Studies of Neutral Current Neutrino-Nucleon Scattering with the MicroBooNE Detector

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On behalf of the MicroBooNE Collaboration

October 20th, 2021

Neutral-current Elastic Cross Section and Δs

- The strange quark contribution to the nucleon spin (Δs) is a long-standing unsolved problem
- A measurement of the neutrino-proton elastic scattering is valuable for determine the value of Δs
- Differential cross section of ν + p elastic scattering

$$\frac{d\sigma}{dQ^2} = \frac{G_F^2}{2\pi}\frac{Q^2}{E_\nu^2}(A \pm BW + CW^2)$$

$$A = \frac{1}{4}\left[(G_A^Z)^2(1+\tau) - \left((F_1^Z)^2 - \tau(F_2^Z)^2\right)(1-\tau) + 4\tau F_1^Z F_2^Z\right]$$

$$B = -\frac{1}{4}G_A^Z(F_1^Z + F_2^Z) \qquad C = \frac{1}{64\tau}\left[(G_A^Z)^2 + (F_1^Z)^2 + \tau(F_2^Z)^2\right]$$

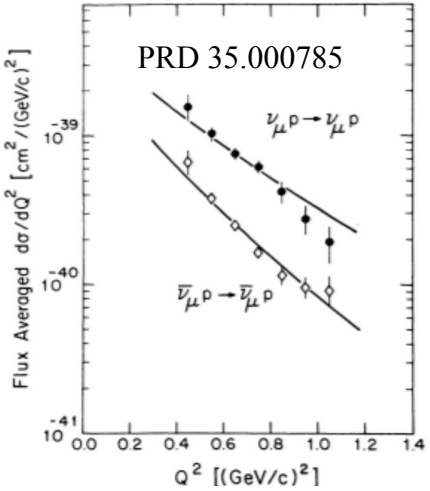
- At low Q^2, it is dominated by axial form factor

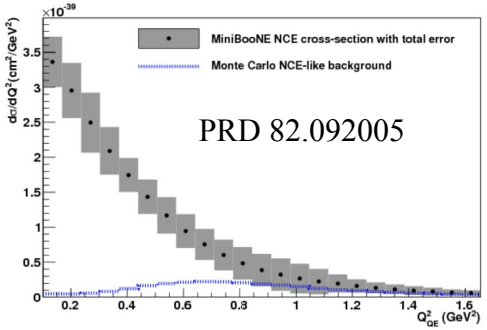
$$\frac{d\sigma}{dQ^2}^{\nu p\to\nu p}(Q^2 \to 0) = \frac{G_F^2}{32\pi}\frac{M_p^2}{E_\nu^2}\left[\left(G_A^Z\right)^2 + \left(1 - 4\sin^2\theta_W\right)^2\right] \sim g_A^2 - 2g_A\Delta s + (\Delta s)^2$$

g_A = 1.2671 is measured precisely from neutron beta decay

Previous Measurements in Neutrino Experiments

- Brookhaven E734 measured νp → νp
  - Included interactions down to $\mathbf{Q^2 = 0.45\ GeV^2}$
  - $\Delta s = -0.12 \pm 0.07$
- MiniBooNE measured (νp → νp)/(νN → νN)
  - Included interactions down to $\mathbf{Q^2 = 0.7\ GeV^2}$
  - Found $\Delta s = 0.08 \pm 0.26$
- Re-analysis shows that uncertainty on Δs of the E734 measurement is underestimated (Phys. Rev. C 48, 761)
- Measurement of ν + p elastic scattering at **lower Q^2** will make a more precise determination of Δs
  - Liquid argon time projection chamber (LArTPC) makes it possible





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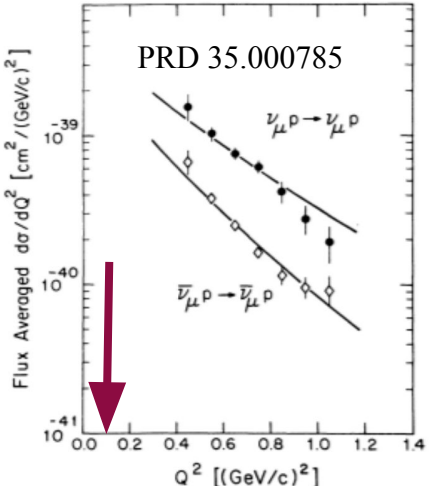
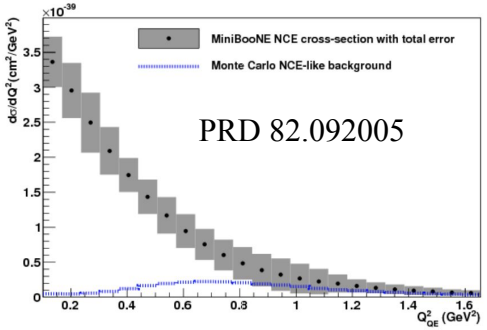
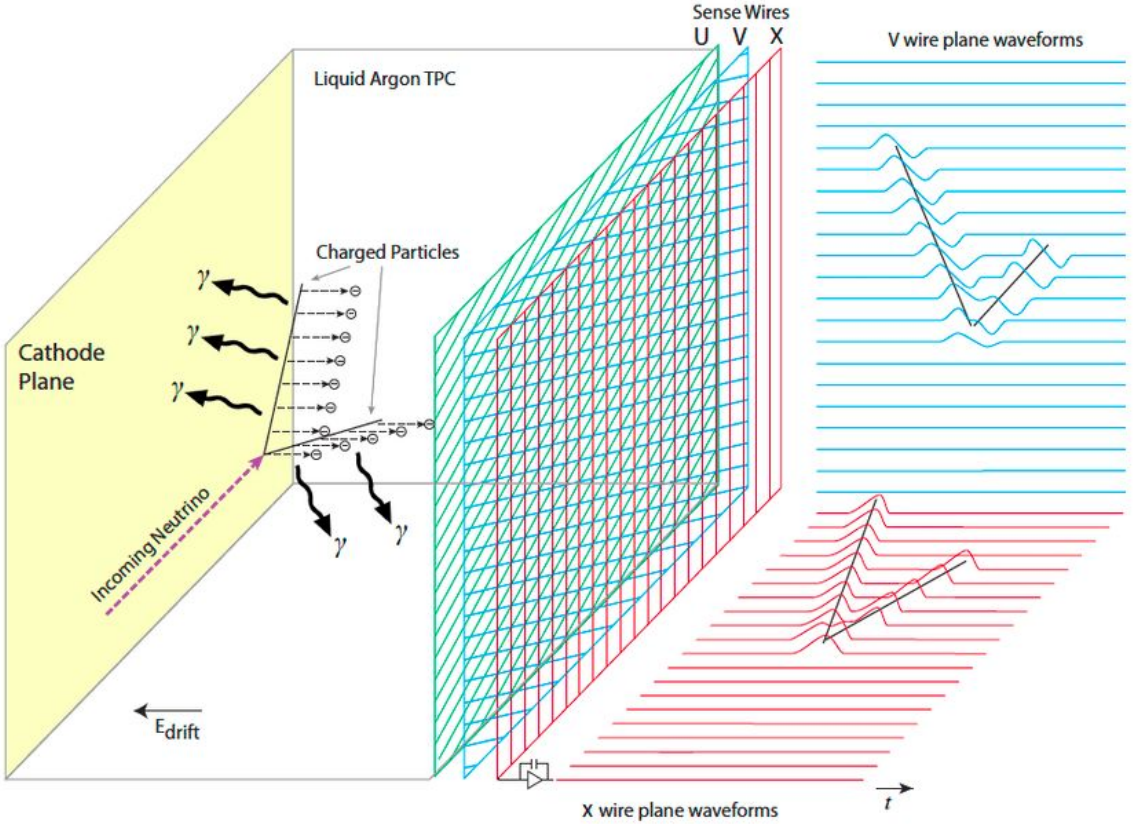




LArTPC



- Being used in current and next-generation neutrino oscillation experiments
- Scintillation light collected by the photomultiplier tubes (PMTs) behind the anode
- Low thresholds and high resolution

MicroBooNE

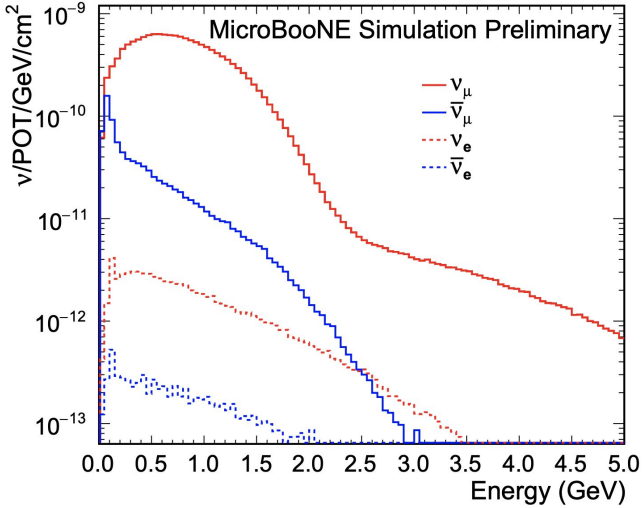
- 85 ton active mass, surface-based LArTPC
- 8192 wires with spacing of 3mm
- 32 PMTs collect light from flash at time of interaction
- Longest running LArTPC to date
  - Stable operation since 2015 Fall
  - Will shut down next week

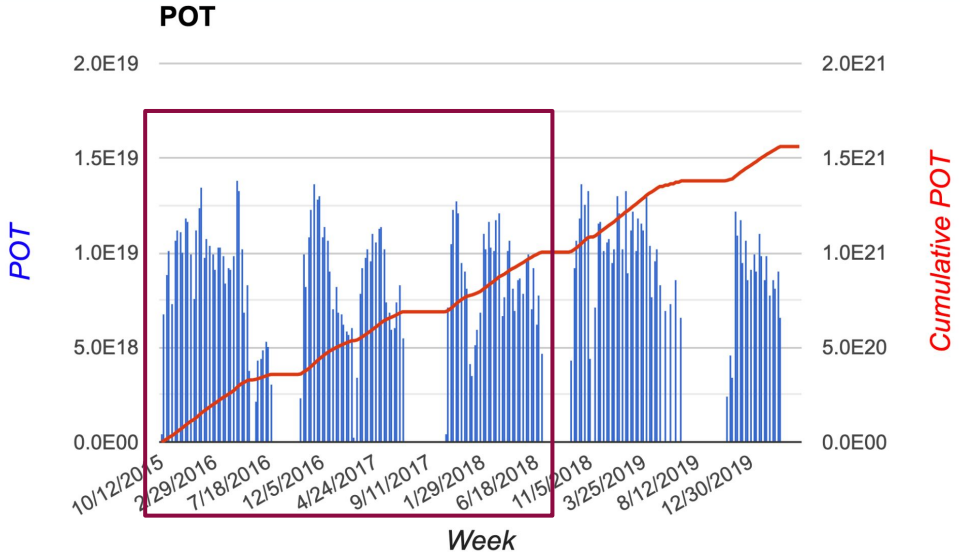
Progress on the search for the sterile neutrino

- https://arxiv.org/abs/2110.00409
- More to come on Oct. 27th!

Booster Neutrino Beam (BNB)

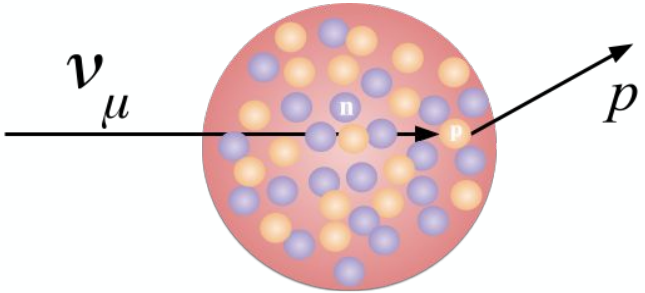
- MicroBooNE is 470 m from the target
- BNB ν_μ flux peaks at 0.7 GeV
- We have collected 1.56×10^{21} Protons On Target (POT)

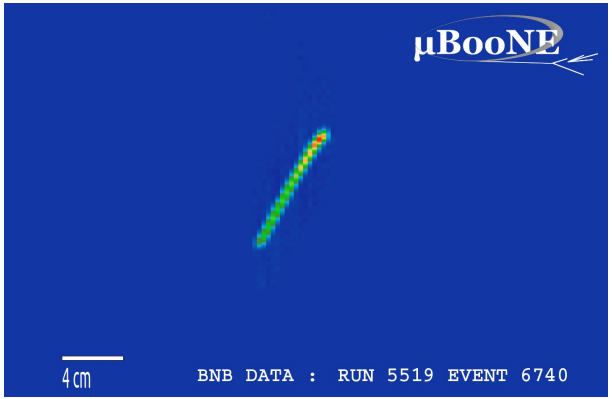




Neutral-current Elastic Scattering in MicroBooNE

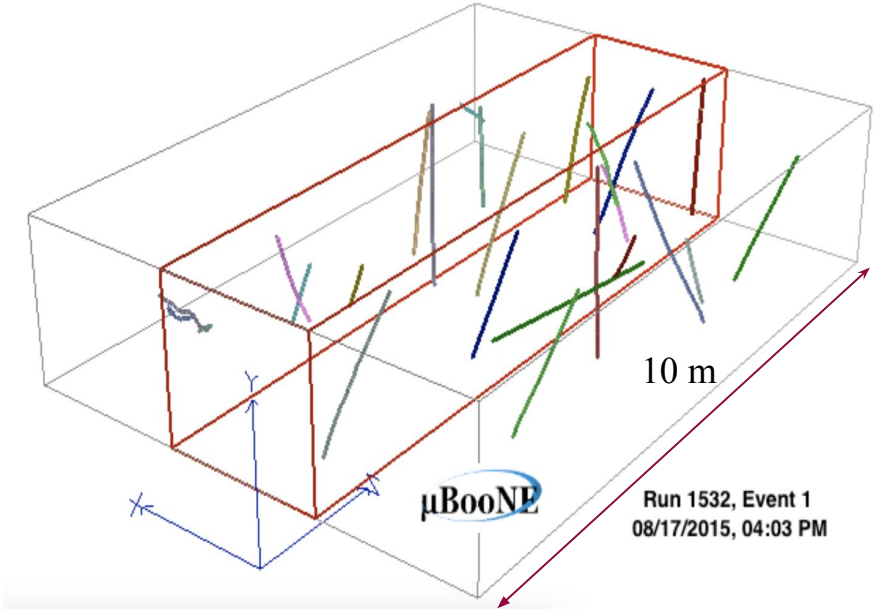
- Neutral-current elastic (NCE) signal
  a. Muon neutrino event
  b. Interaction vertex within fiducial volume
  c. One and only one proton (> 300 MeV/c) in the final state
  d. According to truth information
     - NCE
     - Struck nucleon is proton
- Irreducible background
  - Satisfies a) b) c), but not d)





Neutrino Interactions in MicroBooNE

- Neutrino-argon interactions are generated using GENIE (**G**enerates **E**vents for **N**eutrino **I**nteraction **E**xperiments)



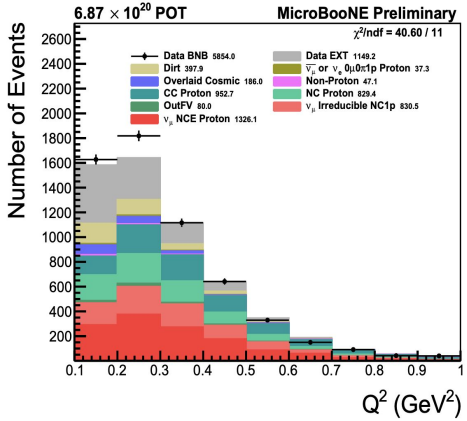
UNIVERSAL NEUTRINO GENERATOR & GLOBAL FIT

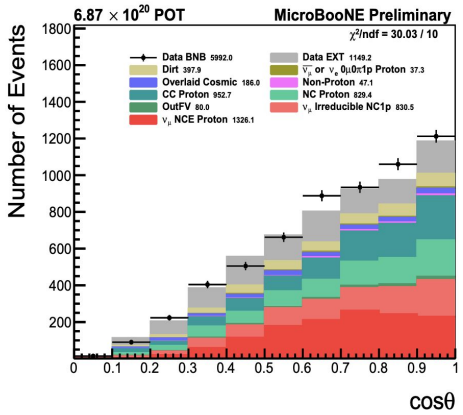
arXiv:2106.09381

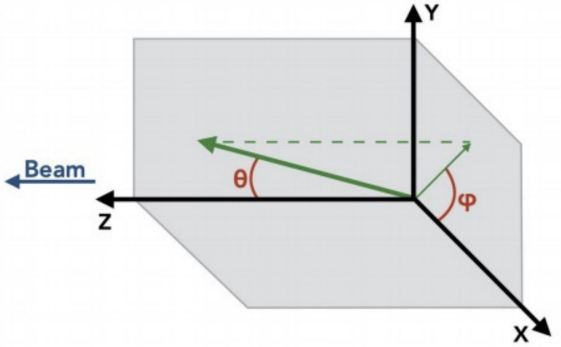
- The biggest challenge
  - After the reconstruction stage, each neutrino-induced event contains ~ 20 cosmic rays
  - $Q^2 = 0.1\ \text{GeV}^2 \rightarrow$ proton track ~2 cm

Event Selection

- Only one contained track and no shower in an event
- Satisfy light-related requirements of neutrino-hypothesis
- Track angle with respect to the incident neutrino beam direction $\theta < 90°$
- Deposited energy profile consistent with a proton
- Cosmic background further reduced by applying a boosted decision tree (BDT) cut
- Overall efficiency is 38%, overall purity is 23%







Differential Cross Section Extraction

- Flux-averaged single-differential cross sections
  - Proton kinetic energy, Q^2, proton momentum, proton angle
- Event rate is background-subtracted and unfolded to truth space using D'Agostini iterative unfolding

$$\left(\frac{d\sigma}{dx}\right)_i = \frac{S_i^{\text{unfolded}}}{\epsilon_i \cdot N_{\text{target}} \cdot \Phi_{\nu_\mu} \cdot (\Delta x)_i}$$

$$\epsilon_i = \frac{N_i^{\text{selected}}}{N_i^{\text{generated}}}$$

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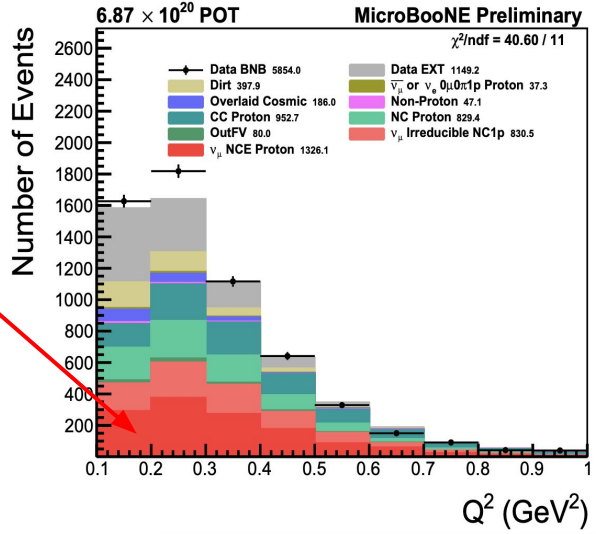
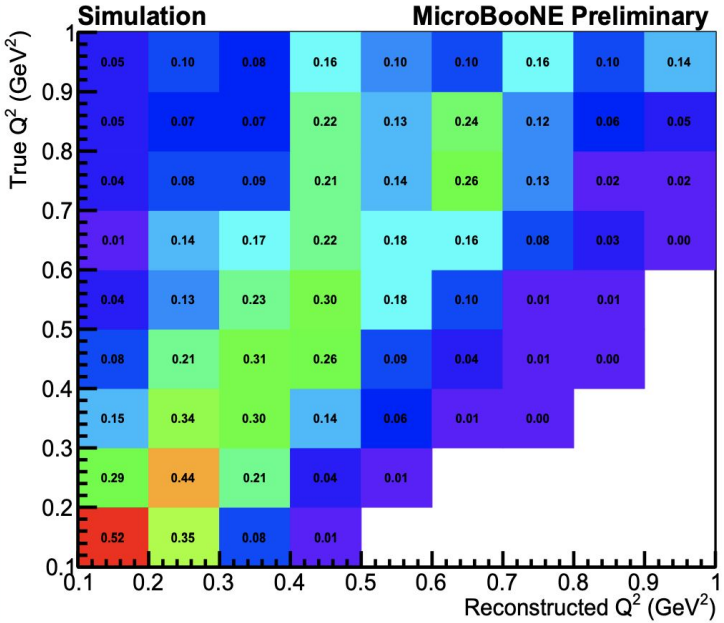
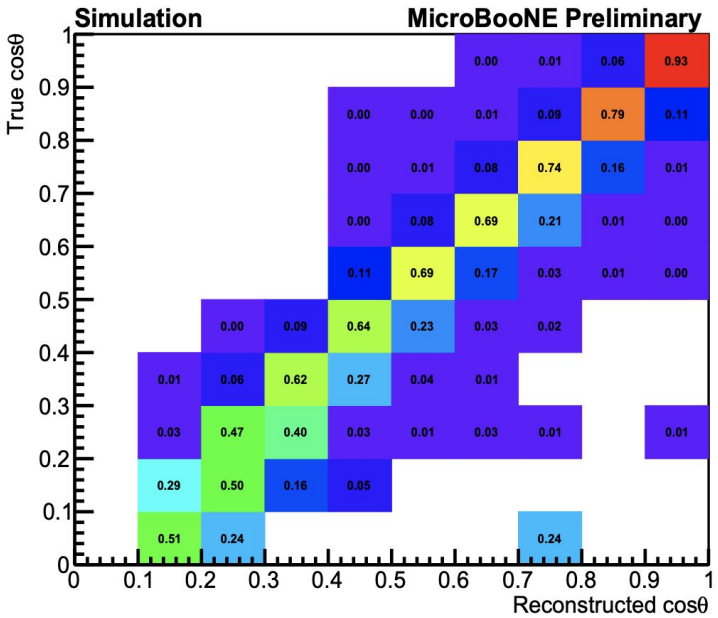


Differential Cross Section Extraction

- Smearing matrix

$$\left(\frac{d\sigma}{dx}\right)_i = \frac{S_i^{\text{unfolded}}}{\epsilon_i \cdot N_{\text{target}} \cdot \Phi_{\nu_\mu} \cdot (\Delta x)_i}$$

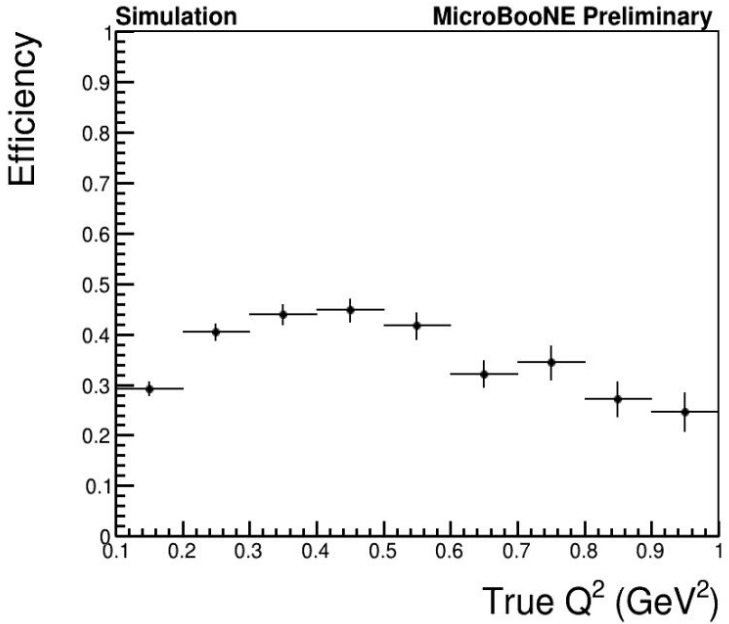


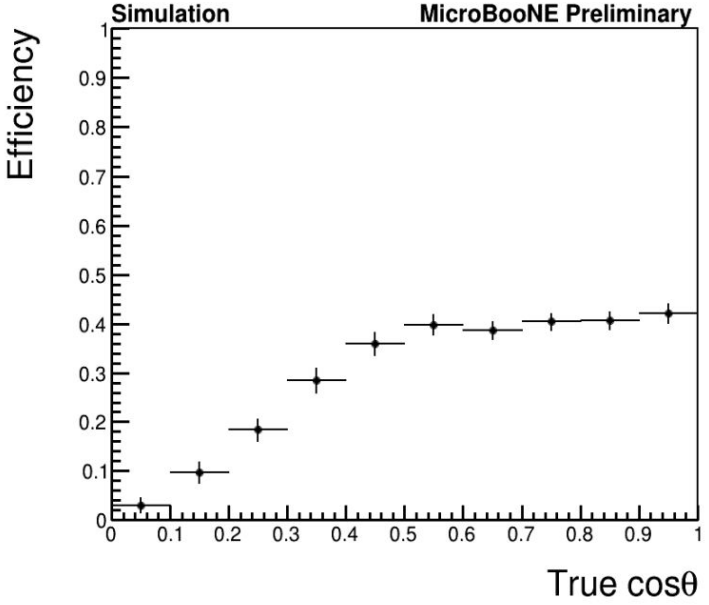


Differential Cross Section Extraction

- Efficiency correction $\epsilon_i = \frac{N_i^{\text{selected}}}{N_i^{\text{generated}}}$

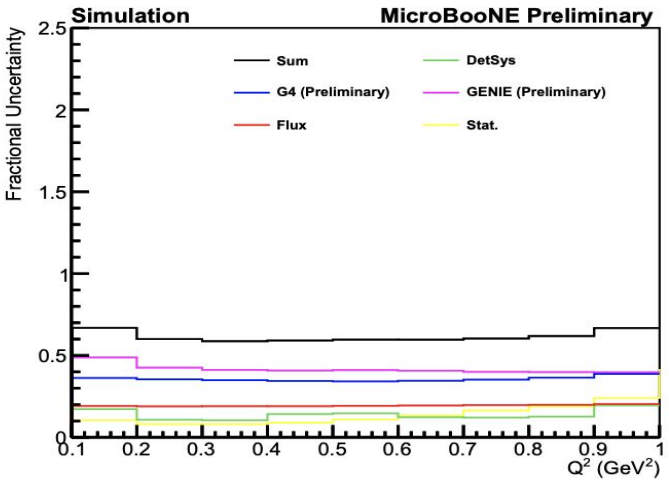
$$\left(\frac{d\sigma}{dx}\right)_i = \frac{S_i^{\text{unfolded}}}{\boxed{\epsilon_i} \cdot N_{\text{target}} \cdot \Phi_{\nu_\mu} \cdot (\Delta x)_i}$$

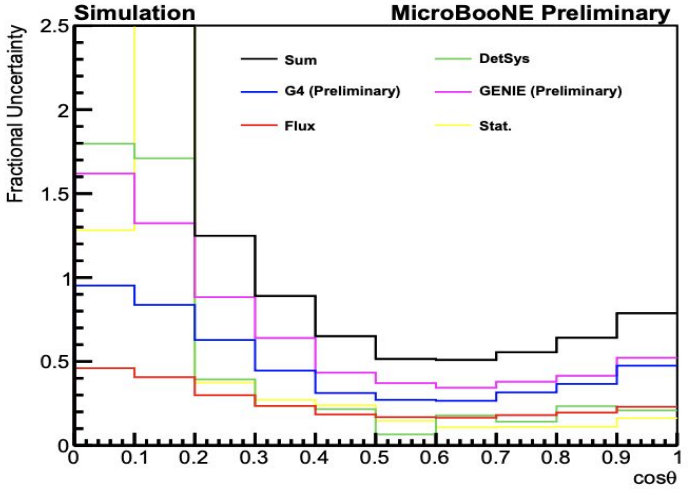




Systematic Uncertainty

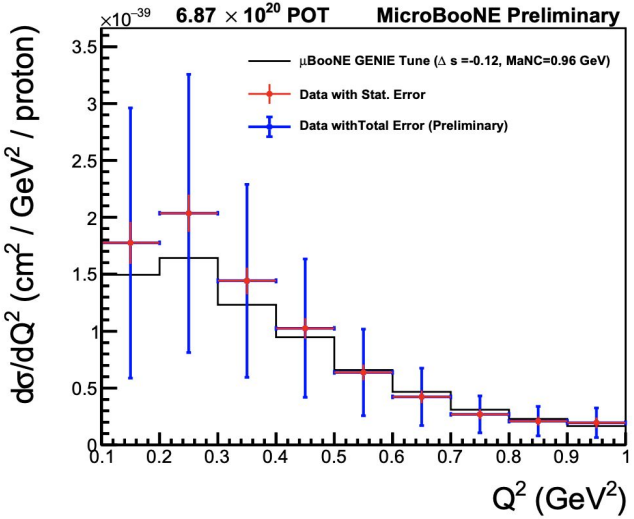
- Main sources of systematic uncertainty
  - **Neutrino-argon interaction modeling (GENIE)**
  - **Secondary re-interaction (G4)**
  - **Flux uncertainty**
  - **Detector simulation (Detsys)**

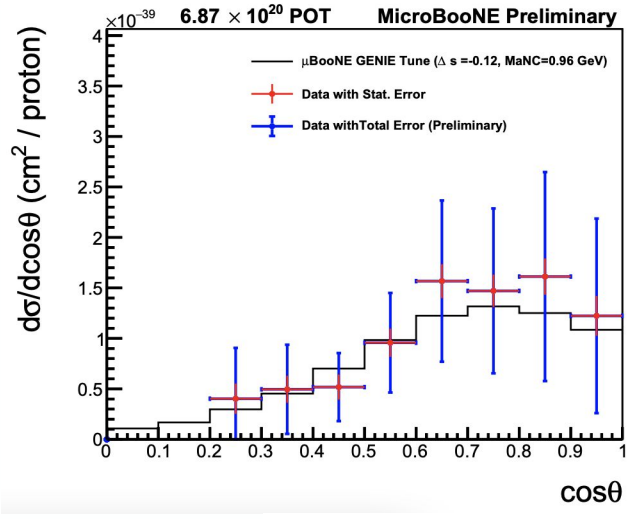




Differential Cross Sections

- Preliminary NCE differential cross sections using 6.87×10^{20} POT data
- Future work
  - Improve the selection purity
  - Optimize the binning
  - Finalize the systematic uncertainty

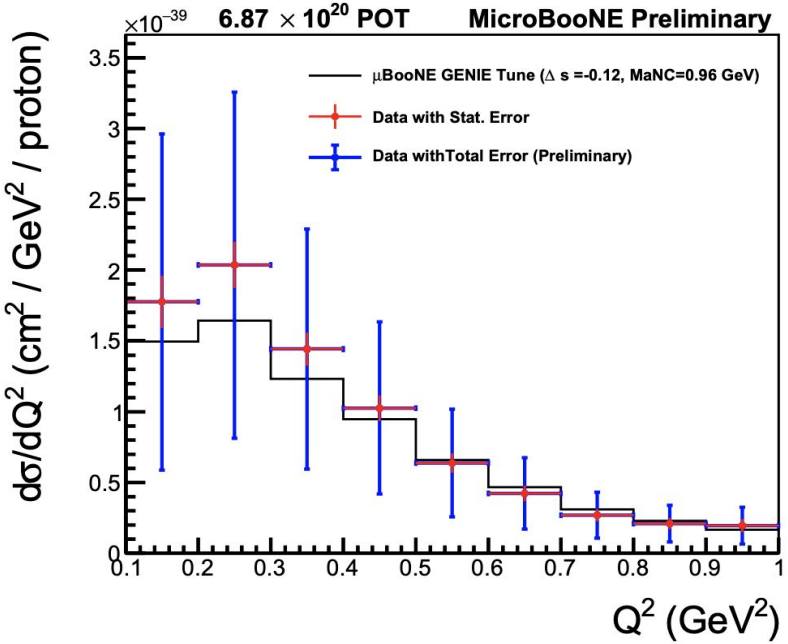




Reference: MICROBOONE-NOTE-1101-PUB

Towards the Δs Measurement

- Shape of $d\sigma/dQ^2$ depends on the neutrino-argon interaction models
  - NCE model
    - $M_A = 0.96$ GeV
    - $\Delta s = -0.12$
  - Will vary the model to find those parameters that describe data the best
- Measure the ratio of NCE to CCQE
  - Reduce systematic uncertainty from flux, detector effect and neutrino-argon interaction modeling



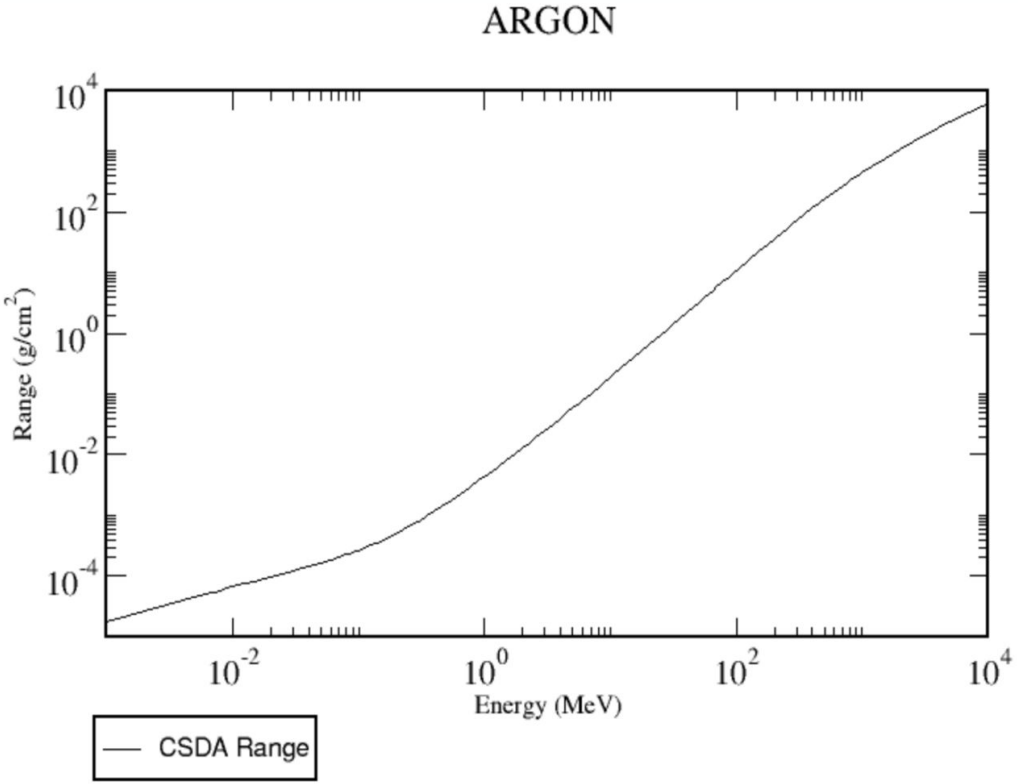
Summary

- First measured neutral current elastic scattering differential cross sections on argon using 6.87×10^{20} POT data
- The differential cross section $d\sigma/dQ^2$ goes as low as $Q^2 = 0.1$ GeV^2 , which is significantly lower than previous measurements from other neutrino experiments
- Work ongoing to finalize those differential cross sections and measure NCE/CCQE
- Stay tuned for our Δs results in the near future

Thank you!

Backup

Q^2 Reconstruction



https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html

- Kinetic energy T

$$T = 31.3 \cdot L^{0.578}$$

- Four-momentum transfer squared

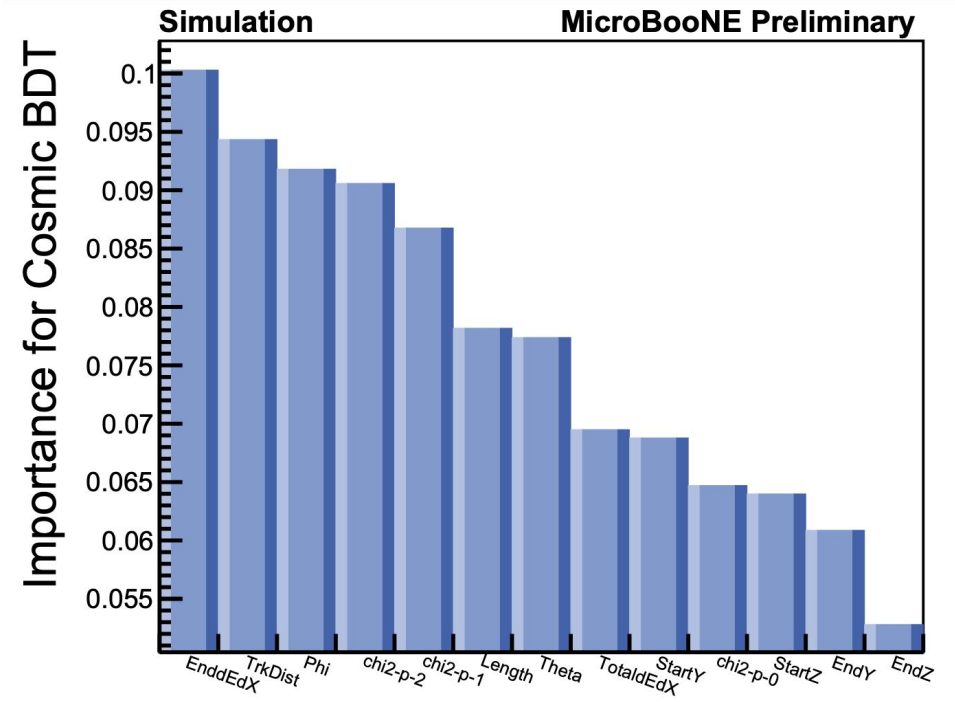
$$Q^2 = 2 * M_p * T$$

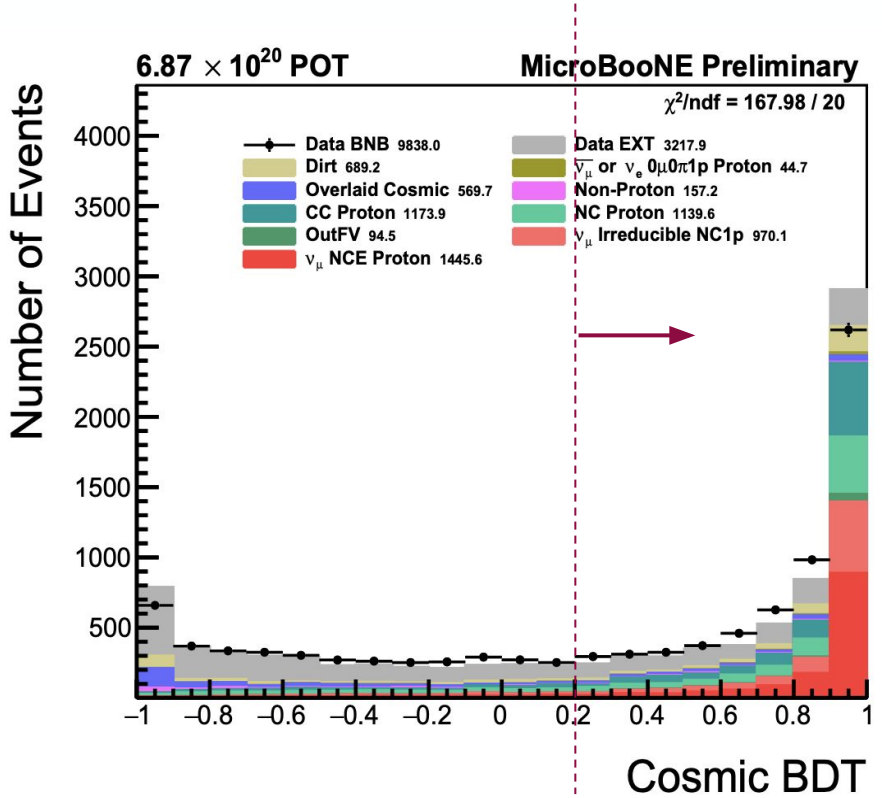
Neutrino-Argon Interaction Modeling

- MicroBooNE GENIE tune
  - Based on GENIE v3.00.06 with model set G18_10a_02_11a
  - More details on the models and systematic uncertainties: HERE
- Models that are related to the neutral-current events

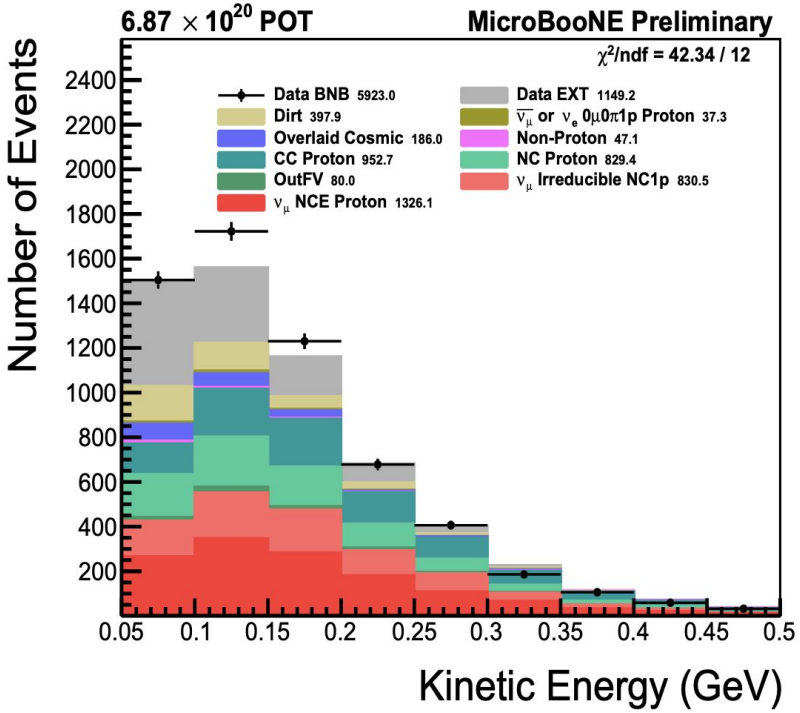
Model	Parameter	Description
Nuclear model	-	Local Fermi Gas (LFG) model
Final State Interaction Model	-	Hadron-nucleus interaction model (hA2018)
NC Elastic model	$M_A = 0.96$ GeV $\eta = 0.12$	Axial mass in Ahrens model Strange quark contribution in Ahrens model
NC Resonance model	$M_A = 1.120$ GeV $M_V = 0.840$ GeV	Axial mass of Berger-Sehgal model Vector mass of Berger-Sehgal model
NC Meson Exchange Current model	-	Empirical Dytman model

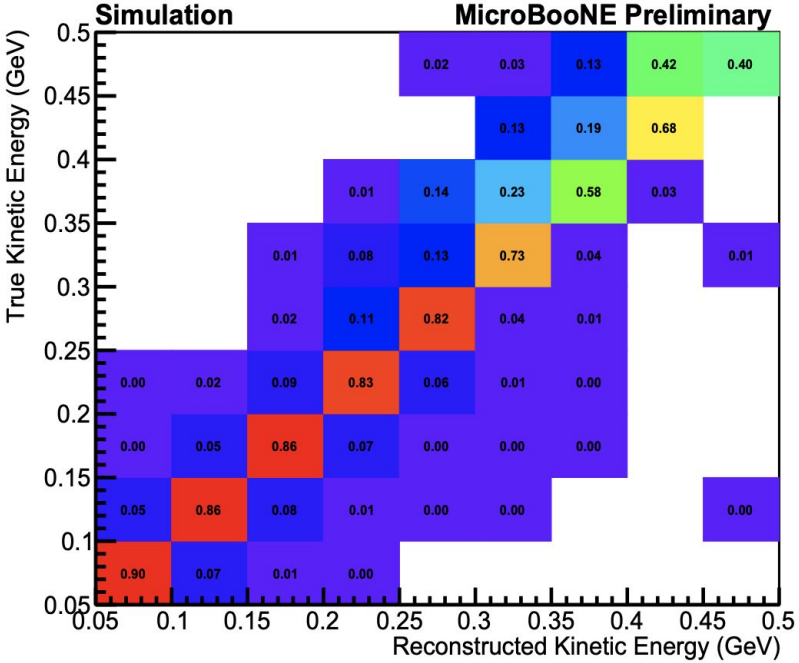
BDT Response



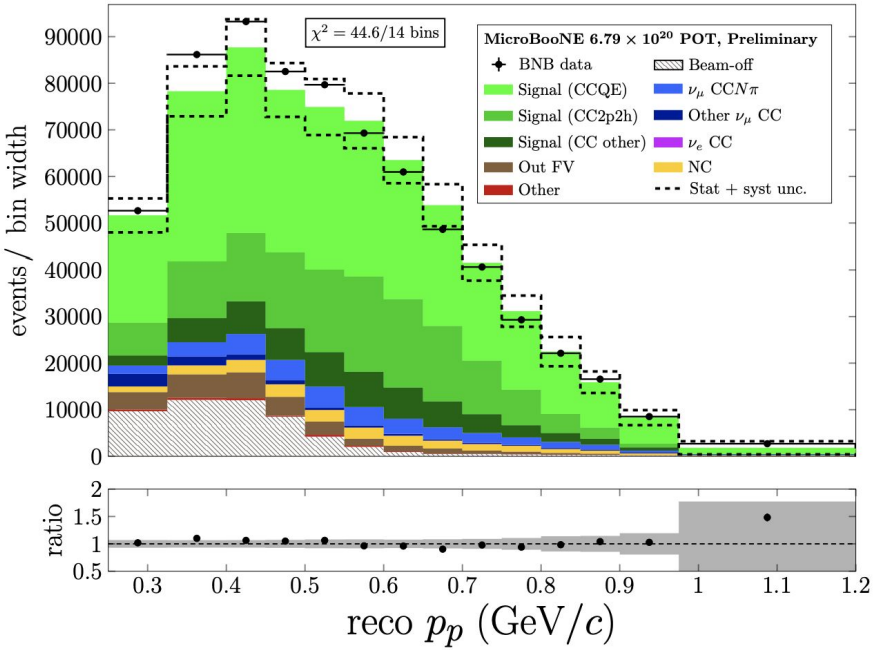


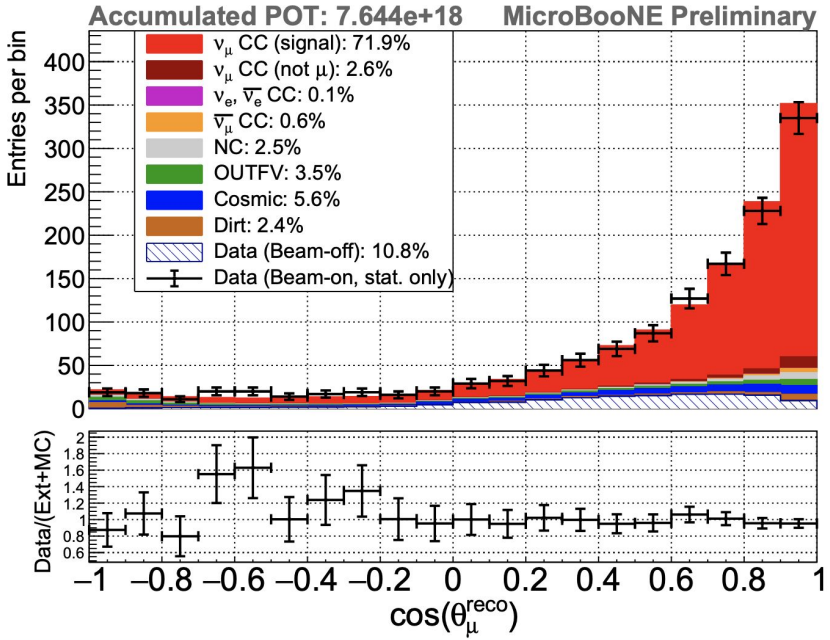
Kinetic Energy





Charged-current Measurements in MicroBooNE





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