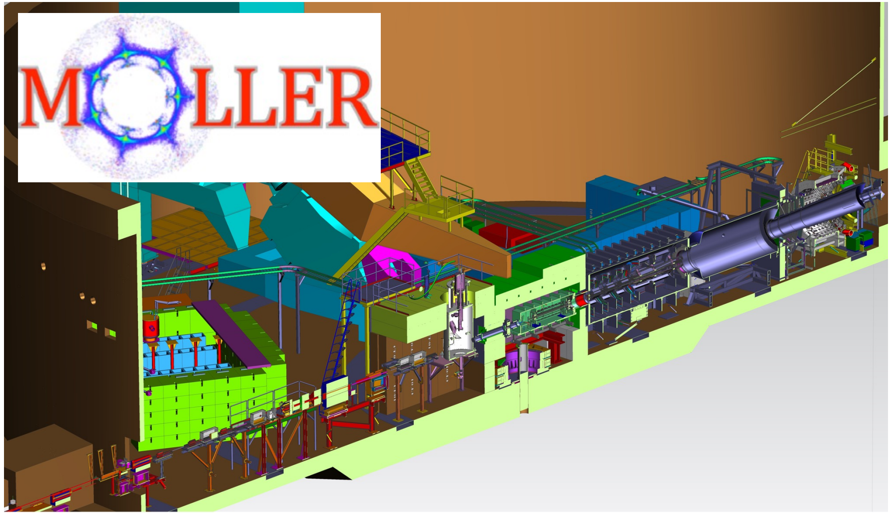
Technical Board May 22 2023

Sieve and Blocker Collimator design

Mainly the work of Hanjie Liu, Vassu Doomra, Kate Evans and Zuhal Demiroglu



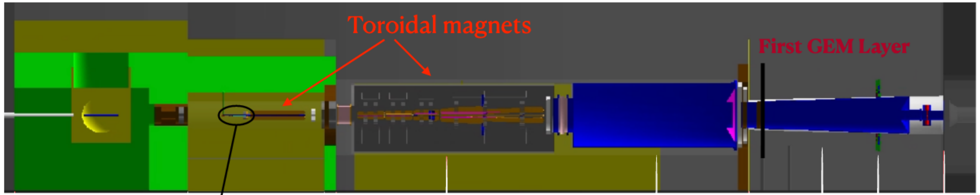
David Armstrong

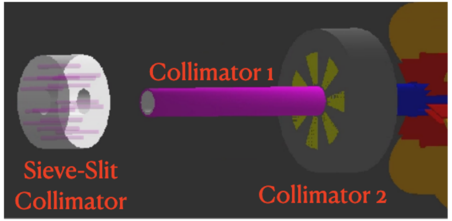
William & Mary

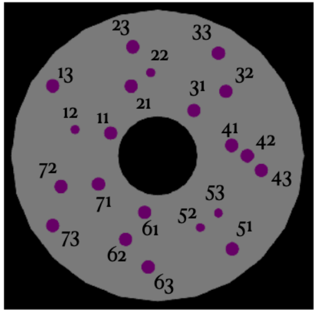
5/22/23

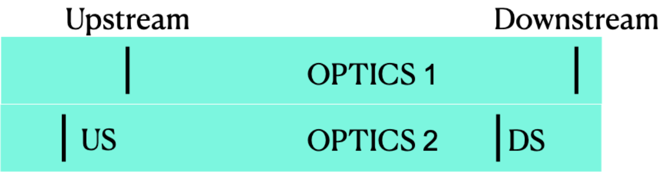
Optics Study: Strategy

- ✦ Measure the track positions r and ϕ and also the directions $r' = \frac{dr}{dz}$ and $\phi' = \frac{d\phi}{dz}$ using GEM detectors.
- ✦ Use GEANT4-based mapping $(\theta_{lab}, \phi_{lab}, E', v_z) \rightarrow (r, \phi, r', \phi')$.
- ✦ Sieve-slit collimator to pick out tracks with particular θ_{lab}, ϕ_{lab} with thin solid target (C12) to select z_{vertex} .
- ✦ Measure at 3 lower beam energies (2.2, 4.4 & 6.6 GeV) to fully map out the Møller phase space.









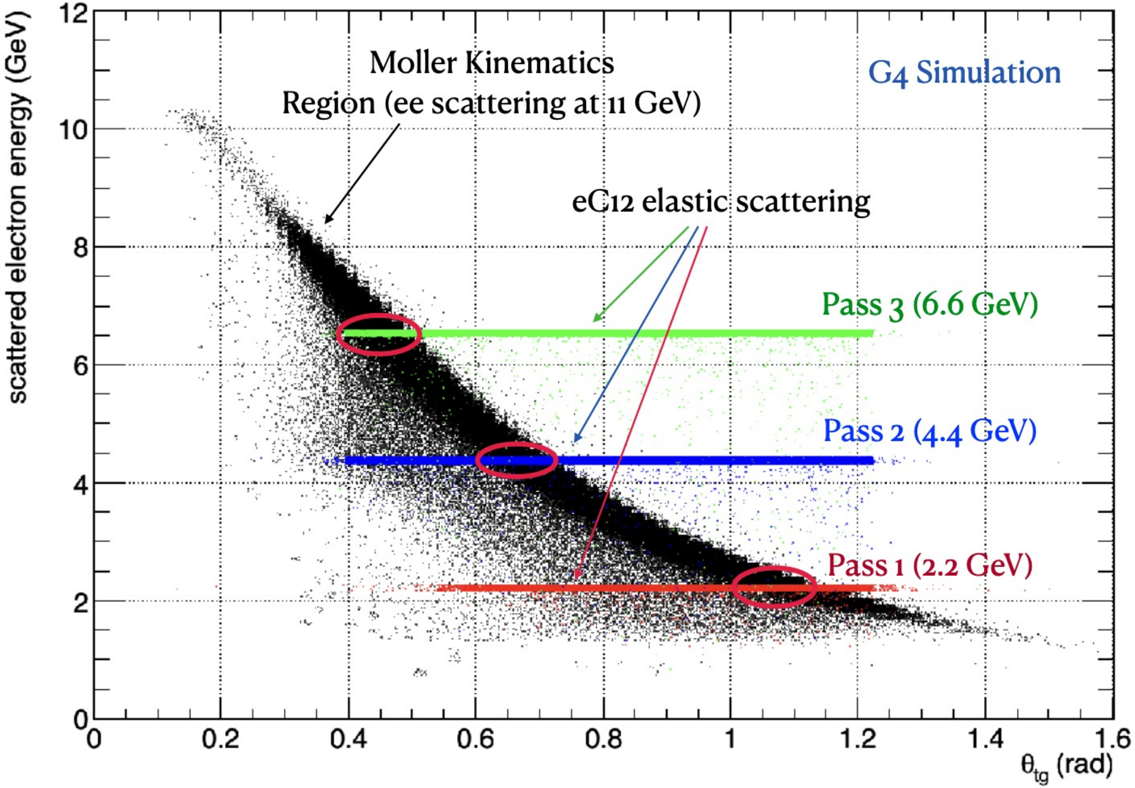
C Foil	Z location (relative to global origin)
Optics 1US	-4800 mm
Optics 1DS	-3900 mm
Optics 2US	-5100 mm
Optics 2DS	-4200 mm

4 different z locations spanned by 4 thin C foils

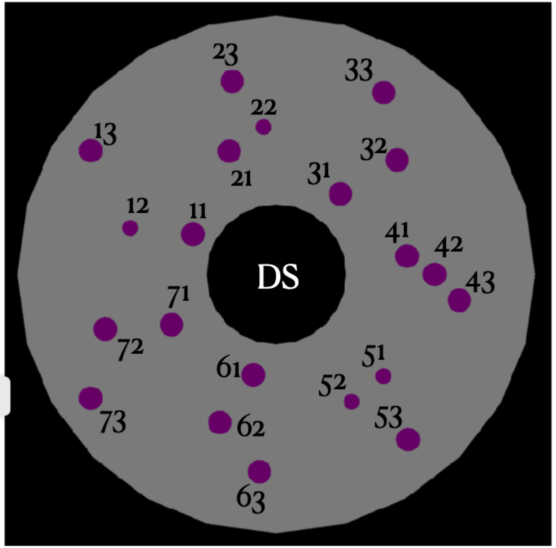
The Møller Kinematics Region

$(\theta_{lab}, \phi_{lab}, E', v_z)$ -> Variables of interest

- ✦ The electrons that are getting scattered off of the C12 nuclei are essentially mono-energetic.
- ✦ We already know v_z down to a 1 mm precision from the known locations of the C foils.
- ✦ The relative cross section of elastic nuclear scattering vs Møller scattering scales as Z^2 which ensures that the C12 data will not be swamped by the Møller events (serves as a background in this study).
- ✦ The optics problem essentially reduces down to the precise determination of θ_{lab} and ϕ_{lab}.



Sieve Hole Locations



IR: 26.5 mm
OR: 98 mm
Thickness 100 mm

Most of the Holes
are 9 mm
in diameter.

Hole ID	Radial Location (mm)	Angular Offset (deg)
11	35	0
12	58(6)	-8
13	84.5	8
21	50	-8
22	56(6)	8
23	75	0
31	39	0
32	63	8
33	80	-8
41	50	-8
42	60	0
43	70	8
51	56(6)	-8
52	56(6)	8
53	80	0
61	39	0
62	60	8
63	75	-8
71	44	0
72	68	8
73	84.5	-8

Holes 51 and 52 —> To check the magnetic field symmetry in a given septant.

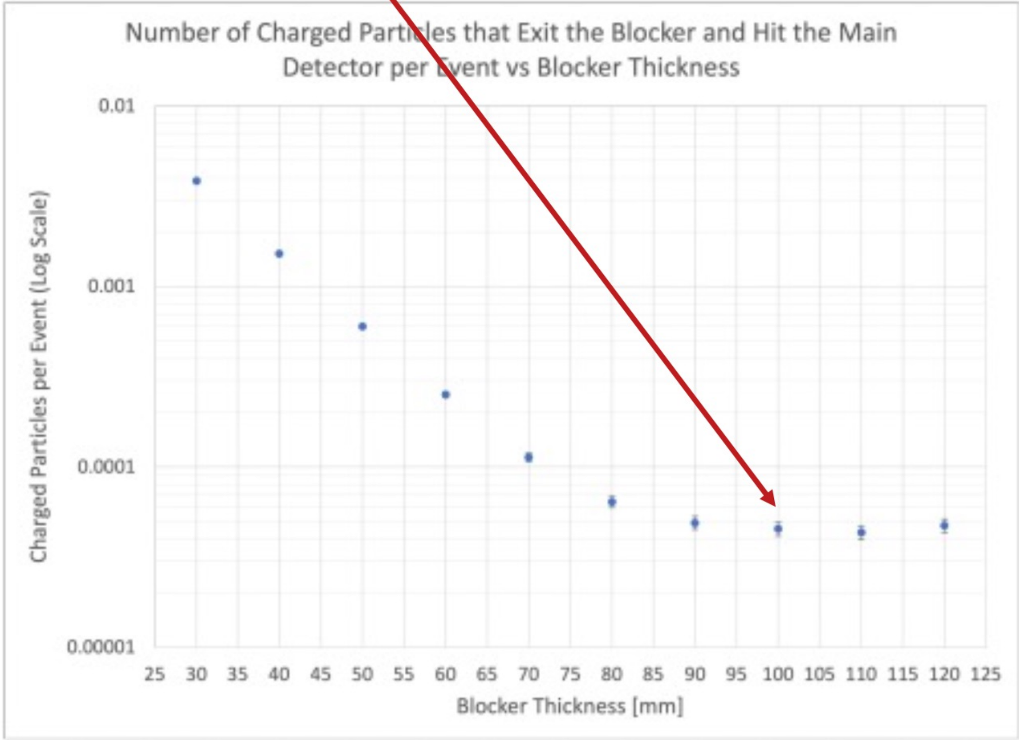
We also have a few symmetry pairs to look for any possible deviations in the magnetic field from it's ideal configuration.

Data Transmission (specs) to MIT engineering would be based on this table

Sieve/Blocker thickness optimization

For both sieve and blocker:

- Full annulus (no open sectors)
- Material = pure W (MIT engineering prefers this to 90/10 W/Cu)
- Inner radius 26.5mm, outer radius 98mm
- Thickness 100mm (21 X_0)

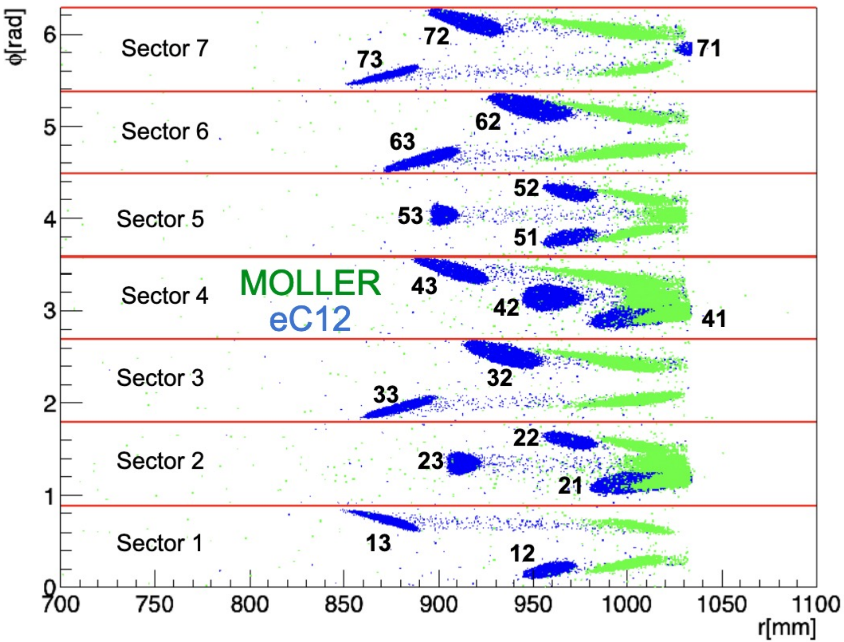


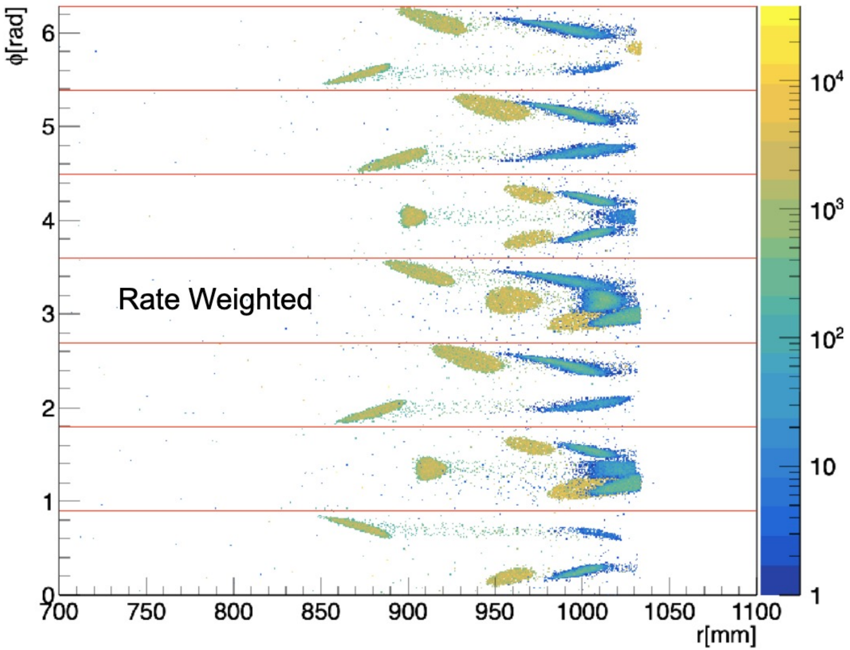
Note: the holes are simple cylinders, orientated parallel to beam axis. We investigated tapering and/or slanting the holes at the nominal average scattering angle, but found no improvement on ^{12}C/Moller separation or any other clear advantage – so, for ease of machining, chose simple cylindrical holes

Can the ^{12}C elastic events be cleanly separated from the Moller events for each sieve hole?

- Need to check for each of the three beam energies (next slides)
- Also checked for all the ^{12}C z-positions (not shown)

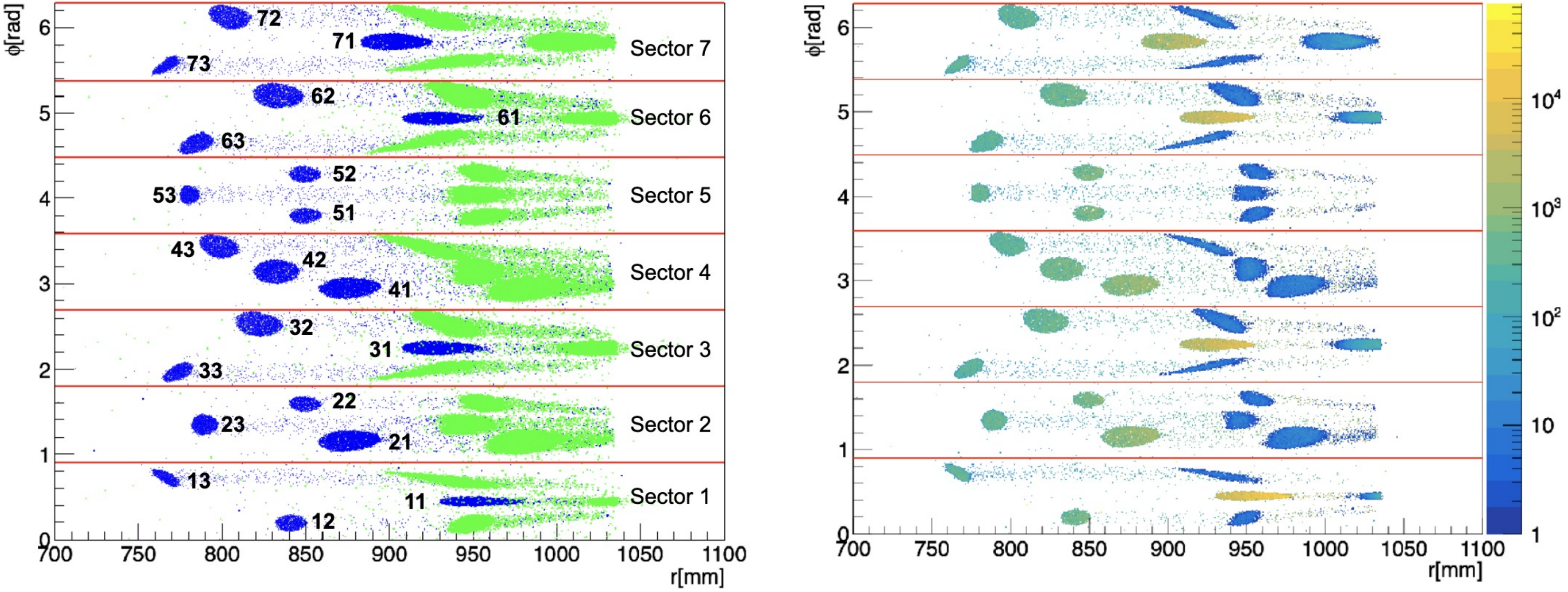
GEM r-ϕ Distributions: Moller + elasticC12 Pass 1



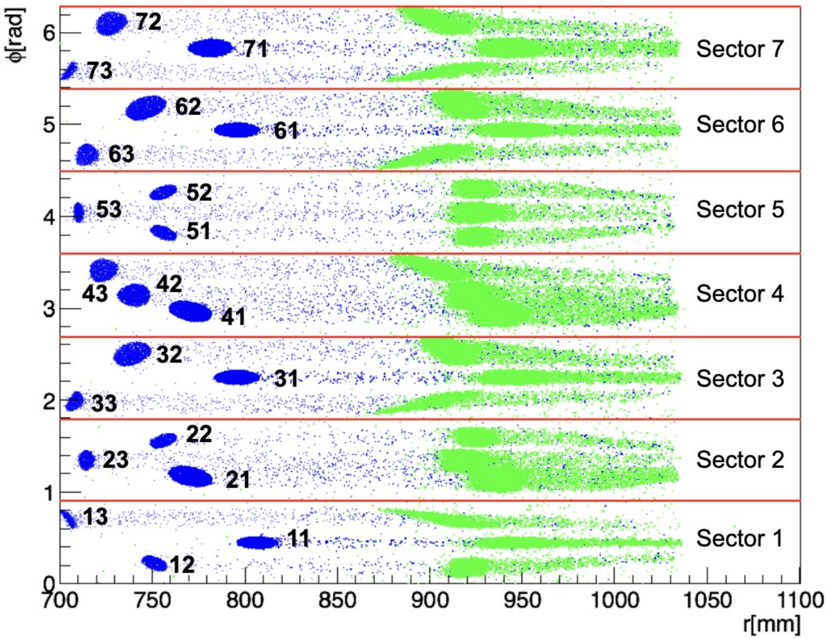


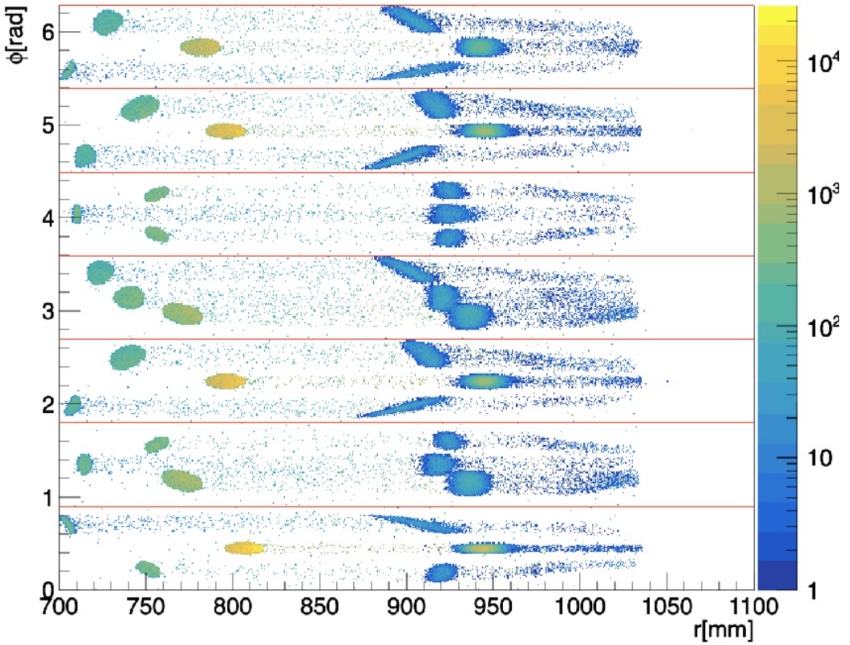
*Some of the holes at lowest pass are cut off by the acceptance.

GEM r-ϕ Distributions: Moller + elasticC12 Pass 2

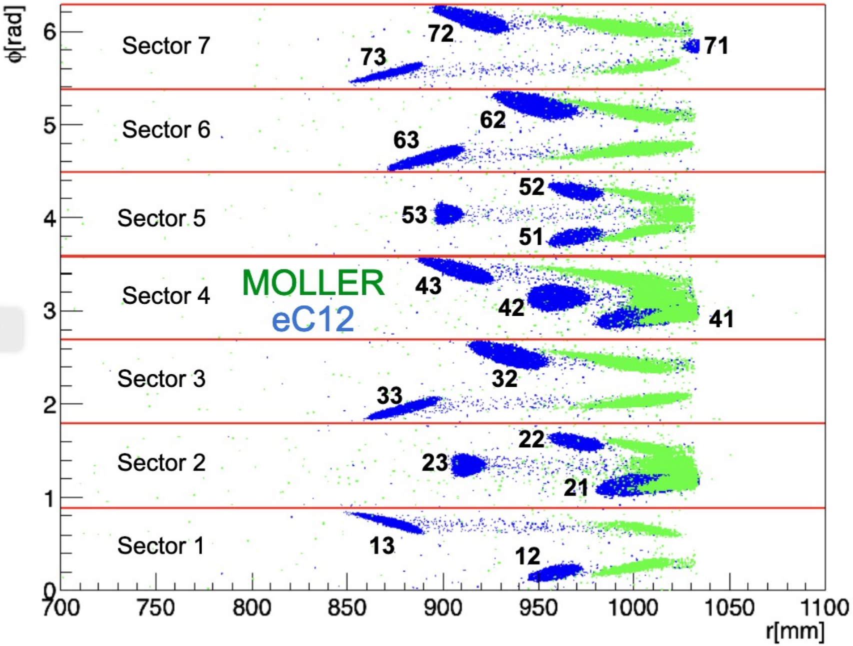


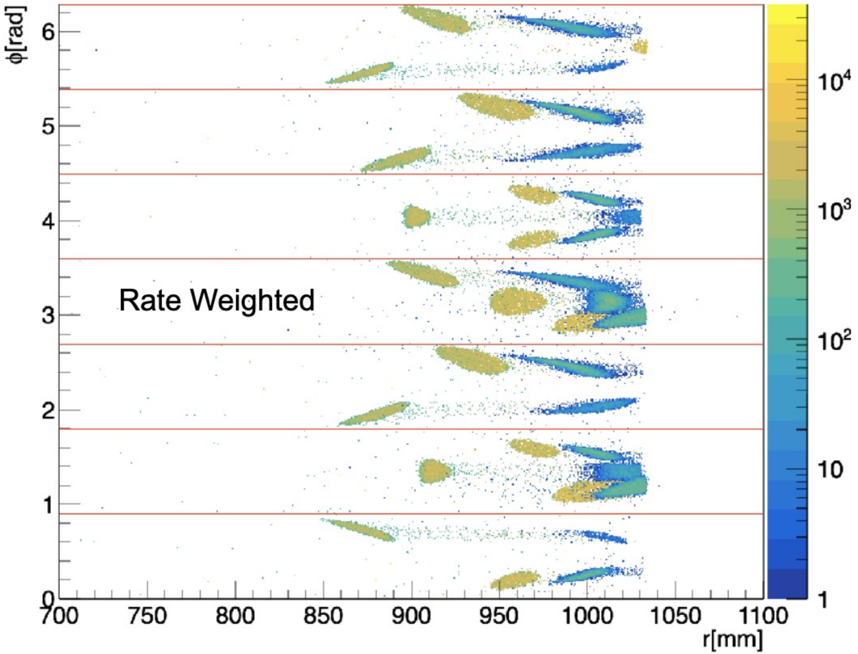
GEM r-ϕ Distributions: Moller + elasticC12 Pass 3





GEM r-ϕ Distributions: Moller + elasticC12 Pass 1



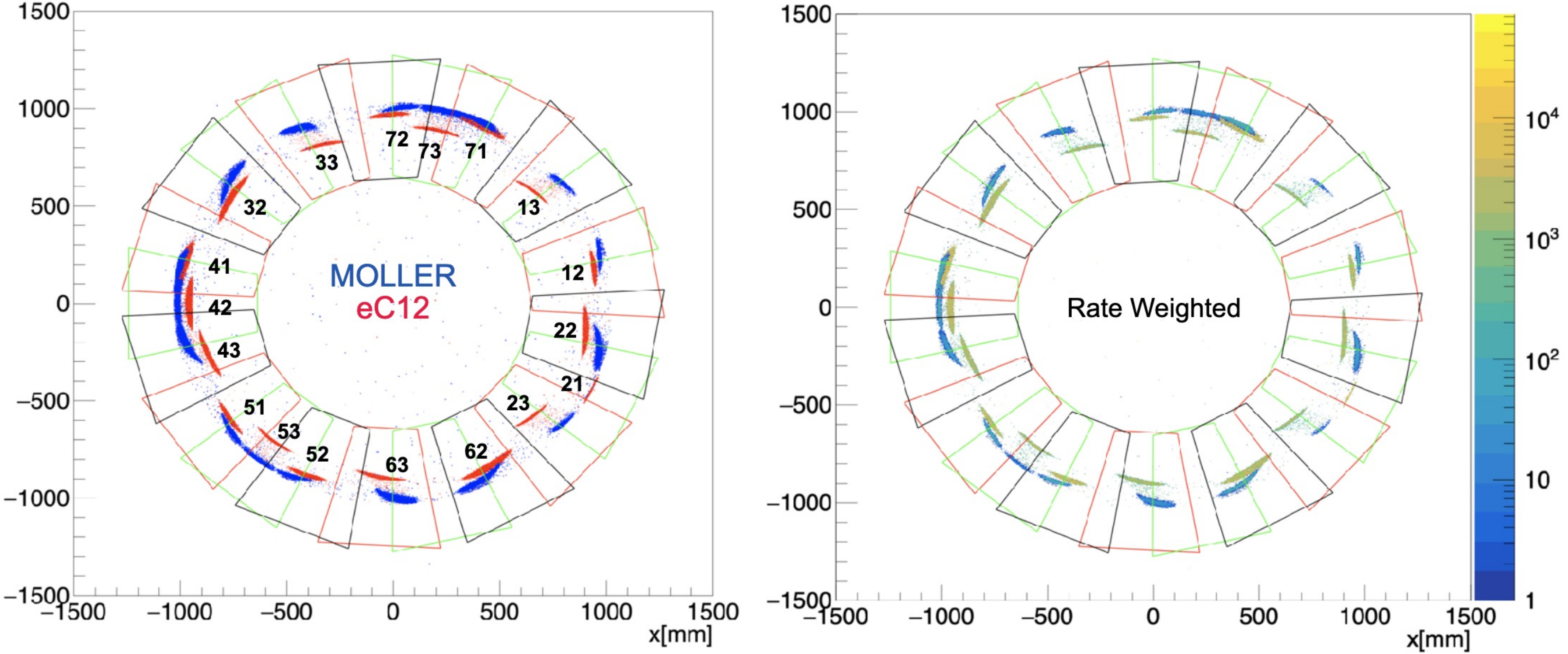


*Some of the holes at lowest pass are cut off by the acceptance.

Next: Can the ^{12}C elastic events from each hole be cleanly seen in at least one of the azimuthal rotation positions of the GEM trackers?

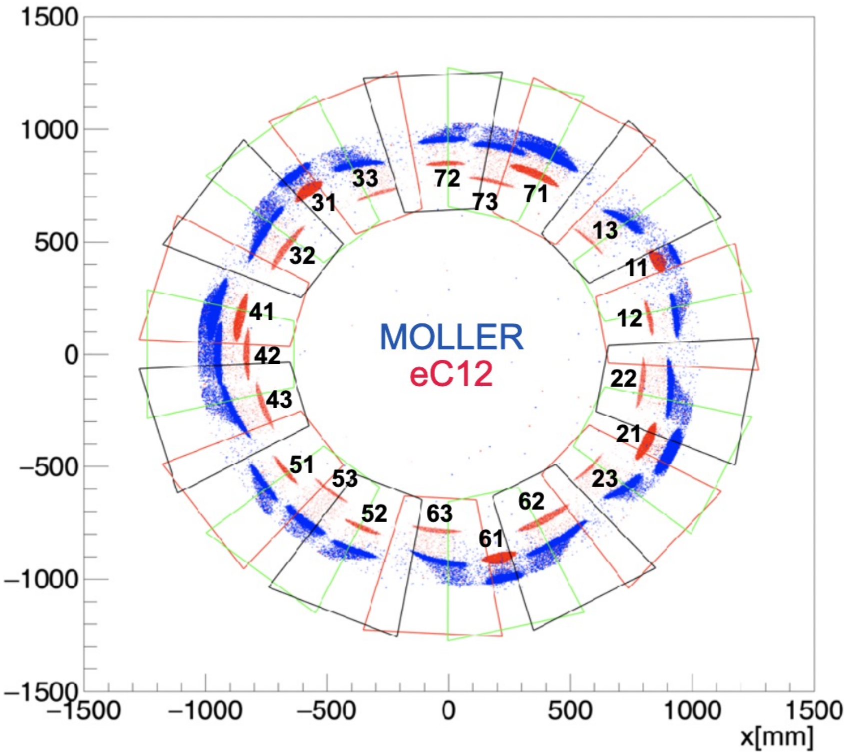
- Need to check for each of the three beam energies (next slides)
- Also checked for all the ^{12}C z-positions (not shown)

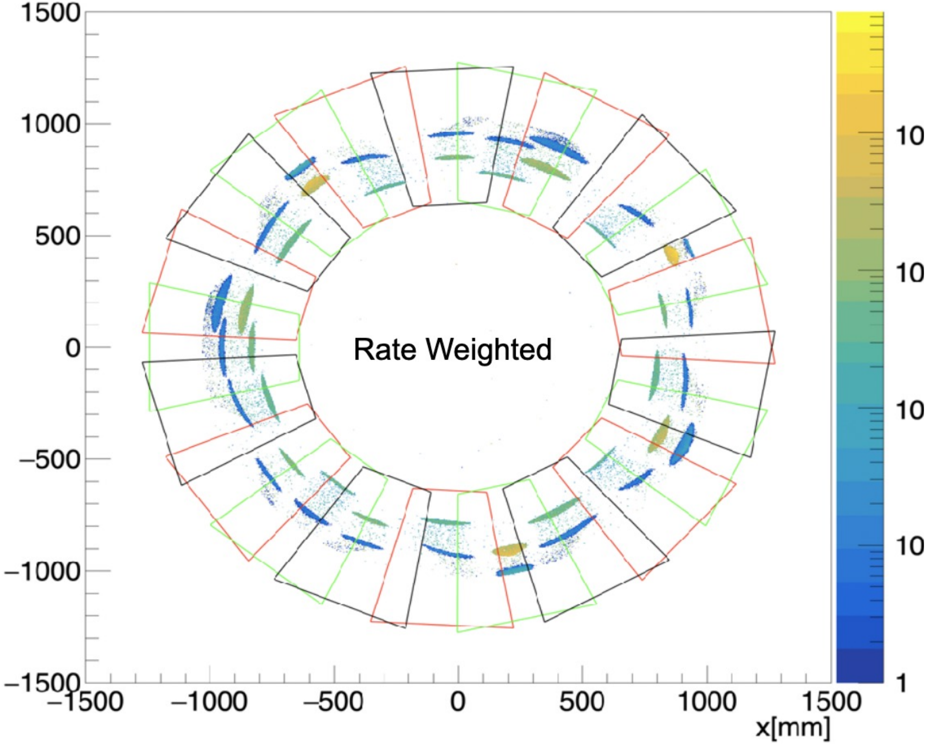
GEM x-y Distributions: Moller + elasticC12 Pass 1



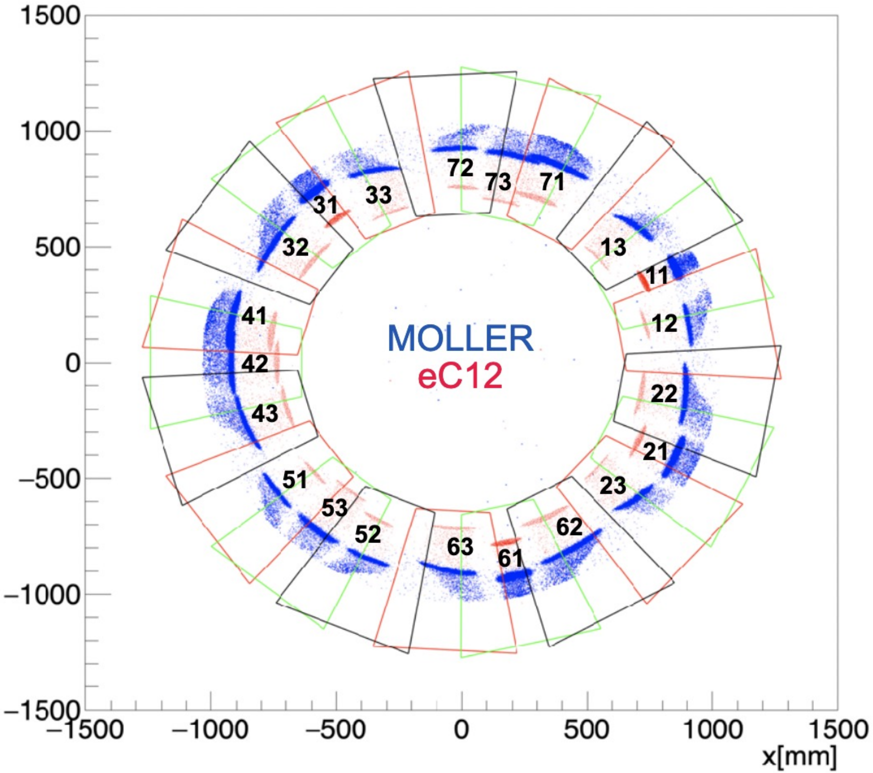
These rectangles represent the GEM active area. Green is when the active area aligns with the open sector of the primary collimator.

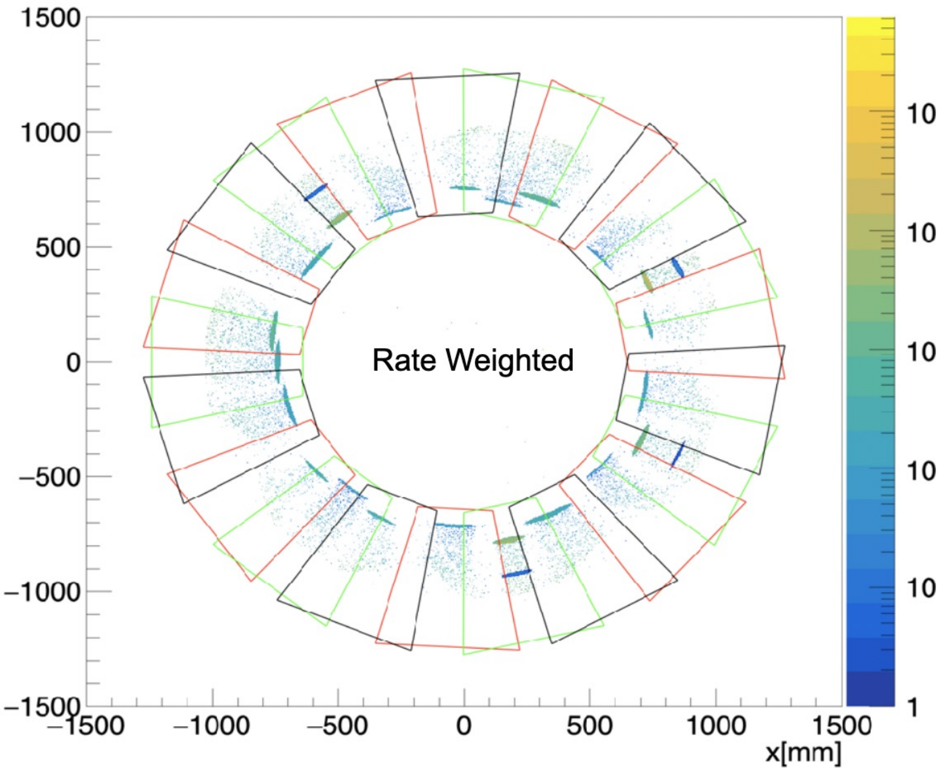
GEM x-y Distributions: Moller + elasticC12 Pass 2





GEM x-y Distributions: Moller + elasticC12 Pass 3





The Reconstruction Algorithm

- The reconstruction algorithm should provide us with a map between the gem variables and the target variables.

$$(r, \phi, r', \phi') \rightarrow (\theta_{lab}, \phi_{lab}, E', v_z)$$

- The first step would be to obtain some kind of a correlation matrix between the two set of variables.
- Currently we are using a ML (Machine Learning) based regression algorithm to obtain this map.

A second degree polynomial in all gem variables r and r'

$$\theta_{tg} = b_0 + b_1 r + b_2 r' + b_3 r^2 + b_4 r r' + + b_5 r'^2$$

A similar equation is used for ϕ_{tg} fitting as well.

Pearson Correlation Matrix: Measure of linear correlation between variables.

	r_{gem}	r'_{gem}	ϕ_{gem}	ϕ'_{gem}
θ_{tg}	-0.98	-0.99	-0.24	-0.22
ϕ_{tg}	0.2	0.22	1	-0.38

Spearman Correlation Matrix: Measure of non-linear correlation between variables.

	r_{gem}	r'_{gem}	ϕ_{gem}	ϕ'_{gem}
θ_{tg}	-0.89	-0.99	-0.27	-0.2
ϕ_{tg}	0.2	0.22	1	-0.38

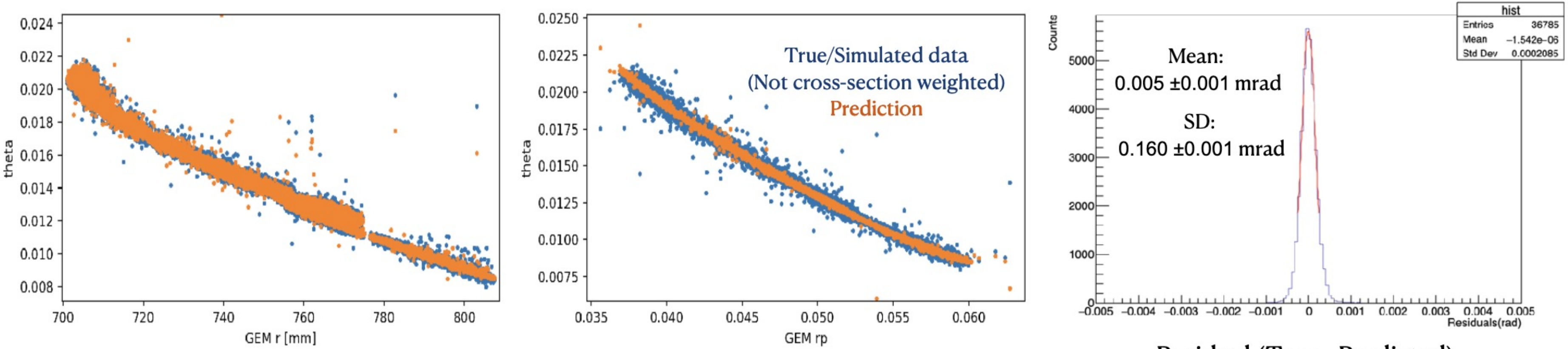
There is a high degree of correlation between:

- θ_{tg} and (r_{gem}, r'_{gem})
- ϕ_{tg} and (ϕ_{gem}, ϕ'_{gem})

However the correlation to other gem variables is not very small.

θ_{tg} Reconstruction

Select events from specific holes as seen in GEM plane (to isolate ^{12}C elastic events)

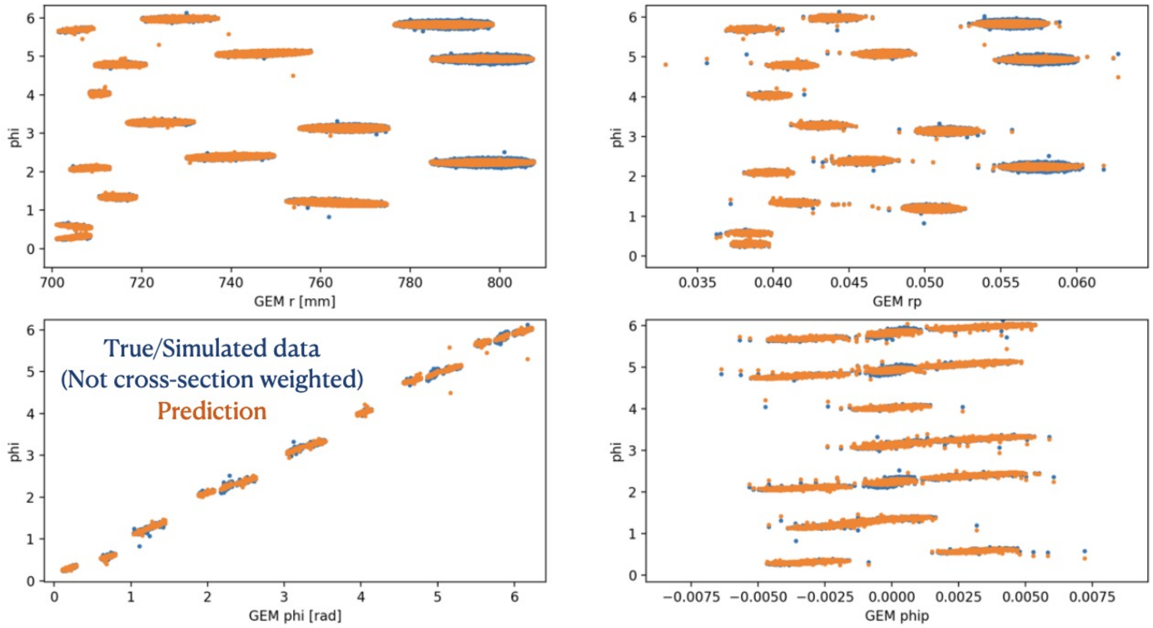


Residual (True - Predicted) Distribution

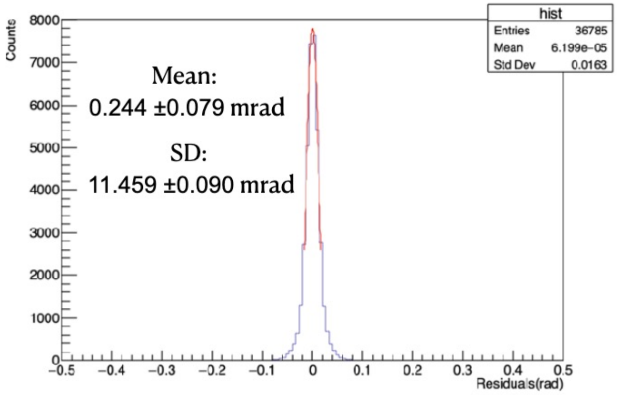
θ_{tg} reconstruction for Pass 3 (6.6 GeV beam energy) data using gem variables r and r′.

Similar results at the other two beam energies.

ϕ_{tg} Reconstruction



True/Simulated data
(Not cross-section weighted)
Prediction



Mean:
0.244 ±0.079 mrad

SD:
11.459 ±0.090 mrad

Residual (True - Predicted)
Distribution

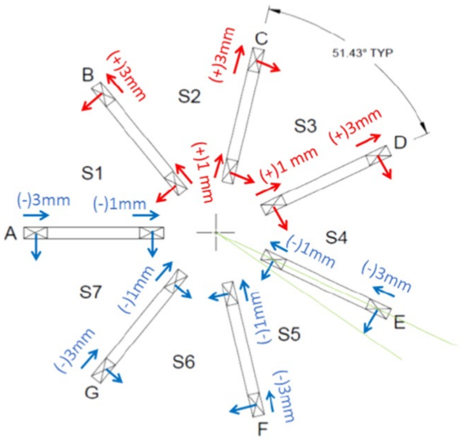
ϕ_{tg} reconstruction for Pass 3 (6.6 GeV beam energy) data using all 4 gem variables.

Similar results at the other two beam energies.

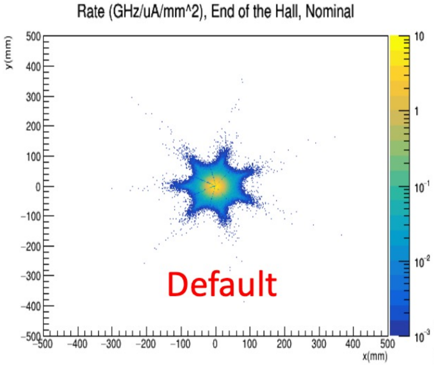
Different Magnetic Field Maps

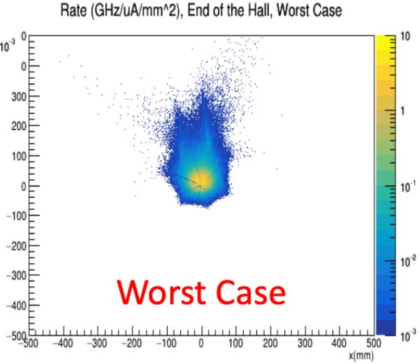
1. Default (“Ideal”): fully symmetric in azimuth
2. Realistic Asymmetric: slight asymmetry, most likely
3. Worst Case Asymmetric: all coils offset by 3mm in the same direction, very unlikely

Worst Case



*looking upstream





Note: the “worst case asymmetric does not change the kinematic factor outside the 0.5% uncertainty budget

Testing Optics Reconstruction with Different Field Maps

- Use the optics parameters to reconstruct variables and check the residuals. Theta example:

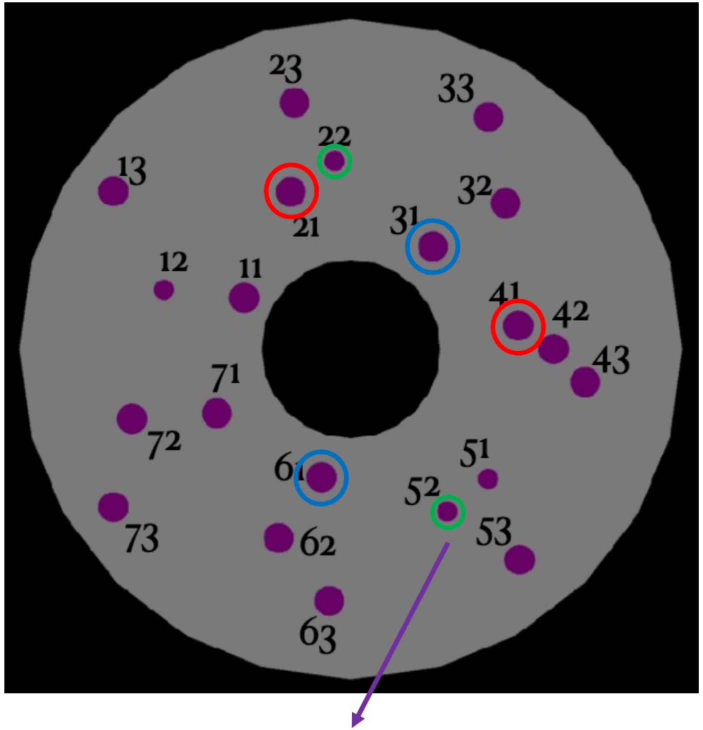
$$\theta_{tg} = b_0 + b_1 r + b_2 r' + b_3 \phi + b_4 \phi' + b_5 r^2 + b_6 r r' + b_7 r \phi + b_8 r \phi' \\ + b_9 r'^2 + b_{10} r' \phi + b_{11} r' \phi' + b_{12} \phi^2 + b_{13} \phi \phi' + b_{14} \phi'^2$$

- A set of parameters created for each variable $[b_0, b_1, \cdots, b_n]_{FieldMap}$
  - The parameters will be different for each field map used.
- Use the parameters made using the *default* field map along with the GEM variables made with each of the three possible field maps $[r, r', \phi, \phi']_{FieldMap}$ to reconstruct the target variables.
  - This generated $\theta_{pred}[default, default]$, $\theta_{pred}[default, asym]$, and $\theta_{pred}[default, worstAsym]$
  - Compare each of these to the true simulated theta θ_{true}

Residuals [milliradians]	$[default, default]$	$[default, asym]$	$[default, worstAsym]$
$(\theta_{true} - \theta_{pred})_{mean}$	0.010±0.003	0.029±0.003	0.154±0.004

Sieve Details – Symmetry Pairs

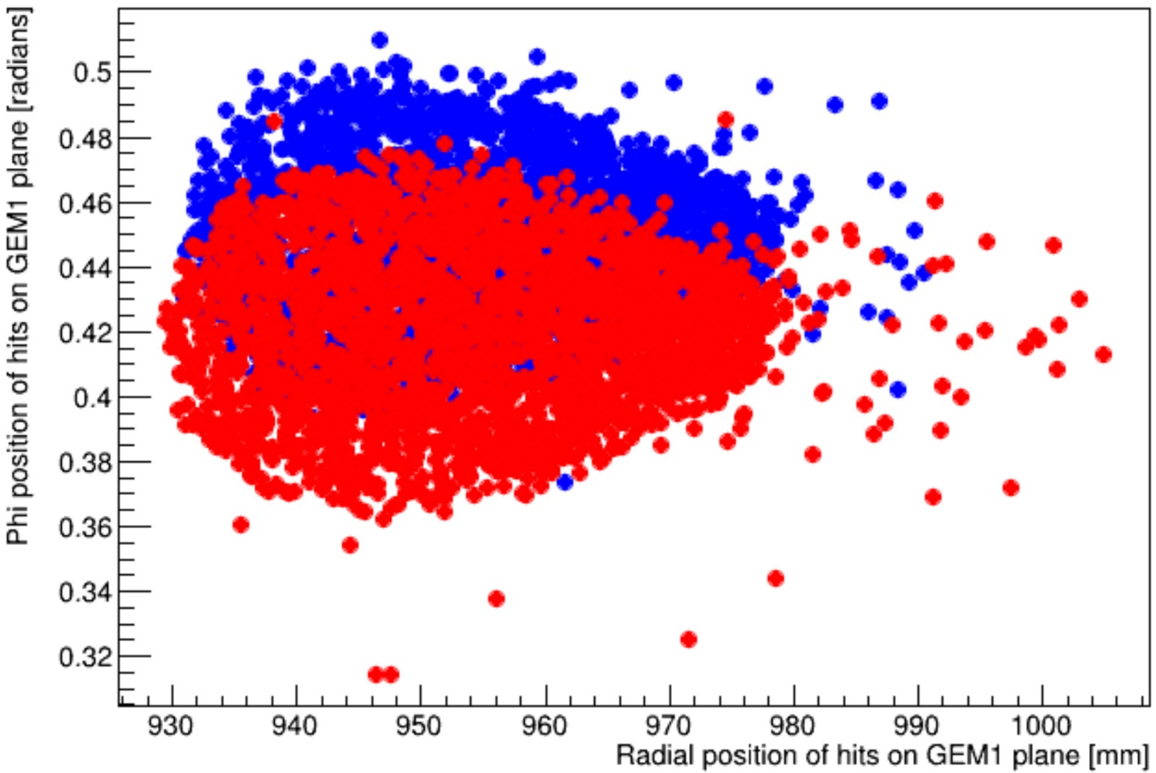
- Holes 21 and 41(red)
  - Center of hole radial position on sieve = 50mm
  - Phi offset of -8 degrees
  - Diameter = 9mm
- Holes 31 and 61(blue)
  - Center of hole radial position on sieve = 39mm
  - No local phi offset
  - Diameter = 9mm
- Holes 22 and 52 (green)
  - Center of hole radial position on sieve = 56mm
  - Phi offset of +8 degrees
  - Diameter = 6mm

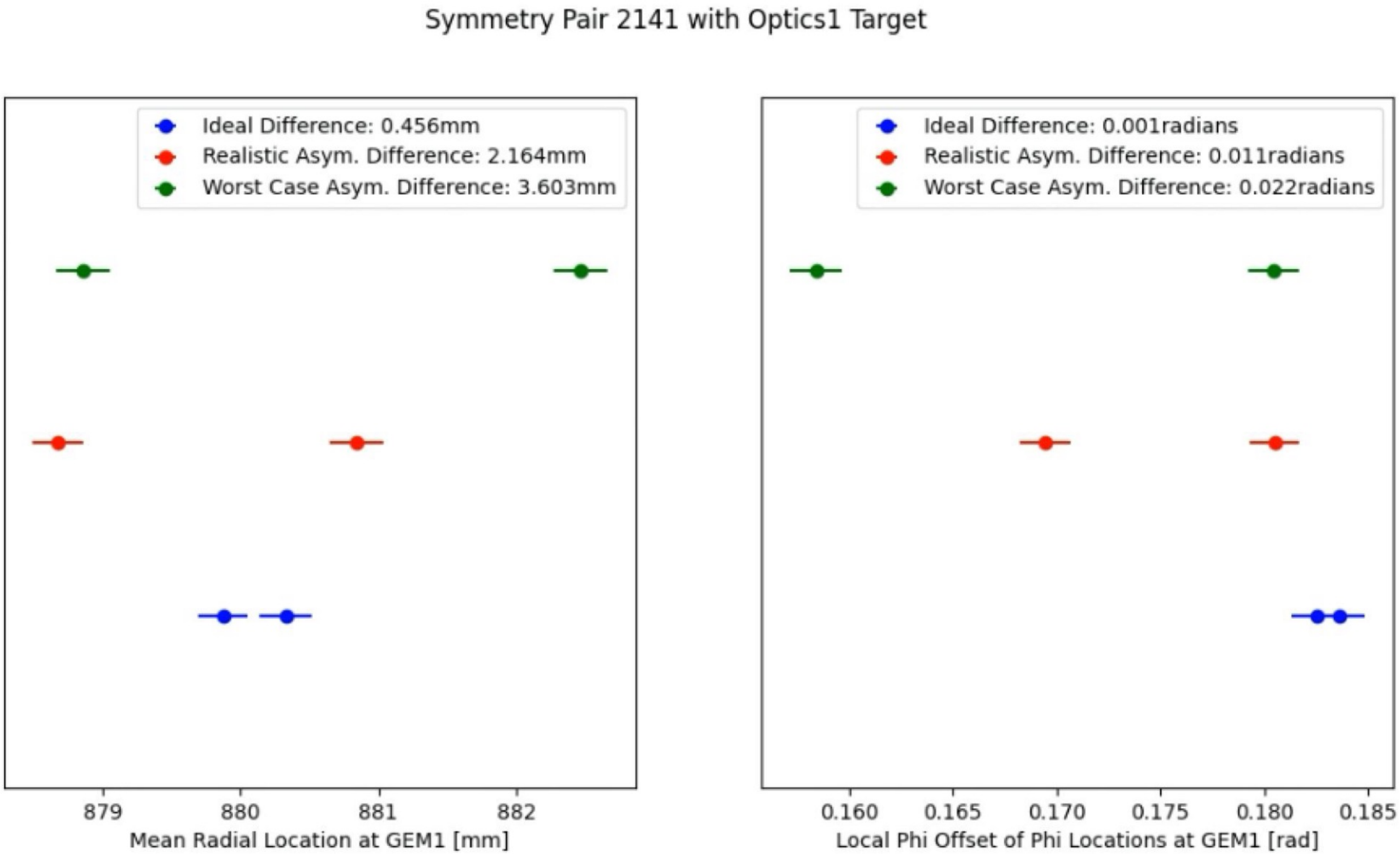


Holes 51 and 52 have the same radial position with equal and opposite local phi offsets.

Compare Sieve Hole Images on the GEMs (Hole 11 Example)

hole 11 for an ideal (blue) field map and worst case asymmetric (red) field map

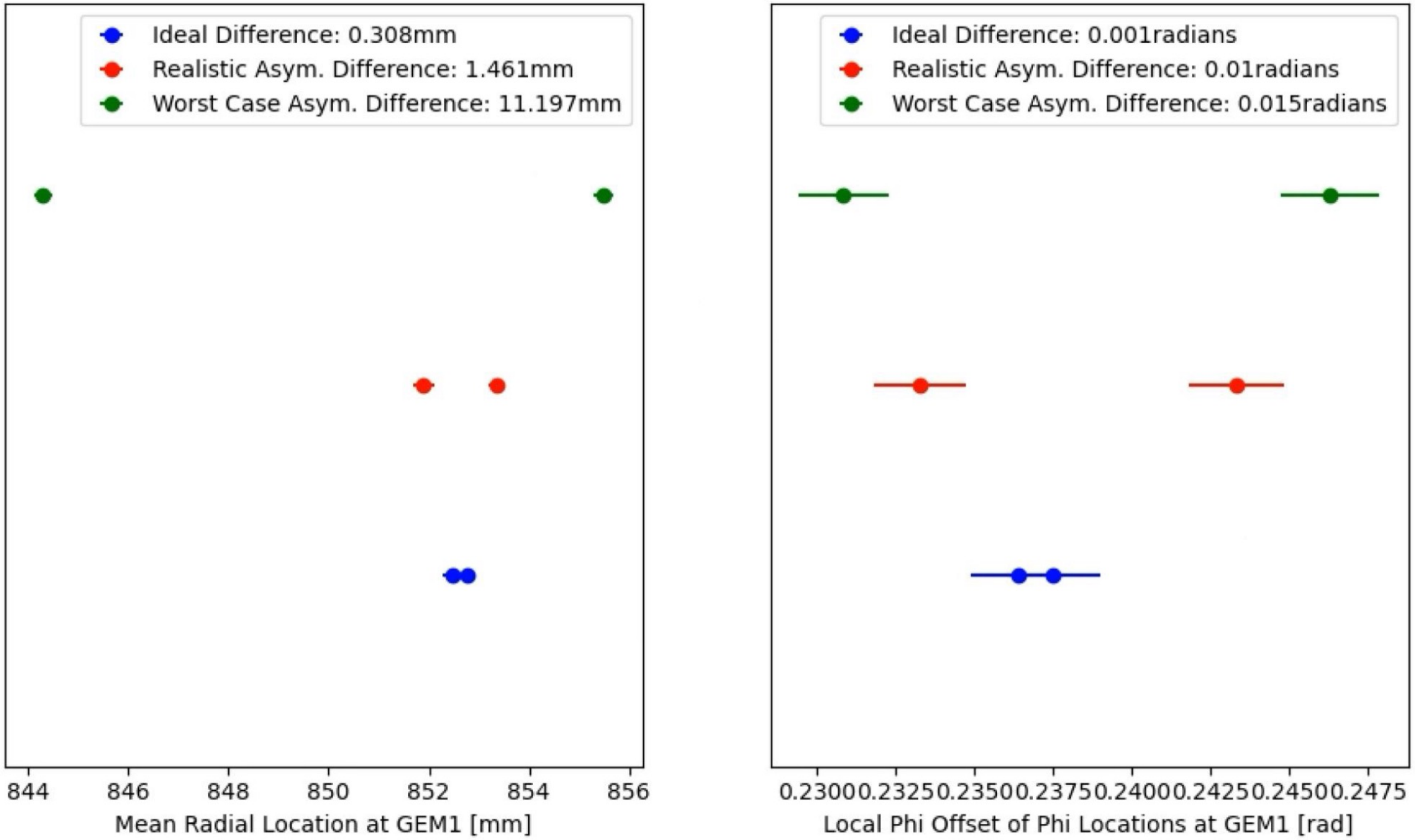



Symmetry Pair 2141 with Optics1 Target

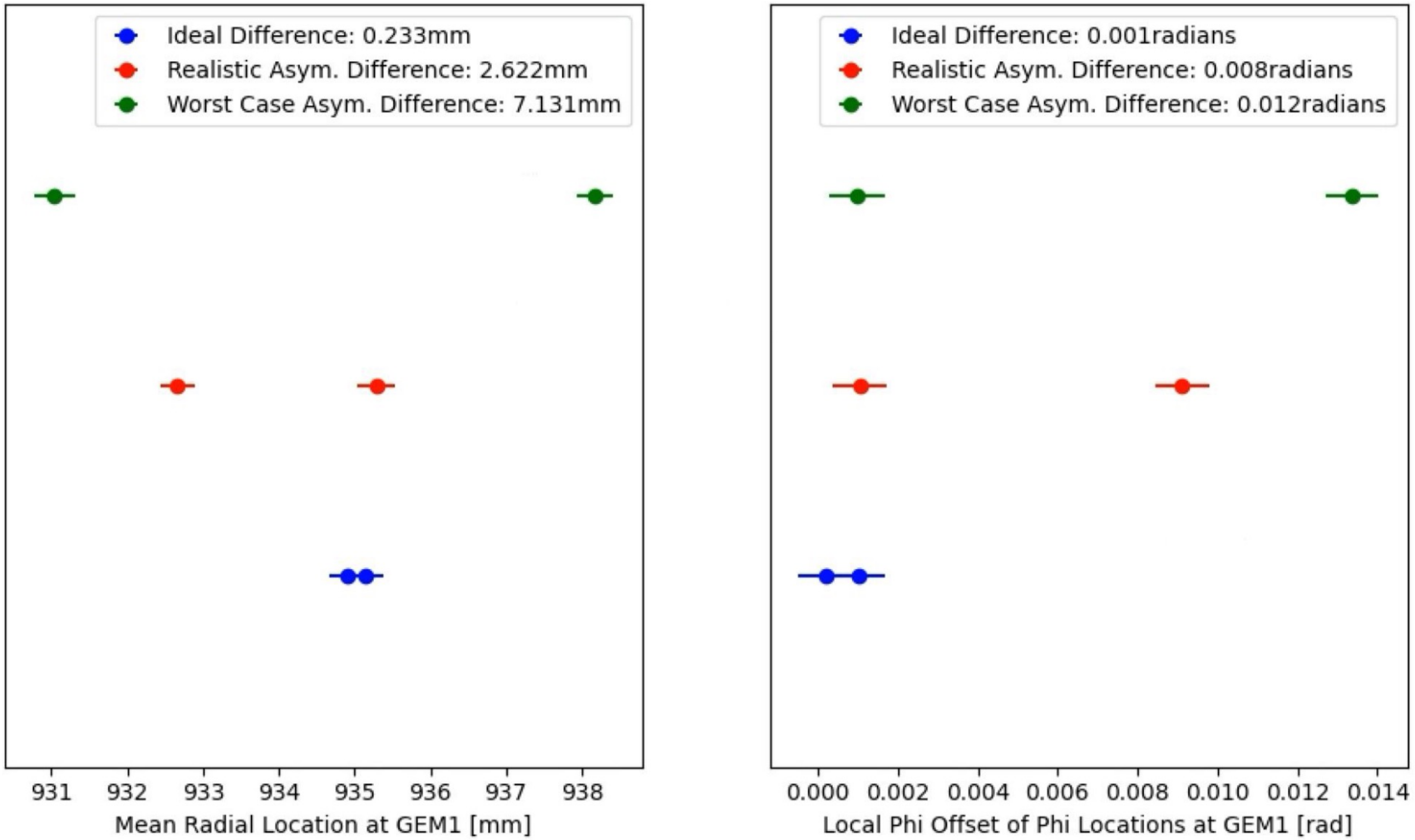
(19 mm difference)

(10 mm difference)

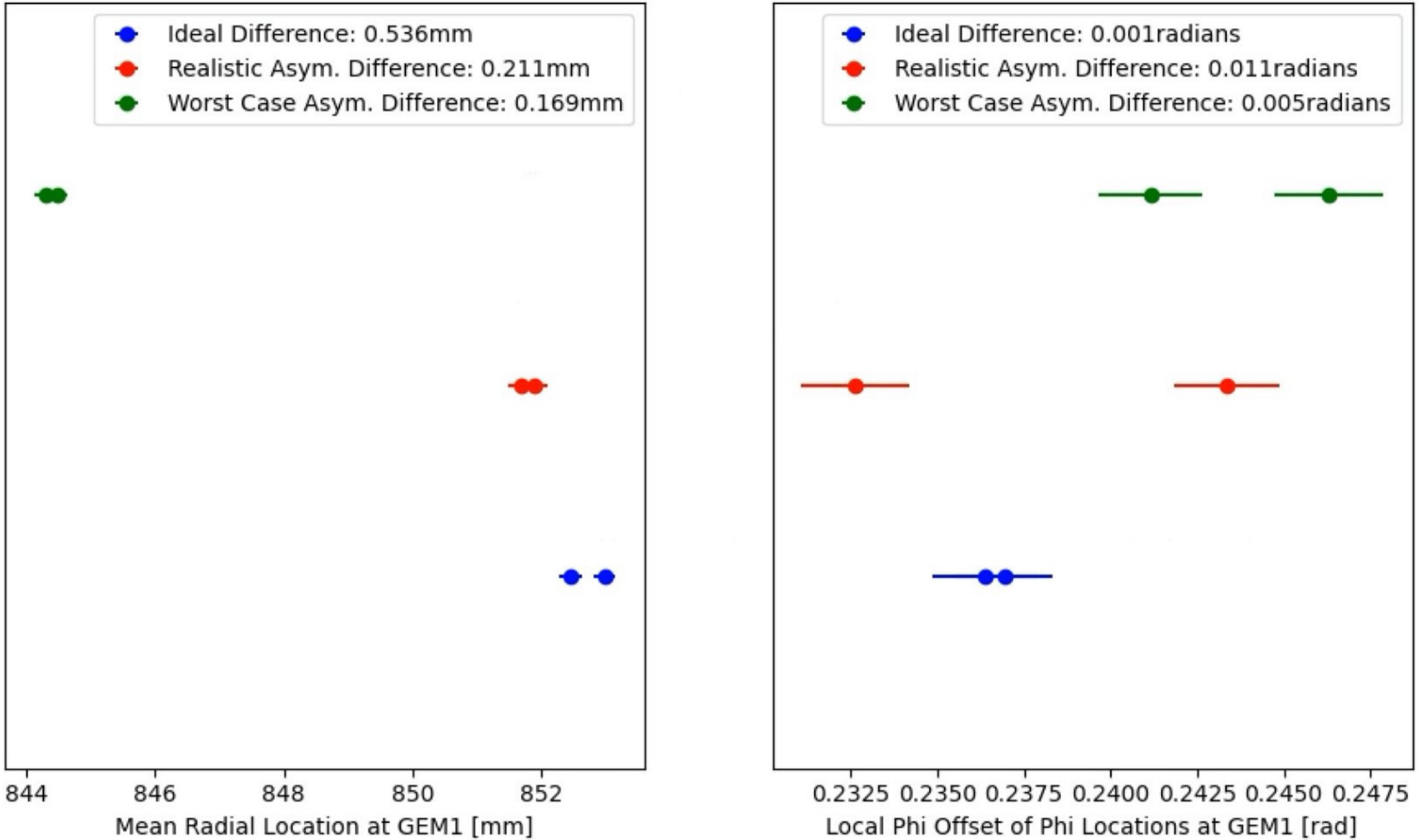
Symmetry Pair 2252 with Optics1 Target



Symmetry Pair 3161 with Optics1 Target



Symmetry Pair 5152 with Optics1 Target



Note: Have rotated the magnetic field with respect to the sieve orientation into all 7 sectors, and verified that we can identify non-ideal magnetic fields in each orientation, even for the “realistic” case (and certainly for the “worst case”).

Sieve/Blocker design summary

- Have selected optimal thickness for sieve/blocker.
- Have specified hole patterns for sieve to ensure adequate separation between ^{12}C elastic and Moller events at all three beam energies.
- Verified that for each hole the ^{12}C elastic events will be cleanly imaged in at least one “rotation” position of the GEMs
- Reconstruction algorithm devised, works well even for “worst case” field maps
- Sufficient information, especially from symmetry holes, to clearly identify likely imperfect field maps, and certainly the “worst case” field map, in all possible orientation.
- I believe we are ready to transmit hole pattern to MIT engineering for CD3 procurement.