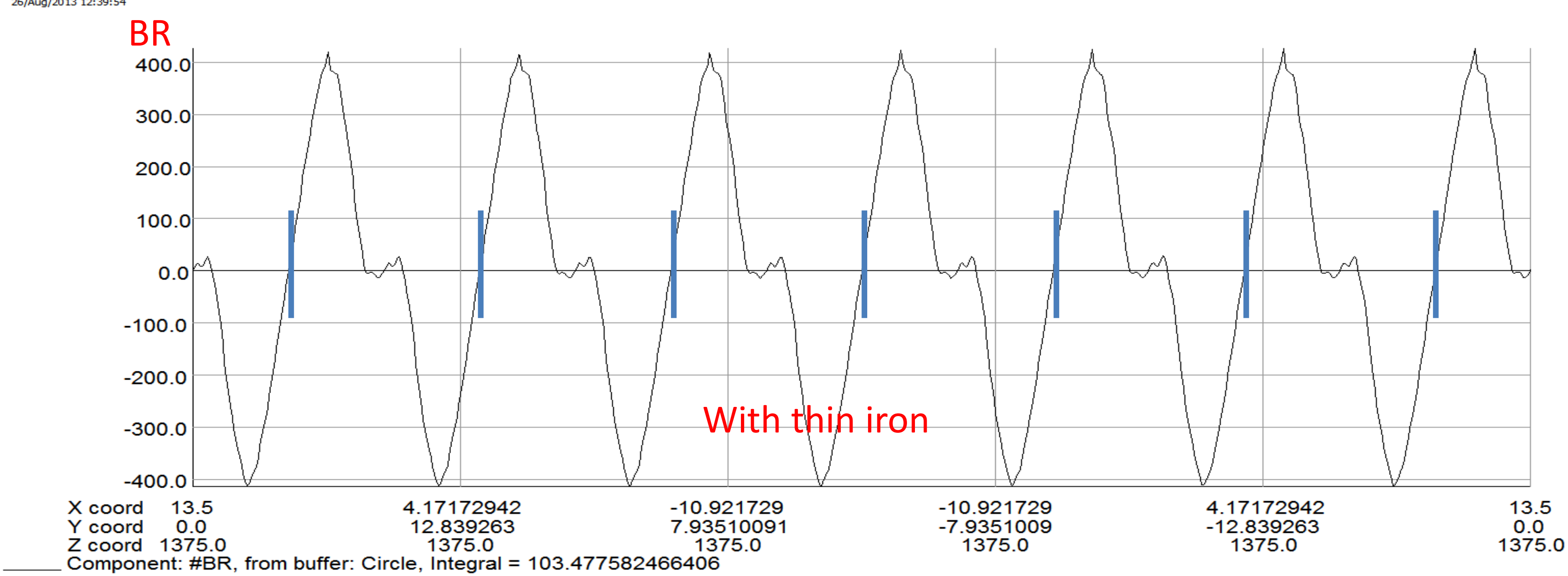
Edge of open sector



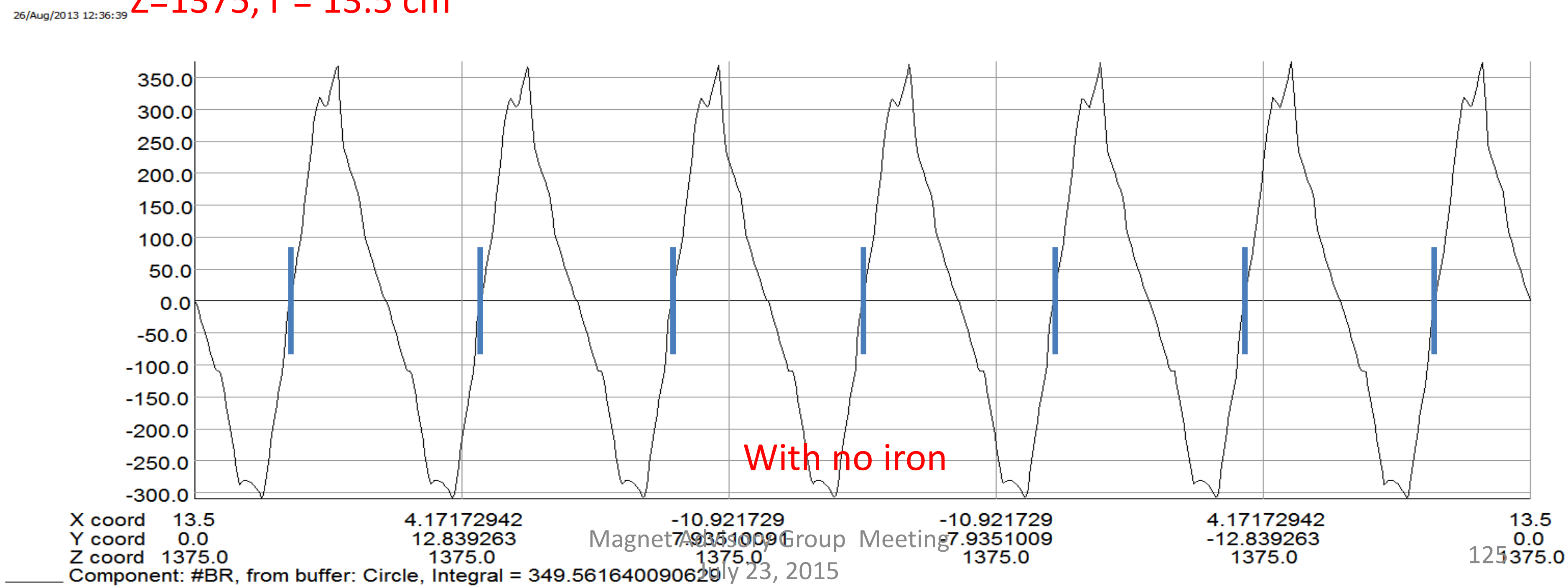


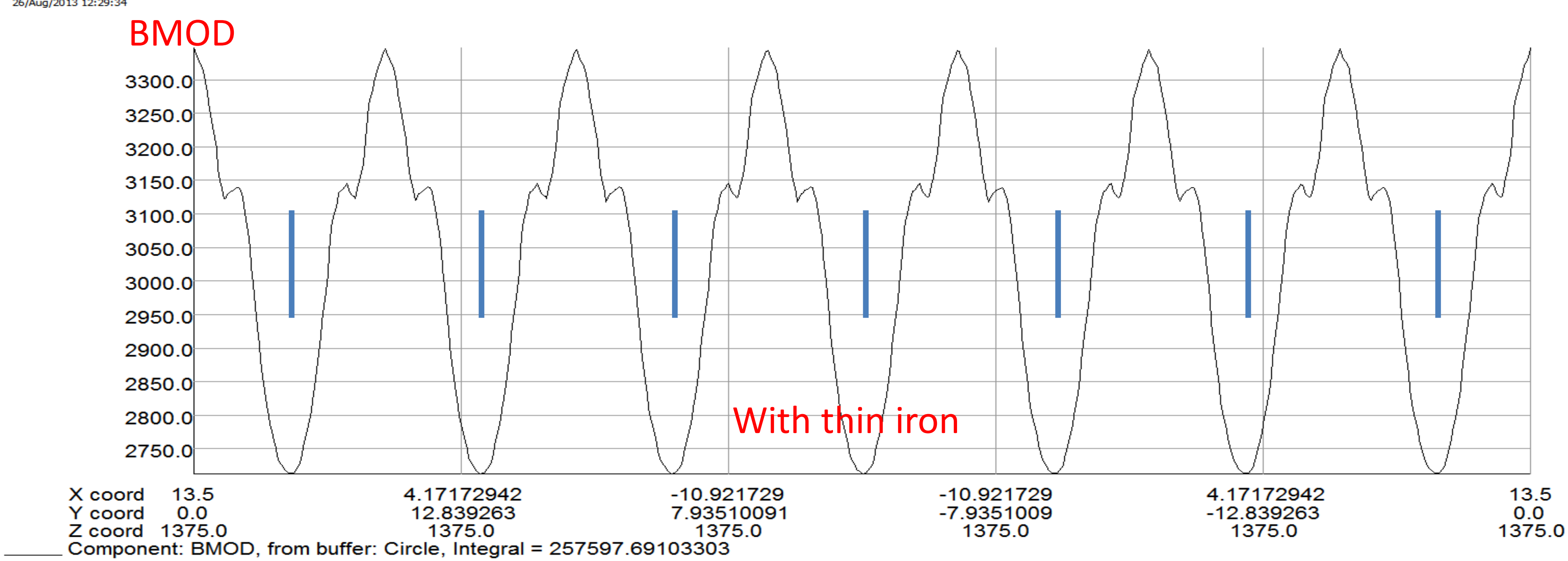
Z=1375, r = 13.5 cm



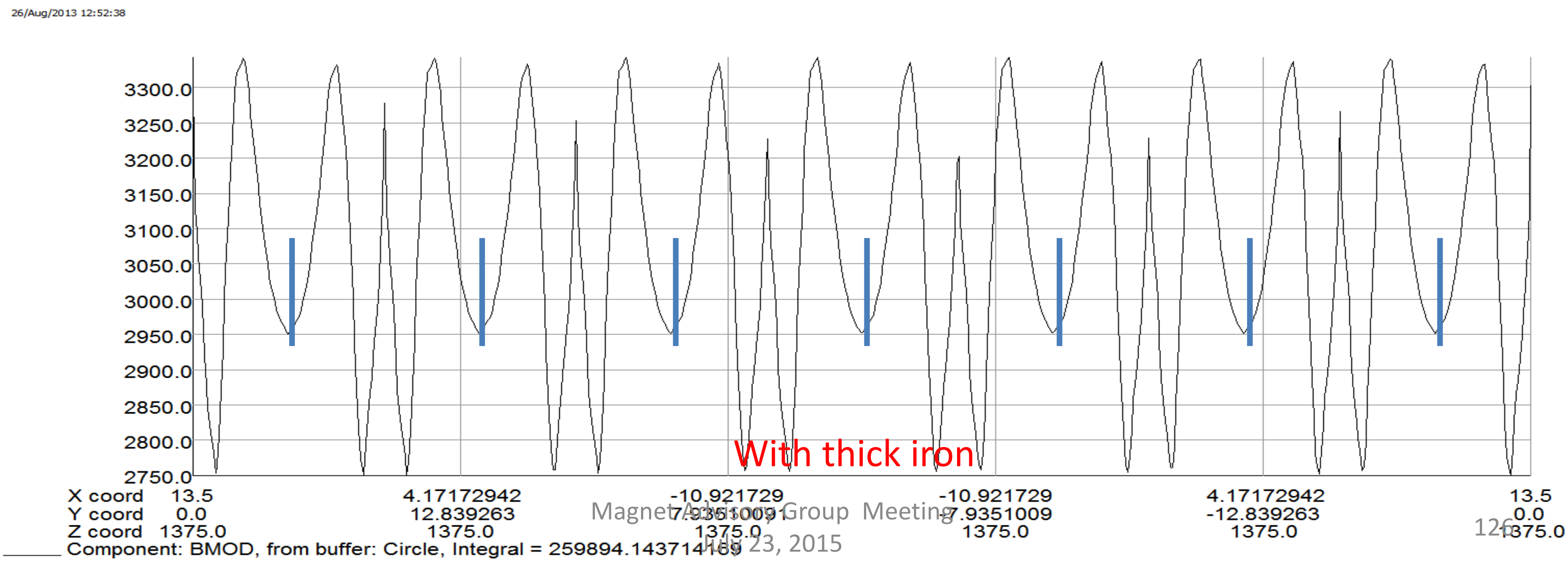


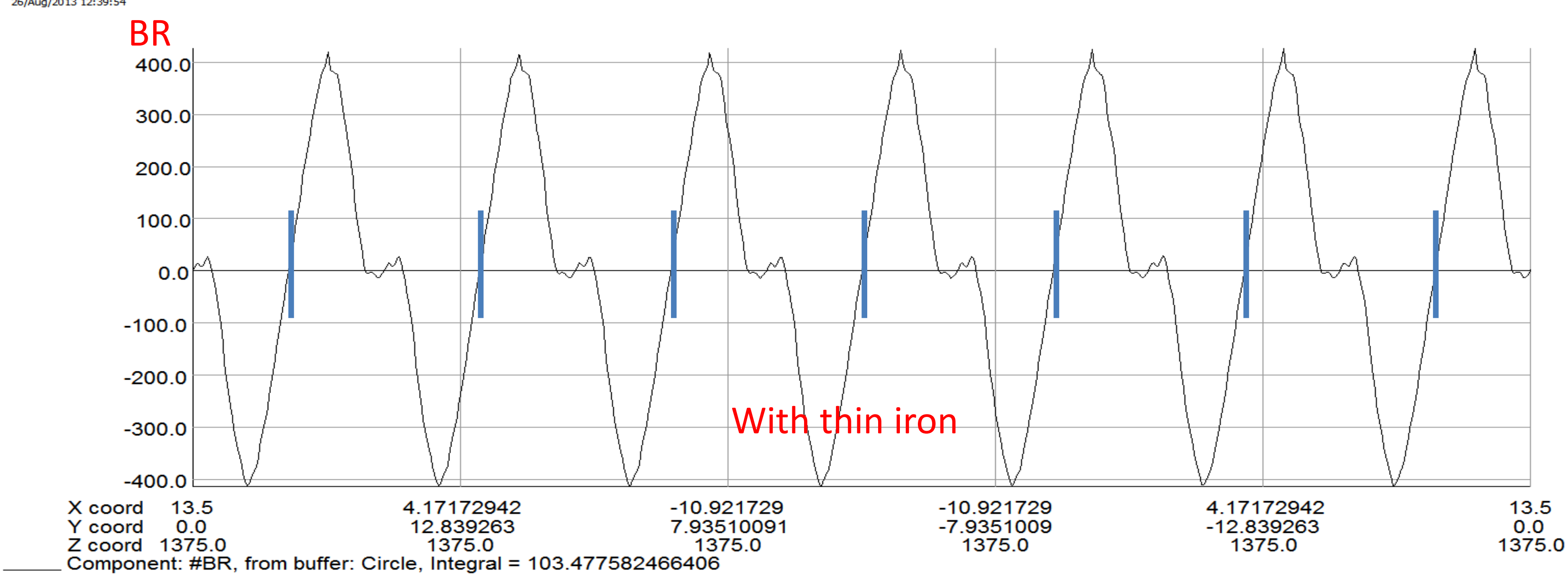
Z=1375, r = 13.5 cm



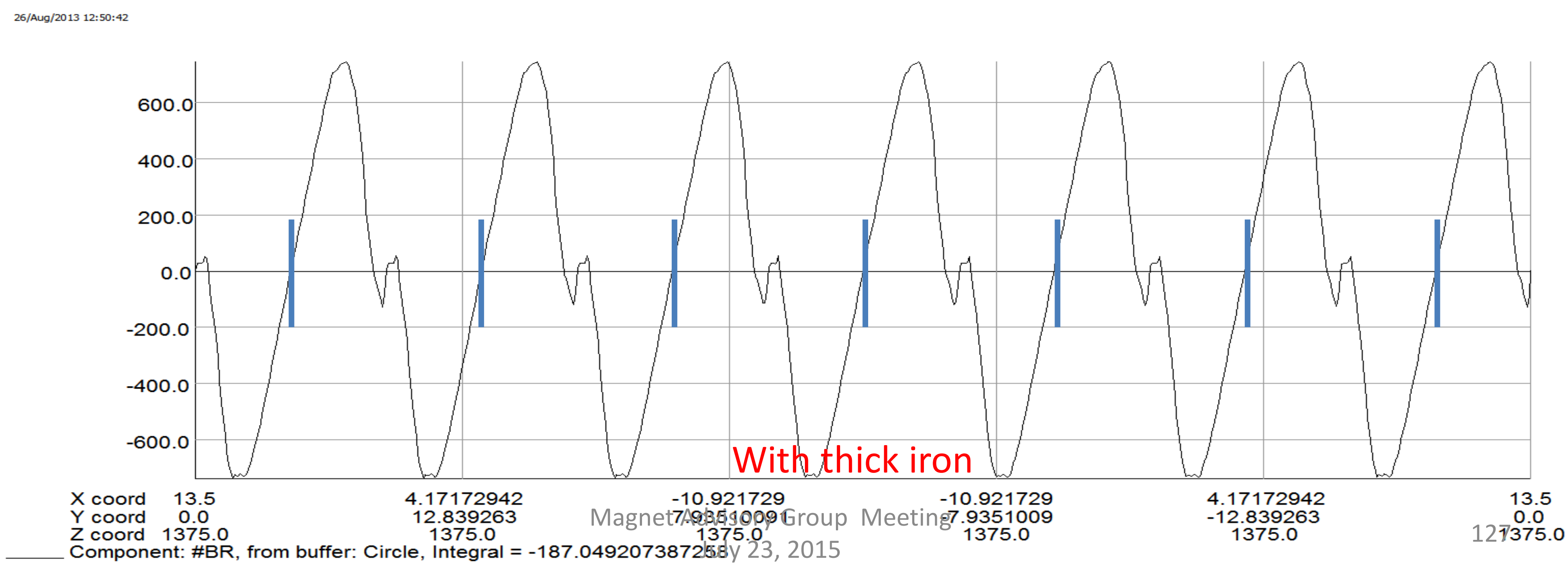


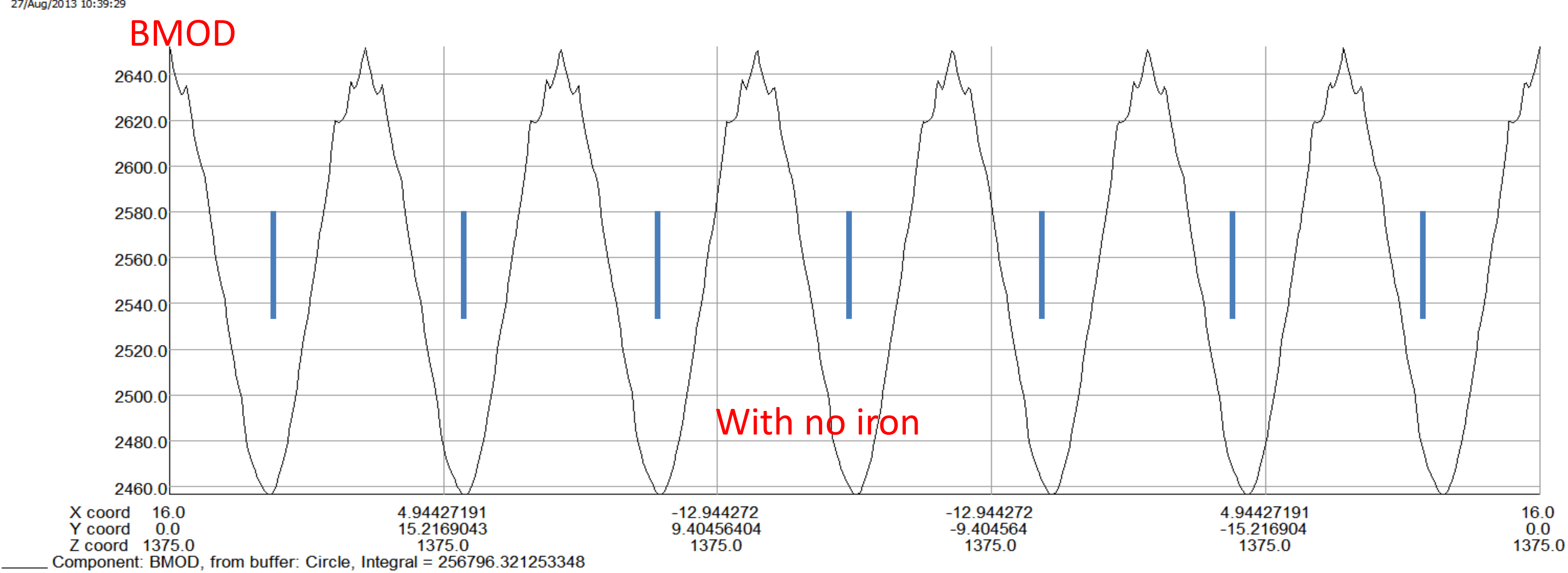
Z=1375, r = 13.5 cm



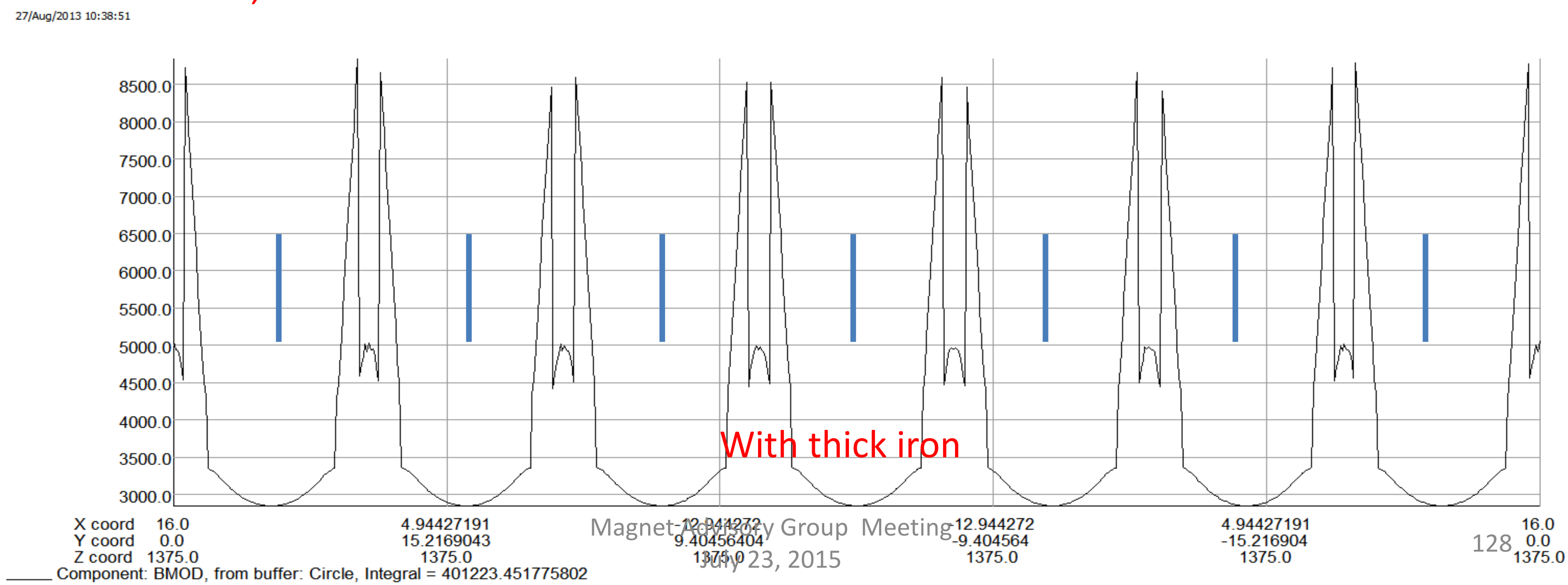


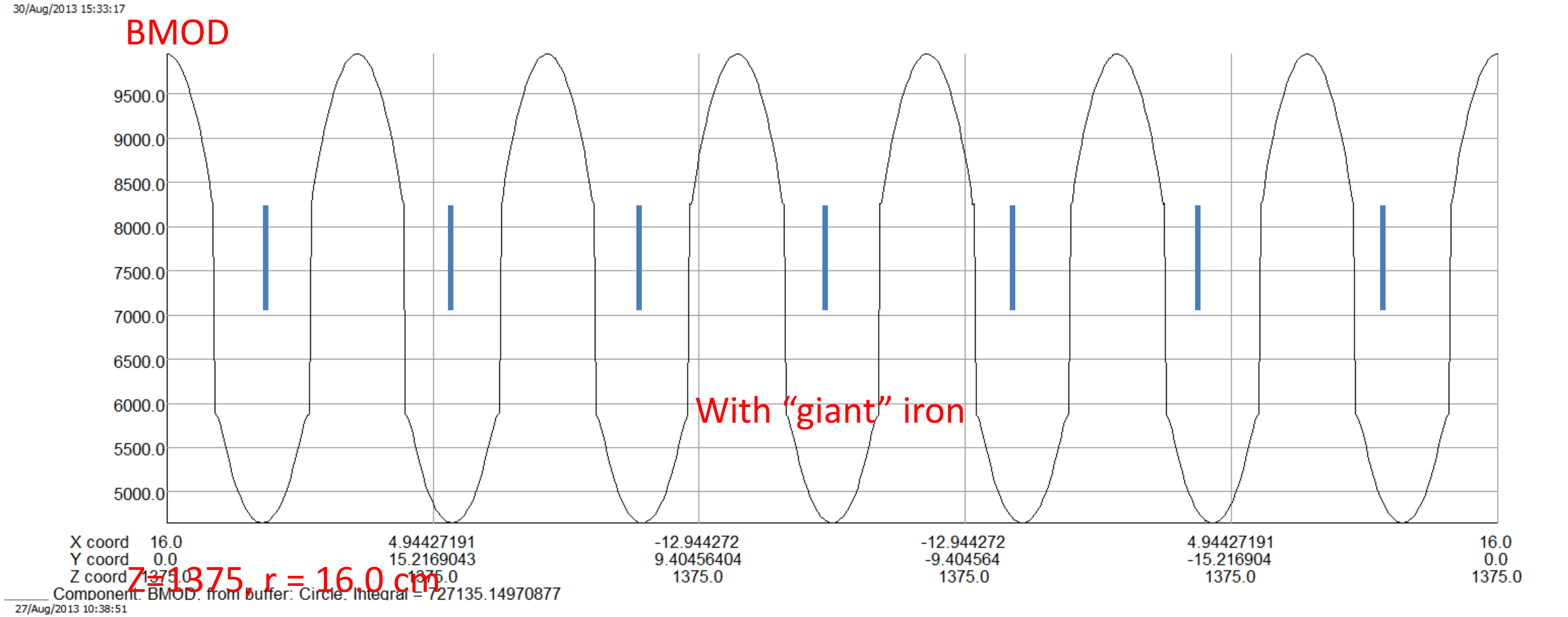
Z=1375, r = 13.5 cm

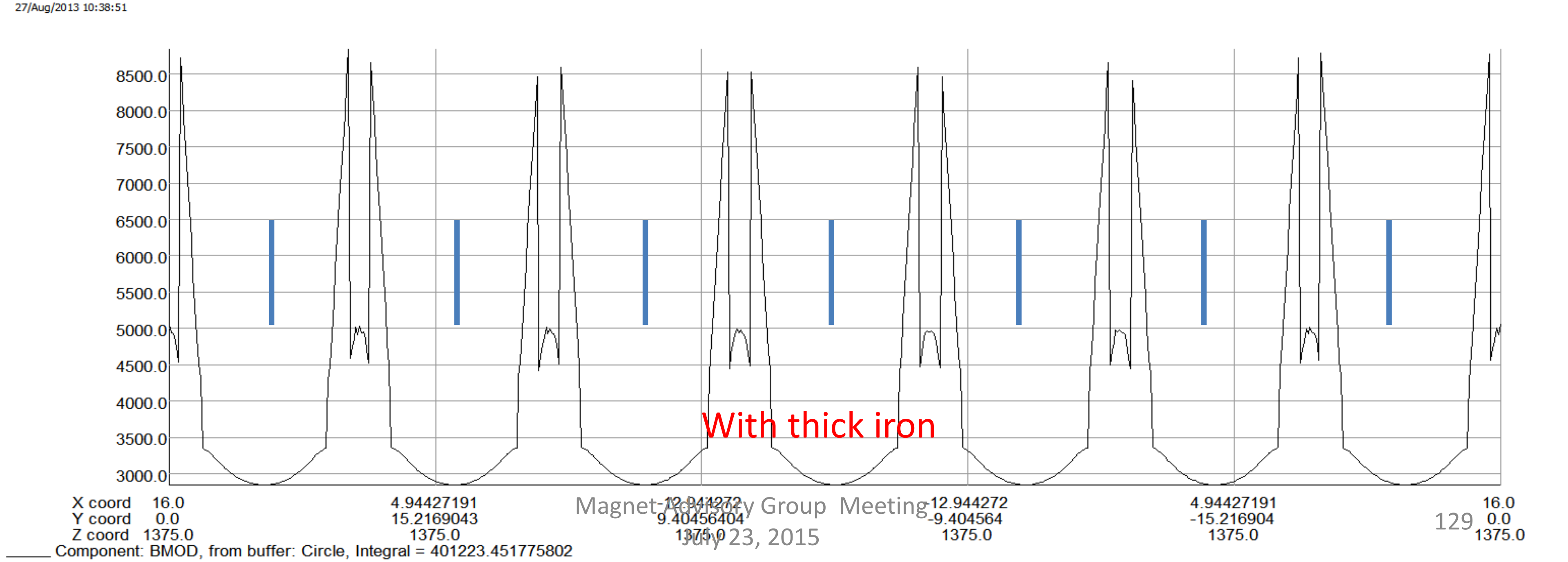


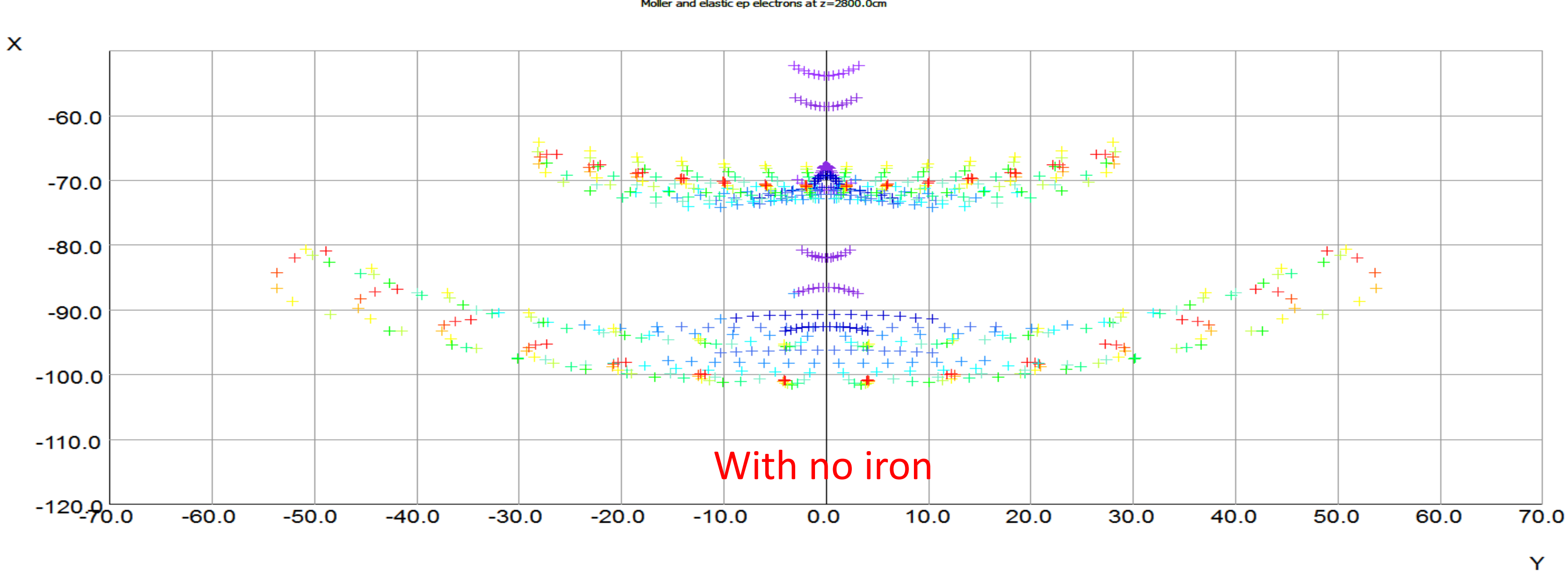


Z=1375, r = 16.0 cm

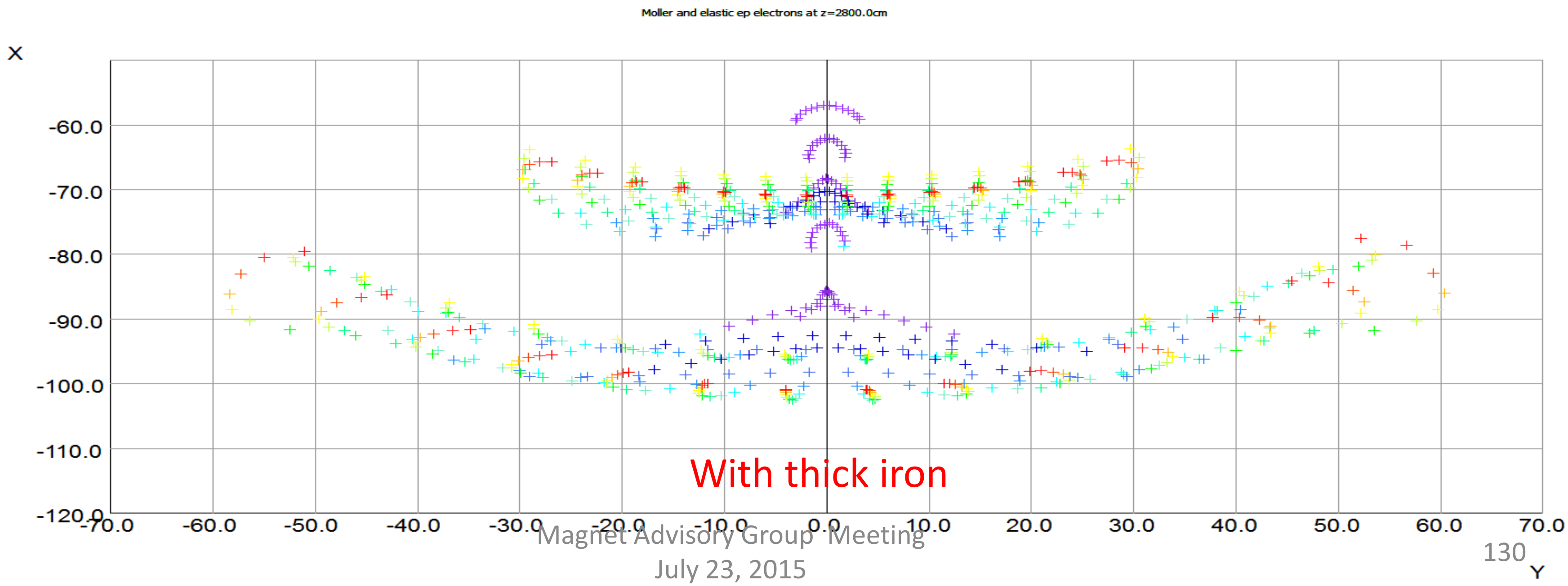



30/Aug/2013 15:33:17
BMOD
9500.0
9000.0
8500.0
8000.0
7500.0
7000.0
6500.0
6000.0
5500.0
5000.0
With “giant” iron
X coord 16.0 4.94427191 -12.944272 -12.944272 4.94427191 16.0
Y coord 0.0 15.2169043 9.40456404 -9.404564 -15.216904 0.0
Z coord 1375.0 1375.0 1375.0 1375.0 1375.0 1375.0
Z=1375, r = 16.0 cm
Component: BMOD, from buffer: Circle, Integral = 727135.14970877

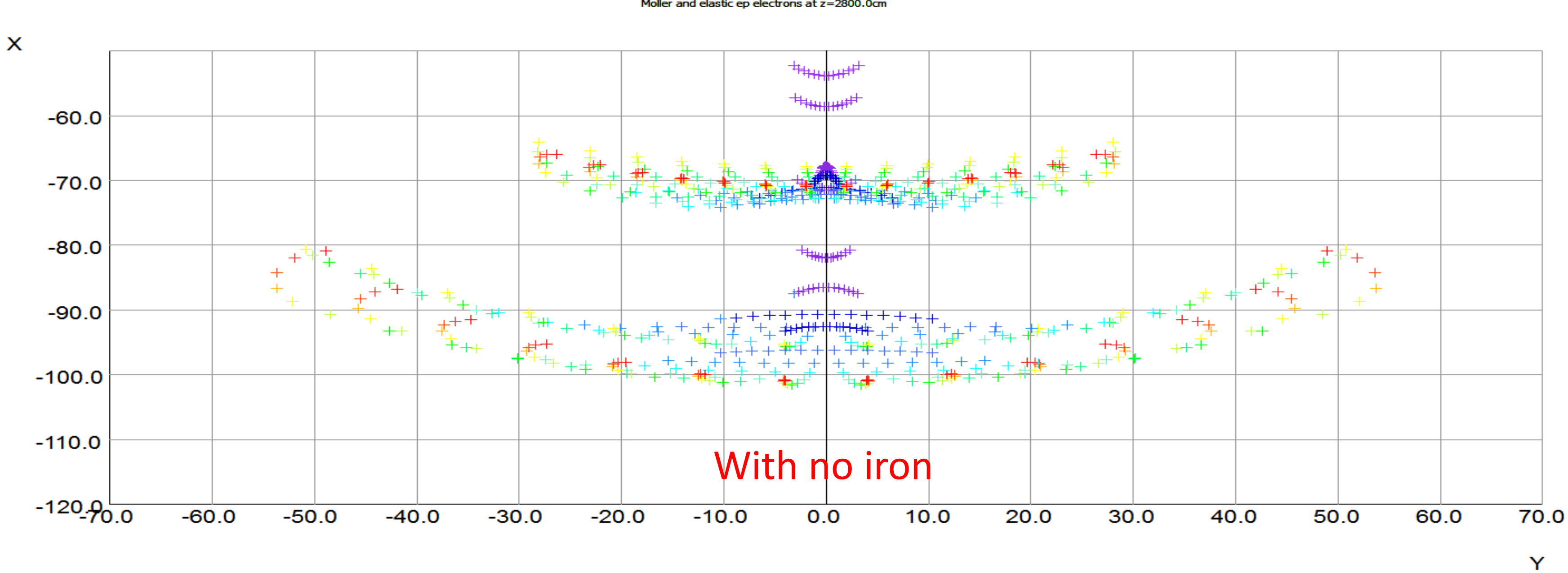

27/Aug/2013 10:38:51
8500.0
8000.0
7500.0
7000.0
6500.0
6000.0
5500.0
5000.0
4500.0
4000.0
3500.0
3000.0
With thick iron
X coord 16.0 4.94427191 -12.944272 -12.944272 4.94427191 16.0
Y coord 0.0 15.2169043 9.40456404 -9.404564 -15.216904 0.0
Z coord 1375.0 1375.0 1375.0 1375.0 1375.0 1375.0
Component: BMOD, from buffer: Circle, Integral = 401223.451775802

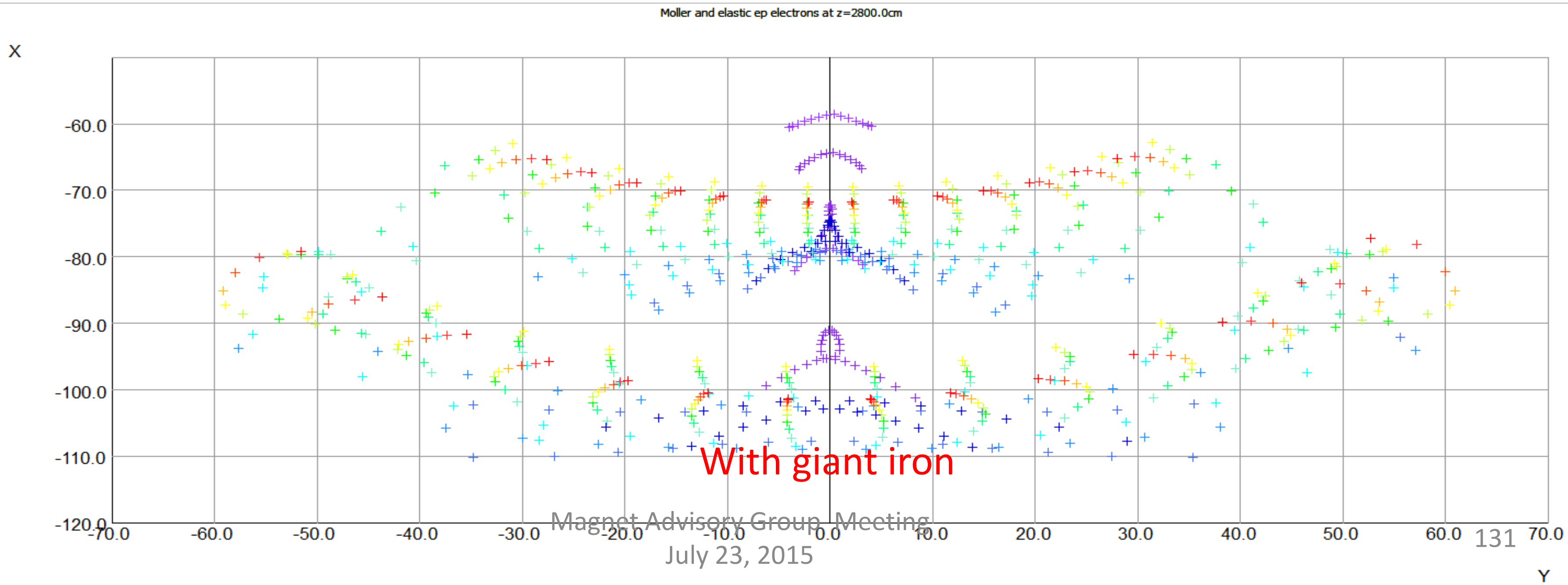


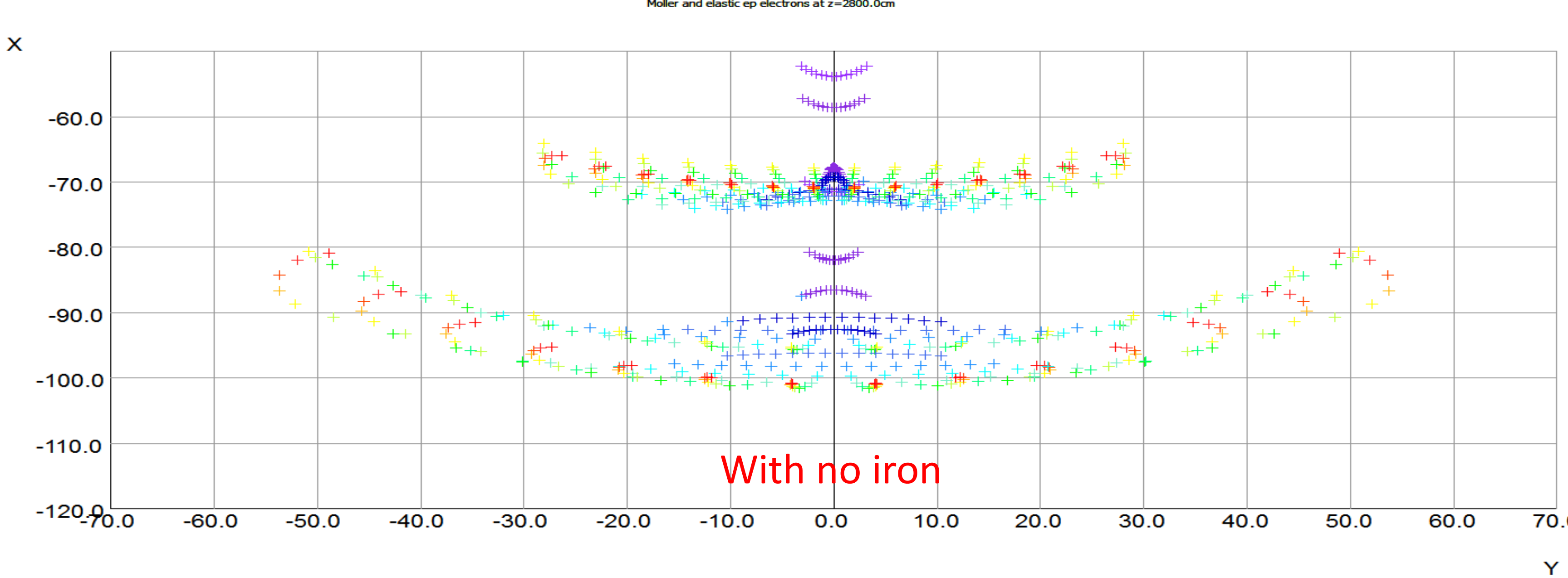
Moller and elastic ep electrons at z=2800.0cm
X
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Y
With no iron

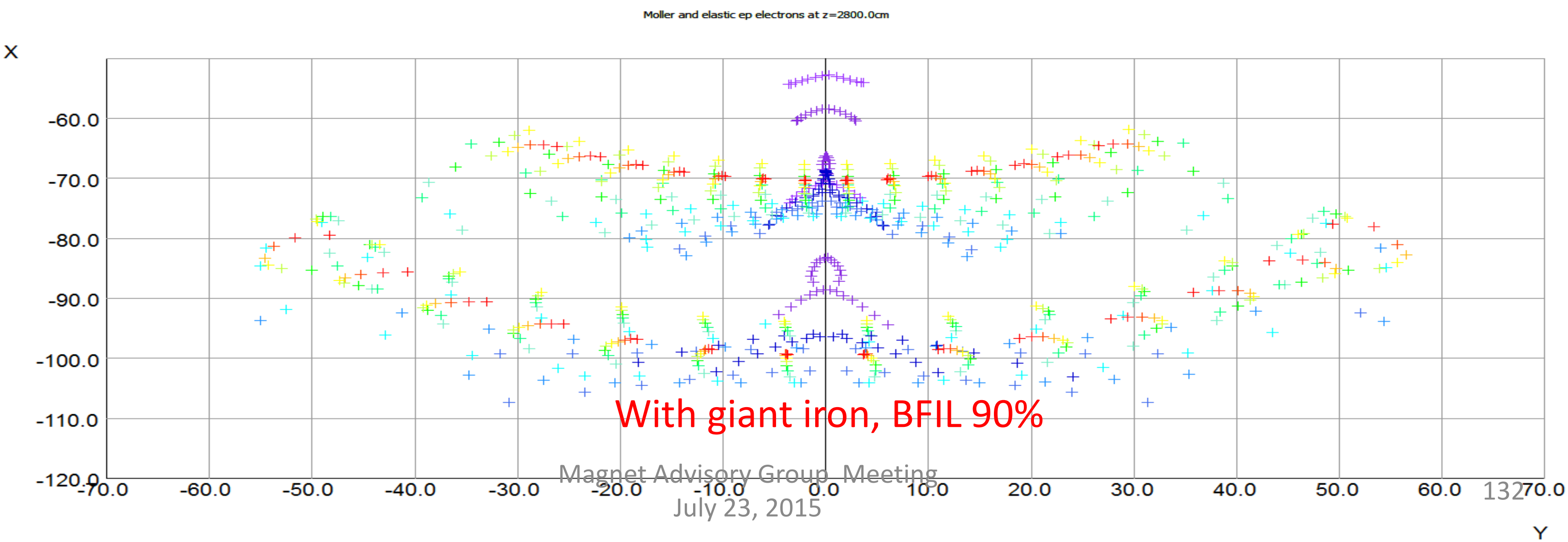


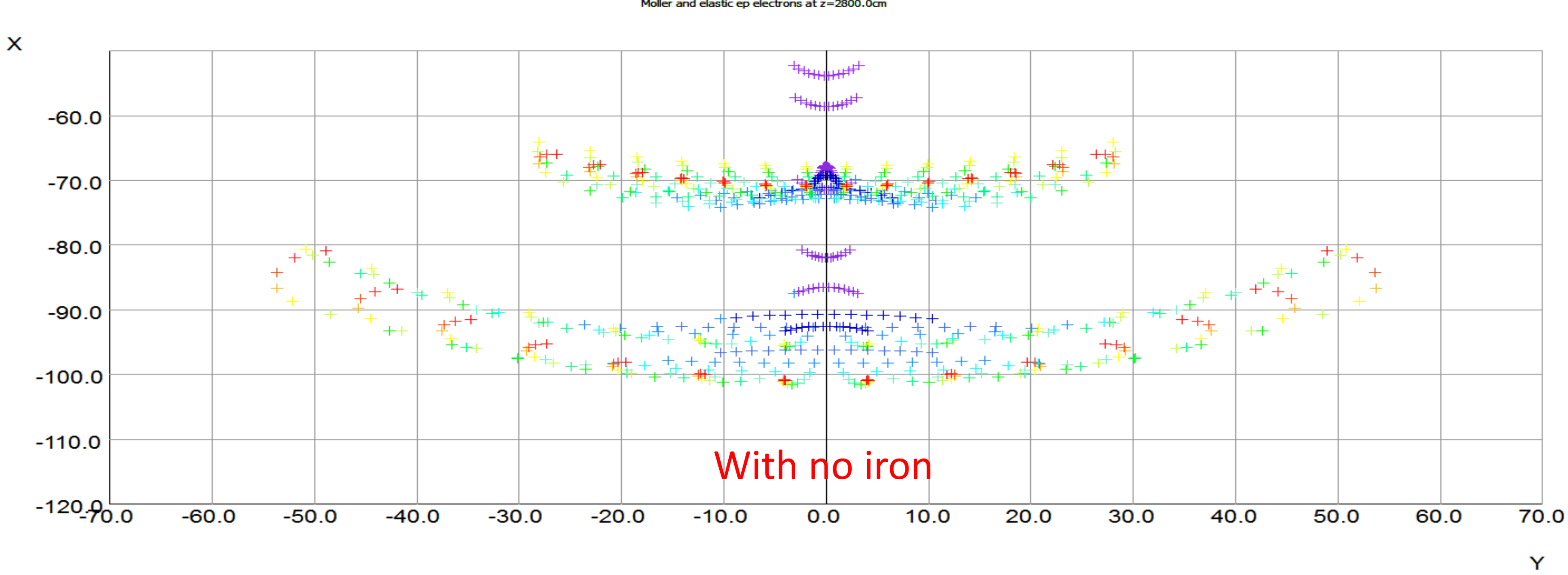
Moller and elastic ep electrons at z=2800.0cm
X
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Y
With thick iron

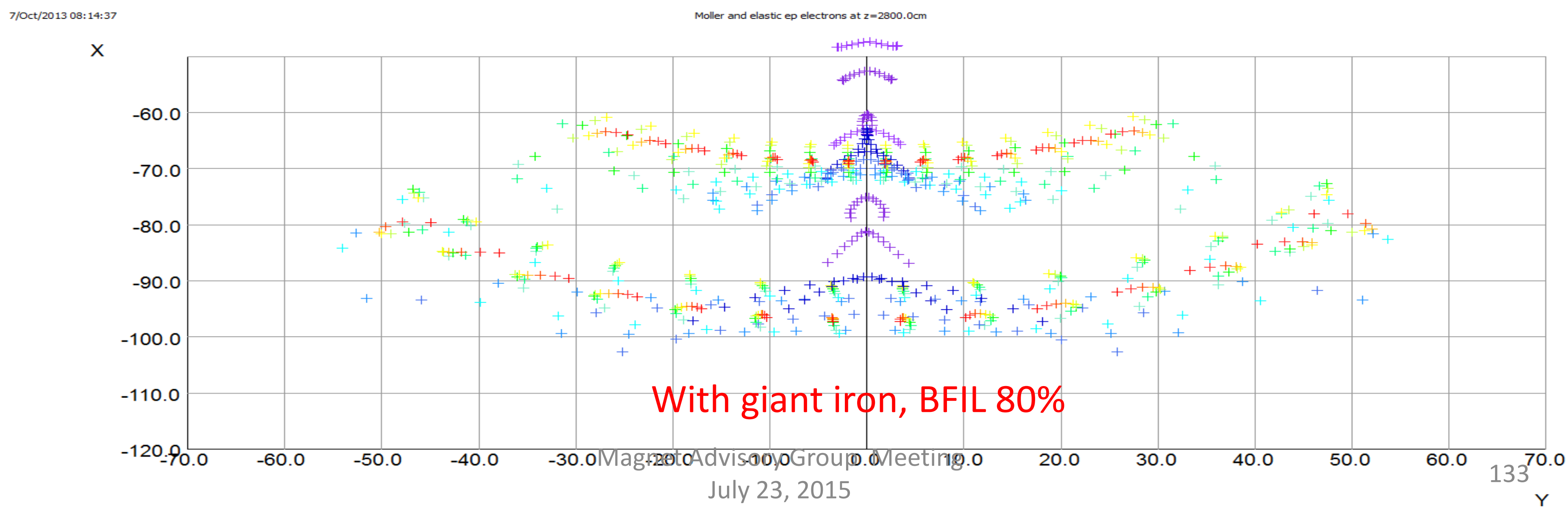

Moller and elastic ep electrons at z=2800.0cm
X
Y
With no iron

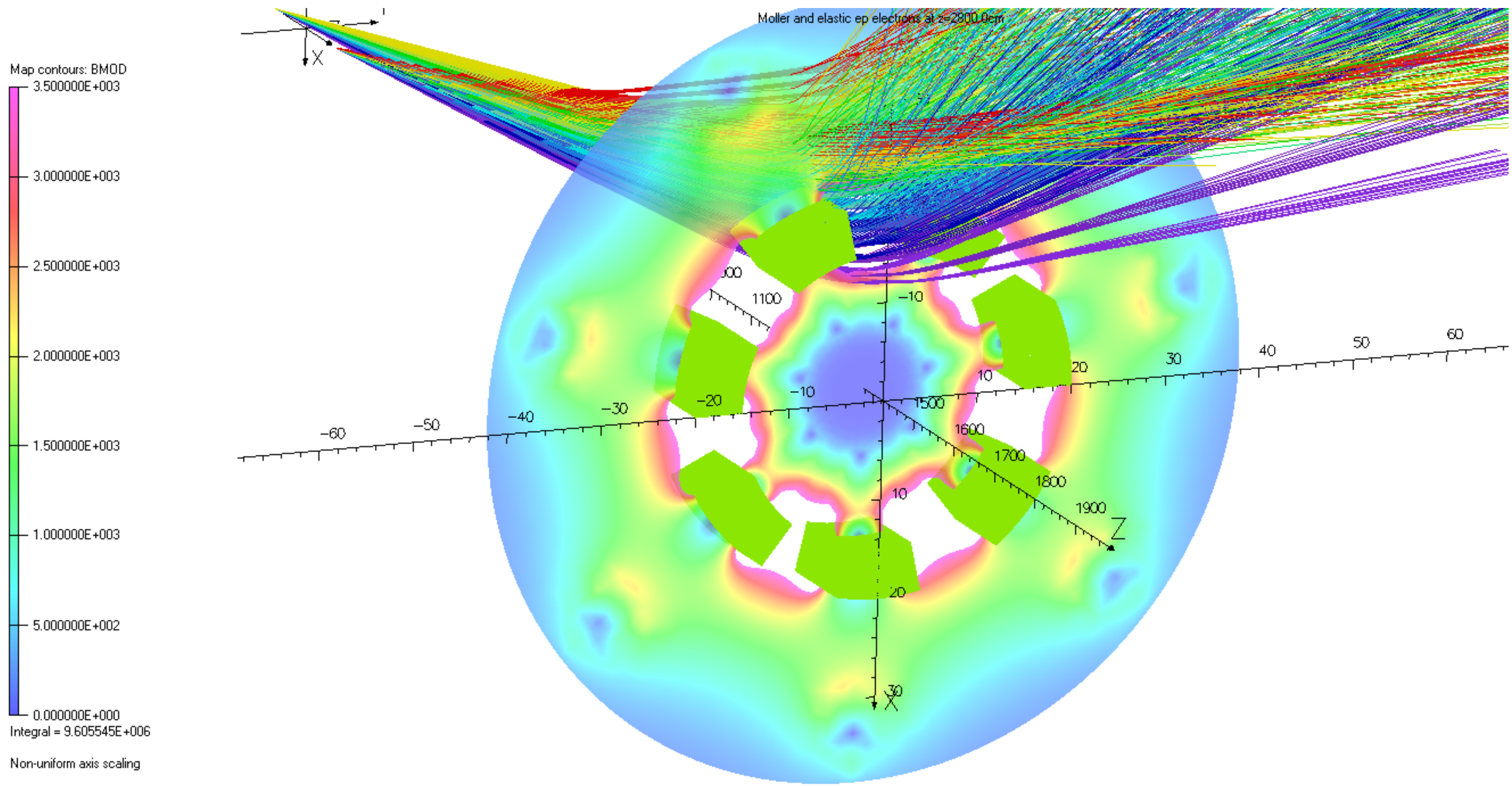

Moller and elastic ep electrons at z=2800.0cm
X
Y
With giant iron


Moller and elastic ep electrons at z=2800.0cm
X
Y
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
With no iron


Moller and elastic ep electrons at z=2800.0cm
X
Y
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
With giant iron, BFIL 90%


Moller and elastic ep electrons at z=2800.0cm
X
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Y
With no iron


7/Oct/2013 08:14:37
Moller and elastic ep electrons at z=2800.0cm
X
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-70.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Y
With giant iron, BFIL 80%


Moller and elastic ep electrons at z=2800.0cm
Map contours: BMOD
3.500000E+003
3.000000E+003
2.500000E+003
2.000000E+003
1.500000E+003
1.000000E+003
5.000000E+002
0.000000E+000
Integral = 9.605545E+006
Non-uniform axis scaling

Summary

No optimization of the iron was done

According to this preliminary work, $\int B \cdot dl$ is 2% greater for the thick iron

$$1.11\ \mathrm{T{\cdot}m} \rightarrow 1.13\mathrm{T} \cdot \mathrm{m}$$

Lowest tracks radial position at detector plane increased 2 cm (compared to 90 cm)

Do NOT see a dramatic increase in the quality of the focus or size of the field

Radial focus may be a little better for transition and closed sectors