PROCEEDINGS OF SCIENCE

Neutrino oscillations in presence of large extra dimensions at JUNO and TAO

Christoph Andreas Ternes[a,*]

[a] *INFN, Sezione di Torino, Via P. Giuria 1, I–10125 Torino, Italy*

E-mail: ternes@to.infn.it

I discuss the sensitivity to parameters describing large extra dimensions (LED) at the next generation reactor experiment JUNO, in combination with its near detector TAO. I discuss the effect of systematic uncertainties on the sensitivity and also how well JUNO+TAO could measure LED parameters if large extra dimensions were present in nature.

**** The 22nd International Workshop on Neutrinos from Accelerators (NuFact2021) ****
**** 6–11 Sep 2021 ****
**** Cagliari, Italy ****

*Speaker

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

PoS(NuFact2021)142

1. Introduction

Neutrino oscillations is the leading mechanism that successfully explains neutrino flavor conversion. Neutrino oscillations have been observed by experiments measuring neutrinos from the Sun, Earth's atmosphere, nuclear reactors, and particle accelerators. The existence of neutrino oscillations implies that neutrinos are massive and mixed and provides a direct evidence of physics beyond the standard model.

Future neutrino oscillation experiments are expected to improve the current precision of the neutrino oscillation parameters and address the remaining unknowns discussed before. To fulfill this goals, large statistics and an unprecedented control of systematic uncertainties have to be achieved. The expected precision provides a unique avenue to probe different beyond the standard model scenarios that might produce sub-leading effects on top of the well established three-neutrino oscillation pattern.

We focus on the next generation reactor experiment JUNO (the Jiangmen Underground Neutrino Observatory) and its near detector TAO (the Taishan Antineutrino Observatory) and discuss its sensitivity to oscillation effects induced by Large Extra Dimensions (LED). The results presented in this proceedings are based on Ref. [1]. For the LED formalism in the context of neutrino physics we refer the interested reader to Refs. [2–4]. The simulation of the experiments follows the discussion presented in Refs. [5–8].

2. JUNO and TAO sensitivity to large extra dimensions

We first estimate the sensitivity of JUNO+TAO to the LED parameters. For this purpose, we create a fake set of data points without LED oscillations using the values of the standard neutrino oscillation parameters from Ref. [9]. We assume only normal neutrino mass ordering. The sensitivity to the LED parameters is obtained by marginalizing over the standard oscillation parameters.

The results for several sets of systematic uncertainties are shown in the left panel of Fig. 1. The blue line is obtained including several uncertainties related to the flux normalization of the different reactors and detectors. It is the minimal set of uncertainties that we consider in this work. We also performed several analyses with different flux shape uncertainties. This systematic has a very important effect on the sensitivity, as can be seen in the figure. The green, magenta and orange lines are obtained using a bin-to-bin shape uncertainty of 1%, 1.5% and 3% respectively. The black line is obtained leaving this systematic uncertainty completely free.

Considering the case with free (no) shape uncertainty, at 90% C.L. for 1 degree of freedom ($\Delta\chi^2$ = 2.71), the LED compactification radius R_{ED} has a sensitivity upper bound of 0.87 μm (0.35 μm). The bounds for the different systematic uncertainties considered in this section are summarized in Tab. 1. These numbers show again the importance of the systematic uncertainties for probing the LED parameters.

In the right panel of Fig. 1, we compare the JUNO+TAO sensitivity corresponding to 1% shape uncertainty (solid green line) with the estimated sensitivities of KATRIN [10] (dotted-dashed blue line), DUNE [11, 12] (dashed purple line), and with the sensitivity of MINOS [13] (dotted red line).

PoS(NuFact2021)142

Case	no shape	1.0% shape	1.5% shape	3.0% shape	free shape
Bound (90% C.L.)	0.35 μm	0.57 μm	0.65 μm	0.81 μm	0.87 μm

Table 1: JUNO+TAO 90% C.L. sensitivity upper bound (1 degree of freedom) on the compatification radius R_{ED} for different values of the flux-shape uncertainty.

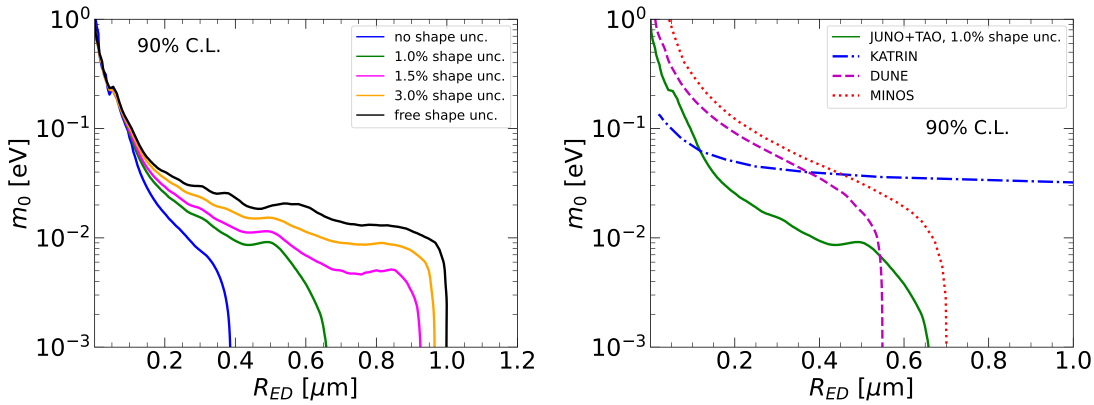

Figure 1: Left: JUNO+TAO 90% C.L. sensitivity in the R_{ED}-m_0 plane for several choices of systematic uncertainties. Right: Comparison of the JUNO+TAO sensitivity with those of KATRIN [10], DUNE [11, 12] and MINOS [13].

As can be seen in Fig. 1, JUNO+TAO can set competitive bounds on the LED parameters, which, depending on the treatment of systematic uncertainties, can be more stringent than those from the other experiments. For the 1% flux-shape systematic uncertainty, the JUNO+TAO sensitivity is compatible with the DUNE sensitivity showing a synergy of future reactor and accelerator neutrino experiments.

3. Measuring LED parameters

Next, we discuss how well JUNO+TAO can measure values of the LED parameters that are consistent with a LED explanation of the reactor and Gallium anomalies [14]. For this purpose, we generate a simulated data set with the same values of the standard oscillation parameters considered previously (the ones from Ref. [9]) and the following specific values of the LED parameters, $R_{ED} = 0.5\ \mu$m and $m_0 = 0.03$ eV. We assume the neutrino mass ordering to be normal. Using this benchmark point one can explain the reactor antineutrino anomaly [15] (see Ref. [16] for a recent reevaluation) and the Gallium neutrino anomaly [17–20] as a result of LED oscillations [14].

As can be seen, relatively small closed contours at 2σ can be obtained with this benchmark point. Indeed, the expected sensitivity to measure the LED parameters is at a similar level ($\lesssim 1\%$) as the expected sensitivity to the standard neutrino oscillation parameters [7]. The JUNO+TAO sensitivity with 1% shape uncertainty (full green line) is also shown in Fig. 2 in comparison with the allowed region from the reactor and Gallium anomalies, extracted from Ref. [14] (blue line).

We considered for illustration only one point in the region of the LED parameters inside of the blue contour in Fig. 2, that is indicated by the LED explanation of the reactor and Gallium anomalies [14]. However, it should be noted that basically all of the region inside of the blue contour

PoS(NuFact2021)142

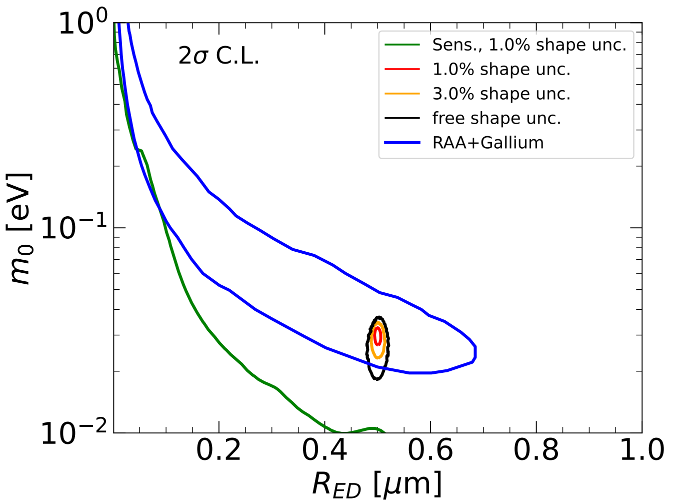

Figure 2: 2σ regions obtained from the analysis of fake data in presence of LED oscillations for a several assumptions on the flux shape uncertainty (red, orange and black lines), in comparison with the region allowed from reactor and Gallium anomalies (blue). We also show the JUNO+TAO sensitivity (green line) to emphasize that JUNO+TAO can test all of the values preferred by the reactor and Gallium anomalies.

lies within the sensitivity reach of JUNO+TAO. Therefore, it is plausible that a similar precision of the JUN+TAO determination of the LED parameters can be obtained for any benchmark point compatible with the LED explanation of the reactor and Gallium anomalies.

References

[1] V. S. Basto-Gonzalez, D. V. Forero, C. Giunti, A. A. Quiroga and C. A. Ternes, *Short-baseline oscillation scenarios at JUNO and TAO*, 2112.00379.

[2] K. R. Dienes, E. Dudas and T. Gherghetta, *Neutrino oscillations without neutrino masses or heavy mass scales: A Higher dimensional seesaw mechanism*, Nucl. Phys. B **557** (1999) 25 [hep-ph/9811428].

[3] N. Arkani-Hamed, S. Dimopoulos, G. R. Dvali and J. March-Russell, *Neutrino masses from large extra dimensions*, Phys. Rev. D **65** (2001) 024032 [hep-ph/9811448].

[4] H. Davoudiasl, P. Langacker and M. Perelstein, *Constraints on large extra dimensions from neutrino oscillation experiments*, Phys. Rev. D **65** (2002) 105015 [hep-ph/0201128].

[5] JUNO collaboration, *Neutrino Physics with JUNO*, J. Phys. G **43** (2016) 030401 [1507.05613].

[6] IceCube-Gen2 collaboration, *Combined sensitivity to the neutrino mass ordering with JUNO, the IceCube Upgrade, and PINGU*, Phys. Rev. D **101** (2020) 032006 [1911.06745].

[7] JUNO collaboration, *JUNO Physics and Detector*, 2104.02565.

PoS(NuFact2021)142

[8] JUNO collaboration, *TAO Conceptual Design Report: A Precision Measurement of the Reactor Antineutrino Spectrum with Sub-percent Energy Resolution*, 2005.08745.

[9] P. F. de Salas, D. V. Forero, S. Gariazzo, P. Martínez-Miravé, O. Mena, C. A. Ternes et al., *2020 global reassessment of the neutrino oscillation picture*, *JHEP* **02** (2021) 071 [2006.11237].

[10] V. S. Basto-Gonzalez, A. Esmaili and O. L. G. Peres, *Kinematical Test of Large Extra Dimension in Beta Decay Experiments*, *Phys. Lett. B* **718** (2013) 1020 [1205.6212].

[11] C. A. Argüelles et al., *New opportunities at the next-generation neutrino experiments I: BSM neutrino physics and dark matter*, *Rept. Prog. Phys.* **83** (2020) 124201 [1907.08311].

[12] DUNE collaboration, *Prospects for beyond the Standard Model physics searches at the Deep Underground Neutrino Experiment*, *Eur. Phys. J. C* **81** (2021) 322 [2008.12769].

[13] MINOS collaboration, *Constraints on Large Extra Dimensions from the MINOS Experiment*, *Phys. Rev. D* **94** (2016) 111101 [1608.06964].

[14] P. A. N. Machado, H. Nunokawa, F. A. P. dos Santos and R. Z. Funchal, *Bulk Neutrinos as an Alternative Cause of the Gallium and Reactor Anti-neutrino Anomalies*, *Phys. Rev. D* **85** (2012) 073012 [1107.2400].

[15] G. Mention, M. Fechner, T. Lasserre, T. A. Mueller, D. Lhuillier, M. Cribier et al., *The Reactor Antineutrino Anomaly*, *Phys. Rev. D* **83** (2011) 073006 [1101.2755].

[16] C. Giunti, Y. F. Li, C. A. Ternes and Z. Xin, *Reactor antineutrino anomaly in light of recent flux model refinements*, 2110.06820.

[17] J. N. Abdurashitov et al., *Measurement of the response of a Ga solar neutrino experiment to neutrinos from an Ar-37 source*, *Phys. Rev. C* **73** (2006) 045805 [nucl-ex/0512041].

[18] M. Laveder, *Unbound neutrino roadmaps*, *Nucl. Phys. B Proc. Suppl.* **168** (2007) 344.

[19] C. Giunti and M. Laveder, *Short-Baseline Active-Sterile Neutrino Oscillations?*, *Mod. Phys. Lett. A* **22** (2007) 2499 [hep-ph/0610352].

[20] V. V. Barinov et al., *Results from the Baksan Experiment on Sterile Transitions (BEST)*, 2109.11482.

PoS(NuFact2021)142