MOLLER Spectrometer Update

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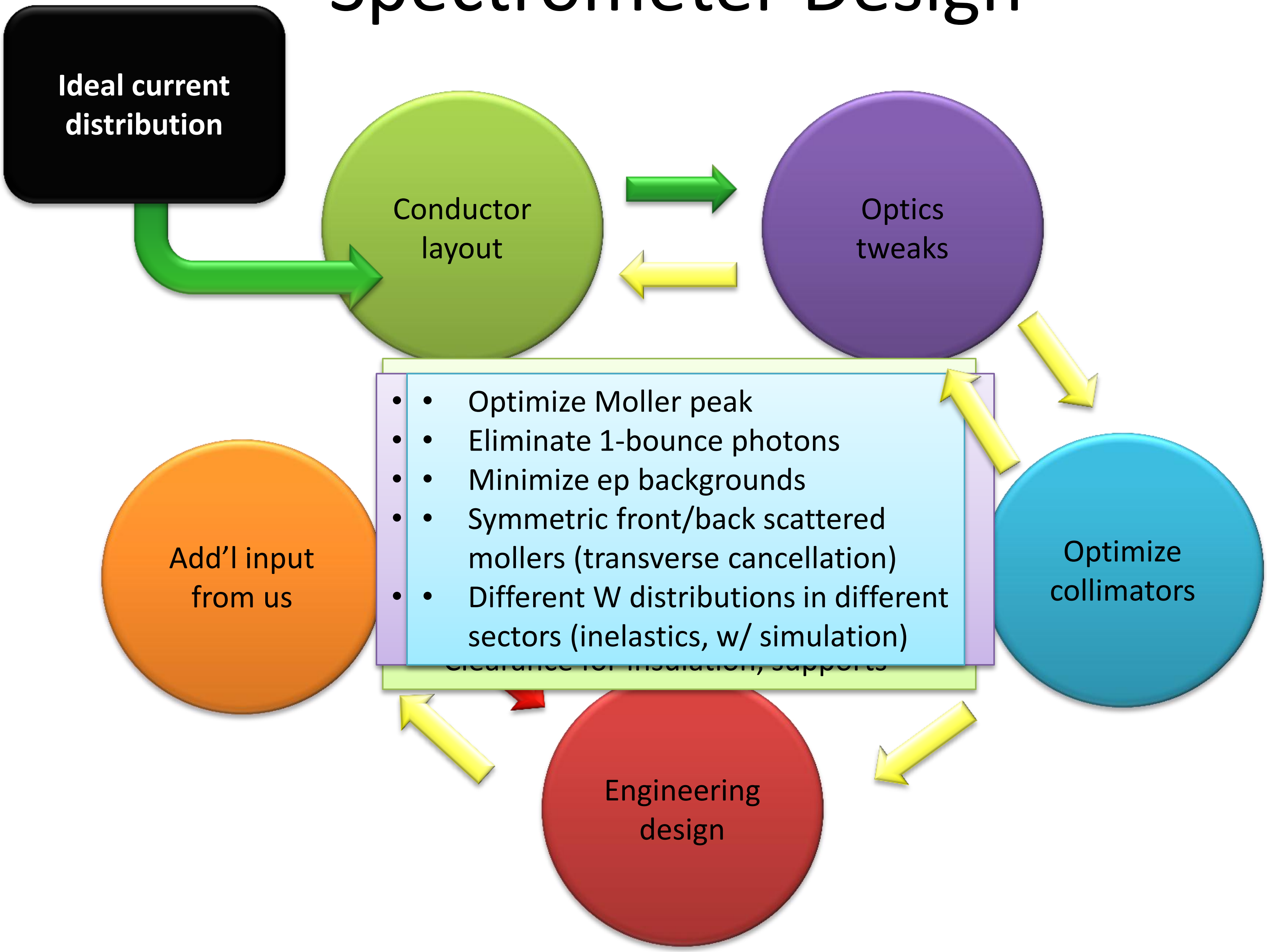
Large Phase Space for Design

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 the 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

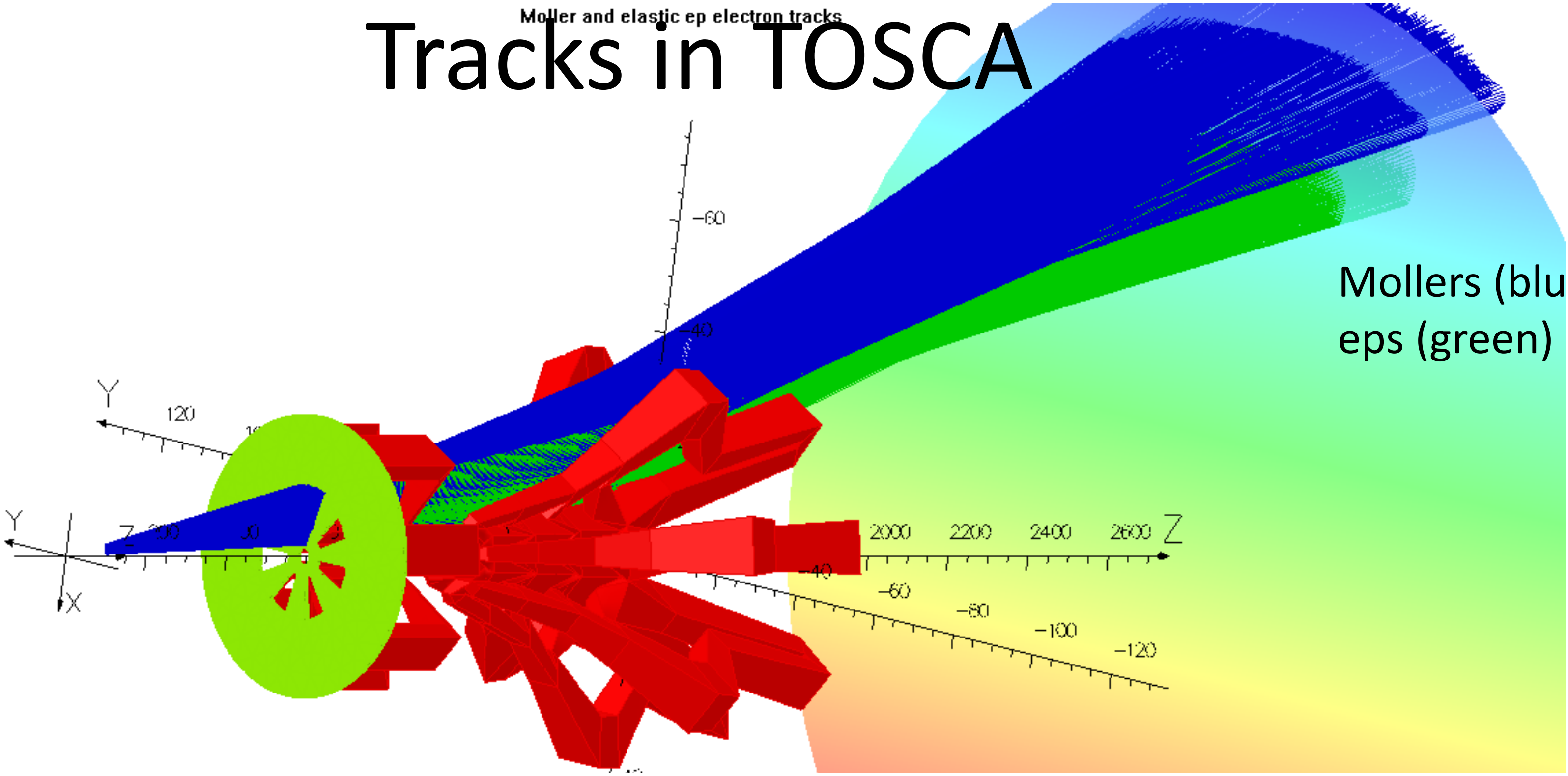
Work since the collaboration meeting

- Interfacing with engineers
  - JLab engineers estimate that pressure head is not an issue
  - New conductor layout with larger water cooling hole "approved"
  - MIT engineers recalculate Robin's initial water cooling calculations
  - Determine what more work is needed on our side

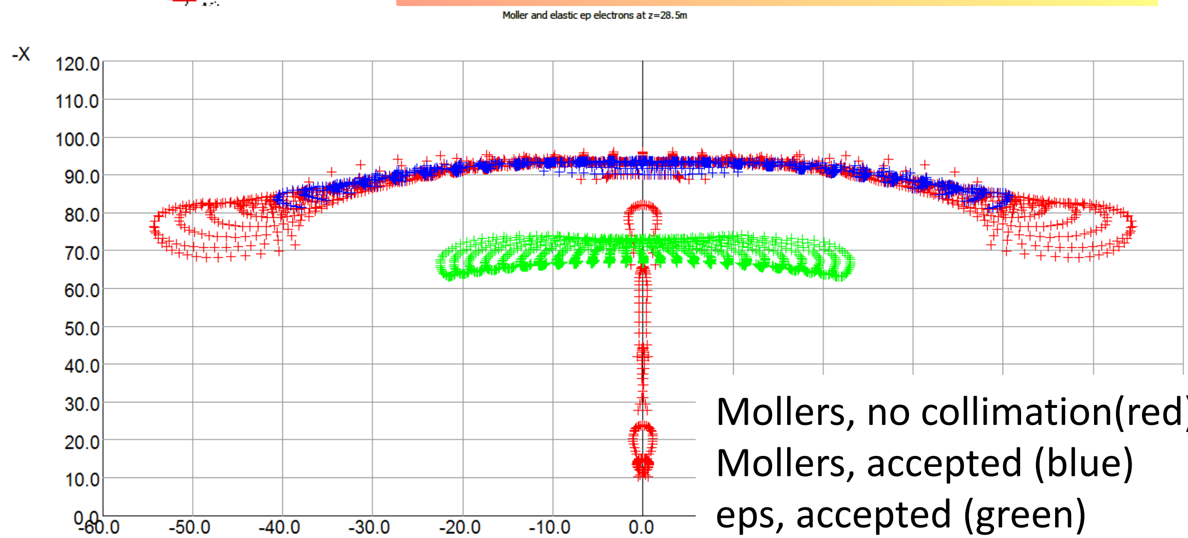
- Ongoing/Future work
  - Optimization of the optics
  - Magnetic force studies
  - Sensitivity studies
  - Collimator optimization
  - Design of the water-cooling and supports
  - Design of electrical connections
  - Look at optics for 3 coils

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

Tracks in TOSCA



Mollers (blue)
eps (green)

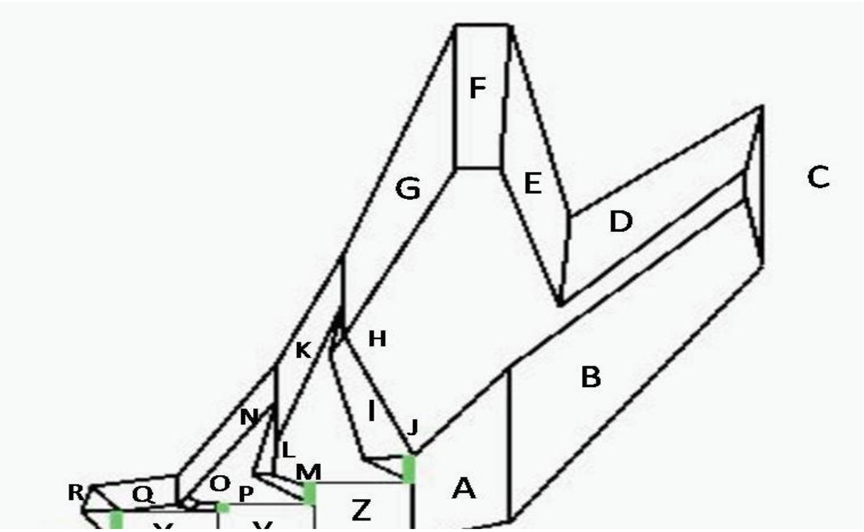


Mollers, no collimation(red)
Mollers, accepted (blue)
eps, accepted (green)

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

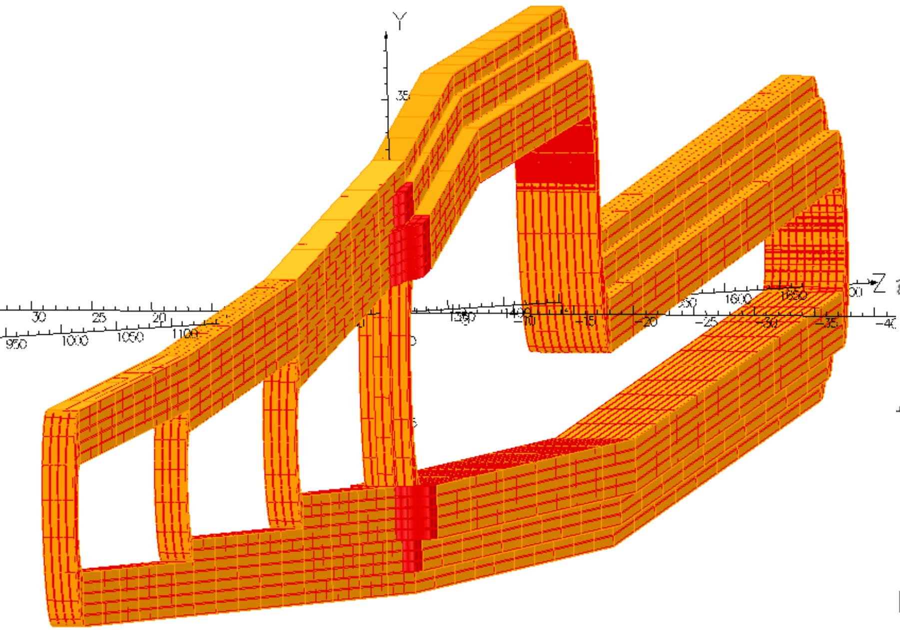


Actual conductor layout, with blocky version

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

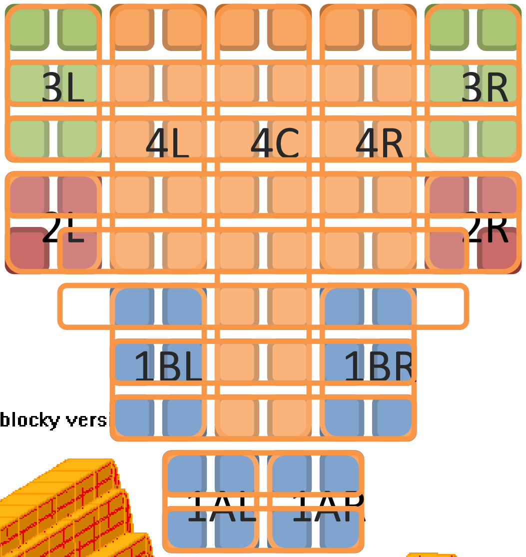
Created a first version with actual coil layout

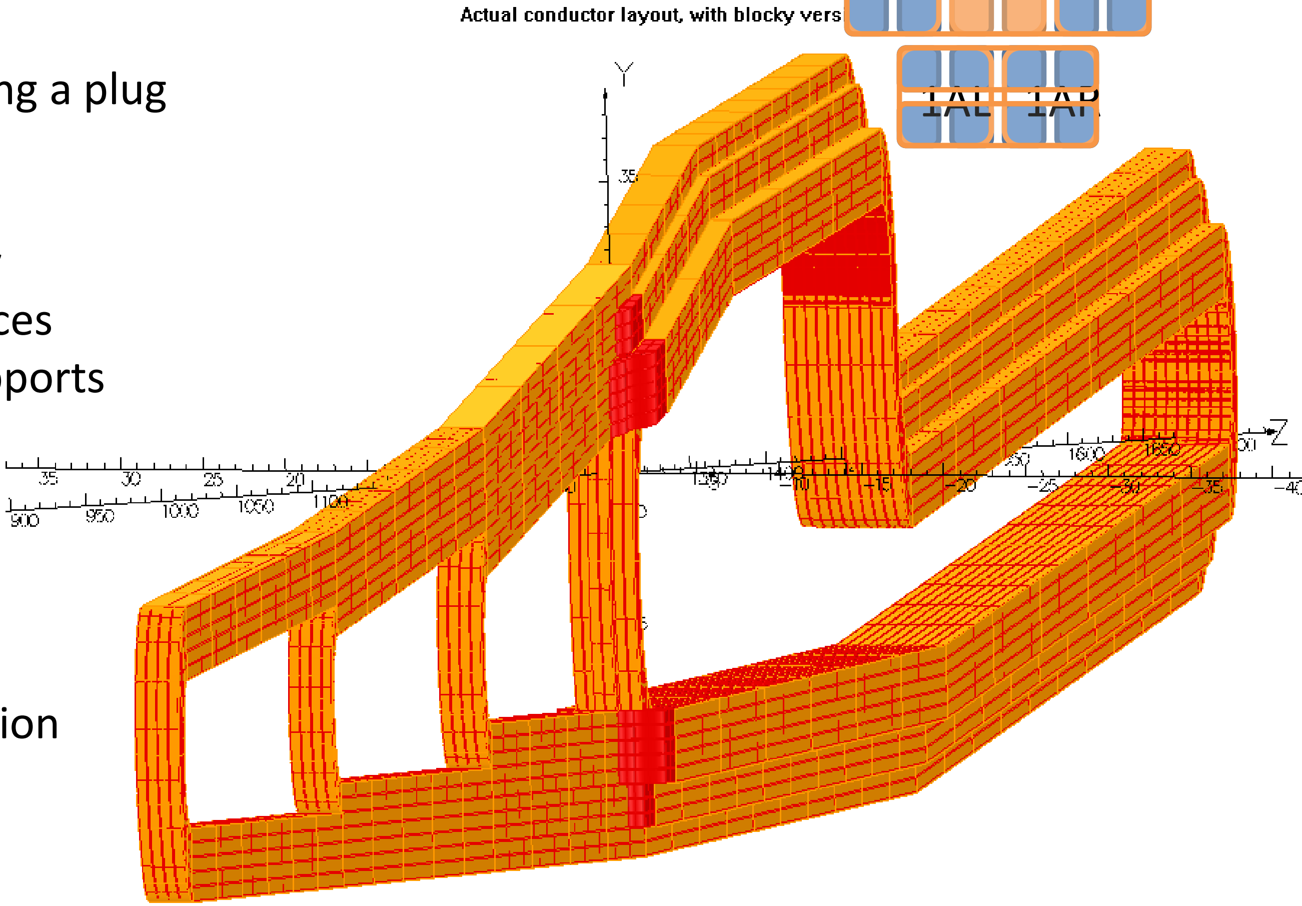
Created second version with larger water cooling hole and nicer profile; obeyed keep-out zones

Concept 2 – Post-review

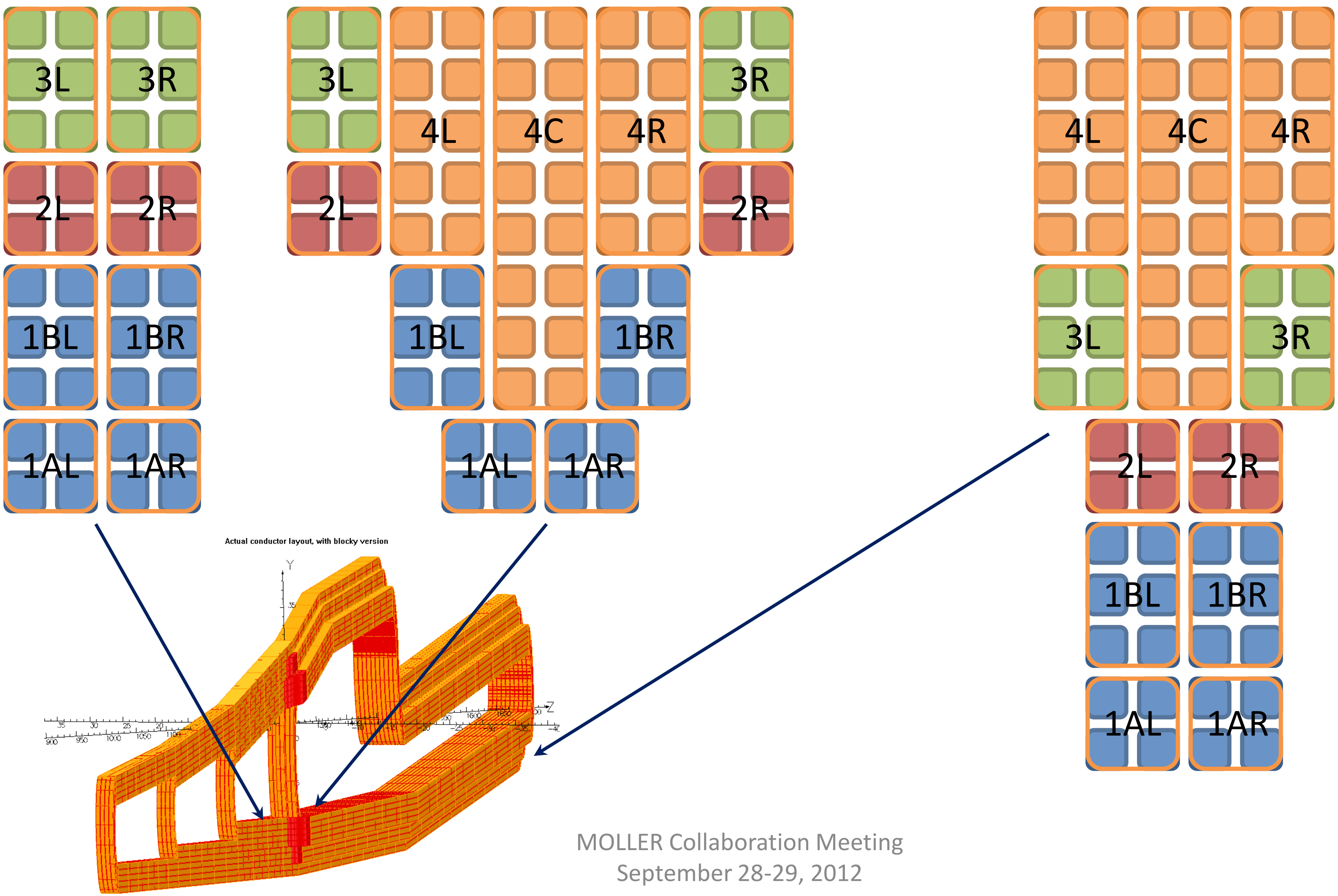
Current density not an issue, but affects cooling

- 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

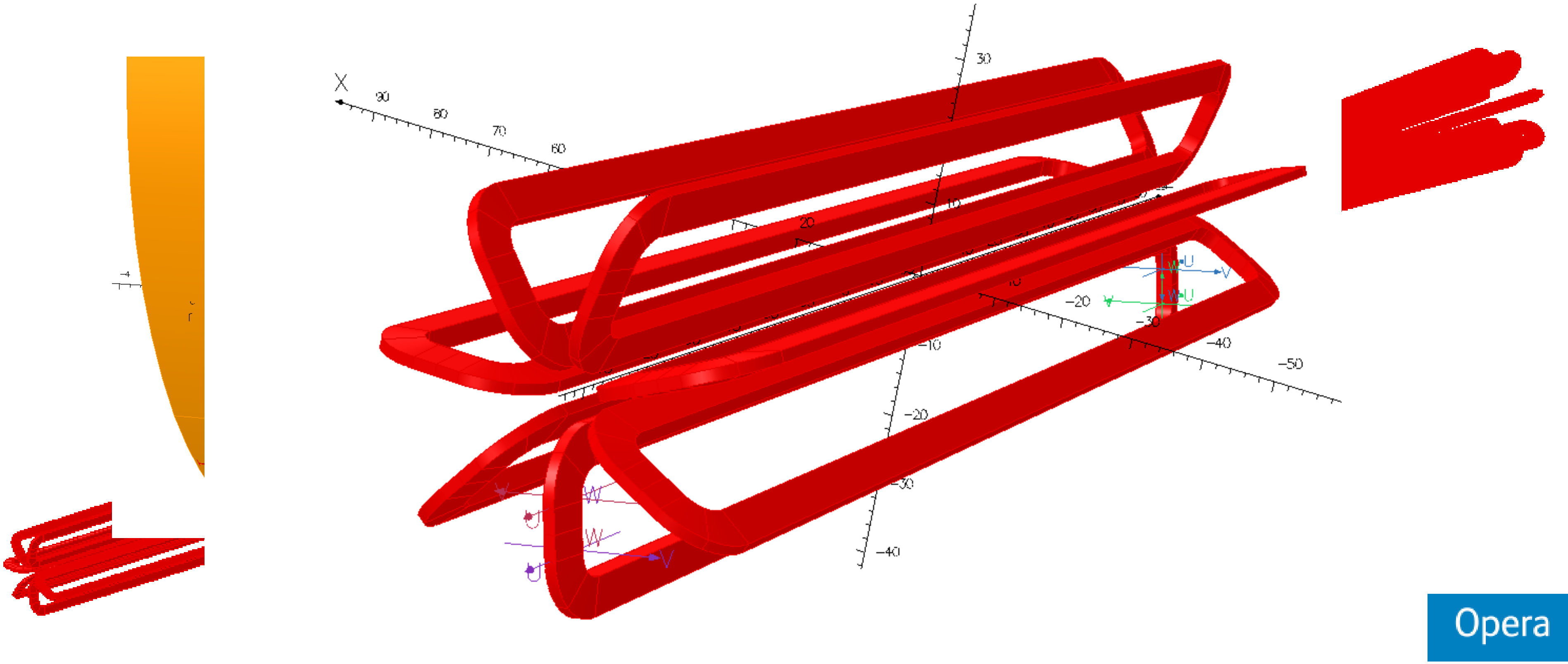




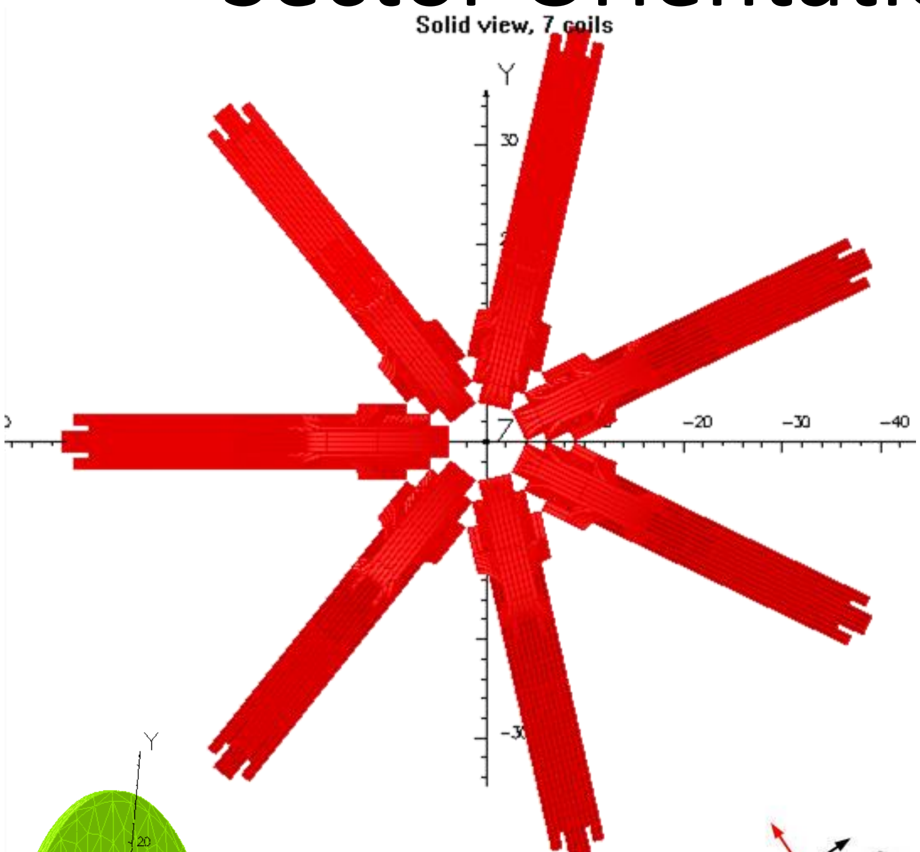
Layout

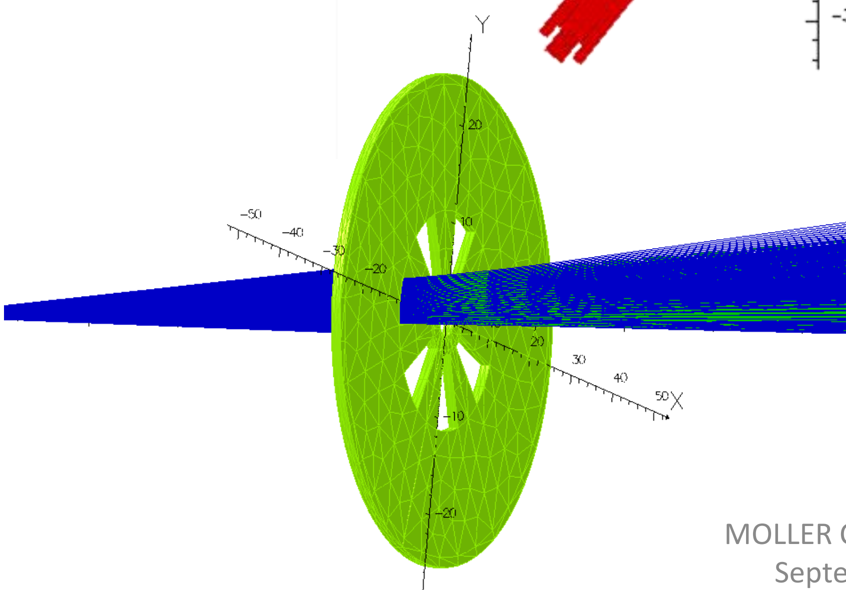

3L
3R
2L
2R
1BL
1BR
1AL
1AR
3L
4L
4C
4R
3R
2L
2R
1BL
1BR
1AL
1AR
4L
4C
4R
3L
3R
2L
2R
1BL
1BR
1AL
1AR
Actual conductor layout, with blocky version

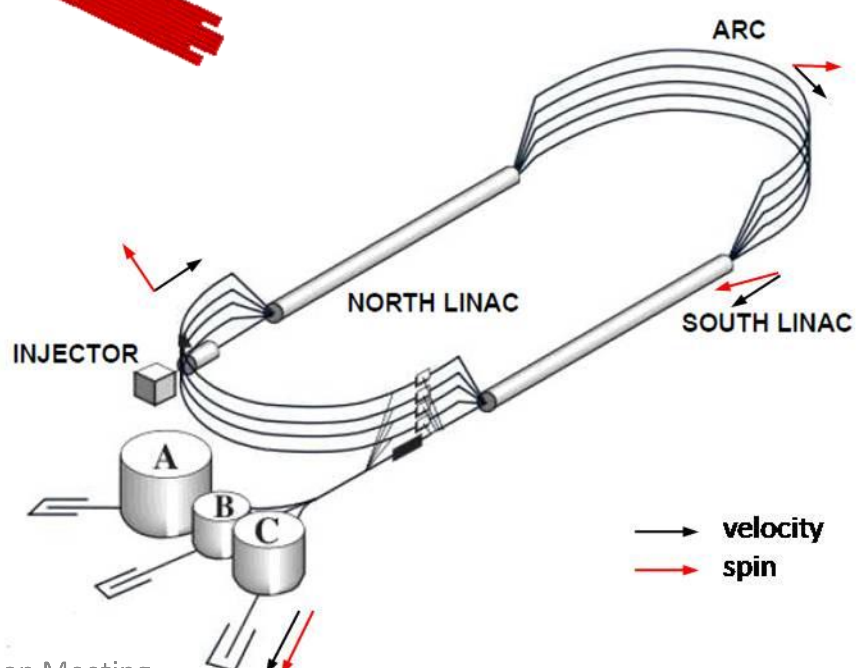
Upstream Torus



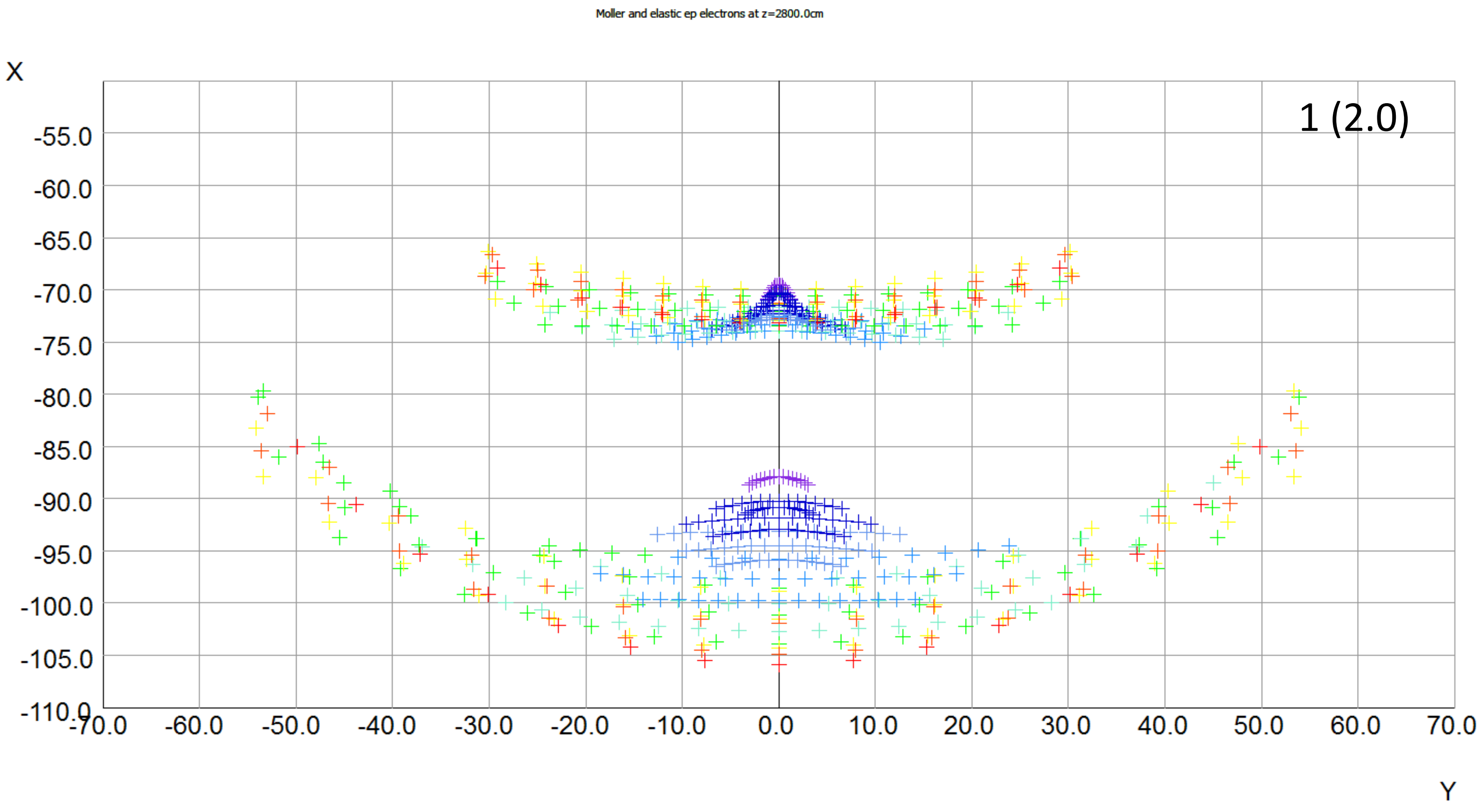
Sector Orientation



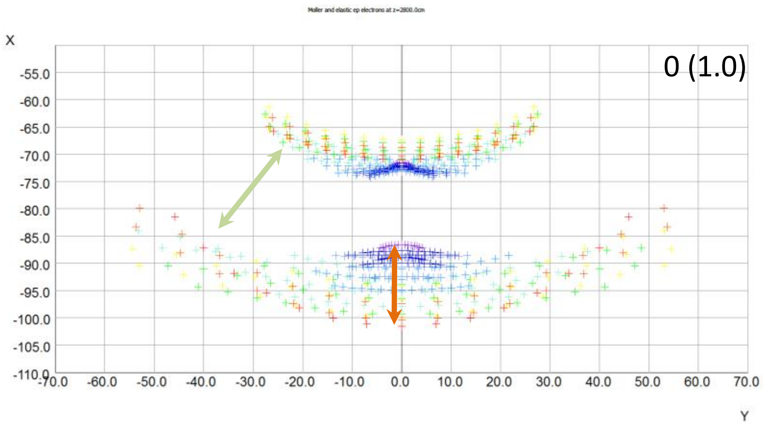


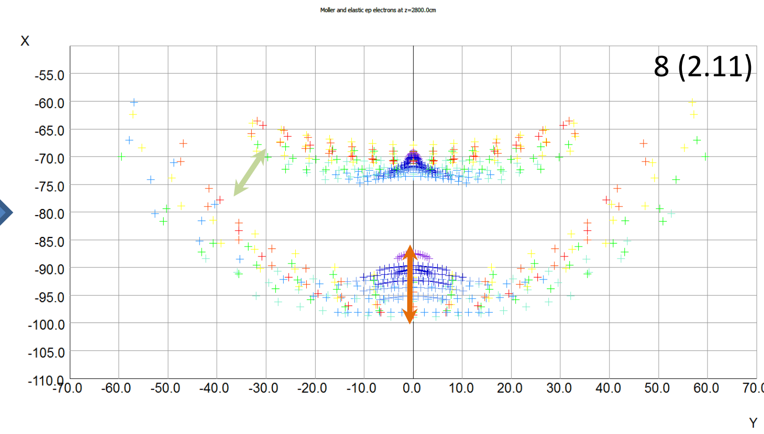


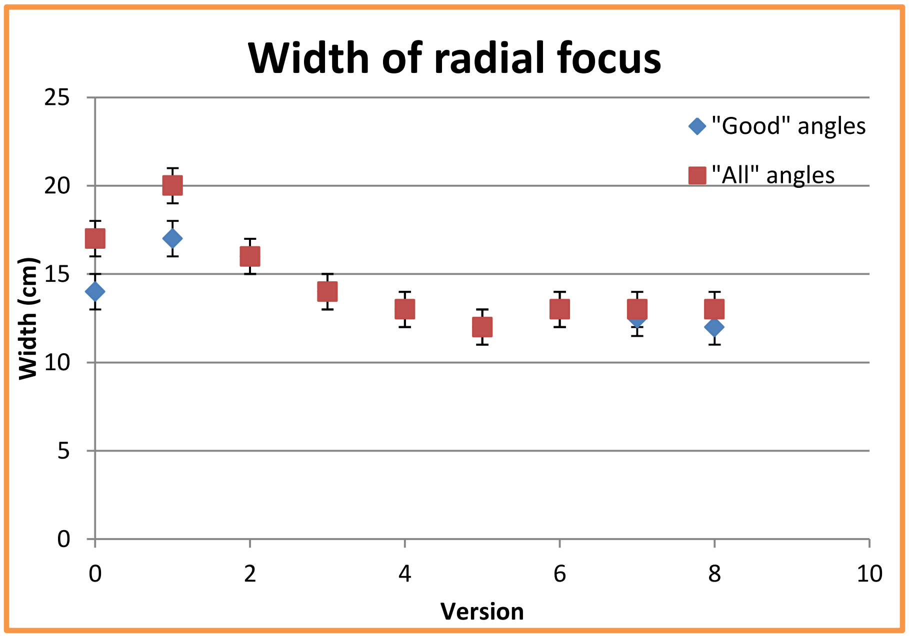
Tweaking the Optics

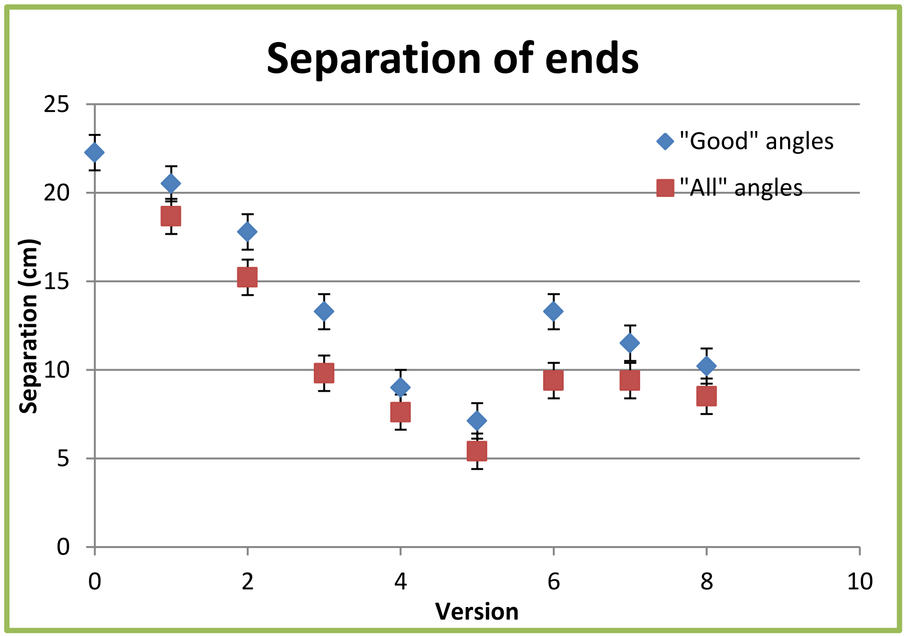


Tweaking the Optics

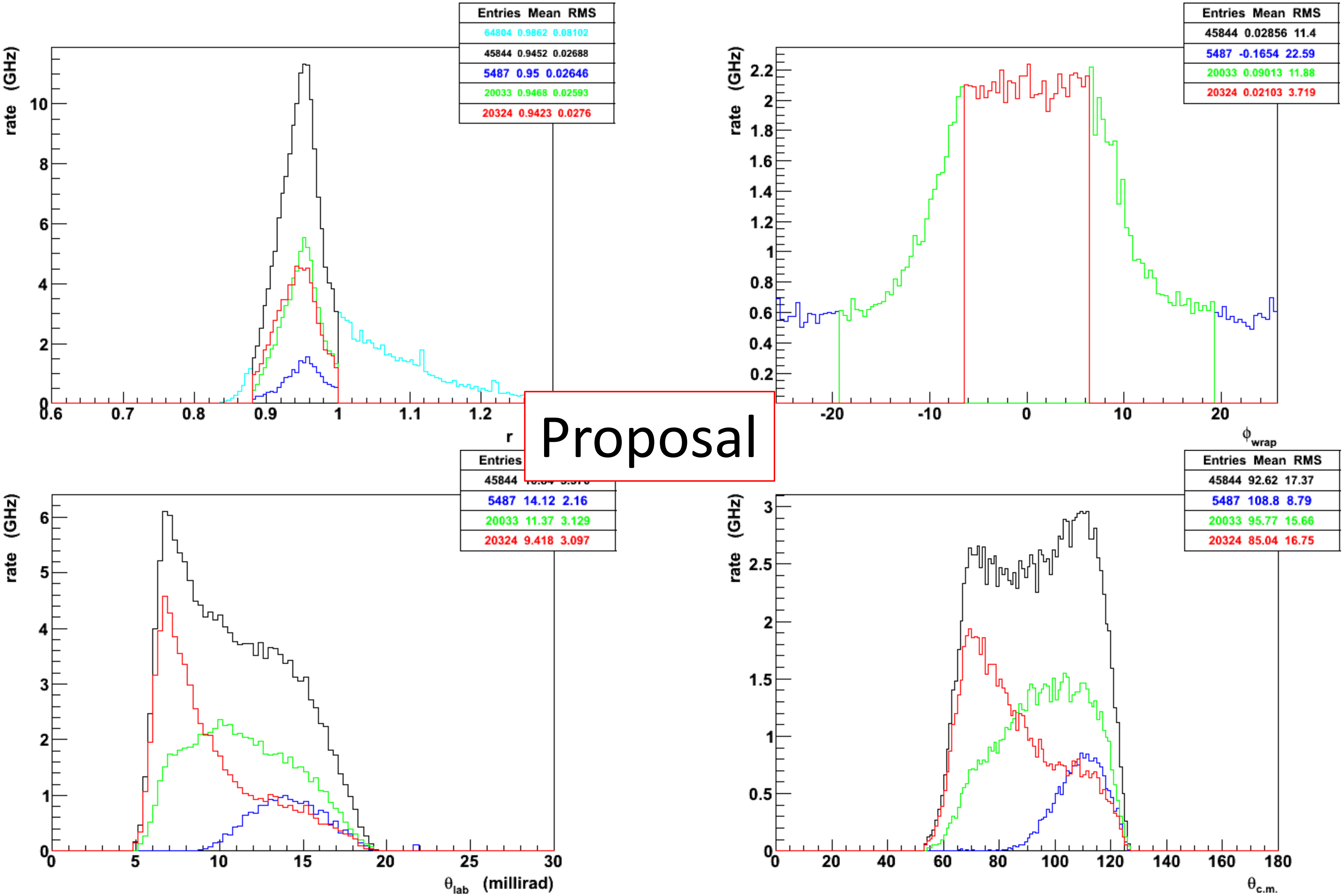








Comparison of GEANT4 Simulations



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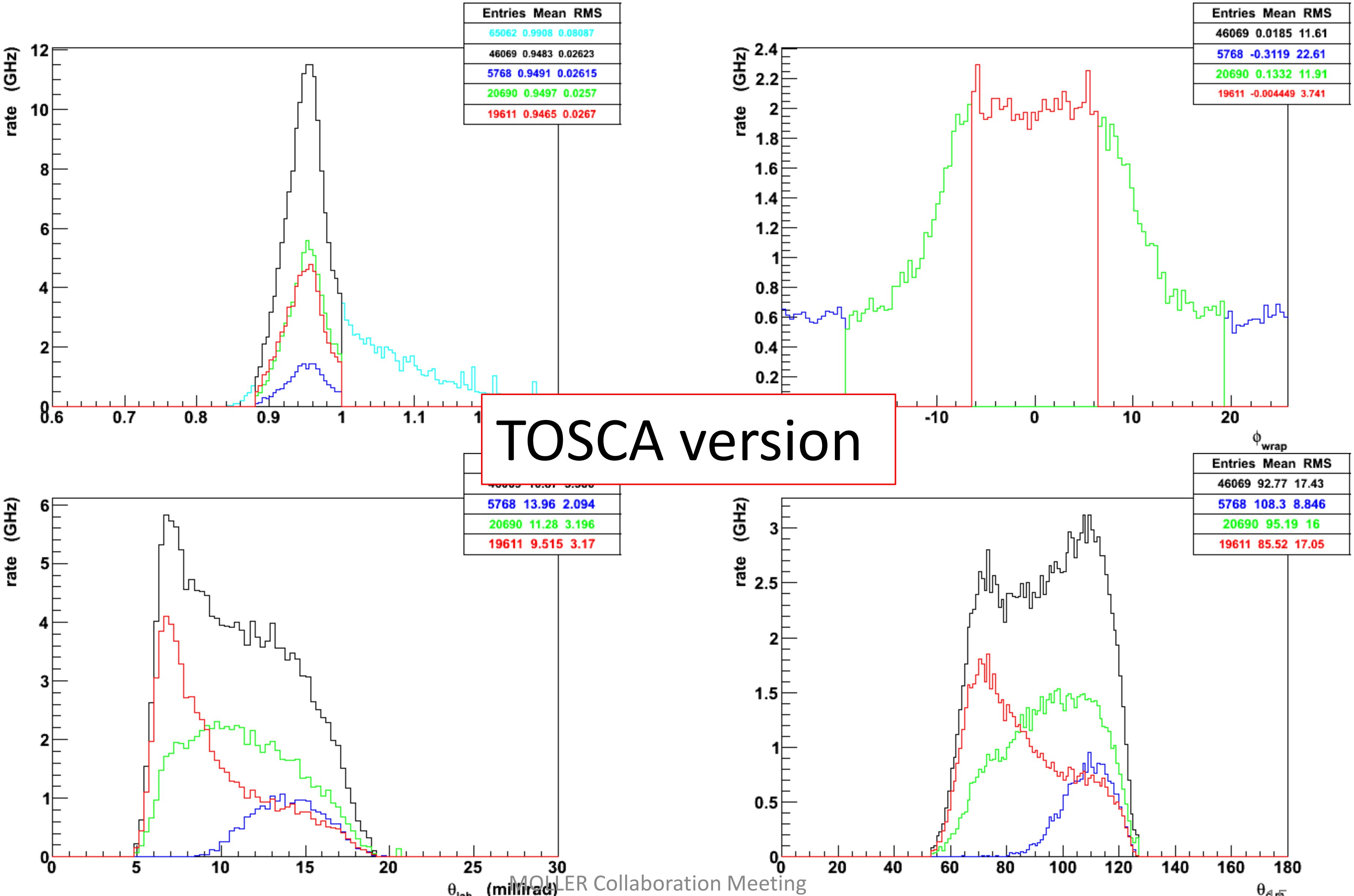
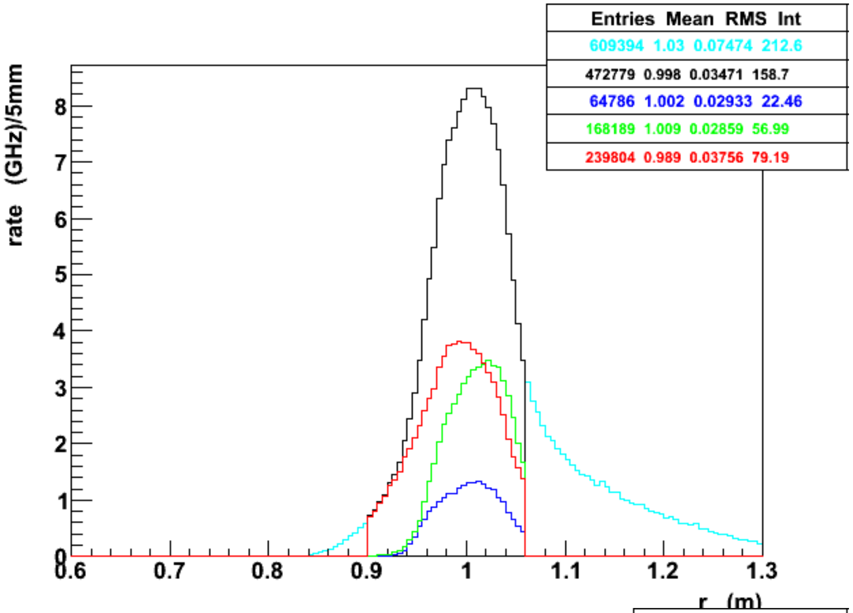
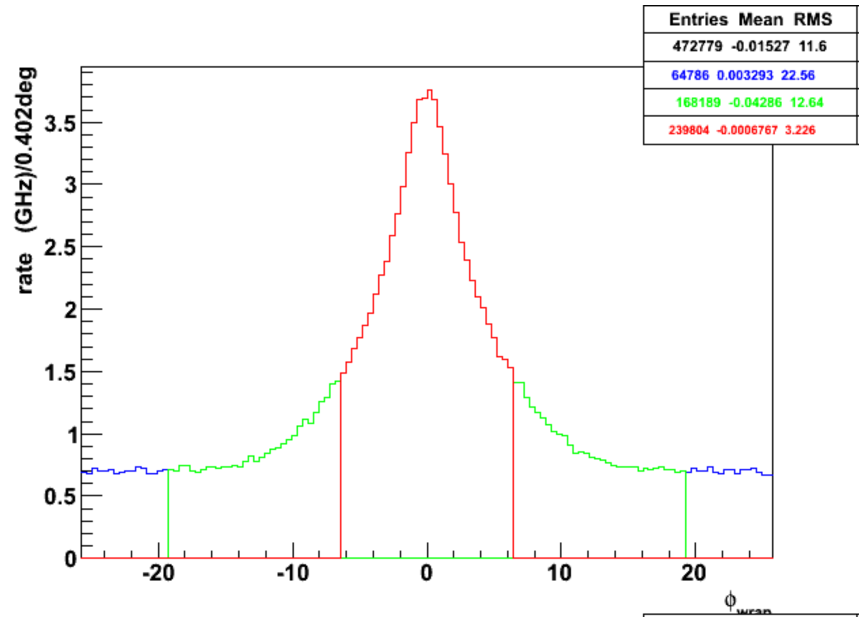


TOSCA version

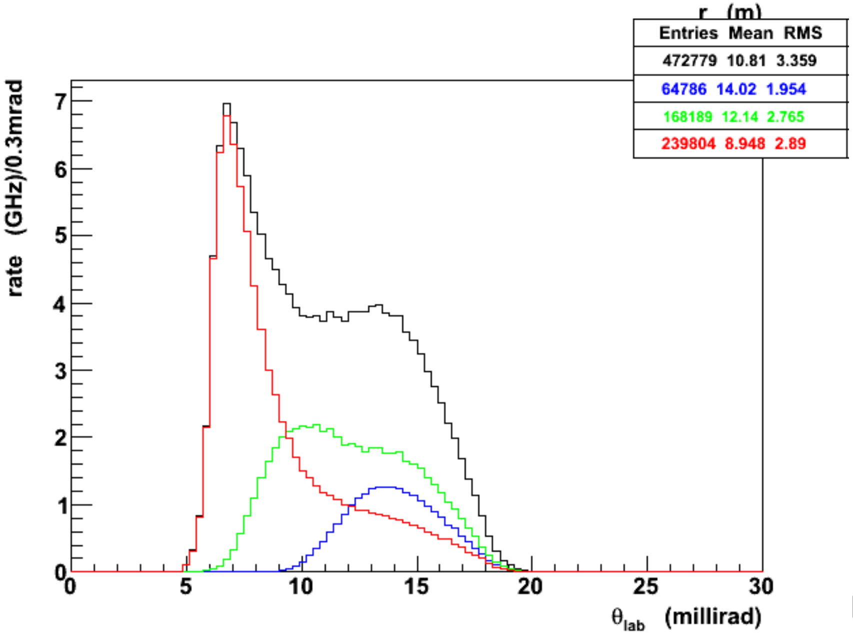
2.6



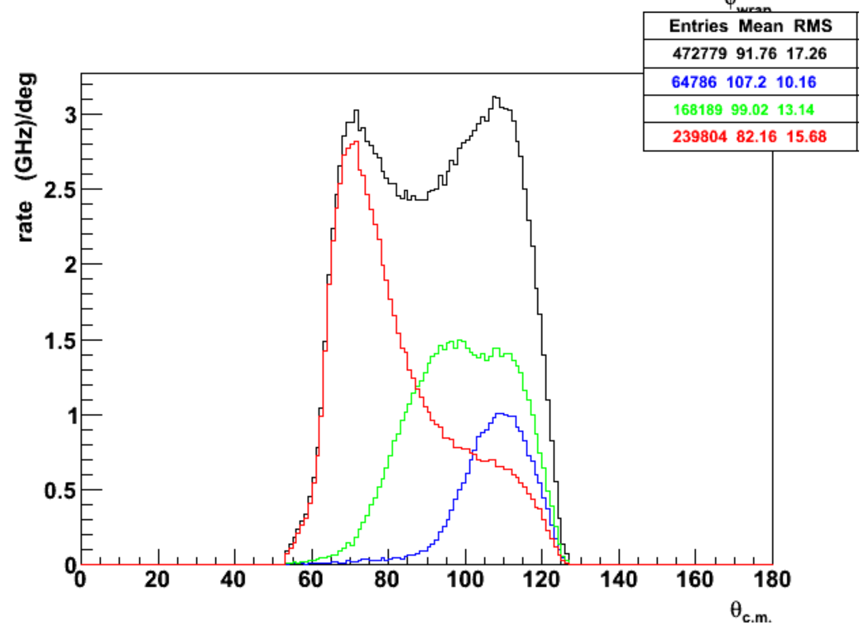
Entries Mean RMS Int
609394 1.03 0.07474 212.6
472779 0.998 0.03471 158.7
64786 1.002 0.02933 22.46
168189 1.009 0.02859 56.99
239804 0.989 0.03756 79.19
rate (GHz)/5mm
r (m)



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

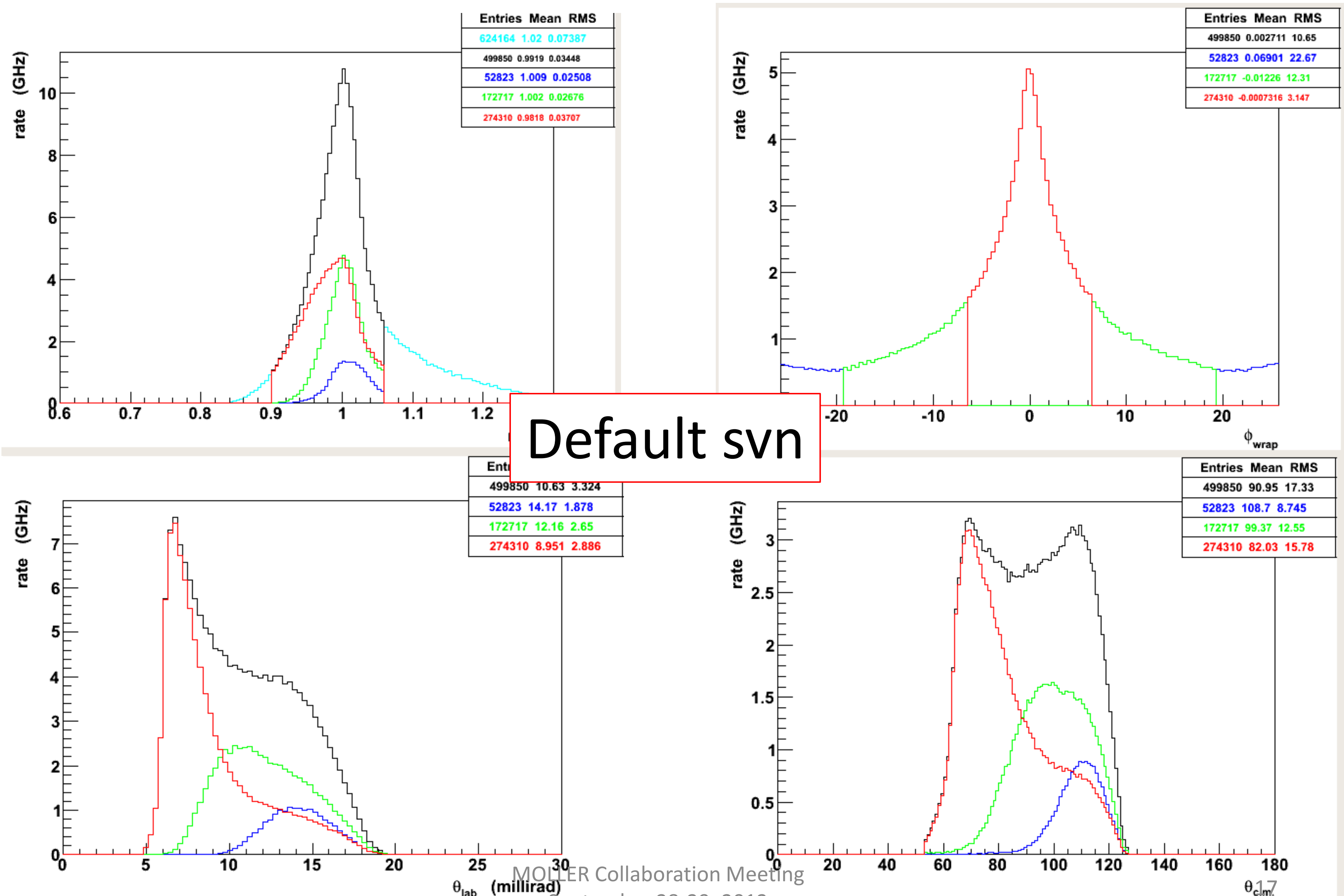


Entries Mean RMS
472779 10.81 3.359
64786 14.02 1.954
168189 12.14 2.765
239804 8.948 2.89
rate (GHz)/0.3mrad
θ_{lab} (millirad)



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

Current Version of the Hybrid and Upstream

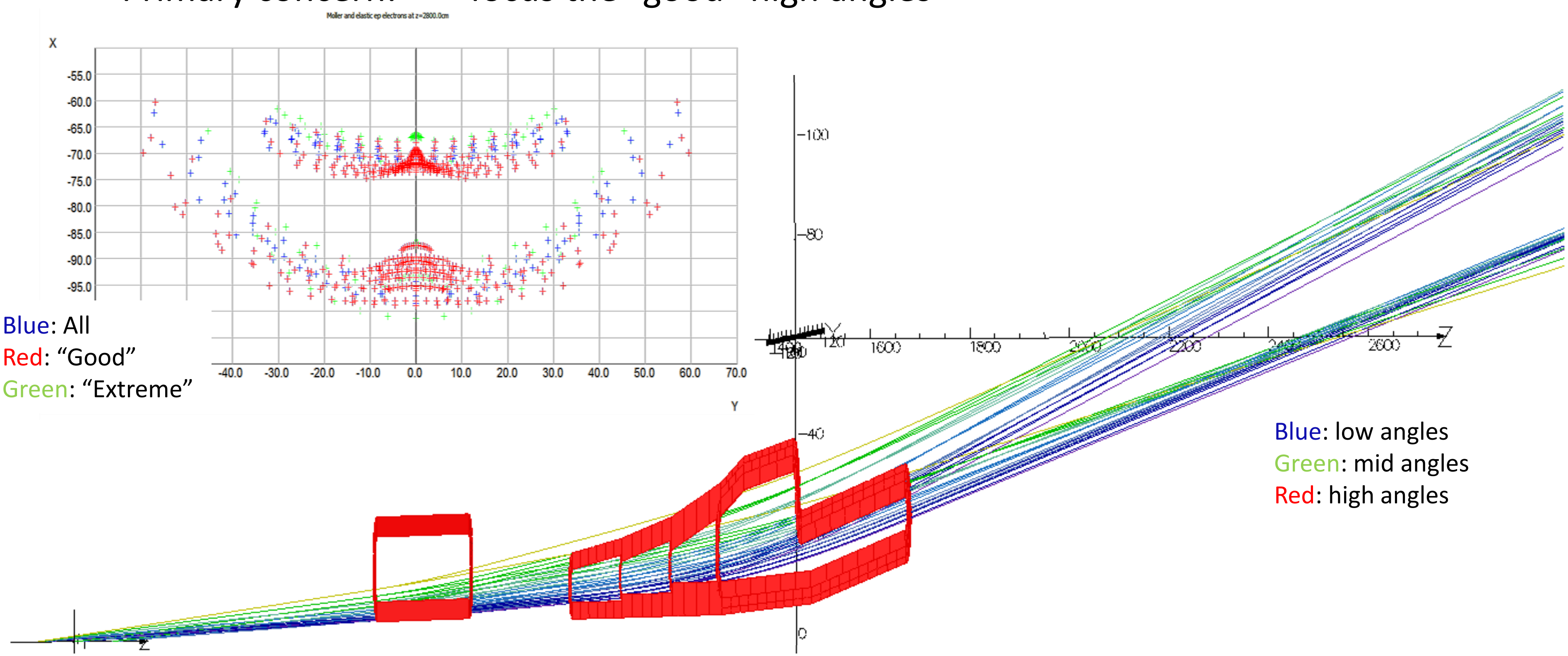


Tweaking the Optics

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

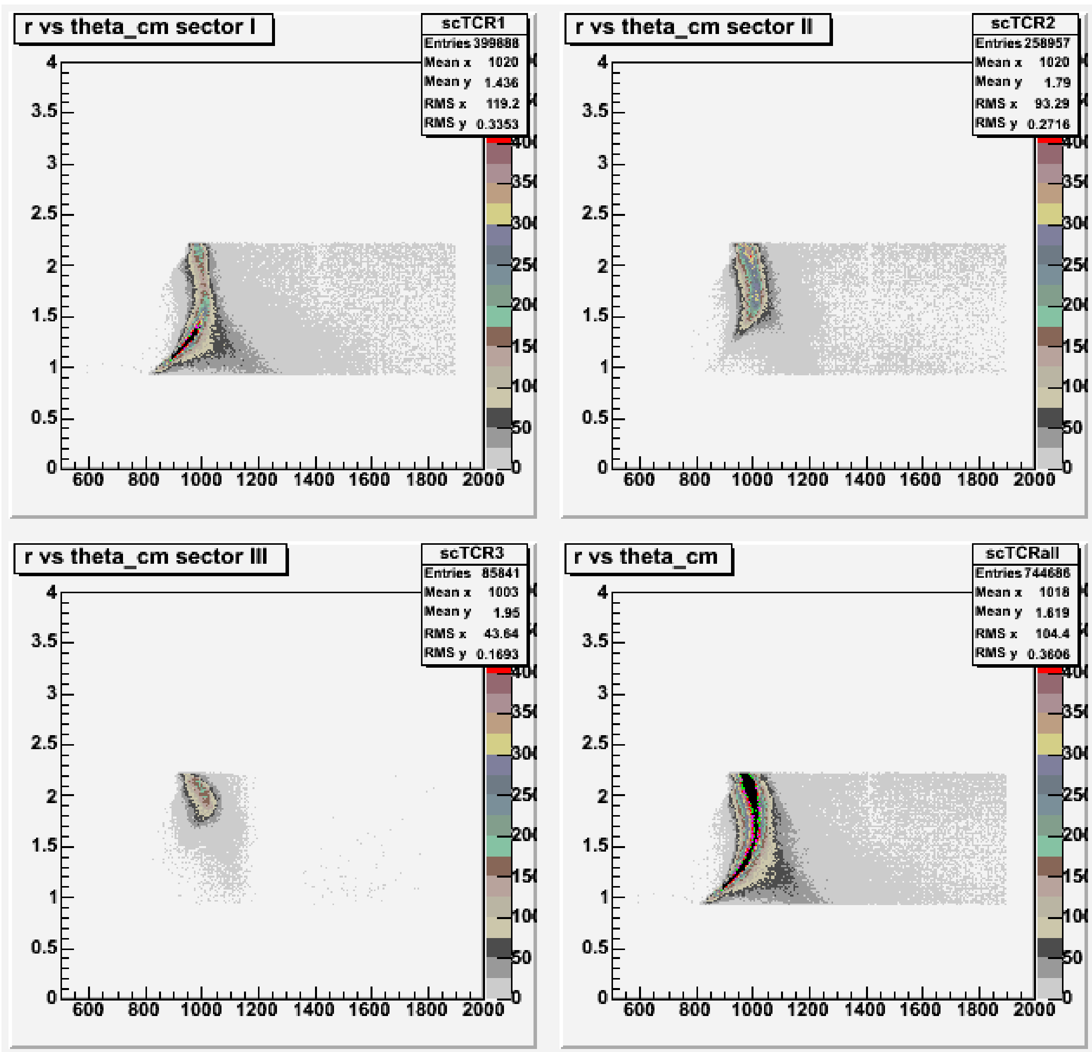
Primary concern: focus the "good" high angles



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

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

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

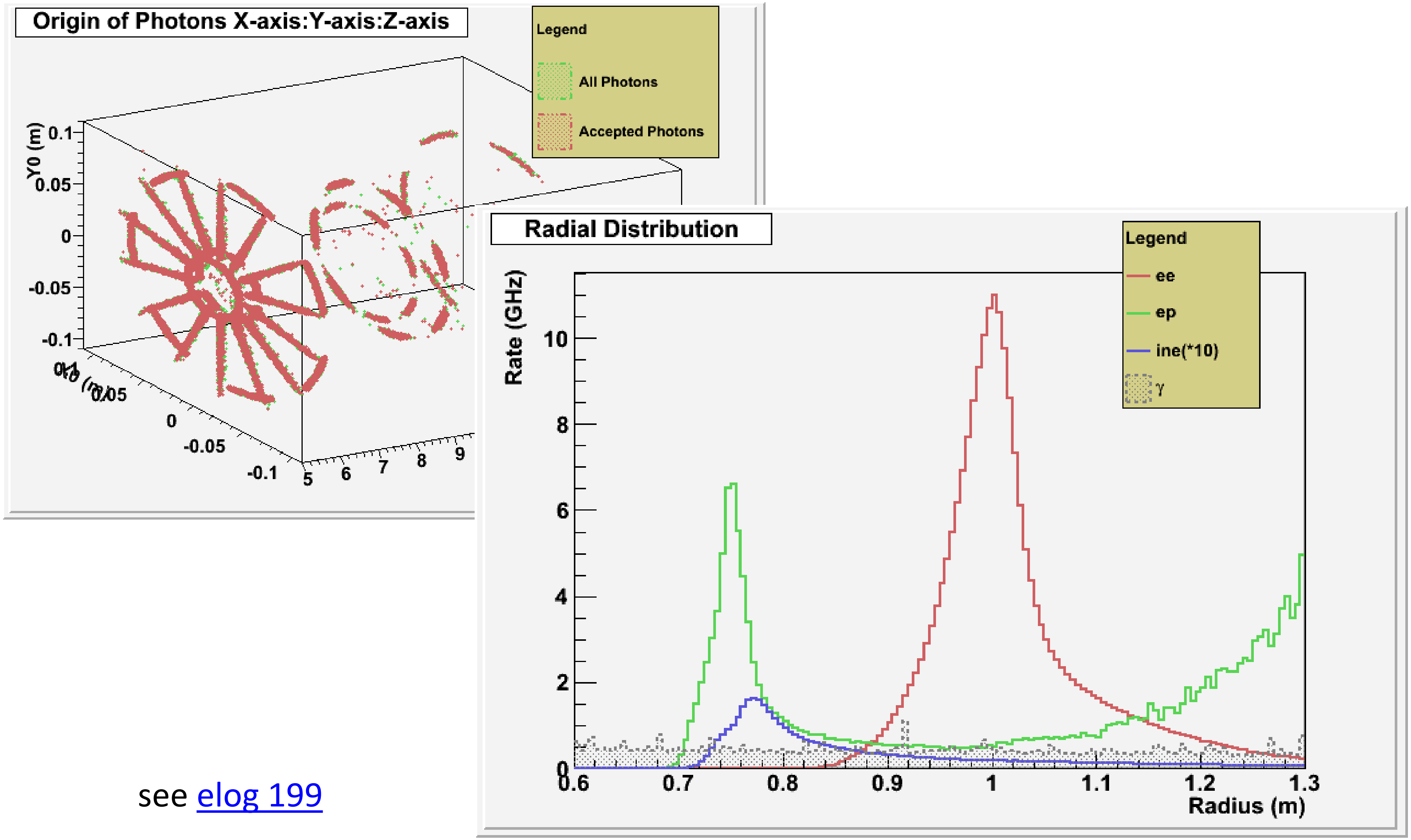
see elog 200

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]

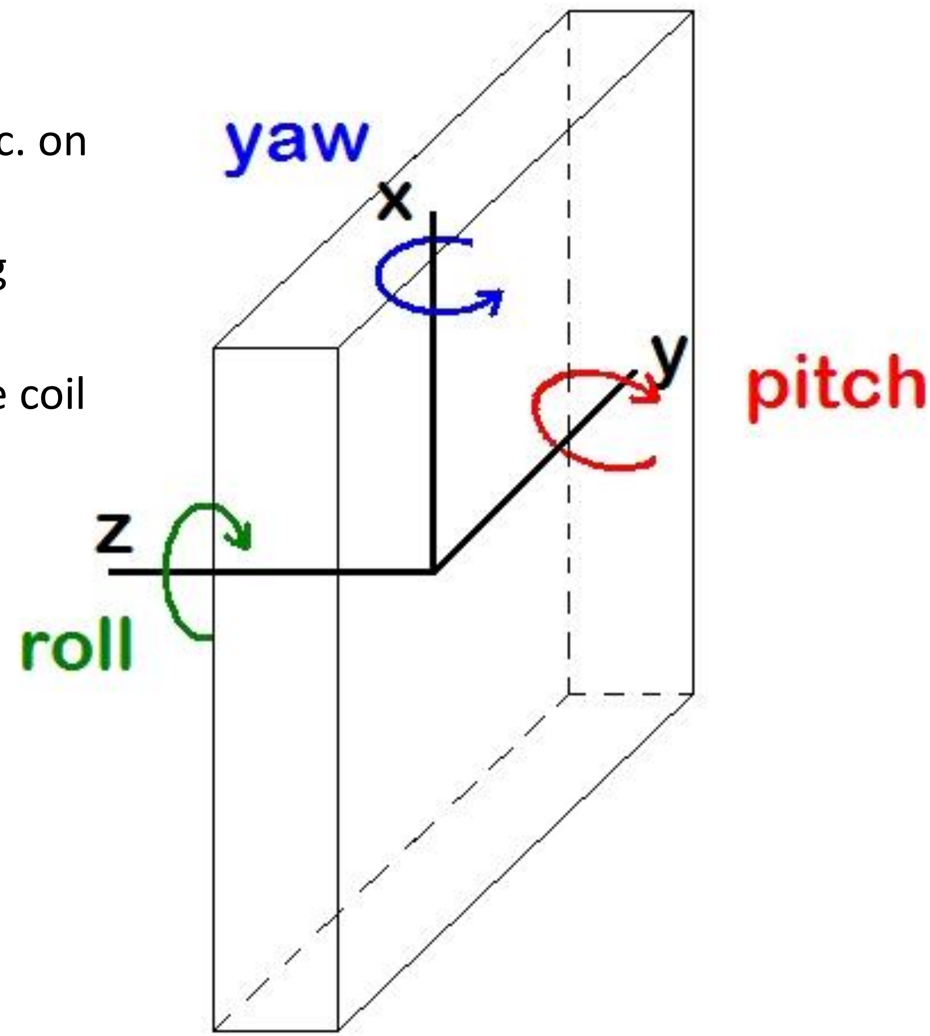
Magnetic Forces

- 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

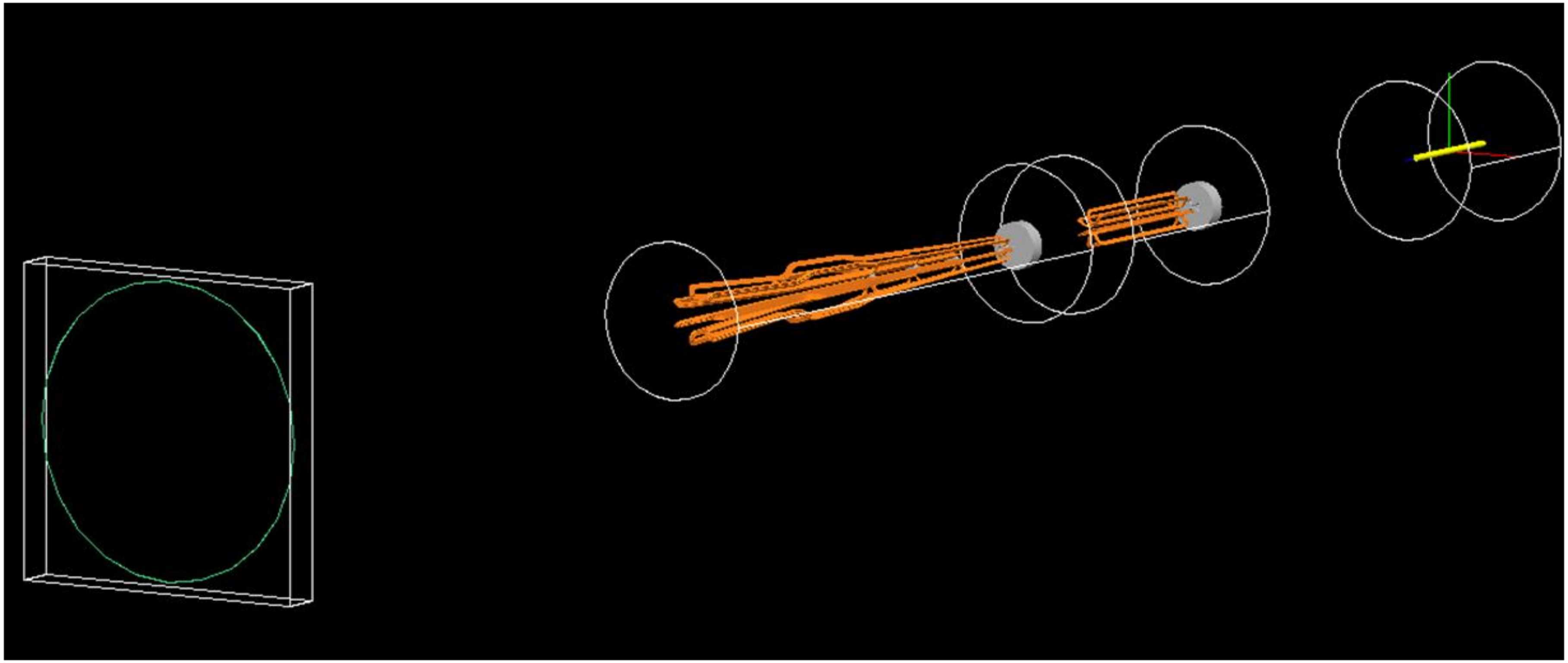
Sensitivity Studies

- 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

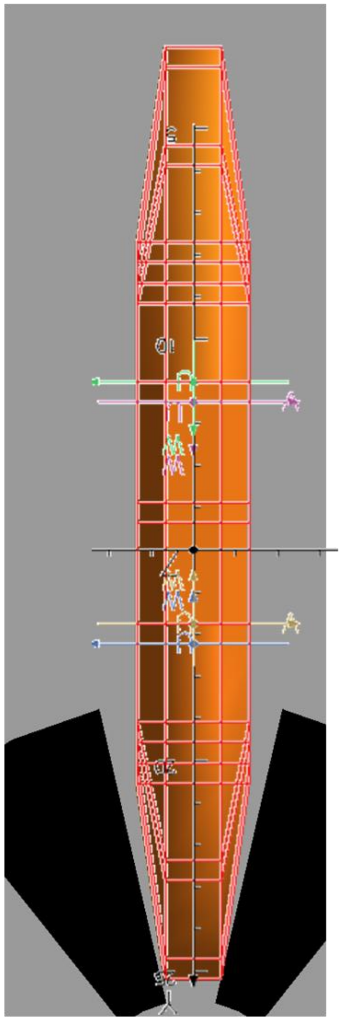


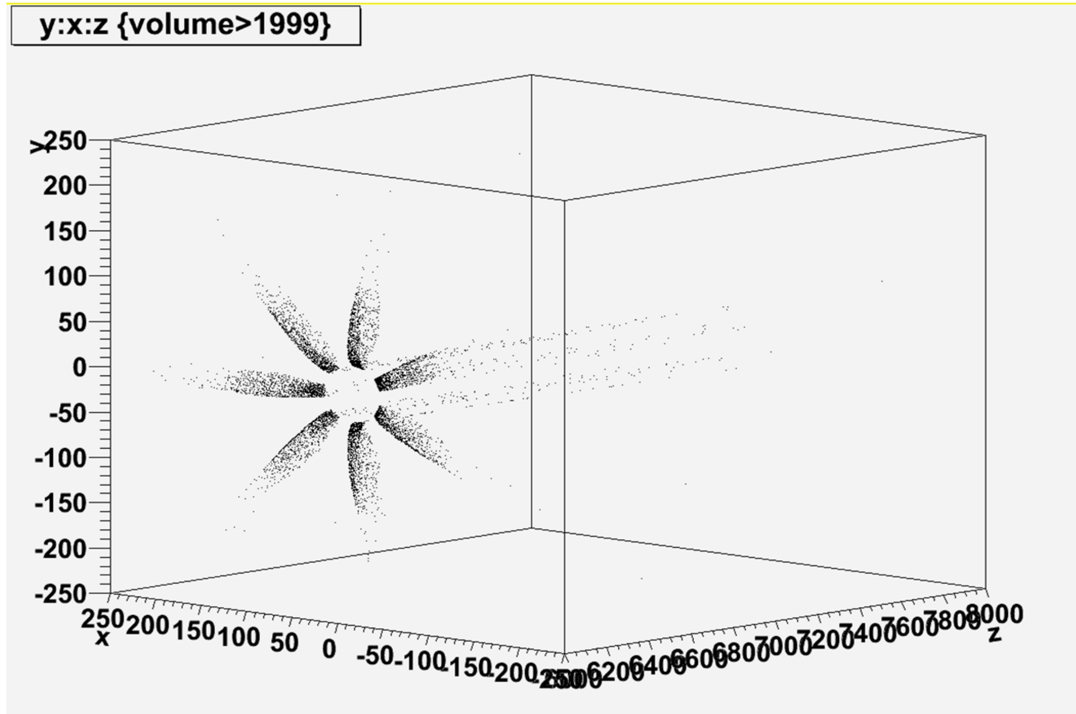
GEANT4

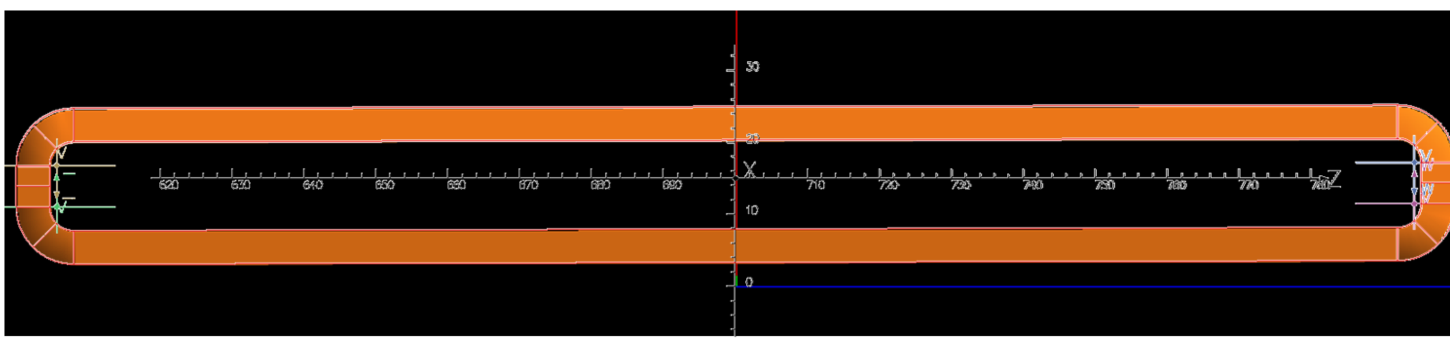
- Moved to GDML geometry description
- Defined hybrid and upstream toroids
  - Parameterized in same way as the TOSCA models



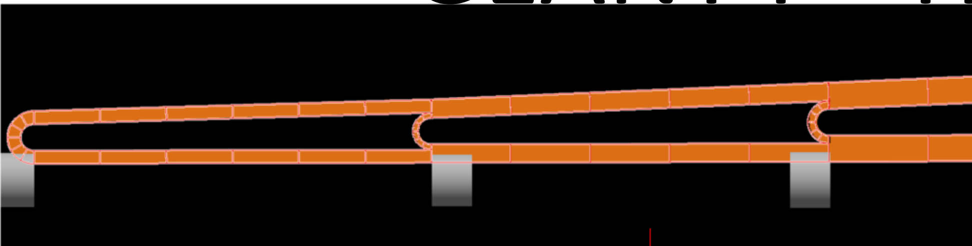
GEANT4 – Upstream Torus

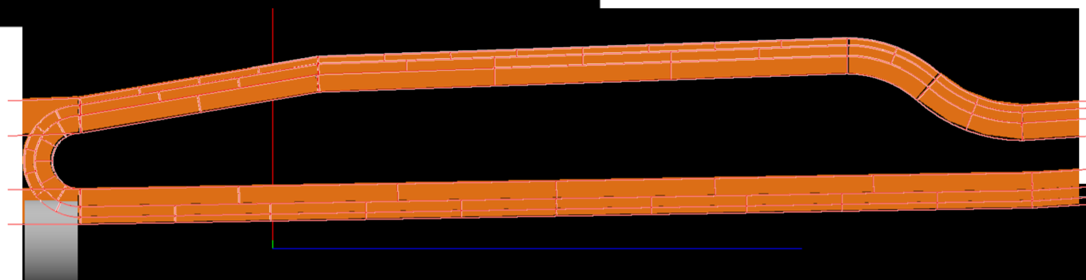


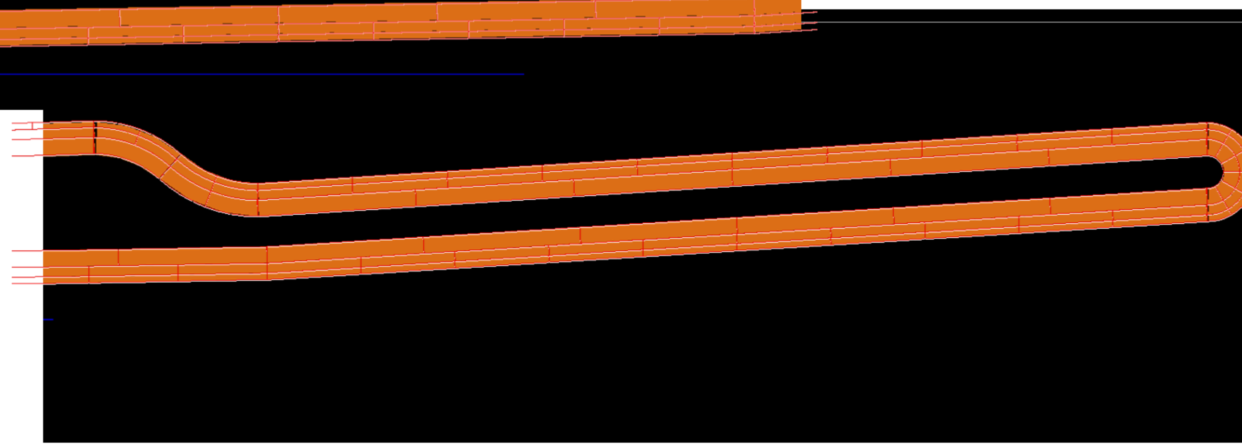


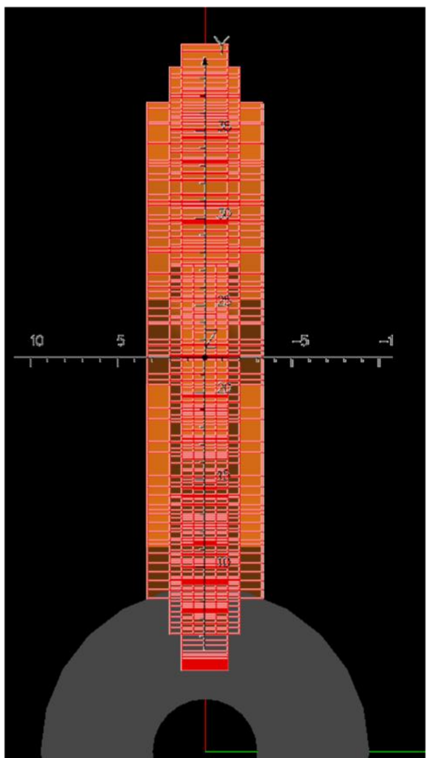


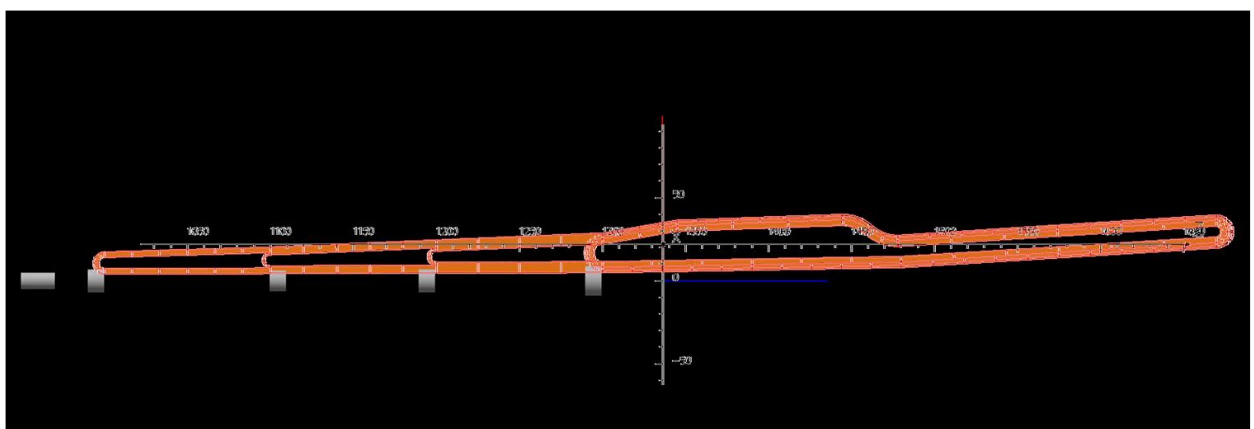
GEANT4 – Hybrid Torus







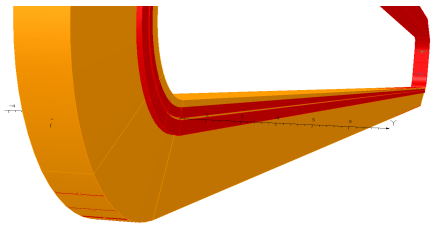


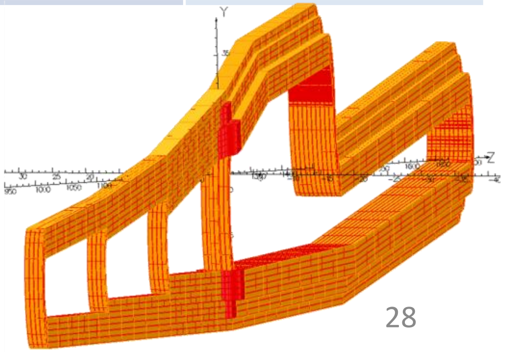


GEANT4

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

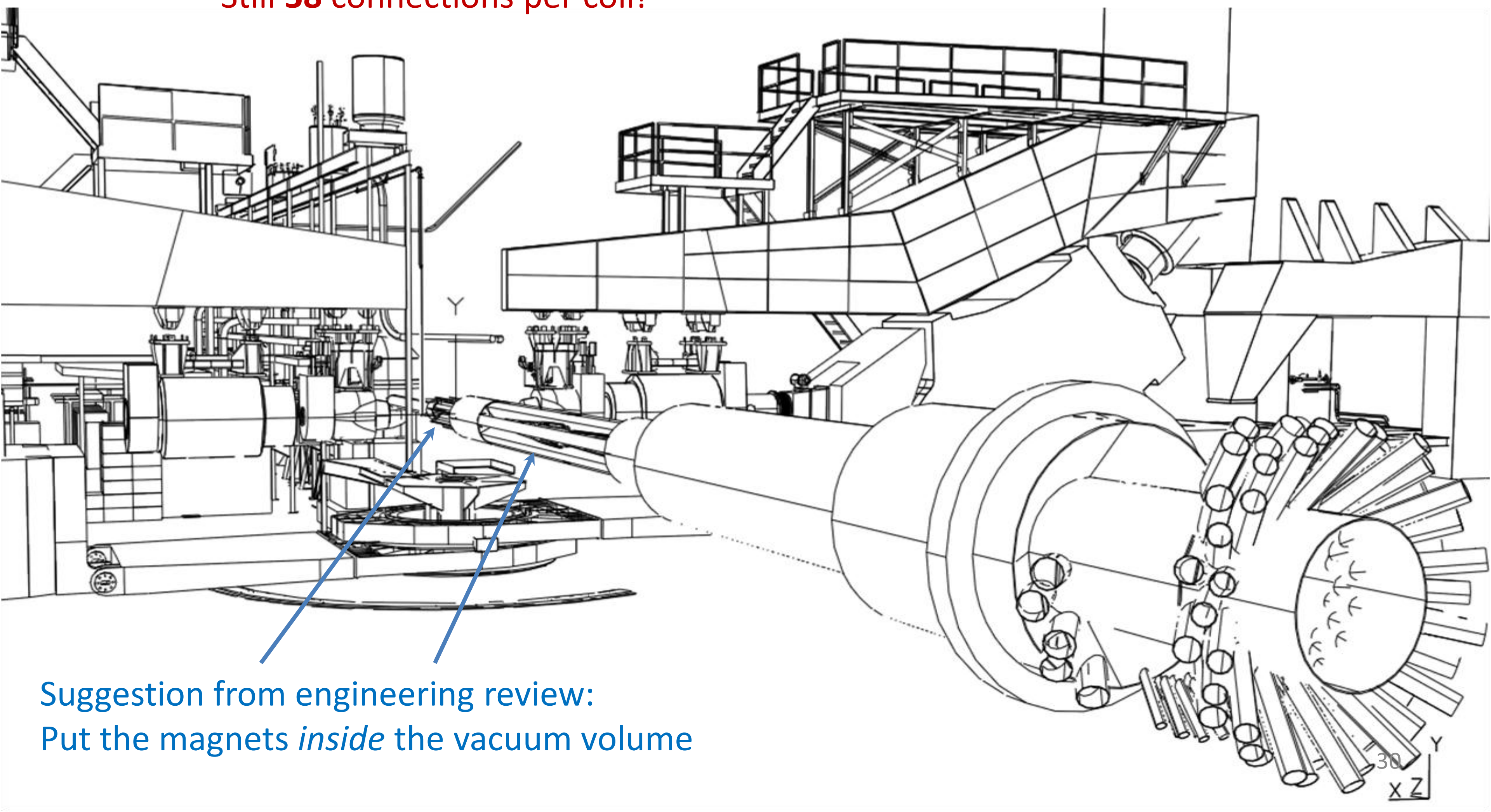




Extra Slides

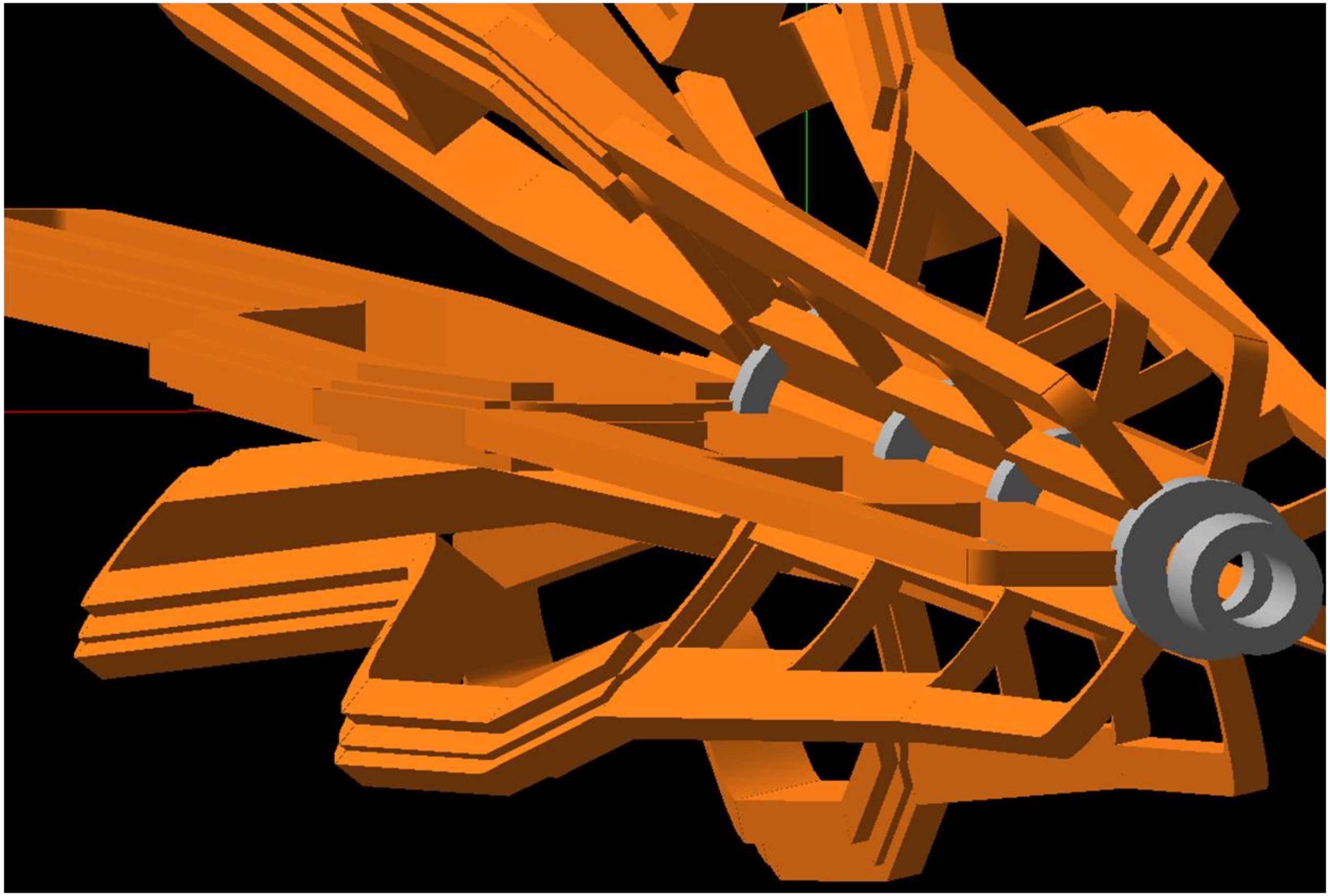
Water-cooling and supports

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

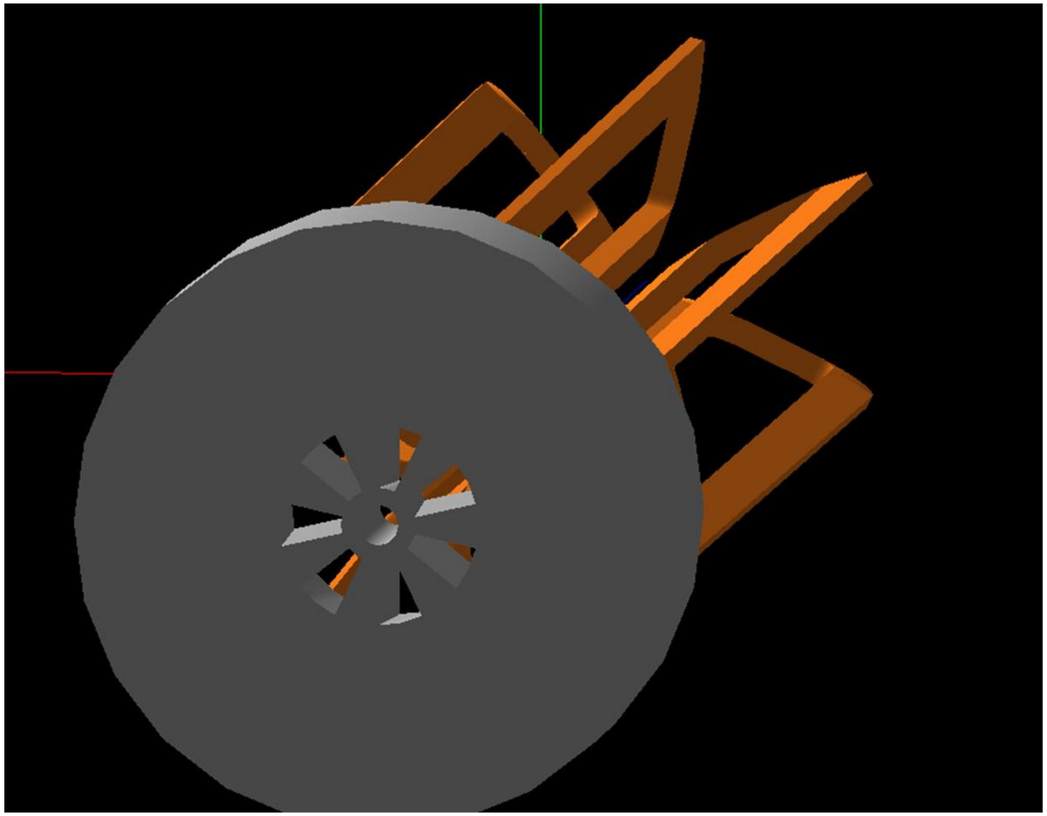


Suggestion from engineering review:
Put the magnets *inside* the vacuum volume

GEANT4 - Collimators

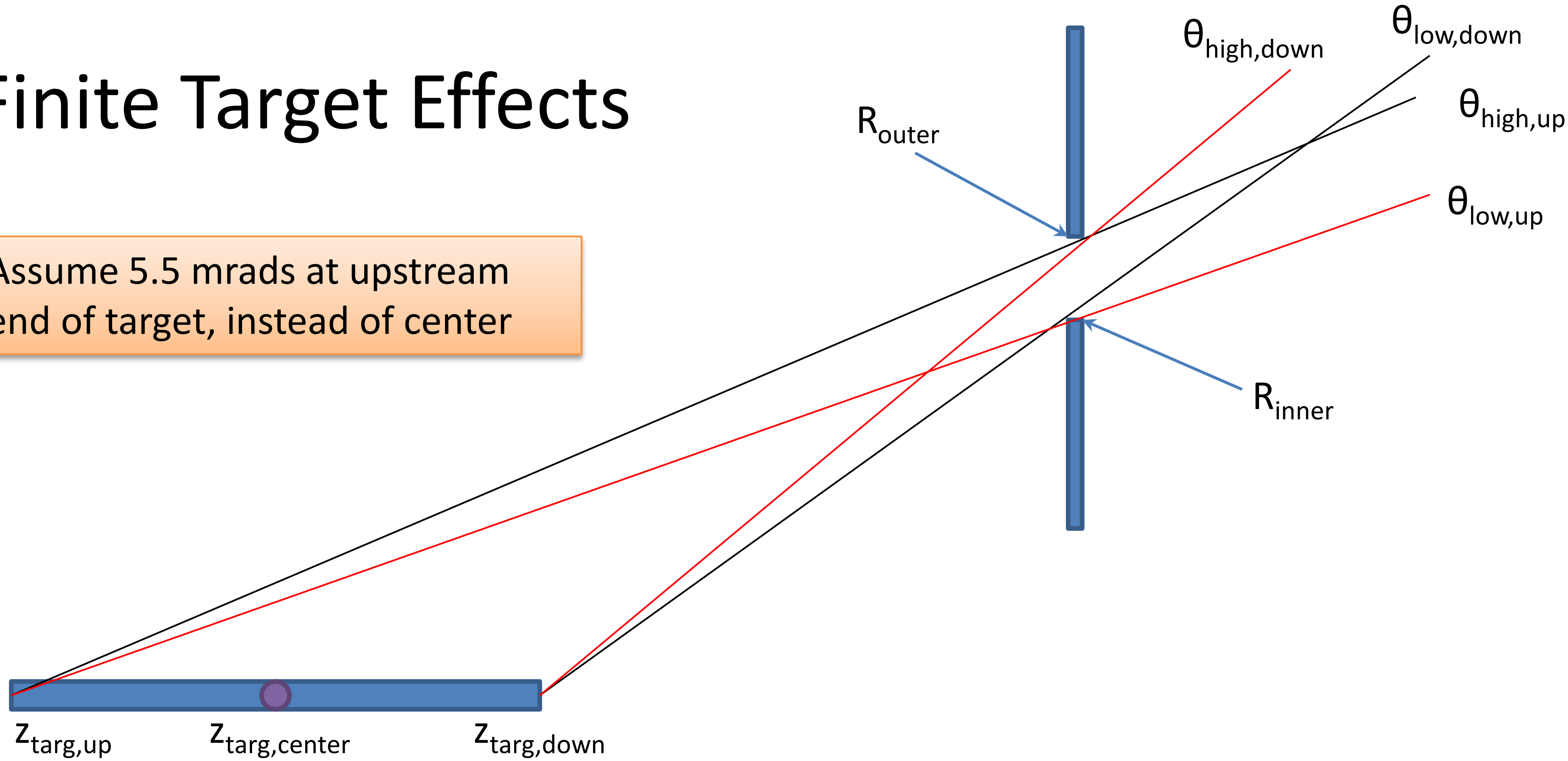


GEANT4 – Acceptance definition



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:

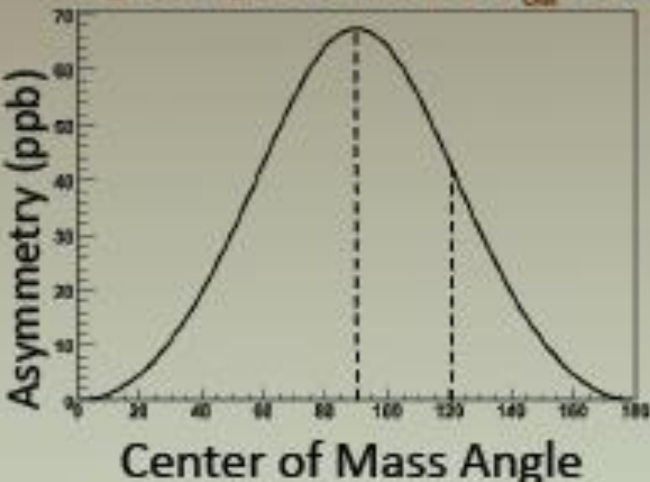
$\theta_{low,cen}$ = 6.200 mrads
$\theta_{high,cen}$ = 19.161 mrads

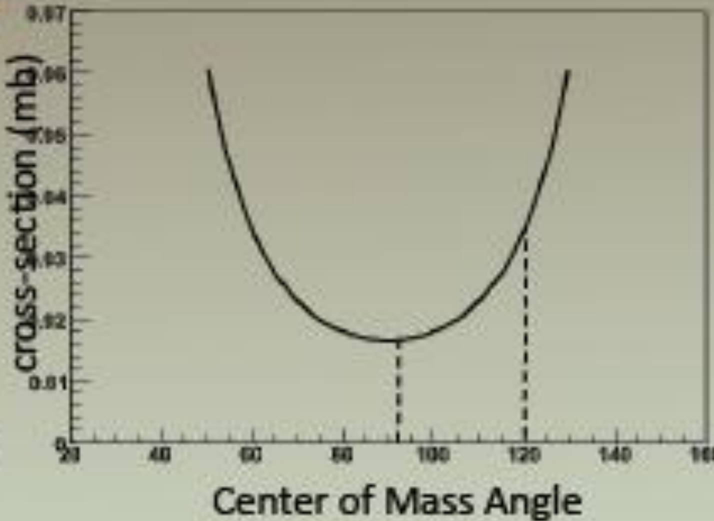
From downstream:

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

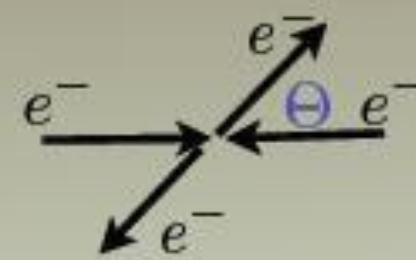
100% Acceptance with Toroids

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



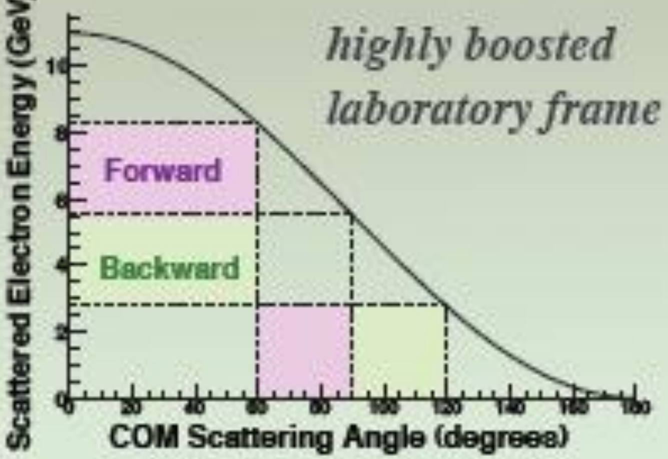


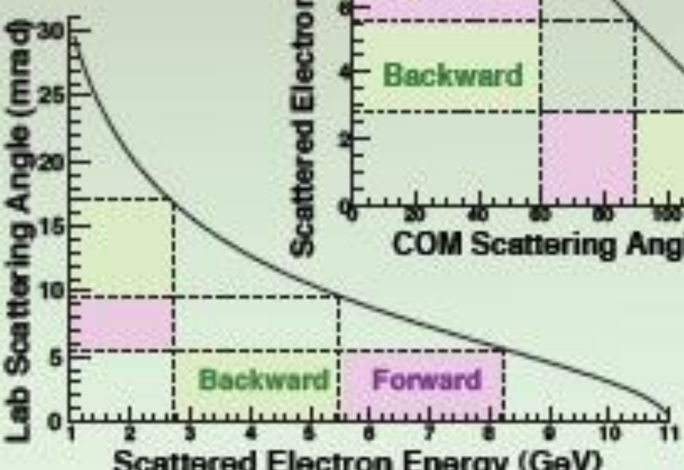
$E_{COM} = 53$ MeV



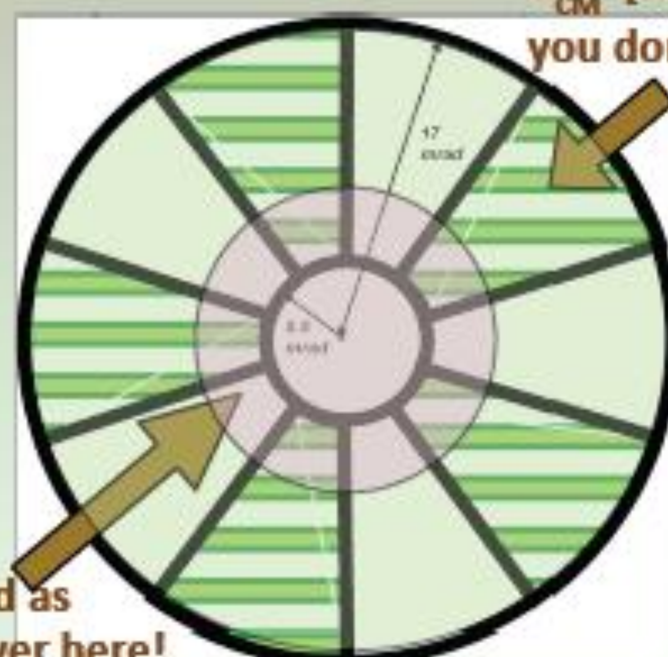
identical particles!

highly boosted laboratory frame





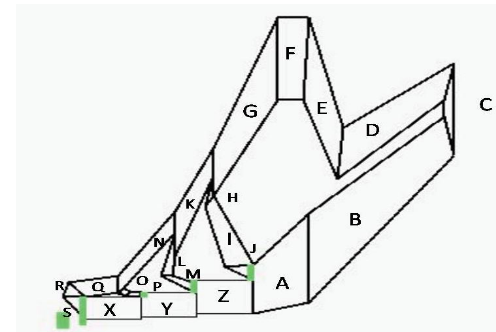
All of those rays of θ_{CM}=[90,120] that you don't get here…

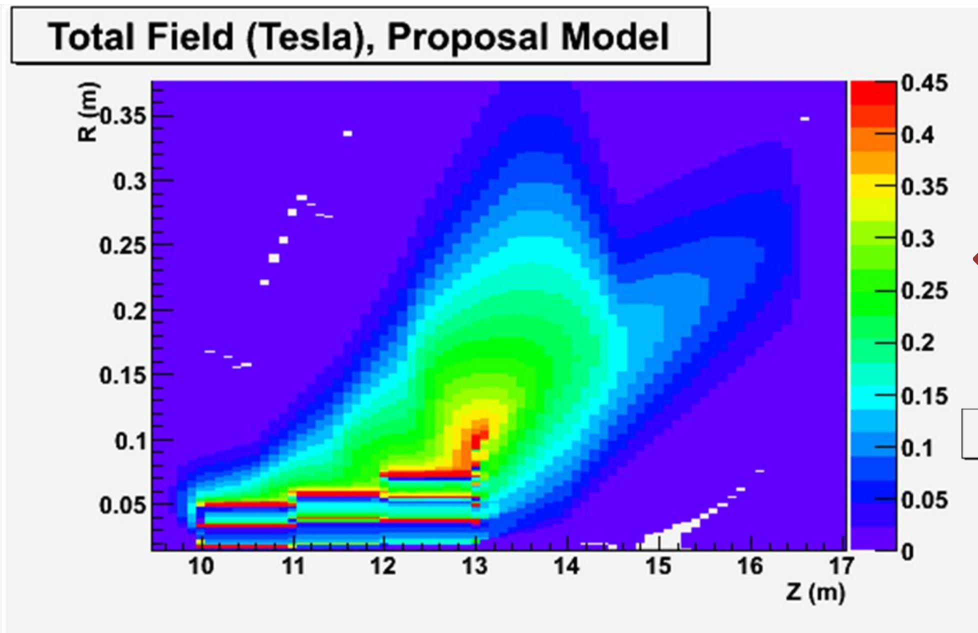


… are collected as θ_{CM}=[60,90] over here!

Direct Comparison of Fields

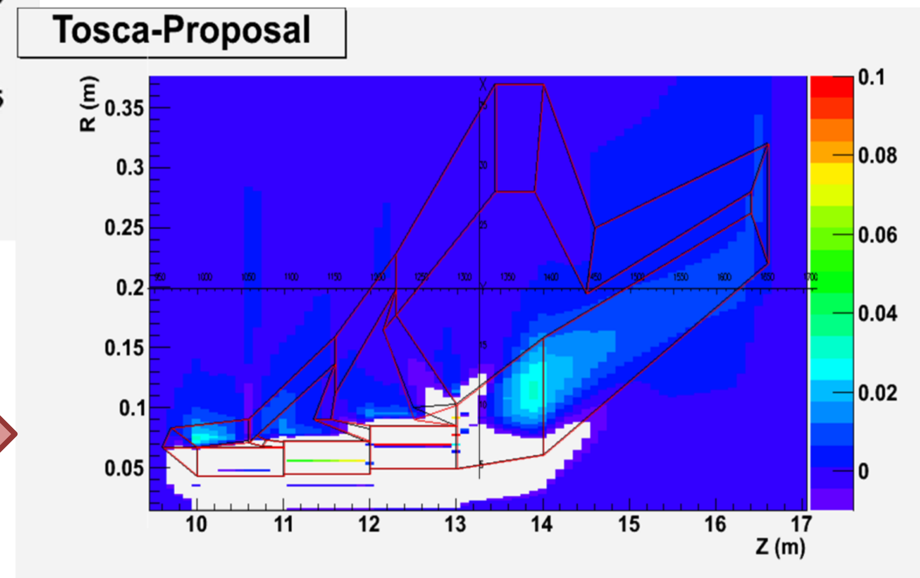
Complicated field because of multiple current returns



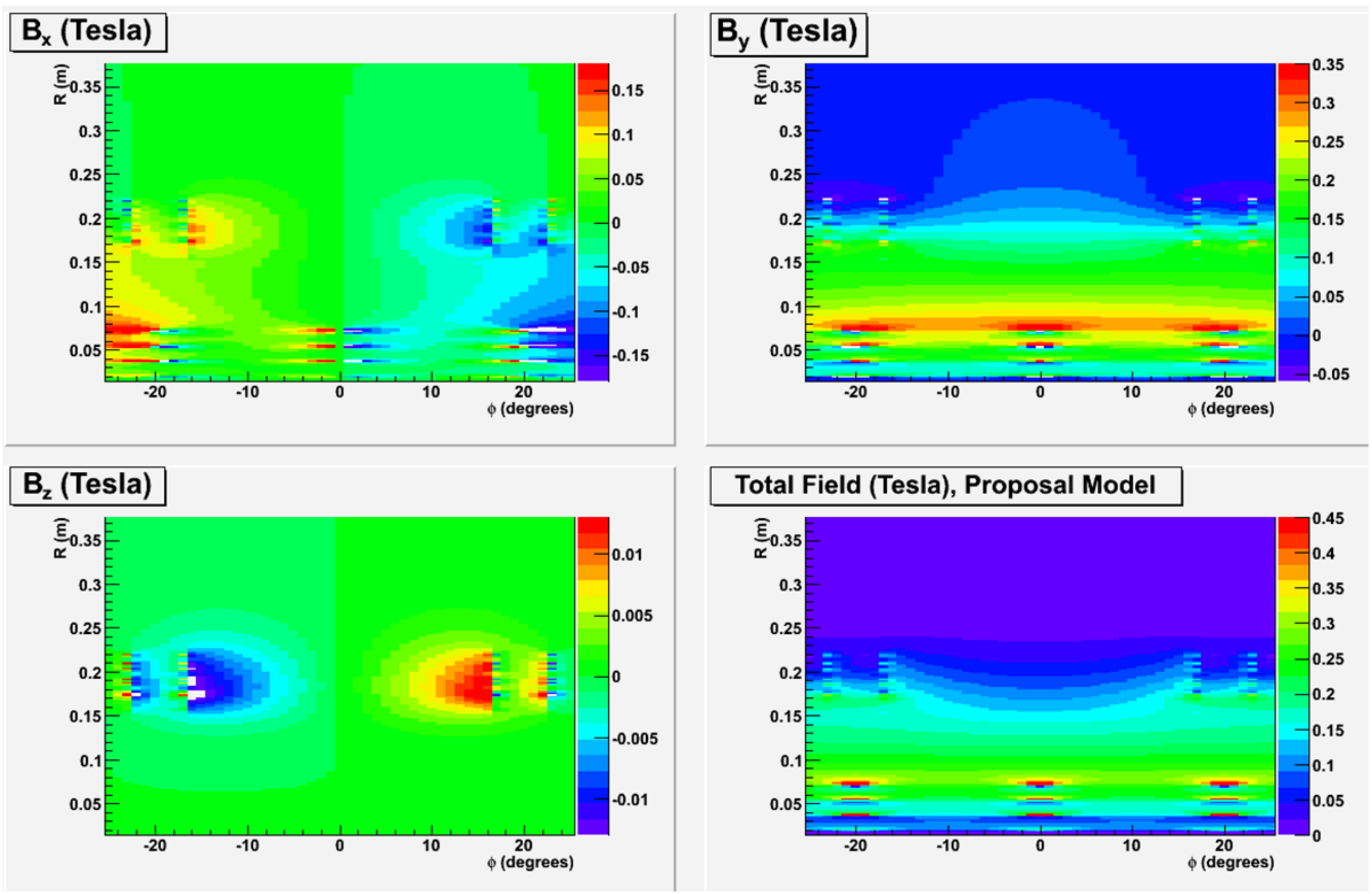


The average total field in a sector in bins of R vs. z

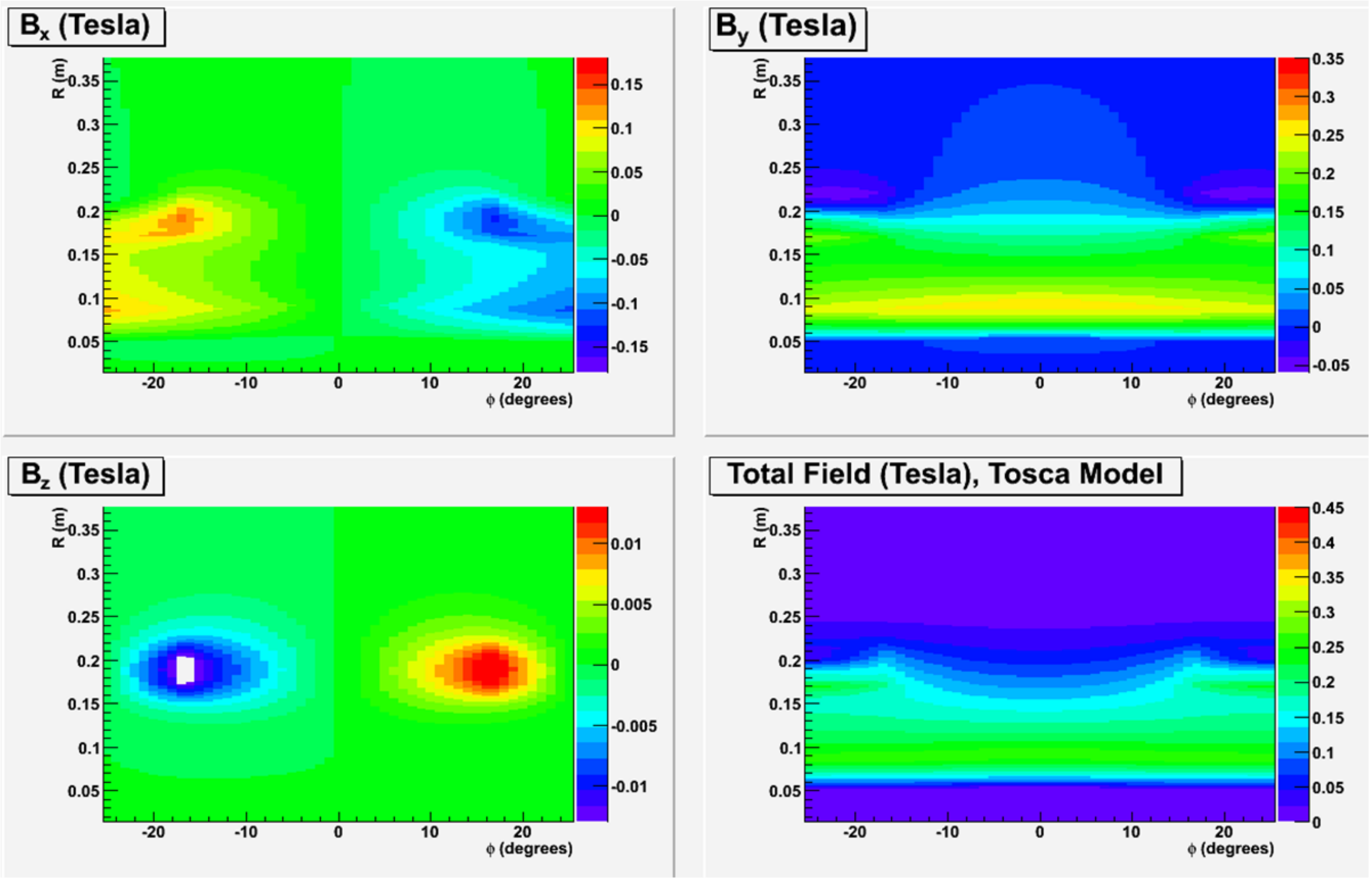
The difference of the total field in a sector in bins of R vs. z for the TOSCA version of the proposal and the original proposal model



Field Components



Field Components

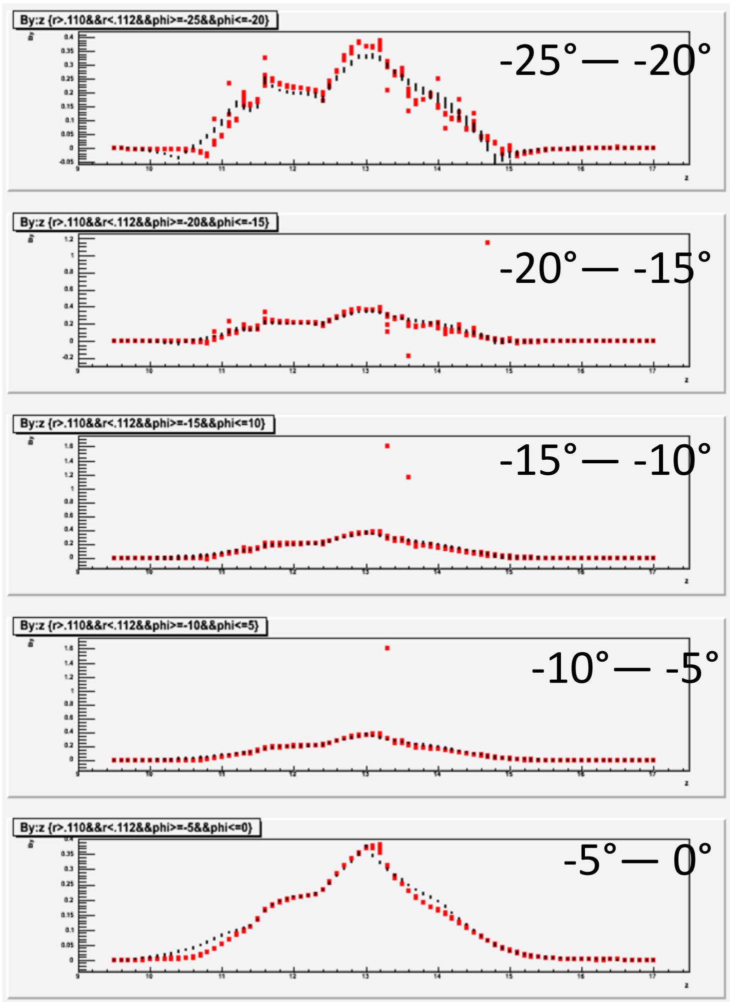


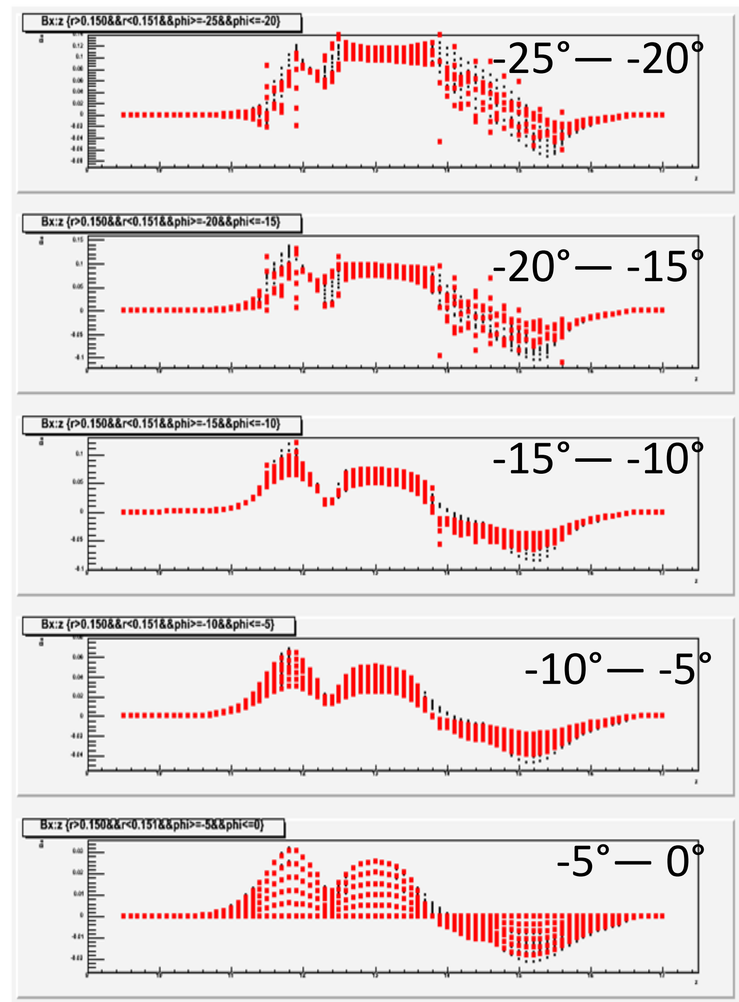
Comparison of field values

Red – proposal model

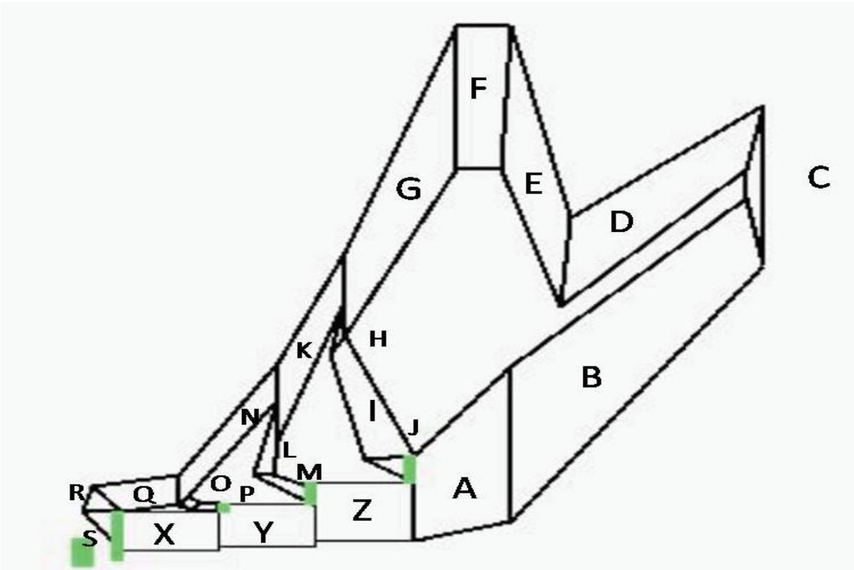
Black – TOSCA model

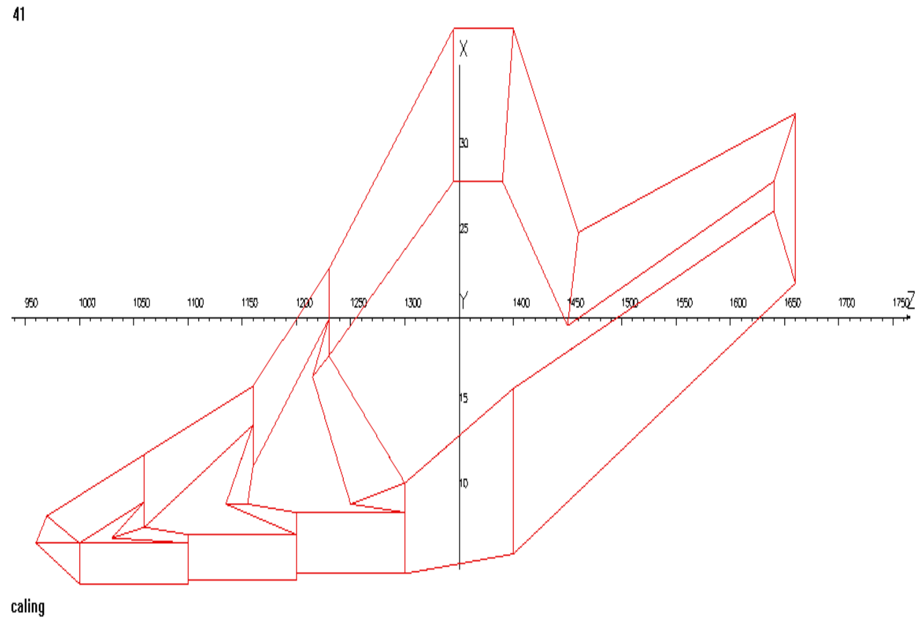
By (left) or Bx (right) vs. z in 5° bins in phi





Proposal Model

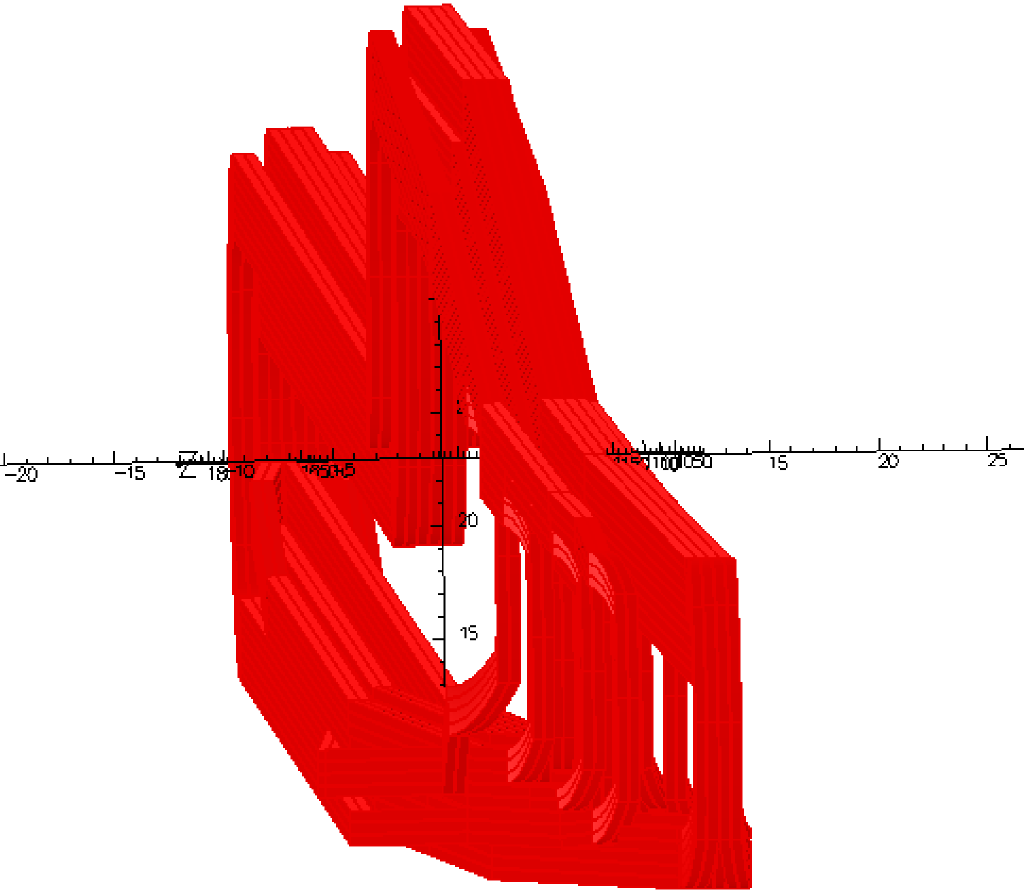


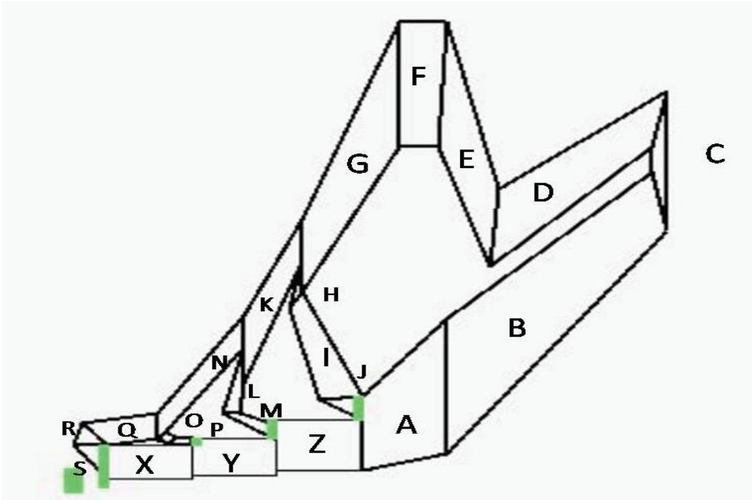


OD (cm)	A_{cond} (cm^2)	Total # Wires				Current (A)				Current per wire	J (A/cm^2)
		X	Y	Z	A	X	Y	Z	A		
Proposal		---	---	---	---	7748	10627	16859	29160	---	1100
0.4115	0.1248	40	54	86	146	7989	10785	17176	29160	200	1600
0.4620	0.1568	32	44	70	120	7776	10692	17010	29160	243	1550
0.5189	0.1978	26	36	56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

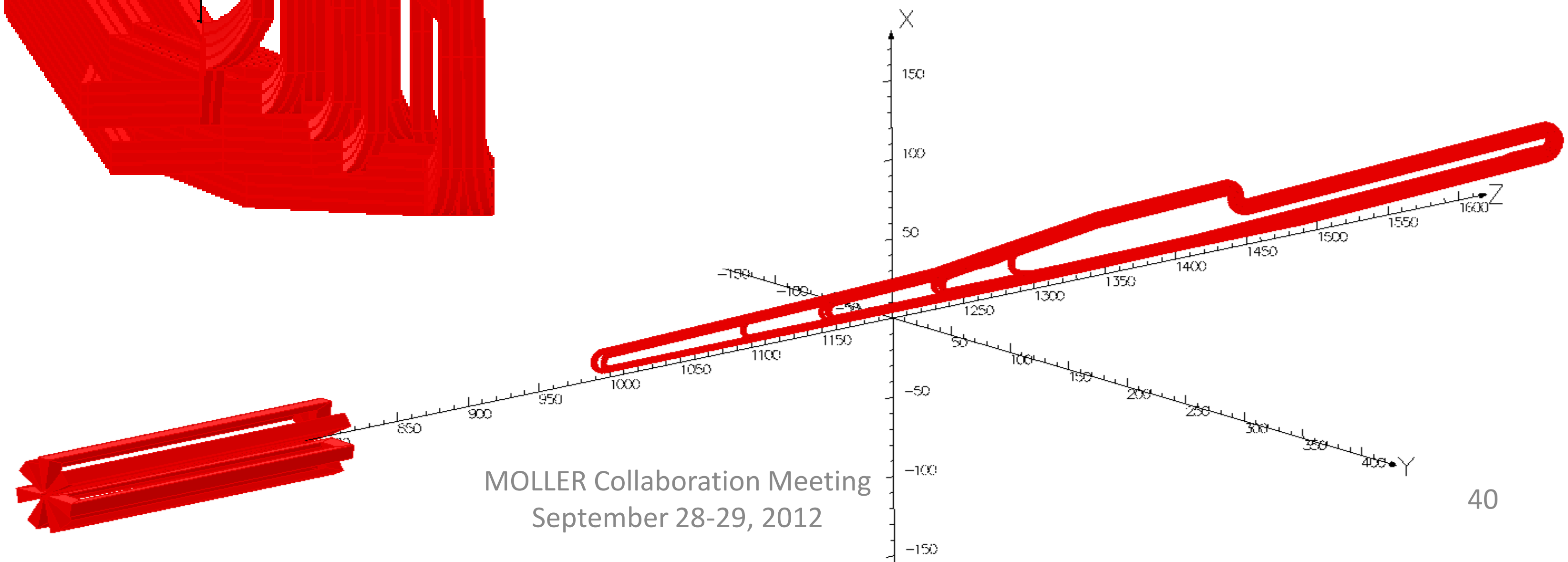
Actual Conductor Layout

Solid model side view





Actual conductor, 1 coil, no z scale



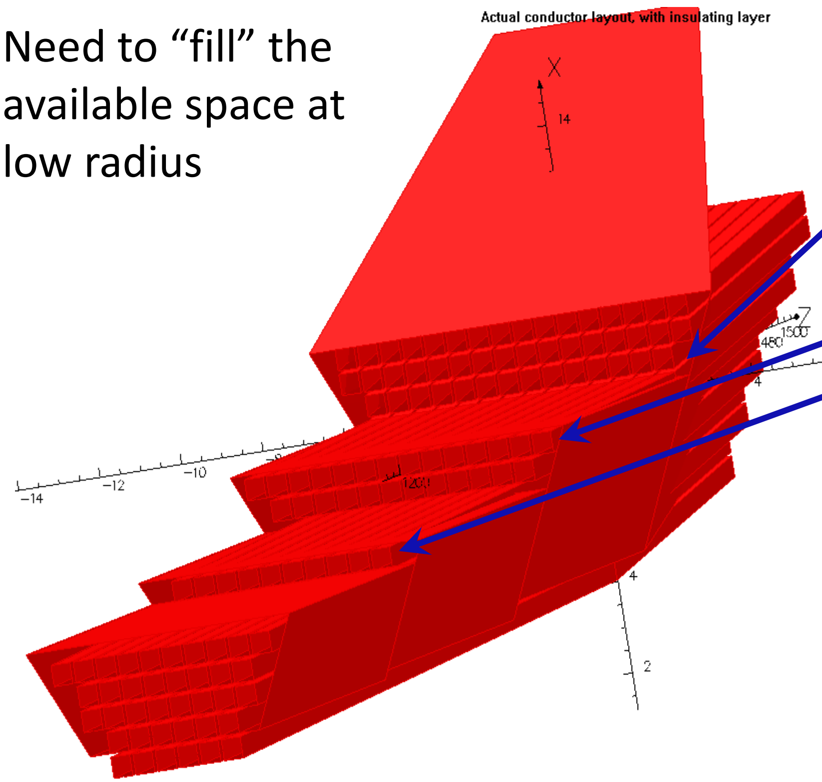
Choose constraints

- 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

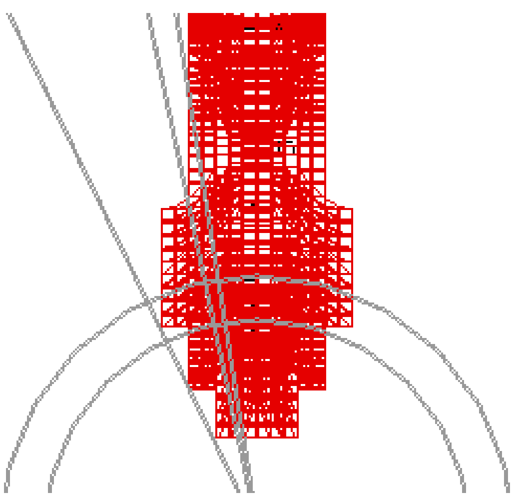
Need to "fill" the available space at low radius

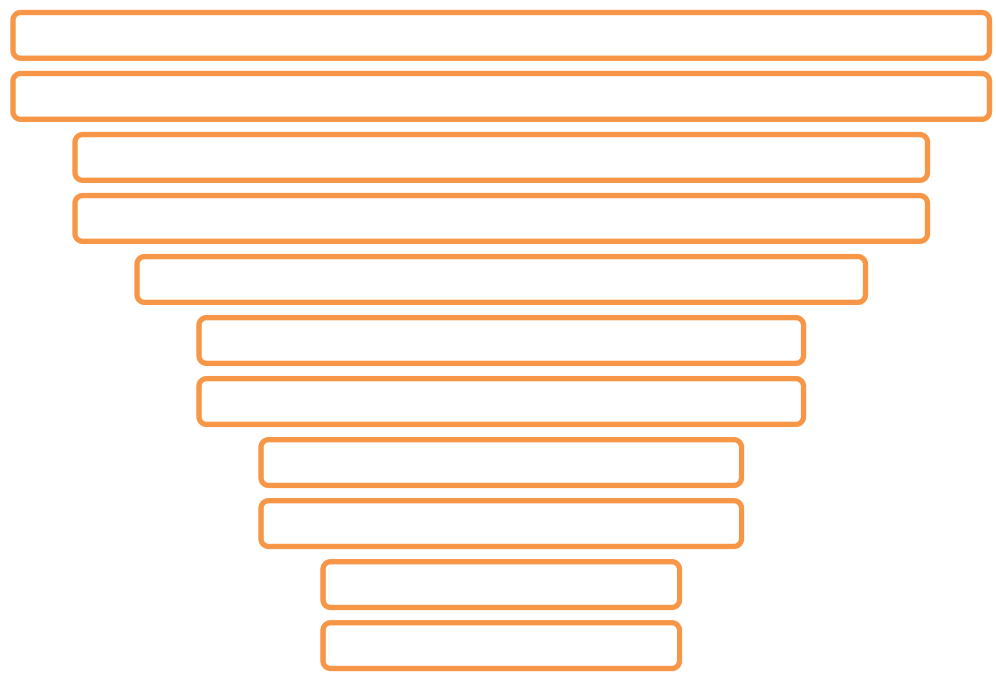


Trade-off between more insulation for smaller conductor and losing space at the "edges" with larger conductor

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

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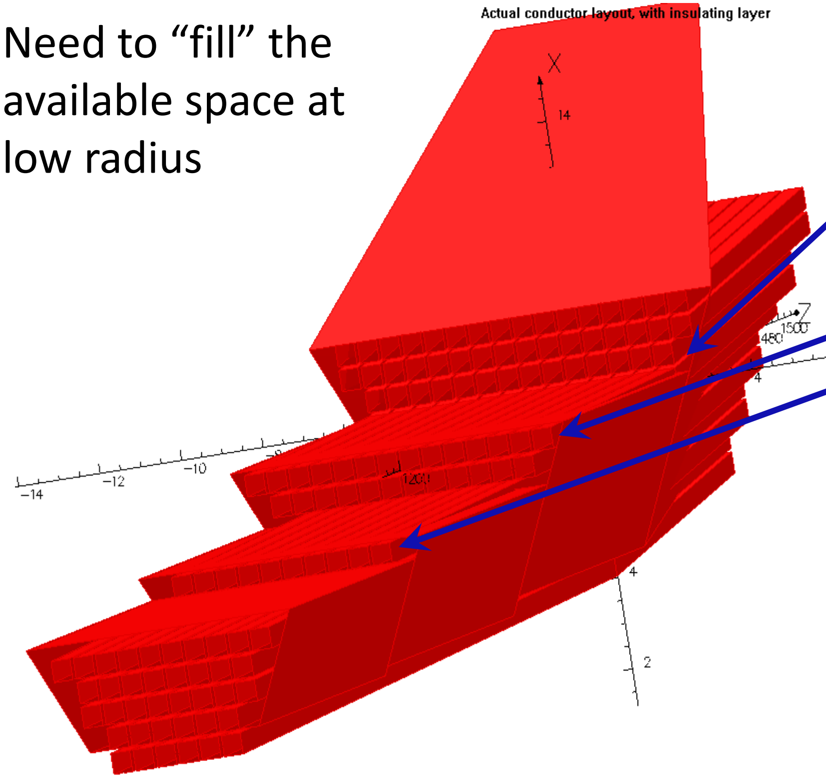

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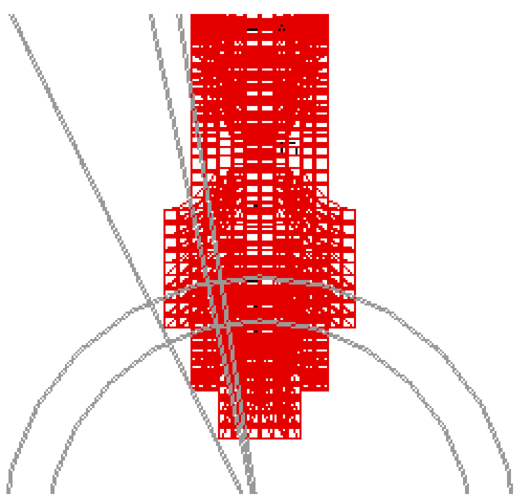

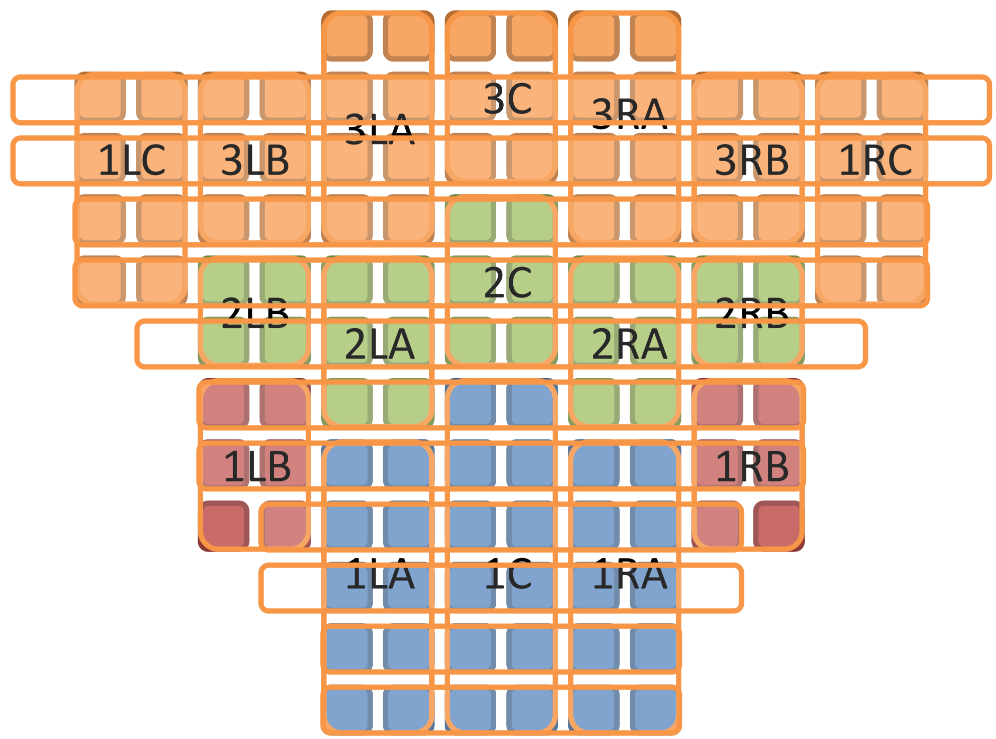

Conductor Size

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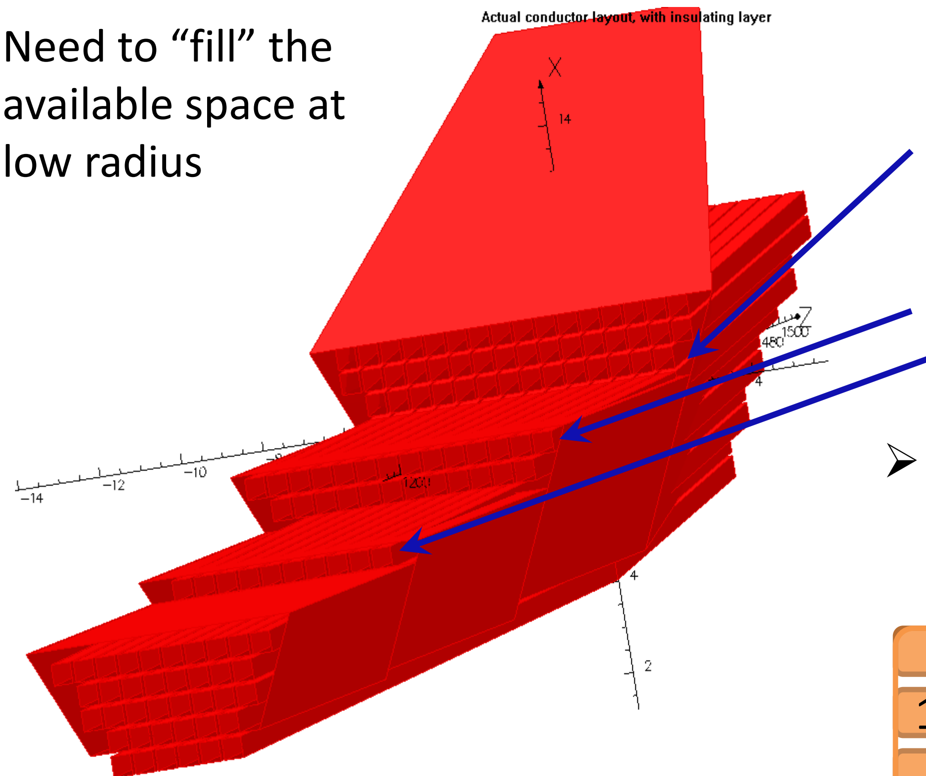

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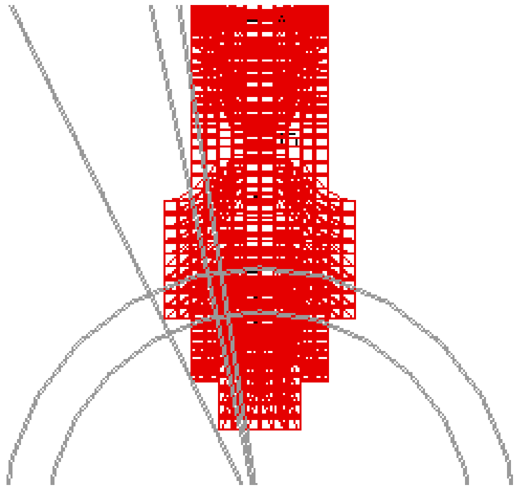
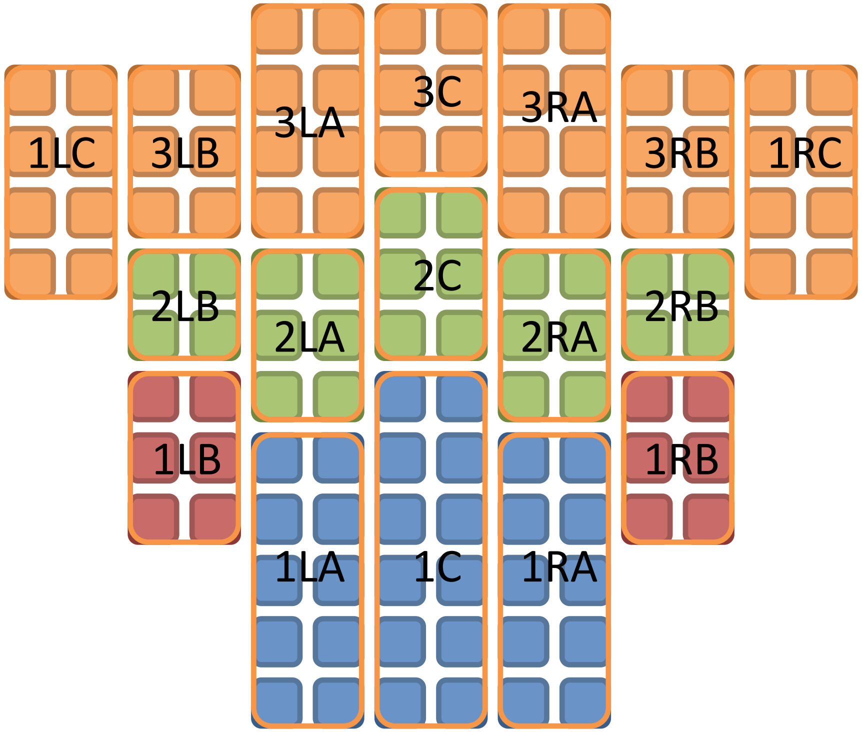
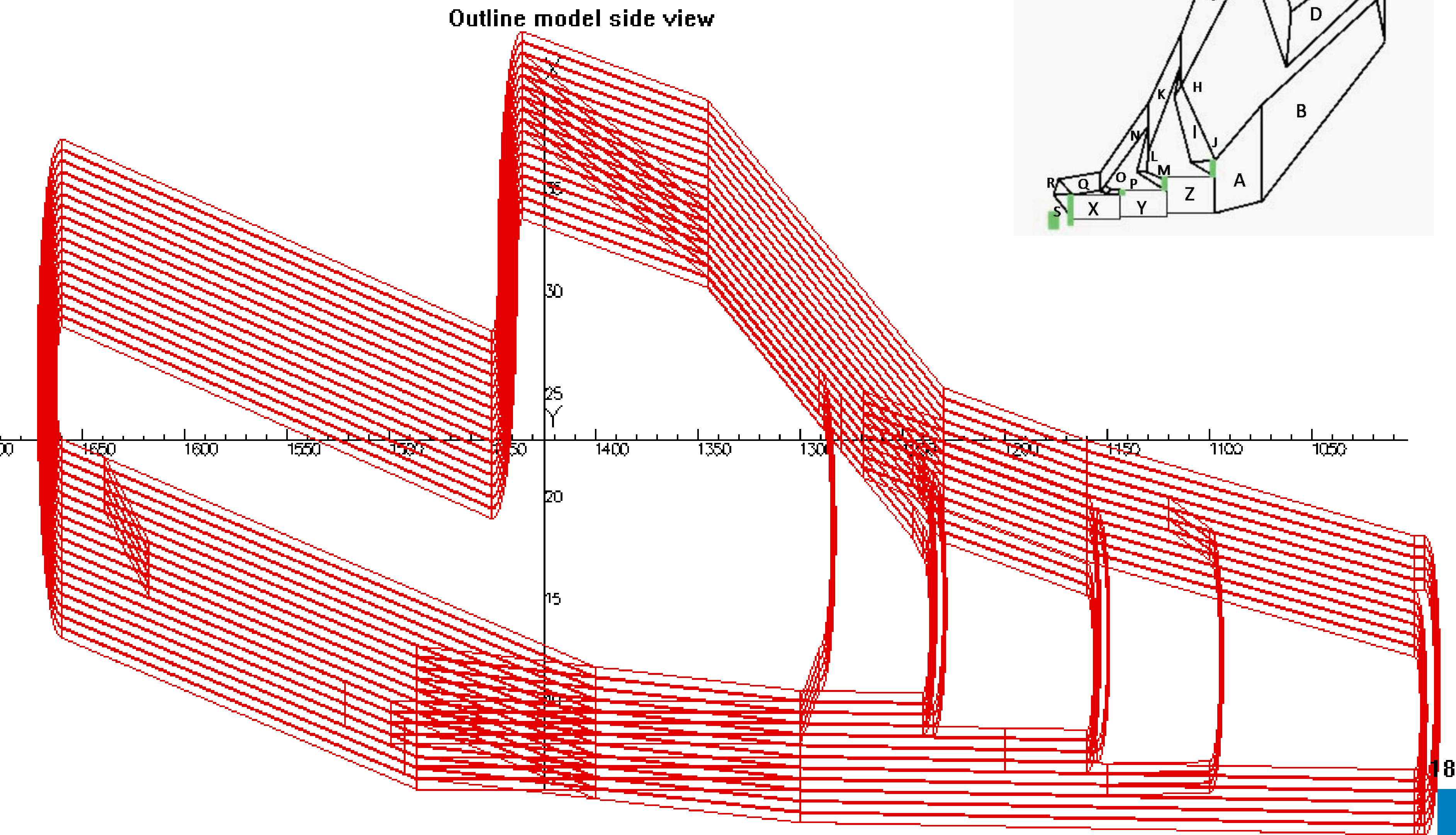
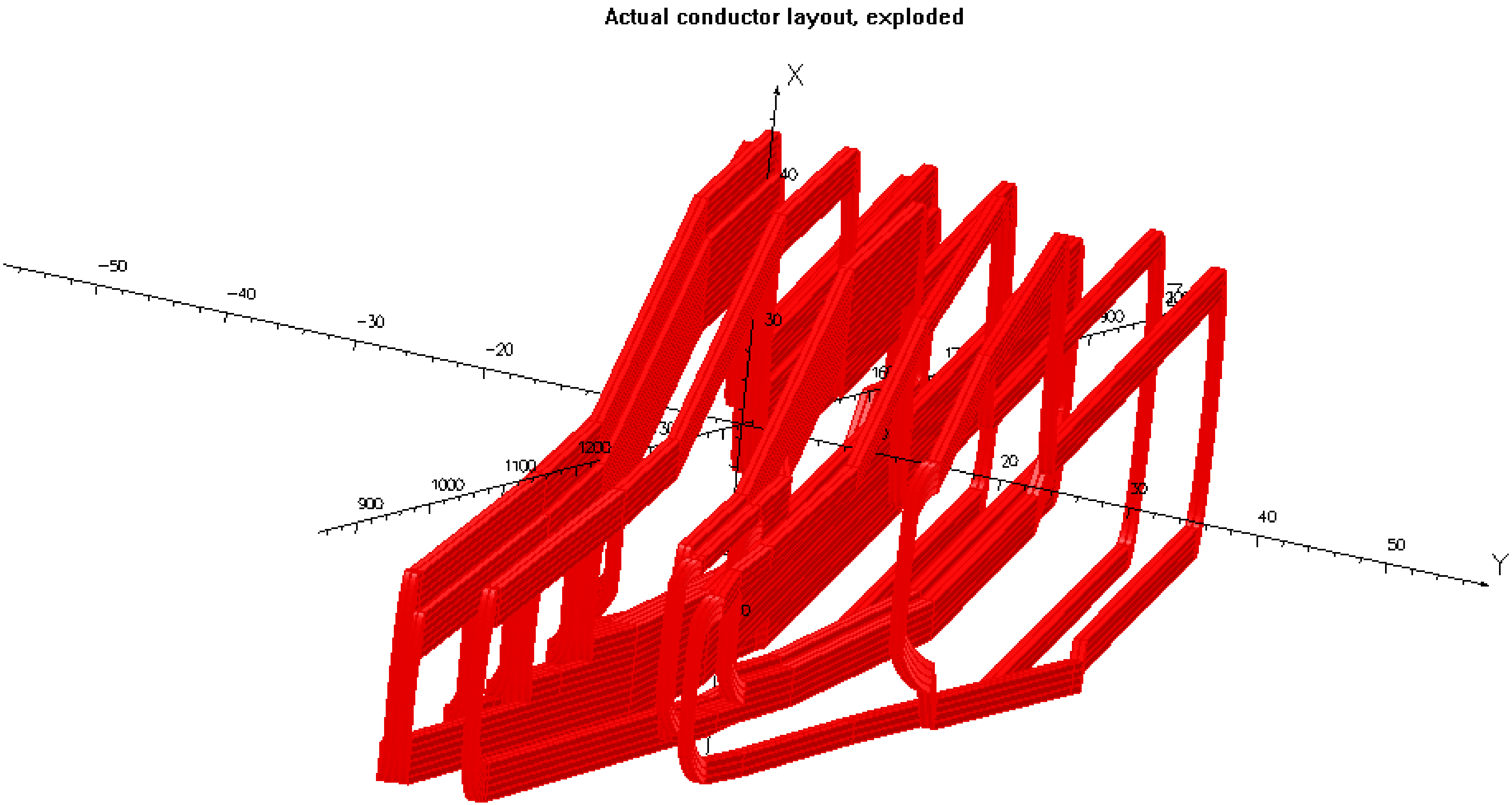




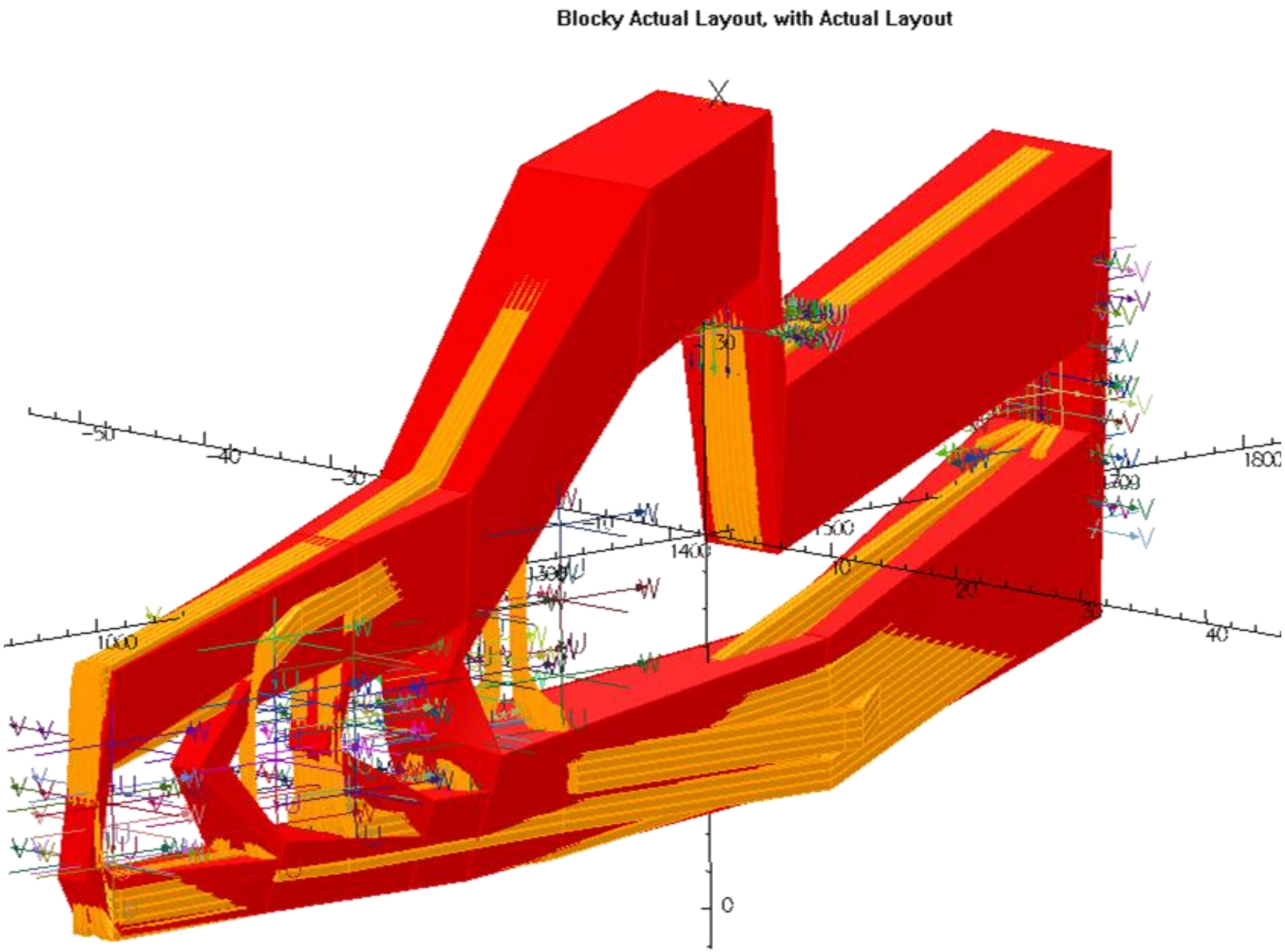
Actual conductor layout



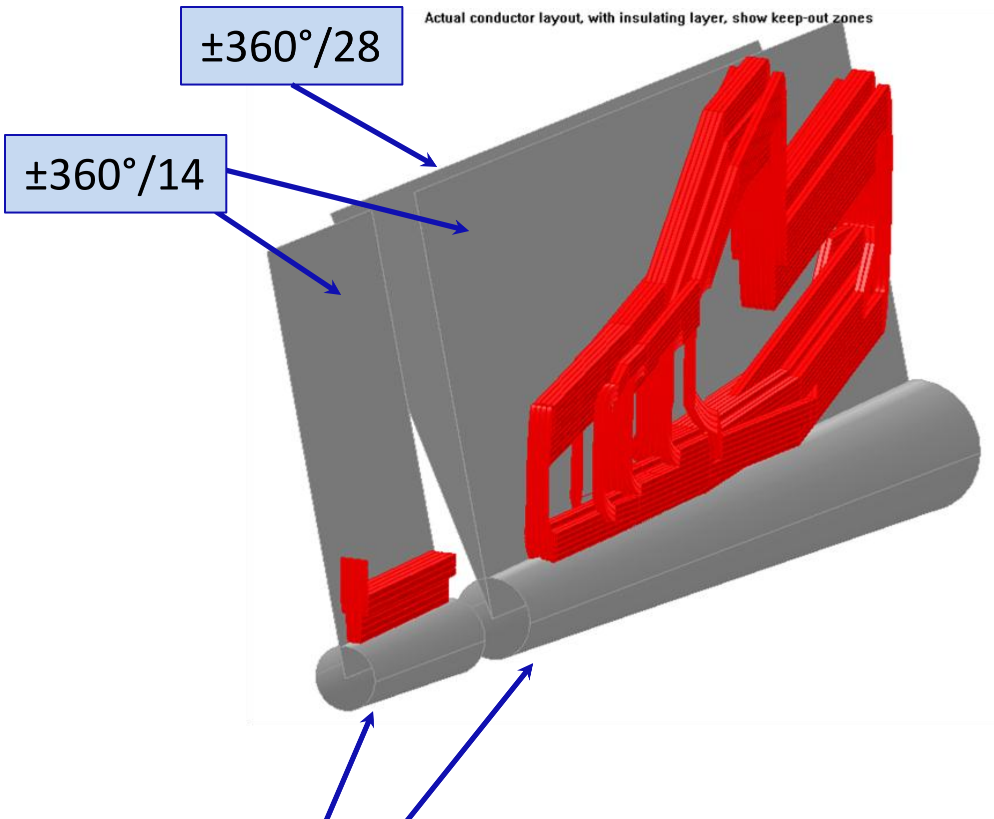
Actual conductor layout



Blocky Model superimposed



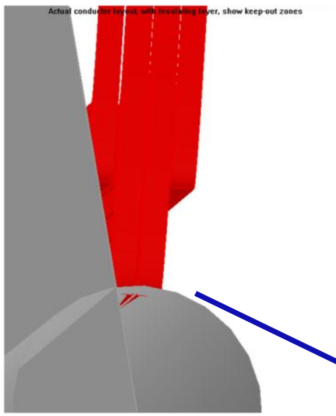
Keep Out Zones

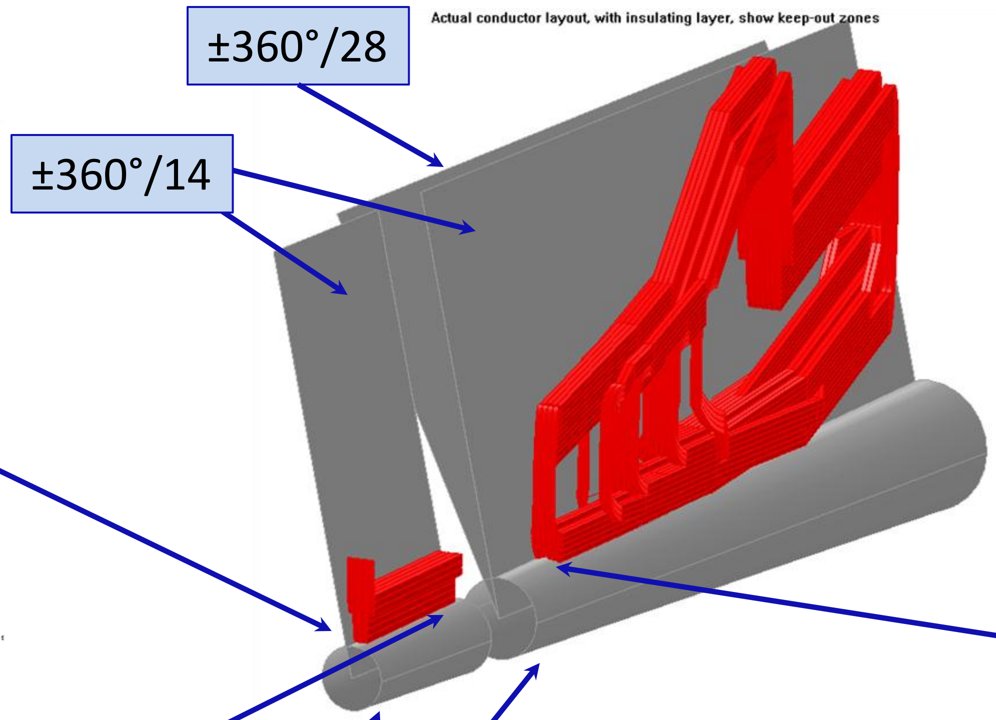


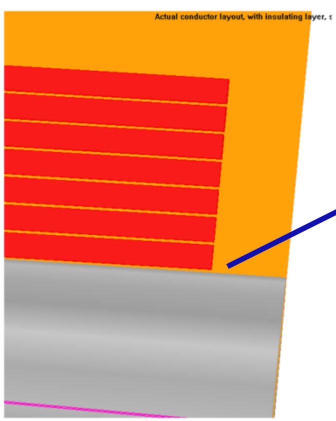
cones are defined using:

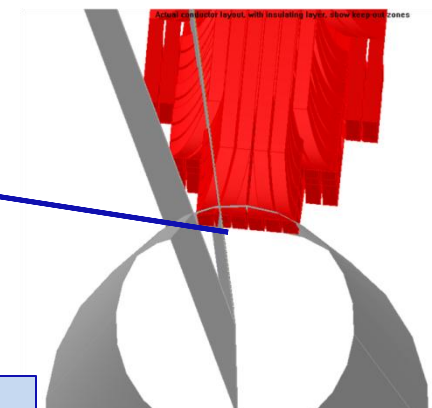
- nothing w/in 5σ of the multiple scattering radius
- + 1/4" each for Al support and W shielding

Keep Out Zones









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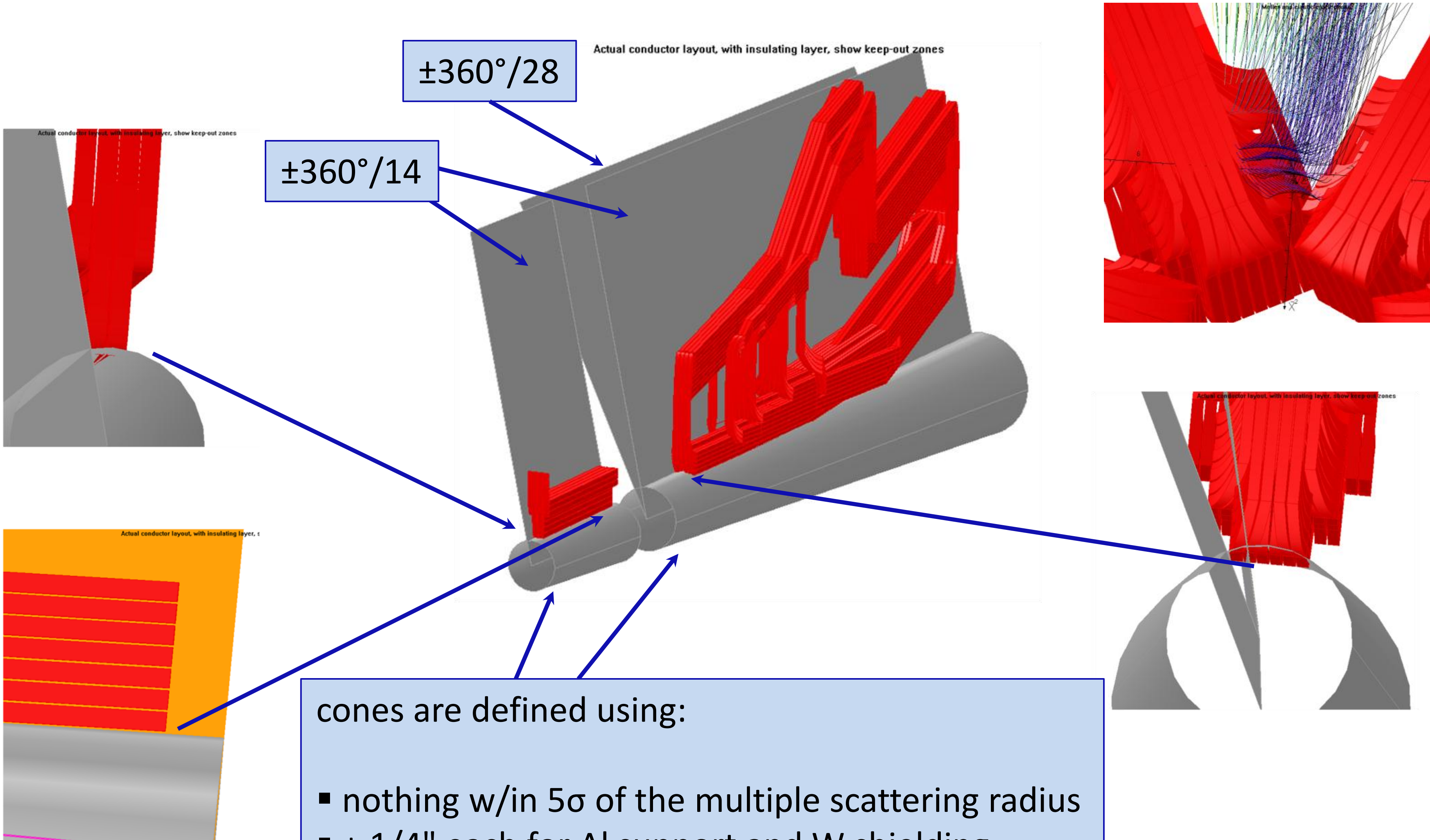
Keep Out Zones



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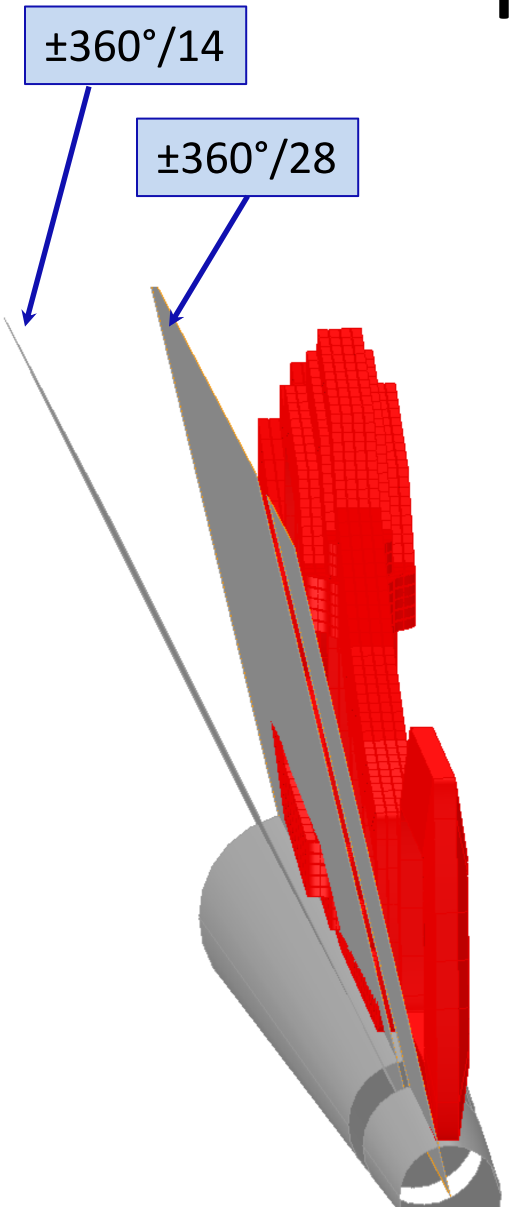
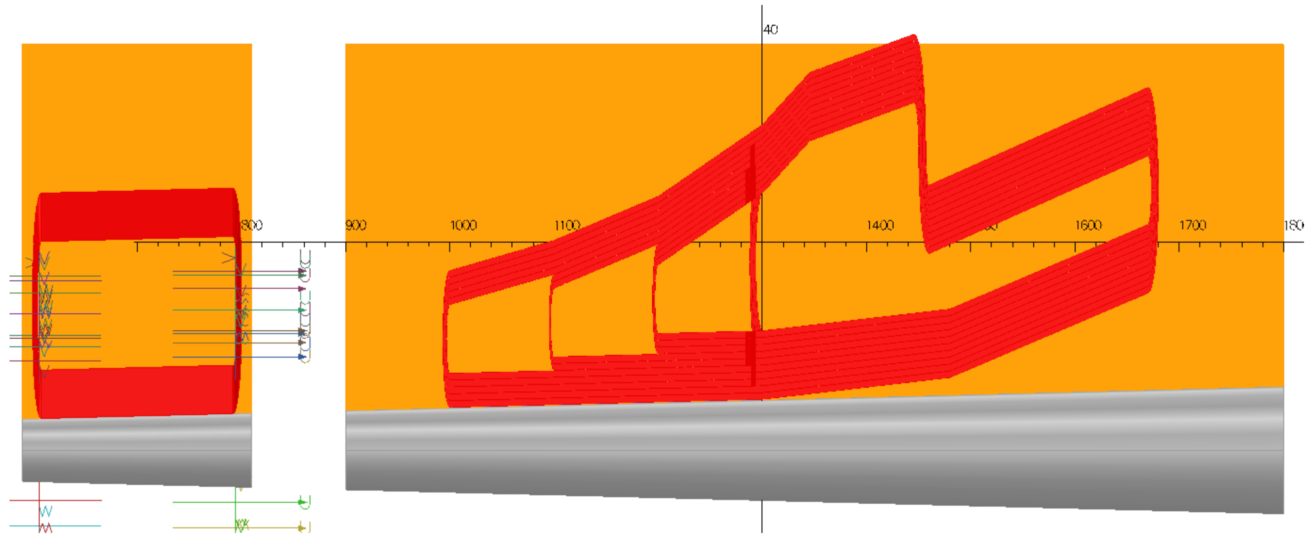
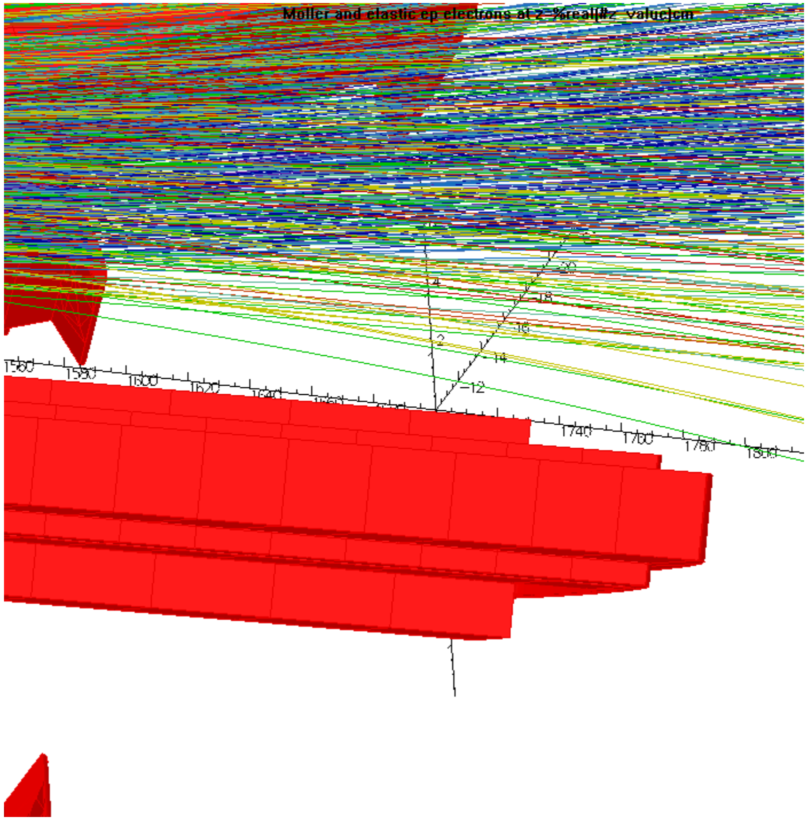
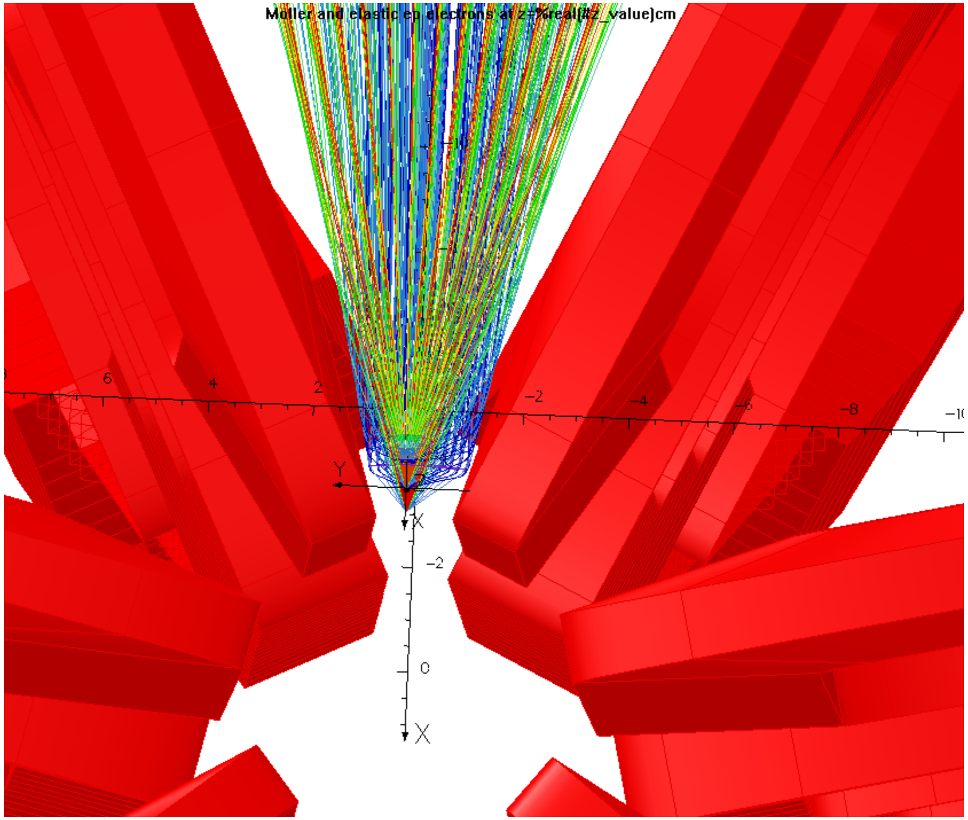
Keep Out Zones/Concept 2



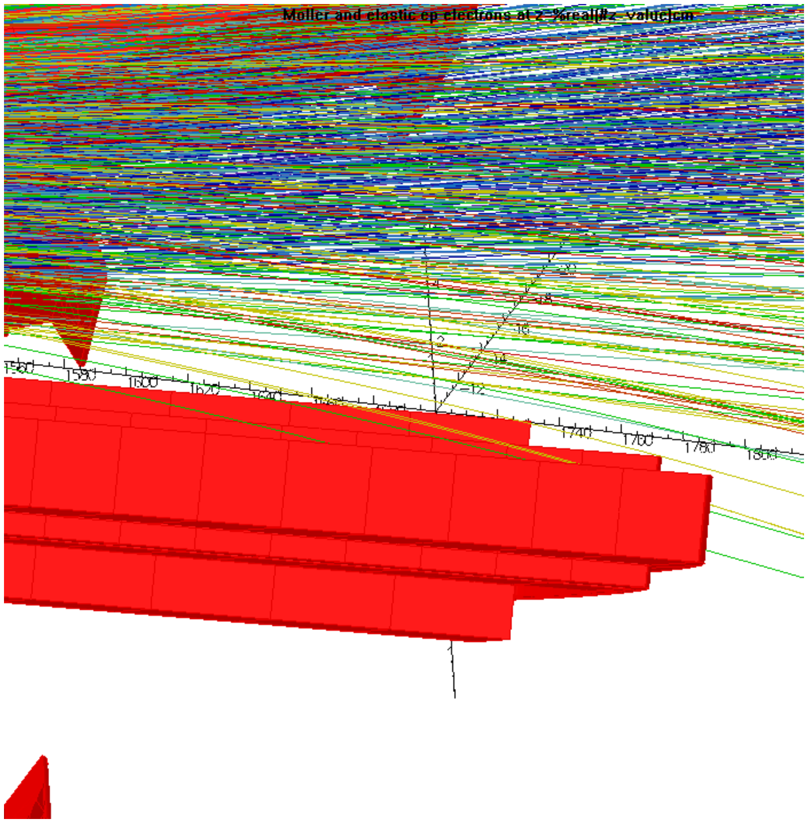


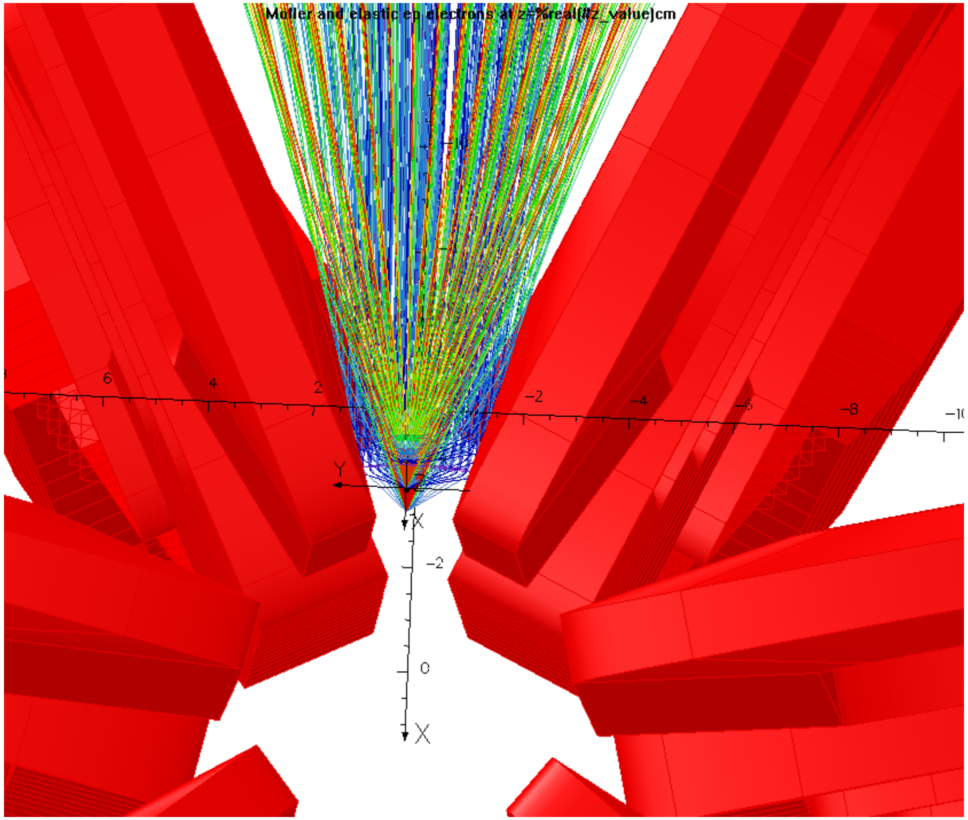
Interferences



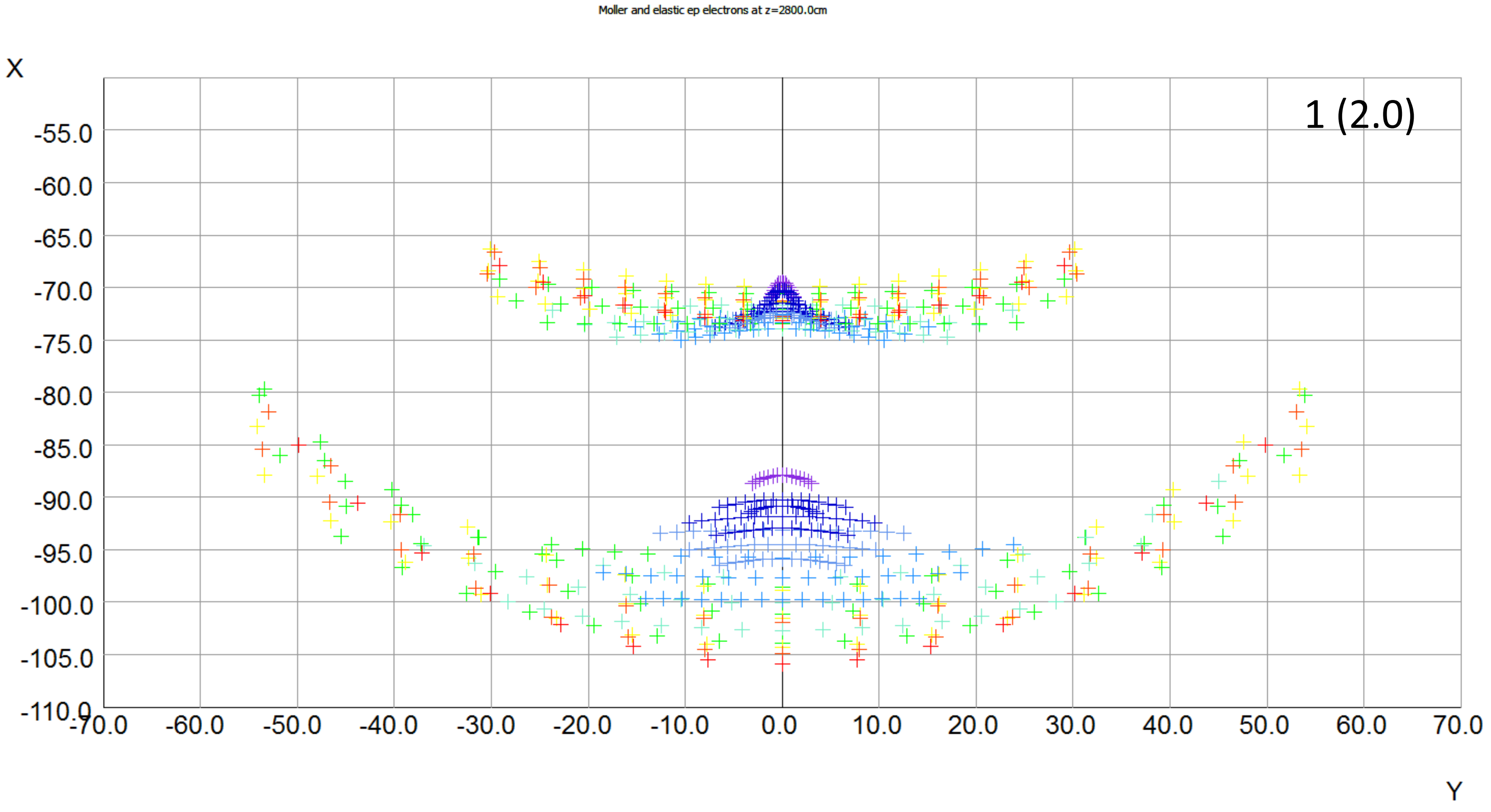


Interferences





Tweaking the Optics



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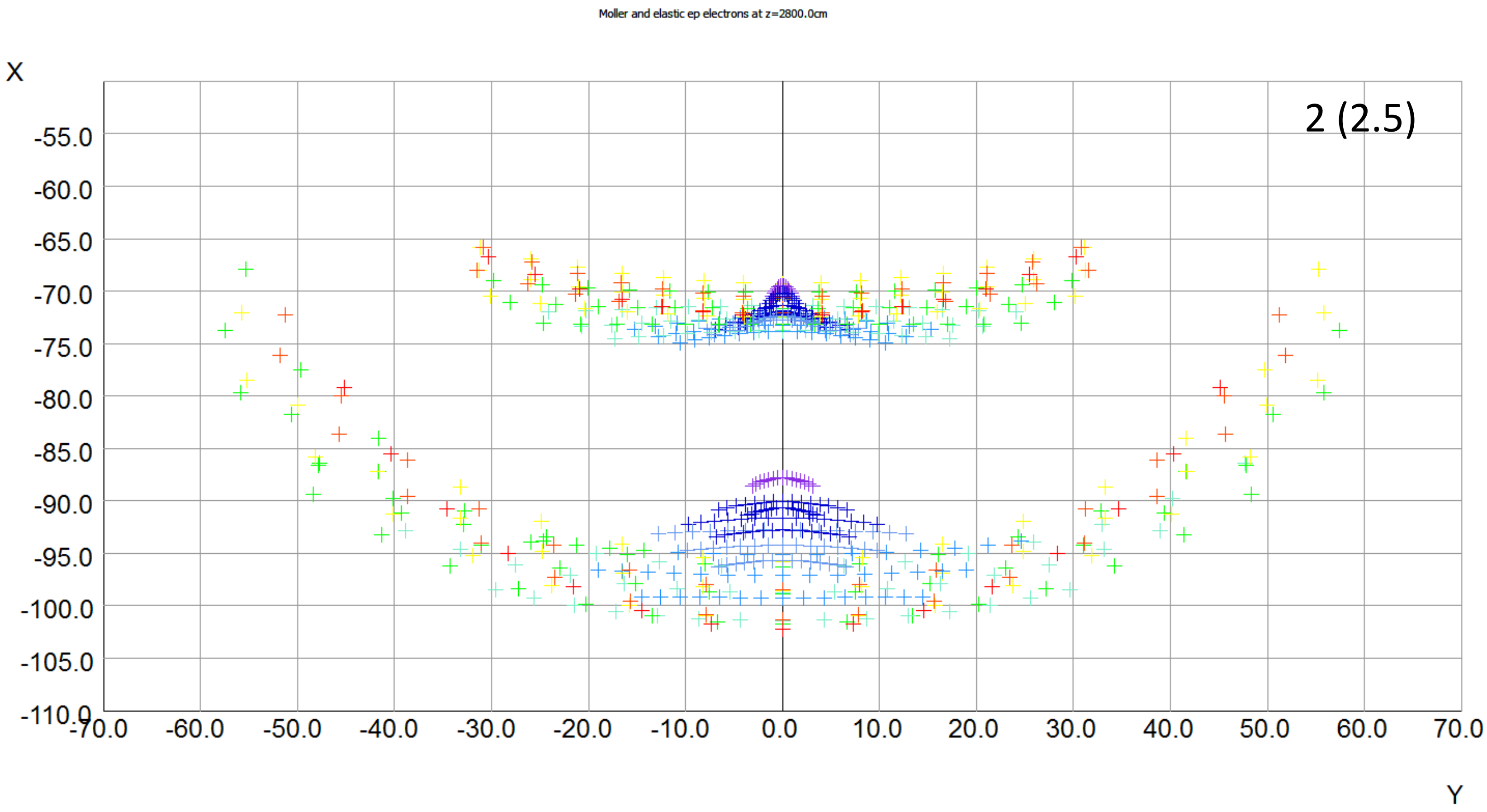

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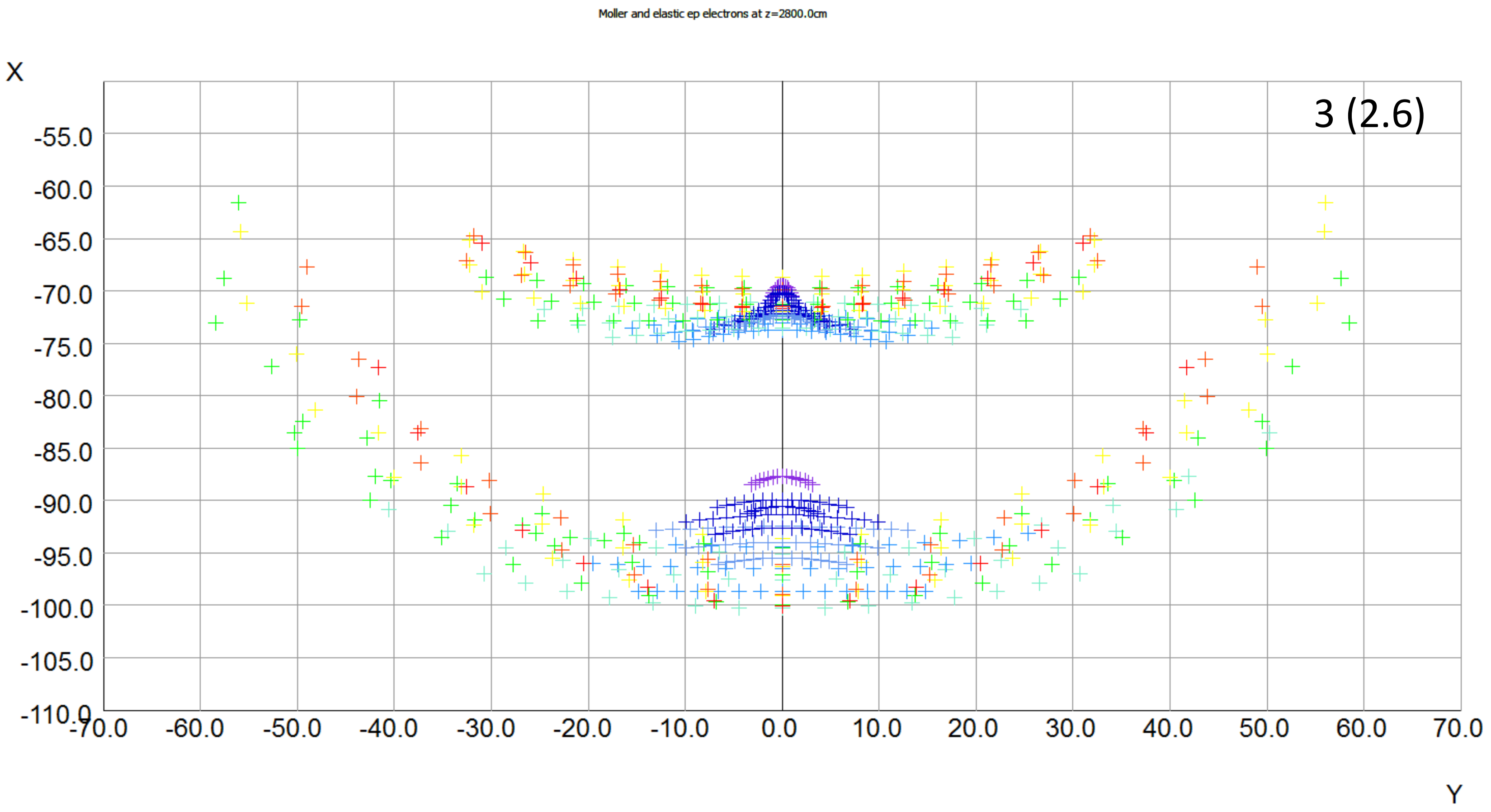

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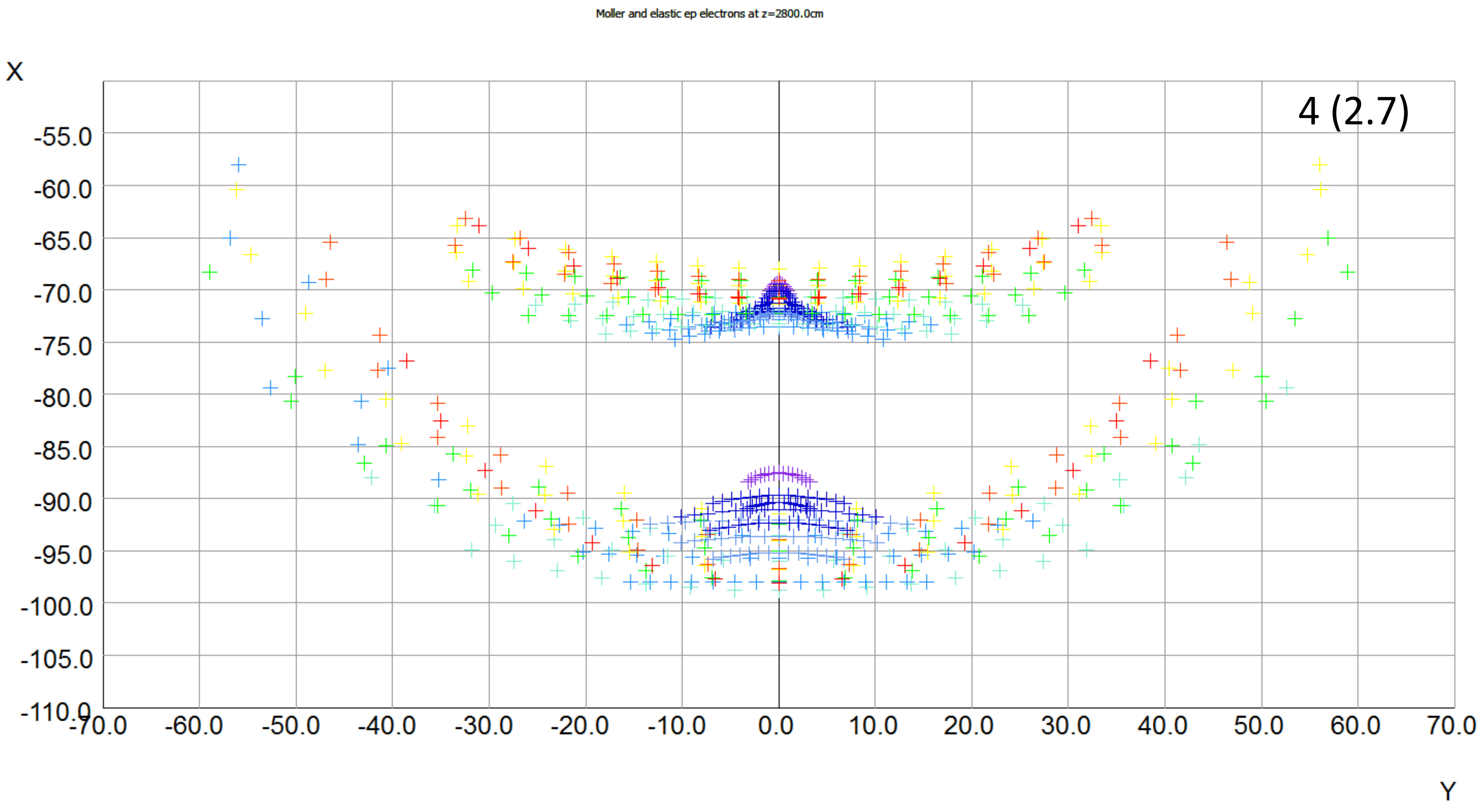

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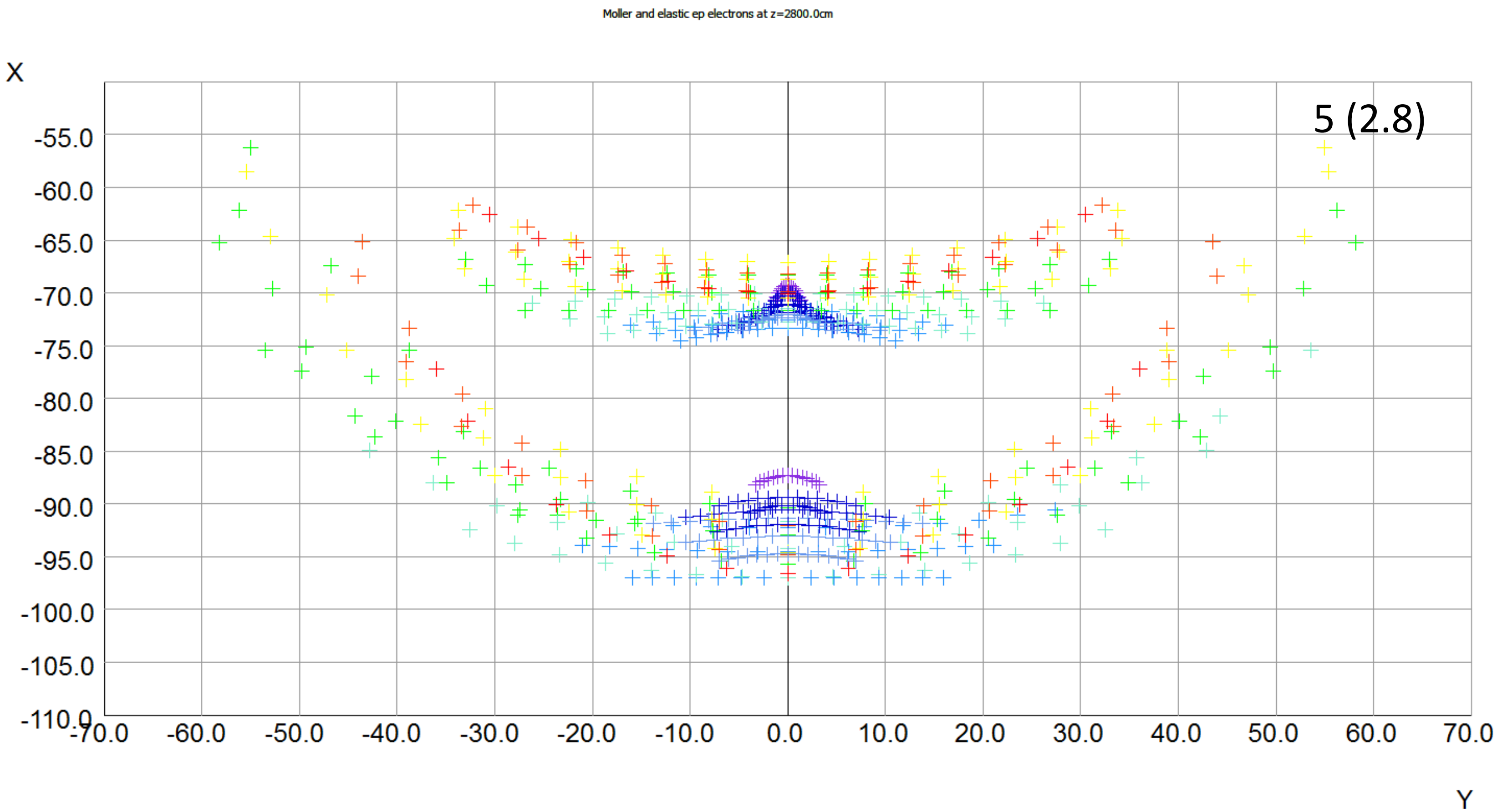

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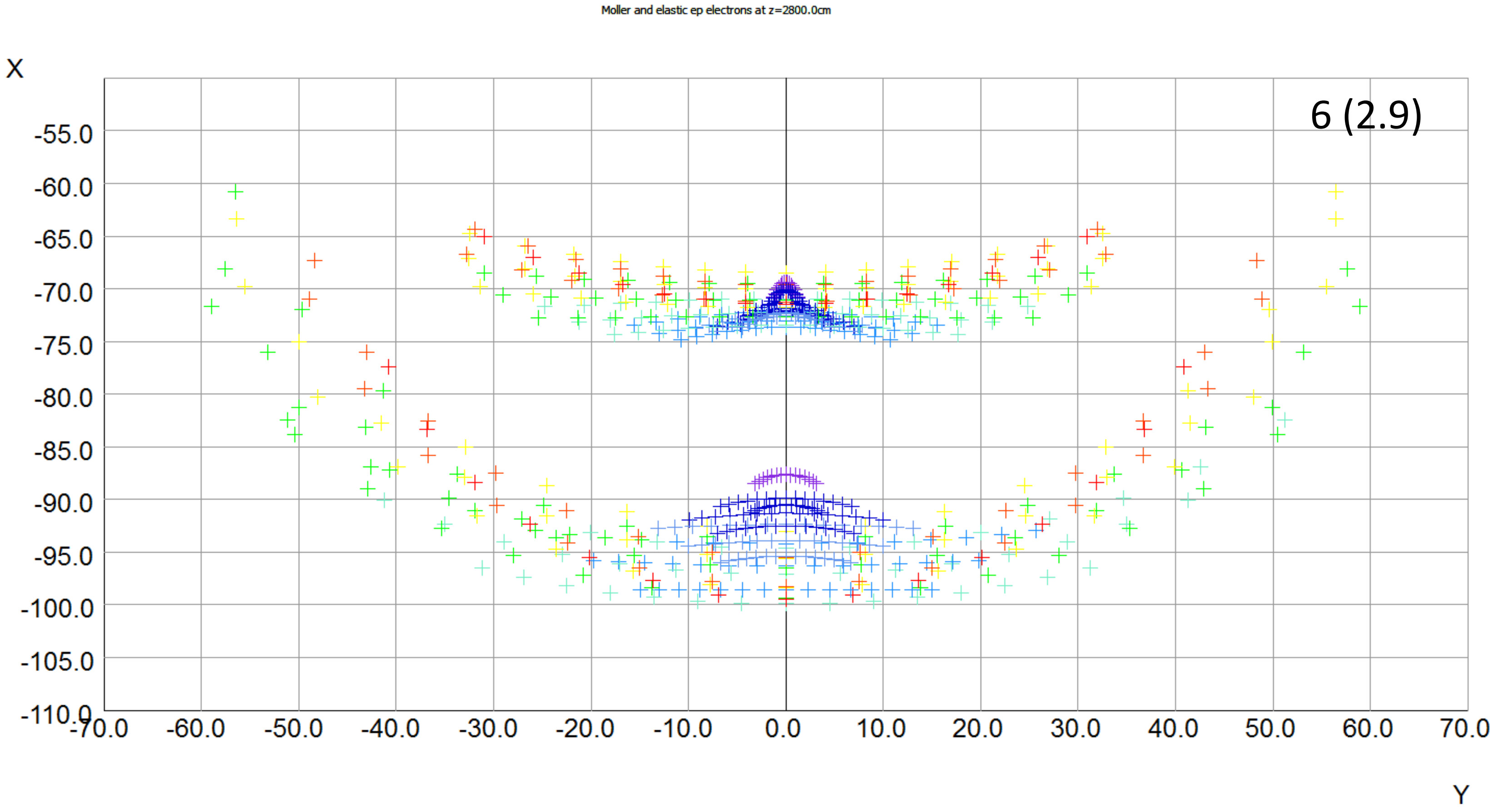

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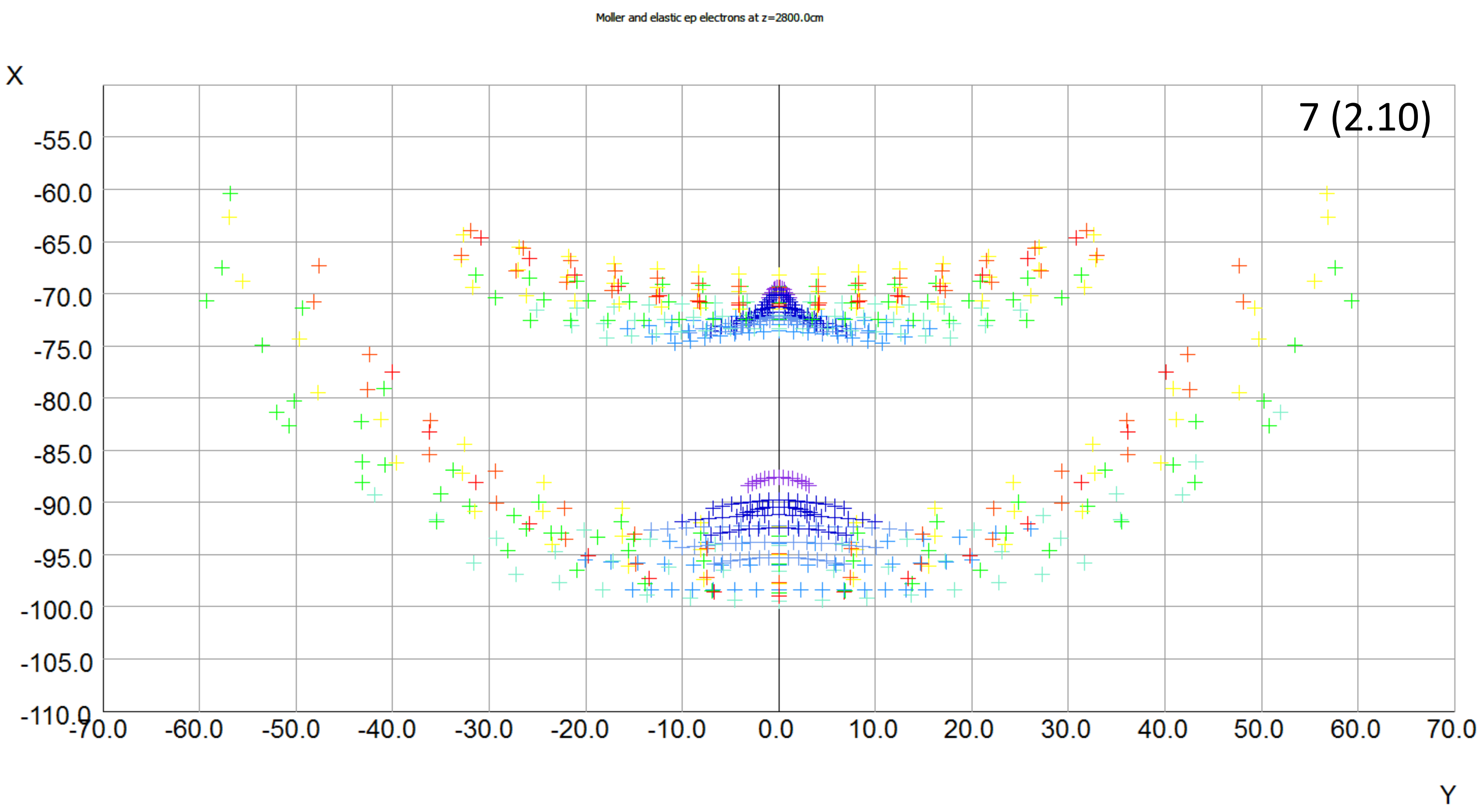

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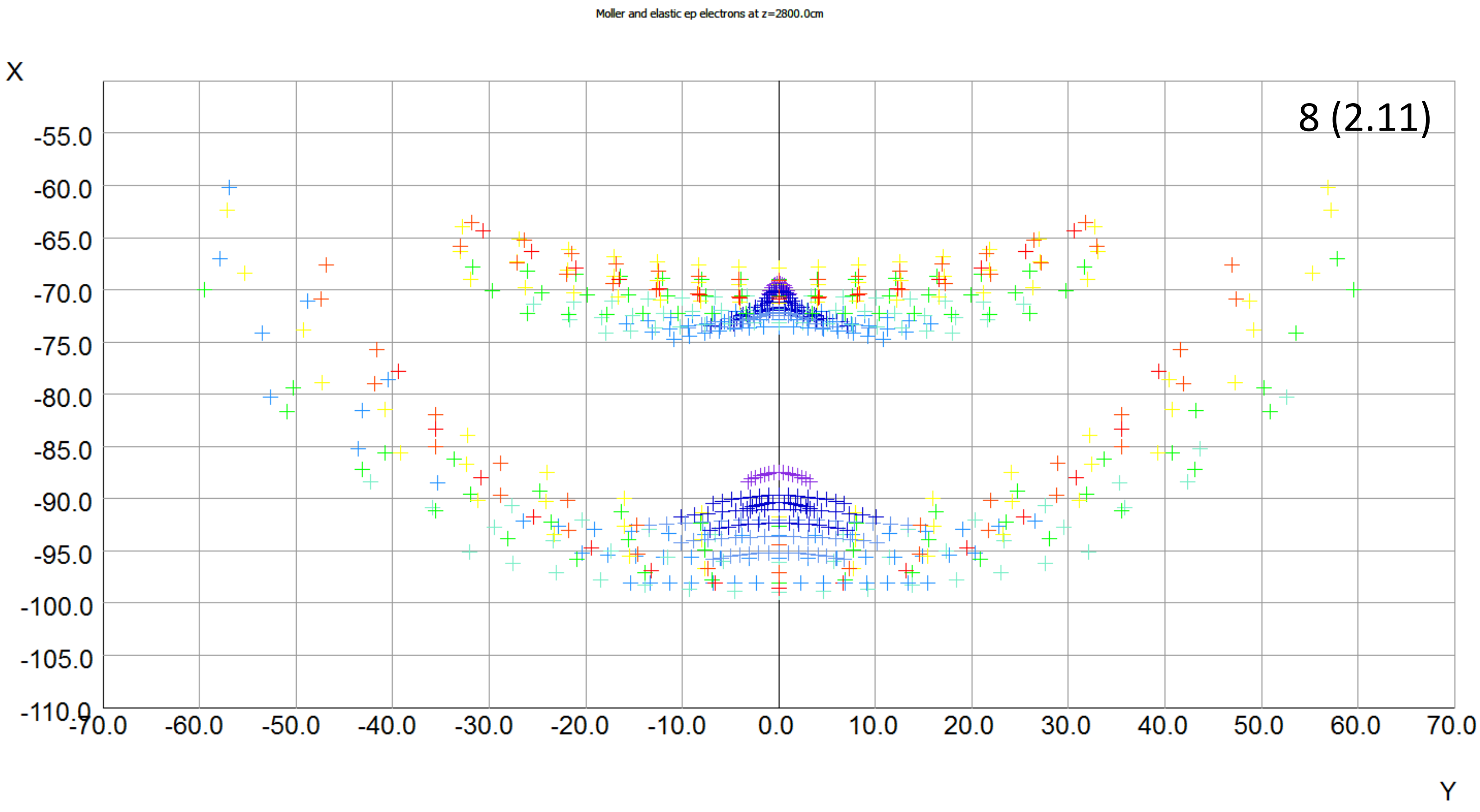

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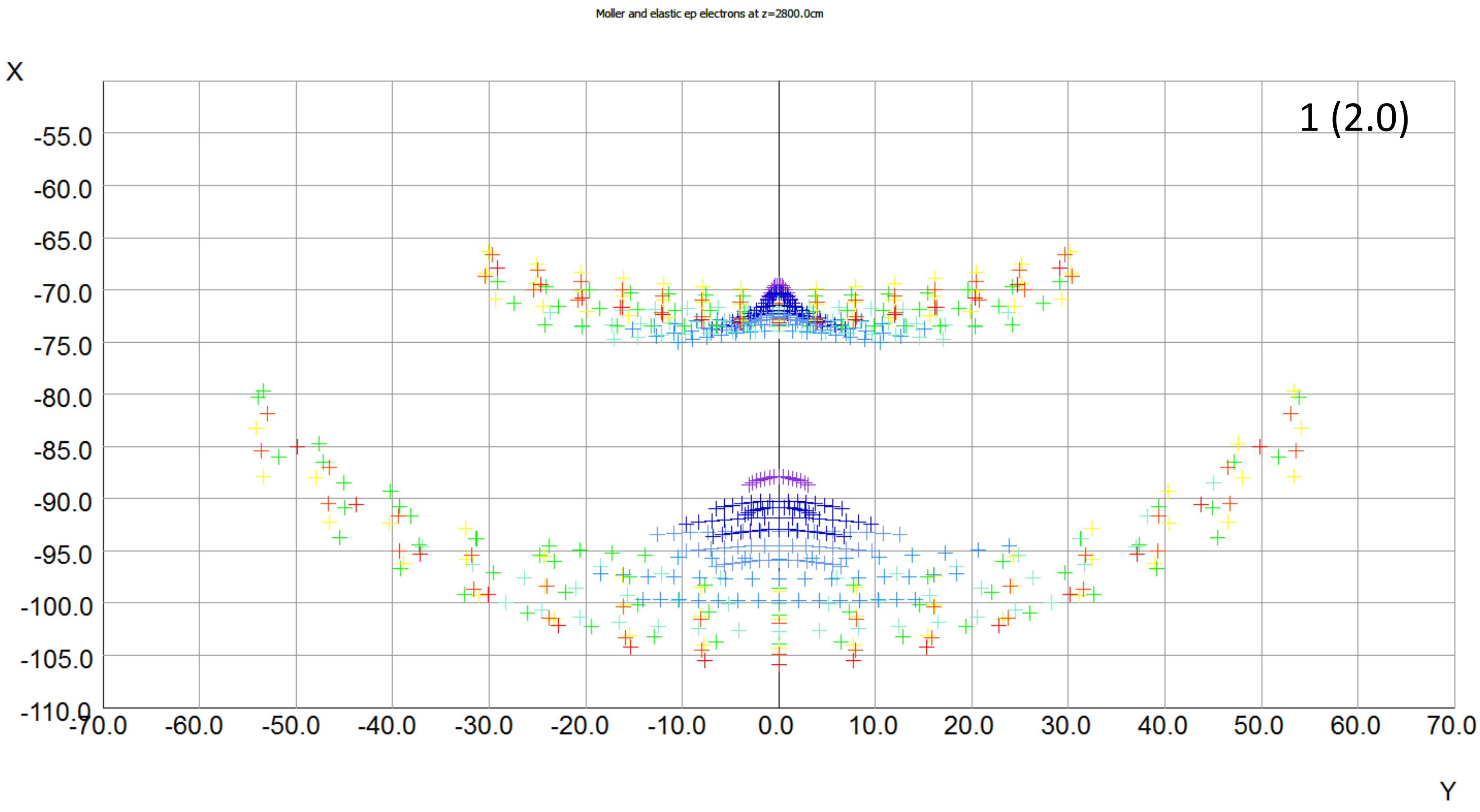
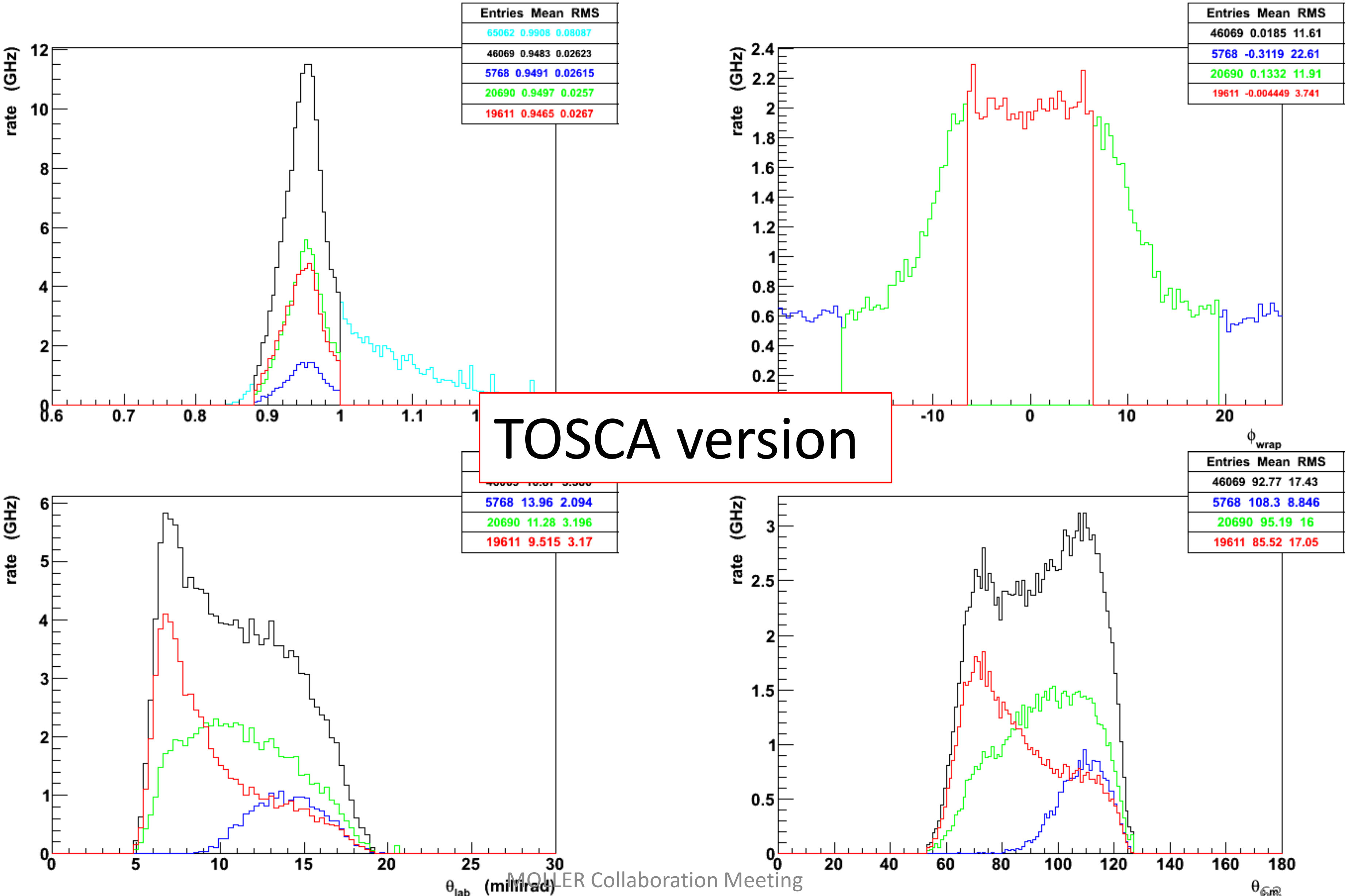
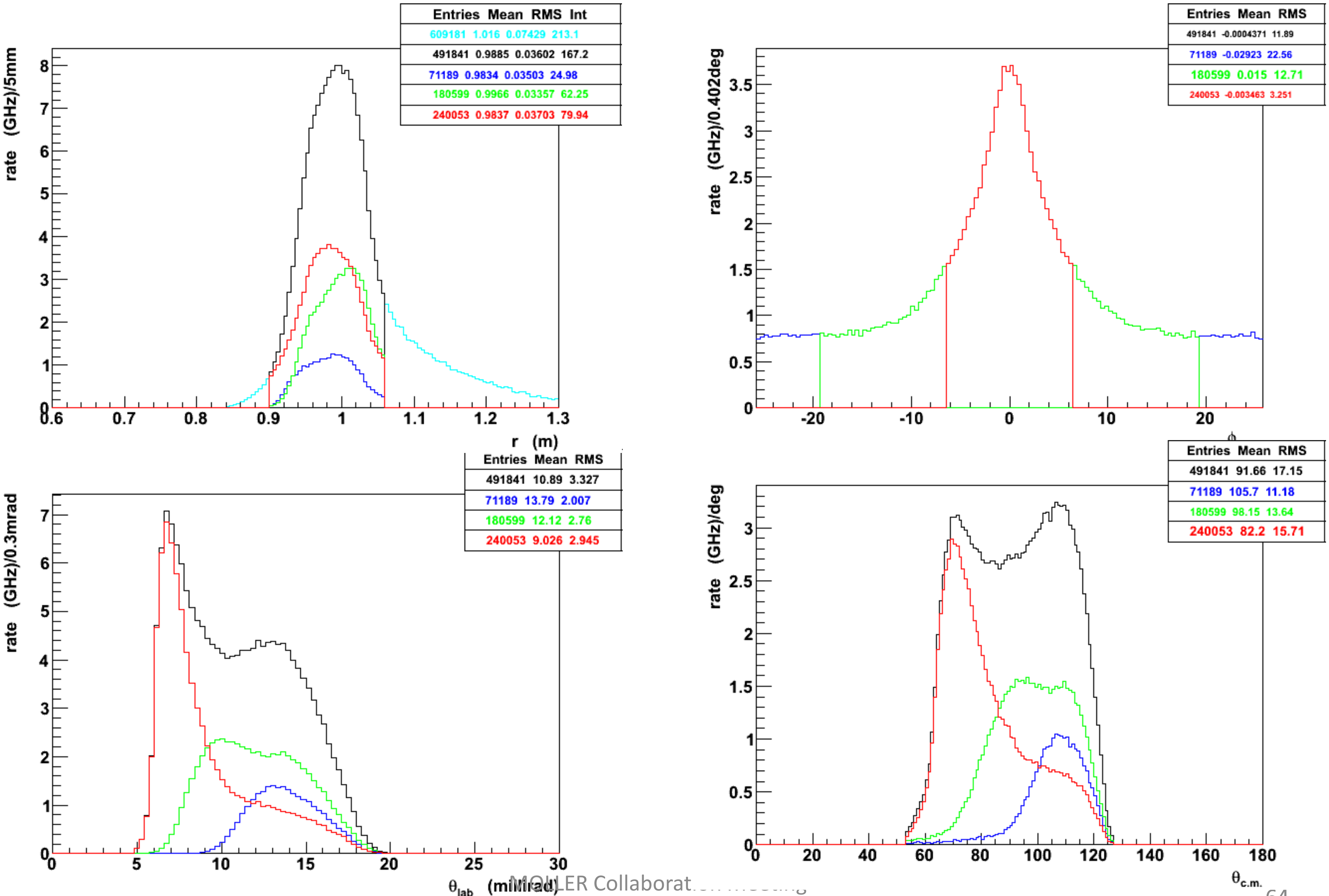


Comparison of GEANT4 Simulations



TOSCA version

2.11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609181 1.016 0.07429 213.1
491841 0.9885 0.03602 167.2
71189 0.9834 0.03503 24.98
180599 0.9966 0.03357 62.25
240053 0.9837 0.03703 79.94
rate (GHz)/5mm
r (m)
Entries Mean RMS
491841 -0.0004371 11.89
71189 -0.02923 22.56
180599 0.015 12.71
240053 -0.003463 3.251
rate (GHz)/0.402deg
ϕ
Entries Mean RMS
491841 10.89 3.327
71189 13.79 2.007
180599 12.12 2.76
240053 9.026 2.945
rate (GHz)/0.3mrad
θlab (millirad)
Entries Mean RMS
491841 91.66 17.15
71189 105.7 11.18
180599 98.15 13.64
240053 82.2 15.71
rate (GHz)/deg
θc.m.

3.0