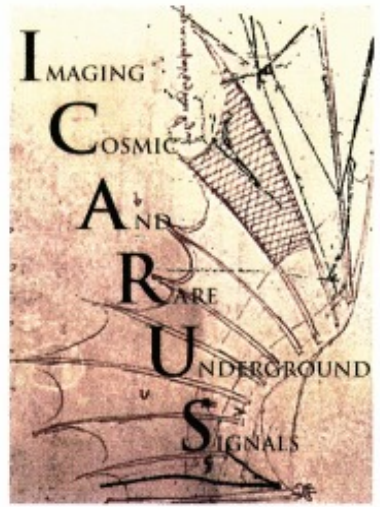
Muon-neutrino selection and reconstruction in ICARUS

Jacob Larkin for the ICARUS collaboration
Brookhaven National Laboratory

New Perspectives

June 17, 2022

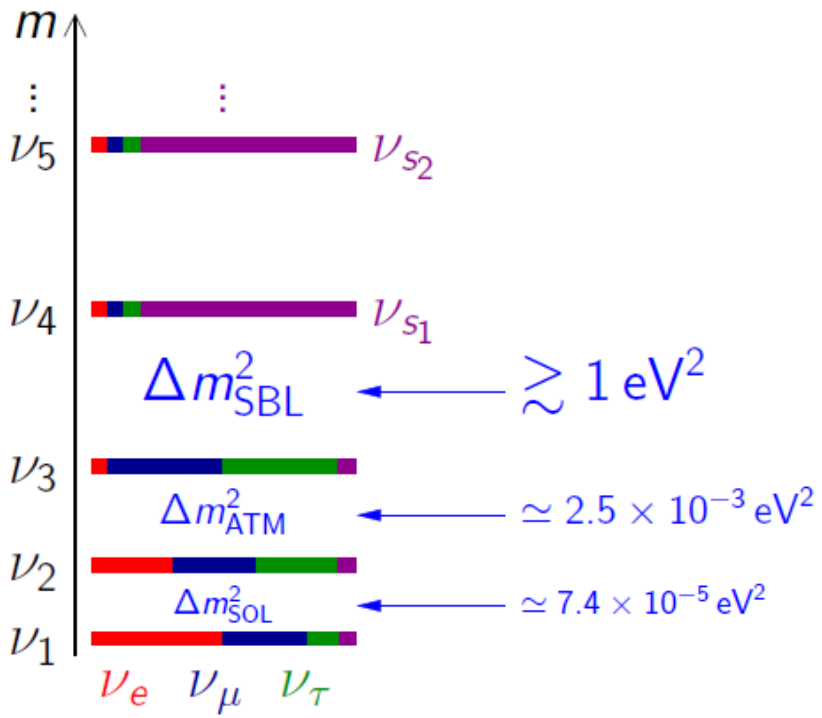


Brookhaven National Laboratory

FERMILAB-SLIDES-22-055-V

Sterile Neutrinos

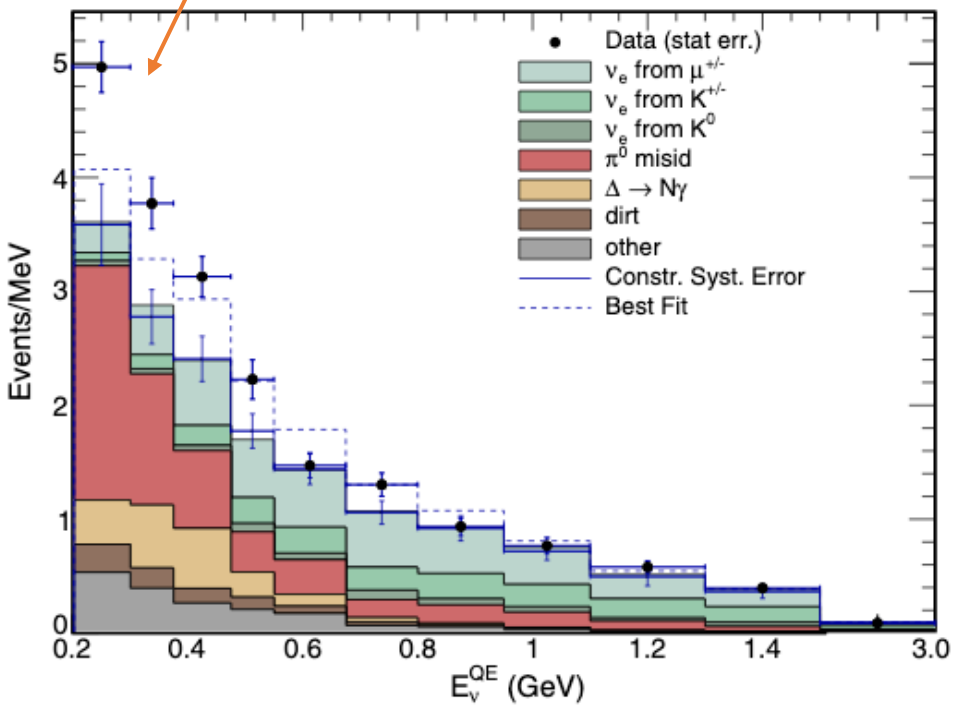
- Sterile neutrinos would be an additional flavor of neutrino which does not interact via the weak interaction
- Sterile neutrinos would affect the observable oscillations compared to what is expected from 3 flavors
  - No observable oscillations from 3 flavor model expected at short baselines



Evidence for Sterile Neutrinos

Excess of events at low energies

MiniBooNE ν_e Spectrum



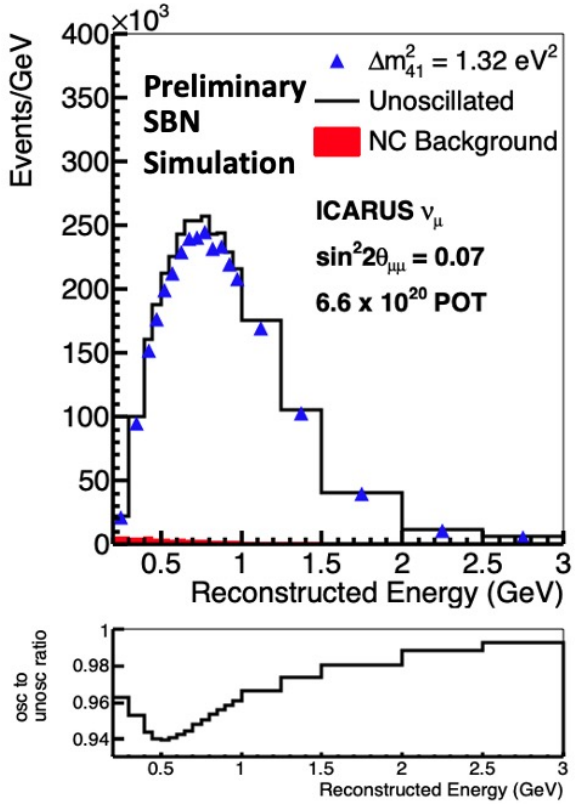
- LSND: $\bar{\nu}_e$ appearance ($\bar{\nu}_\mu$ source)

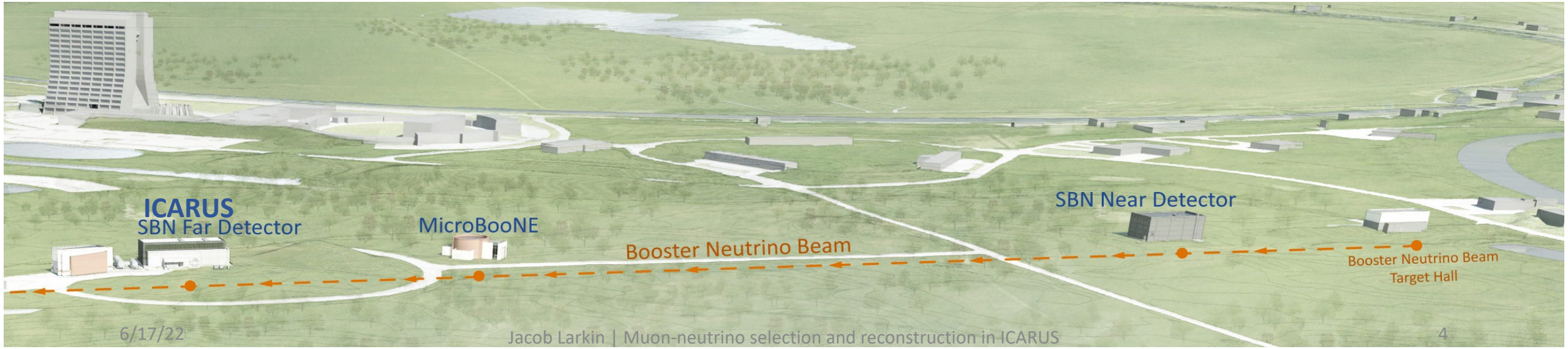
  MiniBooNE: $\bar{\nu}_e$ and ν_e appearance ($\bar{\nu}_\mu$ & ν_μ source)
- Can be interpreted as neutrino oscillations with $\Delta m^2 \sim 1eV^2$
- But this result conflicts with previous measurements of ν_e and ν_μ disappearance
- Recent MicroBooNE result puts additional constraints on these results
- Goal of ICARUS is to measure both appearance and disappearance signals
  - Focus currently on ν_μ disappearance

A. A. Aguilar-Arevalo et al.[MiniBooNE Collaboration], Phys. Rev. Lett. 121(2018) 221801

ICARUS

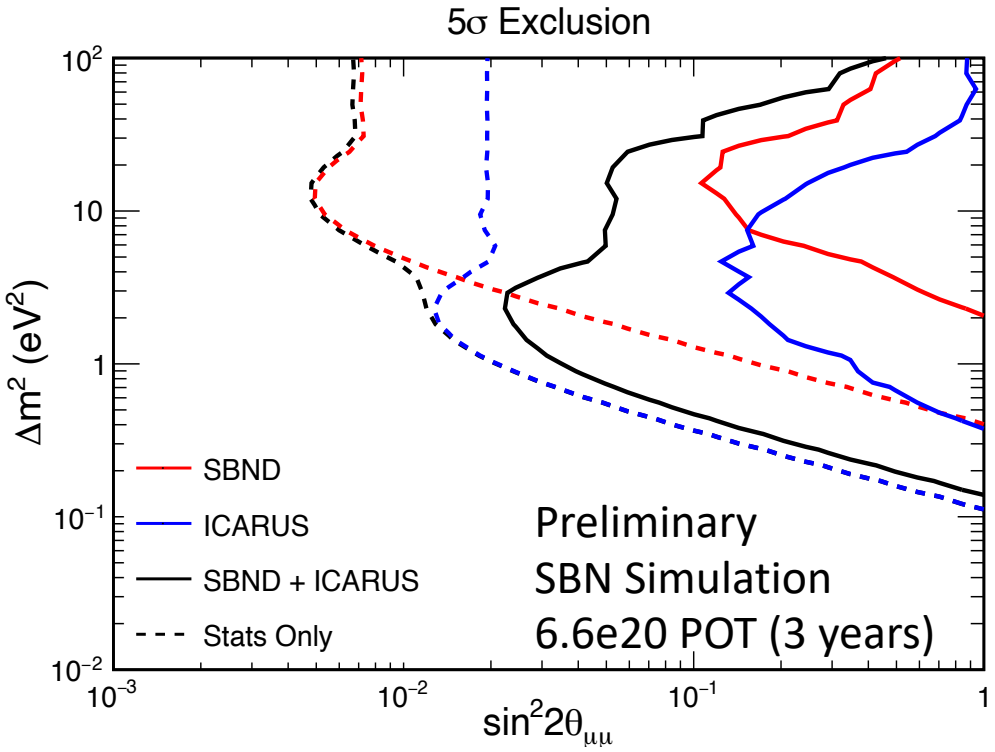
- 500 ton active volume LArTPC located 600 m from the target of Booster Neutrino Beam
- See talk by T. Boone for more on ICARUS

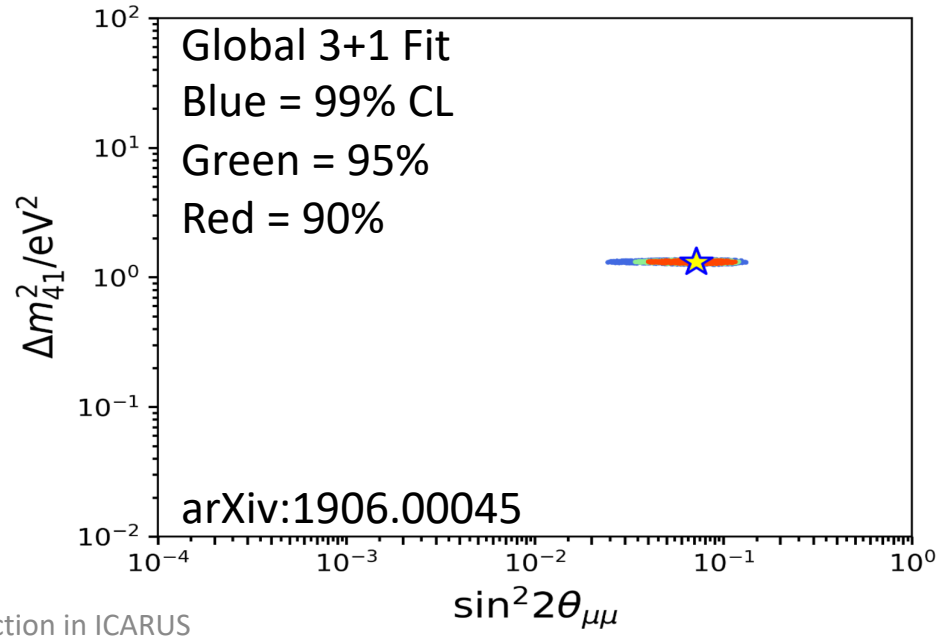




Oscillation Sensitivity Analysis

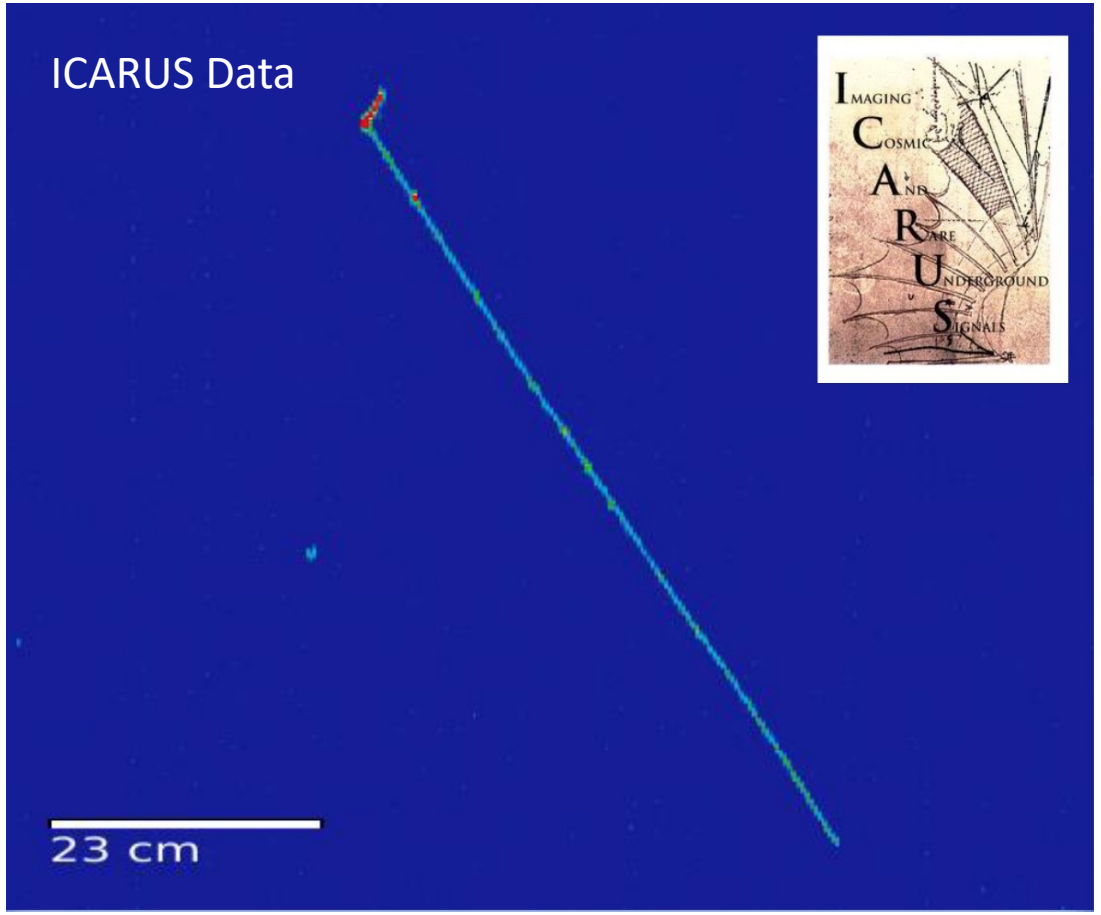
- To estimate sensitivity, use simulated data (MC) with “fake reco,” i.e., smeared true energy
  - 2% gaussian smearing for muons
  - 5% gaussian smearing for protons and pions
  - Sum muon and charged hadron energies to get neutrino energy estimate
- Consider background from neutral current interactions
- Consider systematic uncertainties from flux and interaction model
- Perform fits using CAFAna fitter developed originally for NOvA and used for DUNE long baseline analysis



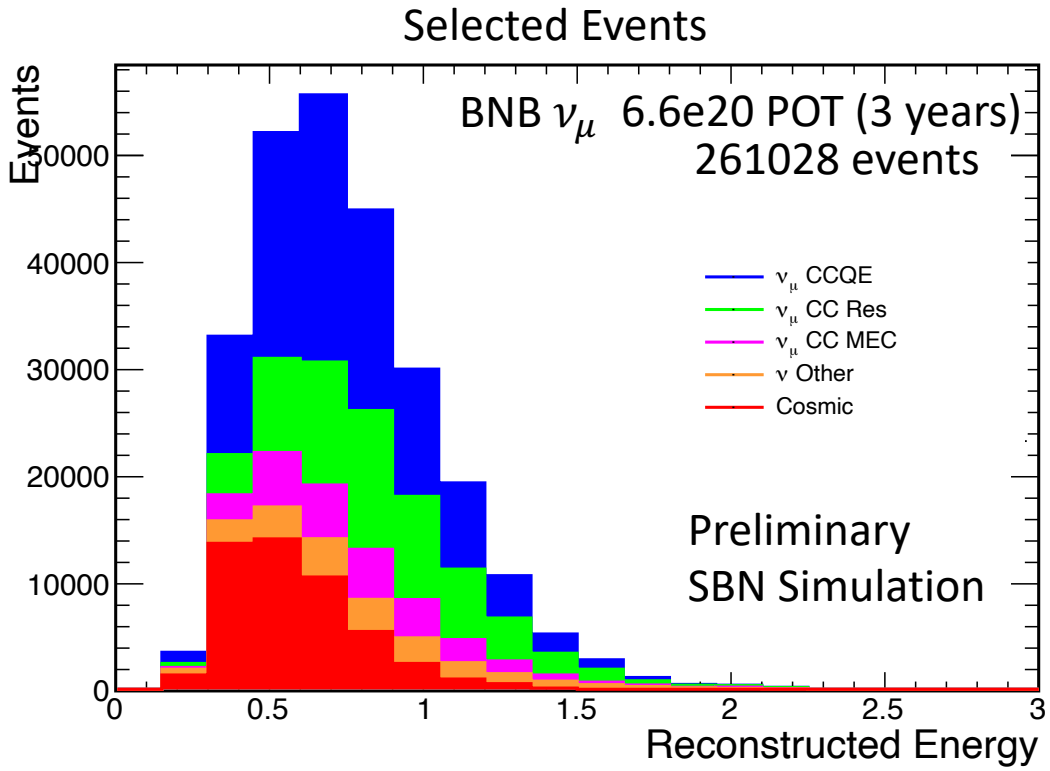


Muon-Neutrinos (ν_μ)

- Expect long muon track coming out from neutrino vertex
- Example of quasi-elastic (QE) candidate shown to the right
  - Long muon track below the vertex
  - Shorter proton track above vertex



ν_μ Selection



- Goal: Select a high purity sample of muon-neutrino events with low cosmic background

- Cuts:
  - In fiducial volume
  - Not clear cosmic
  - Neutrino/Cosmic BDT
  - Matching of PMT signals with time and geometric distribution expected for beam event
  - Identified Muon track
- Muon selection:

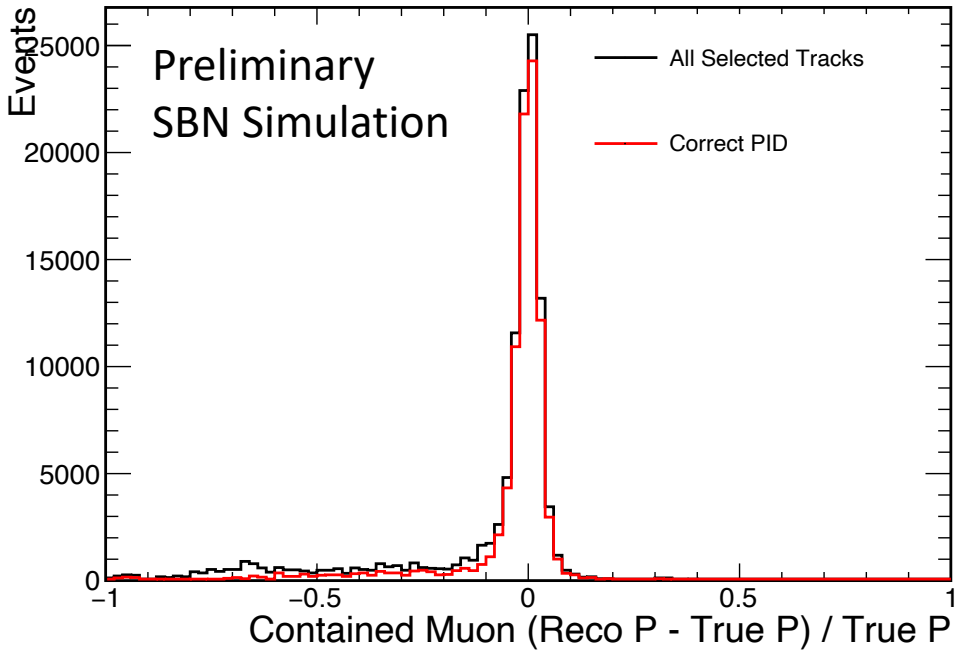
  Longest Track satisfying
  - Start point < 10cm from reconstructed neutrino vertex
  - Exiting Track: length > 100cm
  - Contained Track: length > 50cm and particle ID based on comparison dE/dx to residual range

Muon Momentum

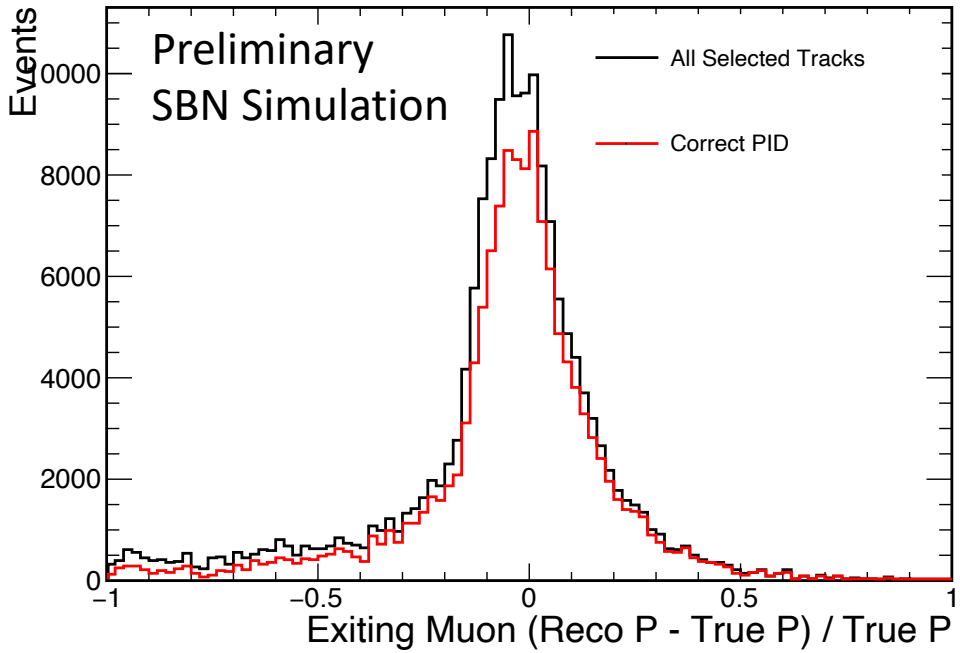
- Two ways to calculate track momentum
  - Range: uses length of track and known behavior of different particle types in LAr
  - Multiple Coulomb Scattering: looks at scattering of particle off argon atoms
- Range is preferred for contained tracks due to greater precision
- MCS used for exiting tracks since total track length is not known
- Looking at muons selected as primary muon by selection on earlier slide

Red = True Muon
(but not necessarily true neutrino events)

Range P for contained tracks



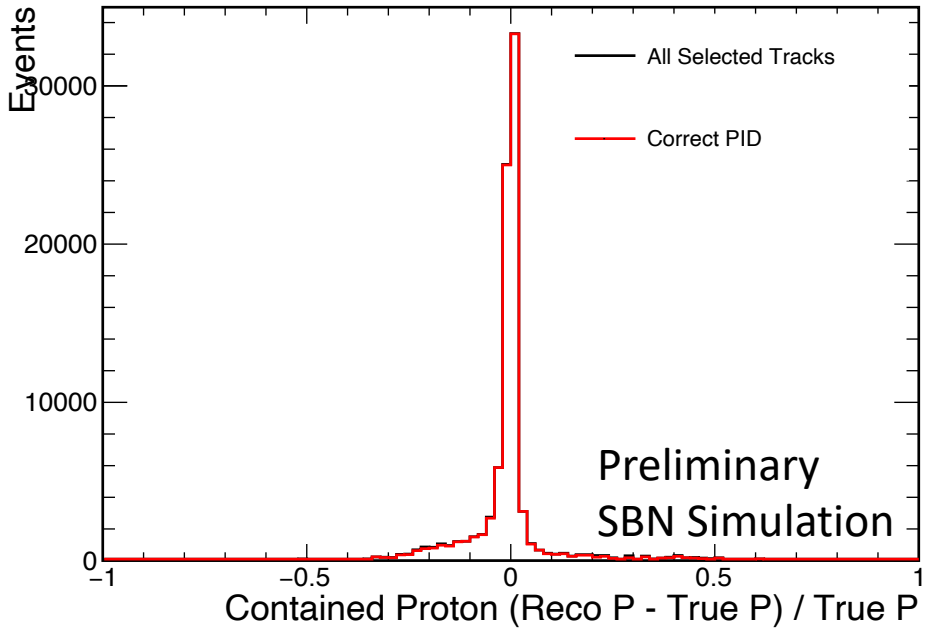
MCS P for exiting tracks



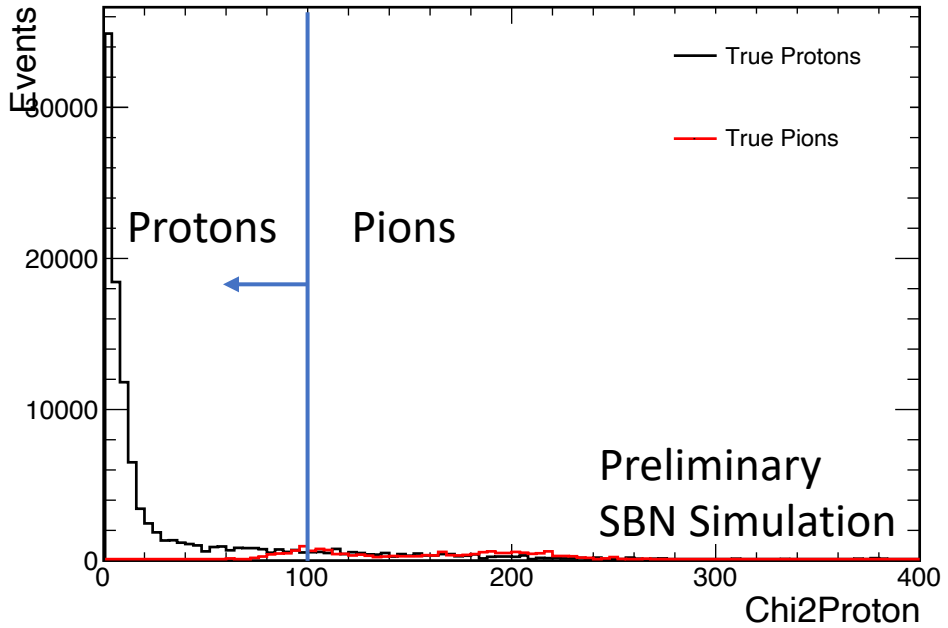
Protons

- Assume that tracks not identified as primary muon track are hadrons, i.e., protons or pions
- Distinguish protons from pions using proton chi2 calculated from dE/dx (right plot)
  - Current cut at 100, but further optimization in progress
- Can use range method to get momentum of contained protons, but MCS not tuned for protons so it cannot be used for exiting protons

Proton Momentum



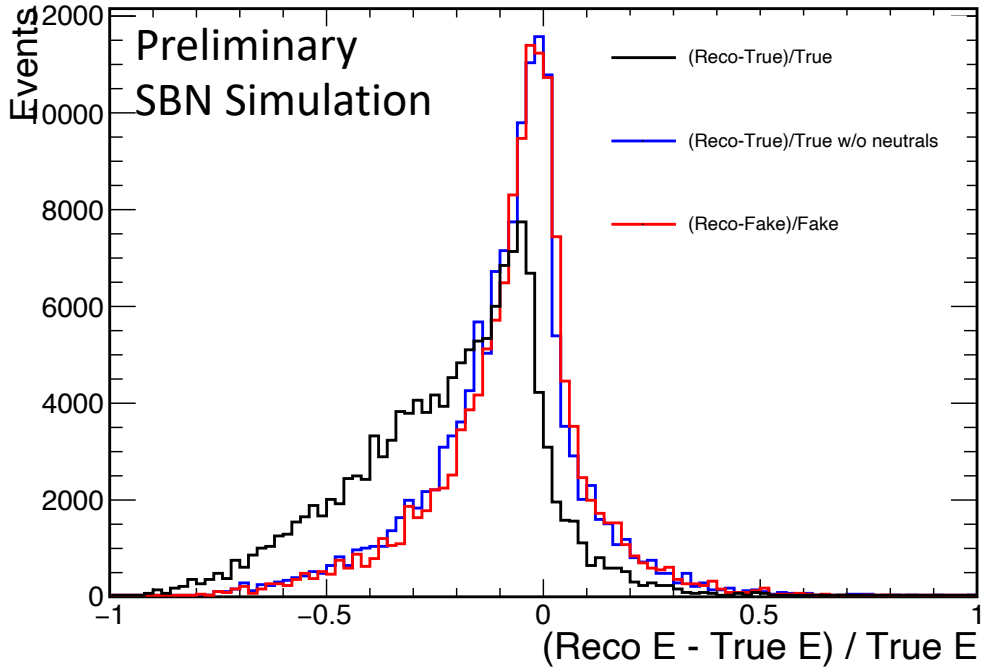
Proton Chi2



Significant proton background in “pion” sample

Neutrino Energy

Contained Hadrons + 0 Pions

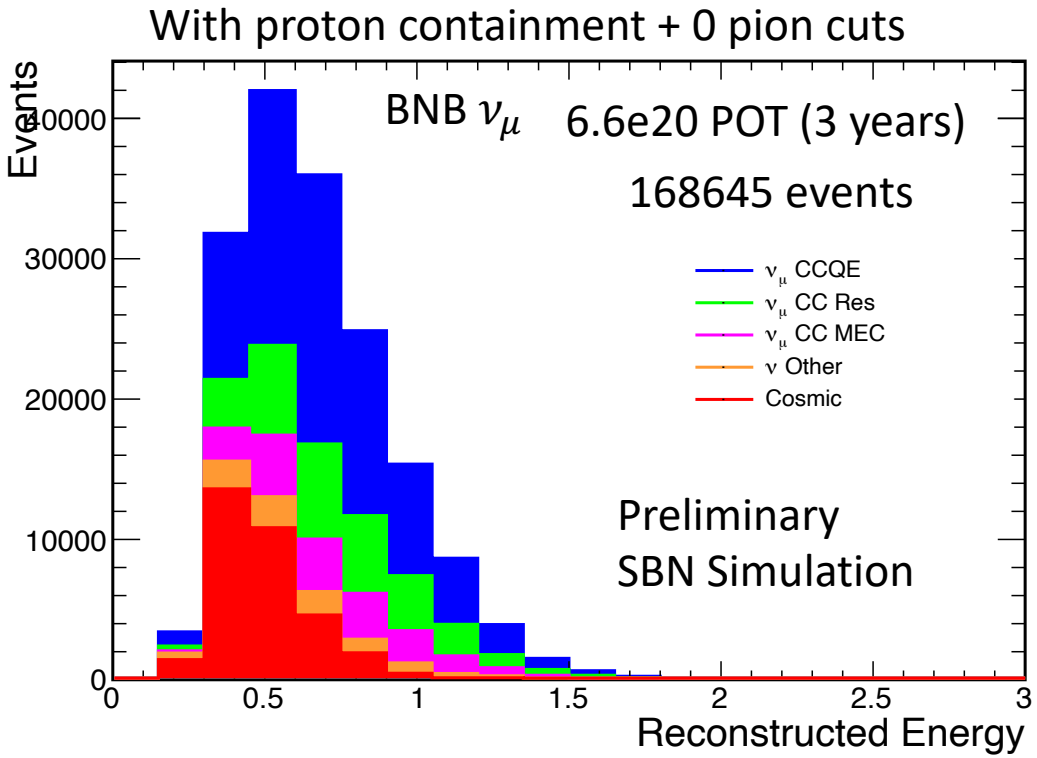


- $E_\nu = E_\mu + \sum_{trk} KE_{trk}$ for tracks identified as protons
- Only events with contained protons and no reconstructed pions
- Fake reco is parametrized reconstruction used by sensitivity analysis
  - only muon, protons, and pions included in fake reco
- Blue curve shows that left side tail partially explained by neutral particles
- Exiting muons have worse momentum resolution which contributes to wider distribution here

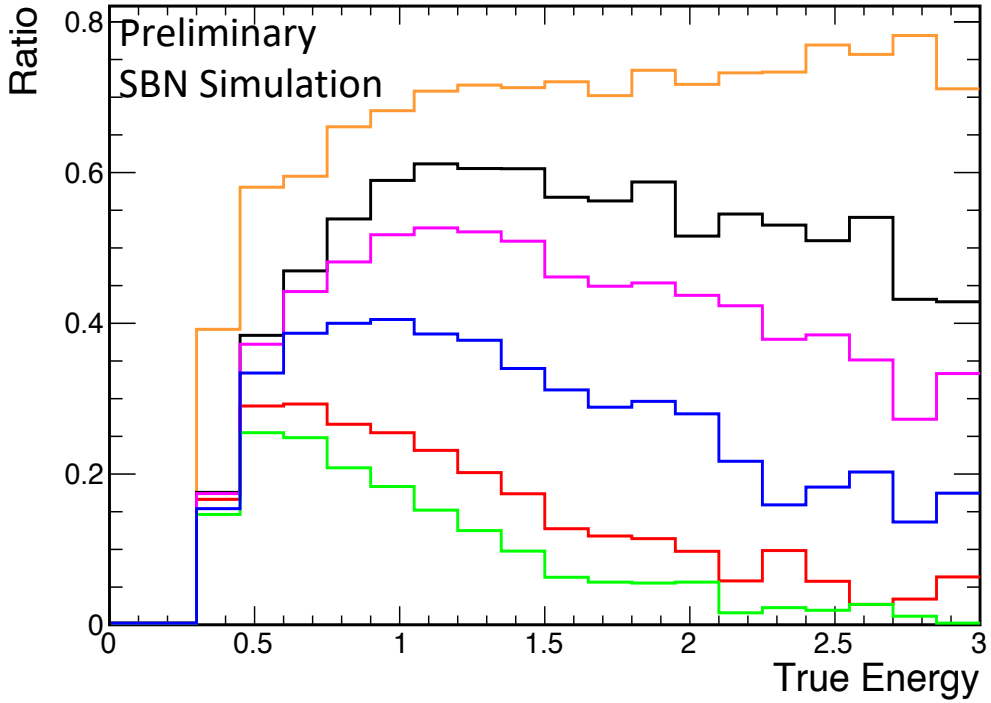
ν_μCC Selected Spectrum

Orange = Fake Reco (66.8%)
Black = ν_μCC selection (53.9%)
Pink = ν_μCC + contained hadrons (46.7%)
Blue = Pink + 0 Pion (35.2%)
Red = ν_μCC + all tracks contained (21.5%)
Green = Red + 0 Pion (15.3%)

Spectrum



Efficiency



Summary

- Can use ν_μ disappearance to study neutrino oscillations in the 3+1 model
- Initial event selection achieves reasonable purity and efficiency
- Performance can likely be improved with improved reconstruction and optimization of selection
- Neutrino energy reconstruction is close to true energy (ignoring neutral particles) for the majority of events
- ICARUS recently completed commissioning
  - Physics data coming soon!