Neutrino interactions in MicroBooNE

Xiao Luo, Yale University

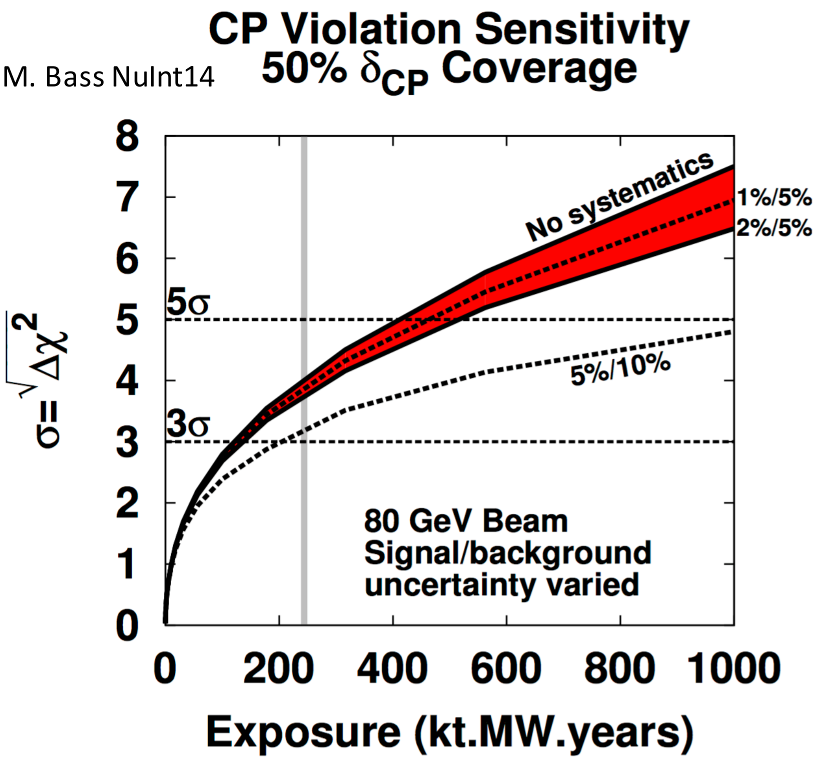
On behalf of the MicroBooNE collaboration

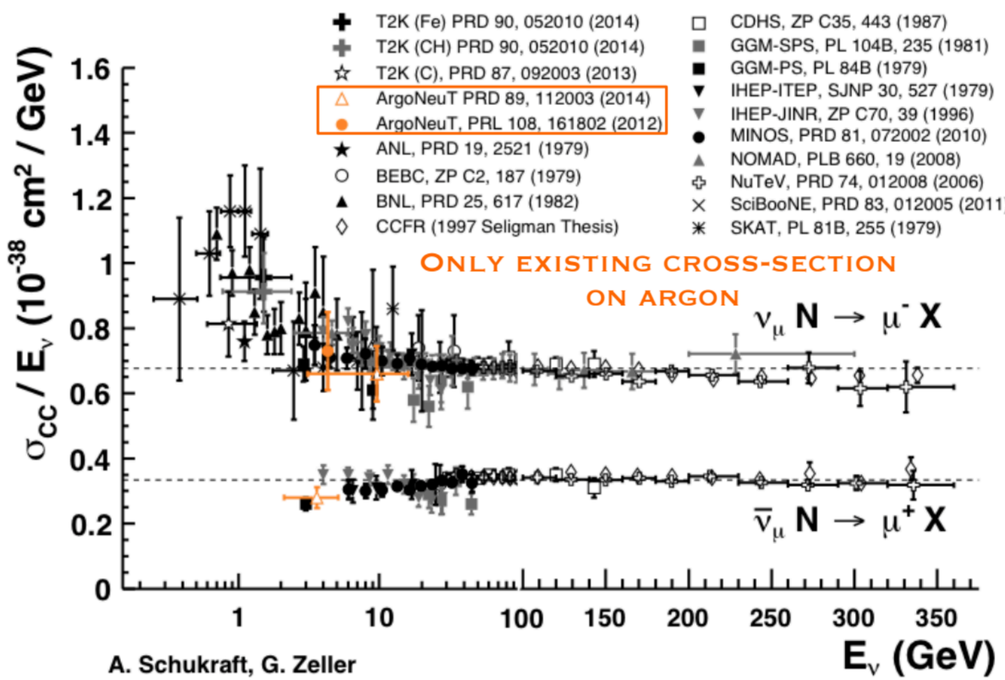
ICHEP 2016

Motivation

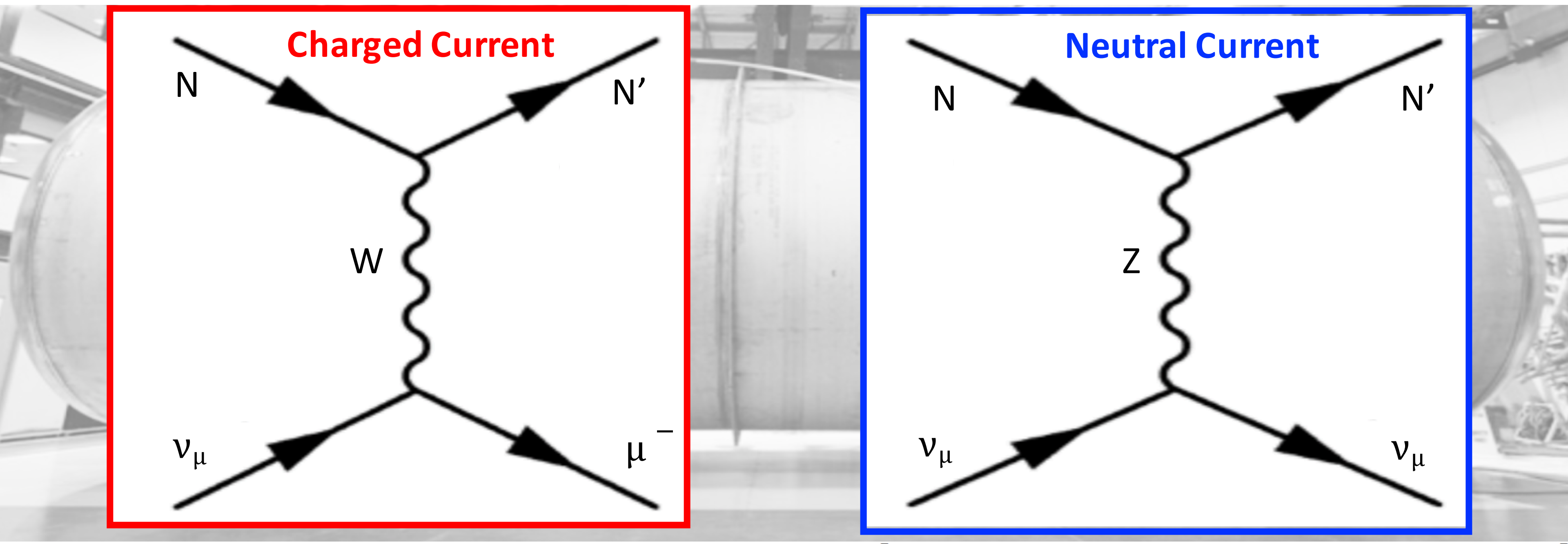
- Neutrino oscillation goals require precise measurements of cross-sections (e.g. DUNE experiment).
- Why ν-Ar: interpretation of results from FNAL LArTPC experiments (Limited measurements of ν-Ar cross-section).
- Interests to nuclear physics community.

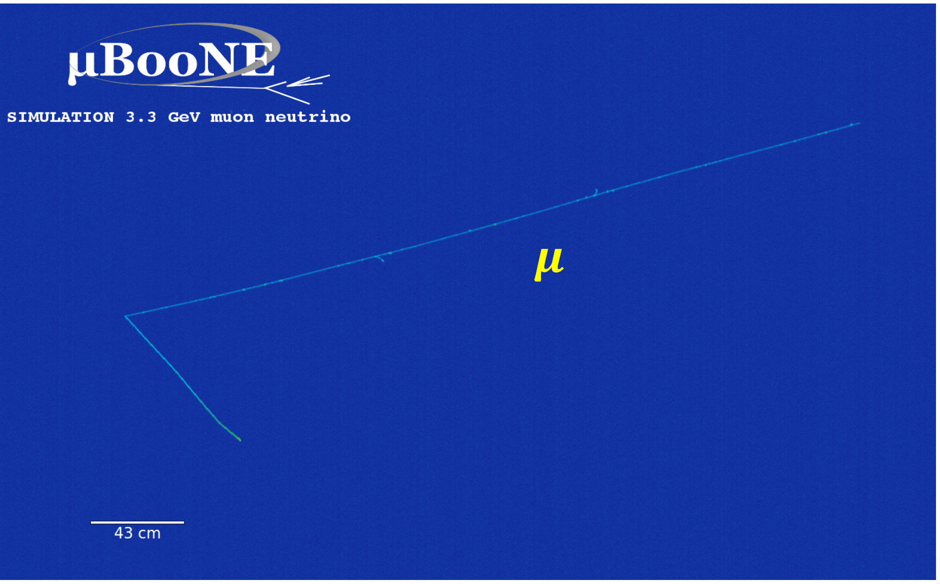
M. Bass NuInt14

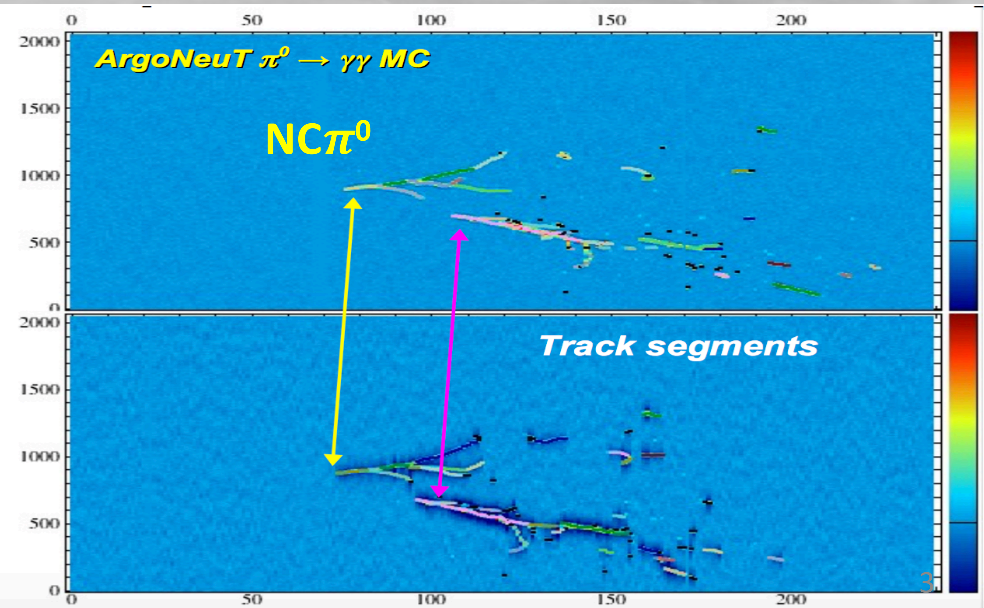




Neutrino interaction in MicroBooNE LArTPC





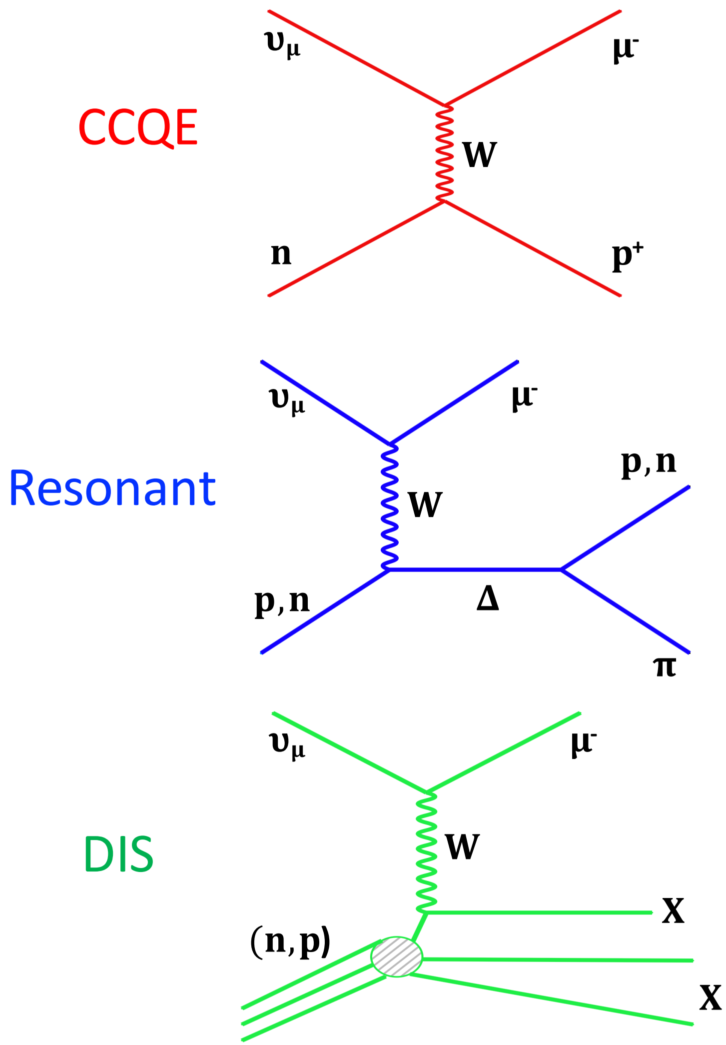


ν_μ CC inclusive cross-section

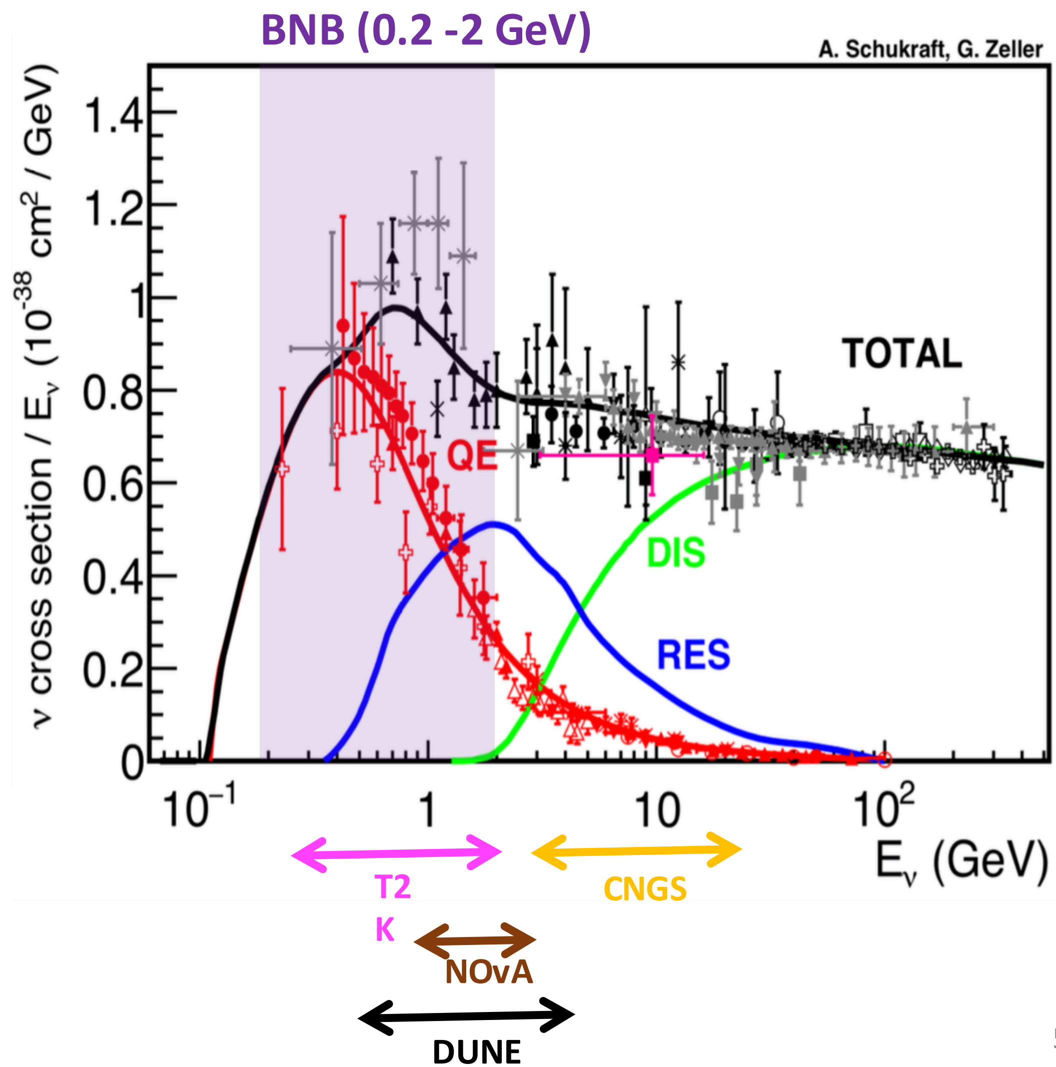
First channel in cross-section program: ν_μ CC inclusive

- Relatively simple event signature – tag outgoing **long muon track**.
- Help to develop reconstruction tools.
- A standard channel to compare with other neutrino experiments.
- Muon kinematics are insensitive to Final state interactions.
- Understanding low energy excess requires precise measurement of $\boldsymbol{\nu_e}$ appearance and various background
    - ν_μ **CC** help to constrain the ν_e flux uncertainty.
    - Build a large sample to study proton, $\pi^0, \pi^{\pm}$ in neutral current (NC) background.

ν_μ CC Inclusive

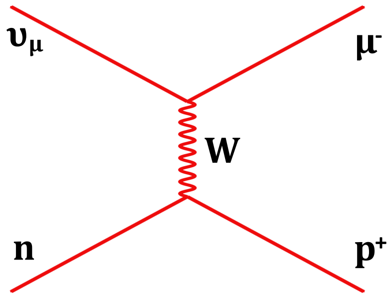


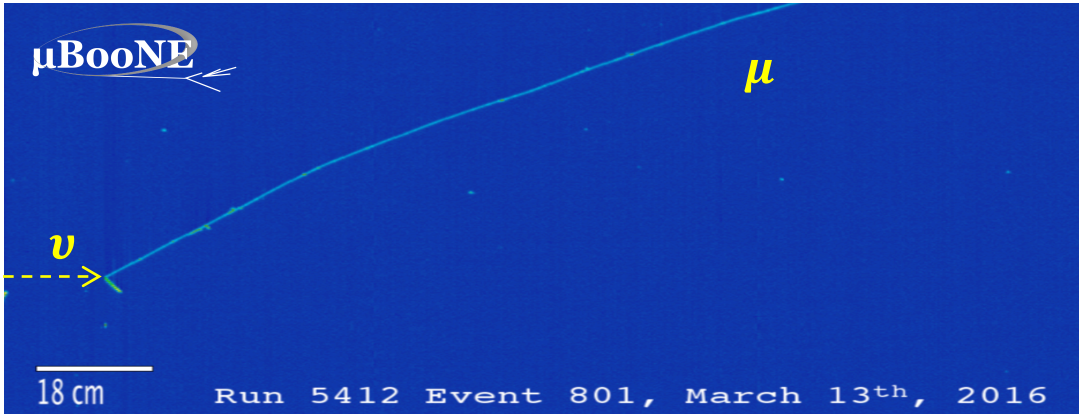
CC inclusive cross-section vs. neutrino energy



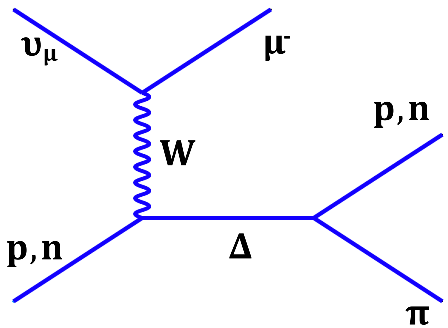
ν_μ CC Inclusive in MicroBooNE

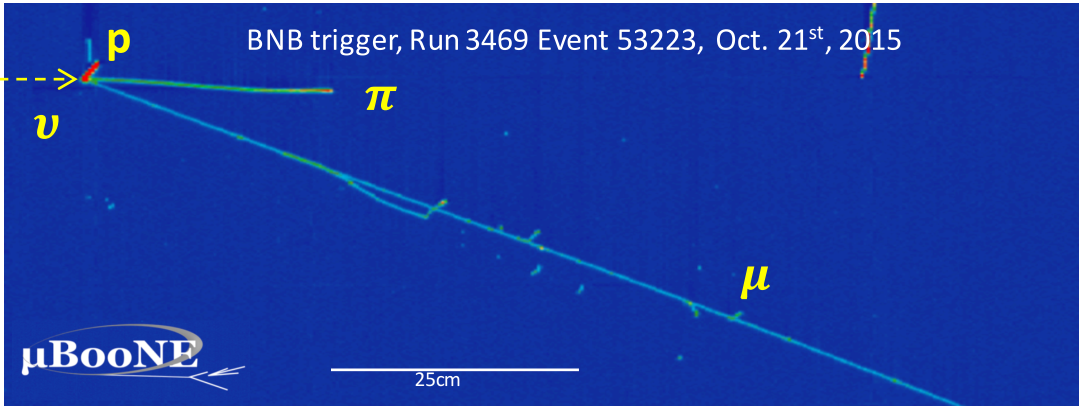
CCQE



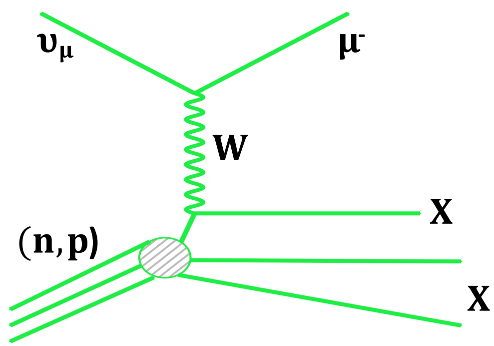


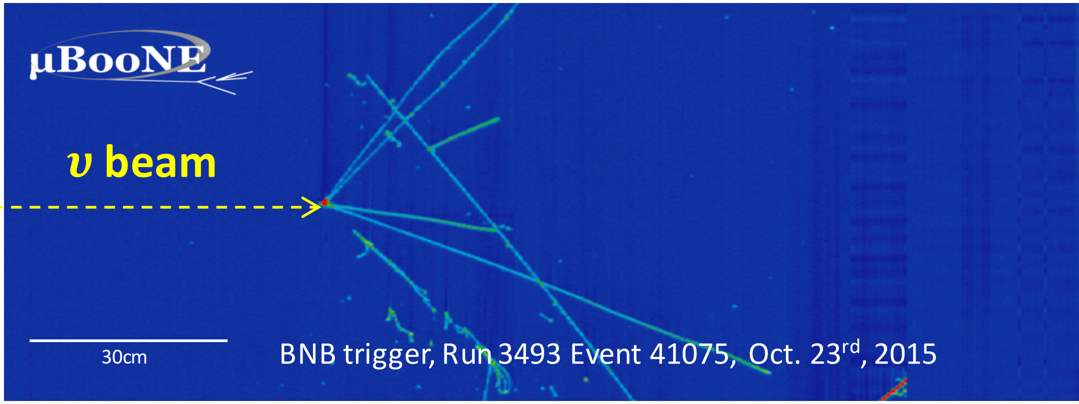
Resonant





DIS

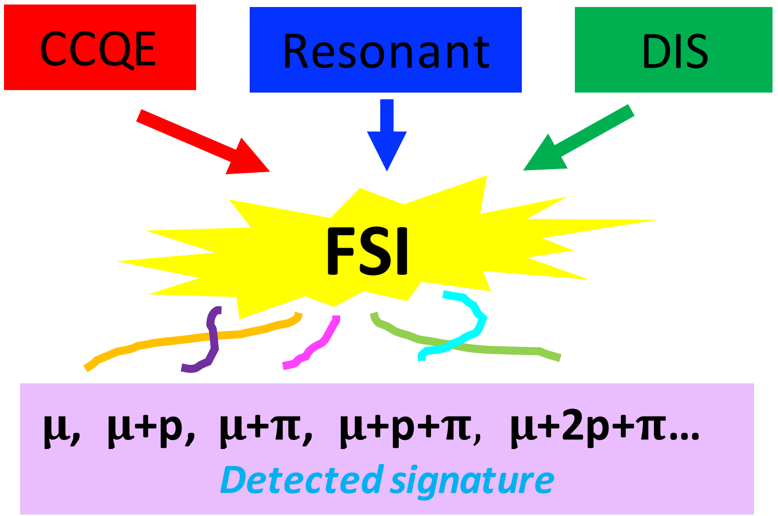




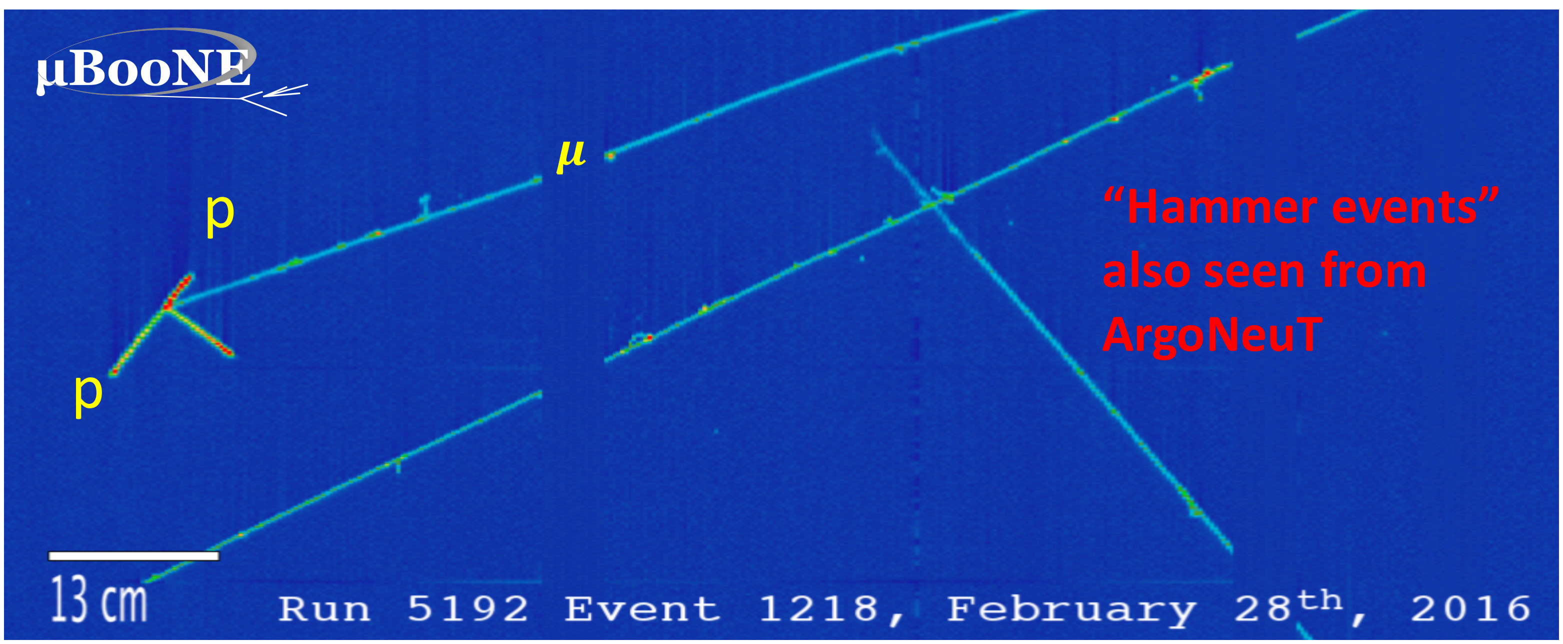
Nuclear Effects complicate things

Complications due to nuclear effects:

- Short Range Correlation
- Meson Exchange Current
- Final State Interactions



MicroBooNE will probe nuclear physics with excellent precision.



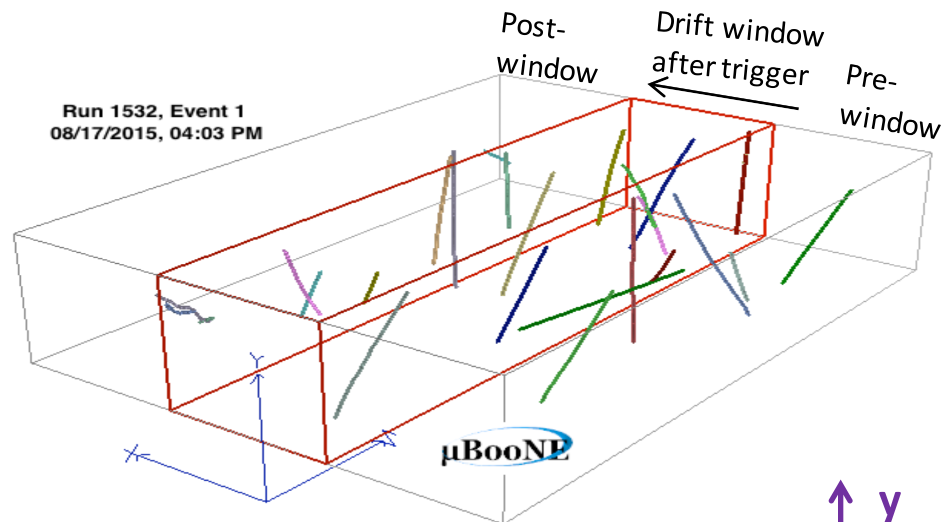
Fully automated event selection

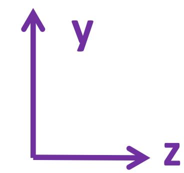
Challenge:

Cosmic rays in the surface LArTPC.

Selection strategy:

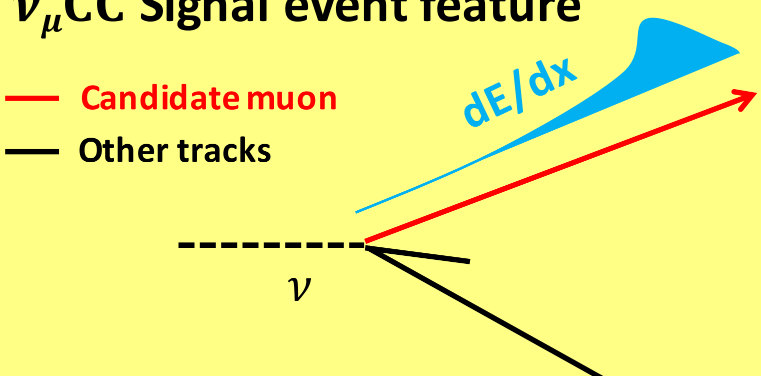
1. Flash inside of Beam trigger window.
2. Simple PMT flash - TPC track matching.
3. Further cuts on topology and calorimetry to suppress cosmic background.





Topological and calorimetric features of signal and cosmic background:

ν_μCC Signal event feature



- **More vertex activity**
- **Muon is likely forward going**
- **Muon has small dE/dx close to the vertex**

Cosmic Background event feature

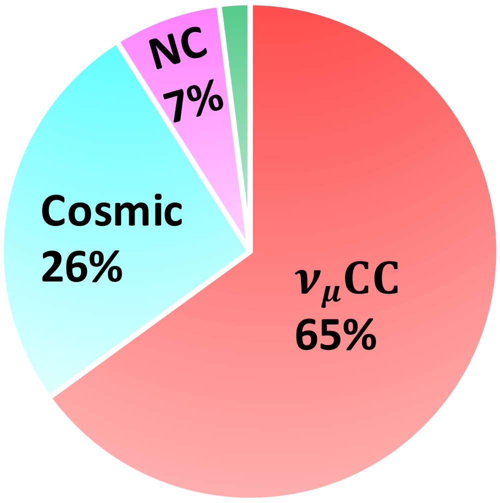
- **Mostly single track, some muon decay**
- **Downward going muon**
- **Muon has bigger dE/dx close to the vertex**

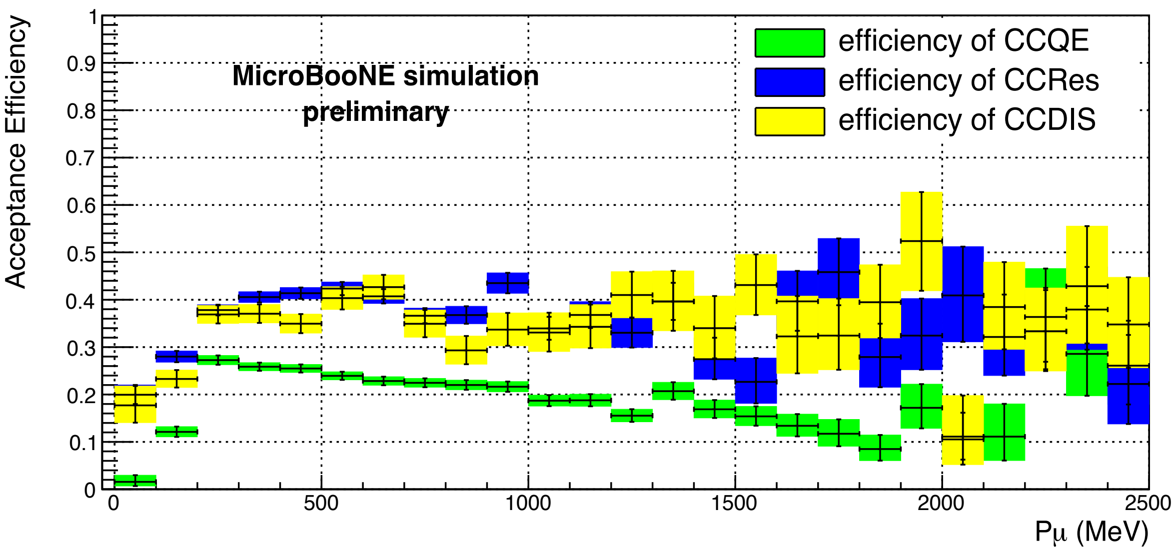
Selection efficiency and purity (From MC)

Purity: 65%

Efficiency: 30%

- If multiplicity >=2, no containment requirement.
- Single track sample requires containment in FV.
- Restrictive cuts to remove cosmic background, in particular, muon decay to Michel electron.



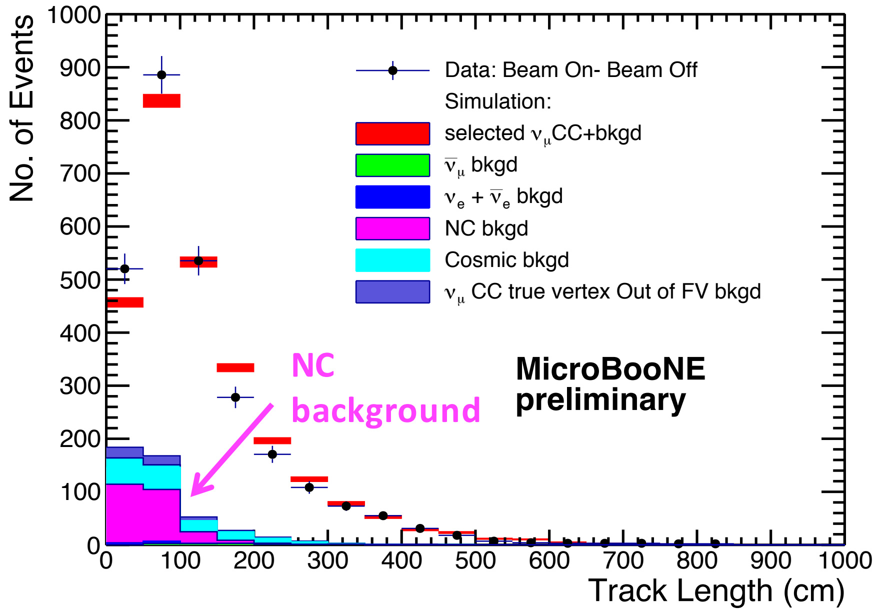


Room for improvement:

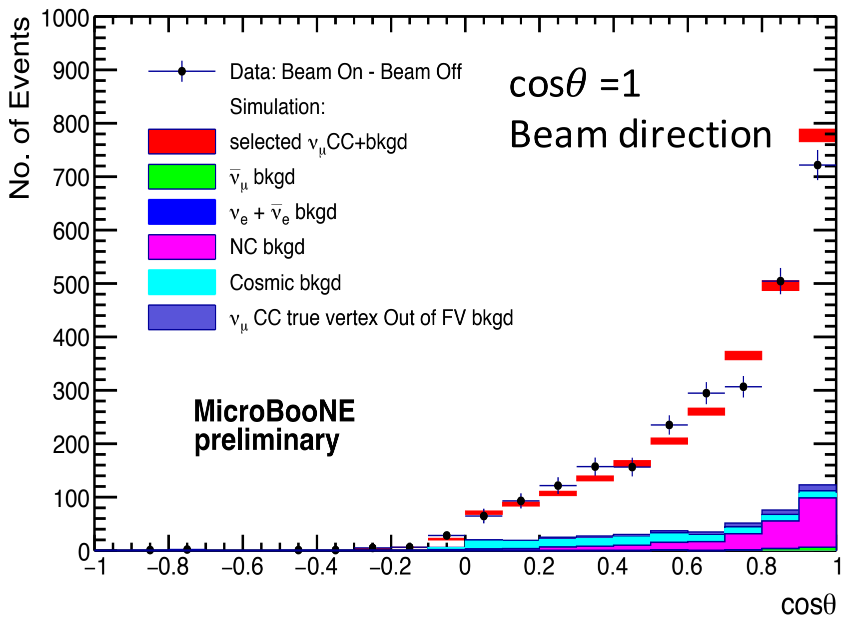
- Better **PMT flash – TPC track matching** can relax the downstream cuts.
- Improve **track reconstruction** especially for **short tracks**.
- Other selection technique such as **BDT, deep learning**, etc.

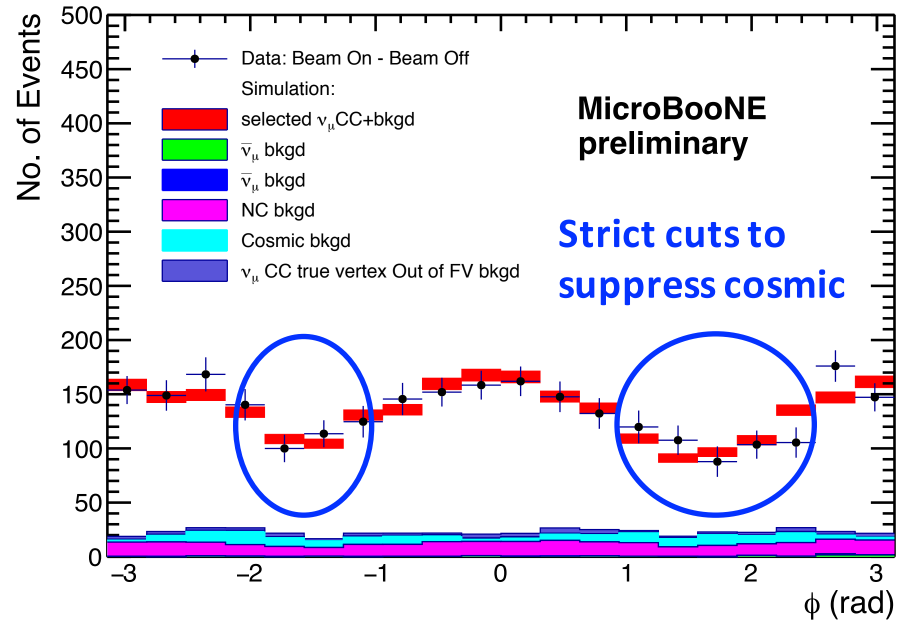
Note: efficiency = # of ν_μCC events after selection / All ν_μCC events inside of FV

Selection Distributions (Data Vs MC)



- Data: (Beam On – Beam Off) corresponds to **4.95 X 10^{19} POT**, about **2700 ν_μCC** candidate events are selected.
- MC: Neutrino interaction (GENIE 2.8.6), cosmic (CORSIKA v7.4003).
- **Area normalized** comparison between data and MC.
- Only **statistical error** is shown here





Cross-section measurement underway

- **Systematics Uncertainties:**
  - **Flux uncertainty** (dominant uncertainty)
  - **Uncertainties from detector effects**
  - **Model uncertainties.**
  - **Reconstruction efficiency**

Unsmearing matrix

$$\frac{d\sigma}{dp_{\mu,i}} = \frac{\sum_j U_{ij} \cdot (N_{\text{measured},j} - N_{\text{BG},j})}{\epsilon_i \cdot \Delta p_{\mu,i} \cdot N_{\text{target}} \cdot \Phi_{\nu_\mu}}$$

True muon momentum

Bin width

- **P_μ reconstruction for differential cross-section.**
  - **Contained track**: from range
  - **Uncontained track**: from multiple scattering

- **Integrated cross-section -> single/double differential cross-section.**

- **ν_μ CC inclusive selection lays a foundation for future study of exclusive topological channels.**

Conclusion

- ν_μ CC inclusive to kick off MicroBooNE cross-section program.
- First result on fully automated ν_μ CC inclusive event selection.
- Area normalized distributions show good data-MC comparison.
- ν_μ CC inclusive cross-section measurement is underway.
- Cross-section studies of many other channels are on going.

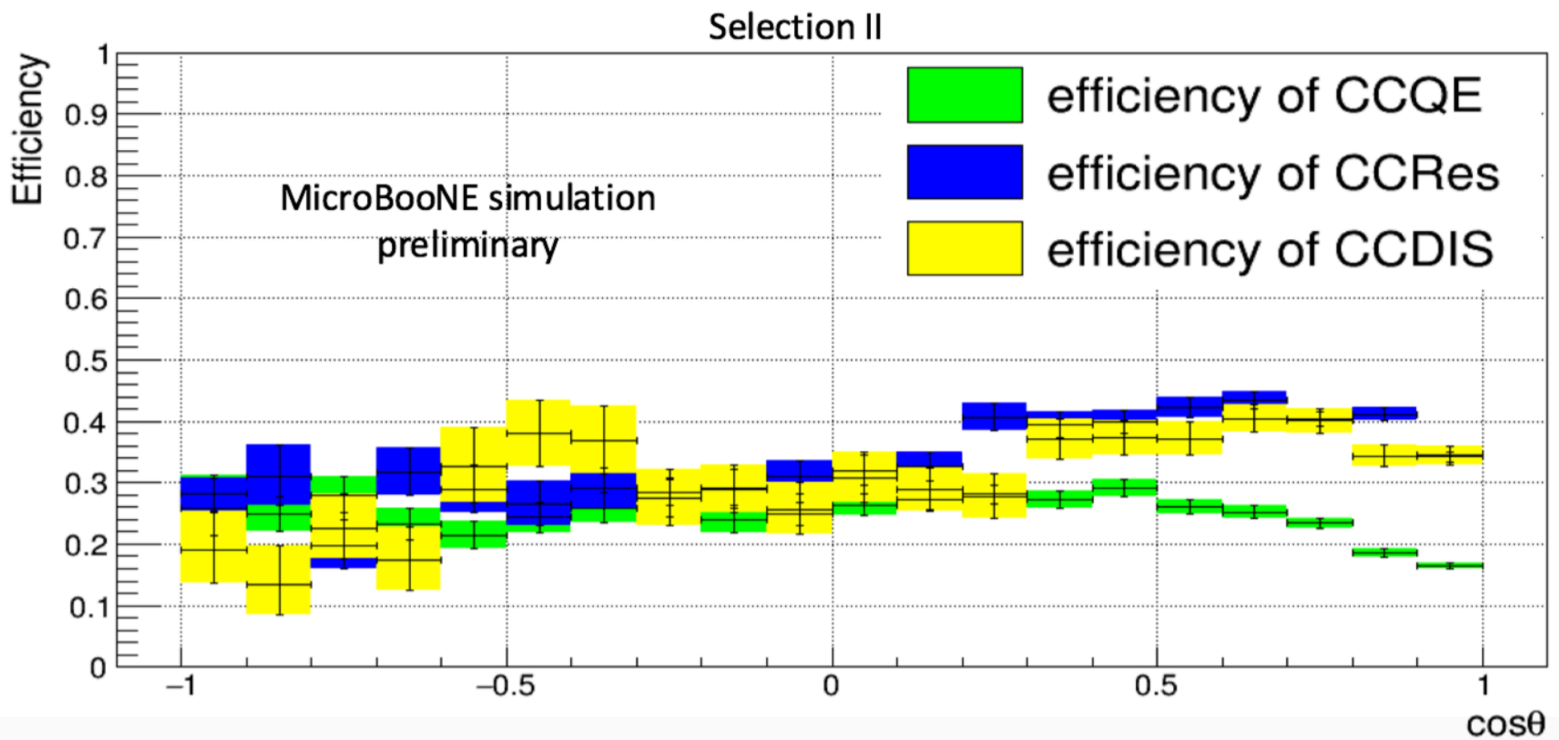
Thank you !

Backup

Composition of the selection

Before selection: 60% QE 30% RES 10% DIS

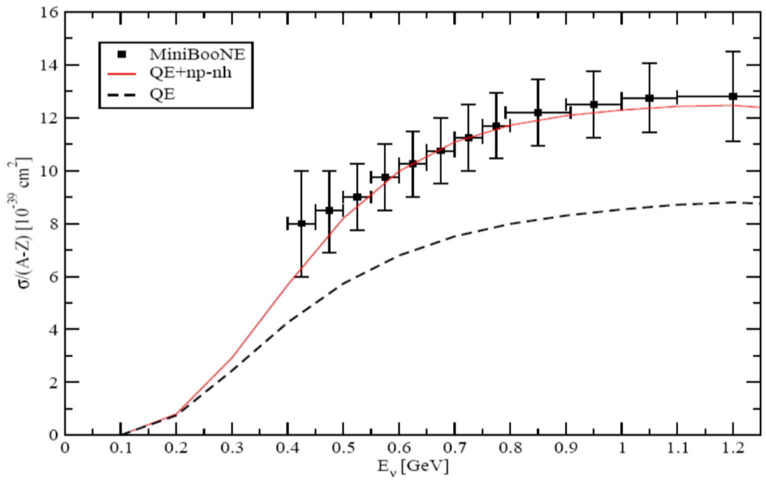
After selection: 43% QE 42% RES 14% DIS



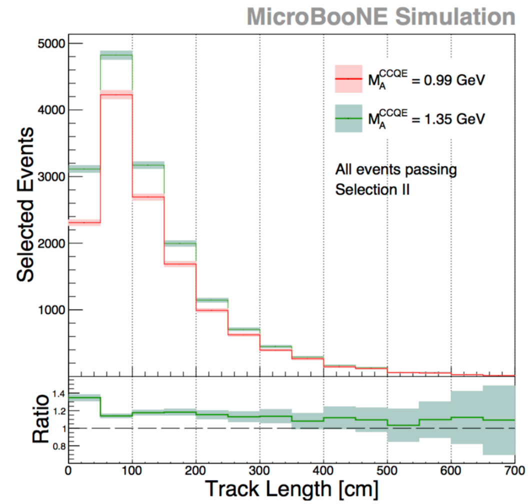
(c) Selection II: Selection efficiency as a function of the true muon angle $\cos(\theta)$.

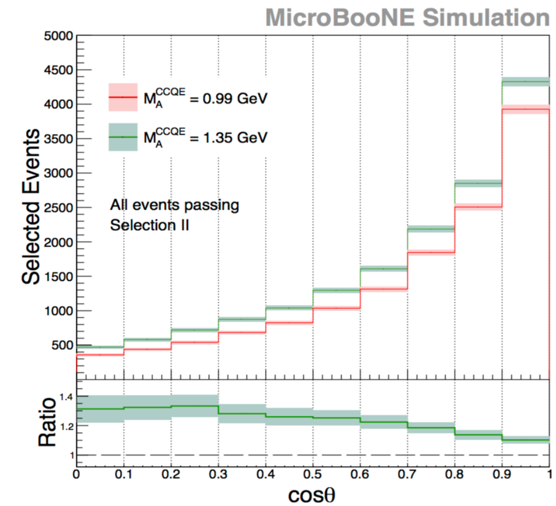
Sensitivity to test different models

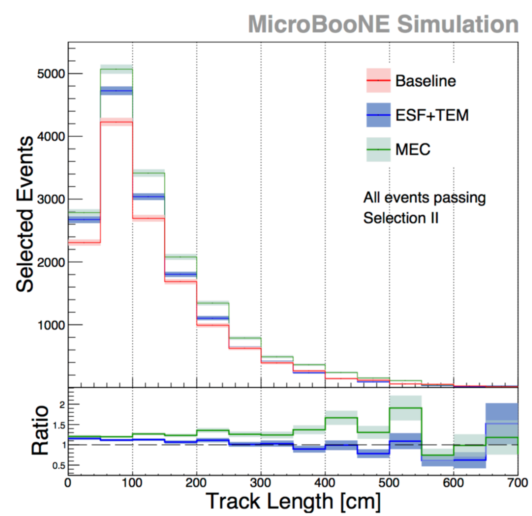
M. Martini, M. Ericson, G. Chanfray, J. Marteau
Phys.Rev. C 80 065501(2009)

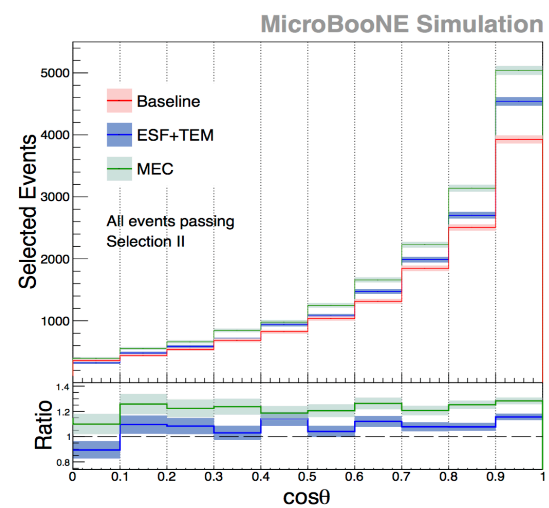


Different models after Selection









Reconstruction

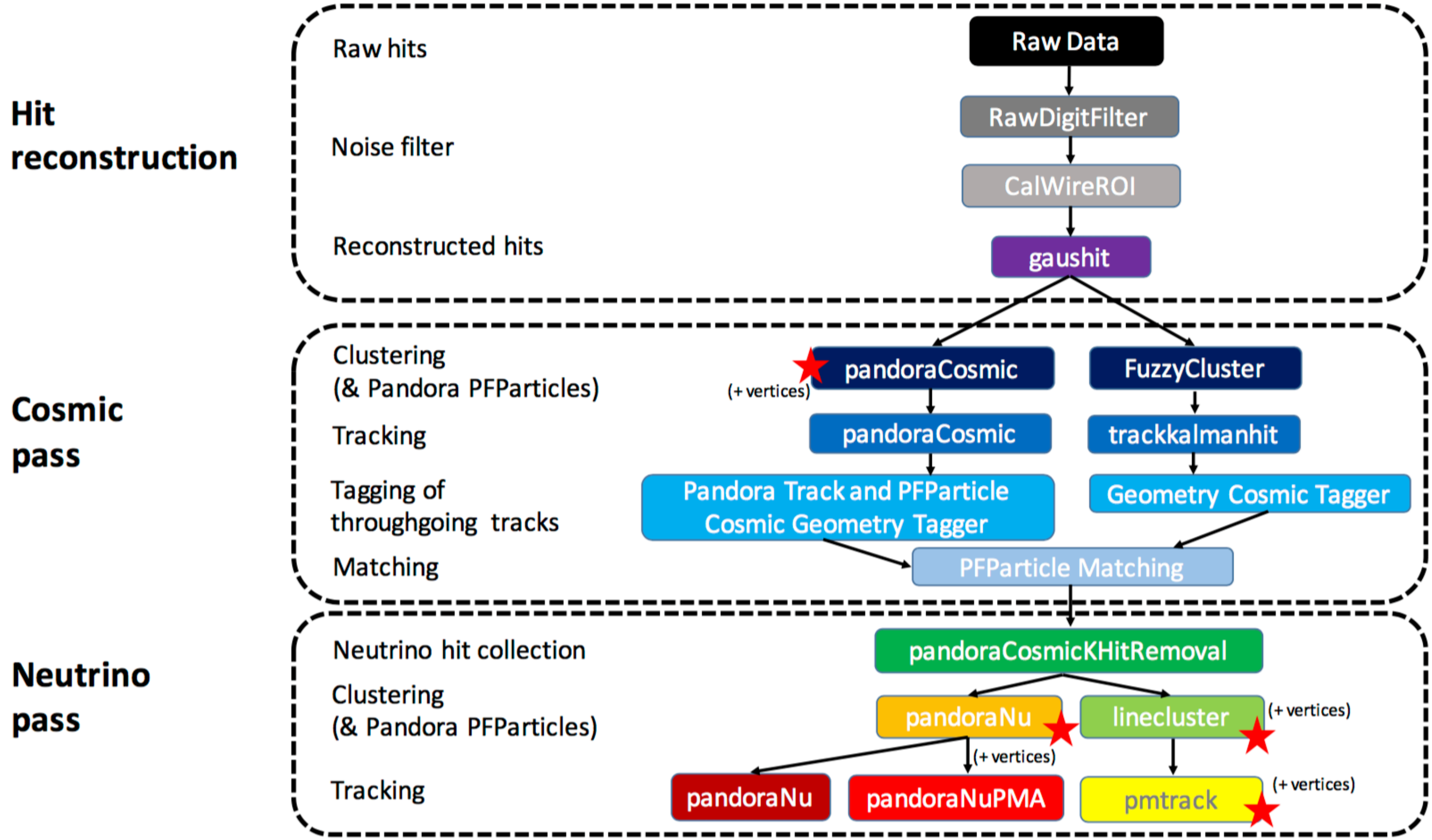
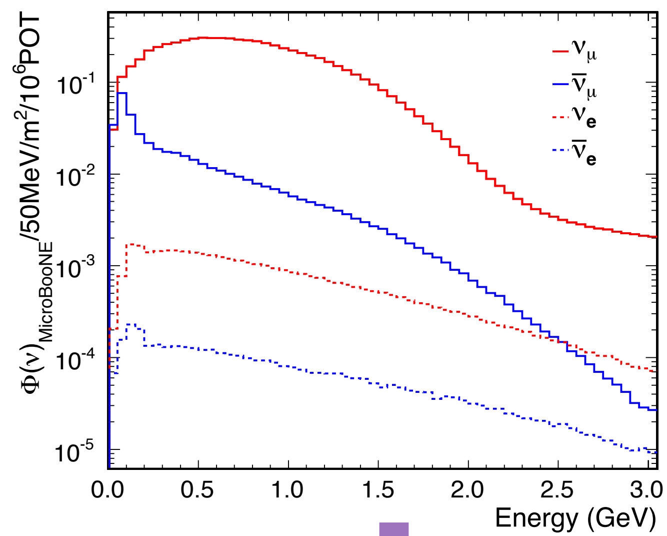
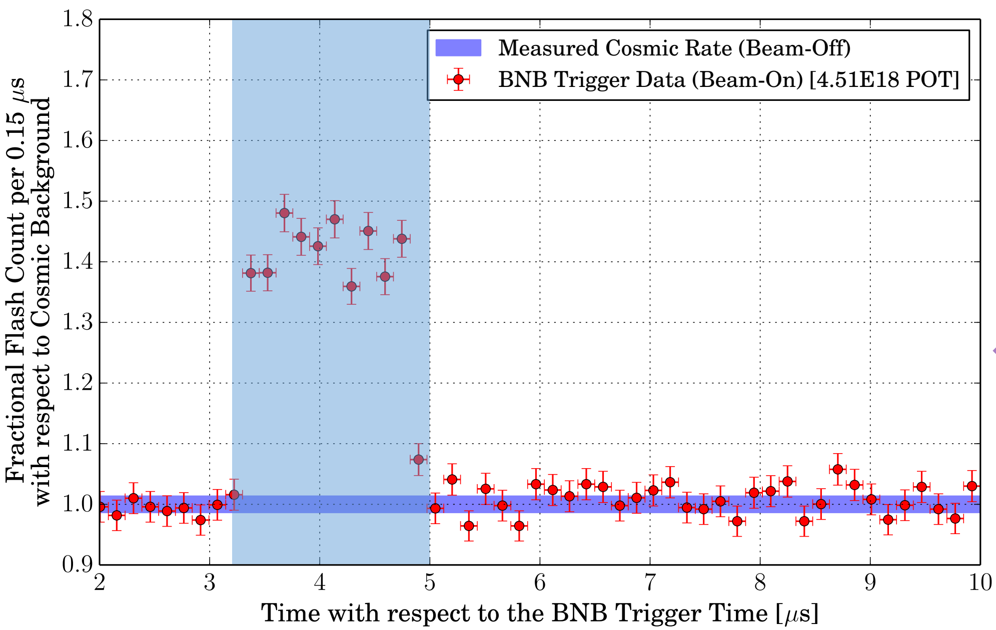


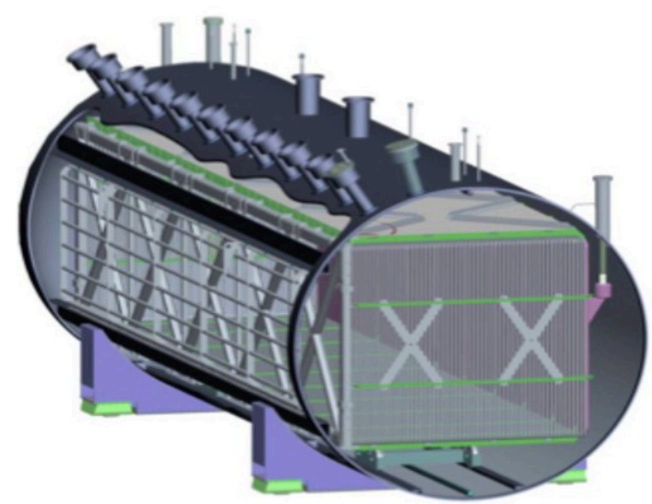
Figure 2: Reconstruction chain for data and MC processing. The red stars on some of the boxes indicate that the algorithms return reconstructed 3D vertices.

MicrobooNE and FNAL neutrino beam

- MicroBooNE Goals:
  - Address MiniBooNE low energy excess
  - **$\nu - Ar$ Cross-section measurement at ~1GeV range**
  - LArTPC R&D
- FNAL Booster Neutrino Beam (BNB), mainly ν_μ with energy peak around 800 MeV.
- Neutrino interactions from the PMT flash.

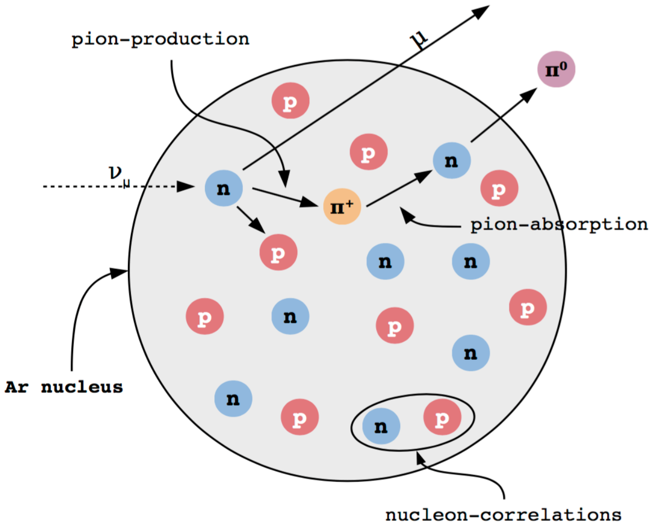




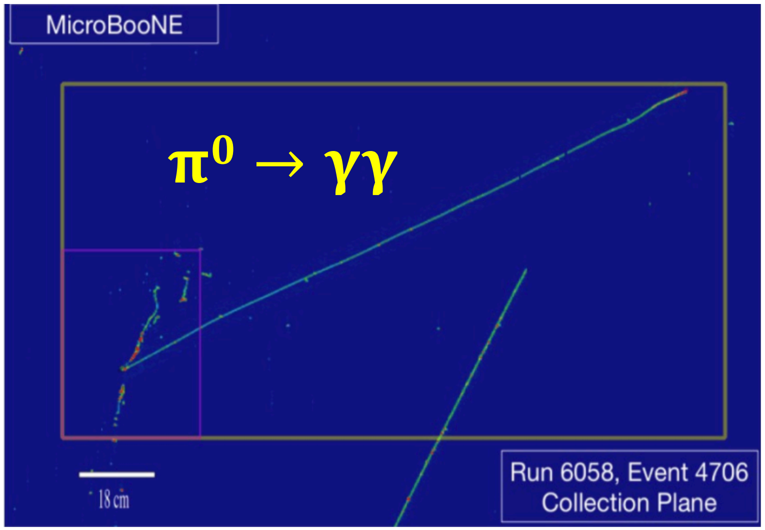


First step of Low energy excess - CC π^0

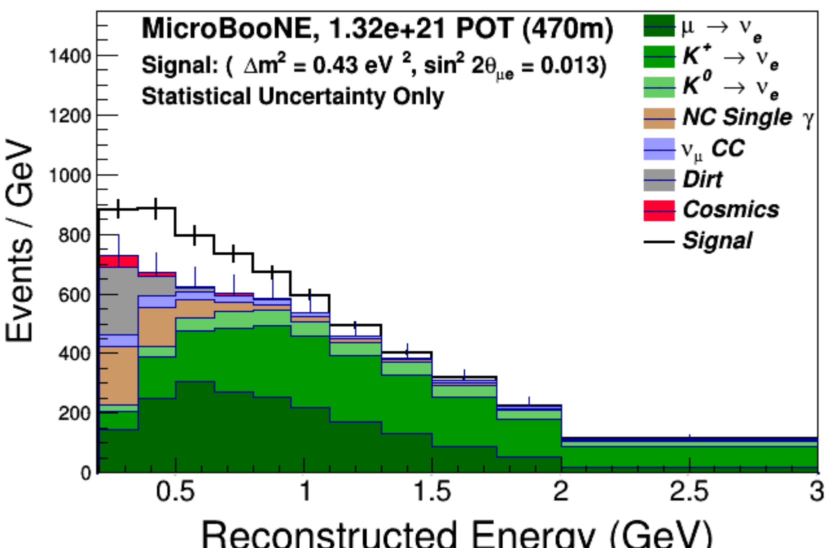
1. Finding $\boldsymbol{\pi^0}$ from the CC inclusive sample



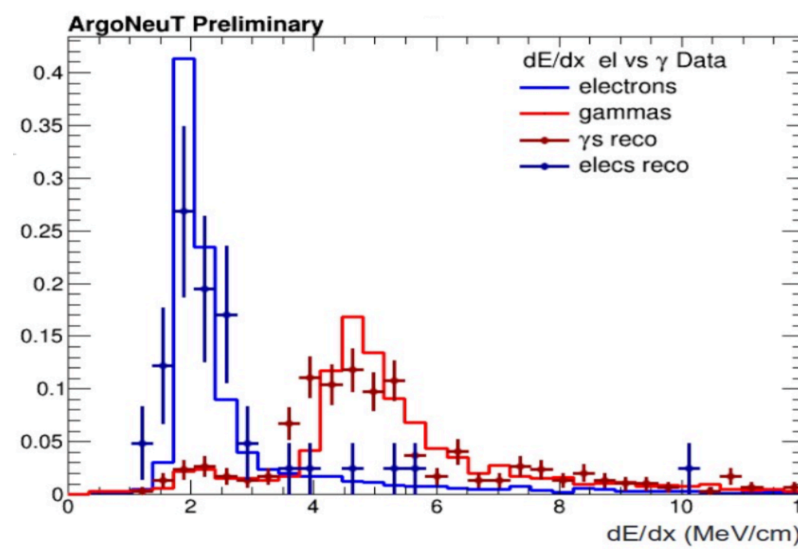
2. Automated **photon** reconstruction for $\boldsymbol{\pi^0}$



4. Photon background in Low energy excess



3. $\boldsymbol{e/\gamma}$ separation in dEdx



Plan of cross-section measurement

CC inclusive integrated and differential cross-section

NCπ^0: "Neutral Pions & Prospects for Neutral Current Interactions in MicroBooNE" by **Ryan Grosso.**

NC elastic: Measure cross section to determine Δs.

ν_μ **CC Track multiplicity**: "Charged particle multiplicity analysis" by **Aleena Rafique.**

Kaon analysis: "A MC study of Kaon Identification Sensitivity in MicroBooNE" by **Elena Gramellini and Varuna Meddage.**

ν_e **Electron**: "Single-Electron Event Selection Techniques for the MicroBooNE Low-Energy Excess Analysis" by **Rui An.**

Public notes (link):

- 7/4/16 MICROBOONE-NOTE-1010-PUB
  Selection and kinematic properties of numu charged-current inclusive events in 5E19 POT of MicroBooNE data
- 5/3/16 MICROBOONE-NOTE-1006-PUB
  Study Towards an Event Selection for Neutral Current Inclusive Single Pi0 Production in MicroBooNE
- 7/4/16 MICROBOONE-NOTE-1015-PUB
  The Pandora multi-algorithm approach to automated pattern recognition in LAr TPC detectors
- 7/4/16 MICROBOONE-NOTE-1014-PUB
  A Comparison of Monte-Carlo Simulations and Data from MicroBooNE