Spectrometer Group Update

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 – *July 2013***

Advisory Group

- (External) Magnet Advisory Group
  - George Clark (TRIUMF)
  - Vladimir Kashikhin (FNAL)
  - Dieter Walz (SLAC)
  - Additional members?
- (Internal) Magnet Advisory Group
  - Jim Kelsey (MIT)
  - Ernie Ilhof (MIT)
  - Jason Bessuille (MIT)
  - Robin Wines (JLAB)
  - Jay Benesch (JLAB)
  - Roger Carlini (JLAB)
  - Additional members?

Suggestions of Advisory Group

- larger conductor and hole (→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 last Advisory group

- New conductor layout with larger conductor
  - MIT engineer suggests larger water-cooling hole, at expense of larger current density
- Optics tweaks
  - Improved ep separation
  - Maximized rate; keep "front-back" symmetry
- Interface with CAD
  - Create scattered electron envelopes
  - Step file translator
- Maps for sensitivity study created
- First look at 1-bounce photons
- Target length study
- Updated collimators
- Coils defined in GEANT4

Engineering Work since last time

- Detailed water-cooling calcs
- New larger water-cooling hole
  - Larger, square conductor 6 mm on a side
  - Trade-off between lowest power, voltage and fewest cooling channels
  - Even larger current density 1750 or 2000 A/cm^2
- Evaluation of stress (from gravity only)

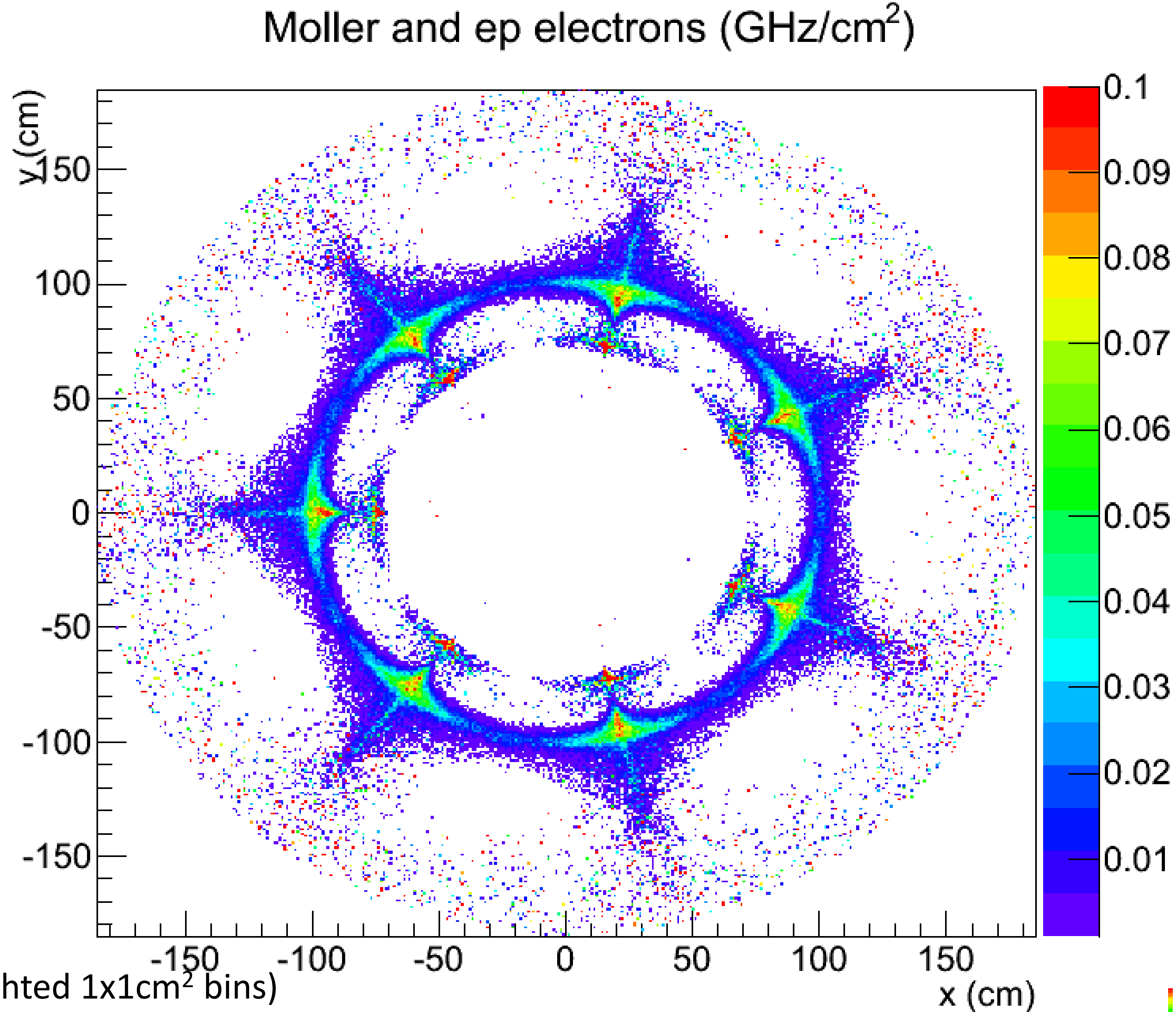
Future work

- Optics Tweaks
  - Fix conductor issues in TOSCA (conductor sizes, s-bends, etc.)
  - Remove negative bend (preliminary work on this)
  - Look at optics with 3 coils?
  - Iron in magnet? (reduce current density; estimate affect on bkgds) – Willy Falk has concept, I'll model in TOSCA
- Sensitivity Study
  - Maps created
  - Summer student working, making good progress
- Radiative Power Deposited in Coils (collimation)

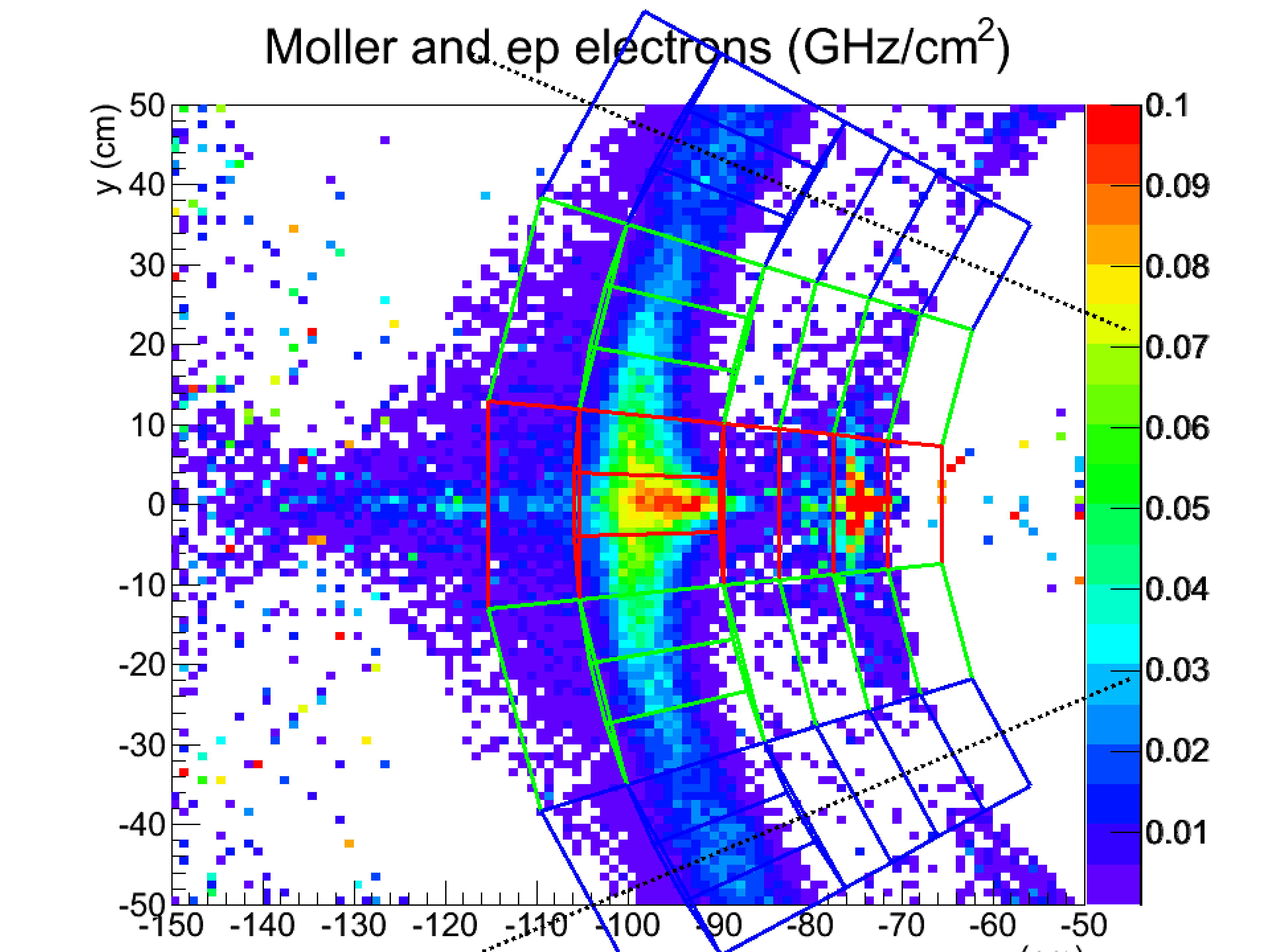
Future Engineering Work

- Water-cooling/electrical connection plan
- Evaluation of stresses with magnetic forces
- Vendors for magnet power supply
- Conceptual design of magnet supports (coils and stand)

Tracks in GEANT4

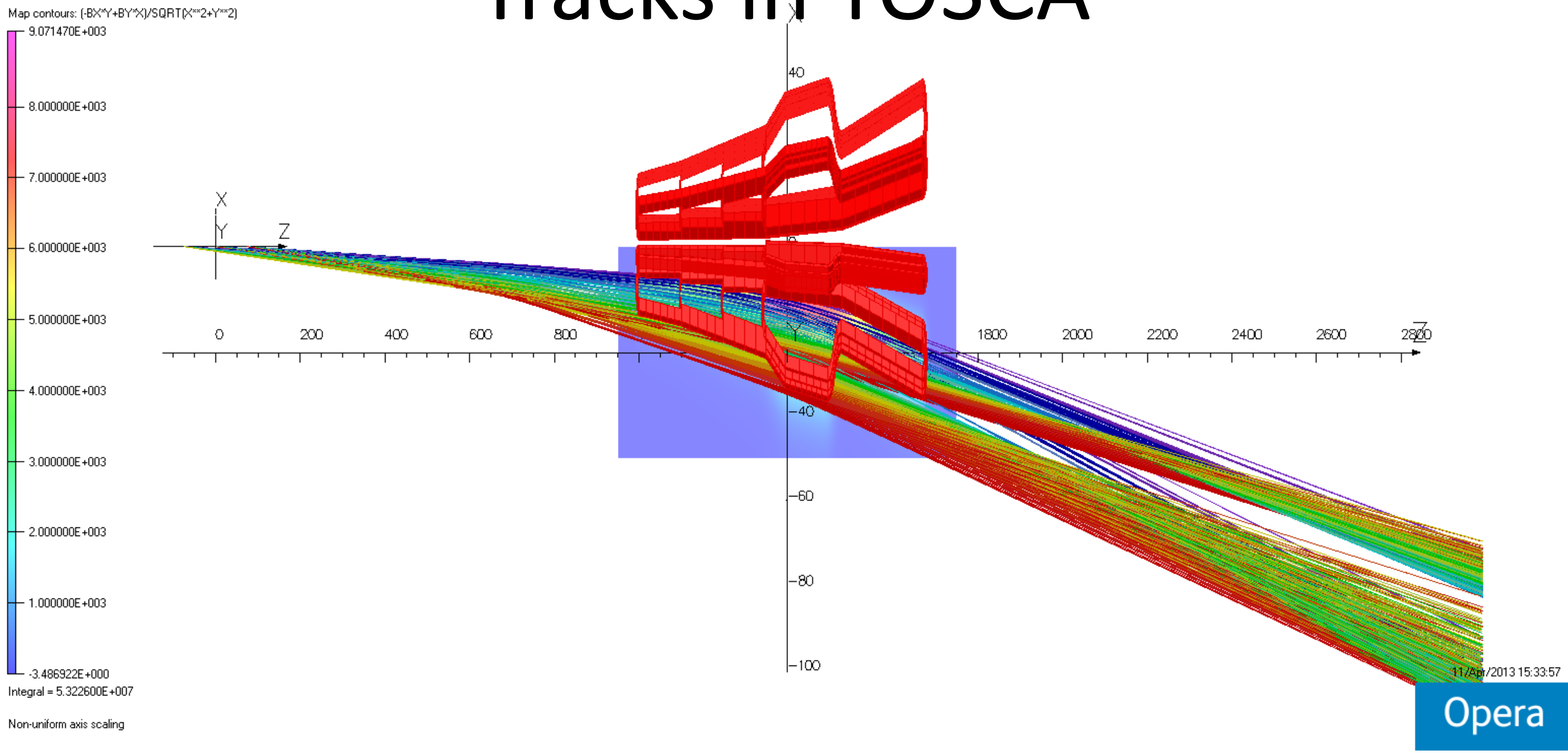


(Rate weighted 1x1cm^2 bins)



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

Tracks in TOSCA

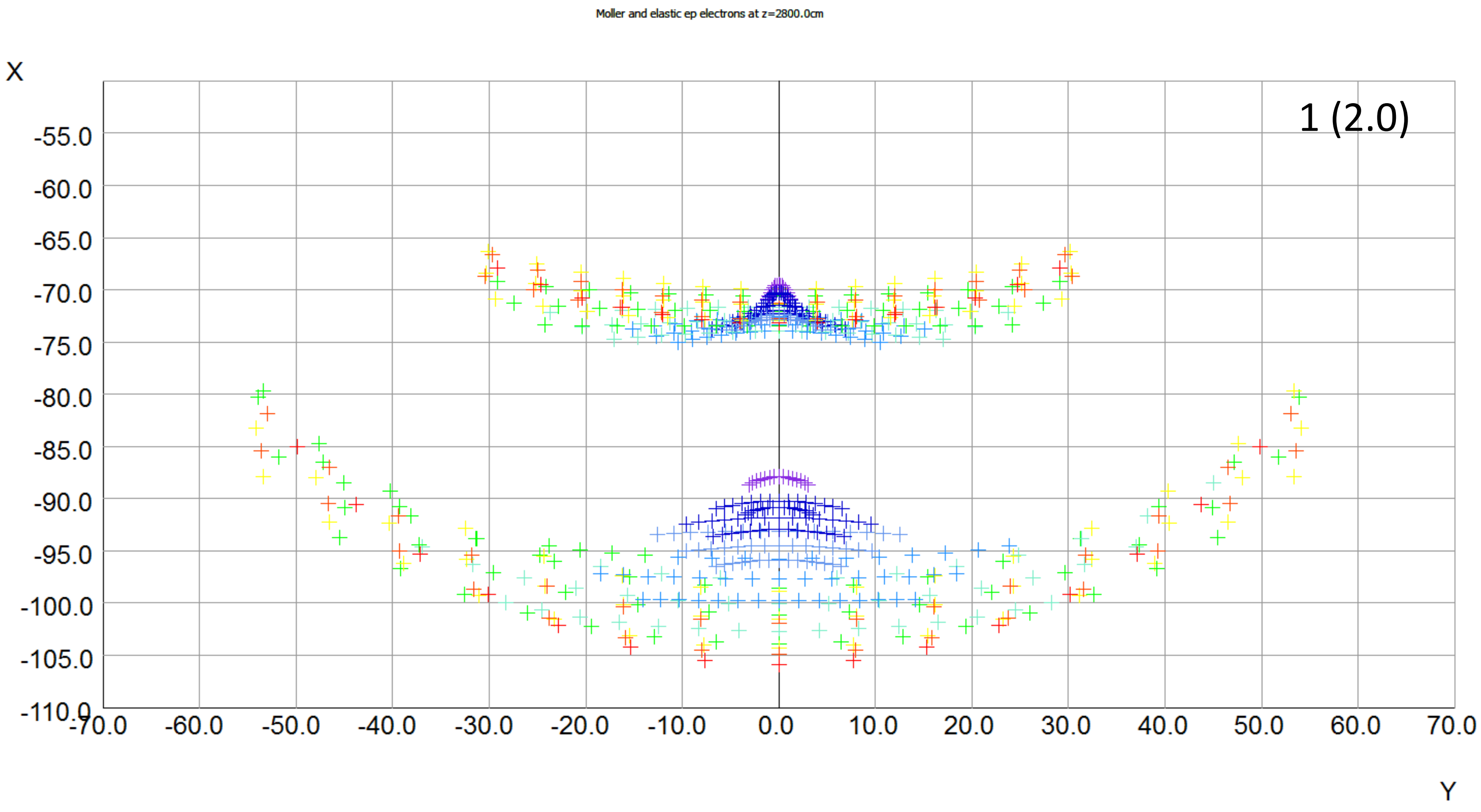


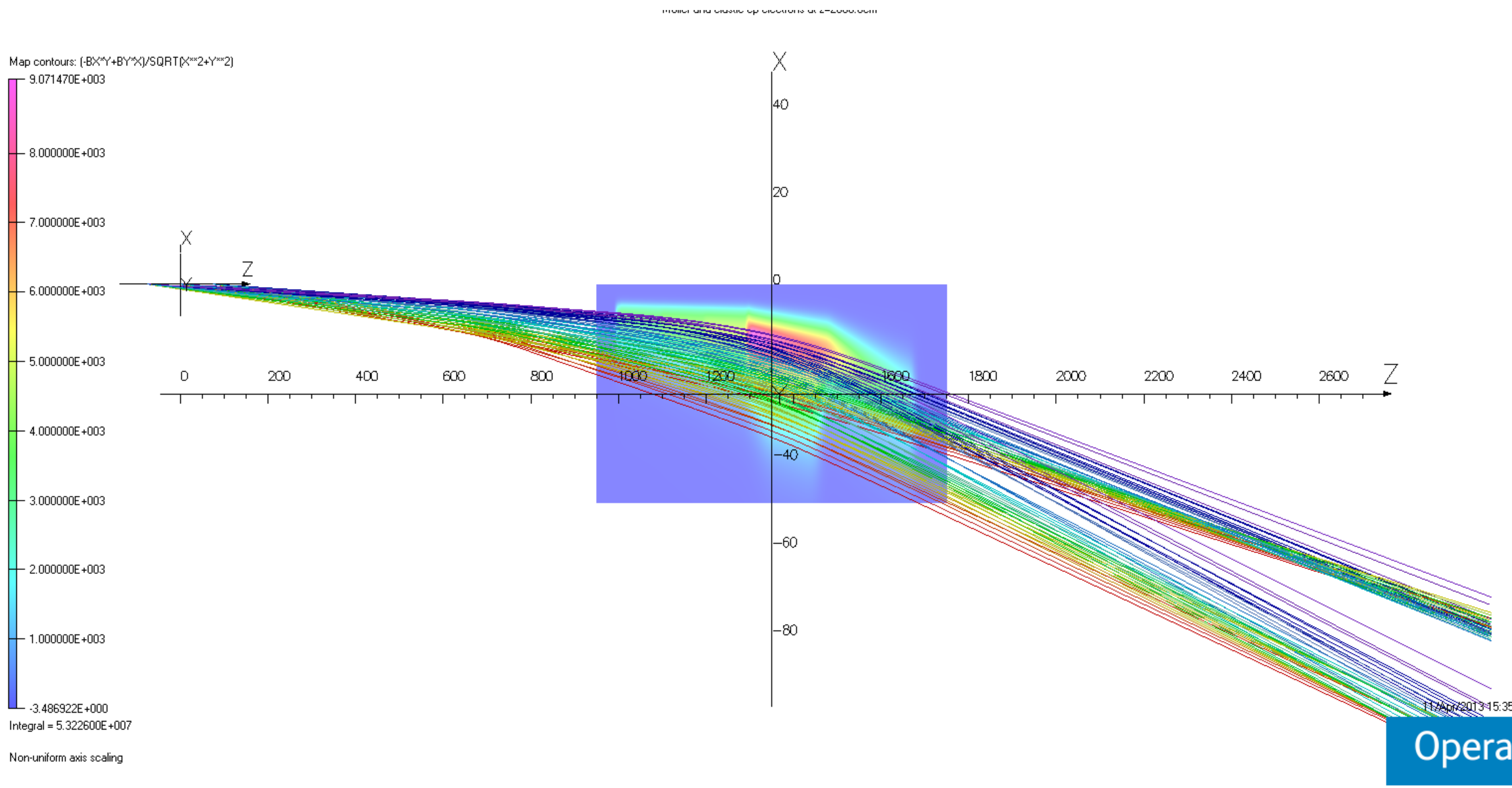
up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

All phi values

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

Tracks in TOSCA

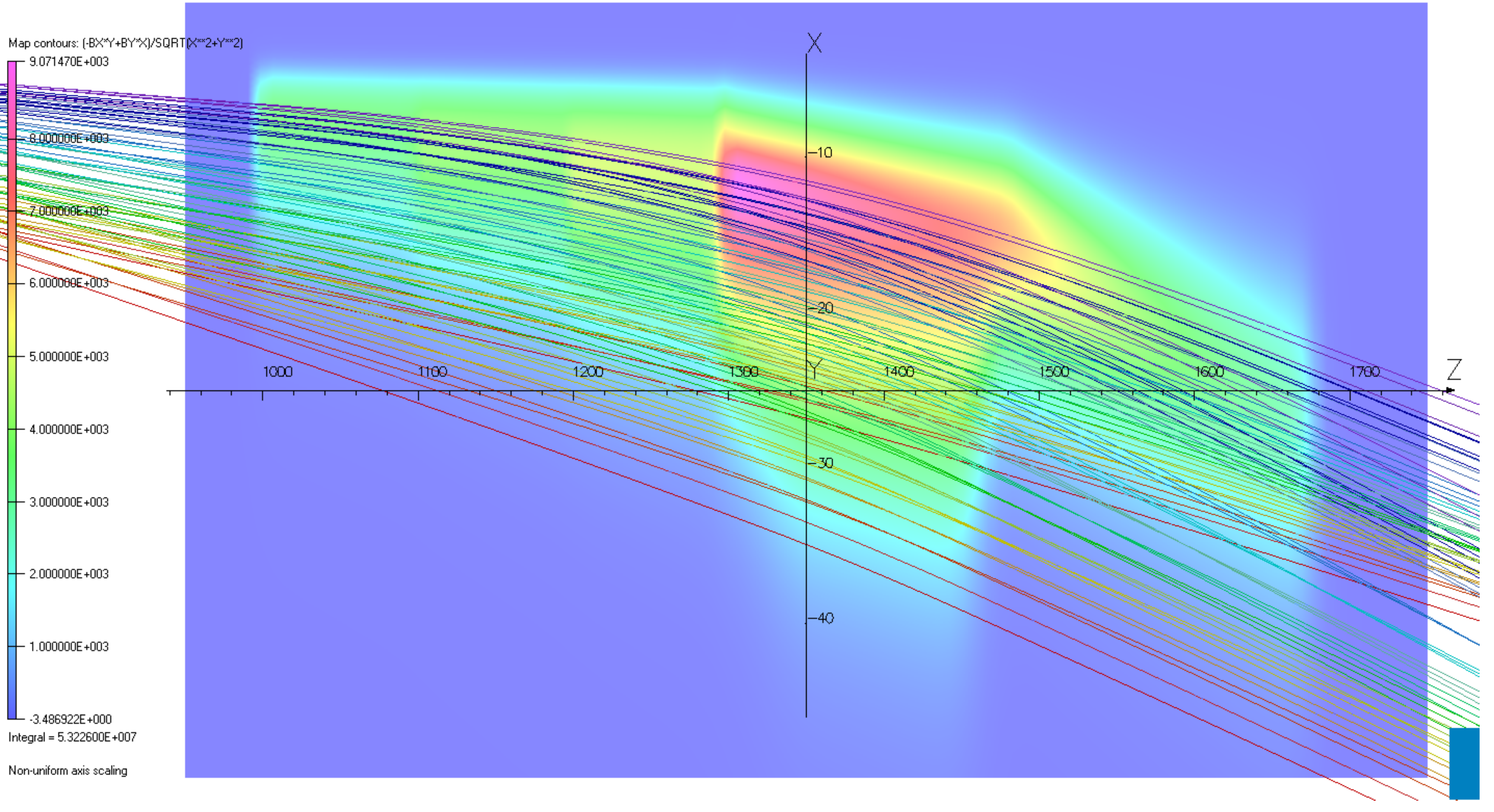




up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

phi=0 only

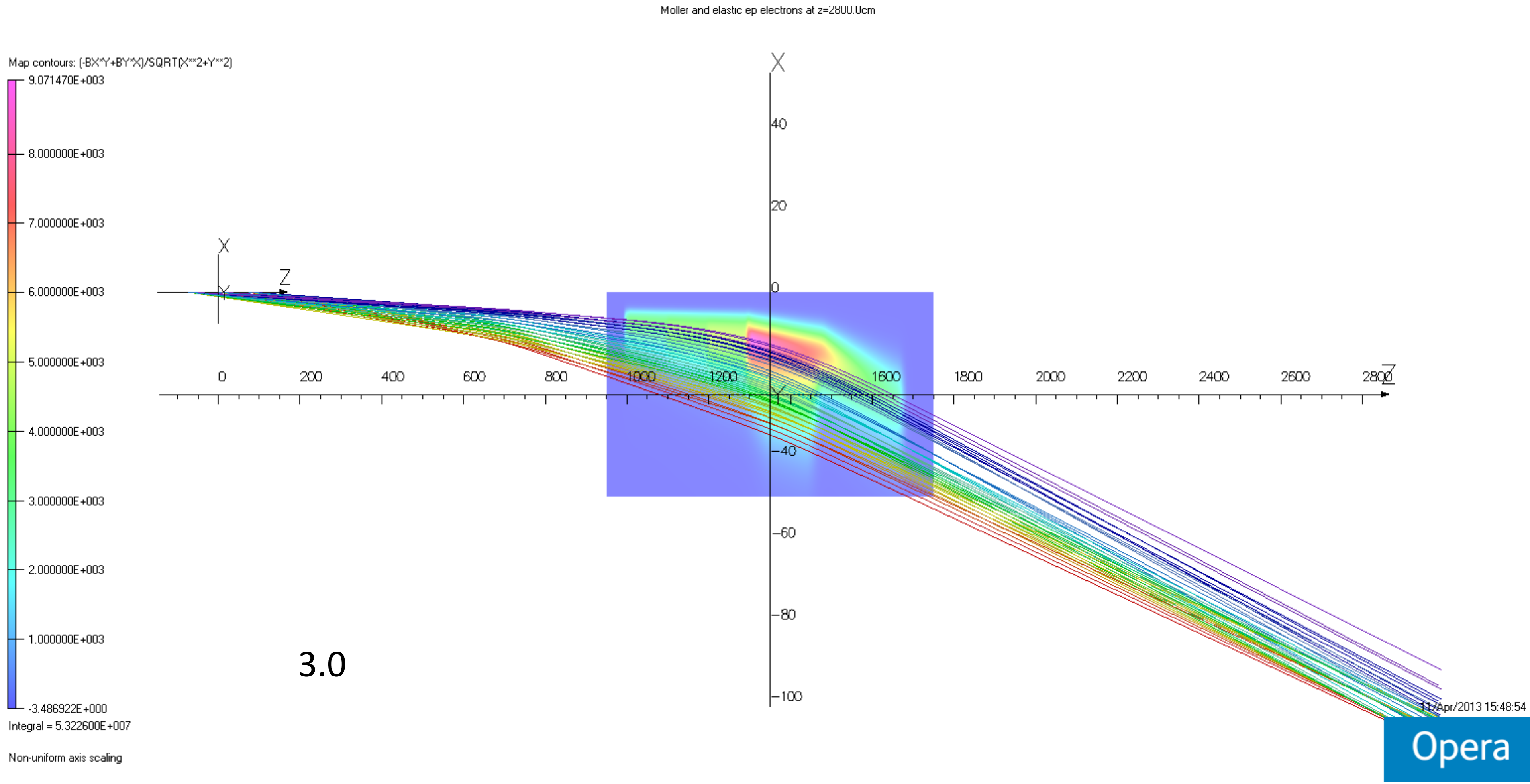
Tracks colored by theta from purple to red (low to high)



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

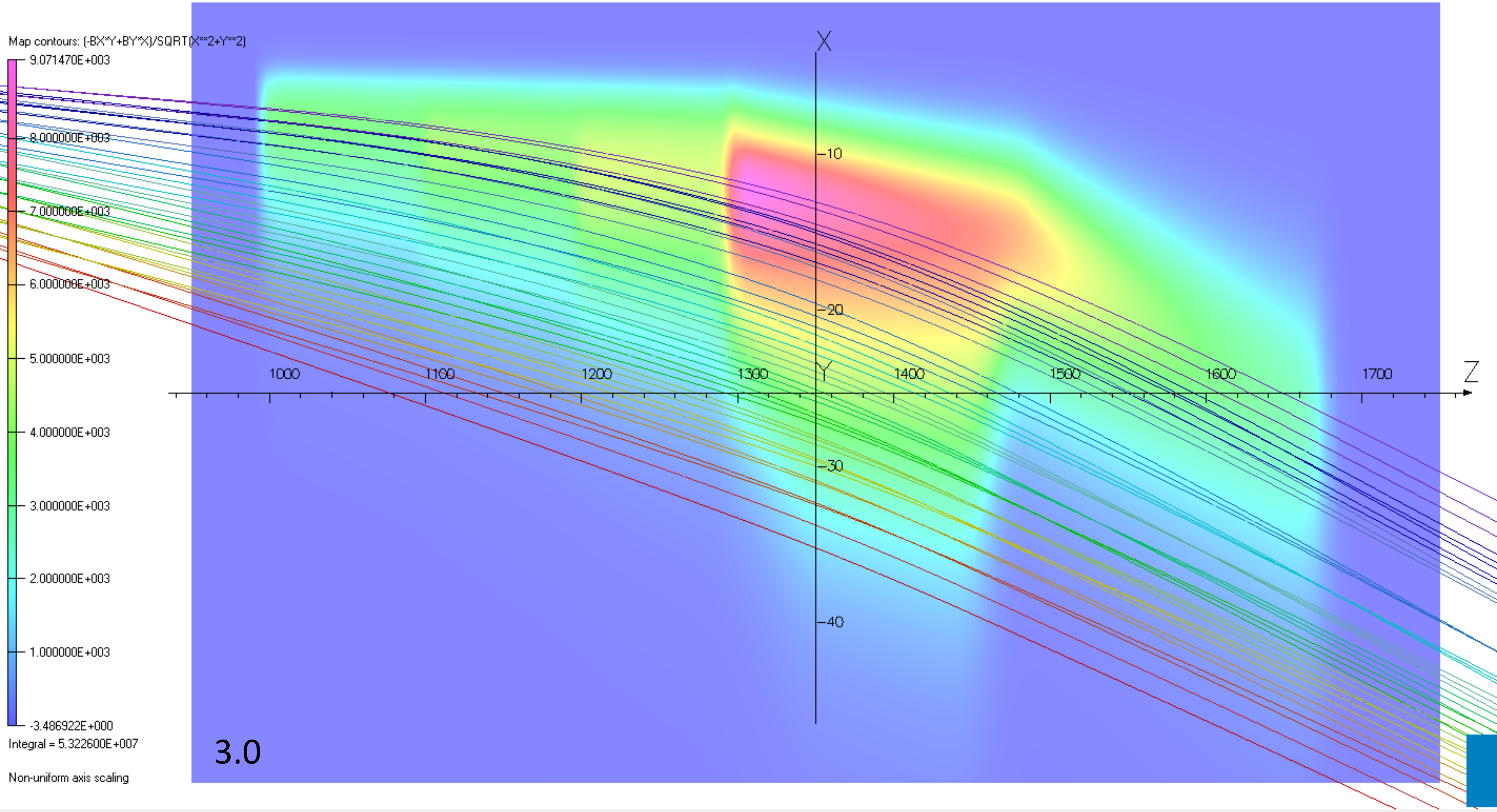
Tracks colored by theta from purple to red (low to high)



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

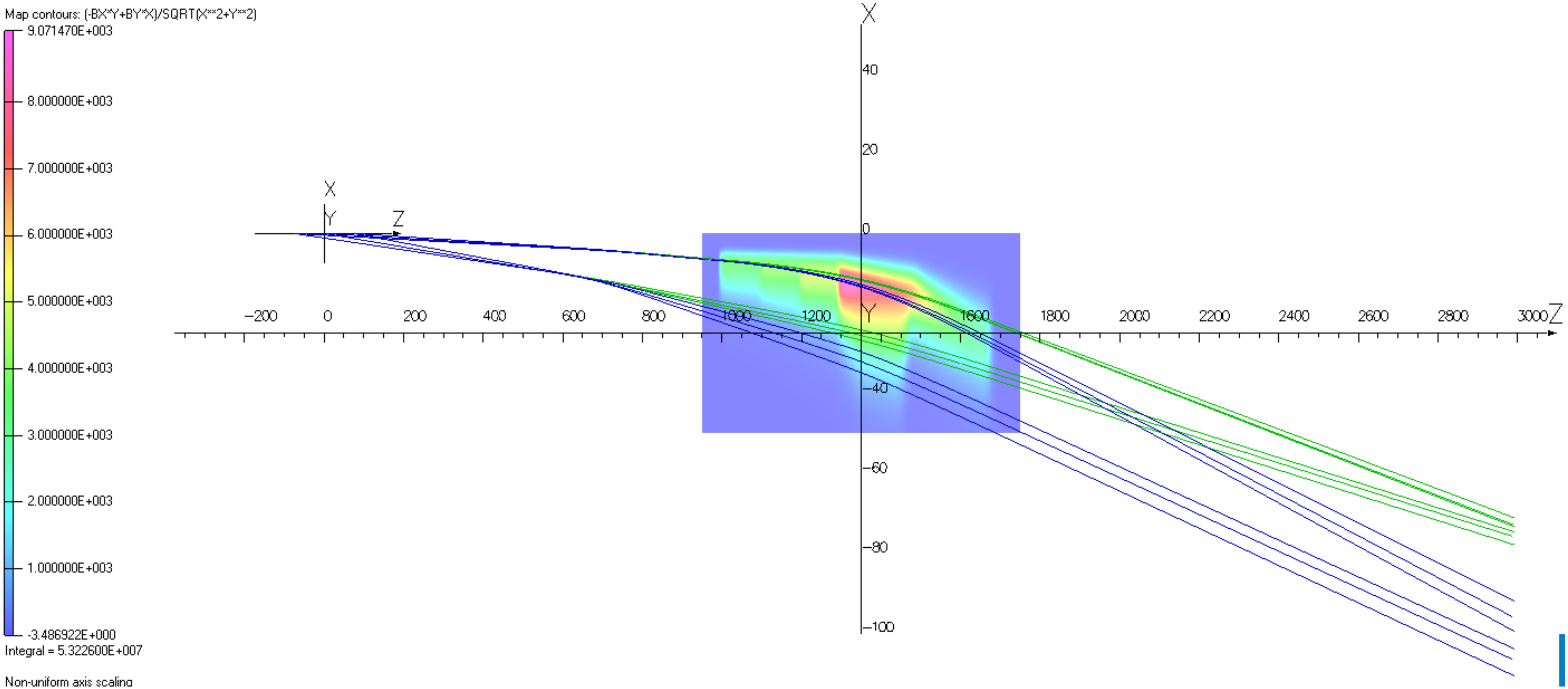
Tracks colored by theta from purple to red (low to high)



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

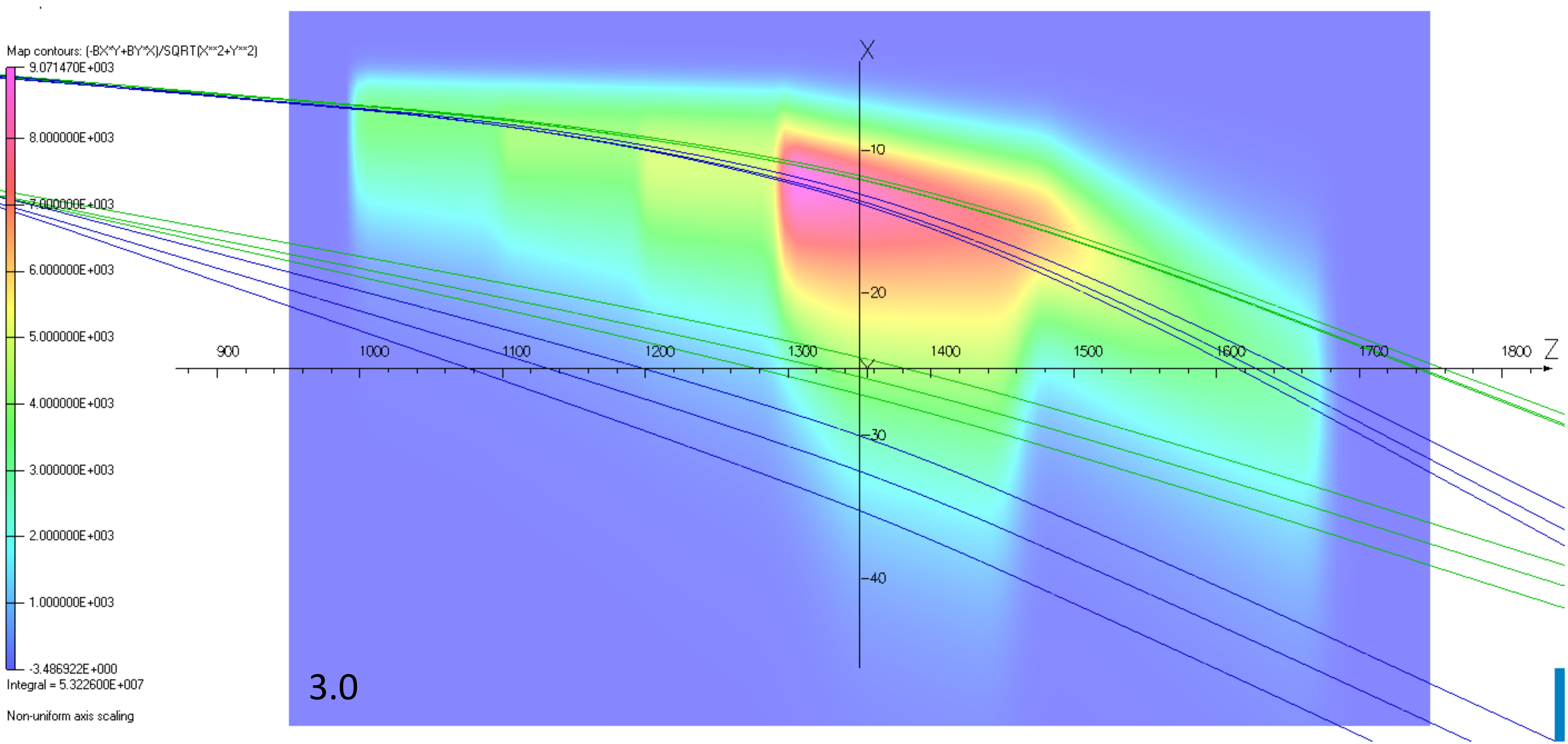
phi=0 only, near magnet, mollers only

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

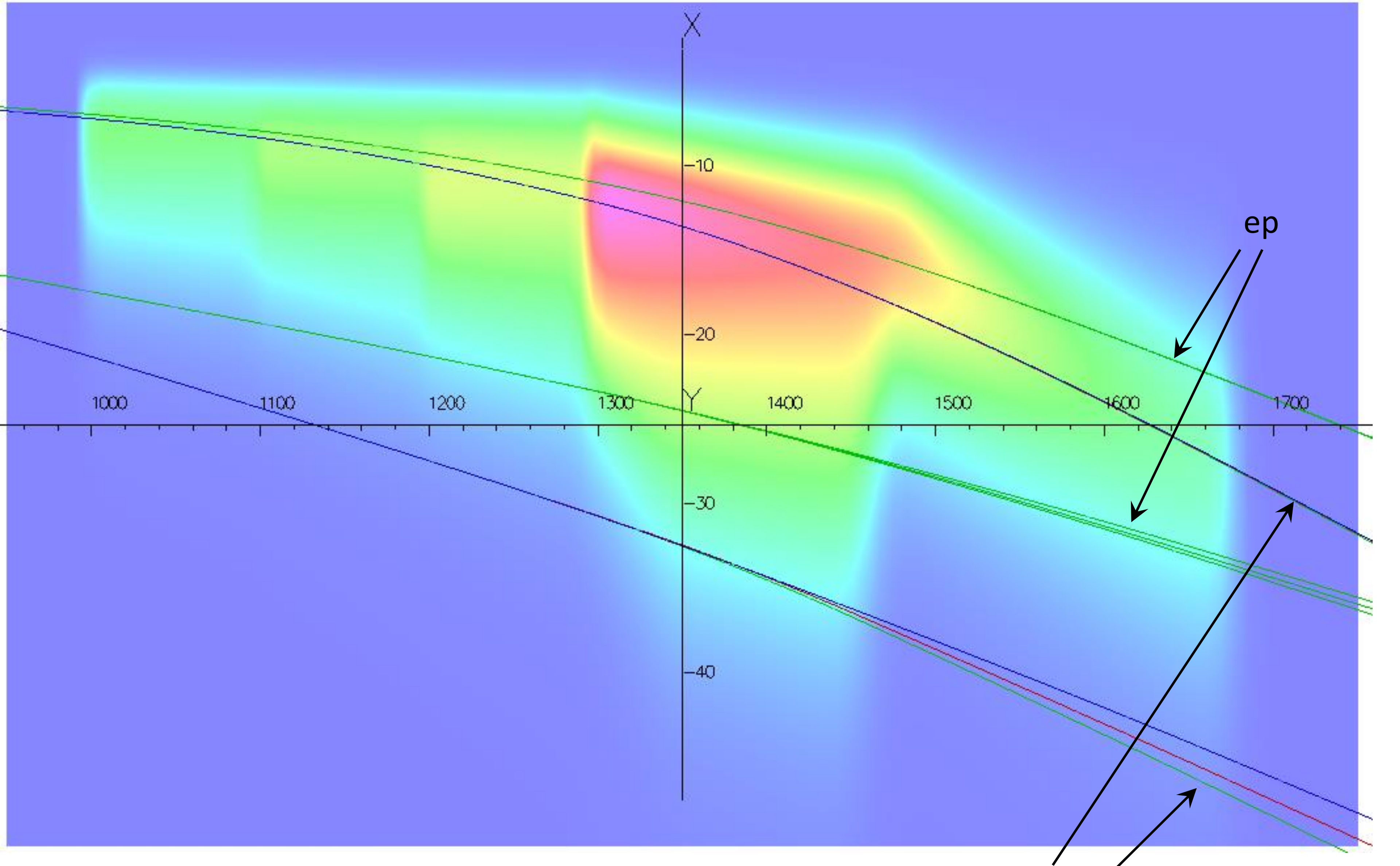
middle (z0 =0 cm) 6.0 and 17 mrads

down (z0 =75 cm) 6.5 and 19 mrads

phi=0 only, near magnet

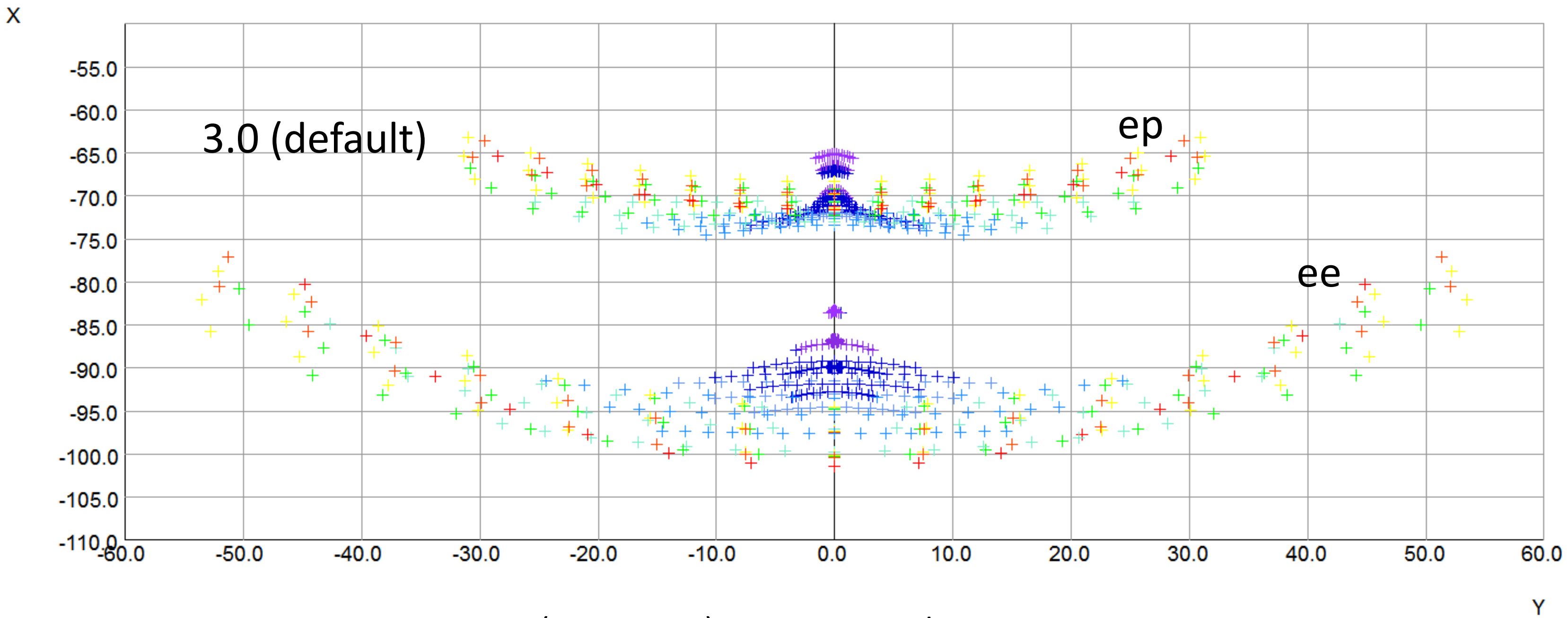
green – eps

blue - mollers



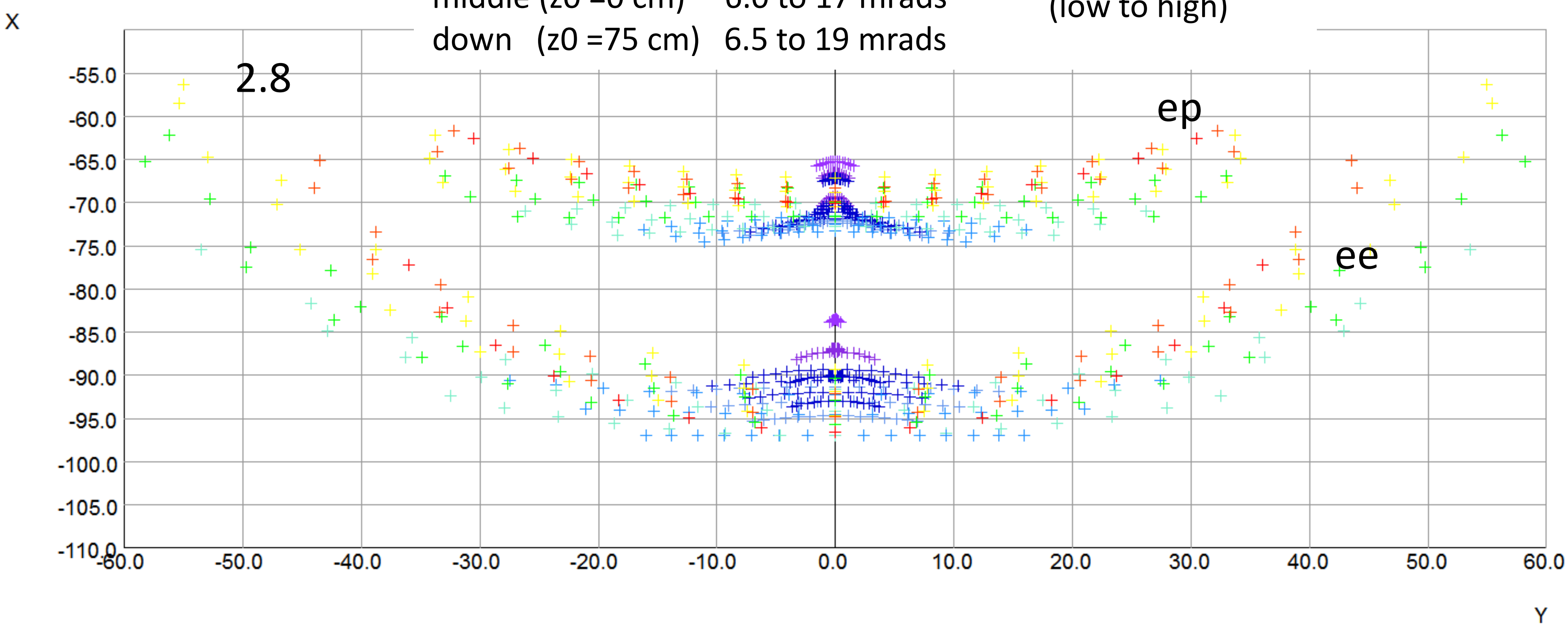
Tracks from middle of target (z=0), phi =0 only
6.0 and 17 mrads

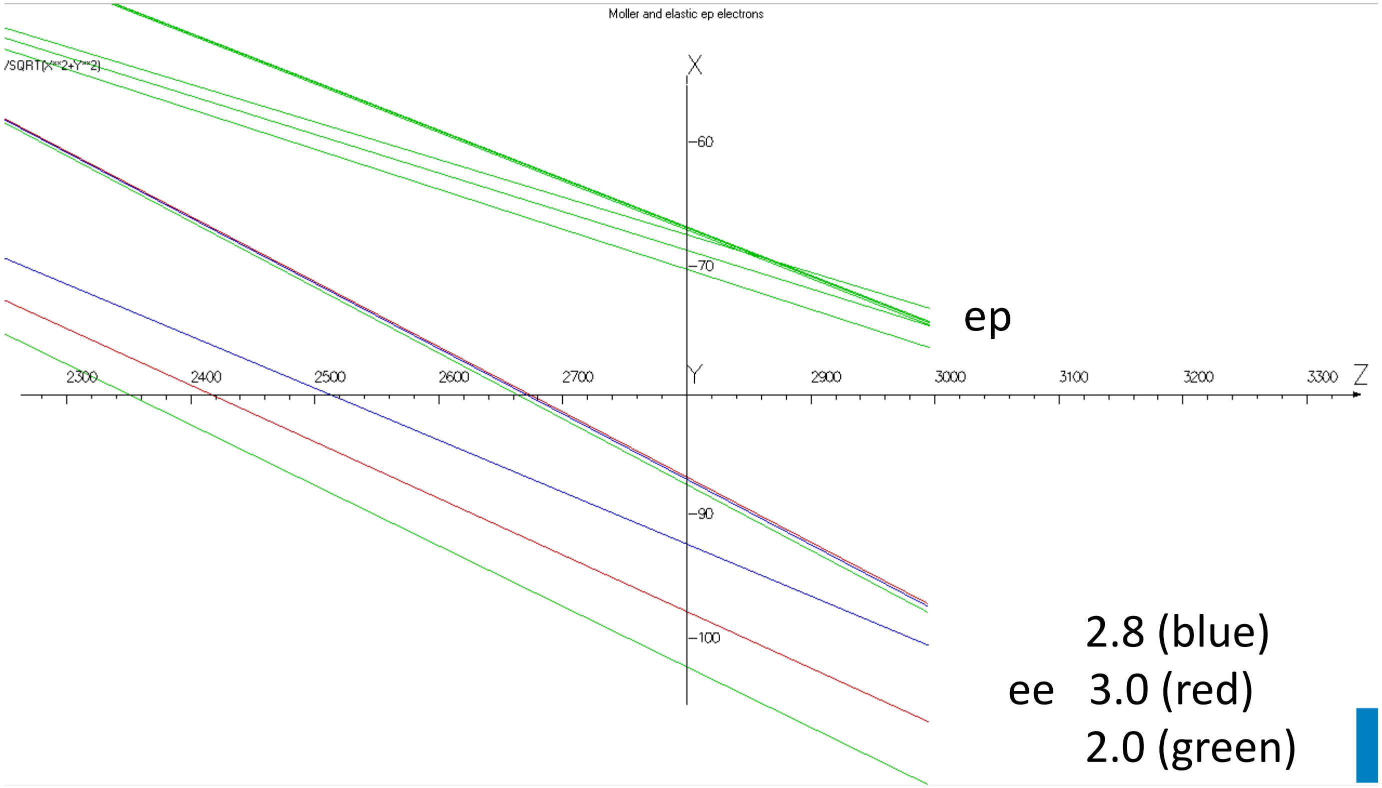
Moller and elastic ep electrons at z=2800.0cm



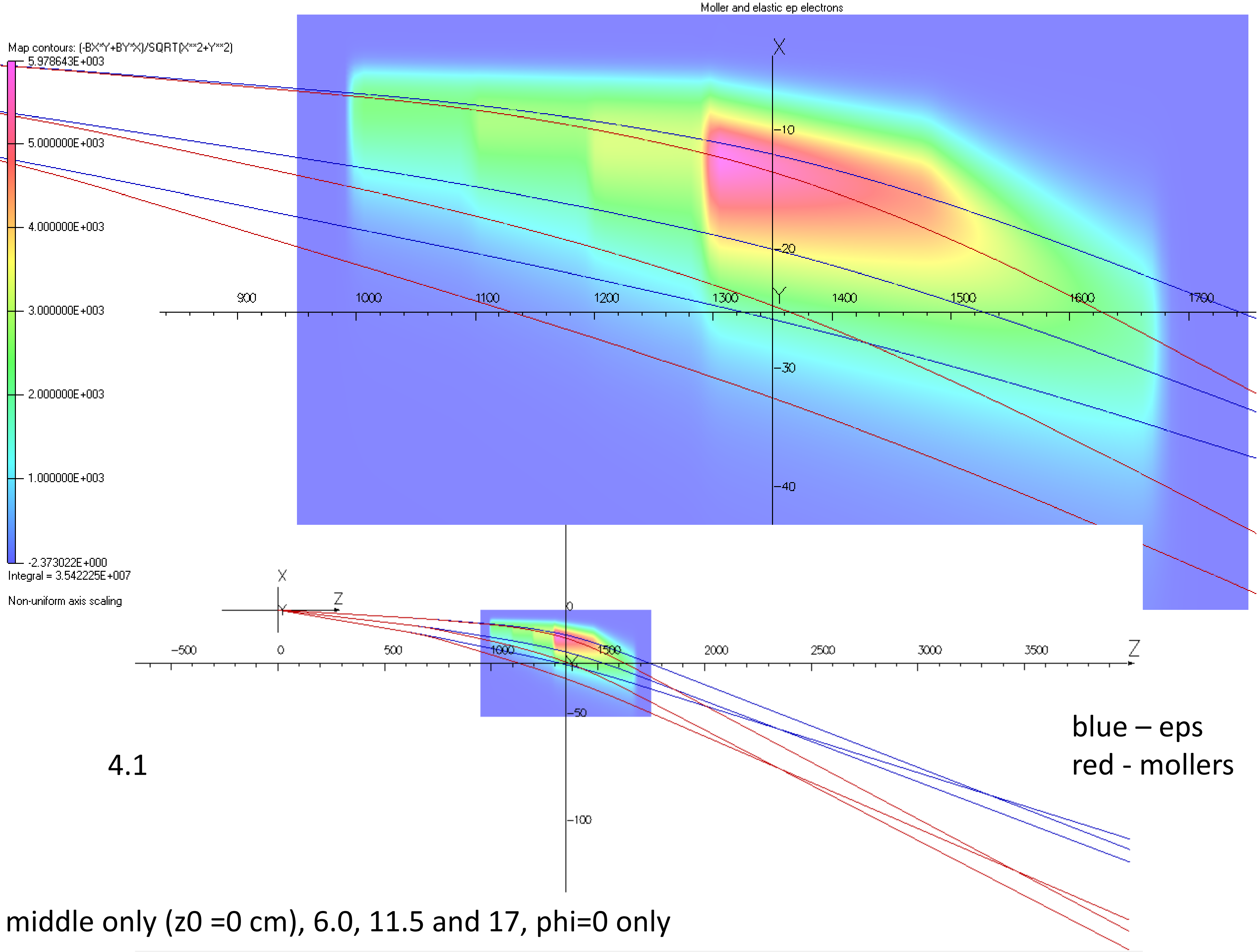
up (z0 =-75 cm) 5.5 to 15 mrads
middle (z0 =0 cm) 6.0 to 17 mrads
down (z0 =75 cm) 6.5 to 19 mrads

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





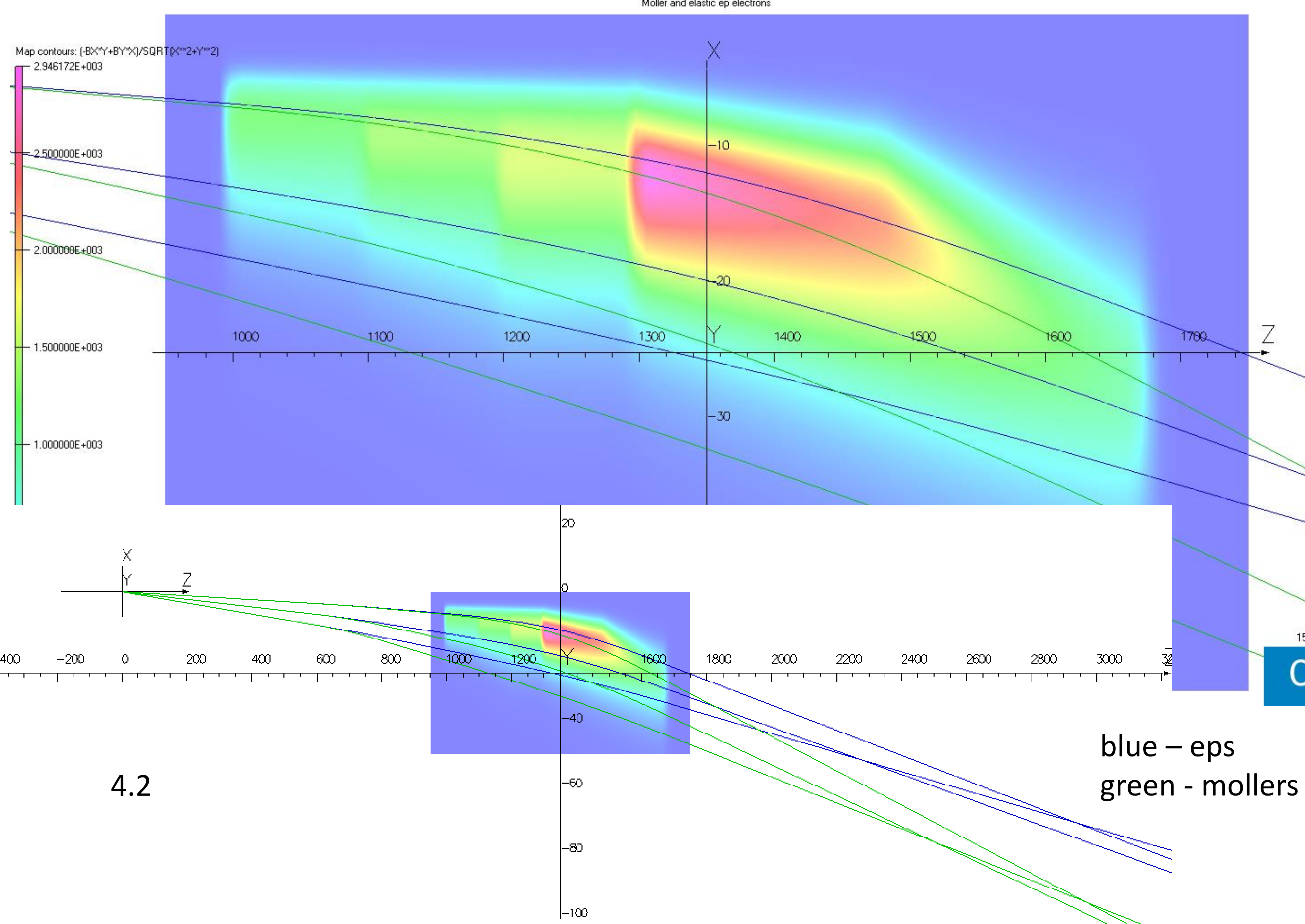
Tracks from center of target, phi =0 only
6.0 and 17 mrads



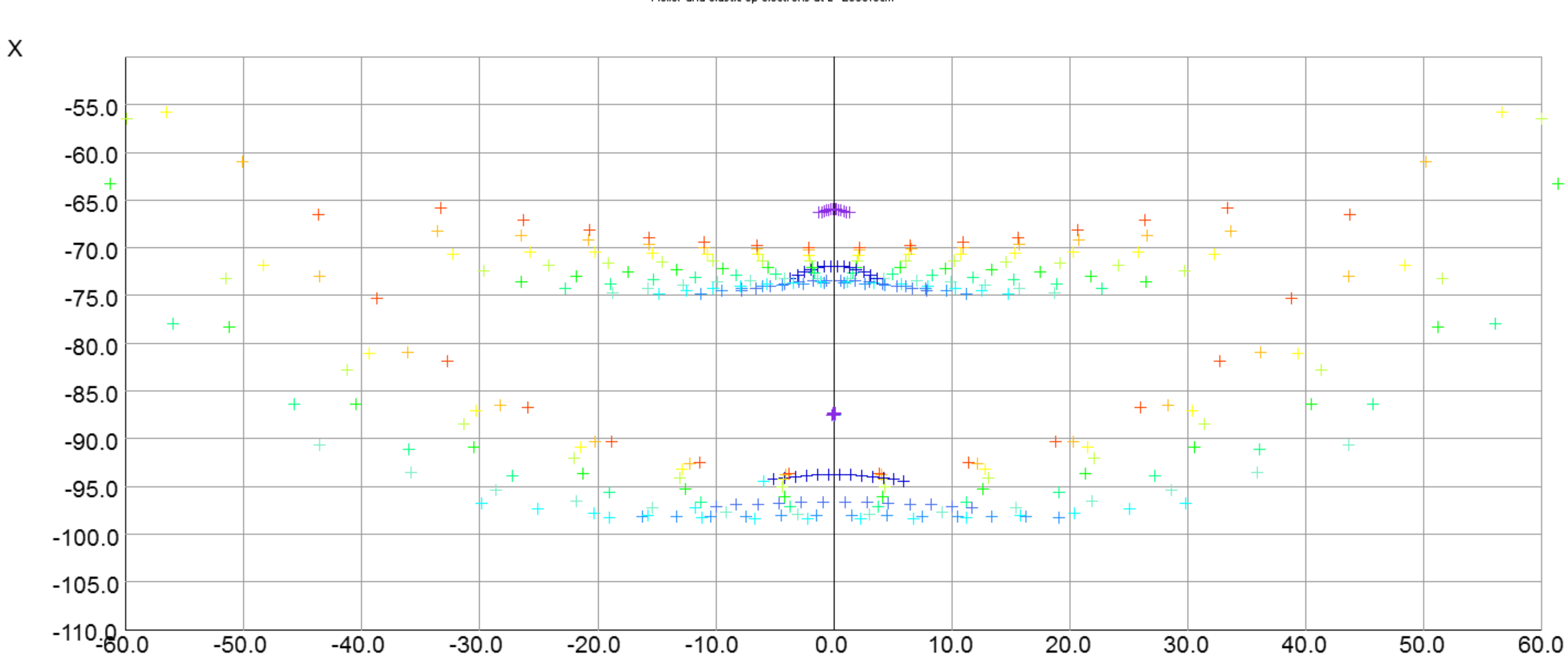
4.1

blue – eps
red - mollers

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



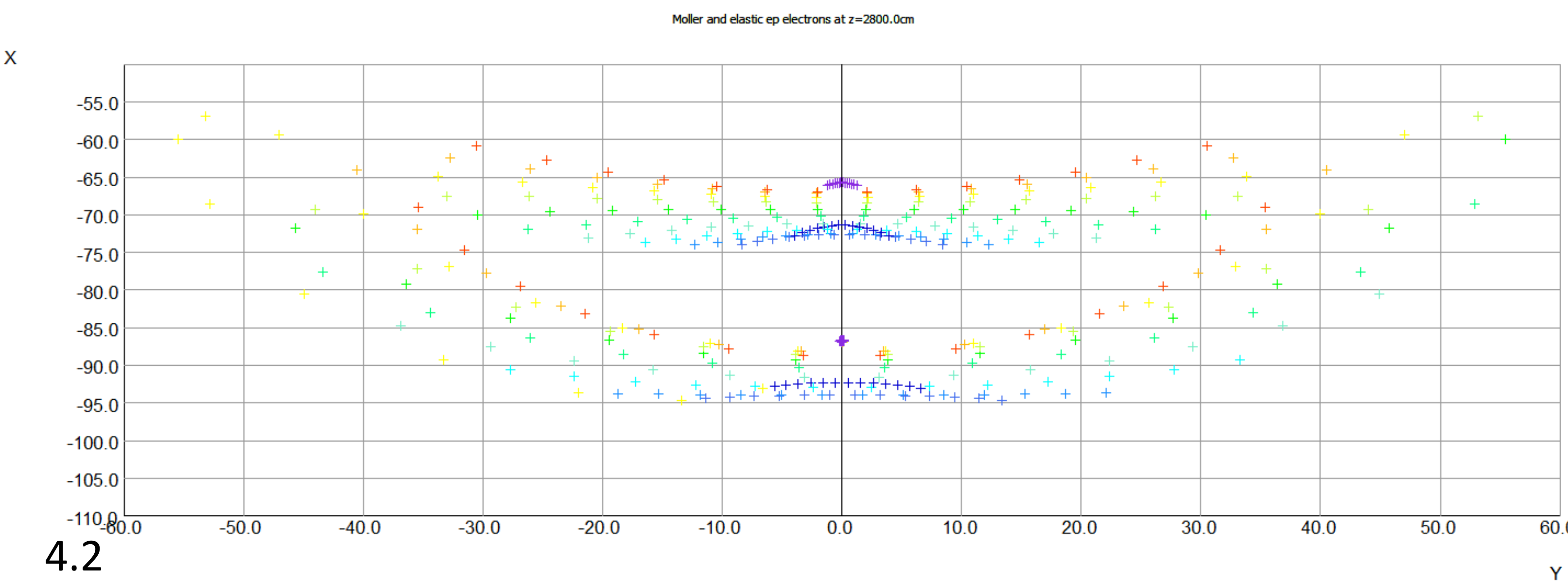
middle only (z0 =0 cm), 6.0, 11.5 and 17, phi=0 only



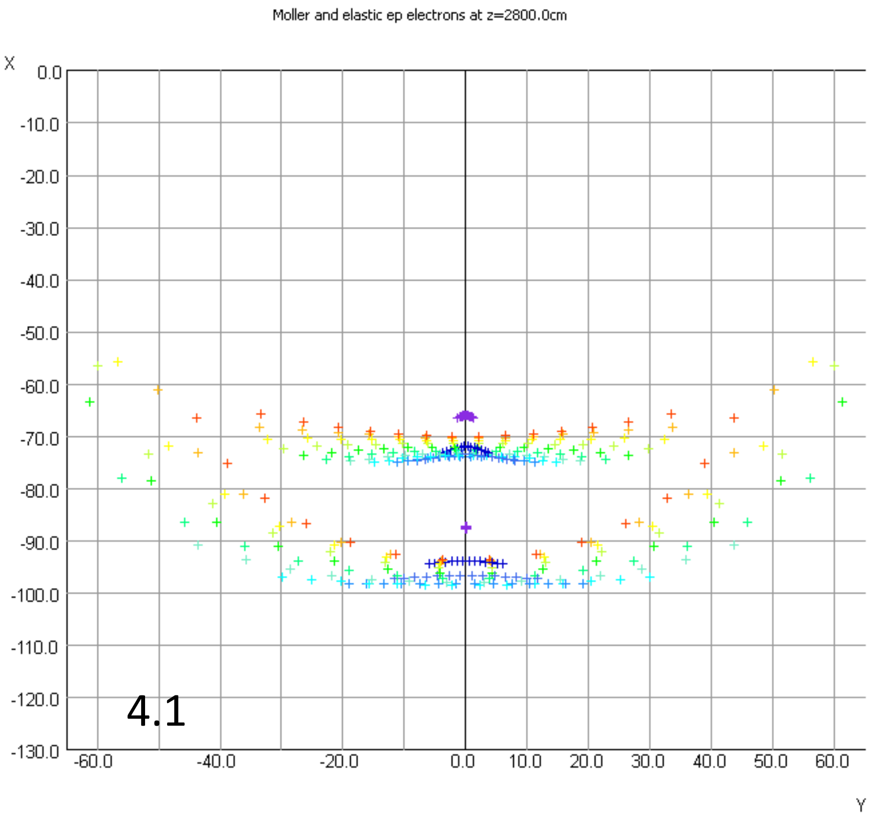
4.1

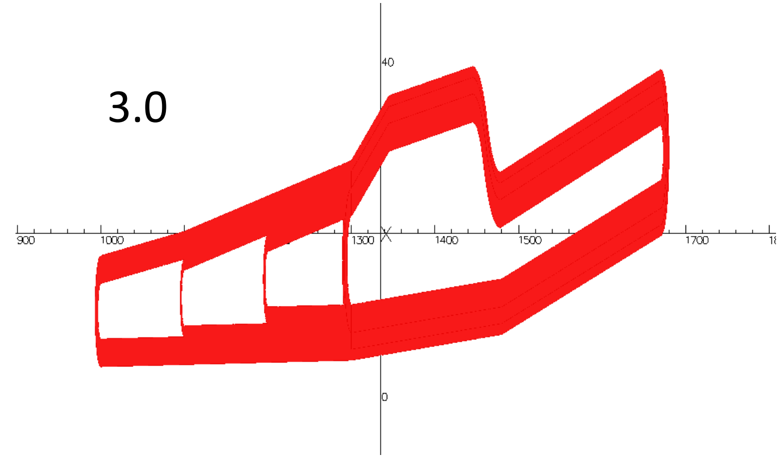
middle (z0 =0 cm) 6.0 to 17 mrads

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



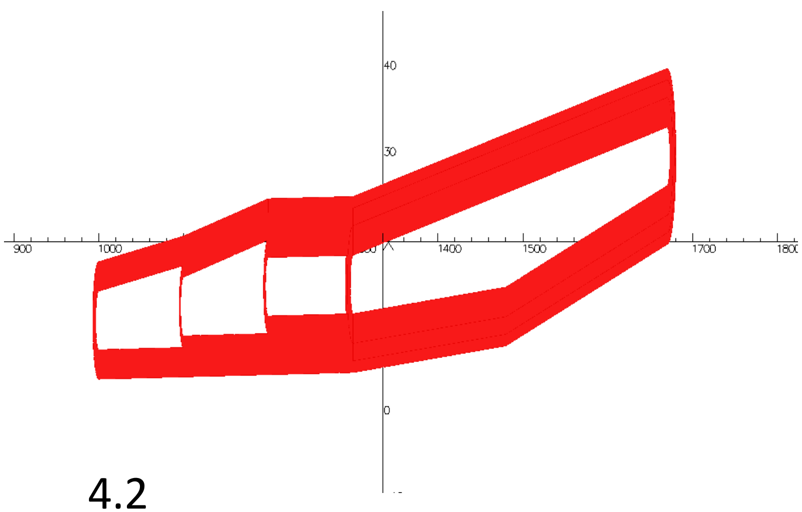
4.2

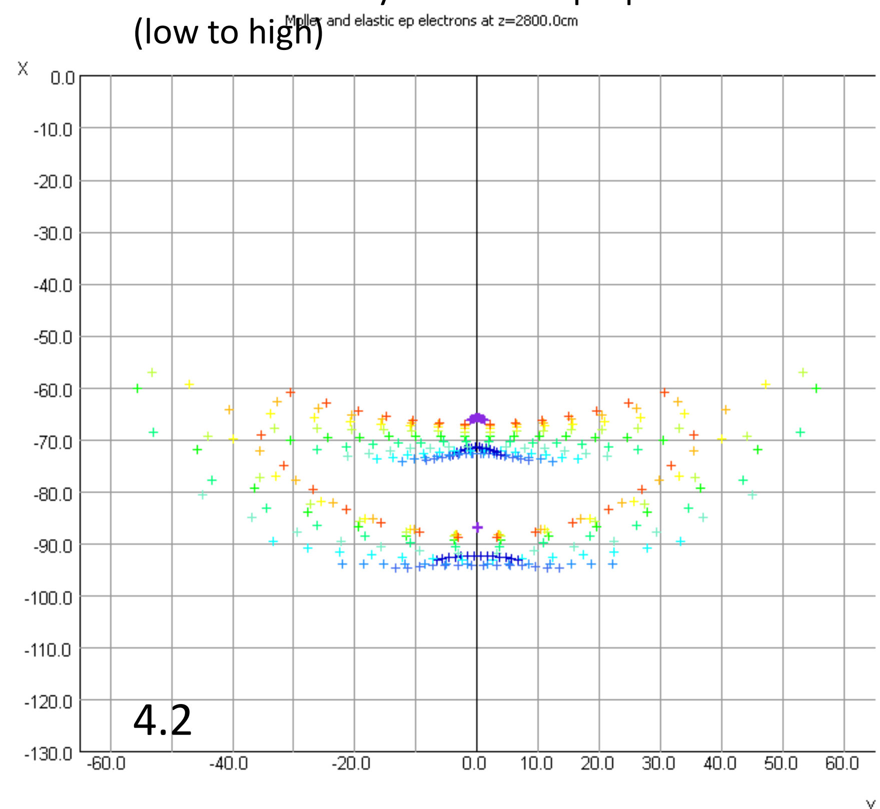


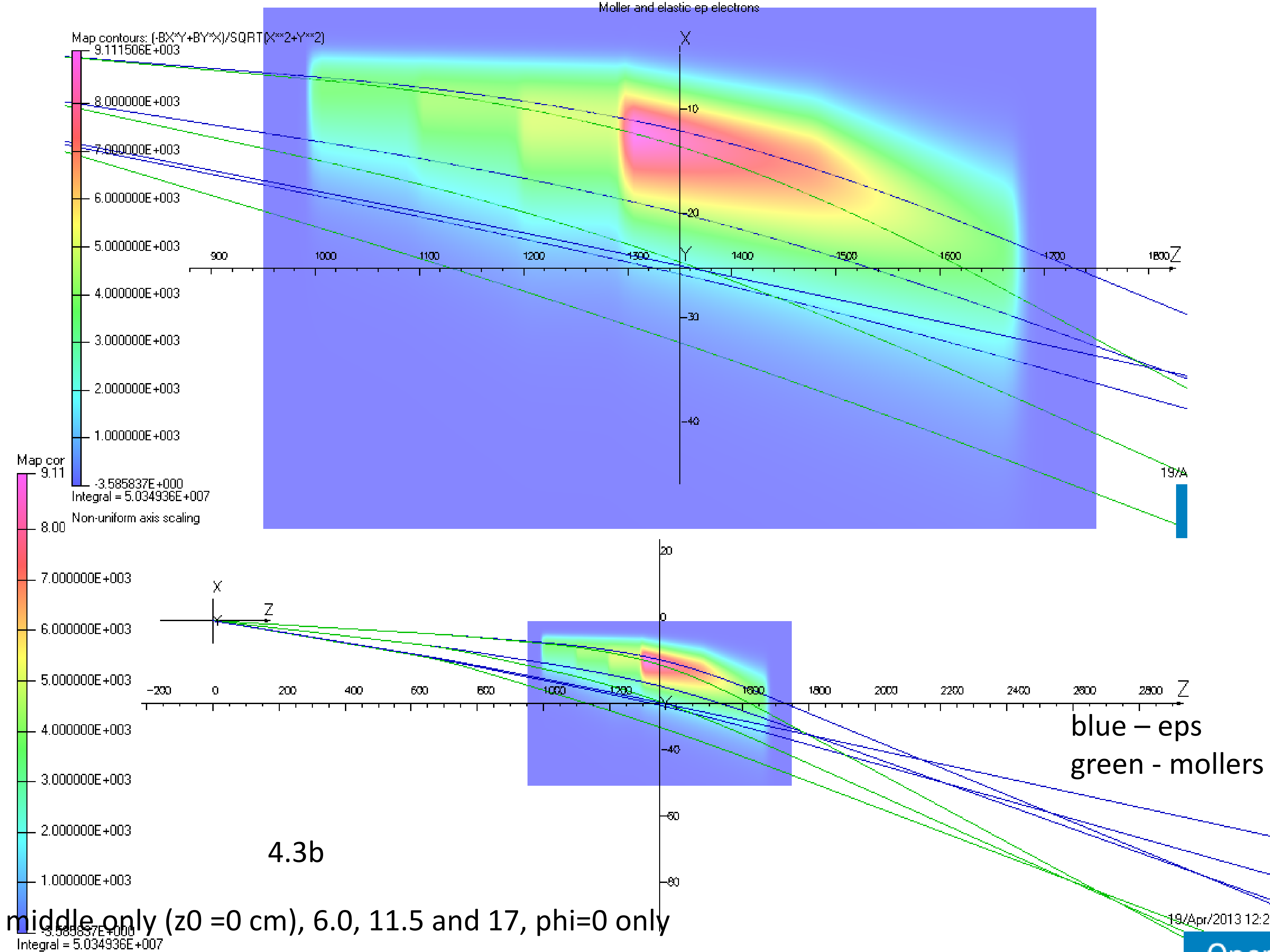


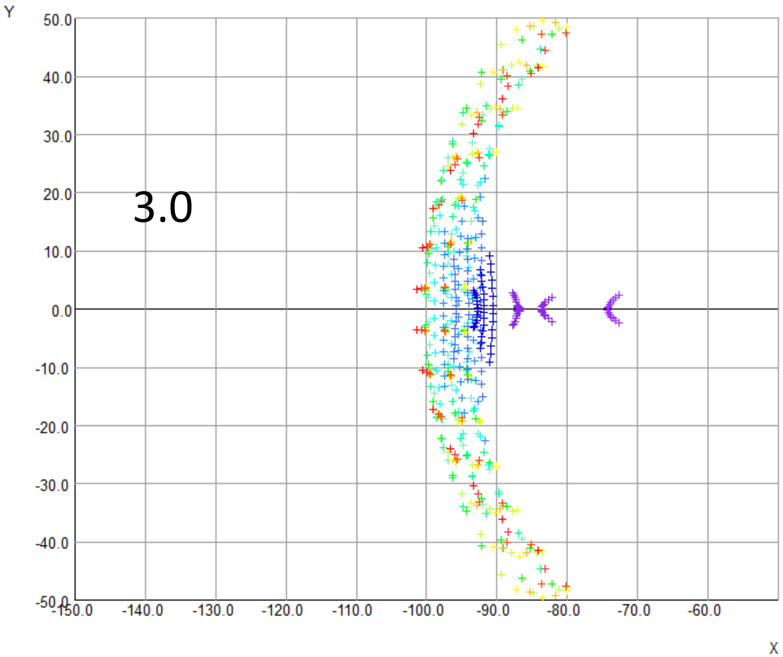
middle (z0 =0 cm)   6.0 to 17 mrads

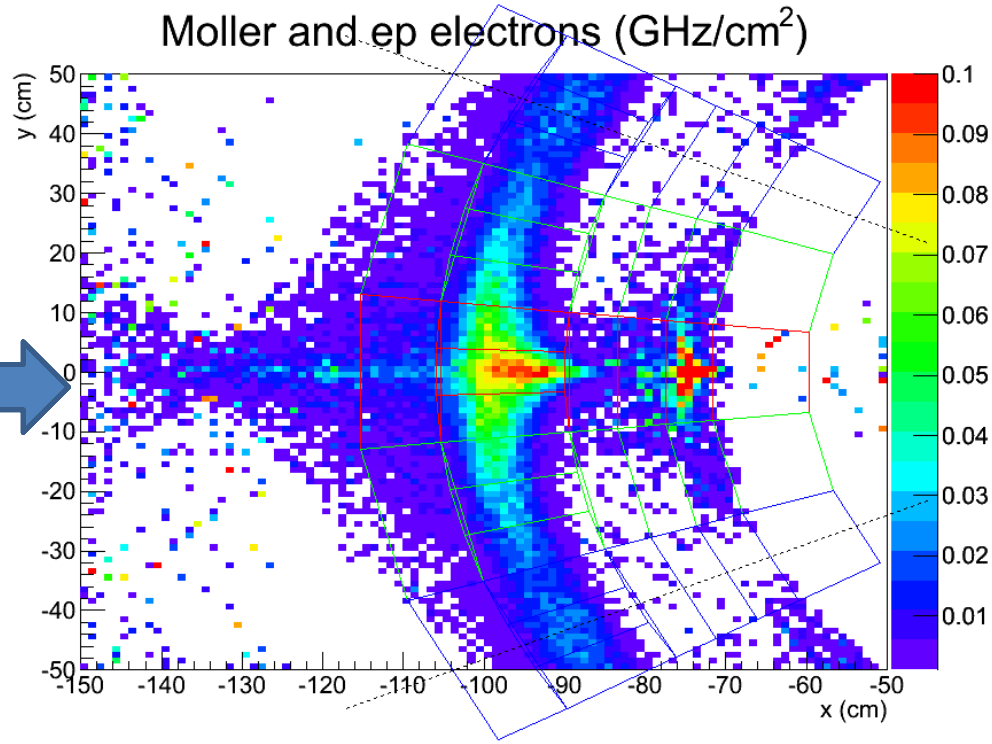
Tracks colored by theta from purple to red (low to high)

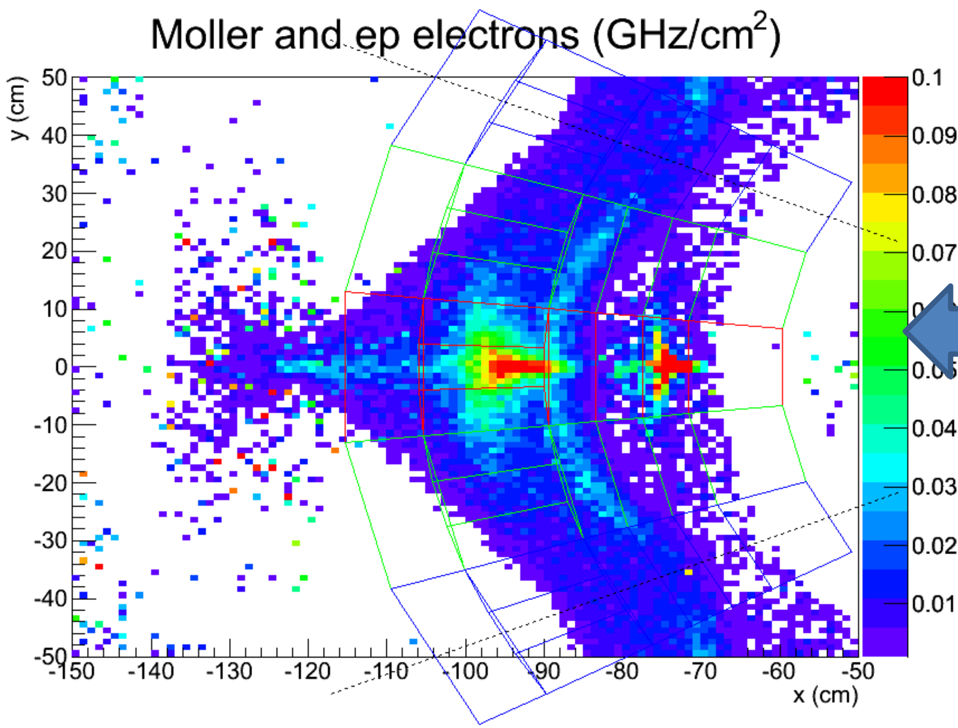


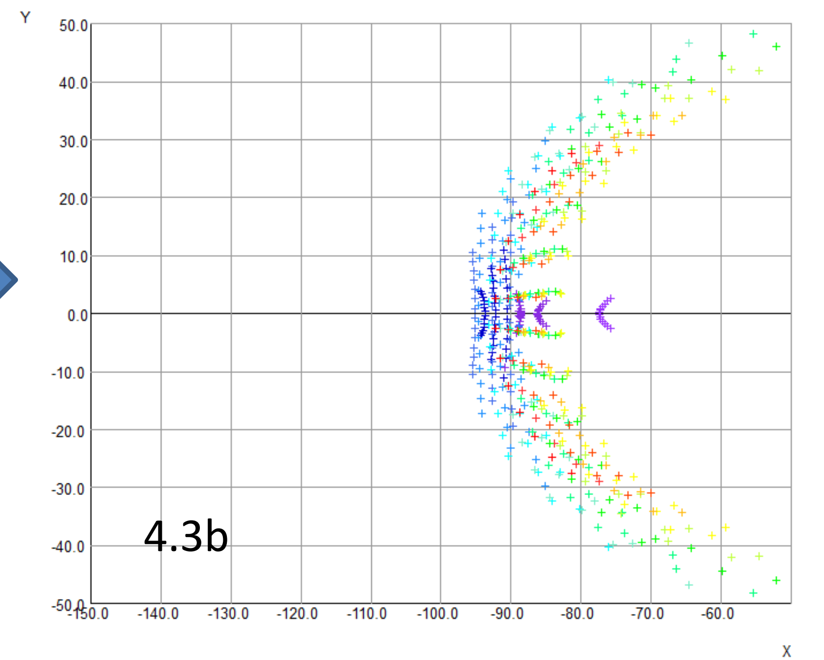



Moller and elastic ep electrons
Map contours: (-BX*Y+BY*X)/SQRT(X**2+Y**2)
9.111506E+003
8.000000E+003
7.000000E+003
6.000000E+003
5.000000E+003
4.000000E+003
3.000000E+003
2.000000E+003
1.000000E+003
-3.585837E+000
Integral = 5.034936E+007
Non-uniform axis scaling
19/A
Integral = 5.034936E+007
19/Apr/2013 12:2
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/cm2)
y (cm)
x (cm)


Moller and ep electrons (GHz/cm2)
y (cm)
x (cm)


4.3b
Y
X

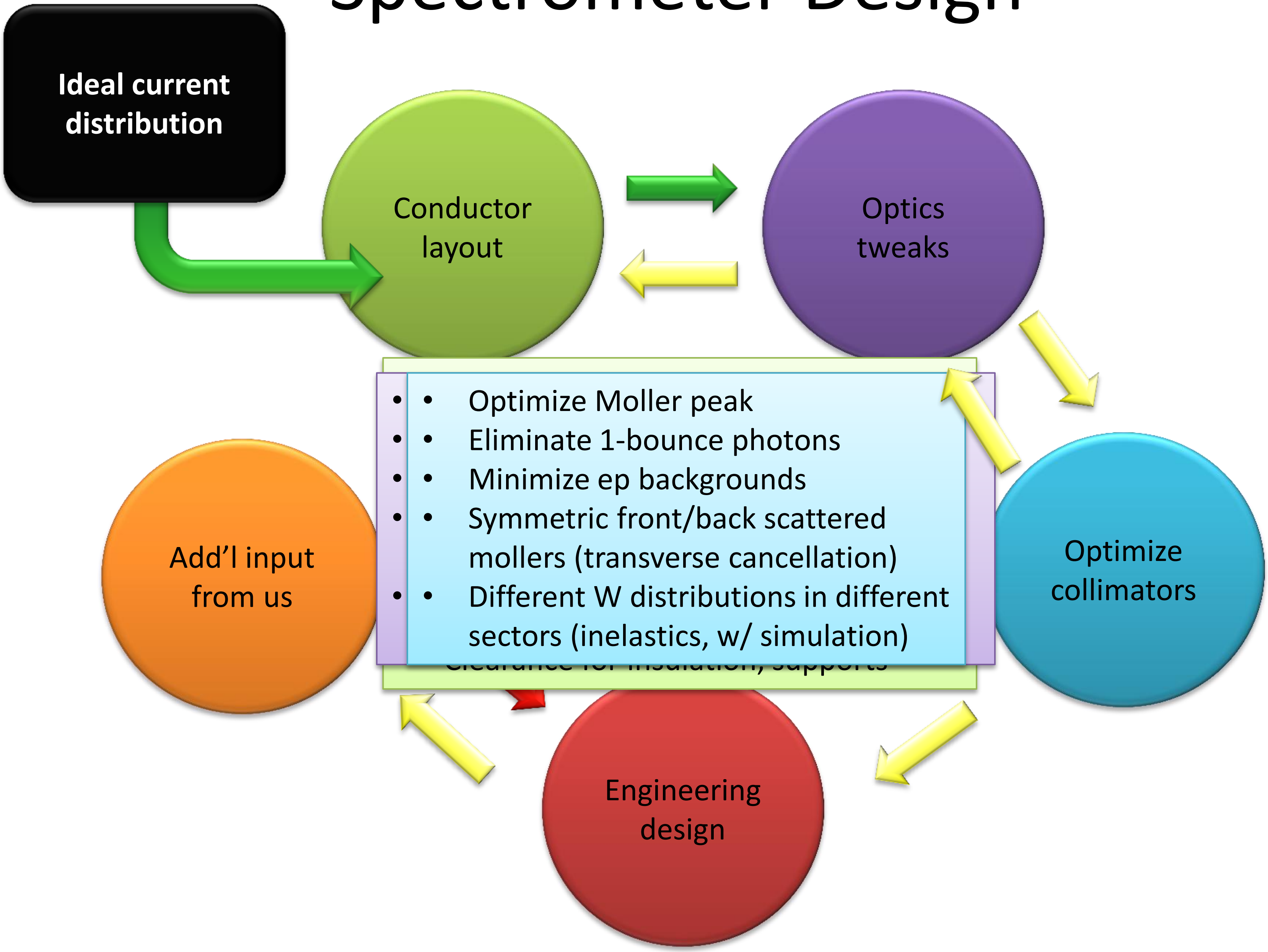
Begin Intro slides for Meeting

Large Phase Space for Design

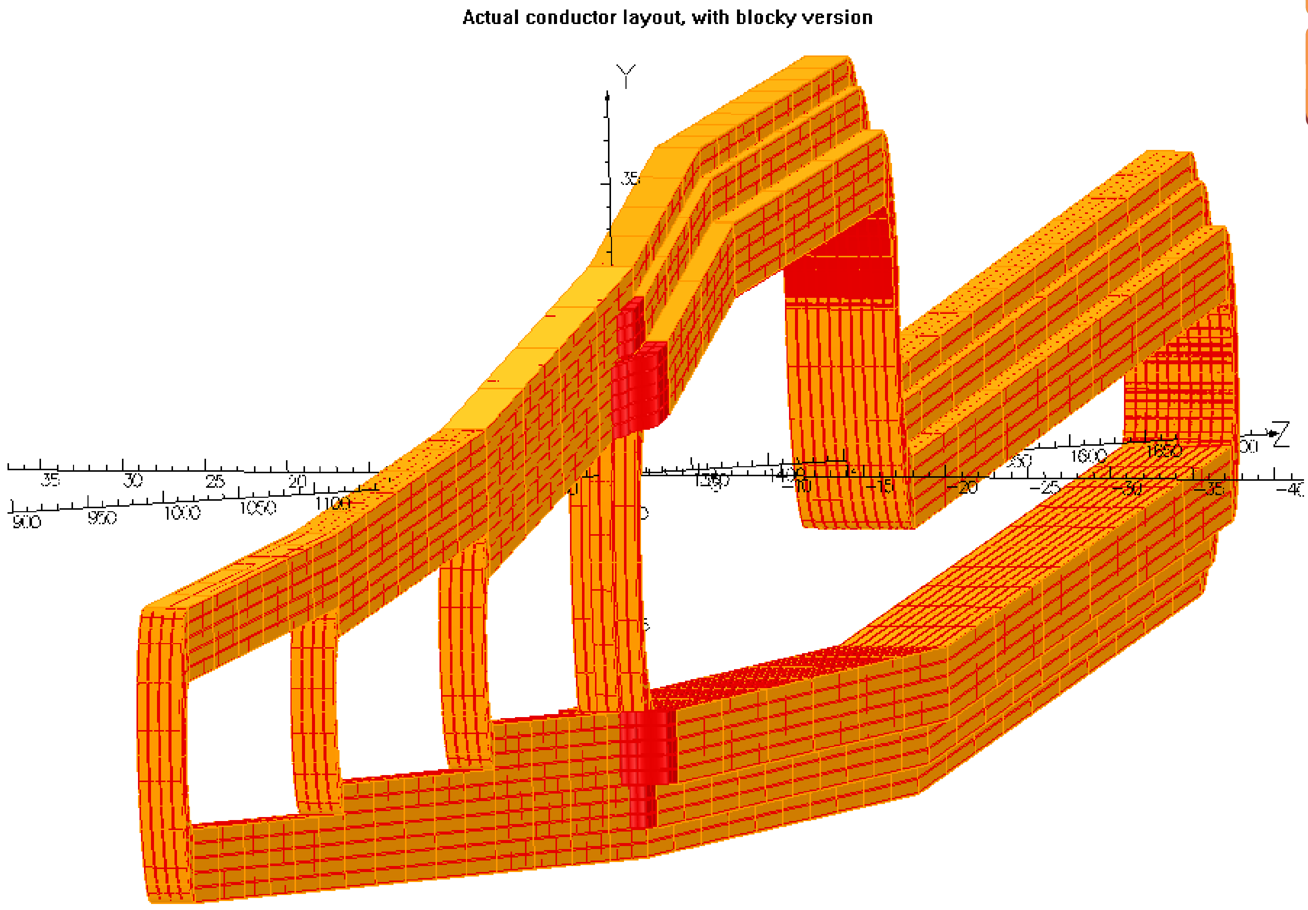
I. Large phase space of possible changes
   A. Field (strength, coil position and profile)
   B. Collimator location, orientation, size
   C. Choice of Primary collimator
   D. Detector location, orientation, size

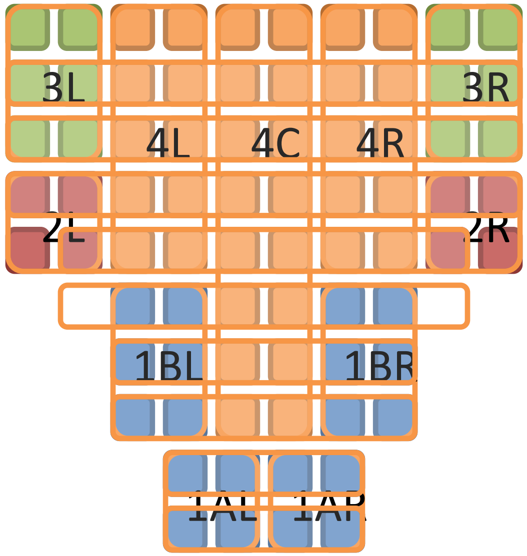
II. Large phase space of relevant properties
   A. Moller rate and asymmetry
   B. Elastic ep rate and asymmetry
   C. Inelastic rate and asymmetry
   D. Transverse asymmetry
   E. Neutral/other background rates/asymmetries
   F. Ability to measure backgrounds (the uncertainty is what's important)
      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)

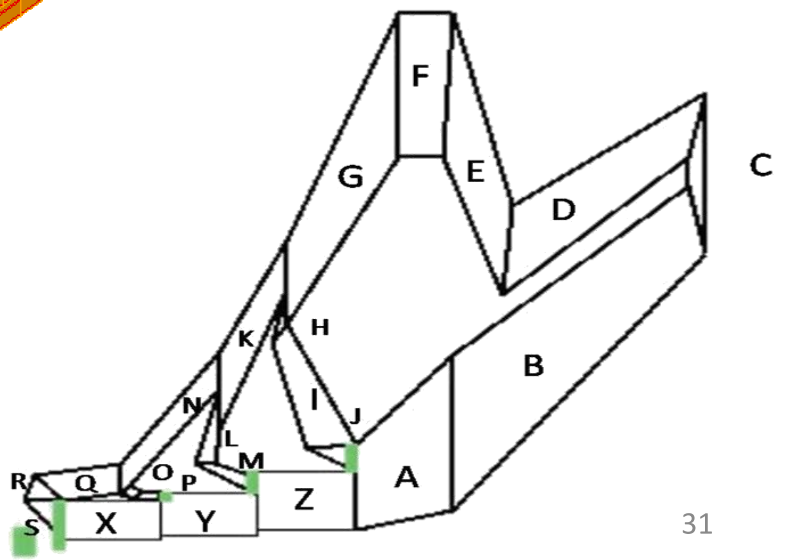
Spectrometer Design



Definitions

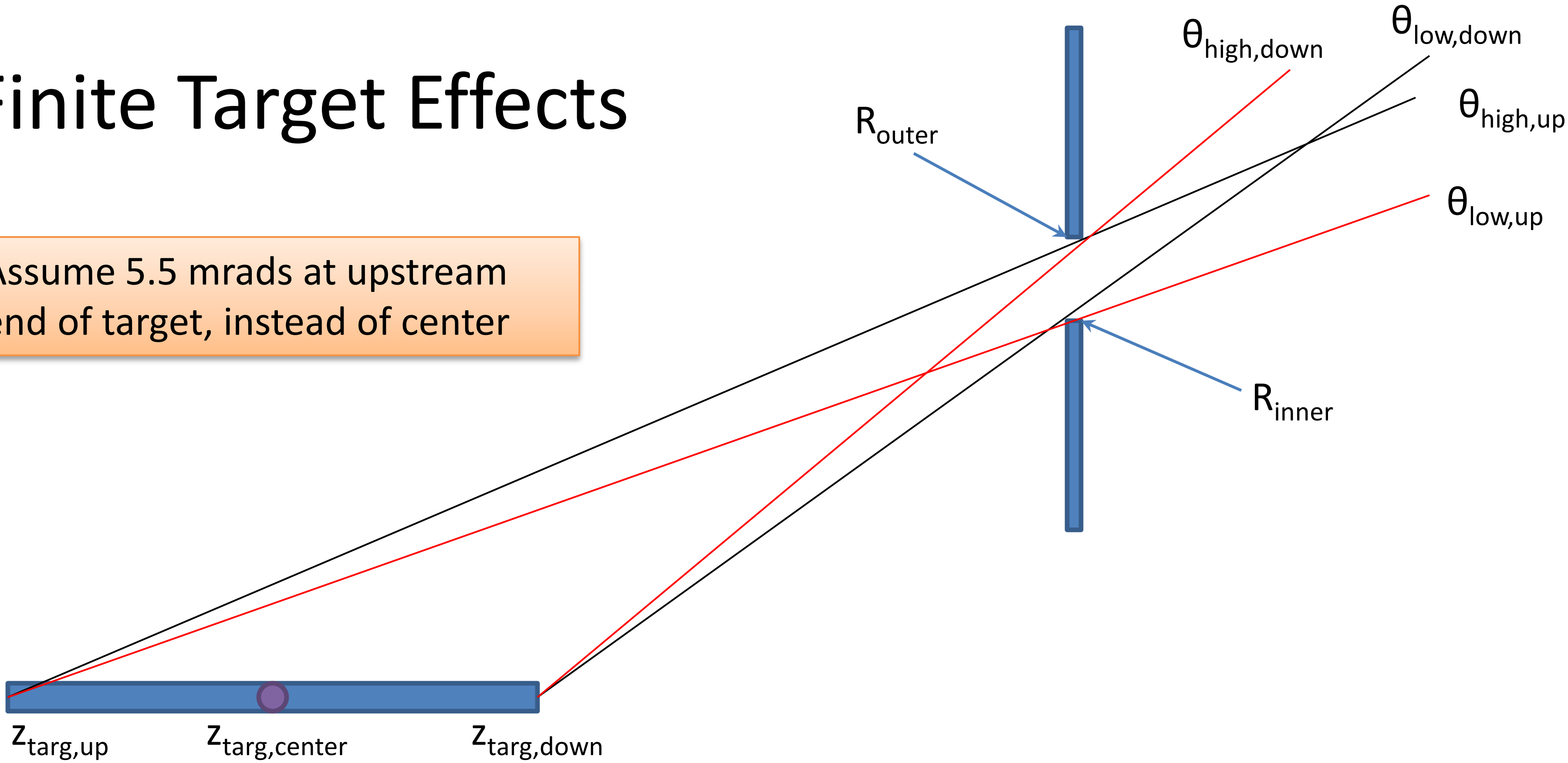






Finite Target Effects

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

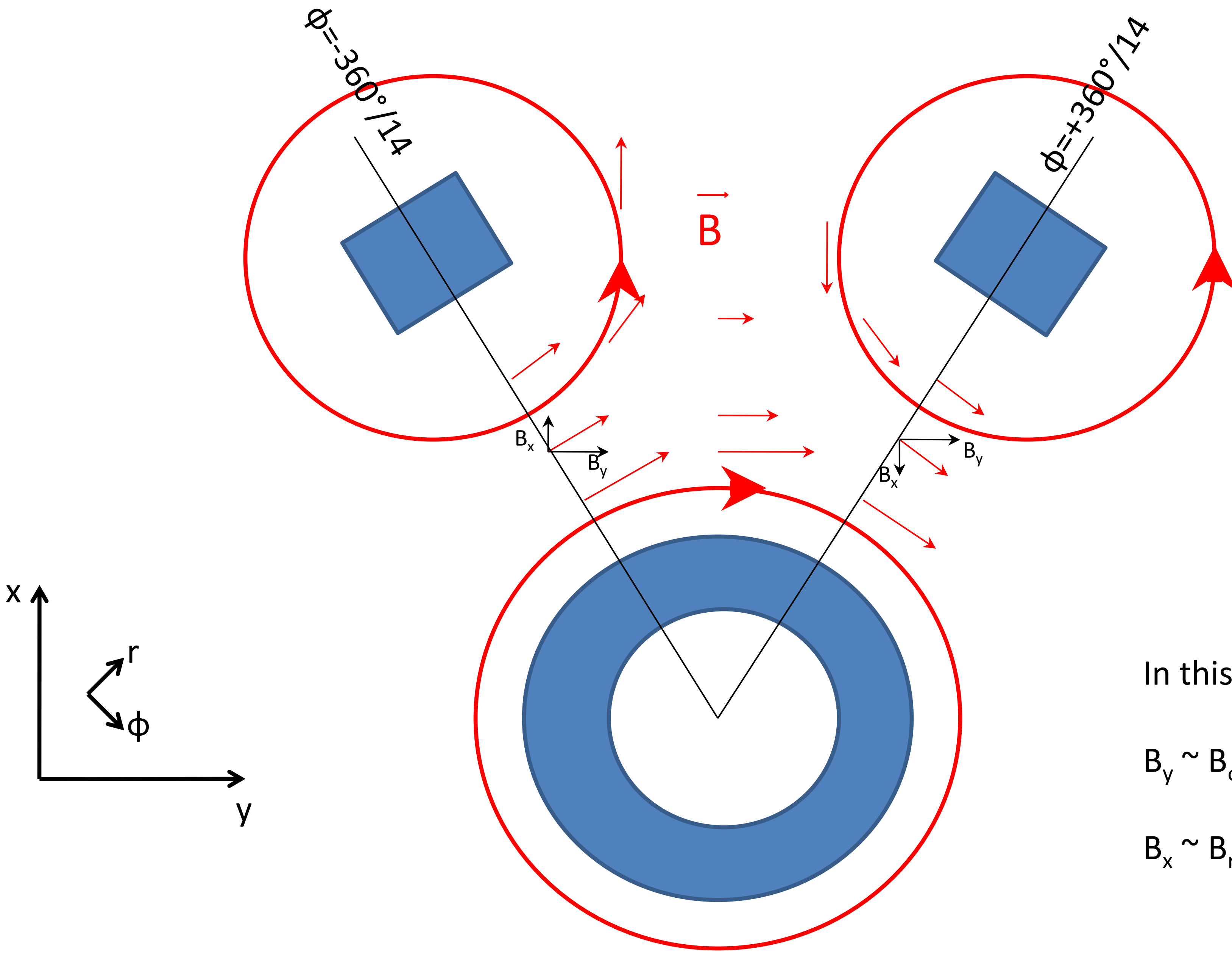
From center:

$\theta_{low,cen}$ = 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



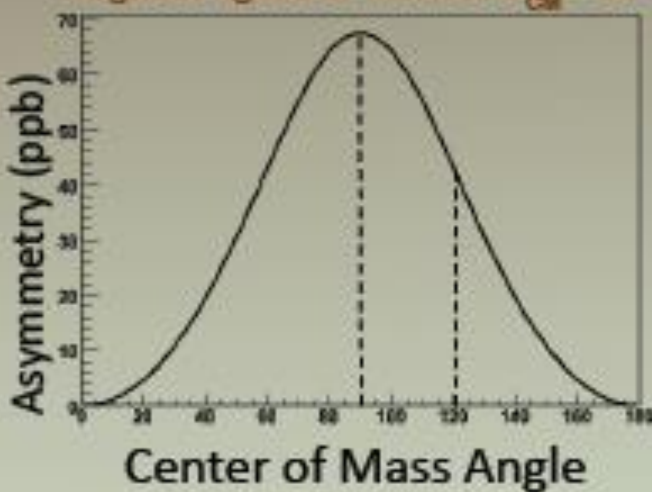
In this septant:

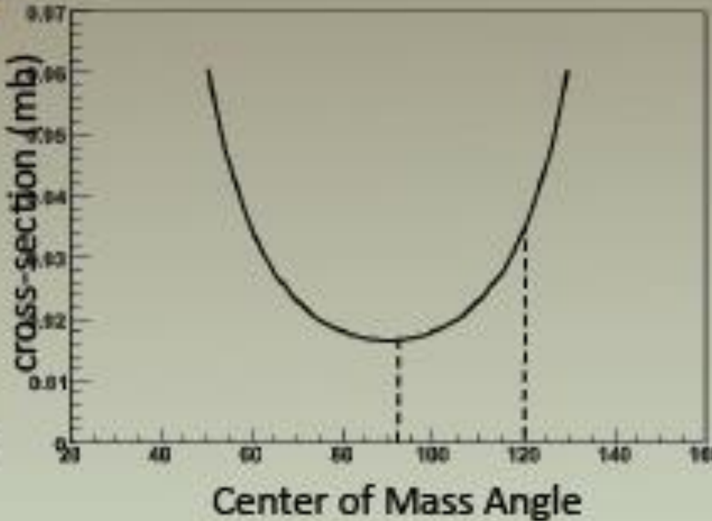
$B_y \sim B_\phi$

$B_x \sim B_r$

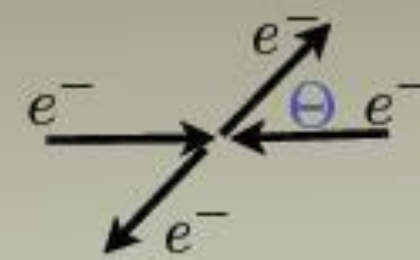
100% Acceptance with Toroids

Highest figure of merit at $\theta_{CM} = 90^o$



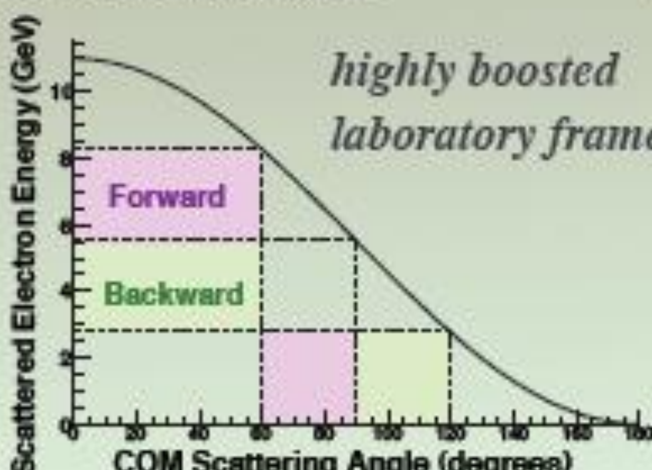


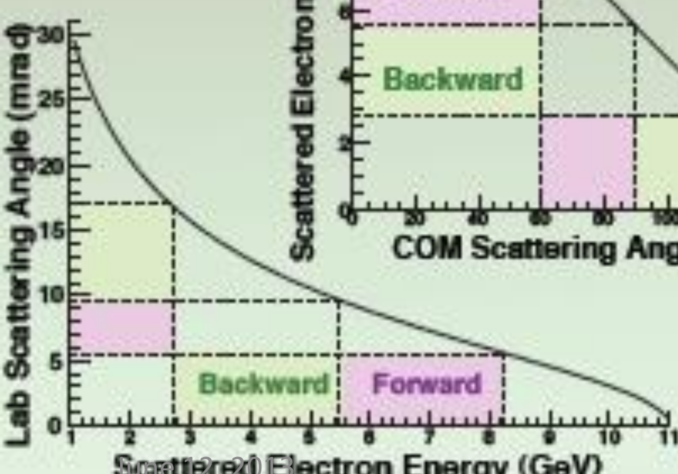
$E_{COM} = 53$ MeV



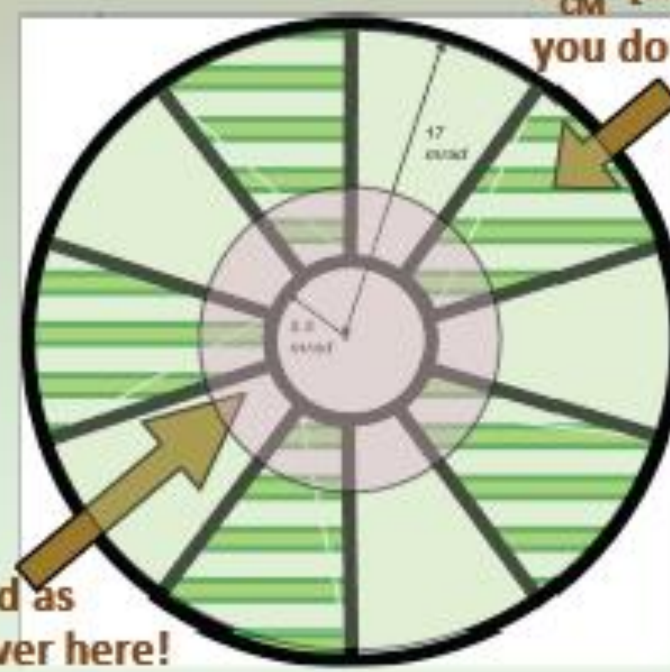
identical particles!

highly boosted laboratory frame



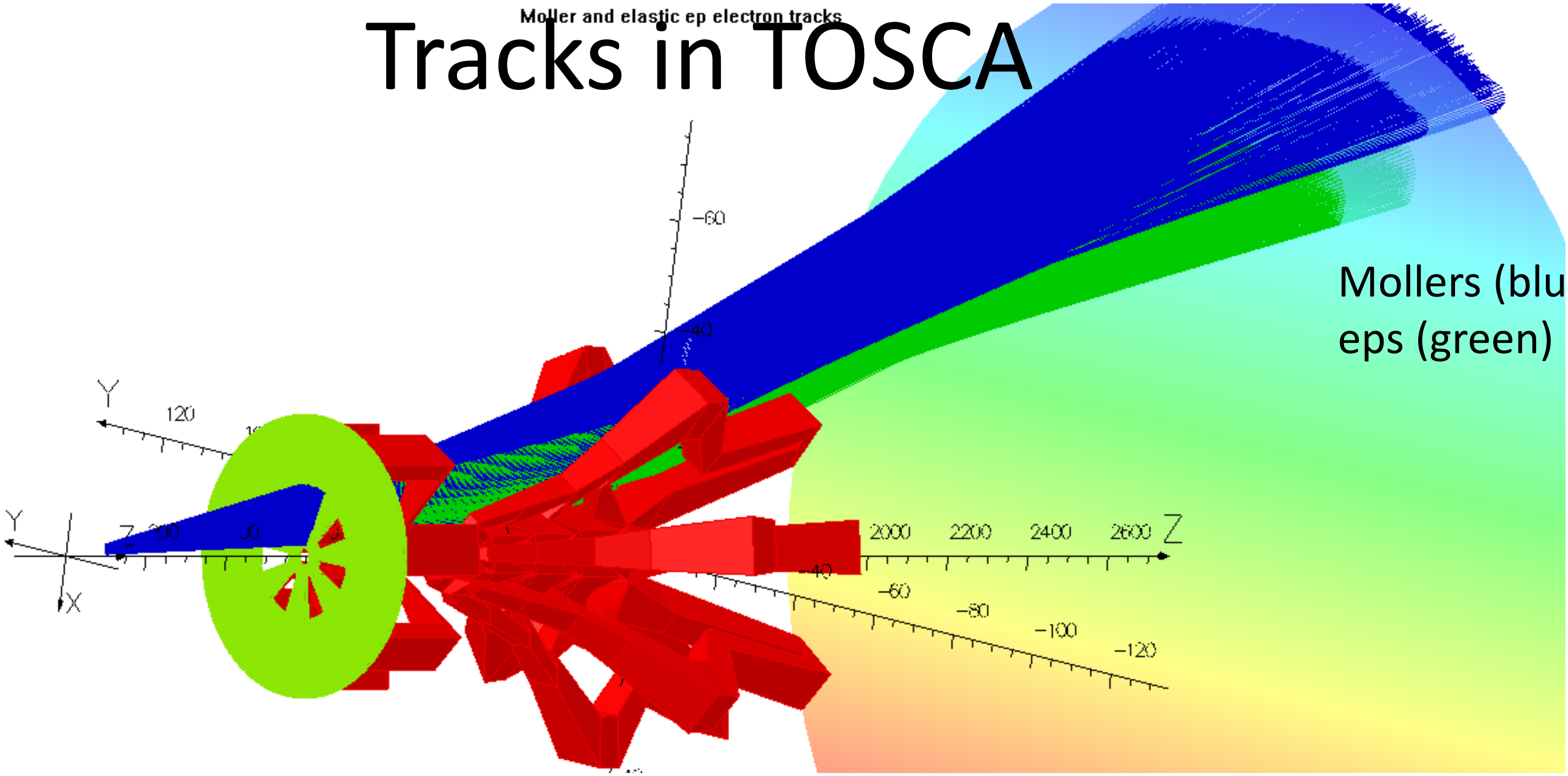


All of those rays of θ_{CM}=[90,120] that you don't get here…

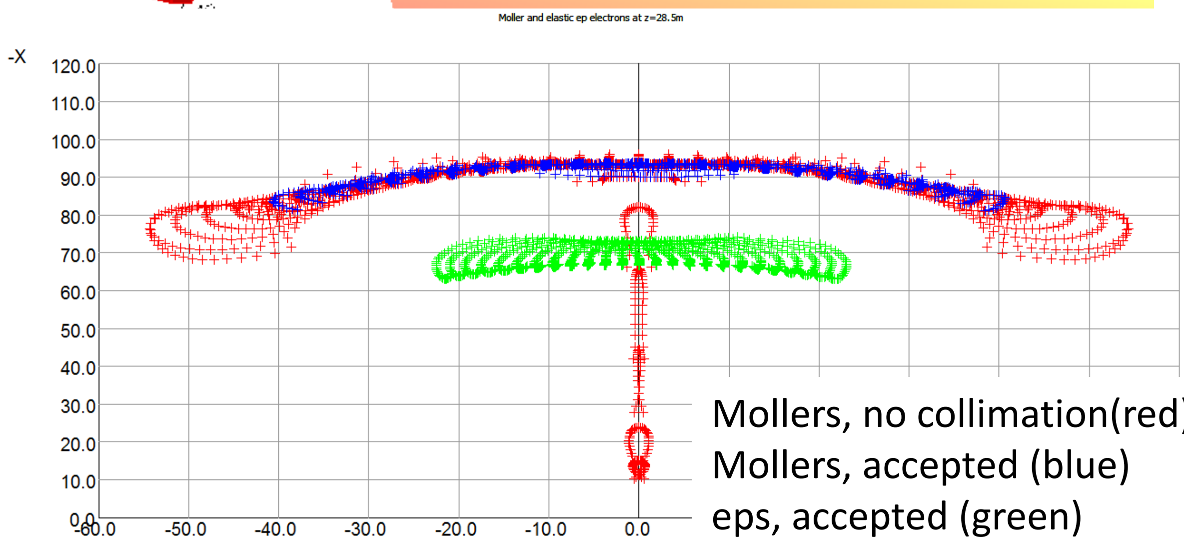


… are collected as θ_{CM}=[60,90] over here!

Tracks in TOSCA



Mollers (blue)
eps (green)

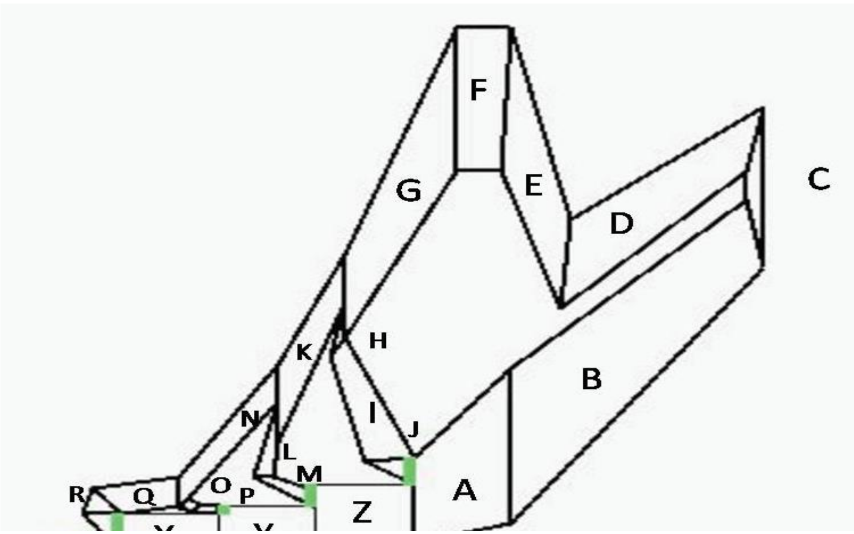


Mollers, no collimation(red)
Mollers, accepted (blue)
eps, accepted (green)

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

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

Proposal Model to TOSCA model

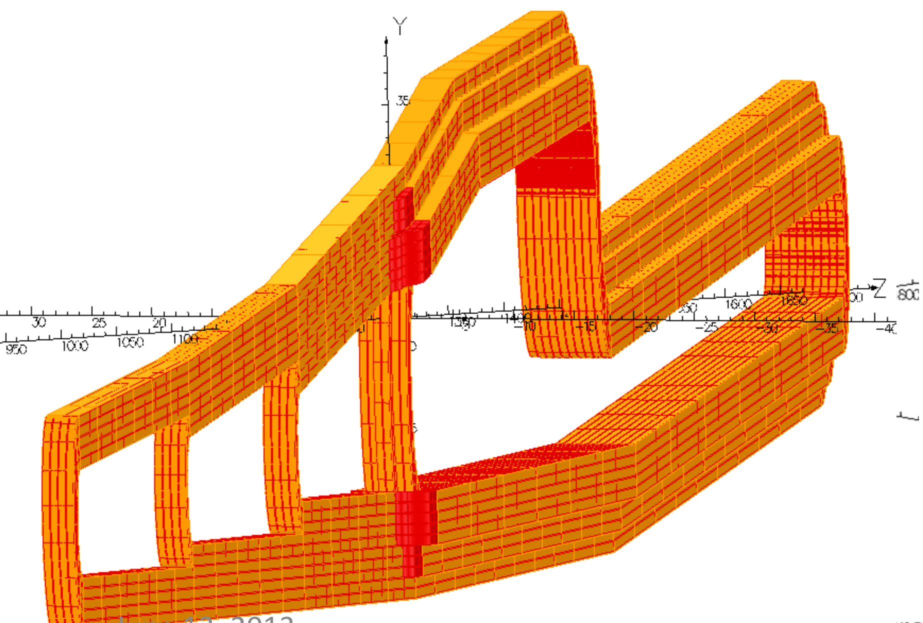


Actual conductor layout, with blocky version

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

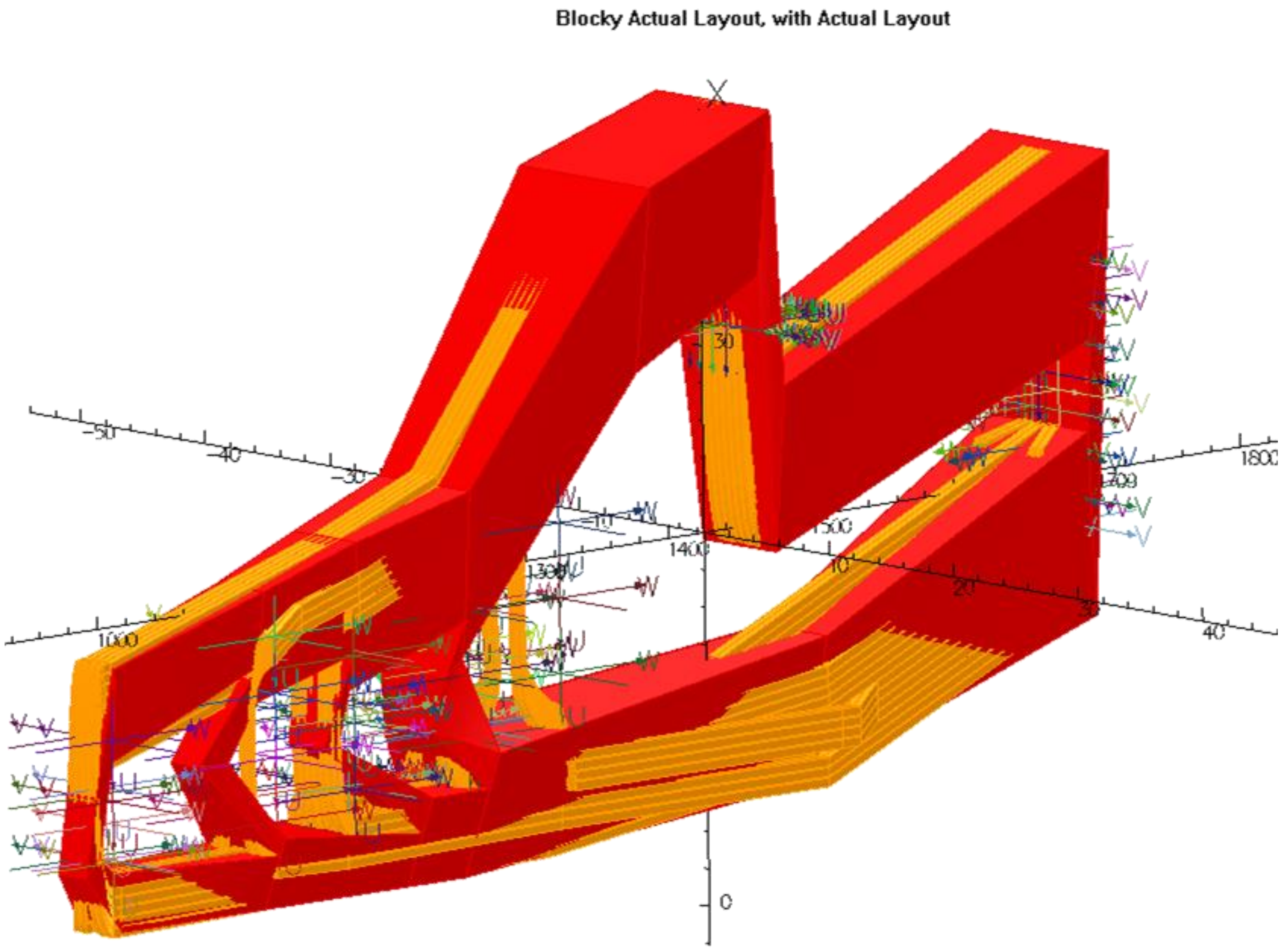
Created second version with larger water cooling hole and nicer profile; obeyed keep-out zones

Concept 1 – choose constraints

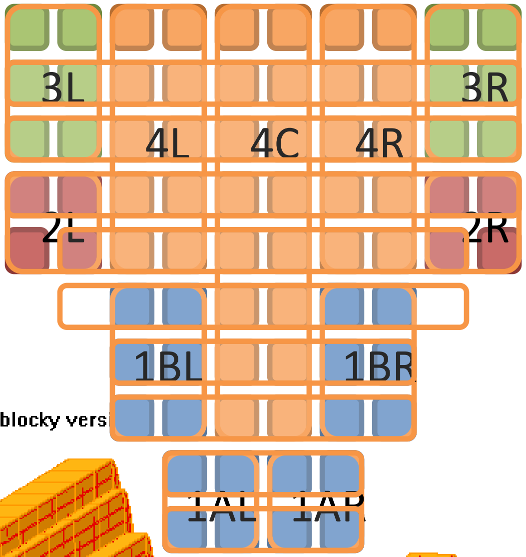
- Try to use “double pancakes” structure
- Choose (standard) conductor size/layout minimizes current density
- Keep individual double pancakes as flat as possible
- Fit within radial, angular acceptances (360/7° at low radius and <360/14° at larger radius)
- Total current in each inner “cylinder” same 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!!

Blocky Model superimposed

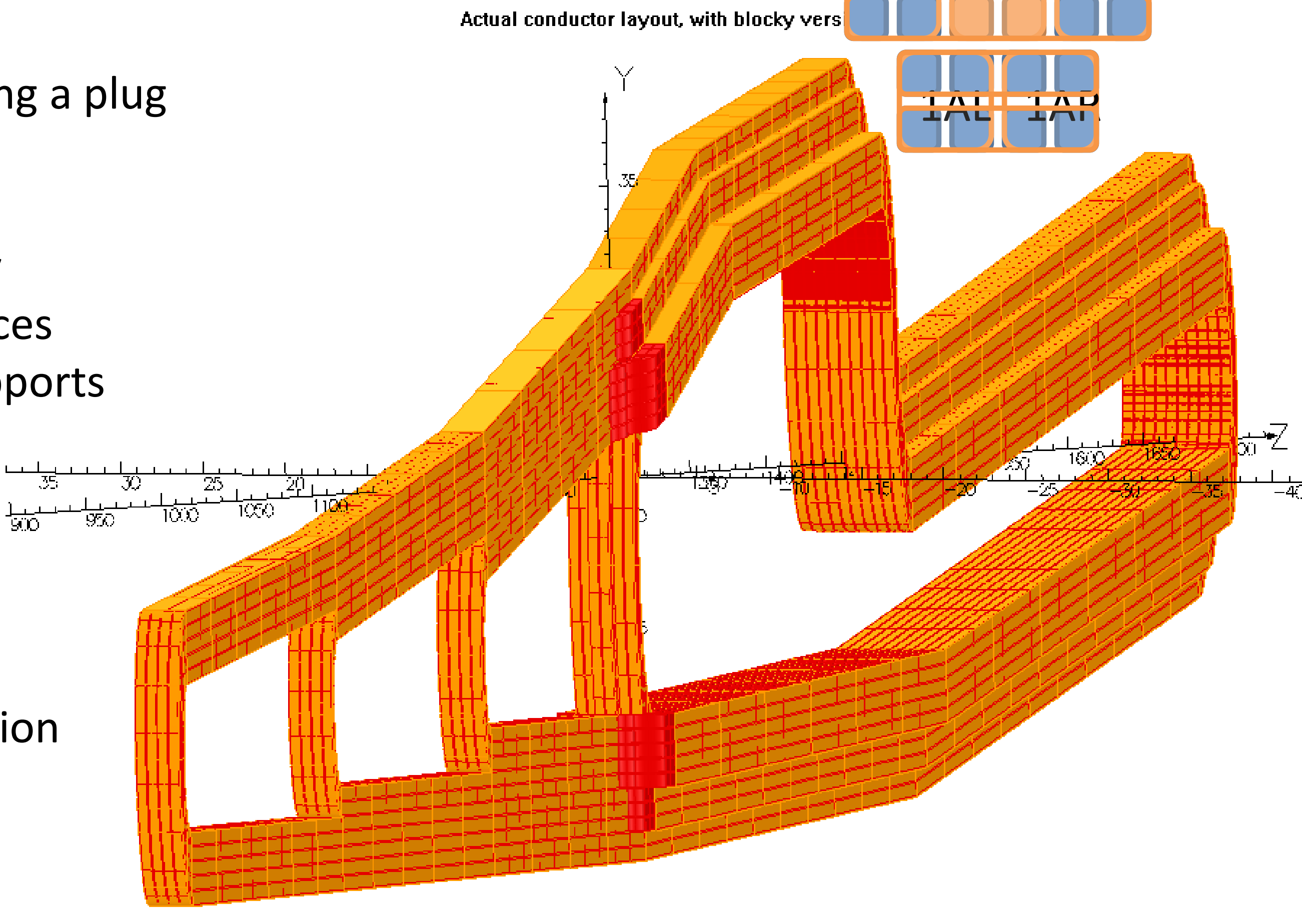


Concept 2 – Post-review

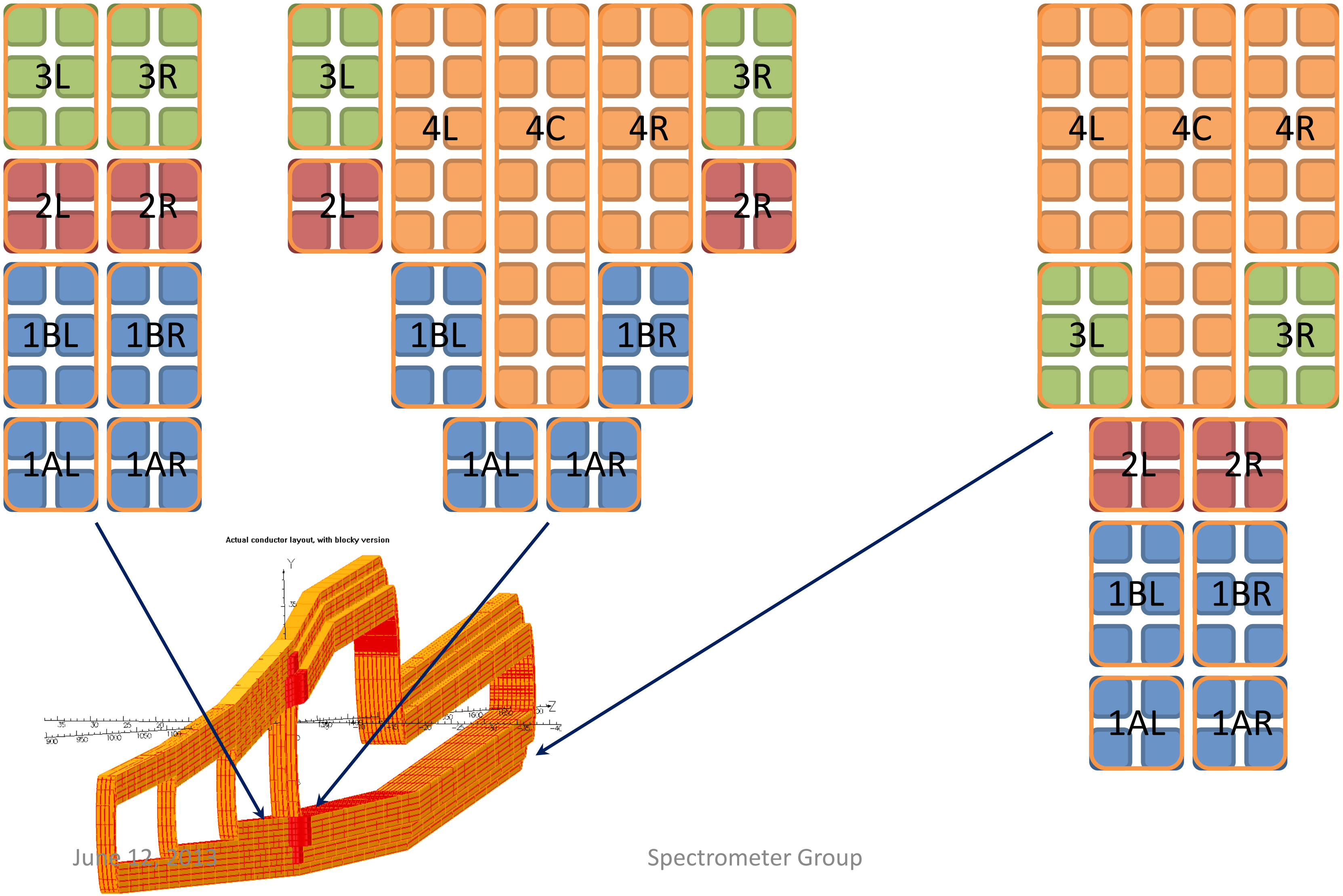


Current density not an issue, but affects cooling

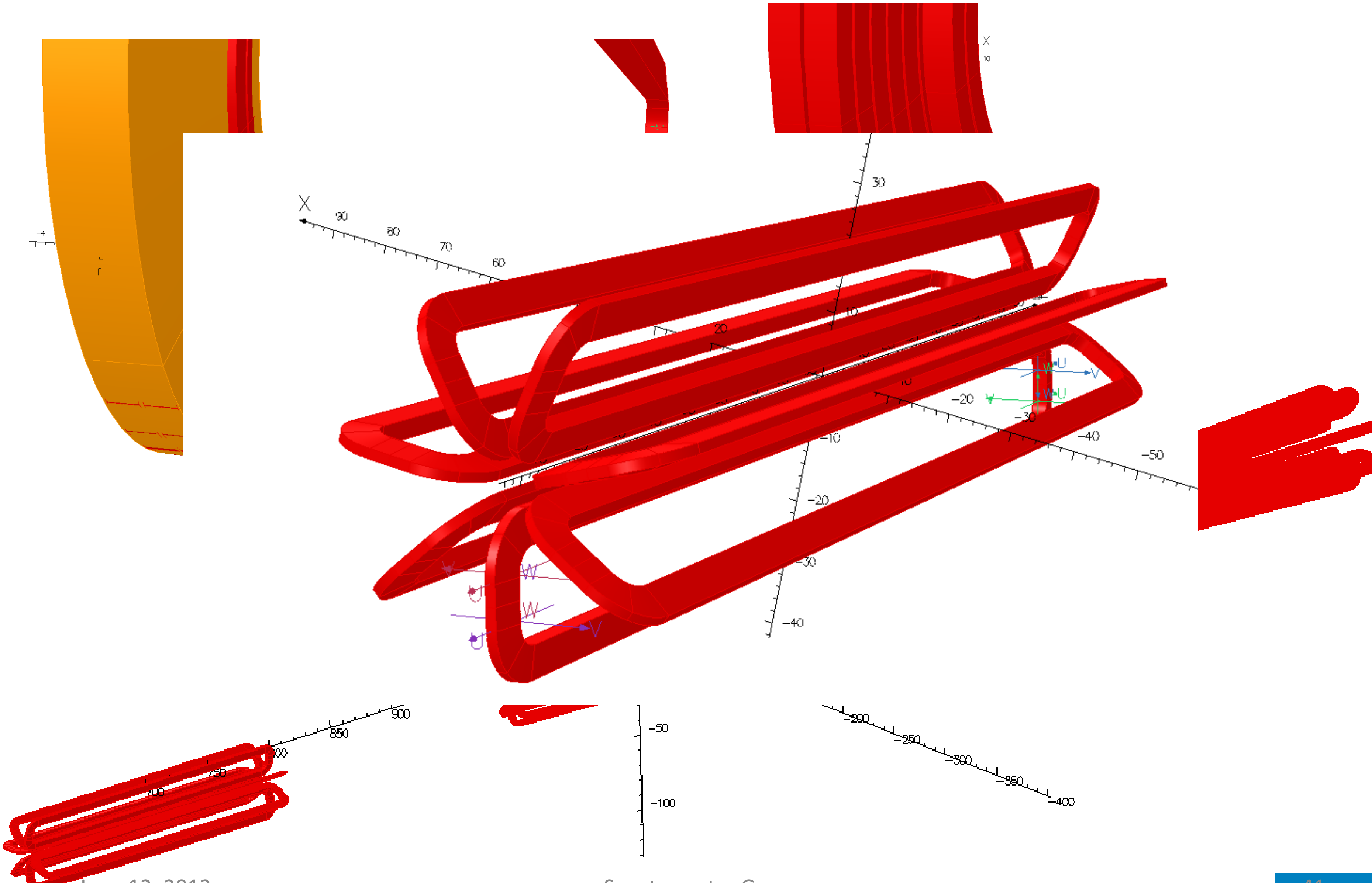
- Larger conductor
  - Larger water-cooling hole
  - Fewer connections
  - Less chance of developing a plug
- New layout
  - Use single power supply
  - Keep-out zones/tolerances
  - Need to think about supports
  - Study magnetic forces
- Continued simulation effort
  - Consider sensitivities
  - Re-design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



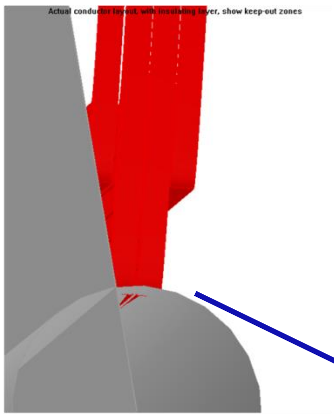
Layout

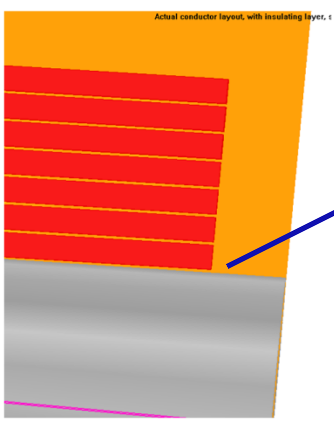

3L
3R
2L
2R
1BL
1BR
1AL
1AR
3L
4L
4C
4R
3R
2L
2R
1BL
1BR
1AL
1AR
4L
4C
4R
3L
3R
2L
2R
1BL
1BR
1AL
1AR
Actual conductor layout, with blocky version

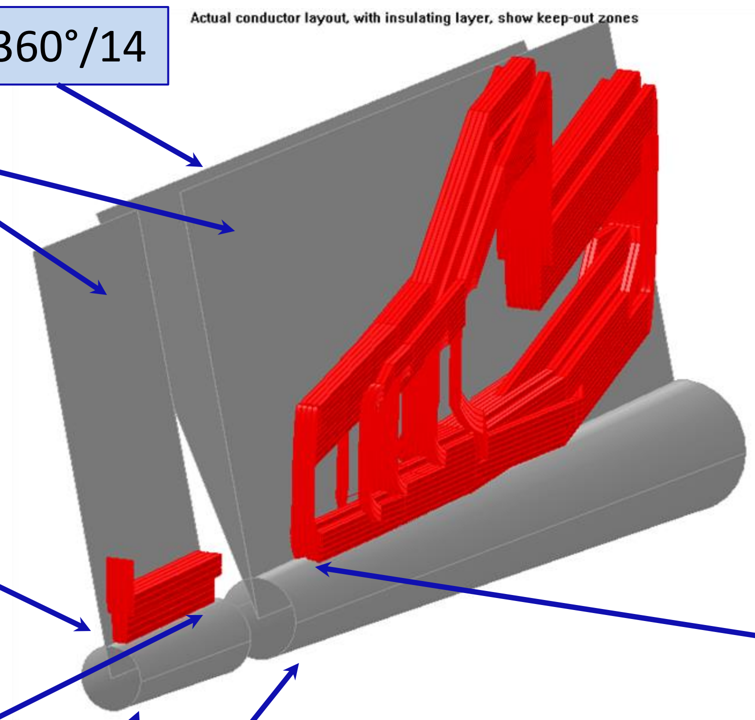
Upstream Torus

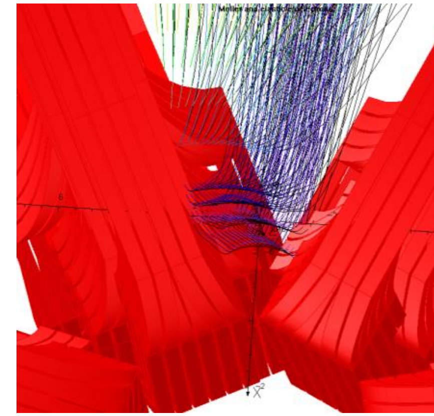


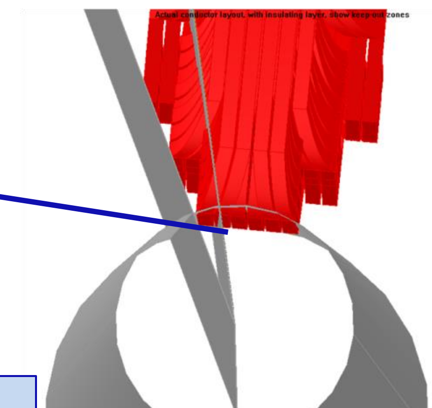
Keep Out Zones







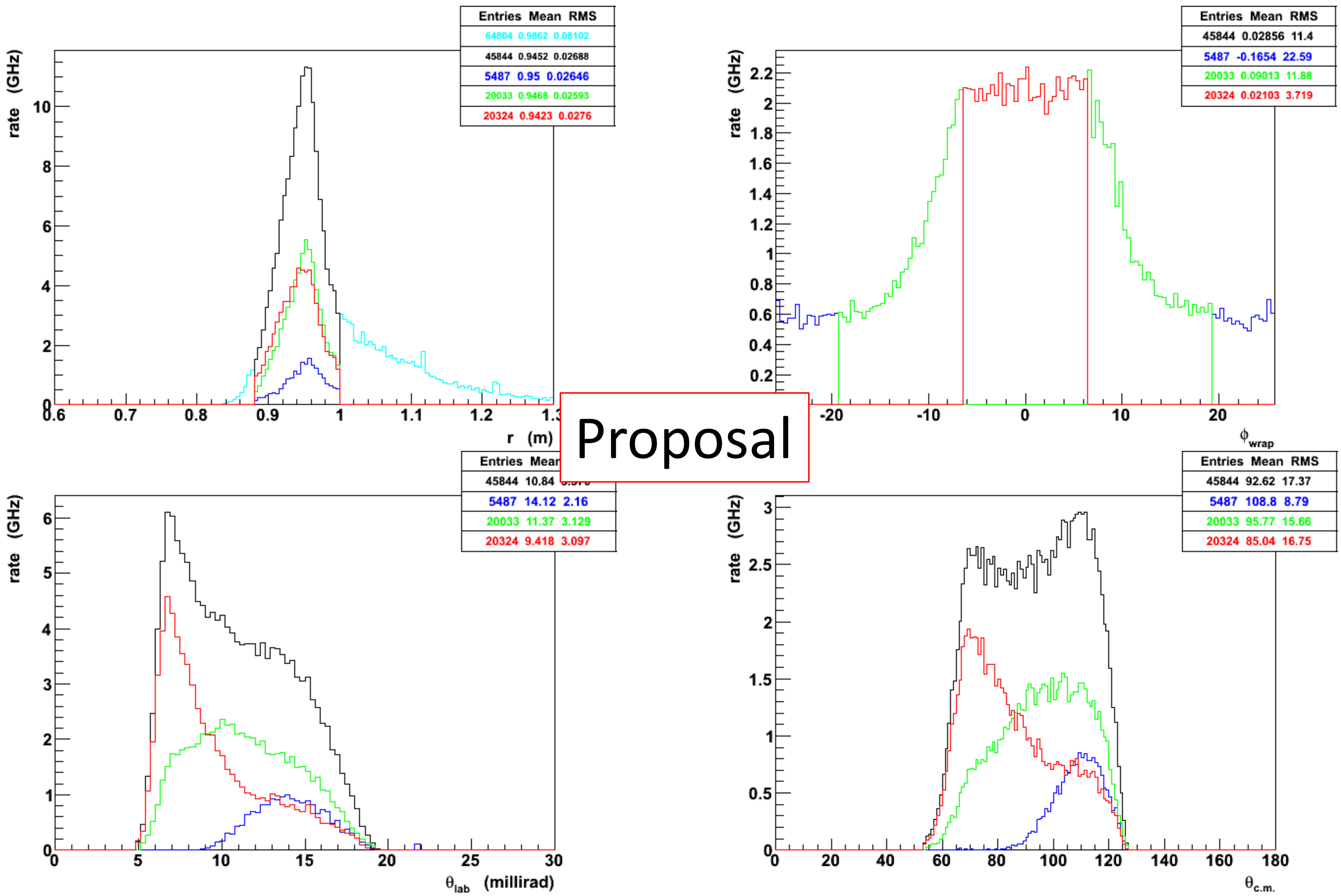




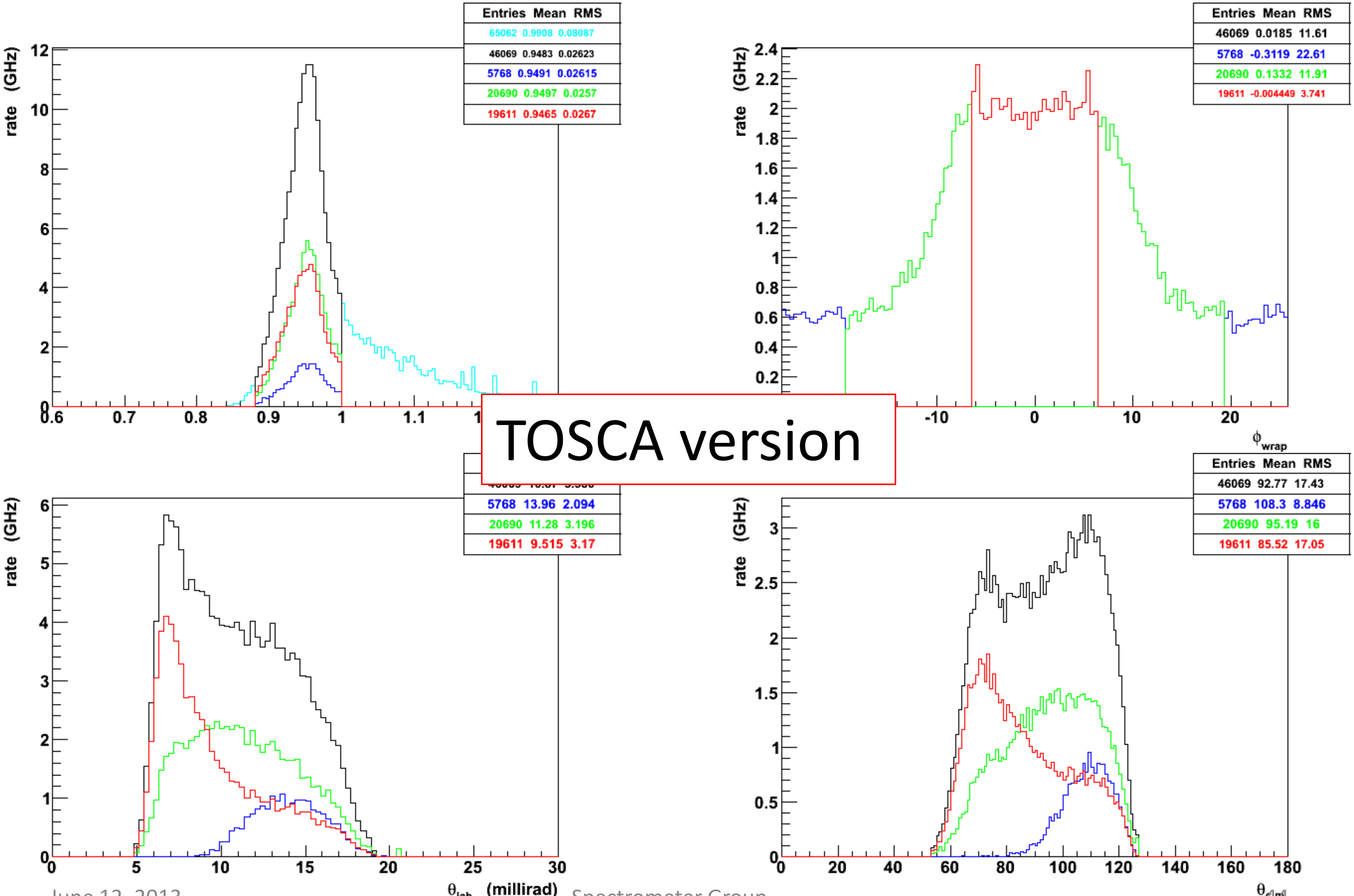
cones are defined using:

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

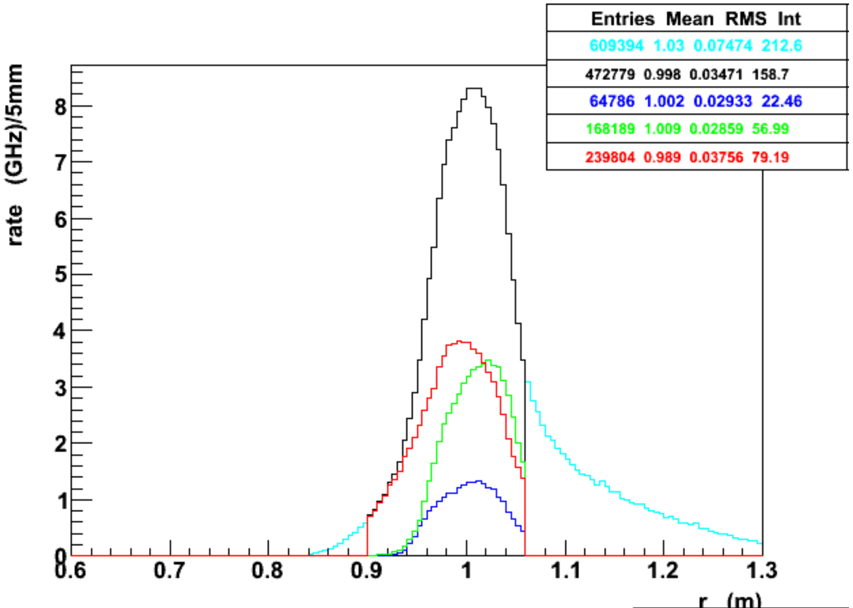
Comparison of GEANT4 Simulations

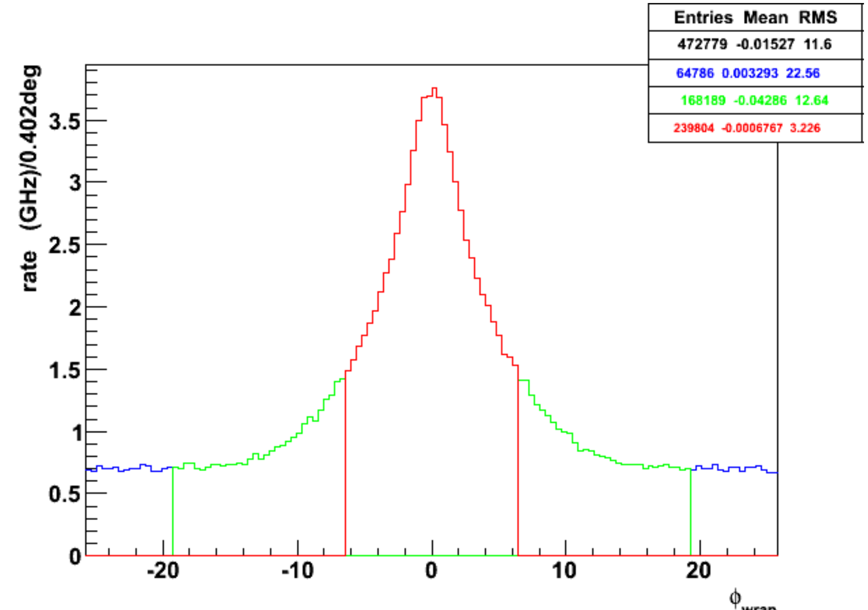


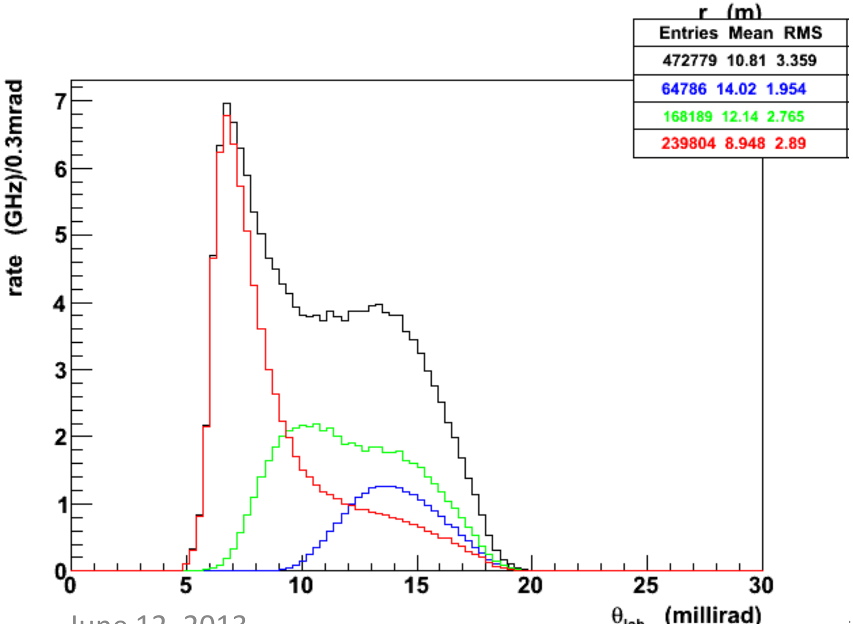
Comparison of GEANT4 Simulations

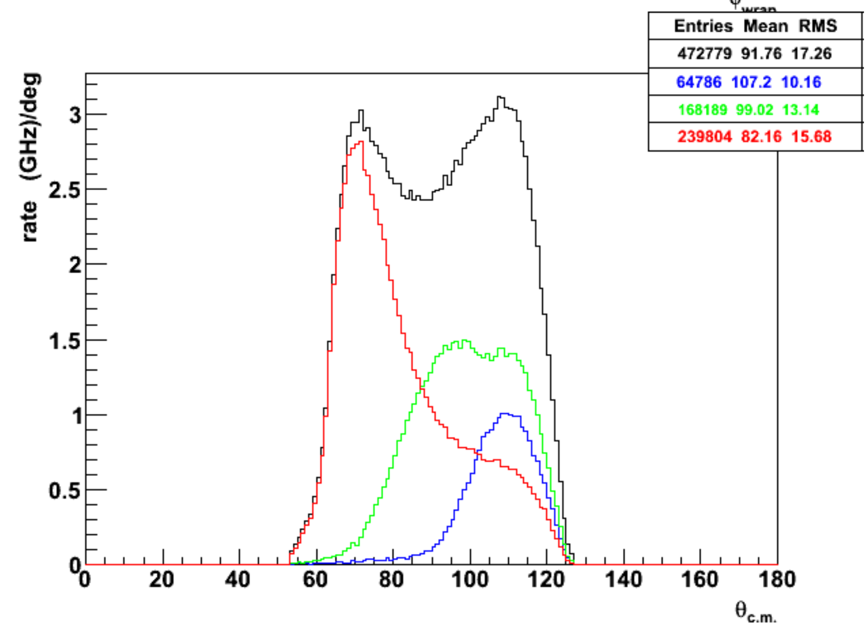


2.6

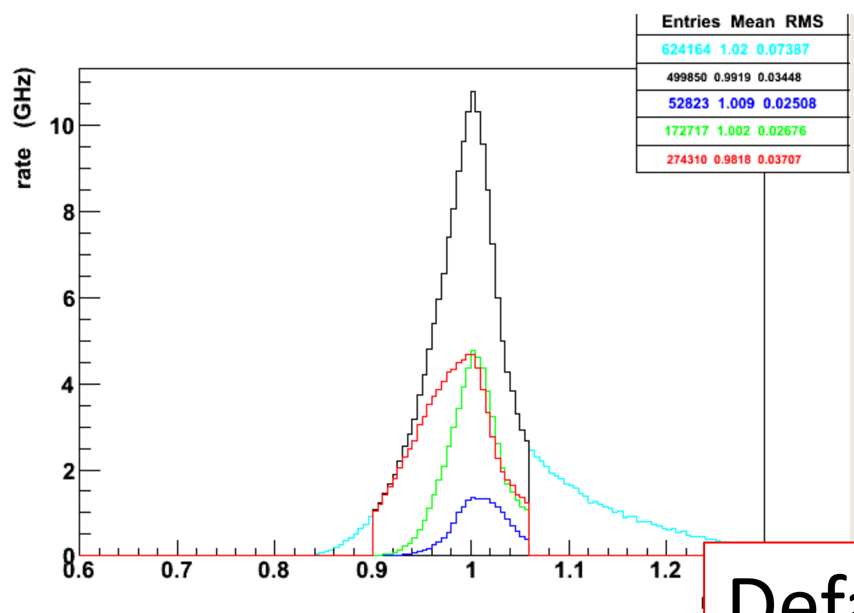

Entries Mean RMS Int
609394 1.03 0.07474 212.6
472779 0.998 0.03471 158.7
64786 1.002 0.02933 22.46
168189 1.009 0.02859 56.99
239804 0.989 0.03756 79.19
rate (GHz)/5mm
r (m)

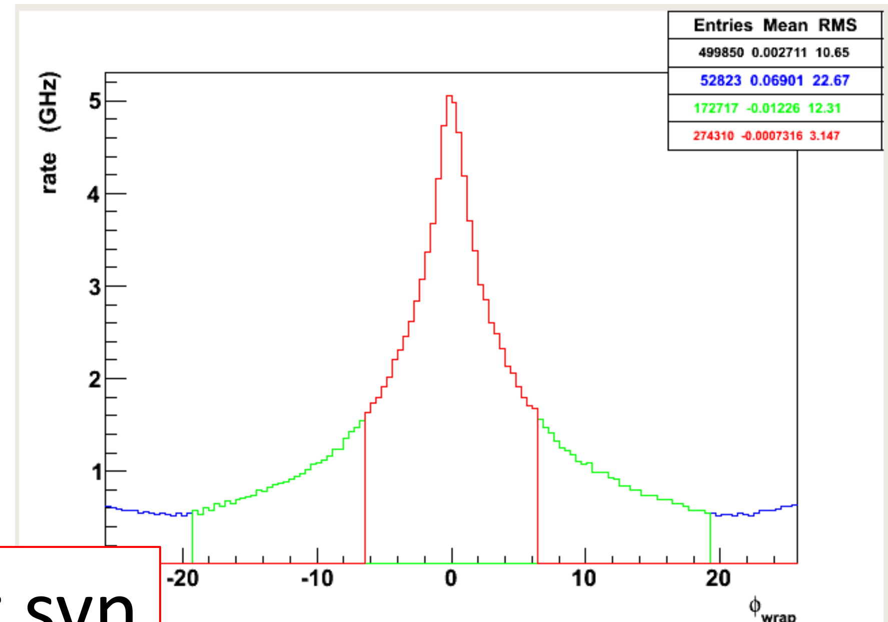

Entries Mean RMS
472779 -0.01527 11.6
64786 0.003293 22.56
168189 -0.04286 12.64
239804 -0.0006767 3.226
rate (GHz)/0.402deg
ϕ_{wrap}


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)

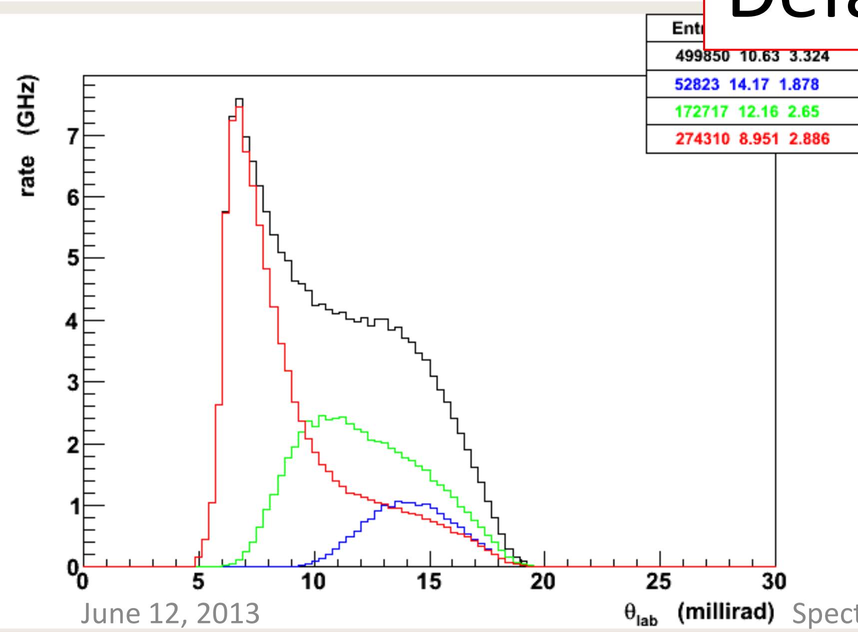

Entries Mean RMS
472779 91.76 17.26
64786 107.2 10.16
168189 99.02 13.14
239804 82.16 15.68
rate (GHz)/deg
$\theta_{c.m.}$

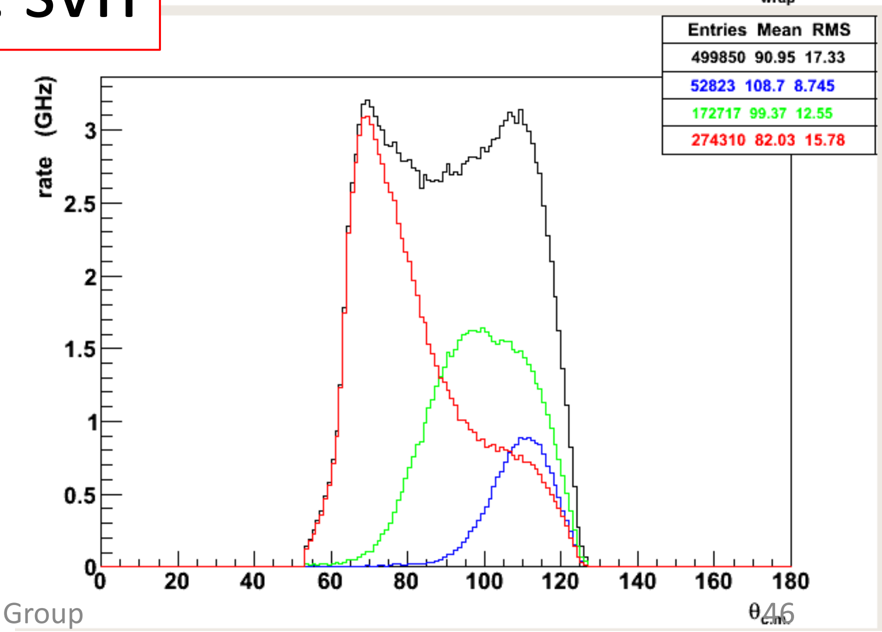
Current Version of the Hybrid and Upstream





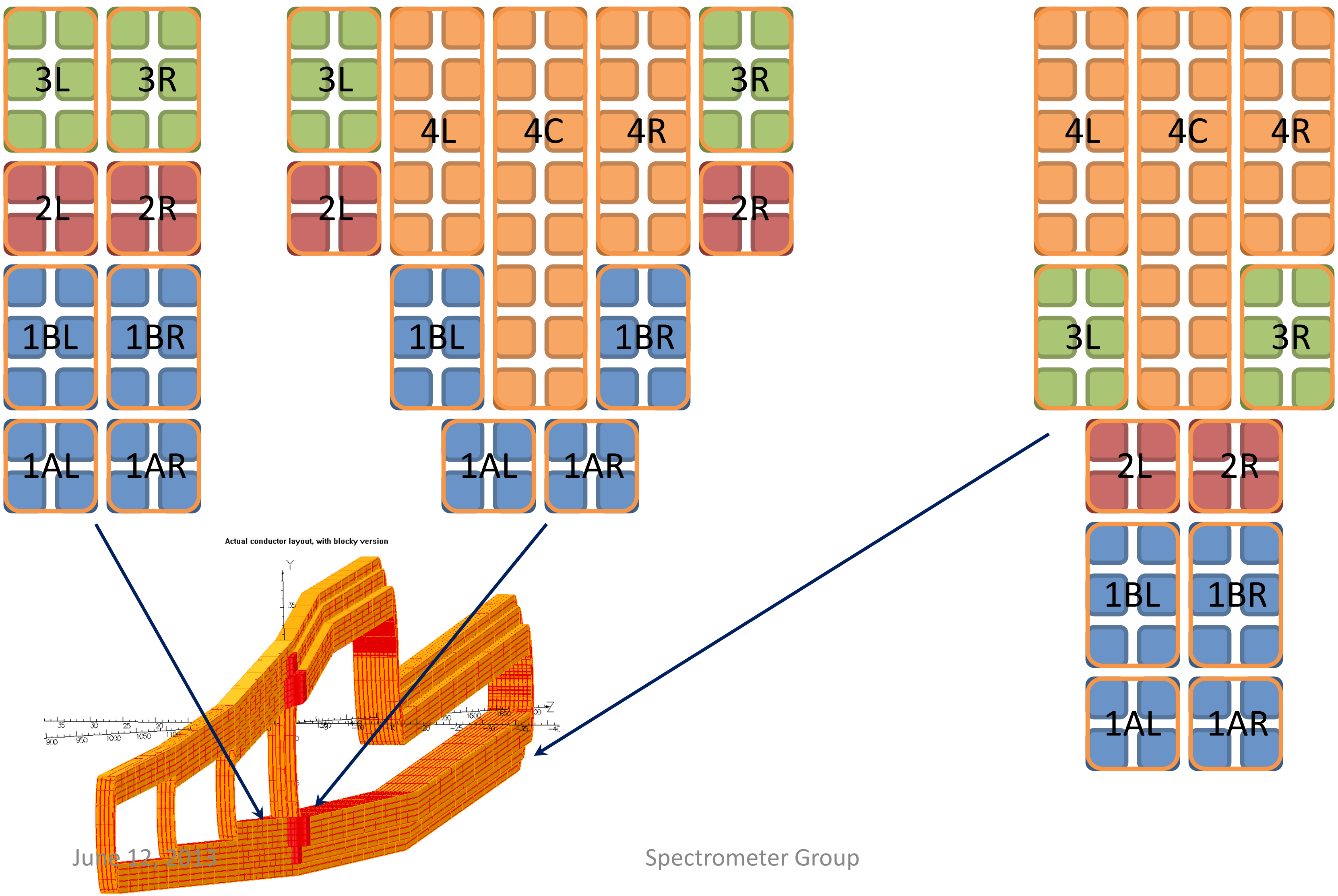
Default svn





Remoll with new collimators?

Layout

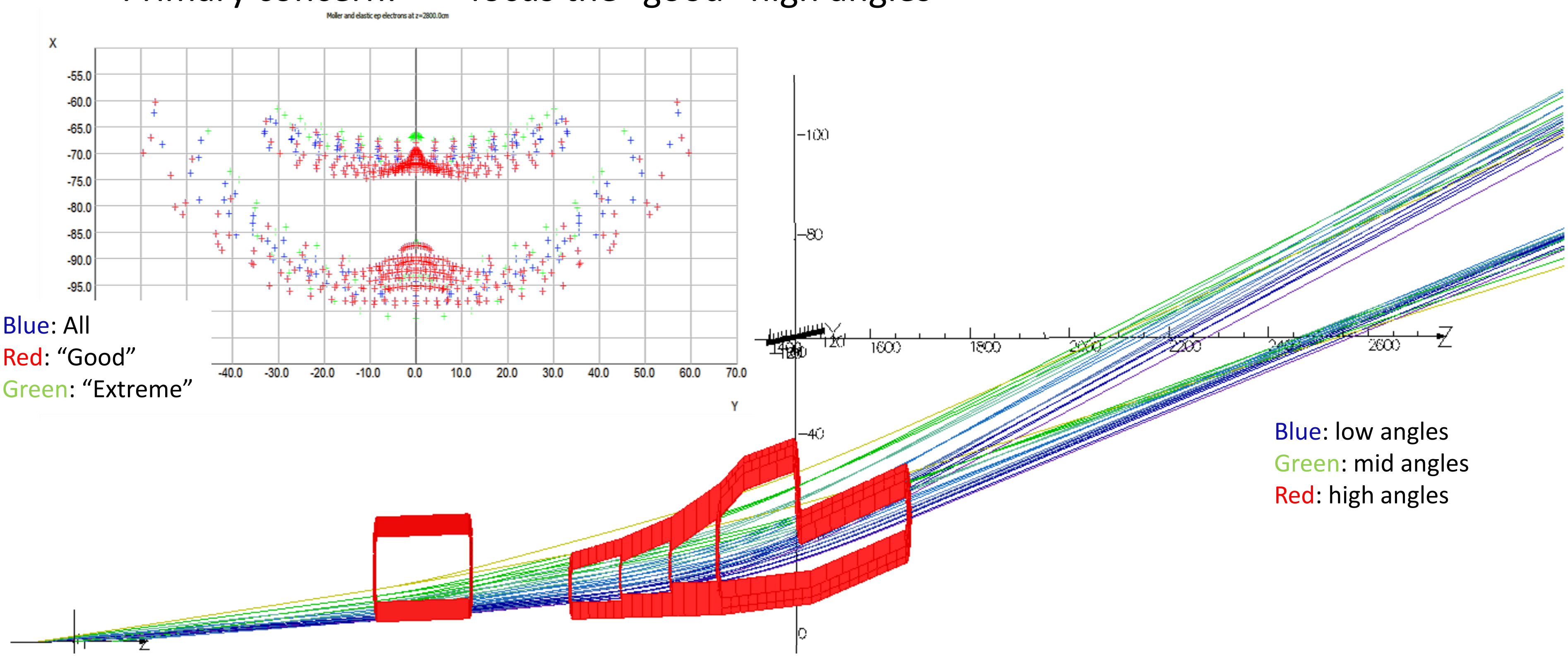

3L
3R
2L
2R
1BL
1BR
1AL
1AR
3L
4L
4C
4R
3R
2L
2R
1BL
1BR
1AL
1AR
4L
4C
4R
3L
3R
2L
2R
1BL
1BR
1AL
1AR
Actual conductor layout, with blocky version

Tweaking the Optics

Assume: 6.0-15.4 mrads from upstream end of target

Finite target effects: We'll accept some high angles from further downstream for which we won't have full azimuthal acceptance

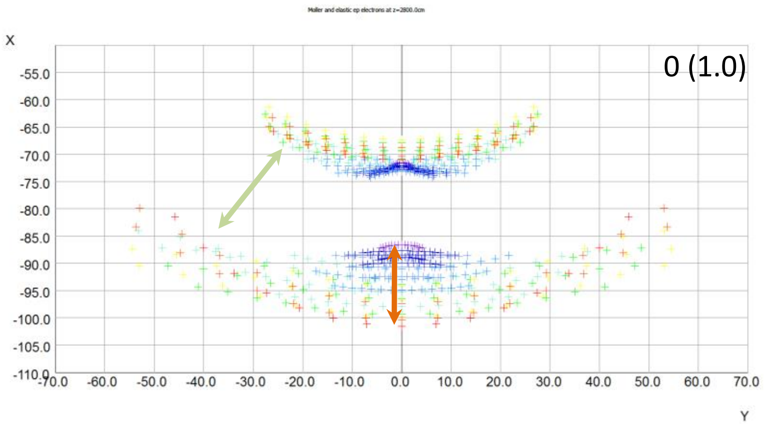
Primary concern: focus the "good" high angles

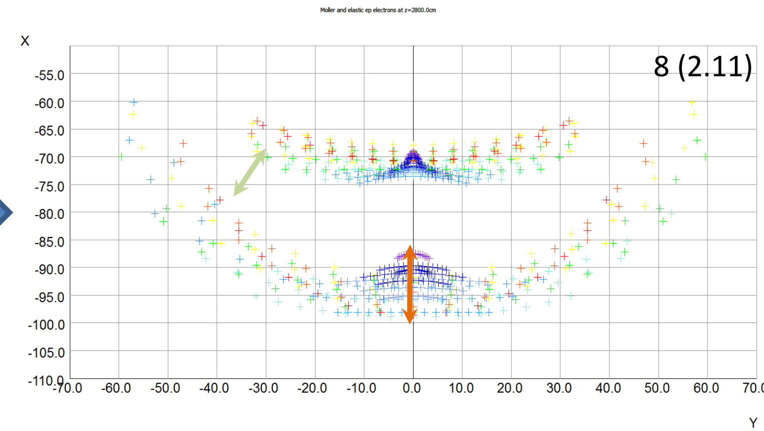


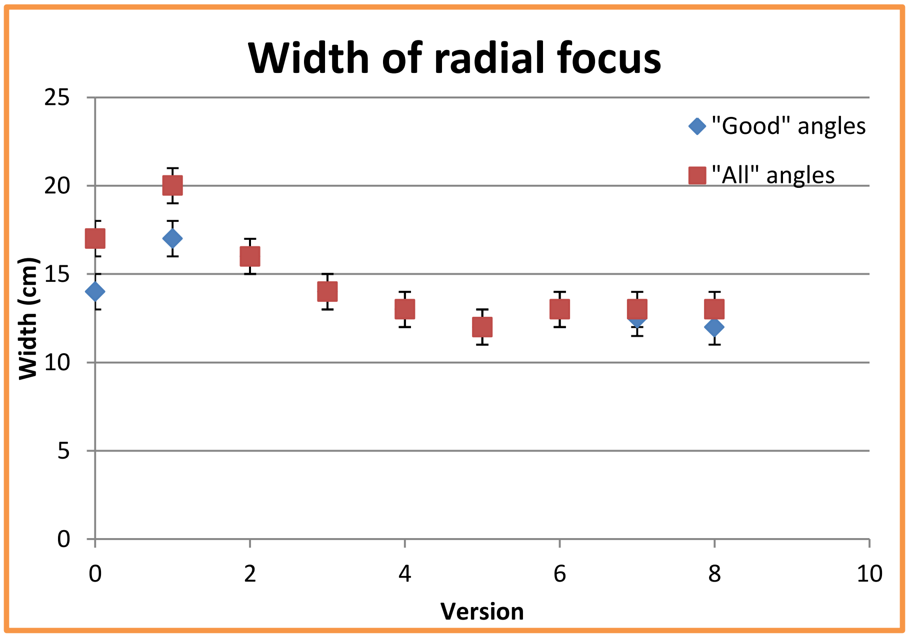
Blue: All
Red: "Good"
Green: "Extreme"

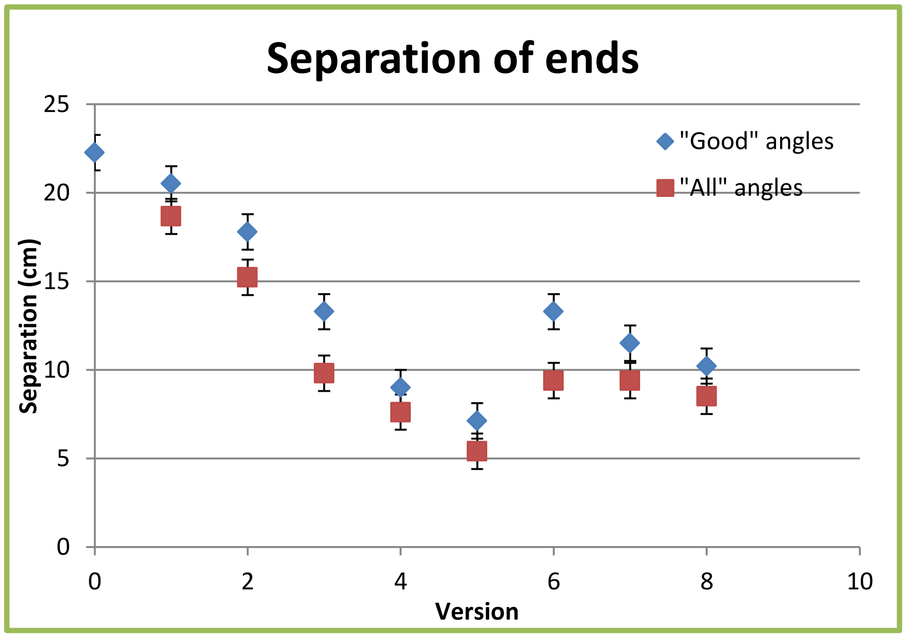
Blue: low angles
Green: mid angles
Red: high angles

Tweaking the Optics

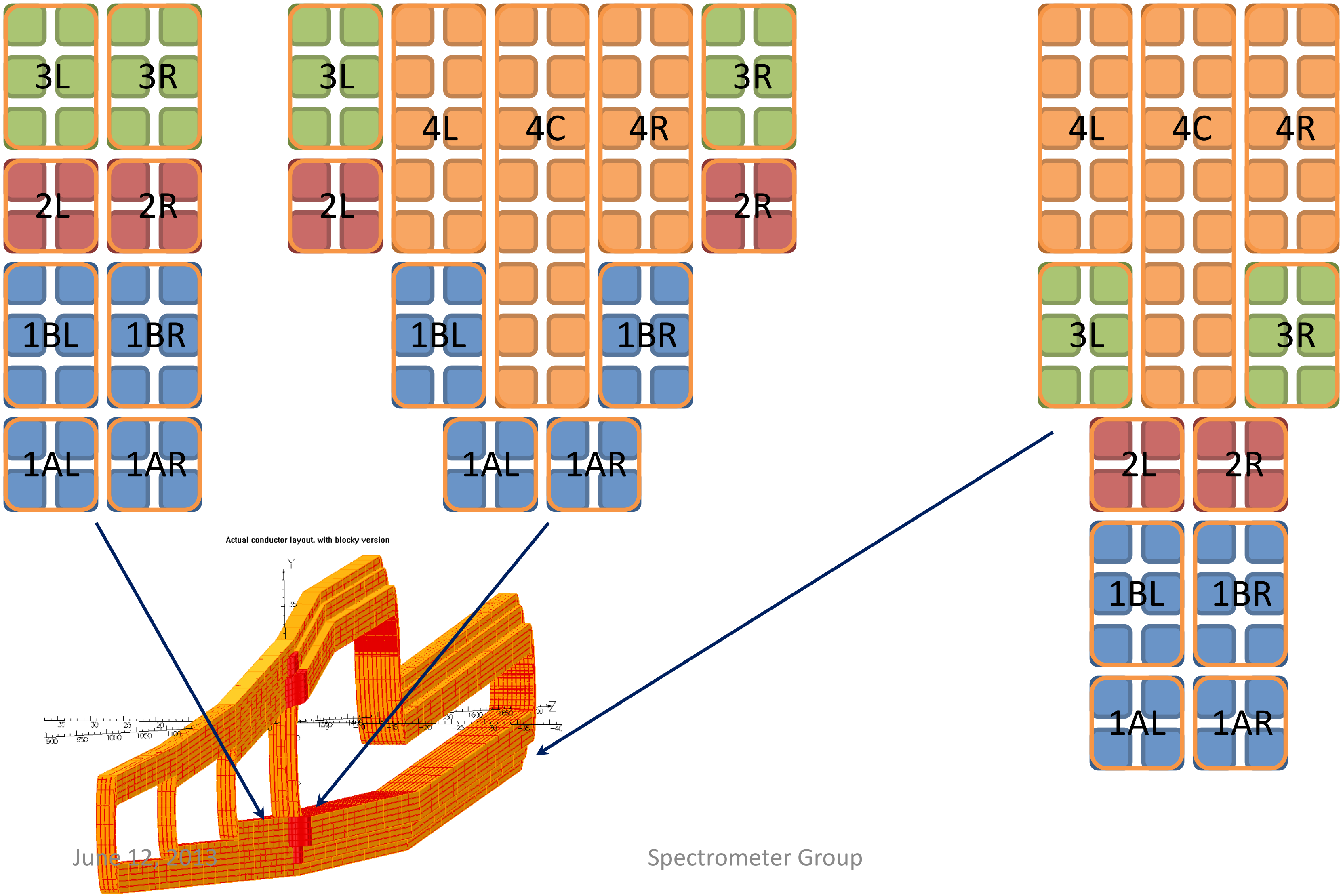








Layout

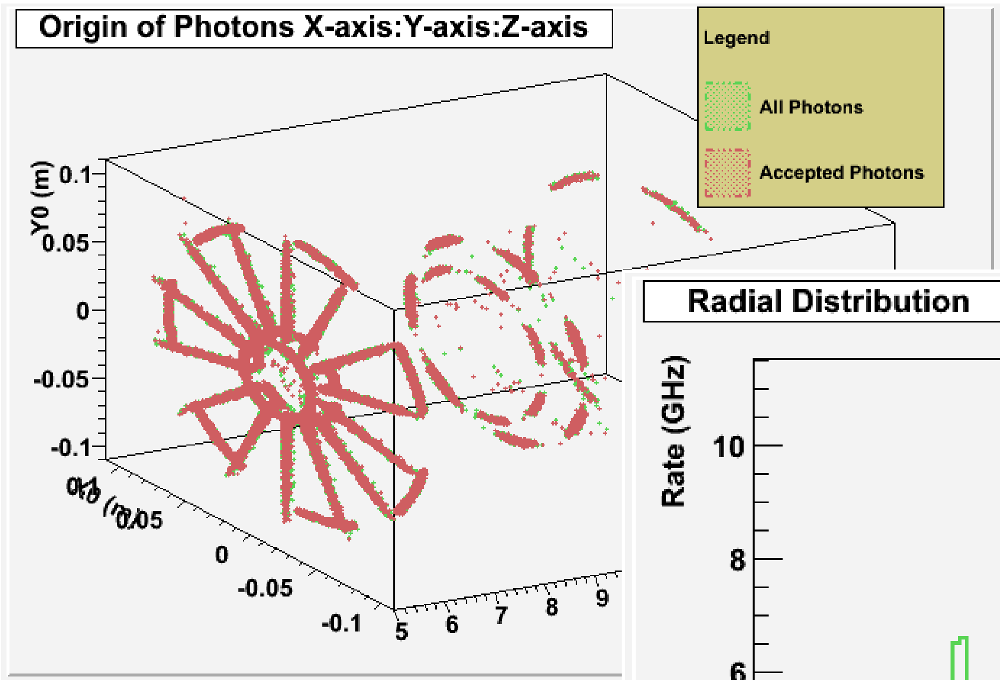

3L
3R
2L
2R
1BL
1BR
1AL
1AR
3L
4L
4C
4R
3R
2L
2R
1BL
1BR
1AL
1AR
4L
4C
4R
3L
3R
2L
2R
1BL
1BR
1AL
1AR
Actual conductor layout, with blocky version

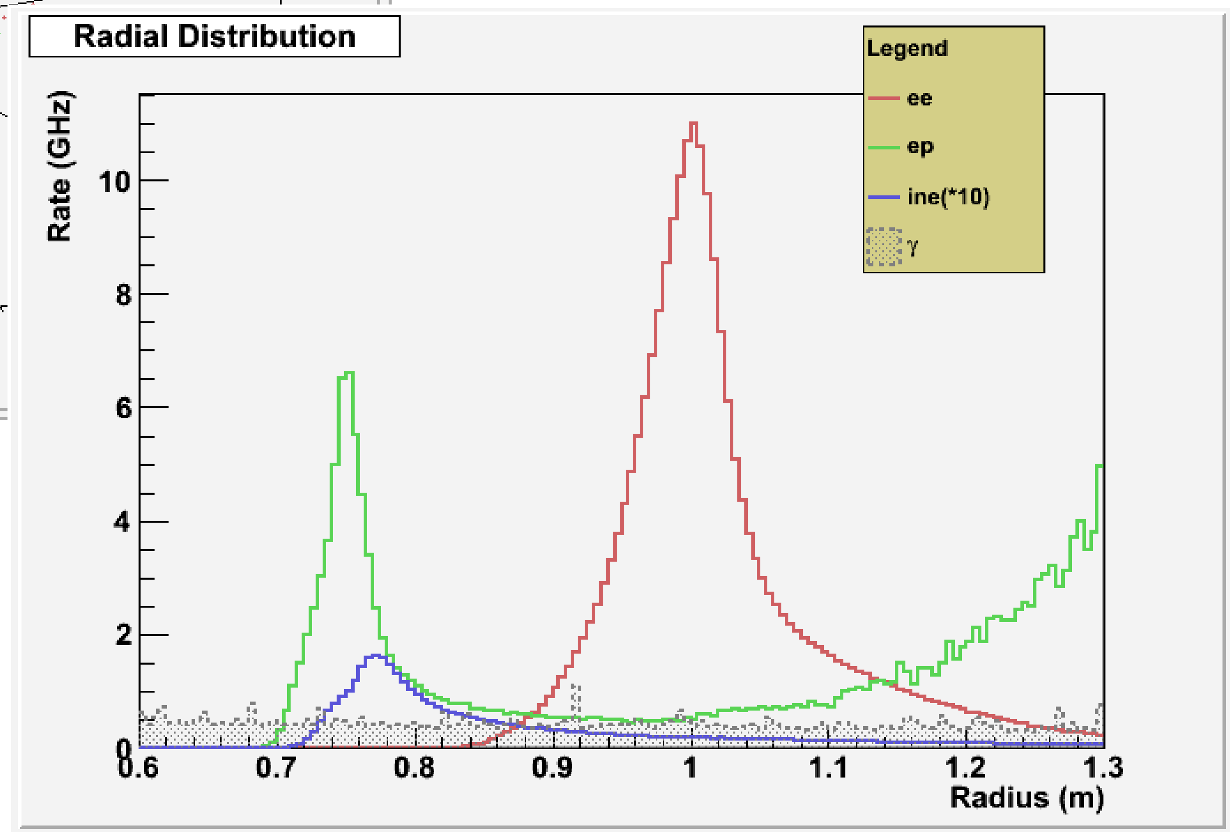
Rate Comparison*

Field Map	Moller (GHz)	Elastic ep (GHz)	Inelastic ep (GHz)	Bkgd. Fraction (%)
Proposal	133	12	0.4	9
Actual 0 (1.0)	162	18	0.6	10
Actual 3 (2.6)	140	13	0.6	10
svn	147	16	0.6	11

*Assuming 75μA

Photons





see [elog 199]

Magnetic Forces

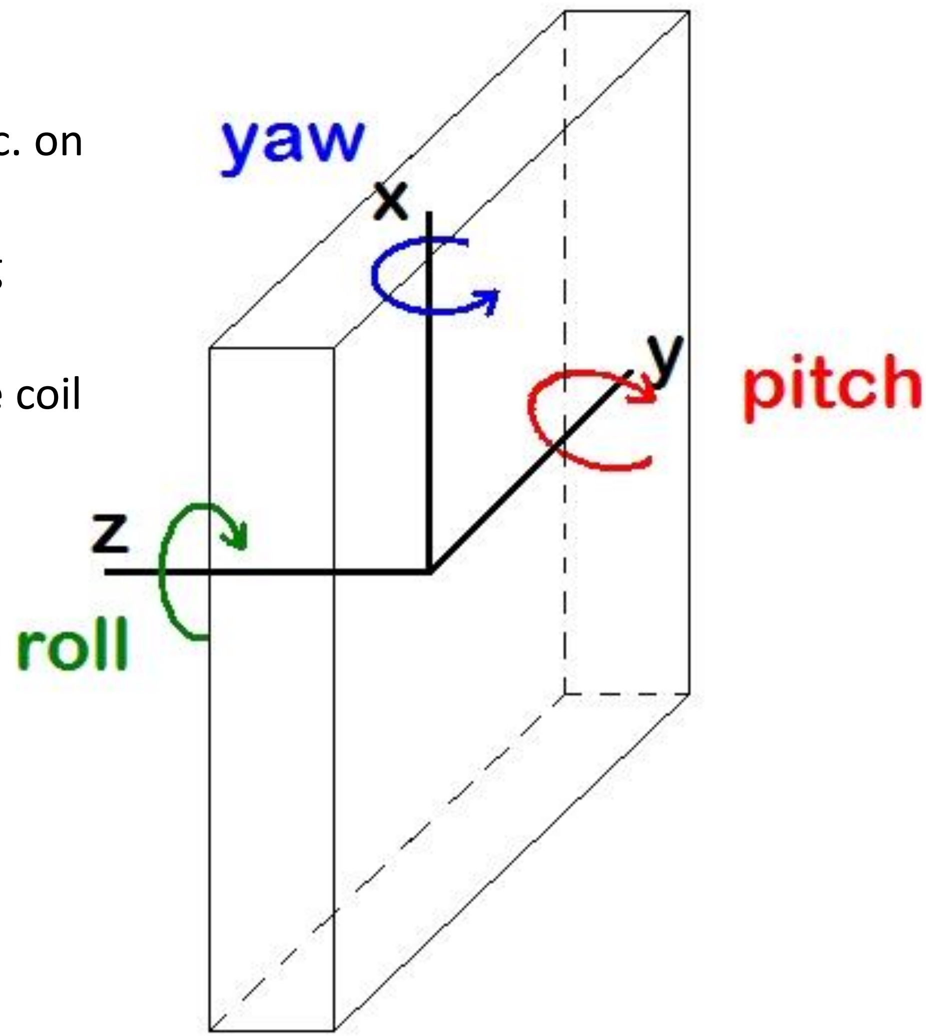
- Use TOSCA to calculate magnetic forces on coils
- Have calculated the centering force on coil:

~3000lbs (compare to Qweak: 28000 lbs)

- Need to look at effects of asymmetric placement of coils
- Could affect the manufacturing tolerances

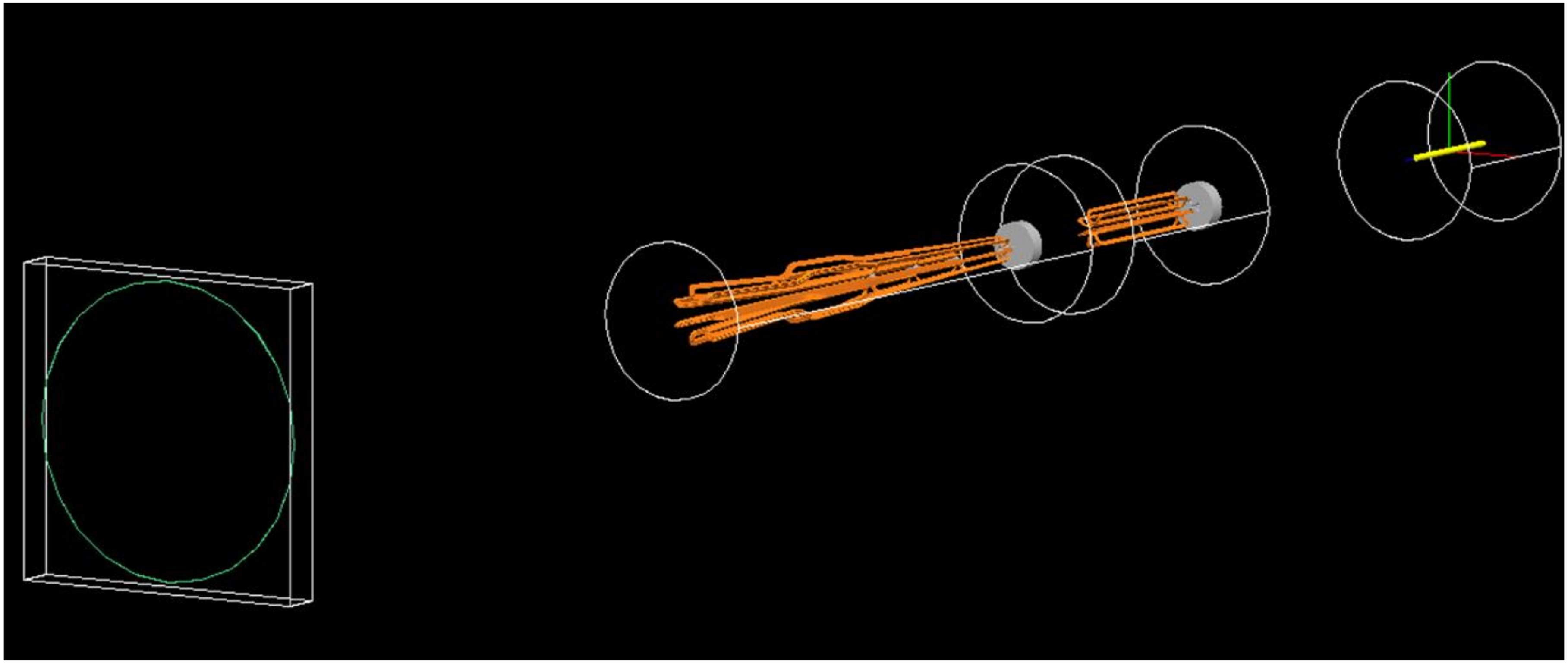
Sensitivity Studies

- 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

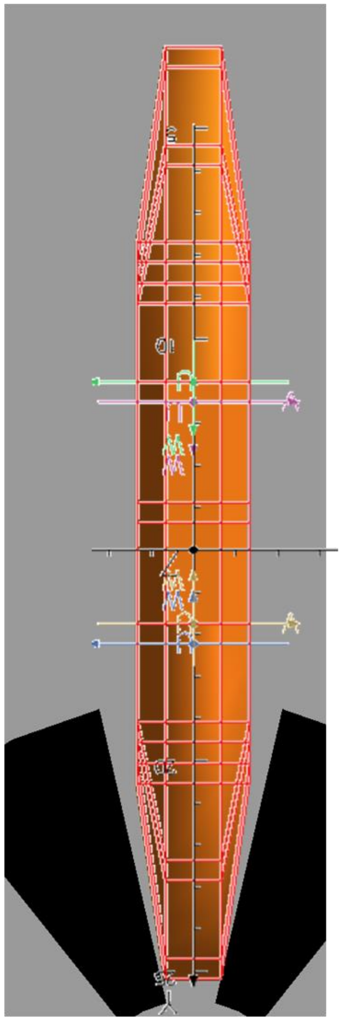


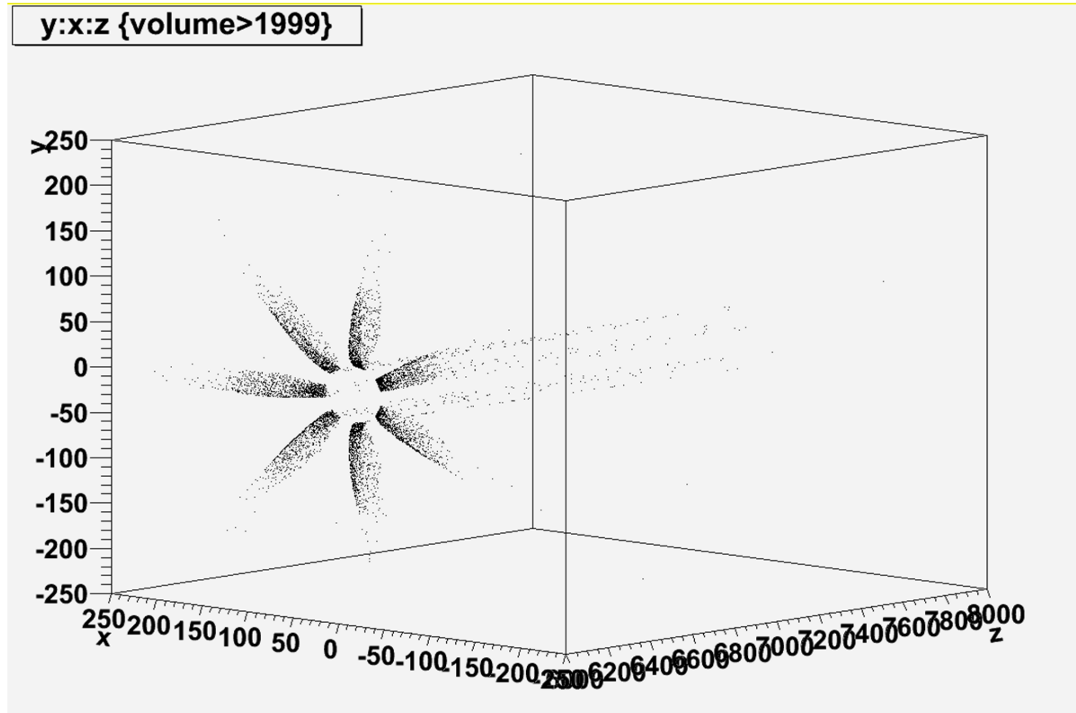
GEANT4

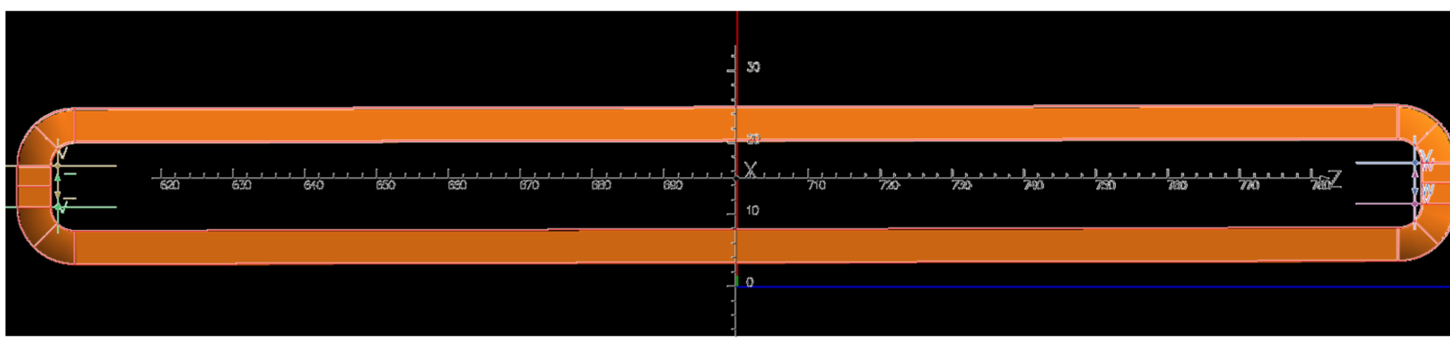
- Moved to GDML geometry description
- Defined hybrid and upstream toroids
  - Parameterized in same way as the TOSCA models



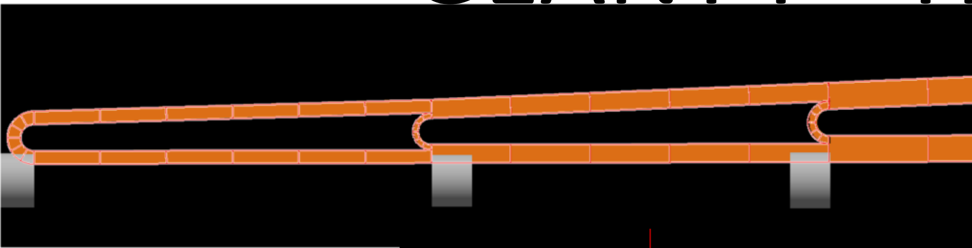
GEANT4 – Upstream Torus

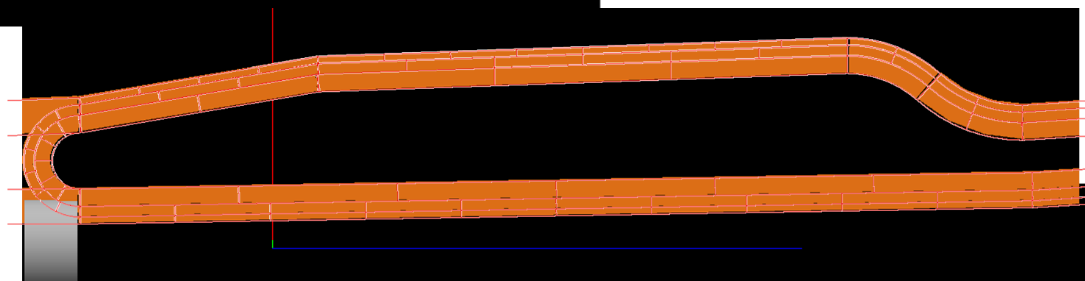


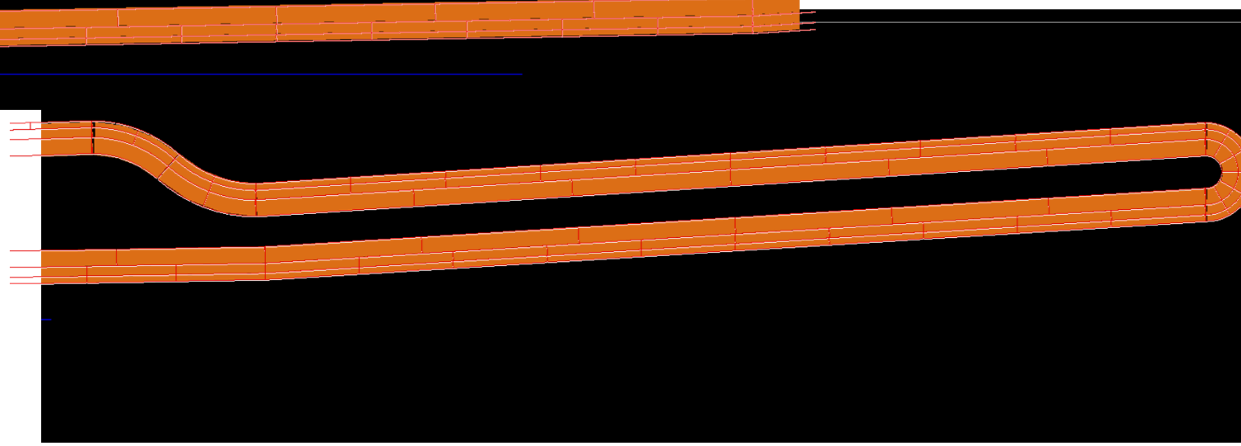


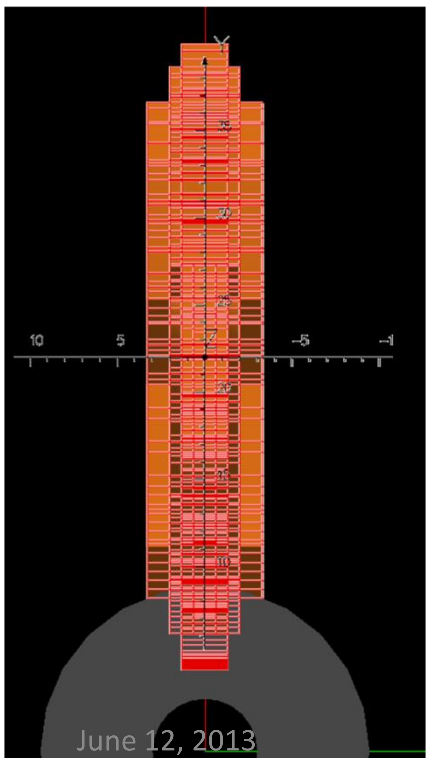


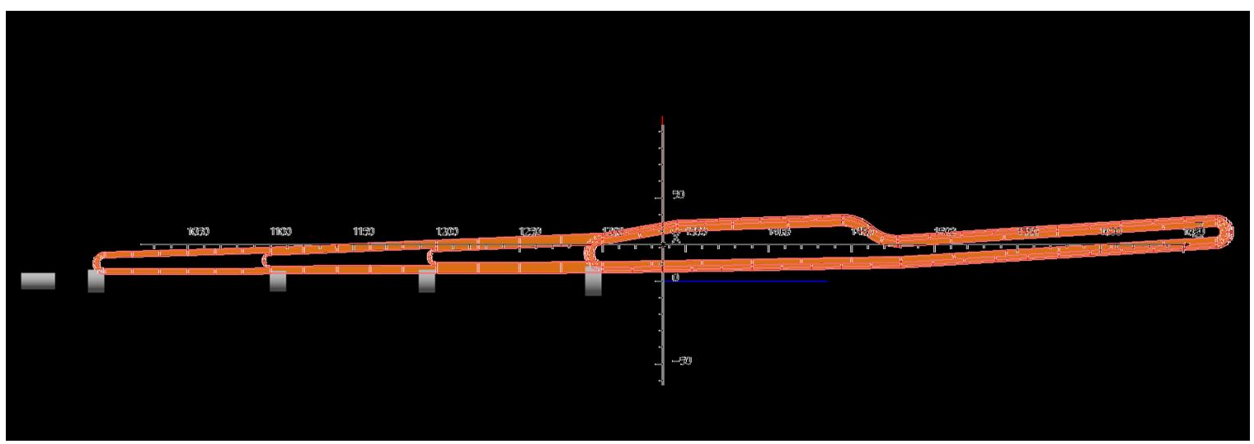
GEANT4 – Hybrid Torus







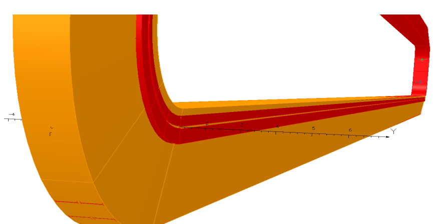


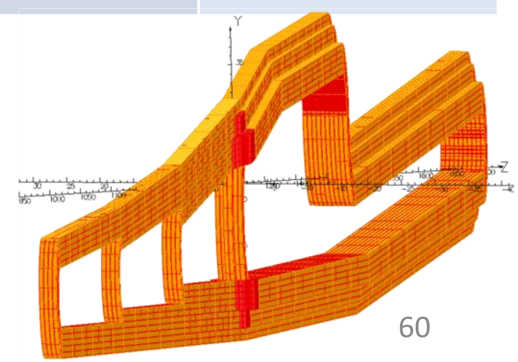


GEANT4

Magnet Stats

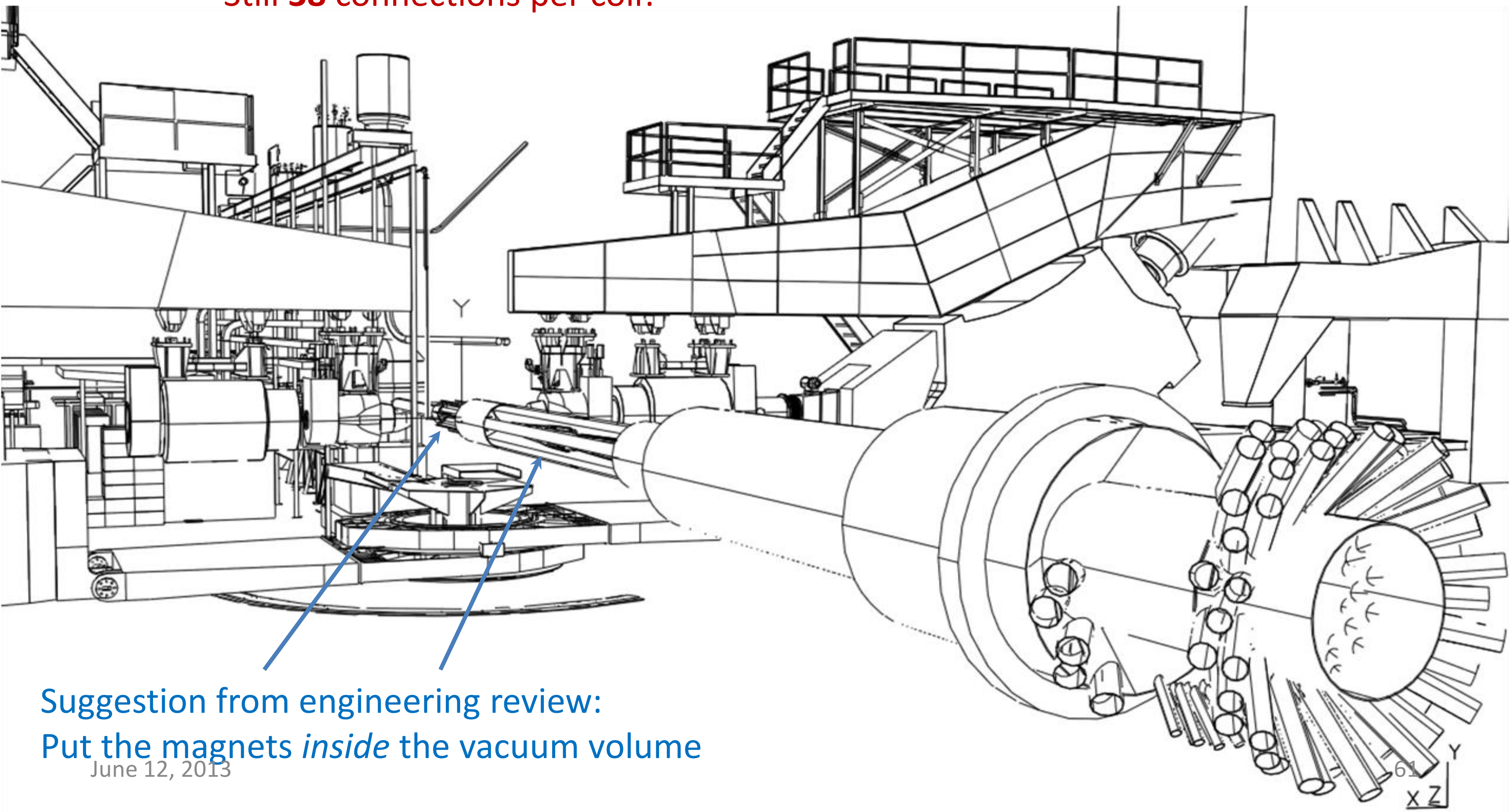
Property	Moller Concept 1	Upstream	Moller Concept 2	Qweak
Field Integral (Tm)	1.4	0.15	1.1	0.89
Total Power (kW)	820	40	765	1340
Current per wire (A)	243	298	384	9500
Voltage per coil (V)	480	19	285	18
Current Density (A/cm^2)	1600	1200	1550	500
Wire cross section (ID: water hole) (in)	0.182x0.182 (0.101)	0.229x0.229 (0.128)	0.229x0.229 (0.128)	2.3x1.5 (0.8)
Weight of a coil (lbs)	556	44	555	7600





Water-cooling and supports

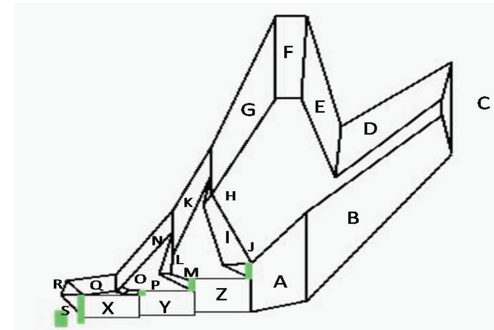
Verified by MIT engineers
– cooling could be accomplished in concept 2 with 4 turns per loop
Still **38** connections per coil!

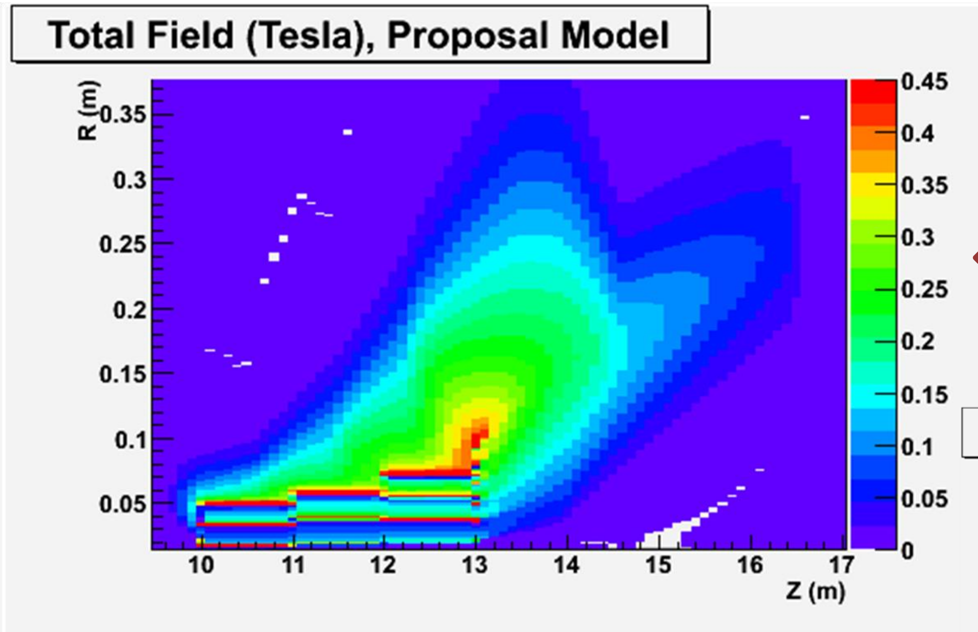


Suggestion from engineering review:
Put the magnets *inside* the vacuum volume

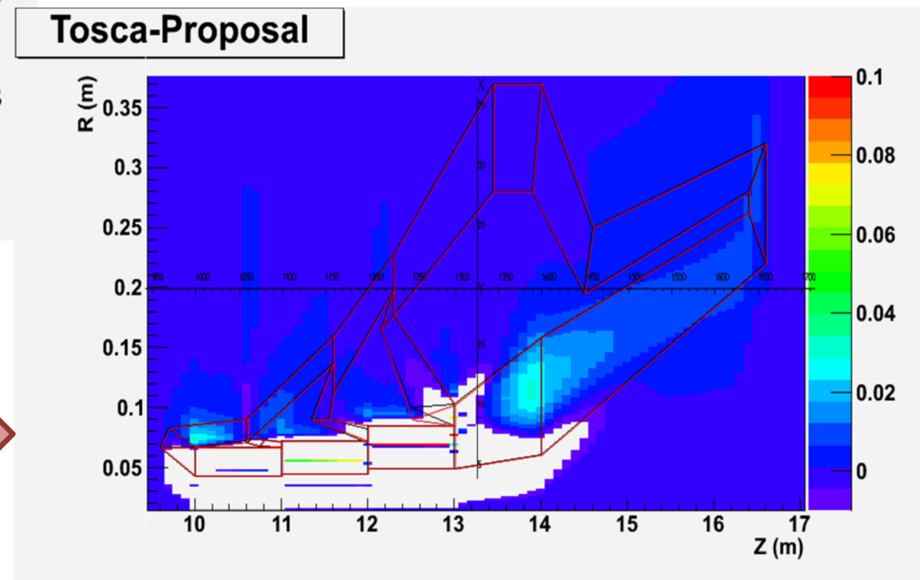
Direct Comparison of Fields

Complicated field because of multiple current returns



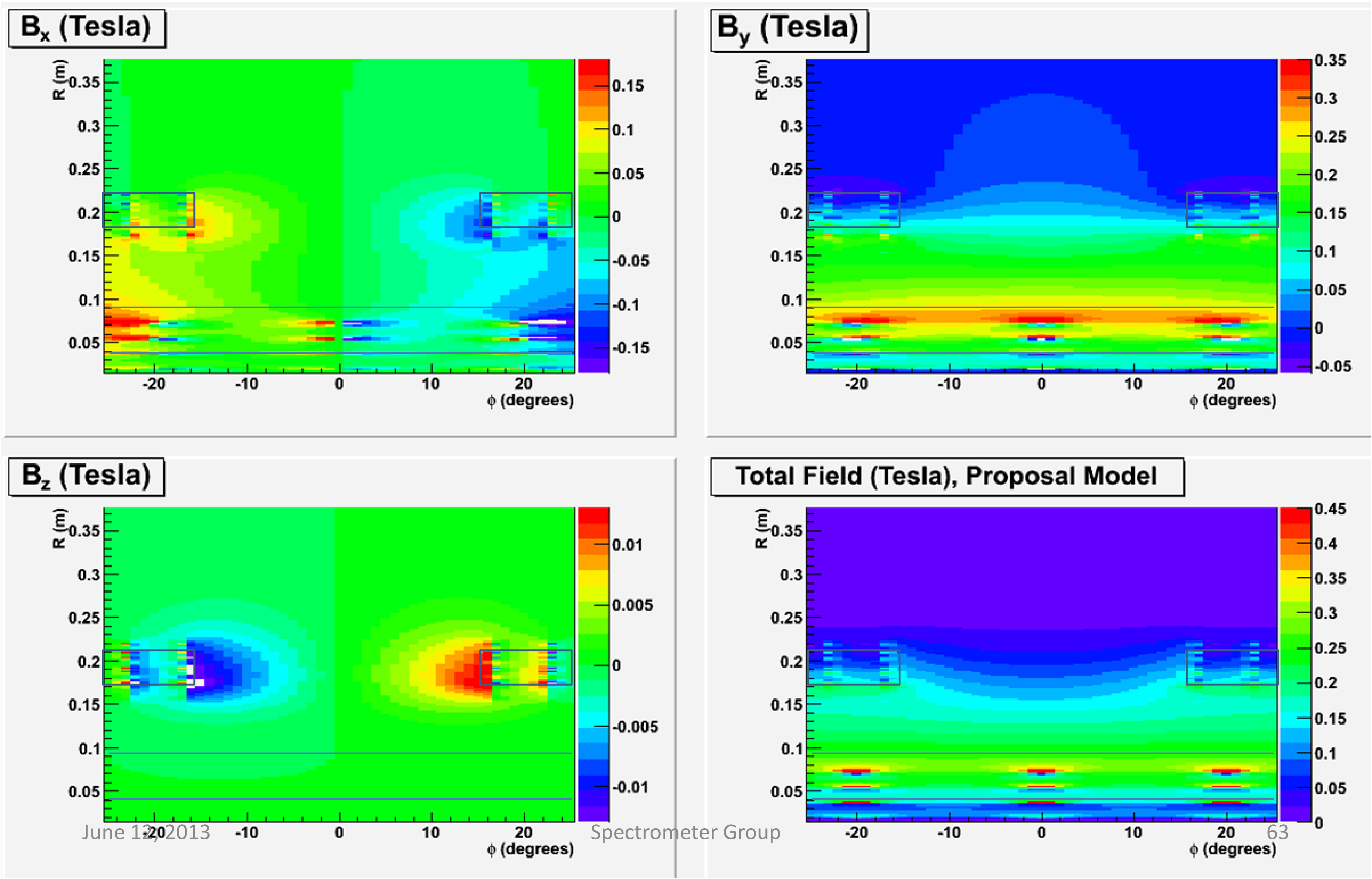


The average total field in a sector in bins of R vs. z

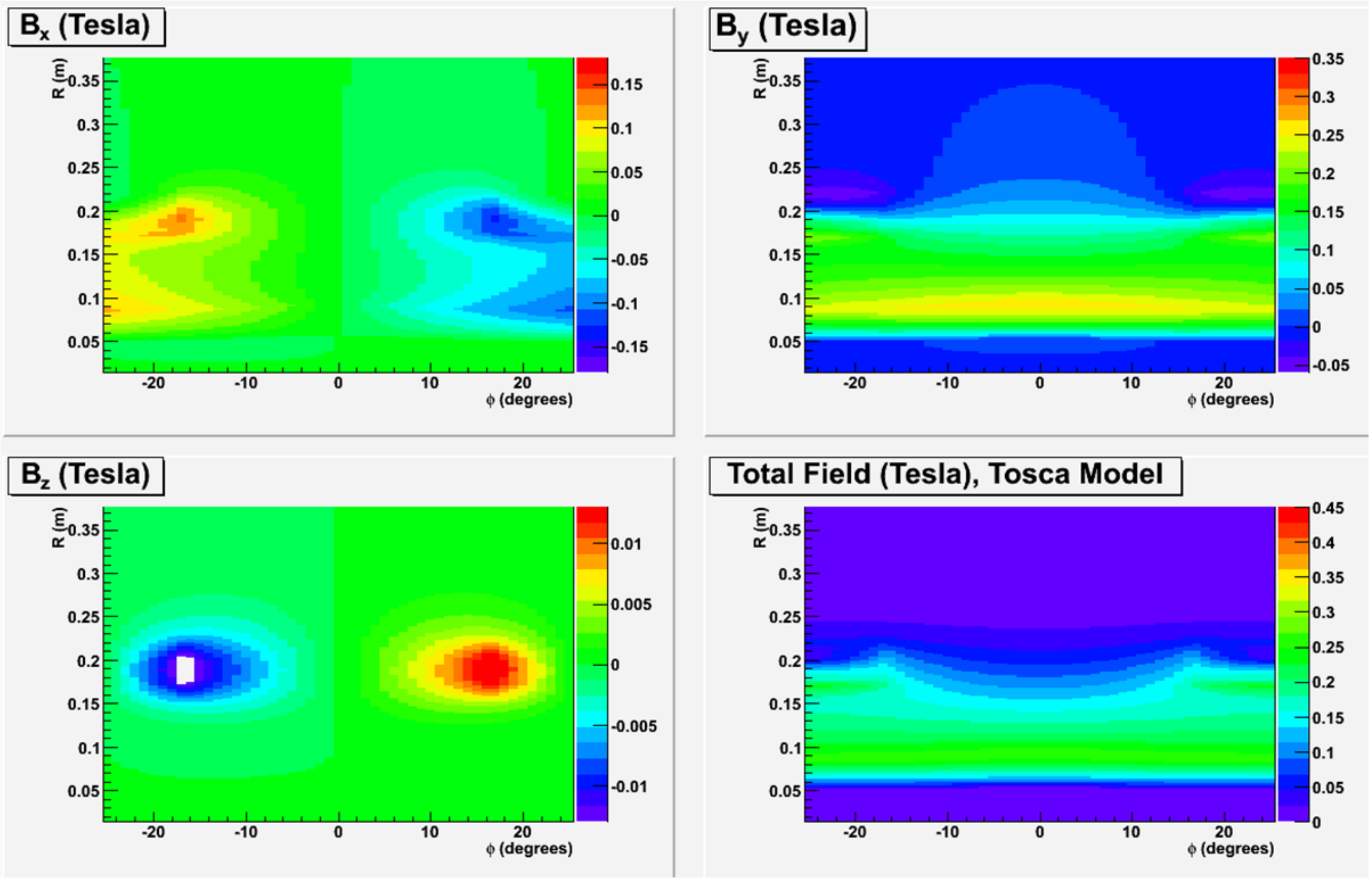


The difference of the total field in a sector in bins of R vs. z for the TOSCA version of the proposal and the original proposal model

Field Components

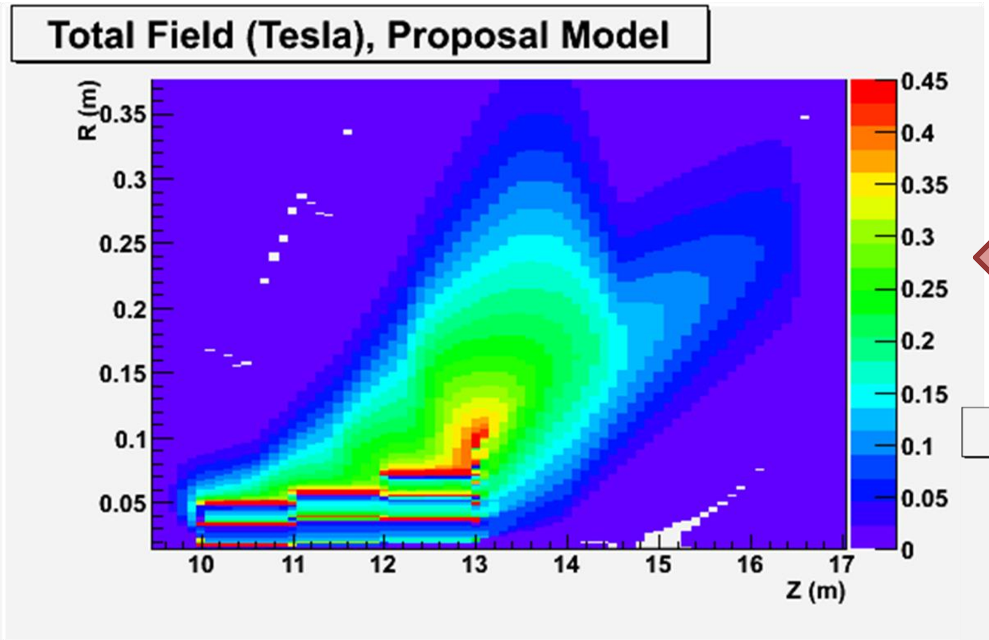


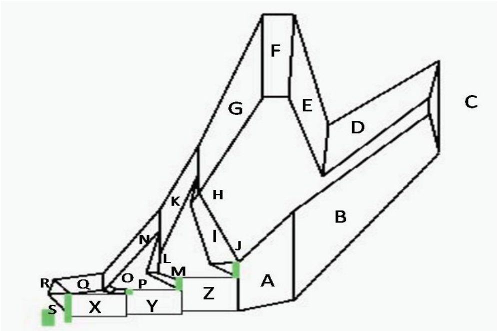
Field Components



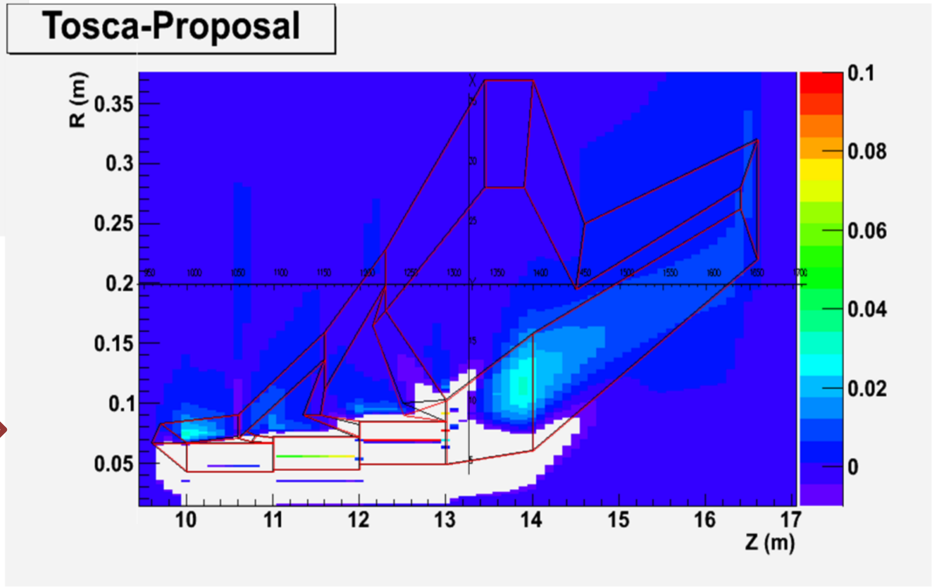
Direct Comparison of Fields

Complicated field because of multiple current returns





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



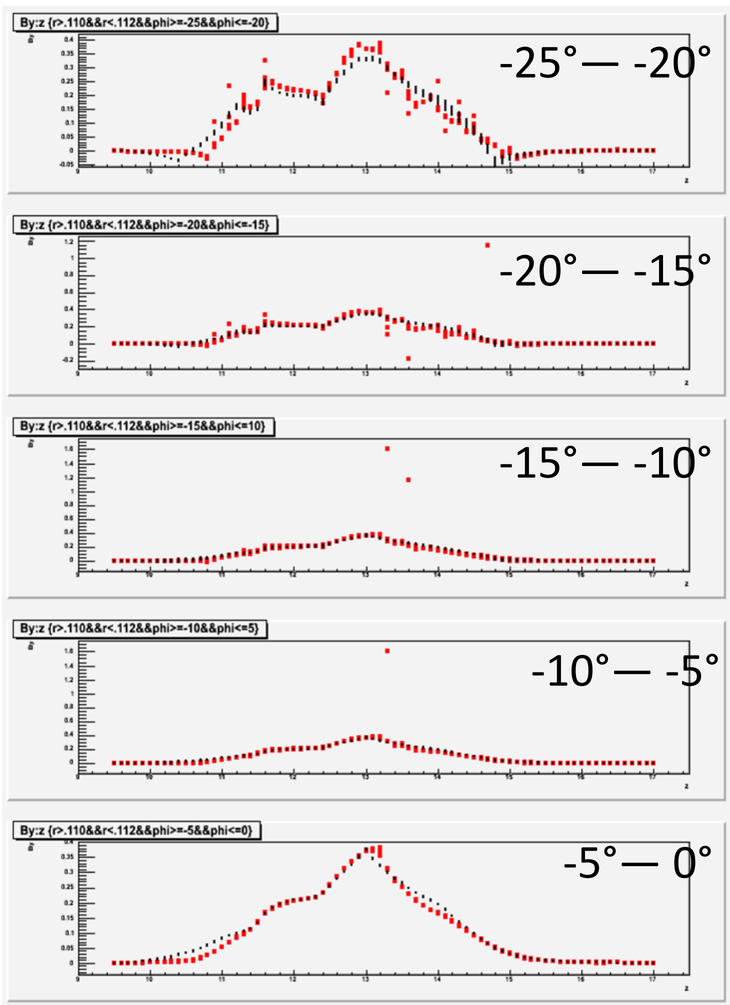
The difference of the total field in a sector in bins of R vs. z for the TOSCA version of the proposal and the original proposal model

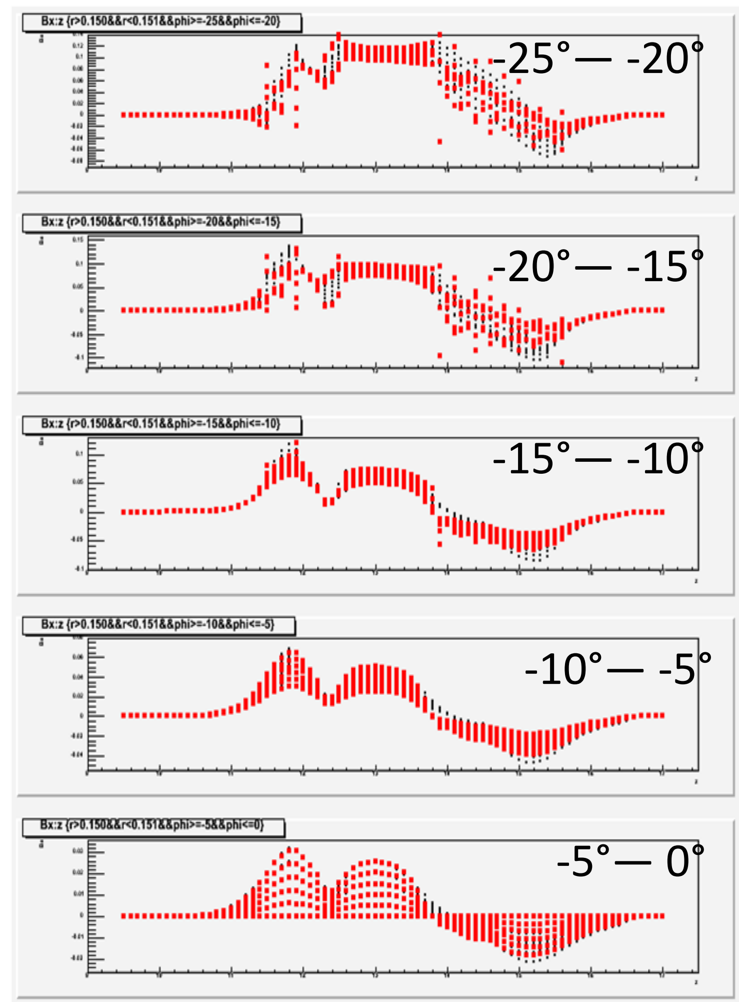
Comparison of field values

Red – proposal model

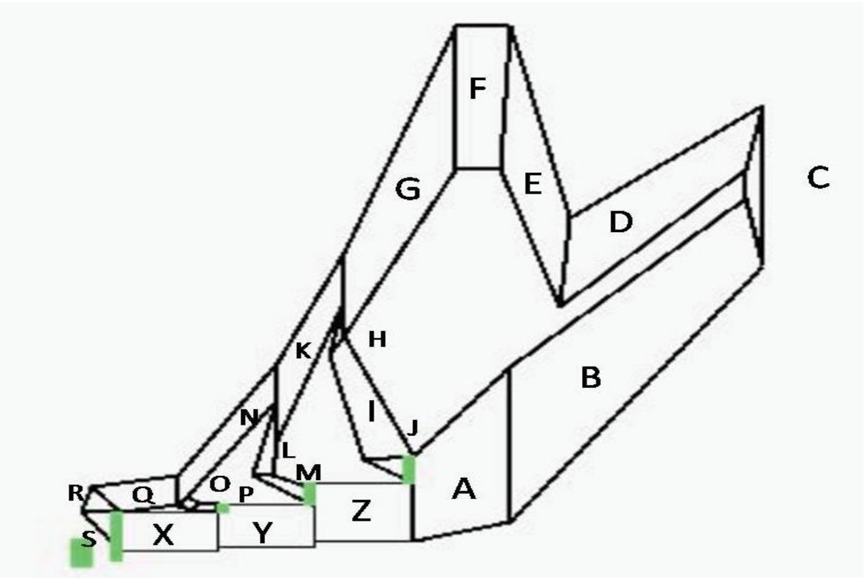
Black – TOSCA model

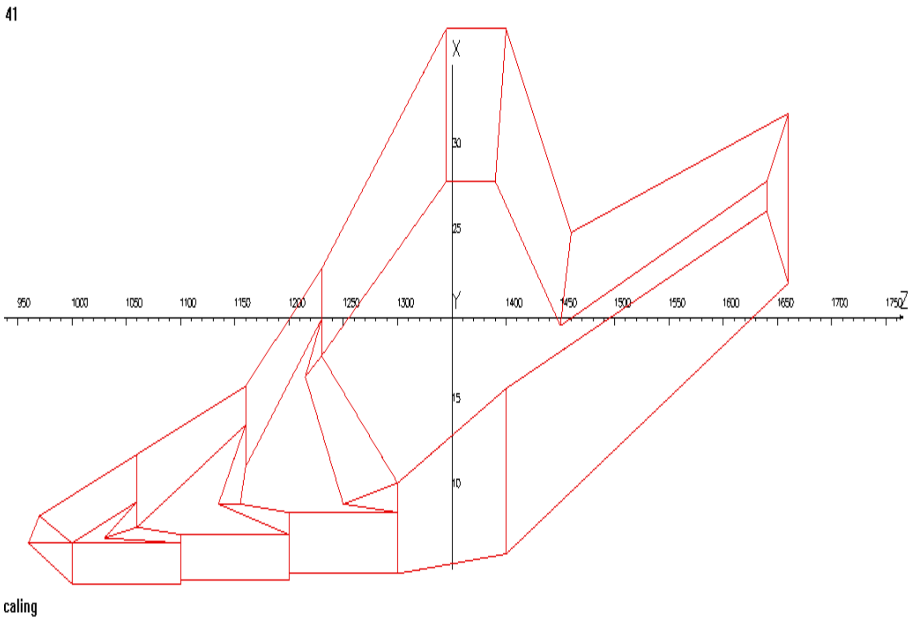
By (left) or Bx (right) vs. z in 5° bins in phi





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