Università di Genova

INFN GENOVA
Istituto Nazionale di Fisica Nucleare
Sezione di Genova

DUNE
DEEP UNDERGROUND NEUTRINO EXPERIMENT

Light simulation and reconstruction with lenses in GRAIN

SAND meeting – 21/01/2022

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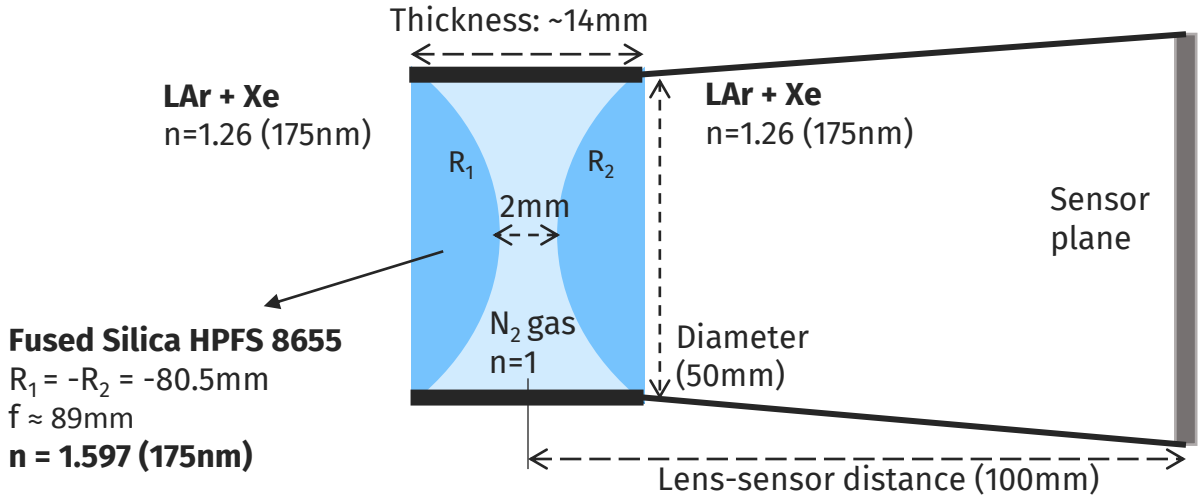
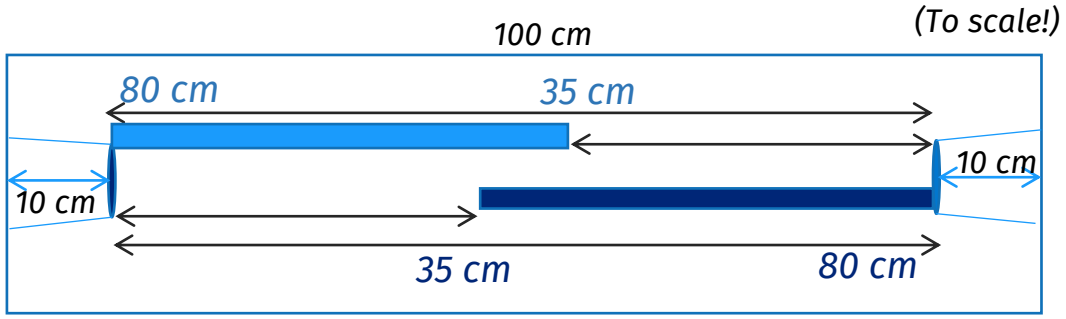
Lenses in GRAIN

- **Gas-lens concept (first prototype):**
  - Xe-doped LAr (175nm)
  - Two plane-convex lenses
  - Focusing with inner gas layer ($n_{gas} < n_{LAr+Xe}$)
  - Lens-sensor distance fixed to optimize the depth of field
- **In the current design, two opposite cameras can cover up to 100 cm:**

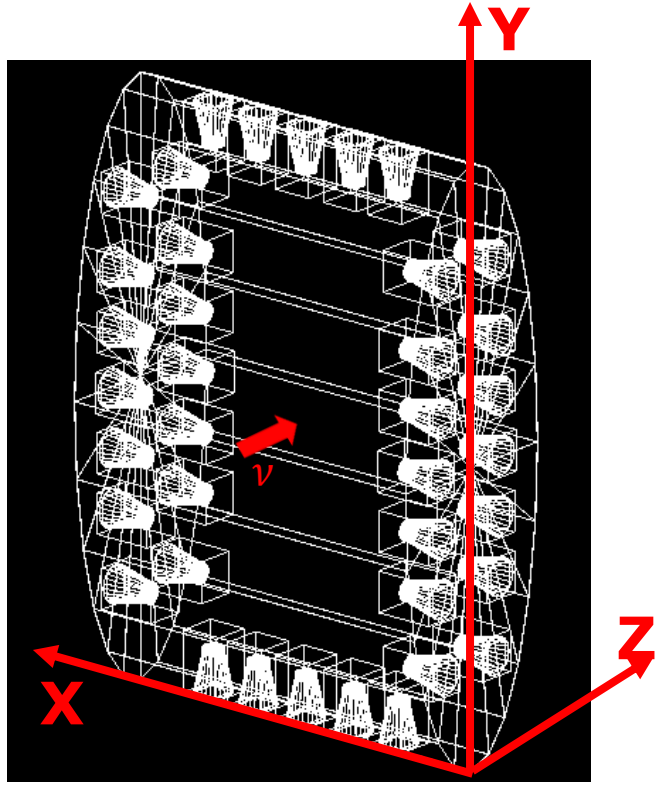




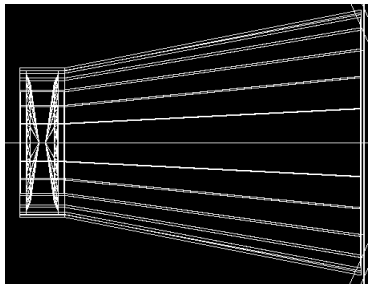
Geometry in GRAIN

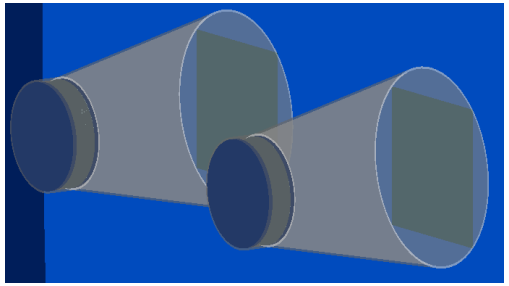
- Latest GRAIN geometry (option 2), equipped with lens-cameras inside the LAr volume.
  - Except $L_x = 1000\ mm$
- 38 cameras, for maximum coverage:
  - 14 pairs on the sides (at optimal distance)
  - 5 pairs on top/bottom
- Assuming 32x32 matrix sensors, with 2 mm pixels and 20% QE.

GDML:



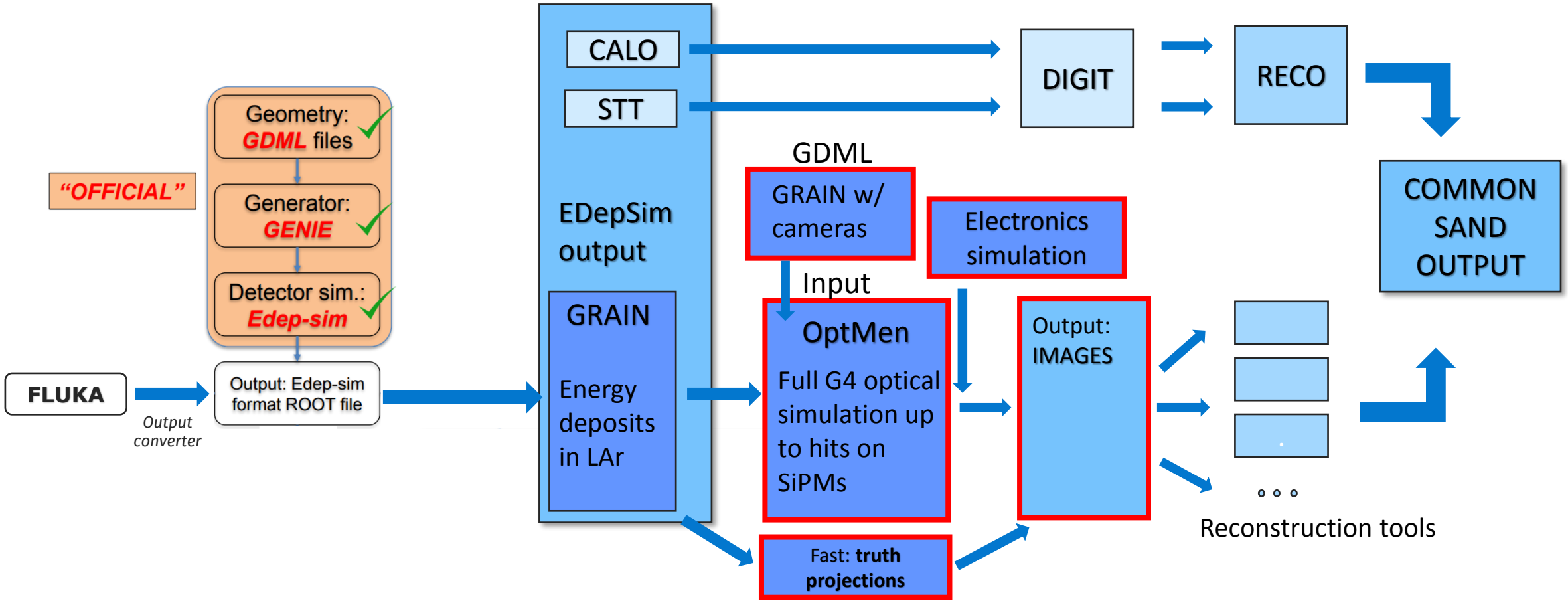
Full GEANT4 implementation:





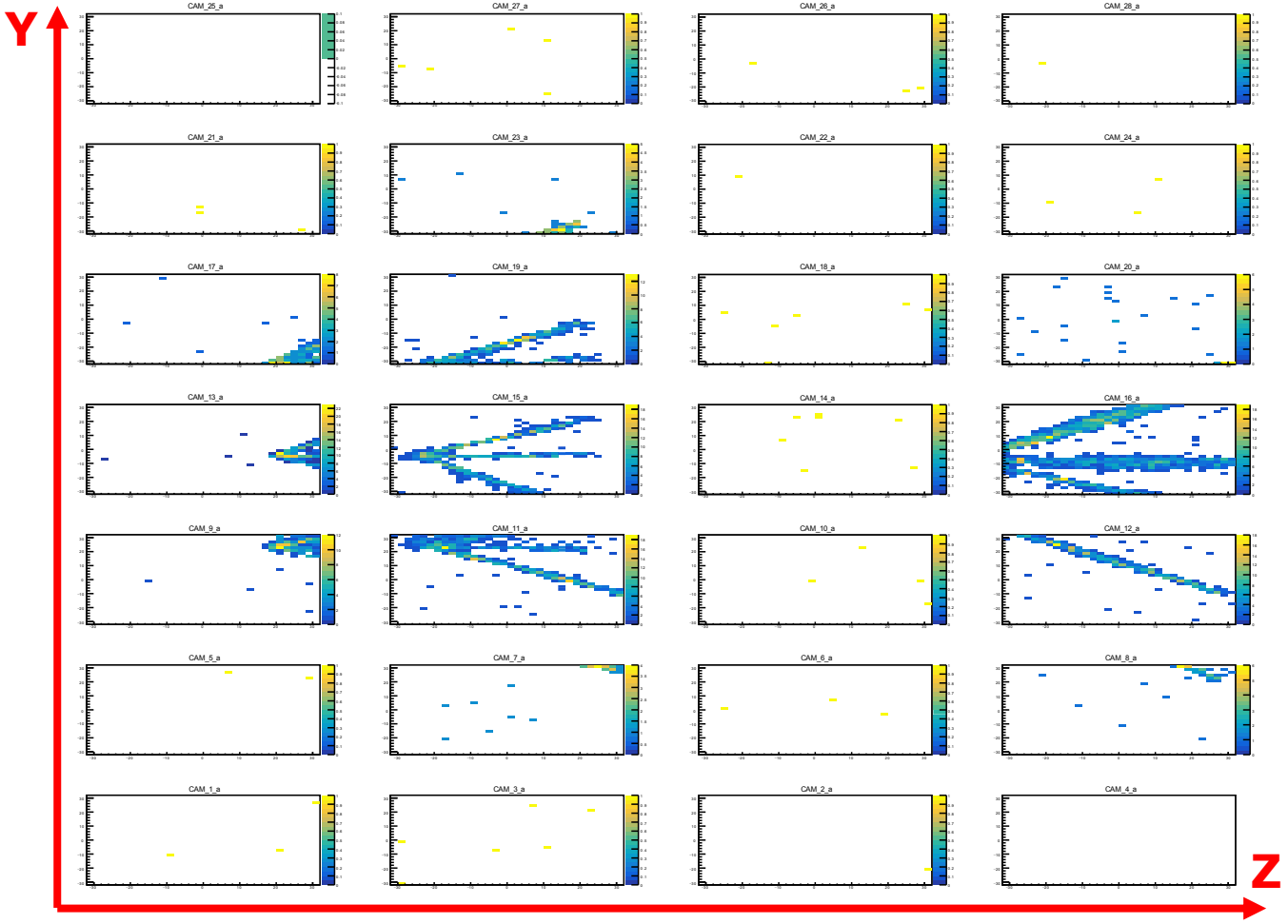
Optical simulation

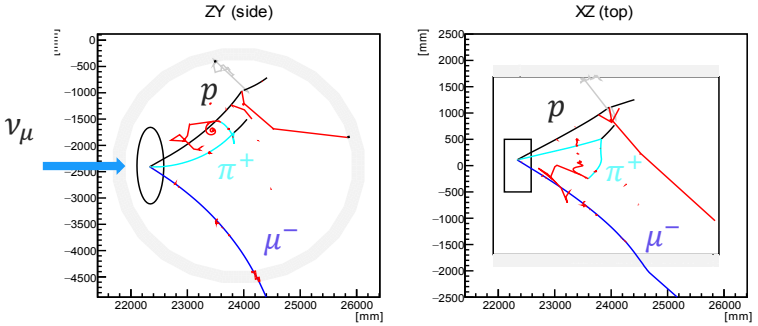
- The optical simulation is integrated in the SAND framework:

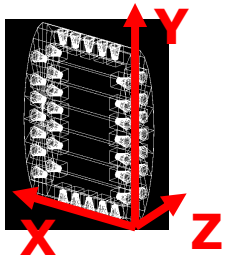


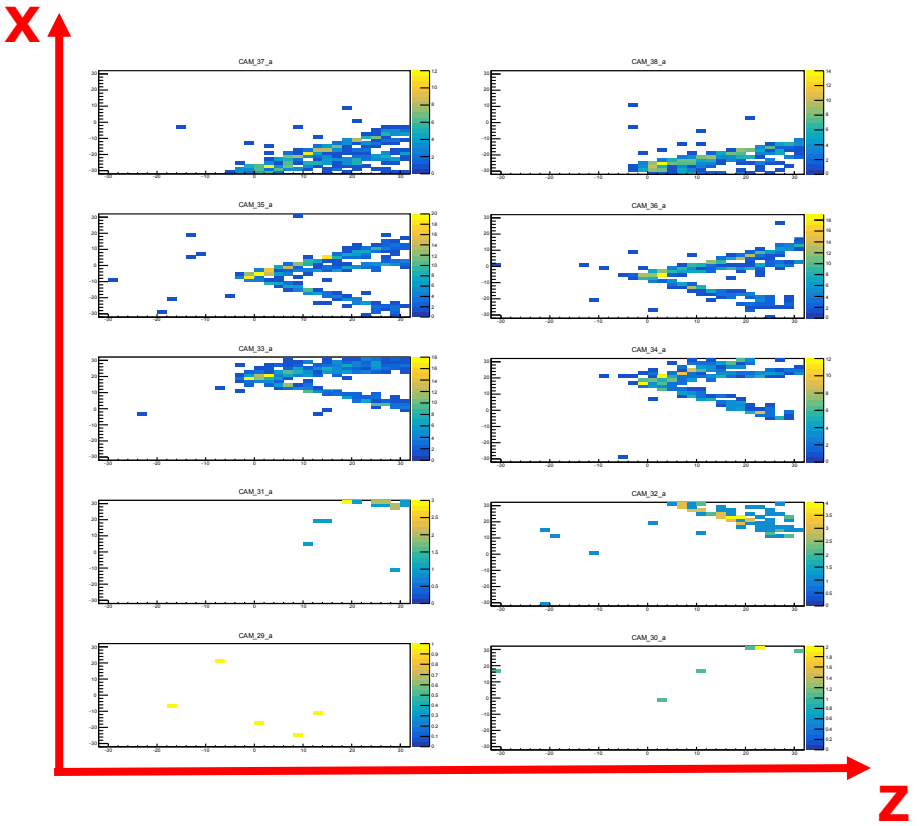
Event in GRAIN

- Example of $\nu_\mu CC$ interaction inside GRAIN





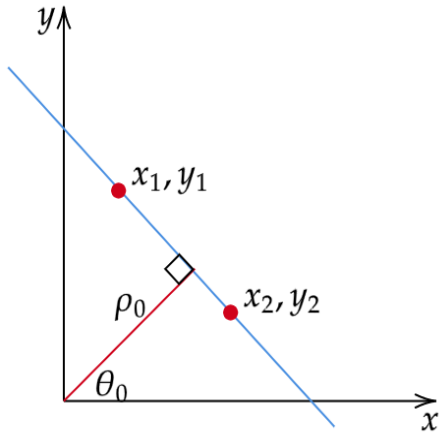




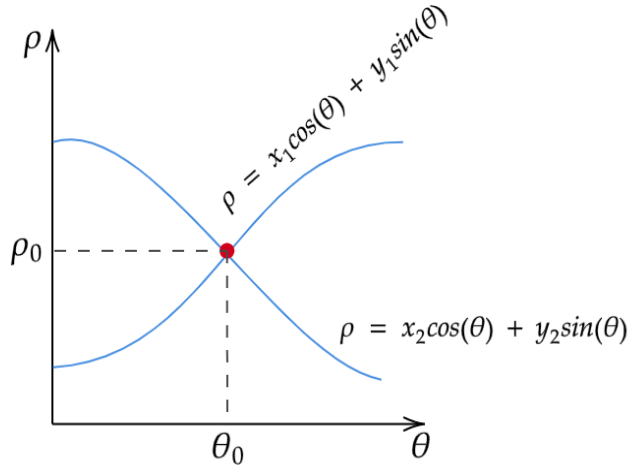
Hough transform

- Reconstruction algorithm to find and fit lines based on Hough Transform.
- Reduces the problem to a local max search in the parameter space (θ, ρ).

Physical space

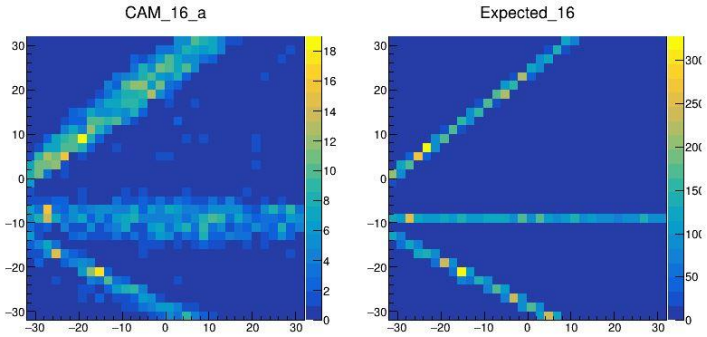


Parameter space



Full simulation

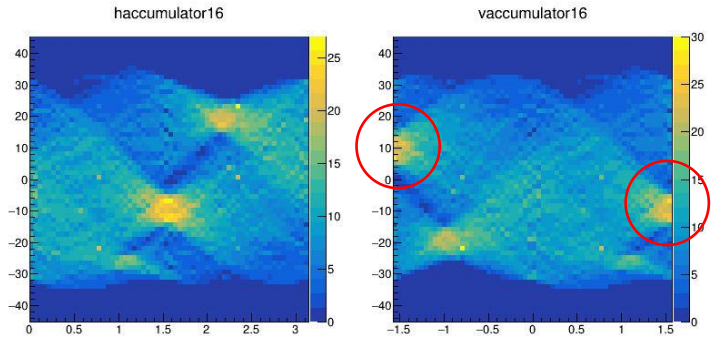
MC-truth projection



True EDepSIm deposits scaled in the sensor area

$[0, \pi]$

$\left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$



Horizontal lines in the middle

Vertical lines in the middle

- **Local max search:**
  - Multi-otsu thresholding
  - DSCAN clustering

Reconstructed lines

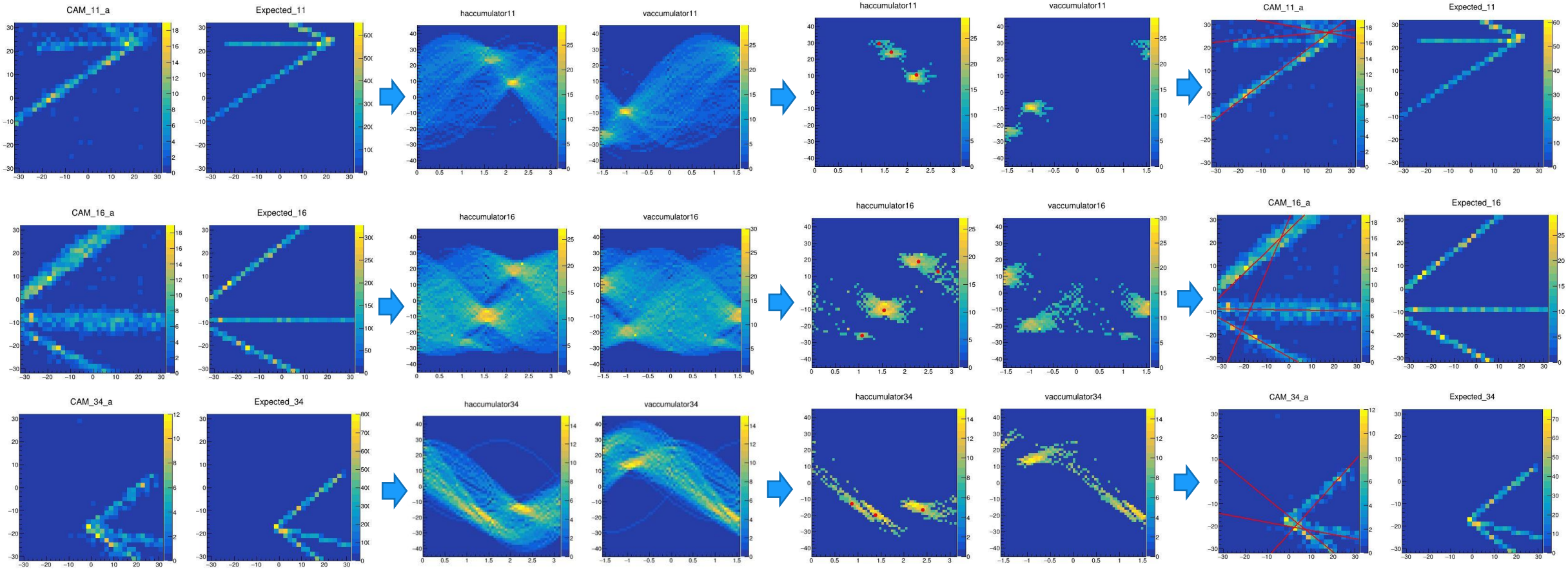
Full simulation

MC-truth projection

Hough transform: «accumulators»

Multi-otsu thresholding + DBSCAN clustering

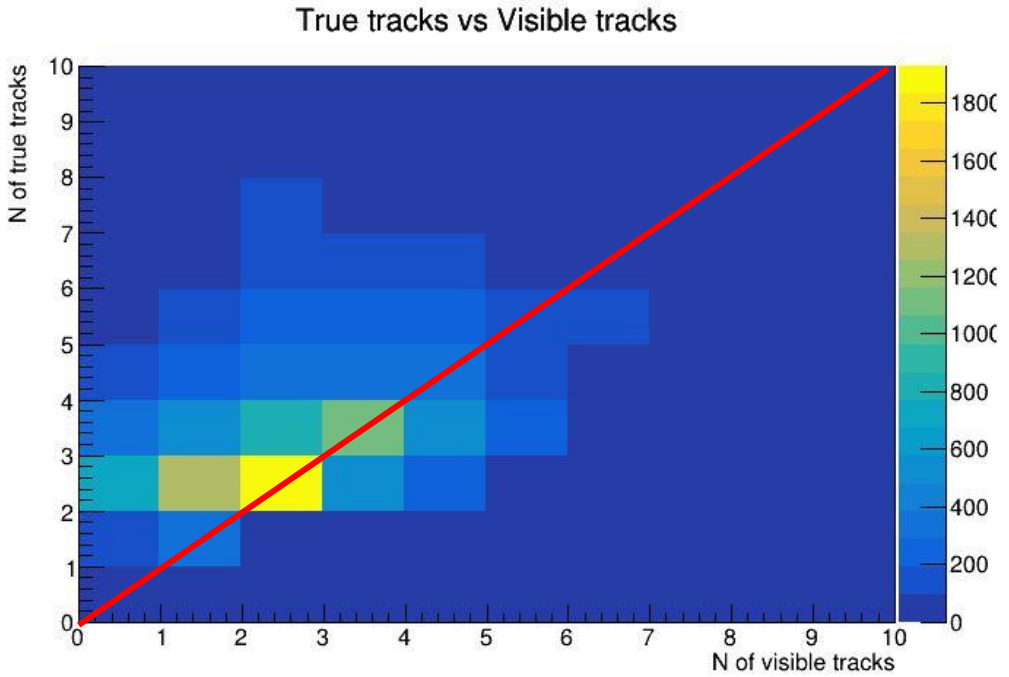
Inverse Hough transform: fitted lines



Visible tracks in an event

- How is the reconstruction algorithm performing?
  - Compare with the «truth projections»
- A true charged track (from EDepSim) is assumed **visible** in a camera if its truth projection is **> 10 pixels**.
- **At event level**, take the number of visible tracks as the **max** number of visible tracks found in any camera.

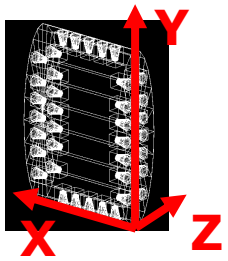
Sample: 15k $\nu_\mu CC$ events



X-axis: number of visible tracks the event (primary or secondary), taken as the **max** number of visible tracks seen among all cameras.

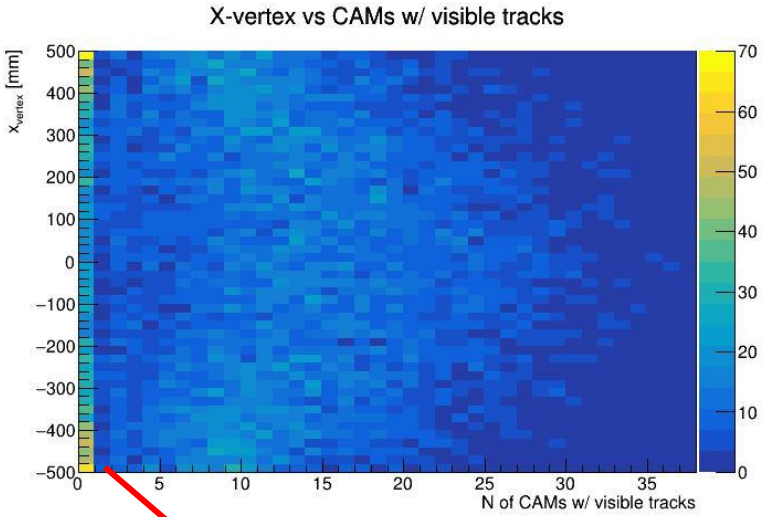
Y-axis: number of PRIMARY charged tracks at vertex from EDepSim.

Cameras with visible tracks

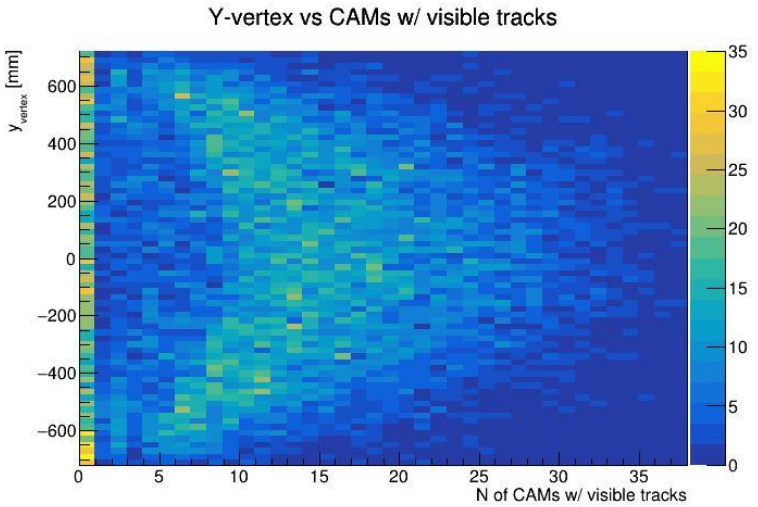


- Number of cameras with visible tracks (truth projections, > 10 pixels) as a function of the vertex position in GRAIN.
- Coordinates in the local reference system of GRAIN.

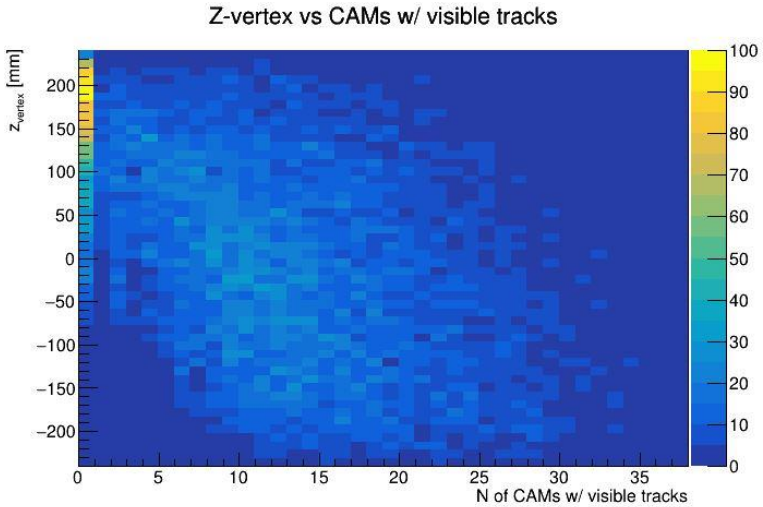
Sample: 15k $\nu_\mu CC$ events



Tracks less visible if close to GRAIN endcaps ($x = \pm 500\ mm$)



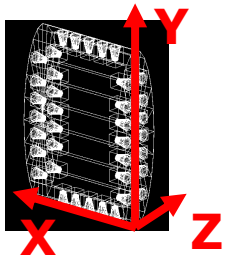
Higher number of cameras with visible tracks in the middle (x and y) of GRAIN



Tracks not visible if too downstream in GRAIN ($z > 150mm$)

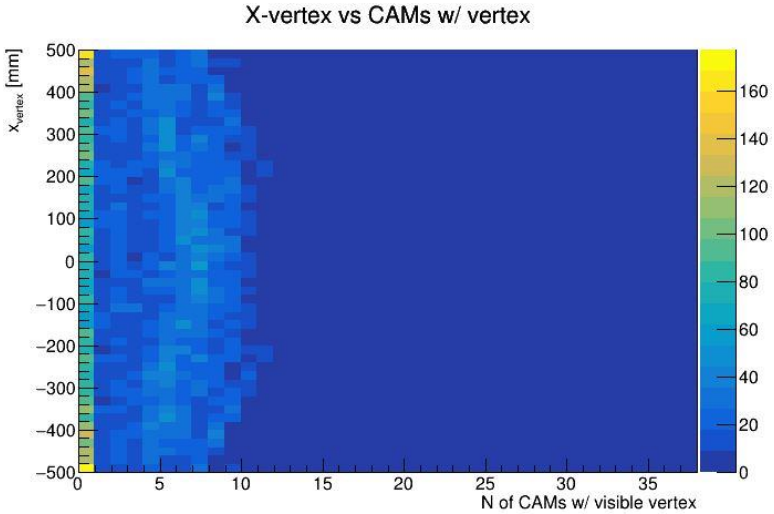
Always cameras with visible tracks if $z < -100mm$

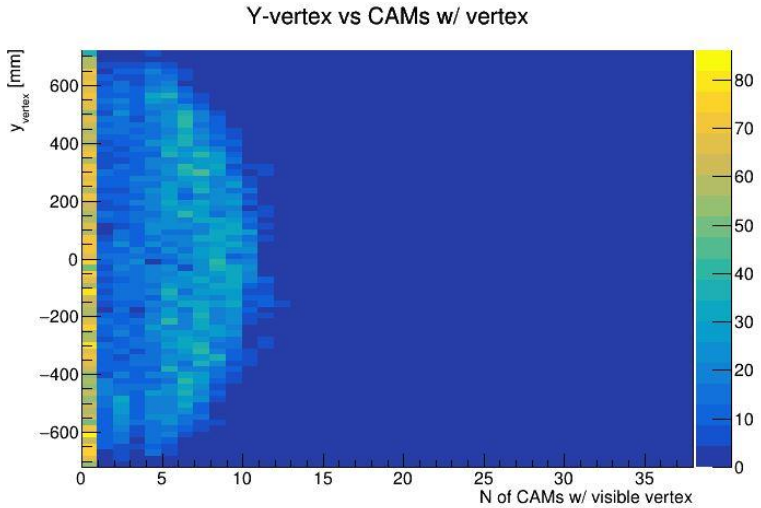
Cameras with visible vertex

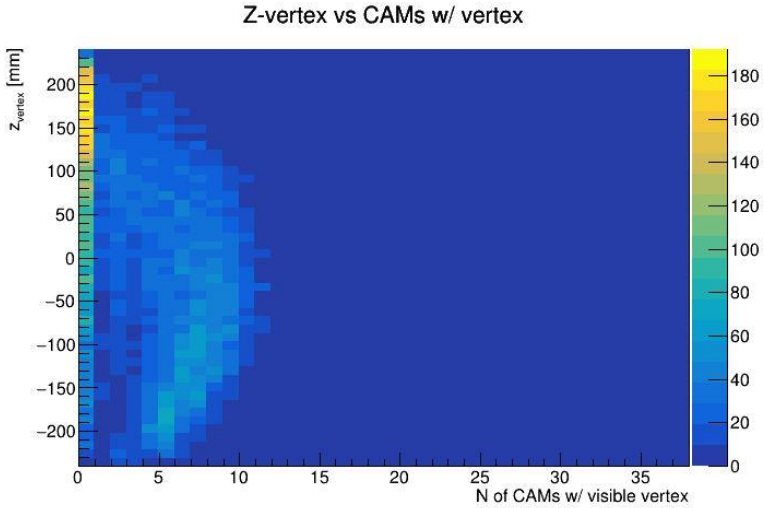


- Number of cameras with a **visible vertex** (**> 2 visible tracks, vertex projection**) as a function of the vertex position in GRAIN.
- Coordinates in the local reference system of GRAIN.

Sample: 15k $\nu_\mu CC$ events





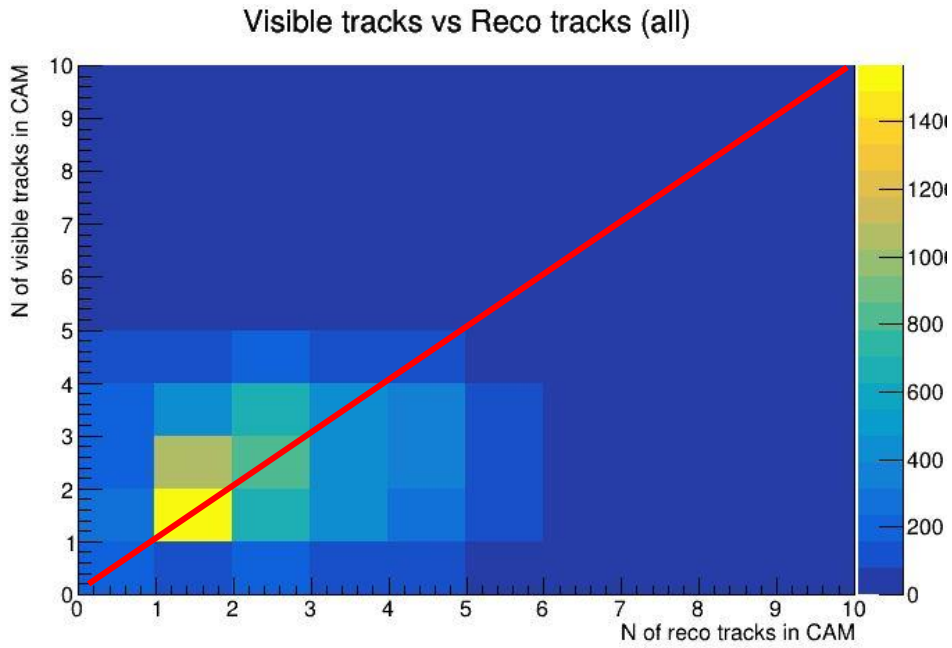


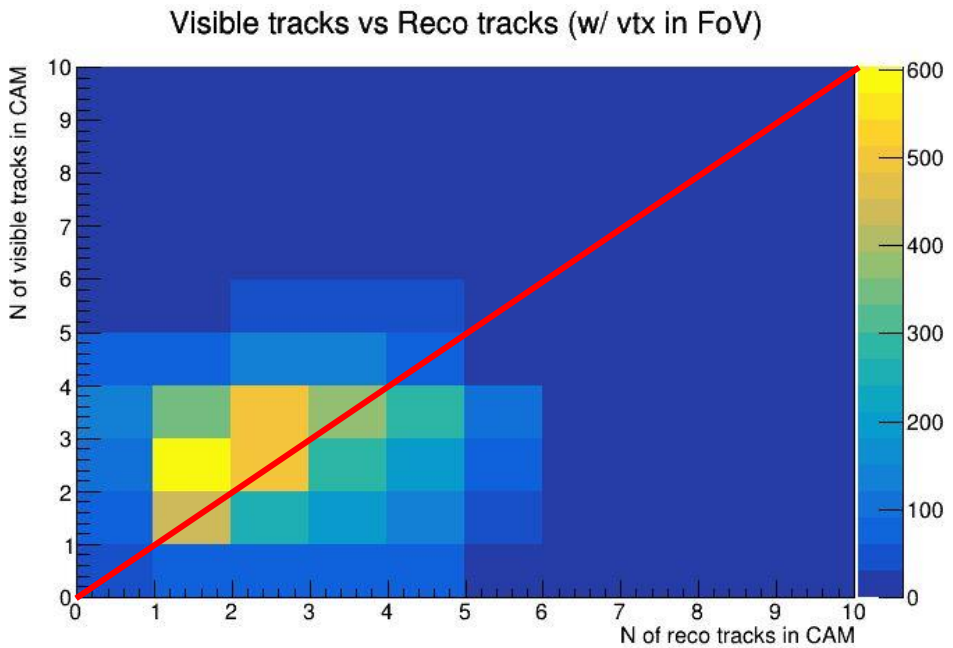
Similar distributions, but overall less cameras
No more than 10 → expected given the geometrical coverage

- Good fiducial volume in the current configuration: up to 5-10 cameras can potentially see the vertex!

Checking the reconstruction…

- **Reconstructed vs visible tracks:**
  - Comparing reconstructed tracks via Hough trasform with visible tracks **in each camera**.
  - Sample: 1k $\nu_\mu CC\ 1p1pi$, each event can have up to 38 cameras



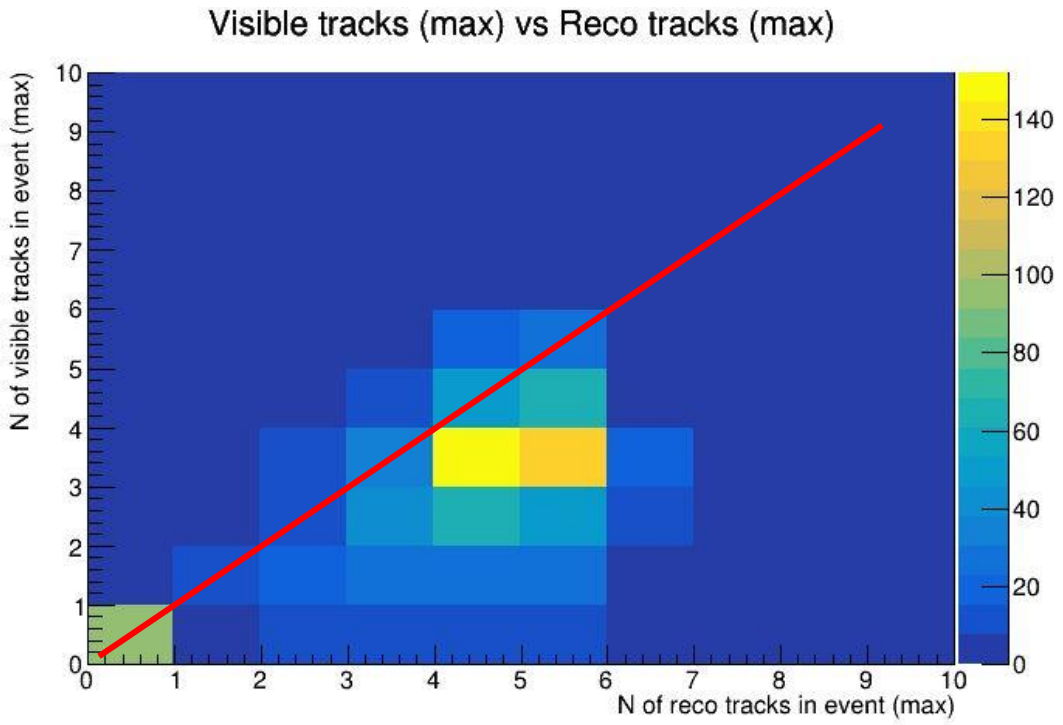


Selecting only cameras with the vertex projection (according to MC-truth)

Reconstructed tracks in event

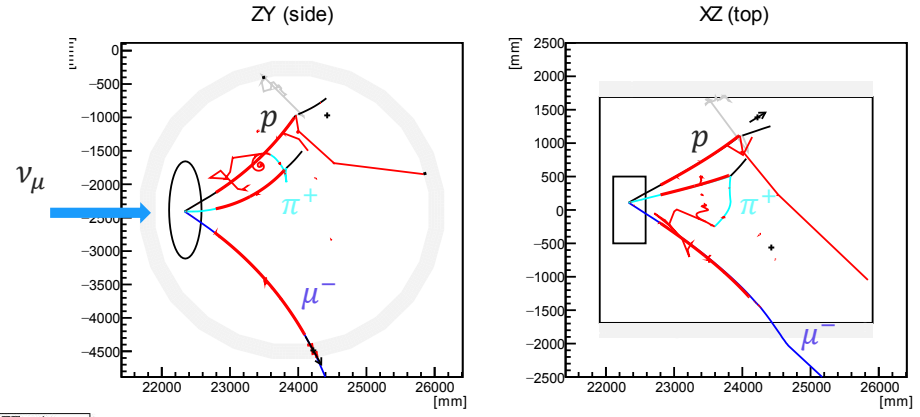
- **At event level**, take the number of reconstructed tracks as the **max** number of visible tracks found in any camera.
- Comparison with the same quantity using visible lines.
  - Visible tracks peaked at 3 in this sample
  - Reco tracks generally > visible tracks (fake lines due to bad clustering, bias from selecting «max»)

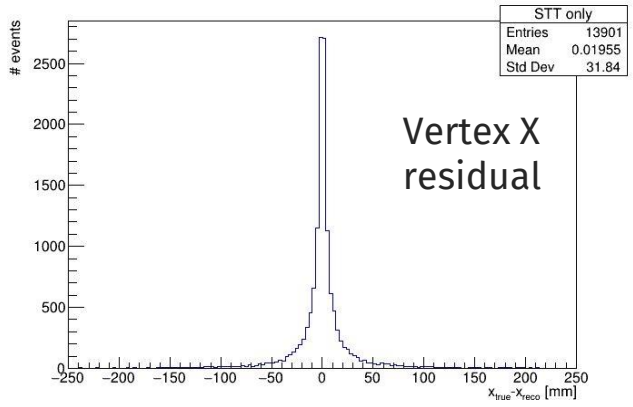
Sample: 1k $\nu_\mu CC\ 1p1pi$



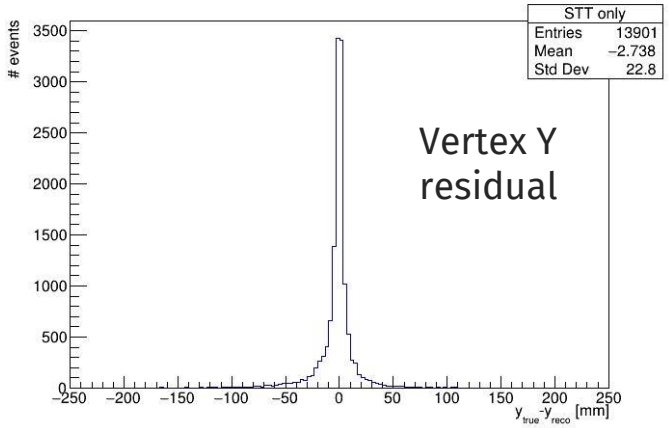
3D vertex performance: STT only

- **Events in GRAIN, with > 2 tracks in STT:**
  - Circular fit in ZY (first 50 ZY STT digits upstream): z_{reco} and y_{reco}
  - Linear fit in XY (first 50 XY STT digits upstream): x_{reco}

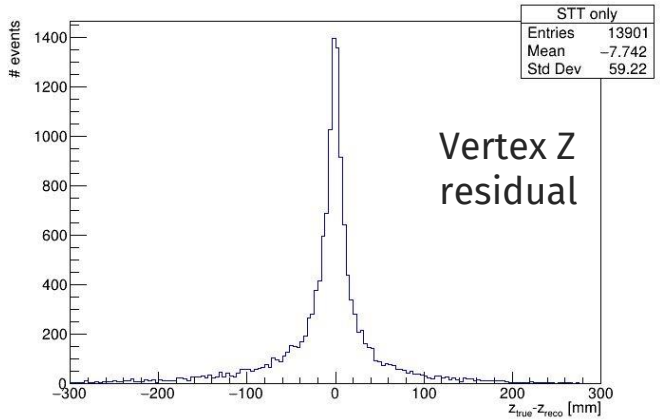




Vertex X residual

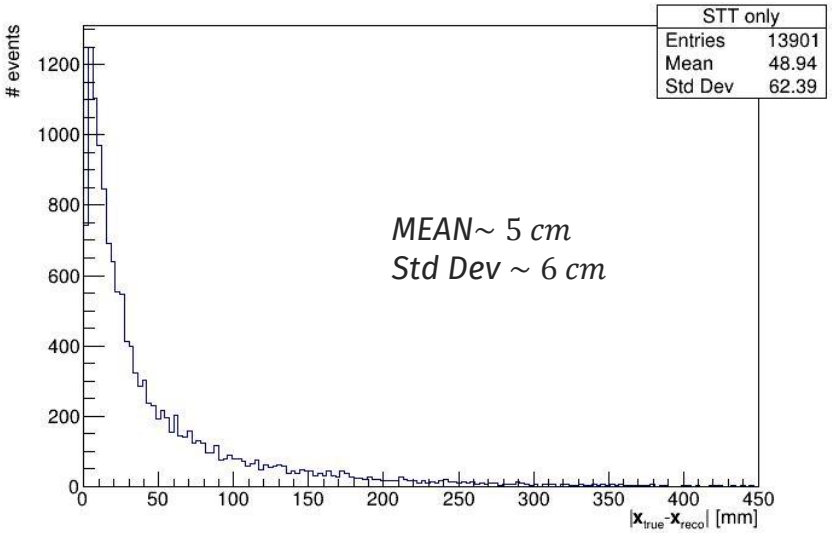


Vertex Y residual



Vertex Z residual

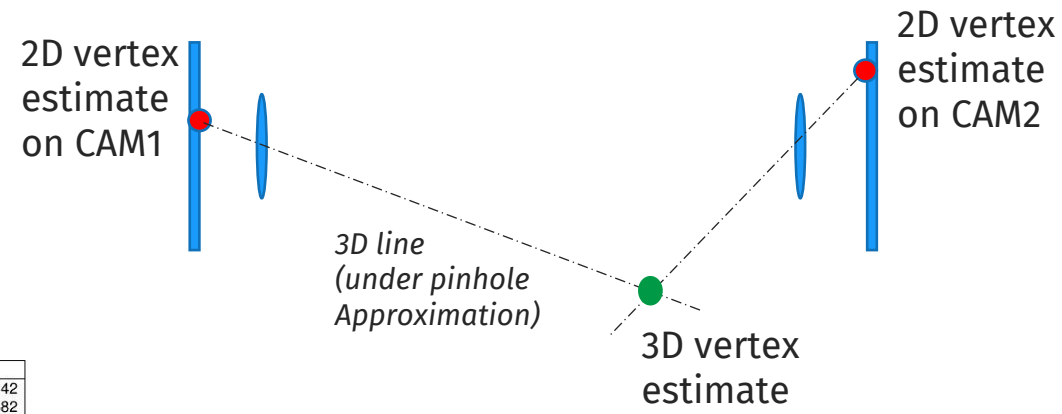
Vertex 3D residual

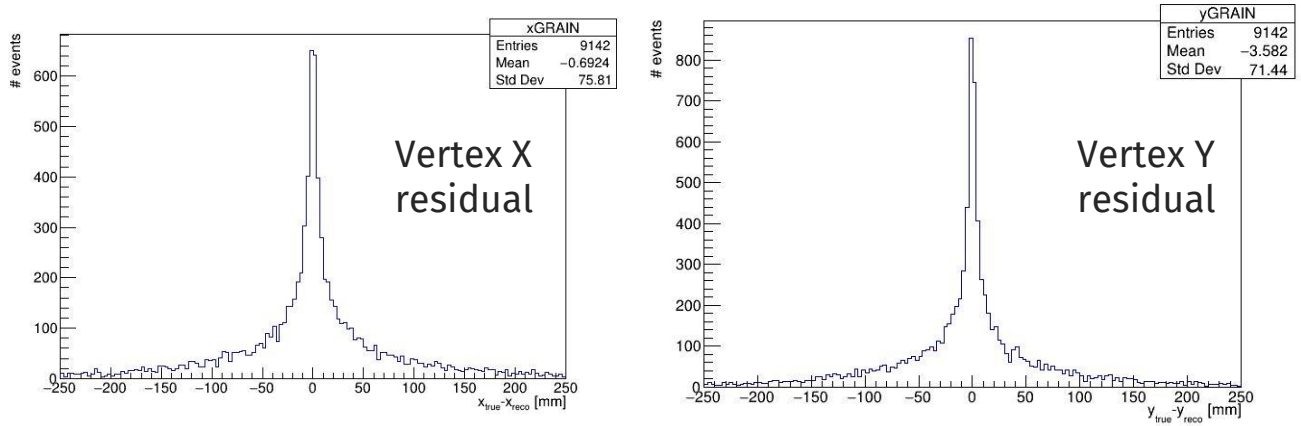


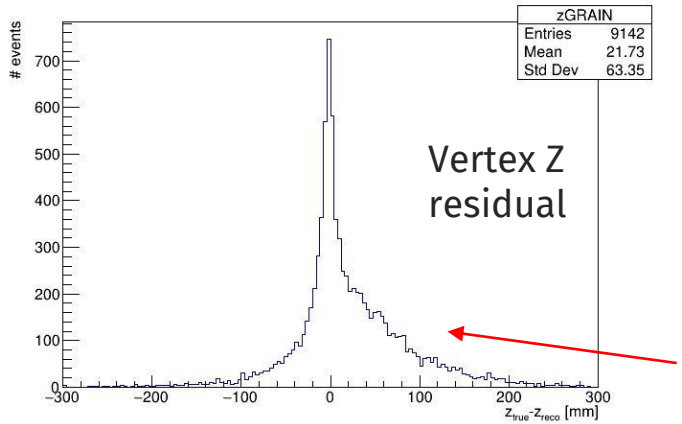
Sample:
$\sim 27k\ \nu_\mu CC\ 1p1pi$

3D vertex: GRAIN only (visible tracks)

- Event in GRAIN, fitted using visible tracks
  - **Simple line fit** (one visible track at a time), intersect to find 2D estimate
  - Propagate to 3D (pinhole approx.), intersect and find the average

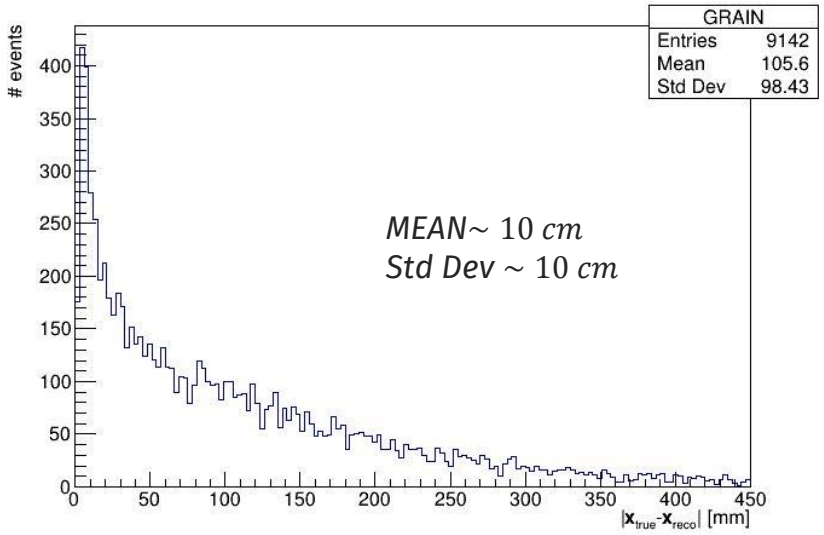






Bias in this rough 2D fitting

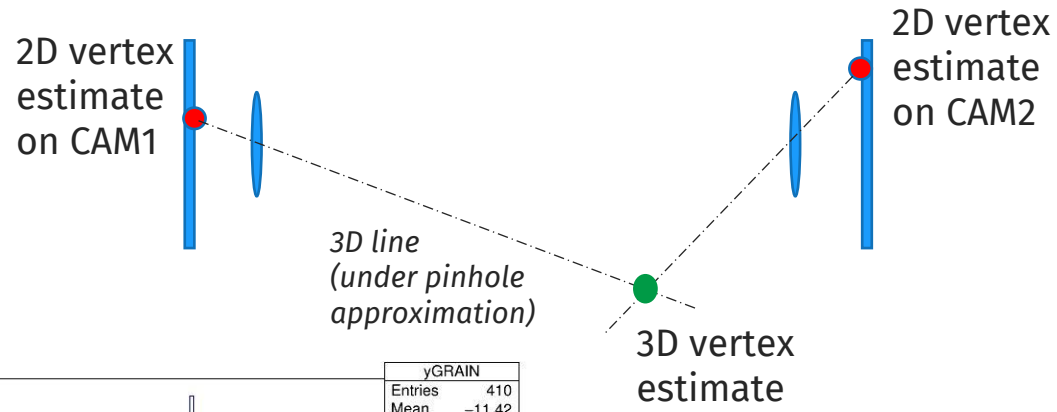
Vertex 3D residual

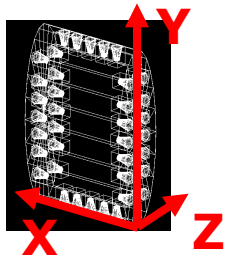


Sample:
$\sim 14k\ \nu_\mu CC\ 1p1pi$

3D vertex: GRAIN only (reco tracks)

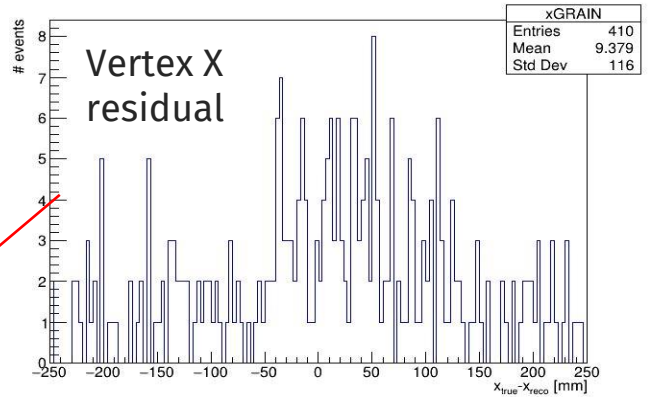
- Event in GRAIN, fitted using reconstructed tracks
  - **Hough transform**, intersect to find 2D estimate
  - Propagate to 3D (pinhole approx.), intersect and find the average

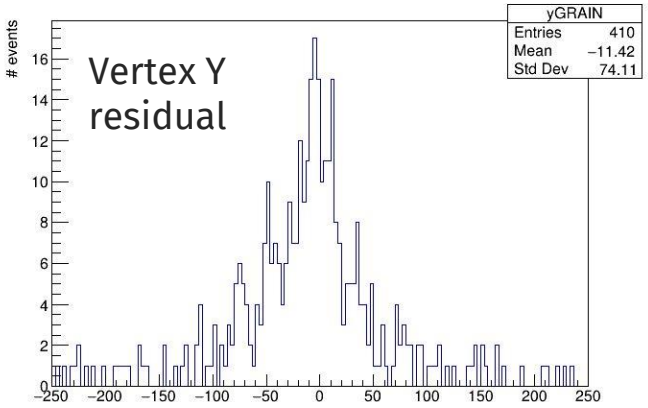


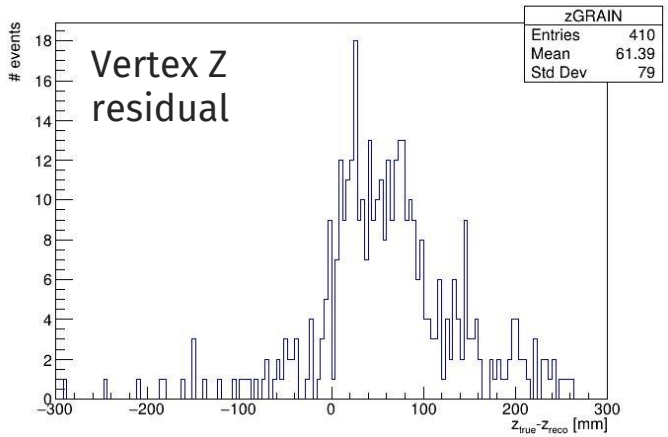


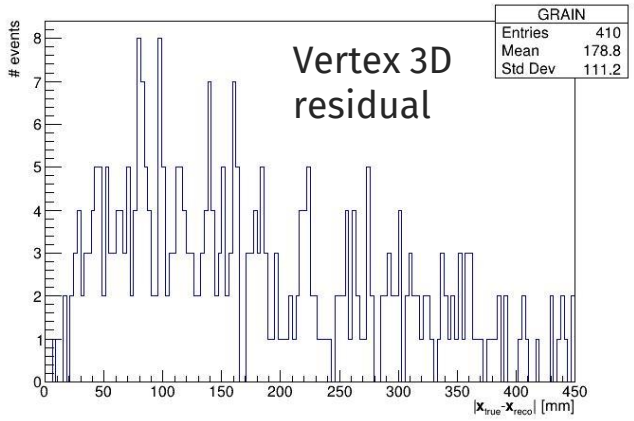
Expected to be worse:

- Depth for the side cameras
- Top/bottom cameras not optimized









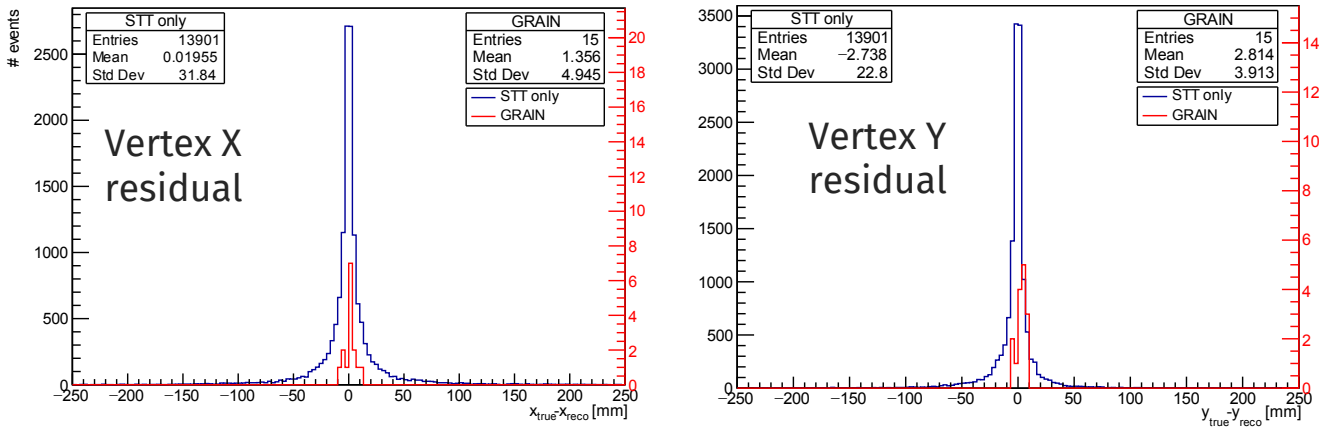
Sample:
$1k\ \nu_\mu CC\ 1p1pi$

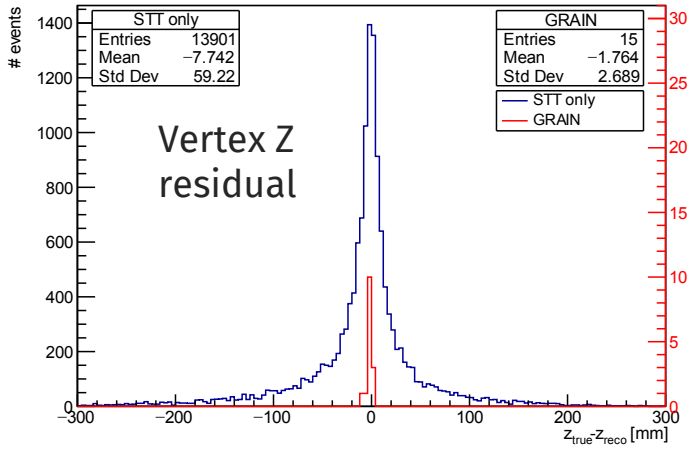
Not surprising: still a lot of things to fix!

3D vertex: GRAIN only (hand-fitted reco tracks)

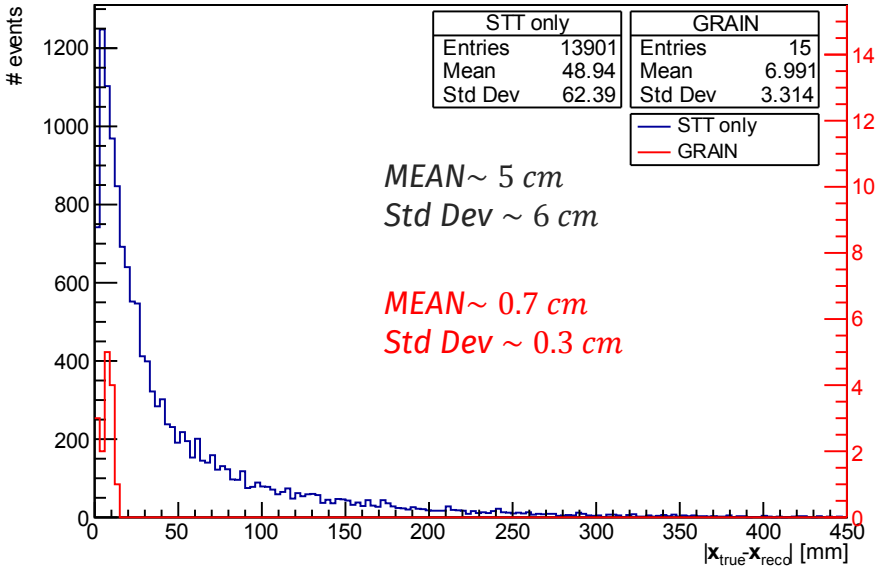
- **Manual check of each fitted track: selection of «good» images and finding (m, q) for each line**
  - 15 events in GRAIN, 2D hand-fitting (same 2D → 3D as before)
  - Comparison with STT-only fit

Sample:
GRAIN: $15\ \nu_\mu CC\ 1p1pi$
STT: $\sim 27k\ \nu_\mu CC\ 1p1pi$





Vertex 3D residual

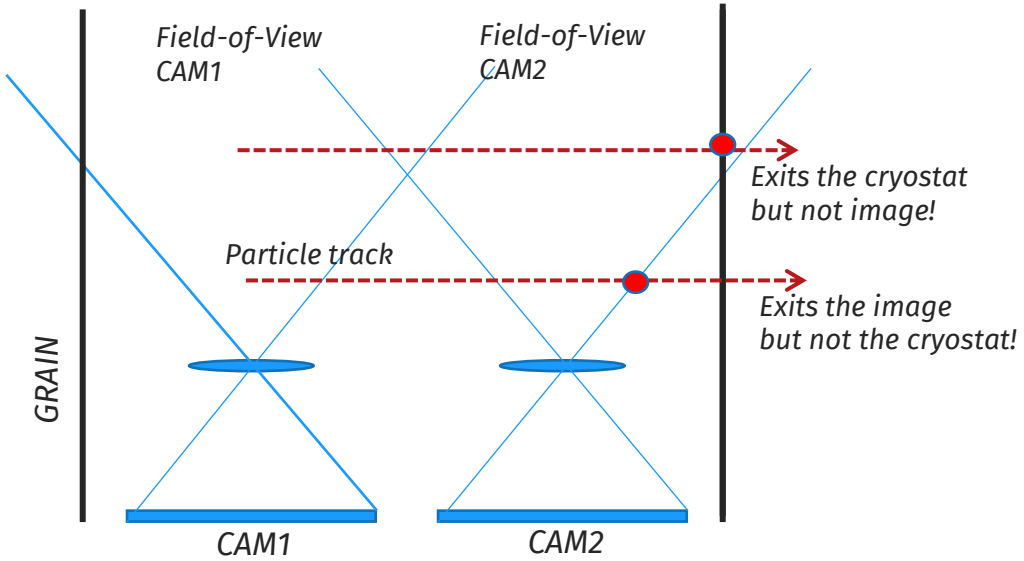


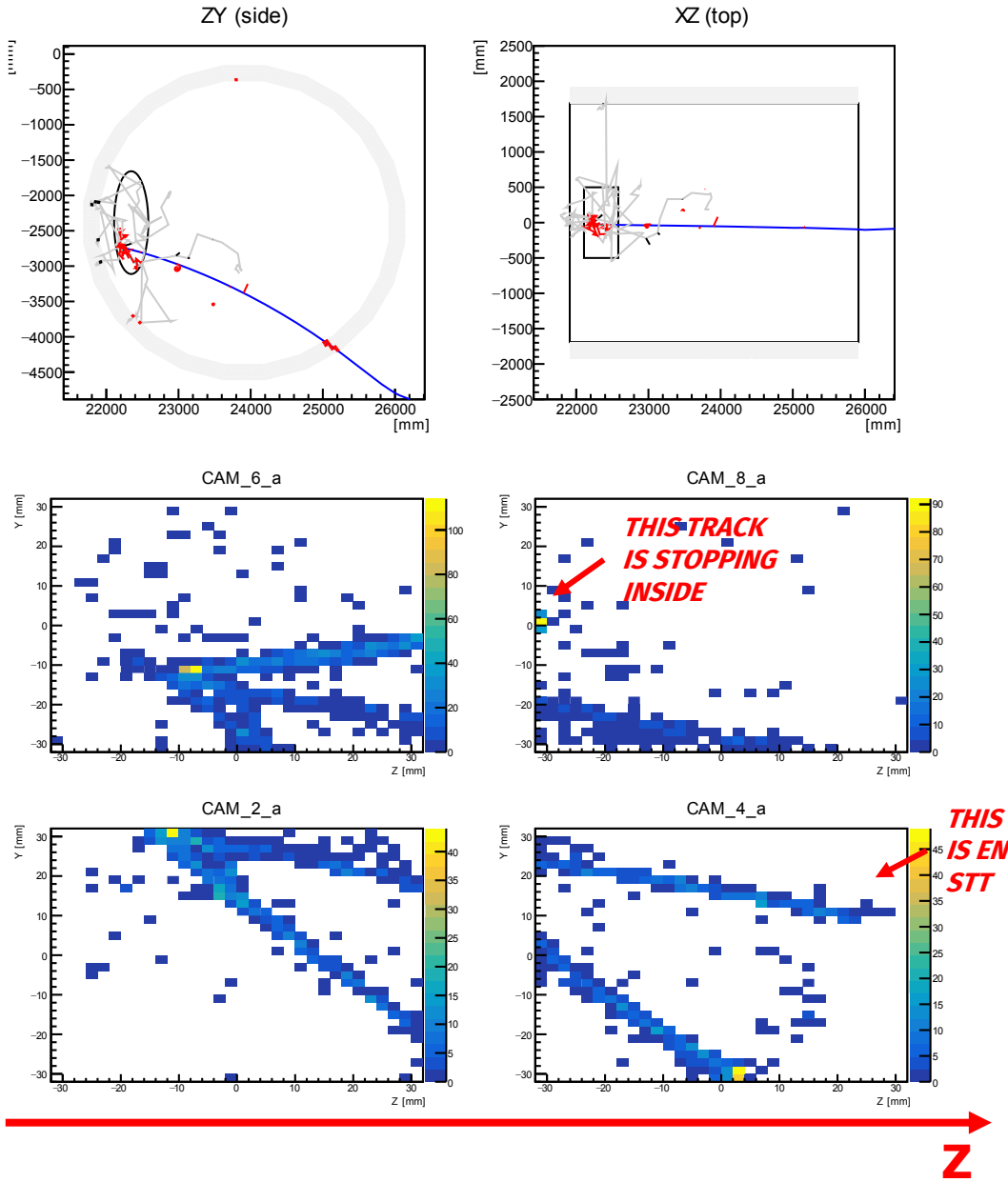
MEAN~ 5 *cm*
Std Dev ~ 6 *cm*

MEAN~ 0.7 *cm*
Std Dev ~ 0.3 *cm*

Next steps: STT matching

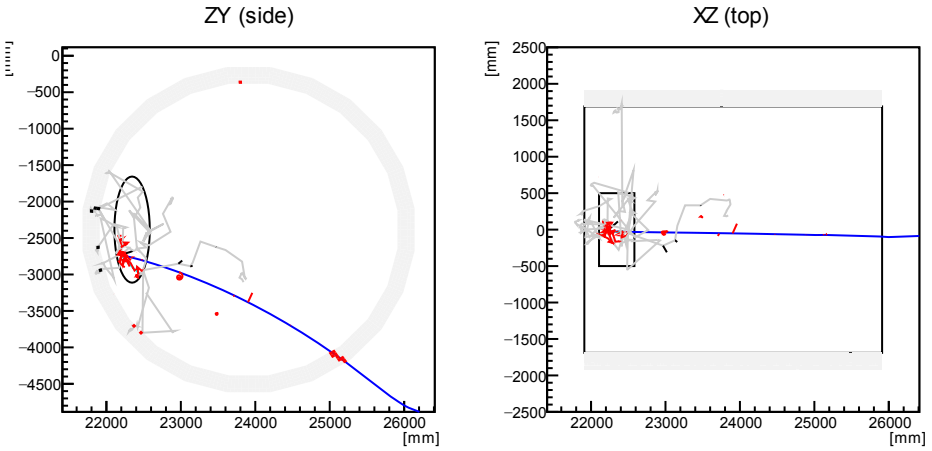
- Checking and matching tracks in STT:
  - Tracks stopping inside GRAIN
  - Tracks exiting GRAIN and matching STT digits.
  - Tracks stopping in GRAIN cryostat
- Working in progress...

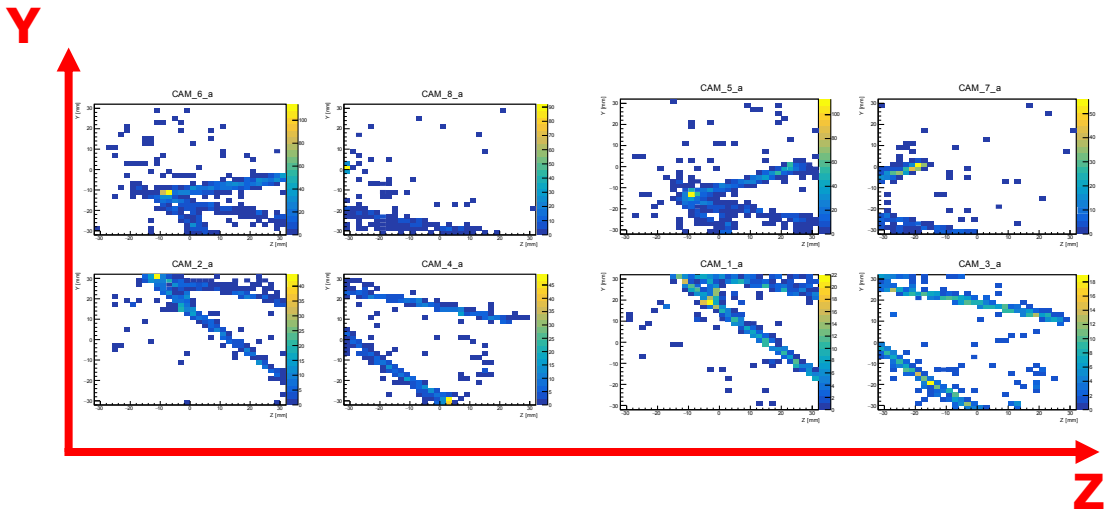


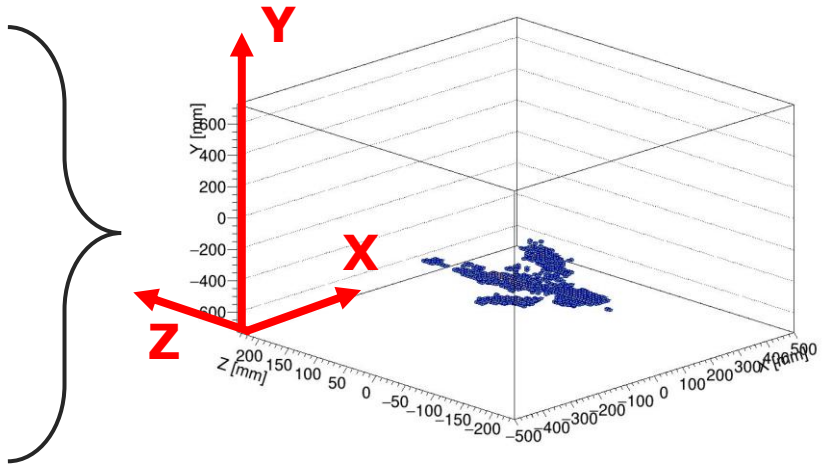


Next steps: 3D tracks

- Matching requires 3D information…
- First examples of combining 2D data into 3D:
  - Finding the 3D volume compatible with all the views…







Summary

- **Cameras with UV lenses as imaging devices in GRAIN**
  - Geometrical configuration in new GRAIN geometry but with smaller x-dimension: good geometrical coverage of events (5-10 cameras with a «visible» vertex)
  - Reconstruction with Hough transform.
- **Preliminary agreement between visible and reconstructed tracks**
- **Preliminary determination of 3D vertex position in GRAIN**
- **Next steps:**
  - 3D tracks and matching with STT

Back-up

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DUNE

DEEP UNDERGROUND
NEUTRINO EXPERIMENT