MicroBooNE and the future SBN program

Roxanne Guenette for the MicroBooNE and SBN collaborations

Short-baseline anomalies

- Puzzling collection of short-baseline anomalies

  ➡ E. Huang's talk on new MiniBooNE results

  ➡ M. Maltoni's talk on global picture of sterile neutrinos

- The search for new physics is the holy-grail of the particle physics community

- The DUNE long-baseline program will strongly rely on the resolution of these anomalies (extra oscillations can lead to mis-interpretation of the flagship δ_{CP} measurement)

References:
S. K. Agarwalla, S. S. Chatterjee, A. Dasgupta and A. Palazzo, JHEP 1602, 111 (2016)
D.Dutta, R. Gandhi, B. Kayser, M. Masud and S. Prakash, JHEP 11, 122 (2016)
B. Kayser, proceedings C16-03-12, 2016

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S. K. Agarwalla, S. S. Chatterjee, A. Dasgupta and A. Palazzo, JHEP 1602, 111 (2016)
D.Dutta, R. Gandhi, B. Kayser, M. Masud and S. Prakash, JHEP 11, 122 (2016)
B. Kayser, proceedings C16-03-12, 2016

**Need to resolve the anomalies ➡ Short-Baseline Neutrino program**

MicroBooNE and the SBN program

- Staged approach: MicroBooNE (phase 1) and the SBN program (phase 2) is a powerful way to address the short-baseline anomalies

- Progress on ICARUS and SBND construction and installation

- MicroBooNE and the search for the low-energy excess:

  1. Strong understanding of the detector and highly developed event reconstruction
     New results and reconstruction techniques (with data), paving the way to future LAr detectors

  2. Neutrino interaction measurements
     New physics results presented here

  3. Towards low-energy excess: solid validation of ν_e and photon analyses
     First results on ν_e and γ selections

> **Many new results from MicroBooNE**
> **Only few highlights presented here**
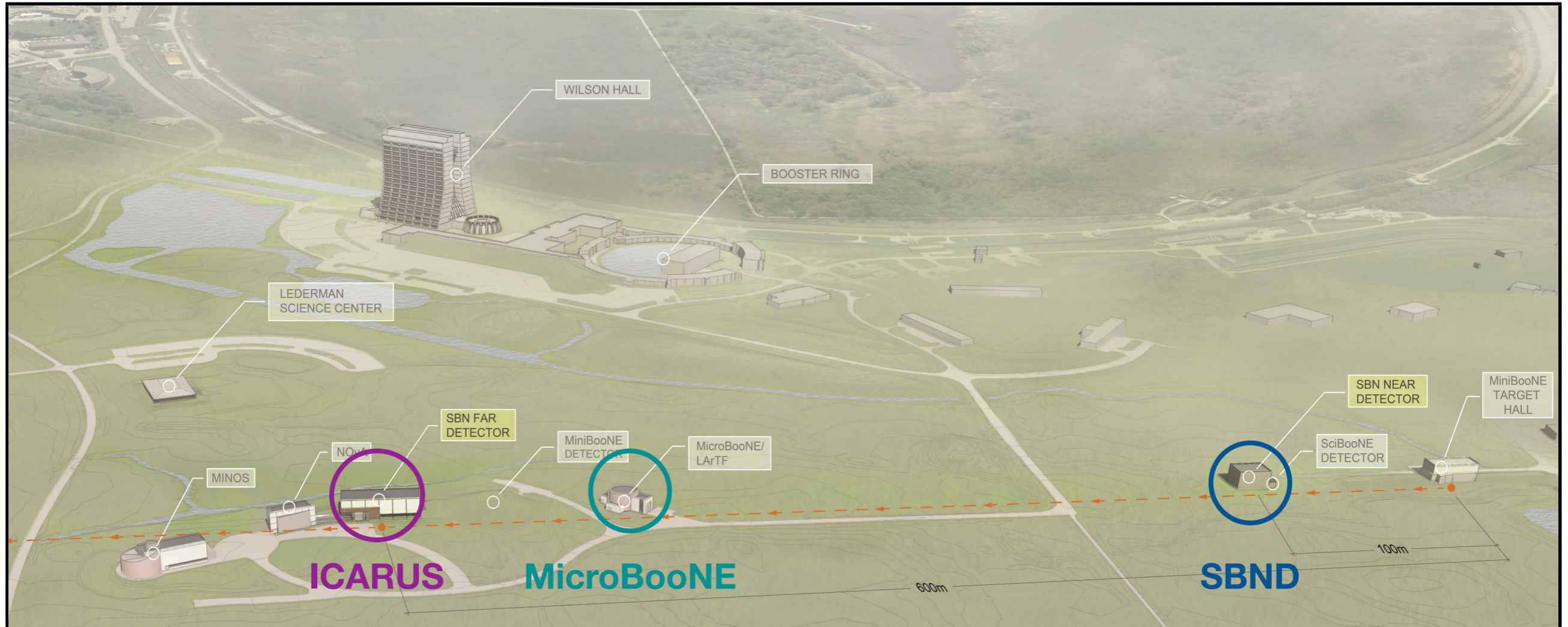> **See all the new Public Notes (http://microboone.fnal.gov/public-notes/)**

The Short-Baseline Neutrino Program
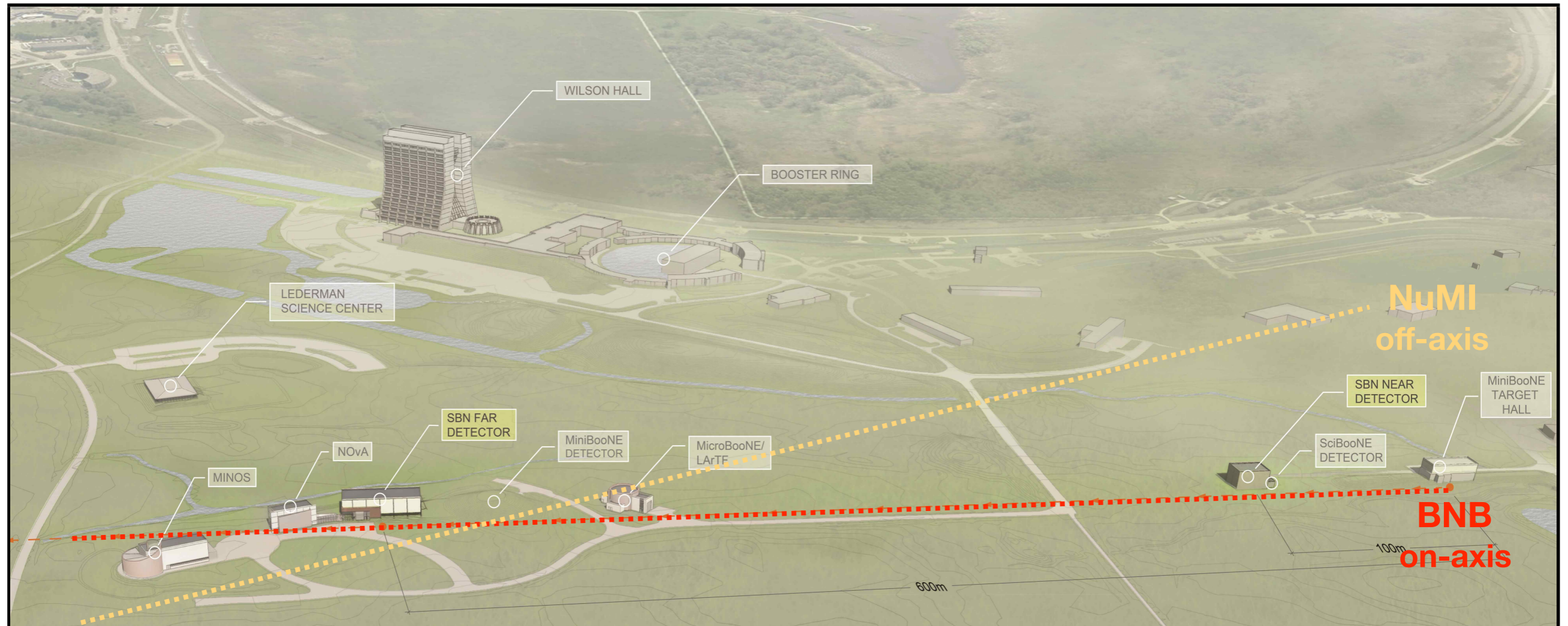
The Short-Baseline Neutrino Program
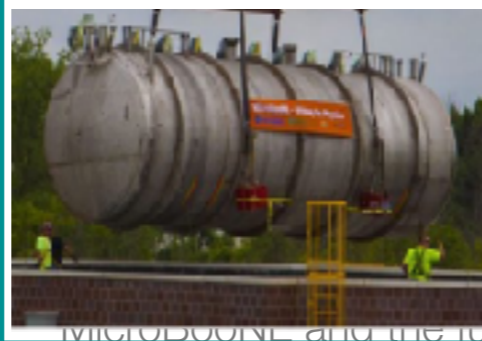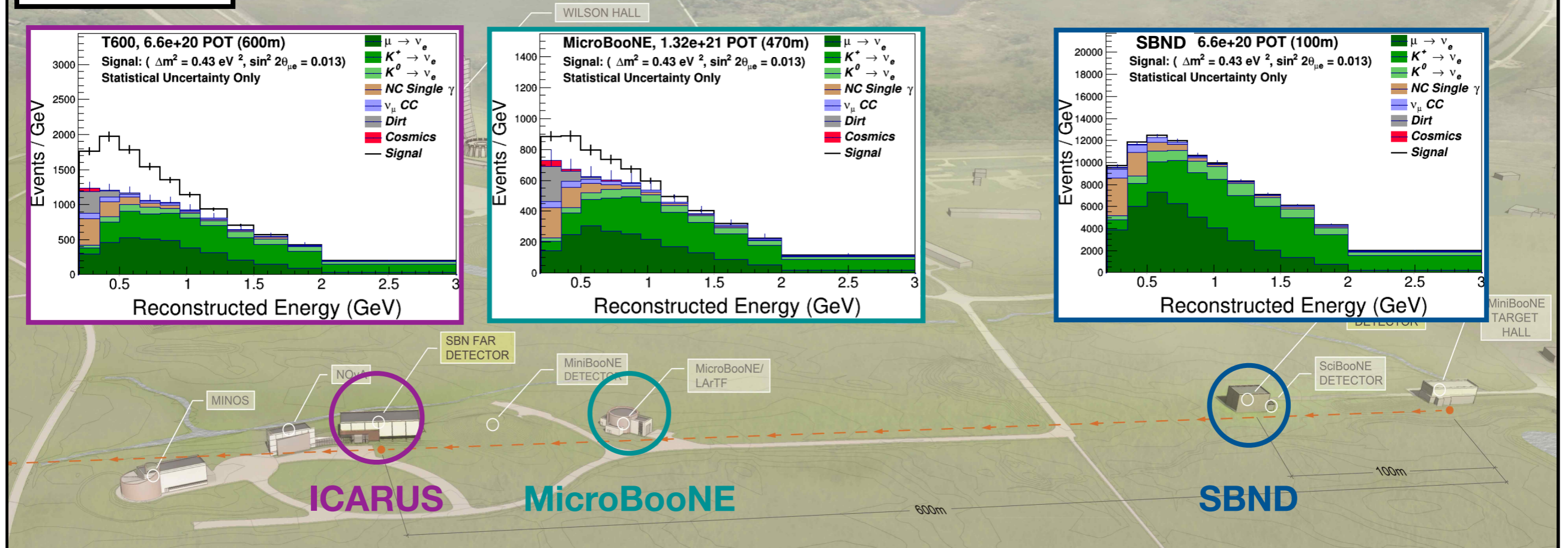
A three liquid argon detector experiment:
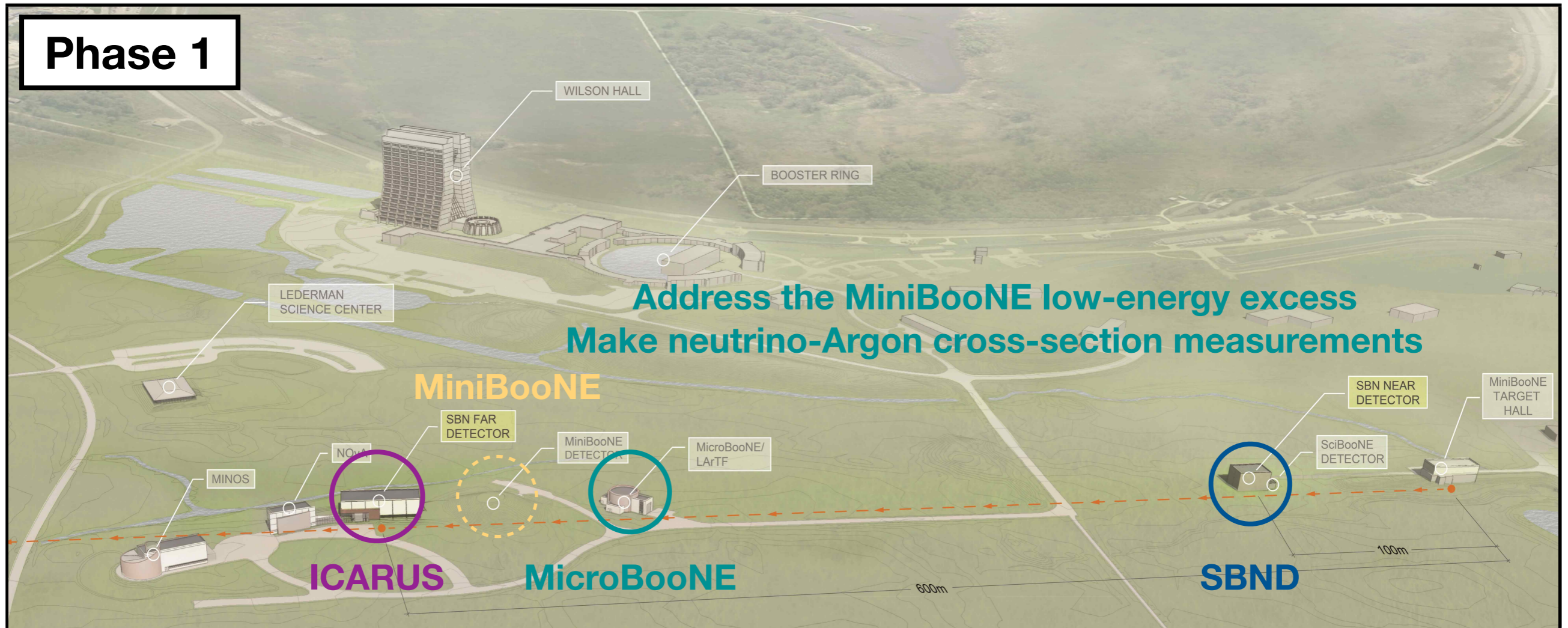
Roxanne Guenette   MicroBooNE and the future SBN program

The Short-Baseline Neutrino Program

A three liquid argon detector experiment:

Phase 1

WILSON HALL

BOOSTER RING

LEDERMAN SCIENCE CENTER

Address the MiniBooNE low-energy excess
Make neutrino-Argon cross-section measurements

MiniBooNE

SBN NEAR DETECTOR

MiniBooNE TARGET HALL

SBN FAR DETECTOR

MiniBooNE DETECTOR

MicroBooNE/ LArTF

SciBooNE DETECTOR

NOvA

MINOS

ICARUS   **MicroBooNE**   **SBND**

600m

100m

First detector
L = 470 m
M = 85 ton

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SBN Program

Phase 2

Example signal for a sterile neutrino (see SBN proposal for details)

L = 600 m
M = 476 ton

Roxanne Guenette

The Short-Baseline Neutrino Program

A three liquid argon detector experiment:
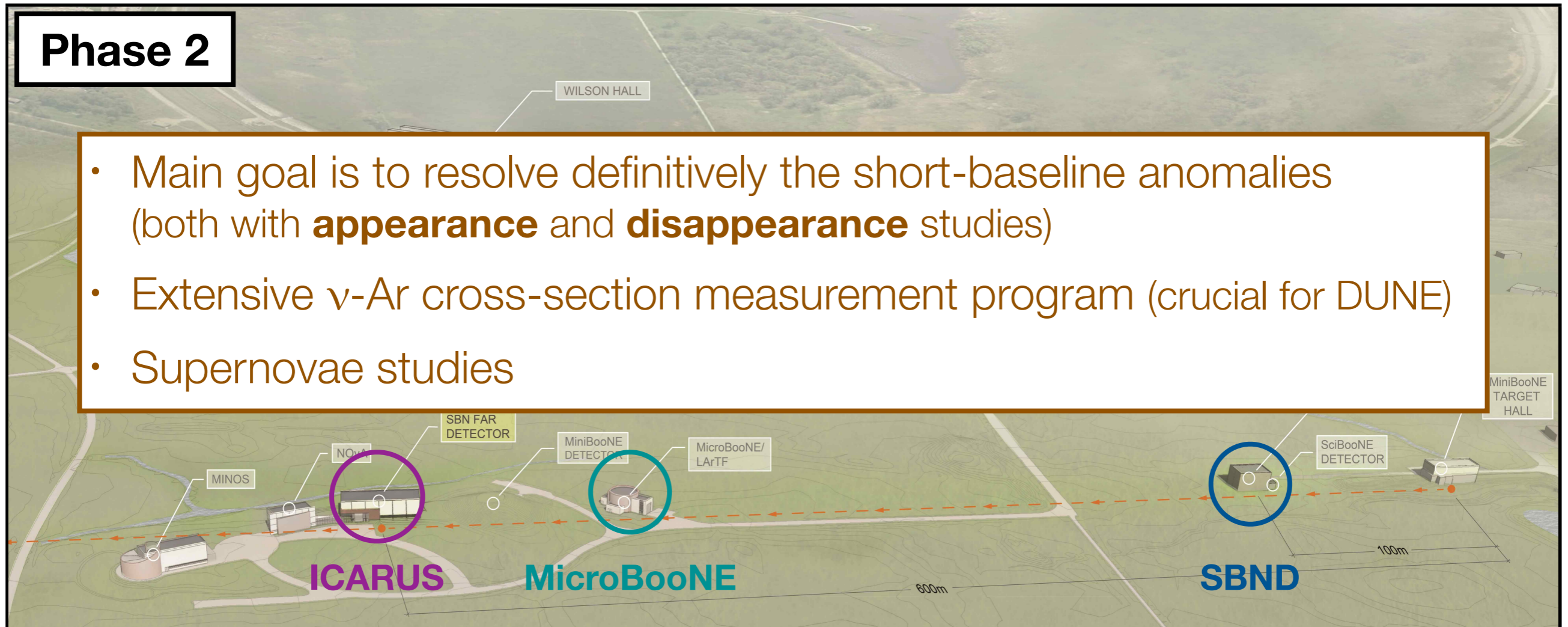
Phase 2

- Main goal is to resolve definitively the short-baseline anomalies (both with **appearance** and **disappearance** studies)
- Extensive ν-Ar cross-section measurement program (crucial for DUNE)
- Supernovae studies

ICARUS   **MicroBooNE**   **SBND**
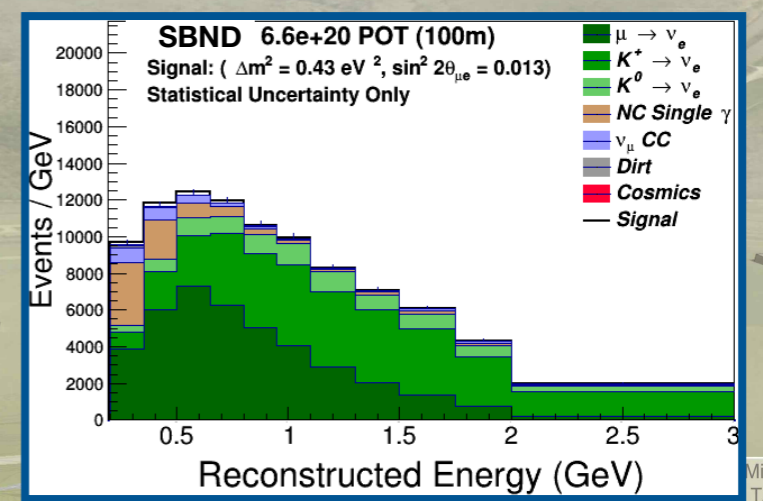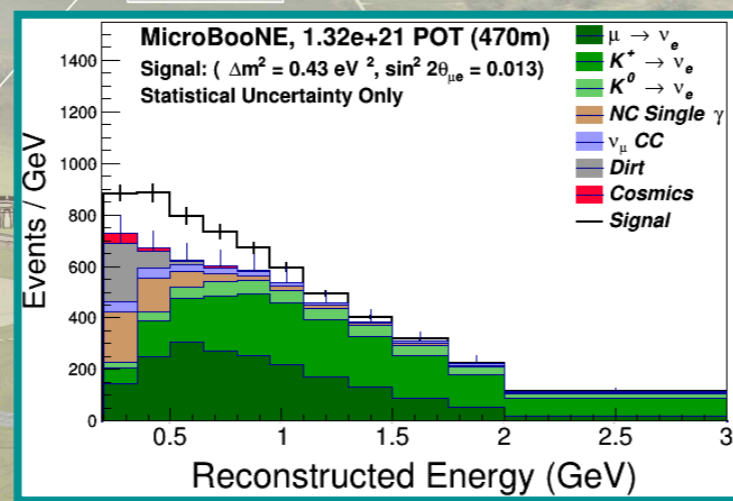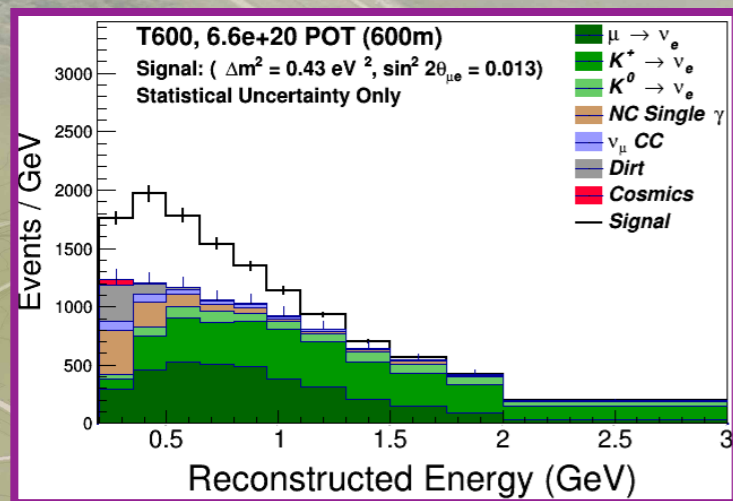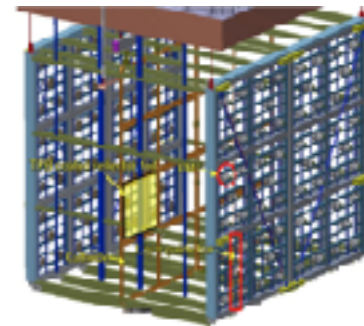
Far detector
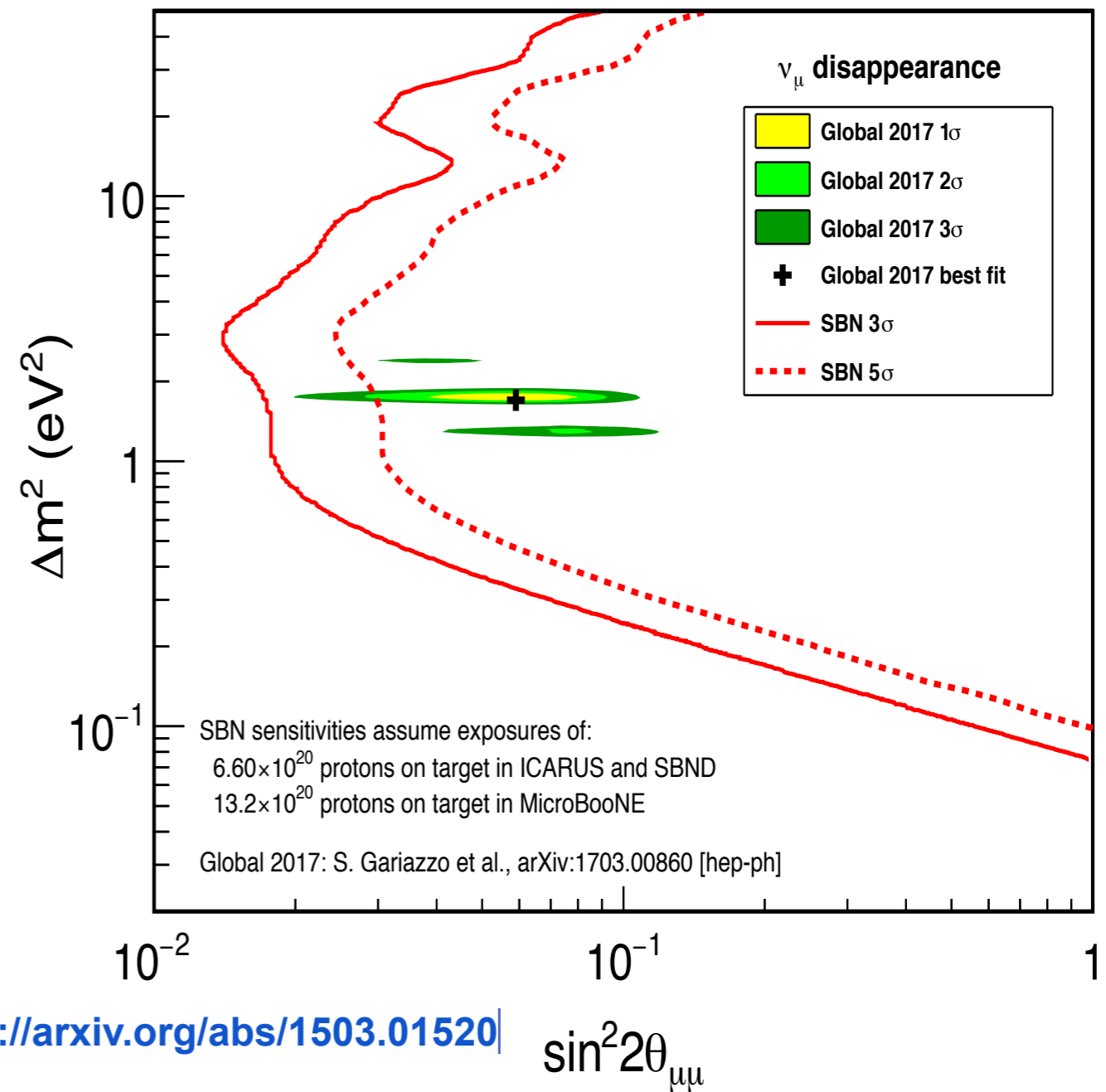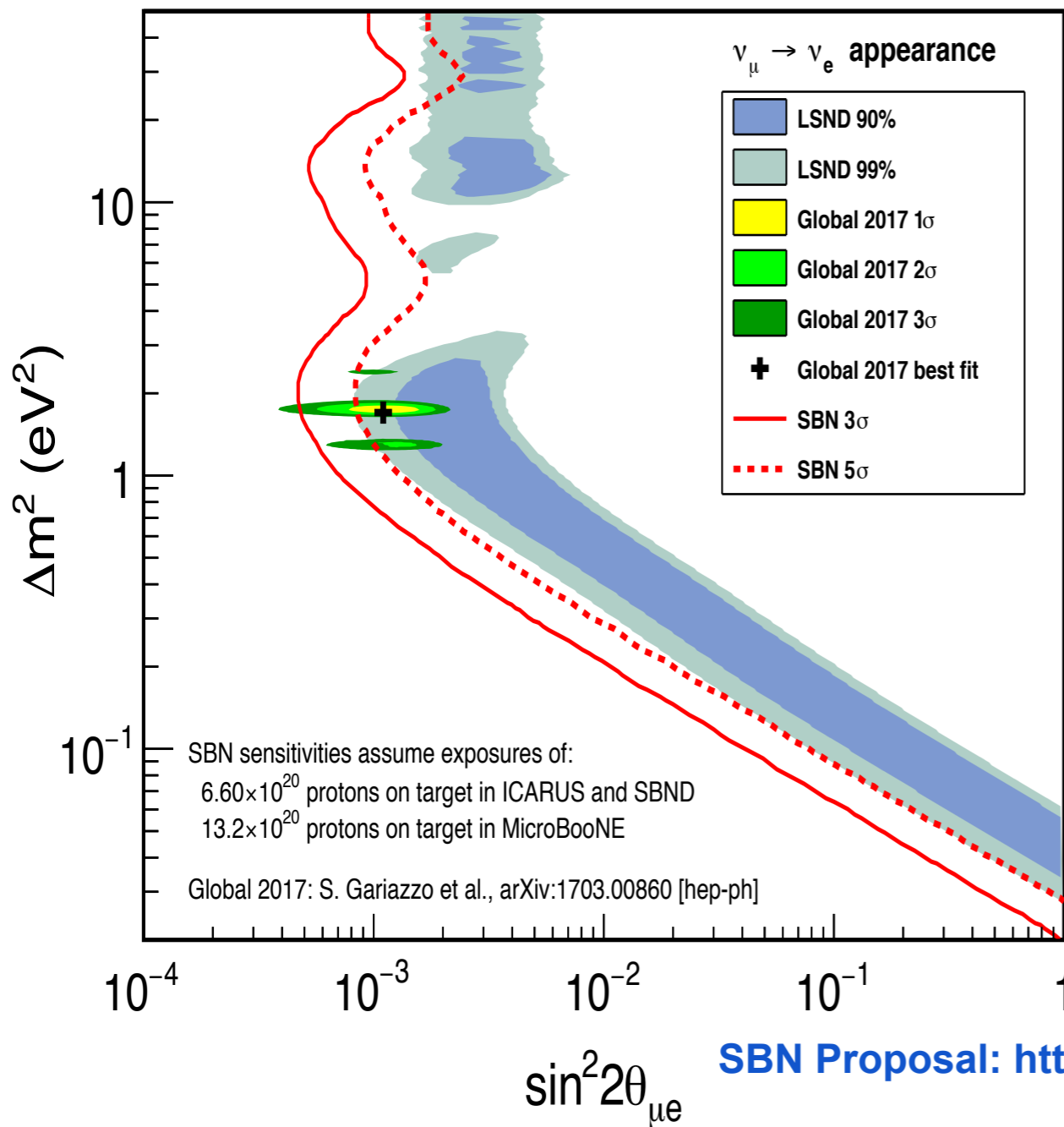L = 600 m
M = 476 ton

First detector
L = 470 m
M = 85 ton

Near detector
L = 110 m
M = 112 ton

The Short-Baseline Neutrino Program

In the 3+1 sterile neutrino analysis context…

SBN Proposal: https://arxiv.org/abs/1503.01520

Definitive answer to the short-baseline anomalies in the next ~5 years

SBN (phase 2) current status: ICARUS and SBND

- Detector **installation** underway
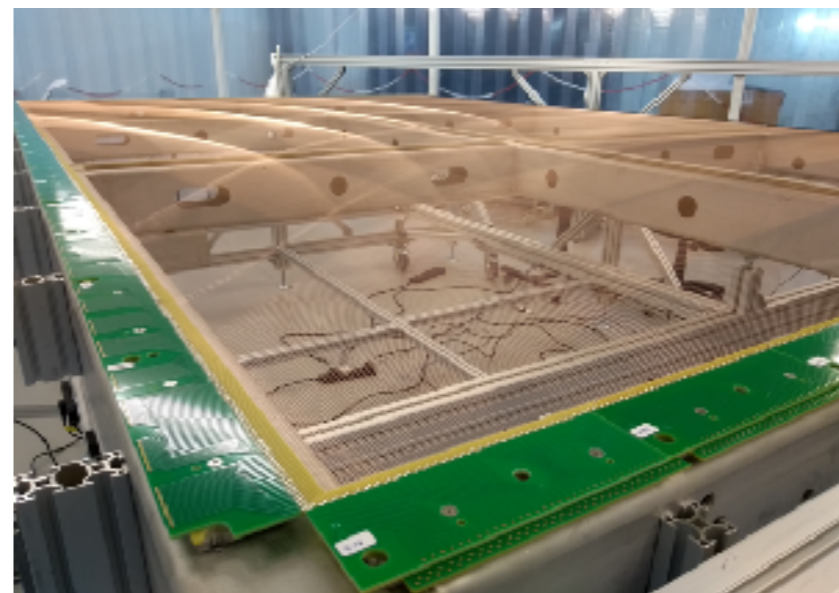- Planned data taking **2019**

- TPCs delivered at FNAL July 2017
- Warm vessel completed
- Cold shield under installation

- Detector **construction** underway
- Planned data taking **2020**

- CRT panels installed for preliminary beam data

- *Anode Plane Assemblies* and other components under construction (US & UK)
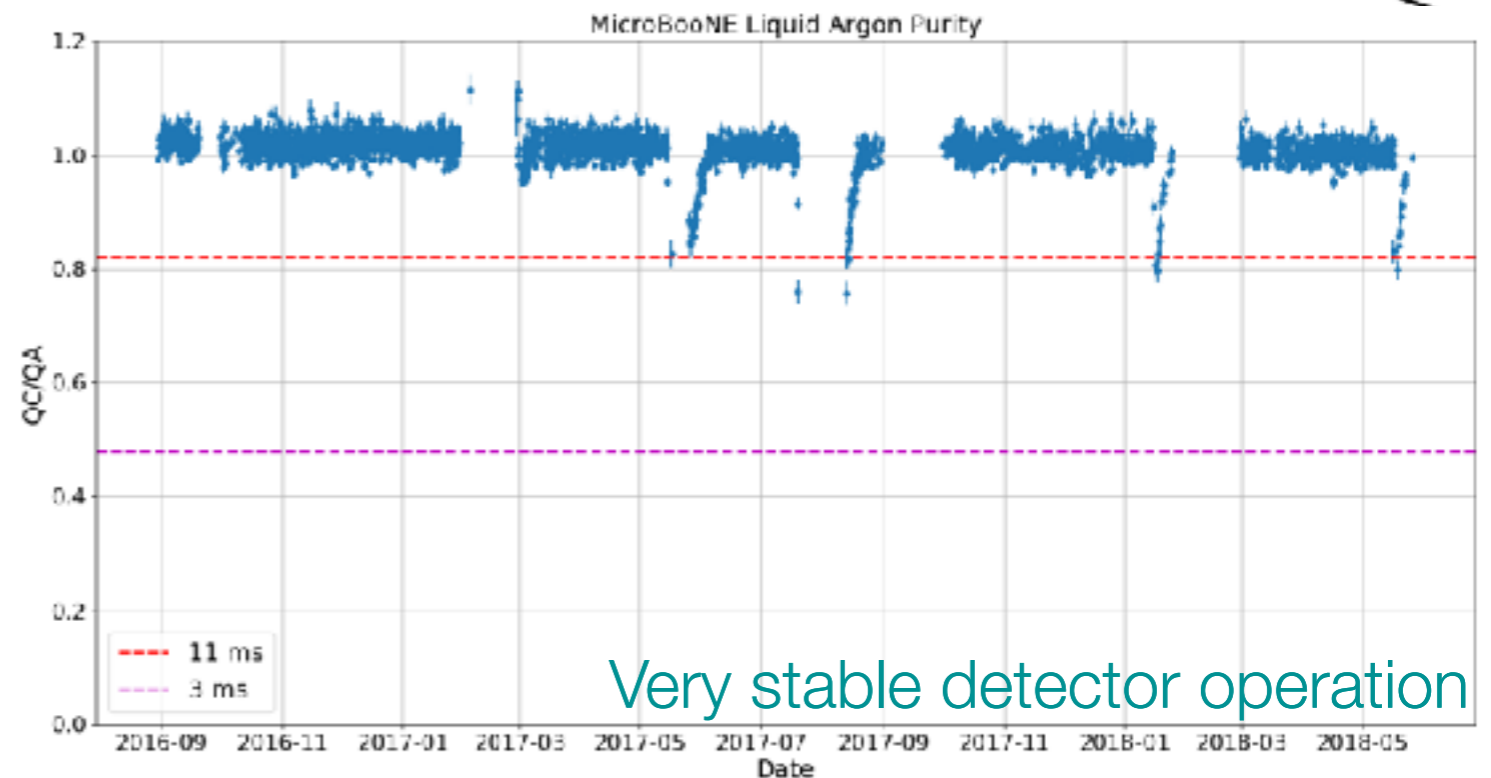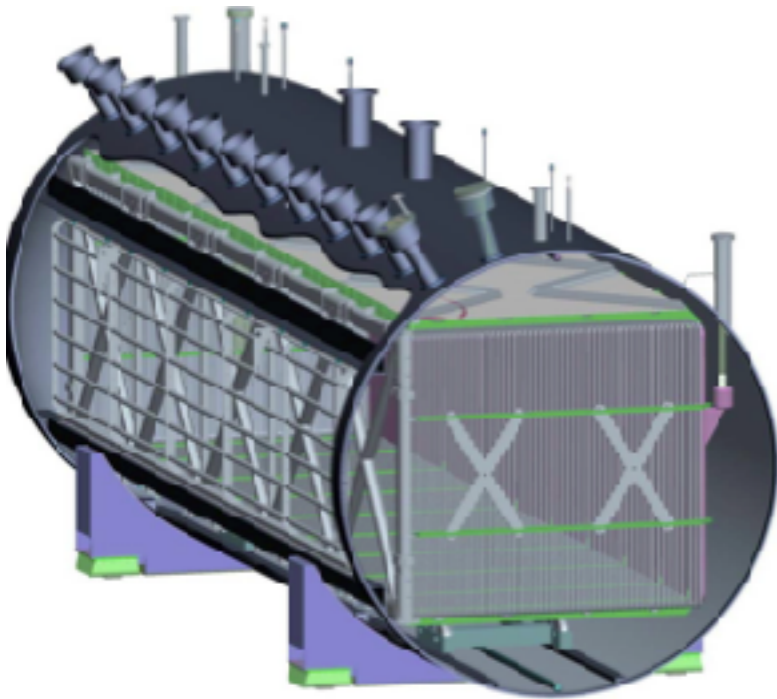
Posters:

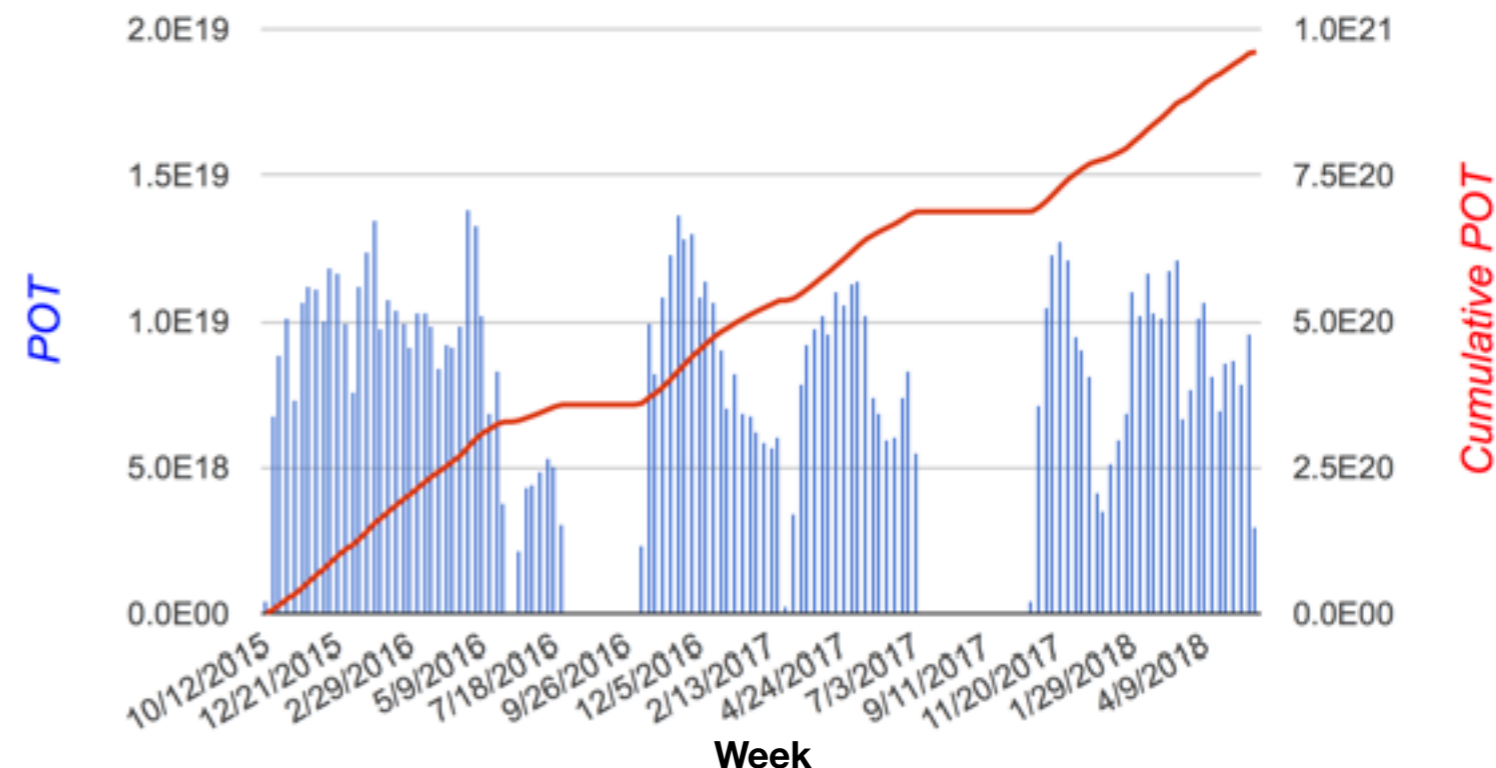C. Adams, Deep learning in LArTPC with SBND | R. Jones, A preliminary ν_μCC-0π event selection in SBND | J. Tena Vidal, ν_μCC-$1\pi^\pm$ event selection in SBND

Roxanne Guenette   MicroBooNE and the future SBN program

MicroBooNE

Very stable detector operation

- 85 ton LArTPC
- 3 wires planes
- 32 PMTs
- Neutrino data taking since October 2015

Publication: *"Design and Construction of the MicroBooNE Detector"*, JINST 12, P02017 (2017)

Public notes: *"A Measurement of the Attenuation of Drifting Electrons in the MicroBooNE LArTPC"*, MICROBOONE-NOTE-1026-PUB, (2017)

"Establishing a Pure Sample of Side-Piercing Through-Going Cosmic-Ray Muons for LArTPC Calibration in MicroBooNE", MICROBOONE-NOTE-1028-PUB, (2017)

"Study of Space Charge Effects in MicroBooNE", MICROBOONE-NOTE-1018-PUB, (2016)

And more...

Smooth and steady data taking

Efficient data acquisition

MicroBooNE

μBooNE

MicroBooNE Liquid Argon Purity

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- 85 ton LArTPC
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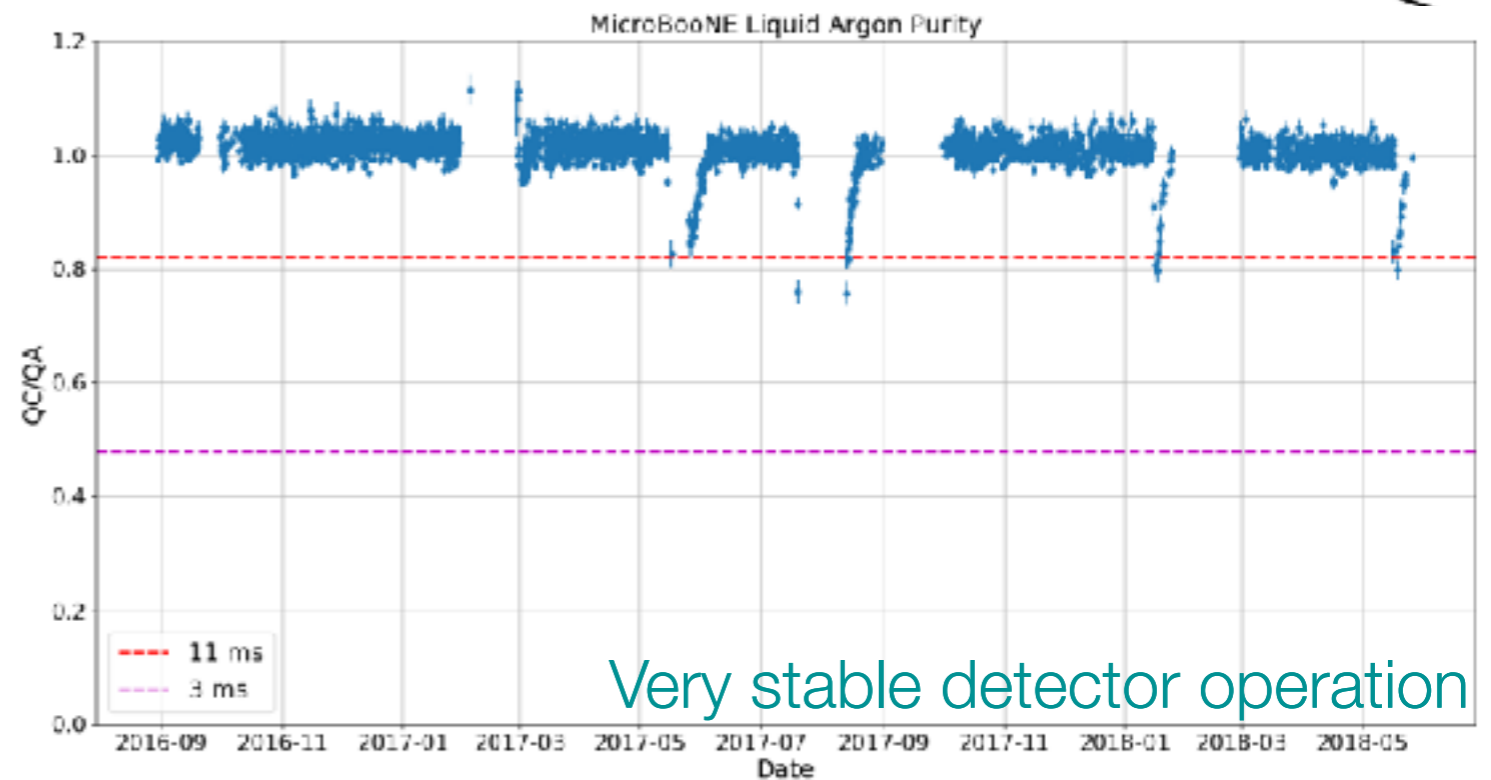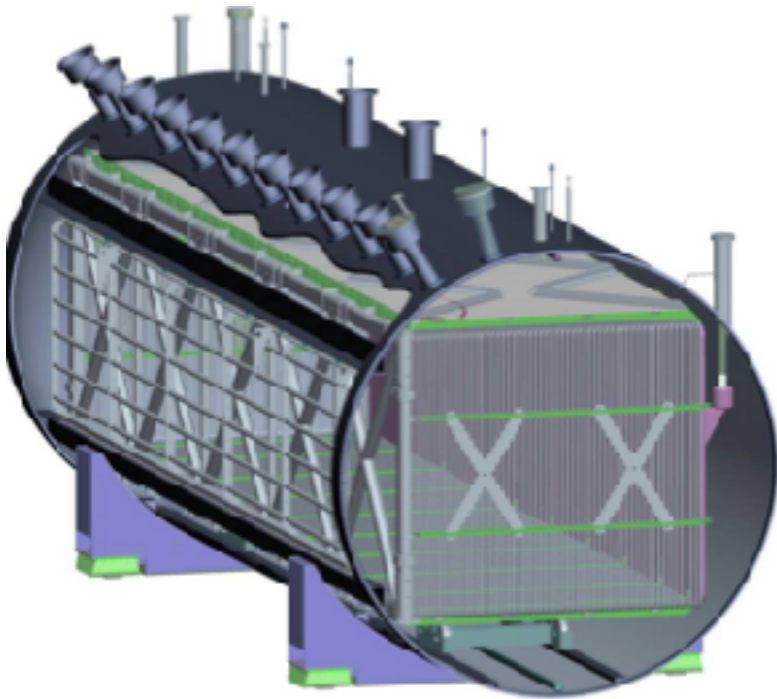
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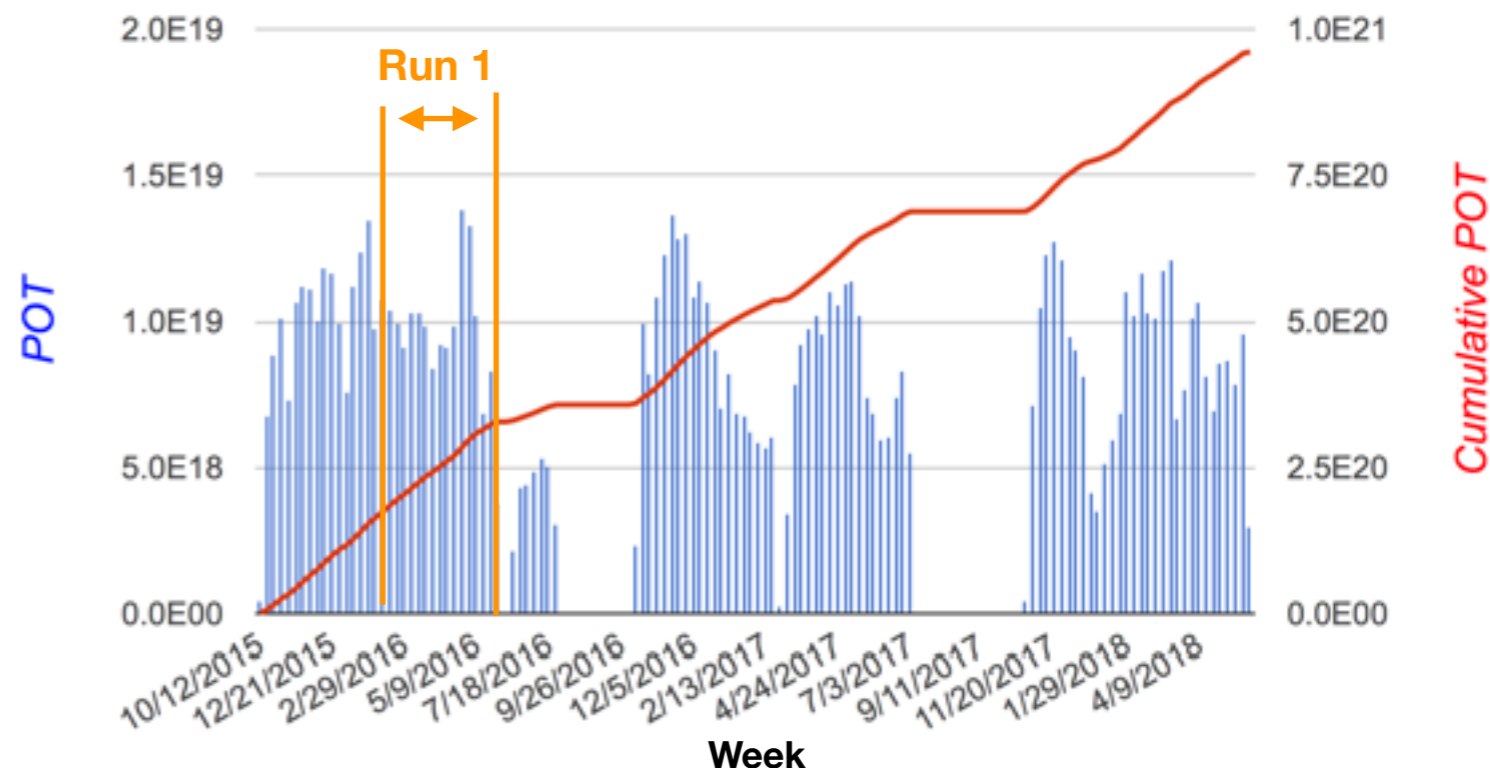*"Study of Space Charge Effects in MicroBooNE"*, MICROBOONE-NOTE-1018-PUB, (2016)

And more...

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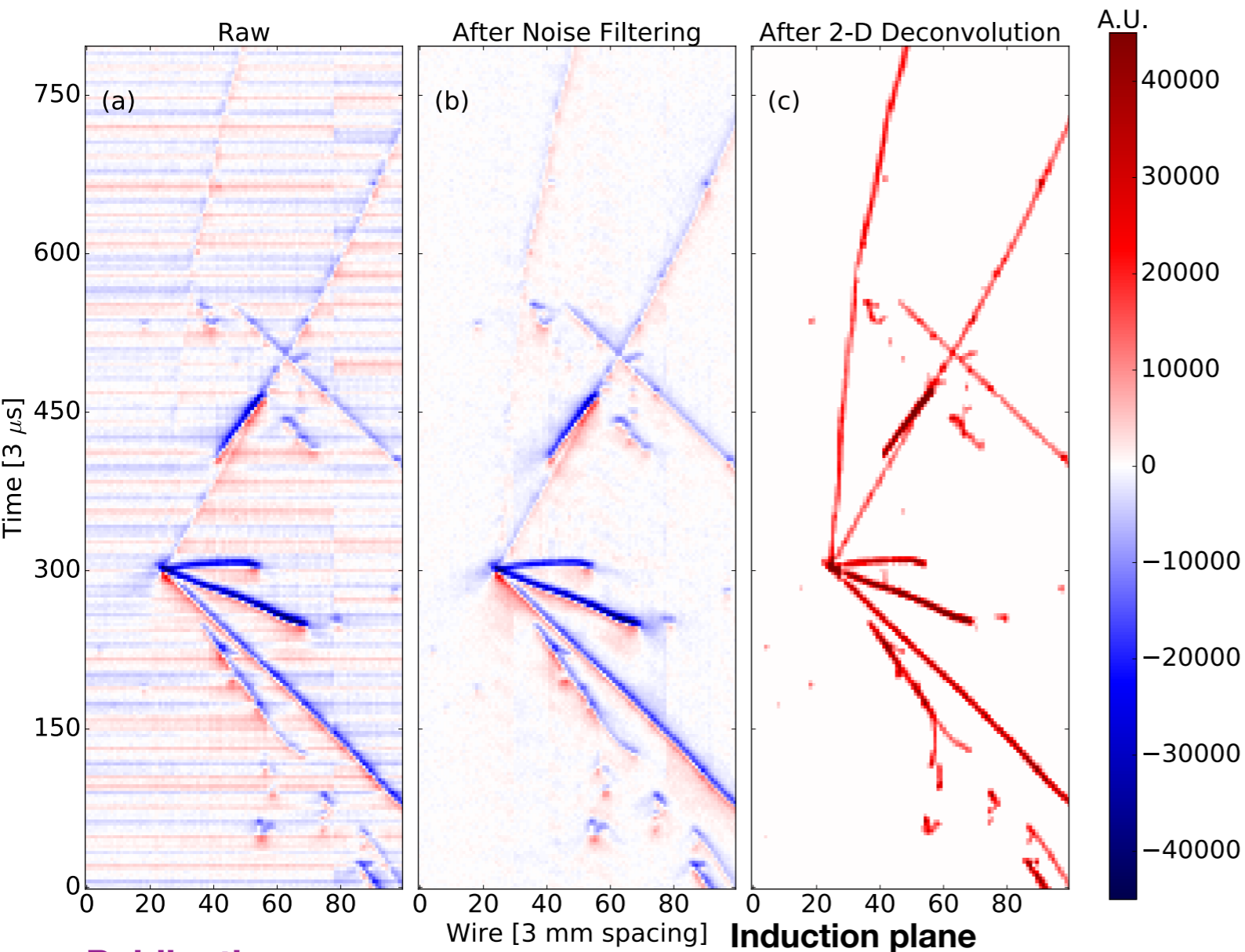
Efficient data acquisition

Understanding a LArTPC

Detailed characterization of the detector is key to our Physics and to our R&D mission for future detectors

Roxanne Guenette   MicroBooNE and the future SBN program

Understanding a LArTPC

Detailed characterization of the detector is key to our Physics and to our R&D mission for future detectors

- Powerful filtering techniques can address many sources of noise

- Excellent characterization of multiple wire signal response (2d-deconvolution)

- Robust signal processing allows calorimetry in all three planes (**enabling induction planes**)

Publications

1. *"Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE"*, arXiv:1804.02583, submitted to JINST

2. *"Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation"*, arXiv:1802.08709, accepted by JINST

3. *"Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC"*, arXiv:1705.07341, JINST 12, P08003 (2017)

4. *"Detector Calibration using through going and stopping muons in the MicroBooNE LArTPC"*, MICROBOONE-NOTE-1048-PUB, 2018

Event reconstruction techniques

- **Different reconstruction techniques have been developed**
- **Reached high level of sophistication**
- **Essential for SBN and DUNE** (shared software between all experiments!)

Pandora

simulated ν_μ event
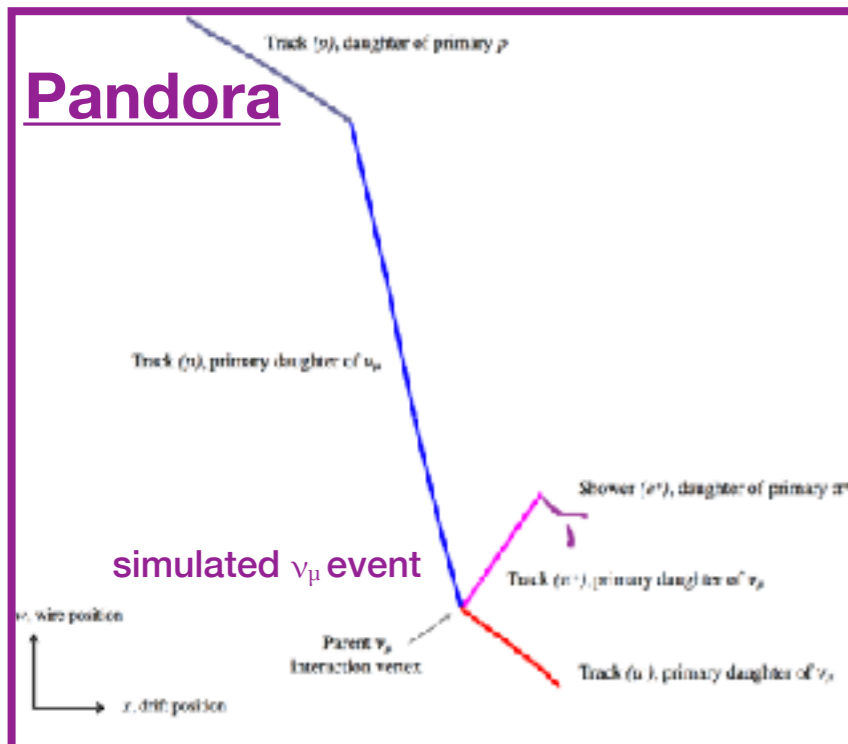
"The Pandora Multi-Algorithm Approach to Automated Pattern Recognition of Cosmic Ray Muon and Neutrino Events in the MicroBooNE Detector", Eur. Phys. J. C78, 1, 82 (2018)*"*

Machine Learning
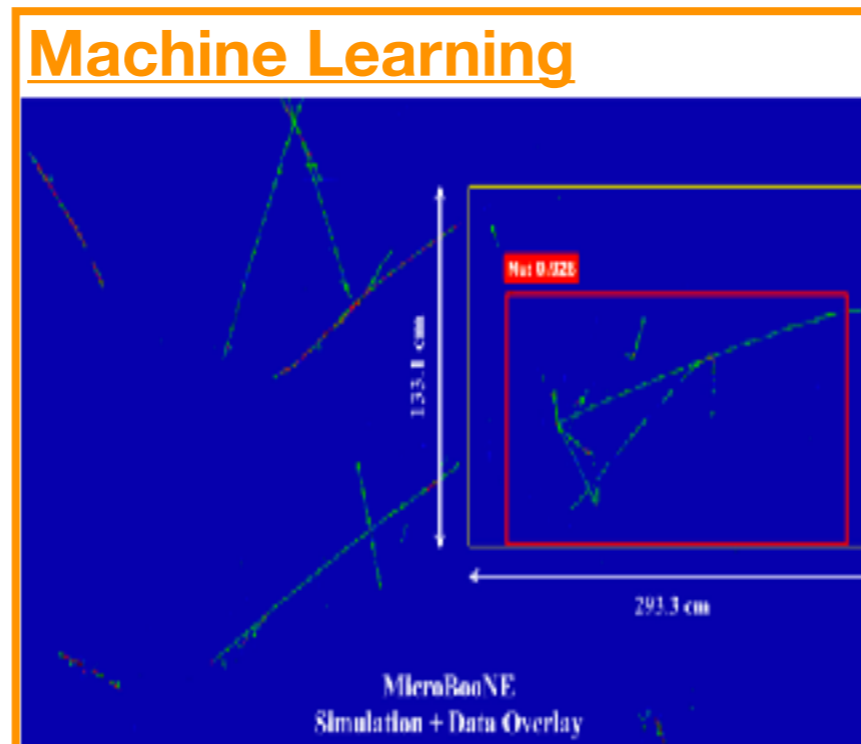
"Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber", JINST 12, P03011 (2017)

WireCell

ν_e data event

3D event image reconstructed with charge matching
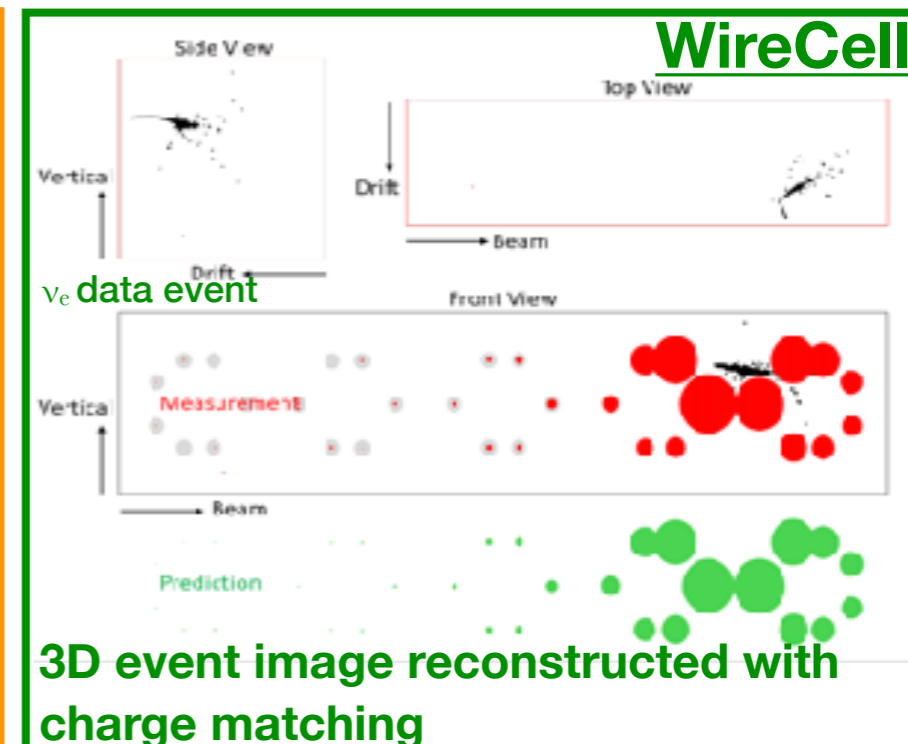
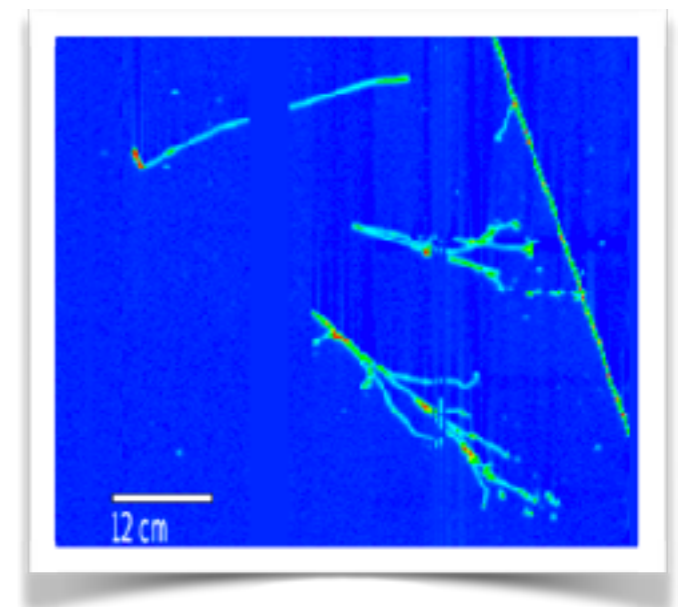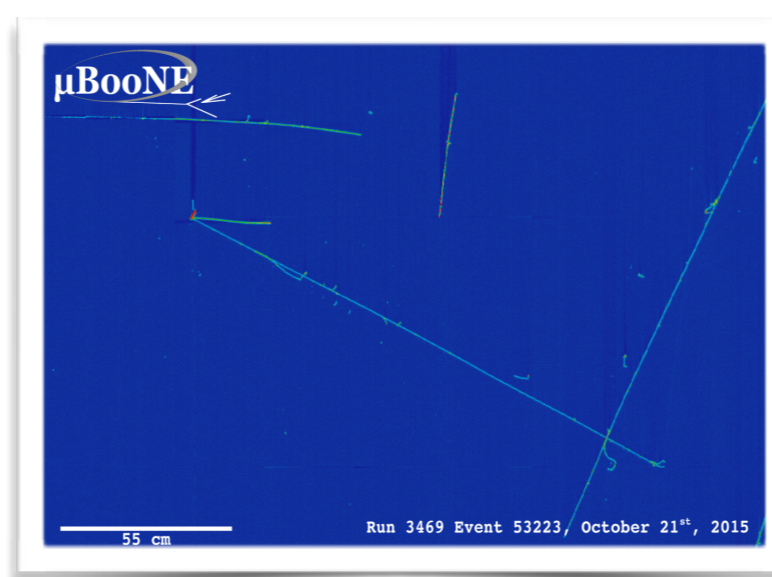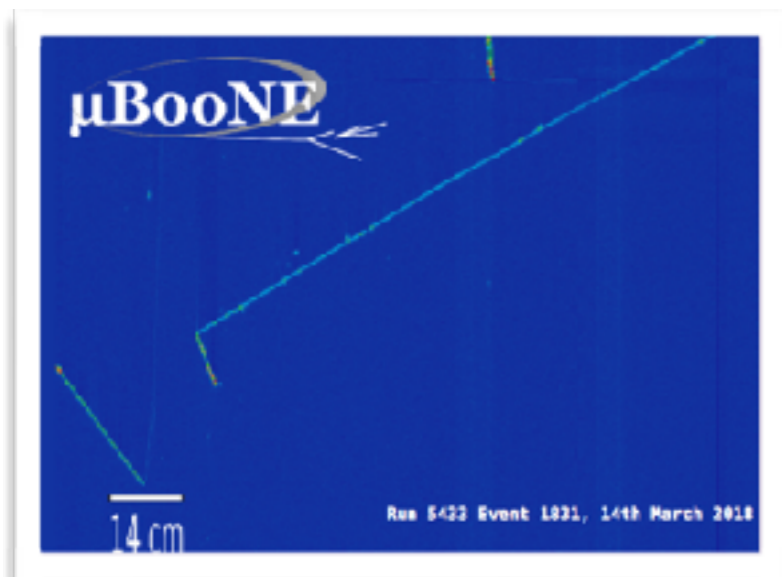**New Public Notes and Posters**

1. A. Hourlier, "Vertex finding and reconstruction for contained two-track events in the MicroBooNE detector", MICROBOONE-NOTE-1042-PUB, 2018
2. B. Russell, "Towards automated neutrino selection at MicroBooNE using tomorgraphic event reconstruction", MICROBOONE-NOTE-1040-PUB, 2018
3. H. Wei, "Recent progress on wire-cell tomographic event reconstruction for LArTPCs",
4. J. Moon, *Hunting muon neutrinos in microboone with deep learning techniques, MICROBOONE-NOTE-1051-PUB, 2018*
5. L. Domine & K. Terao, Applying deep neural network techniques for LArTPC data reconstruction(Kazu/Laura) **Finalist!**
6. Reconstruction performance studies with MicroBooNE data, *MICROBOONE-NOTE-1049-PUB, 2018*

Neutrino interaction measurements

- Cross-section measurements on Ar are **essential for our low-energy excess analysis** and for future LAr experiments (DUNE)

- LArTPCs are powerful to study final state topologies and inform theoretical models (e.g. Charged particle multiplicity studies)

- First step is to perform a ν_μ CC inclusive measurement

- Follow with suites of exclusive channel measurements (by final states)
    - ✓ ν_μ CC 1µNp (where N ≥ 0)
    - ✓ ν_μ CC-π^0
    - ✓ ν_μ CC-$\pi^\pm$
    - ✓ High-statistics analyses

Roxanne Guenette

MicroBooNE and the future SBN program

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    - ✓ High-statistics analyses

New results presented in this talk!
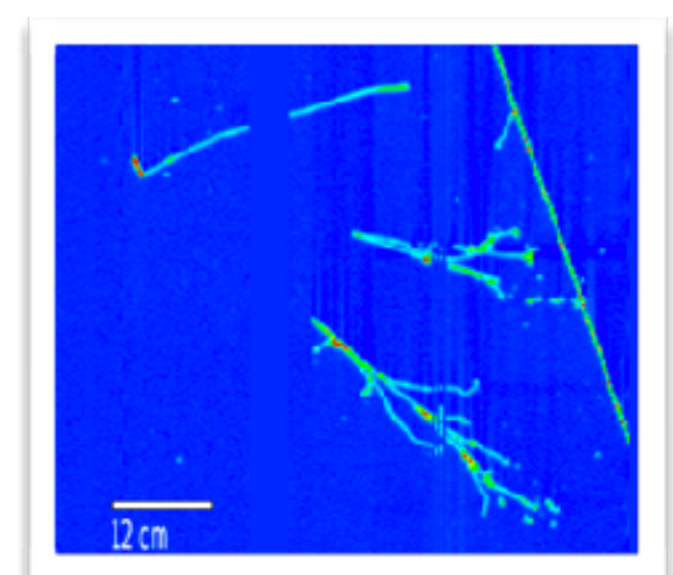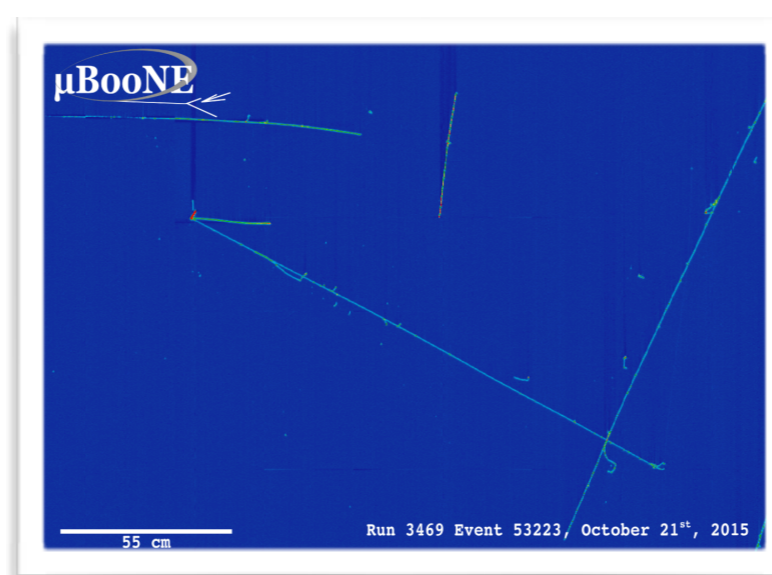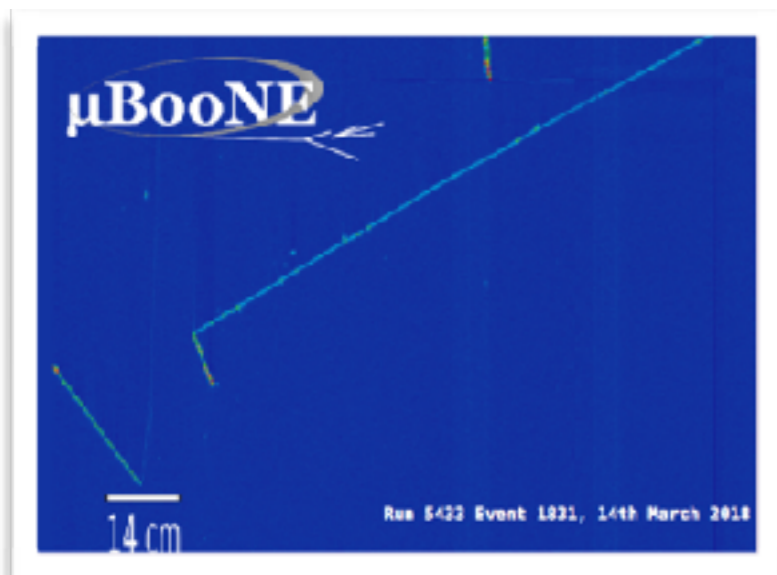
New Public notes and Posters
1. M. Del Tutto & A. Schukraft, First measurement of muon neutrino charged-current inclusive cross-section measurement in MicroBooNE, MICROBOONE-NOTE-1045-PUB, 2018
2. J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC, MICROBOONE-NOTE-1032-PUB, 2018
3. *A. Furmanski, Towards measurements of nuclear effects in MicroBooNE,* MICROBOONE-NOTE-1046-PUB, 2018
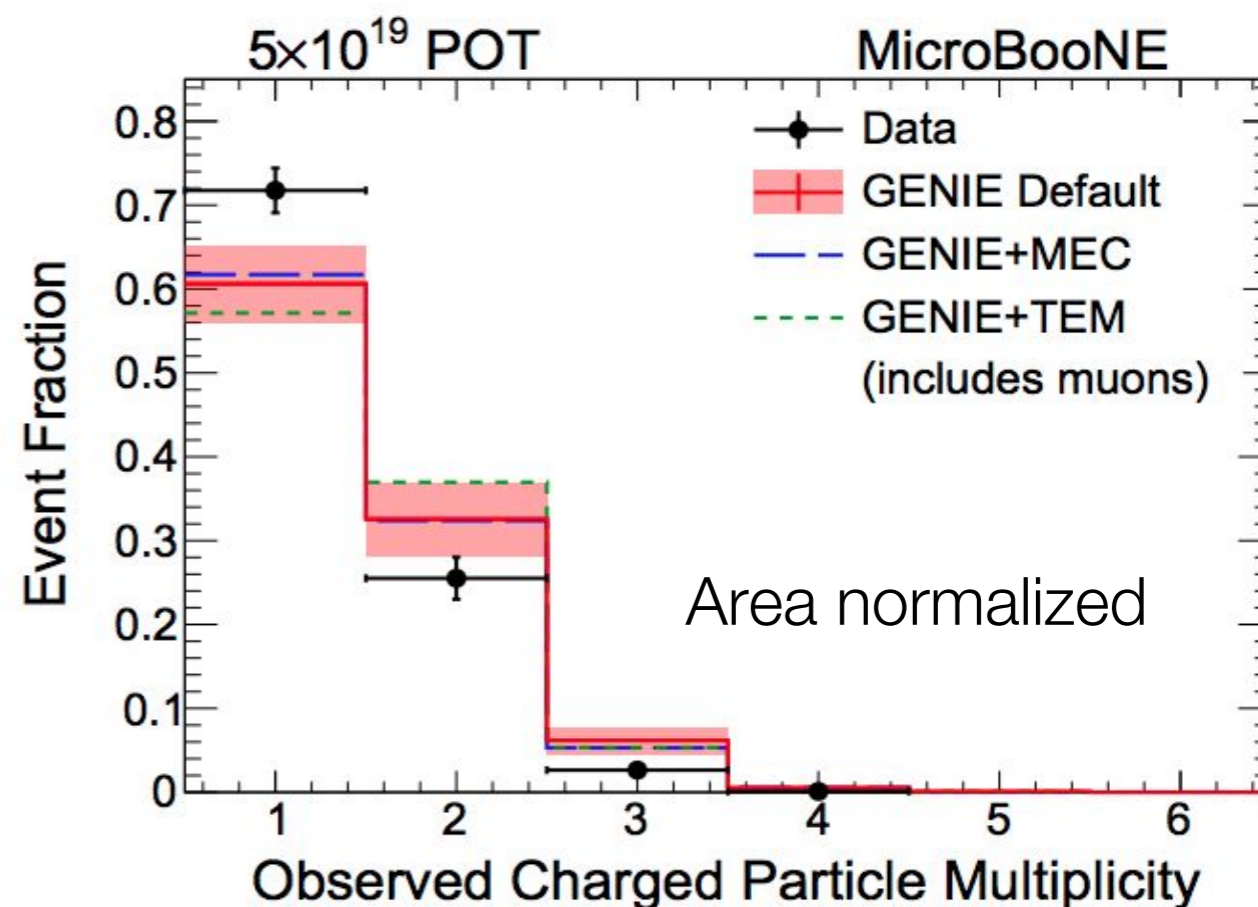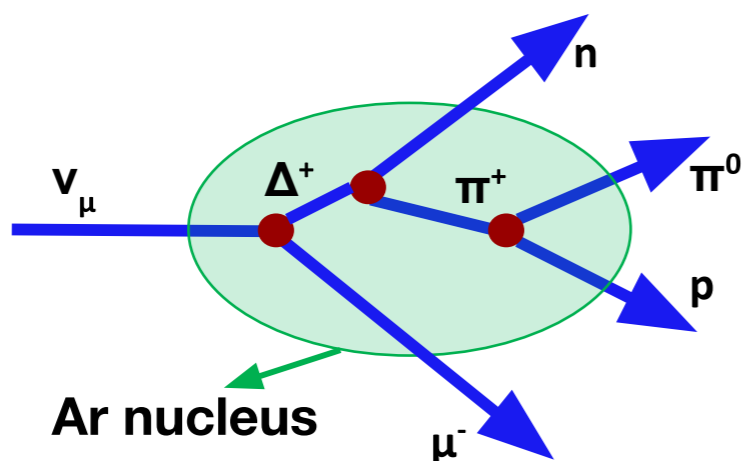
Neutrino interaction measurements

μBooNE

- Important step was to study the charged particle multiplicity (CPM) in ν_μ interactions
- Powerful way to validate nuclear models (and generators)
- First physics result!

Example of neutrino interaction with CPM = 2

Area normalized

"Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions", arXiv:1805.06887, submitted to PRD (2018)

Poster: A. Rafique, Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions

ν_μ CC Inclusive measurement

- Inclusive ν_μ CC interactions is the obvious first cross-section measurement
- It has been measured by many other experiments, making it a great benchmark
- Directly relevant to DUNE ν_μ CC signal

VENu event display   http://venu.physics.ox.ac.uk
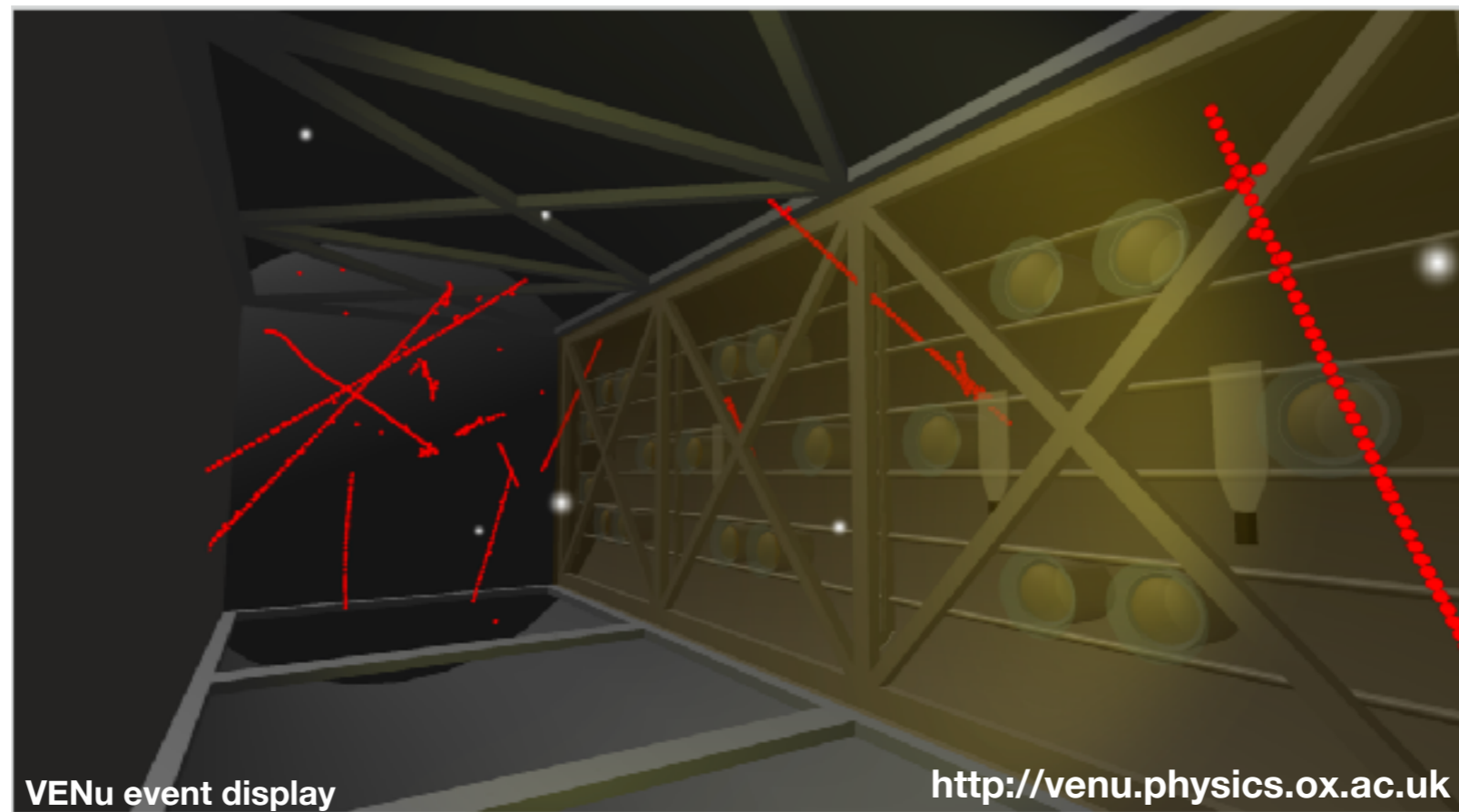
First public presentation of these results!

ν_μ CC Inclusive measurement

MicroBooNE Preliminary

1.6E20 POT

MicroBooNE Preliminary

1.6E20 POT
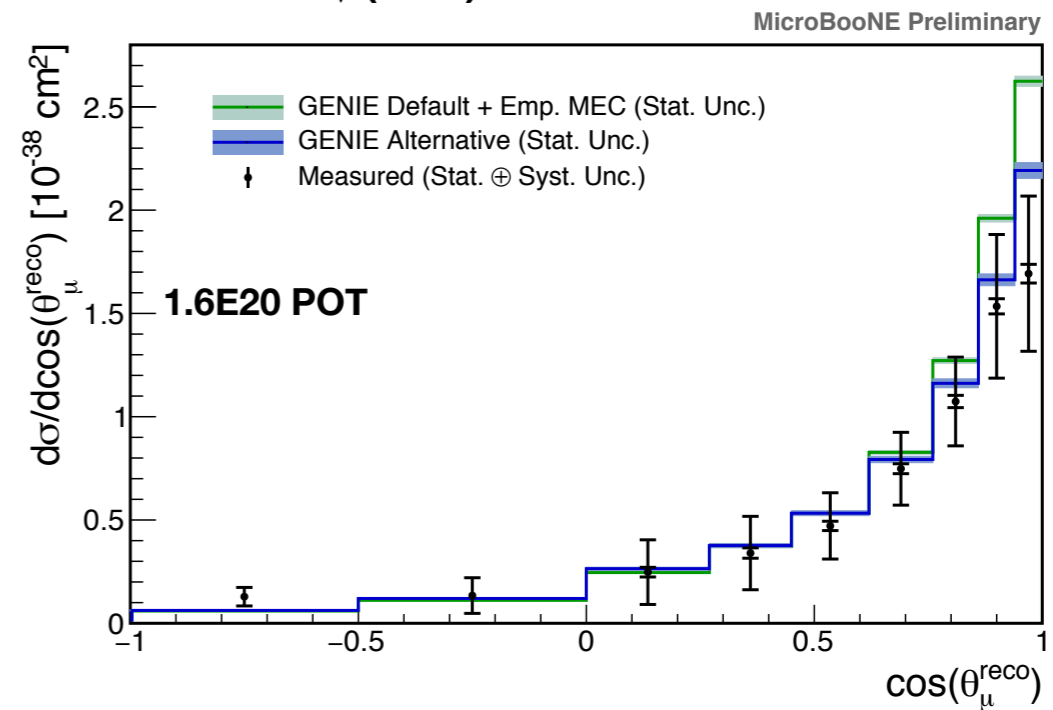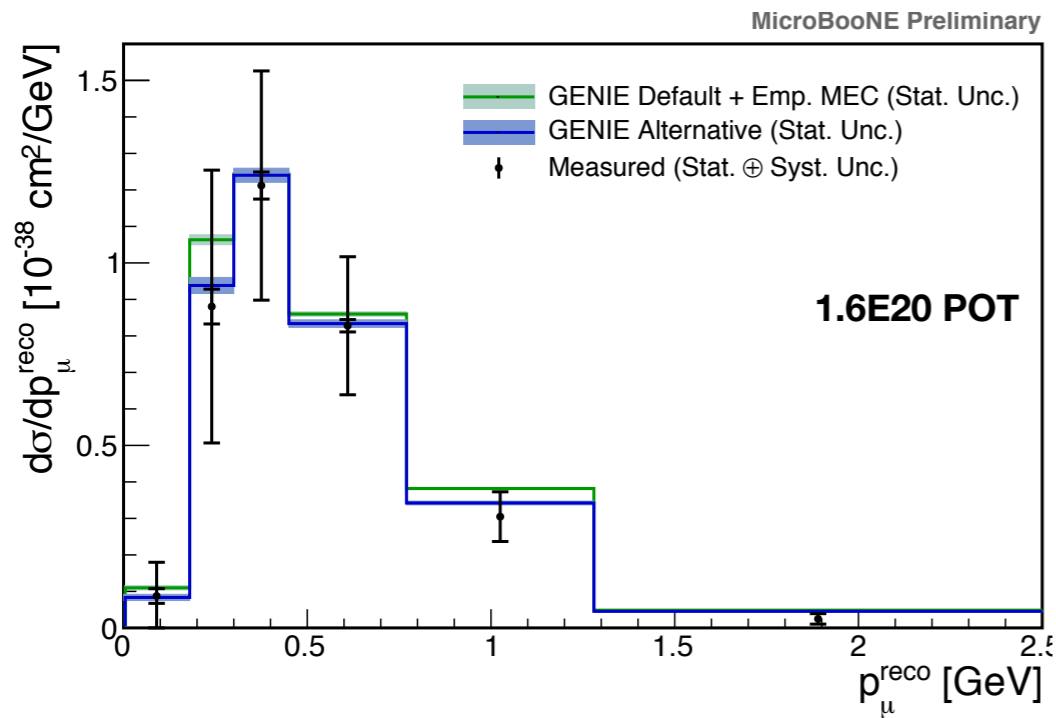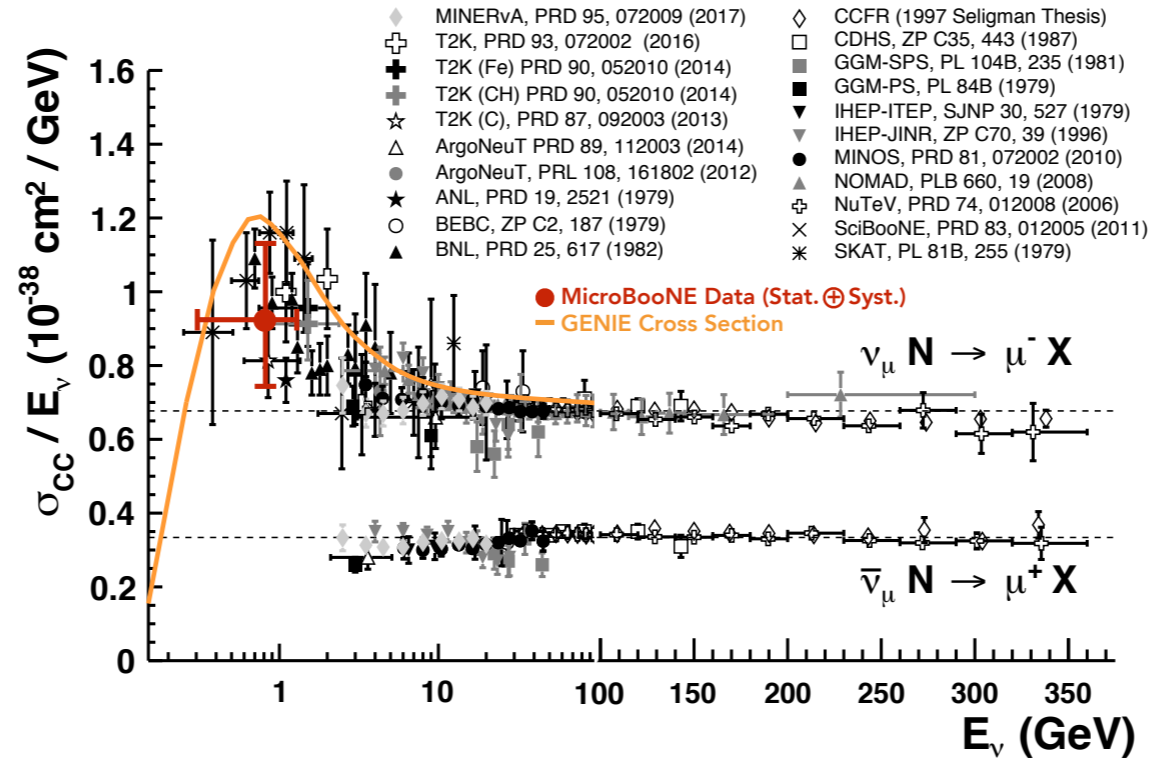
Double-differential cross section coming soon!

21

CC-π^0 cross-section measurement

- Understanding π^0 is a crucial step towards searching for low-energy excess:

  ✓ Test shower reconstruction

  ✓ Validate electromagnetic shower energy resolution

- First measurement of CC-π^0 on Ar

Charged-current π^0 interaction

Roxanne Guenette   MicroBooNE and the future SBN program
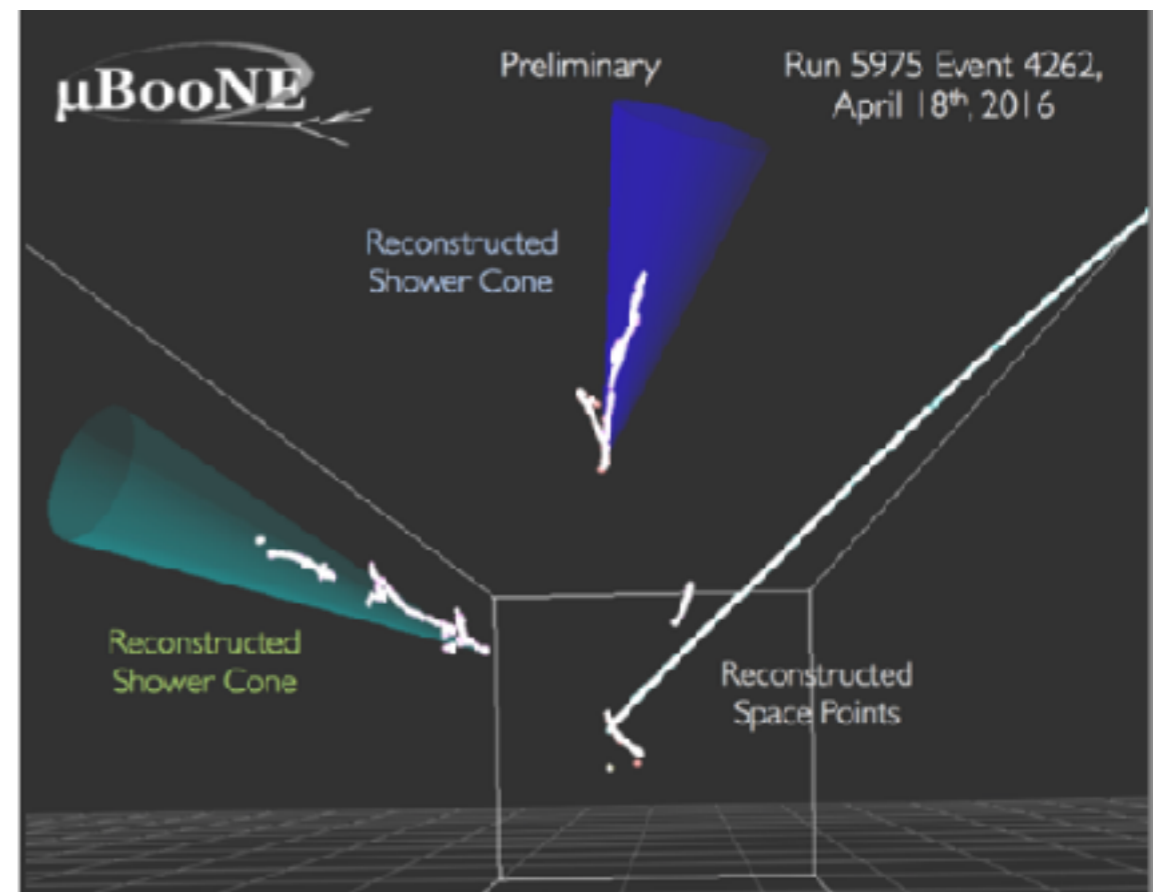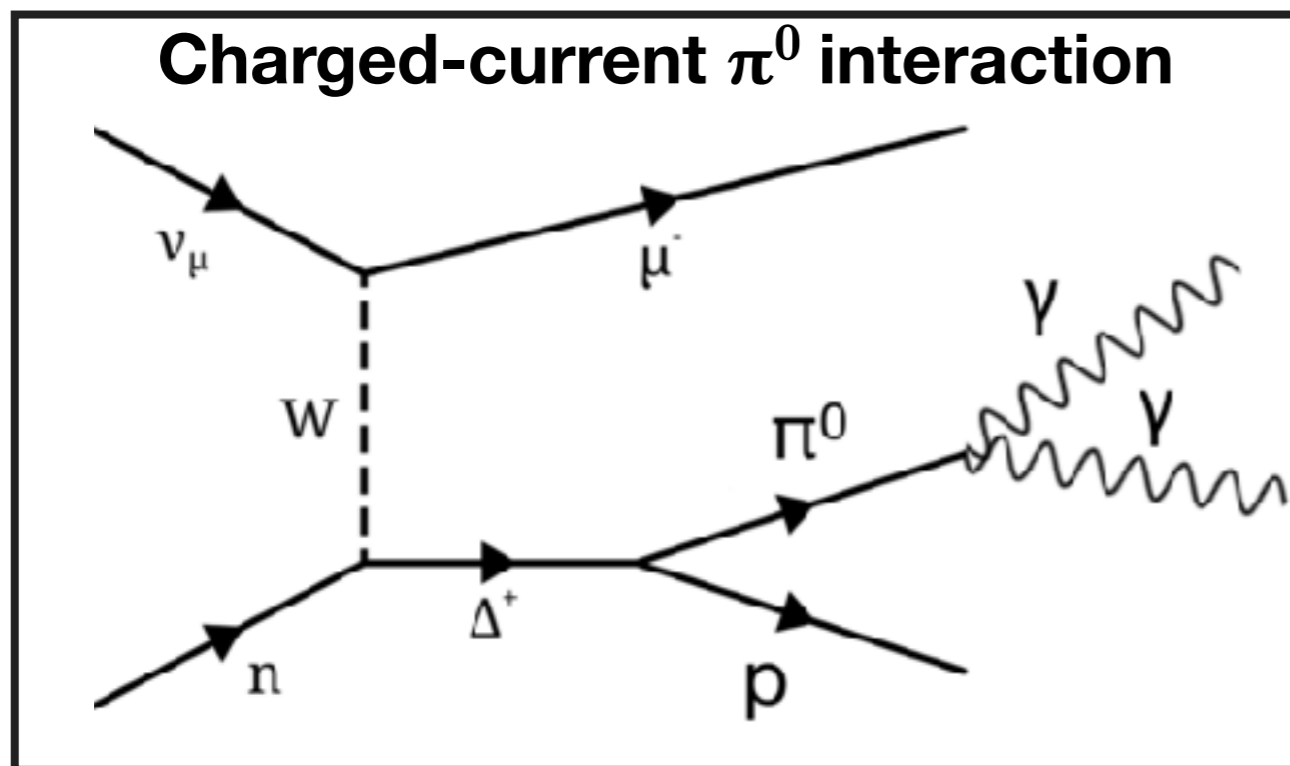
CC-π^0 reconstruction and selection

Reconstruction of the π^0 mass peak:
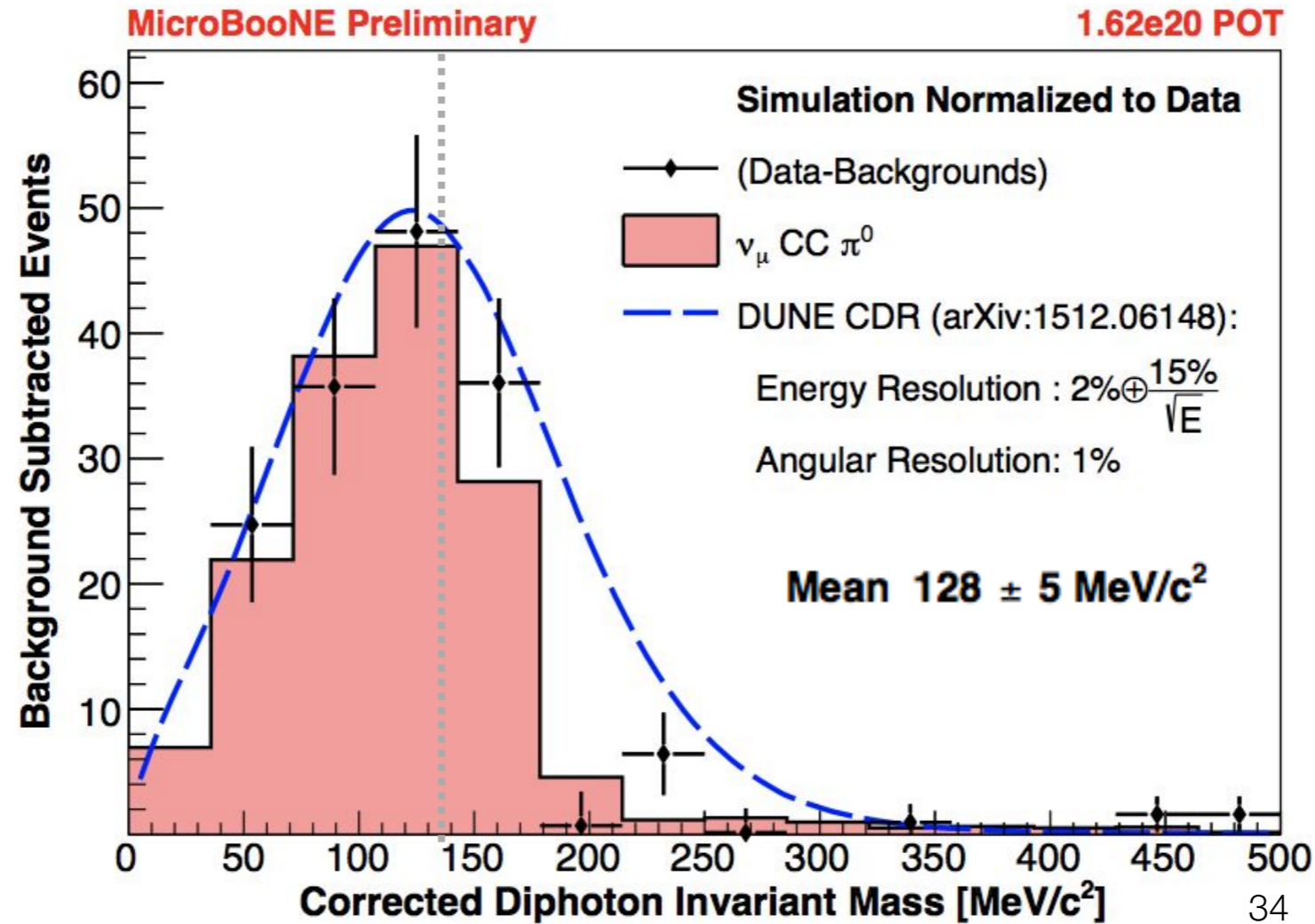
MicroBooNE Preliminary   **1.62e20 POT**

Simulation Normalized to Data

(Data-Backgrounds)

ν_μ CC π^0

DUNE CDR (arXiv:1512.06148):

Energy Resolution : $2\% \oplus \dfrac{15\%}{\sqrt{E}}$

Angular Resolution: 1%

Mean 128 ± 5 MeV/c^2

Background Subtracted Events

Corrected Diphoton Invariant Mass [MeV/c^2]

34

Mass of π^0: 135 MeV/c^2

Roxanne

CC-π^0 reconstruction and selection

µBooNE

Reconstruction of the π^0 mass peak:

MicroBooNE Preliminary   **1.62e20 POT**

Simulation Normalized to Data

- (Data-Backgrounds)
- ν_μ CC π^0
- DUNE CDR (arXiv:1512.06148):
  Energy Resolution : $2\% \oplus \dfrac{15\%}{\sqrt{E}}$
  Angular Resolution: 1%

Mean 128 ± 5 MeV/c^2

y-axis: **Background Subtracted Events**
x-axis: **Corrected Diphoton Invariant Mass [MeV/c^2]**

34
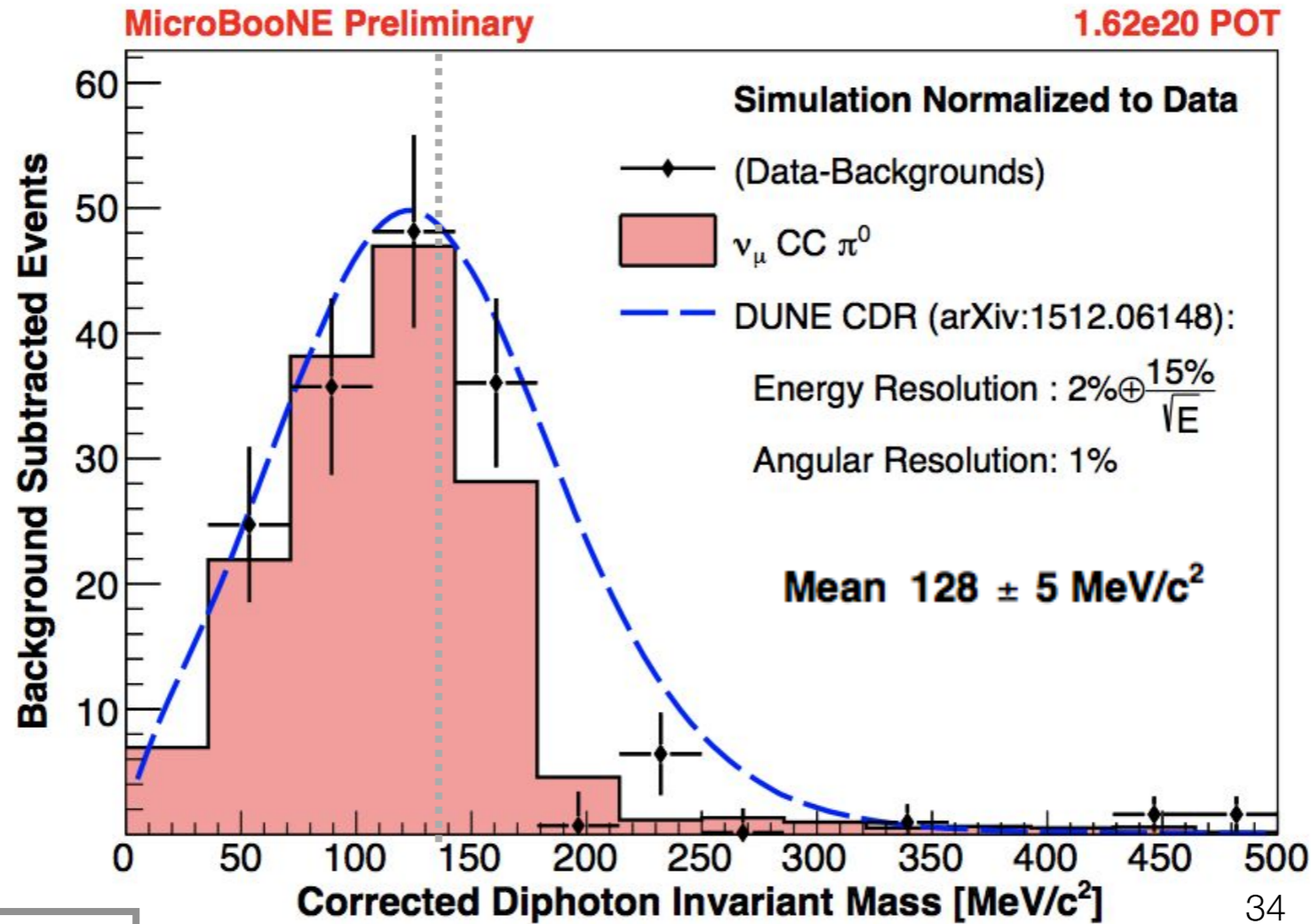
Total cross section:

Mass of π^0: 135 MeV

$$\left\langle \sigma^{\nu_\mu CC\pi^0} \right\rangle_\Phi = (1.94 \pm 0.16 \,[\text{stat.}] \pm 0.60 \,[\text{syst.}]) \times 10^{-38} \frac{cm^2}{Ar}$$

Next steps: Higher statistics analysis → differential cross-section measurement

Poster: J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC
Public Note: MICROBOONE-NOTE-1032-PUB, 2018
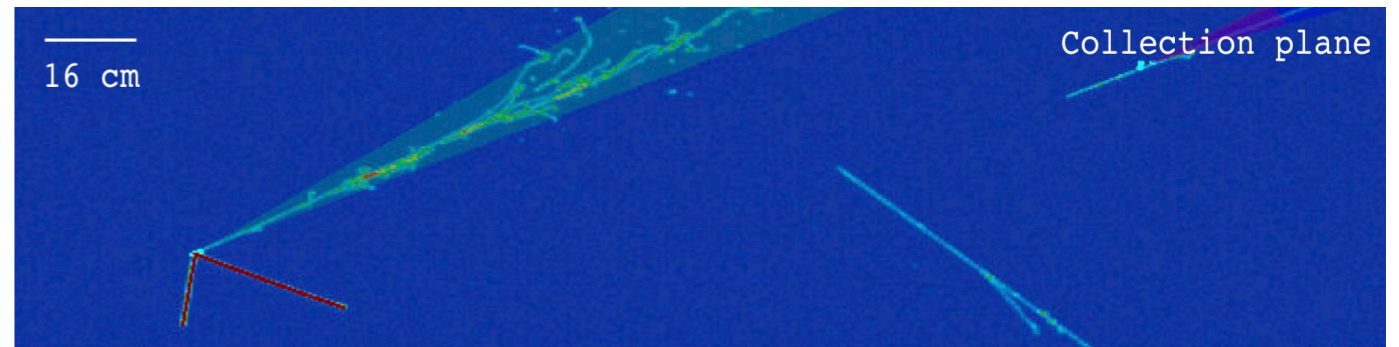
Towards the low-energy excess

Our current plan
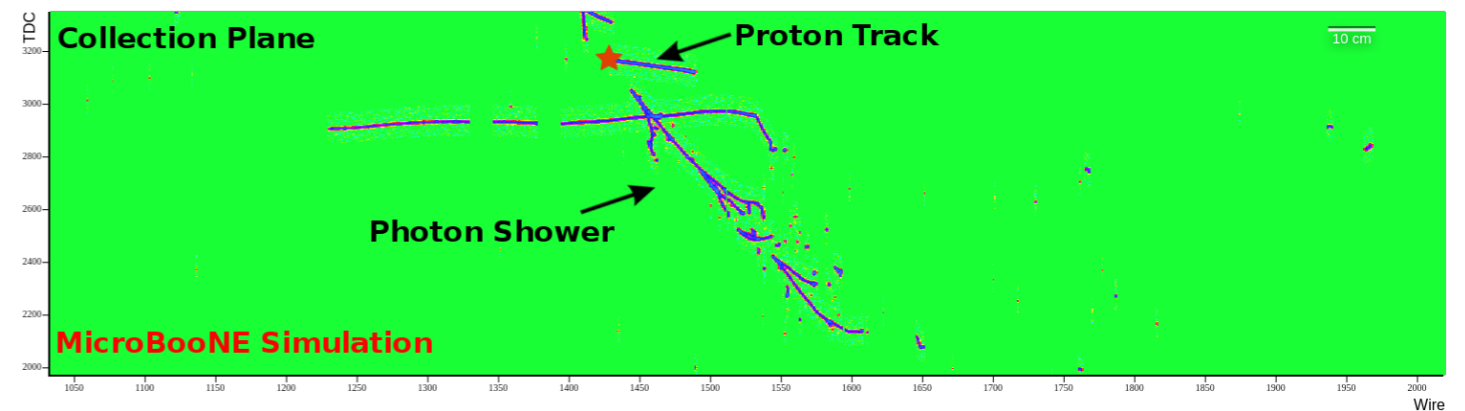
- Several complementary LEE analyses:

  ➡ ν_e analyses

    ✓ 1e1p (Deep Learning)

    ✓ 1eNp (Pandora)

    ✓ Inclusive: 1e (Pandora, WireCell)

    ✓ …

  ➡ Single photon analyses

    ✓ $1\gamma 0p$ (Pandora)

    ✓ $1\gamma 1p$ (Pandora)

    ✓ …

**Crucial for testing different LEE models
(e.g. 3+1 neutrinos, NC Δ radiative decays,…)**

Example of reconstructed nue signal MC event

Example of reconstructed photon signal MC event

Towards the low-energy excess

Our current plan

- Several complementary LEE analyses:

  → ν_e analyses
   - ✓ 1e1p (Deep Learning)
   - ✓ 1eNp (Pandora)
   - ✓ Inclusive: 1e (Pandora, WireCell)
   - ✓ …

  → Single photon analyses
   - ✓ 1γ0p (Pandora)
   - ✓ 1γ1p (Pandora)
   - ✓ …

<div style="border: 2px solid #8B0030; padding: 10px;">

New Public Notes and Posters

1. R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction, MICROBOONE-NOTE-1038-PUB, 2018

2. R. Murrels, Search for NC single photon events in MicroBooNE, MICROBOONE-NOTE-1041-PUB, 2018

3. M. Ross-Lonergan, MicroBooNE tests of the MiniBooNE low-energy excess, MICROBOONE-NOTE-1043-PUB, 2018 Finalist!

</div>

- Blind search strategy → Very small open data sample (~4%) to develop robust and careful analysis

- Large NuMI beam open data sample available for cross-checks

- We first want to perform our cross-section measurements to provide strong understanding of the interactions and backgrounds

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ν_e analysis

- Many different possible channels to study ν_e

- Each have different characteristics

- Power of LArTPC will allow for disentangling the potential effects of the analyzed channels
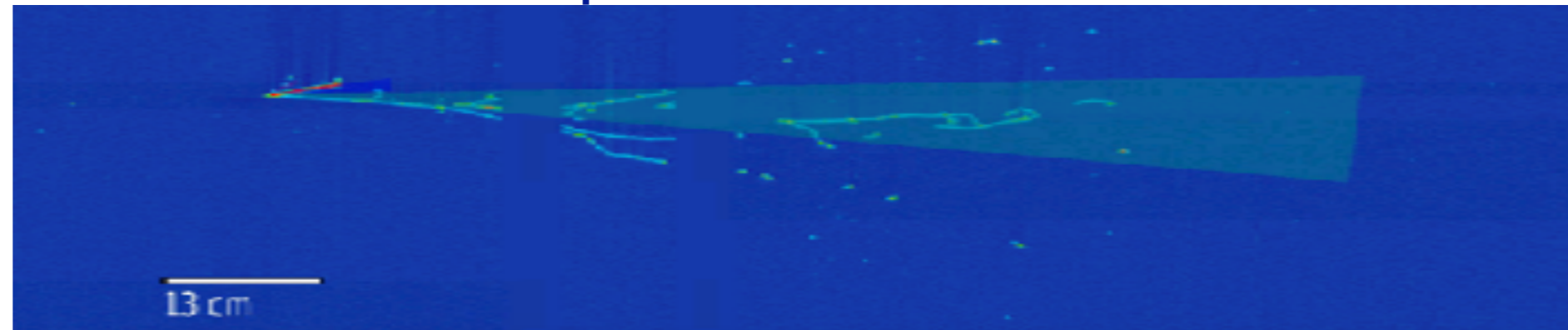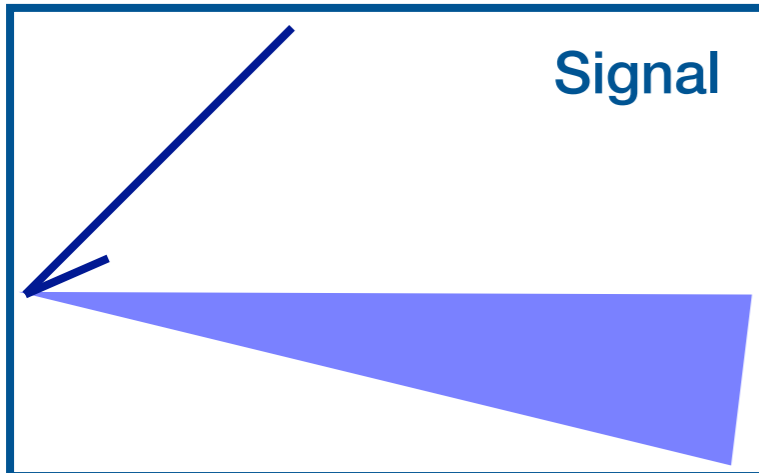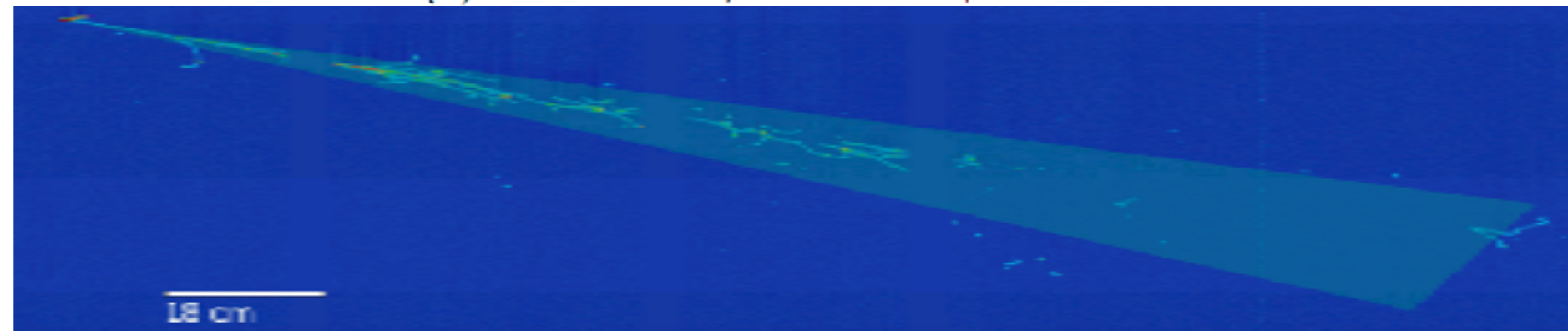
Example of signal topologies for ν_e
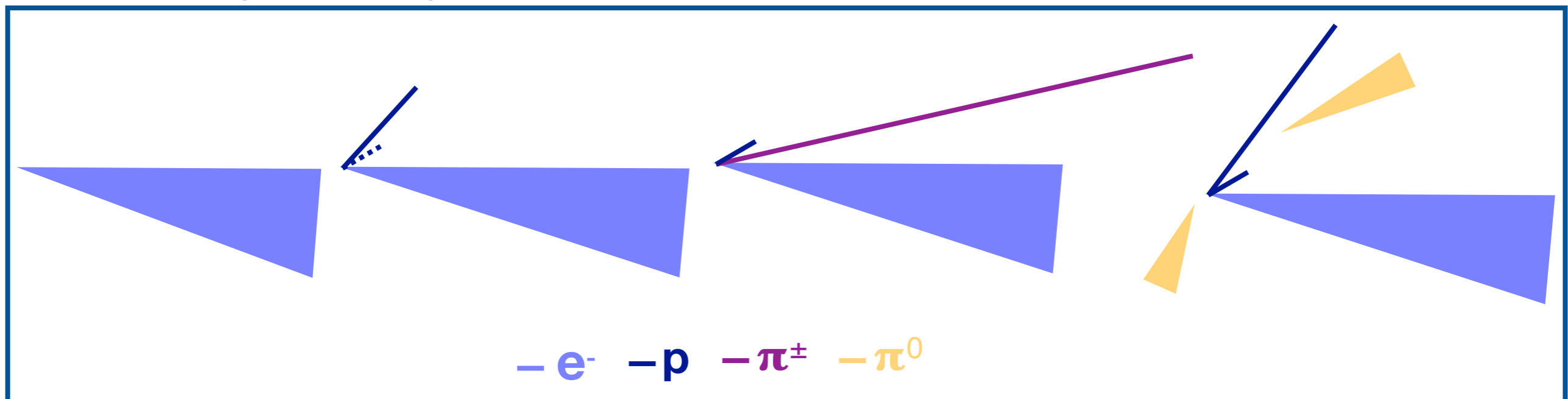
$-$ e⁻ $-$ p $-\pi^{\pm}$ $-\pi^0$

ν_e analysis

One of our first analyses focuses on the signal most similar to the MiniBooNE CC0π definition: 1 electron + N protons
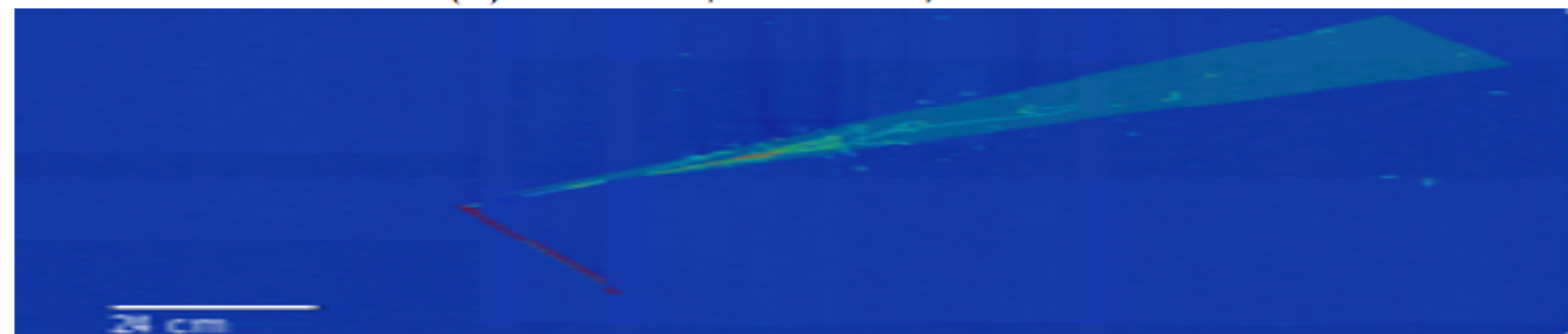
Example of data events selected

Signal

Selected nue data events

(a) Event 1515, Subrun 30, Run 5328

(b) Event 31, Subrun 0, Run 5513

(c) Event 3710, Subrun 74, Run 5906

the future SBN program

MicroBooNE summary

- MicroBooNE is an important milestone for LArTPC development and is providing invaluable LAr data - useful for future detectors

- We have been working at understanding the detector effects (noise, diffusion, recombination, space charge effect…), which are essential to understand our physics - **many new results!**

- We have made great progress on automated event reconstruction in LAr using **data** - significant progress in parallel to our physics results

- First physics results are presented (ν_μ CC inclusive differential cross section and $CC\pi^0$ total cross section) and many more are underway

- We have performed our first fully automated ν_e and single photon selections and are addressing the improvements needed for the low-energy search

Towards the full SBN program

- MicroBooNE has been trailblazing the automated neutrino data reconstruction in LArTPC and in calibration techniques, which should provide a head-start for the other two experiments (note: all surface detectors → cosmic mitigation)

- The first stage (MicroBooNE) of the program will provide an answer of the origin of the MiniBooNE excess

- SBND will provide an unoscillated spectrum to identify the origin of a potential excess, in addition to an unprecedented amount of neutrino data on argon. Construction is underway with data taking planned for 2020

- ICARUS will provide the high-statistics coverage of a wide oscillation parameter space to give a definitive answer to the short-baseline anomalies. Construction is progressing well with data taking planned for 2019

- SBN is a definitive program to address LSND/MiniBooNE anomalies in the immediate future (~5 years)
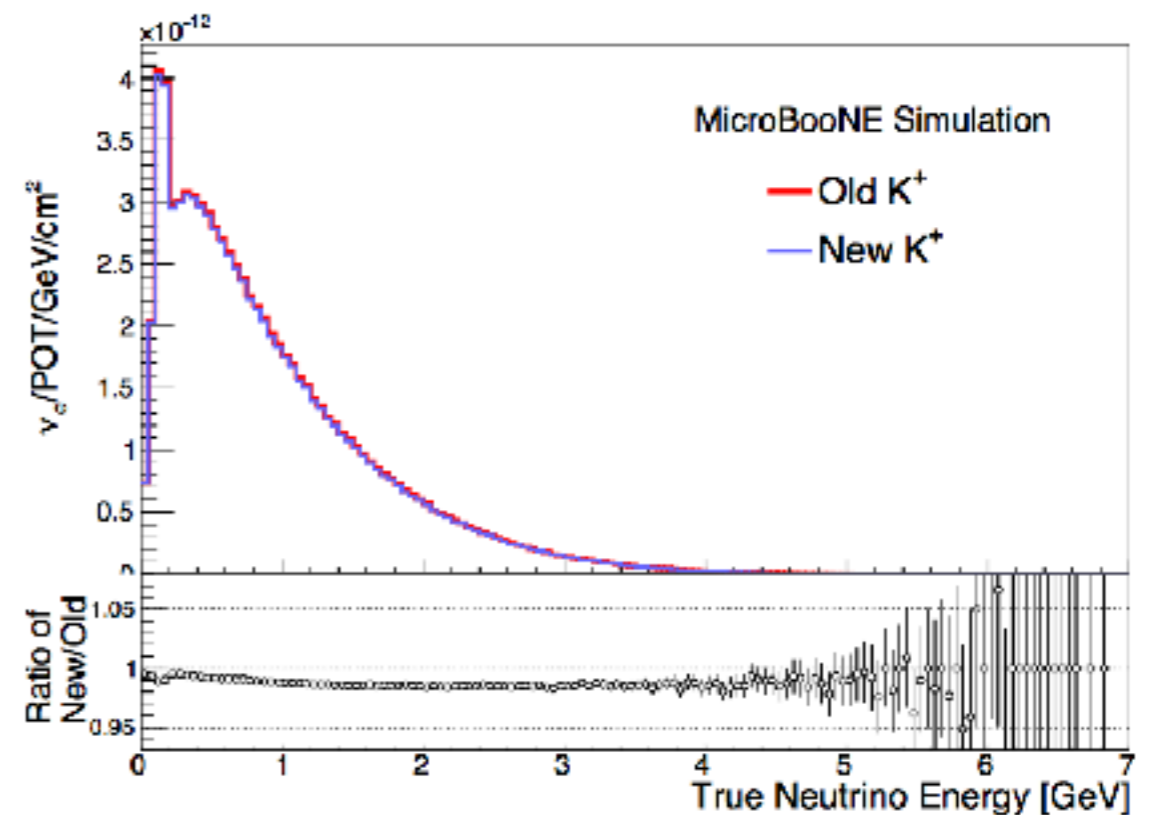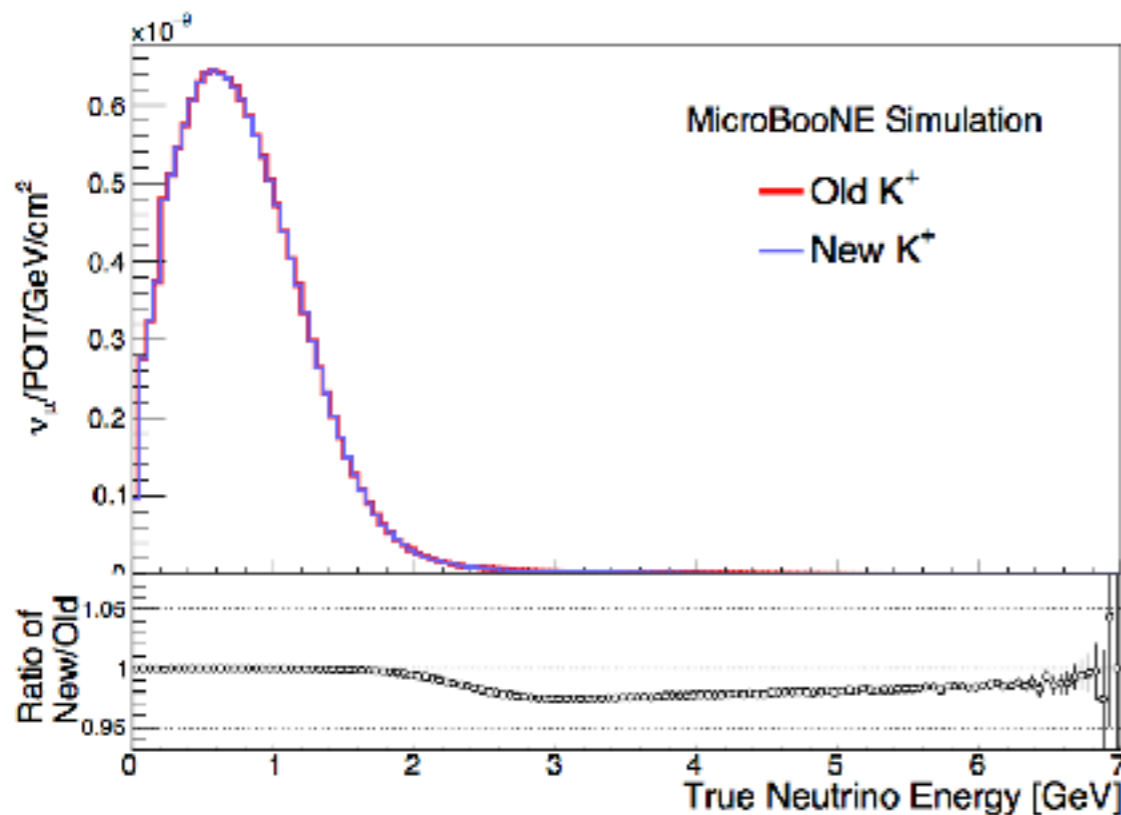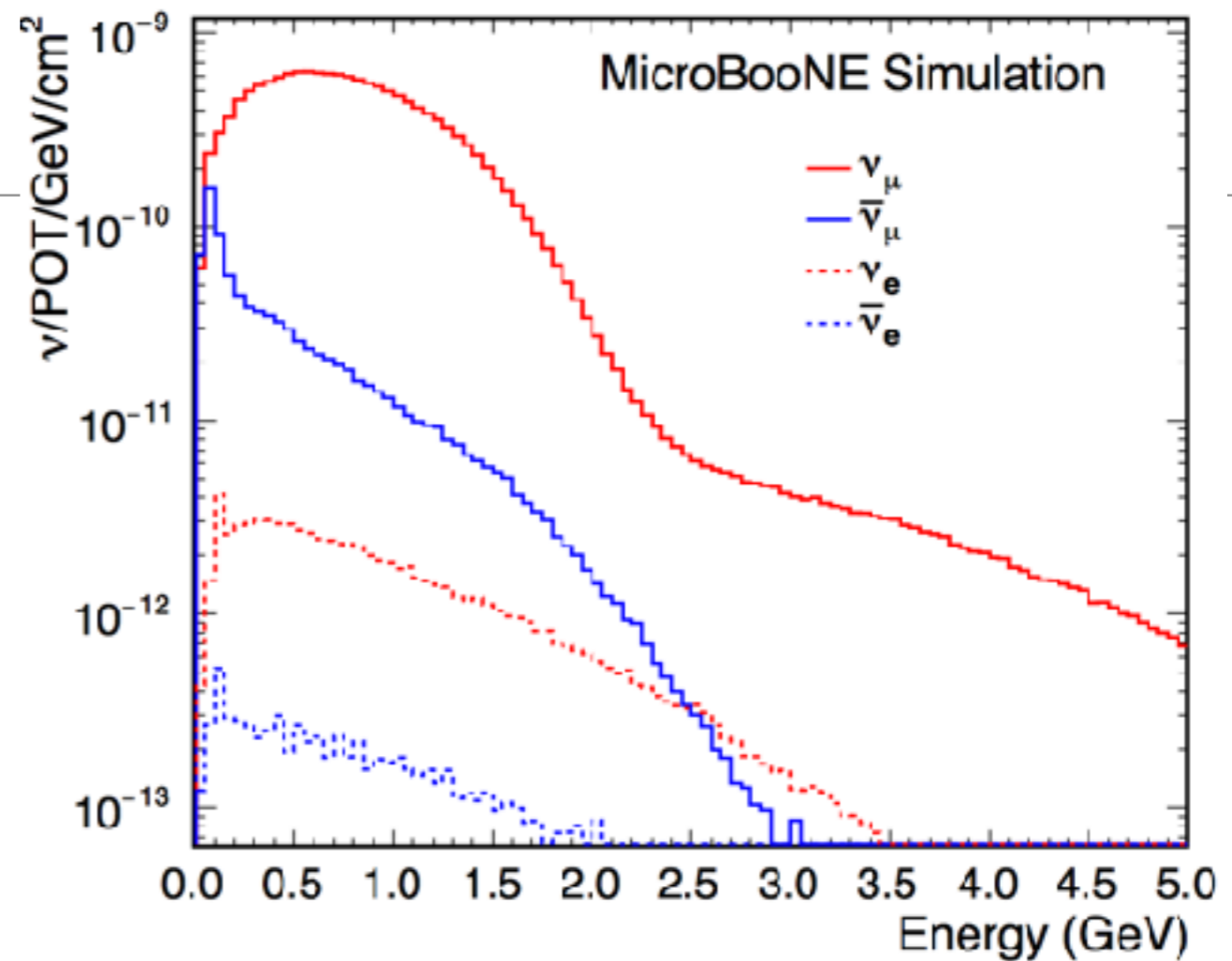
Thank You!

13 cm

Roxanne Guenette   MicroBooNE and the future SBN program

BNB flux

- MicroBooNE flux production based on MiniBooNE flux predictions

- New systematics study for MicroBooNE

Roxanne Guenette

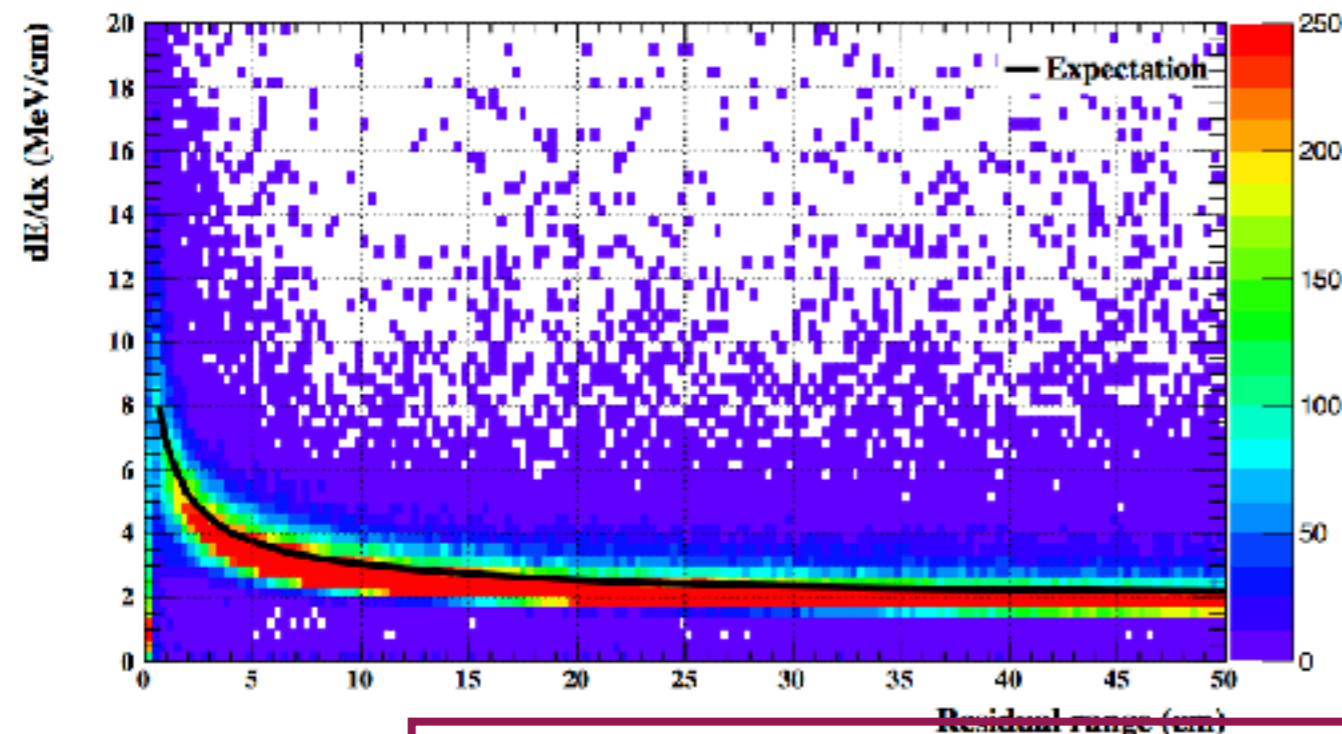**Public Note: MICROBOONE-NOTE-1031-PUB, 2018**

Calibration

- YZ correction factors derived from data (Feb-May 2016). Time variation also studied.

- Calibrated dE/dx for stopping muons and stopping protons

Plane 2

MicroBooNE Preliminary
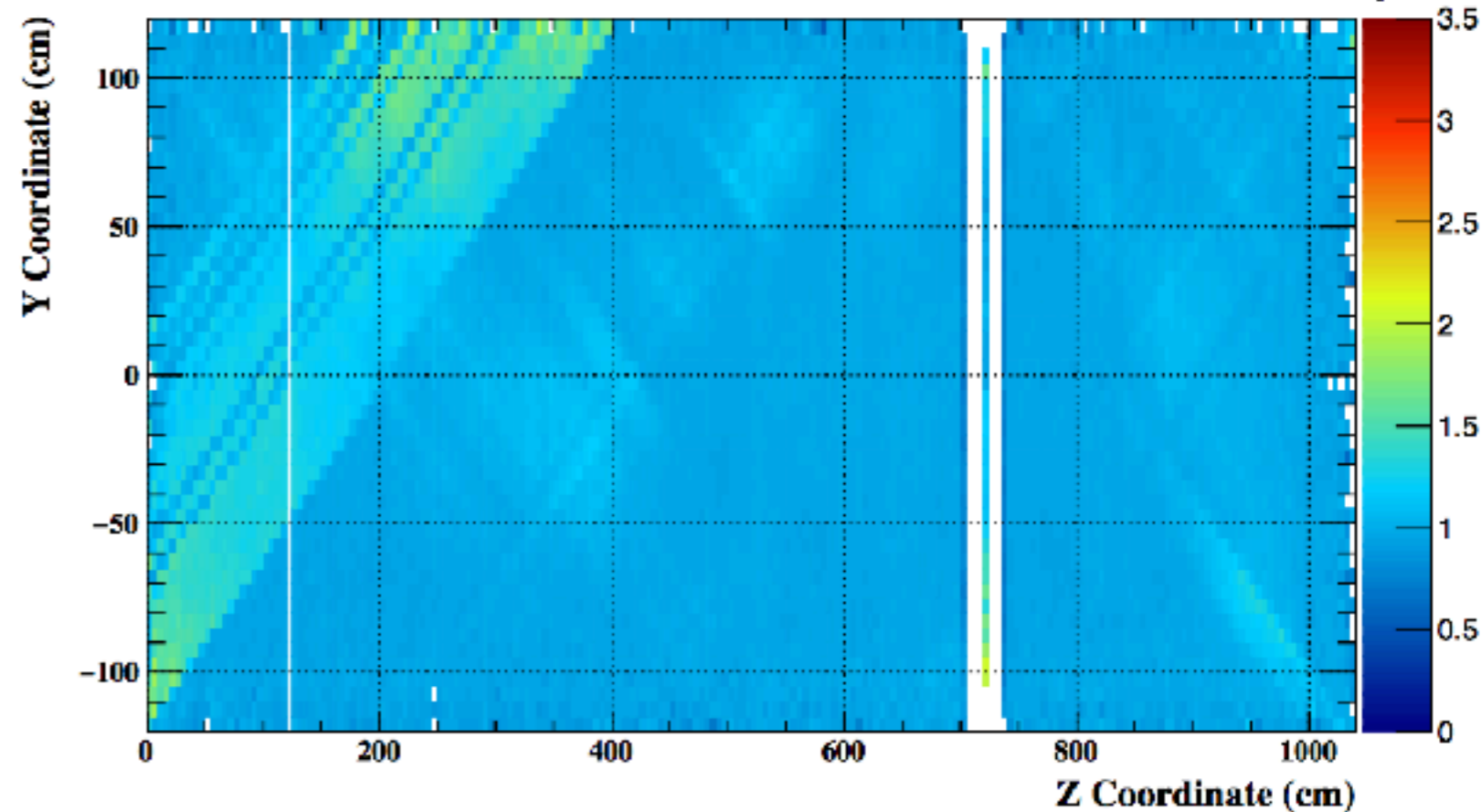
MicroBooNE Simulation Preliminary
dE/dx vs. Residual range

MicroBooNE Simulation Preliminary
dE/dx vs. Residual range
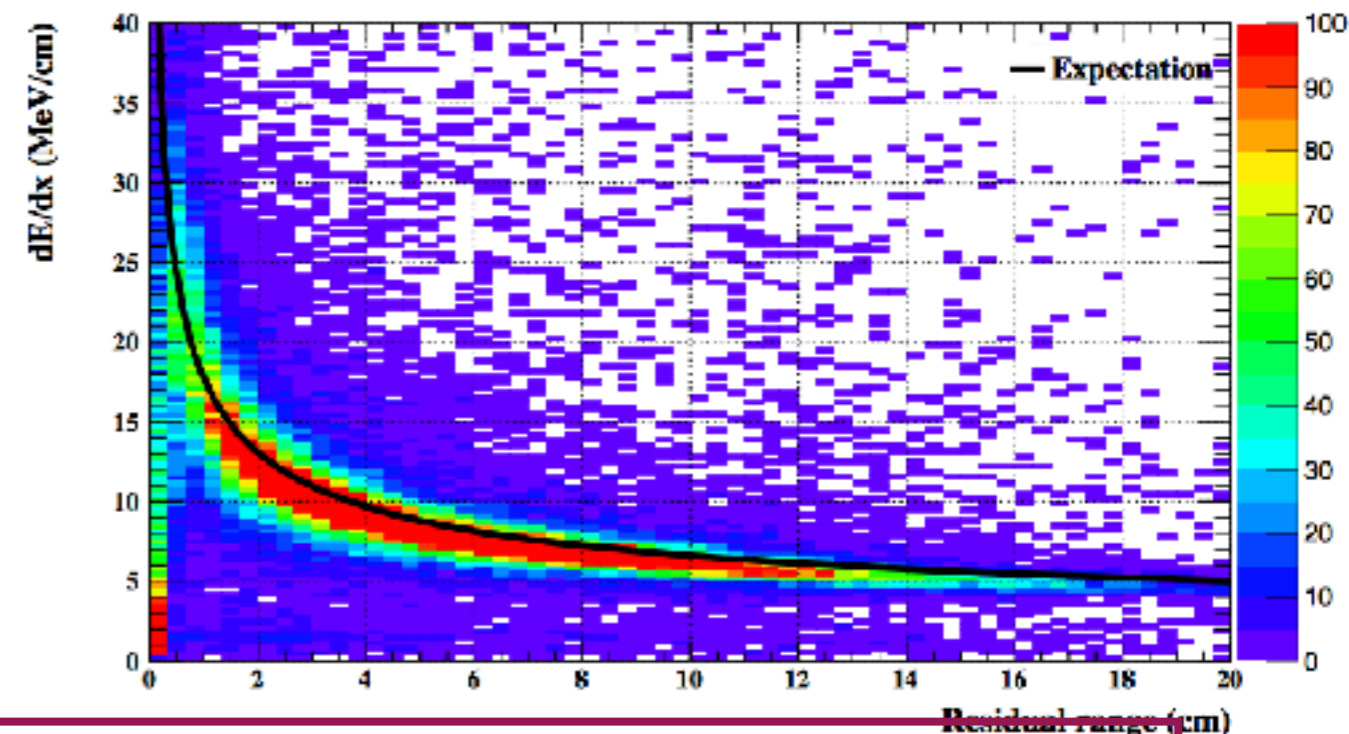
1. "Detector Calibration using through going and stopping muons in the MicroBooNE LArTPC", MICROBOONE-NOTE-1048-PUB, 2018
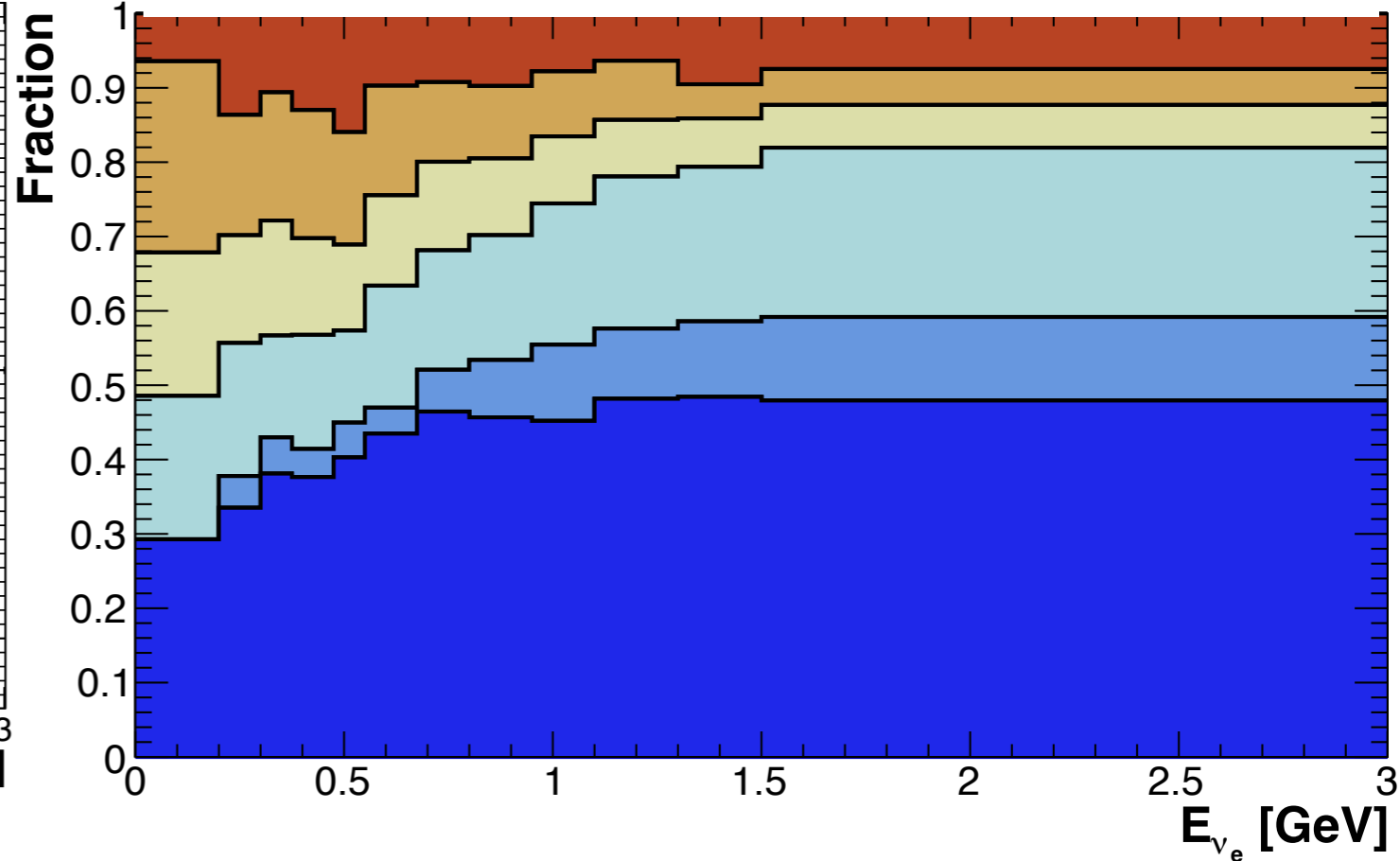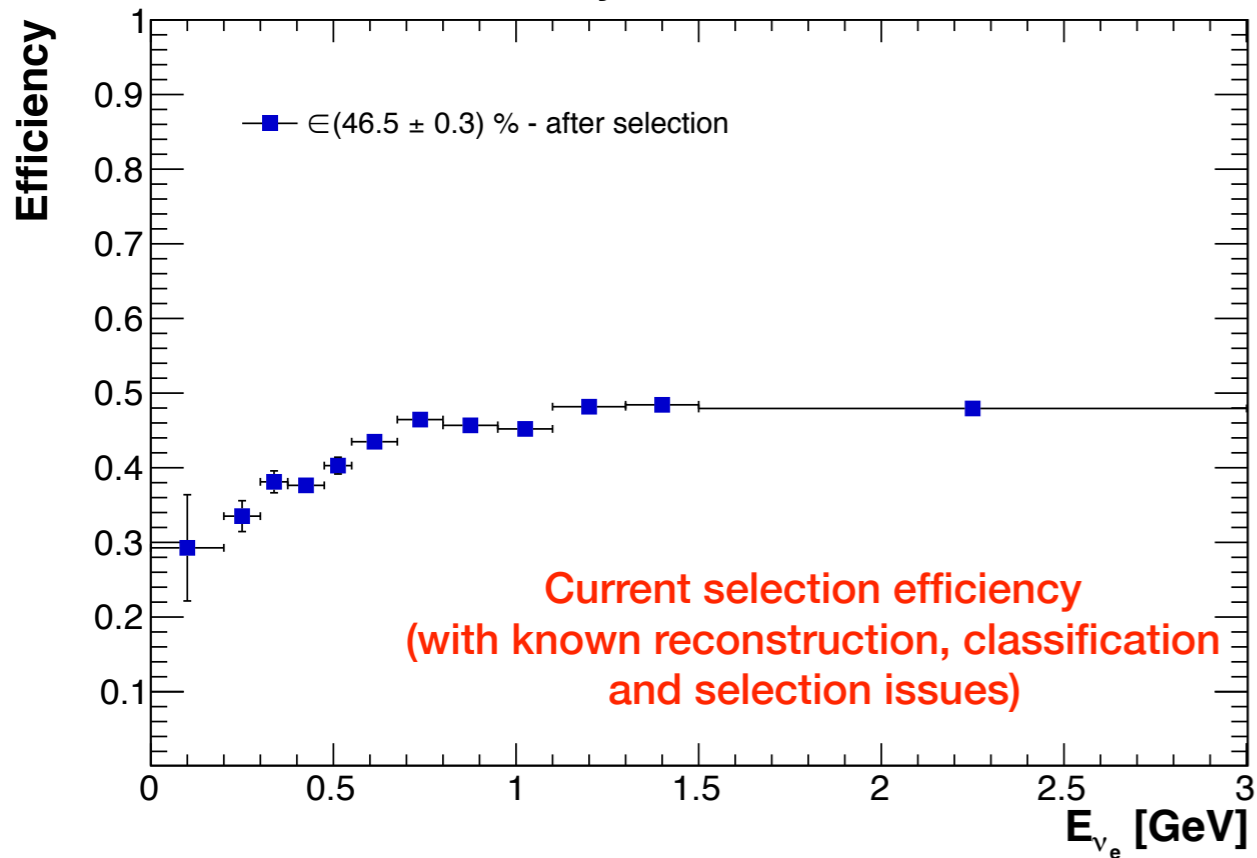
ν_e analysis

One of our first analyses focuses on the signal most similar to the MiniBooNE CC0π definition: 1 electron + N protons

MicroBooNE Simulation Preliminary

■ **Correctly selected ν_e CC0π-Np signal: 46.5%**
■ **Mis-identified bkg. (cosmic): 9.0%**
■ **Not selected (reco./classif. issues): 9.1%**
■ **Mis-identified bkg. (Not fully contained signal): 8.0%**
■ **Mis-identified bkg. (cosmic contaminated): 18.5%**
■ **Not selected (no flash/no candidates): 8.9%**

Selection efficiency for 1e+Np

MicroBooNE Preliminary

■ $\in (46.5 \pm 0.3)$ % - after selection

Current selection efficiency (with known reconstruction, classification and selection issues)

Poster: R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction

Public Note: MICROBOONE-NOTE-1038-PUB, 2018
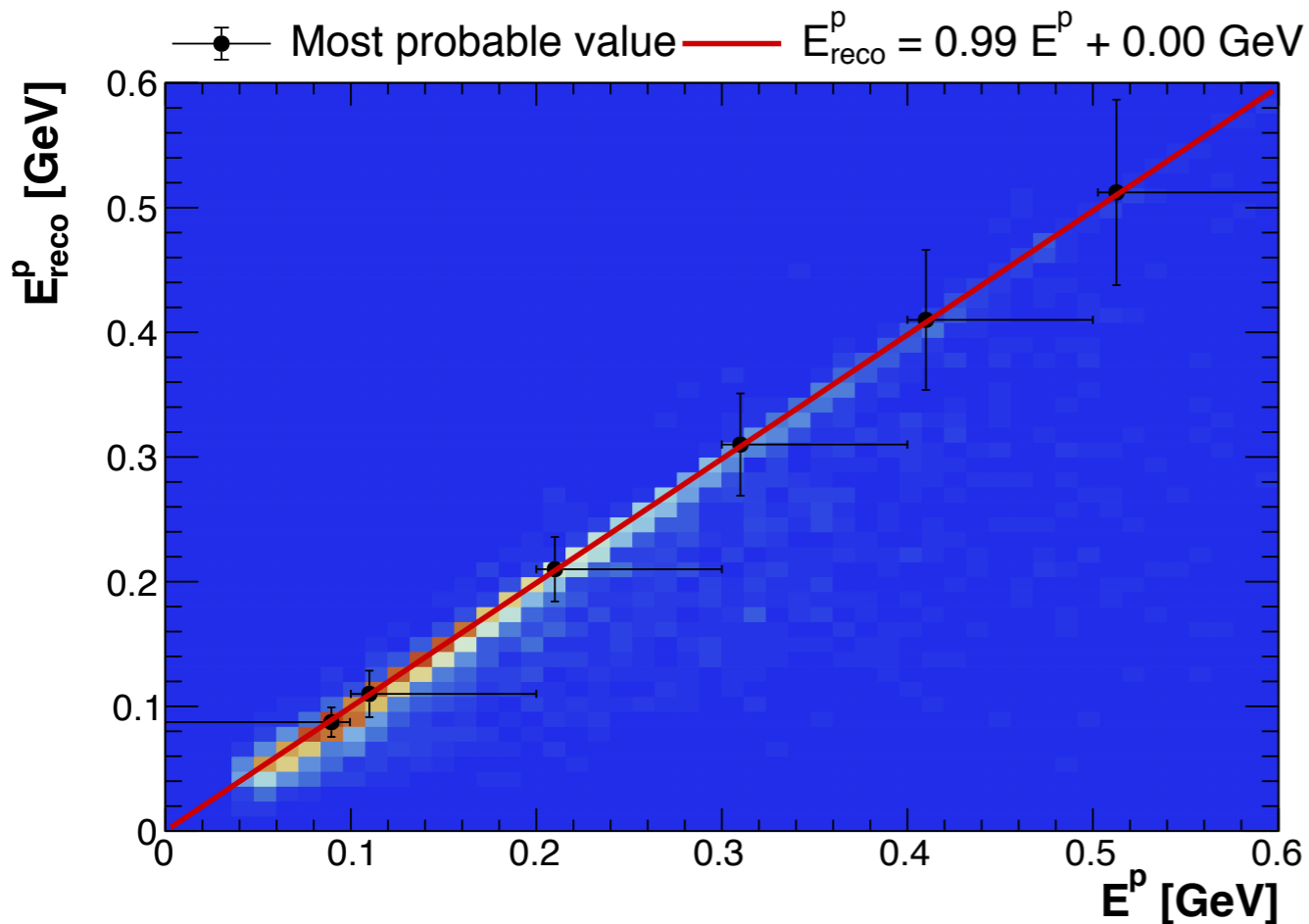
Low-energy excess analysis

- The currently ongoing ν_e (and other) analyses have informed us of where improvements are needed

  - ➡ Improved cosmic removal techniques + cosmic-ray tagger system
  - ➡ Robust PID will be implemented
  - ➡ Calorimetry on the 3 planes will improve the dE/dx measurements
  - ➡ Low energy reconstruction/classification improvements will increase the low energy efficiency
  - ➡ Continue to develop the Machine Learning analyses has they are very promising

- Perform end-to-end analysis with new improvements

- Validate analysis with side-bands

- Use NuMI ν_e events to validate the analysis with high statistics

- Perform the single photon analyses
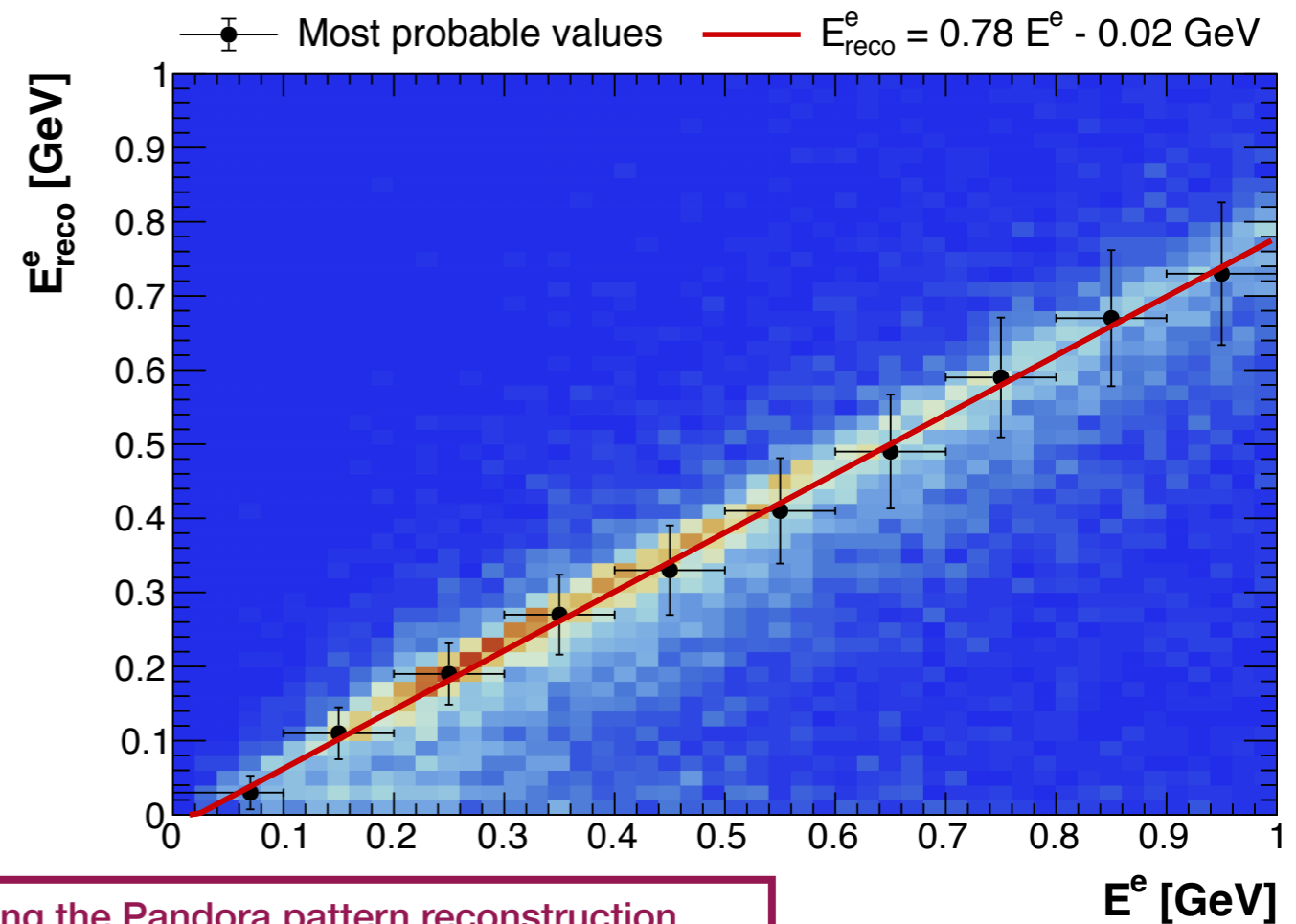
New Public Notes and Posters

1. R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction, MICROBOONE-NOTE-1038-PUB, 2018

2. R. Murrels, Search for NC single photon events in MicroBooNE, MICROBOONE-NOTE-1041-PUB, 2018

3. M. Ross-Lonergan, MicroBooNE tests of the MiniBooNE low-energy excess, MICROBOONE-NOTE-1043-PUB, 2018 **Finalist!**

Energy reconstruction of nue

- Energy reconstruction studies for protons and electrons

Roxanne Guenette   MicroBooNE and the future SBN program

Validating ν_e analysis

- Small unblinded data sample available for testing (4.4x10^{19} POT)

- Validation using side-bands (ν_μ charged current or neutral current events)

- Use cuts to select non-ν_e events:

    ✓ dE/dx of showers

    ✓ Distance between shower start and track start

    ✓ Proton identification score (from boosted decision tree)

MicroBooNE Preliminary 4.4e+19 POT

ν_e CC0π-Np: 1.2 events
ν_e CC: 0.5 events
Beam Intrinsic ν_μ: 10.7 events
Beam Intrinsic NC: 17.6 events
Outside fid. vol.: 0.9 events
Cosmic contaminated: 2.6 events
Cosmic: 0.7 events
Cosmic in-time: 3.8 events
Data BNB: 34 events

χ^2 / n.d.f. = 0.71
Data / (MC + EXT) = 0.90

Photon-enhanced sample

MicroBooNE Preliminary 4.4e+19 POT

ν_e CC0π-Np: 0.1 events
ν_e CC: 0.3 events
Beam Intrinsic ν_μ: 29.4 events
Beam Intrinsic NC: 2.8 events
Outside fid. vol.: 0.3 events
Cosmic contaminated: 7.1 events
Cosmic: 0.6 events
Cosmic in-time: 2.4 events
Data BNB: 41 events

χ^2 / n.d.f. = 0.45
Data / (MC + EXT) = 0.95

ν_μ-enhanced sample

Roxanne Guenette   MicroBooNE and the future SBN program
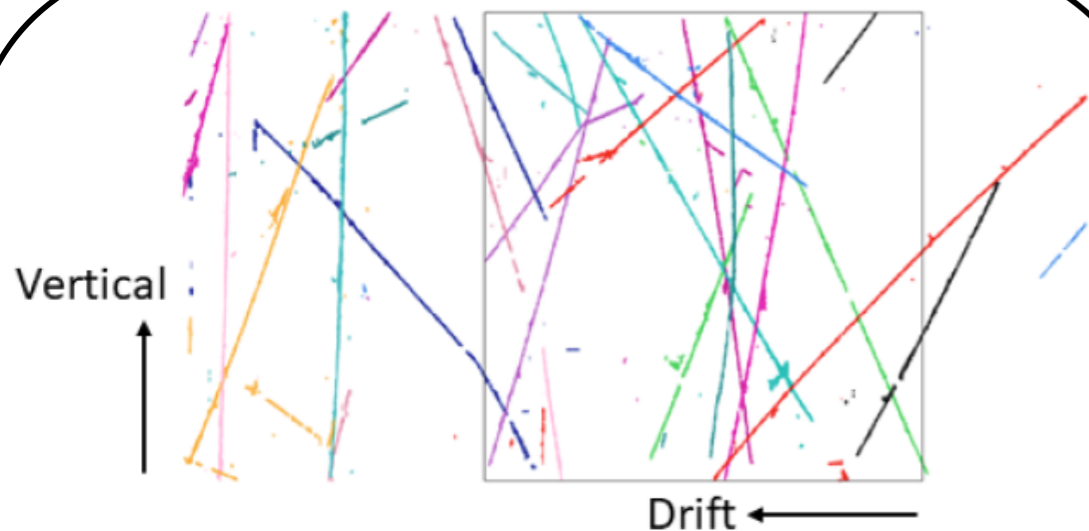
Unresponsive wires

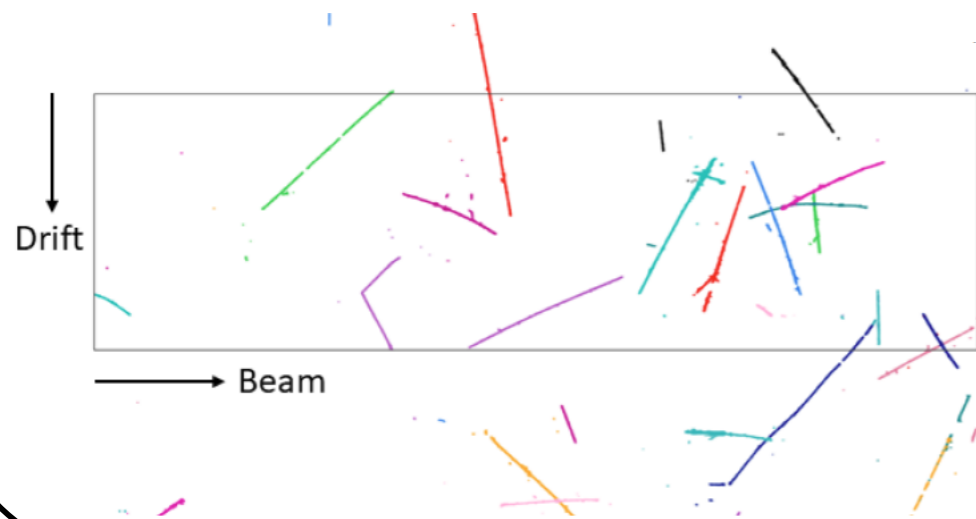**All unresponsive wires on all three planes (~10%)**

All unresponsive wires with no redundancy (~3%)

1. "Towards automated neutrino selection at MicroBooNE using tomorgraphic event reconstruction", MICROBOONE-NOTE-1040-PUB, 2018
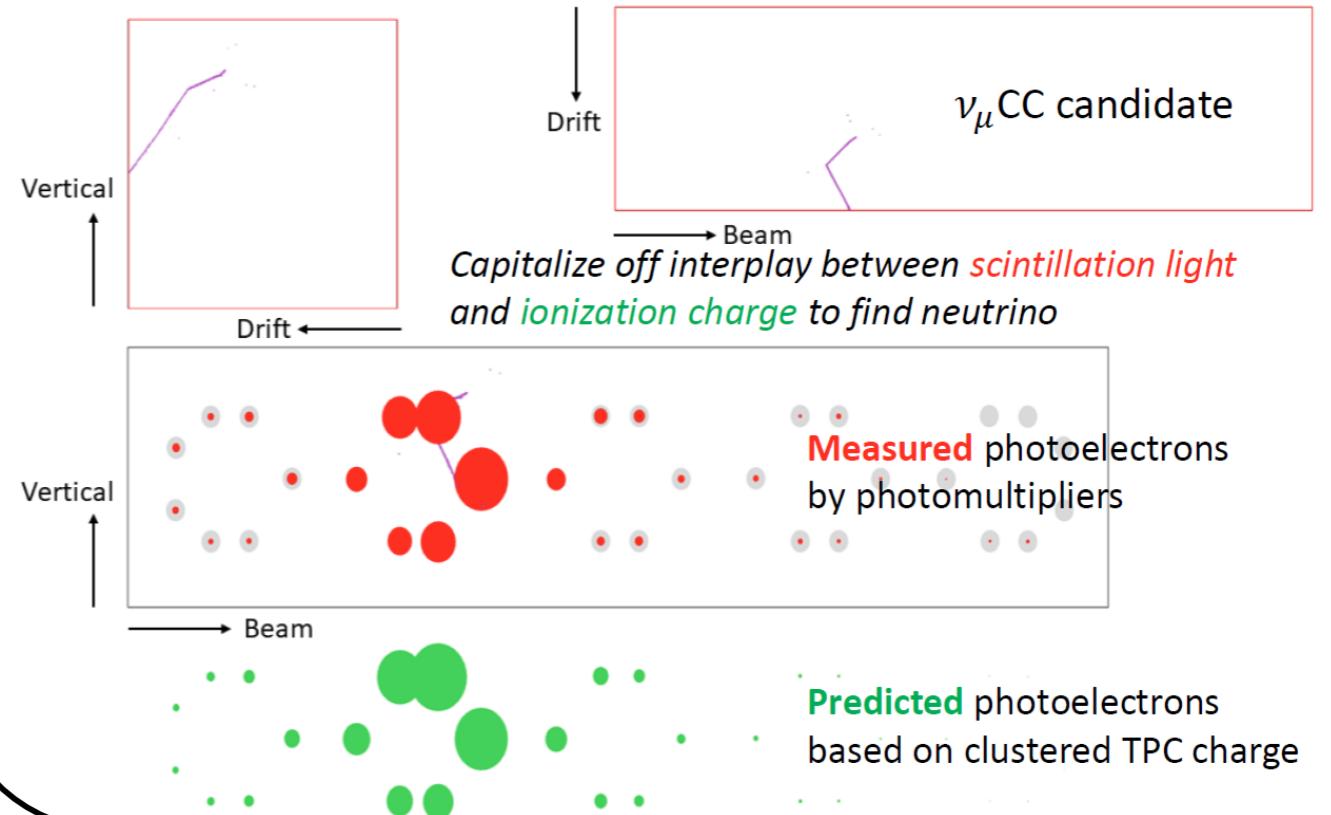
Wirecell

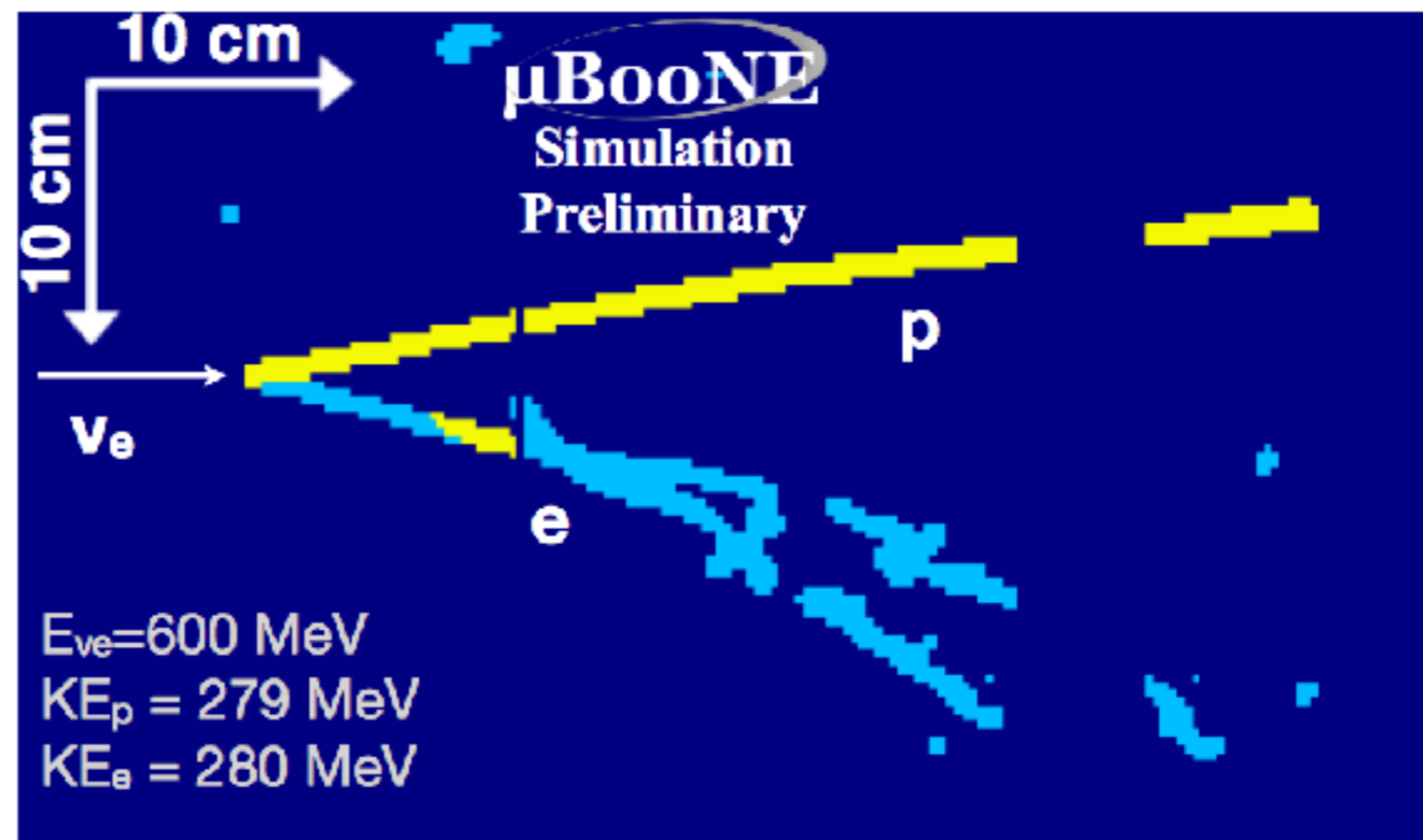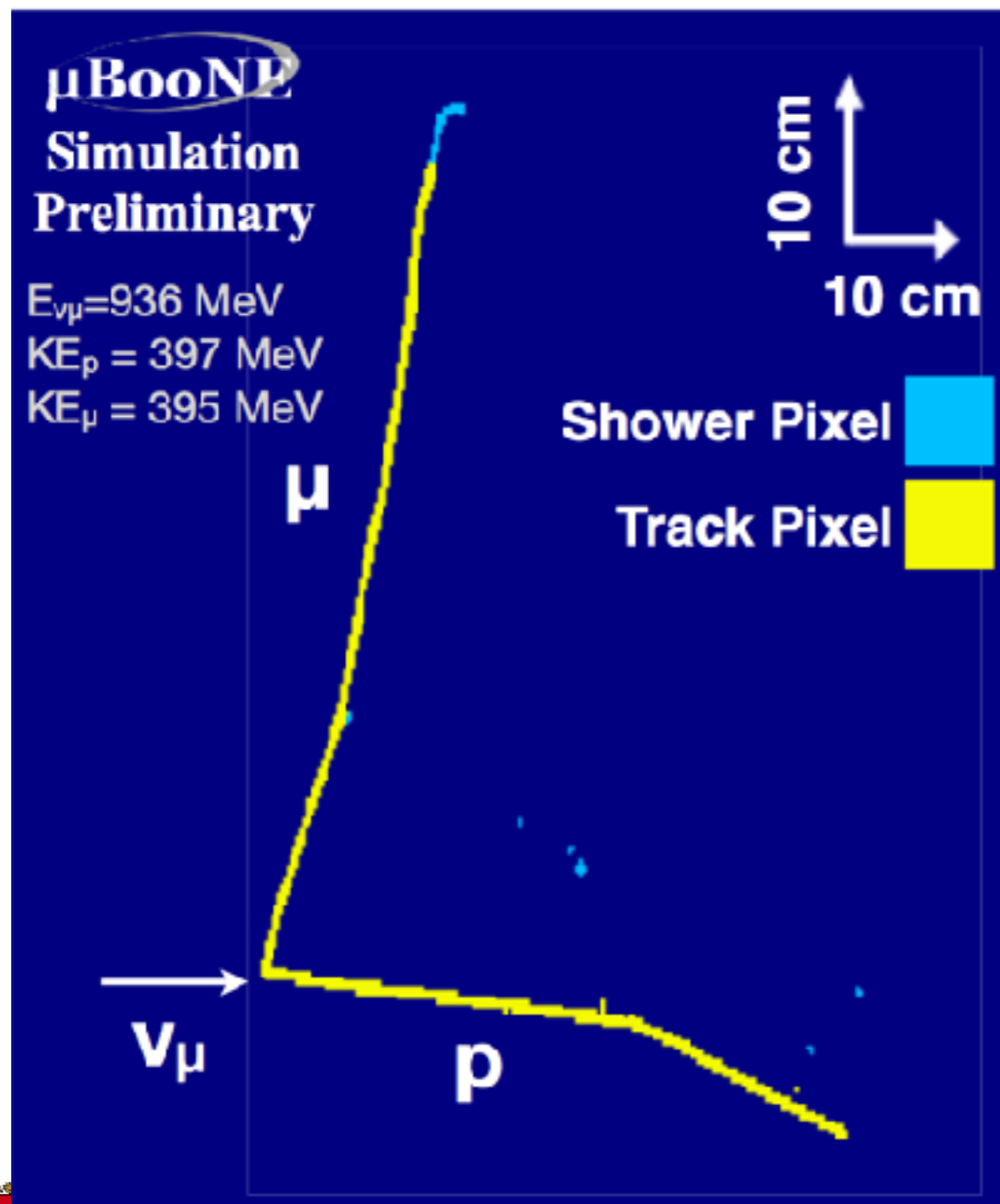Recognized clusters based on 3D event image reconstructed with charge matching

Cosmic removal after TPC cluster/ PMT flash matching

ν_μCC candidate

Capitalize off interplay between scintillation light and ionization charge to find neutrino

Measured photoelectrons by photomultipliers

Predicted photoelectrons based on clustered TPC charge

- "Three-dimensional imaging for large LArTPCs", JINST 13, P05032
- Poster: "Recent Progress on Wire-Cell Tomographic Event Reconstruction for LArTPCs", H. Wei
- Poster: "Towards Automated Neutrino Selection at MicroBooNE using Tomographic Event Reconstruction", B. Russell
- MICROBOONE-NOTE-1040-PUB

Deep Learning

Example of SSNET pixel labeling

μBooNE
Simulation
Preliminary

$E_{\nu\mu}$=936 MeV
KE_p = 397 MeV
KE_μ = 395 MeV

10 cm
10 cm

Shower Pixel
Track Pixel

μ

ν_μ p

10 cm
10 cm

μBooNE
Simulation
Preliminary

p

ν_e

e

$E_{\nu e}$=600 MeV
KE_p = 279 MeV
KE_e = 280 MeV

Noise Filtering in MicroBooNE

- Initial data taking indicated significant "noise" on TPC waveforms above what was expected by the reconstruction team

- Significant effort undertaken on the part of many people to identify the various sources of noise and other issues
  - Identification of the sources of noise seen on the waveforms:
    - Low frequency "coherent" noise due to voltage regulators on the service boards
    - Harmonic noise due to HV power supplies
    - High frequency "Burst" noise probably associated to PMT HV supply
  - Understanding other issues impacting waveforms
    - Misconfigured channels - wrong gain and/or shaping time
    - Shorted channels
    - Periodic saturation of ASIC's

- Sophisticated software noise filtering mitigation package put in place

Publication
1. *"Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC"*, arXiv:1705.07341, JINST 12, P08003 (2017)
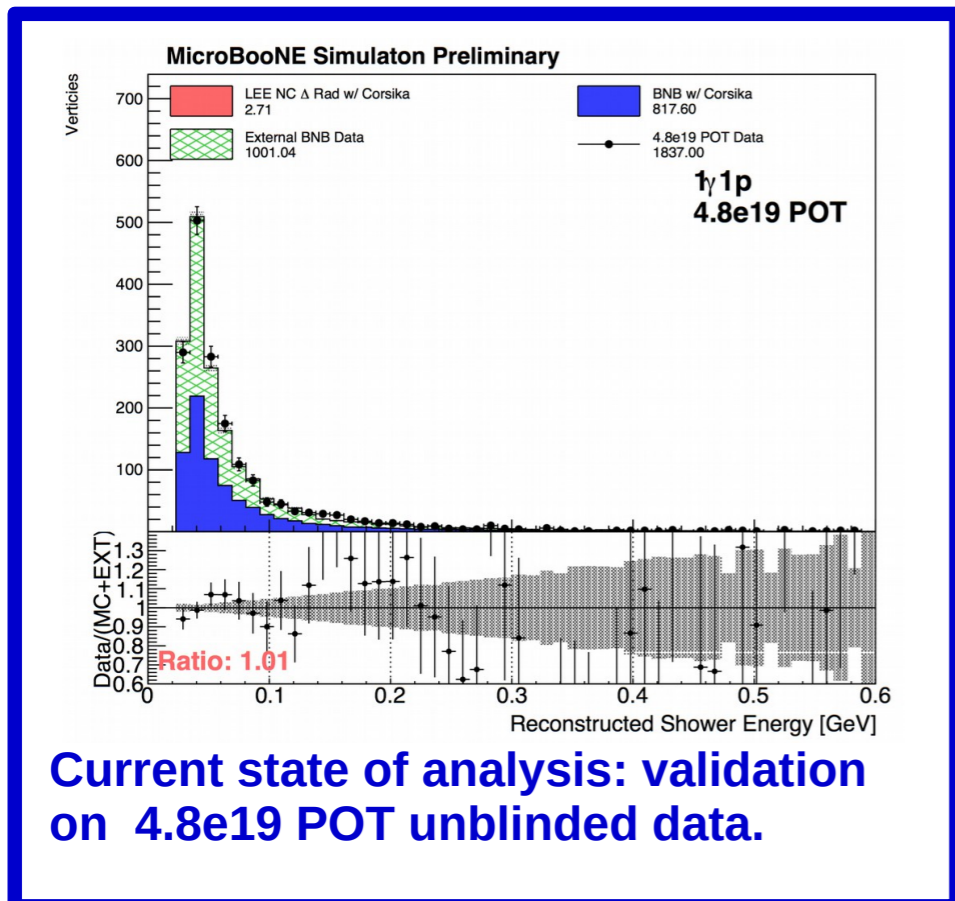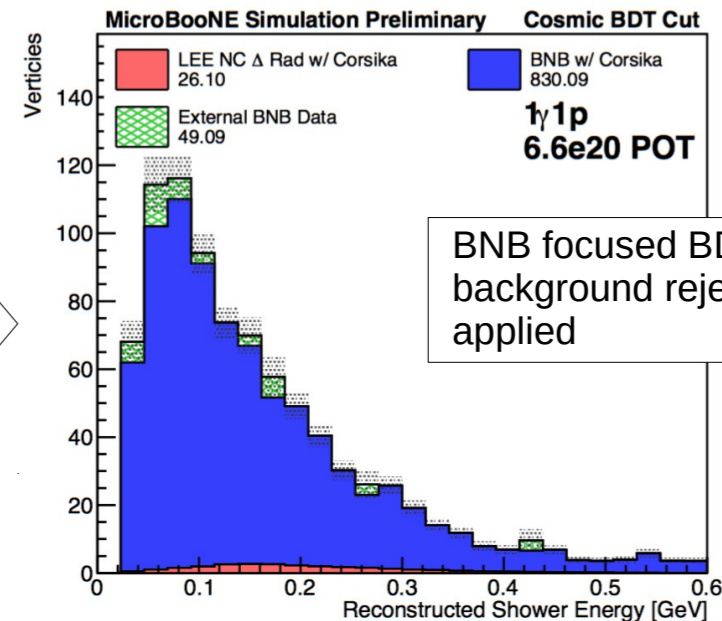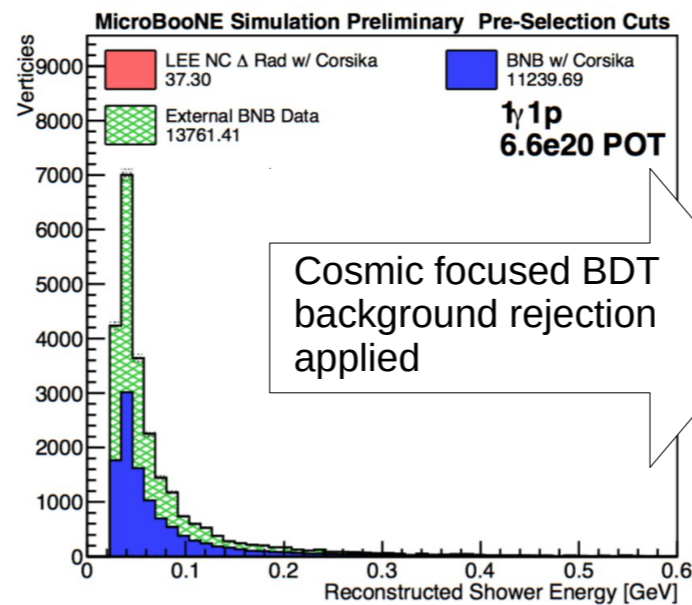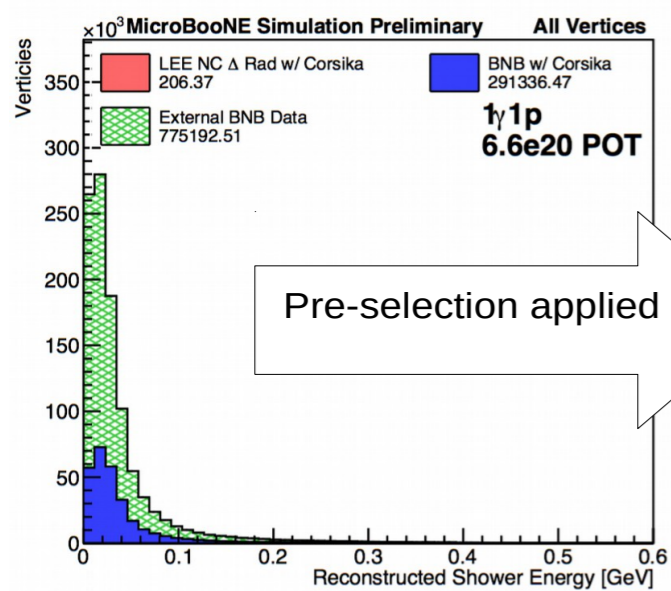
Signal Processing

- Digitized signal we measure differs from the actual ionization deposited by the original particle due to several effects:

  - Physics of the drift: recombination, electron lifetime, diffusion, etc.

  - Electric field signal response on the wires (field response)

  - Electronics response

- The Signal Processing stage has as its primary goal to unfold the field and electronics responses to recover the number of ionization electrons passing by each wire at each sampled time.

  - Recombination, lifetime, diffusion, etc., are addressed in the reconstruction and analysis stages

1. *"Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE"*, arXiv:1804.02583, submitted to JINST
2. *"Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation"*, arXiv:1802.08709, accepted by JINST

Slide from T. Usher
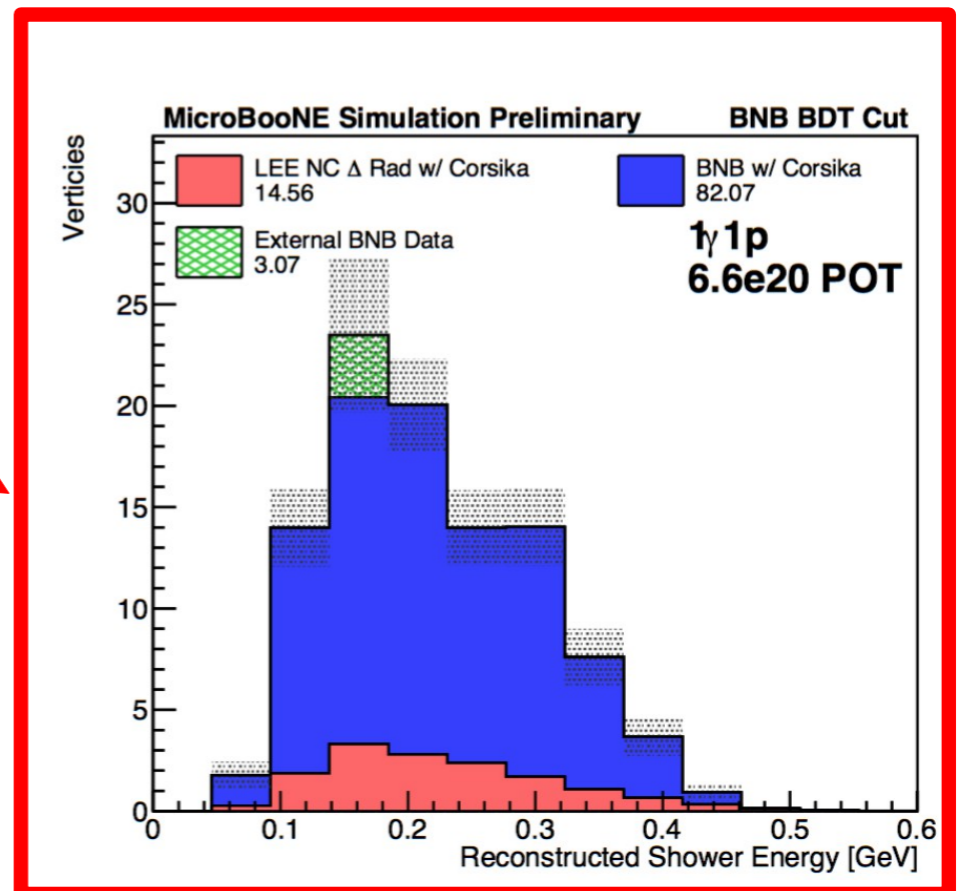
Single photon

Starting with Pandora-reconstructed and vertex-optimized 1g1p events...

Pre-selection applied

Cosmic focused BDT background rejection applied

BNB focused BDT background rejection applied

Final 1γ+1p selection

Current state of analysis: validation on 4.8e19 POT unblinded data.

Single photon

Post BNB BDT: Cut @ 0.52 Total: 82.1
MicroBooNE Simulation Preliminary

$1\gamma 1p$ 6.6e20 POT

NC Δ Radiative γ	**0.00**	(0.0%)
CC $\pi^0 \to \gamma$	**3.62**	(4.4%)
NC $\pi^0 \to \gamma$	**69.45**	(84.6%)
Non π^0 γ	**0.30**	(0.4%)
Intrinsic ν_e electron	**1.17**	(1.4%)
BNB Michel $e^\pm$	**0.00**	(0.0%)
BNB Other	**3.91**	(4.8%)
Cosmic Michel $e^\pm$	**2.41**	(2.9%)
Cosmic Other	**1.21**	(1.5%)
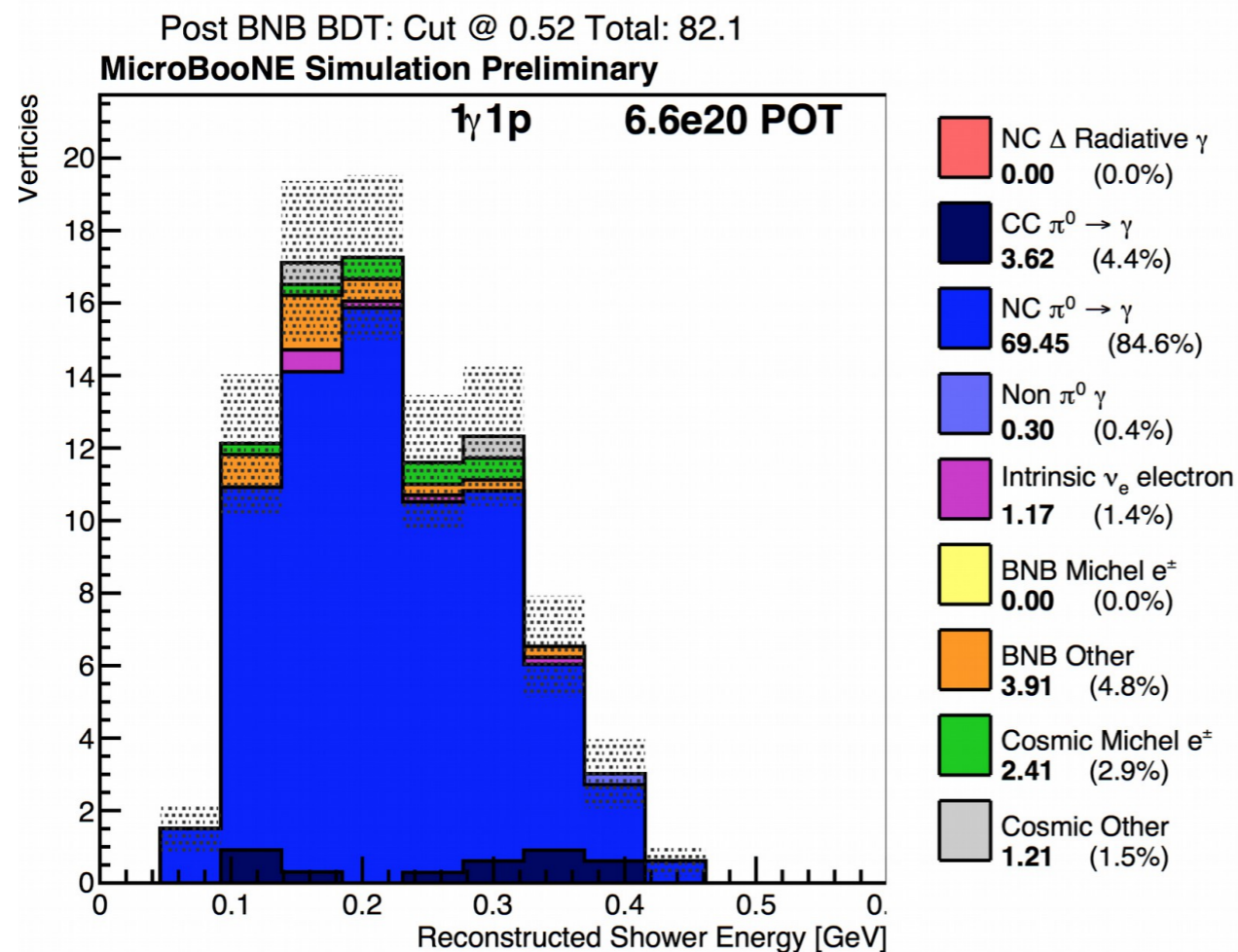
**Vast majority of remaining background comprised of NC $\pi^0 \to 2\gamma$ decay. Working on further background reduction strategies for NC $\pi^0 \to 2\gamma$ decay**

Projected stats-only sensitivity on the 6.6e20 POT dataset would exclude a 4.6xSM cross-section at 99 % C.L. (photon LEE at 3xSM).

CLs Exclusion Sensitivity

MicroBooNE Simulation Preliminary   **Stat Only**

6.6e20 POT

- 95% Experiments
- Median Experiment
- 68% Experiments

90% C.L

95% C.L

99% C.L

LEE (x3)

$\sigma_{(\Delta \to N\gamma)}$ [units of SM σ]
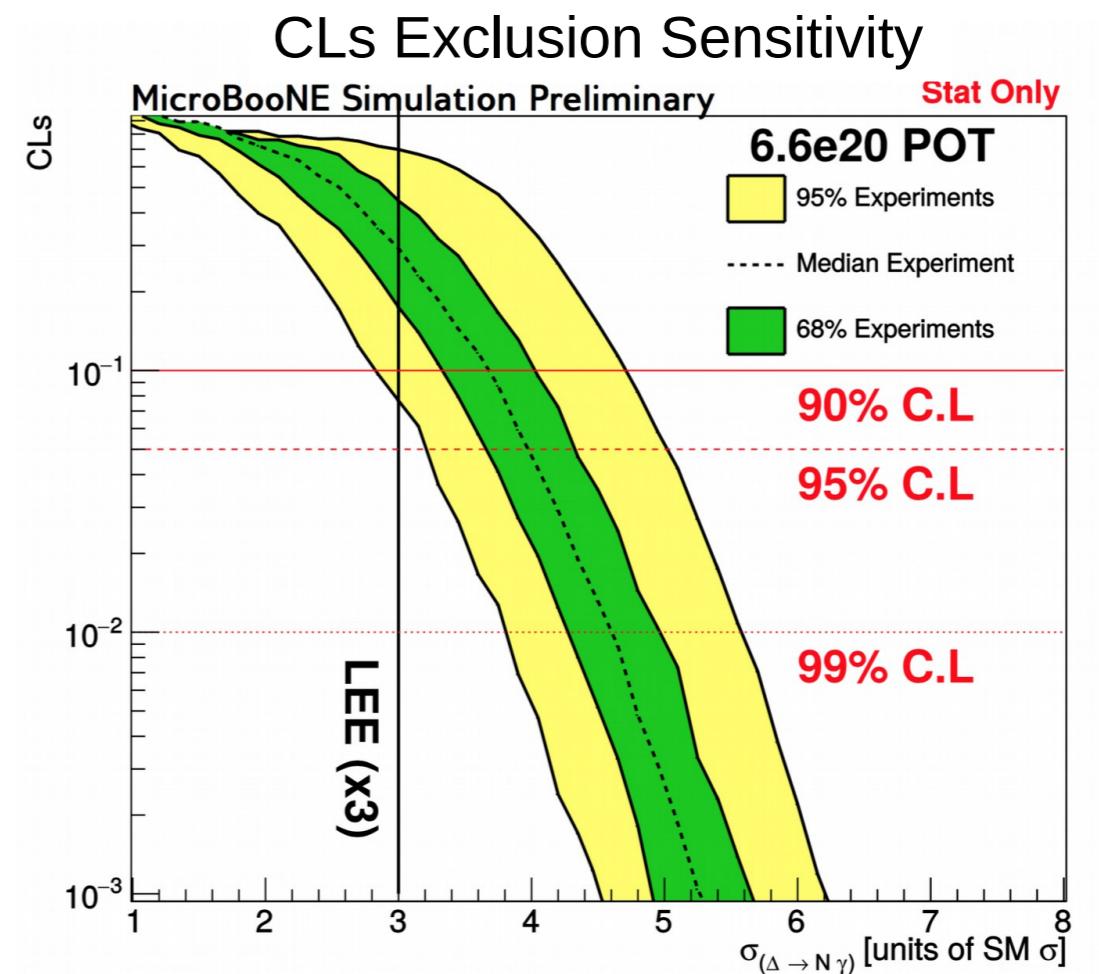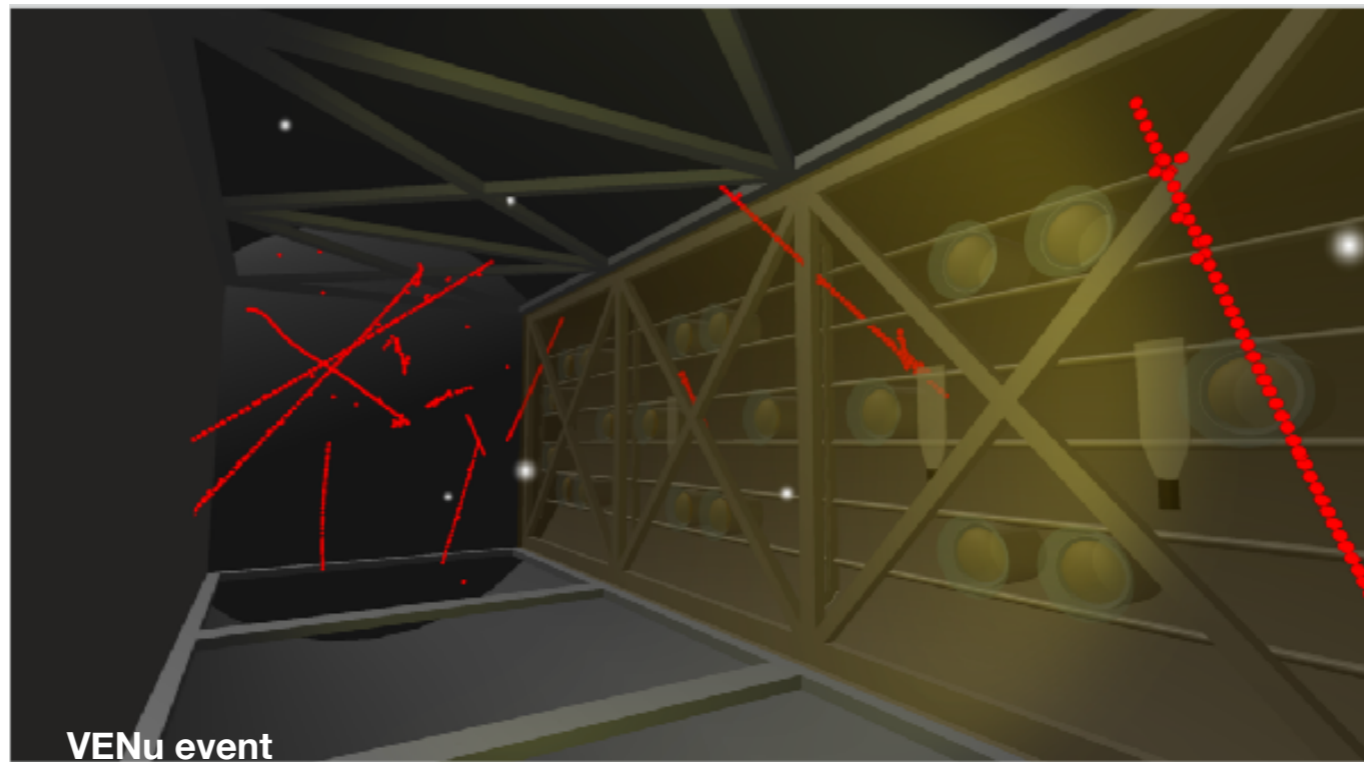
Potential signal modeling

- Example of nueCC and single photon (NC resonant delta production) signal modeling in MicroBooNE
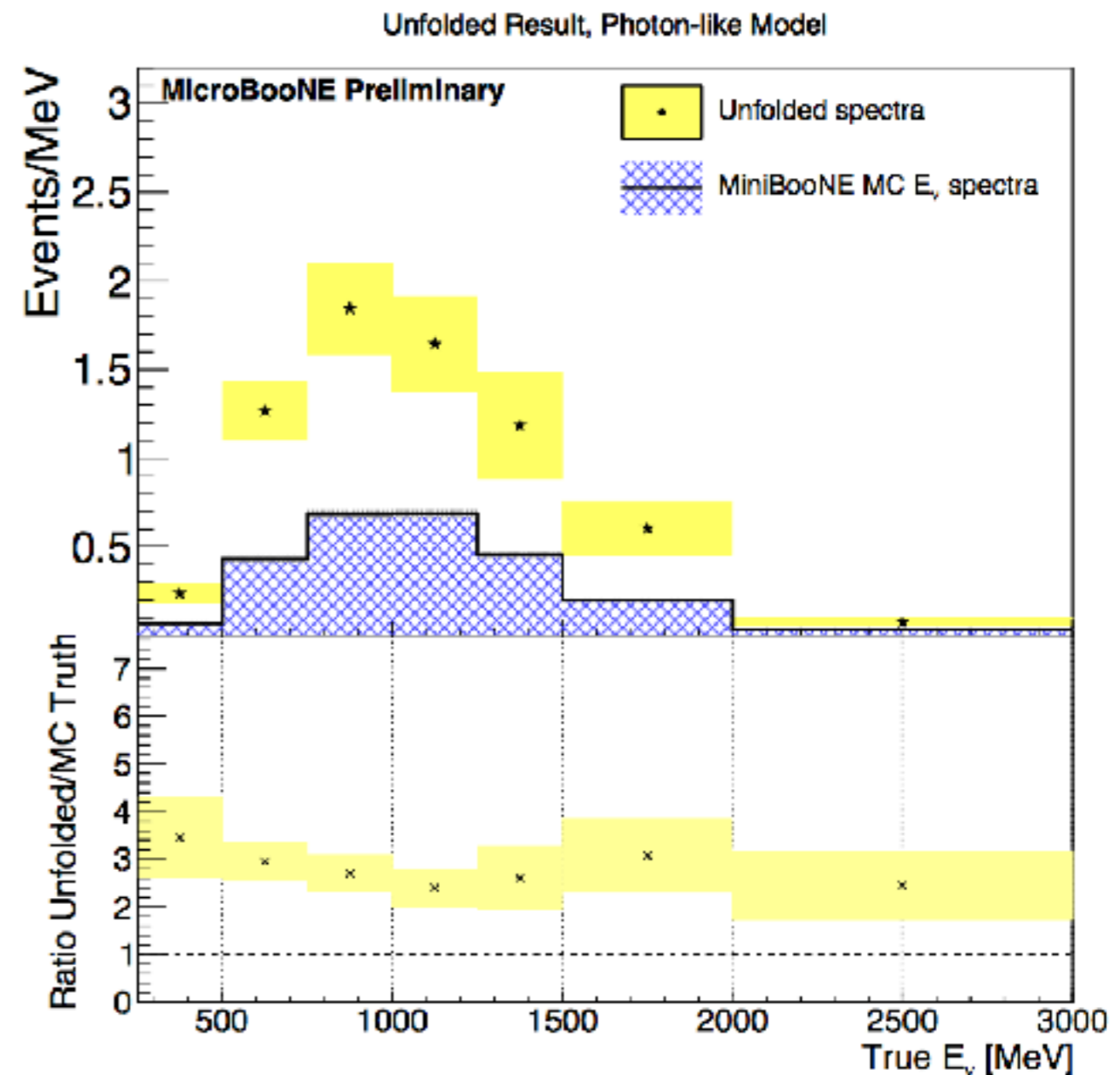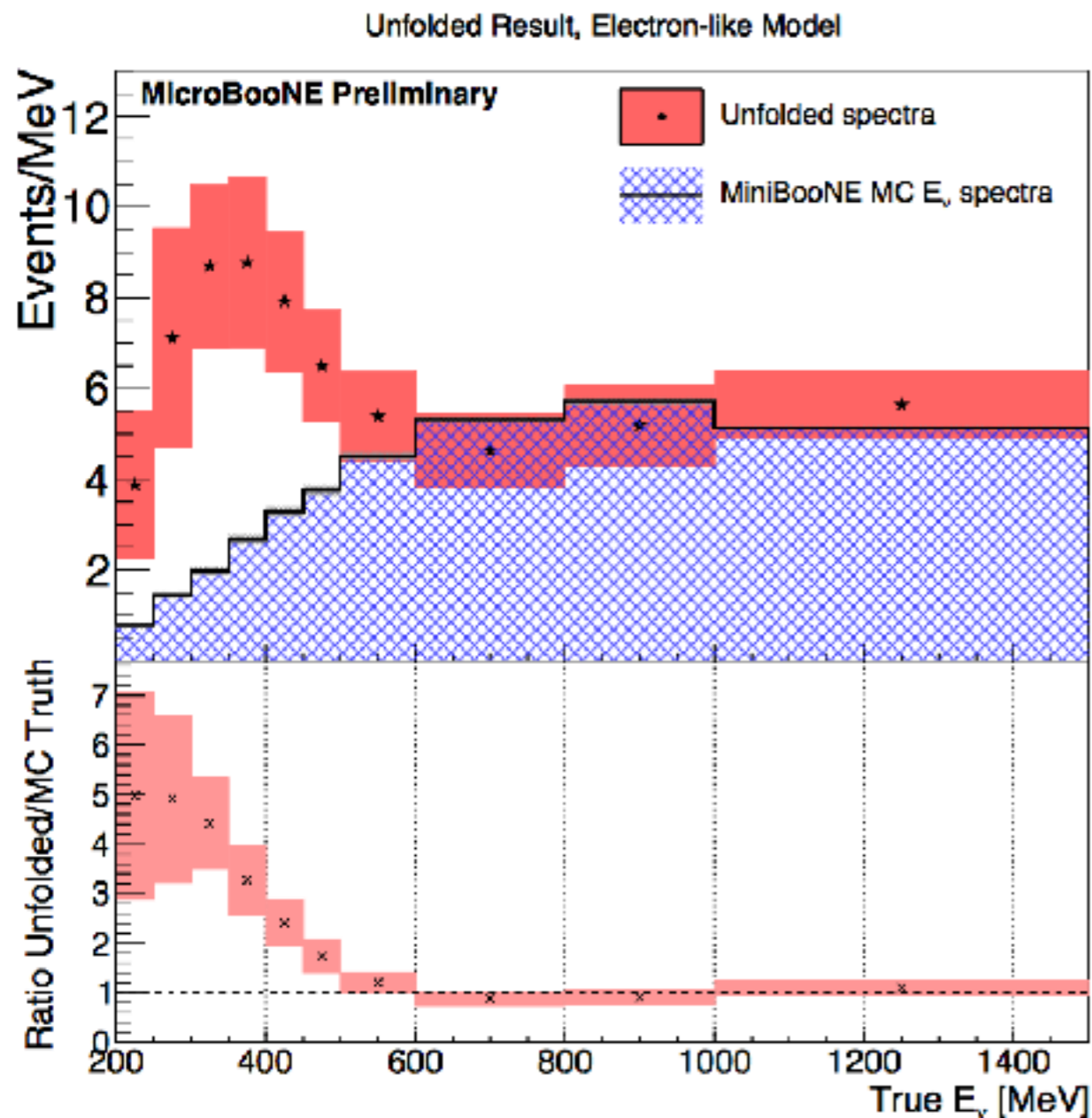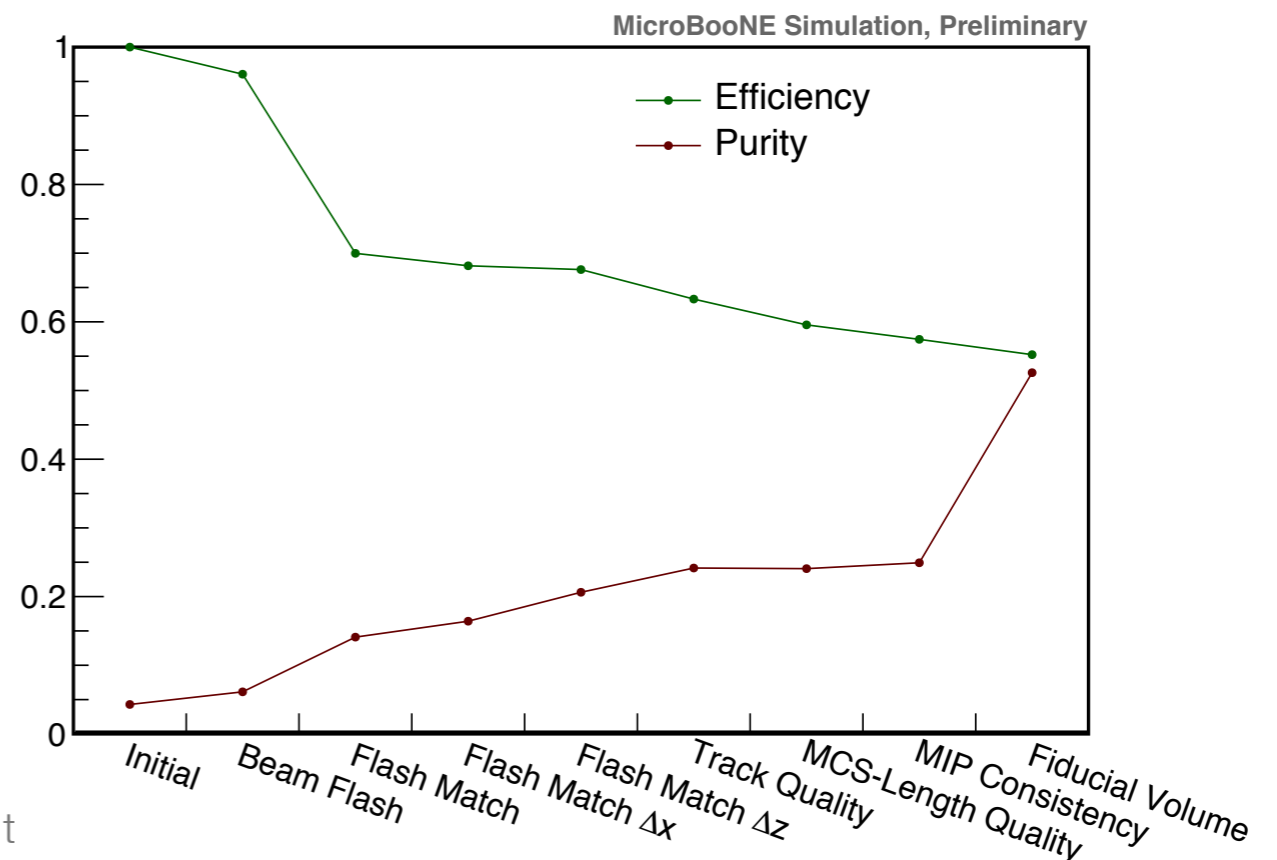

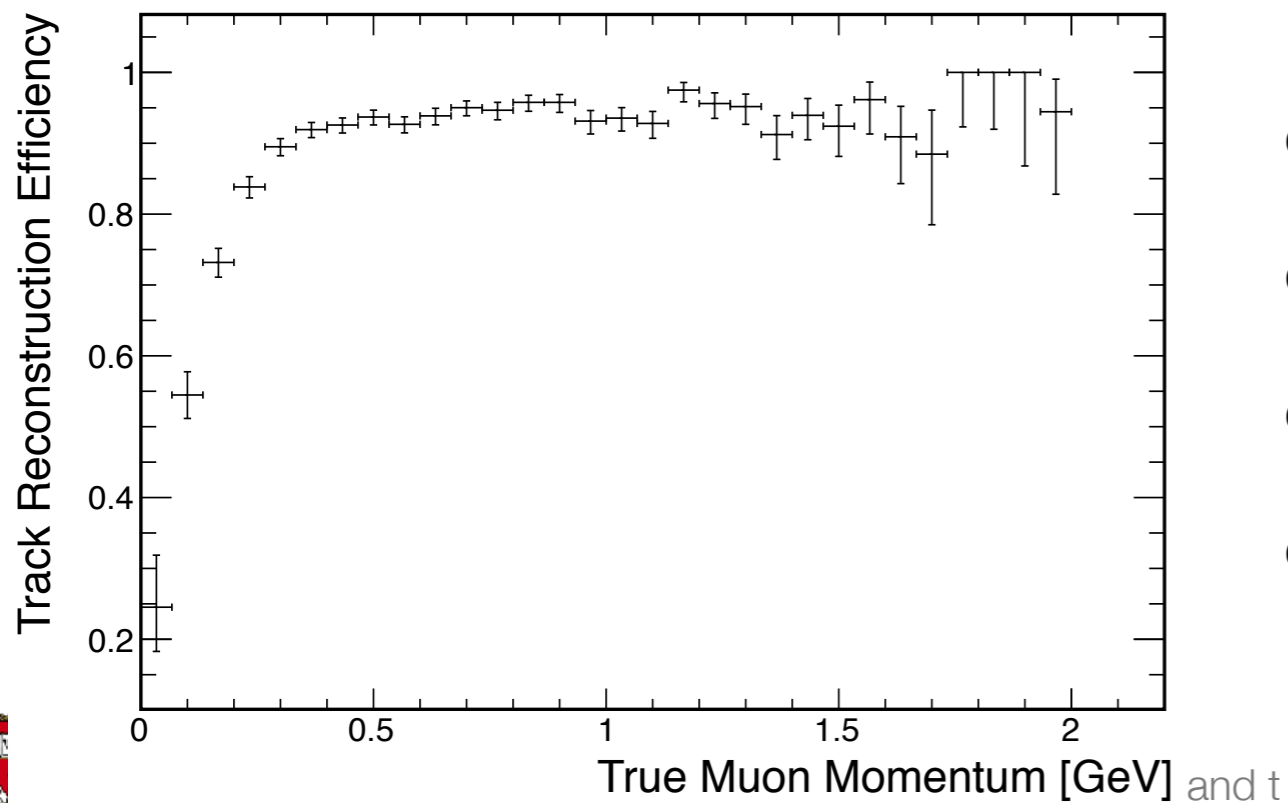**1. MicroBooNE tests of the MiniBooNE low-energy excess, MICROBOONE-NOTE-1043-PUB, 2018**
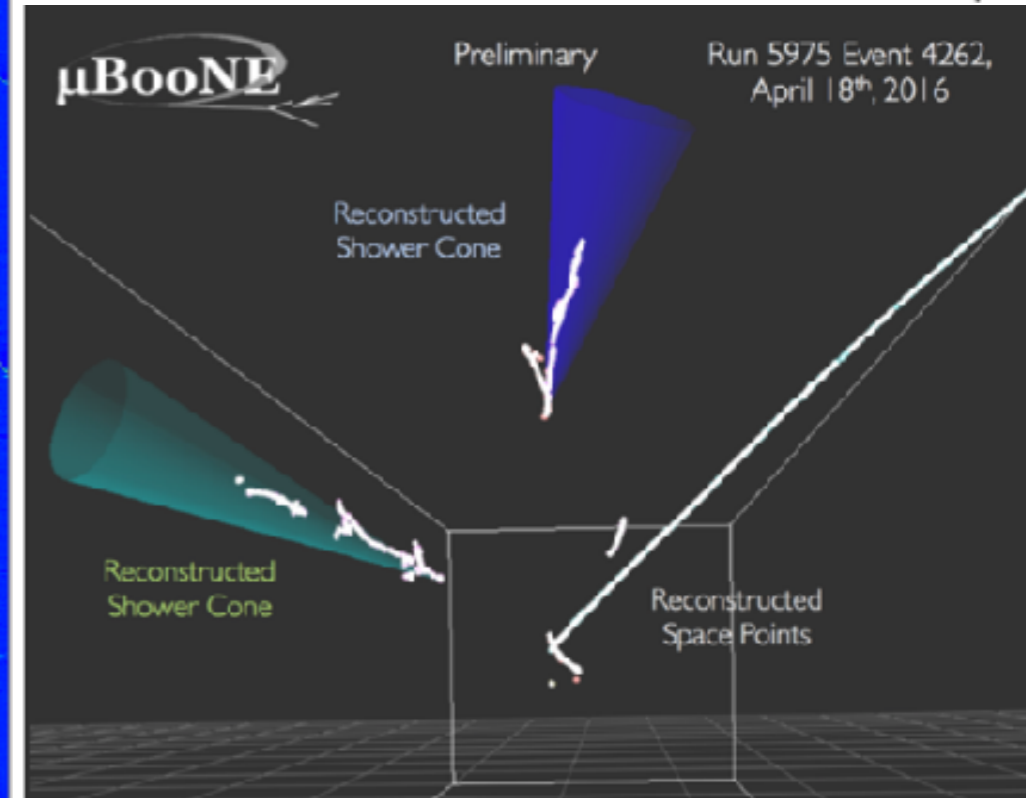
ν_μ CC Inclusive measurement

VENu event

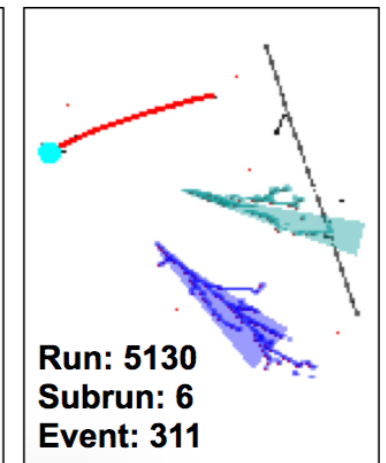MicroBooNE Simulation, Preliminary

CC-π^0 cross-section measurement

Preliminary — Run 5975 Event 4262, April 18th, 2016

Reconstructed Shower Cone

Reconstructed Shower Cone

Reconstructed Space Points

Poster: J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC

Public Note: MICROBOONE-NOTE-1032-PUB, 2018

Run: 5215
Subrun: 28
Event: 1403

Run: 5519
Subrun: 189
Event: 9472

Run: 5850
Subrun: 153
Event: 7760

Run: 5130
Subrun: 6
Event: 311
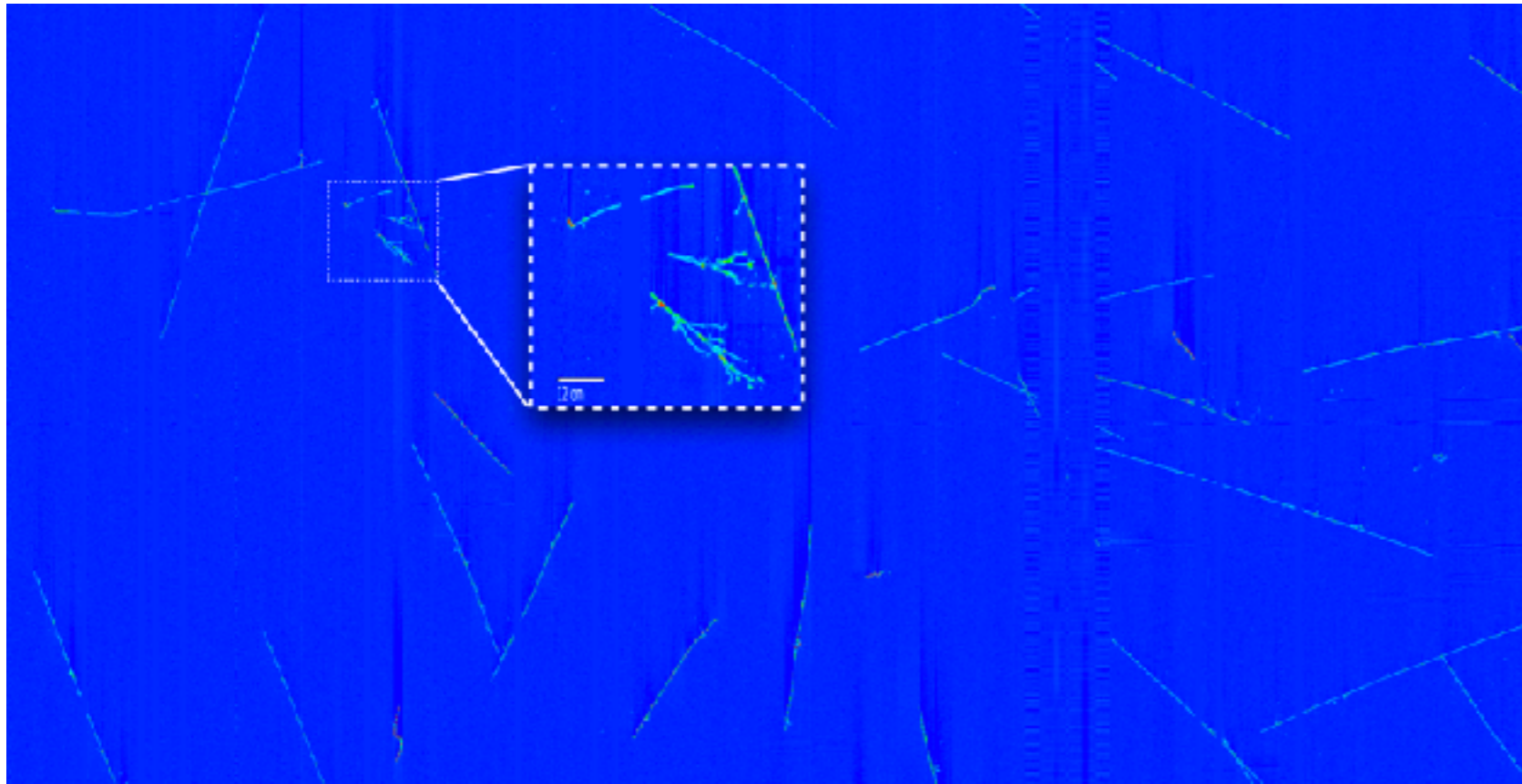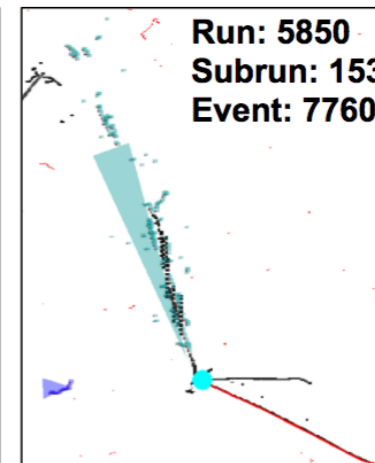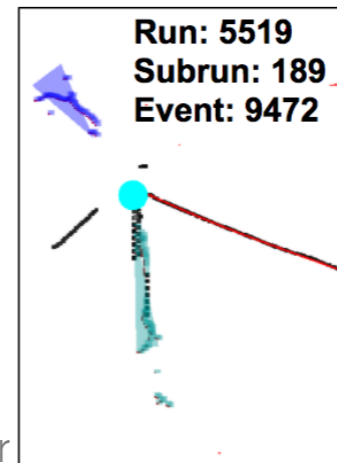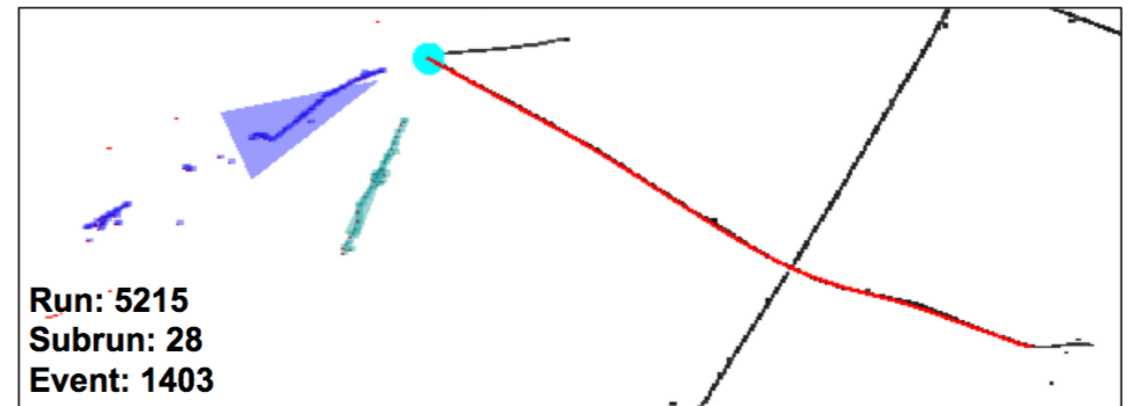
CC-π^0 reconstruction and selection
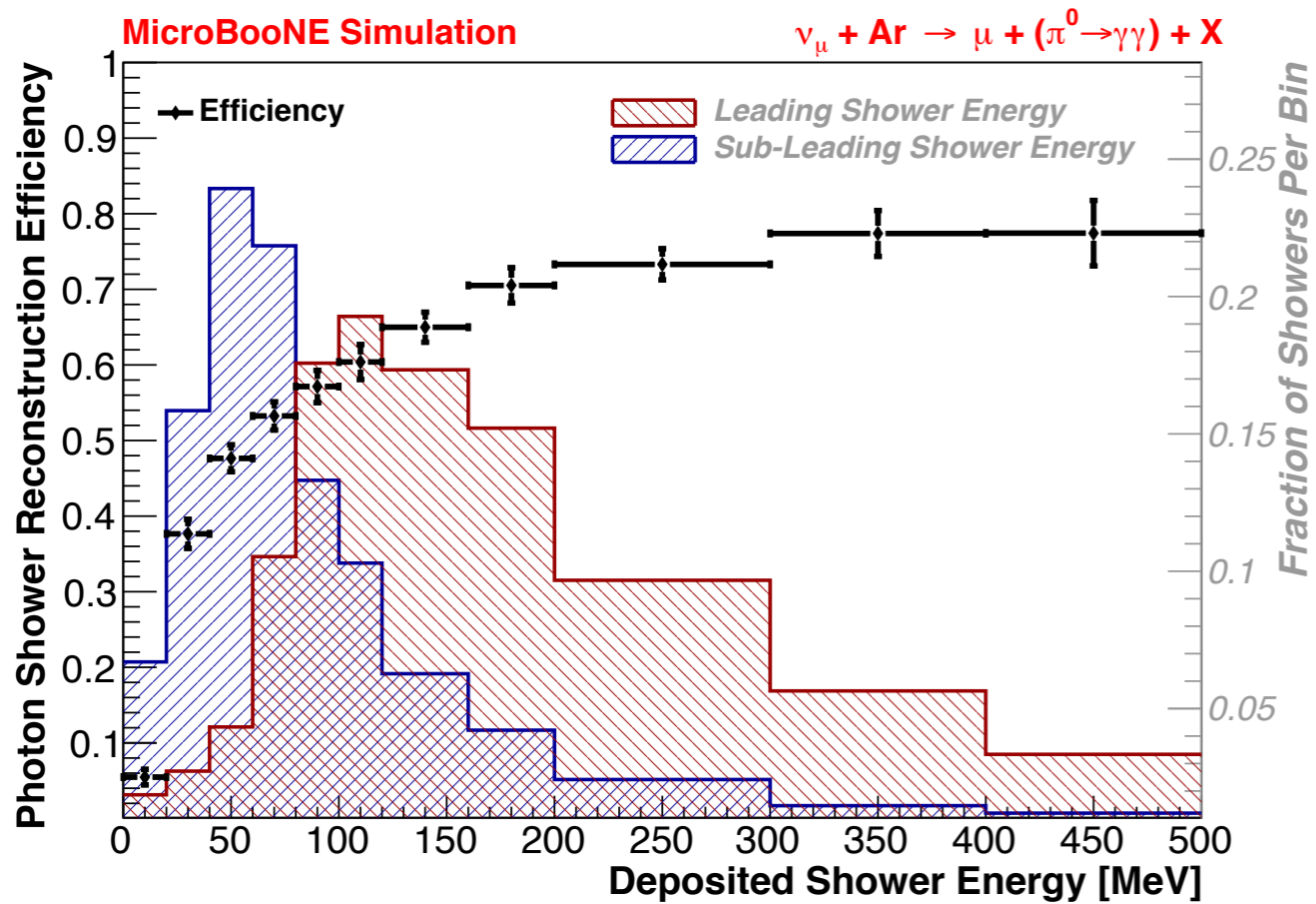
Average reconstruction efficiencies:

62% for leading CC-π^0 shower

50% for subleading CC-π^0 shower

80% above 300 MeV

Roxanne

CC-π^0 results

CC-π^0 selections:

- One shower: 771 events:
  Efficiency 17% and Purity 53%

- Two showers: 224 events
  Efficiency 6% and Purity 64%
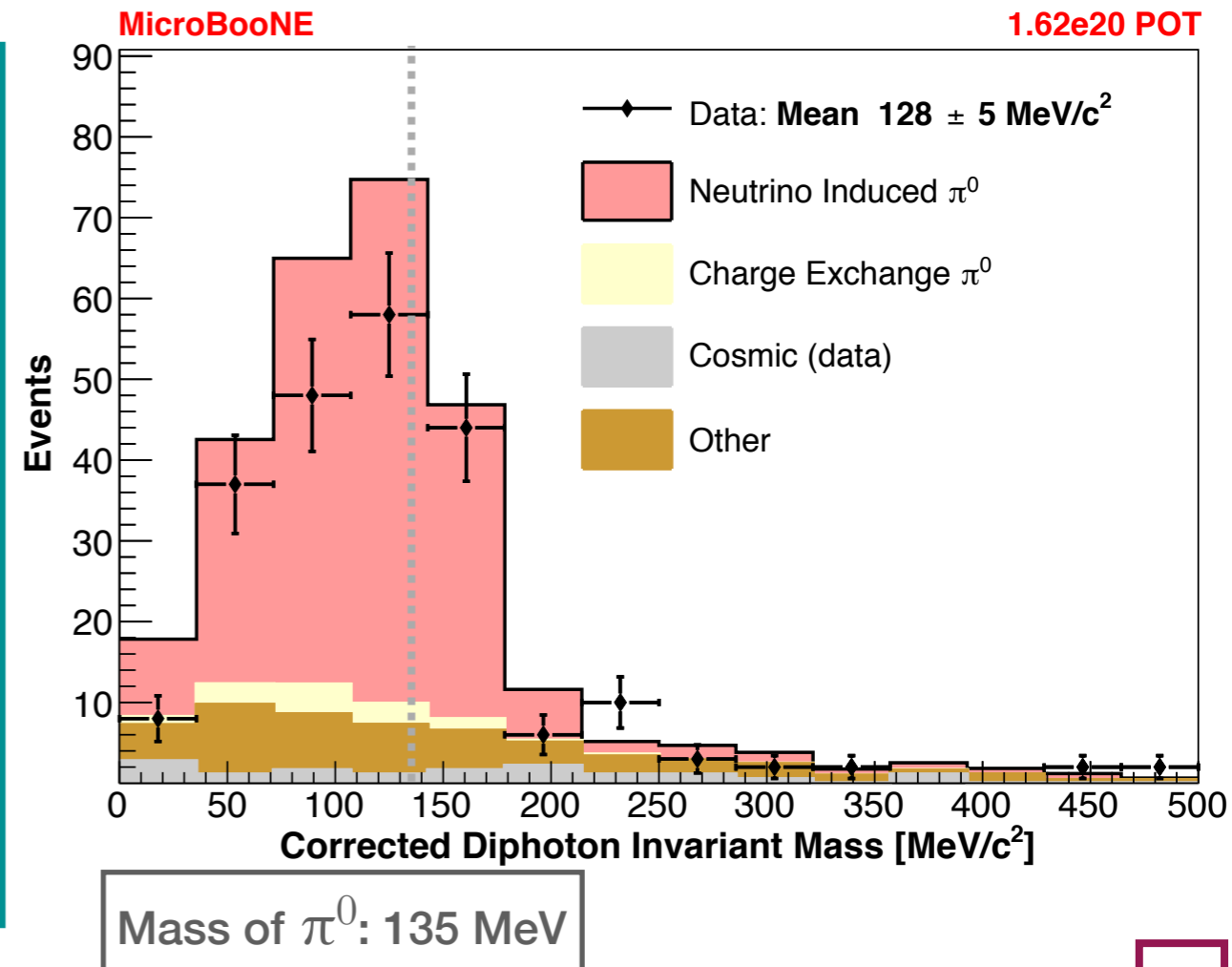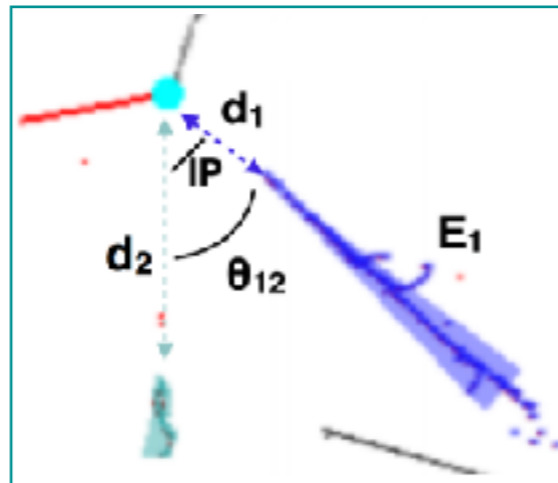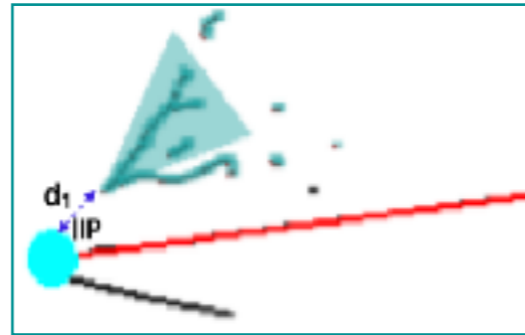
MicroBooNE **1.62e20 POT**

Data: **Mean 128 ± 5 MeV/c^2**

Neutrino Induced π^0

Charge Exchange π^0

Cosmic (data)

Other

Events

Corrected Diphoton Invariant Mass [MeV/c^2]

Mass of π^0: 135 MeV

REFERENCE here

Roxanne

numuCC (1μNp)

run 5386, subrun 10, event 528

1. *"Towards measurements of nuclear effects in MicroBooNE",* MICROBOONE-NOTE-1046-PUB, 2018

Roxanne Guenette   MicroBooNE and the future SBN program
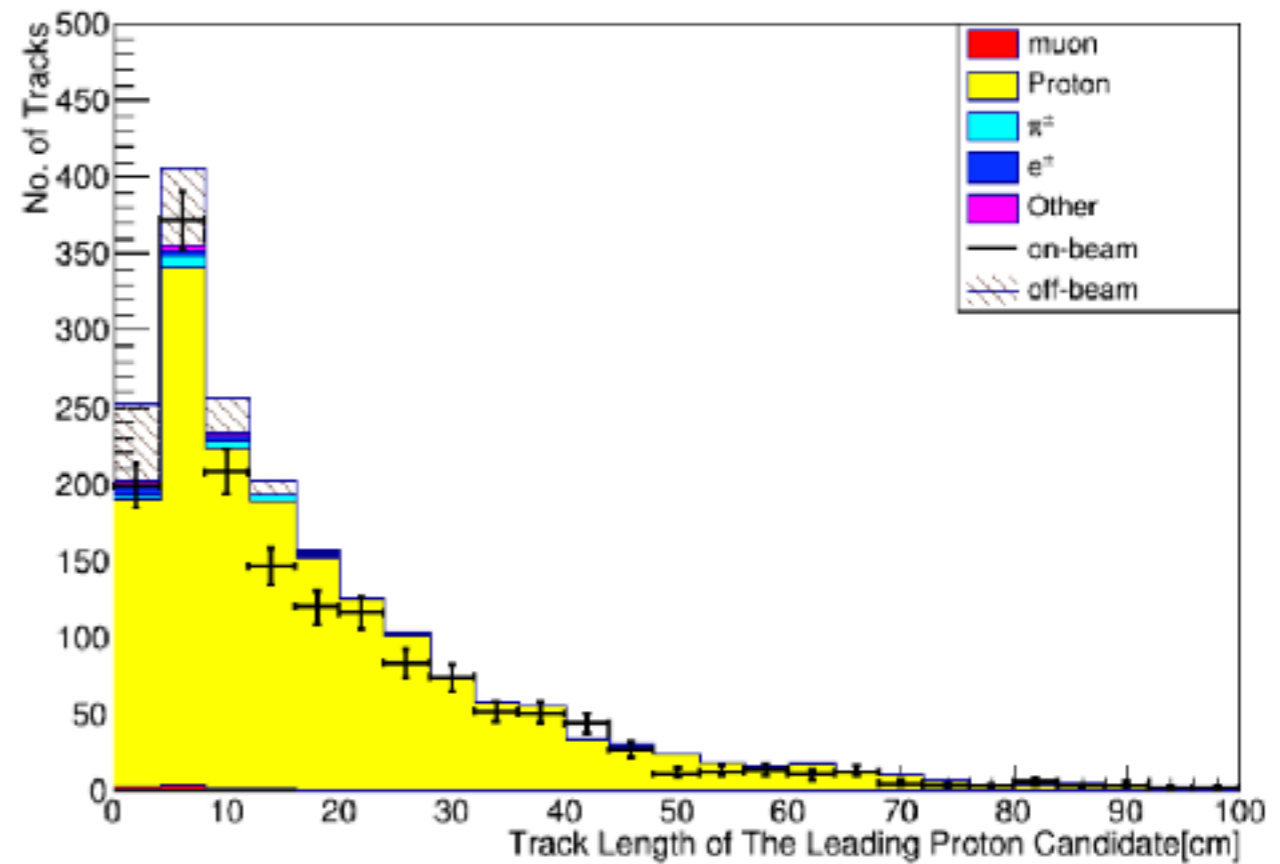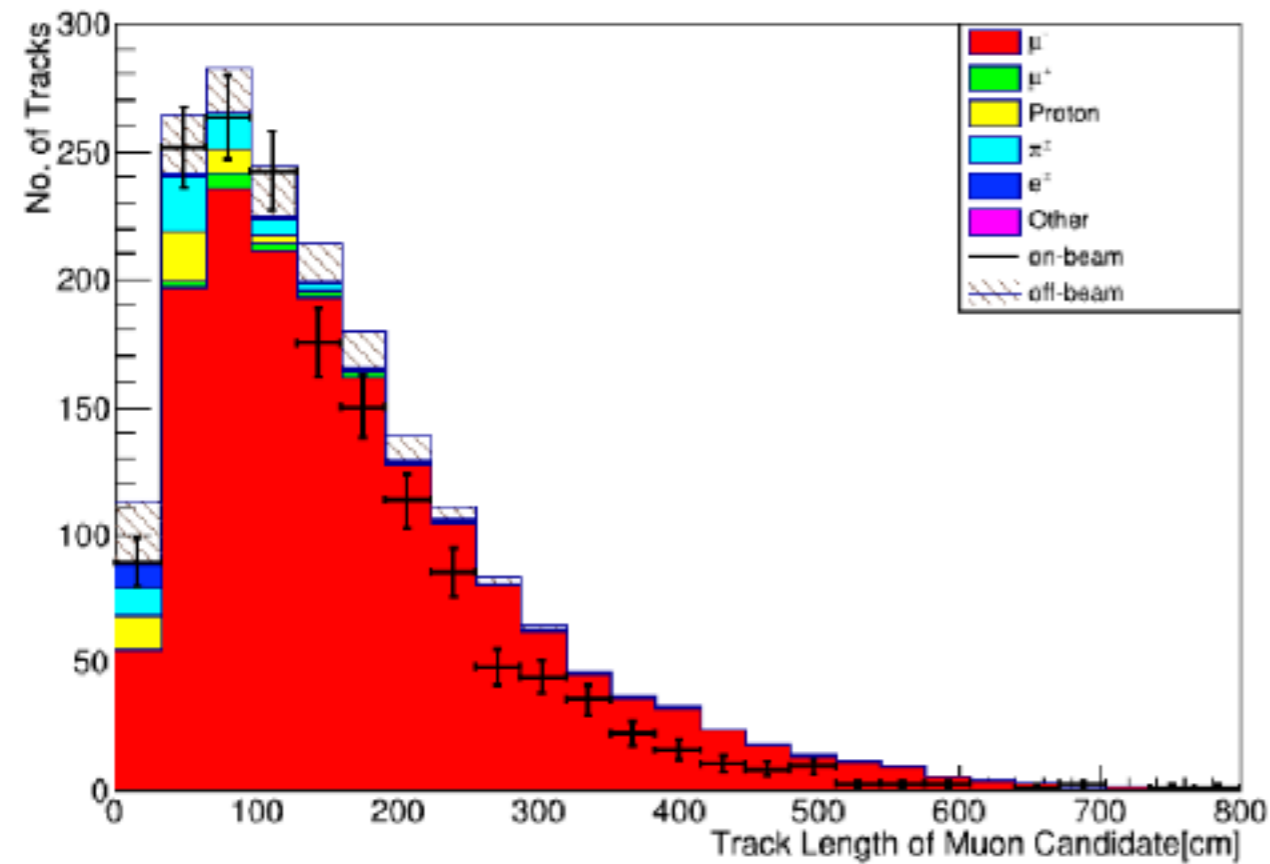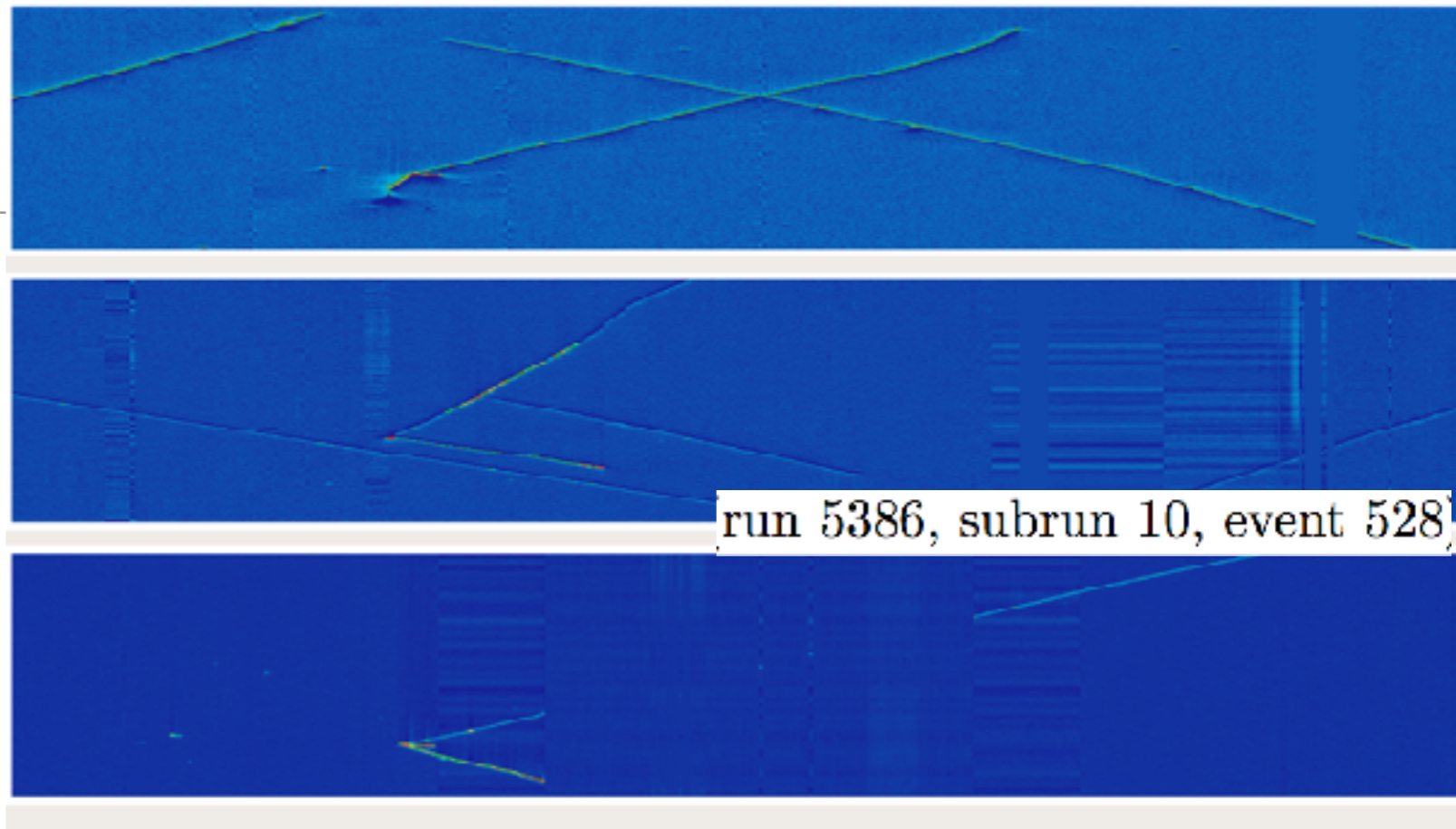
Short-baseline anomalies:

- The search for new physics is the holy-grail of the particle physics community
- The DUNE long-baseline program will strongly rely on the resolution of these anomalies (extra oscillation can lead to mis-interpretation of the flagship δ_{CP} measurement

Example of impact of sterile neutrino on LBL experiment

B. Kayser, proceedings C16-03-12, 2016

Presence of sterile neutrinos directly affect the oscillation spectrum at DUNE, leading to the wrong interpretation

Other references: **S. K. Agarwalla, S. S. Chatterjee, A. Dasgupta and A. Palazzo, JHEP 1602, 111 (2016)**
D.Dutta, R. Gandhi, B. Kayser, M. Masud and S. Prakash, JHEP 11, 122 (2016)

Physics results

Publications

1. "Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions", arXiv:1805.06887, submitted to PRD (2018)

Public Notes

1. "First measurement of muon neutrino charged-current neutral pion production in LArTPC", MICROBOONE-NOTE-1032-PUB, 2018
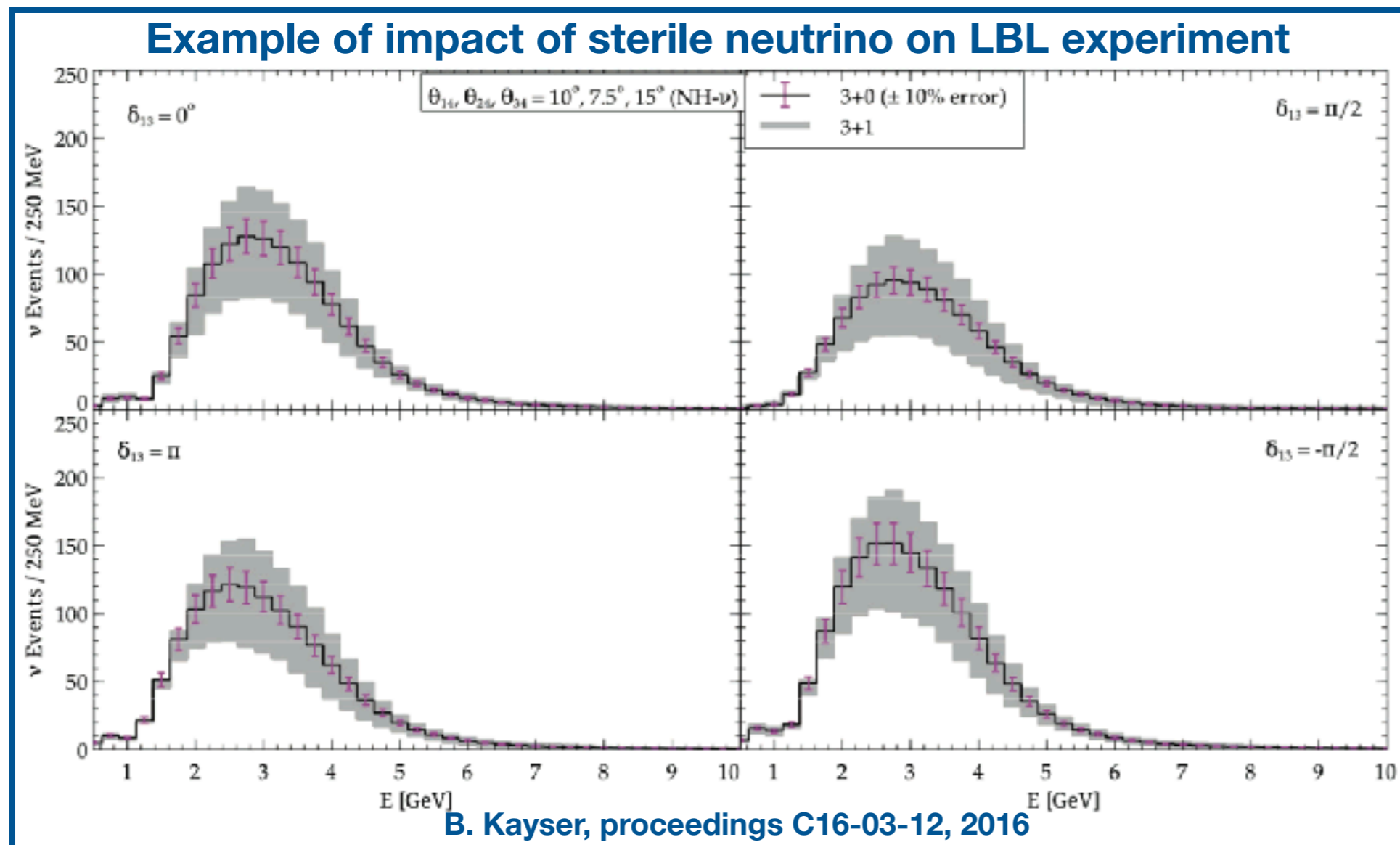
2. "First measurement of muon neutrino charged-current inclusive cross-section measurement in MicroBooNE", MICROBOONE-NOTE-1045-PUB, 2018

3. *"Towards measurements of nuclear effects in MicroBooNE",* MICROBOONE-NOTE-1046-PUB, 2018

4. "Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction", MICROBOONE-NOTE-1038-PUB, 2018

5. "Search for NC single photon events in MicroBooNE", MICROBOONE-NOTE-1041-PUB, 2018

6. "MicroBooNE tests of the MiniBooNE low-energy excess", MICROBOONE-NOTE-1043-PUB, 2018

7. "Booster Neutrino Flux Prediction at MicroBooNE", MICROBOONE-NOTE-1031-PUB, 2018

Detector Physics results

Publications

1. *"Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE"*, arXiv:1804.02583, submitted to JINST

2. *"Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation"*, arXiv:1802.08709, accepted by JINST

3. *"Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC"*, arXiv:1705.07341, JINST 12, P08003 (2017)

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