# $A_T$ Progress

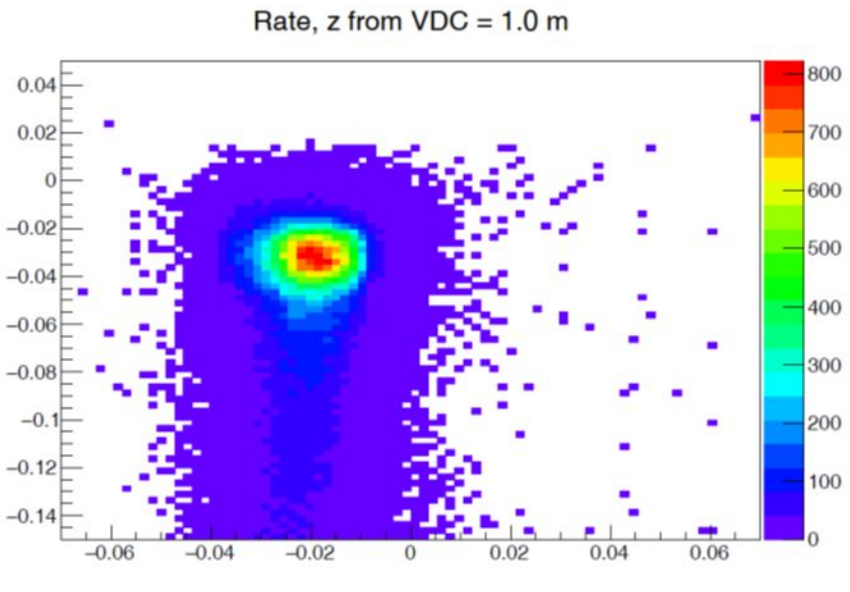
Ryan Richards

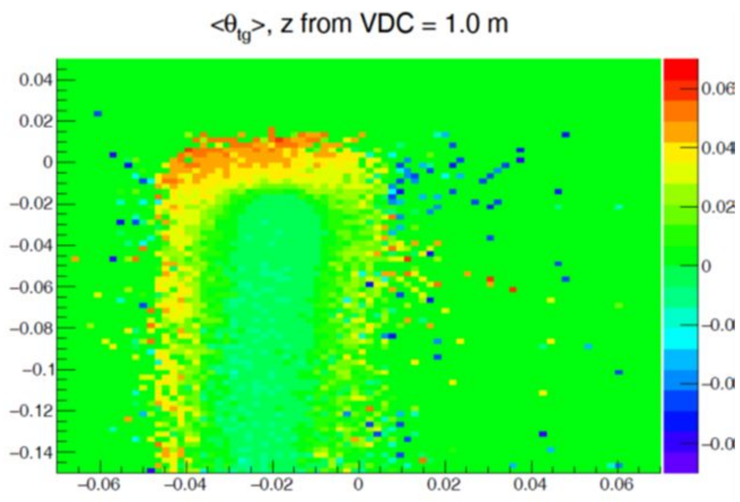
# Exploring $A_T$

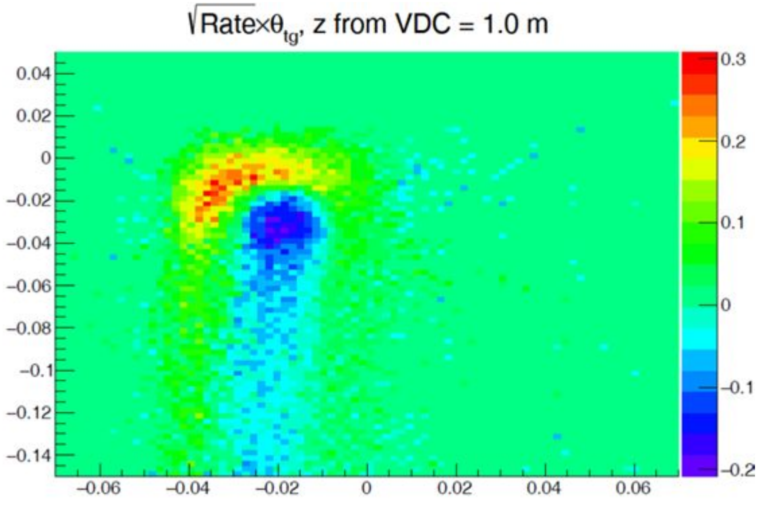
**Question**

**Can we predict where the $A_T$ enhancement using pure optics principles?**

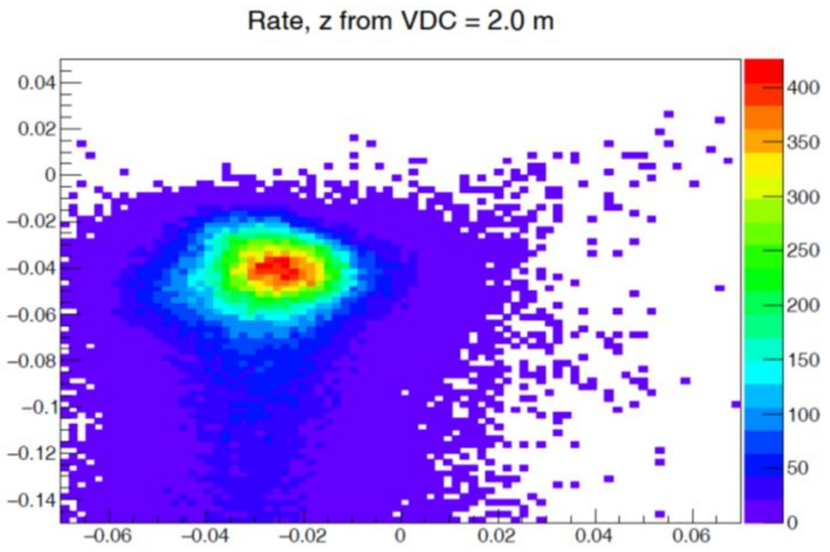
- Would like to place quartz in a unique of focal plane to pick up $A_T$
- Would also like to look at the $\theta_{tg}$ sensitivity, $A_T \propto \theta_{tg}$, $\Phi$

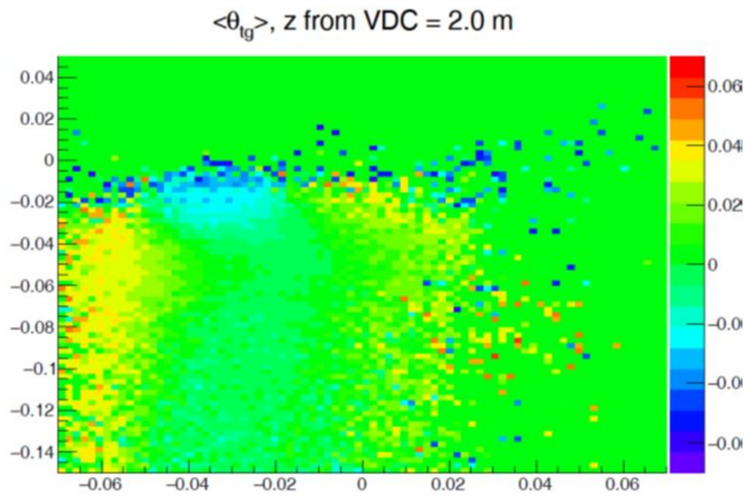


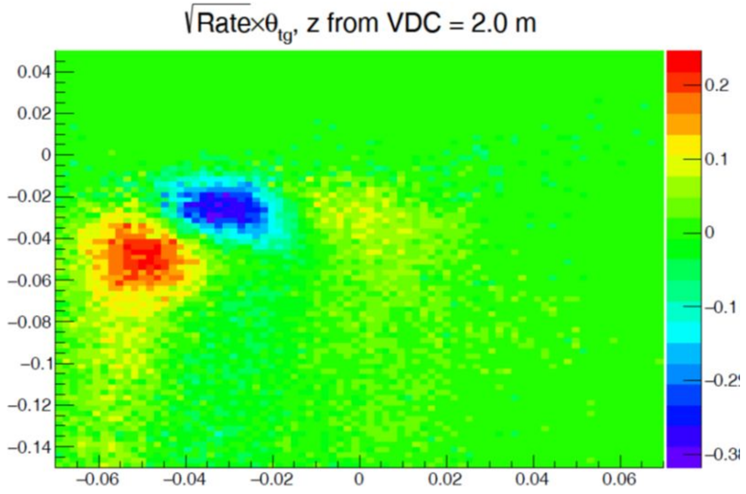



# Concerns




Should be able to predict where the $A_T$ enhancement shows up using second order optics matrix elements
Idea is put $A_T$ detector where the red spot
Sits on the fringe of the acceptance

**Is it possible that the enhancement is outside the calibration region?**

# Optics

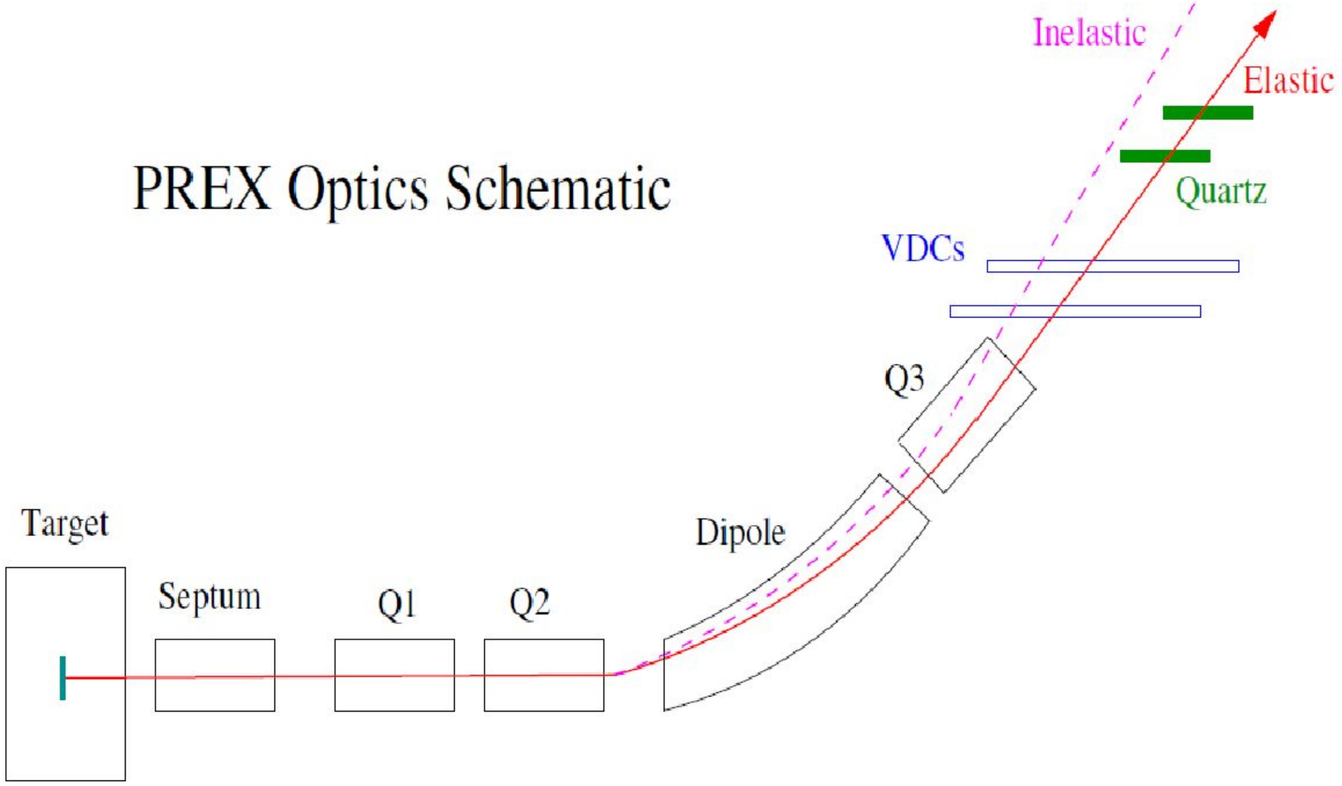
- Beam transport of charged particles through HRS can be studied using optics.

- For PREX ($SQQD_nQ$)

- Would like a way to relate focal plane variables to target variables (Optics Matrix Formalism)

- Taylor expansion around central trajectory ($1^{st}$ order expansion 5D vector, $2^{nd}$ order expansion 20D vector

- Each element in HRS chain represented by a matrix



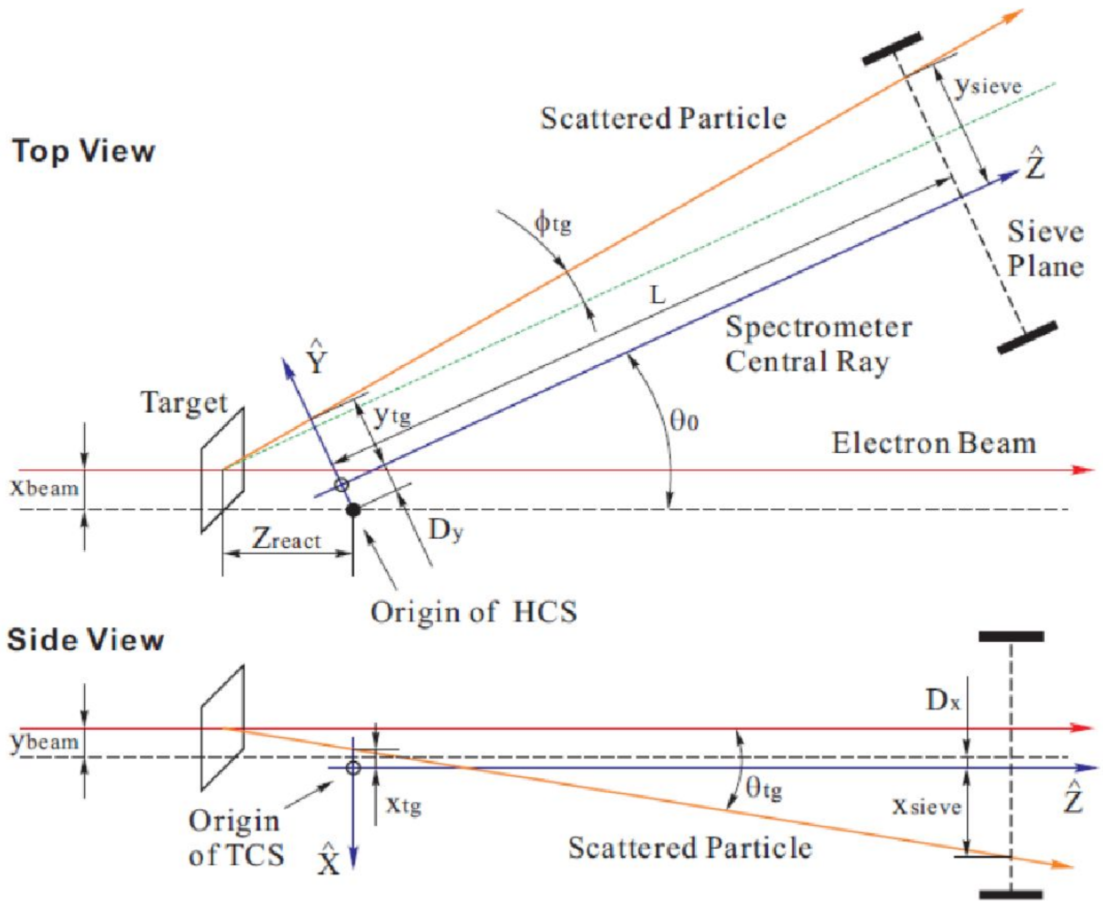
# Beam Transport ($1^{st}$ Order)

$$
\begin{bmatrix} x_{fp} \\ \theta_{fp} \\ y_{fp} \\ \phi_{fp} \\ \delta_{fp} \end{bmatrix}
=
\begin{bmatrix}
(x|x_{tg}) & (x|\theta_{tg}) & (x|y_{tg}) & (x|\varphi_{tg}) & (x|\delta_{tg}) \\
(\theta|x_{tg}) & (\theta|\theta_{tg}) & (\theta|y_{tg}) & (\theta|\varphi_{tg}) & (\theta|\delta_{tg}) \\
(y|x_{tg}) & (y|\theta_{tg}) & (y|y_{tg}) & (y|\varphi_{tg}) & (y|\delta_{tg}) \\
(\varphi|x_{tg}) & (\varphi|\theta_{tg}) & (\varphi|y_{tg}) & (\varphi|\varphi_{tg}) & (\varphi|\delta_{tg}) \\
(\delta|x_{tg}) & (\delta|\theta_{tg}) & (\delta|y_{tg}) & (\delta|\varphi_{tg}) & (\delta|\delta_{tg})
\end{bmatrix}
\begin{bmatrix} x_{tg} \\ \theta_{tg} \\ y_{tg} \\ \phi_{tg} \\ \delta \end{bmatrix}
$$

Fractional momentum deviation from central trajectory ($\delta$ =0)

Express focal plane variables as a Taylor expansion of the target variables ($1^{st}$ order optics matrix is 5 x 5)

# Target Coordinate System




- $\theta_{tg}$ - out of plane angle
- $\varphi_{tg}$ - in plane angle
- Use $x_{tg}$ , $y_{tg}$ = +/- 2mm in each direction to simulate raster
- Flat sample target variables to do optics

# HRS Tune ($1^{st}$ Order Matrix Elements)

Heavy coupling between δ and x

Focal Plane Coordinates

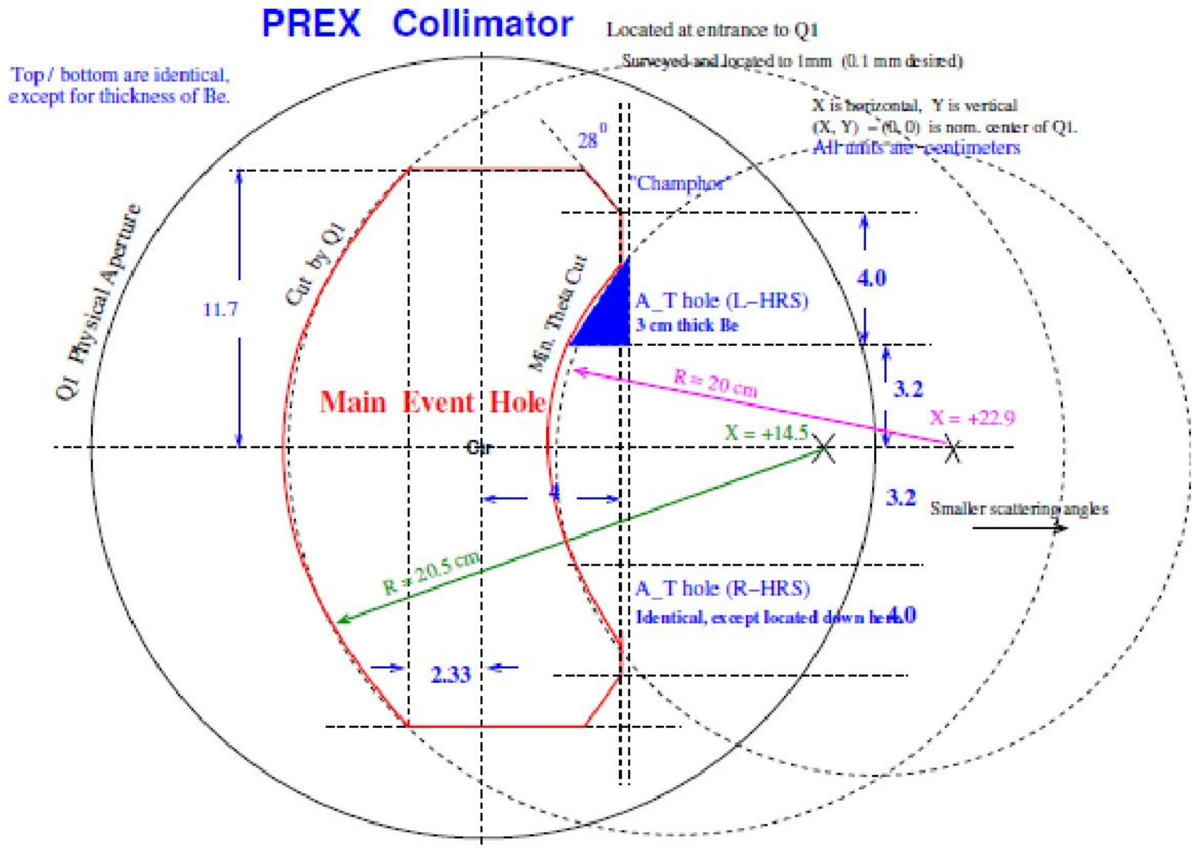
Target Coordinates

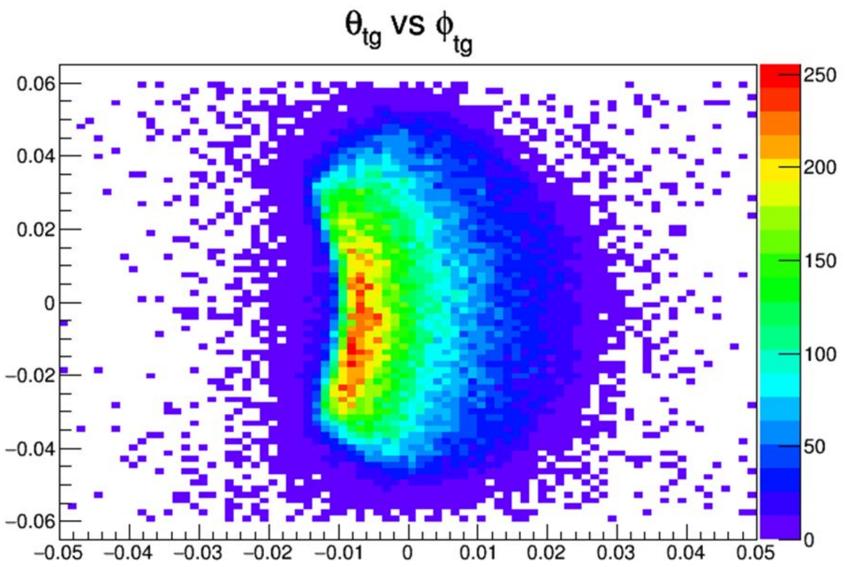
$$\begin{bmatrix} x_{fp} \\ \theta_{fp} \\ y_{fp} \\ \phi_{fp} \\ \delta_{fp} \end{bmatrix} = \begin{bmatrix} -3.09 & -0.02 & 0 & 0 & 16.73 \\ -0.31 & -0.32 & 0 & 0 & 2.5 \\ 0 & 0 & 2.11 & 0.01 & -0.48 \\ 0 & 0 & 1.1 & 0.48 & -0.19 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{tg} \\ \theta_{tg} \\ y_{tg} \\ \phi_{tg} \\ \delta \end{bmatrix}$$

Field values q1 = 0.099950, q2 = -0.132890 q3 = -0.171751

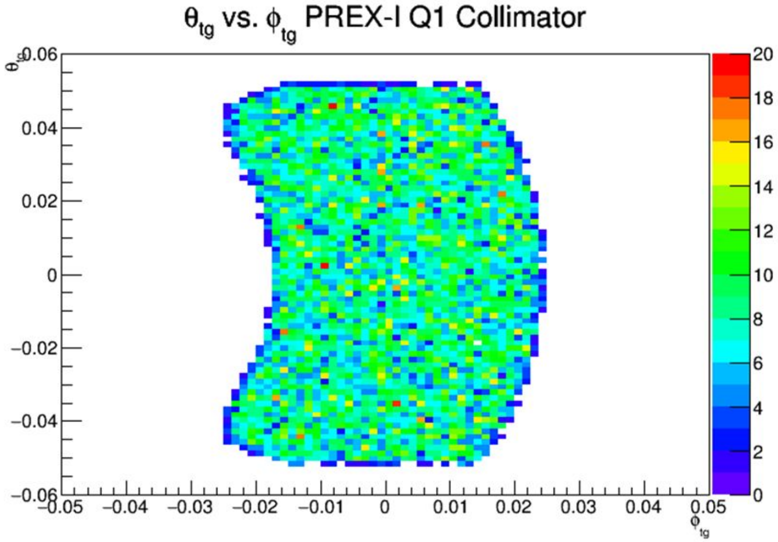
(x|θ) and (y|φ) ~ 0 - Point to point imaging in x,y at focal plane detector

# Collimator




Data




Simulation

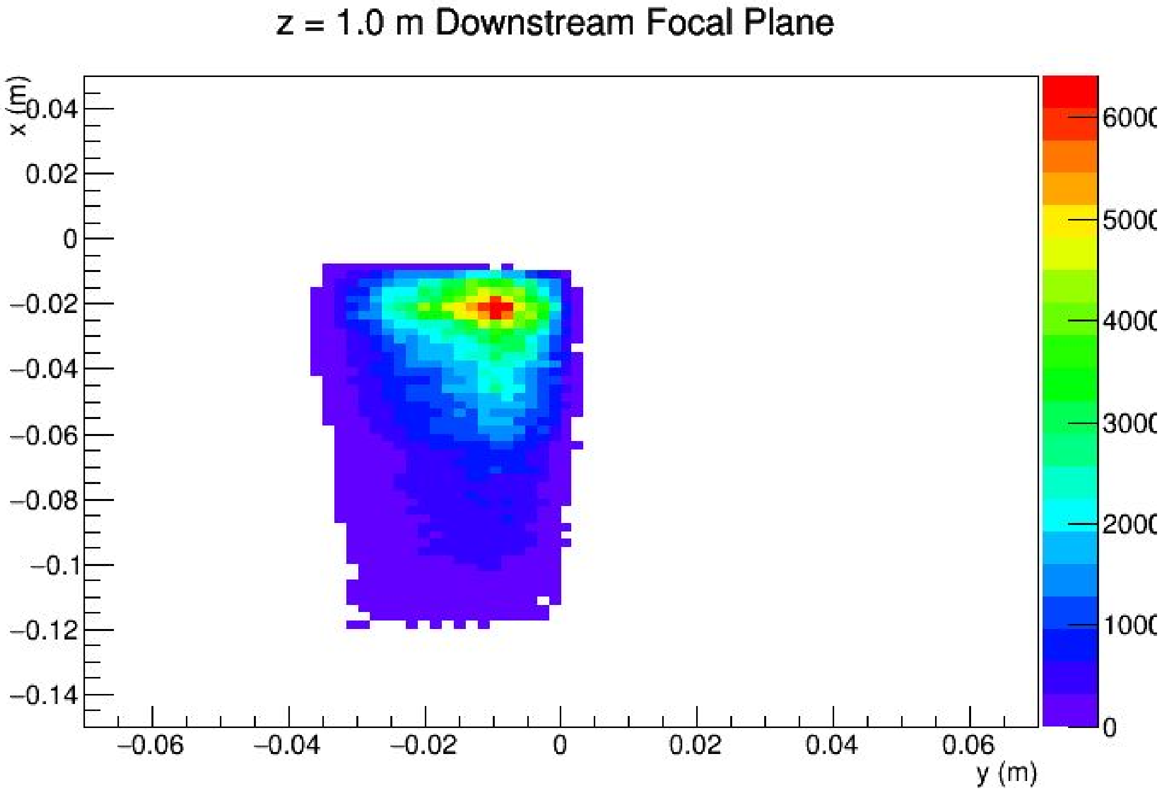
- Enforce collimator cut before looking at detector plane distributions
  (x|x) = 0.91, (x|θ) = 2.28, (y|y) = 0.98, (y|φ) = 2.39

# Optics model Inputs

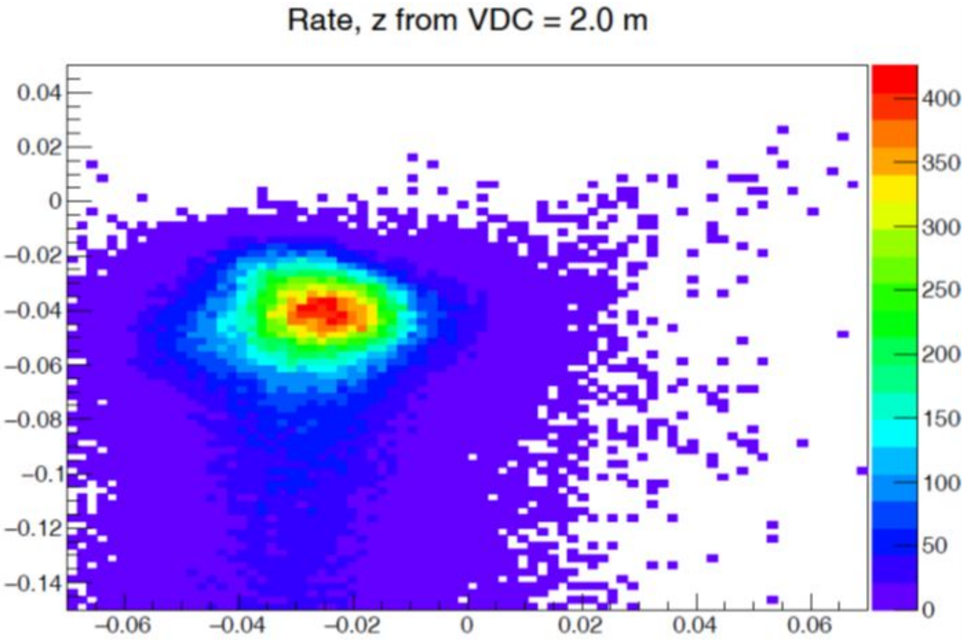
- Want our optics model to be an accurate representation of the data
- Requires septum mistune
- Requires weighted sampling
  - Input Mott cross section
- Requires identifying calibration region (BPM info, target thickness etc.)

# Focal Plane (Rates)

Simulation

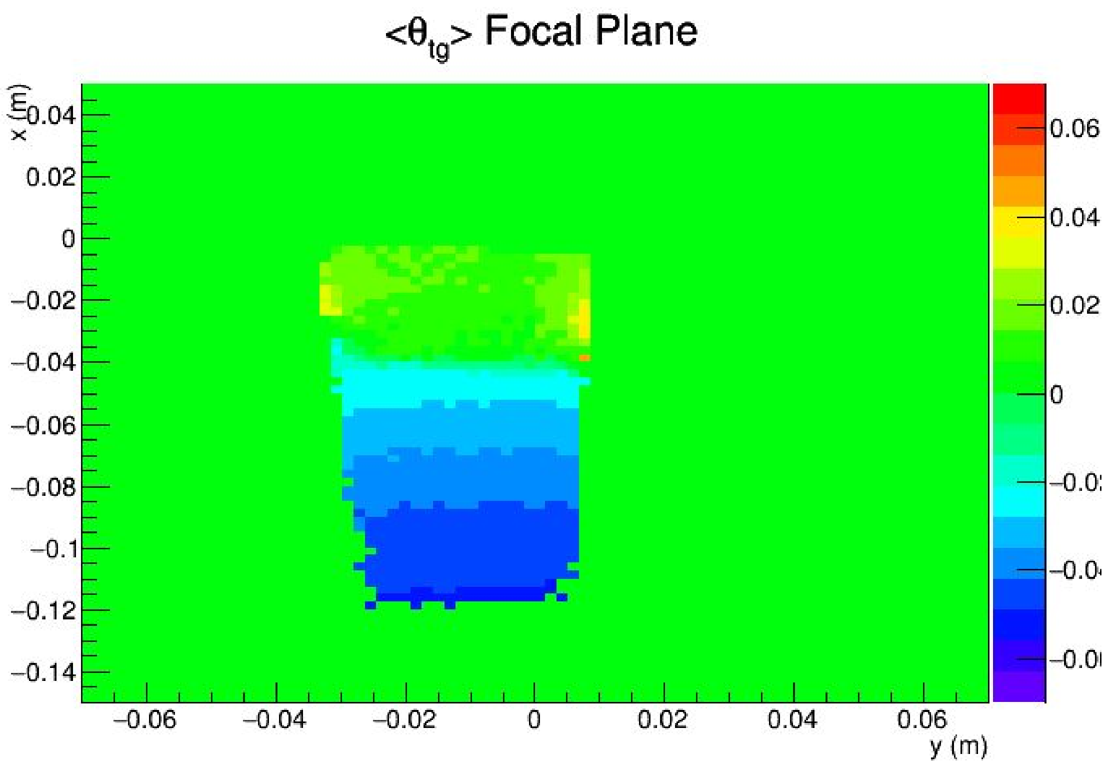



Data

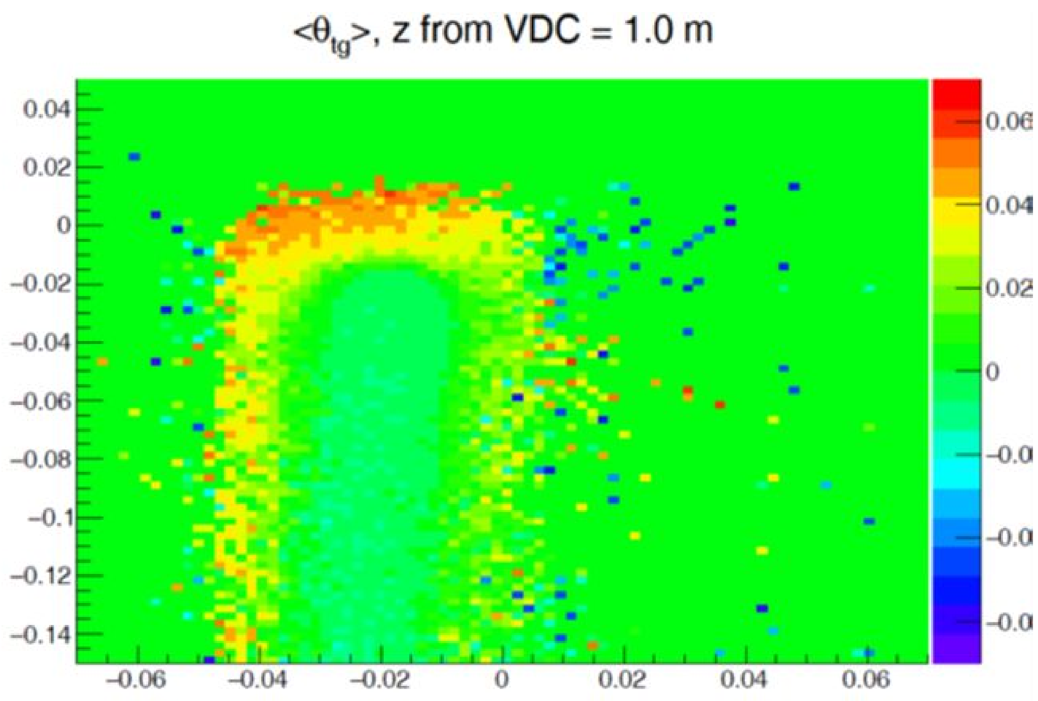


# Focal Plane (Analyzing Power)

Simulation

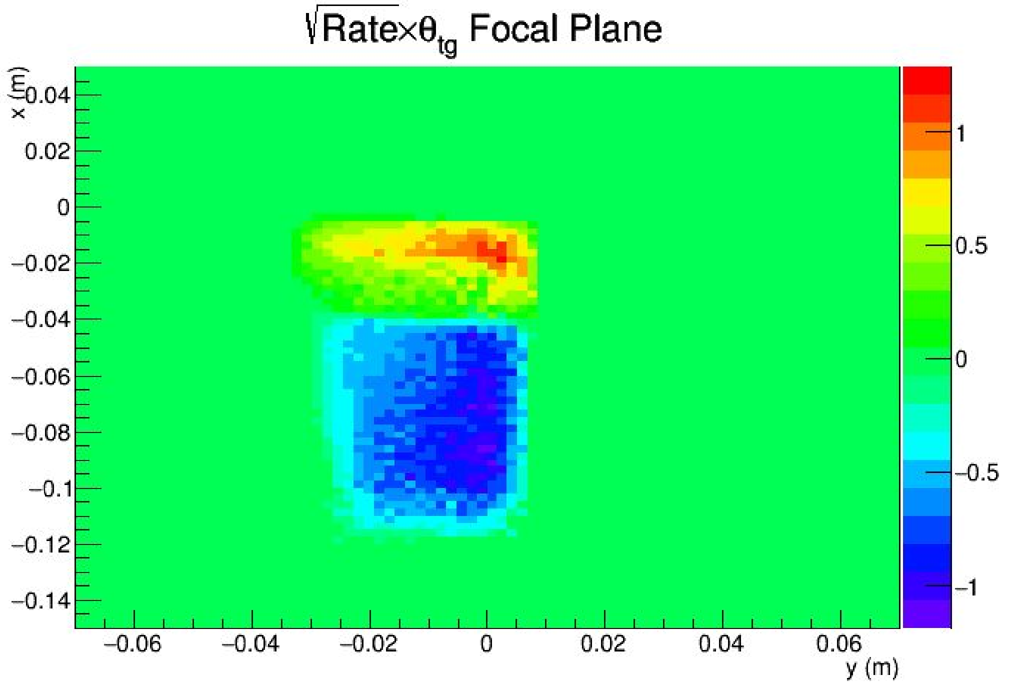



Data

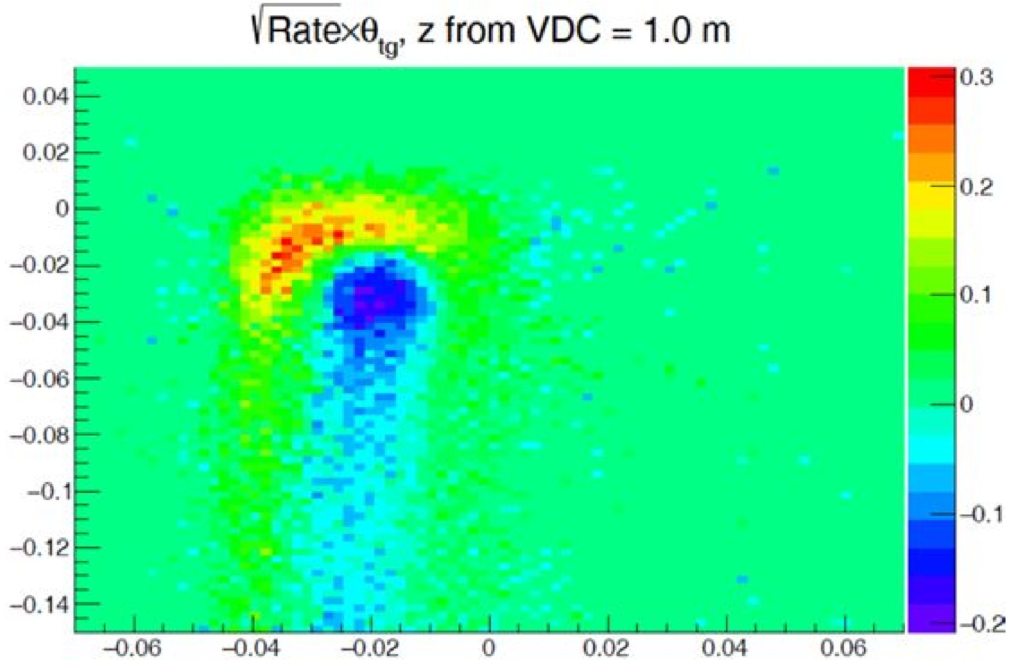


# Focal Plane (Figure of Merit)

Simulation



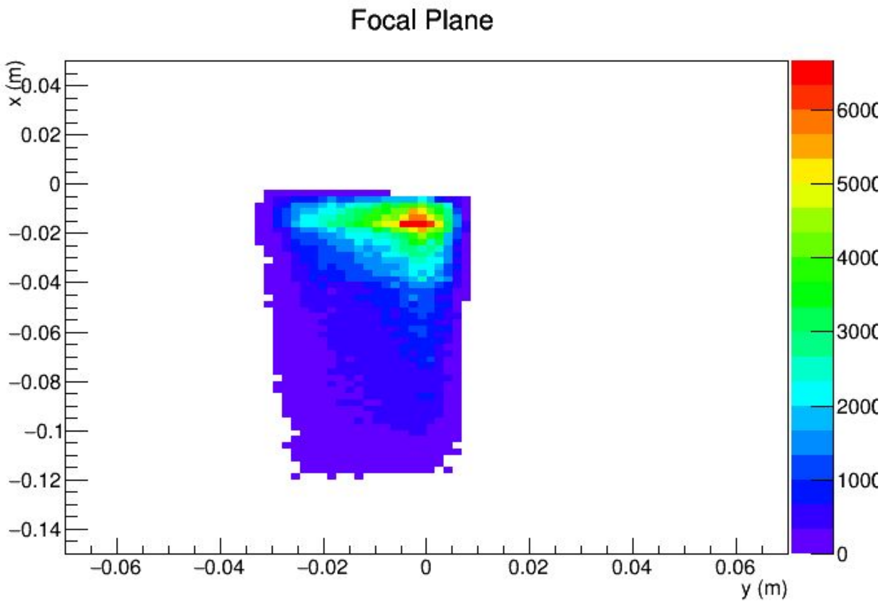

Data

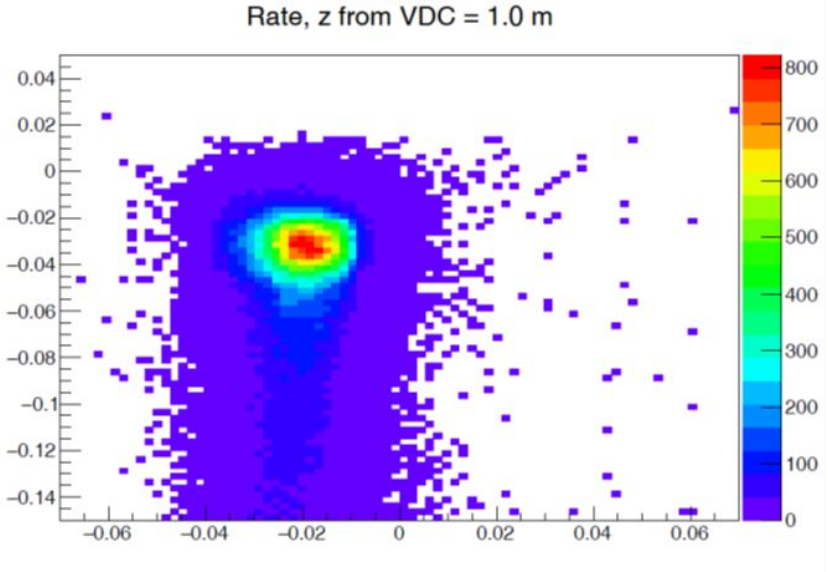


# $A_T$ Plane (Rates)

Simulation

Data

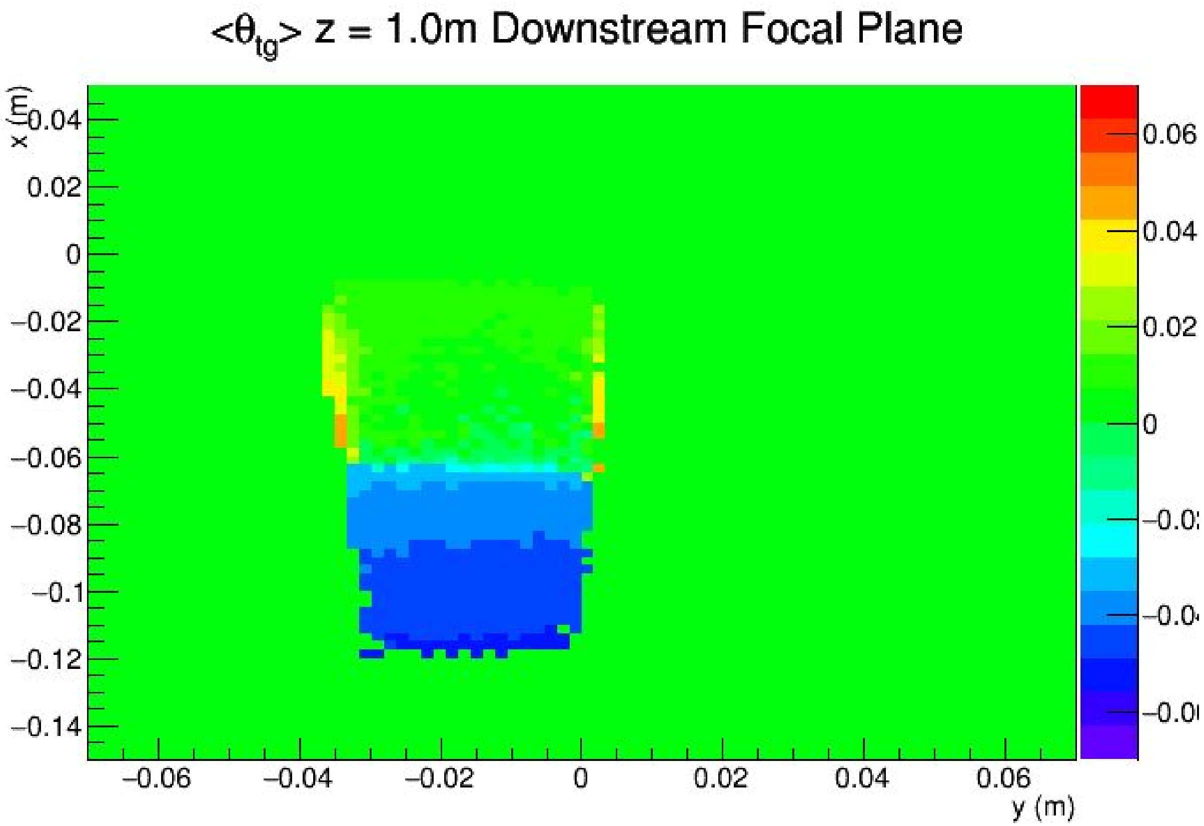


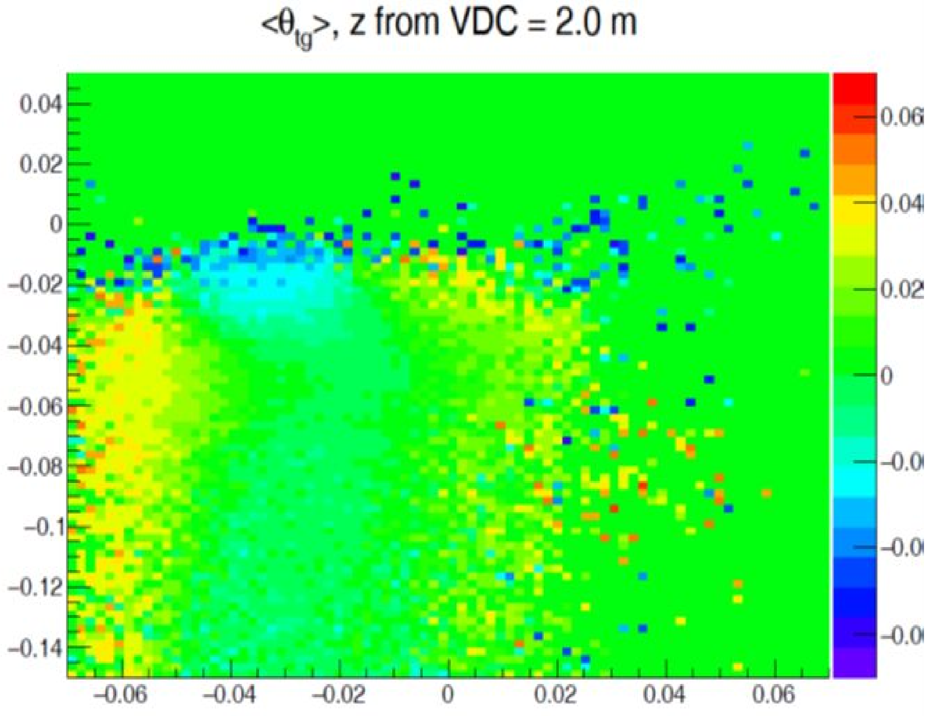

Put 1d plots

# $A_T$ Plane (Analyzing Power)

Simulation

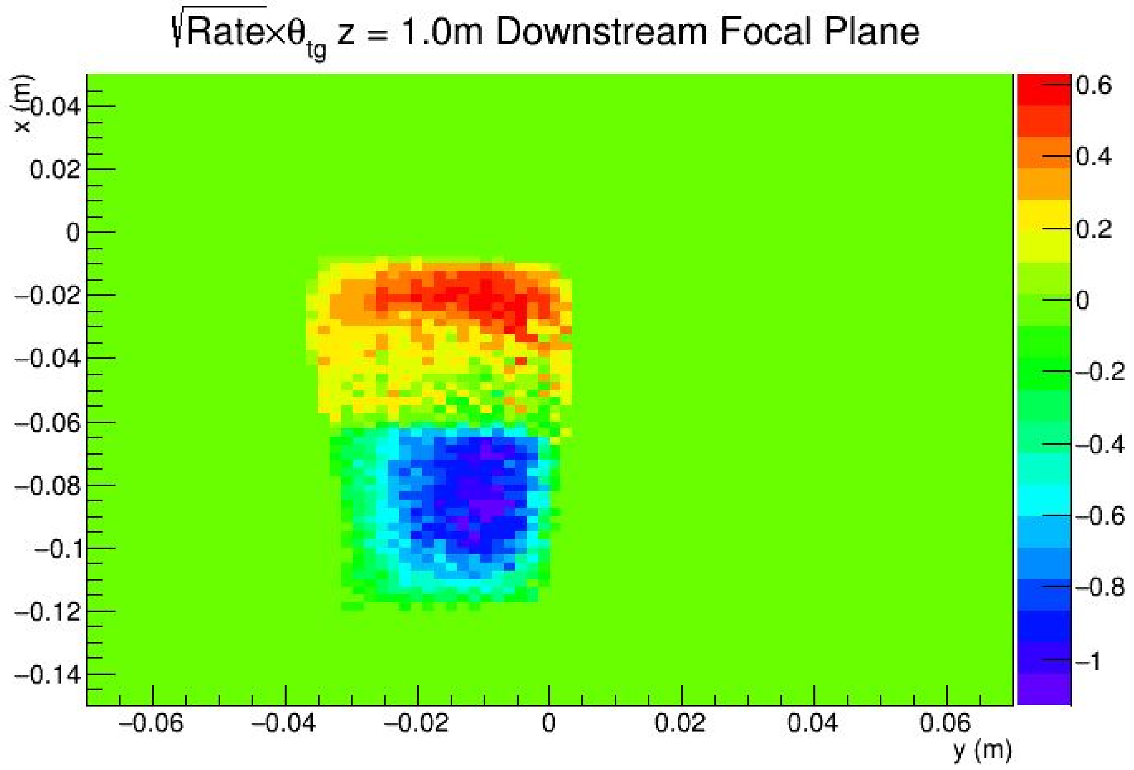



Data

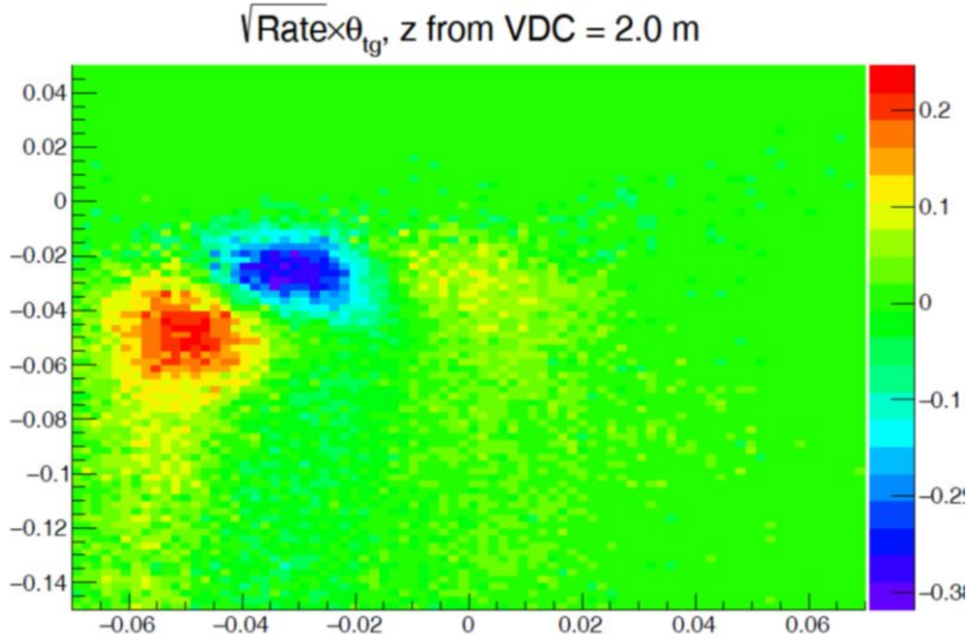


# $A_T$ Plane (Figure of Merit)

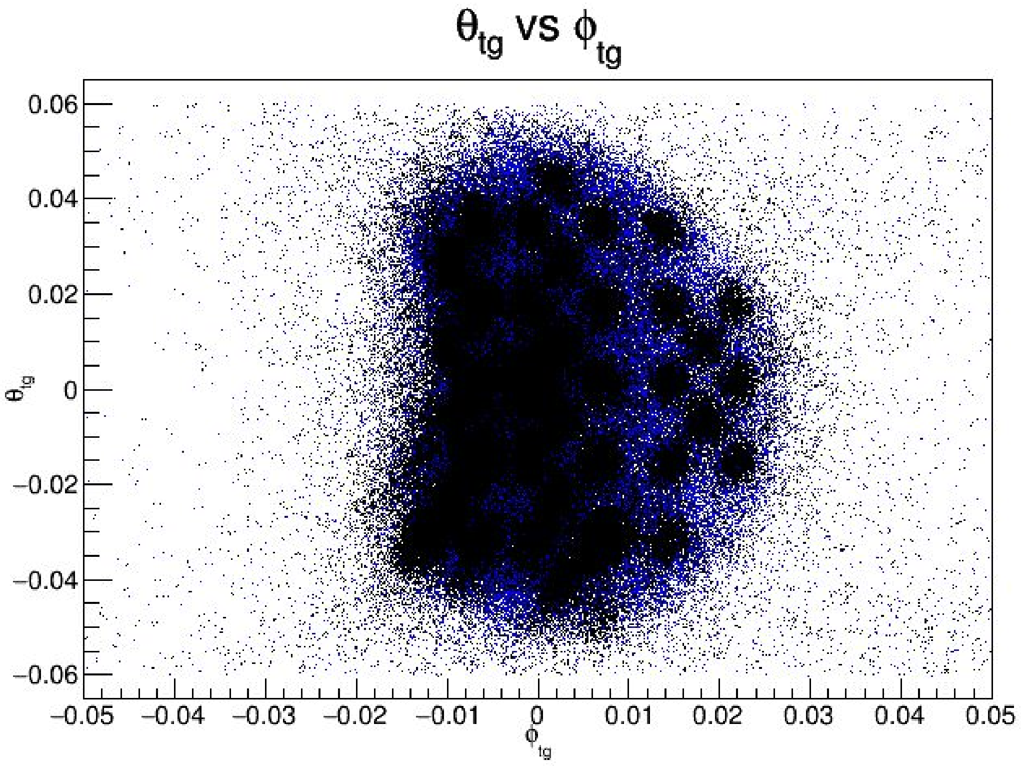
Simulation



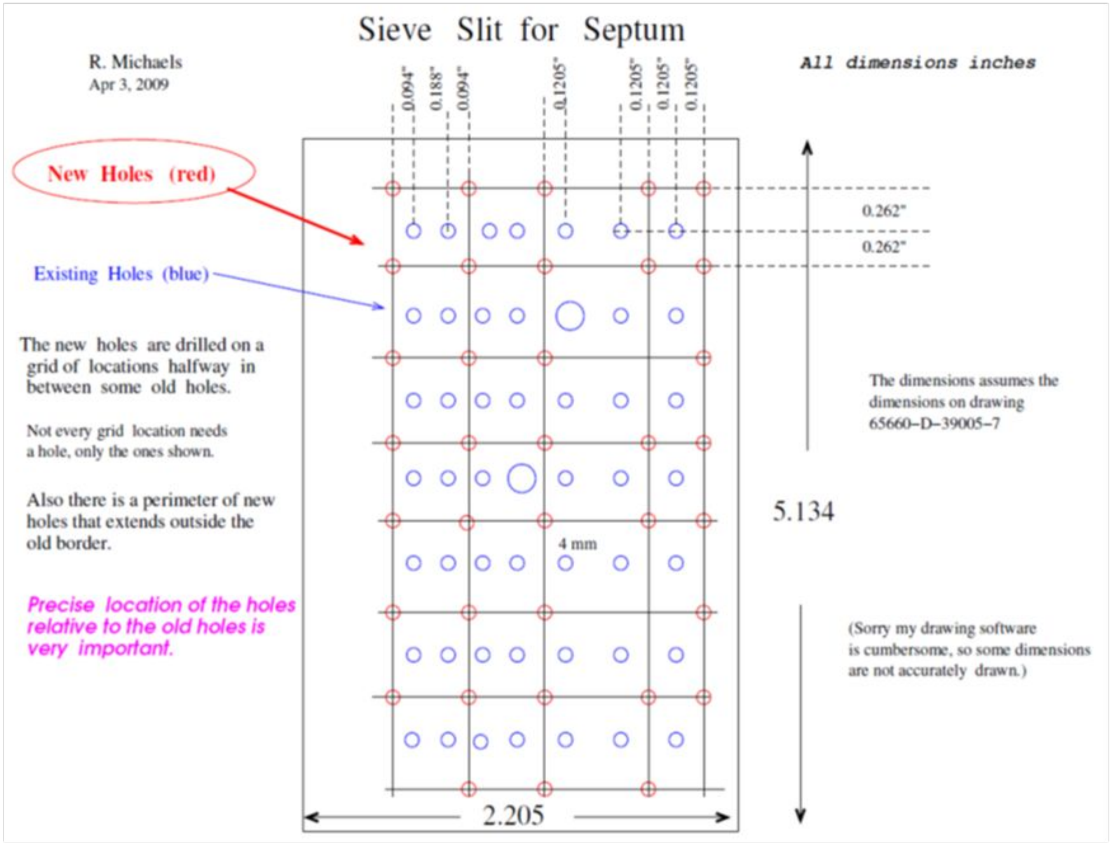

Data



# Sieve Data

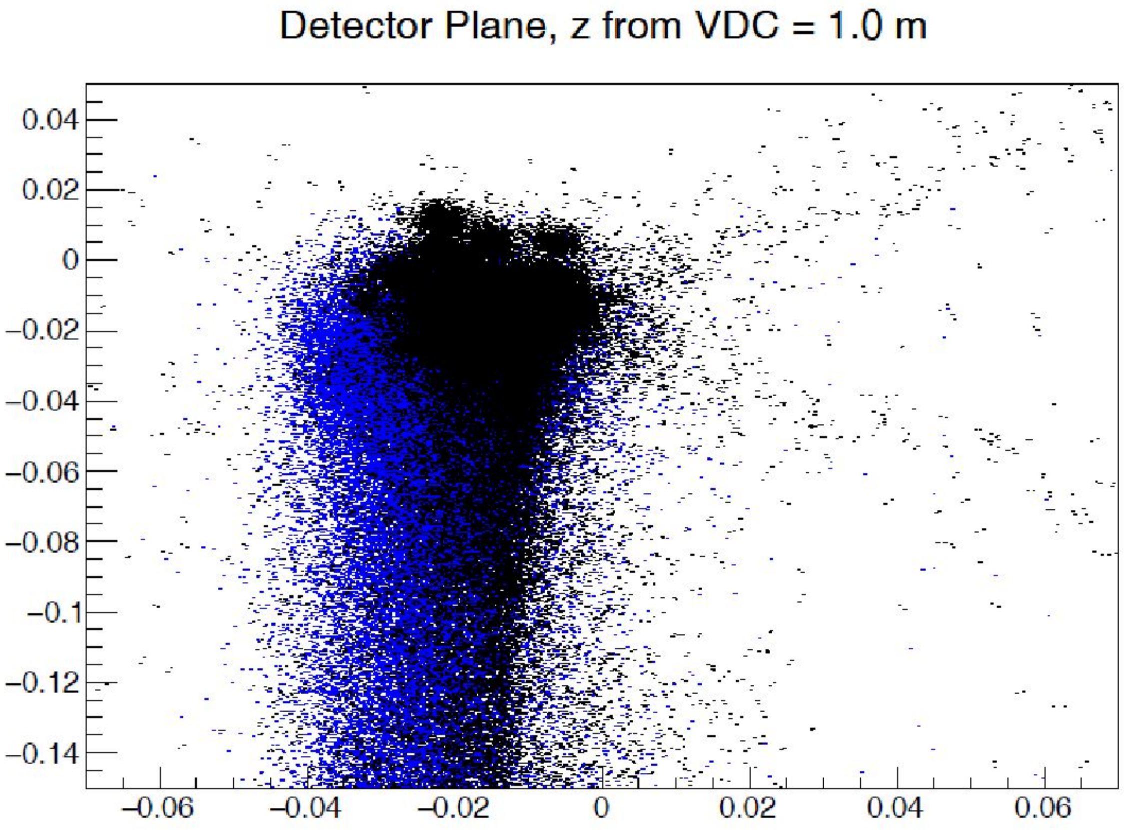



Sieve In( no raster, Super Thin $^{12}C$, 0.075 mm thick)
Sieve Out ( beam raster, $^{208}Pb$/Diamond, 0.8 mm thick)




Identify calibration region by looking at sieve data with different targets

# Focal Plane

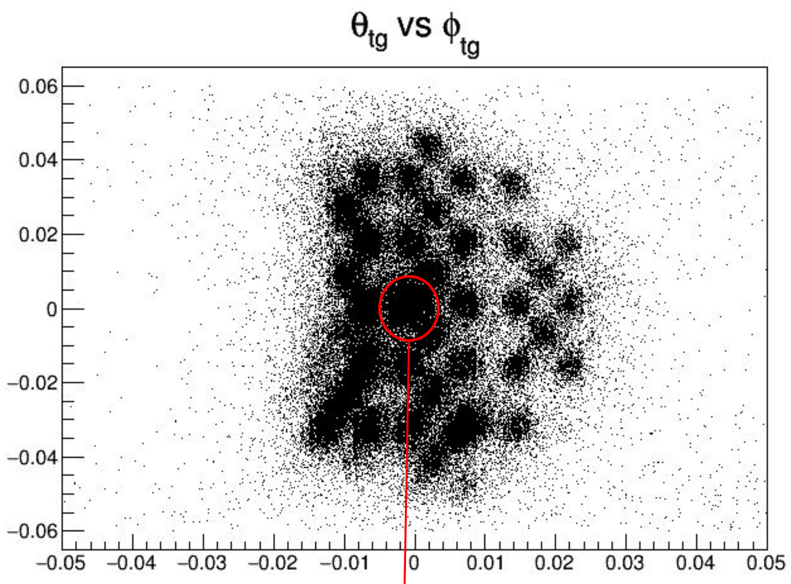



Pb target (sieve out, beam raster)
Super thin $^{12}C$ (sieve in, no beam raster)

**<u>Question</u>**
**Are there sieve holes near where the enhancement shows up?**

- Observe the offset between sieve in an sieve out data
- Is that due energy ionization losses, beam off center?
- Make a sieve cut around the center hole and try to isolate the same set of ray bundles (i.e, $\varphi_{tg}$, $\theta_{tg}$ )

# Data (Full Coverage)




Where the cut will be applied

<u>Central Hole Sieve Slit - Survey measurements</u>

Z = 798.02 mm, X = 69.91 mm , Y = -1.50mm

along central spectrometer line

- Distance between target and sieve = 0.8 m
- diameter = 4mm

$$x_{sieve} = 0.8*\theta_{tg}$$
$$y_{sieve} = 0.8*\varphi_{tg}$$

- Center hole cut - $\mathrm{sqrt}(\theta_{tg}^{2} + \varphi^{2}_{tg}) < 0.0025$
- Use this to explore ionization losses

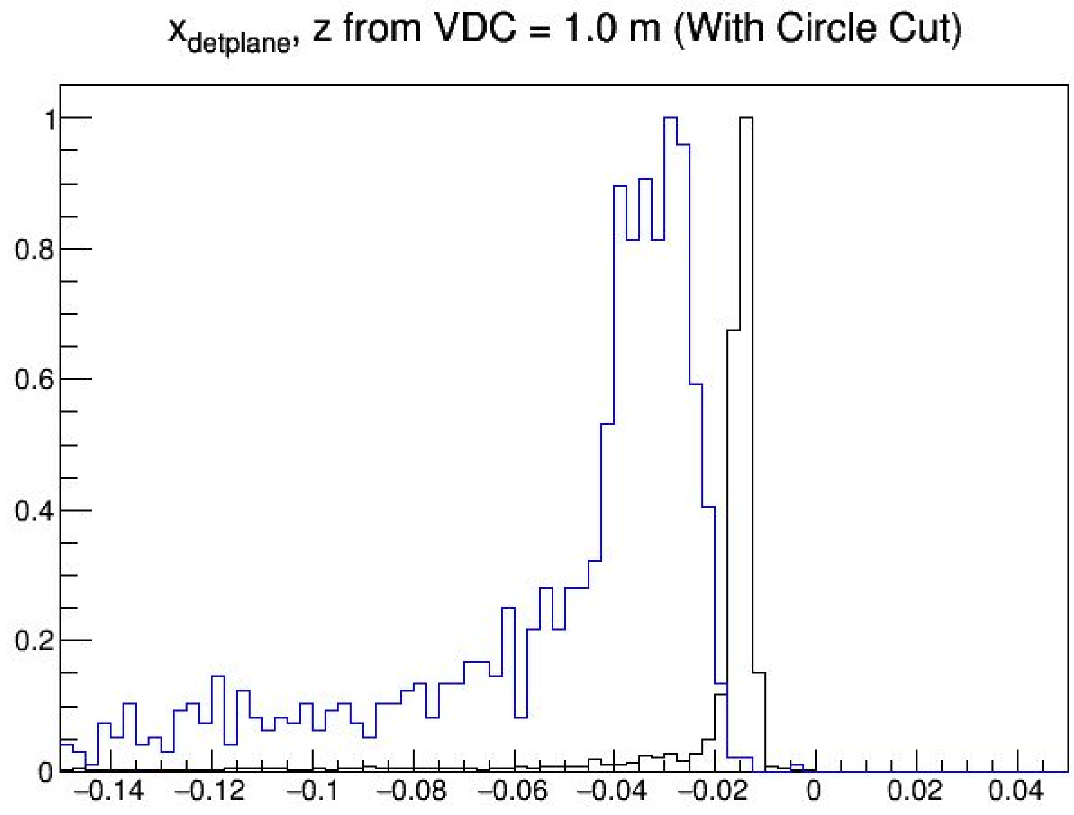
# Ionization Losses

| Target | dE/dx (MeV cm$^2$/g) | Thickness (g/cm$^2$) | Energy Ionization Loss (MeV) |
|---|---|---|---|
| Lead/Diamond | 1.122 | 0.902 | 1.374648 |
| Super Thin $^{12}C$ | 1.749 | 0.017 | 0.029733 |

- dE = (dE/dx) * thickness
- 1063 MeV beam
- dE/dx obtained from Particle Data Group

- Offset due to ionization losses ~ 15.5 mm using $(x|\delta) = 16.73$

# Exploring Ionization Losses



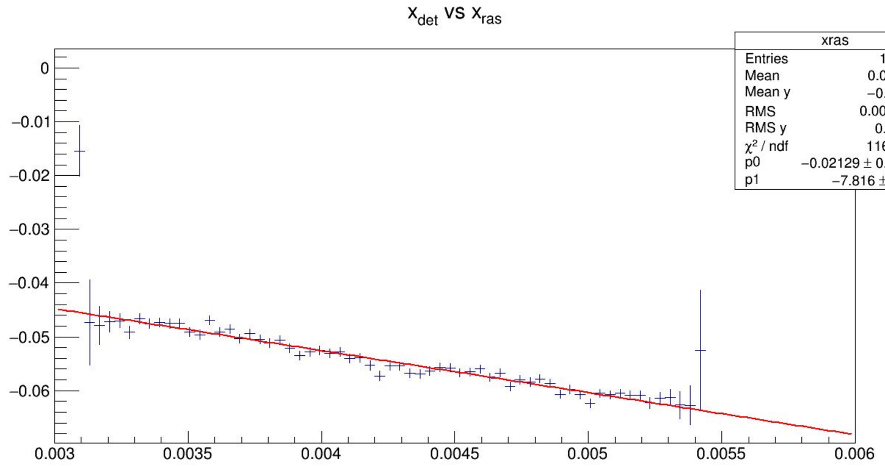

Pb target (sieve out, beam raster)
Super thin $^{12}C$ (sieve in, no beam raster)

- We need to compare these on the same level i.e., compare the data with same set of ray bundles
- Optics calibration data has no raster
- Lead data has beam raster which has to be accounted for
- Crucial to look at beam positions

# Beam Positions

| Run Number | Comment | BPMA.xpos (mm) | BPMA.ypos (mm) | BPMB.xpos (mm) | BPMB.ypos (mm) | Target.xpos (mm) | Target.ypos (mm) |
|---|---|---|---|---|---|---|---|
| 27412 (0.5 µA) | Spot Check (No Target) | -0.0367491 | 0.280214 | -0.0404017 | 0.974841 | -0.0415 | 1.224 |
| 27427 (0.05 µA) | Sieve Out Pb/D | 0 | 0 | 0 | 0 | 0 | 0 |
| 27428 (0.5 µA) | Spot Check (No Target) | -0.0248617 | 0.2189595 | -0.102949 | 1.20861 | -0.119 | 1.41263 |
| 27118 (0.5 µA) | Sieve In Thin Carbon | 0.0186223 | -0.0398863 | -0.0597374 | -0.0173224 | -0.07589 | -0.01267 |
| 27119 (0.5 µA) | Sieve In Thin Carbon | 0.1598886 | 0.0253923 | 0..0796082 | 0.0304588 | 0.06306 | 0.0315 |
| 27120 (0.5 µA) | Sieve In Thin Carbon | 0.0881368 | -0.0146237 | 0.0215824 | 0.0280935 | 0.007862 | 0.0369 |

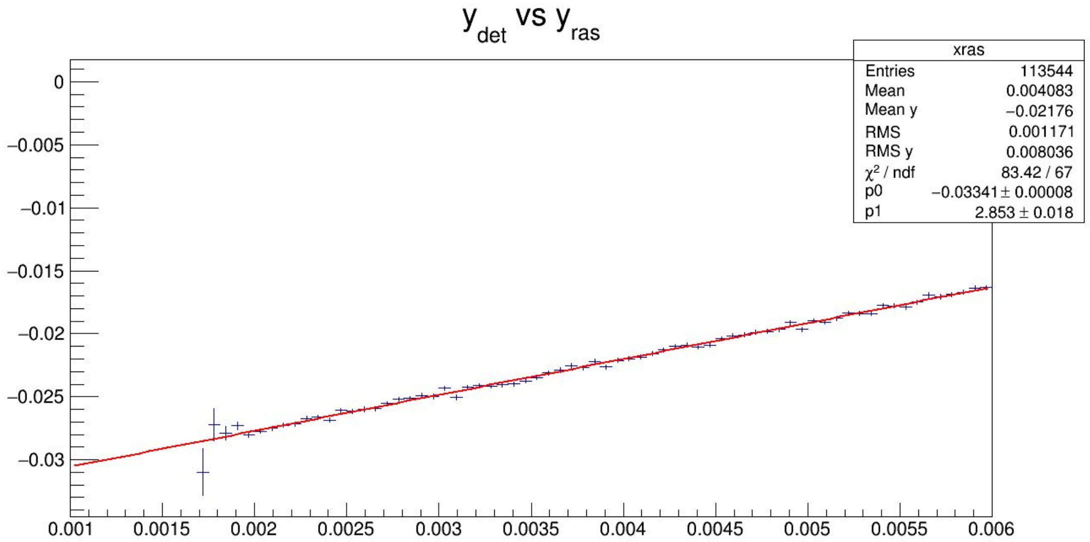
# Beam Positions




Y plot

(y|y) = 2.853 after bpm correction

(y|y) = 2.11 from optics

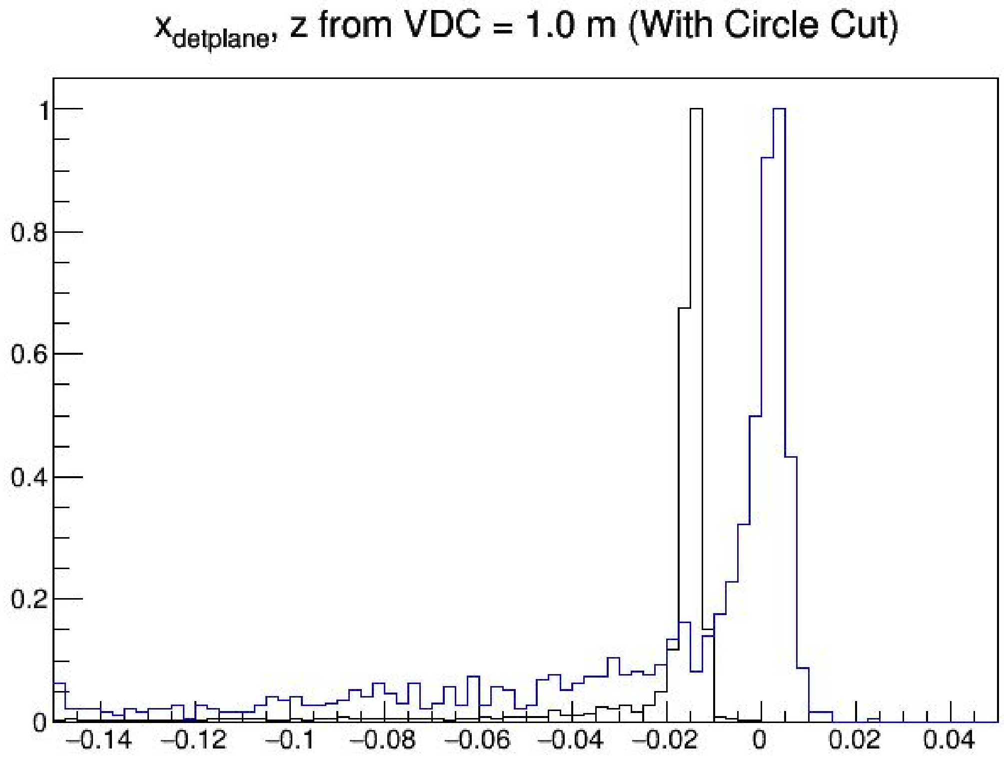



X plot

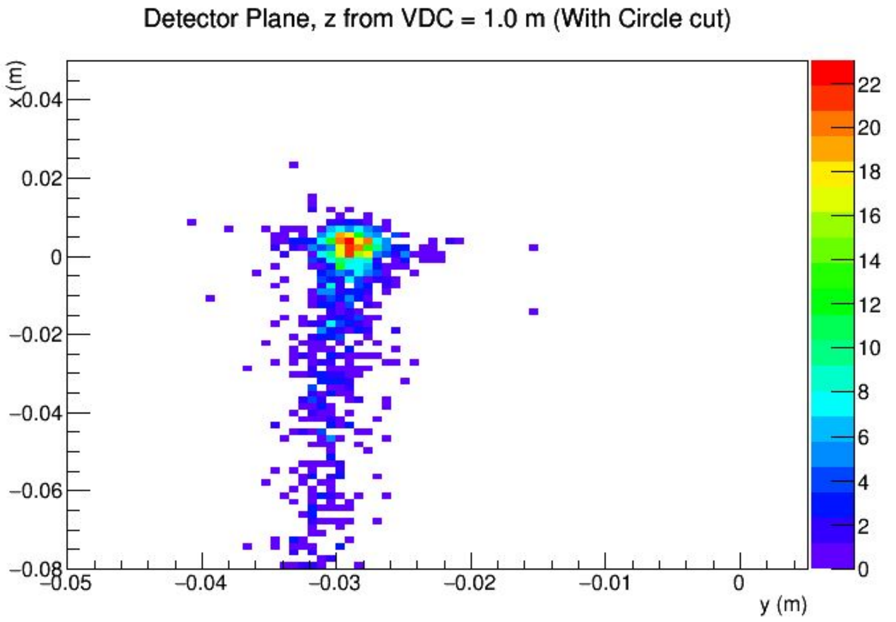
(x|x) = -7.816 after bpm correction

(x|x) = -3.09 from optics

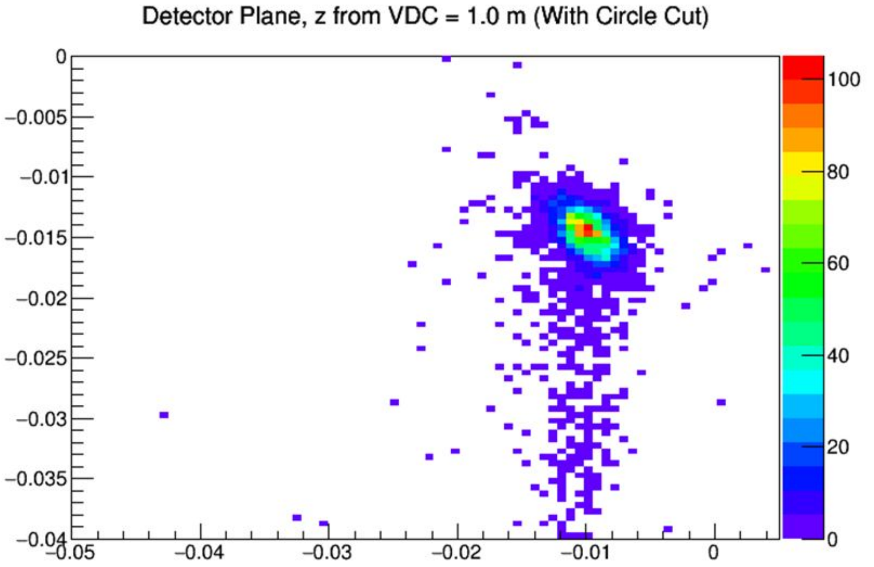
# Plots




Pb target (sieve out)
Super thin $^{12}C$ (sieve in)



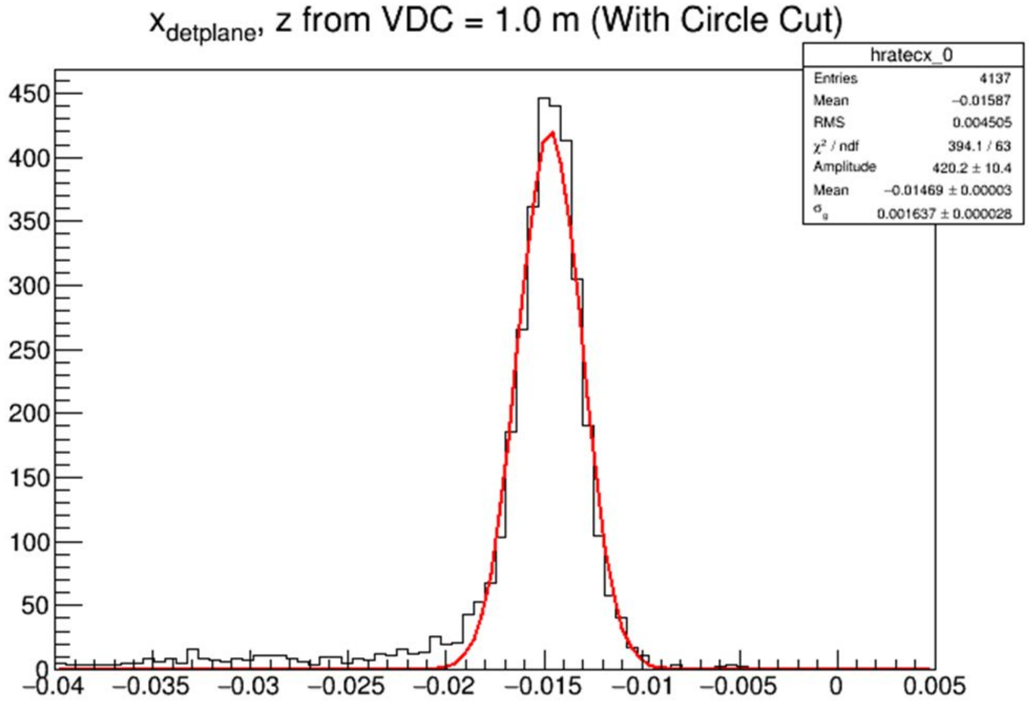

Pb/Diamond




Super Thin $^{12}C$

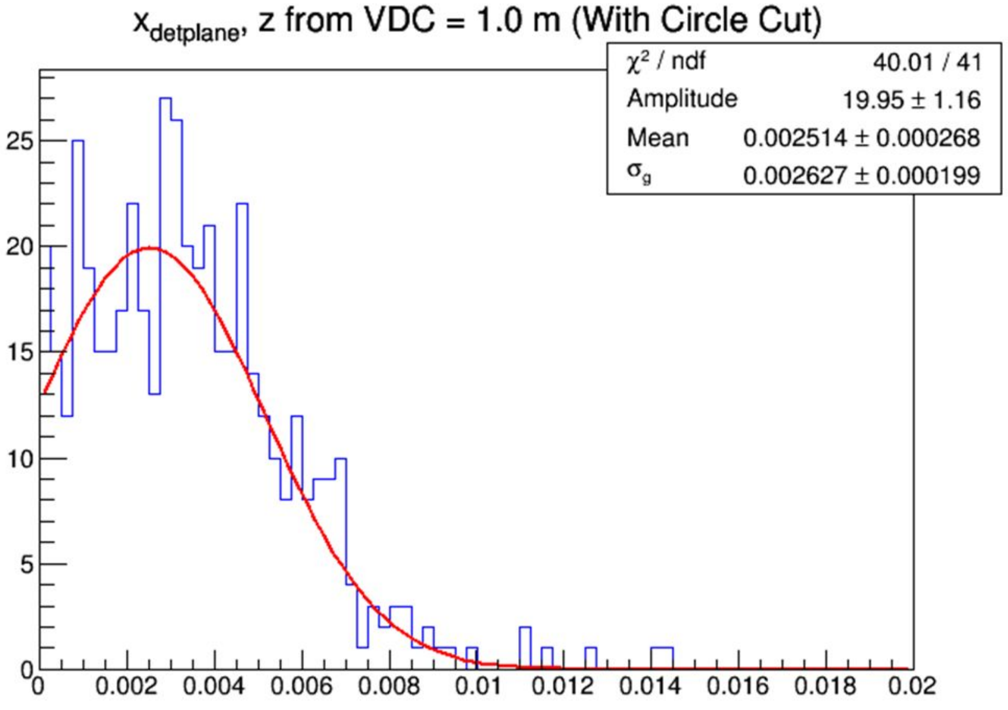
# Fits

Carbon




Peak = -14.69 mm

Lead




Peak = 2.51 mm

# Ionization Losses

| Target | dE/dx (MeV $cm^2/g$) | Thickness ($g/cm^2$) | Energy Ionization Loss (MeV) | Peak Position Fit (mm) | Predicted Peak Position (mm) |
|---|---|---|---|---|---|
| Lead | 1.122 | 0.902 | 1.374648 | 2.51 | -18.7 |
| Super Thin $^{12}C$ | 1.749 | 0.017 | 0.029733 | -14.69 | -5.55 |

- Offset due to ionization losses ~ 15.5 mm using $(x|\delta) = 16.73$
- Difference in those positions ~ 13.2 mm
- $(x|x)$ coupling from optics and data don't agree (-7.905 from data vs -3.09 from optics)

# Summary