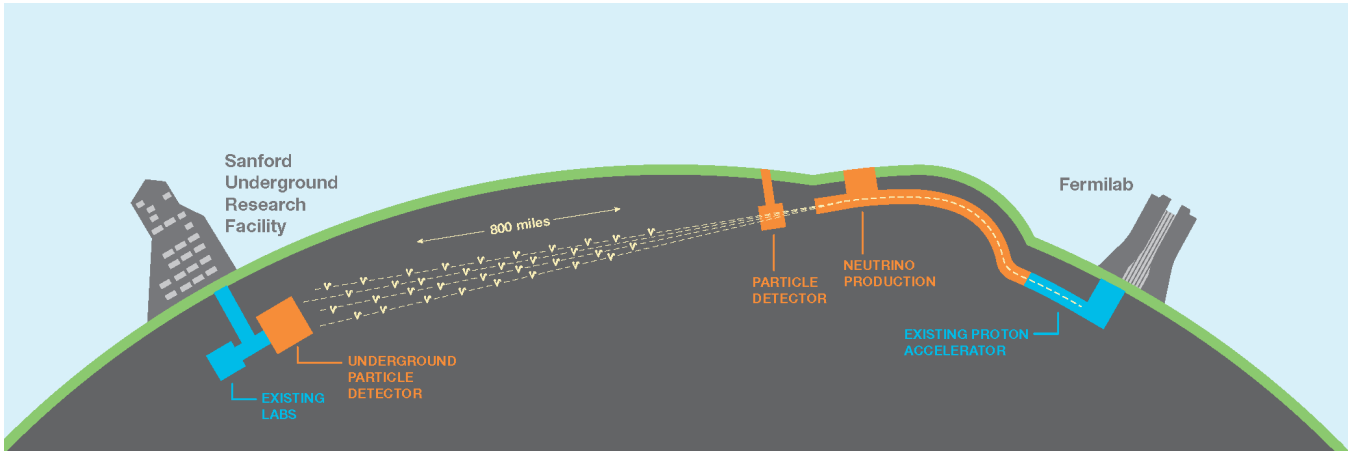


Reconstruction Updates

Alex Himmel (FNAL), Xin Qian (BNL), Tingjun Yang (FNAL)

Major Milestones

Q1/2016: Finish initial simulation and reconstruction chain ✅ (complete, ref: **DUNE-doc-1689**)

Q1/2016: Preliminary nue and numu selection based on reconstruction ✅

Q1/2017: Neutrino energy reconstruction ✅ (complete, ref: **DUNE-doc-2278**)

Q4/2017: Wire Cell LArSoft integration (in progress)

Q4/2017: Realistic TPC signal simulation (in progress)

Q4/2017: Delivery of improved shower reconstruction for TDR (in progress)

Q4/2017: Delivery of improved reconstruction for proton decay analysis in TDR (in progress)

Q4/2017: Support full-size far detector with photon simulation (in progress)

Q4/2017: Improve photon detector simulation and reconstruction (in progress)

Q2/2018: Delivery of reconstruction tools for protoDUNE single phase (in progress)

Q2/2018: Delivery of reconstruction tools for dual phase TPC (in progress)

Response to LBNC Recommendations

From October 2016 Review:

- Senior management should meet with the LBNC referees and the software team regularly to address concerns and queries

  Complete: *Contacts and regular meetings established*

- Fermilab should provide a plan for long-term sustainability of LArSoft that meets the needs of SBN and DUNE

  In progress: *Working closely with LArSoft team to make sure LArSoft is sustainable and meets the needs of SBN and DUNE*

Organizational updates

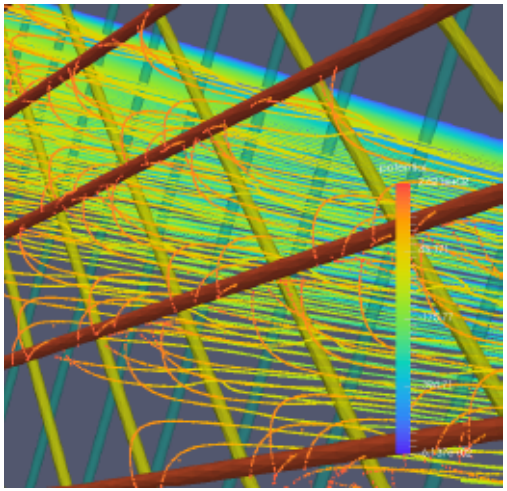
- New convener: Alex Himmel
  - Has been leading the photon detector sim/reco/analysis effort in various roles since LBNE.
- Basic goal:
  - Simulate scintillation light and detector response
  - Collect together light from a single physics event
  - Use this light in physics analysis – focus primarily on T0 so far
- General plan moving forward is the same as that for TPC reconstruction:
  - More specialized final-stage reconstruction is taken over by the physics groups.
  - Underlying simulation and low-level reconstruction lives in the FD Sim/Reco group.

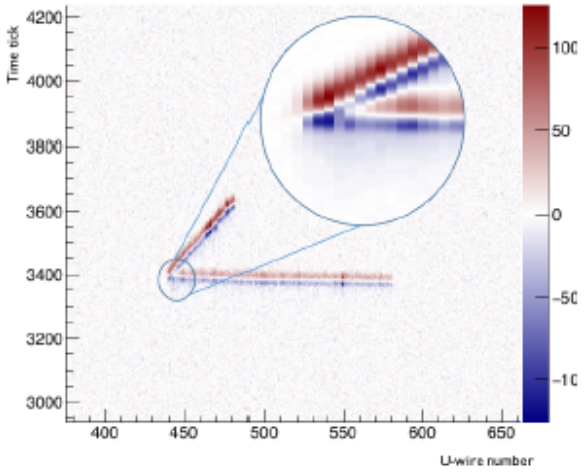
Reconstruction updates since Oct 2016

- Signal processing
  - Realistic TPC signal simulation
  - 2D deconvolution
- FD reconstruction
  - Cluster reconstruction optimized for Kaon events
  - Pandora developments and optimization
  - Neutrino energy reconstruction
- ProtoDUNE reconstruction
  - Convolutional neural networks in reconstruction and analysis
  - PMA improvements
- Photon detector simulation and reconstruction status and plans

Simulation Plan 2017

- Integration the full TPC Simulation with LArSoft (David Adams and Brett)
- 3D field response calculation (Leon Rochester and Brett)
- Full TPC simulation including induced charge on neighboring wires (Xiaoyue Li)

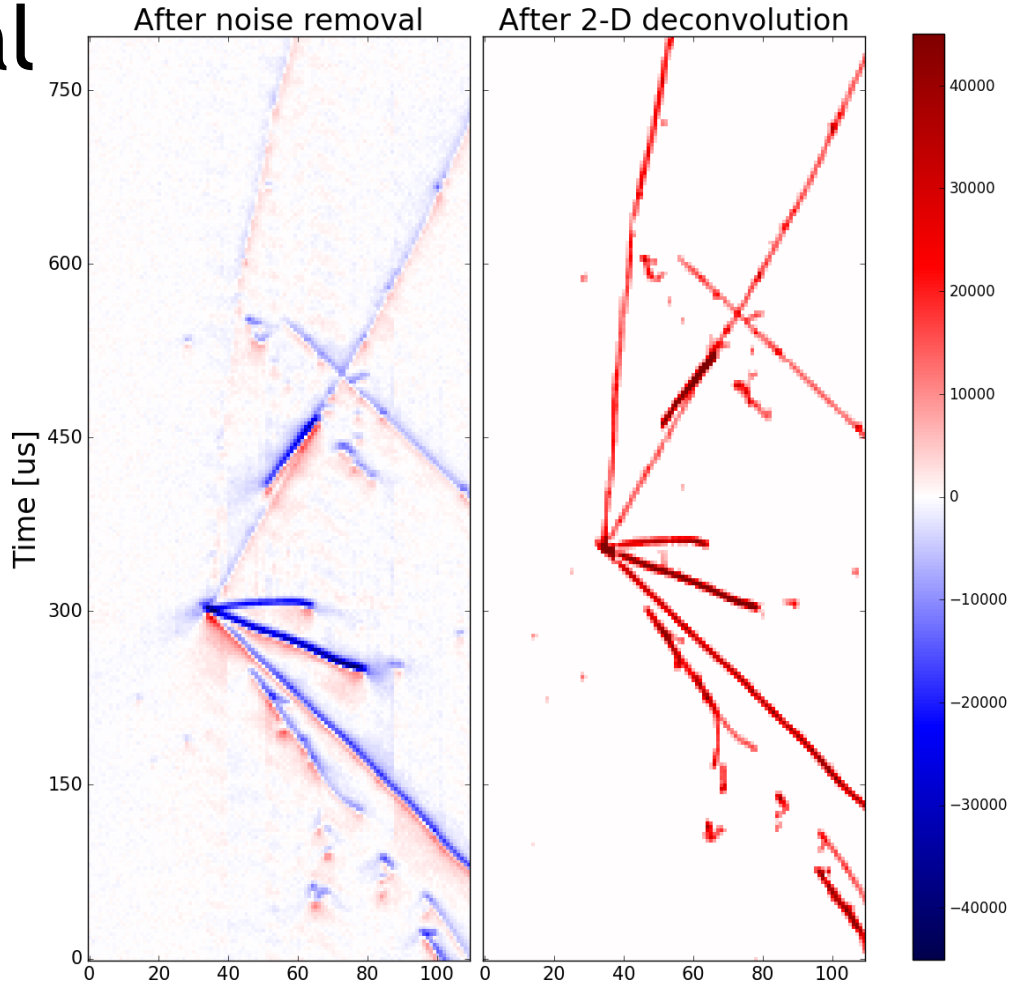




Improved TPC Signal Processing

- 2D deconvolution with field response up to +-10 wires
- Improved Signal ROI finder with low frequency filter and connectivity information
- **<u>Successful charge extraction from induction wire planes!</u>**
  - Large angle track
  - Removal of shadows near vertex

Xin Qian



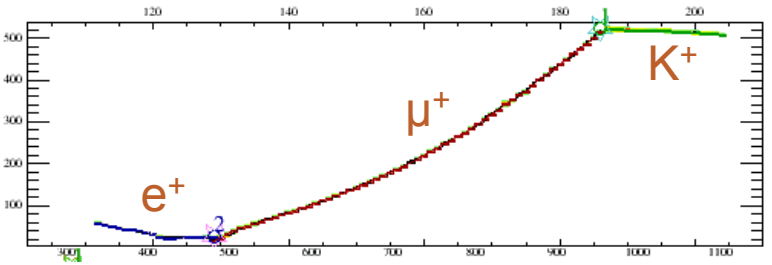
Signal Processing Plan for 2017

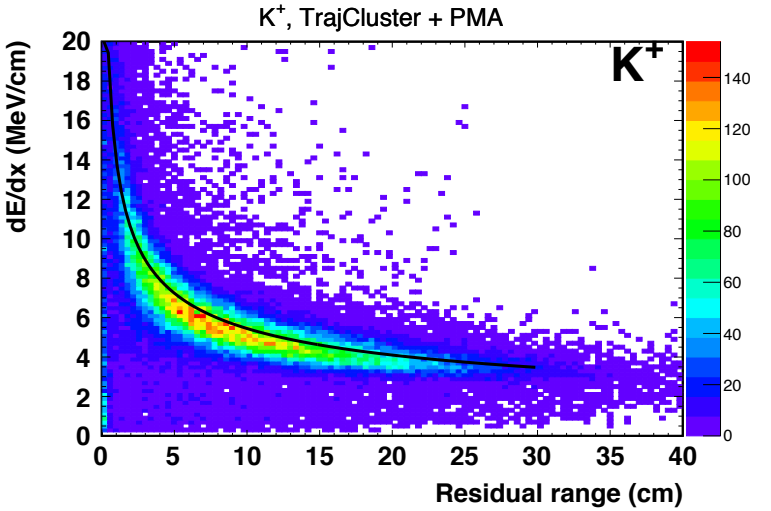
- Code review for TPC signal processing and integration with LArSoft (Brett/David)
- TPC signal processing evaluation with full TPC simulation (Brooke Russell, Brian Kirby, Mike Mooney)
- Data reduction for protoDUNE (Brett/ Xin) → Noise filter + TPC Signal Processing (ROI selection) to reduce data by ~400: protoDUNE 2.5 pB (saved raw data) → 6 TB (reduced data for majority of analyzers)

Tier	Factor	Size (2.5PB)
ADC compression	4-5	~0.5 PB
After Excess Noise Filter	6-8	~0.3 PB
Signal ROI after Signal Processing	150	17 TB
Rebin x3	**415**	**6.0 TB**

Cluster reconstruction improvements

- TrajCluster reconstructs 2D trajectories in each plane. It is created by Bruce Baller. Recently Xiao Luo and Tingjun Yang joined the effort to tune it for MicroBooNE and DUNE.
- Special algorithms were added to TrajCluster to improve the tracking efficiency of low momentum kaons. This should help proton decay search in $p \rightarrow \bar{\nu} K^+$ channel.

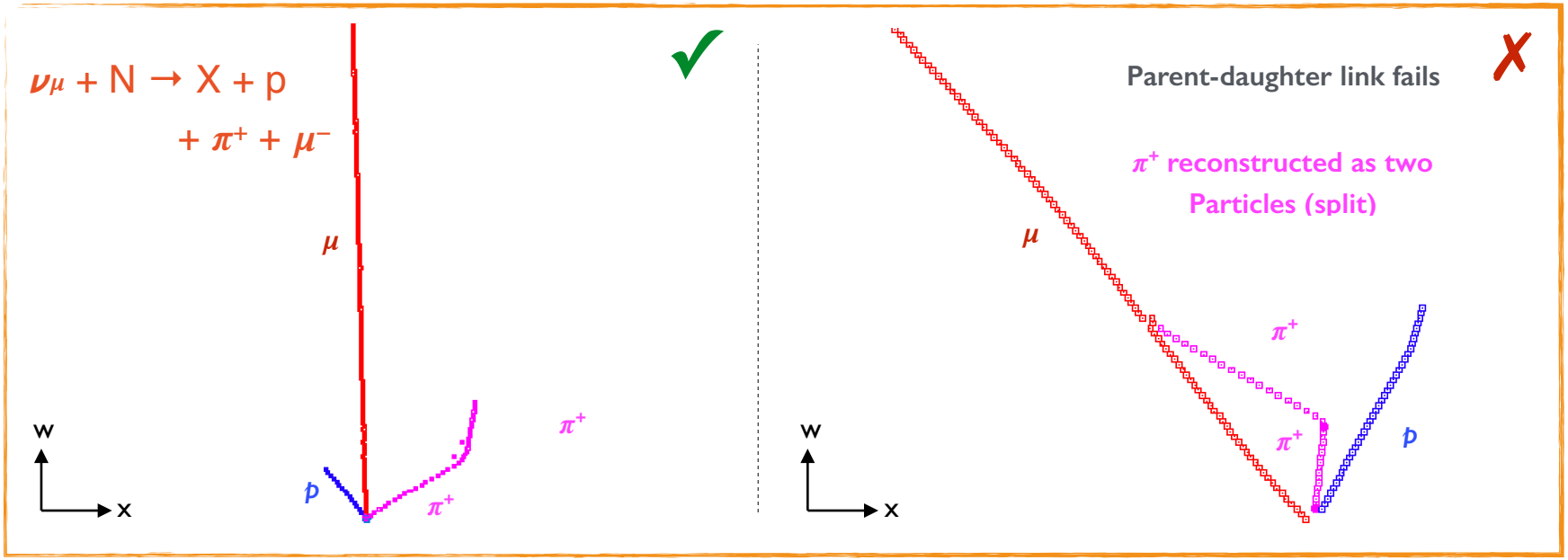




	K^+	μ^+	e^+
Old reco eff.	57.2%	90.8%	76.9%
Improved reco eff.	**73.8%**	**94.9%**	**94.4%**

Pandora Updates

- **Pandora provides a multi-algorithm approach to LAr TPC pattern recognition**
- **Pandora Performance Metrics provides very strict assessment of pattern recognition**

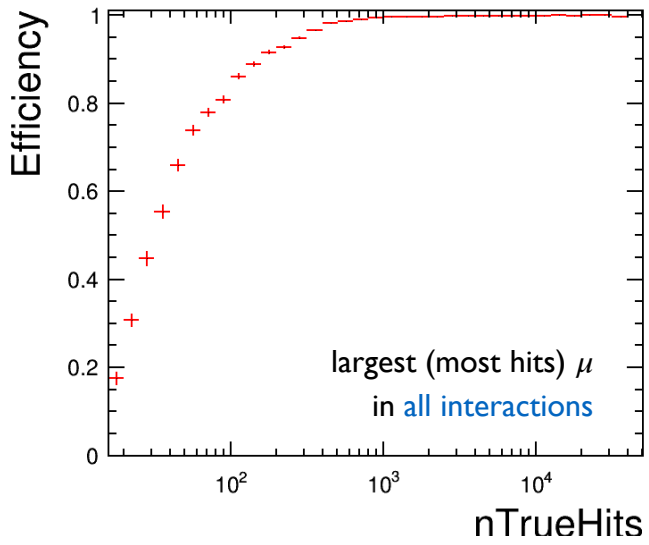


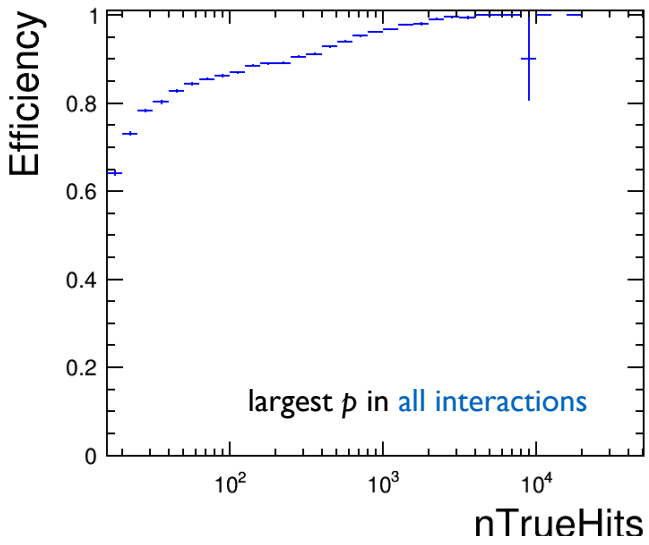
#Matched Particles	0	1	2	3+
μ	$(1.6 \pm 0.1)\%$	$(96.6 \pm 0.2)\%$	$(1.7 \pm 0.1)\%$	$(0.1 \pm 0.0)\%$
p	$(8.5 \pm 0.3)\%$	$(85.3 \pm 0.4)\%$	$(5.8 \pm 0.3)\%$	$(0.4 \pm 0.1)\%$
π^+	$(9.0 \pm 0.3)\%$	$(80.9 \pm 0.4)\%$	$(9.5 \pm 0.3)\%$	$(0.5 \pm 0.1)\%$

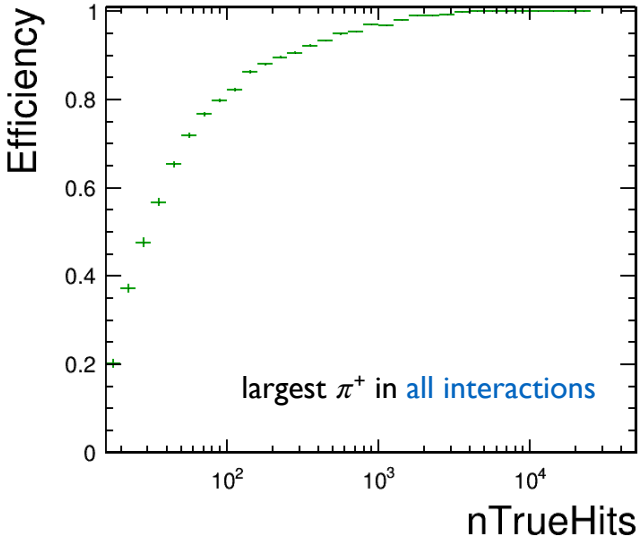
This is the pattern recognition performance obtained by applying algorithms developed for MicroBooNE to events at DUNE (no retuning). **Fraction of "correct" events: 69.3%**

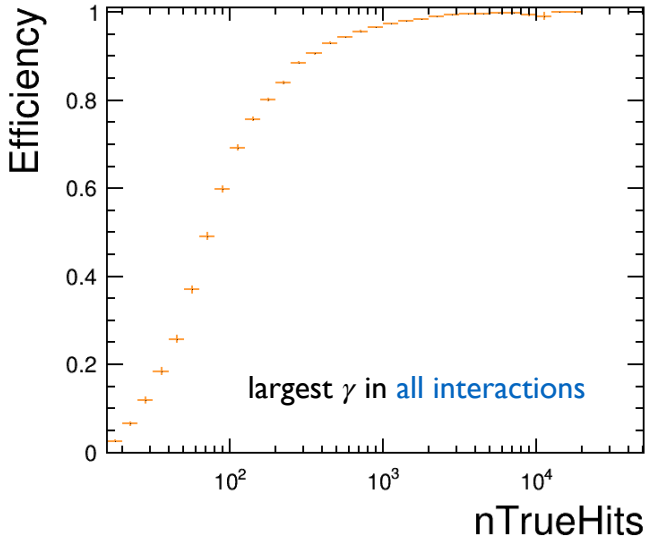
J. S. Marshall et al.

Reconstruction Efficiencies









Expect Pandora work *specific to DUNE* to ramp-up later in 2017.

J. S. Marshall et al.

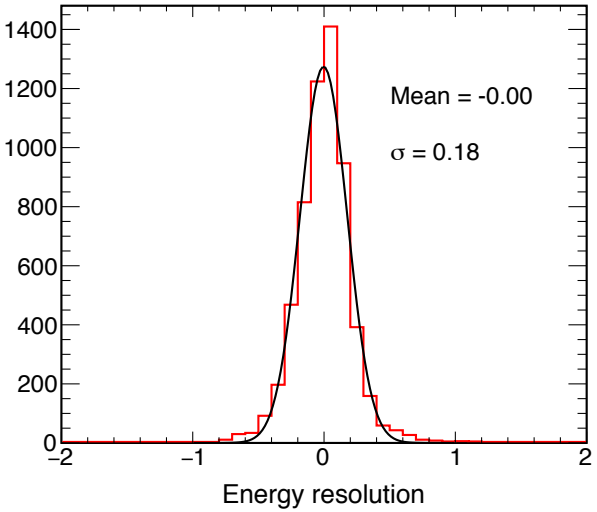
Neutrino energy reconstruction

Nick Grant, Tingjun Yang

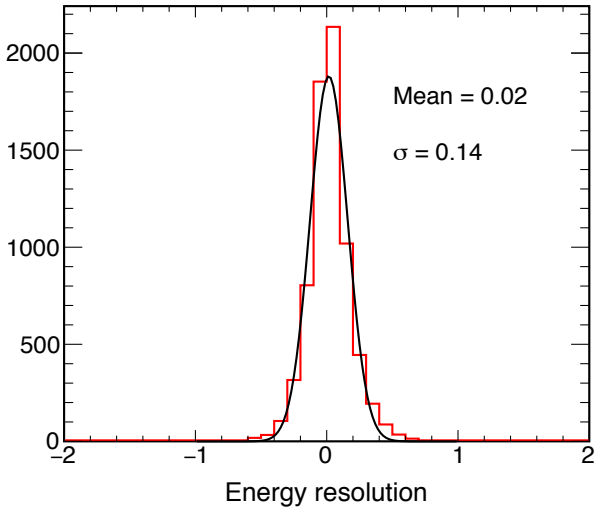
- Separate lepton energy and hadronic energy
  - Lepton energy: longest track for ν_μ events (range or MCS), largest shower for ν_e events (calorimetry)
  - Hadronic energy: remaining hits (calorimetry correcting for neutral particles)

DUNE-doc-2278

ν_μ CC



ν_e CC



ProtoDUNE sim/reco team update

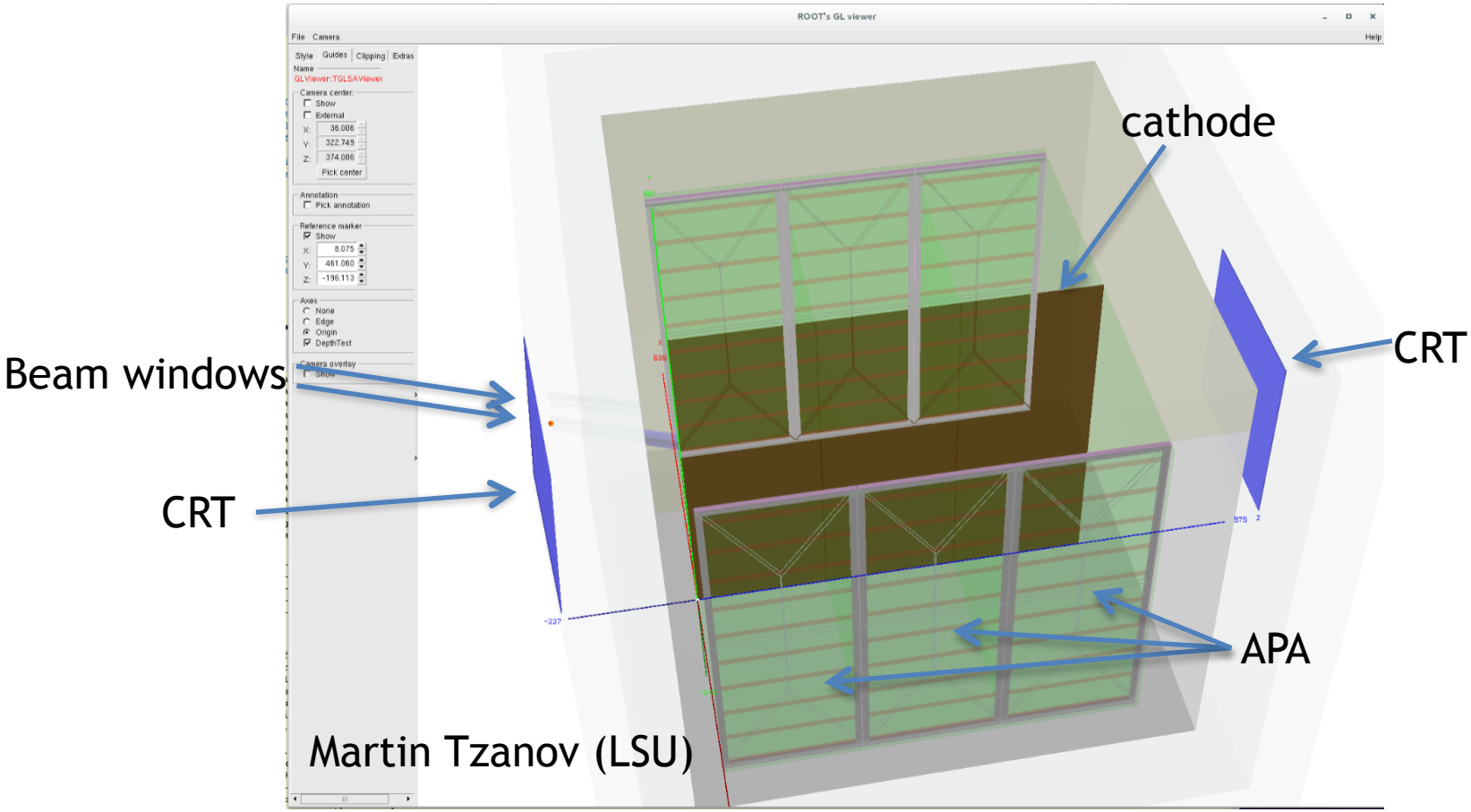
Dorota Stefan, Robert Sulej

- G4 geometry implementation
- Beam particle simulation in TPC
- New developments for Projection Matching Algorithm (PMA)
- Cosmic muon reconstruction
- Beam events reconstruction
- Convolutional Neural Network as reco / analysis tool
- Simulation and reconstruction for dual-phase progress well

Plots and contributions from (in alphabetical order):

Jieyon Han, Tom Junk, Piotr Plonski, Aidan Reynolds, Daniel Smith, Dorota Stefan, Robert Sulej, Arbin Timilsina, Martin Tzanov, Leigh Whitehead, Elizabeth Worcester, Tingjun Yang.

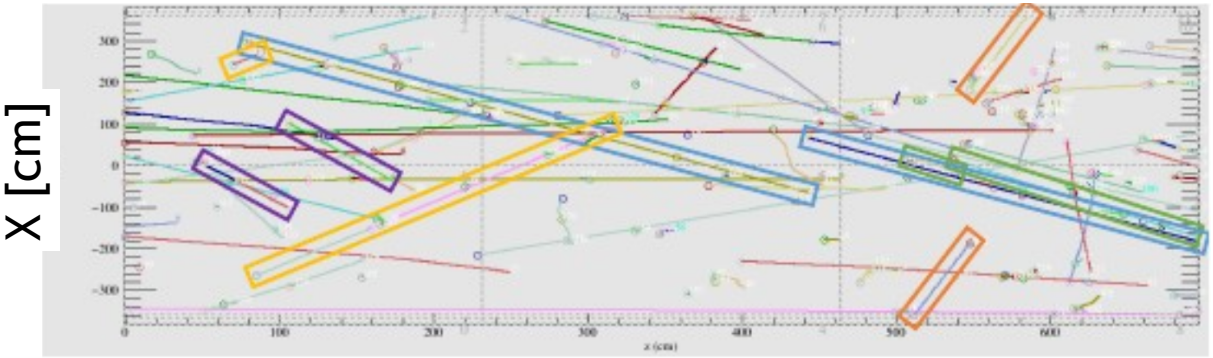
ProtoDUNE G4 geometry implementation in LArSoft



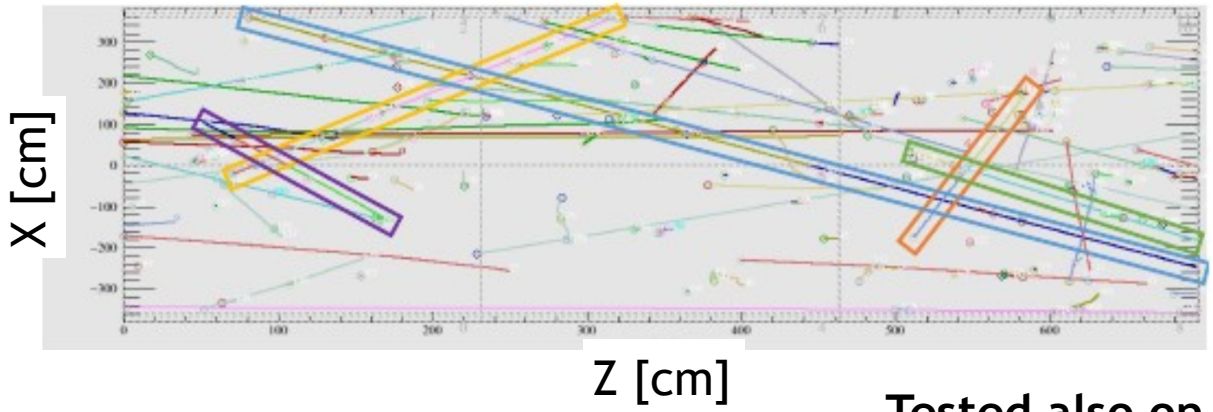
Implementation depends on the avability of drawings, more details:
https://indico.fnal.gov/getFile.py/access?contribId=83&sessionId=12&resId=0&materialId=slides&confId=10641

Cosmic muon reconstruction: stitching

- Stitching of tracks crossing the cathode plus necessary developments in PMA, tracking and vertexing. The work is documented in DUNE-docdb: 2780.



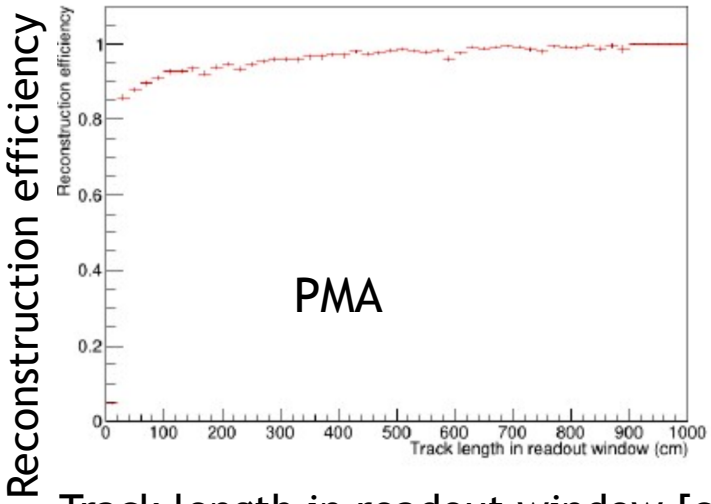
Reconstructed tracks without stitiching



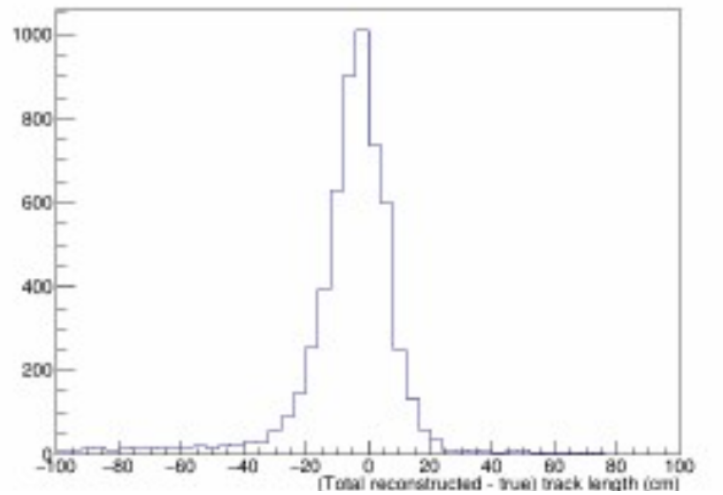
Reconstructed tracks with stitiching switched on

Tested also on 35t and DUNE Far Detector

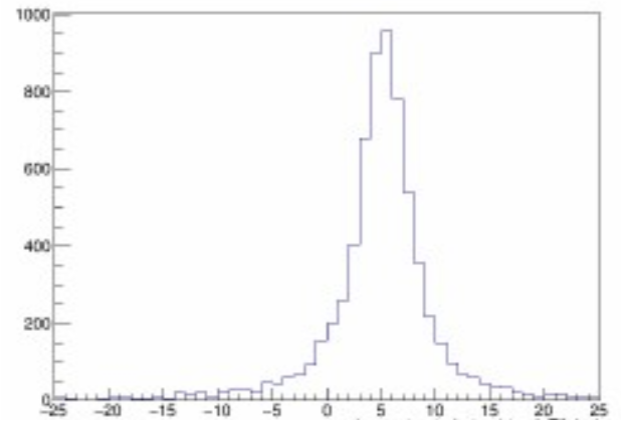
Cosmic muon reconstruction: efficiency



Track length in readout window [cm]



(Track reconstructed – MCTruth) track length [cm]

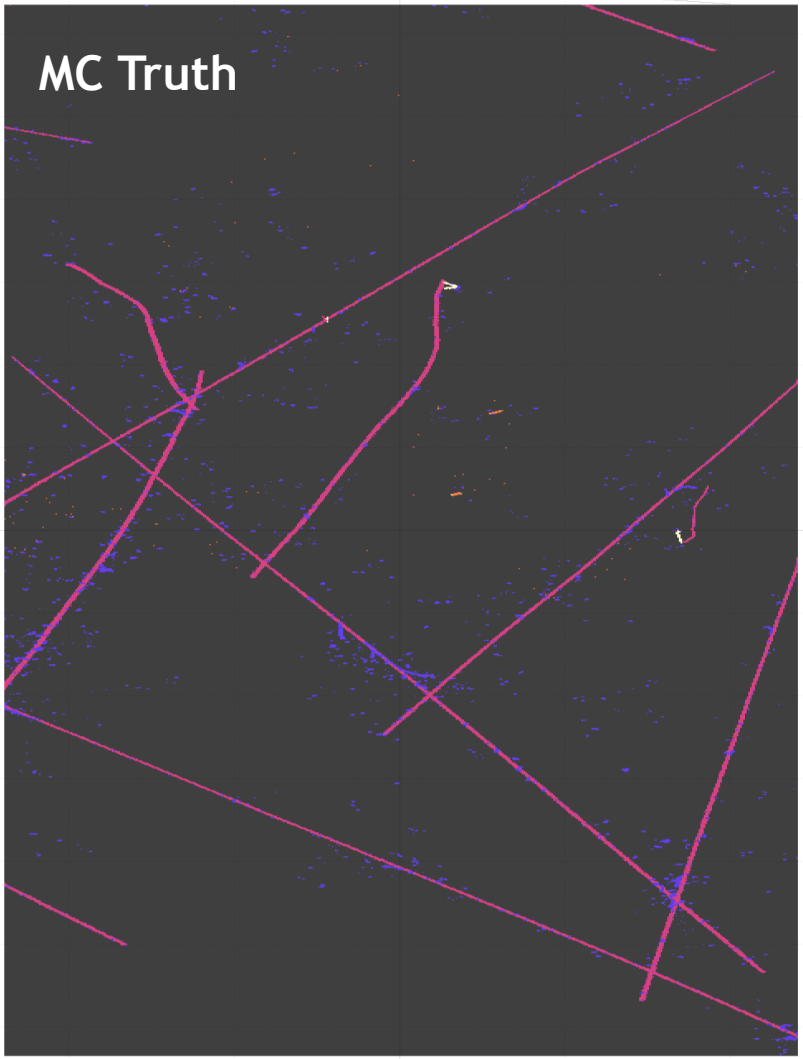


(reconstructed – MCTruth) track t0 [μs]

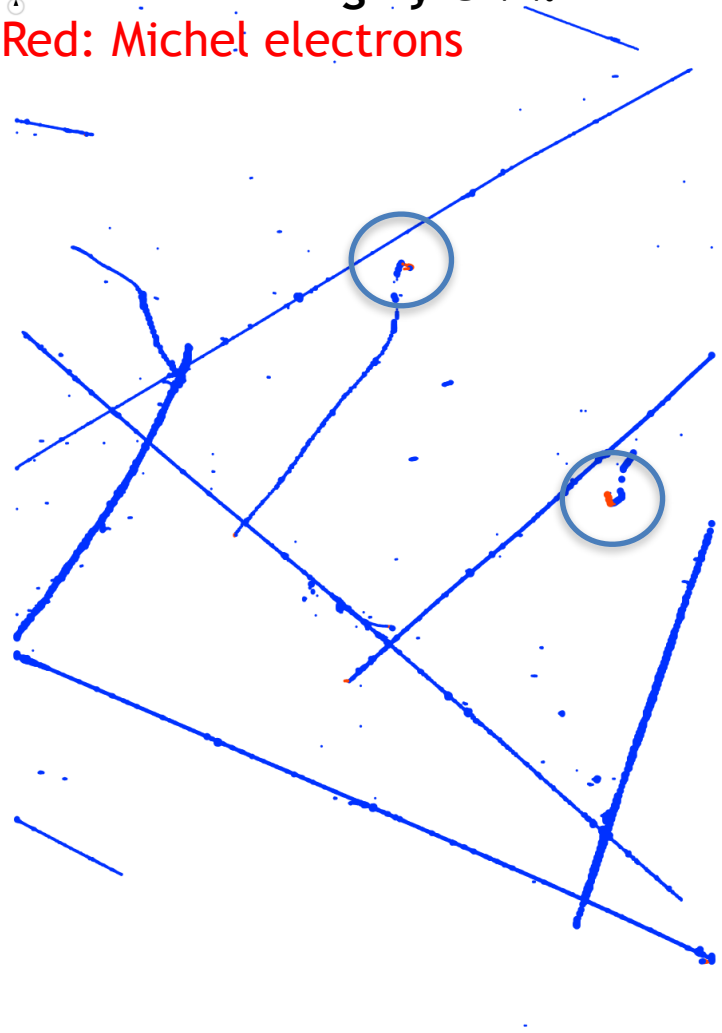
- Efficiency for track length > 0m is 94%, and for length > 1m is 96%.
- Simulation included space charge effect (SCE).
- Reconstruction does not corrected for this effect here.

Details: docdb 2780

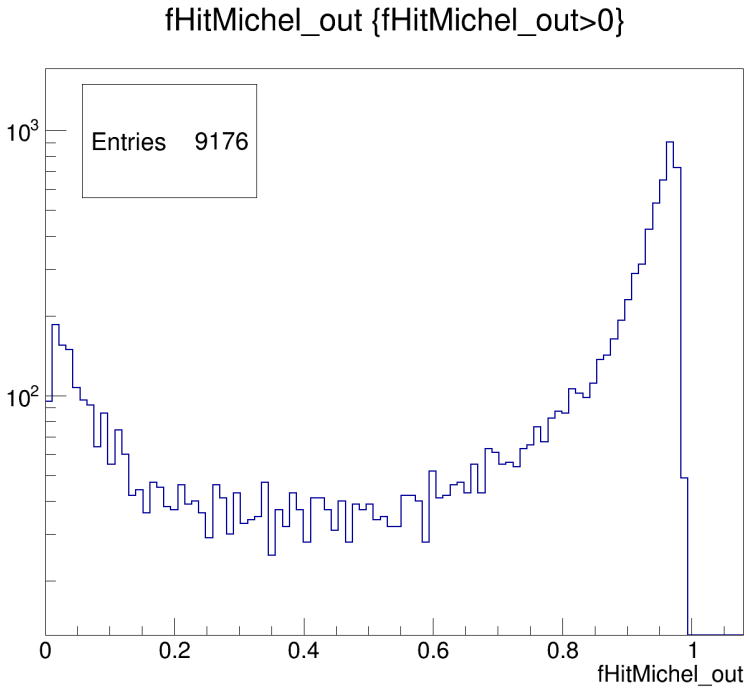
Cosmic muon reconstruction: Michel electron selection using CNN



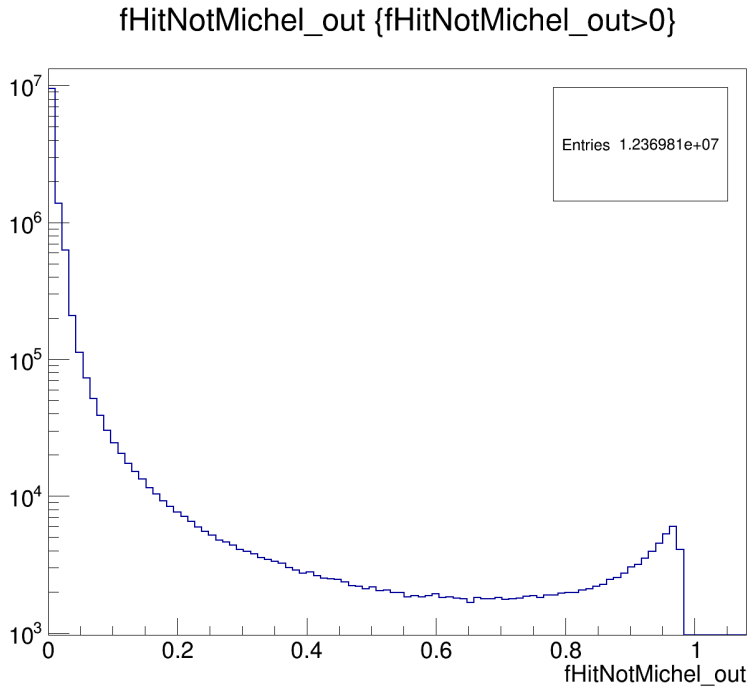
Feature labeling by CNN:
Red: Michel electrons



Cosmic muon reconstruction: Michel electron selection using CNN



CNN output for Michel electron:
probability of a hit to belong to Michel electron



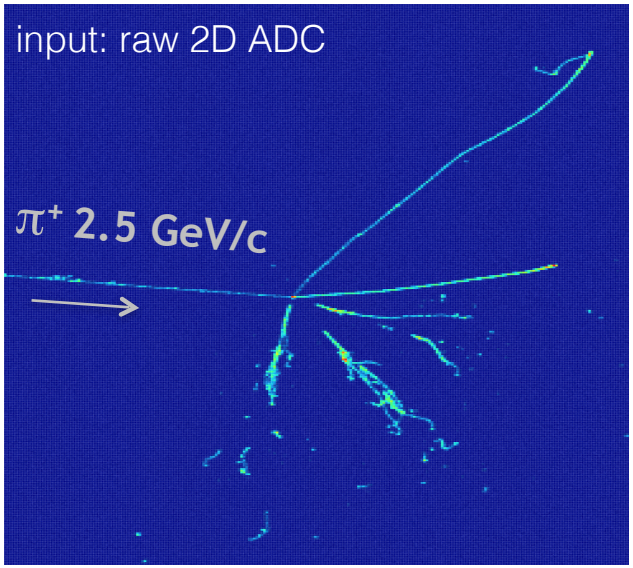
CNN output for all other non Michel electron hits:
probability of a hit to belong to Michel electron

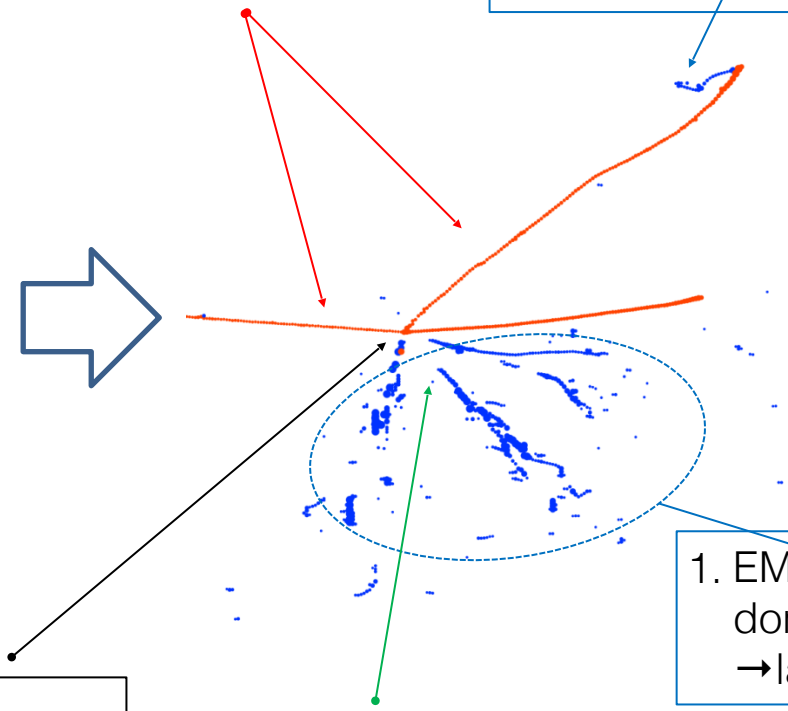
- Currently the threshold is set to 0.5 to consider hit as Michel electron
- **Analysis using the output from CNN just started.**

ProtoDUNE's beam events reco: status/plan

3. hadron tracks reconstruction:
→once EM separated, efficient standard algorithms

2. Michel selection: advanced
→labeling with CNN





1. EM selection: quite done
→labeled with CNN

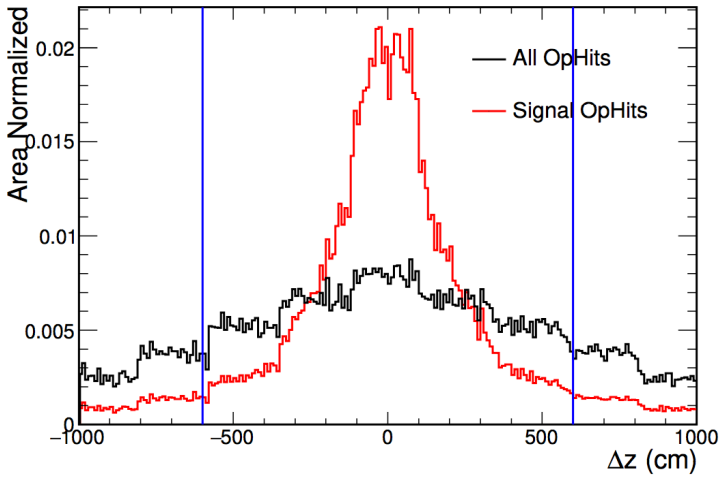
4. interaction vertex:
→reconstructed with standard tracking
→or „todo": labeled with CNN

5. „Todo": EM cascade start finding
→most significant for e/γ separation and ν_e selection
- EM shower displacement from the vertex
- 1m.i.p. vs 2m.i.p. dE/dx in the initial part

A Recent Development in PD Sim/Reco

Alex Himmel

- Introduction of a “truth backtracker”
  - Access to truth information vastly improves the development and debugging process for new reconstruction algorithms.
  - Used by the Radiopurity group:
    - to find and fix an error in the radiological generator.
  - Used by the Nucleon decay group:
    - to explore timing information from various components of NDK events.
  - Used by the Supernova group:
    - to develop a new SN-specific reconstruction algorithm for the photon detectors.



Top Priorities on PD Todo List

- Develop a simulation technique which can handle the full-sized far detector.
  - Currently we can only simulate a small fraction of the detector at a time.
  - Likely requires some structural changes in how the optical simulation is performed.
- Improve our electronics and readout simulation.
  - Introduction of the response of multiple SiPMs ganged together (the protoDUNE design) is imminent.
  - More realistic noise simulation also likely required.
- Improve single channel-level reconstruction algorithms so they can handle noisier signals.
  - Dependent on introducing noise in the simulation, of course.
- Support reconstruction algorithm development in the physics groups.
  - Build off the channel-level reconstruction developed in Sim/Reco.

Working closely with SCD

- LArSoft framework is the core of DUNE software development, which is well maintained by the larsoft team.
- Bug reports and feature requests are usually promptly addressed by the art/larsoft teams.
- LArSoft has recently recently supported dual-phase geometry.
- An updated continuous integration system is being developed. We are working with SCD experts to make this system most useful in monitoring any changes in software.

Conclusions

- There has been a lot of progress in DUNE reconstruction.
- We delivered the full chain of reconstruction algorithms for physics analyses.
- We continue to improve the reconstruction performance, optimize reconstruction for specific analysis, incorporate new tools (e.g. Wire Cell, CNN).
- We are training new people to learn the framework and get involved with reconstruction development.
- Currently there are about 15 people working on the FD reconstruction, 15 people working on the protoDUNE reconstruction. Many tools are shared.