

IL NUOVO CIMENTO **39 C** (2016) 227
DOI 10.1393/ncc/i2016-16227-8

COLLOQUIA: IFAE 2015

Search for New Physics in reactor and accelerator experiments

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received 7 January 2016

Summary. — We consider two scenarios of New Physics: the Large Extra Dimensions (LED), where sterile neutrinos can propagate in a $(4 + d)$ -dimensional space-time, and the Non Standard Interactions (NSI), where the neutrino interactions with ordinary matter are parametrized at low energy in terms of effective flavour-dependent complex couplings $\varepsilon_{\alpha\beta}$. We study how these models have an impact on oscillation parameters in reactor and accelerator experiments.

1. – Details of the models

In both models we can consider the effect of New Physics (NP) as a perturbation of the Standard Model (SM) neutrino oscillation amplitude $\mathcal{A}(\nu_\alpha \rightarrow \nu_\beta) = \mathcal{A}_{\text{SM}}(\nu_\alpha \rightarrow \nu_\beta) + \delta\mathcal{A}(\nu_\alpha \rightarrow \nu_\beta)$. In the case of LED model this is due to the presence of a tower of massive extra sterile neutrinos that can mix with the ordinary SM neutrinos

$$(1) \quad \mathcal{A}_{\text{LED}}(\nu_\alpha \rightarrow \nu_\beta) = \sum_{j=1}^3 \sum_{k=0}^{\infty} U_{\alpha j} U_{\beta j}^* [W_j^{(k)}]^2 \exp\left[\frac{i(\lambda_j^{(k)})^2 L}{2ER^2}\right],$$

where $\lambda_j^{(0)} \simeq m_j R$, $\lambda_j^{(k)} \simeq k + m_j^2 R^2/k$ are the mass eigenstates and $(W_j^{(0)})^2 \simeq 1$, $(W_j^{(k)})^2 \simeq 2m_j^2 R^2/k^2$ are the matrix elements that connect the SM neutrino to the Kaluza-Klein modes, U is the PMNS matrix, m_j are the light neutrino masses and R is the radius of the largest compactified extra dimension. For the NSI scenario the correction to the SM amplitude is due to the fact that neutrinos at source and detector are a linear superposition of physical neutrino eigenstates

$$(2) \quad \mathcal{A}_{\text{NSI}}(\nu_\alpha \rightarrow \nu_\beta) = \left[\langle \nu | (1 + \varepsilon^d) \right]_{\beta\rho} \left[e^{-iHL} \right]_{\rho\sigma} \left[(1 + \varepsilon^s) |\nu \right]_{\sigma\alpha},$$

where H is the evolution operator, which in the mass basis neglecting matter effects reads $H_{\alpha\beta} = U_{\alpha j} \text{diag}\{0, \Delta m_{21}^2, \Delta m_{31}^2\}_{jk} (U^\dagger)_{k\beta} / 2E$.

TABLE I. – Best fit ($\pm 1\sigma$) and 3σ errors of the standard parameters obtained in the fit of T2K \oplus Daya Bay data, using the SM, LED and NSI probabilities. If two values are given, the upper one corresponds to Normal Ordering and the lower one to Inverted Ordering.

Parameter	SM		LED		NSI	
	Best-fit	3σ range	Best-fit	3σ range	Best-fit	3σ range
$ \Delta m_{31}^2 /10^{-3} \text{ eV}^2$	$2.51^{+0.06}_{-0.06}$	2.34–2.69	$2.53^{+0.07}_{-0.05}$	2.37–2.73	$2.56^{+0.06}_{-0.09}$	2.31–2.74
	$2.54^{+0.06}_{-0.06}$	2.37–2.73	$2.54^{+0.07}_{-0.07}$	2.35–2.71	$2.56^{+0.09}_{-0.08}$	2.32–2.77
$\sin^2 \theta_{23}/10^{-1}$	$5.3^{+0.4}_{-0.6}$	4.0–6.3	$5.3^{+0.4}_{-0.5}$	4.1–6.3	$5.2^{+0.6}_{-0.8}$	3.8–6.5
	$5.3^{+0.4}_{-0.5}$	4.1–6.2	$5.3^{+0.4}_{-0.5}$	4.1–6.3	$5.2^{+0.6}_{-0.8}$	3.9–6.5
$\sin^2 \theta_{13}/10^{-2}$	$2.3^{+0.3}_{-0.2}$	1.6–3.0	$2.3^{+0.2}_{-0.4}$	1.4–3.0	$3.9^{+0.4}_{-2.6}$	0.7–5.1
	$2.4^{+0.2}_{-0.3}$	1.6–3.0	$2.2^{+0.1}_{-0.1}$	1.3–2.9	$3.8^{+0.5}_{-2.6}$	0.7–5.1
δ/π	$1.53^{+0.33}_{-0.37}$	—	$1.47^{+0.35}_{-0.31}$	—	$1.65^{+0.55}_{-0.78}$	—
	$1.48^{+0.36}_{-0.35}$	—	$1.59^{+0.30}_{-0.36}$	—	$1.35^{+0.75}_{-0.49}$	—

2. – Statistical analysis and results

We use the T2K (28 events in channel $\nu_\mu \rightarrow \nu_e$ and 120 events in $\nu_\mu \rightarrow \nu_\mu$ [1]) and 217 days of $\bar{\nu}_e \rightarrow \bar{\nu}_e$ Daya Bay data [2] in order to: study how the standard oscillation parameters are modified by the NP and constrain the parameter space of the LED and NSI models [3]. The statistical analysis of the data has been performed using a modified version of the GLOBES software [4]. We consider the effects of experimental systematics with a pull method in the χ^2 analysis. The SM quantities θ_{13} , θ_{23} , δ and Δm_{31}^2 are unconstrained, whereas for the solar angle and the solar mass difference we define gaussian priors: $\sin^2 \theta_{12} = (3.08 \pm 20\%) \times 10^{-1}$ and $\Delta m_{21}^2 = (7.54 \pm 5\%) \times 10^{-5} \text{ eV}^2$.

While the impact of LED on the best fit values and 1σ errors of the standard oscillation parameters is almost negligible, this is not the case for the NSI scenario, where the allowed values of θ_{13} and δ are different from the SM determination, see table I. In fact the 1σ confidence region for θ_{13} is roughly six as large as in the SM case. The situation is similar for the phase δ , where the presence of new phases from the NSI complex couplings reduces the sensitivity and also the hints for a maximal CP violation.

As for the bounds on the parameters of the LED and NSI models at 2σ CL (1 dof), we have found the following results:

- in the combined analysis of the T2K \oplus Daya Bay data we obtain $R \leq 0.60 \mu\text{m}$ for Normal Ordering and $R \leq 0.17 \mu\text{m}$ for Inverted Ordering,
- for $|\varepsilon_{e\mu}| < 4.85 \times 10^{-3}$ and $|\varepsilon_{\mu e}^s| < 6.28 \times 10^{-3}$ (for $\delta = 0$); $|\varepsilon_{e\mu}| < 9.94 \times 10^{-3}$ and $|\varepsilon_{\mu e}^s| < 9.96 \times 10^{-3}$ (for $\delta = \pi$).

REFERENCES

- [1] ABE K. *et al.* (T2K COLLABORATION), *Phys. Rev. Lett.*, **112** (2014) 061802, ABE K. *et al.* (T2K COLLABORATION), *Phys. Rev. Lett.*, **112** (2014) 181801.
- [2] AN F. P. *et al.* (DAYA BAY COLLABORATION), *Phys. Rev. Lett.*, **112** (2014) 061801.
- [3] DI IURA A., GIRARDI I. and MELONI D., *J. Phys. G*, **42** (2015) 6, 065003.
- [4] HUBER P., LINDNER M. and WINTER W., *Comput. Phys. Commun.*, **167** (2005) 195; HUBER P., KOPP J., LINDNER M., ROLINEC M. and WINTER W., *Comput. Phys. Commun.*, **177** (2007) 432.