Application of Hough Transformation in ECAL Reconstruction

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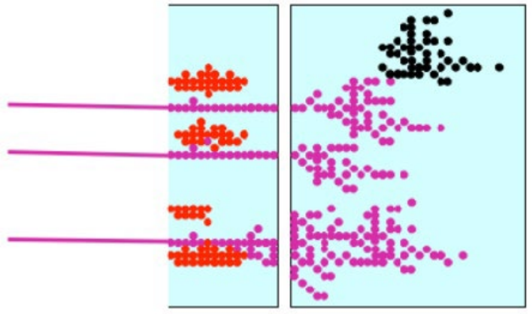
Outline

- Introduction
- Application of Hough transformation in ECAL reconstruction
- Preliminary result of performance
- Summary

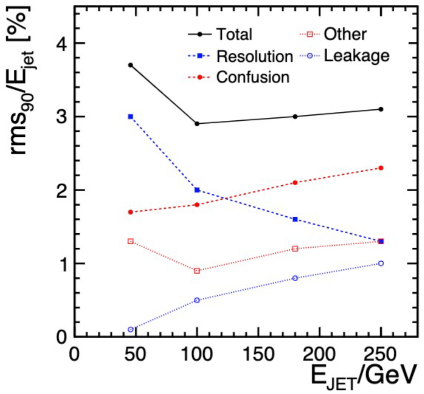
Introduction

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

- CEPC: A high precision Higgs/Z factory
  - Requiring jet energy resolution 3%~4% at 100GeV.
  - Fine γ/π^0 separation for flavor physics.
- Particle Flow Approach (PFA): reconstruct every single particle in an event.
  - Avoid double counting of energy from same particle
  - Separate energy deposits from different particles



$E_{JET} = E_{TRACK} + E_{\gamma} + E_n$



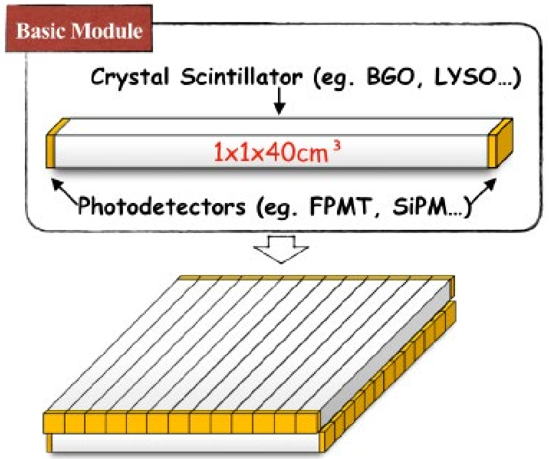
- Components of jet energy resolution:

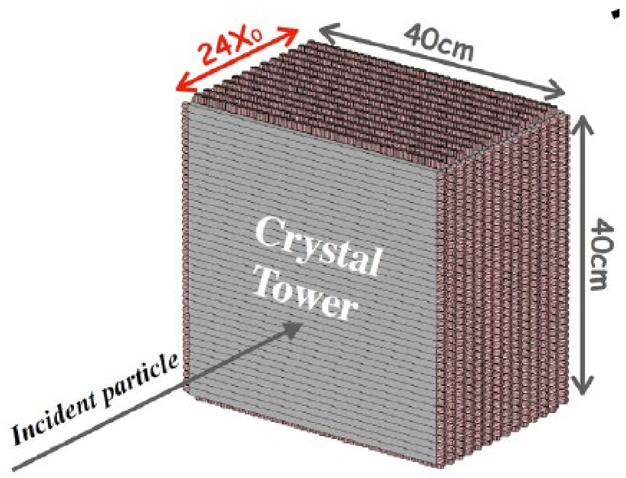
$$\sigma_{jet} = \sqrt{\sigma_{track}^2 + \sigma_{EM}^2 + \sigma_{Had}^2 + \sigma_{confusion}^2}$$

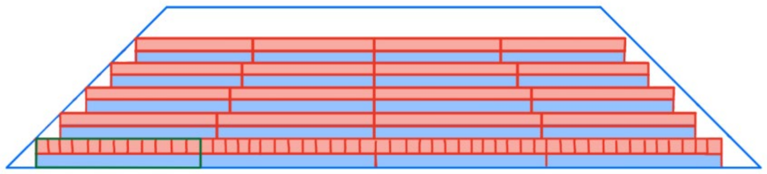
Component	Detector	Energy fraction	Energy resolution	Jet energy resolution
Charged particles($X^{\pm}$)	Tracker	$\sim 0.6E_J$	–	–
Photons(γ)	ECAL	$\sim 0.3E_J$	$0.03\sqrt{E_\gamma}$	$0.016\sqrt{E_J}$
Neutral Hadrons(h^0)	HCAL	$\sim 0.1E_J$	$0.55\sqrt{E_{h^0}}$	$0.17\sqrt{E_J}$

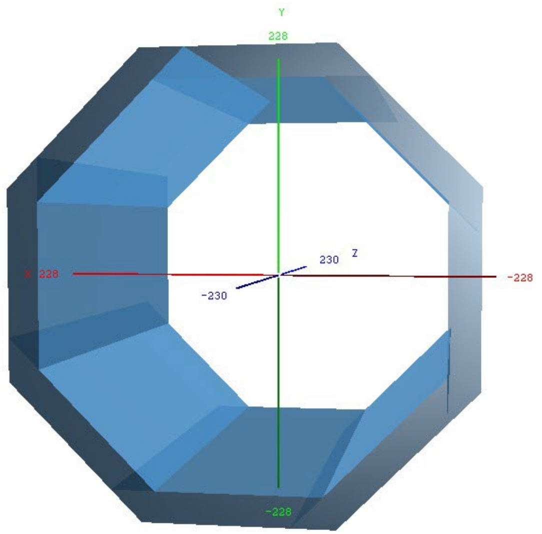
Introduction

- Crystal ECAL:
  - Homogeneous BGO crystal.
  - Optimal energy resolution $\frac{3\%}{\sqrt{E}} \oplus \sim 1\%$
    - meet the requirement.
  - Long bar design
    - Less electronic channels.
    - Bar size: $1 \times 1 \times \sim 40cm^3$.
    - Double-sided readout.
    - Crossed arrangement in adjacent layer.
    - Tower: $\sim 40 \times \sim 40 \times 28cm^3$



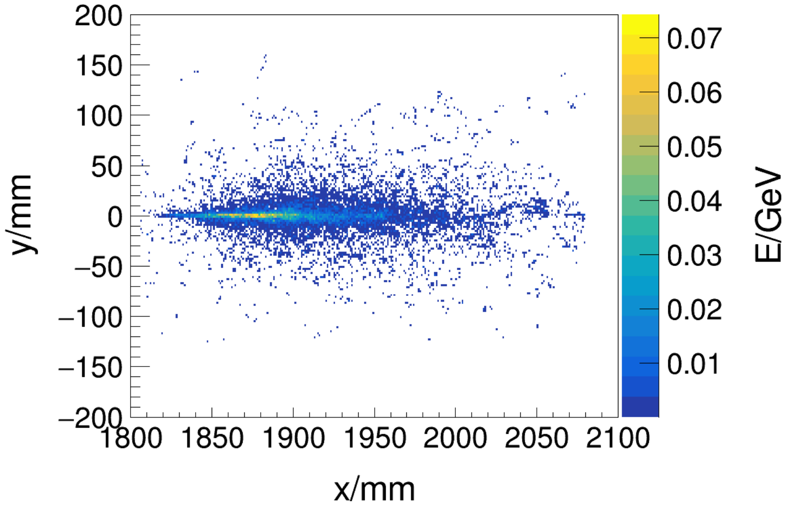




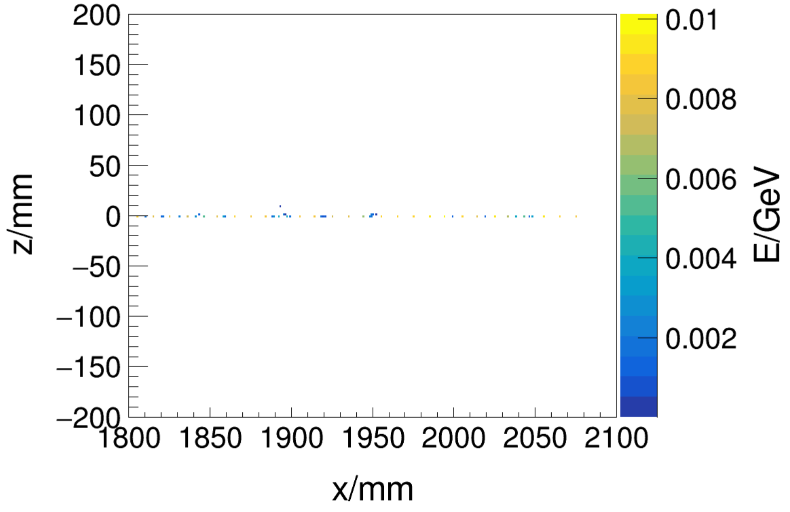


Introduction

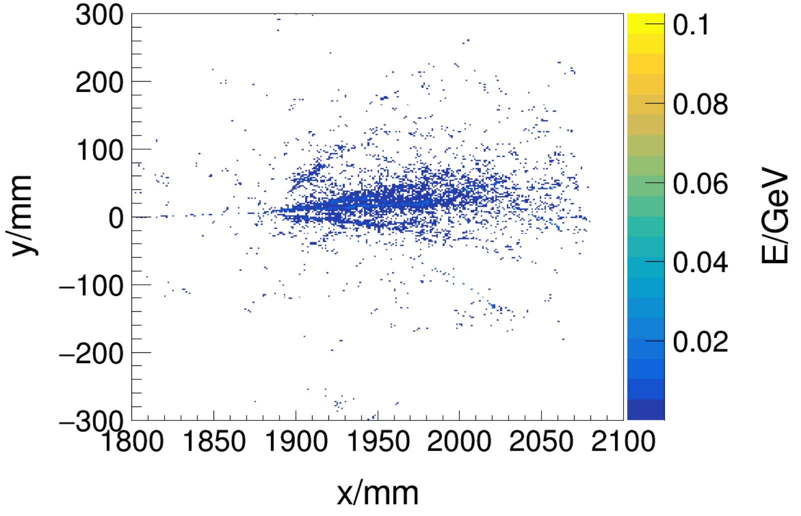
- Recognizing individual cluster in ECAL, associate the energy deposits with correct particles.
- Larger X_0 and R_M & better σ_E of crystal, a feasibility study of ECAL reconstruction using both position and energy & time measurements.
- A distinct "core" of energy deposition could be utilized for cluster recognition in ECAL.



EM cluster

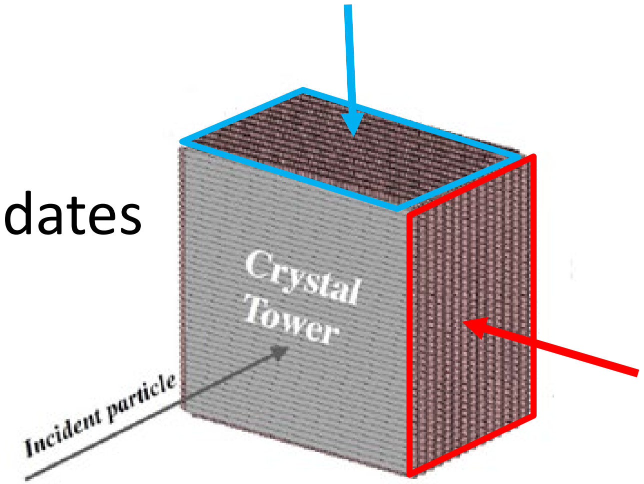


MIP cluster

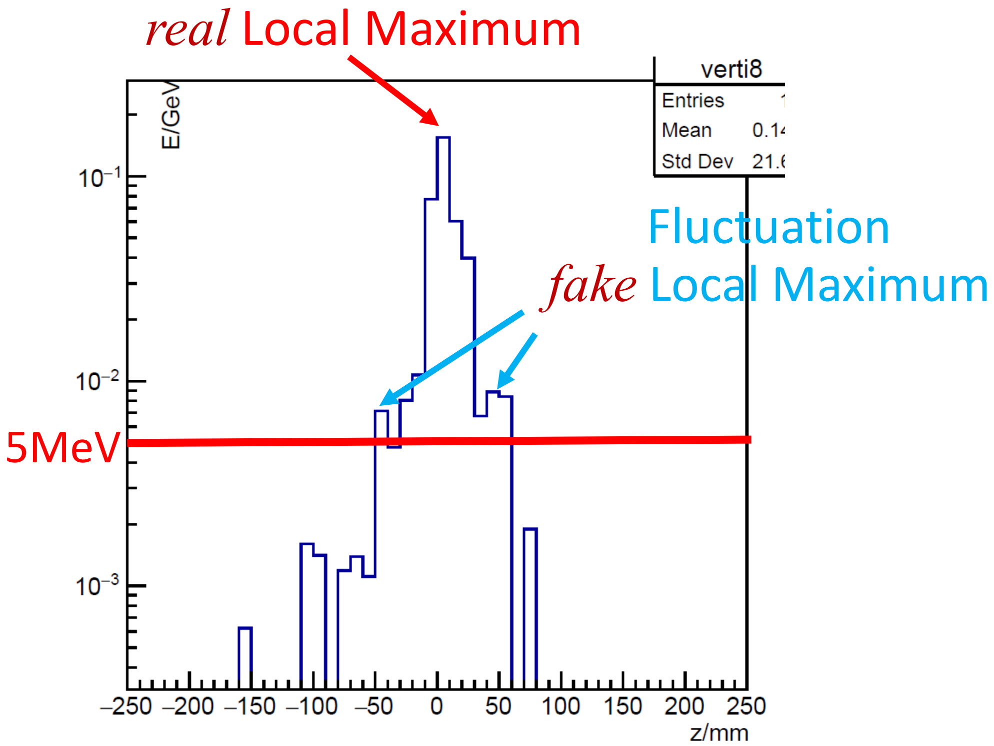


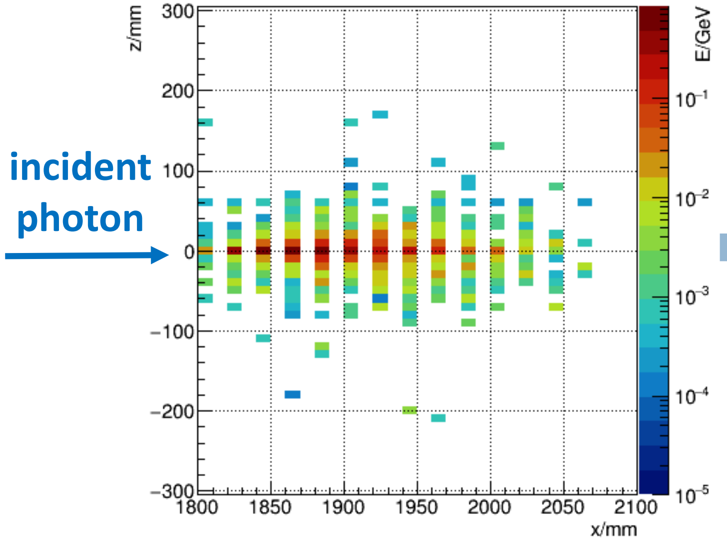
Hadronic cluster

"Seed": Local Maximum

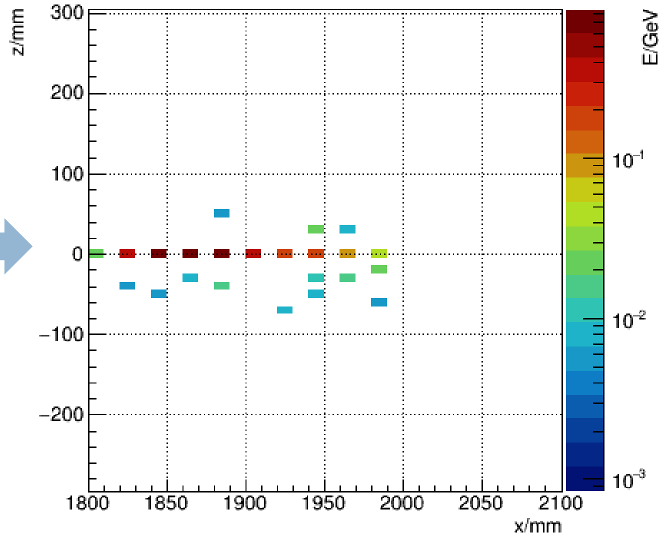


- In each layer / 1D reconstruction: local maximum and "seed" candidates
  - Real: core of energy deposition ➔ real cluster (this talk)
  - Fake: fluctuation ➔ fake cluster (next to do)
- Cluster recognition ➔ Energy "Core" recognition
  - Reduce the negative effects due to wider longitudinal and lateral developments of cluster





Energy deposits in crystals



Local Maximum Distribution

Principle of Hough Transformation

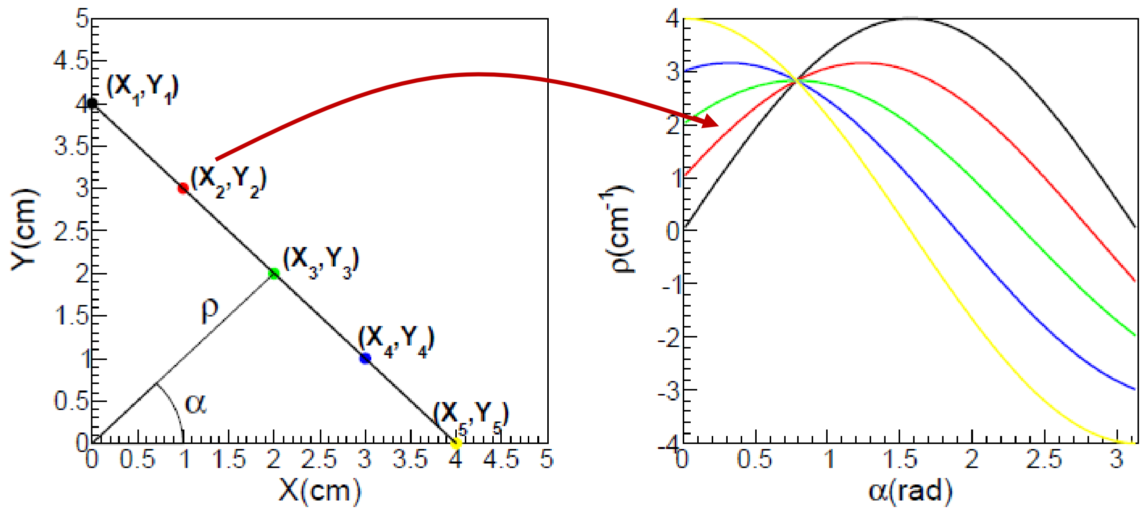
- A feature extraction method for detecting simple shapes (e.g. lines) in an image.
- For straight lines:

$$\rho = x\cos\alpha + y\sin\alpha$$

  - Each point (x, y) in image space is transformed to a curve in Hough space.
  - If several points (x_i, y_i) are collinear, their curves intersect at a point (α, ρ) in Hough space.
  - α and ρ are parameters of the straight line that pass through these points (x, y)

Image Space

Hough Space



(x, y) → $\rho = x\cos\alpha + y\sin\alpha$

A Point — A Curve

(x_i, y_i) → $\rho = x_i\cos\alpha + y_i\sin\alpha$

A series of Points — A Series of Curves

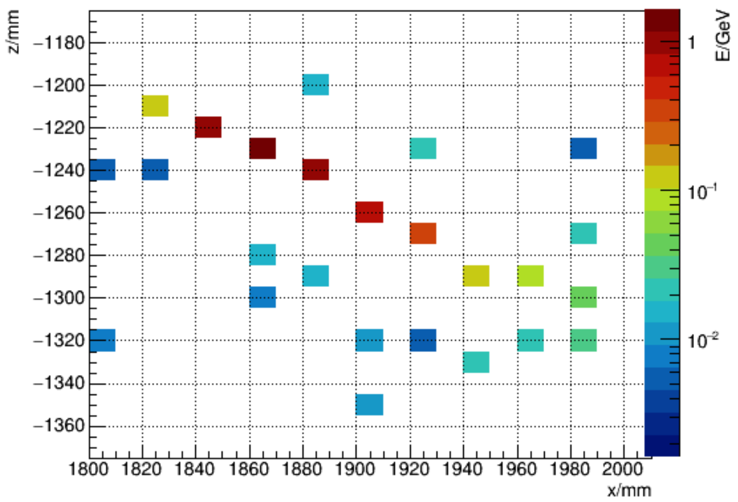
$\rho = x\cos\alpha + y\sin\alpha$ → (α, ρ)

A Line — A Point

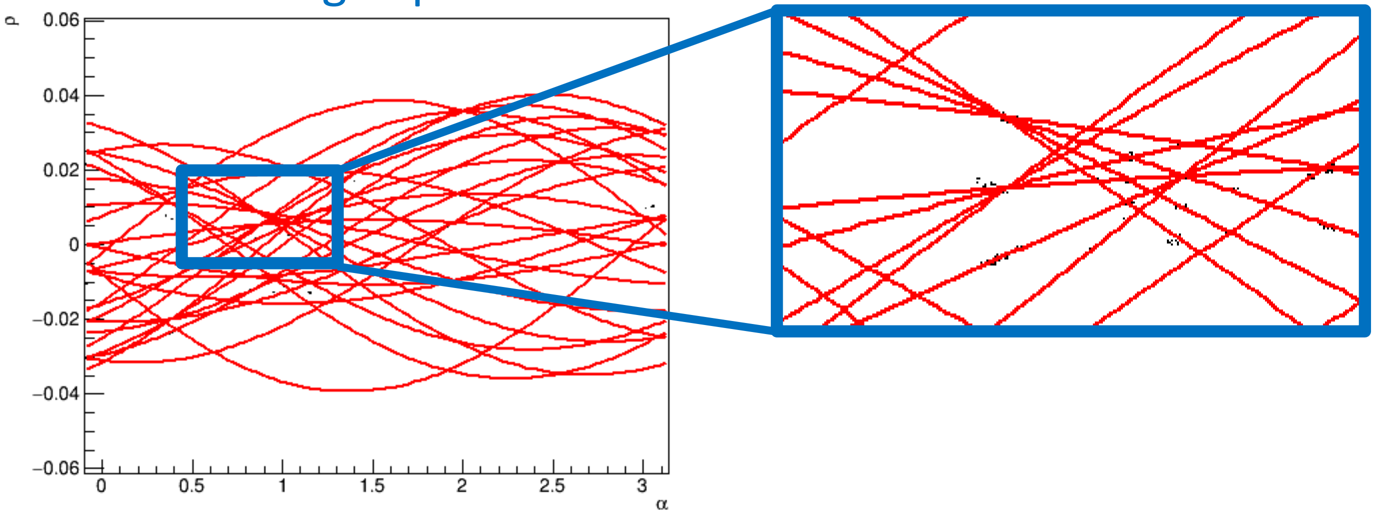
Hough transformation with local maxima

- Transform each local maximum to a curve.

50GeV photon



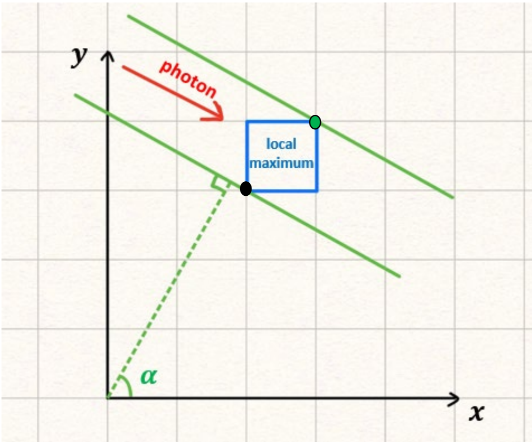
Hough Space

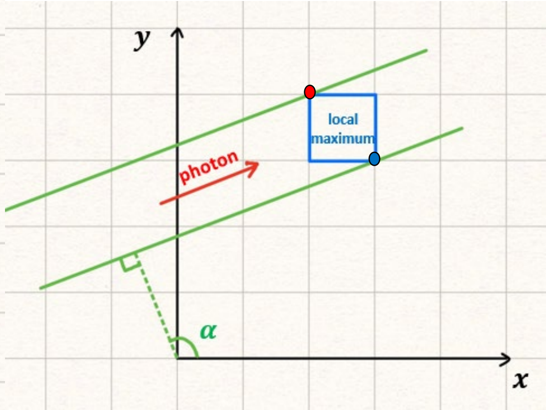


- If local maxima are not perfectly collinear, their curves do not intersect at a point.

$1 \times 1cm^2$ Granularity Hough transformation

- $1 \times 1cm^2$ cross section of long crystal bar could not be regarded as point
  - $0 < \alpha < \frac{\pi}{2}$: $(x_r, y_u) \rightarrow \rho_{ur} = x_r \cos\alpha + y_u \sin\alpha$
  - $0 < \alpha < \frac{\pi}{2}$: $(x_l, y_d) \rightarrow \rho_{dl} = x_l \cos\alpha + y_d \sin\alpha$
  - $\frac{\pi}{2} < \alpha < \pi$: $(x_l, y_u) \rightarrow \rho_{ul} = x_l \cos\alpha + y_u \sin\alpha$
  - $\frac{\pi}{2} < \alpha < \pi$: $(x_r, y_d) \rightarrow \rho_{dr} = x_r \cos\alpha + y_d \sin\alpha$





- Each crystal in image space is transformed to a band in Hough space

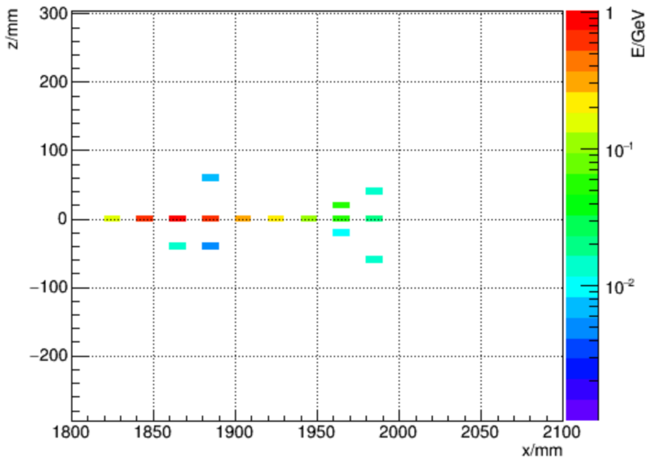
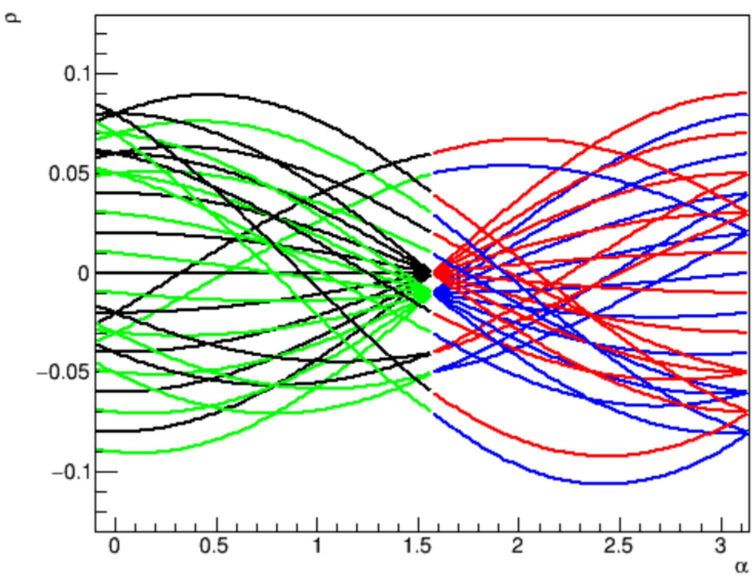


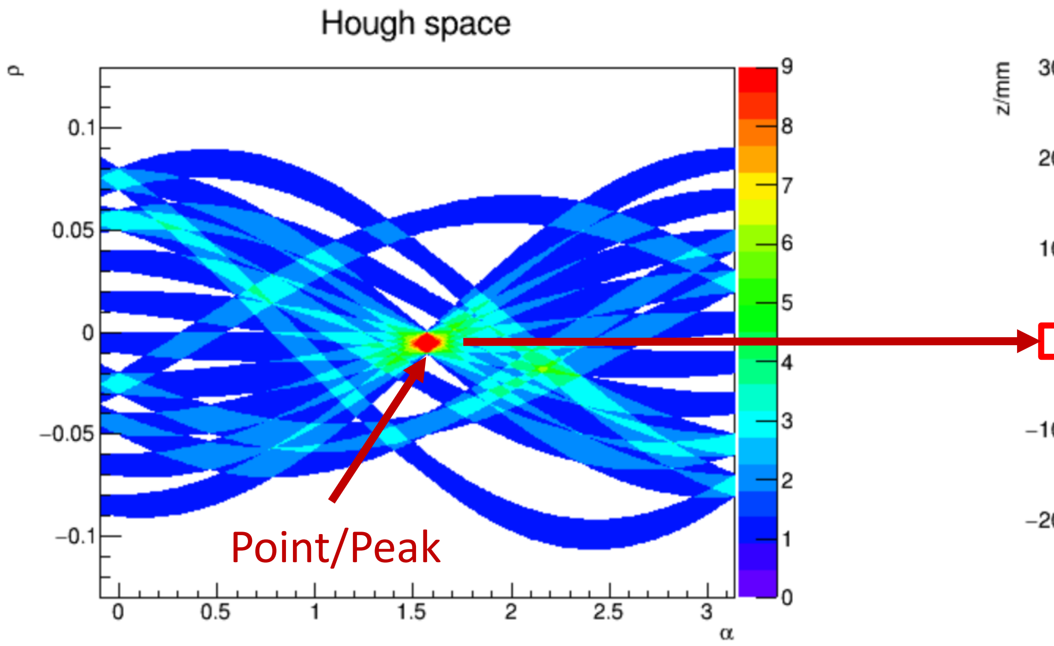
Image Space

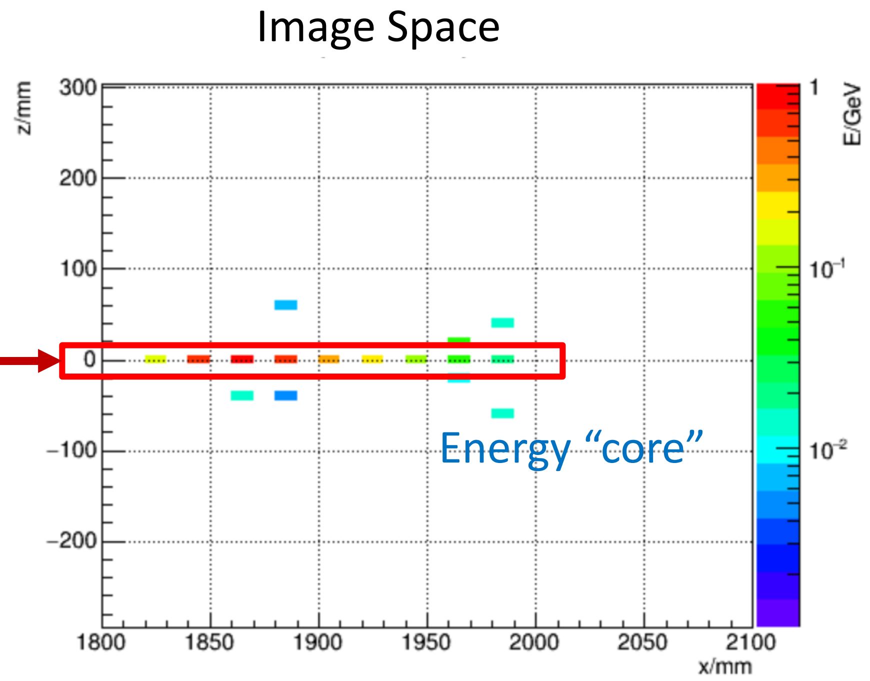
Hough space



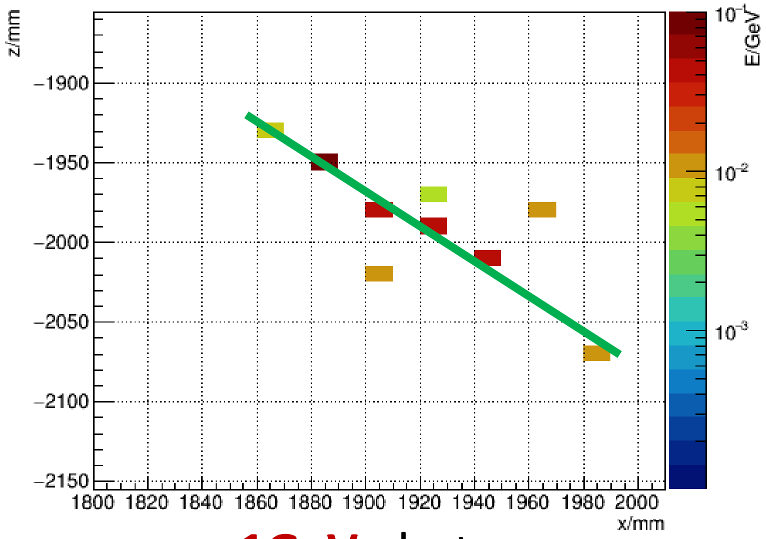
Shower Finding in Hough Space

- In Hough space, “votes” are collected in the accumulated bands representing local maxima.
- Each point/peak (overlap region of band) in Hough space is chosen as a cluster candidate.
- Center (α, ρ) estimation predicts the “core”/axis of a cluster.

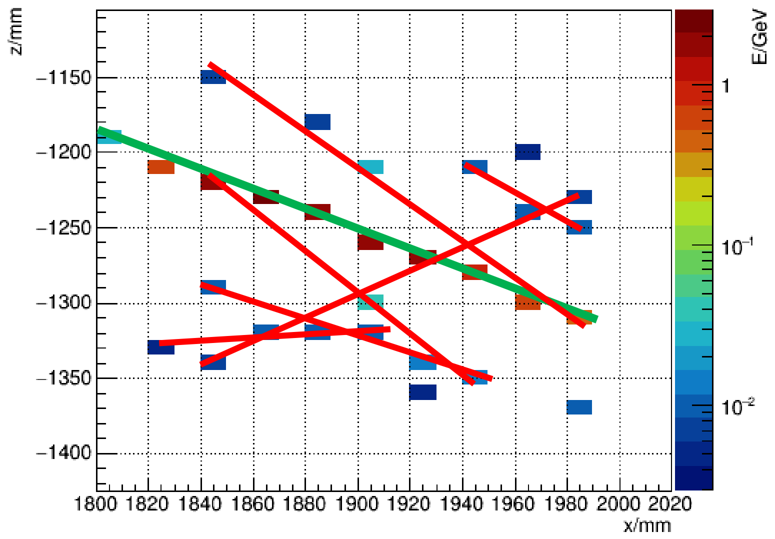




Preliminary Result of Performance



1GeV photon



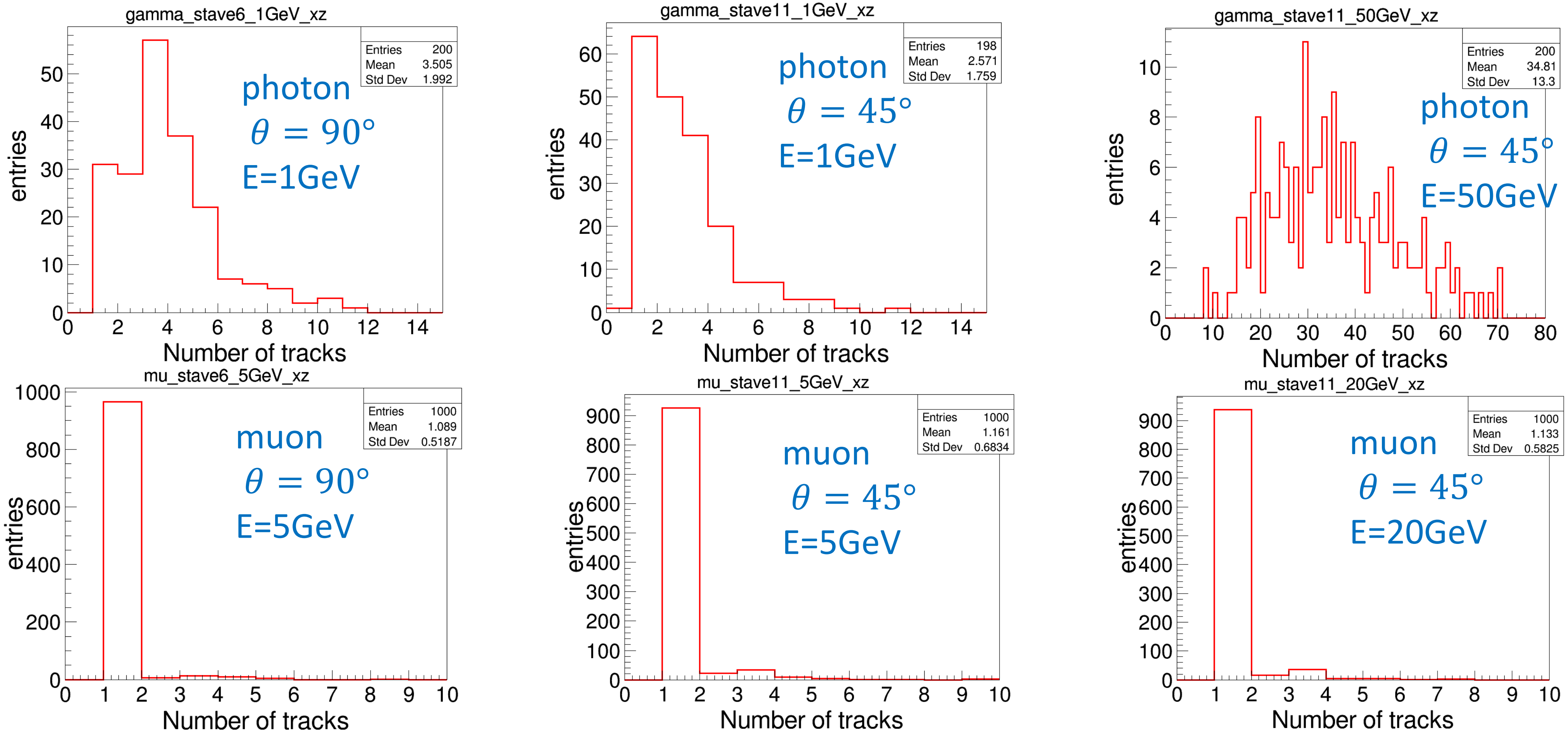
50GeV photon

Energy of cluster ↑ ➔ Energy fluctuation

fake local maximum ↑ ➔ # fake cluster

Preliminary Result of Performance

- A significant impact on the number of clusters for photons, especially for photons with high energy
- Number of clusters for μ independent with energy or polar angle



Validation using MC Truth

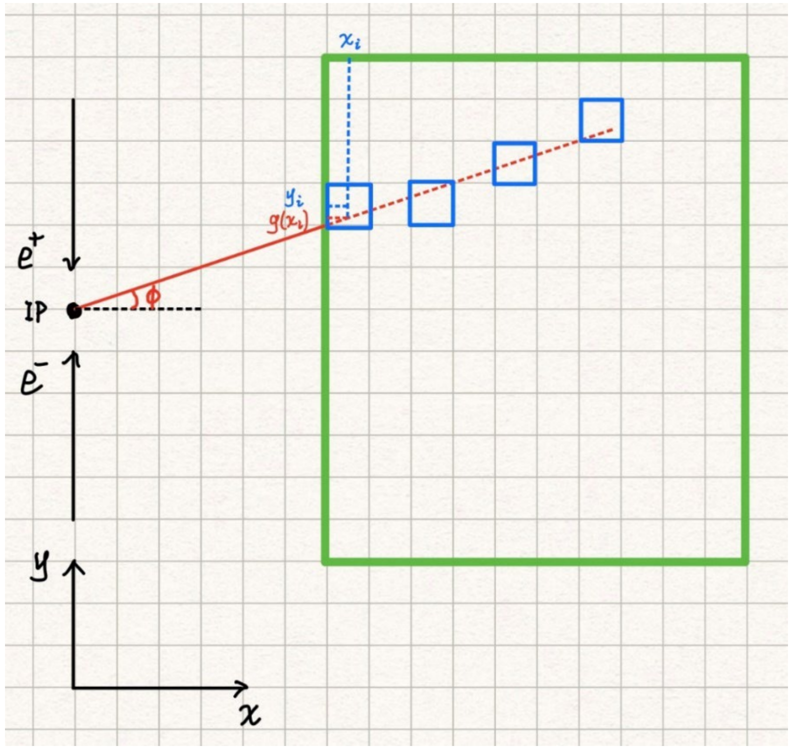
- Multiple clusters are found in one EM cluster, most of them are fake clusters.
- Using MC truth information to validate whether the axis of the real EM cluster is founded

$$\frac{\chi^2}{N} = \frac{1}{N}\sum_{i=1}^{N}\left(y_i - g(x_i)\right)^2$$

where N: number of hits of a track,

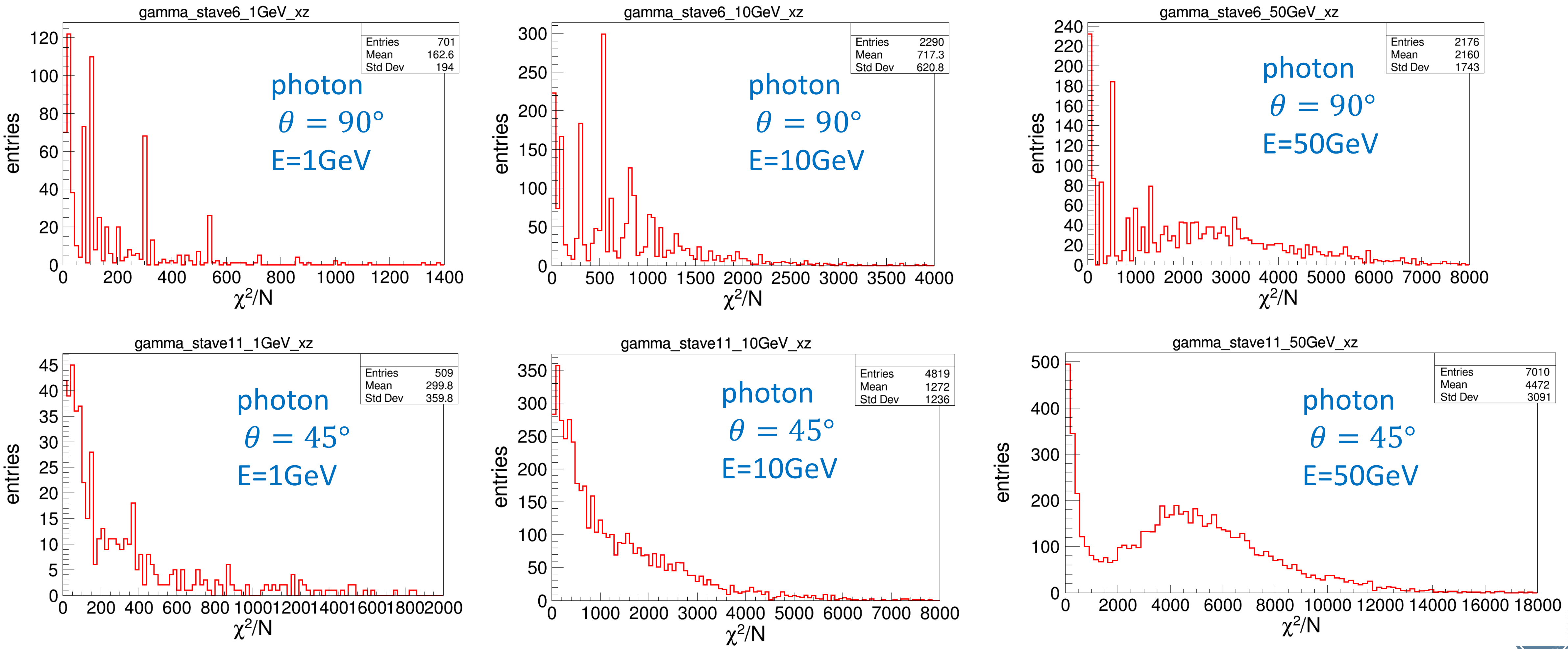
y_i: position of a hit,

$g(x_i)$: extrapolated position with MC truth,



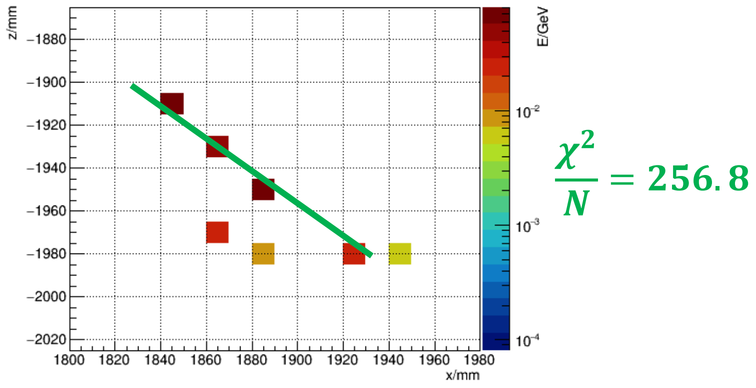
Validation using MC Truth

- $\frac{\chi^2}{N}$ distribution

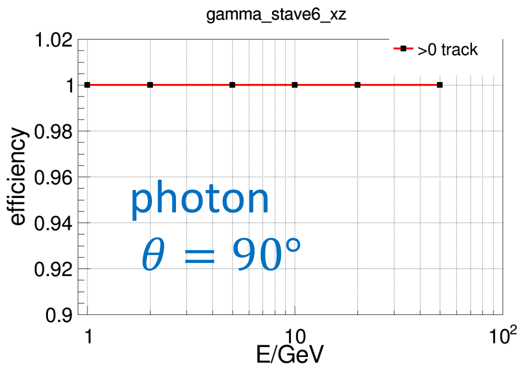


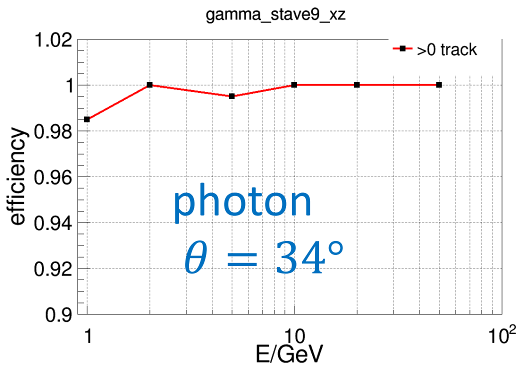
Validation using MC Truth

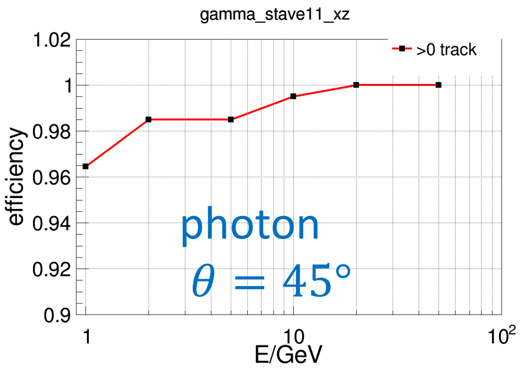
- Clusters with $\frac{\chi^2}{N} < 200$ are treated as real EM cluster.
- Despite the number of fake clusters, the real cluster could be found with an efficiency close to 100%

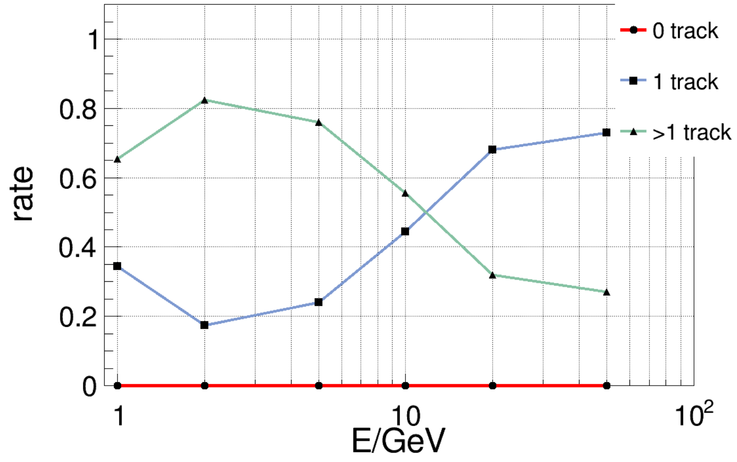


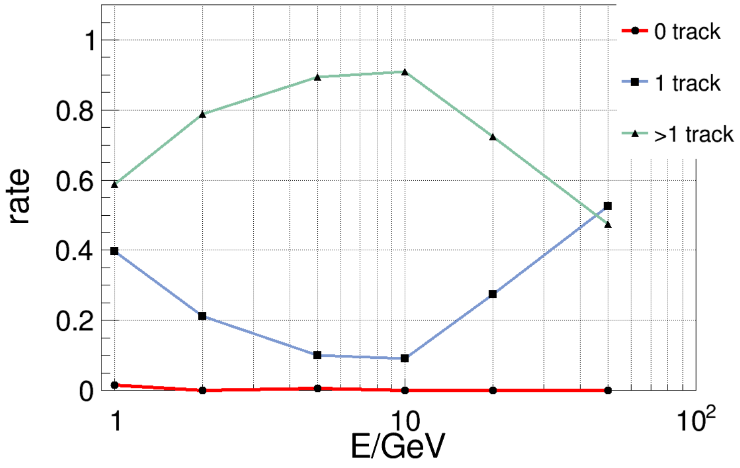
Events with 0 tracks

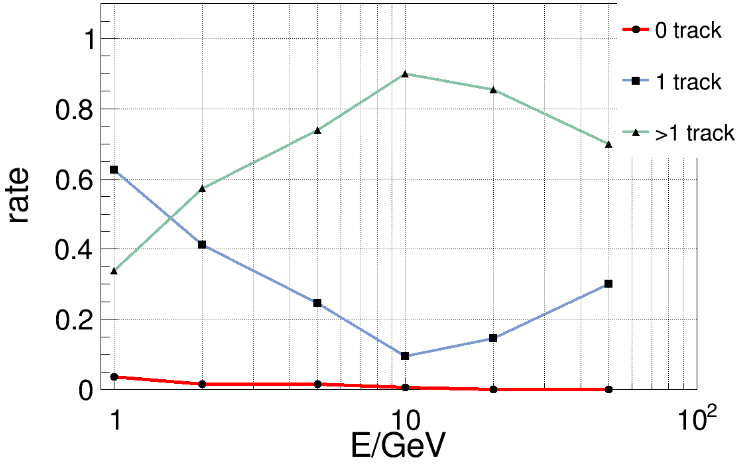












Summary

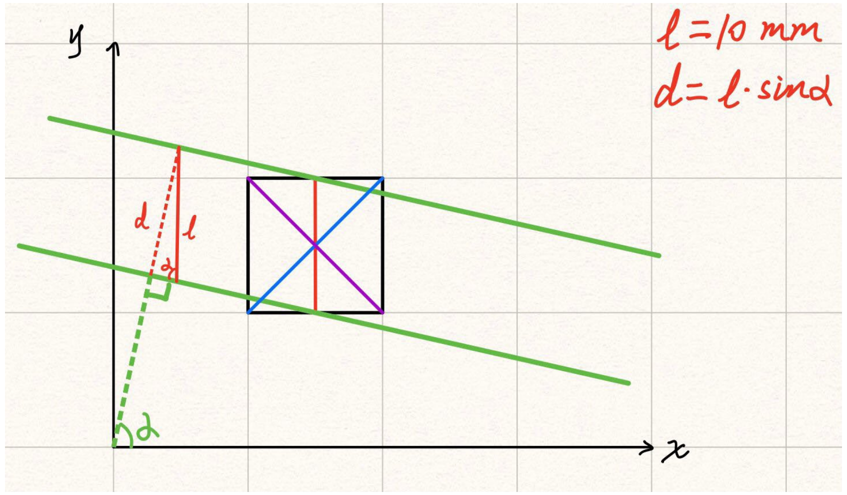
- Wider profile of showers in crystal raises the difficulty to separate energy deposits from different particles.
- A fresh approach of Local Maximum + Hough Transformation is applied in cluster finding, and high efficiency of correct EM clusters finding is achieved in a wide range of energy and polar angle.
- Number of fake clusters raises with increase of cluster’s energy, precise Energy & Time constrains are expected to reduce the contamination caused by the fluctuation.

Thank you!

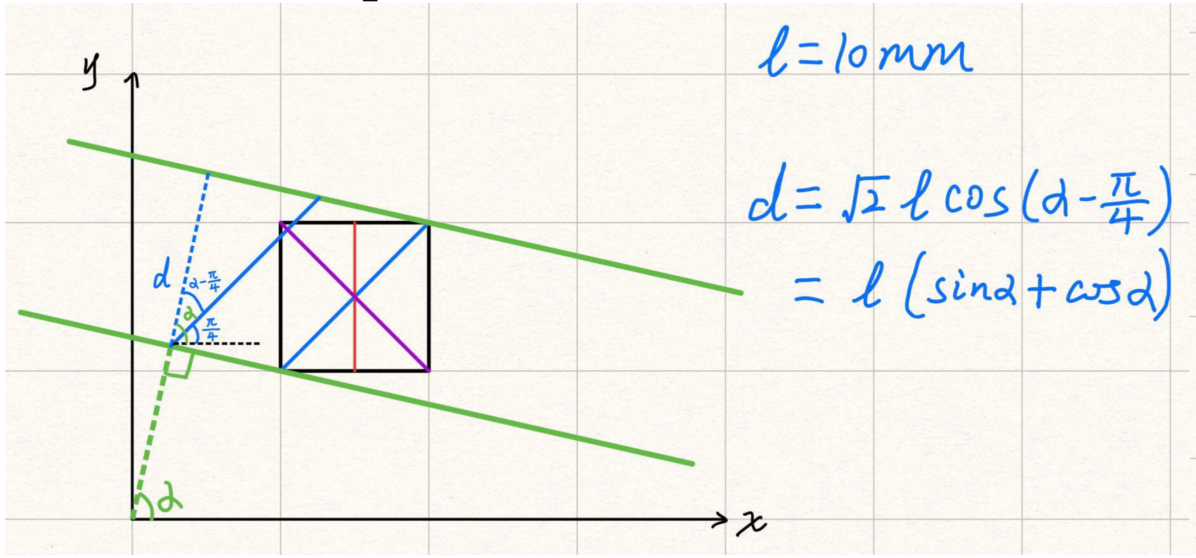
Back up

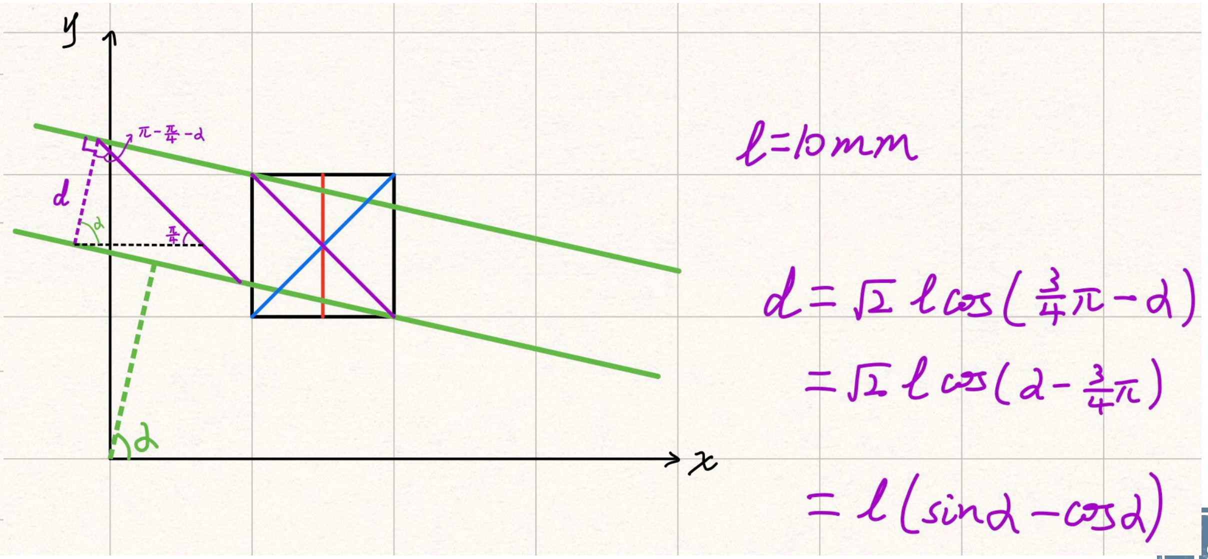
Hough transformation

- For each hit(local maximum), doing Hough transformation with
  - up-right & down-left points when $0 < \alpha < \frac{\pi}{2}$
  - up-left & down-right points when $\frac{\pi}{2} < \alpha < \pi$



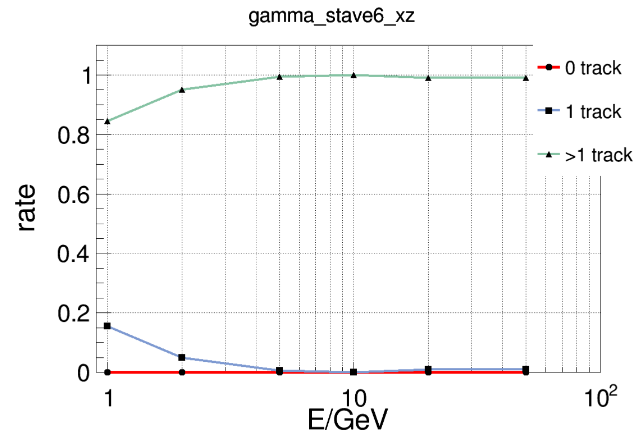
  - d>d when $0 < \alpha < \frac{\pi}{2}$,
  - d>d when $\frac{\pi}{2} < \alpha < \pi$

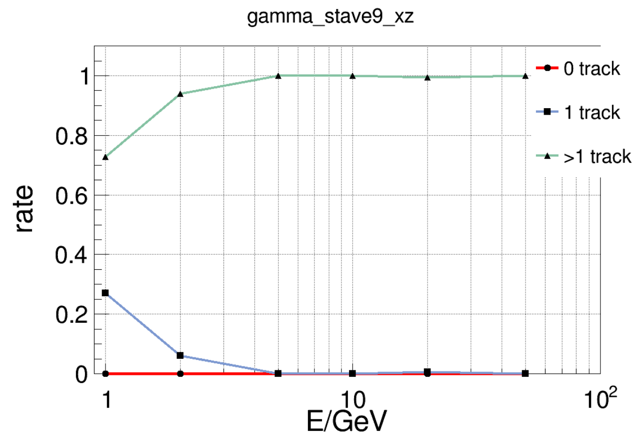


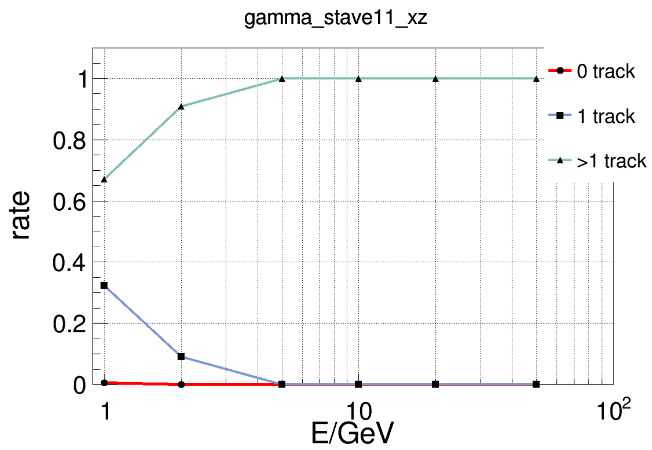


Preliminary Result of Performance

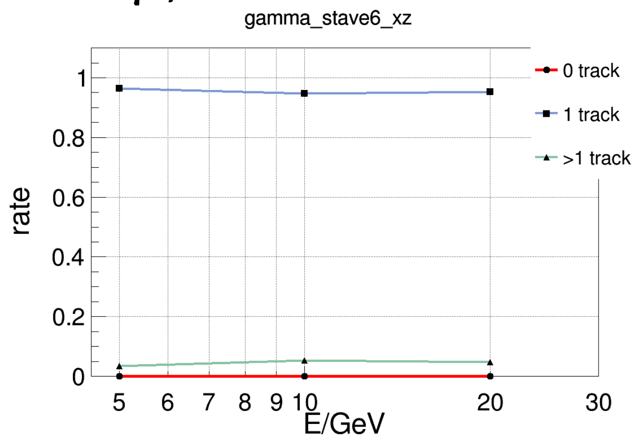
- For photons, almost all shower core will be recognized
  - Due to the fluctuation of local maximums, most EM shower will find more than one tracks

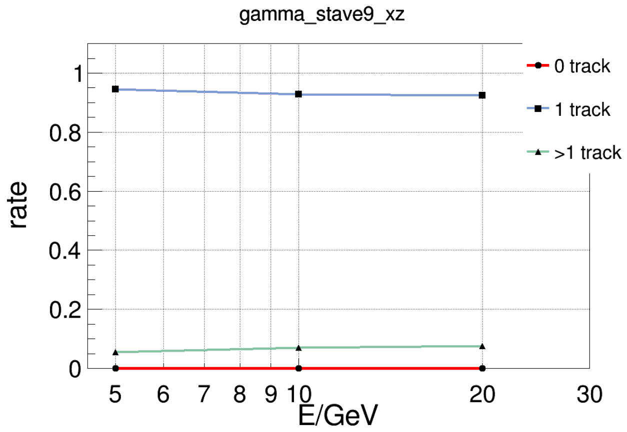


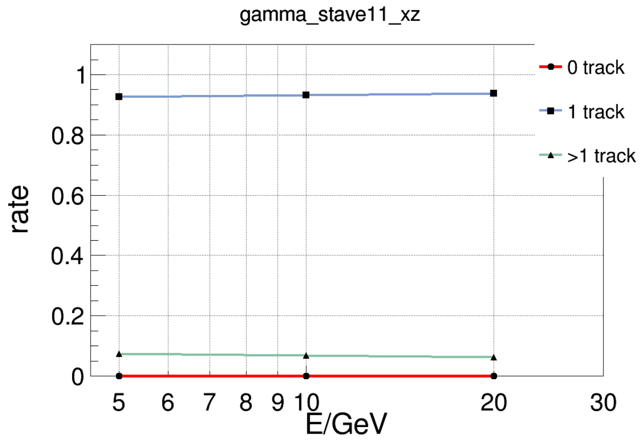




- For μ, over 90% events will find one track

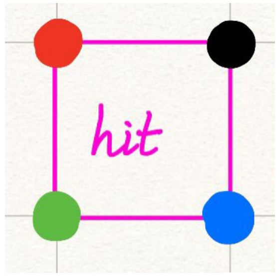




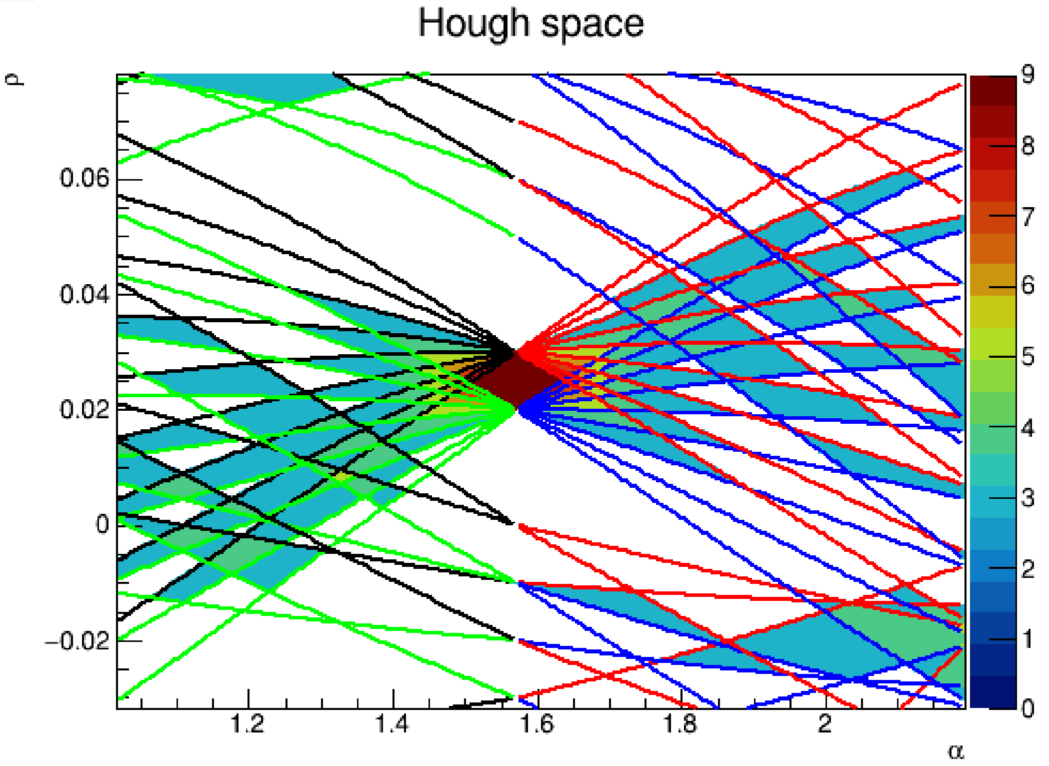


Hough transformation

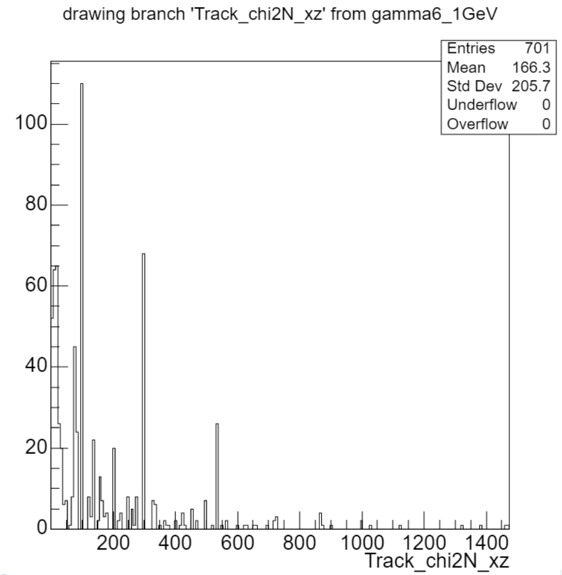
- In xz-plane, doing Hough transformation directly with the 4 points of each hit
  - $(x_r, y_u) \rightarrow \rho_{ur} = x_r \cos\alpha + y_u \sin\alpha, 0 < \alpha < \frac{\pi}{2}$
  - $(x_l, y_d) \rightarrow \rho_{dl} = x_l \cos\alpha + y_d \sin\alpha, 0 < \alpha < \frac{\pi}{2}$
  - $(x_l, y_u) \rightarrow \rho_{ul} = x_l \cos\alpha + y_u \sin\alpha, \frac{\pi}{2} < \alpha < \pi$
  - $(x_r, y_d) \rightarrow \rho_{dr} = x_r \cos\alpha + y_d \sin\alpha, \frac{\pi}{2} < \alpha < \pi$

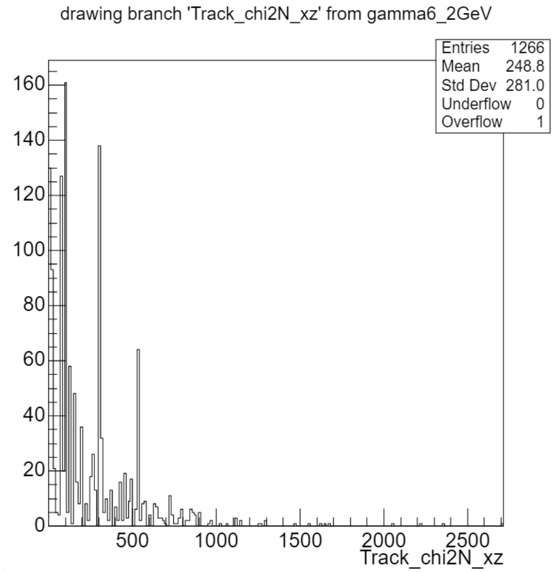


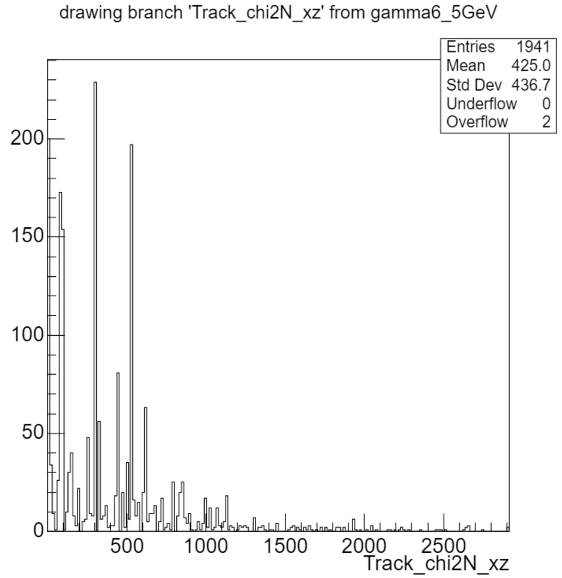
- When $\alpha = \frac{\pi}{2}$,
  - $\rho_{ur} = y_u = \rho_{ul}, \quad \rho_{dl} = y_d = \rho_{dr}$
  - The two up curves and down curves are continuous at $\alpha = \frac{\pi}{2}$

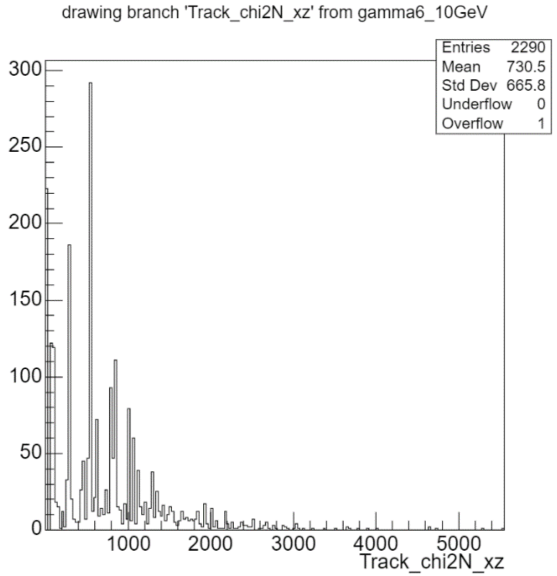


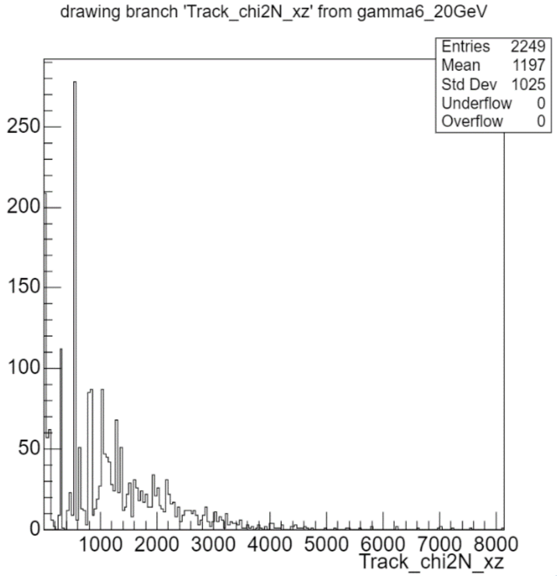
Distribution of χ^2/N

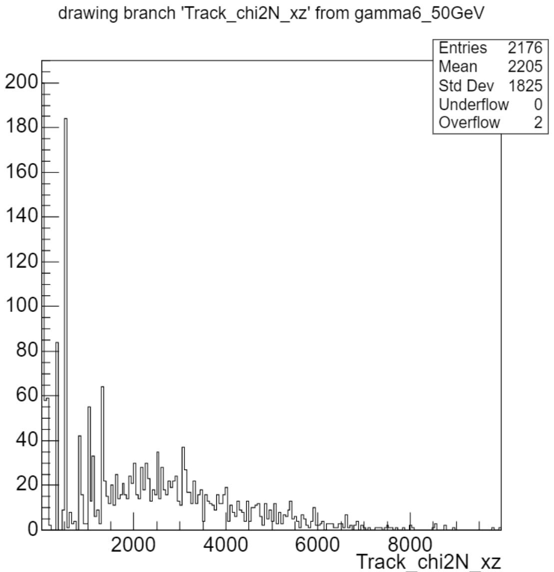




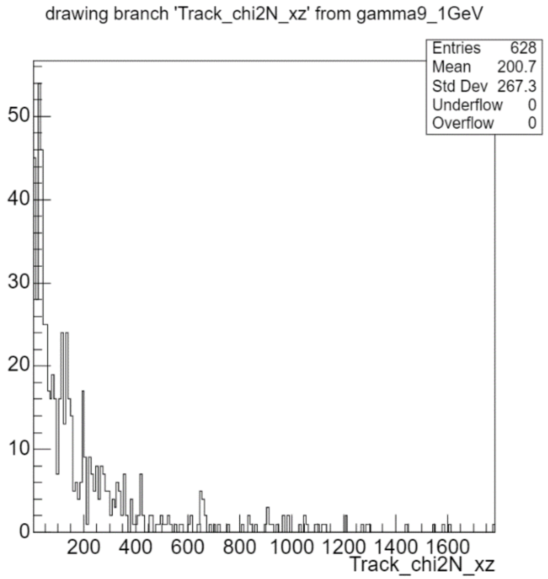


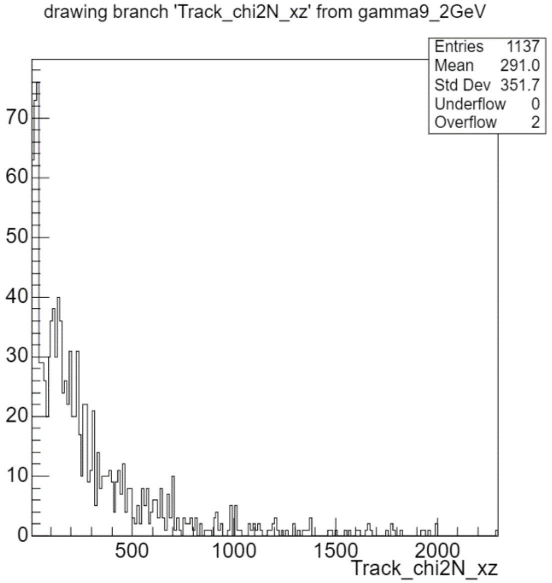


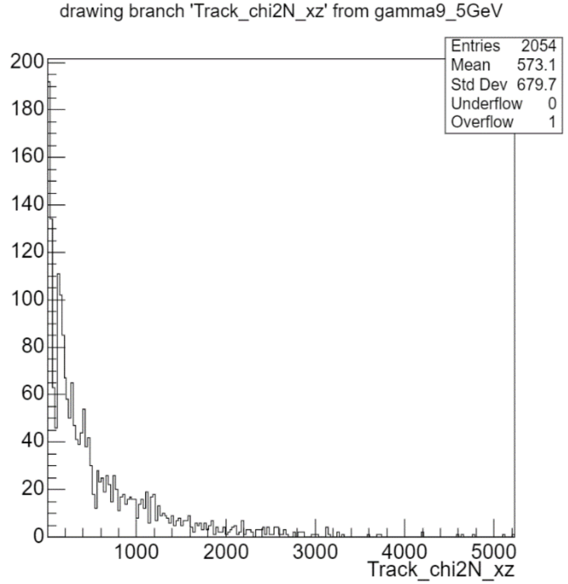


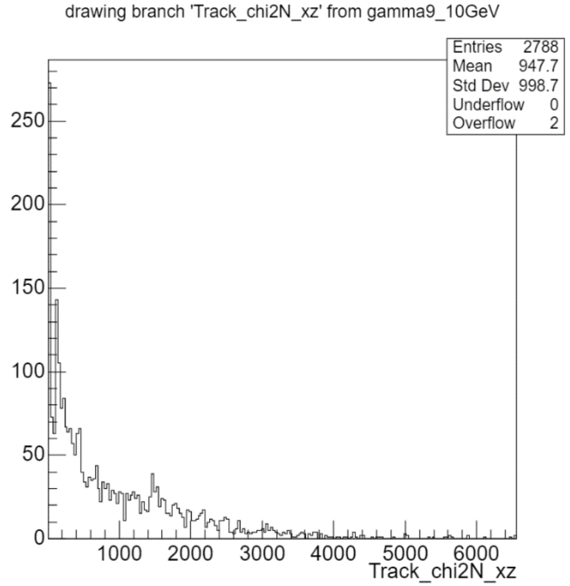


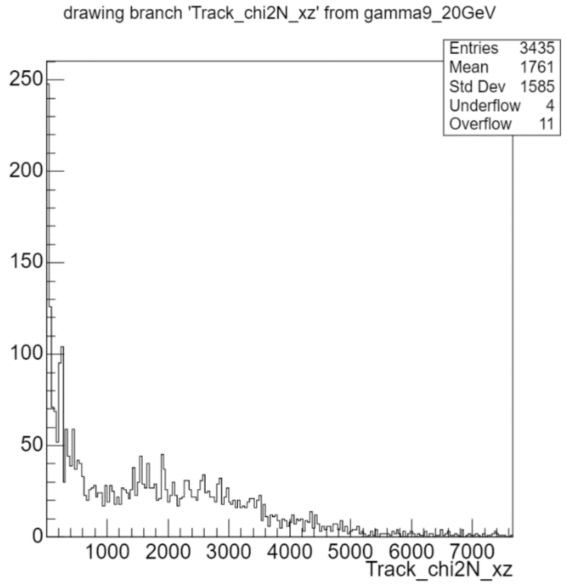
Distribution of χ^2/N

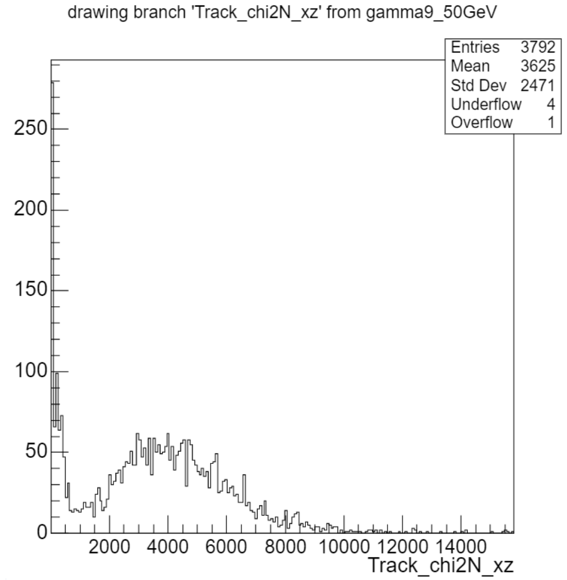




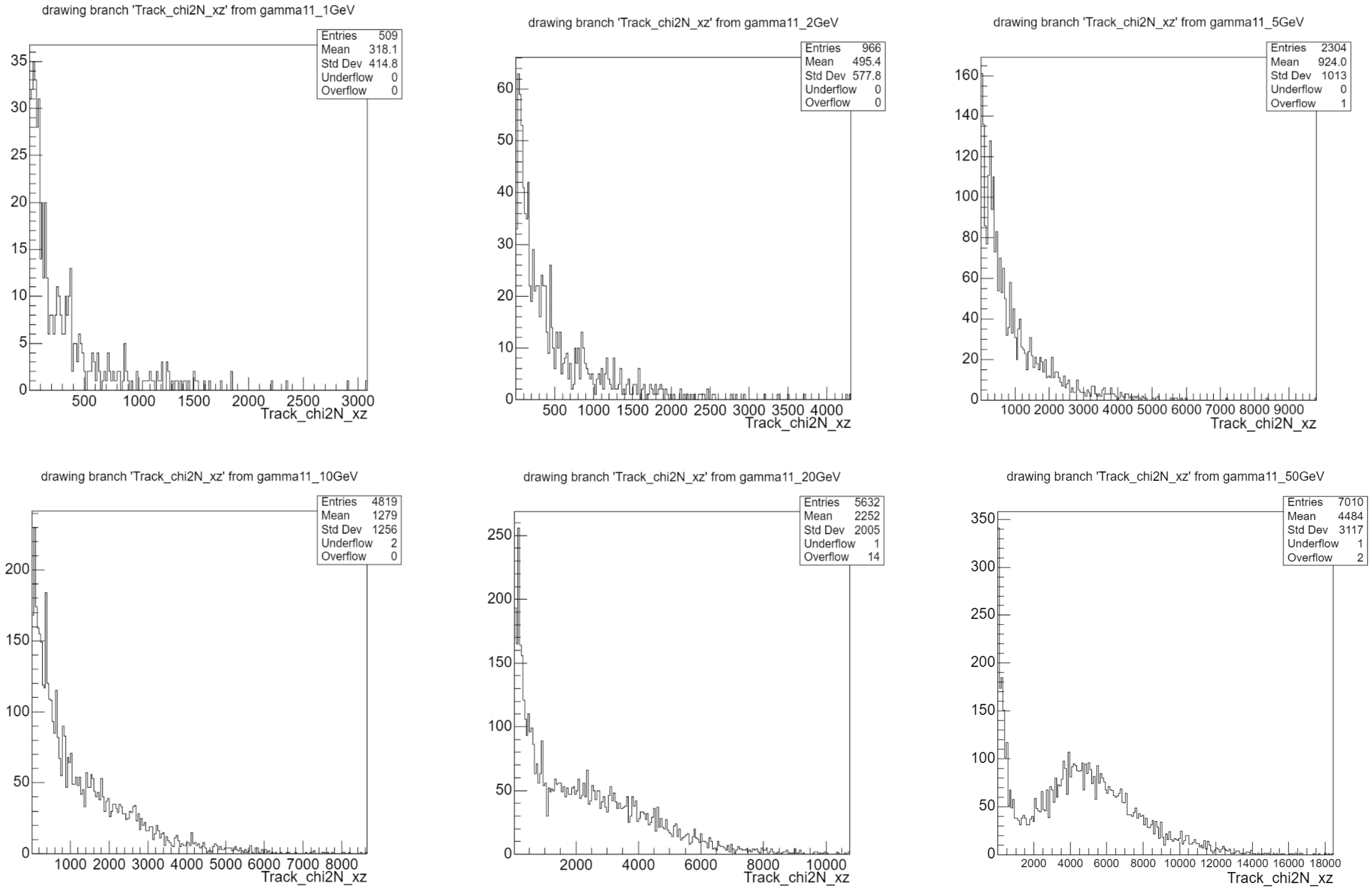








Distribution of χ^2/N



Distribution of χ^2/N