Fermilab and University of Chicago at the INTENSITY FRONTIER

Symposium Celebrating 50 Years of Fermilab-UChicago Connections
October 31, 2017

Stephen Parke, Fermilab
David Schmitz, University of Chicago
What is the Intensity Frontier?

- Fixed-target beam experiments (i.e. not colliding beams)
- Intense beam sources to enable high-precision measurements and searches for rare processes

UChicago + Fermilab researchers have a long history of teaming up to do world-leading experiments at the intensity frontier, particularly in the physics of kaons and neutrinos.

The present and future program is centered around neutrino physics, with world-class experiments currently under development to study neutrinos over both short (1km) and long (1000km) distances using intense beams from Fermilab.
KTeV – Kaons at the Tevatron

---

**KTeV Event Display**

```
/usr/kpasa/data06/data/postcard_2p1o.dat
Run Number: 6918
Spill Number: 3
Event Number: 337734
Trigger Mask: 8
All Slices
```

**Track and Cluster Info**

<table>
<thead>
<tr>
<th>ID</th>
<th>X (μm)</th>
<th>Y (μm)</th>
<th>Z (μm)</th>
<th>P (MeV)</th>
<th>E (MeV)</th>
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<tbody>
<tr>
<td>C1</td>
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<td>0.6272</td>
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<tr>
<td>C2</td>
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<td>C3</td>
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<td>C4</td>
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<td>-0.2878</td>
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</table>

**Vertex:** 4 clusters

<table>
<thead>
<tr>
<th>X (μm)</th>
<th>Y (μm)</th>
<th>Z (μm)</th>
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<tbody>
<tr>
<td>0.1390</td>
<td>-0.0202</td>
<td>152.811</td>
</tr>
</tbody>
</table>

Mass = 0.4969
Pairing chi² = 1.52

---

**super high-precision KTeV calorimeter built by UChicago/FNAL**

---

\[ K_L \rightarrow \pi^0 \pi^0 \rightarrow 4 \gamma \]
KTeV – Kaons at the Tevatron

For $E_K \sim 70$ GeV

- $K_S: \gamma \beta c \tau \sim 3.5$ m
- $K_L: \gamma \beta c \tau \sim 2.2$ km

The Regenerator
• Direct CP violation in the kaon system, but much more, >50 papers total, many highly cited.

• E799 (without regenerator and w/ higher fluxes) supplied most of the rare kaon decay data in the current PDG (Particle Data Group)

\[ \text{Re}(\epsilon' / \epsilon) \approx \frac{1}{6} \left[ \frac{\Gamma(K_L \rightarrow \pi^+\pi^-)}{\Gamma(K_L \rightarrow \pi^0\pi^0)} / \frac{\Gamma(K_s \rightarrow \pi^+\pi^-)}{\Gamma(K_s \rightarrow \pi^0\pi^0)} - 1 \right] \]

**Observation of direct CP violation in \( K_{SL} \rightarrow \pi\pi \) decays**


DOI: 10.1103/PhysRevLett.83.22

E-Print: hep-ex/9905060 | PDF

References | BibTeX | LaTeX(US) | LaTeX(EU) | HarvMac | EndNote

ADS Abstract Service; Fermilab Library Server (fulltext available); Literature search

Detailed record - Cited by 690 records 500+
The *Chicago-Columbia-Fermilab-Rochester* (CCFR) group of neutrino experiments in the 80’s and 90’s

**FNAL-E-0652:** First of the Chicago-Columbia-Fermilab-Rochester neutrino cross-section experiments in Lab E. Follow-up of E616, which was the first expt to use FNAL high-energy neutrino beam.

**FNAL-E-0701:** Add duplicate detector upstream to search for neutrino oscillations with $\Delta m^2$ greater than 10 eV$^2$.

**FNAL-E-744 (1985) & 770 (1987-88):** Tevatron at 800 GeV and new beamline and detectors meant over 10x more statistics collected in E-744+770 compared to E-652+701 and neutrino energies up to 600 GeV. Measurements included the structure of the proton and the electroweak mixing angle.
Nucleon structure functions from high energy neutrino interactions

Columbia University, New York, NY 10027, USA

F. S. Merritt, M. J. Oreglia, P. G. Reutens
University of Chicago, Chicago, IL 60637, USA

R. Coleman, H. E. Fis, D. Levinthal, W. Marsh, P. A. Rapidis, H. B. White, D. Yovanovich
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

A. Bodek, F. Borcherdig, N. Giokaris, K. Lang, I. E. Stockdale
University of Rochester, Rochester, NY 14627, USA

Received 10 June 1991

Limits on Muon-Neutrino Oscillations in the Mass Range
$30 < \Delta m^2 < 1000 \text{ eV}^2/c^4$

Phys. Rev. Lett. 52, 1384 – Published 16 April 1984
Fun Fact

“The armor plate of some 18 Navy ships - ten heavy cruisers, five aircraft carriers and three submarines - now serves the experimental areas at Fermilab.”

https://history.fnal.gov/vessels.html

The Fermilab high-energy neutrino beamline

The USS Worcester

The Baltimore
The Quantum Neutrino

Flavor eigenstates of the weak interaction

Mass eigenstates of the free-particle Hamiltonian

$$|\nu_\alpha\rangle = \sum_i U_{\alpha i}^{*} |\nu_i\rangle$$

$$\delta_{jk} e^{-i \frac{m_j^2 L}{2E_{\nu}}}$$
The Quantum Neutrino

Interactions

Propagation

Neutrino theorists at Fermilab have taught graduate courses at UChicago on Neutrino Physics

Boris Kayser

SP
Three Neutrino Oscillations

Things we don’t yet know:
- ordering of mass states
- absolute $\nu$ mass scale
- dominant flavor of $\nu_3$
- CP violation
- is $U$ unitary?

Quantum interference on a terrestrial scale!

$\Delta m_{32}^2 = 2.5 \times 10^{-3} \text{ eV}^2$

$\Delta m_{21}^2 = 7.5 \times 10^{-5} \text{ eV}^2$

$|U| \sim \begin{pmatrix}
0.83 & 0.55 & 0.15 \\
-0.47 & 0.52 & 0.71 \\
0.31 & -0.65 & 0.69
\end{pmatrix}$
DUNE
DEEP UNDERGROUND NEUTRINO EXPERIMENT

arXiv:1512.06148, 1601.02984, 1601.05471, 1601.05823

UChicago

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blucher, Edward</td>
<td>Faculty/Scientist Spokes</td>
</tr>
<tr>
<td>Elgin, Andrey</td>
<td>Postdoc</td>
</tr>
<tr>
<td>Johnson, Tyler</td>
<td>Under Grad</td>
</tr>
<tr>
<td>Mastbaum, Andrew</td>
<td>Postdoc</td>
</tr>
<tr>
<td>Schmitz, David</td>
<td>IBR Faculty/Scientist</td>
</tr>
<tr>
<td>Zennamo, Joseph</td>
<td>Postdoc</td>
</tr>
</tbody>
</table>

130 Scientist, Post Docs, Engineers from Fermilab

1000+ collaborators  175+ Institutions  30+ Nations
What is DUNE/LBNF

DUNE/LBNF will consist of:

- An intense (1-2 MW) neutrino beam from Fermilab
- A massive (70 kton) deep underground LAr Far Detector in South Dakota
- A large Near Detector at Fermilab
- A large International Collaboration (~1000 scientist)
DUNE Far Detector Site

Black Hills of South Dakota

Sanford Underground Research Facility
DUNE Far Detector Site

Yates Complex

Ross Complex

1.5 km

Four large caverns at the 4850 ft. level
LBNF/DUNE Groundbreaking on July 21, 2017

Four large caverns at the 4850 ft. level
DUNE Far Detector – 40-kton LAr TPC

4 cryostats holding 70-ktons of liquid Ar

40-ktons fiducial mass for physics

62m x 14m x 15m

12m tall active detector elements
Physics of DUNE

- **Neutrino Mass and Mixing**
  - CP violation in neutrinos (matter-antimatter asymmetry)
  - Mass ordering, dominant flavor of $\nu_3$ mass state
  - Precision tests of the 3-neutrino oscillation paradigm

- **Supernova neutrinos**
  - Measure $\nu_e$ flux from a core-collapse supernova in our galaxy
  - 1000s of events for a SN 10-kpc away

- **Proton Decay**
  - Especially $p \rightarrow K^+\bar{\nu}$
  - A prediction of many beyond Standard Model theories

- **Surprises!**
  - Non-standard interactions, sterile neutrinos, Lorentz violation, $\nu$ decay…
CP Violation @ DUNE

\[ P(\nu_\mu \rightarrow \nu_e) \neq P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \]

in vacuum

Sensitivity for $\delta_{\text{CP}}$ between $[-\pi, +\pi]$
Supernova Neutrinos @ DUNE

- LAr detectors are mainly sensitive to $\nu_e$ via: $\nu_e + ^{40}\text{Ar} \rightarrow e^- + ^{40}\text{K}^+$
- Sensitivity to neutronization burst
- Sensitivity to mass hierarchy
- Complementarity to other detector technologies (mostly $\bar{\nu}_e$ sensitivity)

**Flavor composition as a function of time**

- $\nu_e$ and $\bar{\nu}_e$ production
- Neutronization and accretion processes

**Energy spectra integrated over time**

- Events per 0.5 MeV bin
- Observed energy distribution

shown for 40-ktons and SN at 10 kpc
Liquid Argon Time Projection Chamber

1) bubble chamber like imaging
2) fine sampling calorimetry
3) electronic readout
4) scalable to large volumes
The Short-Baseline Neutrino (SBN) Program

A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

arXiv:1503.01520

Far Detector
ICARUS

MicroBooNE

Near Detector
SBND

ICARUS
600m
476 tons

MicroBooNE
470m
89 tons

WILSON HALL

BOOSTER RING

ICARUS
MINOS
LEDERMAN
NOVA

MicroBooNE

MiniBooNE

SBN
110m
112 tons

David Schmitz, Chicago and Stephen Parke, Fermilab
FNAL-UChicago @ Intensity Frontier
Search for new physics in the neutrino sector

- Precision searches for neutrino oscillations at a new mass-scale, 1 eV², a possible indication of light ‘sterile’ neutrino states.

Neutrino-argon interaction physics

- World’s largest dataset of ν-Ar interactions, millions of events, until DUNE era.

LAr-TPC technology development

- SBN detectors provide platform for R&D
- Transferable construction, operational, and analysis experience
Neutrino ID and Reconstruction

more images here: http://www-microboone.fnal.gov/first-neutrinos/index.html
modular design and monolithic nature of LArTPC technology means many commonalities in design and lessons learned are valuable… despite massive scale difference

- wire plane design
- HV system
- QA/QC methods
- readout electronics
- signal processing
- photon detection
- analysis methods
- etc.
Fermilab-UChicago @ Intensity Frontier

- University of Chicago + Fermilab collaborations have been leading teams in the field at the Intensity Frontier for decades

- A common thread, from kaons to neutrinos: CP violation. Why is there something rather than nothing?

- Both kaon and neutrino physics still very strong at Chicago, with neutrino being the focus of today’s Fermilab-Chicago collaboration.

Very strong joint efforts and leadership in both the long-baseline and short-baseline neutrino programs, each world-leading programs into the next decade and beyond.
Extras
Physics Beyond the 3-$\nu$ SM?

\[ \Delta m_{4x}^2 \sim 1 \text{ eV}^2 \]

Short-baseline neutrino oscillations

Long-baseline neutrino oscillations
The Three Detector SBN Program

- Oscillation Probability [%]
- Length of Neutrino Flight [m]
- Neutrino Energy: 700 MeV
- $\Delta m^2_{13} = 1.60 \text{ eV}^2$
- $\sin^2(2\theta) = 0.0014$

increase **statistics** of oscillation signal by adding ICARUS

control **systematics** with near detector

A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

arXiv:1503.01520

- ICARUS 600m 476 tons
- MicroBooNE 470m 89 tons
- SBND 110m 112 tons

David Schmitz, Chicago and Stephen Parke, Fermilab
Oscillation Searches at SBN

**ν_{μ} → ν_{e} appearance**

- LSND 90%
- LSND 99%
- Global 2017 1σ
- Global 2017 2σ
- Global 2017 3σ
- Global 2017 best fit

SBN sensitivities assume exposures of:
- 6.60×10^{30} protons on target in ICARUS and SBND
- 13.2×10^{30} protons on target in MicroBooNE


**ν_{μ} disappearance**

SBN sensitivities assume exposures of:
- 6.60×10^{30} protons on target in ICARUS and SBND
- 13.2×10^{30} protons on target in MicroBooNE

Liquid Argon TPCs: Operating Principle

- Neutrino+Ar → final state charged particles ionize the argon, produce scintillation photons
- Electric field drifts free electrons to wire chamber planes (~1.6 mm/µs at 500 V/cm)
- Induction/Collection planes image charge, record dE/dx

**scintillation light**

**ionization charge**
## The SBN LArTPCs

<table>
<thead>
<tr>
<th>ICARUS</th>
<th>MicroBooNE</th>
<th>SBND</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>600 m from ν production</strong>&lt;br&gt;476 ton active volume</td>
<td><strong>470 m from ν production</strong>&lt;br&gt;89 ton active volume</td>
<td><strong>110 m from ν production</strong>&lt;br&gt;112 ton active volume</td>
</tr>
<tr>
<td>4x 1.5m drift</td>
<td>2.5m drift</td>
<td>2x 2m drift</td>
</tr>
<tr>
<td>0.95 ms drift time (500V/cm)</td>
<td>1.6 ms drift time (500V/cm)</td>
<td>1.28ms drift time (500V/cm)</td>
</tr>
<tr>
<td>75 kV</td>
<td>128 kV</td>
<td>100 kV</td>
</tr>
<tr>
<td>3 wire planes: 0, +/-60 deg, 3mm</td>
<td>3 wire planes: 0, +/-60 deg, 3mm</td>
<td>3 wire planes: 0, +/-60 deg, 3mm</td>
</tr>
<tr>
<td>53246 wires x 2 MHz</td>
<td>8256 wires x 2 MHz</td>
<td>11264 wires x 2 MHz</td>
</tr>
<tr>
<td>Warm analog and digital electronics</td>
<td>Cold analog/warm digital electronics</td>
<td>Cold analog and digital electronics</td>
</tr>
<tr>
<td>360 8” PMTs x 500 MHz</td>
<td>32 8” PMTs x 64 MHz</td>
<td>160 8” PMTs x 500 MHz &amp; scint. bars</td>
</tr>
</tbody>
</table>
Liquid Argon Time Projection Chamber

1) bubble chamber like imaging
2) fine sampling calorimetry
3) electronic readout
4) scalable to large volumes
Analysis of Michel electrons from cosmic muon decay valuable for understanding EM shower reconstruction and determining energy scale calibration – important check of Monte Carlo

https://arxiv.org/abs/1704.02927
Neutrino Masses and Mixing

Flavor eigenstates of the weak interaction

\[ |\nu_\alpha\rangle = \sum_i U^*_\alpha_i |\nu_i\rangle \]

Mass eigenstates of the free-particle Hamiltonian

\[
\begin{pmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau
\end{pmatrix} =
\begin{pmatrix}
U_{e1} & U_{e2} & U_{e3} \\
U_{\mu1} & U_{\mu2} & U_{\mu3} \\
U_{\tau1} & U_{\tau2} & U_{\tau3}
\end{pmatrix}
\begin{pmatrix}
\nu_1 \\
\nu_2 \\
\nu_3
\end{pmatrix}
\]

Neutrino Mixing Matrix

mass states of mass \( m_i \)
Neutrino Oscillations

the neutrino’s quantum nature is observable on terrestrial scales!

\[ |\nu_\alpha\rangle \rightarrow |\nu(L)\rangle = \sum_i U_{\alpha i}^* e^{-i(m_i^2/2E)L} \]

Weak flavor \( \alpha \) at production point is a superposition of mass eigenstates

After traveling a distance \( L \), the \( \nu_i \) get out of phase with one another, and the sum may no longer correspond to a \( \nu_\alpha \)!

\[ P(\nu_\alpha \rightarrow \nu_\beta) = |\langle \nu_\beta | \nu(L) \rangle|^2 \]

2 neutrino case:

\[ P_{ee} = 1 - P_{ea} = \sin^2(2\theta) \sin^2 \left( 1.27 \frac{\Delta m^2 [eV^2]}{E_\nu [GeV]} \frac{L [km]}{E_\nu [GeV]} \right) \]

Amplitude determined by amount of mixing, \( \theta \)

Wavelength determined by mass-splitting \( \Delta m^2 \)
What We Know and Don’t Know

\[
\begin{pmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau
\end{pmatrix} =
\begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \theta_{23} & \sin \theta_{23} \\
0 & -\sin \theta_{23} & \cos \theta_{23}
\end{pmatrix}
\begin{pmatrix}
\cos \theta_{13} & 0 & \sin \theta_{13} e^{-i\delta} \\
0 & 1 & 0 \\
-\sin \theta_{13} e^{-i\delta} & 0 & \cos \theta_{13}
\end{pmatrix}
\begin{pmatrix}
\cos \theta_{12} & \sin \theta_{12} & 0 \\
-\sin \theta_{12} & \cos \theta_{12} & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\nu_1 \\
\nu_2 \\
\nu_3
\end{pmatrix}
\]

“atmospheric mass-splitting”
\[\Delta m_{32}^2 = 2.524 \times 10^{-3} \text{ eV}^2\]

“solar mass-splitting”
\[\Delta m_{21}^2 = 7.5 \times 10^{-5} \text{ eV}^2\]

\[\theta_{12} \approx 34^\circ\]
\[\theta_{23} \approx 45^\circ\]
\[\theta_{13} \approx 8.5^\circ\]
\[\delta_{CP} = 0 \rightarrow 2\pi\]

Do neutrinos violate CP symmetry?

“mass state ordering”

mass state ordering

Normal hierarchy

Inverted hierarchy

\[\nu_1 \rightarrow \nu_2 \rightarrow \nu_3\]

\[\nu_3 \rightarrow \nu_1 \rightarrow \nu_2\]

\[\nu_2 \rightarrow \nu_3 \rightarrow \nu_1\]

\[\nu_1 \rightarrow \nu_3 \rightarrow \nu_2\]

\[\nu_2 \rightarrow \nu_1 \rightarrow \nu_3\]

\[\nu_3 \rightarrow \nu_2 \rightarrow \nu_1\]

dominant flavor of \(\nu_3\)

Do neutrinos violate CP symmetry?
Dominant Flavor of Nu_3

~ 40 ktons x 2 MW x 10 years

Octant Sensitivity

\[ P(\nu_\mu \rightarrow \nu_e) + P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \approx 2 \sin^2 \theta_{23} [1 - P(\bar{\nu}_e \rightarrow \bar{\nu}_e)] \]

Long Baseline @VOM Reactors
Mass Ordering:

\[ \delta m_{atm}^2 \]

\[ \delta m_{sol}^2 \]

OR

\[ \delta m_{atm}^2 \]

\[ \delta m_{sol}^2 \]

Mass Hierarchy Sensitivity

DUNE MH Sensitivity
Normal Hierarchy
\[ \sin^2 \theta_{13} = 0.085 \]
\[ \sin^2 \theta_{23} = 0.45 \]

\[ \sqrt{\Delta \chi^2} \]

Exposure (kt-MW-years)

\[ \theta_{23} \]
Proton Decay:

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Water Cherenkov Efficiency</th>
<th>Water Cherenkov Background</th>
<th>Liquid Argon Efficiency</th>
<th>Liquid Argon Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p \rightarrow K^+ \bar{\nu} )</td>
<td>19%</td>
<td>4</td>
<td>97%</td>
<td>1</td>
</tr>
<tr>
<td>( p \rightarrow K^0 \mu^+ )</td>
<td>10%</td>
<td>8</td>
<td>47%</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>( p \rightarrow K^+ \mu^- \pi^+ )</td>
<td>97%</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>( n \rightarrow K^+ e^- )</td>
<td>10%</td>
<td>3</td>
<td>96%</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>( n \rightarrow e^+ \pi^- )</td>
<td>19%</td>
<td>2</td>
<td>44%</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Sensitivity to \( p \rightarrow K^+ + \bar{\nu} \)
What About Physics Beyond the 3-ν SM?

- Additional flavor states which do not couple to Standard Model forces, i.e. ‘sterile’ neutrinos

**$\nu_e$ disappearance:**

$$P(\nu_e \rightarrow \nu_e) = 1 - \sin^2(2\theta_{ee}) \sin^2 \left(1.27 \Delta m^2 \frac{L}{E}\right)$$

$$\rightarrow 4|U_{e4}|^2 \left(1 - |U_{e4}|^2\right)$$

**$\nu_\mu$ disappearance:**

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \sin^2(2\theta_{\mu\mu}) \sin^2 \left(1.27 \Delta m^2 \frac{L}{E}\right)$$

$$\rightarrow 4|U_{\mu4}|^2 \left(1 - |U_{\mu4}|^2\right)$$

**$\nu_e \rightarrow \nu_\mu$ appearance:**

$$P(\nu_\mu \rightarrow \nu_e) = 1 - \sin^2(2\theta_{\mu e}) \sin^2 \left(1.27 \Delta m^2 \frac{L}{E}\right)$$

$$\rightarrow 4|U_{e4}|^2 |U_{\mu4}|^2$$

A simple “3+1” Model

- A mostly sterile mass state
  - $\Delta m^2_{4\ell} = \Delta m^2_{43}$
  - $\approx \Delta m^2_{42} \approx \Delta m^2_{41}$

$$\nu_1 \rightarrow \nu_2 \rightarrow \nu_3 \rightarrow \nu_4$$

$m^2 (eV^2)$

David Schmitz, Chicago and Stephen Parke, Fermilab

FNAL-UChicago @ Intensity Frontier
Hints of Physics Beyond the 3-ν SM?

- Experimental anomalies ranging in significance have been reported from neutrino experiments at baselines less than 1 km (L/E order 1 km/GeV)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Neutrino Source</th>
<th>Search Channel</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSND</td>
<td>$\pi/\mu$ decay-at-rest</td>
<td>$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance</td>
<td>3.8σ</td>
</tr>
<tr>
<td>MiniBooNE</td>
<td>accelerator decay-in-flight</td>
<td>$\nu_\mu \rightarrow \nu_e$ appearance</td>
<td>3.4σ / 2.8σ</td>
</tr>
<tr>
<td>GALLEX/SAGE</td>
<td>Source, e-capture</td>
<td>$\nu_e$ disappearance</td>
<td>3σ</td>
</tr>
<tr>
<td>Reactors</td>
<td>Beta decay</td>
<td>$\bar{\nu}_e$ disappearance</td>
<td>$\leq$ 2.5σ</td>
</tr>
</tbody>
</table>

A Multi-Faceted Attack!

$\nu_e$ appearance

$\nu_\mu$ disappearance

$\nu_e$ disappearance

LSND + MiniBooNE signals

rest null results

IceCube

SciBooNE

MINOS

IceCube 99% CL Exclusions

IC86 rate+shape

IC86 shape only (blind result)

IC59 result

gallium + reactor signals

only null results

new generation of SBL reactor experiments underway

90% (L_{max} - L < 2.3)

99% (L_{max} - L < 4.6)
MicroBooNE Installation at LArTF (June 2014)
Just completed a ~2 year program of upgrades at CERN in preparation for operation at Fermilab

- updated electronics
- 10x more light collection for surface operation

Leaving CERN any day for 5-week journey to Fermilab!
Building ready to receive the detector this summer
Bottom Cosmic Ray Tracker panel installations beginning now
Short-Baseline Near Detector

Membrane cryostat constructed inside an outer warm steel structure

Central cathode with two 2m drift regions

Two 4m x 2.5m Anode Plane Assemblies (APAs) per side (drift region)

-100 kV
SBND: TPC Construction Is Ongoing

Wire plane frames in production

HV feed-through prototype

Cathode plane mesh prototype

Wiring procedures prototyping
Cryostat constructed in the building pit. Detector to be assembled at Fermilab during 2018. Bottom Cosmic Ray Tracker panel installations beginning soon.