April 2021 MOLLER Forum
Spectrometer Update

Juliette Mammei

Team Acknowledgements

- **JLAB Magnet Group**
    - Ruben Fair *(CAM)*
    - Dave Kashy *(Principal Mechanical Engineer – Spectrometer Lead)*
    - Probir Ghoshal *(Senior Electrical Engineer)*
    - Eric Sun *(Senior Mechanical Engineer)*
    - Sandesh Gopinath *(Mechanical Engineer)*
    - Randy Wilson *(Mechanical Designer)*
    - Dan Young *(Mechanical Designer)*
- **Physics Collaboration**
    - Juliette Mammei (Experimental Contact)
    - Krishna Kumar
    - Chandan Ghosh
    - Sakib Rahman
    - Nazanin Roshanshah
    - Ciprian Gal
    - Kent Paschke
    - and others…
- **MIT Bates REC**
    - James Kelsey
    - Ernie Ihloff
    - Jason Bessuille

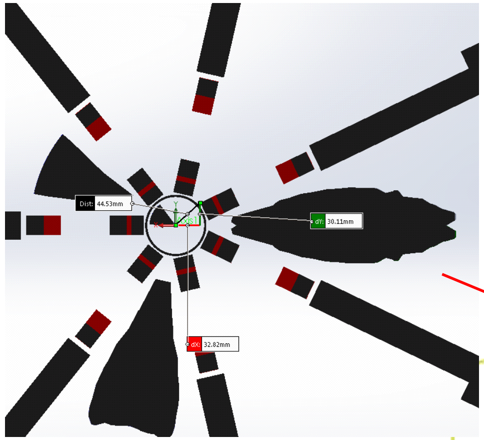
Topics

- Choice of drift medium
- Segmented vs. “hybrid”
- Results from Preliminary Design Review
- Verification of tolerances with “worst-case” offsets
- Engineering driven optimizations
- Coil conductor configurations are now fixed

Exercising our “Change Control” muscles!

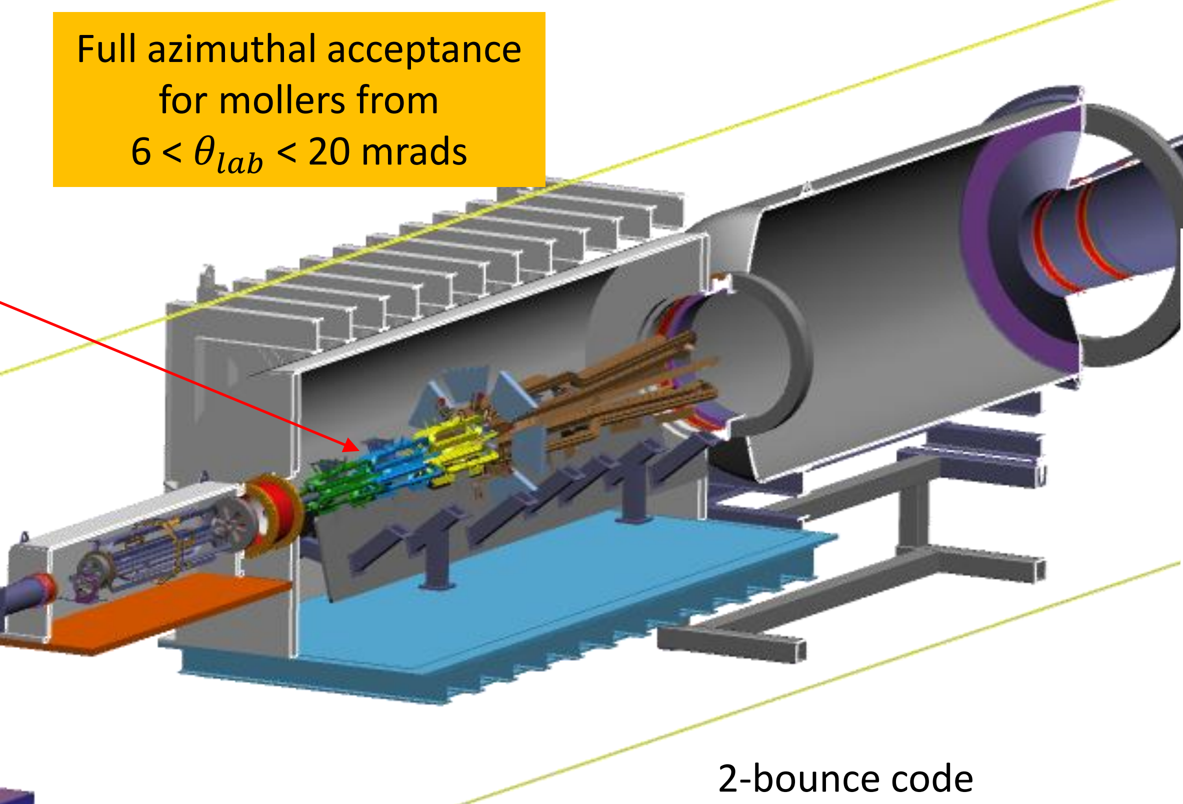
Spectrometer system tools

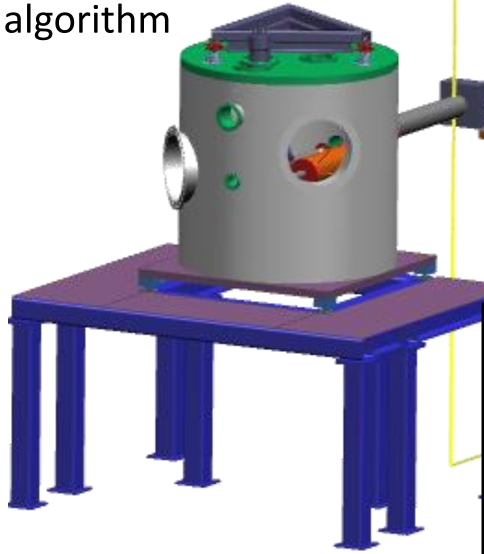
In addition to TOSCA, CAD and GEANT4



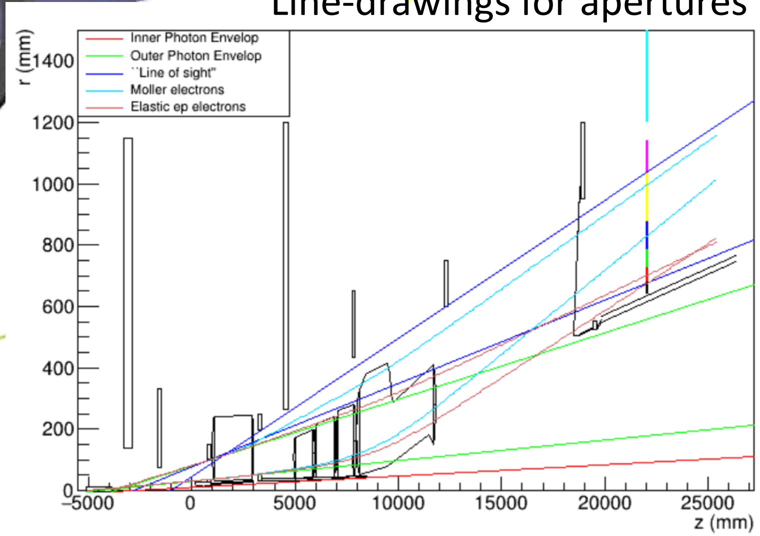
particle envelopes algorithm

Full azimuthal acceptance for mollers from $6 < \theta_{lab} < 20$ mrads

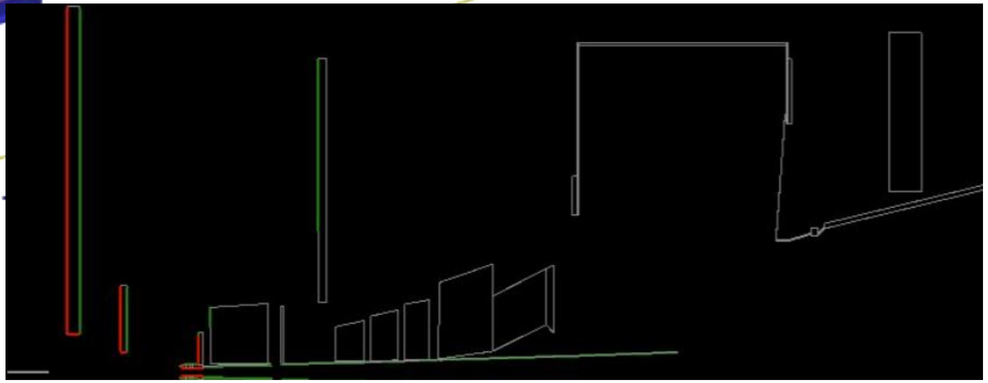




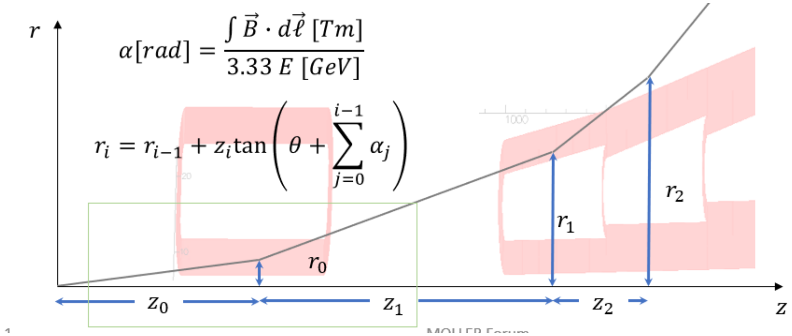
Line-drawings for apertures



2-bounce code



Phase space calcs

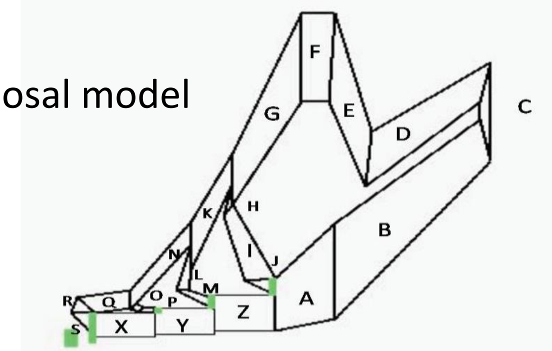


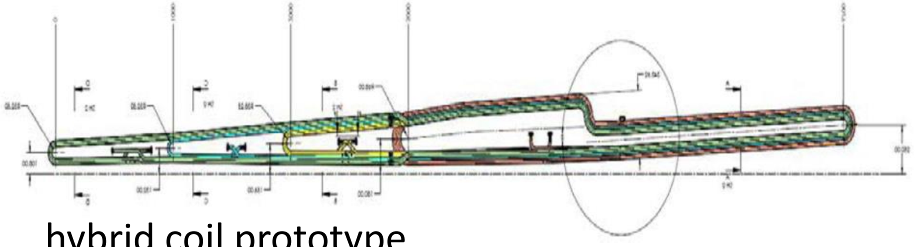
$$\alpha[rad] = \frac{\int \vec{B} \cdot d\vec{\ell}\ [Tm]}{3.33\ E\ [GeV]}$$

$$r_i = r_{i-1} + z_i \tan\left(\theta + \sum_{j=0}^{i-1} \alpha_j\right)$$

Evolution of the downstream torus

Proposal model





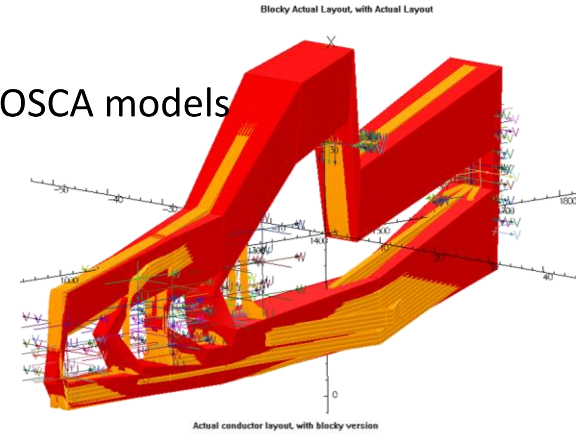
hybrid coil prototype

Careful planning helped to simplify the engineering design of the DS torus, though there have been some changes

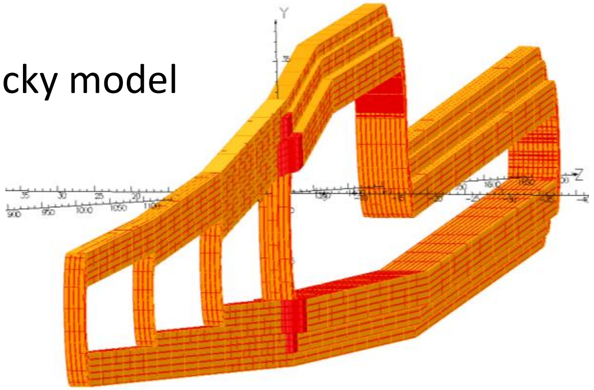
Fit within radial, angular acceptances (360°/7 and <360°/14 at larger radius)

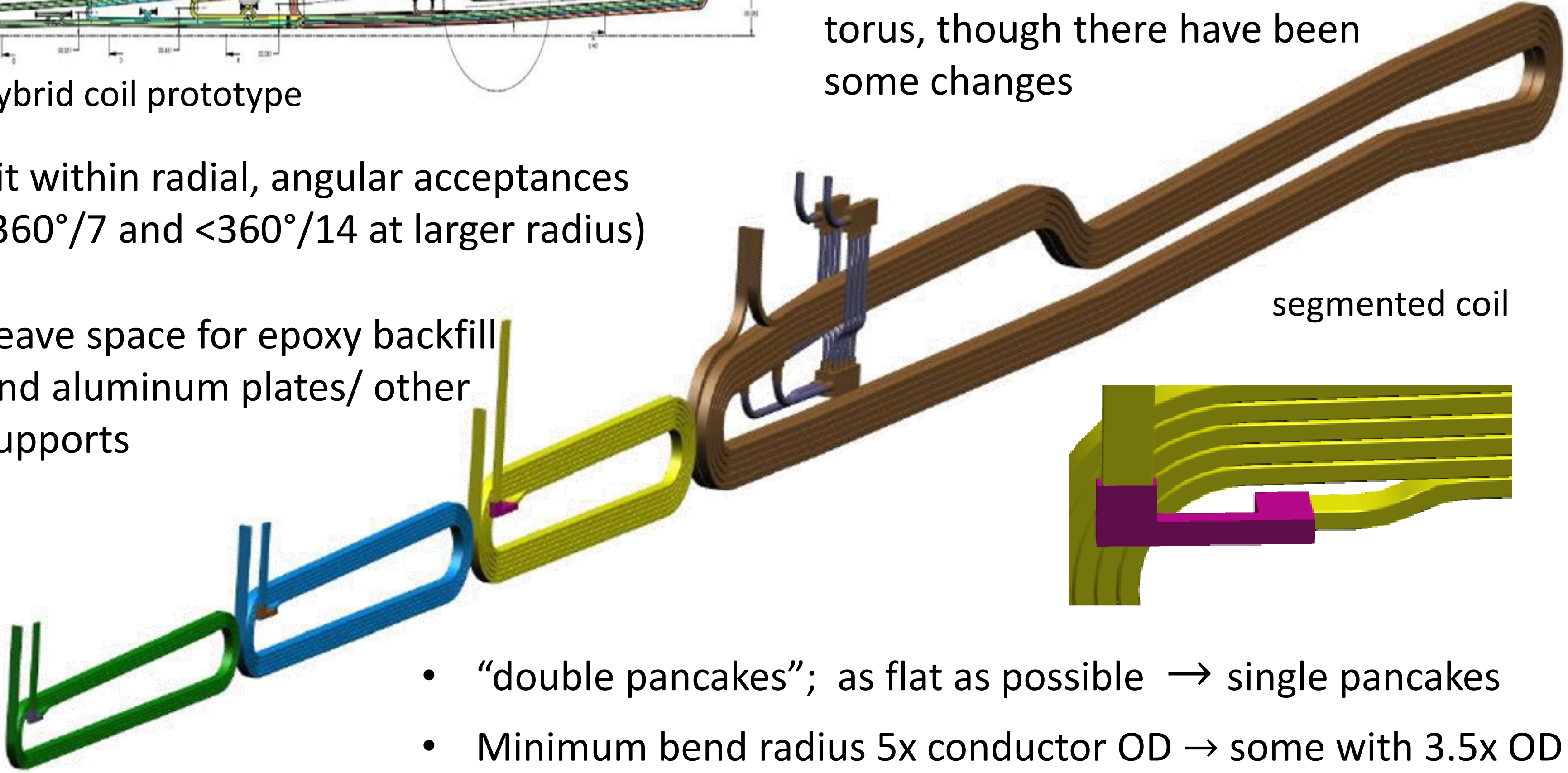
Leave space for epoxy backfill and aluminum plates/ other supports

1st TOSCA models



Blocky model



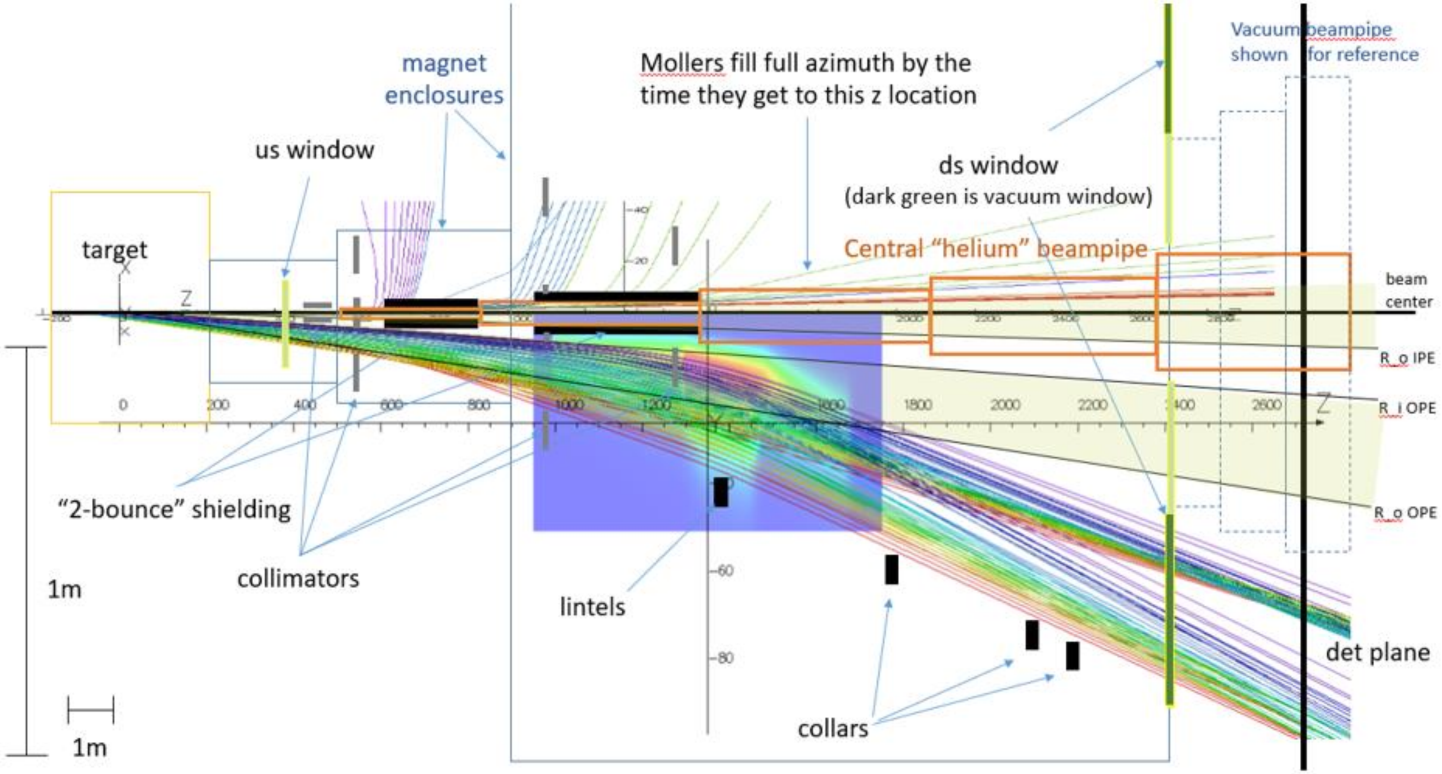


segmented coil

- “double pancakes”; as flat as possible → single pancakes
- Minimum bend radius 5x conductor OD → some with 3.5x OD

- NI same as proposal model → segmented magnet
- 1550 A/cm^2 (<1200 A/cm^2 initially recommended) → $\Delta T < 35\ ^\circ C$ (2060 A/cm^2)

Choice of drift medium – vacuum



Figures from the CCB document submitted for approval to use a vacuum vessel for the magnet enclosures

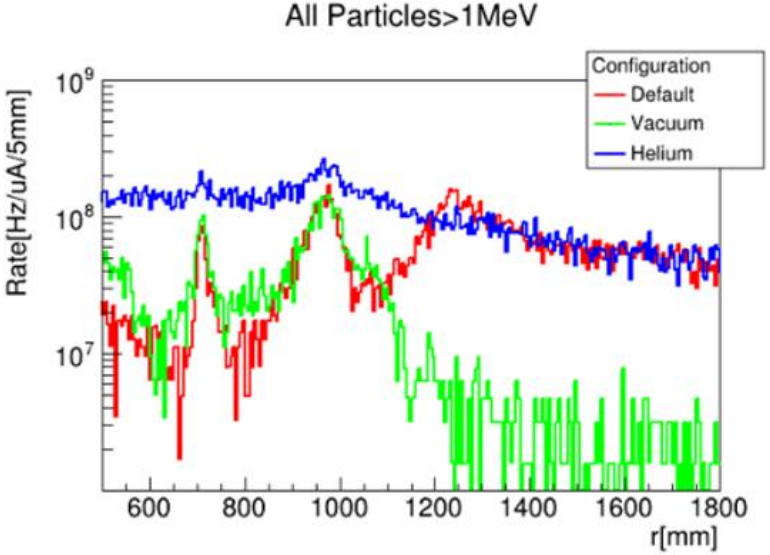


Figure 2 – *Plot of the rate-weighted radial distribution of all particles at the detector plane (z location of ring 5, the moller ring. The green (blue) lines are for a realistic vacuum (helium) configuration. The red line is for the default (historical) configuration. Note that the vertical scale is a log plot, and that a detector response factor of 1/300 has been applied for photons.*

Presence of the central He pipe causes unacceptable backgrounds

Physics optics ok w/ ~atm of air or He

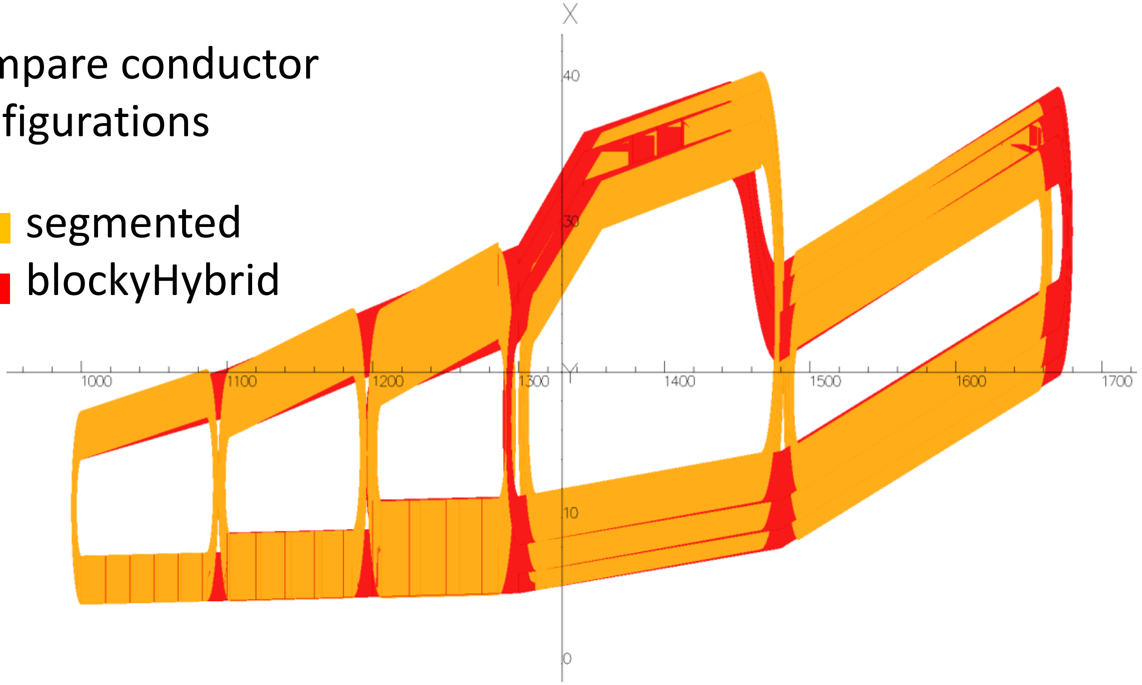
Still need to test beamline backgrounds

Segmented vs. Hybrid

Compare conductor configurations

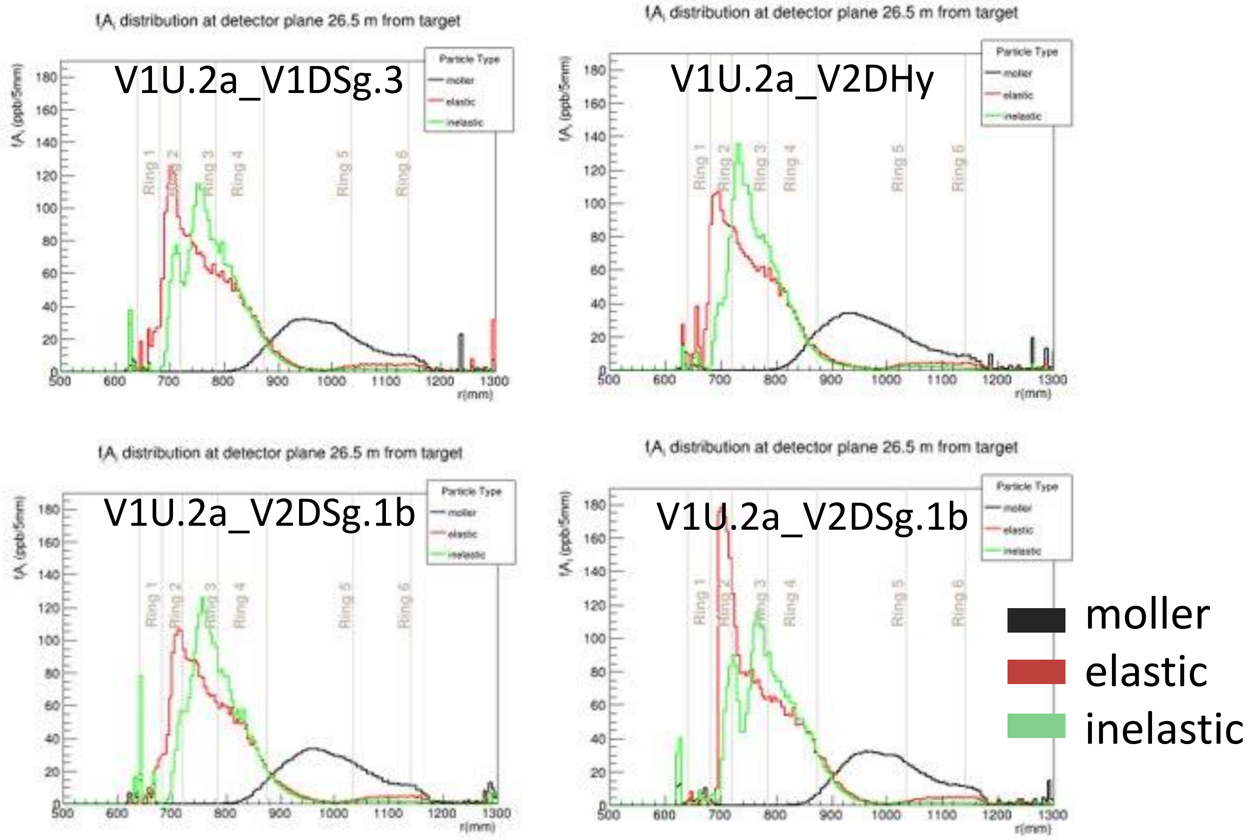
🟨 segmented

🟥 blockyHybrid

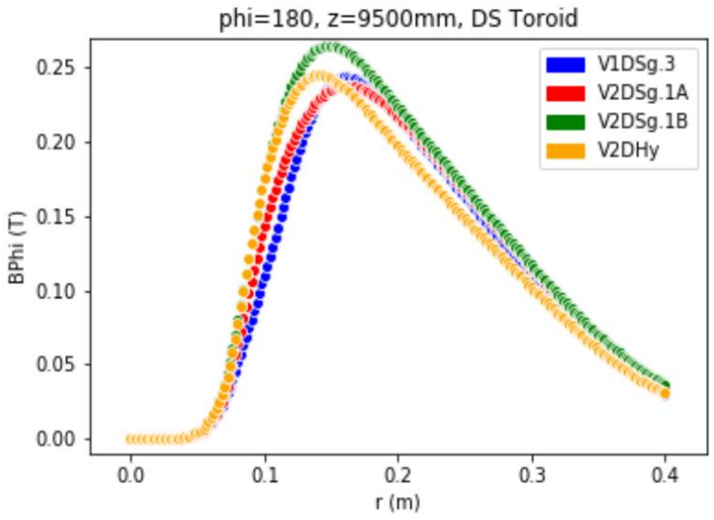


Hybrid vs. segmented – segmented wins!

f_iA_i distributions at detector plane



Direct comparison of fields

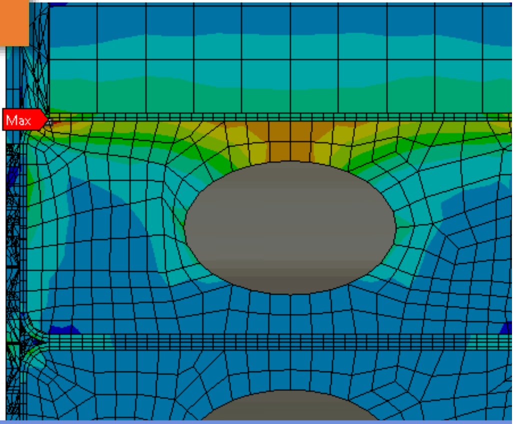


Preliminary Design Review – 60% DS

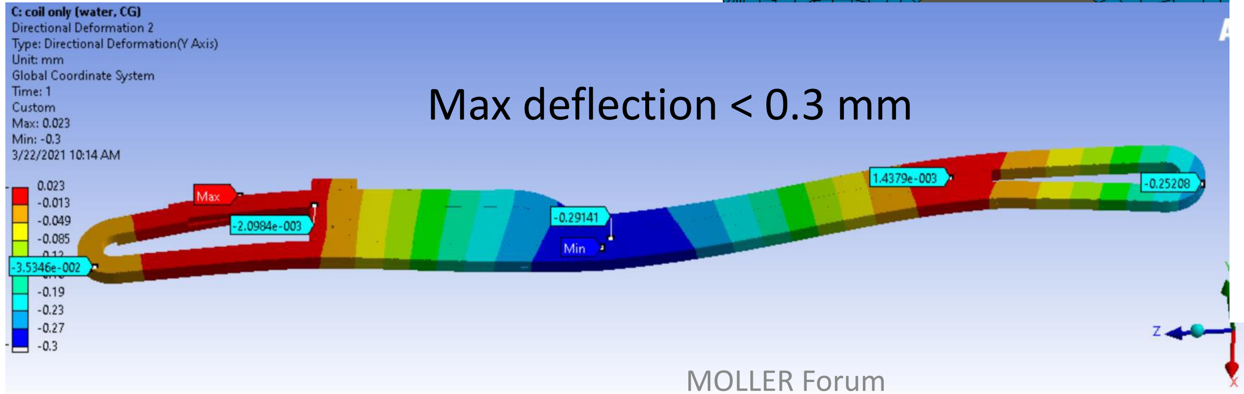
- Specifications document - PMAG0000-0100-A0007
- The field parameters and physics requirements can be met
  - Clearance to particle envelopes (PMAG0000-0100-A0009)
  - Current density
  - Water cooling system
    - Temperature rise
    - Pressure drop
  - Support system
    - Alignment tolerances
    - Fiducilization
    - Forces analyses
  - Interfaces (electrical, water, supports)
  - Fabrication
  - Validation

Only recommendation is to include schedule risk in the risk registry

Tolerable stresses

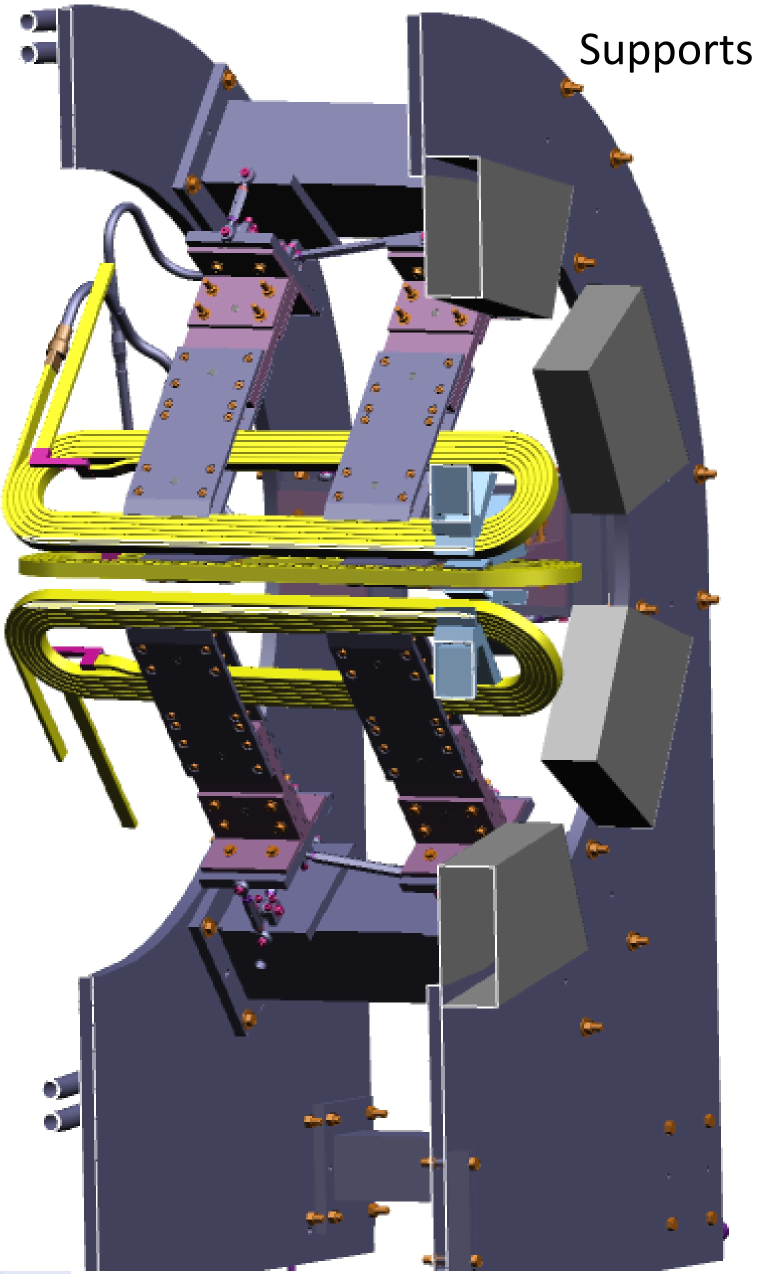


Max deflection < 0.3 mm

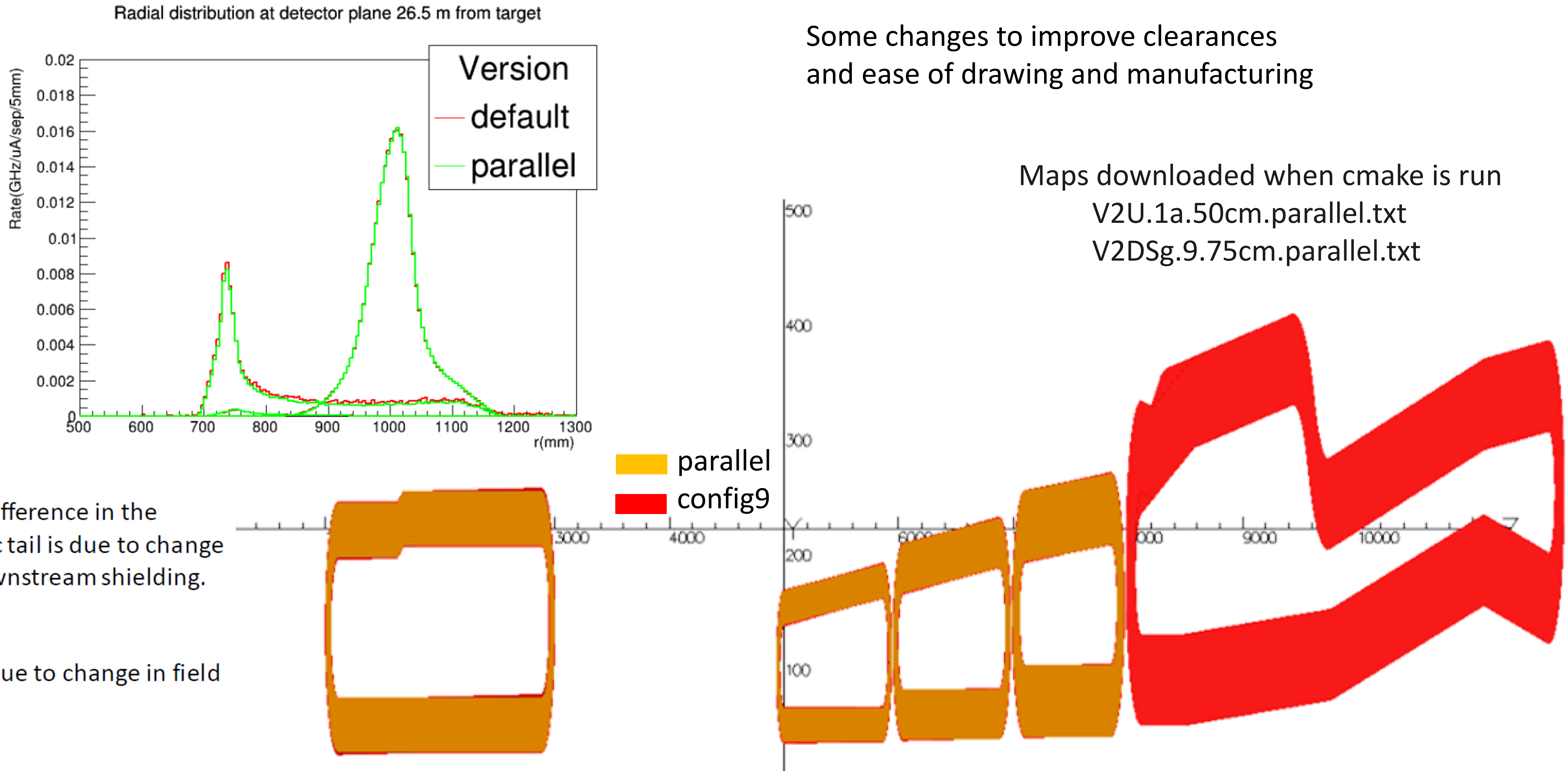


C: coil only (water, CG)
Directional Deformation 2
Type: Directional Deformation(Y Axis)
Unit: mm
Global Coordinate System
Time: 1
Custom
Max: 0.023
Min: -0.3
3/22/2021 10:14 AM

Supports



Final conductor configuration



Some changes to improve clearances
and ease of drawing and manufacturing

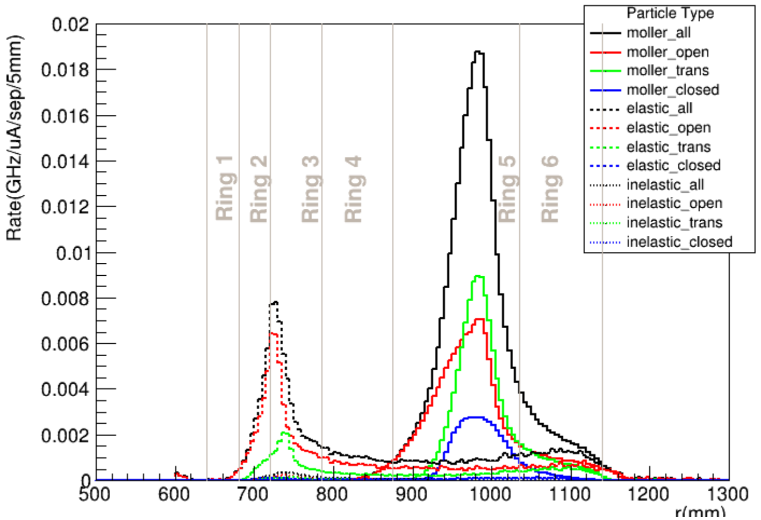
Maps downloaded when cmake is run
V2U.1a.50cm.parallel.txt
V2DSg.9.75cm.parallel.txt

The difference in the elastic tail is due to change in downstream shielding.

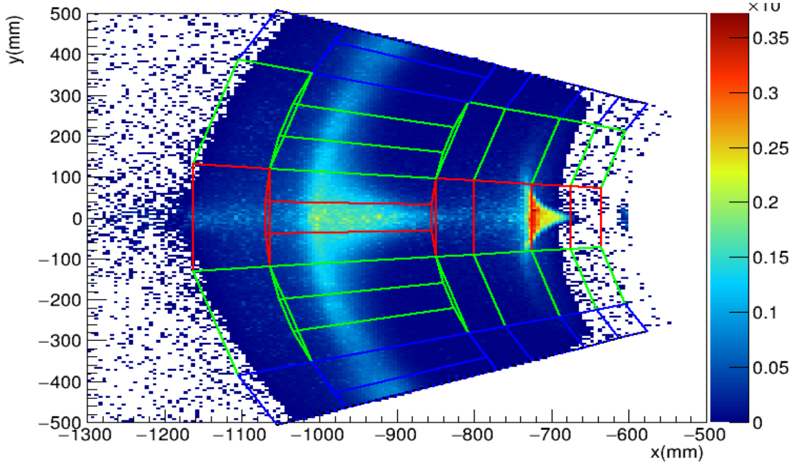
NOT due to change in field maps.

Checking the maps – qualitative to quantitative

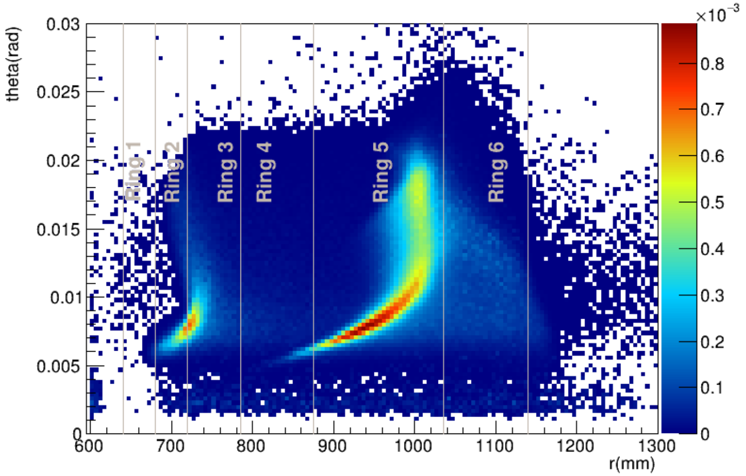
Radial Rate distributions



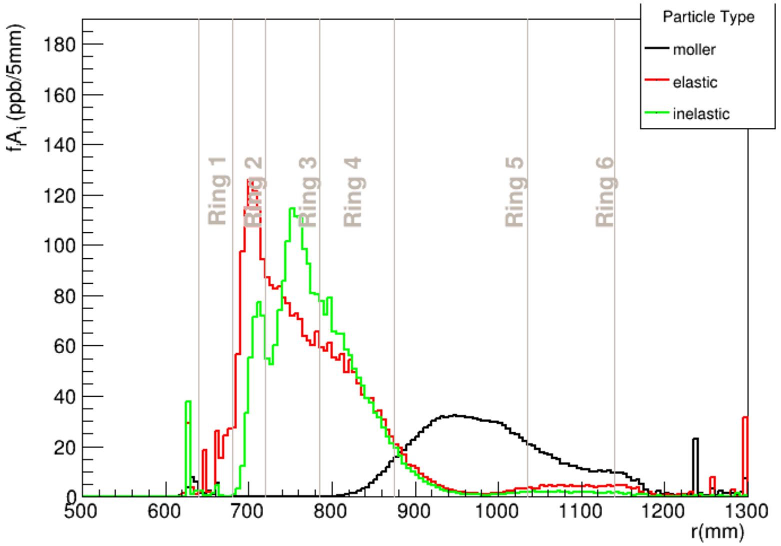
Y-X Rate distributions



θ-R Rate distributions



Radial f_iA_i distributions

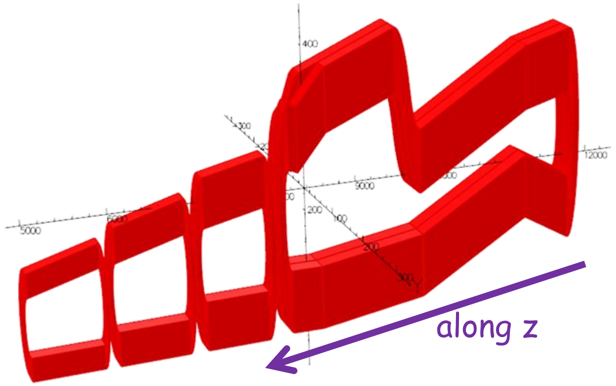


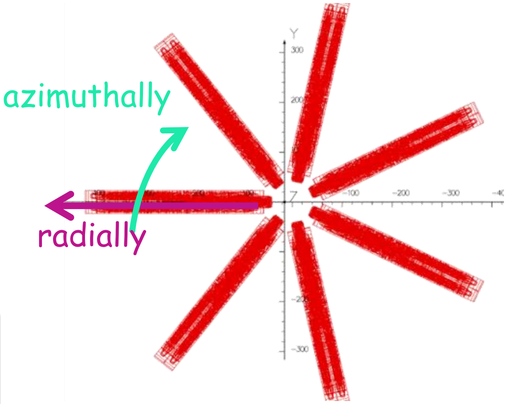
- Adjust the detector tiling if necessary (not optimized)
- Each tile has different contributions from the different processes
- In particular, three W regions for the inelastics

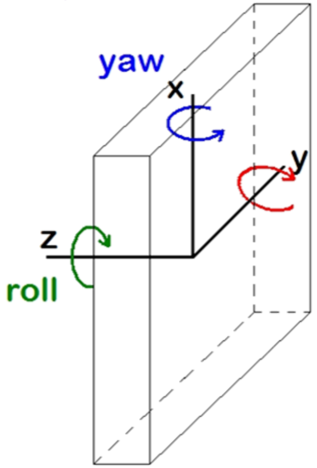
- Fit the simulated total asymmetries in each tile, using the simulated dilutions (fractional rates) to determine the asymmetry of each process

Alignment tolerances

- Single coil/single offset (6) studies estimate position sensitivity
  1. create field maps for offset coils (11 steps for each)
  2. run simulations with each of the field maps
  3. determine the effect on the moller asymmetry (assuming we don't know about the offset)
  4. inverse of slope × the uncertainty is the tolerance



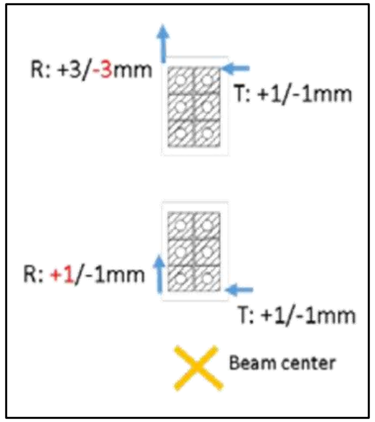




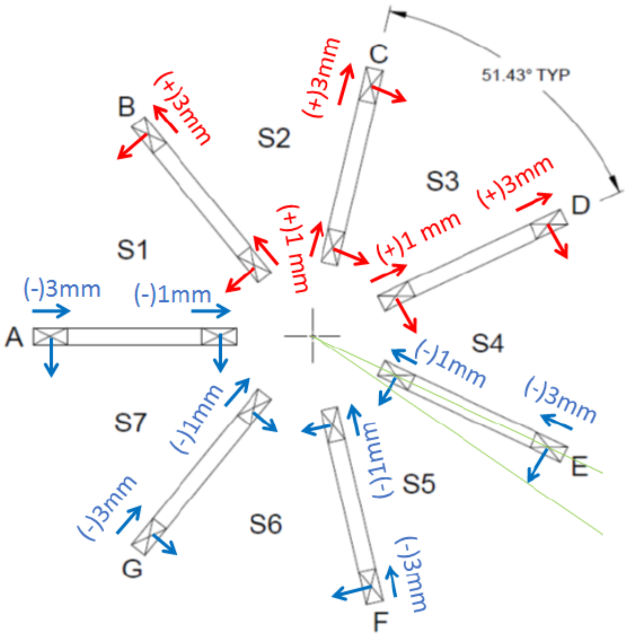
- Considerations
  - physics optics (ability to "deconvolute" the asymmetries with desired uncertainty)
    - signal electron focal plane distributions
    - backgrounds
  - clean transport to the dump
  - clearance with the scattered particle envelopes
  - doses on coils (epoxy, especially at inner radius)

relatively insensitive

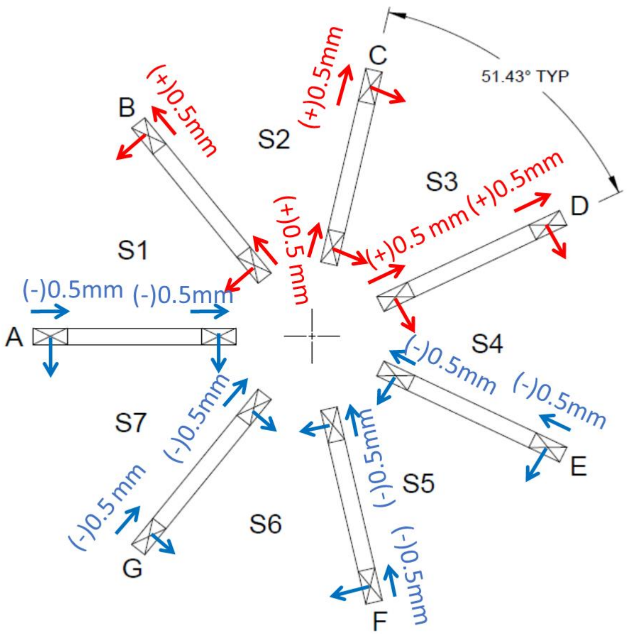
Tolerances determined by single coil/single offset studies have been verified with "worst-case" multiple coil/multiple offsets within the specified tolerances



Alignment Tolerance Cases

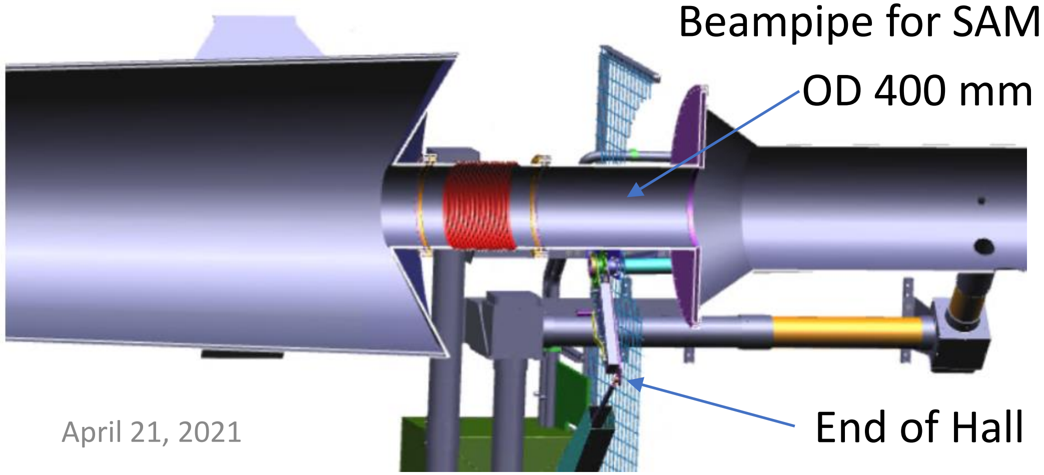


CASE 1



CASE 2 and 3

Beampipe for SAMs



OD 400 mm

End of Hall

Physics worst case

- All coils offset in same direction (without us knowing)
- Least likely (survey, tracking)

BEAM worst case is coils aligned in a "conspiratorial" way within tolerances

→ induces dipole

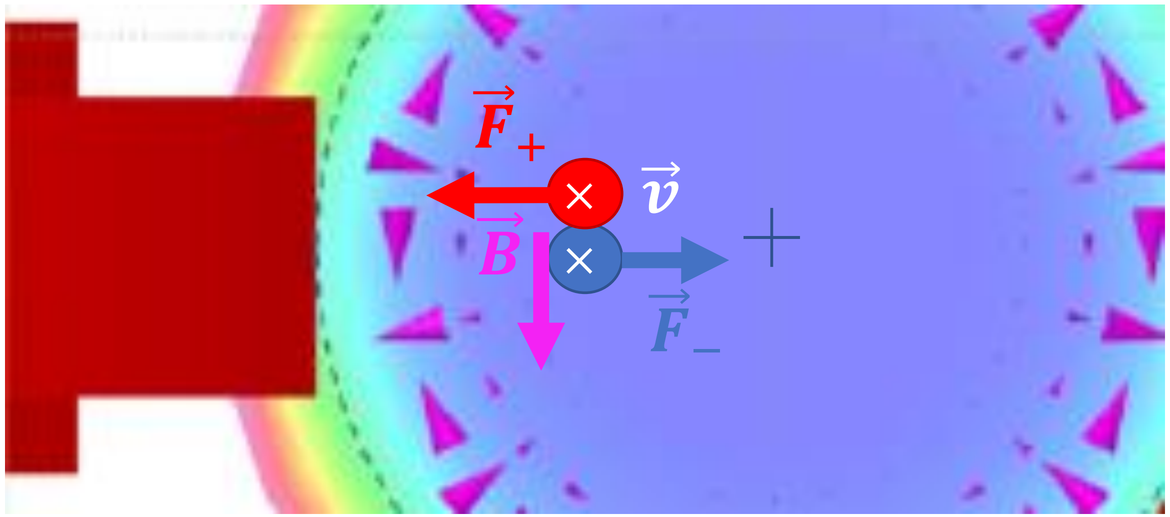
- affects beamline shielding (dose on coils)
- backgrounds from end of hall apertures
- Irradiation

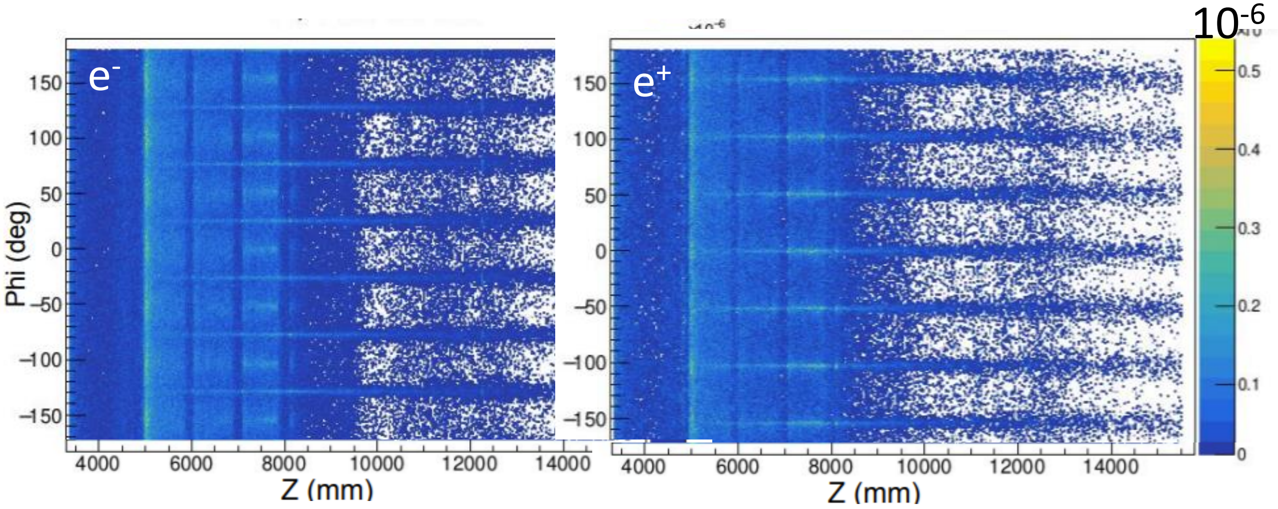
Several offset cases considered:

1. All sub-coils offset to induce maximum dipole within allowed tolerances
2. All subcoils offset without deformation and to ±0.5 mm
3. Same as case 2, but dipole field has different orientations in each subcoil

Stray fields in beampipe deflect $e^{\pm}$

Looking downstream





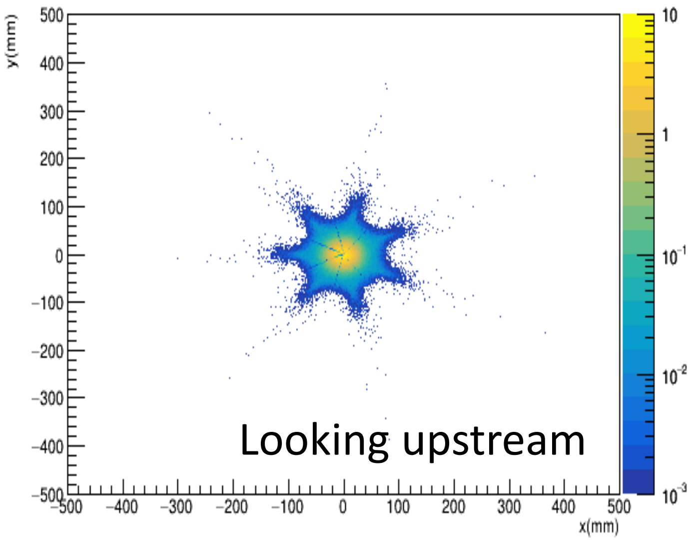
Consider the horizontal coil, in the perfectly symmetric case

- all velocity in the z-direction
- field is vertical along the x axis, (mid-plane of coil)

- e^- will be bent to the right
- e^+ will be bent to the left (onto the coil)

- just off the axis,
    - the field direction is dramatically different
    - $e^{\pm}$ would feel both horizontal and vertical components of force
    - dispersed

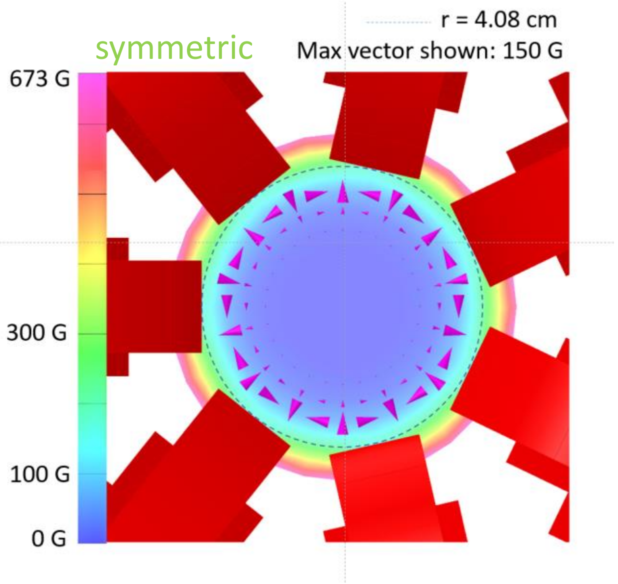
Rate (GHz/uA/mm^2), End of the Hall, Nominal



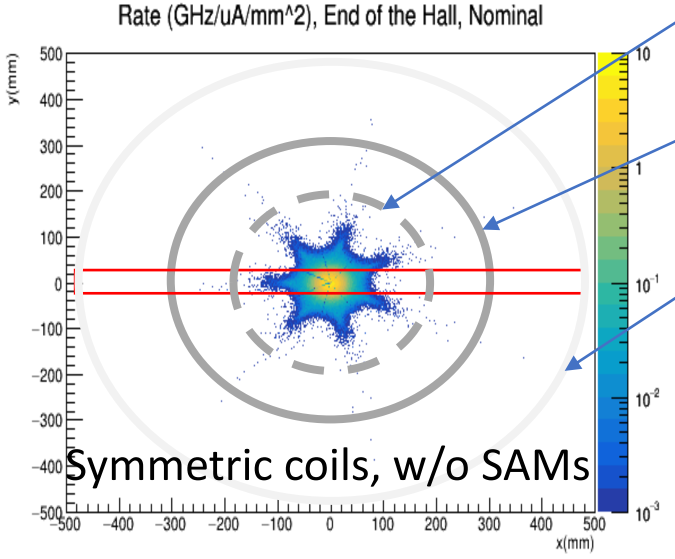
Looking upstream

Beam backgrounds - nominal (symmetric) case

Looking downstream



Looking upstream



Symmetric coils, w/o SAMs

Beampipe intrusion for the SAMs

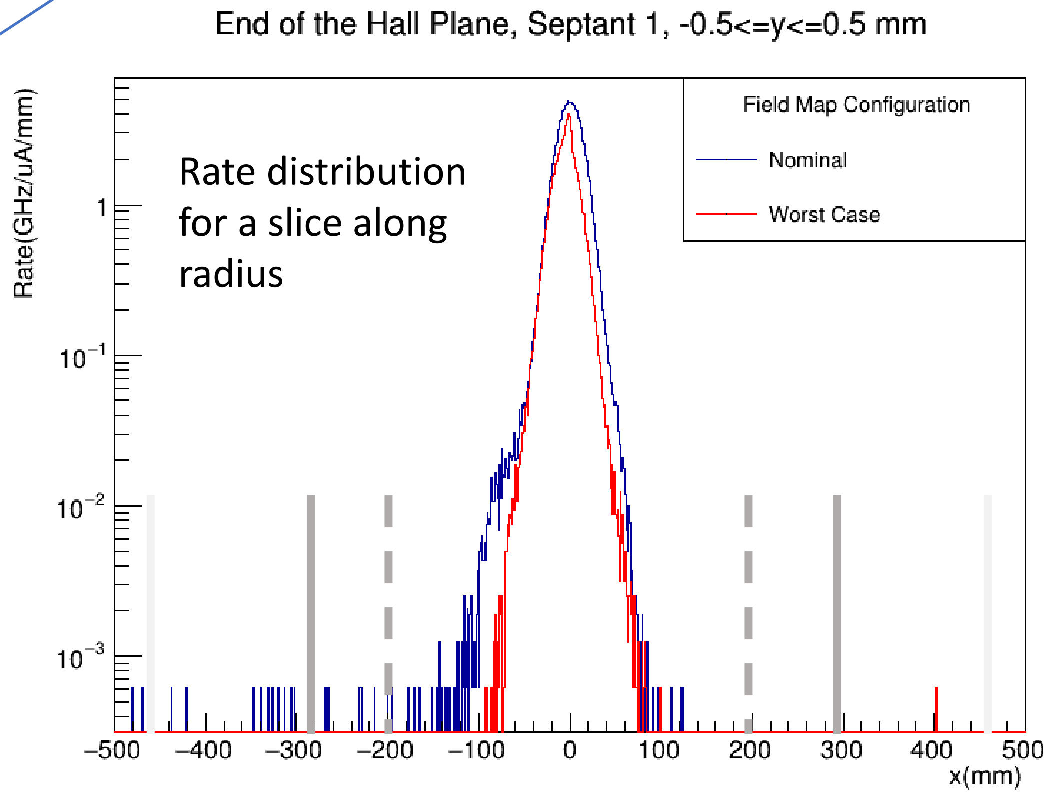
(~0.5m upstream)

Limiting aperture in dump tunnel

(~0.5 m downstream)

Dump entrance flange

(same z location as plots)



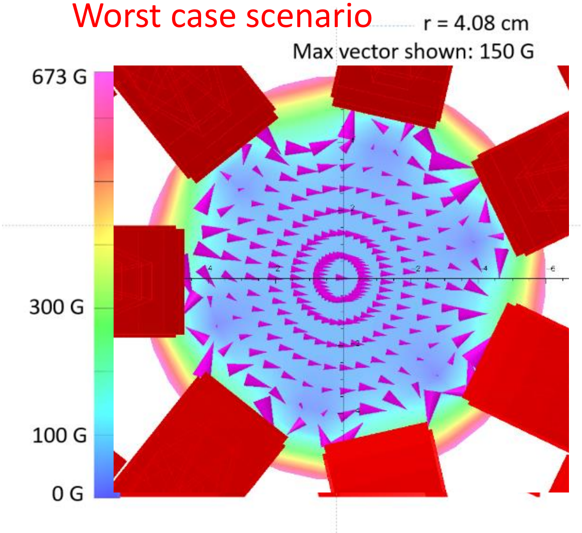
Rate distribution for a slice along radius

- In the top left plot you see a picture of the ds coils at a particular z location with the magnetic field contours and vectors
- Middle top plot is a 2D rate distribution at the entrance to the dump tunnel
- To the right is a 1D distribution of the rate in horizontal septant (1); the vertical lines indicate the radius of various apertures

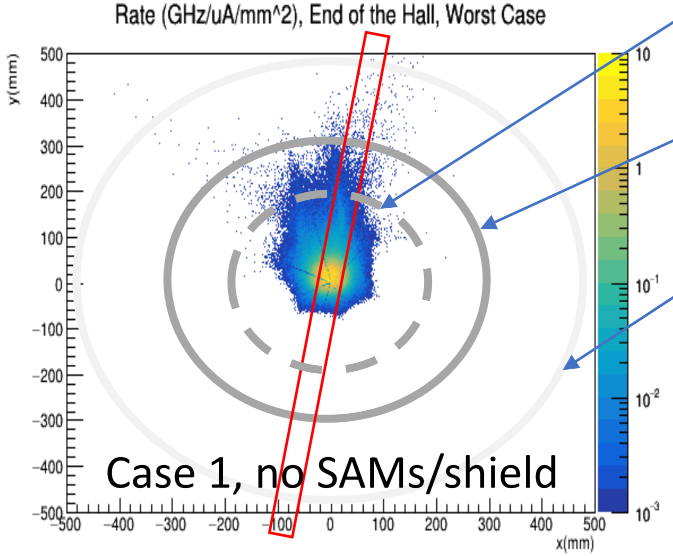
Beam backgrounds - worst case

Looking downstream

Worst case scenario



Looking upstream

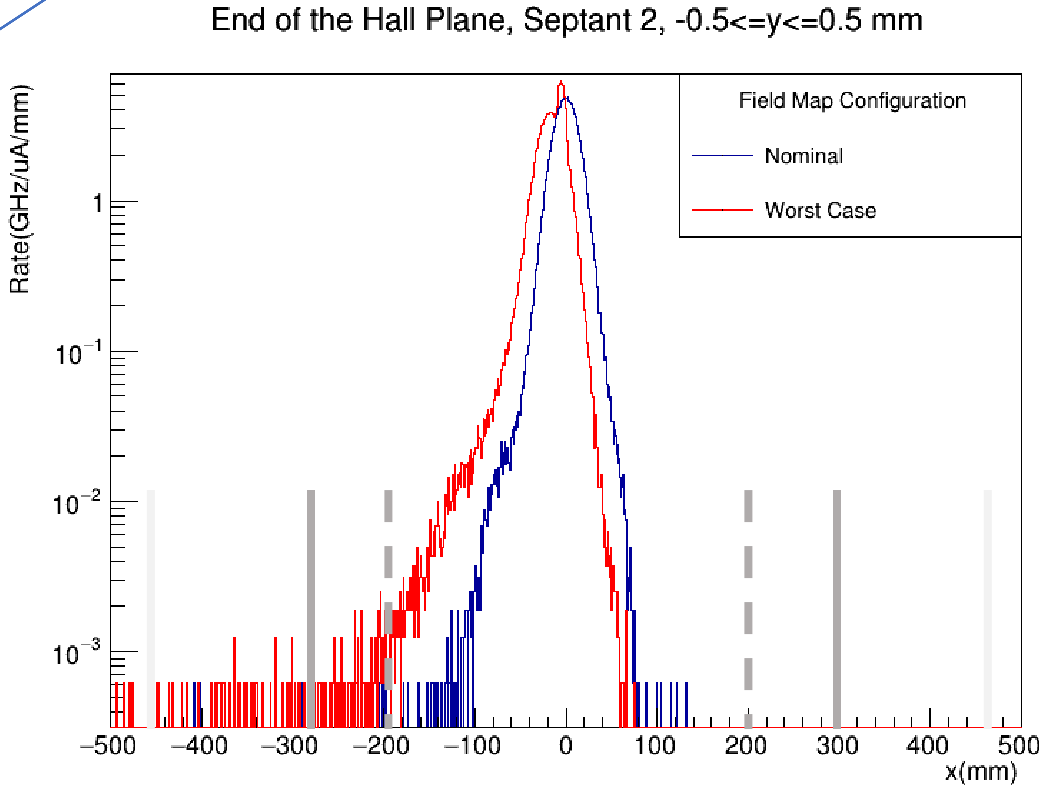


Case 1, no SAMs/shield

Beampipe intrusion for the SAMs
(~0.5m upstream)

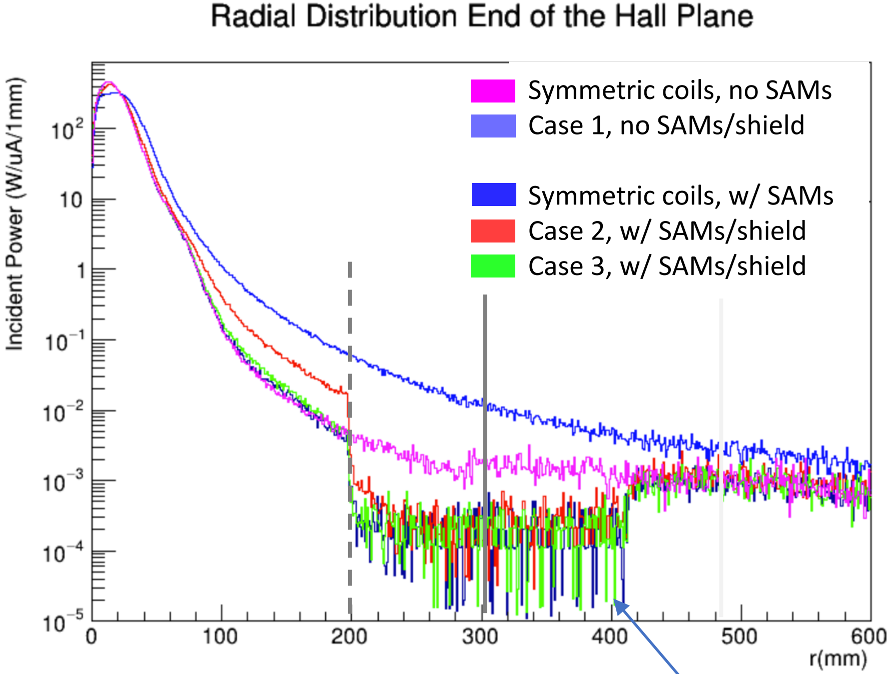
Limiting aperture in dump tunnel
(~0.5 m downstream)

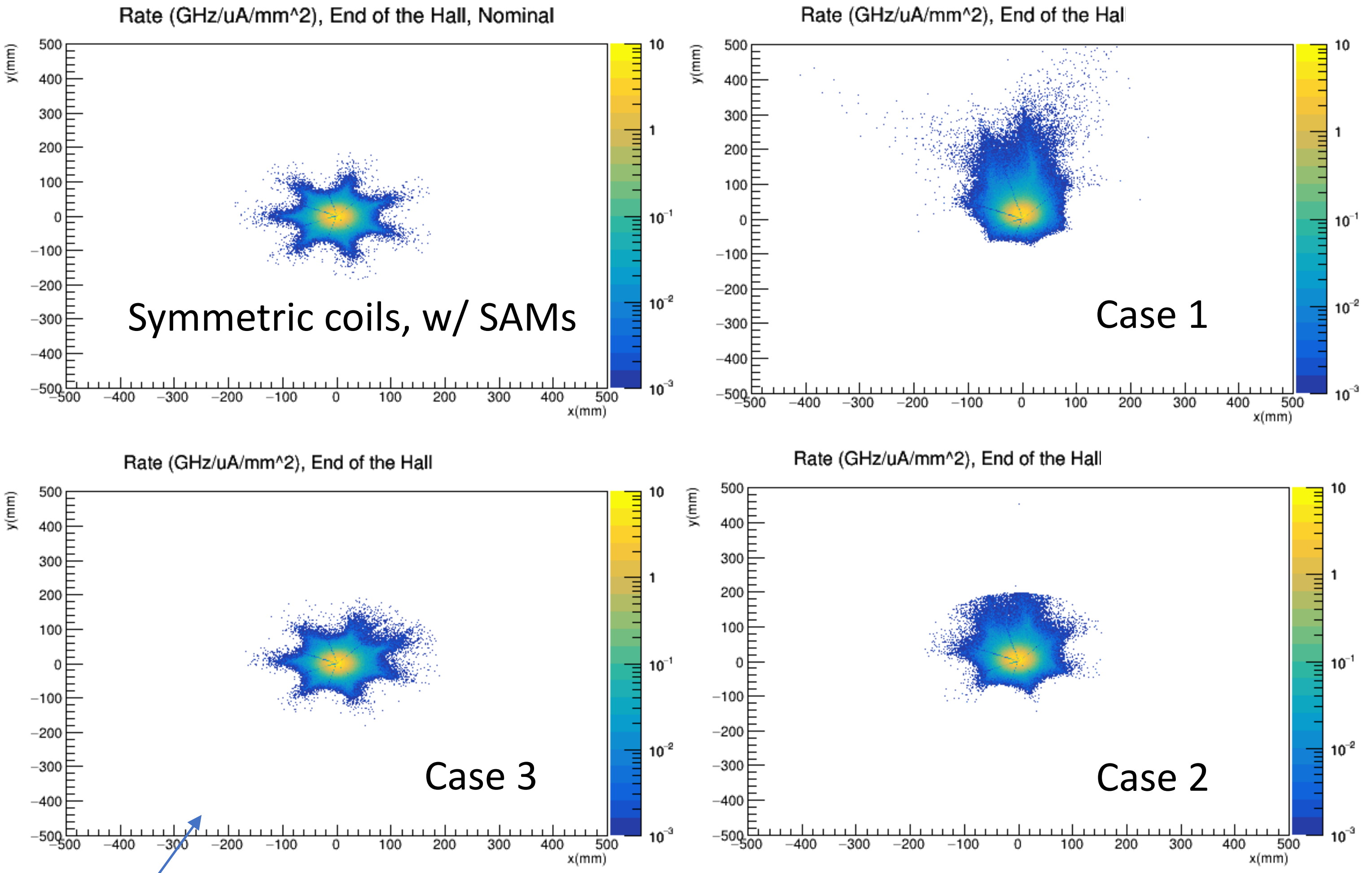
Dump entrance flange
(same z location as plots)



- In the top left plot in the worst case scenario there is an induced dipole field > 100 G over most of the area inside the coils
- In this particular orientation, the electrons are bent upward into septant 2
- To the right is a 1D distribution of the rate in the worst septant (2); even in the worst-case scenario the beam is mostly clearing

Comparison of cases





Total Beam Power 715 kW

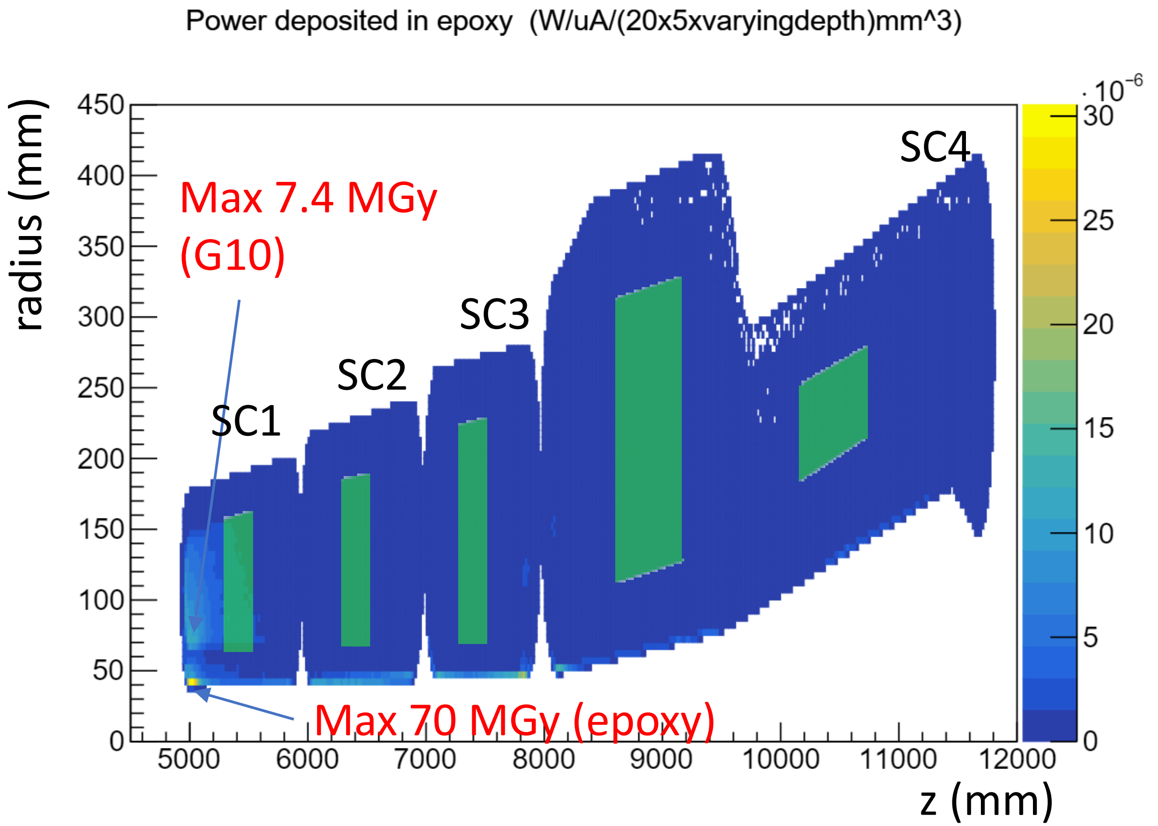
Integrated Power from
200 mm < r < 600 mm

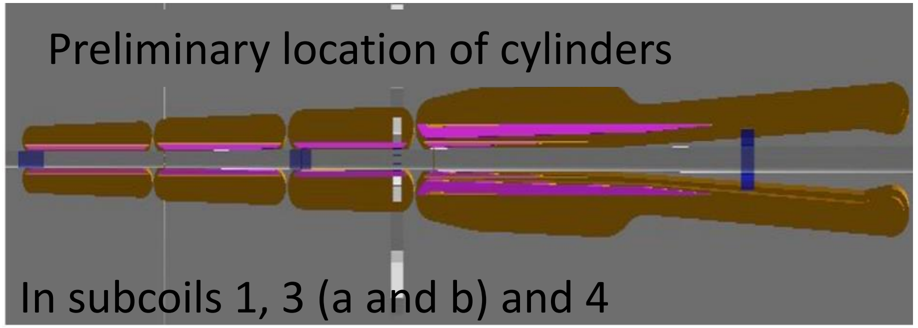
Symmetric coils, no SAMs	38.1 W
Case 1, no SAMs/shield	260 W
Symmetric coils, w/ SAMs	13.4 W
Case 2, w/ SAMs/shield	17.8 W
Case 3, w/ SAMs/shield	14.2 W

Most likely

worst case is 10^{-4} of total beam power
order of magnitude lower for most likely case

Power deposition in the epoxy – doses



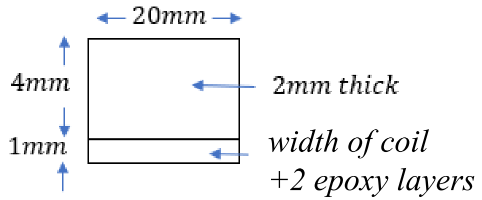


The power deposition in the epoxy (plot to the upper left) is calculated in a volume of G10 in the simulation

- fills the "window"
- surrounds the conductor (1 mm thick)
- volume of epoxy varies from pixel to pixel

There are shields along the beamline (see bottom left picture) that have NOT YET been optimized to reduced the resulting doses

The G10 filler in subcoils 2-4 have maximum doses of < 1MGy



Subcoil	Max Dose (MGy)
1	70
2	34
3	41
4	22

Positrons in the middle

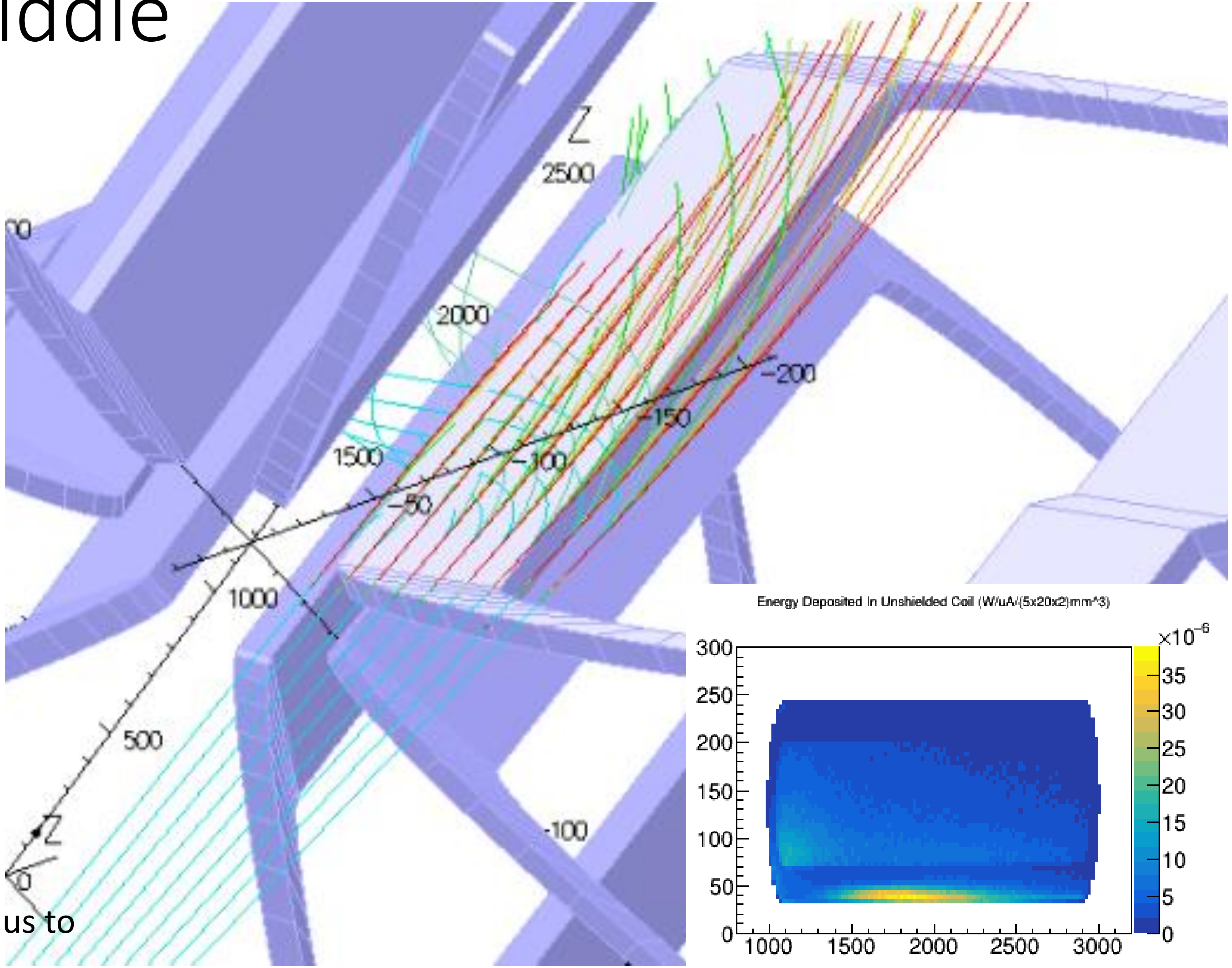
Phi = 12 degrees
50 < E < 1100 MeV (steps 200 MeV > 100
6 < th < 22 mrad (steps of 2)

Colored by energy (MeV)

0.1 purple
50 cyan
300 green
700 orange
1100 red

Which ones are the most important?

Produce plot of E_{dep} weighted E_{scatt} vs. radius to see what the most important tracks are



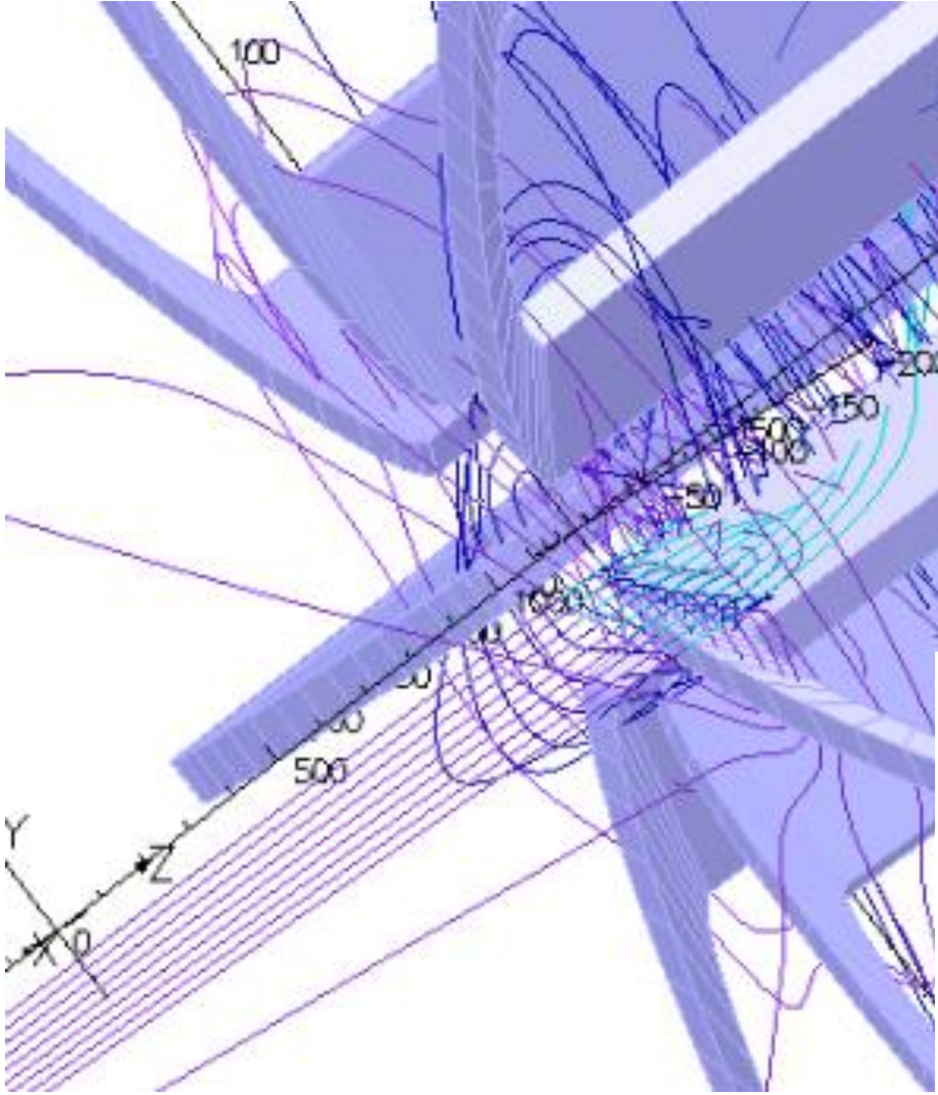
Max 320 MGy

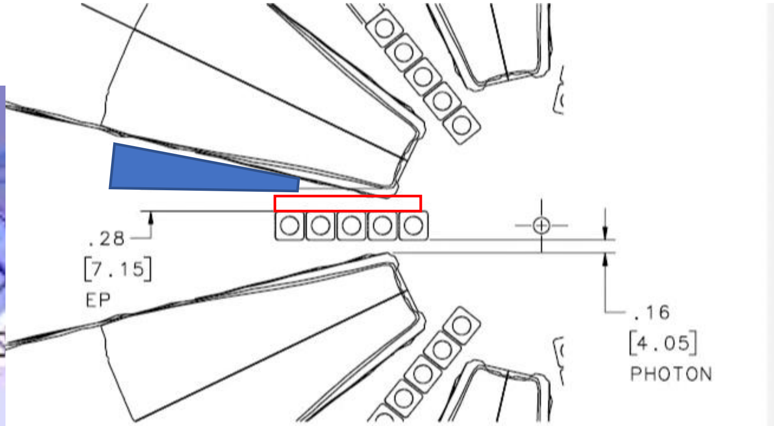
Positrons at the nose

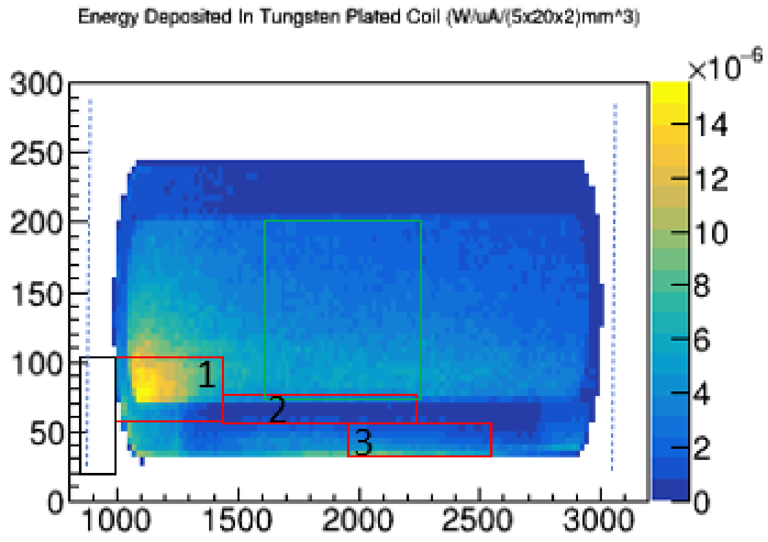
Phi = 12 degrees
E = 0.1, 1, 10, 50 MeV
6 < th < 22 mrad (steps of 2)

Colored by energy (MeV)

0.1 purple
50 cyan
300 green
700 orange
1100 red

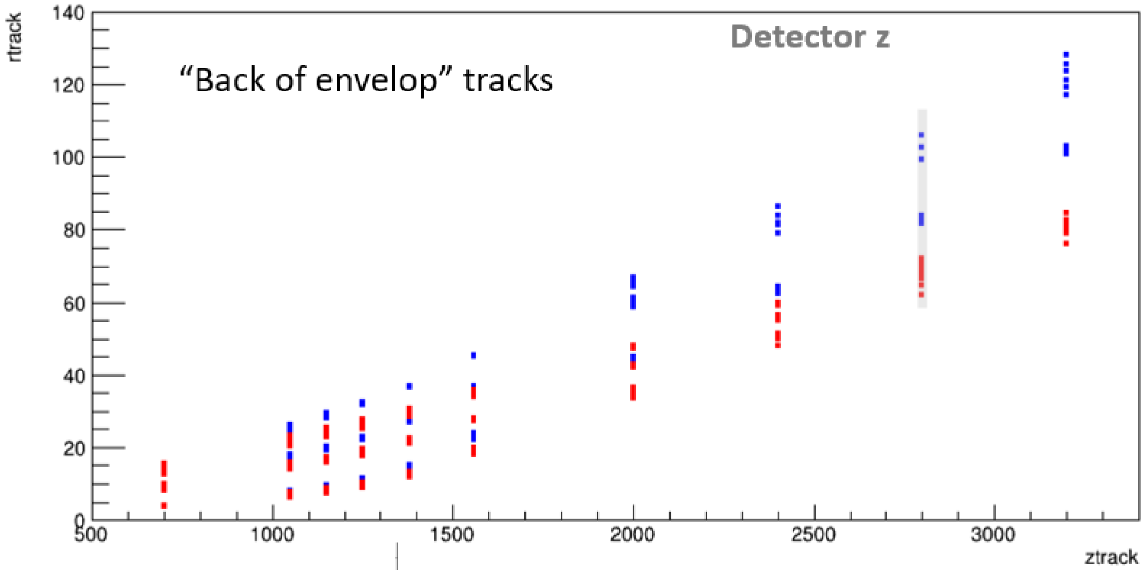


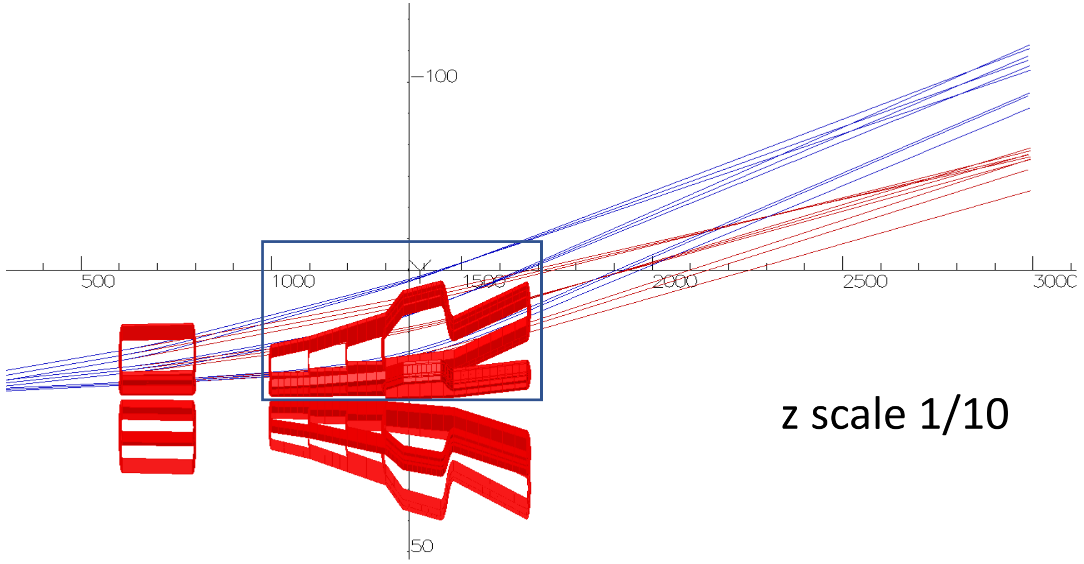




Max 60 MGy

Field map tests – granularity and extent





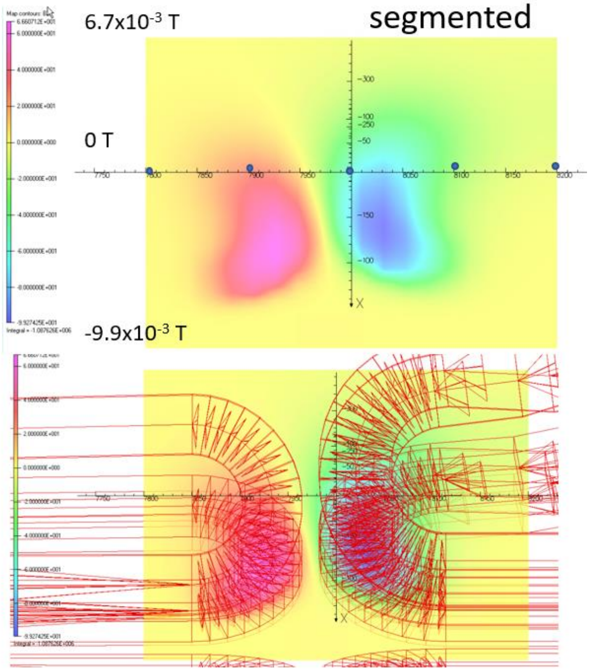
z scale 1/10

For the downstream torus, the map extends from:

0 < r < 40 cm
4.5 < z < 12.5m
Full azimuth

The spacing is:

Radial	0.5 mm
Azimuthal	3°
Along z	10 cm



The field maps are generated in TOSCA with a Biot-Savart calculation (assumes no non-linear materials)

Outstanding questions for physicists

- Field map and interpolation tests
  - Extent – can/should it be smaller than 75 cm in the downstream?
  - Coarseness of grid – probably okay; want to test the limits, optimize
  - Interpolation – default is linear interpolation, investigating cubic as well
- Dose reduction on epoxy
  - Downstream – absolutely possible; just needs to be done
  - Upstream – needs careful design
- Effects of offset coils – needs to be considered in every study
- Tolerable vacuum level determination – beamline backgrounds
- Dipole field specification – depends somewhat on some of the things above
- Field measurement system needs
- Continued iteration with JLAB and MIT engineers

Backups

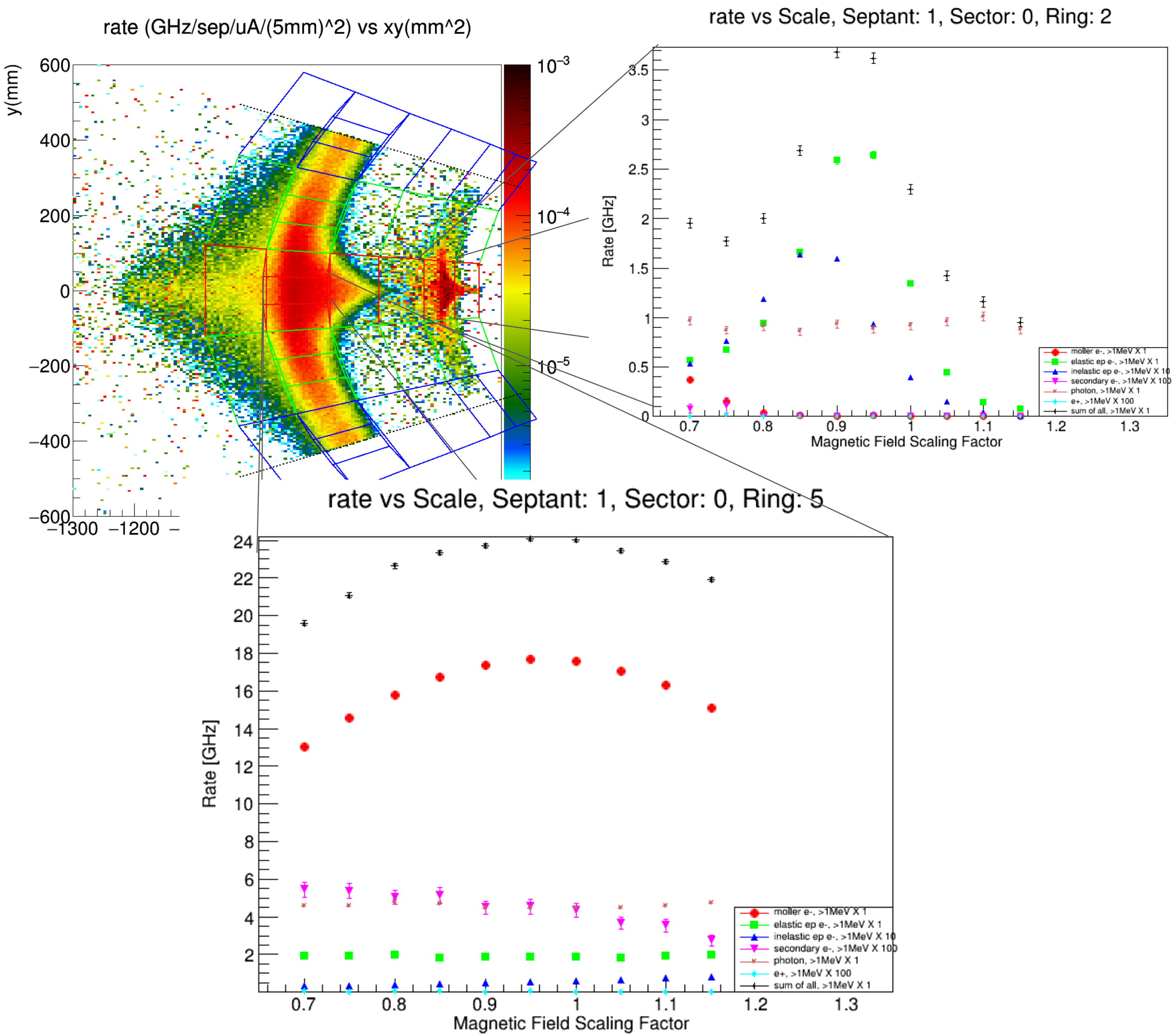
Simulations

- Core
  - Shielding
    - (target – semi-done)
  - Spectrometer
    - Coil dose, coil shielding
  - Collimation
    - Early (semi-done)
  - Background stuff
    - Asymmetric coils
    - Beamline backgrounds (absolute rate)
    - Clean transport to the dump (beamline elements need to be in the simulation)
    - 1 Torr on beamline
    - Ferrous materials (bellows)
    - Lintels and collars

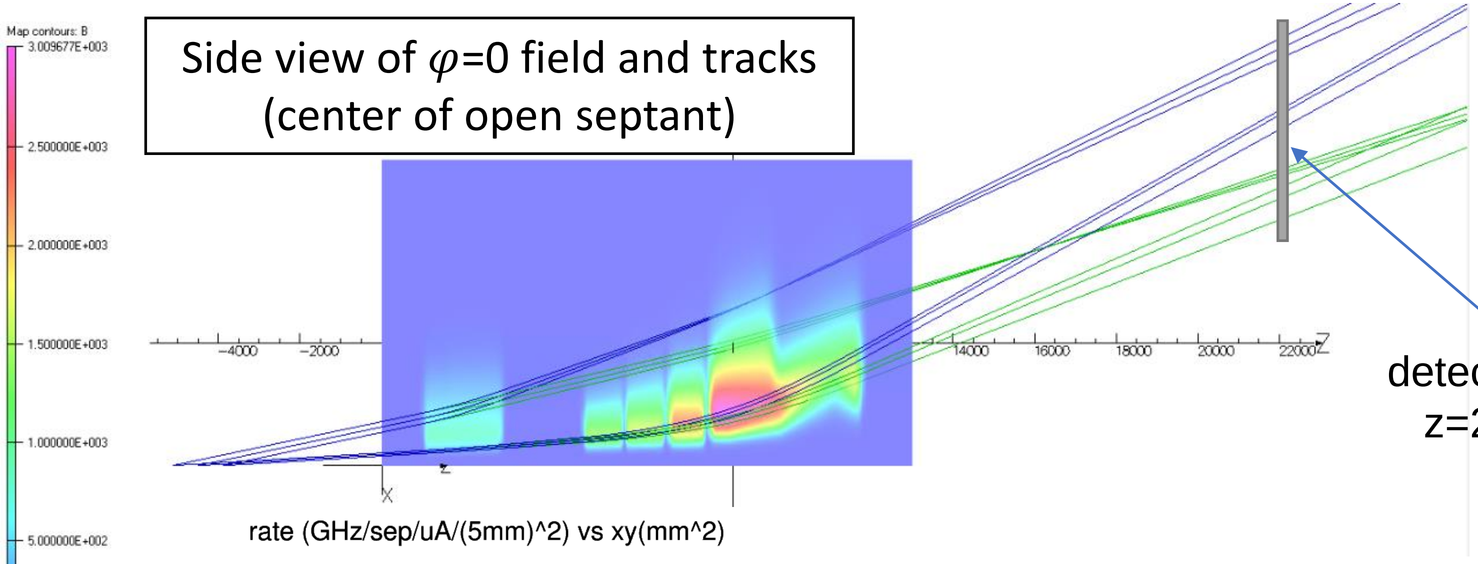
- Projects
  - Detector tiling
  - Pion
  - Sams
  - Tracking

Deconvolution

- Although we call the rings moller or ep rings, we actually use more than one ring to determine the moller asymmetry
- We will use the different contributions of the rate and asymmetry for each of the processes in each of the detector tiles to “deconvolute” the asymmetries for each process
- Need measurements to benchmark simulation
    - Tracking system – low current runs
    - Magnet current scans
    - Alternate beam energies?
- Should do further studies to test this procedure to determine if additional systematic measurements are needed



Fields and particle tracks



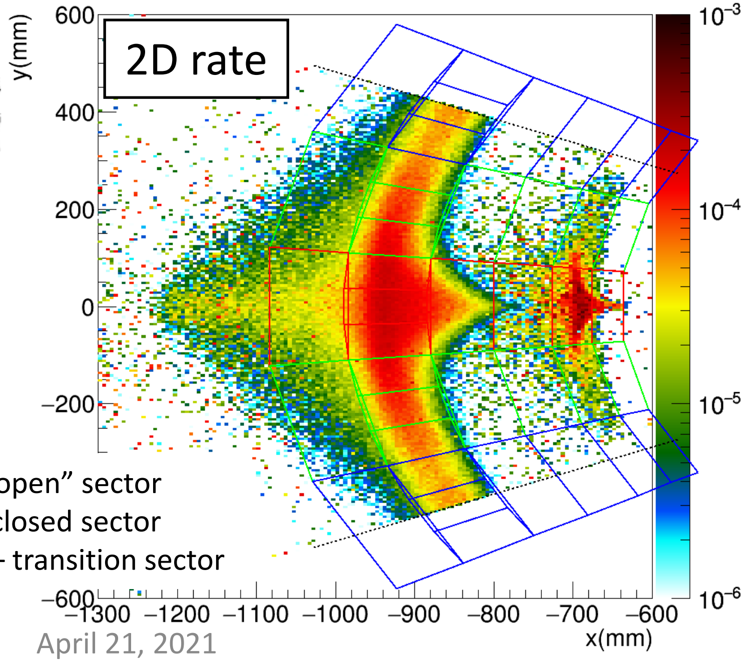
Side view of φ=0 field and tracks
(center of open septant)

Tracks are 6 and 21 mrads for both ep and mollers, from 3 different parts of the target

Tracks have energy/angle correlation, but not the radiative effects in the target

detector plane
z=2650cm

rate (GHz/sep/uA/(5mm)^2) vs xy(mm^2)

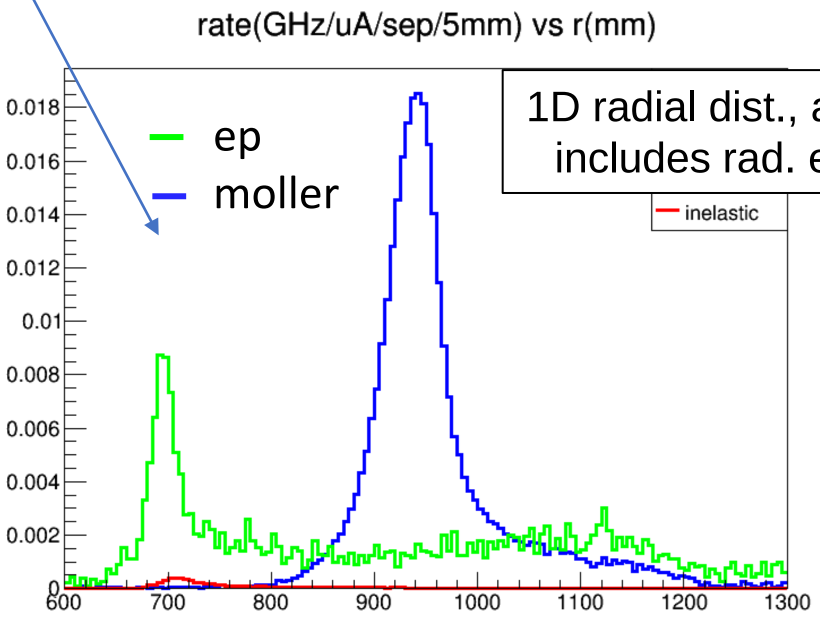


2D rate

Red – "open" sector
Blue – closed sector
Green – transition sector

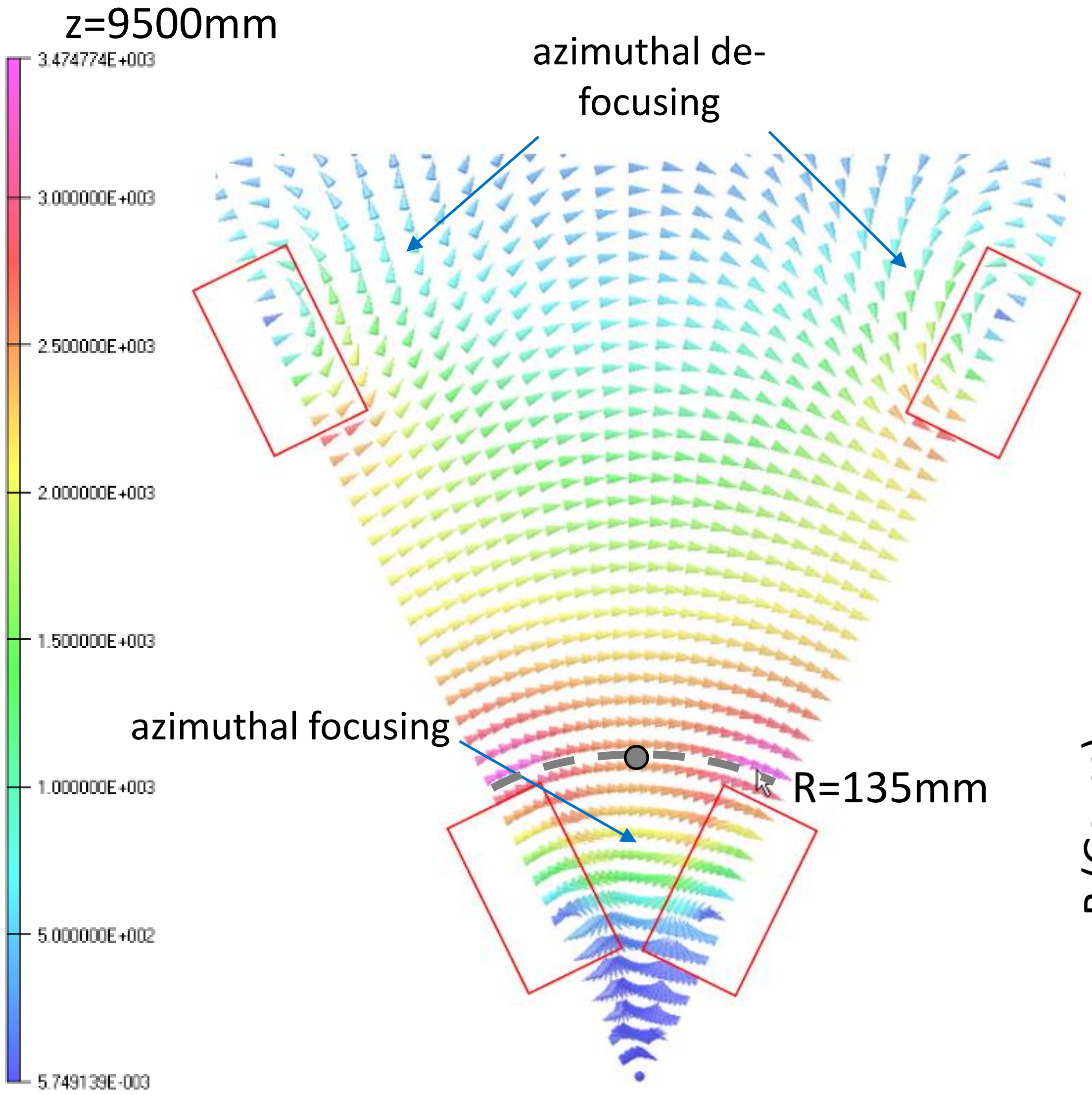
- Dashed lines indicate the extent of a single septant
- Transport through the magnets causes the moller "envelope" to be azimuthally defocussed
- The add'l segmentation in moller ring allows for monitoring of systematics

- Require 20% less up to 10% higher current for background determination



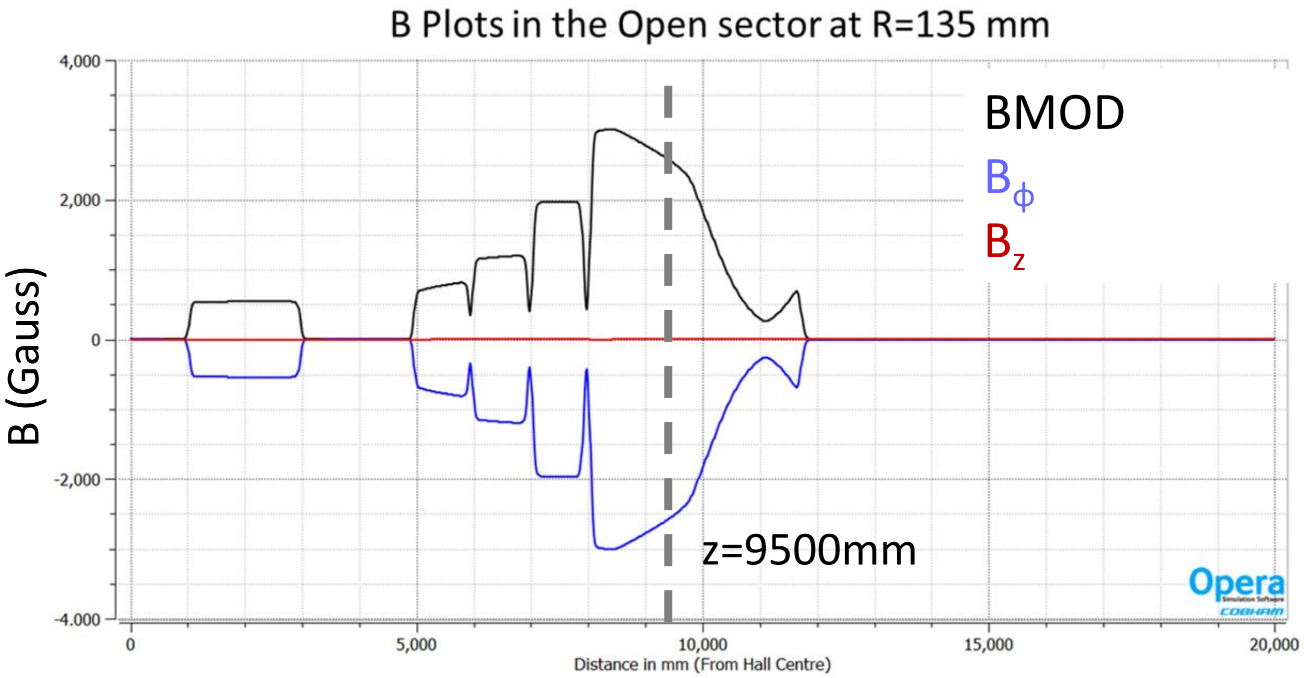
1D radial dist., all φ
includes rad. eff.

Shape of field in a septant – varies along z, and also along r and φ



$B_{ideal} = \frac{\mu N I}{2\pi r}$ in the φ direction

- Vector map colors show relative total field strength in a septant
- Radial components of field cause azimuthal (de-)focussing near the conductor at the (outer) inner radius of the conductor
    - Provides required inelastic electron separation
    - Causes mid-angle mollers to fill full azimuth at detector
- Field varies along z to separate the low E moller and high E eps

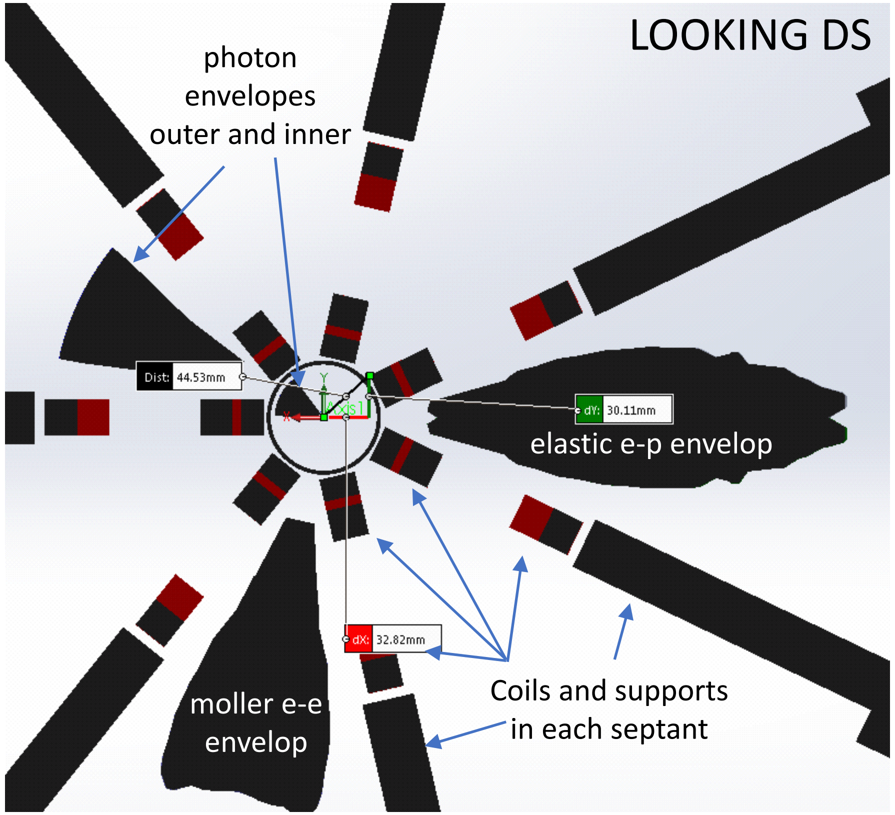


Keep Out Zones – showing coils in one septant - notional

Acceptance
defined by
collimator 2
(IPE by coll. 1)

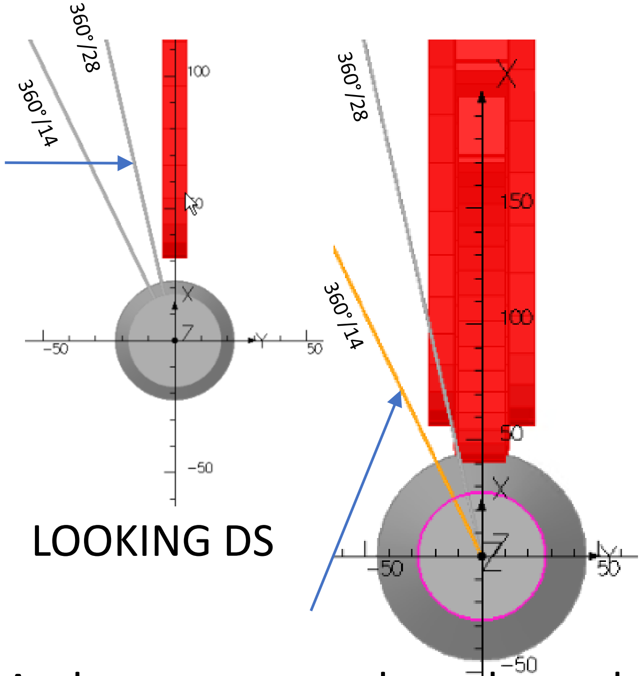
5x MS radius cones

Cross-section at z=6000 mm



At upstream end, tracks go between conductor, so can only fill half azimuth with conductor or supports

- Need to avoid interfering with the accepted electrons (maximize signal, simply defined angular acceptances)
- Also need to avoid interfering with the photon envelopes (reduce backgrounds)



At downstream end, tracks are bent to a larger radius than the conductor, so can fill the full azimuth

PDR Summary

The spectrometer system must

- Achieve the physics optics (bend particles) by
  - defining the angular acceptance in a well-defined way
  - separating the moller and elastic ep electrons
  - providing 3 kinematic regions of the inelastic electrons (to deconvolve the asymmetries)
- Shield the experiment by
  - minimizing the backgrounds at the detector
  - reducing the conductor epoxy and G10 filler dose from excessive radiation to acceptable levels
  - ensuring clean transport of the primary beam to the dump
- Operate for a long running time (344 PAC days)

- The acceptance of the moller electrons is defined at collimator 2
- The shape of the coils and the specified tolerances achieve the physics optics
- Field stability requirements modest due to averaging over time and cancellation b/c measuring asymmetry

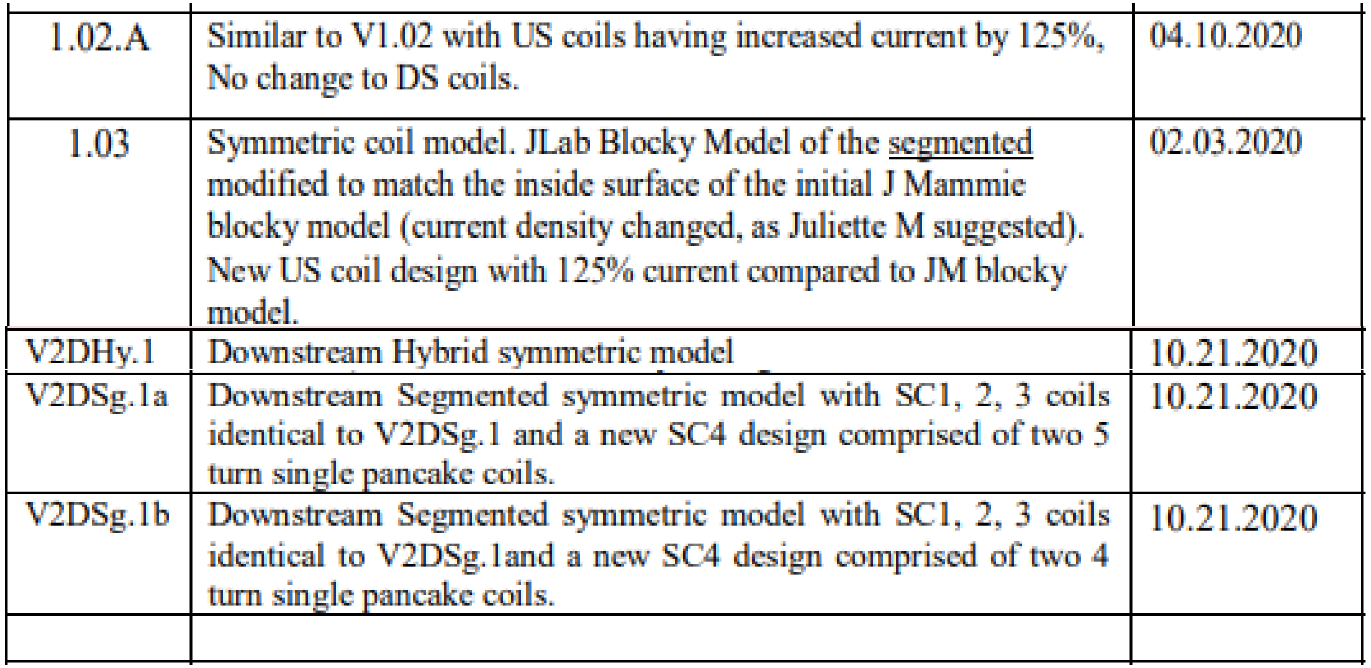
- Collimator 1 defines the primary beam through experiment to the dump
- Coils and supports obey > 5x multiple scattering radius by design
- The collimators, lintels and beam shields are all designed to minimize the backgrounds at the detector plane
- The shielding will be optimized* to shield the coil epoxy/ G10 filler as well to maintain shear and compressive strength

*The downstream coil conductor will not require modification to accommodate any of the proposed updated shielding configurations

Procedure for testing conductor configs

- JLAB produces conductor config (blocky version of CAD)
- Juliette reads in the conductor, produces map in TOSCA
- Sakib reads map into GEANT4 to run sims/do analysis

Purpose: to check whether reasonable changes to the segmented to improve engineering make a difference to the downselect



1.02.A	Similar to V1.02 with US coils having increased current by 125%, No change to DS coils.	04.10.2020
1.03	Symmetric coil model. JLab Blocky Model of the segmented modified to match the inside surface of the initial J Mammie blocky model (current density changed, as Juliette M suggested). New US coil design with 125% current compared to JM blocky model.	02.03.2020
V2DHy.1	Downstream Hybrid symmetric model	10.21.2020
V2DSg.1a	Downstream Segmented symmetric model with SC1, 2, 3 coils identical to V2DSg.1 and a new SC4 design comprised of two 5 turn single pancake coils.	10.21.2020
V2DSg.1b	Downstream Segmented symmetric model with SC1, 2, 3 coils identical to V2DSg.1and a new SC4 design comprised of two 4 turn single pancake coils.	10.21.2020

V1U.2a_V1DSg.3

V1U.2a_V2DHy

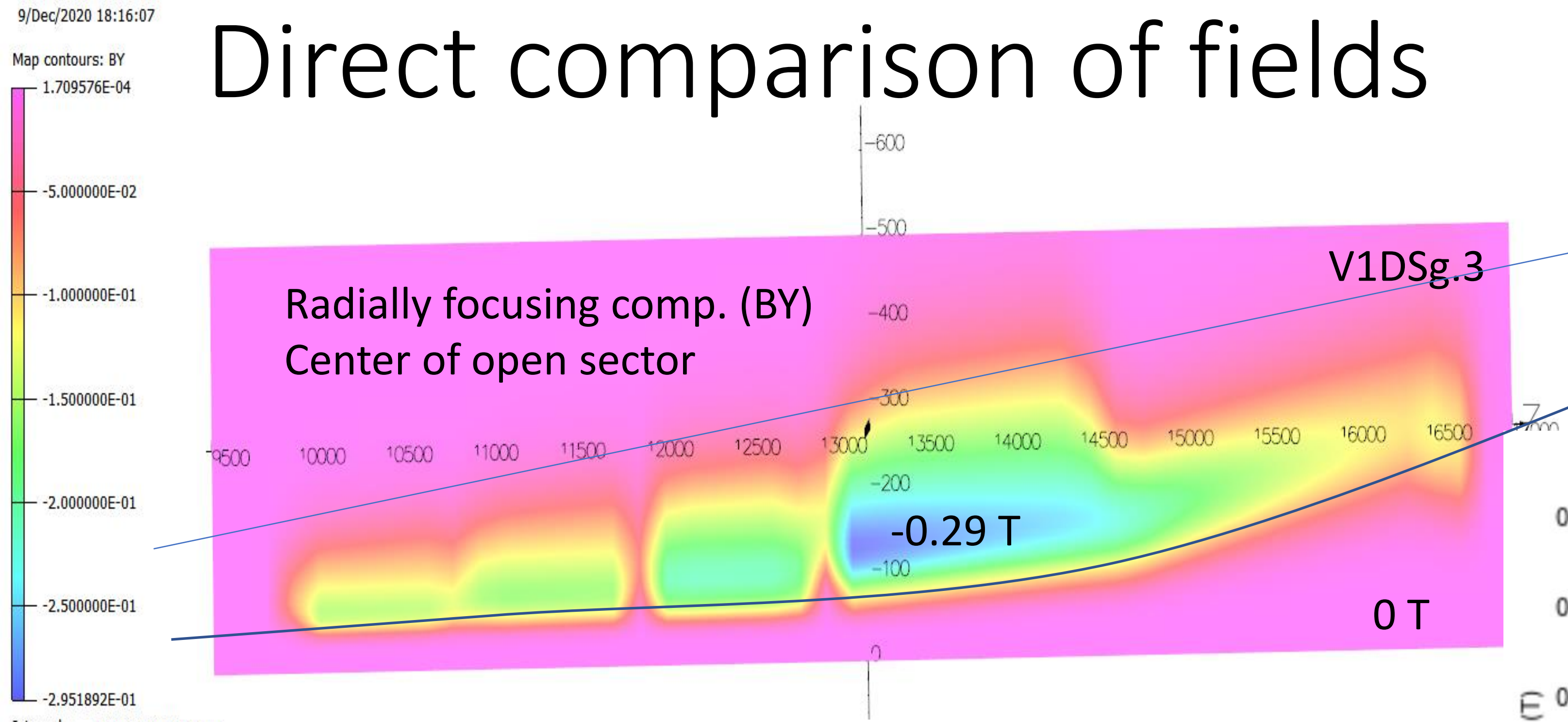
V1U.2a_V2DSg.1a

V1U.2a_V2DSg.1b

Configuration labels

Direct comparison of fields

Approximate path of moller tracks

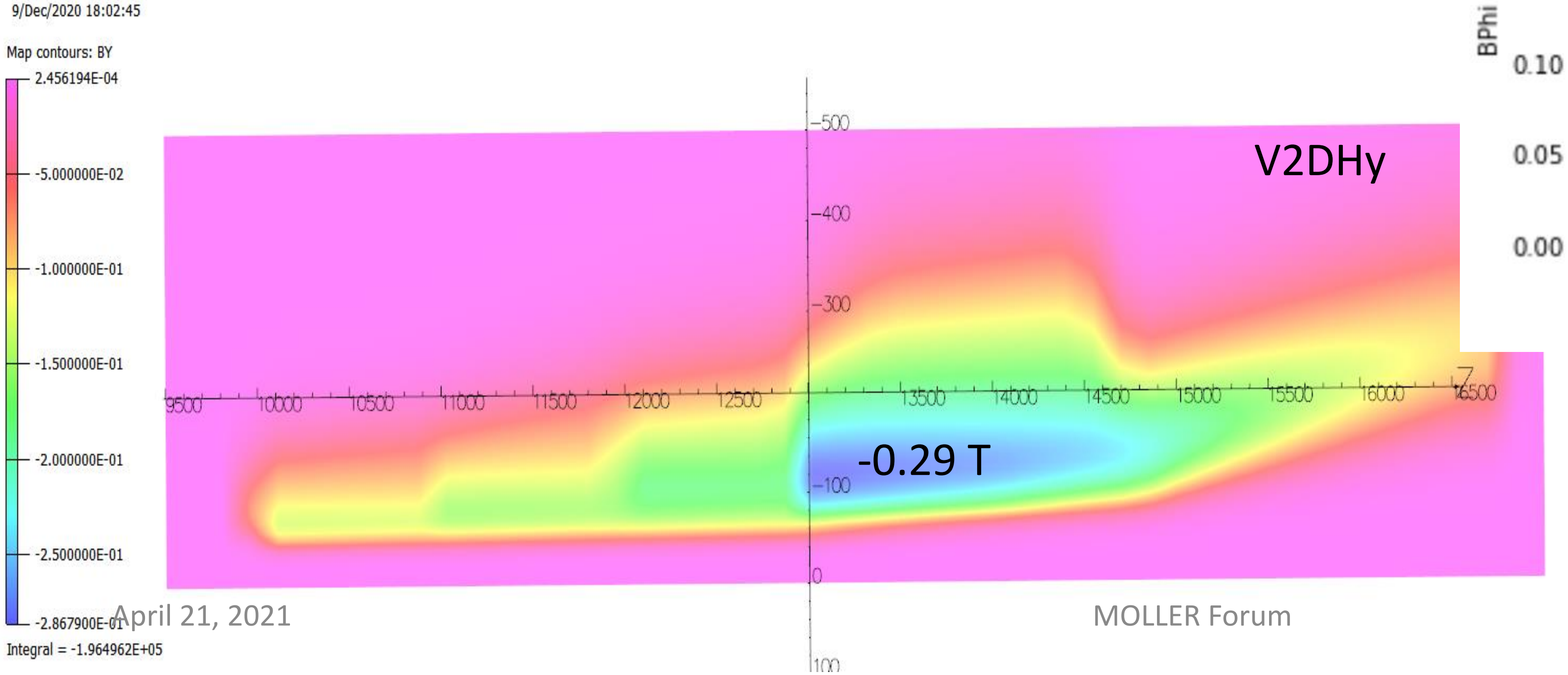


Radially focusing comp. (BY)
Center of open sector

V1DSg.3

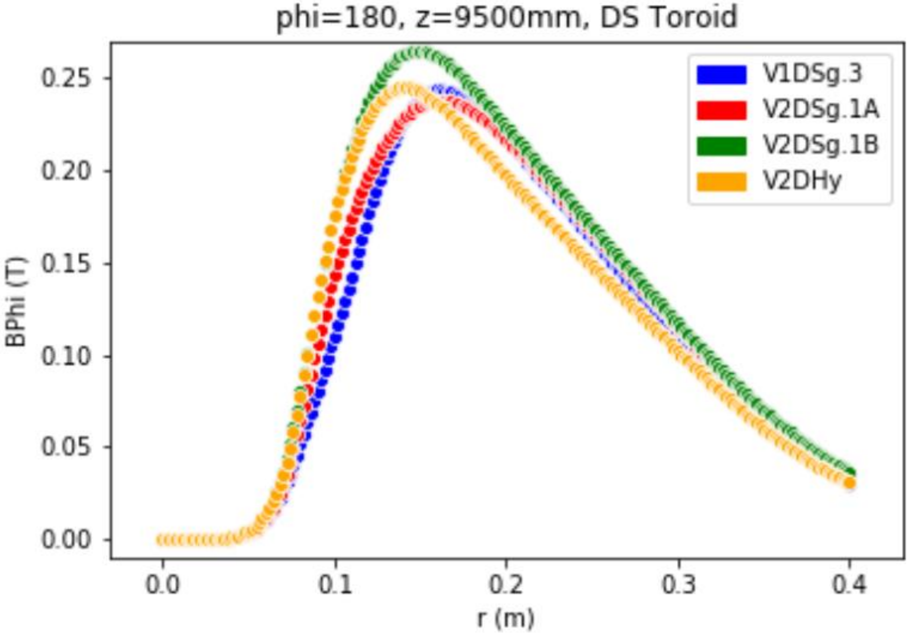
-0.29 T

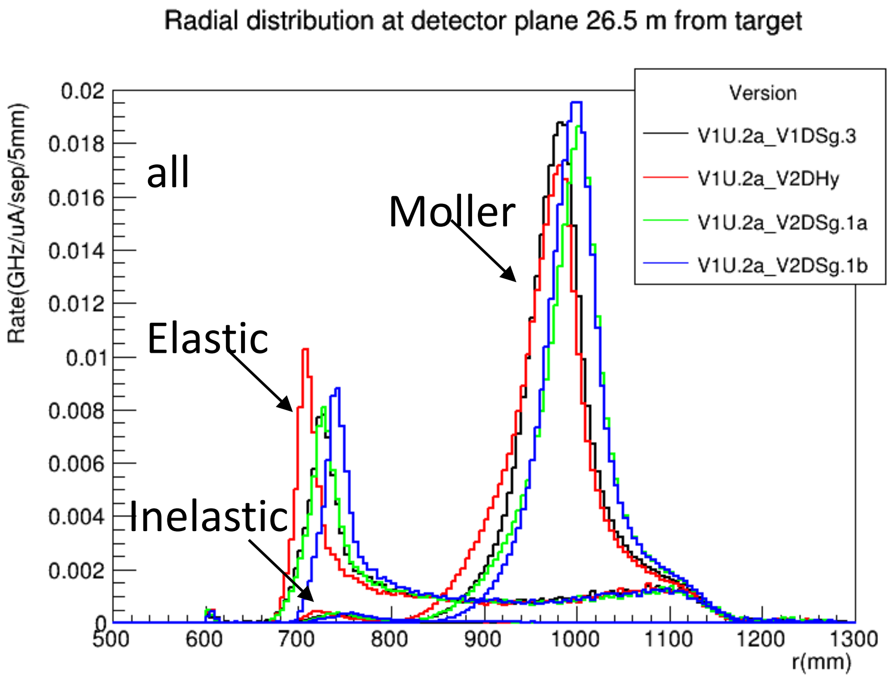
0 T

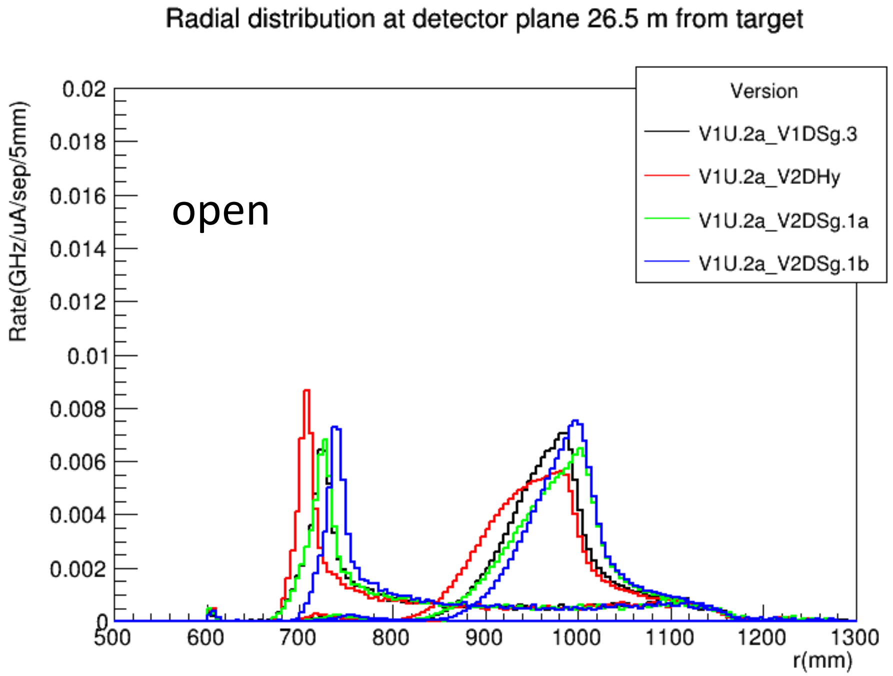


V2DHy

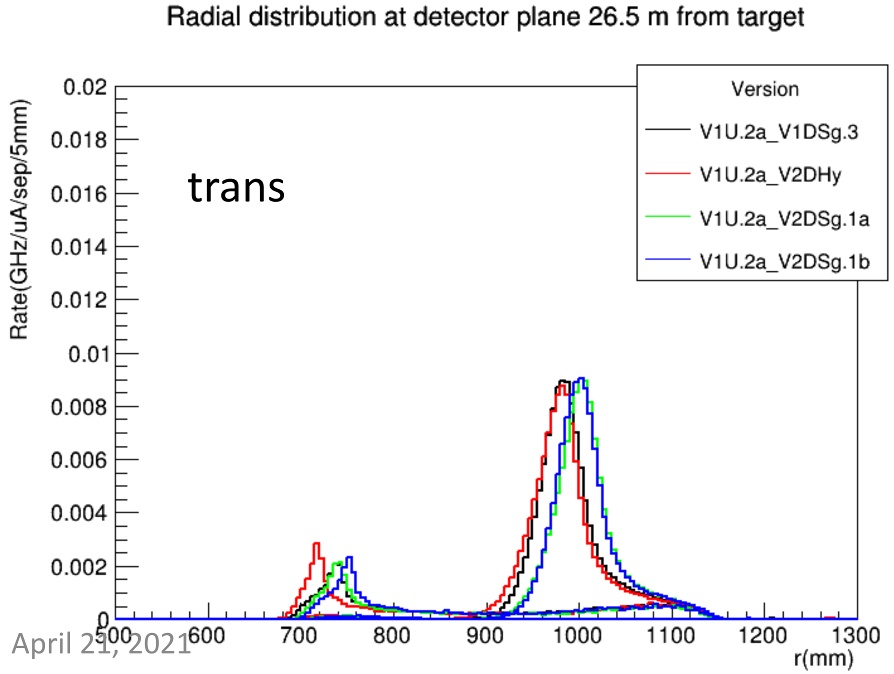
-0.29 T

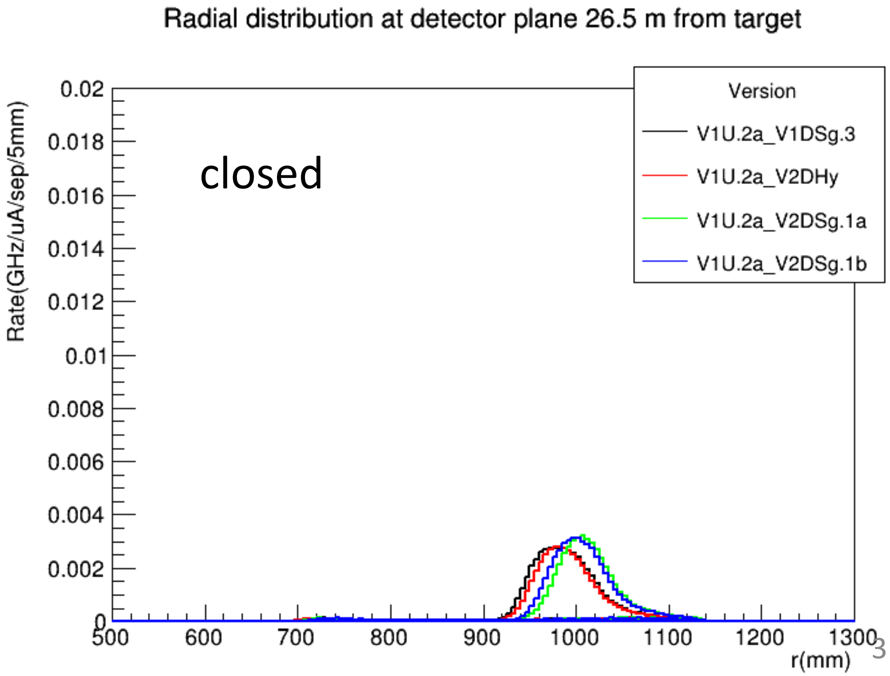


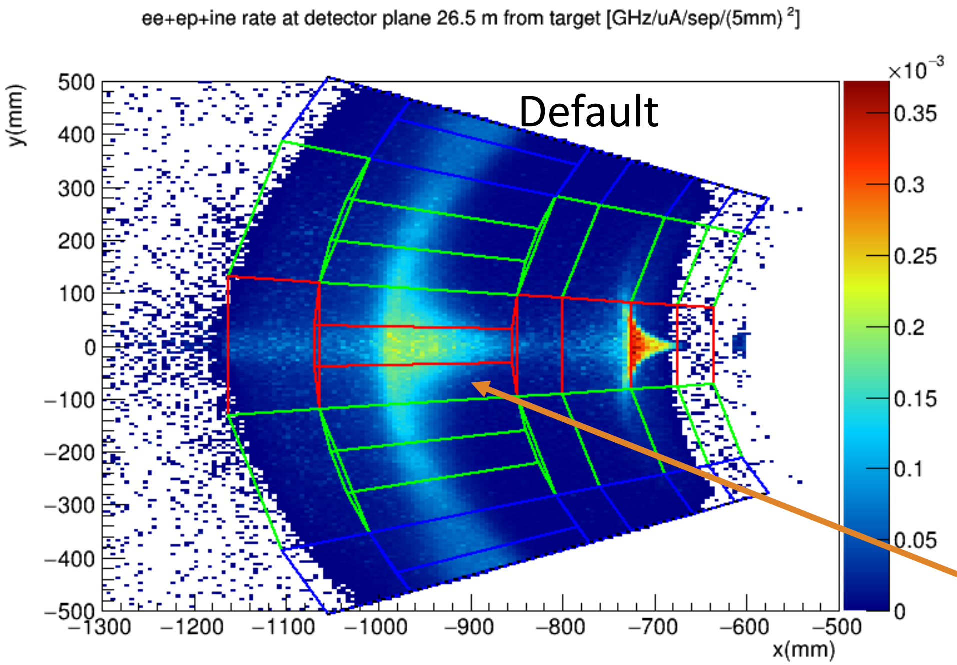




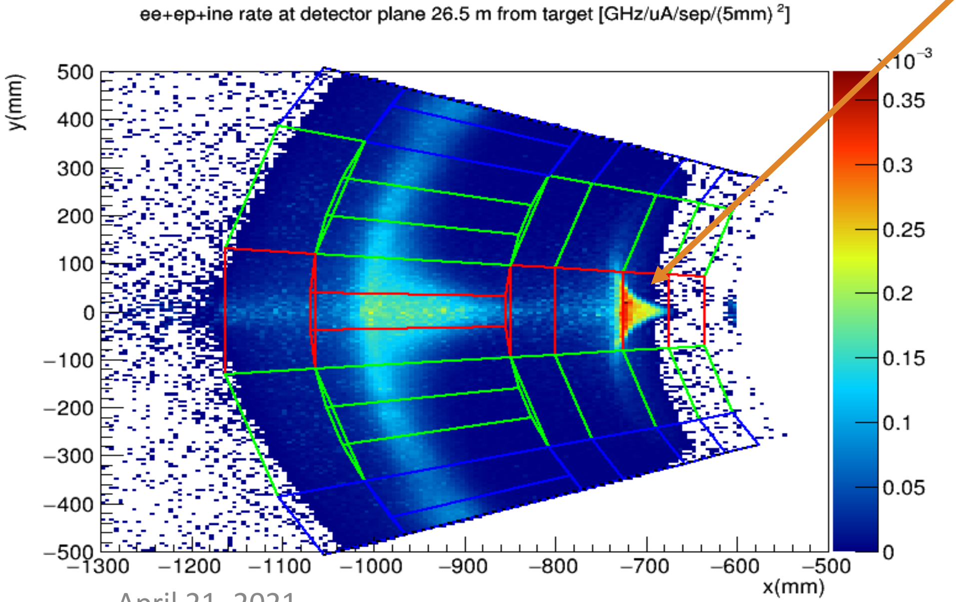
Radial distributions by process in the different φ sectors






ee+ep+ine rate at detector plane 26.5 m from target [GHz/uA/sep/(5mm) ^{2}]

V1U.2a_V1DSg.3

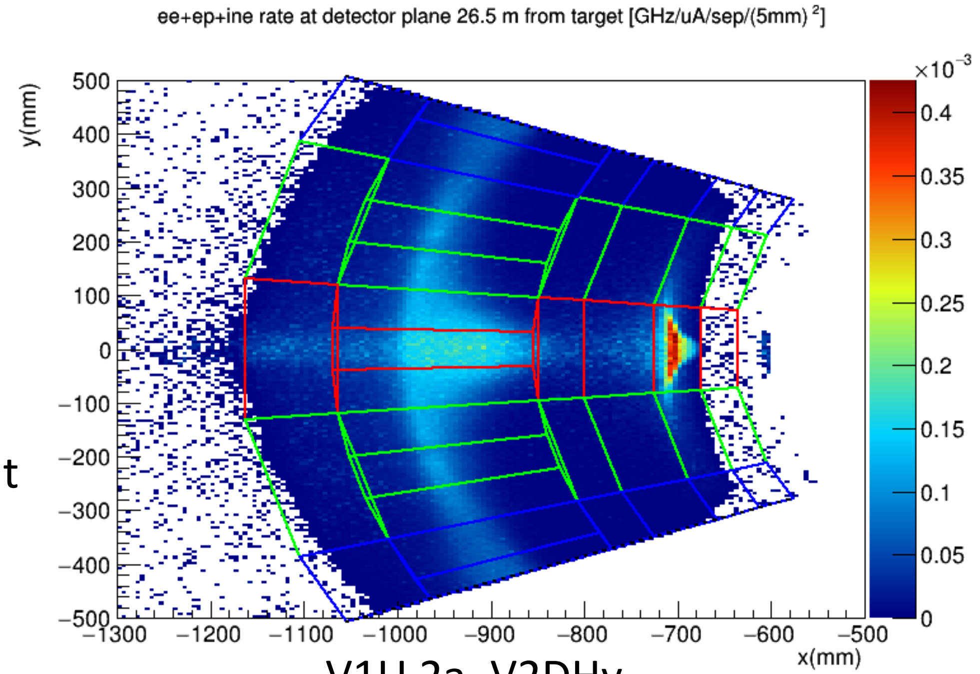

ee+ep+ine rate at detector plane 26.5 m from target [GHz/uA/sep/(5mm) ^{2}]

V1U.2a_V1DSg.1a

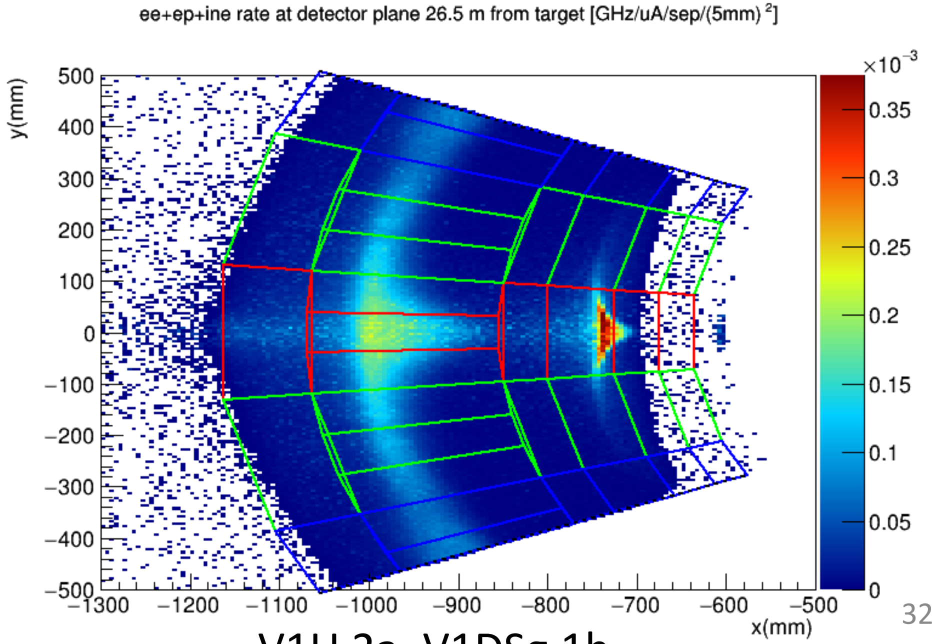
2D distributions at detector plane

Moller: Ring 5
Elastic ep: Ring 2

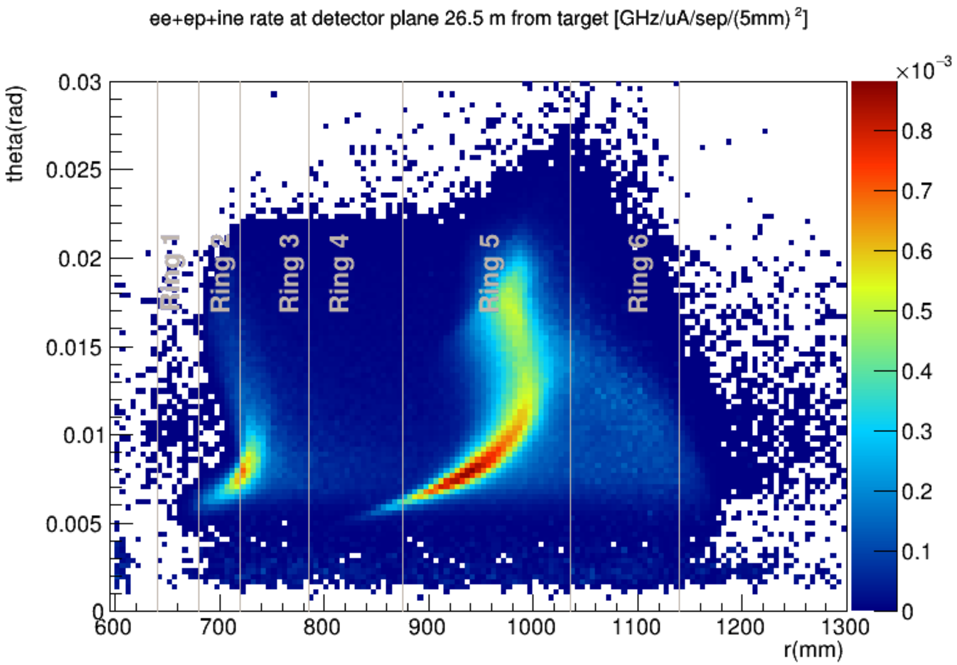
Red: Open
Blue: Closed
Green: Trans.


ee+ep+ine rate at detector plane 26.5 m from target [GHz/uA/sep/(5mm) ^{2}]

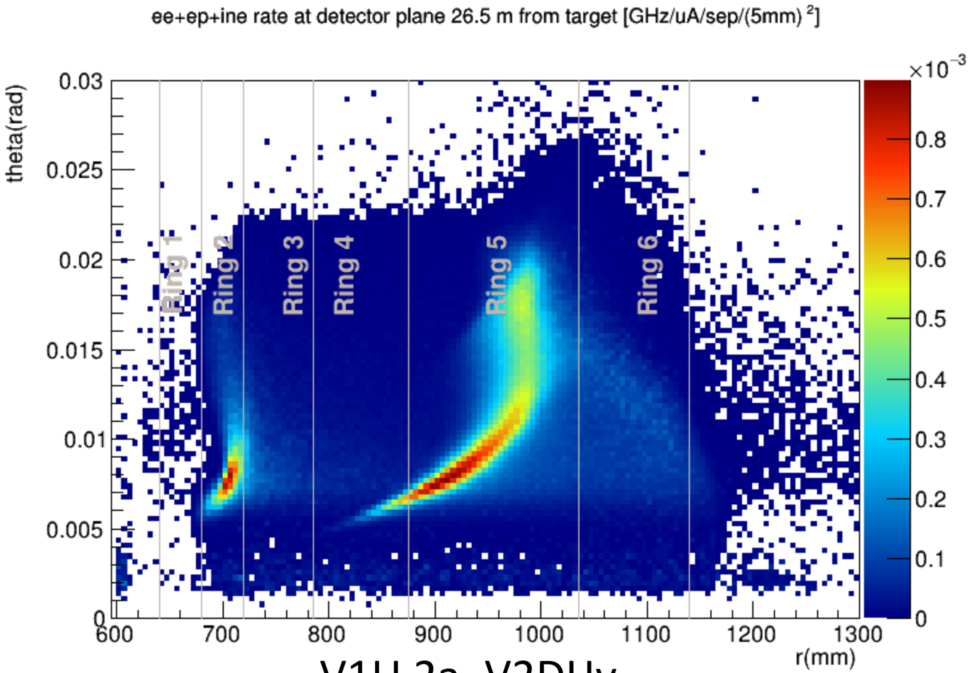
V1U.2a_V2DHy


ee+ep+ine rate at detector plane 26.5 m from target [GHz/uA/sep/(5mm) ^{2}]

V1U.2a_V1DSg.1b



V1U.2a_V1DSg.3

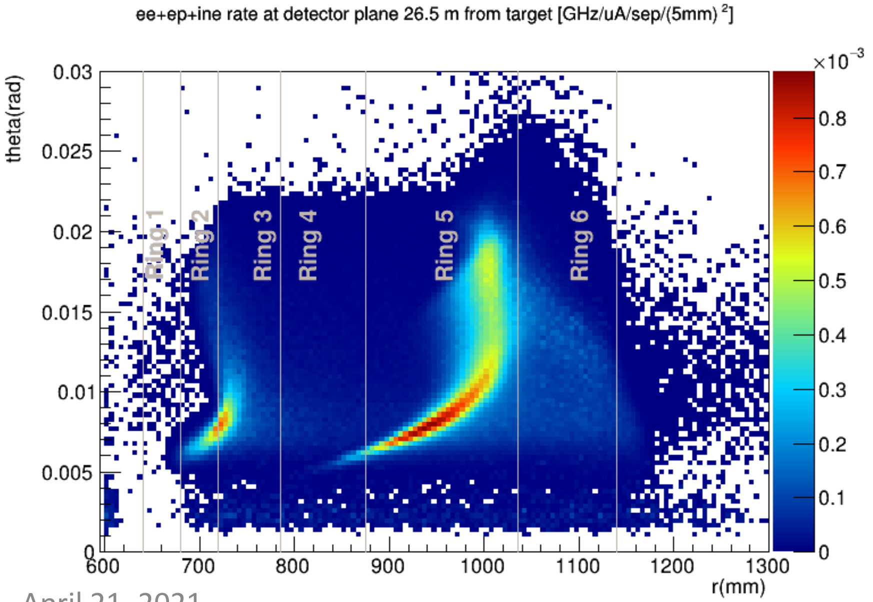


V1U.2a_V2DHy

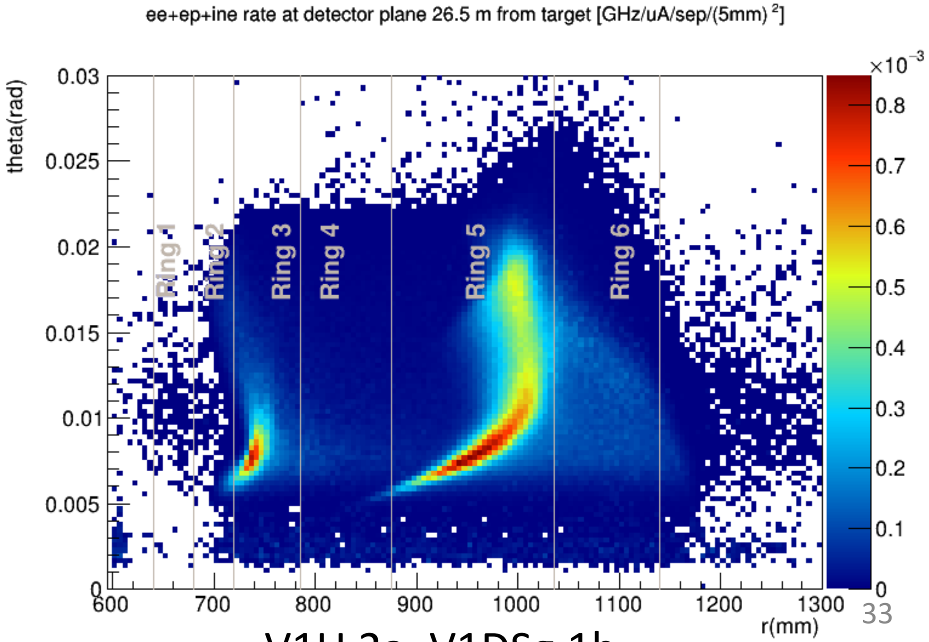
θ-r distributions at detector plane

Approximate radial ring def’ns shown

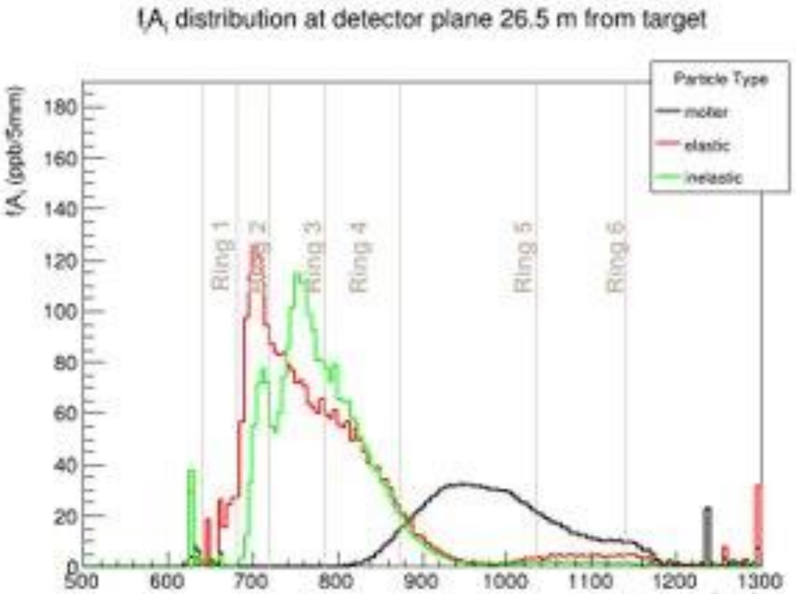
Moller: Ring 5
Elastic ep: Ring 2



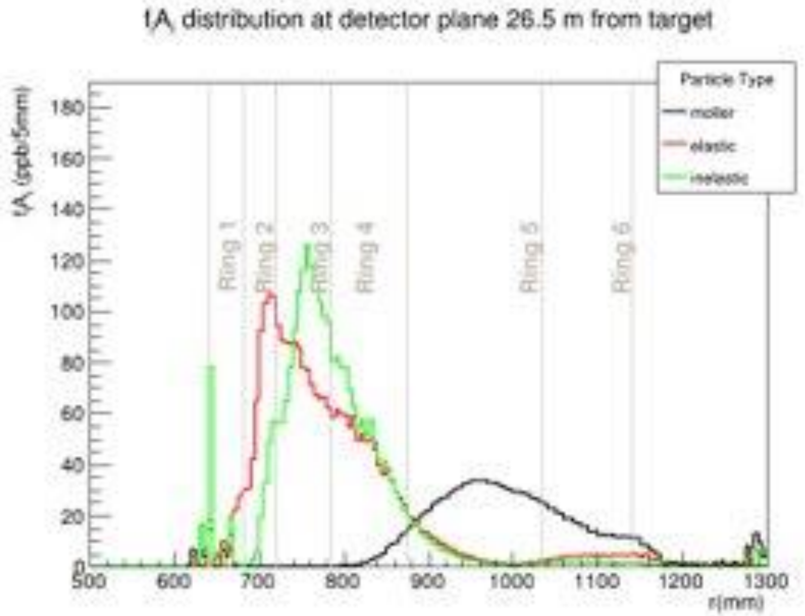
V1U.2a_V1DSg.1a



V1U.2a_V1DSg.1b



V1U.2a_V1DSg.3



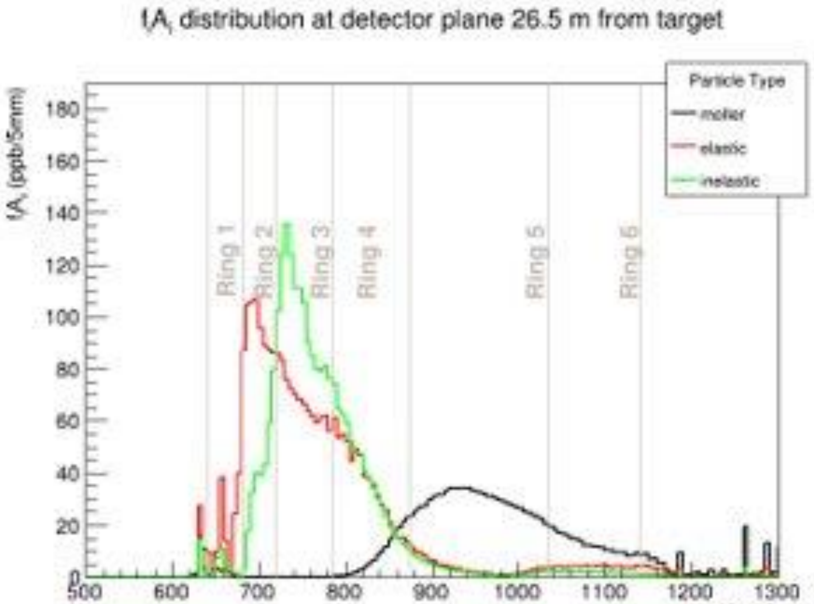
V1U.2a_V2DSg.1b

⬛ moller
🟥 elastic
🟩 inelastic

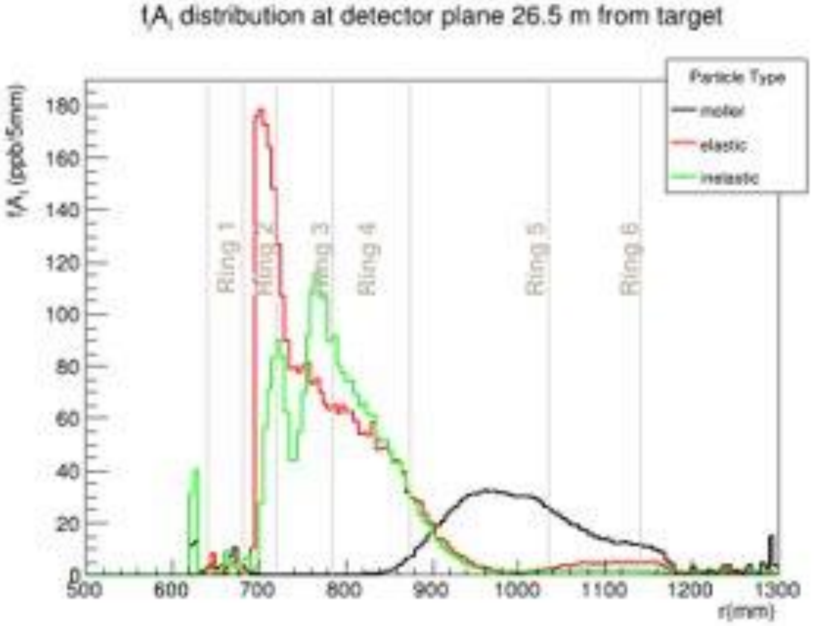
$f_i A_i$ distributions at detector plane

Approximate radial ring def’ns shown

Moller: Ring 5
Elastic ep: Ring 2



V1U.2a_V2DHy



V1U.2a_V2DSg.1b

Deconvolution study summary

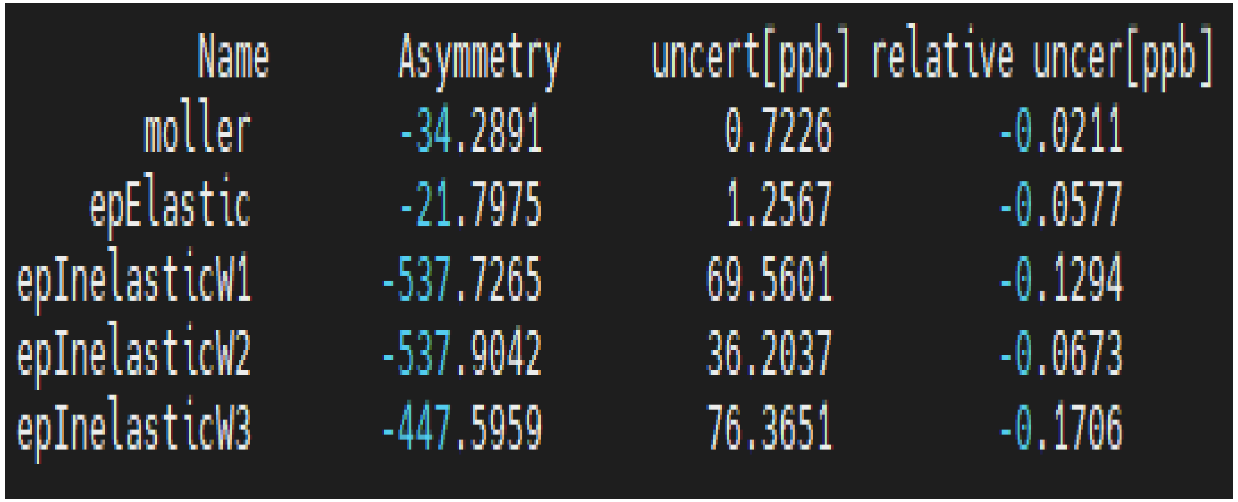
		Relative uncertainty			
	Process	**V1U.2a_V1DSg3**	**V1U.2a_V2DHy**	**V1U.2a_V2DSg.1a**	**V1U.2a_V2DSg.1b**
Primaries only	Møller	0.0211	0.0210	0.0212	0.0211
	e-p Elastic	0.0577	0.0560	0.0515	0.0614
	e-p Inelastic (W1)	0.1294	0.1529	0.1249	0.1370
	e-p Inelastic (W2)	0.0673	0.0681	0.0638	0.0709
	e-p Inelastic (W3)	0.1706	0.1658	0.1662	0.1742
Secondaries	Møller	0.0214	0.0214	0.0217	0.0215
	e-p Elastic	0.0631	0.0618	0.0560	0.0680
	e-p Inelastic (W1)	0.1495	0.1779	0.1413	0.1576
	e-p Inelastic (W2)	0.0804	0.0823	0.0752	0.0876
	e-p Inelastic (W3)	0.2309	0.2279	0.2313	0.2420
		Segmented	Hybrid	Alternate Segmented	

- The relative uncertainty on the moller asymmetry is the same between hybrid and segmented
- There is no *significant* difference between the hybrid and segmented from a physics perspective
- a slight preference for the segmented

- Changes for engineering concerns do affect the focal plan distributions
- Adjusting the detector tiling allows us to achieve the same relative uncertainty on the moller asymmetry

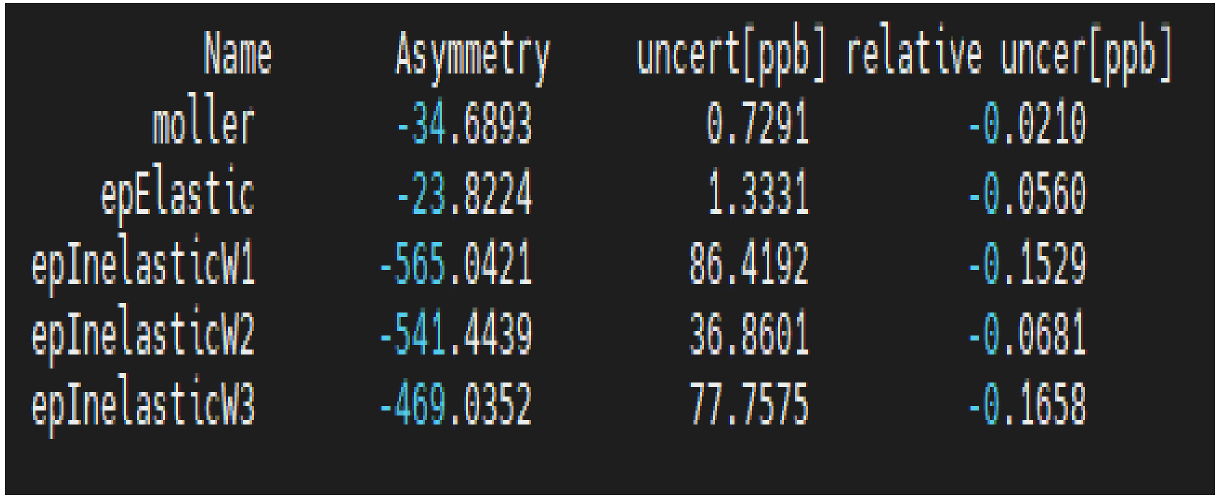
Recommend segmented configuration as new baseline

5 process deconvolution (Using only primaries)



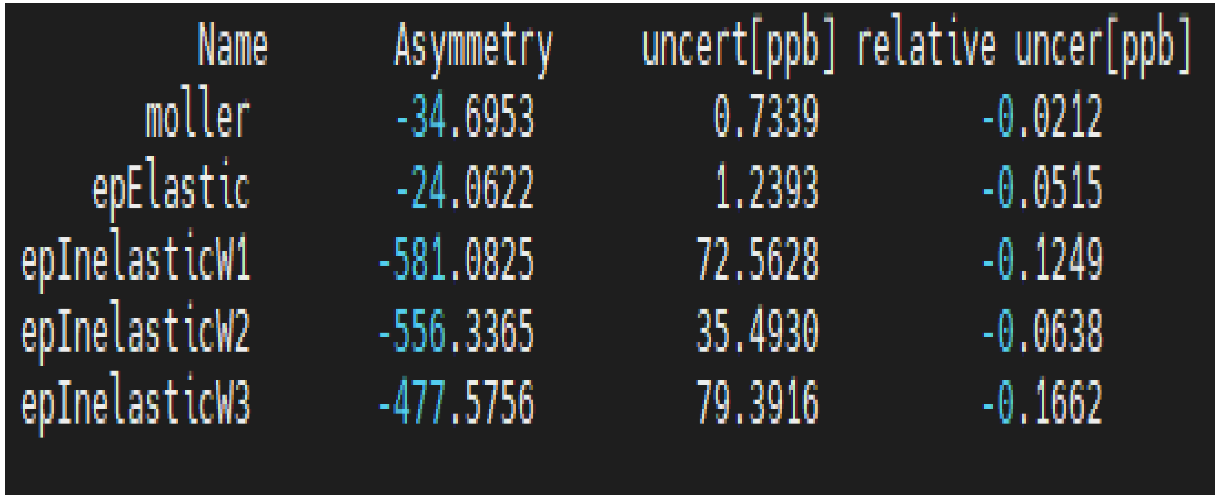
```
          Name      Asymmetry   uncert[ppb] relative uncer[ppb]
        moller       -34.2891        0.7226            -0.0211
     epElastic       -21.7975        1.2567            -0.0577
epInelasticW1       -537.7265       69.5601            -0.1294
epInelasticW2       -537.9042       36.2037            -0.0673
epInelasticW3       -447.5959       76.3651            -0.1706
```

V1U.2a_V1DSg.3



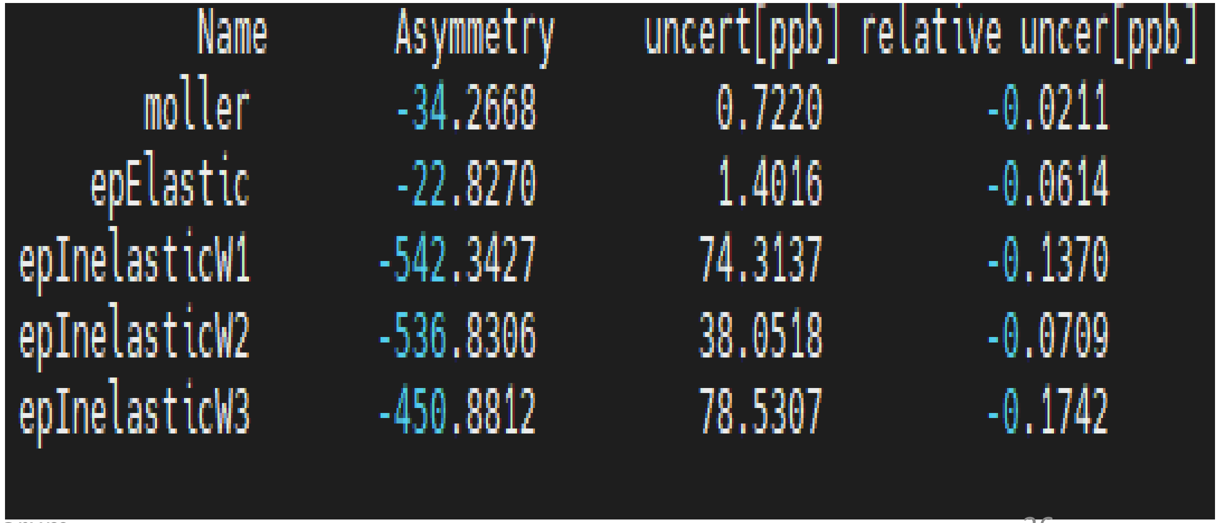
```
          Name      Asymmetry   uncert[ppb] relative uncer[ppb]
        moller       -34.6893        0.7291            -0.0210
     epElastic       -23.8224        1.3331            -0.0560
epInelasticW1       -565.0421       86.4192            -0.1529
epInelasticW2       -541.4439       36.8601            -0.0681
epInelasticW3       -469.0352       77.7575            -0.1658
```

V1U.2a_V2DHy



```
          Name      Asymmetry   uncert[ppb] relative uncer[ppb]
        moller       -34.6953        0.7339            -0.0212
     epElastic       -24.0622        1.2393            -0.0515
epInelasticW1       -581.0825       72.5628            -0.1249
epInelasticW2       -556.3365       35.4930            -0.0638
epInelasticW3       -477.5756       79.3916            -0.1662
```

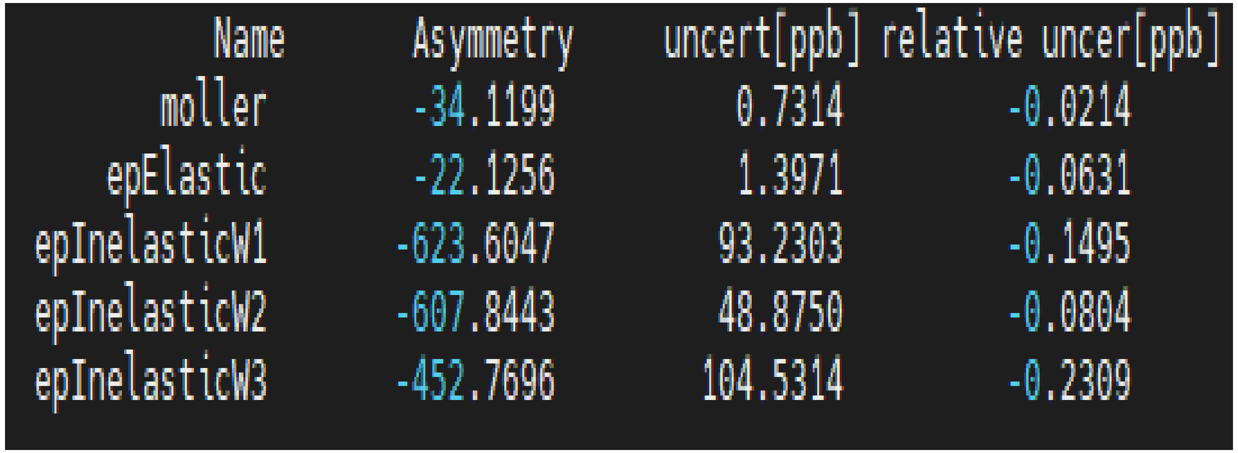
V1U.2a_V2DSg.1a



```
          Name      Asymmetry   uncert[ppb] relative uncer[ppb]
        moller       -34.2668        0.7220            -0.0211
     epElastic       -22.8270        1.4016            -0.0614
epInelasticW1       -542.3427       74.3137            -0.1370
epInelasticW2       -536.8306       38.0518            -0.0709
epInelasticW3       -450.8812       78.5307            -0.1742
```

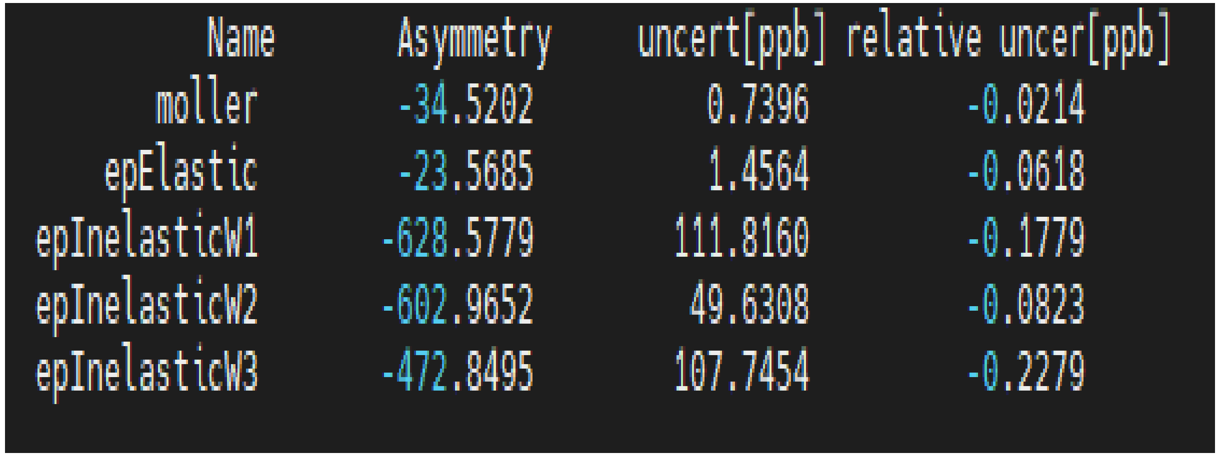
V1U.2a_V2DSg.1b

5 process deconvolution (including secondaries)



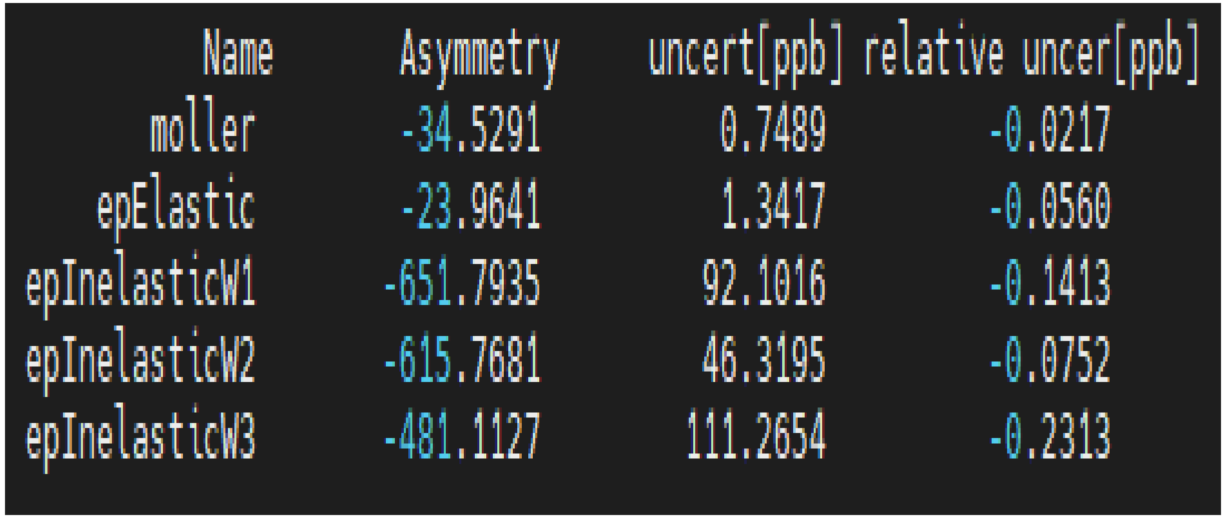
```
        Name       Asymmetry   uncert[ppb] relative uncer[ppb]
      moller        -34.1199        0.7314          -0.0214
   epElastic        -22.1256        1.3971          -0.0631
epInelasticW1      -623.6047       93.2303          -0.1495
epInelasticW2      -607.8443       48.8750          -0.0804
epInelasticW3      -452.7696      104.5314          -0.2309
```

V1U.2a_V1DSg.3



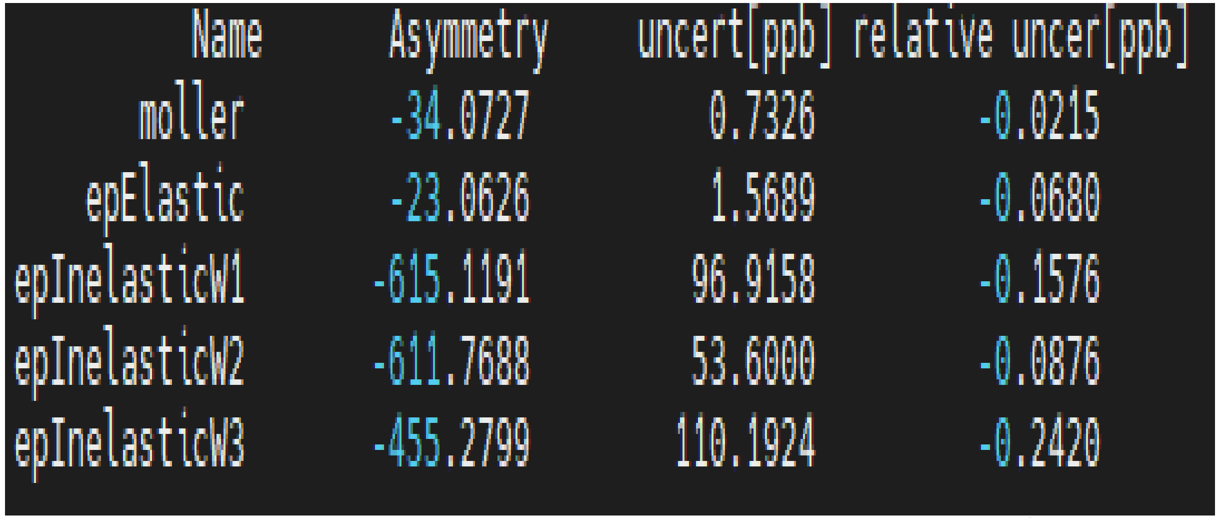
```
        Name       Asymmetry   uncert[ppb] relative uncer[ppb]
      moller        -34.5202        0.7396          -0.0214
   epElastic        -23.5685        1.4564          -0.0618
epInelasticW1      -628.5779      111.8160          -0.1779
epInelasticW2      -602.9652       49.6308          -0.0823
epInelasticW3      -472.8495      107.7454          -0.2279
```

V1U.2a_V2DHy



```
        Name       Asymmetry   uncert[ppb] relative uncer[ppb]
      moller        -34.5291        0.7489          -0.0217
   epElastic        -23.9641        1.3417          -0.0560
epInelasticW1      -651.7935       92.1016          -0.1413
epInelasticW2      -615.7681       46.3195          -0.0752
epInelasticW3      -481.1127      111.2654          -0.2313
```

V1U.2a_V2DSg.1a



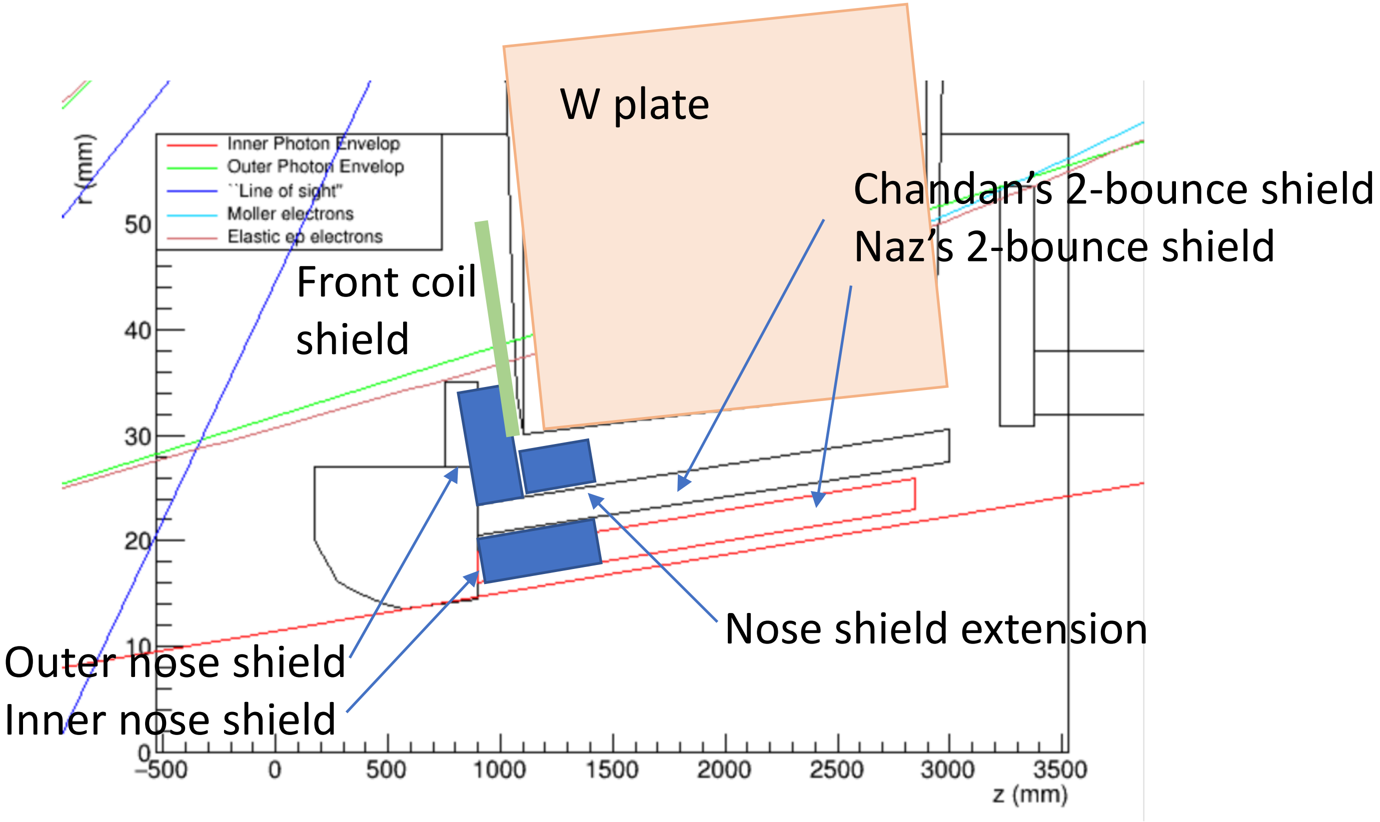
```
        Name       Asymmetry   uncert[ppb] relative uncer[ppb]
      moller        -34.0727        0.7326          -0.0215
   epElastic        -23.0626        1.5689          -0.0680
epInelasticW1      -615.1191       96.9158          -0.1576
epInelasticW2      -611.7688       53.6000          -0.0876
epInelasticW3      -455.2799      110.1924          -0.2420
```

V1U.2a_V2DSg.1b

Conclusion

- The relative uncertainty on the moller asymmetry is the same between hybrid and segmented (0.0214)
  - There is no *significant* difference between the hybrid and segmented from a physics perspective
  - a slight preference for the segmented
- Changes for engineering concerns do affect the distributions at the detector plane
  - Adjusting the detector tiling allows us to achieve the same relative uncertainty on the moller asymmetry (0.0217, 0.0215)

Recommendation: segmented configuration as new baseline



W plate

Front coil shield

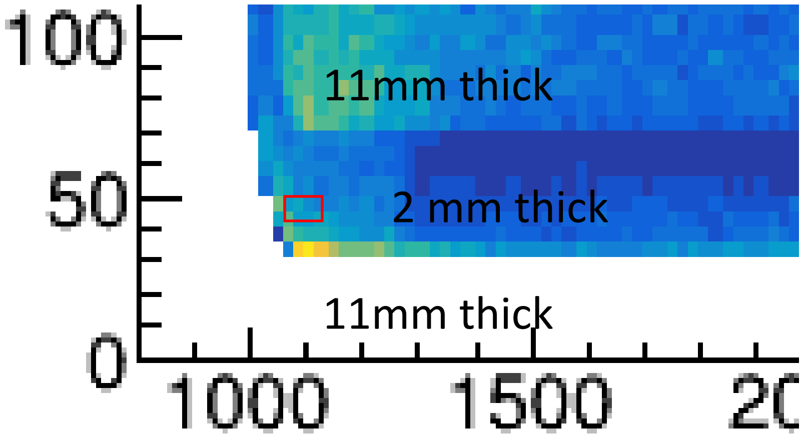
Chandan's 2-bounce shield

Naz's 2-bounce shield

Nose shield extension

Outer nose shield

Inner nose shield



11mm thick

2 mm thick

11mm thick

- Default: Use Chandan's 2-bounce shield (black), the merged collimator 1+2, and the extended 2mm thick W plates
- Try larger region near hottest spot (reproduce the table – check dose calculations, use larger region for more statistics)

New sims:

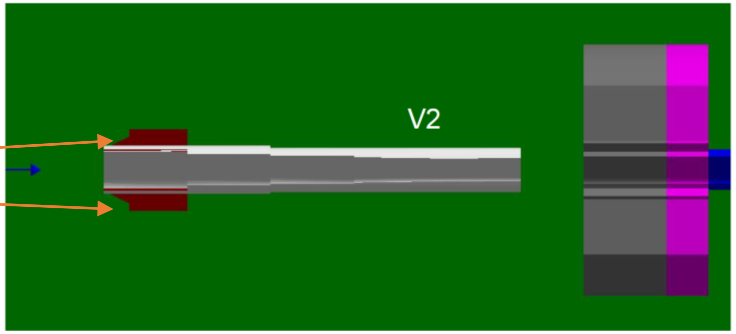
- Nose shield
    - Inner nose shield
    - Outer nose shield
    - Nose shield extension

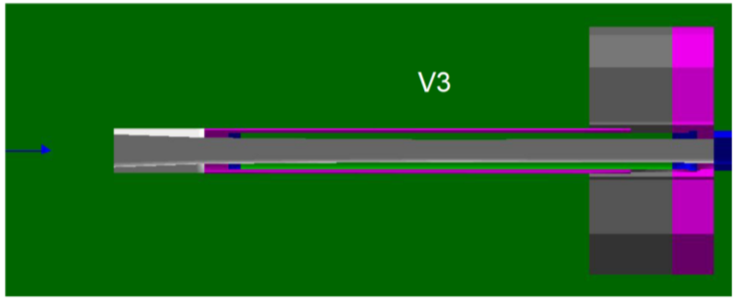
Radial thickness, length along z

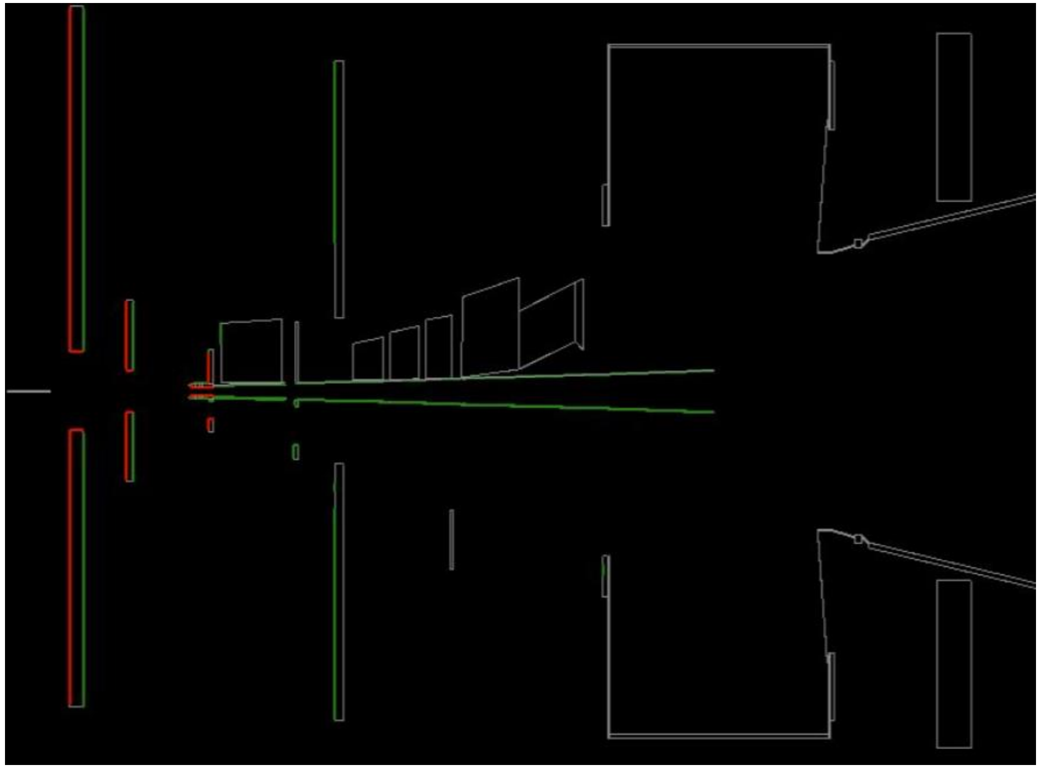
- Different thickness and material for 2 bounce shield (dose vs different thickness)
- Different W plate thicknesses (how does 1 or 1.5 mm work)

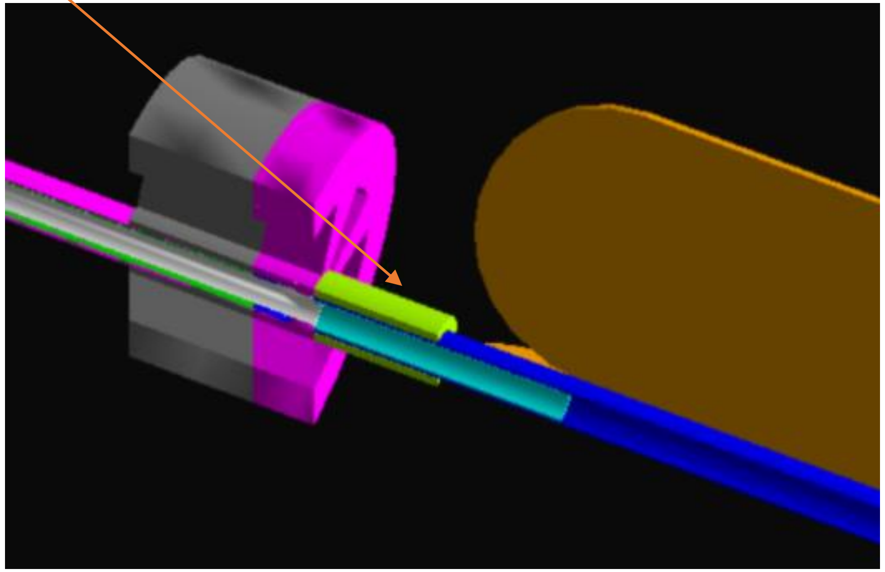
Collimator/epoxy shield updates

- Col 1+2 merge (fins were a source of rate at upstream coil)
- Upstream region shielding (W plates and nose shield)
- Downstream region
  - coll 5, 2-bounce/septapus, $e^{\pm}$ spokes



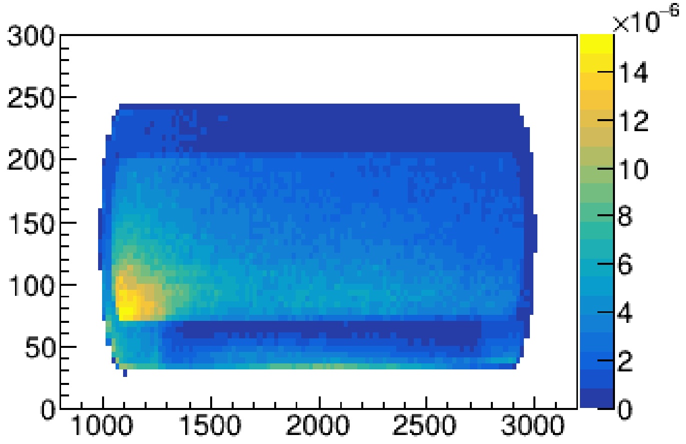


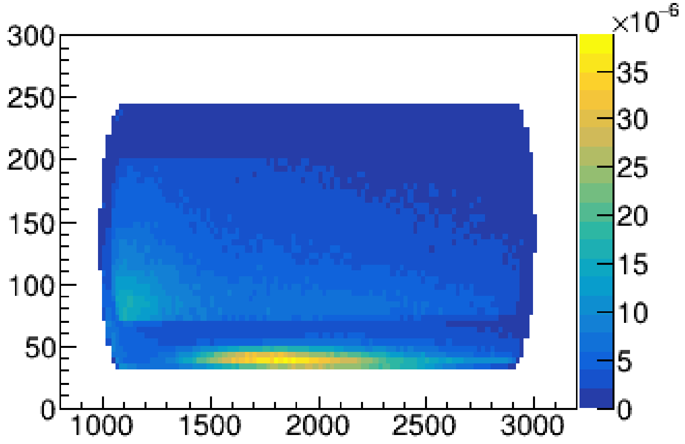




Power deposition in the us epoxy

Appendix

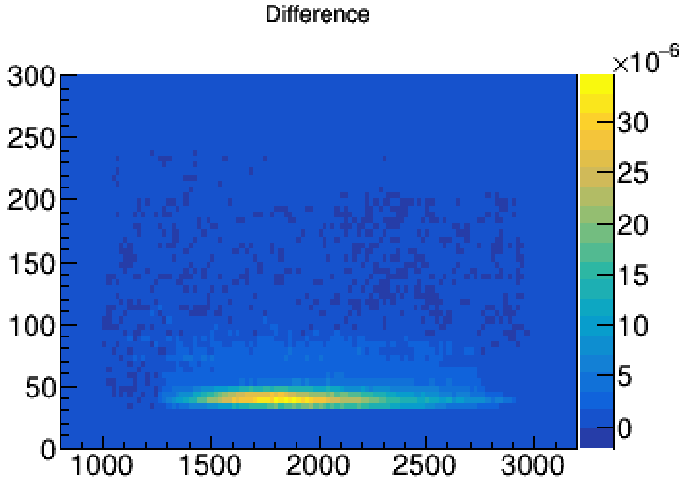

Energy Deposited In Tungsten Plated Coil (W/uA/(5x20x2)mm^3)

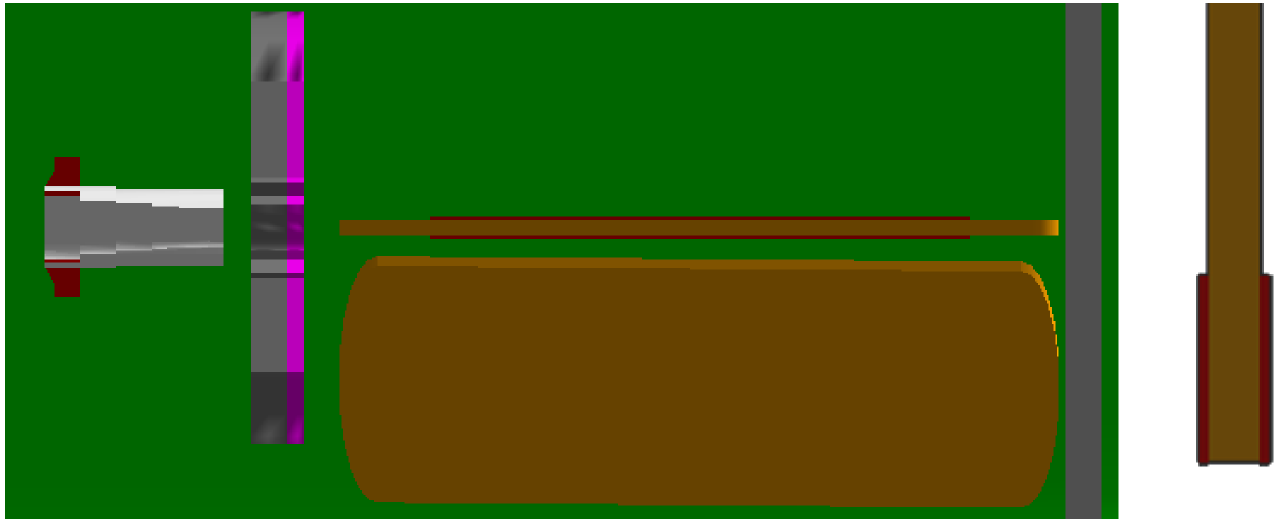

Energy Deposited In Unshielded Coil (W/uA/(5x20x2)mm^3)

2 mm tungsten plating (both sides of coil)
factor of ~8 suppression of middle hot spot

$$P\left[\frac{W}{\mu A}/bin\right]\cdot 7.42\times 10^{6} = Dose[MGy]$$

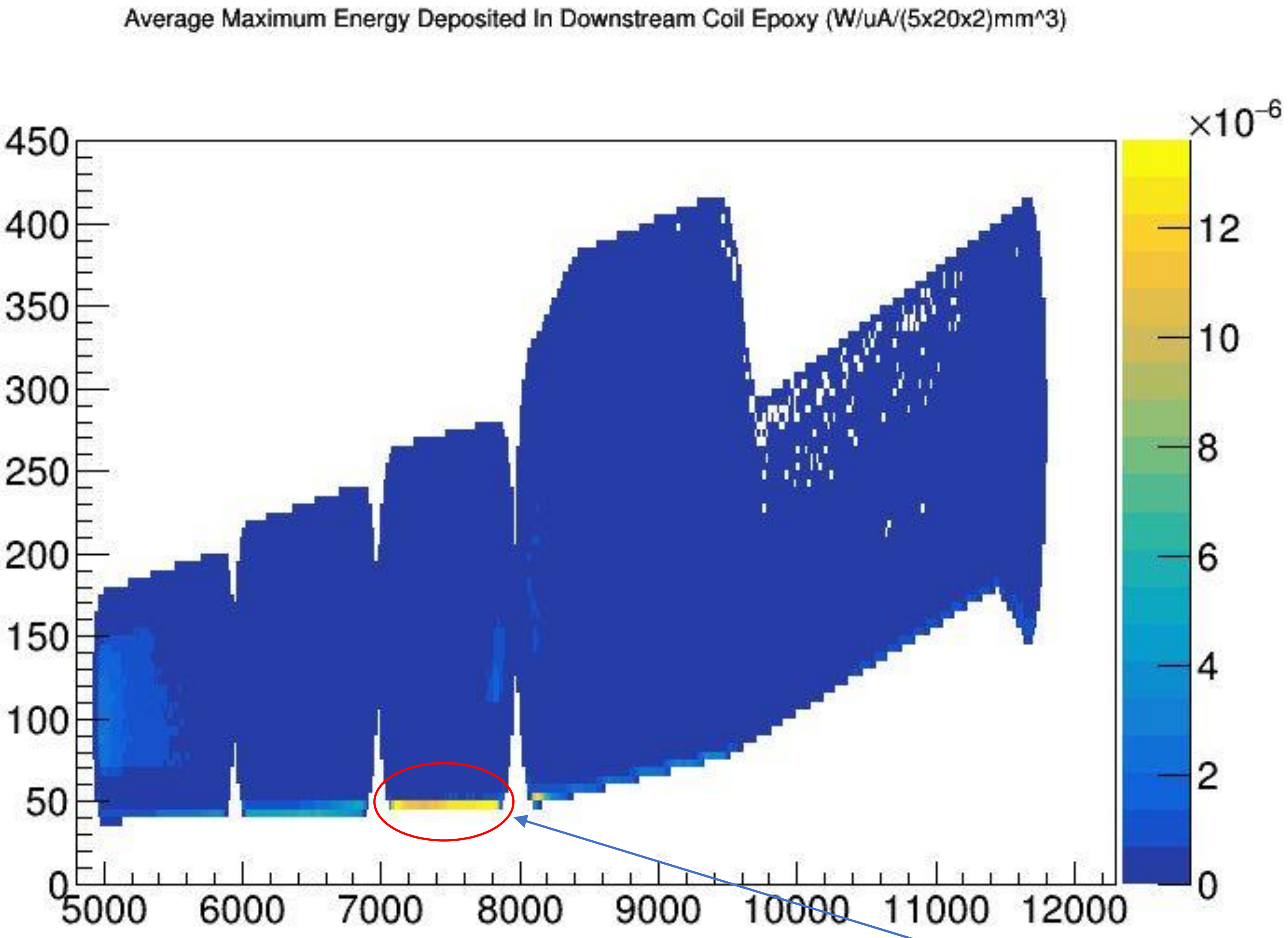
estimate of maximum dose:
$5\mu W \cdot 7.42\times 10^{6} = 37 \text{ MGy}$


Difference



What about the ds toroid?

Appendix

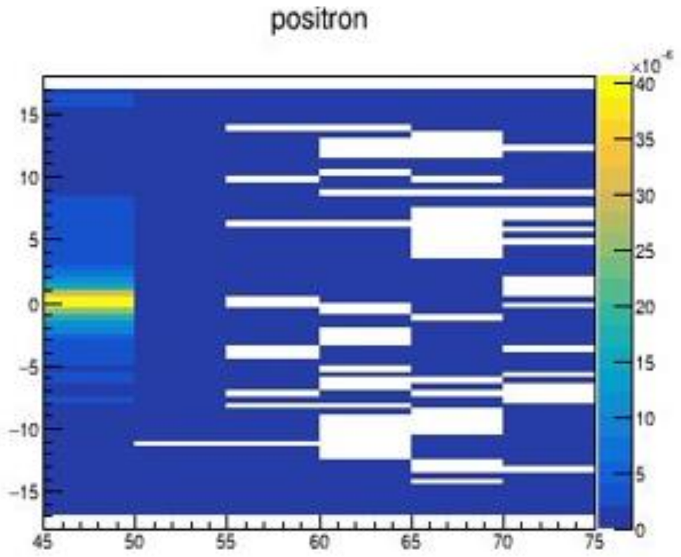


in coil segment 3, the approximate volume of epoxy in a “hot region” pixel is

$$
\begin{aligned}
&2mm \times (4 \times 20mm^2) \\
&+ 33mm \times (1 \times 20mm^2) \\
&= 820mm^3
\end{aligned}
$$

Estimate of maximum dose:

$$13.6\mu W \cdot 1.81 \times 10^6 = 25\ \mathrm{MGy}$$



“middle” hot region

Epoxy Resin tolerance to radiation

Recommendation by
R. Fair, 08.15.20, after review of reference materials by D. Kashy and E. Sun

Table shows shear strength of glass cloth and copper, impregnated with CTD403 @ 70°C

Comparing cases with the copper both PRIMED and UNPRIMED with CTD450

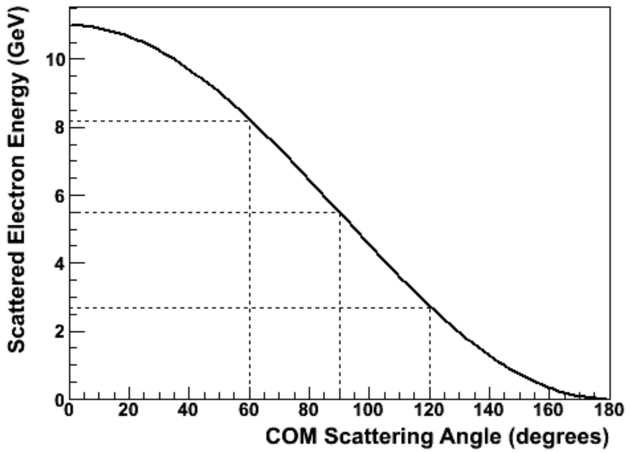
Irradiated shear strength with priming: higher than unprimed, unradiated CTD403

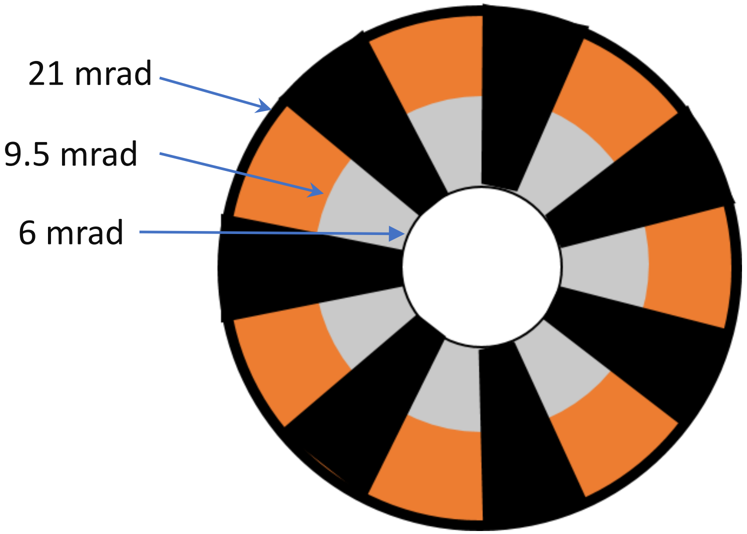
Radiation Dose	Shear strength of Cu	
	Unprimed	Primed
0 MGy	43.6 MPa	71.9 MPa
60 MGy	37 MPa	61 Mpa*

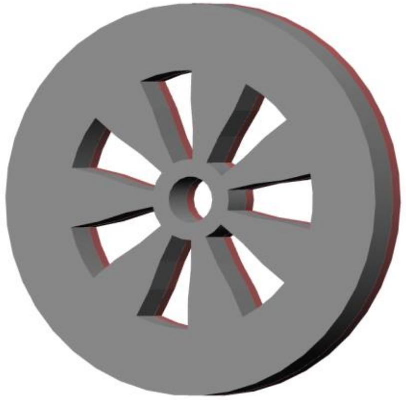
→ (i.e. a 15 % reduction)

* Using the same 15 % reduction in strength

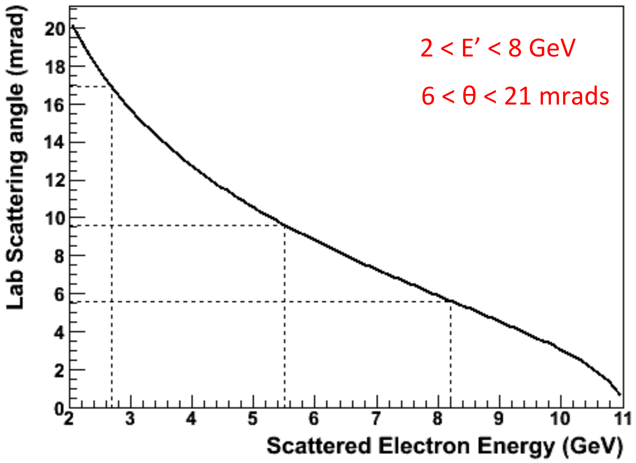
100% Azimuthal Acceptance Possible



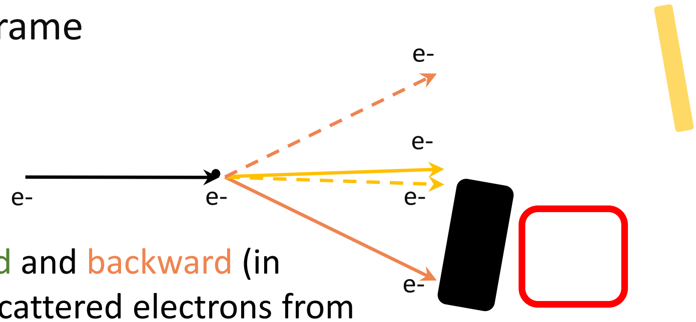




Acceptance defining collimator



Lab Frame



Detectors in open sectors

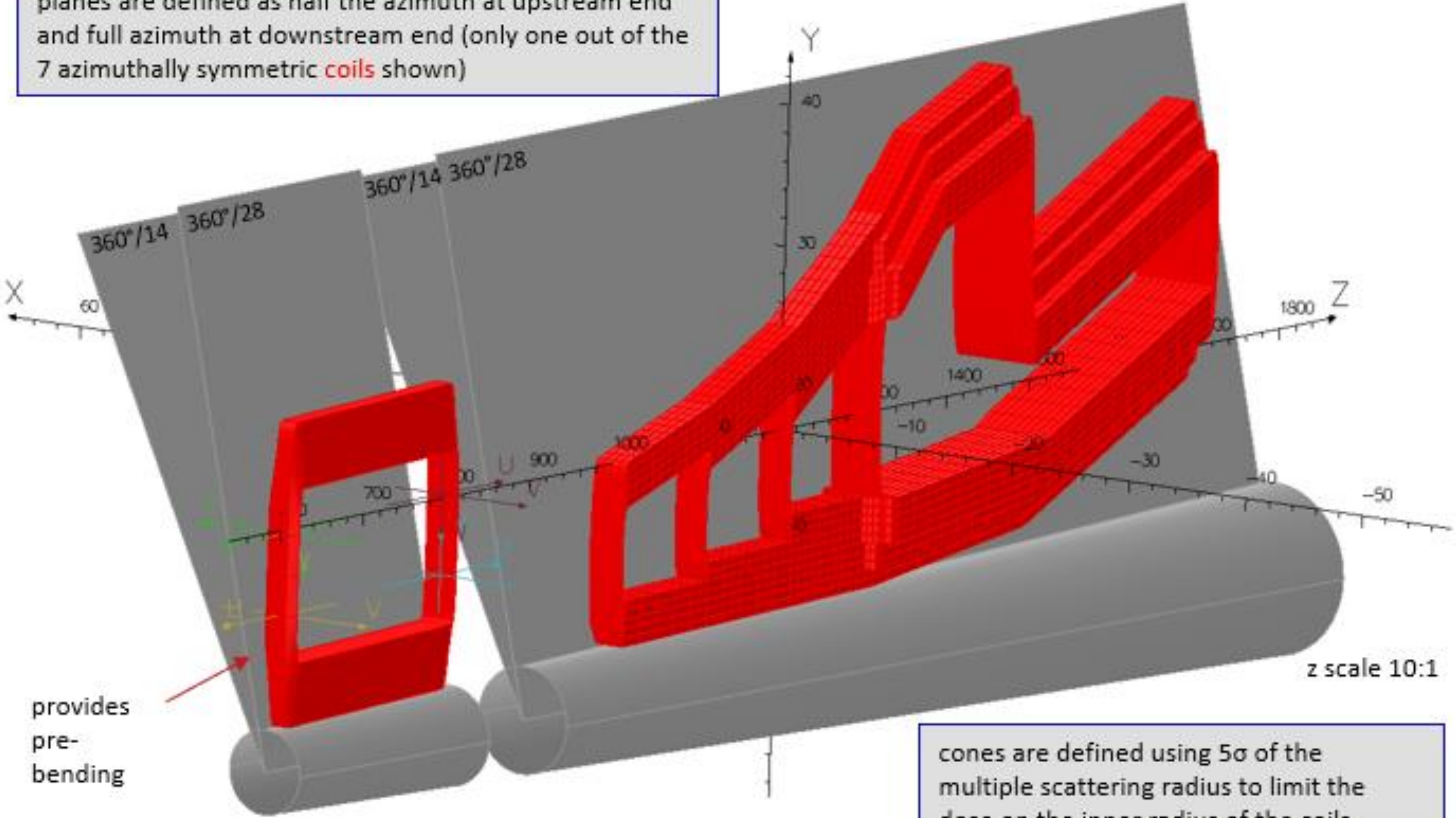
Forward and backward (in COM) scattered electrons from two events (line type links electrons from same event)

Coils in closed sectors

Any odd number of coils will allow for 100% φ acceptance

Conductor Layout (Current Distribution)

Appendix



planes are defined as half the azimuth at upstream end and full azimuth at downstream end (only one out of the 7 azimuthally symmetric coils shown)

provides pre-bending

z scale 10:1

cones are defined using 5σ of the multiple scattering radius to limit the dose on the inner radius of the coils

Collimators

Appendix

Collimators and beam shields are designed to provide a 2-bounce system to eliminate line of sight photons to detectors

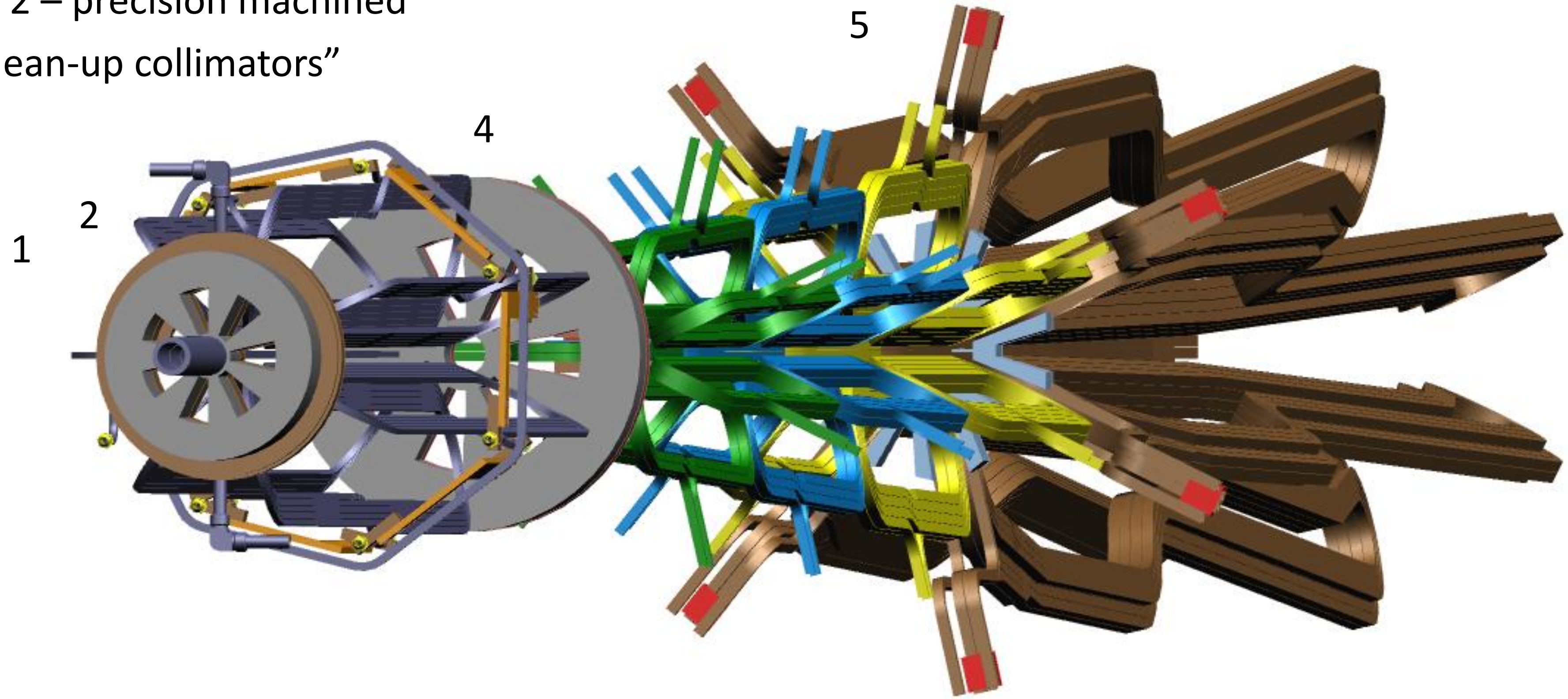
Pb rings at large radius downstream are to shield detectors from bkgds

In addition, "blockers" at collimator 2 will be used for systematic studies

Collimator 1 – water-cooled

Collimator 2 – precision machined

4, 5 are "clean-up collimators"

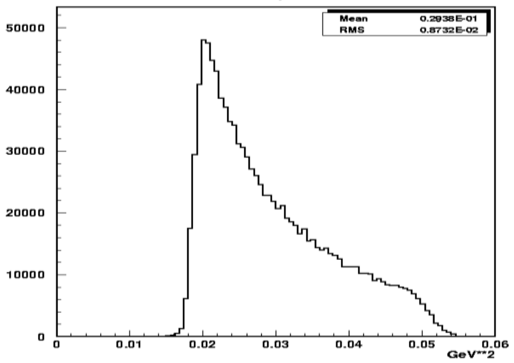


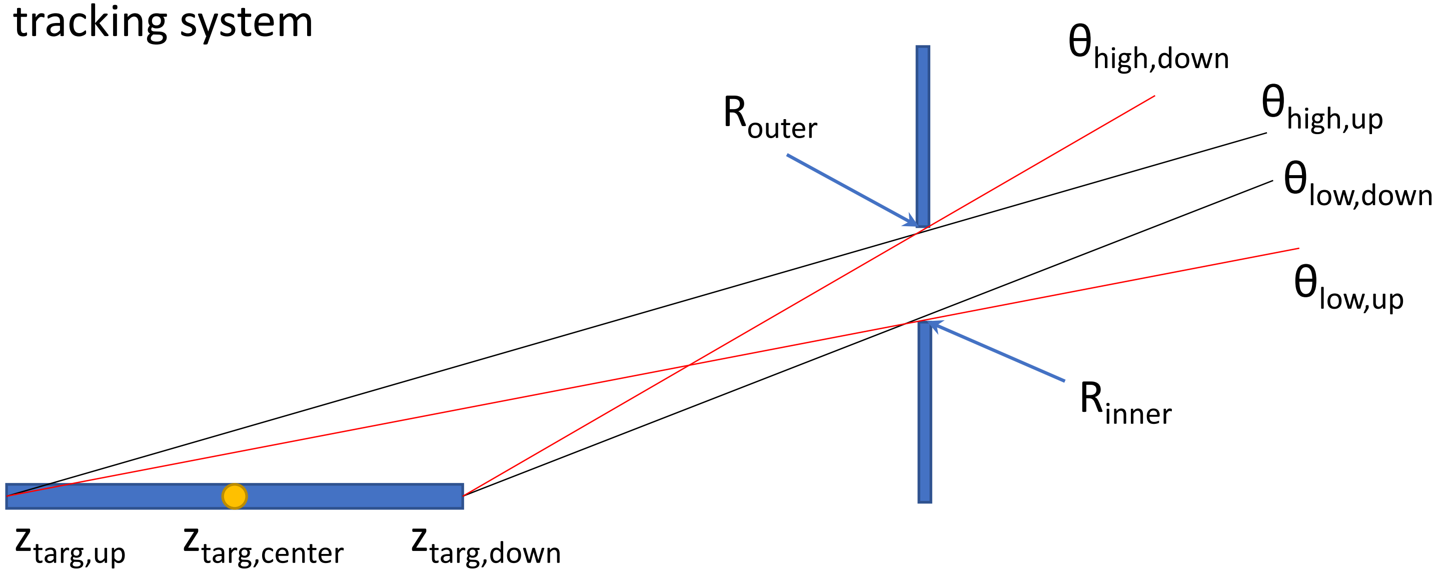
Finite Target Effects

Appendix

- The acceptance varies along the length of the target
- Requires mapping with the tracking system

Expected Q^2 distribution





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

θ_{low} = 5.5 mrad
θ_{high} = 17 mrad

$\Rightarrow$

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

$\Rightarrow$

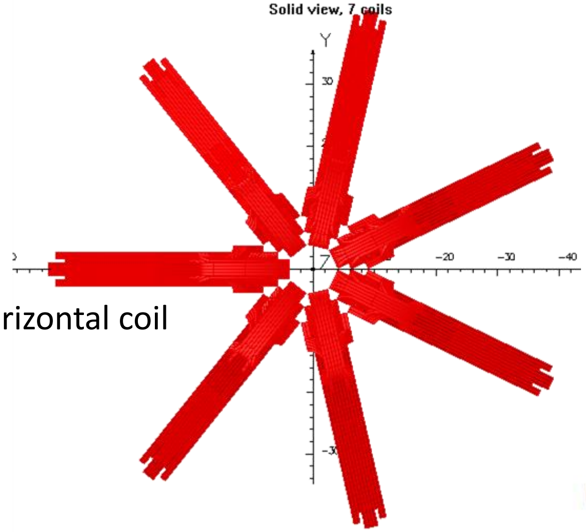
$\theta_{low,cen}$ = 6.2 mrads
$\theta_{high,cen}$ = 19.2 mrads

$\theta_{low,down}$ = 7.1 mrads
$\theta_{high,down}$ = 21 mrads

z_{coll} = 590 cm

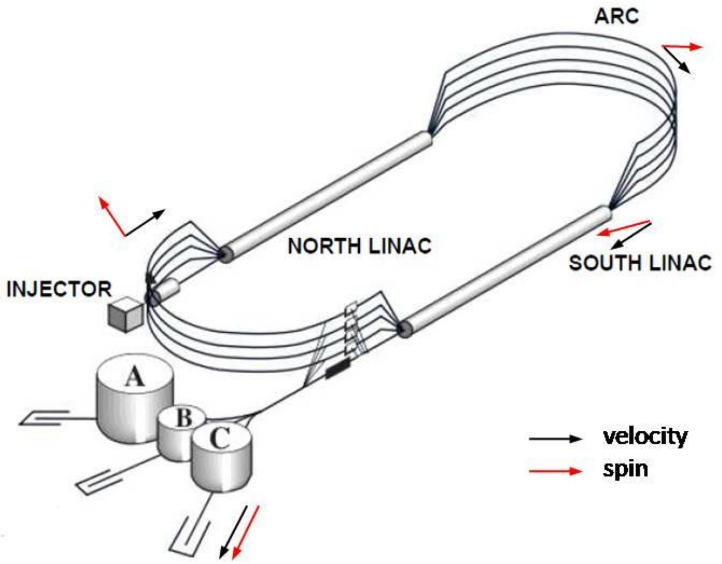
Sector Orientation

Appendix

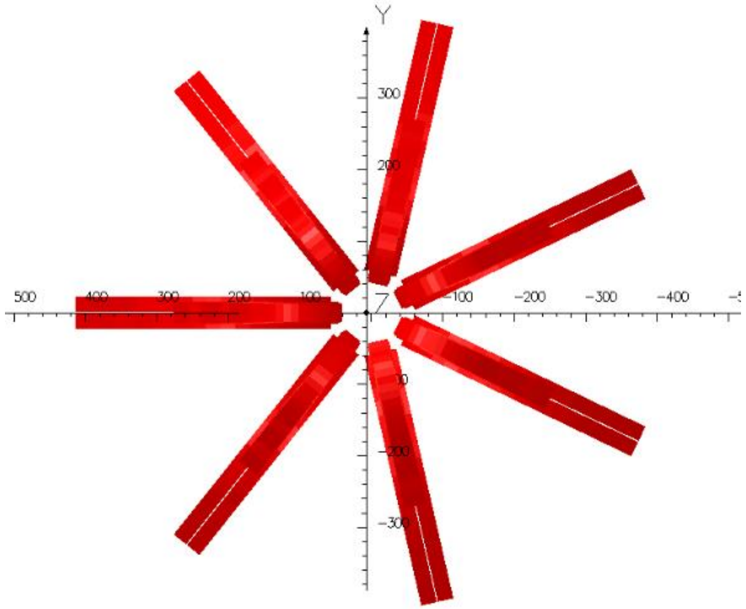


Horizontal coil

Closed sector to beam left to shield synchrotron radiation from hall A arc



Effect of returns



In this septant:

$B_y \sim B_\varphi$ Radially focussing

$B_x \sim B_r$ Azimuthally focussing

The component of the field that is most different is the z component

- Only applied for a short distance (x10 reduction)
- Only act on v_r component (x100 reduction)
- Is small – 10-100x smaller than radial focussing component

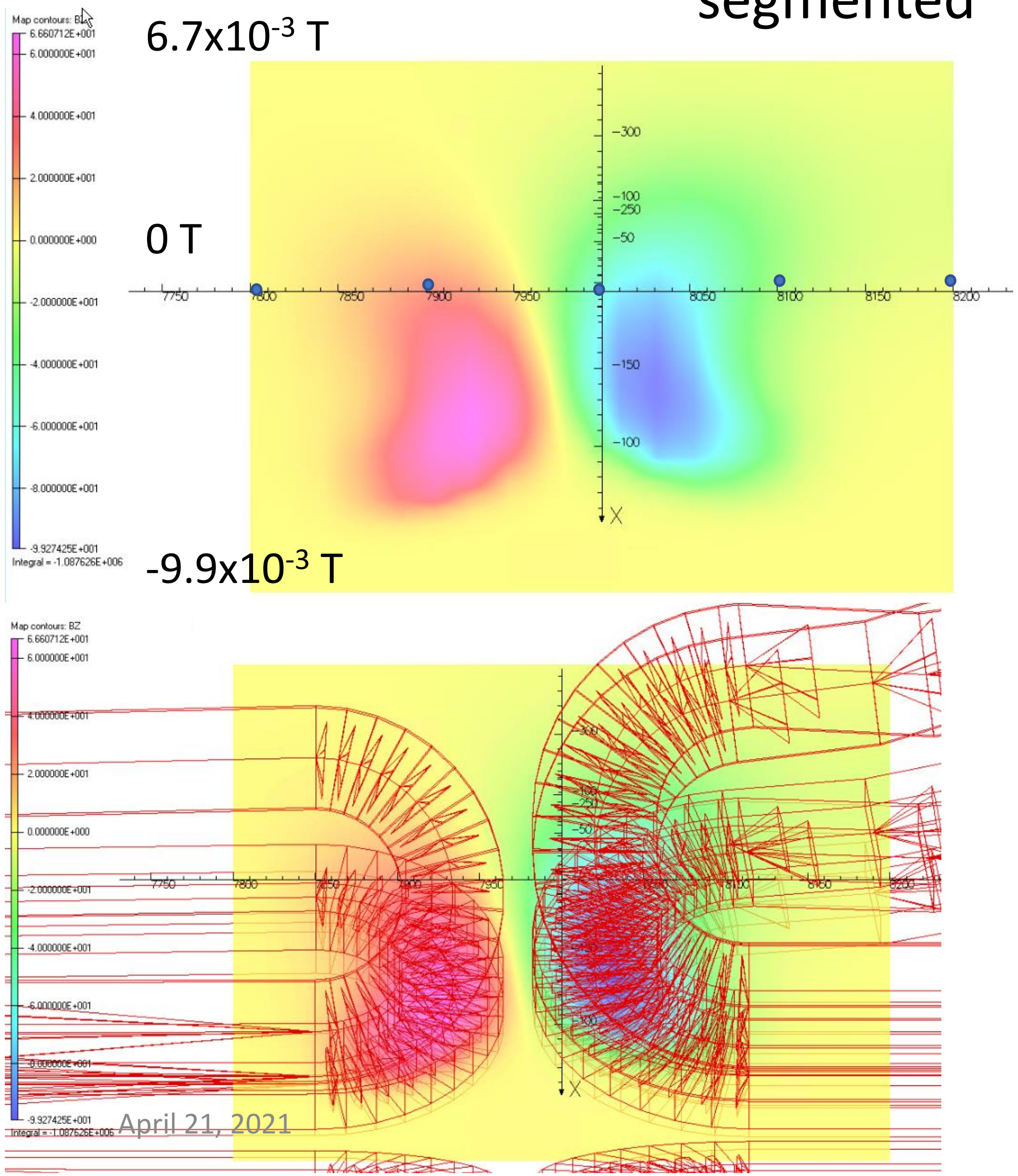
$$\vec{F} = q\vec{v} \times \vec{B} = -\begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ v_x & v_y & v_z \\ B_x & B_y & B_z \end{vmatrix} = \begin{array}{l} -(\cancel{v_y B_z} - v_z B_y)\hat{\imath} \\ -(v_z B_x - \cancel{v_x B_z})\hat{\jmath} \\ -(\cancel{v_x B_y} - \cancel{v_y B_x})\hat{k} \end{array}$$

$v_x, v_y \ll v_z$

- 1e4 – 1e5 reduction in strength

Z component of the field

segmented

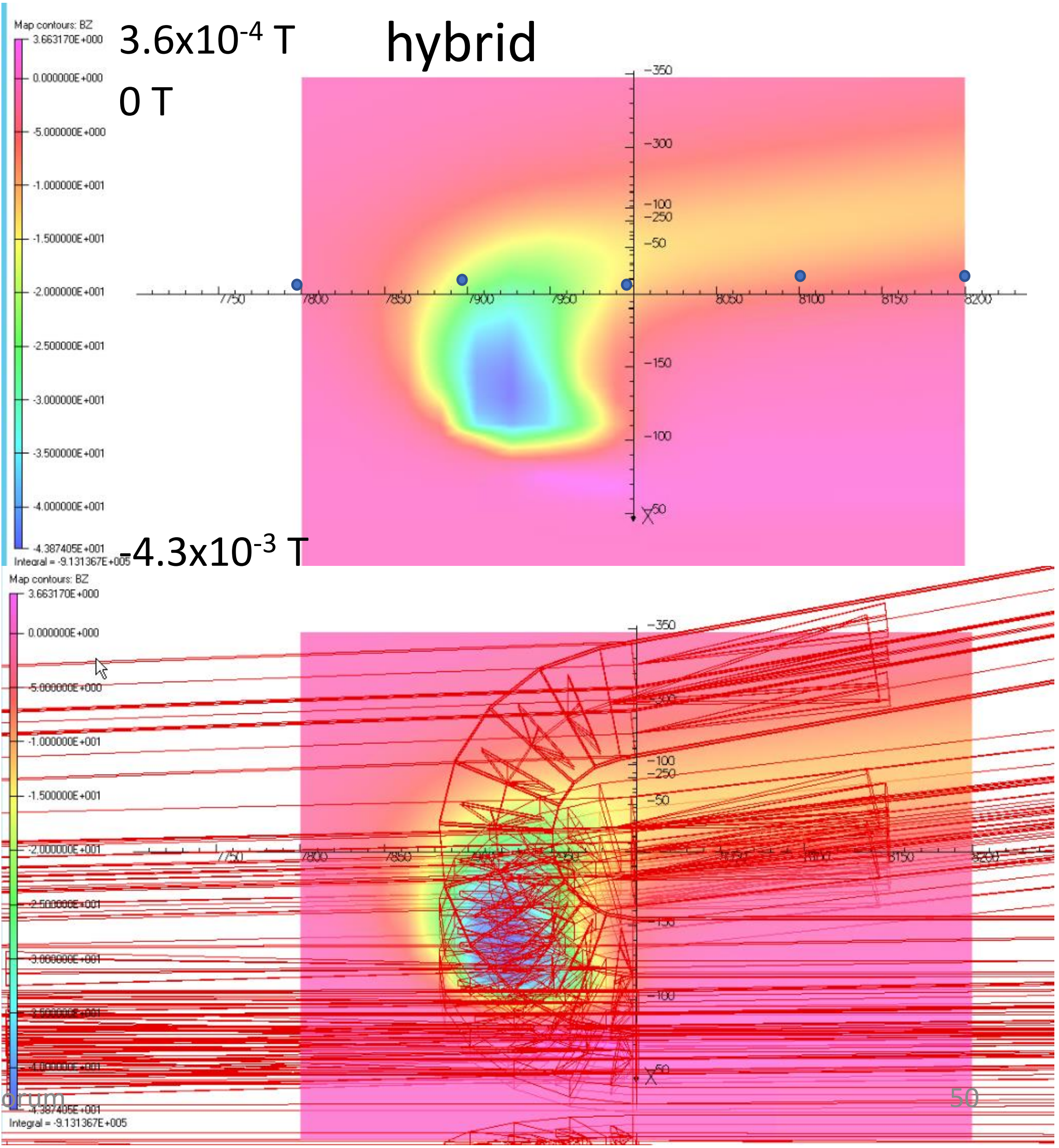


6.7x10^{-3} T

0 T

-9.9x10^{-3} T

hybrid



3.6x10^{-4} T

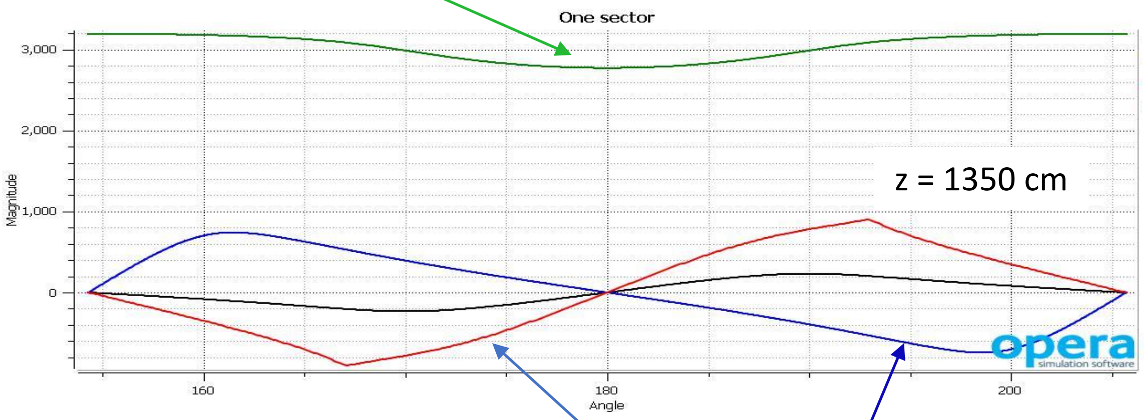
0 T

-4.3x10^{-3} T

Fields along ϕ @ z=1350 cm for different r

Appendix

φ component “sags” in the center of the septant from the ideal case

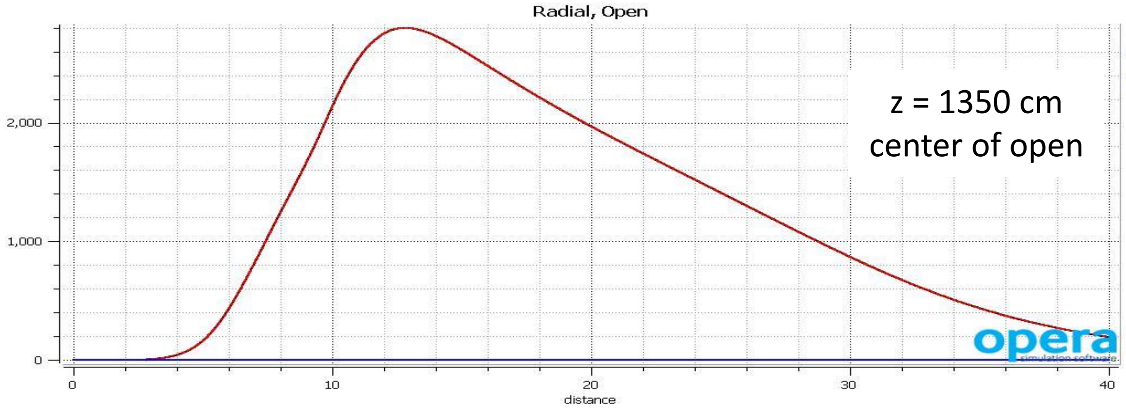


B_ϕ(13.5 cm)
B_r(13.5 cm)
B_r(29 cm)
B_r(9 cm)

r component changes sign at the edges of the septant at the inner and outer radii

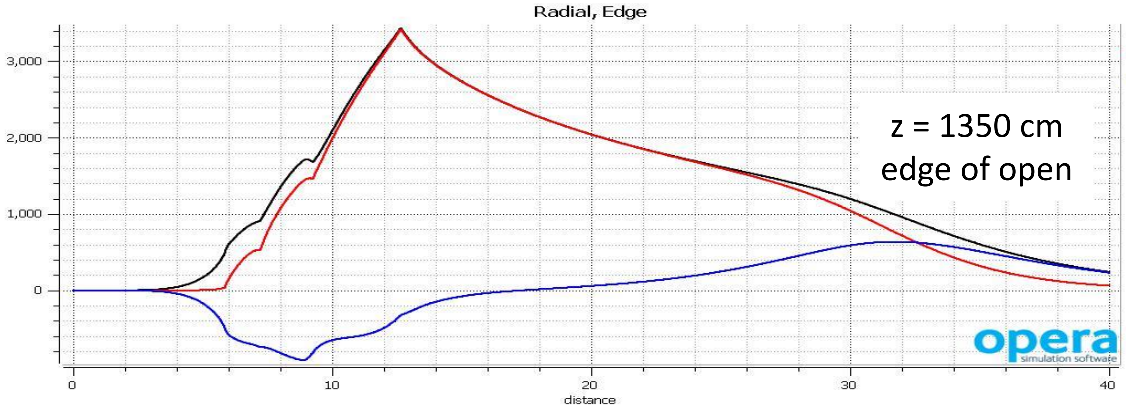
Fields along r @ z= 1350 cm

Appendix



z = 1350 cm
center of open

BMOD
$B_ø$
B_r

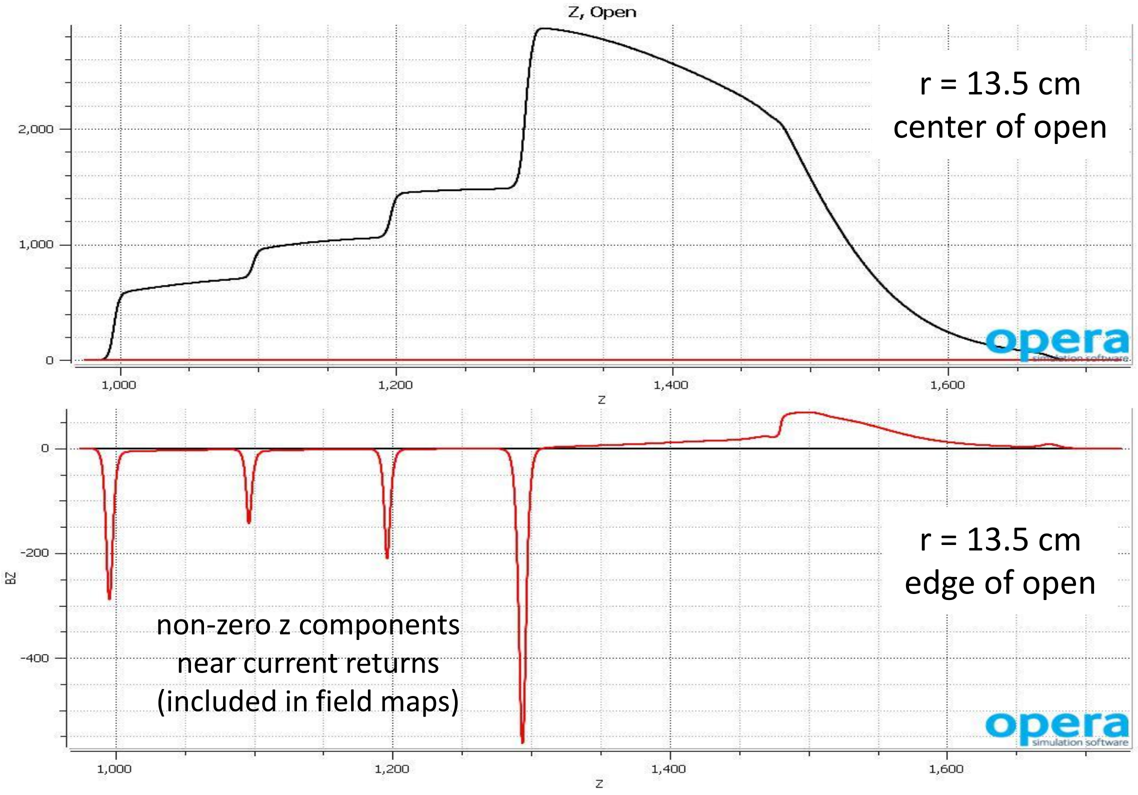


z = 1350 cm
edge of open

BMOD
$B_ø$
B_r

Fields along z @ r = 13.5 cm

Appendix



r = 13.5 cm
center of open

BMOD
B_z

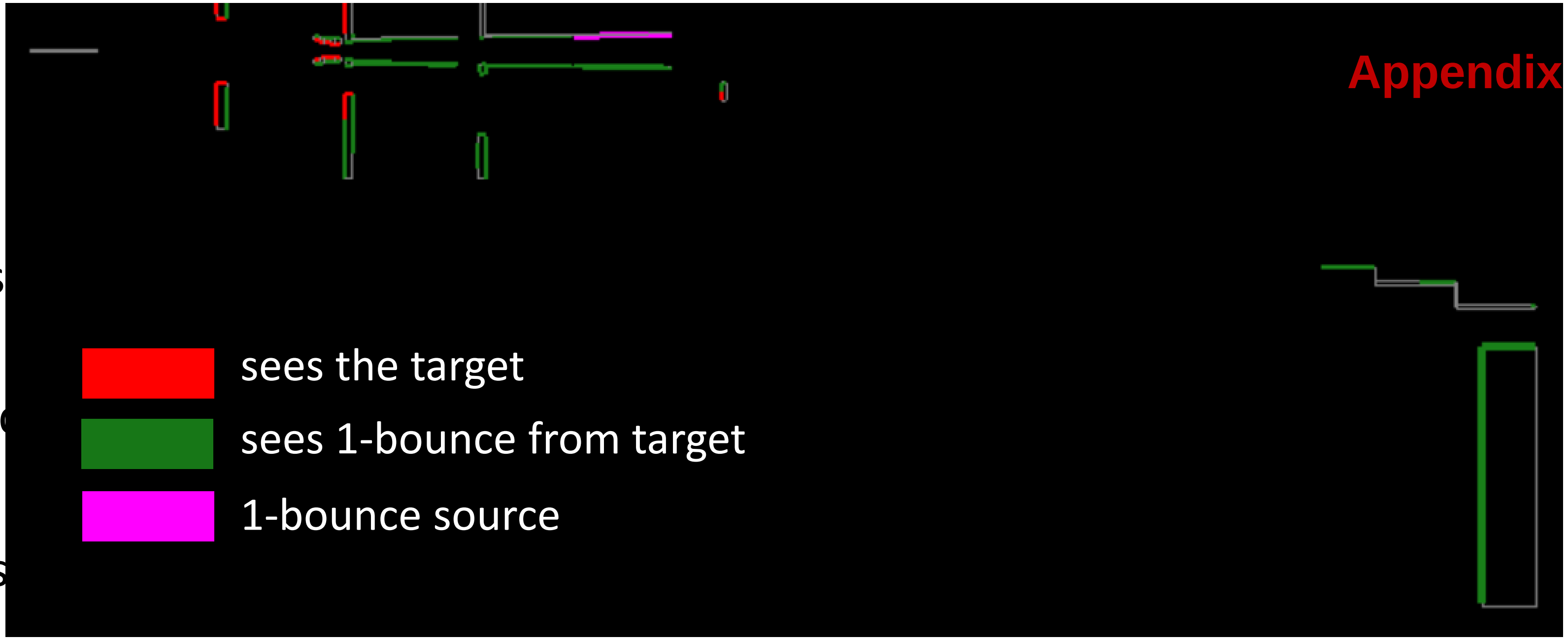
r = 13.5 cm
edge of open

non-zero z components
near current returns
(included in field maps)

B_z at edge
B_z center

2 bounce code

- Python code
  - Target, collar, collimators, beam s
  - Uses straight lines to simulate an
  - Surfaces that “see” the target (re
- Tolerance study
  - move the collimators and/or coils

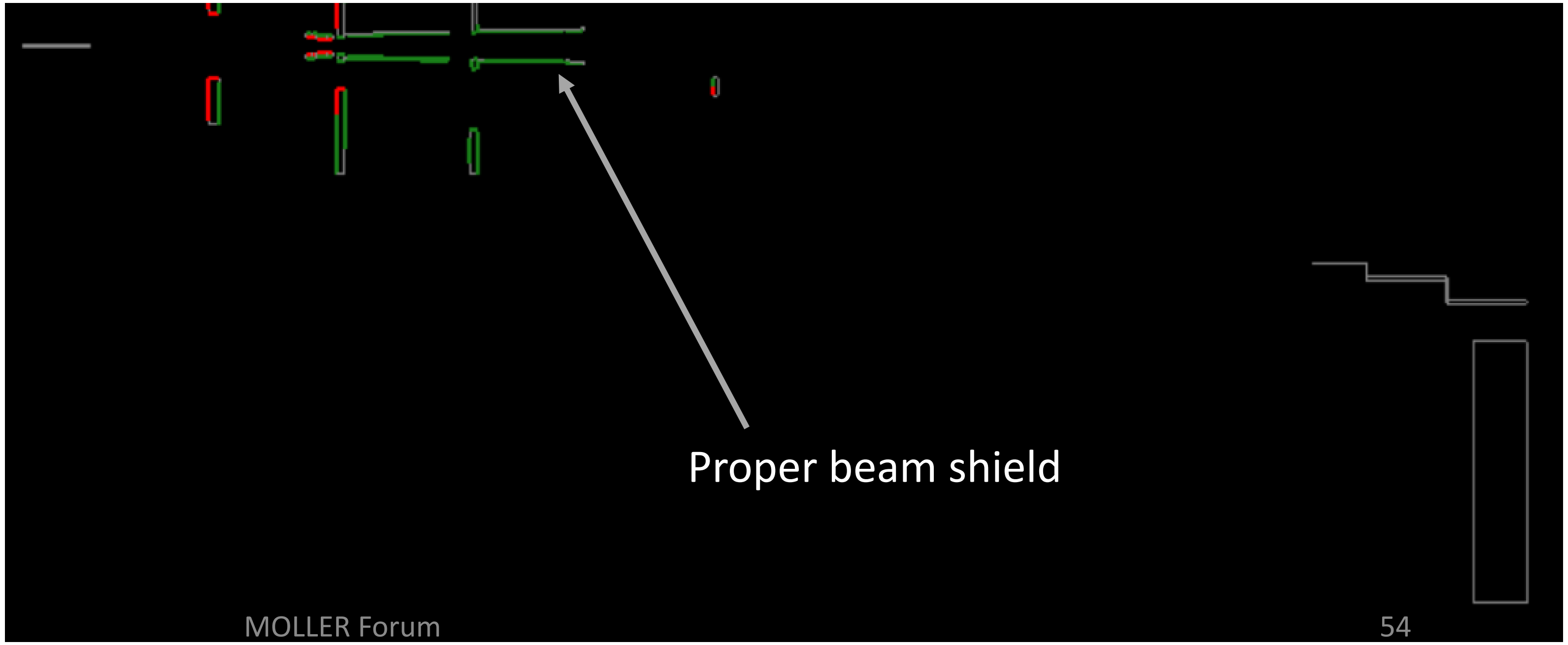


Appendix

🟥 sees the target

🟩 sees 1-bounce from target

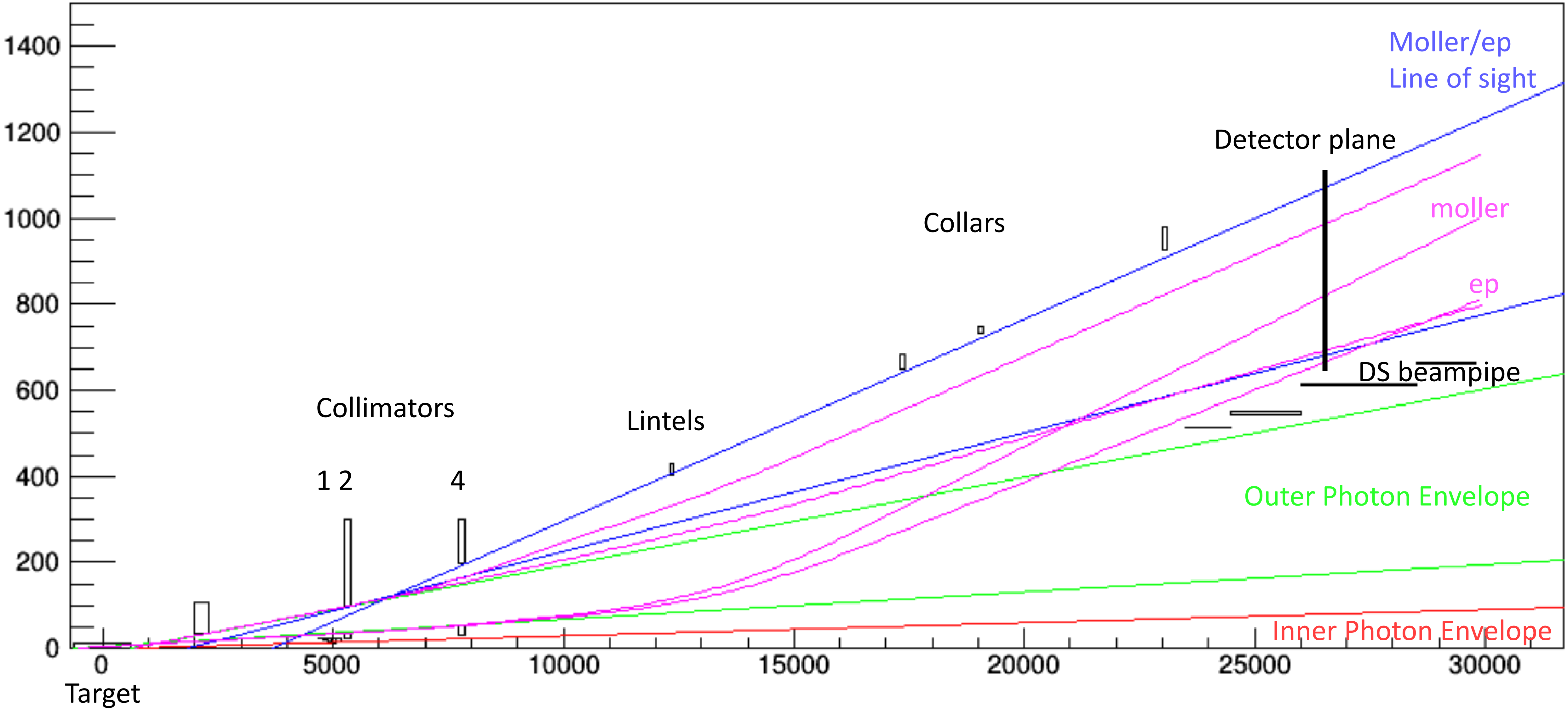
🟪 1-bounce source



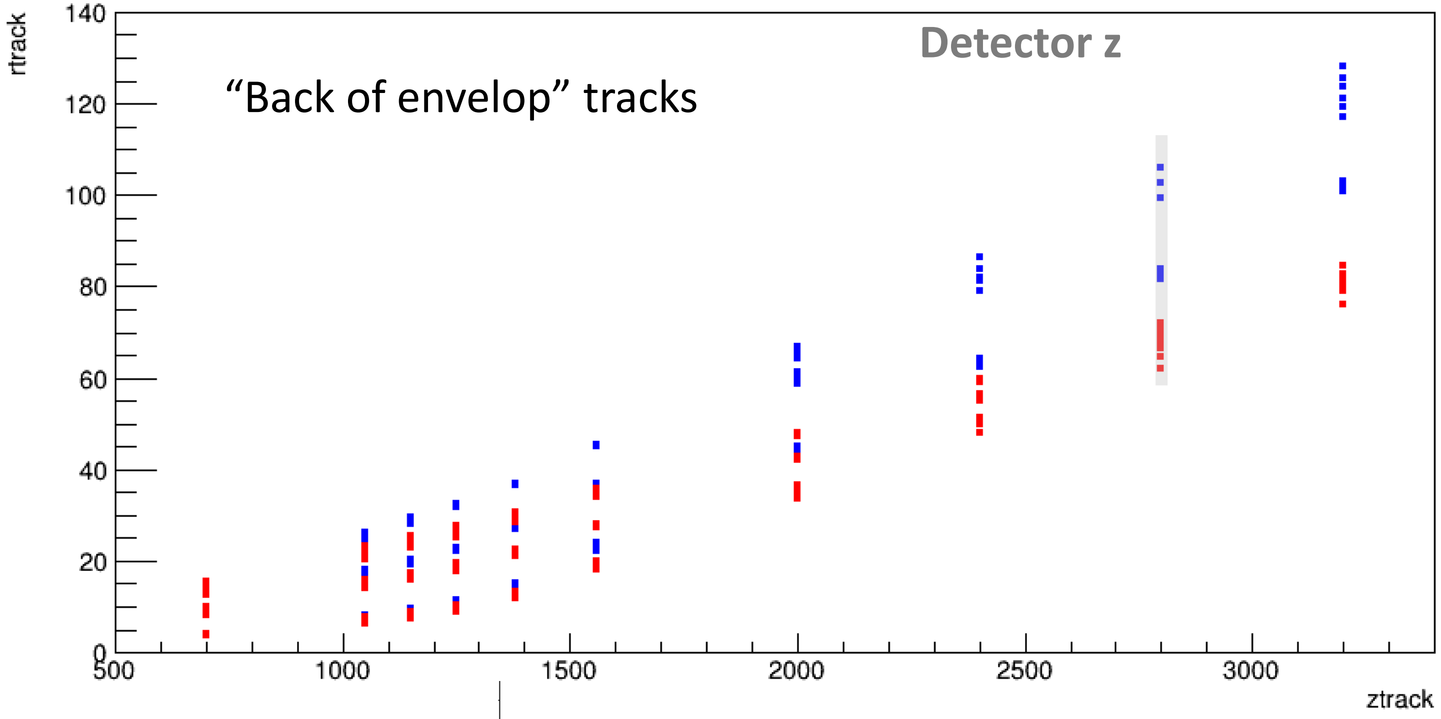
Proper beam shield

Root script

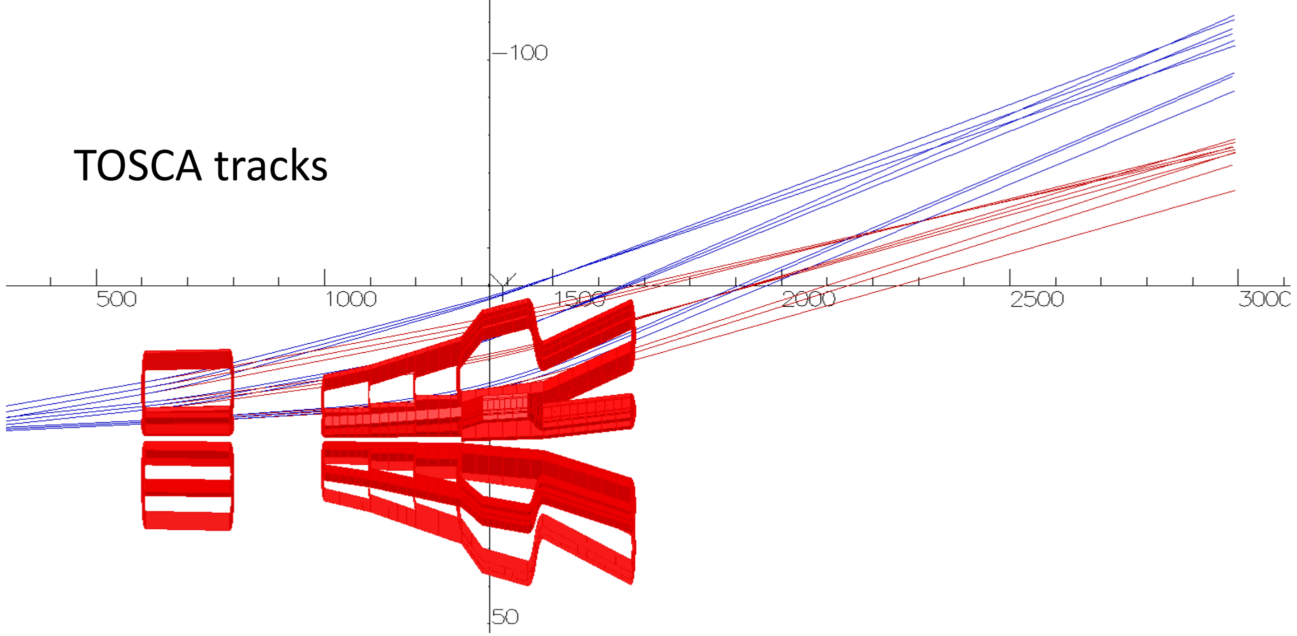
Appendix



Phase space study



“Back of envelop” tracks



TOSCA tracks

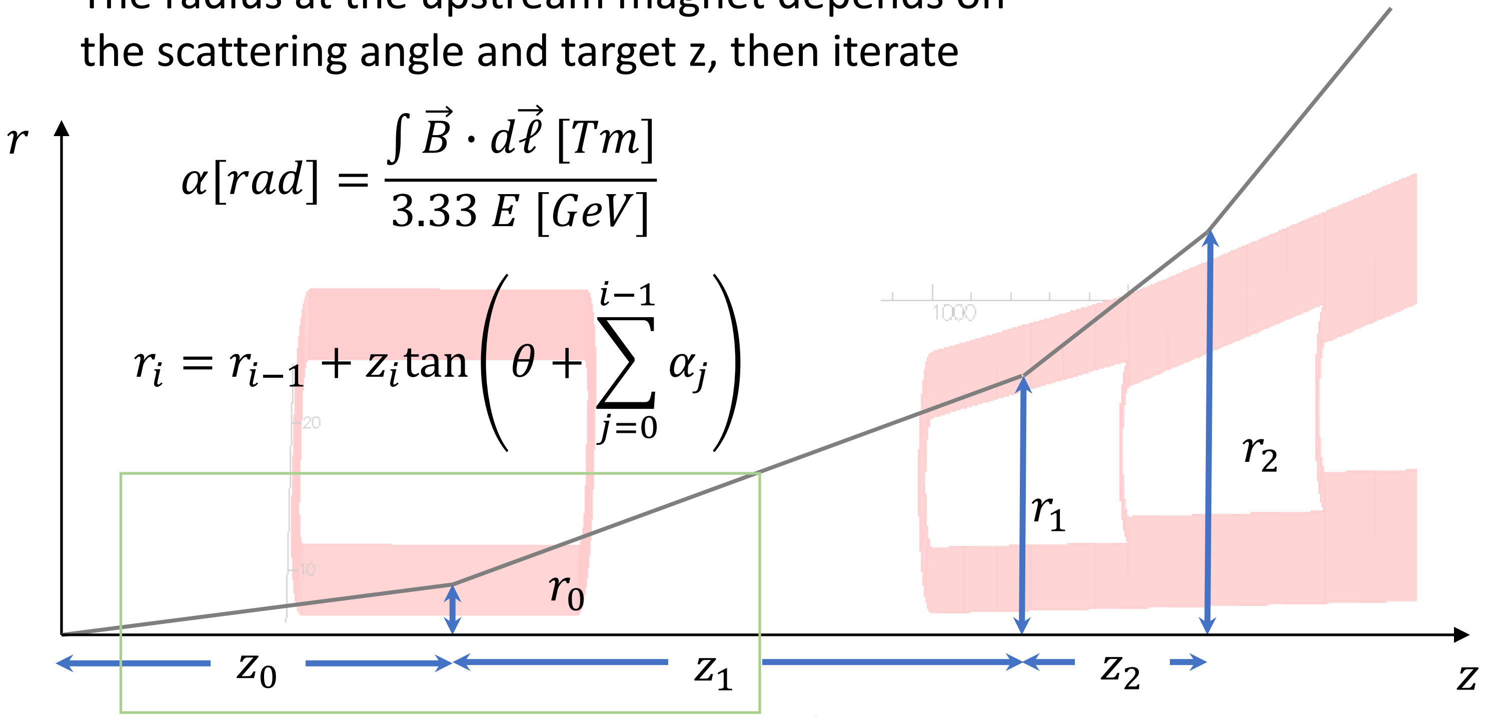
Back of the envelop calculations

(n-dimensional envelop)

1. Get $B_{\varphi,i}(r)$ from TOSCA
2. Calculate α
3. Get r in next segment
4. Drift to detector

- Each segment gives a “kick” at the central z location
- Field integral depends on radius of the track in that segment and the length of the segment
- Radius in a given segment depends on fields of upstream magnet segments
- The radius at the upstream magnet depends on the scattering angle and target z, then iterate

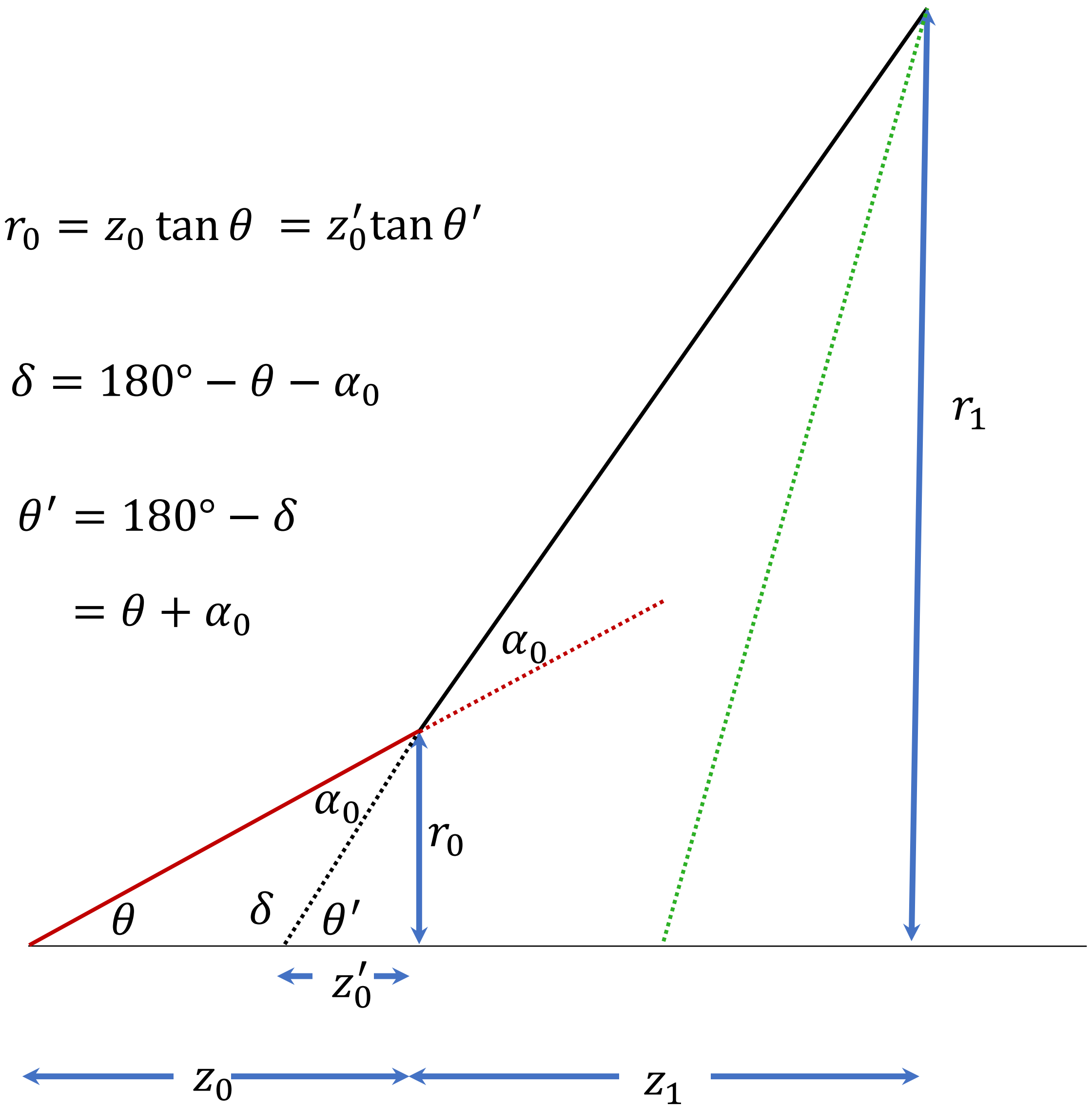
$$= \frac{B_{\varphi,i}(r)[T]\Delta L_i[m]}{3.33\ E_{particle}\ [GeV]}$$



$$\alpha[rad] = \frac{\int \vec{B} \cdot d\vec{\ell}\ [Tm]}{3.33\ E\ [GeV]}$$

$$r_i = r_{i-1} + z_i \tan\left(\theta + \sum_{j=0}^{i-1} \alpha_j\right)$$

Combining kicks



$$r_0 = z_0 \tan\theta = z_0' \tan\theta'$$

$$\delta = 180° - \theta - \alpha_0$$

$$\theta' = 180° - \delta$$
$$= \theta + \alpha_0$$

$$r_1 = (z_0' + z_1)\tan\theta'$$

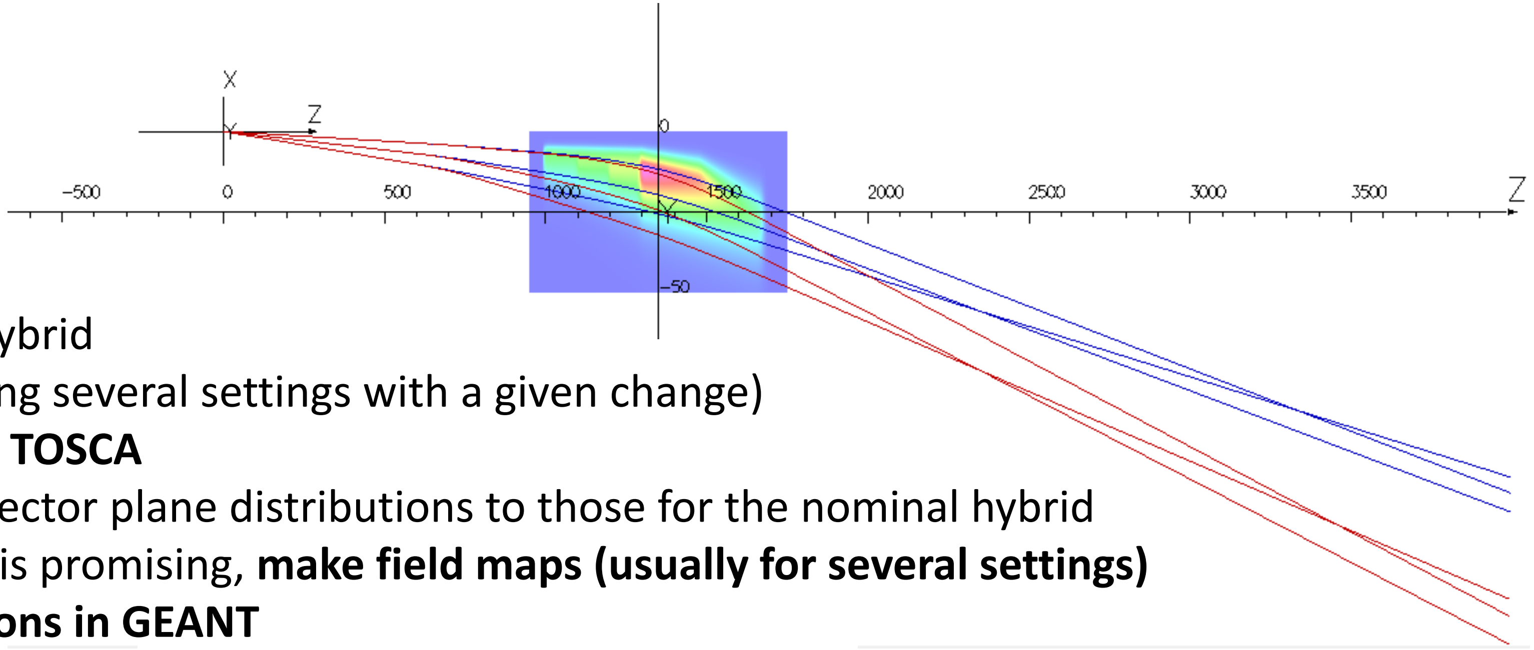
$$= \left(\frac{r_0}{\tan\theta'} + z_1\right)\tan(\theta')$$

$$= r_0 + z_1 \tan(\theta')$$

$$= r_0 + z_1 \tan(\theta + \alpha_0)$$

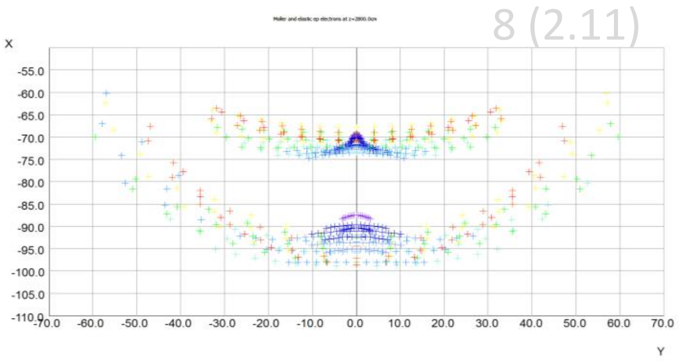
$$\boxed{r_i = r_{i-1} + z_i \tan\left(\theta + \sum_{j=0}^{i-1} \alpha_j\right)}$$

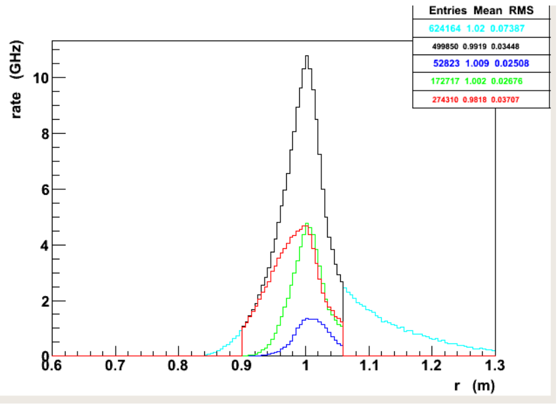
Exploring the parameter space



Steps:

1. Modify the hybrid
   (usually making several settings with a given change)
2. **Run tracks in TOSCA**
3. Compare detector plane distributions to those for the nominal hybrid
4. If something is promising, **make field maps (usually for several settings)**
5. **Run simulations in GEANT**
6. Look for Moller and elastic ep rates, asymmetries and background percentages



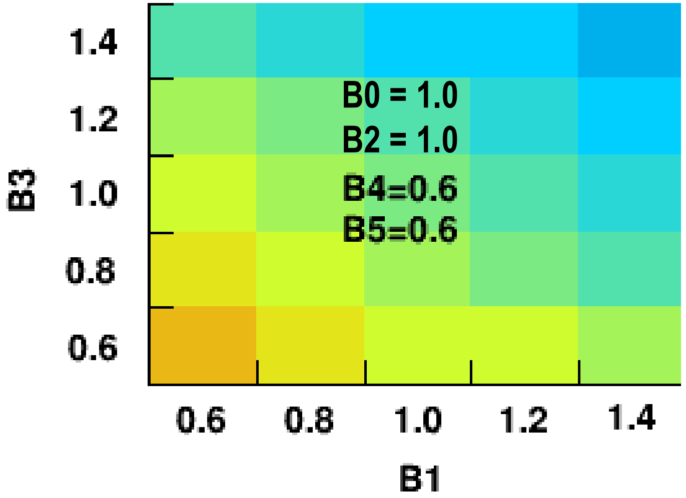


Exploring the parameter space

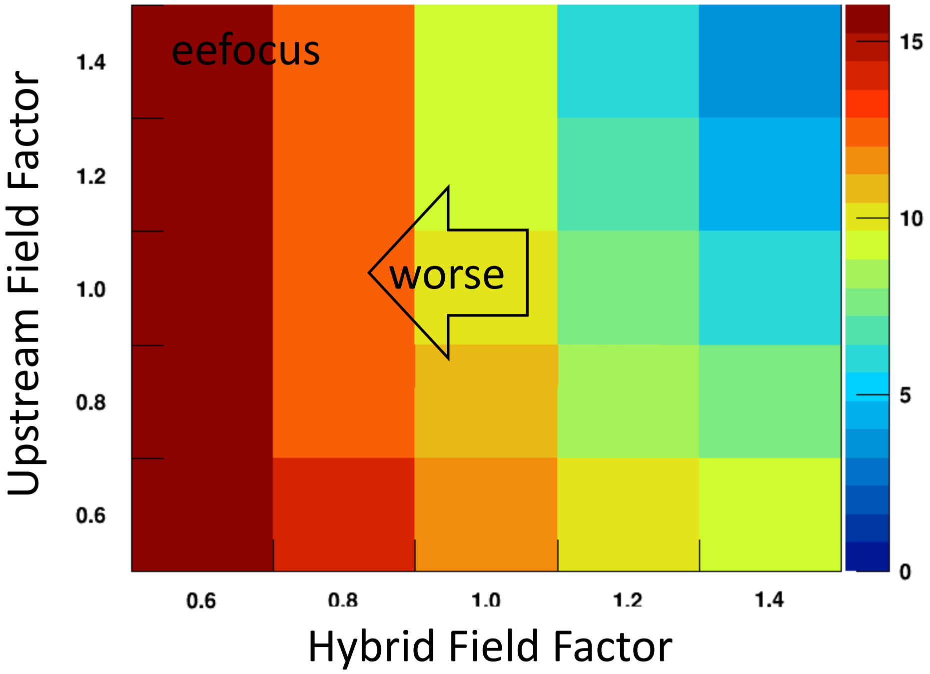
Plot field factor of one segment vs. field factor of another segment and weight by the quantity of interest

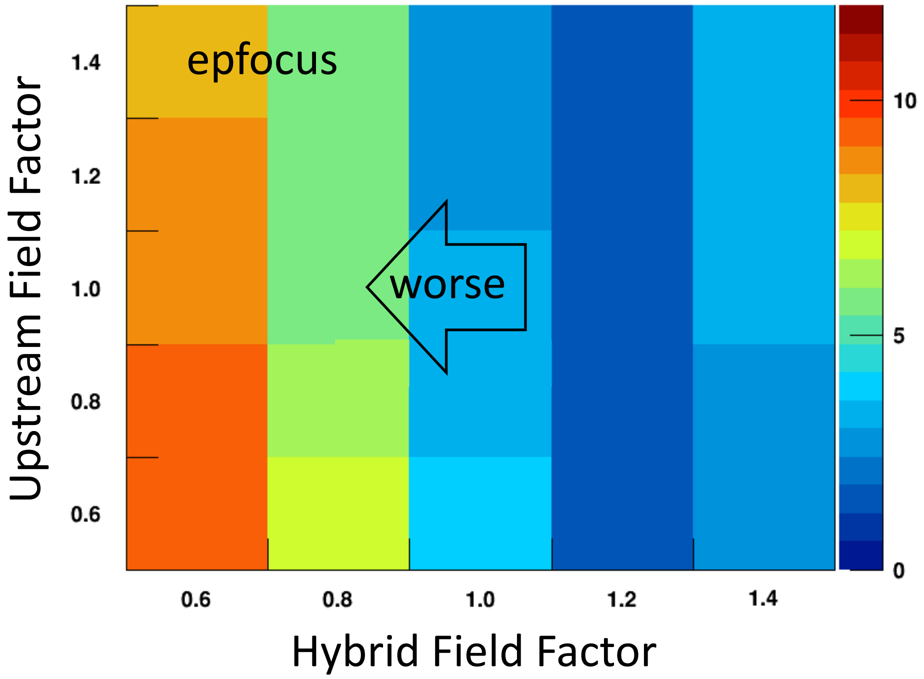
$5^6 = 15625$ combinations

B2=1.0 because it is very shallow
Reduces the number of plots to show



Dark Blue < epfocus < Red
0 cm < epfocus < 12 cm





Plots of focus (top) and peak separation (bottom) in cm for different scale factors for the upstream vs. downstream field

eefocus - 0-16 cm,
epfocus - 0-12 cm, } red is worse

eeepsep - 15-23 cm red is better

Better focus and separation for higher current densities in hybrid torus