



# Recent Results from MicroBooNE

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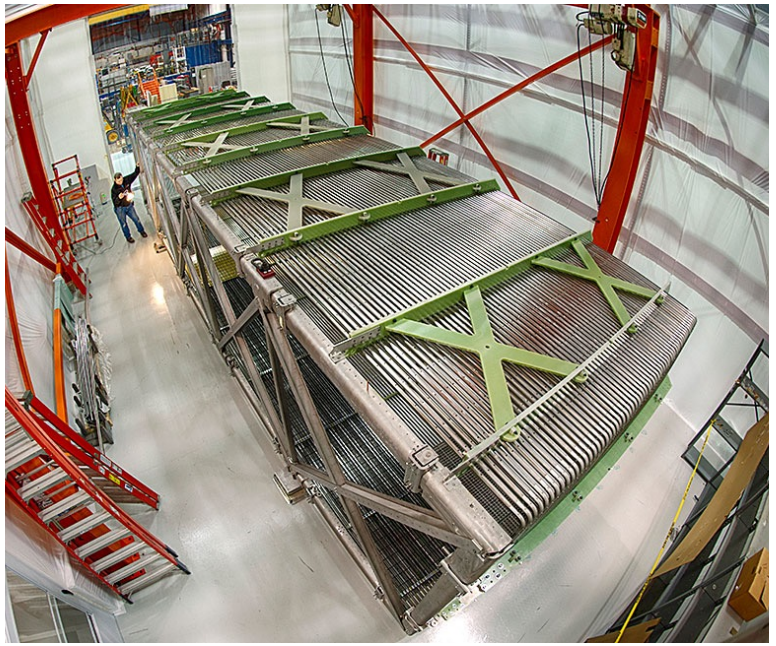
University of Oxford

# The MicroBooNE Experiment

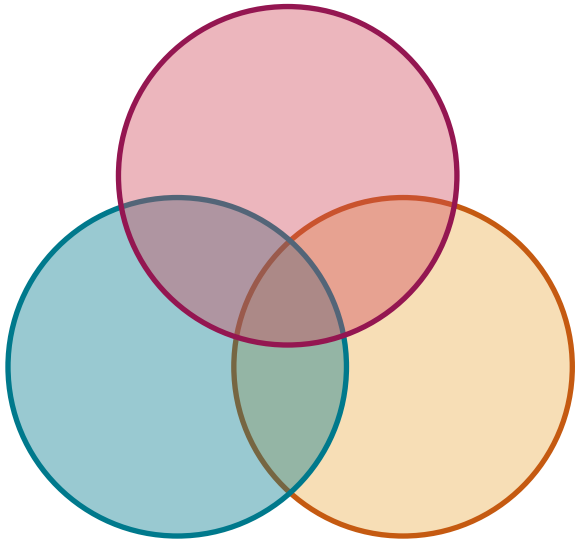
MicroBooNE is an 85-tonne Liquid Argon Time Projection Chamber (LArTPC) neutrino detector:

- located at Fermilab, US; exposed to two neutrino beams, BNB and NuMI
- collected data 2015-2021: accumulated over 0.5M neutrino interactions
- 195 collaborators from 38 institutions; 82 papers + over 60 public notes



# MicroBooNE's Science Goals

Investigate the MiniBooNE Low Energy Excess and search for BSM physics



Neutrino interactions:
precision measurements on argon

Detector Physics:
pushing the capabilities of LArTPCs

# MicroBooNE LArTPC detector

Fully active tracking calorimeter:

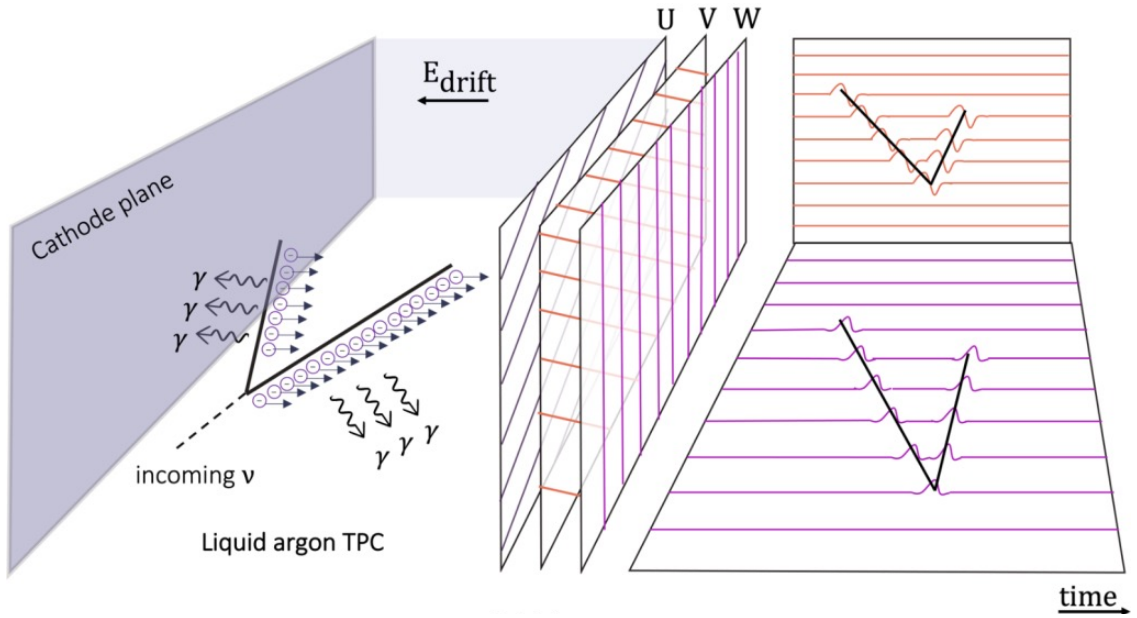
- 2.5 × 2.3 × 10.4 $m^3$ instrumented volume
- 3 planes of wires collecting ionization charge, 32 PMTs collection scintillation light
- 3D neutrino interaction reconstruction

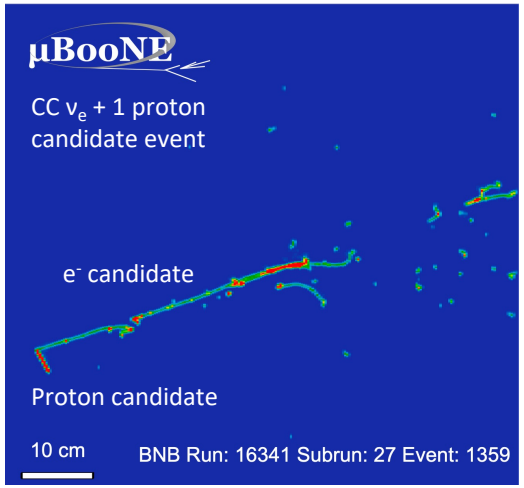
Precision neutrino measurements at scale:

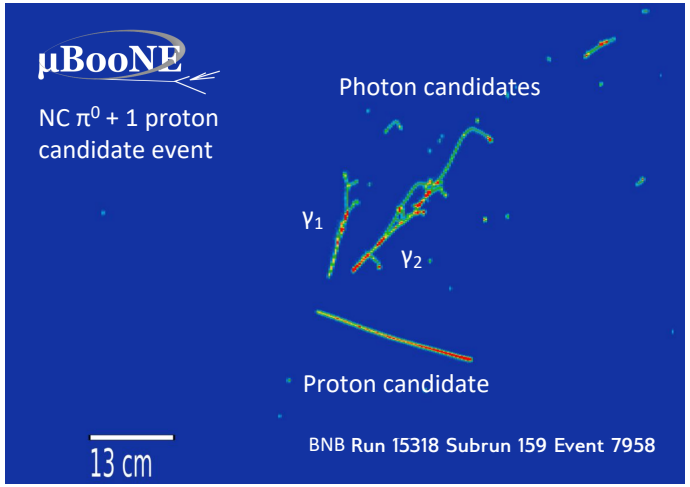
- mm-level resolution, ns-scale timing
- MeV-scale detection thresholds

Excellent particle identification:

- topological and calorimetric
- electrons and photon separation
- distinguish muons, protons, pions



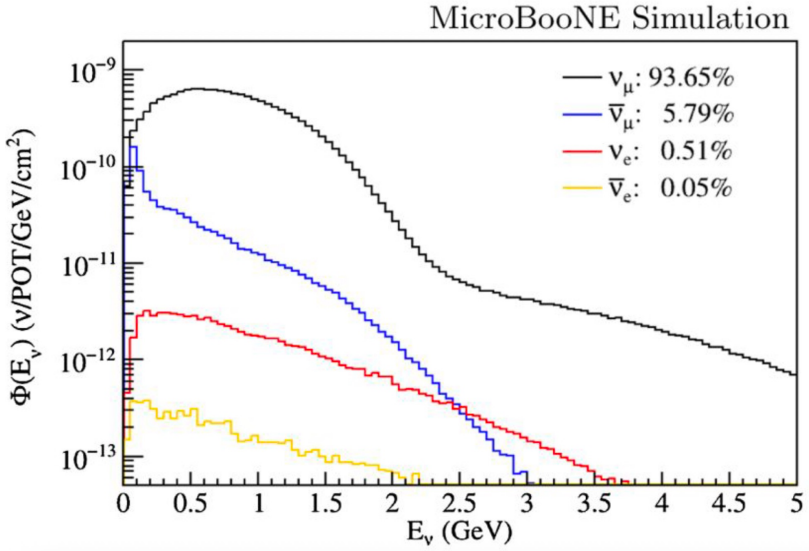



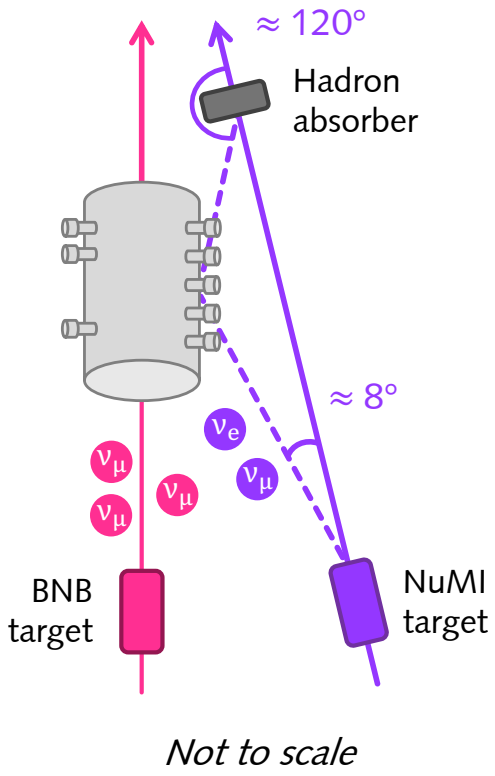



# Two neutrino beams

**Booster Neutrino Beam (BNB)**

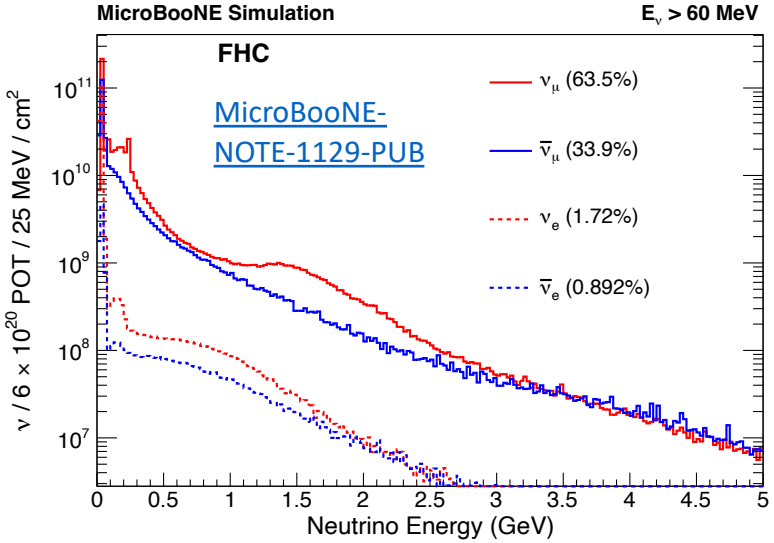
- on-axis, primary beam
- 8 GeV protons, 1.3 × $10^{21}$ POT
- $\langle E_\nu \rangle$ ~ 800 MeV




**Neutrinos at the Main Injector (NuMI)**

- off-axis: 8° (target), 120° (absorber)
- 120 GeV protons, 2.0 × $10^{21}$ POT
- $\langle E_\nu \rangle$ ~ 500 MeV
- higher $\nu_e$ content; powerful for BSM
- recently updated modeling



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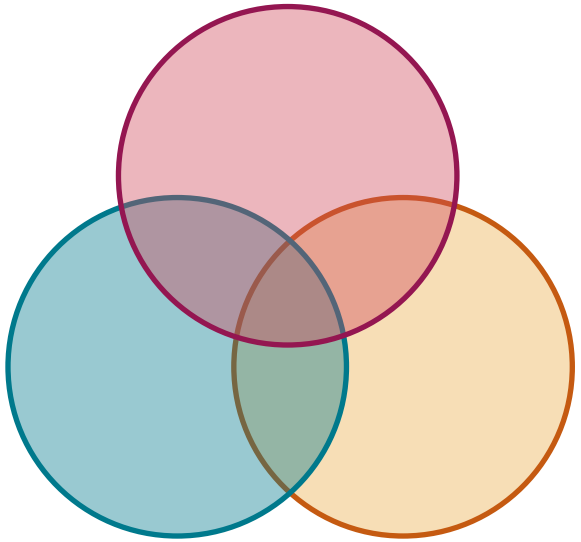
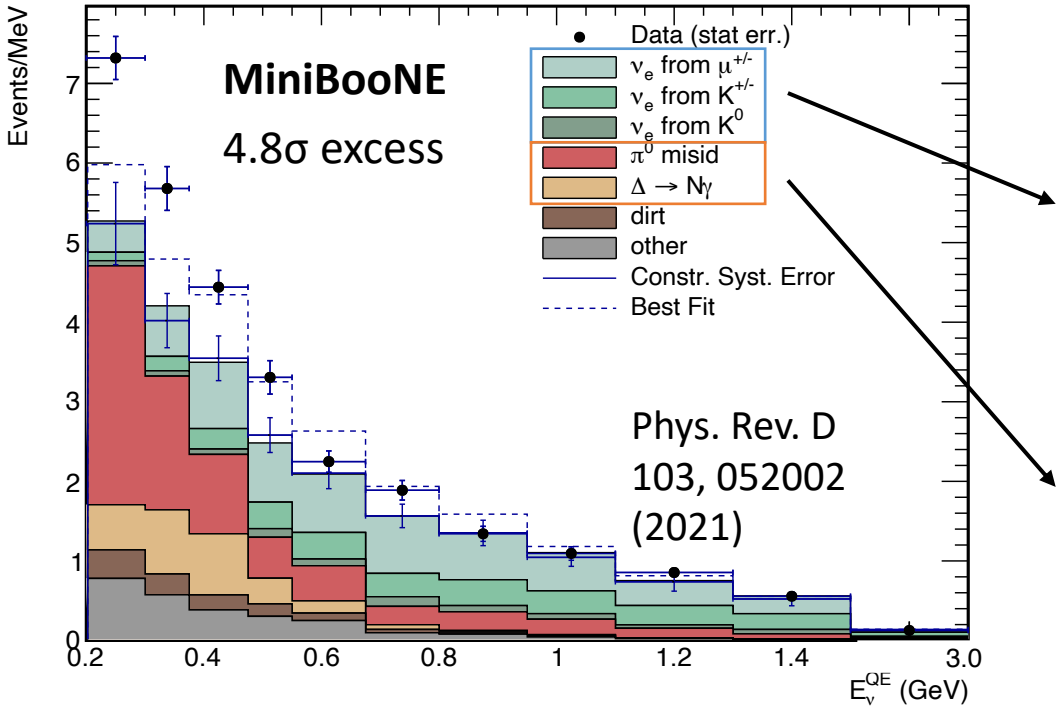
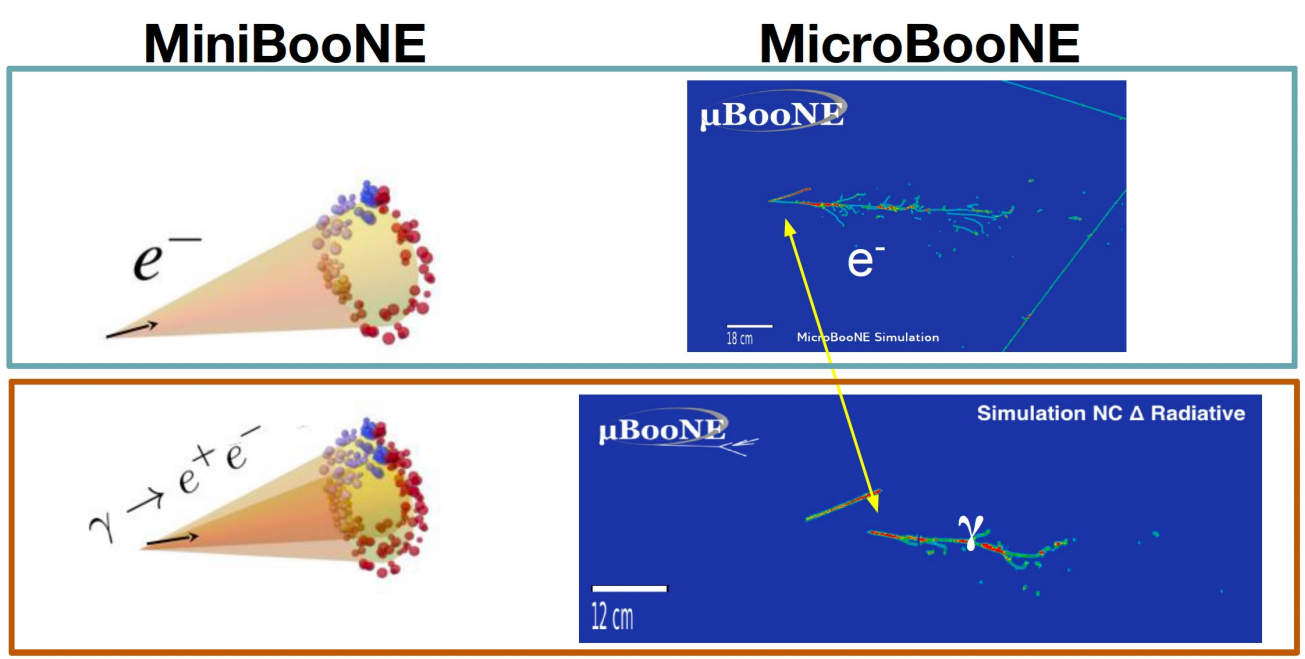


# MiniBooNE Low Energy Excess (LEE) anomaly

MiniBooNE was a Cherenkov detector @ Fermilab exposed to same beamline as MicroBooNE

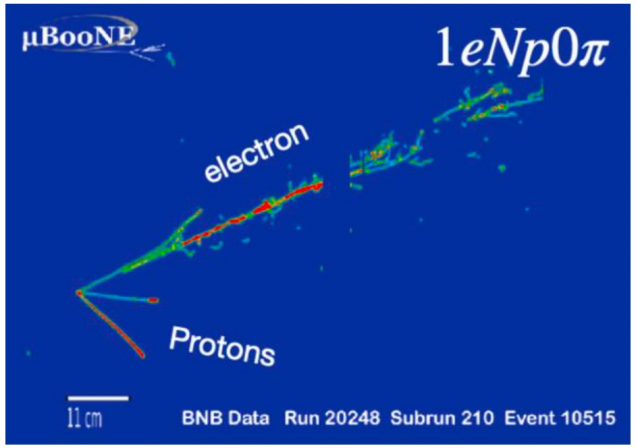
- saw 4.8σ excess of single electromagnetic showers at low energies
- remains unexplained, potentially consistent with eV-scale sterile neutrino oscillations
- MiniBooNE could not distinguish between $e^-$ and $\gamma$ → MicroBooNE allows detailed investigation into anomaly

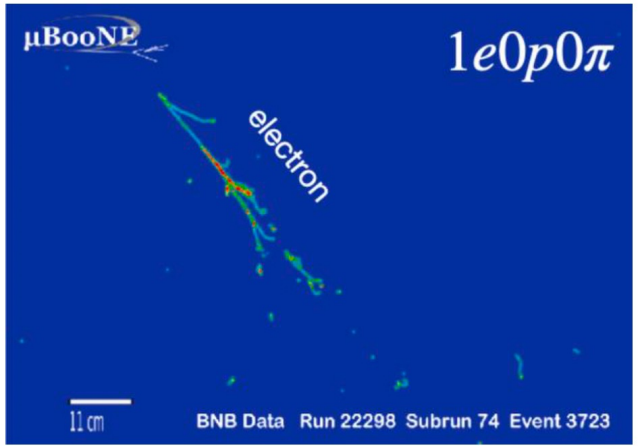


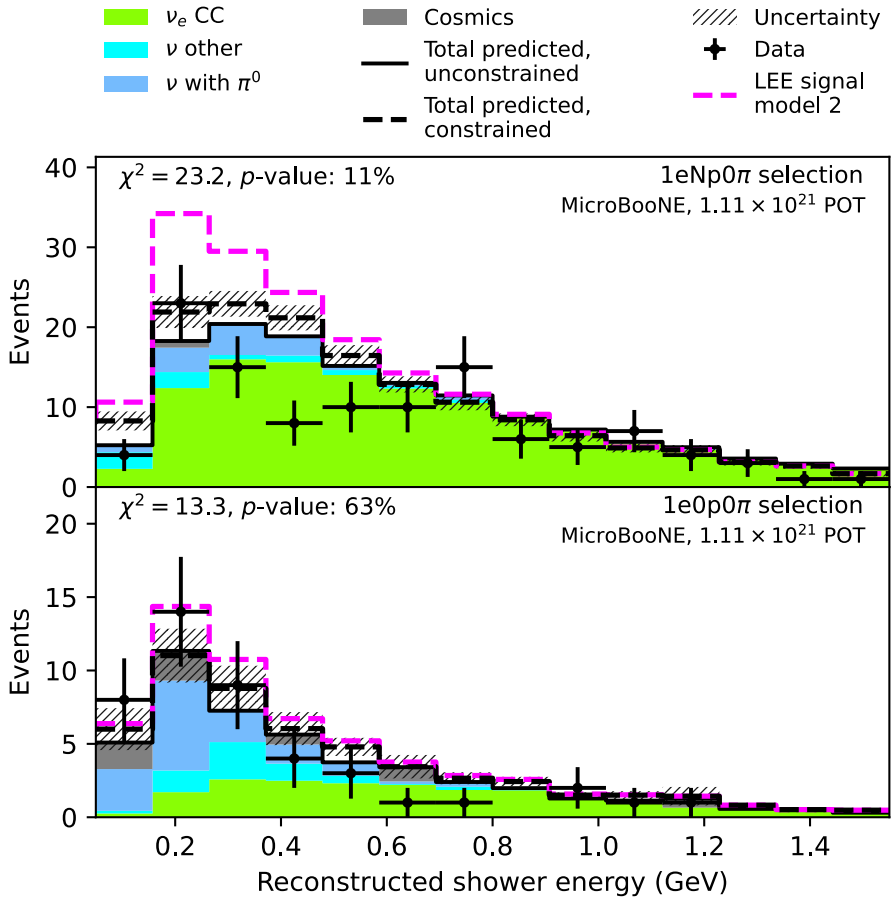



# Electron-like results

New




**Exclusive $\nu_e$ CC 0π 0p/Np search:**

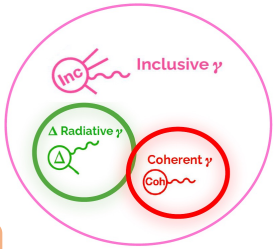
arXiv: 2412.14407

- new full-dataset measurement with improved selection and LEE modelling
- **excludes $\nu_e$-like interpretation of MiniBooNE excess at >99% CL**

Updated inclusive search underway:

- will double statistics of 2022 result, Phys. Rev. D **105**, 112005 (2022)

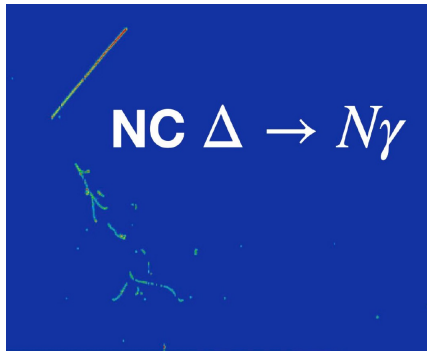
# Photon-like results: exclusive

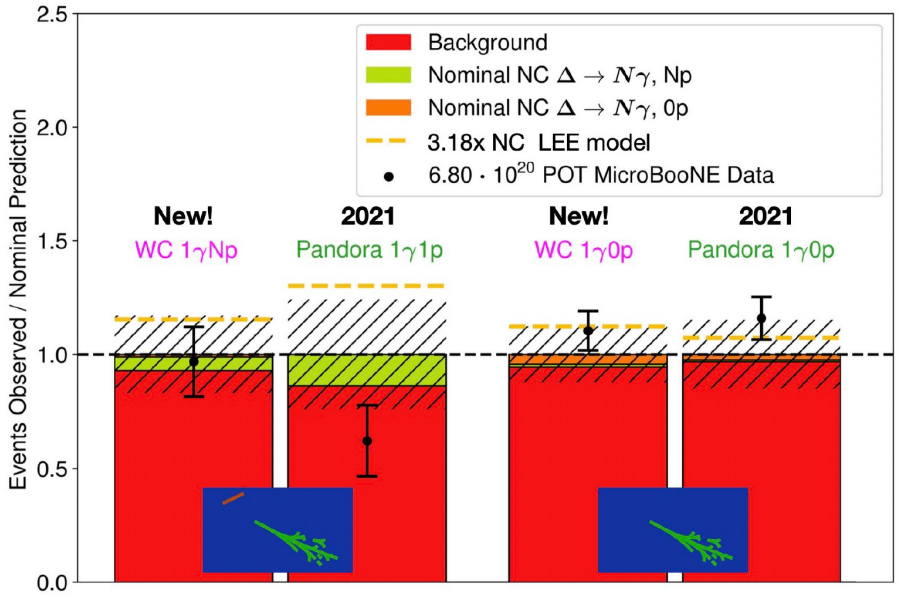



New

**Expanded NC Δ → Nγ search:**
arXiv: 2502.05750

- doubled statistics of 2021 result incorporating new reconstruction paradigm
- **no excess seen at 94.4% CL**



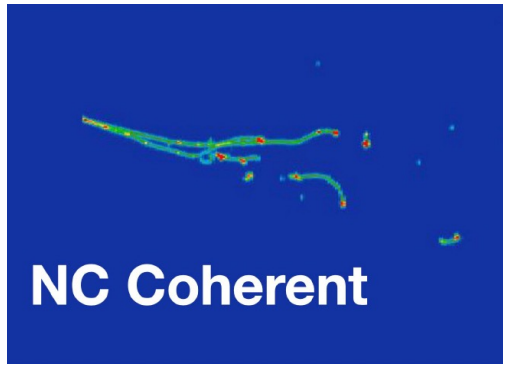



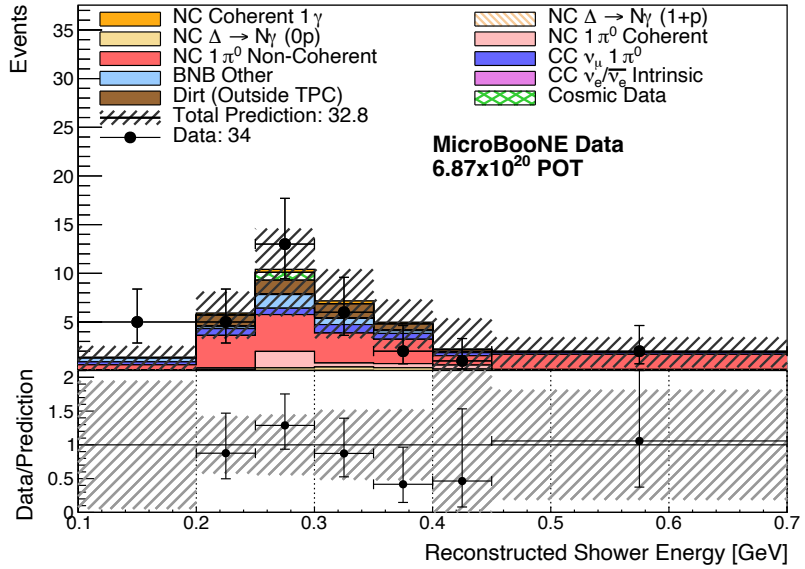

New

**First search for NC Coherent 1γ:**

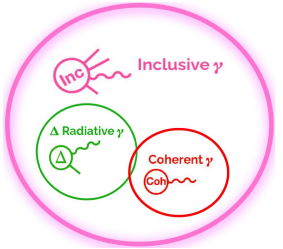
arXiv: 2502.06091

- very rare process, **no excess seen**
- $\sigma < 1.49 \times 10^{-41}$ cm$^2$



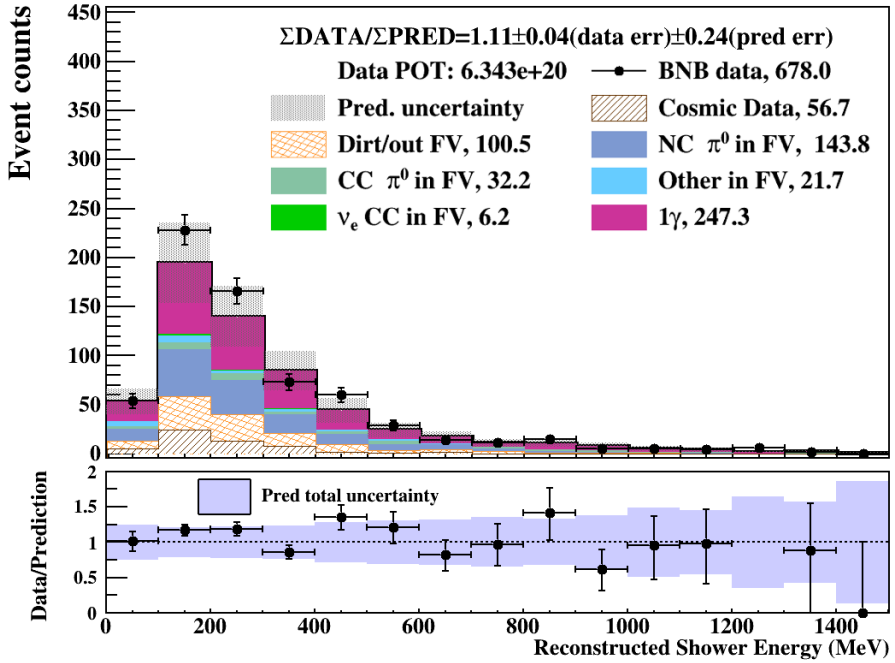



# Photon-like results: inclusive




New

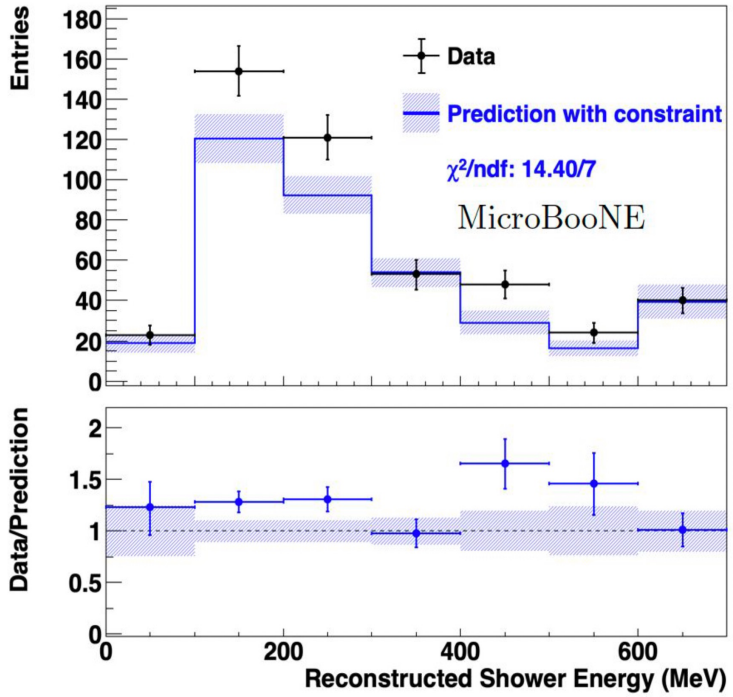
**First inclusive 1γ search:**
arXiv: 2502.06064



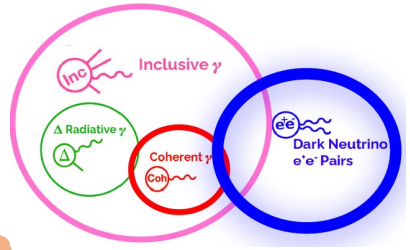


- sensitive to broad range of topologies and phase space, both SM and BSM
- **overall result agrees well with prediction < 2σ**
- **hint of excess (2.2σ) in 0p subsample** below 600 MeV photon energy

1γ0p subsample:



# Photon-like results: dark-sector possibilities

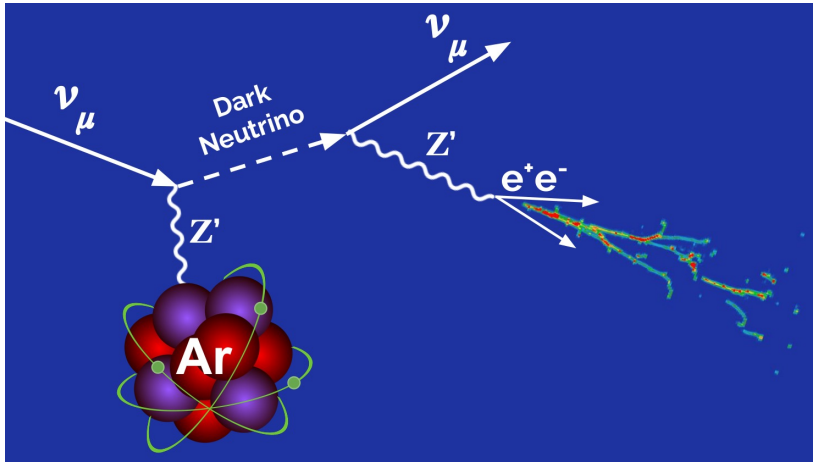


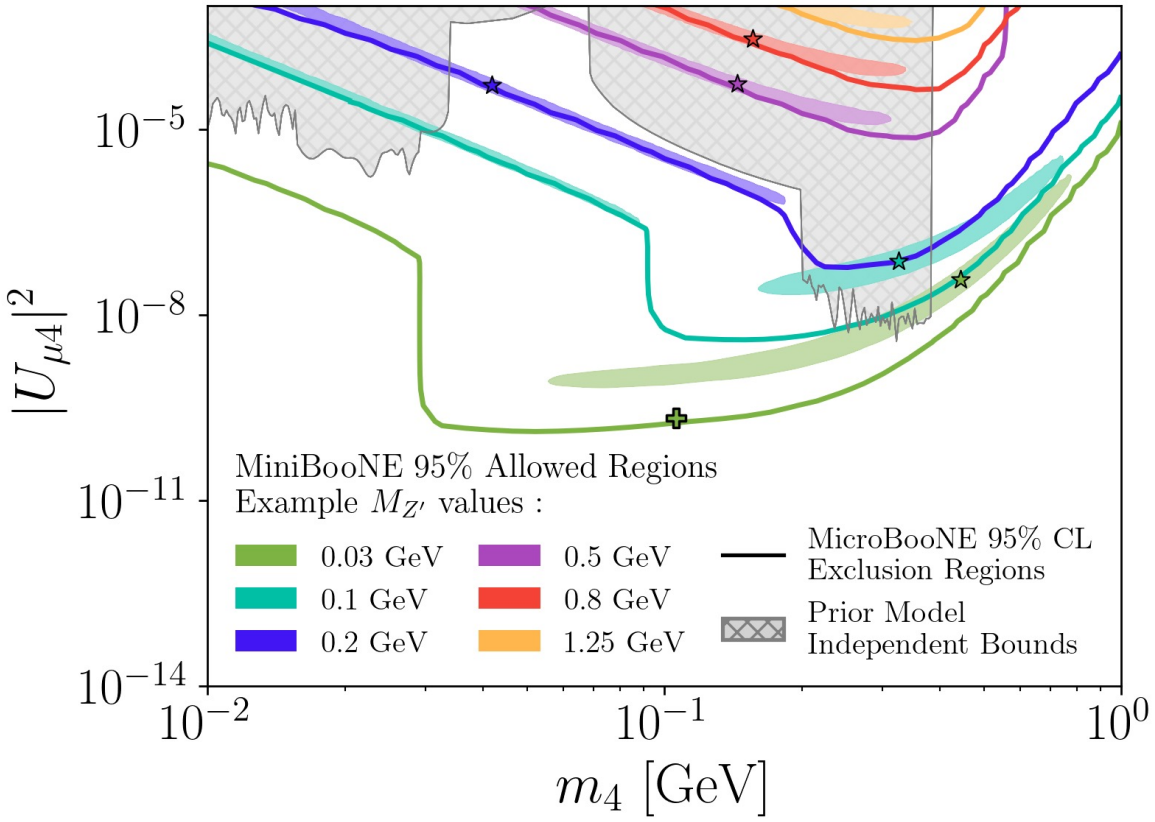

New

**Dark-sector $e^+e^-$ production:**

arXiv: 2502.10900

- first search for dark-sector explanations of MiniBooNE anomaly: dark neutrino model
- **majority of phase space ruled out at 95% CL**



# BSM beyond the low energy excess

MicroBooNE has set leading limits on a broad range of beyond-the-standard model particles:

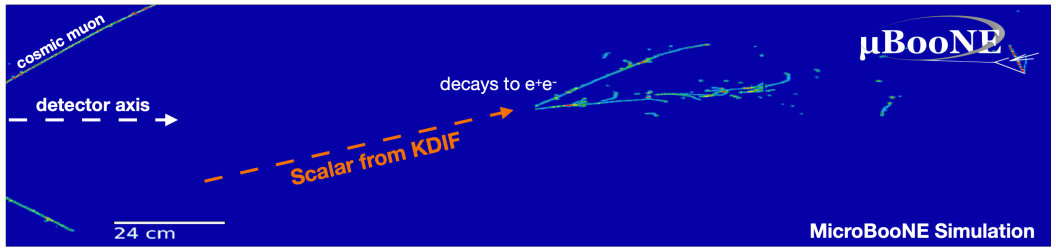
- recent results include limits on Heavy Neutral Leptons (PRL **132**, 041801 (2024)), Dark Tridents (PRL **132**, 241801 (2024))
- many more searches in progress: axion-like particles, millicharged particles, etc.

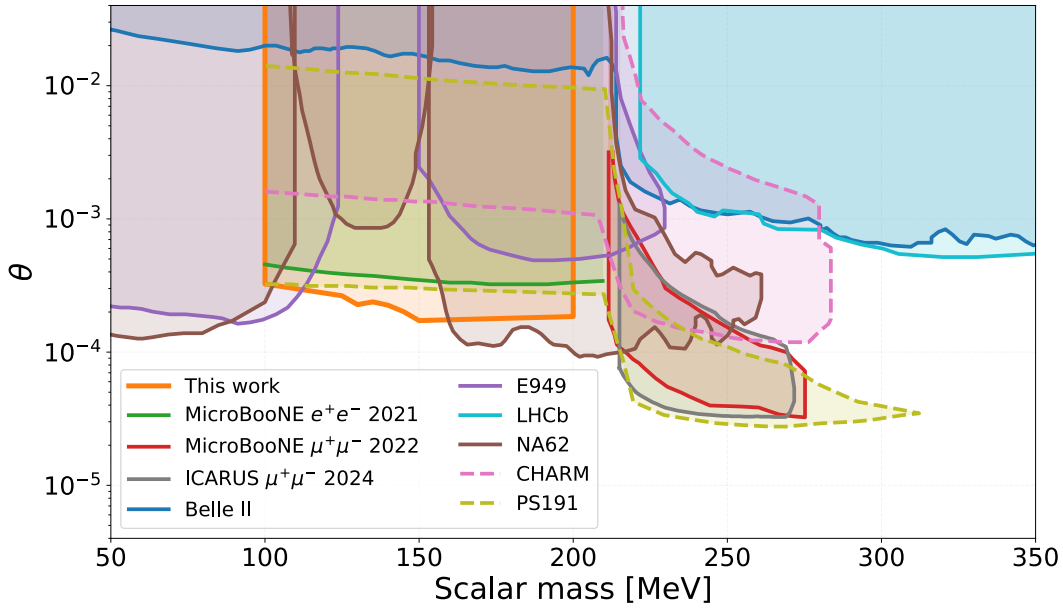
New

**Higgs Portal Scalars:**

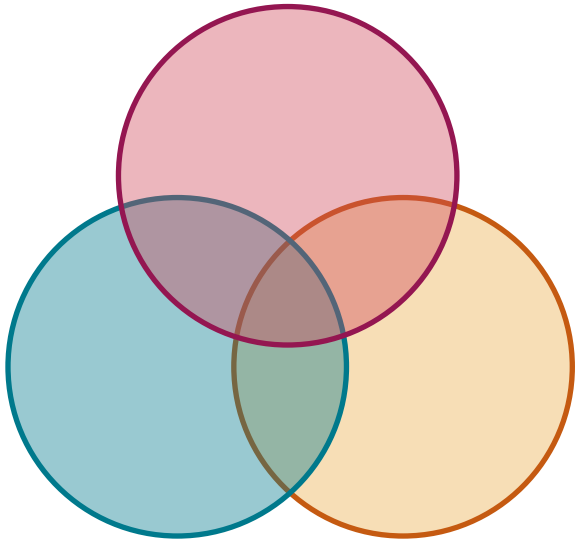
arXiv: 2501.08052

- search for decay to $e^+e^-$
- set strongest limits to date for Higgs Portal Scalar masses 100 – 155 MeV



# MicroBooNE's Science Goals

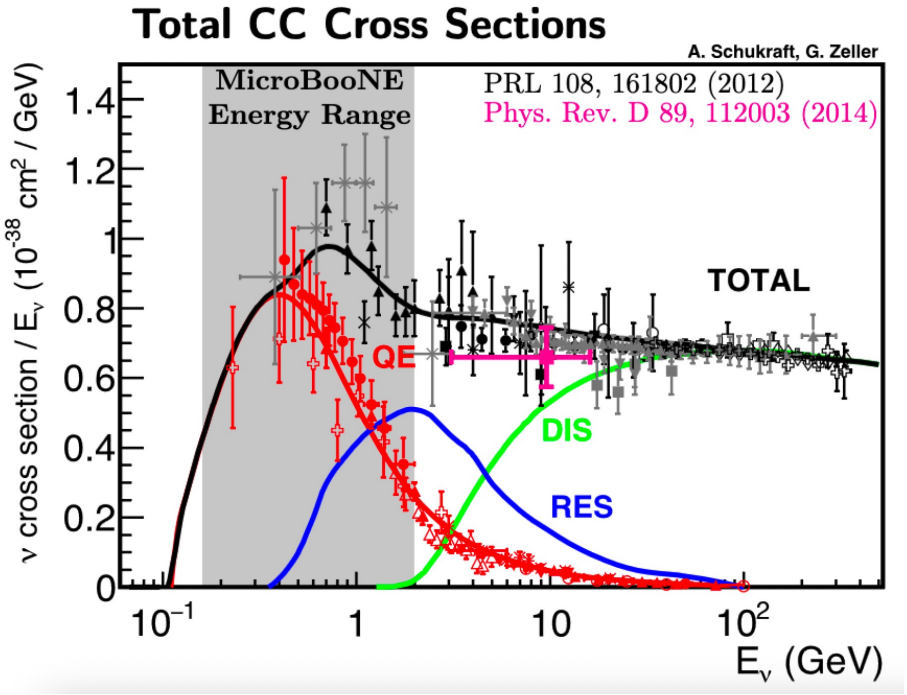


Neutrino interactions:
precision measurements on argon

# ν-Ar cross sections

Neutrino oscillation measurements and BSM searches limited by ν-Ar interaction modeling

- crucial inputs for DUNE and SBN
- broad program: 28 cross section papers!




## MicroBooNE Cross Sections

### Inclusive Measurements

- 1D $\nu_\mu$ CC Inclusive @ BNB: PRL **123** 131801 (2019), PRL **128** 151801 (2022)
- 2D $\nu_\mu$ CC Inclusive @ BNB: PRL **133** 041801 (2024), PRD **110** L013006 (2024)
- 3D $\nu_\mu$ CC Inclusive @ BNB: arXiv:2307.06413
- 1D $\nu_e$ CC Inclusive @ NuMI: PRD **104** 052002 (2021), PRD **105** 051102 (2022)

### Pionless Measurements

- 1D, 2D $\nu_\mu$ CC 0π Np @ BNB: PRD **102** 112013 (2020), arXiv:2403.19574, arXiv:2507.00921
- 1D $\nu_\mu$ CC 0π 1p @ BNB: PRL **125** 201803 (2020)
- 1D, 2D $\nu_\mu$ CC 0π 1p TKI @ BNB: PRL **131** 101802 (2023), PRD **108** 053002 (2023)
- 1D, 2D $\nu_\mu$ CC 0π 1p GKI @ BNB: PRD **109** 092007 (2024)
- 1D, 2D $\nu_\mu$ CC 0π 1p AKI @ BNB: PRD **111** 113007 (2025)
- 1D $\nu_\mu$ CC 0π 2p @ BNB: arXiv:2211.03734
- 1D $\nu_e$ CC 0π Np @ BNB: PRD **106** L051102 (2022)

### Pion Production Measurements

- 1D $\nu_\mu$ CC $1\pi^0$ @ BNB: PRD **99** 091102 (2019), PRD **110** 092014 (2024)
- 1D, 2D $\nu_\mu$ NC $1\pi^0$ @ BNB: PRD **107** 012004 (2023), PRL **134** 161802 (2025)
- 1D $\nu_\mu$ CC $1\pi^\pm$ @ BNB: arXiv in the next days
- 1D $\nu_e$ CC $1\pi^\pm$ @ NuMI: arXiv:2503:23384

### Rare Channels and Novel Techniques

- Λ Production @ NuMI: PRL **130** 231802 (2023)
- η Production @ BNB: PRL **132** 151801 (2024)
- $K^+$ Production @ BNB: arXiv:2503.00291
- Neutrons Identification: EPJC **84** 1052 (2024)
- Model Validation: PRD 111 092010 (2025)

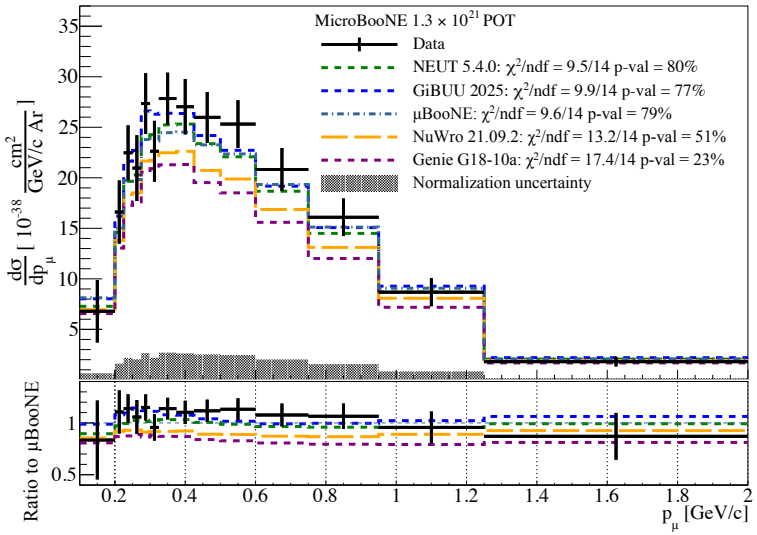
# Precision probes of nuclear effects

High statistics $\nu_\mu$ CC pionless measurements: precision probes of nuclear modeling and final state interactions

New

**$\nu_\mu$ CC 0π: arXiv: 2507.00921**

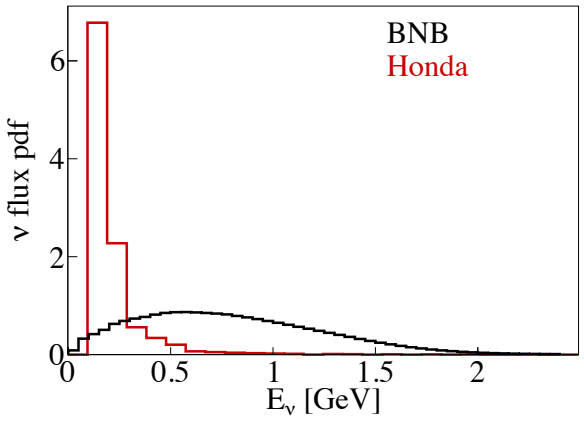
- full data-set 1D and 2D measurements
- joint analysis with ANNIE on-going, water Cherenkov detector same beam

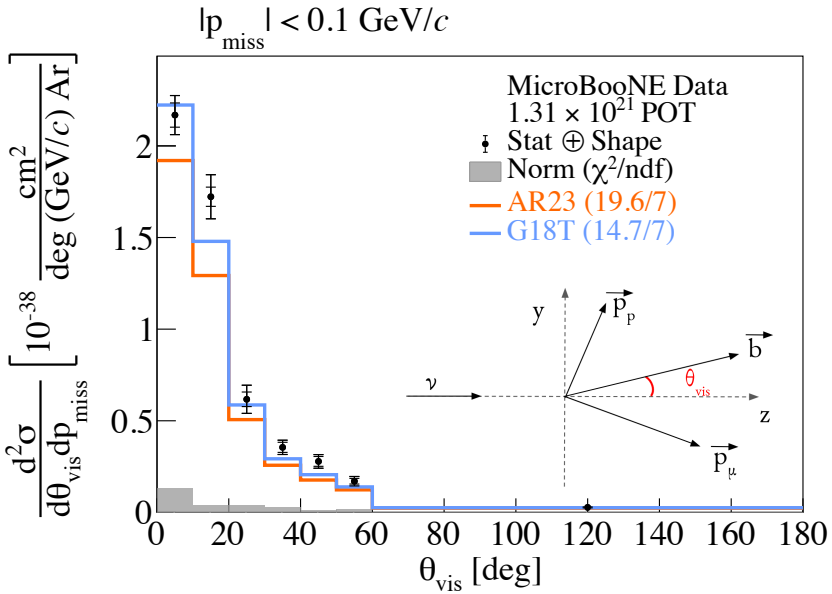



New

**$\nu_\mu$ CC 0π 1p "AKI": Phys. Rev. D 111, 113007 (2025)**

- neutrino direction reconstruction resolution, key for DUNE atmospherics
- prediction re-weighting to DUNE Honda atmospherics flux
- angular kinematic imbalance, sensitive to nuclear effects impacting direction determination



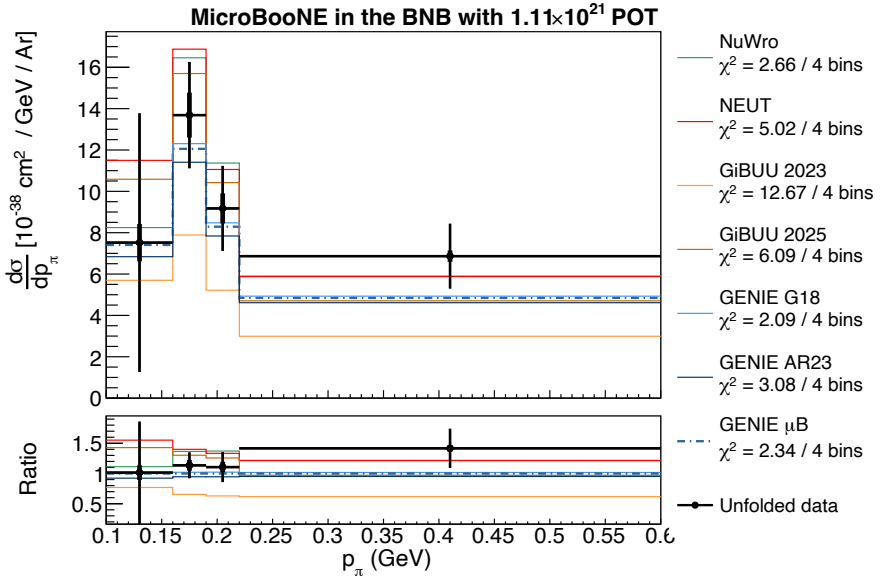
# Pion production: charged pions

First measurements of charged-pion production: one of the dominant interaction modes at energy of DUNE

New

**$\nu_\mu$ CC $1\pi^\pm$:** arXiv coming in the next days

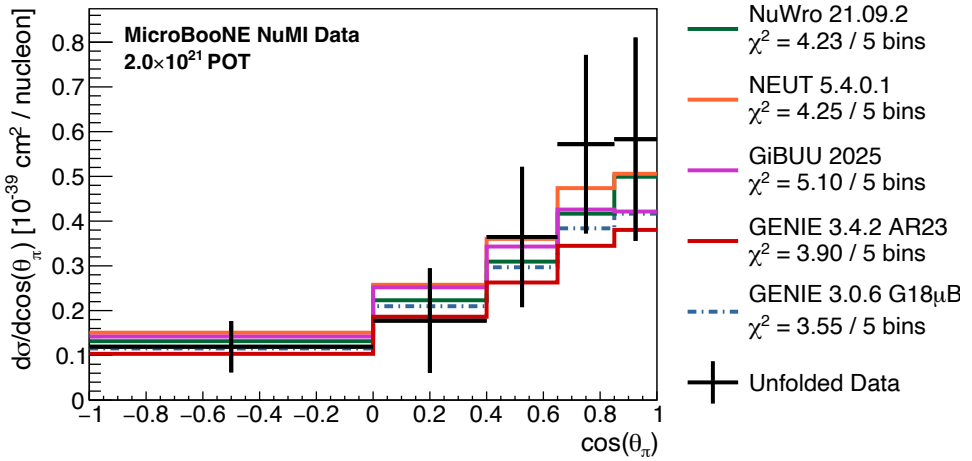
- full data-set, first measurement of pion momentum
- signs of mismodelling at low $Q^2$ and for high pion momenta driven by final state interactions




New

**$\nu_e$ CC $1\pi^\pm$:** [Phys. Rev. Lett. **135**, 061802 (2025)]

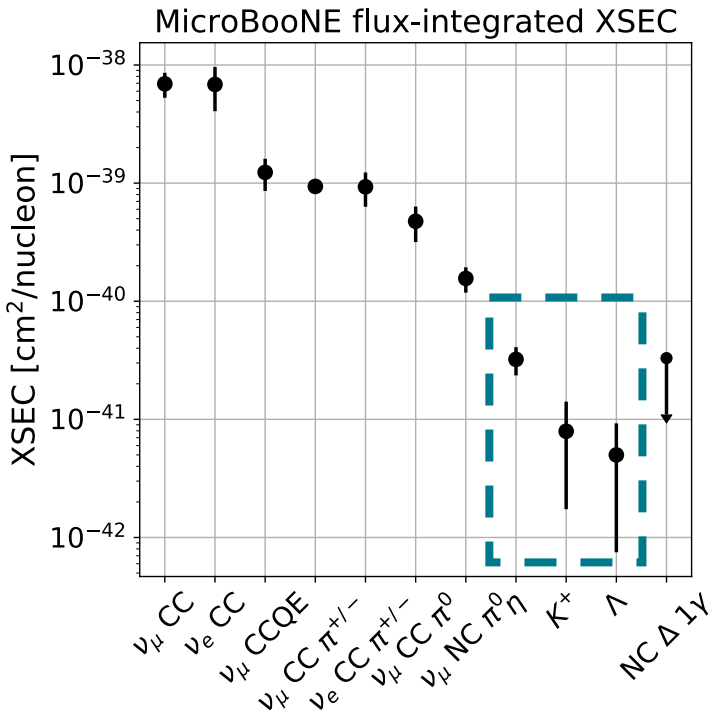
- first measurement of $\nu_e$ CC $1\pi^\pm$ on argon
- uses full NuMI dataset, higher $\nu_e$ content
- good modeling seen within uncertainties



# Rare processes

Provide insights into higher resonances and help with constraints of key backgrounds for nucleon decay:

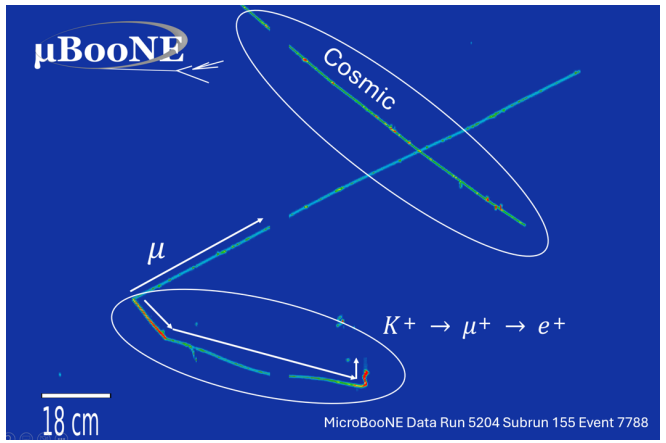
- recent measurements: **$\nu_\mu$ CC Λ** (Phys. Rev. Lett. 130, 231802 (2023)) and **$\nu_\mu$ CC/NC η** (Phys. Rev. Lett. 132, 151801 (2024))

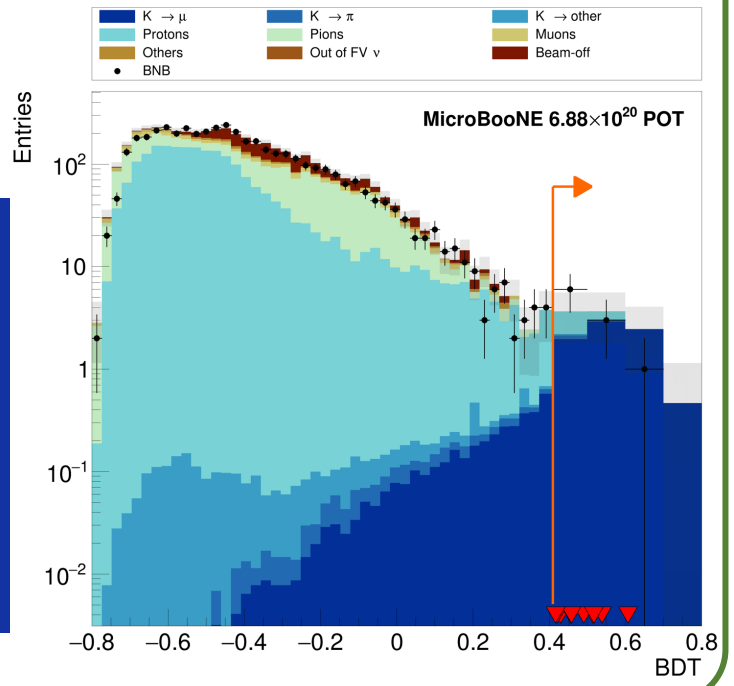



New

**$\nu_\mu$ CC $K^+$:** arXiv: 2503.00291

- first measurement of **$K^+$** on argon, background for proton decay p → $K^+$ **ν** in DUNE



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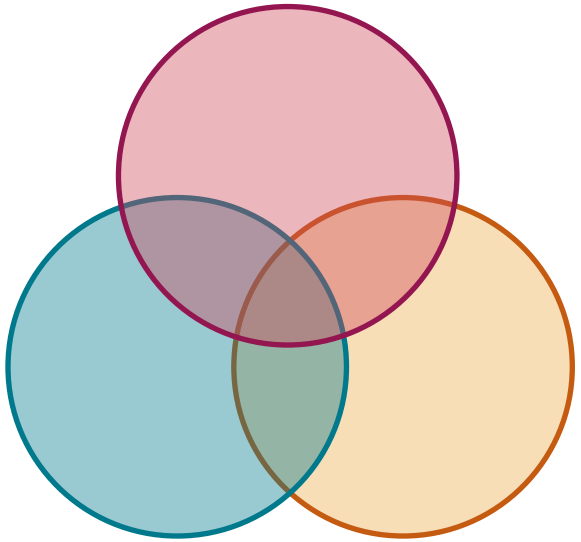
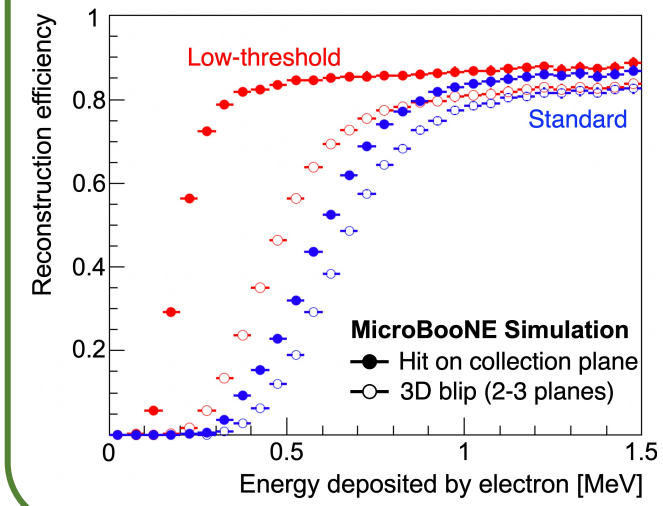


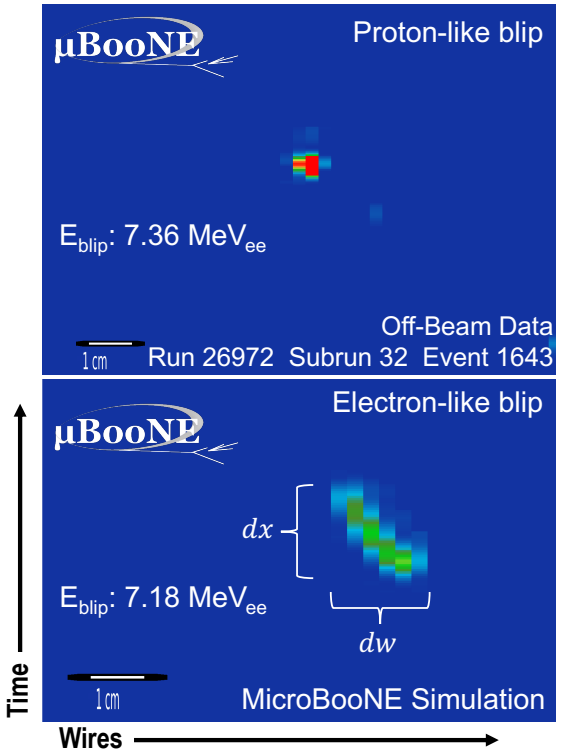
Detector Physics:
pushing the capabilities of LArTPCs

# Novel Particle Identification and Detector Physics

**MeV-scale "Blips":** [Phys. Rev. D **110**, 092014 (2024)](#) [Phys. Rev. D **111**, 032005 (2025)](#) New

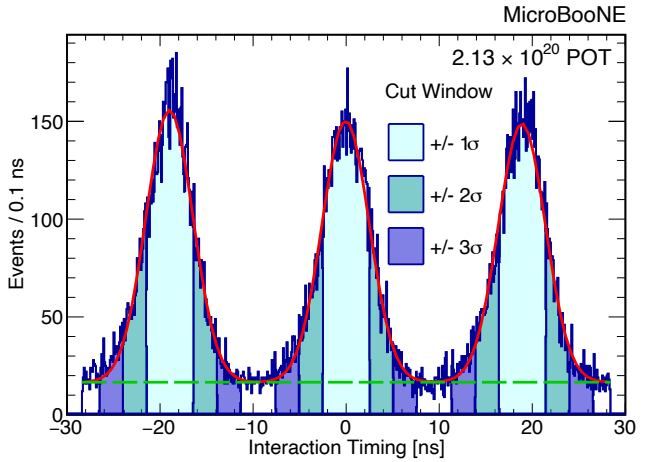
- 150 keV detection threshold
- vast range of applications: improved calorimetry, lower particle thresholds, BSM searches, muon/pion separation, neutron tagging, etc.



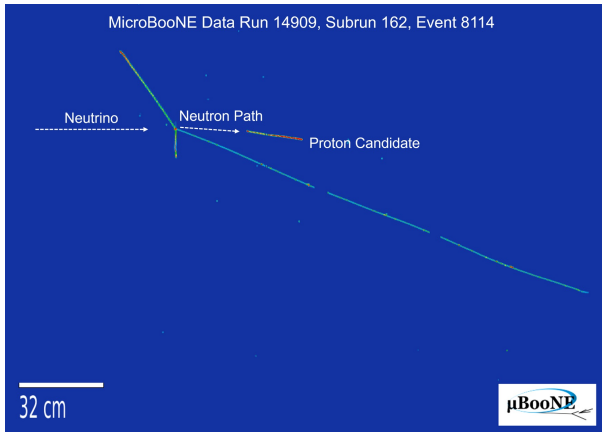

**ns-scale timing:** [PRD 108, 052010 (2023)](#)

- O(1ns) resolution
- recover BNB beam structure: powerful tool for non-beam background rejection




**Neutron identification:** [EPJC **84**: 1052 (2024)](#)

- reconstruct neutrons through n-Ar inelastic proton production
- effort underway to harness MeV "blips" tools to lower threshold



# Summary

MicroBooNE actively analyzing full dataset:

- 5 years of data, two neutrino beams

Broad range of physics:

- new physics searches and investigations of the MiniBooNE LEE anomaly
- precision neutrino interaction measurements on argon
- pioneering work in LArTPC detector physics and reconstruction tools

Exciting new results out across all areas, with many more in the works!

May 2025 Collaboration Meeting
@ Indiana University Bloomington

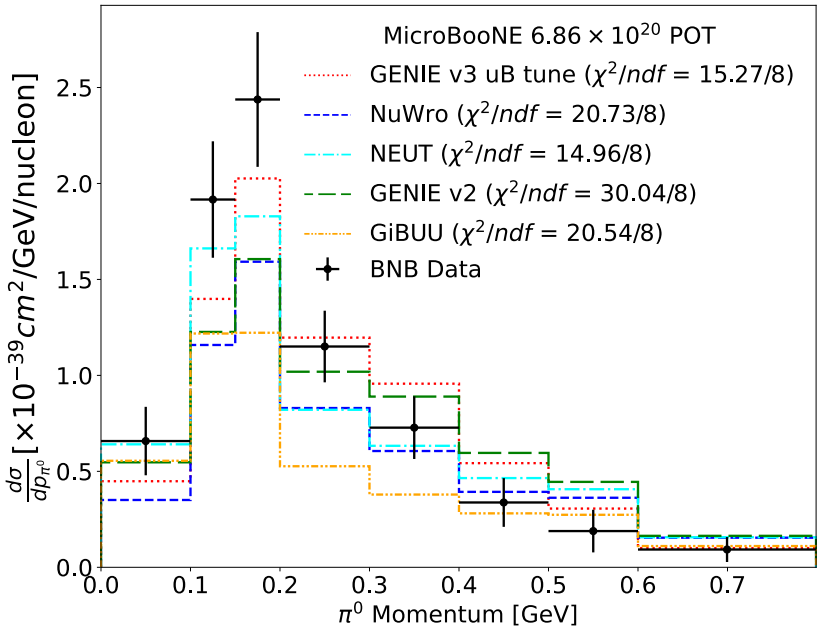
# Backups

# Pion production: neutral pions

Neutral-pion production measurements: key channel for DUNE and important background for BSM searches

**1D $\nu_\mu$ CC $1\pi^0$:** Phys. Rev. D **110**, 092014 (2024)

- mismodeling in $\pi^0$ momenta and at low $Q^2$
- CC/NC $1\pi^0$ ratio measurement coming soon




New

**2D $\nu_\mu$ NC $1\pi^0$:** Phys. Rev. Lett. **134**, 161802 (2025)

- double-differential Xp measurement: sensitive probe of form factor modeling
- simultaneous 0p and Np measurement: sensitivity to final state interaction modeling