THE LSND "APPEARANCE" EFFECT

A SEARCH FOR $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ OSCILLATIONS.

NEUTRINO SOURCE: AT LOS ALAMOS NAT'L LAB.

NO $\bar{\nu}_e$ IN DECAY CHAIN!

SEARCHING FOR $\bar{\nu}_e$ APPEARANCE:

$L = 30$ meters; $E = 30-55$ MeV.

SIGNAL:
$\bar{\nu}_e - ^{12}$C interaction produces $e^+$ and neutron in oil.

$e^+ \rightarrow$ prompt flash of light

$n \rightarrow$ eventually captured to form $^2$H + $\gamma$ (2.2 MeV)

$\gamma$ produces another flash

LOOK FOR DELAYED COINCIDENCE.
**LSND $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Results for 1993–1998**

20<E<60 MeV

<table>
<thead>
<tr>
<th>Selection</th>
<th>Beam On</th>
<th>Beam Off</th>
<th>$\nu$ Background</th>
<th>Total Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&gt;100</td>
<td>27</td>
<td>8.3+-0.7</td>
<td>5.4+-1.0</td>
<td>13.3+-5.2+-1.0</td>
</tr>
<tr>
<td>R&gt;10</td>
<td>86</td>
<td>36.9+-1.5</td>
<td>16.9+-2.3</td>
<td>32.2+-9.4+-2.3</td>
</tr>
<tr>
<td>R&gt;1</td>
<td>205</td>
<td>106.8+-2.5</td>
<td>39.2+-3.1</td>
<td>59.0+-14.5+-3.1</td>
</tr>
</tbody>
</table>

20<E<60 MeV

<table>
<thead>
<tr>
<th>Data Sample</th>
<th>Fitted Oscillation Excess</th>
<th>Oscillation Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993–1998</td>
<td>87.9+-22.4+-6.0</td>
<td>(0.264+-0.067+-0.045)%</td>
</tr>
</tbody>
</table>
FIG. 14: Comparison of oscillation searches performed by different short baseline experiments.

Both experimental results. At high $\Delta m^2$ values, the LSND solutions are in clear contradiction with the KARMEN upper limit.

VIII. CONCLUSION

Results based on the entire KARMEN2 data set collected from 1997 through to 2001 have been presented. The extracted candidate events for $\bar{\nu}_e$ are in excellent agreement with background expectations showing no signal for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations. A detailed likelihood analysis of the data leads to upper limits on the oscillation parameters $\sin^2(2\Theta)$ and $\Delta m^2$ excluding parameter regions not explored analyzed by other experiments.
• Solar Neutrinos
  The oldest "Neutrino Problem"
  (known for ~30 years)
• Several processes in the sun produce large numbers of $\nu_e$.
• Experiments detect these $\nu_e$ and compare to the "Standard Solar Model" prediction.

$E: \ 0.1-10 \ MeV$
$L: \ 1 \ astronomical \ unit$

Processes observed:

"Chlorine" experiments:
  $\nu_e + ^{37}\text{Cl} \rightarrow ^{37}\text{Ar} + e^-$
  Homestake

"Gallium" experiments:
  $\nu_e + ^{71}\text{Ga} \rightarrow ^{71}\text{Ge} + e^-$
  SAGE, Gallex

Water target: $e^- - \nu$ scattering:
  $\nu_e + e^- \rightarrow \nu_e + e^-$
  Kamiokande, Super K
Comparing the results of these experiments to "The Standard Solar Model (SSM)"

... They see only ~ 1/2 the expected rate!
Oscillation parameters for solar $\nu$:

"MSW" solutions rely on interference effects in matter to enhance oscillations.

Allowed regions

**MSW Solution**

$\nu_e \leftrightarrow \text{NOT-}\nu_e$

Excluded by Super K Day/Night

- CI + Water + Gallium, rates only
- BP98 SSM
- 90% CL allowed

With "vacuum oscillations", chlorine result can only be accommodated with others if $\Delta m^2 \sim 10^{-10}$ eV$^2$ ("Just-So" solution)

Plot obsolete!
**Neutrino Oscillation:**

The experimental picture is very confusing.

**LSND:** \( \Delta m^2 > 0.1 \text{ eV}^2 \) \( \bar{\nu}_\mu \leftrightarrow \bar{\nu}_e \)

**Atmospheric:** \( \Delta m^2 \approx 2 \times 10^{-3} \text{ eV}^2 \) \( \nu_\mu \leftrightarrow ? \)

**Solar:** \( \Delta m^2 < 10^{-4} \text{ eV}^2 \) \( \nu_e \leftrightarrow ? \)

With only 3 \( \nu \) masses, you can't construct 3 \( \Delta m^2 \) values with different orders of magnitude.

Is there a fourth neutrino?

If so, it can't interact weakly, because it would contribute to the decay width of the \( \Xi^0 \) (this is measured to be consistent with only 3 \( \nu \)'s.)

We need:
- A "sterile" fourth \( \nu \) (theoretically unmotivated)
- One of the observed effects is not oscillations
- A new idea
An Alternative Model

Motivated by branes with extra dimensions
- Generates independent masses for $\nu_s$ and $\nu_l$
- Barndorn, Borsoso, Lykke, and Smirnov

Maximal CPT violation in Dirac mass terms

PH/0108199
Next Step: Atmospheric \( \nu \) Problem

Long Baseline Accelerator Experiments—

- create a \( \nu \) beam
- aim through ~hundreds of km of Earth at a neutrino detector
- place second detector near \( \nu \) source to measure initial flux
- use far detector to measure "oscillated" flux

\[ \rightarrow \text{better beam control, purity} \]
\[ \rightarrow \text{lower systematic errors} \]

<table>
<thead>
<tr>
<th>&quot;K2K&quot; (KEK to Kamioka)</th>
<th>MINOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam from KEK synchrotron to SuperKamiokande detector</td>
<td></td>
</tr>
<tr>
<td>( E \sim 3 ) GeV</td>
<td></td>
</tr>
<tr>
<td>( L \sim 250 ) km</td>
<td></td>
</tr>
<tr>
<td>Running 1999-?</td>
<td></td>
</tr>
<tr>
<td>Very preliminary ~2( \sigma ) evidence for ( \nu_\mu ) disappearance</td>
<td></td>
</tr>
<tr>
<td>Beam from Fermilab (Illinois) to Soudan Mine (Minnesota)</td>
<td></td>
</tr>
<tr>
<td>( E = 3-20 ) GeV (variable)</td>
<td></td>
</tr>
<tr>
<td>( L \sim 730 ) km</td>
<td></td>
</tr>
<tr>
<td>Scheduled run 2003-4</td>
<td></td>
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</tbody>
</table>
Very approximate sensitivity of long-baseline accelerator experiments
NEXT STEP ON LSND EFFECT: MINI-BOONE AT FERMILAB

- Look for $\nu_e$ - nucleon scattering in a $\nu_m$ beam
- Pure mineral oil Čerenkov detector
- Currently under construction
- $E = 0.2 - 1.0$ GeV
- $L = 500$ meters

Getting ready to take data at end of 2001.
The SNO Detector

Host: INCO Ltd., Creighton #9 mine
Coordinates: 46°28'30"N 81°12'04"W
Depth: 2092 m (6810 ft w.e., ~70 μ day)

17.8m dia. PMT Support Structure
5300 tonnes of outer shielding H₂O
12.0m dia. acrylic vessel
1700 tonnes of inner shielding H₂O
9496 PMTs, 56% coverage

First search for solar ν Neutral current interactions (Flavor-independent)

Deuteron dissociation:

$\nu + p \rightarrow p + n + p$
\[ Q = 2 \varphi_1 \]

**Standard Solar Model w/o Oscillations:**

\[ \Phi \]

\[ \phi_{\nu} = 3.41_{-0.45}^{+0.65} \text{ (syst.)} \times 10^6 \text{ cm}^{-2} \text{s}^{-1} \]

\[ \phi_{\nu} = 1.76_{-0.05}^{+0.06} \text{ (syst.)} \times 10^6 \text{ cm}^{-2} \text{s}^{-1} \]

**Signal Extraction in \( \phi_{\nu} \)**

\[ \Phi \]

\[ \nu_{cc}(\nu^+) = 5.09_{-0.44}^{+0.46} \text{ (syst.)} \times 10^6 \text{ cm}^{-2} \text{s}^{-1} \]

\[ \nu_{es}(\nu^+) = 2.39_{-0.24}^{+0.12} \text{ (syst.)} \times 10^6 \text{ cm}^{-2} \text{s}^{-1} \]

\[ \nu_{cc}(\nu^+) = 1.76_{-0.05}^{+0.06} \text{ (syst.)} \times 10^6 \text{ cm}^{-2} \text{s}^{-1} \]

**Shape Constrained Neutrino Fluxes**

SNO Results April 2002
CONCLUSIONS:

WE DON'T KNOW...

- How many neutrinos there are
- How they mix (is there CP violation?)
- What they weigh (even to orders of magnitude!)
- If they have nonstandard interactions
- If they have distinguishable antiparticles

... BUT... We have tantalizing hints and powerful new experiments which will test key notions.

This is about where we were understanding quarks 25 years ago.

There will be major discoveries soon.

It's an extremely exciting time.