MiniBooNE
"Windows on the Universe"

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Fermilab

Outline:

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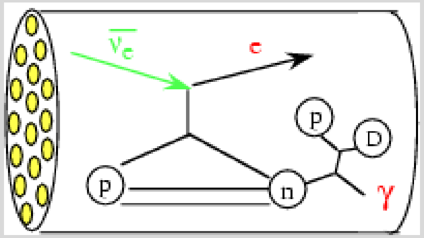
Introduction

Liquid Scintillator Neutrino Detector (LSND)



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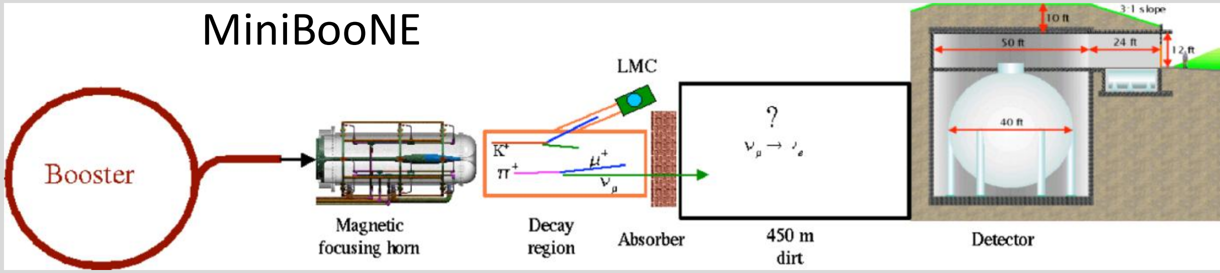
MiniBooNE



oscillation experiments

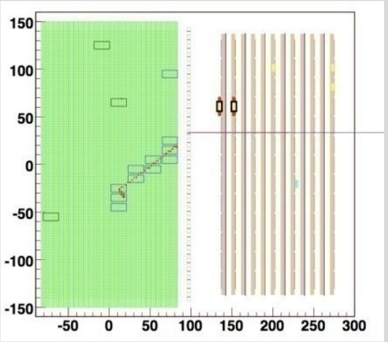
$$\text{appearance}: \quad \nu_\mu \to \nu_e$$

$$\overline{\nu}_\mu \to \overline{\nu}_e$$

$$\text{disappearance}: \quad \nu_\mu \mapsto \nu_\mu$$

$$\overline{\nu}_\mu \mapsto \overline{\nu}_\mu$$

SciBooNE ↓



accelerator sources

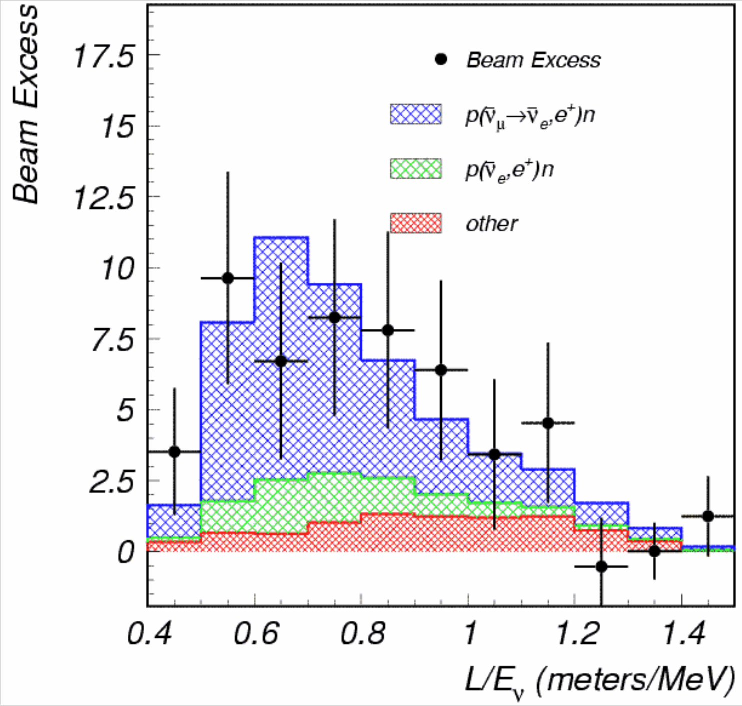
- stopped muons @ LANL -> LSND
- BNB @ FNAL -> MiniBooNE
  - -> SciBooNE
- NuMI @ FNAL -> MINOS
  - -> NOVA
  - -> MiniBooNE

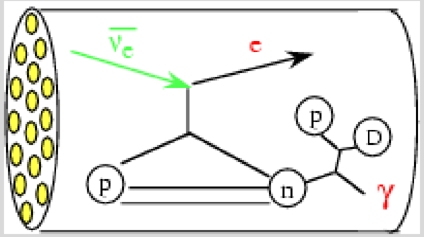
3 active ν families

2 or more sterile νs

Liquid Scintillator Neutrino Detector (LSND)

A 3.8 σ signal at Δm^2 ~ 0.6 eV^2 @ $\sin^2(2\theta)$ ~0.001





Excellent control of systematics :

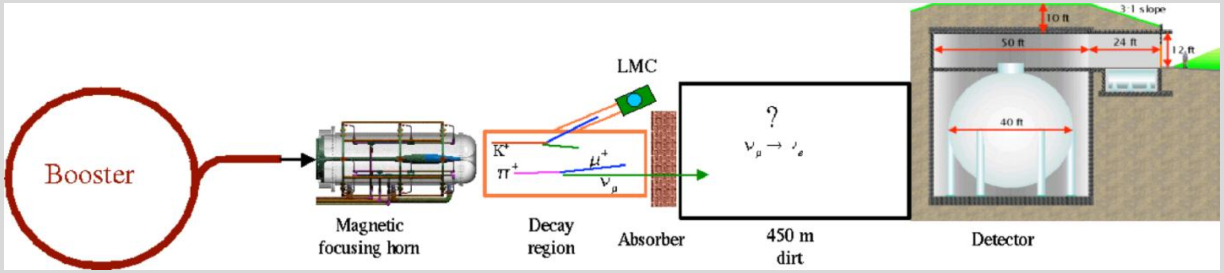
ν_e interactions eliminated from background

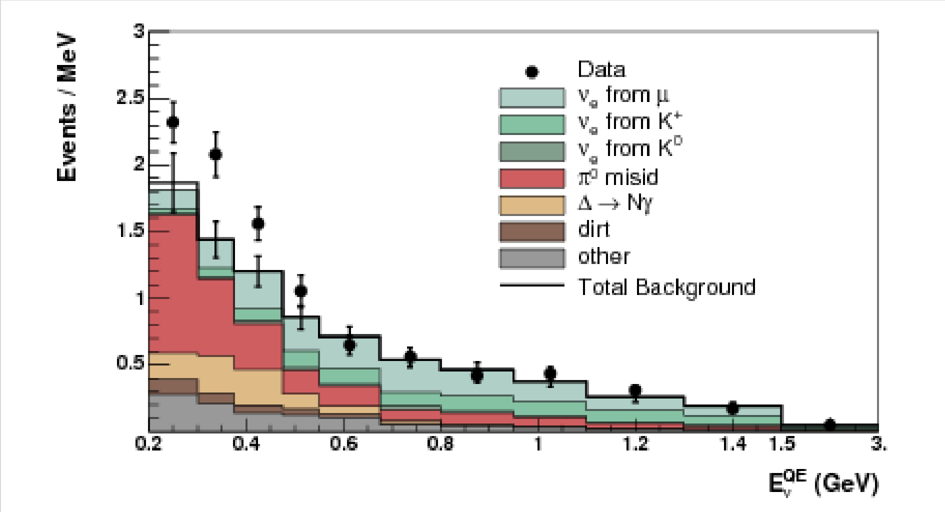
detected γ from neutrino capture.

much like a Reines, Cowen detetctor

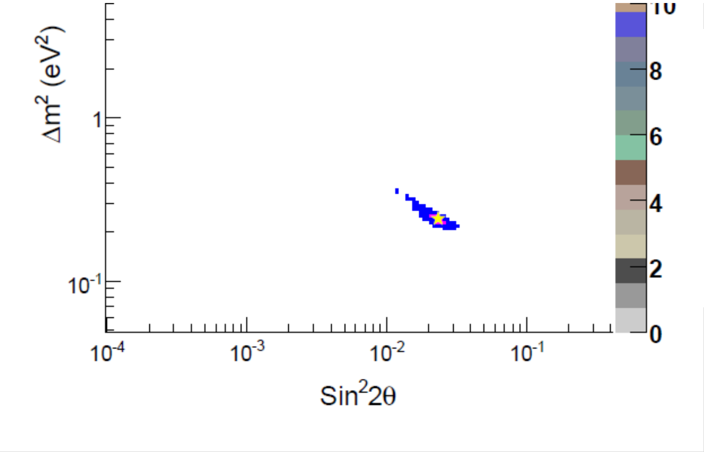
A.A. Aguilar *et al.,* Phys. Rev. D **64** (2001) 112007
E. Church *et al.,* Phys. Rev. D **66**, 013001 (2002)

Current Status





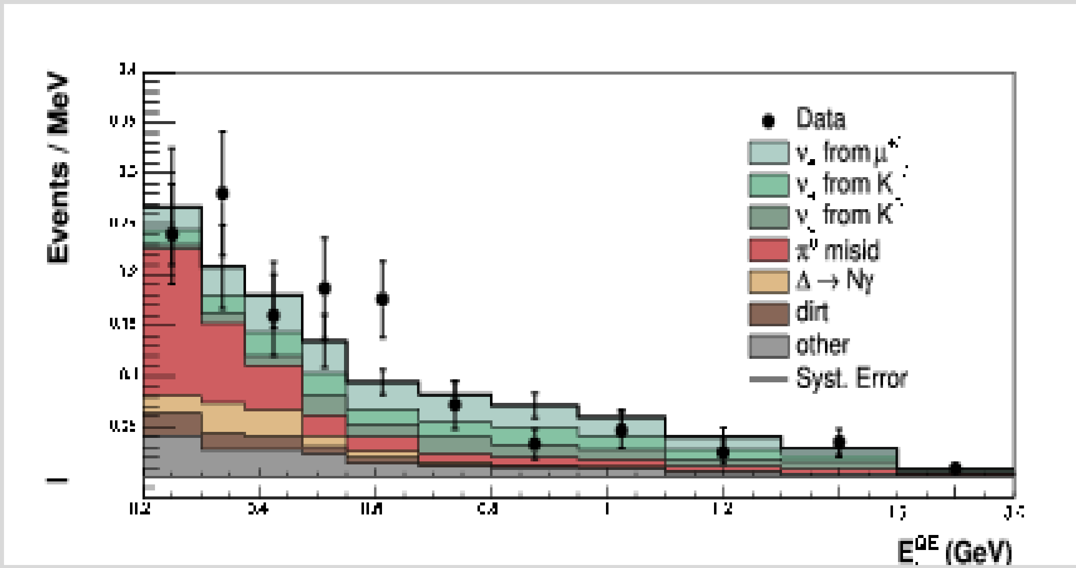
E_ν^{QE} distribution for data (points with statistical errors) and backgrounds (histogram with systematic errors). Note that E_ν^{QE} range begins at 0.2 GeV. There is a clear low-energy excess in the data.



Summed 2D $\Delta\chi^2$ compatibility grid from LSND, KARMEN2, MiniBooNE and Bugey. The star indicates the point of maximal compatibility (3.94%).

Aguilar-Arevalo *al.,* Phys. Rev. Lett. **98,** 231801 (2007)
Data are available on-line.
Aguilar-Arevalo *et al.,* Phys. Rev. **D 78**, 012007 (2008)

The E_ν^{QE} distribution for $\overline{\nu}_e$ CCQE data (points with statistical errors) and background (histogram with unconstrained systematic errors).



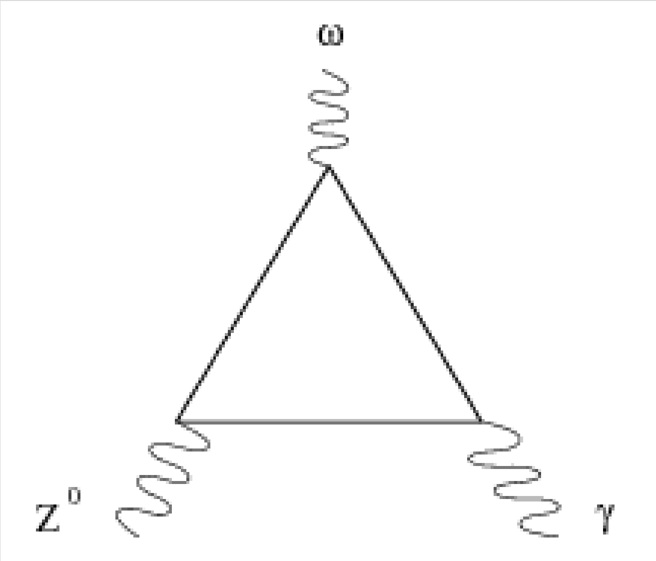
Constraints on models now include:

~50 MeV excess in ν mode

~350 MeV excess in ν mode

No excess at ~350MeV in $\overline{\nu}$ mode.

Aguilar-Arevalo *et al.*. Phys. Rev. Lett. **102**, 101802 (2009)



A potential explanation of the low energy anomaly within the standard model: an application of the axial vector anomaly to radiative neutrino scattering, where the radiated photon mimics an electron in MiniBooNE

Triangle diagram at chiral constituent quark level treating γ, Z, ω as background gauge fields.

This approach is disfavored, because it doesn't distinguish between ν and $\bar{\nu}$

Harvey, Hill & Hill, [hep-ph/0708.1281] (2007)

Current Status

MiniBooNE has produced many results that we wish to explore within the context of "Windows on the Universe." We need a phenomenological basis or backbone for MiniBooNE's contributions.

"Altered Dispersion Relations or ADRs are due to the ... interaction of neutrinos with background fields and particles, or are attributable to ... CPT- violating extensions of the Standard Model, or ... additional space-time dimensions. " They are of interest in exploring the interactions of active-sterile neutrinos.

MiniBooNE does not test for matter effects, but resonant features within the context of ADRs could have observables accessible to short-baseline neutrino experiments.

Examples of such theories that depend on sterile neutrinos and are the familiar physical territory of MiniBooNE:

a. extra dimensional shortcuts
   – in which sterile neutrinos can propagate in an other dimension
b. or theories in which Lorentz invariance is broken and CPT might be violated.

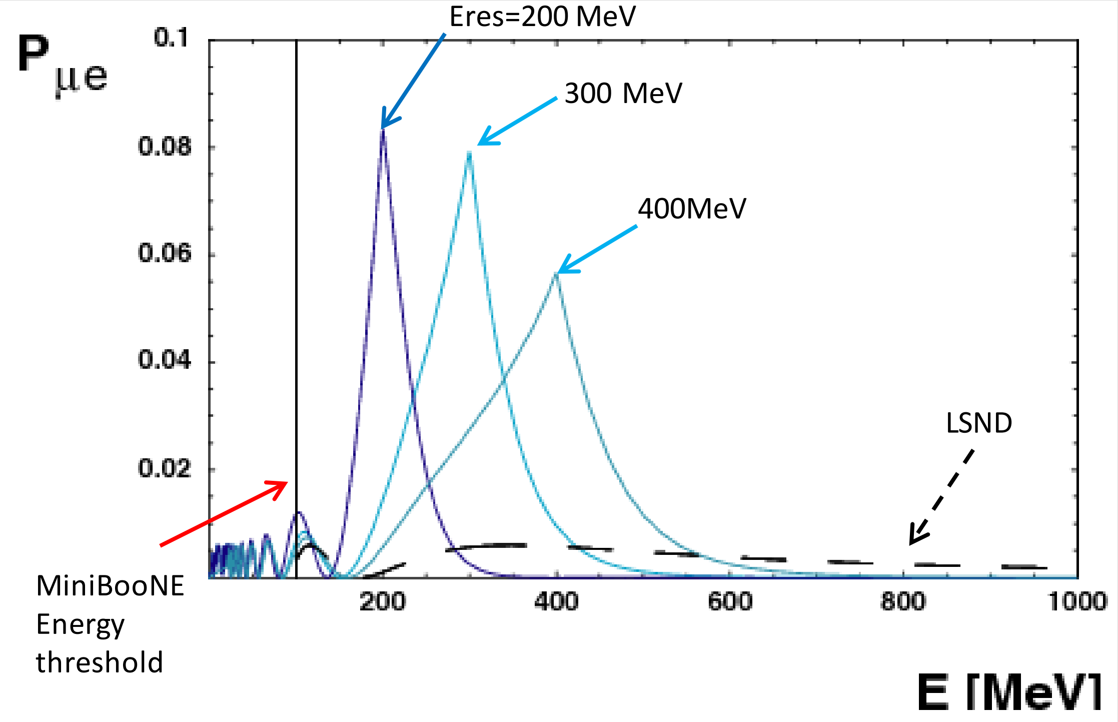
We'll also refer explicitly to a 3+2 scenario: models with 3 active and 2 sterile neutrinos that consolodate existing data

Hollenberg and Pas, hep-ph/0904.21011

ν_μ to ν_e oscillation analysis and the low energy excess

An example of extra dimensional shortcuts leading to resonant oscillation behavior that might explain the MiniBooNE low energy effect.

	MiniBooNE	LSND
$\sin^2 \vartheta_*$	0.1	0.1
$\sin^2 2\theta$	0.45	0.006
δm^2	0.8 eV	0.8 eV

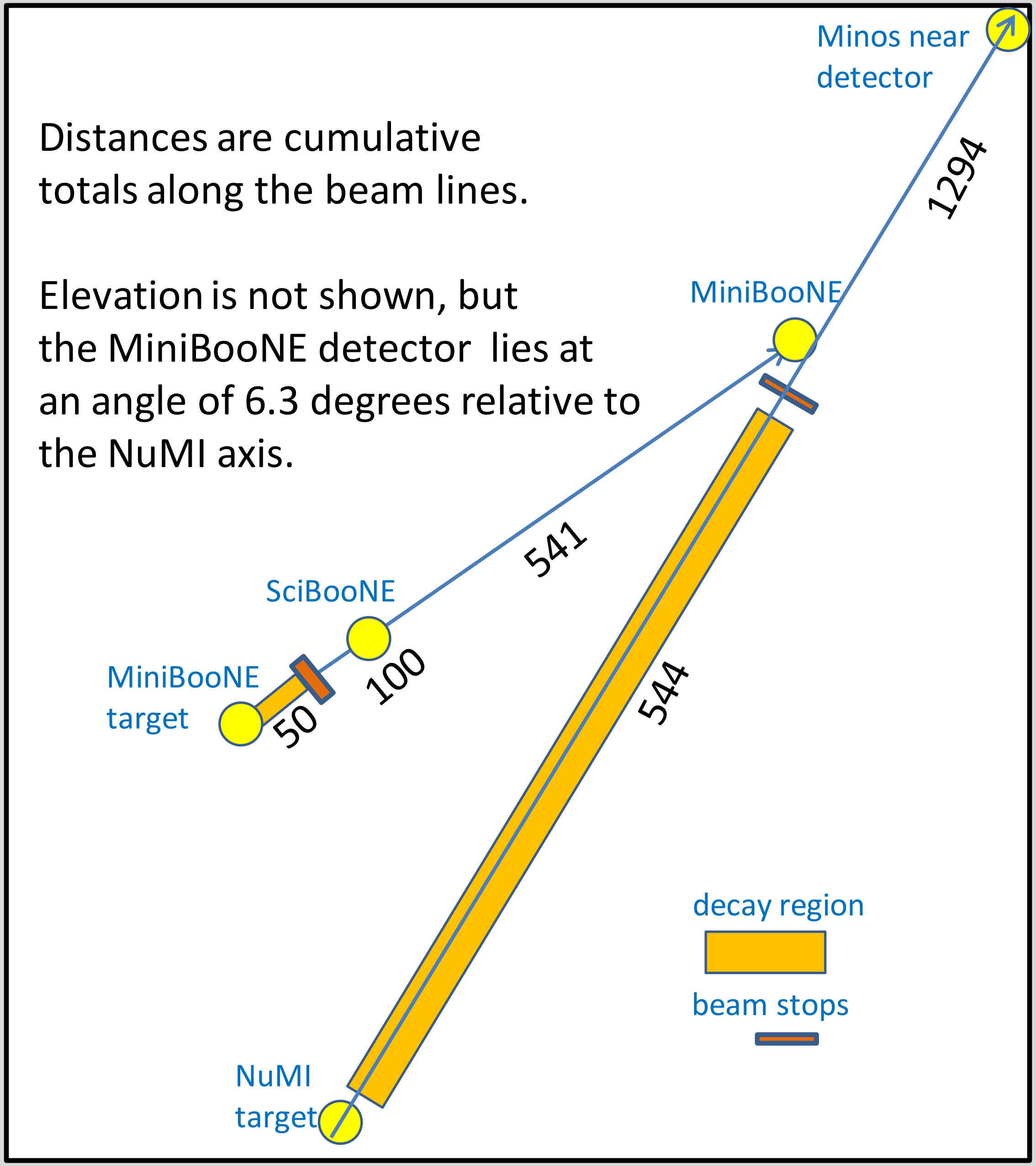


In the context of ADRs, this resonant effect can occur only within a normal hierarchy, and the LSND effect would be larger than the effect in the neutrino sector.

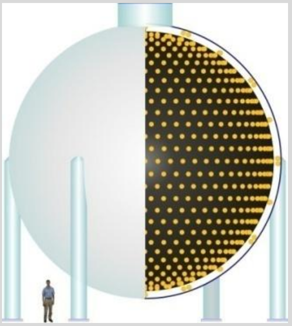
Pas, Pakvasa & Weirler, Phys Rev D **72**, 090517 (2005)

We analyzed the consequences of our model in the context of LSND and MiniBooNE oscillation anomalies: ... using potentials generated by Lorentz symmetry violation the ...data might ...be explained via non-standard matter effects. Matter effects .. due toStandard Model weak interactions are negligible at sub-GeV energies.....but new interactions in Standard Model extensions could give rise to non-standard matter effects affecting the analysis of these ...experiments. Such non-standard matter effects could reduce the widths of resonance peaks and shift the resonance energies of neutrinos with respect to the resonance energies of anti-neutrinos, thus improving data fits for ADR solutions to the LSND and MiniBooNE anomalies.

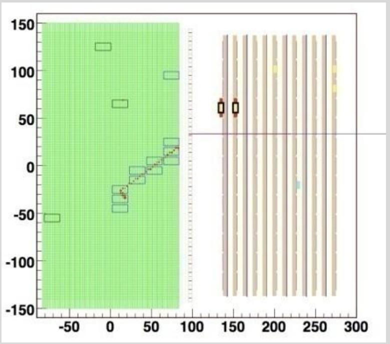
Hollenberg and Pas, hep-ph/0904.21011



MiniBooNE



SciiBooNE

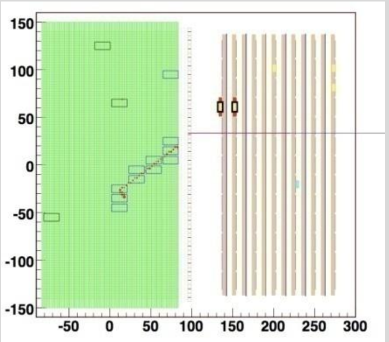


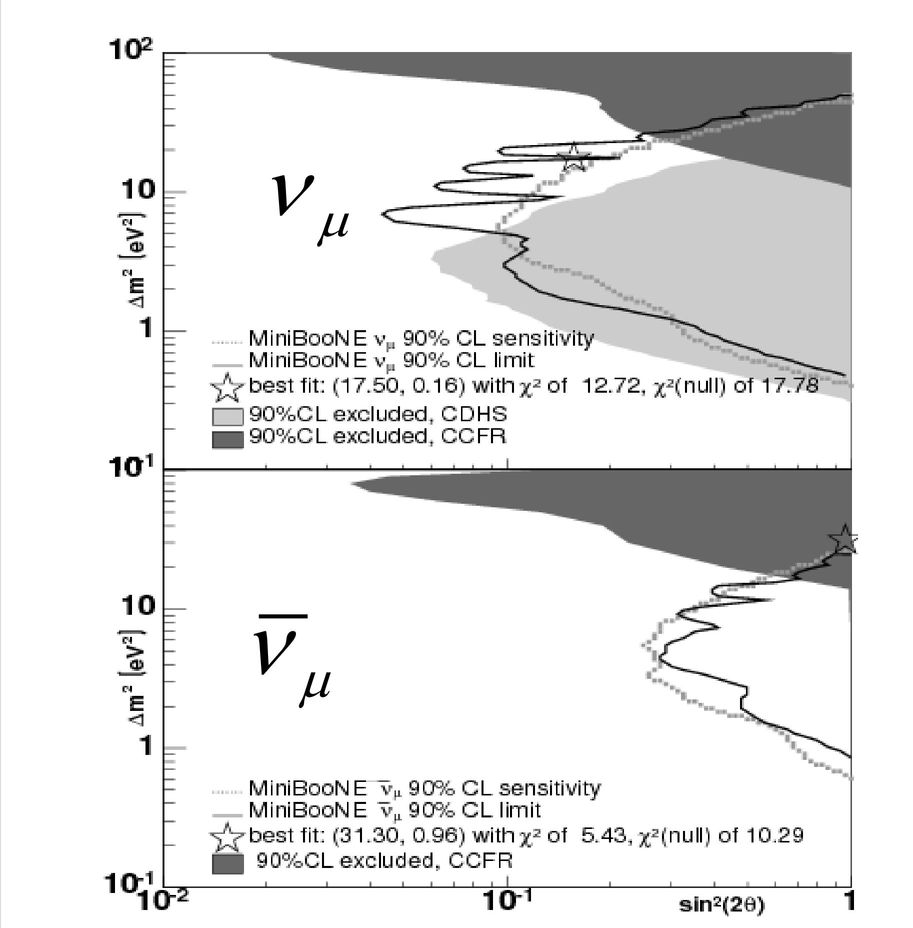
&

the NuMI target

New Results ν_μ & $\bar{\nu}_\mu$ disappearance search

Sensitivity (dashed line) and limit (solid line) for 90% CL for ν_μ & $\bar{\nu}_\mu$ disappearance.





$$X^{S/M}_{\nu_\mu/\bar{\nu}_\mu} = \text{CCQE events per proton on target}$$

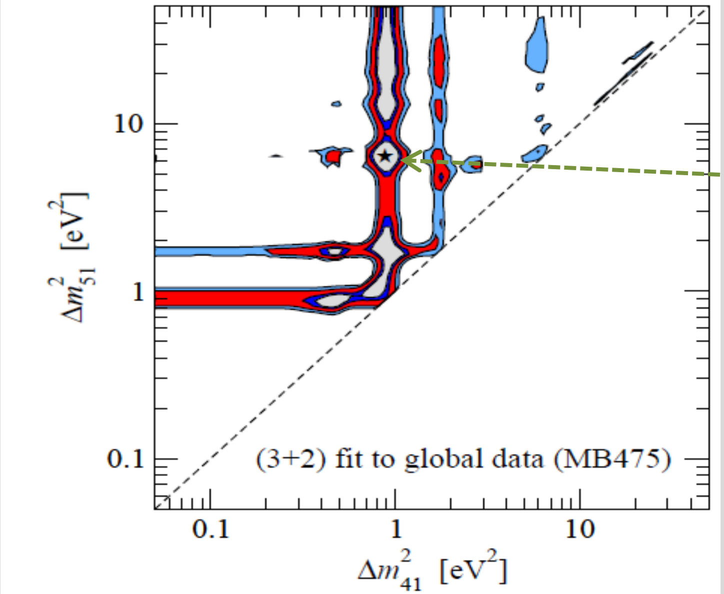
for SciBooNE/MiniBooNE and for $\nu_\mu / \bar{\nu}_\mu$

$$\text{Define } R'' = (X^M_{\bar{\nu}_\mu} / X^S_{\bar{\nu}_\mu}) / (X^M_{\nu_\mu} / X^S_{\nu_\mu})$$

If CPT is conserved in the neutrino sector, this double ratio will be identically equal to unity within statistical and systematic effects.

Aguilar-Arevalo *etal.* hep-ex/0903.2465.

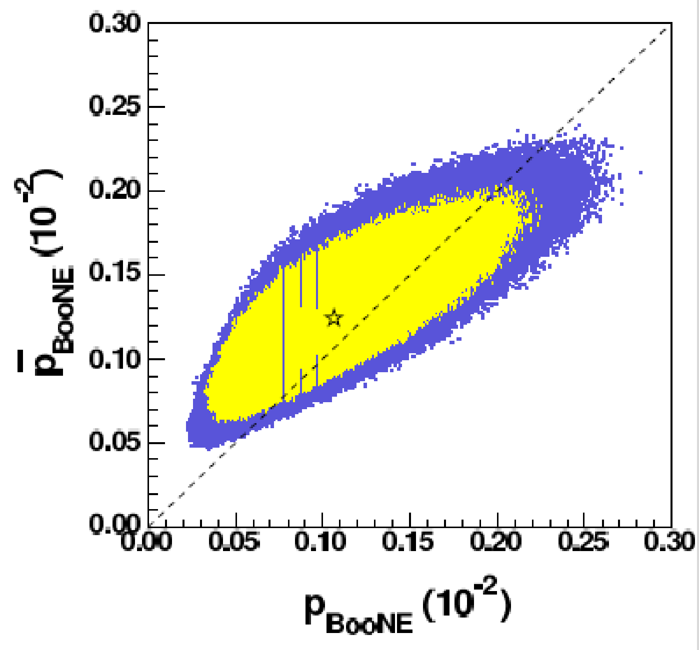
ν_μ to ν_e oscillation analysis and the low energy excess



MB "disappearance" result rules out the best-fit point

Allowed regions for global data in (3+2) schemes in the planes Δm^2_{41} & Δm^2_{51} , with all other parameters minimized.

ν_μ & $\bar{\nu}_\mu$ disappearance search

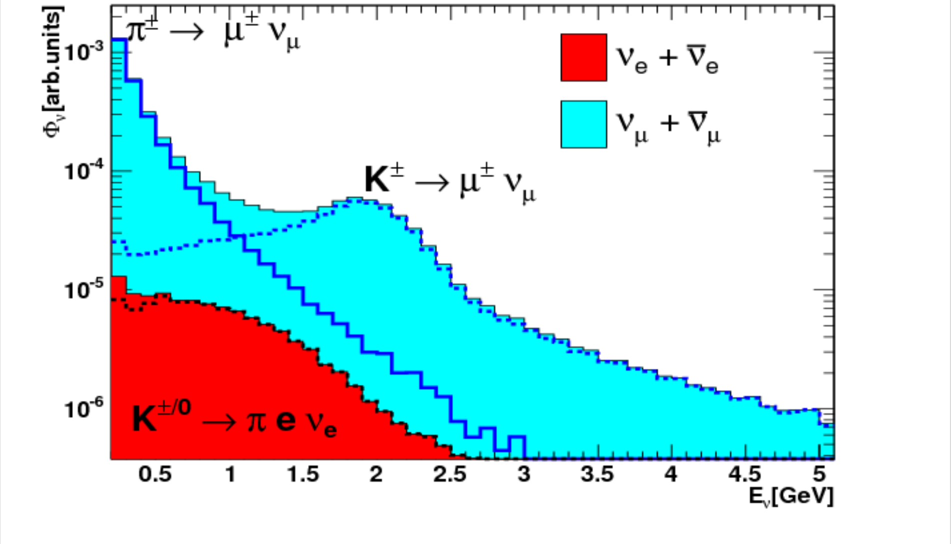


Expected oscillation probabilities at MiniBooNE in ν & $\bar{\nu}$ running modes. The model is consistent with the MiniBooNE results. (G. Karagiorgi *et al*.)

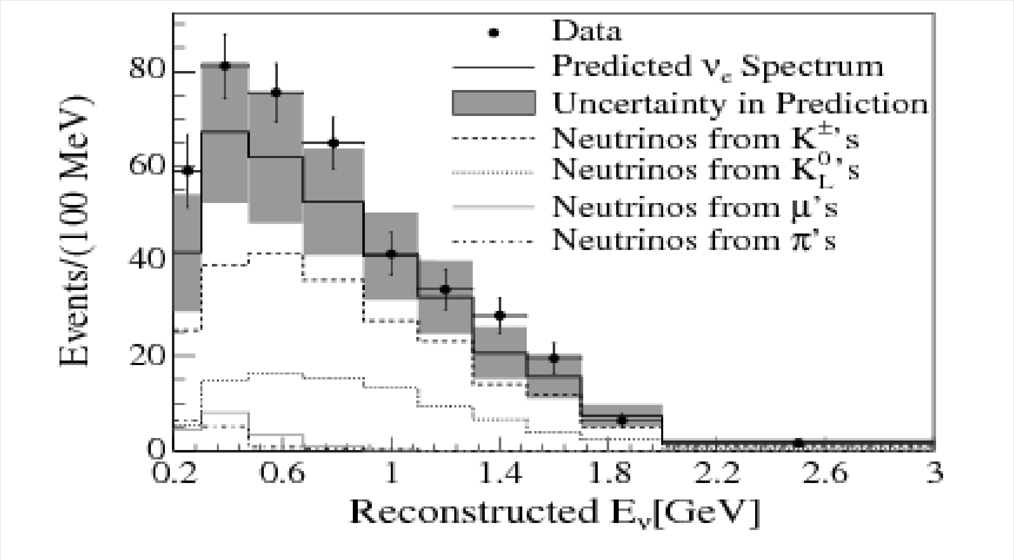
Maltoni & Schwetz, Phys. Rev. D **76** 093005 (2007)
Karagiorgi *et al.* hep-ph/0609177 (2007)

Expectations

NuMI



Simulation of the neutrino flux seen at MiniBooNE as generated at the NuMI target, plotted as a function of neutrino energy.

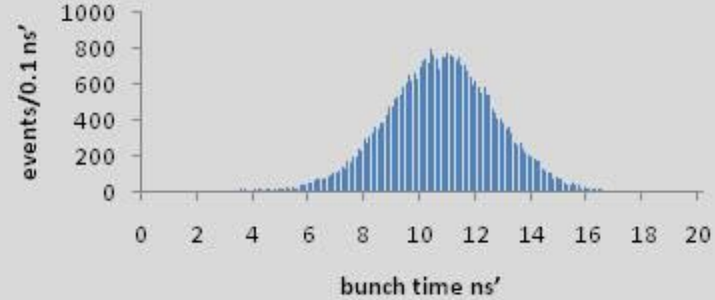


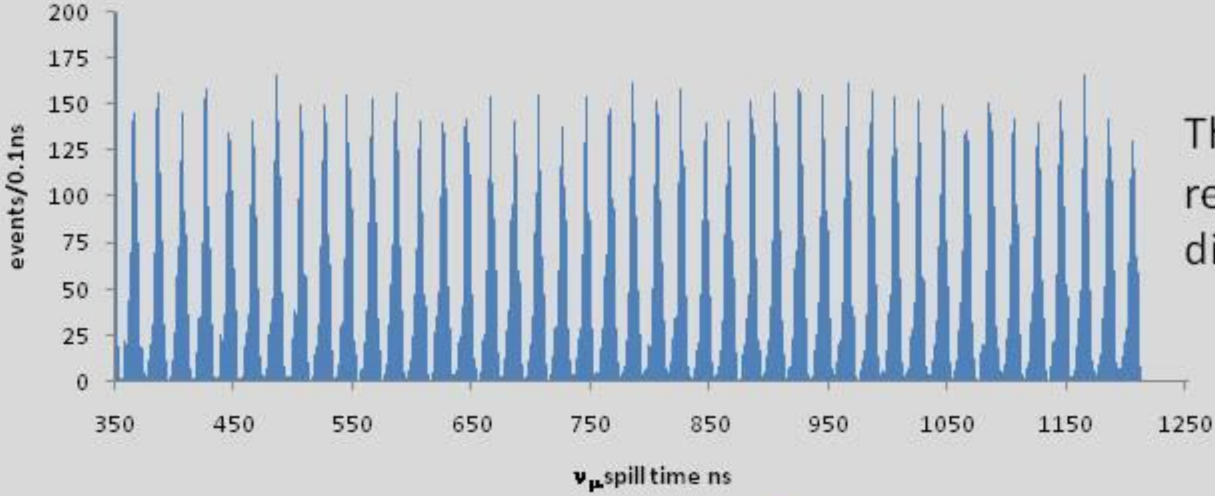
Reconstructed E_ν^{QE} for ν_e candidates. The band indicates the total systematic uncertainty associated with the Monte Carlo prediction. Kaon parents contribute 93% of the events in this sample.

Aguilar-Arevalo *et al.* Phys. Rev. Lett. **102**, 211801 (2009)

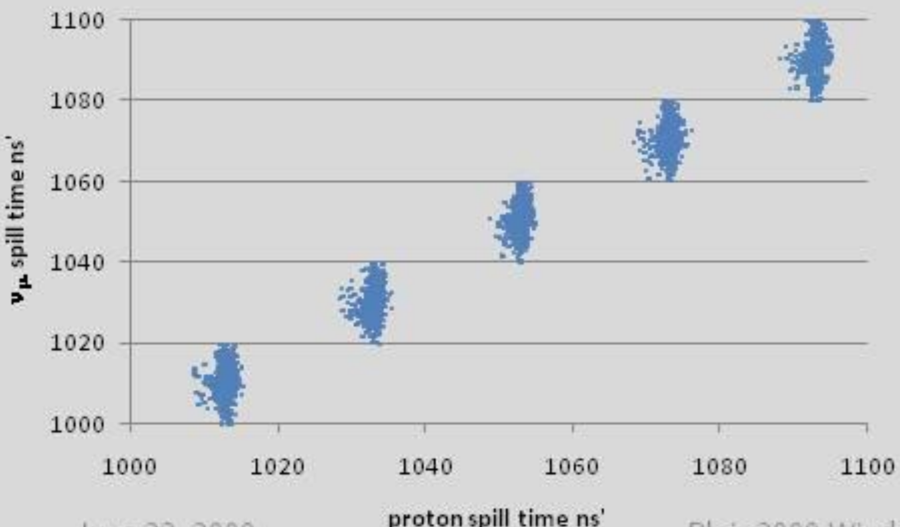
Expectations

Timing techniques





The proton beam RF structure reflected in the ν_μ event distribution with time.



The correlation in time between neutrino events and beam protons can provide a measure of the existence of massive particles.

Formaggio *et al.* Phys. Rev. Lett., vol. 84. No. 18 (2000)
Kusenko, Pascoli & Semikov, hep-ph/0405198
Adamson *et al.*, hep-ex/0706.0437

Summary

MiniBooNE results act as constraints
for a variety of models, including those built on Altered Dispersion Relations using sterile neutrinos

Additional running in antineutrino mode will clarify the distinction between the low energy excess for ν and $\bar{\nu}$.

Combined analysis from SciBooNE and MiniBooNE will further clarify the disappearance results and may offer a direct test of CPT invariance.

Further analysis with data from the NuMI beam and analysis using timing techniques will also add to our vision through "Windows on the Universe."