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

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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** →

- **NEUTRINO OSCILLATION PROBABILITY IN PRESENCE OF NSI** →

Milestones of the **analysis and phenomenological opportunities**

Lorentz Invariance Violation (LIV) and neutrino physics

- ❑ **Neutrino physics** ideal playground to search for **LIV effects** (mainly studying oscillation)
- ❑ Rich phenomenology in **anisotropic scenario**. For instance Standard Model Extension (**SME**) by Colladay, Kostelecky et al.; often **connected with CPT violation** (*See Symmetry* 12 (2020) 11, 182 for a review)

❑**New approach: HMSR** (Homogeneousy 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) ⊗ SU(2) ⊗ 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**: $E_i^2 - \|\vec{p}_i\|^2\,(1 - \varepsilon_i) = m_i^2$

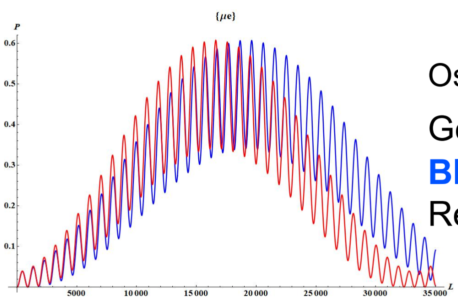
Different LIV corrections for ≠ flavors ($\delta_{ij} = \varepsilon_i - \varepsilon_j \neq 0$) ⟹ the ν flavor **oscillation probabilities get modified**: new *phase* in the sin² term argument:

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

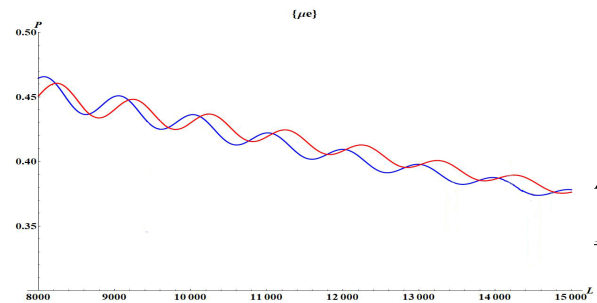
⟵ **LIV correction** (proportional to δ_{ij})

- By means of different **phenomenological analyses**: constraints on δ_{ij} values

(V. A., L. M., M.D.C. T. **EPJC 78 (2018) n.8, 667;** M.T. **Universe2020, 6(3),37**; V.A., L.M.,G. Ranucci **Universe2020,6(4),52)**



Osc.prob. $\nu_\mu \rightarrow \nu_e$ E_ν=1 GeV $\delta_{32} = \delta_{21} = 1x10^{-23}$
Blue = LIV ;
Red = No LIV



Integrated osc. prob. from 1 to 100 GeV for $\delta_{21} = 5\,x\,10^{-25}$

$$\frac{\int_{E\,min}^{E\,max} \Phi_\nu(E) P_{\nu_\mu \to \nu_e}(E)\, dE}{\int_{E\,min}^{E\,max} \Phi_\nu(E)\, dE}$$

Phenomenological opportunities

- **High E neutrinos** E from TeV to PeV @ Neutrino Telescopes (ANTARES, KM3NET and IceCube)
- **Ultra high E cosmic neutrinos** (i.e. E ≥ EeV neutrinos investigated by Auger)
- **Medium and high E atmospheric neutrinos** (Results from SuperKamiokande; JUNO, … in future HyperKamiokande)
- **Possible investigation for solar ν** (eventual impact on MSW resonance) (See SNO talk; JUNO)

Non Standard neutrino Interactions (NSI)

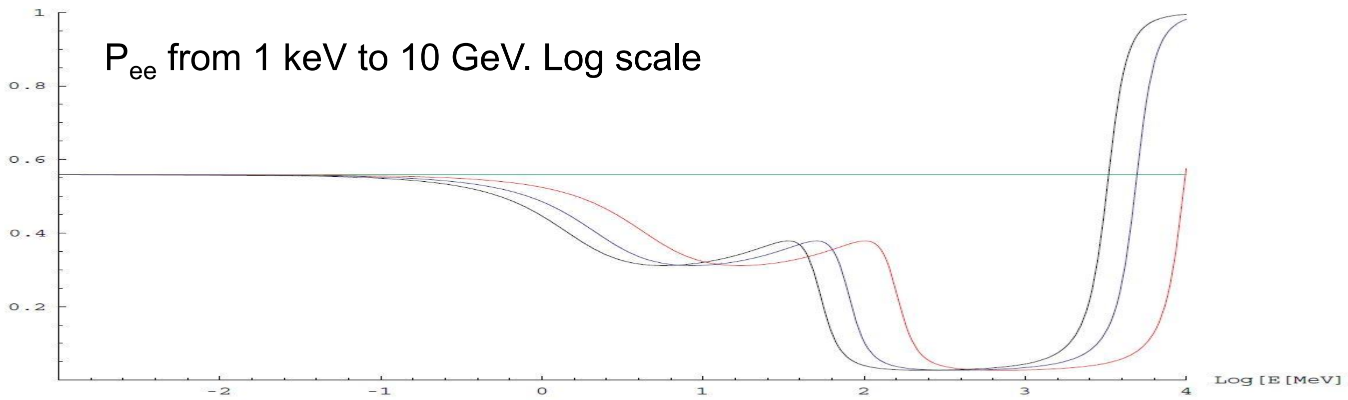
- Search for **deviations from** the **standard oscillation pattern**, induced by **new interaction tems** in the Lagrangian. Possible tests in **LBL accelerator, atmospheric** (see **SuperK**, Smy's talk), **reactors** and mainly **solar neutrino experiments.**
- Connection with theories Beyond the Standard Model and Dark Matter searches
- Solar neutrinos. **Consistency tests of the LMA solution**, by means of spectrum analysis and day-night asymmetry: ^{7}**Be** contribution (recently Borexino) and **^{8}B in the transition region between vacuum and matter oscillations** **(**results from **SNO** and, mainly **SuperK**. **<u>JUNO very promising</u>** for high statistics, low E threshold and unprecedented energy resolution)

➡ **Constraints on Flavor-Diagonal Non-Standard Neutrino Interactions**

(mainly ε_{ee} and $\varepsilon_{\tau\tau}$). **Possible extension to non diagonal interaction terms.**

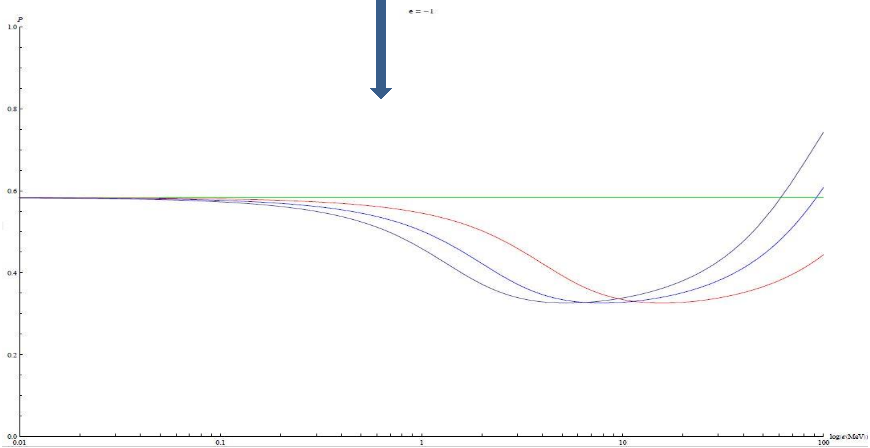
NSI and MSW modification: 3 flavor analysis

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

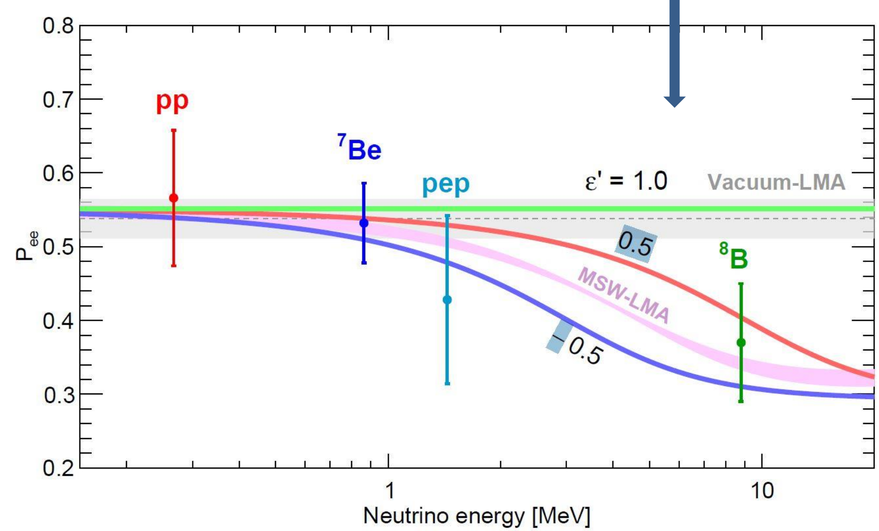


Interesting region for vacuum to matter MSW transition

Our 3 flavor analysis



Taken from Borexino Coll.
JHEP 02 (2020) 38



MSW modification with NSI in 3 flavors analysis

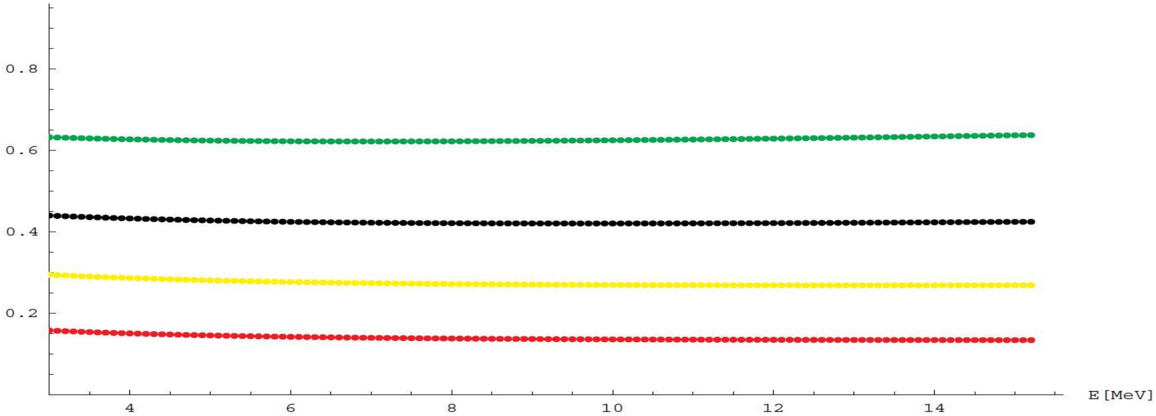
- **Differential spectrum** given by:

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

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

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 $\varepsilon_{\varepsilon\Lambda}$ values (for E region from 3 to 15 MeV)



Black curve: Standard case
ε_{eL} = 0
Green: ε_{eL} = +0.2
Yellow: ε_{eL} = - 0.2
Red : ε_{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

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….. Looking forward to returning to normal life