GBP MC Analysis

Hits Profiles and Estimation of Reconstruction Precision

K Fleck, N Cavanagh, G Sarri - 01/12/21

Hits Profile

- Following the standalone MC analysis, a hit is defined as

  An energy deposition event in which Edep > 1 keV

- Hits are a 'counting process' - follows Poisson statistics so error in each bin is given by $\sigma = \sqrt{N_{hits}}$
- From GEANT4 data (/nfs/dust/luxe/group/MCProduction/Signal/g4/ptarmigan-v0.8.1/e-laser/phase0/lp/), Hits tree was used to determine hits profile by placing appropriate cuts
- Energies are in GeV and distances in mm
- Bin sizes are assumed to be $100\,\mu m$ (200 x 200 cells)

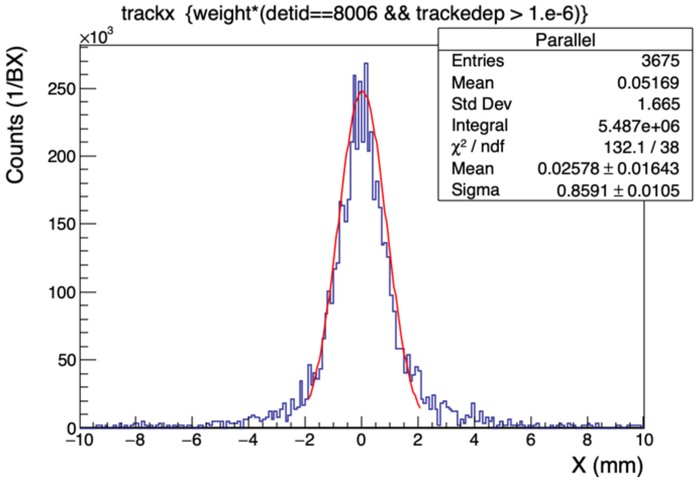
Gaussian Fit

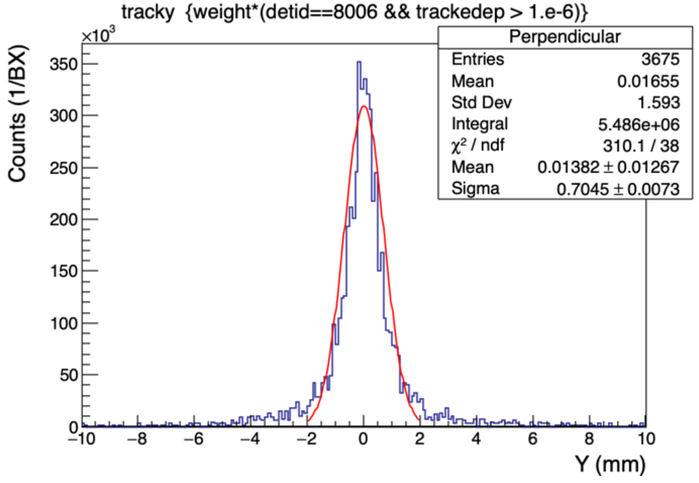
- Gaussian fit applied to central range of distribution - taken to be ± 2.0 mm
- ROOT fit settings:
    - "WL" - weighted log-likelihood; recommended in ROOT documentation for histograms representing counts
    - "R" - fit to sub-range
    - "I" - use integral of bin content rather than value at centre
- Bin errors are more complicated - GEANT4 data uses macroparticles and so is weighted. Use sumw1() or sumw2()?
- Sumw1() determines the error in each bin to be $\sigma = \sqrt{\sum w_i}$ i.e. Sqrt of sum of bin weights
- Sumw2() determines the error in quadrature: $\sigma = \sqrt{\sum w_i^2}$
- Sumw2() is recommended when performing arithmetic (scaling, adding, subtracting, etc.) histograms to propagate errors correctly
- For our purposes, sumw1() is more appropriate

Fit Results

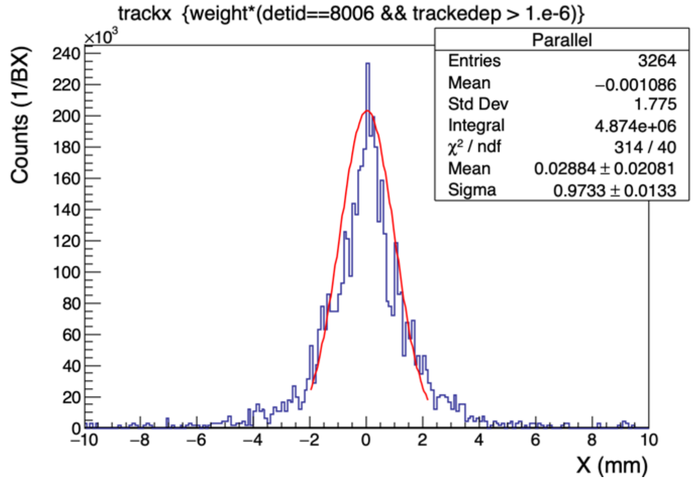
Upstream Profiler - Gaussian

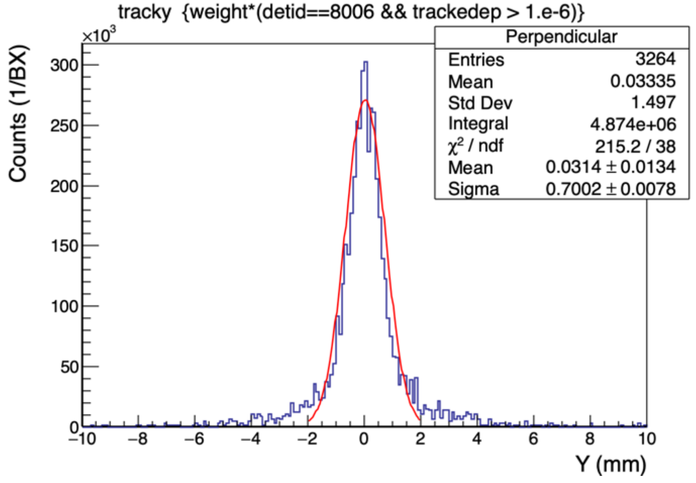
$\xi = 5$



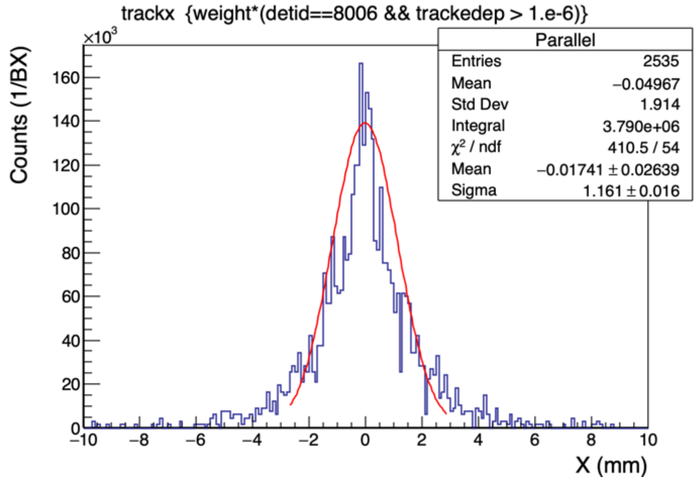


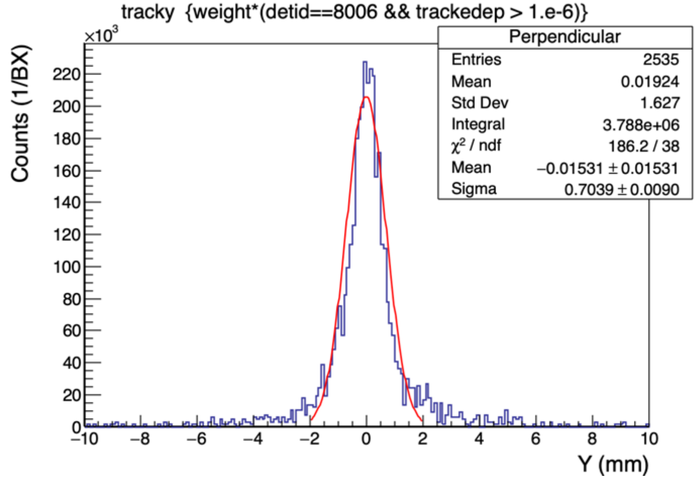
$\xi = 7$





$\xi = 10$

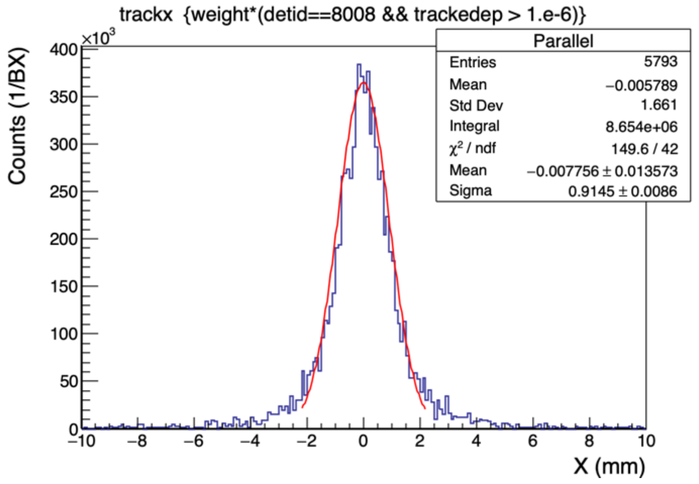


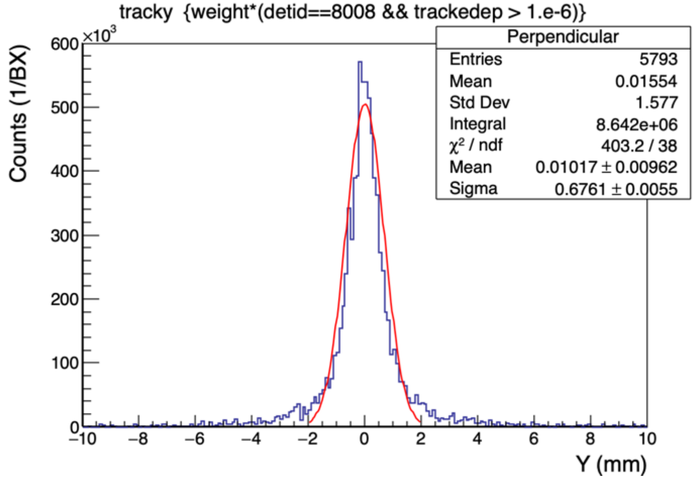


Fit Results

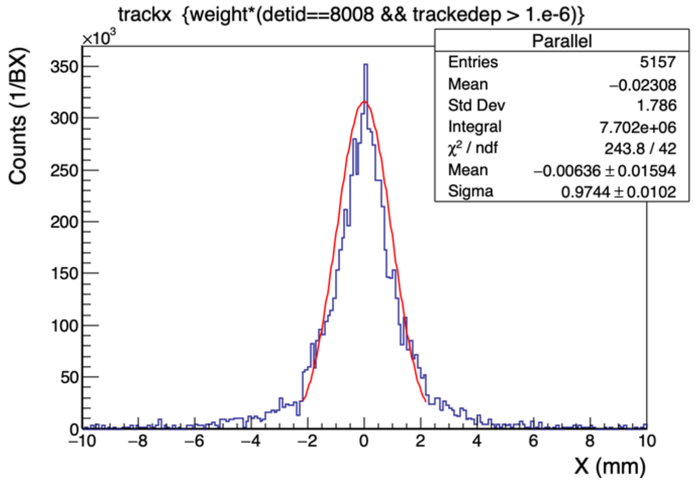
Downstream Profiler - Gaussian

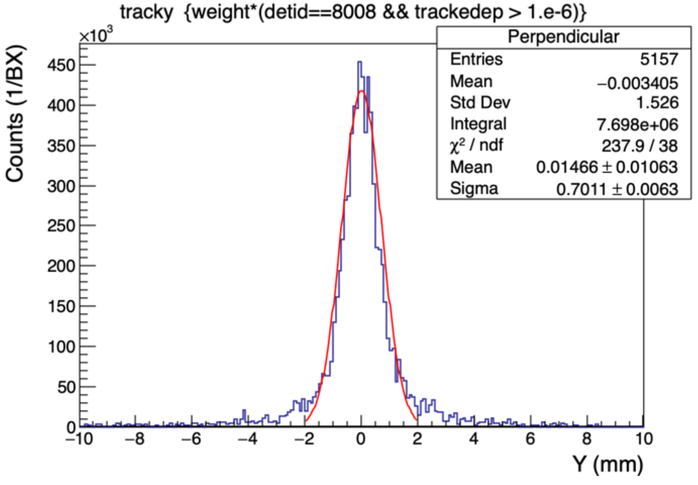
$\xi = 5$



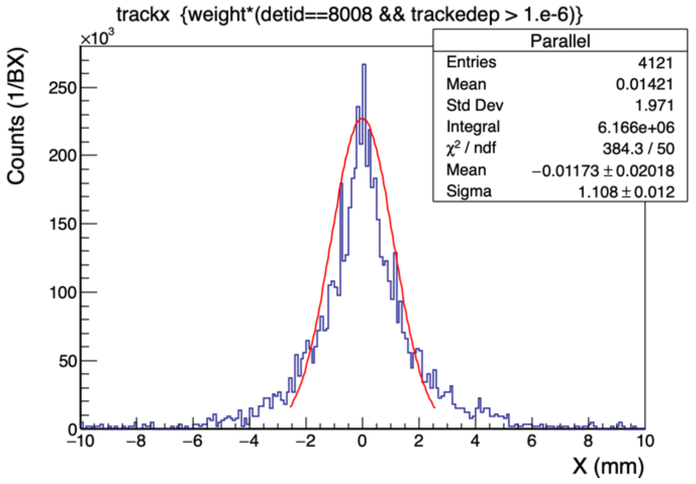


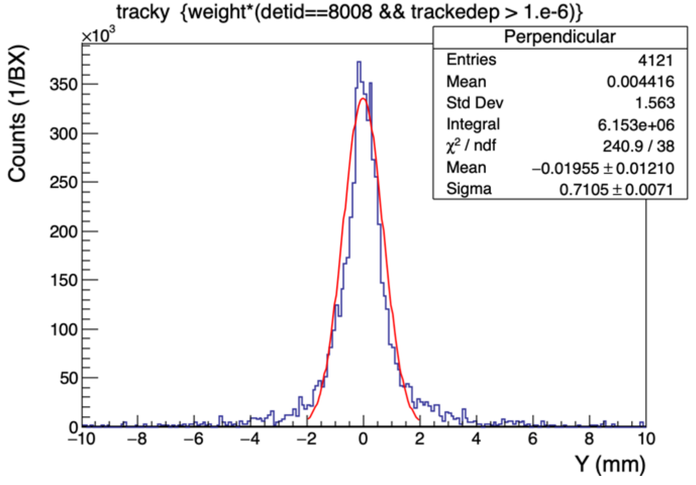
$\xi = 7$





$\xi = 10$





Fit Results

Estimation of Resolution

- An estimate of the resolution can be obtained from the average error in the fitted Gaussian standard deviation (σ)
- Unweighted arithmetic mean:
    - Parallel - $25.0\,\mu m$, $18.6\,\mu m$
    - Perpendicular - $11.6\,\mu m$, $9.1\,\mu m$
- Weighted (by integral) arithmetic mean:
    - Parallel - $23.2\,\mu m$, $18.0\,\mu m$
    - Perpendicular - $11.5\,\mu m$, $12.3\,\mu m$

Estimation of xi

- From Blackburn 2020 (10.1103/PhysRevAccelBeams.23.064001), model-independent formula for estimating xi is

$$\bar{\xi}^2 = \frac{1}{\beta^2} 4\sqrt{2}\langle\gamma_i\rangle\langle\gamma_f\rangle(\sigma_{\parallel}^2 - \sigma_{\perp}^2)$$

- Here, σ^2 is the variance of the **energy-weighted** distribution - this should be Gaussian
- GBP measures **number-weighted** distribution
- Current Ptarmigan simulations use LCFA which overestimates low energy (high angle) photons giving profile heavier tails
- Moving to LMA later (more accurate than LCFA) may reduce this effect
- Energy-weighted distribution rather than number-weighted also takes this into account and gives a more reasonable Gaussian shape

Voigt Profile

- Voigt profile is the convolution of a Gaussian and a Lorentzian function

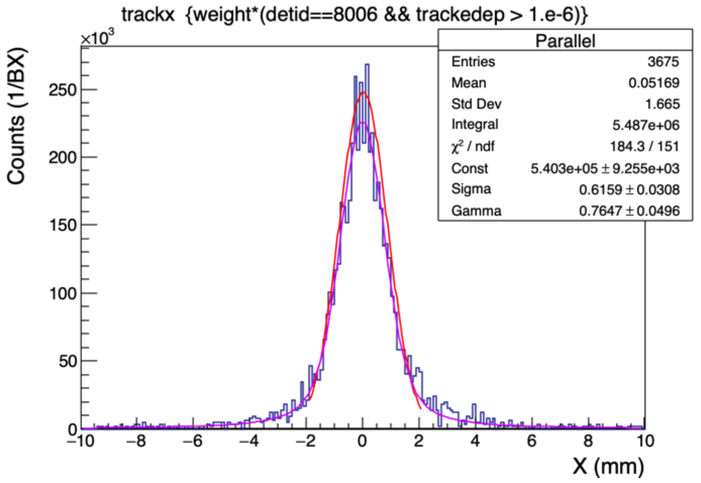
$$V(x;\sigma,\gamma) = \int dt\, G(t;\sigma) \cdot L(x-t;\gamma)$$

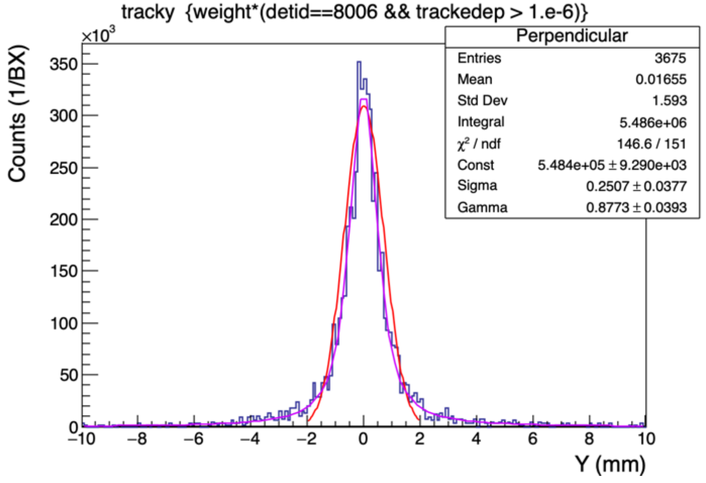
- Definition assumes distributions centred at zero
- ROOT provides an in-built function to evaluate and fit Voigt profiles to histograms
- May provide a way of separating the Gaussian and Lorentzian 'signatures' seen in the profiler results

Fit Results

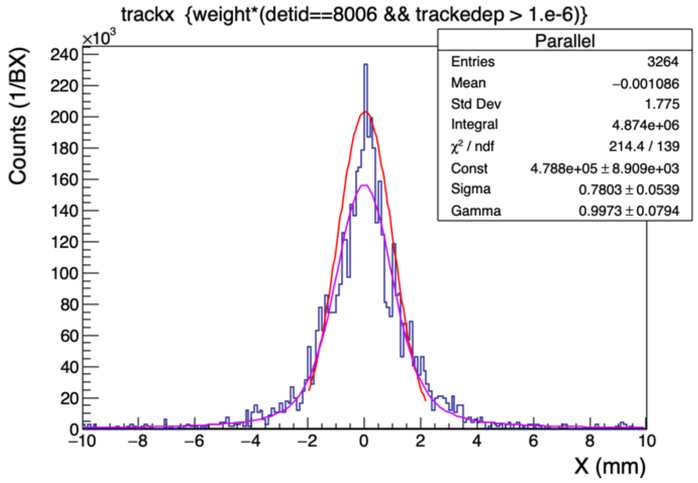
Upstream Profiler - Voigt

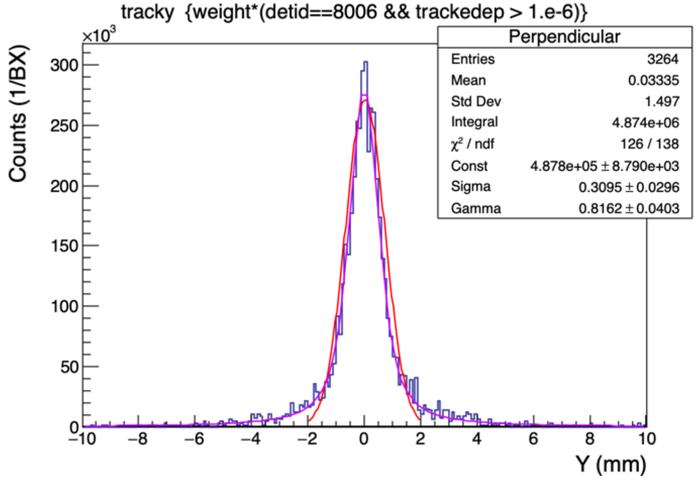
$\xi = 5$



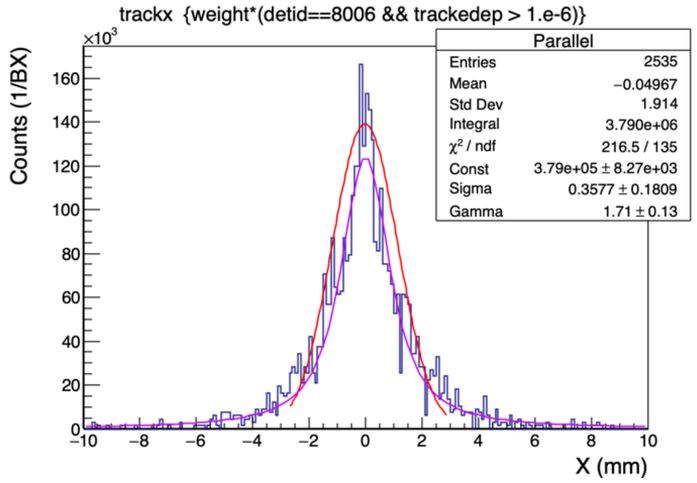


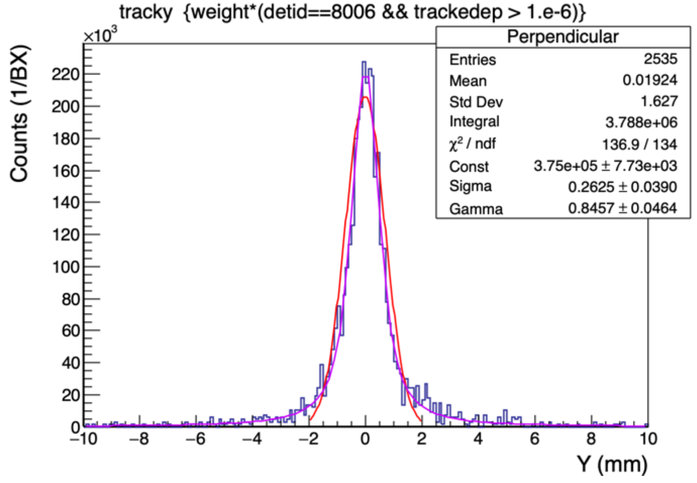
$\xi = 7$





$\xi = 10$

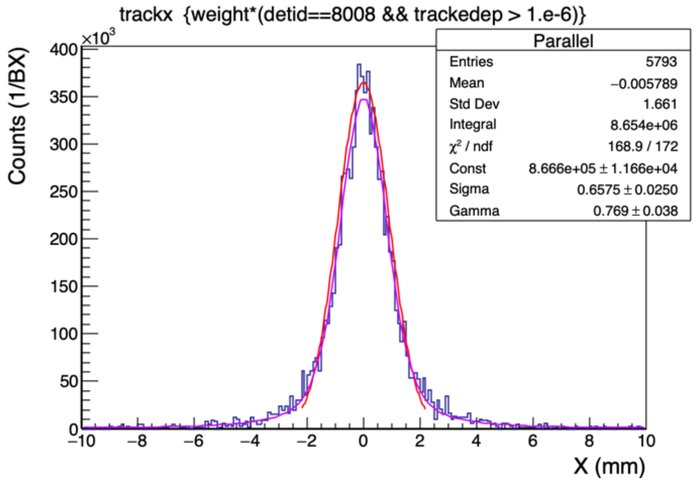


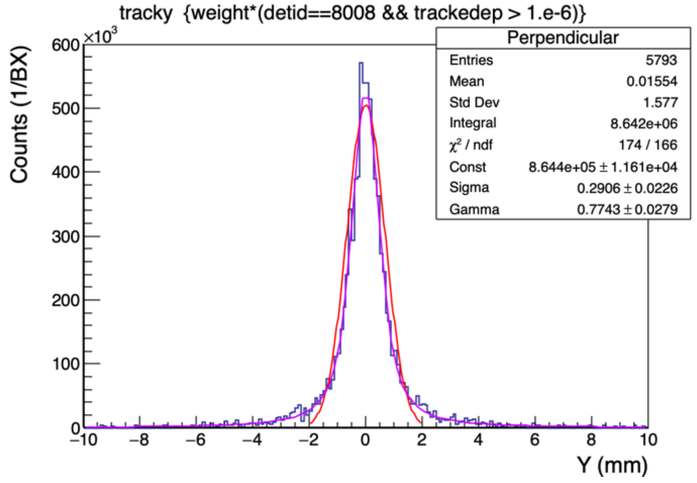


Fit Results

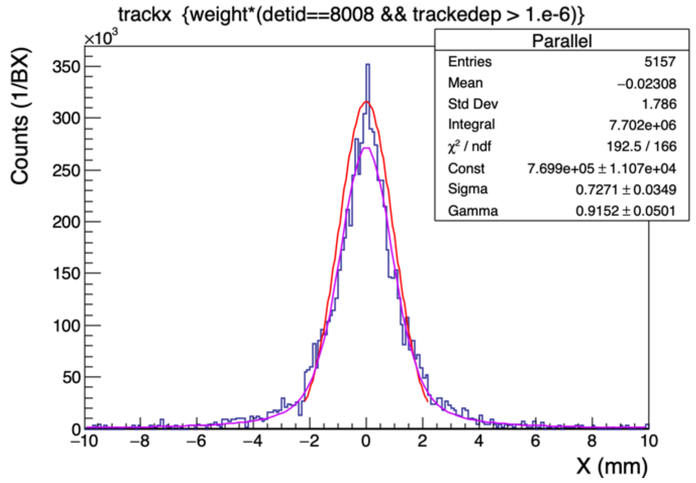
Downstream Profiler - Voigt

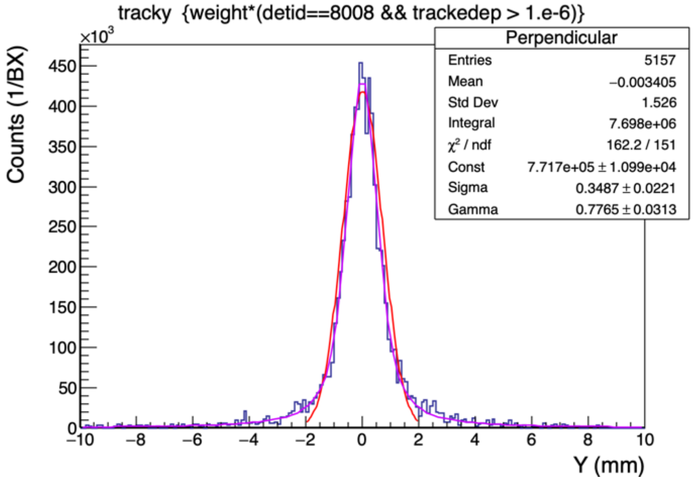
$\xi = 5$



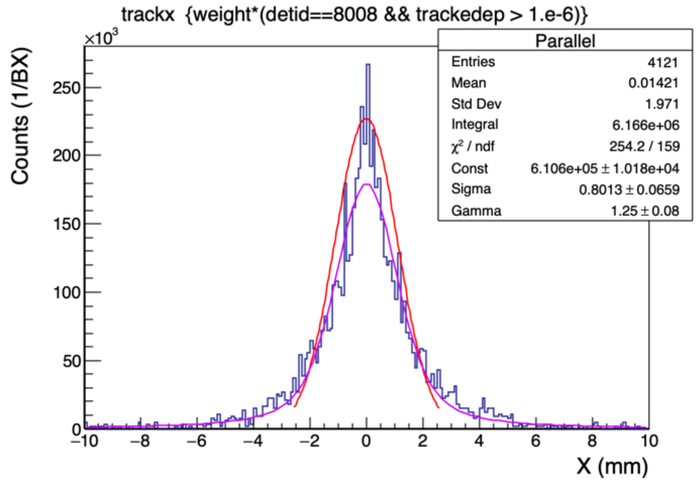


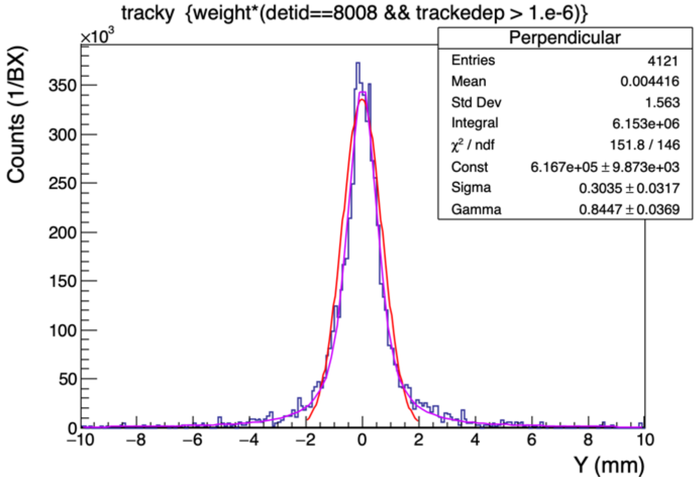
$\xi = 7$





$\xi = 10$





Dose Estimation

- Dose is defined as

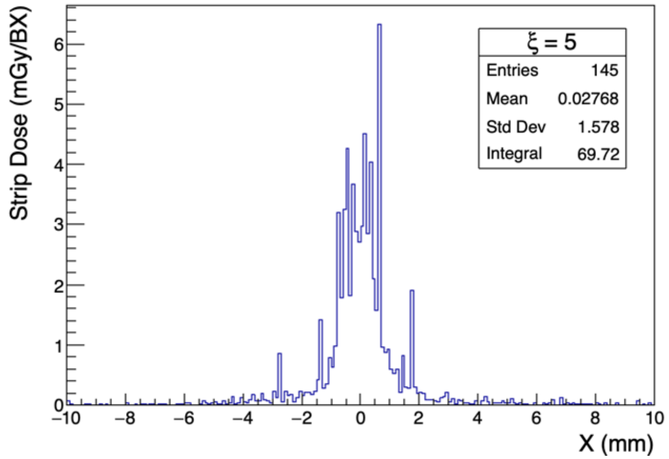
$$D[\mathrm{Gy}] = \frac{\text{Energy Deposited}}{\text{Mass of Absorber}} = 1.60 \times 10^{-7} \cdot \frac{E_{dep}[\mathrm{GeV}]}{\rho[\mathrm{g/cm^3}]V[\mathrm{cm^3}]}$$

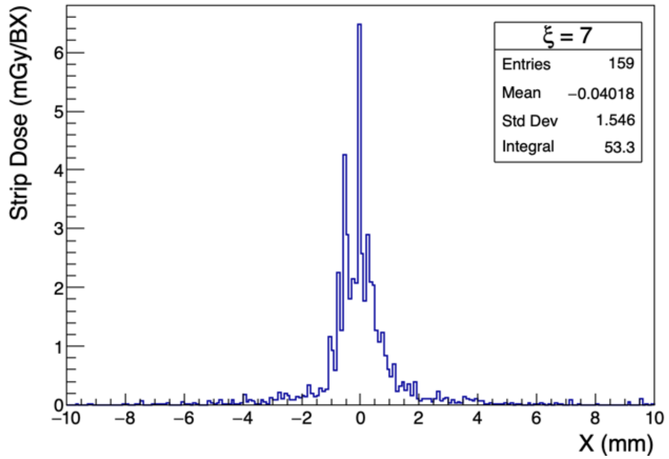
- Following Pietro's analysis, two dose quantities of interest:
  - Total (average) dose (dose absorbed by the entire profiler volume)
  - Strip dose (dose absorbed by each strip)
- For total dose, define active area to be a circle which contains $p = 95\ \%$ of hits:

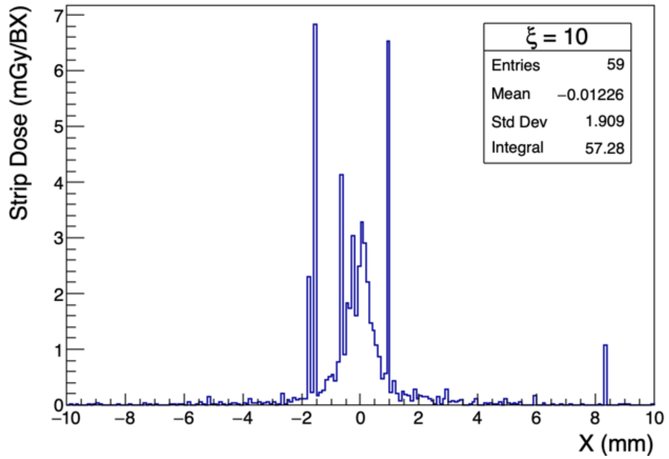
$$r_{X,Y} = \sigma_{X,Y}\sqrt{-2\ln(1-p)}$$

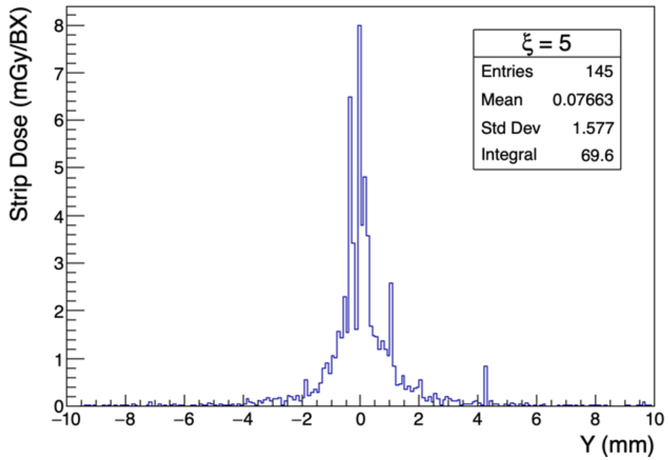
Dose Estimation

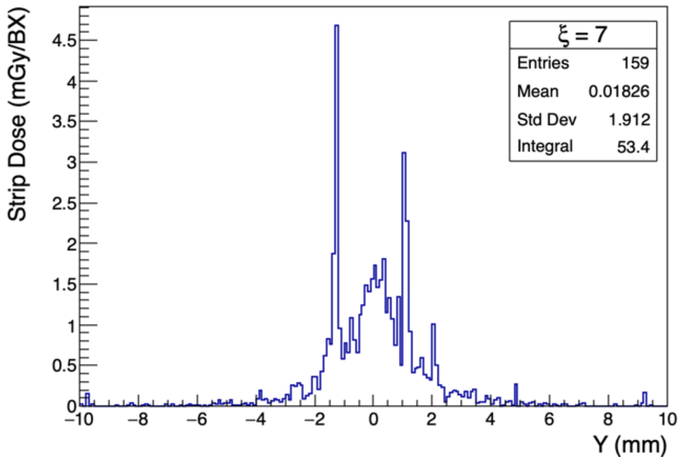
Strip Dose - Upstream

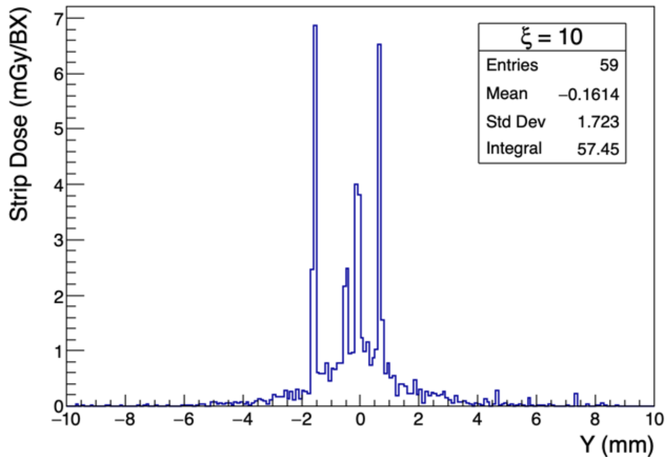






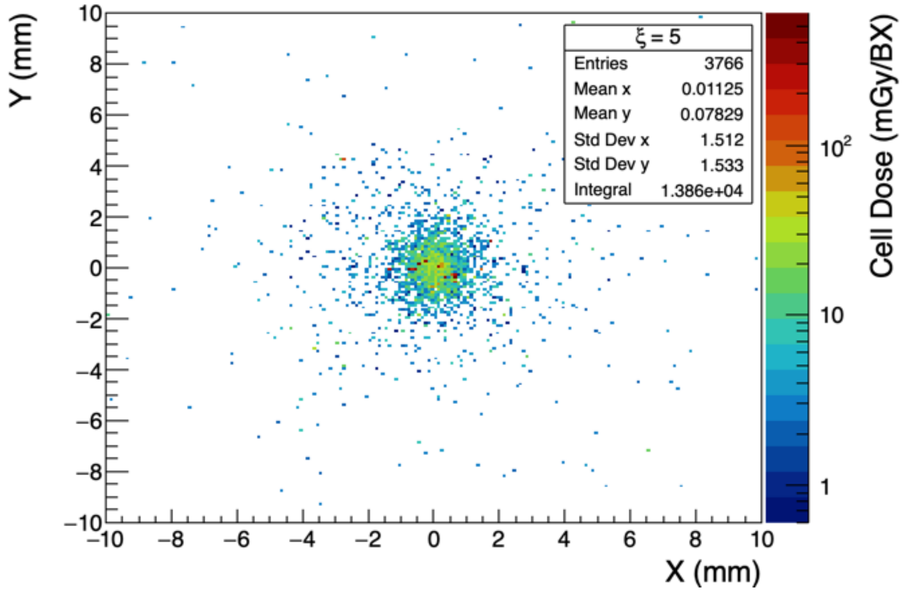


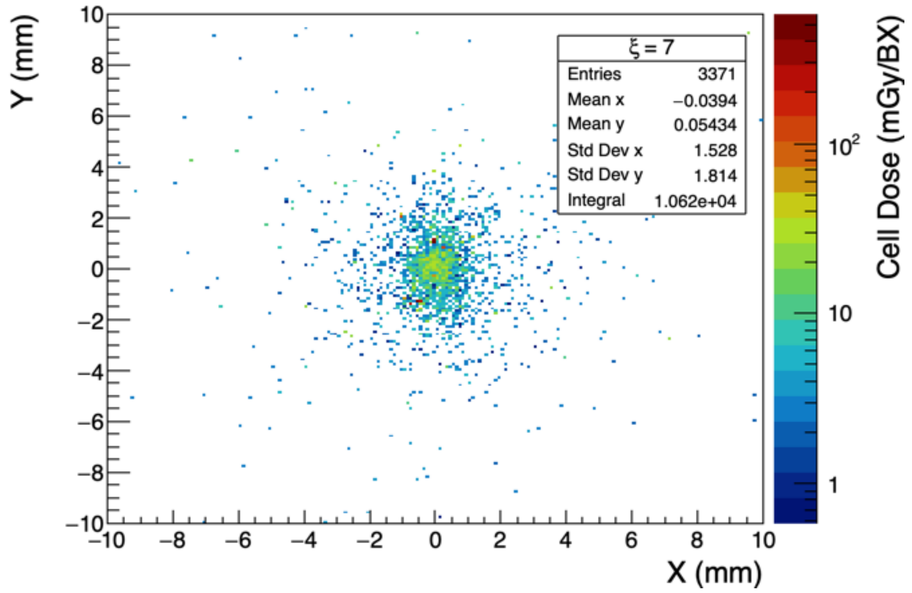


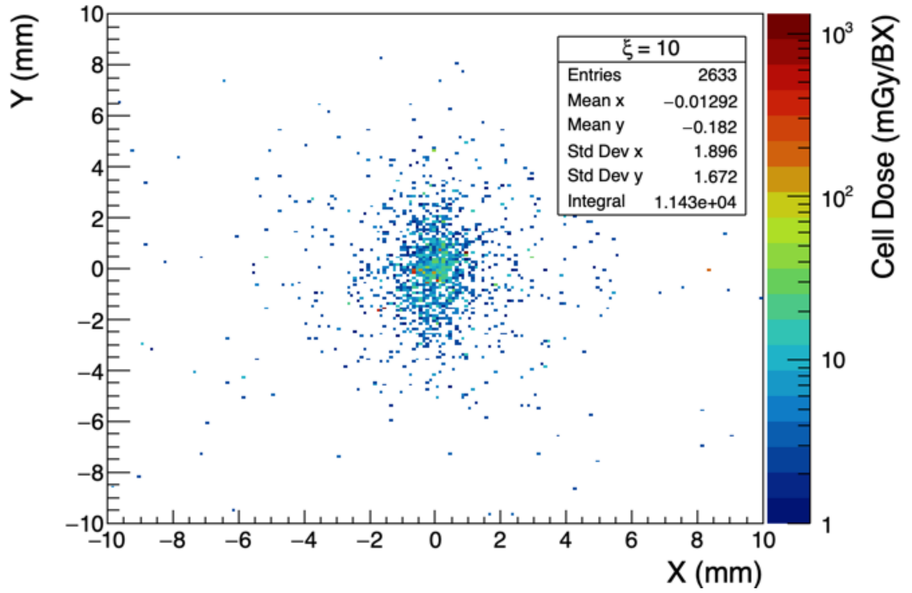


Dose Estimation

Cell Dose - Upstream

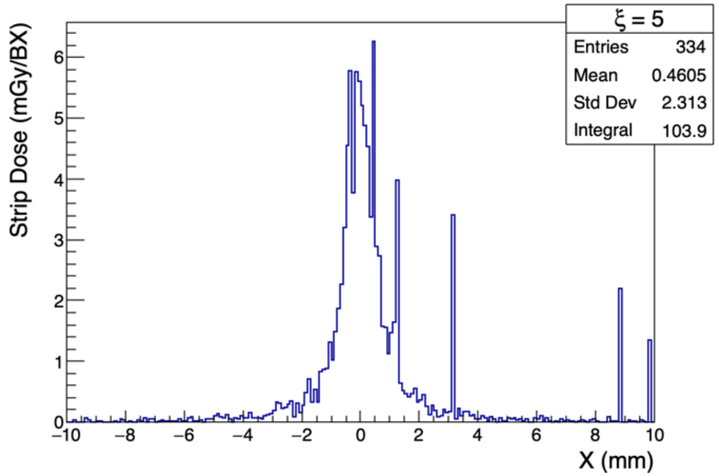


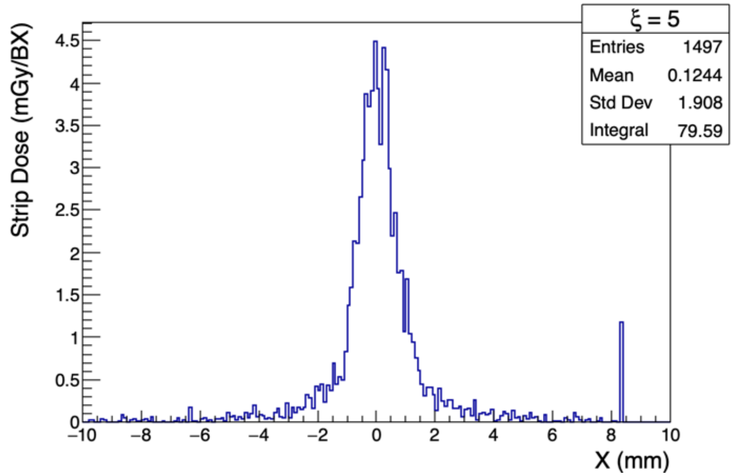


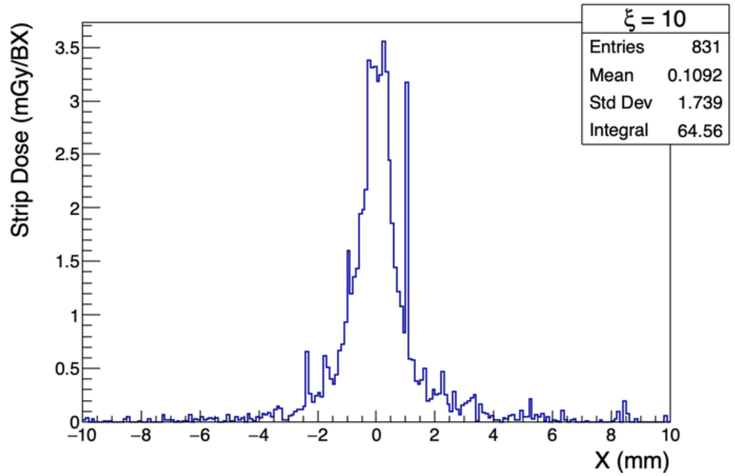


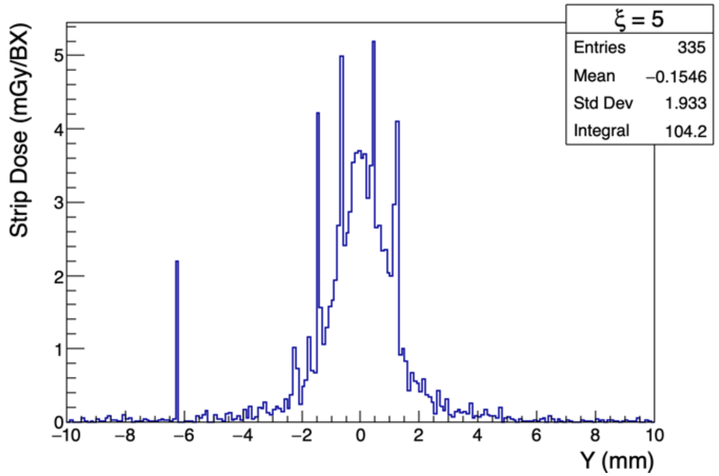
Dose Estimation

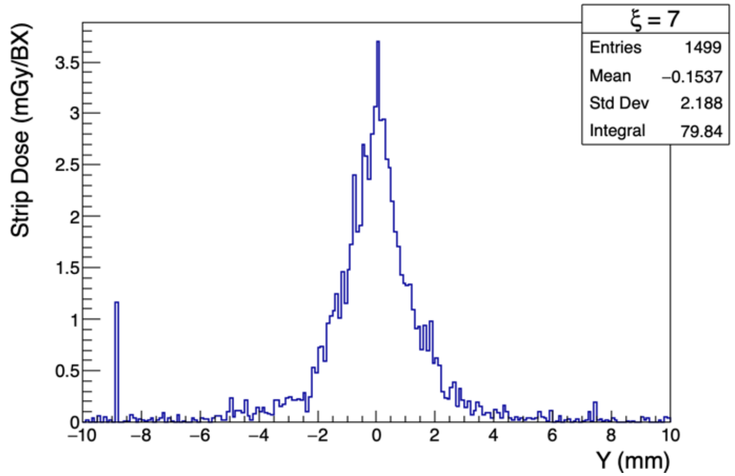
Strip Dose - Downstream

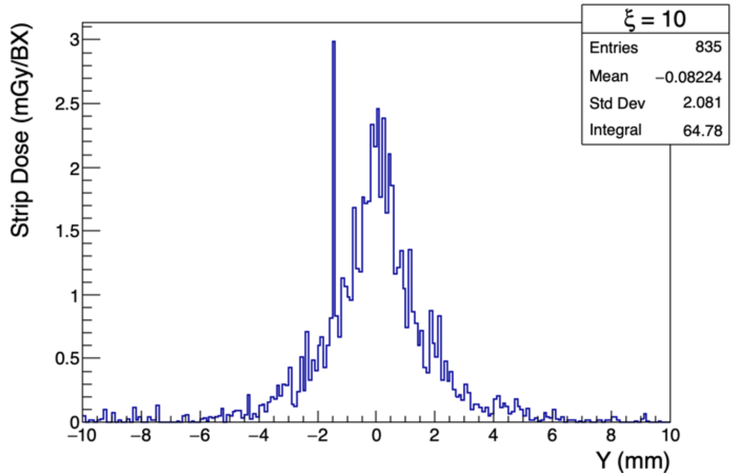






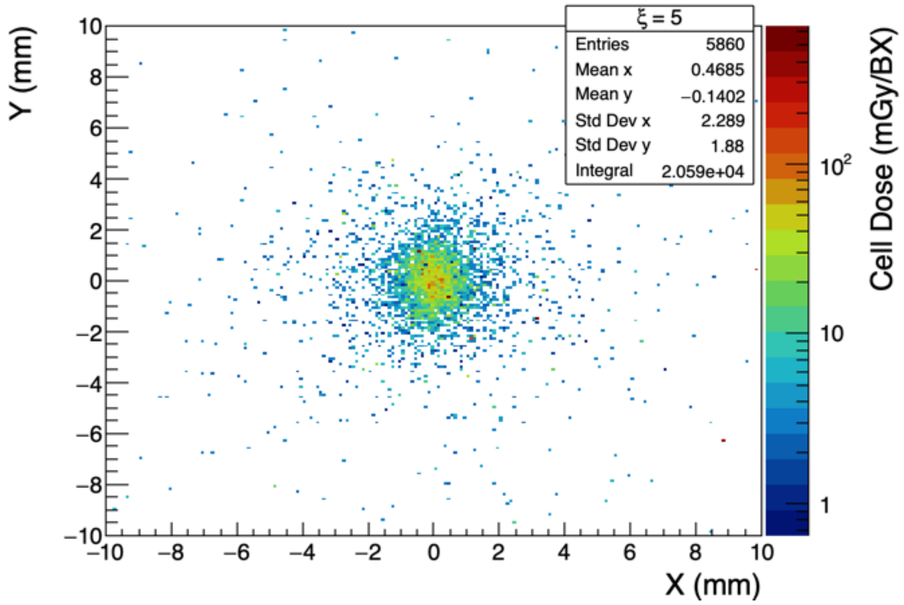


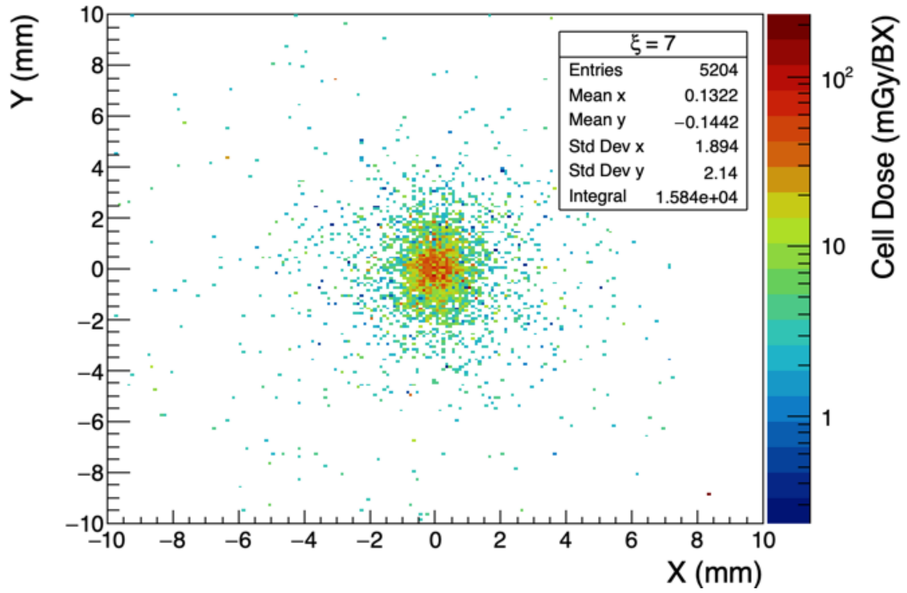


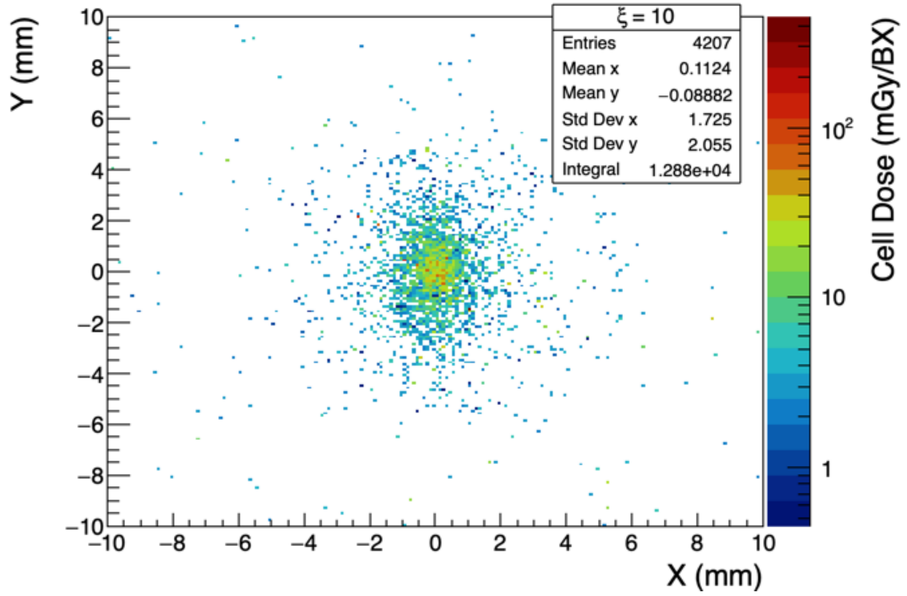


Dose Estimation

Cell Dose - Downstream







Dose Estimation

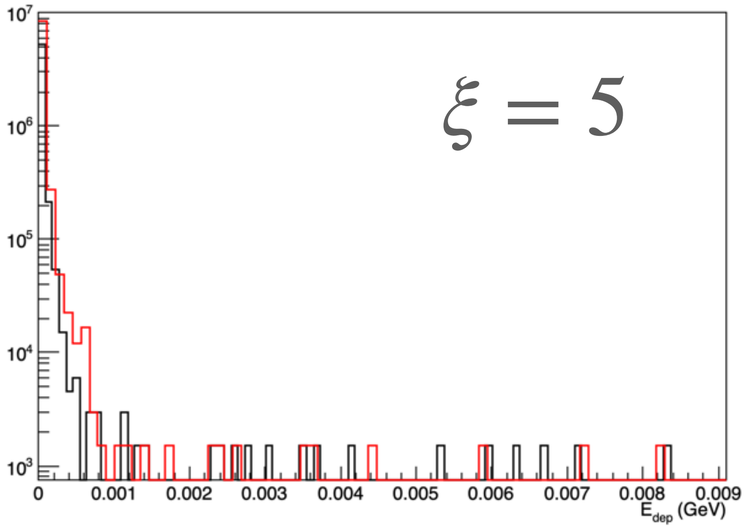
Comparison

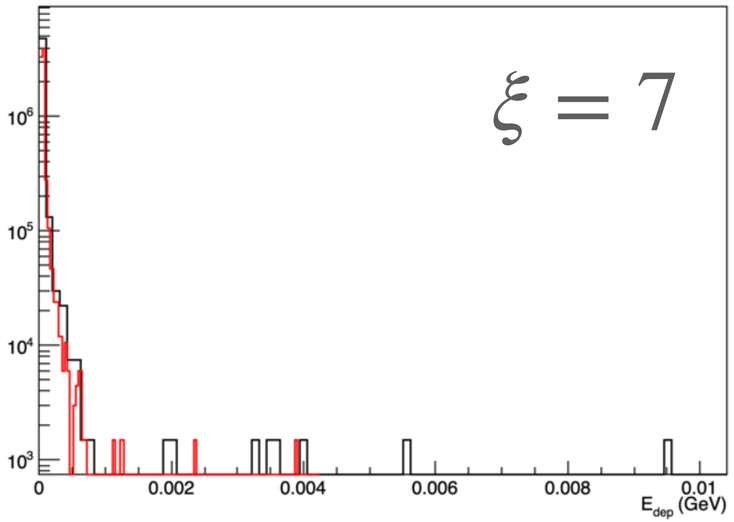
Xi	Radius (mm) X	Y	Total Energy Deposition (GeV)	Total Dose (mGy)	Peak Energy Deposited (GeV)		Peak Dose (mGy)	
5	2.10	1.72	287.3	0.10	30.7	39.3	6.2	7.9
7	2.38	1.71	204.15	0.06	30.5	23.3	6.1	4.7
10	2.84	1.72	228.26	0.06	33.5	34.0	6.7	6.8
5	2.24	1.65	377.91	0.13	29.2	24.3	5.9	4.9
7	2.39	1.72	295.72	0.09	19.9	17.5	4.0	3.5
10	2.71	1.74	231.03	0.06	14.6	14.8	2.9	3.0

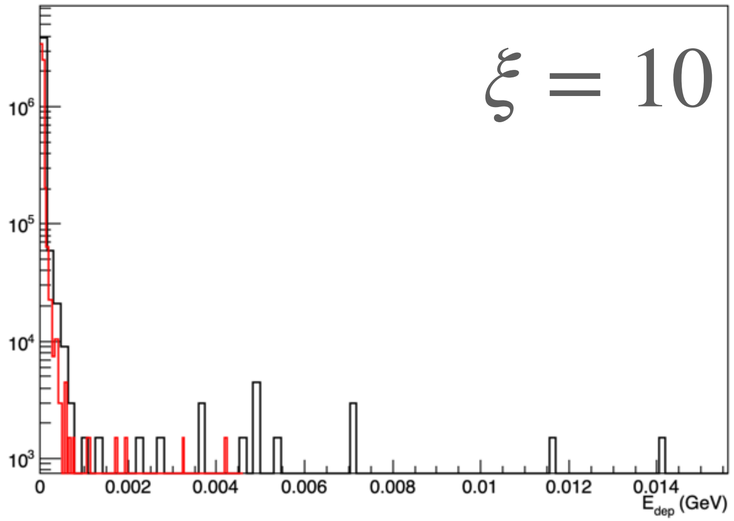
Backup

Dose Estimation

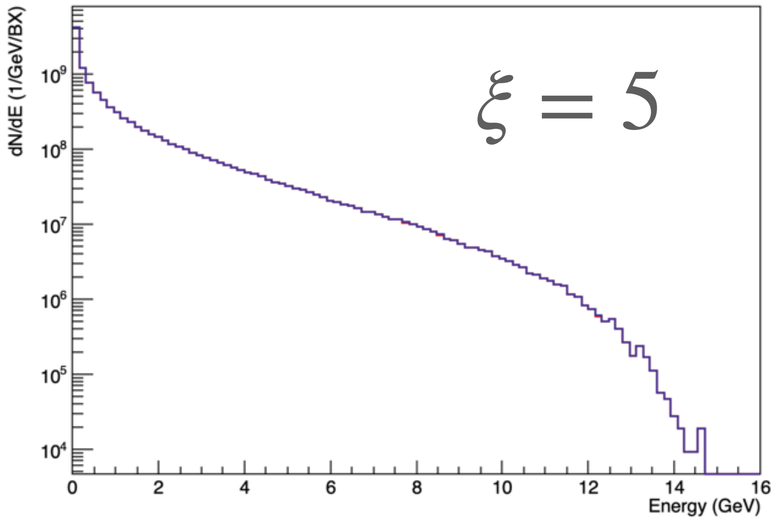
Distribution of Energy Deposition

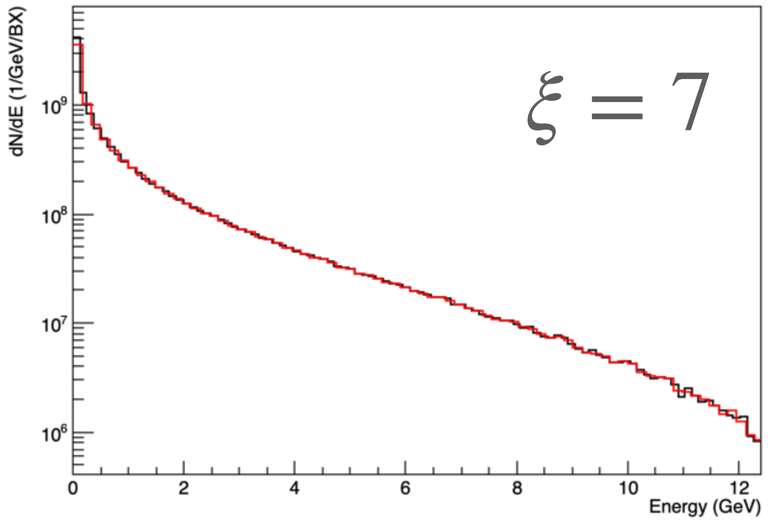


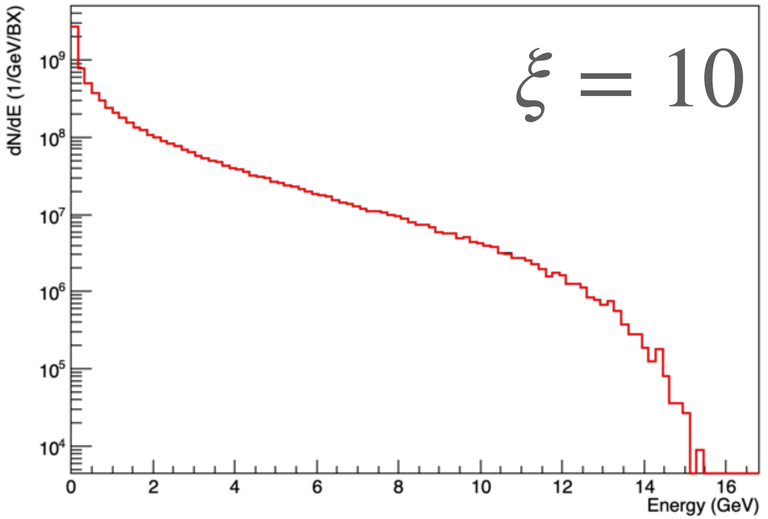




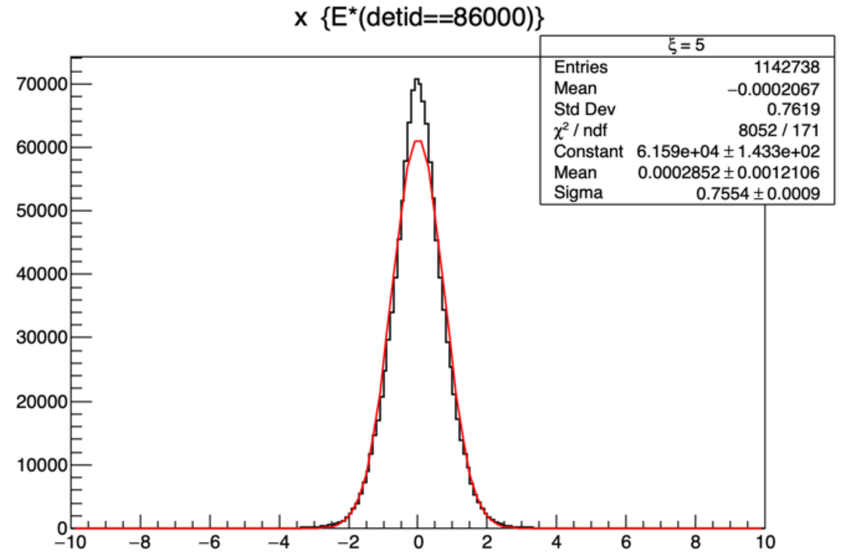
Photon Spectra

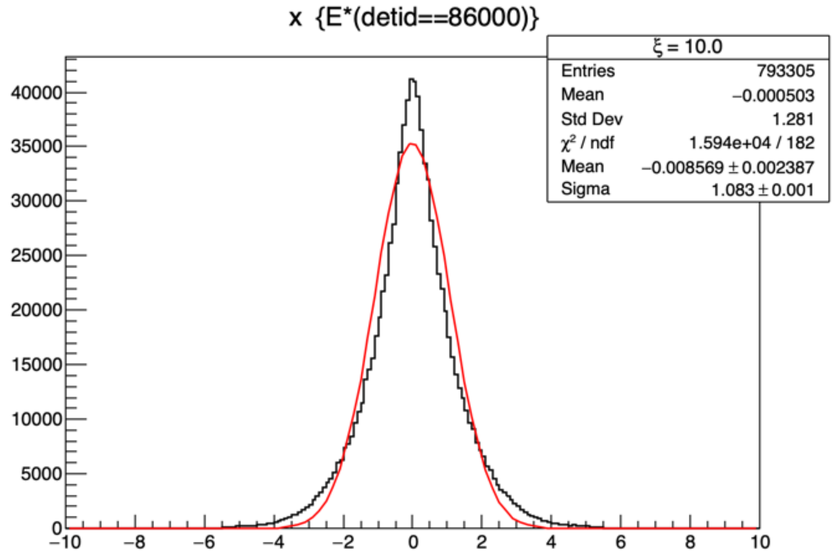


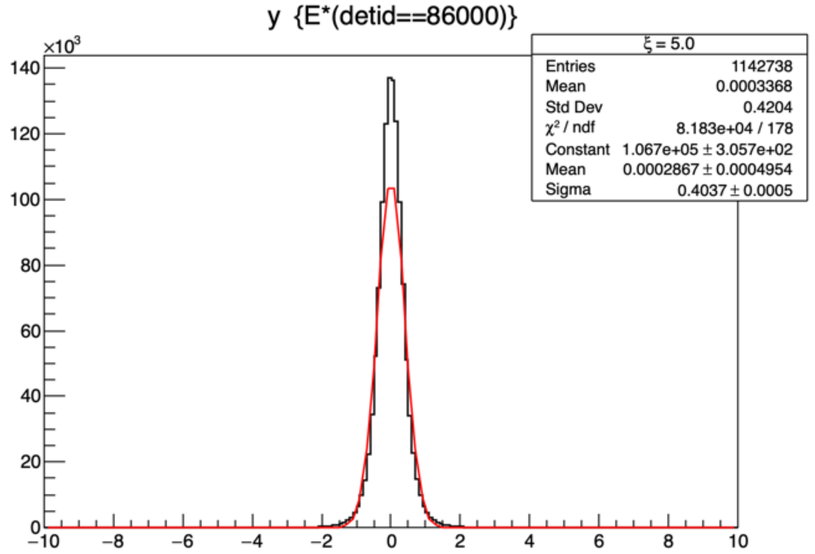


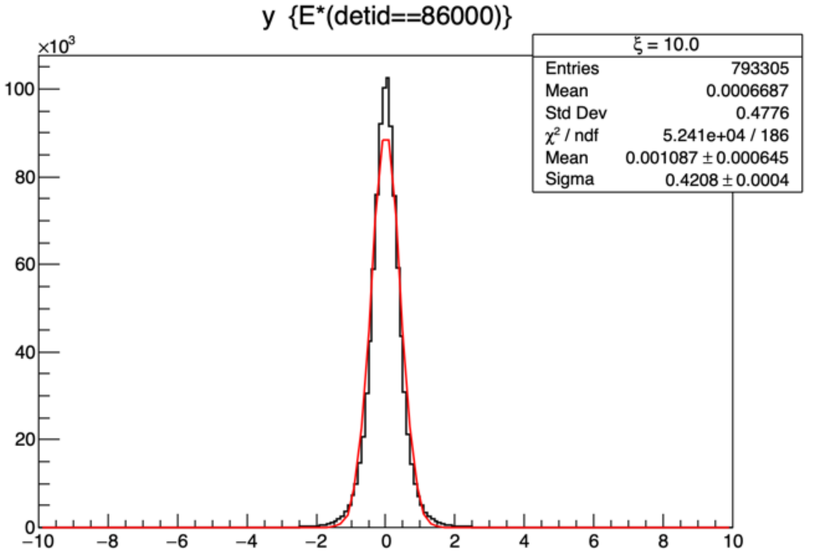


Energy-weighted profiles









Xi reconstruction

Geometrical factor

- The model-independent formula for xi contains the geometrical factor

$$\beta = \sqrt{\frac{P}{Q}} \exp\left(-\frac{\delta^2}{PQ}\right)$$

- $P = 1 + 4\rho^2 \qquad Q = 1 + 8\rho^2 \qquad \rho = \frac{r_b}{w_0} \qquad \delta = \frac{x_b}{w_0}$

- Impact parameter is zero for MC simulations