Neutrino Oscillation Physics with a Stopped Pion/Muon Source

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P-25 Seminar

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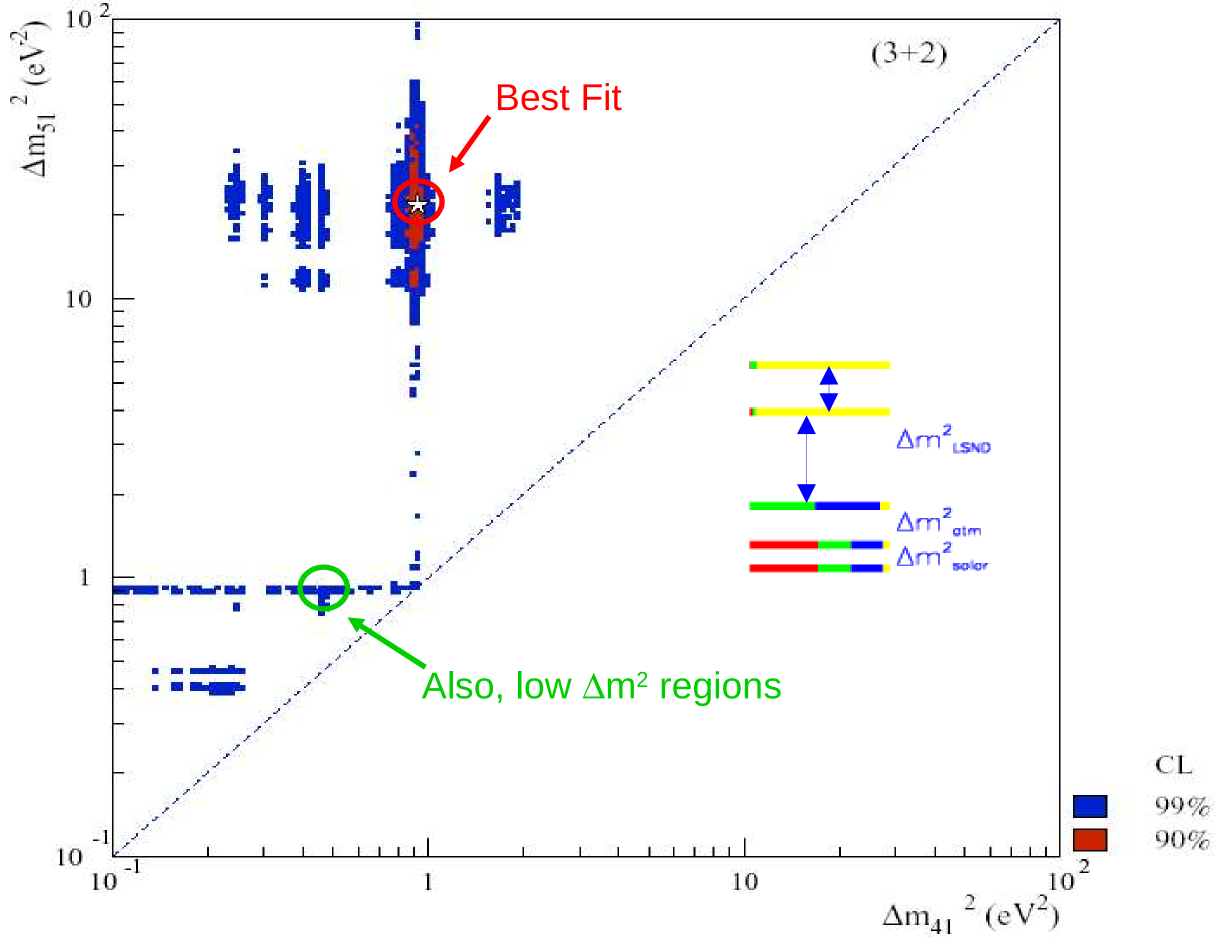
Outline

- **Beyond the Standard Model with SBL oscillations.**
- **New high intensity stopped pion/muon sources.**
- **High precision tests of LSND, CPT, and active-sterile oscillations.**
- **Conclusions.**

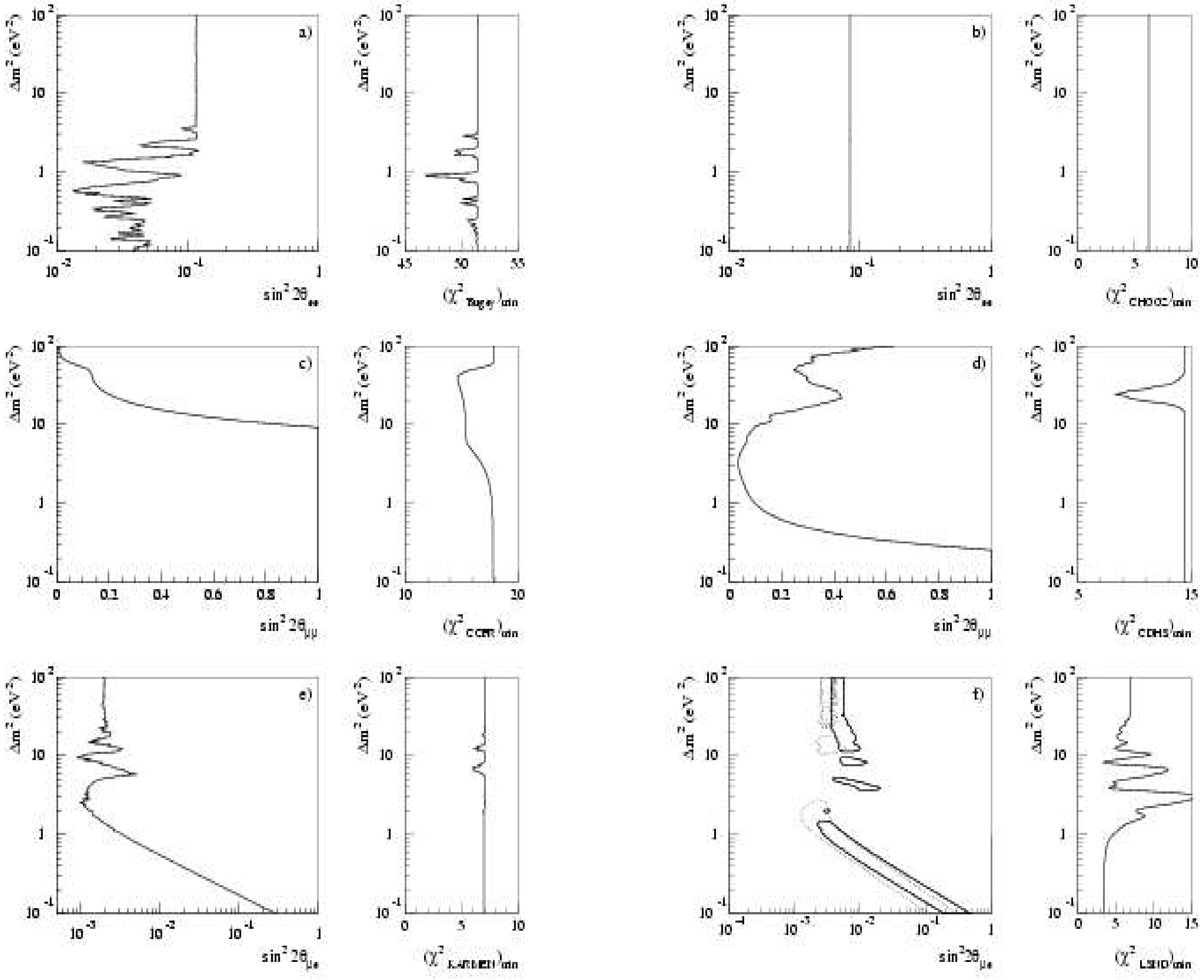
Beyond the Standard Model

- If MiniBooNE confirms LSND signal, strong indications of new physics, but what type?
  - Light – medium mass right handed (sterile) neutrino, can explain LSND anomaly, solar neutrino spectrum+Homestake anomaly, supernova R-process, pulsar kicks, dark matter, dark energy....
  - 3+**n** sterile neutrino models (hep-ph 0305255):
    - **n=1**, SBL fit: δm^2 ~0.9 eV^2, $\sin^2(2\theta)$~0.16, χ^2/DOF= 0.98
    - **n=2**, SBL fit: δm^2 ~0.9 eV^2 and ~22 eV^2, χ^2/DOF= 0.94

3+2 Model Fits



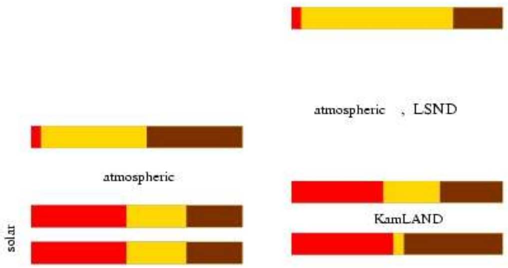
3+2 Model Inputs



Beyond the Standard Model

- If MiniBooNE confirms LSND signal, strong indications of new physics, but what type?

  - CPT violation (hep-ph 0212116).



  - Mass varying ν, mass depends on medium (hep-ph 0401099).

  - Lorentz violation, mass depends on direction (hep-ph 0406255).

- Need new high intensity short baseline neutrino experiments!

Short Baseline Tests of New Physics

- **Sterile neutrinos:**
  - **Measure neutral current rates with two detectors.**
- **CPT violation:**
  - **Run in antineutrino mode, compare P($\nu_\mu \rightarrow \nu_e$) to P($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$).**
- **Mass Varying neutrinos:**
  - **Oscillation probability depends on absence/presence of matter. Build tunnel to detector to be filled with water/air.**
- **Lorentz Violation:**
  - **Oscillation probability depends on direction, look for sidereal effects.**

Physics

New Short Baseline Experiments and Sources

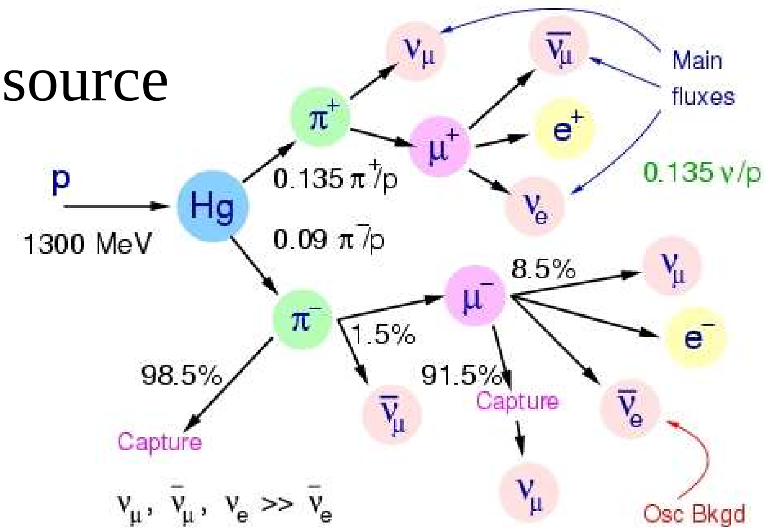
- BooNE is a planned second detector for MiniBooNE to improve measurement of mixing parameters and run in antineutrino mode.
- Two detector setup at a stopped pion/muon source similar to LAMPF:
  - SNS at ORNL, will be online in 2008 (1.3 GeV, 1.4 MW, 695nsec).
  - FNAL proton driver, 8GeV, 2MW, short beam spill.
- Advantages of a stopped pion neutrino source:
  - Low intrinsic background to a $\bar{\nu}_e$ appearance oscillations.
  - Well determined flux and energy spectrum.
  - Well known neutrino cross sections on Carbon.

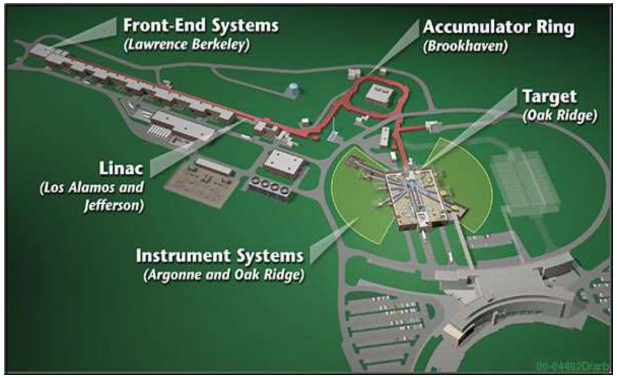
Stopped Pion/Muon Neutrino Source

- **Neutrino Production from a Stopped Pion/Muon Source:**

nucl-ex/0309014
hep-ex/0408135

4π source





	FNAL (8 GeV)	FNAL (5 GeV)	SNS
P/yr	4.9×10^{22}	4.9×10^{22}	2.2×10^{23}
DAR $\nu(\nu/P)$	1.5	0.9	0.13
DAR $\nu(\nu/yr)$	7.3×10^{22}	4.4×10^{22}	2.9×10^{22}

FNAL ~2.5 x SNS

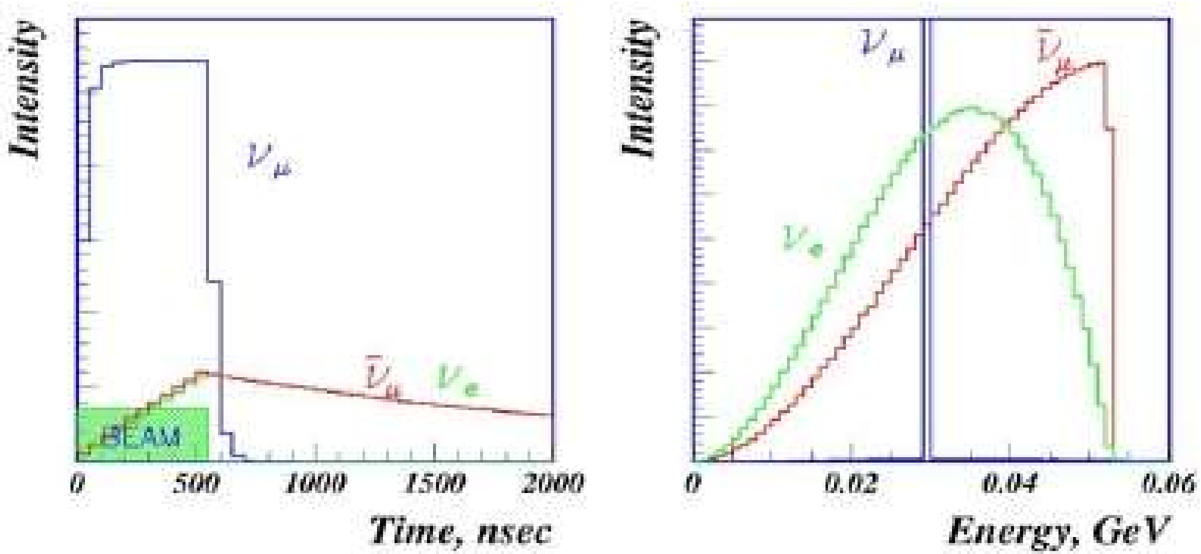
Stopped Pion/Muon Neutrino Source

- **Neutrino Flux from a Stopped Pion/Muon Source:**

$\pi^+ \rightarrow \mu^+ \nu_\mu, \quad \tau = 26 nsec$

$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e, \quad \tau = 2.2 \mu sec.$

event types	$0 \rightarrow 0.695 \mu$sec	$0.695 \rightarrow 5 \mu$sec	$> 5 \mu$sec
π^+ DAR and $\pi^\pm$ DIF events	96.3%	3.7%	0
μ^+ DAR and oscillation candidates	14.3%	73.6%	12.1%



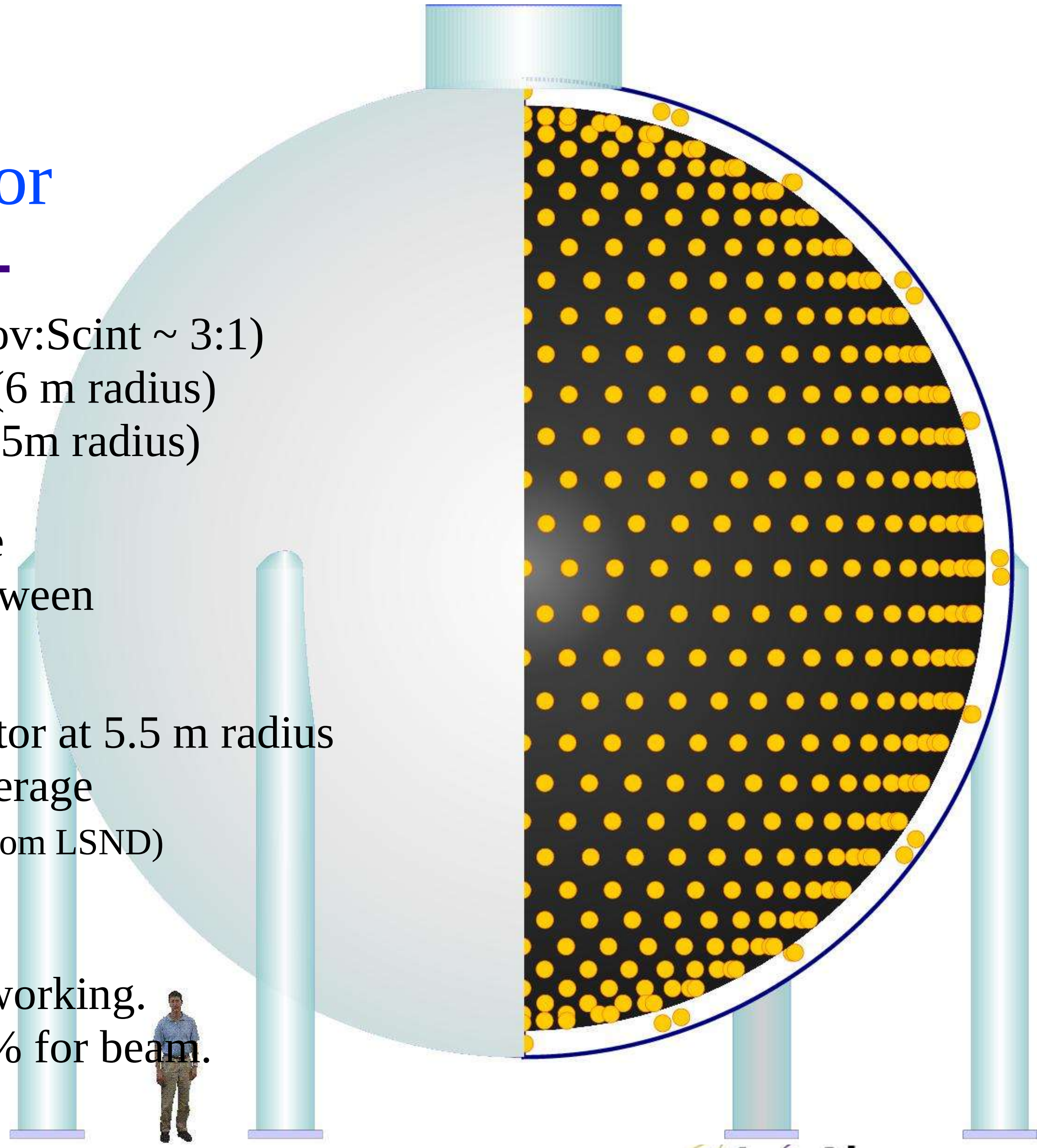
MiniBooNE detector

- Pure mineral oil (Cherenkov:Scint ~ 3:1)
  Total volume: 800 tons (6 m radius)
  Fiducial volume: 445 tons (5m radius)

- Phototube support structure provides opaque barrier between veto and main volumes.

- 1280 20-cm PMTs in detector at 5.5 m radius
  10% photocathode coverage
  → (330 new tubes, the rest from LSND)
  240 PMTs in veto.

- 99% electronics channels working.
  Detector livetime over 99% for beam.



Neutrino Reactions from a Stopped Pion/Muon Source

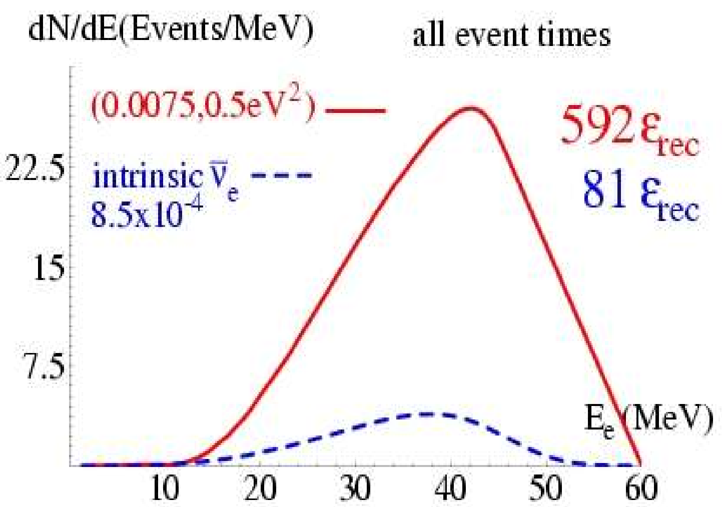
250 ton mineral oil detector 60m from SNS source.

Process	Neutrino Source	ν Source Life Time	Total Events per Beam Year
$\nu_\mu\ e$	π^+ DAR	26ns	69 $\varepsilon_{\rm rec}$
$\overline{\nu}_\mu\ e$	μ^+ DAR	2197ns	99 $\varepsilon_{\rm rec}$
$\nu_e\ e$	μ^+ DAR	2197ns	630 $\varepsilon_{\rm rec}$
Total $\nu\ e$ events	$T_e > 20$MeV		**798** $\varepsilon_{\rm rec}$
^{12}C$(\nu_e, e^-)^{12}$N$_{\rm gs}$	μ^+ DAR	2197ns	4689 $\varepsilon_{\rm rec}$
^{12}C$(\nu_e, e^-)^{12}$N*	μ^+ DAR	2197ns	2147 $\varepsilon_{\rm rec}$
^{13}C$(\nu_e, e^-)X$	μ^+ DAR	2197ns	308 $\varepsilon_{\rm rec}$
Total ν_e C events	$T_e > 20$MeV		**7144** $\varepsilon_{\rm rec}$
^{12}C$(\nu_\mu, \nu_\mu)^{12}$C$^*_{15.11}$	π^+ DAR	26ns	1851 $\varepsilon_{\rm rec}$
^{12}C$(\overline{\nu}_\mu, \overline{\nu}_\mu)^{12}C^*_{15.11}$	μ^+ DAR	2197ns	3752 $\varepsilon_{\rm rec}$
^{12}C$(\nu_e, \nu_e)^{12}$C$^*_{15.11}$	μ^+ DAR	2197ns	3093 $\varepsilon_{\rm rec}$
Total ν_e C NC events			**8696** $\varepsilon_{\rm rec}$
^{12}C$(\nu_\mu, \mu^-)X$	π^+ DIF	26ns	≤ 278 $\varepsilon_{\rm rec}$
^{12}C$(\overline{\nu}_\mu, \mu^+)X$	π^- DIF	26ns	≤ 82 $\varepsilon_{\rm rec}$
$p(\overline{\nu}_\mu, \mu^+)n$	π^- DIF	26ns	272 $\varepsilon_{\rm rec}$

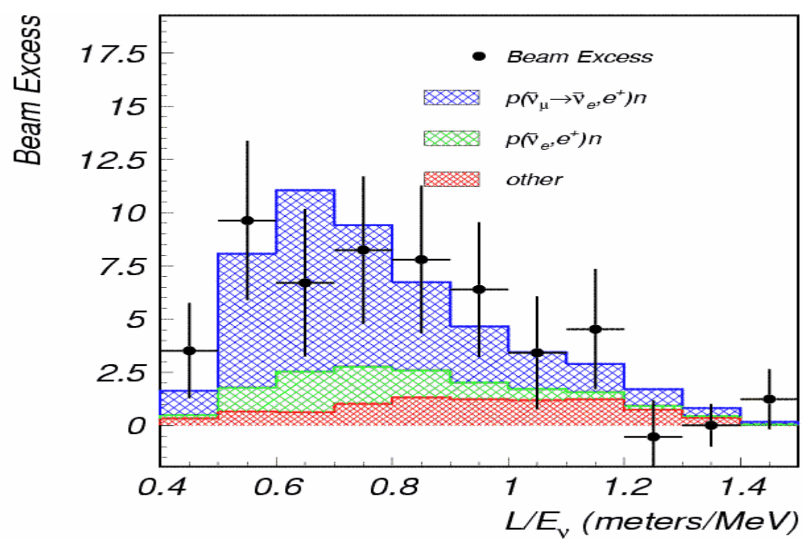
Test of LSND Stopped Muon $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillations (nucl-ex/0309014)

- Single 250 ton mineral oil detector (ELVIS) at 60m from SNS source.
- Oscillation $\bar{\nu}_e$ detected via $\bar{\nu}_e p \rightarrow n\, e^+$, then $np \rightarrow d\gamma$(2.2MeV).
- Backgrounds/yr: 81 intrinsic $\bar{\nu}_e$, ~9 DIF+cosmics.

SNS 1 year



LSND All Data



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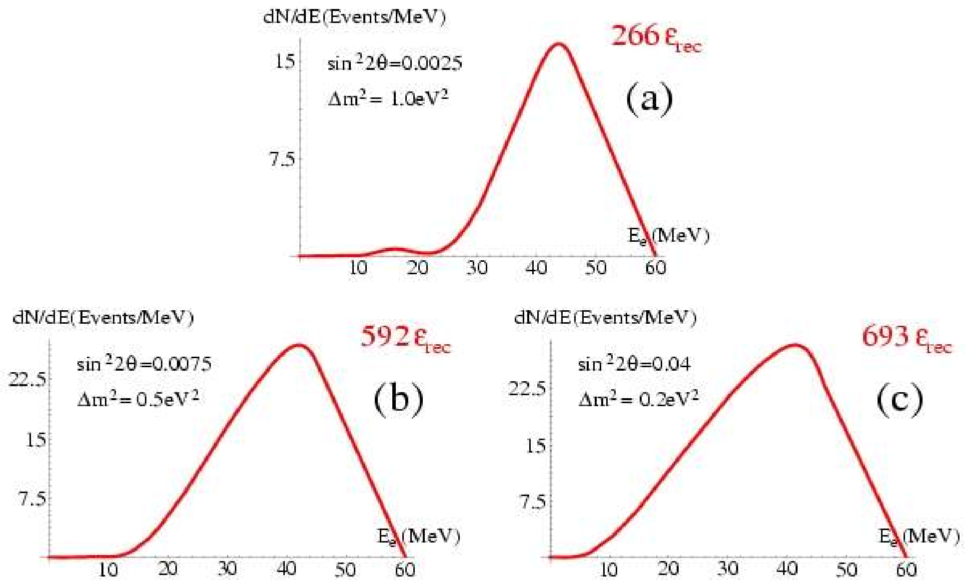
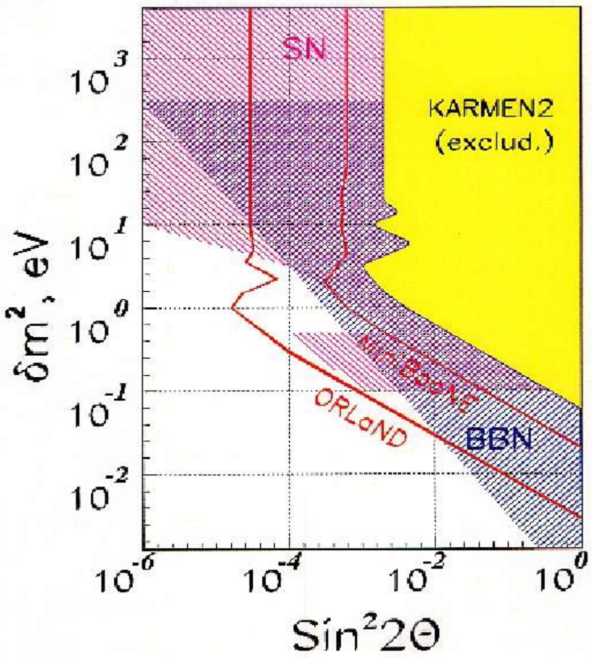
Test of LSND Stopped Muon $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillations (nucl-ex/0309014)

- **Spectrum Shape Analysis**

Improved Sensitivity





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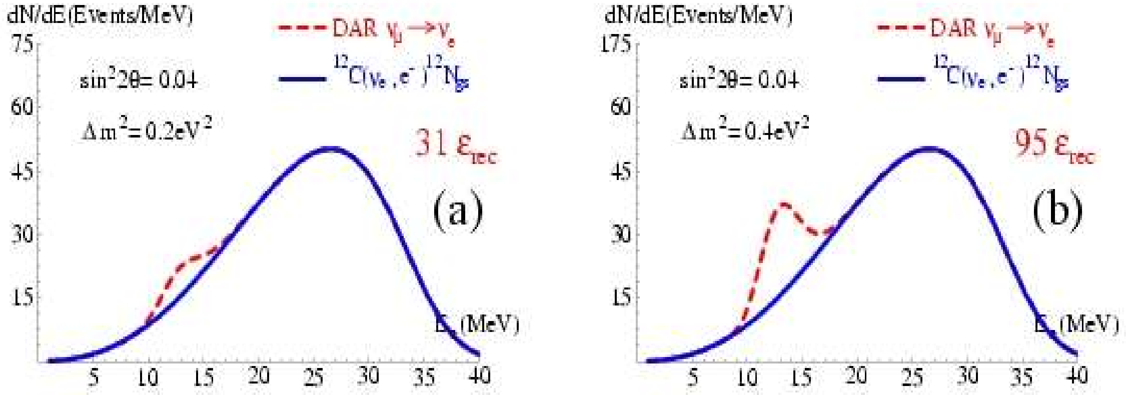
Measurement of Stopped Pion $\nu_\mu \rightarrow \nu_e$ Oscillations (nucl-ex/0309014)

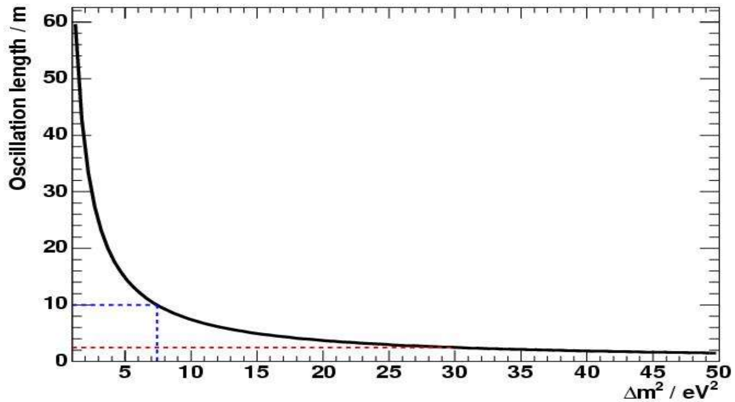
- **Single 250 ton mineral oil detector (ELVIS) at 60m from SNS source.**
- **Oscillation ν_e detected via ν_e ^{12}C -> e^- $^{12}N_{gs}$, then ~8 MeV beta (11msec).**
- **Monoenergetic electron bump at 13 MeV (7% E resolution) on large background from stopped muon DAR ν_e.**
- **Test CPT by comparing with $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ measurement on previous slide.**



Active-Sterile Neutrino Oscillations with Stopped Pions

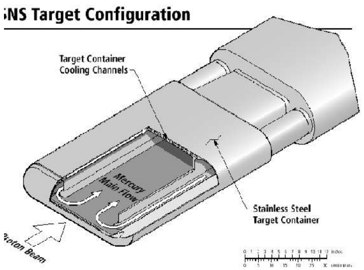
- **If LSND oscillations is $\nu_\mu \rightarrow \nu_s \rightarrow \nu_e$, then we expect P($\nu_\mu \rightarrow \nu_s$) > 0.10**
- **Can detect all neutrinos via NC reaction, $\nu_x\,^{12}C \rightarrow \nu_x\,^{12}C^*(15.11 MeV)$.**
- **Since we have monoenergetic ν_μ source , then look for NC rate distortion as a function of L.**

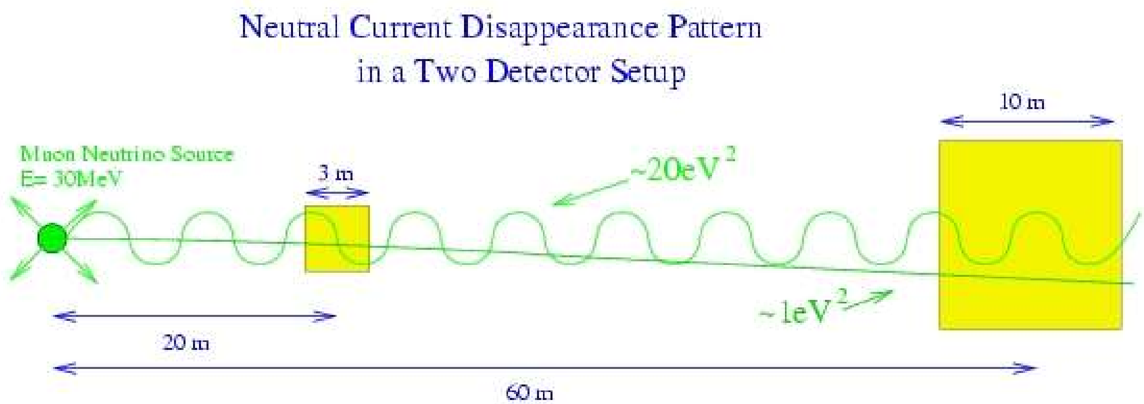
$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - sin^2(2\theta)\sin^2(\frac{1.27}{30}\delta m^2 L)$$



Sterile Neutrino Oscillations with $\nu_\mu\ ^{12}C \rightarrow \nu_\nu\ ^{12}C^*$(15.11MeV)

SNS source L=50 cm

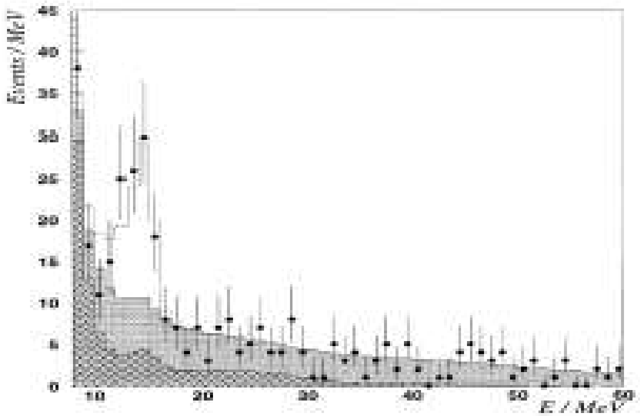




Detector	Source Dist. (m)	FD Size (tons)	FD Length (m)	$\nu_x\ ^{12}C \rightarrow \nu_x\ ^{12}C^*$ events/year
SNS Near	18	25	3	2056
SNS Far	60	500	10	3702
FNAL Near	10	116	5	77100
FNAL Far	100	1300	12	8663

Sterile Neutrino Oscillations with $\nu_\mu\ ^{12}C \rightarrow \nu_\nu\ ^{12}C^*(15.11MeV)$

- KARMEN measures $\sigma = (3.2 \pm 0.6) \times 10^{-42}\ cm^2$

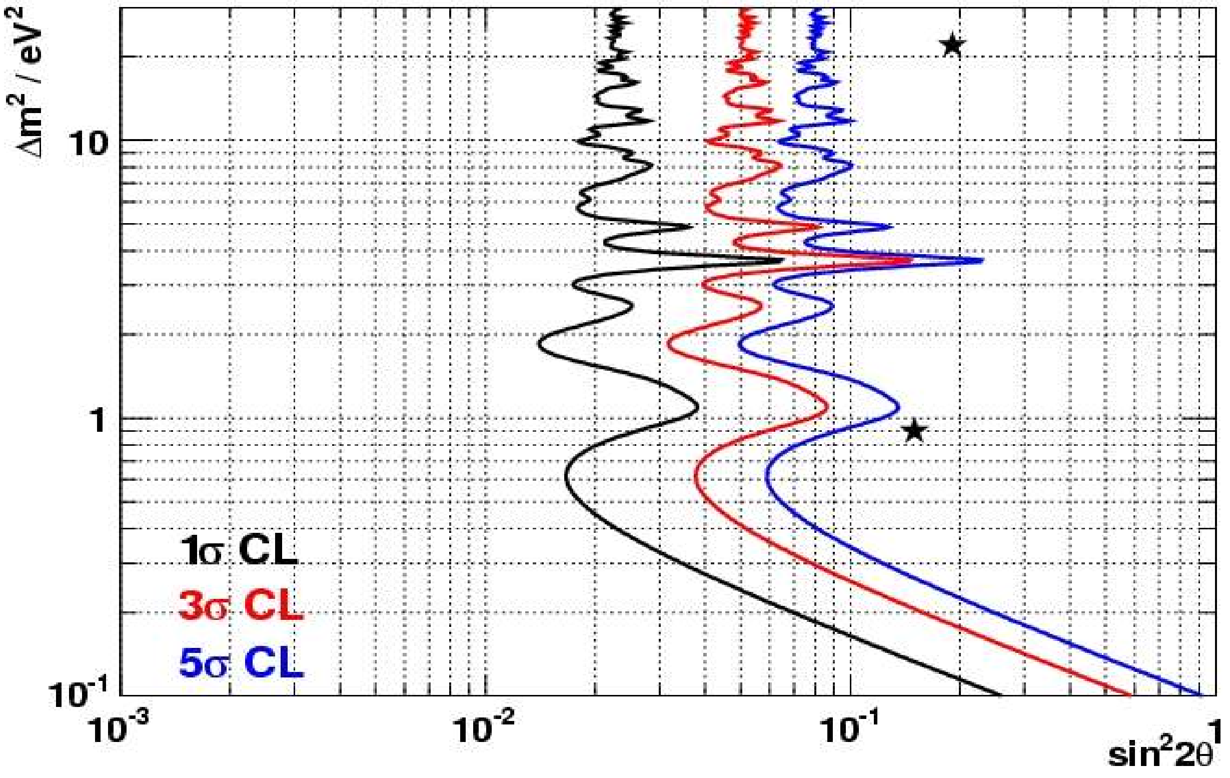


KARMEN gamma $\sigma(E) \sim 2\%$

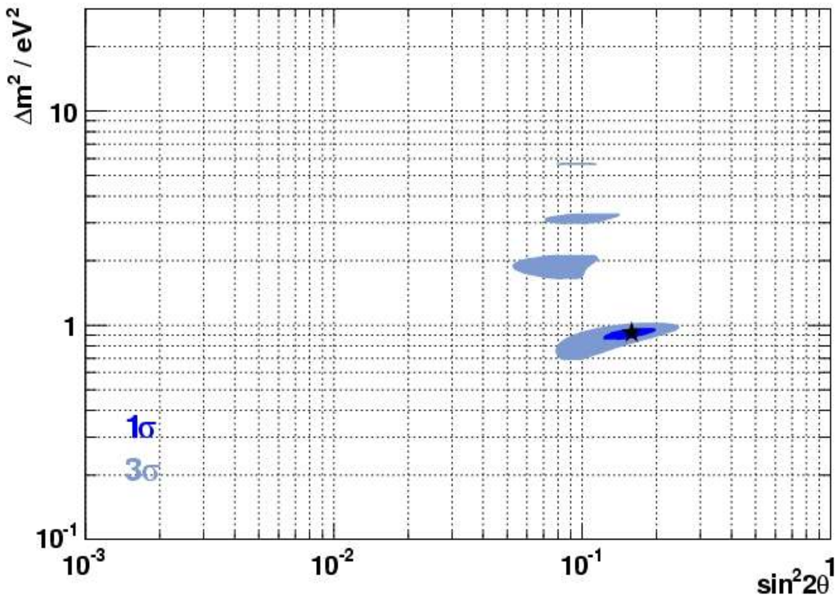
At SNS design for $\sigma(E) \sim 4$ to 7%

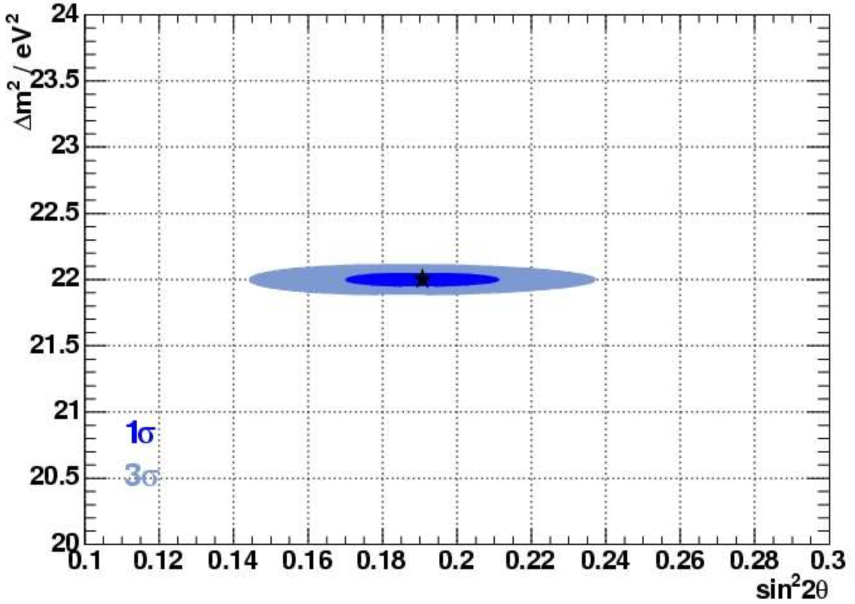
- Expected Backgrounds:
  - ➔NC $\bar{\nu}_\mu$ and CC ν_e, measured from beam off, ~45% stat.
- L Reconstruction:
  - ➔25 cm source size, 60 cm gamma compton scattering.

Sterile Neutrino Oscillations Sensitivity with SNS Source and Two Detectors (3 years)



(3+2) Sterile Neutrino Oscillations Measurement with SNS Source and Two Detectors (3 years)





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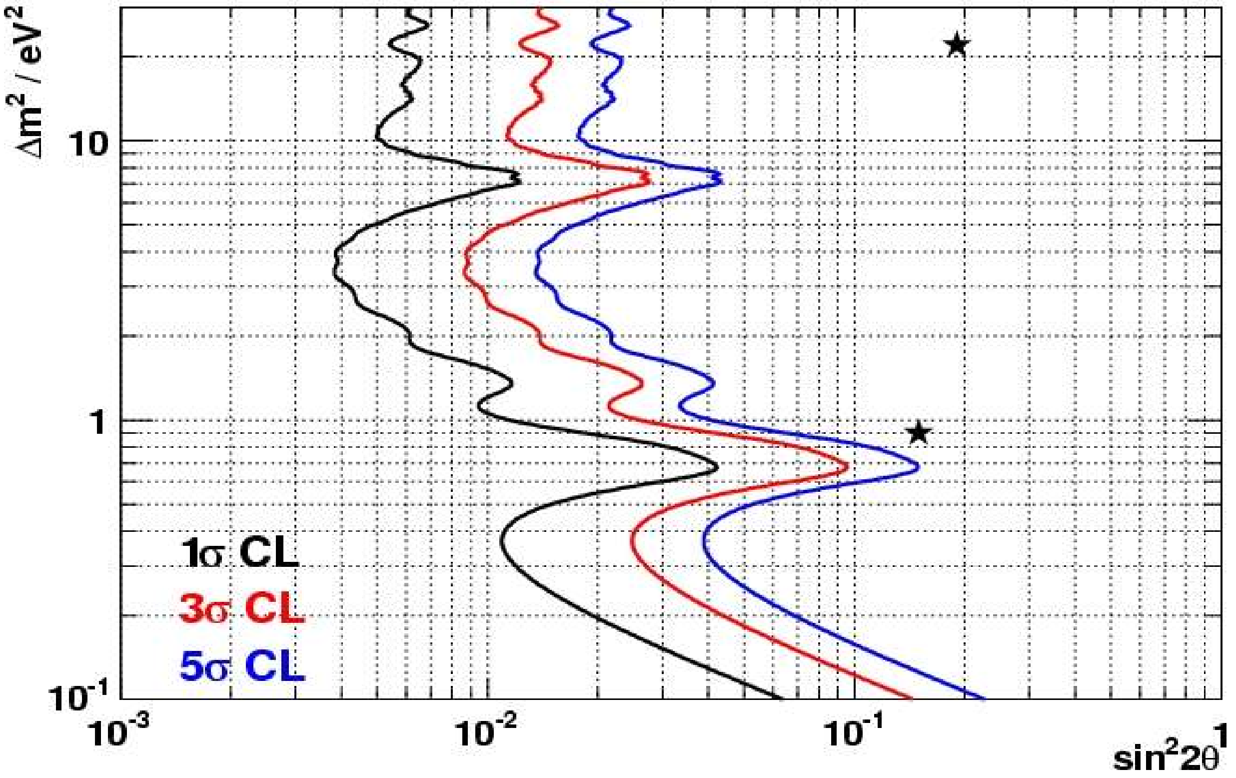
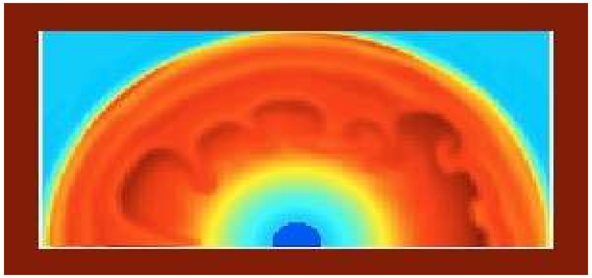
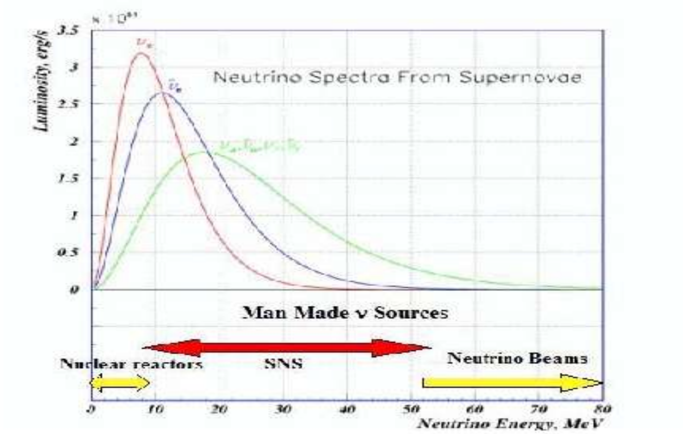
Sterile Neutrino Oscillations Sensitivity with FNAL 8GeV PD and Two Detectors (3 years)

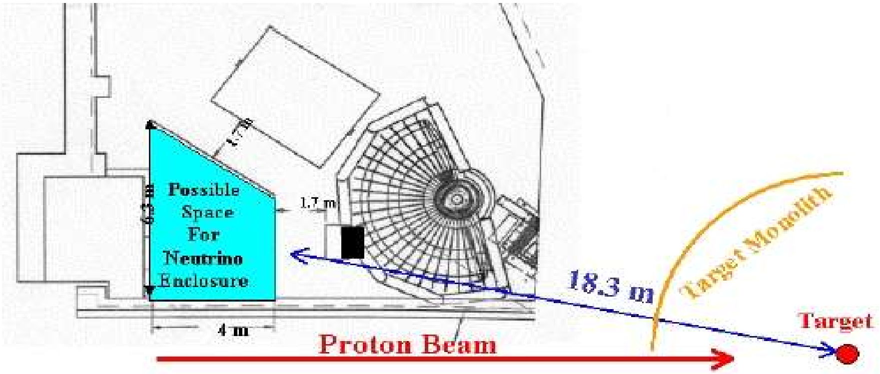


Cross Section Measurements at SNS

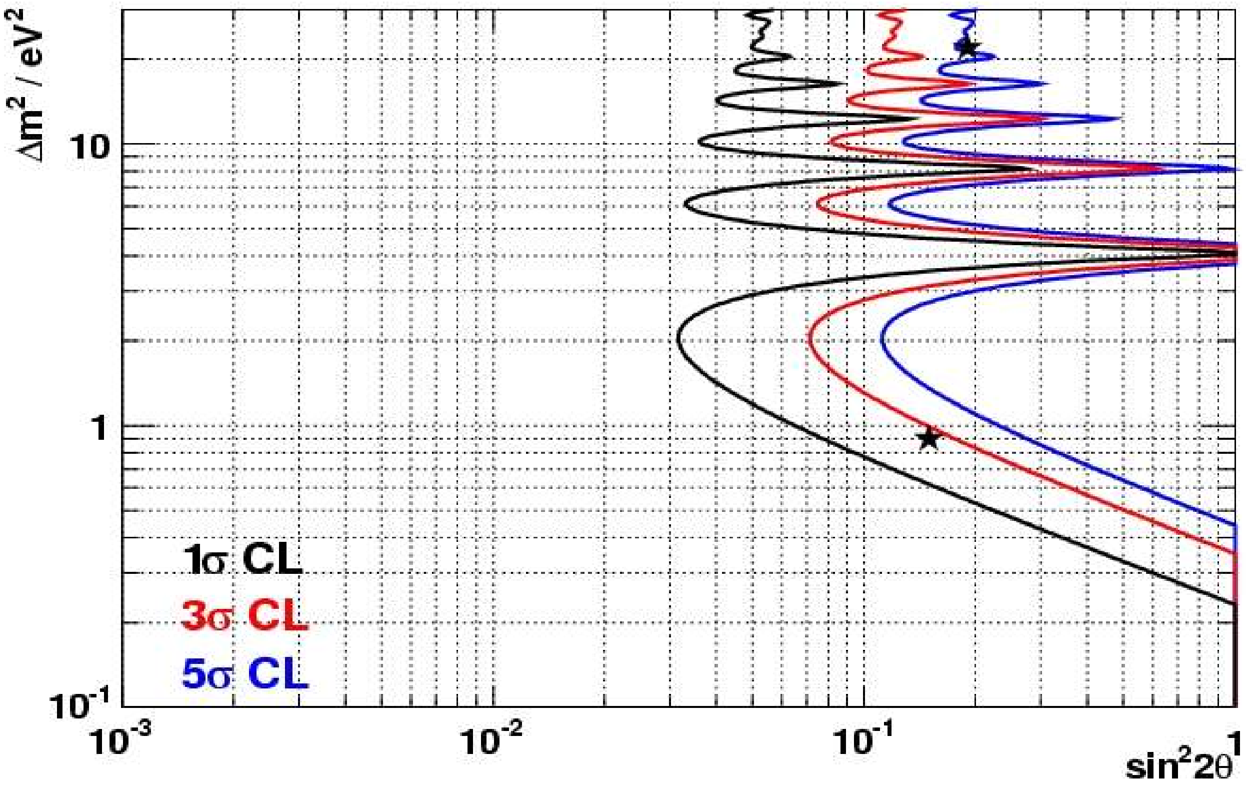


- SNS proposal in the works to measure neutrino nucleus cross sections on Pb, Fe, Al, C, O, D_2O. Strong endorsement from the Aspen APS neutrino meeting.
- Neutrino energies in the supernova type II core collapse region. This is important to studying the astrophysics of supernova, and for supernova neutrino detectors.





Sterile Neutrino Oscillations Sensitivity with SNS Source and One Near Detector (3 years), 5% flux+xsec systematic error.



Conclusions

- There are many interesting, novel, and bizarre models of neutrino oscillations beyond the standard model.
- Many of these models can be tested with a new high intensity stopped pion/muon source like the SNS.
  - 2014 upgrade to two sources and 3MW!
- We are submitting a LDRD-ER this year to study xsection and neutrino oscillations measurements at the SNS. Submitted preprint hep-ph/0501013.
- Study feasibility of doing full scale VLADD with SNS oscillation far detector.