Università di Genova

INFN GENOVA
Istituto Nazionale di Fisica Nucleare
Sezione di Genova

DUNE
DEEP UNDERGROUND NEUTRINO EXPERIMENT

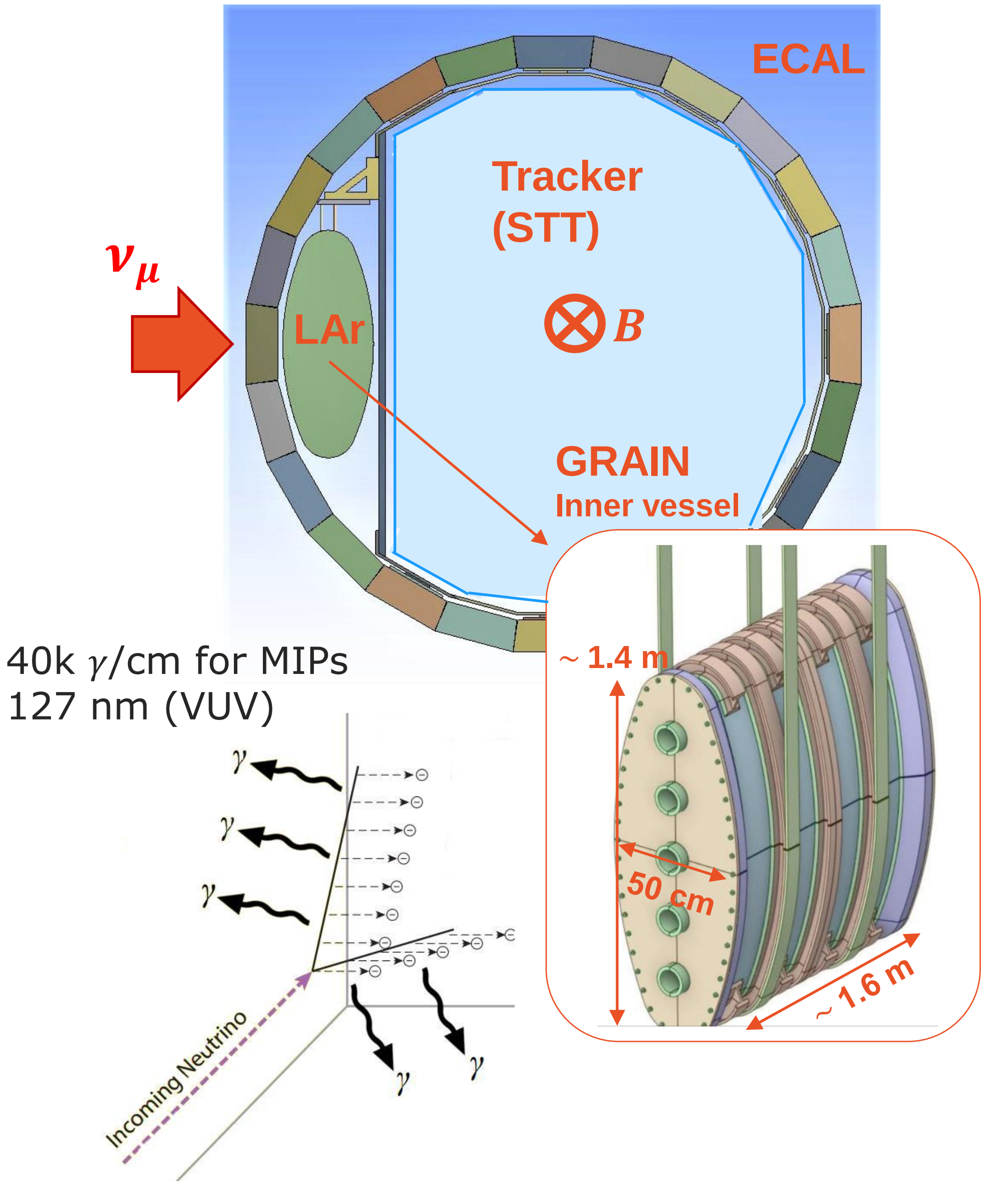
SVILUPPO DELL'OTTICA CON LE LENTI E RICOSTRUZIONE 2D, 3D

Meeting Annuale Collaborazione Nazionale DUNE
Laboratori Nazionali di Frascati
8 Novembre 2022

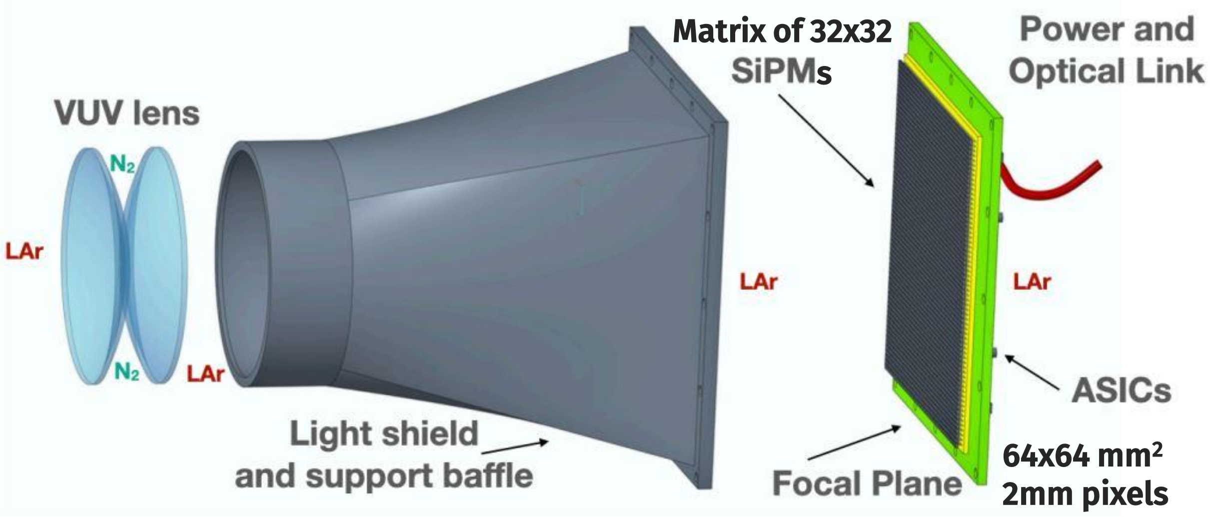
Matteo Vicenzi, Lea Di Noto, Marco Pallavicini

GRAIN optical readout

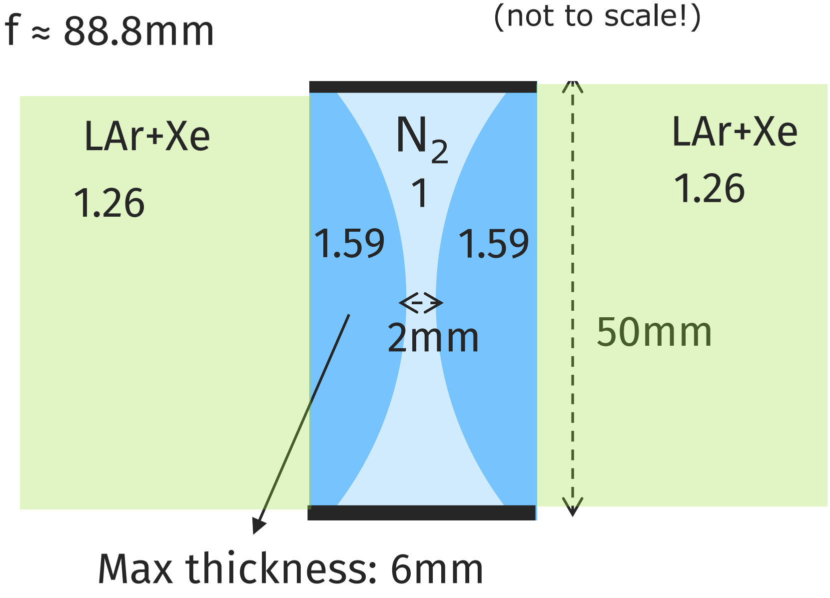
- **Active** target in $\vec{B}$ field:
  - ➢ No charge collection
  - ➢ Timing and calorimetry w/ scintillation light
  - ➢ imaging → spatial reconstruction
- Technologies: coded masks, **lenses**
- Lenses are more traditional, but there are challenges:
  - ➢ VUV wavelength → no transparent materials (CaF_2, MgF_2...) + low PDE
  - ➢ Refractive indexes
  - ➢ Fixed focus: cameras are static!



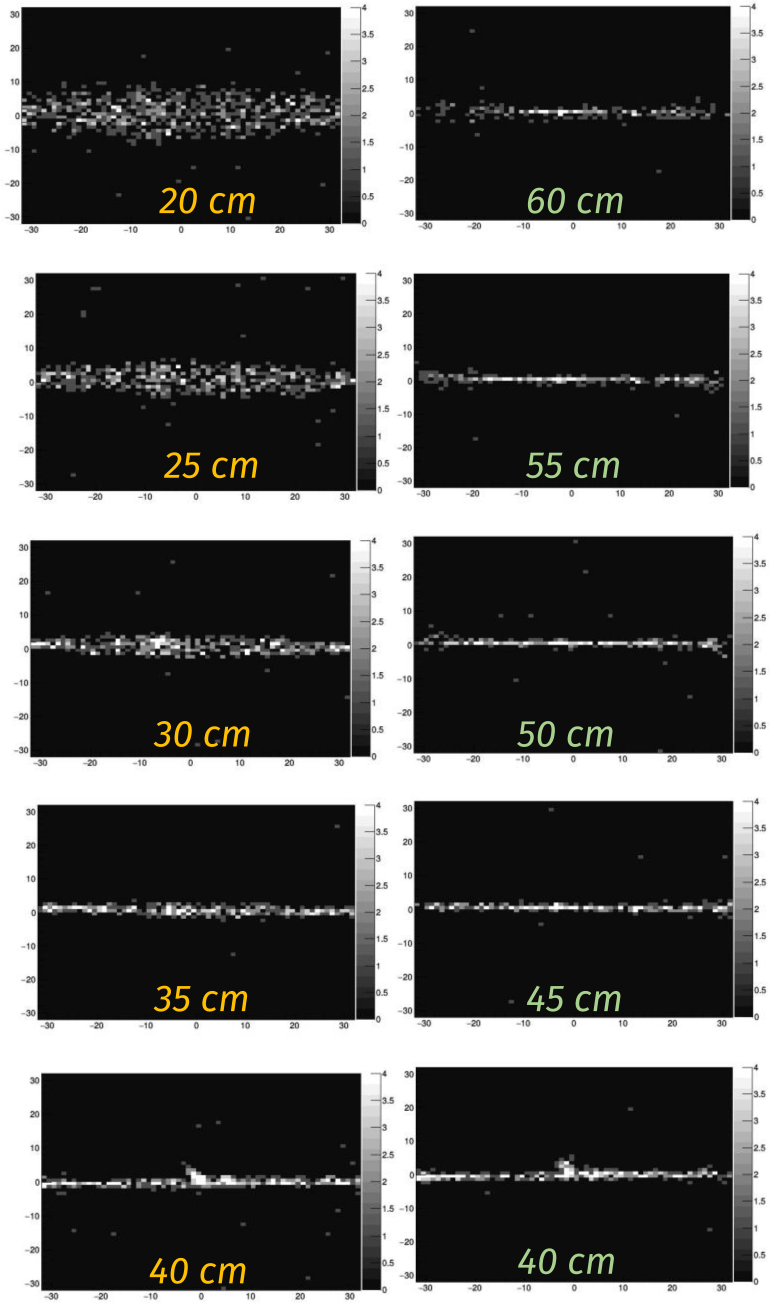
UV lenses

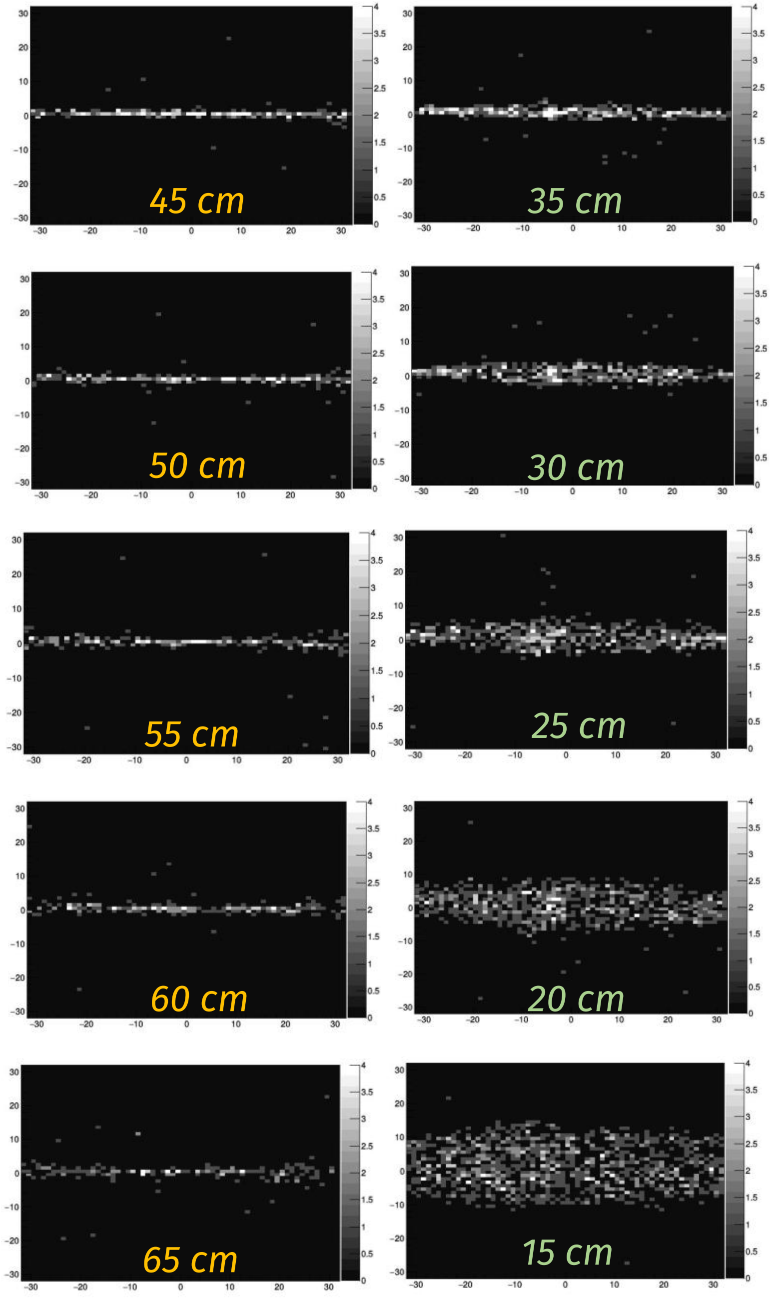


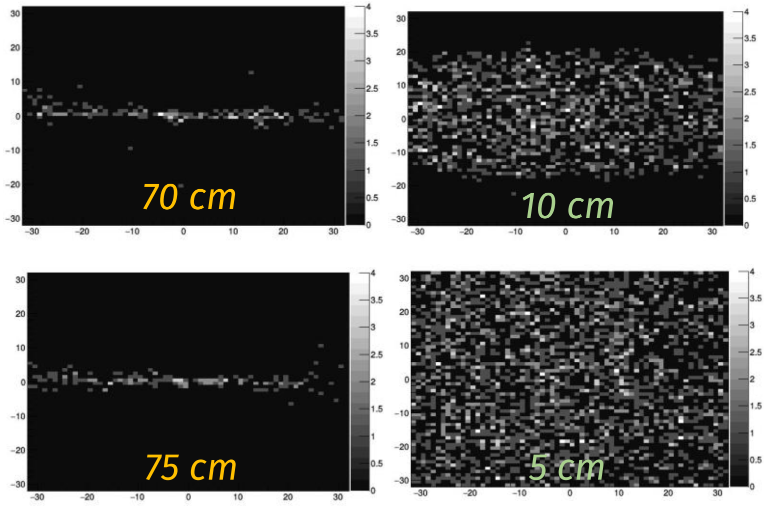
R1 = -R2 = -80.5mm
f ≈ 88.8mm

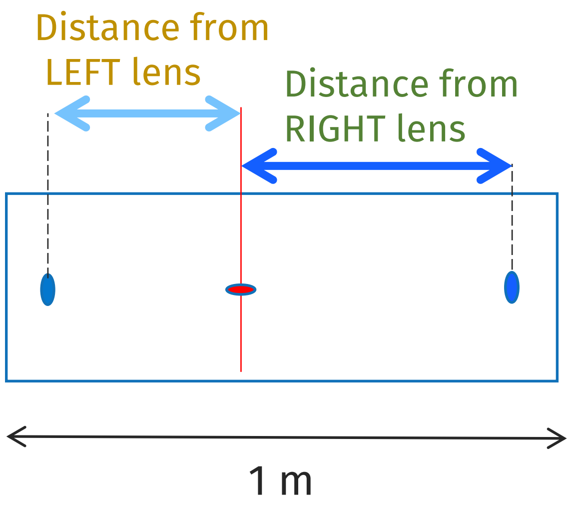


- **LAr + Xe doping: 127nm → 174nm**
  - Better PDE for SiPMs, easier to find suitable materials, larger scattering length + light-yield.
  - Fused Silica HPFS 8655 (n=1.59, T> 99.6%/cm @ 174nm)
- **Two plane-convex lenses + inner gas layer (n = 1): optical work done at the gas interfaces.**
  - Robustness: $\Delta n = 0.59$ fixed by the materials, independent of the external medium.
- **Geometrical complementarity between cameras.**
  - Lens-sensor distance: $10\ cm$ → Depth-of-field between $35\ cm$ to $80\ cm$.


20 cm
60 cm
25 cm
55 cm
30 cm
50 cm
35 cm
45 cm
40 cm
40 cm

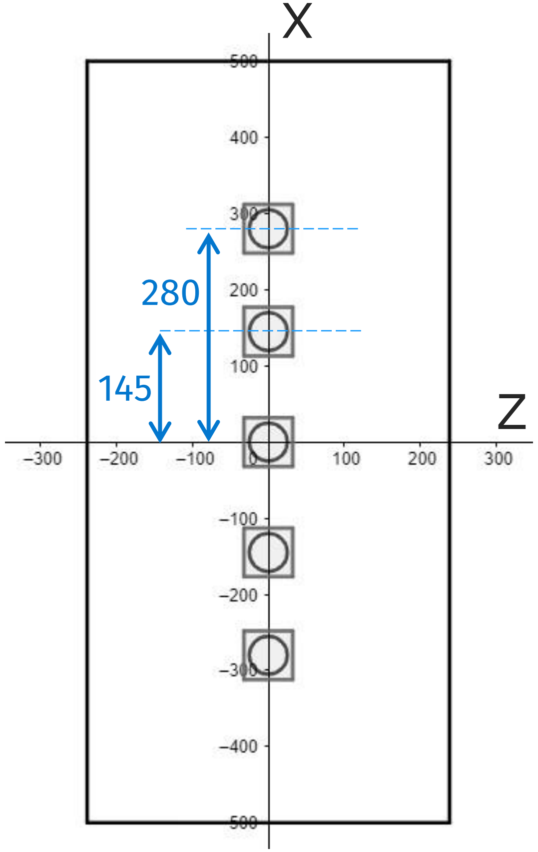

45 cm
35 cm
50 cm
30 cm
55 cm
25 cm
60 cm
20 cm
65 cm
15 cm


70 cm
10 cm
75 cm
5 cm

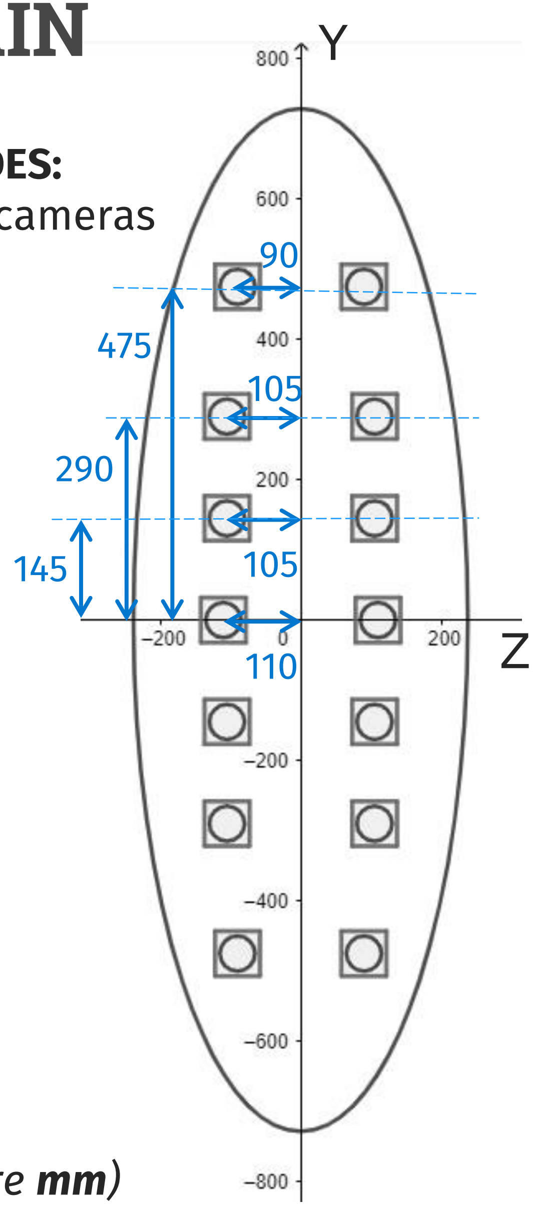

Distance from LEFT lens
Distance from RIGHT lens
1 m

Geometry in GRAIN

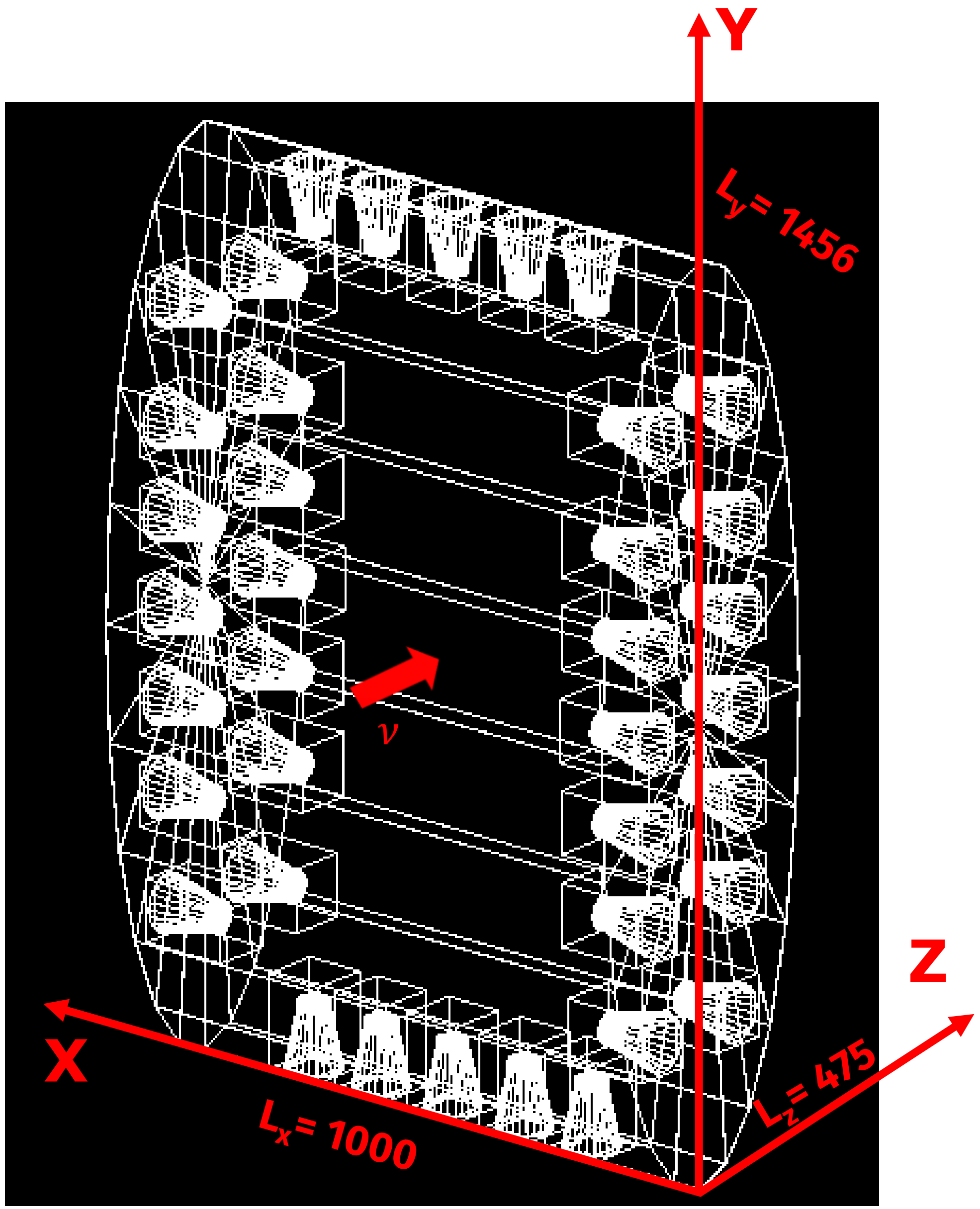
TOP/BOTTOM:
5 cameras



SIDES:
14 cameras

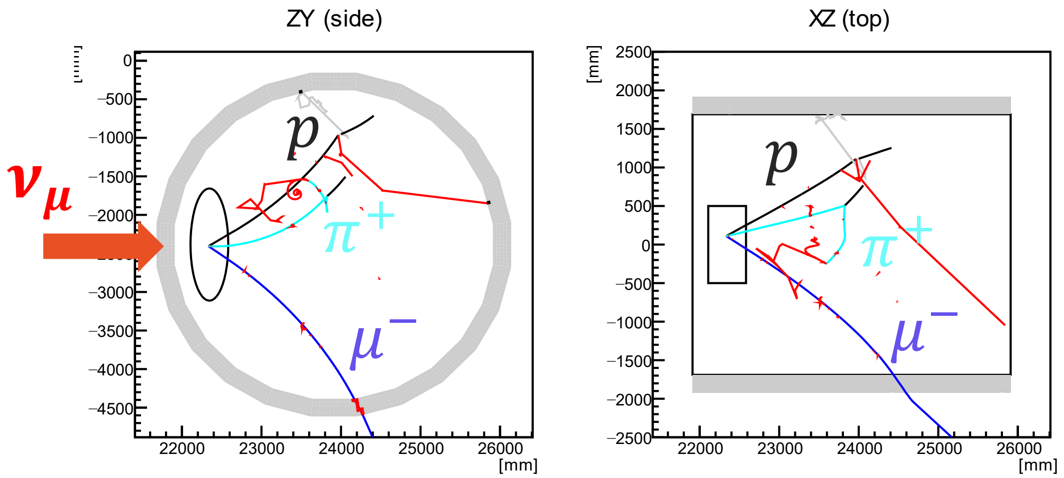


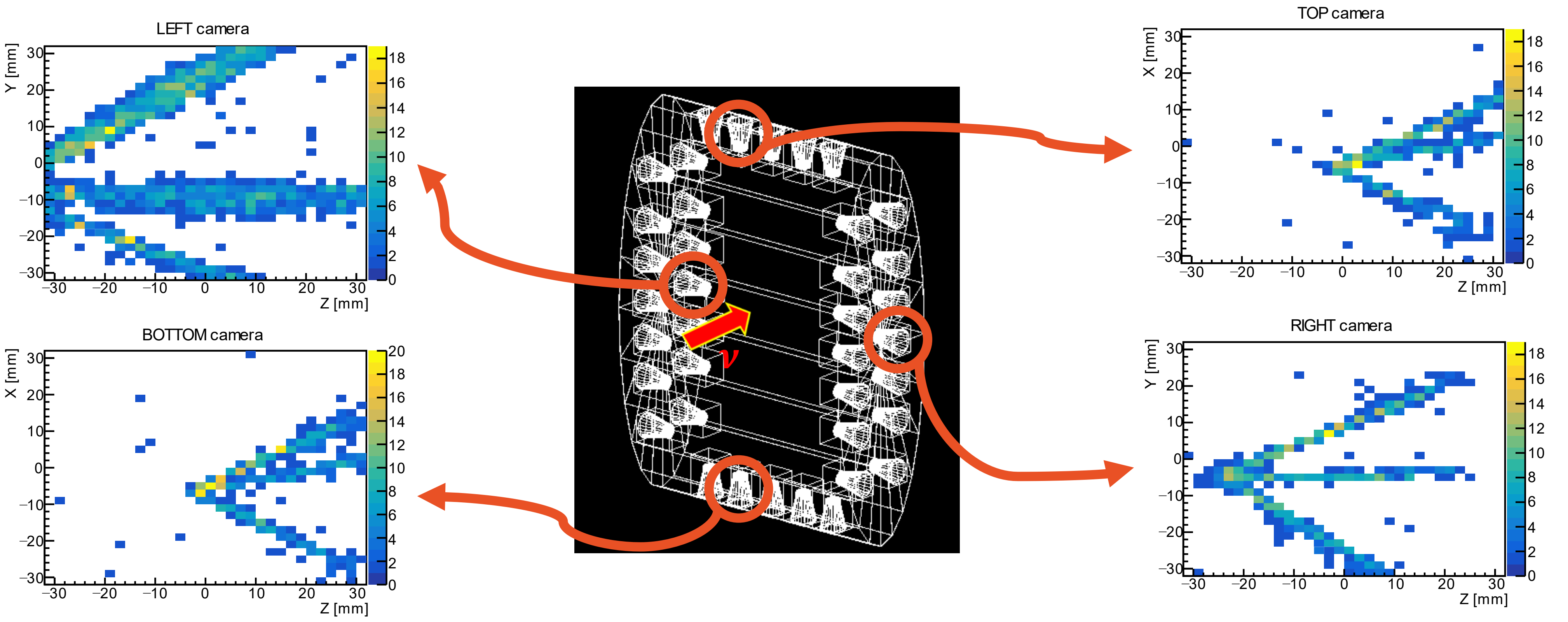
*(Units are **mm**)*



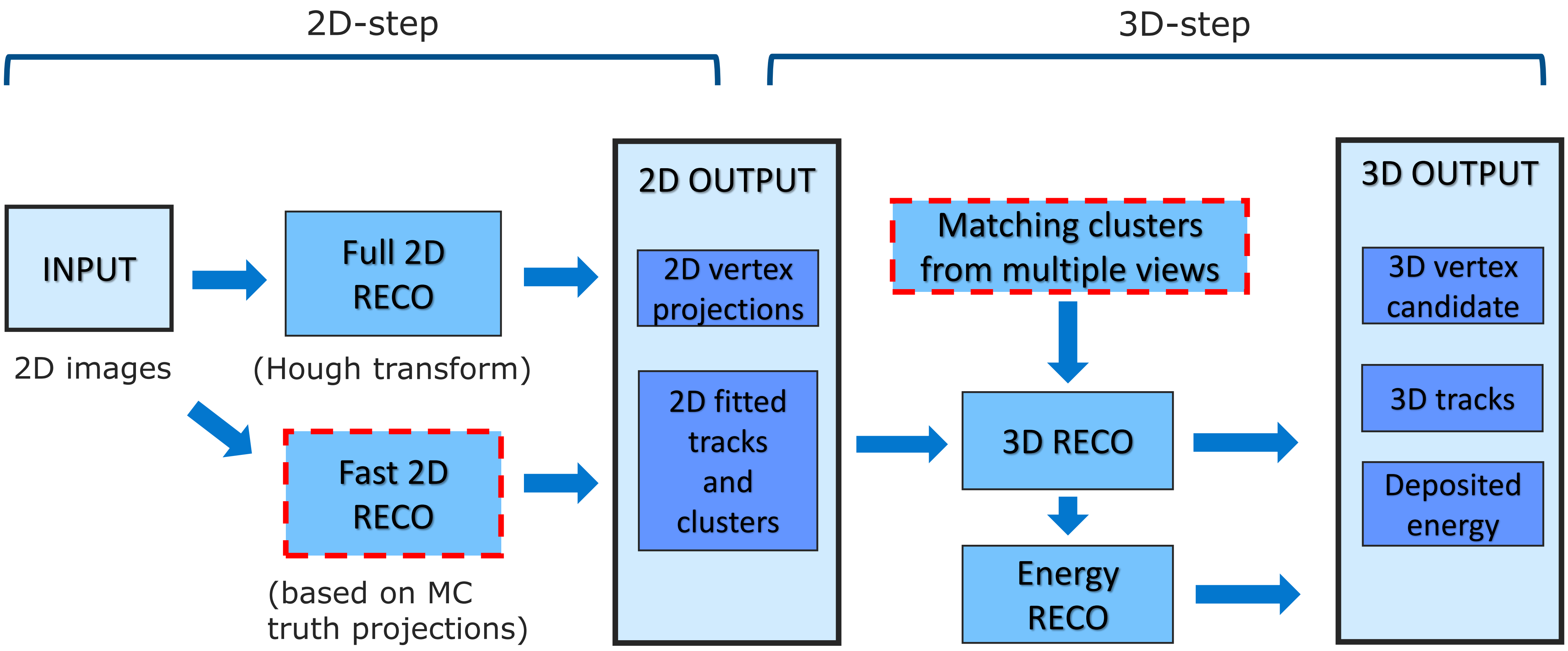
Neutrino event

- ν_μ CC event in GRAIN.
- Example of four images recorded by the lens-cameras.





Reconstruction flow



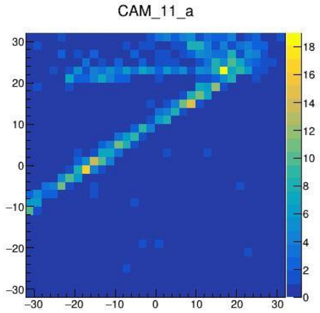
Use of Monte Carlo truth information

2D reconstruction

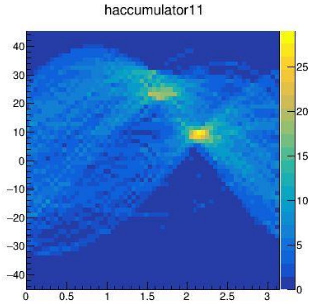
«Full» 2D reconstruction

- Reconstruction algorithm to find and fit lines based on the **Hough Transform**.

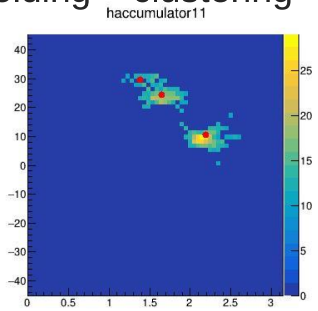
Full simulation



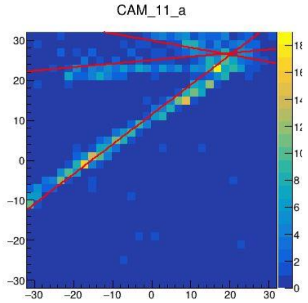
Hough transform



Thresholding + clustering

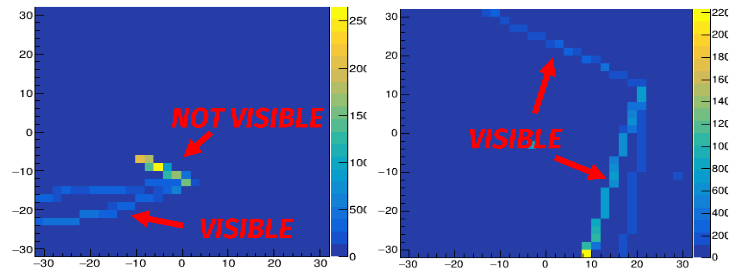


Inverse Hough transform



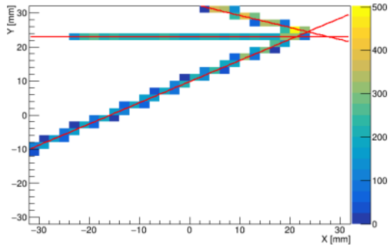
«Fast» 2D reconstruction

- Fit directly on the Monte Carlo **truth projections** of the tracks, if long enough (>10 pixels) to be visible.

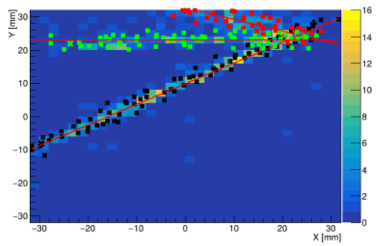


True energy deposits scaled in the sensor area

Fitted MC-truth projection

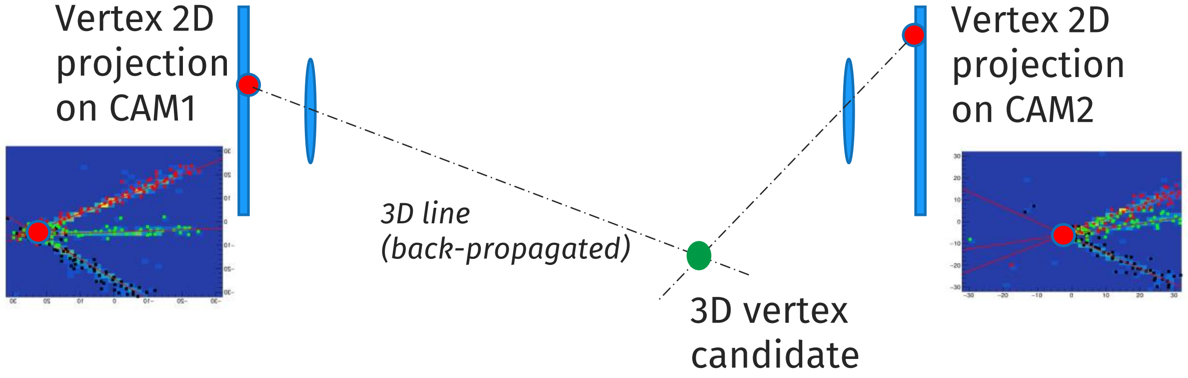


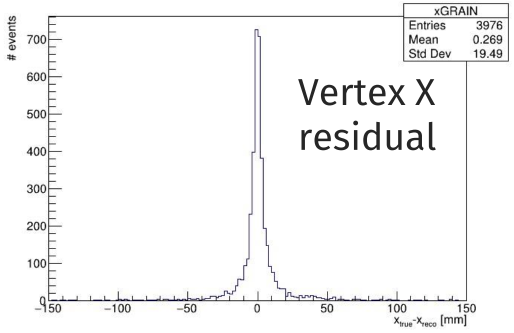
Cluster around fast-fitted lines

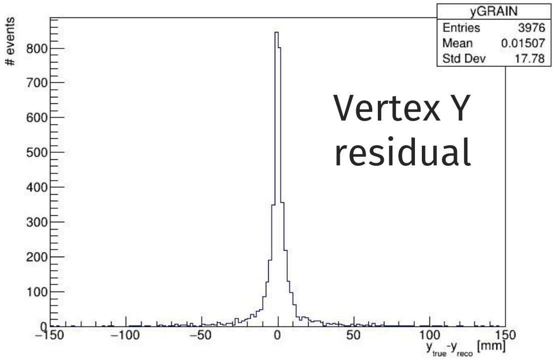


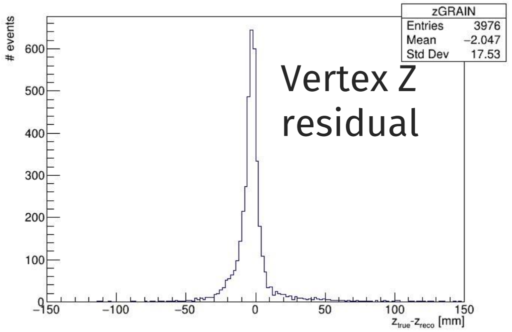
Vertex reconstruction

- If single points can be clearly matched between views (such as **vertex projections**), they can be propagated back into 3D.

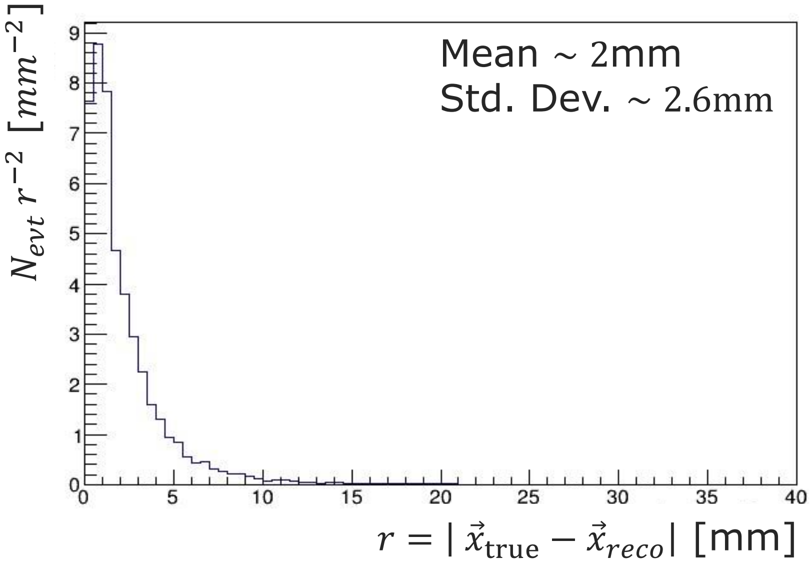






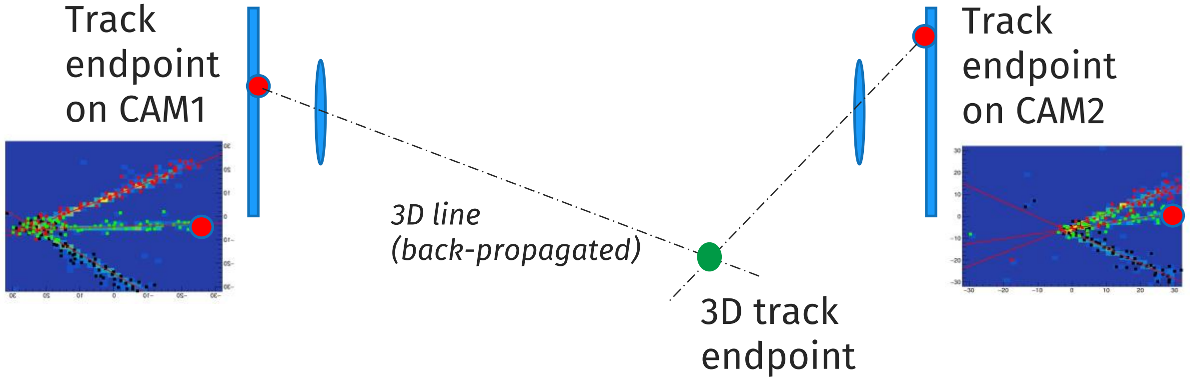


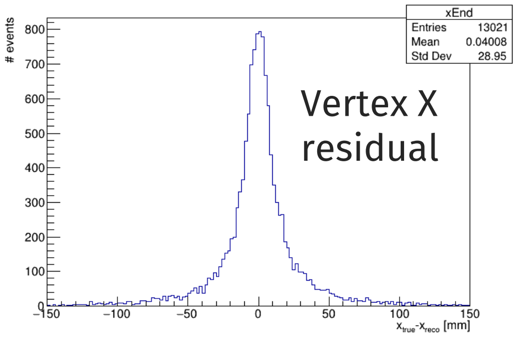
VERTEX 3D residual

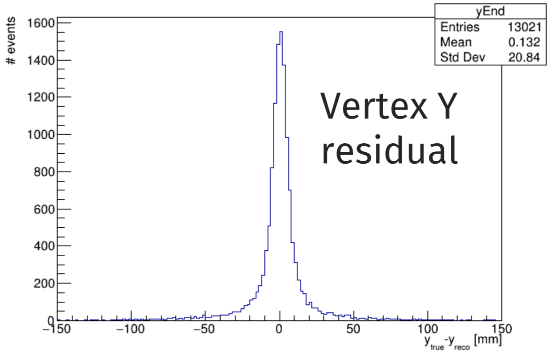


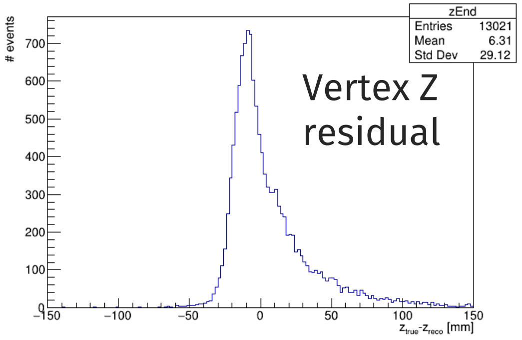
Endpoint reconstruction

- Same for **track endpoints:** selected as the average of the most forward (along Z) pixels of the cluster.

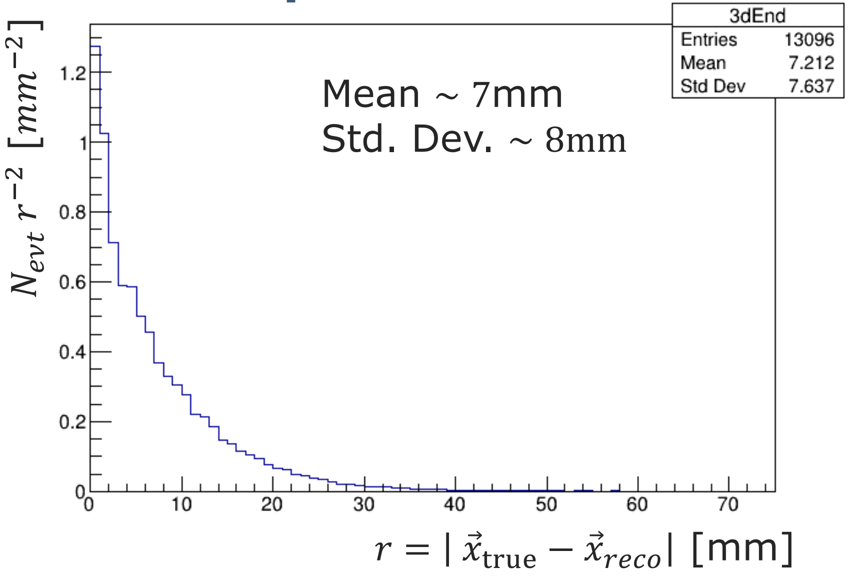






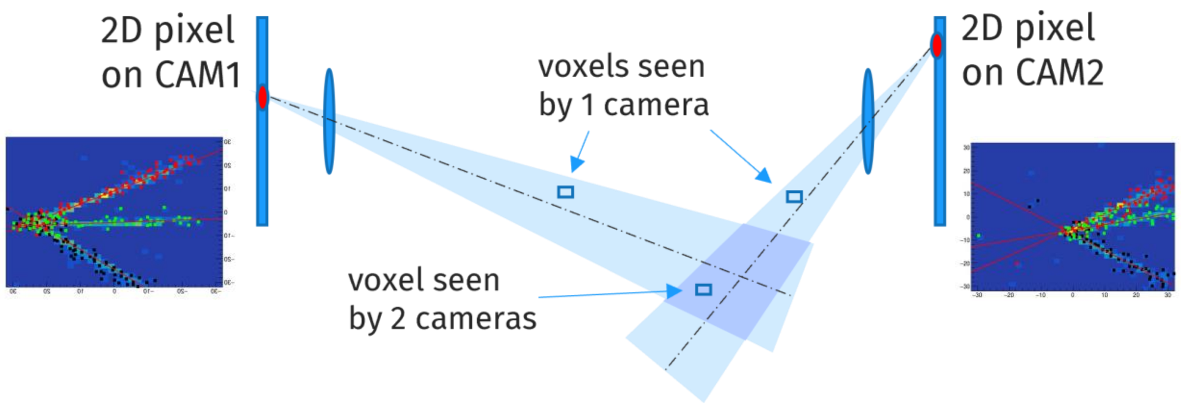


Endpoint 3D residual



3D reconstruction

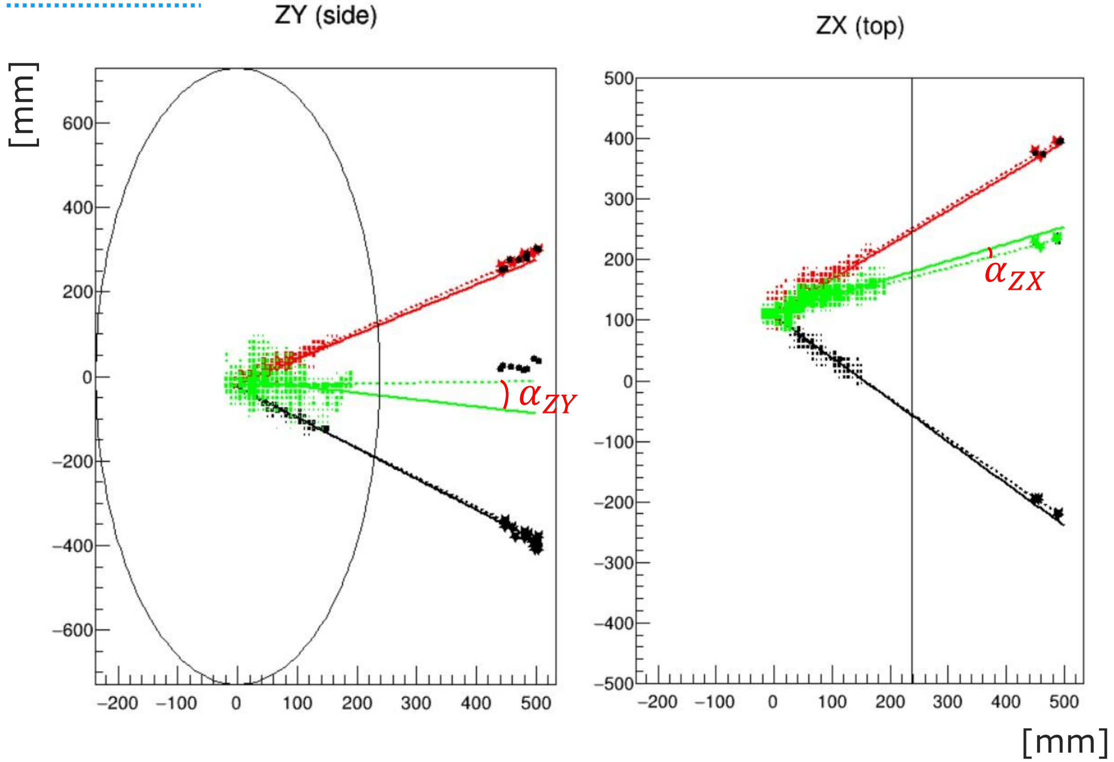
- Track clusters in **multiple views** can be combined for a 3D reconstruction of the interaction.

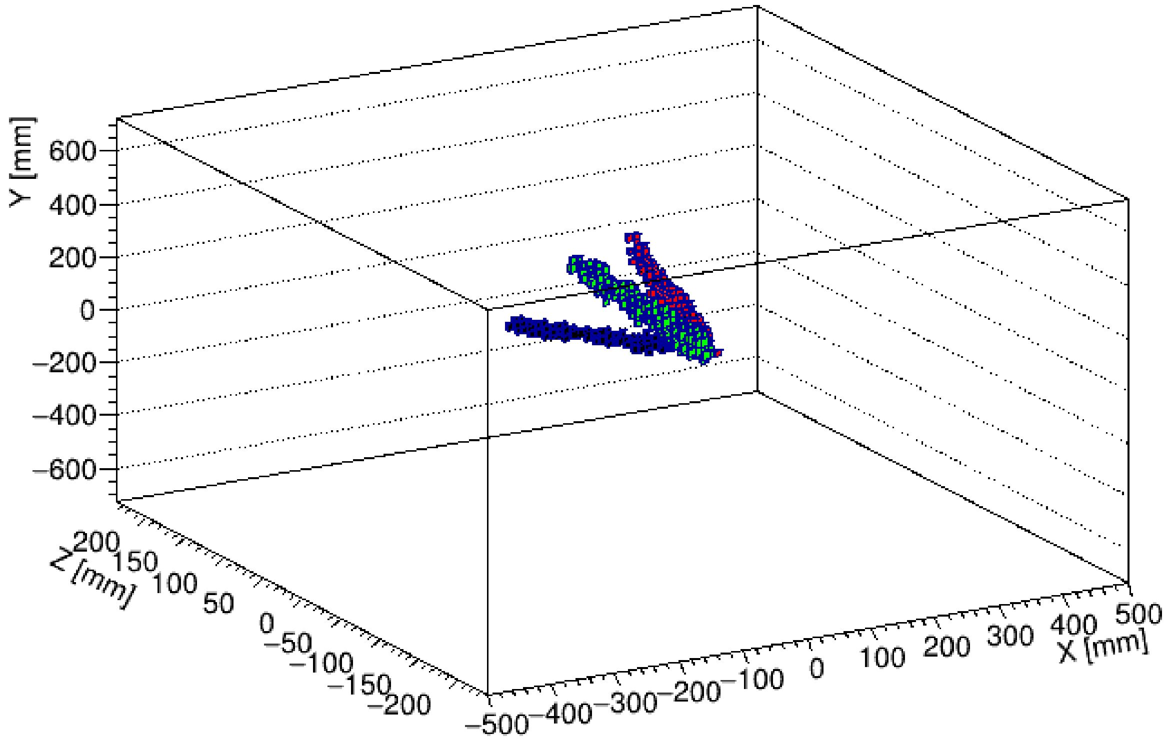


Reco track

MC-truth track

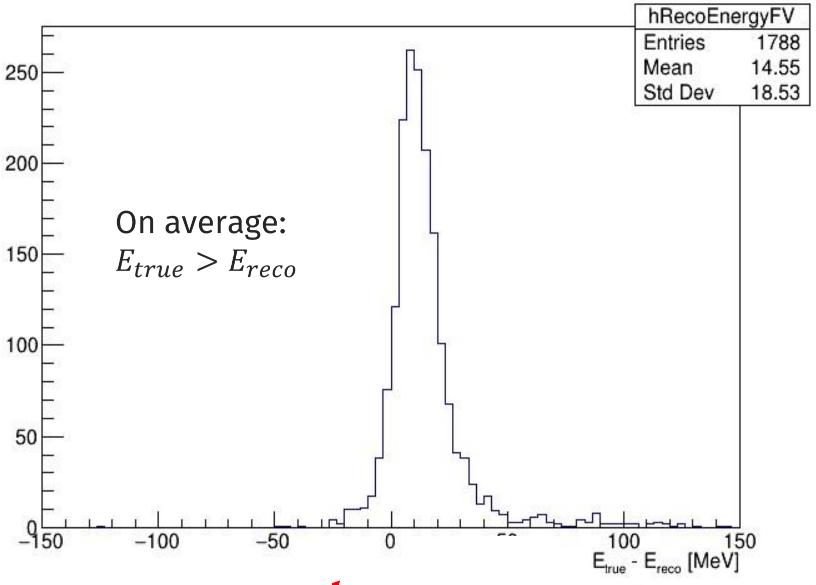
Automatic thresholds on the voxels via multi-Otsu method



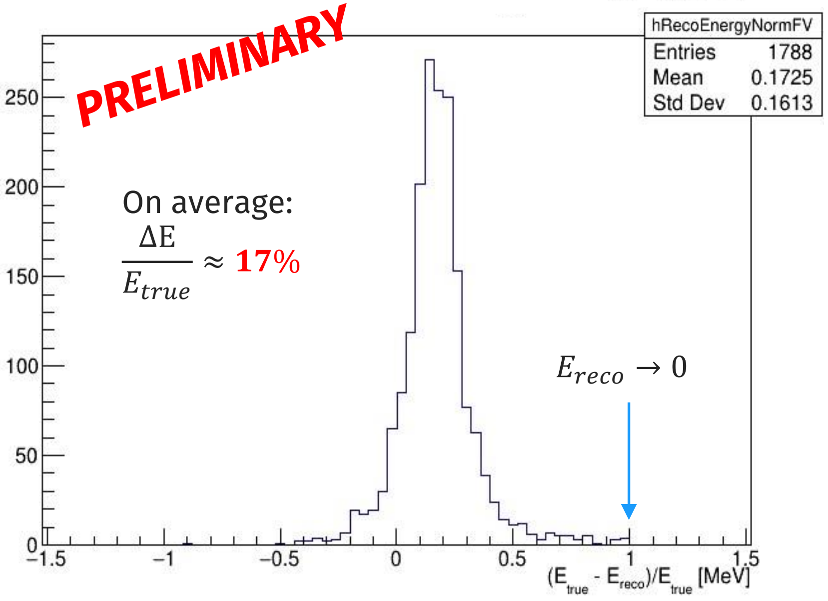


Energy reconstruction

Single muon tracks with direction $\vec{r} \cdot \hat{z} > 0.1$

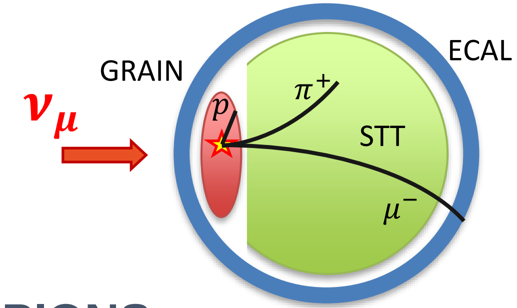


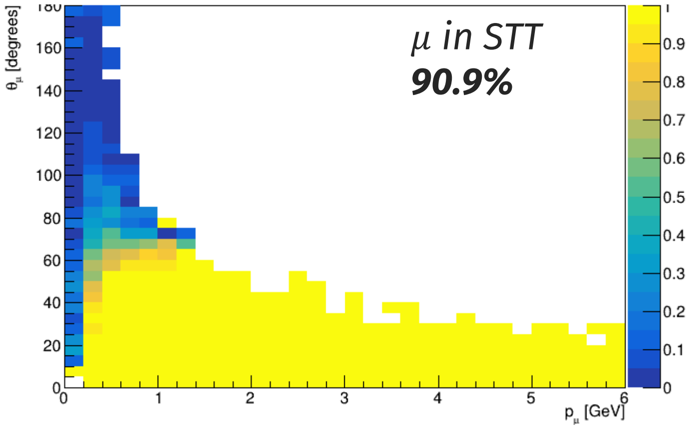
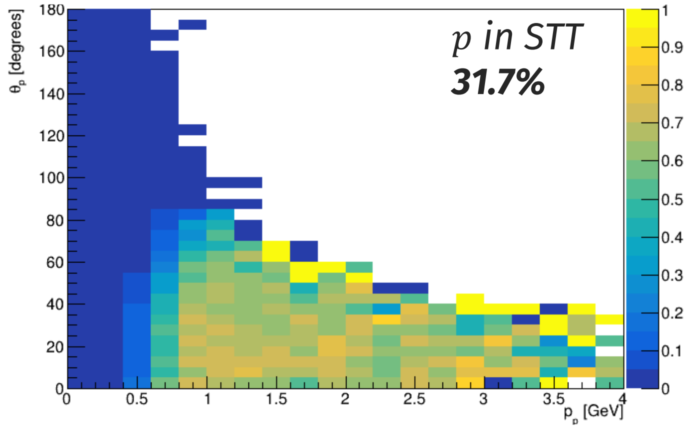
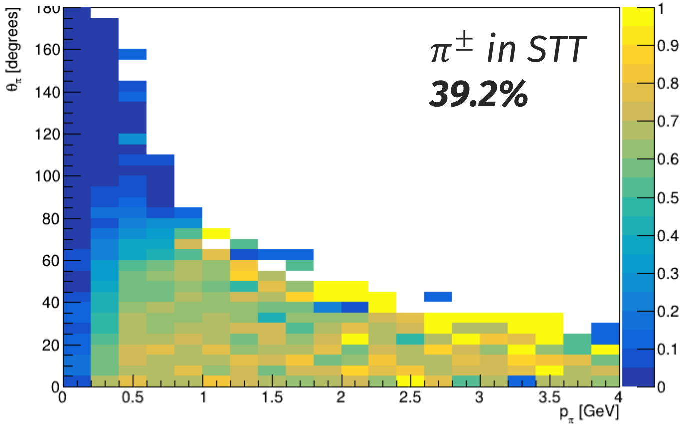
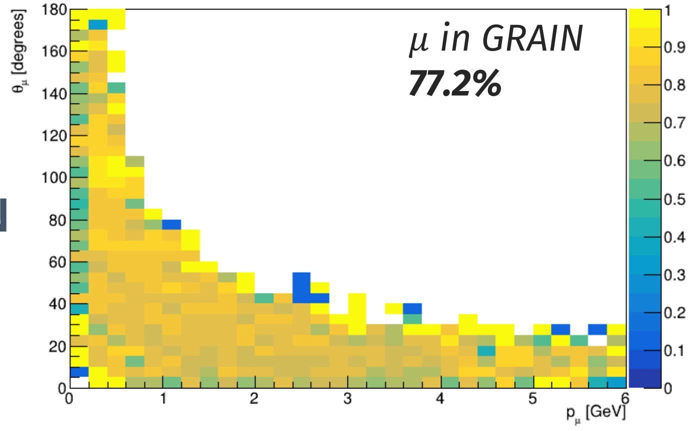
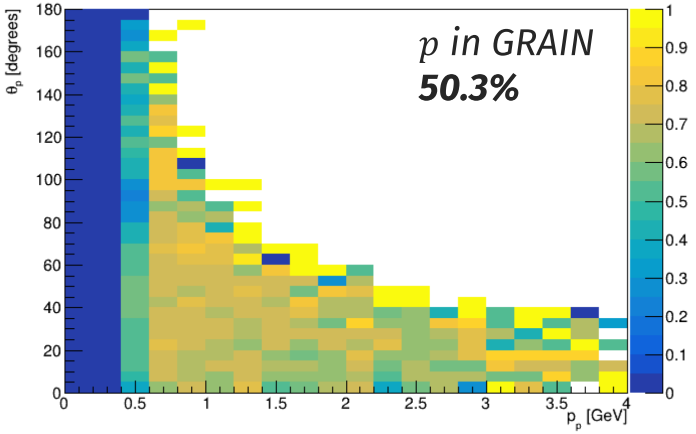
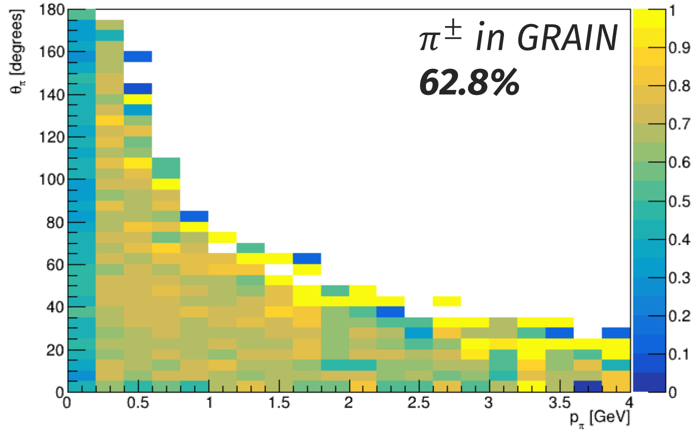
- Total energy deposited → calorimetry
- Track-by-track energy reconstruction:
  - ➢ Exploits track separation in the images
  - ➢ $N^i_{photons} = \alpha^i_{QE}\alpha^i_{GEOM}N_0$ → for *i*-th camera
  - ➢ α^i_{GEOM}: estimated from 3D reco using toy MC
- Very **crude** method → not impossible but requires further development especially for ν events.



Acceptance

for particles produced in GRAIN

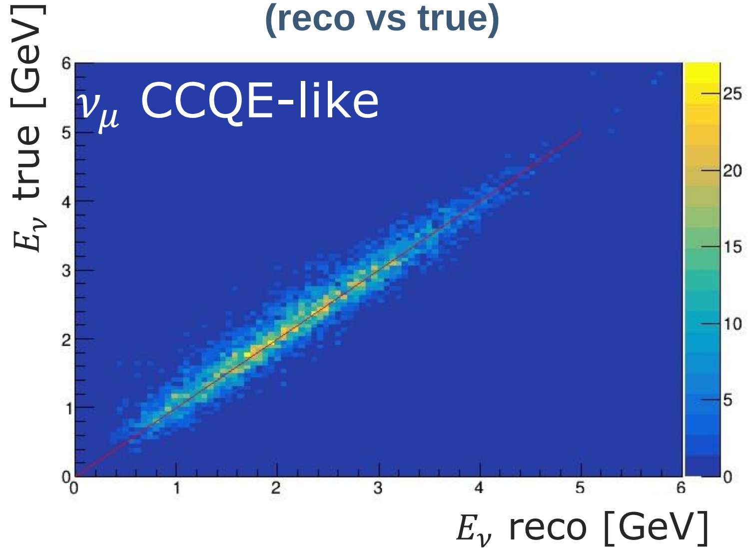


	MUONS	PROTONS	PIONS
STT			
GRAIN			

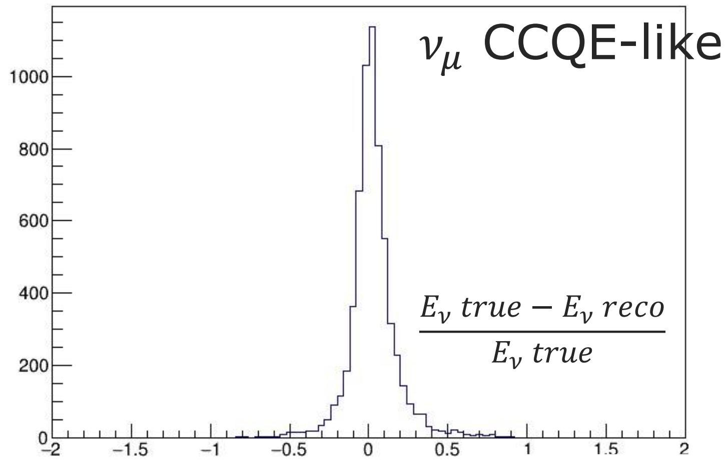
Neutrino energy

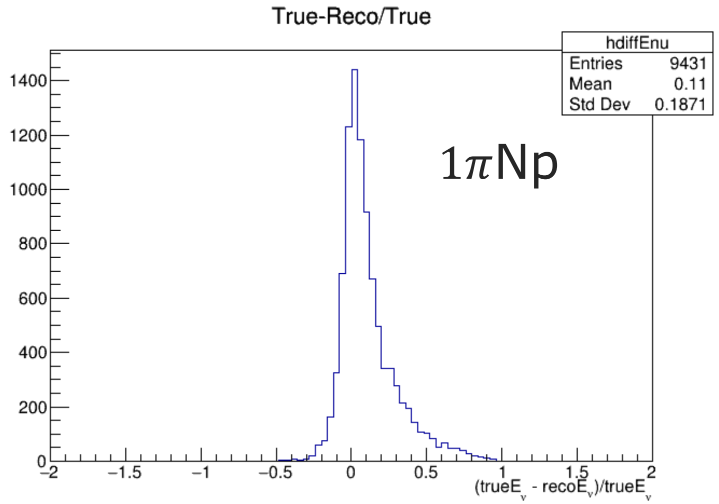
- **FastReco for STT and ECAL + GRAIN info (track direction, track energy 20% smear)**
  - Helps with p stopping in LAr
  - Less with $\pi^{\pm}$ (secondaries not reconstructed)

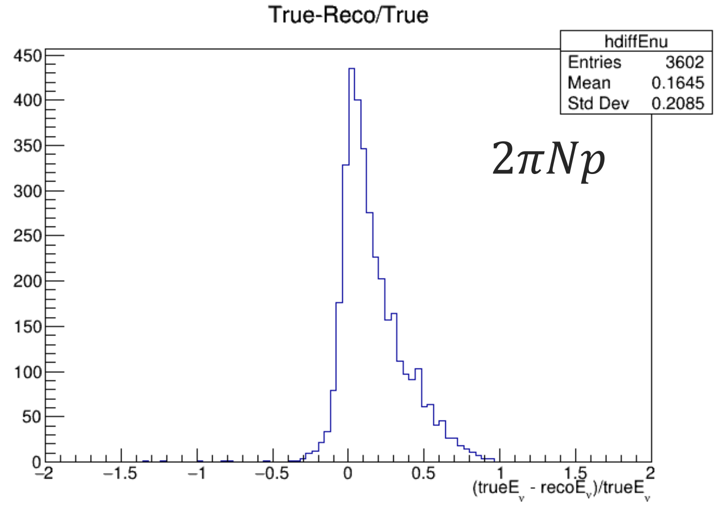
Neutrino energy (reco vs true)

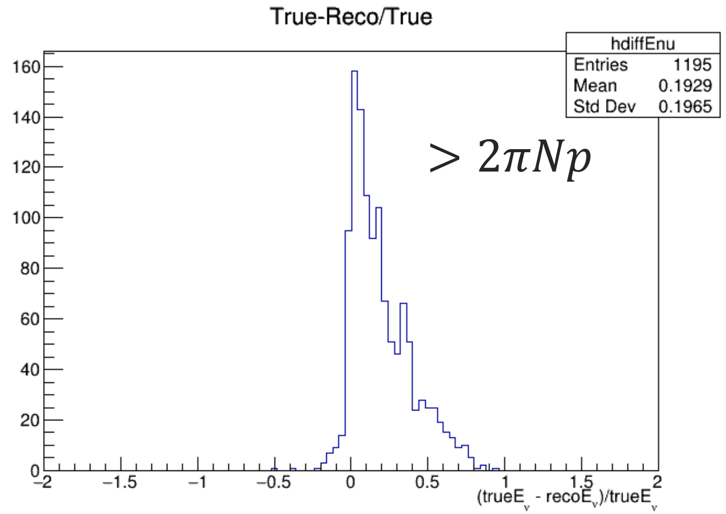


Residual neutrino energy









Summary and outlook

- Baseline design for an **imaging system in LAr** based on VUV lenses
- Preliminary reconstruction algorithm → 3D reconstruction, vertex location, ~energy
- Combined with FastReco for ECAL/STT → neutrino energy
- Warm prototype tested
- Next steps:
  - ➢ Adjust optical design for GRAIN at 1.6m (→ bigger diameter, different focal length?)
  - ➢ Reco improvements: remove MC-truth, investigate energy reconstruction
  - ➢ Cold test in preparation (see L. Di Noto's talk)

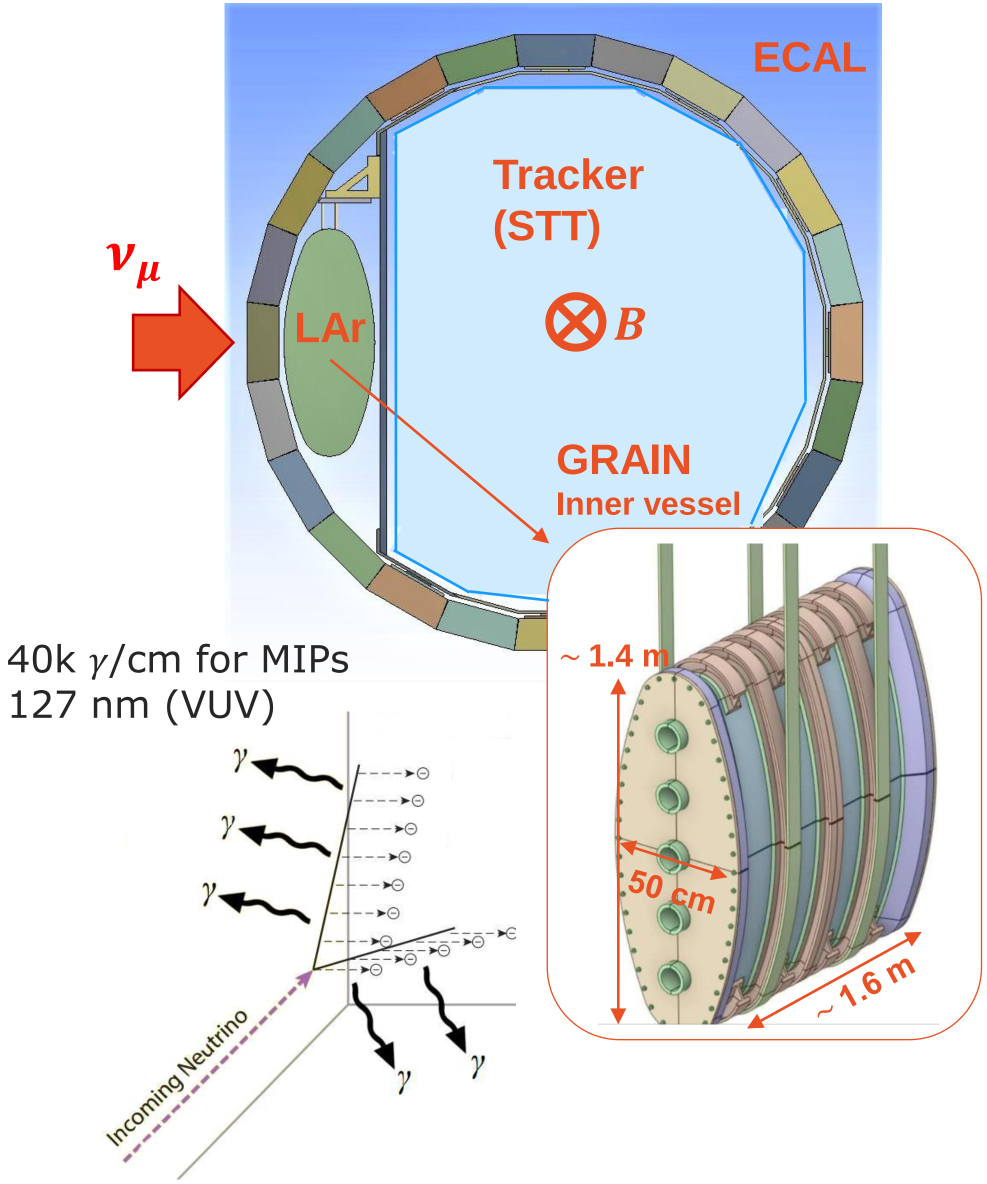
Università di Genova

INFN GENOVA
Istituto Nazionale di Fisica Nucleare
Sezione di Genova

Back-up

GRAIN: LAr target in SAND

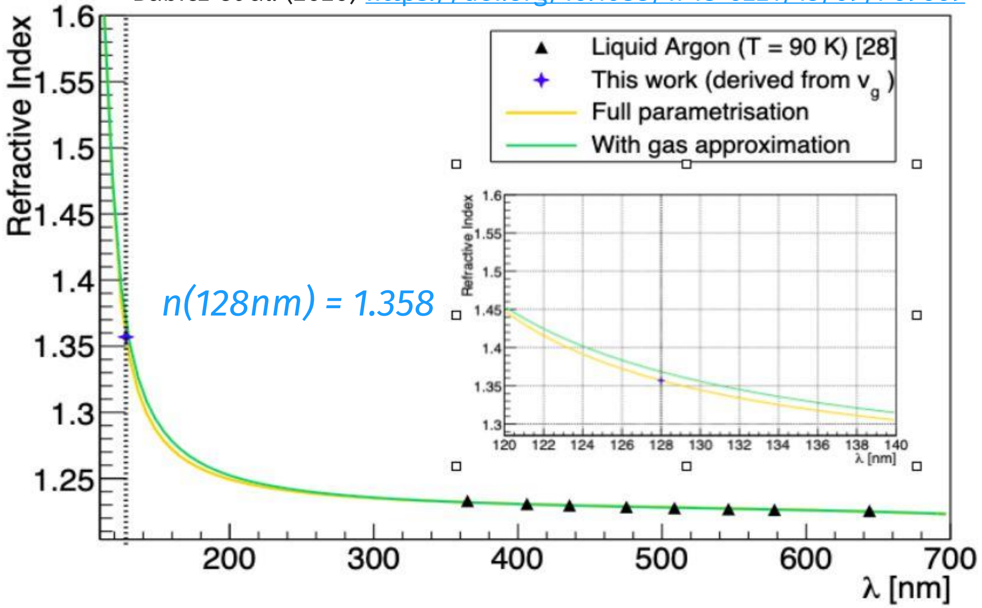
- As a **passive** target:
  - 1-ton LAr (~1X_0) inside the magnetic field.
  - Compromise between mass (event statistics) and thickness (transparency to charged particles).
  - Study ν-Ar interactions with downstream tracker/calorimeter
- As an **active** target:
  - No charge collection → too slow (few $mm/\mu s$ vs 10μs wide beam spill).
  - Collect LAr scintillation light with arrays of SiPMs for timing and calorimetry
  - Perform imaging of the event with VUV scintillation light (**R&D for UV cameras**) → vertex location, event topology

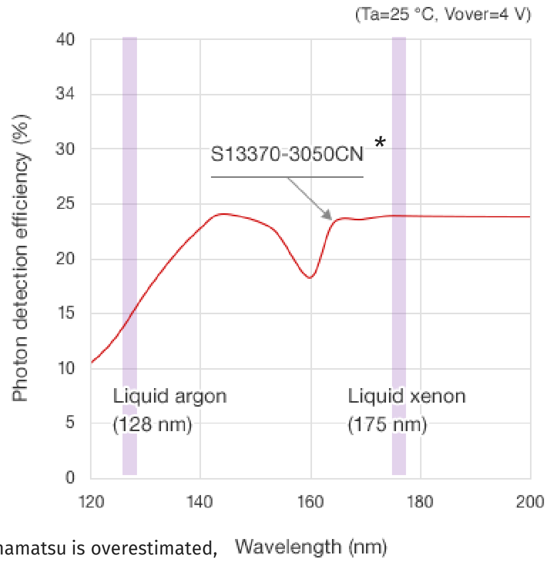


Challenges for lenses

- **VUV wavelenght:**
  - ➢ Hard to find suitable materials (MgF_2, CaF_2, …)
  - ➢ Low PDE (10-15%) even for UV-grade SiPMs
- **Refractive index:**
  - ➢ LAr is close to ~1.4, too similar to some materials. Difficulty in designing the optics.
- **Fixed focal plane:**
  - ➢ Focus is fixed by lens-sensor distance but covering up to $O(1m)$ is required.

Babicz et al. (2020) https://doi.org/10.1088/1748-0221/15/09/P09009

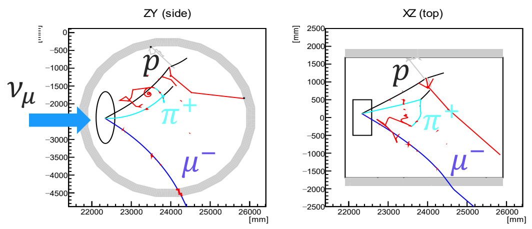


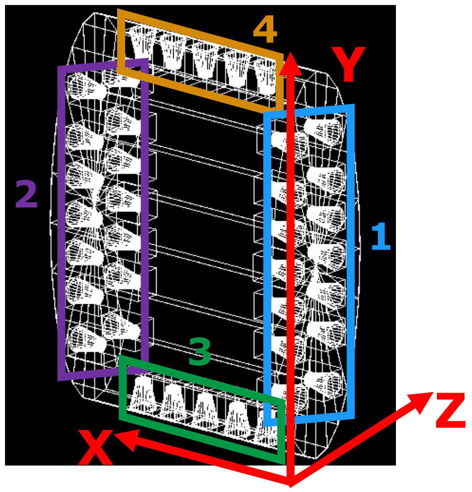


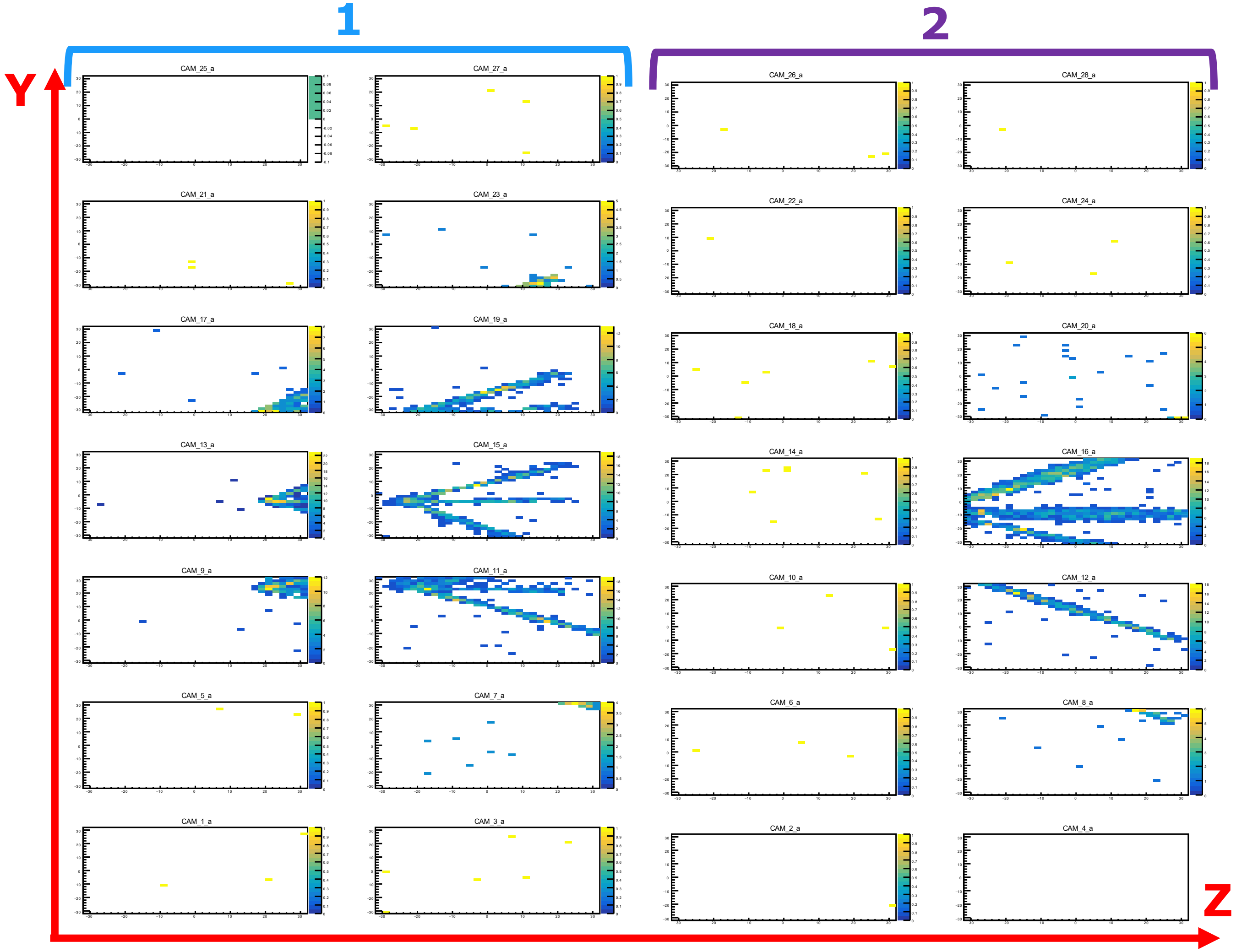
* this PDE reported by Hamamatsu is overestimated, but its behavior is indicative of other models (https://doi.org/10.1016/j.nima.2019.05.096)

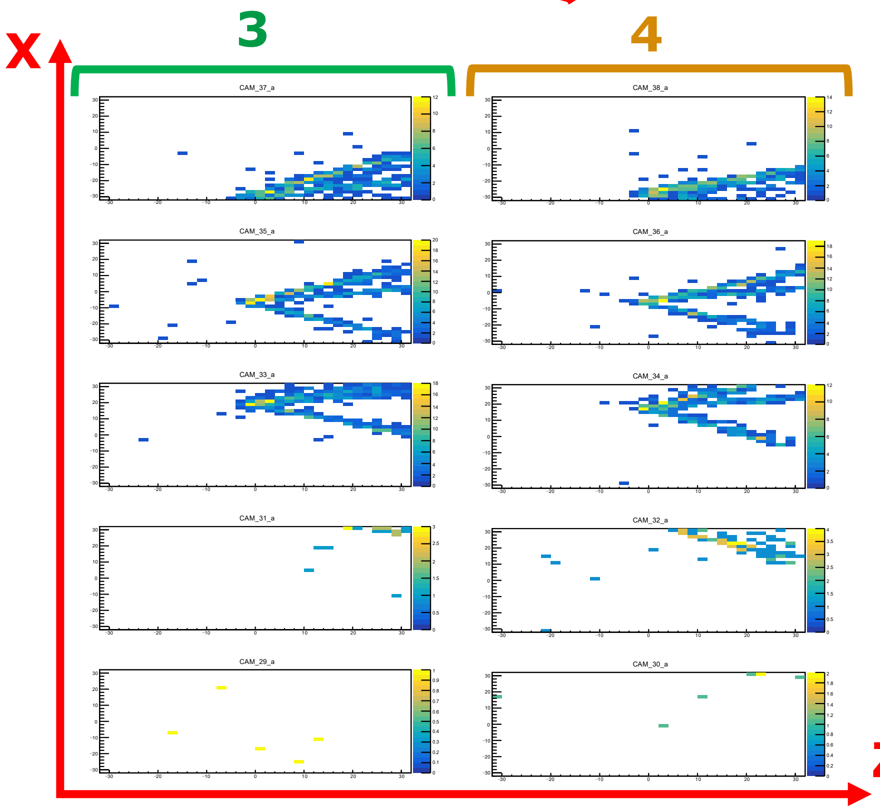
Event in GRAIN

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



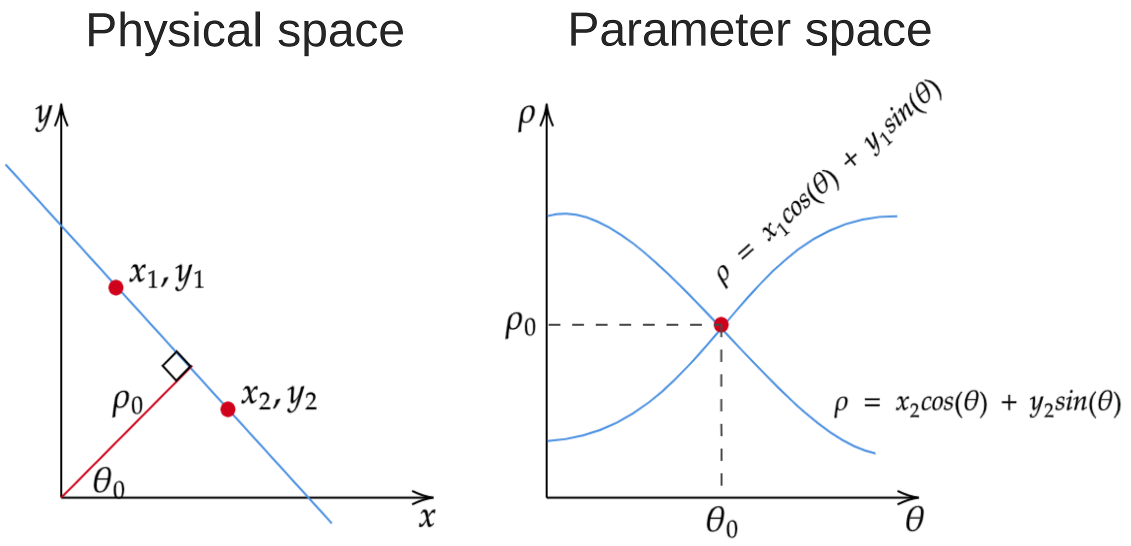


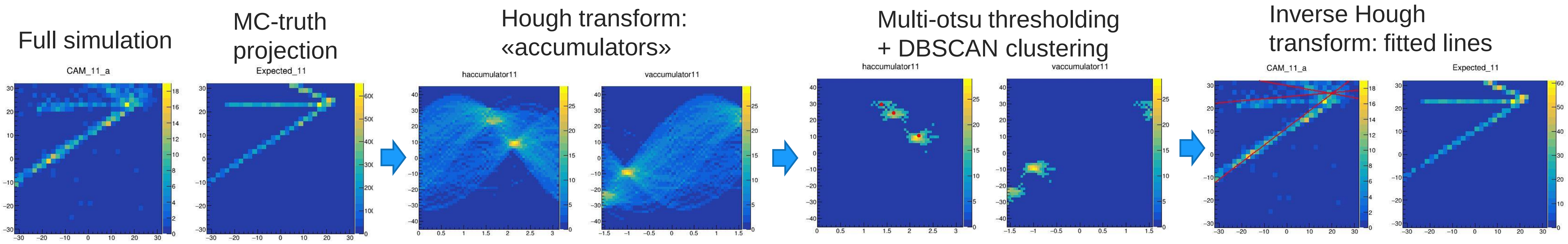




Hough transform

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





True energy deposits scaled in the sensor area

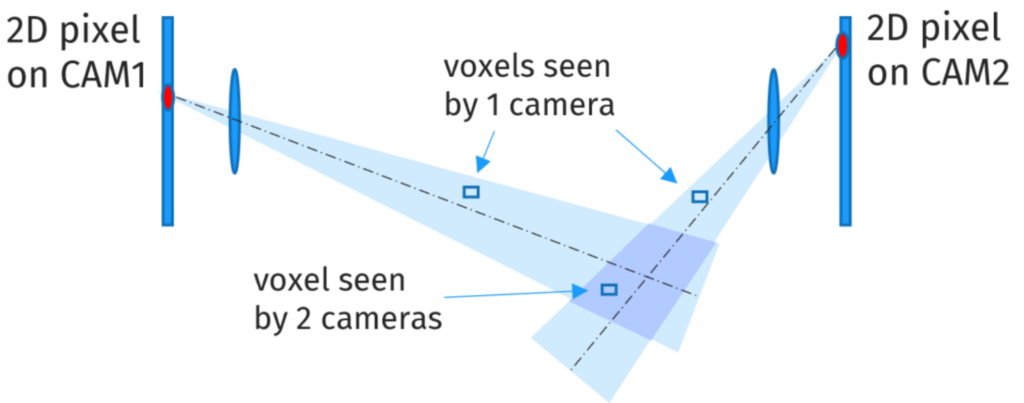
$[0, \pi]$

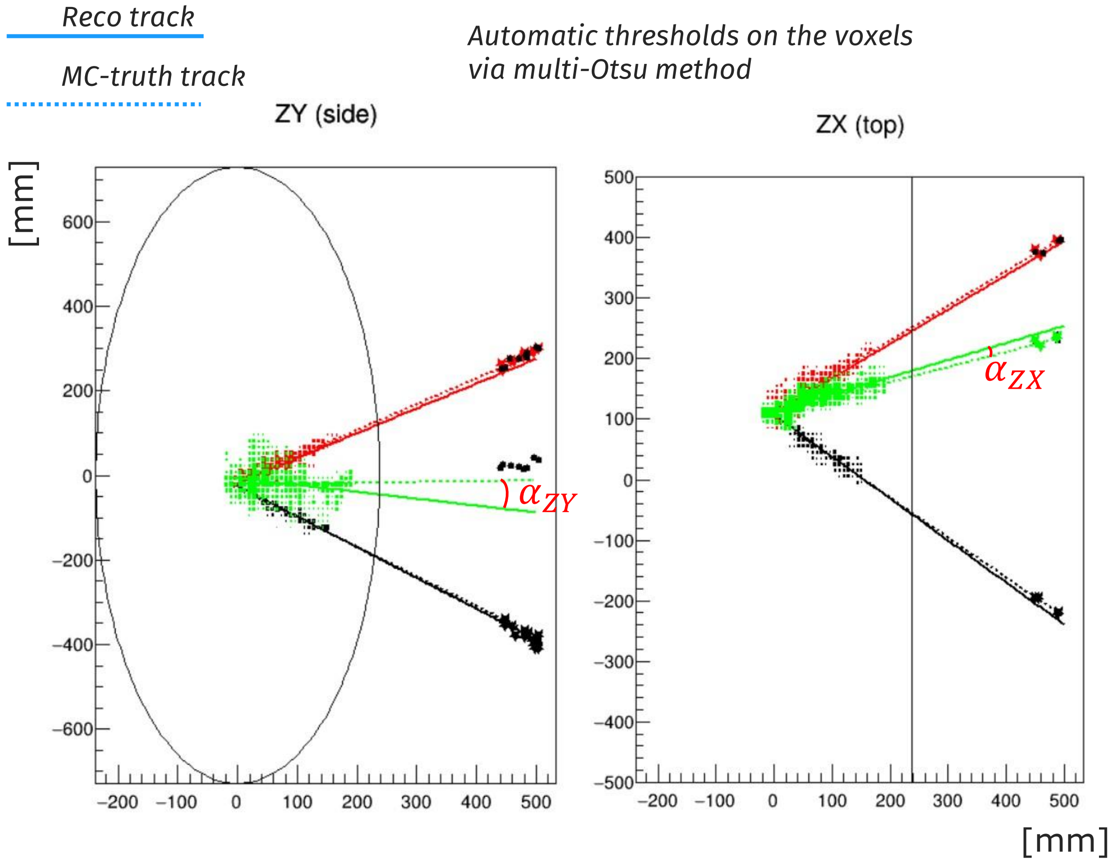
$\left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$

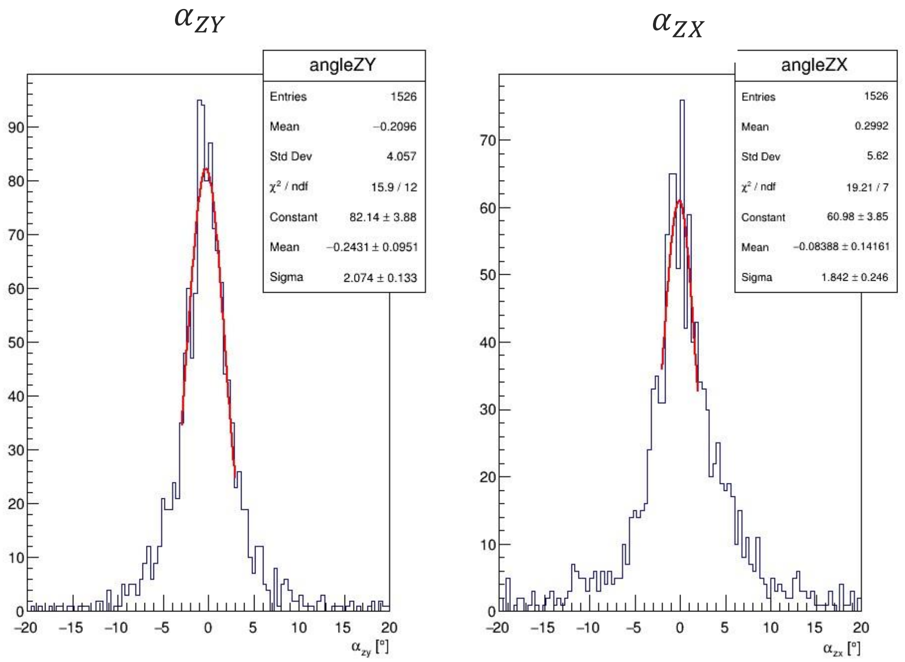
The center of each cluster provides (θ, ρ) of the track.

3D reconstruction

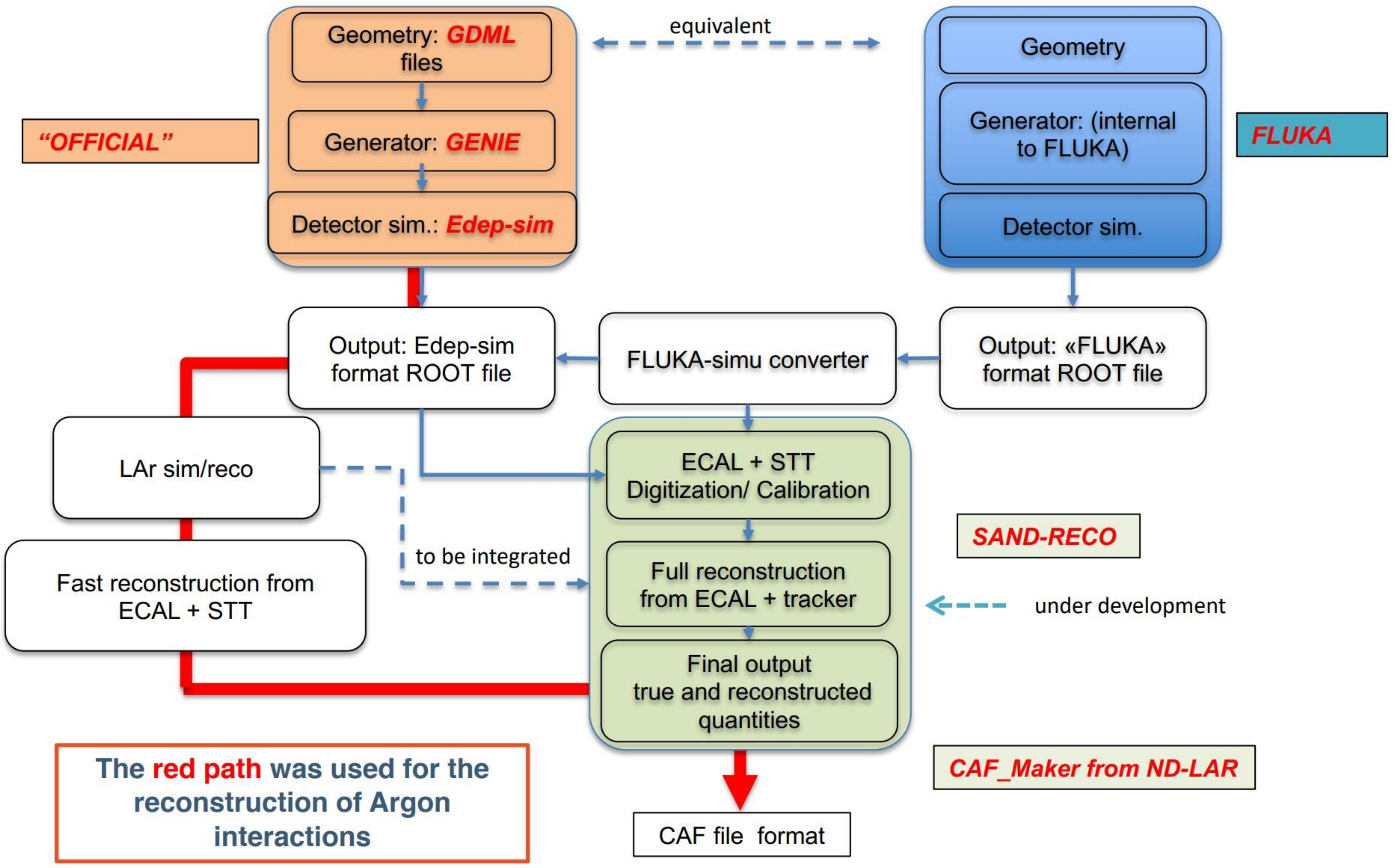
- Track clusters in **multiple views** can be combined for a 3D reconstruction of the interaction.







Software flowchart



Università di Genova

INFN GENOVA

Istituto Nazionale di Fisica Nucleare
Sezione di Genova