Implications of Confirmation of the LSND $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ Oscillation Signal

Heather Ray
hray@fnal.gov

Los Alamos National Laboratory
Outline

- Introduction to Oscillations
- LSND
- MiniBooNE
- NP Theories
- NP Experiments
Current Oscillation Status

\[ P = \sin^2 2\theta \sin^2 (1.27 \Delta m^2 L / E) \]

Solar \( \nu \)
- Deficit of \( \nu_e \) from \( \odot \)
- \( \Delta m^2 \approx 8 \times 10^{-5} \text{eV}^2 \)

Atmospheric \( \nu \)
- Zenith < deficit of \( \nu_\mu \)
- \( \Delta m^2 \approx 2 \times 10^{-3} \text{eV}^2 \)

LSND Accelerator \( \nu \)
- Excess of \( \bar{\nu}_e \) in \( \bar{\nu}_\mu \) beam
- \( \Delta m^2 \approx 0.1 \rightarrow 10 \text{eV}^2 \)
• 800 MeV proton beam, 600 $\mu$s pulses 120 Hz apart $\rightarrow$ water target
• 167 ton, liquid scintillator, 25% PMT coverage
• $E_\nu \sim 20 - 53$ MeV, $L \sim 25 - 35$ m ($L/E \sim 1$ m/MeV)
• Measure $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ osc. from DAR : $P = 2.64 \pm 0.67 \pm 0.45 \times 10^{-3}$, see 4 $\sigma$ excess
MiniBooNE

- 8 GeV proton beam, 1.6 μs pulses 5 Hz apart → Be target
- 800 ton, non-scintillating mineral oil, 10% PMT coverage
- $E_\nu \sim 700$ MeV, L $\sim 541$ m (L/E $\sim 0.77$ m/MeV)
- Measure $\nu_\mu \rightarrow \nu_e$ osc. from DIF
## MiniBooNE vs LSND

<table>
<thead>
<tr>
<th></th>
<th>MiniBooNE</th>
<th>LSND</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>8 GeV</td>
<td>800 MeV</td>
</tr>
<tr>
<td><strong>Duty Factor</strong></td>
<td>8*10^{-6}</td>
<td>0.072</td>
</tr>
<tr>
<td><strong>ν source</strong></td>
<td>π⁺ → μ⁺ DIF</td>
<td>π⁺ → μ⁺ DAR</td>
</tr>
<tr>
<td><strong>Backgrounds</strong></td>
<td>mis-ID, intrinsic νₑ</td>
<td>Beam-Off, intrinsic νₑ, π⁻ DIF</td>
</tr>
<tr>
<td><strong>Oil</strong></td>
<td>No Scint.</td>
<td>Scint</td>
</tr>
</tbody>
</table>
Physics of Positive LSND

Sterile $\nu$s

- Weak isospin singlets - high mass states (LSND) mostly sterile $\nu$, 3+n models
- hep-ph 0403158, Cirelli, Marandella, Strumia, Vissani,
  hep-ph 0305255, Sorel, Conrad, Shaevitz

Mass Varying $\nu$s

- Mass depends on medium

CPT Violation

- Allow $\Delta m^2_{\nu} > \Delta m^2$, 3 $\nu$ model
- hep-ph 0402005, Mavromatos

Lorentz Violation

- $\nu$ oscillations explained by small Lorentz violation
- Osc. depends on direction of prop.
- hep-ph 0406255, Kostelecky, Mewes
Tests of NP: MiniBooNE

- Sterile $\nu_s$
  - Second detector (BooNE), measure NC cross section
- Mass Varying $\nu_s$
  - If measure oscillation in $0.1\text{eV}^2 < \Delta m^2 < 0.25\text{eV}^2$ (BUGEY excludes)
- CPT
  - Run in $\bar{\nu}$ mode, compare $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$, $P(\nu_\mu \rightarrow \nu_e)$
- Lorentz Violation
  - Look for sidereal variations in oscillation probability
- $\rightarrow$ DIF = difficult sys. from beam flux, $\sigma$
Tests of NP : SNS

- 1 GeV proton beam, 700 ns pulses 60 Hz apart → Hg target
- Hg absorbs most $\pi^-, \mu^-$ before decay
- provides DAR $\nu$ from $\pi^+, \mu^+$
- $\tau_{\pi^+} < 700$ ns $< \tau_{\mu^+}$ → good temporal separation of $\nu_\mu, \nu_e, \bar{\nu}_\mu$
- Primary backgrounds : cosmic rays ($\mu$, neutrons), machine neutrons
- Secondary backgrounds : DAR $\pi^-, \mu^-$
Two detectors: one inside the Target Hall, one ~100 m from target.

Target Hall det: fill with liquid or aqueous nuclei ($^{12}C, ^2H$), test cross sections (calibrate $\nu$ flux).

BooNE-like: 800 ton, liquid scintilllator.

Elvis: 250 ton, 25% pmt coverage.

*hep-ex 0309014, VanDalen*
SNS vs LSND

<table>
<thead>
<tr>
<th></th>
<th>SNS</th>
<th>LSND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>1.3 GeV</td>
<td>800 MeV</td>
</tr>
<tr>
<td>Duty Factor</td>
<td>$4.2 \times 10^{-5}$</td>
<td>0.072</td>
</tr>
<tr>
<td>S/B</td>
<td>$\sim 10$</td>
<td>$\sim 1$</td>
</tr>
<tr>
<td>Bgd</td>
<td>no DIF</td>
<td>DIF</td>
</tr>
</tbody>
</table>

- Both DAR : $E$ for $\nu_\mu$ same (35 MeV)
- SNS $\rightarrow$ larger detector, higher $E = \nu$ flux, more statistics
- SNS $\rightarrow$ two detectors, test C cross section for better flux measurement, measure NC (15.11 NC)
Tests of NP : Minos

- Two detectors: one at FNAL (1 km from source), one 735 km away
- 120 GeV proton beam → graphite
- 5.4, 1 kton plastic scintillator detectors
- FNAL beam = high E, produce \( \tau \) from \( \nu_\mu \rightarrow \nu_\tau \) osc
- Sterile \( \nu_s \)
  - NC cross section, distinguish \( \nu_\mu \rightarrow \nu_\tau \) from \( \nu_\mu \rightarrow \nu_{\text{sterile}} \)
- Mass Varying \( \nu_s \)
  - If measure \( \sin^2 2\theta_{13} > \text{CHOOZ} \)
Summary

- If LSND signal confirmed need to determine which NP model is correct, measure oscillation parameters more precisely
- 4 possible models, many permutations
- NP can be explored with additional detector at FNAL (BooNE), SNS
- Eagerly awaiting MiniBooNE results!