Fermilab

Important Reconstruction Topics for MicroBooNE

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About this talk

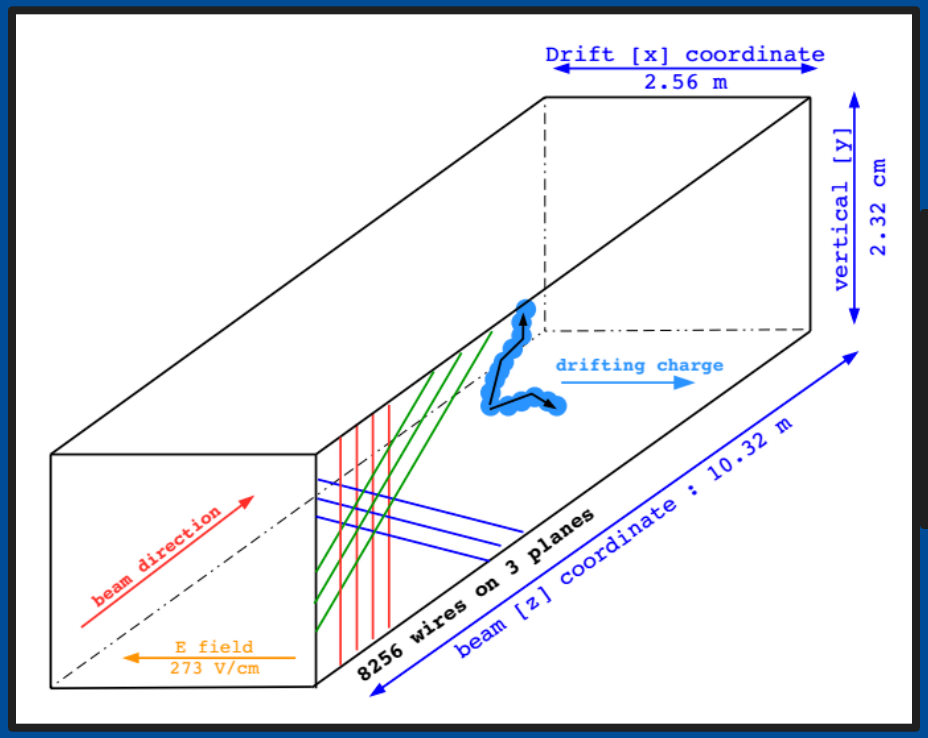
- Presenting some of the key challenges and focuses for our current and projected future reconstruction efforts
  - Will give sense of overall priorities and general timelines
  - Lots of overlap with simulation, calibration, and physics analysis work
  - Give examples and highlights from our recent Neutrino2016 analysis push
    - See full selection of public notes here: http://www-microboone.fnal.gov/publications/publicnotes/index.html
- We are in the middle of our campaign focused on the next round of improvements
  - Lots of activity on high-priority items
  - Lots of hot-off-presses material
  - Not showing that here, though will talk about what we're working on of course

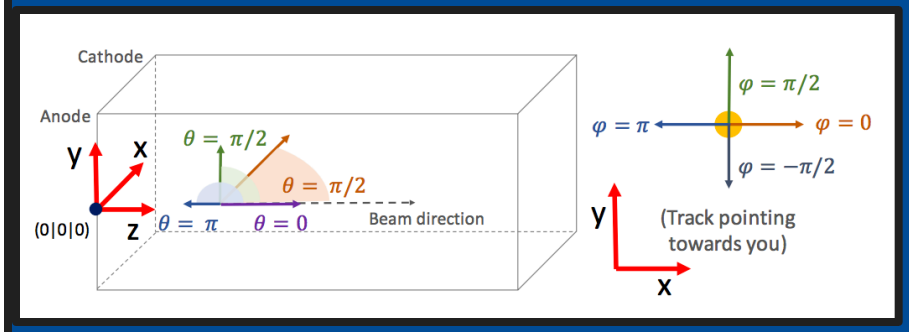
MicroBooNE Physics Goals

- Reconstruction in MicroBooNE must work to meet the needs of our physics analysis goals
  1. Determine the origin (electron or photon) of the “MiniBooNE Low-E excess”, and prepare to participate in SBN program search for non-standard oscillations
  2. Measure neutrino interaction cross sections on Ar from both BNB and NuMI neturinos
  3. Push forward the development, operation, and analysis of data from large LArTPCs, leading towards future LArTPCs (SBN, DUNE)

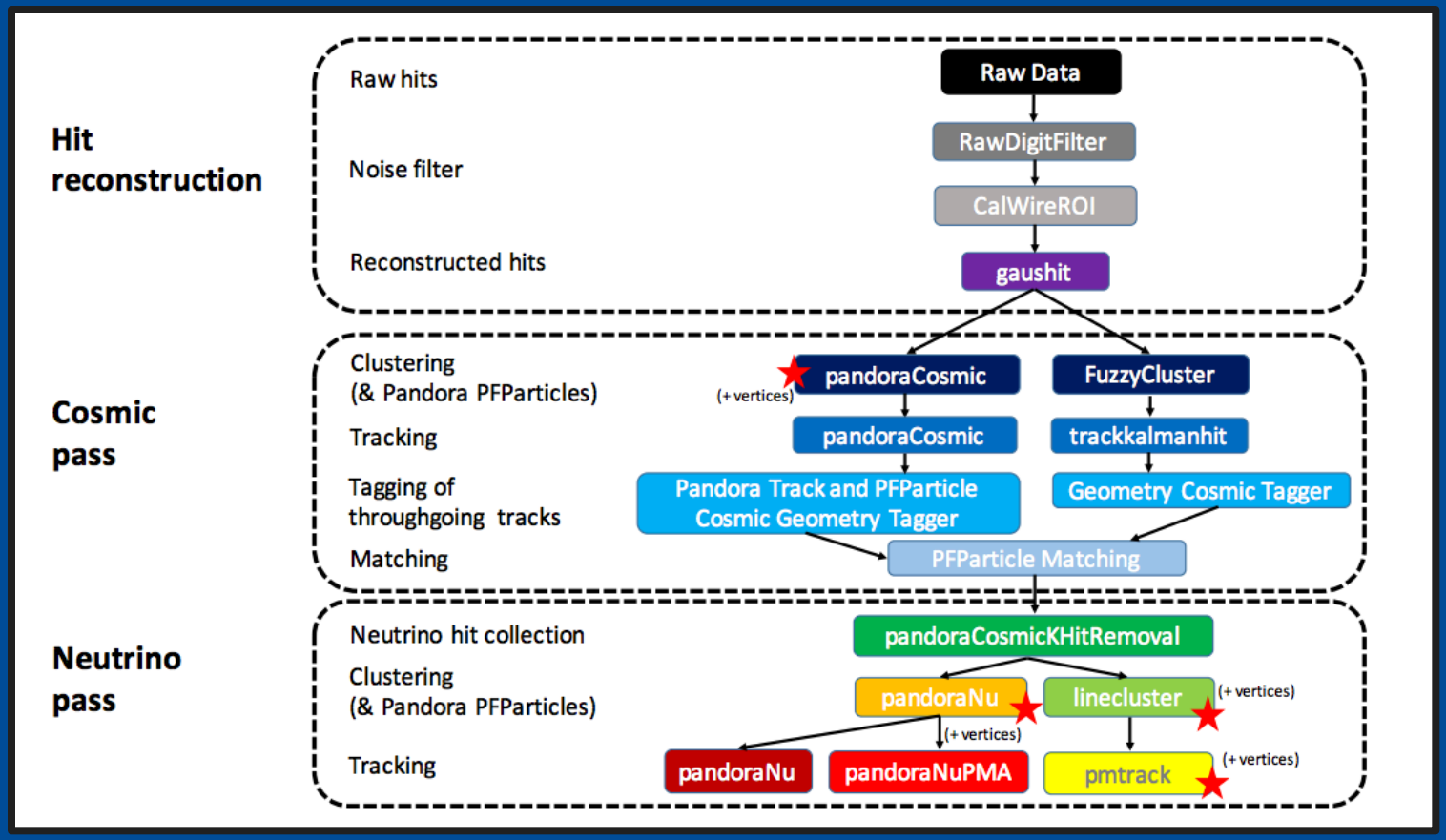
- We work hard to keep a close connection between “reconstruction” and “analysis”
  - Reconstruction *is a fundamental part of our physics analyses*
  - Our physics analyses will live and die by the reconstruction and tools we use to do the reconstruction
    - HUGE thanks to our collaborators in LArSoft and *art* community, and a reminder that we count on you

First, our detector/coordinate system





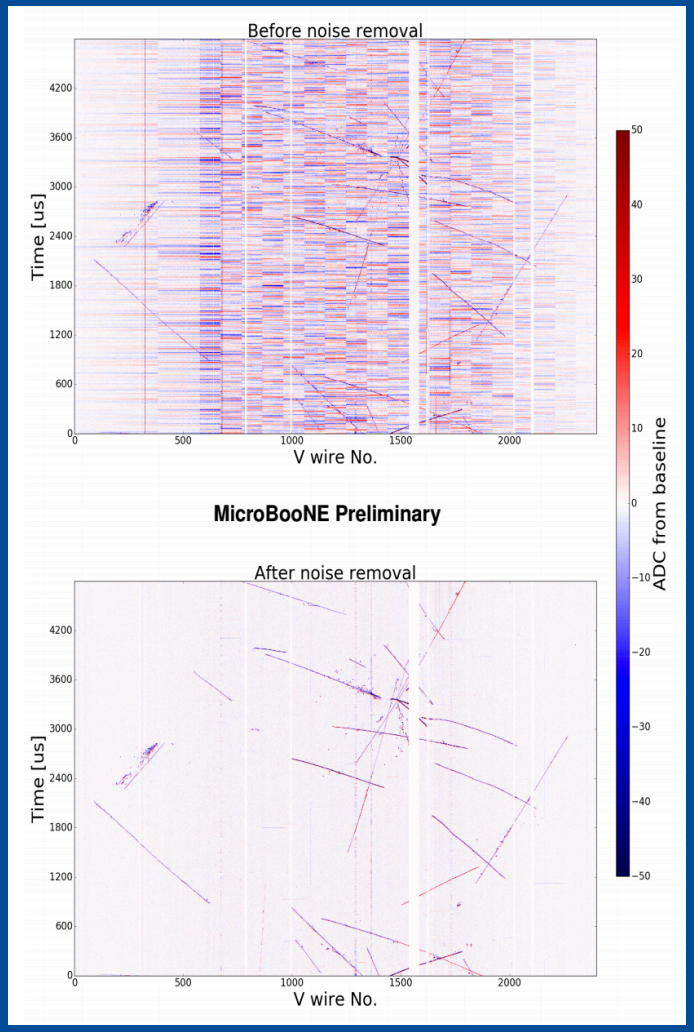
Second, the MicroBooNE reco chain

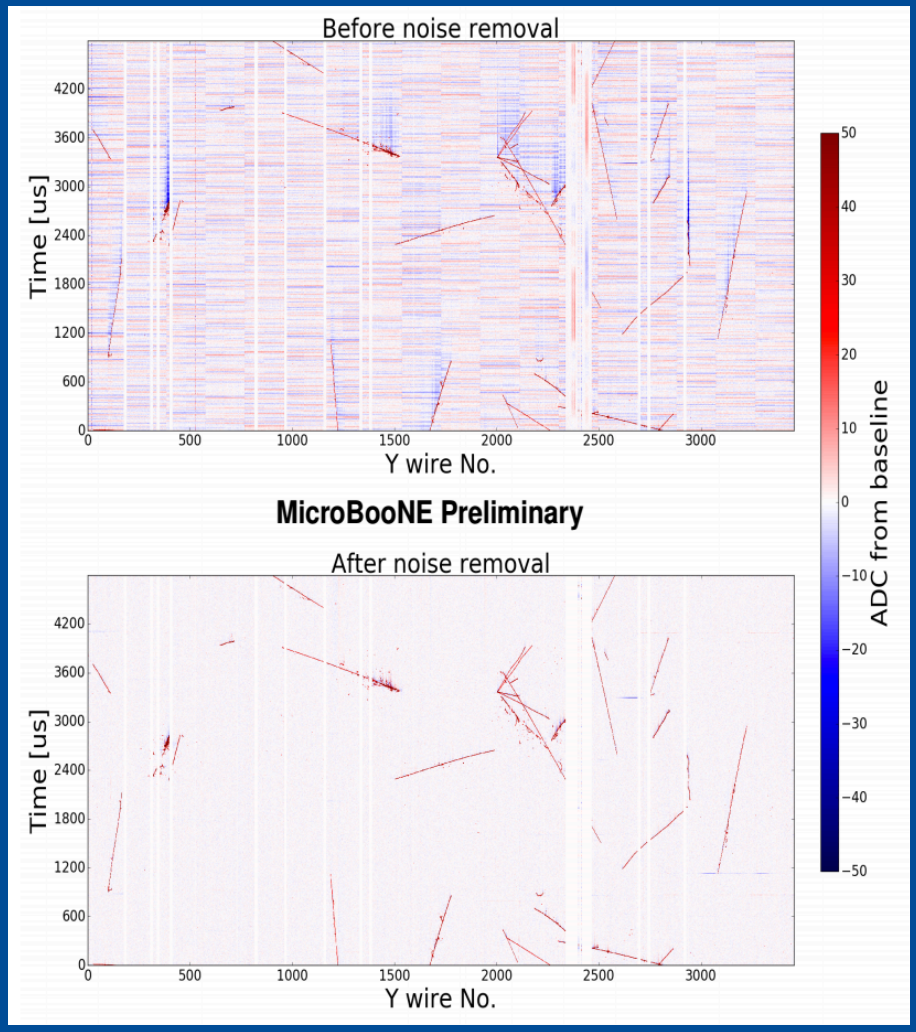


Importance of our noise filtering

- We have noise from various sources inside our detector
  - Read more than you probably want to know: http://www-microboone.fnal.gov/publications/publicnotes/MICROBOONE-NOTE-1016-PUB.pdf
- Noise is bad
  - Hurts our signal-to-noise ratio → potential impacts on analyses
    - Especially important to PID
  - Downstream reconstruction complexity/time/performance is directly affected by presence of noise hits
  - Image-type analysis of waveforms can be very sensitive to changes in noise levels/behavior across wires
- Huge effort to filter out noise
  - State-of-art presented in that note, and being applied to all data now
  - Further improvements to handle additional cases
  - Longer outlook: improve speed! (currently ~10-20 s per event!)

Noise filter: before/after





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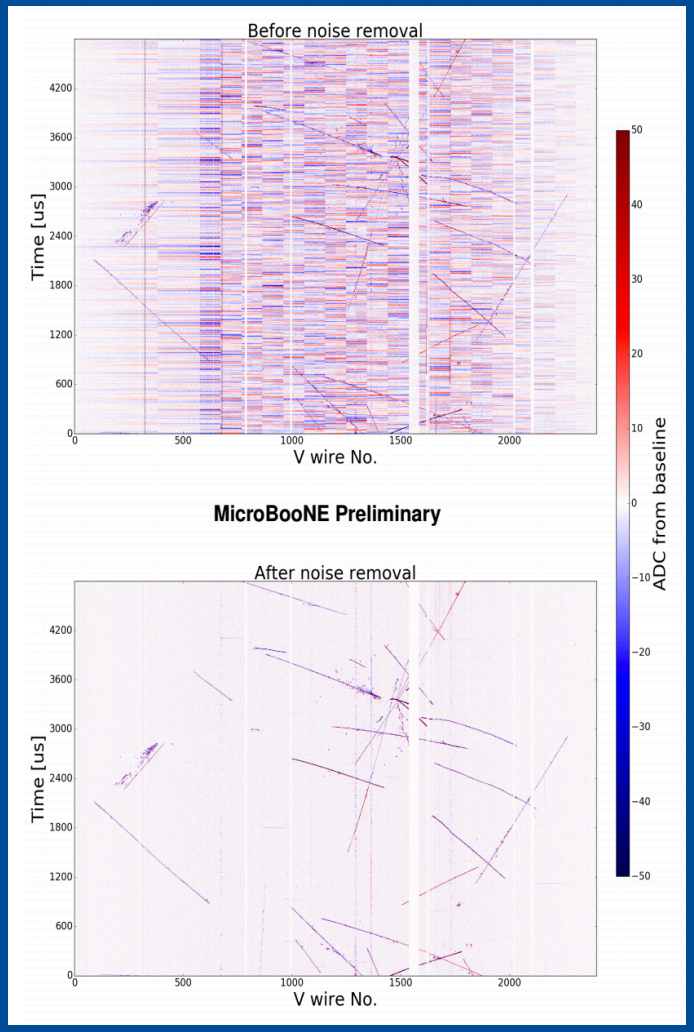
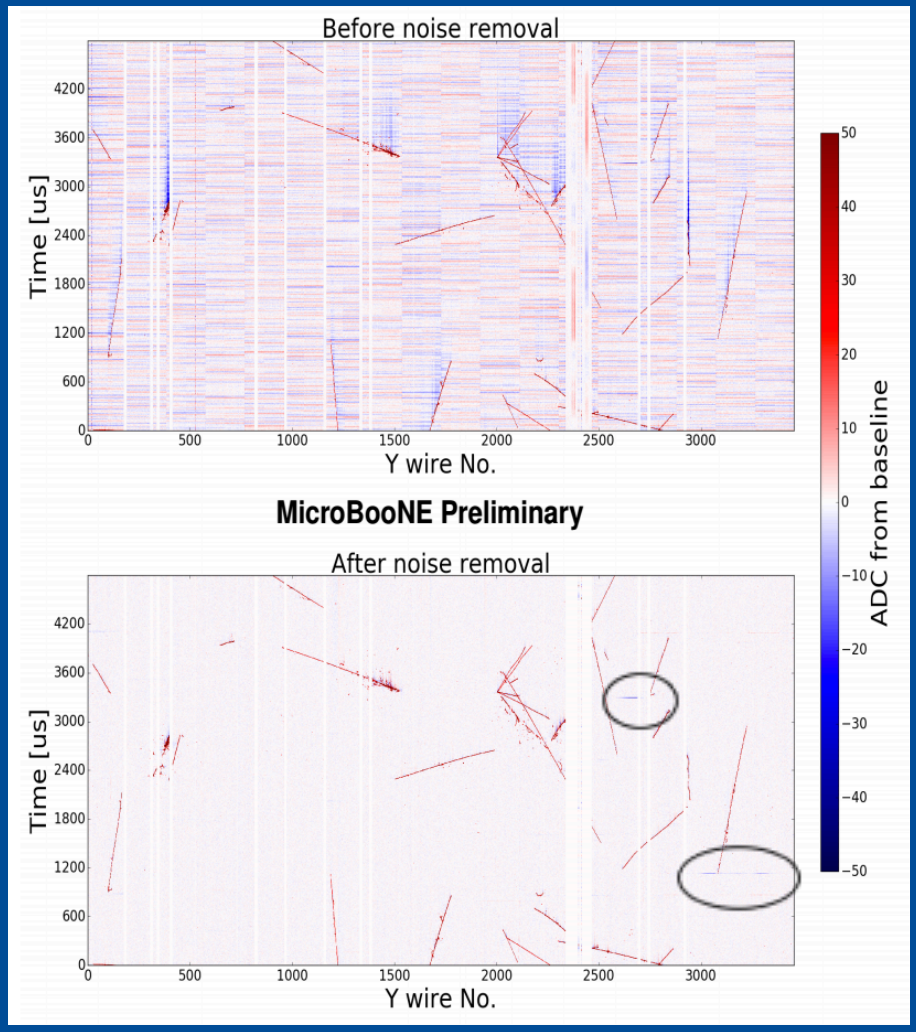
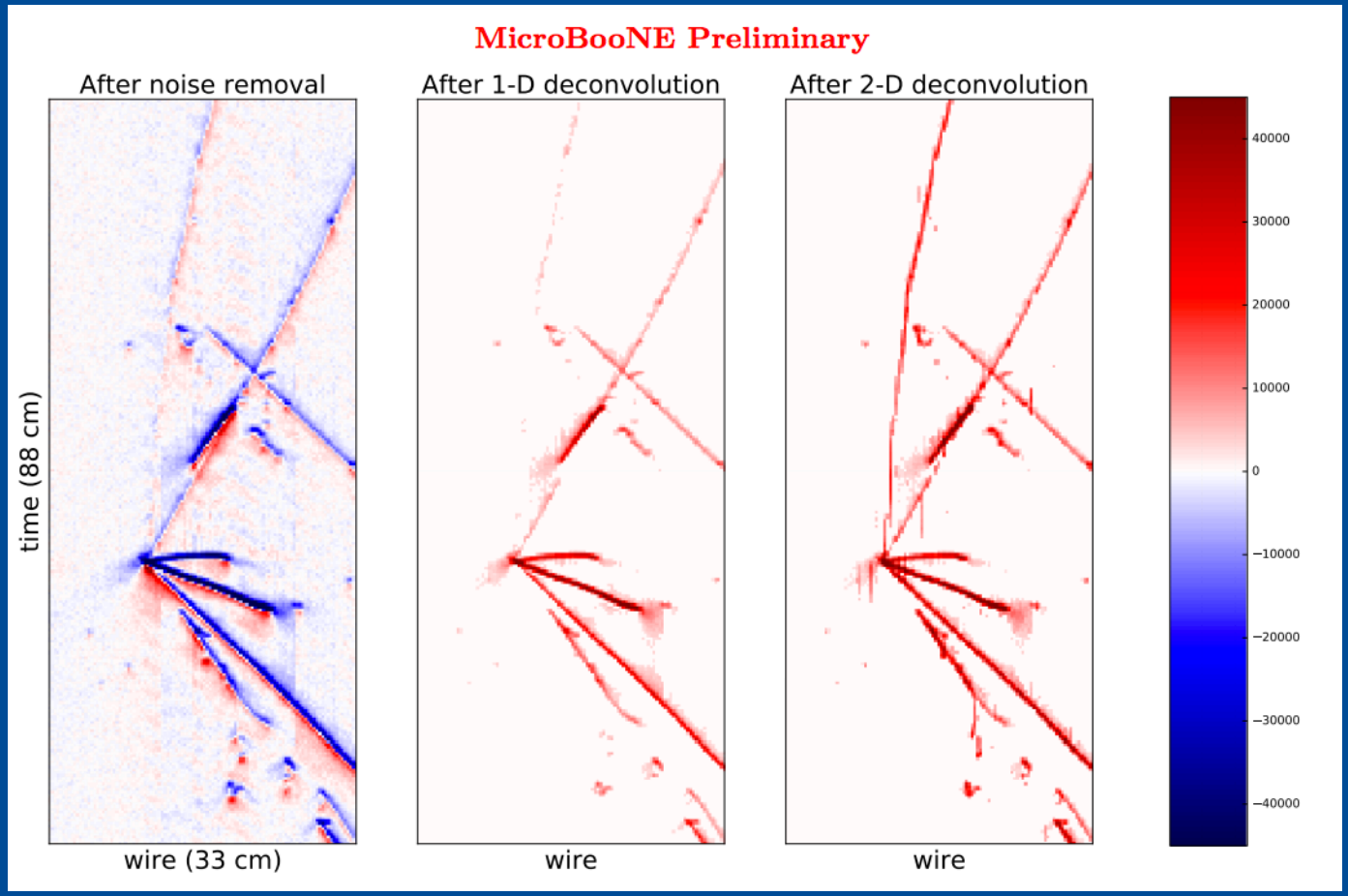




"CalWire": Translating raw signals to ionized e^-

- Downstream reconstruction depends on a normalized response per wire and per plane
  - Application of calibration constants for wire response
  - Deconvolution of E-field effects (electron drift near wires) and signal shaping from electronics
    - COMPLICATED: there are induced charges from neighboring wires
      - We don't perfectly understand what happens in a perfect detector
      - Our detector is not perfect
    - 3D simulation of E-field response, data-driven field response determination, and 2D deconvolution methods underway
      - Targeted for next major software releases
- See here: http://www-microboone.fnal.gov/publications/publicnotes/MICROBOONE-NOTE-1017-PUB.pdf

Deconvolution example in U plane



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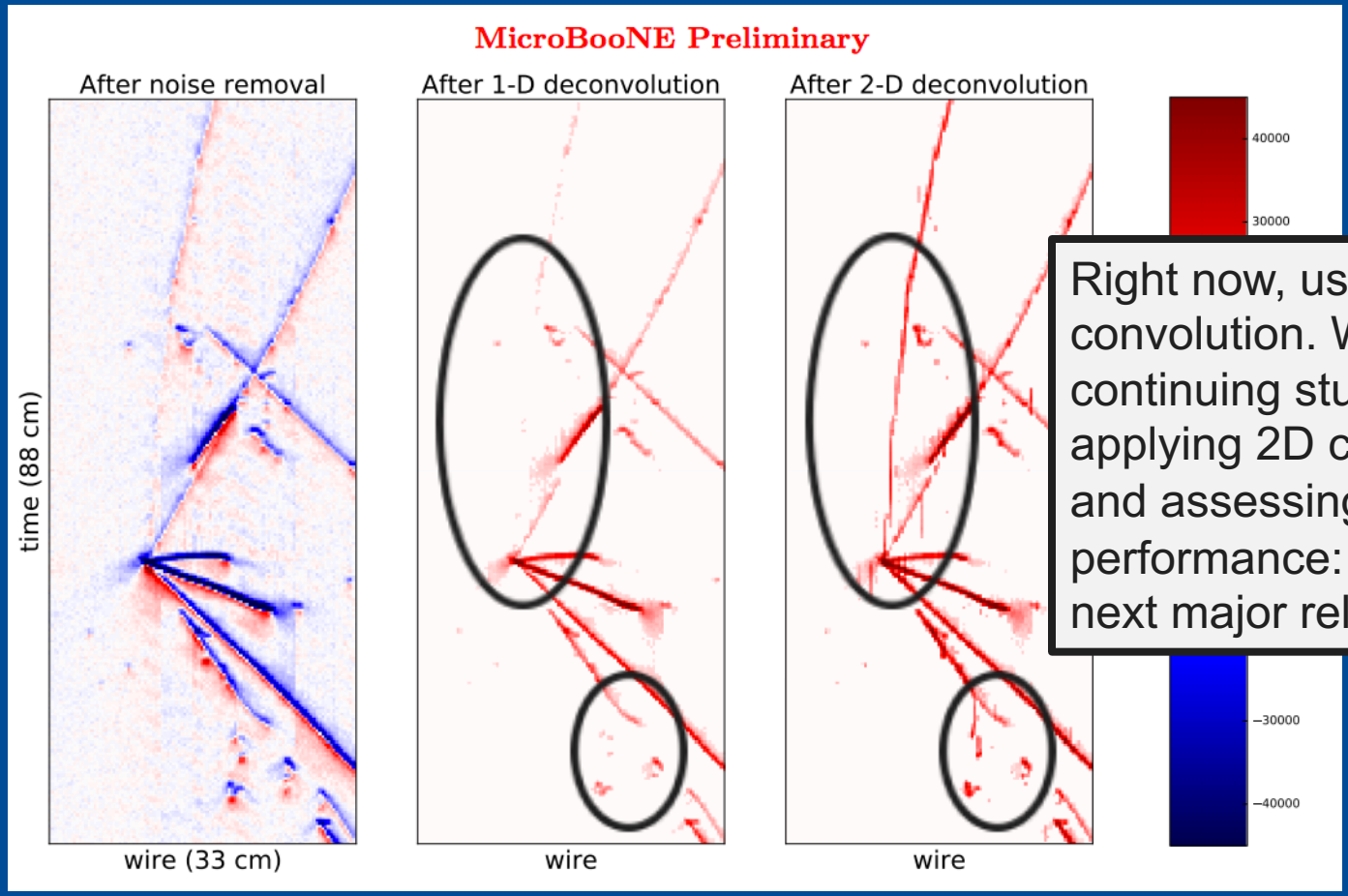


Right now, using a 1D convolution. We are continuing studies on applying 2D convolution and assessing overall performance: potential for next major release

Cosmic rays are a major challenge

- ***Every*** MicroBooNE event has significant cosmic-ray-related activity in our "signal" region
  - Long drift + large detector + surface operation → heavy exposure
  - We are probably not at LHC-level of complexity, but we have our own challenges
    - LARGE overlap from wires in each plane
    - No "beam constraint" → search for neutrinos everywhere
- This has a direct affect on our ability to achieve our physics
  - Cosmic-ray-induced showers represent significant background at low-E "electron" selection region
  - Cosmic ray muons can be mis-identified as muons from interactions
- In MicroBooNE (and ICARUS…) cosmic rays are predominant source of triggers
  - Cosmic ray in coincidence with beam gate > neutrino interaction rate

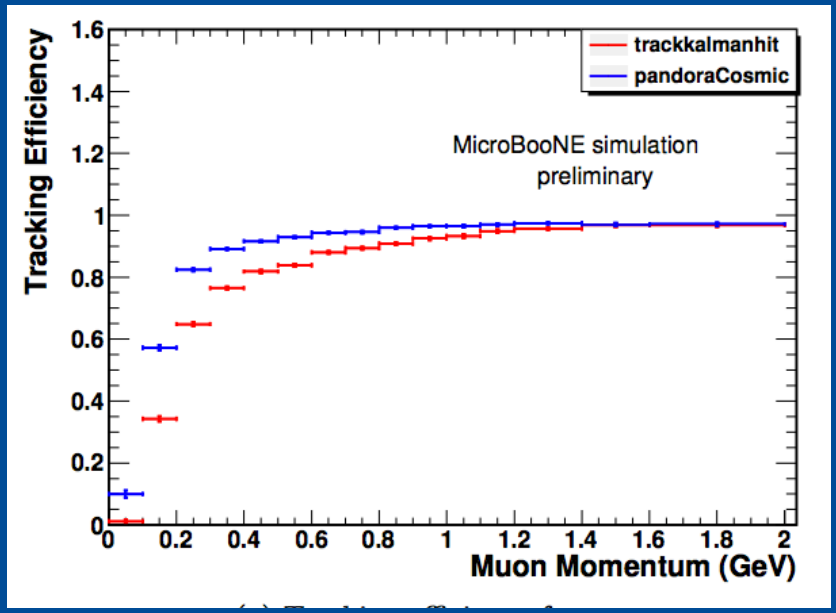
Example of impact in nu_mu CC analysis

- We can model/predict cosmic-ray contamination with “off-beam” data events
  - For this selection, we cut *very* hard to reduce cosmic contamination, and still ~40% of events are just cosmic fakes with no beam activity
- EVEN STILL, that’s not all of our cosmic background
  - Beam-related activity + cosmic mis-ID’ed as neutrino is significant part of remaining background!

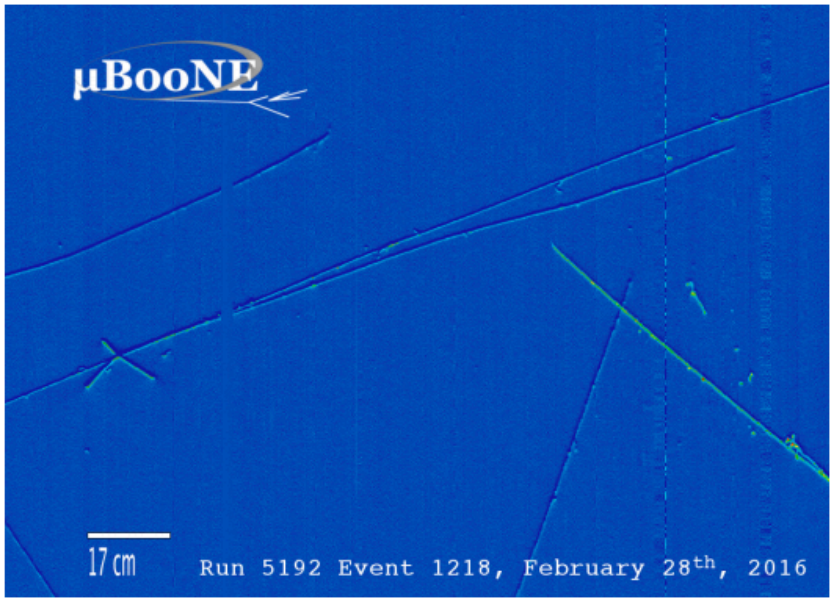
MicroBooNE Preliminary	on-beam		off-beam measured	off-beam [scaled]	
Triggered	546910		388471	[477819]	
$\geq$ 1 flash with $\geq$ 50 PE	135923	(25%/25%)	78657	[96748]	(20%/20%)
$\geq$ 1 track within 5 cm of vertex	134744	(99%/25%)	77868	[95778]	(99%/20%)
vertex candidate in FV	74827	(55%/14%)	41844	[51468]	(54%/11%)
flash matching of longest track	22059	(29%/4.0%)	9946	[12234]	(24%/2.6%)
track containment	10722	(49%/1.9%)	4295	[5283]	(43%/1.1%)
track $\geq$ 75 cm	3213	(30%/0.6%)	1080	[1328]	(25%/0.3%)

Cosmic ray removal strategy part 1

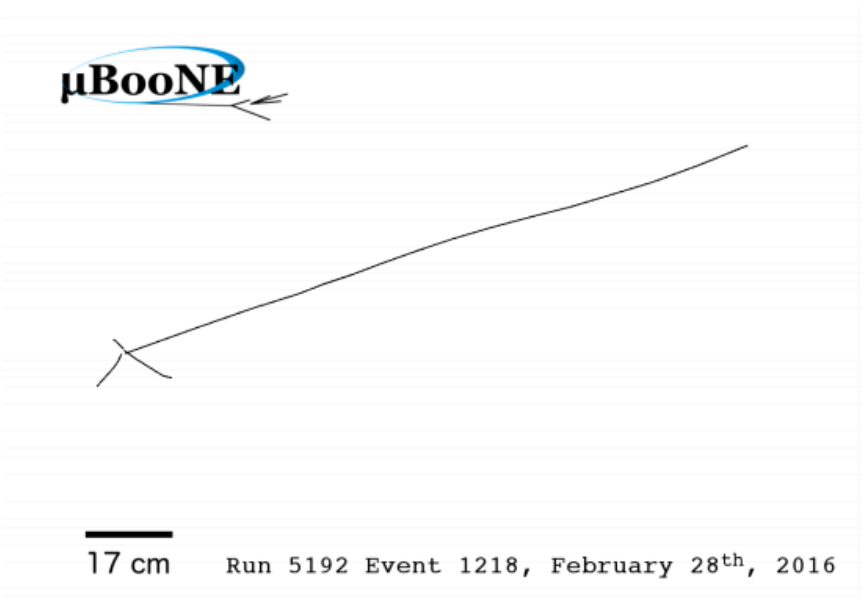
- We use geometry of TPC to identify through-going and out-of-time tracks
  - Broken tracks can fool reconstruction, thinking something is contained
  - Mis-reconstructed length or track positions can lead to failures in geometrical tagging of tracks
  - Non-reconstructed tracks → invalidated proximity cuts for EM showers
  - No great handle on track direction
    - If contained, can look for charge deposition at end of track
    - If not … delta rays? This would need work!



Example from nu_mu CC analysis



(e) Induction plane (V)



(f) Reconstructed 3D image (V plane projection)

Specifically for tracking/vertexing

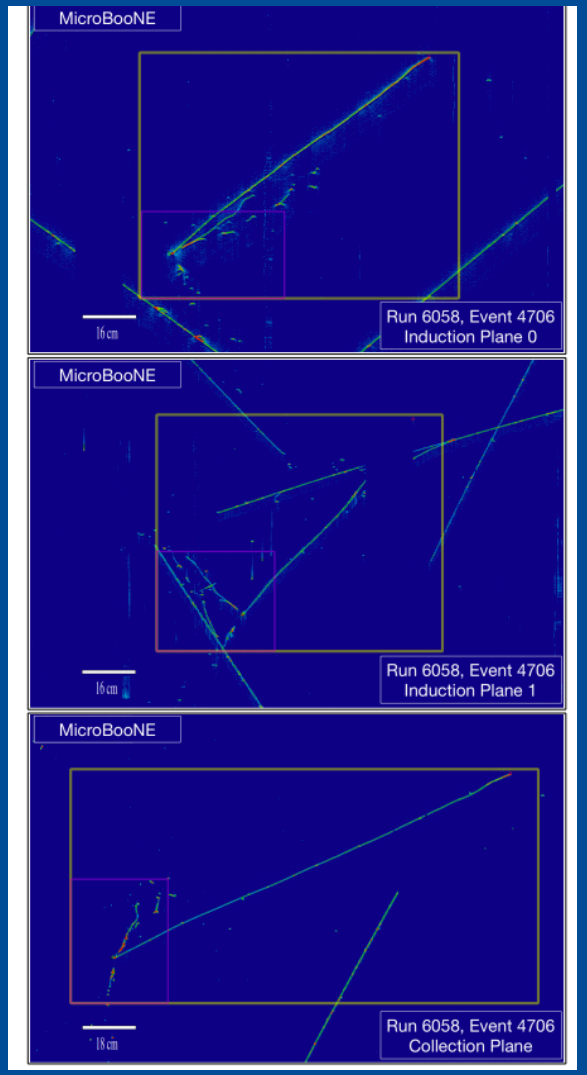
- Need to reduce fake reconstruction of “neutrino” vertices from Pandora
- Need to reduce effects of gaps/dead wire regions on tracking/vertexing
- Improve the handling of remnant cosmic-ray tracks
  - For instance, need to be careful about CR tracks close to neutrino activity! Important for shower reconstruction!
- Improve reconstruction for shorter tracks
  - → proton reconstruction and cross section measurements!
- Improve fitting of tracks to trajectories
  - Important for improving efficiency and length reconstruction
  - Crucial for future studies on multiple coulomb scattering on exiting tracks
- Except for very last point, these are all being actively worked on and planned for next major software release (January-ish)

Cosmic ray removal strategy part 2

- We use matching of scintillation light information to TPC activity to try to assign an interaction time
  - Currently this is not very robust: basic checking of consistency between “light flash” inside beam gate and TPC muon candidate track based on geometry
- Improvements here are ***high priority for us*** for the next software release
  - And may be *the* driver on the time of that release
- We need:
  - Better simulation of our expected light yields in detector, and better measurements using external cosmic taggers to pin that down
  - Improvement and validation of our optical reconstruction, using PMT array to better determine Y/Z position of scintillation light origin
  - Improvement in construction of “light hypotheses” for TPC activity
  - Improvement in comparison of light hypotheses to reconstructed light → t0 for all observed TPC objects

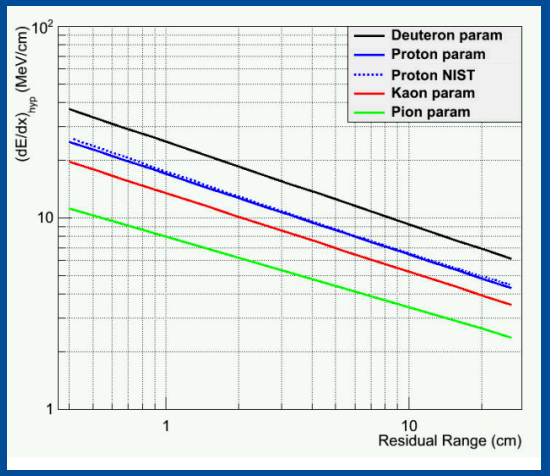
Shower reconstruction

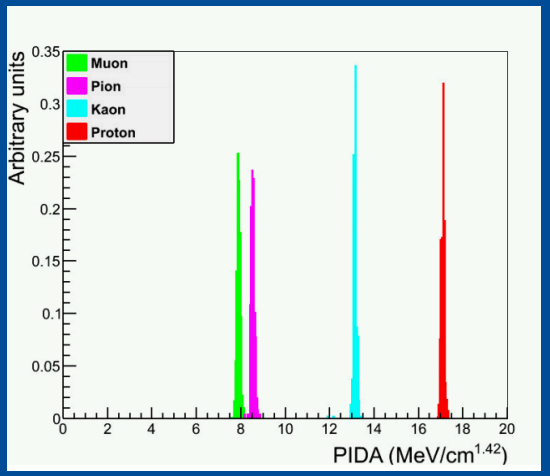
- This is hard!
  - See http://www-microboone.fnal.gov/publications/publicnotes/MICROBOONE-NOTE-1012-PUB.pdf
- Need to reconstruct EM showers across a range of energies
  - GeV showers do not look like ~100-MeV showers
- Energy reconstruction is crucial!
  - It's the "E" in low-E
  - Properly cluster hits from showers in a busy environment
  - Properly account for recombination effects
  - Shower profiling may help?
- Simple shower selection is also difficult!
- ***This is very active effort right now, and important for next results***



Not far down the road

- Calorimetry and PID
  - MicroBooNE has not yet fully invoked robust calorimetry and PID in analyses yet
    - Much of this work has been done in ArgoNeut and LArIAT, and we hope to benefit from that expertise
    - For track-like objects: exploit dE/dx vs. residual range
      - PIDA parameterization from B. Baller
    - For showers, need dE/dx at start point of shower
  - I expect there will be potential improvements to standard methods here
    - Optimization of selection, improving fits to dE/dx vs. residual range, etc.

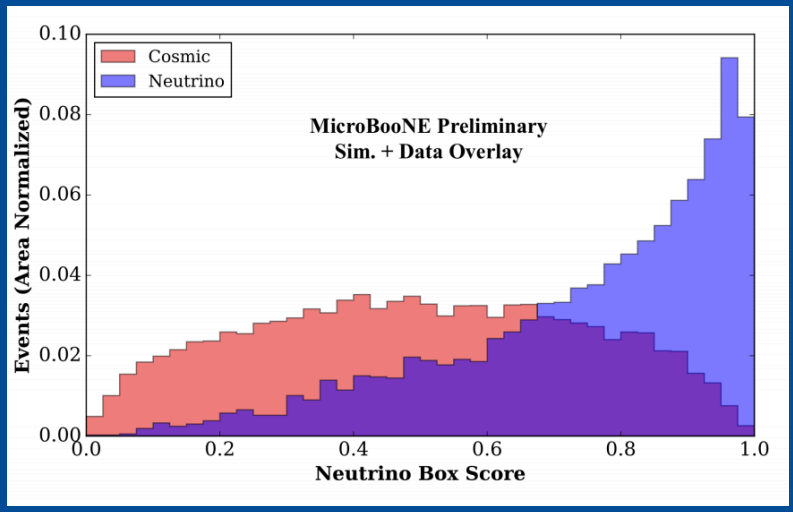




Truth-level info for PID. From ArgoNeuT: Acciarri et al, 2013 JINST Vol. 8 P08005

Deep Learning

- There is a growing effort towards applying deep learning techniques across many facets of reconstruction
  - Neutrino identification inside cosmics
  - Particle identification
  - Energy reconstruction
- Promising early-stage results, but many challenges remain
  - Understanding data vs. data+MC vs. MC-only response
  - Evaluation of systematic uncertainties
  - Specialization/generalization of network response to other LArTPCs



- See http://www-microboone.fnal.gov/publications/publicnotes/MICROBOONE-NOTE-1019-PUB.pdf