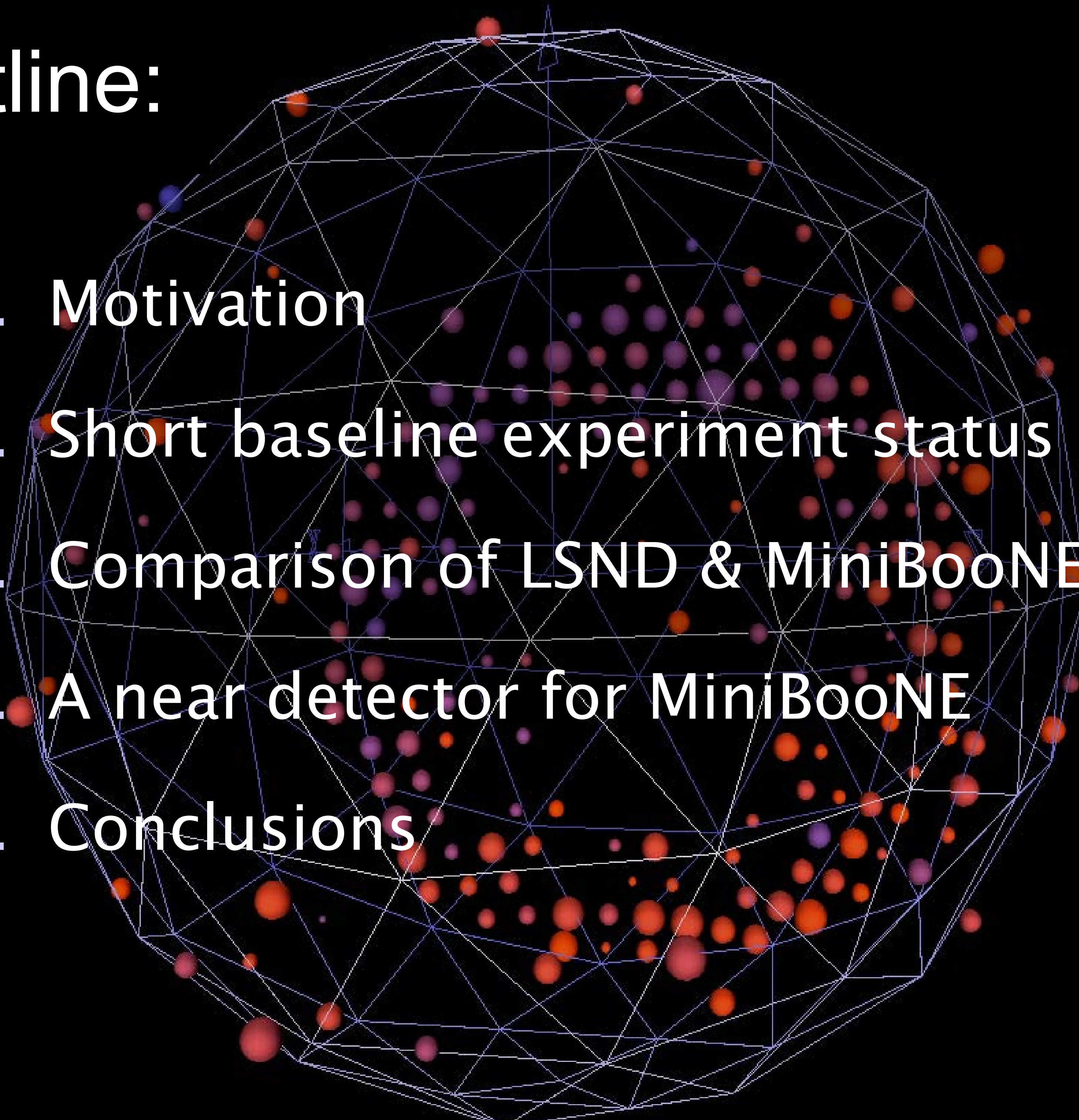
# Short Baseline Neutrino Physics

# MiniBooNE and Beyond…

Geoffrey Mills, Los Alamos

ERICE, SICILIA, 19 SETTEMBRE MMIX

# Outline:



1. Motivation
2. Short baseline experiment status
3. Comparison of LSND & MiniBooNE
4. A near detector for MiniBooNE
5. Conclusions

# Neutrino Oscillations

- The oscillation patterns between the 3 known active neutrino species have been demonstrated by a number of experiments over the last two decades:
  - SNO, Kamland
  - Super-K, K2K, MINOS

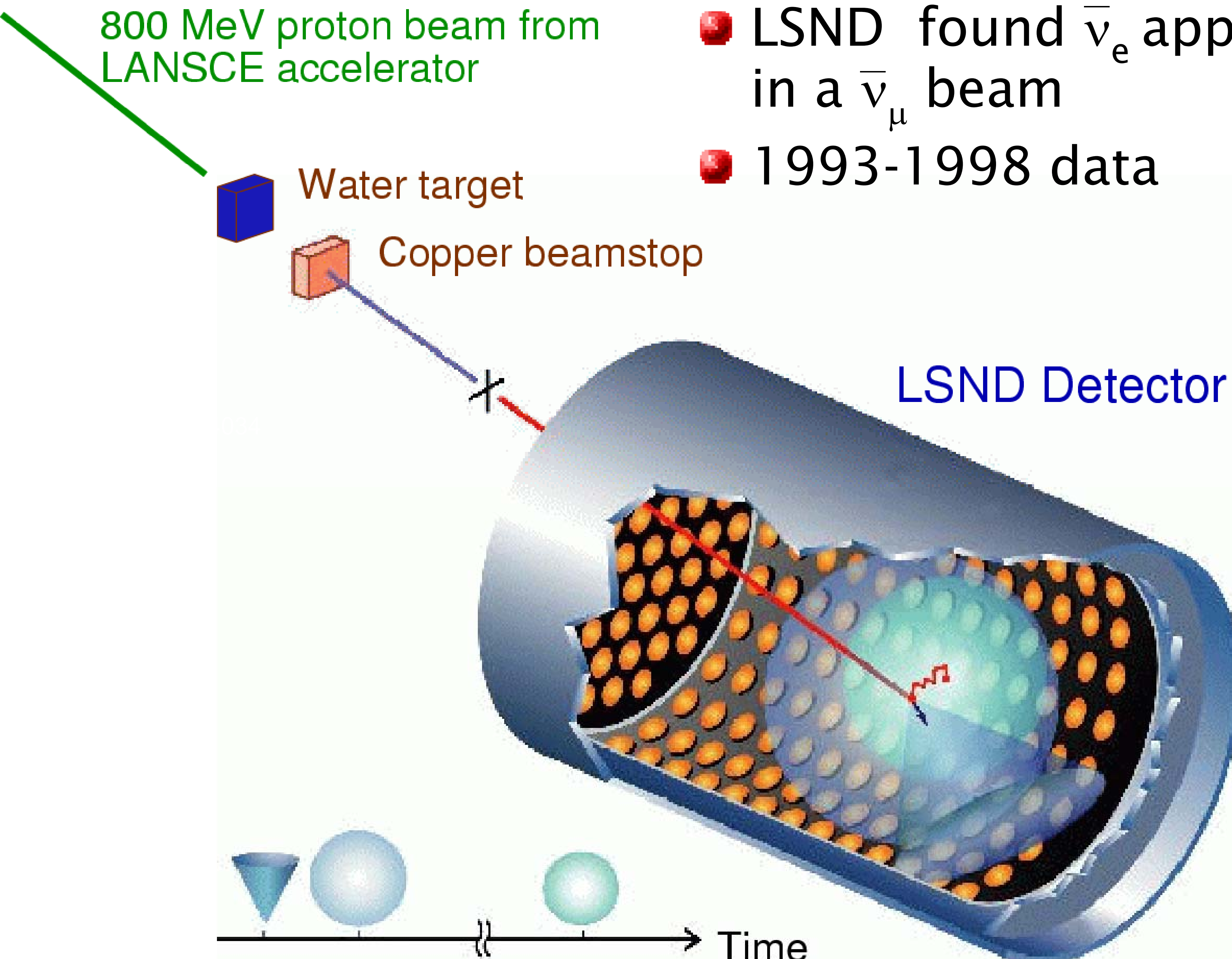
- Armed with that knowledge, measurements of neutrino behavior outside the standard 3 generations of active neutrinos indicate new physics:
  - LSND indicates that new physics may be operating

- Interpretations of such a non-standard result probe some deep theoretical issues, for example:
  - Light sterile neutrinos, neutrino decays, CP and/or CPT violation, Lorentz invariance, Extra dimensions

*The investigation of neutrino oscillations at the <1% level is unique in its physics reach*

# The Liquid Scintillator Neutrino Detector at LANL

- LSND found $\bar{\nu}_e$ appearing in a $\bar{\nu}_\mu$ beam
- 1993-1998 data

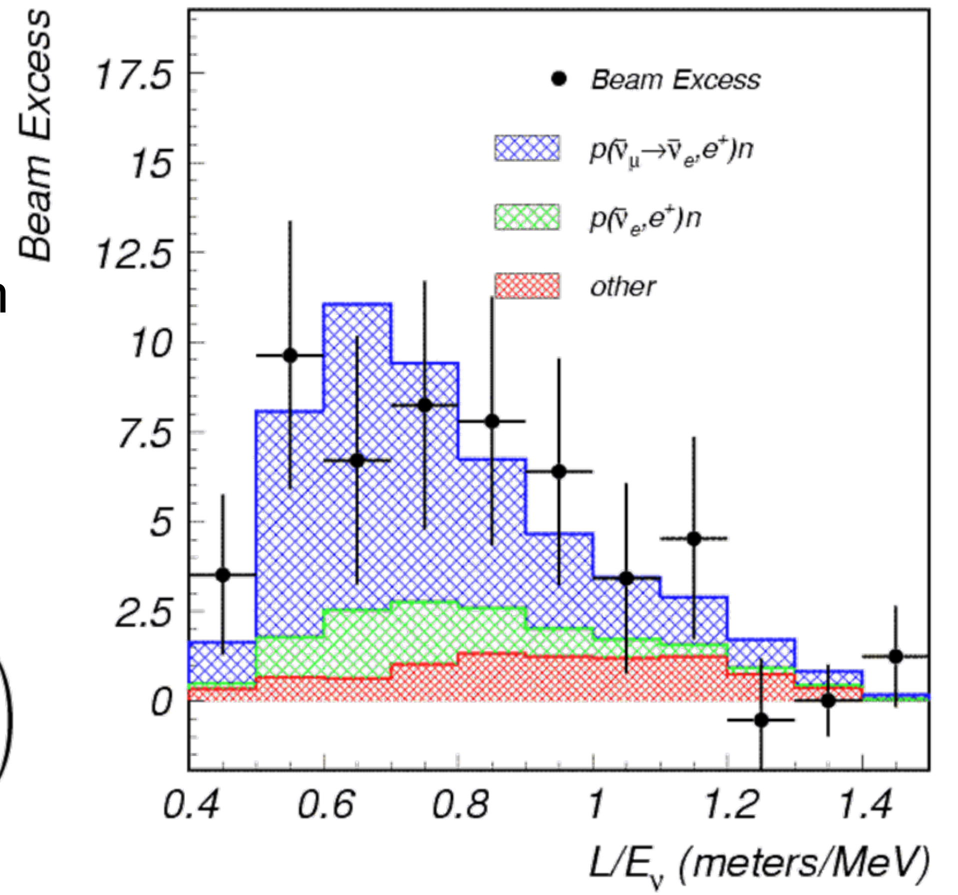


# Excess Events from LSND

- LSND found an excess of $\bar{\nu}_e$ in $\bar{\nu}_\mu$ beam
- Signature: Cerenkov light from $e^+$ with delayed n-capture (2.2 MeV)
- Excess: 87.9 ± 22.4 ± 6.0 (3.8σ)
- *The data was analysed under a two neutrino mixing hypothesis**

$$P(\bar{\nu}_\mu \to \bar{\nu}_e) = \sin^2(2\theta)\sin^2\left(\frac{1.27\, L\, \Delta m^2}{E}\right)$$

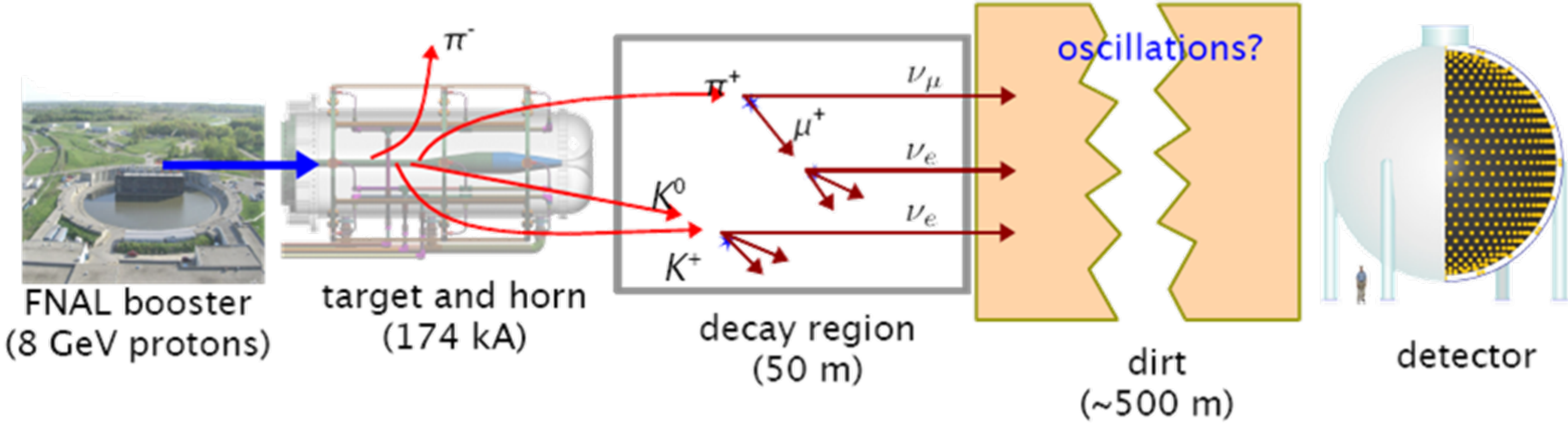
$$= 0.245 \pm 0.067 \pm 0.045\ \%$$

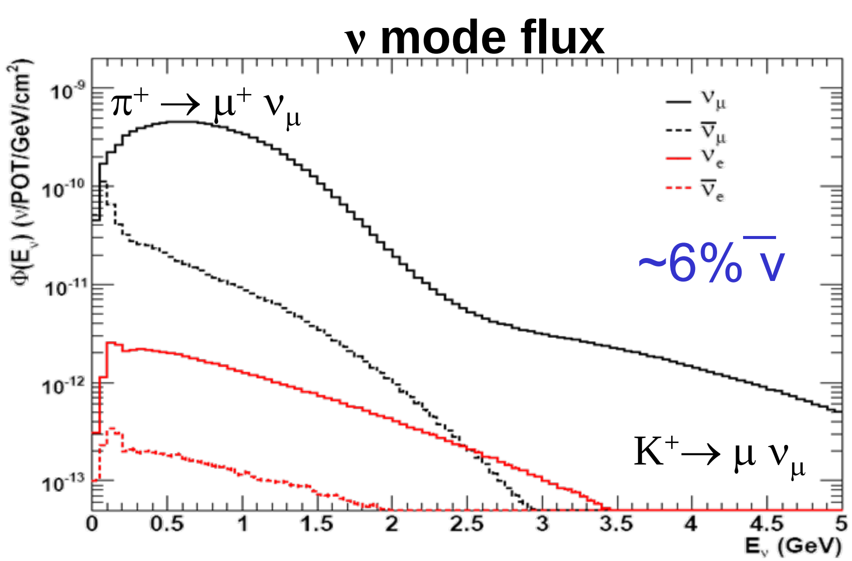


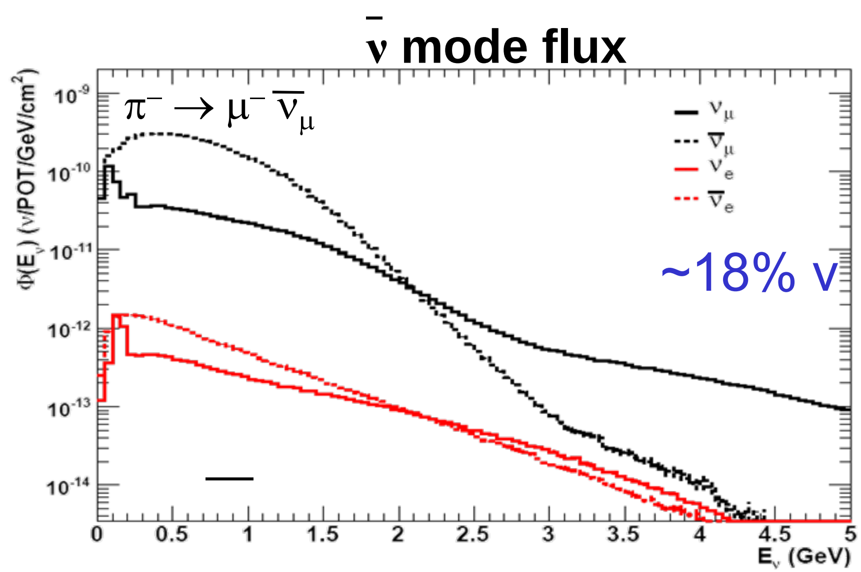

KARMEN at a distance of 17 meters saw no evidence for oscillations → low $\Delta m^2$

*at least 5 neutrinos are required to accommodate all experiments

# Appearance experiment: it looks for an excess of electron neutrino events in a predominantly muon neutrino beam



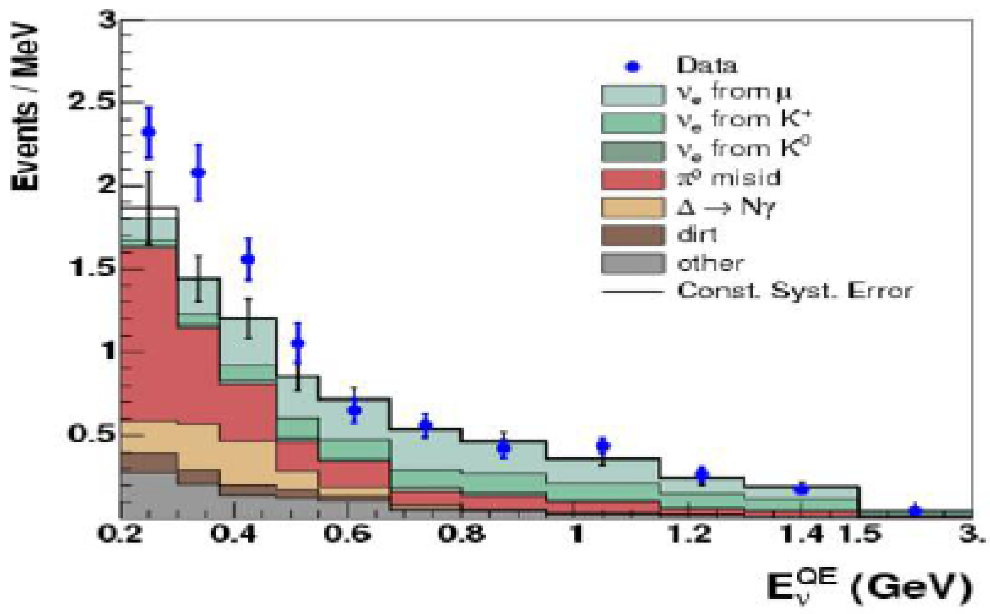




neutrino mode: $\nu_\mu \rightarrow \nu_e$ oscillation search

antineutrino mode: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation search

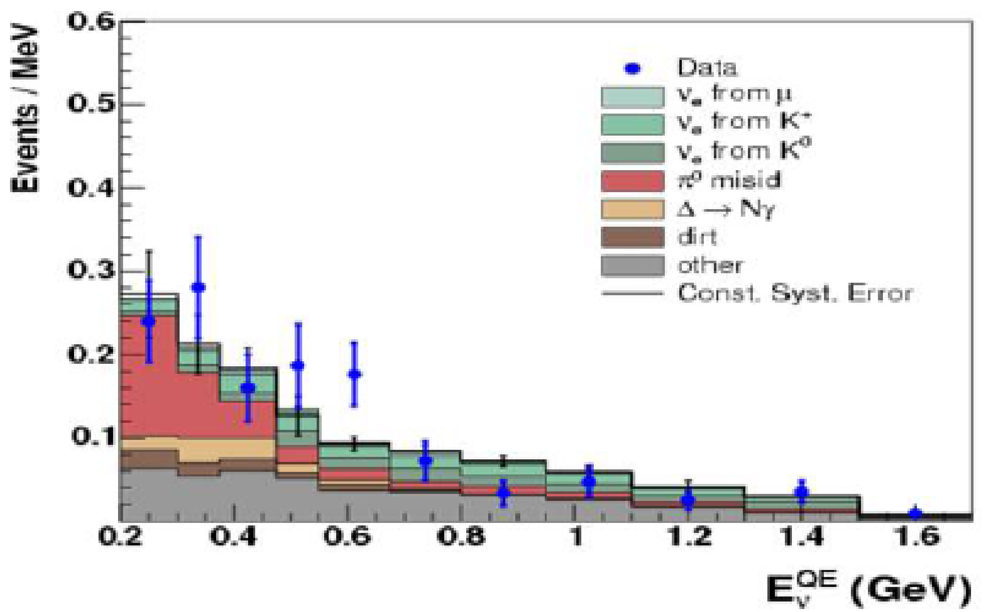
# MiniBooNE Results

*Neutrino Mode*

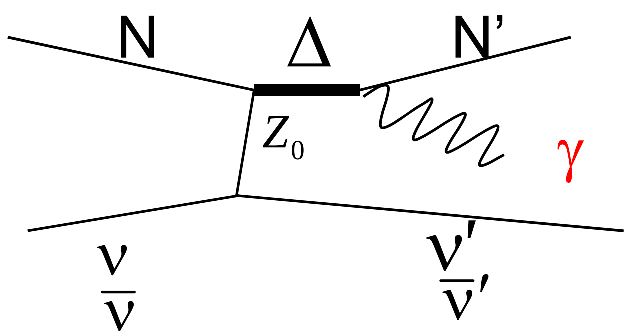



*Anti-neutrino Mode*

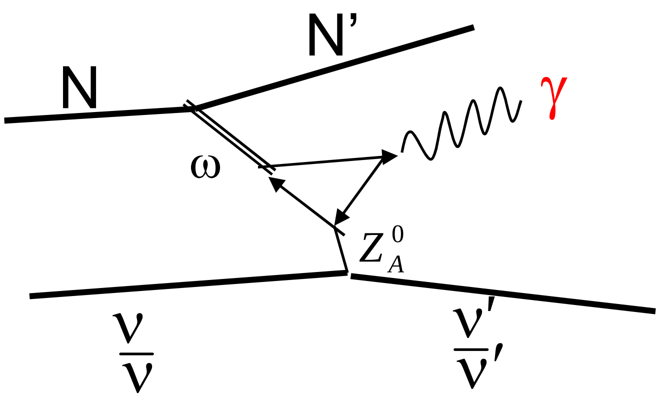
(Not yet sensitive to LSND)



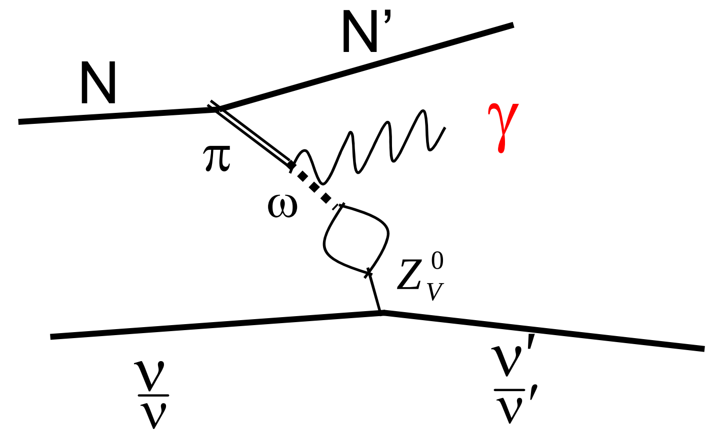
# Backgrounds: Order(α x NC) , single photon FS




Radiative Delta Decay

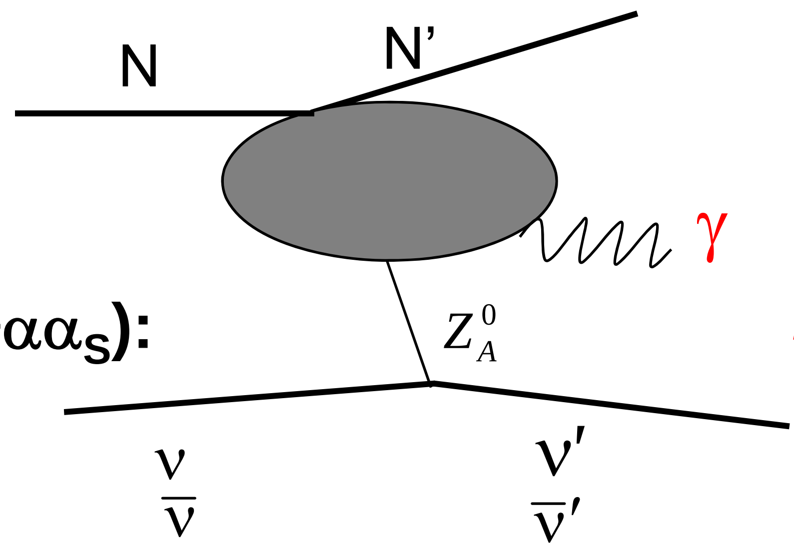



Axial Anomaly




Other PCAC

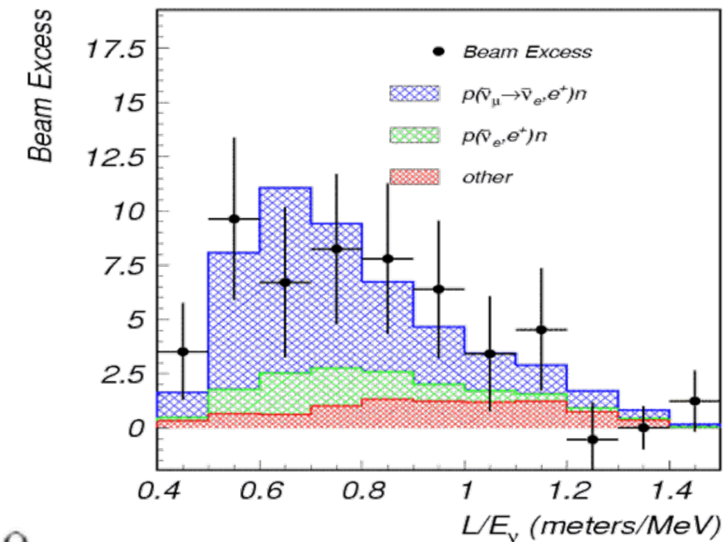
**All order ($G^2\alpha\alpha_S$):**




*So far we have not found a process to account for the $\nu,\bar{\nu}$ difference. Work is in progress…*

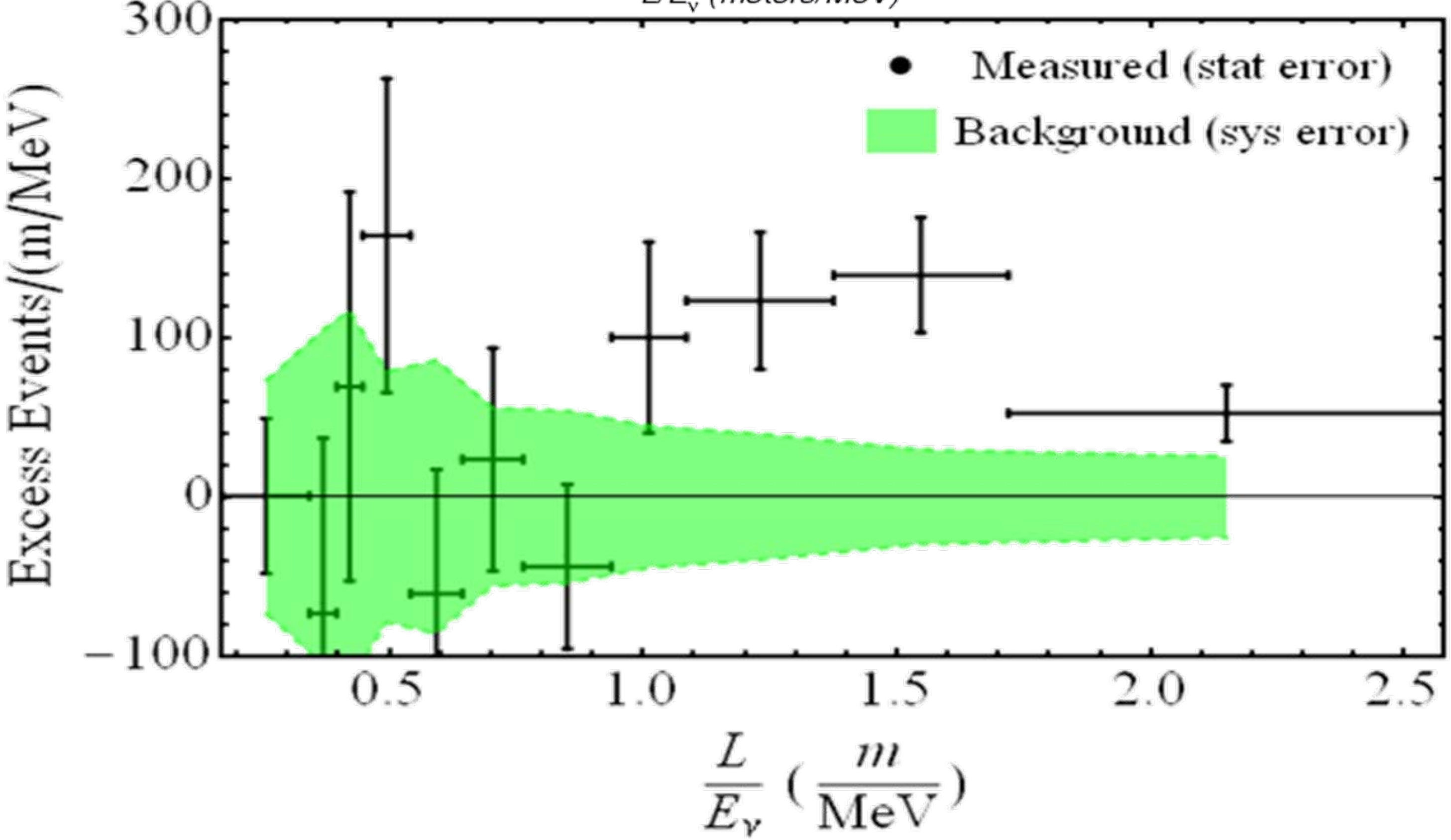
# MiniBooNE and LSND Comparison

LSND
(anti-neutrino)

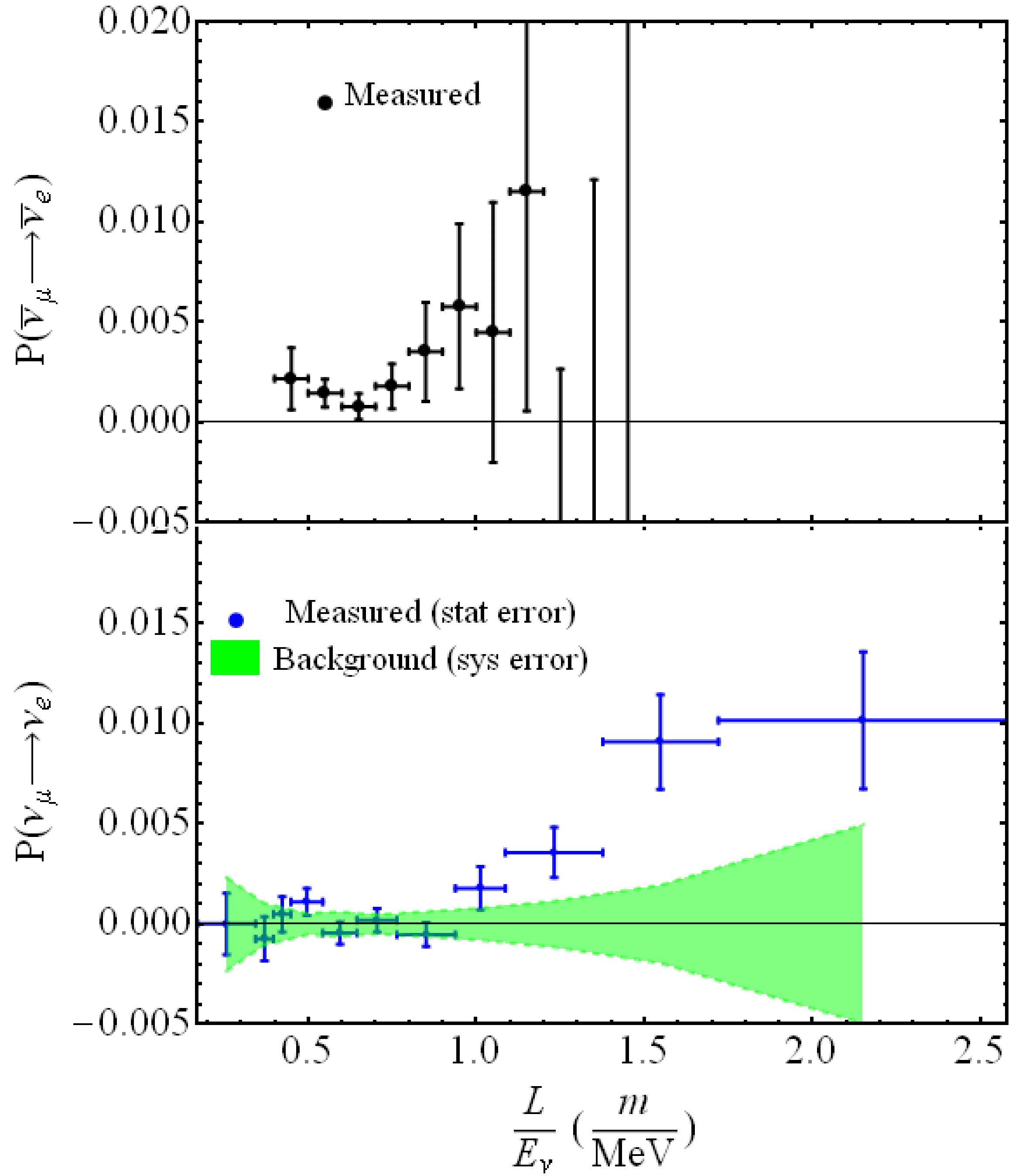



L/E ~ neutrino proper time
(in rest frame of neutrino)

MiniBooNE
(neutrino)



# LSND and MiniBooNE oscillation probabilities



# LSND and MiniBooNE oscillation probabilities

My own attempts to reconcile Data:

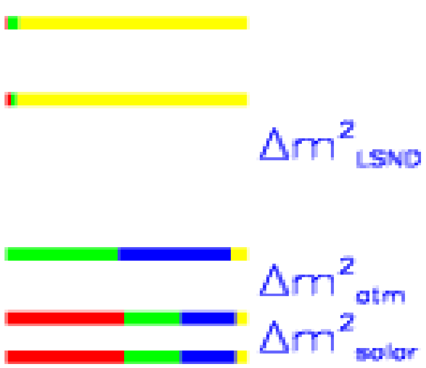
***"low-low" solution***

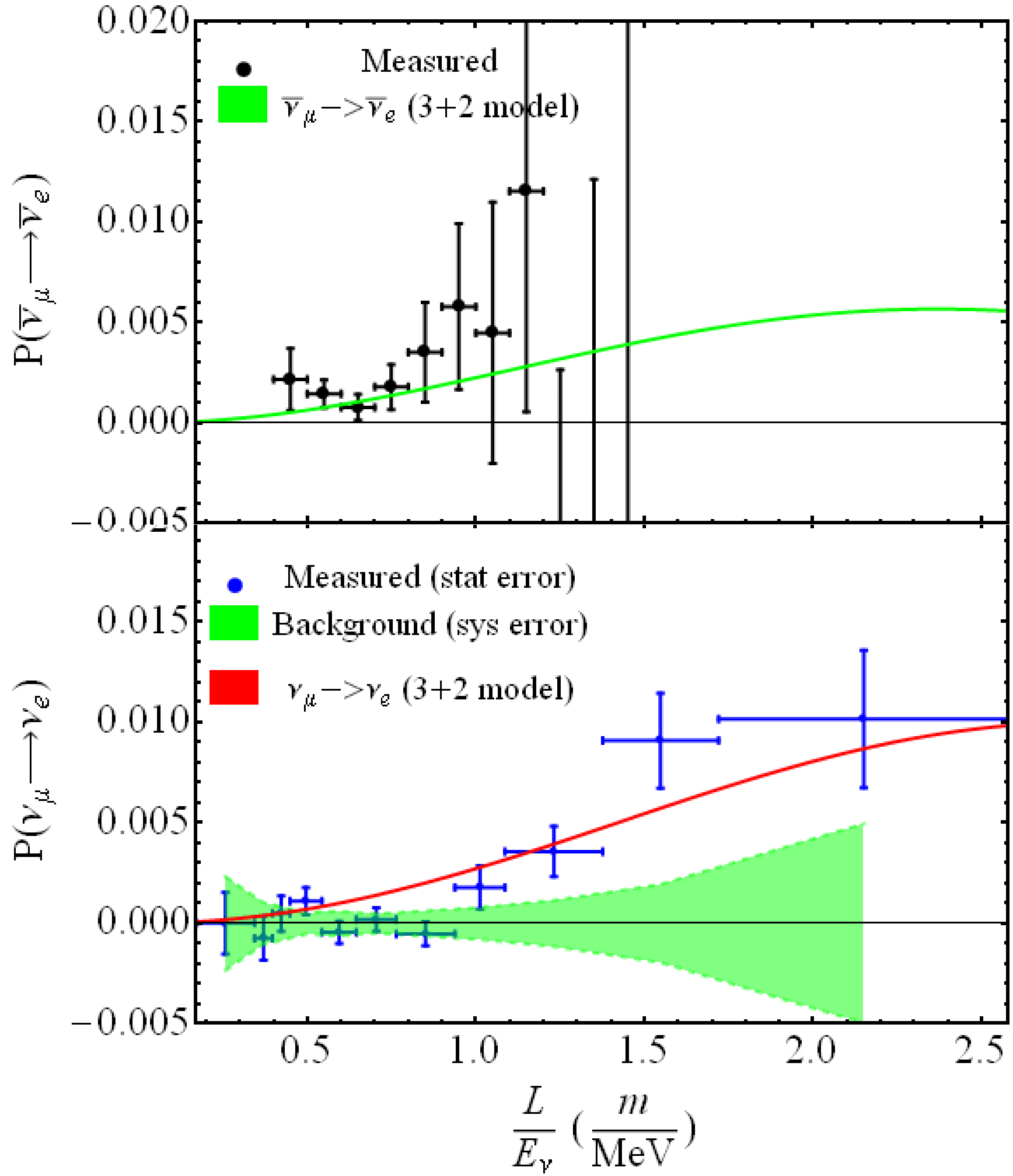
3+2 model (suggestive)

$\Delta m_a^2 = 0.5\ \text{eV}^2, P_a = 0.04$

$\Delta m_b^2 = 0.25\ \text{eV}^2, P_b = 0.025$

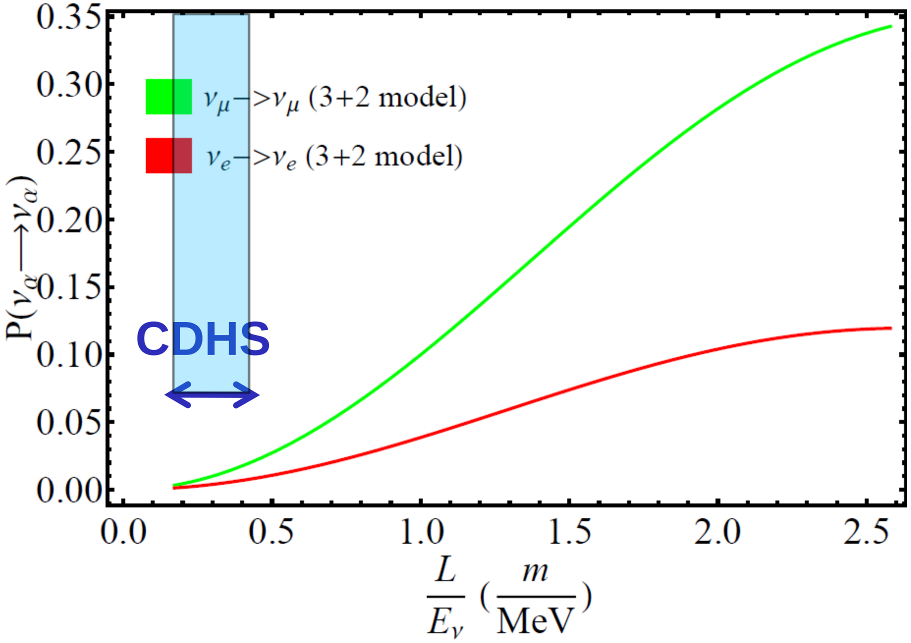
$\phi_{CP} = \frac{\pi}{2}$ rad

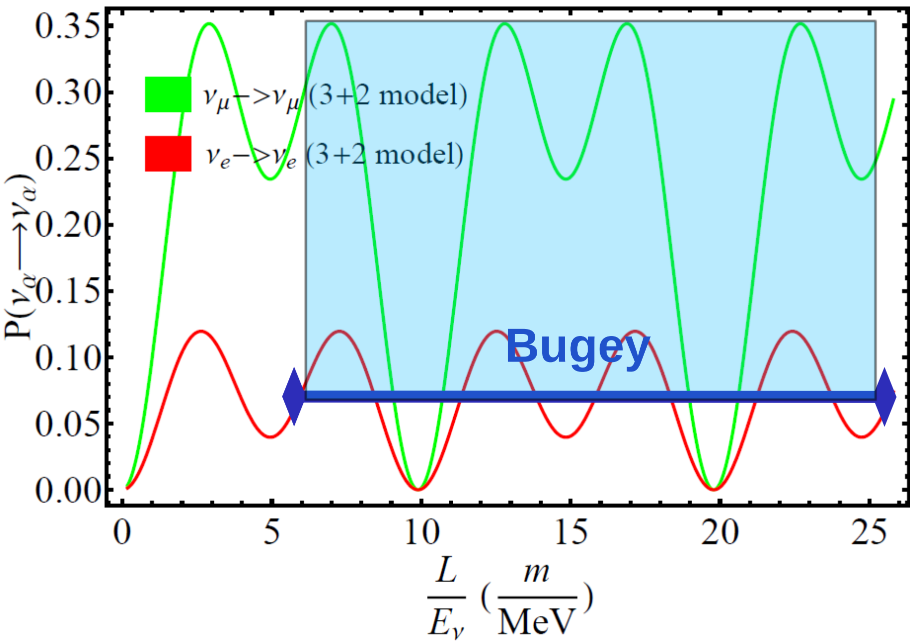


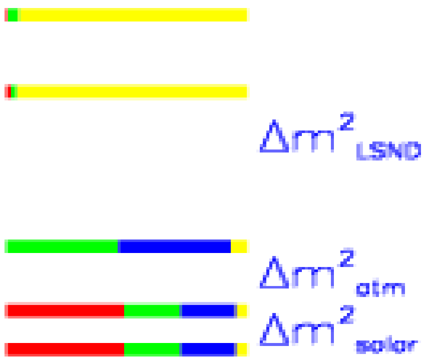



# Disappearance oscillation probabilities

***"low-low" 3+2 example***




3+2 model (suggestive)

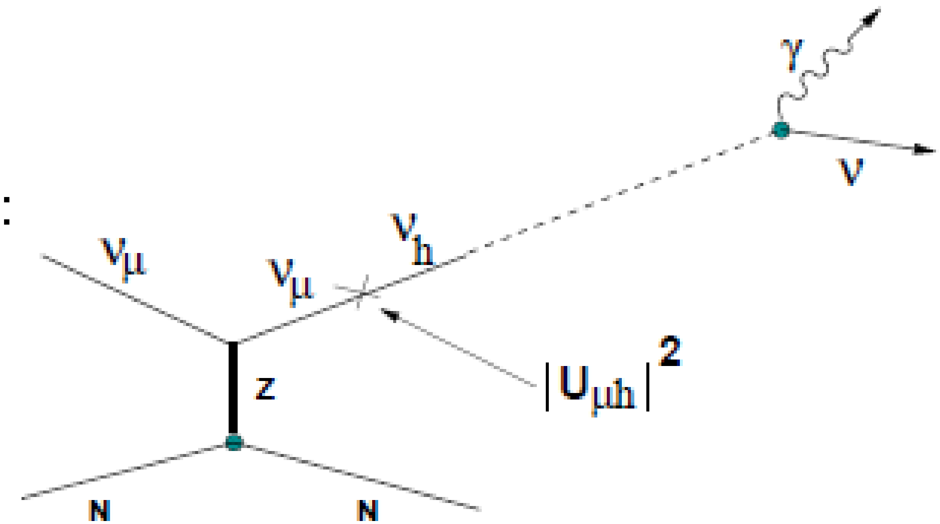
$\Delta m_a^2 = 0.5\ \mathrm{eV}^2, P_a = 0.04$

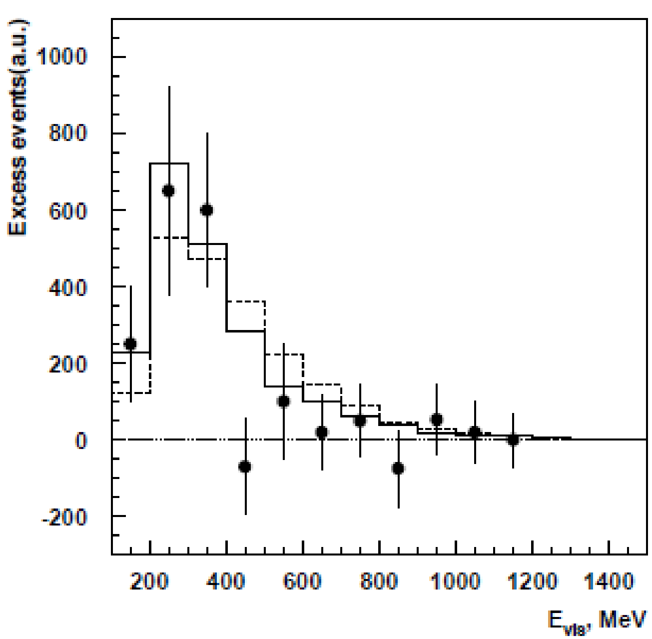
$\Delta m_b^2 = 0.25\ \mathrm{eV}^2, P_b = 0.025$

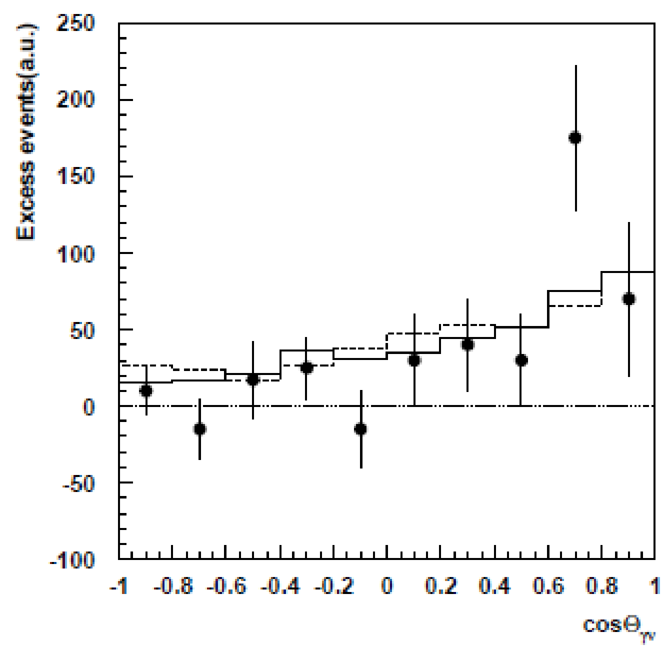
$\phi_{CP} = \frac{\pi}{2}$ rad

# Neutrino Decays?

- MiniBooNE low energy excess could be due to heavy neutrino decays in the detector
  - Gninenko et al, (arXiv:0902.3802):



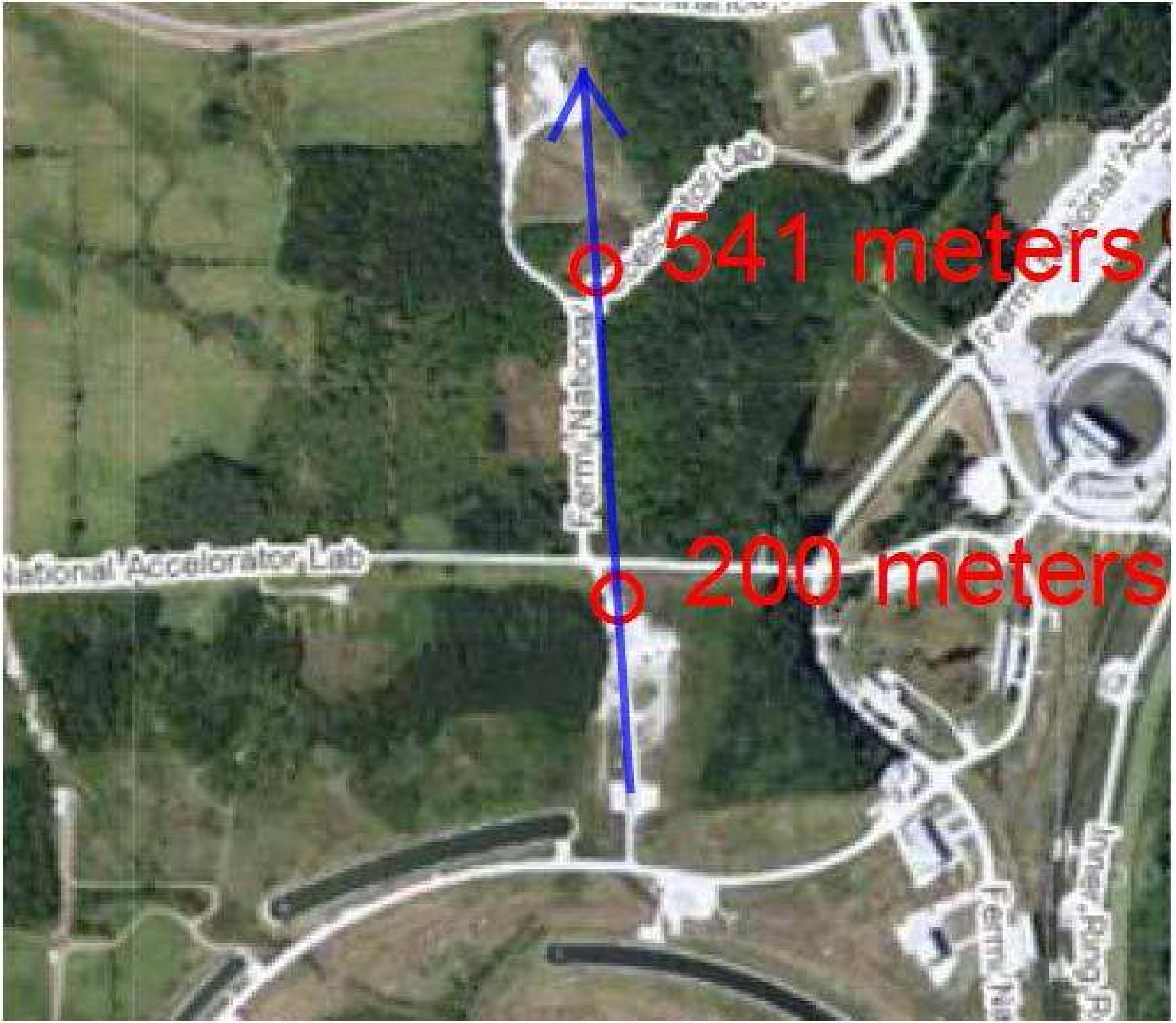



# Resolving the MiniBooNE Low Energy Excess

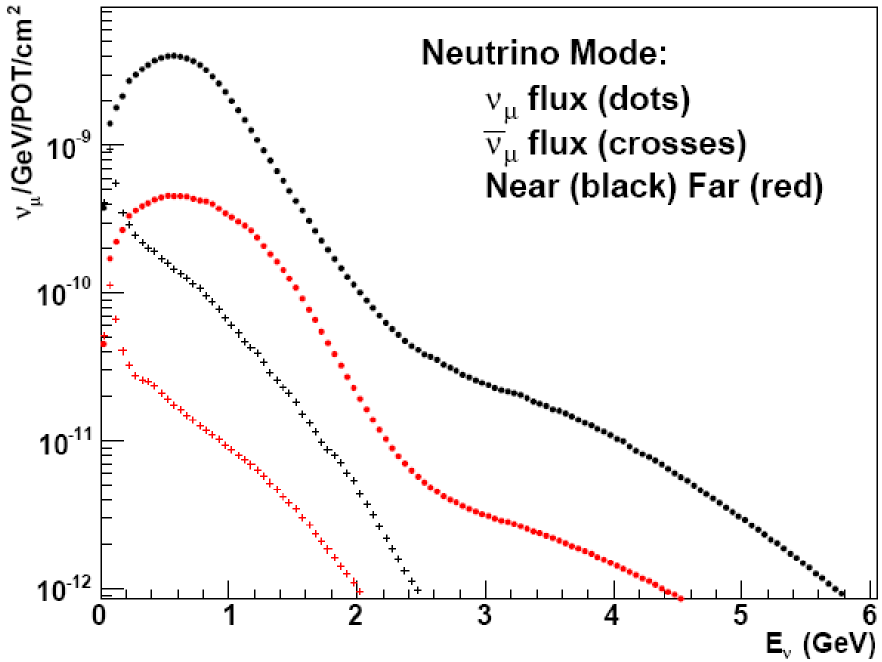
- Moving the MiniBooNE detector to 200m (~4M$) (or building a new detector at 200m (~$8M$))
  - Accumulate a sufficient data sample in < 1 year
  - will dramatically reduce systematic errors (low energy excess is ~ 6 sigma significance with statistical errors only.
  - Can study L dependence of excess: backgrounds scale as 1/L**2, oscillation signal as $\sin^2(L/E)$, and decay as L/E.

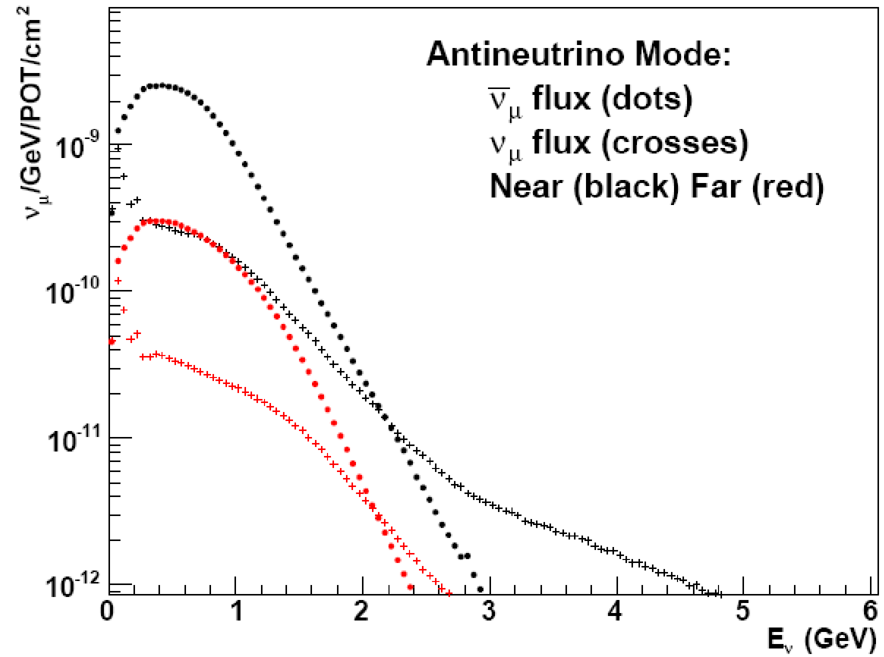
- MicroBooNE:
  - is a 70 ton liquid argon time projection chamber planned for the booster neutrino beam line
  - can differentiate single gamma-rays from electrons (MiniBooNE cannot do this)

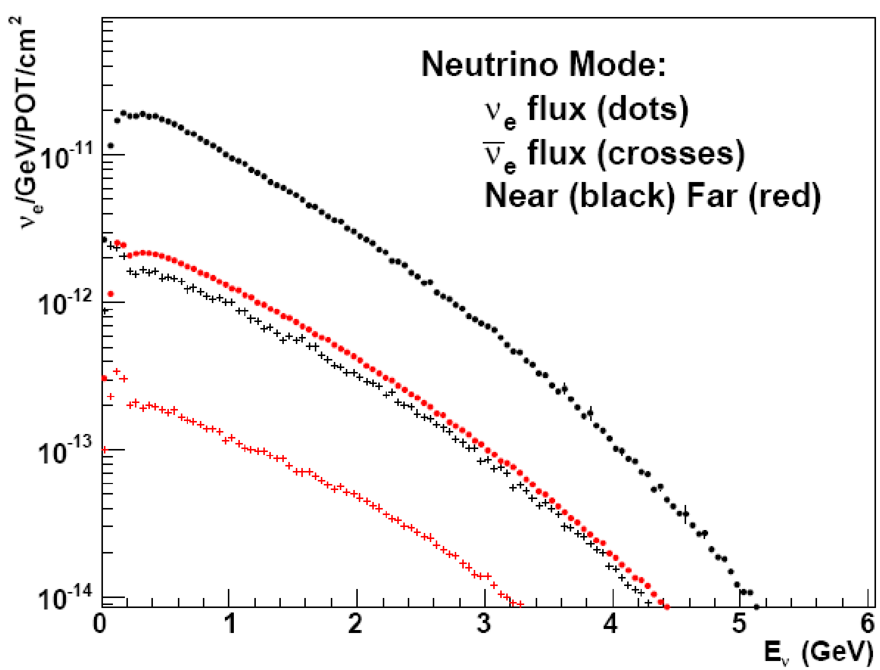
# 200 meter site for a near detector

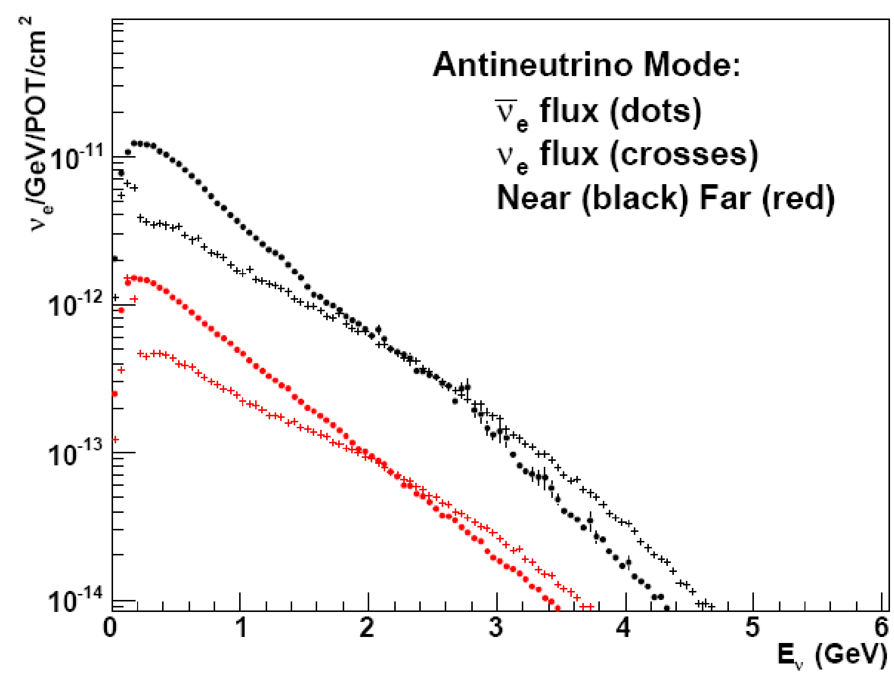


# Fluxes at near and far positions

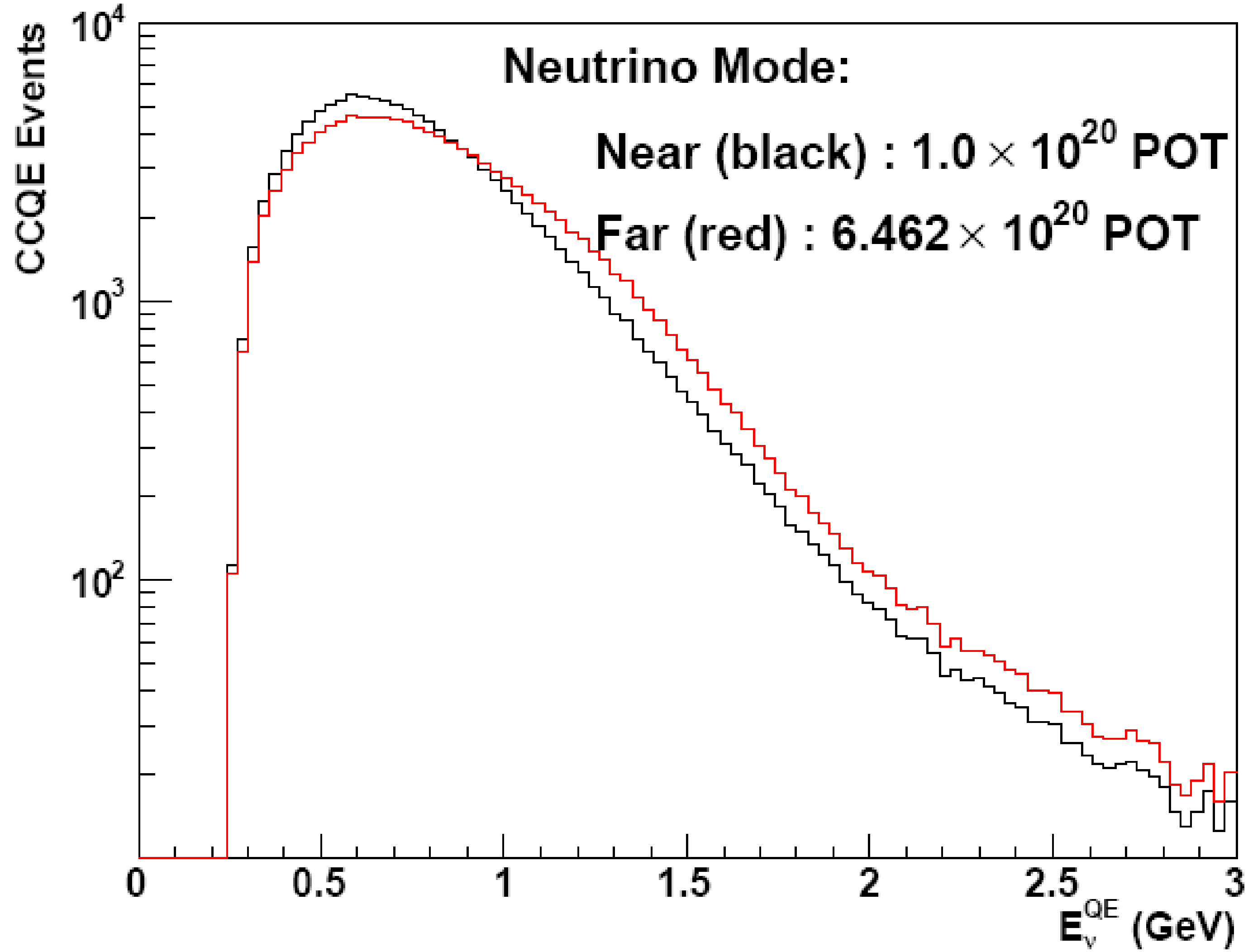


# Event rates in neutrino mode




Charged current quasi elastic (CCQE) event rate

# Options for a Near BooNE Detector

- Transport existing MiniBooNE detector (~80 tons) to new location 150-200 meters from BNB target (~4M$)

- Dismantle existing MiniBooNE detector and construct a new detector at 150-200 meters. (~4M$)

- Construct brand new detector at 150-200 meters (~8M$)

# Conclusion

- Moving MiniBooNE to 200 meters and running for one year would resolve whether or not the low-e excess is due to a (L,E) dependent phenomena at the ~ 5 sigma level
- It would also provide a high statistics, low systematic error numu/numu-bar disappearance measurement
- The timing of the project is ideal for post-antineutrino running in the BNB
- MicroBooNE will at the same time run to look for excess gamma events
- A “LSND”-like detector at the SNS (OscSNS) would directly test the LSND excess

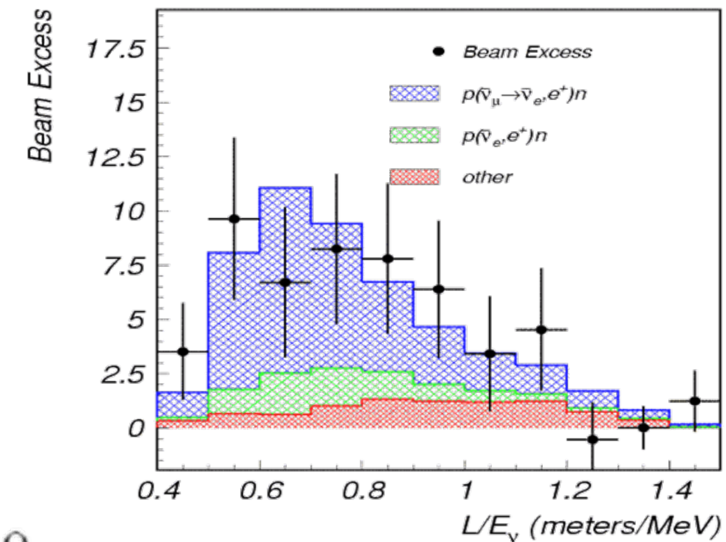
- More….

Lift of 260 ton Generator

Transporting 550 ton Coker Drum from ship to crane hook

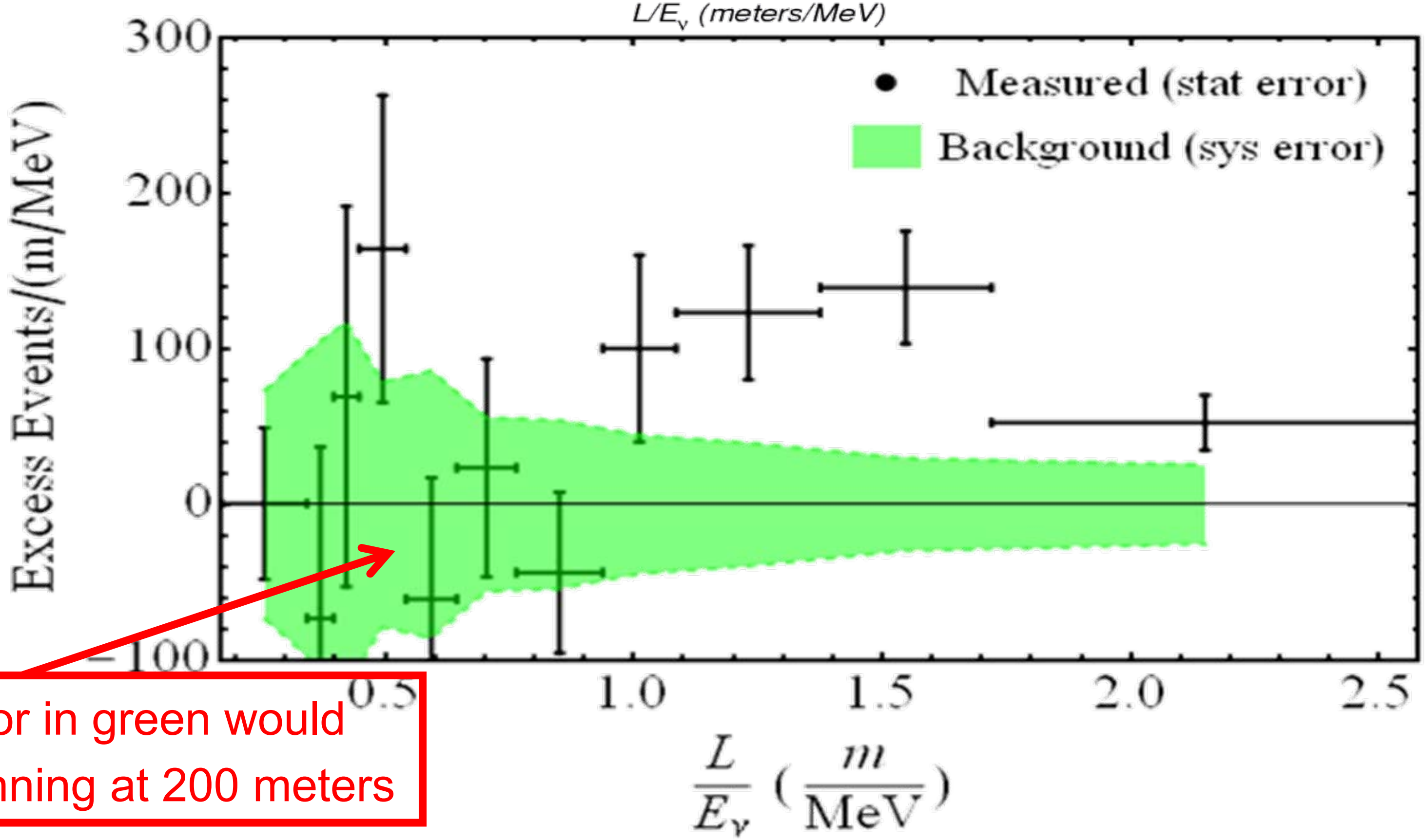
# MiniBooNE at 200 meters

LSND
(anti-neutrino)




L/E ~ neutrino proper time
(in rest frame of neutrino)

MiniBooNE
(neutrino)




The systematic error in green would disappear after running at 200 meters

# Systematic Errors :

- Neutrino Cross Sections
  - target material is the same (mineral oil)
- Detector Efficiencies
  - With the same detector, we should have nearly identical detection efficiencies
- Flux ?
  - the opening angles of neutrinos from pion or kaon decays are tens of mrad or greater
  - Most pions and kaons contribute to both the 200 and 500 meter fluxes

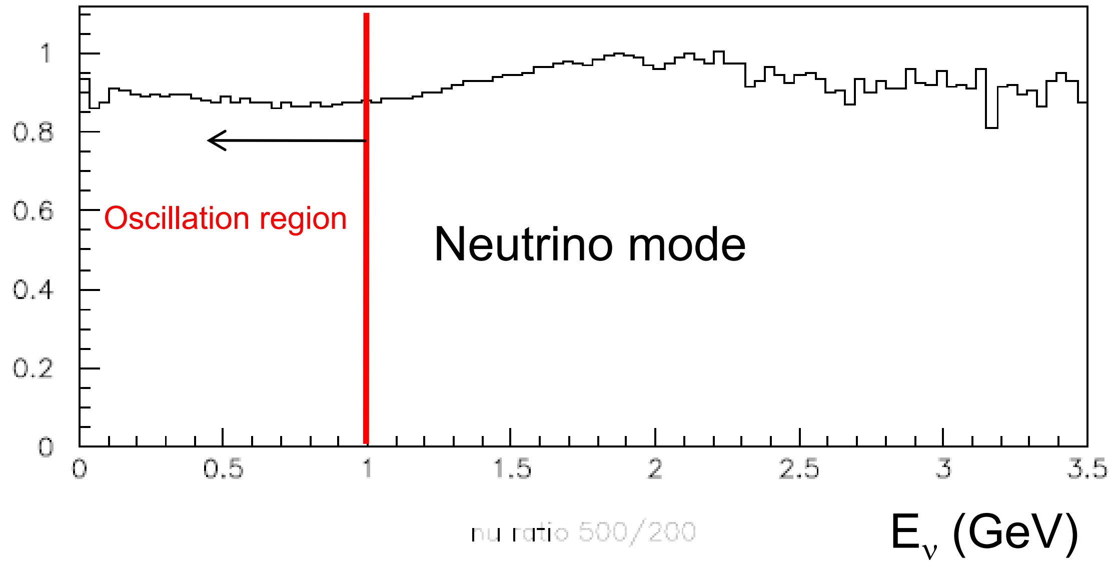
# Near BooNE Detector

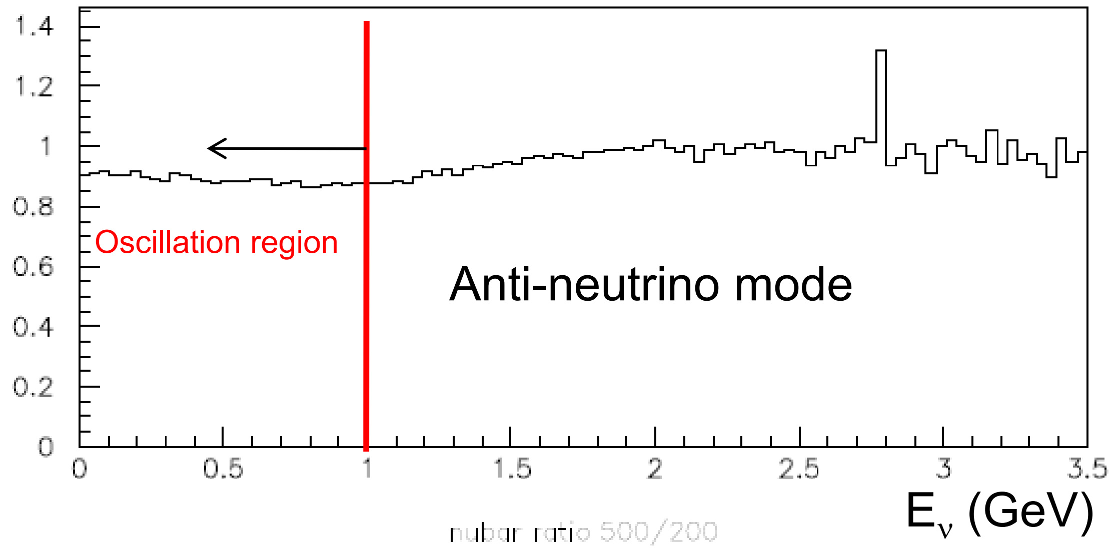
- In the low-e analysis we are dominated by systematic errors
  - The low-e excess is ~ 6 sigma statistically, but only ~3 sigma including systematic errors
    - it might be due to a unforeseen background or…
    - it might be due to new, non-standard physics

- Running MiniBooNE for 1 year at a position 200 meters would increase the data rate per pot x6 and:
  - *Make flux, cross section, and optical model systematic errors small in the 200 meter/500 meter comparison*
  - Demonstrate at ~ 5 sigma level whether or not the low-e excess depends on $1/L^2$ or (L,E) e.g. oscillations

# Far to Near Neutrino Flux Ratios at 200 m

MiniBooNE Far/Near fluxes
Scaled by $1/r^2$



# Statistical Errors

- In order to achieve reasonable sensitivity ~ ½-1 year of running would be required for each focus
  - Current proton delivery rates of $2 \times 10^{16}$ protons/hour give $\sim 1.75 \times 10^{20}$ protons/year
  - Current 6.5 $\sigma$ statistical significance translates to ~5 $\sigma$ statistical significance for one year of running in nu mode

# LSND and MiniBooNE oscillation probabilities

My own attempts to reconcile Data:

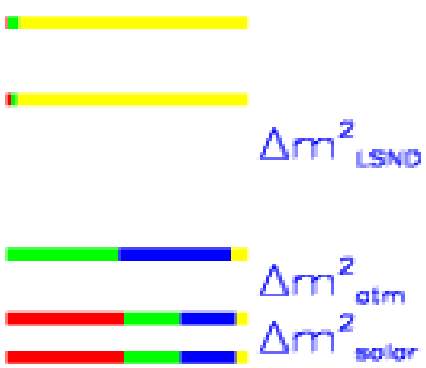
***"high-low" solution***

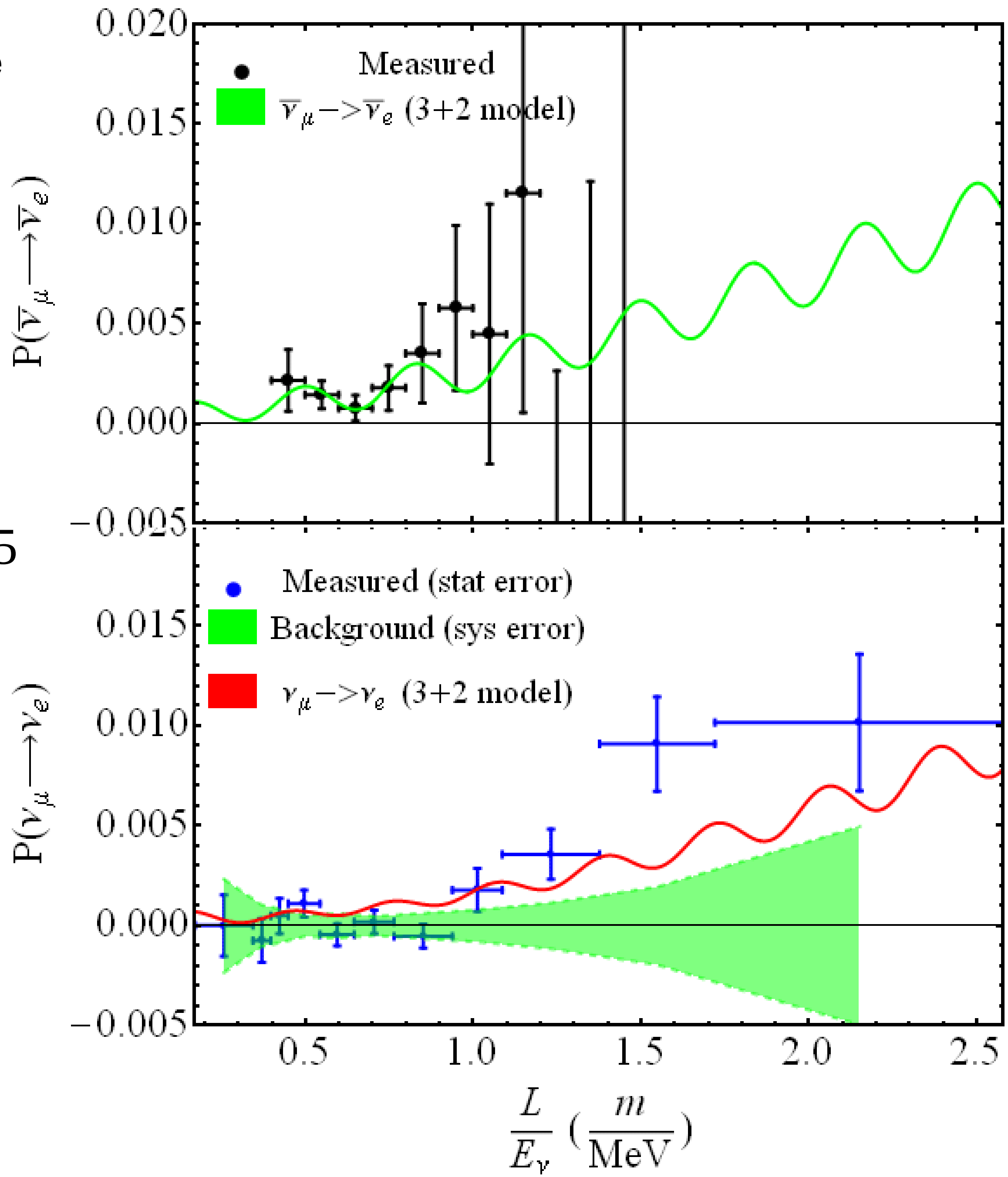
3+2 model (suggestive)

$\Delta m_a^2 = 7.5\ \mathrm{eV}^2, P_a = 0.015$

$\Delta m_b^2 = 0.25\ \mathrm{eV}^2, P_b = 0.065$

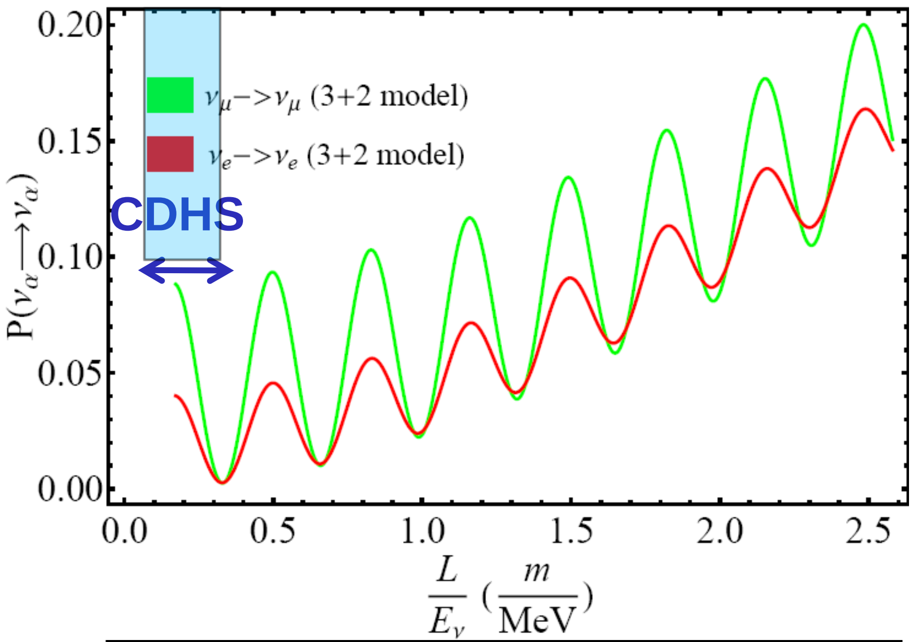
$\phi_{CP} = 1.3\ \mathrm{rad}$

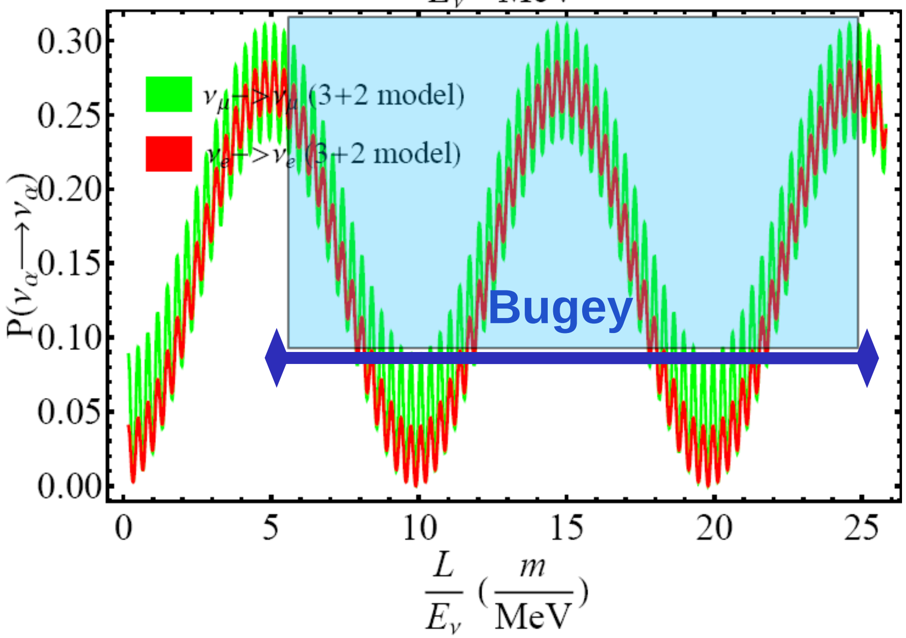


# Disappearance oscillation probabilities

***"high-low" 3+2 example***




***"low-low" 3+2 example***