Muon Neutrino Disappearance with the Fermilab Short-Baseline Neutrino Program

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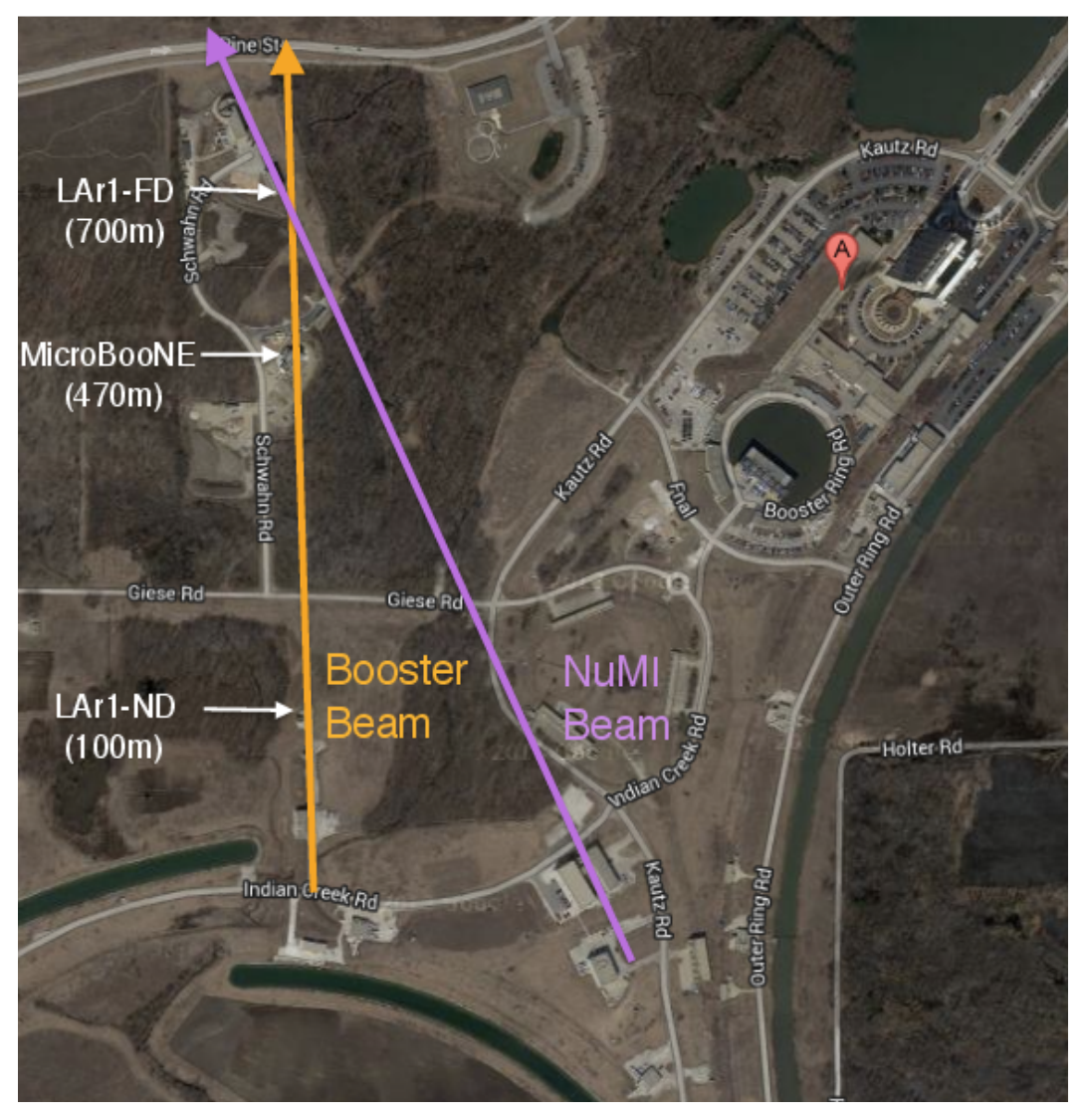
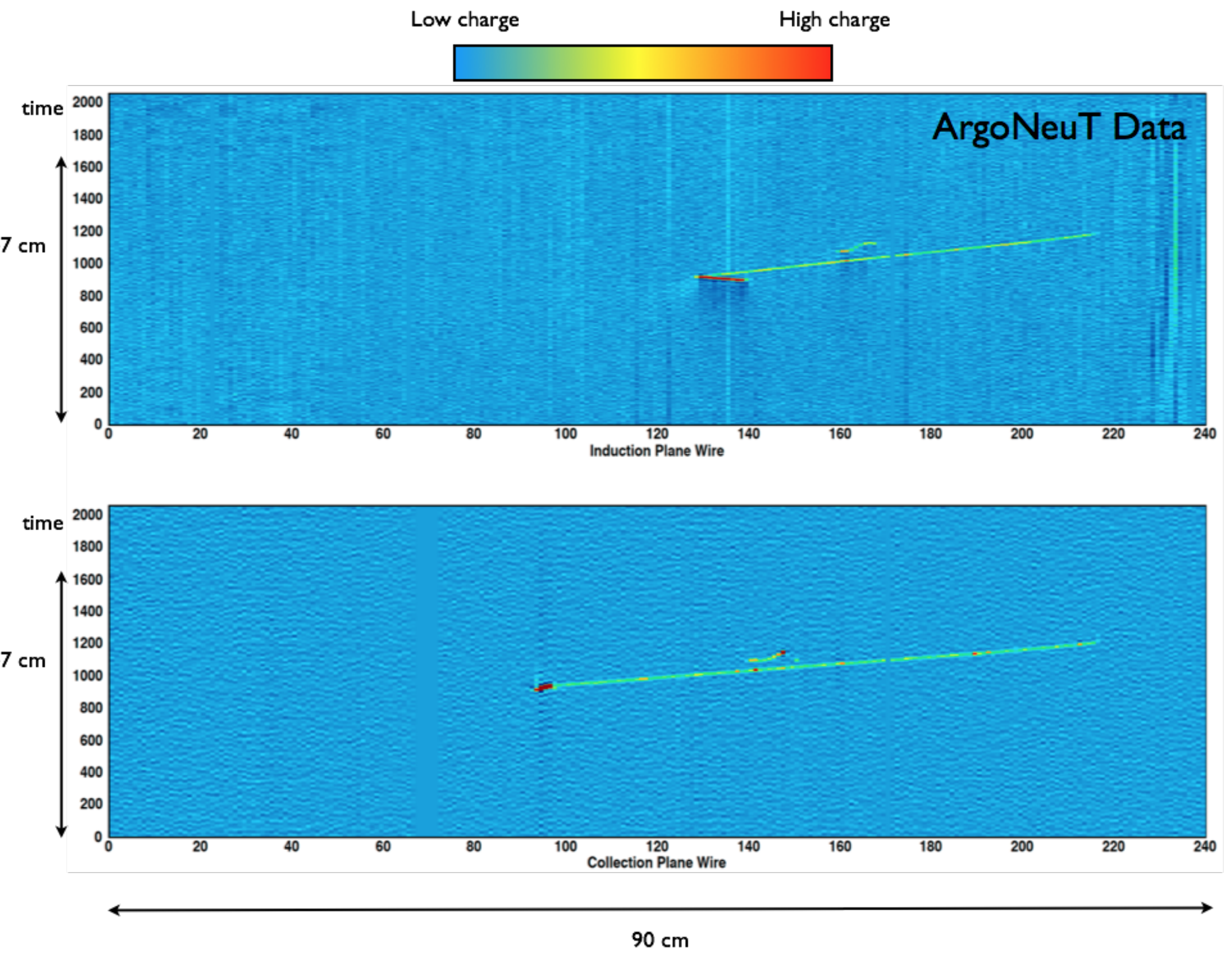
Fermilab SBN Program

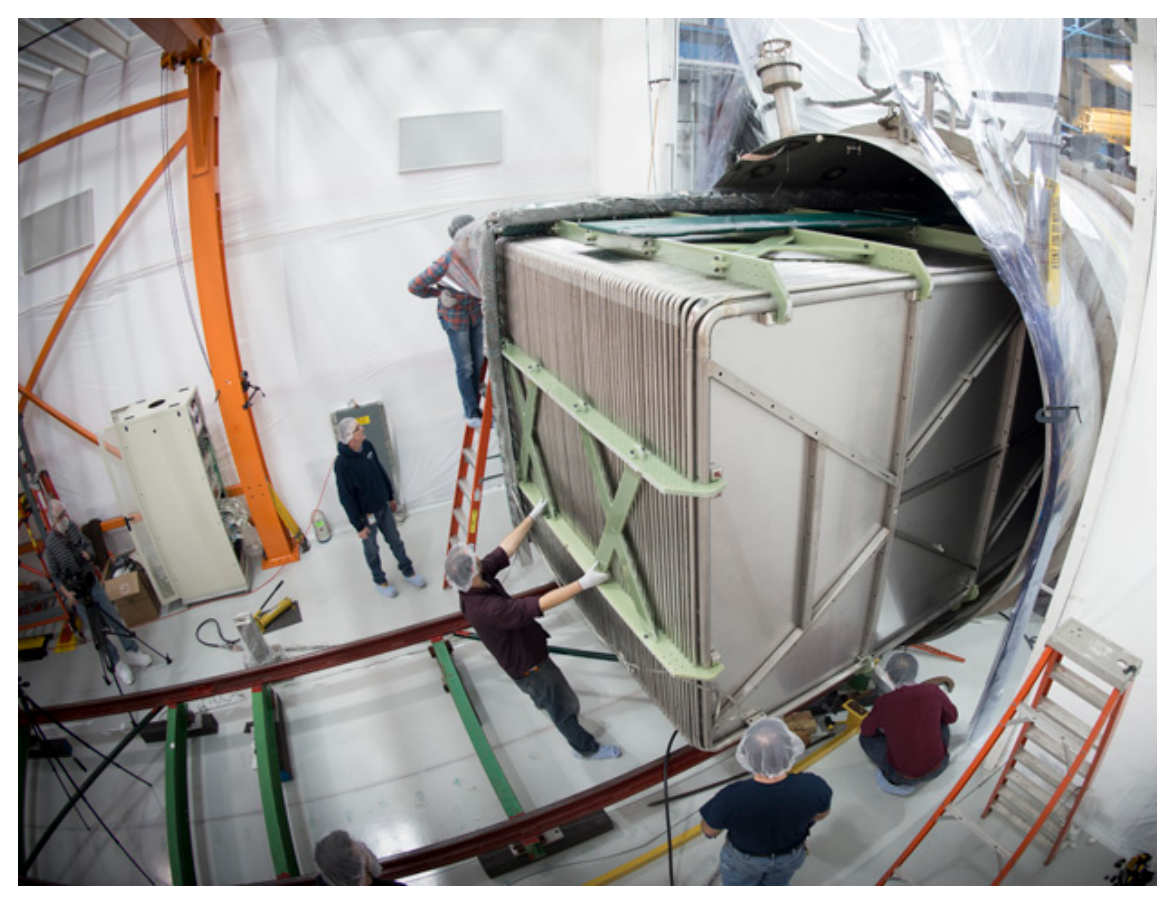


The existing Booster Neutrino Beam (BNB) and the exceptional reconstruction capabilities of the liquid argon TPC detector technology provide an opportunity to execute a world-leading short-baseline neutrino (SBN) physics program at Fermilab.

The main physics goals are to search for neutrino oscillations in different channels over a short-baseline (i.e. at high Δm^2) and to study the unexplained excess of electromagnetic events previously reported by the MiniBooNE experiment.



MicroBooNE



MicroBooNE is a 60 ton fiducial mass LAr TPC located 470 meters from the Booster neutrino target.

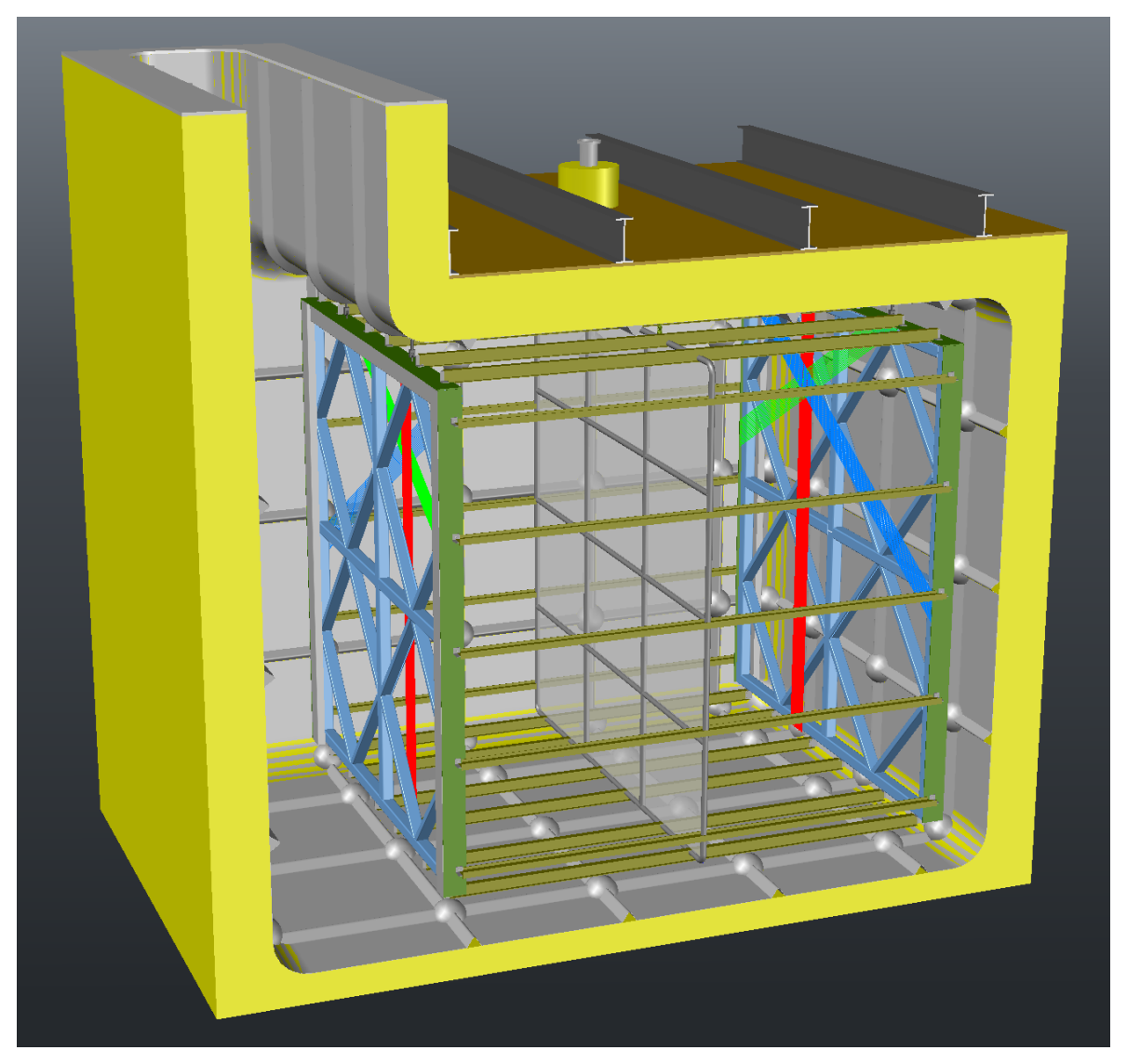
MicroBooNE will start taking data in late 2014/early 2015!

LAr Near Detector

The LAr Near Detector (LAr1-ND) is a proposed detector which would sit ~100 meters away from the Booster target.

It will provide a detailed characterization of the BNB, allowing for a near-to-far extrapolation between the two detectors and enabling precision searches for neutrino oscillations

At this location and with a 50 ton fiducial mass, LAr1-ND will accumulate 1 million neutrino events per year!



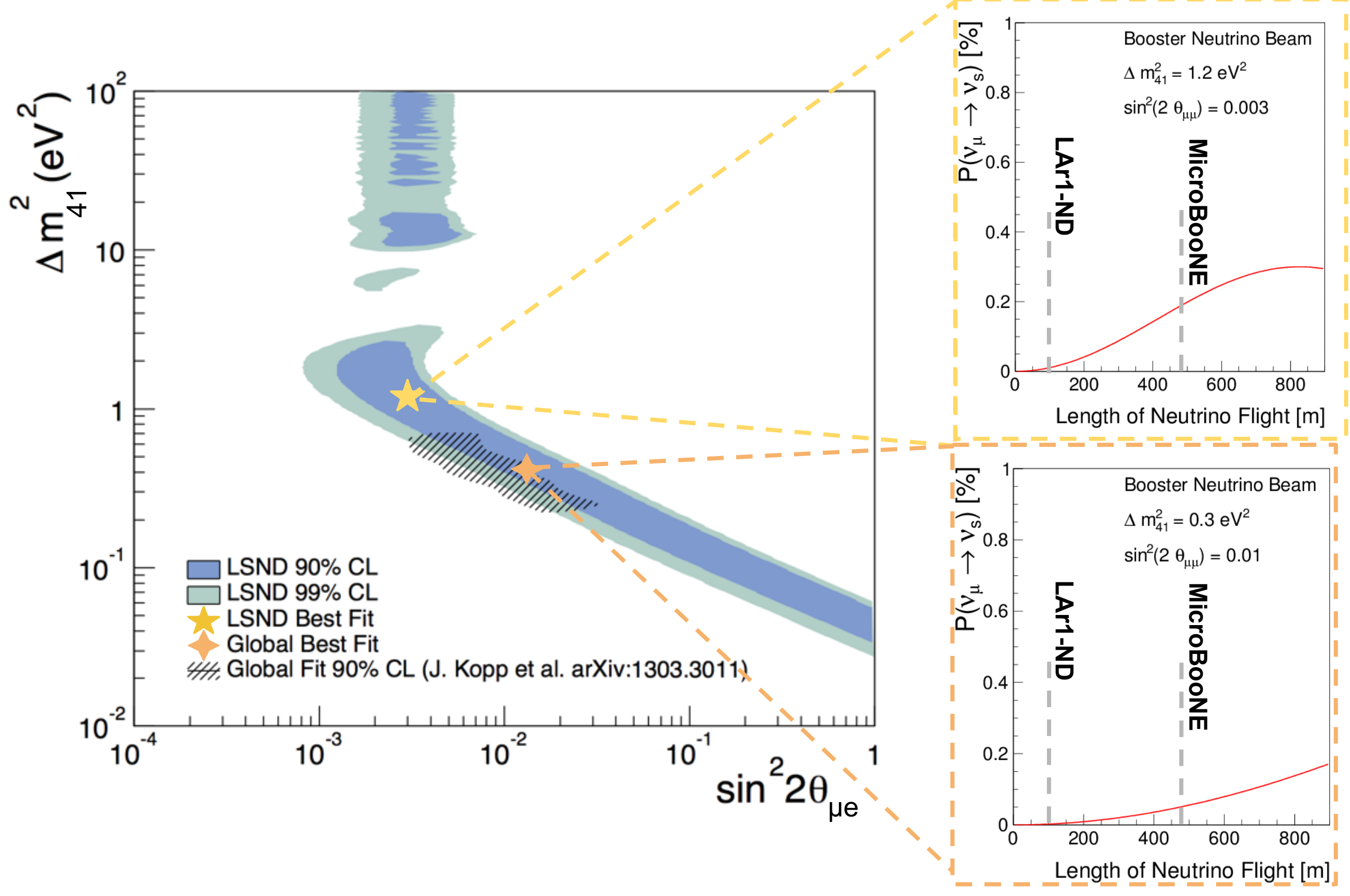
ν_μ *Events (By Final State Topology)*

Process		No. Events
CC Inclusive		787,847
CC 0 π	$\nu_\mu N \rightarrow \mu + Np$	535,673
	$\cdot\ \nu_\mu N \rightarrow \mu + 0\text{p}$	119,290
	$\cdot\ \nu_\mu N \rightarrow \mu + 1\text{p}$	305,563
	$\cdot\ \nu_\mu N \rightarrow \mu + 2\text{p}$	54,287
	$\cdot\ \nu_\mu N \rightarrow \mu + \geq 3\text{p}$	56,533
CC 1 $\pi^\pm$	$\nu_\mu N \rightarrow \mu + \text{nucleons} + 1\pi^\pm$	176,361
CC $\geq 2\pi^\pm$	$\nu_\mu N \rightarrow \mu + \text{nucleons} + \geq 2\pi^\pm$	14,659
CC $\geq 1\pi^0$	$\nu_\mu N \rightarrow \text{nucleons} + \geq 1\pi^0$	76,129
NC Inclusive		300,585
NC 0 π	$\nu_\mu N \rightarrow \text{nucleons}$	206,563
NC 1 $\pi^\pm$	$\nu_\mu N \rightarrow \text{nucleons} + 1\pi^\pm$	39,661
NC $\geq 2\pi^\pm$	$\nu_\mu N \rightarrow \text{nucleons} + \geq 2\pi^\pm$	5,052
NC $\geq 1\pi^0$	$\nu_\mu N \rightarrow \text{nucleons} + \geq 1\pi^0$	54,531

From GENIE Simulations

SBN Oscillations

Multiple experimental results have provided tantalizing hints of the existence of an eV scale sterile neutrino. A SBN beam is an excellent place to search for such a particle through the oscillation of the initial neutrinos into this sterile state.



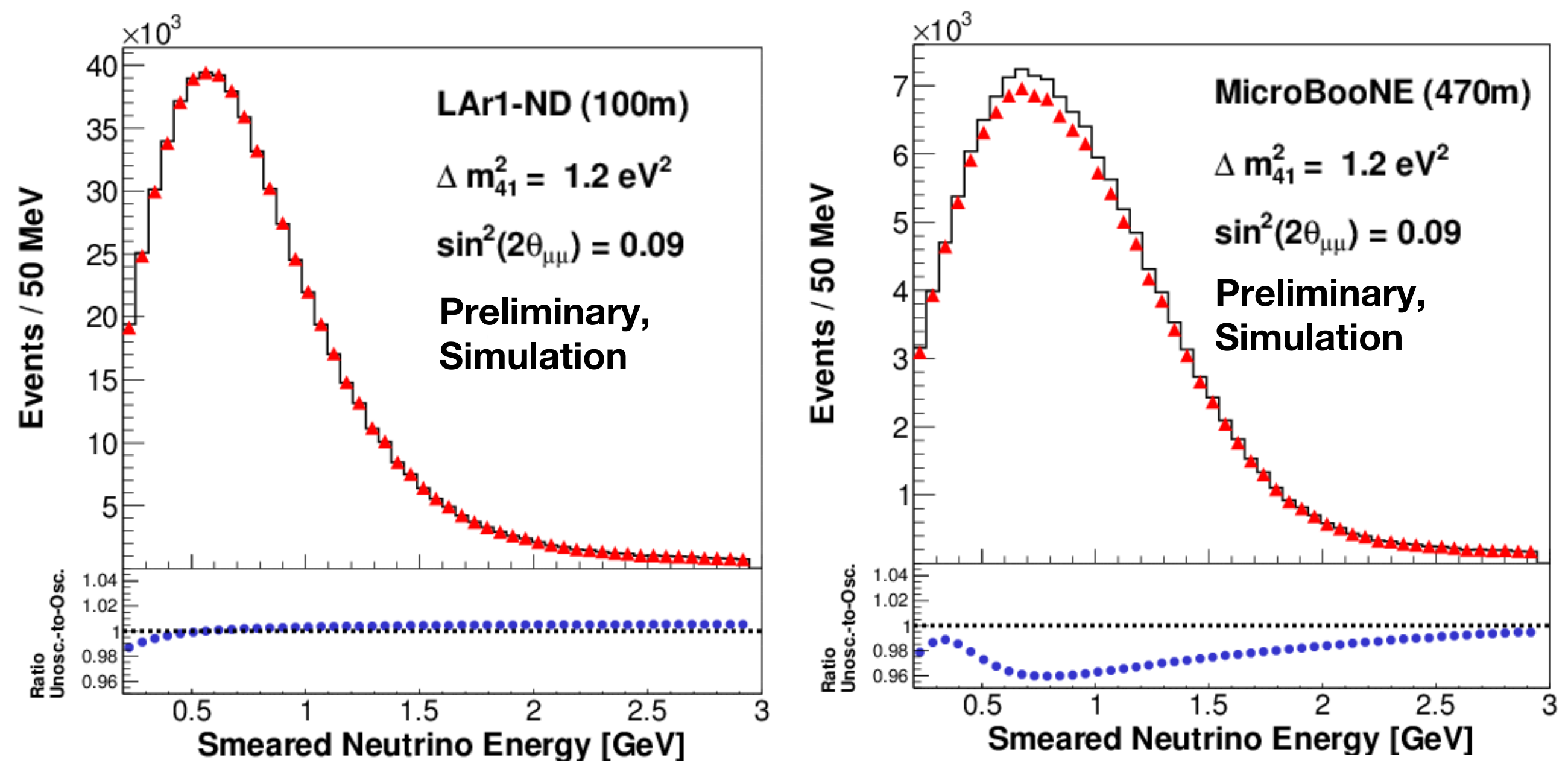
An important channel to look for evidence of oscillations with sterile neutrinos is muon neutrino disappearance. The disappearance oscillation probability is given by:

$$P^{3+1}_{\nu_\mu \rightarrow \nu_s} = \sin^2 2\theta_{\mu\mu} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

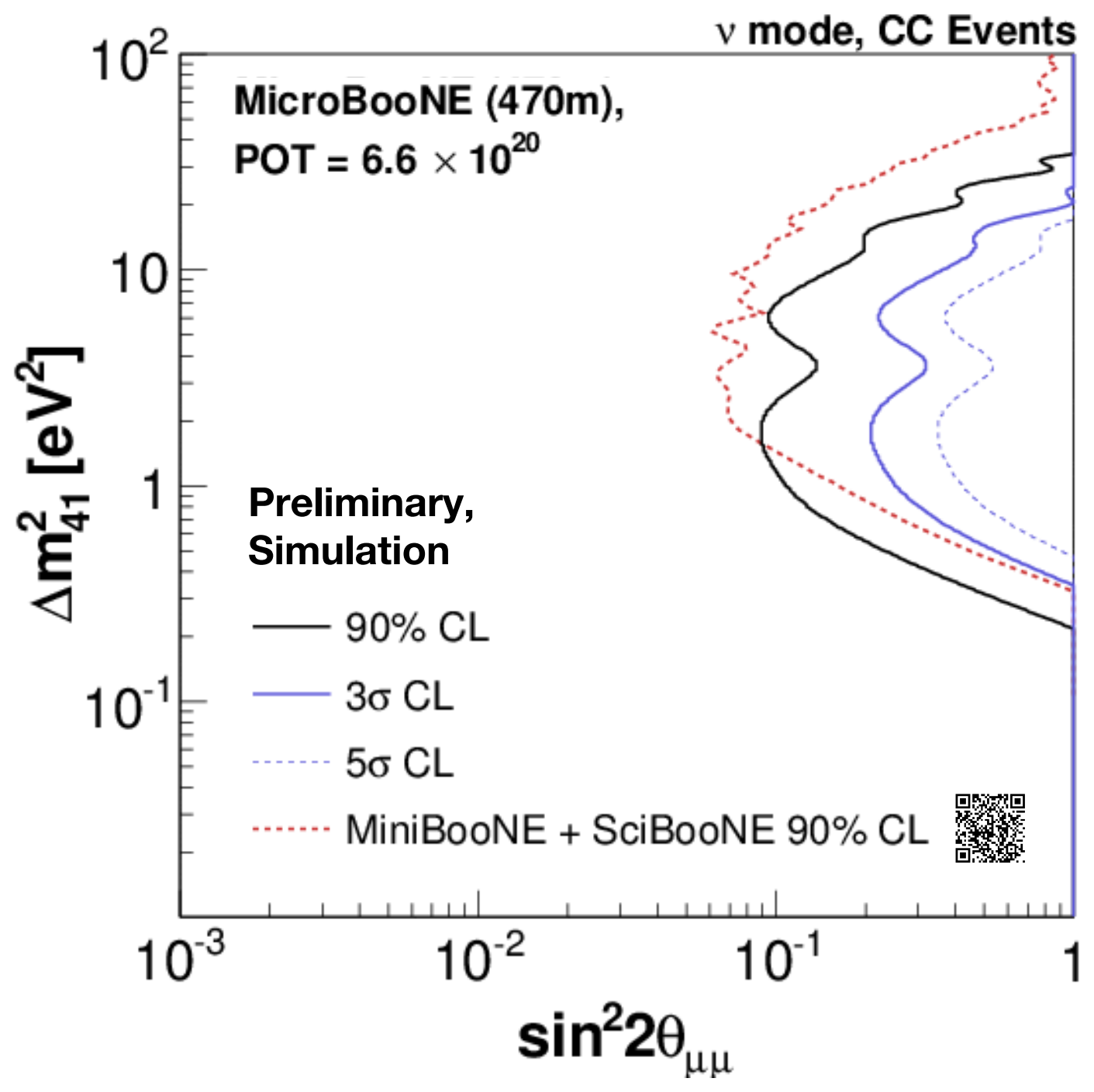
ν_μ Disappearance Oscillation Signal

Legend

▲ = Oscillated Signal ▬ = Unoscillated Spectrum ● = Ratio



One Detector ν_μ Disappearance



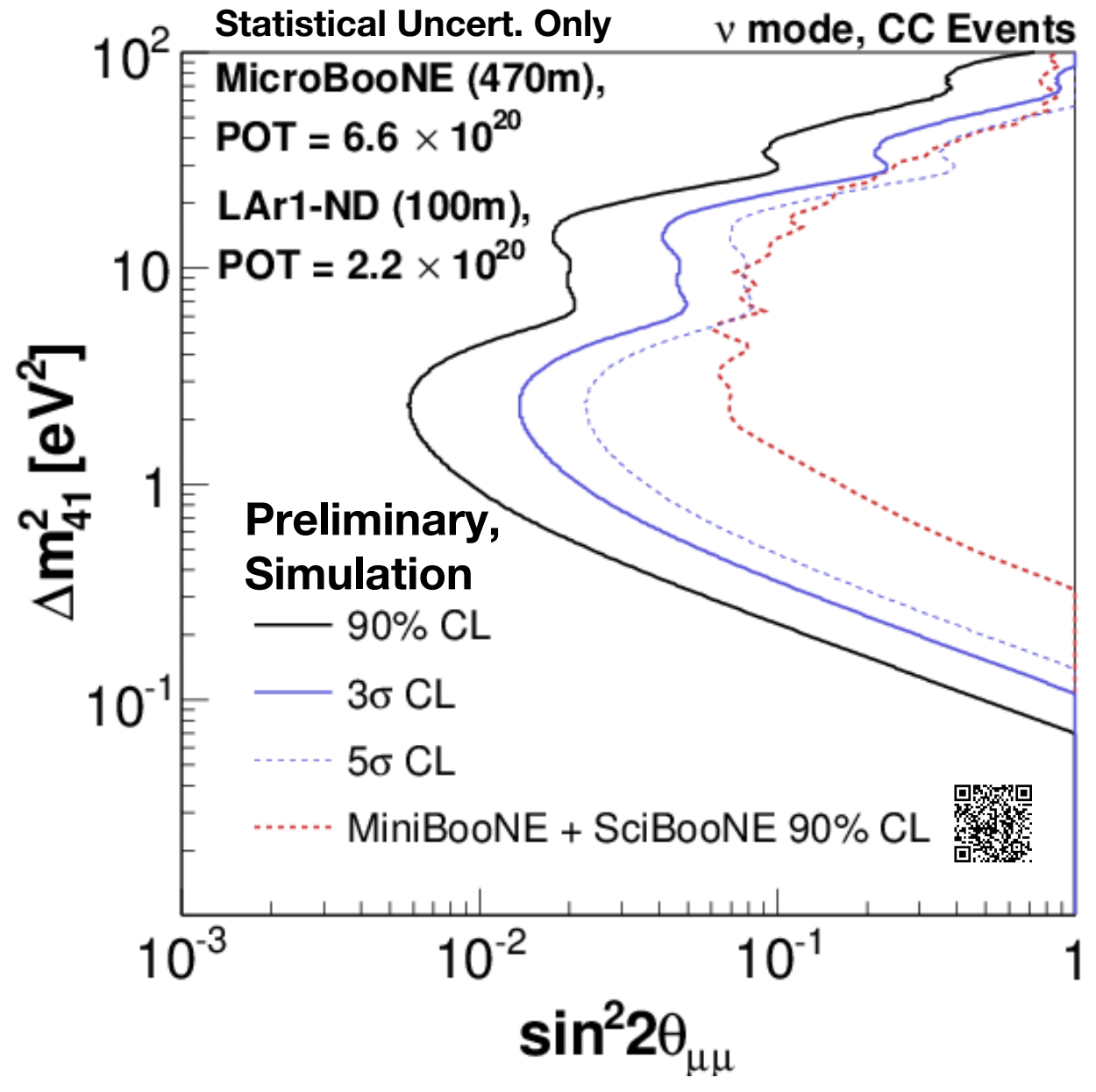
When using only a single detector, large uncertainties (~15-20%) in the absolute event rate obscure our ability to resolve oscillation effects in the muon neutrino energy spectrum.

Two Detector Sensitivities

With two detectors at different baselines, the systematics can be significantly reduced by taking the unoscillated spectrum from the near detector and extrapolating it to the far detector.

This reduces the uncertainties associated with the cross section and flux, which are constrained by the statistical precision of the near detector measurement. Relative detector effects are assumed to be negligible for these studies.

Statistical Uncertainty Only

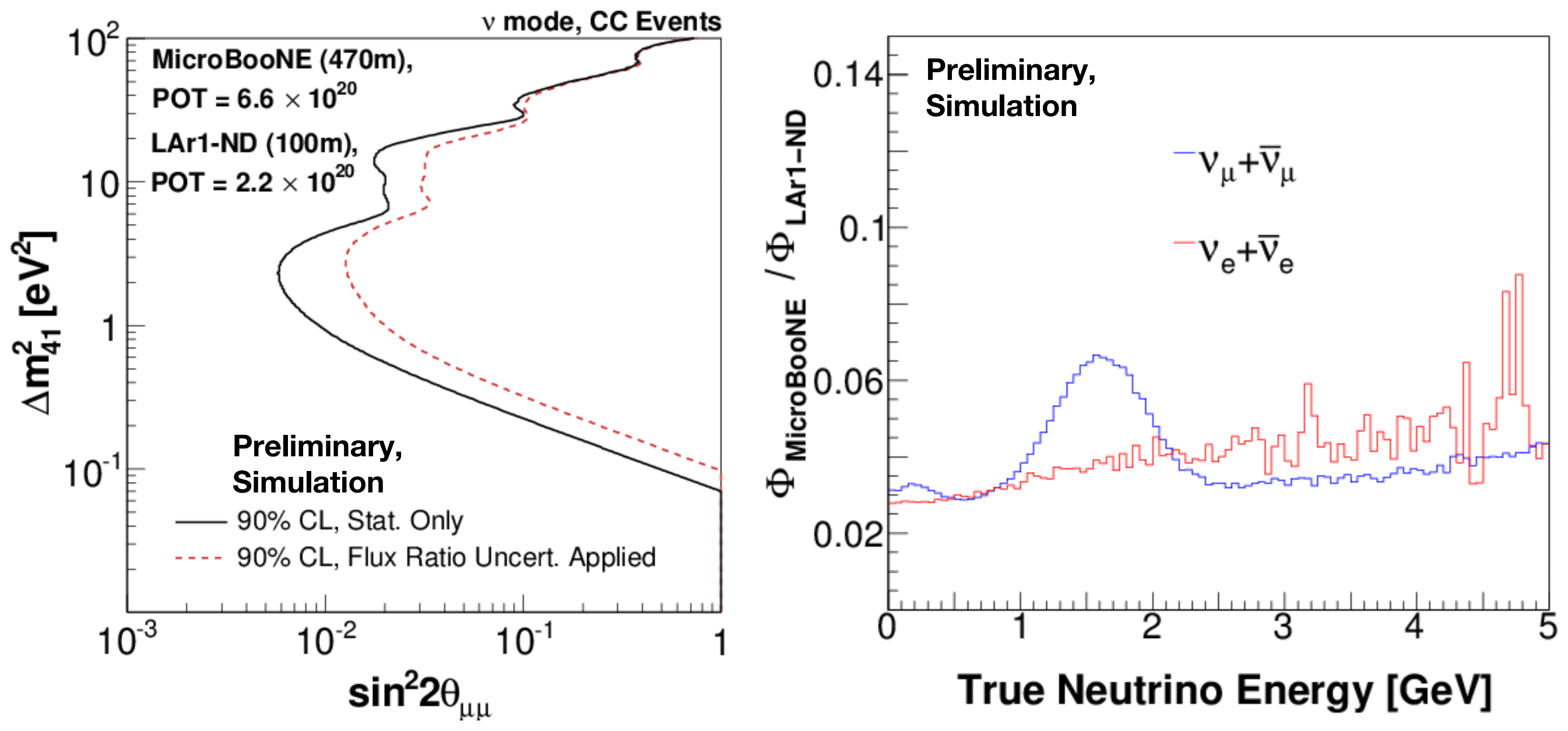


LAr1-ND will provide a large data sample with small statistical uncertainties.

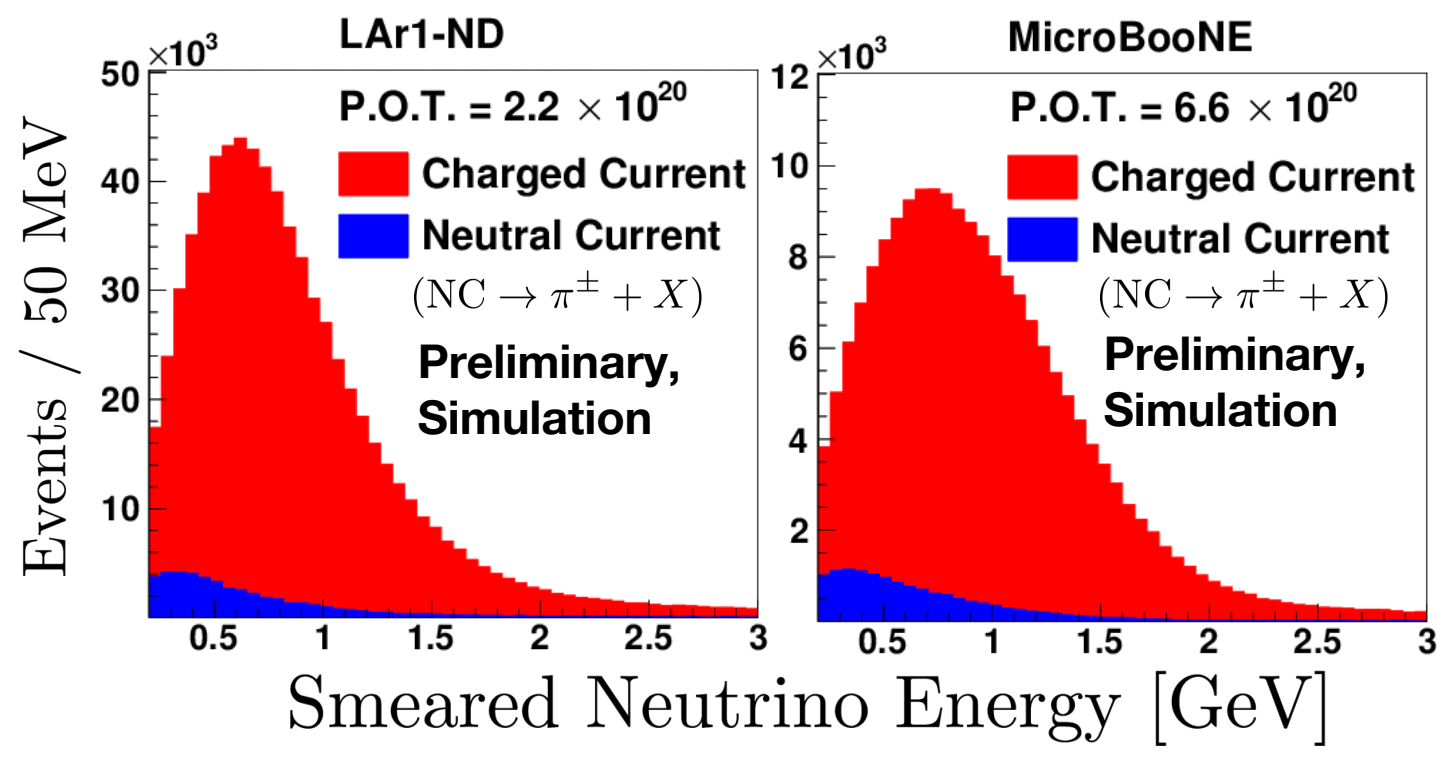
If we assume no other systematics associated with the extrapolation we see that we can cover the previous MiniBooNE+SciBooNE limit (PRD **86**, 05200) at 5σ.

Near-to-Far Flux Ratio

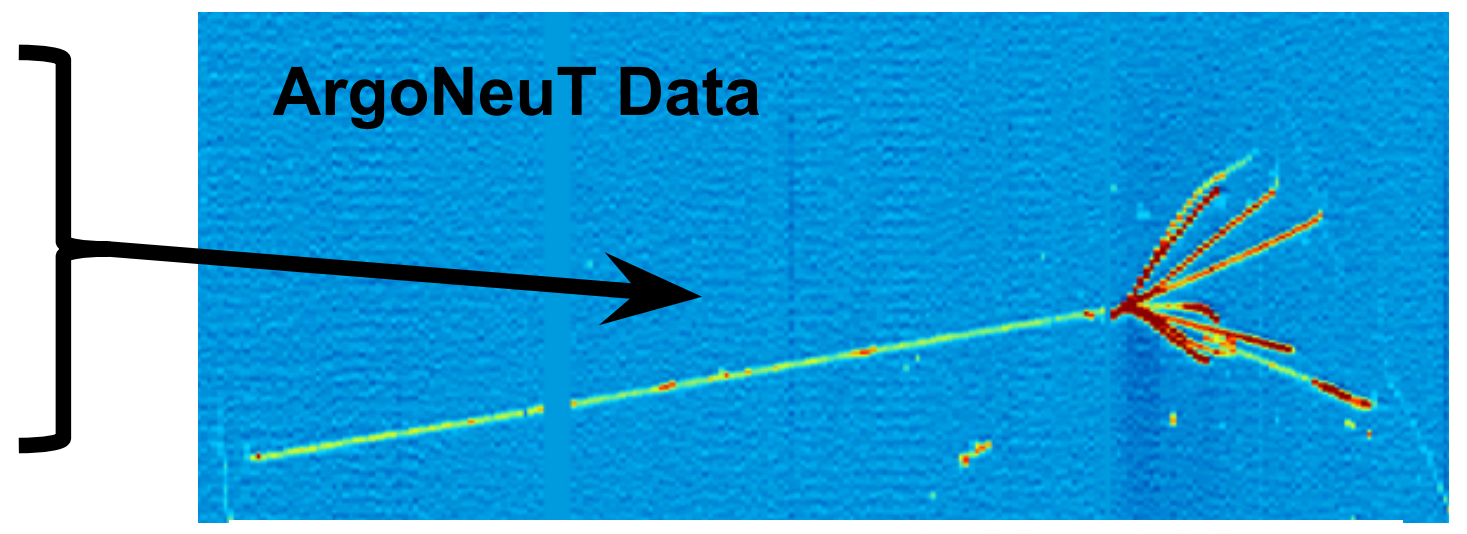
An advanced BNB simulation, based on dedicated hadron production data, will allow detailed study of the correlations between near and far fluxes. Here we show the impact of a 3% uncorrelated systematic uncertainty as an example.



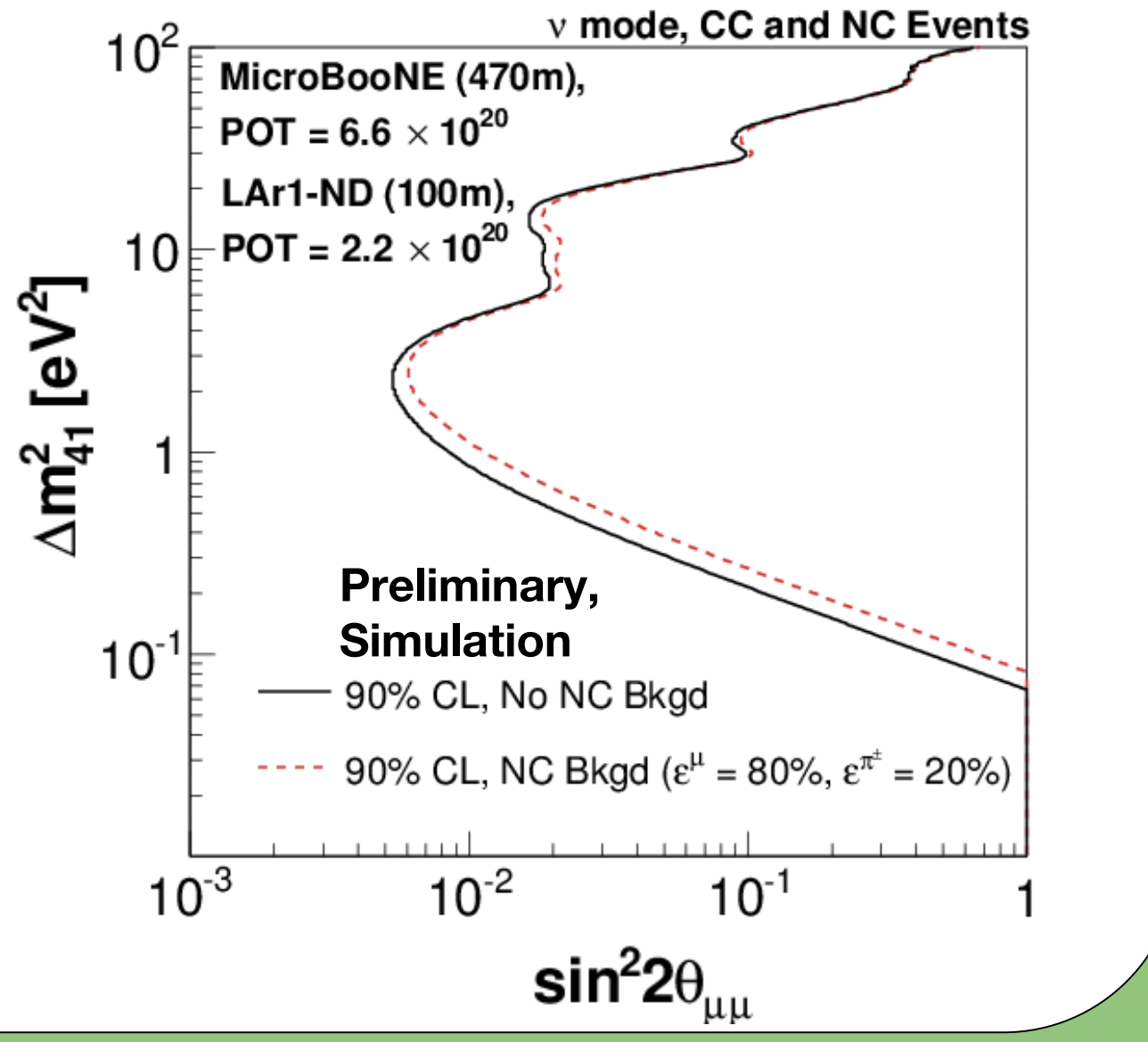
Neutral Current Events



Neutral Current (NC) events containing a charged pion form a background for this analysis since the pion ionization energy loss is the same as for muons.



Efficiencies for separating muons from charged pions in LAr are being investigated.



Here we show, as an example, an 80% efficiency for identifying muons with a 20% charged pion misidentification rate and a 30% uncertainty on this NC background fraction. The impact on the muon neutrino disappearance sensitivity is small.