Search for Lorentz Invariance Violation and Non Standard Interactions in Neutrino physics

Vito Antonelli *, Marco Danilo Claudio Torri, Lino Miramonti

INFN, Sezione di Milano
Plan of the talk

- **INTRODUCTION**
  - Study of “exotic” effects: Lorentz Invariance Violation (LIV) and Non Standard neutrino Interactions (NSI), exploiting the potentialities of present and forthcoming neutrino experiments (Neutrino Telescopes, JUNO, LBL accelerator experiments, HyperKamiokande)

- **HMSR MODEL**
  - Possibility of introducing LIV effects in oscillation preserving space time isotropy

- **NEUTRINO OSCILLATION PROBABILITY IN PRESENCE OF LIV**
  - Milestones of the analysis and phenomenological opportunities

- **NEUTRINO OSCILLATION PROBABILITY IN PRESENCE OF NSI**
New approach: HMSR (Homogeneously Modified Special Relativity) Model preserving isotropy

(Antonelli, Miramonti, Torri, EPJC78 (18) n.8, 667; Torri, Antonelli, Miramonti, EPJC79 (19) no.9, 808,1)

- Internal **gauge symmetry** $SU(3) \otimes SU(2) \otimes U(1)$ preserved
- **No new interactions** or exotic particles
- **Modifications** limited to free particle kinematics
- **LIV corrections** and modified Lorentz transformations preserving isotropy

**Important experimental advantage** (possibility of full data collection with no need to select a preferred reference frame)

**LIV impact on neutrino oscillation**: modifications of oscillation probability (with different $E$ dependence) relevant at high energies.
Isotropic LIV corrections to neutrino oscillations

- Isotropic LIV, modified dispersion relations: $E_i^2 - \|\mathbf{p}_i\|^2 = m_i^2$

- Different LIV corrections for $\neq$ flavors ($\delta_{ij} = \varepsilon_i - \varepsilon_j \neq 0$) modify the $\nu$ flavor oscillation probabilities get modified: new phase in the $\sin^2$ term argument:

\[
\sin^2 \left( \left( m_i^2 - m_j^2 \right) x \frac{L}{2E} + \frac{\delta_{ij}}{2} x L E \right)
\]

- By means of different phenomenological analyses: constraints on $\delta_{ij}$ values


---

**Phenomenological opportunities**

- **High E neutrinos** $E$ from TeV to PeV @ Neutrino Telescopes (ANTARES, KM3NET and IceCube)

- **Ultra high E cosmic neutrinos** (i.e. $E \geq EeV$ neutrinos investigated by Auger)

- **Medium and high E atmospheric neutrinos** (Results from SuperKamiokande; JUNO, ... in future HyperKamiokande)

- **Possible investigation for solar $\nu$** (eventual impact on MSW resonance)

(See SNO talk; JUNO)
Non Standard neutrino Interactions (NSI)

- Search for deviations from the standard oscillation pattern, induced by new interaction terms in the Lagrangian. Possible tests in LBL accelerator, atmospheric (see SuperK, Smy’s talk), reactors and mainly solar neutrino experiments.

- Connection with theories Beyond the Standard Model and Dark Matter searches

- Solar neutrinos. Consistency tests of the LMA solution, by means of spectrum analysis and day-night asymmetry: $^7\text{Be}$ contribution (recently Borexino) and $^8\text{B}$ in the transition region between vacuum and matter oscillations (results from SNO and, mainly SuperK. JUNO very promising for high statistics, low E threshold and unprecedented energy resolution)

Constraints on Flavor-Diagonal Non-Standard Neutrino Interactions

(mainly $\varepsilon_{ee}$ and $\varepsilon_{\tau\tau}$). Possible extension to non diagonal interaction terms.
**NSI and MSW modification: 3 flavor analysis**

**Full 3 flavor analysis** (without usual approximation). Oscillation probability in presence of NSI

\[ P_{ee} \] from 1 keV to 10 GeV. Log scale

Interesting region for vacuum to matter MSW transition

Our 3 flavor analysis

Taken from Borexino Coll. JHEP 02 (2020) 38
MSW modification with NSI in 3 flavors analysis

- Differential spectrum given by:

\[
\frac{dN(T)}{dT} = \int_{E_{MIN}}^{E_{MAX}} \sum_{\alpha} \left[ \phi_{\nu\alpha}(E_{\nu}) P_{e\alpha}(E_{\nu}) \frac{d\sigma_{e\alpha}(T)}{dT} \right] dE_{\nu}
\]

\[
d\sigma_{e\alpha}(T) = \frac{2}{\pi} G_F^2 m_e \left[ \tilde{g}_{\alpha L}^2 + \tilde{g}_{\alpha R}^2 \left( 1 - \frac{T}{E_{\nu}} \right)^2 - \tilde{g}_{\alpha L} \tilde{g}_{\alpha R} \frac{m_e T}{E_{\nu}^2} \right]
\]

The \(\tilde{g}_{\alpha L}, \tilde{g}_{\alpha R}\) coupling constants include the NSI parameters

Plot of the expected (oscillated) events divided by the unoscillated one for different \(\varepsilon_{e\alpha}\) values (for \(E\) region from 3 to 15 MeV)

Black curve: Standard case \(\varepsilon_{eL} = 0\)
Green: \(\varepsilon_{eL} = +0.2\)
Yellow: \(\varepsilon_{eL} = -0.2\)
Red: \(\varepsilon_{eL} = -0.5\)

The analysis for specific experimental situations (including resolution, efficiency, background, ...) is in progress, in collaboration also with M. Magoni. →

Interesting opportunities
Thanks

- Thanks for the attention and many thanks to the organizers, for their huge efforts

......

...... Looking forward to returning to normal life