Estimating the Upper Limit of Electron Neutrino mass

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1 Introduction

Neutrinos are elusive particles that belong to the fermions of the Standard Model of Particle Physics. But they have many unique properties which make them interesting and special among the fermions. One of the appealing topics relating to neutrinos has been their mass. Neutrinos carry very little mass as compared to their counterpart fermions

In the beginning, it was thought that neutrinos have no mass. But the neutrino oscillations show that neutrinos carry some little mass. The three flavors of the neutrino: electron-neutrino ν_e, muon-neutrino ν_μ, and tau-neutrino ν_τ including their anti-particle counterpart oscillates from one flavor to another flavor, which is known as neutrino oscillations. These neutrino oscillations are explained using non-zero mass states [1].

The neutrinos have very little mass and only take part in weak interactions. Therefore, it becomes very hard to measure its mass. [2] A study of the upper limit in the mass of ν_e is presented here.

This paper has three main sections: Sec. 2 gives a brief explanation of the measurement of the neutrino mass and a way to hypothetically generate the data for it using the random number generation technique. Sec. 3, will provide the analysis of the given data to estimate the parameter, and finally, the conclusion will be given at Sec. 4.

2 Code and Experimental Simulation

The neutrino oscillation experiments are able to measure the mass square difference Δm_{ij}^2 values corresponding to the set of (i, j) neutrinos. But the measurement of the absolute mass of the neutrino remains a hard topic in the field of Particle physics and Astroparticle physics. Following the [2], I have generated the data for the mass of $\bar{\nu_e}$. It explains that the measurement of the effective mass of $\bar{\nu_e}$ is carried out using the equation,

$$m_{\nu_e}^2 = \sum_i^3 |U_{ei}|^2 m_i^2 \tag{1}$$

Where, m_{ν_e}, m_i are the flavor and mass states, and U_{ei} are the elements of the elements of the PMNS (Pontecorvo–Maki–Nakagawa–Sakata) matrix that describes the mixing of neutrino.

One of the finest ways to measure and estimate the upper limit is to search the neutrinoless (also known as double beta)decays. In this case, we treat the neutrinos as Majorana Particles. The Feynman diagram of this kind of decay can be seen in 1

In short, I have simulated the data based on the results of the second run of the famous Karlsruhe Tritium Neutrino experiment (KATRIN) which accounts for the decay channel of the tritium $T_2 -> HeT^+ + e + \bar{\nu_e}$ and puts an upper limit in the mass of the $\bar{\nu_e} < 0.8$ eV at 90% of the confidence Level.

A cpp and root-based code can be accessed at `https://github.com/shoukatphy/Proejct4-/tree/main/files`

3 Analysis

It has been seen that the probability density function of this data is Gaussian. Therefore, the likelihood function can be set up as,

$$P(\lambda|X) = P(\lambda)P(X|\lambda) \tag{2}$$

Where λ is the unknown parameter and then X is the set of data. The estimation of the unknown parameter (which in our case, will be the upper limit of the mass of the $\bar{\nu_e}$) can be made by maximizing the likelihood function. As said, this data follows the Gaussian distribution. Therefore, the maximization of the likelihood function will turn into the mean value making the analysis more simple.

I have developed a program that plots the distribution of the data and then makes a fit by using a kernel density estimation class of root. The maximization of the function yields the unknown parameter 1.

I have analyzed 3000 events through my program and it estimated the upper limit value at 0.801525.

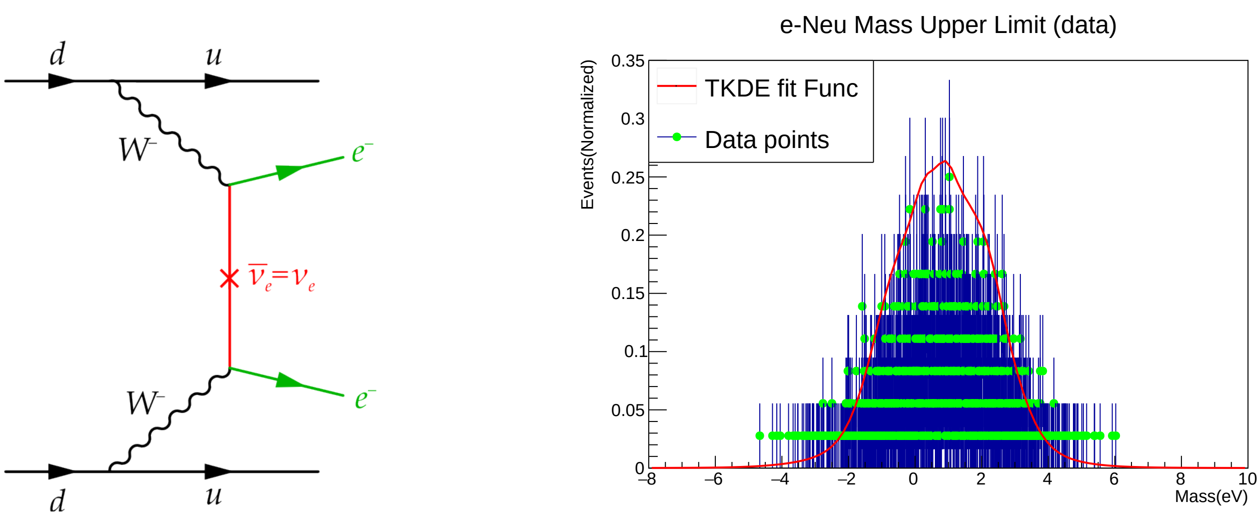

Figure 1: Left: Neutrinoless beta decay. Figure source: https://cuore.lngs.infn.it/en/about/physics
Right: Histogram and a fit for the distribution of the data

4 Conclusion

A simulated data based on the results of the second run of the KATRIN experiment is analyzed and it is found that the upper limit in the mass of the $\bar{\nu_e}$ is 0.801525. These results make a complete agreement with the results of the above-mentioned experiment. Moreover, the decay channel used to probe the absolute mass of the neutrinos is considered one of the most powerful techniques.

References

[1] P. Lipari, *INTRODUCTION TO NEUTRINO PHYSICS*, *Dipartimento di Fisica, Universita‘ di Roma “la Sapienza”* (Jan, 2018) .

[2] T. K. Collaboration, *Direct neutrino-mass measurement with sub-electronvolt sensitivity*, *nature Physics* (May, 2021) .