Recent Cross-Section Results From MicroBooNE

Jairo H. Rodriguez Rondon
On behalf of the MicroBooNE collaboration

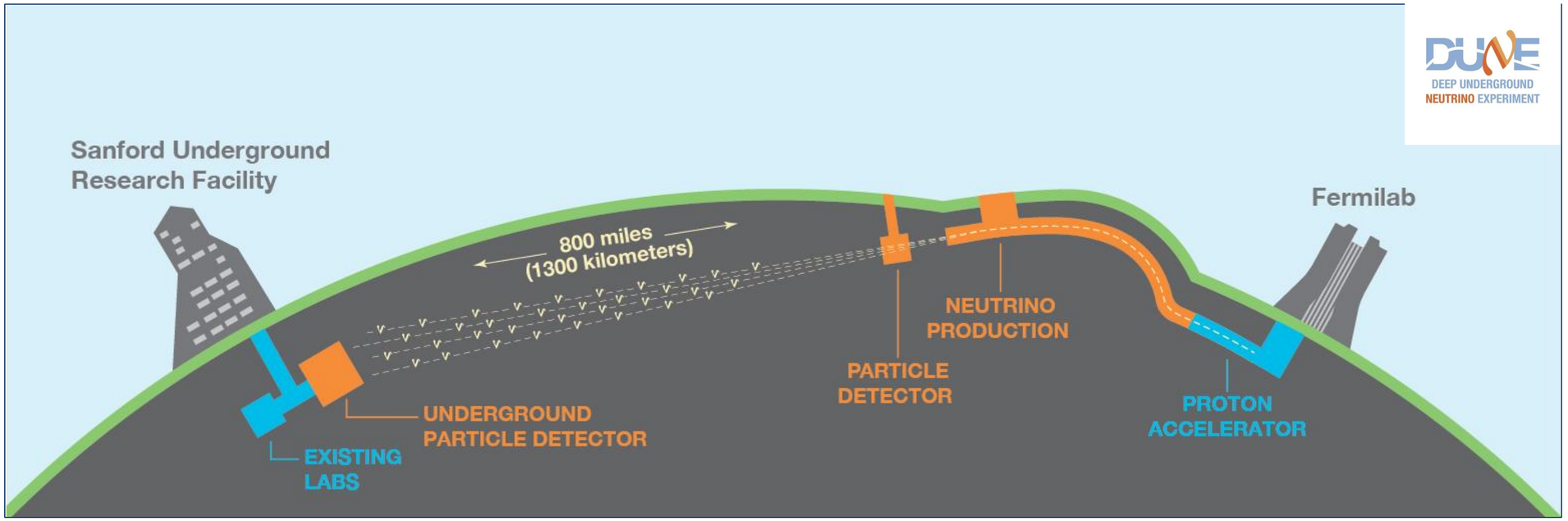
XXI Workshop on Neutrino Telescopes
Padova, Italy, October 1st 2025

Overview

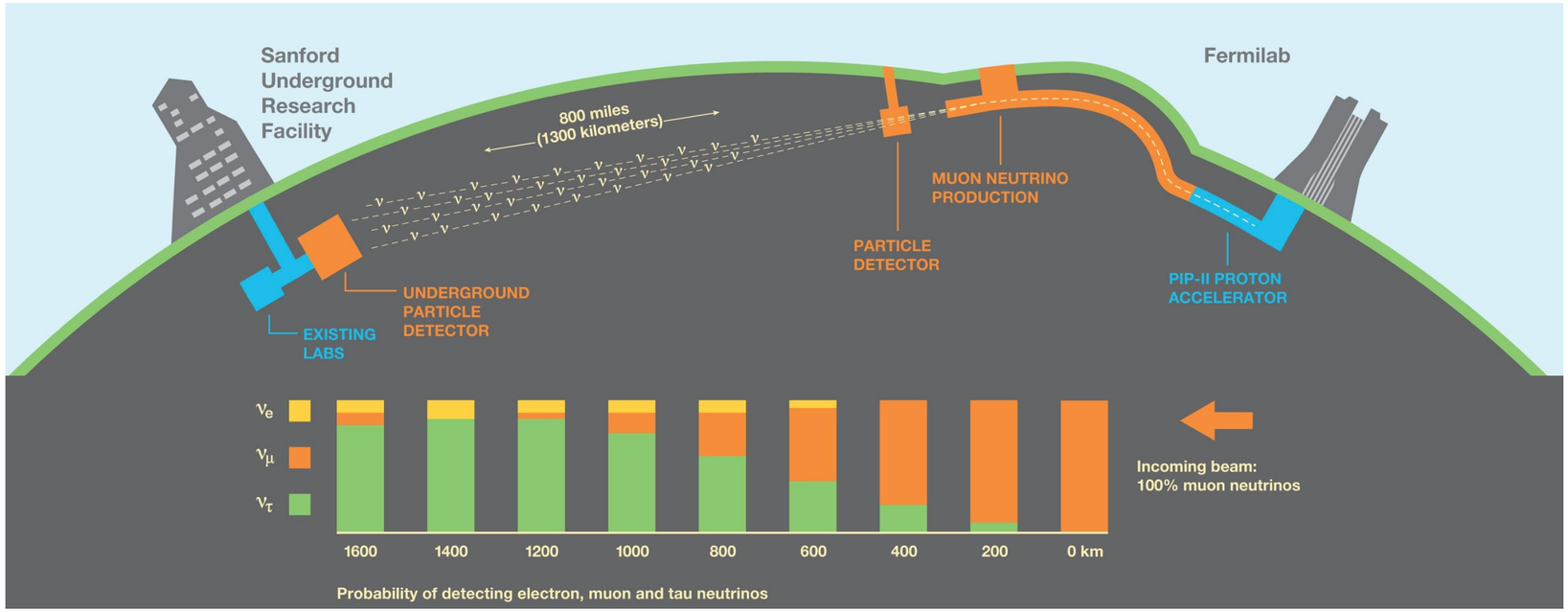
- Neutrino physics is in a great moment pushing towards high precision measurements to refine oscillation parameter and to determine the neutrino mass hierarchy.

- Liquid Argon Time Projection Chambers (LArTPCs) has become the state-of the art detectors in neutrino physics.

- Precise neutrino cross-section measurements are essential to understand interactions with complex nucleus



Important of Cross-Section Measurements



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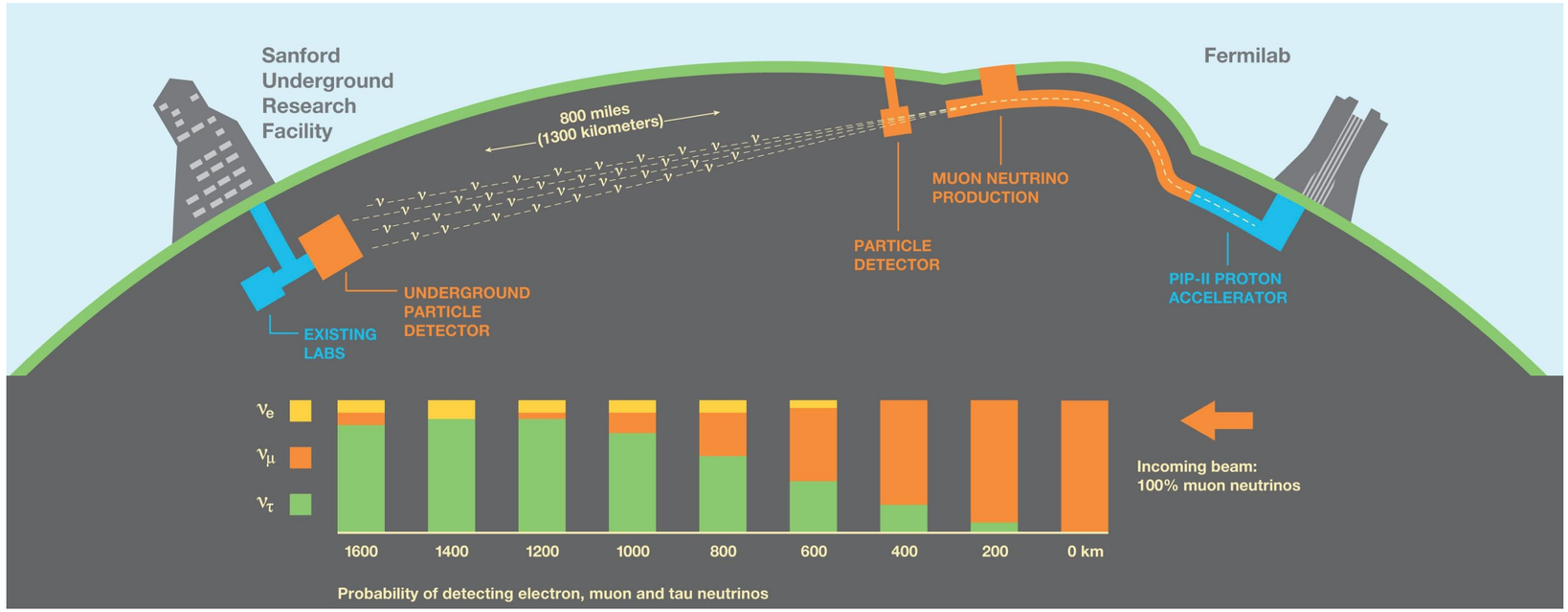

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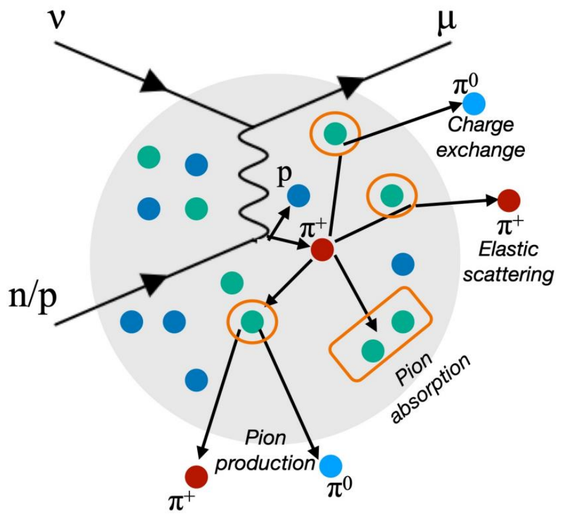
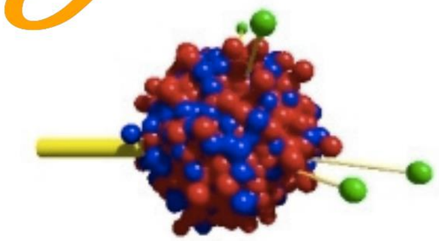


Genie

NuWro Wrocław Neutrino Event Generator

NEUT



GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

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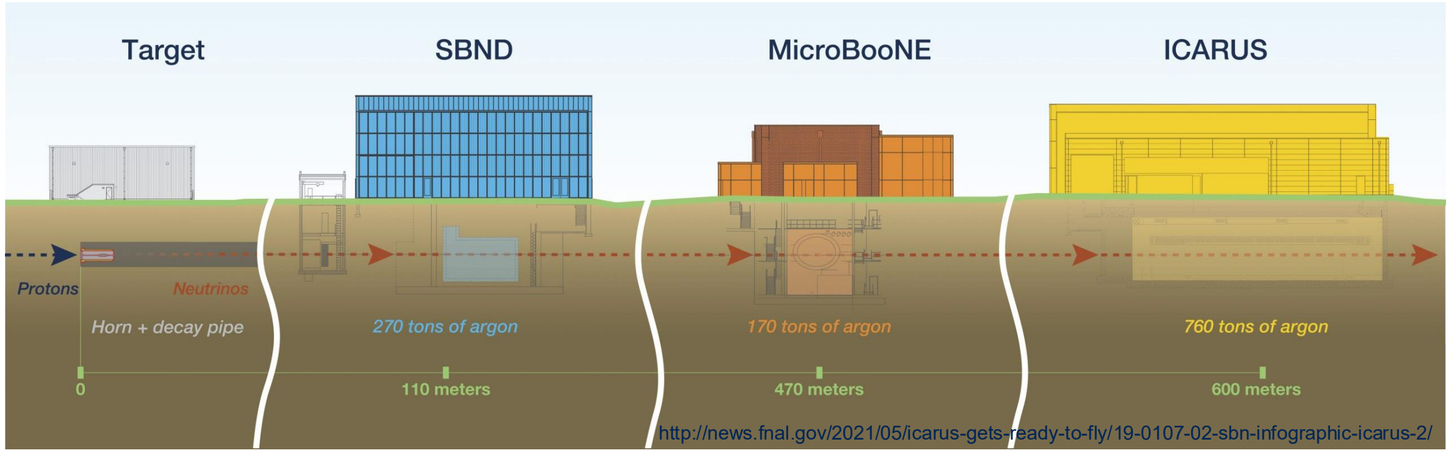
LArTPC Experiments

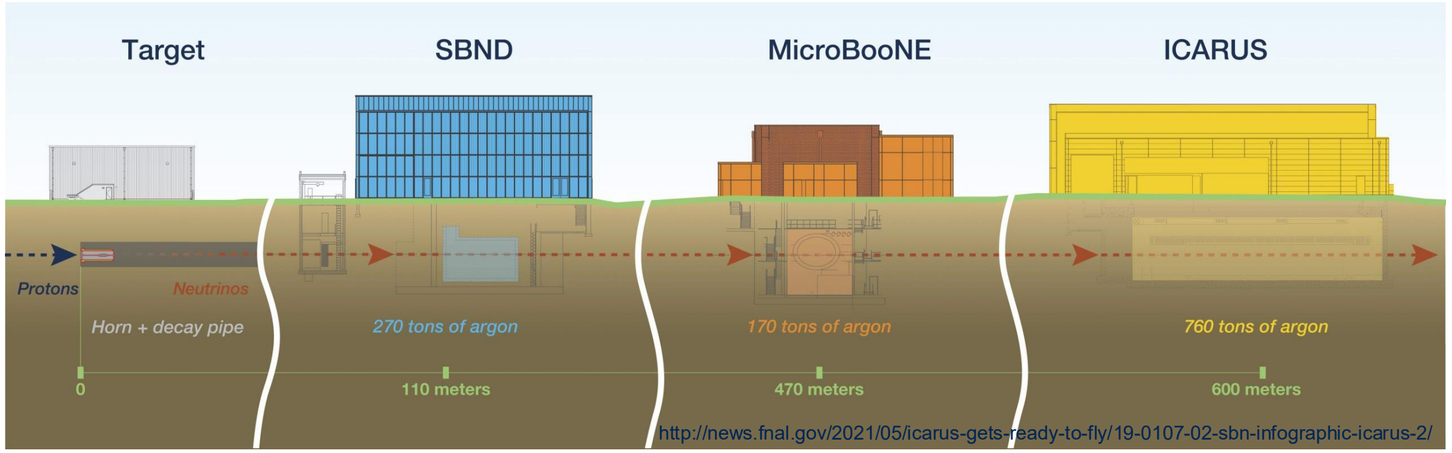


Short-Baseline

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Long-Baseline

LArTPC Experiments



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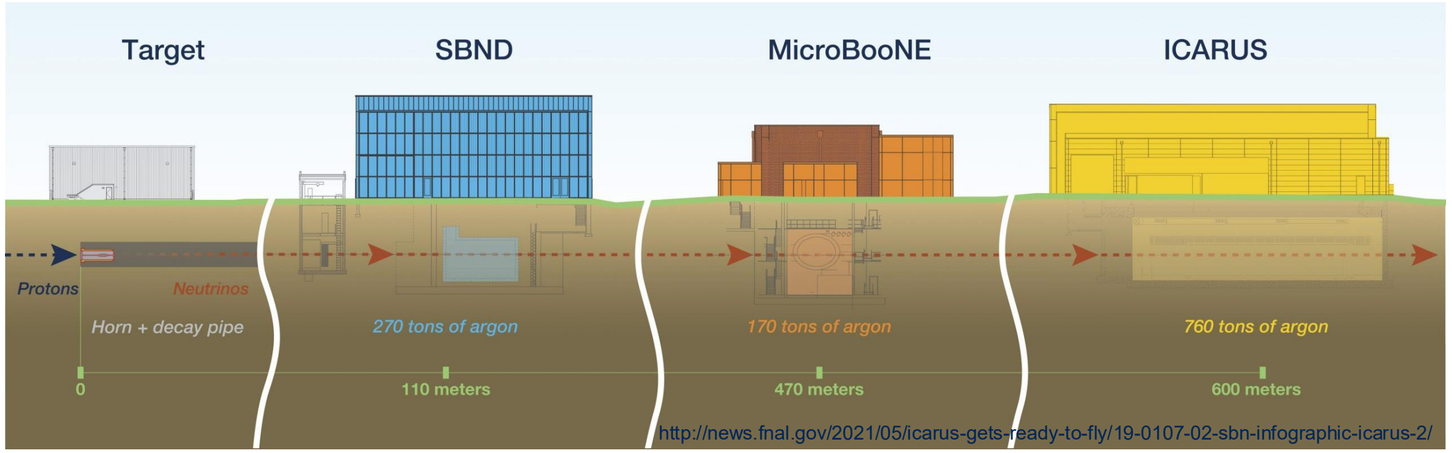

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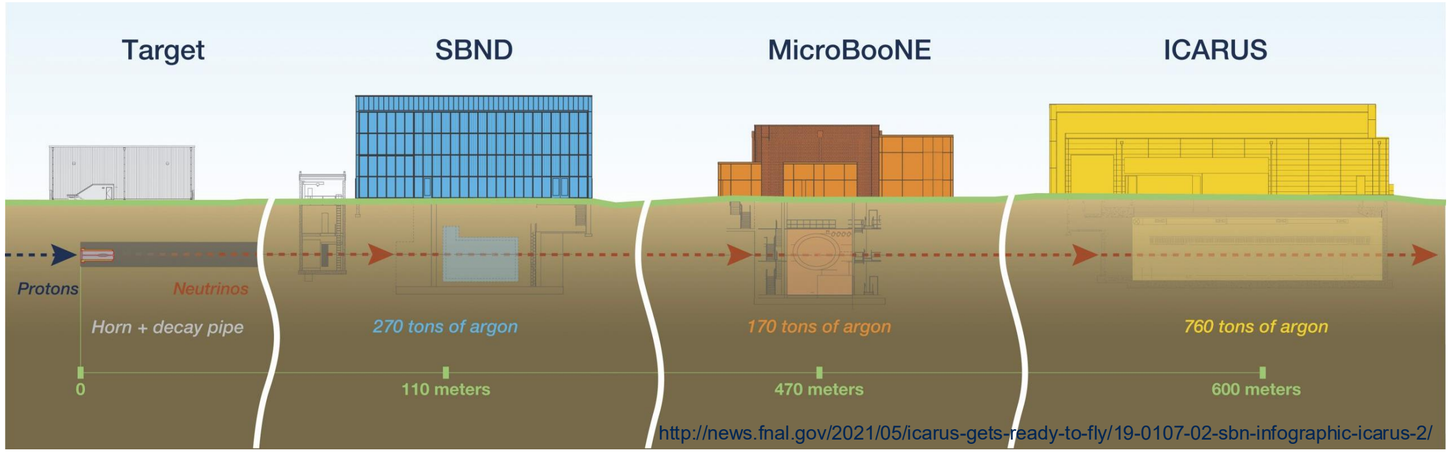

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- MicroBooNE has a large neutrino-argon dataset recorded (~700K neutrino interactions) over its operational period.

The MicroBooNE Experiment

The MicroBooNE detector is a Liquid Argon Time Projection Chamber (LArTPC) with a capacity of 170-tonne of LAr with an active volume of 85-tonne.

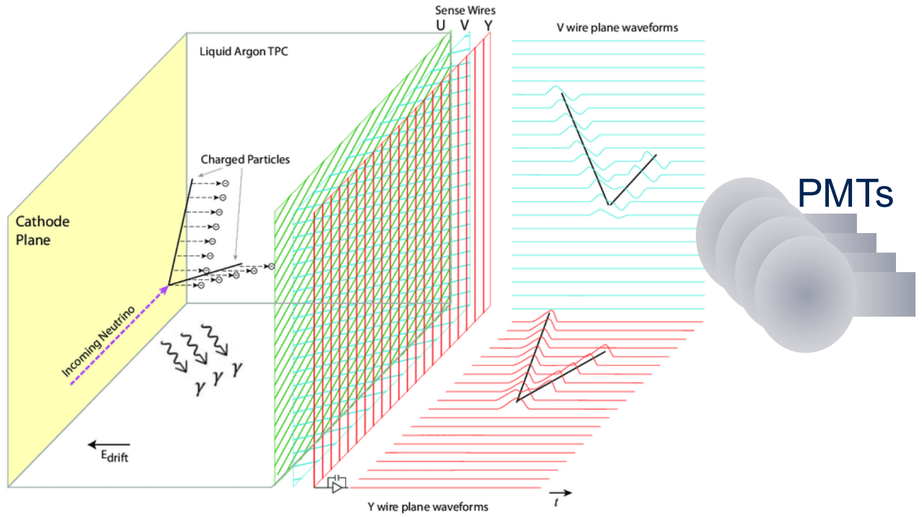
- Located at Fermilab, US. Exposed to two neutrino beams: Booster Neutrino Beam (BNB) and Neutrino Main Injector (NuMI)
- Operational between 2015 - 2021, collected extensive neutrino interaction data $O(10^{21})$ protons-on-target (POT).
- 195 collaborators from 38 institutions. Prolific experiment producing 82 papers and over 60 public notes

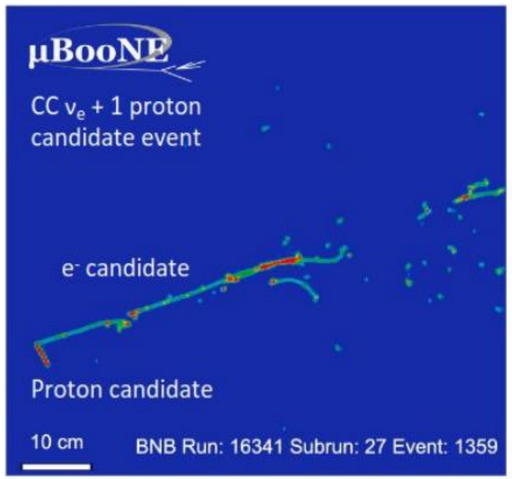
The MicroBooNE LArTPC Detector

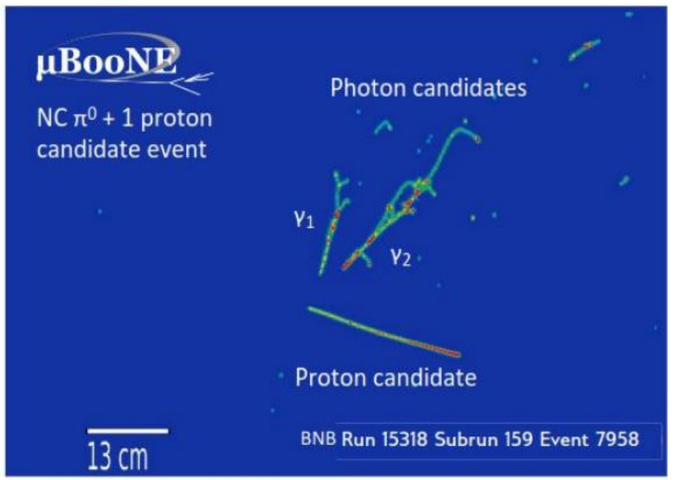
Fully active tracking calorimeter:
- 2.5 × 2.3 × 10.4 m^3 active volume
- 3 planes of wires collecting ionization charge, 32 PMTs collection scintillation light
- 3D neutrino interaction reconstruction

Precision neutrino measurements at scale:
- mm-level resolution, ns-scale timing
- MeV-scale detection thresholds

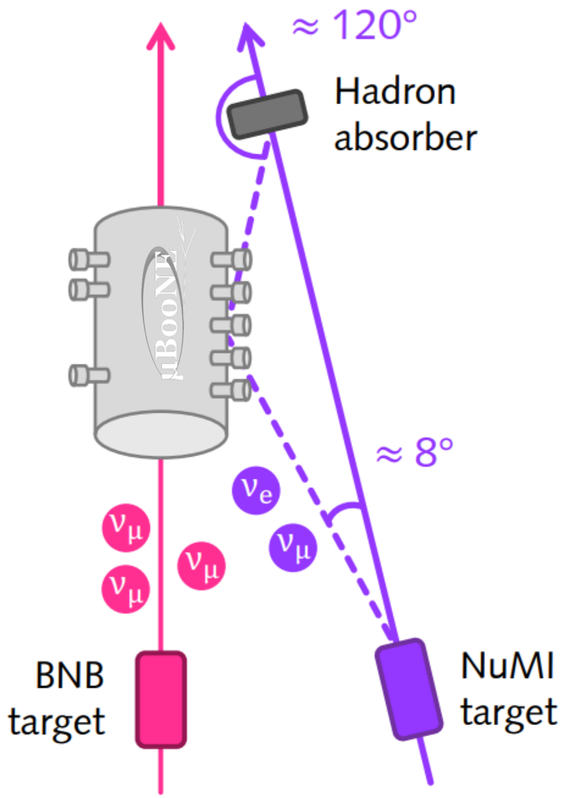
Excellent particle identification:
- topological and calorimetric
- electrons and photon separation
- distinguish muons, protons, pions







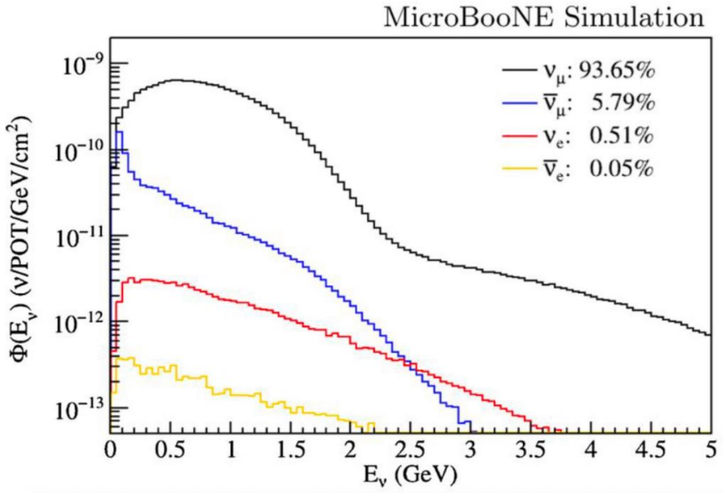
The MicroBooNE LArTPC Detector

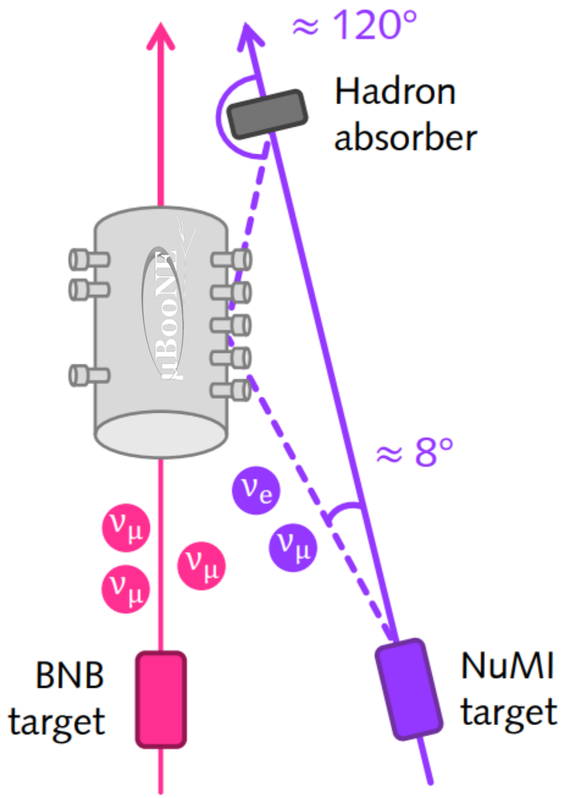


Not to scale

The MicroBooNE LArTPC Detector

BNB
- Primary beam, on-axis
- 8 GeV protons, 1.2×10^{21} POT
- $\langle E_\nu \rangle \sim 800$ MeV
- Mainly ν_μ contribution





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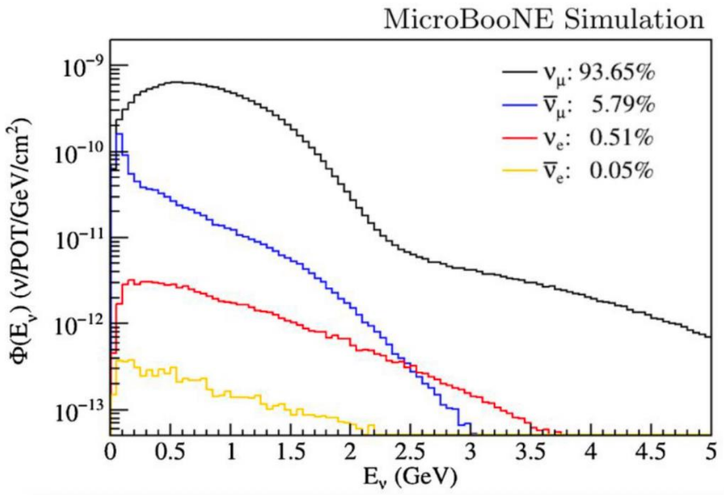
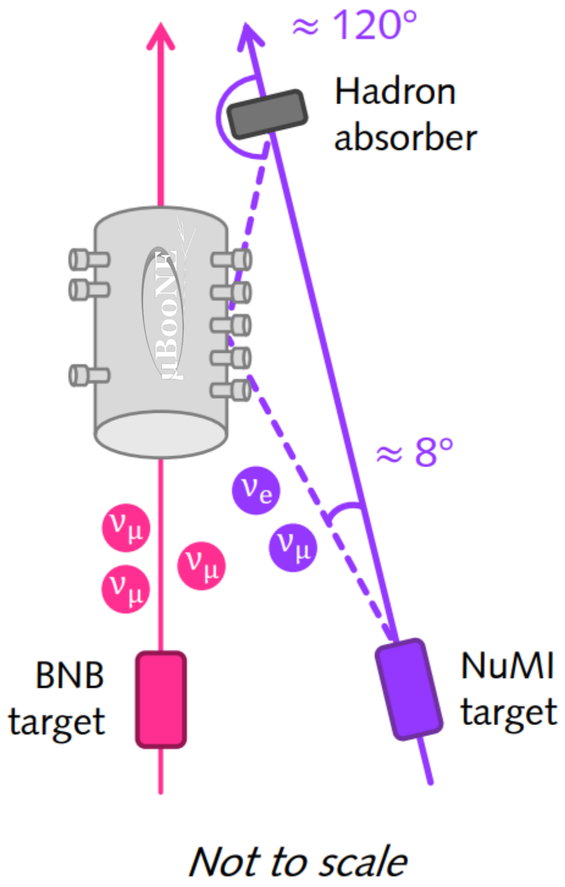
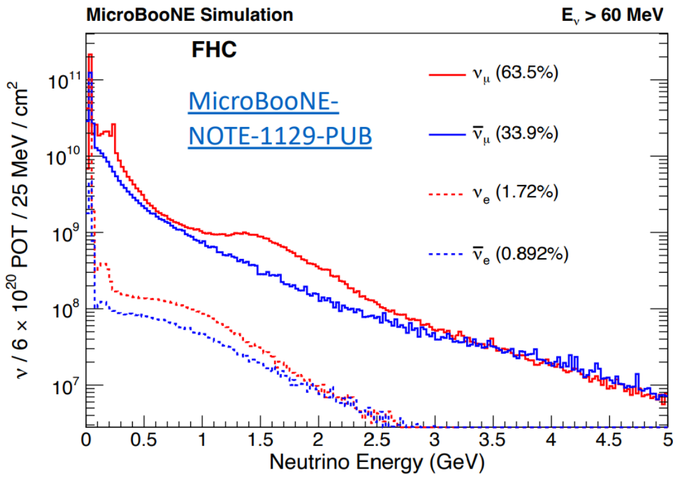


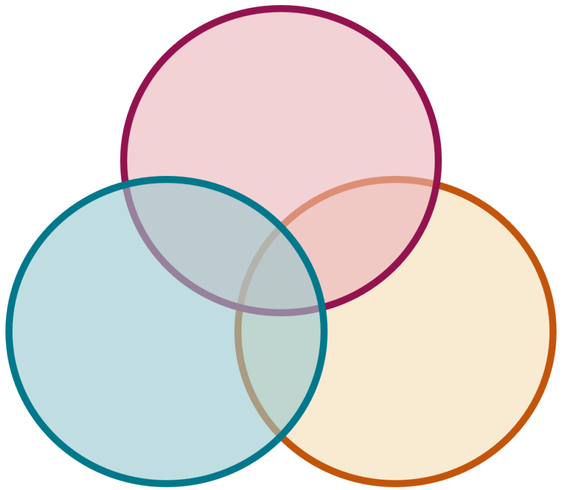


NuMI
- Off-axis, 8 ° (target), 120 ° (absorber)
- 120 GeV protons, 2×10^{21} POT
- $\langle E_\nu \rangle \sim 500$ MeV
- Higher ν_e contribution



MicroBooNE Science Program

Investigate the MiniBooNE Low Energy Excess and search for BSM physics



Neutrino interactions: precision measurements on argon

Detector Physics: pushing the capabilities of LArTPCs

Investigate the MiniBooNE Low Energy Excess and search for BSM physics

SOUTH DAKOTA MINES

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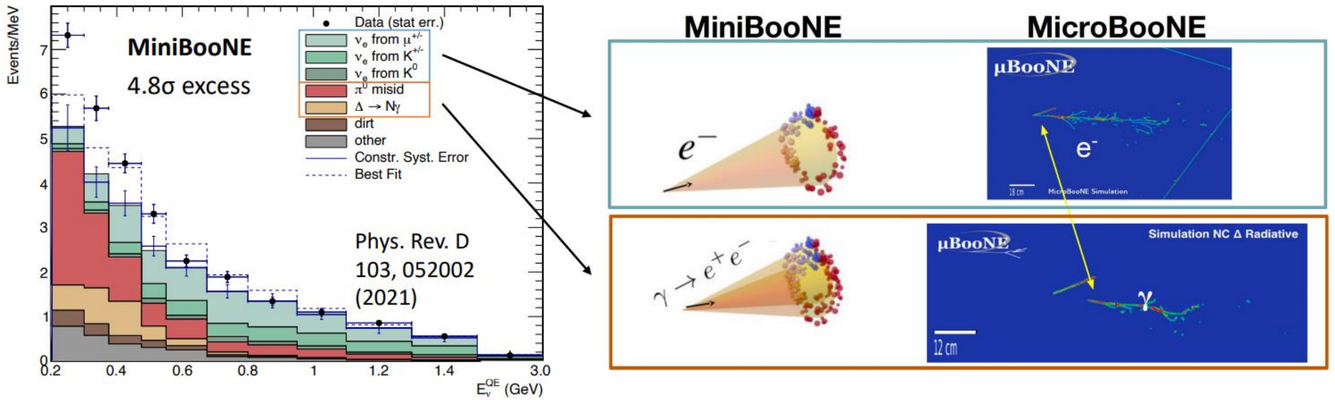
Investigate MiniBooNE low energy excess

- MiniBooNE reports a 4.8 σ excess of single electromagnetic showers at low energy range.
- MicroBooNE, due its intrinsic capability to distinguish electrons and gamma, will allow to further investigate this anomaly.
- Different hypotheses has been proposed for the still unexplained excess, even though, MicroBooNE analyses has contributing with strong constrains for many of them.



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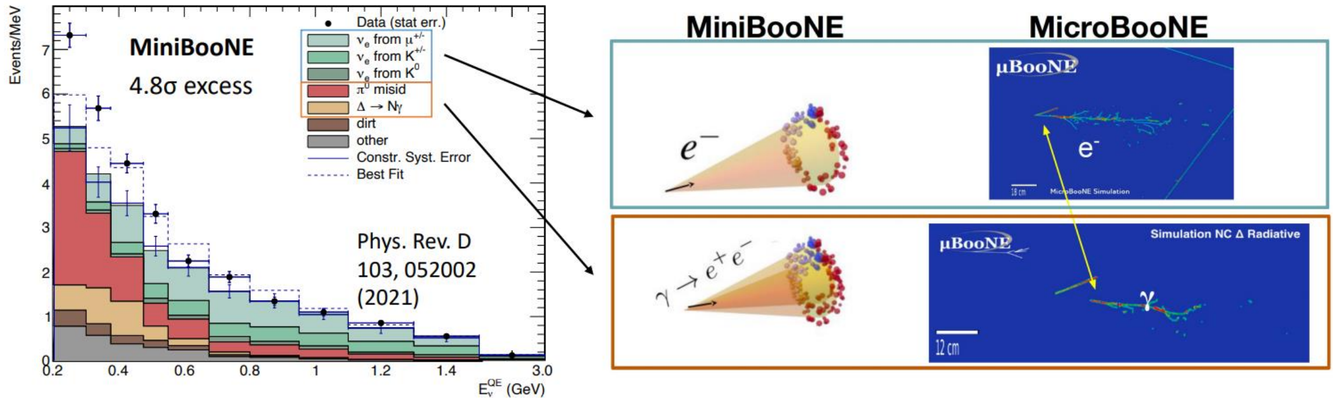
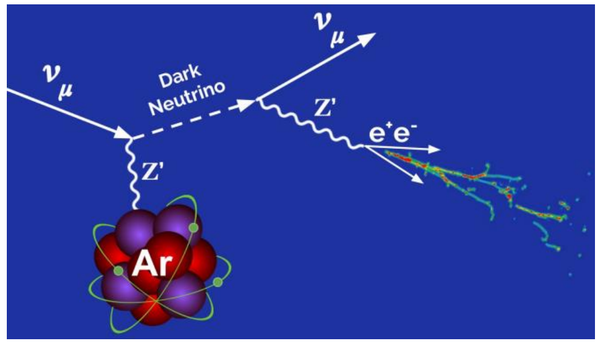
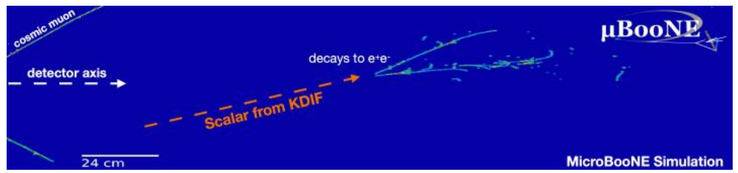


Searches in BSM physics

- First search for dark-sector explanations of MiniBooNE anomaly.
- Recent results include limits on Heavy Neutral Leptons (PRL **132**, 041801 (2024)), Dark Tridents (PRL **132**, 241801 (2024)), and Higgs Portal Scalars (arXiv:2501.08052).
- Many more searches in progress: axion-like particles, millicharged particles, etc.





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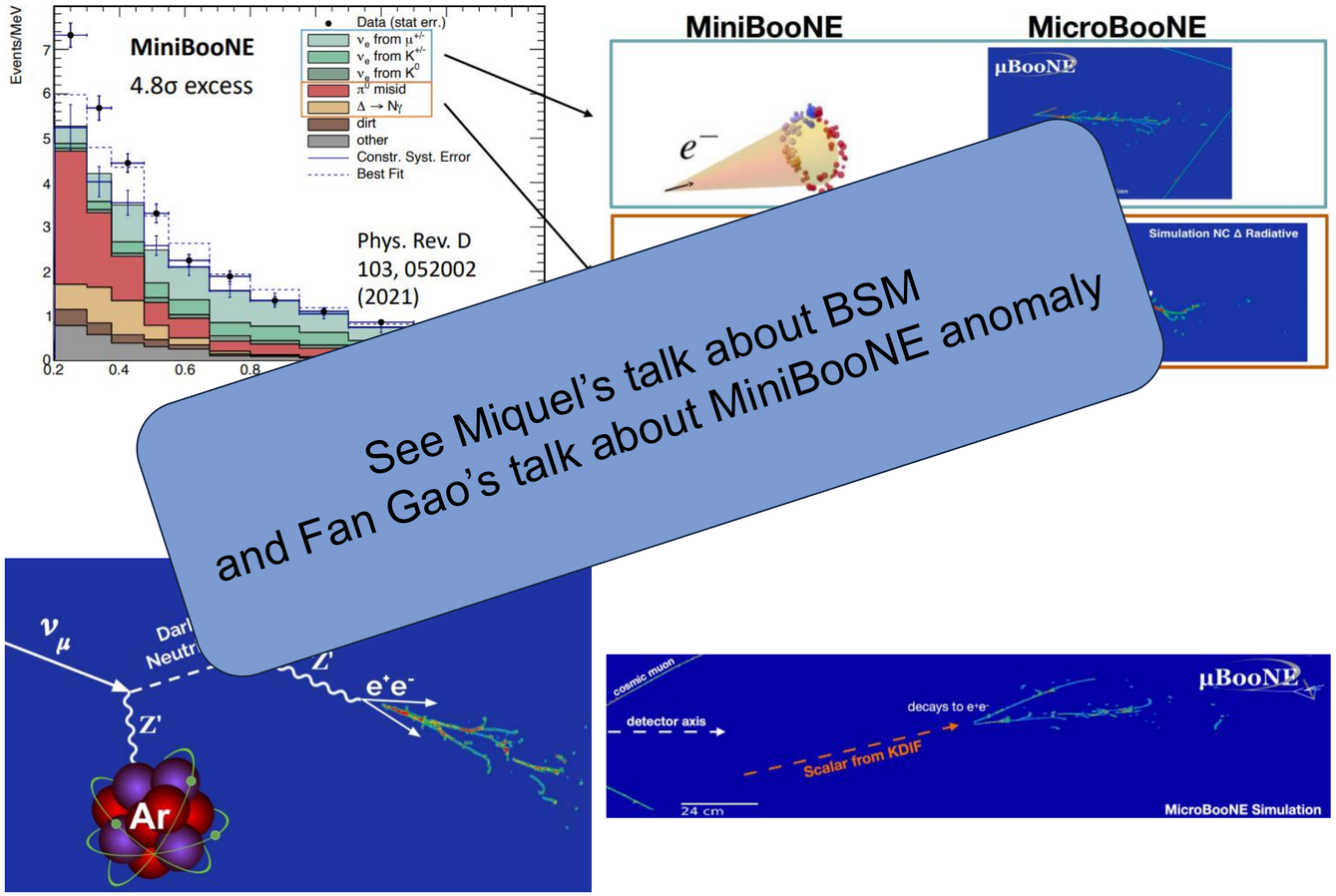

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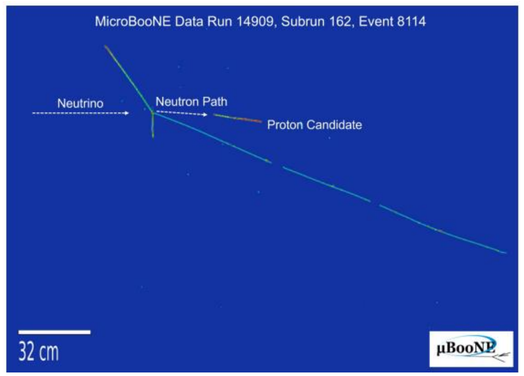
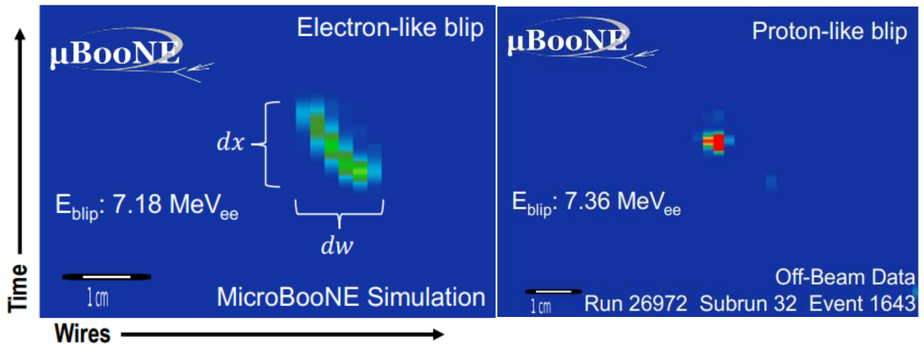
    - MeV-scale “Blips” which has a wide range of applications as: improving calorimetry, muon/pion separation, neutron tagging, lower particle threshold, etc.

Eur. Phys. J. C **84**, 1052



Phys. Rev. D **111**, 032005



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  - Detector Physics:
    - ns-scale timing: Achieve neutrino interactions time resolution of O(1ns), powerful tool for non-beam background rejection

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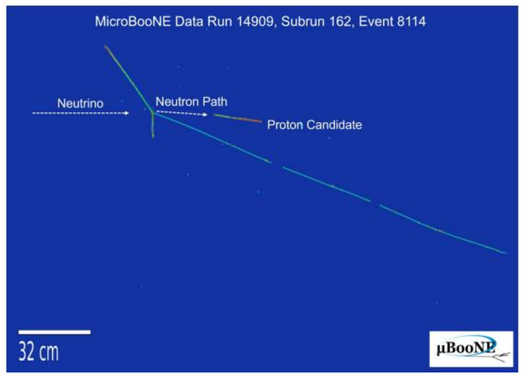

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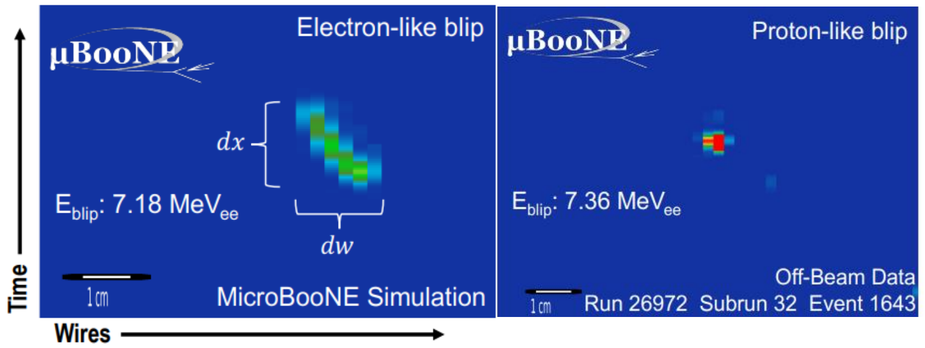
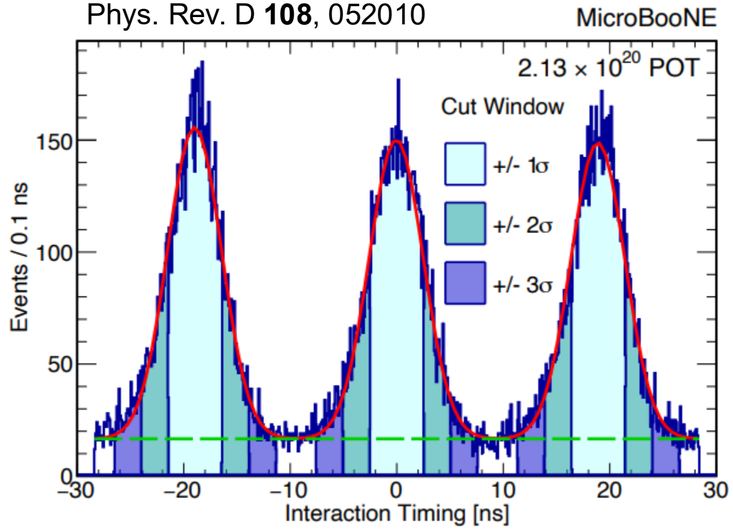


Phys. Rev. D **108**, 052010



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- Exploring various reconstructions chains to provide robust results.

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MicroBooNE cross-section analyses published

CC inclusive

- 1D $\nu_\mu CC$ inclusive @ BNB, PRL 123, 131801
- 1D $\nu_\mu CC$ Ev @ BNB, PRL 128, 151801
- 3D $\nu_\mu CC$ Ev @ BNB, arXiv:2307.06413
- 1D $\nu_e CC$ inclusive @ NuMI, PRD 104 052002, PRD 105 L051102
- 2D $\nu_\mu CC0pNp$ inclusive @ BNB, PRL 133, 041801, PRD 110, 013006

Pion production

- $\nu_\mu CC\pi^0$ @ BNB, PRD 110, 092014
- $\nu_\mu NC\pi^0$ @ BNB, PRD 107, 012004
- 2D $\nu_\mu NC\pi^0$ @ BNB, PRL 134, 161802
- $\nu_e CC1\pi^\pm$ @ NuMI, PRL 135, 061802
- $\nu_\mu CC1\pi^\pm$ @ BNB, arXiv:2509.03628

$CC0\pi$

- 1D & 2D $\nu_\mu CC0\pi$ @ BNB, arXiv:2507.00921
- 1D $\nu_e CCNp0\pi$ @ BNB, PRD 106, L051102
- 1D & 2D $\nu_\mu CC1p0\pi$ TKI @ BNB, PRL 131, 101802, PRD 108, 053002
- 1D & 2D $\nu_\mu CC1p0\pi$ GKI @ BNB, PRD 109, 092007
- 1D & 2D $\nu_\mu CC1p0\pi$ angle reconstruction @ BNB, PRD Phys. Rev. D 111, 113007
- 1D $\nu_\mu CC1p0\pi$ @ BNB, PRL 125, 201803
- 1D $\nu_\mu CC2p$ @ BNB, arXiv:2211.03734
- 1D & 2D $\nu_\mu CCNp0\pi$ @ BNB, arXiv:2507.00921

Rare channels & novel techniques

- η production @ BNB, PRL 132, 151801
- Λ production @ NuMI, PRL 130, 231802
- K^+ production @ BNB, arXiv:2503.00291
- Neutron identification @ BNB, EPJC 84, 1052

On this cross-section talk

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See London's talk for Oscillation related results

$CC0\pi$

- 1D & 2D $\nu_\mu CC$ [illegible] 507.00921
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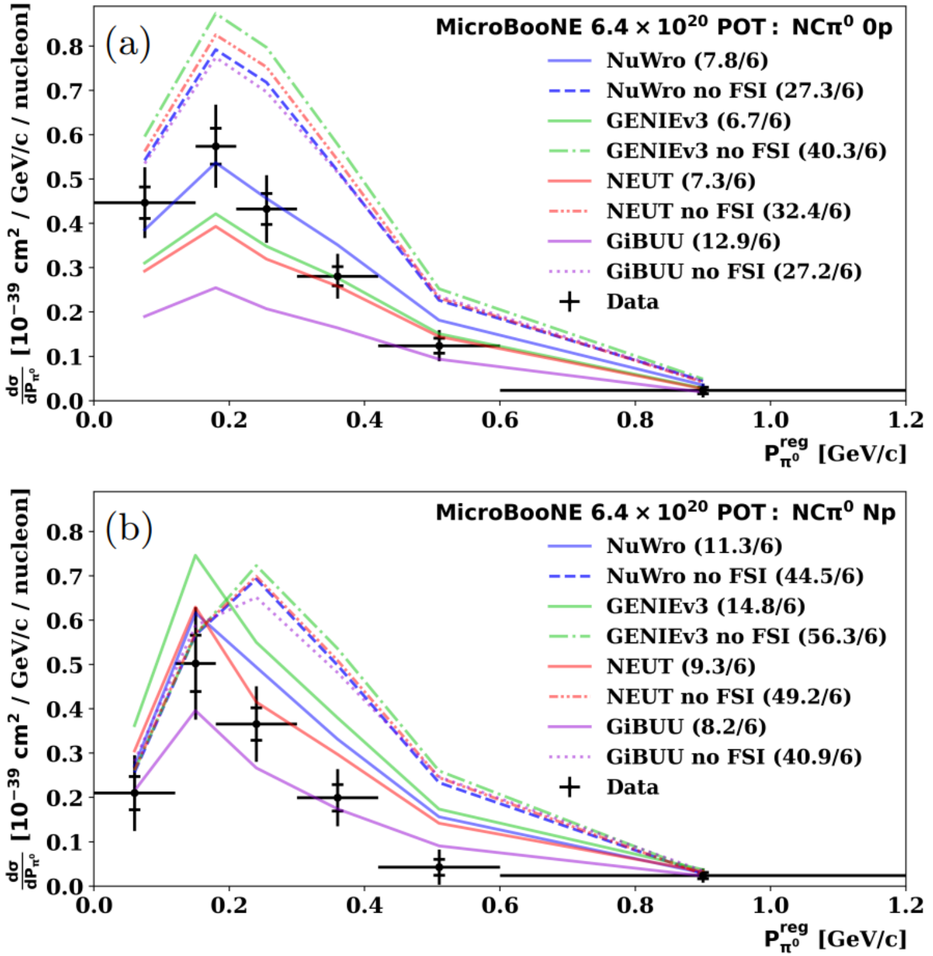
Pion Production Results - 2D $\nu_\mu NC\pi^0(0p, Np)$

- New differential cross-section measurement.
- BDT based event selection.
- Results shows good agreement, with preference for the NuWro model.
- This analysis was based on 4971 events collected from BNB (1452 $Np\pi^0$, 3519 $0p\pi^0$).
- Reported a purity of 54% and efficiency of 35%.

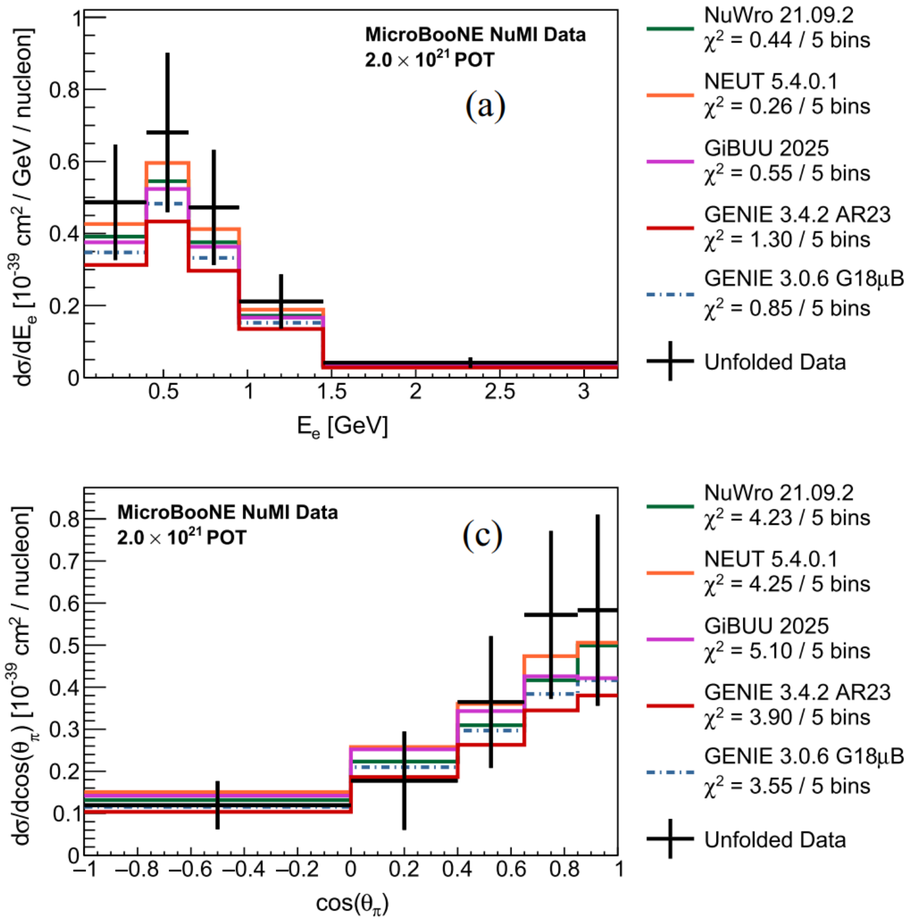
Phys. Rev. Lett. 134, 161802



Pion Production Results - $\nu_e CC1\pi^{\pm}$

- First measurement of $\nu_e cc1\pi^{\pm}$ on argon.
- This result use the full NuMI dataset, with higher ν_e content.
- The cross section measured in this analysis shows good modeling within the reported uncertainties.
- The data slightly prefer the higher cross sections predicted by NEUT, NuWro, and GiBUU compared with the lower cross sections predicted by GENIE
- 116 events candidates were found. (78% ν_e and 22% $\bar{\nu}_e$ predicted)

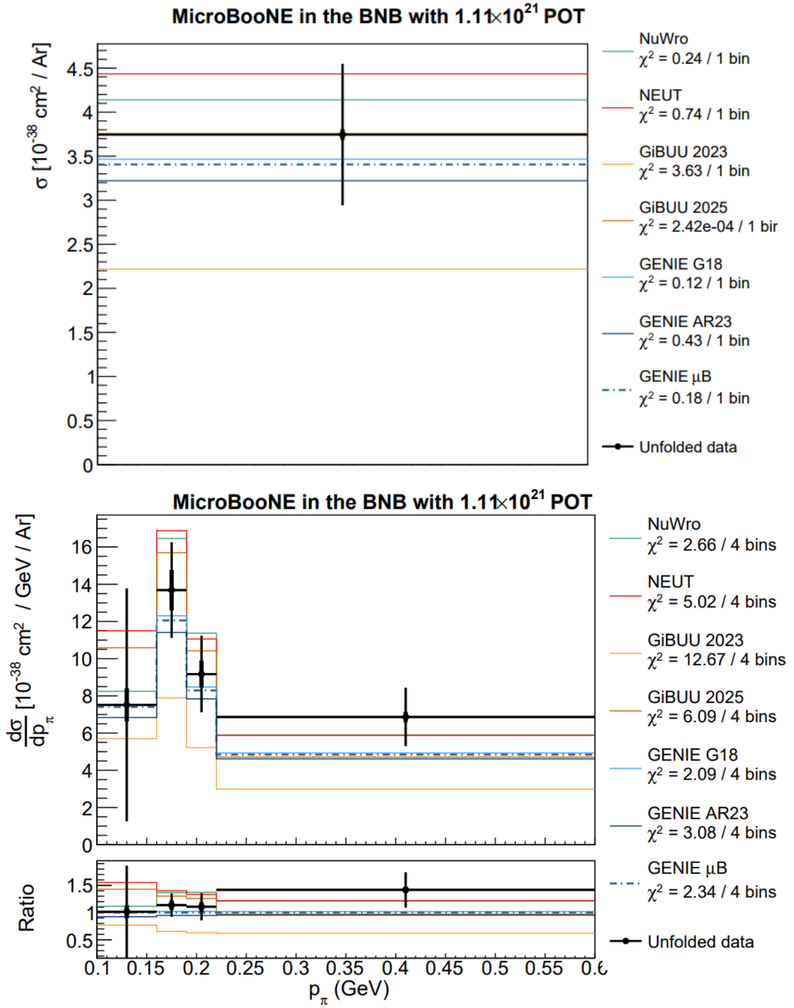
Phys. Rev. Lett. 135, 061802



Pion Production Results - $\nu_\mu CC1\pi^\pm$

- Full MicroBooNE dataset, first measurement of pion momentum.
- Signs of mismodelling at low Q2 and for high pion momenta driven by final state interactions.
- The total cross-section measured in data shows agreement with GiBUU 2025, while GENIE and NuWro are the closest predictions for the differential cross sections reported.
- This analysis relies on BDTs to identify particles in the final state of the interaction.
- This analysis reported 6816 event selected.

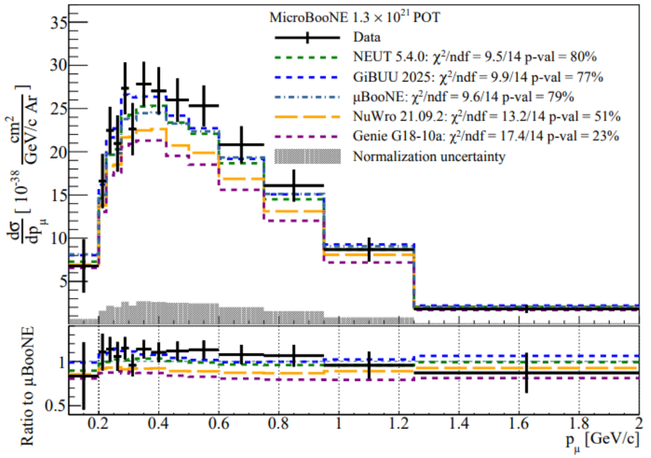
arXiv:2509.03628



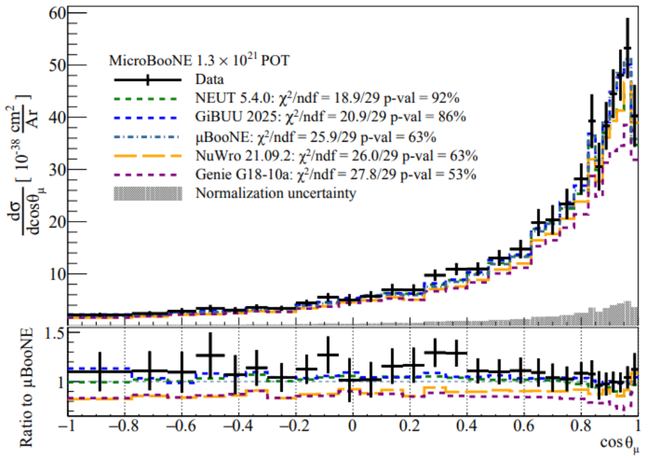
$CC0\pi$ Results - 1D & 2D $\nu_\mu CCNp0\pi$

- This work enables correlated multi-target cross-section measurements using Cherenkov detectors in the same neutrino beam (BNB).
- Dominated by QE-like interactions.
- The average total uncertainty reported is below 20%.
- The GiBUU 2025 and NEUT models show best performance for the extracted 1D and 2D cross sections as a function of p_μ and $\cos\theta_\mu$

arXiv:2507.00921



(a) p_μ differential cross section.

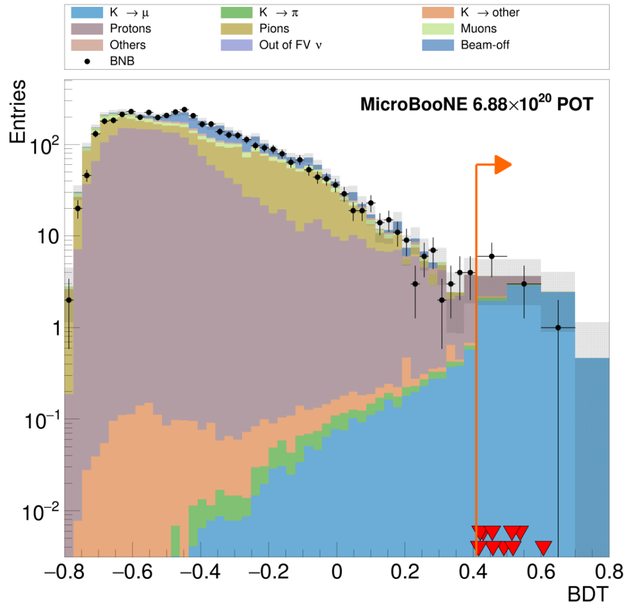


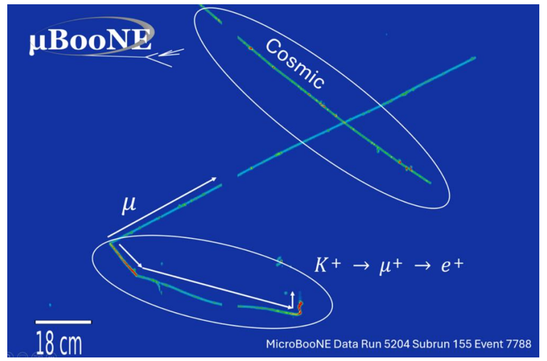
(b) $\cos\theta_\mu$ differential cross section.

Rare Channels Results

- First measurement of muon neutrino interactions with charged kaon in the final state.
- Key measurement for the improvement of the identification and mitigation of atmospheric neutrino backgrounds for nucleon decay searches for DUNE.
- The event selection was based on BDTs for kaon identification.
- This work reported 10 events from a dataset of 6.88×10^{20} POT.
- The measured cross section shows agreement, within the total reported uncertainty (54.1%), with different neutrino generators.

arXiv:2503.00291





Generator	cross section (10^{-42}cm^2/nucleon)
GENIE v2.12.10	8.67
GENIE v3.00.06	8.42
GENIE v3.4.0 (AR23)	9.85
GiBUU 2025, patch 1	6.52
NEUT 5.4.0.1	9.71
NuWro 19.02.1	10.87
MicroBooNE Data	**7.93 ± 3.22 (stat.) ± 2.83 (syst.)**

More results to come!

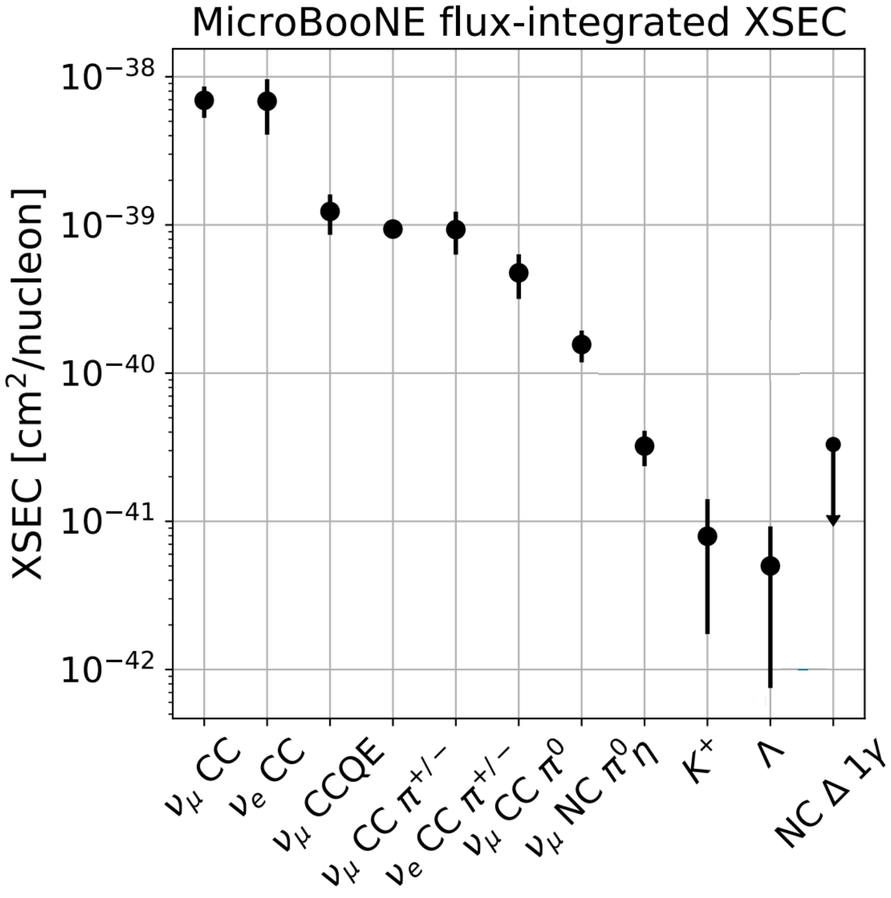
ONGOING

CC inclusive
$\nu_\mu CC$ inclusive @ NuMI
ν_e/ν_μ ratios @ BNB, NuMI
$\bar{\nu}_e$ @ NuMI

Pion production
$\nu_\mu CC1\pi^+$ @ BNB & NuMI
$\nu_\mu CCN\pi$ @ NuMI
1D $\nu_\mu CC\pi^0$ @ BNB
2D $\nu_\mu CC/NC\ \pi^0$ @ BNB
2D $\nu_{e,\mu} NC\pi^0$ @ BNB

CC/NC 0π
2D $\nu_\mu CC1p0\pi$ GKI @ BNB
1D & 2D $\nu_\mu CC0\pi$ @ BNB
2D $\nu_\mu CCNp0\pi$ @ BNB
1D $\nu_e CC0\pi Np$ @ NuMI
1D $\nu_\mu NC1p0\pi$ @ BNB

Rare channels & novel techniques
MeV-scale physics @ BNB
Low-energy neutrons @ BNB
Multi-pion production @ BNB



Summary

- MicroBooNE is still running a diverse and comprehensive cross section program.

- MicroBooNE actively analyzing full dataset:
  - 5 years of data, two neutrino beams

- Showcasing result from different neutrino interaction channels, development of novel event selection and analysis techniques

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

Thank you!