Accelerator neutrino searches for eV-scale sterile neutrinos

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Introduction

• I will give a brief review of the main accelerator-based neutrino experimental searches for eV-scale sterile neutrinos
  • Both short-baseline and long-baseline searches

• Appearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$
• Disappearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ and $\nu_\mu \rightarrow \nu_\mu$
• NC Disappearance: $1 - (\nu_\mu \rightarrow \nu_s)$

• I’ll predominantly stick with published results but will include a couple of results presented this summer

• I’ll close with a few comments on future measurements
### Parameter dependencies

- **Expanded 4x4 PMNS matrix** has the following form:

\[
\begin{pmatrix}
U_{e4} \\
U_{\mu 4} \\
U_{\tau 4} \\
U_{s4}
\end{pmatrix}
\]

\[
U_{PMNS} =
\begin{pmatrix}
U_{s1} & U_{s2} & U_{s3} & U_{s4}
\end{pmatrix}
\]

- **Appearance:** \( \bar{\nu}_\mu \rightarrow \bar{\nu}_e \) and \( \nu_\mu \rightarrow \nu_e \)
  - Sensitive to both \( \theta_{14} \) and \( \theta_{24} \)

- **Disappearance:** \( \bar{\nu}_\mu \rightarrow \bar{\nu}_\mu \) and \( \nu_\mu \rightarrow \nu_\mu \)
  - Sensitive to \( \theta_{24} \)

- **NC Disappearance:** \( 1 - (\nu_\mu \rightarrow \nu_s) \)
  - Sensitive to \( \theta_{24} \) and \( \theta_{34} \)

3+1 hypothesis:

\[
|U_\mu 4|^2 = \sin^2 \theta_{24} \cos^2 \theta_{14}
\]

\[
|U_\tau 4|^2 = \sin^2 \theta_{34} \cos^2 \theta_{24}
\]

All depend on a new mass splitting \( \Delta m^2_{41} \)
The story of the 1eV\(^2\) scale sterile (anti)neutrino starts with LSND.

Saw an excess of electron-like events in short-baseline \(\bar{\nu}_\mu \rightarrow \bar{\nu}_e\)

- Beam came from stopped pion decay

Excess: \(87.9 \pm 22.4 \pm 6.0\)

\[
\sin^2 2\theta = \sin^2 2\theta_{14} \sin^2 \theta_{24}
\]

• KARMEN2 also searched for short-baseline $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations but saw no signal

MiniBooNE

- Short-baseline experiment searching for oscillations $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$

- Low energy excesses seen in both neutrino and antineutrino modes

- No disappearance signal seen

MiniBooNE at Neutrino 2018

• Analysis repeated with the full data exposure (neutrino-mode sample doubled)

• The integrated excess remains and stands at 4.8σ combined from neutrino and antineutrino mode

IceCube

• Not an accelerator neutrino detector, but still probes a combination of $\bar{\nu}_\mu \to \bar{\nu}_\mu$ and $\nu_\mu \to \nu_\mu$
  • Reliant on a matter effect resonance at high energy for neutrinos traversing Earth
  • Strong exclusion of the sterile neutrino hypothesis in the $0.1 - 2.0$ eV$^2$ range

• Deep-core search sets limits on $\theta_{24}$ and $\theta_{34}$
  • At $\Delta m^2_{41} = 1$eV$^2$

MINOS

- MINOS probes sterile neutrinos through two channels:
  - Charged-current muon neutrino disappearance
  - Neutral-current disappearance
  - Also performed a combined analysis with Daya Bay (+Bugey-3)

MINOS+ at Neutrino 2018

- Updated result containing first two years of MINOS+ data
- Updated analysis technique and inclusion of two years of MINOS+ data
- Strong exclusion of the sterile neutrino hypothesis

NOvA

- NOvA has searched for the disappearance of NC interactions
  - Separate analyses for neutrino and antineutrino beam modes
  - Rate-only analysis
  - Valid for the range $0.05 < \Delta m_{41}^2 (\text{eV}^2) < 0.5$
- No signal seen so a limit is set in the $(\theta_{24}, \theta_{34})$ parameter space
- Plans for ND $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\tau$ searches

The Future

- FNAL SBN programme will consist of three detectors in the same booster beam that provided neutrinos to MiniBooNE
  - Near: SBND
  - Intermediate: MicroBooNE (currently running)
  - Far: ICARUS T600
- Sensitivity to exclude LSND allowed region at 5σ

R. Acciarri et al., arXiv:1503.01520
The Future

- **JSNS²** is a proposed pion decay-at-rest experiment:
  - Provides a direct test of LSND
  - First results expected in 2021

- **DUNE** is a next-generation neutrino oscillation experiment and will consider a number of different channels:
  - Appearance: \( \bar{\nu}_\mu \rightarrow \bar{\nu}_e \) and \( \nu_\mu \rightarrow \nu_e \)
  - CC Disappearance: \( \bar{\nu}_\mu \rightarrow \bar{\nu}_\mu \) and \( \nu_\mu \rightarrow \nu_\mu \)
  - NC Disappearance: \( 1 - (\nu_\mu \rightarrow \nu_s) \)
  - Can hence measure all three mixing angles in a single experiment

S. Ajimura et al., arXiv:1705.08629
The Future

- NuSTORM will produce a neutrino beam from stored muons
  - Very high statistics and low flux uncertainties
  - Search for short-baseline $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\mu$

D. Adey et al., JINST 12 07 (2017), P07020
Summary

- The results for eV-scale sterile neutrinos from accelerator experiments are very conflicted
  - Very strong tension for the eV^2 sterile neutrino hypothesis

- Excesses seen in (some) appearance experiments that can be analysed under a sterile neutrino hypothesis

- Many null results from both appearance and disappearance searches

- Some very high precision searches coming up in the (near) future