Probing Source and Detector NSIs at ESSvSB

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arXiv:1507.02868 - Mattias Blennow, Sandhya Choubey, Tommy Ohlsson, SR
Outline

- Non-standard neutrino interactions: NSIs
- The proposed ESSνSB experiment
- Neutrino oscillations with NSIs
- Results of simulations
- Conclusions
In the Standard Model, non-standard neutrino interactions: NSIs

\[ \mathcal{L}_{CC} = (\bar{\ell}_\alpha \gamma^\mu P_L \nu_\alpha)(\bar{f} \gamma_\mu P_L f') \]

\[ \mathcal{L}_{NC} = (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha)(\bar{f} \gamma_\mu P_L f') \]
In the Standard Model,

\[ \mathcal{L}_{\text{CC}} = (\bar{\ell}_\alpha \gamma^\mu P_L \nu_\alpha)(\bar{f} \gamma_\mu P_L f') \]

\[ \mathcal{L}_{\text{NC}} = (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha)(\bar{f} \gamma_\mu P_L f') \]

With new physics, we could have

\[ \mathcal{L}_{\text{CC}} = (\bar{\ell}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{f} \gamma_\mu P_{L,R} f') \]

\[ \mathcal{L}_{\text{NC}} = (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{f} \gamma_\mu P_{L,R} f') \]
Non-standard neutrino interactions: NSIs

- In the Standard Model,

\[ \mathcal{L}_{CC} = (\ell \gamma^\mu P_L \nu \bar{\ell} \gamma^\mu P_L f') \]

\[ \mathcal{L}_{NC} = (\nu \gamma^\mu P_L \nu \bar{f} \gamma^\mu P_L f') \]

- With new physics, we could have

\[ \mathcal{L}_{CC} = (\ell \gamma^\mu P_L \nu \bar{\ell} \gamma^\mu P_L, R f') \]

\[ \mathcal{L}_{NC} = (\nu \gamma^\mu P_L \nu \bar{f} \gamma^\mu P_L, R f') \]

production, detection

propagation
The proposed ESSνSB experiment

- European Spallation Source (ESS): under construction in Lund, Sweden
- Proposal to use the proton beam to produce a beam of neutrinos – peak energy 250 MeV
- Possible site for detector: mine in Garpenberg, Sweden – 540 km
- The mine can host a MEMPHYS-like Water Cerenkov detector

1309.7022: Baussan et al.
For a 540 km baseline, the second oscillation maximum (which is sensitive to $\delta$) is at 400 MeV.

The peak energy of the ESS$\nu$SB unoscillated spectrum lies at this energy, giving this experiment good sensitivity to $\delta$. 
ESS$\nu$SB

1406.2219: Agarwalla, Choubey, Prakash
Question 1: How will these results be affected by NSIs?

Question 2: Can we use ESS\nuSB to measure NSIs?

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- Question 1: How will these results be affected by NSIs?
- Question 2: Can we use ESSνSB to measure NSIs?

We have written a GLoBES-compatible probability engine and used it in conjunction with MonteCUBES to simulate this experiment.
Propagation NSIs are only relevant for large matter effects and high energy. Therefore we only consider source and detector NSIs here.

\[ |\nu^s_\alpha\rangle = |\nu_\alpha\rangle + \sum_{\gamma=e,\mu,\tau} \epsilon^{s}_{\alpha\gamma} |\nu_\gamma\rangle \quad ; \quad \langle \nu^d_\beta | = \langle \nu_\beta | + \sum_{\gamma=e,\mu,\tau} \epsilon^{d}_{\beta\gamma} \langle \nu_\gamma | \]

Since ESSνSB will only observe \( \nu_\mu \to \nu_\mu \) and \( \nu_\mu \to \nu_e \) channels, the relevant NSI parameters are

\[
\begin{pmatrix}
\epsilon^{s}_{ee} & \epsilon^{s}_{e\mu} & \epsilon^{s}_{e\tau} \\
\epsilon^{s}_{\mu e} & \epsilon^{s}_{\mu\mu} & \epsilon^{s}_{\mu\tau} \\
\epsilon^{s}_{\tau e} & \epsilon^{s}_{\tau\mu} & \epsilon^{s}_{\tau\tau}
\end{pmatrix}
\quad ; \quad
\begin{pmatrix}
\epsilon^{d}_{ee} & \epsilon^{d}_{e\mu} & \epsilon^{d}_{e\tau} \\
\epsilon^{d}_{\mu e} & \epsilon^{d}_{\mu\mu} & \epsilon^{d}_{\mu\tau} \\
\epsilon^{d}_{\tau e} & \epsilon^{d}_{\tau\mu} & \epsilon^{d}_{\tau\tau}
\end{pmatrix}
\]
Existing knowledge

\[
\begin{align*}
|\varepsilon^{s}_{\mu e}| < 0.026, & \quad |\varepsilon^{s}_{\mu\mu}| < 0.078, & \quad |\varepsilon^{s}_{\mu\tau}| < 0.013 \\
|\varepsilon^{d}_{ee}| < 0.041, & \quad |\varepsilon^{d}_{\mu e}| < 0.025, & \quad |\varepsilon^{d}_{\tau e}| < 0.041 \\
|\varepsilon^{d}_{e\mu}| < 0.026, & \quad |\varepsilon^{d}_{\mu\mu}| < 0.078, & \quad |\varepsilon^{d}_{\tau\mu}| < 0.013
\end{align*}
\]

0907.0097: Biggio, Blennow, Fernandez-Martinez

For a physical understanding of the oscillations, we refer to the analytical expressions in the presence of NSIs

0708.0152: Kopp, Lindner, Ota, Sato
Interplay of NSI parameters with $\delta$
Worsening of $\delta$-precision because of NSIs
Salient features:

- Same features seen across all $\theta_{23}$
- $\theta_{23}$-precision is largely unaffected by NSIs
- Worsening of $\delta$-precision is most for $\delta = 180$
- Worsening of precision is at most twice as bad: The measurement of $\delta$ at ESS$\nu$SB is quite robust against NSIs
Over-optimistic precision in $\delta$ due to “ignorance” about the existence of NSIs
Limits on NSI parameters from ESSνSB
## Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Realistic limits</th>
<th>Optimistic limits</th>
<th>Existing limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon^s_{\mu e}$</td>
<td>(-0.024, 0.025)</td>
<td>(-0.014, 0.013)</td>
<td>0.026</td>
</tr>
<tr>
<td>$\varepsilon^s_{\mu \mu}$</td>
<td>(-0.27, 0.27)</td>
<td>(-0.25, 0.27)</td>
<td>0.078</td>
</tr>
<tr>
<td>$\varepsilon^s_{\mu \tau}$</td>
<td>(-0.040, 0.040)</td>
<td>(-0.040, 0.037)</td>
<td>0.013</td>
</tr>
<tr>
<td>$\varepsilon^d_{ee}$</td>
<td>(-0.13, 0.15)</td>
<td>(-0.13, 0.15)</td>
<td>0.041</td>
</tr>
<tr>
<td>$\varepsilon^d_{e\mu}$</td>
<td>(-0.080, 0.087)</td>
<td>(-0.082, 0.082)</td>
<td>0.026</td>
</tr>
<tr>
<td>$\varepsilon^d_{\mu e}$</td>
<td>(-0.025, 0.024)</td>
<td>(-0.014, 0.013)</td>
<td>0.025</td>
</tr>
<tr>
<td>$\varepsilon^d_{\mu \mu}$</td>
<td>(-0.27, 0.28)</td>
<td>(-0.27, 0.25)</td>
<td>0.078</td>
</tr>
<tr>
<td>$\varepsilon^d_{\tau e}$</td>
<td>(-0.11, 0.10)</td>
<td>(-0.11, 0.12)</td>
<td>0.041</td>
</tr>
<tr>
<td>$\varepsilon^d_{\tau \mu}$</td>
<td>(-0.038, 0.040)</td>
<td>(-0.033, 0.029)</td>
<td>0.013</td>
</tr>
</tbody>
</table>
Results

Role of the near detector, and systematics
Conclusions

- Worsening of precision in $\delta$ due to presence of NSIs is at most by a factor of 2, i.e. The measurement of $\delta$ at ESS$\nu$SB is rather robust to the presence of NSIs.

- Not accounting for NSIs gives a slightly over-optimistic precision in $\delta$.

- ESS$\nu$SB can impose strong bounds on $\varepsilon^s_{\mu e}$ and $\varepsilon^d_{\mu e}$, which are stronger than current bounds.

- Using the near detector improves the precision in $\delta$. 