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Review

Neutrino mass from triton decay

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Abstract

Since the discovery of neutrino flavor oscillation in different fields and by many different experiments we believe that neutrinos have non-vanishing masses in contrast to their current description within the Standard Model of particle physics. However, the absolute values of the neutrino masses, which are as important for particle physics as they are for cosmology and astrophysics, cannot be determined by oscillation experiments alone. There are a few ways to determine the neutrino mass scale, but the only model-independent method is the investigation of the electron energy spectrum of a β decay near its endpoint with tritium being the ideal isotope for the classical spectrometer set-up. The tritium β decay experiments at Mainz and Troitsk have recently been finished. At Mainz all relevant systematic uncertainties have been investigated by dedicated experiments yielding an upper limit of $m(\nu_e) < 2.3$ eV/c^2 (90% C.L.). The new Karlsruhe Tritium Neutrino Experiment (KATRIN) will enhance the sensitivity on the neutrino mass by an ultra-precise measurement of the tritium β decay spectrum near the endpoint by another order of magnitude down to 0.2 eV/c^2 by using a very strong windowless gaseous molecular tritium source and a huge ultra-high resolution electrostatic spectrometer of MAC-E-Filter type. The recent achievements in test experiments show, that this very challenging experiment is feasible.

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1. Introduction

The recent discovery of neutrino oscillation by various experiments with atmospheric, solar, reactor and accelerator neutrinos [1] proved that neutrinos mix and can change their flavor. We believe that these neutrino oscillations are caused by non-zero masses of neutrinos in

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contrast to their current description in the Standard Model of particle physics. Unfortunately, these oscillation experiments are sensitive to the differences of squared neutrino mass states $|\Delta m^2_{ij}| = |m^2(\nu_i) - m^2(\nu_j)|$,[1] but not directly to the neutrino masses $m(\nu_i)$ themselves. On the other hand, if one neutrino mass is measured absolutely the whole neutrino mass spectrum can be calculated using the values Δm^2_{ij} from the oscillation experiments.

Theories beyond the Standard Model try to explain the smallness of neutrino masses in comparison with the much heavier charged fermions [2]. One prominent explanation is the Seesaw type I mechanism using heavy right-handed Majorana neutrinos yielding usually a hierarchical pattern of neutrino masses. Alternatively, Seesaw type II models usually produce a scenario of quasi-degenerate neutrino masses with the help of a Higgs triplet [2]. Here all masses are 0.1 eV/c^2 or heavier exhibiting small mass differences between each other to explain the oscillations. In this quasi-degenerate case – due to a huge abundance of relic neutrinos in the universe left over by the big bang – neutrinos would make up not the major, but a significant contribution to the dark matter. Therefore the open question of the value of the neutrino masses is not only crucial for particle physics to decide between different theories beyond the Standard Model but it is also very important for astrophysics and cosmology.

There are different ways to determine the neutrino mass scale:

- **Cosmology**

  Information on the absolute scale of the neutrino mass can be obtained from astrophysical observations like the power spectrum of the matter and the energy distribution in the universe at different scales. Usually these analyses use the combination of Cosmic Microwave Background data (e.g. from the WMAP satellite), the distribution of the galaxies in our universe, the so-called "Large Scale Structure", and information from the so-called "Lyman α-Forest" or x-ray clusters to describe the distribution at large, medium and small scales, respectively. In most cases they give upper limits on the mass of the neutrinos on the order of several 0.1 eV/c^2 [3], in some cases non-zero neutrino masses are found [4] illustrating the dependence on the assumptions and the data used to obtain the cosmological limits. One should not forget that these models describe 95% of the matter and energy distribution of the universe by yet non-understood quantities like the cosmological constant [5] and the Cold Dark Matter. And, the limits on the neutrino mass rely on the existence of the not yet observed relic neutrinos [6].
- **Neutrinoless double β decay**

  One laboratory way to access the neutrino mass scale is the search for the neutrinoless double β decay [7,8]. This process is a conversion of two neutrons (protons) into two protons (neutrons) within a nucleus at the same time. Usually two electrons (positrons) and two antineutrinos (neutrinos) are emitted. In the case, that the neutrino is a Majorana particle (particle is equal to its antiparticle) the double β decay could occur without emission of any neutrinos. This transition is directly proportional to the neutrino mass (in the absence of right-handed weak charged currents or the exchange of other new particles). The observable of double β decay neutrinoless is the so-called effective neutrino mass

  $$m_{ee} = \sum_i |U^2_{ei} \cdot m(\nu_i)| \tag{1}$$

  which is a coherent sum over all neutrino mass eigenstates $m(\nu_i)$ contributing to the electron neutrino with their (complex) mixing matrix elements U_{ei}. A subgroup of the most sensitive

[1] In the case of matter effects involved – like for solar neutrinos – the sign of Δm^2_{ij} can be resolved.