First Anti-Neutrino oscillation results from MiniBooNE

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LSND signal

- MiniBooNE designed to test LSND
- LSND observed excess of $\bar{\nu}_e$ in $\bar{\nu}_\mu$ beam
  $87.9 \pm 22.4 \pm 6.0 \ (3.8\sigma)$
- Assuming two neutrino oscillation:

\[
P(\bar{\nu}_\mu \to \bar{\nu}_e) = \sin^2(2\theta)\sin^2\left(\frac{1.27 \ L \ \Delta m^2}{E}\right)
\approx 0.245 \pm 0.067 \pm 0.045 \%
\]
LSND anomaly

- Within Standard Model 3 neutrino framework LSND signal is not compatible with atmospheric and solar neutrino data

\[ \Delta m_{23}^2 = m_2^2 - m_3^2 \]

\[ \Delta m_{12}^2 = m_1^2 - m_2^2 \]

\[ \Delta m_{13}^2 = \Delta m_{12}^2 + \Delta m_{23}^2 \]
MiniBooNE

- Similar L/E as LSND
- MB detector:
  - 800 ton mineral oil Čerenkov detector
  - 12m diameter
  - 1280 inner PMT’s, and 240 outer veto PMT’s
- Focus either positive or negative mesons
- Collected & analysed:
  - 6.5e20 POT in neutrino mode
  - 3.4e20 POT in anti-neutrino mode

Decay region ~50m
Dirt ~500m

(antineutrino mode)
Neutrino events

- Čerenkov rings used to identify the products of $\nu$ interactions
- Looking for $\nu_e$ CCQE signal events
- Backgrounds:
  - Intrinsic $\nu_e$
  - Mis-identified events
- Use $\nu_\mu$ CCQE to constrain intrinsic nues
Neutrino run results

- No excess of events in signal region
- Ruled out 2 $\nu$ oscillations as source of LSND signal (assuming no CP or CPT violation)

Neutrino run results

- Excess of events observed at low energy: $128.8 \pm 20.4 \pm 38.3$ (3.0σ)
- Shape not consistent with 2ν oscillations
- Magnitude consistent with LSND

Anti-Neutrino run

- Further insight in low energy excess
- Provides direct test of LSND
- Statistics low at present
  - First result with $3.4 \times 10^{20}$ POT
  - The total number of CCQEs down by order of magnitude compared to neutrino run
- By the end of run this summer will have $5 \times 10^{20}$ POT
  - Approved for additional $5 \times 10^{20}$ POT run
- Same analysis as for neutrino mode with few checks
Antineutrino results

- No significant excess observed at either low or high energy
Limit from anti-neutrino run

- No significant excess observed at either low or high energy
- Assumes that neutrinos don't oscillate, only antineutrinos do
- Both LSND and null signal consistent with data at 90% CL
- Need more data
Low Energy Excess

- Preliminary results of the fits to $\nu$ and $\bar{\nu}$ data in low E region
- Ignoring what we know about various backgrounds and looking only at how compatible two datasets are
- Preferred model: excess is due to neutrinos in the beam (no contribution from antineutrinos)

<table>
<thead>
<tr>
<th>Source</th>
<th>Stat. Error Only</th>
<th>100% Correlated Syst. Error</th>
<th>Uncorrelated Syst. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same $\nu,\bar{\nu}$ NC</td>
<td>0.1%</td>
<td>0.1%</td>
<td>6.7%</td>
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<tr>
<td>NC $\pi^0$ scaled</td>
<td>3.6%</td>
<td>6.4%</td>
<td>21.5%</td>
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<tr>
<td>POT scaled</td>
<td>0.0%</td>
<td>0.0%</td>
<td>1.8%</td>
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<td>Bkgd scaled</td>
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<td>4.7%</td>
<td>19.2%</td>
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<tr>
<td>CC scaled</td>
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<td>5.2%</td>
<td>19.9%</td>
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<tr>
<td>Low-E Kaons</td>
<td>0.1%</td>
<td>0.1%</td>
<td>5.9%</td>
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<tr>
<td>$\nu$ scaled</td>
<td>38.4%</td>
<td>51.4%</td>
<td>58.0%</td>
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</tbody>
</table>

Maximum $\chi^2$ probability from fits to $\nu$ and $\bar{\nu}$ data in 200-475 MeV range
Conclusion

• MiniBooNE observes excess of low energy events in neutrino run consistent in magnitude with LSND signal, however energy shape not consistent with $2 \nu$ oscillations

• With $3.4 \times 10^{20}$ POT MiniBooNE does not observe low energy excess in anti neutrino data

• High energy data consistent with both LSND best fit point and no oscillations

• Collecting more anti-neutrino data (approved for a new $5 \times 10^{20}$POT run)