LAr TPC reconstruction and systematics for SBN*

Andy Furmanski

IPPP/NuSTEC meeting

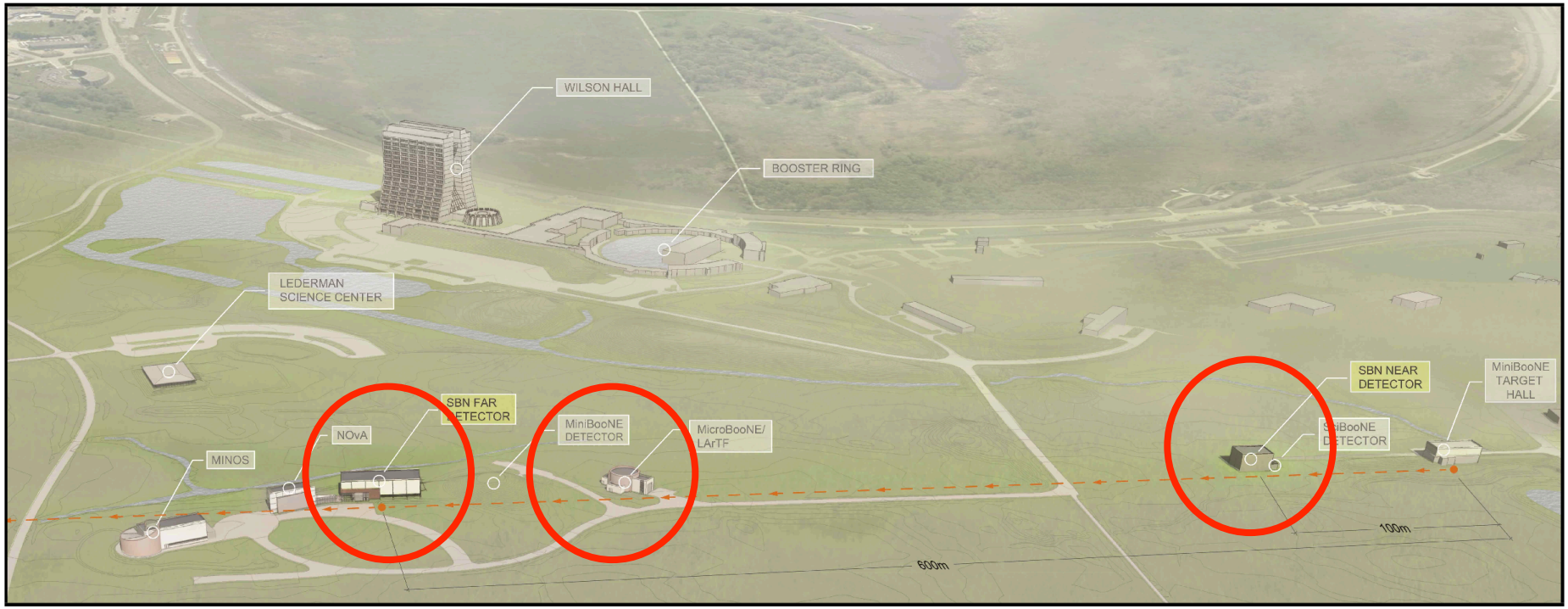
18th April 2017 - Durham, UK

* shortened from “Reconstruction of neutrino events in Liquid Argon and their impact on short-baseline sterile-neutrino oscillation searches”

The SBN project

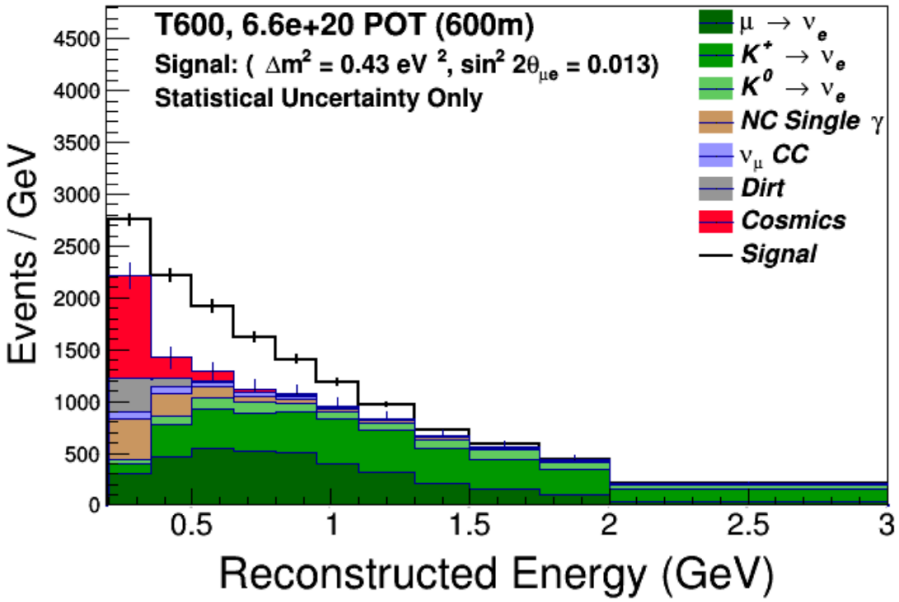
- Three LAr TPCs in the Booster Neutrino Beam at Fermilab
- Almost 1kt total liquid argon!

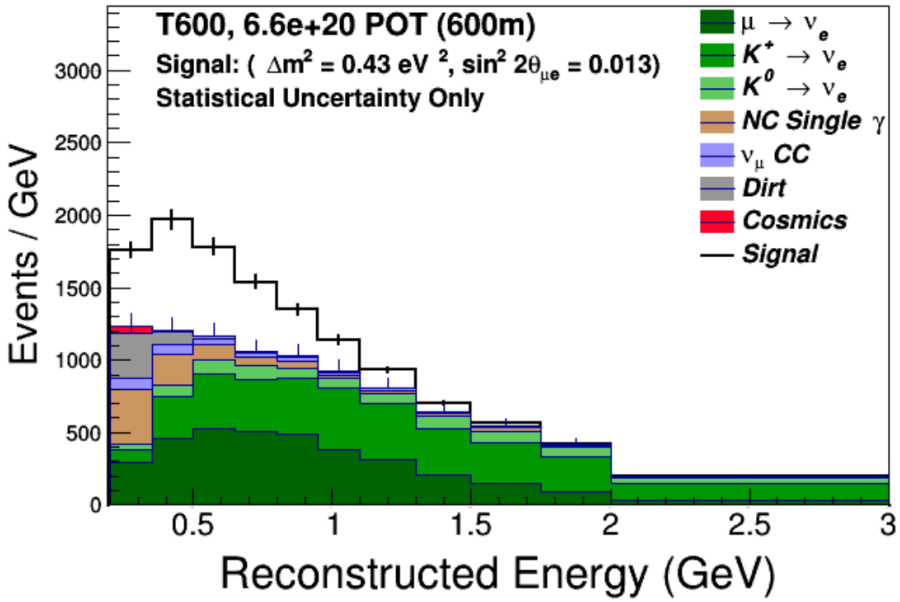
arXiv:1503.01520



SBN appearance

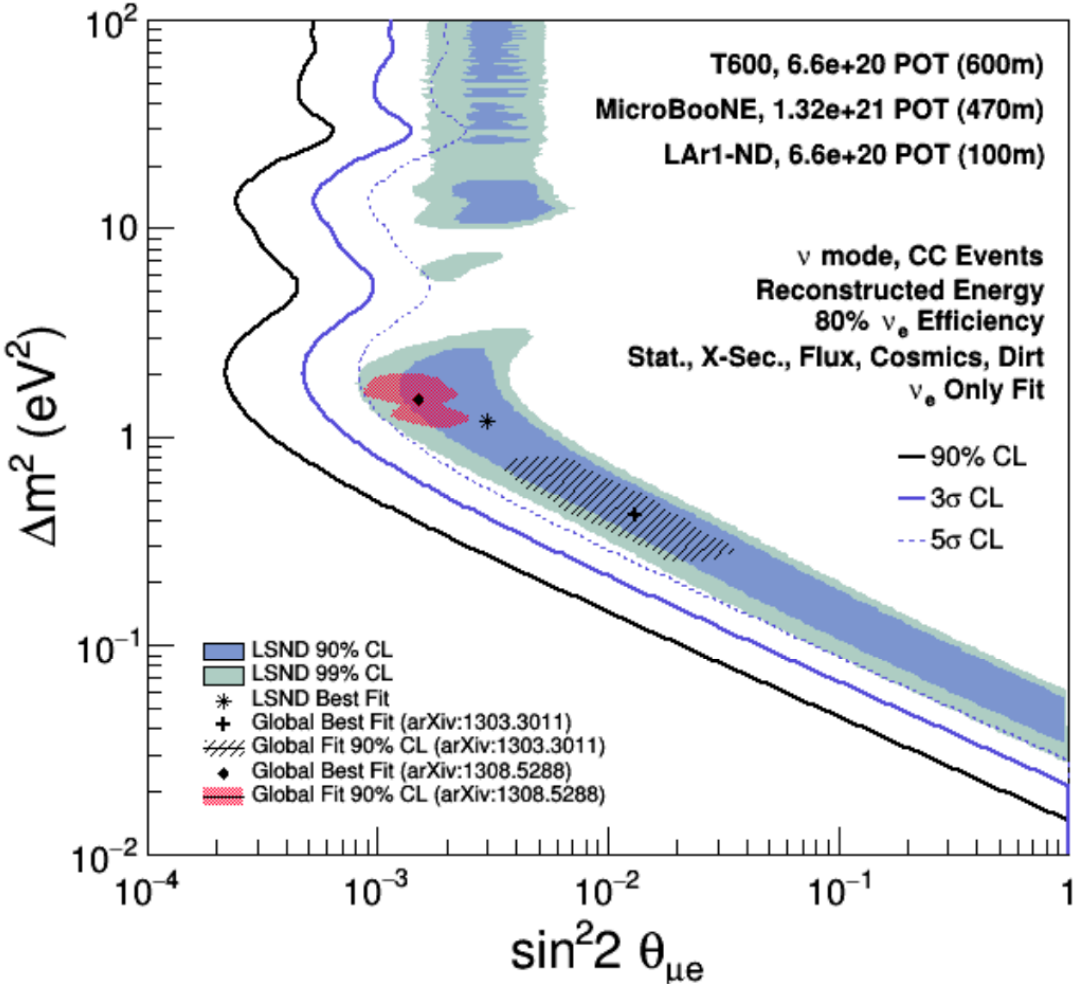
- ICARUS predictions for single-electron events
  - Left: only TPC-based cosmic tagging. Right: include PMT system and an external tagger





SBN sensitivity

- Sensitivity to ν_e appearance
- Only detector systematics considered are due to cosmics and "dirt" events
  - Dirt = anything outside the active TPC
- Missing – uncorrelated detector effects



LArTPC reconstruction

- Facts:
  - LArTPC provides **high-resolution calorimetric** information
  - **Electrons and photons shower** in Lar
    - Muons/protons/pions all form tracks
  - SBN detectors all on-surface – high cosmic backgrounds
- General strategy:
  1. Find hits above noise baseline
  2. Cluster hits, determine track-like or shower-like
  3. Match 2D views to form 3D objects
  4. Fit tracks (Kalman filter, etc) – PID from dE/dx
  5. Determine shower energies/directions
  6. Group tracks/showers in an "interaction"

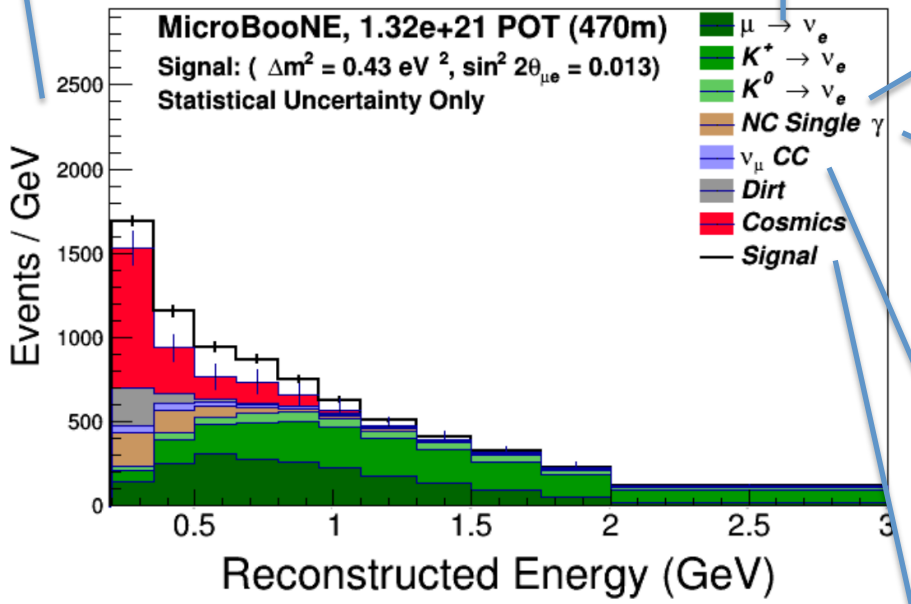
(mis-)reconstruction effects

Signal efficiency

muon constraint – momentum resolution etc

Shower energy resolution, hit efficiency

Electron/photon separation



π^0 removal

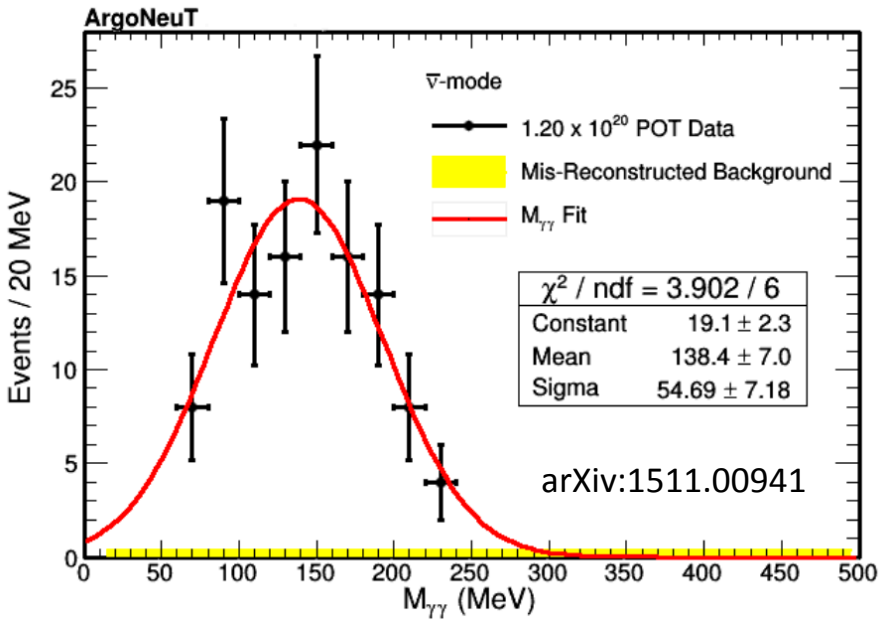
Hadronic energy reconstruction

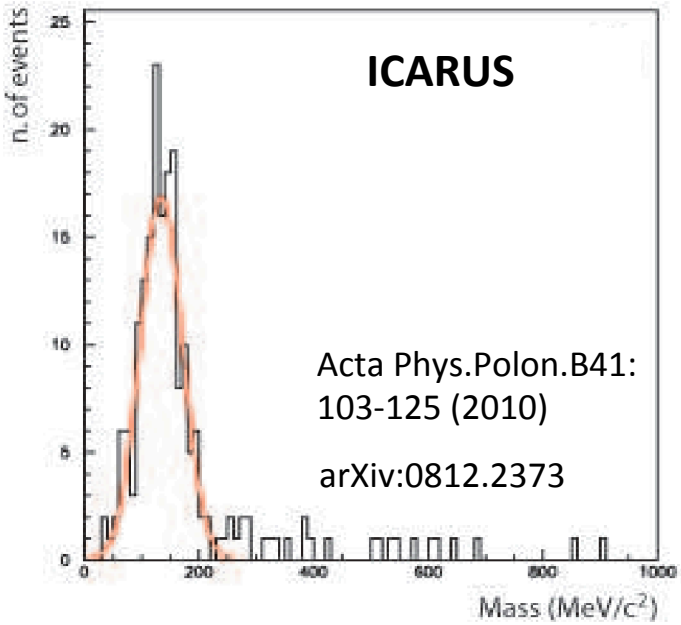
Cosmic tagging efficiency

Previous LAr measurements

Semi-automated reconstruction

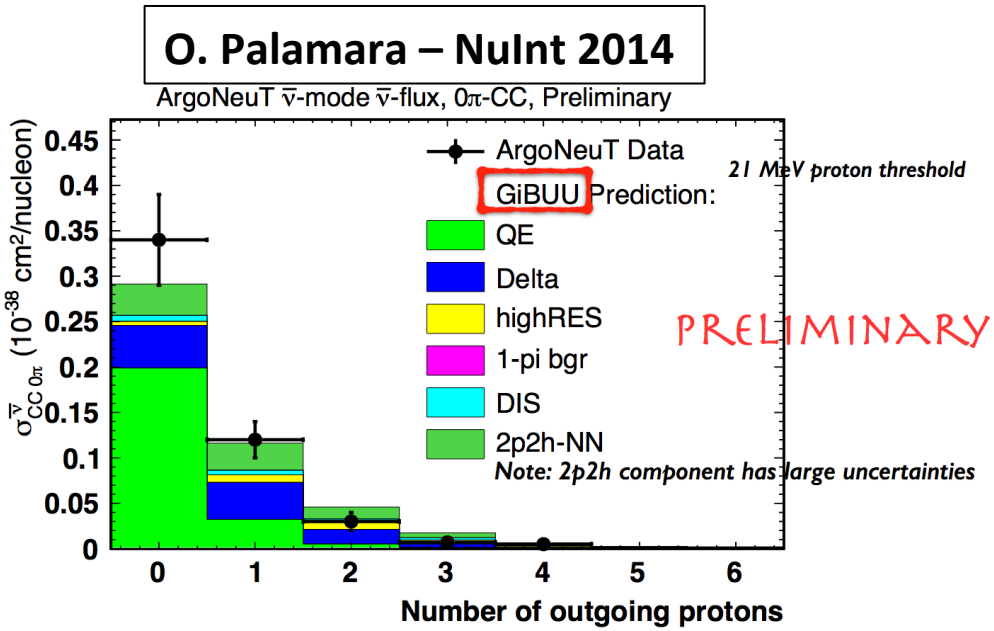
- ArgoNeuT made good use of "semi-automated" techniques
  - Cluster by hand, then proceed as usual
- This was most powerful for showers

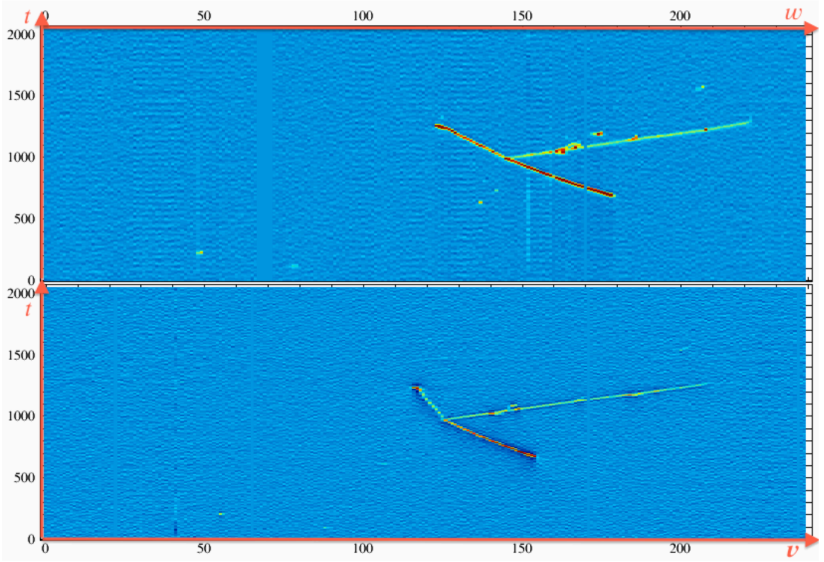




Proton reconstruction

- ArgoNeuT: semi-automated proton reconstruction
- 21MeV KE threshold

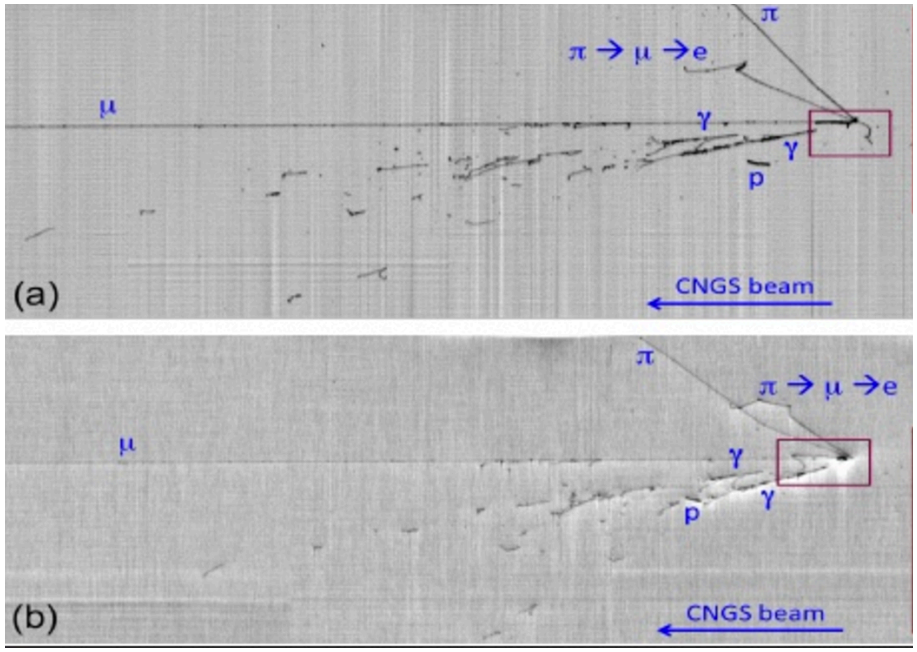




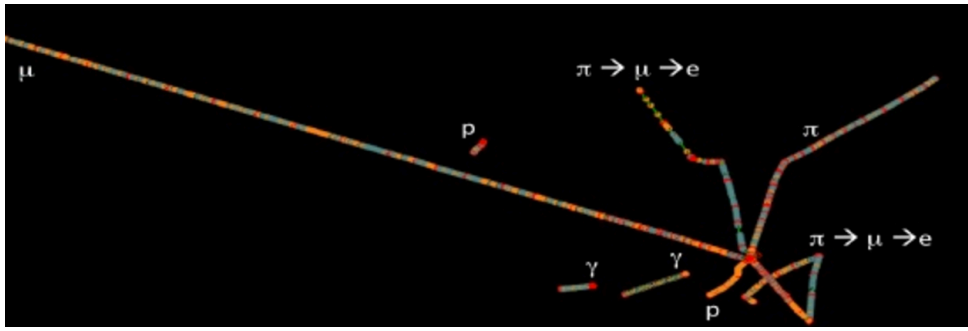
Fully automated reconstruction

- ICARUS and ArgoNeuT both demonstrated fully automated track reconstruction

PoS (GSSI14) 019



ICARUS event 284 from run 9722

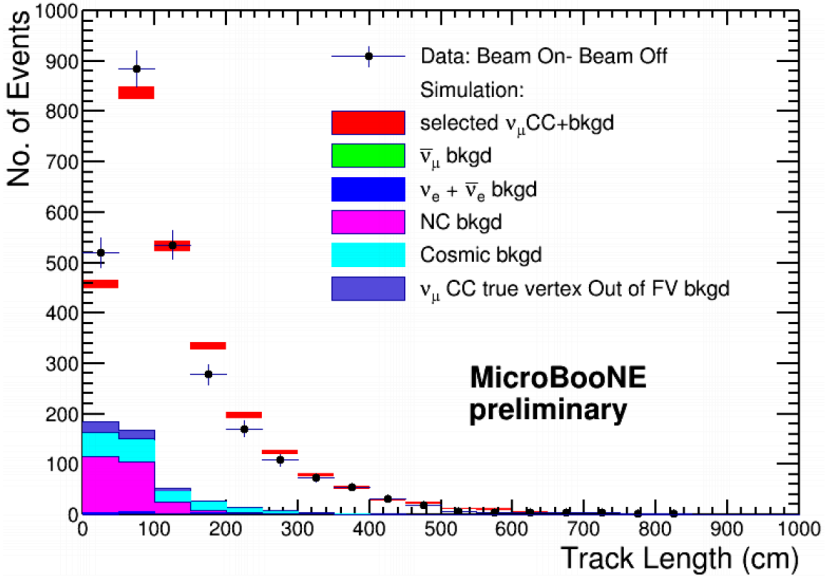


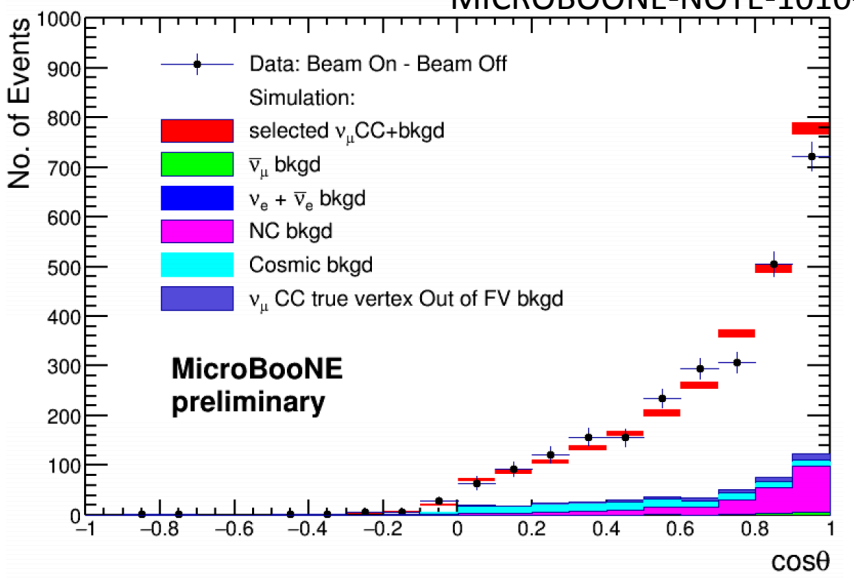
Recent developments

MicroBooNE automated event selections

- Summer 2016: CC-inclusive event selections **fully automated**
  - Muon only, no hadronic part
- Utilise PMT system – cosmic rejection

MICROBOONE-NOTE-1010-PUB

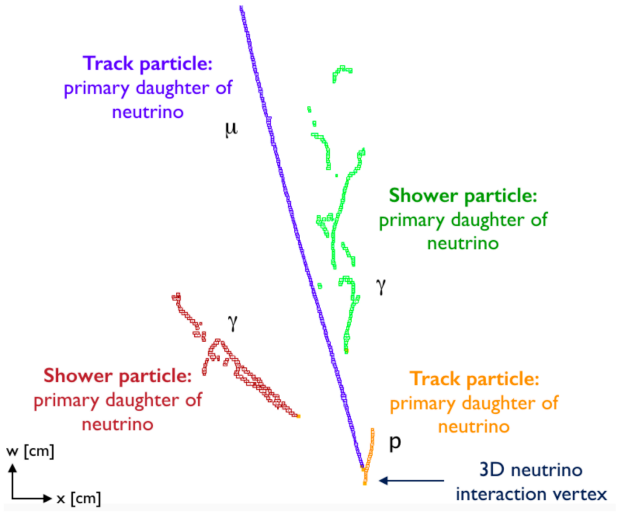


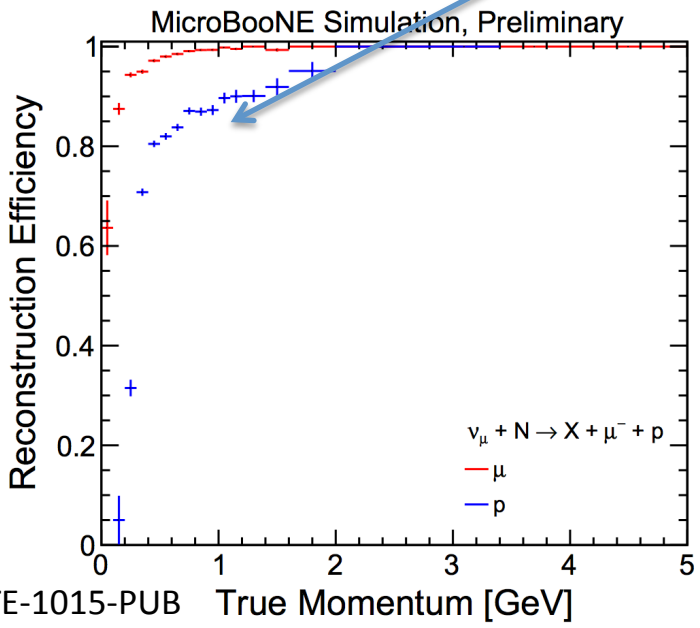


Pandora reconstruction package

- Pandora incorporated into LArSoft
  - Used in MicroBooNE CC-inclusive selection
- Well understood mature reconstruction algorithms
  - Tuned to work on real data
- Shown to have good efficiency
  - For single particles, and neutrino interactions

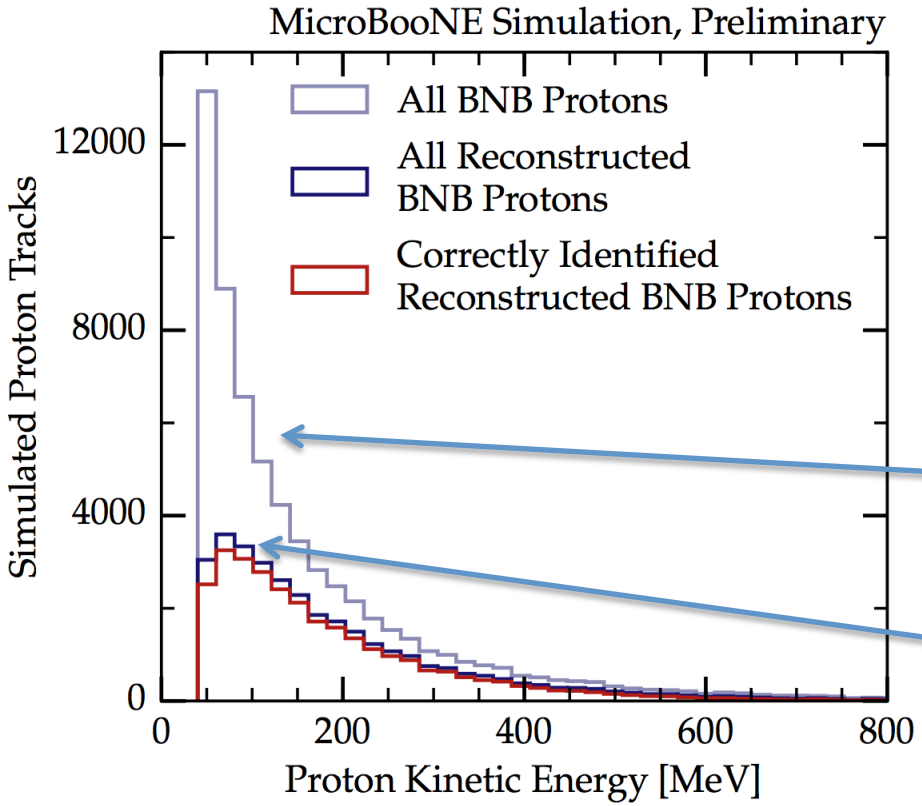
Losing hadronic energy here – correct with MC





MICROBOONE-NOTE-1015-PUB

Proton identification



- Pandora reconstruction of proton tracks in MicroBooNE
- BDT-based discriminator identifies protons with high efficiency

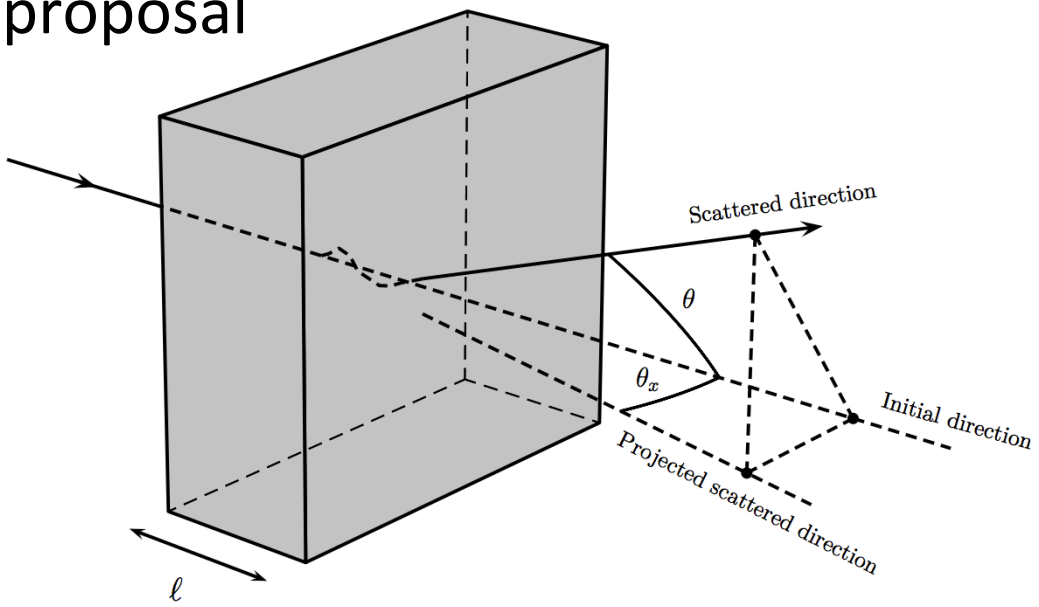
Uncertainties:

- MC needed to correct for these lost protons
- mis-ID protons counted as pions – energy wrong, or muons – event topology wrong

MICROBOONE-NOTE-1025-PUB

Multiple Coulomb Scattering

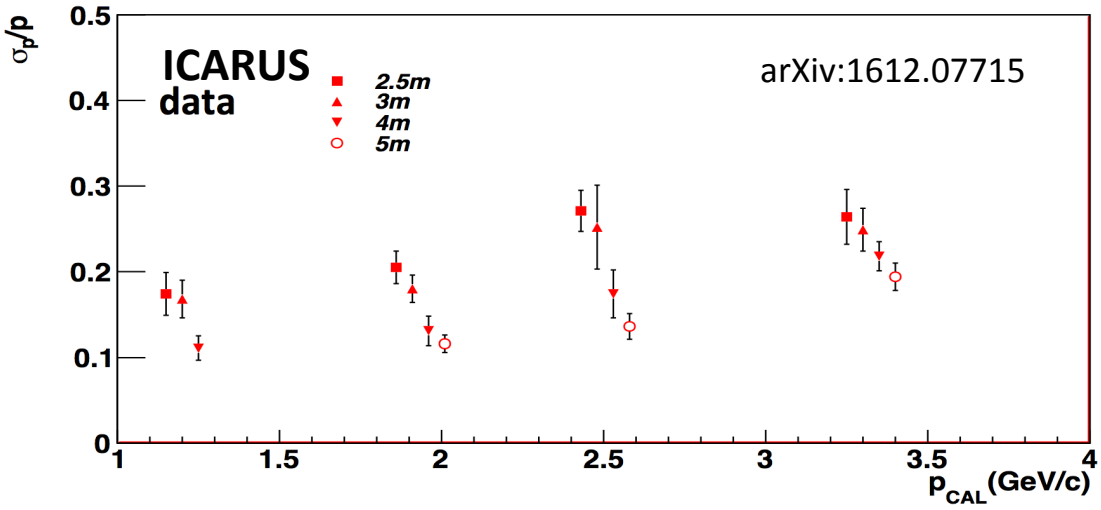
- MCS – Multiple Coulomb Scattering
  - Momentum/direction/PID information from "wobbliness" of tracks
- Allows you to **utilise non-contained tracks**
  - Assumed in the SBN proposal

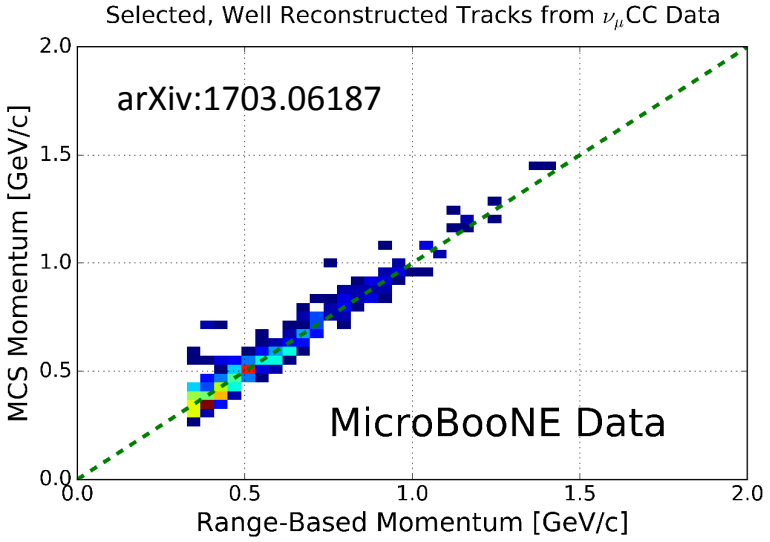


A particle scattering as it traverses a length of material.
The average angular scatter depends on the particle's momentum

MCS – proof-of-principle

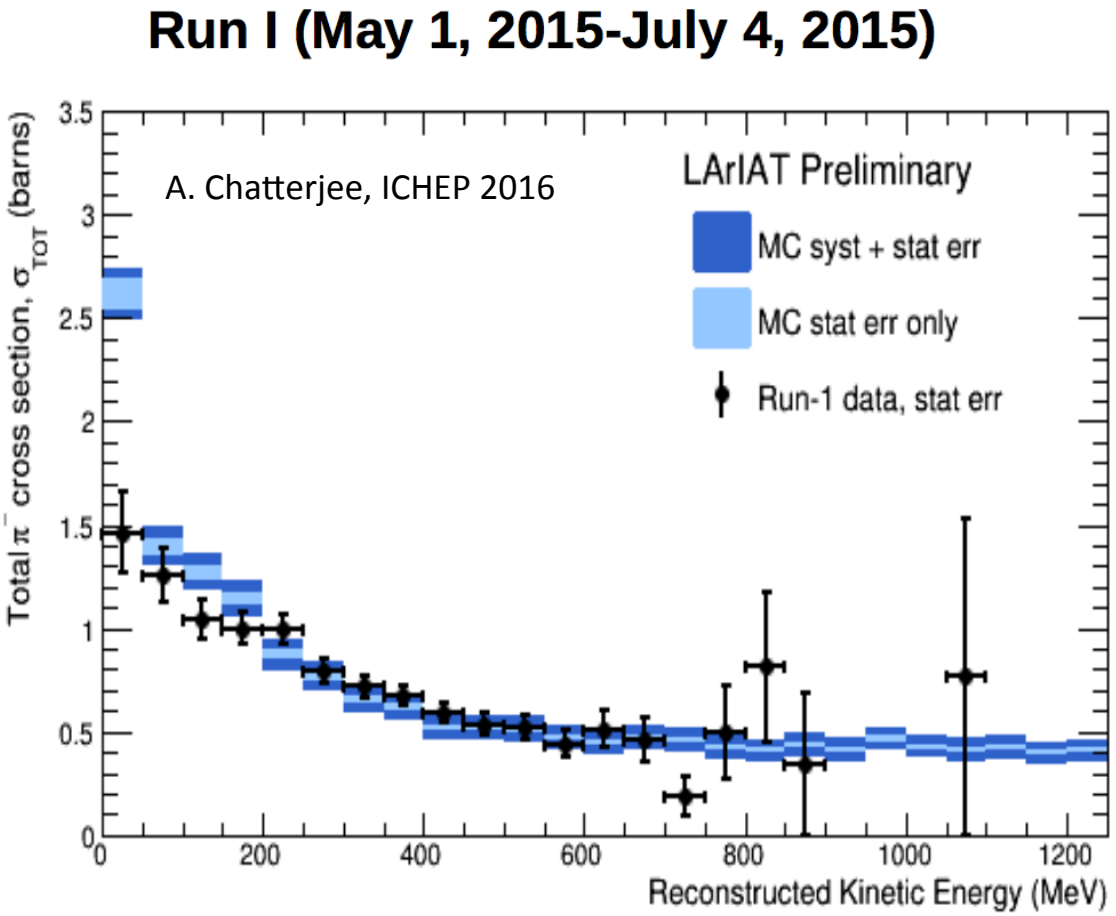
- Papers from ICARUS and MicroBooNE: **demonstrated on data**
  - Some hand-scanning required
- **Resolutions of 10-20%**
  - Depends on momentum, length of contained track





Testbeam measurements

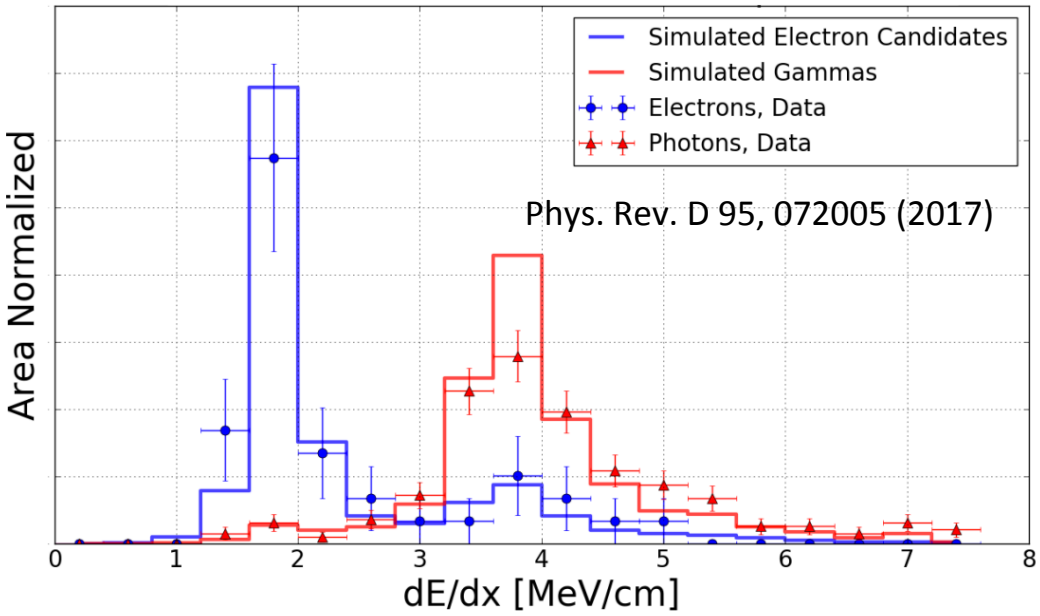
- **LArIAT** – **L**iquid **Ar**gon **I**n **A** **T**estbeam
- Measuring pion-argon, proton-argon cross sections
- **Parallel test** of similar reconstruction methods
- Informs simulation of **re-interactions** in argon
  - Can select pions through identifying interactions
- Also informs **FSI modelling** for generators!



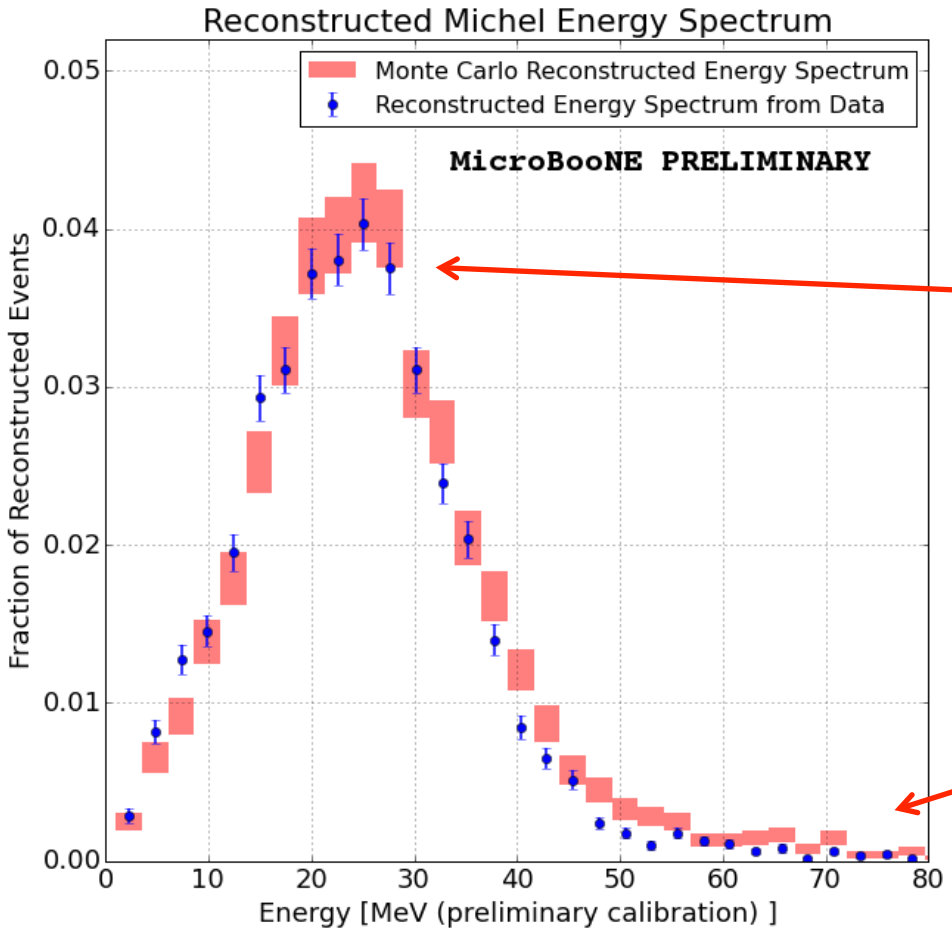
Shower reconstruction

electron/photon separation

- ArgoNeuT show **dE/dx at start of shower** can distinguish e/gamma
- Assumption of the power of this was made in the SBN proposal – it was correct!

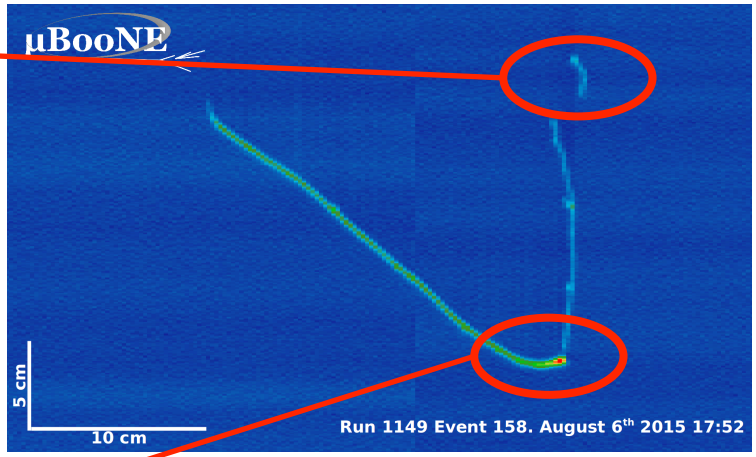


Michel electrons



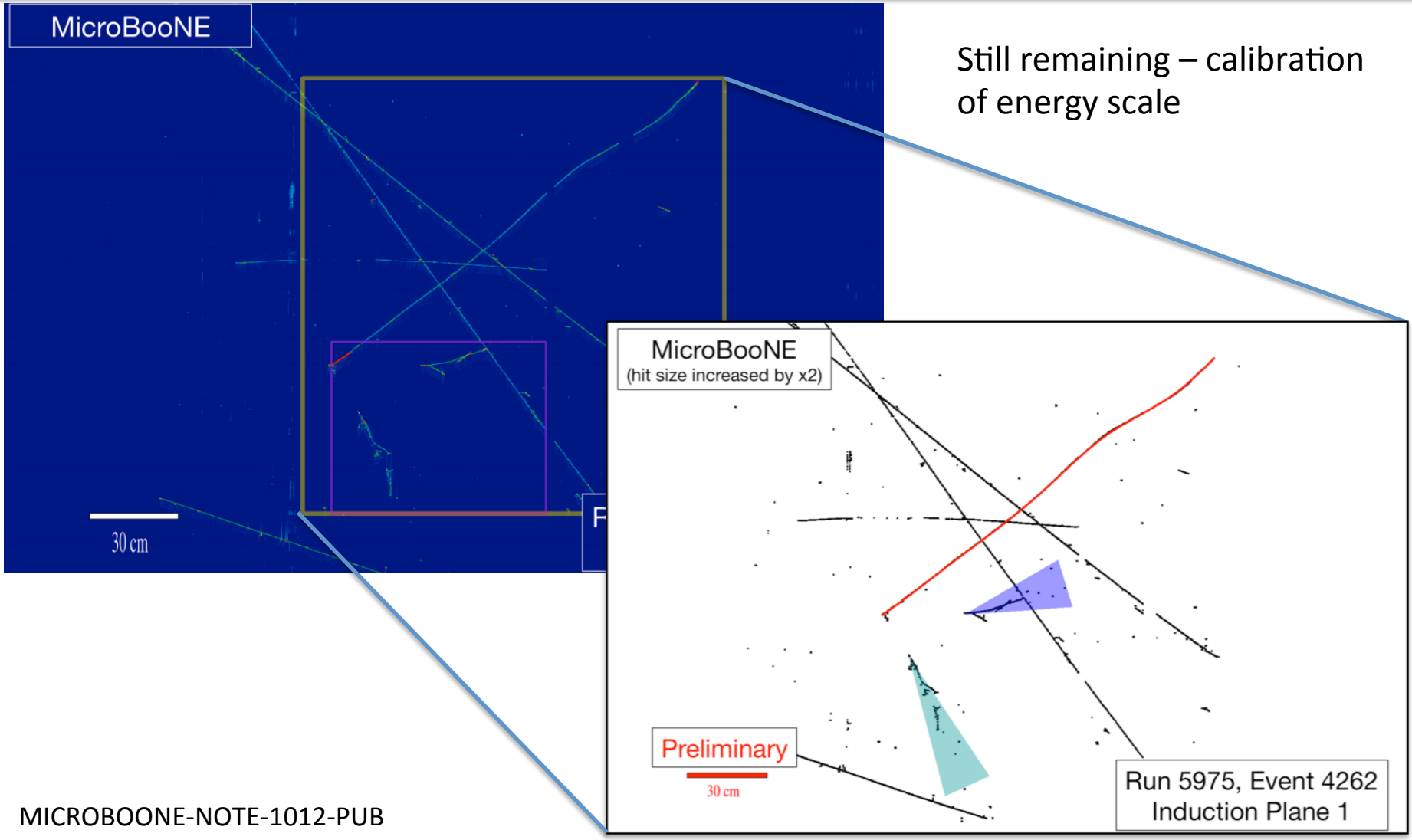
MICROBOONE-NOTE-1008-PUB

Peak shifted down – some charge lost due to radiative losses which is difficult to cluster



High tail – accidentally pull in some charge deposited by the muon Bragg peak

Neutral pions (fully-automated)

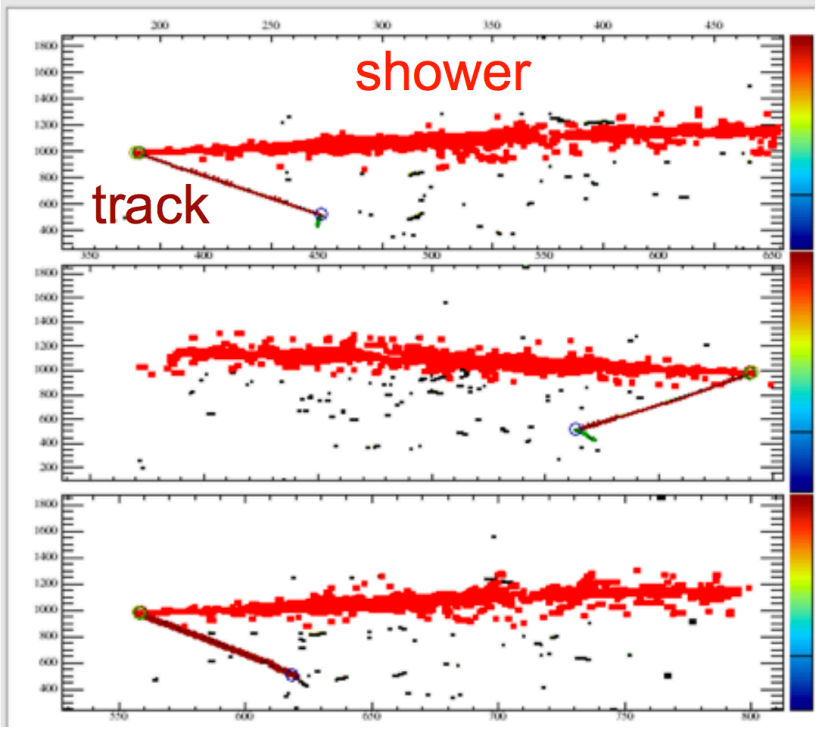


Still remaining – calibration of energy scale

MICROBOONE-NOTE-1012-PUB

Shower clustering

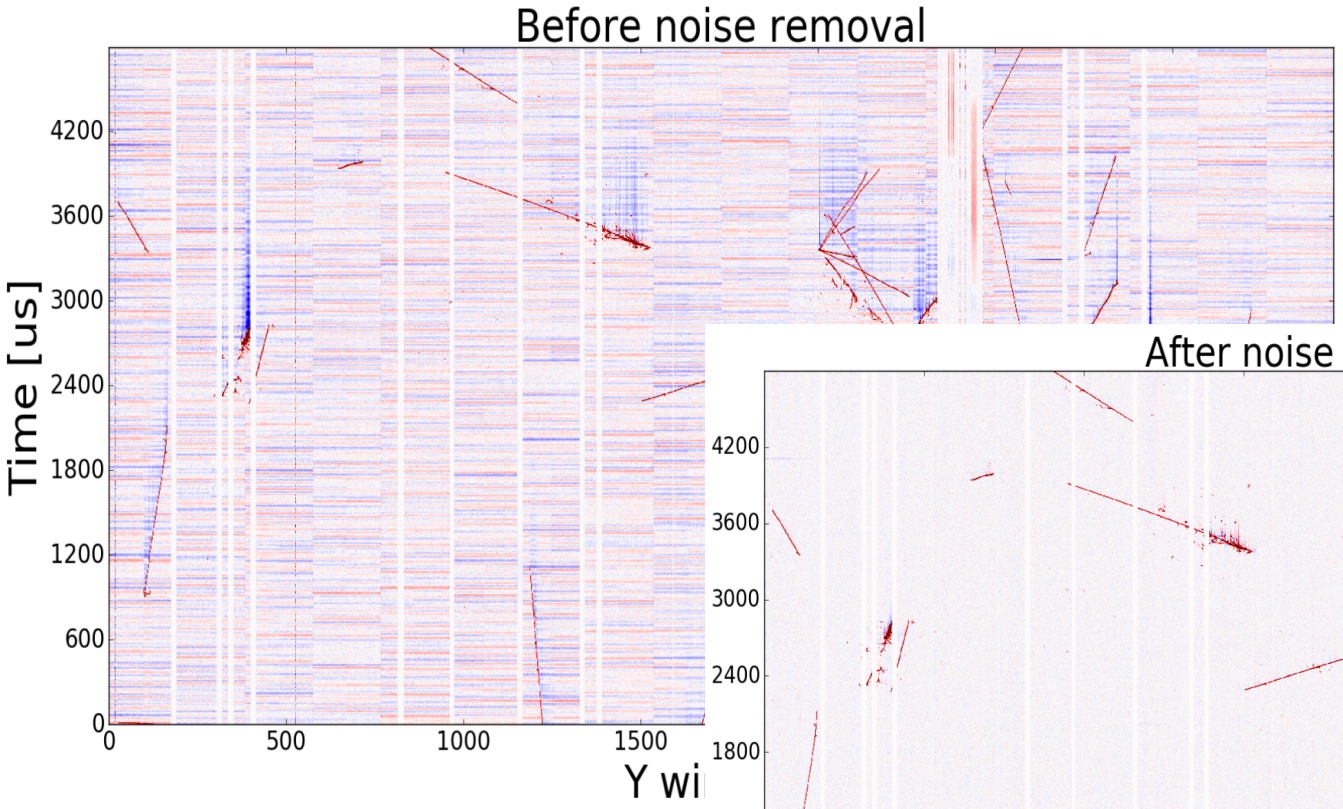
- Blurred clustering – gaussian blurring of hits
- Easier to cluster charge together
- Being studied for DUNE



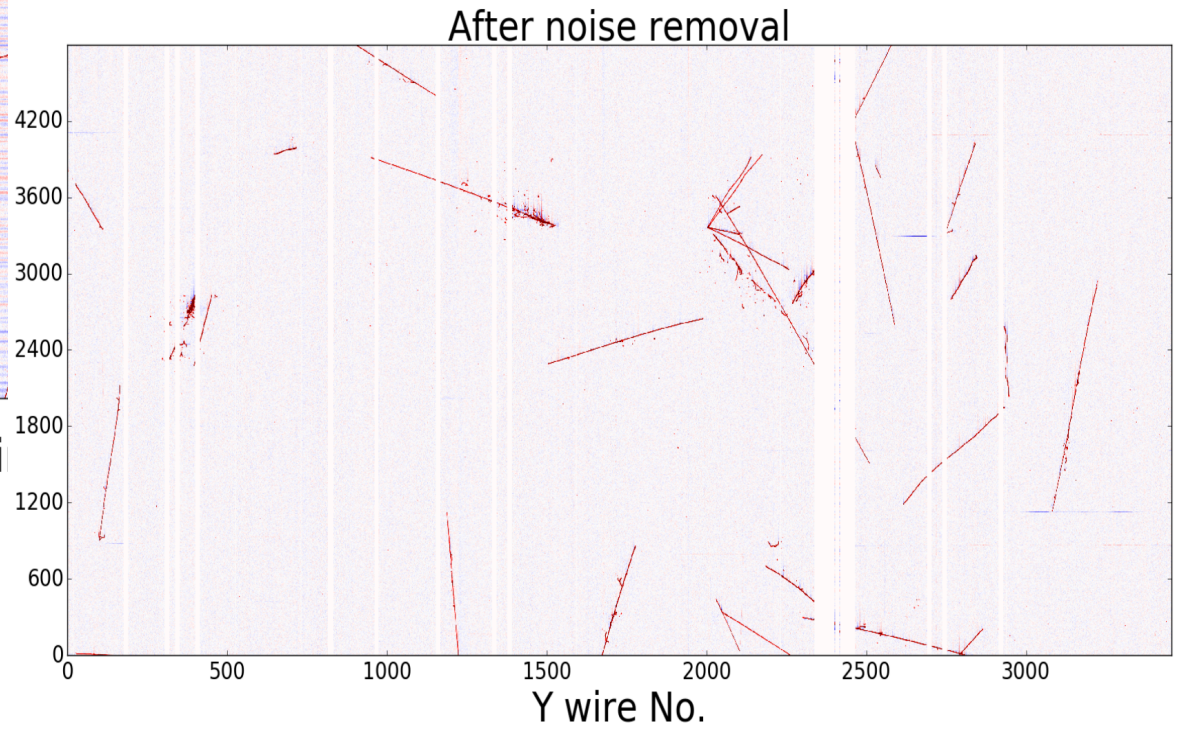
T. Yang, ICHEP 2016

Other detector effects

Noise removal



Often not considered with reconstruction, but in LArTPC noise is important



MicroBooNE preliminary

MICROBOONE-NOTE-1016-PUB

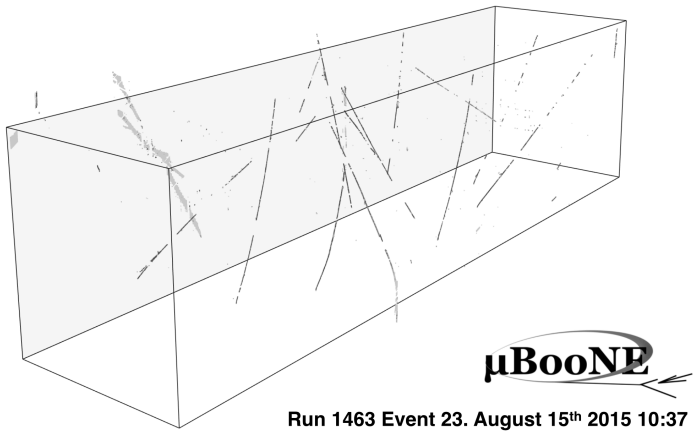
Impact of noise levels

- Noise can largely be **software-filtered**
  - But some impact on signal
- **Highly parallel tracks** can be removed when filtering correlated noise
  - MicroBooNE added **hardware noise filtering** over the summer to prevent this
  - Important to do for SBND and ICARUS too
- Differences in noise levels and noise filtering can impact efficiency matching between detectors
- Hit efficiencies impact **shower energy resolution**

Alternate reconstruction paths

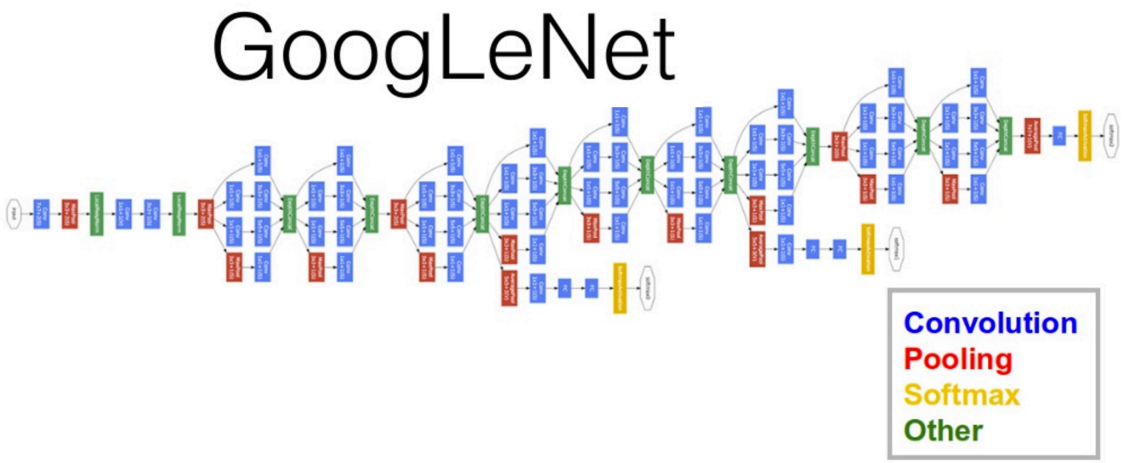
Wire-cell reconstruction

- Direct-to-3D approach
  - Makes 3D space points which are turned into tracks/showers
- Likely to outperform "traditional" reconstruction in high-multiplicity events
- High hopes for showers
- Under study in MicroBooNE



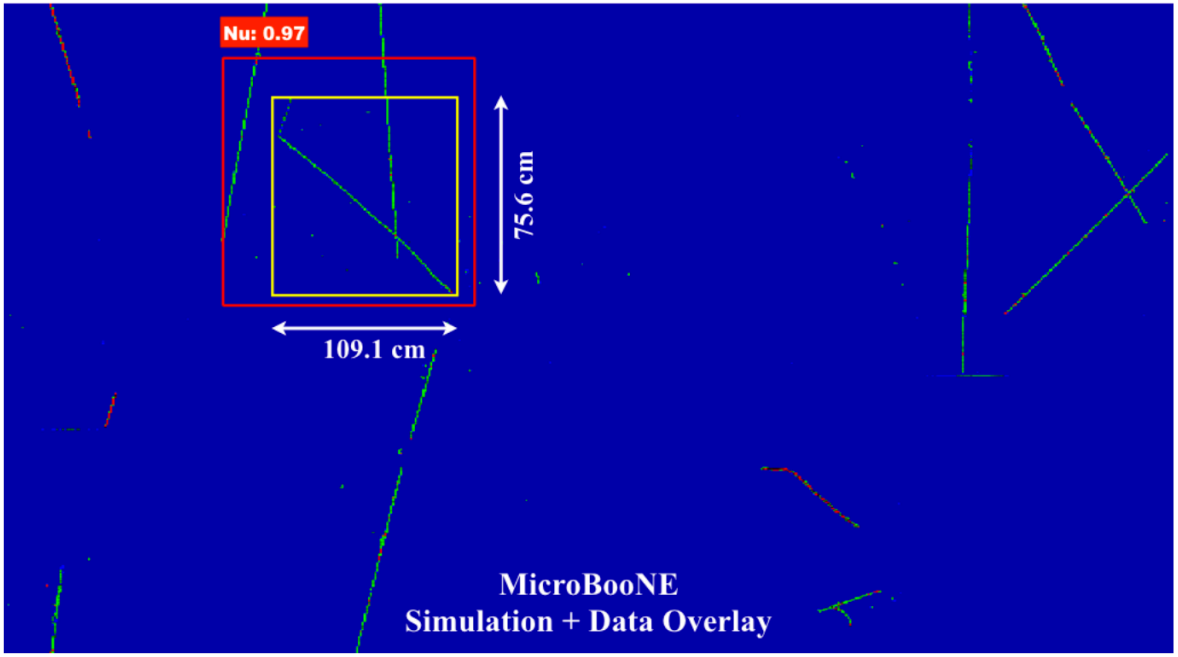
Deep learning techniques

- Another alternative to traditional reconstruction
- High-resolution images + sophisticated image-recognition networks
  - Works well for google searches, voice recognition, etc



Deep Learning proof-of-principle

- MicroBooNE MC (with data cosmics overlaid) shows very good efficiency
- Can do PID for you!

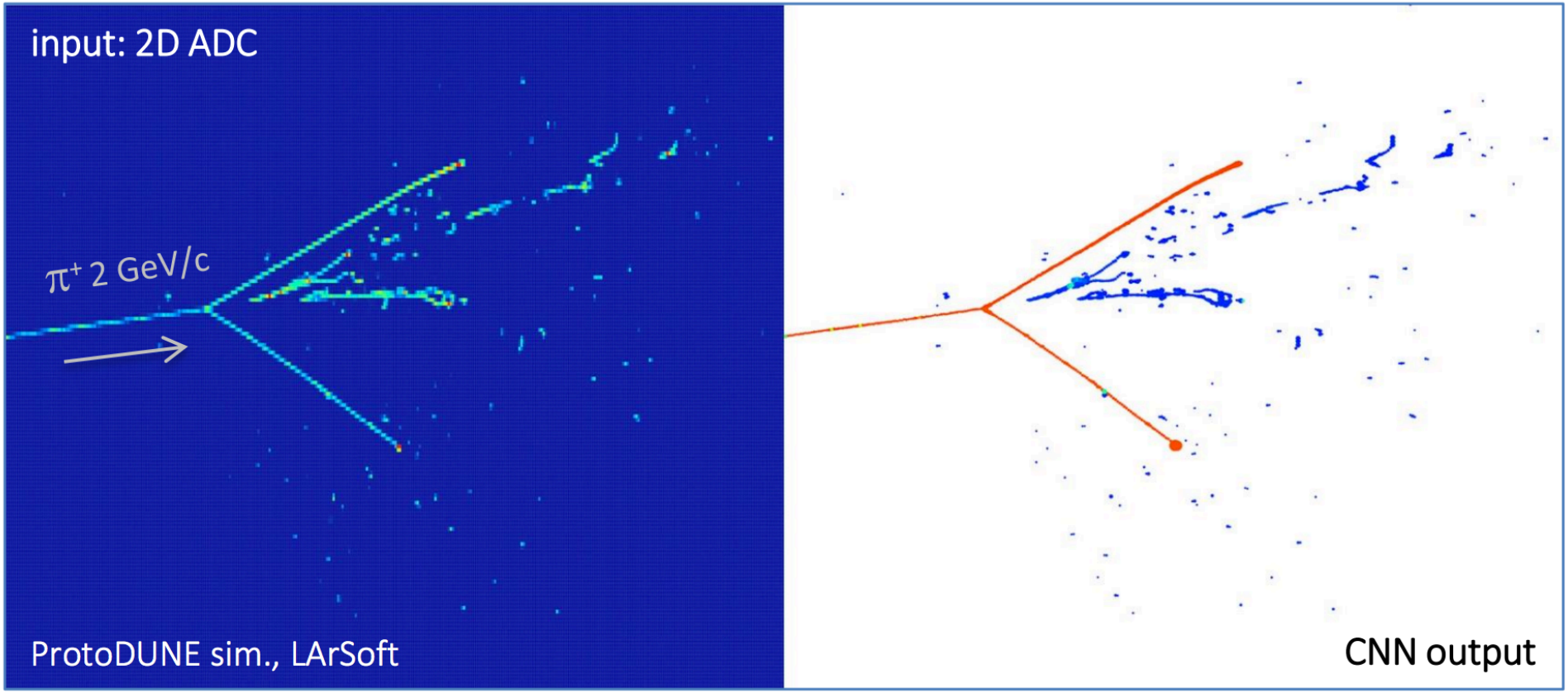


Yellow –true neutrino interaction
Red – identified neutrino ROI

JINST 12:03,P03011 (2017)

Deep learning at DUNE

- ProtoDUNE simulation demonstrating “semantic segmentation”



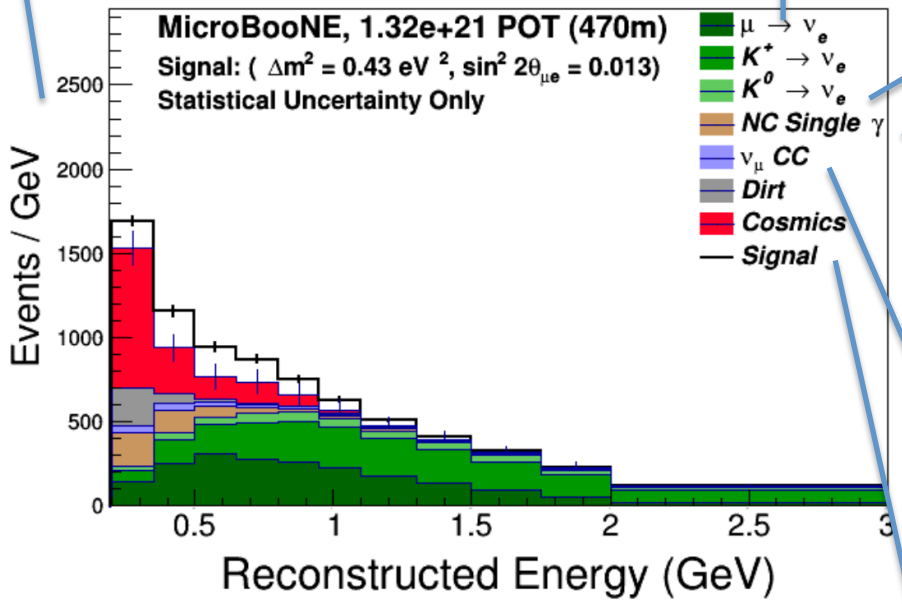
How does this all help?

Signal efficiency

muon constraint – momentum resolution etc

Shower energy resolution, hit efficiency

Electron/photon separation



π^0 removal

Hadronic energy reconstruction

Cosmic tagging efficiency

How does this all help?

Signal efficiency

muon constraint – momentum resolution etc

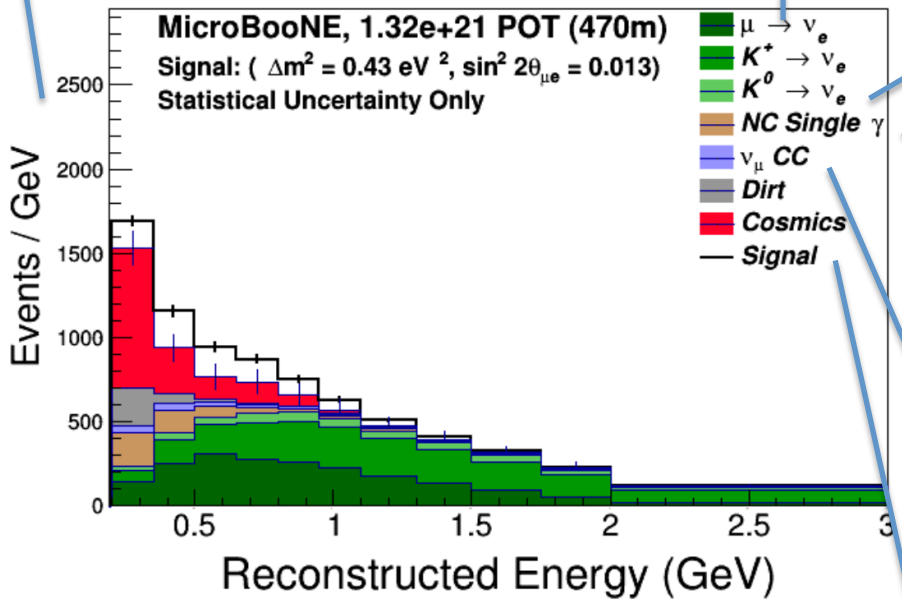
MCS, range, calorimetry

Michel, π^0

Shower energy resolution, hit efficiency

Electron/photon separation

ArgoNeuT



π^0 removal

π^0 in MicroBooNE

Hadronic energy reconstruction

Proton reconstruction in ArgoNeuT

Cosmic tagging efficiency

External tagger

Conclusions

- LArTPCs provide lots of information
- Reconstruction can be hard
- Key techniques being demonstrated
- Alternative reconstruction methods under investigation
  - Wire-cell and deep learning
- Detector systematics expected to be under control for SBN oscillation searches
- Looking forward to having two more detectors to play with!

Thank you

SBN detector (un)correlations

- Different sizes and shapes
  - Contained track efficiency/resolution
  - Space charge distortions
- Readout electronics
  - Noise differences
  - Calorimetry resolution
- Light collection/cosmic tagging systems
  - Timing precision
  - Cosmic rejection efficiency

These are now under study – cannot be fully understood until all three detectors have data!

Impact on SBN oscillations

- Impact of uncorrelated detector effects is **predicted to be small**
- Testing of previous assumptions in data
- Assumptions seem to hold
  - Noise levels under control
  - MCS verified to work in data
  - e/gamma separation demonstrated in ArgoNeuT
  - Fully automated reconstruction and selection demonstrated in MicroBooNE – efficiencies good but needs some work

Pion interactions

- Taken from talk – A. Chatterjee, ICHEP, 2016