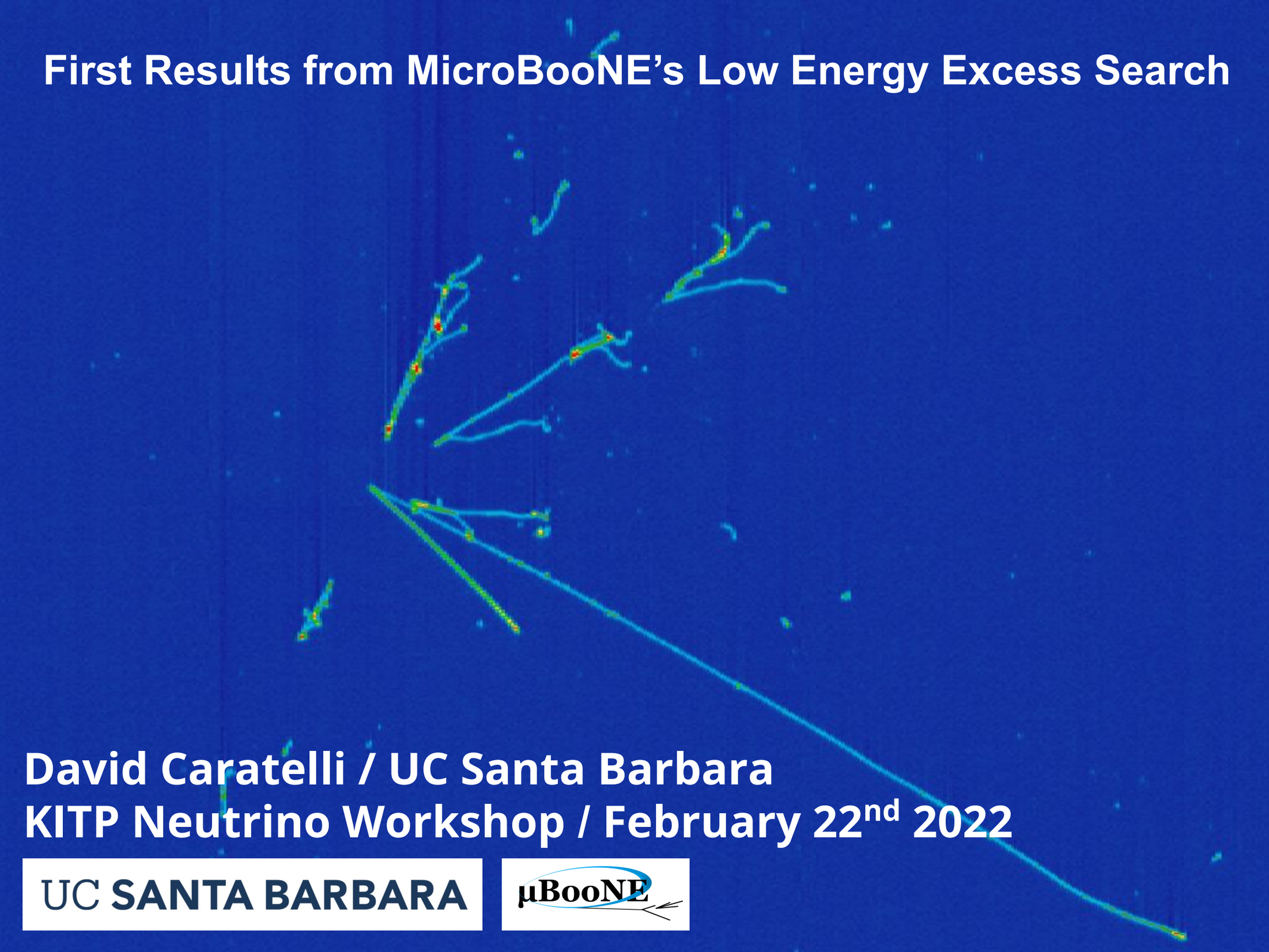
First Results from MicroBooNE's Low Energy Excess Search



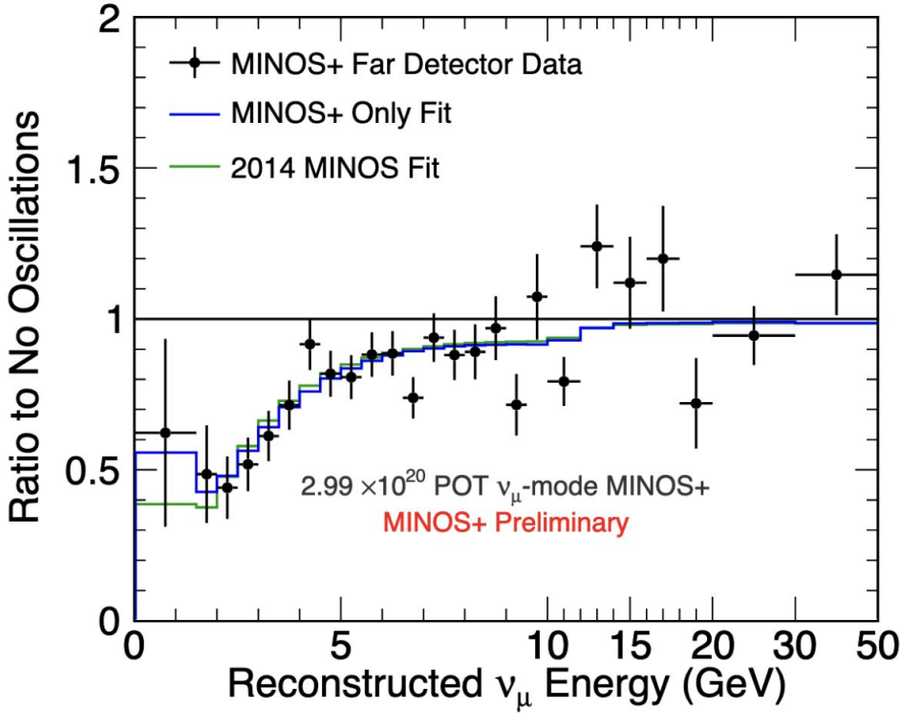
David Caratelli / UC Santa Barbara

KITP Neutrino Workshop / February 22nd 2022

UC SANTA BARBARA

μBooNE

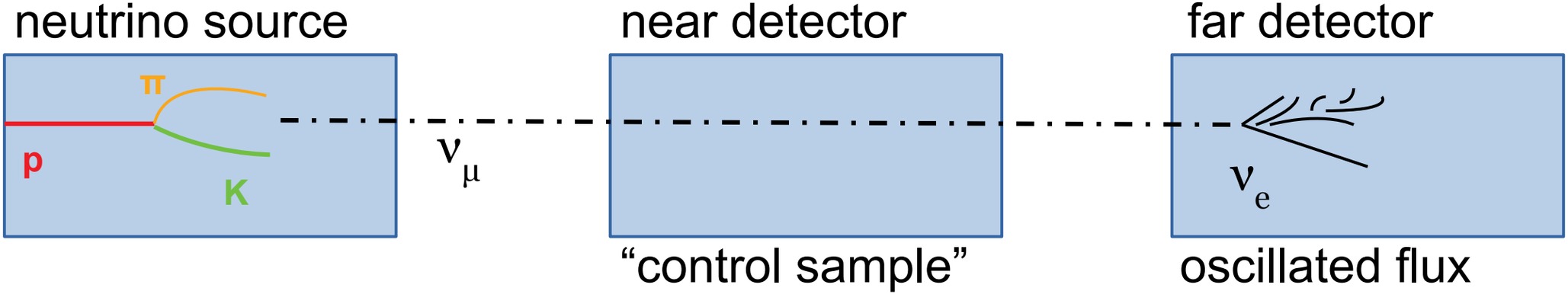
Neutrino Oscillations



Freq. Of oscillation.
Choose L, E appropriate for Δm^2.

$$P_{\nu_\mu \to \nu_e} \approx \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

sets amplitude of oscillation.
large → "easy" to detect.



Short-Baseline Neutrino Anomalies

Freq. Of oscillation.
Choose L, E appropriate for Δm^2.

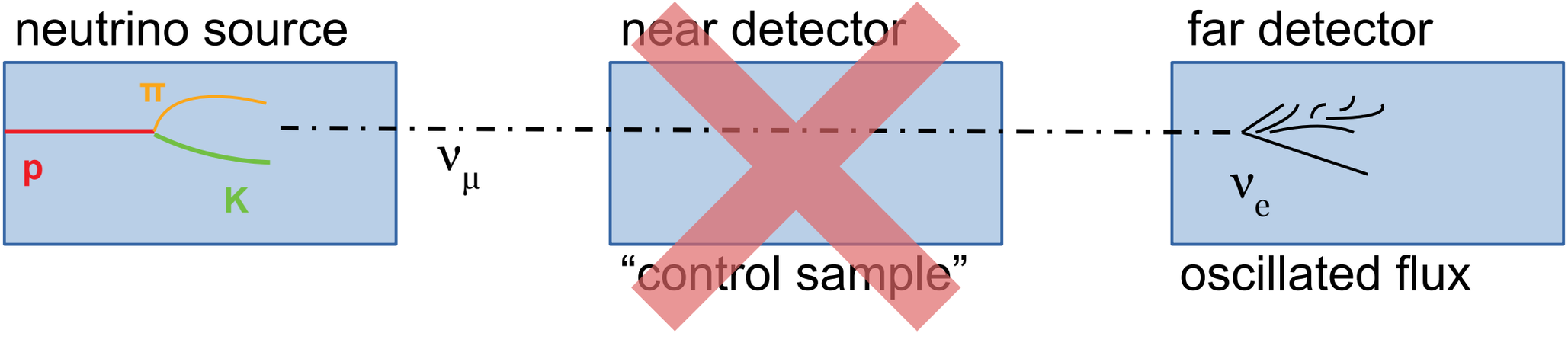
$$P_{\nu_\mu \to \nu_e} \approx \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

sets amplitude of oscillation.
large → "easy" to detect.

Lack of "near detector" → larger uncertainty on predicted neutrino rate

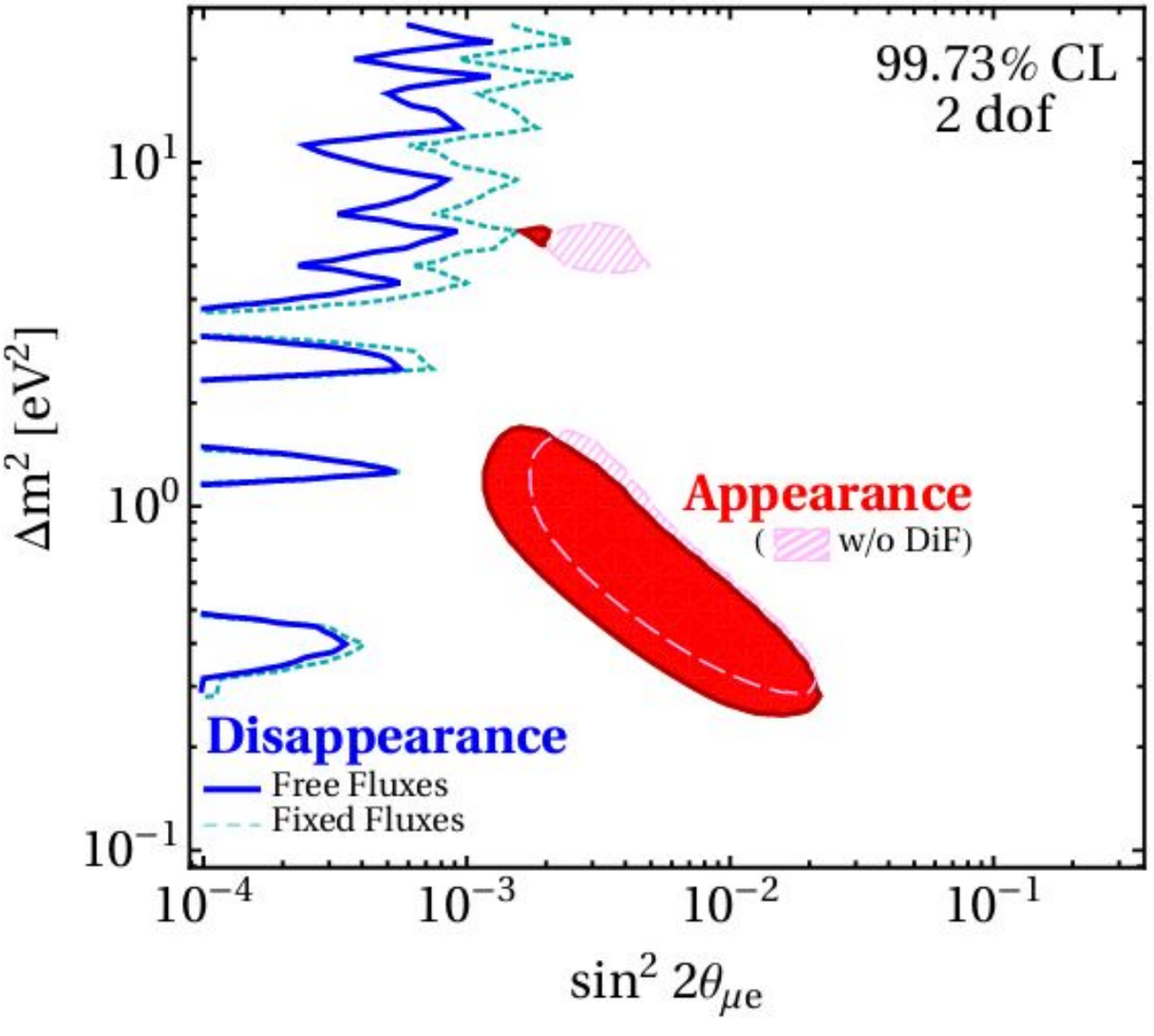
- flux uncertainties
- ν cross-section systematics

→ both boil down to nuclear physics



eV Sterile Neutrinos?

Dentler M, et al. *JHEP* 08:010 (2018)

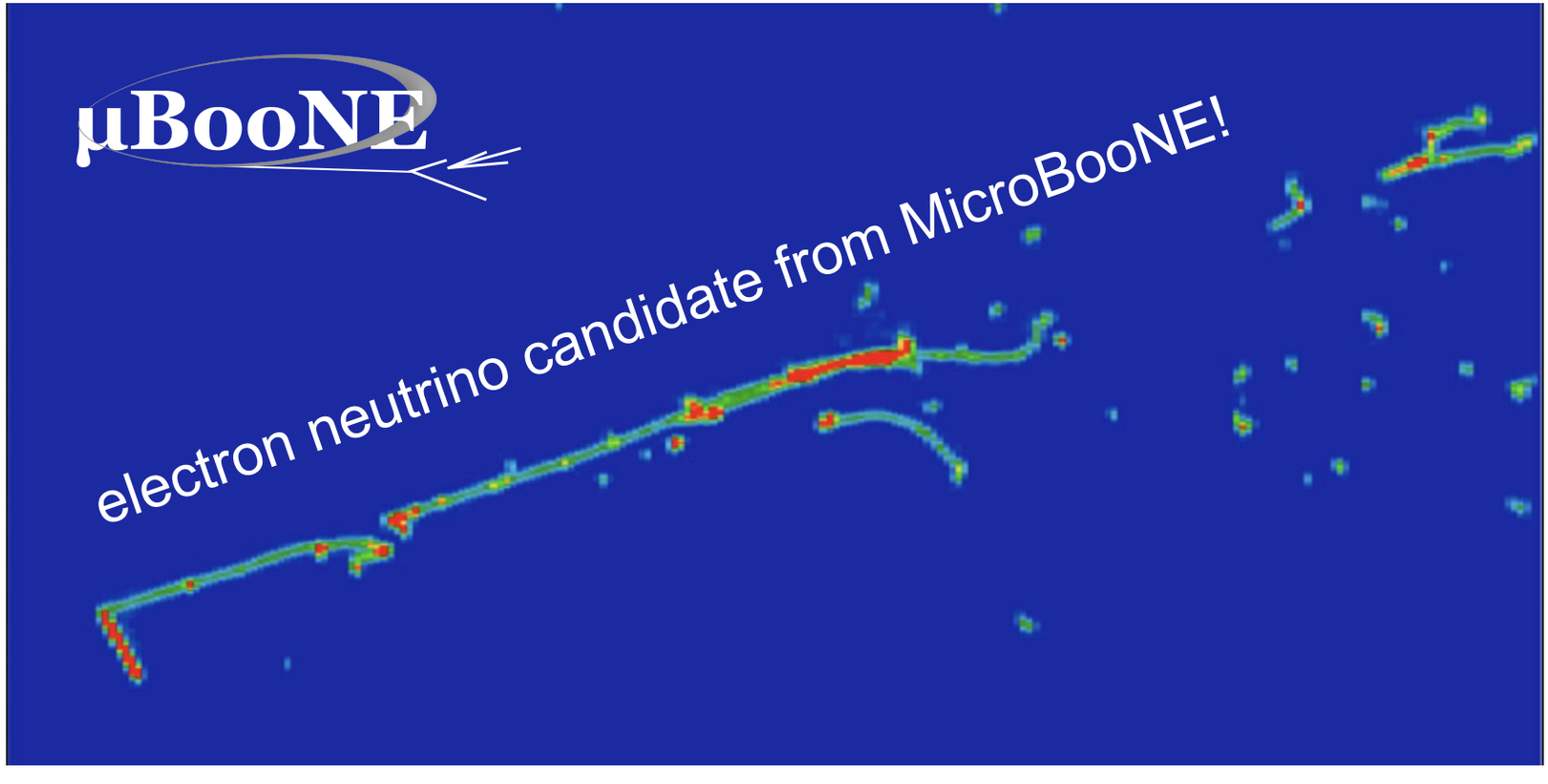


eV sterile neutrinos: an unclear picture…

New Results from MicroBooNE

Many recent results which directly tie to this question.

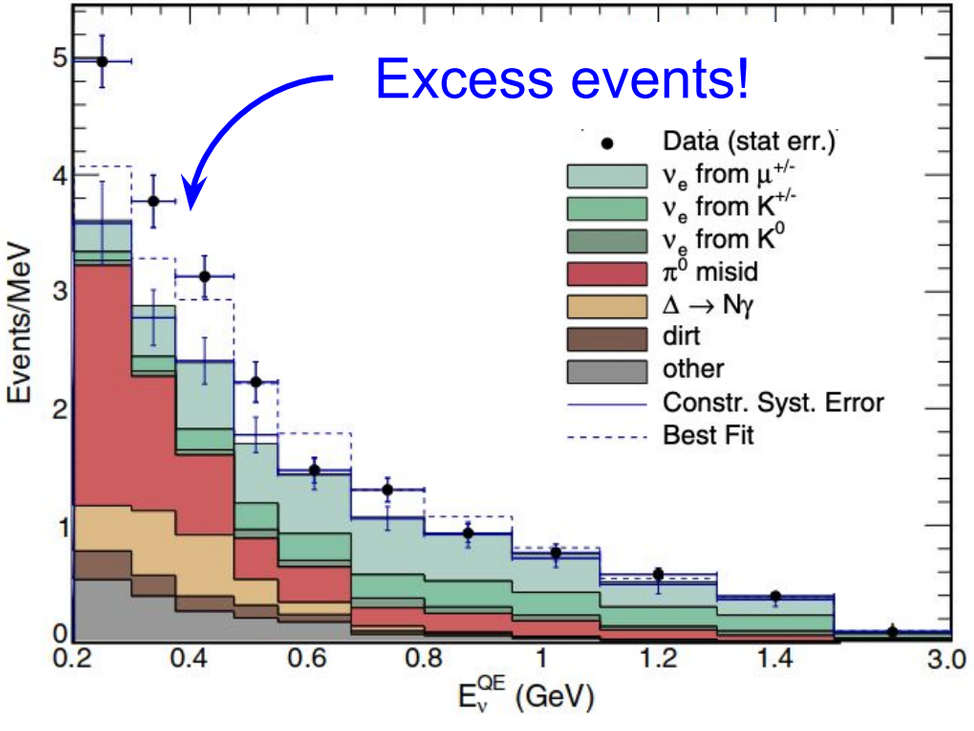
This talk will highlight recent results from MicroBooNE.



eV sterile neutrinos: a changing landscape…

Neutrino Anomalies: MiniBooNE

MiniBooNE, PRL **121**, 221801 (2018)

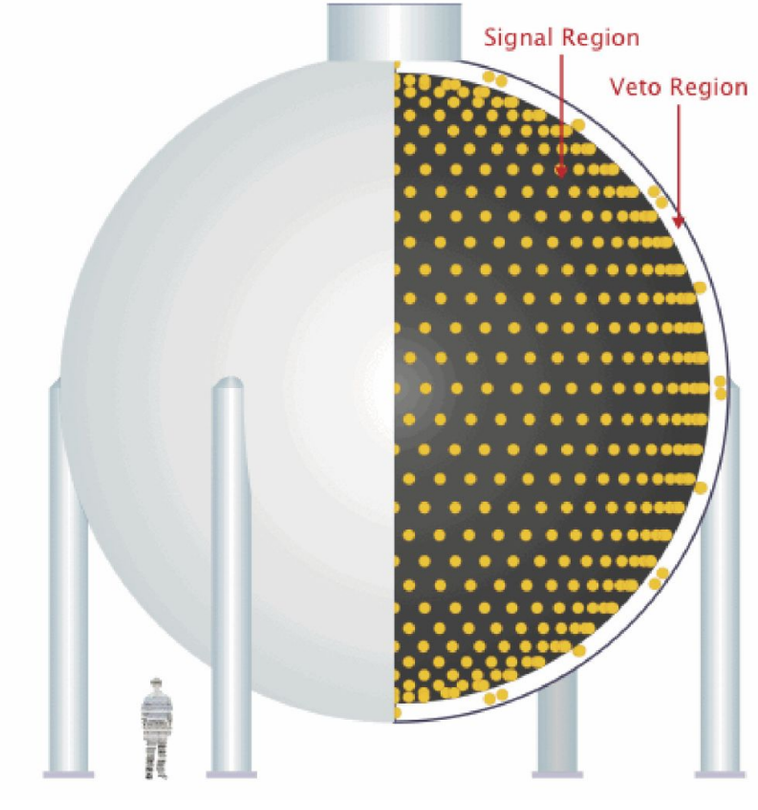


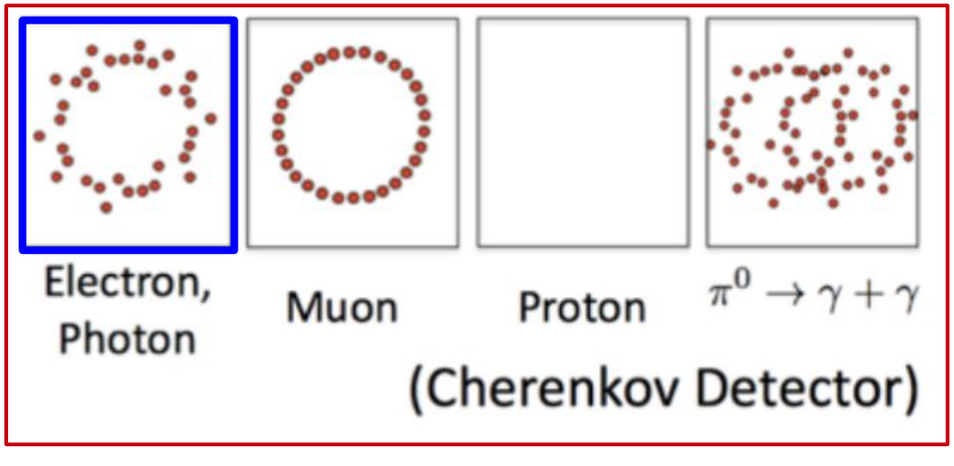
O(100s) MeV

"**Low-Energy-Excess**" EM activity in detector.

4.5σ significance.

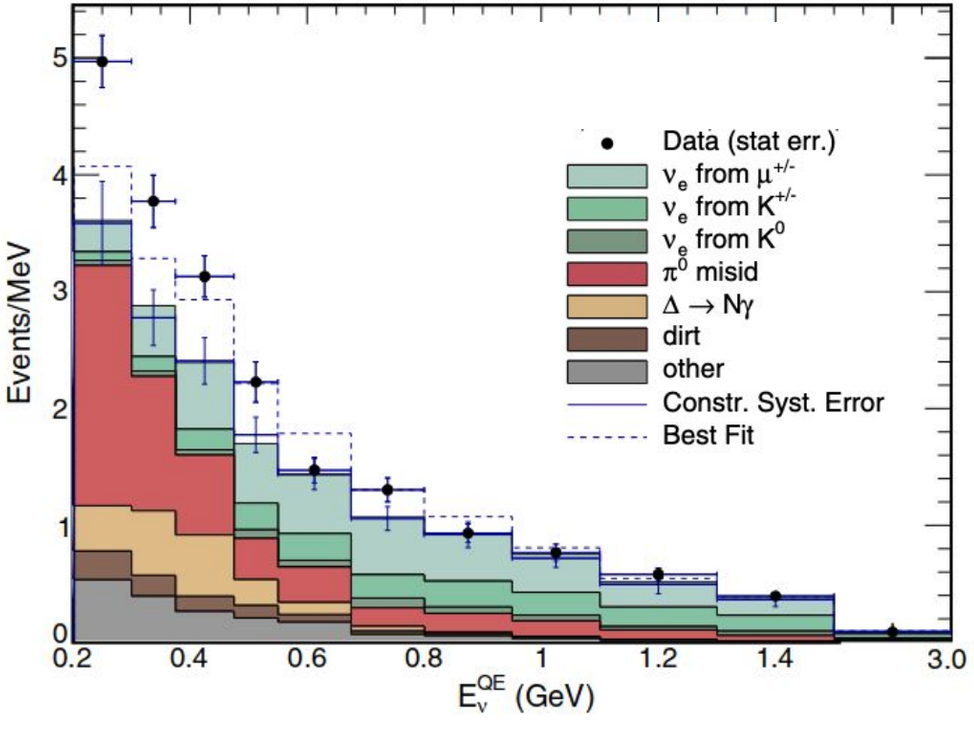
Cannot distinguish electrons from photons.





MiniBooNE as eV-scale Sterile Neutrinos

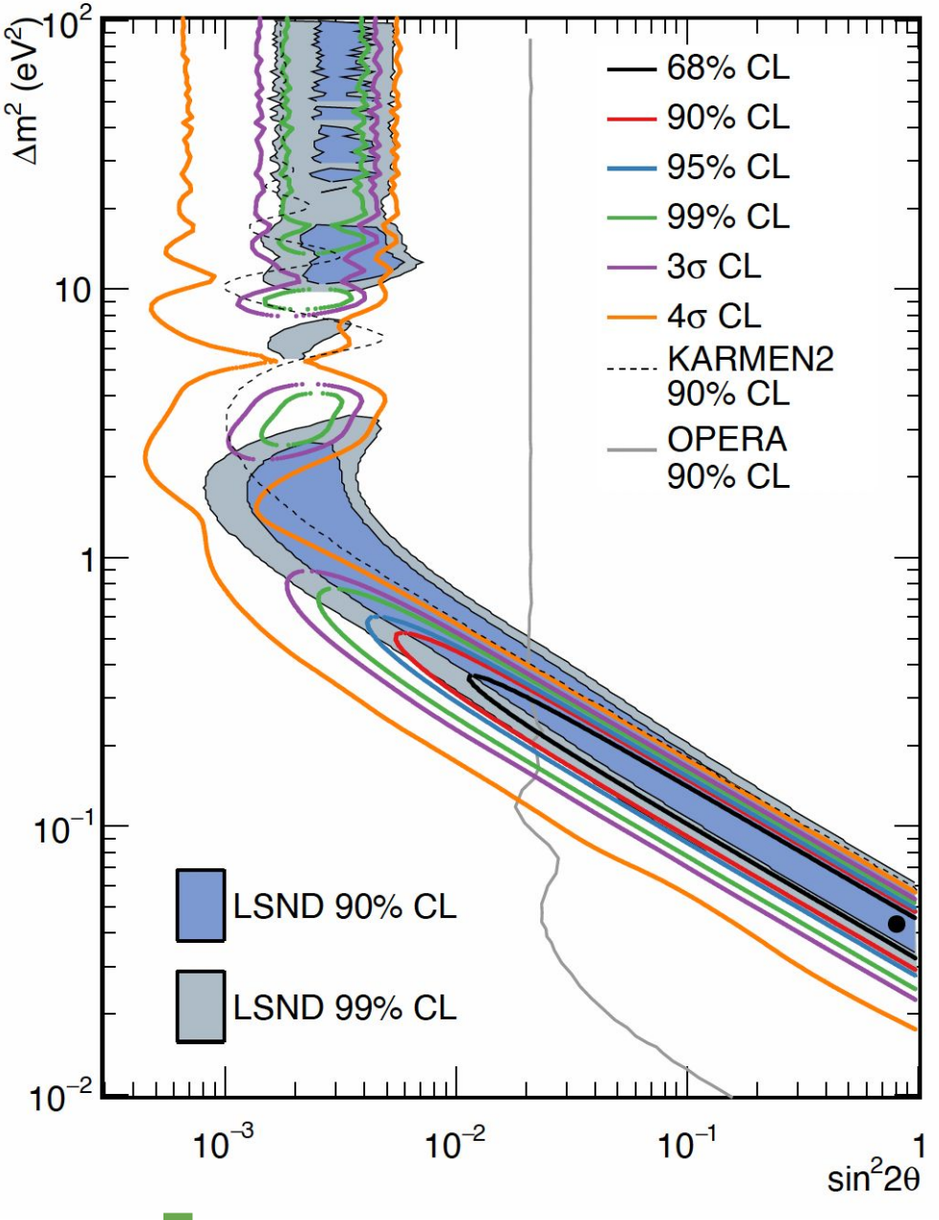
MiniBooNE, PRL **121**, 221801 (2018)



MiniBooNE's result a key motivation for eV-scale sterile neutrino searches.

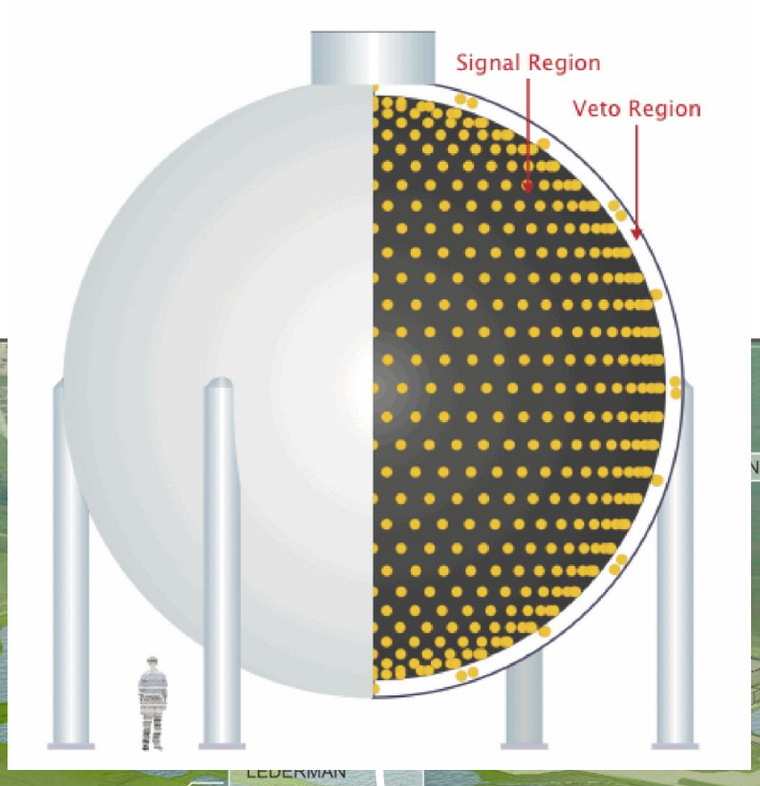
Motivation arises from interpretation of excess as "extra" oscillated electron neutrinos.

MiniBooNE, Phys. Rev. D 103, 052002 (2021)

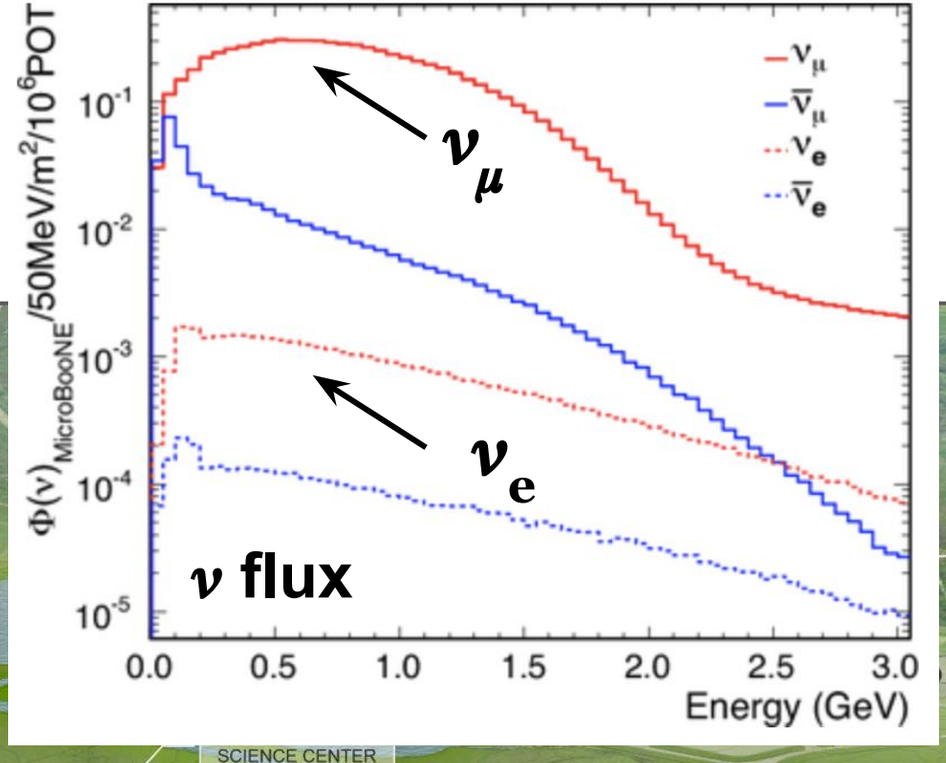


active neutrinos are down here….

The MicroBooNE Experiment

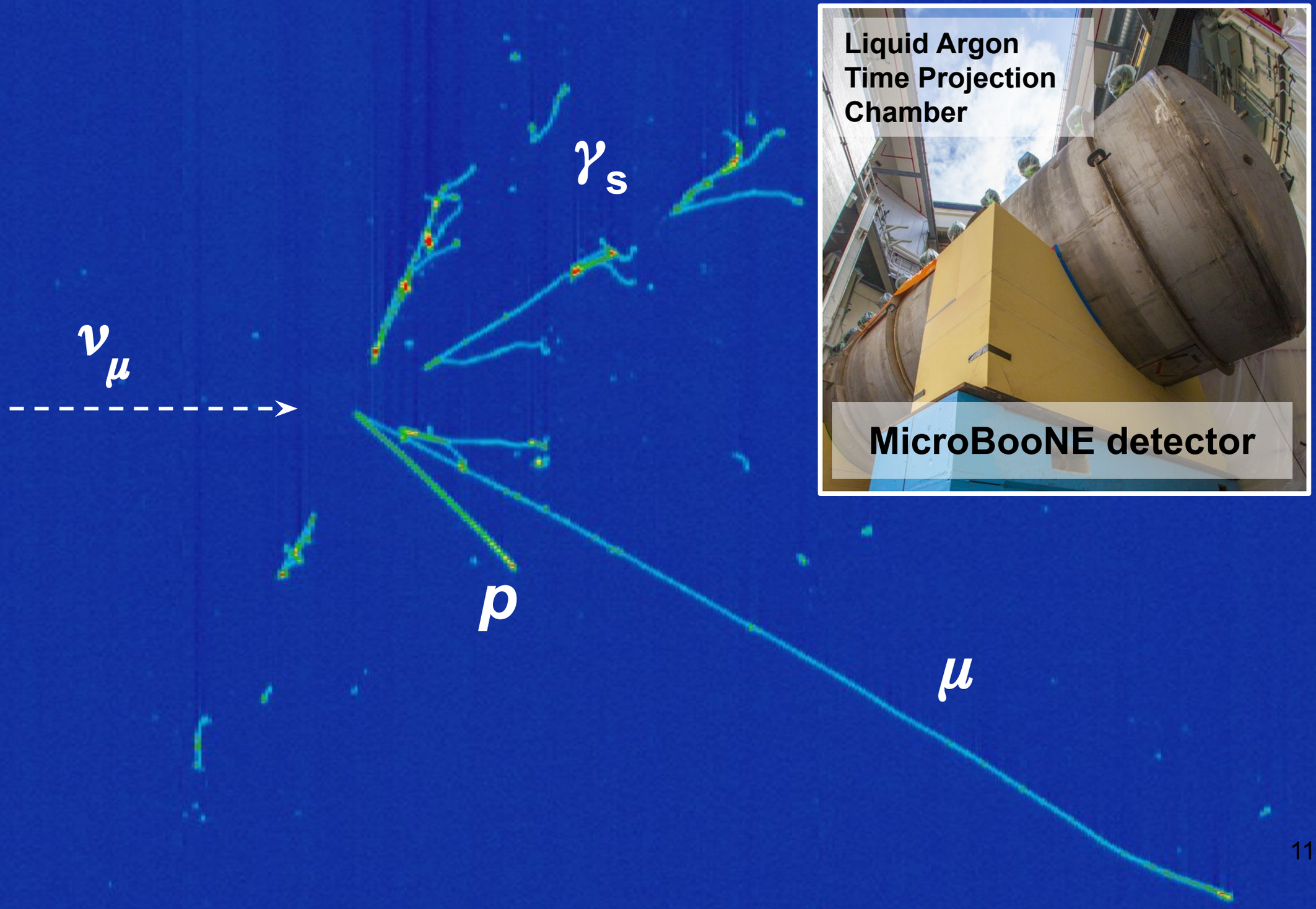


The Booster Neutrino Beamline @ Fermilab

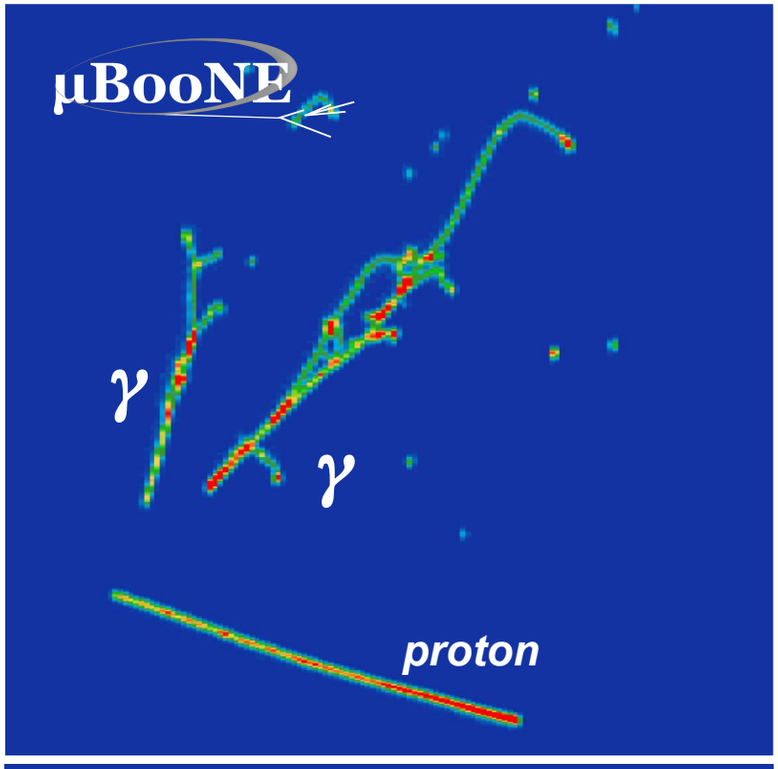


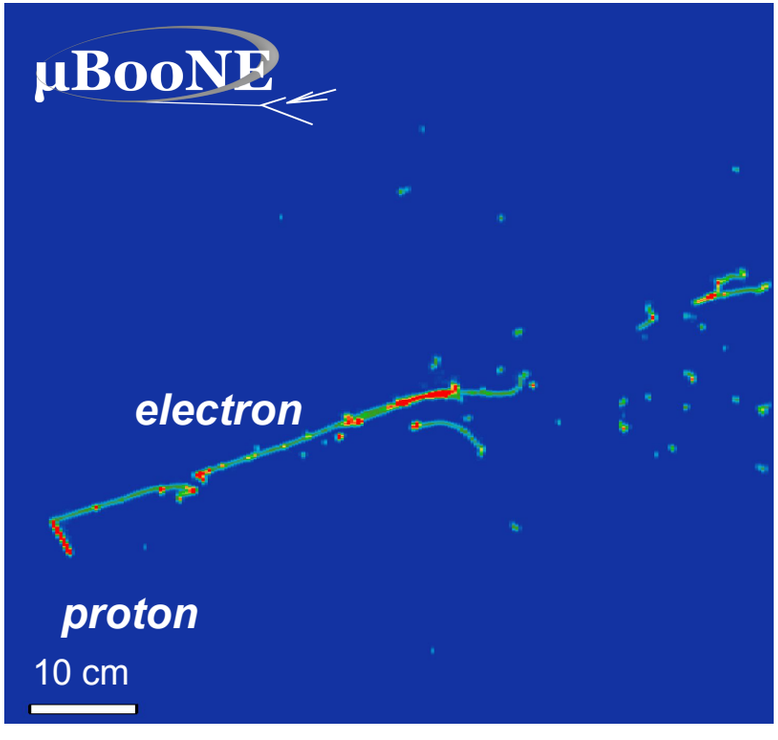
- 99% ν_μ / 1% ν_e beam composition
- O(1) GeV neutrino energy
- ~400 meter baseline
- one neutrino interaction per minute @ μB

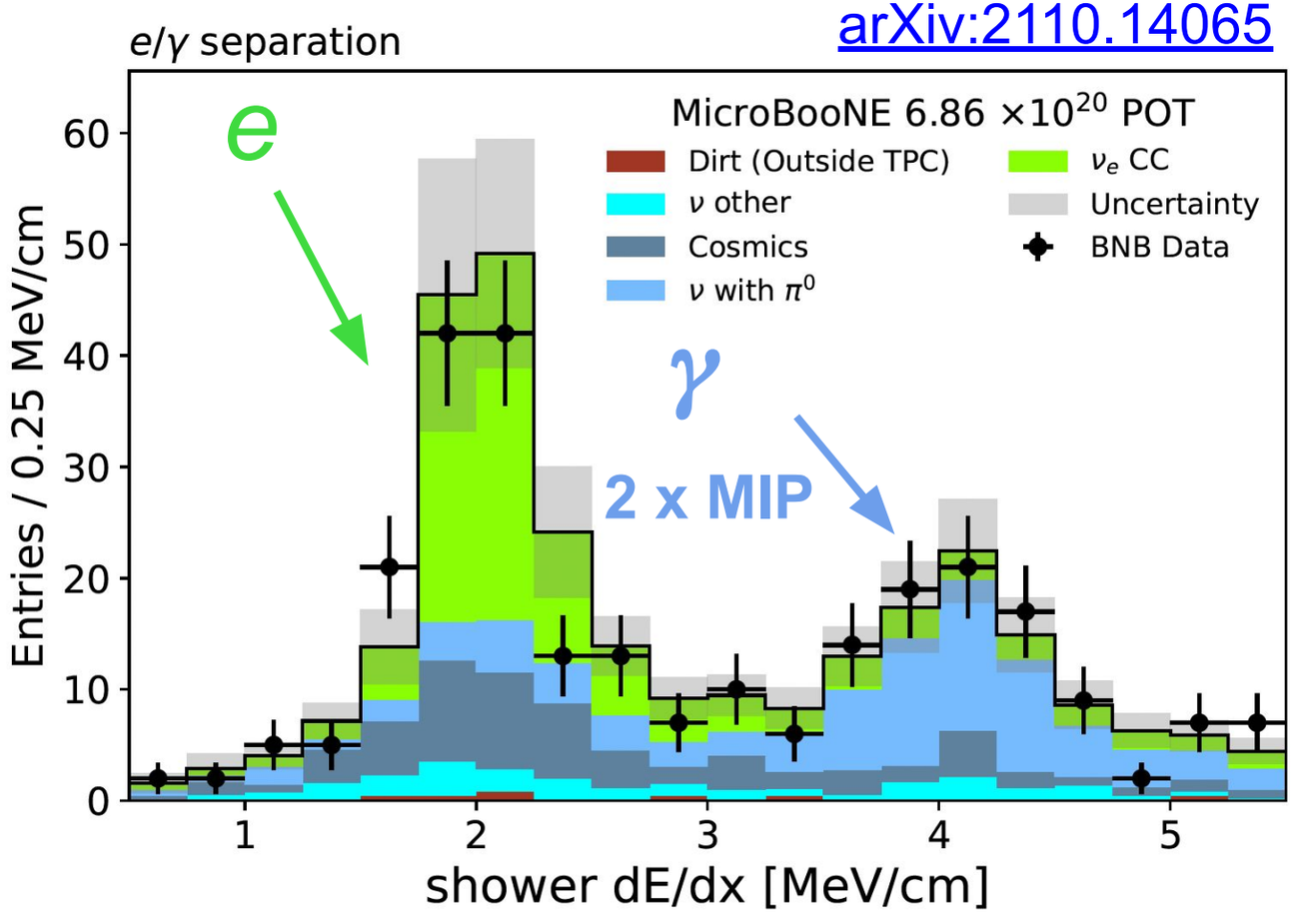
The MicroBooNE Experiment



e/γ separation







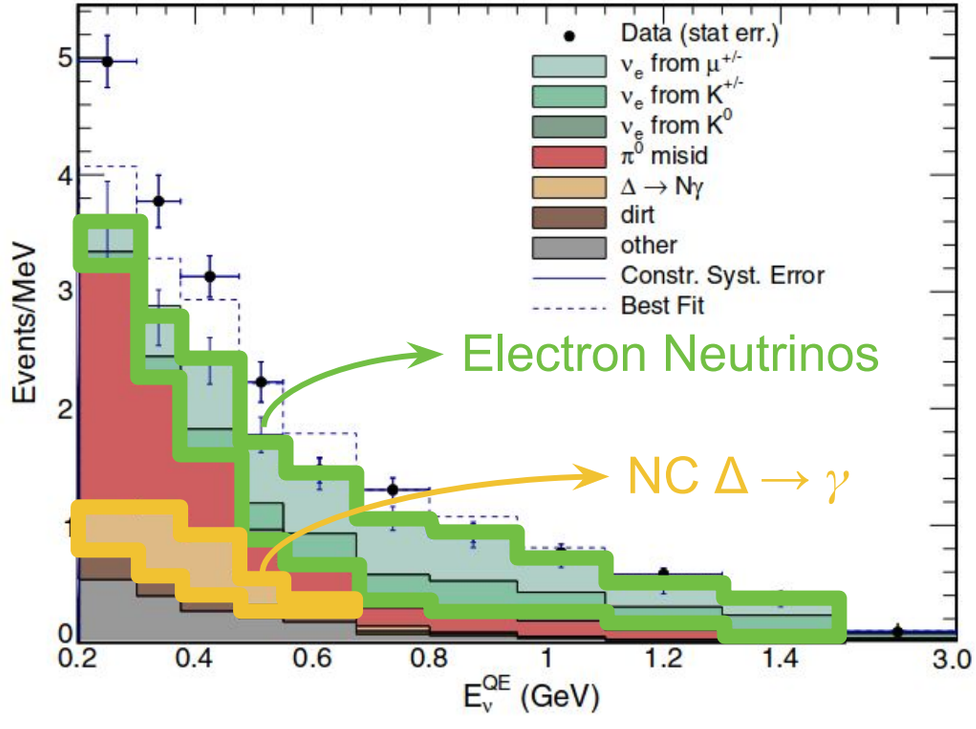
arXiv:2110.14065

Can separate electron and photon showers

→ address the nature of MiniBooNE's excess

MicroBooNE Low-Energy-Excess Search

MiniBooNE, PRL **121**, 221801 (2018)



Investigated two key hypotheses for MiniBooNE excess:

NC $\Delta \rightarrow \gamma$
SM background

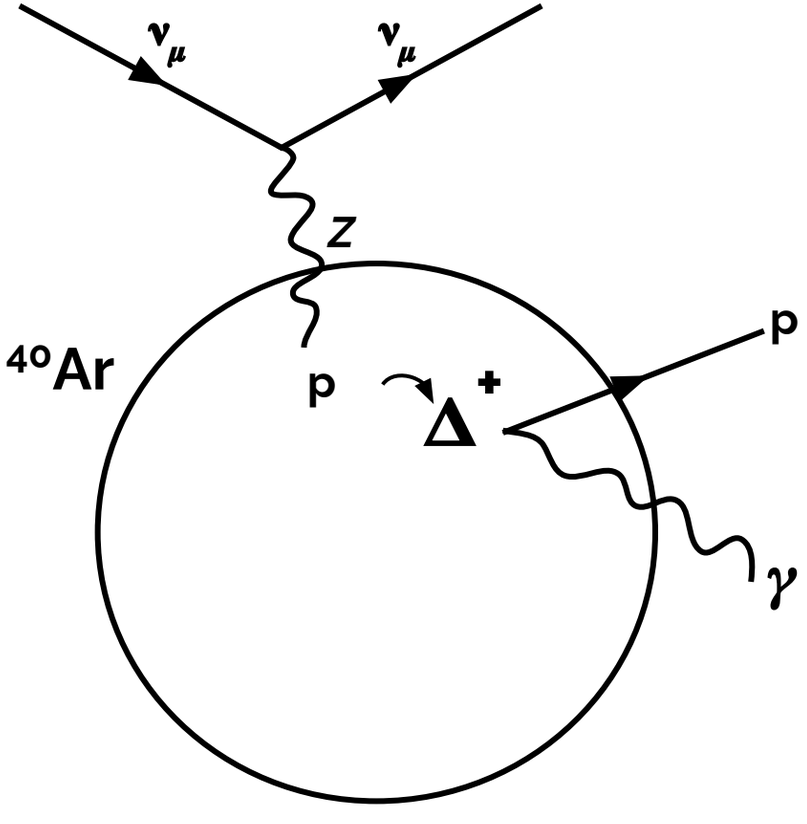
Electron Neutrinos
eV steriles?

Both leading hypotheses for source of anomaly.

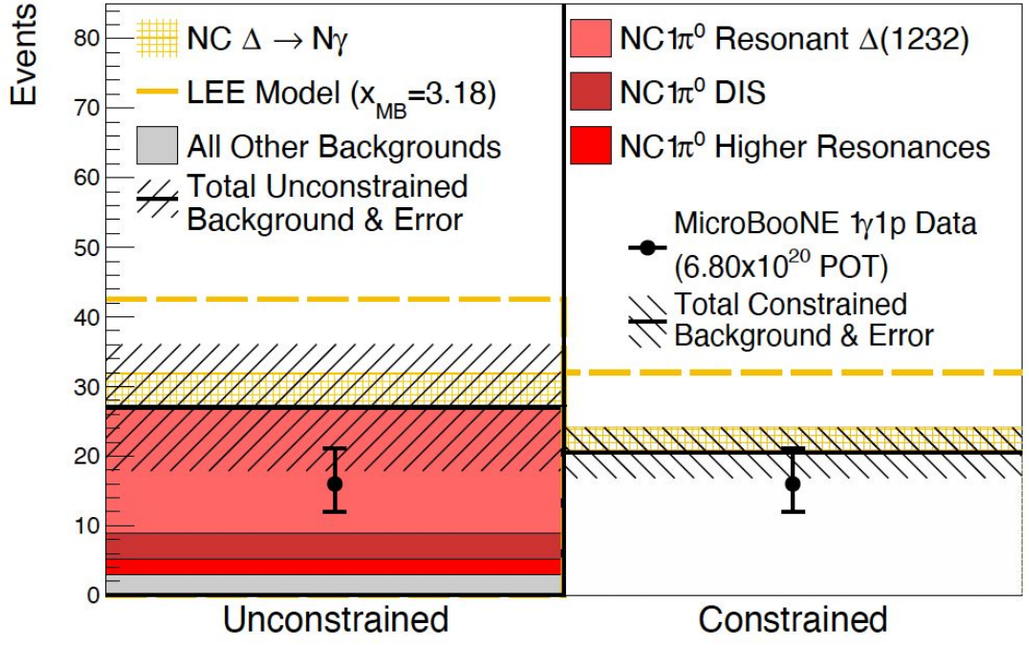
NC $\Delta \rightarrow \gamma$ Analysis

NC $\Delta \rightarrow \gamma$ background looked with interest from community.

Is this responsible for MiniBooNE's excess? Excess consistent with x3 flat scaling.



arXiv:2110.00409



arXiv:2110.00409 (submitted to PRL)

Search for Neutrino-Induced Neutral Current Δ Radiative Decay in MicroBooNE and a First Test of the MiniBooNE Low Energy Excess Under a Single-Photon Hypothesis

NC $\Delta \rightarrow \gamma$ Analysis

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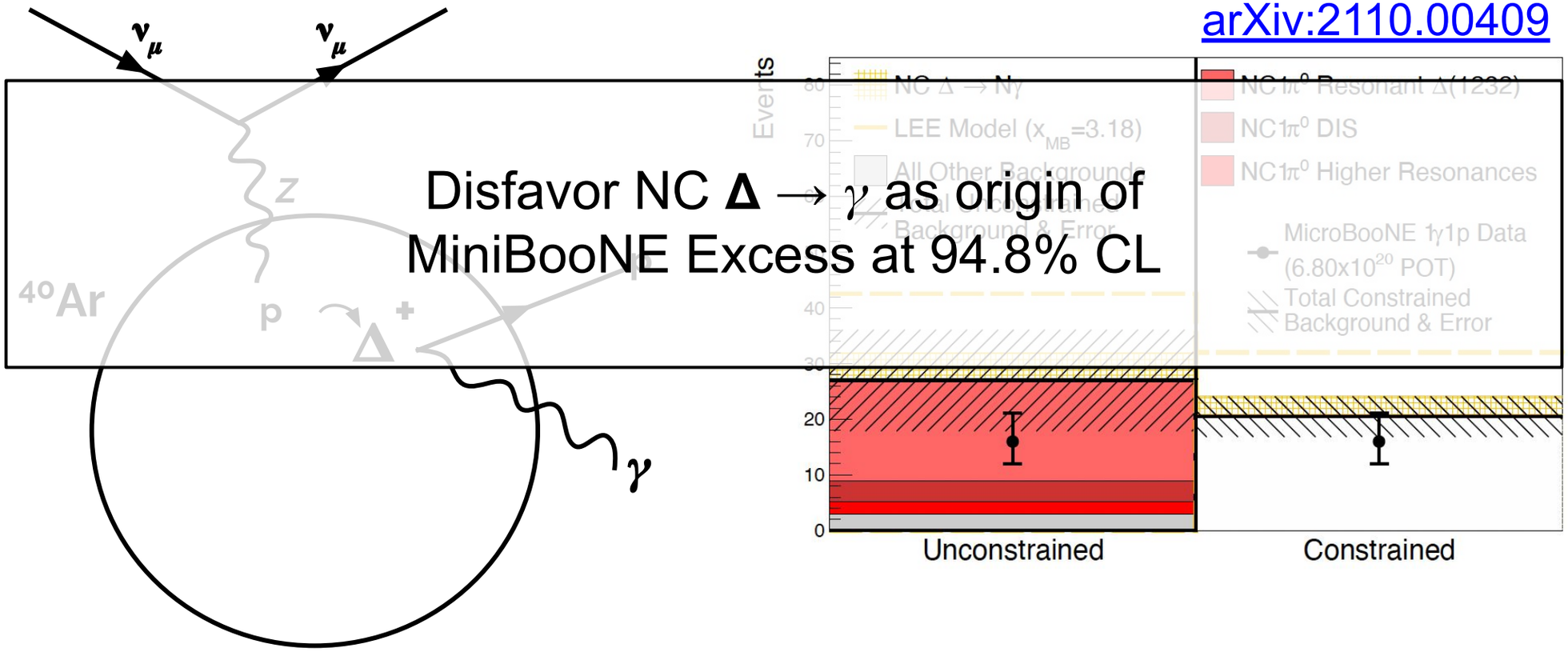


Disfavor NC $\Delta \rightarrow \gamma$ as origin of MiniBooNE Excess at 94.8% CL

arXiv:2110.00409

arXiv:2110.00409 (submitted to PRL)

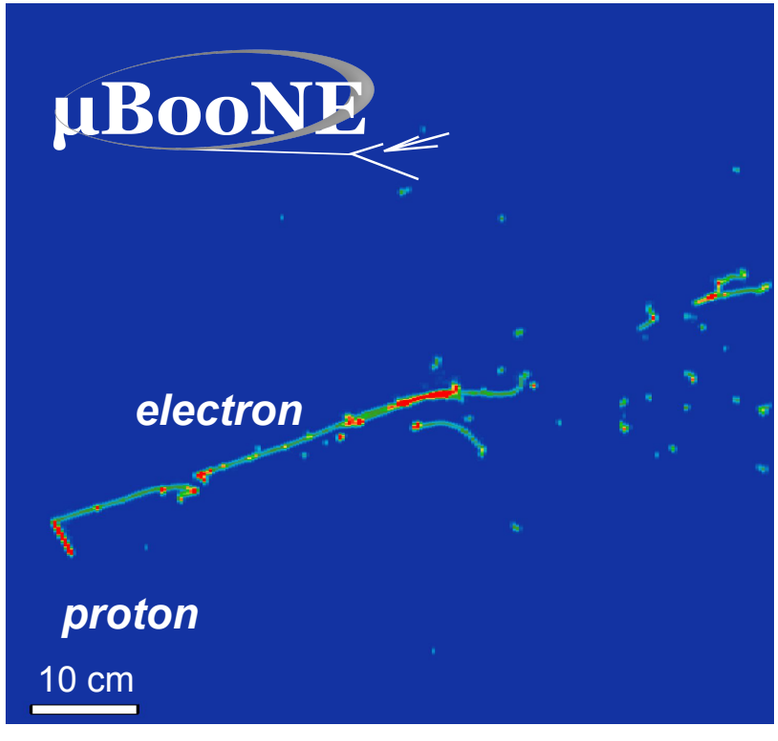
Search for Neutrino-Induced Neutral Current Δ Radiative Decay in MicroBooNE and a First Test of the MiniBooNE Low Energy Excess Under a Single-Photon Hypothesis

ν_e Analyses

MiniBooNE conceived to search for eV sterile neutrinos as follow-up to LSND.

Electron-like nature of excess would support hypothesis that MiniBooNE saw appearance of electron neutrinos in a muon neutrino beam.

MicroBooNE can test the electron-neutrino hypothesis for the MiniBooNE excess.

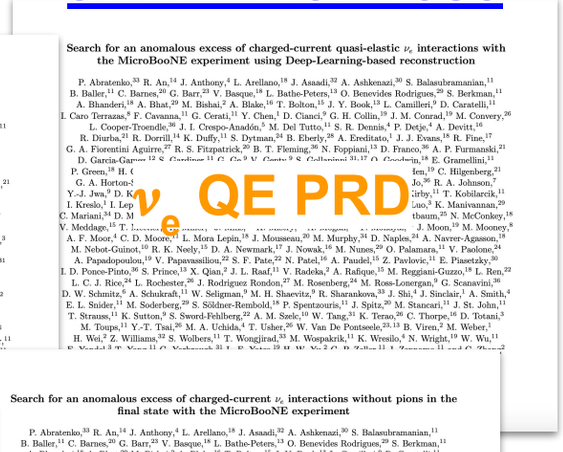


arXiv:2110.13978


Search for an anomalous excess of inclusive charged-current ν_e interactions in the MicroBooNE experiment using Wire-Cell reconstruction

ν_e inclusive PRD

arXiv:2110.14080


Search for an anomalous excess of charged-current quasi-elastic ν_e interactions with the MicroBooNE experiment using Deep-Learning-based reconstruction

ν_e QE PRD


Search for an Excess of Electron Neutrino Interactions in MicroBooNE Using Multiple Final State Topologies

ν_e PRL

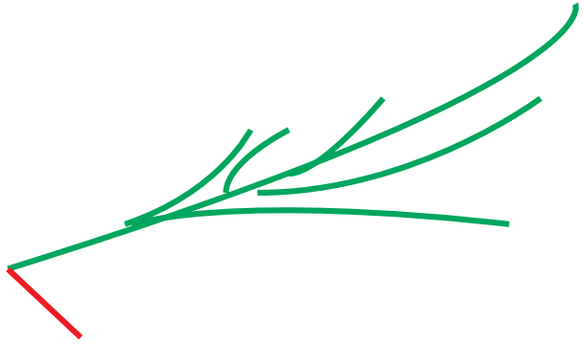
arXiv:2110.14054


Search for an anomalous excess of charged-current ν_e interactions without pions in the final state with the MicroBooNE experiment

ν_e pionless PRD

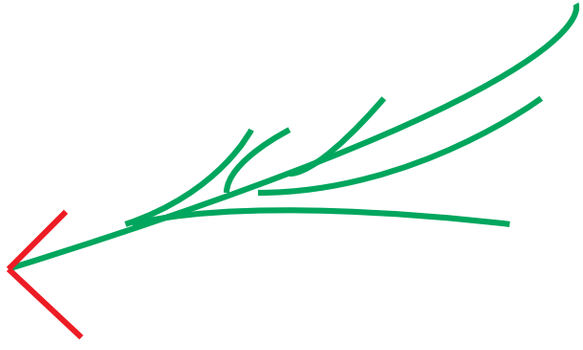
arXiv:2110.14065

ν_e Analyses



1e1p0π : QE-like

arXiv:2110.14080



1eXp0π : pionless

arXiv:2110.14065

1eX : inclusive

arXiv:2110.13978

Three independent & blind analyses:

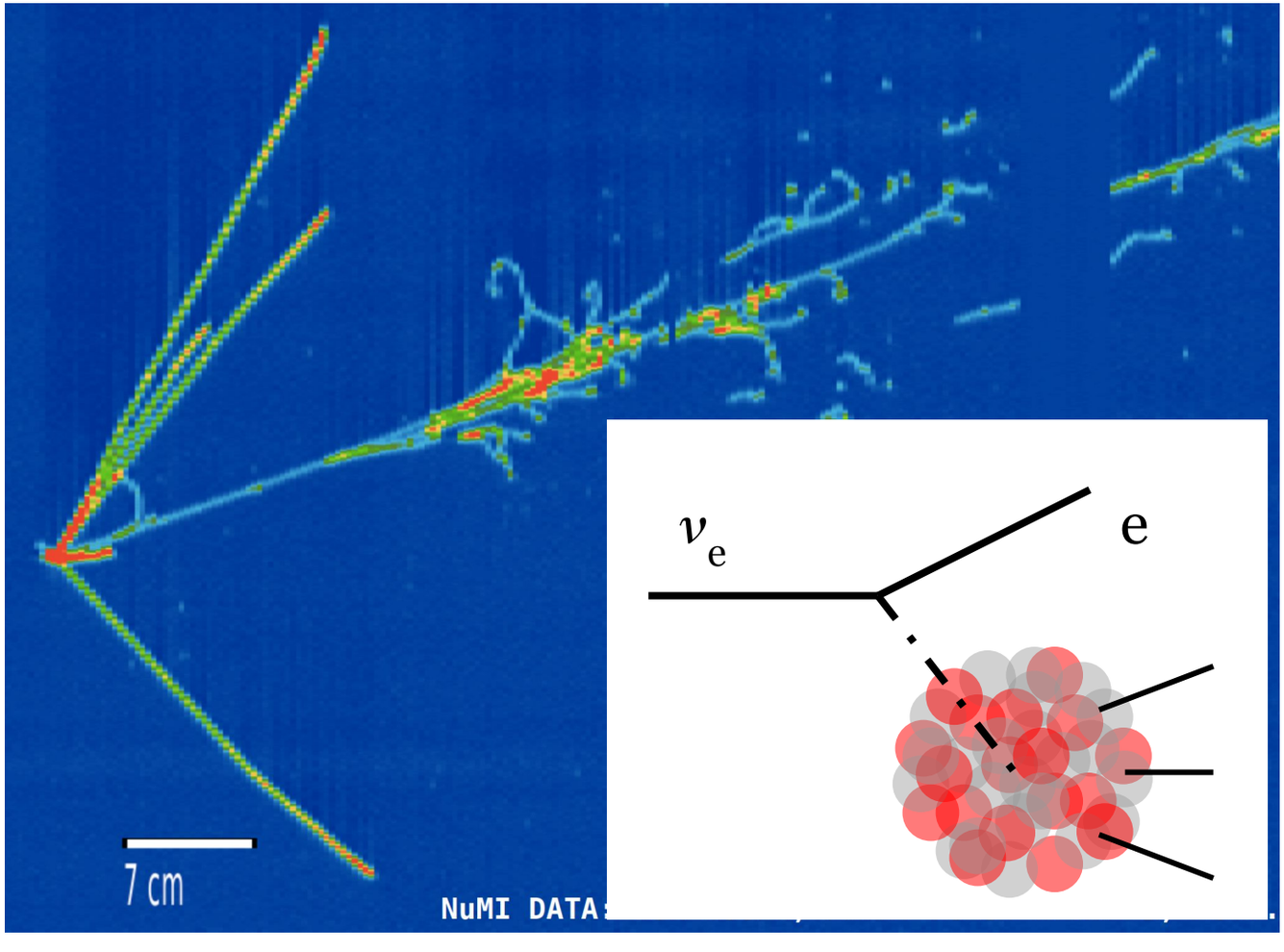
1. Different reconstruction techniques
   → LArTPC technology

2. Different final-states
   → different interaction modes & FSI
   → new physics may lurk in different channels.

Neutrino Interactions

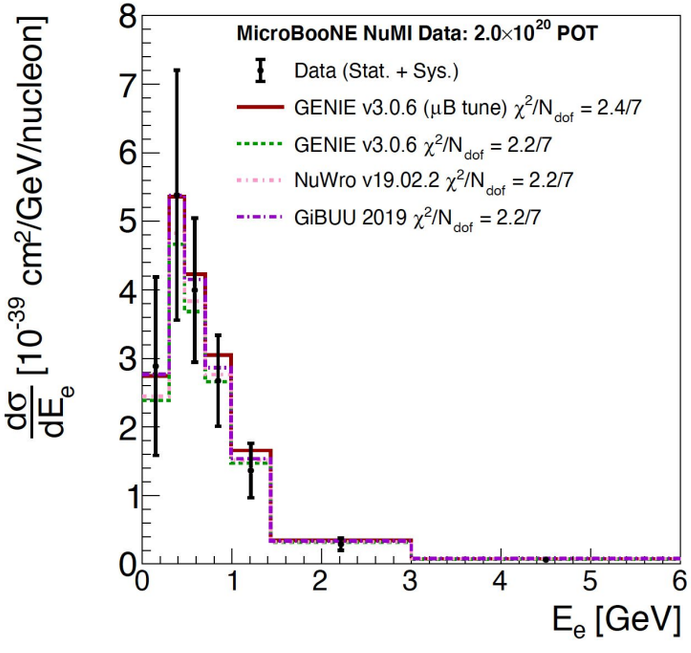
Neutrino interactions on argon target lead to complex final-states.

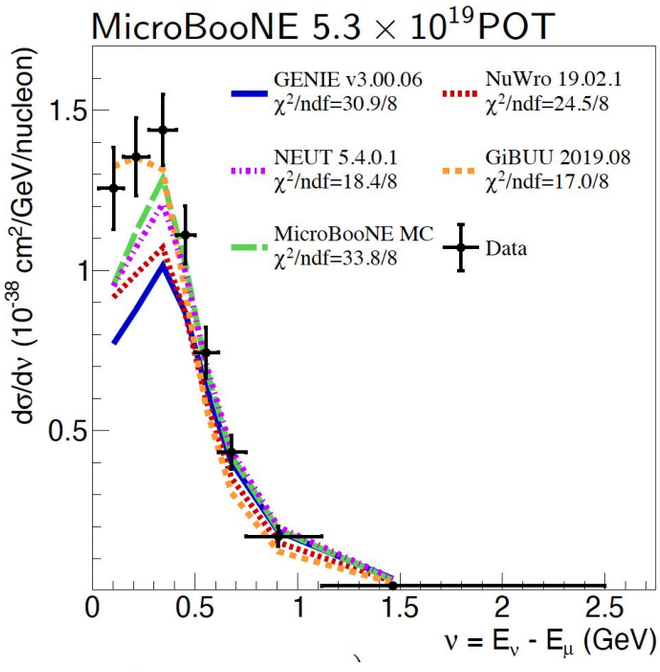
Rate and final-state observables need to be modeled accurately to carry out this analysis.

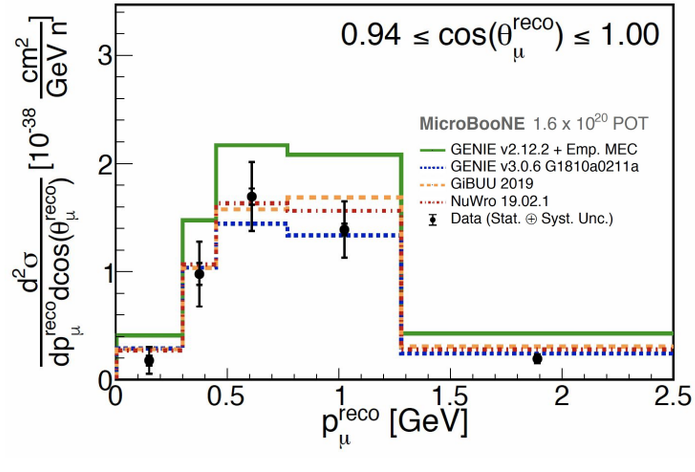


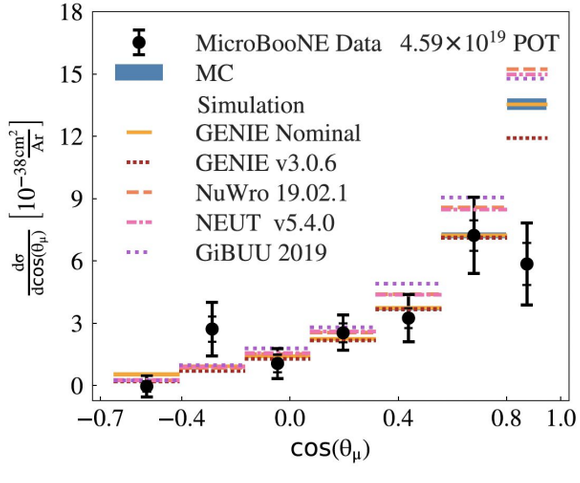
high energy electron neutrino interaction candidate with large track multiplicity

MicroBooNE's Cross-Section Program









MicroBooNE xsec measurements:

ν_μ CC Np0π [1D differential]
Phys.Rev.D 102 (2020) 11, 112013

ν_μ CCQE-like [1D differential]
Phys.Rev.Lett. 125 (2020) 20, 201803

ν_μ CC inclusive [2D differential]
Phys.Rev.Lett. 123 (2019) 13, 131801

ν_μ CC π^0 [integrated]
Phys.Rev.D 99 (2019) 9, 091102

ν_e CC [inclusive]
Phys.Rev.D 104 (2021) 5, 052002

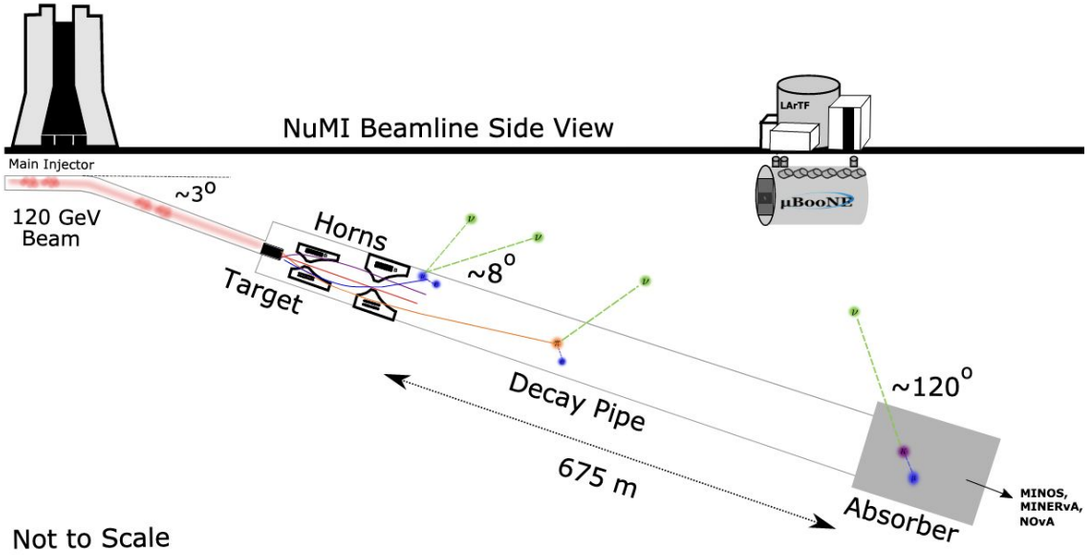
ν_e CC [1D differential]
arXiv:2109.06832 [submitted PRL]

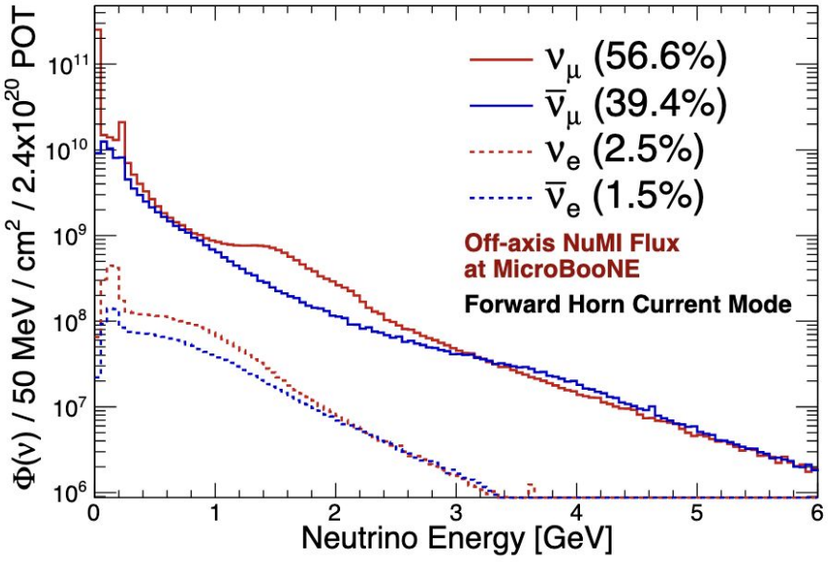
ν_μ CC inclusive [1D differential]
arXiv:2110.14023 [submitted PRL]

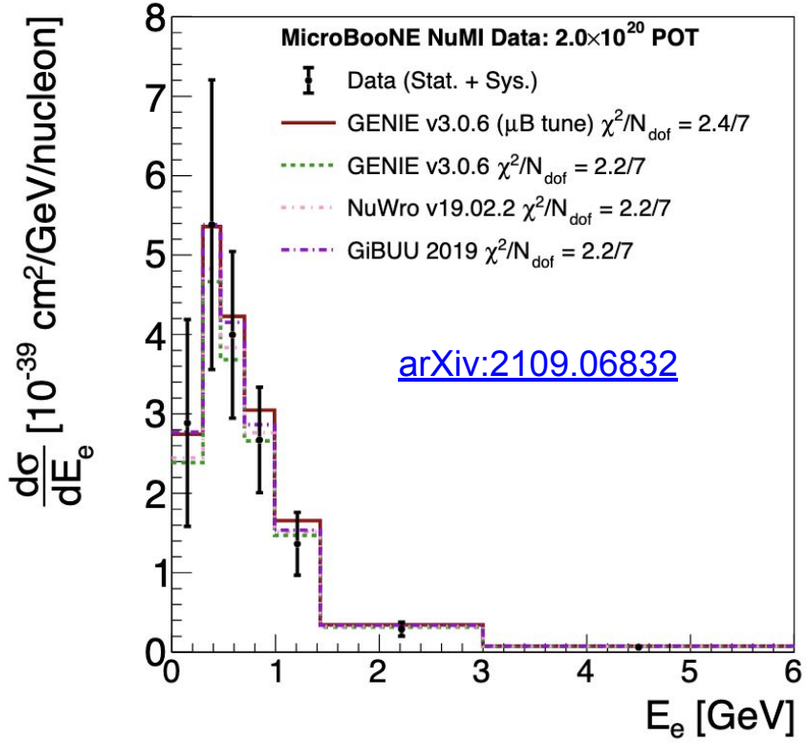
… and many more in the pipeline

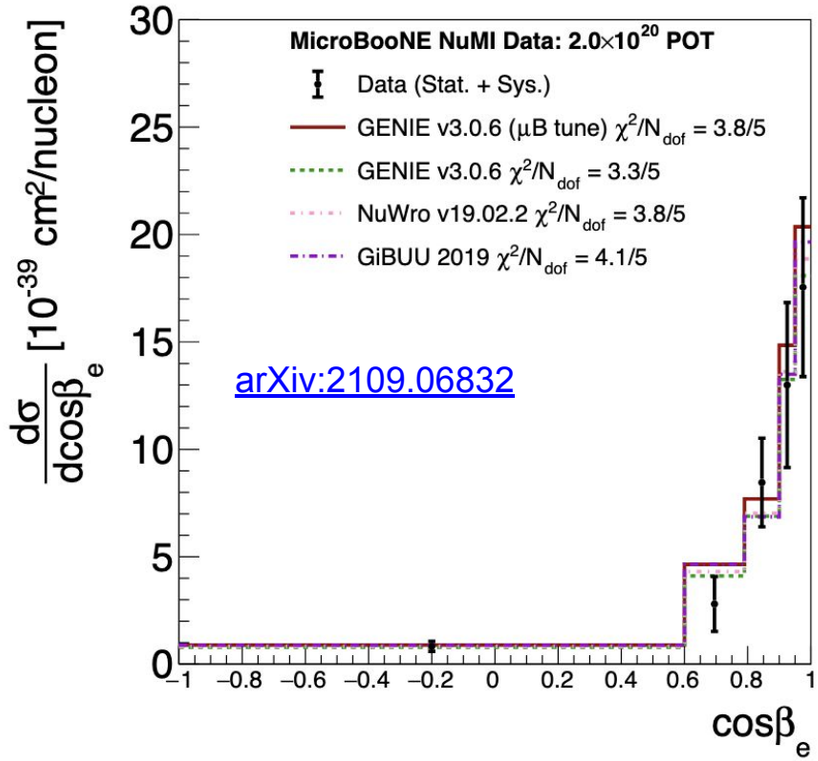
Extensive xsec program performing high-statistics measurements of neutrino interactions on argon for the first time.
Help improve our understanding and modeling of -Ar interactions for our own physics program and for the broader neutrino community.

Electron Neutrino Cross-Sections with NuMI









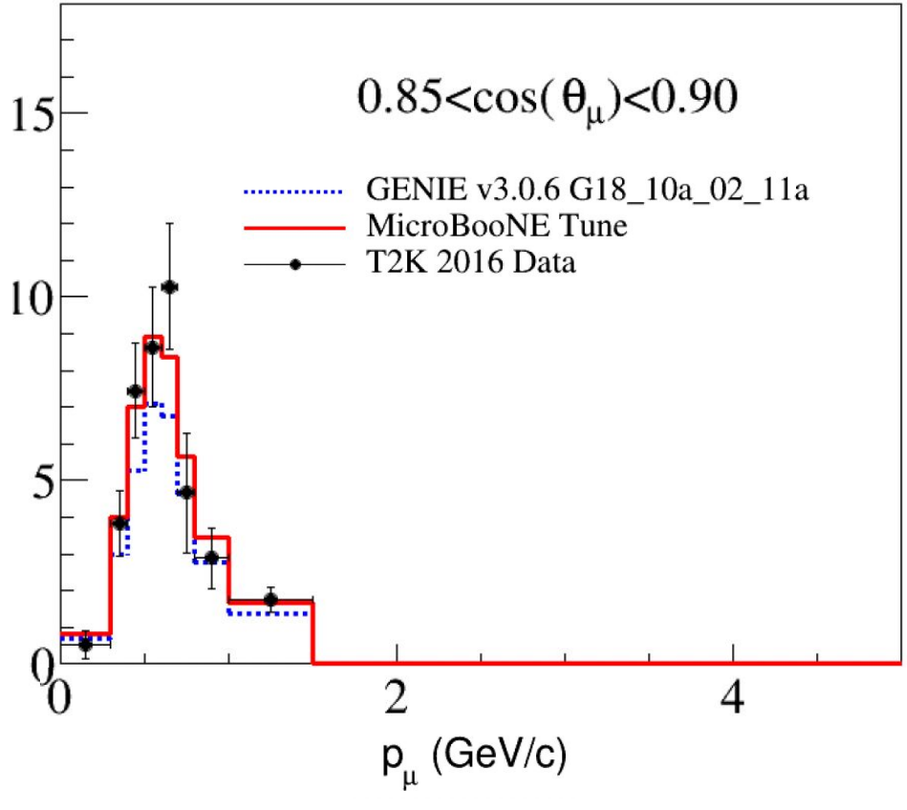
Neutrino Interaction Model and Tune

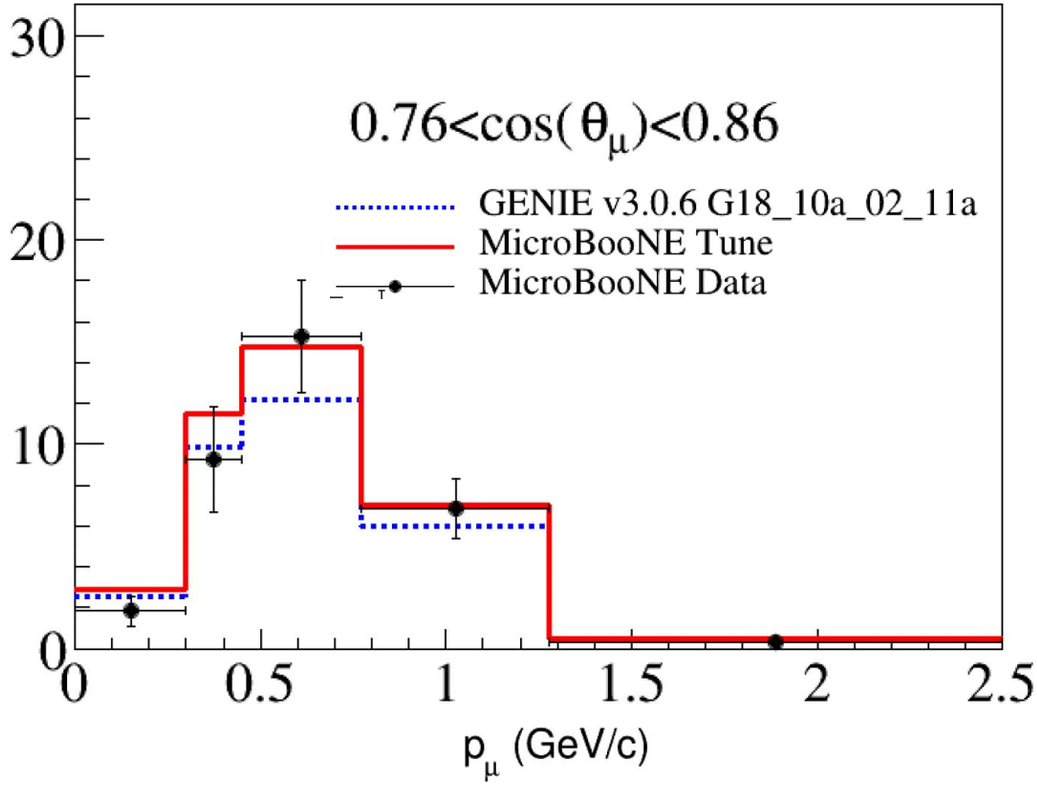
Utilize the GENIE neutrino interaction generator.

GENIE v3 for choice of model.

Tuned to external data: T2K CC0π cross-section data.
- O(GeV) energy beam, similar flux as BNB

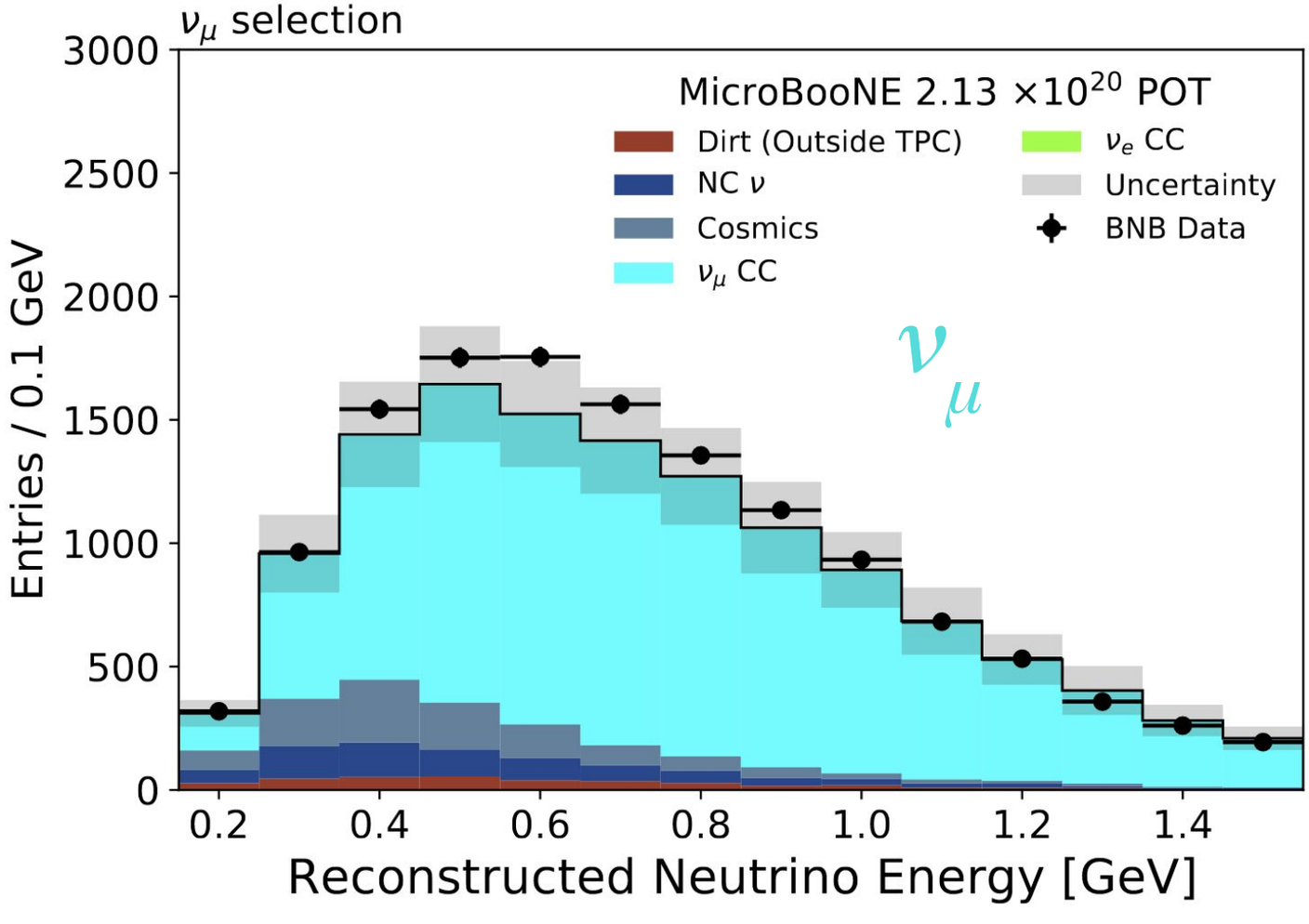
4-parameter fit for CCQE and MEC processes





"New Theory-driven GENIE Tune for MicroBooNE" arXiv:2110.14028

In-Situ Data-Driven Constraint

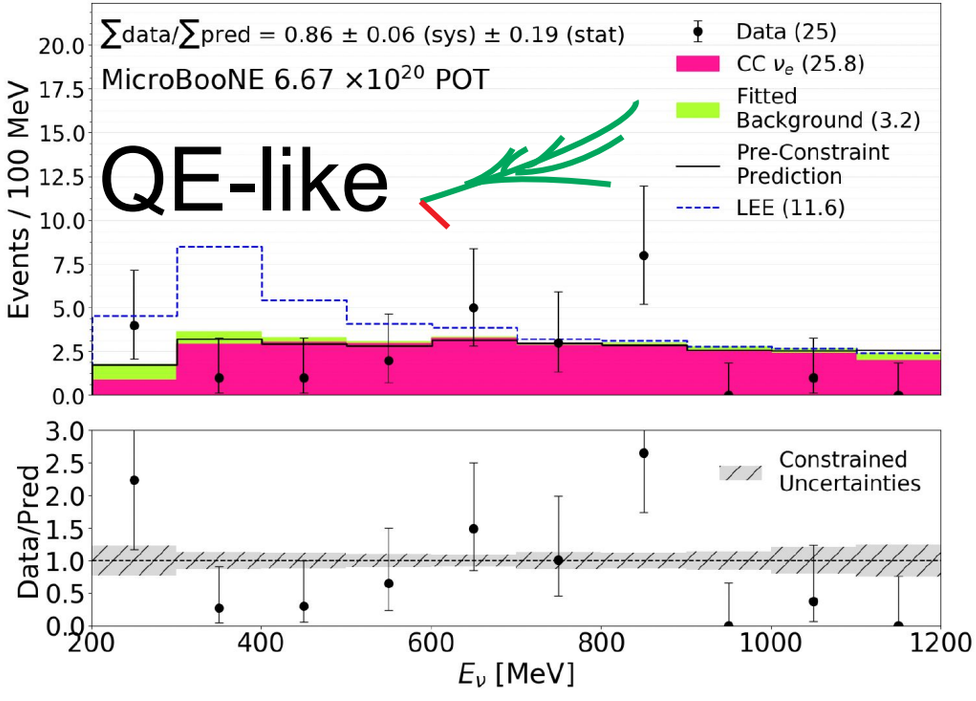


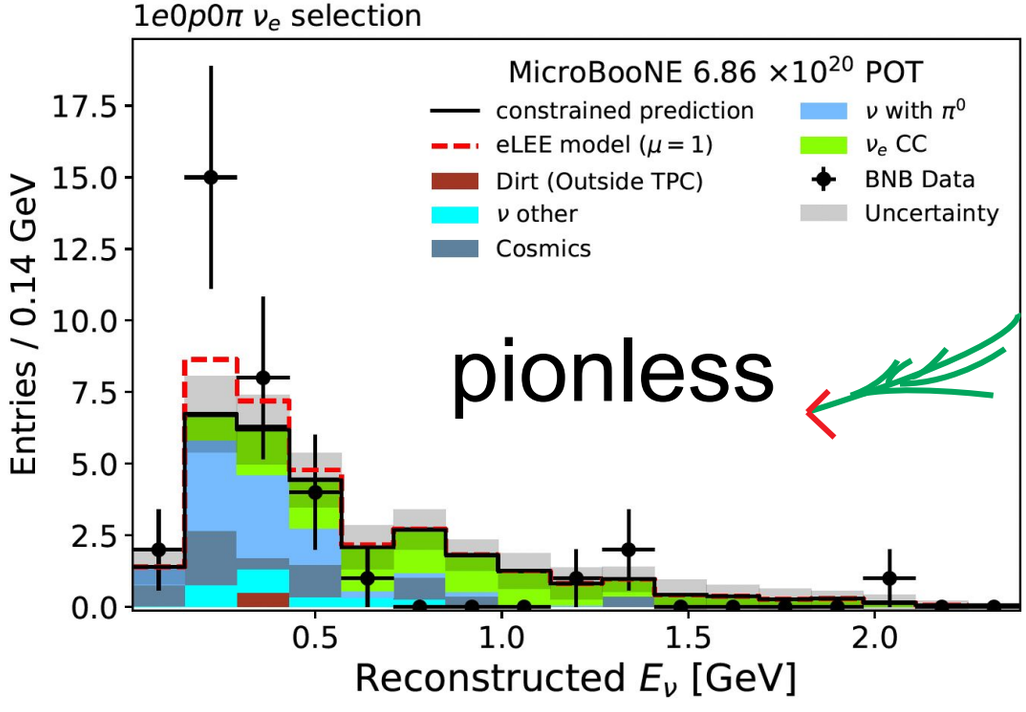
ν_μ CC constraint sample for electron analysis

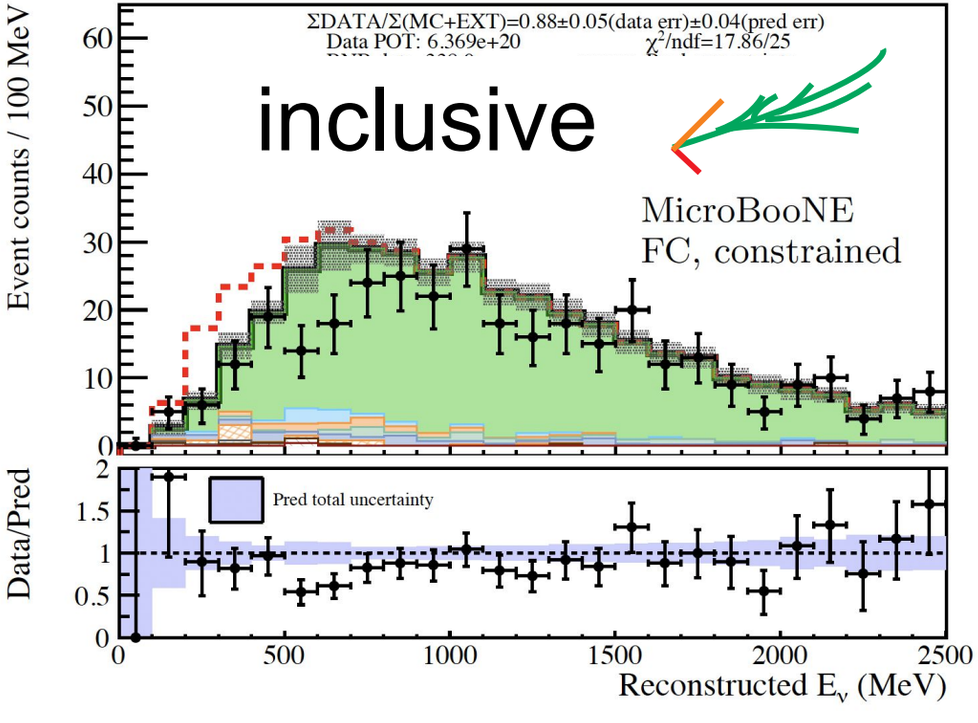
High statistics ν_μ: same flux and xsec model as backgrounds and ν_e.

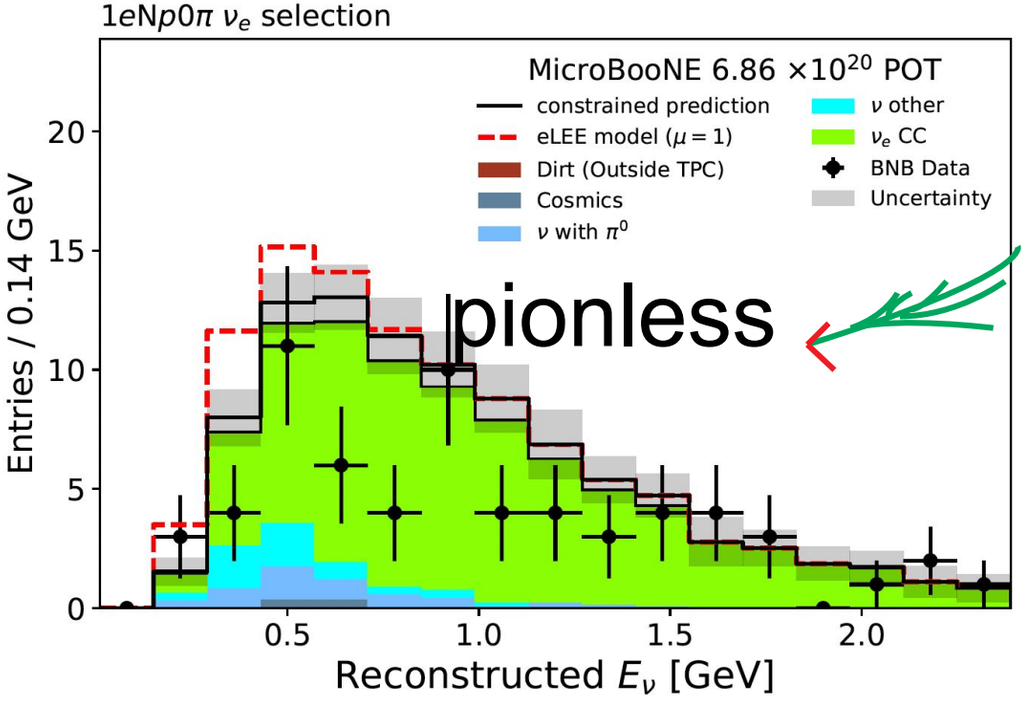
(1) Validate neutrino rate modeling.
(2) Constrain uncertainties on prediction → reduction of ½.

Electron Neutrino Energy Spectra









ν_e Results Summary

Results indicate no electron neutrino excess in data

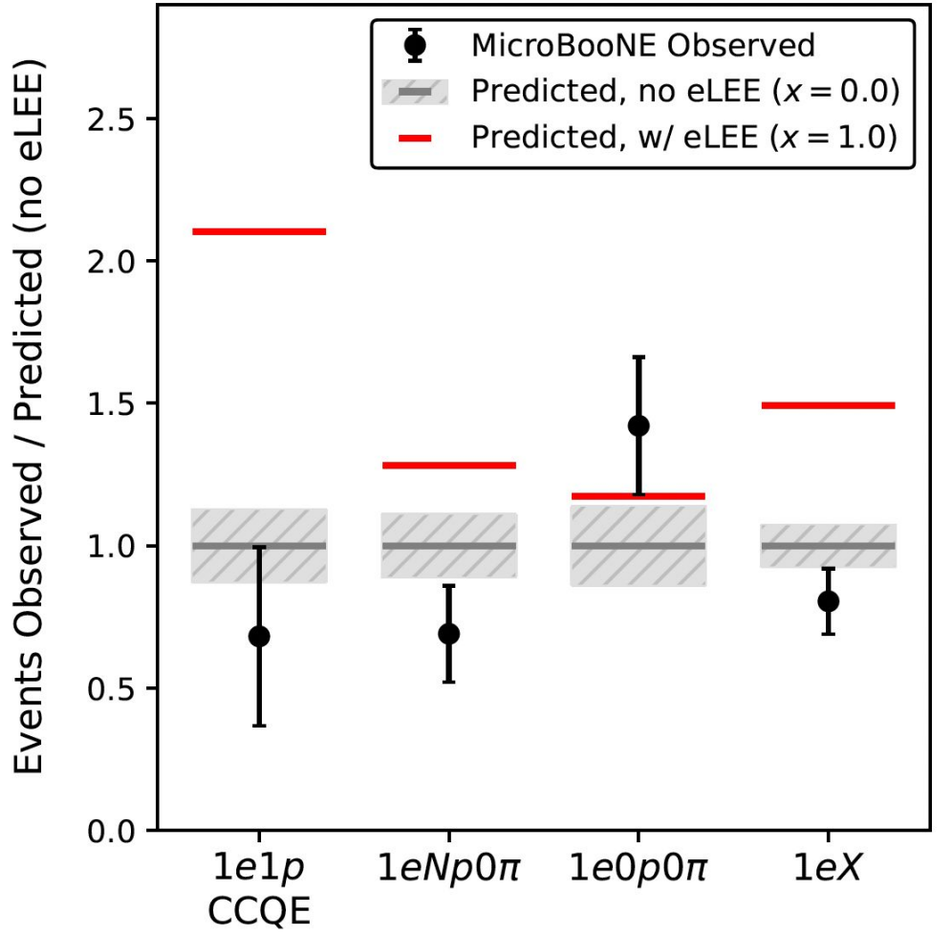
- Consistent across analyses
- CL varies from 97% to >3σ

arXiv:2110.14054

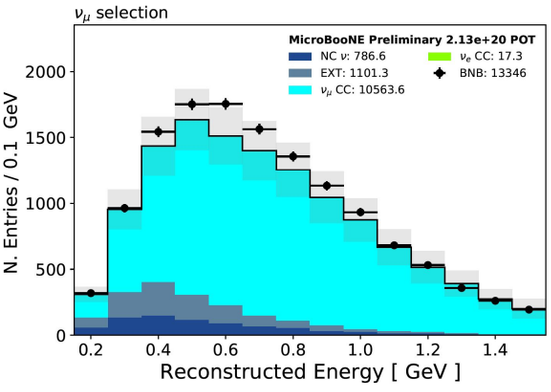
Overall observe slight deficit of electron neutrinos relative to prediction in ν_e dominated selections.

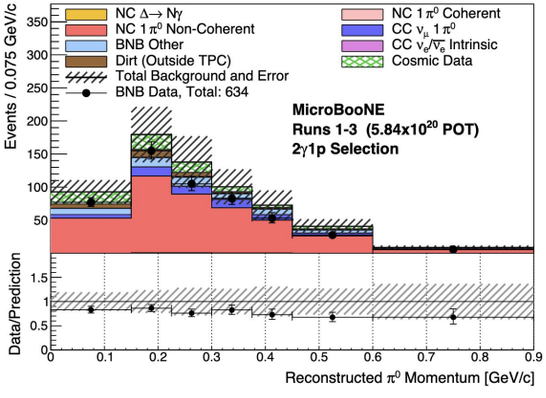
1e0p0π channel has slight excess.

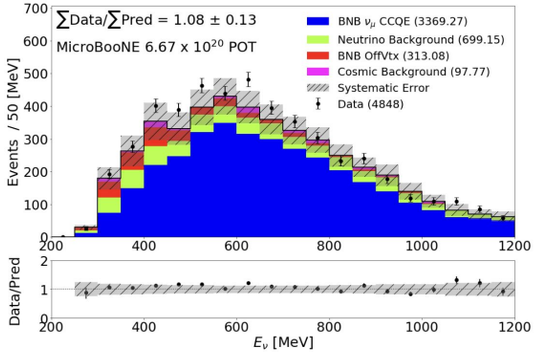
- Low sensitivity, consistent with prediction
- Single shower measurement, γ dominated prediction.

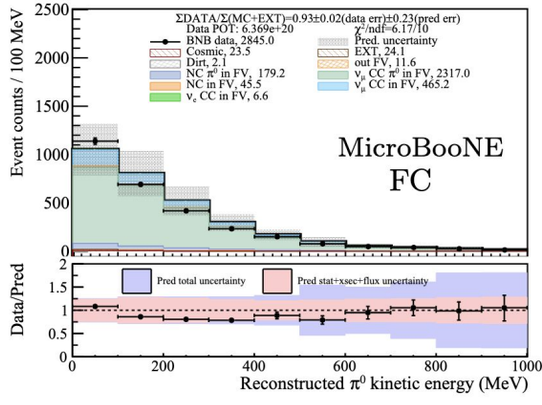


A Milestone Beyond the Analysis Results…



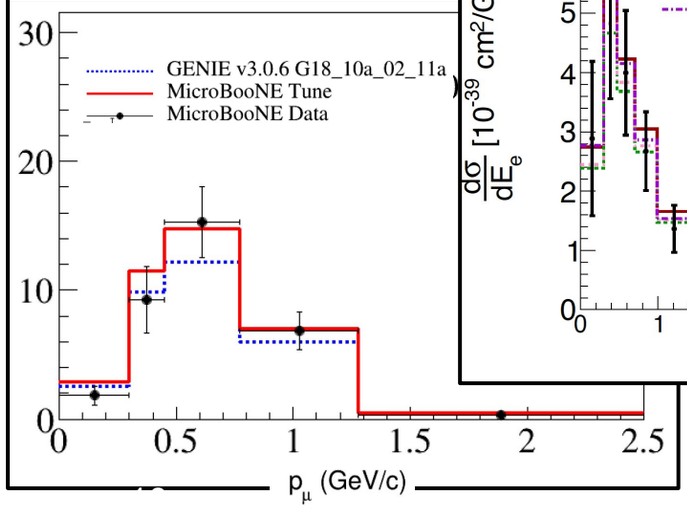


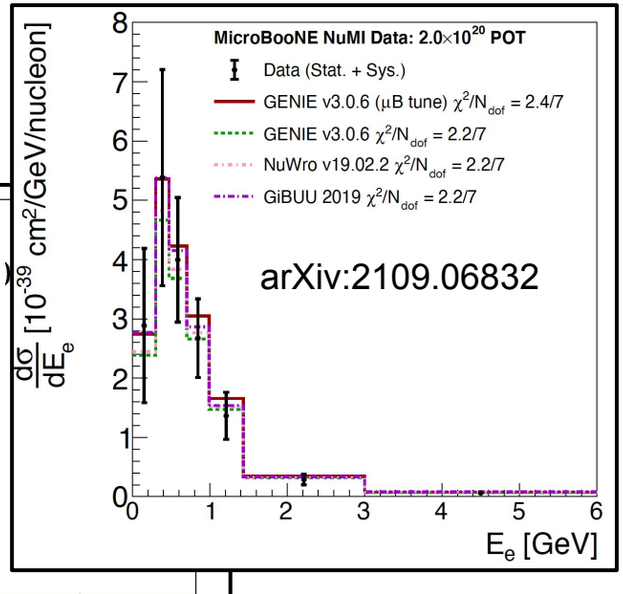




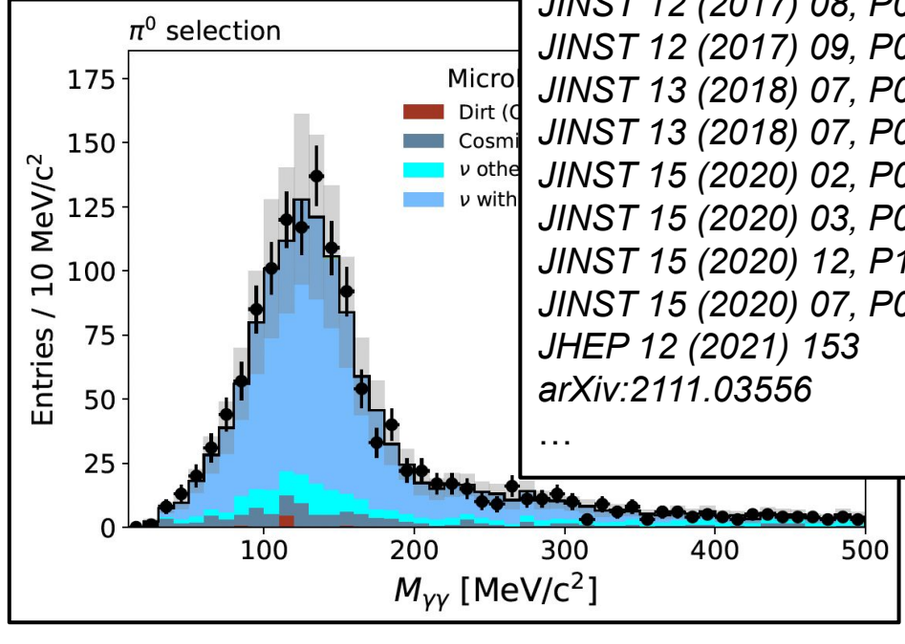
data-driven background constraints throughout these analyses

arXiv2110.14028





multiple rounds of XSEC measurements



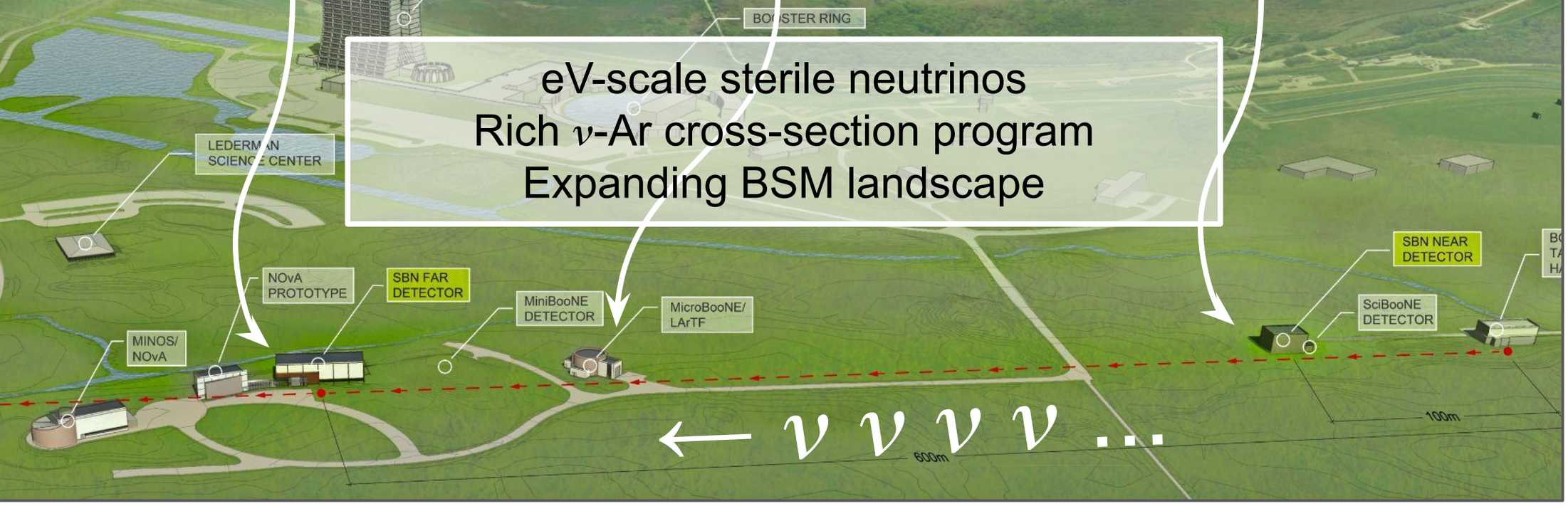
years of LArTPC analysis development…

JINST 12 (2017) 08, P08003
JINST 12 (2017) 09, P09014
JINST 13 (2018) 07, P07006
JINST 13 (2018) 07, P07007
JINST 15 (2020) 02, P02007
JINST 15 (2020) 03, P03022
JINST 15 (2020) 12, P12037
JINST 15 (2020) 07, P07010
JHEP 12 (2021) 153
arXiv:2111.03556
…

The Road Ahead

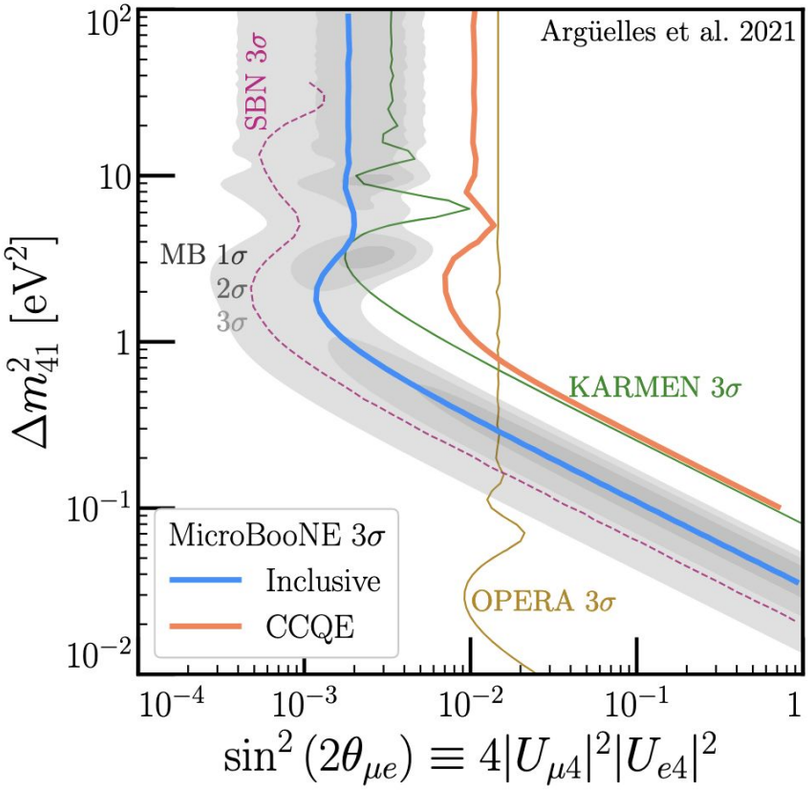
Short-Baseline Neutrino (SBN) Program

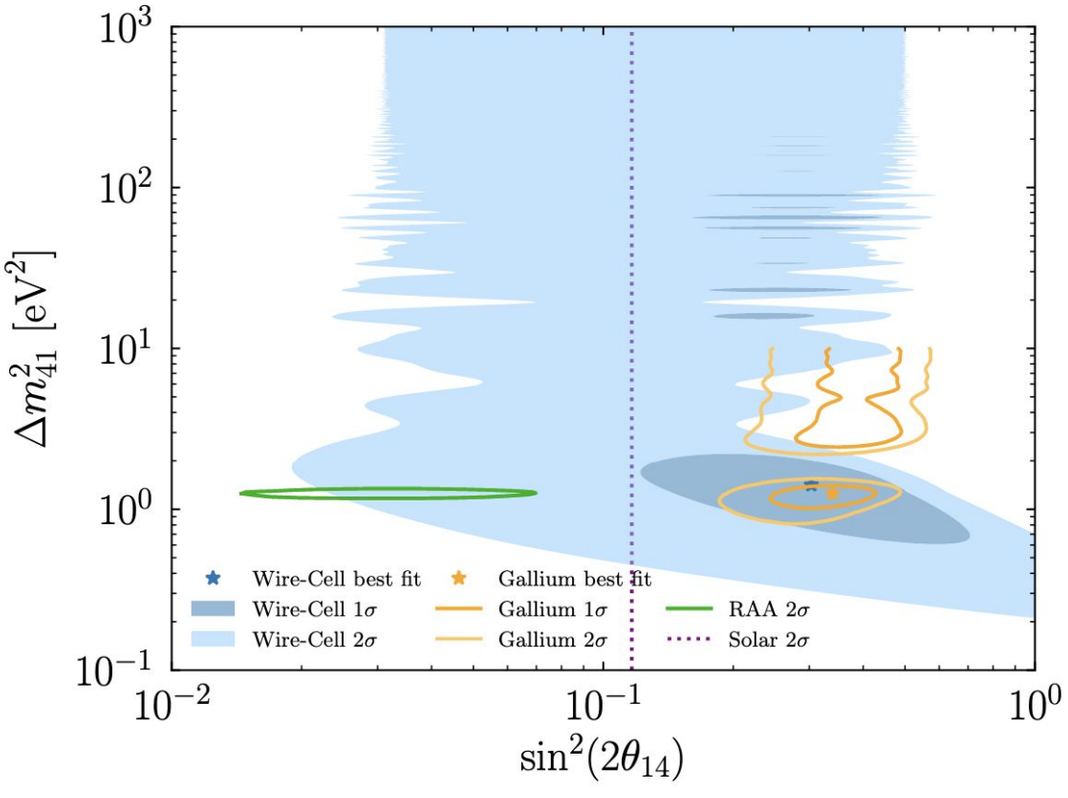
eV-scale sterile neutrinos
Rich ν-Ar cross-section program
Expanding BSM landscape



$\leftarrow \nu\ \nu\ \nu\ \nu\ \ldots$

MicroBooNE's Result Under 3+1 Hypothesis





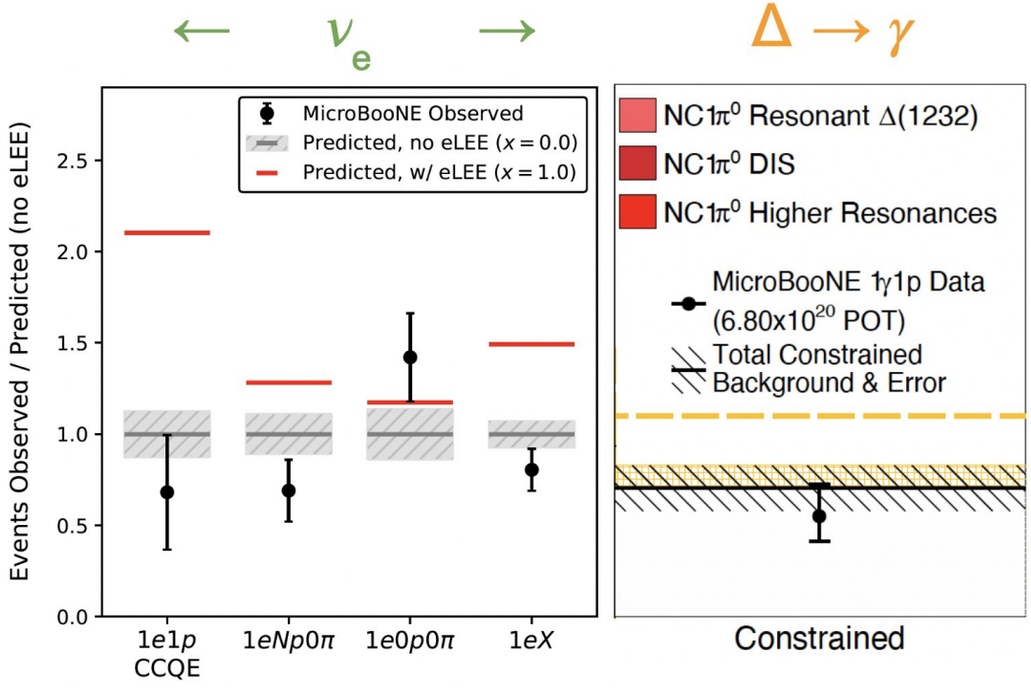
arXiv:2111.10359
C. A. Arguelles et al.

arXiv:2111.05793
Peter Denton, BNL

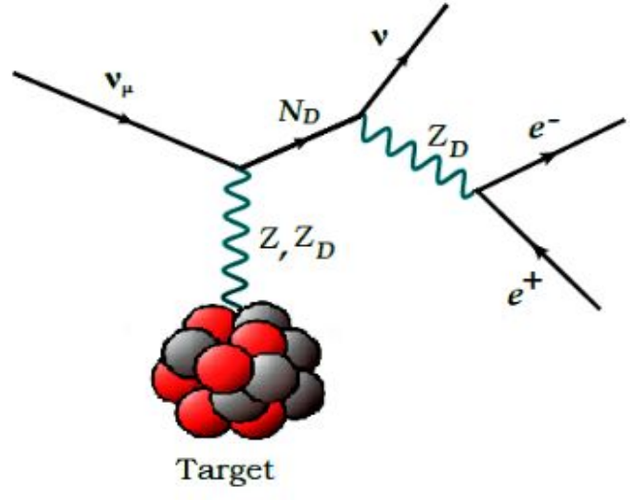
What does MicroBooNE's result say about eV-scale Sterile Neutrino models in 3+1 scenario?

Active interest from theory community. We are catching up…

MicroBooNE's BSM Program



E. Bertuzzo et al., PRL **121** 241801 (2018)

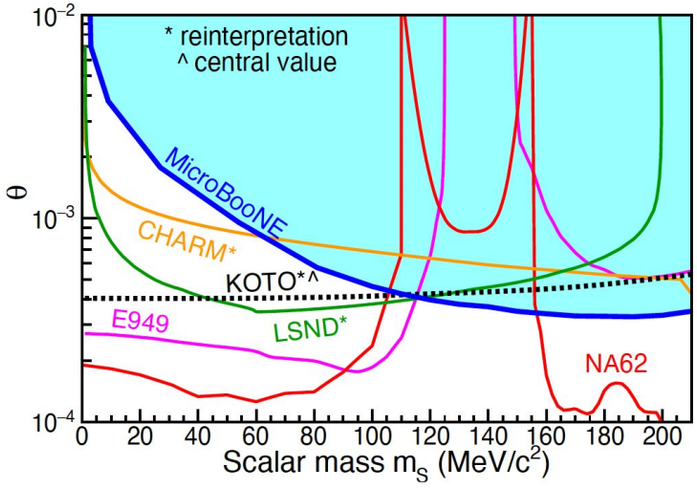


e^+e^- / Inclusive γ search

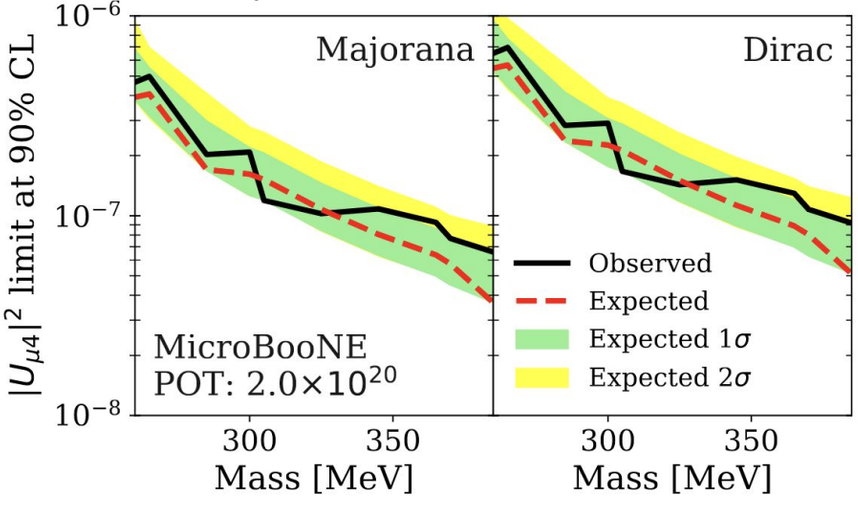
Current Results…

…in the works!

Phys.Rev.Lett. 127 (2021) 15, 151803

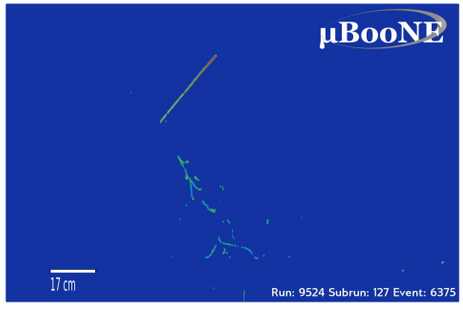


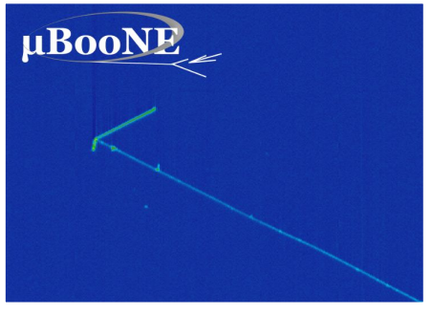
Phys.Rev.D 101 (2020) 5, 052001

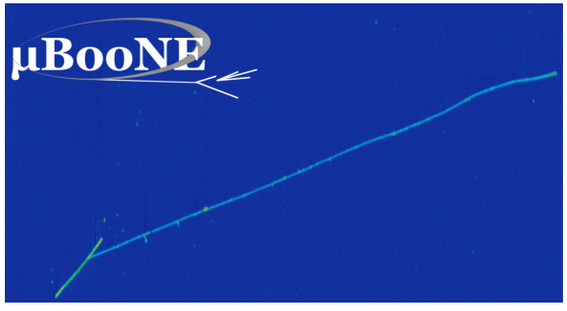


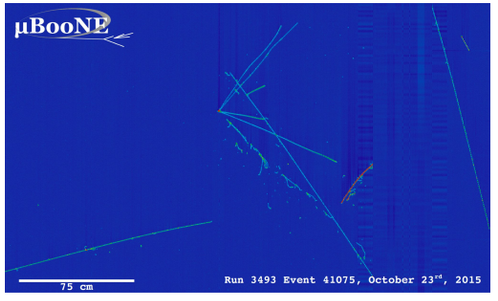
…and more to come!

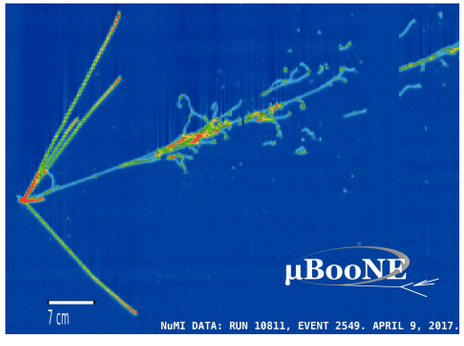
MicroBooNE Data Set

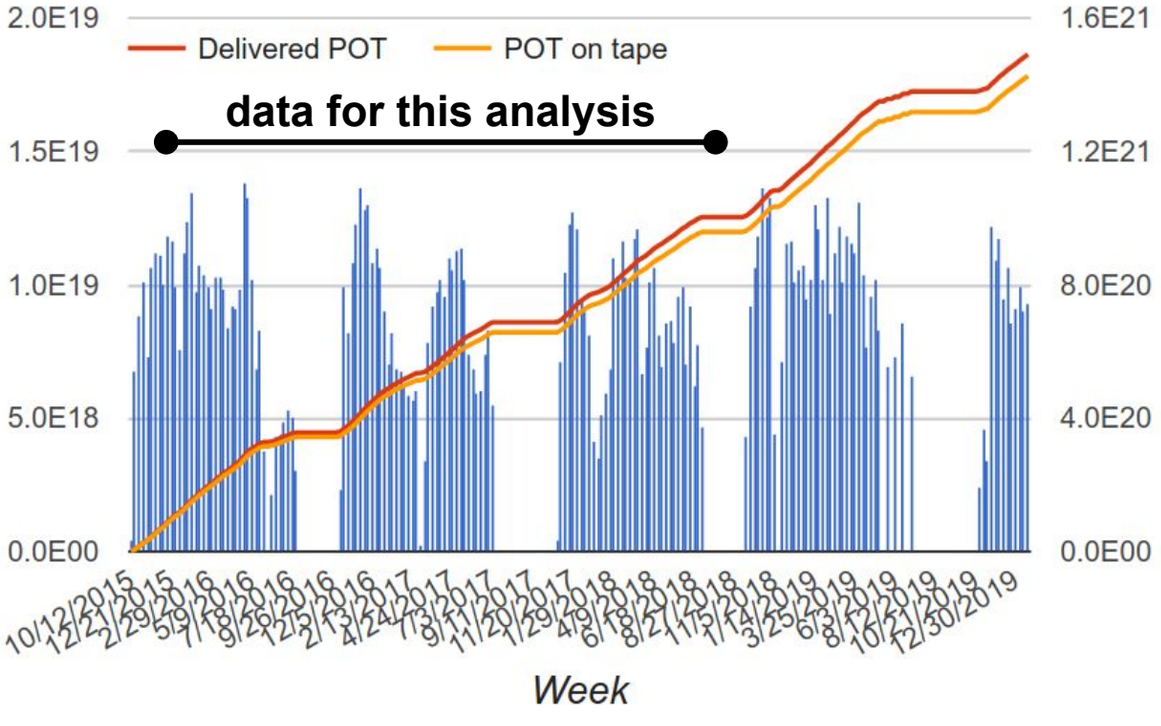


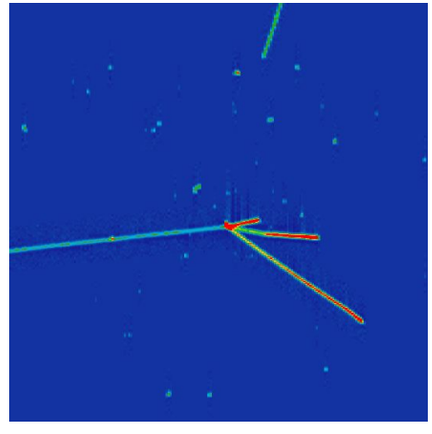


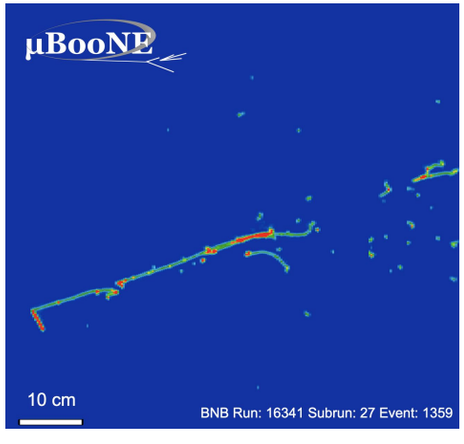


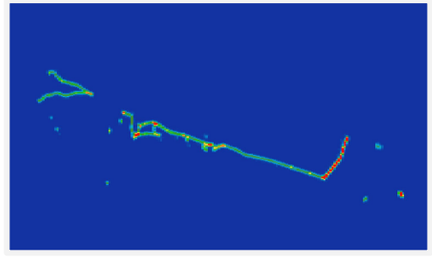


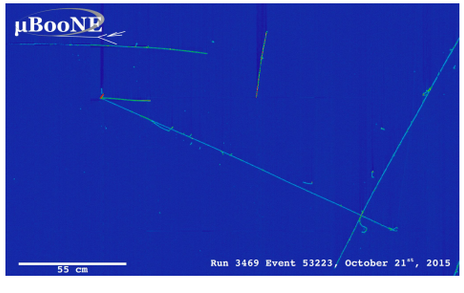




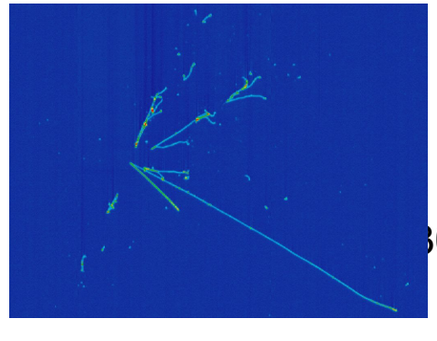




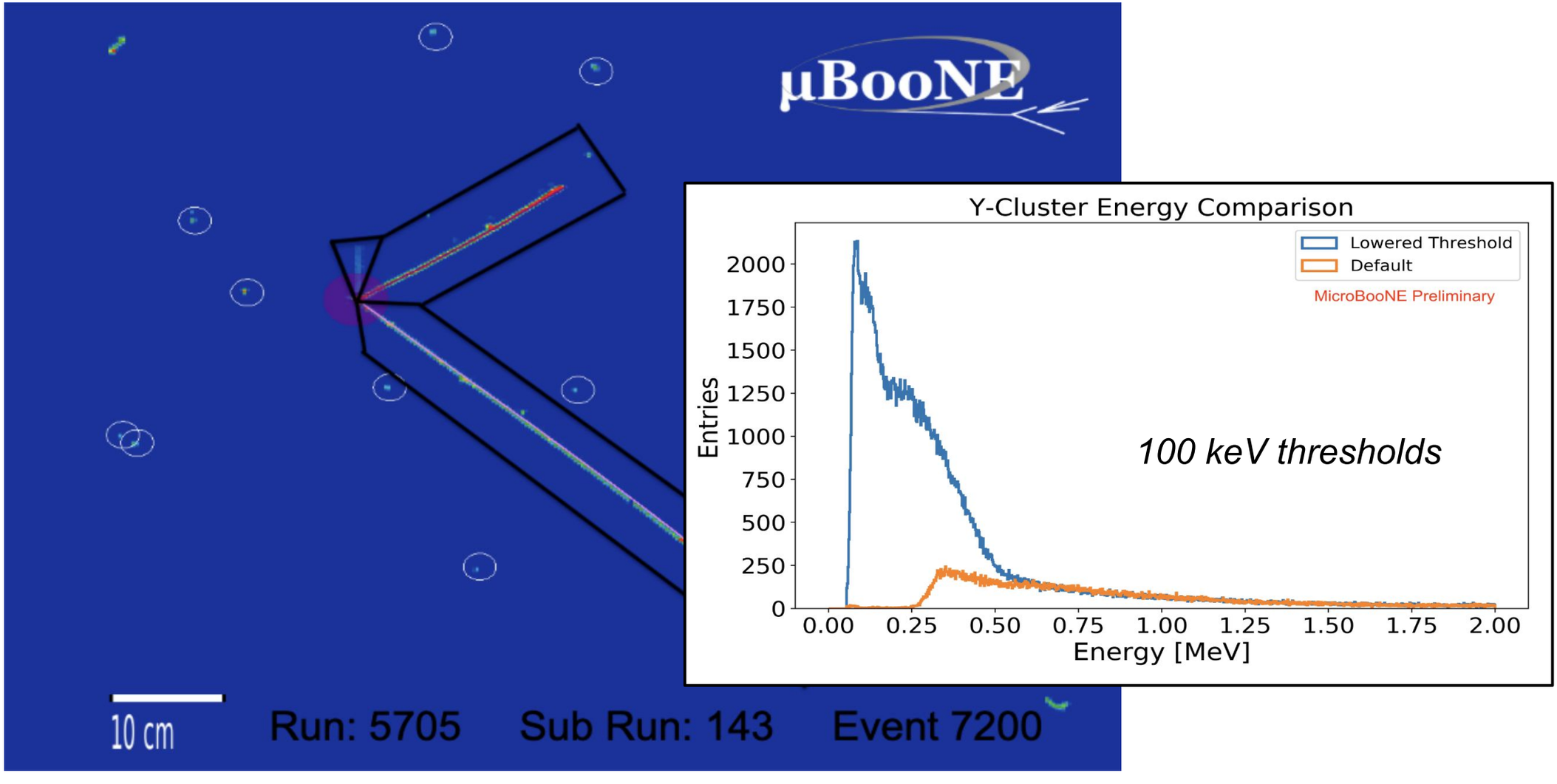




- Longest running large-scale LArTPC to date.
- Dataset of 500k ν - Ar interactions!



MeV-scale Physics @ MicroBooNE



Reconstruction and Potential for MeV-Scale Physics in MicroBooNE

sub-MeV thresholds and meter-scale volumes

MICROBOONE-NOTE-1076

Summary

MicroBooNE has followed-up on one of the most intriguing puzzles in neutrino physics.

- see no excess of NC $\Delta \rightarrow \gamma$ or Electron Neutrinos in Booster Neutrino Beamline.

Demonstrated power of LArTPC technology for precision measurements.

- Foundational for the broader LArTPC program

Exciting new chapter ahead!

- double the data from MicroBooNE, new measurements actively being pursued.
- Expanded reach with SBN program.