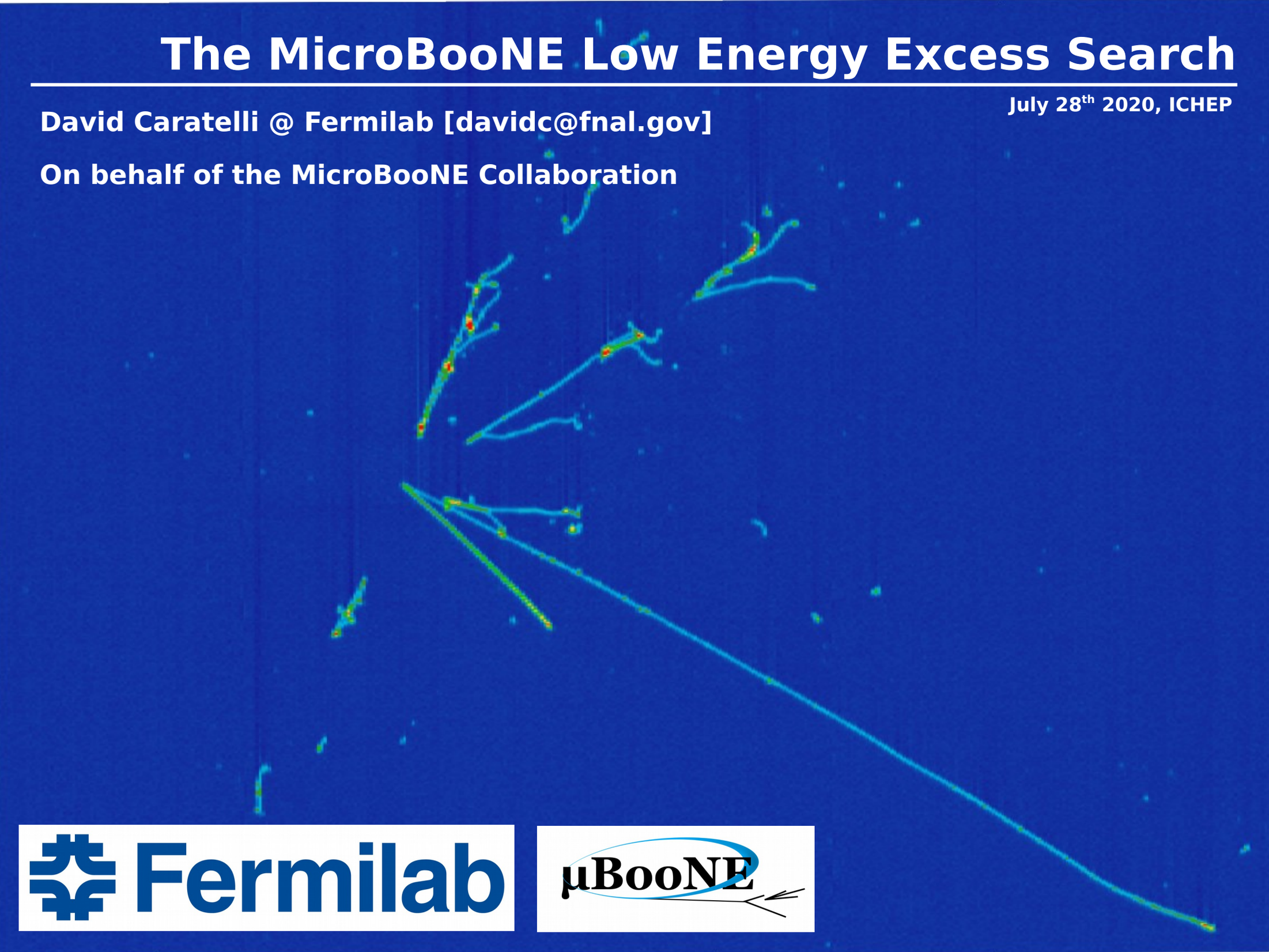
The MicroBooNE Low Energy Excess Search

David Caratelli @ Fermilab [davidc@fnal.gov]

On behalf of the MicroBooNE Collaboration

July 28th 2020, ICHEP



Fermilab

µBooNE

Low Energy Excess in MiniBooNE

David Caratelli, Fermilab : ICHEP 2020

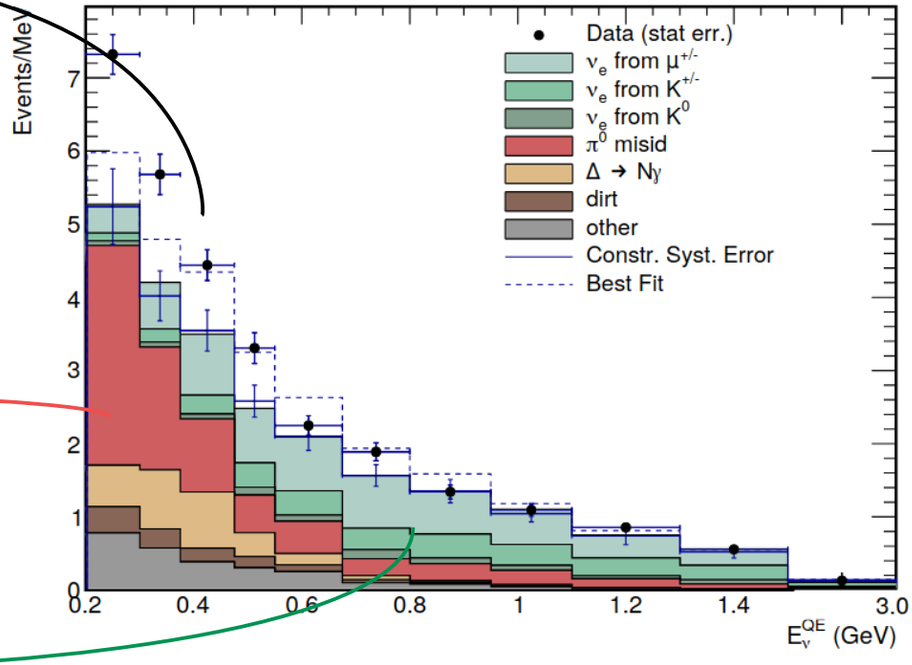
MiniBooNE observed an excess of EM activity at low energies in the Booster Neutrino Beam at Fermilab.

→ “low energy excess” or LEE.

Part of a broad range of Short Baseline Anomalies.

Electron or photon? New physics?

MiniBooNE Collaboration, 06/2020. arXiv:2006.16883

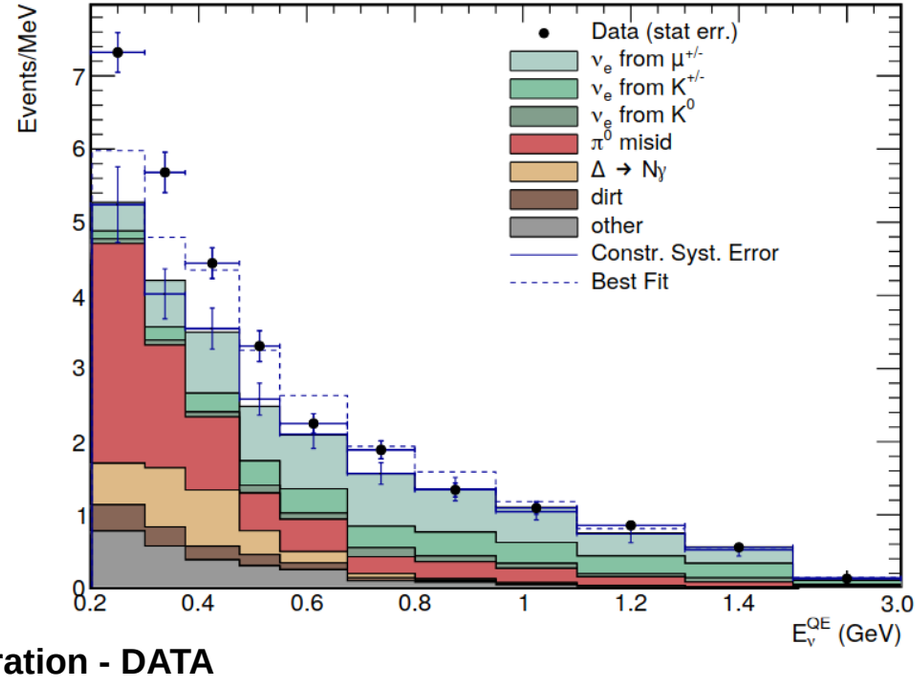


Why MicroBooNE?

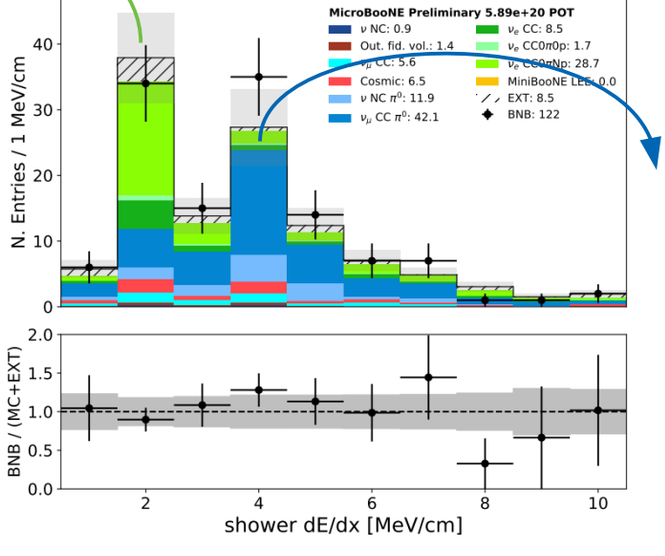
MicroBooNE was built to determine the nature of this excess.

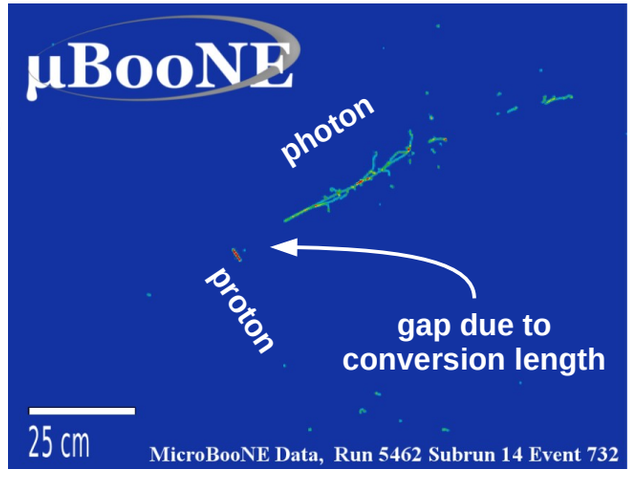
Rely on the LArTPC detector technology to disambiguate electron vs. photon signals.

MiniBooNE Collaboration, 06/2020. arXiv:2006.16883



dE/dx e/γ separation - DATA

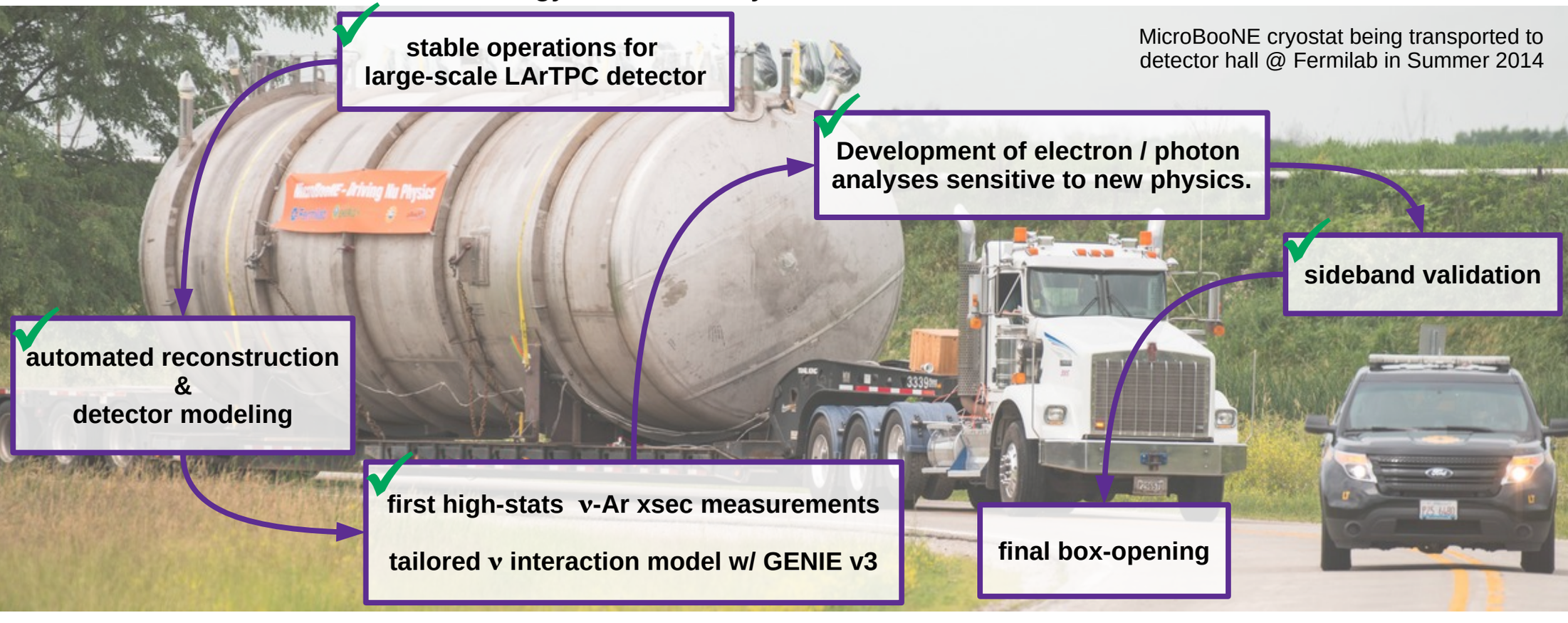




The Road to MicroBooNE physics

David Caratelli, Fermilab : ICHEP 2020

The road to MicroBooNE's low-energy-excess analysis...



Many milestones along the way. MicroBooNE has pioneered the development of the LArTPC detector technology towards enabling precision neutrino physics.

Testing the e^- and γ LEE hypotheses

David Caratelli, Fermilab : ICHEP 2020

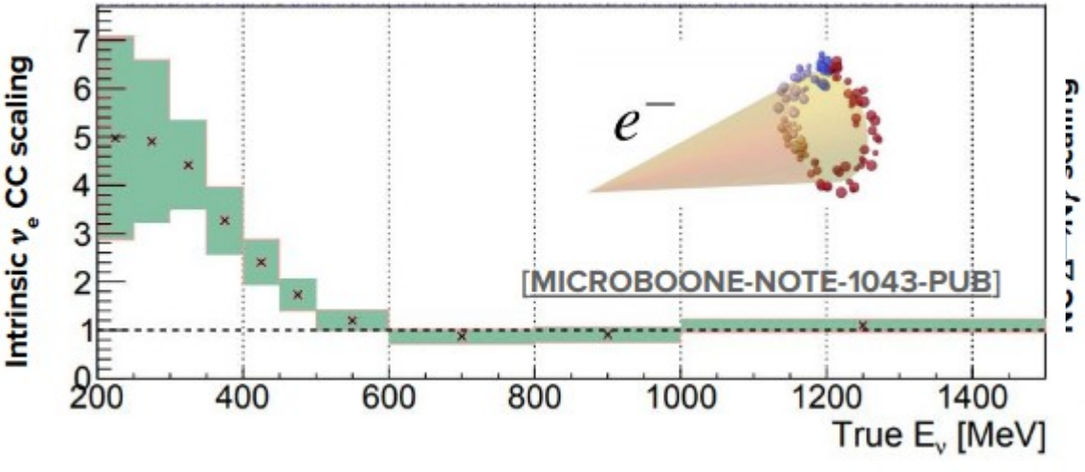
Extensive literature rich in ideas to explain the origin of the MiniBooNE low-energy-excess.

The first generation of MicroBooNE analyses target two specific hypotheses:

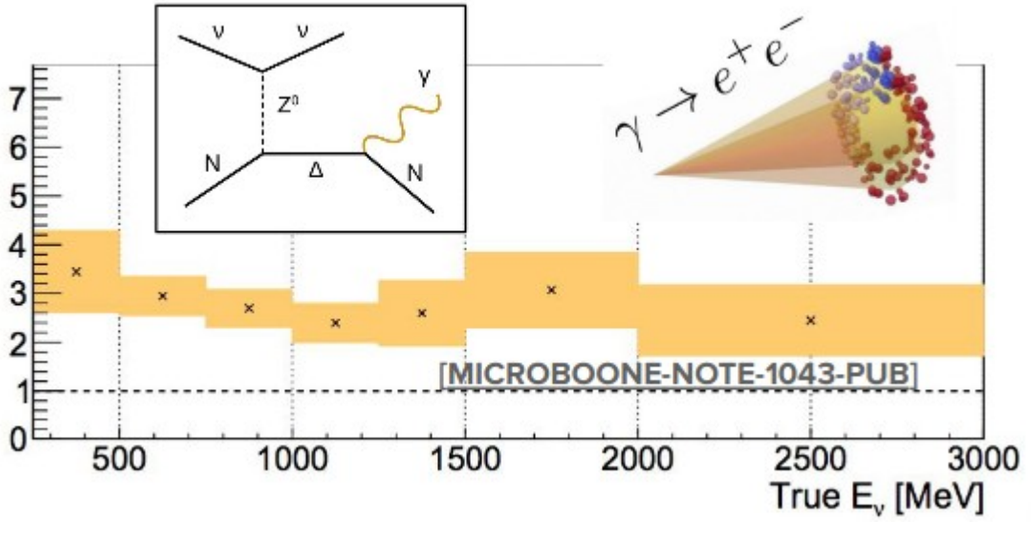
Both start with the MiniBooNE excess [PRL 121, 221801 (2018)] unfolded into a true electron-like or photon-like signal which is propagated through the MicroBooNE flux simulation.

Analyses' sensitivity benchmarked against these hypotheses.

electron signal model:
scaling of intrinsic ν_e from the beam



photon signal model:
scaling of NC Δ radiative decay to single γ.



MiniBooNE signal unfolding to MicroBooNE: MICROBOONE-NOTE-1043

New Physics in MicroBooNE

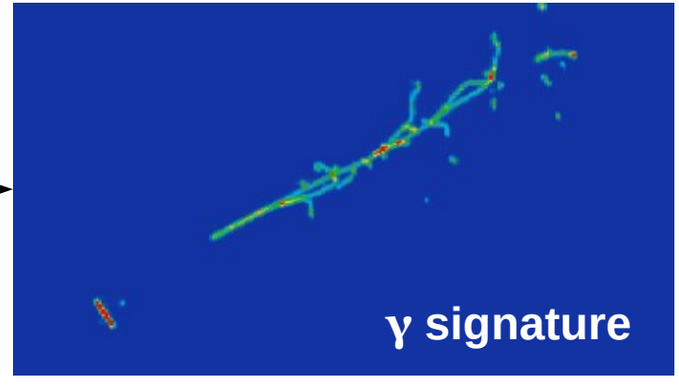
Multiple analyses utilizing different tools and approaches.

Will highlight common aspects to the various analyses, and briefly introduce each analysis' key features.

Many more details in the Public Notes describing each of the analyses. Can reach out with questions at *microboone_info@fnal.gov*

γ channel:

"The MicroBooNE Single-Photon Low-Energy Excess Search" [MICROBOONE-NOTE-1087]



e^- channel:

"Event Selection in the MicroBooNE Deep Learning Based Low Energy Excess Analysis Using Two-Body ScatteringCriteria" [MICROBOONE-NOTE-1086]

"Search for Electron Neutrinos in Multiple Topologies with the MicroBooNE Experiment" [MICROBOONE-NOTE-1085]

"Status of Electron Neutrino Event Selection at1MicroBooNE Using the WireCell-Pandora Hybrid Reconstruction Approach" [MICROBOONE-NOTE-1088]

Identifying Neutrinos in MicroBooNE

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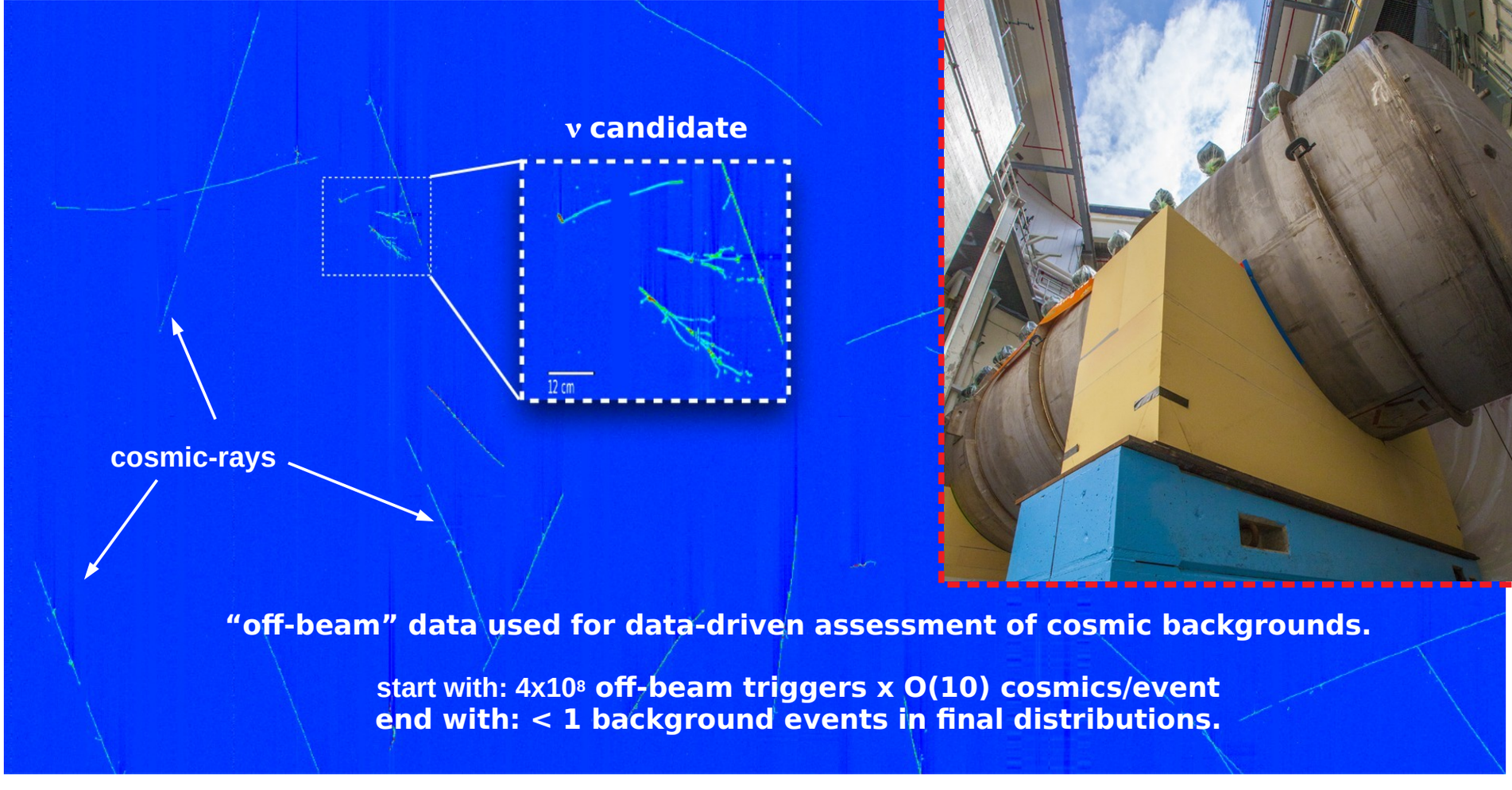
Surface LArTPC + slow e- drift → large cosmic background.

All LEE analyses start with the need to isolate neutrinos in a sea of cosmic-rays.



Detector Modeling

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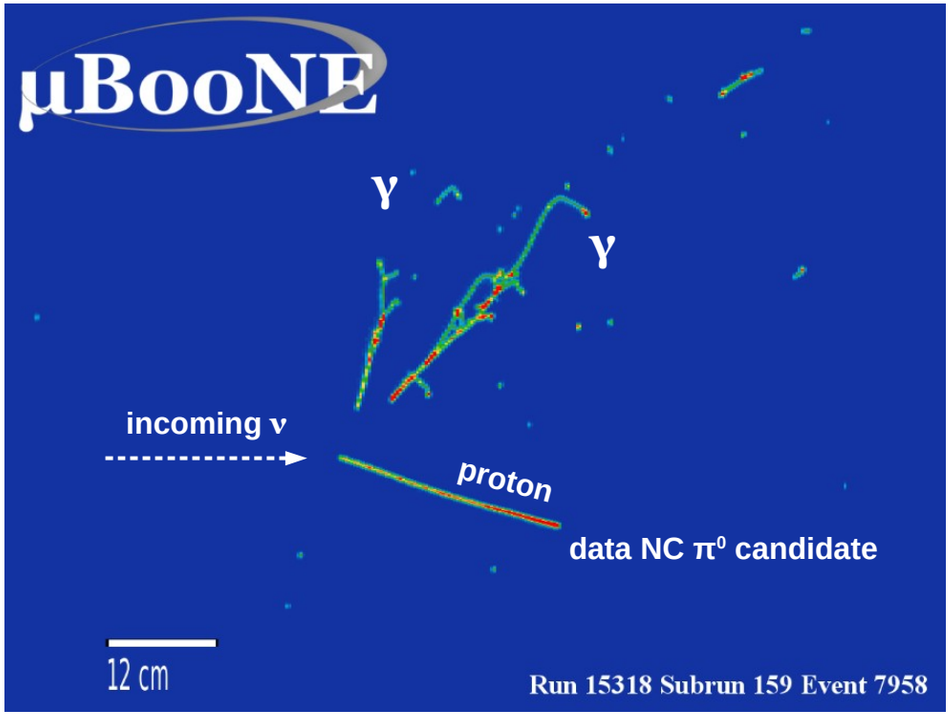
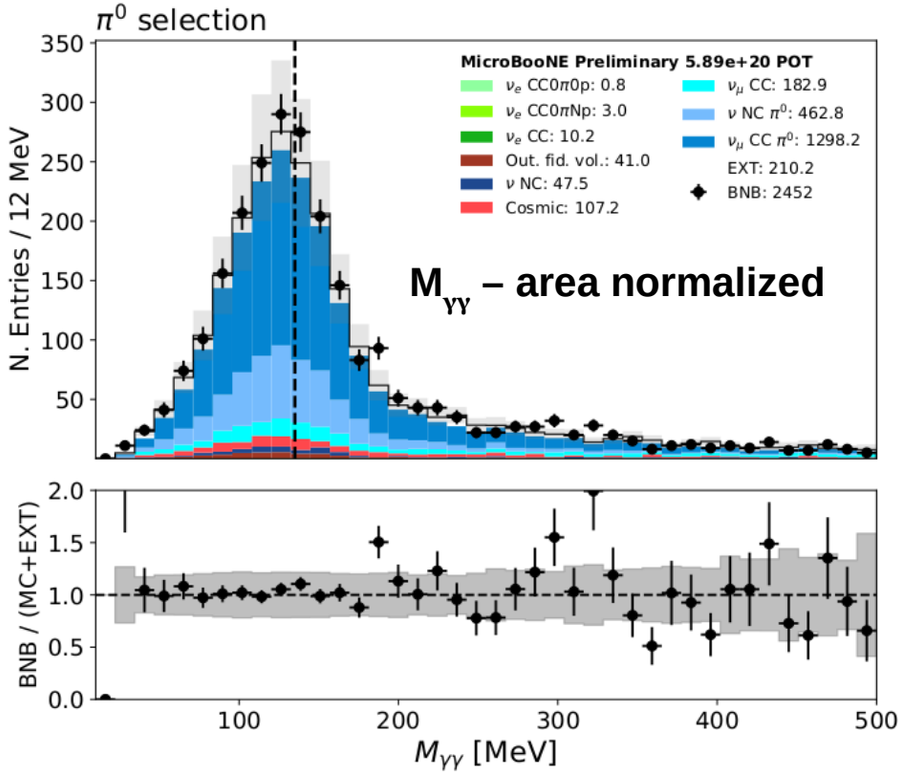
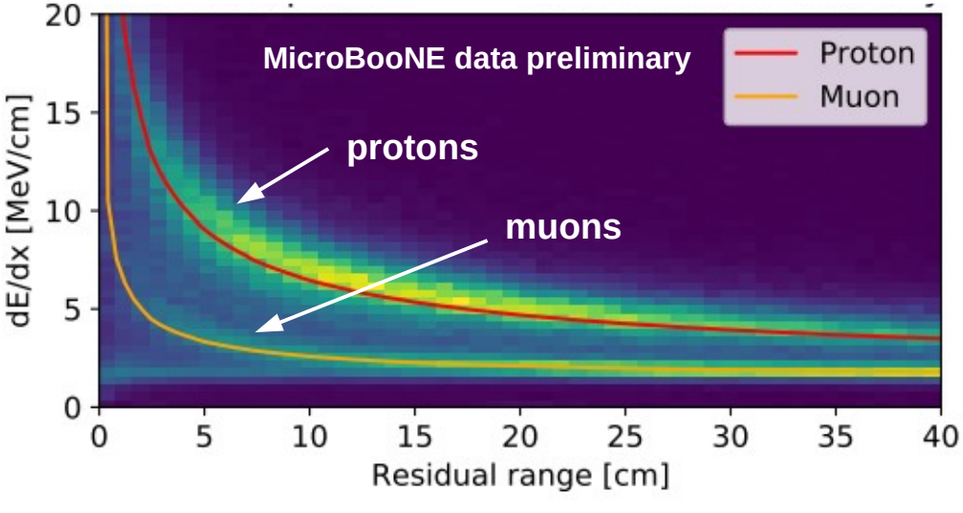




proton and muon data dE/dx vs.
residual range and theoretical expectation



Leverage a strong program of low-level detector modeling:

- signal-processing [JINST 13 (2018) 07, P07007, JINST 13 (2018) 07, P07006]
- data-driven E-field map calibration [JINST 15 (2020) 07, P07010].
- Calorimetric [JINST 15 (2020) 03, P03022] and EM shower [JINST 15 (2020) 02, P02007] calibrations.

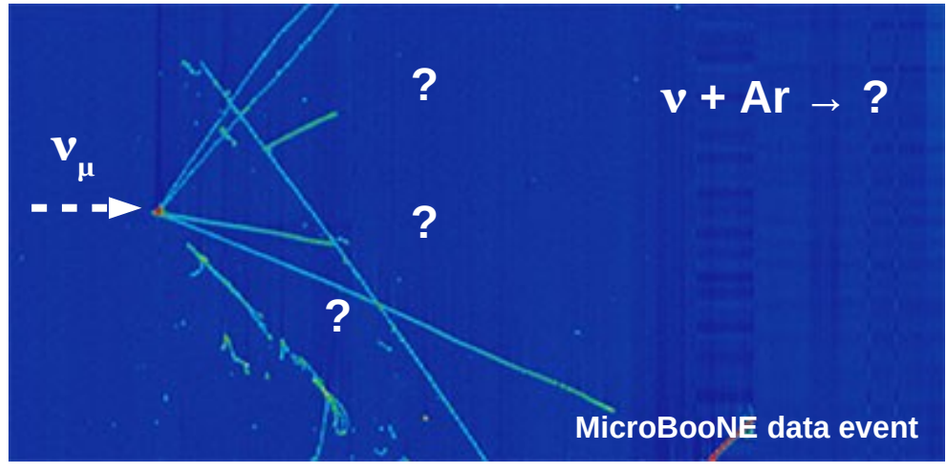
→ good understanding of detector response and precise measurement of particle kinematics.

Neutrino Interaction Modeling

Accurate modeling of ν-Ar interactions is paramount to this analysis.

Sparse ν-Ar measurements and few constraints at low energies require in-situ measurements.

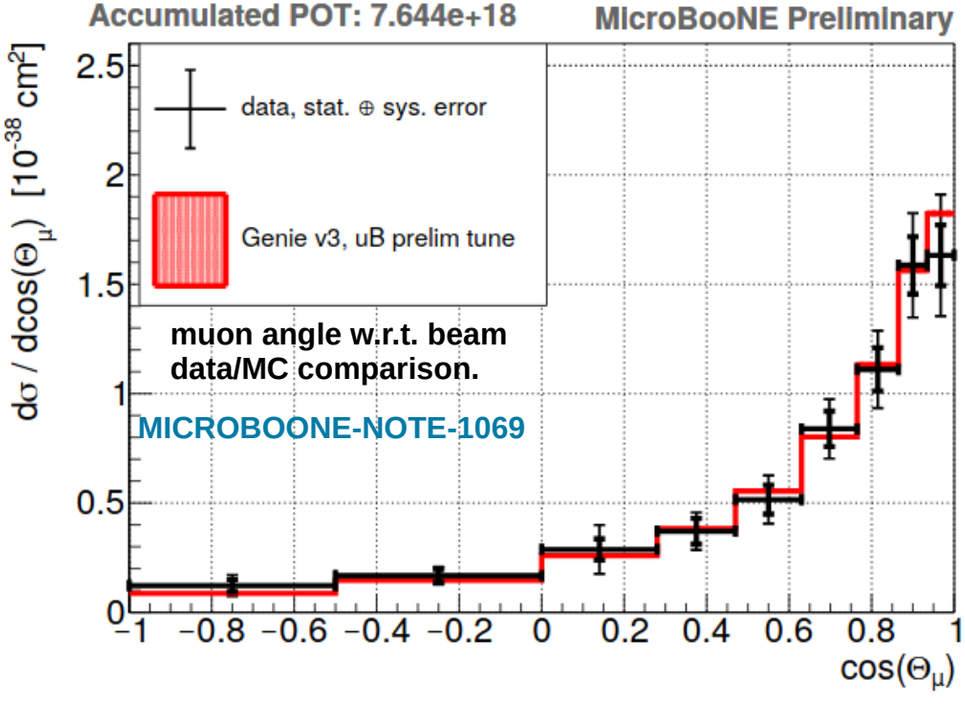
See talk by Raquel Castillo Fernandez.



Three generations of MicroBooNE analyses with progressive improvements on simulation, reconstruction, analysis tools.

State-of-the-art neutrino interaction model with GENIE-v3 + data-driven model tune with T2K CC0π data

MICROBOONE-NOTE-1074



- Detector systematics O(10s %) → O(few %)
- Reconstruction tools capable of 4π measurements.
- Robust ν interaction modeling and good data/MC agreement.

Constraining Backgrounds to LEE analyses

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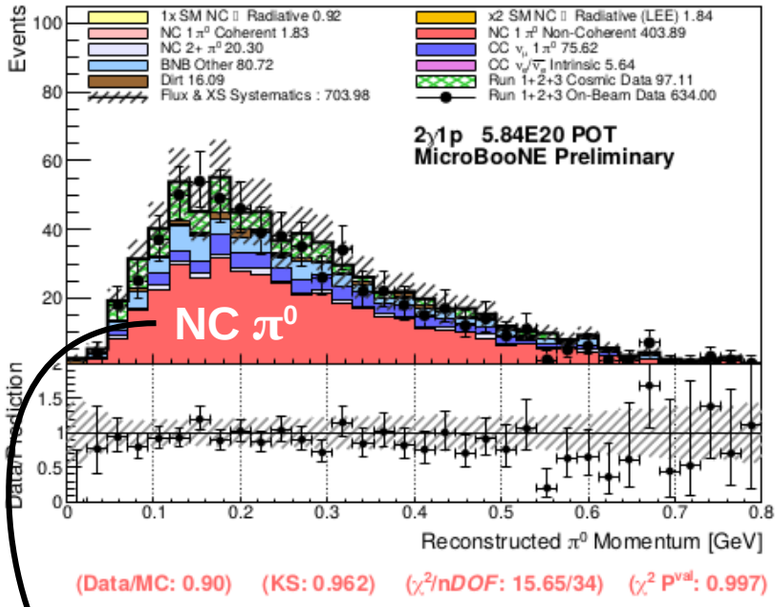
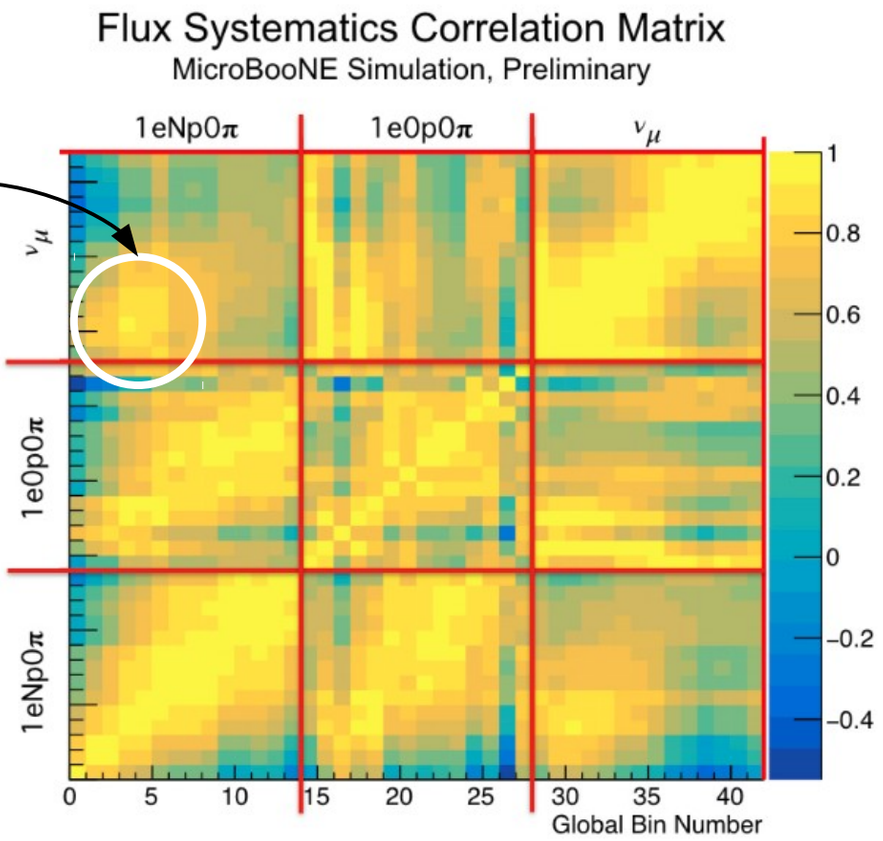
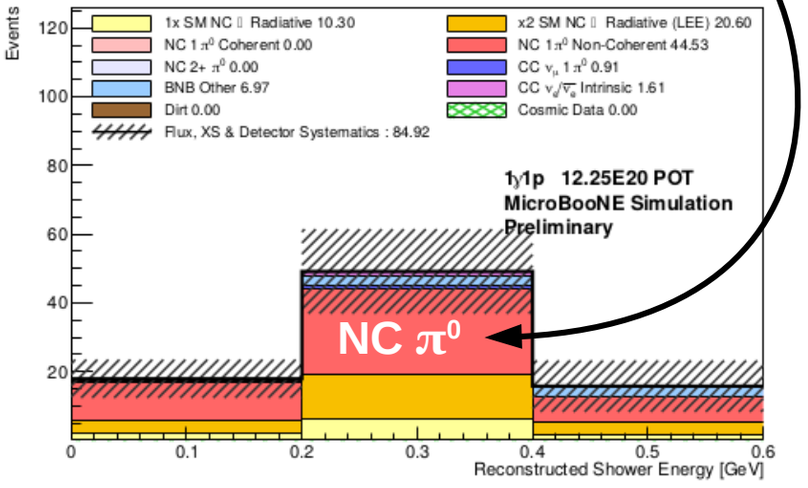
Background uncertainties drive sensitivity to new physics.



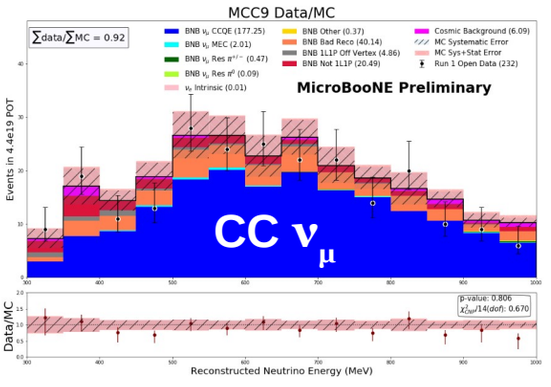
Leverage flux & cross-section correlations between ν_e and ν_μ.

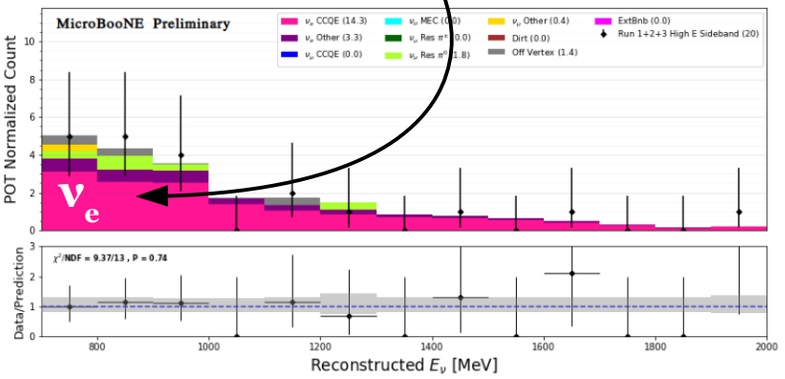


NC π^0 measurement constraints single-γ background.



CC ν_μ constrains intrinsic ν_es





MicroBooNE’s low-energy-excess analyses

The single-photon LEE search

MICROBOONE-NOTE-1087

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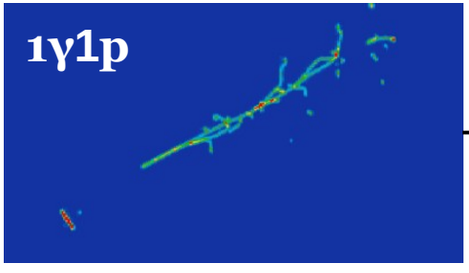
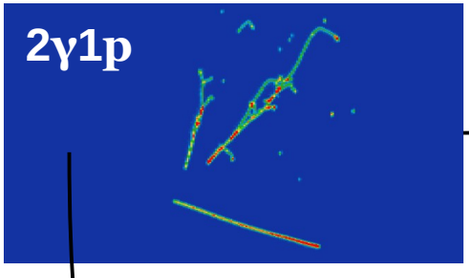
Select final-state compatible with a single photon shower and one or zero protons.

BDT tailored to NC $\Delta \rightarrow \gamma + N$ signature.

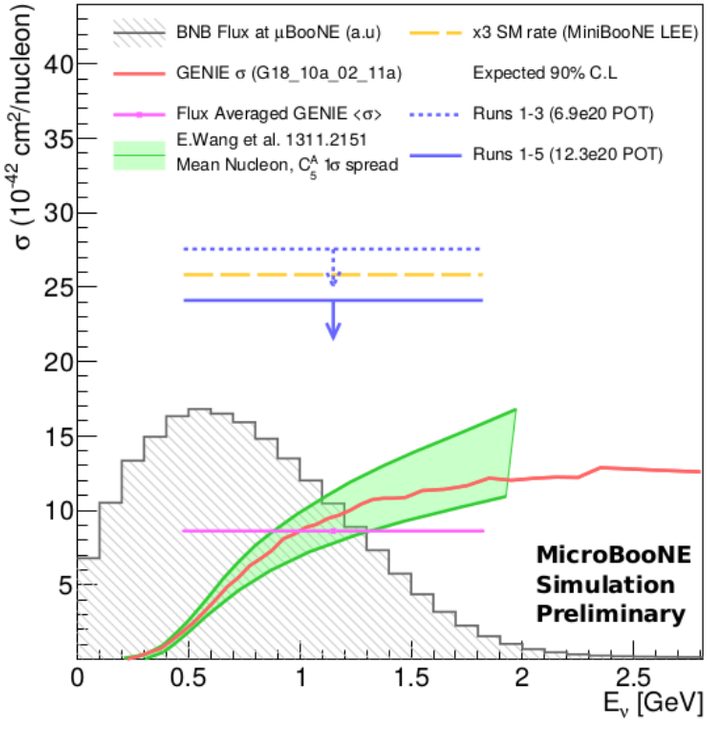




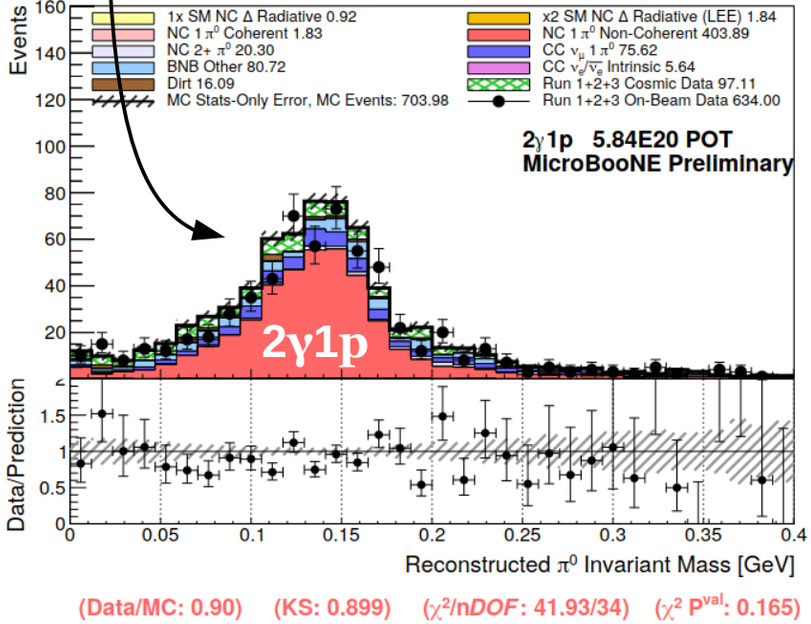
signal

NC background constraint

See talk by Mark Ross-Lonergan.



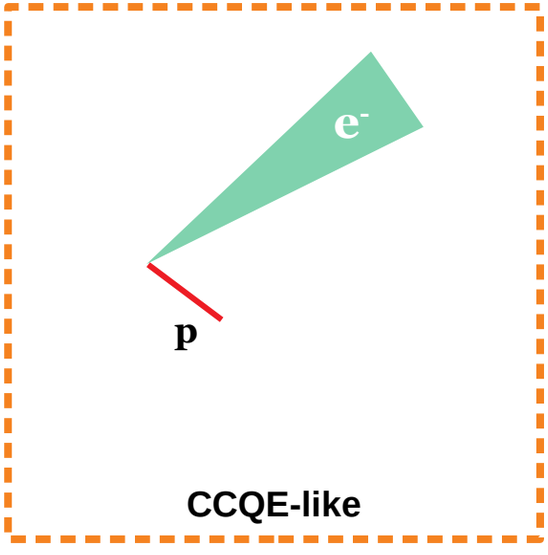
Leverage **Pandora** reconstruction
[Eur.Phys.J.C 78 (2018) 1, 82]

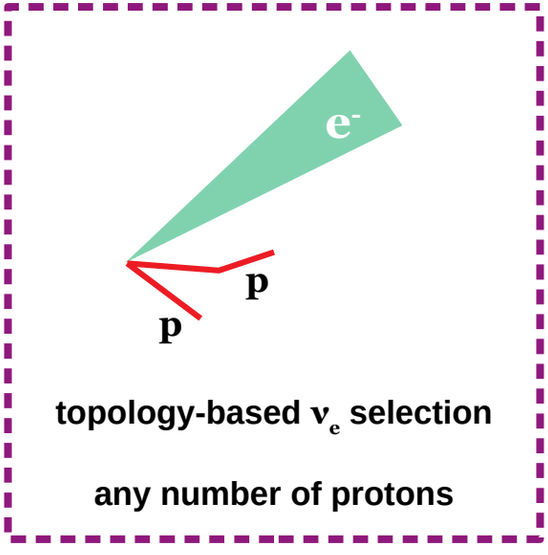


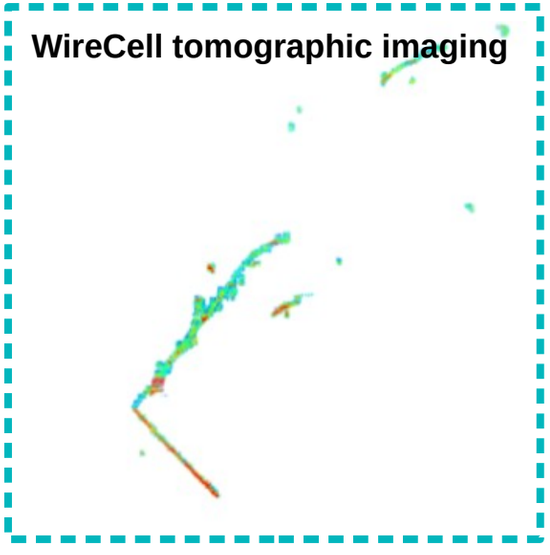
- Most stringent constraint of standard model NC $\Delta \rightarrow \gamma + N$ in neutrino scattering.
- Capable of excluding radiative Δ decay interpretation of LEE hypothesis at > 95% CL

The electron channel LEE search

Three distinct efforts within the collaboration:







MICROBOONE-NOTE-1086

Tailored search for low-energy CCQE-like ν_e.

Deep-Learning techniques.

MICROBOONE-NOTE-1085

multi-topology search over broad energy range.

Leverage LArTPC PID.

MICROBOONE-NOTE-1088

Aim for inclusive ν_e search.

ongoing development.

The electron channel LEE search

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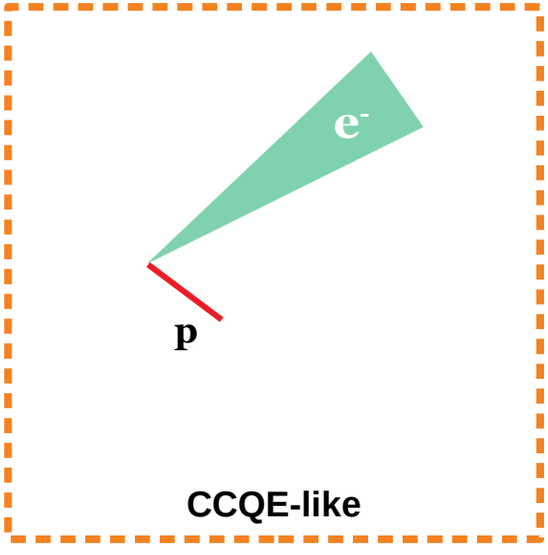
"Event Selection in the MicroBooNE Deep Learning Based Low Energy Excess Analysis Using Two-Body Scattering Criteria" [MICROBOONE-NOTE-1086]



over-constrain interaction kinematics under two-body scattering CCQE-like hypothesis

$$E^{\nu}_{CCQE}(E_{proton},\theta_{proton}) = E^{\nu}_{CCQE}(E_{lepton},\theta_{lepton}) = E^{\nu}_{range}(E_{proton},E_{lepton})$$

pixel-level PID
MICROBOONE-NOTE-1091

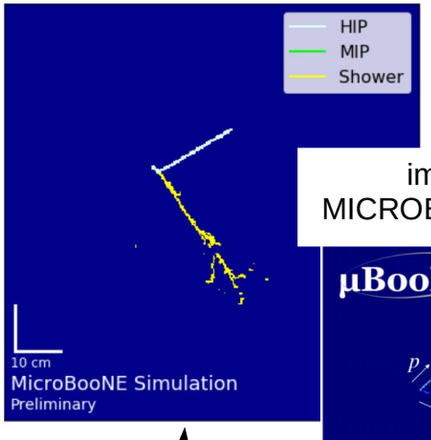
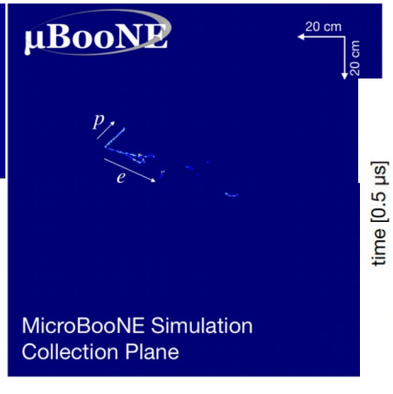
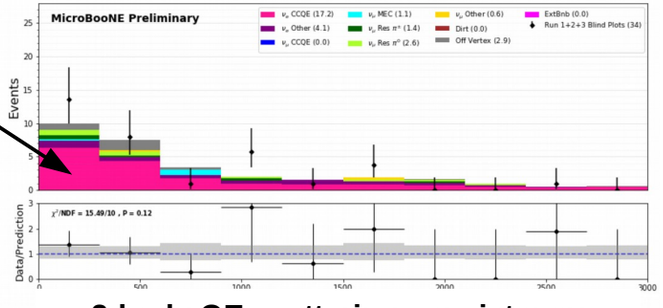


image-level PID
MICROBOONE-NOTE-1080



ν_e



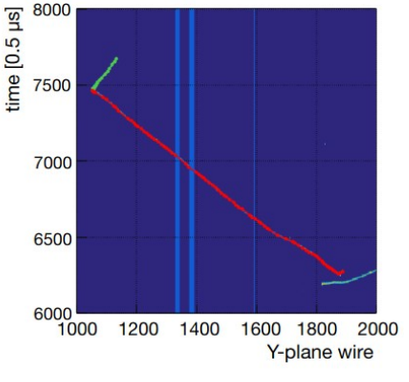
2-body QE scattering consistency

MICROBOONE-NOTE-1086

Tailored search for low-energy CCQE-like ν_e.

Deep-Learning techniques.

1μ1p reconstruction
arXiv:2002.09375



The electron channel LEE search

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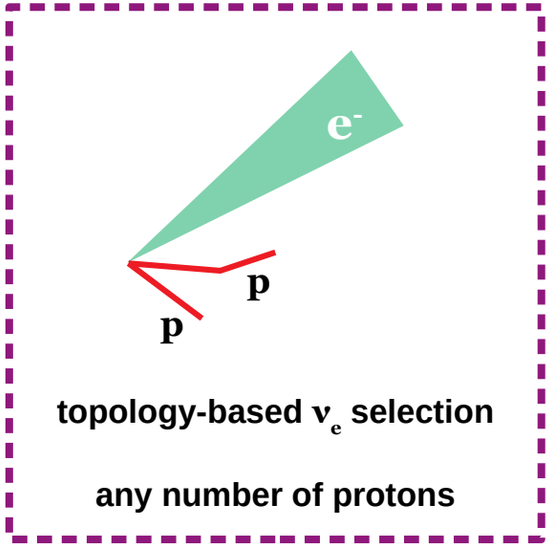
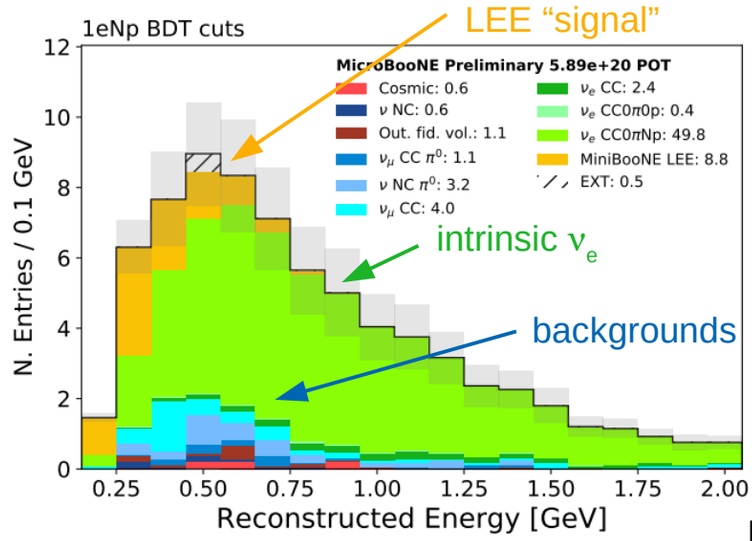
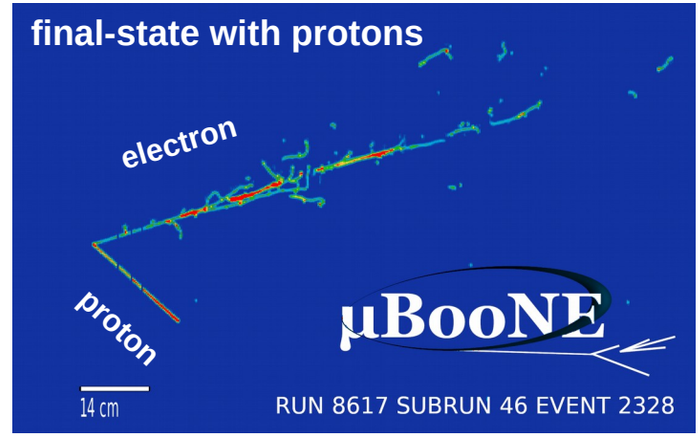
"Search for Electron Neutrinos in Multiple Topologies with the MicroBooNE Experiment" [MICROBOONE-NOTE-1085]







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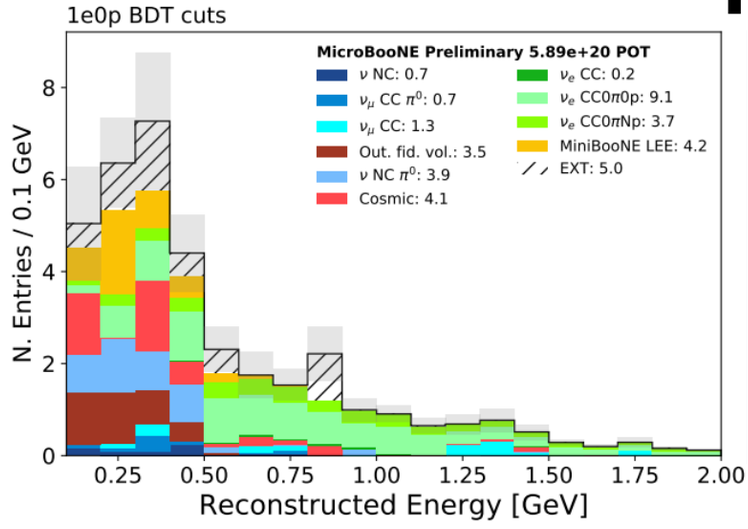

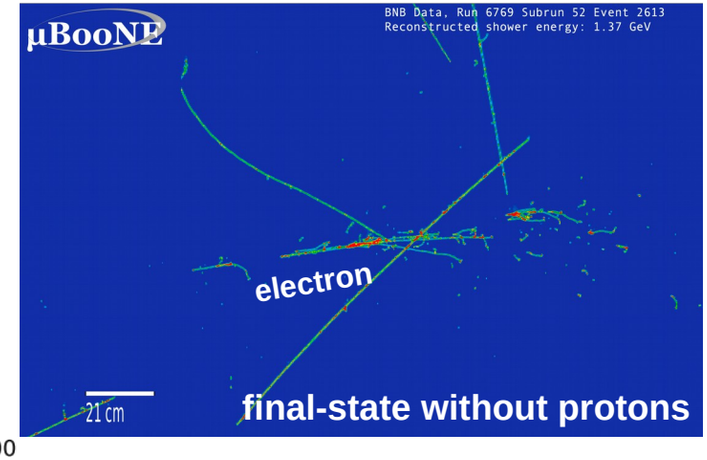

MICROBOONE-NOTE-1085

multi-topology search over broad energy range.

Leverage LArTPC PID.

See talk by Wouter Van De Pontseele on inclusive measurement within this analyysis

→ 3σ sensitivity to exclude SM in favor of ν_e LEE interpretation

The electron channel LEE search

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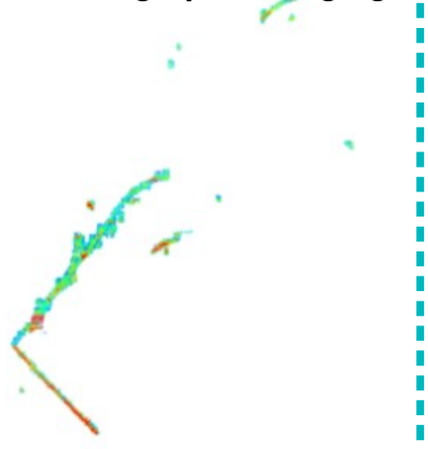
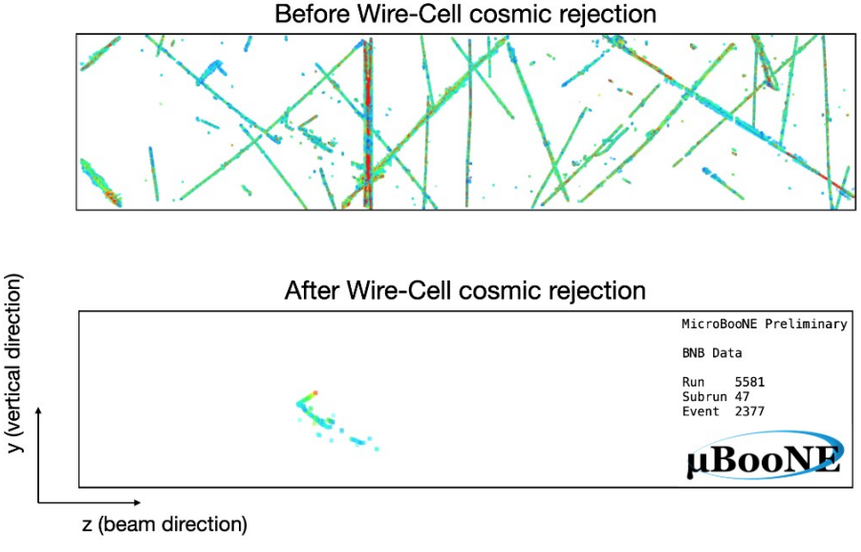
"Status of Electron Neutrino Event Selection at MicroBooNE Using the WireCell-Pandora Hybrid Reconstruction Approach" [MICROBOONE-NOTE-1088]

WireCell tomographic imaging





Aim to leverage strengths of different reconstruction paradigms for high efficiency ν_e measurement.

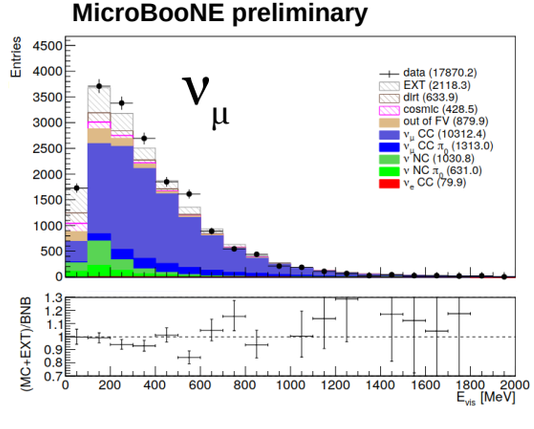
At earlier stages of development.

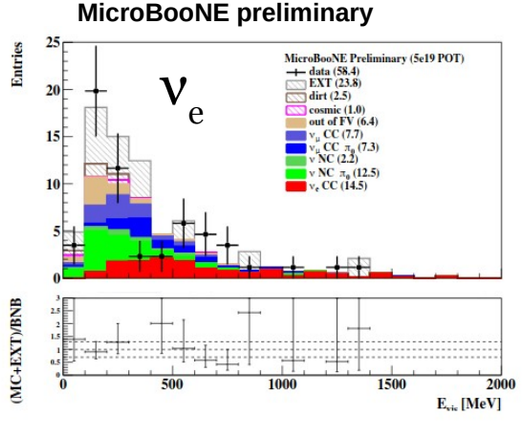
First event selections from Wire-Cell "hybrid" analysis.

MICROBOONE-NOTE-1088

Aim for inclusive ν_e search.

ongoing development.





Analysis Status : sidebands and box-opening

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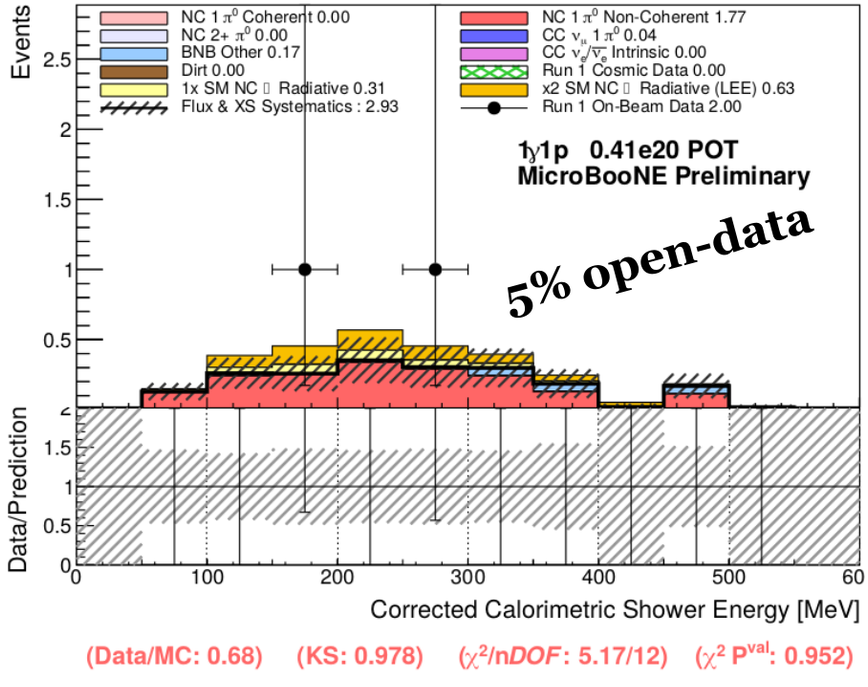
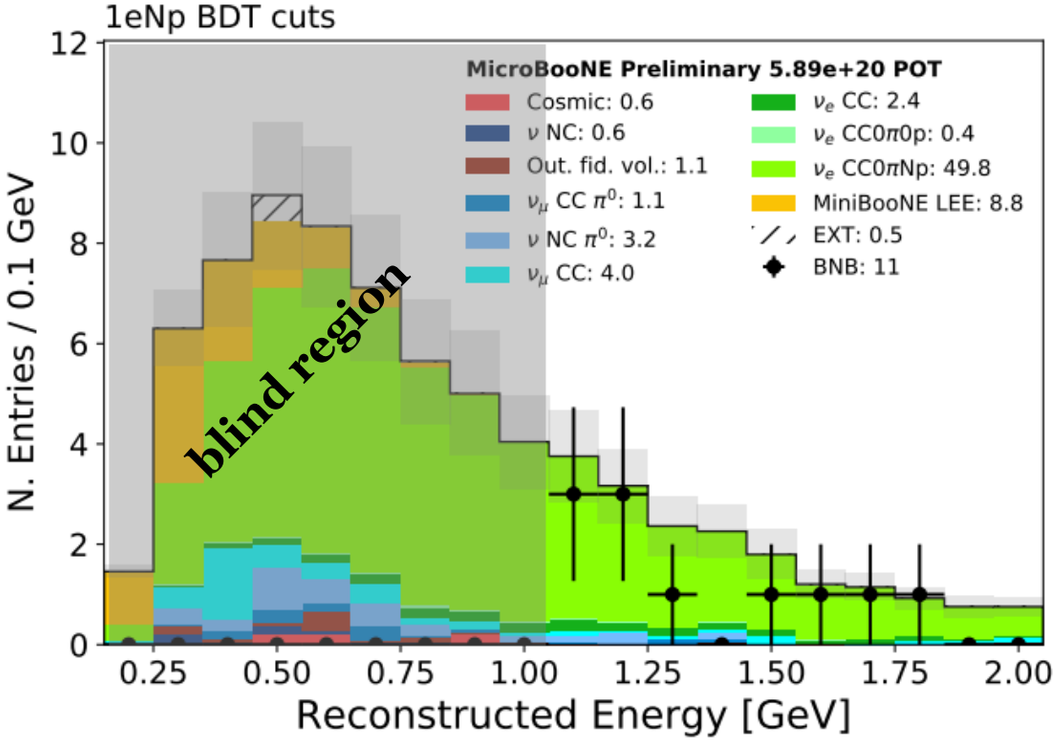


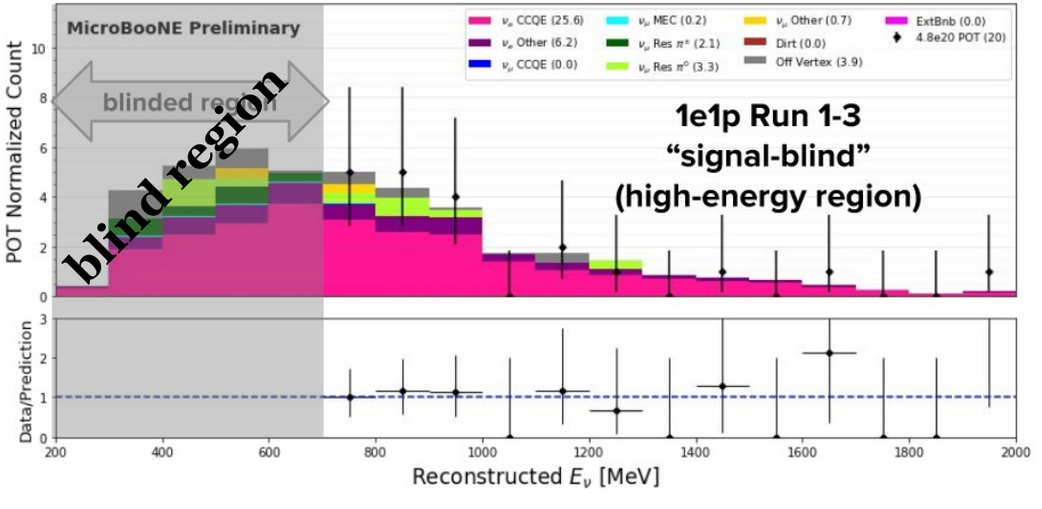


MicroBooNE's "Low Energy Excess" analyses:

- being validated with 5% open-data and through ν_e / π^o sidebands far from signal region

- nearing a full box-opening.

Promising results indicating robust analyses.



Summary

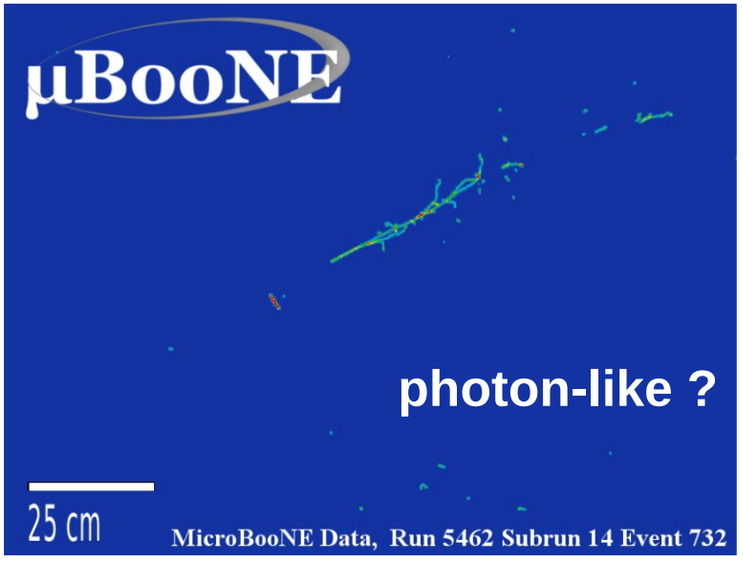
MicroBooNE aims to address the origin of MiniBooNE's low-energy-excess anomaly, shedding light on a significant anomaly in short baseline neutrino experiments.

Leveraging multiple years of development in analyzing ν-LArTPC data MicroBooNE has multiple complementary analyses sensitive to new physics at low-energy.

Mature analyses have been validating performance with sidebands.

First generation of analyses getting ready for final box-opening.

vs.



→ stay tuned!