[VOLUME 2 I ISSUE 3 I JULY – SEP. 2015] E ISSN 2348 –1269, PRINT ISSN 2349-5138

Search of Sterile Neutrino

R. B. Singh[1] & Jyotsna Singh[2]
Assistant Professor,
Department of Physics,
University of Lucknow, Lucknow, India[1,2]

Received Aug. 21, 2015 Accepted Sept. 08, 2015

ABSTRACT *Neutrino oscillation experiments are powerful and mysteriously attractive experiments in the field of particle physics. The anomalies observed in past few decade, data collected from different neutrino oscillation experiments has expedite the search for physics beyond the standard model. These anomalous signatures were reported by different neutrino oscillation experiment. In search of the origin of these anomalies one of the different hypothesis formed by different working group was the existence of at least one neutrino state which do not participate in weak interactions. These neutrino states are known as sterile state. In this work we have explored the potential of neutrino factory in imposing bounds on the sterile mixing angles.*

Key words:*Anomalies, neutrino oscillation, weak interaction, sterile neutrino.*

Introduction

Many neutrino experiments have given the signatures of neutrino oscillation. Takkaki Kajita of University of Tokyo (Super-Kamiokande Collaboration) and Arthur B. McDonald of Queen's University in Ontario (Sudbury Neutrino Observatory Collaboration) were awarded the Nobel Prize in Physics 2015 for the discovery of neutino oscillations [1]. By assigning masses to the neutrino this discovery opened the new door for particle physics. The current theoritical and experimental searches of the physics of neutrinos are based on the standard paradigm of three active neutrino mixing [2][3][4]. The completeness of this paradigm has been challenged by the following observations; the reactor antineutrino anomaly [5], which reported 2.8 deficit in the rate of in comparison to, what was expected from the calculations of reactor neutrino fluxes [6][7], gallium neutrino anomaly [8][9] and LSND anomaly [10][11].

These anomalies required the existence of at least one additional mass squared difference $\Delta m \geq 1e$ to explain the results. The LEP measurement of invisible width of the Z bosons [12] restricted the number of active neutrino to be 3, hence a sterile neutrino was required to answer these anomalies [13]. The sterile neutrino studies are in interesting phase. Different groups are studying different aspects of sterile neutrino; sterile neutrino at mass scale smaller than 0.1 eV [14][15], sterile neutrino at KeV scale [16][17], sterile neutrino at MeV scale [18][19] and sterile neutrino at electroweak scale or above [20][21].

The discovery of sterile neutrino in upcoming and ongoing neutrino oscillation experiment needs to be addressed as this discovery will give us a clue of particle physics beyond the standard model.

II. Sterile Neutrino and Oscillation Physics

Light sterile neutrinos are the additional states in three active neutrino frame work. These neutrino states do not interact via the exchange of W or Z bosons [22]. These states are introduced as gauge singlets. Experimental data has indicated the existence of light sterile neutrino [23], which in early years was assumed to be less natural. The number of sterile neutrino is not predicted by theories. Upcoming Plank data is expected to give a clear picture of number of available sterile states [24]. In this work we have considered 3+1 neutrino framework to study the neutrino oscillation physics. In this frame work there are three active neutrino and one sterile neutrino. The parametrzation scheme selected for this work is

$$U = U_{34}(\theta_{34},0)U_{24}(\theta_{24},0)U_{14}(\theta_{14},0)U_{23}(\theta_{23},\delta_3)U_{13}(\theta_{13},\delta_2)U_{12}(\theta_{12},\delta_1)$$

The effective Hamiltonian of neutrinos in matter can be expressed as:

$$H_f = \frac{1}{2E}\left[Udiag(0,\Delta m_{21}^2,\Delta m_{31}^2,\Delta m_{41}^2)U^\dagger + diag(A_e + A_n, A_n, A_n, A_n)\right]$$

Here $\Delta m$is the neutrino mass square difference and $A_{e(n)}=2EV_{e(n)}$.

The Hamiltonian can be diagonalized to H_D by an Unitary matrix . The expression for the H_D can be given as

$$H_D = \tilde{U}^\dagger H_f \tilde{U}$$

After the formation of unitary matrix , the neutrino oscillation probability is developed for 3+1 framework[25].

Probability equation for $\nu_\mu \rightarrow$ can be written as

$$P_{\mu\mu} = 1 - 2s_{24}^2 cos^2\Delta_{31} - (1-8s_{23}^2)sin^2\Delta_{31} + (c_{12}^2\Delta_{12} - 2s_{24}s_{34}cos\delta_3\Delta_n)sin2\Delta_{31} + \frac{s_{13}^2\Delta_{31}}{(\Delta_{31}-\Delta_e)^2} \times$$
$$2\Delta_{31}sin\Delta_e cos\Delta_{31} sin(\Delta_{31}-\Delta_e) - (\Delta_{31}-\Delta_e)\Delta_e sin2\Delta_{31}$$

In the above equation $\Delta_e = A_e L/4$, $\Delta_e = \Delta m_{31}^2 L/4$and $s_{ij},$ are sin(ij) and cos(ij) .

III: Bounds on Sterile angles with Neutrino Factory

A 50 GeV neutrino factory with 1.4 x 10^{21} useful muon decay per polarity per year is taken into consideration for this work. We have used two different detectors (i) Liquid argon Detector as near and far detector(20% energy resolution for muons) (ii) Magnetized Iron Detector as near and far detector(15% energy resolution for muon). A near detector of mass 200 tons is placed at distance of 20 m and far detector of fiducial mass 50 Kt is kept at a distance of 7500 Km.

The general long baseline experiment simulator GloBES is used to simulate the neutrino factory setup for our analysis [26][27].

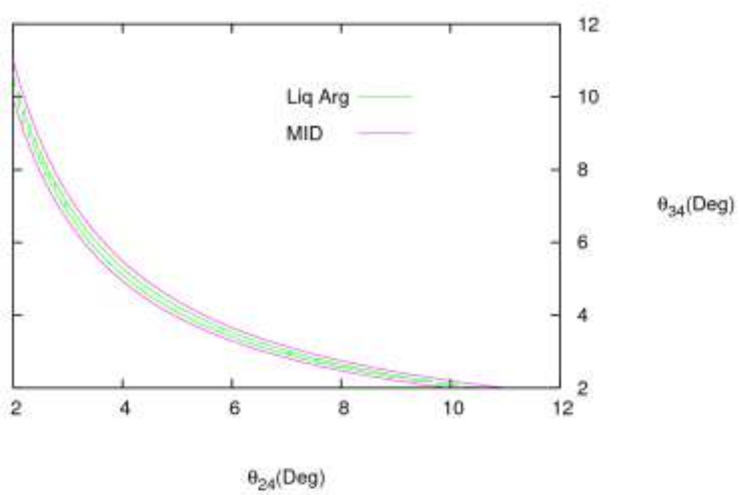

Fig. 1. The above plot shows bounds on the product of θ_{23} δimposed by (i) Liquid Argon Detector, green line (ii) Magnetized Iron Detector, magenta line.

The values of oscillation parameter selected for the above analysis are

$\theta_{23} = 45^0, \theta_{13} = 8^0, \theta_{12} = 34^0, \Delta m^2_{21} = 8x10^{-5}, \Delta m^2_{31} = 2.5x10^{-3}, \delta_3 = \pi/2$

IV:Result and Conclusion

From Fig. 1. we can observe the allowed range of, sterile parameters $\theta_{23}\theta$. Liquid argon detector imposes tighter bounds on the product of sterile angles. Liquid argon detector will be a better a better choice to study sterile parameters with neutrino factory. With 500 kt years exposure, neutrino factory establishes $\theta_{23}\theta_{24} \geq 2$.

The sterile parameters needs to be determined very carefully and fortunately, impressive new experiments are being planed and are running to check the existence of sterile neutrino at eV scale. With these strong efforts in the coming years we willbe able to give a concrete statement on the existence of sterile neutrino. The existence of sterile neutrino will be a landmark discovery and it will allow us to revisit the standard model physics in the light of new physics.

REFERENCES

1. Press Release, 6 Oct 2015,https://www.nobelprize.org.
2. G. Bellini et al, Adv. High Energy Phys.2014,191960, arXiv1310.7858[hep-ph].
3. Y. Wang, Z. z. Xing, arXiv1504.06155[hep-ph].
4. M. Gonzalez-Garcia, M. Maltoni, T. Schwetz, Nucl. Phys. B. 908,199(2016), arXiv:1512.06856[hep-ph].
5. G. Mention et. al., Phys. Rev. D 83, 073006(2011),arXiv:1101.2755[hep-ex].
6. T.A. Mueller et. al., Phys. Rev. C 83, 054615 (2011), arXiv:1101.2663[hep-ex].
7. P. Huber, Phys. Rev. C 84, 024617 (2011), arXiv:1106.0687[hep-ph].
8. M. Laveder, Nucl. Phys. Proc. Suppl. 168, 344 (2007).
9. C. Giunti et al. Phys. Rev. D 86, 113014 (2012), arXiv:1210.5715[hep-ph].
10. C. Athanassopoulos et al., Phys. Rev. Lett. 75, 2650 (1995), arXiv:nucl-ex/9504002.
11. A. Aguilar et al.,Phys. Rev. D 64, 112007 (2001), arXiv:hep-ex/0104049.
12. C. Giunti, C.W. Kim, Fundamentals of Neutrino Physics and Astrophysics, Oxford University Press, Oxford, UK,2007.
13. B. Pontecorvo, Sov. Phys. JETP 26, 984 (1968).
14. S. K. Kang et al., Adv. High Energy Phys. 2013, 138109 (2013).
15. P. C. de Holand, A. Y. Smirnov, Phys. Rev. D 69, 113002 (2004), arXiv:hep-ph/0307266.
16. R, Adhikari et al., arXiv:1602:04816[hep-ph].
17. T, Asaka, M. Shaposhnikov, Phys. Lett. B 620, 17 (2005), arXiv:hep-ph/0505013.
18. G. Gelmini et al., J. Cosmol. Astropart. Phys. 0810, 029 (2008), arXiv:0803.2735 [astro-ph].
19. H. Ishida, M. Kusakabe, H. Okada, Phys. Rev. D 90, 083519 (2014), arXiv:1403.5995[astro-ph.CO].
20. S. Antusch, O. Fischer, J. High Energy Phys. 1505, 053 (2015), arXiv:1502.05915[hep-ph].
21. F.F. Deppisch et al., New J. Phys. 17, 075019 (2015), arXiv:1502.06541[hep-ph].
22. LEP Electroweak Working Groups, "Precision electroweak measurements on the Z resonance," Phys. Report, vol. 427, pp.257-454,2006.
23. M. A. Acero et al., Physical Review D, Vol. 78, Article ID 073009,2008.
24. J. Hamann et al., Journal of Cosmology and Astroparticle Physics, vol. 1109, article 034, 2011.
25. Yogita Pant et al., vol. 909, Pg. 1079-1103 , Nuclear Physics B, arXiv:hep-ph/1509.04096.
26. P. Huber, M. Linder and W. Winter, Comput. Phys. Commun. 167.195 (2005), arXiv:hep-ph/0407333.
27. P. Huber, J. Kopp, M. Linder, M.Rolinec and W. Winter, Comput. Phys. Commun. 177, 432 (2007), arXiv:hep-ph/07071187