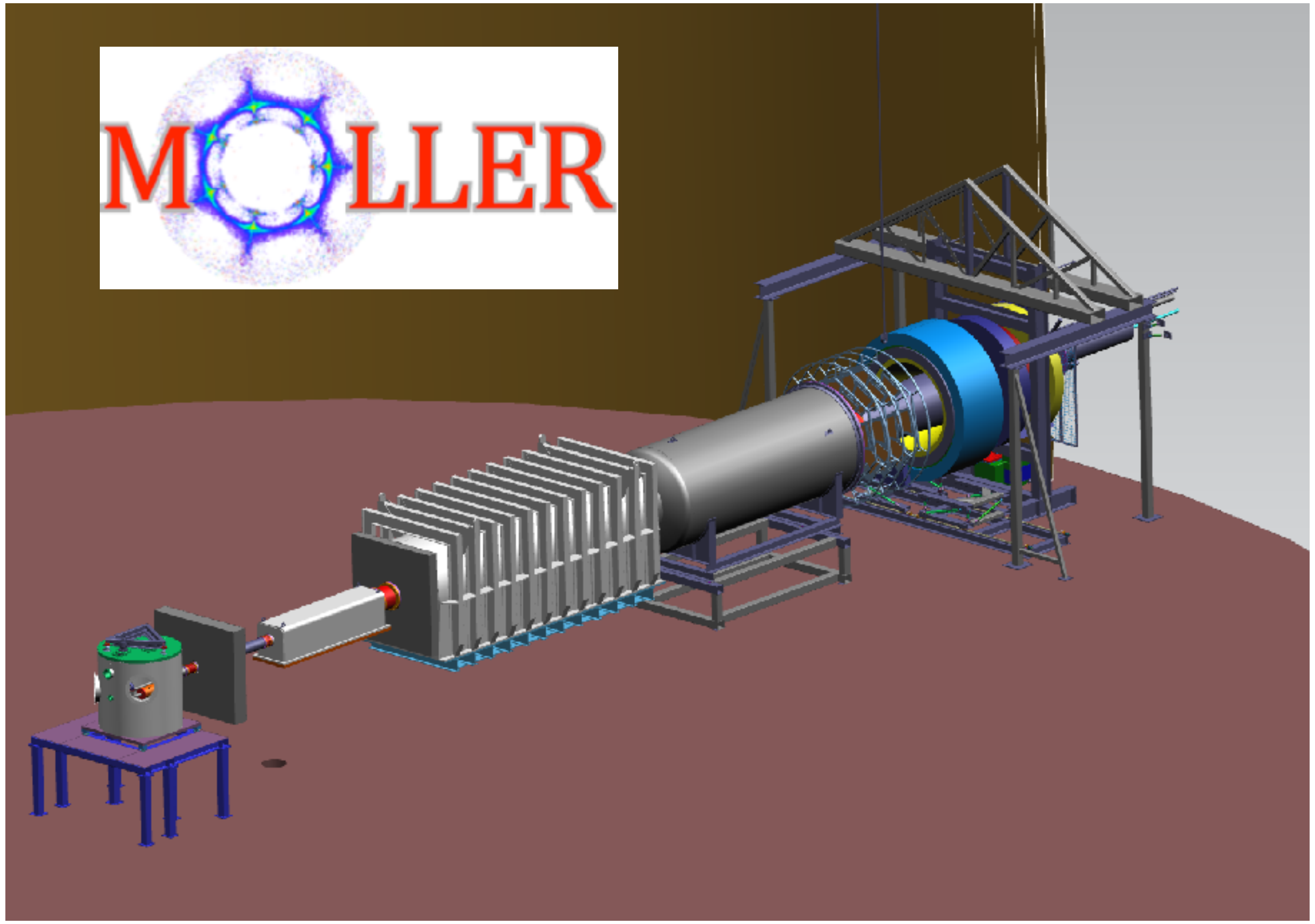
MOLLER Sieve Design Update

Measurement **O**f a **L**epton **L**epton **E**lectroweak **R**eaction



MOLLER Collaboration Meeting 2023

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Jefferson Lab · Stony Brook University · Center for Frontiers in Nuclear Science · U.S. Department of Energy Office of Science · JSA

Introduction to Optics study: Goals

- ✦ Verify the acceptance of the toroidal spectrometer and the quartz detectors.
- ✦ Measure the position dependent light-output response of the quartz detector.
- ✦ Determine the average kinematic factor and its uncertainty.

$$\Lambda \equiv \frac{A_{PV}}{Q_W^e} = mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{4sin^2\theta_{COM}}{(3+cos^2\theta_{COM})^2}$$

- ✦ Need to know Λ to a fractional accuracy of 0.5%.

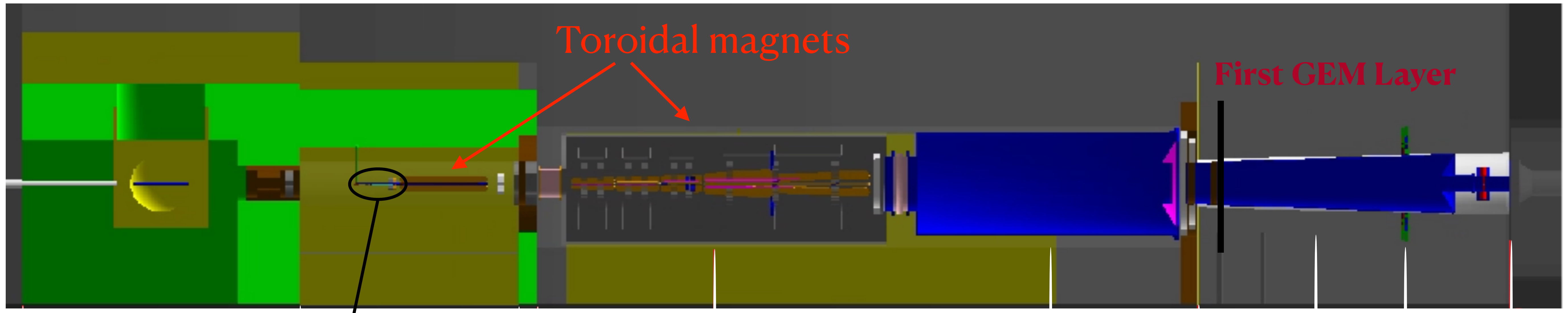
Optics Study: Strategy

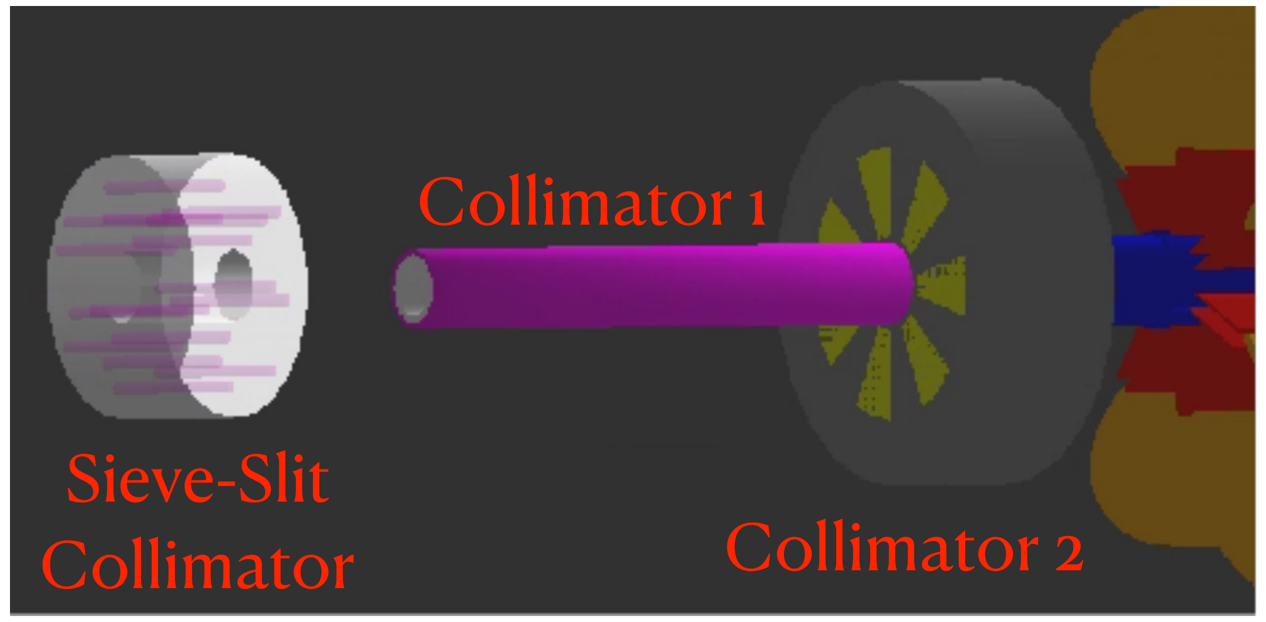
✦ Measure the track positions r and ϕ and also the directions r' = $\frac{dr}{dz}$ and $\phi' = \frac{d\phi}{dz}$ using GEM detectors.

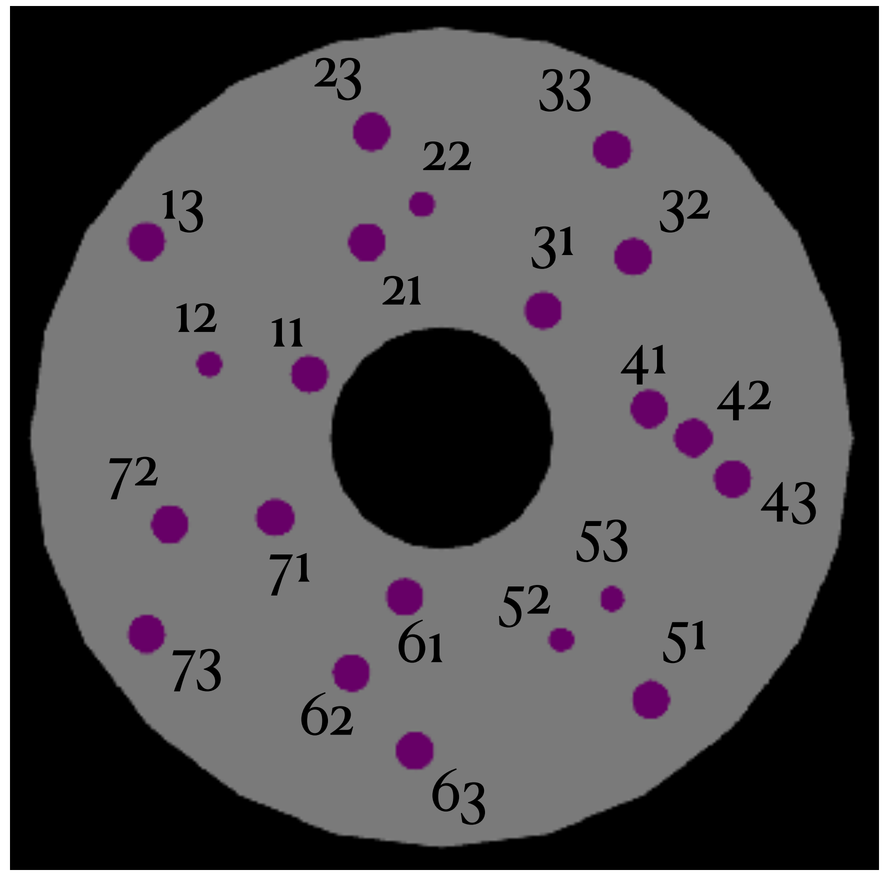
✦ Use GEANT4-based mapping $(\theta_{lab}, \phi_{lab}, E', v_z) \rightarrow (r, \phi, r', \phi')$.

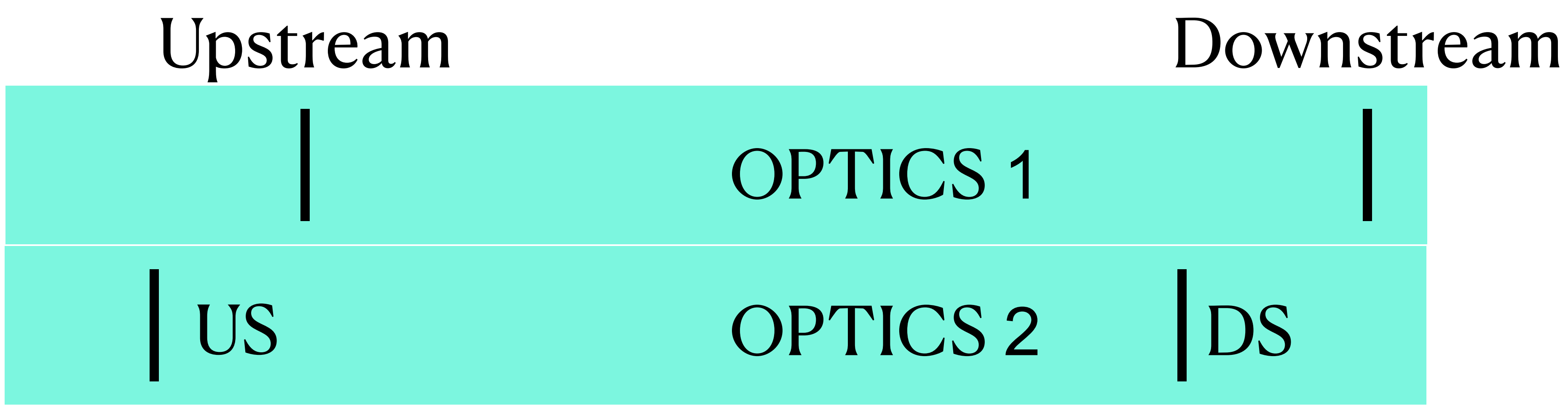
✦ Sieve-slit collimator to pick out tracks with particular θ_{lab}, ϕ_{lab} with thin solid target (C12) to select z_{vertex} .

✦ Measure at 3 lower beam energies (2.2, 4.4 & 6.6 GeV) to fully map out the Møller phase space.









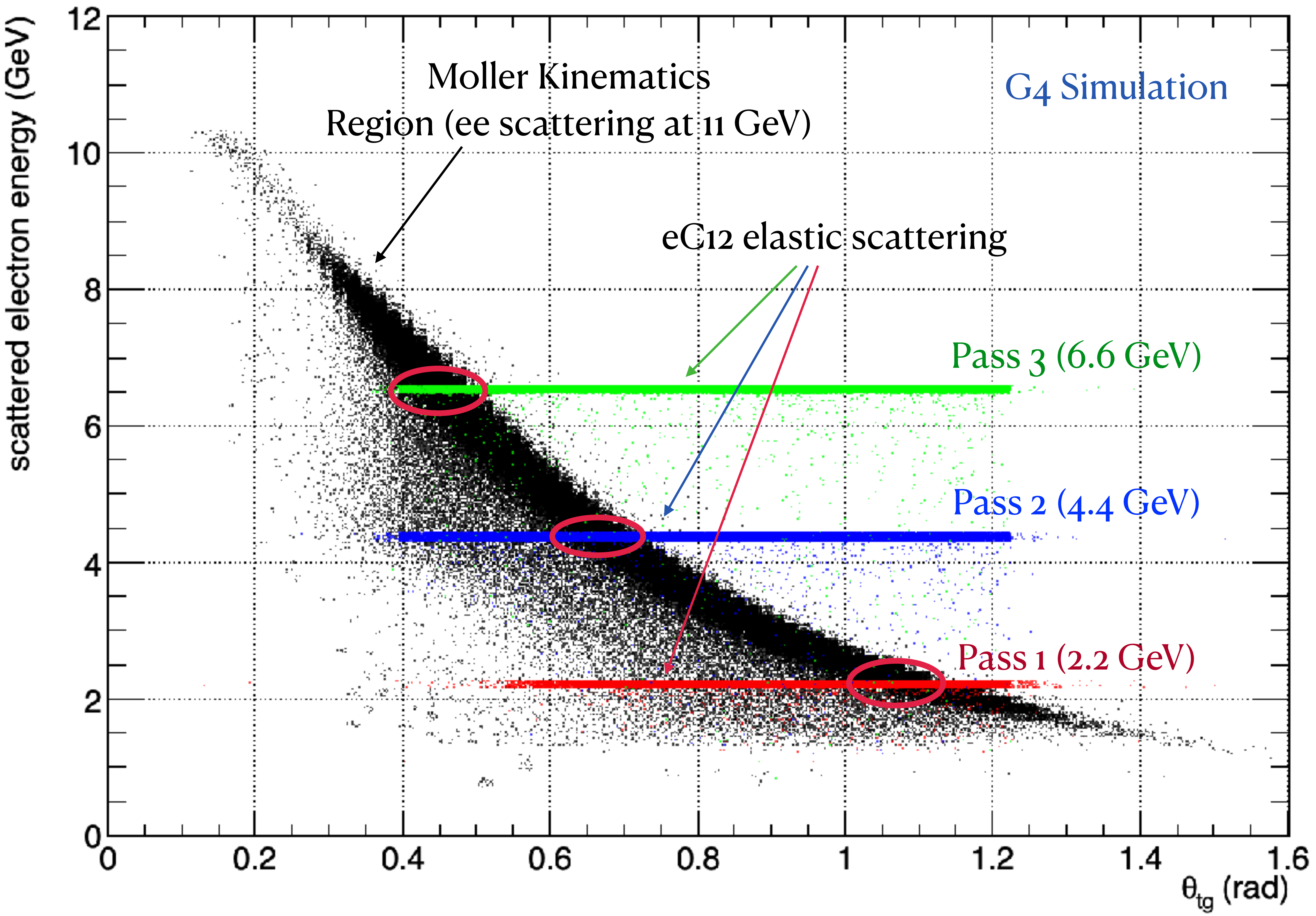
C Foil	Z location (relative to global origin)
Optics 1US	-4800 mm
Optics 1DS	-3900 mm
Optics 2US	-5100 mm
Optics 2DS	-4200 mm

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}.



Designing the Sieve: Holes Acceptance

✦ Since the sieve collimator is upstream of the acceptance defining collimator, it puts constraint on the radial locations of the holes in the sieve.

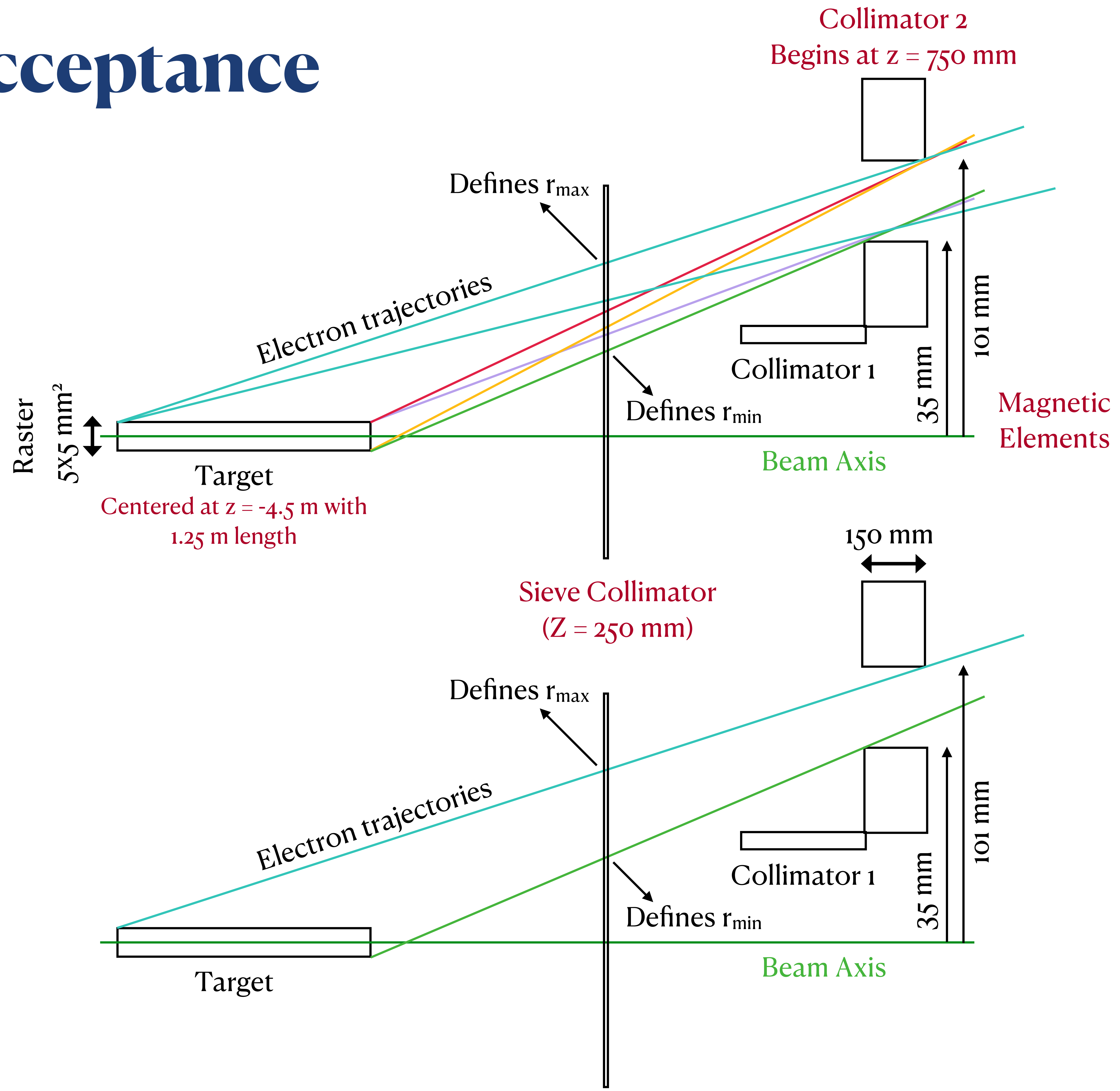
✦ Important reminder: The magnetic elements are downstream of the collimator 2.

✦ A simple geometrical calculation to determine the acceptance of the sieve holes is possible!

✦ The calculation yields:

$$r_{min} = 31.39mm \quad \& \quad r_{max} = 89.28mm$$

All the holes in the sieve must be placed between 32 and 89 mm!



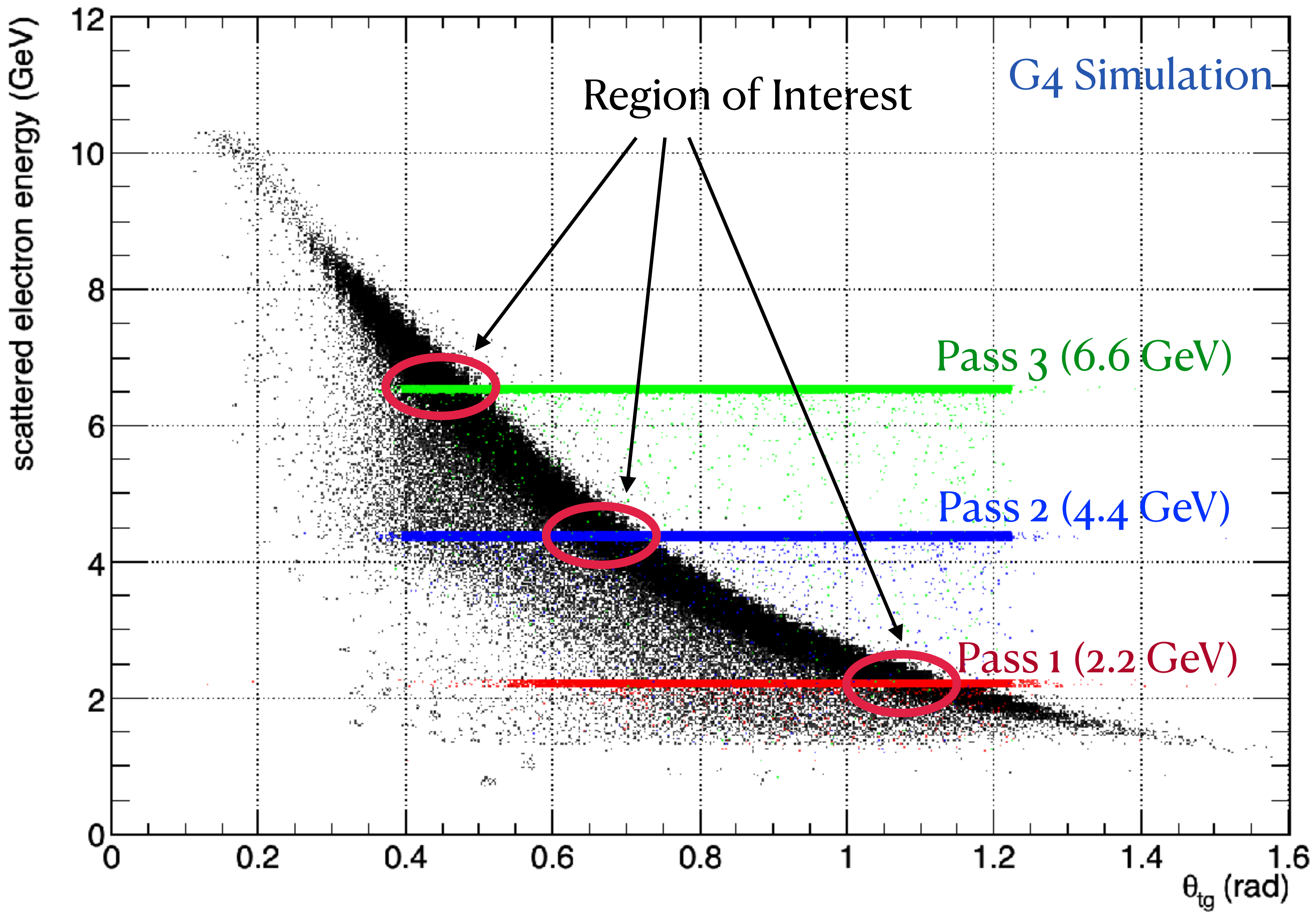
Designing the Sieve: Holes Placement Strategy

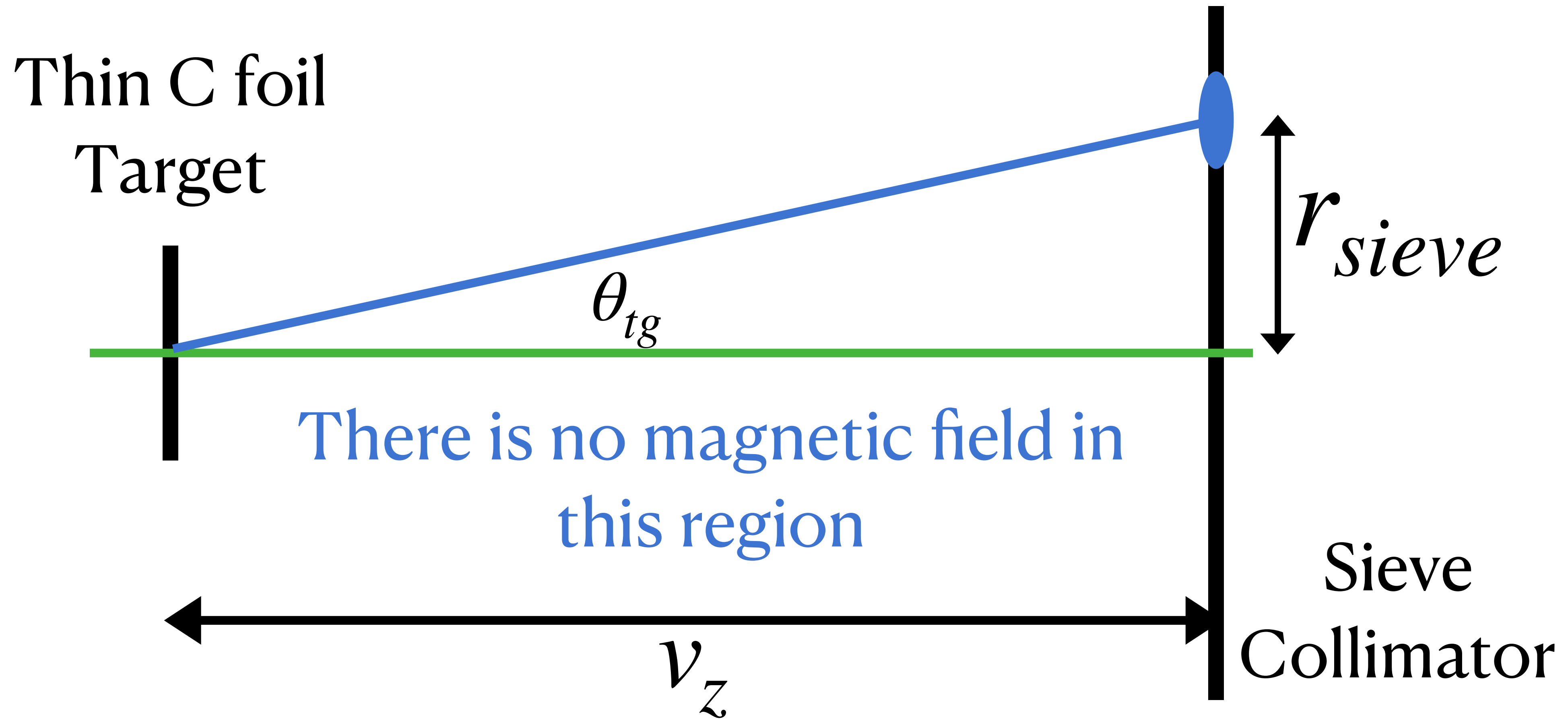
- ✦ For any given beam energy/pass, we must be able to separate the elastic eC12 and the Møller events (serving as a background in the optics study).
- ✦ The holes must be placed in the sieve such that the moller kinematics region can be covered.
- ✦ There is a direct relationship between the scattering angle and the radial location at which the track will intercept the sieve collimator.
- ✦ We can also verify the symmetry/asymmetry of magnetic field in a given septant.

$$tan(\theta_{tg}) = \frac{r_{sieve}}{v_z}$$

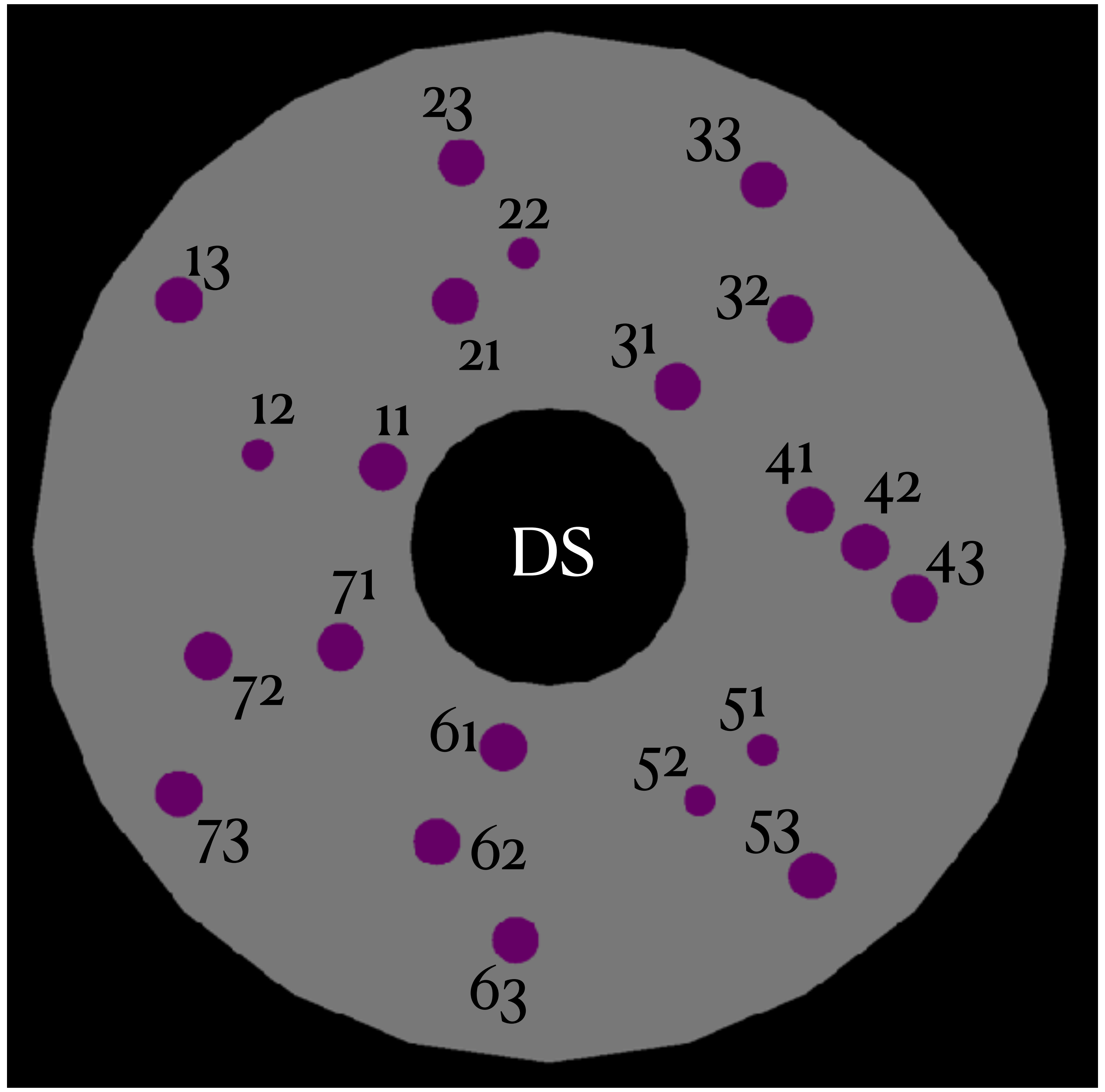
C foil	Sieve r values
Optics 1 US	55.27 - 64.22 mm
Optics 1 DS	45.26 - 52.61 mm
Optics 2 US	58.60 - 68.13 mm
Optics 2 DS	48.53 - 56.41 mm

For Pass 2





Sieve Hole Locations



IR: 26.5 mm
OR: 98 mm
Thickness 100 mm

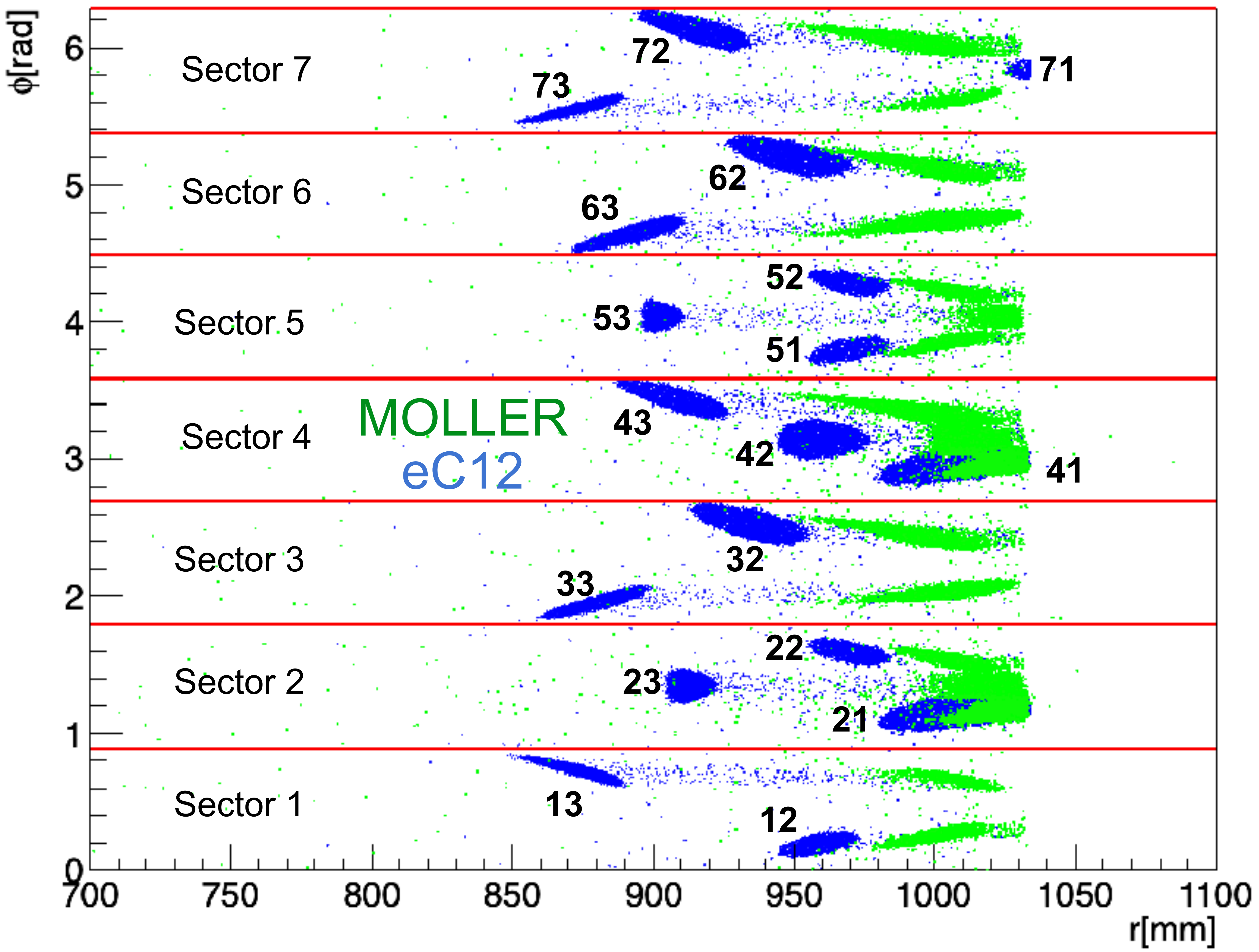
Most of the Holes are 9 mm in diameter.

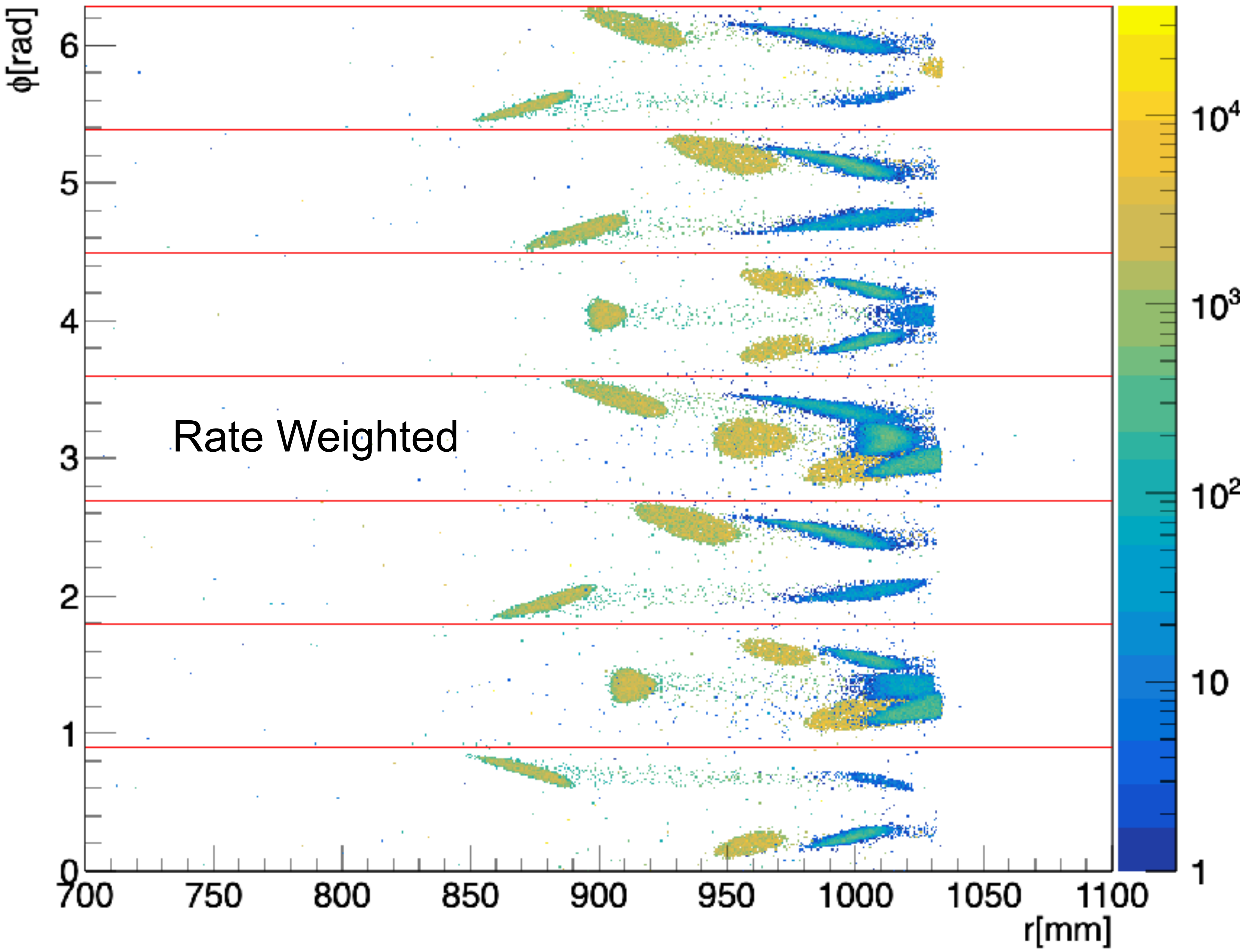
Holes 51 and 52 —> To check the magnetic field symmetry in a given septant.

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

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

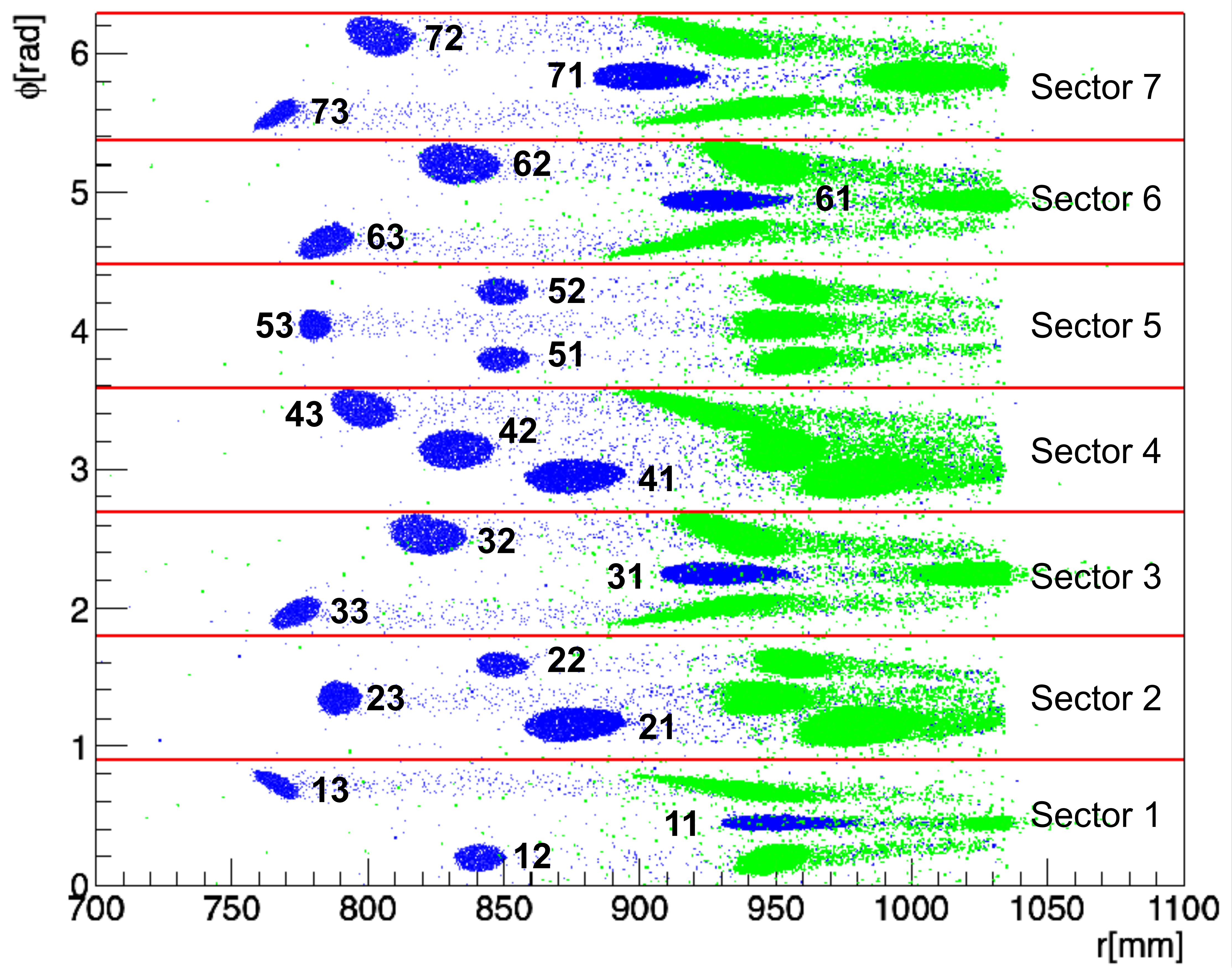
GEM r-ϕ Distributions: Moller + elasticC12 Pass 1

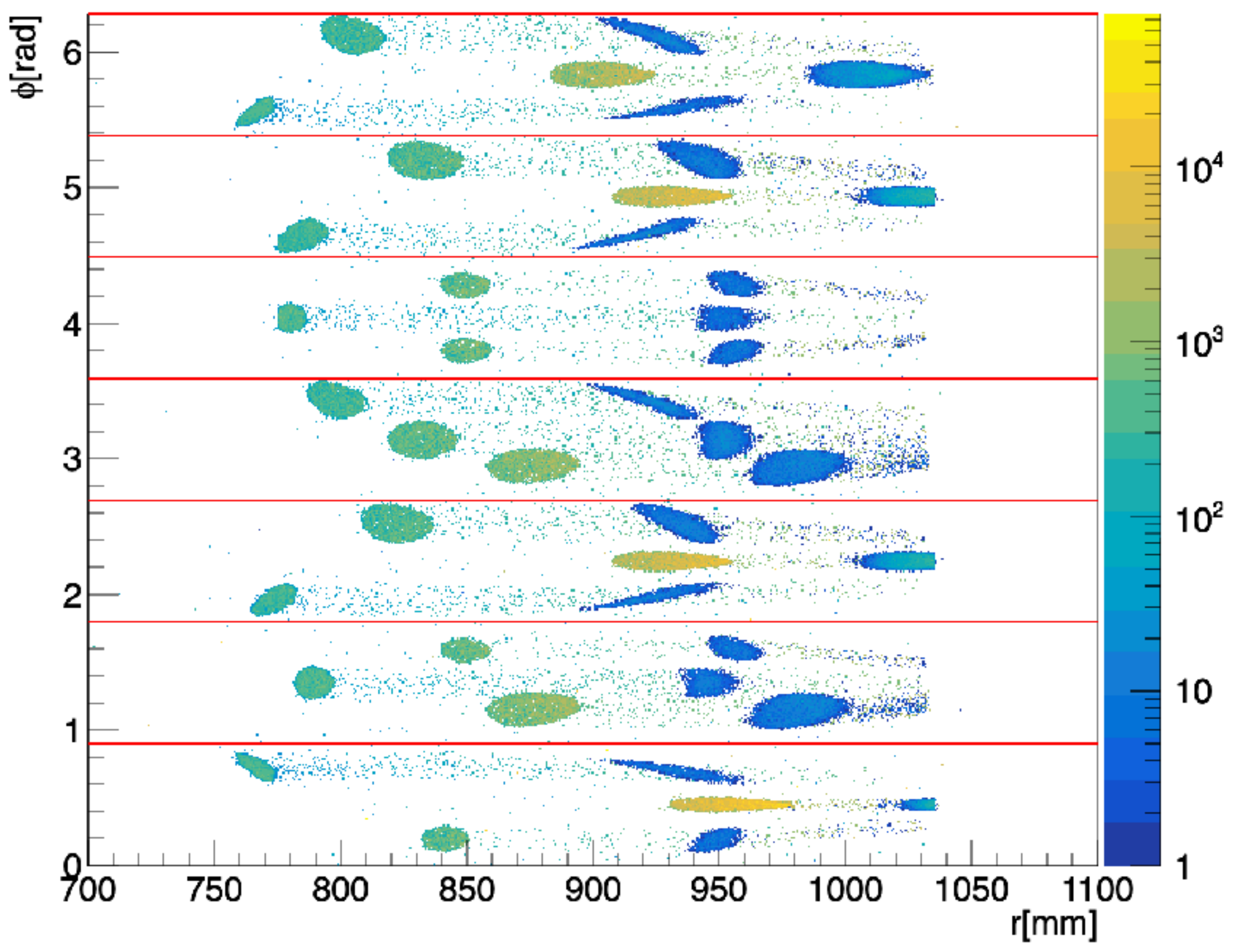




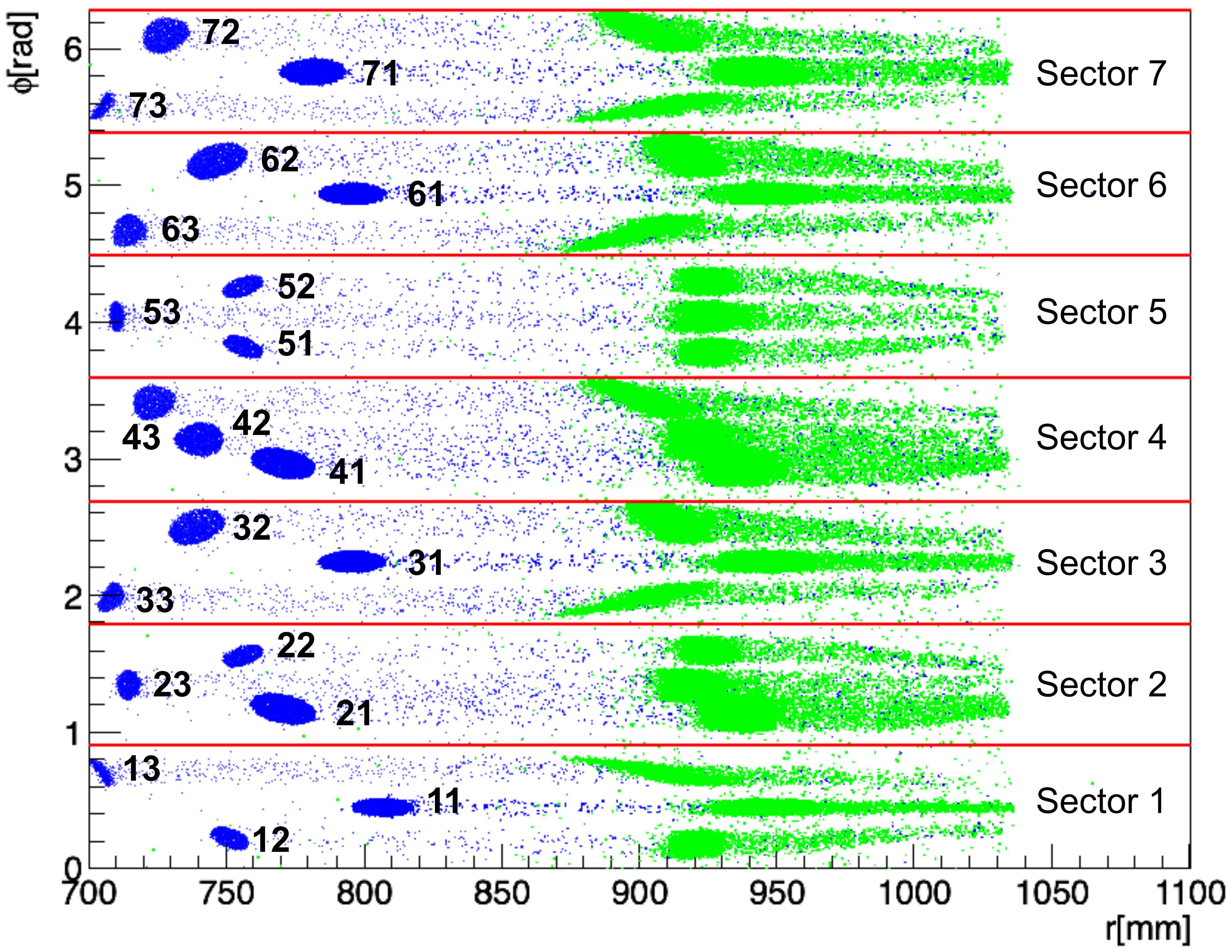
*Some of the holes at lowest pass are cut off by the acceptance.

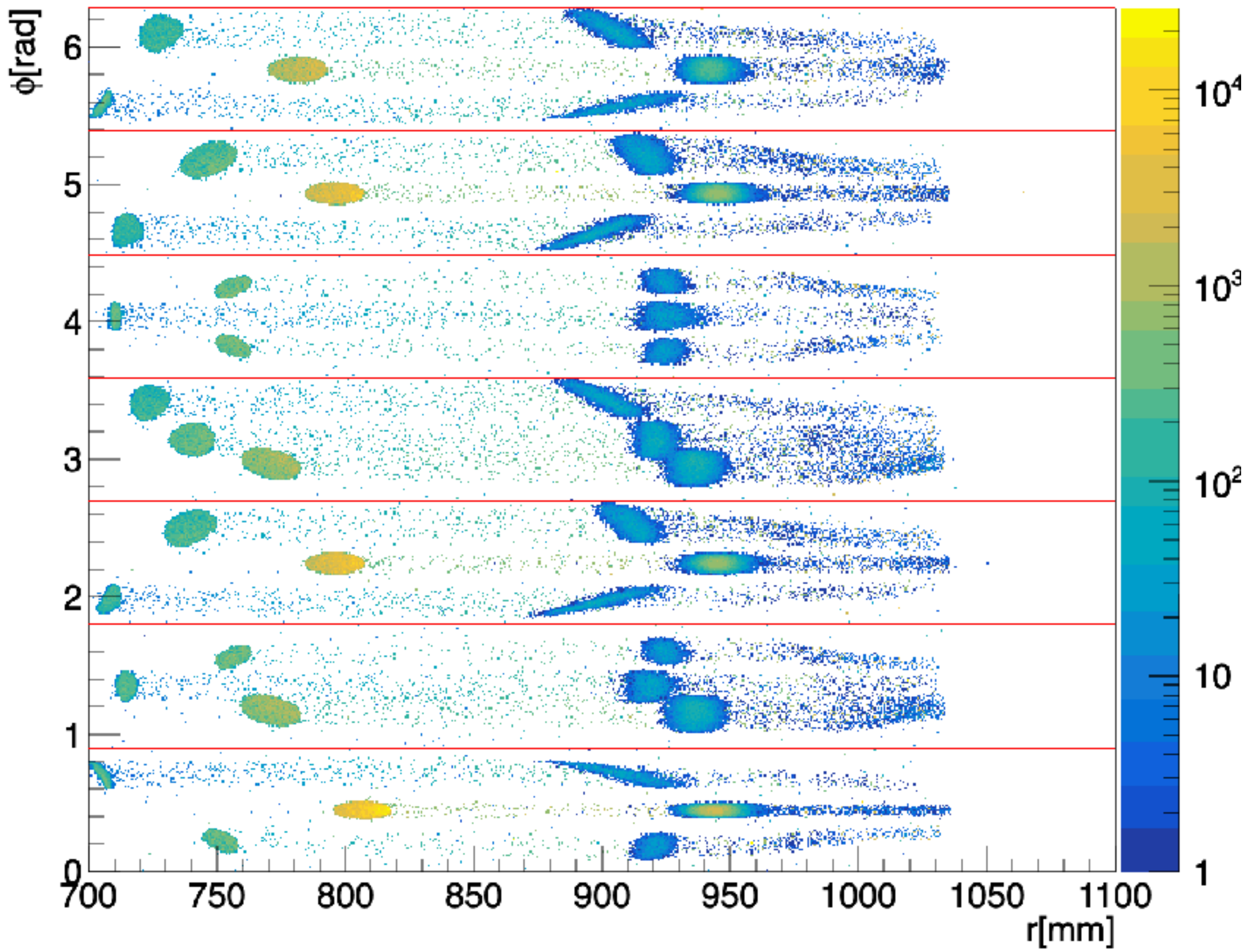
GEM r-ϕ Distributions: Moller + elasticC12 Pass 2



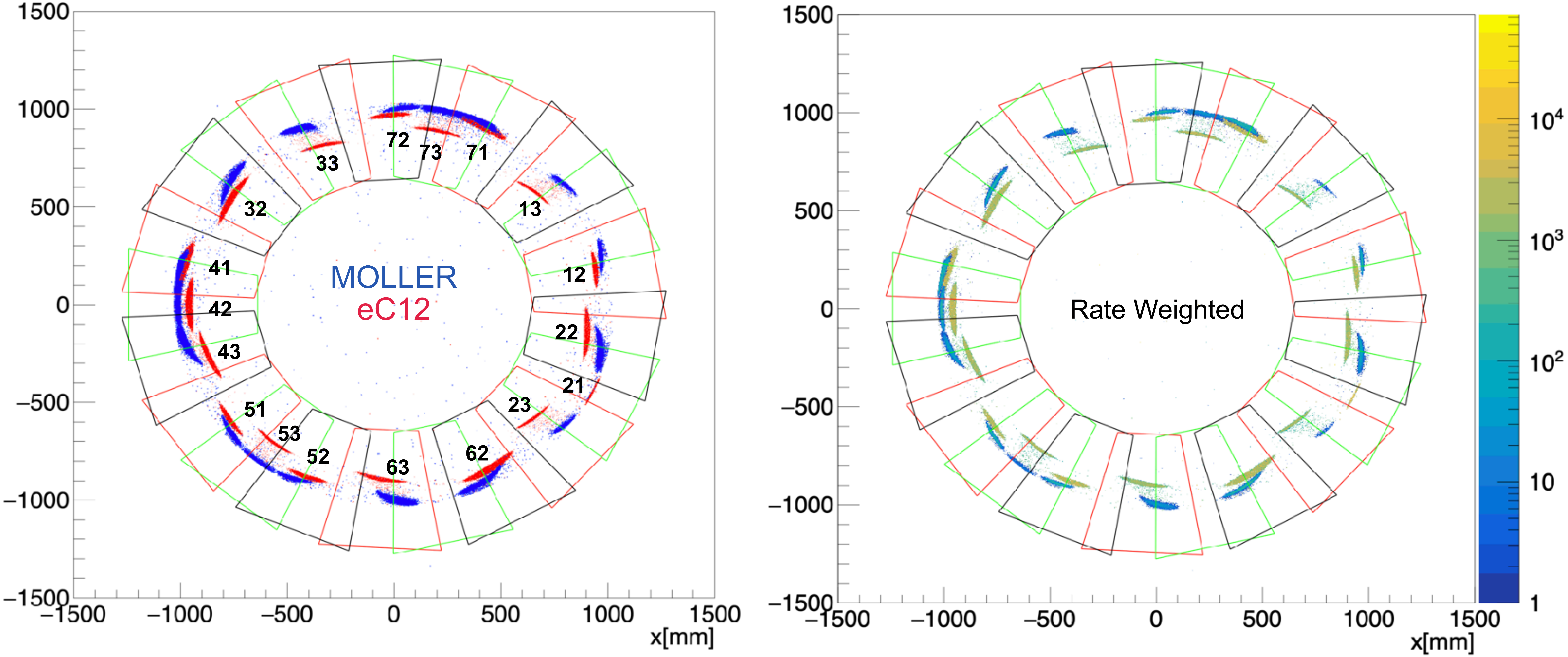


GEM r-ϕ Distributions: Moller + elasticC12 Pass 3



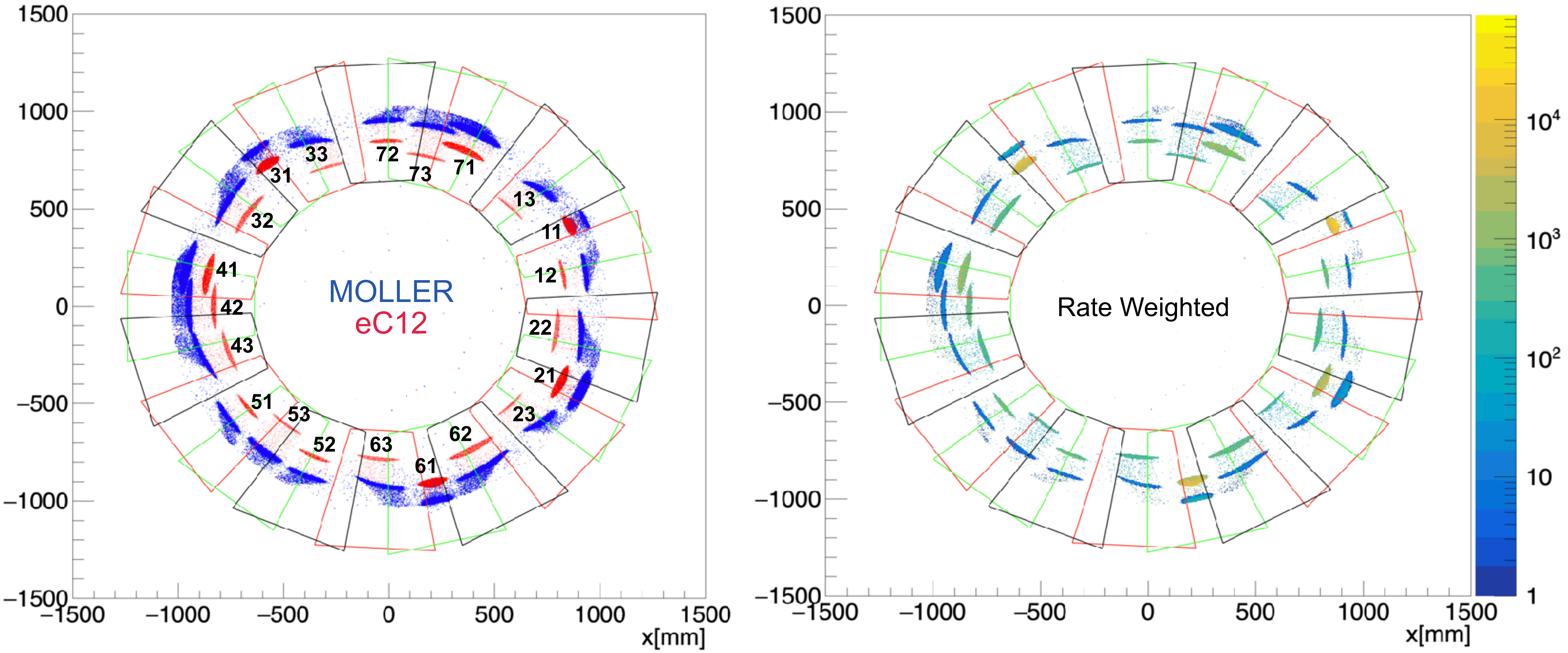


GEM x-y Distributions: Moller + elasticC12 Pass 1

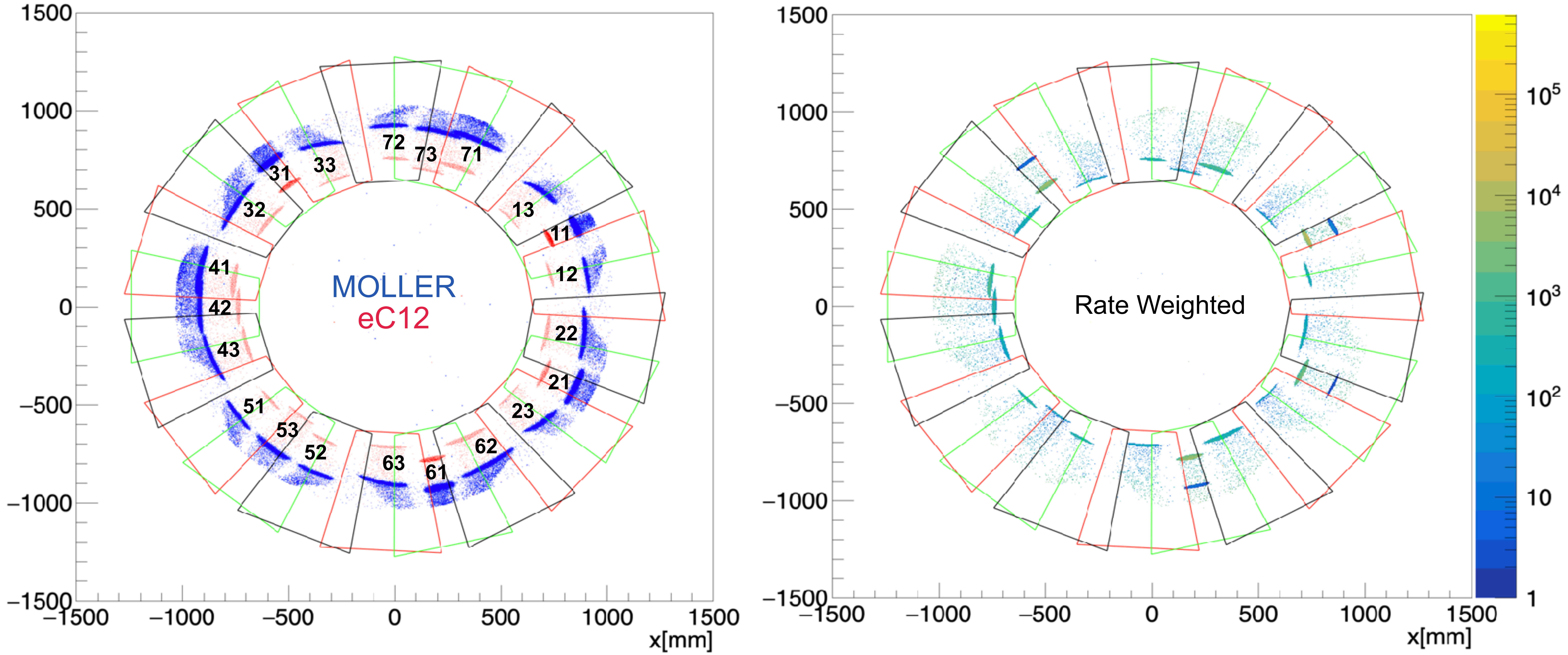


These rectangles represent the GEM active area. Green is when the active area aligns with the open sector of the primary collimator.

GEM x-y Distributions: Moller + elasticC12 Pass 2



GEM x-y Distributions: Moller + elasticC12 Pass 3

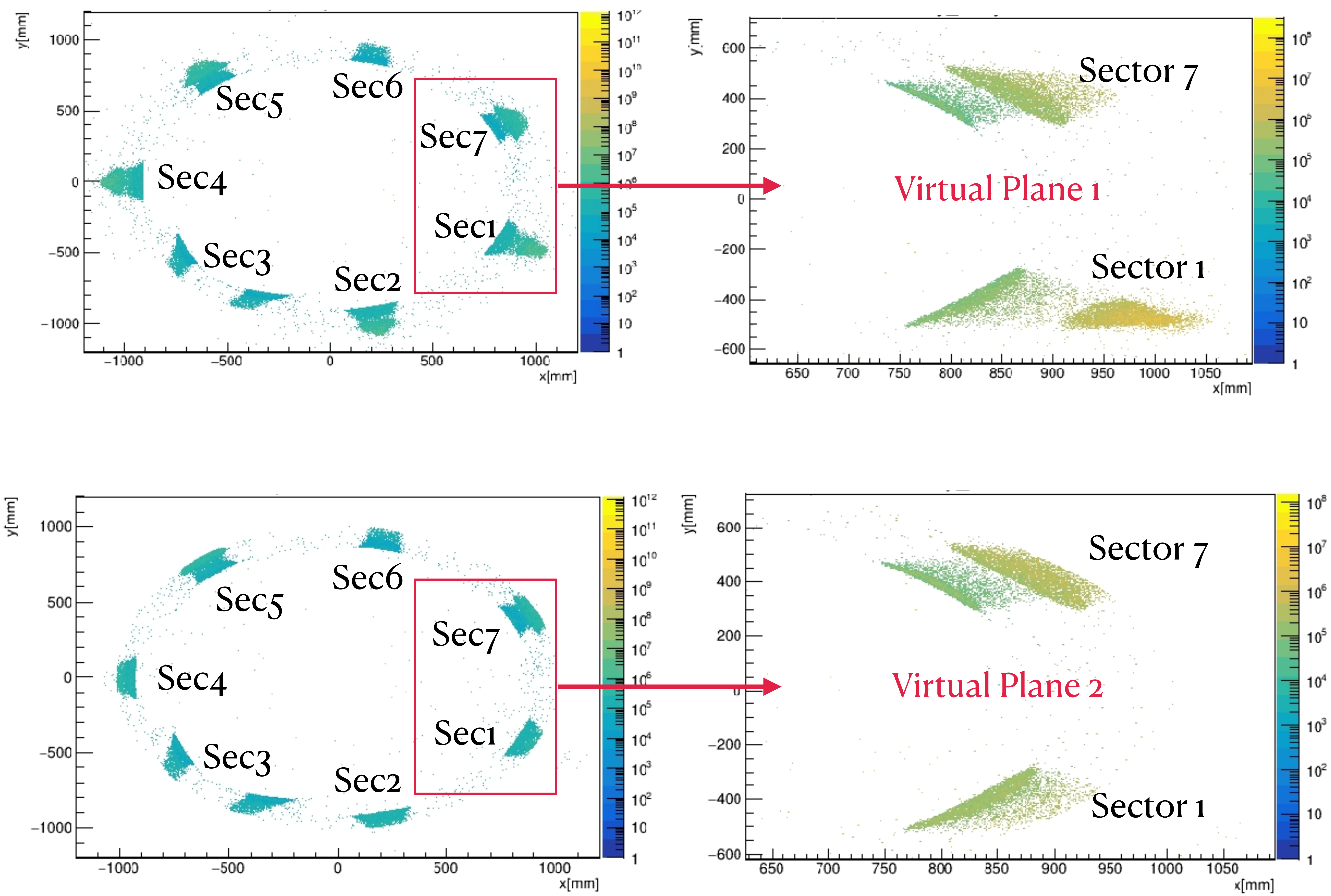


Conclusions

- ✦ We are in a pretty good shape with the sieve design and is more or less finalized.
- ✦ With the current sieve design, we are able to cleanly separate the elastic eC12 and Moller scattered electrons at the GEM planes at all three passes.
- ✦ There is at least one GEM measurement position for which the data from each collimator hole is contained.
- ✦ We have been in contact with the engineers as well to avoid any surprises.
- ✦ Significant progress in optics reconstruction algorithm development.

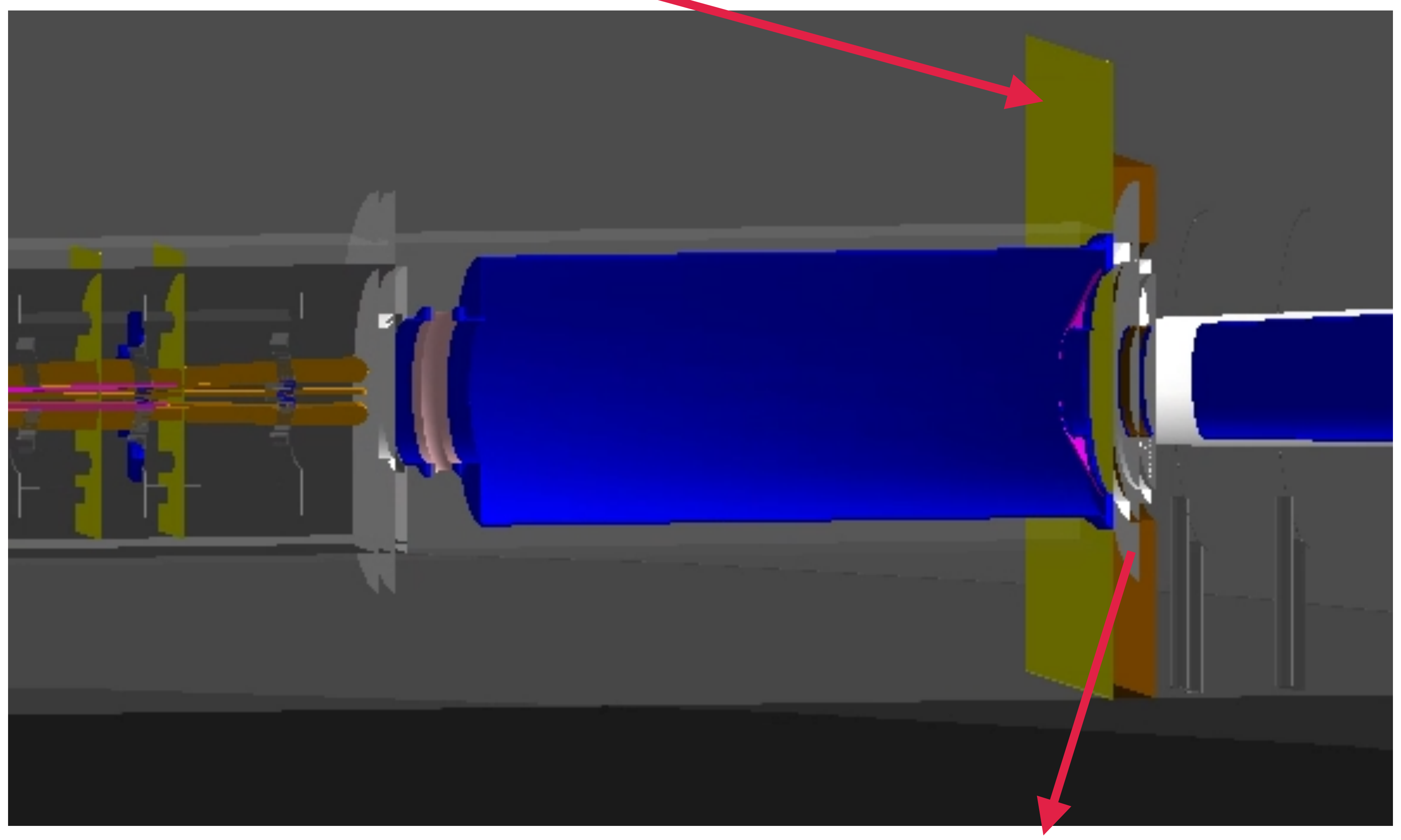
Back Up

Acceptance cutoff for certain holes in Pass 1



The sieve was a bit different when this study was performed.

Virtual Plane 1 (Just before the detector wall)

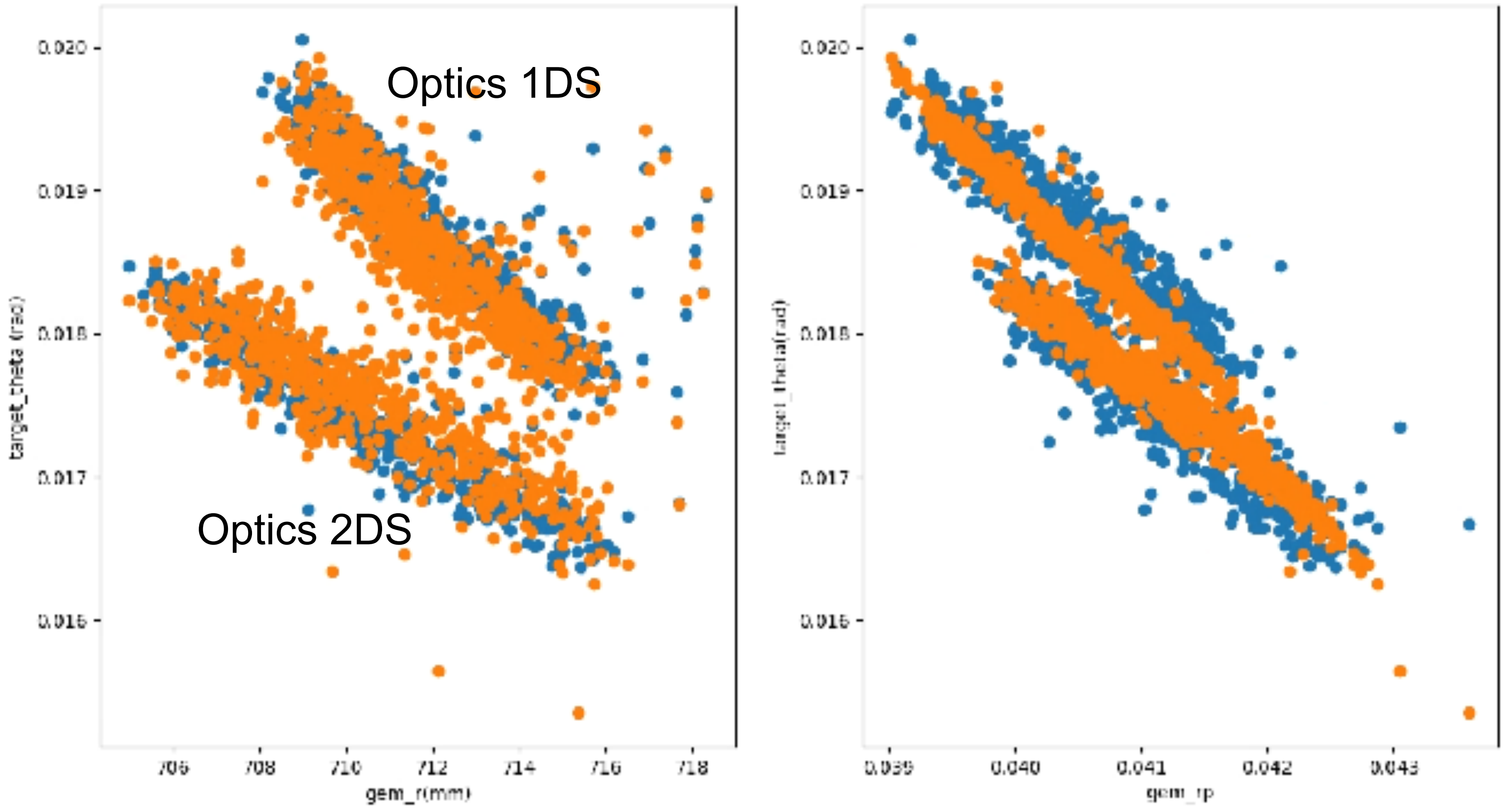


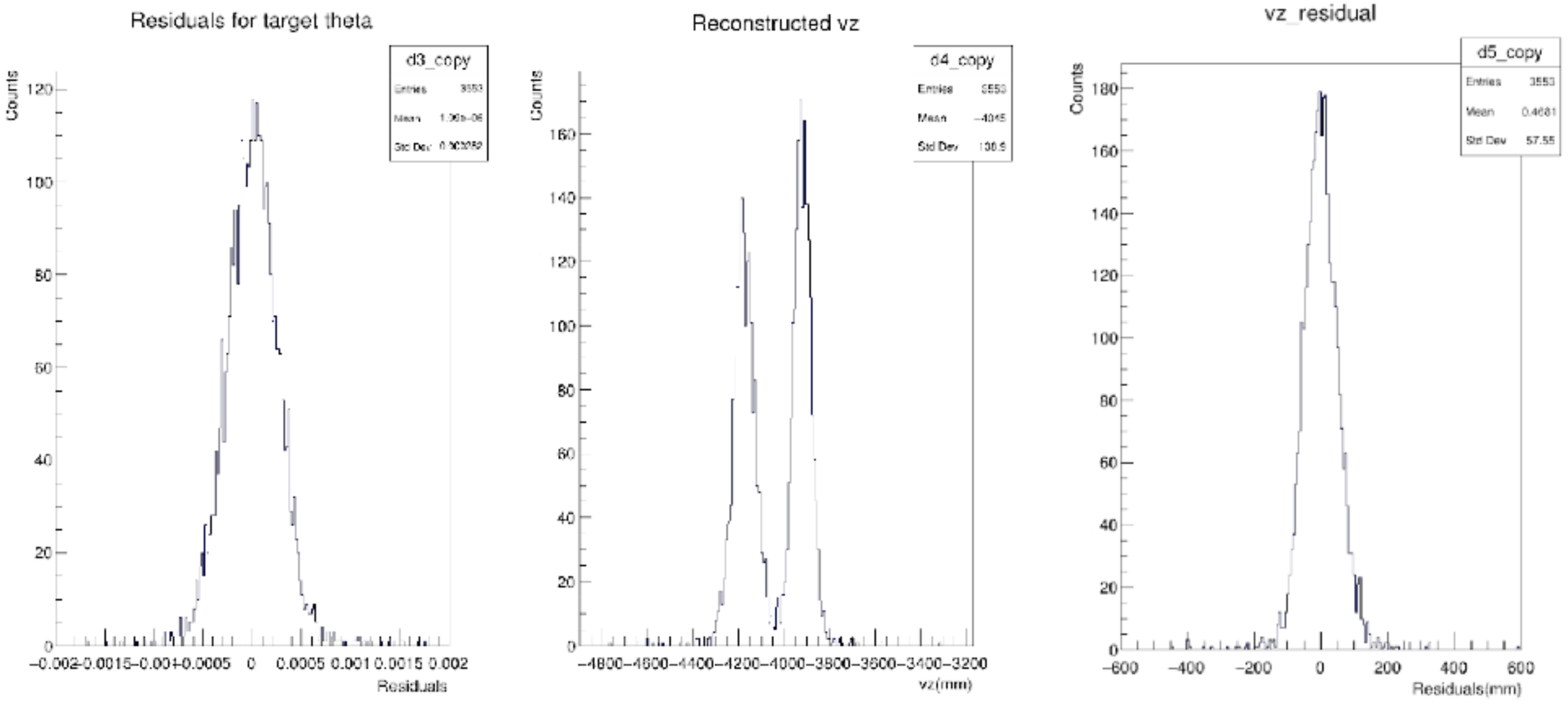
Virtual Plane 2 (Placed after the outer ring of collar 2)

The electrons were tracked all the way down to the GEM plane.
It was found that the certain holes are getting cutoff due to outer ring of Collar 2.

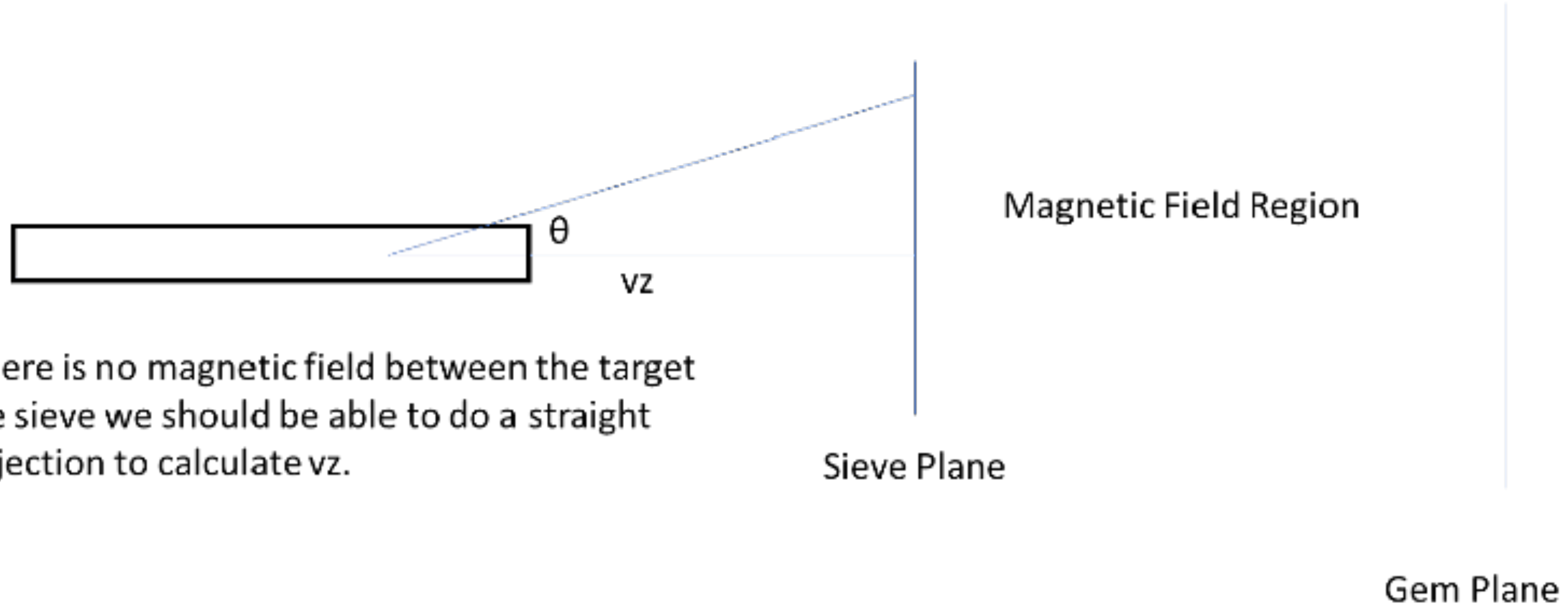
We will be able to do a v_z reconstruction as well!

We performed a study in which both the optics 1 and optics 2 DS C foils (only 30 cm apart) were sampled. The results suggested that we should be able to reconstruct the primary z location with good accuracy.





Data from a single hole lying at 75 mm radial location.



Since there is no magnetic field between the target and the sieve we should be able to do a straight line projection to calculate vz.

Can we do sieve_r reconstruction using the gem variables?

The relative rates of elastic C12 and Moller scattered electrons were also studied and more information on that can be found here: https://moller.jlab.org/wiki/images/ElasticC12_and_Moller_Rates_for_the_optics_study.pdf

Sive Hole Placement Calculations

	Old Values	New Values
Optics 1 US	NA	NA
Optics 1 DS	72.82 – 81.24 mm	75.53 - 84.15 mm (8.62)
Optics 2 US	NA	NA
Optics 2 DS	78.29 – 87.31 mm	80.98 - 90.24 mm (9.26)

Pass 1 The old (correspond to sieve plane at z = 105 mm) and the new values (correspond to sieve plane at z = 250 mm)

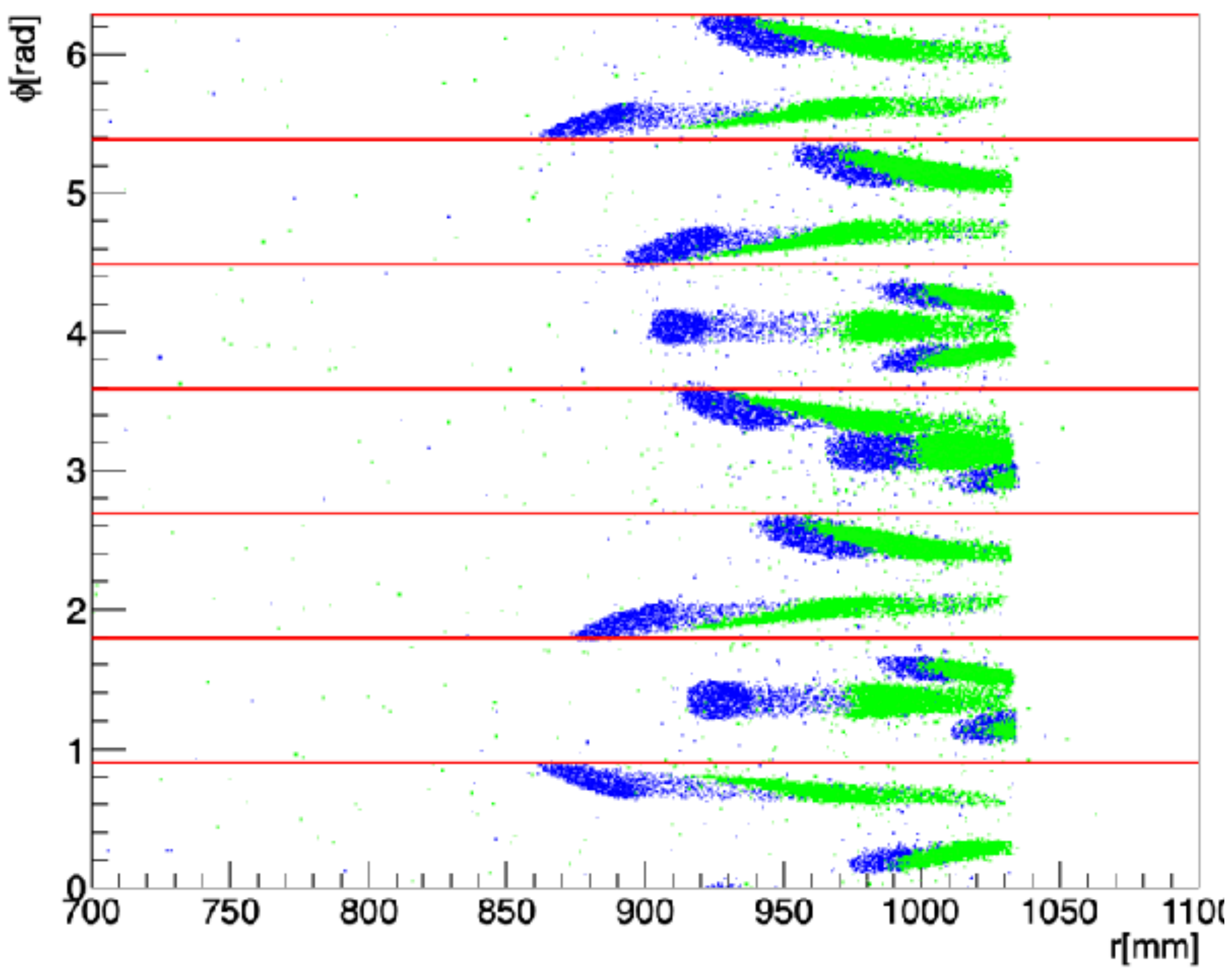
Optics 1 US	53.54 – 62.18 mm	55.27 - 64.22 mm (9)
Optics 1 DS	43.67 – 50.72 mm	45.26 - 52.61 mm (7.35)
Optics 2 US	56.80 – 65.96 mm	58.60 - 68.13 mm (10)
Optics 2 DS	46.94 – 54.53 mm	48.53 - 56.41 mm (7.88)

Pass 2

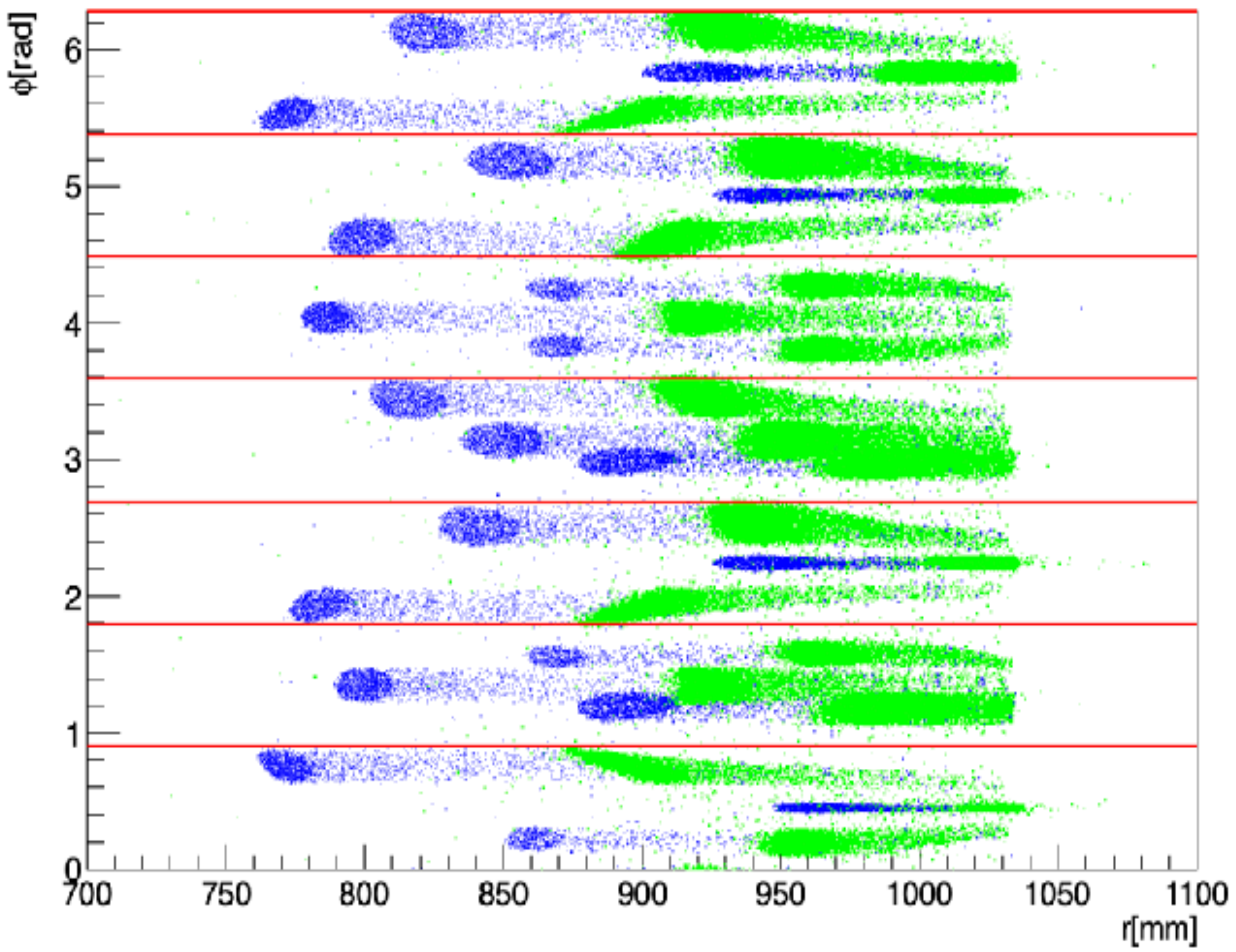
Optics 1 US	34.3 – 42 mm	35.32 - 43.33 mm (8)
Optics 1 DS	Not a likely fit	Not a likely fit
Optics 2 US	36.4 – 44.58 mm	37.47 - 45.90 mm (8.43)
Optics 2 DS	30.08 – 36.84 mm	31.06 - 38.08 mm (7)

Pass 3

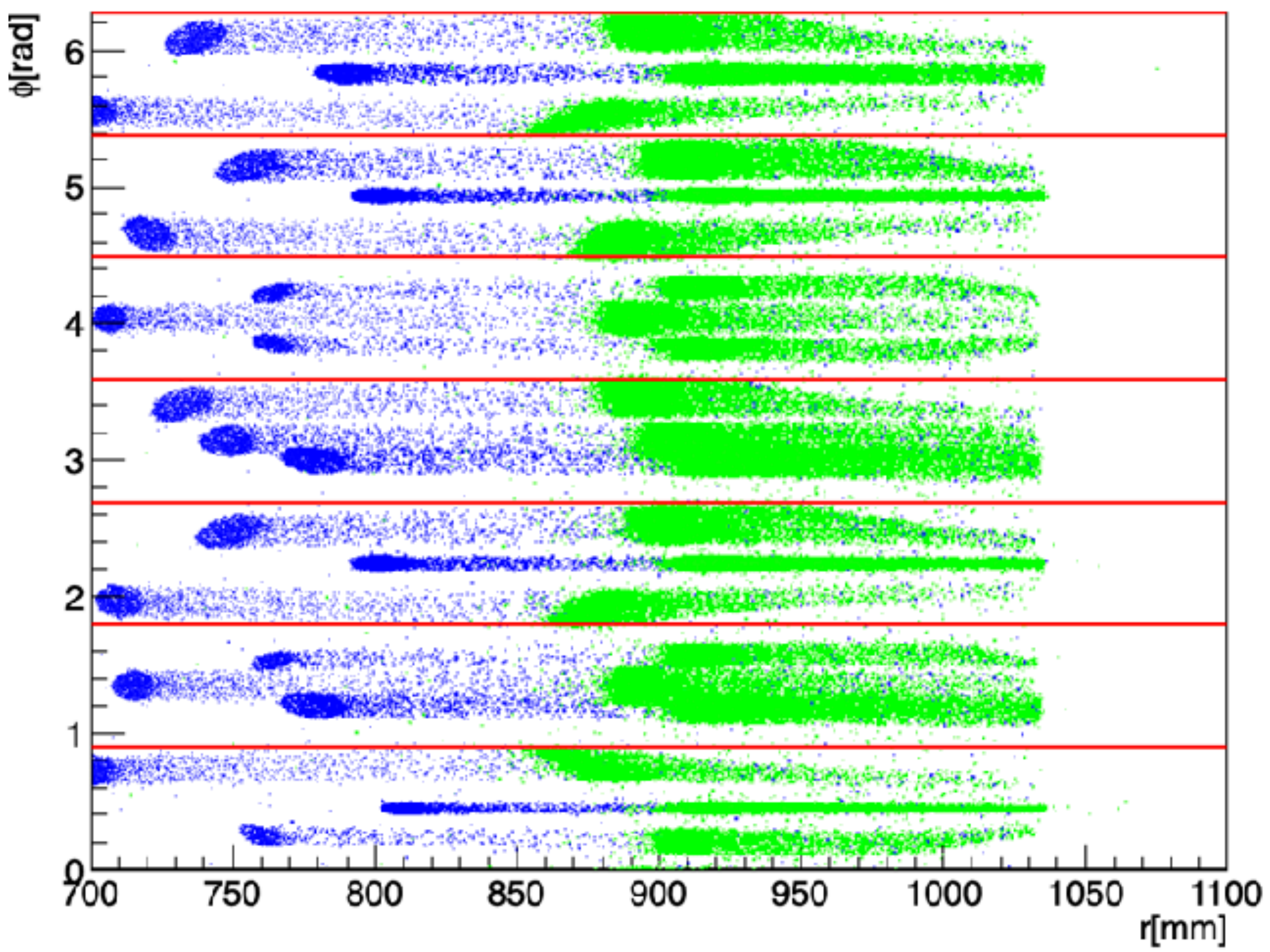
Results with Optics1 US C foil



Pass 1



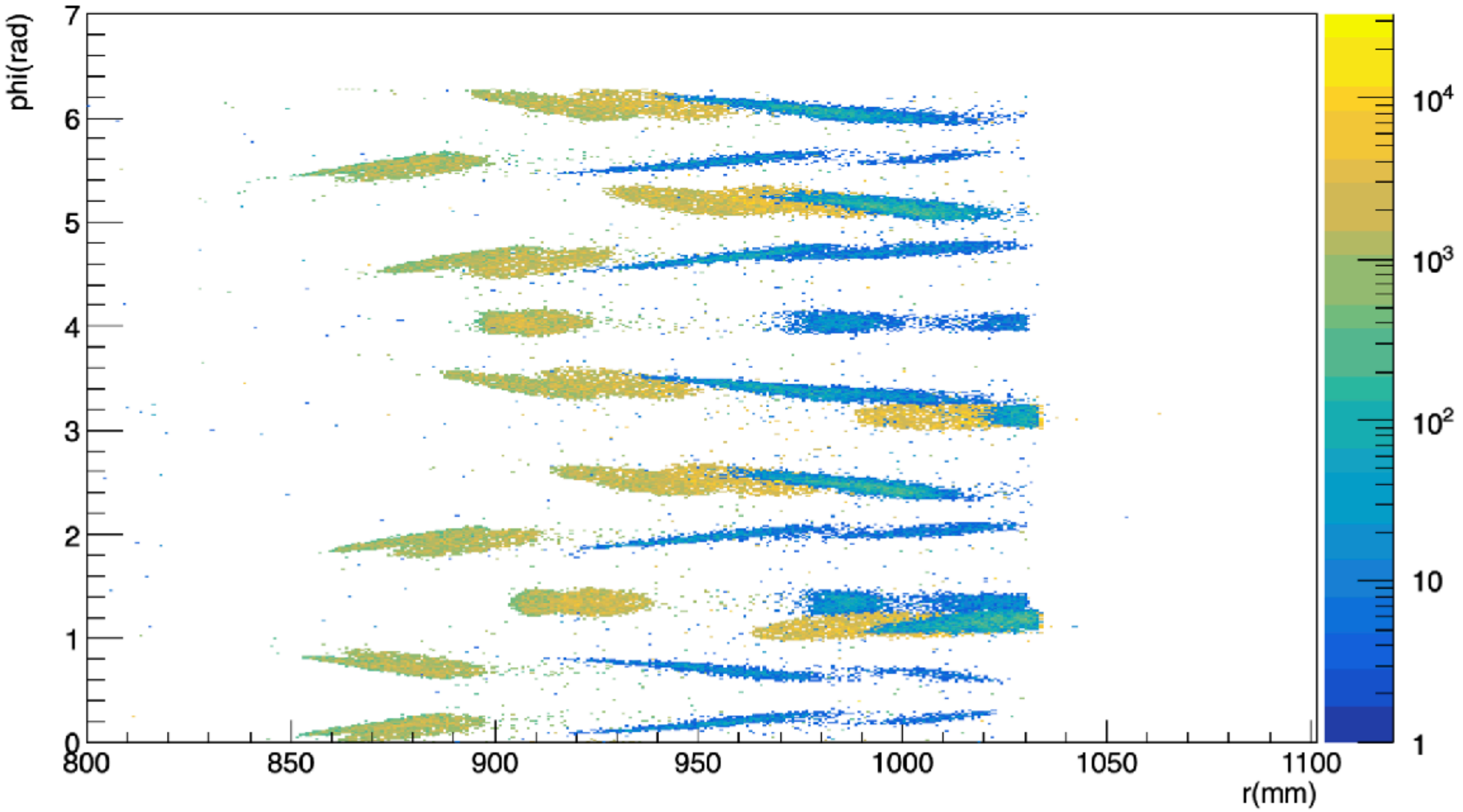
Pass 2



Pass 3

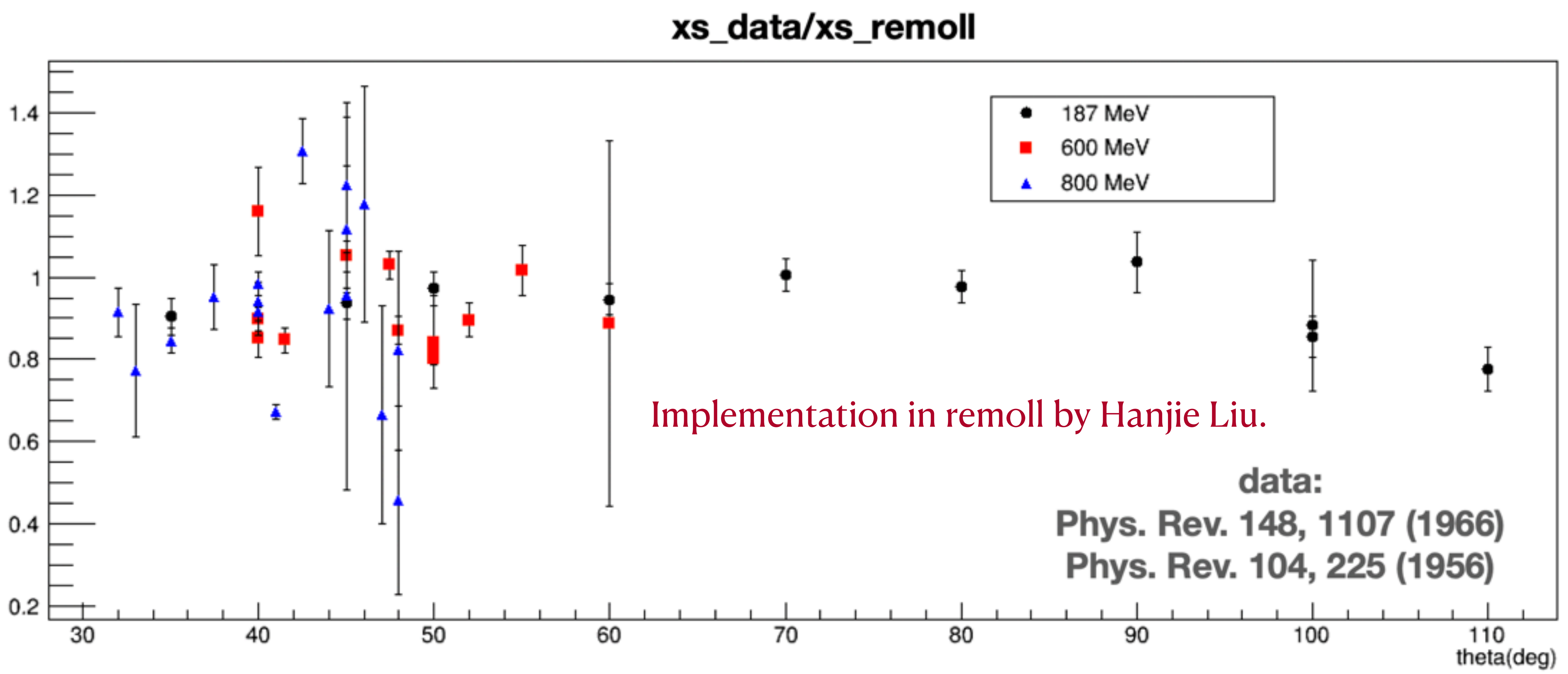
Using both the US and the DS C Foils simultaneously will make the measurement with the lowest beam energy challenging!

The sieve design was a bit different but the general idea still holds.

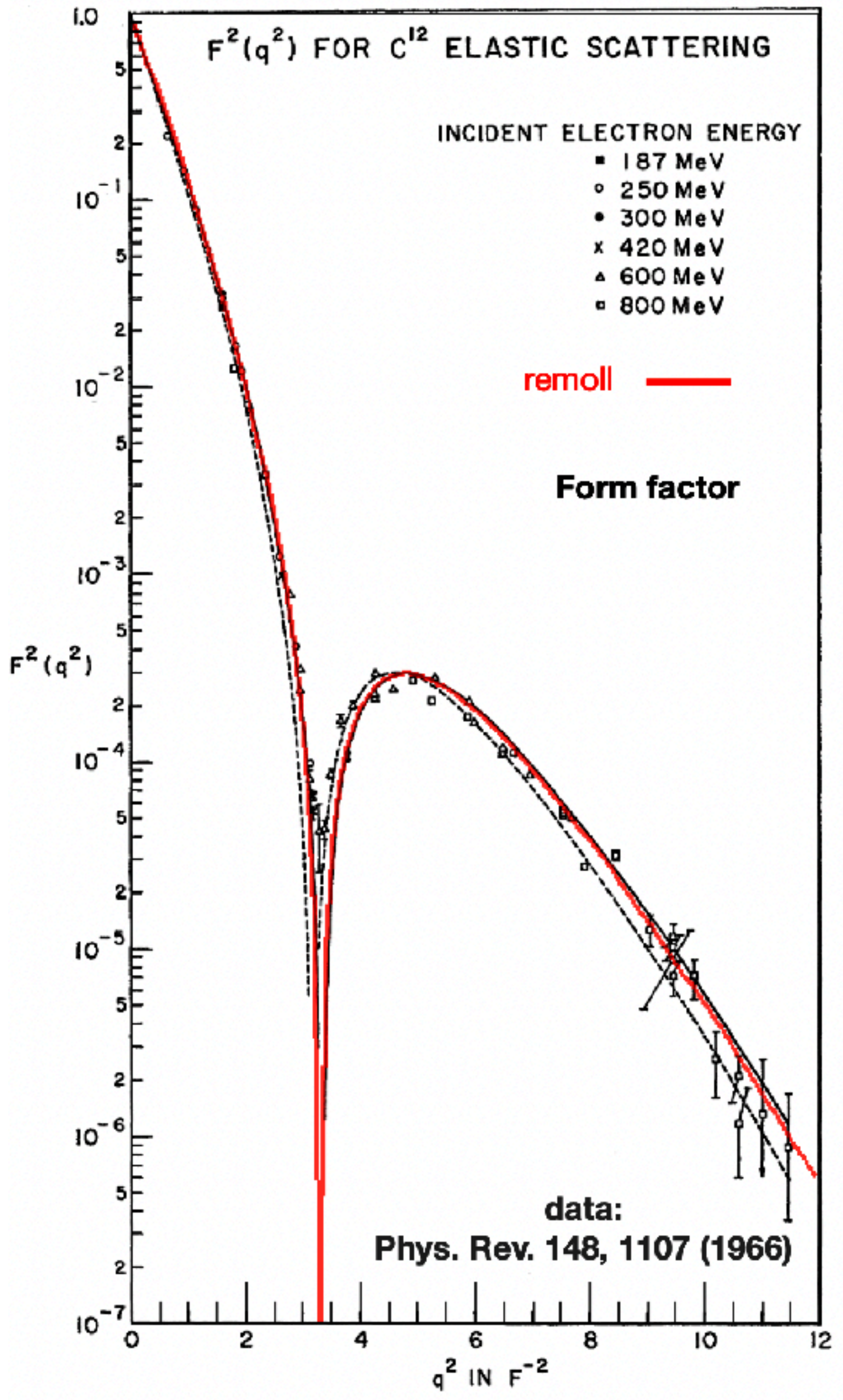


The US C Foils in both the optics targets don't even help us with covering the Moller Kinematics Region.

C12 Elastic Generator in remoll



Ratio of cross section between data and remoll



The cross sections for the scattering of electrons off C12 nuclei are implemented to a fairly good accuracy in remoll.

The Reconstruction Algorithm

- The reconstruction algorithm should provide us with a map between the gem variables and the target variables.
  $(\theta_{lab}, \phi_{lab}, E', v_z) \rightarrow (r, \phi, r', \phi')$
- 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.

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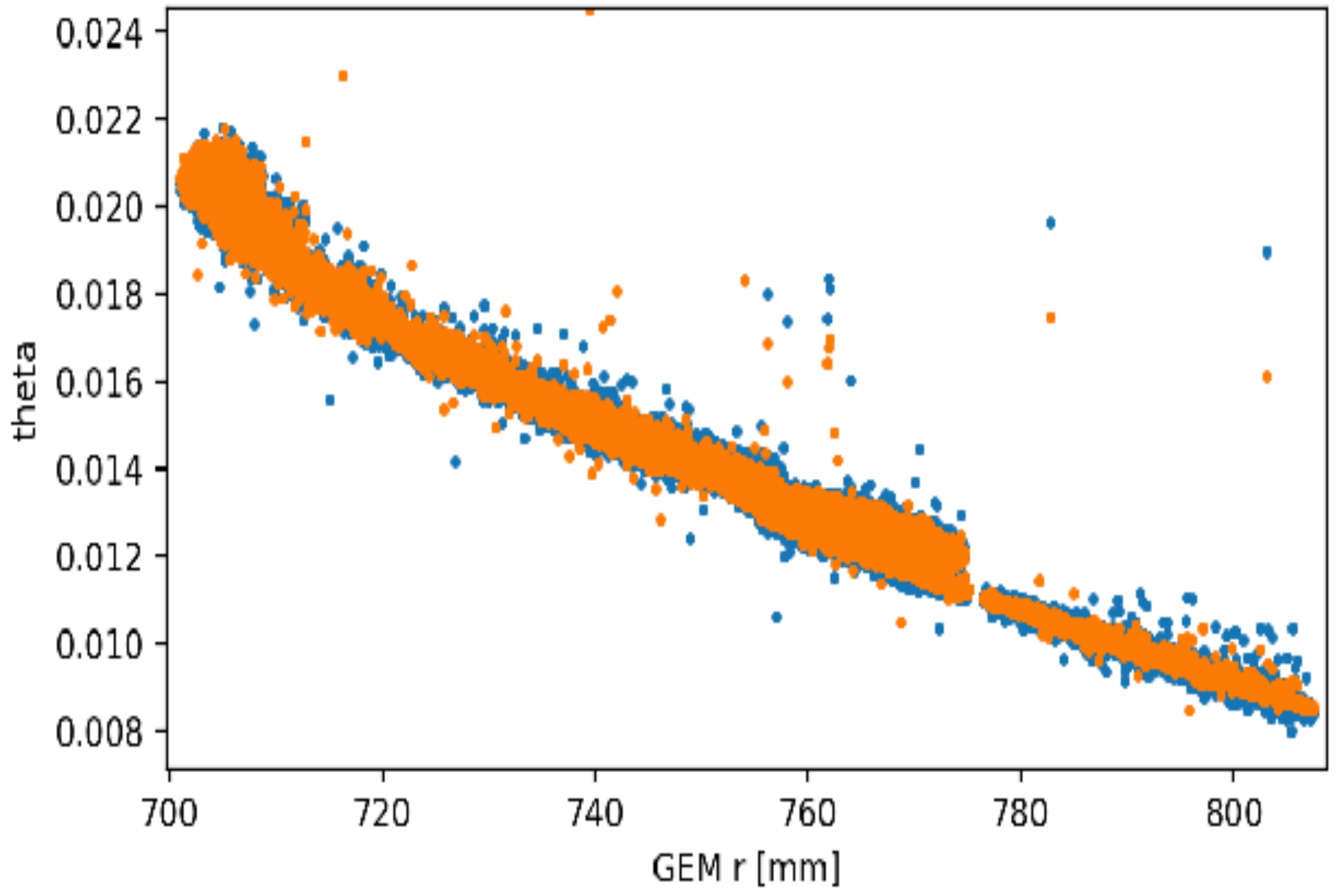
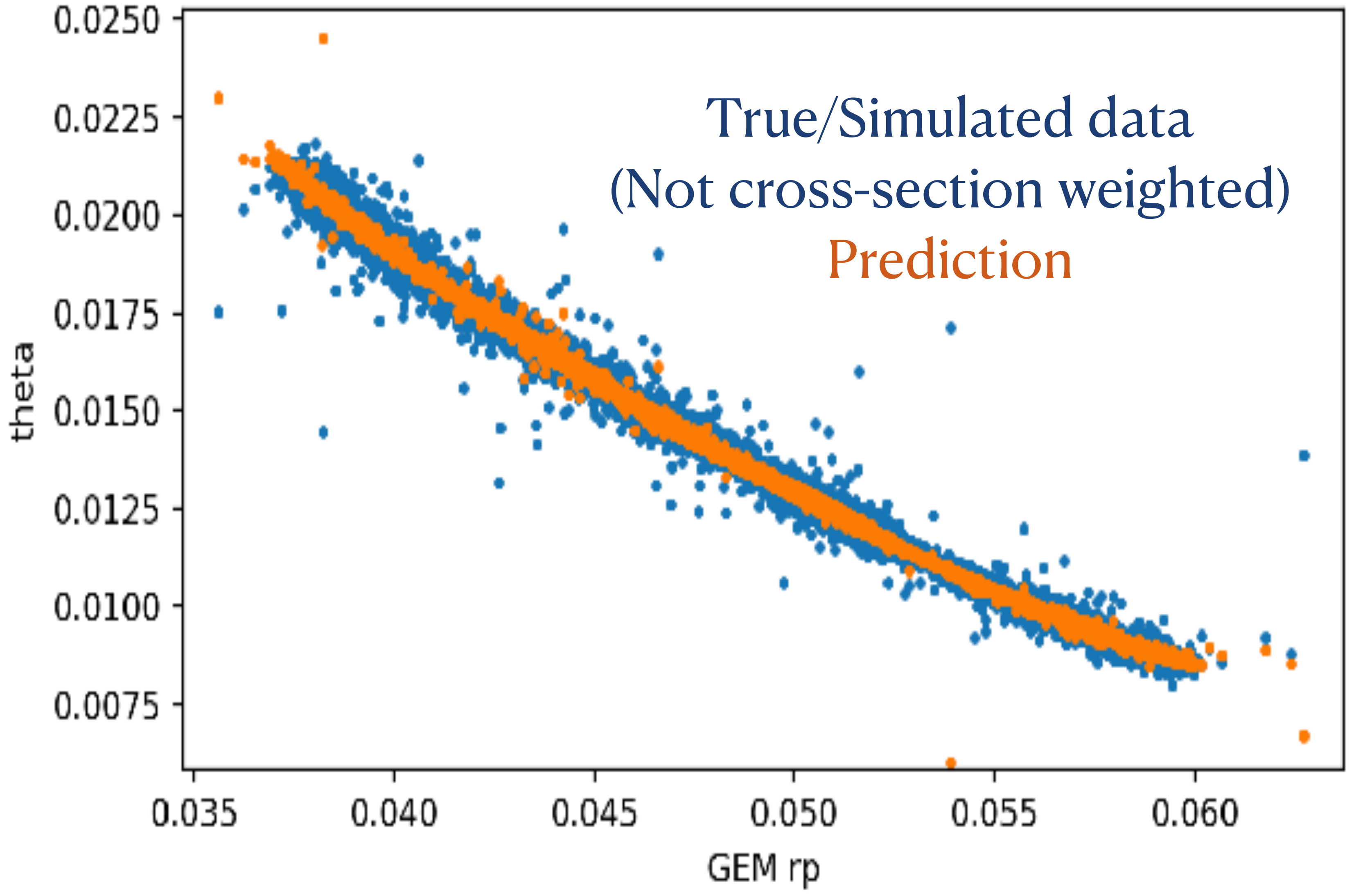
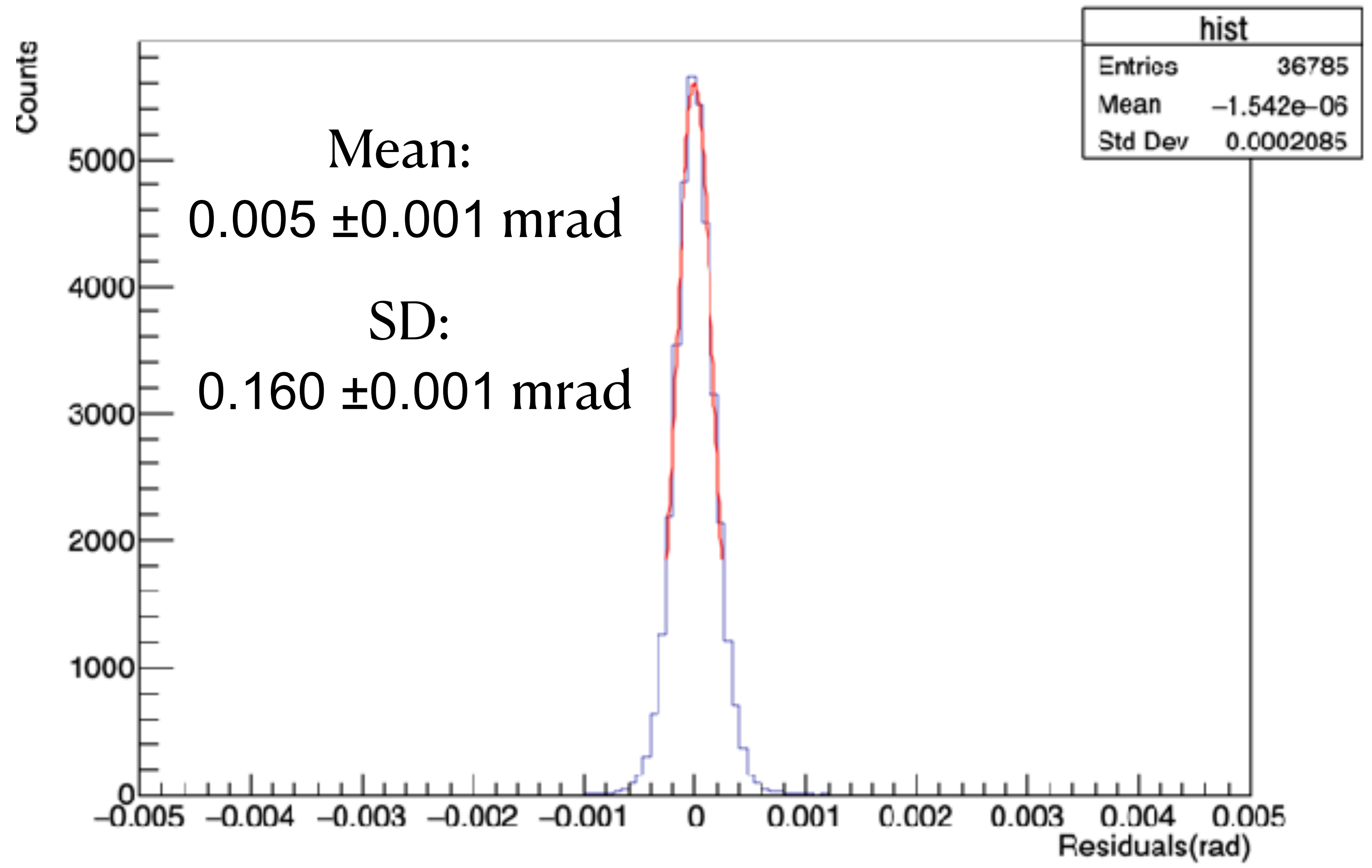
θ_{tg} Reconstruction







Residual (True - Predicted) Distribution

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

As can be seen from the Residual Distribution our reconstruction algorithm works pretty well for θ_{tg} reconstruction! It does pretty good job for the other two passes as well.

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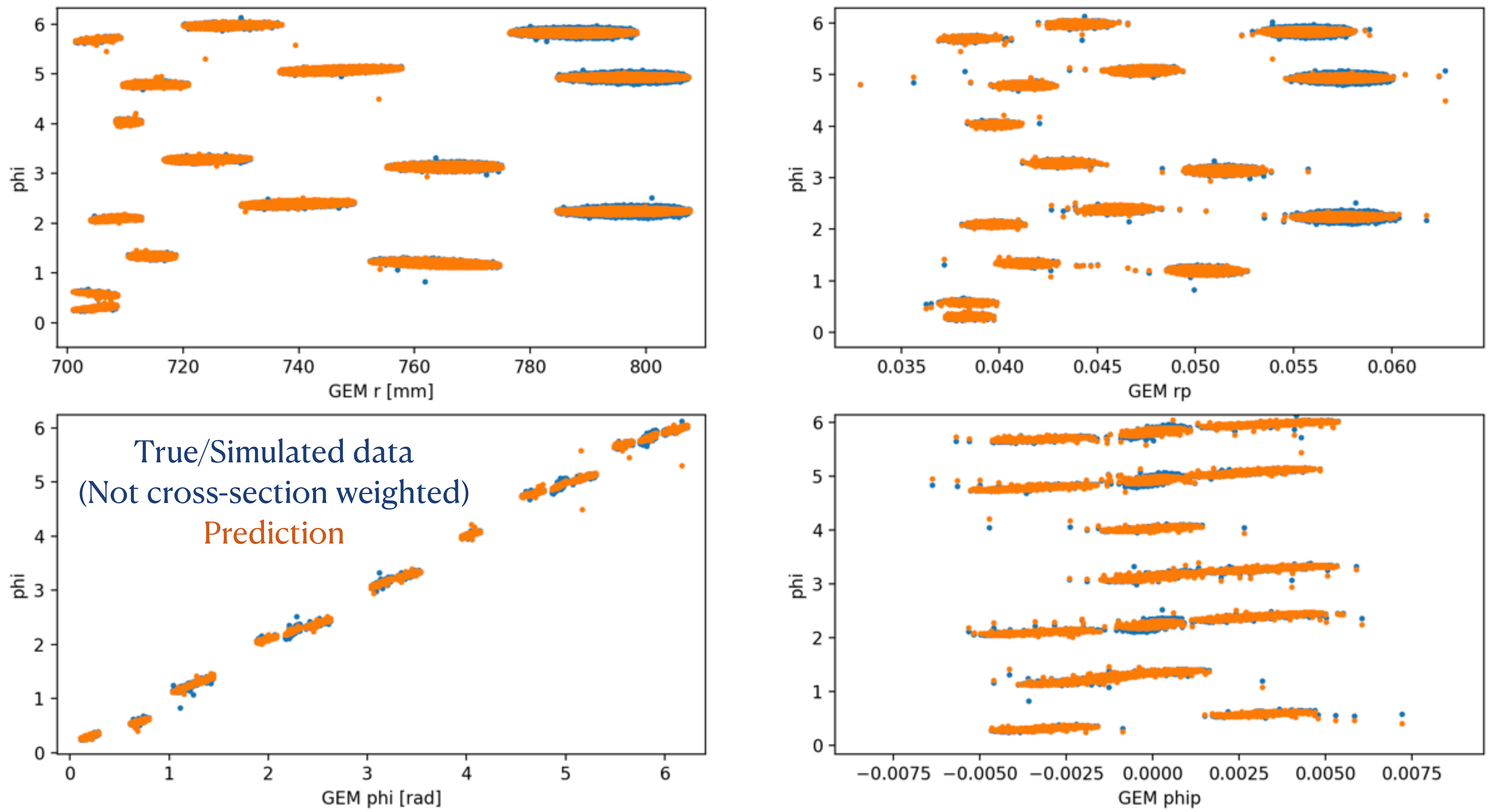
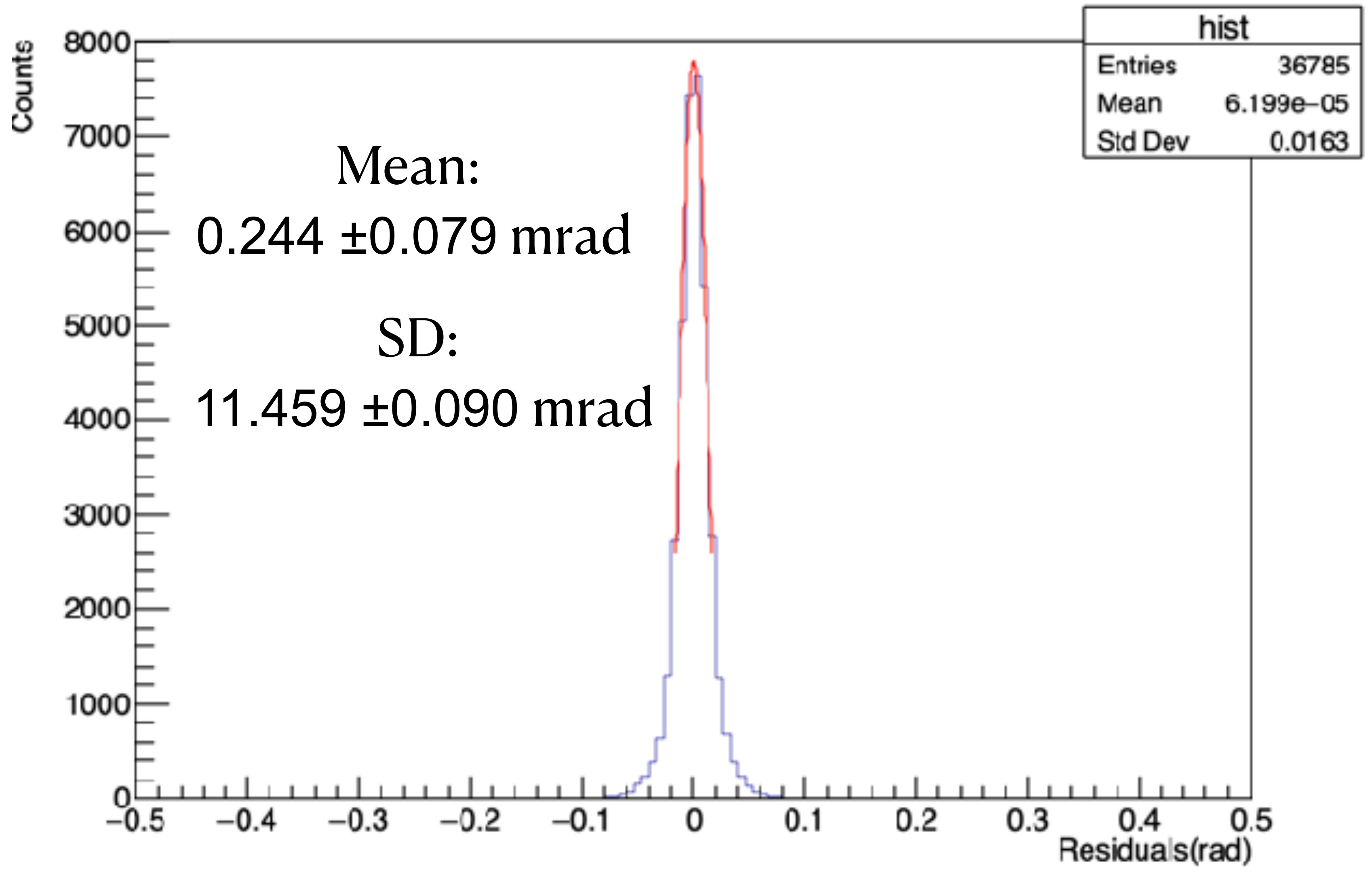
ϕ_{tg} Reconstruction





Residual (True - Predicted) Distribution

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

The reconstruction algorithm works pretty well for ϕ_{tg} reconstruction as well for all 3 passes!

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