Neutrino Physics in Elementary Particle Physics

Mateus Marques

Renata Zukanovich Funchal

Institute of Physics of the University of São Paulo (IFUSP)

mateusmarques2001@usp.br

Objectives

This project concerns the study of neutrino phenomenology through theoretical and computational approaches. As we see in [1], the Standard Model (SM) implies that the mass of the neutrino is zero. However, due to neutrino oscillations [2], this represents a disagreement between the SM and the experiment. Thus, we seek to understand and simulate computationally the oscillation phenomenon in order to compare our results with data from the KamLAND experiment [3].

Materials and Methods

Our approach is based on the hypothesis that the neutrino interacts only in its interaction eigenstates $(\nu_e, \nu_\mu, \nu_\tau)$, while the hamiltonian of its time evolution has different mass eigenstates (ν_1, ν_2, ν_3).

While in vacuum and in the ultrarelativistic limit, the hamiltonian H is such that

$$H\,|\nu_i\rangle = \frac{m_i^2}{2E}\,|\nu_i\rangle. \qquad (1)$$

Performing a change of basis to the interaction basis with components $(\psi_e, \psi_\mu, \psi_\tau)$ through the Maki-Nakagawa-Sakata mixing matrix U [1], adding the interaction potential V and assuming the normal ordering of neutrino masses, we obtain the equation

$$i\frac{d}{dt}\begin{pmatrix}\psi_e\\ \psi_\mu\\ \psi_\tau\end{pmatrix} = \left[\frac{1}{2E}\,U\begin{pmatrix}-\Delta m_{21}^2 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & \Delta m_{31}^2\end{pmatrix}U^\dagger + V\right]\begin{pmatrix}\psi_e\\ \psi_\mu\\ \psi_\tau\end{pmatrix}. \quad (2)$$

Using the parameters of the NuFIT group [4], we solve (2) by the Runge-Kutta method in a vacuum and obtain Figure 1, which describes the transition probabilities to the other leptonic flavors.

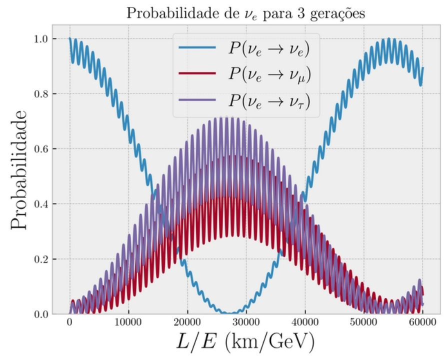

Figure 1: Transition probability for an electron neutrino in vacuum.

Inside the Sun we may only take into account the charged current weak interactions with elastic and coherent scattering [1], which leads to the potential

$$V = diag(\sqrt{2}G_F N_e, 0, 0), \qquad (3)$$

where G_F is the Fermi constant and N_e is the solar electron number density.

Results

By (3), we used the data from the solar model BS2005 [5] to interpolate N_e and solve equation (2) for two generations (ν_e, ν_μ) of neutrinos, obtaining Figure 2:

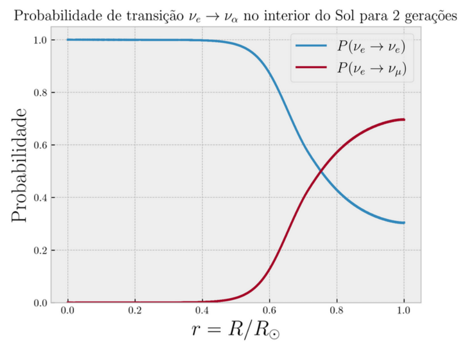

Figure 2: Transition probability (two generations) for an electron neutrino inside the Sun.

Conclusions

In Figure 2, we notice the decay of the transition probability due to the presence of matter, which is called the Mikheyev-Smirnov-Wolfenstein (MSW) effect [6]. This behavior is quite different from Figure 1, being the MSW effect relevant to explain the solar neutrino fluxes arriving at Earth. In the rest of this project, we intend to delve deeper into this analysis, doing numeric simulations with the presence of matter for three generations also taking into account the probability distributions of neutrinos' energy and point of production. This will allow us to compare our results with the KamLAND experiment.

References

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