



Neutrino Oscillation Physics with a Stopped Pion/Muon Source

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PANIC05, Neutrino Meeting
Oct 29, 2005

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, extraD's....
 - 3+n sterile neutrino models (hep-ph 0305255):
 - **n=1**, SBL fit: $\delta m^2 \sim 0.9 \text{ eV}^2$, $\sin^2(2\theta) \sim 0.16$, $\chi^2/\text{DOF} = 0.98$
 - **n=2**, SBL fit: $\delta m^2 \sim 0.9 \text{ eV}^2$ and $\sim 22 \text{ eV}^2$, $\chi^2/\text{DOF} = 0.94$

Beyond the Standard Model

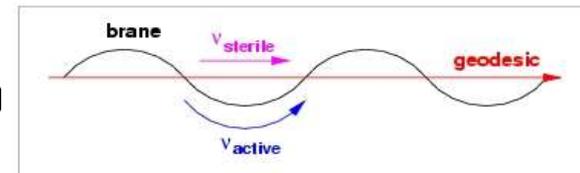
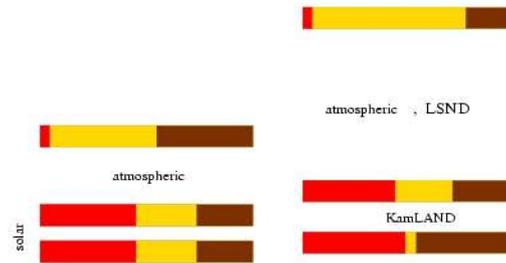
→ If MiniBooNE confirms LSND signal, strong indications of new physics, but what type?

→ CPT violation (hep-ph 0212116).

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

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

→ ν_s short cuts in extra dimensions (hep-ph 0504096)



→ **Need new high intensity short baseline neutrino experiments!**

Short Baseline Tests of New Physics

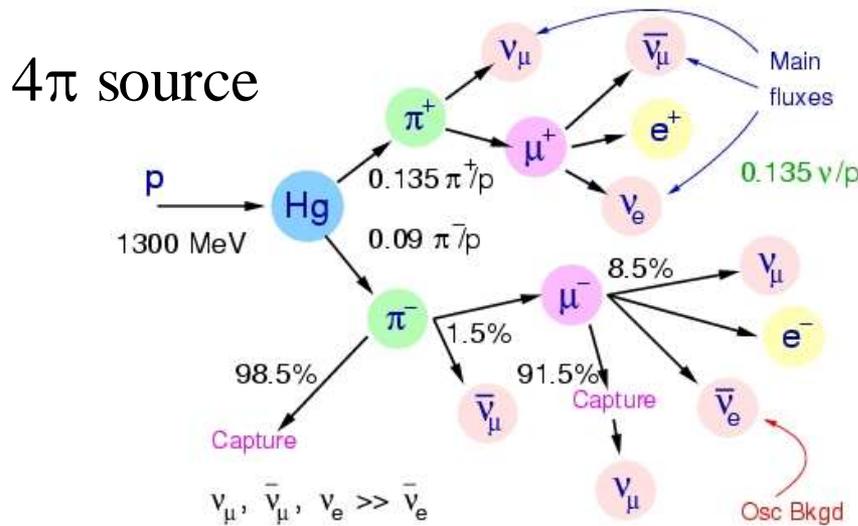
- **Sterile neutrinos:**
 - Measure neutral current rates with two detectors.
- **CPT violation:**
 - Run in antineutrino mode, compare $P(\nu_{\mu} \rightarrow \nu_e)$ to $P(\bar{\nu}_{\mu} \rightarrow \bar{\nu}_e)$.
- **Mass Varying neutrinos:**
 - Oscillation probability depends on absence/presence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

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](#)



FNAL $\sim 2.5 \times$ SNS

	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}

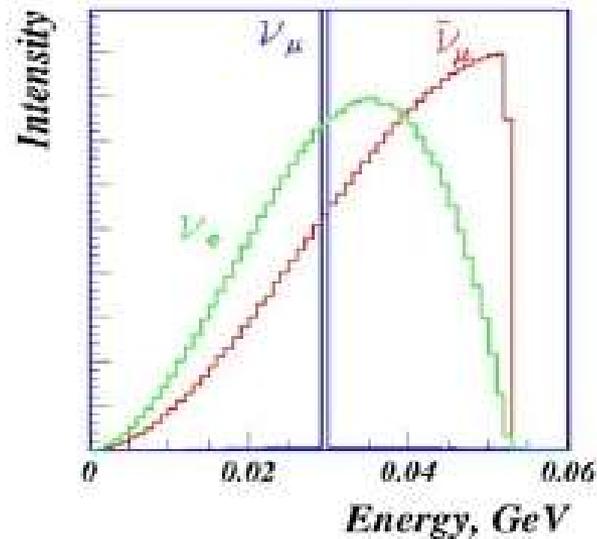
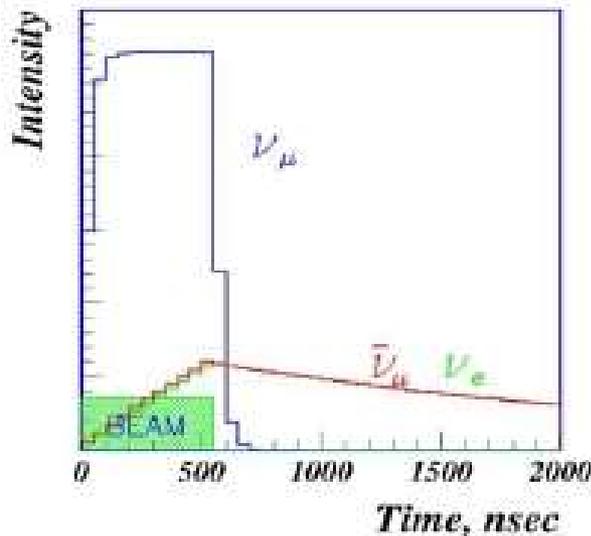
Stopped Pion/Muon Neutrino Source

→ Neutrino Flux from a Stopped Pion/Muon Source:

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

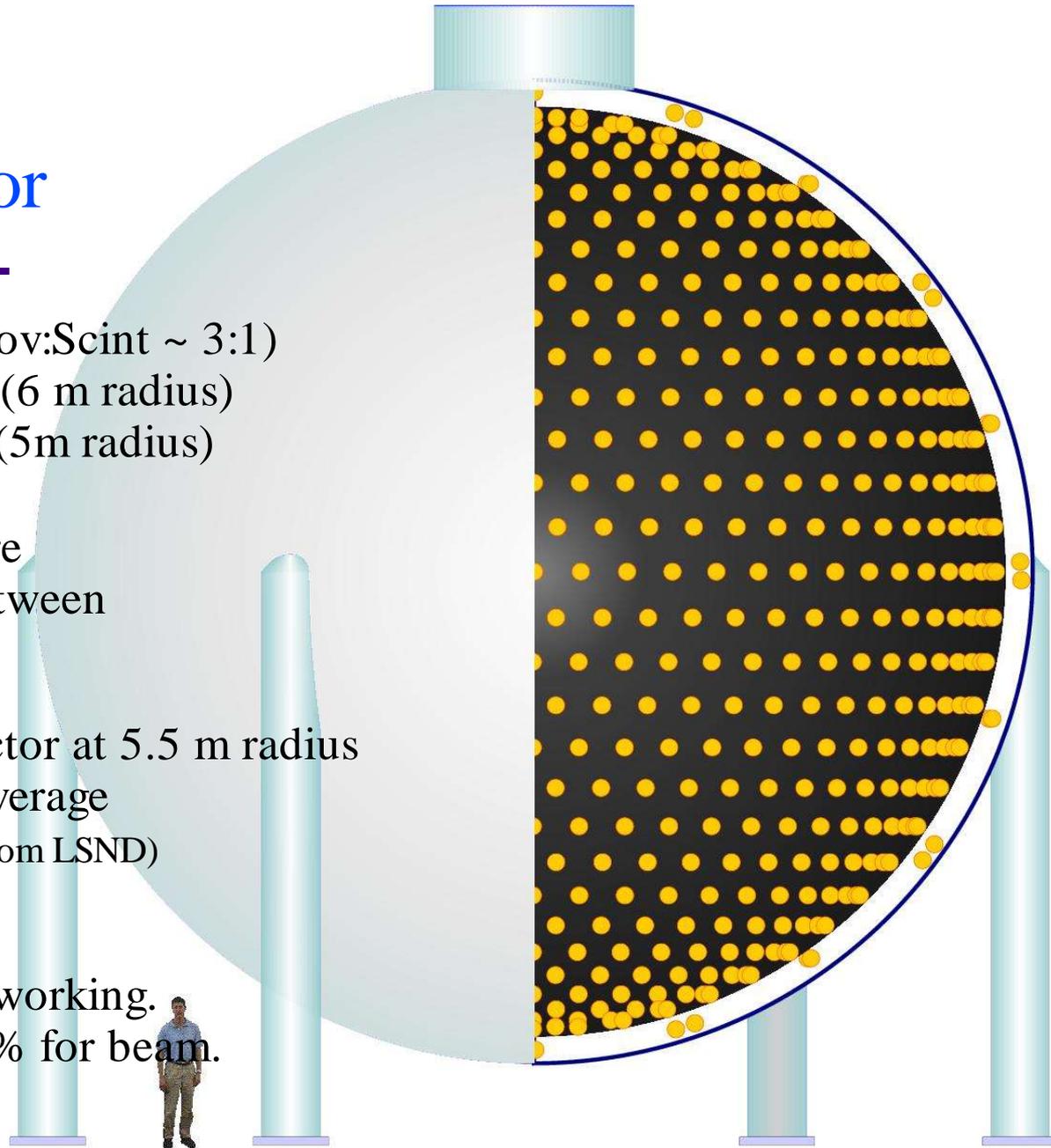
$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e, \quad \tau = 2.2 \mu\text{sec.}$$

event types	0 → 0.695 μsec	0.695 → 5 μsec	> 5 μsec
π ⁺ DAR and π [±] 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

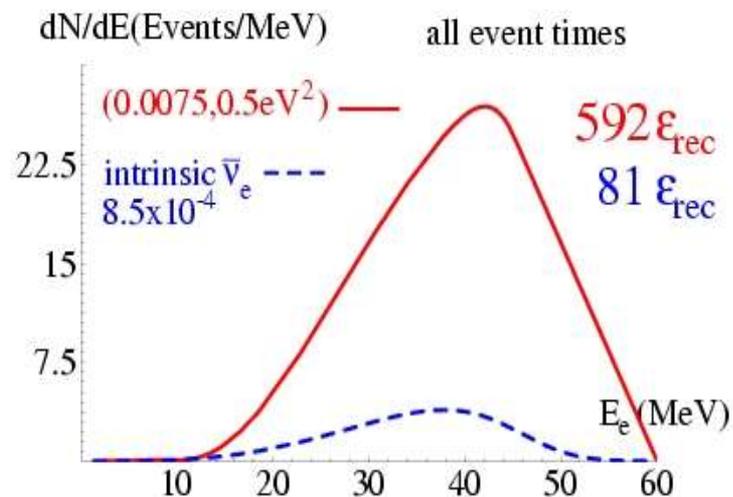
250 ton mineral oil detector 60m from SNS source.

Process	Neutrino Source	ν Source Life Time	Total Events per Beam Year
$\nu_\mu e$	π^+ DAR	26ns	69 ϵ_{rec}
$\bar{\nu}_\mu e$	μ^+ DAR	2197ns	99 ϵ_{rec}
$\nu_e e$	μ^+ DAR	2197ns	630 ϵ_{rec}
Total νe events $T_e > 20\text{MeV}$			798 ϵ_{rec}
$^{12}\text{C}(\nu_e, e^-)^{12}\text{N}_{gs}$	μ^+ DAR	2197ns	4689 ϵ_{rec}
$^{12}\text{C}(\nu_e, e^-)^{12}\text{N}^*$	μ^+ DAR	2197ns	2147 ϵ_{rec}
$^{13}\text{C}(\nu_e, e^-)X$	μ^+ DAR	2197ns	308 ϵ_{rec}
Total $\nu_e \text{ C}$ events $T_e > 20\text{MeV}$			7144 ϵ_{rec}
$^{12}\text{C}(\nu_\mu, \nu_\mu)^{12}\text{C}_{15,11}^*$	π^+ DAR	26ns	1851 ϵ_{rec}
$^{12}\text{C}(\bar{\nu}_\mu, \bar{\nu}_\mu)^{12}\text{C}_{15,11}^*$	μ^+ DAR	2197ns	3752 ϵ_{rec}
$^{12}\text{C}(\nu_e, \nu_e)^{12}\text{C}_{15,11}^*$	μ^+ DAR	2197ns	3093 ϵ_{rec}
Total $\nu_e \text{ C NC}$ events			8696 ϵ_{rec}
$^{12}\text{C}(\nu_\mu, \mu^-)X$	π^+ DIF	26ns	≤ 278 ϵ_{rec}
$^{12}\text{C}(\bar{\nu}_\mu, \mu^+)X$	π^- DIF	26ns	≤ 82 ϵ_{rec}
$p(\bar{\nu}_\mu, \mu^+)n$	π^- DIF	26ns	272 ϵ_{rec}

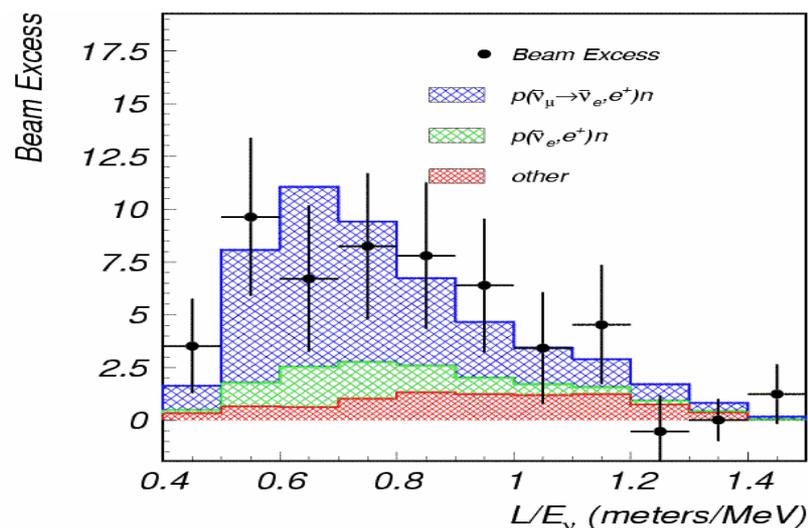
Test of LSND Stopped Muon $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillations (nucl-ex/0309014)

- 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 $np \rightarrow d\gamma(2.2\text{MeV})$.
- Backgrounds/yr: 81 intrinsic $\bar{\nu}_e$, ~ 9 DIF+cosmics.

SNS 1 year



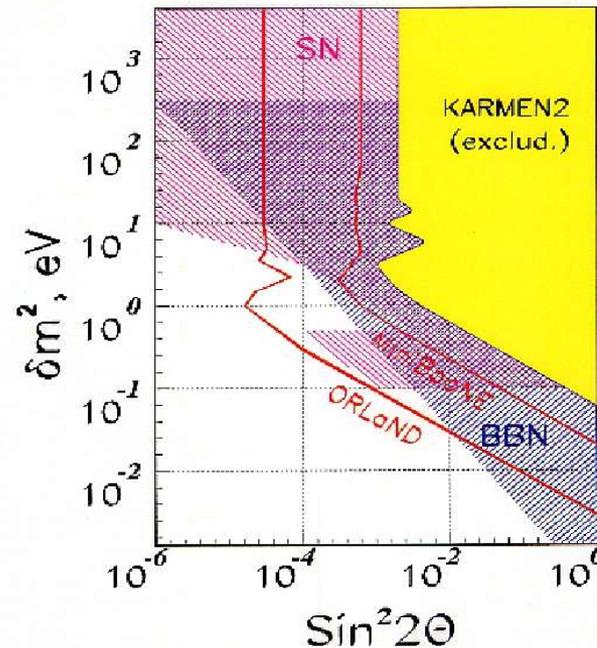
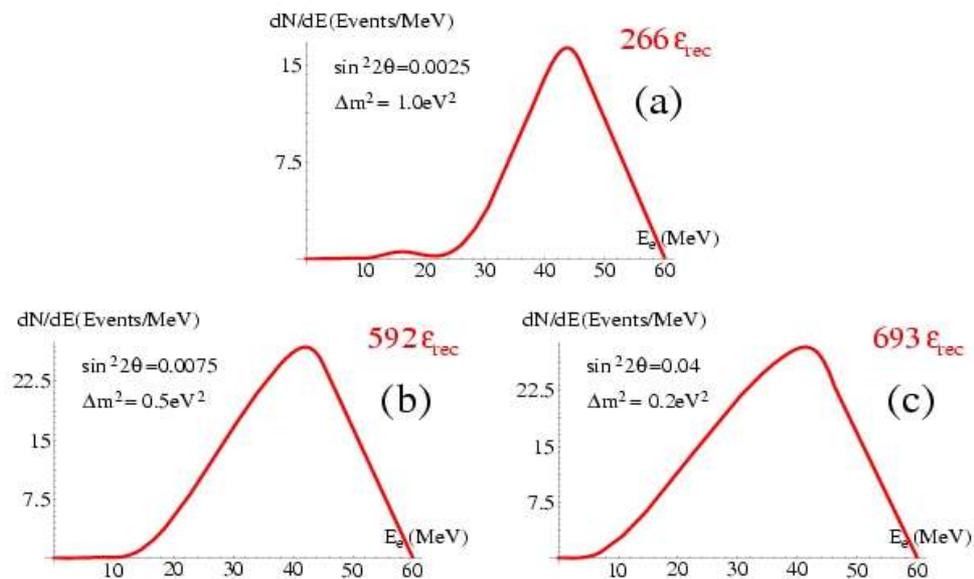
LSND All Data



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

→ Spectrum Shape Analysis

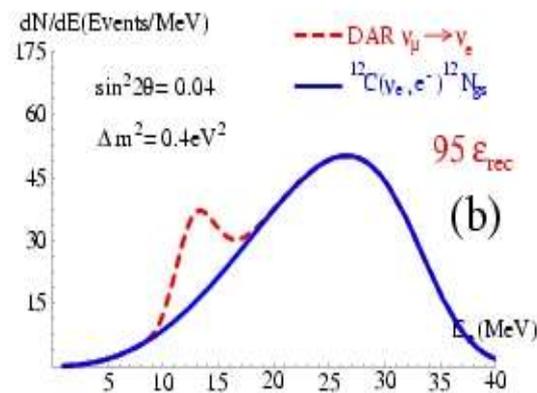
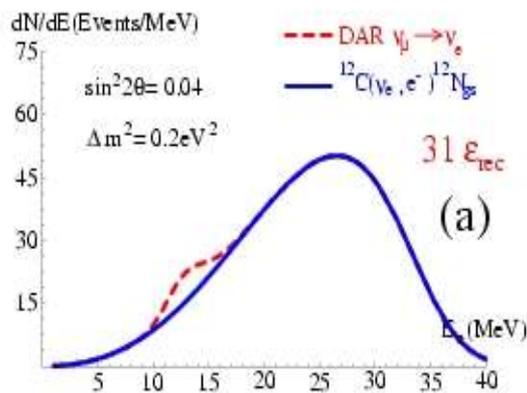
Improved Sensitivity



Measurement of Stopped Pion $\nu_\mu \rightarrow \nu_e$ Oscillations

(nucl-ex/0309014)

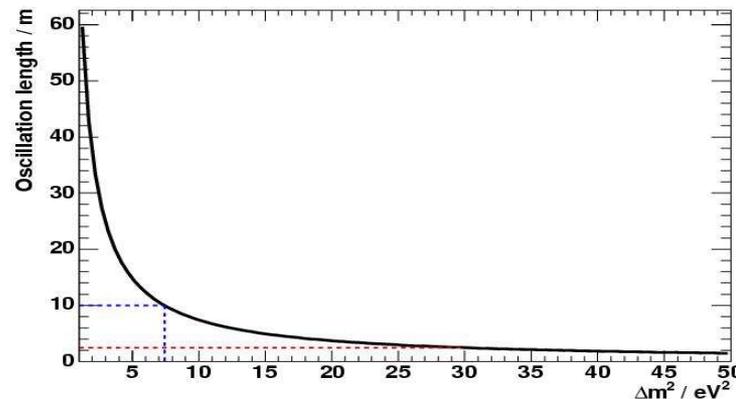
- Single 250 ton mineral oil detector (ELVIS) at 60m from SNS source.
- Oscillation ν_e detected via $\nu_e {}^{12}\text{C} \rightarrow e^- {}^{12}\text{N}_{\text{gs}}$, then ~ 8 MeV beta (11msec).
- Monoenergetic electron bump at 13 MeV (7% E resolution) on large background from stopped muon DAR ν_e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



Active-Sterile Neutrino Oscillations with Stopped Pions (hep-hp/0501013)

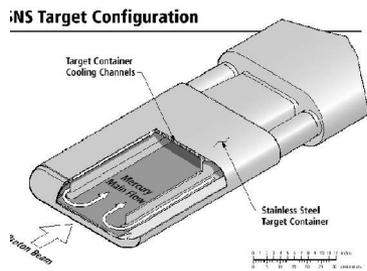
- If LSND oscillations is $\nu_\mu \rightarrow \nu_s \rightarrow \nu_e$, then we expect $P(\nu_\mu \rightarrow \nu_s) > 0.10$
- Can detect all neutrinos via NC reaction, $\nu_x {}^{12}\text{C} \rightarrow \nu_x {}^{12}\text{C}^*(15.11\text{MeV})$.
- Since we have **monoenergetic** ν_μ source, then look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

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

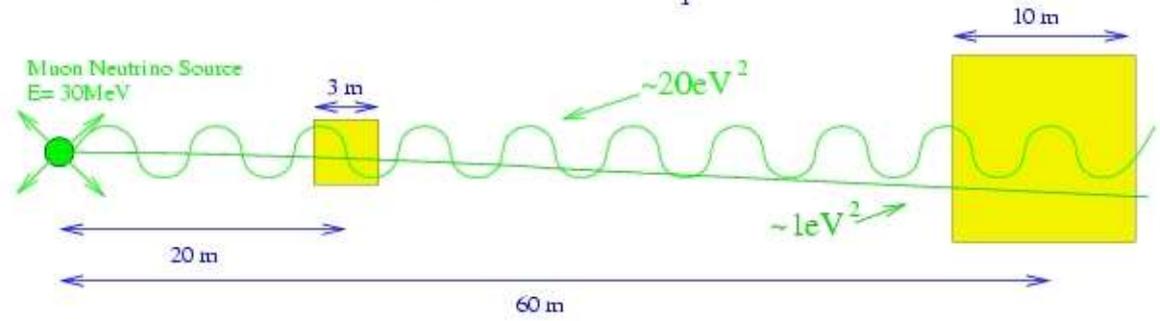


Sterile Neutrino Oscillations with $\nu_{\mu}^{12}\text{C} \rightarrow \nu_{\nu}^{12}\text{C}^*(15.11\text{MeV})$

SNS source L=50 cm



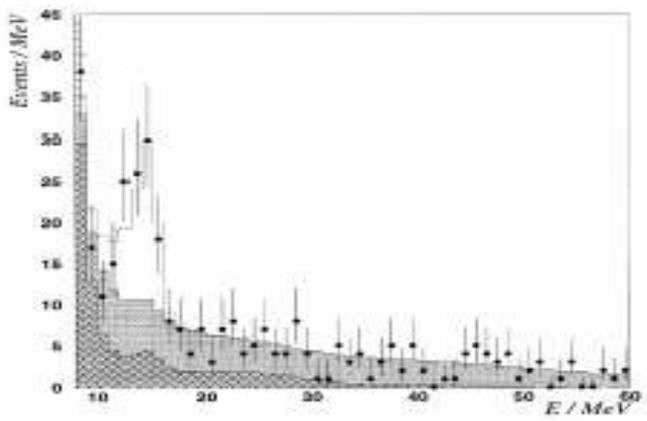
Neutral Current Disappearance Pattern in a Two Detector Setup



Detector	Source Dist. (m)	FD Size (tons)	FD Length (m)	$\nu_{\mu}^{12}\text{C} \rightarrow \nu_{\nu}^{12}\text{C}^*$ 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 $\nu_{\mu}^{12}\text{C} \rightarrow \nu_{\nu}^{12}\text{C}^*(15.11\text{MeV})$

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

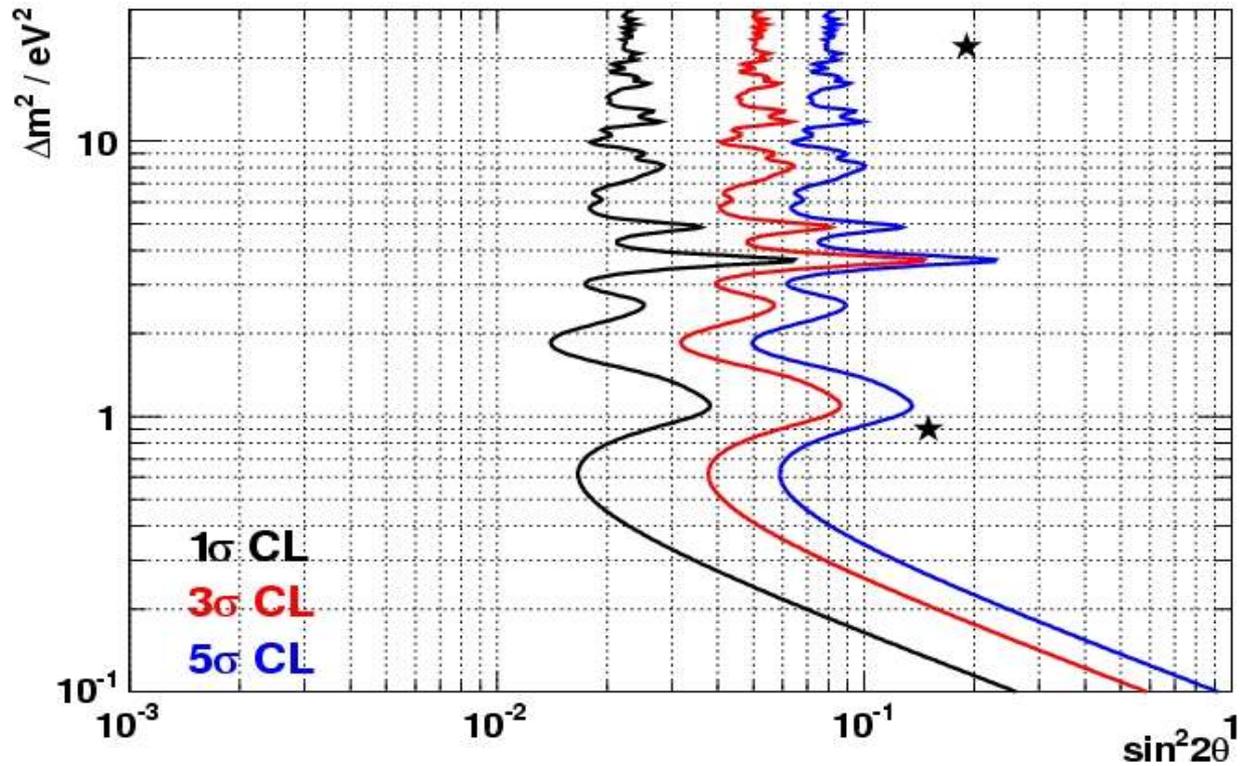


KARMEN gamma $\sigma(E) \sim 2\%$

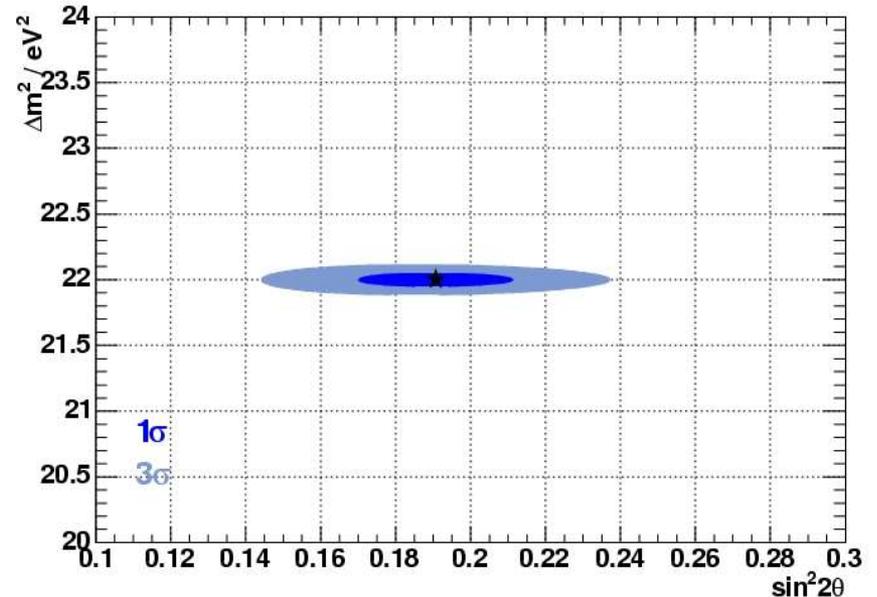
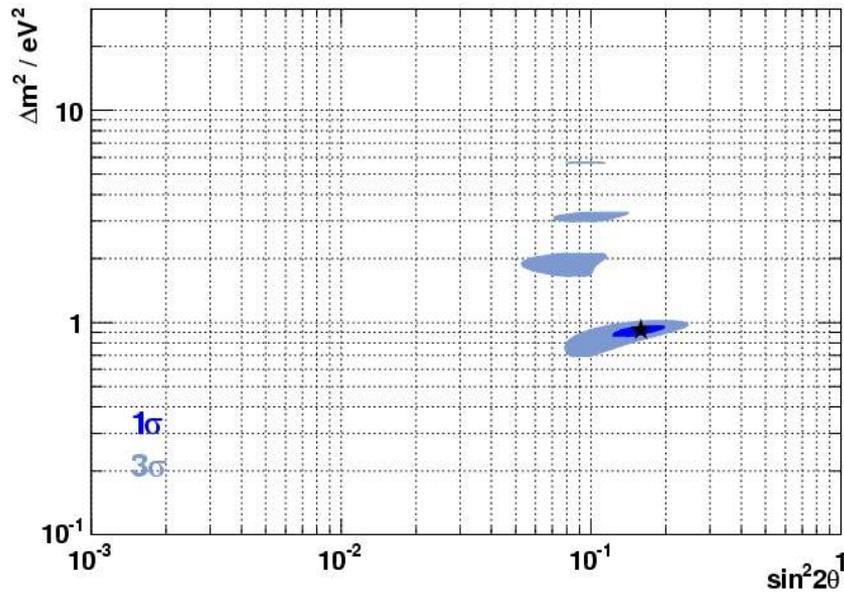
At SNS design for $\sigma(E) \sim 4$ to 7%

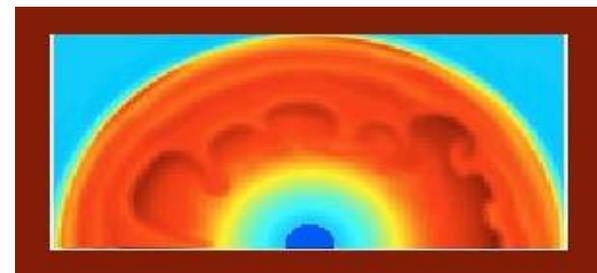
- Expected Backgrounds:
 - NC $\bar{\nu}_{\mu}$ and CC ν_e , measured from beam off, $\sim 45\%$ stat.
- L Reconstruction:
 - 25 cm source size, 60 cm gamma compton scattering.

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



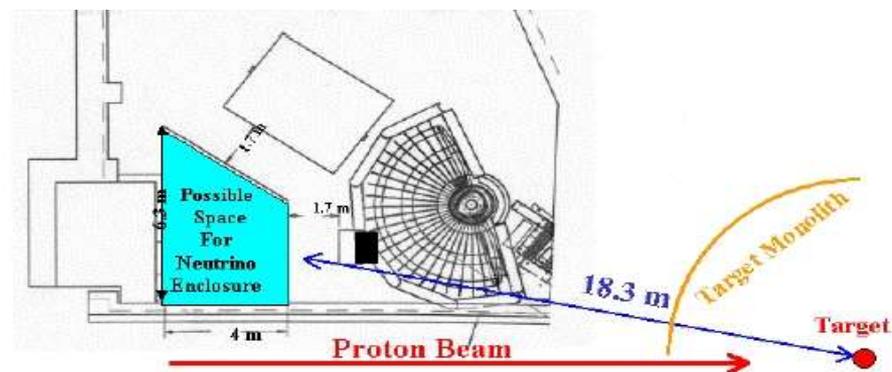
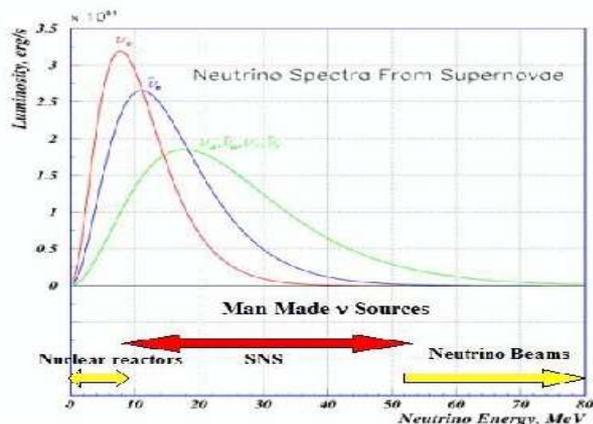
(3+2) Sterile Neutrino Oscillations Measurement with SNS Source and Two Detectors (3 years), 5% flux+xsec systematic error.



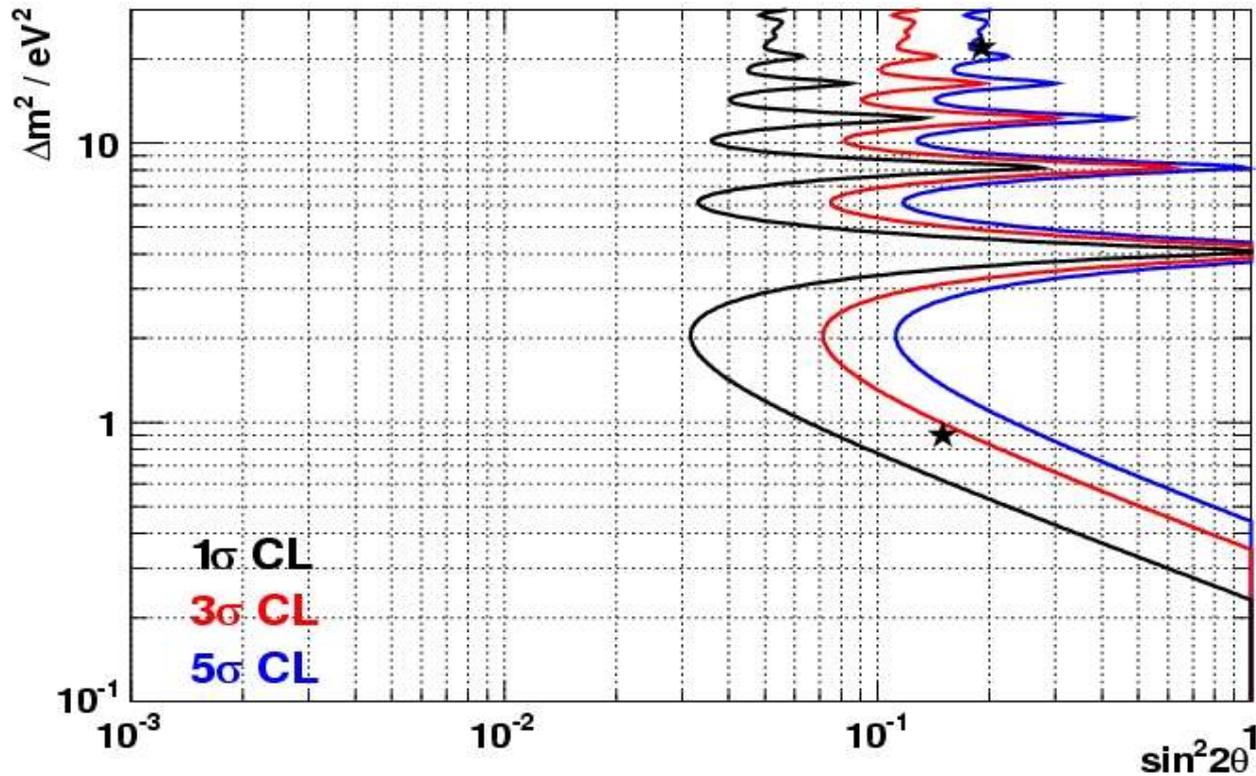


Cross Section Measurements at SNS

- SNS proposal in the works to measure neutrino nucleus cross sections on Pb, Fe, Al, C, O, D₂O.
- 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 the new high intensity stopped pion/muon source at the SNS.**
 - **2014 upgrade to two sources and 3MW!**
- **Coupled with a MiniBooNE class detector, can explore interesting SBL oscillation physics. Preparing white paper for funding possibilities.**