MOLLER Spectrometer Update

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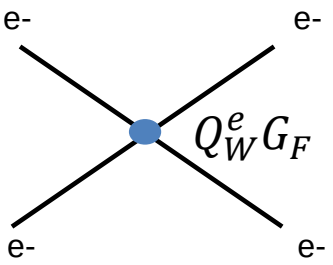
- The Physics
  - Search for ***physics beyond the Standard Model***
  - Interference of Z boson with single photon in Møller scattering
  - Measure the weak charge of the electron and $sin^2\theta_W$
  - Sensitivity comparable to the two high energy collider measurements

- 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

$$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx \frac{\left[\gamma \quad \gamma + Z^0 \quad Z^0\right]}{\left|\gamma \quad \gamma\right|^2} \approx 1 \times 10^{-8}$$

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



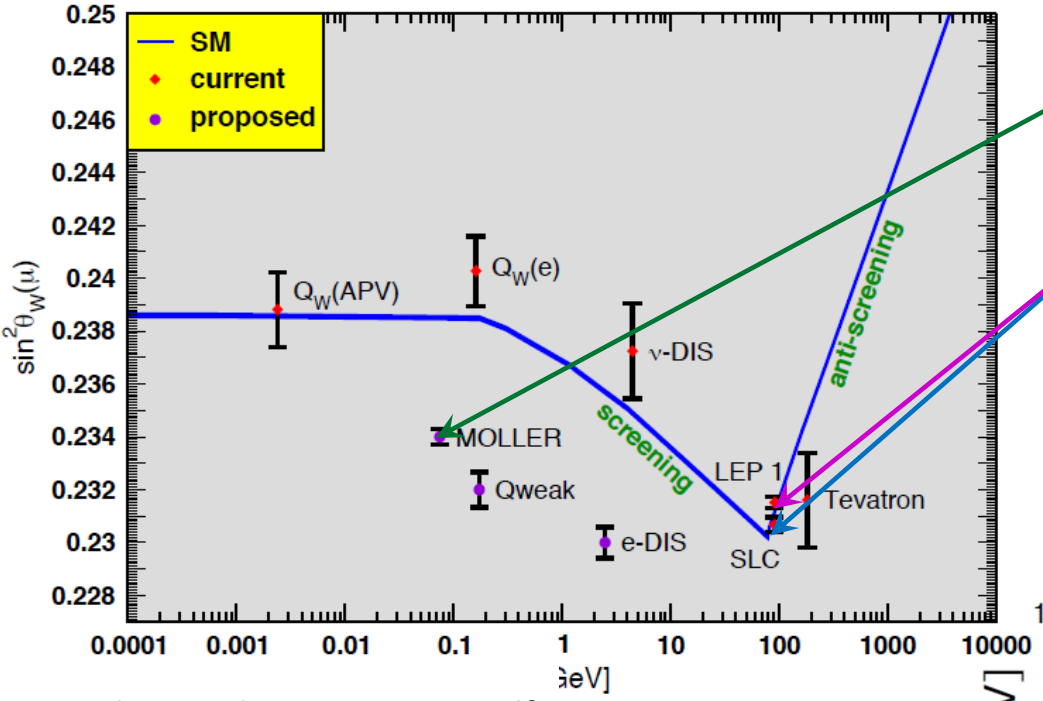
A_{PV}= 35.6 ± 0.73 *ppb*

$$\frac{\delta \sin^2 \theta_W}{\sin^2 \theta_W} \simeq .05 \frac{\delta A_{PV}}{A_{PV}}$$

$\delta Q_W^e = 2.3\%, \sim 5 \times smaller$ *than* $E158$ $(\delta Q_W^e = 10.9\%)$

$$\mathcal{L}_{e_1 e_2}^{PV} = \mathcal{L}_{SM}^{PV} + \mathcal{L}_{NEW}^{PV}$$

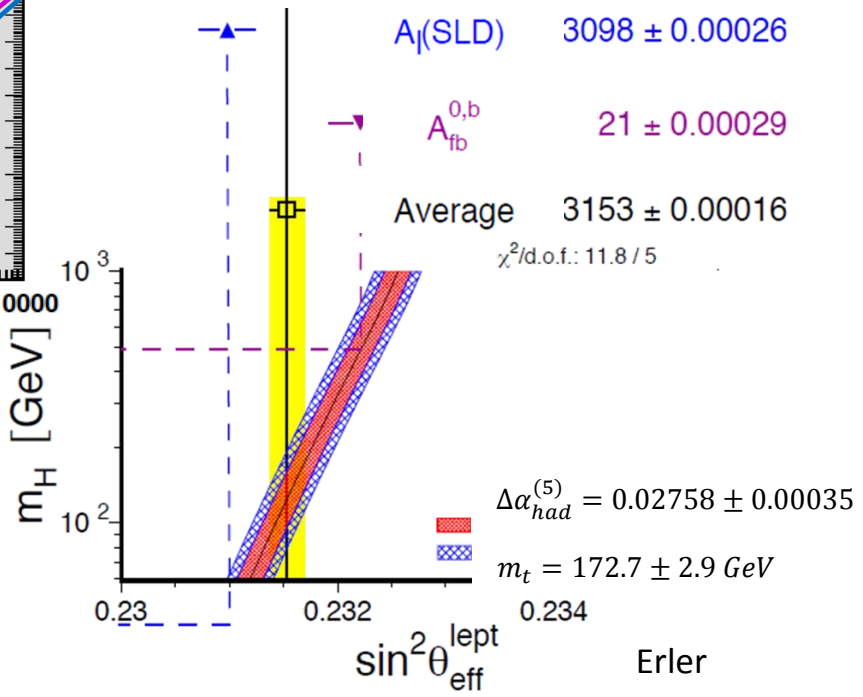
MEASUREMENT OF $\sin^2\theta_W$



Erler, Kurylov, Ramsey-Musolf

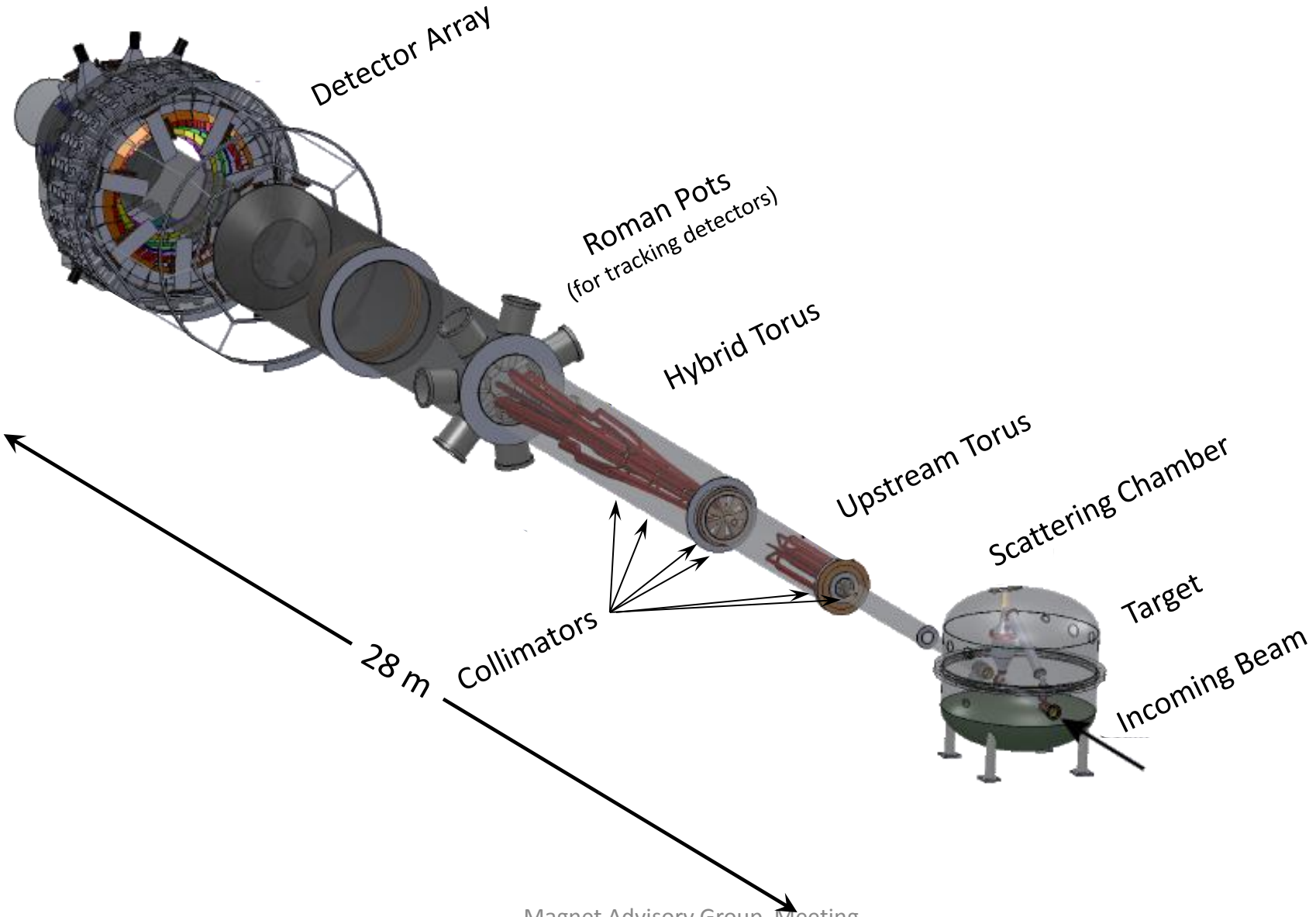
MOLLER

Z-pole

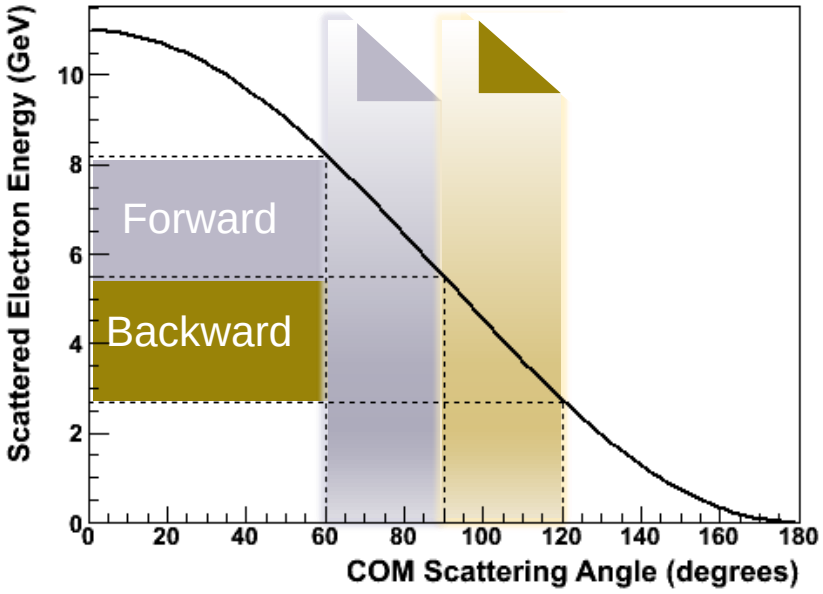


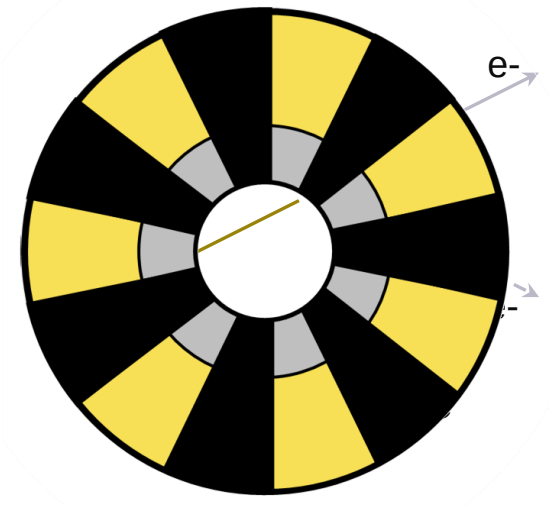
Erler

THE EXPERIMENT

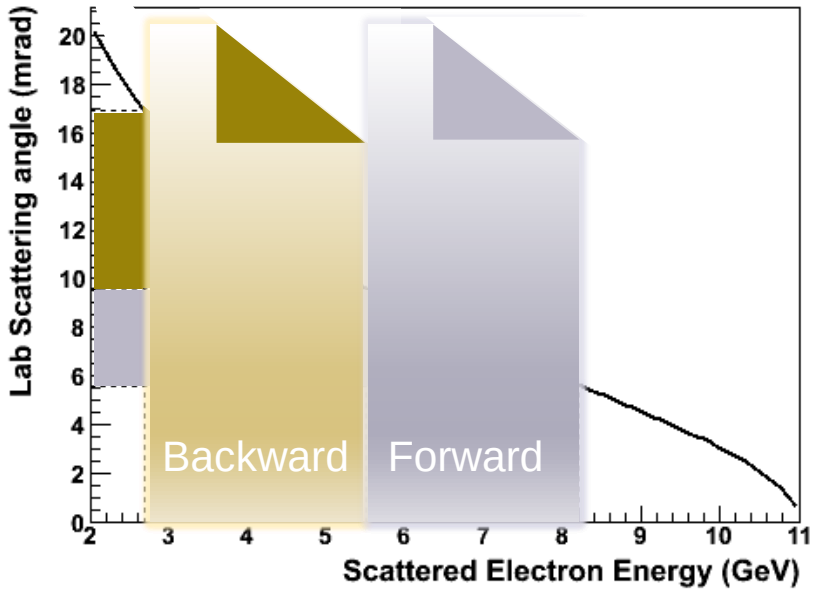


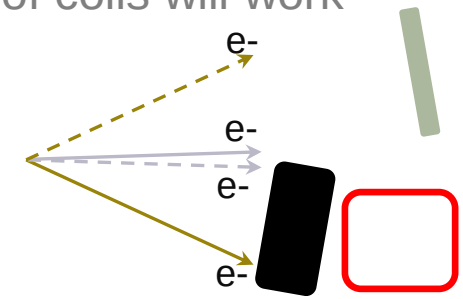
100% Azimuthal Acceptance





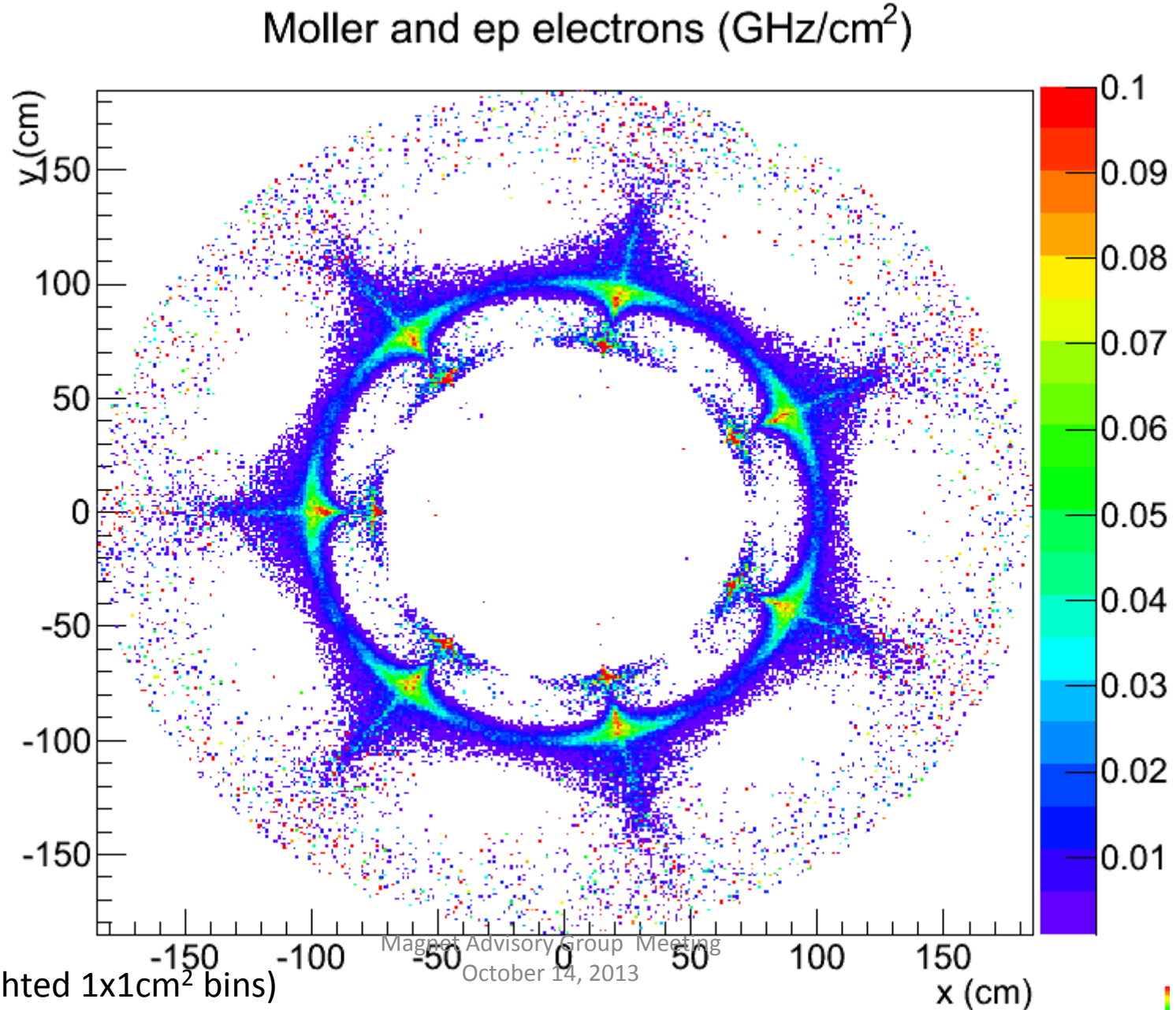
Any odd number of coils will work



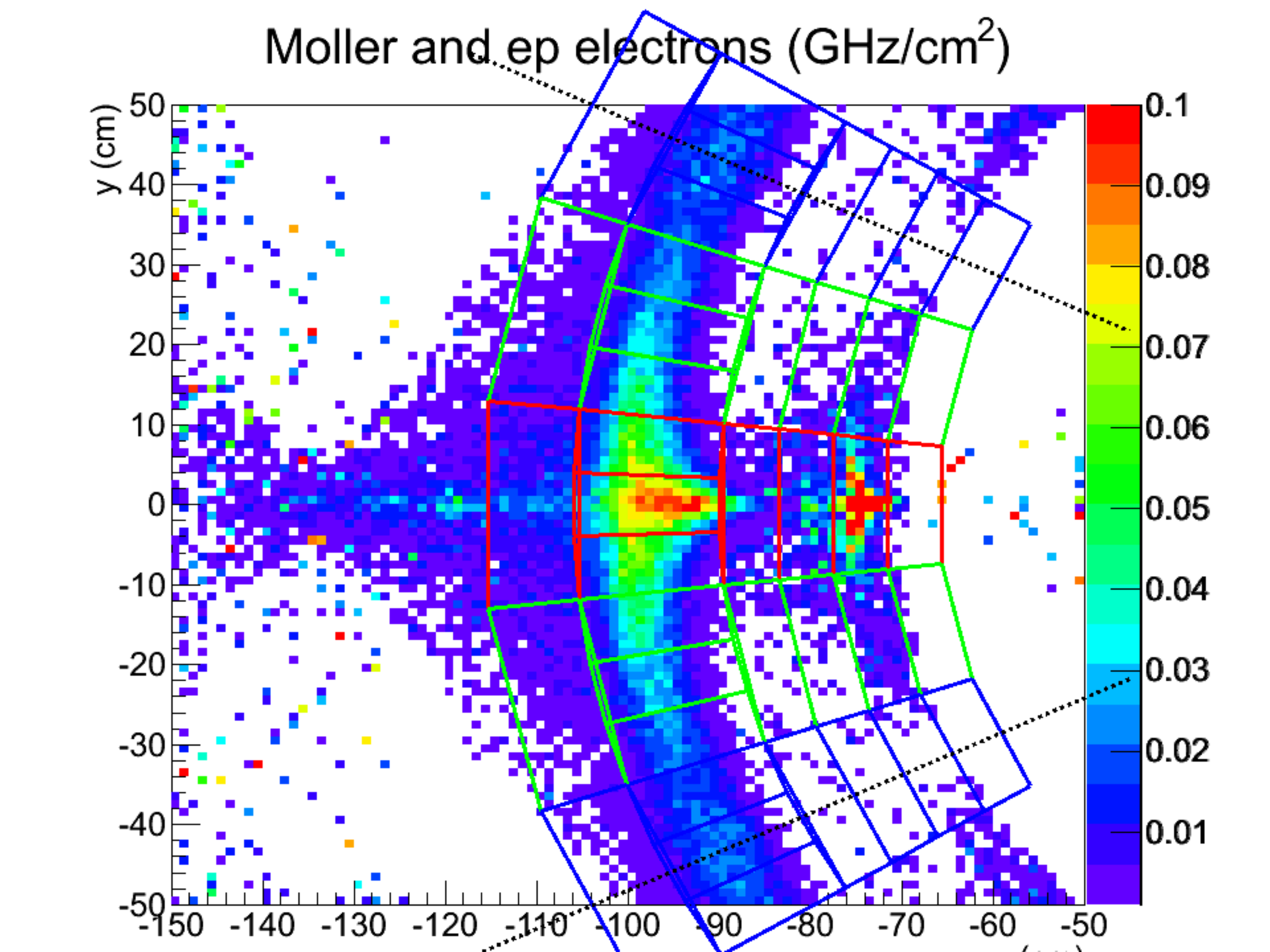


Lab Frame

Tracks in GEANT4



(Rate weighted 1x1cm^2 bins)

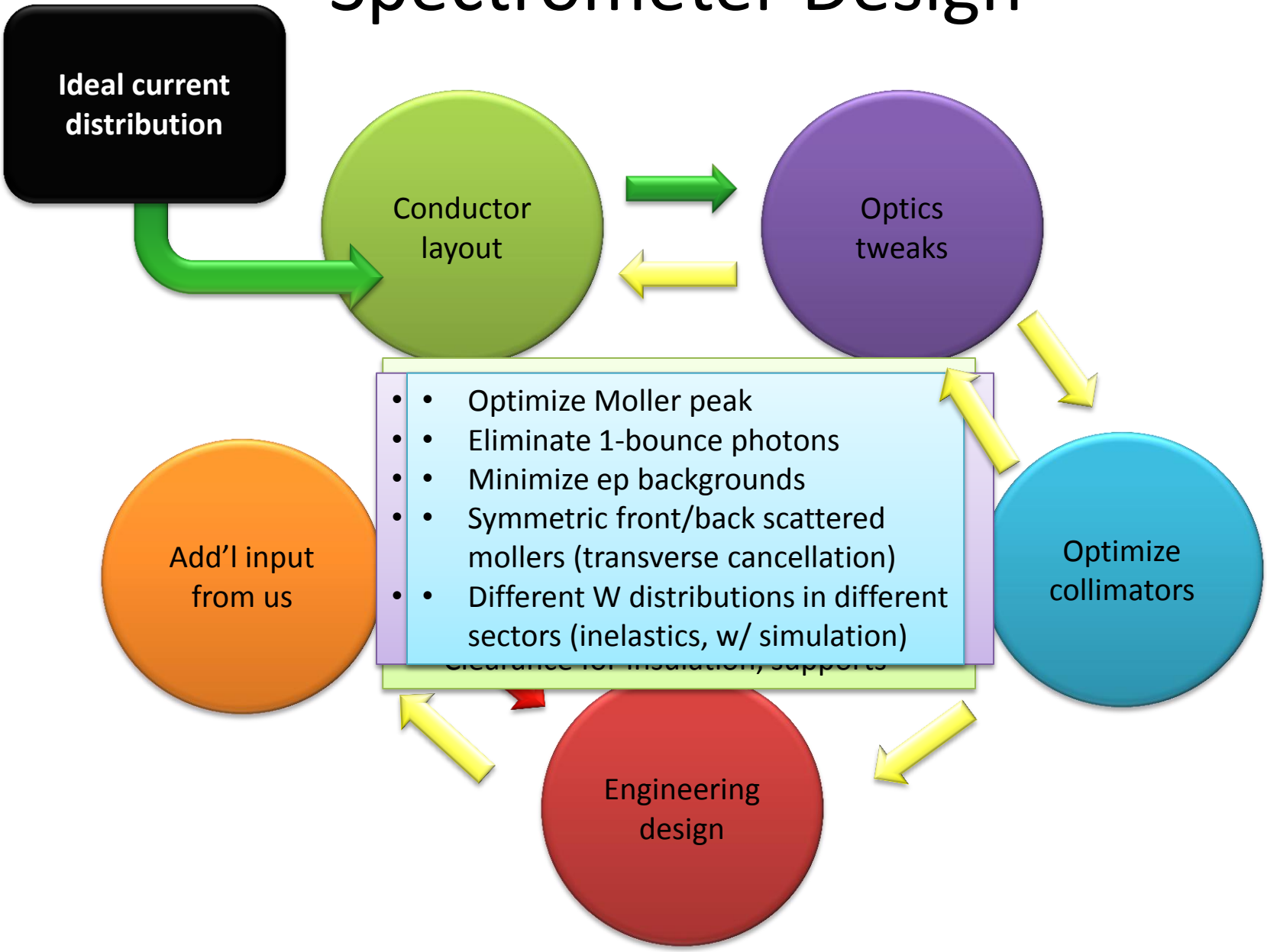

Moller and ep electrons (GHz/cm^2)
y (cm)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01

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



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***

Suggestions of Advisory Group

- larger conductor and hole ($\rightarrow$1550 A/cm^2)
- wanted a better representation of the fields, space constraints, etc., wanted Br, Bphi
- larger vacuum chamber instead of petals
- Wish list:
  - Get rid of negative bend
  - Use iron to reduce current density

No showstoppers!

Work since original proposal

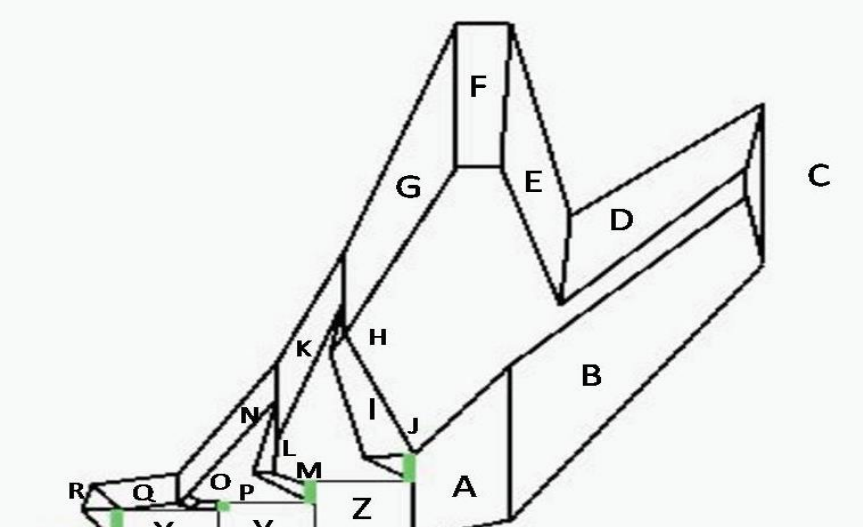
- First Engineering Review
  - Verified the proposal map in TOSCA
  - Created an actual conductor layout with acceptable optics

- 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

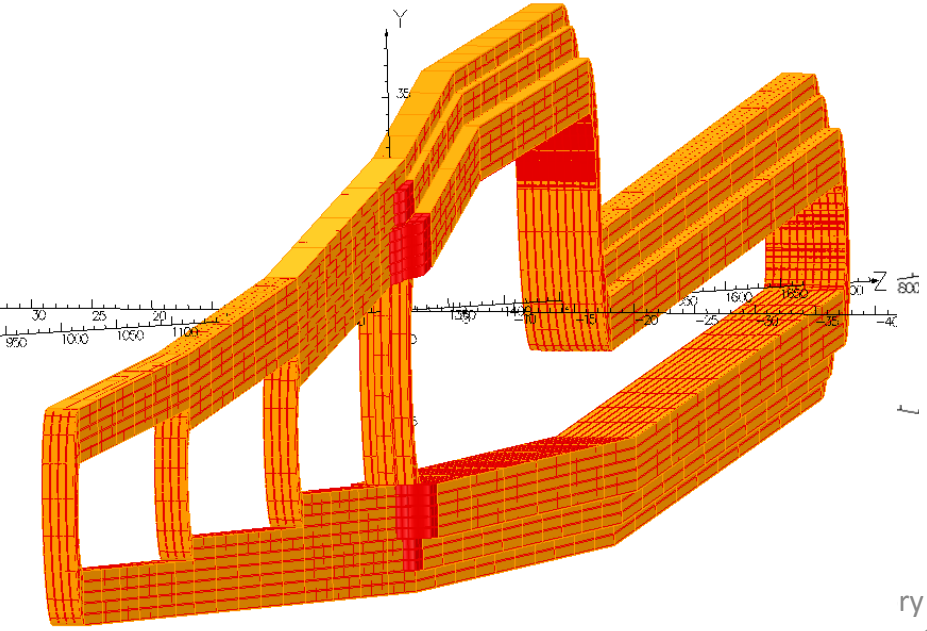


Actual conductor layout, with blocky version

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

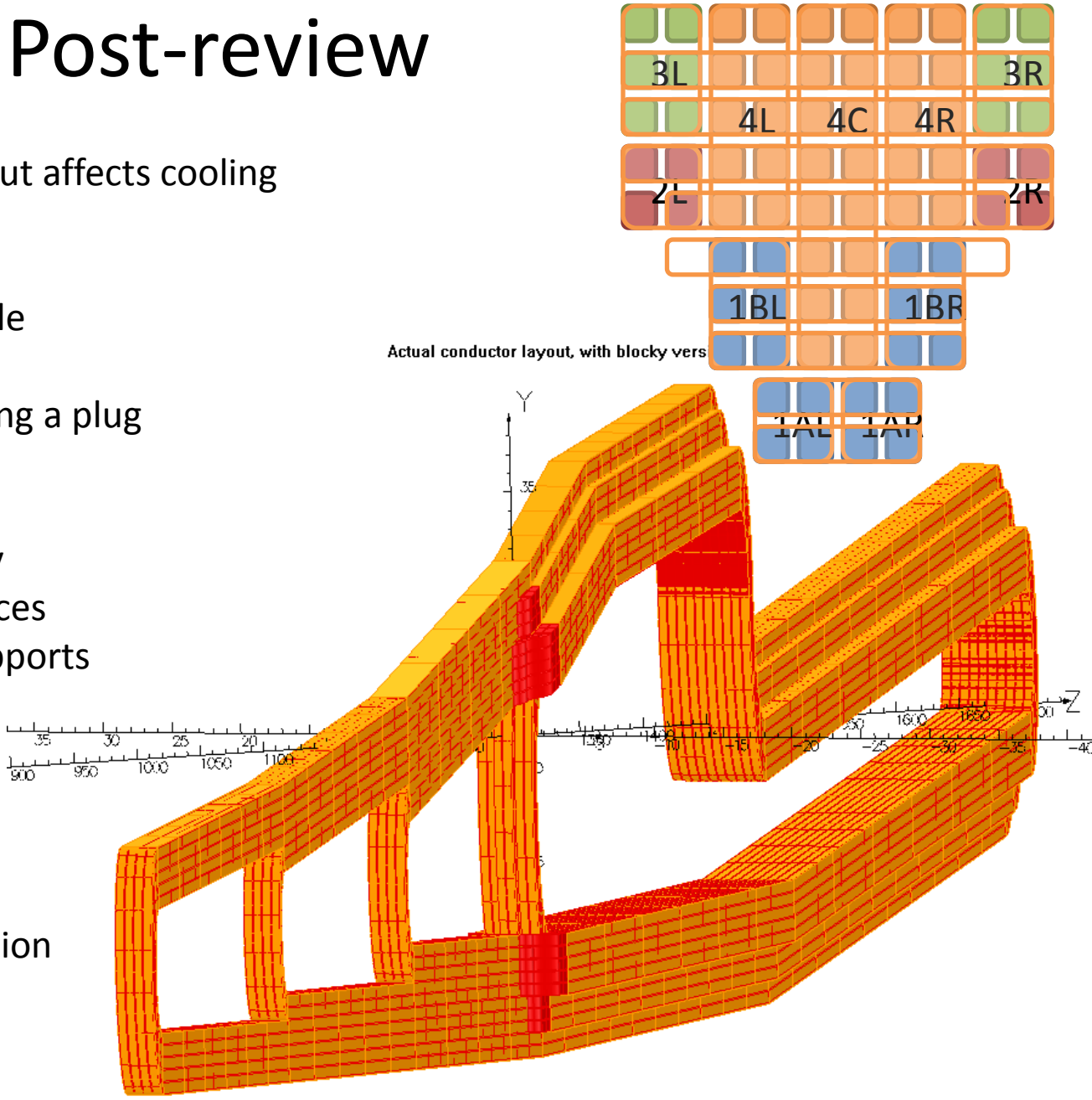
Created a first version with actual coil layout

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

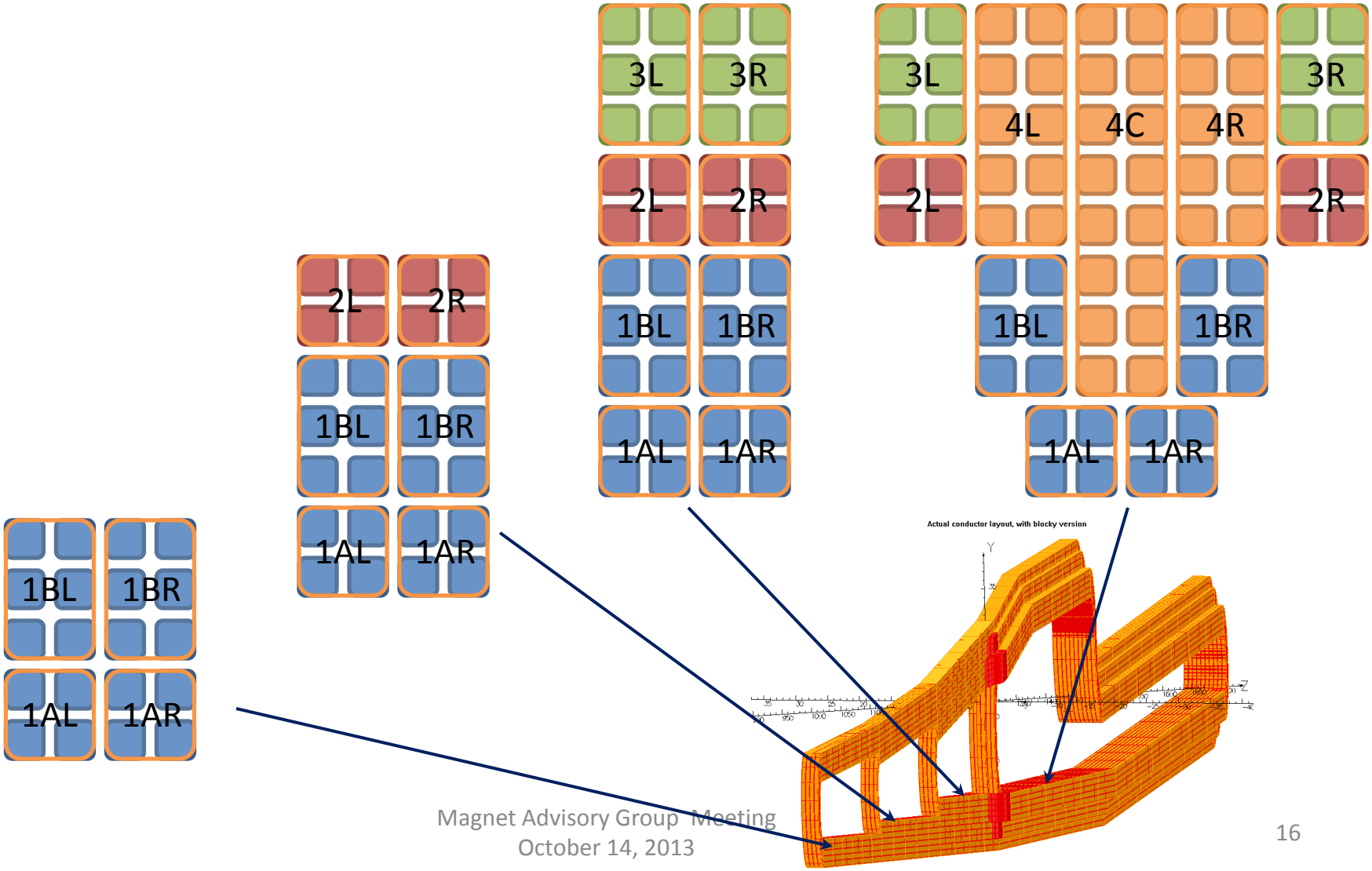
Concept 2 – Post-review

Current density not an issue, but affects cooling

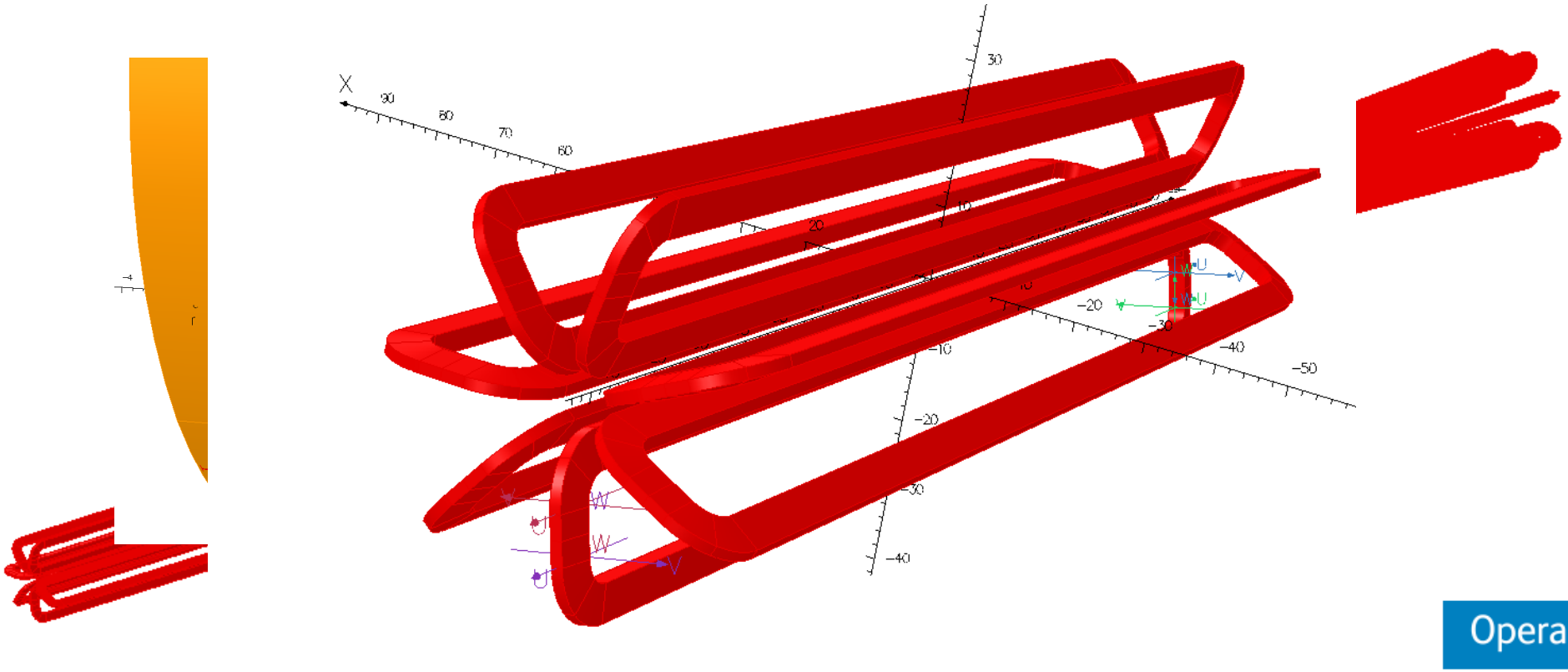
- Larger conductor
  - Larger water-cooling hole
  - Fewer connections
  - Less chance of developing a plug
- New layout
  - Use single power supply
  - Keep-out zones/tolerances
  - Need to think about supports
  - Study magnetic forces
- Continued simulation effort
  - Consider sensitivities
  - Re-design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



Layout

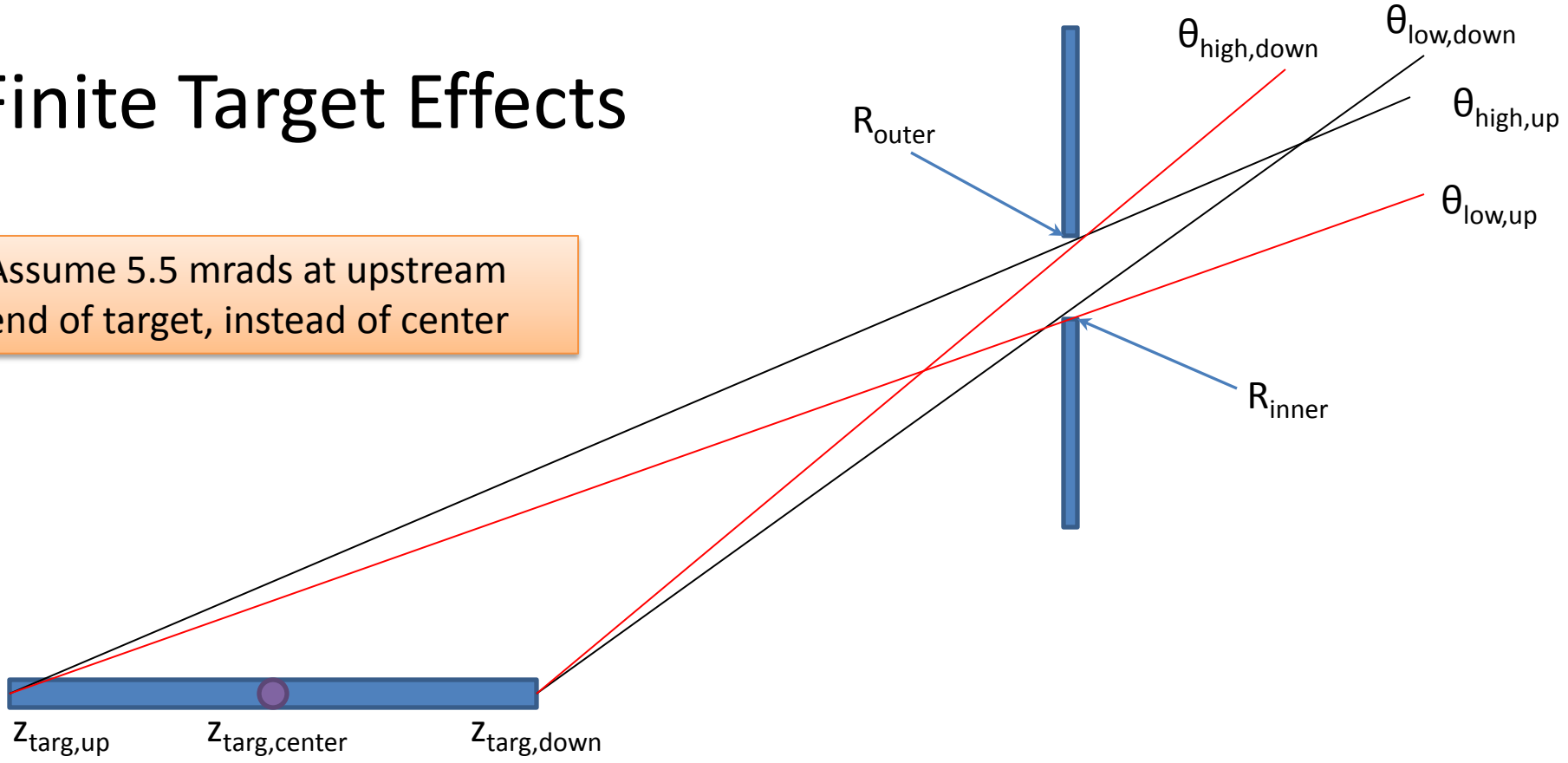

3L
3R
2L
2R
1BL
1BR
1AL
1AR
4L
4C
4R
Actual conductor layout, with blocky version

Upstream Torus



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

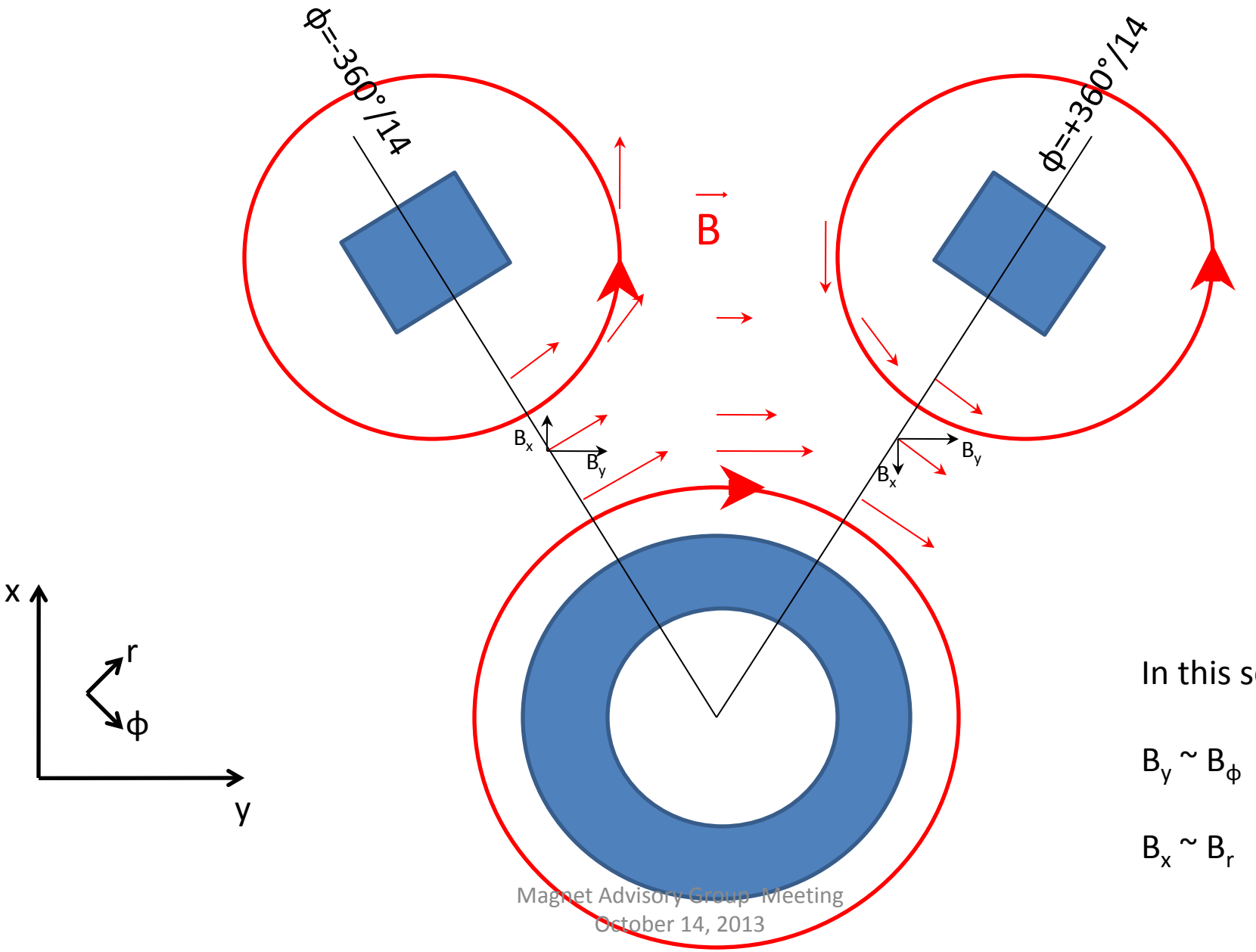
From center:

$\theta_{low,cen}$ = 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

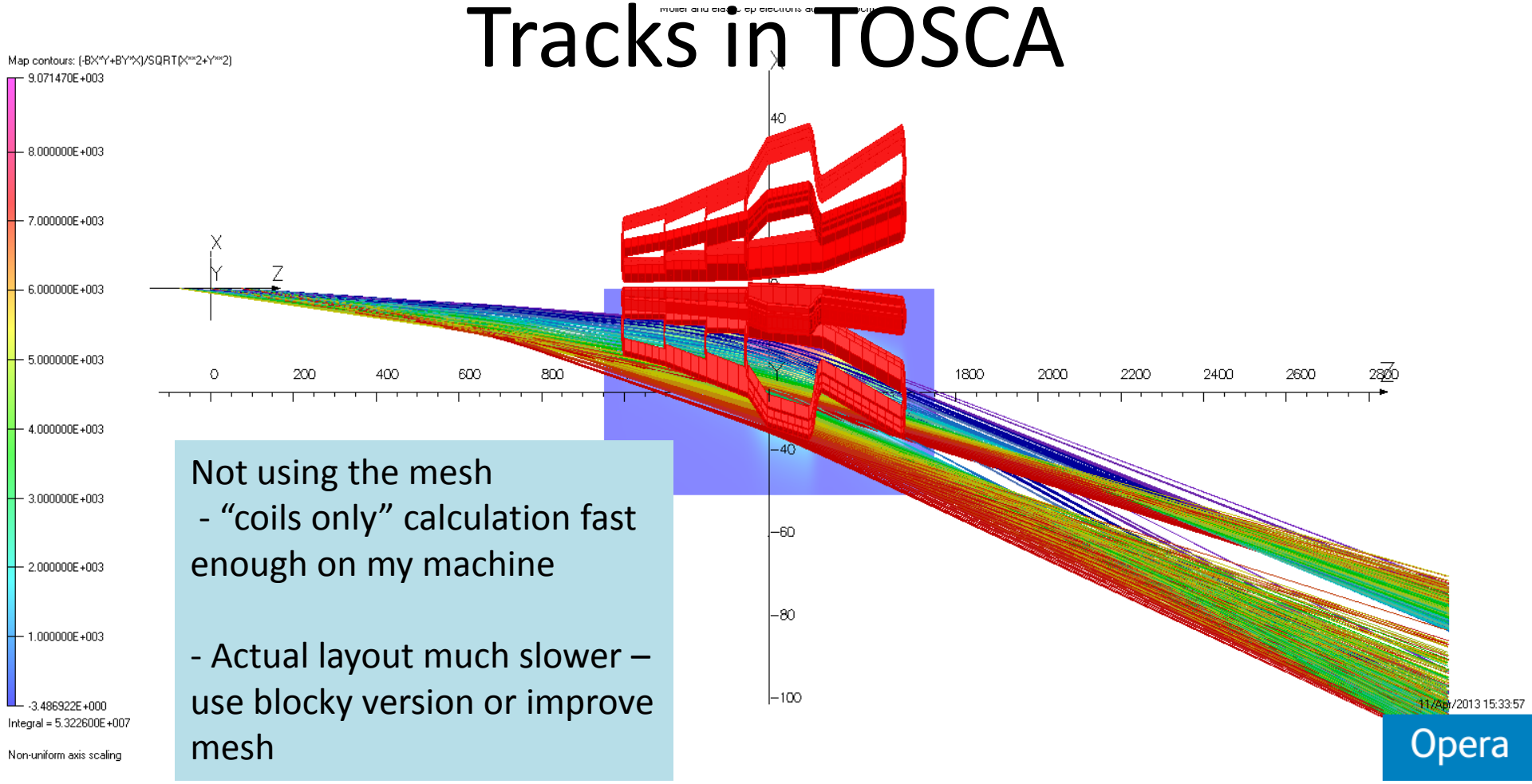


In this septant:

$B_y \sim B_\phi$

$B_x \sim B_r$

Tracks in TOSCA



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

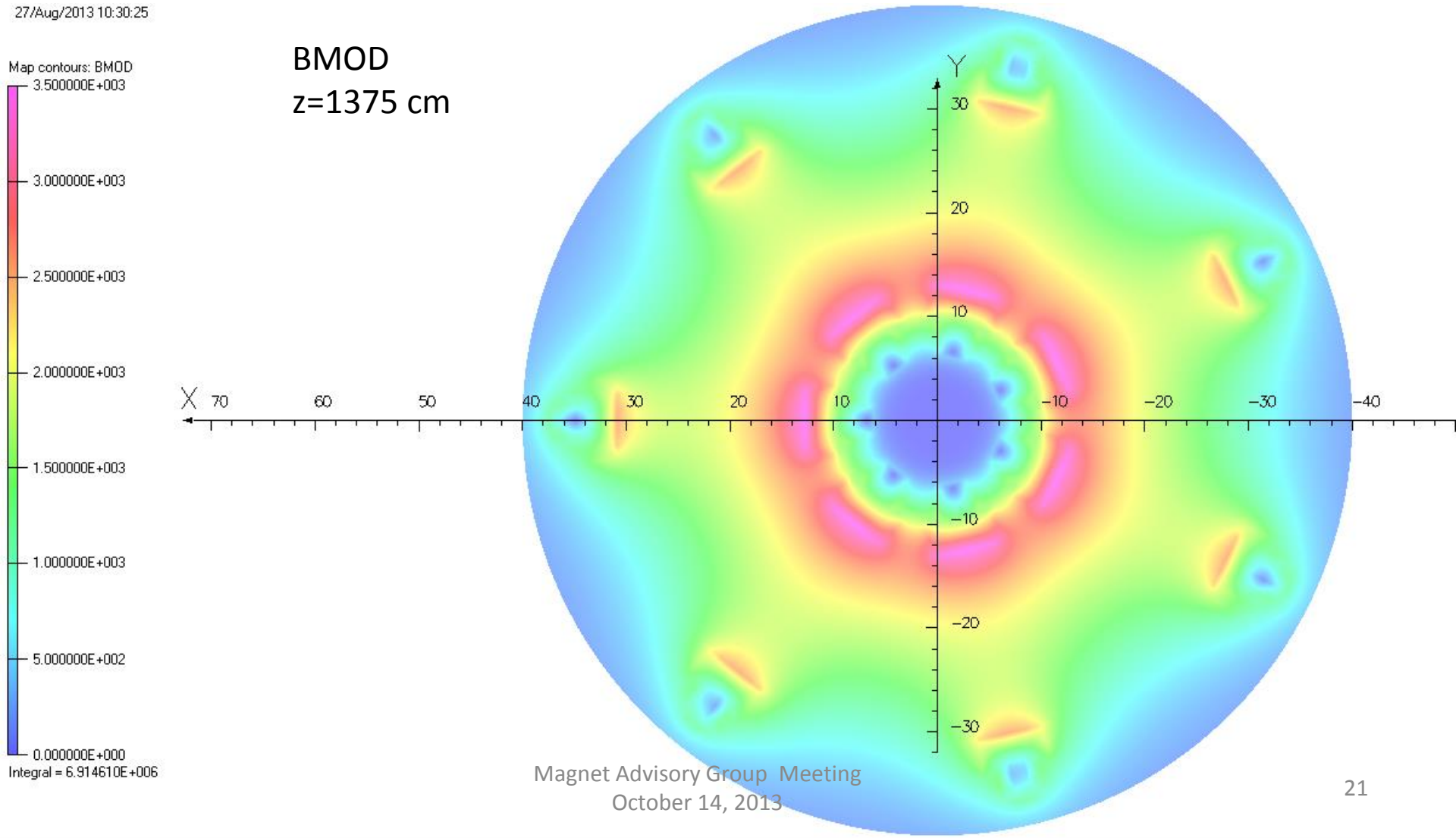
- Actual layout much slower – use blocky version or improve mesh

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

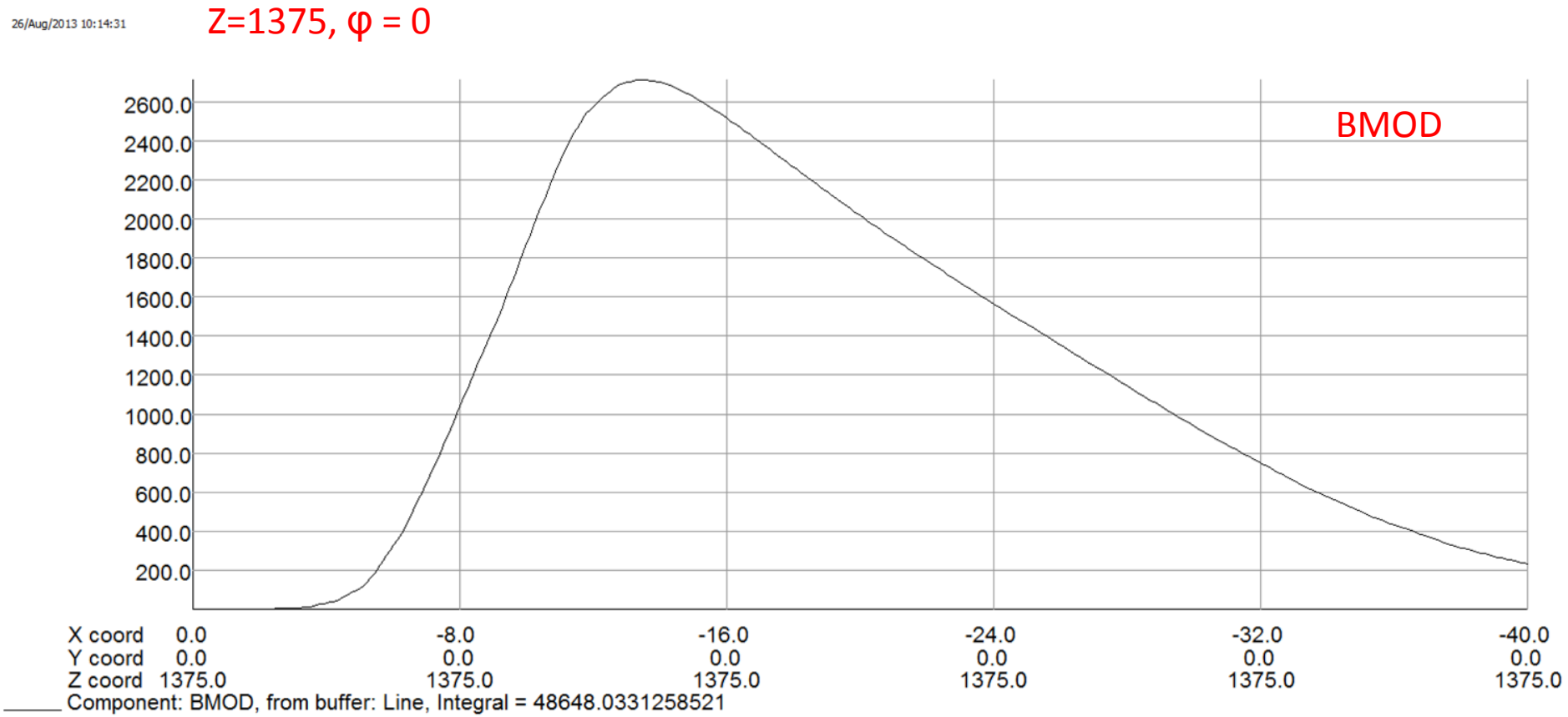
All phi values

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

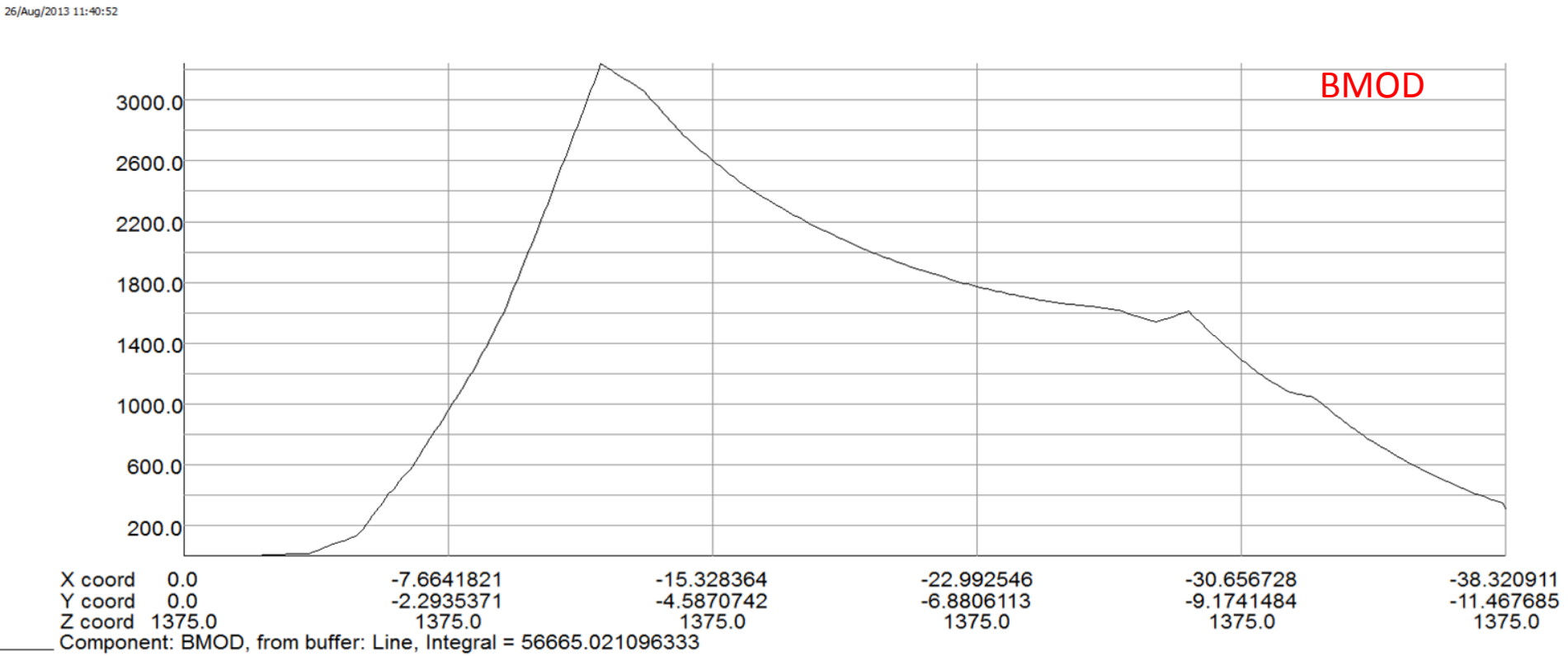
Field representations



Radial plot, middle of open sector

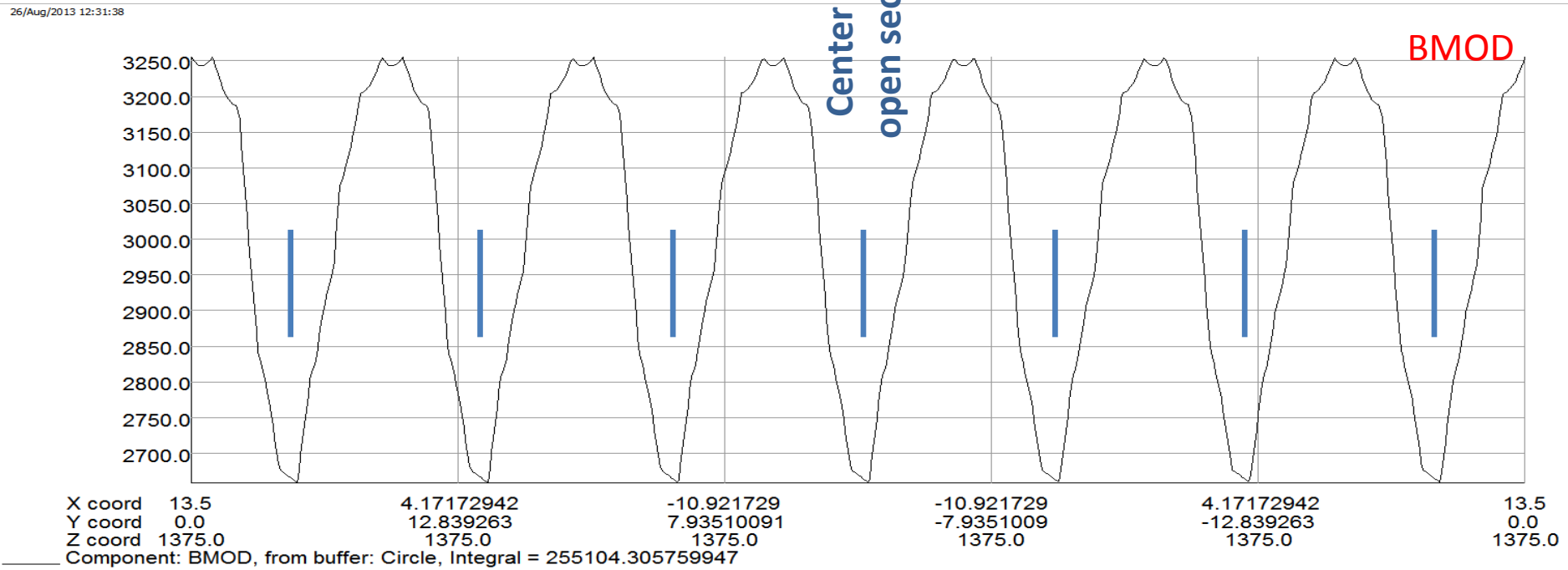


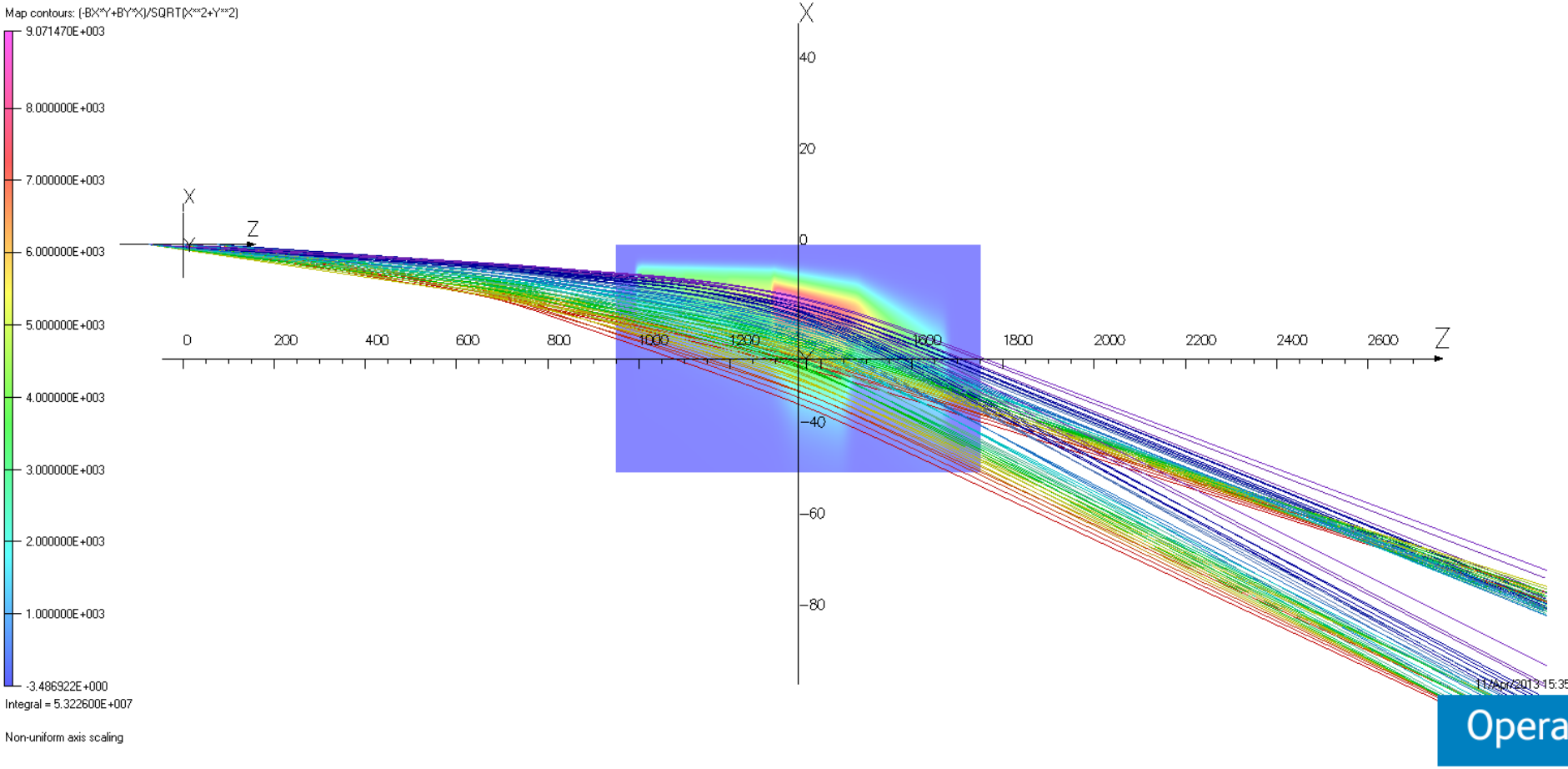
Radial plot, edge of open sector



Around Azimuth

Z=1375, r = 13.5 cm

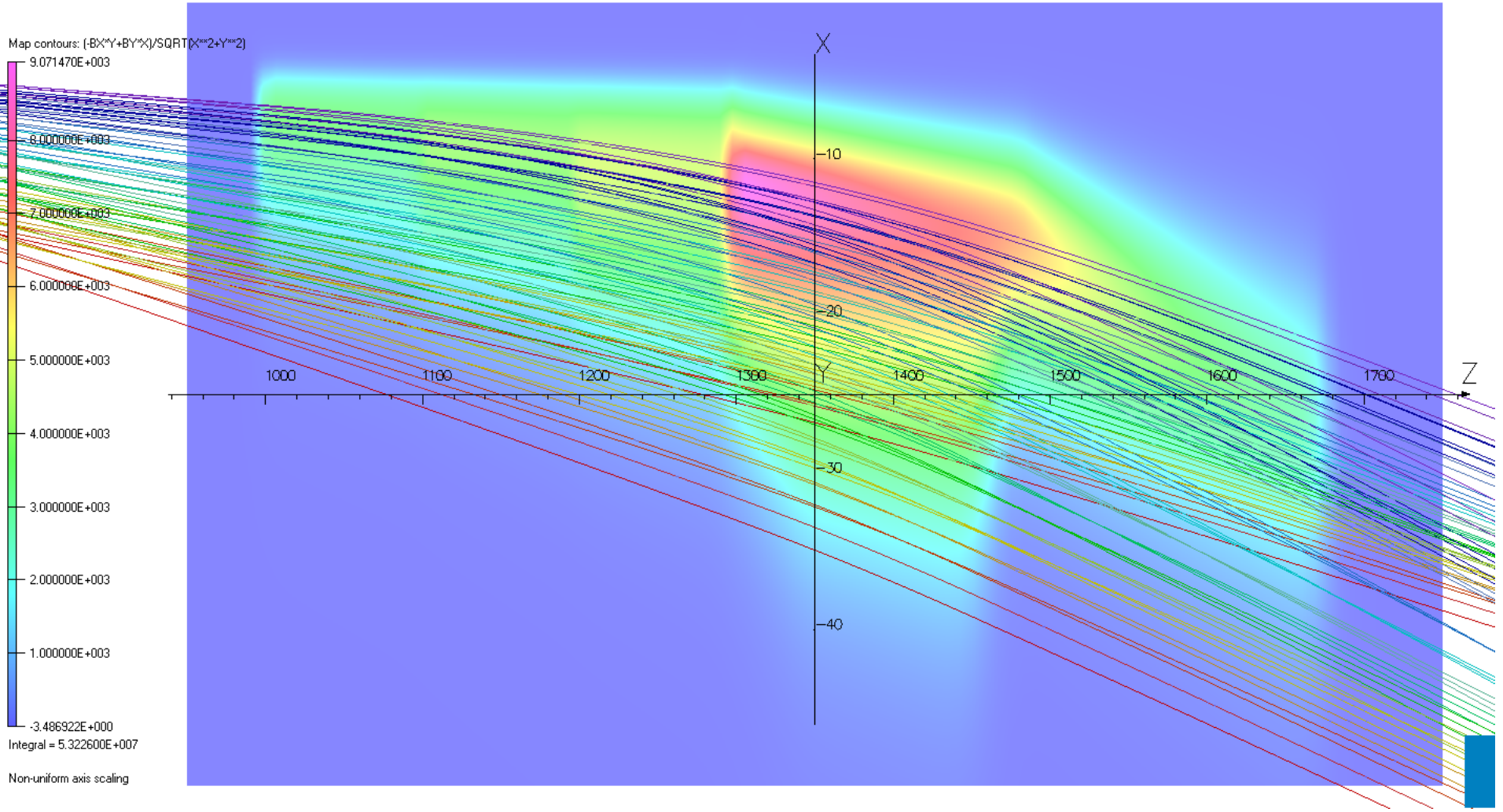




up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

phi=0 only

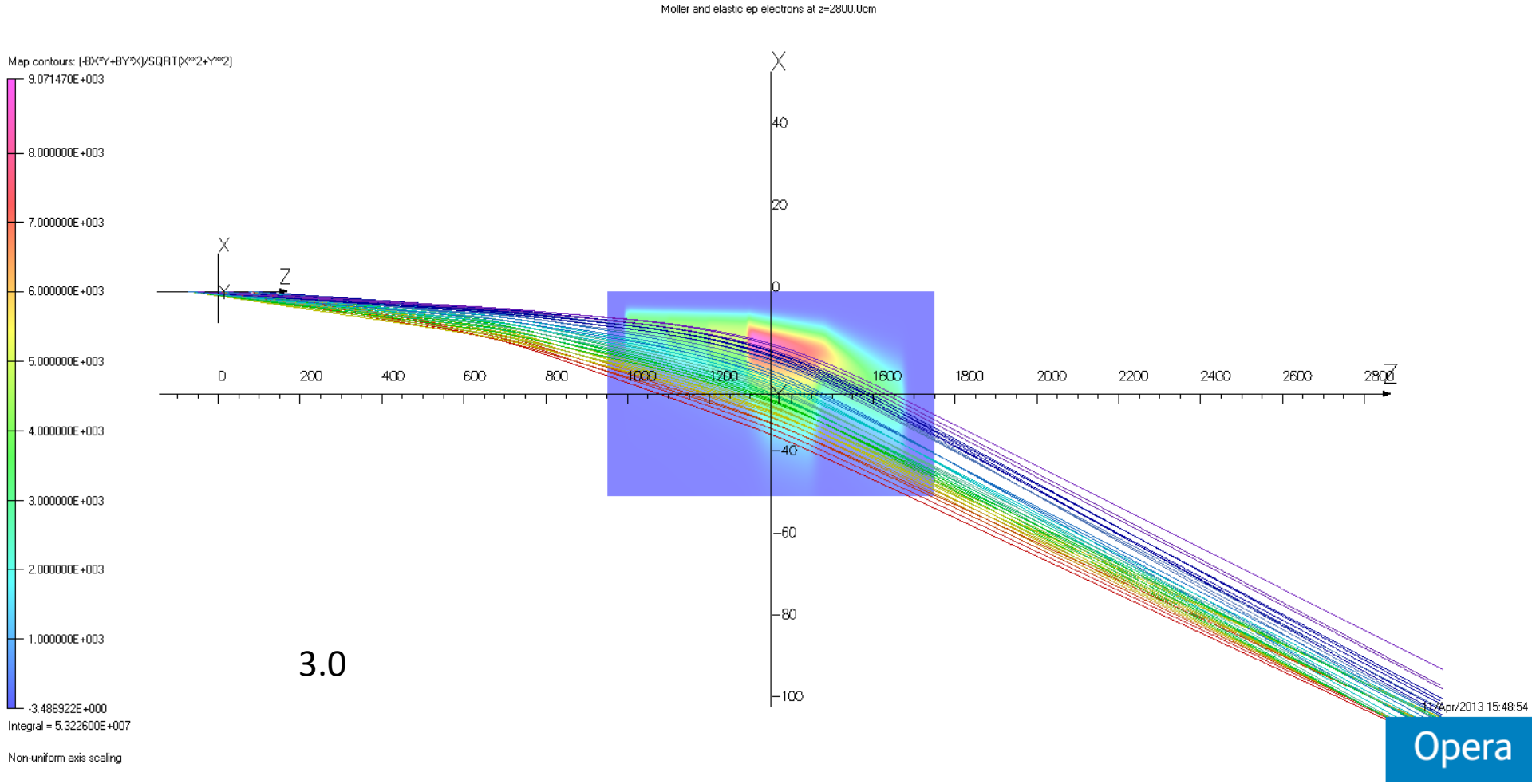
Tracks colored by theta from purple to red (low to high)



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

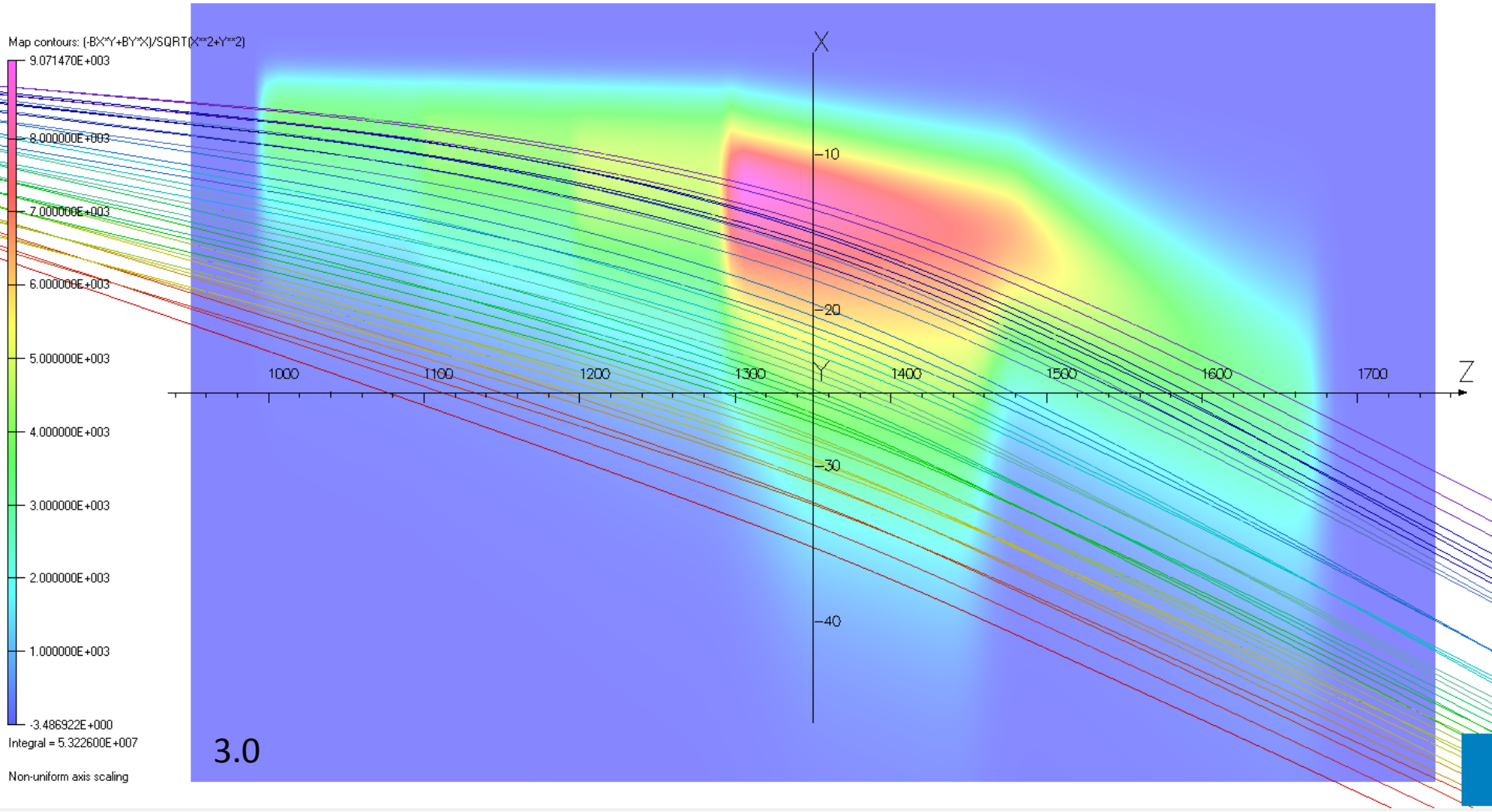
Tracks colored by theta from purple to red (low to high)



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 , Mollers only

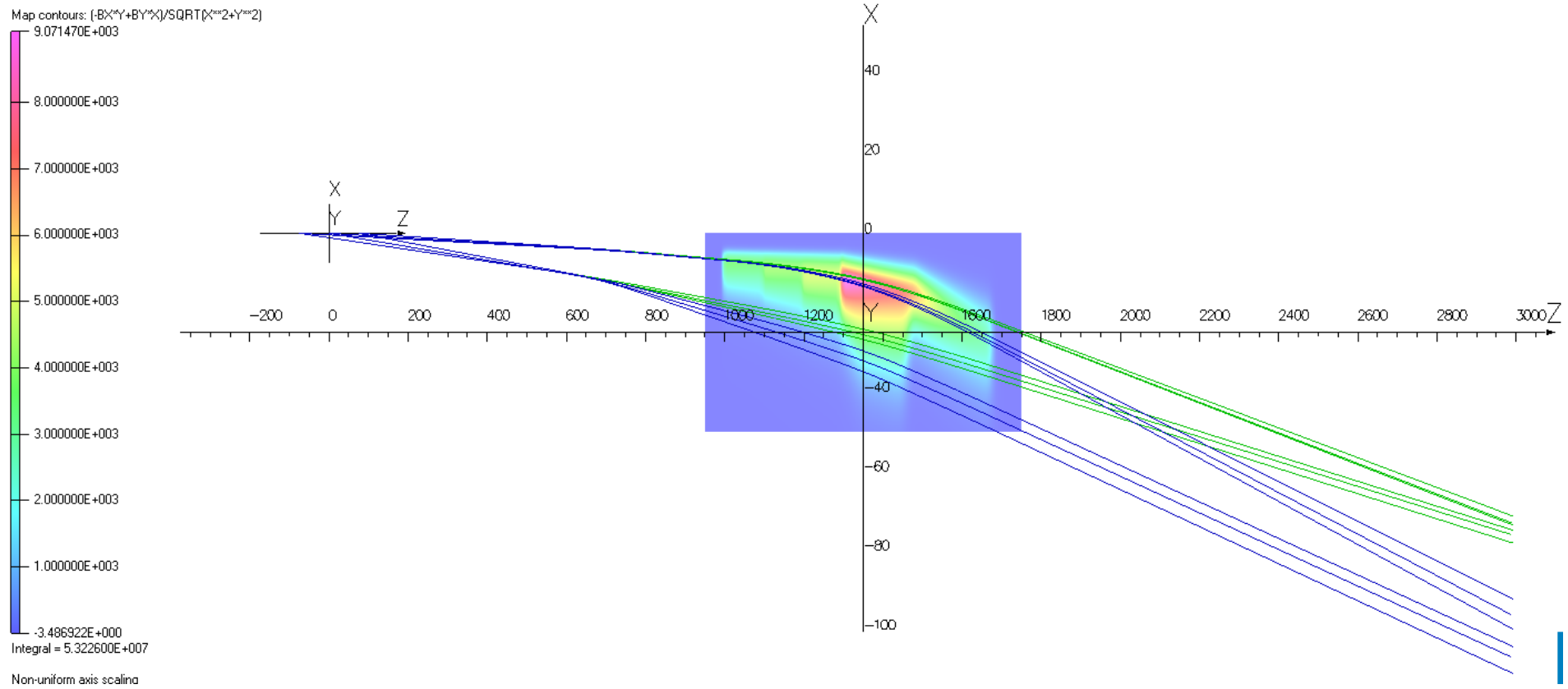
Tracks colored by theta from purple to red (low to high)



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

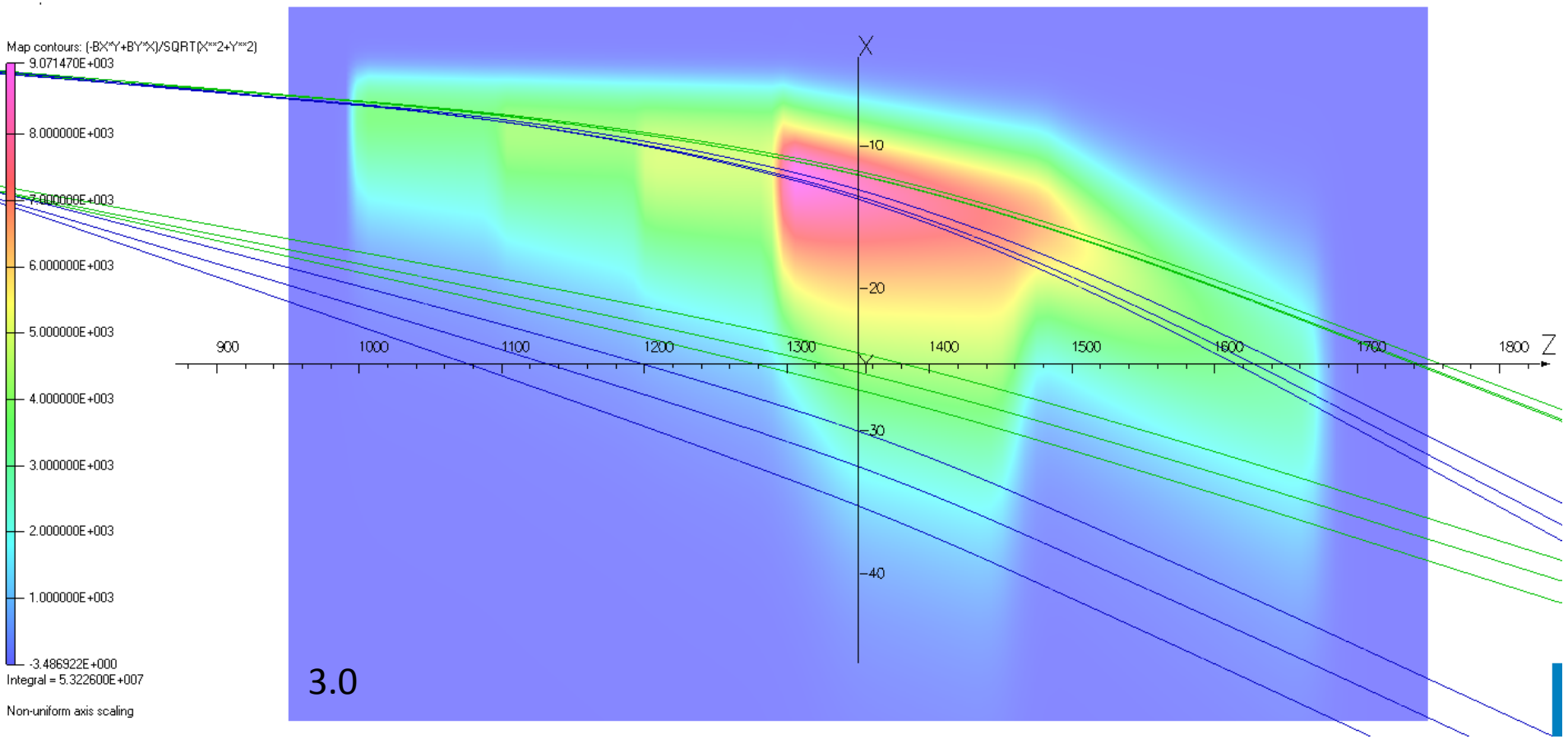
phi=0 only, near magnet, mollers only

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

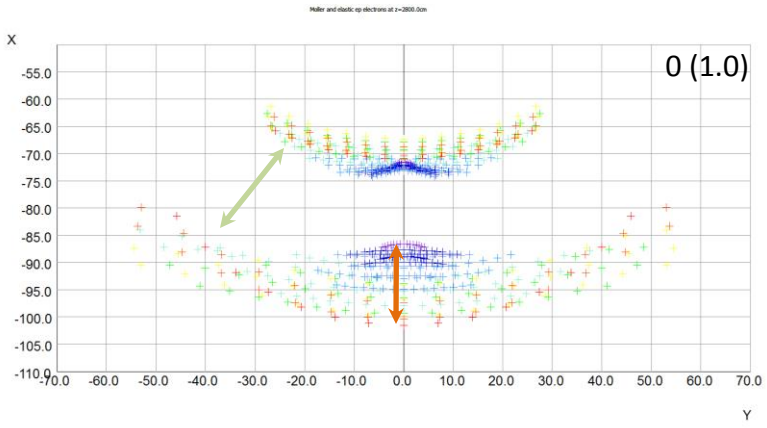
green – eps
blue - mollers

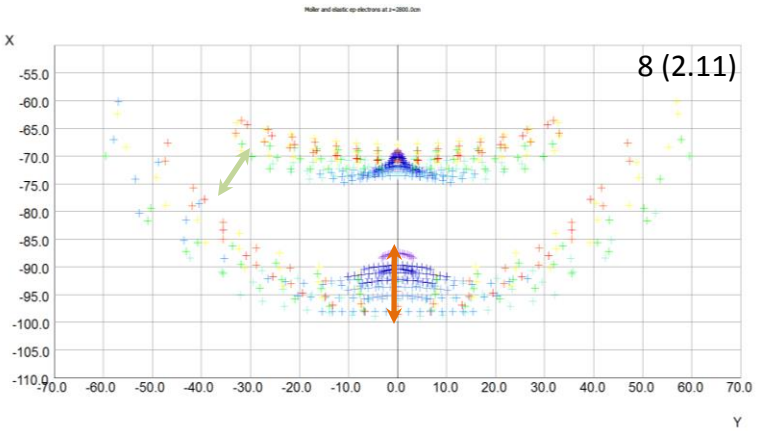


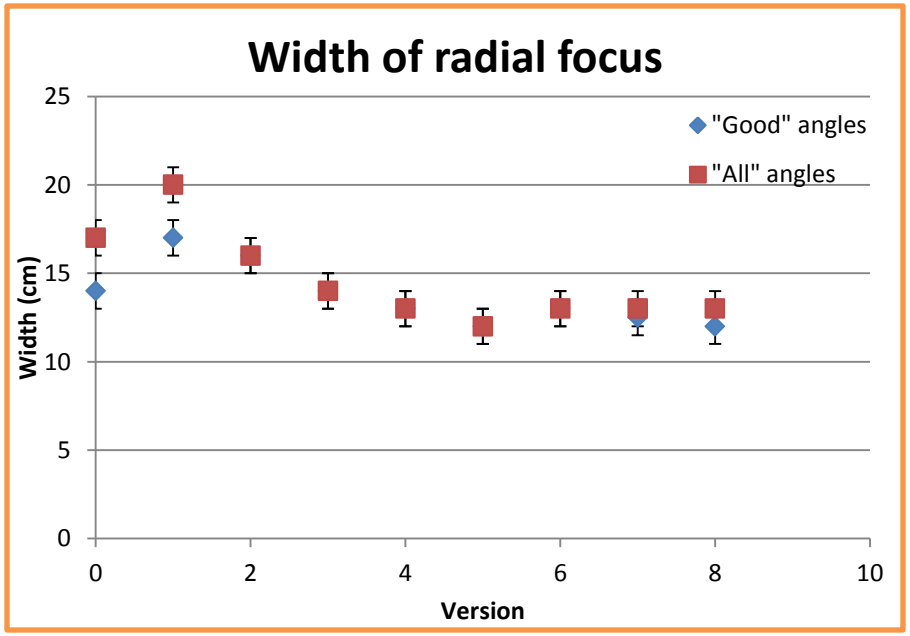
up (z0 =-75 cm) 5.5 and 15 mrads
middle (z0 =0 cm) 6.0 and 17 mrads
down (z0 =75 cm) 6.5 and 19 mrads
phi=0 only, near magnet

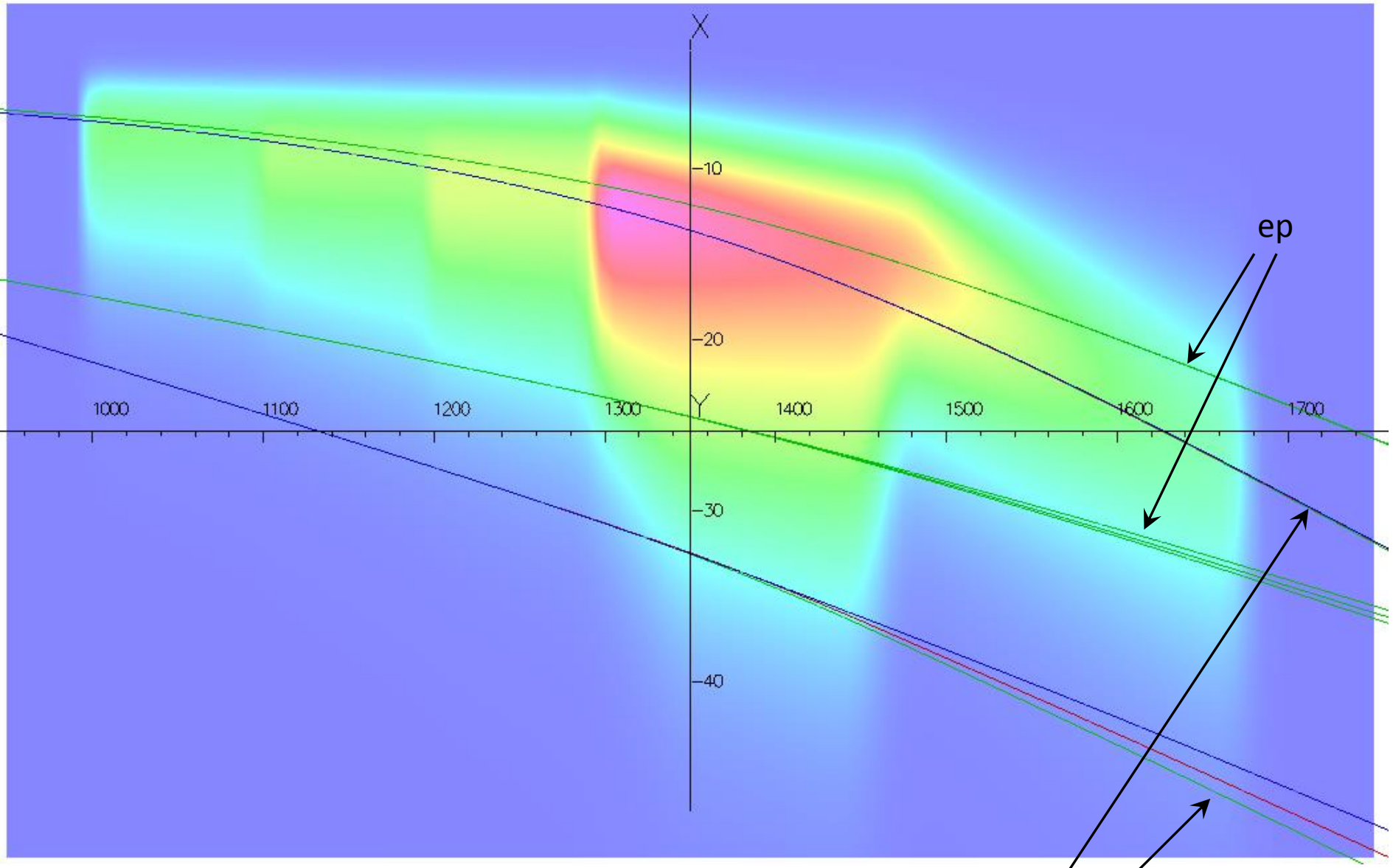
green – eps
blue - mollers

Tweaking the Optics



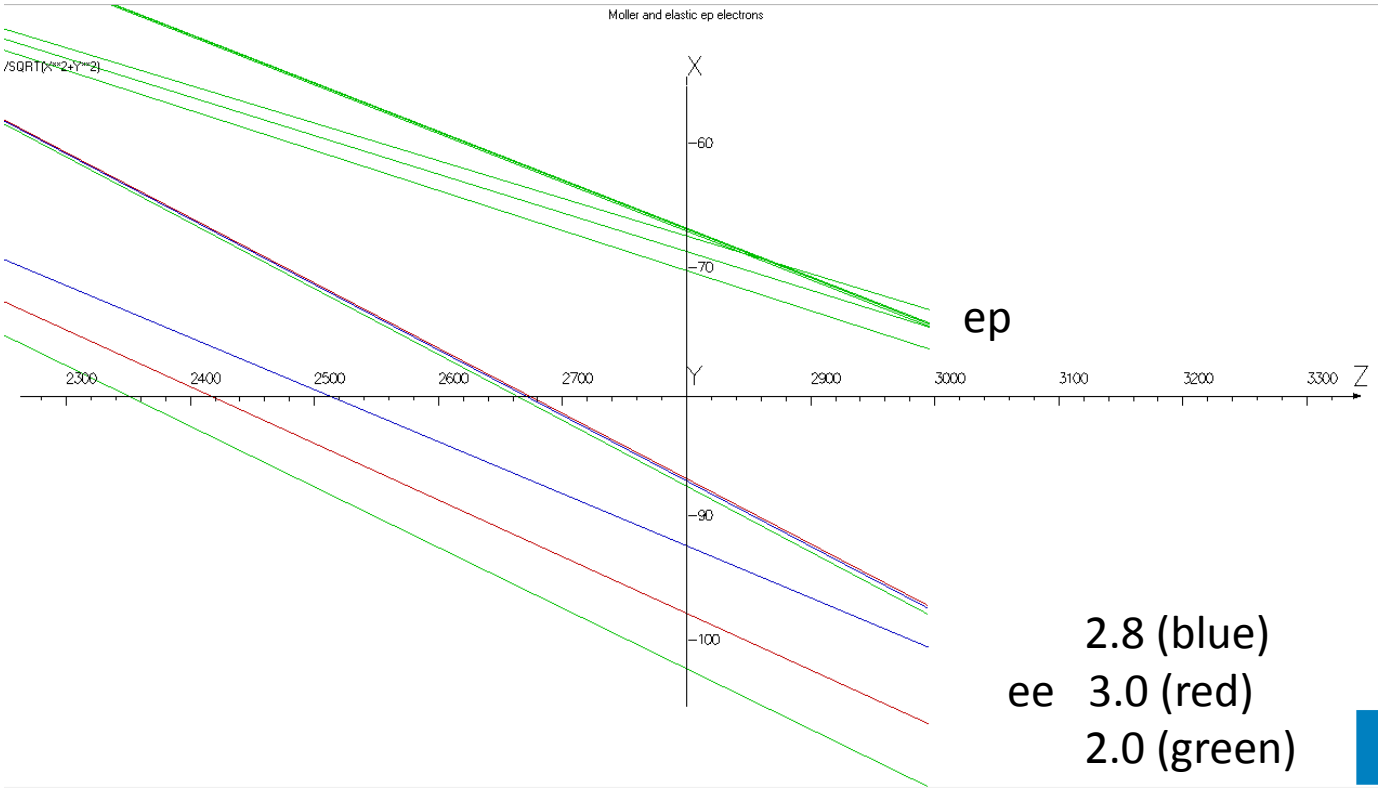




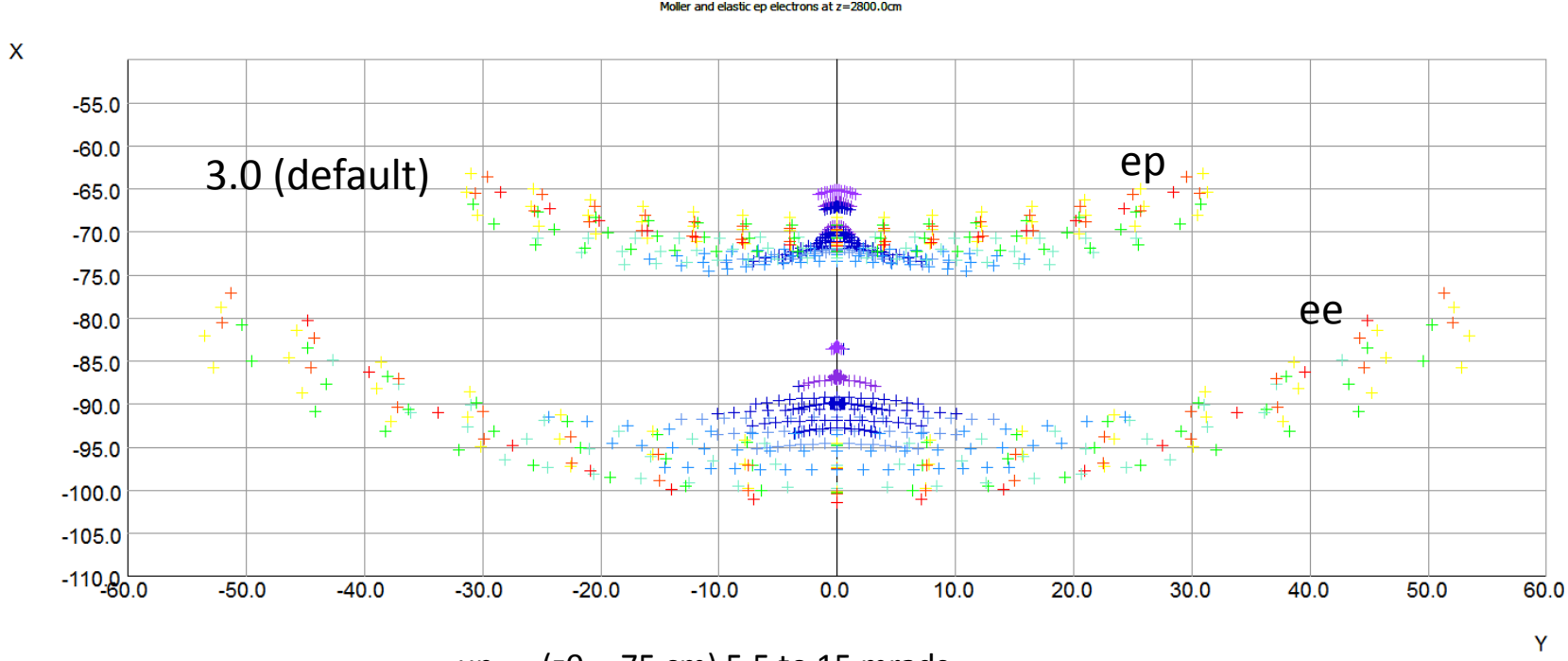


Tracks from middle of target (z=0), phi =0 only
6.0 and 17 mrads

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

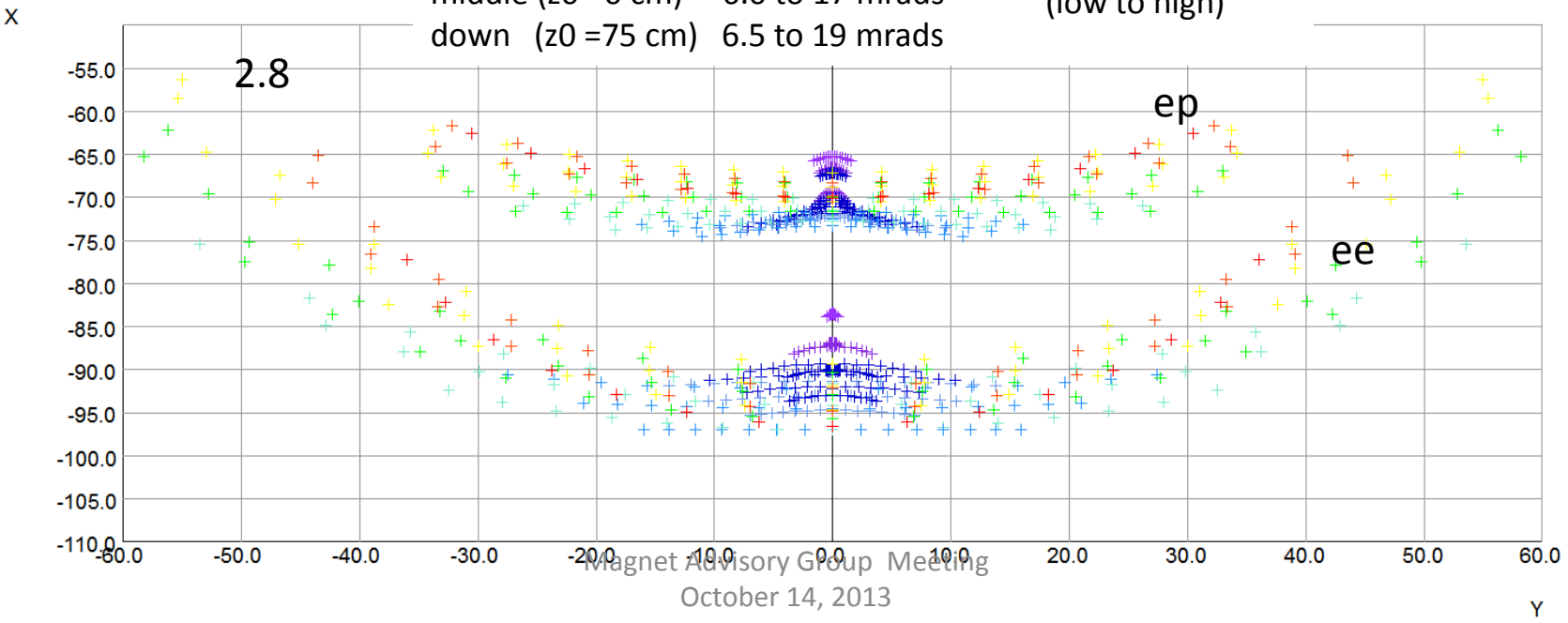


Tracks from center of target, phi =0 only
6.0 and 17 mrads



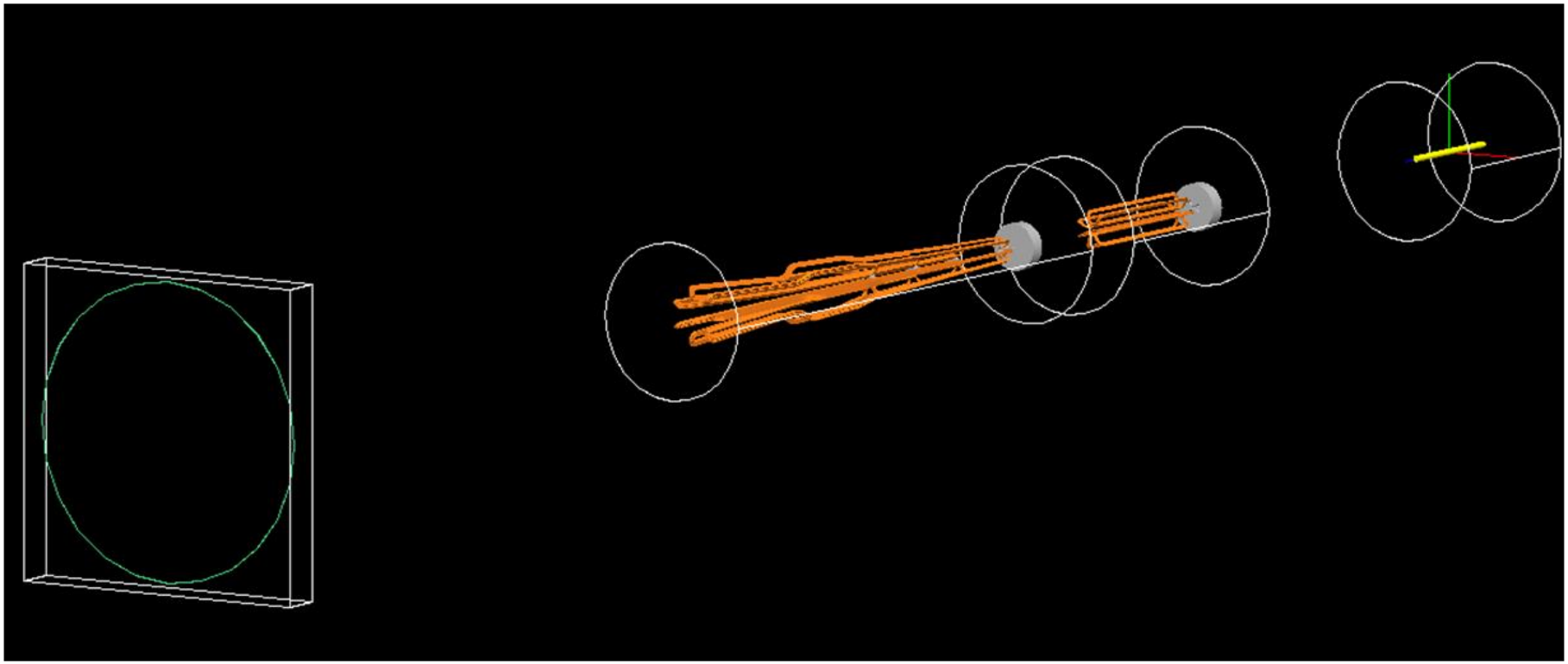
up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

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

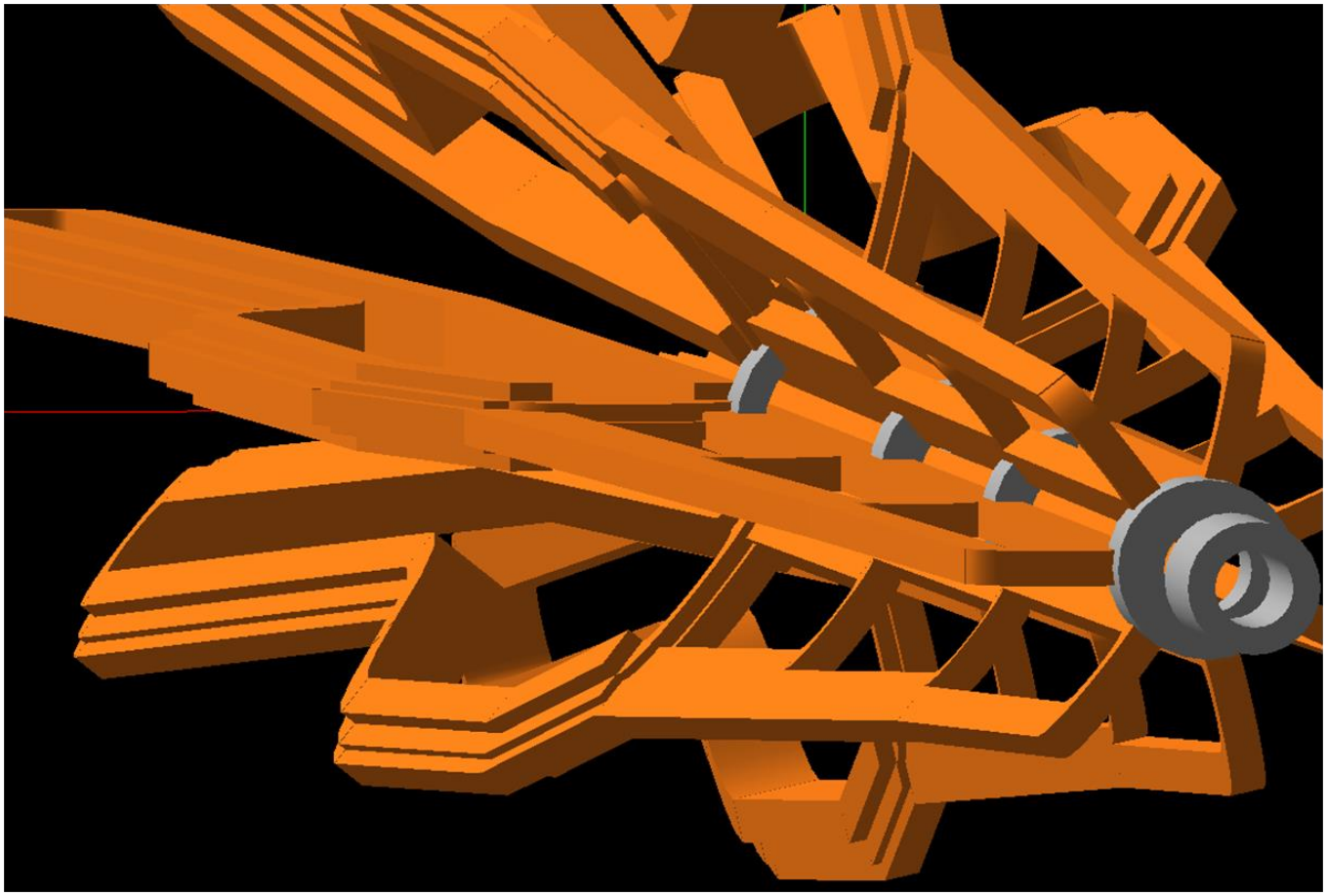


GEANT4

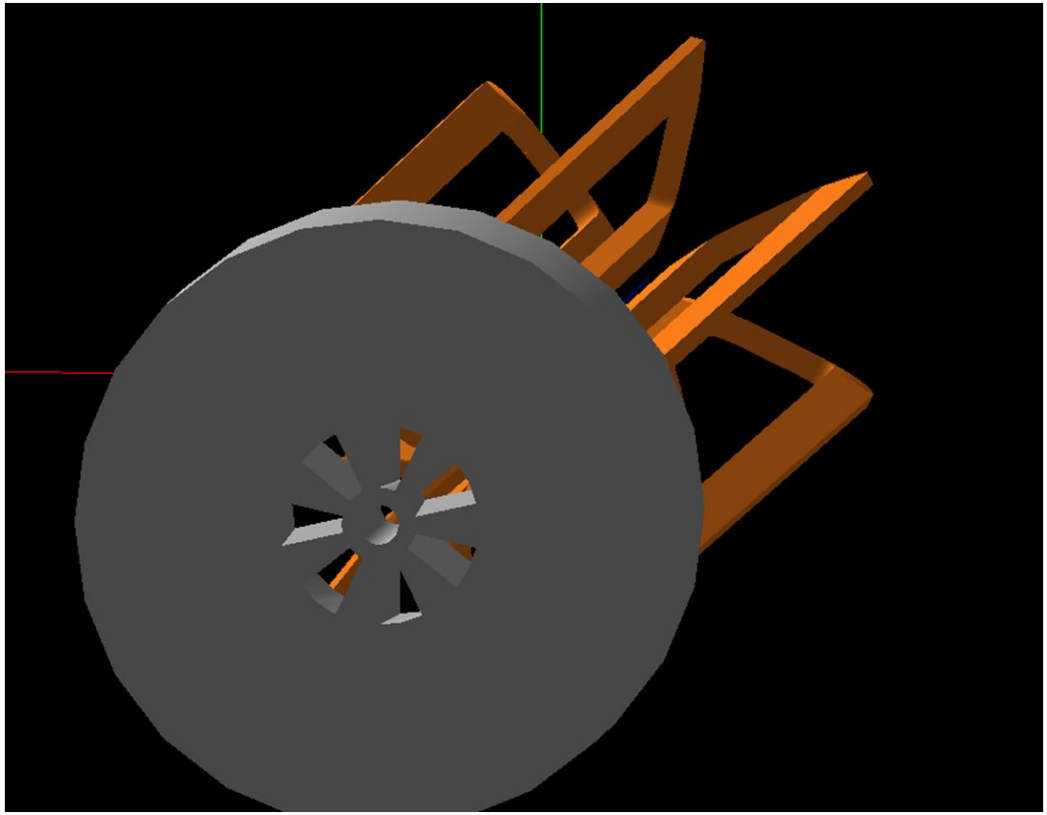
- Moved to GDML geometry description
- Defined hybrid and upstream toroids
  - Parameterized in same way as the TOSCA models



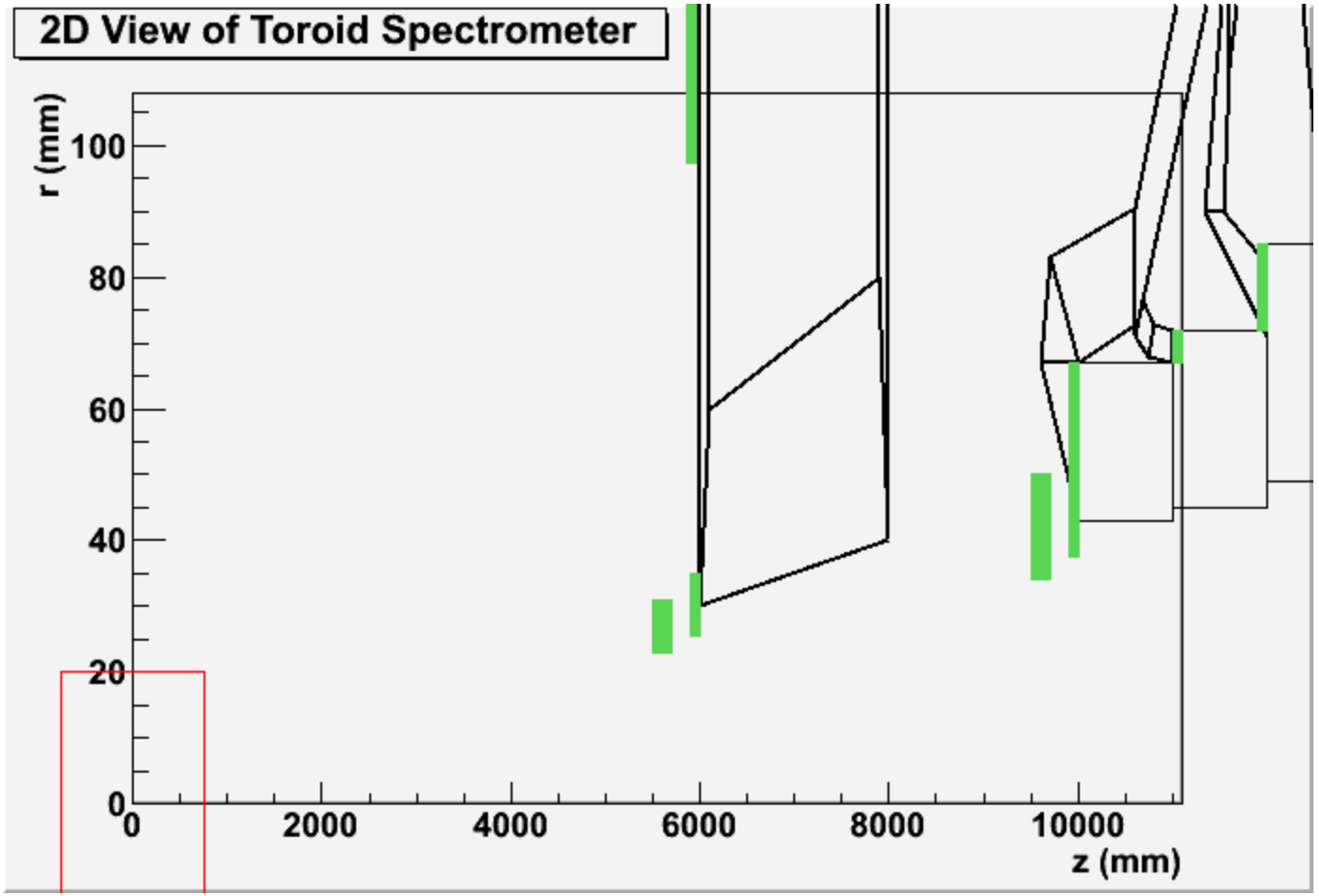
GEANT4 - Collimators

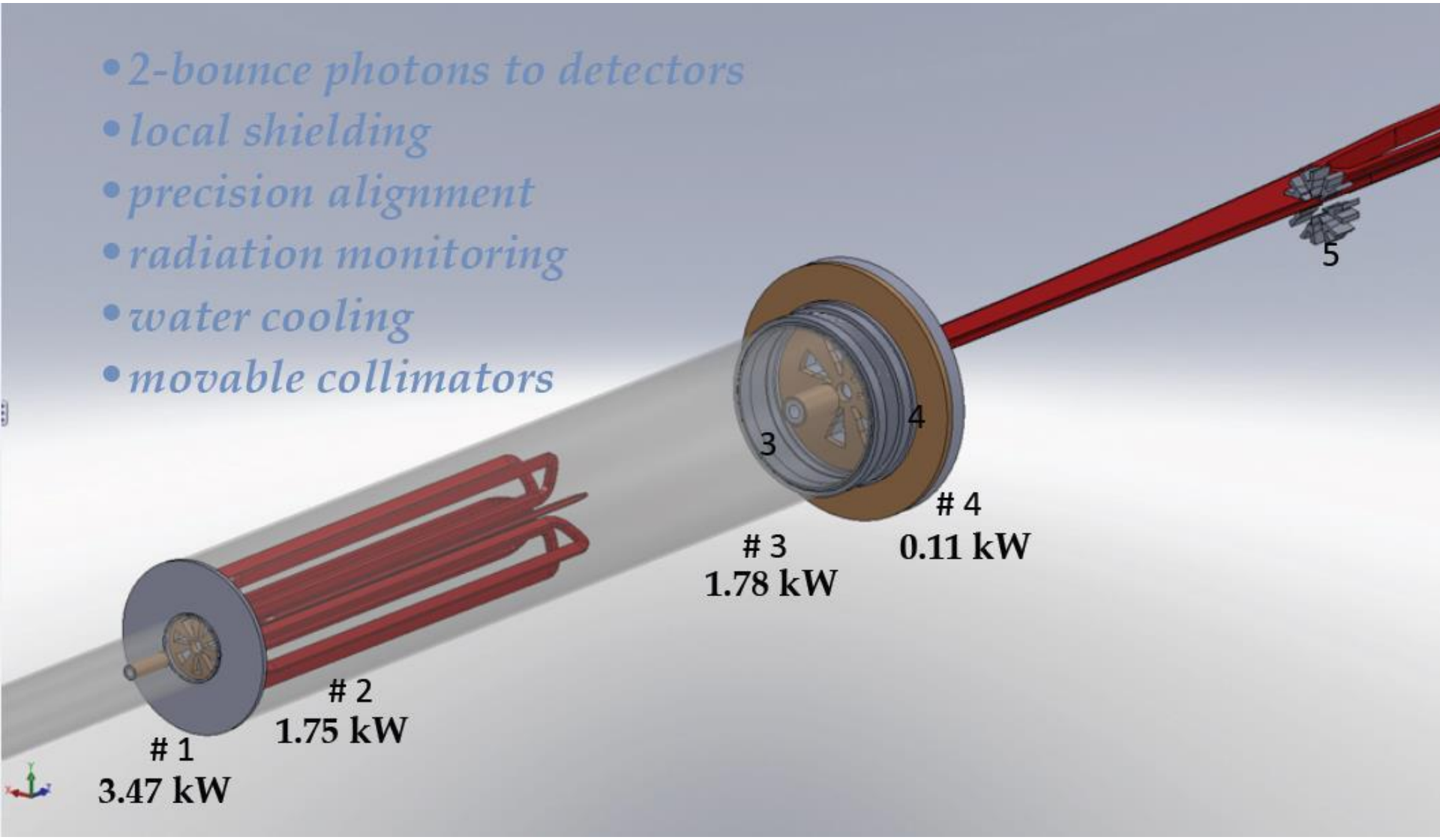


GEANT4 – Acceptance definition

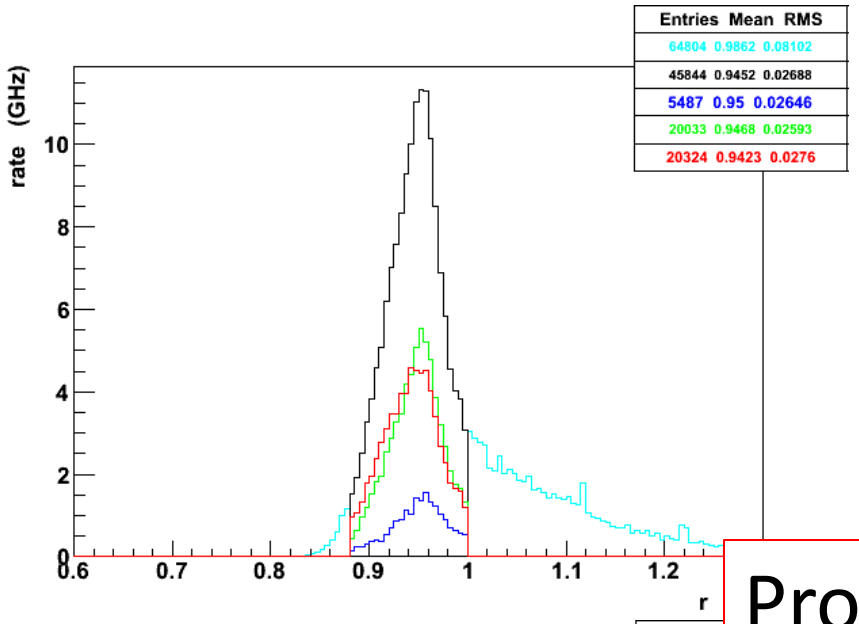


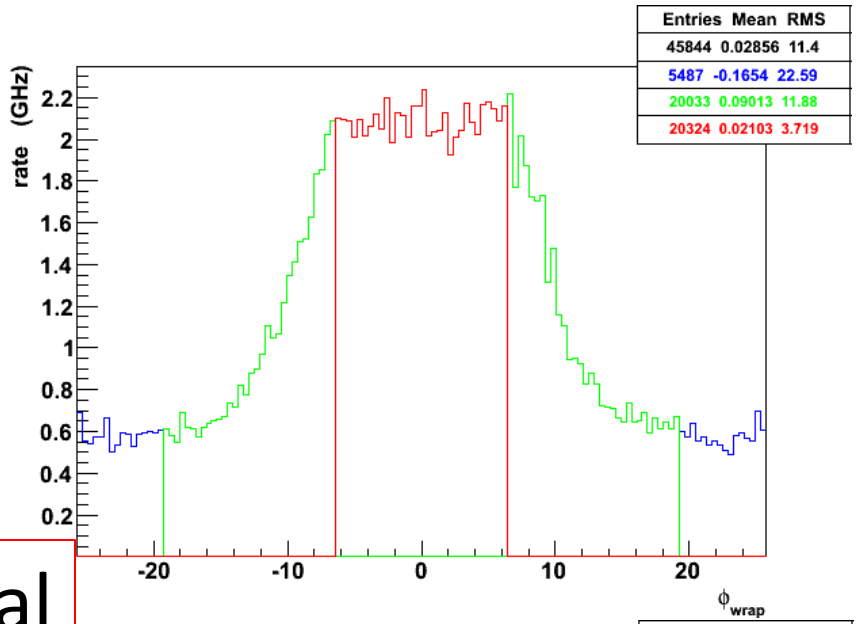
Collimator Optimization



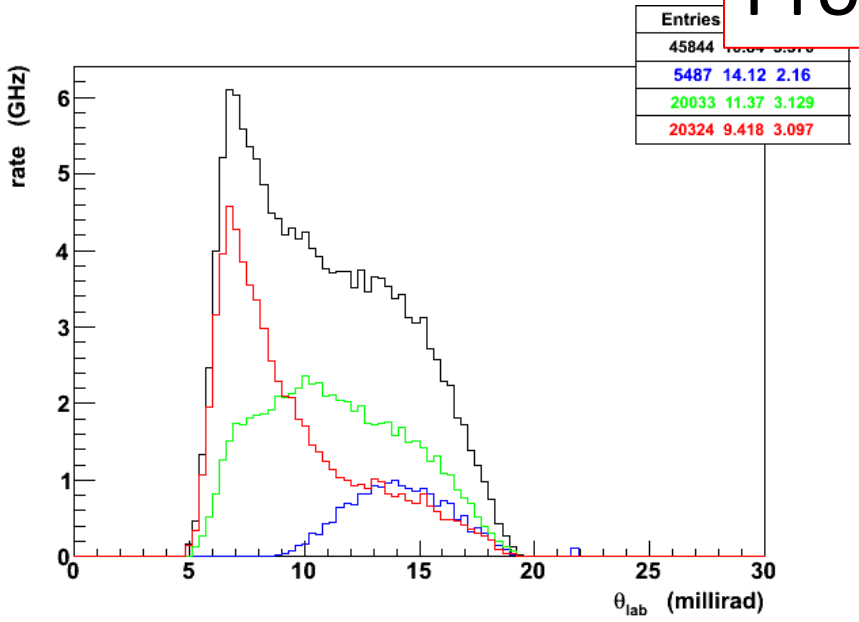

• 2-bounce photons to detectors
• local shielding
• precision alignment
• radiation monitoring
• water cooling
• movable collimators
5
4
3
4
0.11 kW
3
1.78 kW
2
1.75 kW
1
3.47 kW

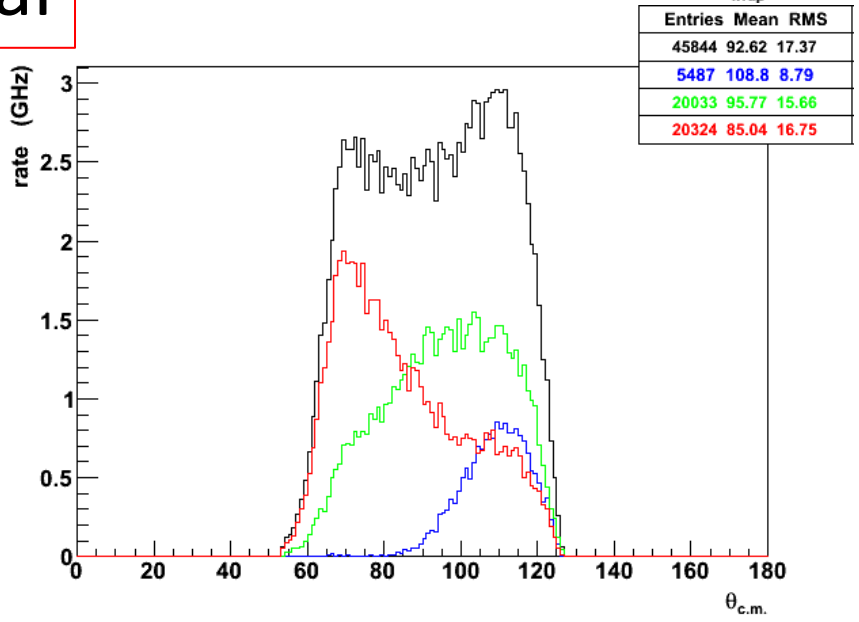
Comparison of GEANT4 Simulations



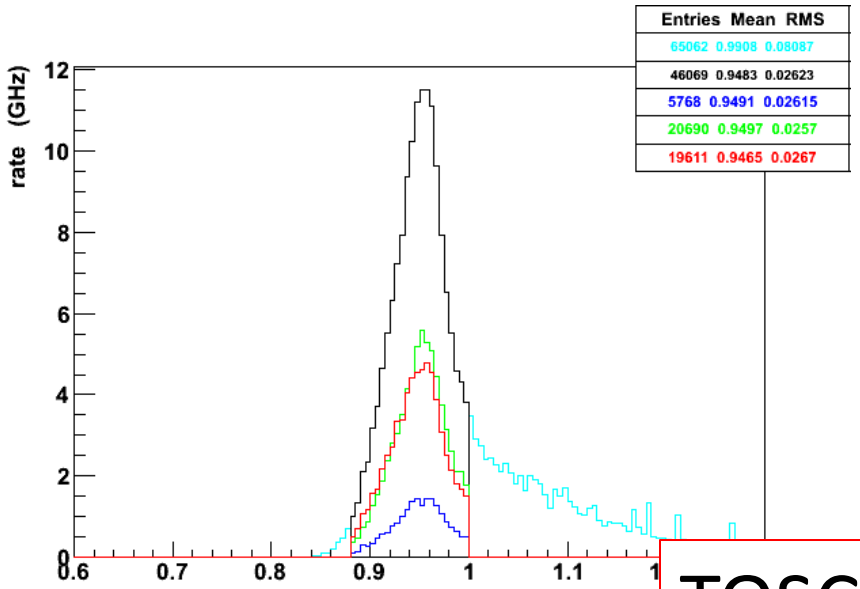


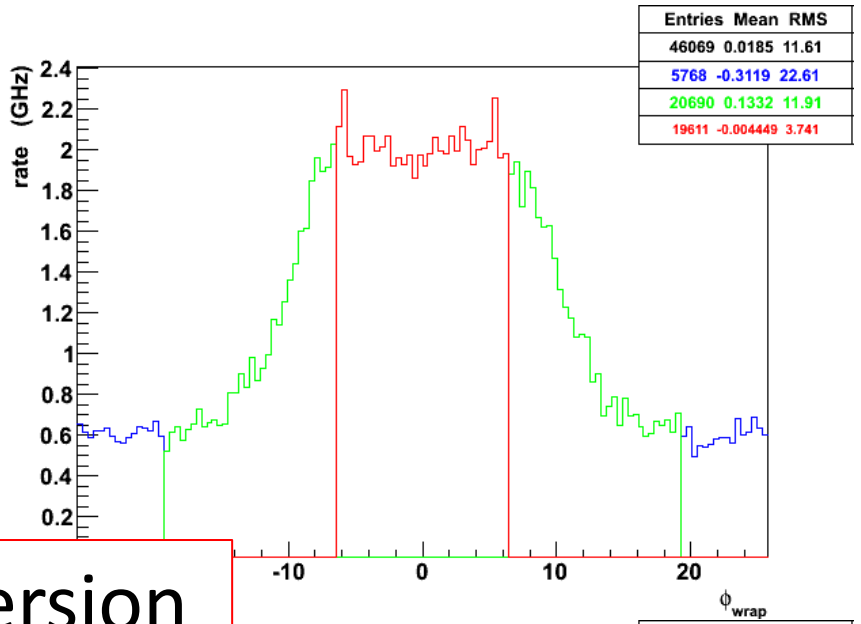
Proposal



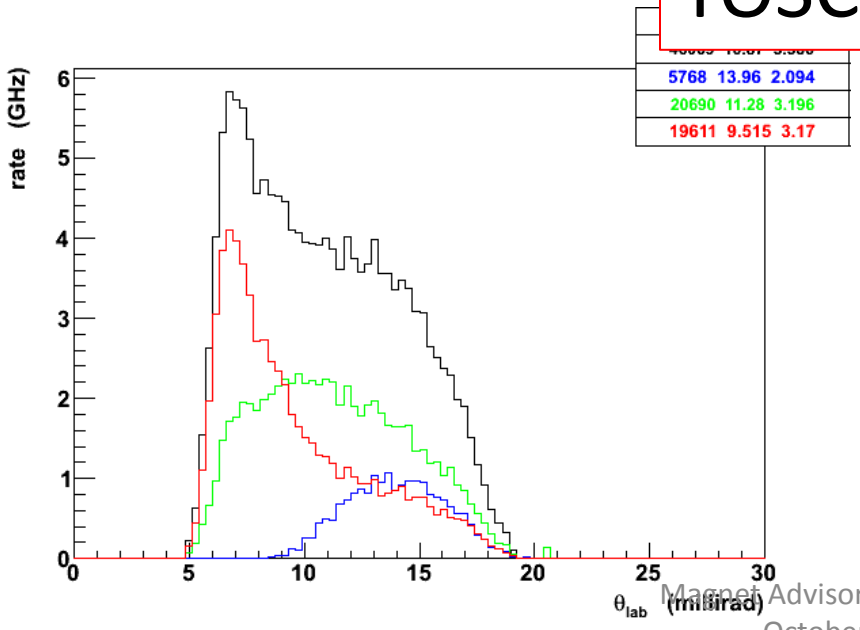


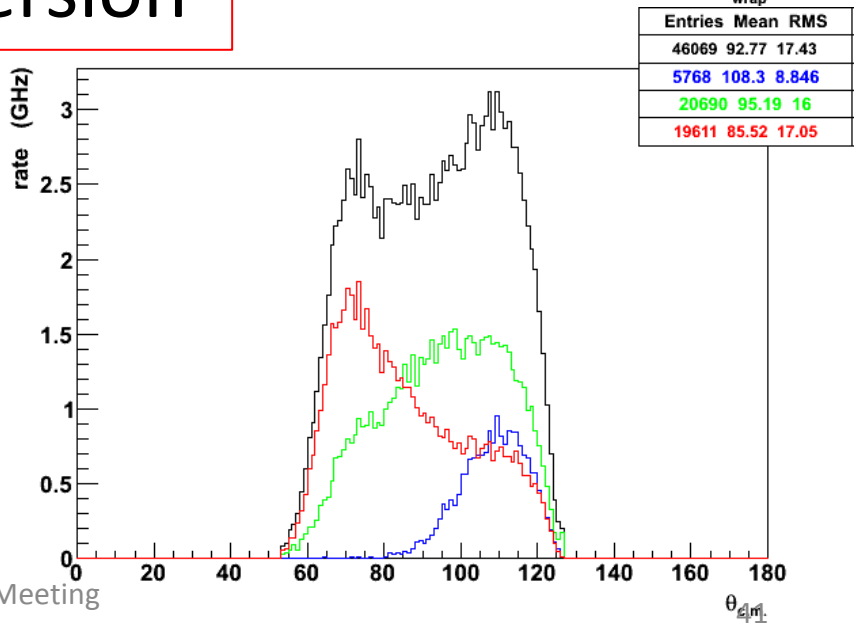
Comparison of GEANT4 Simulations



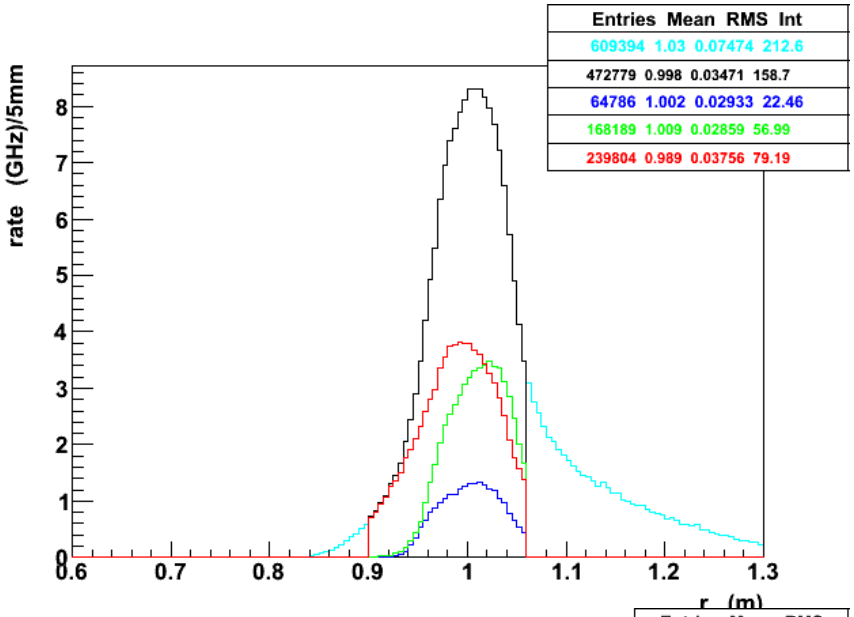


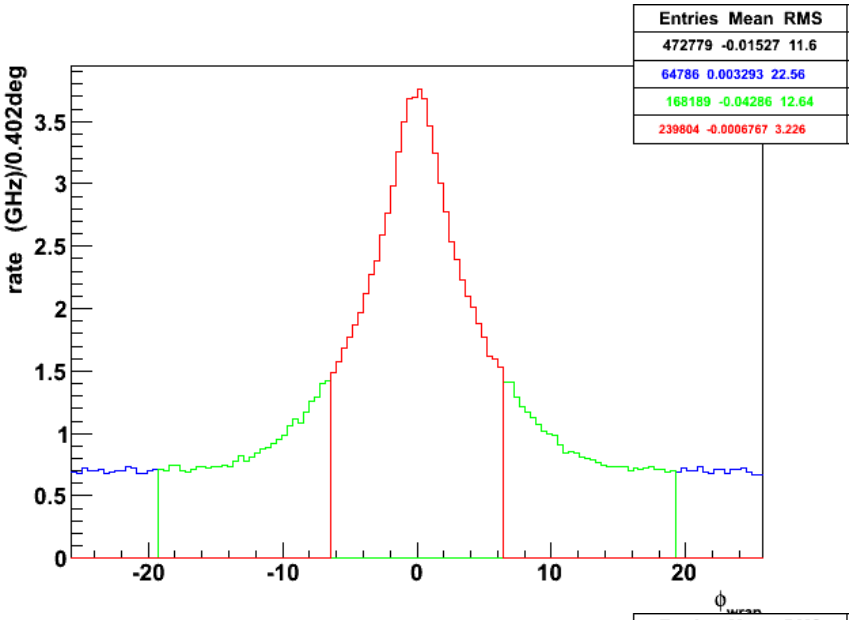
TOSCA version

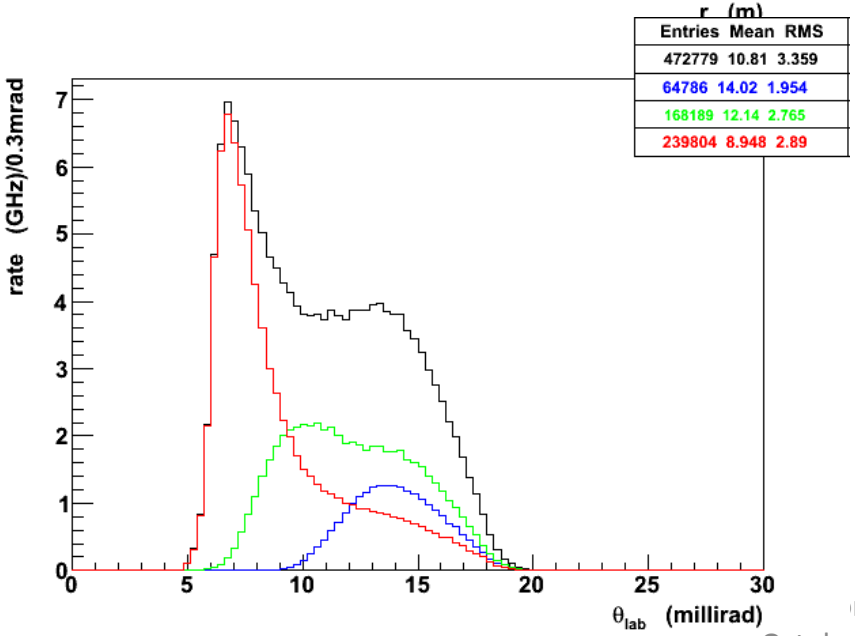


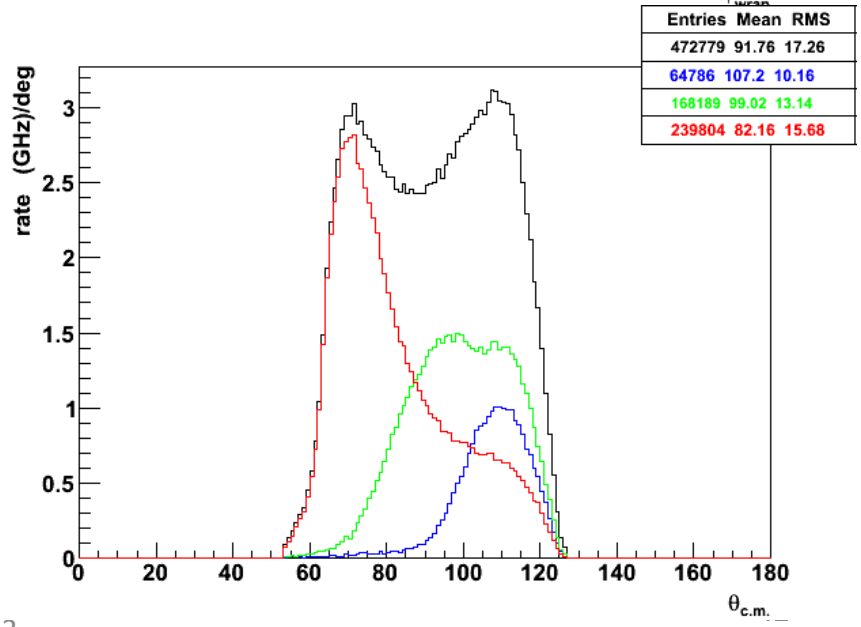


2.6

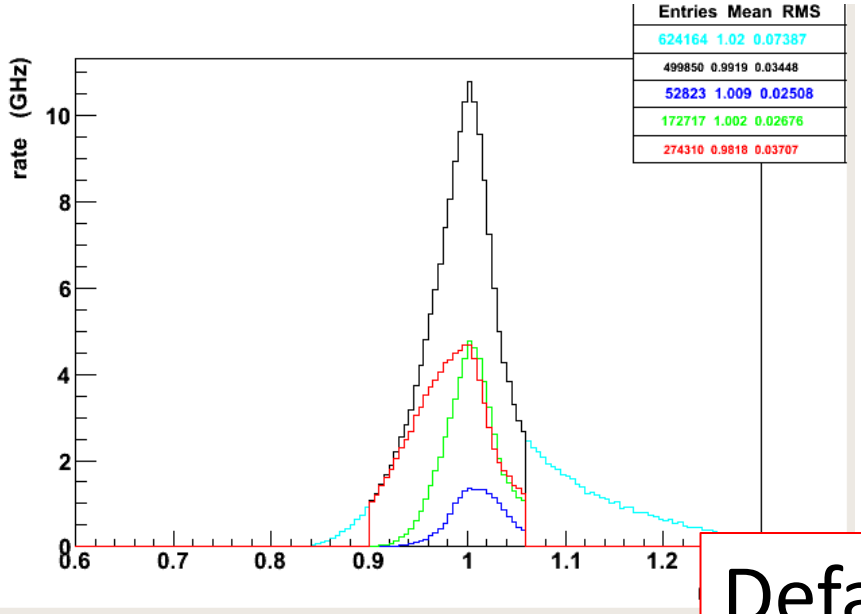

Entries Mean RMS Int
609394 1.03 0.07474 212.6
472779 0.998 0.03471 158.7
64786 1.002 0.02933 22.46
168189 1.009 0.02859 56.99
239804 0.989 0.03756 79.19
rate (GHz)/5mm
r (m)

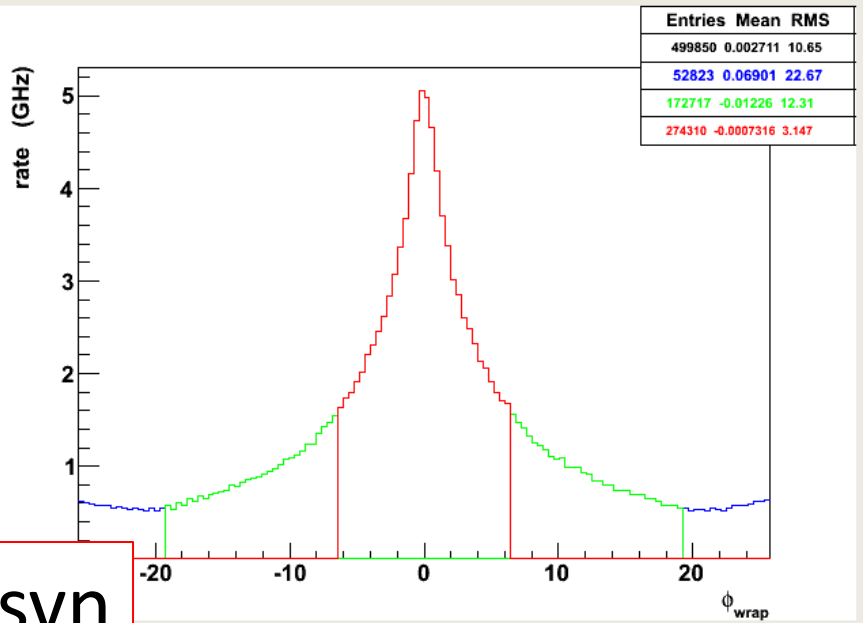

Entries Mean RMS
472779 -0.01527 11.6
64786 0.003293 22.56
168189 -0.04286 12.64
239804 -0.0006767 3.226
rate (GHz)/0.402deg


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
θlab (millirad)

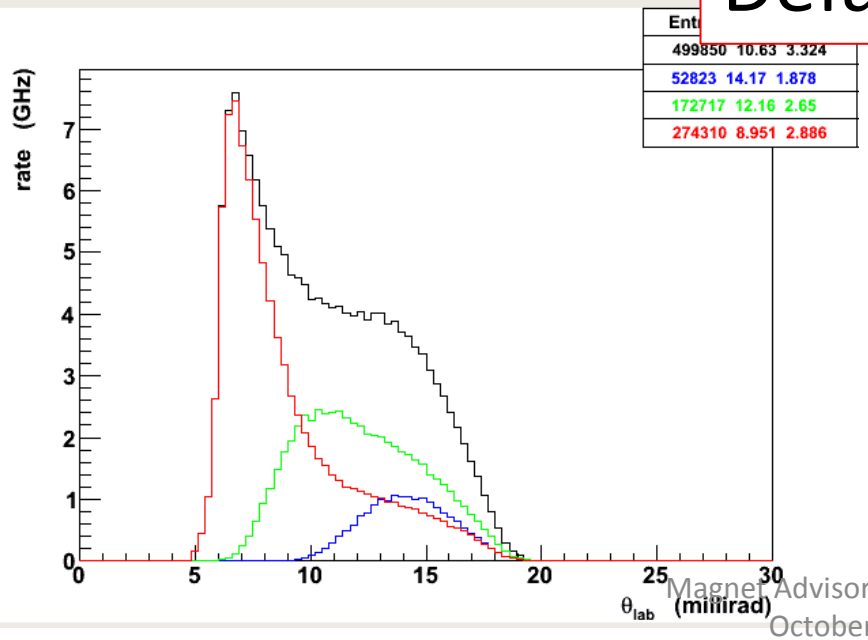

Entries Mean RMS
472779 91.76 17.26
64786 107.2 10.16
168189 99.02 13.14
239804 82.16 15.68
rate (GHz)/deg
θc.m.

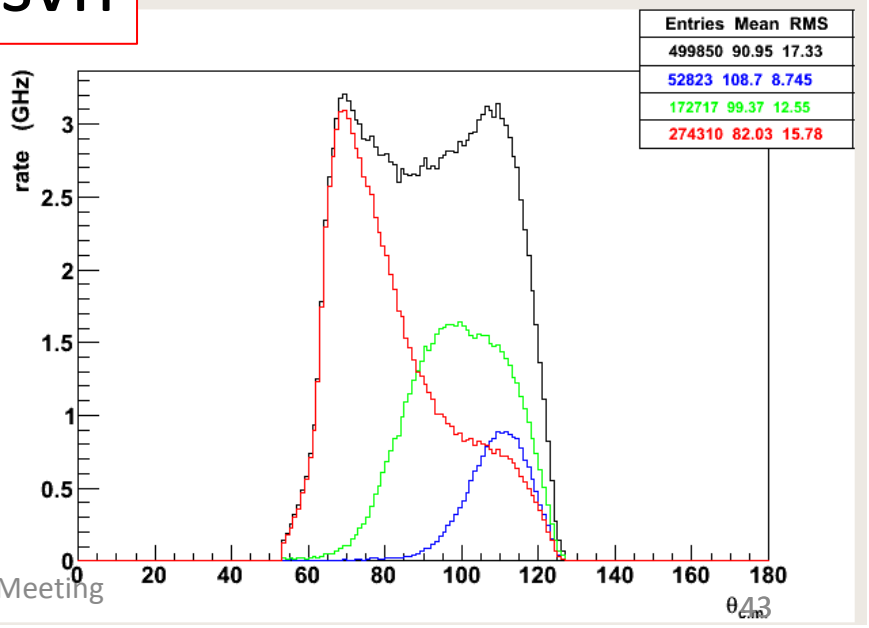
Current Version of the Hybrid and Upstream





Default svn





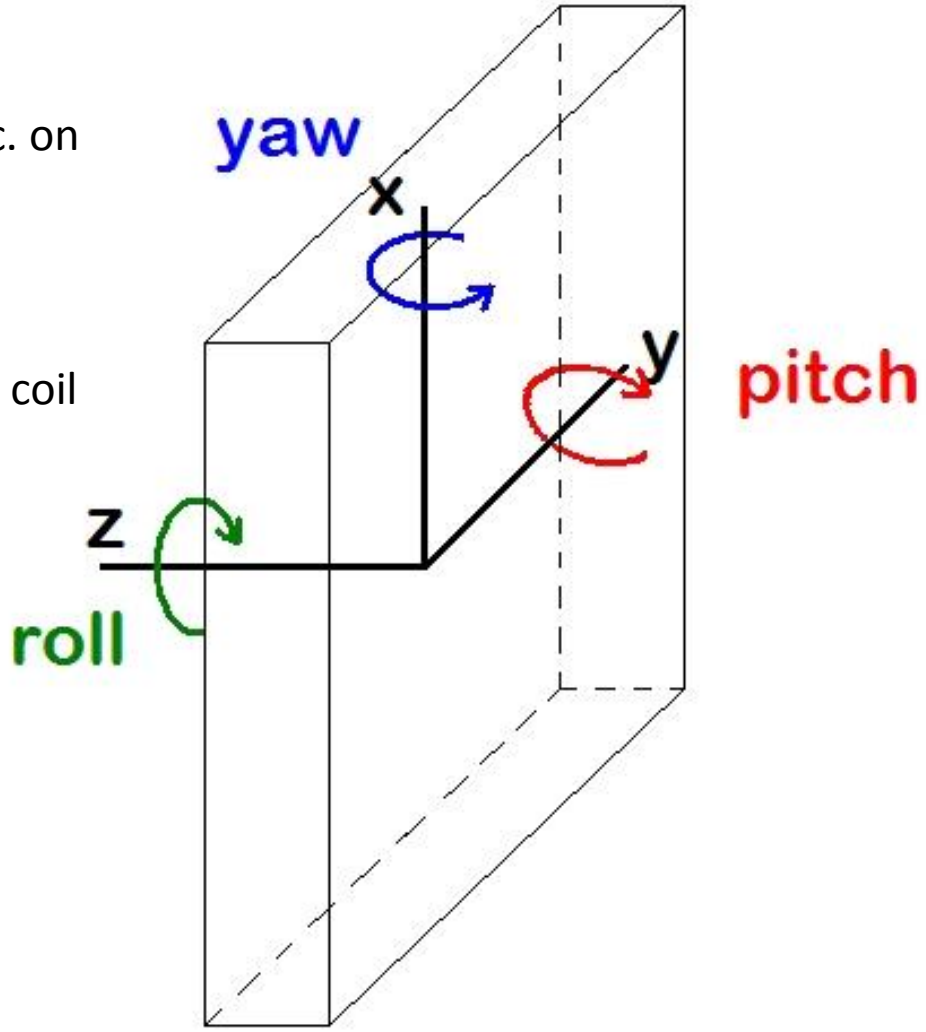
Magnetic Forces

- Use TOSCA to calculate magnetic forces on coils
- Have calculated the centering force on coil:

  ~3000lbs (compare to Qweak: 28000 lbs)
- Need to look at effects of asymmetric placement of coils
- Could affect the manufacturing tolerances

Sensitivity Studies

- Need to consider the effects of asymmetric coils, misalignments etc. on acceptance
- This could affect our manufacturing tolerances and support structure
- Have created field maps for a single coil misplaced by five steps in:
  - -1° < pitch < 1°
  - -4° < roll < 4°
  - -1° < yaw < 1°
  - -2 < r < 2 cm
  - -10 < z < 10 cm
  - -5° < ϕ < 5°
- Simulations need to be run and analyzed



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