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Nuclear Physics B 909 (2016) 1079–1103

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Checking T and CPT violation with sterile neutrino

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Received 16 February 2016; received in revised form 13 May 2016; accepted 23 May 2016

Available online 1 June 2016

Editor: Tommy Ohlsson

Abstract

Post LSND results, sterile neutrinos have drawn attention and motivated the high energy physics, astronomy and cosmology to probe physics beyond the standard model considering minimal $3+1$ (3 active and 1 sterile) to $3+\text{N}$ neutrino schemes. The analytical equations for neutrino conversion probabilities are developed in this work for $3+1$ neutrino scheme. Here, we have tried to explore the possible signals of T and CPT violations with four flavor neutrino scheme at neutrino factory. Values of sterile parameters considered in this analysis are taken from two different types of neutrino experiments viz. long baseline experiments and reactor+atmospheric experiments. In this work golden and discovery channels are selected for the investigation of T violation. While observing T violation we stipulate that neutrino factory working at 50 GeV energy has the potential to observe the signatures of T violation through discovery channel if sterile parameter values are equal to that taken from reactor+atmospheric experiments. The ability of neutrino factory for constraining CPT violation is enhanced with increase in energy for normal neutrino mass hierarchy (NH). Neutrino factory with the exposure time of 500 kt-yr will be able to capture CPT violation with $\delta c_{31} \geq 3.6 \times 10^{-23}$ GeV at 3σ level for NH and for IH with $\delta c_{31} \geq 4 \times 10^{-23}$ GeV at 3σ level.

1. Introduction

The standard model of particle physics considers neutrinos to be massless. Sudbury Neutrino Observatory [1,2] gave evidence of neutrino oscillations which was further confirmed by Kam-

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http://dx.doi.org/10.1016/j.nuclphysb.2016.05.021

LAND experiment [3]. This landmark research assigned mass to the neutrinos and gave a clear indication of new physics beyond the standard model. A simple stretch in the standard model was able to stand up with the mass of neutrino. In neutrino physics the standard three flavor neutrino oscillations can be explained with the help of six parameters namely θ_{12}, θ_{13}, θ_{23}, Δm^2_{12}, Δm^2_{31} and δ_{CP}. Amongst these six parameters, solar parameters (θ_{12}, Δm^2_{12}) and atmospheric parameters (θ_{23}, Δm^2_{31}) have been measured with high precision. Furthermore, Daya Bay and RENO reactor experiments have strongly constrained the value of mixing angle θ_{13}. Now we are in need of such neutrino experiments which can impose tight constraints on the value of δ_{CP} and mass hierarchy. Some anomalies popped up while observing appearance channel and disappearance channel of ν_e at LSND experiment. While observing $\bar{\nu}_\mu \to \bar{\nu_e}$ appearance channel, LSND [4–9] was the first experiment to publish evidence of a signal at $\Delta m^2 \sim 1$ eV^2. Later in 2002, MiniBooNE [10,11] checked the LSND result for $\nu_e \to \nu_\mu$ ($\bar{\nu}_e \to \bar{\nu}_\mu$) appearance channel. At MiniBooNE experiment, while observing the CCQE events rate through $\nu_e n \to e^- p(\bar{\nu}_e p \to e^+ n)$ above 475 MeV energy, no excess events were found but for energies < 475 MeV $\nu_e(\bar{\nu}_e)$ excess events were observed. In this way, MiniBooNE data supported the LSND result. The LEP data [12,13] advocates the number of weakly interacting light neutrinos, that couple with the Z bosons through electroweak interactions, to be 2.984 ± 0.008; thus closing the door for more than three active neutrinos. Hence, the heavy neutrino announced by LSND group should be different from these three active neutrinos. This higher mass splitting in the standard three active neutrino model was accommodated by introducing sterile neutrinos. Sterile neutrinos carry a new flavor which can mix up with the other three flavors of standard model but they do not couple with W and Z bosons. The number of sterile neutrinos can vary from minimum one to any integer N.

Some cosmological evidences like CMB anisotropies [14–18] and Big Bang nucleosynthesis [19,20] also stood up with the LSND data. The results reported by the combined analysis [21] of Baryonic Acoustic Oscillations (BAO) [22–26] 'H_0 + PlaSZ + Shear + RSD' indicated the presence of sterile neutrinos, by stipulating the number of effective neutrinos $N_{eff} \equiv 3.62^{+0.26}_{-0.42}$, $m_\nu^{eff}\,(sterile) = 4.48^{+0.11}_{-0.14}$ eV and giving preference for $\triangle N_{eff} \equiv N_{eff} - 3.62^{+0.26}_{-0.42}$ at 1.4σ level and non-zero mass of sterile neutrino at 3.4σ level. The gallium solar neutrino experiments (gallium anomaly) GALLEX [27], SAGE [28] and the antineutrino reactor experiments ($\bar{\nu}_e$) like Bugey-3, Bugey-4, Gosgen, Kransnogark, IIL [29] (reactor anomaly) indicated that electron neutrinos and antineutrinos may disappear at short baselines. Such disappearance can be explained by the presence of at least one massive neutrino (of the order of 1 eV). Thus, these experiments also indicated the presence of sterile neutrino and supported the LSND results. Some constraints imposed by the combined fit of reactor, gallium, solar and $\nu_e C$ scattering data are $\triangle m^2_{41} \gtrsim 1$ eV^2 and $0.07 \le \sin^2 2\nu_{ee} \lesssim 0.09$ at 95% CL [30]. Few atmospheric neutrino experiments such as IceCube [31], MINOS [32–34], CCFR [35] have also imposed strong constraints on sterile parameters.

The four flavors of neutrino can be studied in either of the two different neutrino mass schemes, $3+1$ or $2+2$ schemes [36]. For our work we have selected $(3+1)$ four flavor neutrino mass scheme. In this framework, Maki–Nakagawa–Sakata (MNS) mixing matrix (4×4), includes six mixing angles θ_{ij}, three Dirac phases and three Majorana phases.

Neutrino factory [37,38] provides excellent sensitivity to the standard neutrino oscillation parameters and therefore seems to be one of the promising option to explore and reanalyze the global fits for sterile neutrino parameters. To mention, it provides a platform to constrain one of the most searched CP violation in leptonic sector [39,40]. Hence neutrino factory seems to provide a promising environment for the study of T and CPT violation. The neutrino factory set