

MicroBooNE Status & Results

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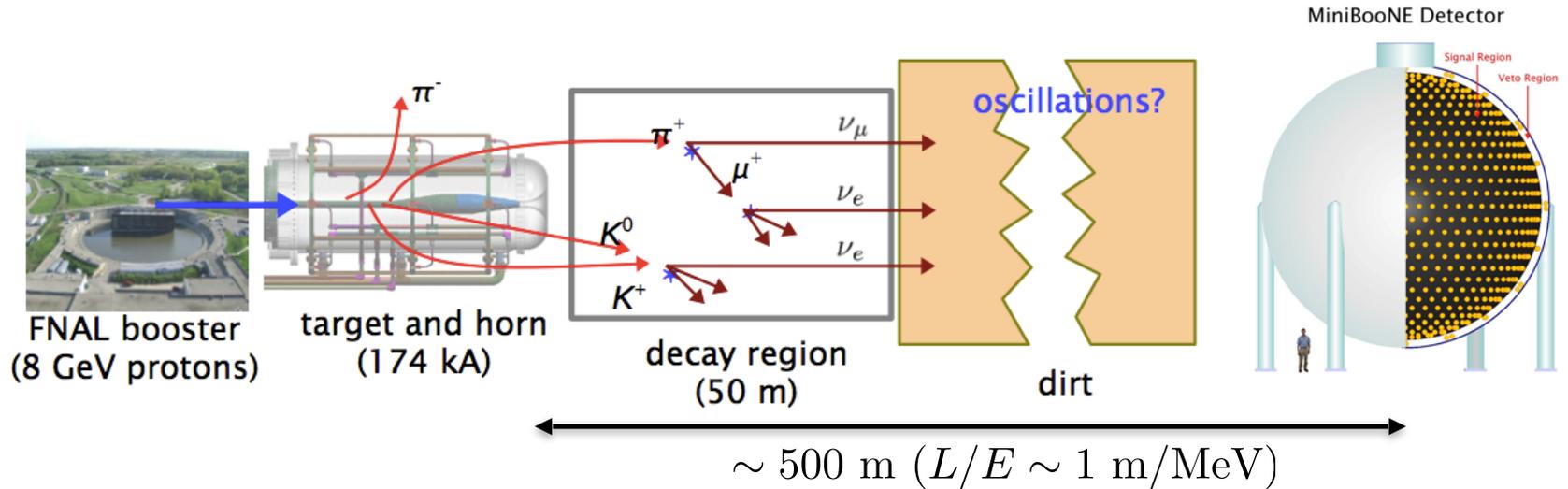
NOW 2018 Conference
9/10/2018

26 cm

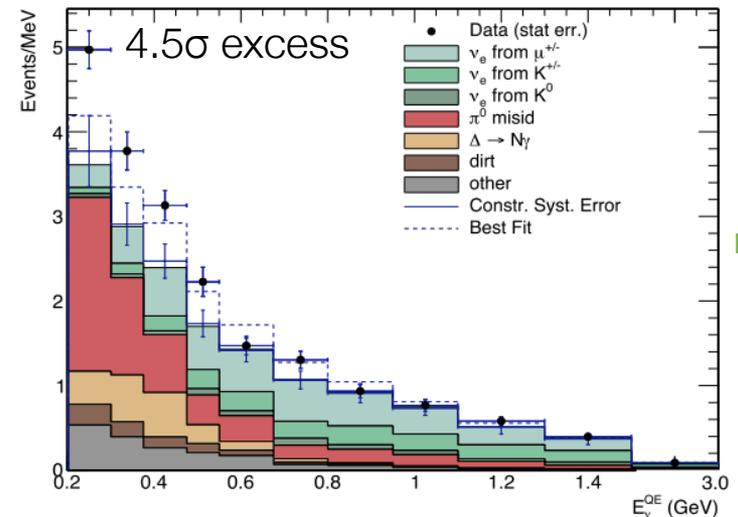
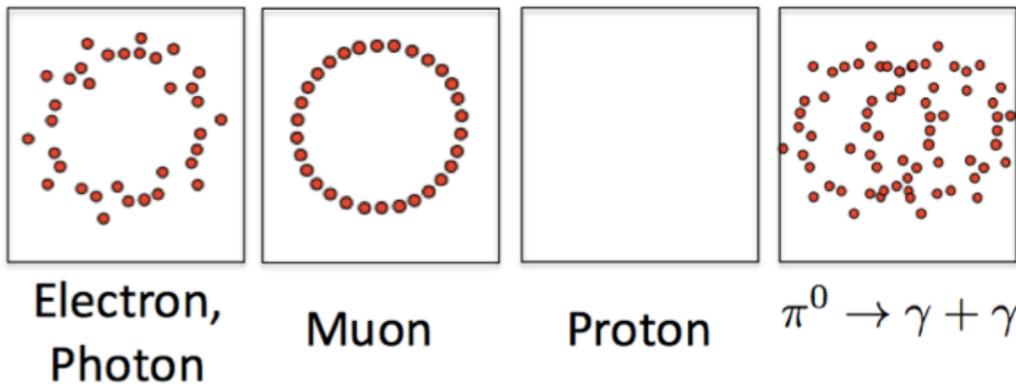
40 cm

Run 1148 Event 778. August 6th 2015 17:16

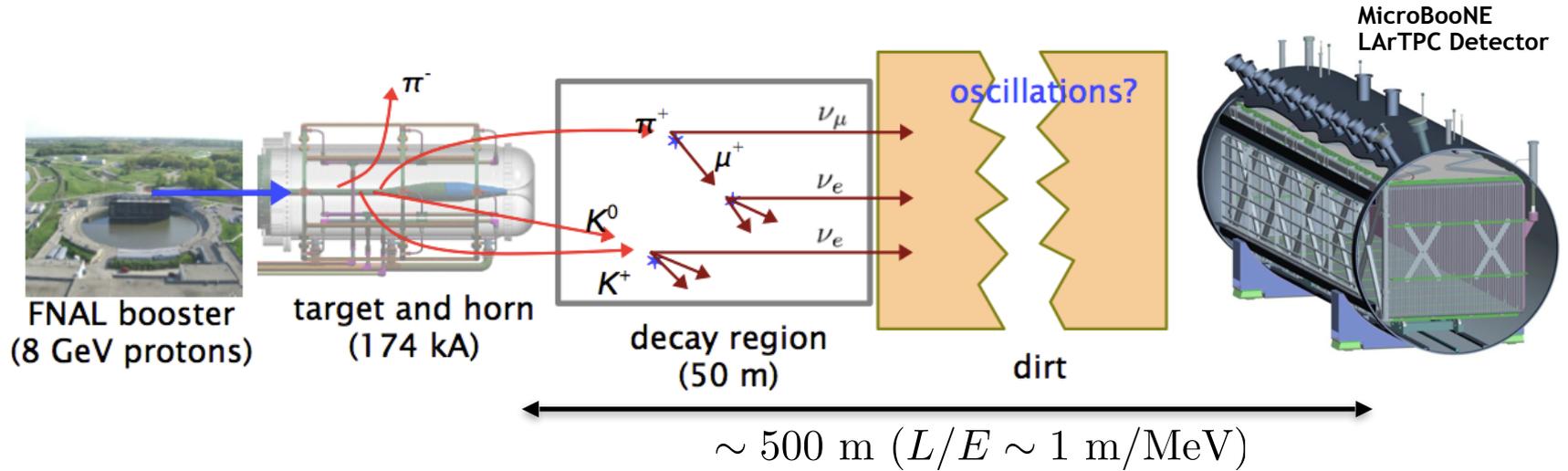
MiniBooNE Low Energy Excess



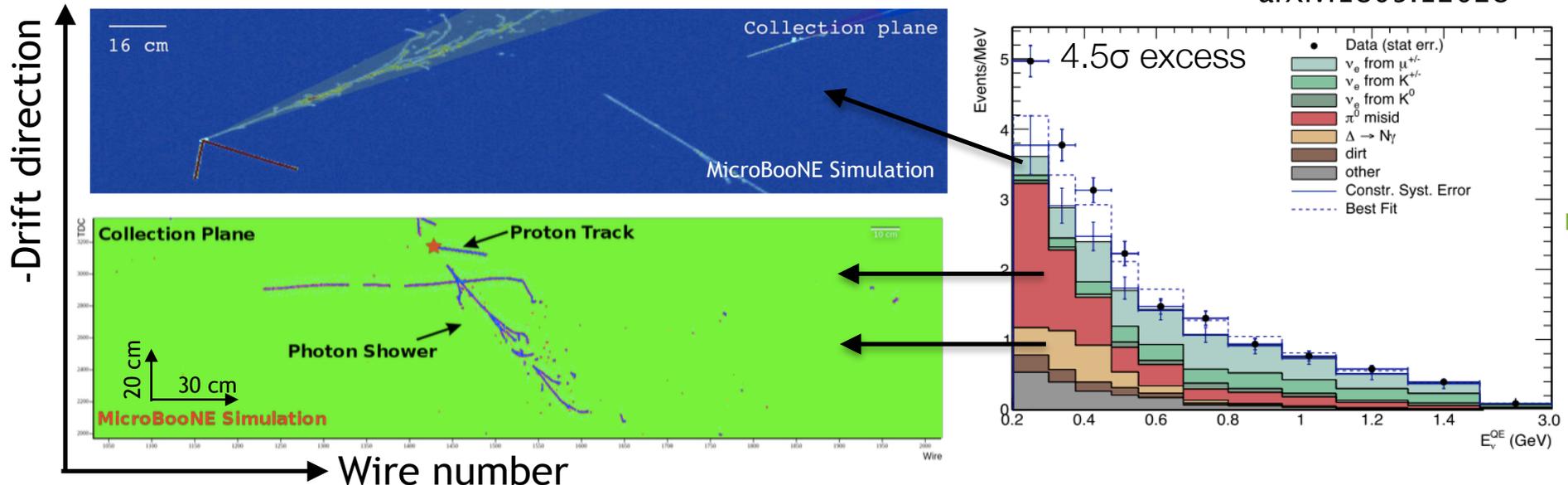
arXiv:1805.12028



LArTPC Detector Can Separate e/ γ Excesses



arXiv:1805.12028

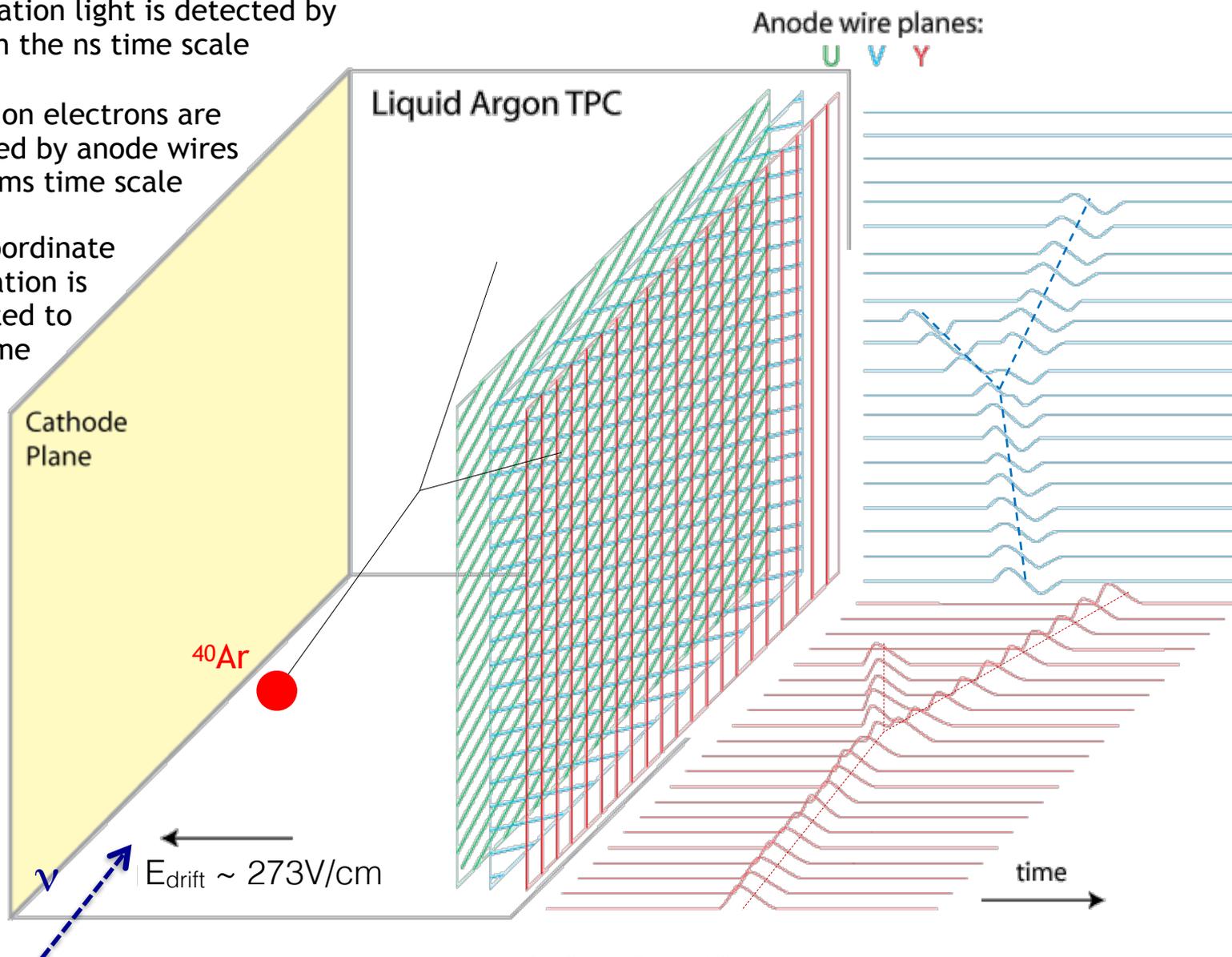


Charged particle tracks ionize
Argon atoms

Scintillation light is detected by
PMTs on the ns time scale

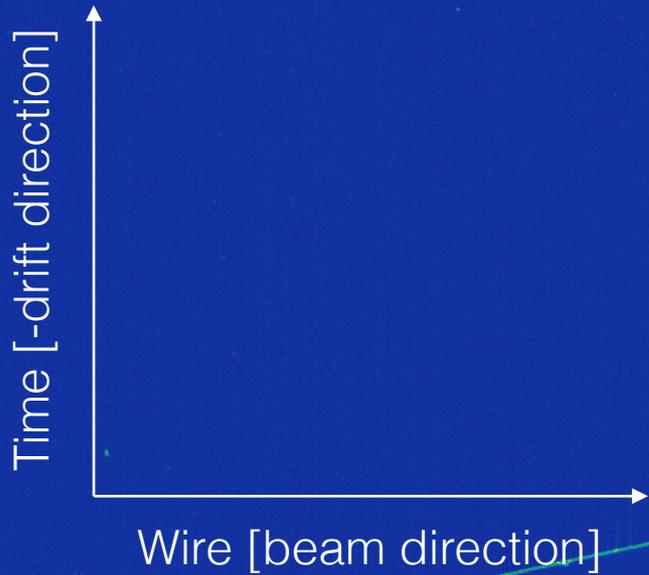
Ionization electrons are
collected by anode wires
on the ms time scale

Drift coordinate
information is
converted to
drift time



μ BooNE

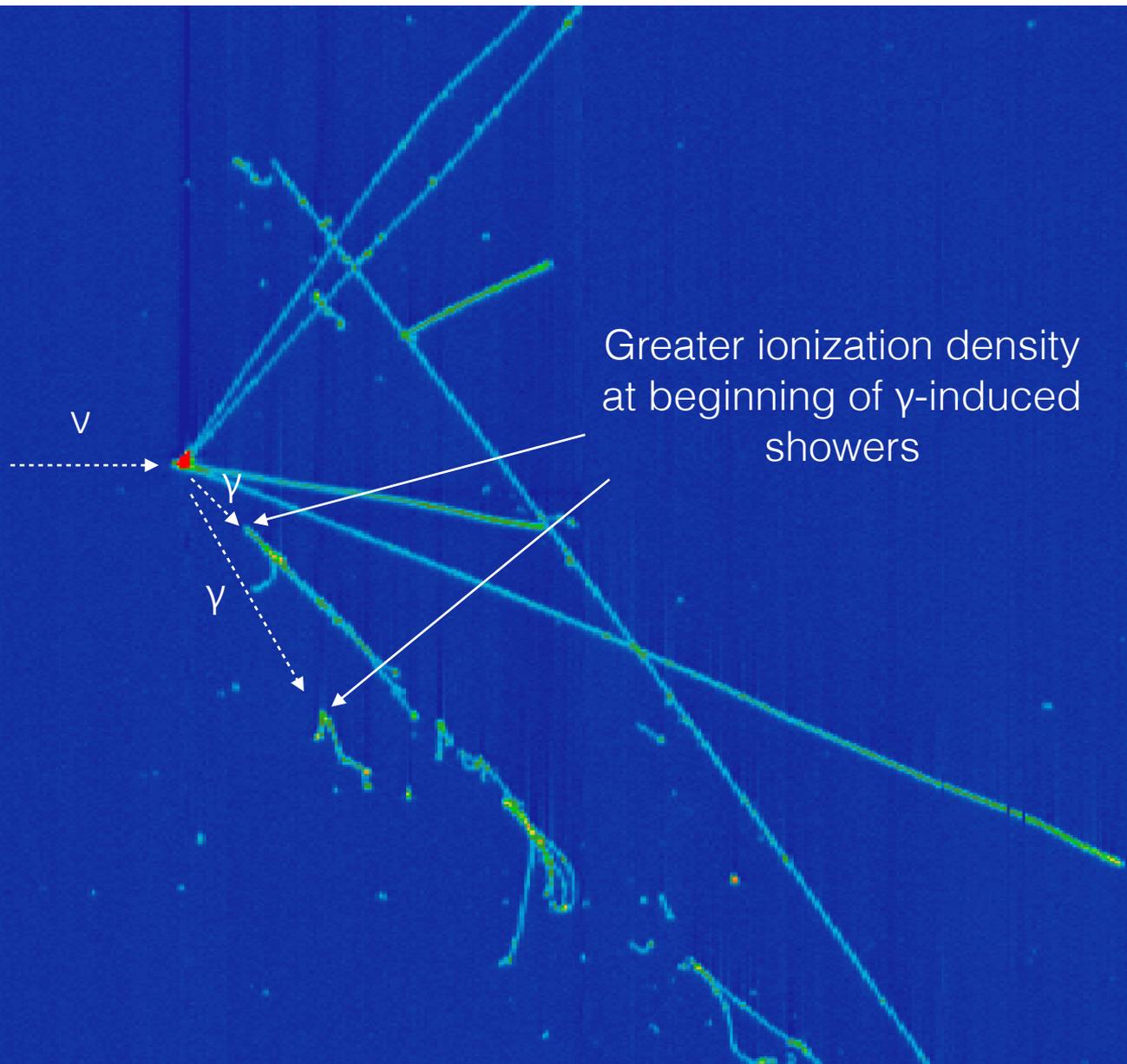
Color scale indicates amount of deposited charge

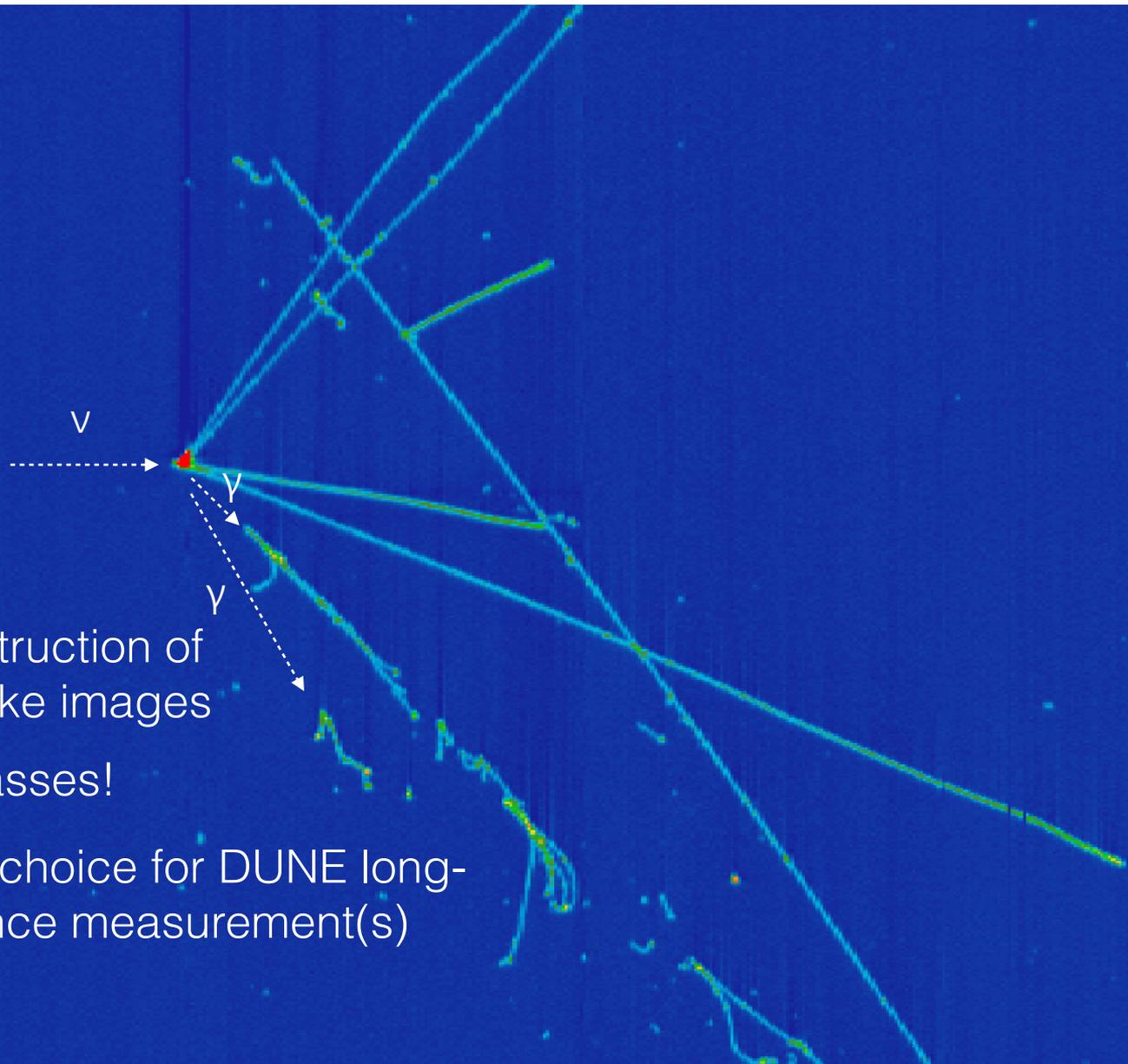


Scale bar applies to both vertical and horizontal directions

75 cm

Run 3493 Event 41075, October 23rd, 2015





Beauty of LArTPCs:

Automated reconstruction of
bubble-chamber-like images

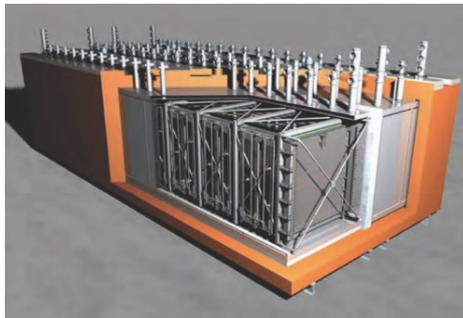
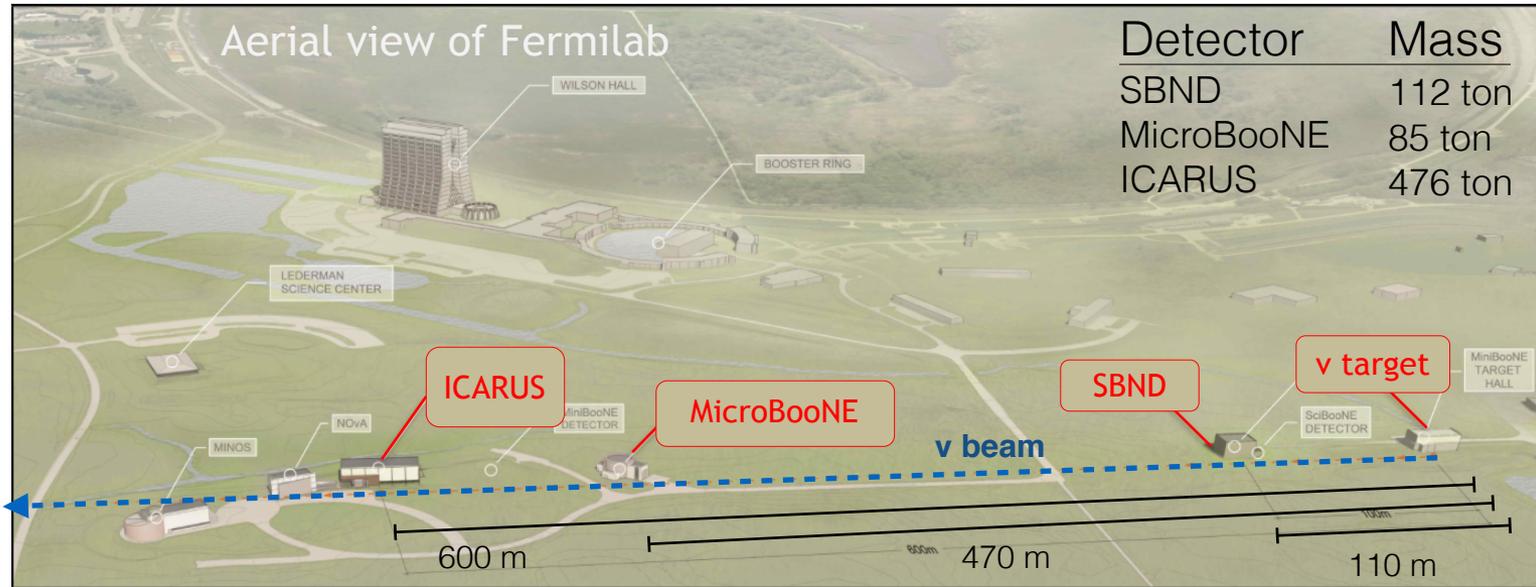
Scales to large masses!

Detector technology choice for DUNE long-
baseline $\bar{\nu}_e$ appearance measurement(s)

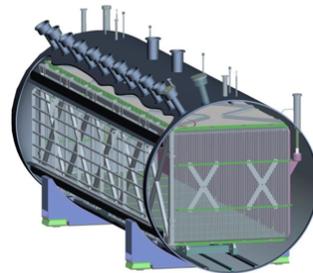
Short Baseline Neutrino (SBN) Program

Phase I: Address MiniBooNE low energy excess with MicroBooNE (running now)

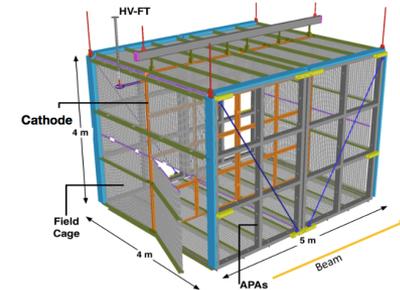
Phase II: Definitively test the light sterile neutrino hypothesis with functionally identical Near and Far Detector(s) (installation & construction ongoing)



ICARUS



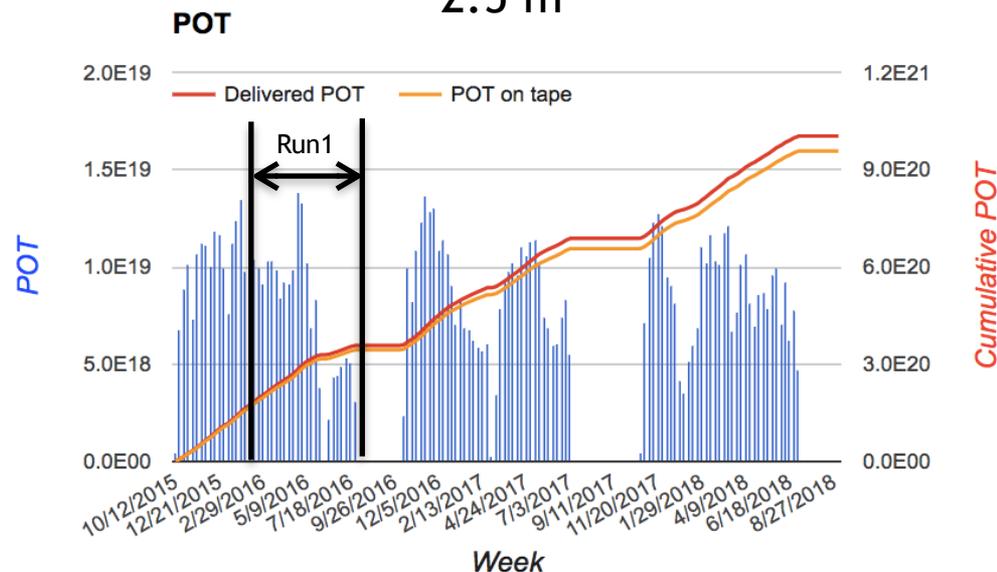
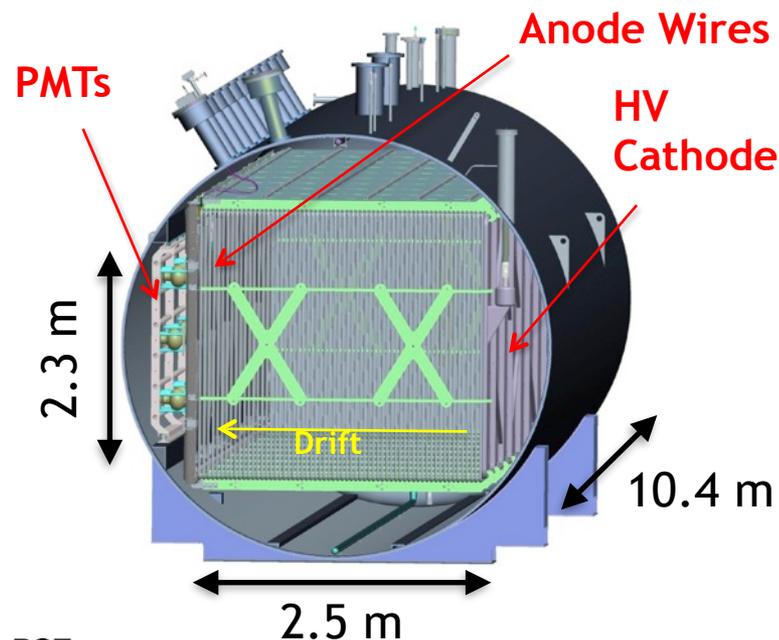
MicroBooNE



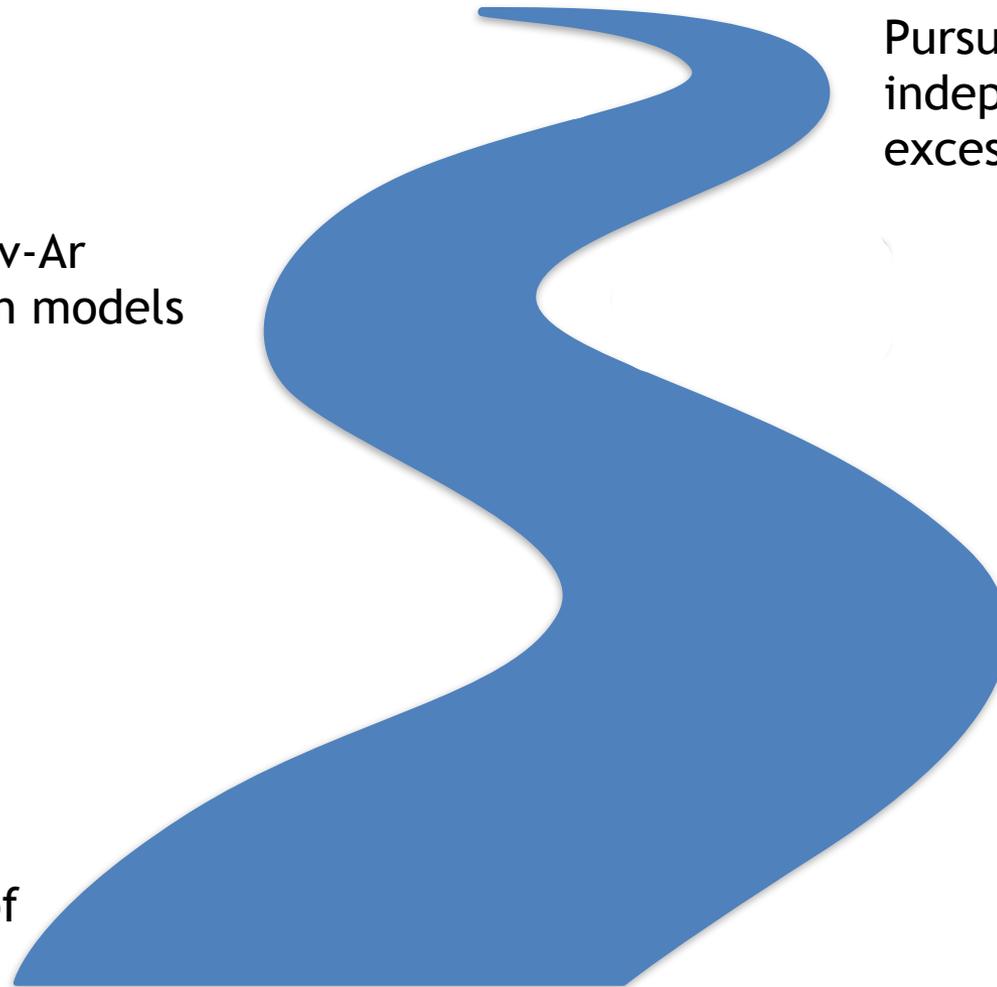
Short Baseline Near Detector (SBND)

The MicroBooNE Detector

- 170 (85) ton total (active) mass LArTPC
- 8192 wires (3 mm pitch)
 - 3456 collection channels (oriented vertically)
 - 4736 induction channels (oriented at $\pm 60^\circ$)
- 32 8" Cryogenic PMTs
- UV laser calibration system
 - 2 ports: upstream, downstream
- External muon tagger system
- Taking data since Oct. 2015
 - Good uptime and purity
 - Results shown for Run 1 data



Systematically Building Towards A Low Energy Excess Search Result



Constrain ν -Ar interaction models with data

Pursue multiple independent low energy excess searches

Develop several unique approaches to automated LArTPC reconstruction

Thorough understanding of our detector

Understanding Our Detector

- We wrote the (150-page) book on LArTPC noise sources, mitigation strategies, and signal extraction techniques
- Demonstrated the best noise performance ever achieved in a large scale LArTPC
- Ground-breaking work to develop signal processing techniques to account for induced signal on neighboring wires (“2-D deconvolution”)
- Results of these investigations led to numerous improvements in LArTPC & cold ASIC design for SBND & DUNE

Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC

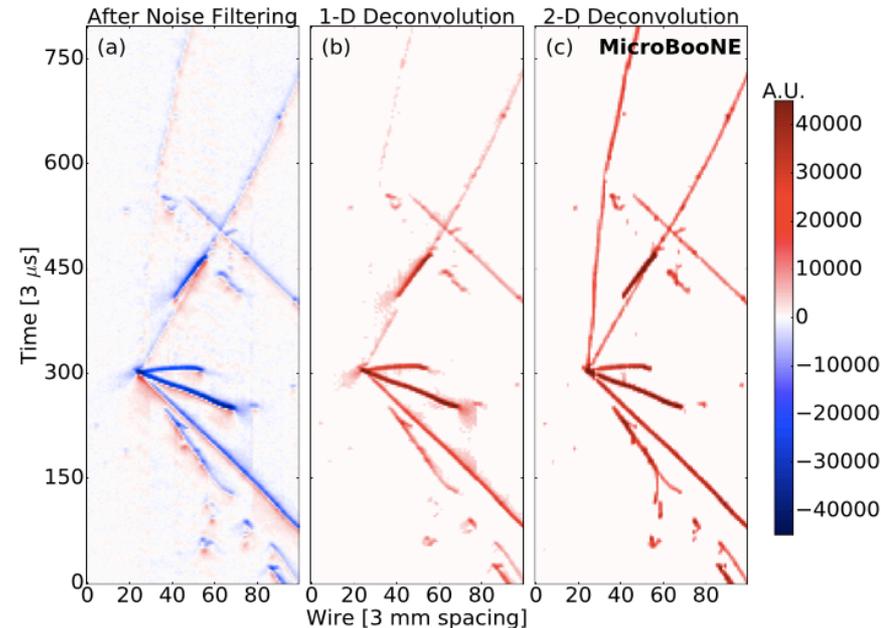
MicroBooNE Collaboration (R. Acciarri (Fermilab) *et al.*). May 20, 2017. 36 pp.
Published in JINST 12 (2017) no.08, P08003

Ionization electron signal processing in single phase LArTPCs. Part I. Algorithm Description and quantitative evaluation with MicroBooNE simulation

MicroBooNE Collaboration (C. Adams (Harvard U.) *et al.*). Feb 23, 2018. 60 pp.
Published in JINST 13 (2018) no.07, P07006

Ionization electron signal processing in single phase LArTPCs. Part II. Data/simulation comparison and performance in MicroBooNE

MicroBooNE Collaboration (C. Adams (Harvard U.) *et al.*). Apr 7, 2018. 54 pp.
Published in JINST 13 (2018) no.07, P07007



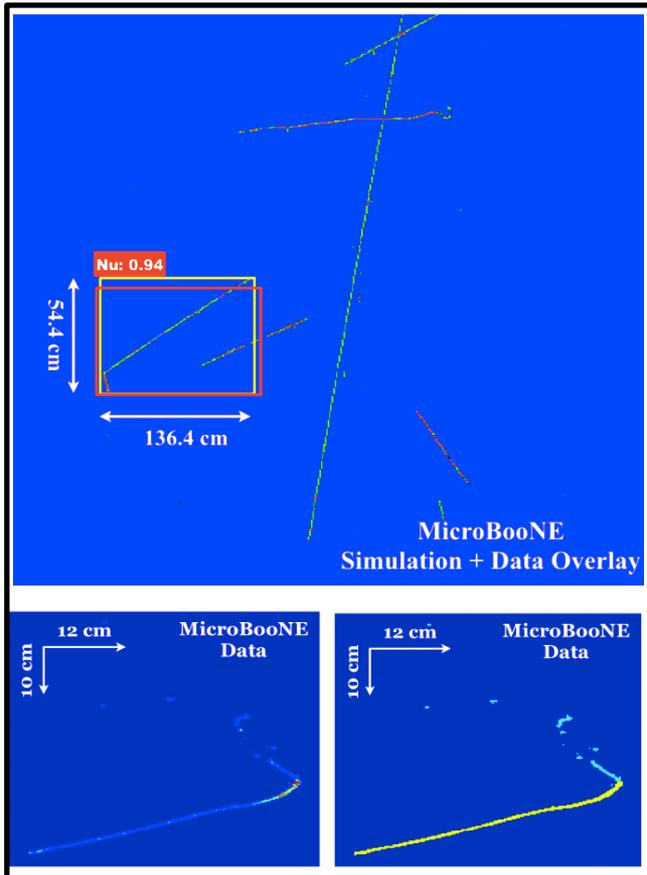
JINST 13 (2018) P07006

Automated Reconstruction

Deep Learning

Convolutional Neural Nets

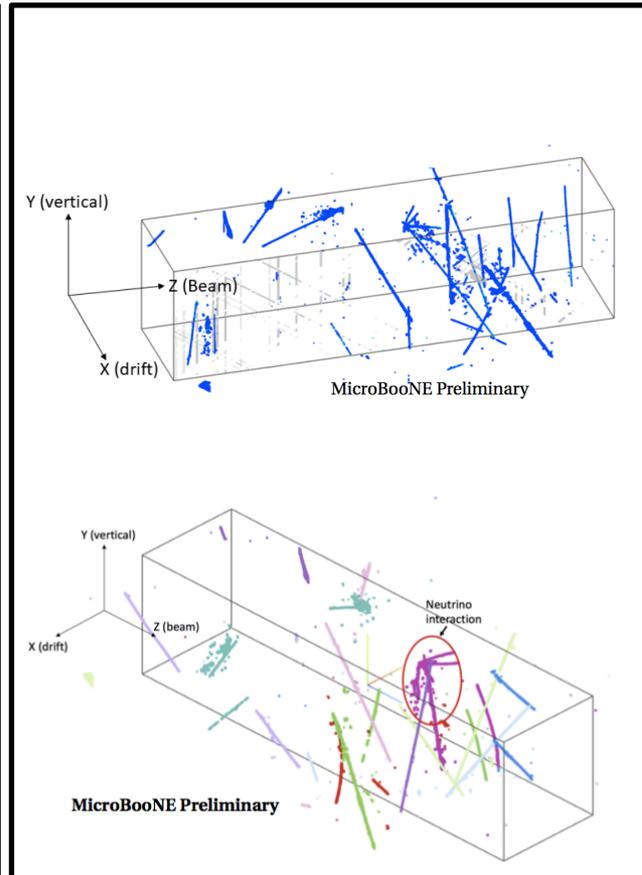
Leverage advances in computer vision and AI techniques to identify neutrino interactions or label pixels



WireCell

Tomographic reconstruction

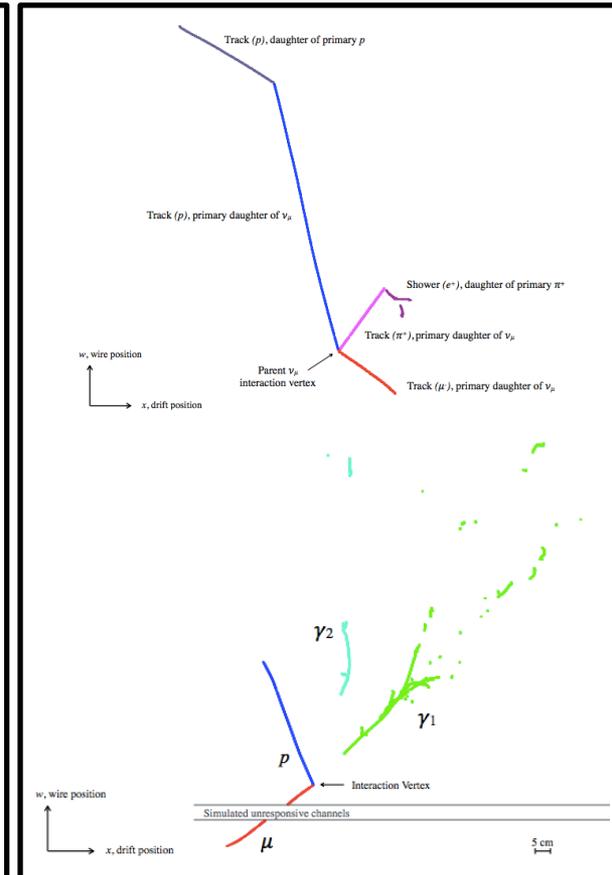
Directly reconstruct 3D space points and perform clustering in 3D



Pandora

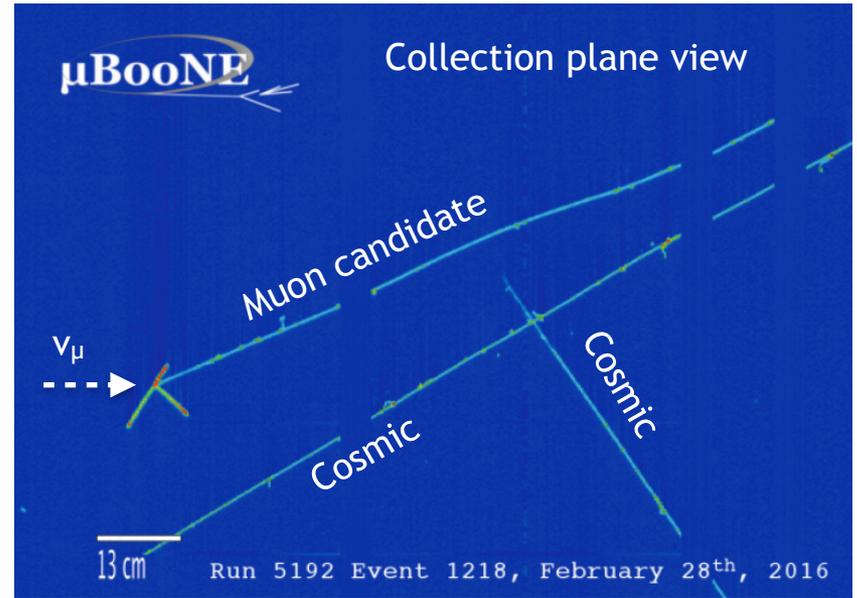
Multi-algorithm approach

3 projected views are clustered in 2D and then later combined in 3D using the common time dimension

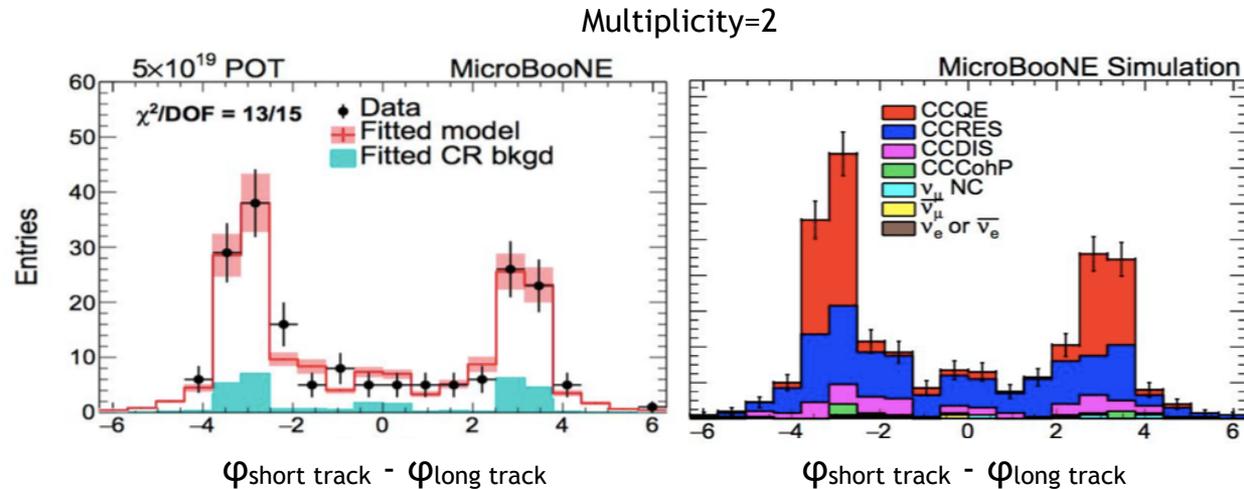
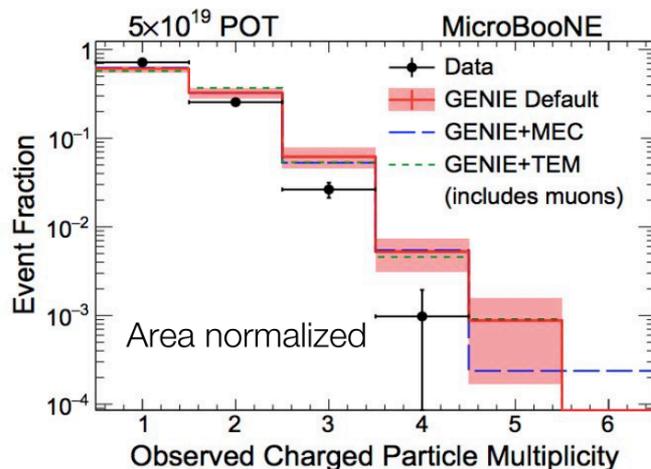


Inclusive ν_μ Charged Current Selection

- Basis for further exclusive channel measurements
 - Charged particle multiplicity
 - Extensive tests of GENIE
 - ν_μ CC π^0
 - ν_μ CC+N protons
 - ν_μ CC π^+
 - etc



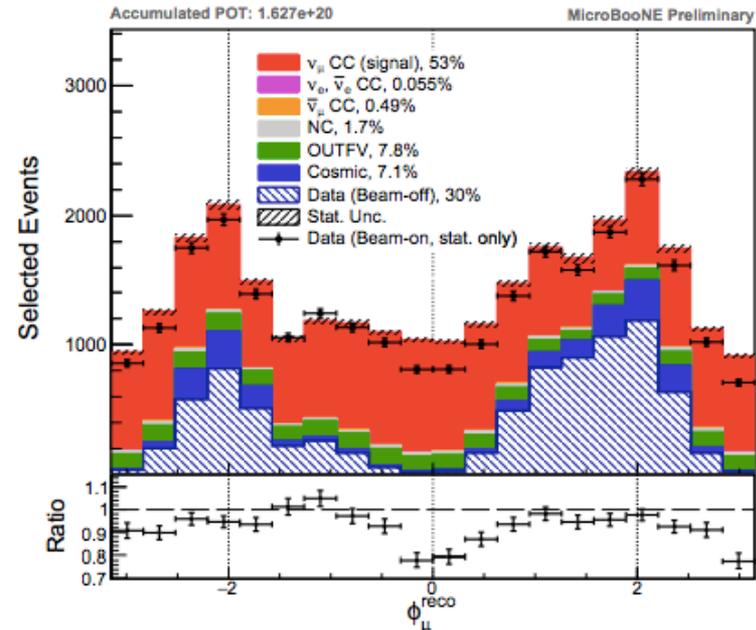
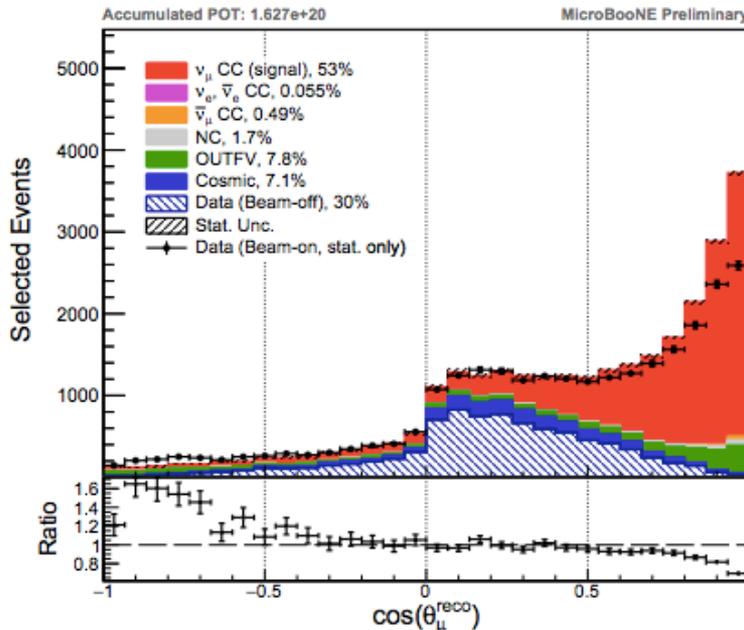
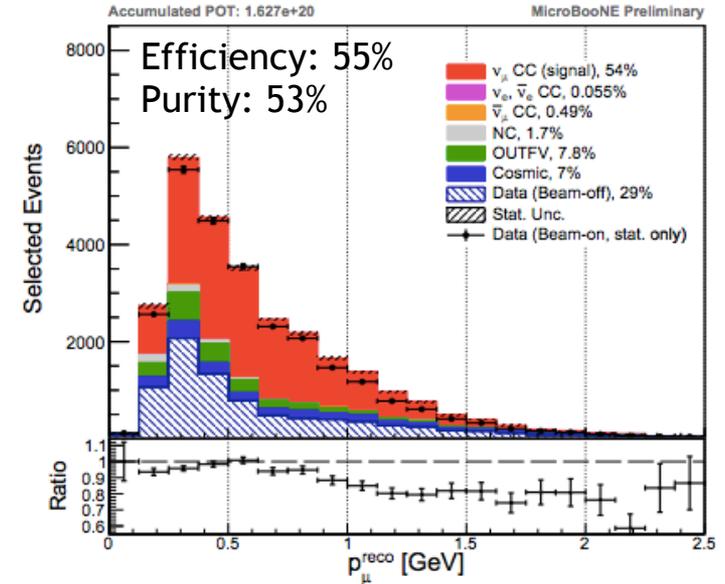
arXiv:1805.06887



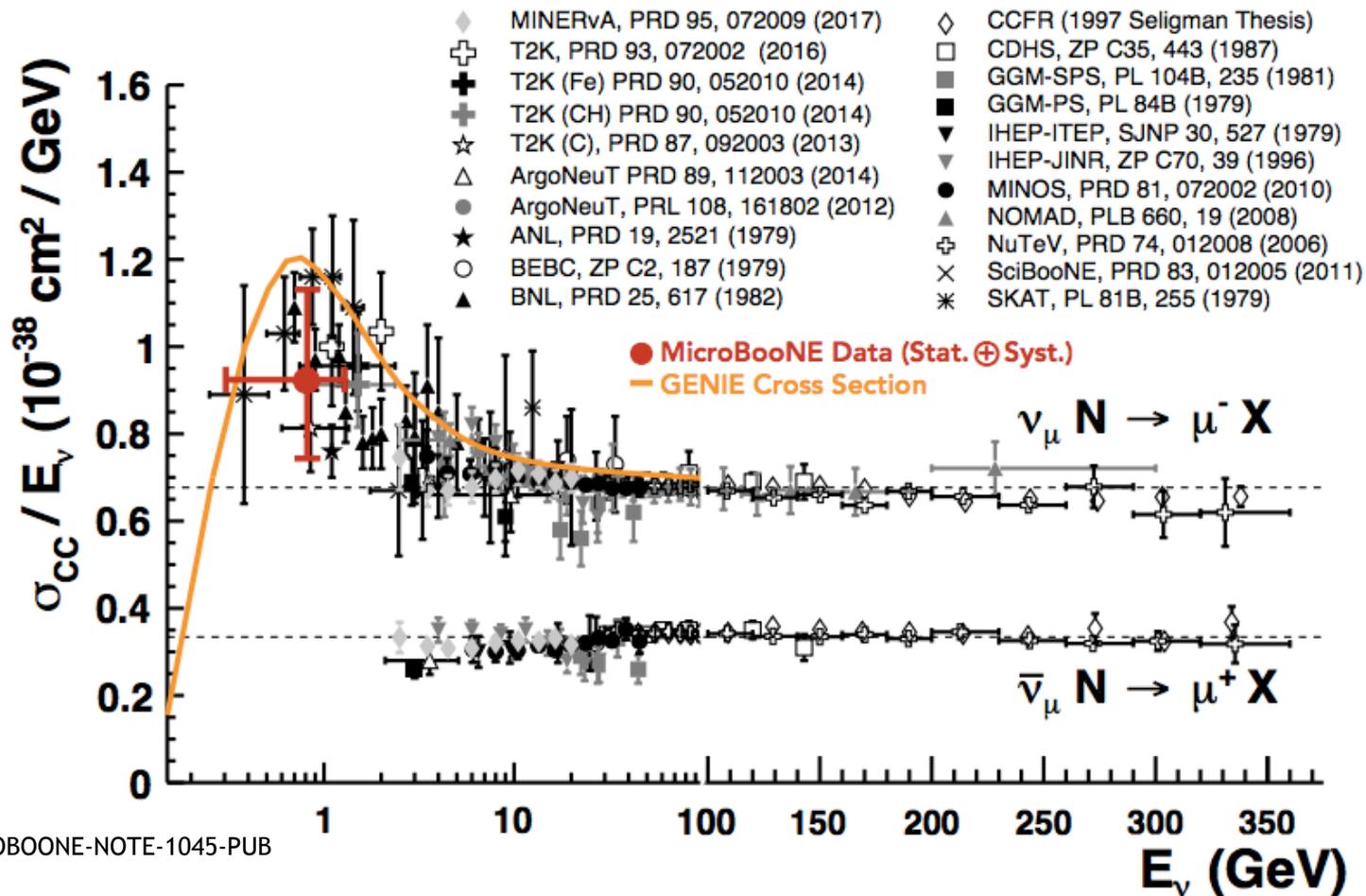
Inclusive ν_μ -Ar Charged Current Cross Section

- Novel in a number of ways:
 - First measurement on Ar at low energies
 - MCS to estimate momenta for both contained and uncontained tracks
 - Full angular coverage

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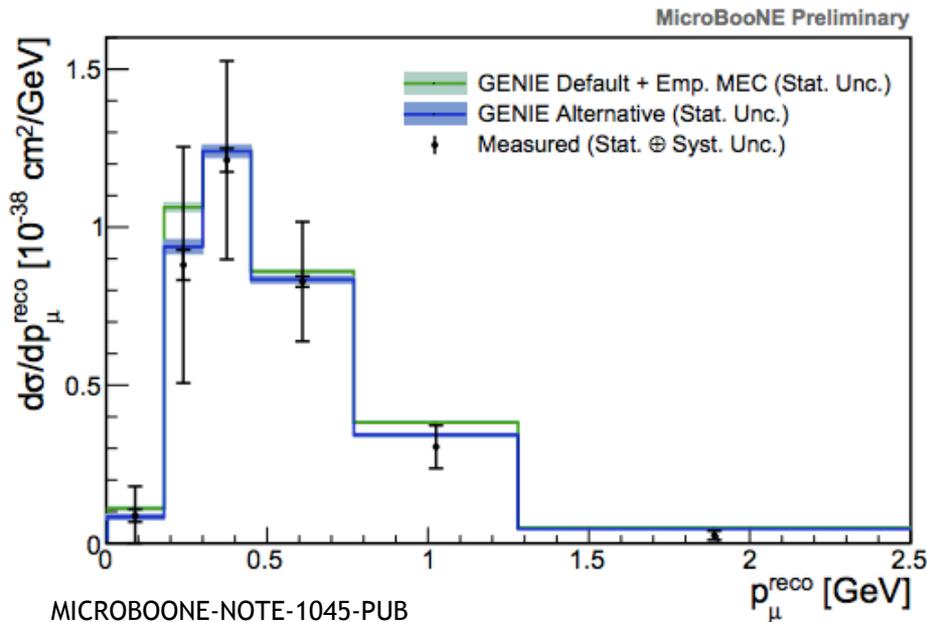
Flux integrated total cross section



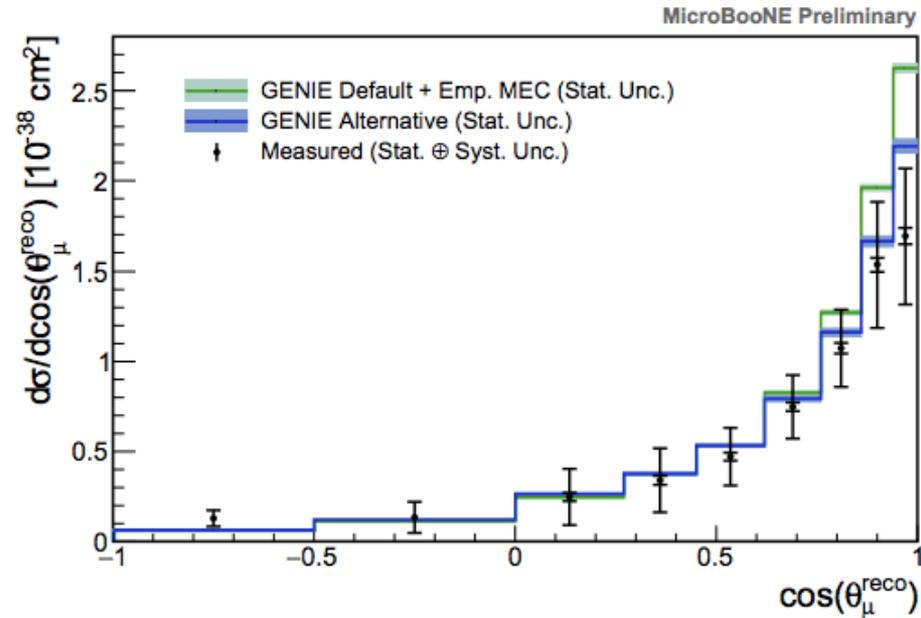
$$\sigma = 0.756 \pm 0.011 (\text{stat}) \pm 0.027 (\text{genie}) \pm 0.114 (\text{flux}) \pm 0.141 (\text{det}) \times 10^{-38} \text{ cm}^2$$

$$\sigma_{\text{MC}} = 0.867 \pm 0.004 (\text{stat.}) \times 10^{-38} \text{ cm}^2$$

Single differential cross sections



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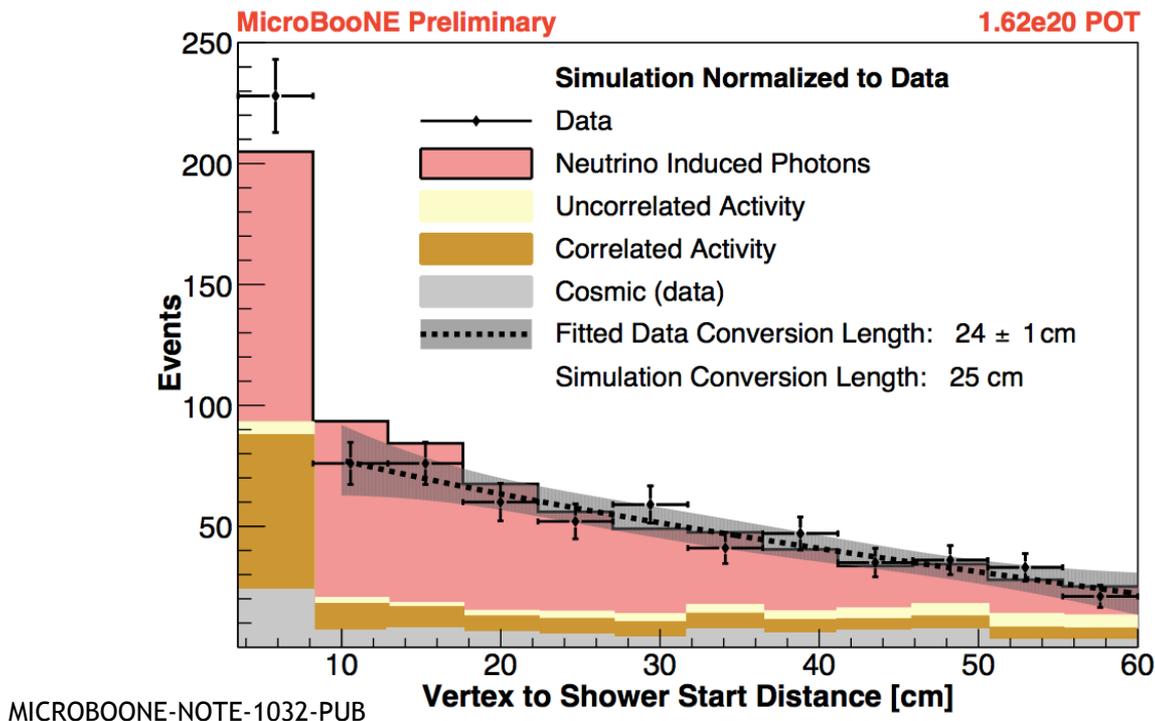


Model element	Default GENIE + Emp. MEC	GENIE Alternative
Nuclear Model	Bodek-Ritchie Fermi Gas [17]	Local Fermi Gas [18, 19]
Quasi-elastic	Llewellyn-Smith [20]	Nieves [18, 19]
Meson-exchange Currents	Empirical [21]	Nieves [18, 19]
Resonant	Rein-Seghal [22]	Berger-Seghal [23]
Coherent	Rein-Seghal [22]	Berger-Seghal [23]
FSI	hA [24]	hA2014 [24]

GENIE v2.12

Exclusive CC1pi⁰ cross section

- First such measurement on Argon
 - Can study scaling assumptions in models of the production and transport of pions by comparing to past measurements on lighter nuclei
- First application of fully-automated EM shower reco to LArTPC v data
 - Important step towards a low energy excess search

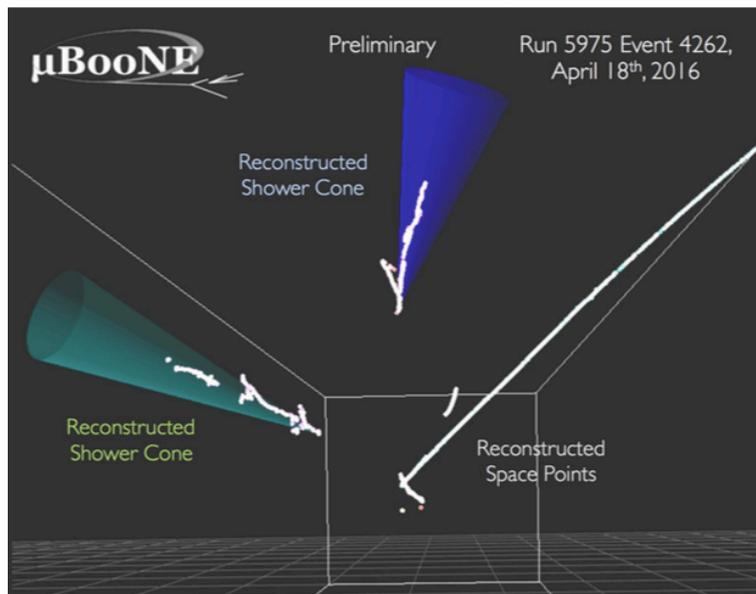


One shower selection

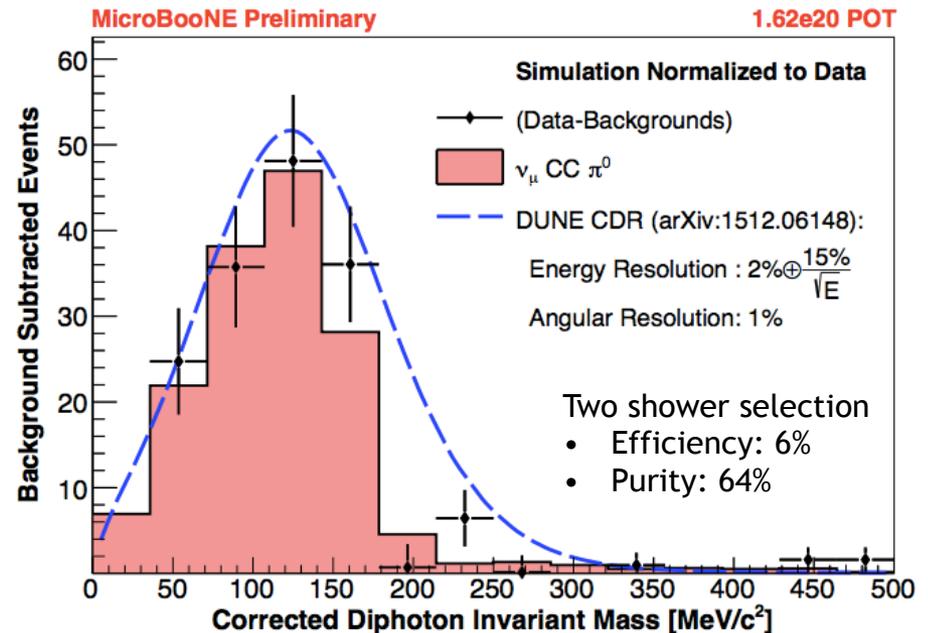
- Efficiency: 17%
- Purity: 53%

Exclusive CC1pi⁰ cross section

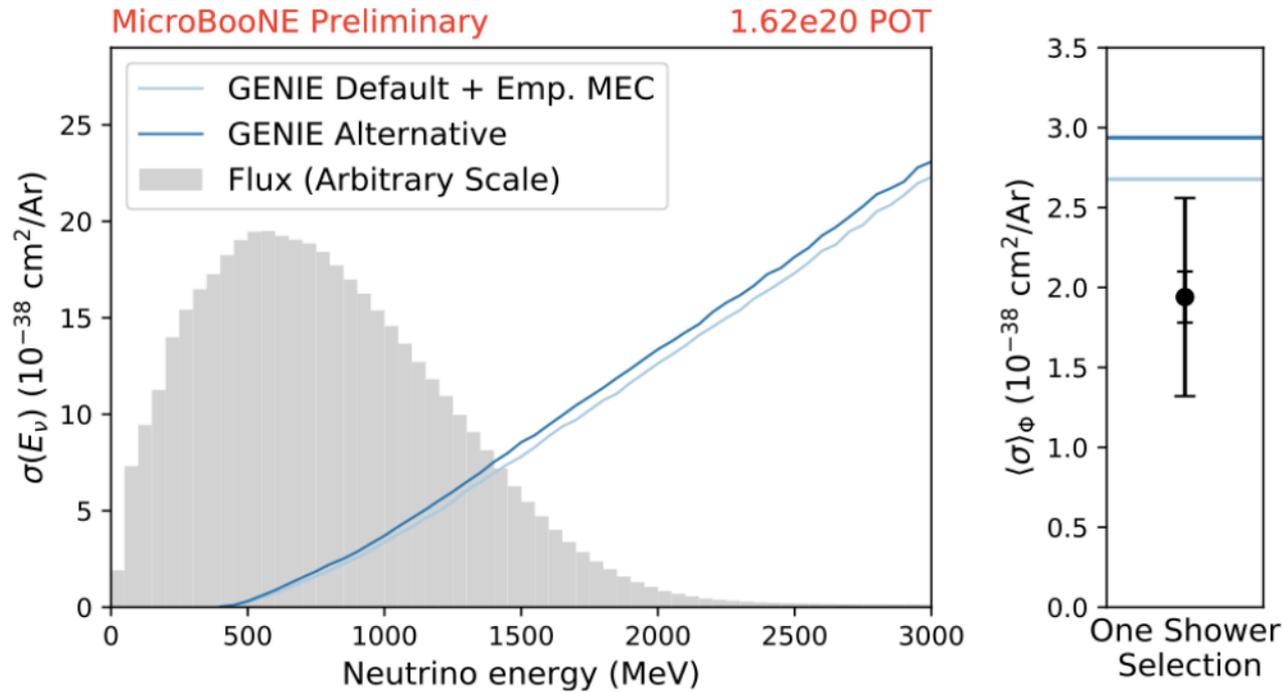
- First such measurement on Argon
 - Can study scaling assumptions in models of the production and transport of pions by comparing to past measurements on lighter nuclei
- First application of fully-automated EM shower reco to LArTPC ν data
 - Important step towards a low energy excess search
- Enables studies of shower energy reconstruction & resolution in data



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Flux integrated CC1pi⁰ total cross section



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

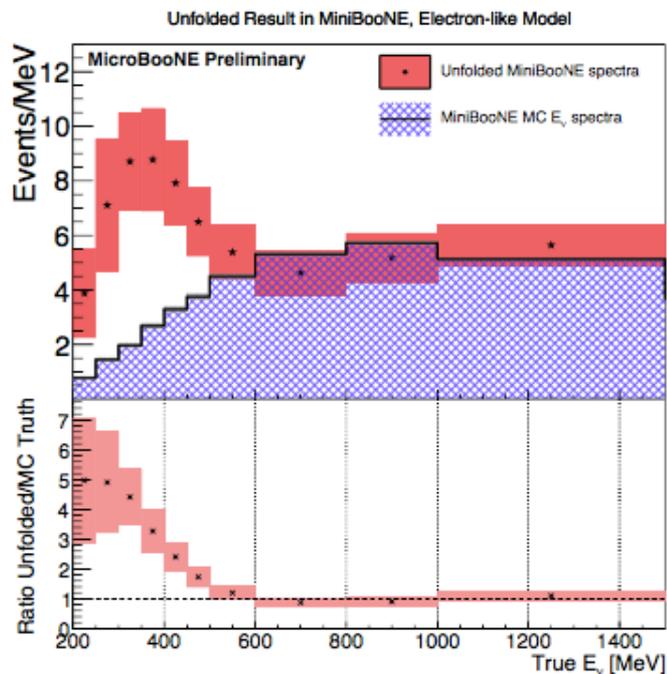
Systematic	1 σ uncertainty
Flux	15.5%
GENIE	17.2%
Detector	21.1%

MICROBOONE-NOTE-1032-PUB

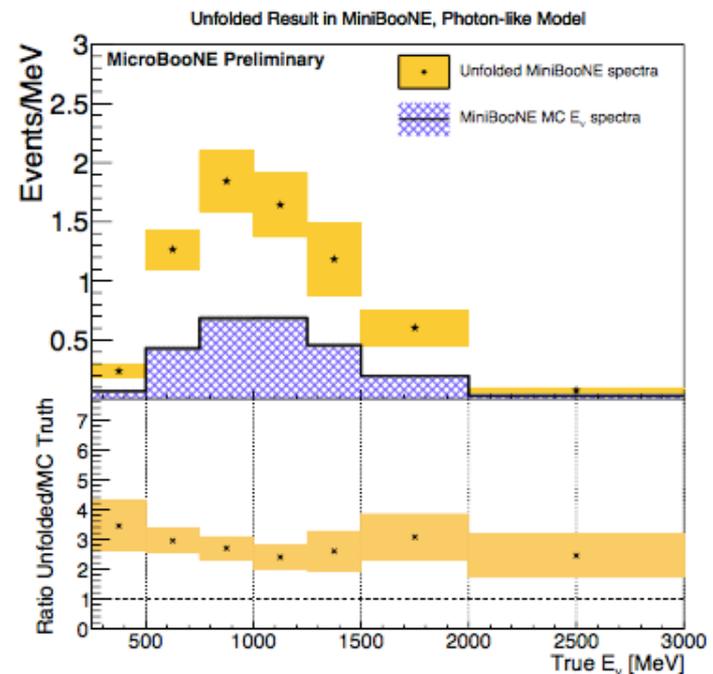
Low Energy Excess Search Strategy (I)

- Leverage the e/ γ separation power of LArTPCs:
 - Independent e-like and γ -like searches targeting two different models for the MiniBooNE excess

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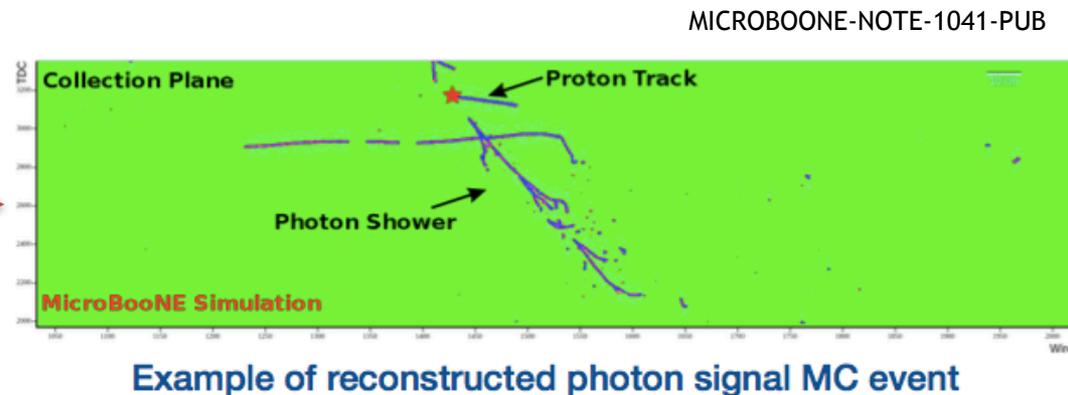
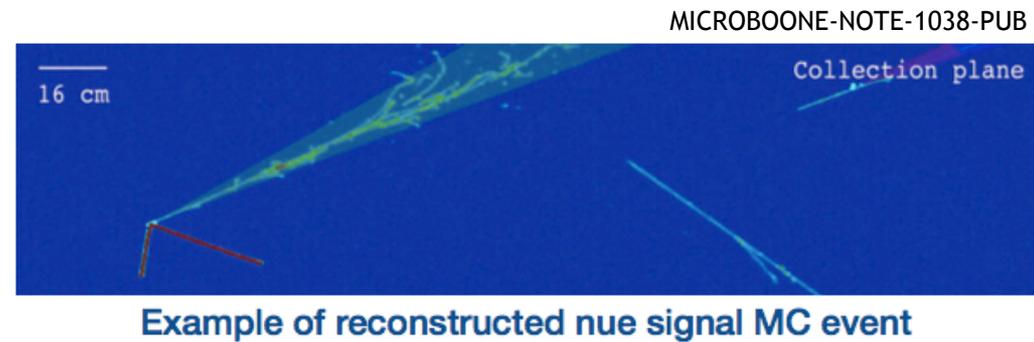
Scaling intrinsic ν_e events



Scaling NC $\Delta \rightarrow N_\gamma$ events

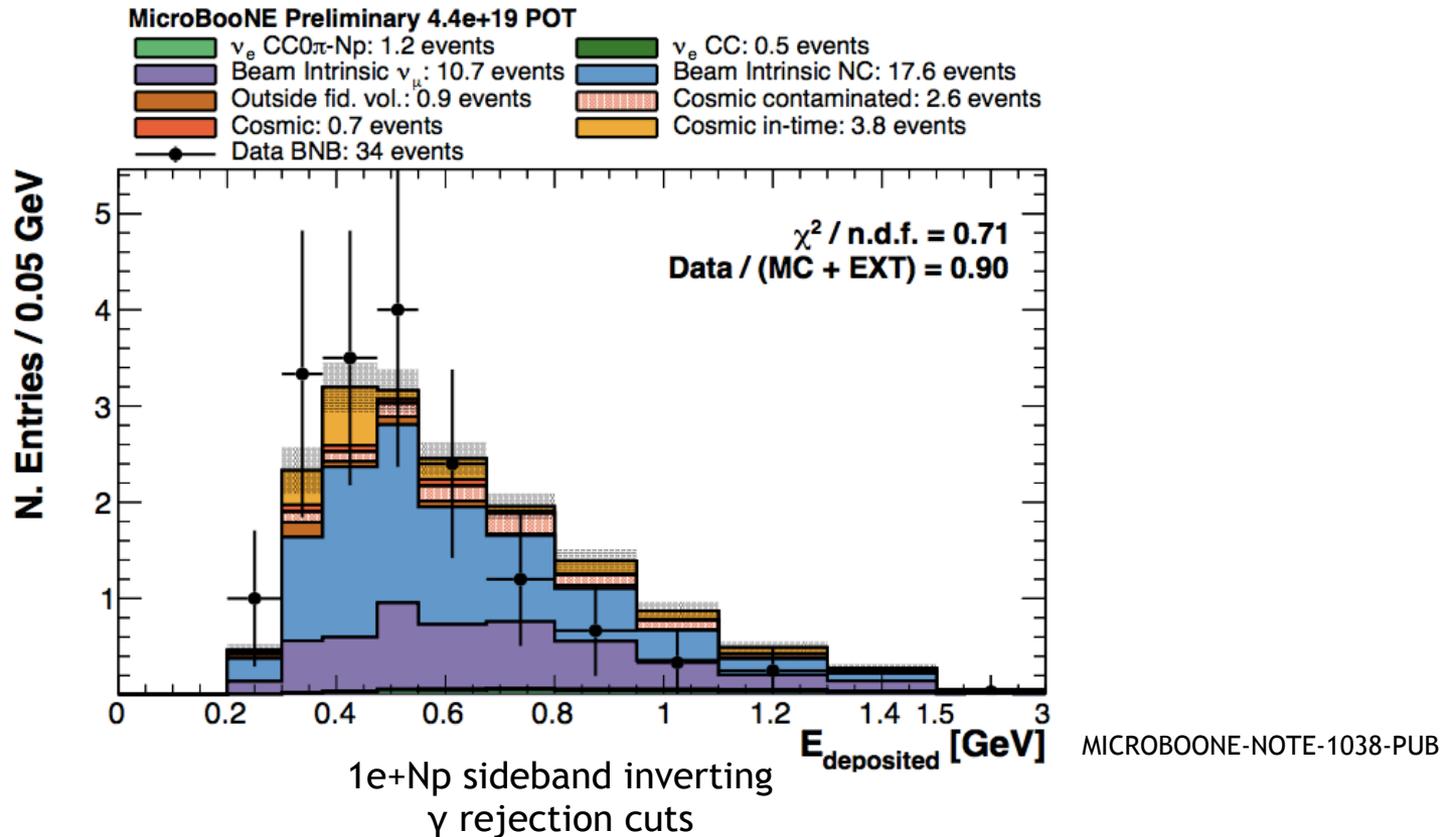
Low Energy Excess Search Strategy (II)

- Complementary analyses targeting different final states yielding different trade-offs between efficiency & purity
- ν_e analyses
 - $1e+1p$ (Deep Learning)
 - $1e+Np$ (Pandora) →
 - $1e+X$ (Pandora, WireCell)
- Single photon analyses
 - $1\gamma+0p$ (Pandora)
 - $1\gamma+1p$ (Pandora) →



Low Energy Excess Search Strategy (III)

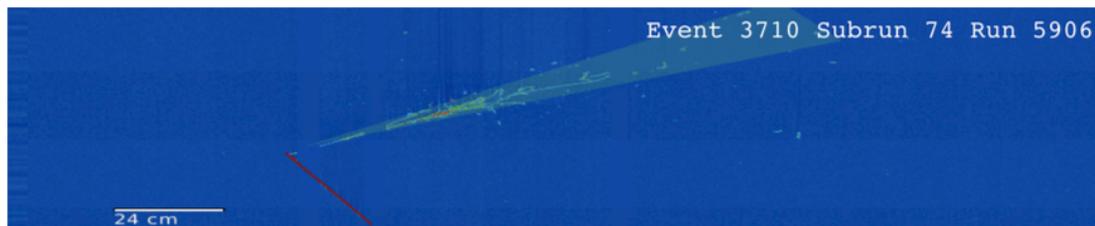
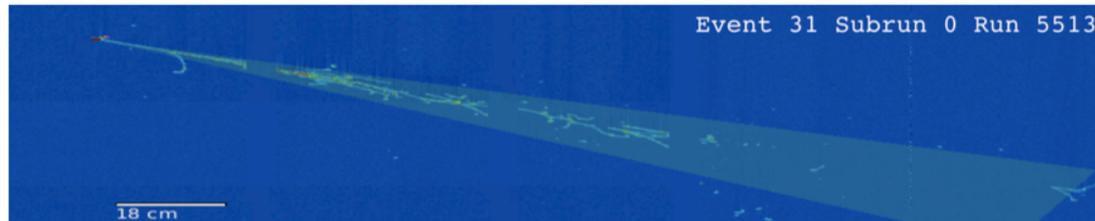
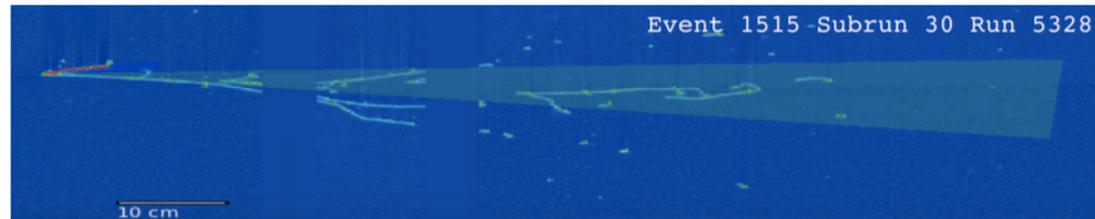
- Blind search strategy (small subset of open data)
- Simultaneous $\nu_e - \nu_\mu$ fit to constrain flux & cross section uncertainties
- Backgrounds constraints from data using sidebands



Low Energy Excess Search Status

- Completed first iteration of fully-automated ν_e and single photon selections
- Working on areas identified for targeted improvement
 - “2-D deconvolution”
 - Cosmic Ray Tagger
- In the meantime, also developing ν_e selections for NuMI beam data

Candidate $1e+Np$ ν_e events selected in BNB data



MICROBOONE-NOTE-1038-PUB

Conclusion

- SBN program at Fermilab to address MiniBooNE excess and light sterile neutrino hypothesis is well underway
 - MicroBooNE taking data smoothly since Oct. 2015
- MicroBooNE is playing a pivotal role in LArTPC R&D
- We have presented our first physics results on ν -Ar interactions with more on the way
- We have performed our first fully automated ν_e and single photon selections and are systematically building towards our low energy excess search analysis



Thank you, on behalf of MicroBooNE Collaboration

August 2018

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171 collaborators
32 institutions (7 non-U.S.)
42 postdocs
53 grad students

*spokespeople

See latest MicroBooNE results at <http://microboone.fnal.gov/documents-publications/>

A long, narrow tunnel with a red glow. The tunnel is illuminated with a strong red light, creating a monochromatic atmosphere. On the left side, there is a metal walkway or ladder structure with several circular lights or sensors. The tunnel walls are curved and appear to be made of metal or concrete. At the far end of the tunnel, there is a large circular opening, possibly a doorway or a tunnel junction. The word "End." is written in white text in the center of the tunnel, near the opening.

End.