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Neutrino Physics:

event reconstruction tools

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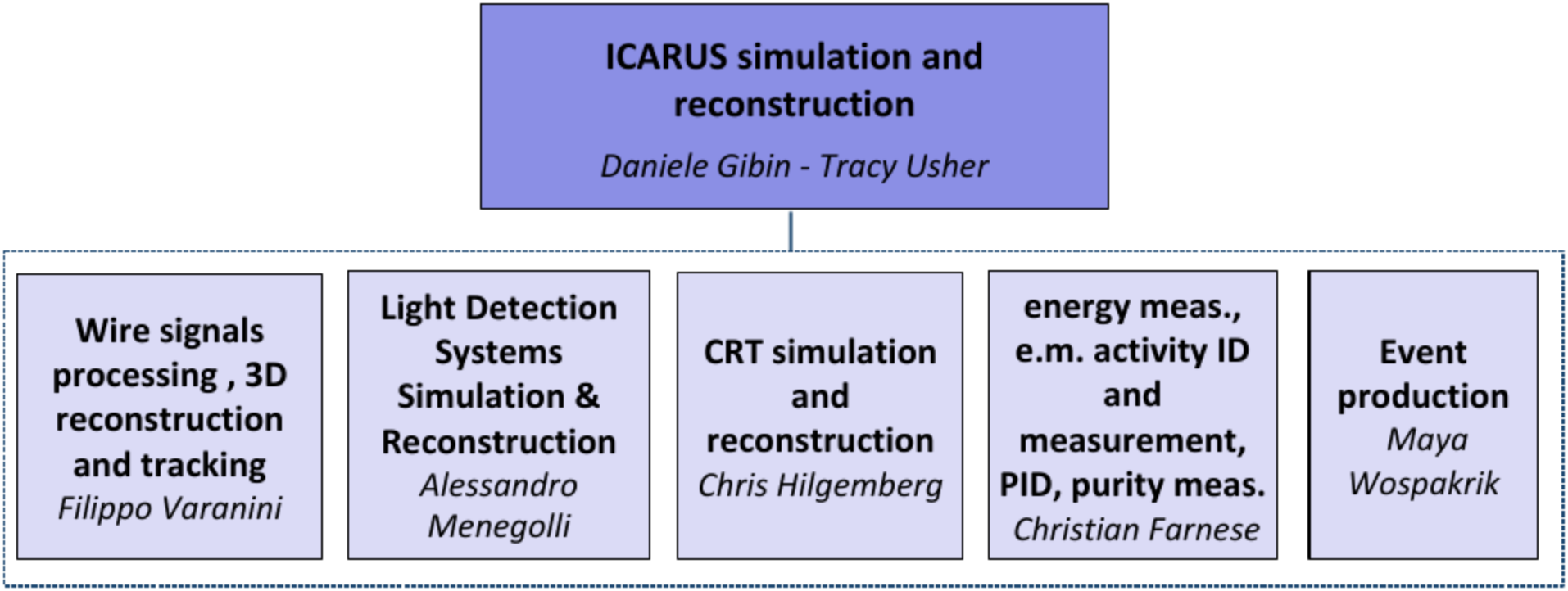
Organization

- The ICARUS simulation and reconstruction group is responsible for the preparation and maintenance of the software tools needed for the simulation and the reconstruction of the data collected in the experiment.

- Many of sub-groups are convened by ICARUS INFN people:



Status of activities – 1

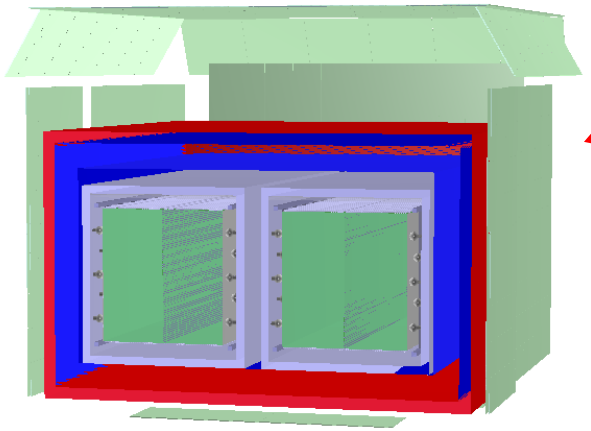
- The present activities are concentrated on the simulation of events to be ready for the arrival of the real data.
- The basic functionality for the simulation of ν interactions (BNB and NuMI beams) and cosmic rays crossing the detector is in place and operational. In particular:
  - Description of the signal provided by the new wire front end electronics. Wire noise model from past running and from testing of the new electronics;
  - PMT "library" allowing reasonable simulation of the light response in both cryostats;
  - Working CRT simulation.

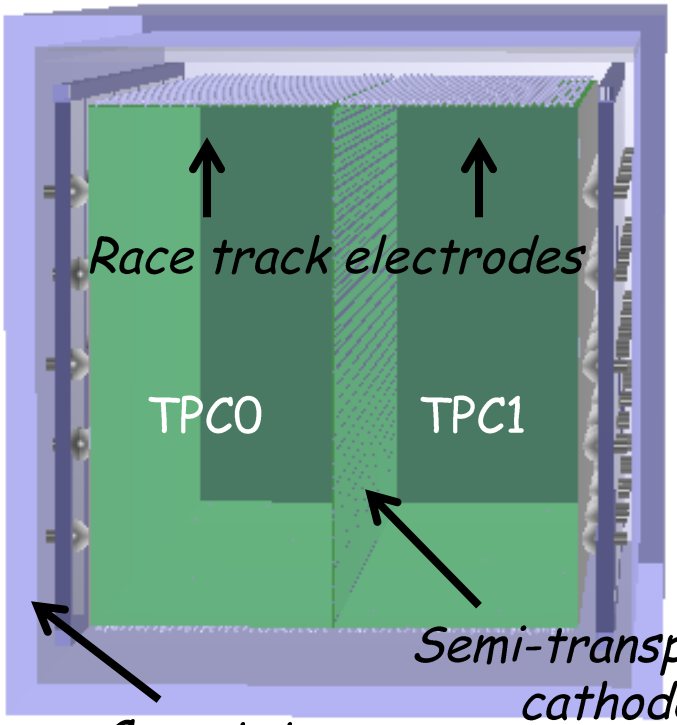
Status of activities - 2

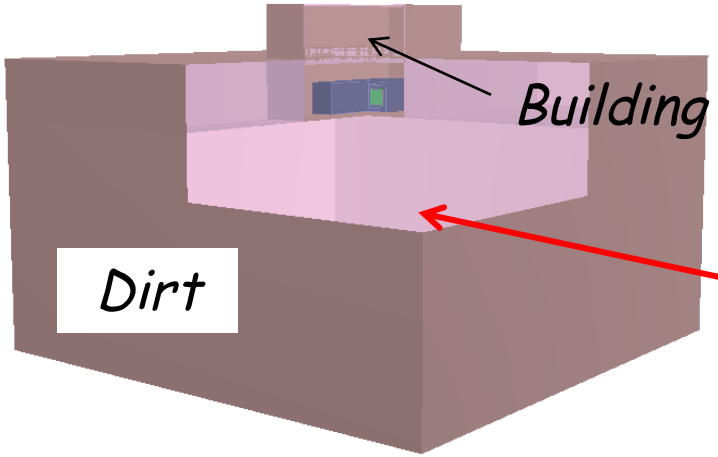
- Basic signal processing chain available:
  - A suite of noise filtering tools available, inspired also by the features observed in past ICARUS run;
  - Original "raw hits" path developed from the original ICARUS hit finding and fitting and treatment of the now bipolar induction signals;
  - 1D deconvolution algorithm to convert the induction signals to unipolar signals with good response and using the LarSoft hit finding algorithm.
- We have optical hit and light flashes reconstruction.
- We have integrated the Basic tracking and shower reconstruction.
- The code to create 3D Space Points which are being fed into the deep learning effort is running.
- We have some final stage code now running for:
  - Track fitting.
  - Track momentum determination from MCS.

Detector description

- Correct size/composition/mass of materials surrounding active LAr;
- Realistic description of PMT;
- Stainless steel chamber lateral mechanical structure.



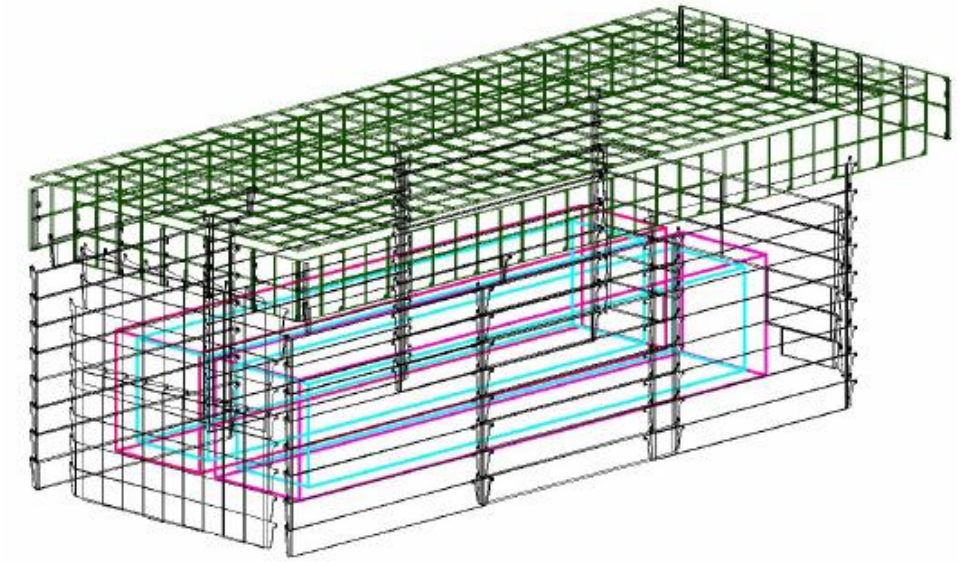




ICARUS «World»

CRT description and reconstruction

- *The geometrical description of the CRT is quite realistic, including support structures and drawings of the detector.*



- *Detector simulation has been validated with data from CRT test stand.*

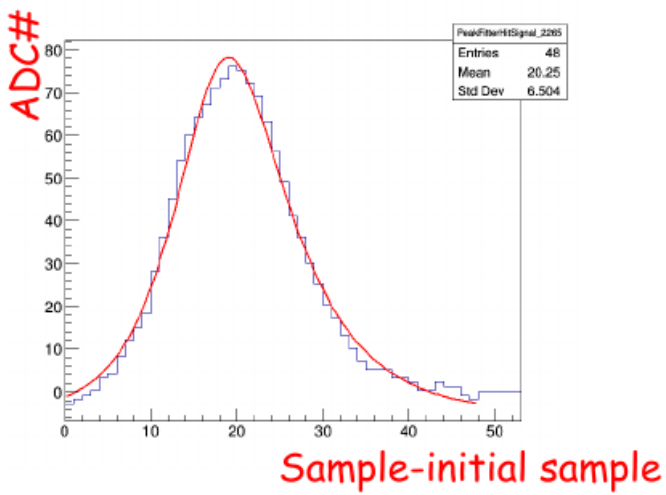
- *Reconstructed CRT hit are now available and are being analysed to evaluate detector tagging efficiency in more realistic way than exploiting truth information in MC.*

Wire signal: processing and hit finding

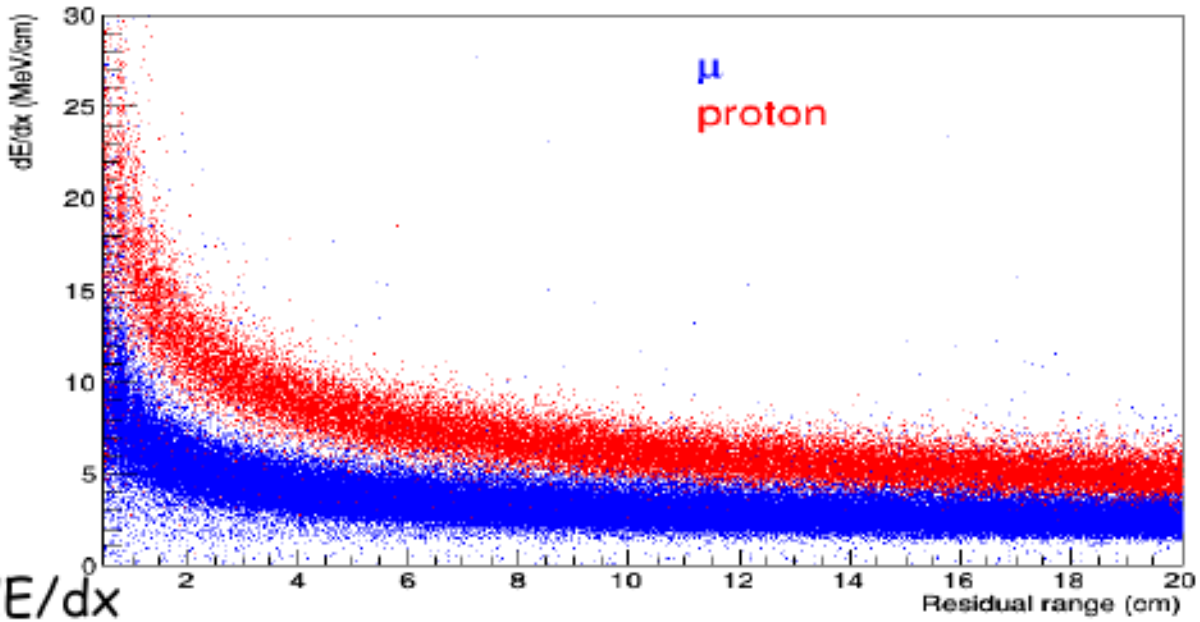
- Two different and complementary approaches are available in the code:

- Raw (used by ICARUS@LNGS): no deconvolution takes place.
  - Hit-finding directly performed on raw signal from wires
  - Different hit shapes for different wire-planes
  - Offline integration/filtering of Induction-2 signal

- Deconvolution: response functions are first inverted to (ideally) recover the intrinsic drift electron signal. Then:
  - ROI identification and hit-finding performed on deconvolved signal.
  - MIP hit shape is Gaussian and independent of wire-plane.

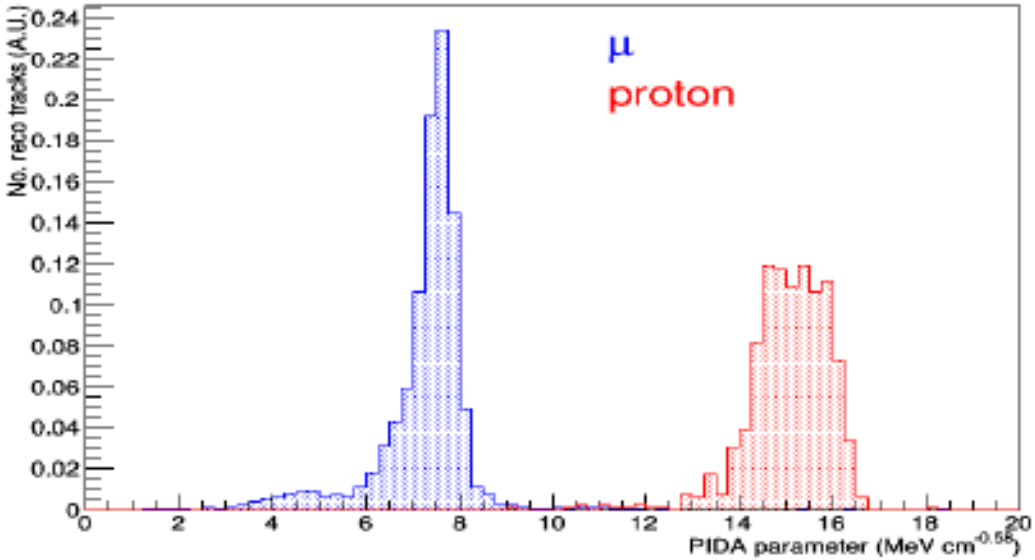


Reco tool: PID with dE/dx for stopping particles

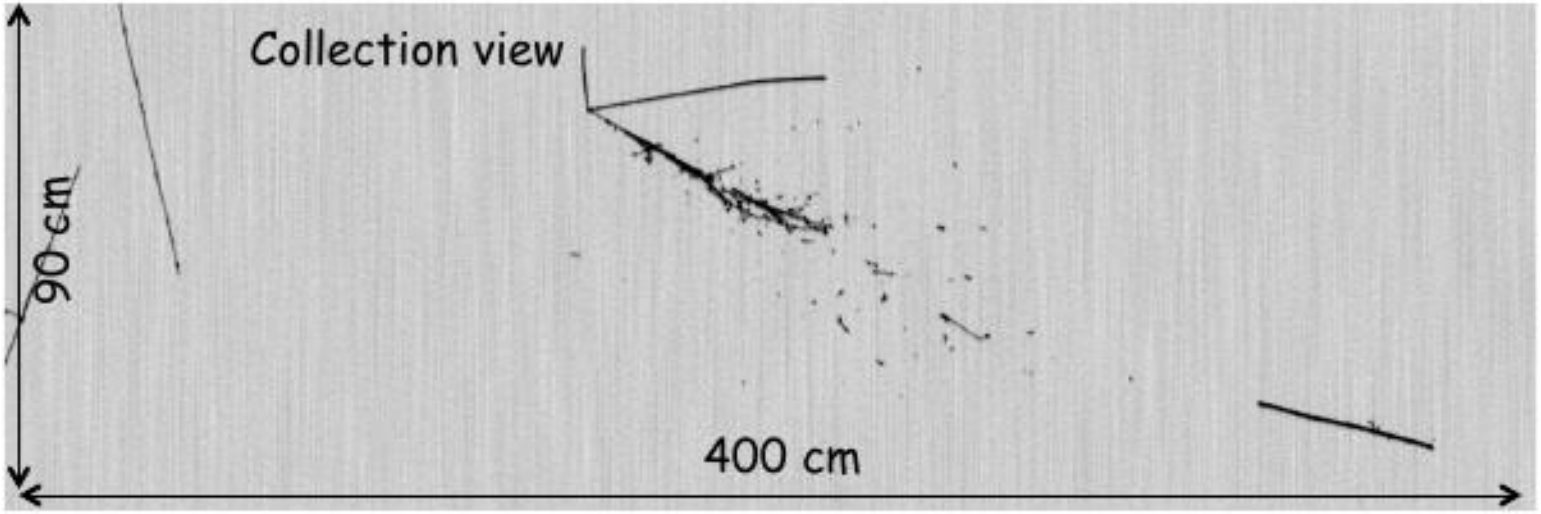


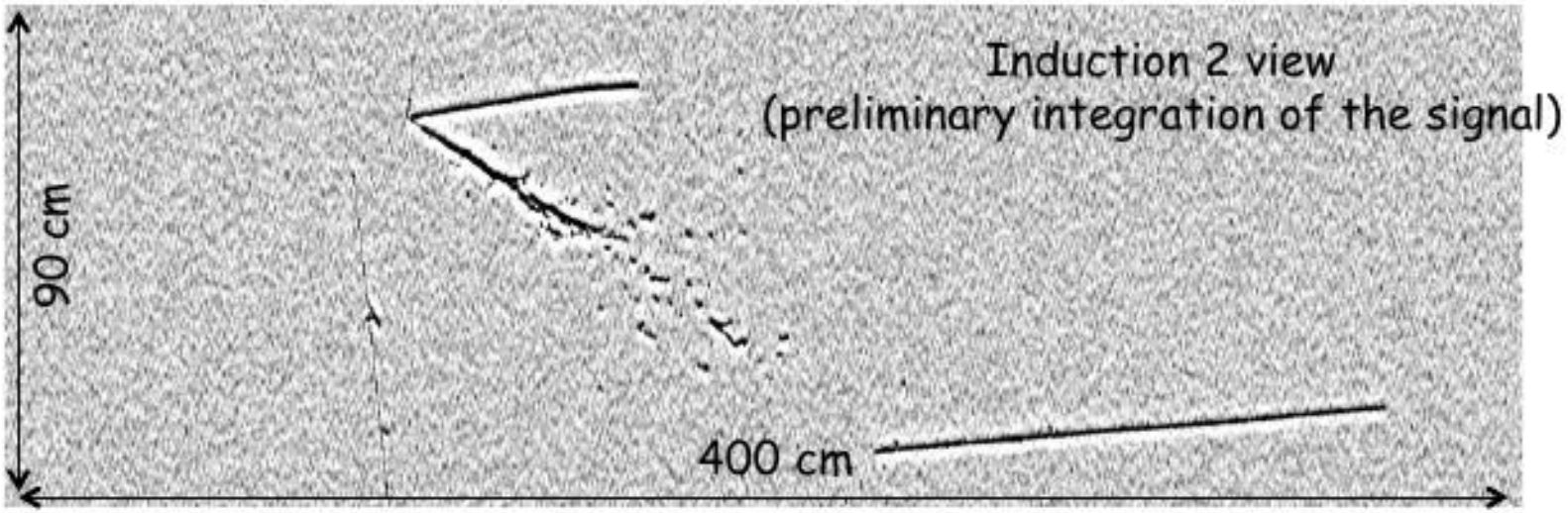
- First plot for the dE/dx vs range and for the particle identification test obtained for protons and muons.

- In this analysis only the Collection view has been used for the calorimetric reconstruction



Reco tool: simulation of BNB events



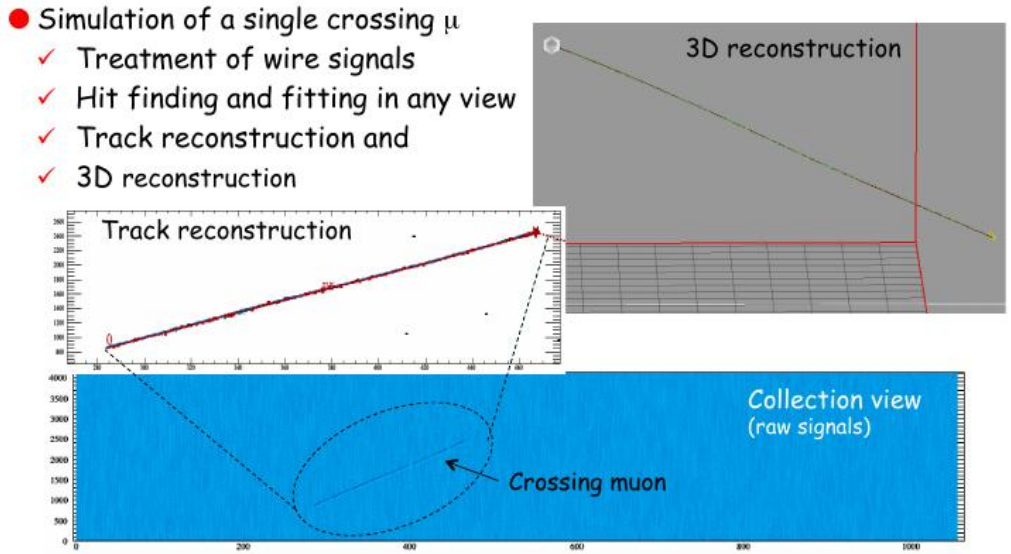


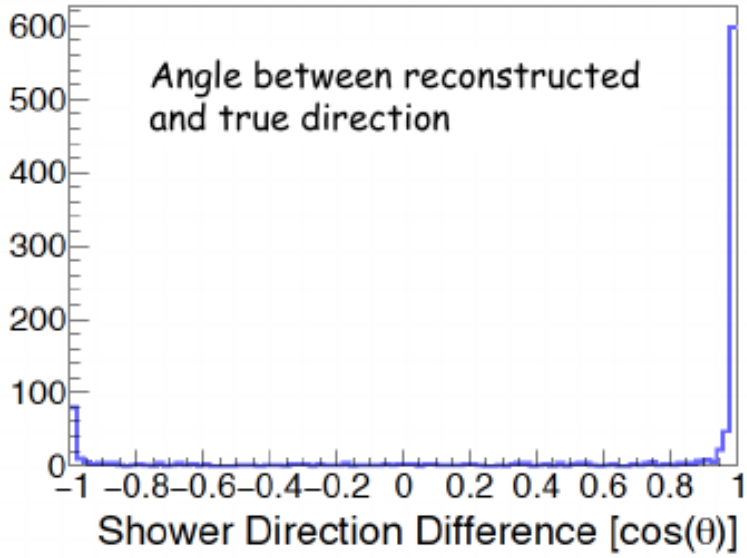
- Close view of one 1.8 GeV ν_eCC

Reco tool: Track/Shower Reconstruction

- The hits are the final result of the signal processing. To reduce noise, hits from each plane are combined to form SpacePoints. Fake hits from noise will not form valid SpacePoints and can be removed.

- Resulting collection of hits are input to the Pandora framework
  - Three stages: overview, track finding, shower finding
  - Track and shower pattern recognition package
  - Returns candidate vertices for tracks/showers/particles
  - Creates particle hierarchy (PFParticles) for "connected" tracks and showers – describes structure of, for example, neutrino interactions





Reco tool: light simulation and reconstruction

- A computer-intensive simulation is first performed: 10^5 scintillation photons are generated in a grid (5x5x5 cm^3 cells) over full LAr volume.
- The probability (visibility) that a photon generated in a given point of the LAr hits any PMT is computed as a 3D map called photon library.
- Photo-electrons generated by ionizing tracks on each PMT are parameterized as the visibility of their production point (stored into the photon library) × the PMT quantum efficiency.
- The arrival time distribution is then parameterized as a function of the distance from the light production point and individual PMT.
- PMT waveforms are generated including PMT noise, fluctuations in PMT gain.
- We have the full chain from digitized signals to global objects:
  - Hit PMT ("OpHit") identification;
  - Grouping of hit PMTs into clusters ("OpFlash") based on their time coincidence.