Track and vertex reconstruction with lenses in GRAIN

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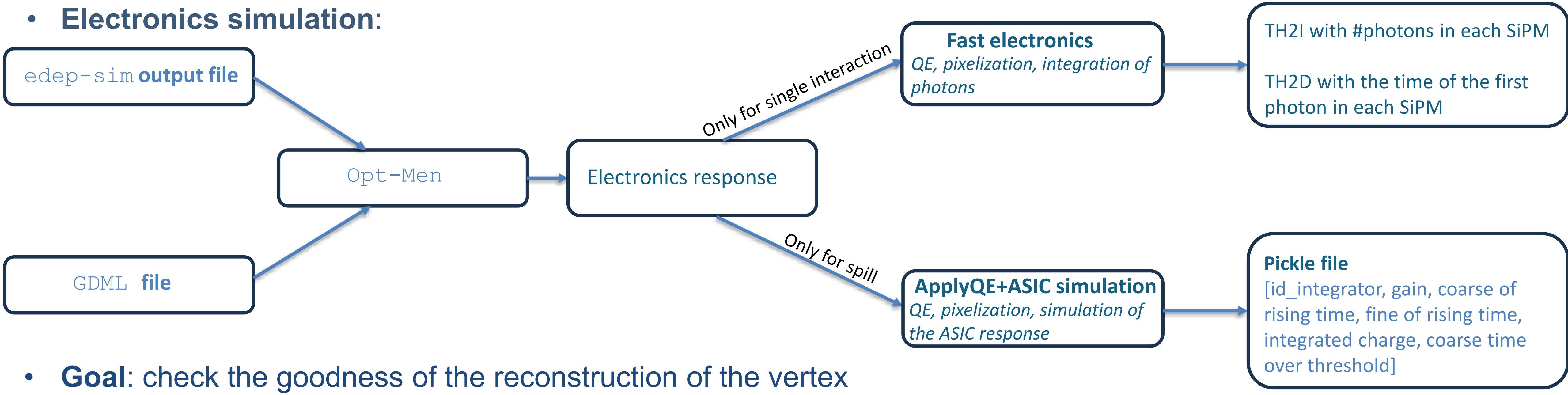
GRAIN performance studies

- The performance of GRAIN internal reconstruction on ν-Ar events is studied by simulating samples of neutrino interactions in its LAr volume.
- **Samples**: 20k ν_μ CCQE interactions in the whole GRAIN volume
  - Only single neutrino events have been considered
  - Integration time: 500 ns
- **Electronics simulation**:



- **Goal**: check the goodness of the reconstruction of the vertex coordinates, the track endpoint and the angle of the track

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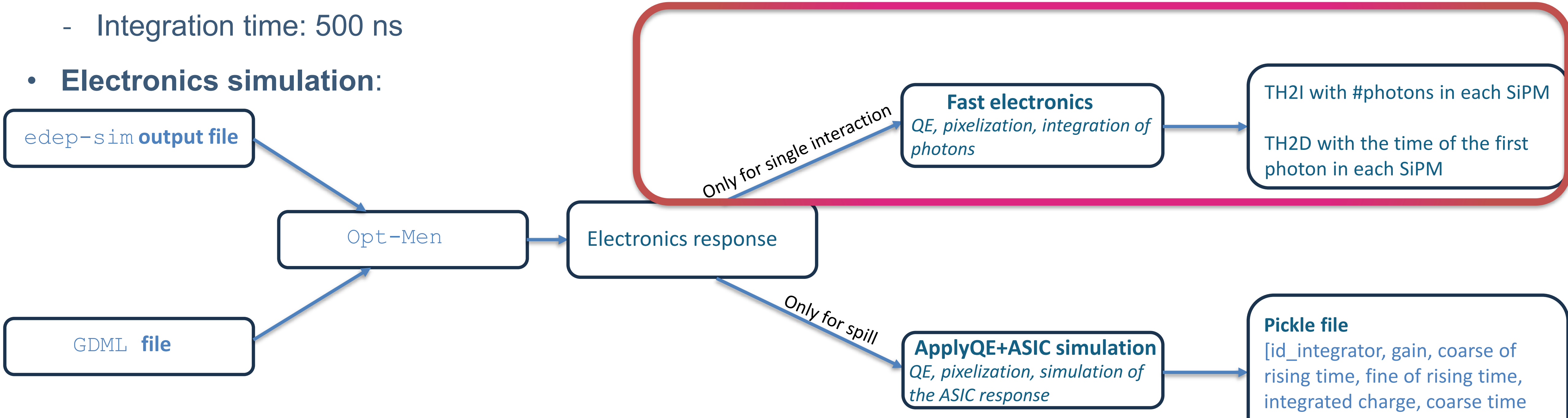

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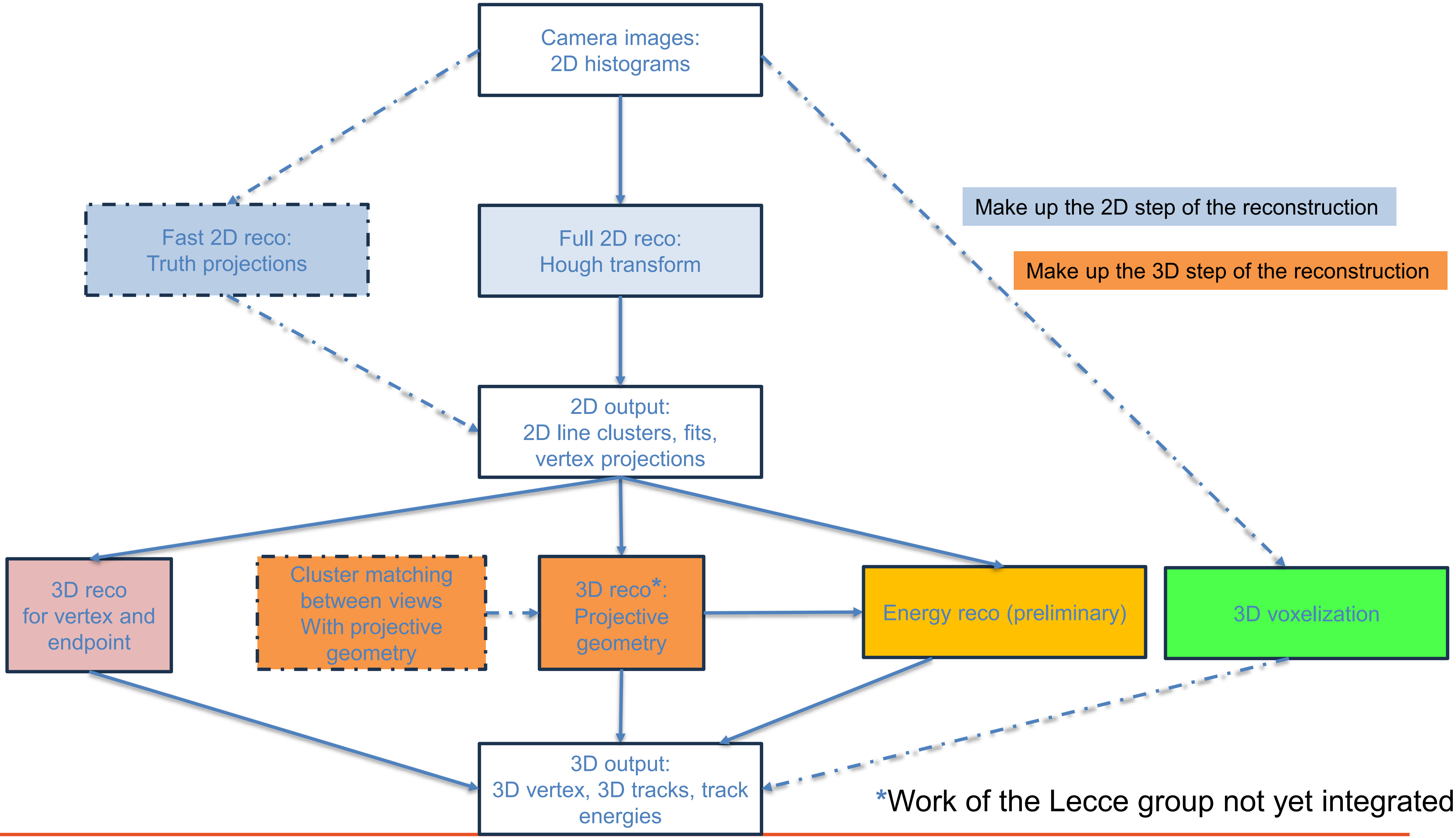
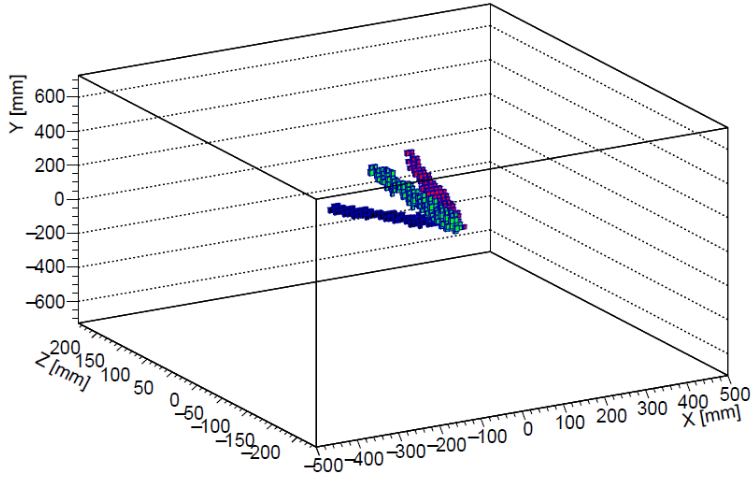


*Work of the Lecce group not yet integrated

Vertex and track reconstruction

- To obtain plots, we need as input:
  - The geometry file (gdml file)
  - The EdepSim file (energy deposit)
  - The output of FastElectronics

- **3D vertex reconstruction** is done by identifying 2D vertex projections as track intersections in at least two cameras, then back-projecting them.

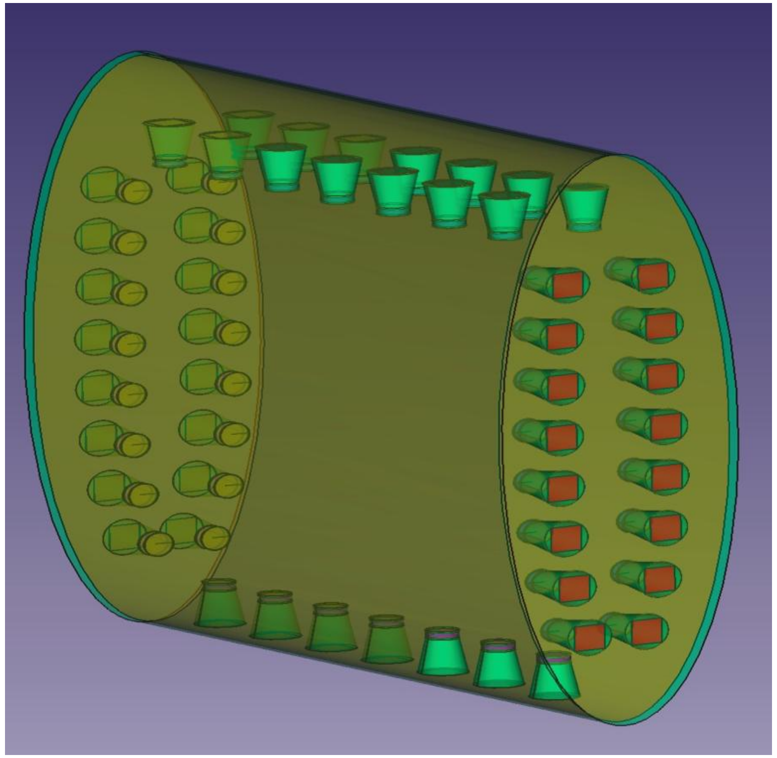


- **The 2D endpoints** on the images are identified by taking the ends of each track cluster. Because of this, the 2D endpoint estimates are affected by the image quality and shape of the clusters.

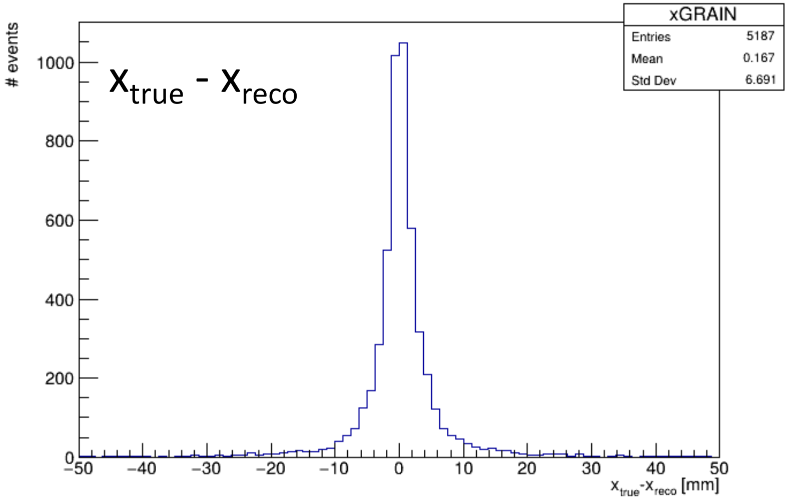
- **Track directions** are estimated using either:
  - **The endpoint method** (vertex-to-endpoint vector)
  - **A voxel-based 3D fit** using 2D projections

New geometry – lens configuration

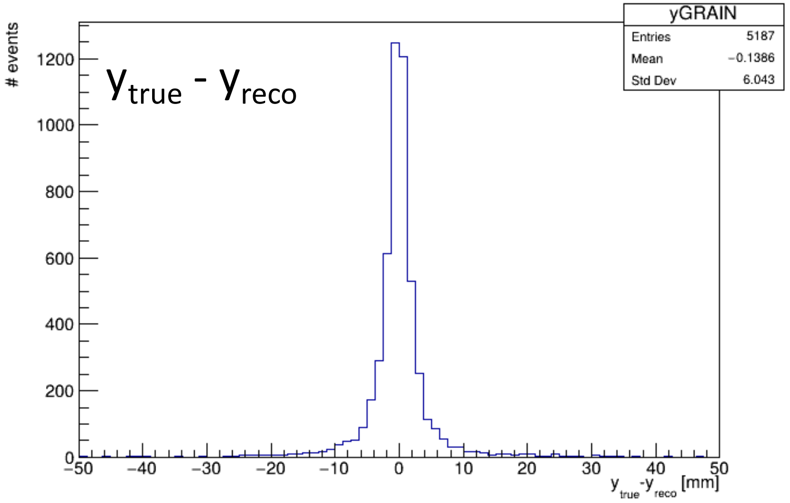
Item	Old geometry	New geometry
Total cameras	38	53
Side cameras	28	32
Top row	5	14
Bottom row	5	7
Camera length	10 cm	14 cm
GRAIN x	1000 mm	1500 mm
GRAIN y	1456 mm	1478 mm
GRAIN z	475 mm	487 mm



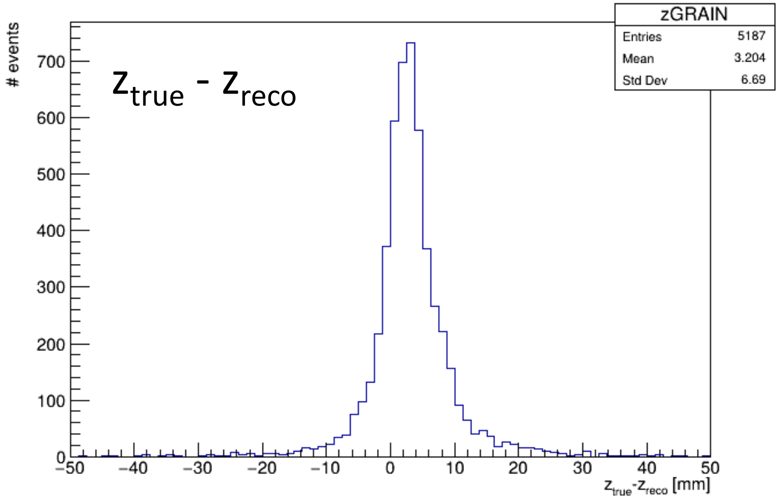
Vertex reconstruction – residuals



With the ***old geometry***
Mean 0.269
Std Dev 19.49



With the ***old geometry***
Mean 0.01507
Std Dev 17.78



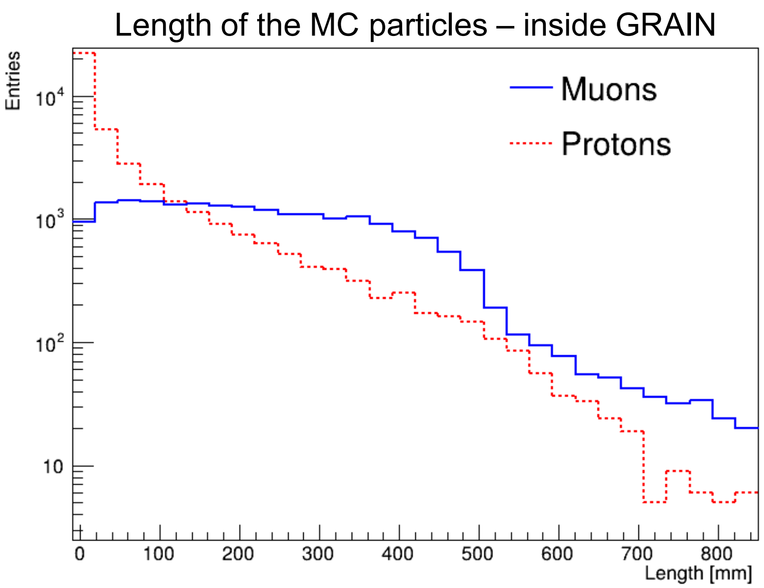
With the ***old geometry***
Mean -2.047
Std Dev 17.53

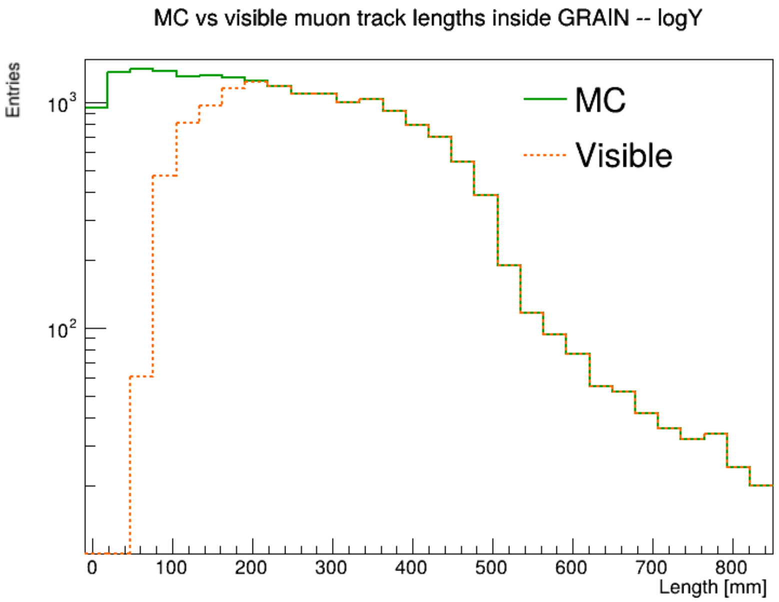
vertices reconstructed: 5187 over 20k ν_μ CCQE interactions in the whole volume

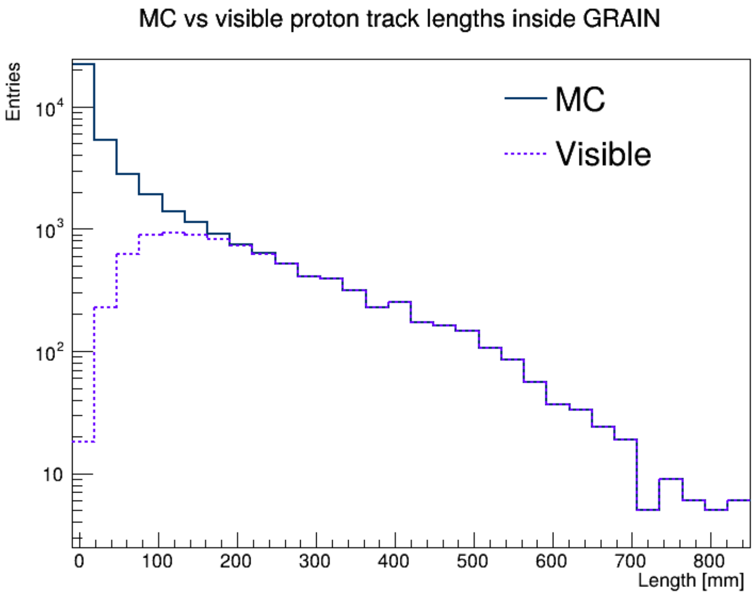
Considering the volume inside the lenses, the number of events is 9439 → 55% of success

All distributions appear centered in zero and symmetric, however a small positive bias is present in the z residuals showing a preference for $z_{reco} < z_{true}$.

Tracks inside GRAIN



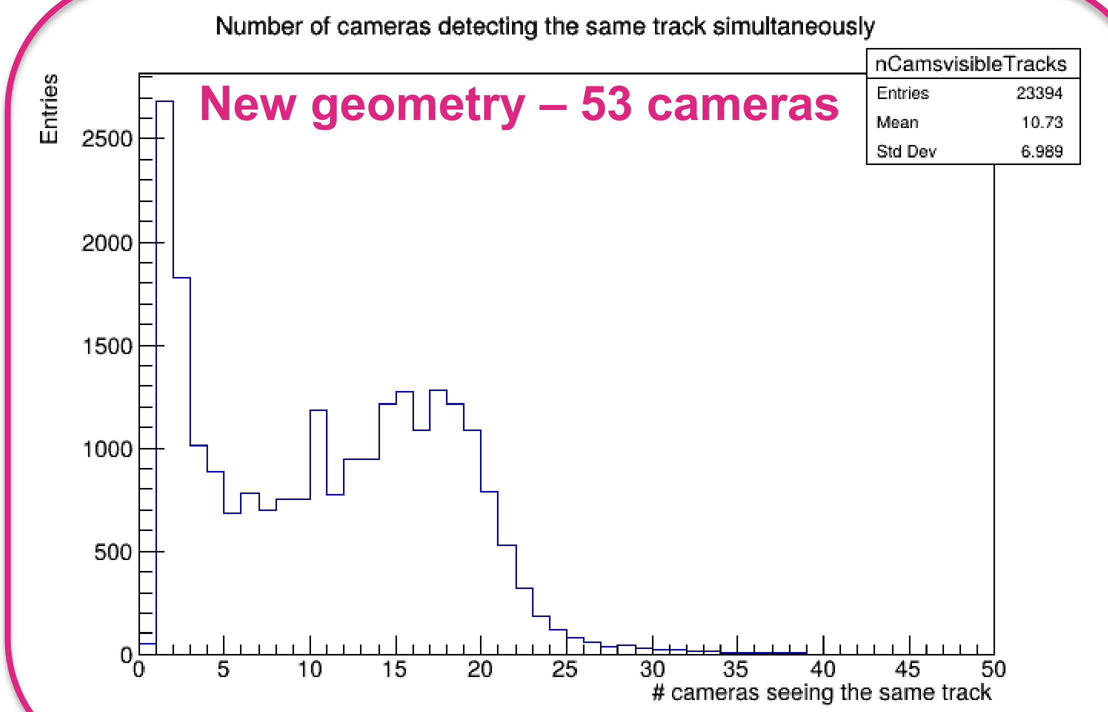


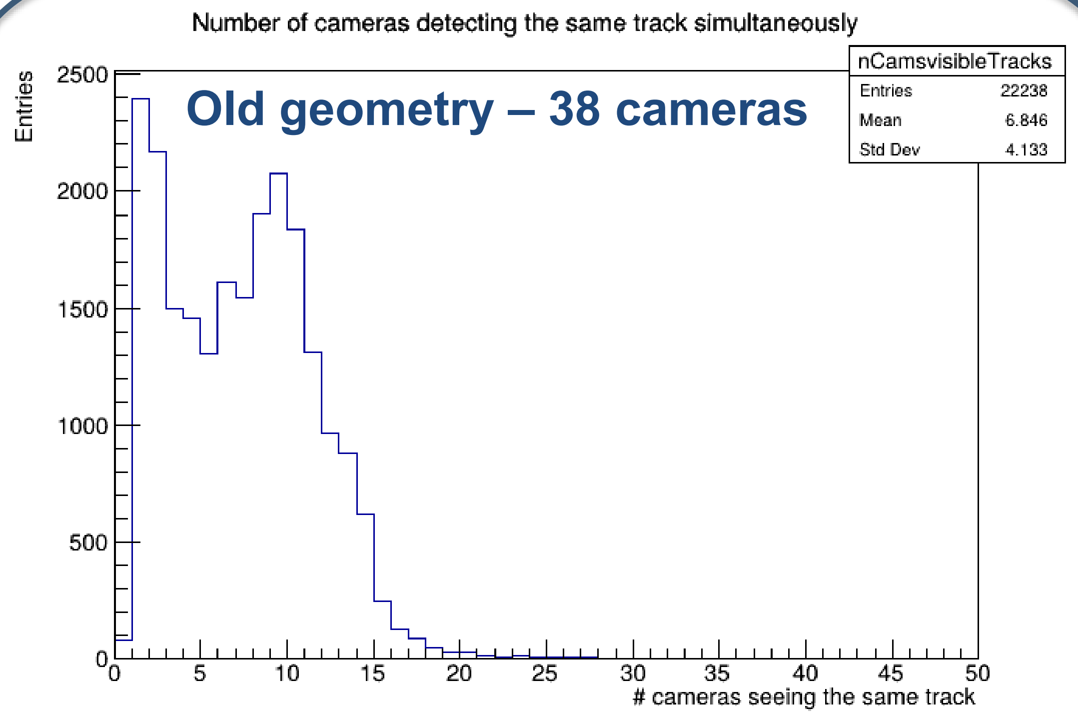


≈40% of the tracks is ***visible***
A track is visible if its truth-level projection is longer than 10 pixels

The lengths have been calculated inside GRAIN. This is necessary if you want to compare the MC lengths with the visible lengths.

#cameras detecting the same track simultaneously



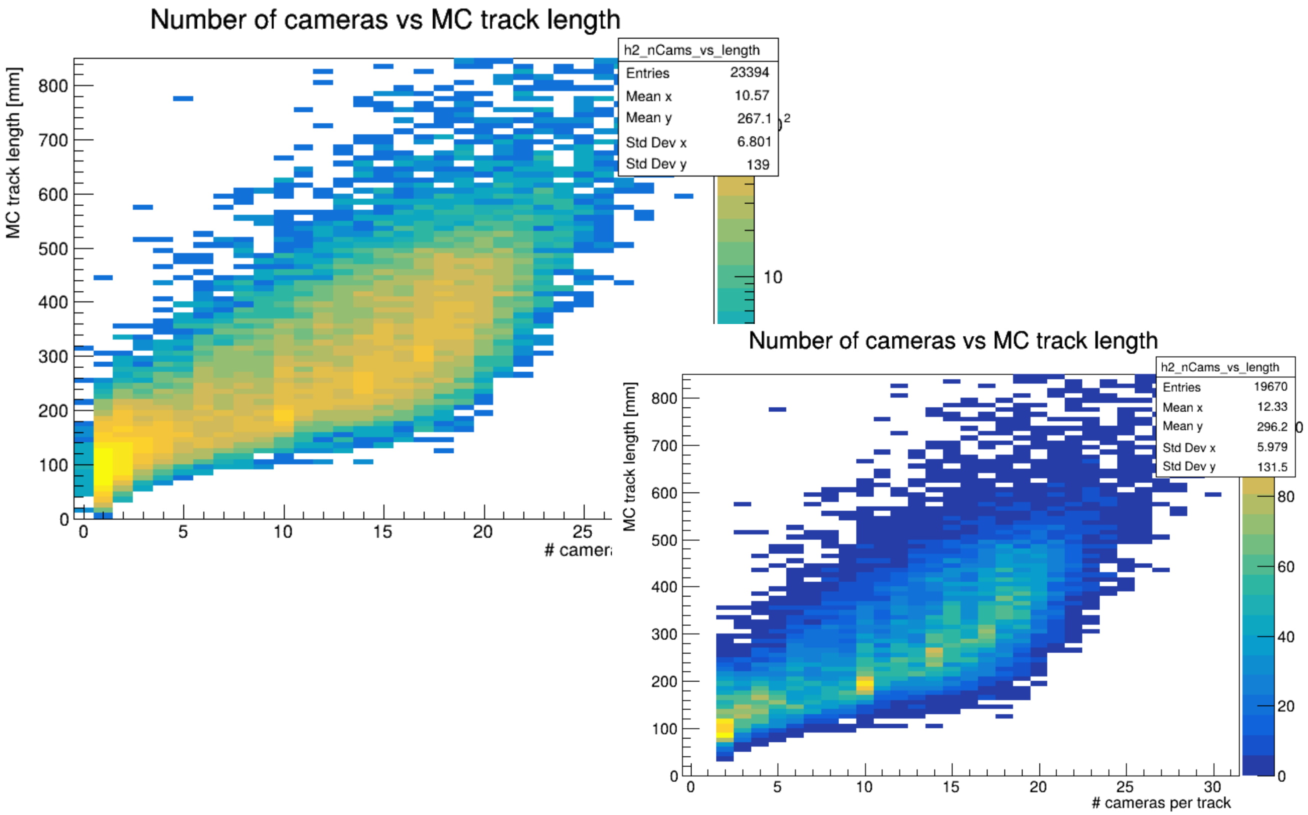


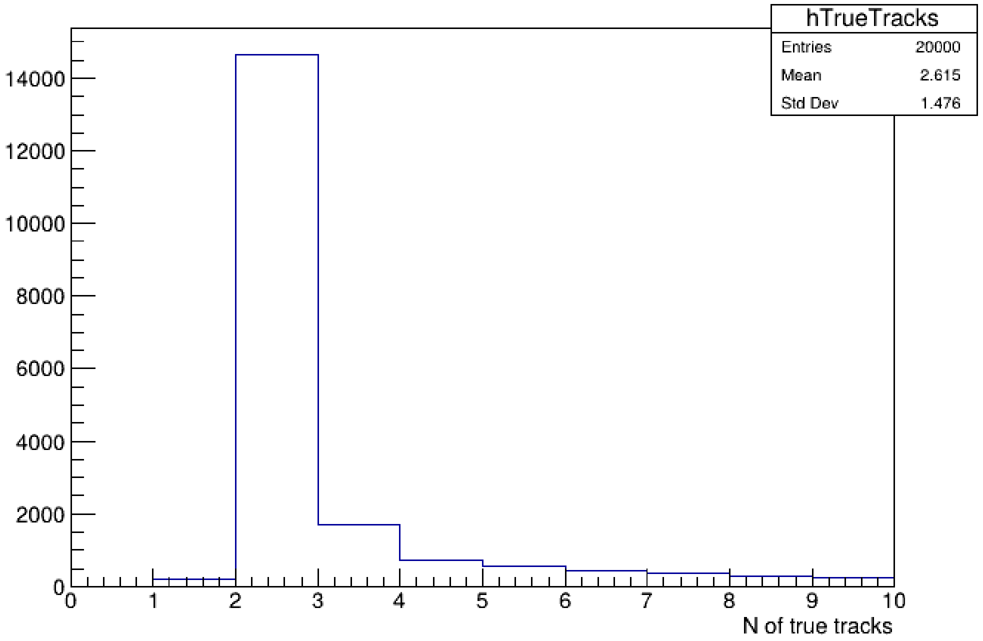
Old geometry: ~7 cameras record the same track simultaneously

New geometry: ~11 cameras record the same track simultaneously

→ Clear improvement!

Track visibility and number of tracks per event

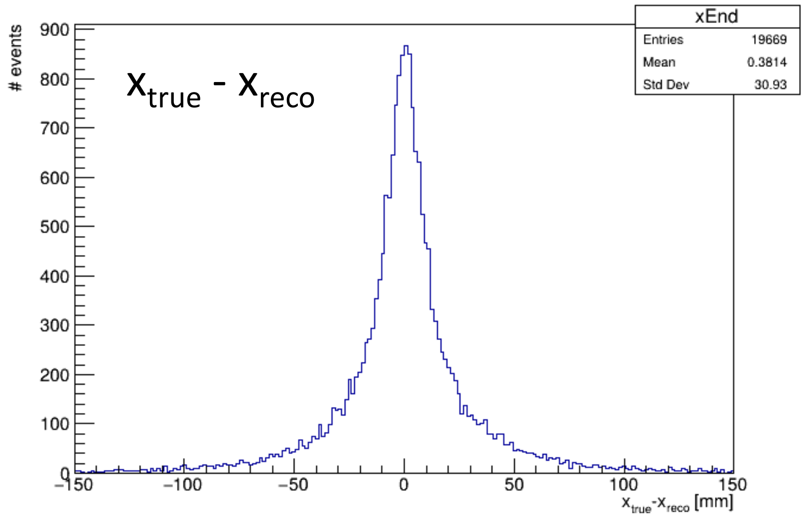




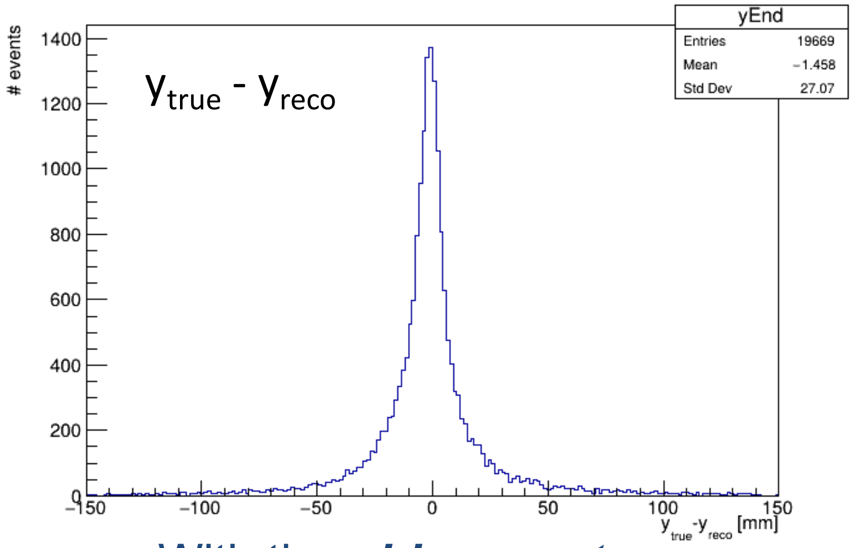
Left plots: the top-left plot shows the distribution for ***visible tracks***, while the bottom-right plot corresponds to ***reconstructed tracks***. Out of 23394 visible tracks, 19669 were successfully reconstructed, corresponding to a reconstruction efficiency of ~84%.

Right plot: distribution of the number of true tracks per event. Most events have 2 true tracks, while 201 events out of 20k interactions feature only one track, which is consistently identified as a muon → FSI

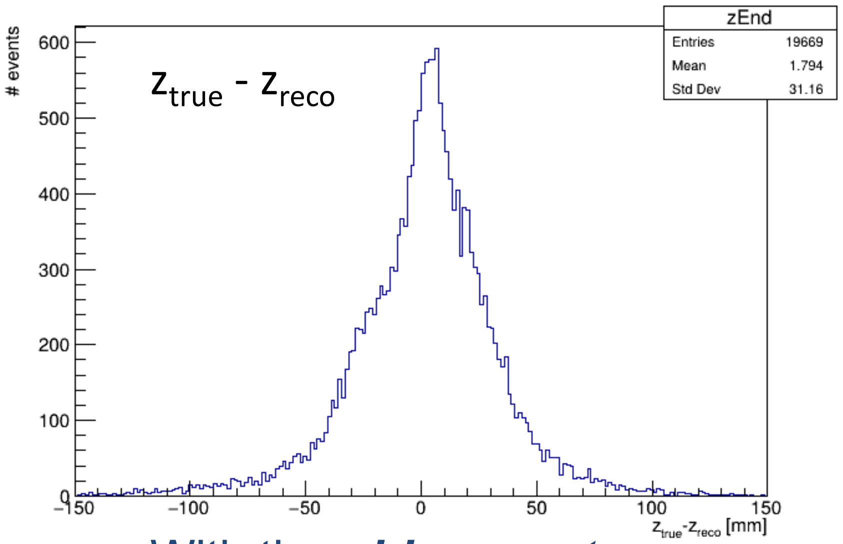
Endpoint reconstruction – residuals



With the ***old geometry***
Mean 0.04
Std Dev 28.95



With the ***old geometry***
Mean 0.132
Std Dev 20.84



With the ***old geometry***
Mean 6.31
Std Dev 29.12

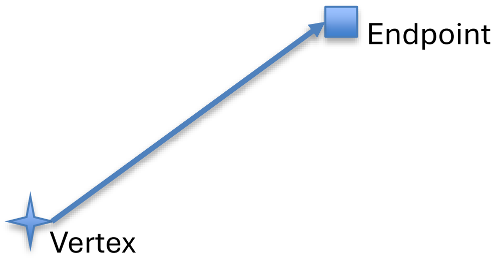
reconstructable tracks: 23394 (considered as visible tracks)
endpoints reconstructed: 19669 → the reconstruction is successful for 84% of the cases

All distributions are approximately centered around zero and roughly symmetric; however, small deviations in both directions are present in the z residuals, indicating occasional over- or underestimation of the reconstructed positions relative to the true position.

Track direction reconstruction – methods

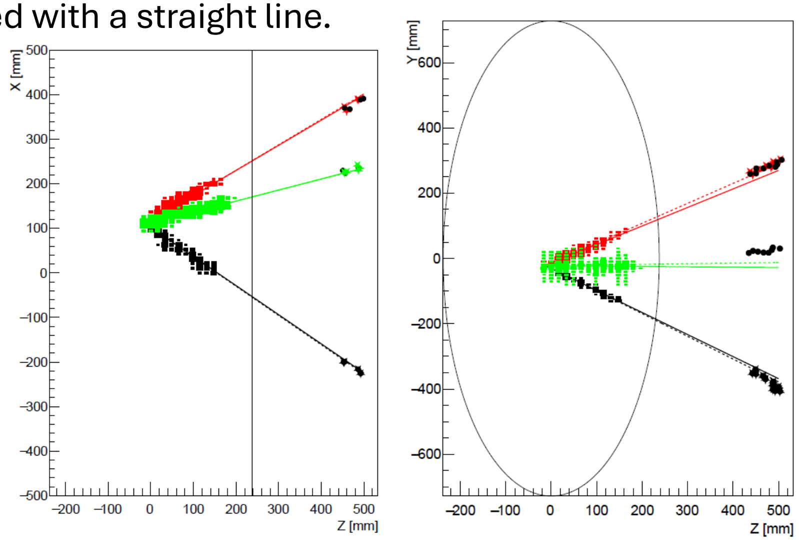
Endpoint method

The simplest method for determining the track direction is known as the "endpoint method." This approach involves calculating the vector from the vertex to the track's endpoint. Essentially, a basic representation of the track is the line segment connecting these two points. However, relying on this two-point estimation can be more susceptible to inaccuracies in the reconstruction, particularly regarding the position of the endpoint.



Voxel fit method

A more robust method for extracting the 3D direction can be obtained by utilizing the output of the voxel-based reconstruction. In this case, tracks are represented by a collection of voxels in space. A 3D fit over these clouds of voxels returns the actual shape and direction of the track. For simplicity, instead of a direct 3D fit, the 2D projections of the track voxels in the ZY and ZX planes are fitted with a straight line.

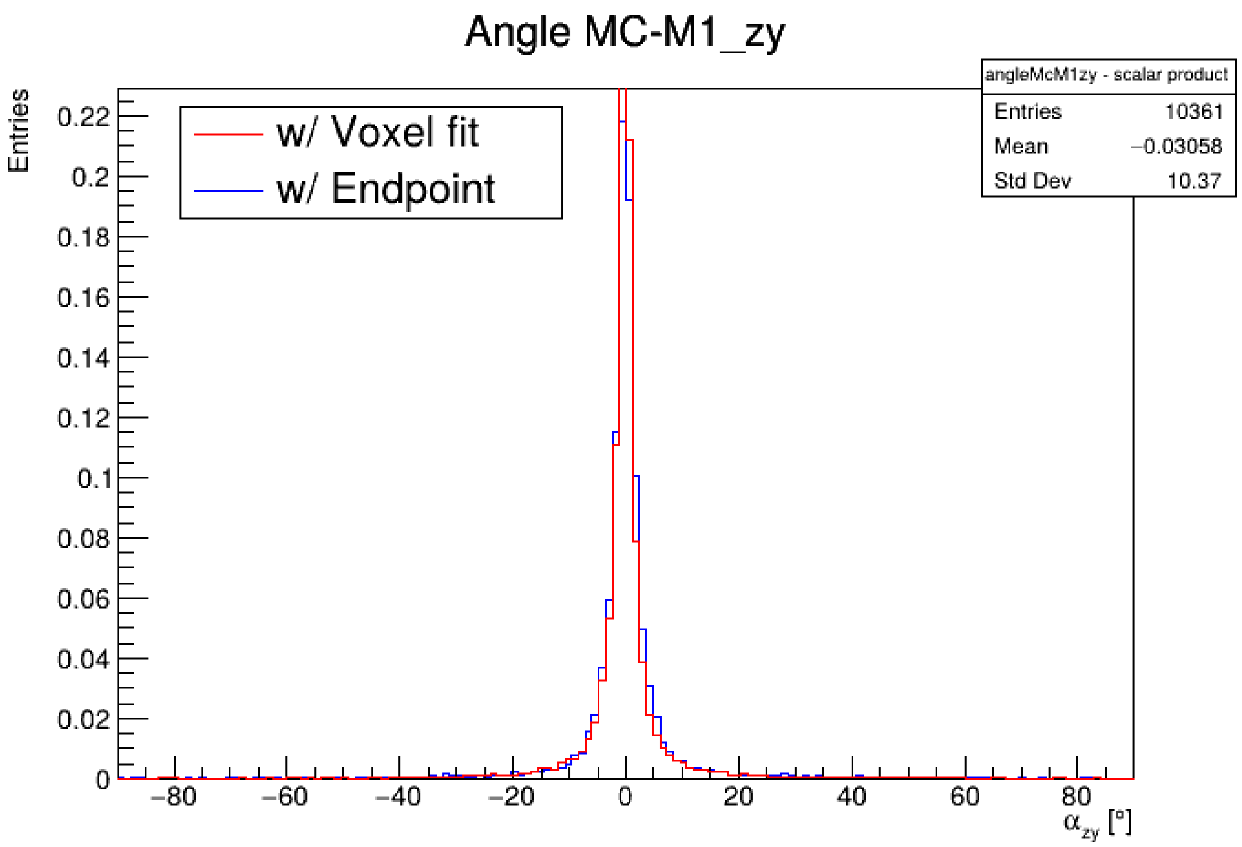


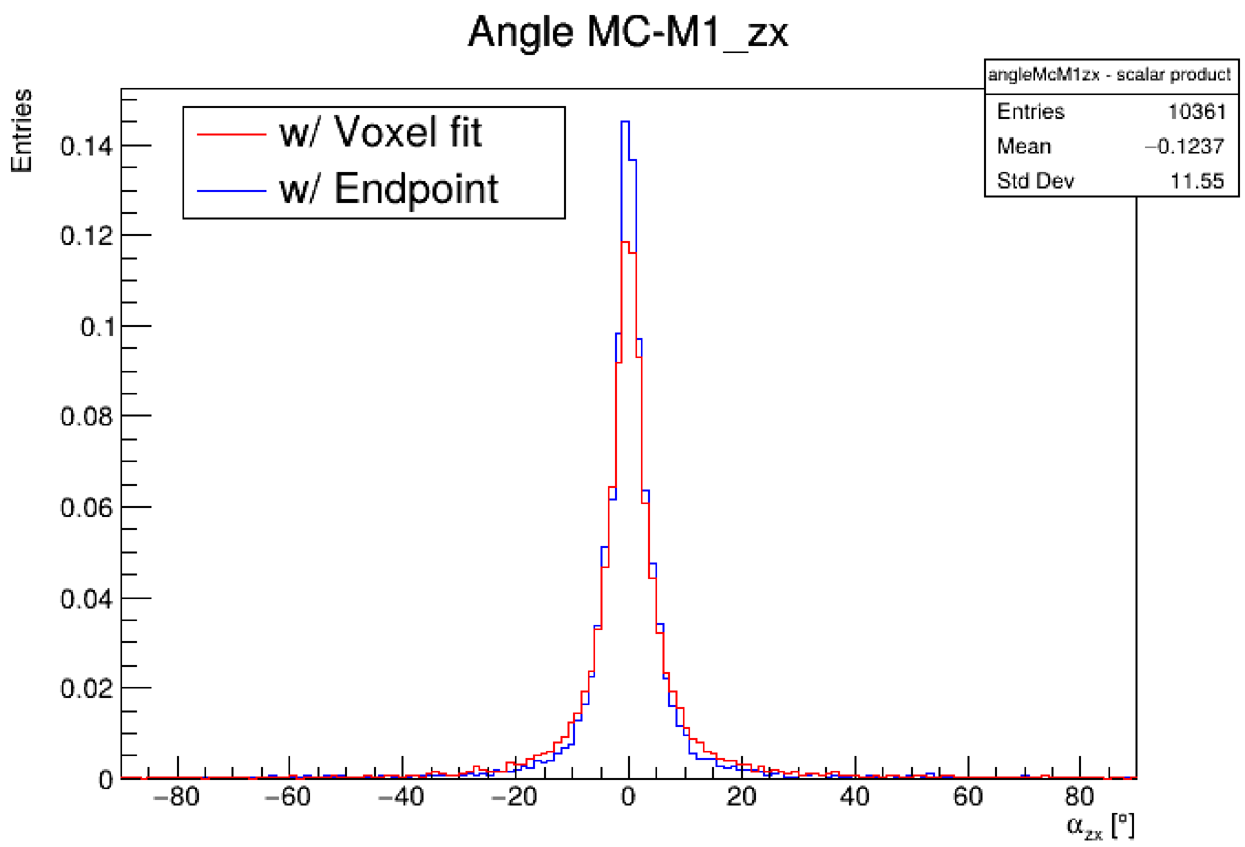
(a) ZX (top) (b) ZY (side)

Voxel fit method ——

Endpoint method - - - - -

Track direction reconstruction – residuals



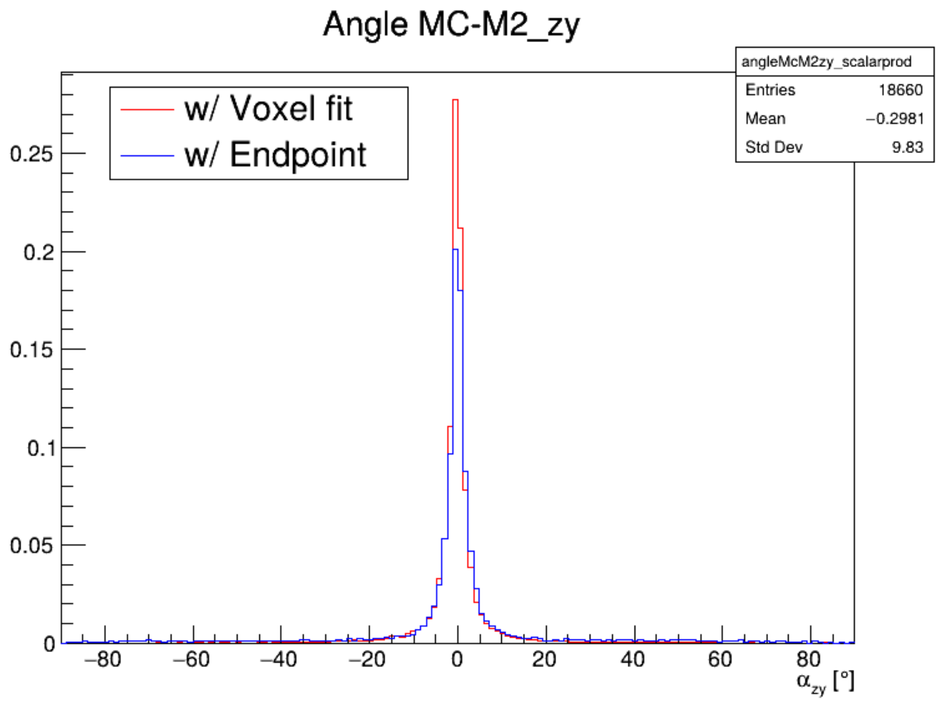


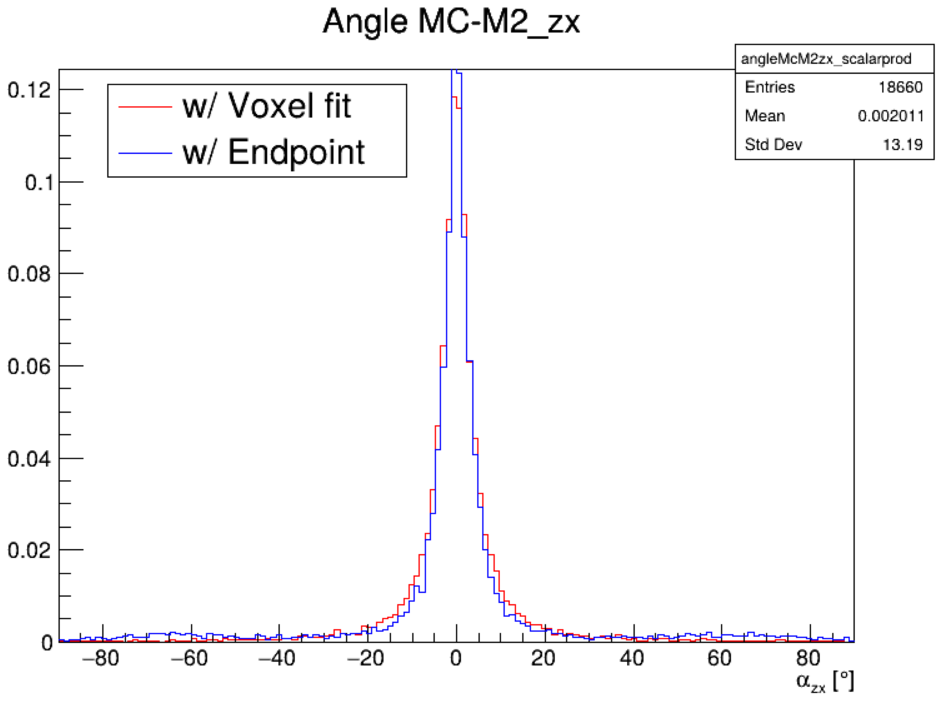
Out of 23394 visible tracks, 19669 are reconstructed. For track angle reconstruction, two methods are used:

1) **Endpoint method** → reconstruction is successful in 10989 cases (≈55% of cases)
2) **Voxel fit method** → reconstruction is successful in 18660 cases (94% of cases)

Track direction reconstruction – residuals – 2

Since the M1 method fails when the vertex is not reconstructed, I use the M2 method to obtain the track direction and then recover the vertex from it. This improves the M1 reconstruction performance, increasing the success rate from **55%** to **93%**.





Out of 23394 visible tracks, 22164 should be reconstructed and 19669 are reconstructed (valid endpoint).
For track angle reconstruction, two methods are used:

1) **Endpoint method** → reconstruction is successful in **10361**+**7826** cases (≈93% of cases)
2) **Voxel fit method** → reconstruction is successful in 18660 cases (94% of cases)

Next steps

- The results presented are from the initial studies
- The results obtained are satisfactory and compatible with those obtained with the old geometry
- In future, the neutrino energy will be extracted by combining information coming from the downstream tracker and calorimeter of SAND
- The ultimate goal will be evaluating the impact of the reconstructed sample on the DUNE Near Detector physics for a precise estimation of the neutrino flux

THANK YOU FOR YOUR ATTENTION