Sterile neutrino oscillation at a neutrino factory

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1. Four flavor neutrino
   1.1. Four flavor neutrino with LSND

(2+2) scheme

Maltoni et al, hep-ph/0405172

(3+1) scheme

Excluded by solar $\nu$ and atm $\nu$ ($4.9\sigma$)

Strongly disfavored by SBL disappearance data ($3.1\sigma$)
1.2.1. Four flavor neutrino without LSND

\[ U = U(\theta_{34})U(\theta_{24})U(\theta_{23}, \delta_3)U(\theta_{14})U(\theta_{13}, \delta_2)U(\theta_{12}) \]

\( \theta_{14} \) and \( \theta_{24} \) are small.

In contrast, Large \( \theta_{34} \) is allowed

Donini-Maltoni-Meloni-Migliozzi-Terranova
arXiv:0704.0388v2
1.2.2. Sensitivity limit at the CNGS/OPERA

Large $\theta_{34}$ is still allowed

Nominal intensity of $4.5 \times 10^{19}$ pot/yr

Donini-Maltoni-Meloni-Migliozi-Terranova
arXiv:0704.0388v2
2. (3+1)scheme at Neutrino Factory

2.1. 1st order expansion of probabilities in matter

\[ \delta P_{\alpha\beta} = P^{(4-\text{flavor})}_{\alpha\beta} - P^{(3-\text{flavor})}_{\alpha\beta} \]

\[
\delta P_{e\mu} = O(s^2_{13}) \sim \delta P_{e\tau} \\
\delta P_{\mu\mu} = (A_n L) \sin^2 2\theta_{23} s_{24} s_{34} \cos \delta_3 \sin \frac{\Delta m^2_{31} L}{2E} \\
\delta P_{\mu\tau} = -\sin^2 \theta_{23} s^2_{34} \sin^2 \frac{\Delta m^2_{31} L}{4E} \\
+ \{ \sin 2\theta_{23} s_{24} s_{34} \sin \delta_3 - (A_n L) \sin^2 2\theta_{23} s_{24} s_{34} \cos \delta_3 \} \sin \frac{\Delta m^2_{31} L}{2E} \\
\]

\[ s_{13} \sim s_{14} \sim s_{24} \sim s^2_{34} \]

\[ A_n = \frac{\sqrt{2}}{2} G_F n_n \]

Ve decouples!!
2.2. Set up

\[ P(\nu_\mu \rightarrow \nu_\mu) \]

\[ P(\nu_\mu \rightarrow \nu_\tau) \]

Set up:

- Relevant

<table>
<thead>
<tr>
<th>[ 2 \times 10^{20} ] muon decay / yr \times 4 yr / baseline</th>
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<tbody>
<tr>
<td>[ L=3000\text{km}, 7500\text{km} ]</td>
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- A maximal muon energy = 50 GeV

- Hybrid-emulsion / Magnetized iron calorimeter of 50 kton
  “HYBRID-MIND”

- No background / No systematic errors

- 100\% efficiency for both \( \varepsilon_\mu \) and \( \varepsilon_\tau \)

  \[ \downarrow \downarrow \]

  In reality \( \sim 90\% \sim 25\% \)

Input:

- \( \Delta m^2_{41} > 0.1\text{eV}^2 \)

- No CP phases

Ref. Cervera @ GOLDEN'07 for HYBRID-MIND;
De Lellis @ GOLDEN'07 for MAGNETIZED ECC

VERY PRELIMINAR ANALYSIS
2.3. Sensitivity in $\theta_{13}$, $\theta_{14}$, $\theta_{24}$ and $\theta_{34}$

Very low sensitivity to $\theta_{13}$ and $\theta_{14}$

High sensitivity in $\theta_{24}$ and $\theta_{34}$

1). Highest sensitivity in $\theta_{34}$ from the 7500km baseline

2). Highest sensitivity in $\theta_{24}$ from the 3000km baseline

$\nu_e$ decouples !! However, similar results marginalizing on $\theta_{13}$ and $\theta_{14}$
2.4. Contribution of $P(\nu_\mu \rightarrow \nu_\mu)$ and $P(\nu_\mu \rightarrow \nu_\tau)$ at 3000km

- $\nu_\mu \rightarrow \nu_\tau$
  - Sensitive to both $\theta_{24}$ and $\theta_{34}$
- $\nu_\mu \rightarrow \nu_\mu$
  - No sensitivity to $\theta_{34}$, only to $\theta_{24}$
2.5. Contribution of $P(\nu_\mu \rightarrow \nu_\mu)$ and $P(\nu_\mu \rightarrow \nu_\tau)$ at 7500km

Sensitivity to both $\theta_{24}$ and $\theta_{34}$

$\nu_\mu \rightarrow \nu_\tau$

$\nu_\mu \rightarrow \nu_\mu$

Sensitivity to both $\theta_{24}$ and $\theta_{34}$

90%CL

$\Theta_{34}=25 \succ \Theta_{24}=10 \succ \Theta_{34}=25$

$P_{\mu\tau}$

3-flavor

4-flavor

$\Theta_{24}=10 \Box \Theta_{34}=25 \Box$

$P_{\mu\mu}$

3-flavor

4-flavor

$\Theta_{24}=10 \Box \Theta_{34}=25 \Box$
3. Summary

- Golden and Silver channels are not optimal to study 3+1 sterile neutrinos. $\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_\tau$ are the relevant channels.

- We have performed a preliminary analysis at a two-baseline (L=3000km+7500km) 50GeV nufact with ideal HYBRID-MIND detectors (no background and 100% efficiency).

- $\theta_{34}$ sensitivity down to $\sim 4 \degree$ and $\theta_{24}$ sensitivity down to $\sim 1 \degree$ at 90%CL.

  - Highest sensitivity in $\theta_{34}$ from the 7500km baseline and Highest sensitivity in $\theta_{24}$ from the 3000km baseline.
  - Highest sensitivity in $\theta_{24}$ from the $\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_\tau$ channels at 3000km.
  - Highest sensitivity in $\theta_{34}$ from the $\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_\tau$ channels at 7500km.
  - The channel $\nu_\mu \rightarrow \nu_\tau$ has a high sensitivity in $\theta_{34}$ and $\theta_{24}$ at both 3000km and 7500km, even though the event number is not large.

- The $\nu_\mu \rightarrow \nu_\mu$ channel alone gives $\theta_{24} \leq 1 \degree$ and $\theta_{34} \leq 5 \degree$ at 90%CL.

- It is very important to have a reasonable efficiency for $\tau$ to improve on $\theta_{24}$, $\theta_{34}$ combination.