Sterile Neutrino Global Context and nuSTORM Short-Baseline Sensitivity

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The Evidence for Sterile Neutrinos

**LSND** ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)

- Event Excess: $32.2 \pm 9.4 \pm 2.3$

**MiniBooNE** ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)

- Event Excess: $78.4 \pm 28.5$

**Gallium Anomaly** ($\nu_e$ Disappearance)


**Reactor Anomaly** ($\bar{\nu}_e$ Disappearance)

Evidence from Cosmology

Cosmological data like CMB, Baryon Acoustic Oscillations (BAO), Large Scale Structure, Big-Bang Nucleosynthesis and the Hubble Constant ($H_0$) are sensitive to the effective number of light degrees of freedom ($N_{\text{eff}}$)

With 3 $\nu$, $N_{\text{eff}} = 3.046$

$N_{\text{eff}} = 3.36^{+0.68}_{-0.64}$ (95%; Planck+WP+highL).

$N_{\text{eff}} = 3.30^{+0.54}_{-0.51}$ (95%; Planck+WP+highL+BAO).

$N_{\text{eff}} = 3.62^{+0.50}_{-0.48}$ (95%; Planck+WP+highL+$H_0$).

$N_{\text{eff}} = 3.52^{+0.48}_{-0.45}$ (95%; Planck+WP+highL+$H_0$+BAO).

$N_{\text{eff}} > 3.046$ may be evidence of a one or more sterile neutrino states

The Evidence Against Sterile Neutrinos

KARMEN ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)

The Evidence Against Sterile Neutrinos

KARMEN ($\bar{\nu}_\mu \to \bar{\nu}_e$)

Joint LSND & KARMEN analysis

No $\bar{\nu}_e$ Excess


Bugey Reactor ($\bar{\nu}_e$ Disappearance)

Effective $\bar{\nu}_\mu \to \bar{\nu}_e$ under certain assumptions


$\nu_\mu$ Disappearance (where is it?)

Joint LSND & KARMEN analysis

No $\nu_\mu$ Excess

Kopp et al., JHEP 1305, 050 (2013)

MiniBooNE ($\nu_\mu \to \nu_e$) 2007

No Excess Above 475 MeV

The Evidence Against Sterile Neutrinos

KARMEN ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)

$\nu_\mu$ Disappearance (where is it?)

No $\bar{\nu}_e$ Excess


Joint LSND & KARMEN analysis

MiniBooNE ($\nu_\mu \rightarrow \nu_e$) 2013

Bugey Reactor ($\bar{\nu}_e$ Disappearance)

Event Excess: $162.0 \pm 47.8$

Effective $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ under certain assumptions


Kopp et al., JHEP 1305, 050 (2013)
STUDY GROUPS

Energy Frontier
- Luis Alvarez (UC Berkeley)
- Henry Kendall (MIT)
- Fred Reines (UC Irvine)
- Melvin Schwartz (BNL)
- Raymond Davis (U Penn)
- Hans Bethe (Cornell)
- Simon van der Meer (CERN)
- Georges Charpak (CERN)
- Richard Feynman (CalTech)
- Eugene Wigner (Princeton)
- Emilio Segre (UC Berkeley)
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- Julian Schwinger (UCLA)

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- Louie Duck (Virginia Tech)
- Minnie Mouse (William and Mary)
- Mickey Mouse (Virginia Tech, Chair)
- Peter Pan (Duke)
- Captain Hook (Virginia Tech)
- Wendy Darling (Duke)
- Pinocchio (University of Virginia)
- Geppetto (University of Tennessee)
- Cheshire Cat (North Carolina State)

Cosmic Frontier
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- Georges Charpak (CERN)
- Richard Feynman (CalTech)
- Eugene Wigner (Princeton)
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- Maria Goeppert-Mayer (UCSD)
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Instrumentation Frontier
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- Richard Feynman (CalTech)
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- Emilio Segre (UC Berkeley)
- Maria Goeppert-Mayer (UCSD)
- Julian Schwinger (UCLA)

Computing Frontier
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- Emilio Segre (UC Berkeley)
- Maria Goeppert-Mayer (UCSD)
- Julian Schwinger (UCLA)

LOCAL ORGANIZING COMMITTEE

Donald Duck (University of Virginia)
- Daisy Duck (Virginia Tech)
- Huey Duck (University of North Carolina)
- Dewey Duck (Virginia Tech)
- Louie Duck (Virginia Tech)
- Minnie Mouse (William and Mary)
- Mickey Mouse (Virginia Tech, Chair)
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- Pinocchio (University of Virginia)
- Geppetto (University of Tennessee)
- Cheshire Cat (North Carolina State)

DPF EXECUTIVE COMMITTEE

Chair: Albert Einstein
- Chair-Elect: Marie Curie
- Vice Chair: Max Planck
- Past Chair: Niels Bohr
- Secretary/Treasurer: Paul Dirac
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Members at Large:
- Enrico Fermi
- Ernest Lawrence
- Wolfgang Pauli
- Max Born
- James Chadwick
- Erwin Schrödinger

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Imagine what we may know just before the turn-on of LBNE in 2023:

- The mass hierarchy – from the combination of Pingu, Juno and Nova
- Majorana vs. Dirac – if the hierarchy is inverted
- The absolute mass scale – from Katrin or $0\nu2\beta$ if the masses are degenerate
- Hints of $\delta_{CP}$ and the $\theta_{23}$ – look at this cool plot from T2K:

But we still may not have a resolution of the LSND anomaly.
Several Ideas to Search for Sterile Neutrinos

Some have neat signatures and good discovery potential, but most will not be definitive

Radioactive Source Experiments

Reactor Short Baseline

\(\nu_e\) Disappearance

\(\bar{\nu}_e\) Disappearance

(Self reported sensitivities)
Appearance searches are almost exclusively accelerator based.

LAr1 and ICARUS/NESSiE are both $\pi$ decay-in-flight beams (so called super beams).

OscSNS is a $\pi$ decay-at-rest beams and therefore makes a direct test of LSND.
Ideas for Appearance Searches

Appearance searches are almost exclusively accelerator based.

LAr1 and ICARUS/NESSiE are both $\pi$ decay-in-flight beams (so called super beams).

OscSNS is a $\pi$ decay-at-rest beams and therefore makes a direct test of LSND.

nuSTORM’s primary channel is $\nu_e \rightarrow \nu_\mu$, the CPT conjugate to LSND (or $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ if $\mu^-$ are stored)

It has the best reach in $\sin^22\theta$ over the interesting $\Delta m^2$ region.
νₑ are Bad News

Super beam νₑ appearance experiments are very difficult. You’ve got an ambiguous event signature and beam intrinsic νₑ.
T2K demonstrated that a superbeam $\nu_e$ appearance experiment can be made to work when the mixing angle is of order 10%.

For a mixing angle of 1% for an expected $S/N = 0.5$

The $\nu_\mu \to \nu_e$ allowed region from global fits extends below 0.4% for $S/N < 0.2 \ (\approx \sigma_{BG})$.

So T2K: great success, but not a demonstration of feasibility for short-baseline $\nu_e$ appearance searches.

Observed 28 events over an anticipated background of $4.46 \pm 0.53$
In nuSTORM, $\nu_e \rightarrow \nu_\mu$ can be cleanly identified by looking at the charge of the produced muon. There is no source of intrinsic, wrong-sign muons. The muon signature in the detector is unique.
In addition to the $\nu_\mu$ and $\bar{\nu}_\mu$ appearance channels, the clean, well-characterized beams of nuSTORM can do:

- $\nu_\mu$ and $\bar{\nu}_\mu$ disappearance
- $\nu_e$ and $\bar{\nu}_e$ disappearance

As a machine for short-baseline oscillations, nuSTORM is unique:

1. It produces clean, well-understood beams of $\nu_e$ and $\bar{\nu}_\mu$.

2. The signature of the golden mode oscillation channel, $\nu_e \rightarrow \nu_\mu$, is hard to fake in the detector.

3. In addition to $\nu_\mu$ appearance, $\nu_\mu$ and $\nu_e$ disappearance channels are accessible (in both neutrinos and antineutrinos).

4. nuSTORM is the next step on a path to a full neutrino factory and a muon collider.