Booster Neutrino Experiment

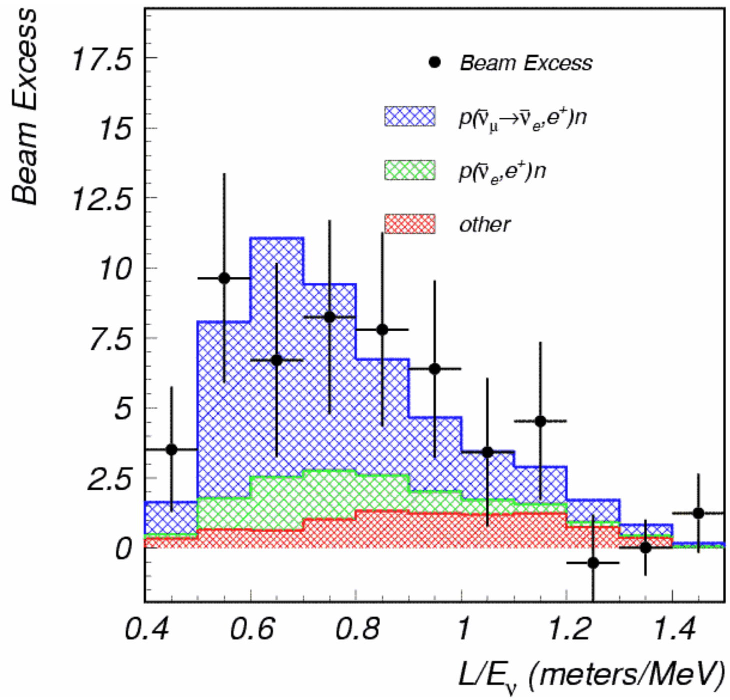
Alexis Aguilar-Arevalo
Columbia University
MiniBooNE Collaboration

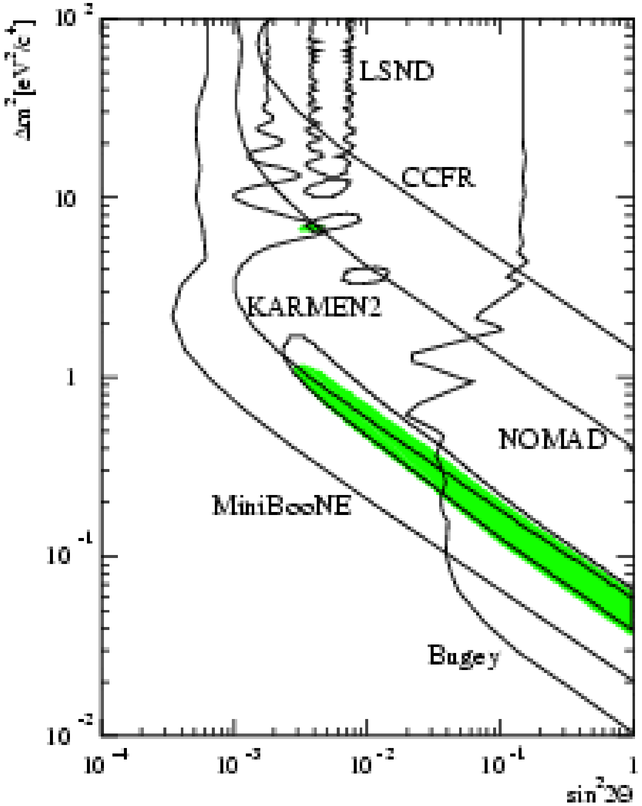
Neutrino Planning Meeting
Santa Fe, New Mexico
October 29, 2005

The MiniBooNE experiment and LSND

MiniBooNE was designed to confirm or refute the LSND oscillations signal

The LSND oscillations signal





Observed excess:
87.9 ±22.4±6.0
ν_e events

Oscillation Probability:
0.264 ±0.067±0.045 %

LSND + Karmen2 combined analysis allowed region

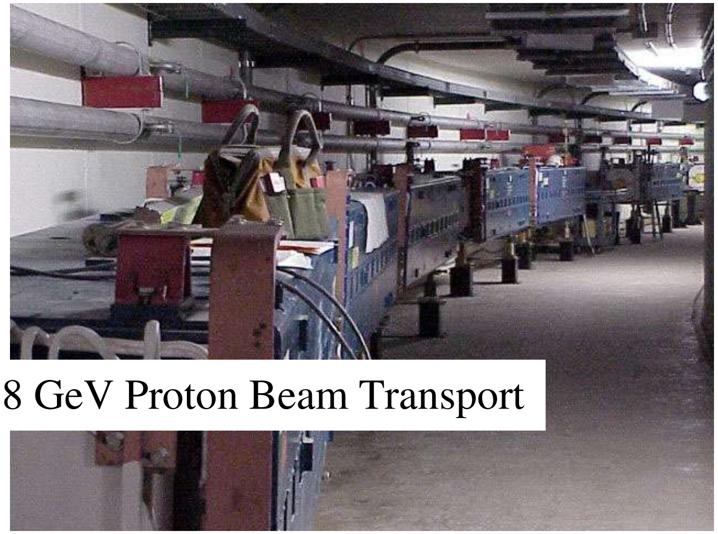
BooNE: a 2nd generation experiment that will come to life if MiniBooNE confirms LSND. MiniBooNE design allows to build on to BooNE.

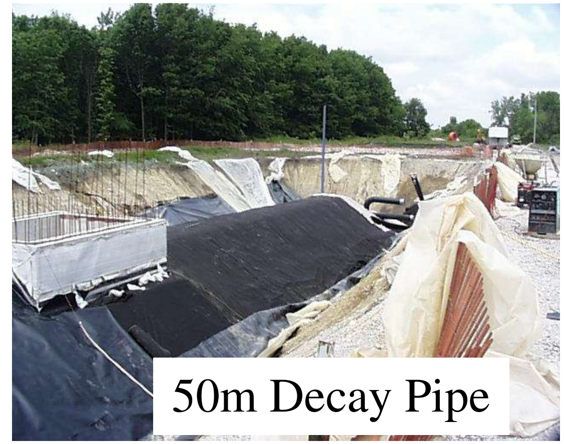
Mini-BooNE Collaboration

MiniBooNE consists of about 70 scientists from 14 institutions.

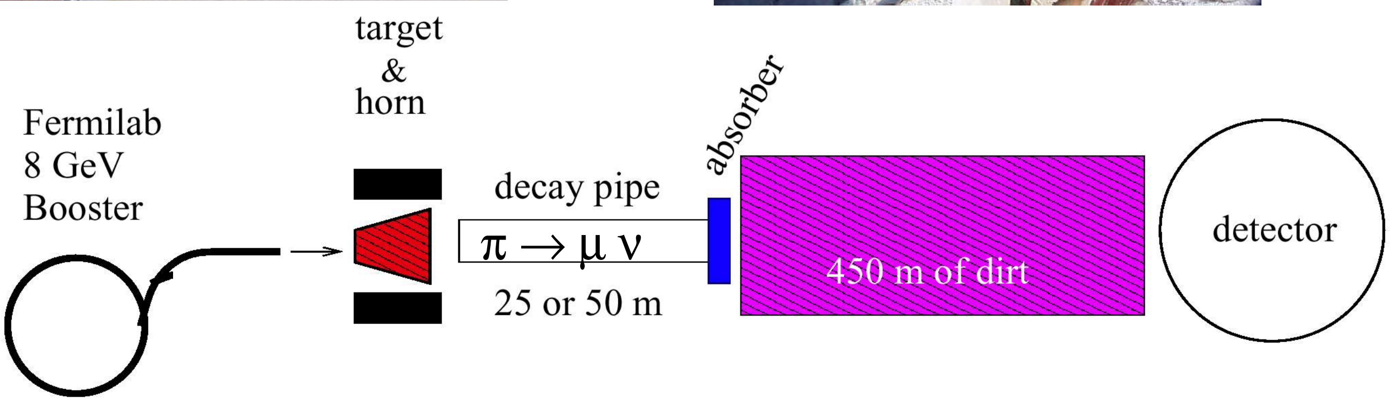
Y. Liu, D. Perevalov, I. Stancu *Alabama*
S. Koutsoliotas *Bucknell*
E. Hawker, R.A. Johnson, J.L. Raaf *Cincinnati*
T. Hart, R.H. Nelson, E.D. Zimmerman *Colorado*
A. Aguilar-Arevalo, L.Bugel, L. Coney, J.M. Conrad, J. Link, J. Monroe, K. Mahn, D. Schmitz, M.H. Shaevitz, G.P. Zeller, Z. Djurcic *Columbia*
D. Smith *Embry Riddle*
L.Bartoszek, C. Bhat, S J. Brice, B.C. Brown, D.A. Finley, R. Ford, F.G.Garcia, P. Kasper, T. Kobilarcik, I. Kourbanis, A. Malensek, W. Marsh, P. Martin, F. Mills, C. Moore, P. Nienaber, E. Prebys, A.D. Russell, P. Spentzouris, R. Stefanski, T. Williams *Fermilab*
D. C. Cox, A. Green, H.-O. Meyer, R. Tayloe , T. Kattori *Indiana*
G.T. Garvey, C. Green, W.C. Louis, G.McGregor, S.McKenney, G.B. Mills, V. Sandberg, B. Sapp, R. Schirato, R. Van de Water, D.H. White *Los Alamos*
R. Imlay, W. Metcalf, M. Sung, M.O. Wascko *Louisiana State*
J. Cao, Y. Liu, B.P. Roe, H. Yang *Michigan*
A.O. Bazarko, P.D. Meyers, R.B. Patterson, F.C. Shoemaker, H.A.Tanaka *Princeton*
M. Sorel*, U. Valencia*
B.T. Flemming, A. Curionni*, Yale*

MiniBooNE Neutrino Beam

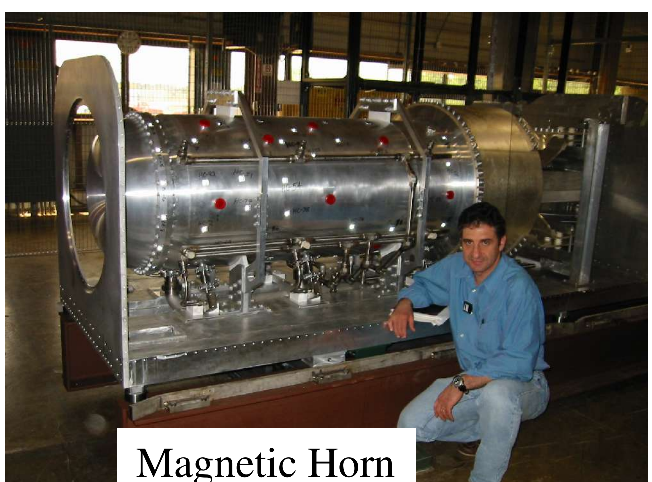

8 GeV Proton Beam Transport

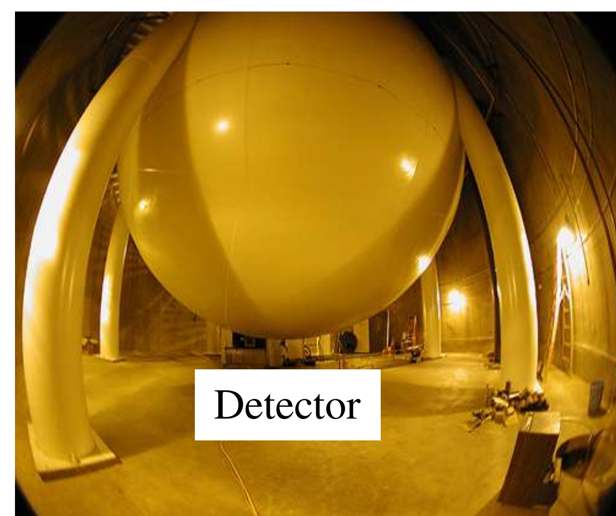

50m Decay Pipe

Variable decay pipe length (2 absorbers @ 50m and 25m)

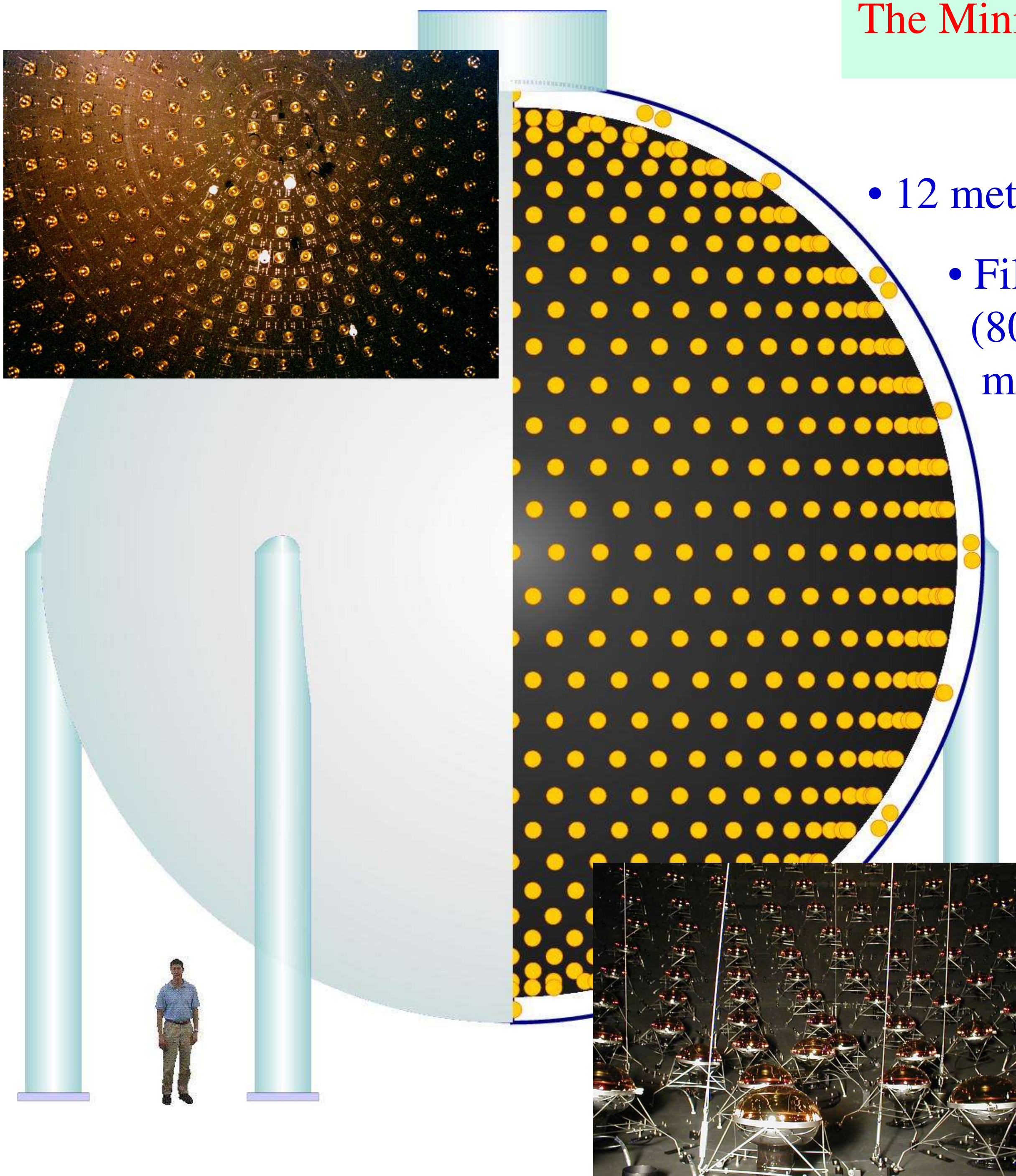


One magnetic horn, with Be target


Magnetic Horn


Detector

The MiniBooNE Detector

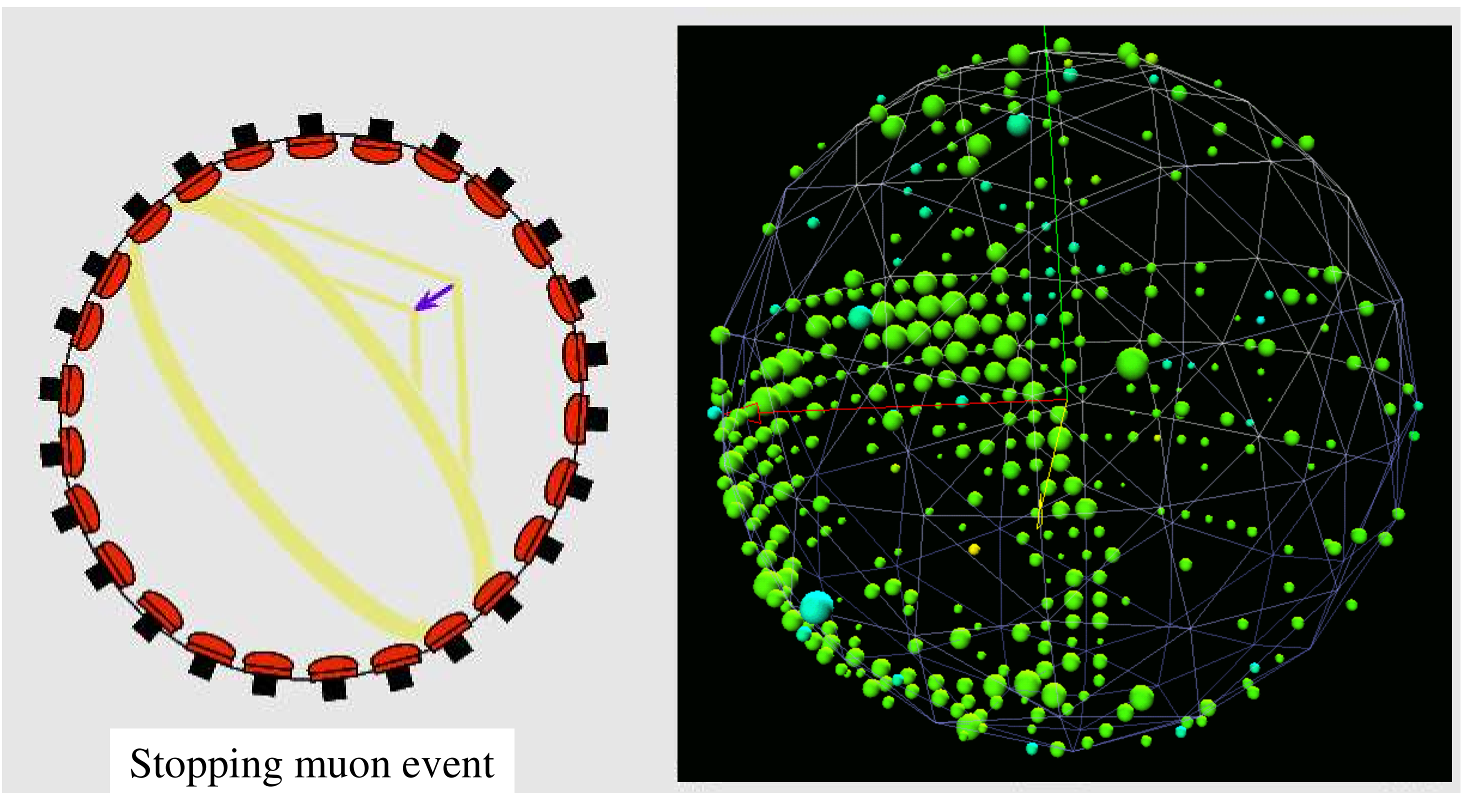


- 12 meter diameter sphere
- Filled with 950,000 liters (800 tons) of very pure mineral oil
- Light tight inner region with 1280 photomultiplier tubes
- Outer veto region with 241 PMTs.
- Oscillation Search Method:

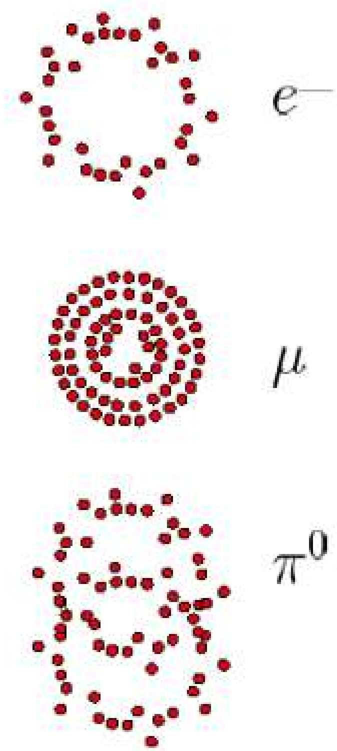
  Look for ν_e events in a pure ν_μ beam

Particle Identification

- Separation of ν_μ from ν_e events
  - Exiting ν_μ events fire the veto
  - Stopping ν_μ events have a Michel electron after a few μsec
  - Also, scintillation light with longer time constant ⇒ enhanced for slow pions and protons
  - Čerenkov rings from outgoing particles
    - Shows up as a ring of hits in the phototubes mounted inside the MiniBooNE sphere
    - Pattern of phototube hits indicates the particle type



Stopping muon event



Intrinsic ν_e in the beam

Small intrinsic ν_e rate $\Rightarrow$ Event Ratio $\nu_e/\nu_\mu = 6 \times 10^{-3}$

$\pi^+ \to \mu^+ \nu_\mu$, $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ $\Rightarrow$

ν_e from μ–decay

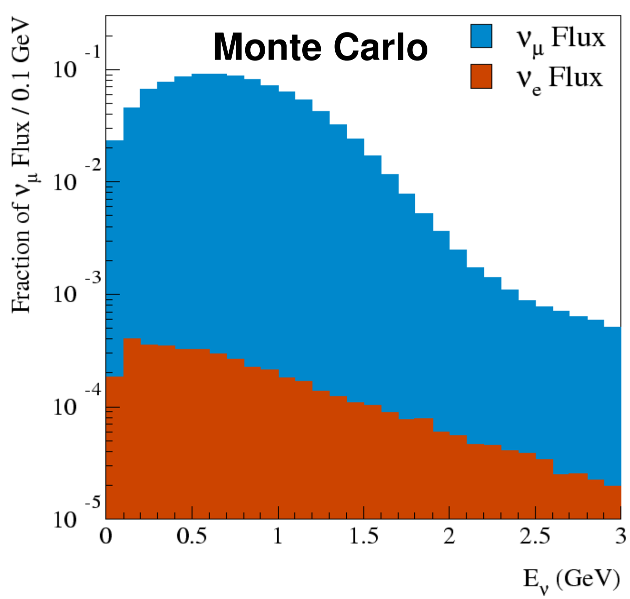
– Directly tied to the observed half-million ν_μ interactions

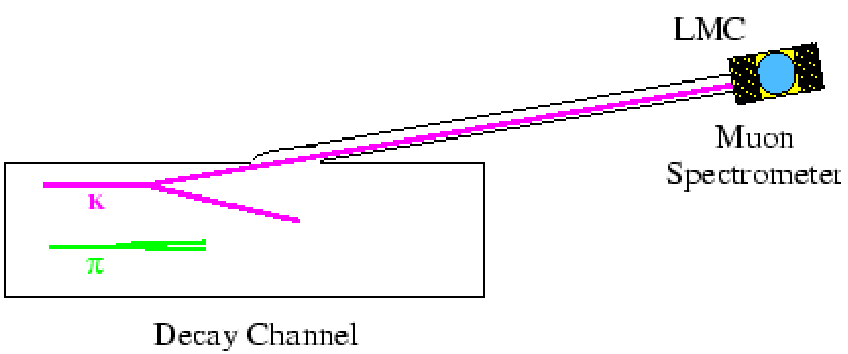
$K^+ \to \pi^0 e^+ \nu_e$ $\Rightarrow$

Kaon rates measured in low energy proton production experiments

– HARP experiment (CERN)
– E910 (Brookhaven)
– MiniBooNE "High Energy Box" data

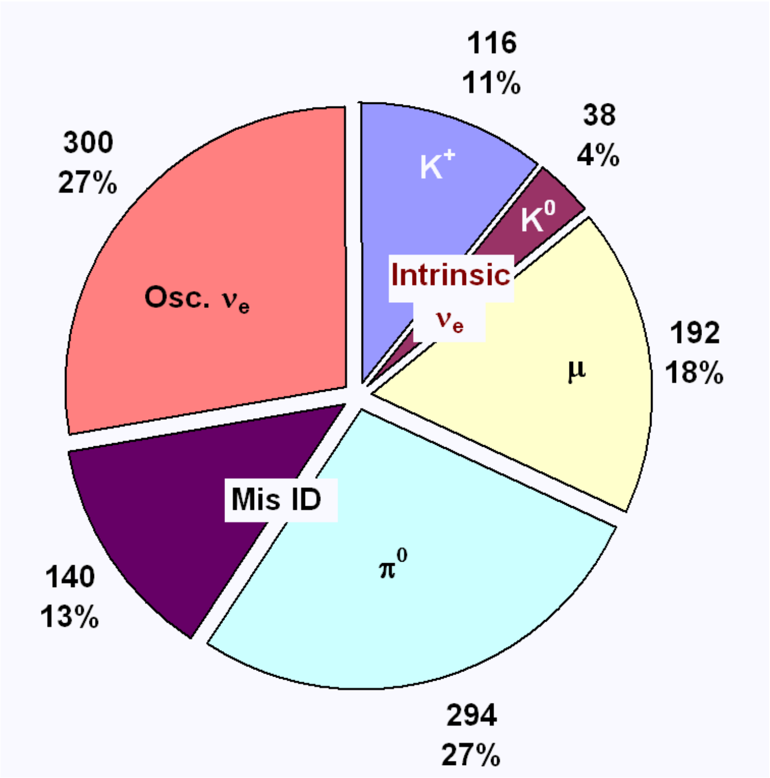
- "Little Muon Counter" measures rate of kaons in-situ



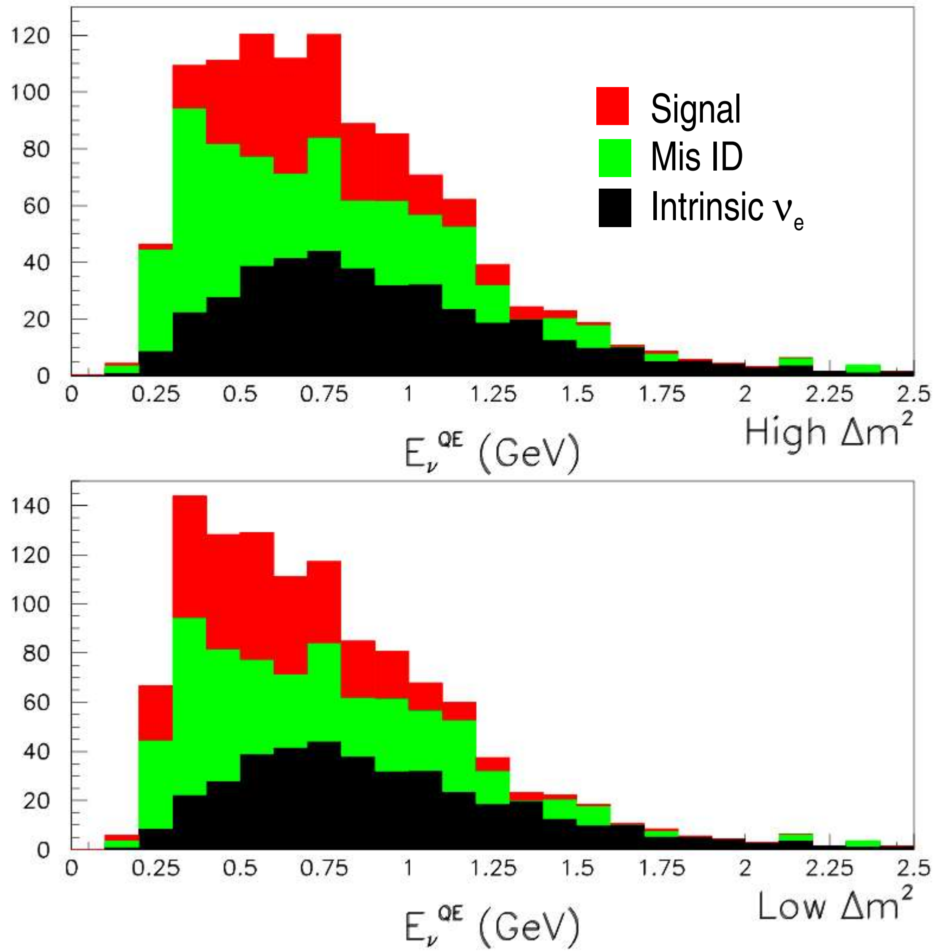


Estimates for the $\nu_\mu \rightarrow \nu_e$ Appearance Search

- Look for appearance of ν_e events above background expectation
  - Use data measurements both internal and external to constrain background rates

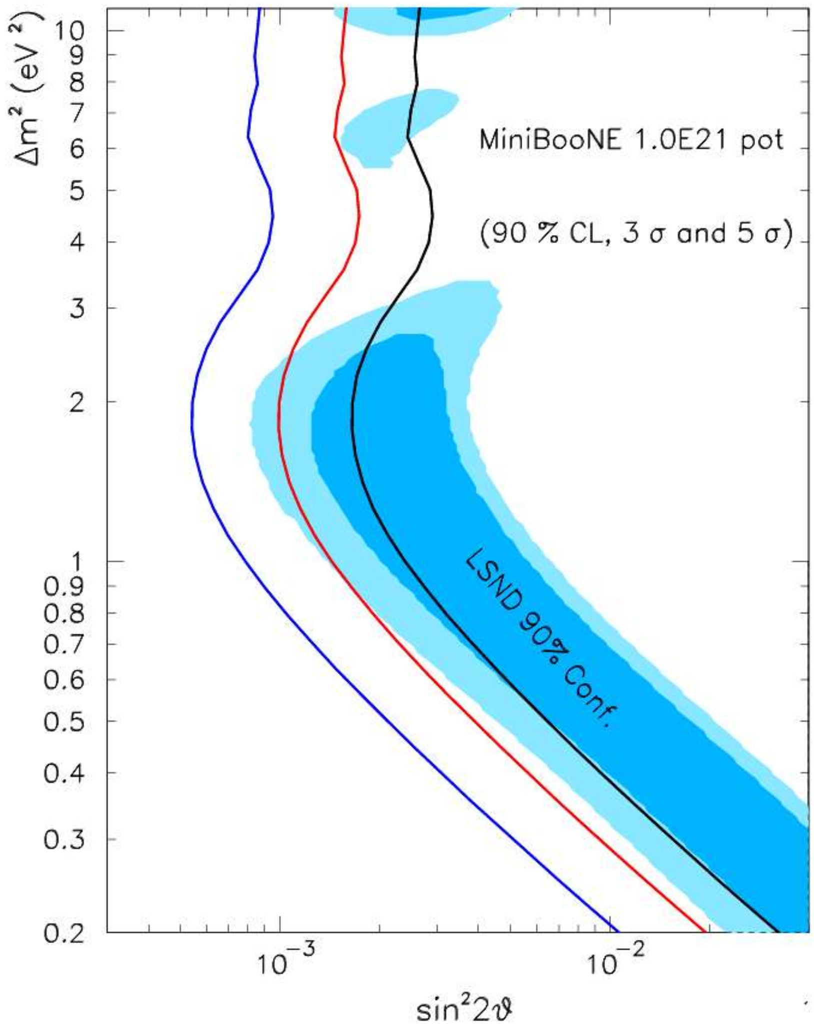


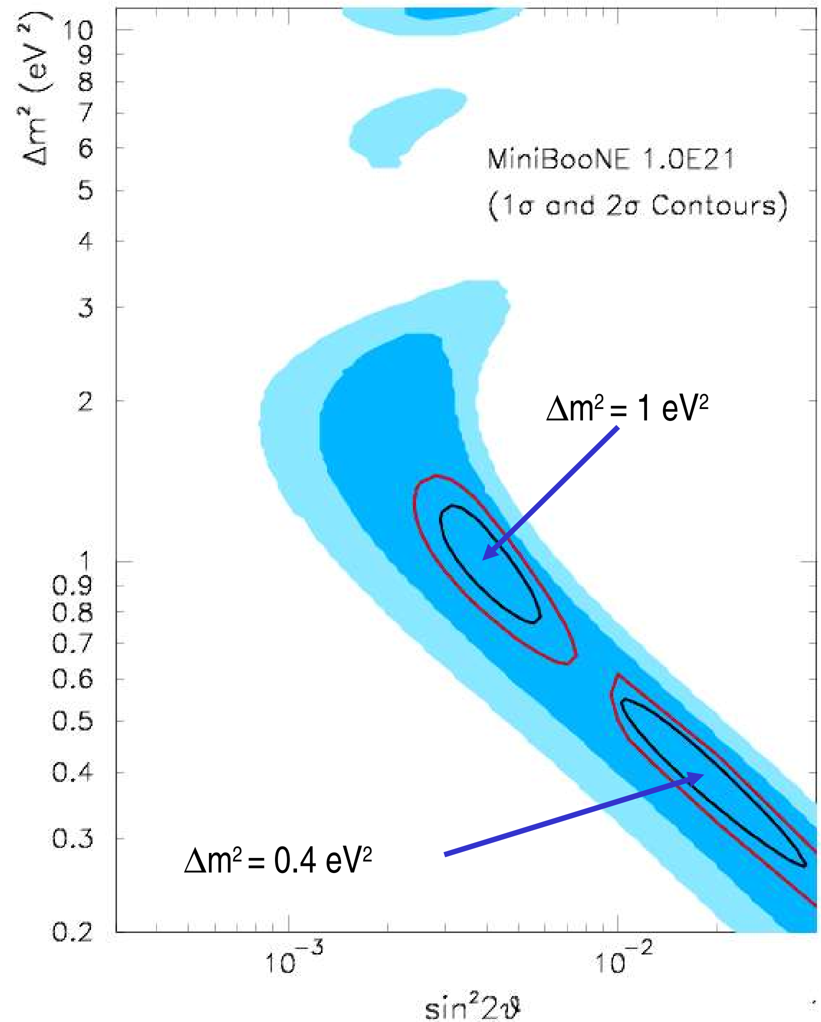
- Fit to E_ν distribution used to separate background from signal.



MiniBooNE Oscillation Sensitivity

- Oscillation sensitivity and measurement capability
  - Data sample corresponding to $1x10^{21}$ pot
  - Systematic errors on the backgrounds average ~5%





If MiniBooNE sees a signal...

* If MiniBooNE sees no indications of oscillations with ν_μ

⇒ **Need to run with $\bar{\nu}_\mu$ since LSND signal was $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$**

(Morgan O. Wascko, PANIC'05)

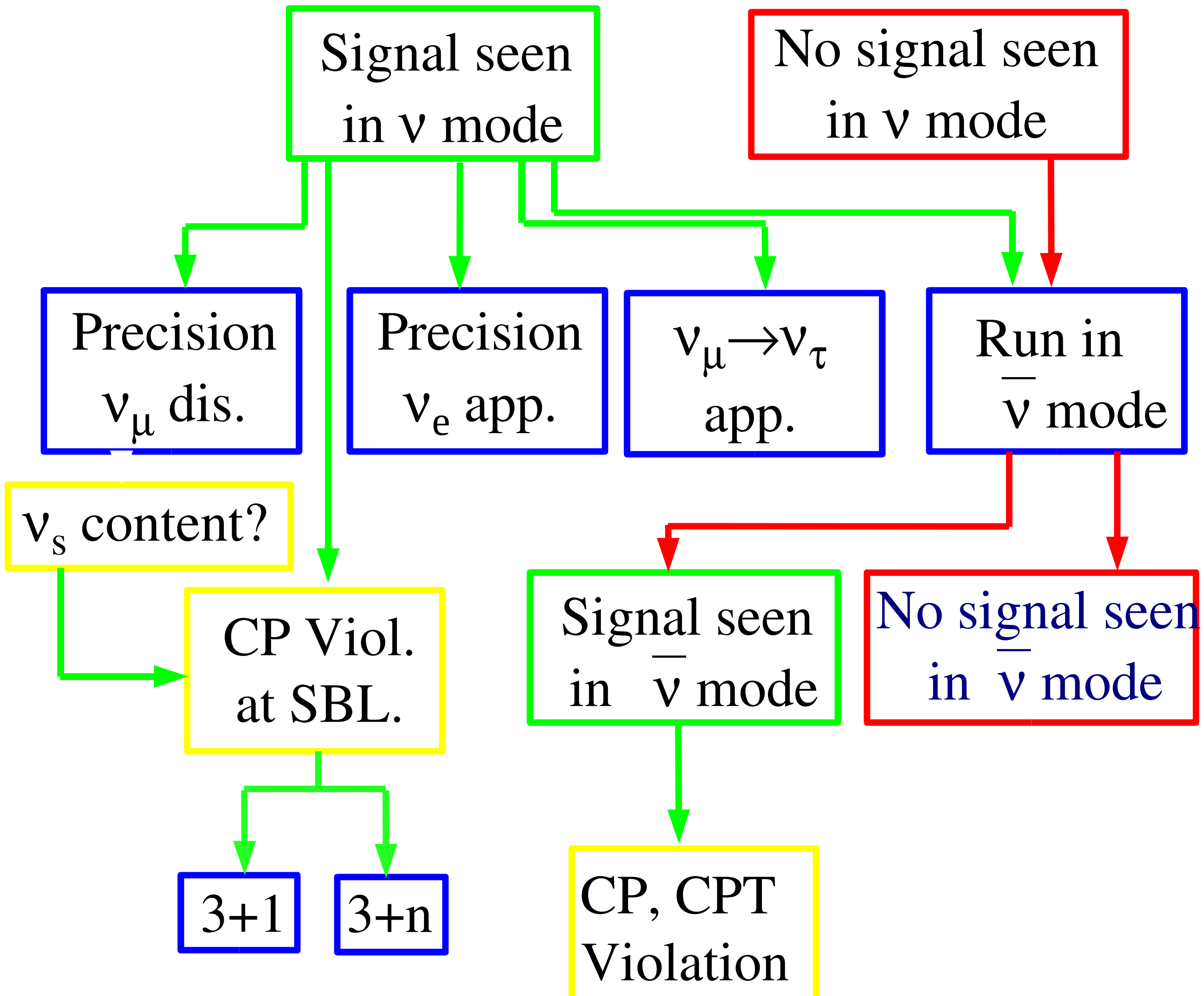
- If MiniBooNE sees an oscillation signal

  ⇒ **There are 3 Δm^2 scales involved in oscillations**

How can there be three distinct Δm^2's?

- Additional "sterile" neutrinos involved in oscillations
- One of the experimental measurements is not neutrino oscillations
  - [e.g. Neutrino decay (Palomares-Ruiz *et.al.,* hep-ph/0505216)]
- CP violation and sterile ν's (allows different mixing for ν's and anti-ν's)
- Even stranger things (CPT violation,...)

MiniBooNE possibilities -- oscillations



Experimental Program with Sterile Neutrinos

If sterile neutrinos is the answer, then many mixing angles, CP phases, and Δm^2 could be included

- Measure number of extra masses $\Delta m_{14}^2, \Delta m_{15}^2 \ldots$

- Measure mixings
  Could be many small angles

Map out mixings associated with $\nu_\mu \to \nu_e$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \\ \nu_{s'} \\ \vdots \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & U_{e5} & \cdots \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & U_{\mu 5} & \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & U_{\tau 5} & \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} & U_{s5} & \\ U_{s'1} & U_{s'2} & U_{s'3} & U_{s'4} & U_{s'5} & \\ & & \cdots & & & \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \\ \nu_5 \\ \vdots \end{pmatrix}$$

Map out mixings associated with $\nu_\mu \to \nu_\tau$

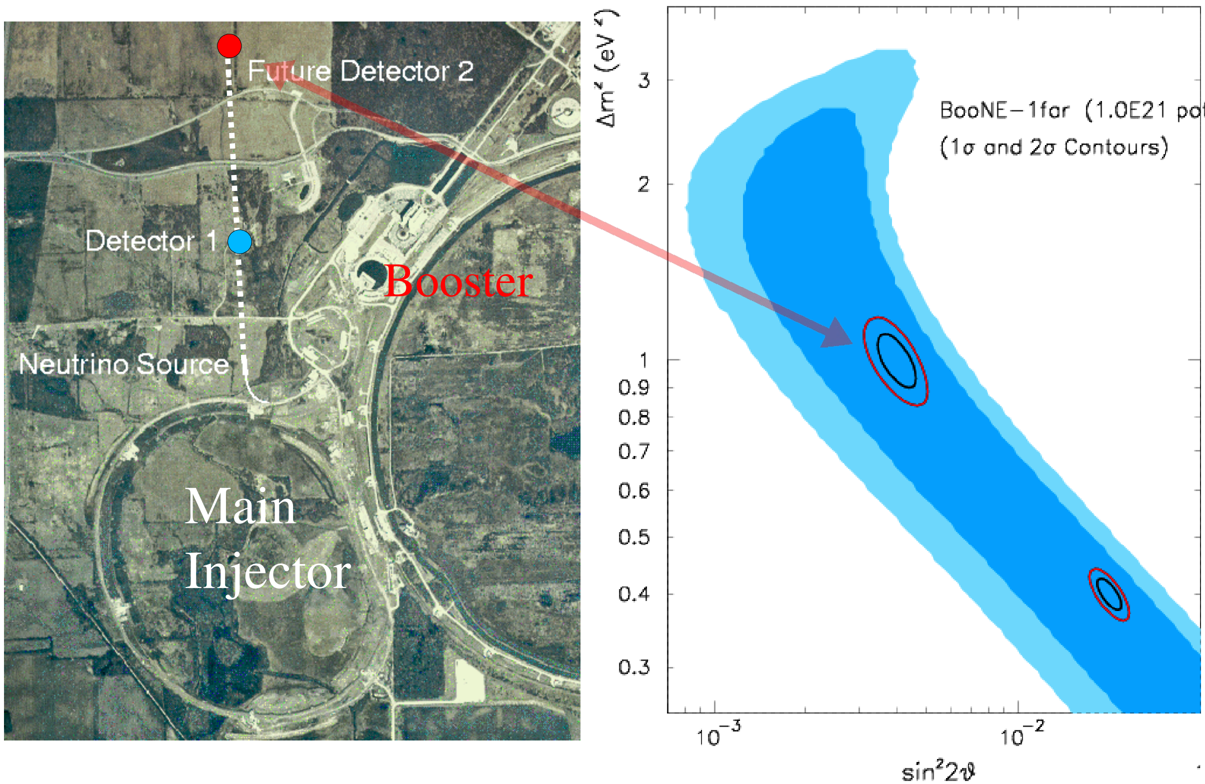
- Oscillations to sterile neutrinos could affect long-baseline measurements and strategy

- Compare ν_μ and $\bar{\nu}_\mu$ oscillations $\Rightarrow$ CP and CPT violations

If MiniBooNE sees $\nu_\mu \rightarrow \nu_e$ then: BooNE: Two Detector Exp.

– Far detector at 1.025 km for high Δm^2 signal or 2.025km for low Δm^2 signal.

– Cost of one additional detector ranges from 5 to10 Million Dollars (conceivable to think about more than one)



- Precision measurement of oscillation parameters
  - $\sin^2 2\theta$ and Δm^2
  - Map out the n x n mixing matrix
- Determine how many high mass Δm^2 's
  - 3+1, 3+2, 3+3 …
- Show the L/E oscillation dependence
  - Oscillations or ν decay or ???

<u>Two location BooNE experiment:</u>

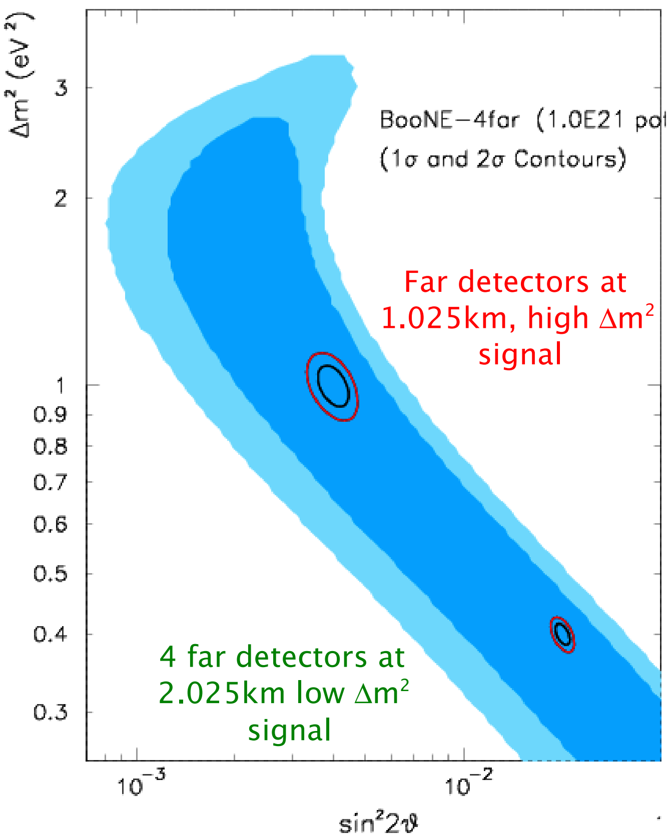
1 near detector at current MiniBooNE location and 1 far detector at 1025m, (2025m) if observe a signal with oscillation parameters: $[\sin^2 2\theta, \Delta m^2]$ = [0.4 eV^2 , 0.017] ***Low*** $\boldsymbol{\Delta m^2}$

$[\sin^2 2\theta, \Delta m^2]$ = [1.0 eV^2 , 0.004] ***High*** $\boldsymbol{\Delta m^2}$

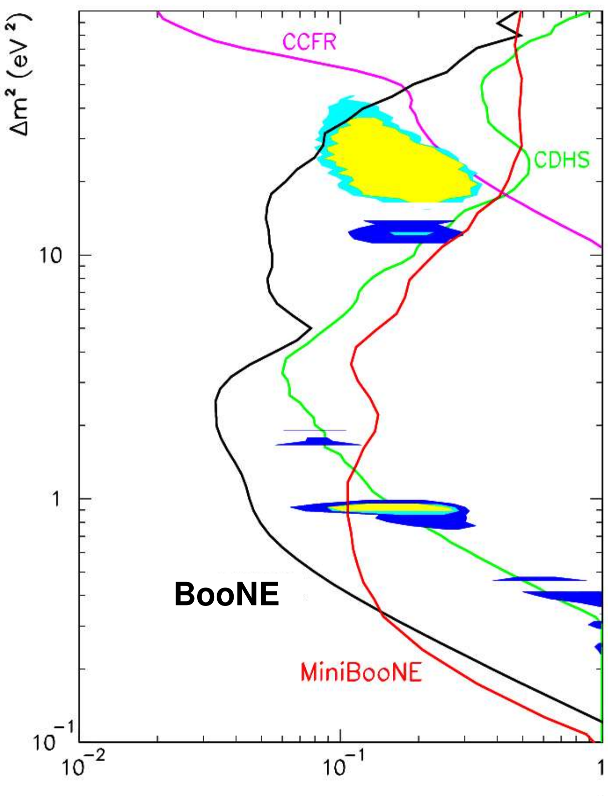
BooNE: 1near+ 4far Detector Exp., and other possibilities

Much higher precision can be achieved by adding more detectors (e.g.4- det)

Also explore disappearance in high Δm^2 to probe oscillations into sterile ν's.



Two location BooNE experiment:
1 near detector at current MiniBooNE location and 4 far detectors at second location. Same correspondence to signals as in previous slide.

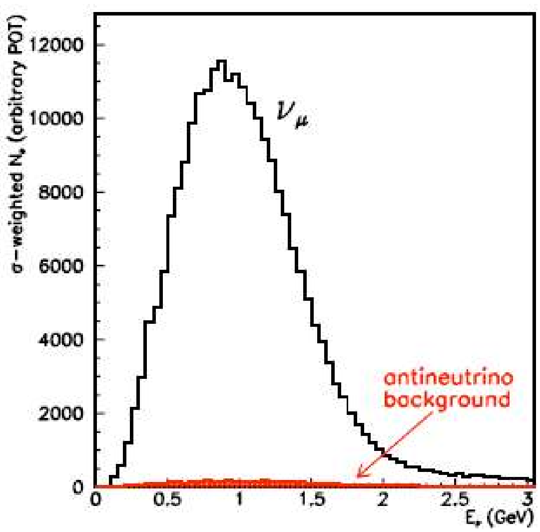


A near detector at ~100m (Finesse proposal) for disappearance and background determination could be useful (See R.Tayloe's talk)

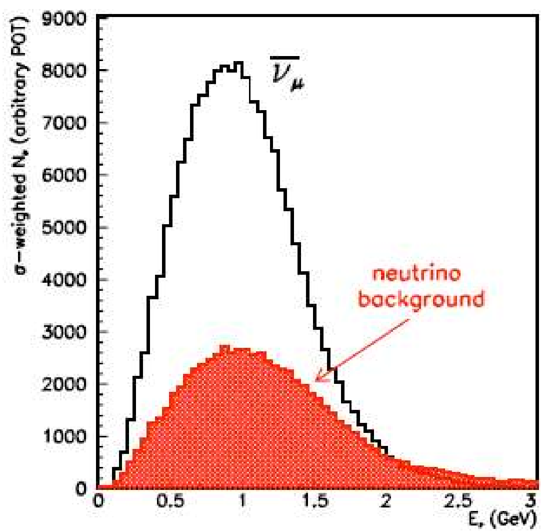
If MiniBooNE sees $\nu_\mu \to \nu_e$ (or not) then:

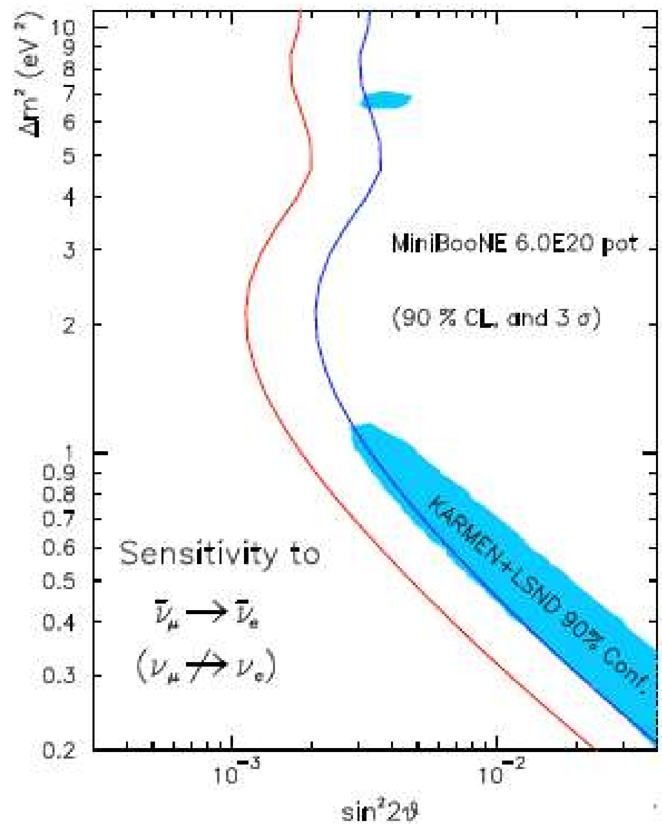
run MiniBooNE with anti-neutrinos for $\bar{\nu}_\mu \to \bar{\nu}_e$

- Are ν_μ and $\bar{\nu}_\mu$ the same?
  - Mixing angles, Δm^2 values
- Explore CP (or CPT) violation by comparing ν_μ and $\bar{\nu}_\mu$ results
- Running with anti-neutrinos takes longer to obtain similar sensitivity



[M.O.Wascko, PANIC'05]





MiniBooNE appearance sensitivity region for anti-neutrino oscillations in case of no oscillation in neutrinos

If we see a signal in anti-neutrinos:
run BooNE with anti-neutrinos for $\bar{\nu}_\mu \to \bar{\nu}_e$

A possible time scale for BooNE (2 detector system)

- 2006 appearance results and anti-ν running
- 3 years after signal is observed start detector construction.
- ~2 years later begin data taking with 2-detector system

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Things to note:
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  * Detector identical in design to MiniBooNE
    (systematics motivated)
  * Would use:
        - New Oil
        - New electronics (Los Alamos developing design)
  * Construction timescales and costs well understood
        - Estimated 5-7 MD for one additional Detector
  * WBS already in place
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Ready to go in the event of a positive MiniBooNE result!

Conclusions

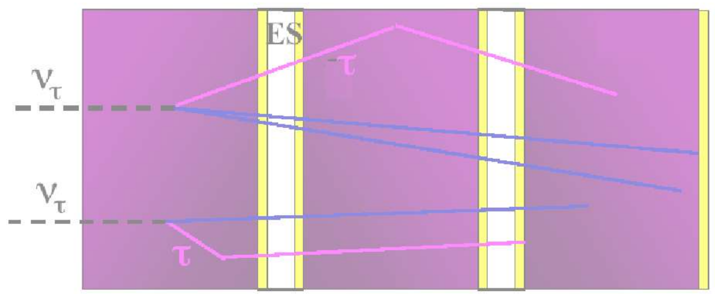
- A positive MiniBooNE result will bring us to a new and exciting era in neutrino physics.
- Additional detector(s) can boost the measurement capabilities of the booster neutrino beam at Fermilab and make it unique in its kind.
- Precision measurements will allow us to test CP conservation in neutrino sector with the existing beamline and its capability of change in polarity.
- The direction of the field will be determined by what we discover in these experiments

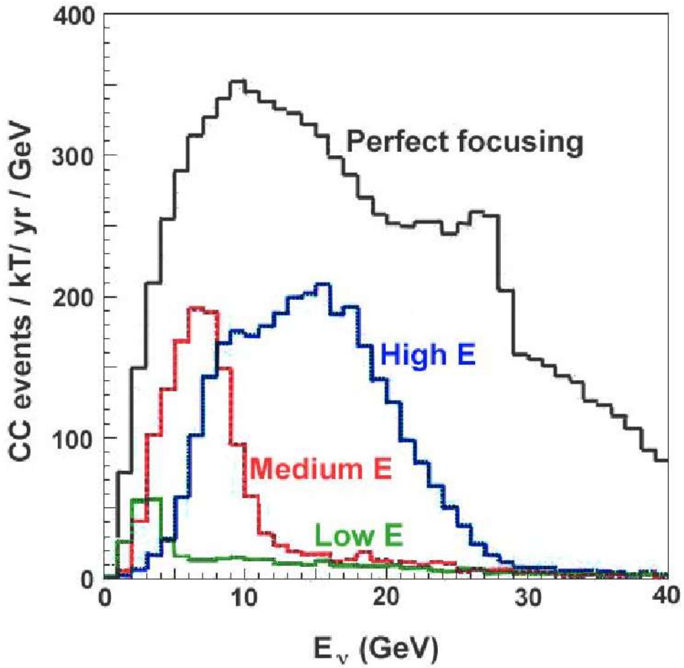
Backup Slides

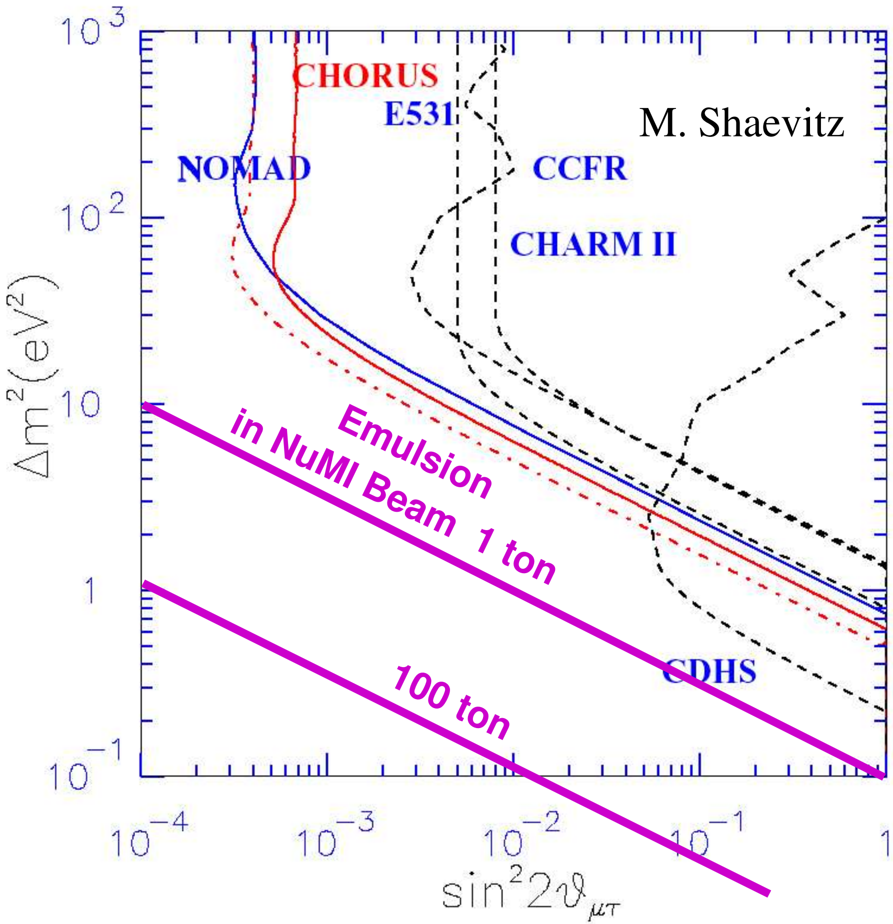
$\nu_\mu \rightarrow \nu_\tau$ Appearance at High Δm^2

- Appearance of ν_τ helps to sort out the mixings through the sterile components
- Need moderately high neutrino energy to get above the 3.5 GeV τ threshold (~6-10 GeV)
- Example: NuMI Med energy beam 8 GeV with detector at L=2km (116m deep)

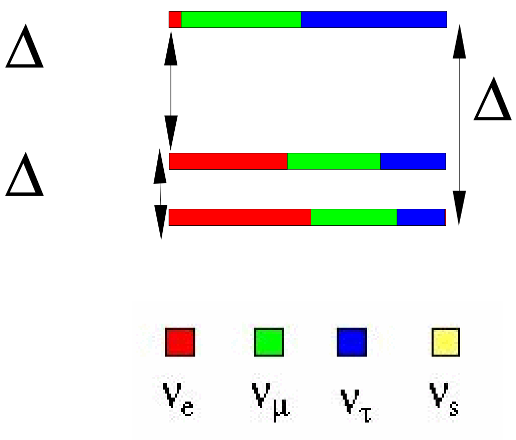
Emulsion Detector or Liquid Argon

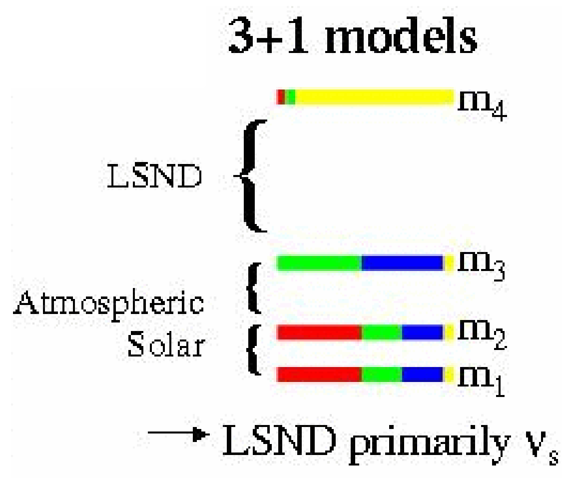


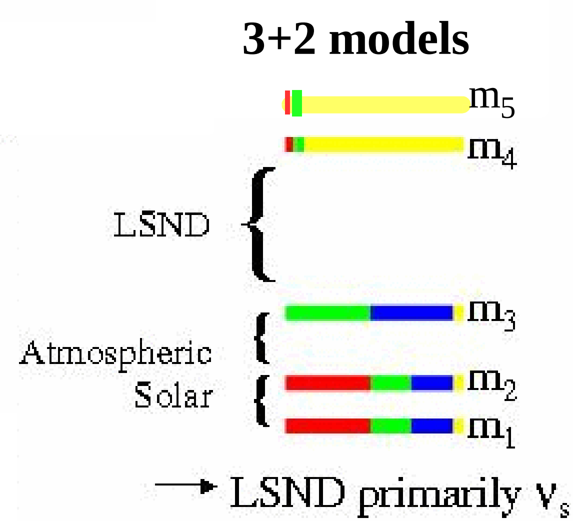




Explain LSND with Sterile Neutrinos







- Constraints from the atmospheric and solar data indicate:

  ⇒ **Sterile neutrino is mainly associated with the LSND Δm^2**

Then these are the main mixing matrix elements

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \\ \nu_{s'} \\ \vdots \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & U_{e5} & \cdots \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & U_{\mu 5} & \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & U_{\tau 5} & \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} & U_{s5} & \\ U_{s'1} & U_{s'2} & U_{s'3} & U_{s'4} & U_{s'5} & \\ & & \cdots & & & \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \\ \nu_5 \\ \vdots \end{pmatrix}$$

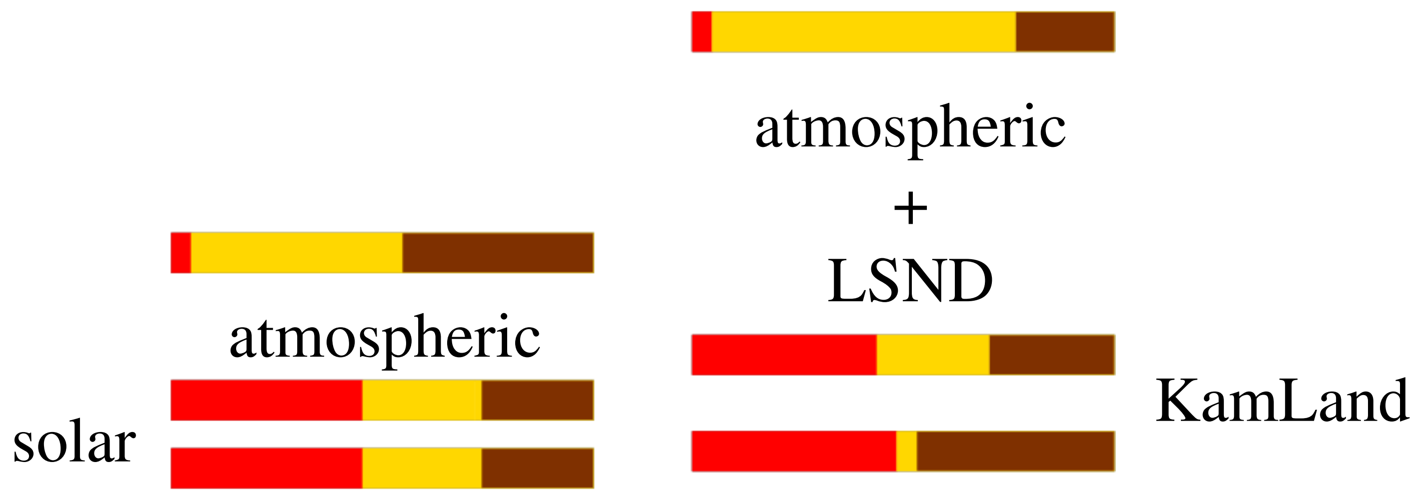
Check via precision ν_e appearance and ν_μ disappearance

CPT Violation in the neutrino sector ($m_\nu \neq m_{\bar{\nu}}$)

Accomadates all three signals with three standard model neutrinos

Neutrinos: Antineutrinos:

inspired by Murayama,
Developed by Barenboim,
Lykken and Borissov



hep-ph/0210411
Barenboim, Lykken

- A new non-local field theory
  - not Lorentz violating
  - introducing a whole new "Dirac Eq."
- Fit all present data, including Super K and KamLand

Check by comparing neutrino and anti-neutrino modes