April 2021 MOLLER Forum Spectrometer Update

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Team Acknowledgements

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

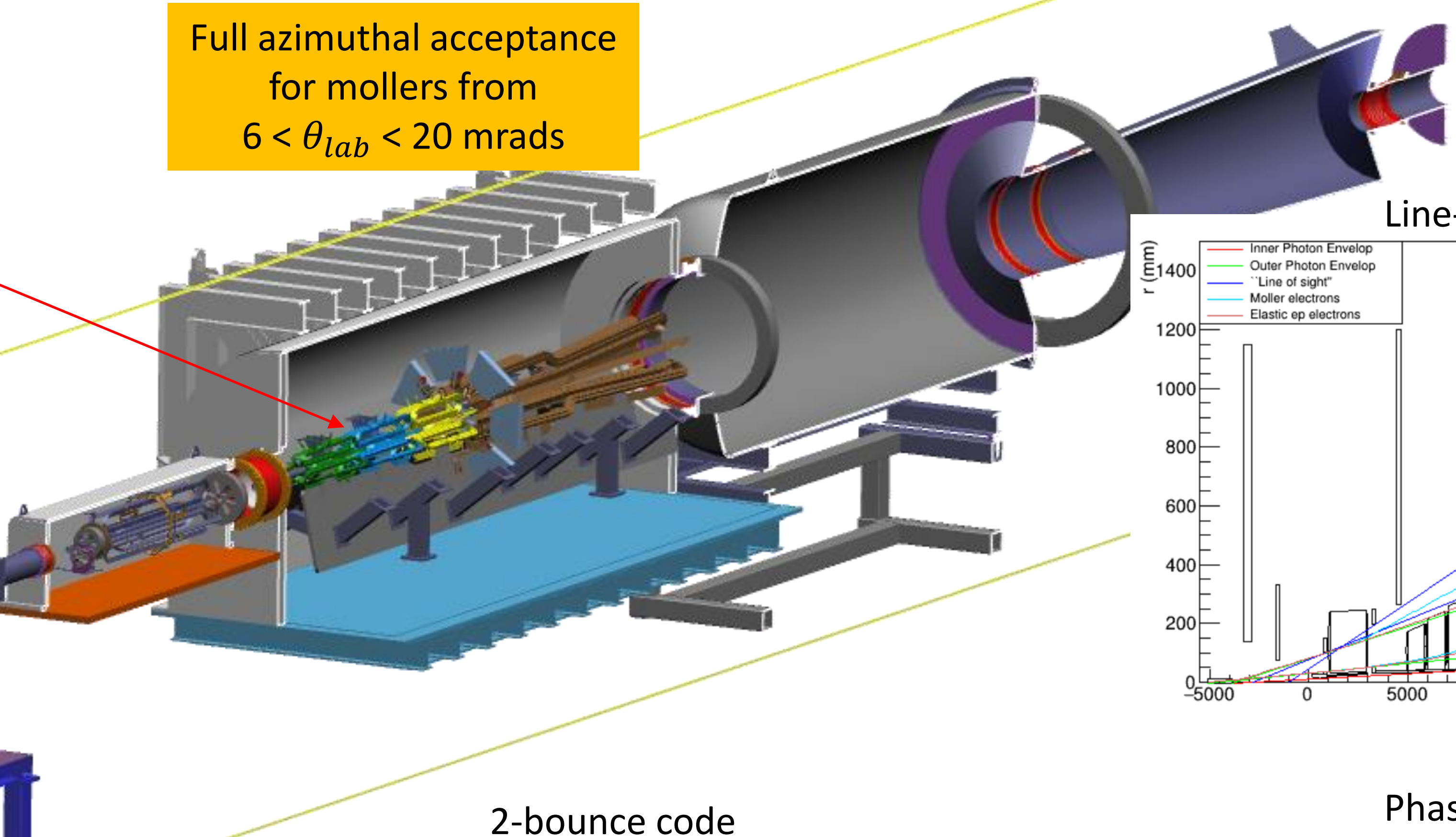
Topics

- 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

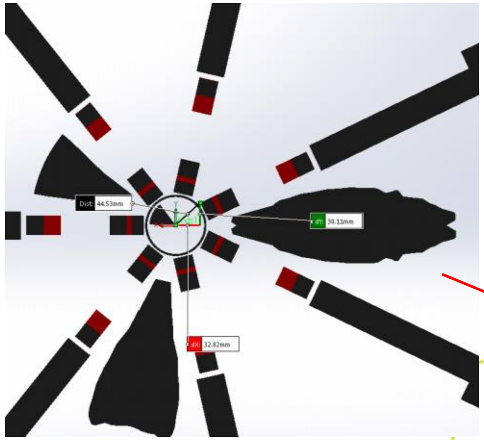
Exercising our “Change Control” muscles!

Spectrometer system tools

In addition to TOSCA, CAD and GEANT4

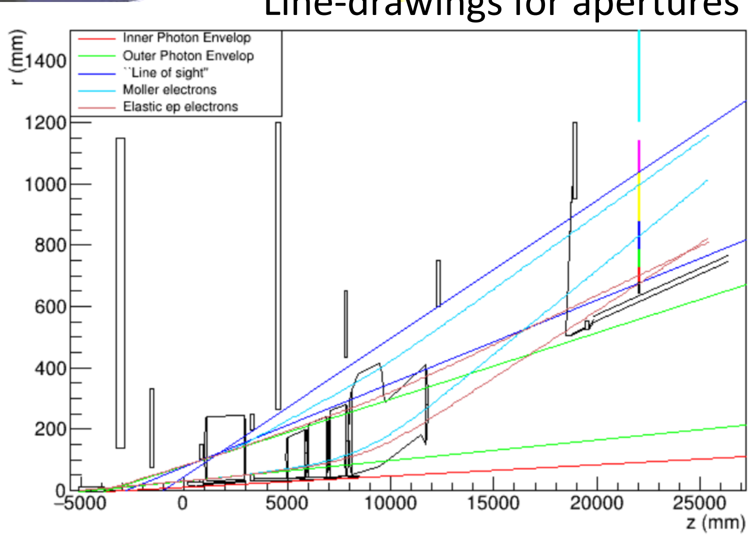


Full azimuthal acceptance for mollers from $6 < \theta_{lab} < 20$ mrads

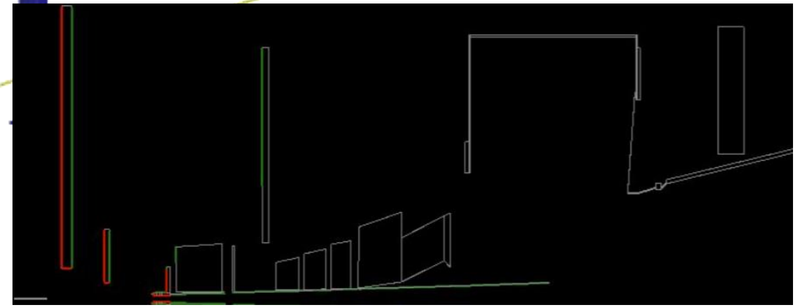


particle envelopes algorithm

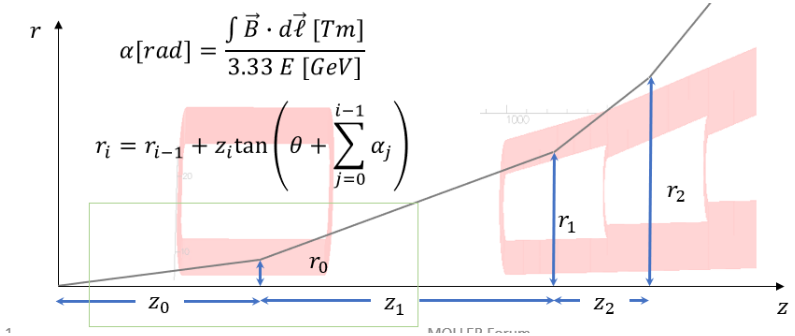
Line-drawings for apertures



2-bounce code

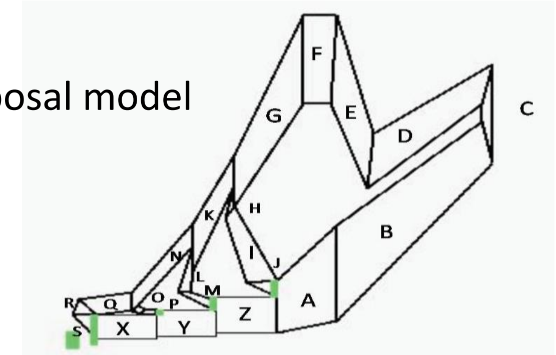


Phase space calcs

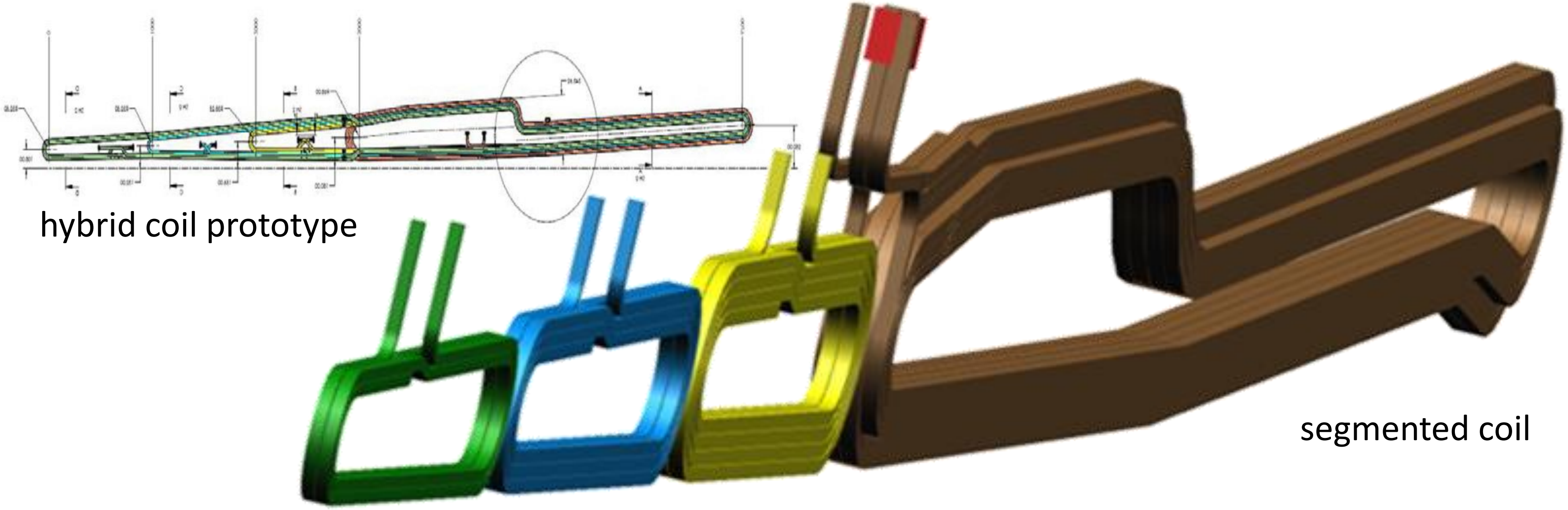


Evolution of the downstream torus

Proposal model

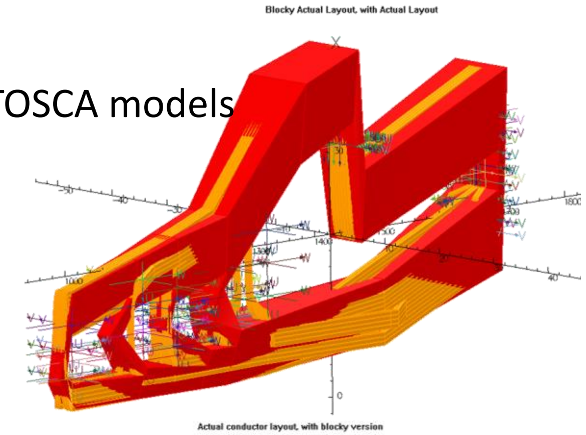


hybrid coil prototype

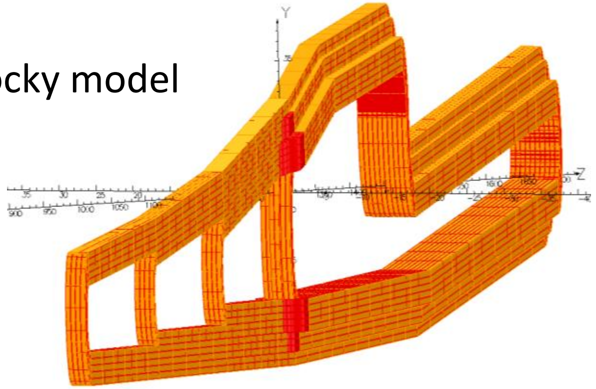


segmented coil

1st TOSCA models



Blocky model



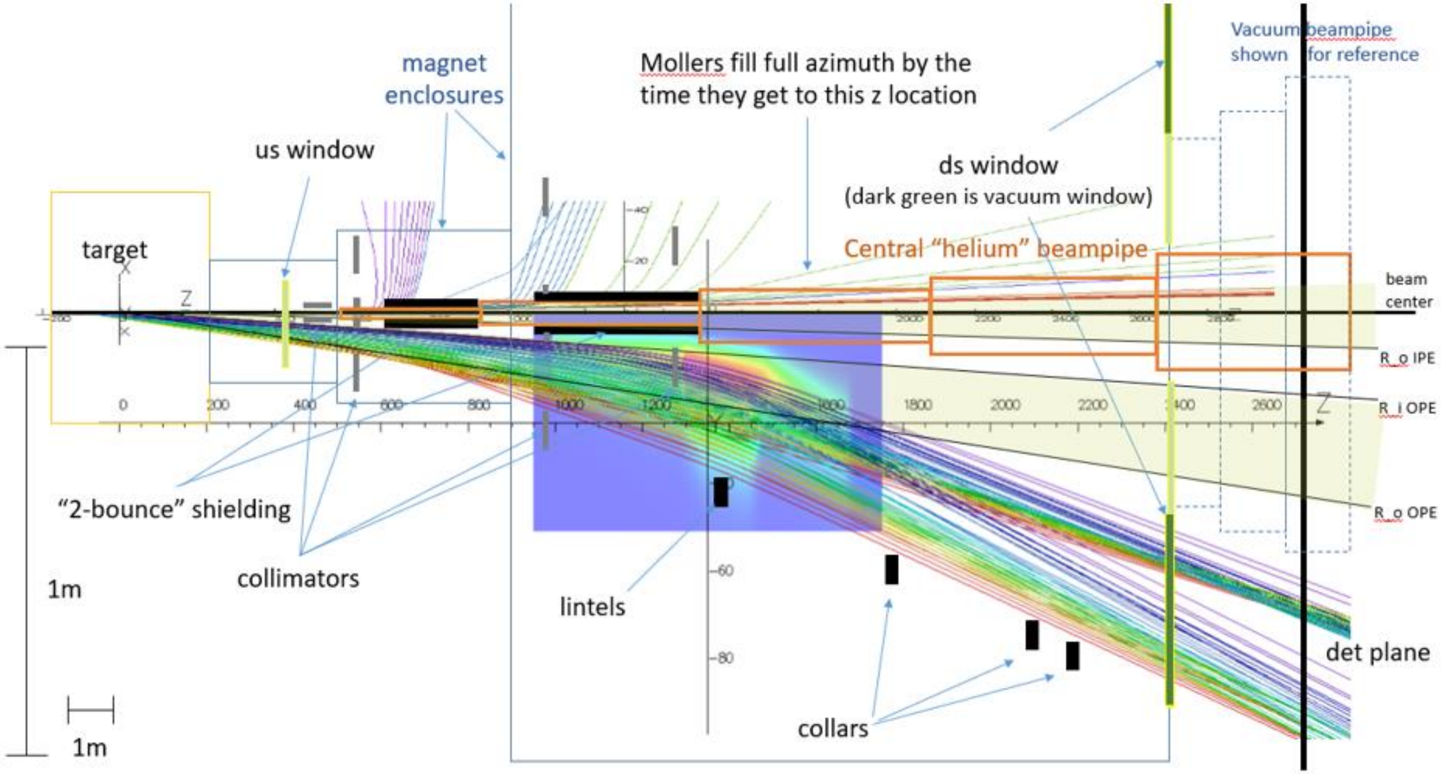
Careful planning has helped to simplify the engineering design of the spectrometer, though there have been some changes

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

Leave space for epoxy backfill and aluminum plates/ other supports

- “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

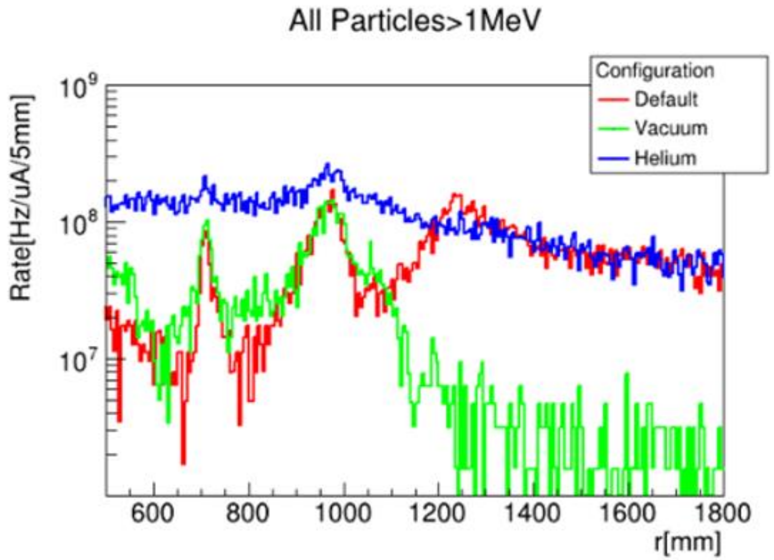


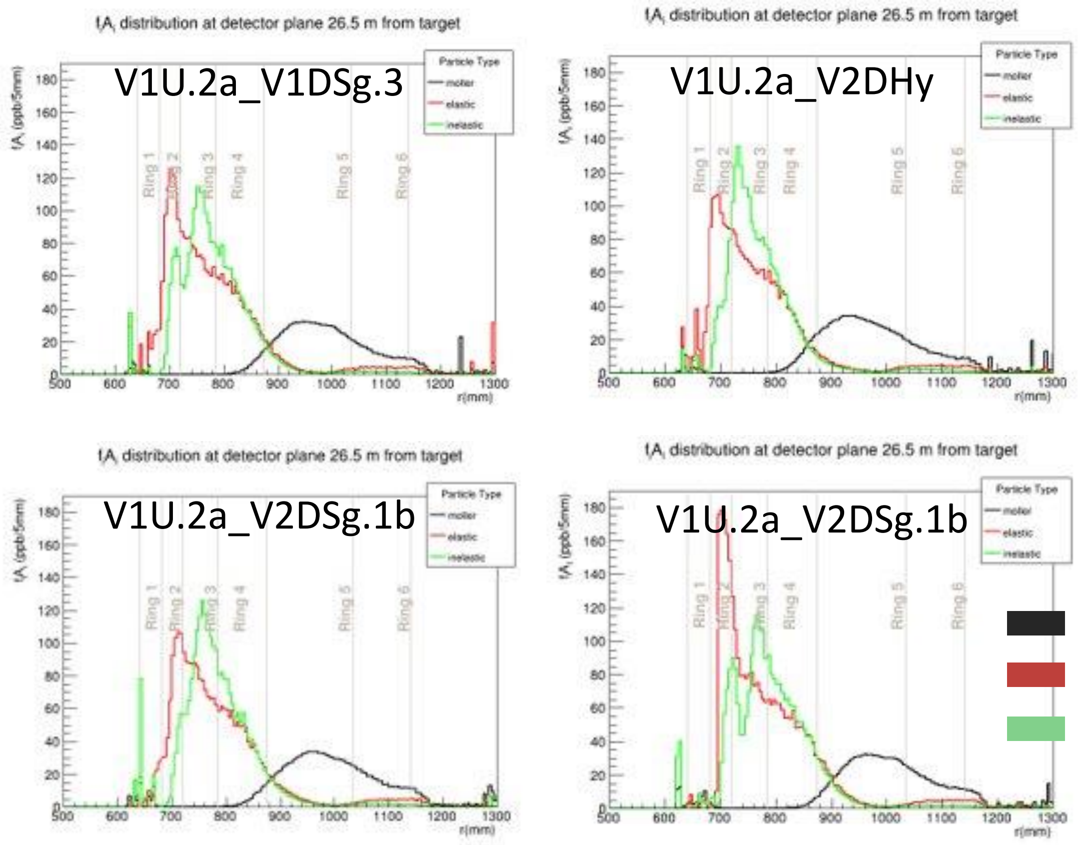
Figure 2 – *Plot of the rate-weighted radial distribution of all particles at the detector plane (z location of ring 5, the moller ring. The green (blue) lines are for a realistic vacuum (helium) configuration. The red line is for the default (historical) configuration. Note that the vertical scale is 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

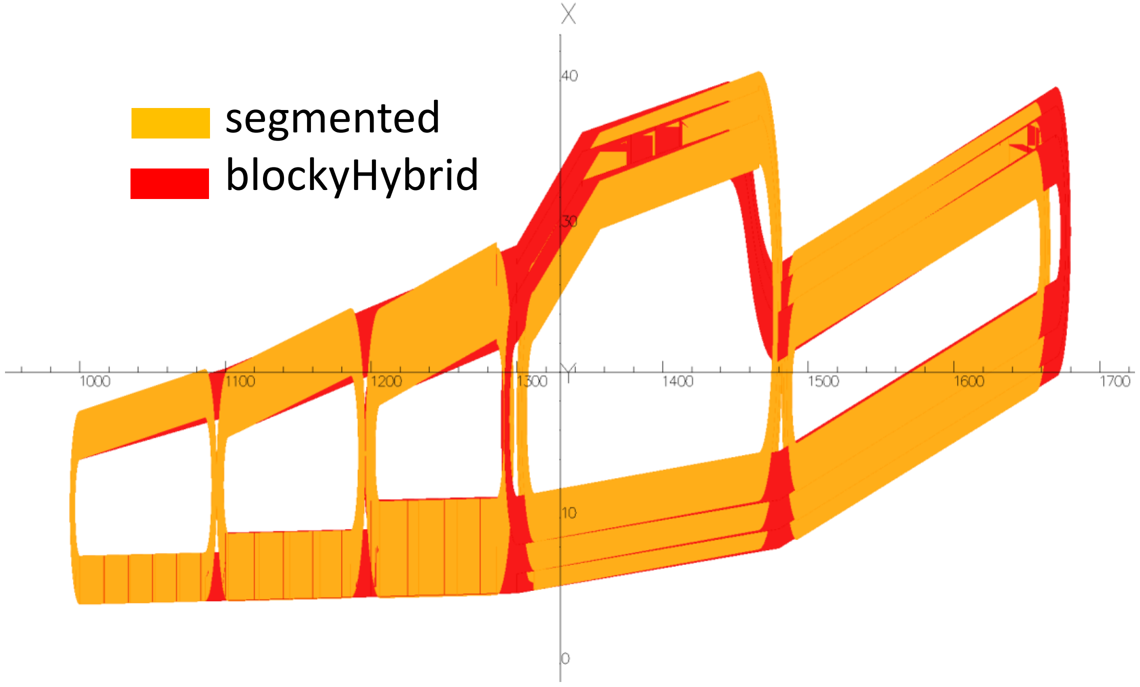
Segmented vs. Hybrid

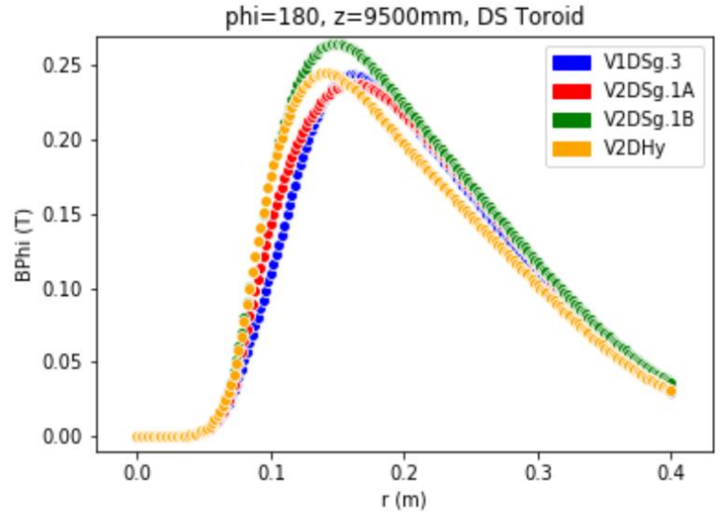
Hybrid vs. segmented – segmented wins!

$f_i A_i$ distributions at detector plane



moller
elastic
inelastic



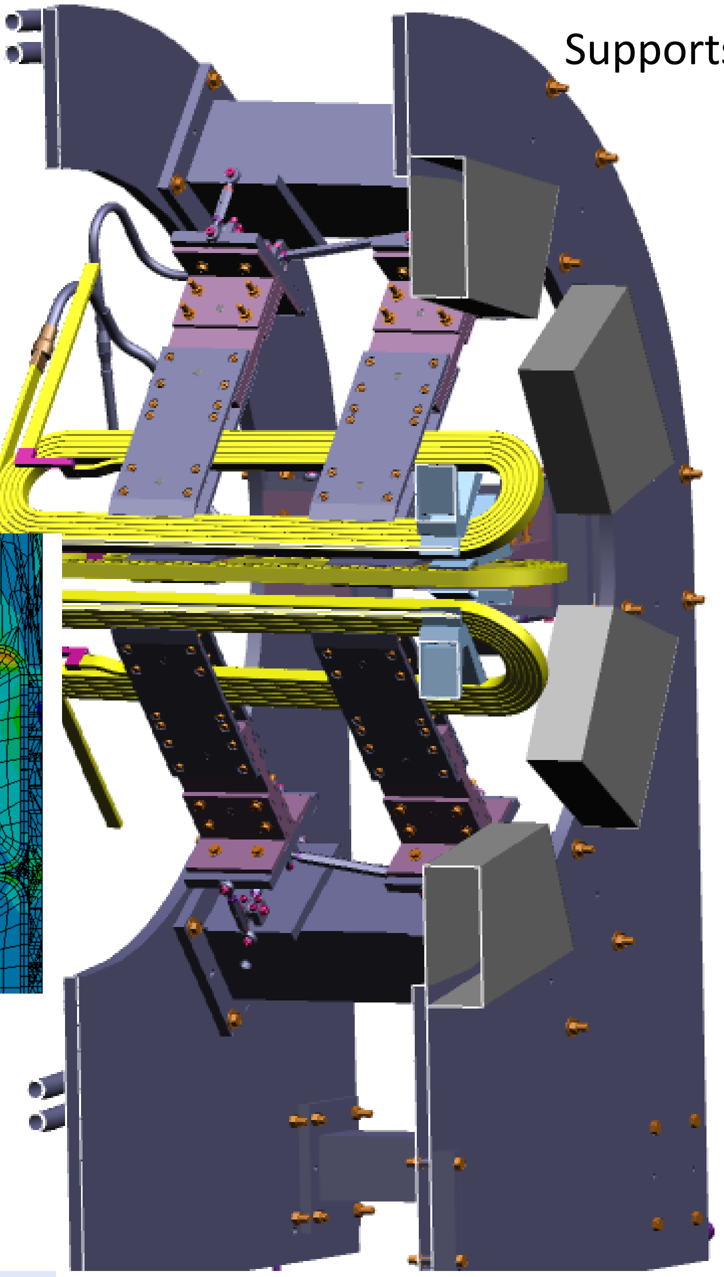


Preliminary Design Review – 60% DS

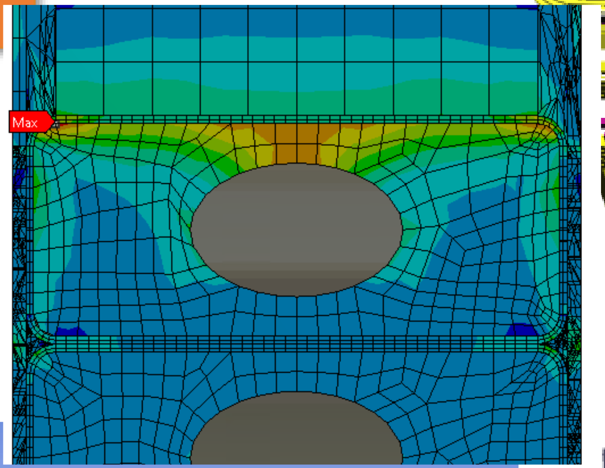
- Specifications document - PMAG0000-0100-A0007
- The field parameters and physics requirements can be met
  - Clearance to particle envelopes (PMAG0000-0100-A0009)
  - Current density
  - Water cooling system
    - Temperature rise
    - Pressure drop
  - Support system
    - Alignment tolerances
 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

Only recommendation is to include schedule risk in the risk registry

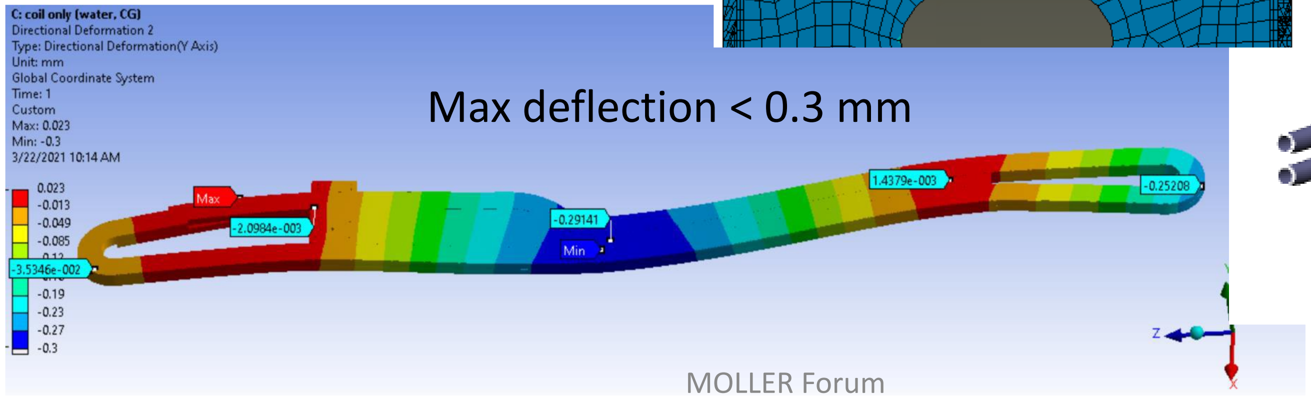
Supports



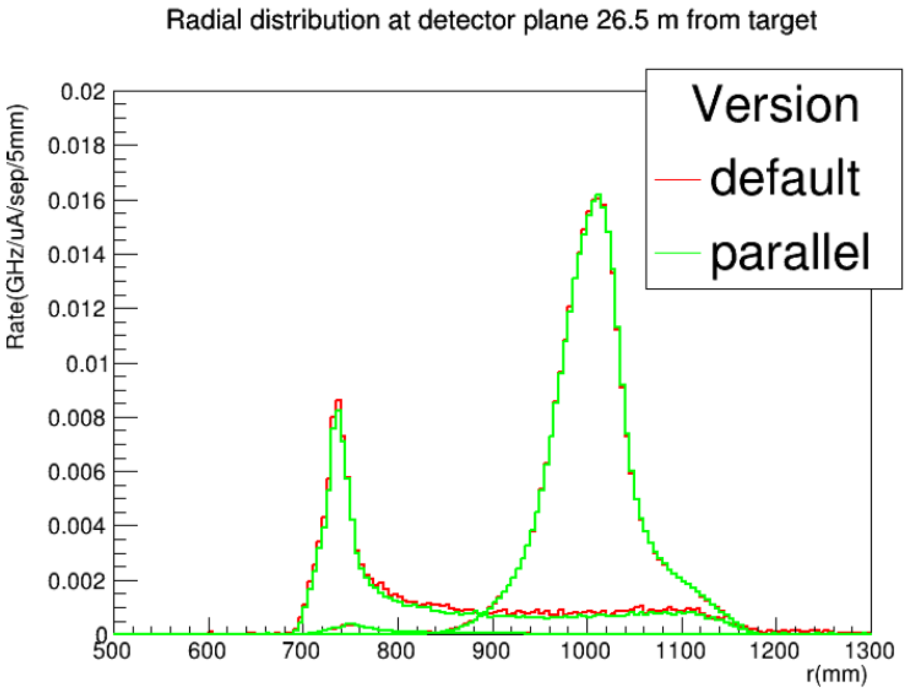
Tolerable stresses



Max deflection < 0.3 mm



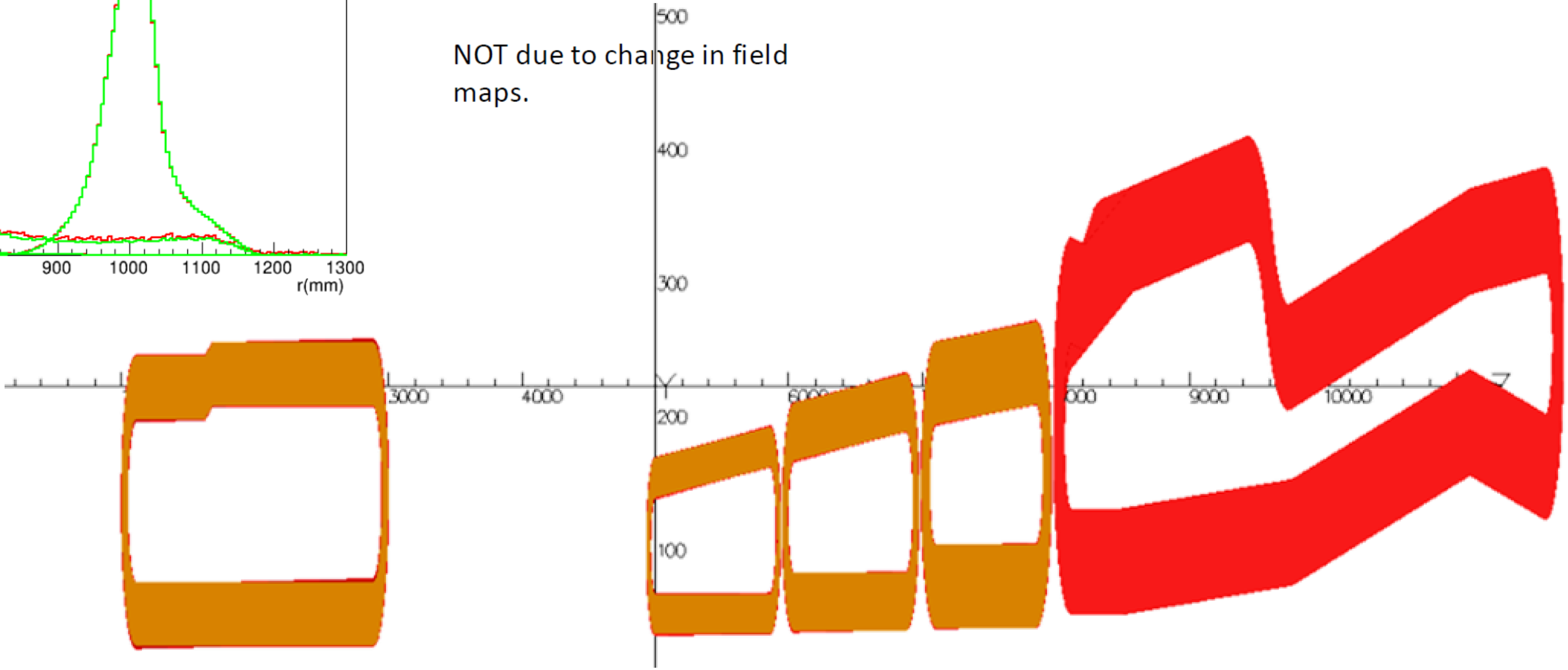
Final conductor configuration



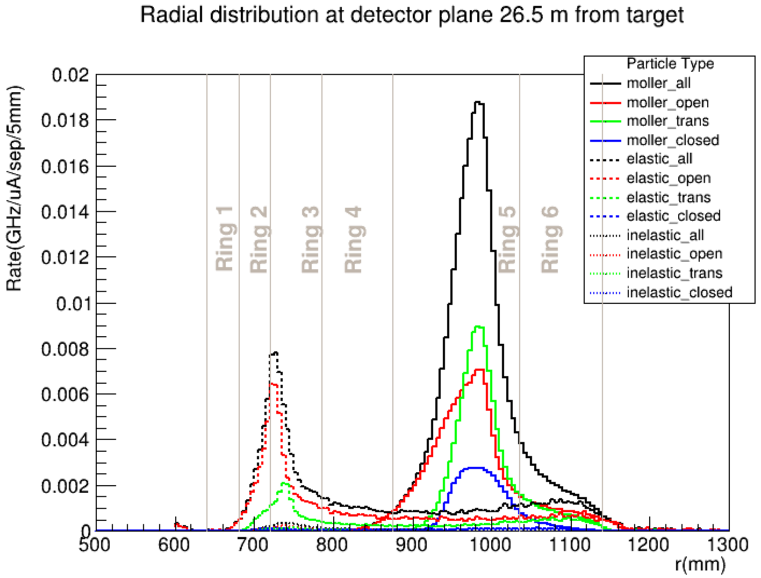
The difference in the elastic tail is due to change in downstream shielding.

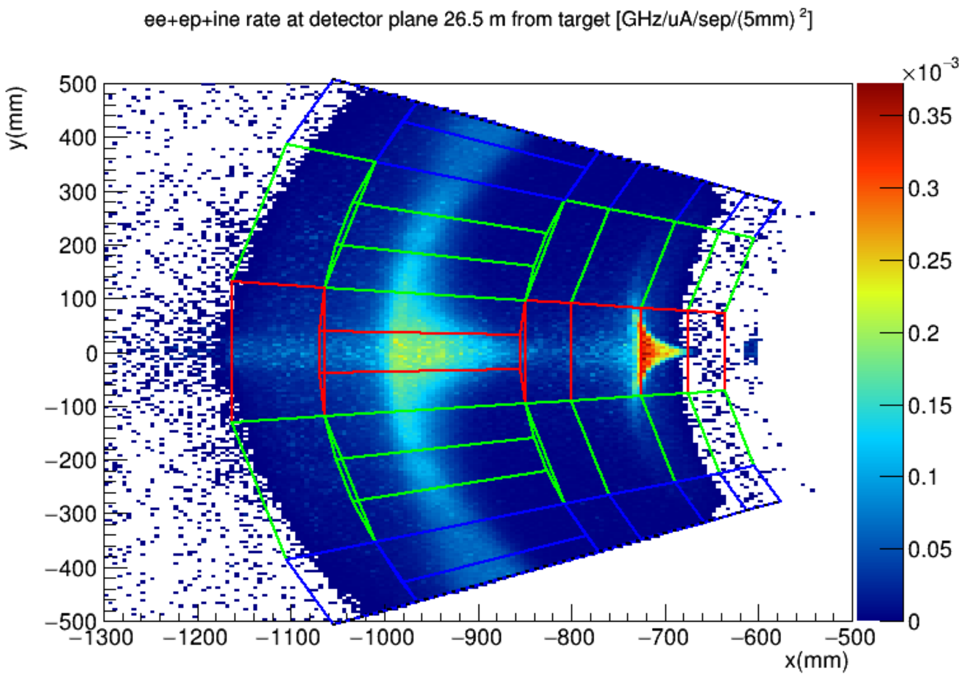
NOT due to change in field maps.

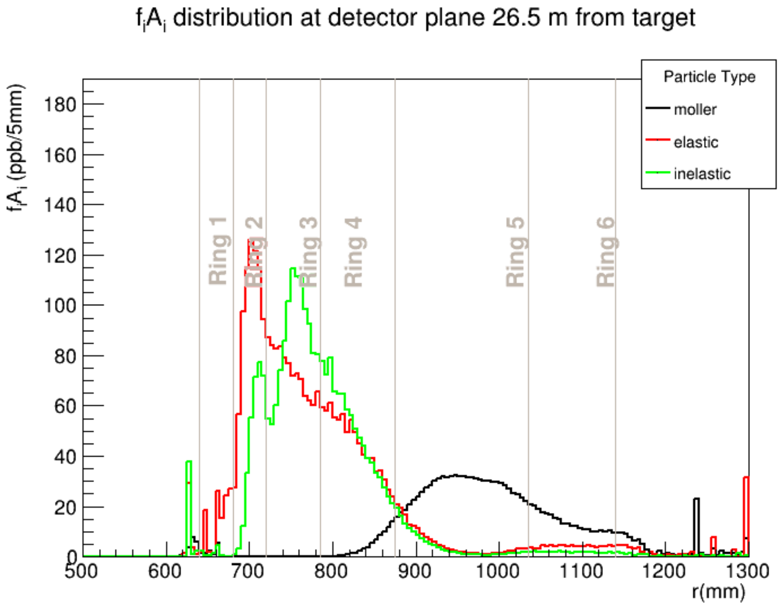
Some changes to improve clearances and ease of drawing and manufacturing



Deconvolution checks





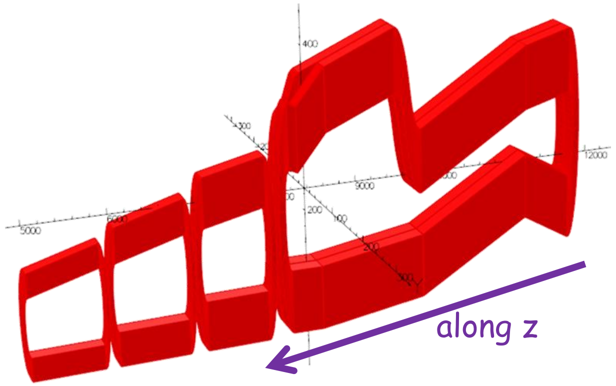


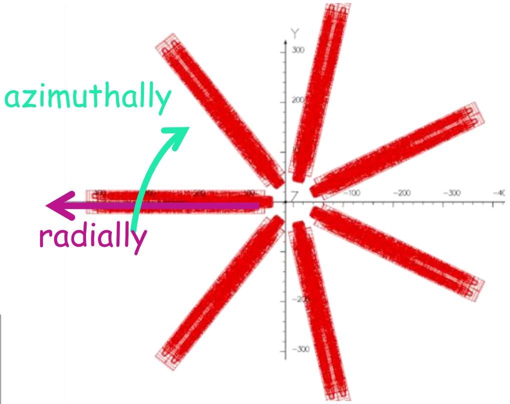
- Design the detector tiling to use the phi defocussing
- Have different contributions from the different processes
- three W regions for the inelastics

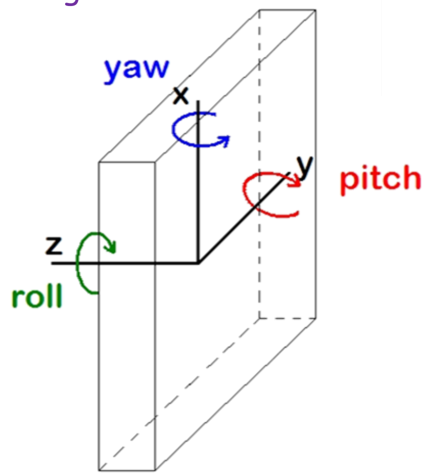
- Fit the simulated total asymmetries in each tile, using the simulated dilutions (fractional rates) to determine the asymmetry of each process

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 $\times$ the uncertainty is the tolerance





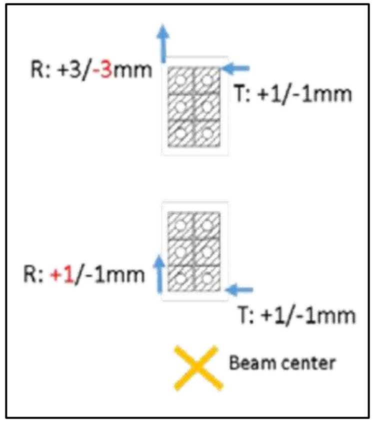


- Considerations
  - physics optics (ability to "deconvolute" the asymmetries with desired uncertainty)
    - signal electron focal plane distributions
    - backgrounds

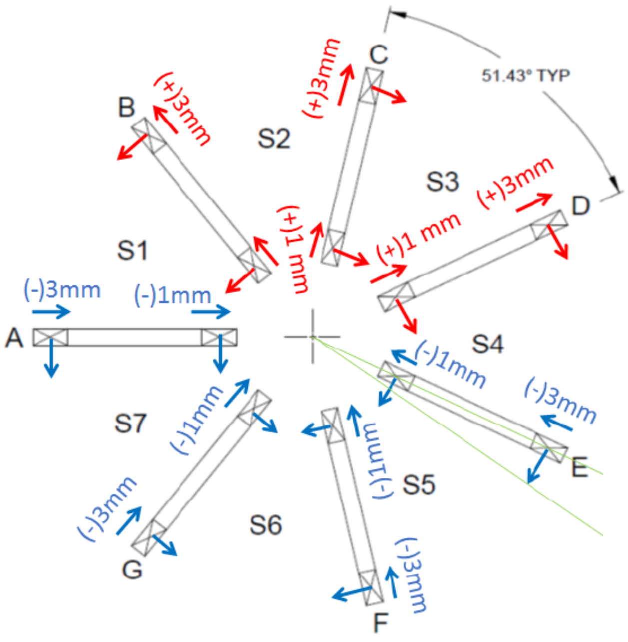
  relatively insensitive

  - clean transport to the dump
  - clearance with the scattered particle envelopes
  - doses on coils (epoxy, especially at inner radius)

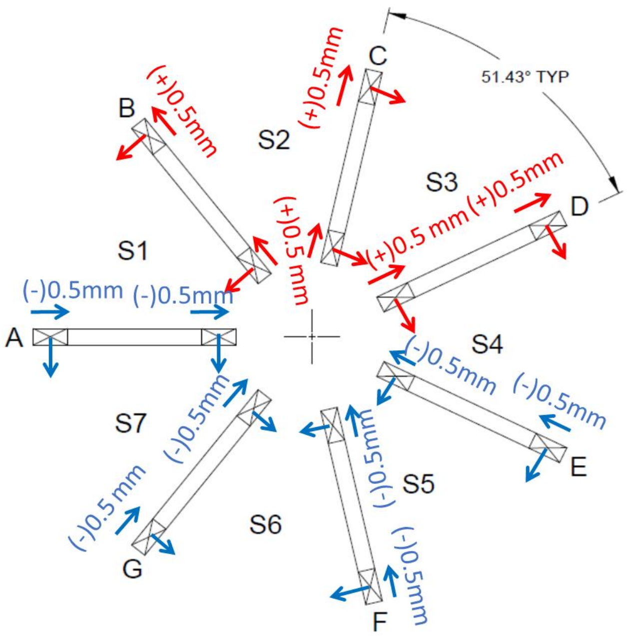
Tolerances determined by single coil/single offset studies have been verified with "worst-case" multiple coil/multiple offsets within the specified tolerances



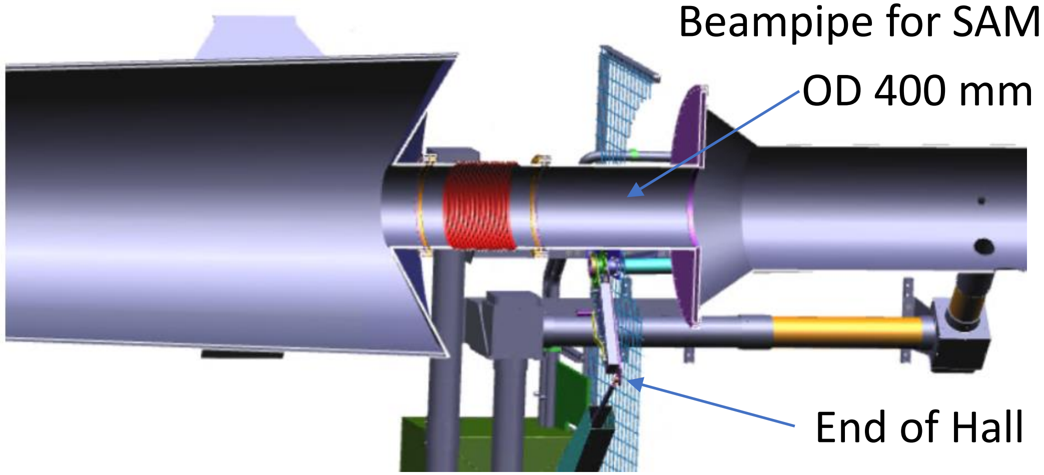
Alignment Tolerance Cases



CASE 1



CASE 2 and 3



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

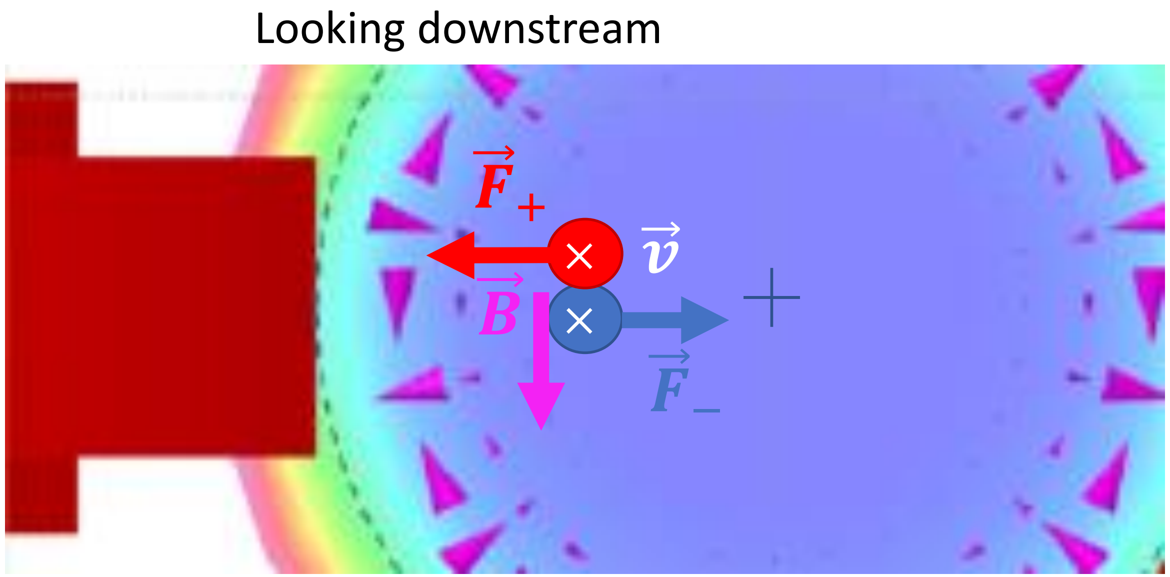
→ induces dipole

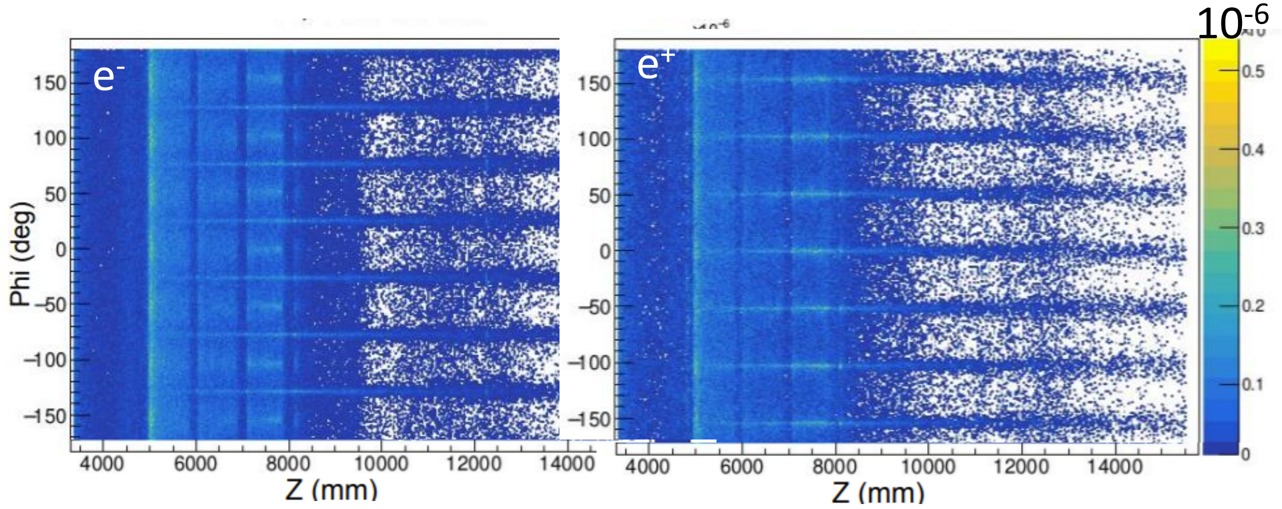
- affects beamline shielding (dose on coils)
- backgrounds from end of hall apertures
- Irradiation

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 $e^{\pm}$



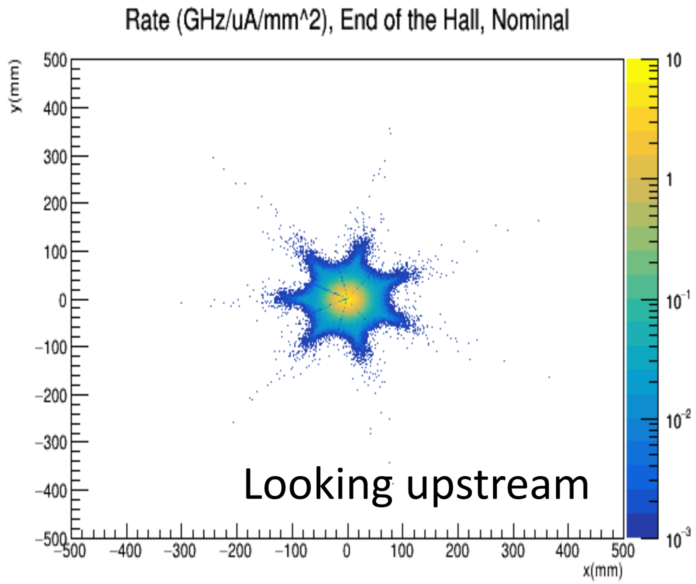


Consider the horizontal coil, in the perfectly symmetric case

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

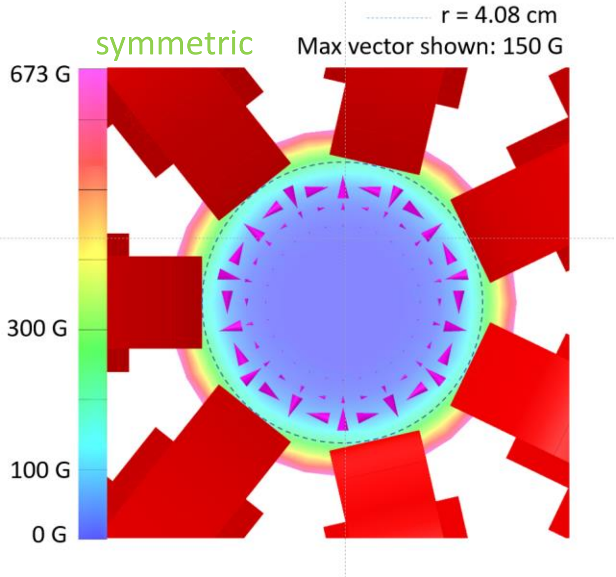
- e^- will be bent to the right
- e^+ will be bent to the left (onto the coil)

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

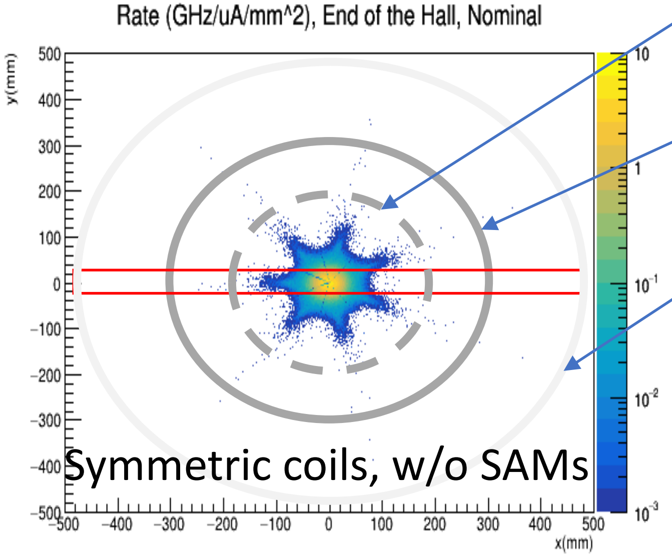


Nominal (symmetric) case – clean transport to dump

Looking downstream



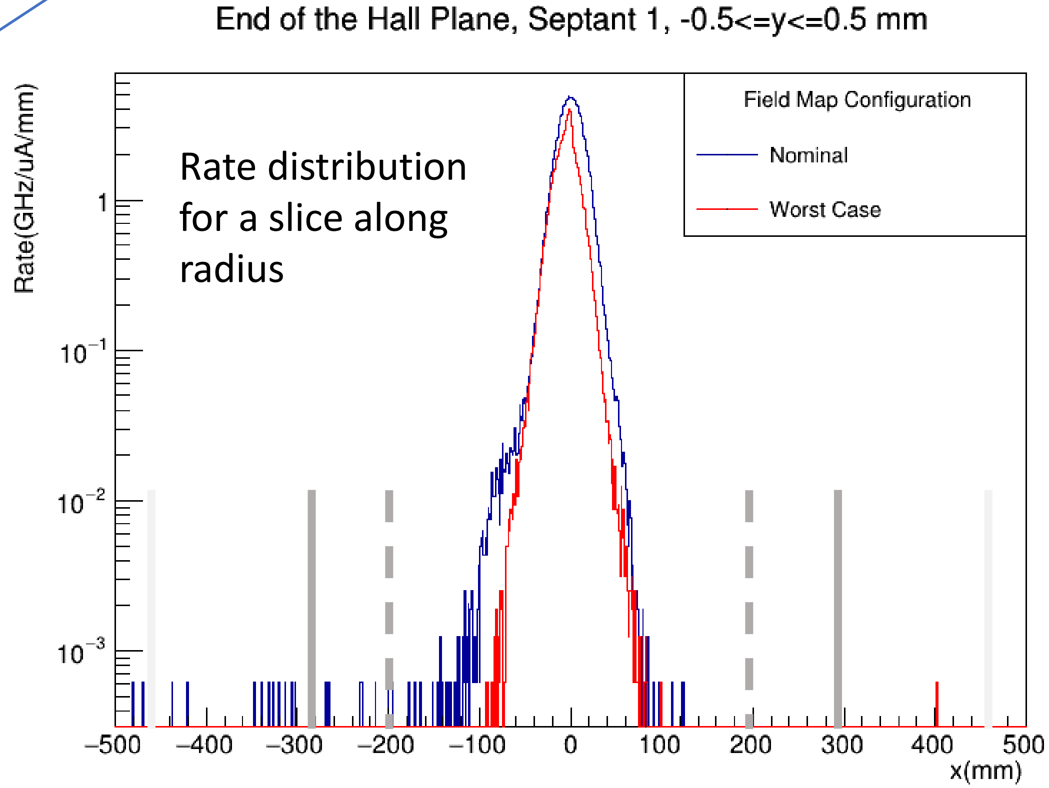
Looking upstream



Beampipe intrusion for the SAMs
(~0.5m upstream)

Limiting aperture in dump tunnel
(~0.5 m downstream)

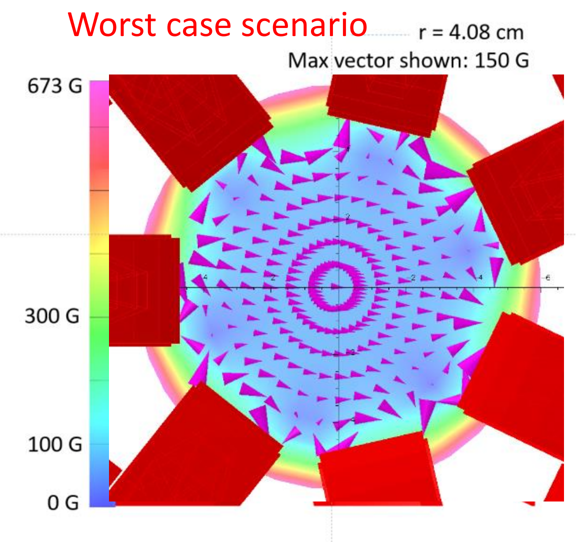
Dump entrance flange
(same z location as plots)



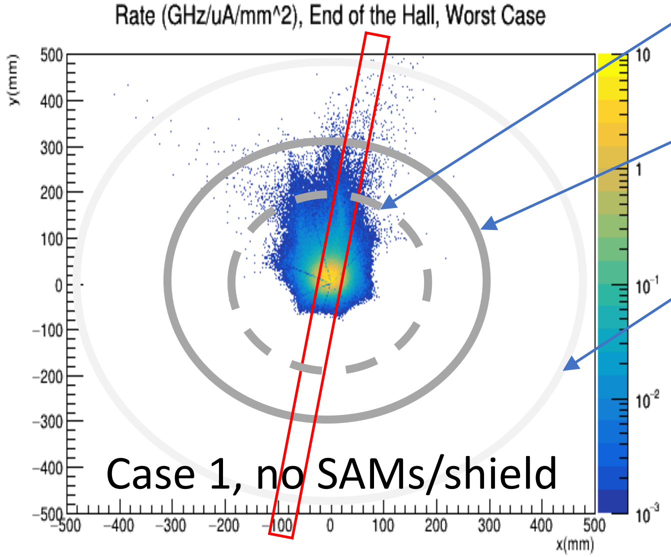
- In the top left plot you see a picture of the ds coils at a particular z location with the magnetic field contours and vectors
- Middle top plot is a 2D rate distribution at the entrance to the dump tunnel
- To the right is a 1D distribution of the rate in horizontal septant (1); the vertical lines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

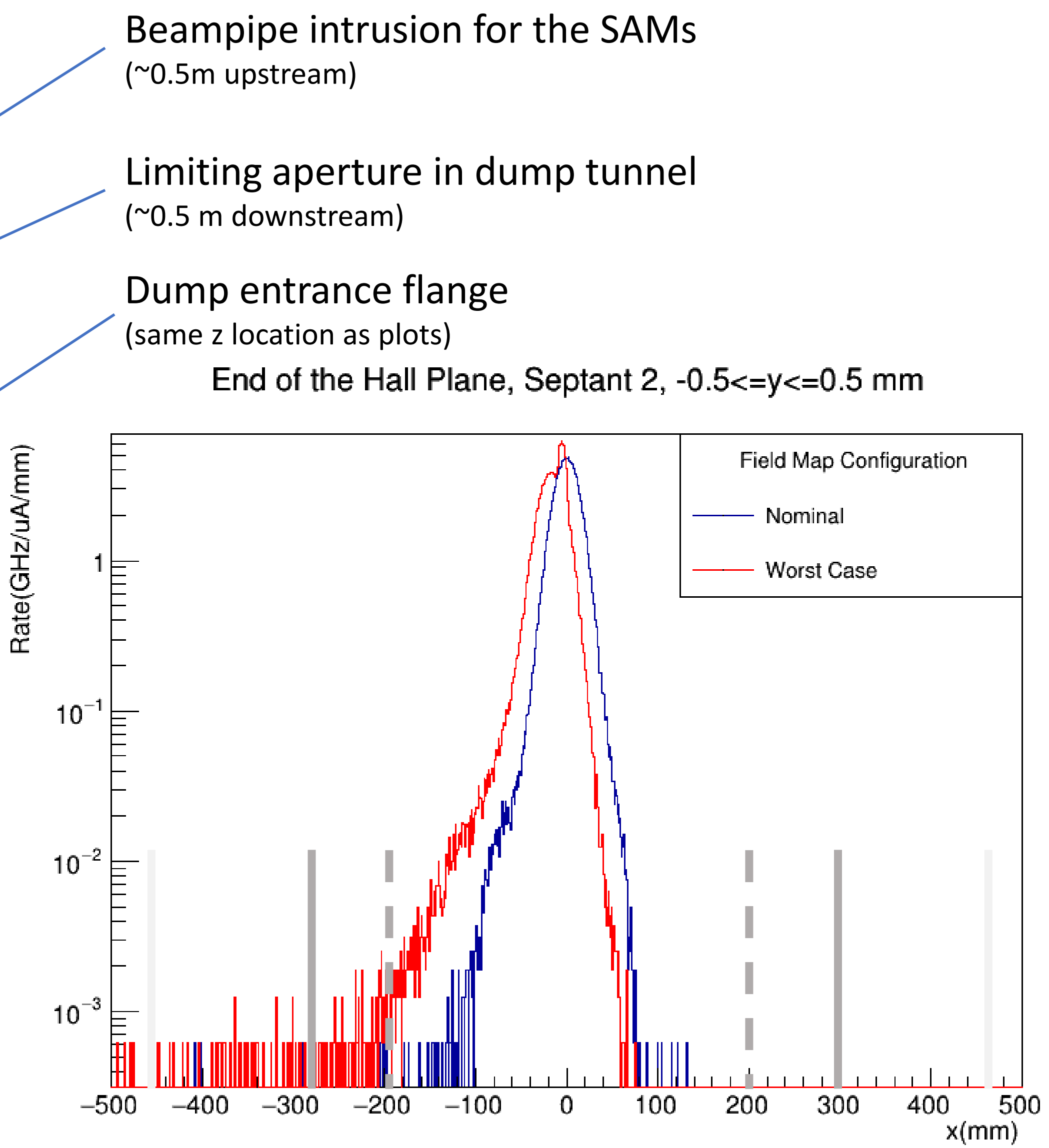
Worst case – clean transport to dump

Looking downstream



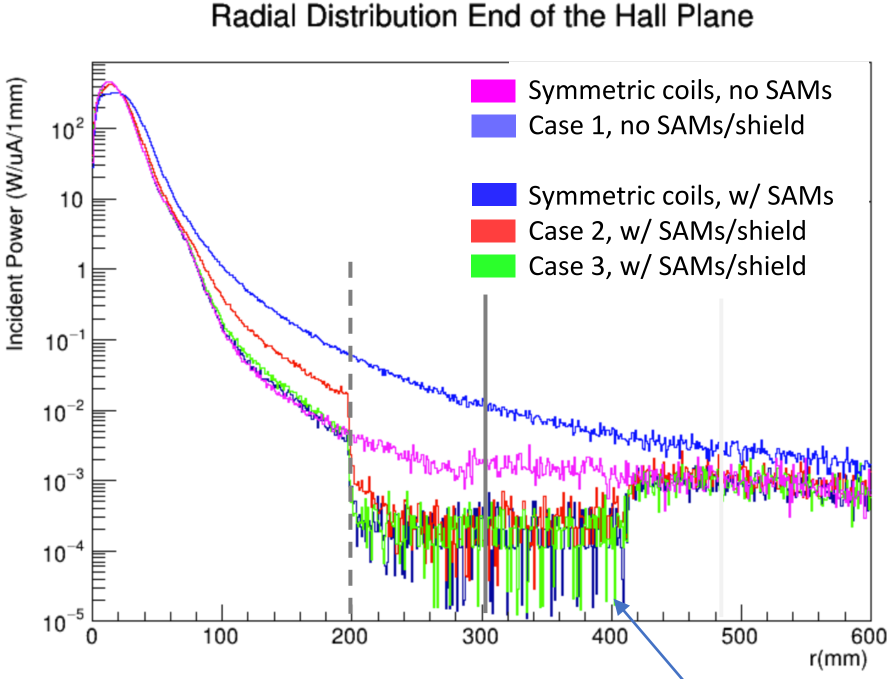
Looking upstream

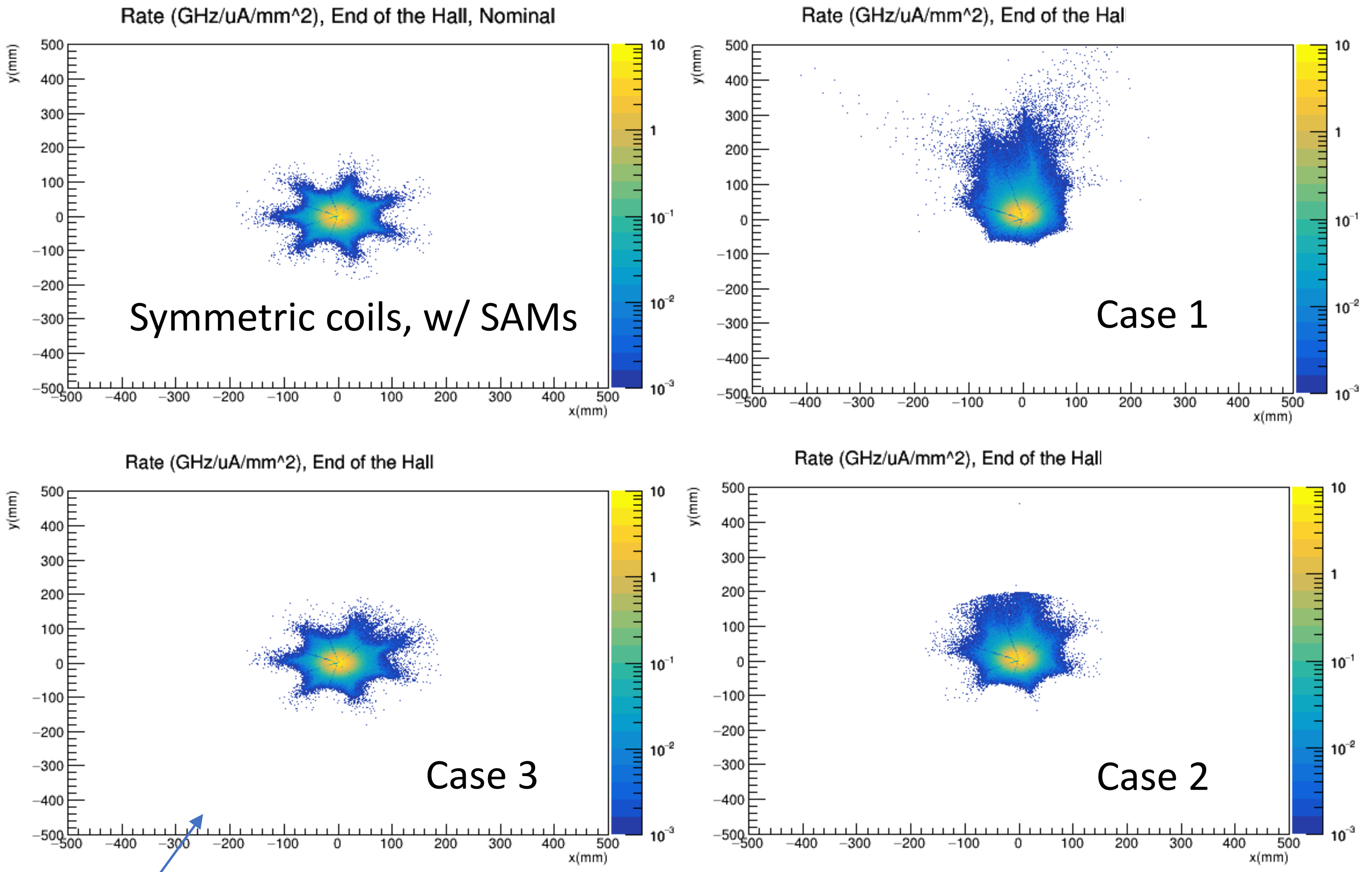




- In the top left plot in the worst case scenario there is an induced dipole field > 100 G over most of the area inside the coils
- In this particular orientation, the electrons are bent upward into septant 2
- To the right is a 1D distribution of the rate in the worst septant (2); even in the worst-case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

Comparison of cases – clean transport to the dump





Total Beam Power 715 kW

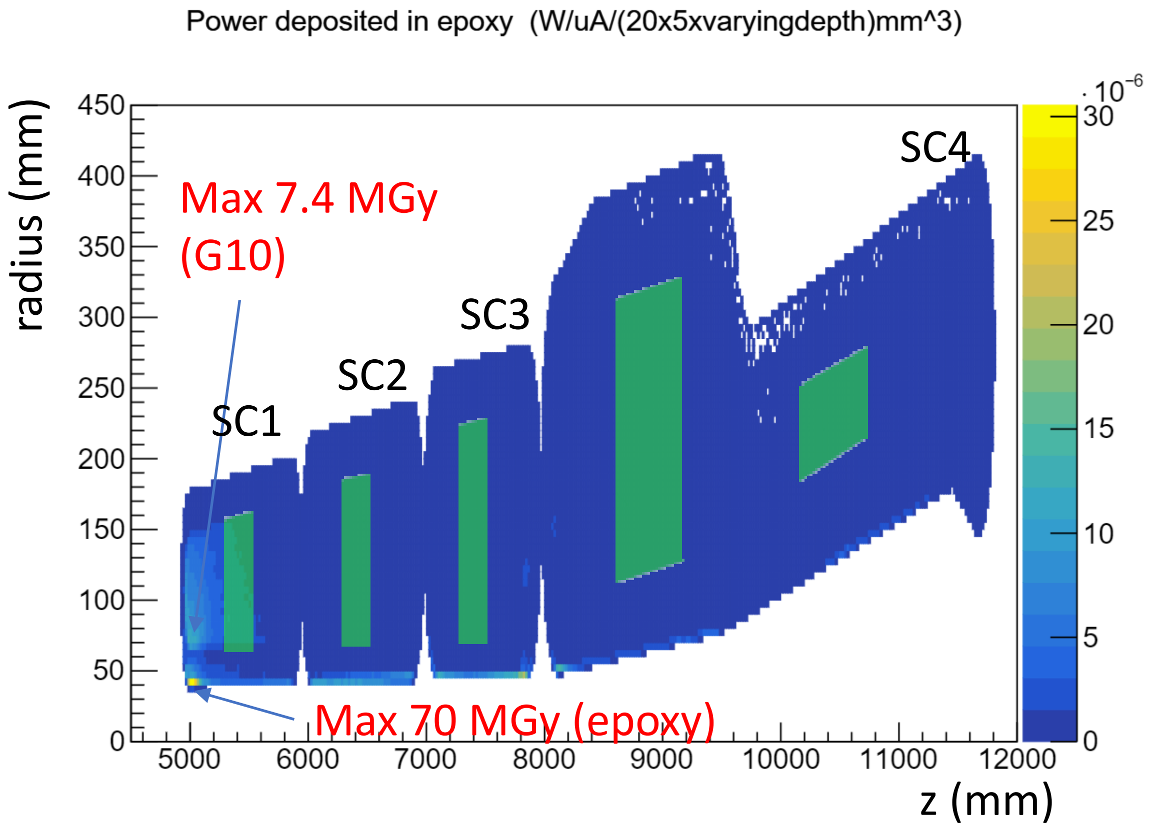
Integrated Power from
200 mm < r < 600 mm

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

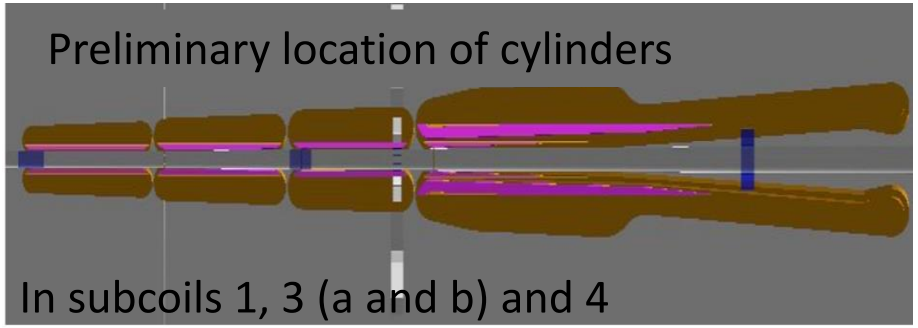
worst case is 10^{-4} of total beam power
order of magnitude lower for most likely case

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

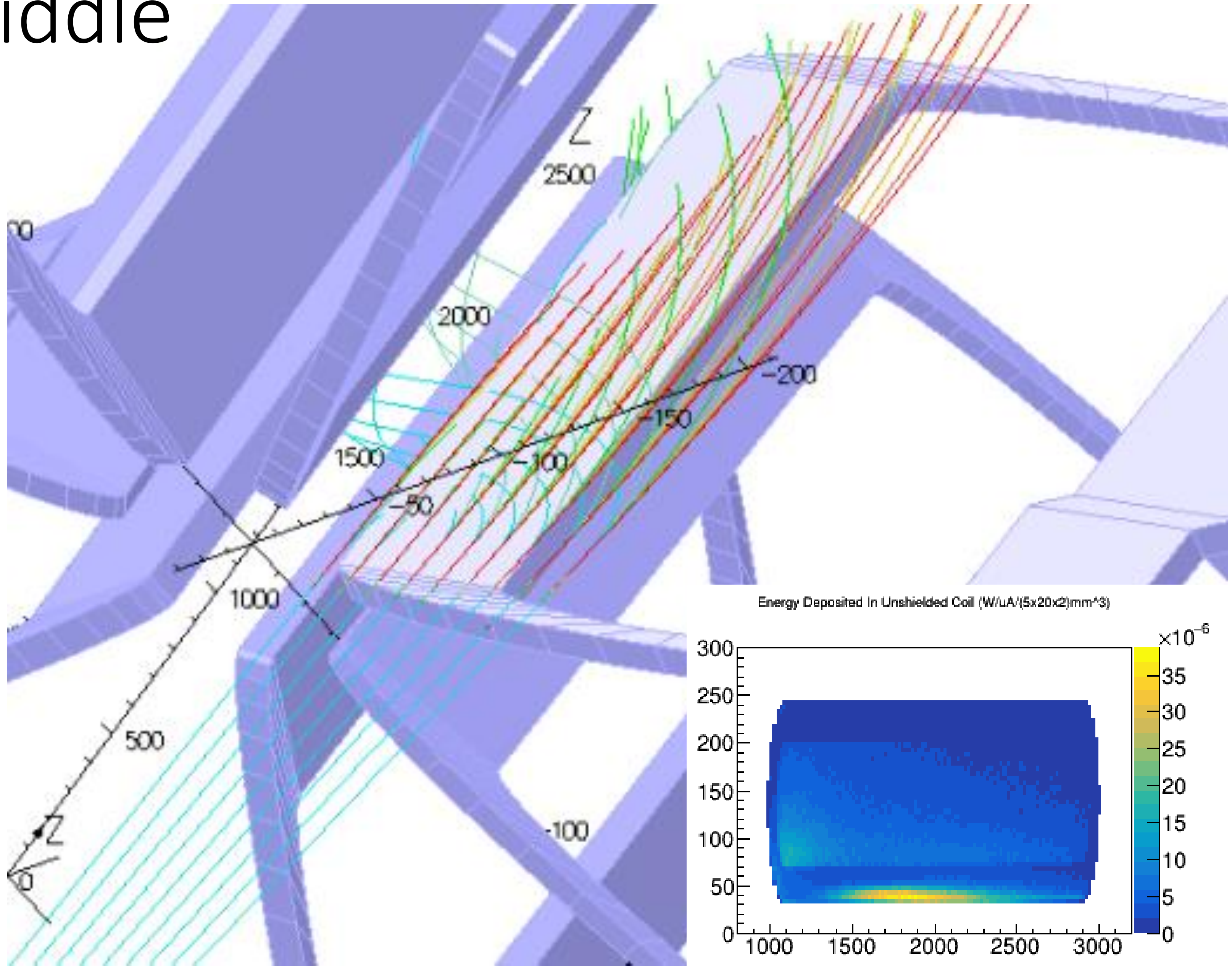
Positrons in the middle

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

Colored by energy

0.1 purple
50 cyan
300 green
700 orange
1100 red

Which ones are the most important?



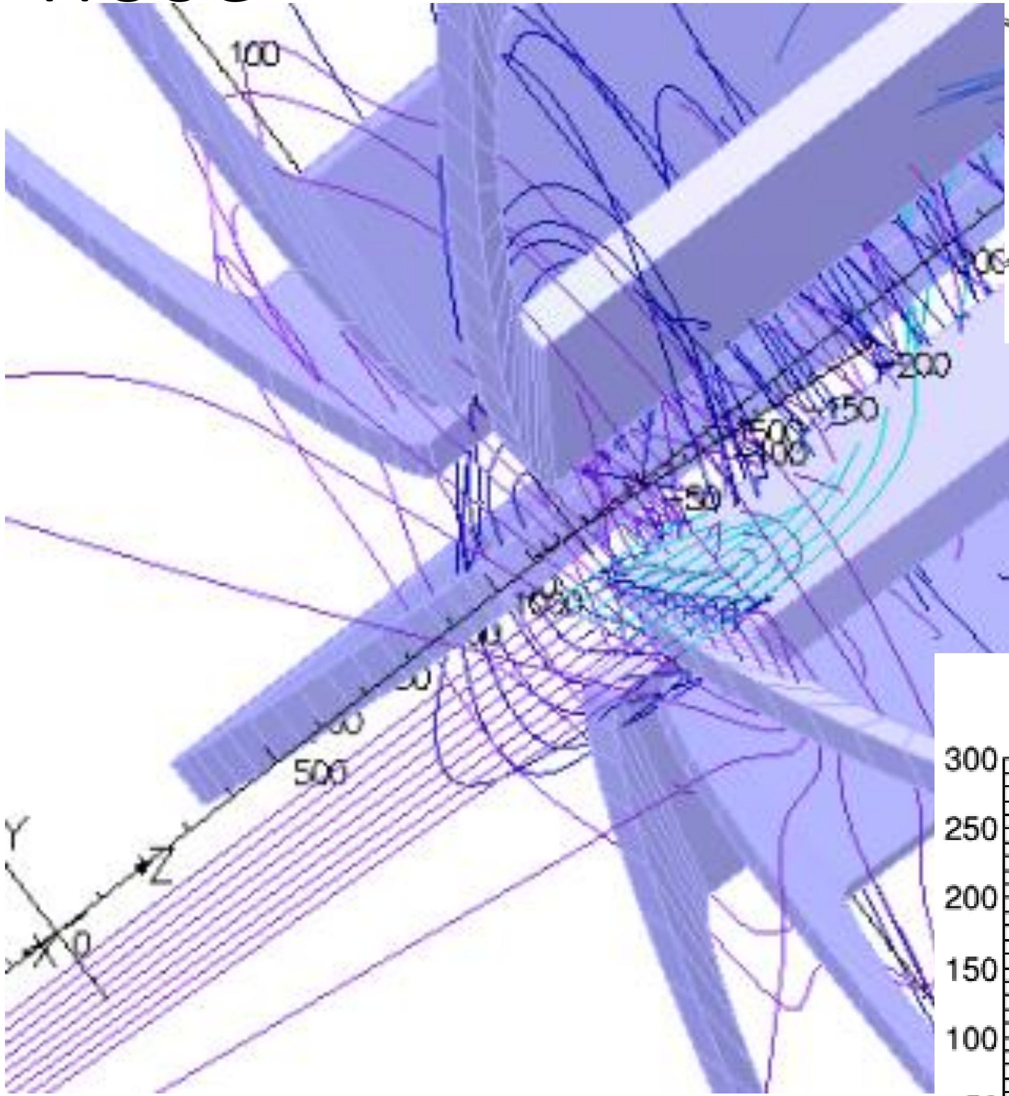
Max 320 MGy

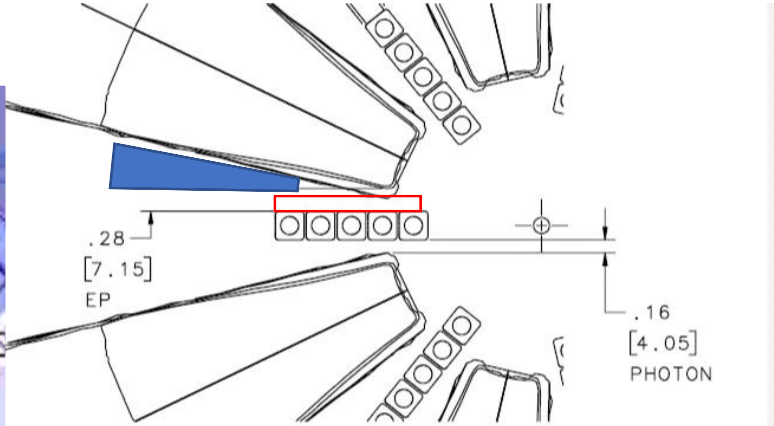
Positrons at the nose

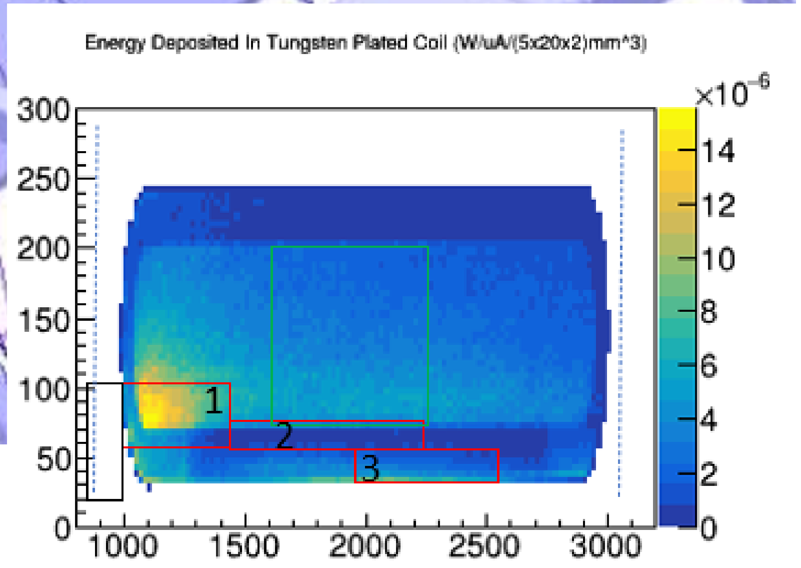
Phi = 12 degrees
E = 0.1, 1, 10, 50 MeV
6 < th < 22 mrad (steps of 2)

Colored by energy

0.1 purple
50 cyan
300 green
700 orange
1100 red



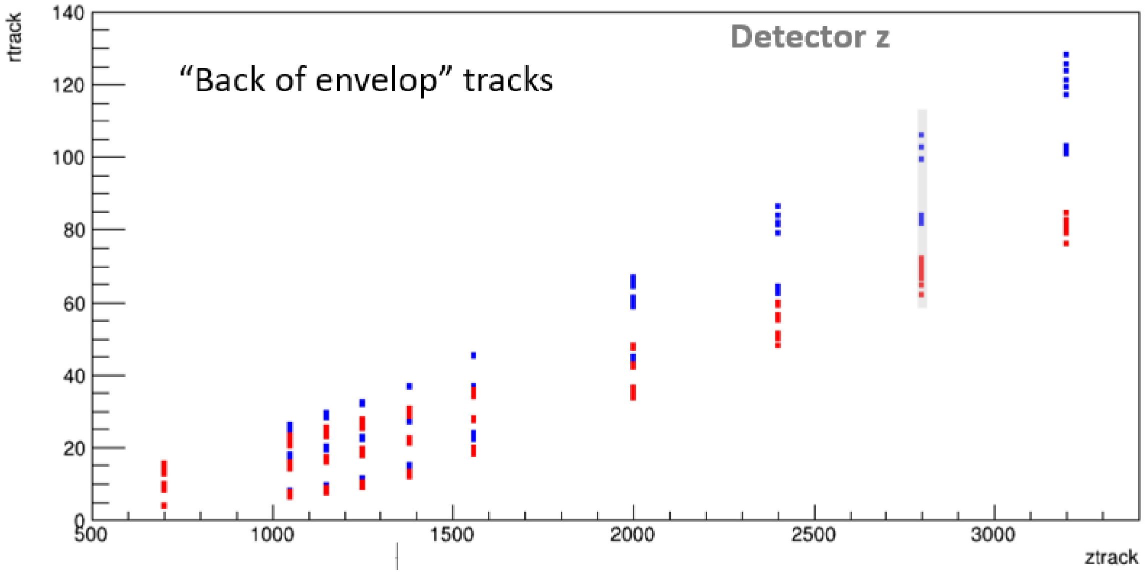


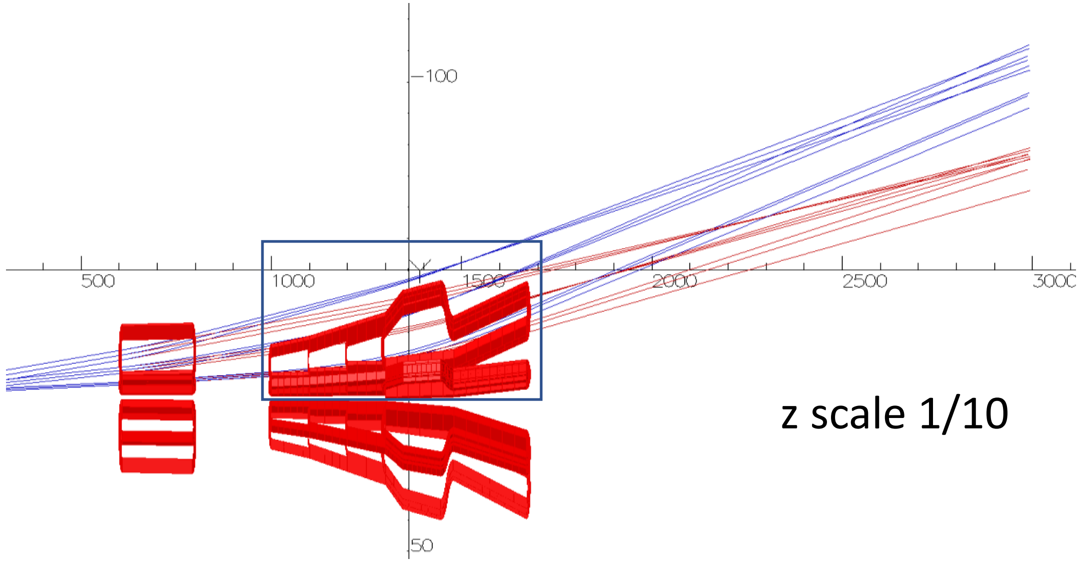


Produce plot of E_{dep} weighted E_{scatt} vs. radius to see what the most important tracks are

Max 60 MGy

Field map tests – granularity and extent





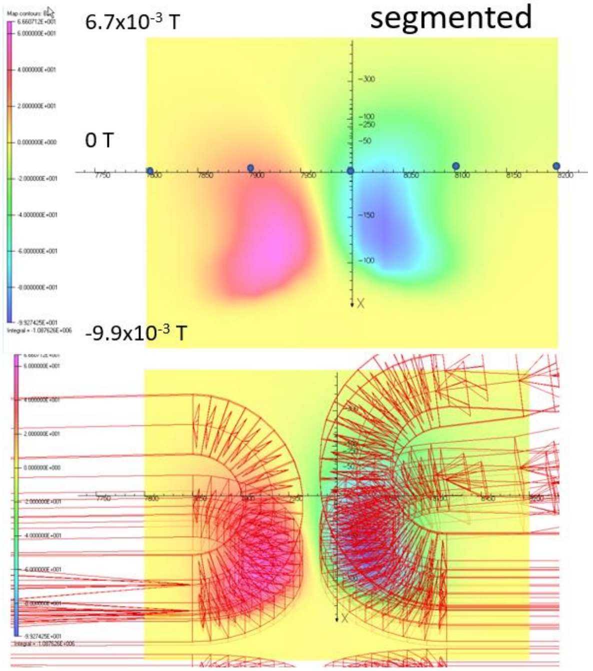
z scale 1/10

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

- 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 limit
  - 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