Neutrino Interactions in MicroBooNE's Precision LArTPC

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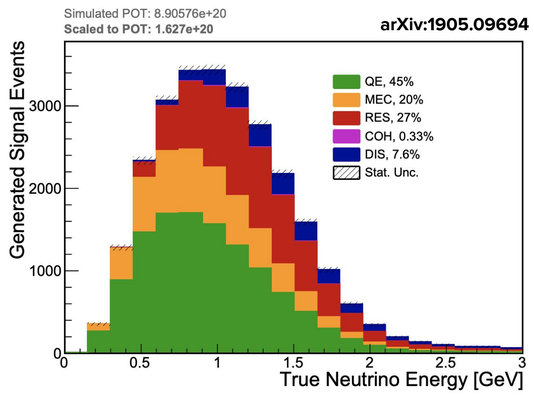
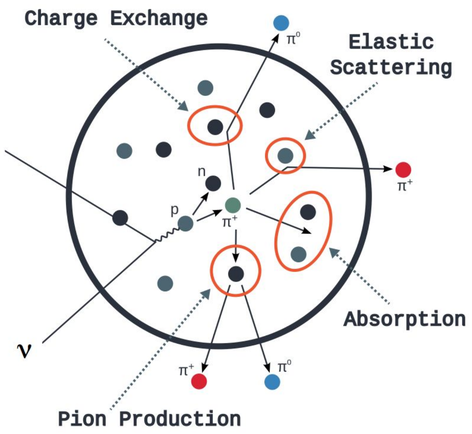
ν-Argon cross sections in MicroBooNE



Model element	GENIE Default	GENIE Alternative
Nuclear Model	Bodek-Ritchie Fermi Gas	Local Fermi Gas
Quasi-elastic	Llewellyn-Smith	Nieves
Meson-Exchange Current	Empirical	Nieves
Resonant	Rein-Seghal	Berger-Seghal
Coherent	Rein-Seghal	Berger-Seghal
FSI	hA	hA2014



MOTIVATION

- Understanding ν-nucleus interactions is crucial for conducting precision ν oscillation measurements.
- Argon is a heavier nucleus than carbon, to which most generators are tuned => ν-Ar cross-section measurements form a probe for better understanding little known nuclear effects.
- Cross-section measurements specifically allow direct discriminating power between different theoretical models, and comparison with other experimental results.
- Different signal topologies promote development of data reconstruction techniques.

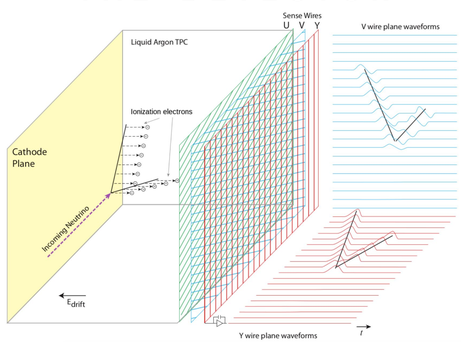
NEUTRINOS @ MICROBOONE

- FNAL's Booster Neutrino Beam: almost pure ν_μ beam (0.5% intrinsic ν_e)
- E_ν ~ 0.8GeV.
- Dominant ν-nucleus processes: quasi-elastic, resonant production, meson exchange current
- ν-nucleus interactions undergo a variety of final state interactions (FSI) that are yet to be perfectly modeled.

MicroBooNE [1]

A Liquid Argon Time Projection Chamber neutrino oscillations experiment on Fermi National Laboratory's Booster Neutrino Beam.

THE DETECTOR



85 tons active mass of liquid Argon.

ν beam spill ~1.6 μs

Goals:

1. investigate MiniBooNE's low-energy excess [could point to sterile neutrinos]

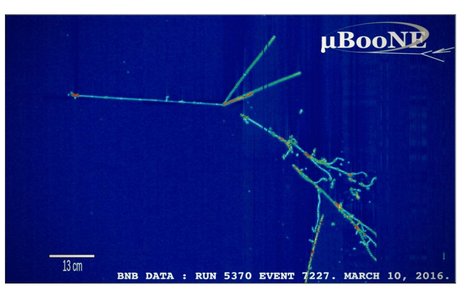
2. LArTPC R&D for DUNE

SIMULATION

ν interactions on Argon: GENIE, NuWro, GiBUU

propagation of particles exiting ν-Argon interactions: GEANT4

cosmic ray backgrounds: CORSIKA



Full 3D reconstruction of neutrino interaction using topological & calorimetric information.

ν_μCC inclusive

First double differential cross-section measurement[2] on Argon at low energy.

SIGNAL TOPOLOGY

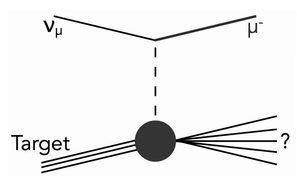
All ν_μ charged current interactions with Argon nuclei.

EVENT SELECTION

Highly efficient cosmic rejection + inclusive neutrino selection with μ^- track.

FEATURES

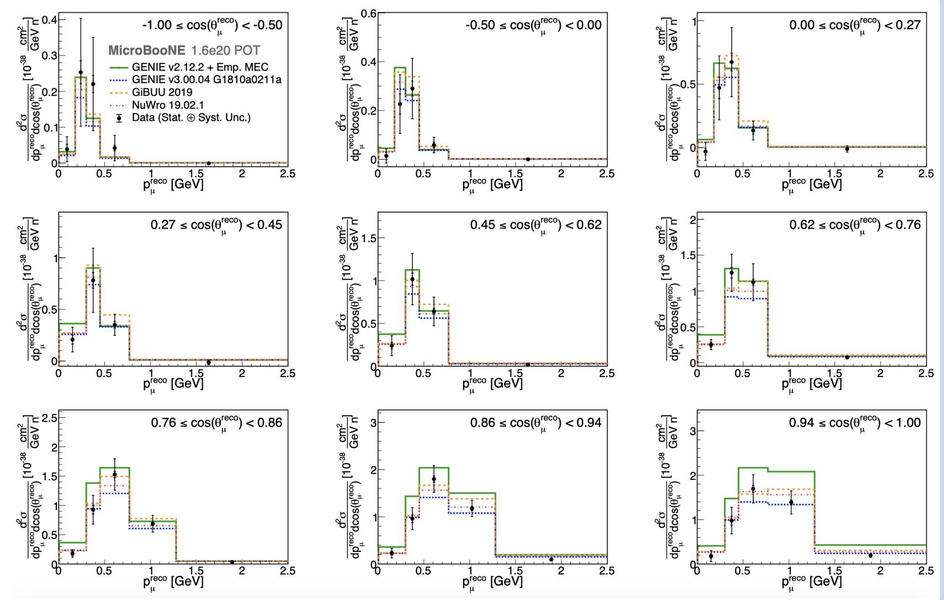
- **Low model-dependence + clear signature => can compare with theory & other experiments.**
- **Essential input for MC simulations of ν-Ar interactions for DUNE.**
- **High-statistics event selection for exclusive channels [protons, pi0, etc.]**



DOUBLE DIFFERENTIAL CROSS SECTION

$$\left(\frac{d^2\sigma}{dp_\mu d\cos\theta_\mu}\right)_i = \frac{N_i - B_i}{\tilde{\epsilon}_i \cdot T \cdot \Phi_{\nu_\mu} \cdot (\Delta p_\mu \cdot \Delta\cos\theta_\mu)_i}$$

arXiv:1905.09694



ν_μCC π^0

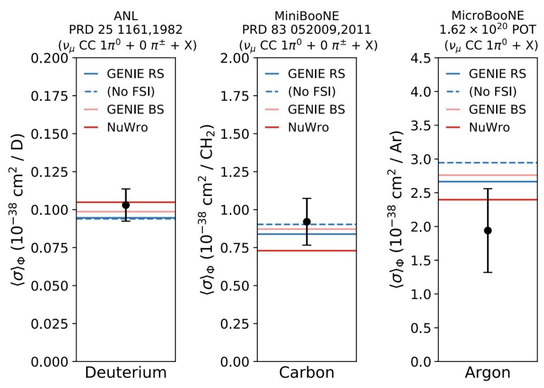
Total cross-section measurement[2] of charged current neutral pion production on Argon.

SIGNAL TOPOLOGY

ν_μ charged current interactions that produce a single π^0.

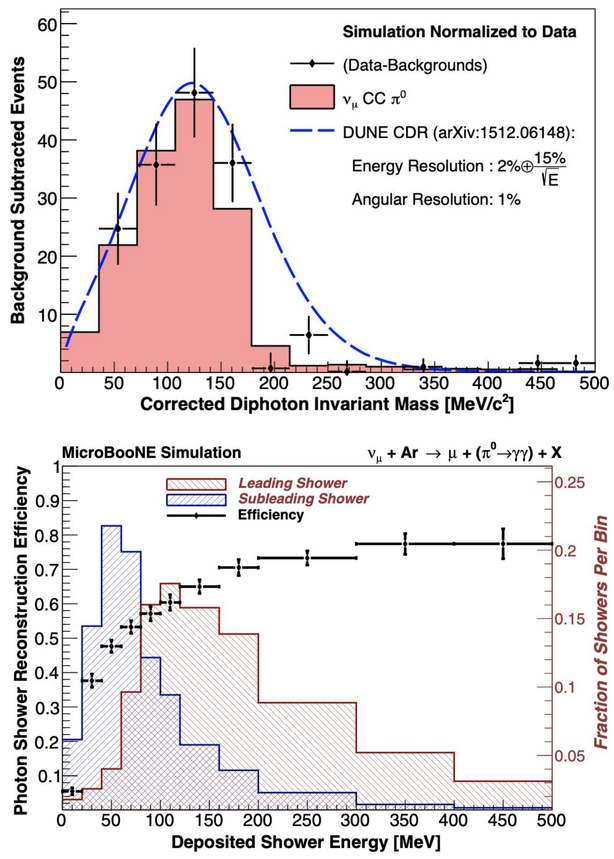
FEATURES

- **Affected by final state interactions [e.g. pion charge exchange, π^0 absorption, etc.] => probe for discriminating between FSI models.**
- **First fully automated shower reconstruction in a LArTPC.**



TOTAL CROSS SECTION

$$\langle\sigma\rangle_\Phi = \frac{N - B}{\epsilon T \Phi}$$



ν_μCC N proton

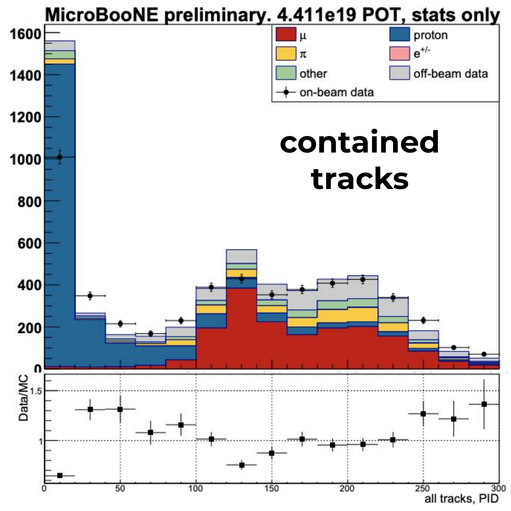
Cross-section measurement of charged current proton production in progress[4].

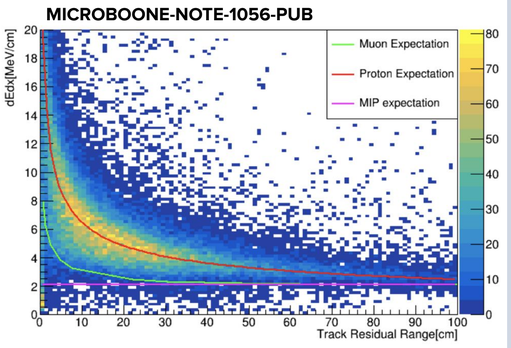
SIGNAL TOPOLOGY

ν_μ charged current interactions with at least one proton produced in the final state.

FEATURES

- **Proton final states act as probe for the initial & final state of the nucleus.**
- **Crucial for understanding hadronic interactions, relevant for recovering ν energy.**
- **Requires excellent LArTPC particle identification capabilities.**
- **Uses χ^2 proton hypothesis for PID.**





$$PID = \chi^2_{\text{proton}}/ndof = \sum_{hit}\left(\frac{(dE/dx_{measured} - dE/dx_{theory})}{\sigma_{dE/dx}}\right)^2/ndof$$

References

[1] JINST 12.P02017 (2017)

[2] arXiv:1905.09694 FERMILAB-PUB-19-235-ND (2019)

[3] Phys. Rev. D **99**, 091102(R) (2019)

[4] MICROBOONE-NOTE-1056-PUB (2018)