Effect of Neutrino Interaction Systematics for Future Sterile Neutrino Searches with Accelerator Beams

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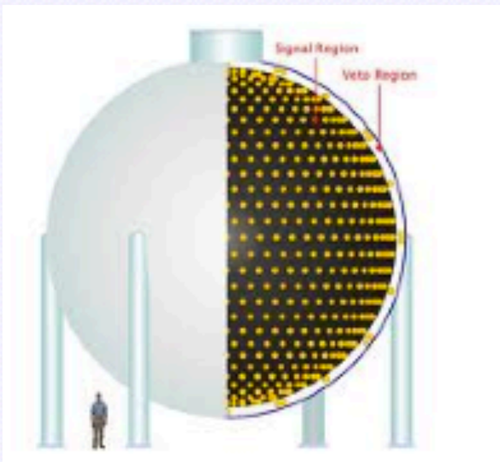
Yale University

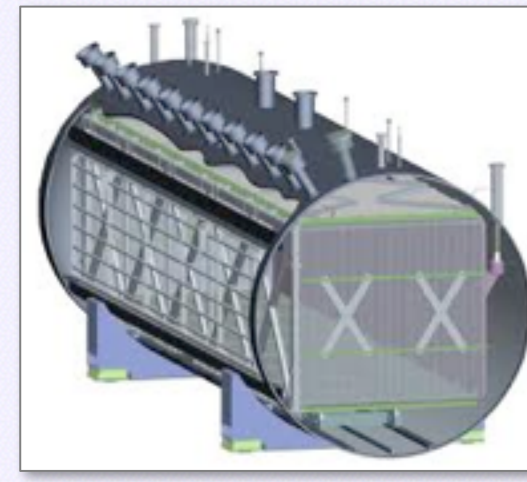
NuInt 2014

Roadmap

Focusing on **Booster Neutrino Beam**

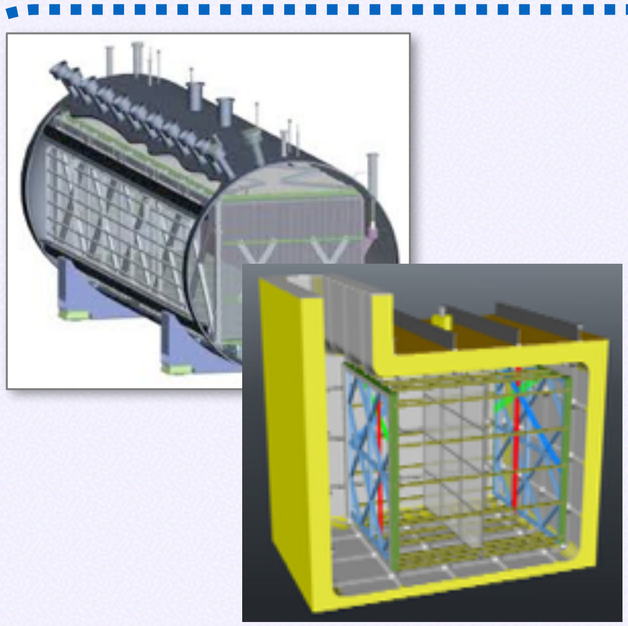


Reduce Photon Background →

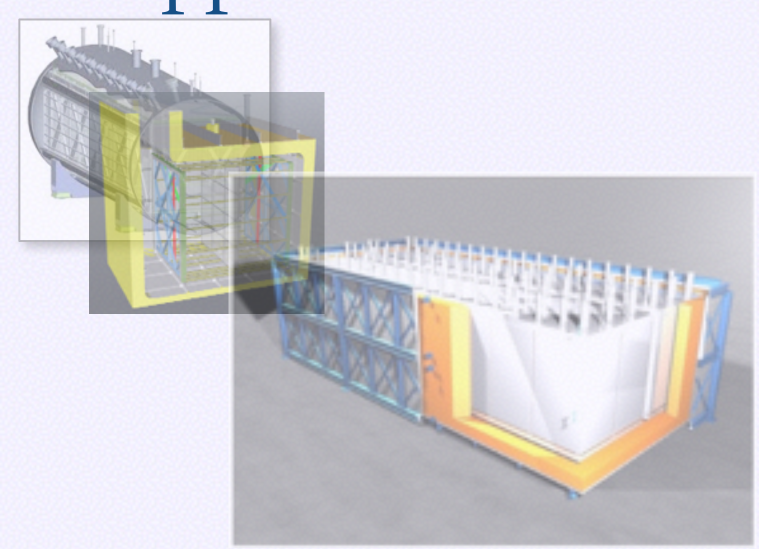


← Reduce flux and cross section uncertainties

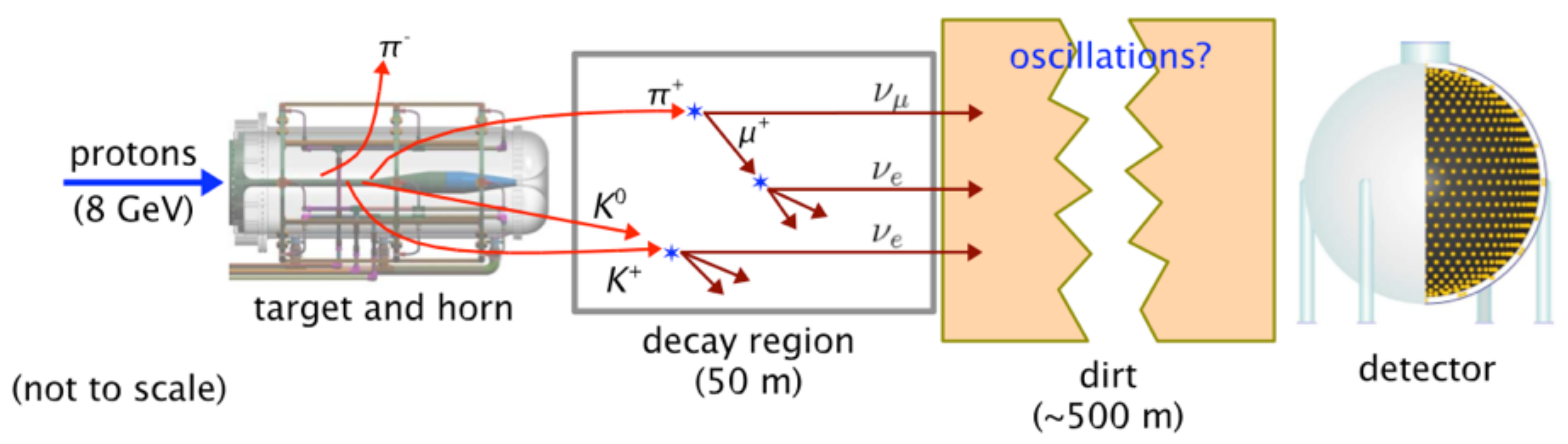
Oscillation searches happen here



Increase Statistics? Multiple Baselines? →

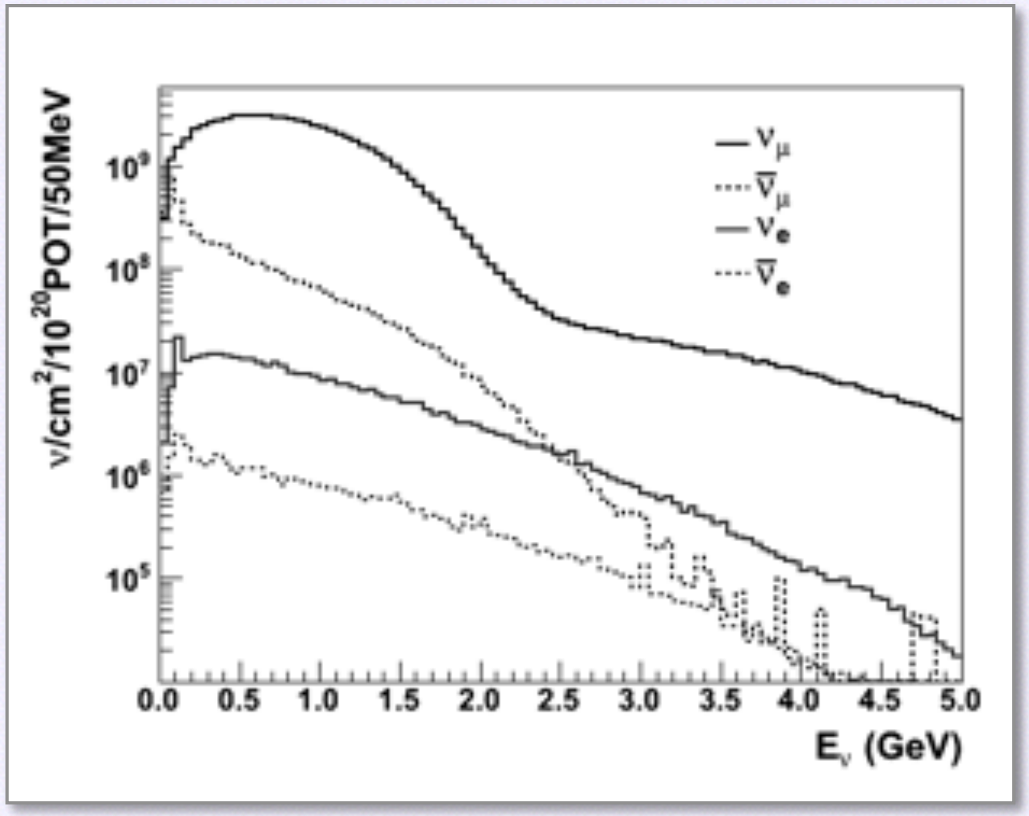


Booster Neutrino Beam @ FNAL



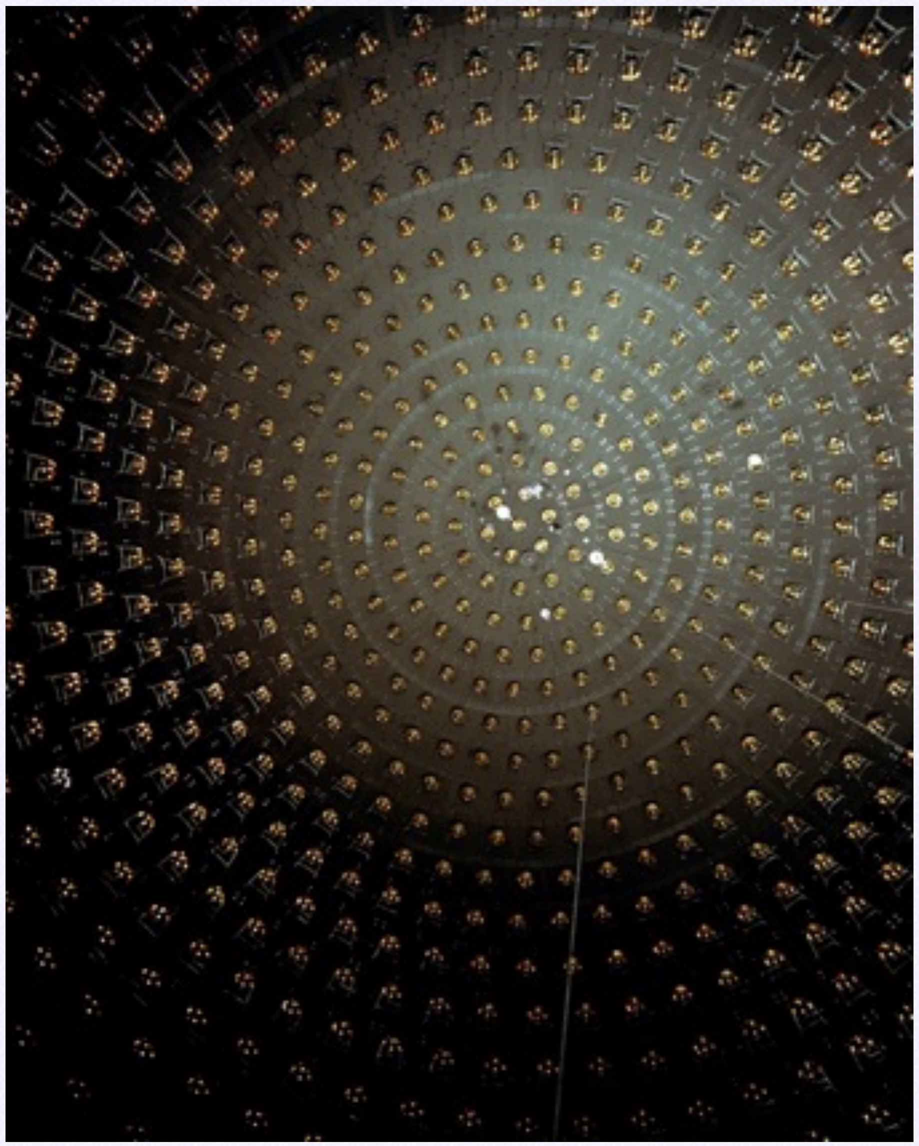
	ν_μ	$\bar{\nu}_\mu$	ν_e	$\bar{\nu}_e$
Neutrino	93.5%	5.9%	0.5%	0.1%
Anti-Neutrino	83.7%	15.7%	0.4%	0.2%

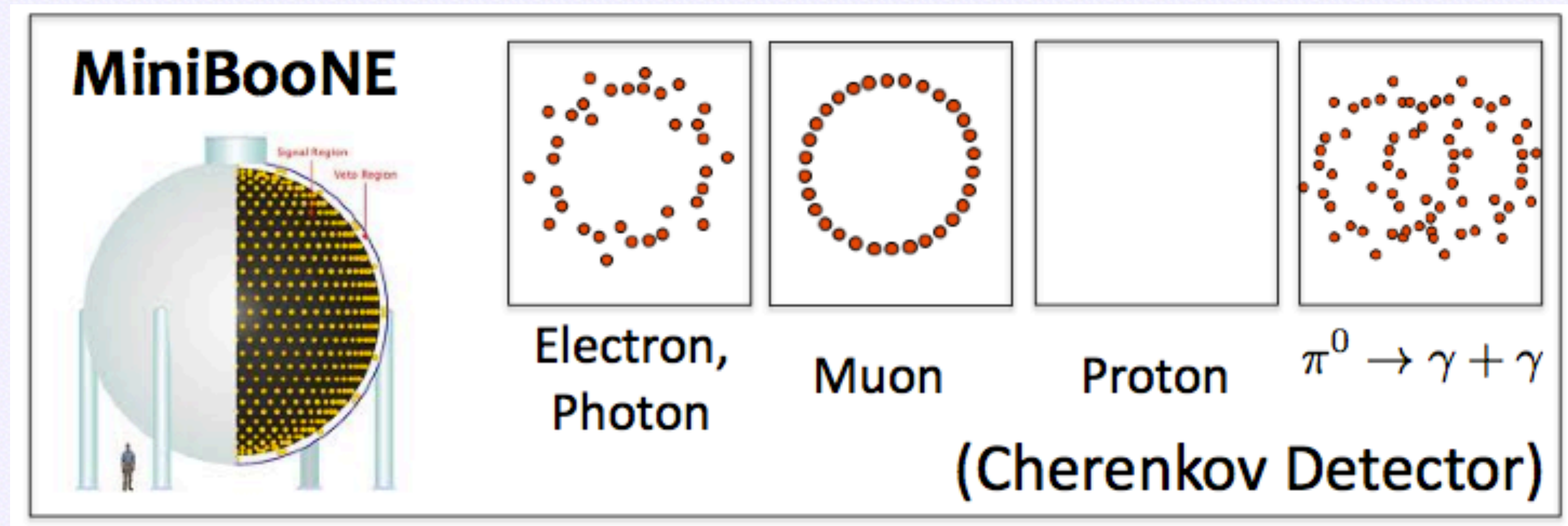
A. A. Aguilar-Arevalo et al., Phys. Rev. Lett. 110 161801 (2013)



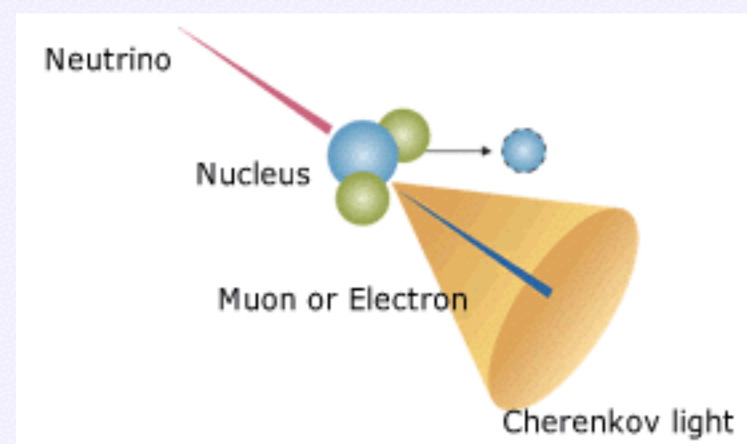
Intrinsic ν_e from the beam are the irreducible background in a ν_e appearance search.

MiniBooNE Detector





$$\nu_e + n \to e^- + p$$



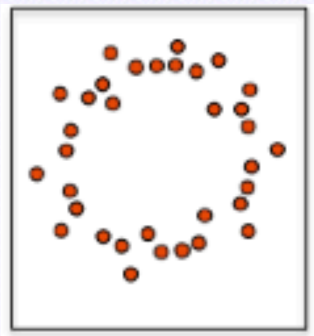
Neutral Pion Background

Largest Backgrounds:

π°, single γ misID

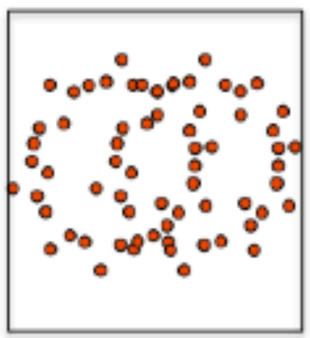
$$\nu_\mu + N \rightarrow \Delta + \nu_\mu$$
$$\Delta \rightarrow N + \pi^0$$
$$\Delta \rightarrow N + \gamma$$

(not to mention all the other channels and FSI)



Electron, Photon

vs.

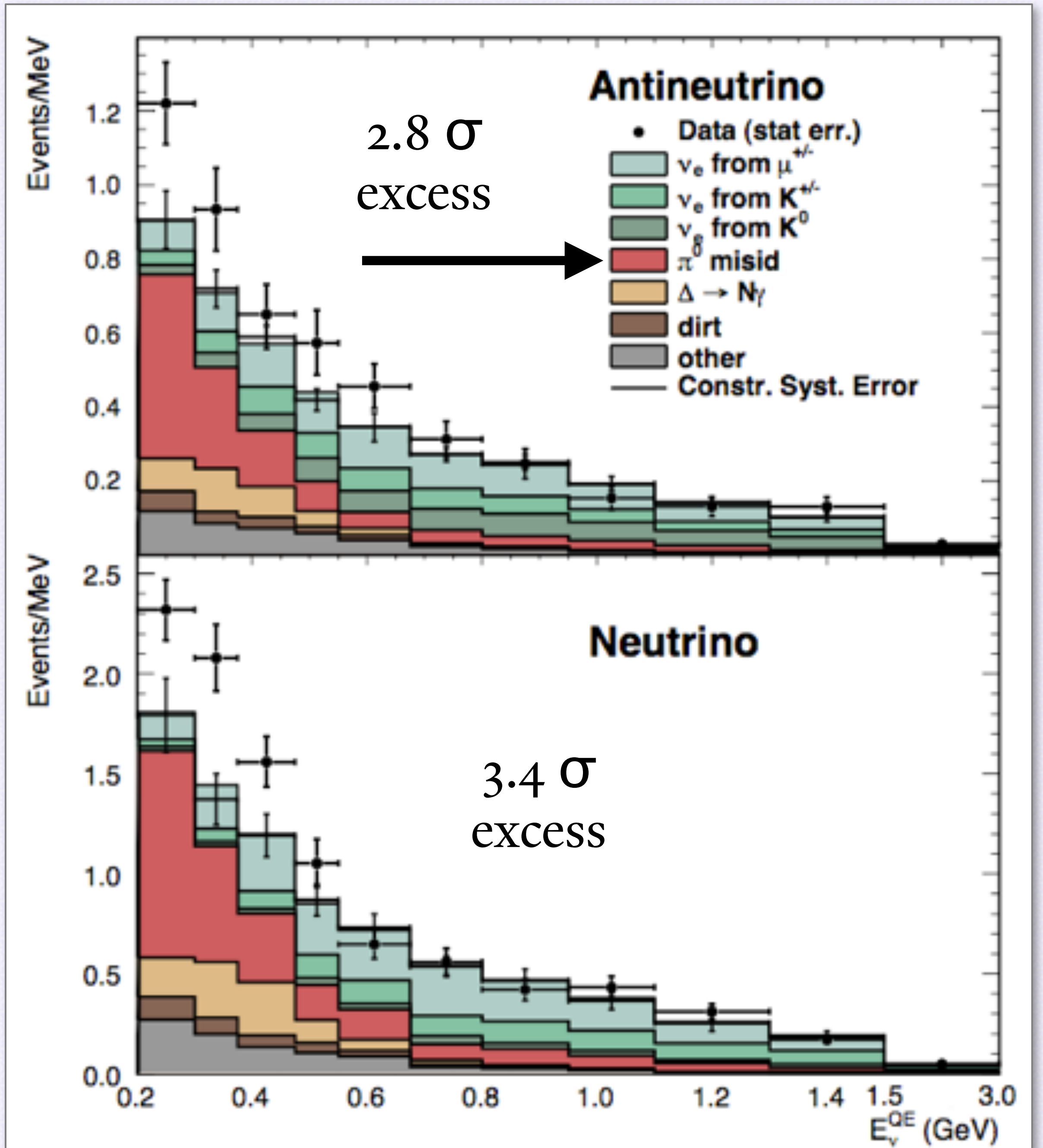


$\pi^0 \rightarrow \gamma + \gamma$

Easy to tag a π° as an electron if only one ring is visible (no particle ID for electron vs. photon).

Dominant Background - rate of π° production + detector response needs to be well understood.

MiniBooNE ν_e Appearance



A. A. Aguilar-Arevalo et al., Phys. Rev. Lett. 110 161801 (2013)

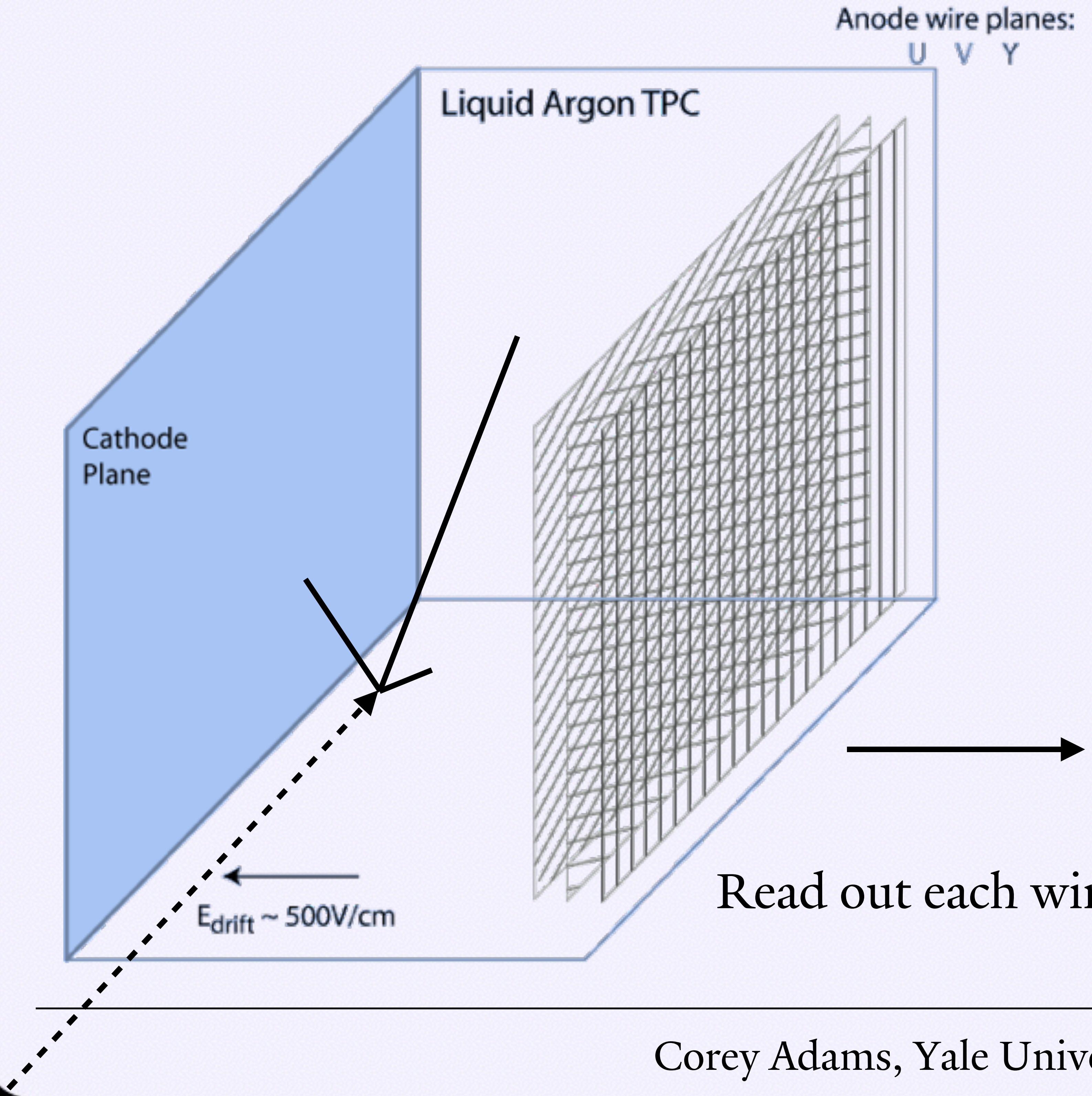
Not Hopeless!

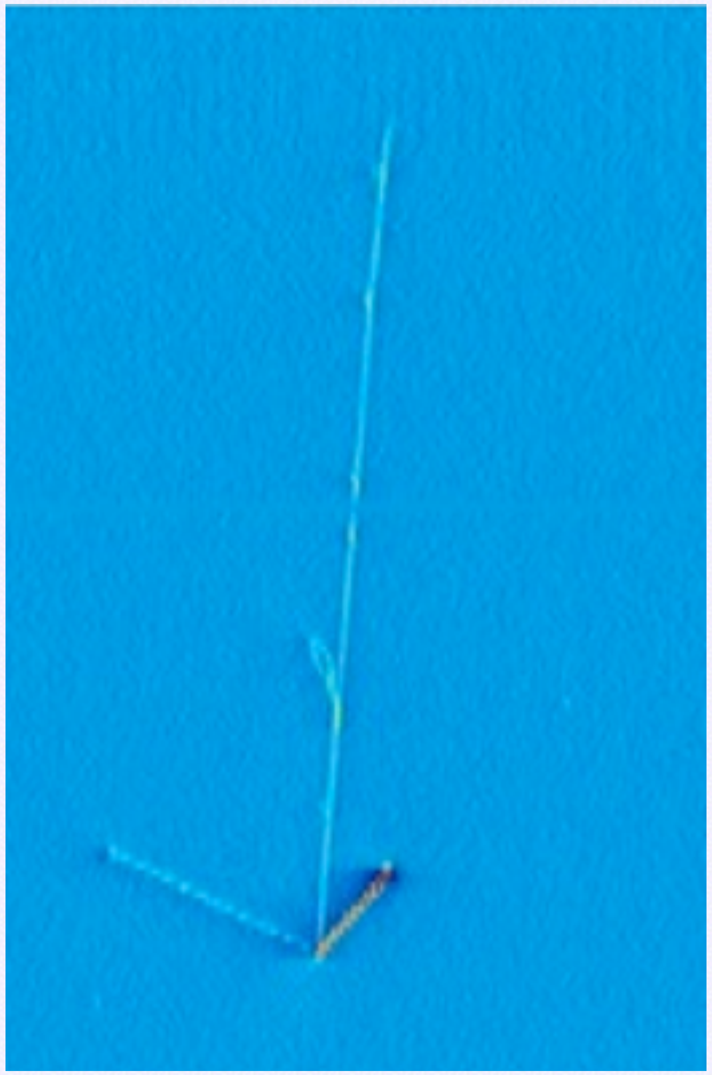
High Statistics **2 photon** measurement can constrain single photon background.

Need to control neutral pions in future ν_e appearance experiments.

LArTPC

The **L**iquid **Ar**gon **T**ime **P**rojection **C**hamber

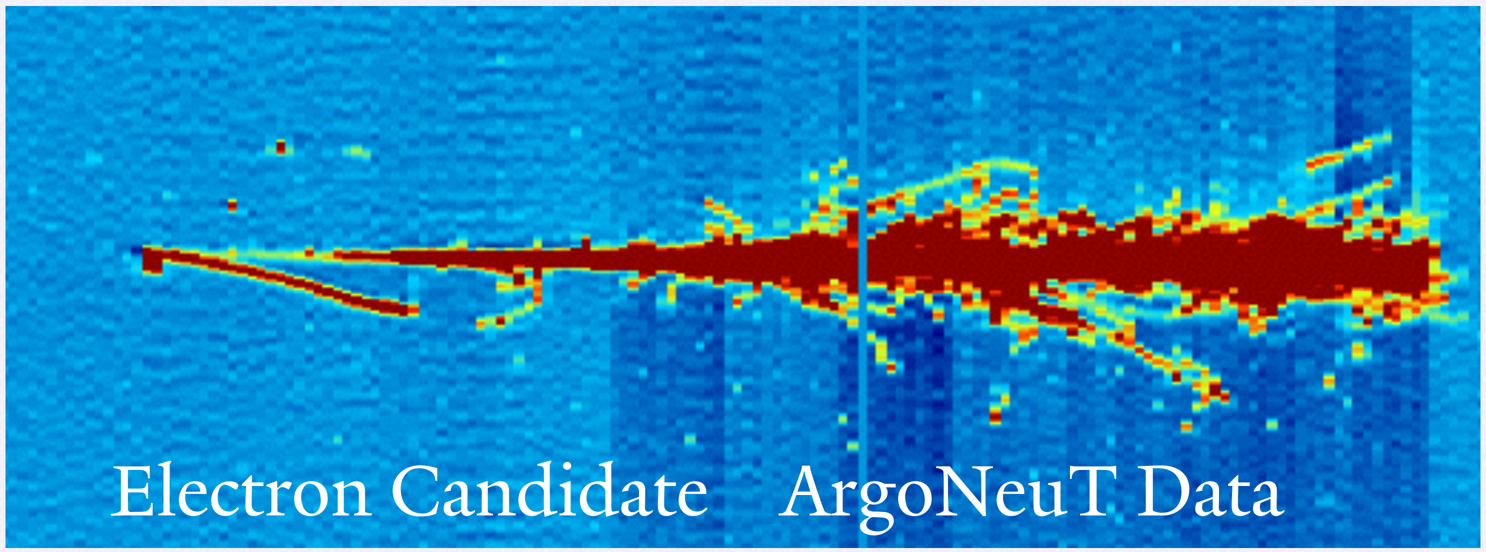




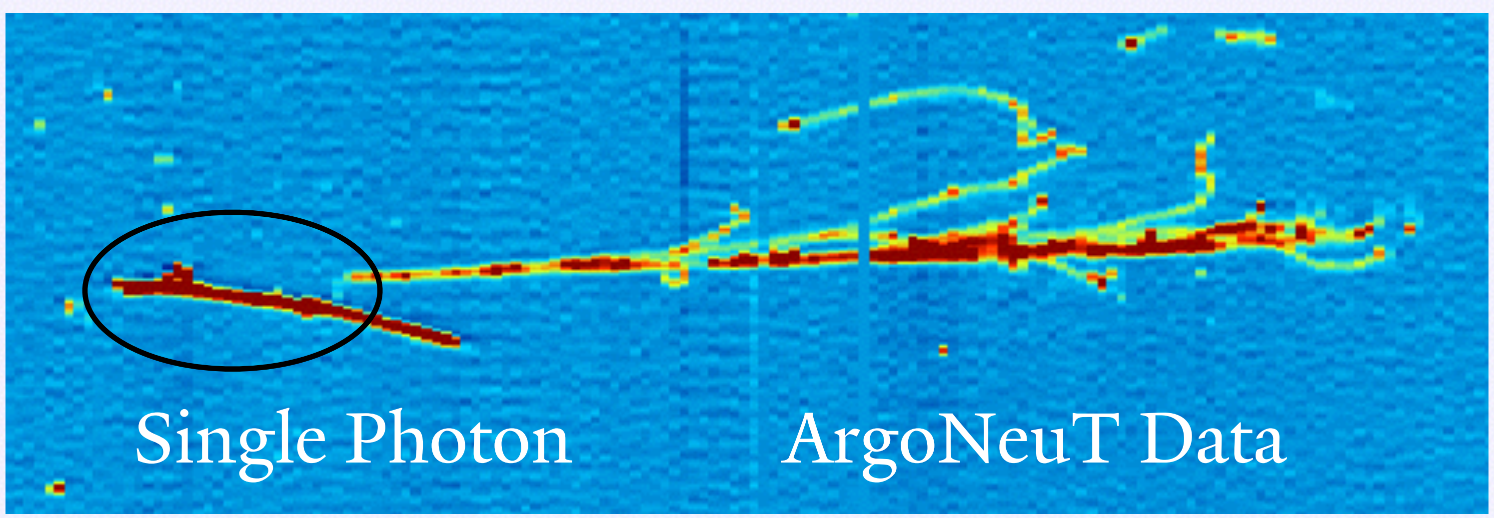
Read out each wire

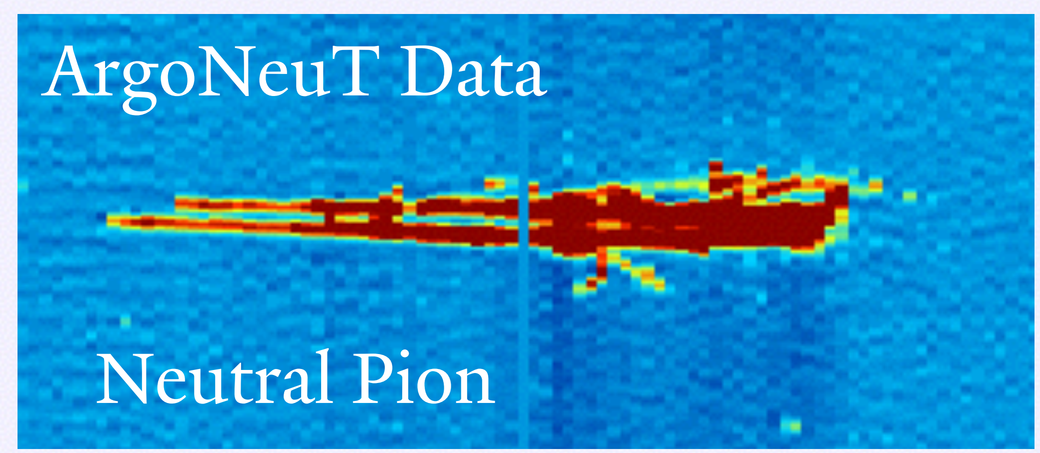
ν_e experimental Signature - LAr

Topological Separation of Electrons, Neutral Pions and Photons



Only Possible with a fine grained detector

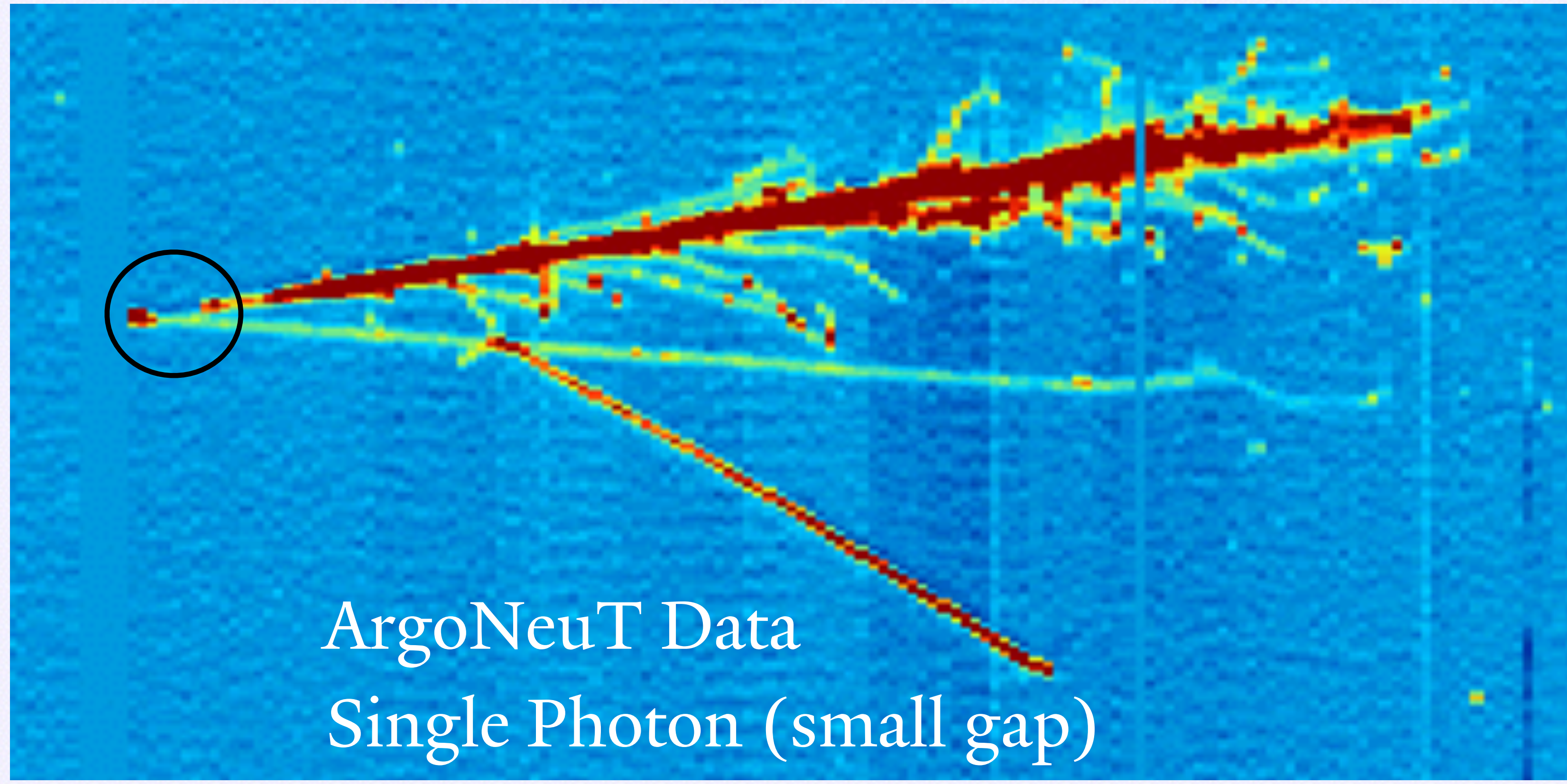




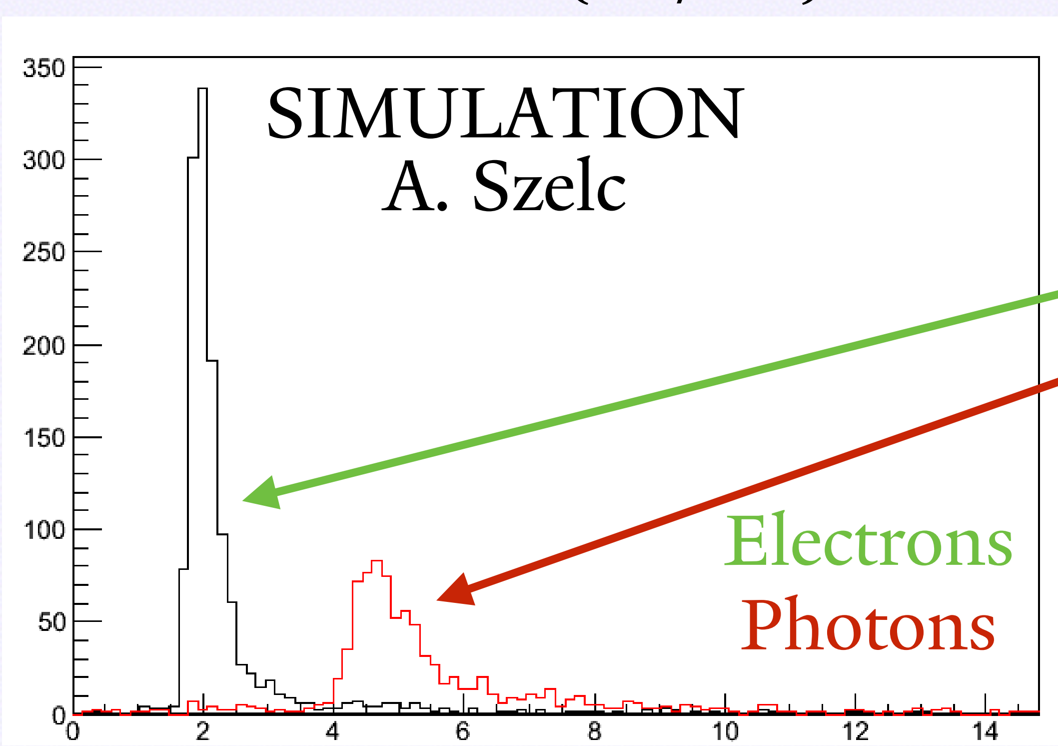
~5cm gap

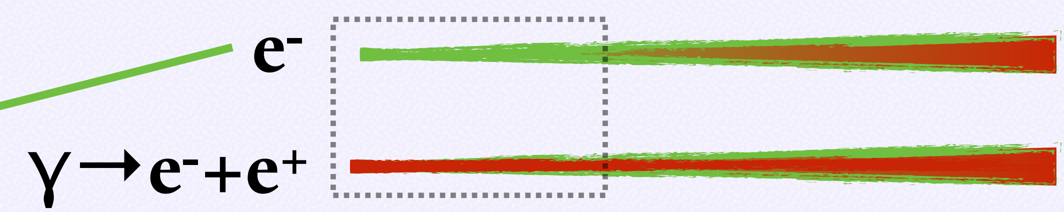
ν_e experimental Signature - LAr

Calorimetric Separation of Electrons and Photons



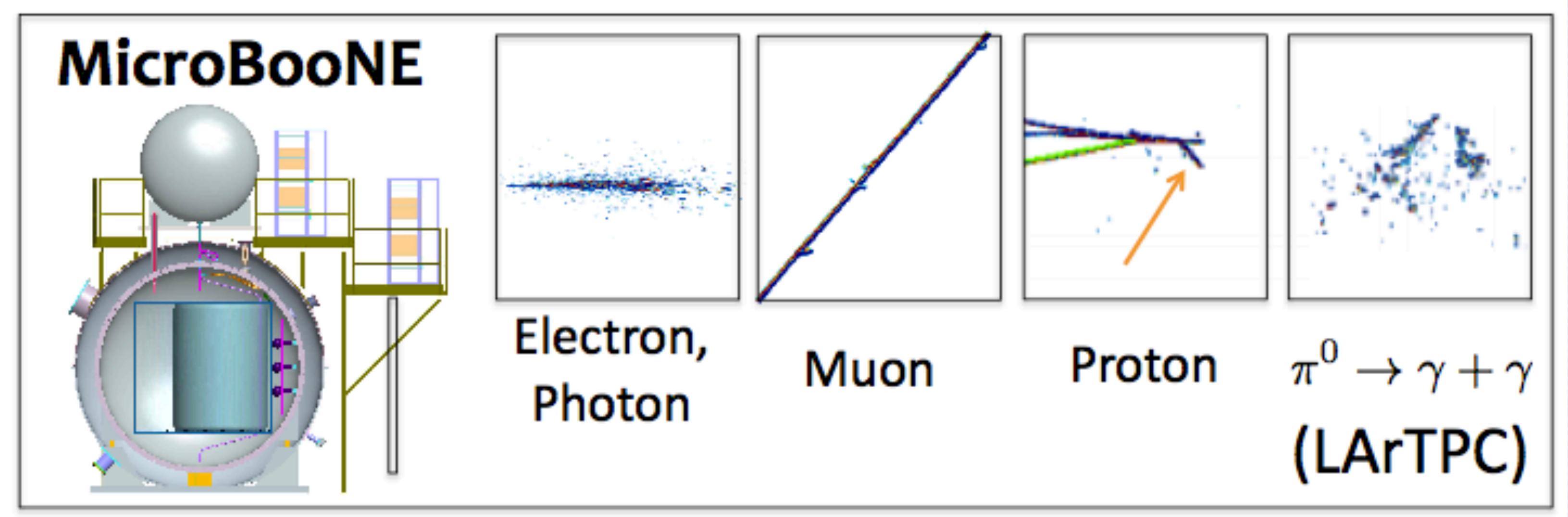
Charge per length at the start of the shower (dE/dX)





See talk by J. Asaadi - Sat 24 May
New results from A. Szelc expected @ Neutrino 2014!

Energy Reconstruction



$$E_\nu^{QE} = \frac{ME_\mu - m_\mu^2/2}{M - E_\mu + |\vec{p}_\mu| cos\theta_\mu}$$

$$E_\nu^{Cal.} = E_{lep} + \sum KE_{vis} + E_{missing}$$

CCQE Formula

Calorimetric Reconstruction

Visible KE can be constrained by test beam experiments (LArIAT)

E missing can be constrained, for example, by measuring neutron interactions in LAr (Captain)

What is the multiplicity and spectrum of neutrons produced in neutrino interactions?
Question for this workshop!

The MicroBooNE Detector

TPC Assembly began 2012

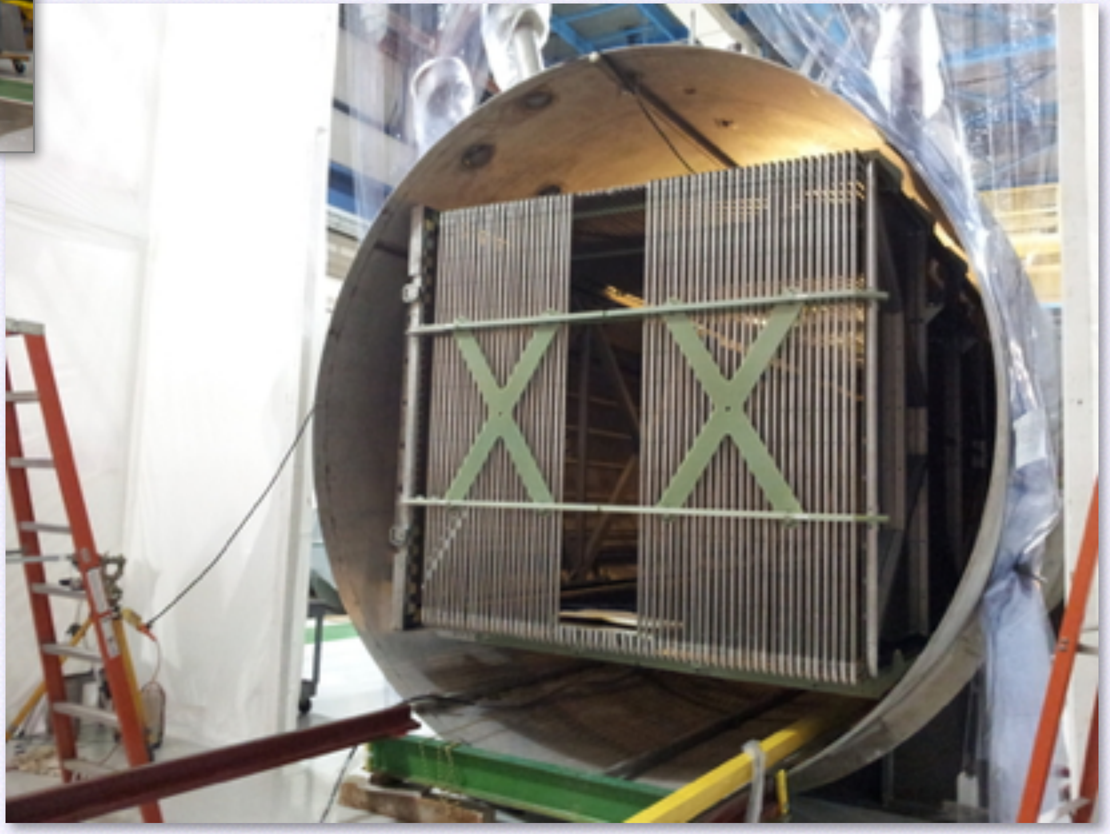
Cryostat Arrival mid 2013

TPC Insertion Dec. 2013

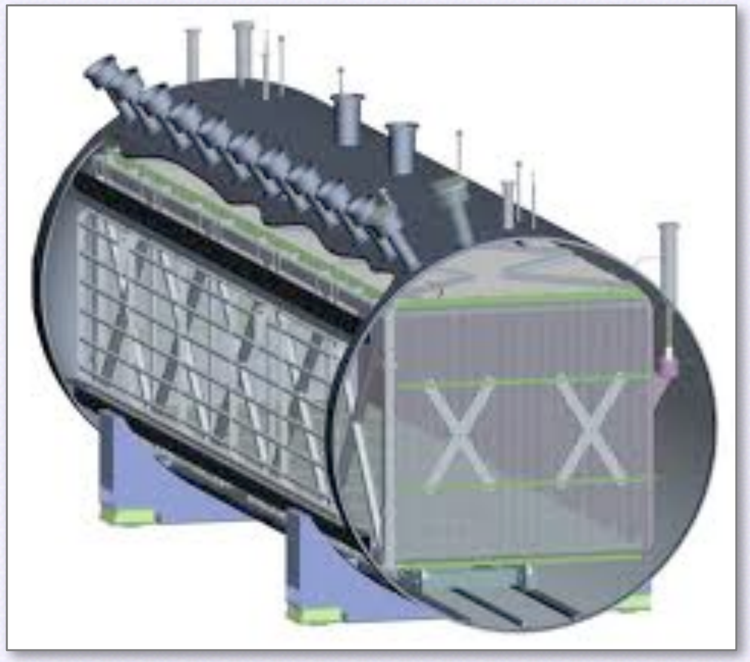
Endcap Welding mid 2014

Commissioning 2014

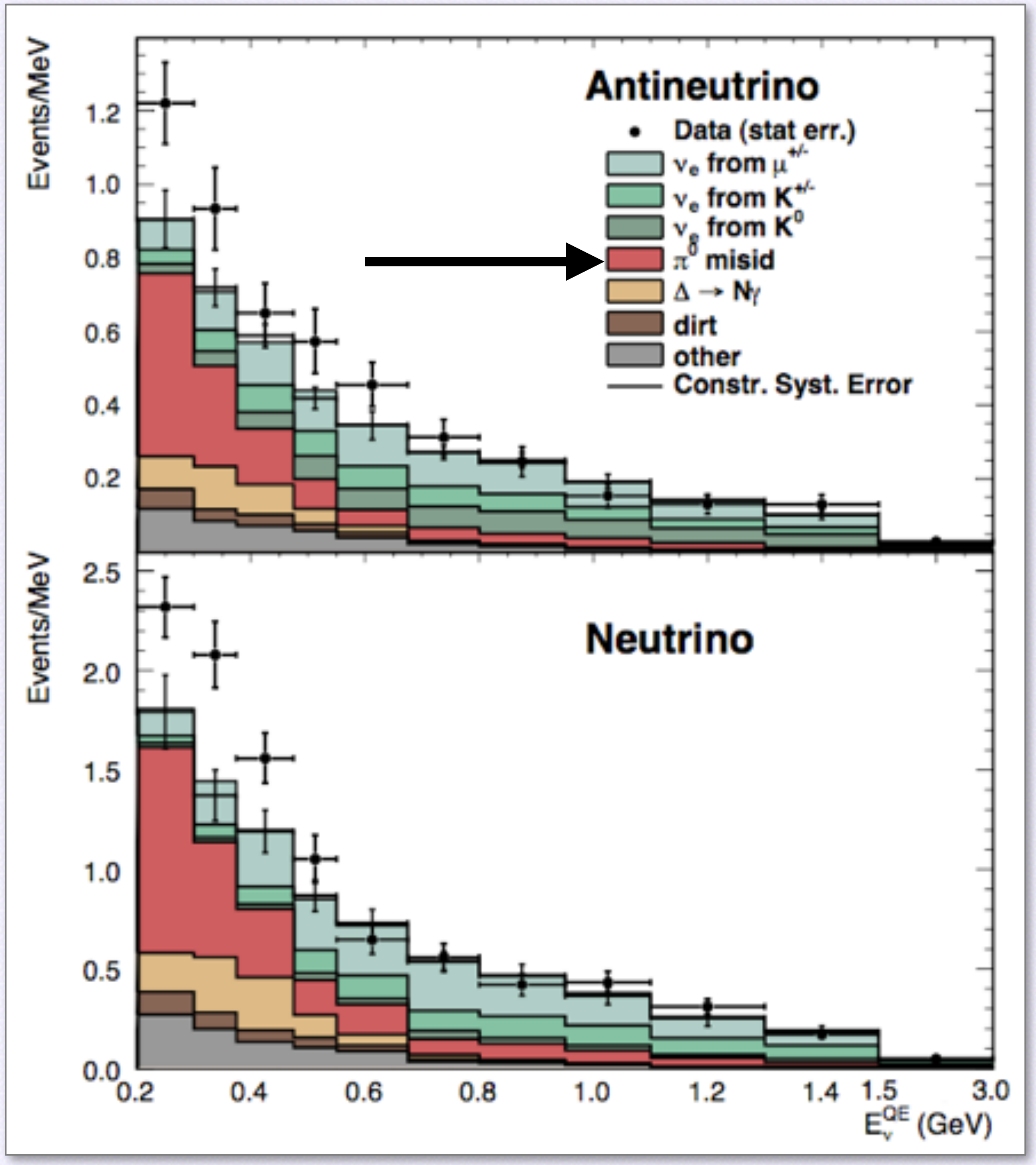
Data taking 2014/15 and on!



See Talks By:
O. Palamara (Wed)
S. Gollapinni (Thurs)



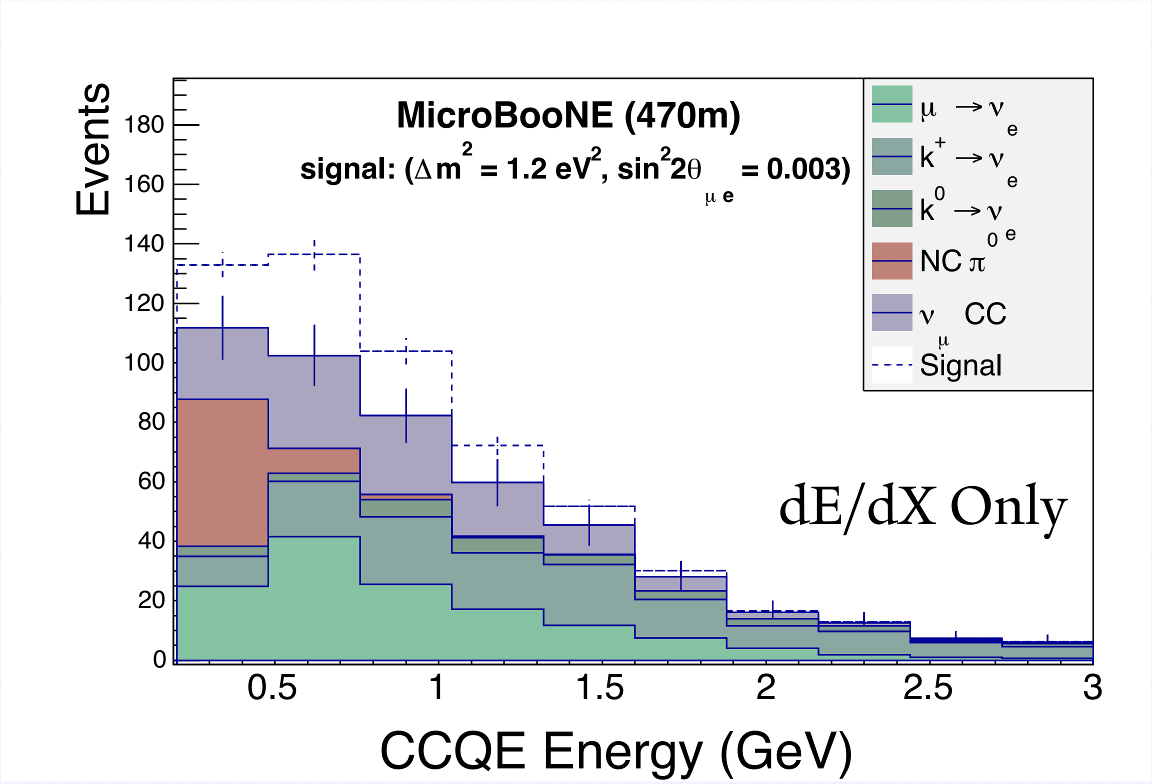
MicroBooNE ν_e Appearance



A. A. Aguilar-Arevalo et al., Phys. Rev. Lett. 110 161801 (2013)

Primary Background is no longer π^o

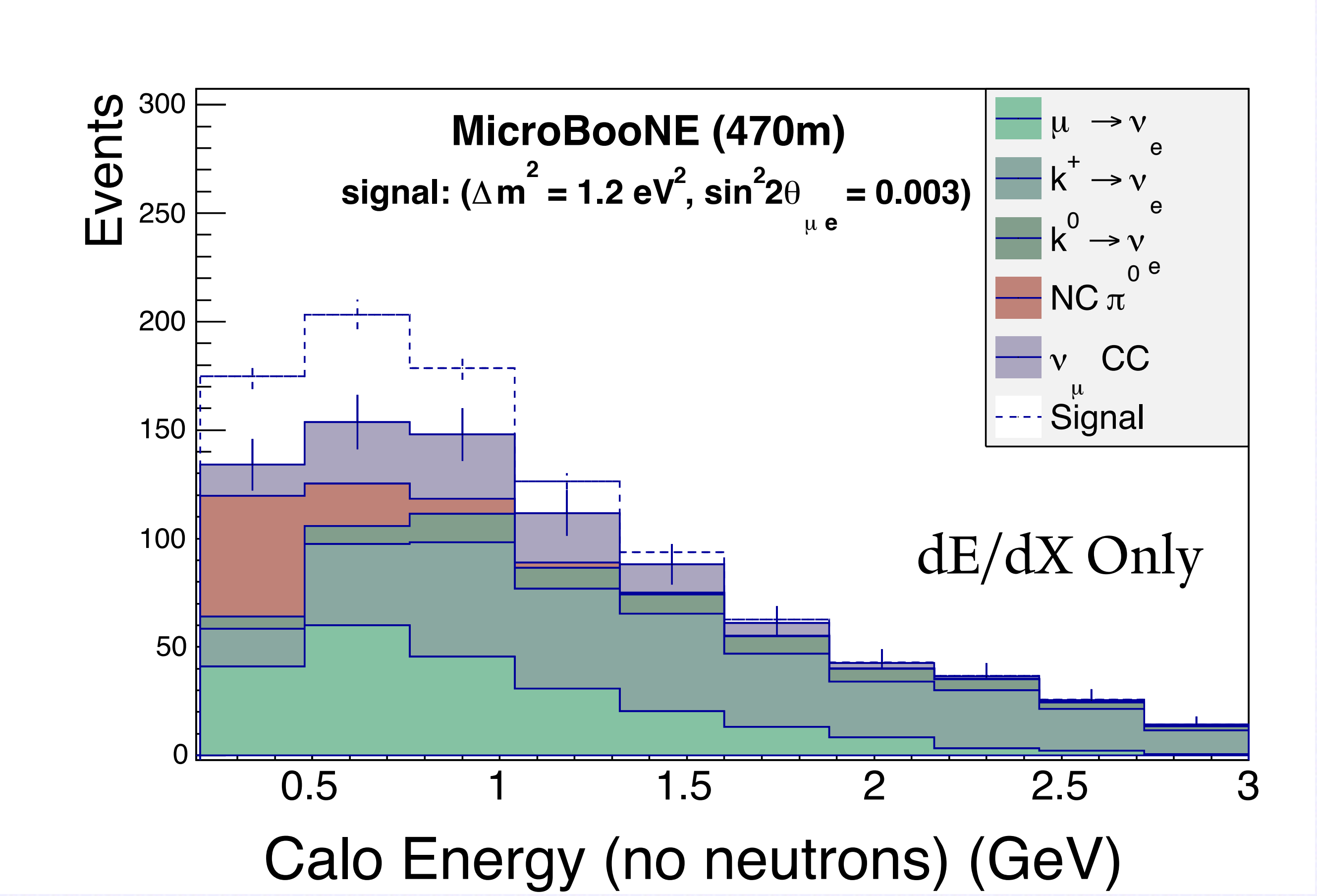
Instead, beam contamination is the dominant background.



MicroBooNE ν_e Event Rates

Constraints on beam ν_e are just as important as π^o for MicroBooNE.

π^o background has high statistics, 2 photon measurement as constraint.



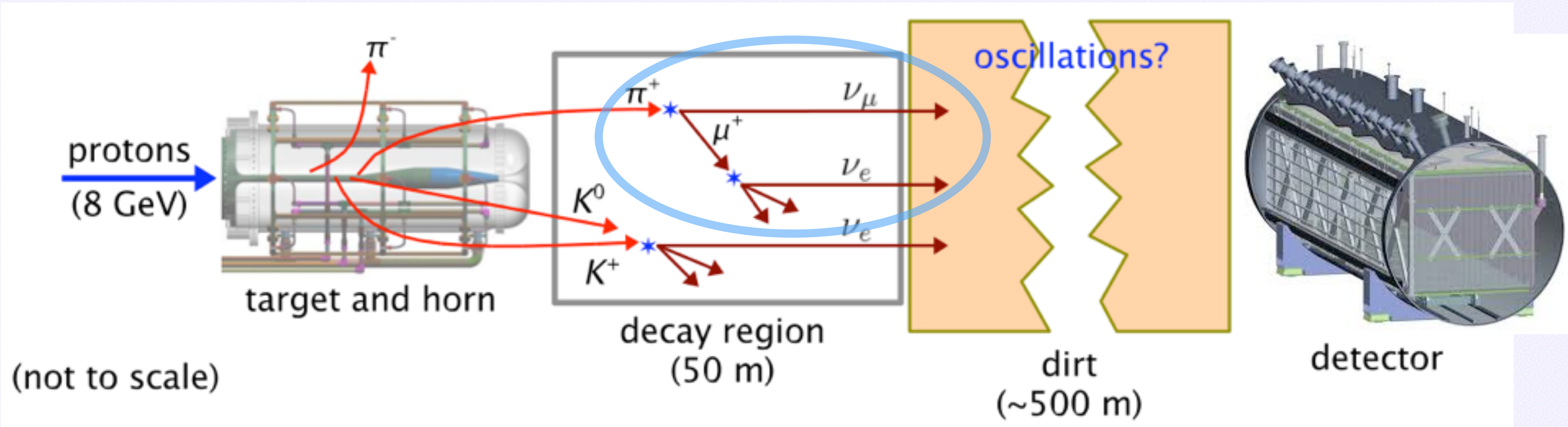
How to constrain the intrinsic event rate?

ν	$\bar{\nu}$	ν	$\bar{\nu}$
93.5%	5.9%	0.5%	0.1%

A. A. Aguilar-Arevalo et al., Phys. Rev. Lett. 110 161801 (2013)

LSND Best Fit Amplitude: 0.3%
Intrinsic beam contamination: 0.6%

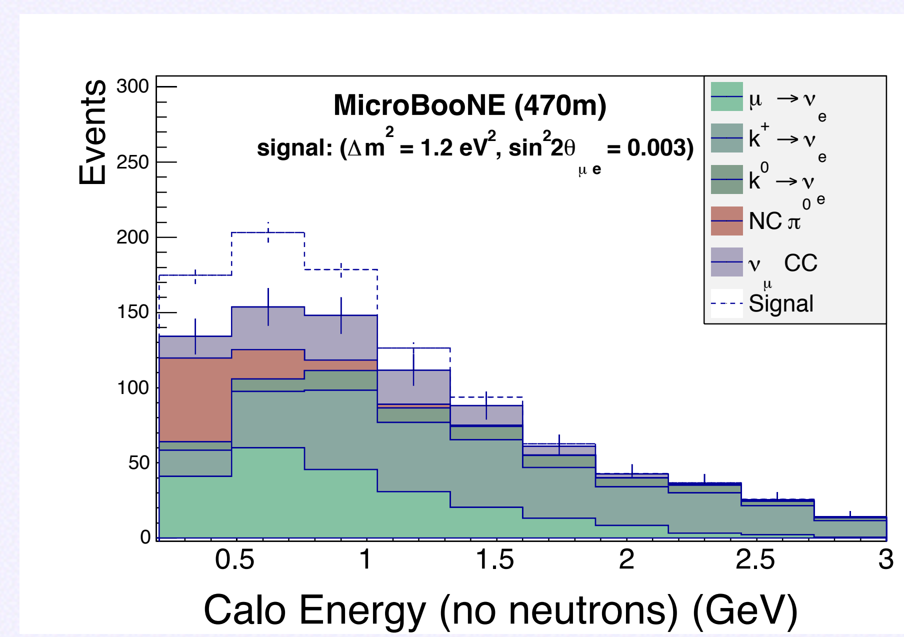
Prospects for MicroBooNE - ν_e



The ν_μ: ν_e event rate is partially correlated, which can reduce a systematic uncertainty on the intrinsic ν_e rate with a high statistics measurement of ν_μ rate.

$$\frac{\text{Events } \nu_\mu}{\text{Events } \nu_e} \propto \frac{\Phi_{\nu_\mu}}{\Phi_{\nu_e}} \frac{\sigma_{\nu_\mu}}{\sigma_{\nu_e}}$$

(Plus detector response!)



Future Experiments: LAr1-ND

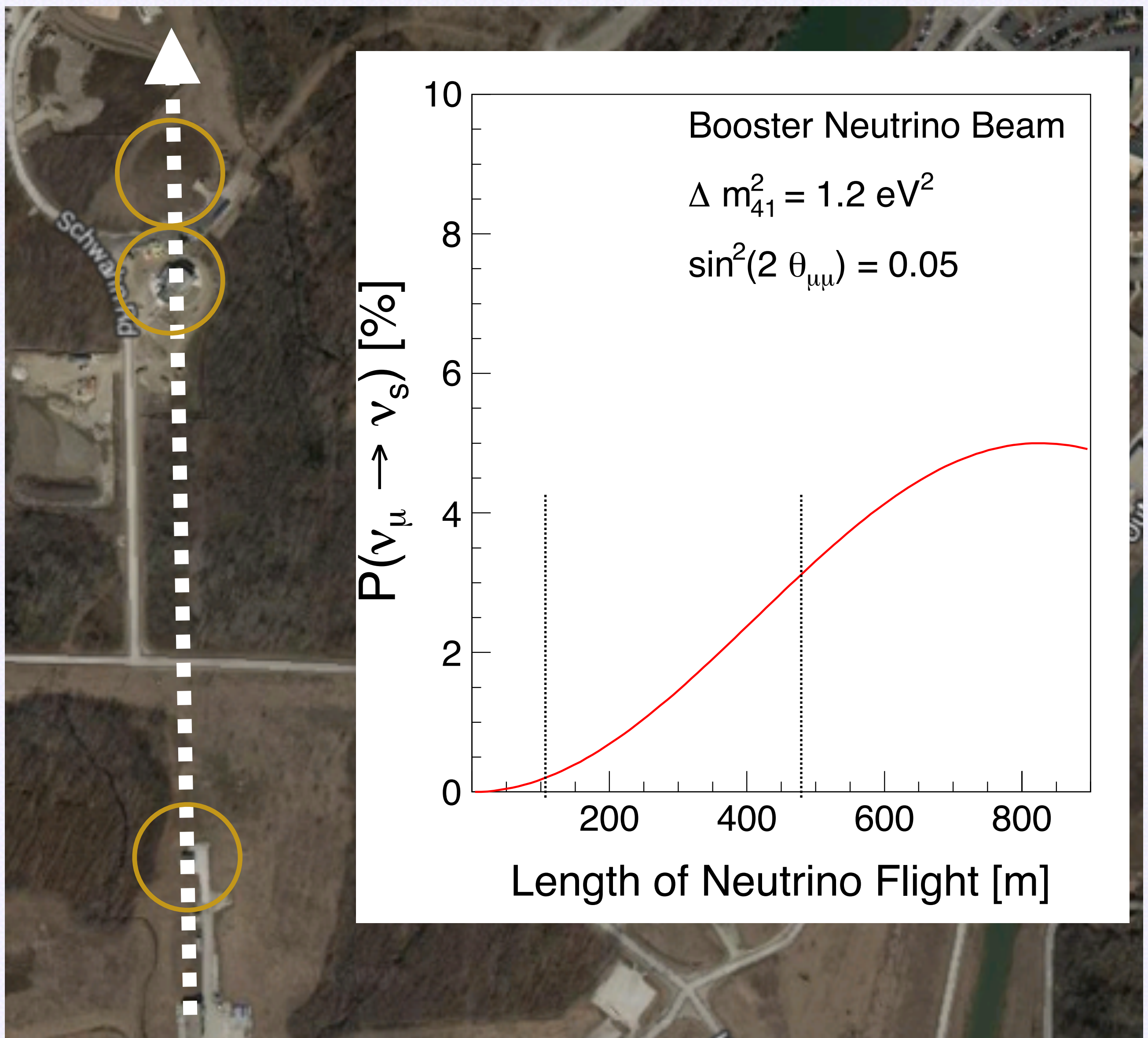
The best way to constrain event rates is with a 2 detector experiment.

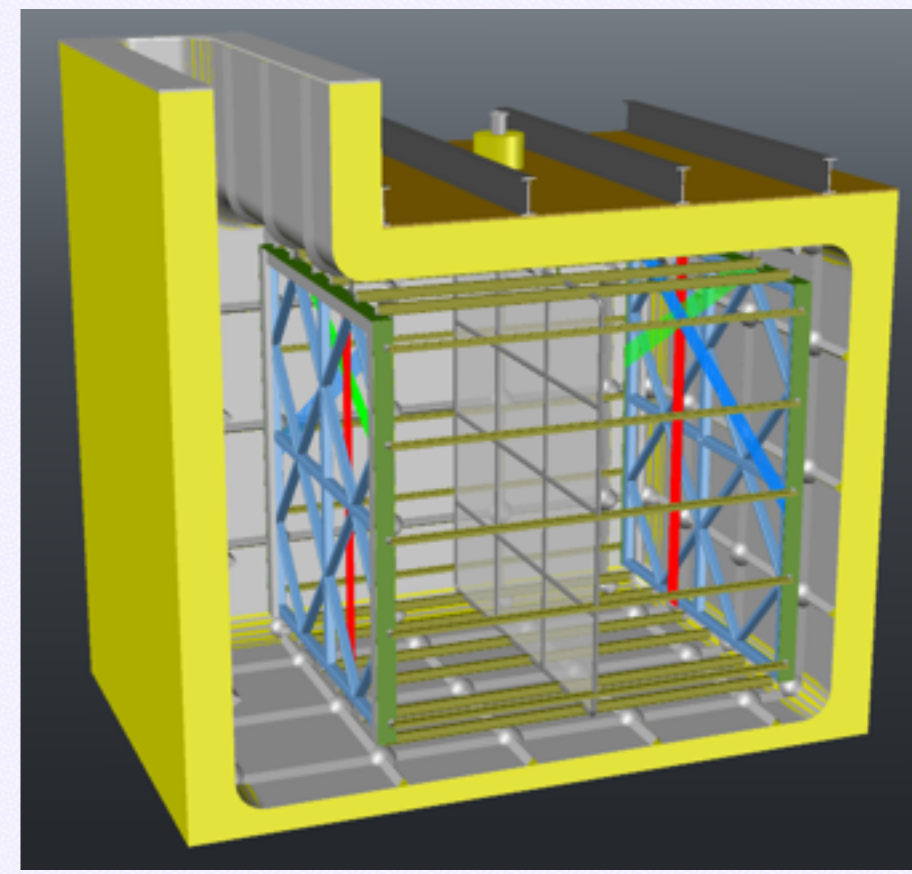
Booster Neutrino Beam

MiniBooNE

MicroBooNE (2015)

LAr1 - ND (2018)





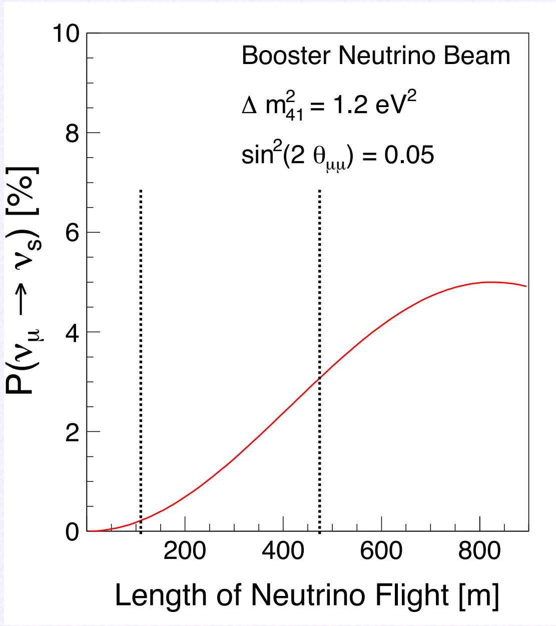
See Talk by R. Guenette (Thursday)

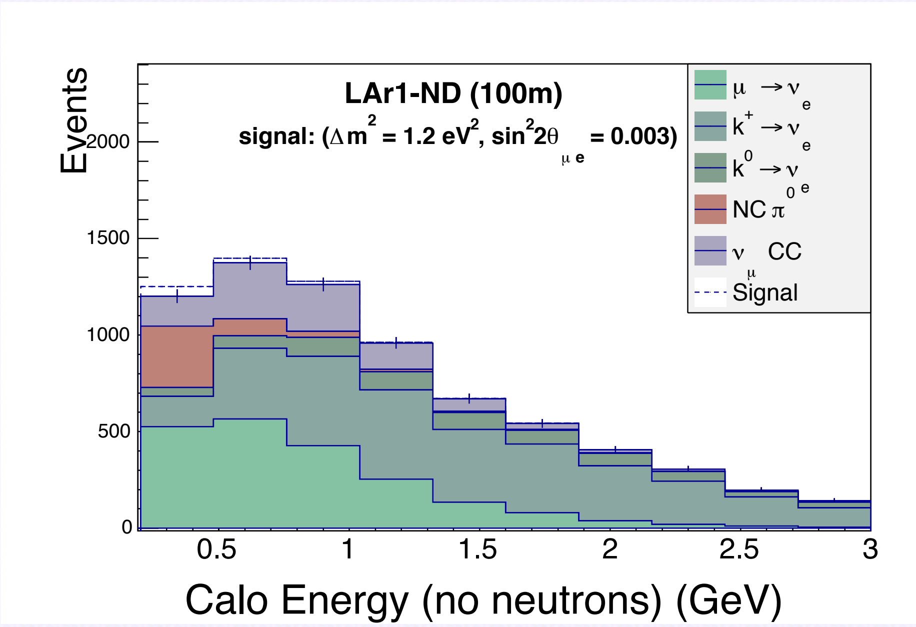
LAr1-ND - Event Rate Predictions

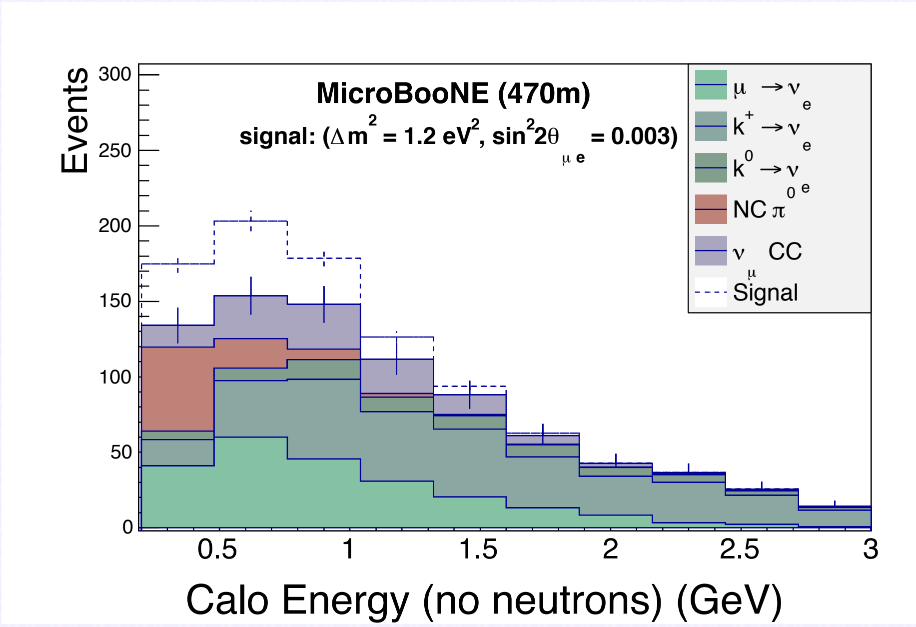
$$\frac{\text{Events } ND}{\text{Events } \mu B} \propto \frac{\Phi_{ND}}{\Phi_{\mu B}} \frac{\sigma_{\nu_e}}{\sigma_{\nu_e}} \frac{\epsilon_{ND}}{\epsilon_{\mu B}}$$

A near detector allows cancellation of event rate systematics (at least to first order).

The flux prediction extrapolation is not as clean as cross section, but will still be a great improvement to the dead reckoning that MicroBooNE must do.



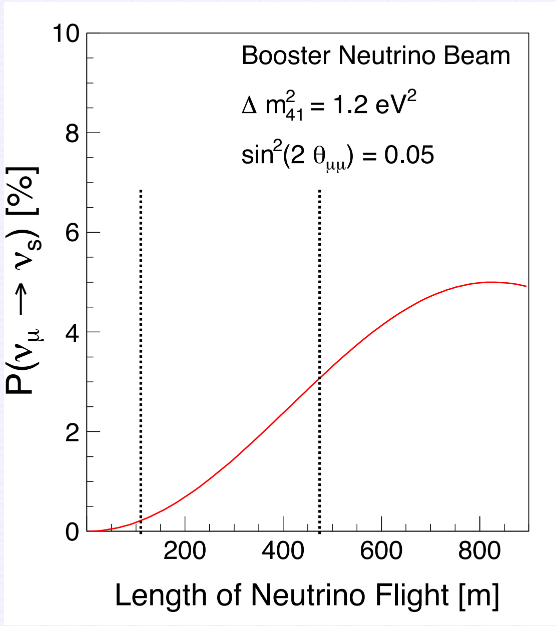


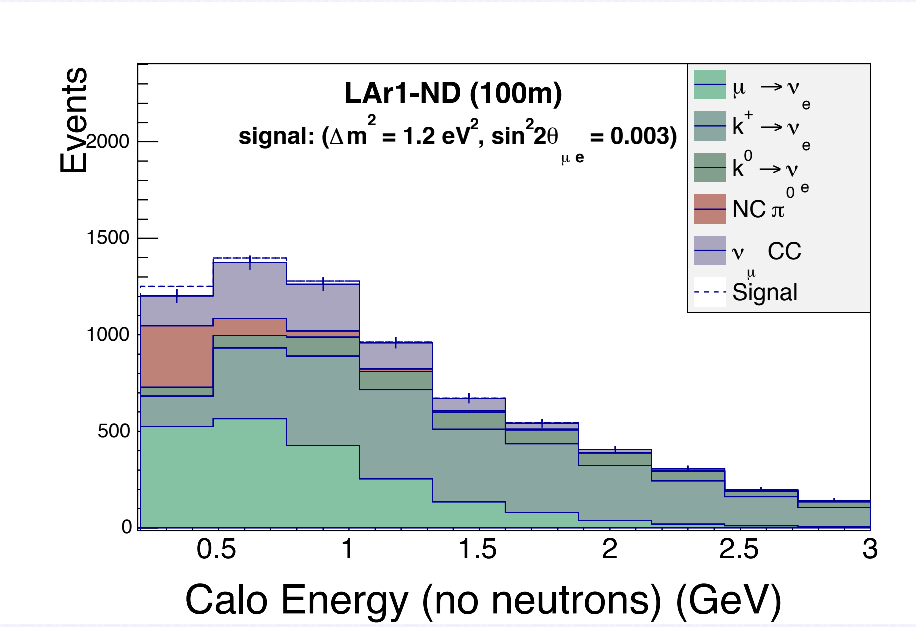


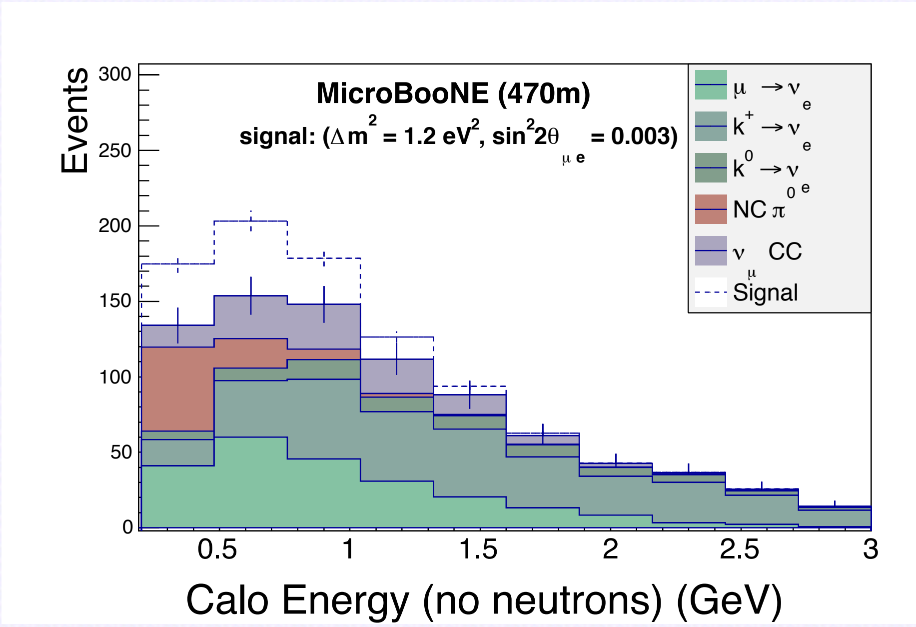
LAr1-ND - Oscillations?

If MicroBooNE confirms the MiniBooNE excess as electrons, only with a near detector can we truly confirm an oscillation explanation - with complimentary analysis.

$\bar{\nu}_\mu \rightarrow \bar{\nu}_X \rightarrow \bar{\nu}_e$	ν_e Appearance
$\bar{\nu}_\mu \rightarrow \bar{\nu}_X$	ν_μ Disappearance
$\bar{\nu}_{\mu,e} \rightarrow \bar{\nu}_X$	Neutral Current Disappearance

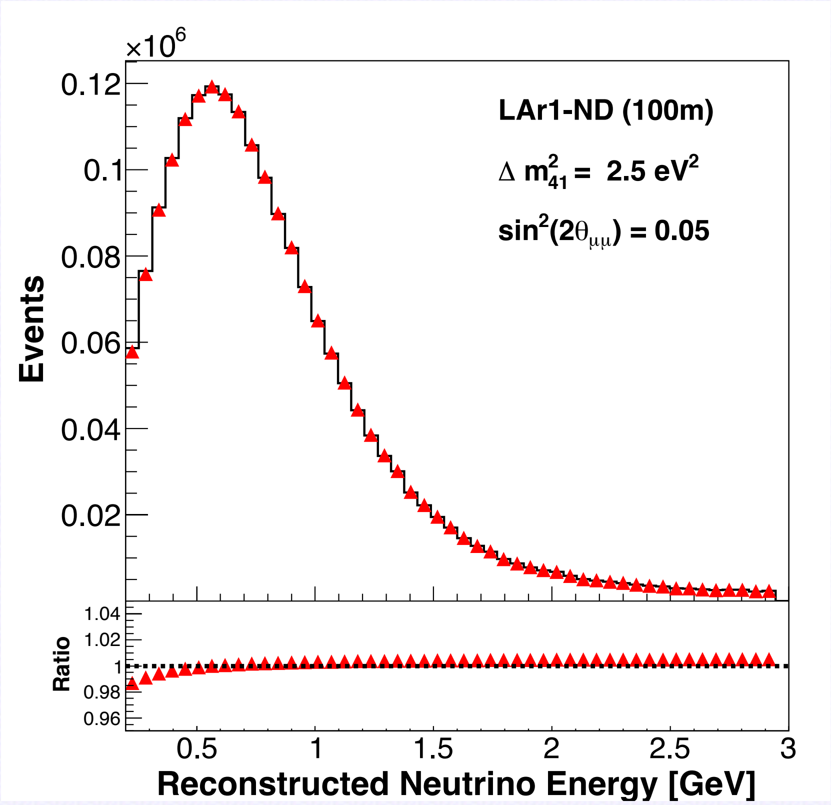


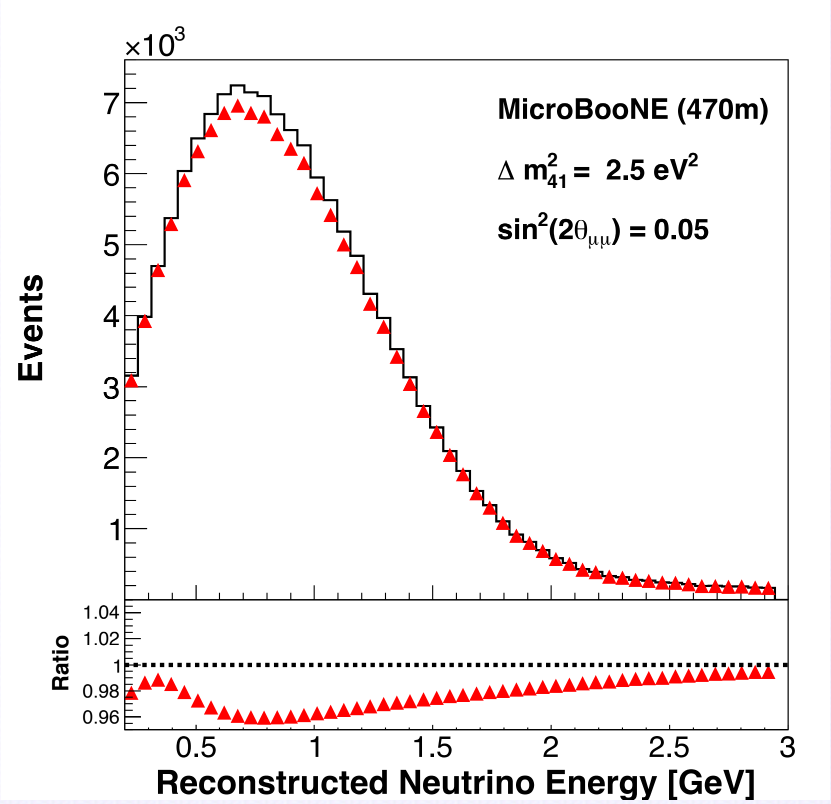


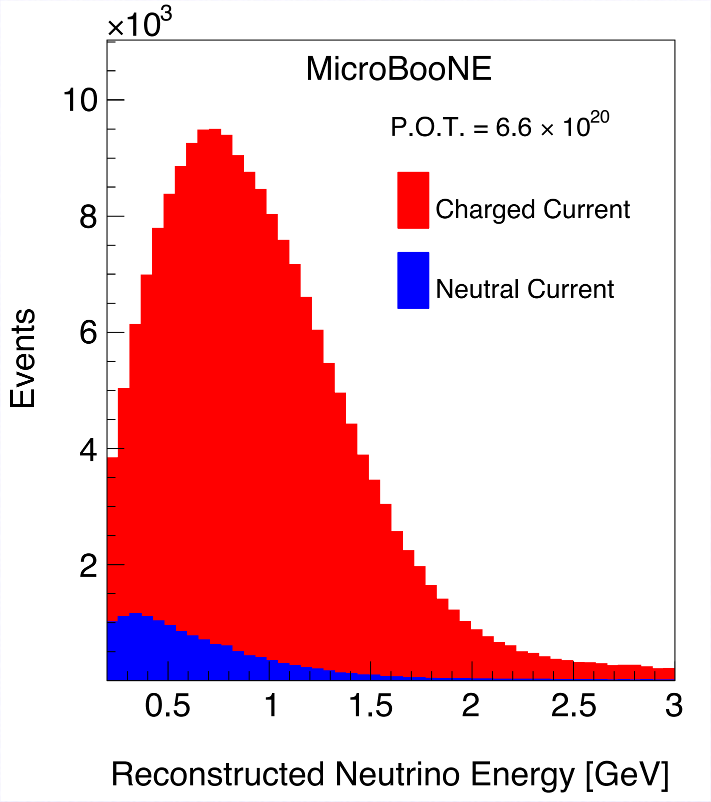


ν_μ Disappearance

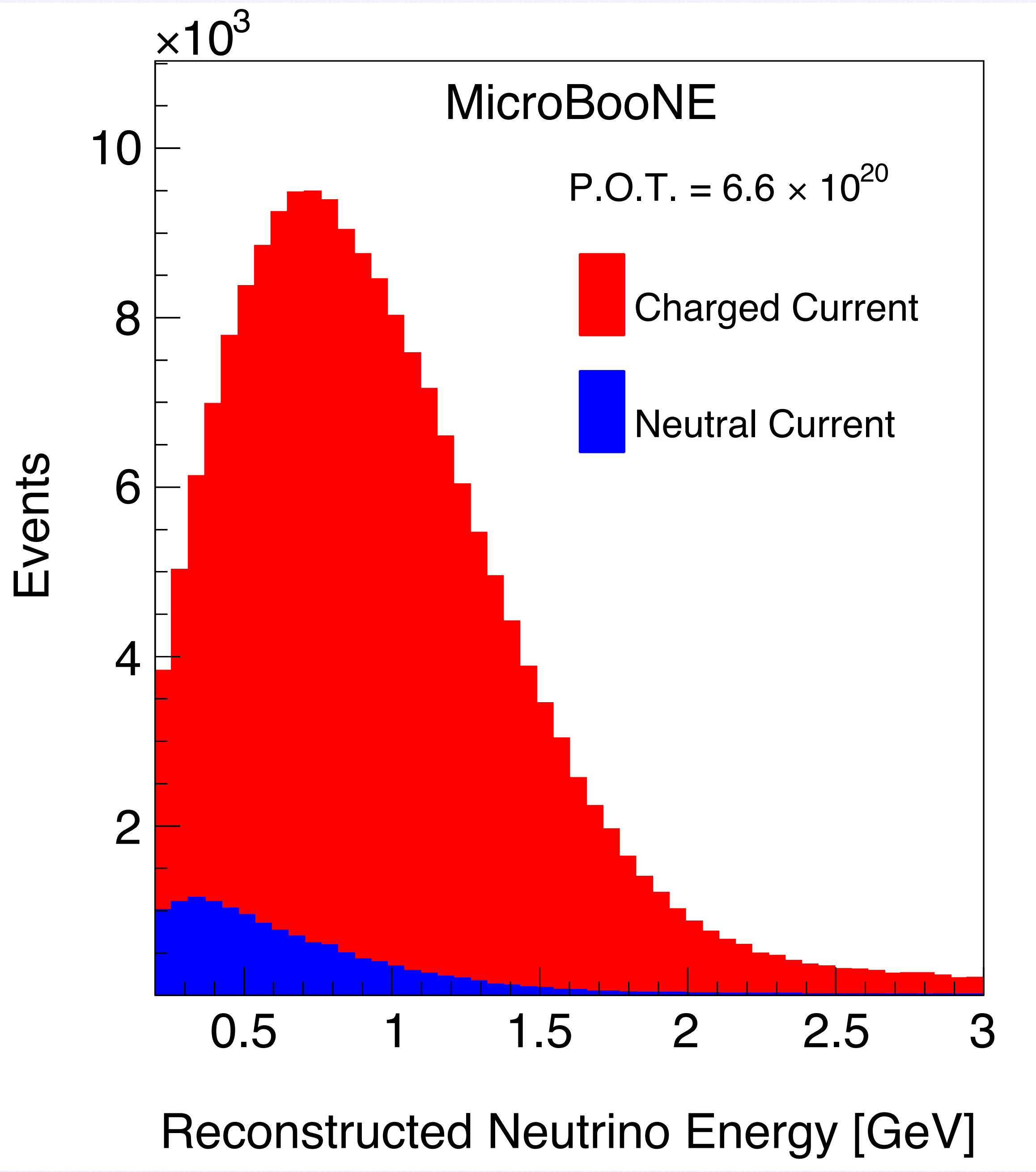
- ν_e appearance isn't the only sterile neutrino signature, ν_μ disappearance is also promising - and complimentary.
- Only possible with ND - **cross section and flux uncertainties are too high for one detector alone**.
- Primary background is still pion production!







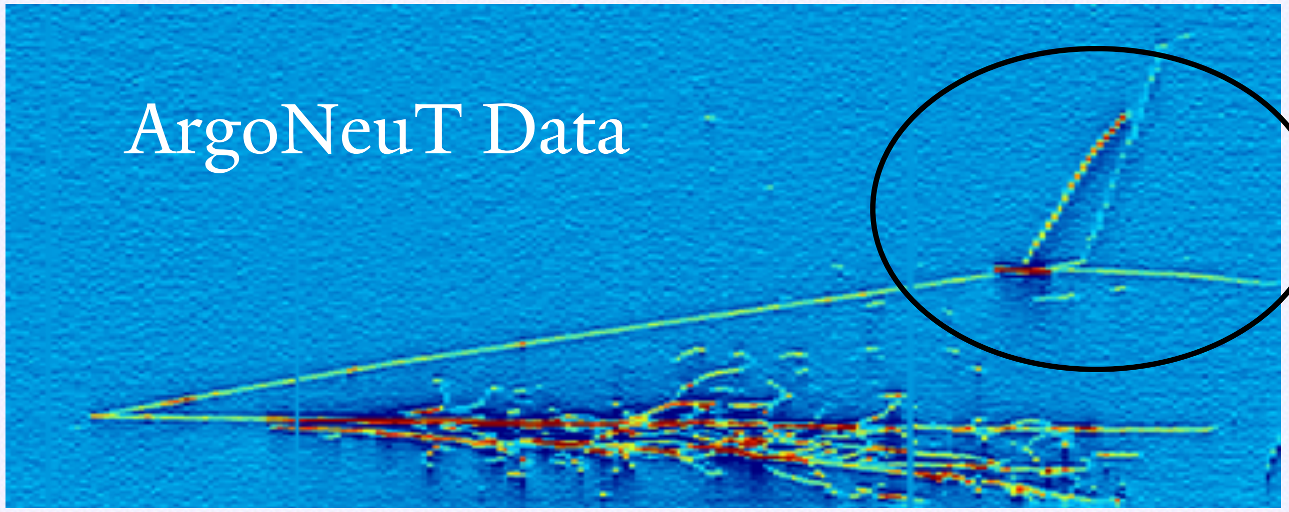
Charged Pion Background



Charged pions from NC interactions can mimic a muon.

If the pion decays before interacting hadronically, it is indistinguishable from a muon.

Pion interaction cross sections in Liquid Argon are important!

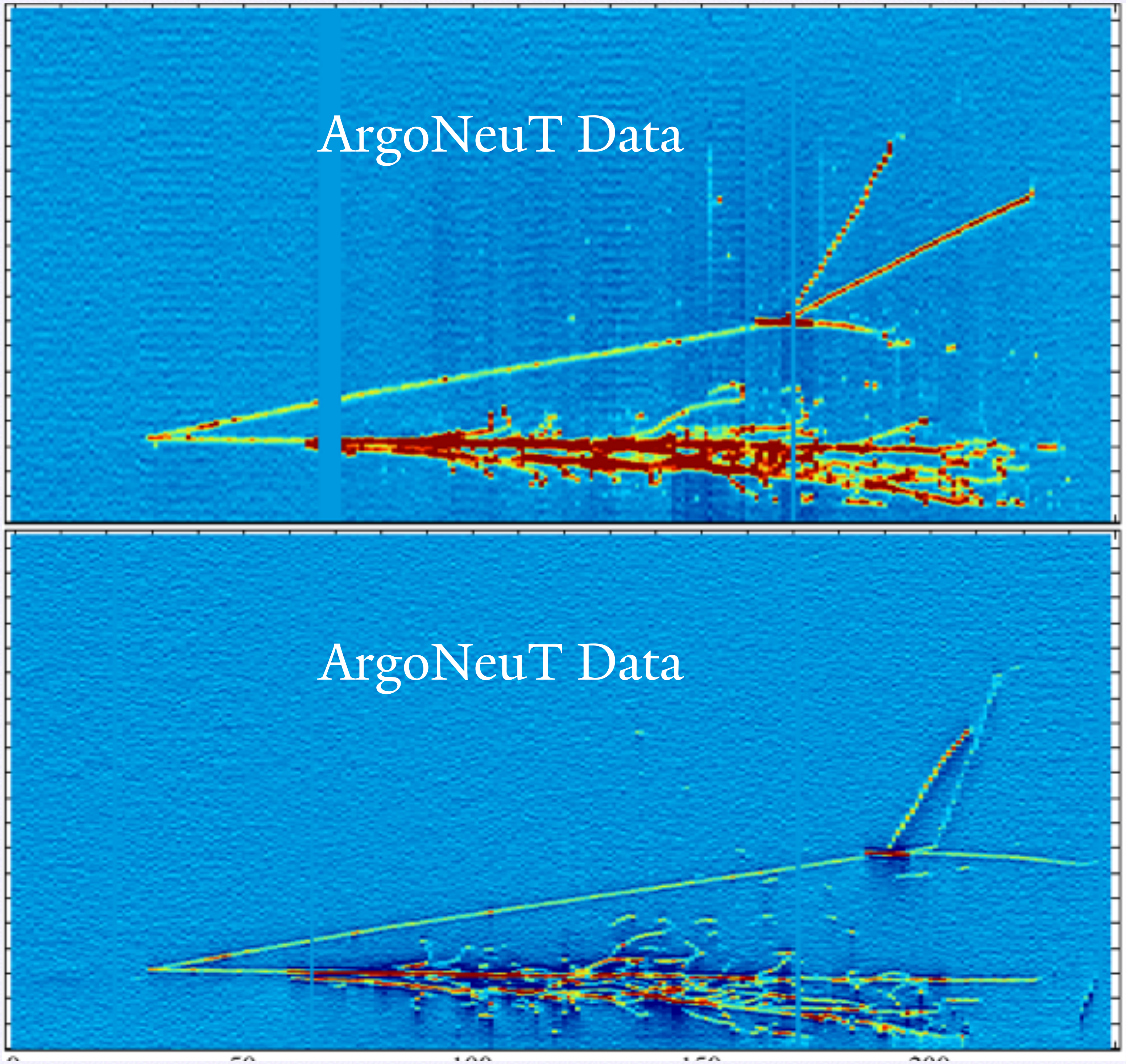


Conclusions

- Future experiments will mitigate the primary interaction systematic - pion production - through improved detector technology.
- Rate of pion production is important!
- Cross Section uncertainties on argon will play a big role - 2 detector experiments will allow reduction of these systematics.
- Resolving the question of sterile neutrinos with accelerator based experiments is **only** possible with a near detector.

Backup

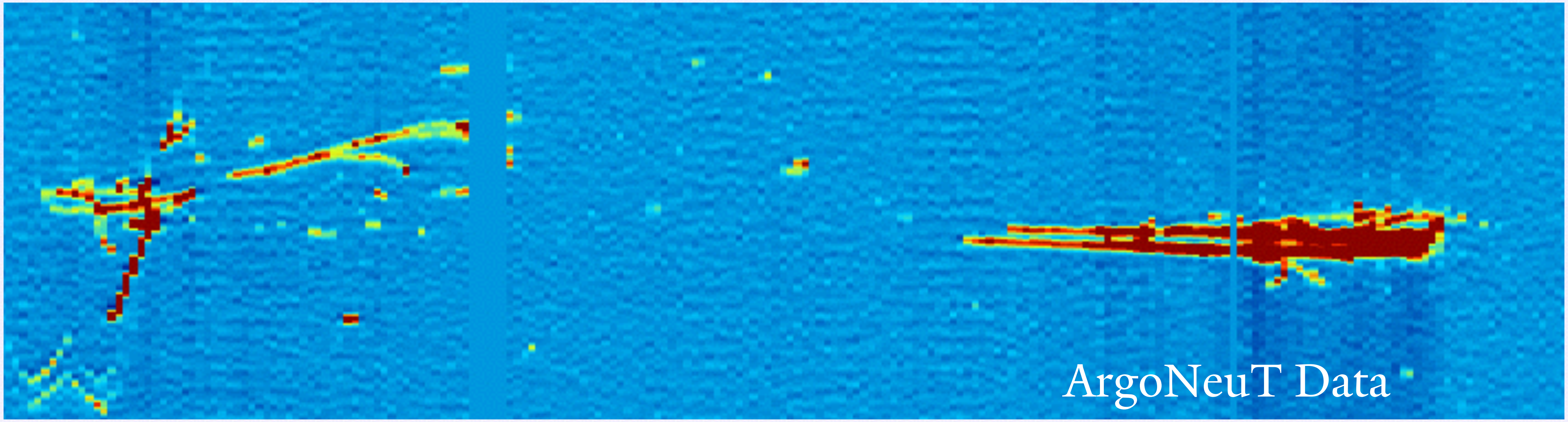
ν_μ CC Background in the ν_e Sample?

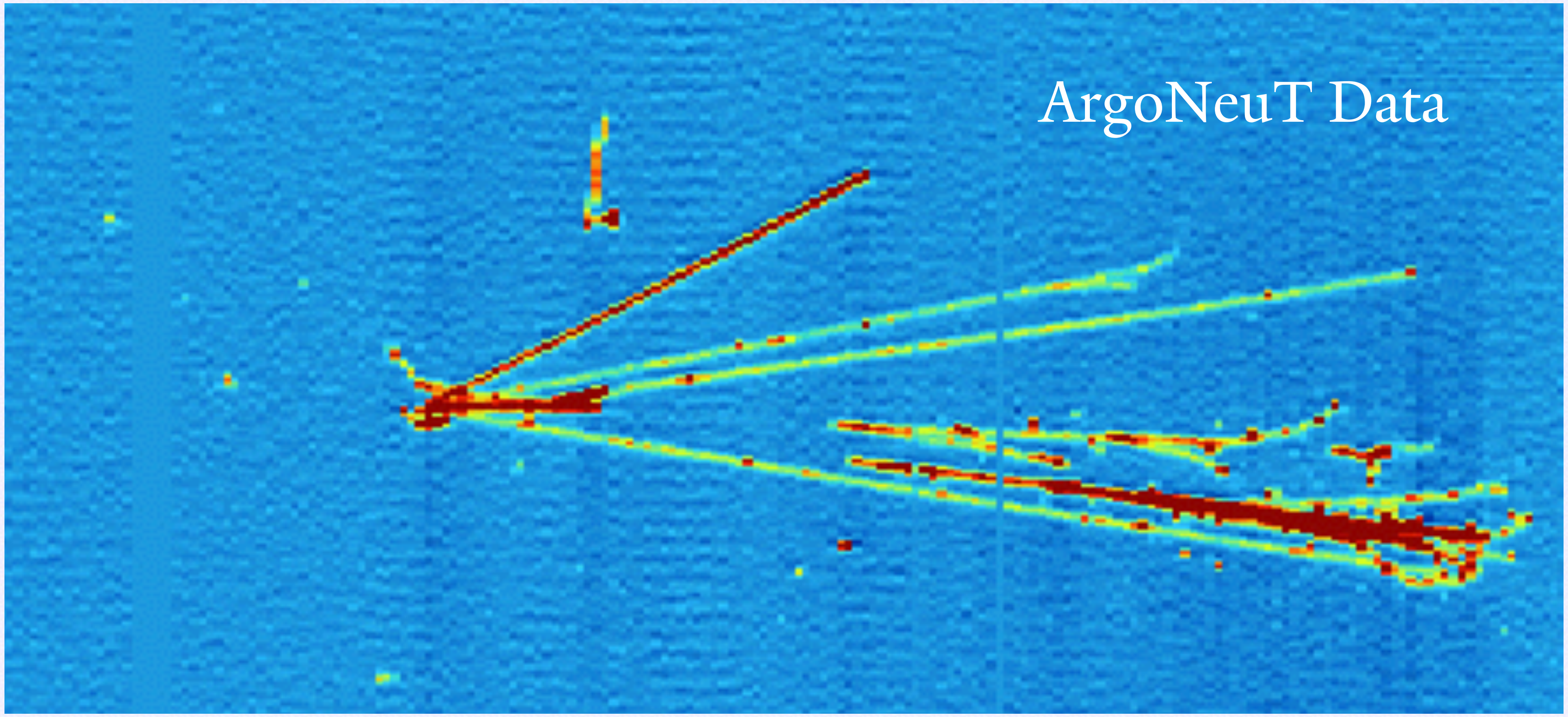


Need to **not** ID the muon (tag it as a pion? Not see it?) and the event must have a shower.

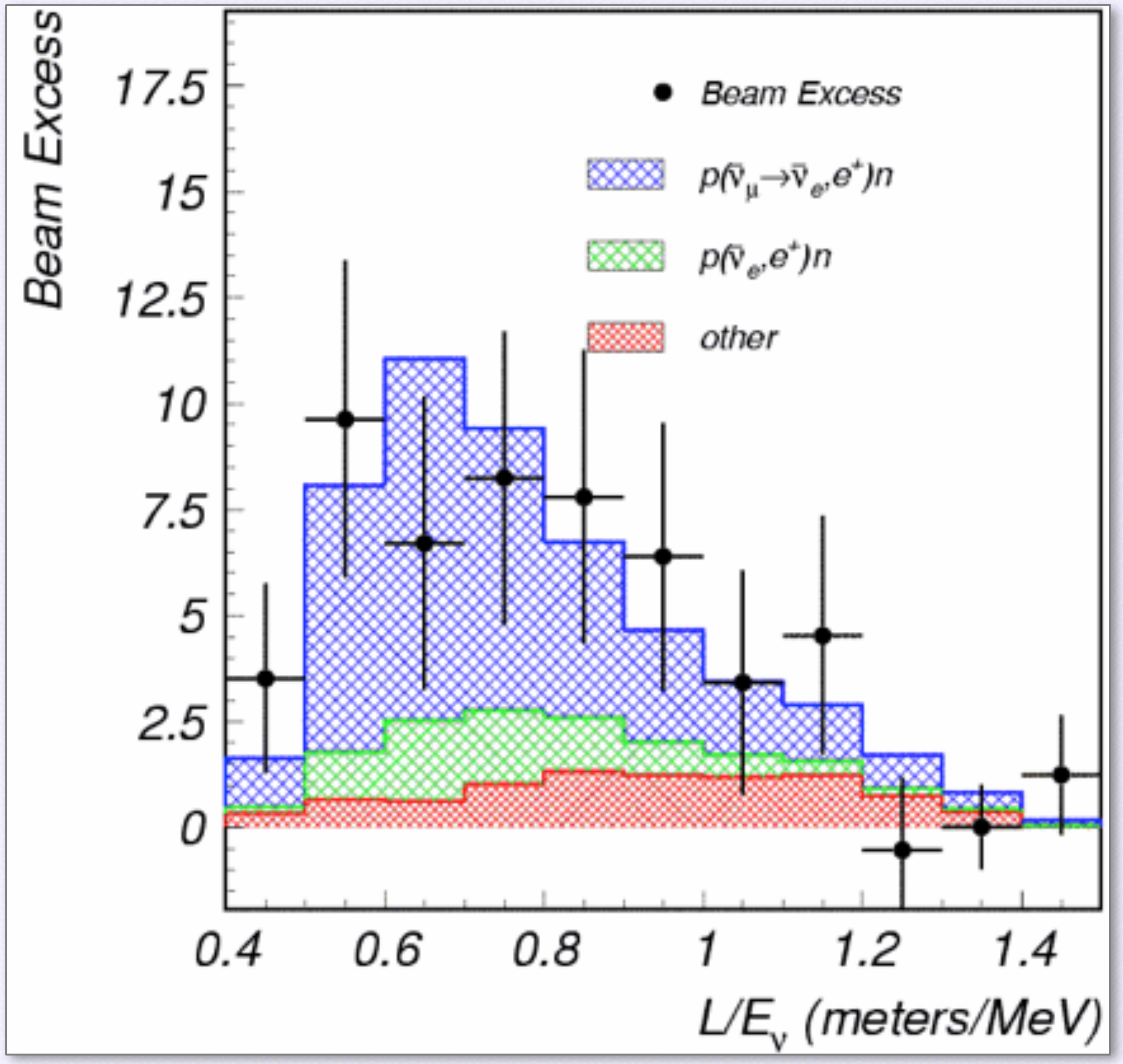
Used a flat, 0.1% misID rate while we develop better estimates of this background.

Neutral Pions in LAr

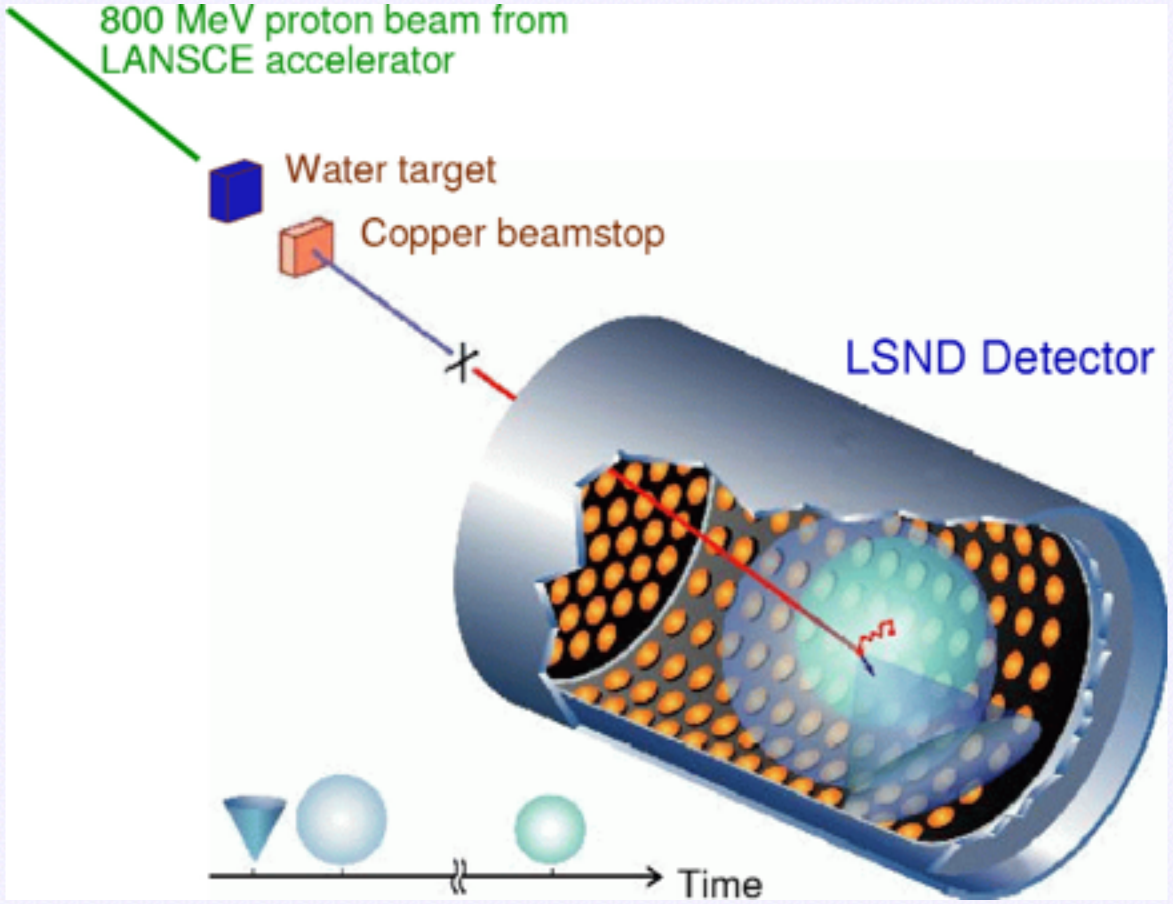




The LSND Result

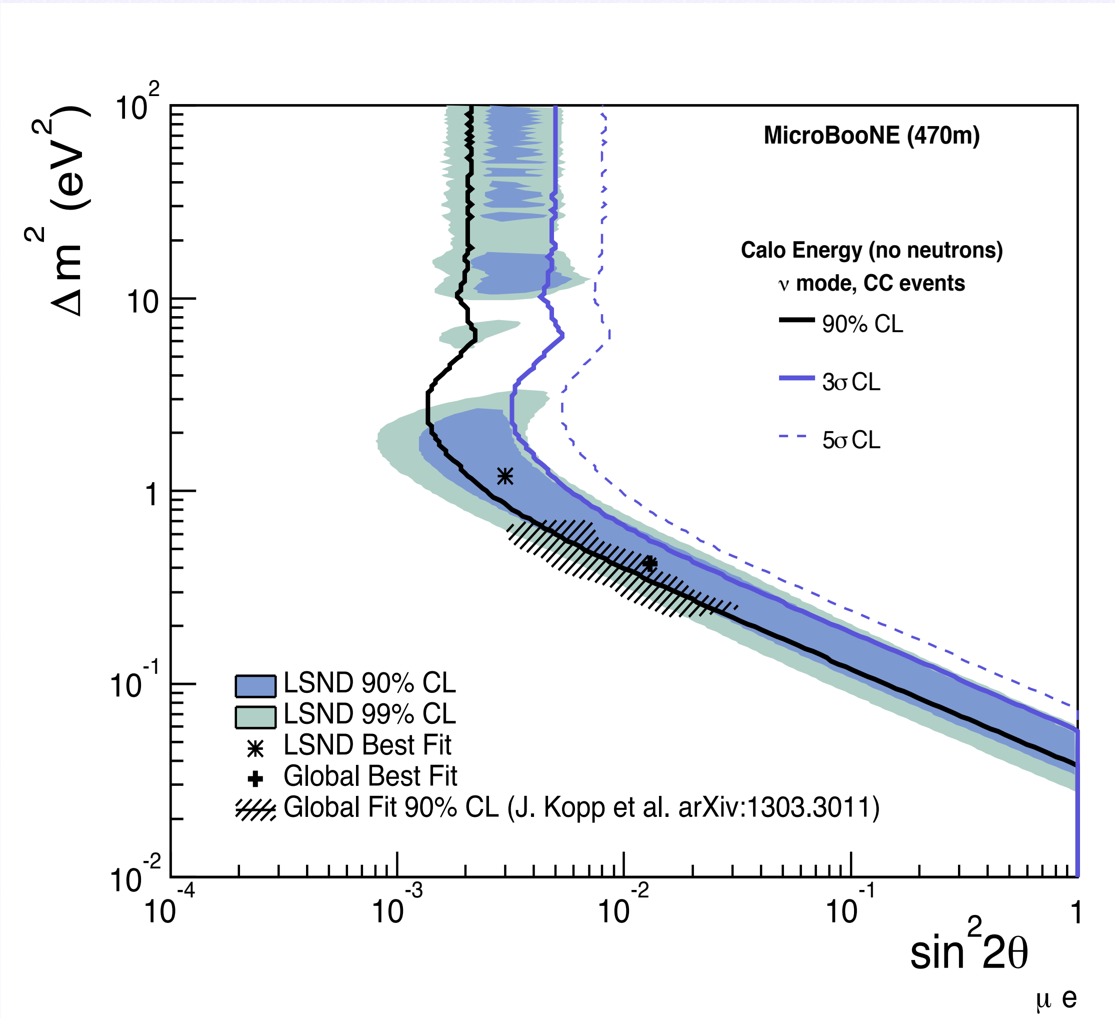


[C. Athanassopoulos et al., Phys. Rev. Lett. 75, 2650 (1995); 81,1774(1998); A.Aguilar et al., Phys. Rev. D64, 112007(2001).]

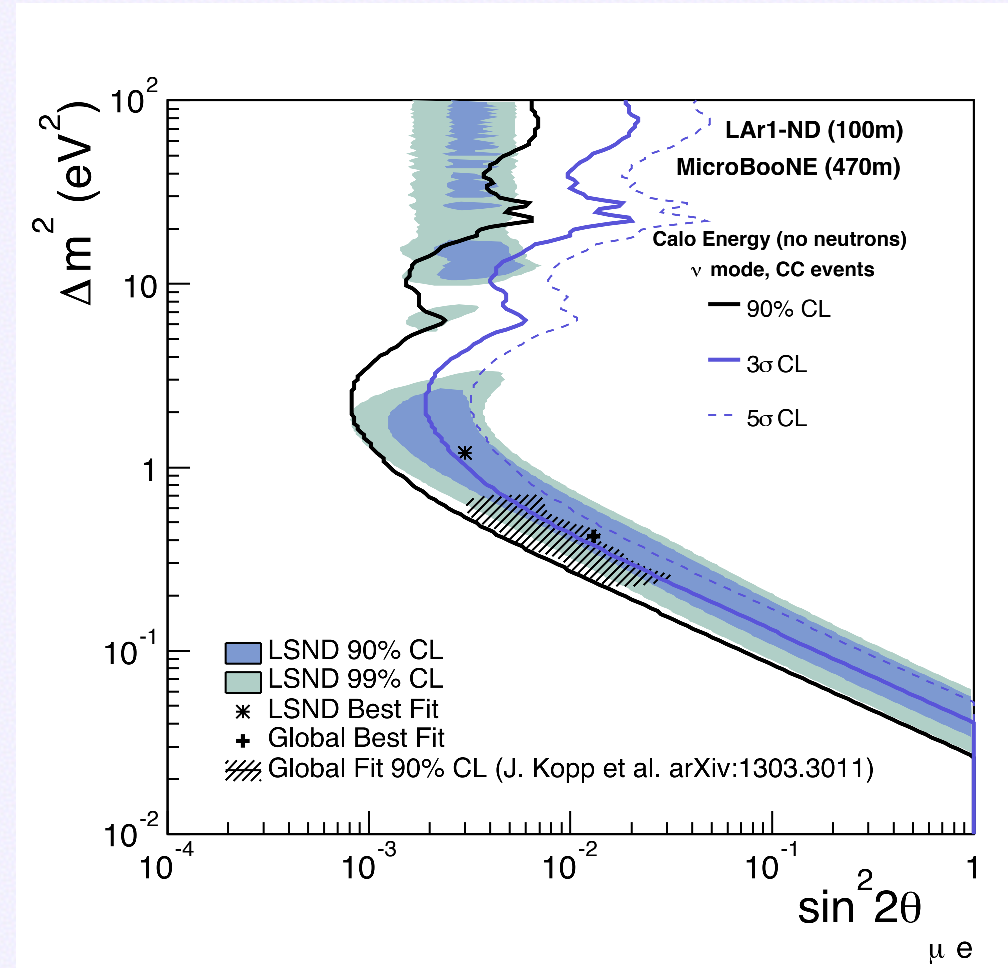


$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Sterile Neutrino Sensitivity



MicroBooNE



MicroBooNE + LAr1-ND

A near detector on the Booster Beam Line can extend the reach of MicroBooNE by allowing cancellation of many systematic errors **- particularly cross section uncertainties.**

Also allows high statistics, precision cross section measurements due to high flux.
see talk by R. Guenette

Three Detector Program