Vertex Track Perfomance Studies

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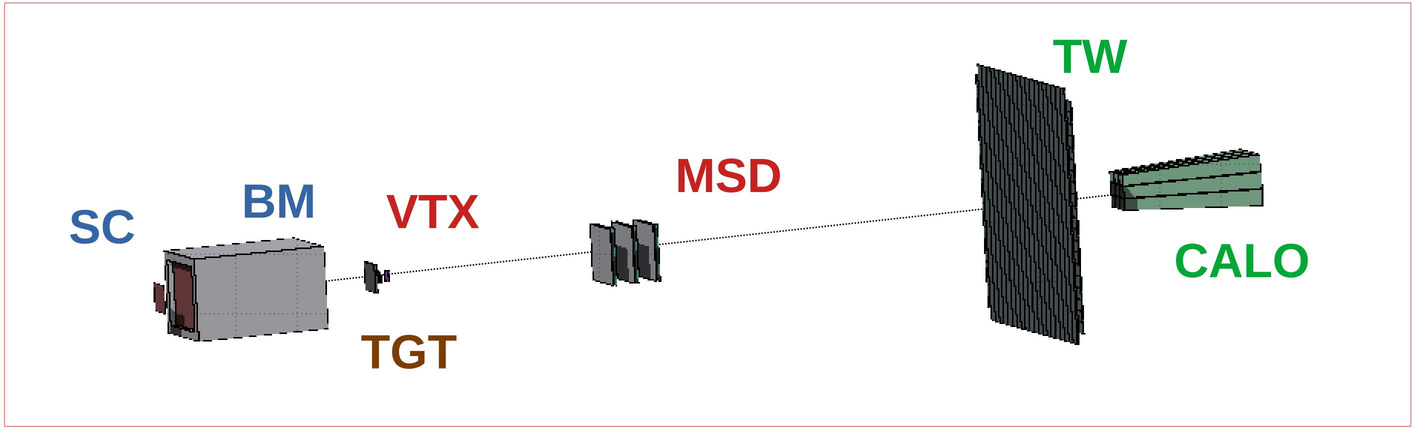
XIV FOOT Collaboration Meeting

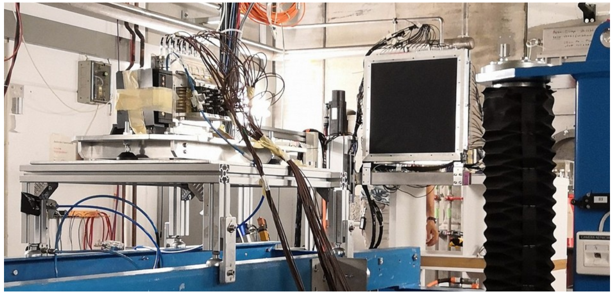
Bergamo

06/06/2023

- Performance studies applied on **MC GSI 2021** campain

- Data-taking at GSI (Darmstadt, Germany) in 2021
- **^{16}O 400 MeV/u** on 5 mm **C target**
- Partial setup: no magnet, only one module of calorimeter





Definitions for performance factors

- **Reference set: $N_{reference}$ (truth side)**
  all the tracks that an algorithm performing ideally should find and reconstruct:
  - all the tracks associated to a MC particle that crosses the FOOT apparatus at least until the last plane of the vertex (using MCRegion)
    - beam
    - primary fragment generated in the target

- **Good reconstructed set: $N_{GoodReco}$**
  all the tracks that are reconstructed by the tracking algorithm which are associated to MCparticles in the reference set .

- **Bad reconstructed set: $N_{BadReco}$**
  all the tracks that are reconstructed by the tracking algorithm but associated to MC particle that do not belong to the reference set.

Track reconstruction

For the track reconstruction I considered:
case 1: a track is reconstructed with 4 clusters (one for each VT plane)
case 2: a track is reconstructed with at least 3 clusters
case 3: a track is reconstructed with at least 3 clusters + random noise pixels are generated

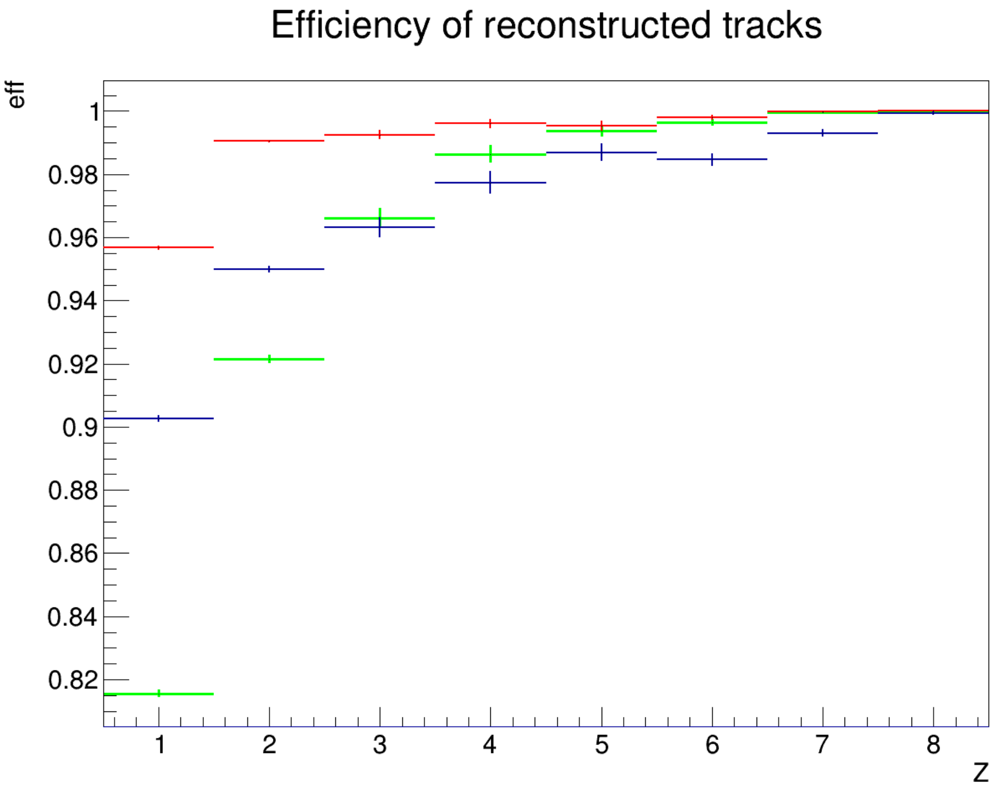
NB:
To associate a MC Particle to a reconstructed track:

- I consider the MC ID of all the clusters belonging to the track
- I take the most frequent one: this is the ID of the MC Particle matched

Performance factors

- **Reconstruction efficiency:**

$$\epsilon_{track}(Z) = \frac{N_{GoodReco}(Z)}{N_{reference}(Z)}$$



tracks with 4 clusters (case 1)
tracks with >=3 clusters (case 2)
tracks with >= 3 clus + noise (case 3)

FIRST vertex efficiency:

Table 2
Tracking efficiencies and associated errors for different charge values of detected particles (simulated data).

Z	1	2	3	4	5	6
Efficiency (%)	93.6	88.9	97.5	97.7	98.8	99.9
Error (%)	0.3	0.6	0.7	0.8	0.4	0.1

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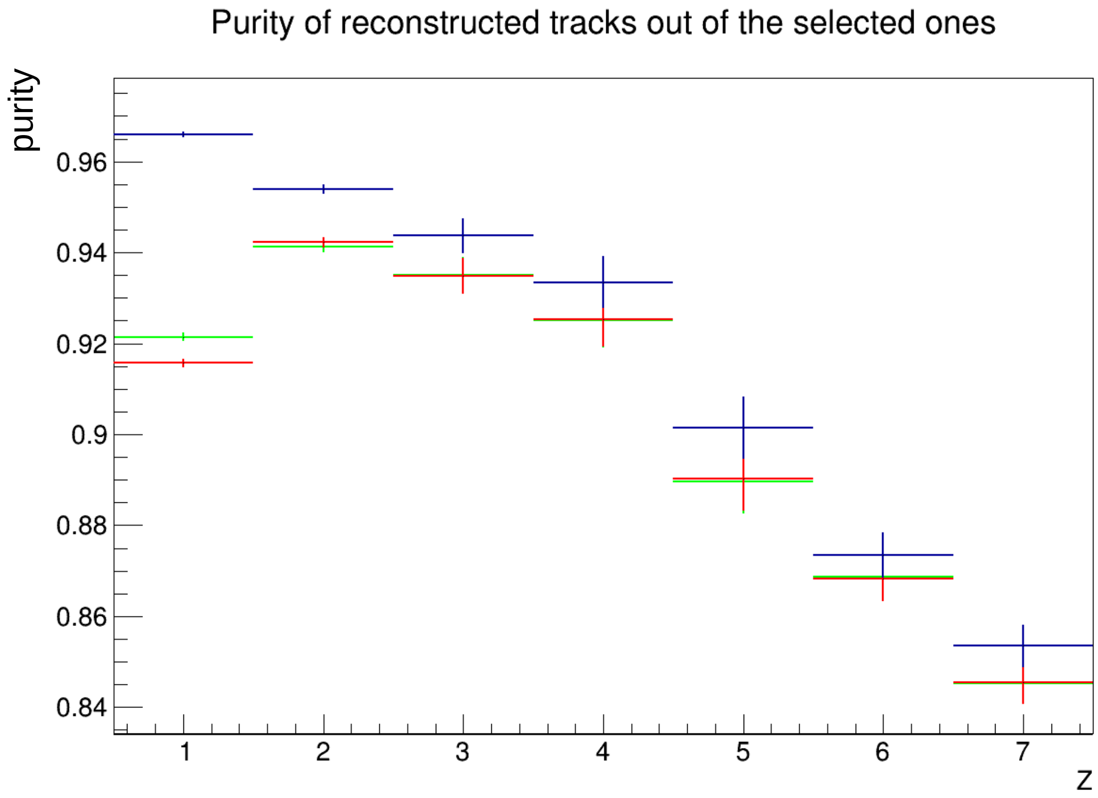
- elemental efficiency higher than 0.9 for Z≥2 , close to 1 for Z≥3

Performance factors

- **Purity:**

$$p_{track}(Z) = \frac{N_{GoodReco}(Z)}{N_{GoodReco}(Z) + N_{BadReco}(Z)}$$



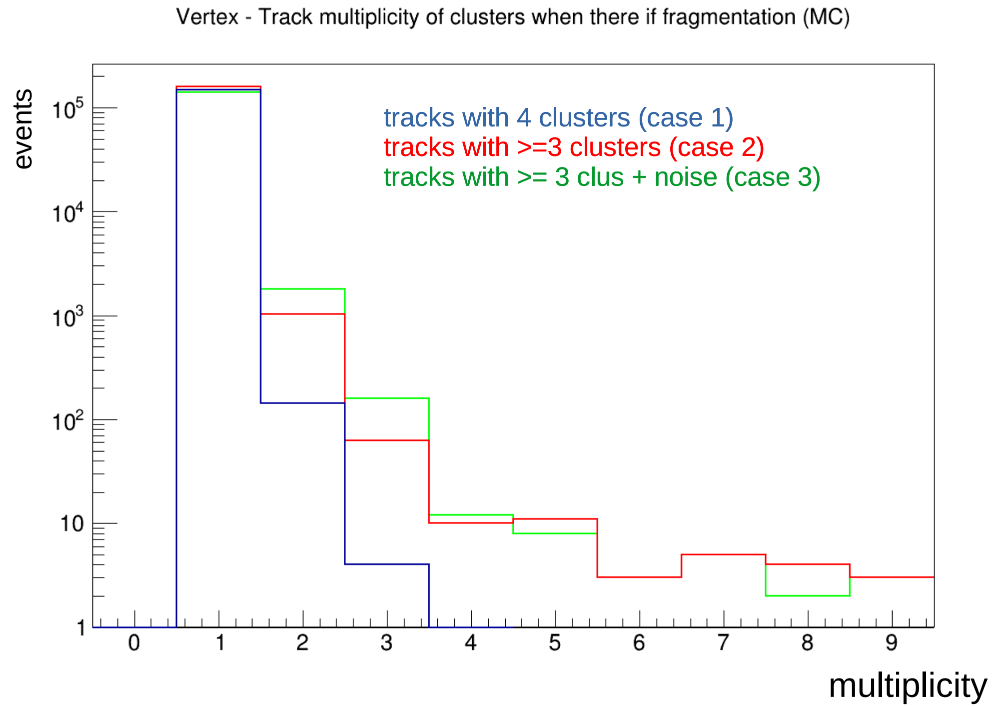
tracks with 4 clusters (case 1)
tracks with >=3 clusters (case 2)
tracks with >= 3 clus + noise (case 3)

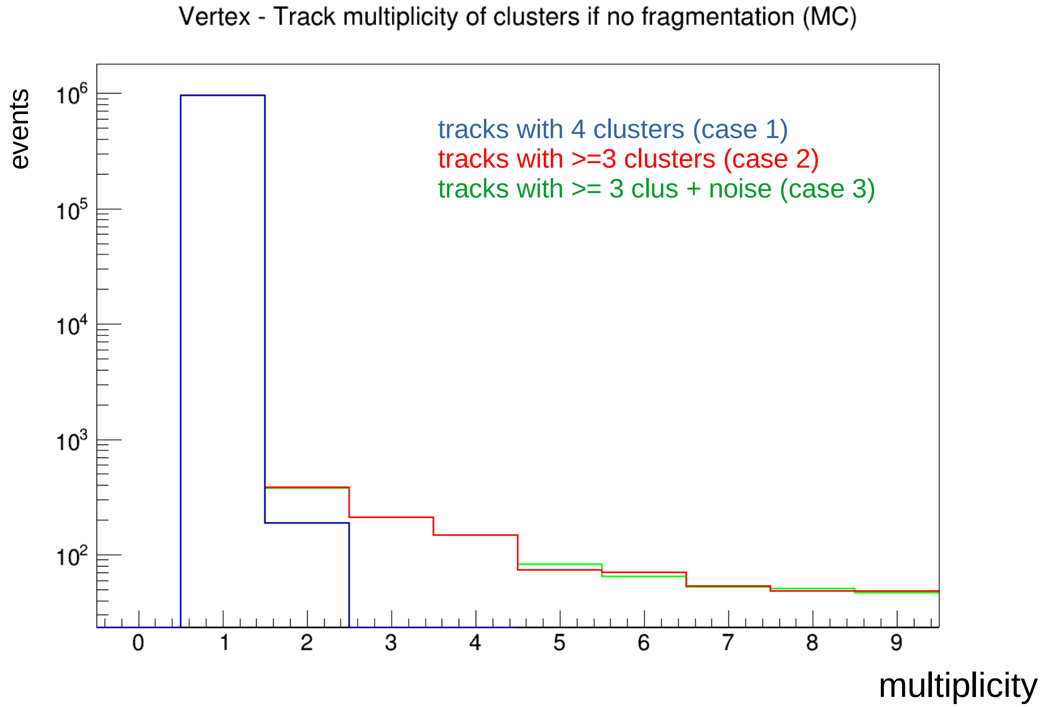
- elemental purity higher than 0.8, it decreases with heavier Z

Performance factors

- **Multiplicity**: n° of different clusters MC_ID associated to a given track
  - es: m=1 all clusters are of the same MC particle
  - es: m=2 clusters belong to two different MC particle (1-3,2-2)

NB: multiplicity can be higher than 4 (despite the clusters are at max 4) because every one can be associated to different MC particles (with different MC_ID)



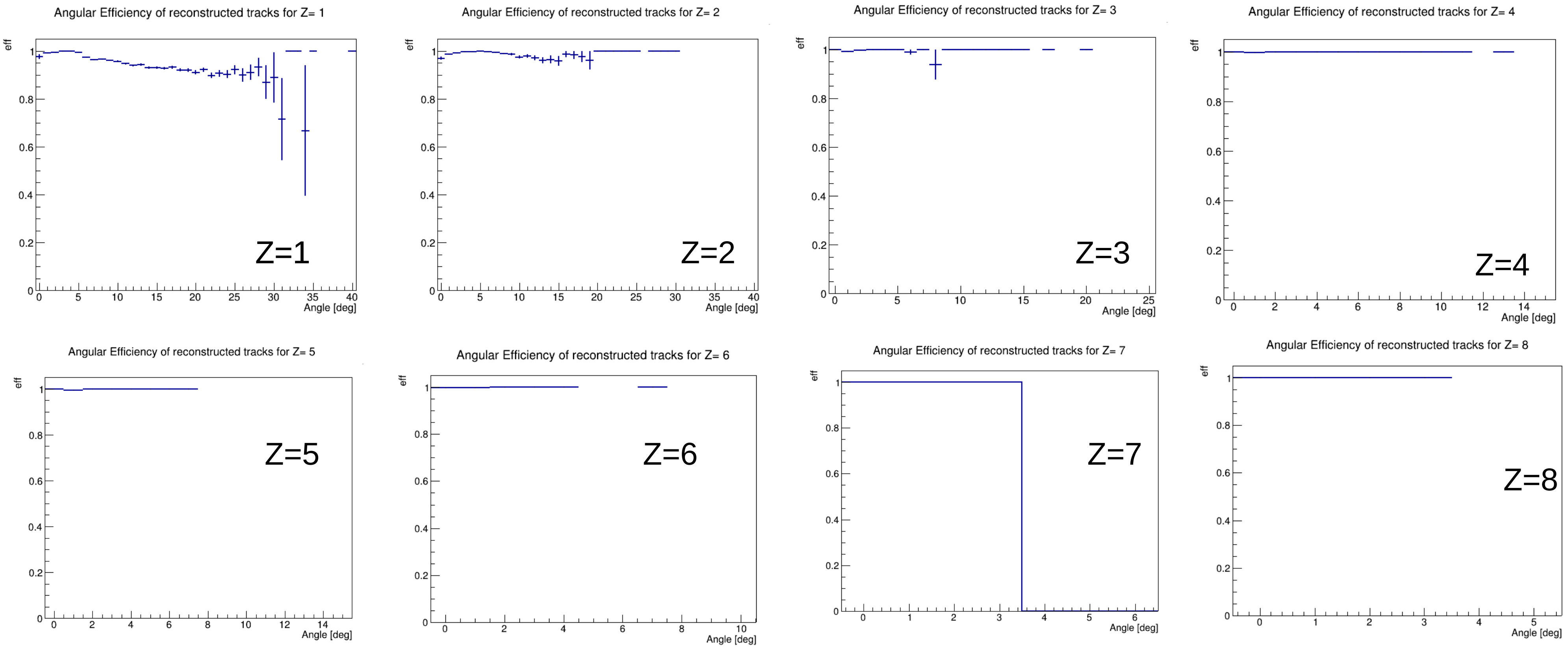


Performance factors

- **Angular efficiency:**
  - angular efficiency decreases with angle > 10°

tracks with >= 3 clus + noise (case 3)

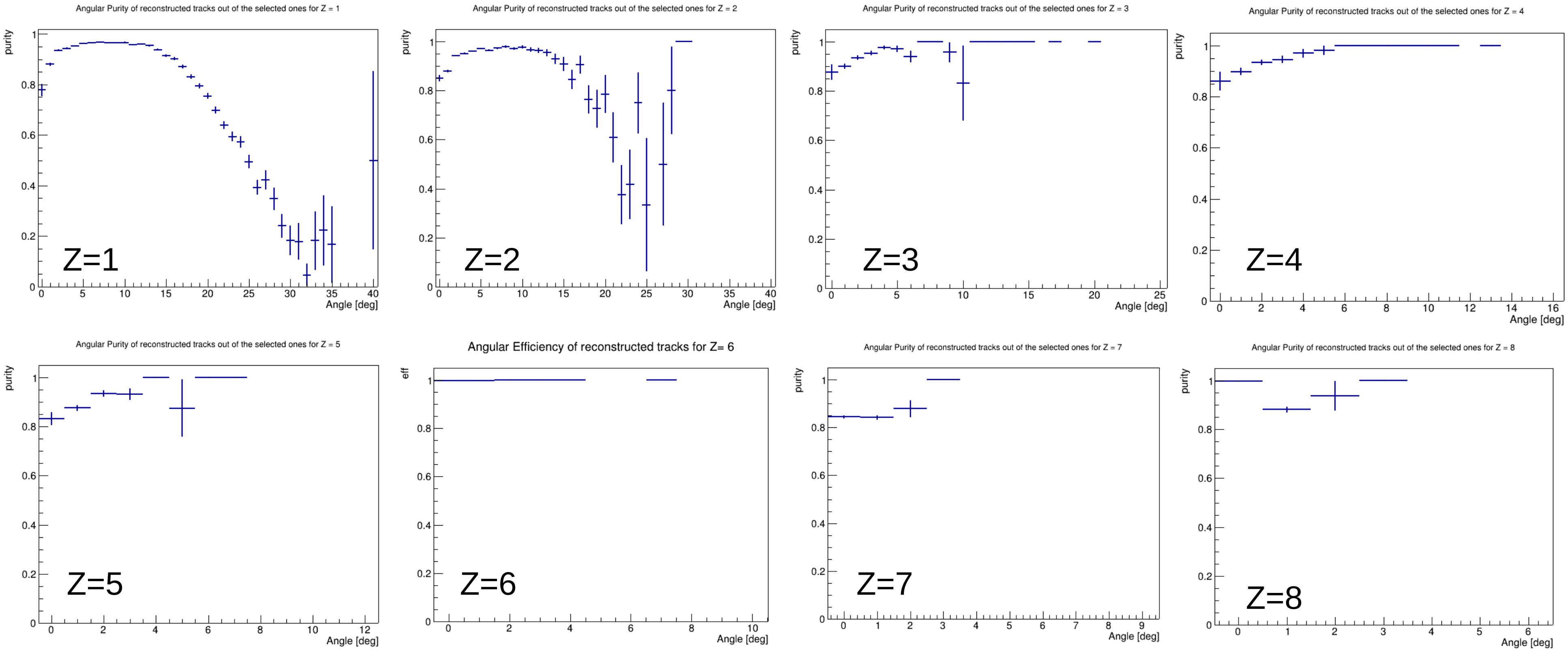
$$\epsilon_{track}(Z,\theta) = \frac{N_{GoodReco}(Z,\theta)}{N_{reference}(Z,\theta)}$$



Performance factors

- **Angular Purity:** tracks with >= 3 clus + noise (case 3)
- angular efficiency decreases with angle > 10°

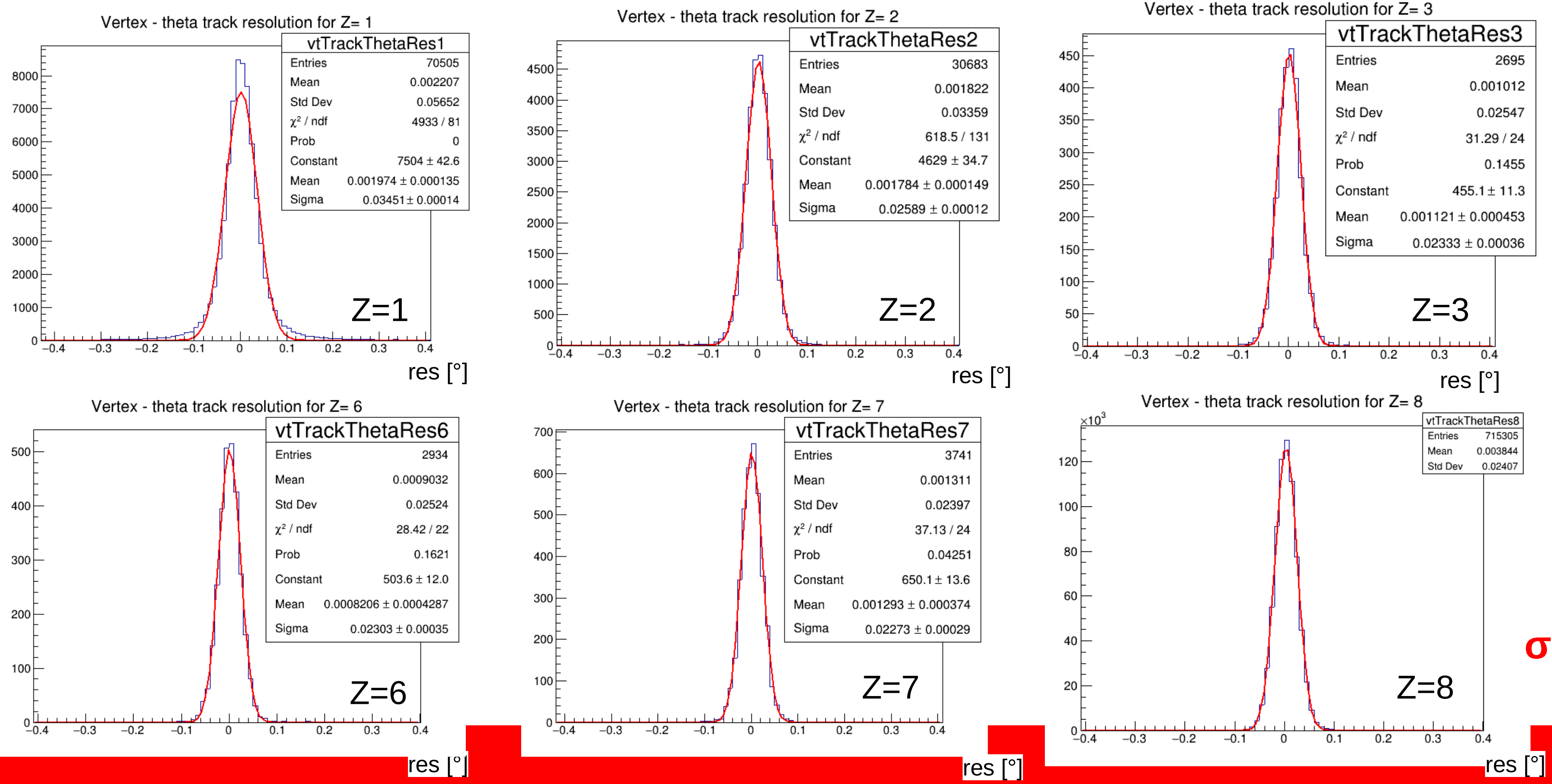
$$p_{track}(Z,\theta) = \frac{N_{GoodReco}(Z,\theta)}{N_{GoodReco}(Z,\theta) + N_{BadReco}(Z,\theta)}$$



Resolution Measurements

Track Polar Resolution

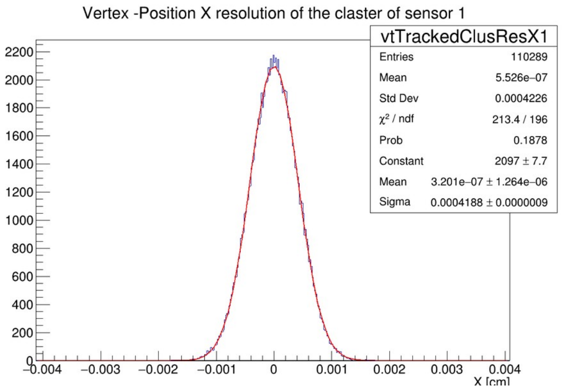
Polar angle resolution of the reconstructed track vs the mc particle: $res_\theta = \theta_{track} - \theta_{MCparticle}$

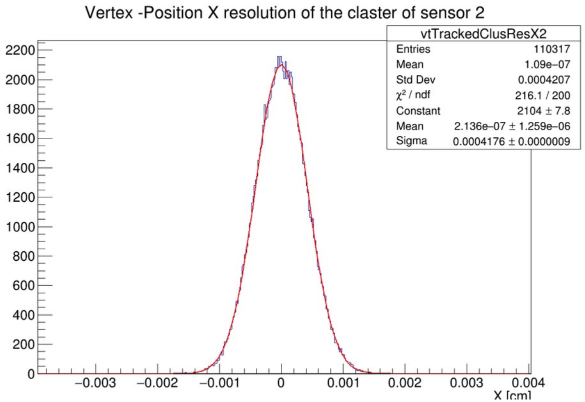


σ ~ 0.02°

Track – Cluster position Resolution

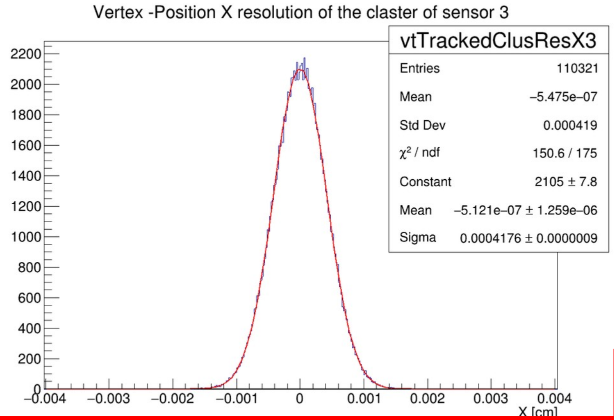
Position resolution of the reconstructed cluster of a track vs the MC Hit (from which the cluster is generated) for every sensor of the vertex in X and Y

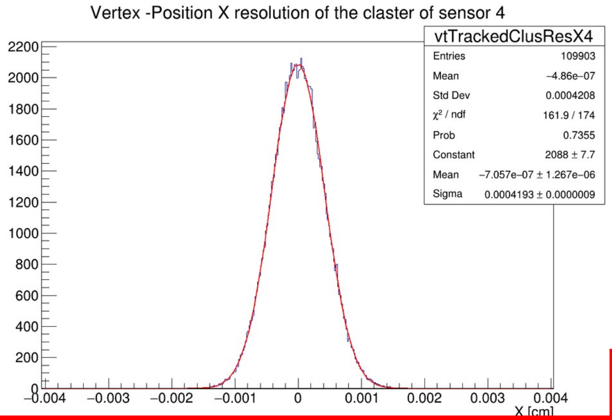




$$res_X = X_{cluster} - X_{MChit}$$

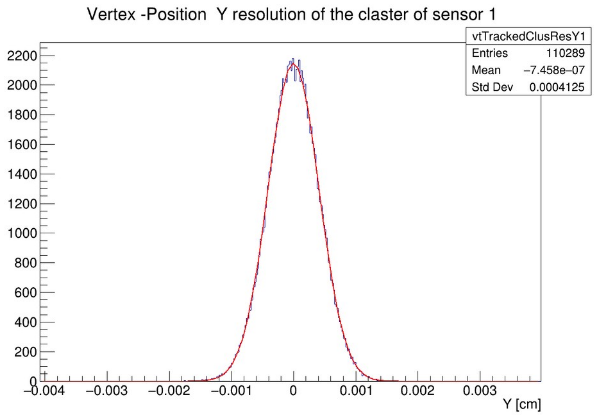
σ ~ 4 μm

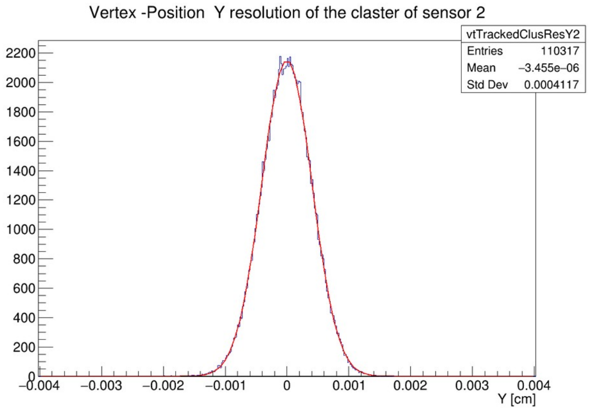




Track – Cluster position Resolution

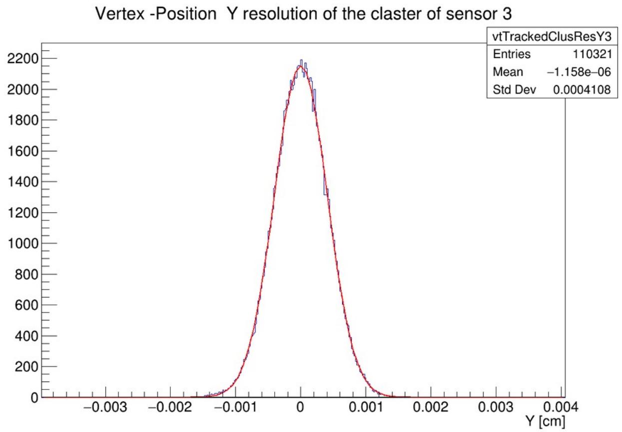
Position resolution of the reconstructed cluster of a track vs the
MC Hit (from which the cluster is generated) for every sensor of the vertex in X and Y

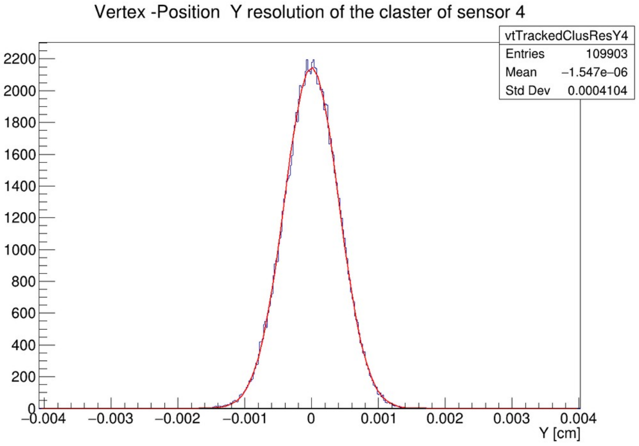




$$res_Y = Y_{cluster} - Y_{MChit}$$

σ ~ 4 μm





Vertex position Resolution

Position resolution of the reconstructed vertex of tracks vs the MC fragmentation position

$$res_X = X_{vtx} - X_{MC}$$

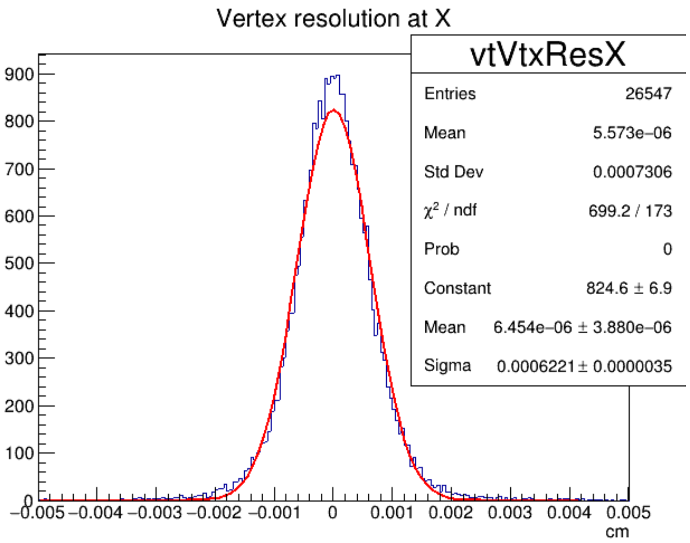
σ ~ 6 μm

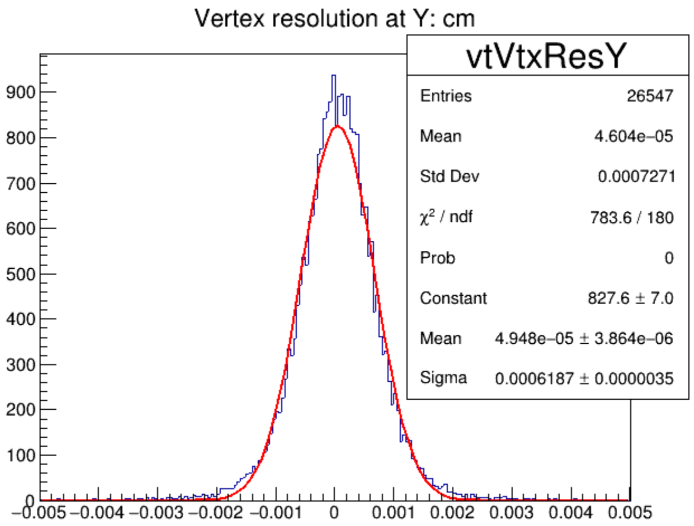
$$res_Y = Y_{vtx} - Y_{MC}$$

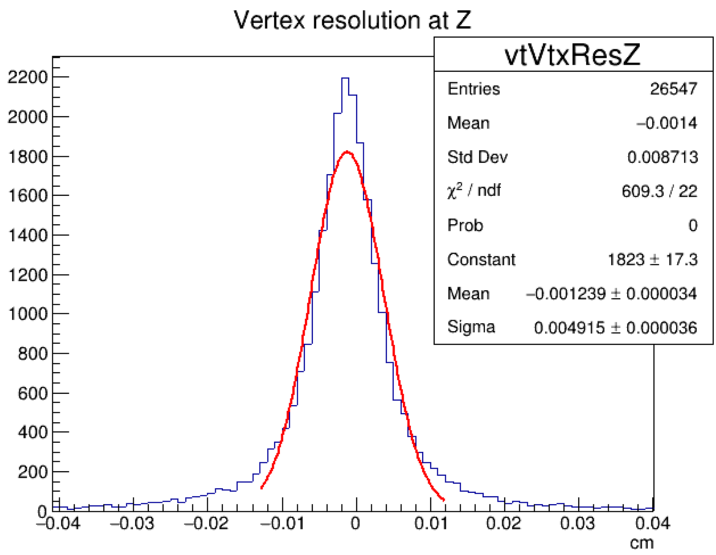
σ ~ 6 μm

$$res_Z = Z_{vtx} - Z_{MC}$$

σ ~ 50 μm







Conclusions

- Good efficiencies over ~90% and purities over ~80%
- Spatial resolution at the order of ~ μm
- good vertex identification, fundamental for out of target fragmentation removal
- performances in agreement with already published results.

- Performance studies to be run on every campaign

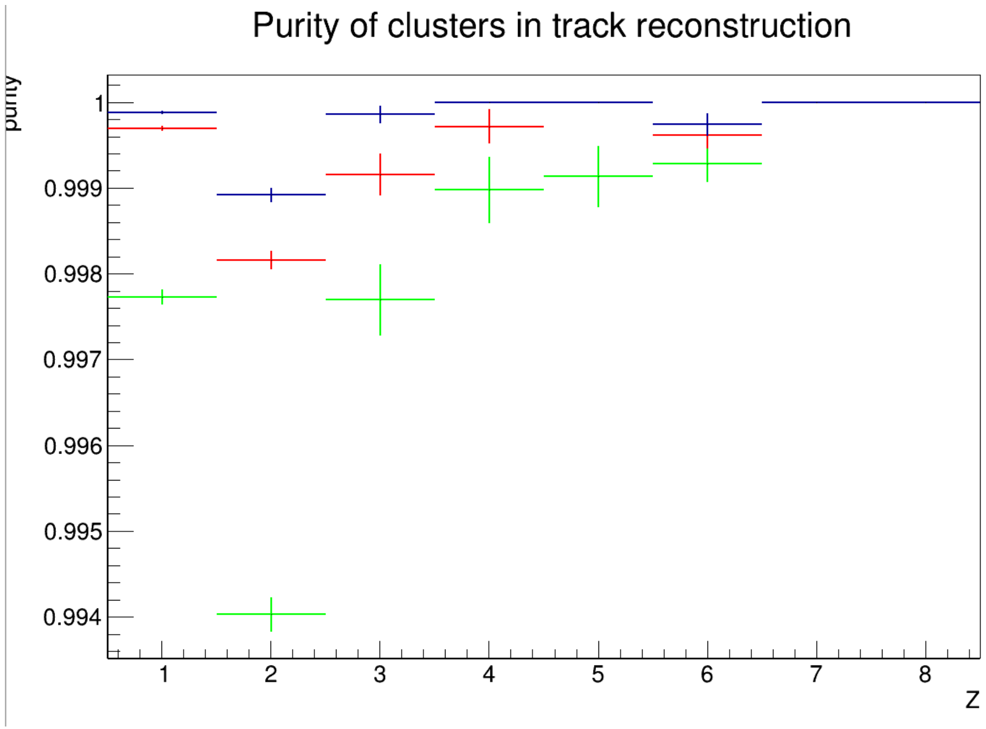
Thanks to Marco and Chris for the assistance and help!

Performance factors

- **Cluster purity**

counts of all the clusters matched well with the track MC_ID (in reference set) among all clusters of all $N_{GoodReco}$ tracks

$$\rho = \frac{\sum_{m=0}^{M} N_{correct}^{(m)}}{\sum_{m=0}^{M} N_{total}^{(m)}}$$

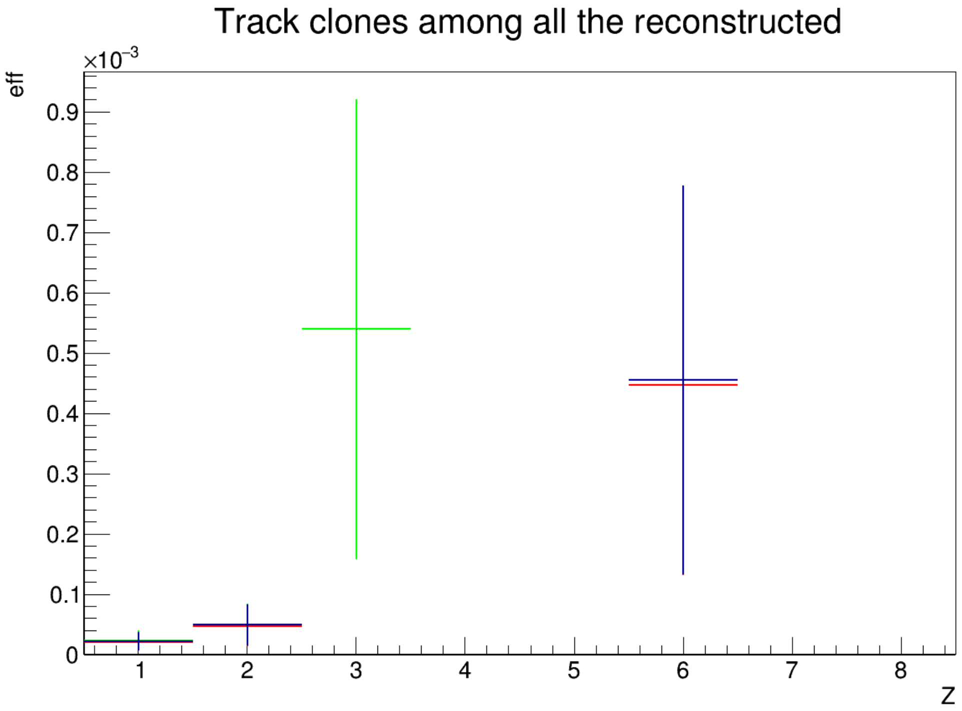


tracks with 4 clusters (case 1)
tracks with >=3 clusters (case 2)
tracks with >= 3 clus + noise (case 3)

Definitions for performance factors

- **Clone multiplicity**

  quantification of the number of multiple cloned trajectories produced for the same MC particle matched to the track



tracks with 4 clusters (case 1)
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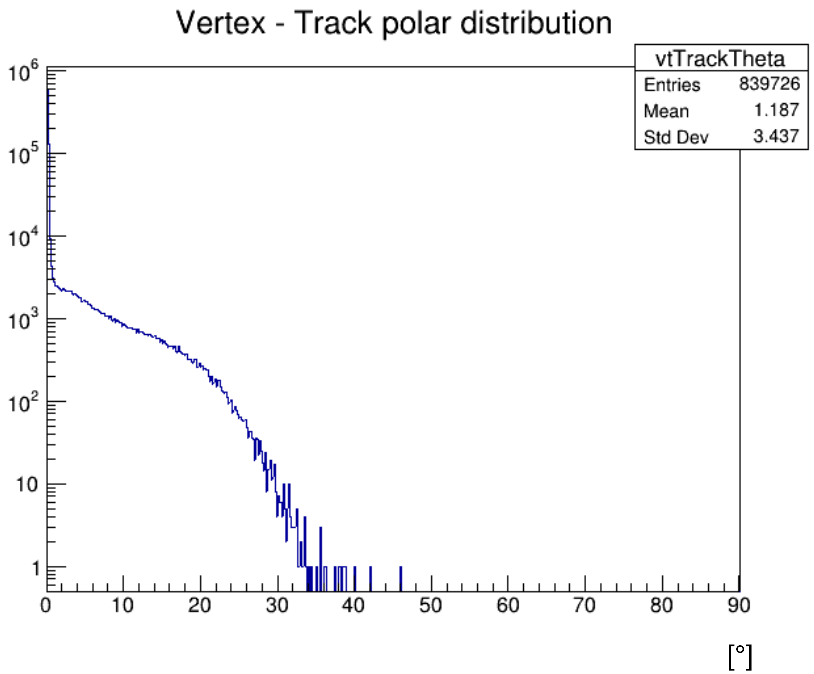
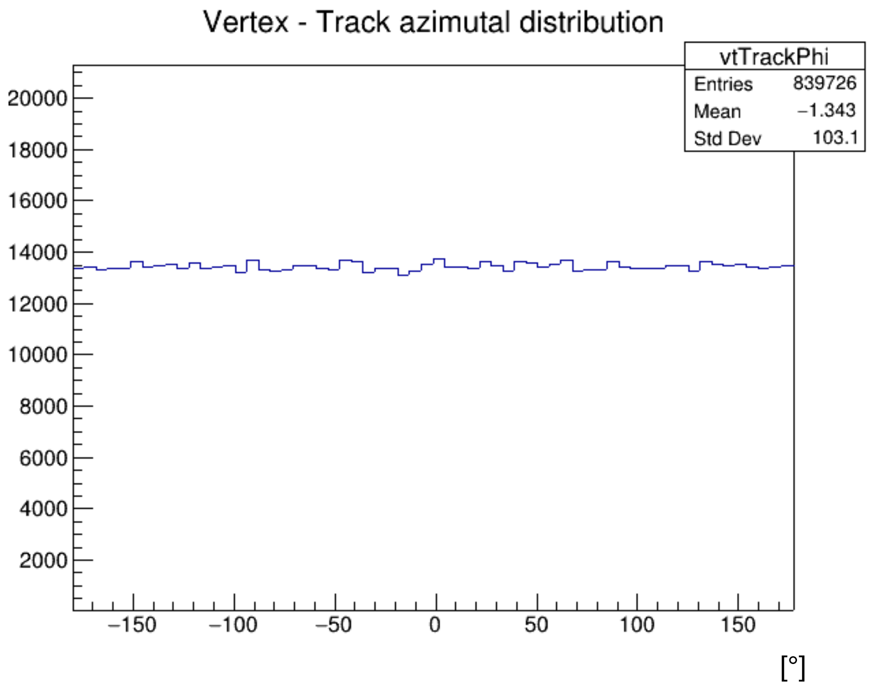
Vertex track angular distribution





efficiency resolution

- I consider the selection of an event of a given Z and theta as distributed with a binomial distribution

$$P(N_{sel}|N_{tot},\epsilon) = B(n; N_{tot},\epsilon)$$

- A good estimator of the efficiency is $\hat{\epsilon} = \frac{N_{sel}}{N_{tot}}$

- The associated error is $$\sigma^2_{\hat{\epsilon}} = V[\hat{\epsilon}] = V[\frac{N_{sel}}{N_{tot}}] = \frac{V[N_{sel}]}{N^2_{tot}} = \frac{N_{tot}\epsilon(1-\epsilon)}{N^2_{tot}}$$

then $$\sigma_{\hat{\epsilon}} = \sqrt{\frac{\epsilon(1-\epsilon)}{N_{tot}}}$$

N reference

- **Reference set: $N_{reference}$ (truth side)**
  all the tracks that an algorithm performing ideally should find and reconstruct:
  - all the tracks associated to a MC particle that crosses the FOOT apparatus at least until the last plane of the vertex (using MCRegion)
    - beam
    - primary fragment generated in the target

```
if (
    (particle_ID == 0                  // if the particle is a primary OR
    || (Mid == 0 && Reg == target_region) // if the particle is a primary fragment born in the target
    ) &&  particle->GetCharge() > 0 &&
    particle->GetCharge() <= primary_charge && // with reasonable charge
    OldReg == last_vtx_plane_region && NewReg == RegAirAfterVtx // it crosses the last plane of the vertex
)
 return true;
```