Automated Reconstruction, Signal Processing and Particle Identification in DUNE

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FNAL

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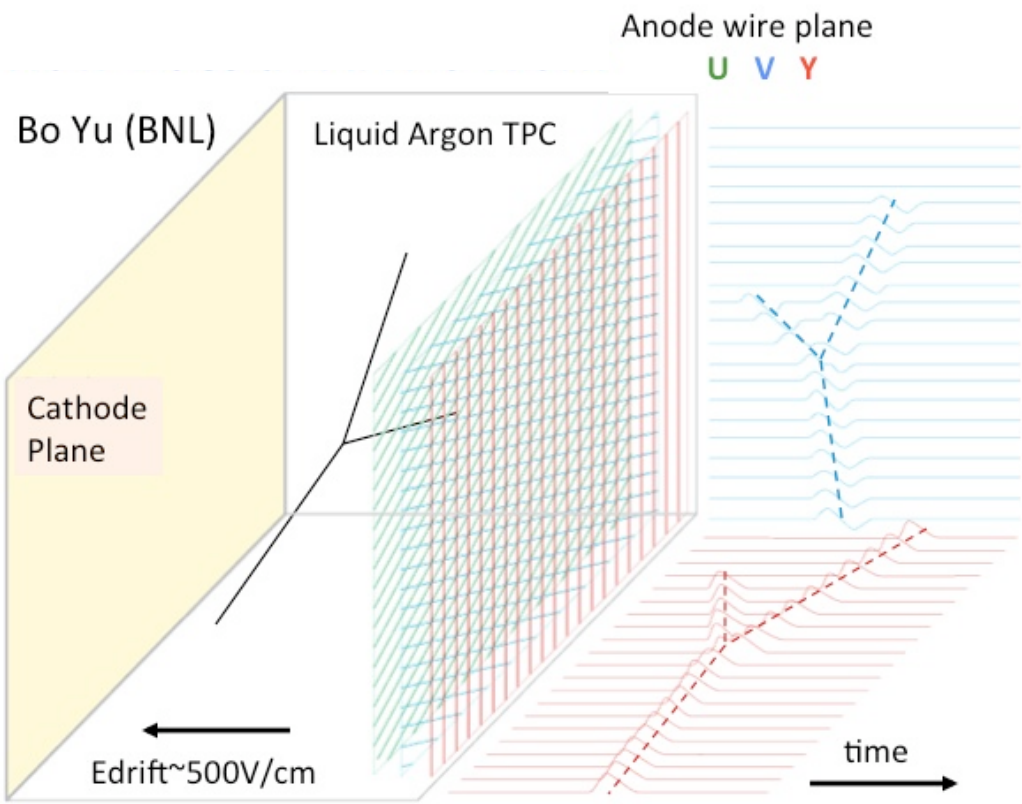
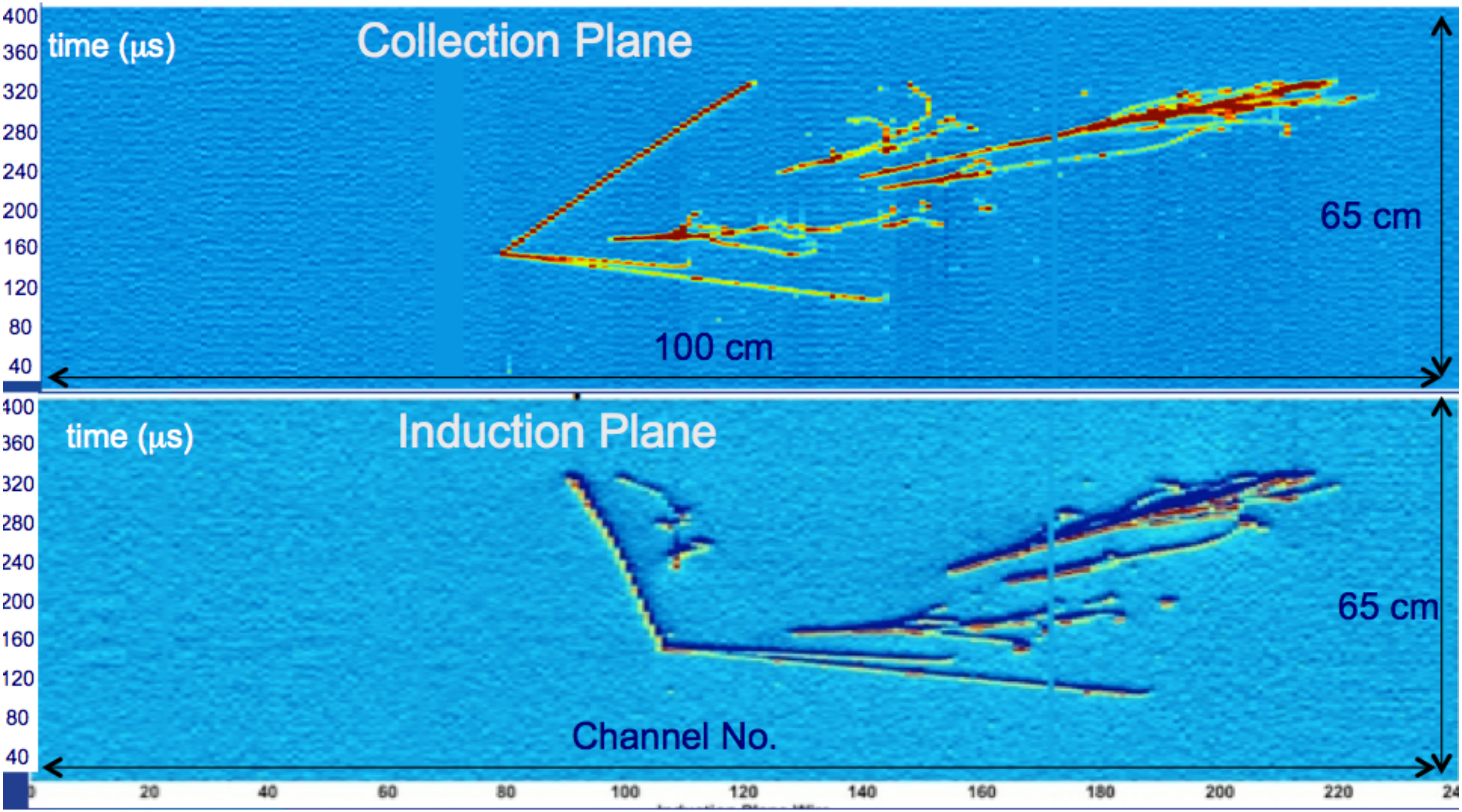
Liquid Argon Time Projection Chamber



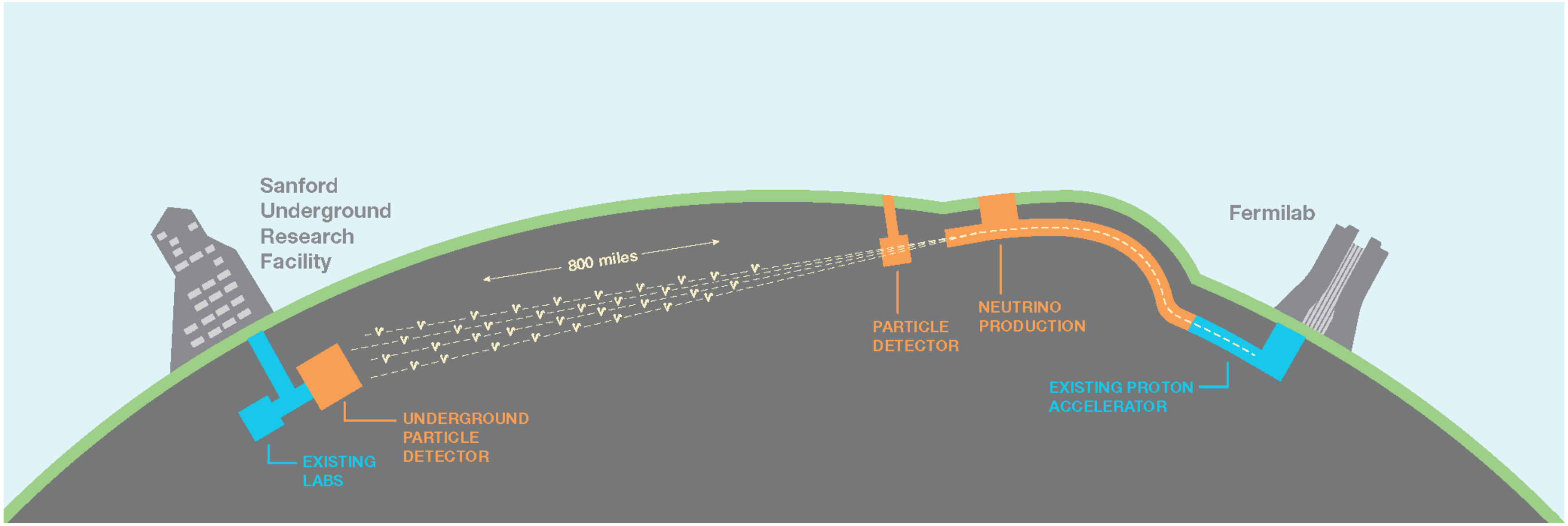
- HV on cathode to provide electric field to drift ionization electrons.
- Three wire planes to record electron signals. Wire spacing 5 mm.
- Photon detectors to record scintillation light.

High Resolution Image

A real neutrino event in ArgoNeuT TPC: 3 track, 4 photons.



Deep Underground Neutrino Experiment (DUNE)



- The DUNE experiment is designed to achieve discoveries that could transform our understanding of the origins and evolution of the universe by studying neutrino oscillations and other phenomena.
- Two detectors 1300 km away, far detector (FD) uses LArTPC.

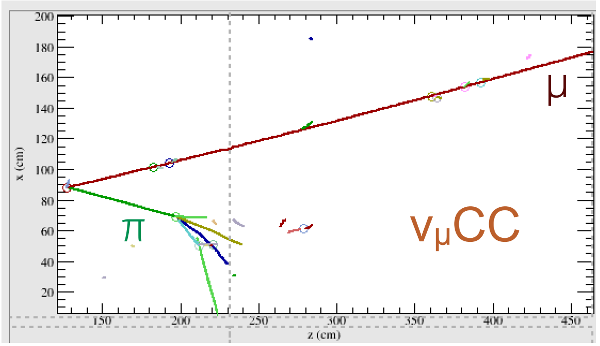
Event Reconstruction in DUNE

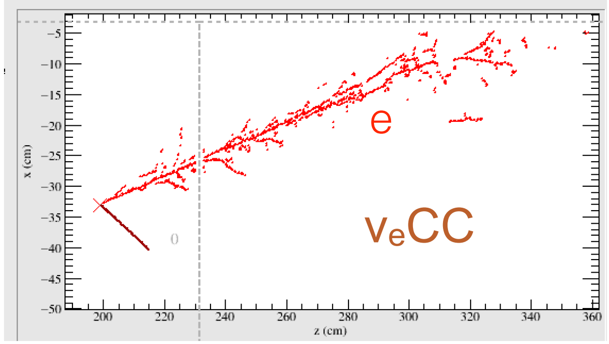
- LArTPC provides 3D event imaging with excellent spatial resolution.
- Reconstruction of events in LArTPC is challenging.
  - Large amount of information.
  - Tracks and showers overlap near the neutrino vertex.
  - Wire readout loses information.
- A lot of progress has been made in the development of reconstruction tools over the past years.
- This talk reviews the latest reconstructions tools in DUNE.
- Most algorithms are available in the common software framework LArSoft. http://larsoft.org/

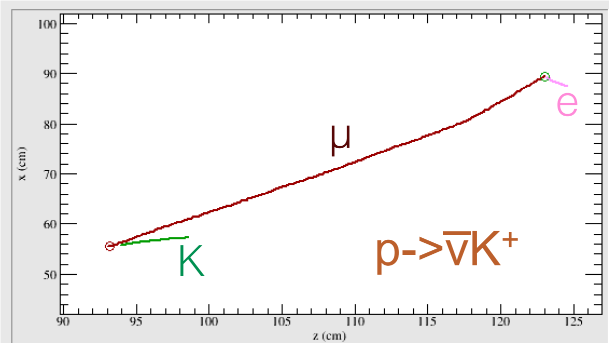
Requirements for Reconstruction

- **Neutrino oscillations (beam and atmospheric)**
  - Neutrino vertex reconstruction
  - Muon reconstruction and μ/π/proton separation.
  - Electron reconstruction and e/γ separation.
- **Proton decays**
  - Track and vertex reconstruction.
  - Calorimetry reconstruction.
  - Photon detector reconstruction.
- **Supernova neutrinos**
  - Low energy electron neutrino reconstruction.
  - Photon detector reconstruction to help determine energy.
- **Cosmogenics**
  - Background to many physics analyses.
  - Sources for detector calibration.

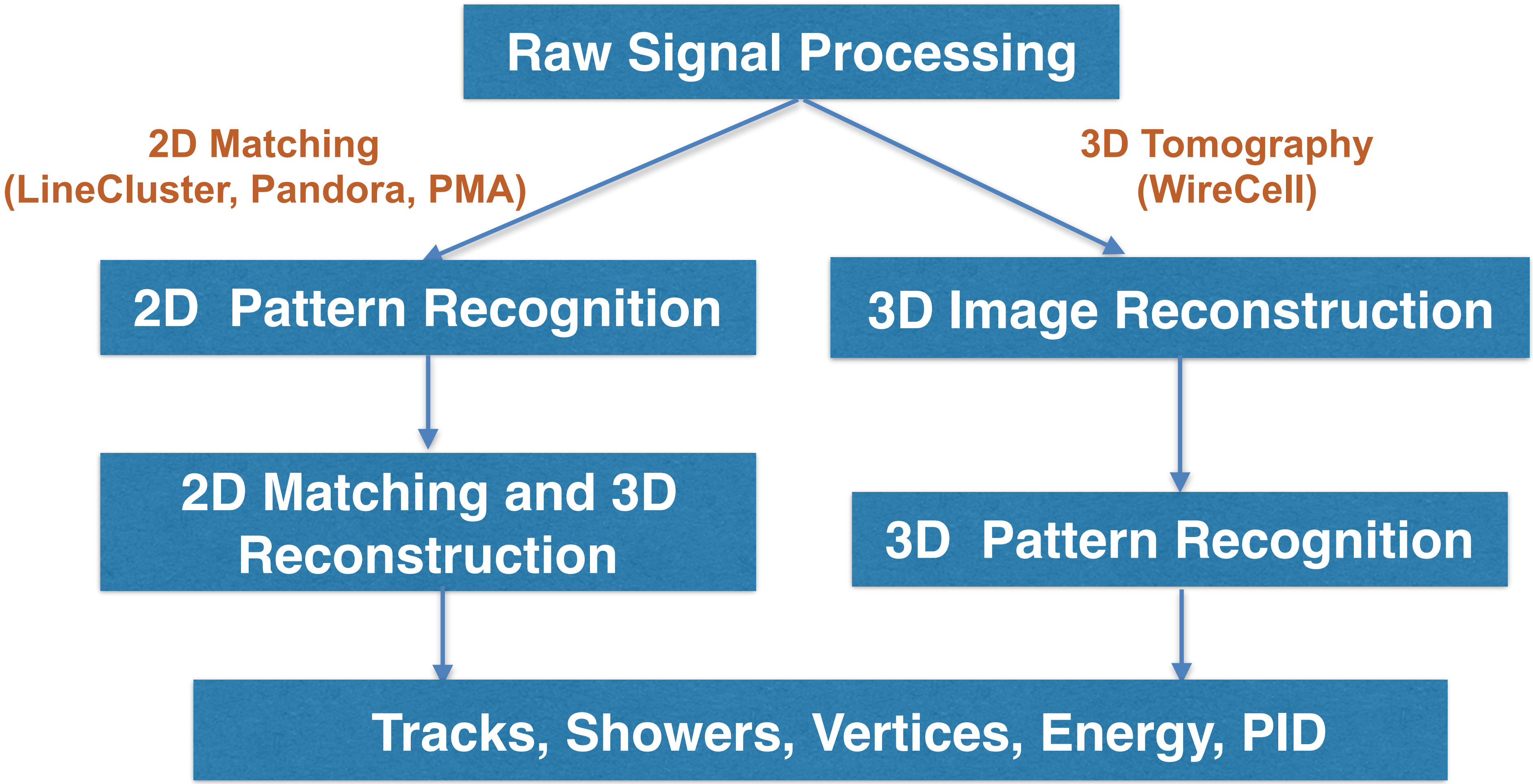
More in Elizabeth Worcester's talk on Saturday.







Two Reconstruction Approaches



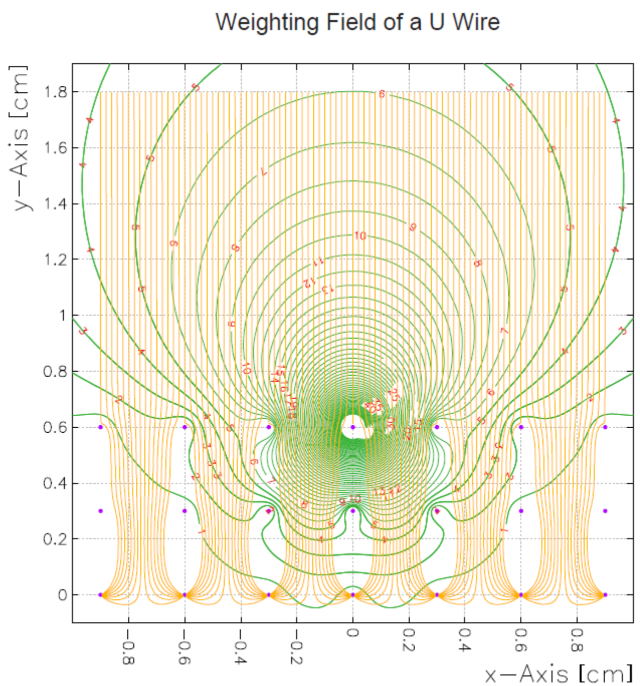
Each approach uses the same information in different order!

TPC Signal Formation

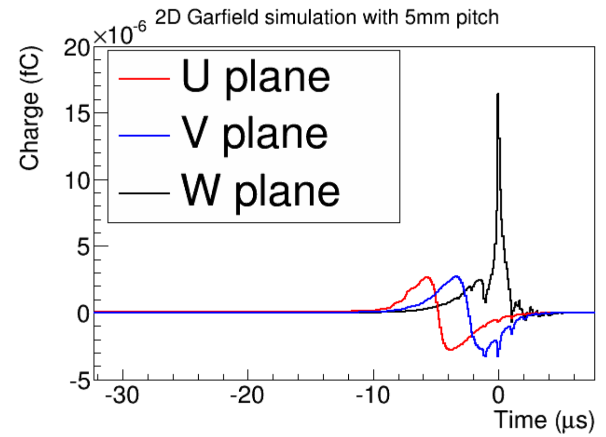
Shockley–Ramo theorem

$$i = -q \cdot \vec{E}_w \cdot \vec{v}_q$$

v_q: velocity
E_w: weighting field
q: charge



Garfield simulation of weighting field

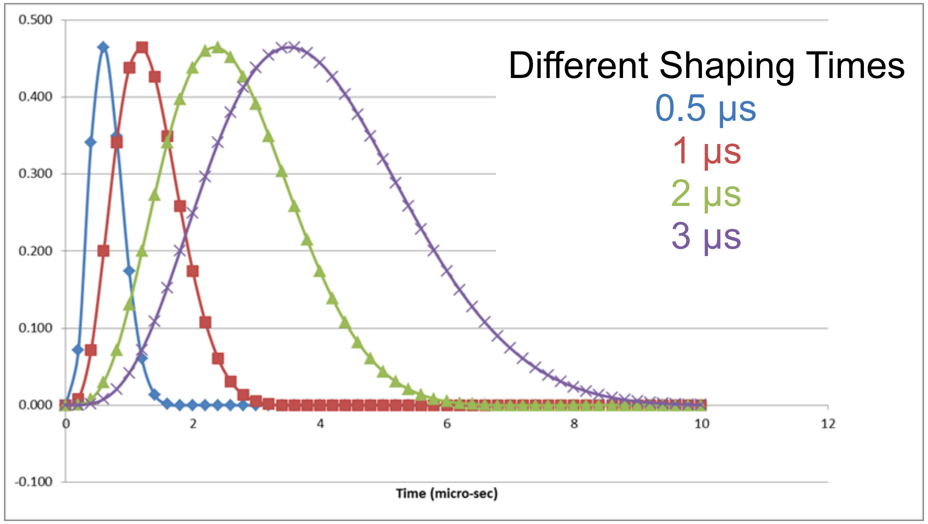


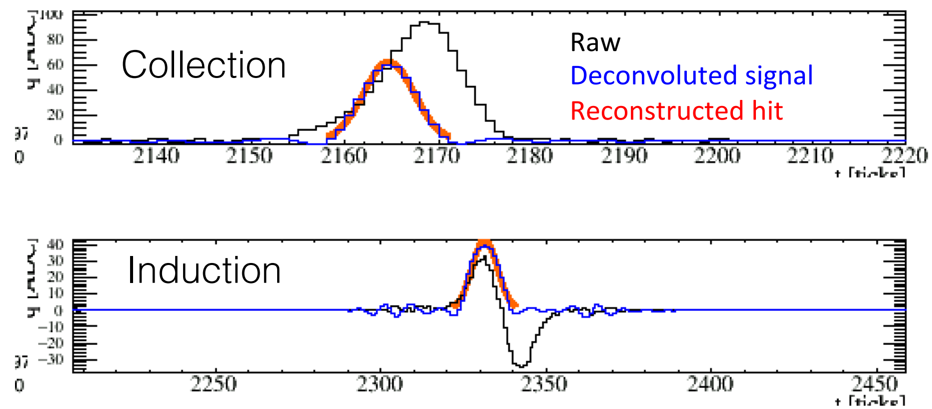
Garfield simulation of field responses

- More details: http://www-microboone.fnal.gov/publications/publicnotes/MICROBOONE-NOTE-1017-PUB.pdf

Signal Processing

BNL SPICE ASIC simulation

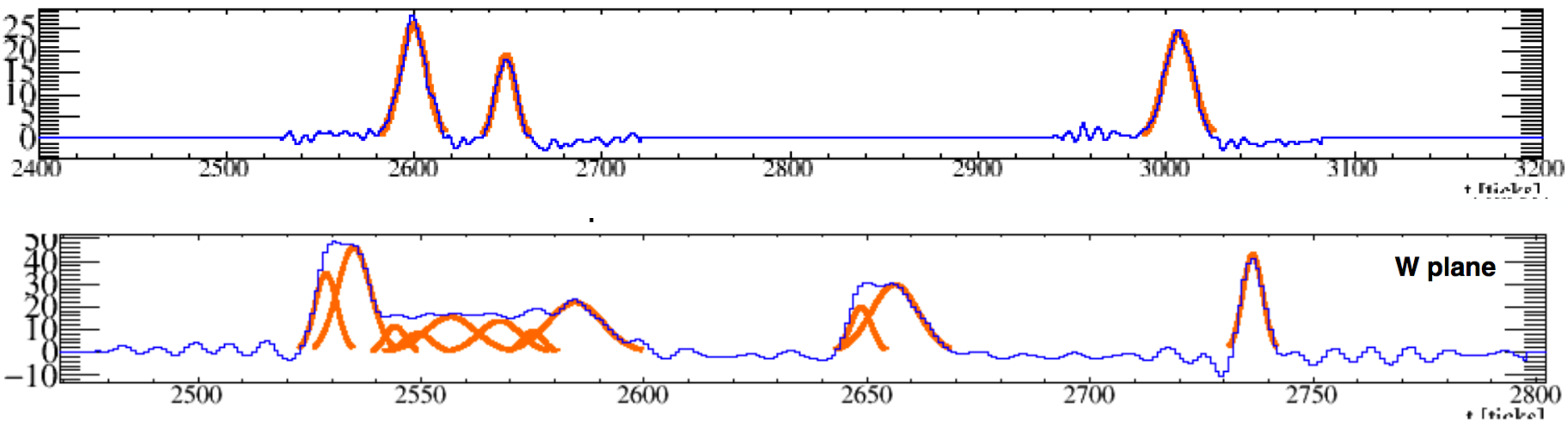




- Filter noise and remove effects of field response and electronics response through deconvolution.
- It is important to take into account induced signals from far away electrons to recover ionization charge.

Hit Finder

- Default hit finder in LArSoft is GausHitFinder.
- Start from deconvoluted signals on wire and define areas above threshold known as “pulses”.
- Once a pulse is found, a “n” Gaussian hypothesis is applied where “n” is defined by the number of peaks initially identified within the pulse.

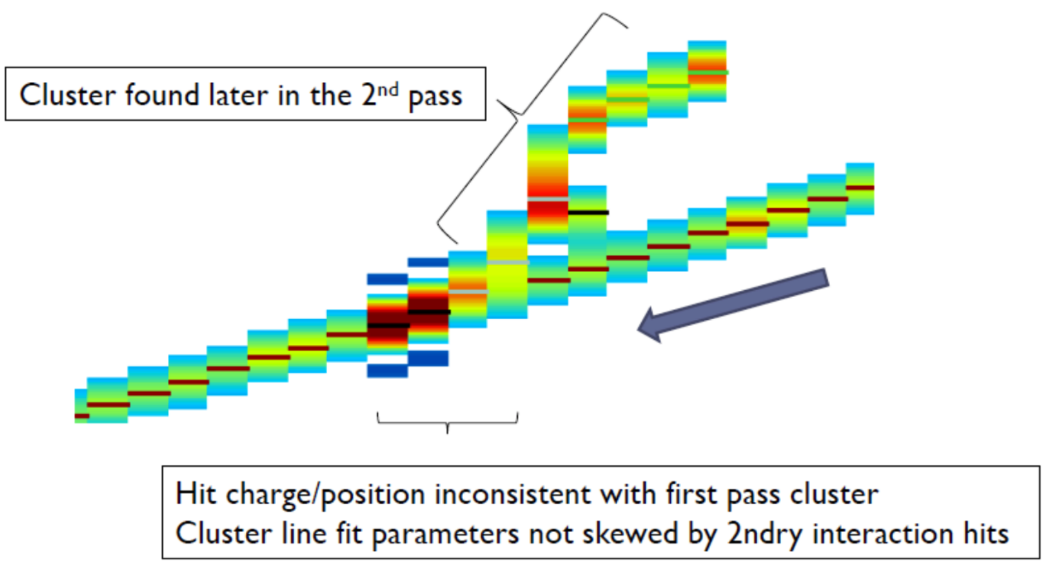


Track and Shower Reconstruction

- First discuss the 2D matching approach.
- Reconstruct clusters in each view by grouping hits belonging to the same particle.
- Match clusters between different views based on time information and reconstruction 3D tracks and showers.
- Several cluster reconstruction algorithms:
  - **LineCluster**: optimized for tracks.
  - **BlurredCluster**: optimized for showers.
  - **Pandora**: reconstruct both track-like and shower-like clusters.
- Track Reconstruction algorithms:
  - **PMA** and **Pandora**
- Shower Reconstruction
  - **EMShower**

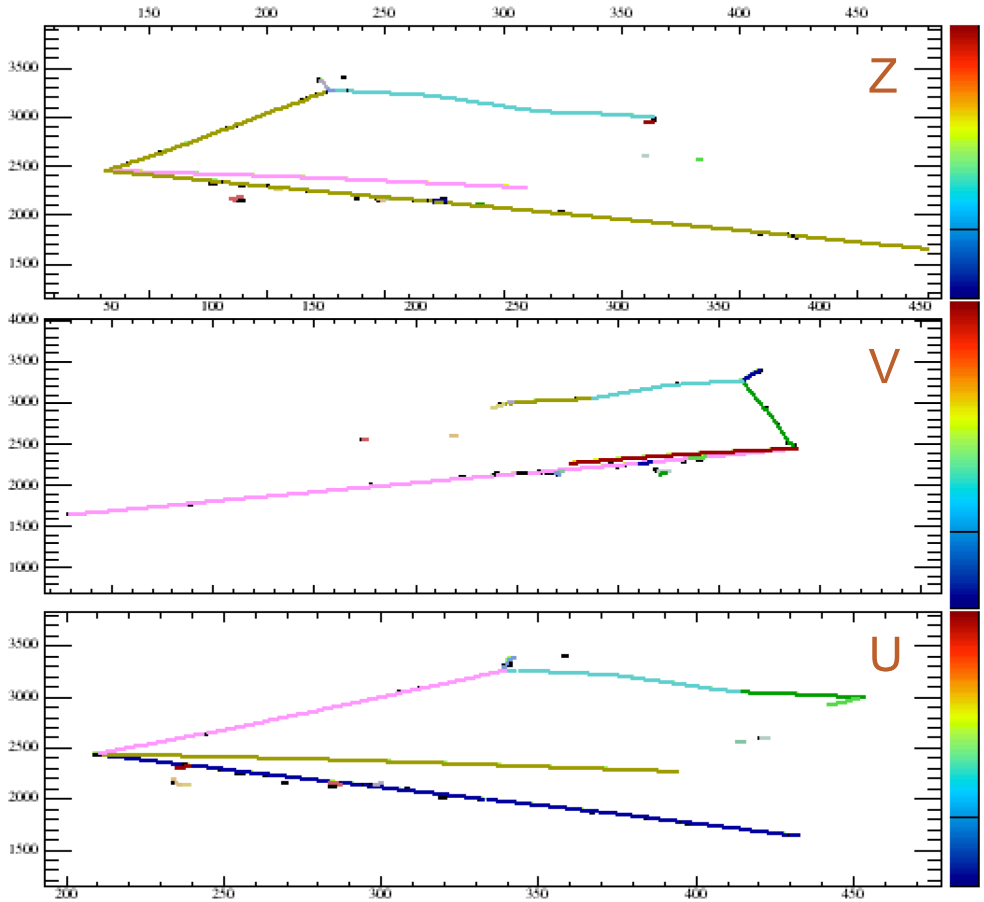
LineCluster

- Proximate hits in a cluster or track should have similar characteristics, e.g.
  - Hit charge = integral of the hit signal (not the pulse height)
- Use cluster tracking information from low hit density regions (down stream of primary vertex) to extrapolate into high density regions (at the primary vertex) or through high hit density regions (δ-rays and showers)



One example

2.4 GeV muon neutrino in DUNE TPC



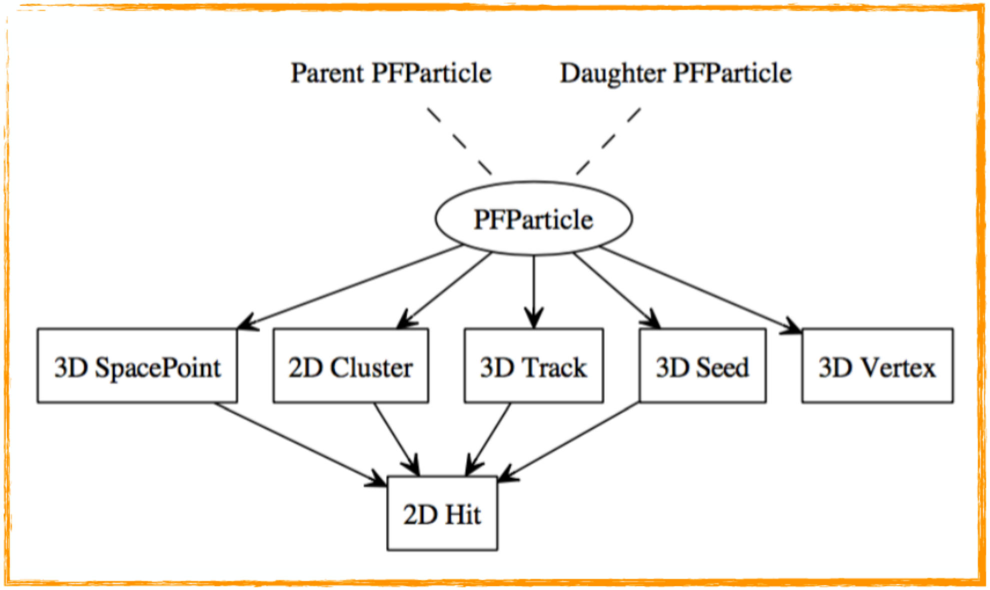
Different colors represents different line clusters.

More in https://cdcvs.fnal.gov/redmine/documents/727

Pandora

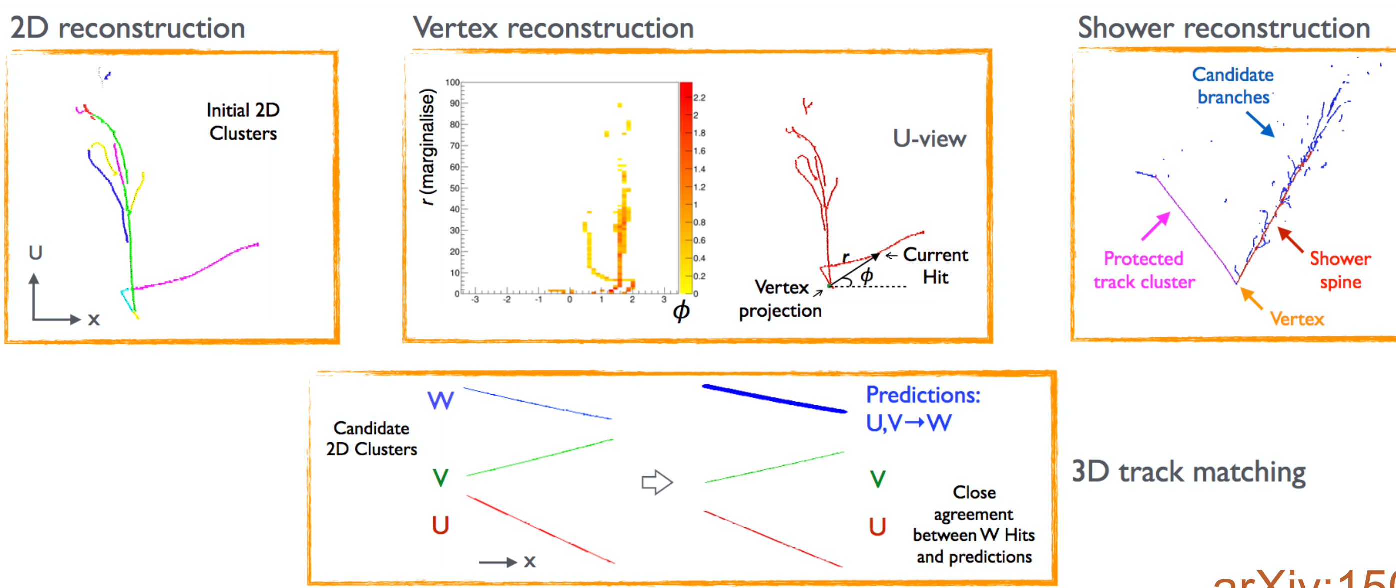
https://github.com/PandoraPFA

- Pandora is a well-established tool for fine-grain pattern recognition in high energy physics (future linear collider, LHC, LArTPCs)
- Supports multi-algorithm approach to automated and optimized pattern recognition.
- Takes hits as input. Outputs PFParticles with hierarchies
  - Reconstruct both track-like and shower-like PFParticles for further track/shower reconstruction.



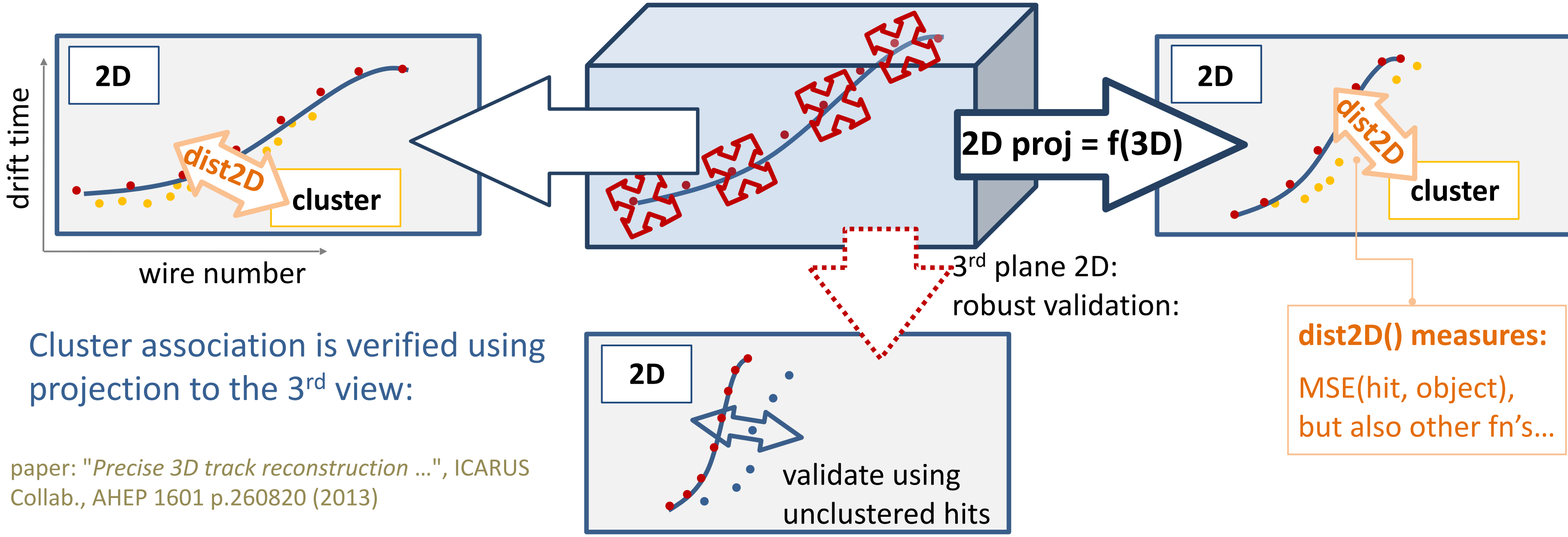
Two Chains of Algorithms

- PandoraCosmic:
  - more strongly track-oriented; showers assumed to be delta rays, added as daughters of the muons; muon vertices at track high-y coordinate.
- PandoraNu:
  - more careful to find interaction vertex and to protect particles emerging from vertex. Careful treatment to address track/shower tension.



arXiv:1506.05348

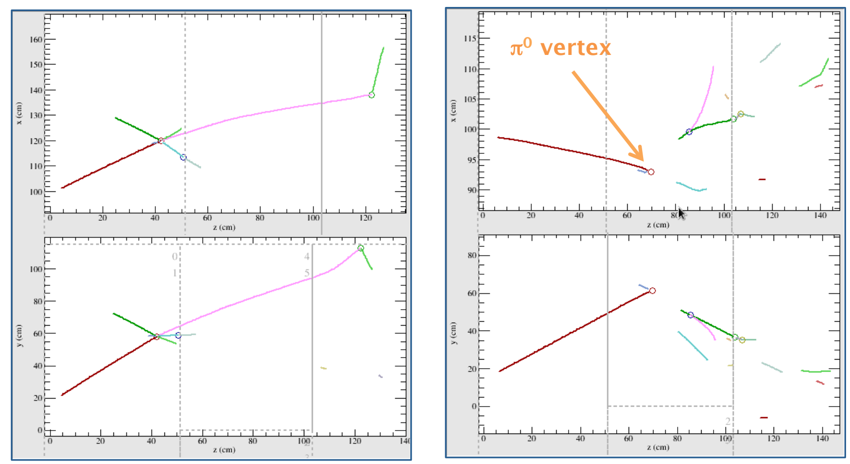
Projection Matching Algorithm (PMA)



Cluster association is verified using projection to the 3rd view:

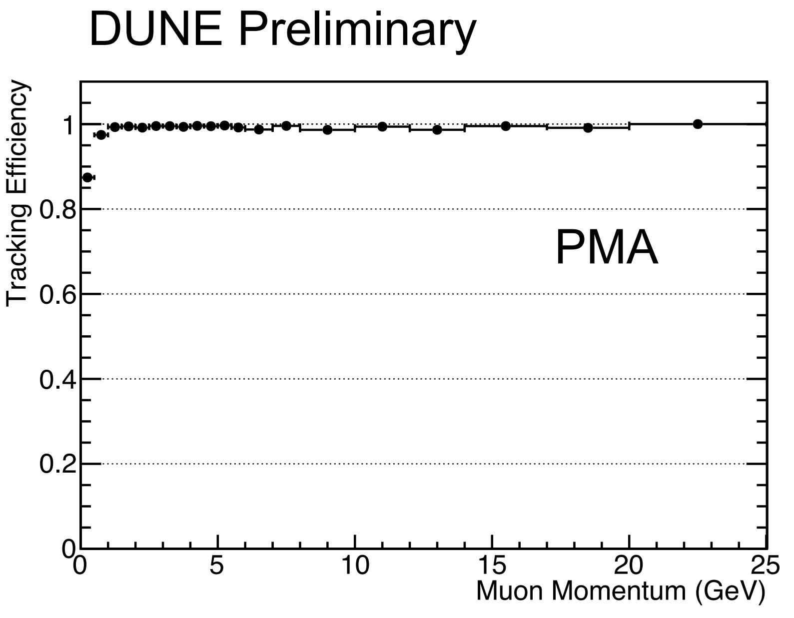
paper: "*Precise 3D track reconstruction …*", ICARUS Collab., AHEP 1601 p.260820 (2013)

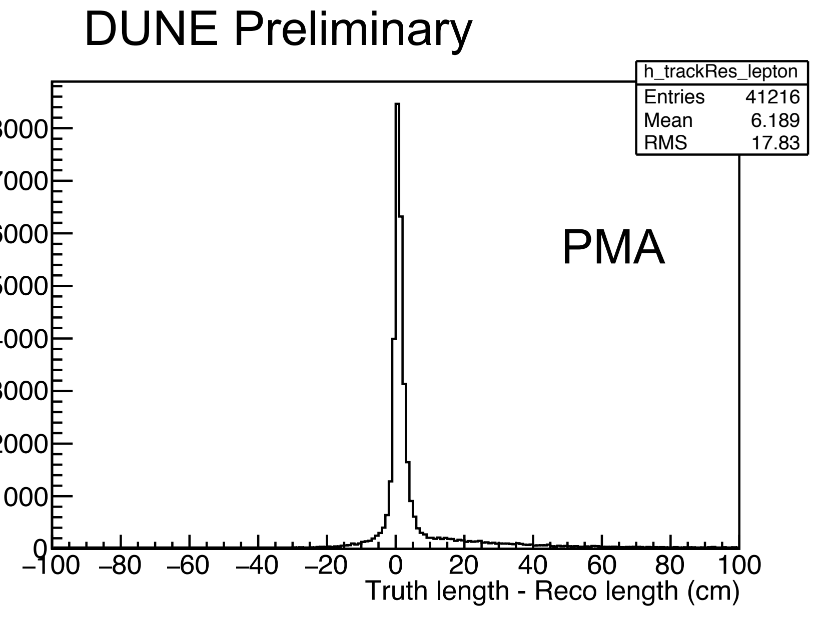
- Instead of building 3D object by matching 2D hits between different views, build 3D object by minimizing distance the object's 2D projection to 2D hits.
- Fit vertex and reoptimize tracks.



Reconstructed event examples: π^- @ 2GeV/c, 35t geometry, vertices indicated with circles, red track: incident particle.

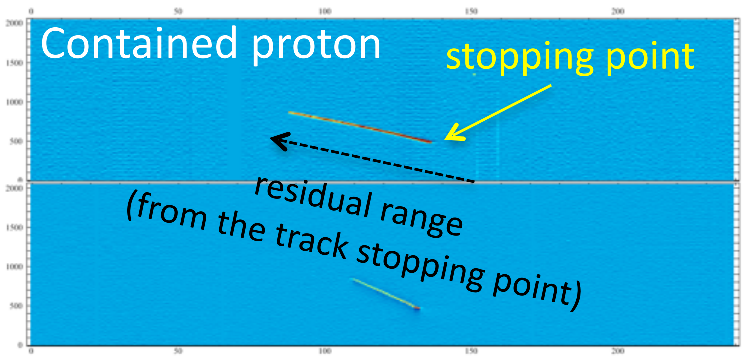
Tracking Efficiency

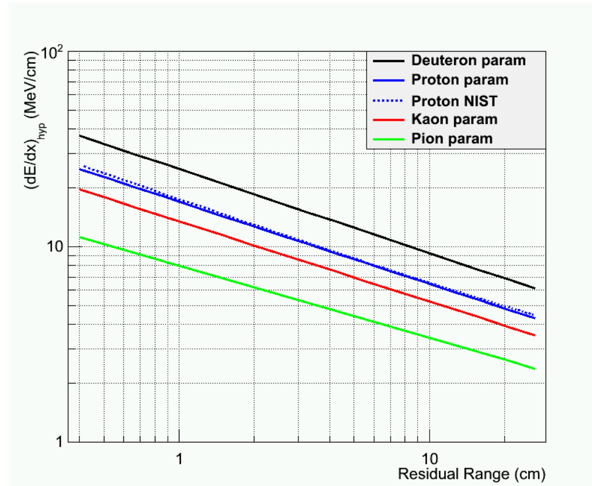




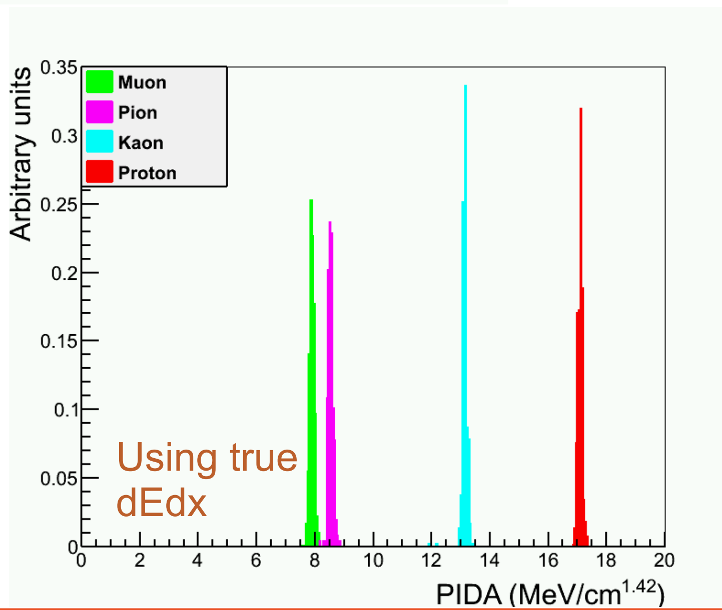
- The efficiency to reconstruct muons in the neutrino beam is very high.
- The reconstructed track length matches true length very well.

Particle Identification





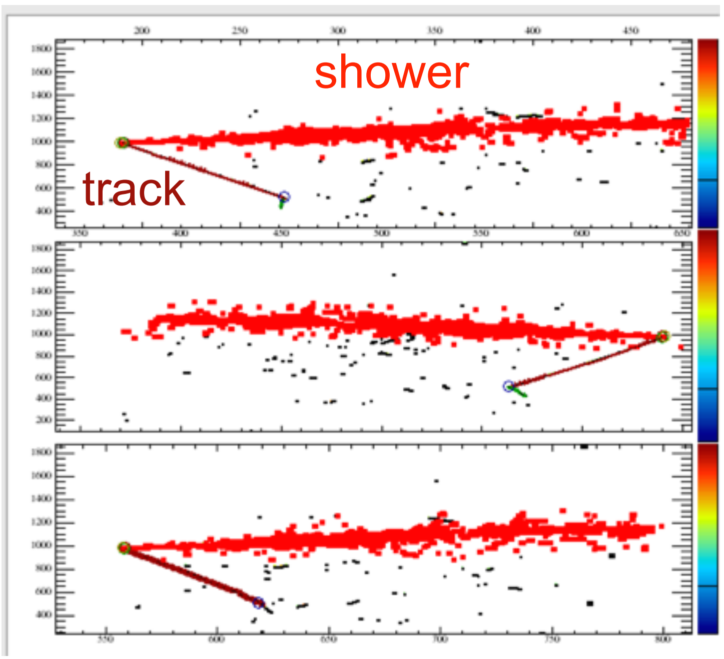
- Similar slopes
- Different intercepts
- Use intercept to do particle ID



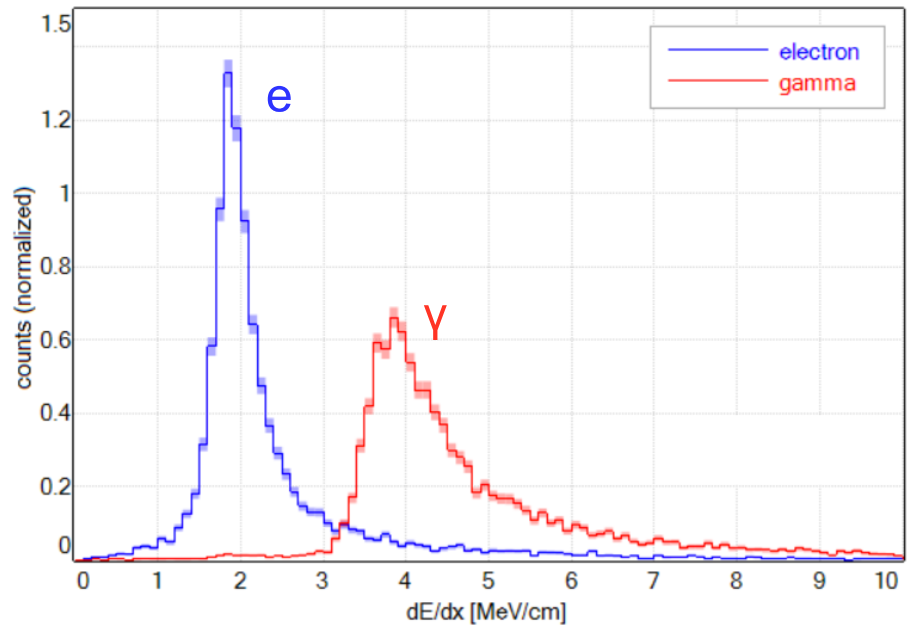
- Calorimetry information provide powerful particle ID.
- <Ai> for each track
- $Ai = (dE/dx)_{calo}\ R^{0.42}$
  - R is residual range

arXiv:1306.1712

Shower Reconstruction



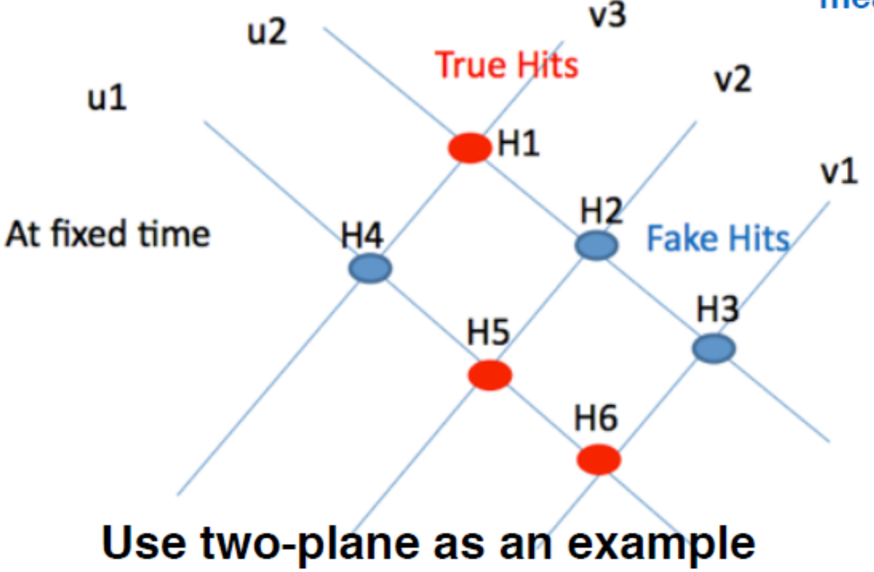
DUNE Preliminary



- Blurred cluster: uses a Gaussian blurring on an image of the hit map to form more complete clusters. http://larsoft.org/single-record/?pdb=110
- Match clusters in different views to construct 3D shower object. http://larsoft.org/single-record/?pdb=113
- Average dE/dx of the first 1 cm of shower provides information for e/gamma separation.

Wire-Cell Reconstruction

- 3D Tomographic reconstruction
- Reduce degeneracy by using the charge information: same charge in a voxel is measured 3 times by wires on the three wire planes



measured charges on wires

true charges to be solved

$$\begin{pmatrix} u1 \\ u2 \\ v1 \\ v2 \\ v3 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & a & a & a \\ a & a & a & 0 & 0 & 0 \\ 0 & 0 & a & 0 & 0 & a \\ 0 & a & 0 & 0 & a & 0 \\ a & 0 & 0 & a & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} H_1 \\ H_2 \\ H_3 \\ H_4 \\ H_5 \\ H_6 \end{pmatrix}$$

Matrix determined by geometry

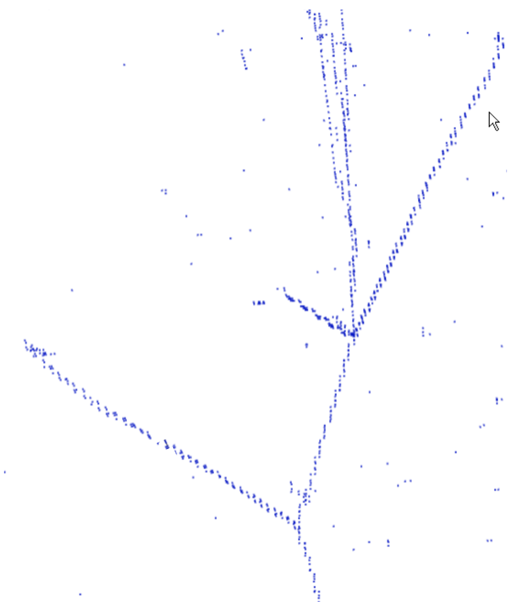
(a=1)

DUNE

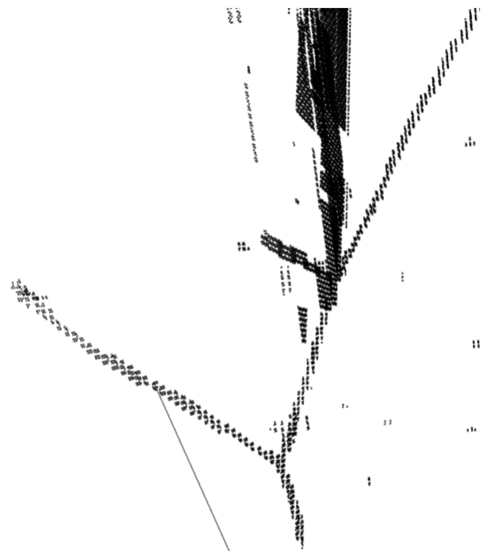
Reconstruction Procedures

- Obtain 3D space points (with charge) with close to 100% efficiency by solving charge-equations in the 2D tomographic plane
- Do clustering and tracking in 3D directly

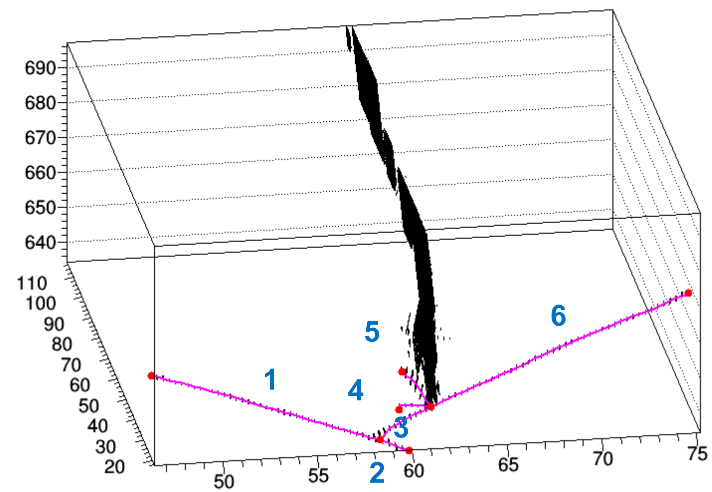
Truth



Wire-Cell reconstructed space points



3D track finding



http://www.phy.bnl.gov/wire-cell/

Conclusions

- After many years of dedicated efforts, the event reconstruction in liquid argon TPC has reached an advanced level.
- There is a fully automatic reconstruction chain in DUNE to do signal processing, pattern recognition, track and shower reconstruction and particle identification.
- The common framework LArSoft has boosted the reconstruction development.