# Testing non-standard neutrino interactions in (anti)-electron neutrino disappearance experiments

**Mariano E. Chaves**, O.L.G. Peres and P.C. de Holanda

Instituto de Física Gleb Wataghin - Universidade Estadual de Campinas, Brazil

XVII INTERNATIONAL CONFERENCE ON TOPICS IN ASTROPARTICLE AND UNDERGROUND PHYSICS — TAUP 2021 VALENCIA — 26 August - 3 September 2021 — Online conference

## Summary

We investigate **scalar** and **tensor** non-standard interactions in reactors and solar neutrino production and detection. We consider:

- The formalism of **Quantum Field Theory** for neutrino oscillations [1];
- Only **beta decay** reactions (for both: solar and reactor neutrinos);
- Solar and reactor **oscillation experiments**;

## Introduction

We assume (anti-)neutrinos are produced in $\beta^{\pm}$ decay mediated by $W$ Boson and a new scalar or tensor interaction given by the **effective Lagrangian**:

$$L_{\rm NSI} = -\frac{2}{\sqrt{2}} G_F V_{ud} \Big\{ \frac{1}{2} [\epsilon_S]_{\alpha\beta} (\bar{u}d)(\bar{\ell}_\alpha P_L \nu_\beta) + \frac{1}{4} [\epsilon_T]_{\alpha\beta} (\bar{u}\sigma^{\mu\nu} P_L d)(\bar{\ell}_\alpha \sigma_{\mu\nu} P_L \nu_\beta) \Big\} + {\rm hc}\,. \quad (1)$$

The total number of events in the detector will be dependent on the amplitudes for the process as illustrated in Fig. 1. The summation of all diagrams under the coherence of massive neutrinos will generate oscillation and interference terms between the:

1. production and detection;
2. Standard Model and new interactions;

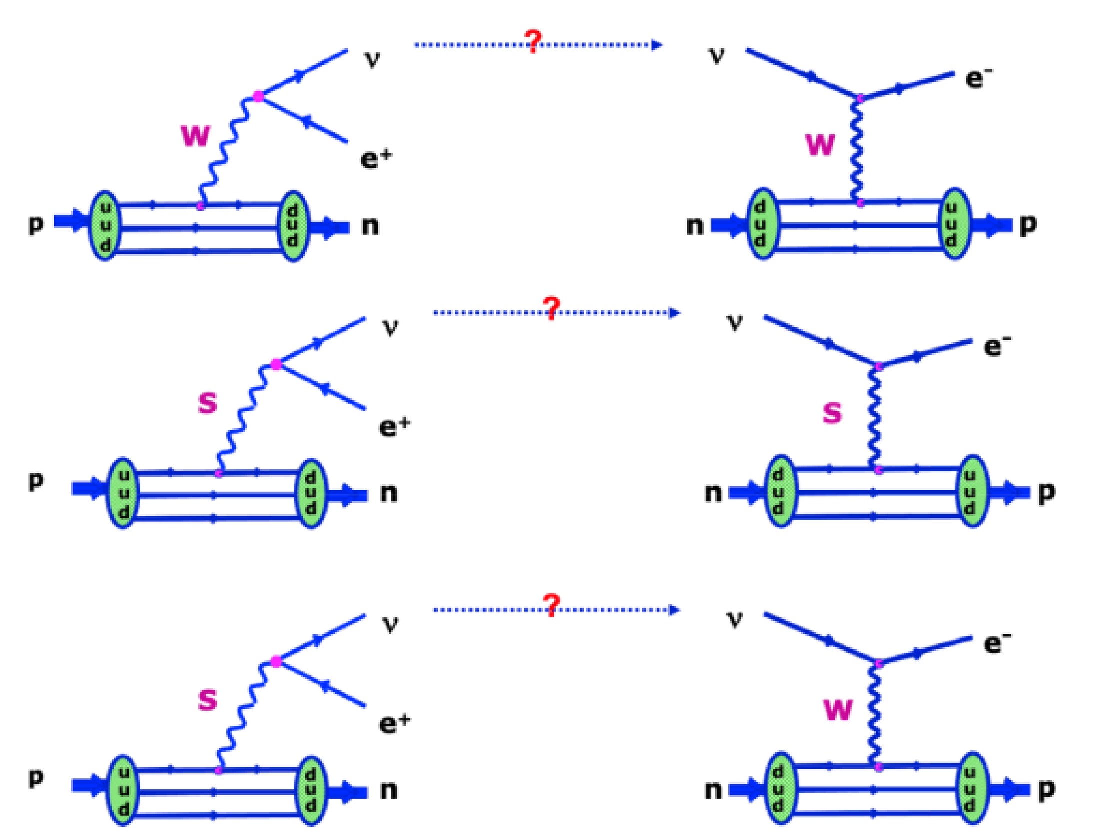


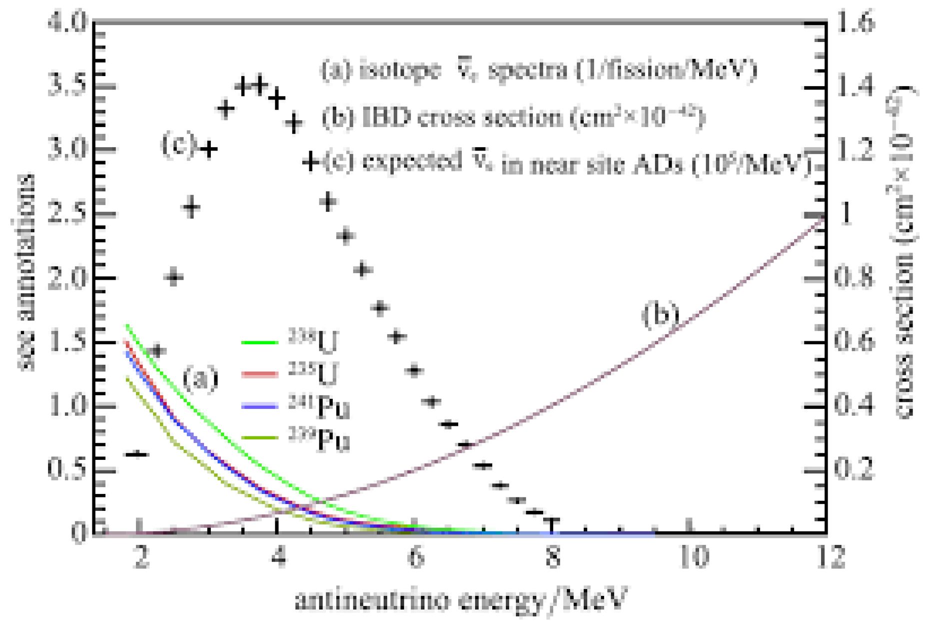

Figure 1: Diagram illustrating the processes used in this work.

## Reactor neutrinos

For reactor neutrinos, we considered the experiments:

- Daya Bay, RENO and Double Chooz (MBR);
- Kamland (LBR);

The neutrino reactor flux considered was the recent ab-initio neutrino flux.




## Solar neutrinos

For solar neutrinos, we use the data of

- the full spectral data from Super-Kamiokande phases I, III and IV;
- the combined analysis of all three SNO phases;
- Borexino and Homestake results;
- combined Gallex+GNO and SAGE data.

We consider NSI affects only the beta decay spectrum in the sun and the detection process:

$$\beta^+ : {}^A_Z N_i \to {}^A_{Z-1} N_f + e^+ + \nu_e, \quad \text{(production)}$$
$$\text{inv. } \beta^- : {}^A_Z N_i + \nu_e \to e^- + {}^A_{Z+1} N_f. \quad \text{(detection)}$$

## Important Result

We found a preference for **non-zero CP violation**, coming from both tensor and scalar interactions with a **significance that reaches** $1.7\sigma$ compared to the standard oscillation.

## Analysis

In our analysis, we define the effective NSI parameters $[\tilde{\epsilon}_X] \equiv [\epsilon_X] U(\theta_{23}, \delta)$, only the

$$[\tilde{\epsilon}_X]_{e\mu} = c_{23} [\epsilon_X]_{e\mu} - s_{23} [\epsilon_X]_{e\tau} e^{-i\delta},$$
$$[\tilde{\epsilon}_X]_{e\tau} = c_{23} [\epsilon_X]_{e\mu} e^{i\delta} + s_{23} [\epsilon_X]_{e\tau},$$

are important; $[\tilde{\epsilon}_X]_{e\mu}$ in the solar scale and $[\tilde{\epsilon}_X]_{e\tau}$ in the atmospheric scale. The analysis was made in groups: MBR, LBR and solar, see Fig. 2. Then, we combine the results in a global analysis summing each $\chi^2$ function.

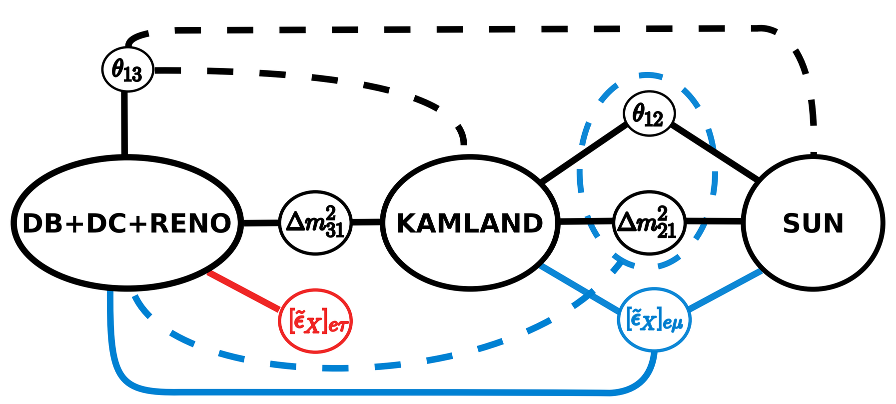



Figure 2: Only connected objects are important for each case.

## Results

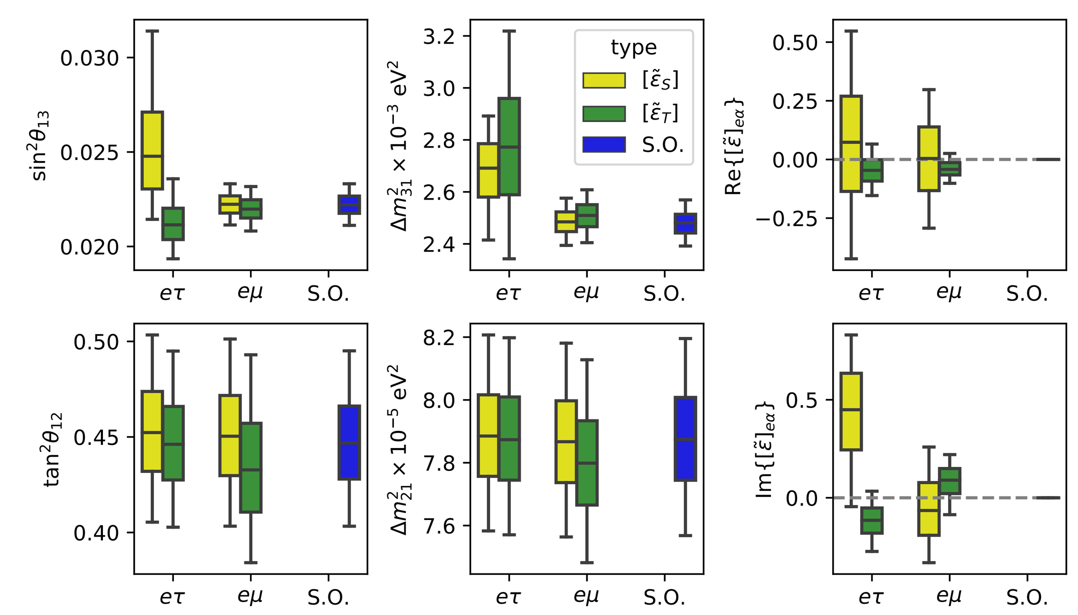


Figure 3: The whiskers were set to 90% C.L.

| | $([\tilde{\epsilon}_X]_{e\beta})$ | $(\chi^2_{\rm S.O.})_{\rm min} - \chi^2_{\rm min}$ |
|---|---|---|
| $[\tilde{\epsilon}_T]_{e\tau}$ | $-0.12^{+0.08}_{-0.10}$ | 1.4 ($1.2\sigma$) |
| $[\tilde{\epsilon}_S]_{e\tau}$ | $+0.62^{+0.23}_{-0.41}$ | 2.4 ($1.6\sigma$) |
| $[\tilde{\epsilon}_T]_{e\mu}$ | $-0.13^{+0.09}_{-0.07}$ | 2.8 ($1.7\sigma$) |
| $[\tilde{\epsilon}_S]_{e\mu}$ | $-0.16^{+0.31}_{-0.09}$ | 0.4 ($0.6\sigma$) |

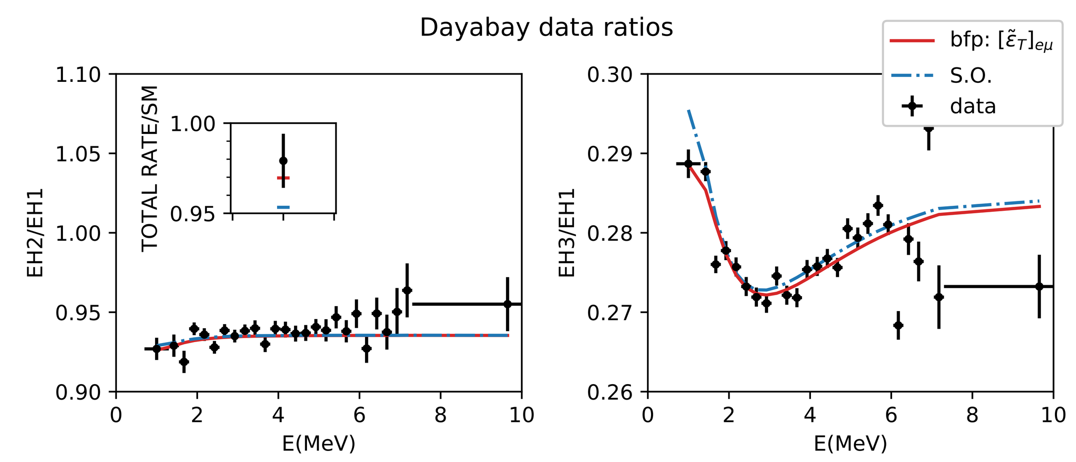
Table 1: Summary statistics of the global analysis.

## Conclusion

We found **new limits** on the NSI parameters $[\tilde{\epsilon}_X]_{e\alpha}$. The limits are presented in Fig. 2 at 90%C.L., and the statistical comparison with the Standard model is given in table 1 together with the value of the CP violation term. The improvement in the fit is due to a **non-zero CP violation** effect.

## Additional Information

1. When $[\tilde{\epsilon}_X]_{e\mu}$ is active, a CP violation from the solar scale affects the Daya Bay experiment making it sensitive to $\Delta m^2_{21}$ and $\theta_{12}$.
2. Most of the improvements in the fit comes from the Daya Bay low energy data:




## References

[1] A. Falkowski, M. González-Alonso, and Z. Tabrizi. *JHEP*, 11:048, 2020.

[2] M.E. Chaves, P.C. de Holanda, and O.L.G. Peres. arXiv:2106.15725 [hep–ph], 2021.

## Acknowledgements

M.E.C. is thankful for 140564/2018-7 funding from CNPQ and 88887.477371/2020-00 funding from CAPES.

## Contact Information

- Web: http://marianochaves.github.io
- Email: mchaves@ifi.unicamp.br

CAPES CNPq UNICAMP FAPESP