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Absolute neutrino mass scale: session summary

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Abstract

Oscillation experiments have by now established beyond doubt that neutrinos have a mass. The absolute scale of neutrino masses is the target of single beta decay and neutrinoless double beta-decay (0νDBD) experiments, and can also be measured through cosmological observations, like those of the cosmic microwave background anisotropy spectrum or of the clustering of cosmic structures. Here we summarize the "Absolute neutrino mass scale" session of the *Neutrino Oscillation Workshop 2014*. In the session, recent experimental results on the absolute neutrino mass scale from single and double beta decay experiments and from cosmology were presented, as well as proposals for future experiments in these and related fields. On the theoretical side, the talks discussed the issues concerning the uncertainties in 0νDBD experiments, the role of neutrinos in the non-linear evolution of cosmic structures, non-standard cosmological scenarios with sterile neutrinos, and flavour evolution in the early Universe.

Keywords:
neutrino mass, single beta decay, double beta decay, cosmology, sterile neutrinos

1. Introduction

Oscillation experiments provide compelling evidence that neutrinos have a mass. They cannot however provide information on the absolute scale of neutrino masses, on the mass hierarchy, nor on their nature (i.e., if Dirac or Majorana). Moreover, the smallness of neutrino masses with respect to the charged leptons and quarks represents a puzzling fact, possibly related to the mechanism of neutrino mass generation (see the talk by **Alexei Smirnov** in this conference).

There are different experimental probes of the absolute neutrino mass scale, each with its own advantages. The most direct strategy is to exploit kinematic effects, like e.g. looking for the effect of finite neutrino mass on the energy spectrum of electrons produced in the β decay of nuclei [1], as in tritium beta decay experiments. The key advantage of this approach is that, being based on kinematic arguments, it is very direct and model-independent. This kind of measurements is sensitive to the effective mass $m_\beta \equiv \left(\sum_i |U_{ei}|^2\, m_i^2\right)^{1/2}$ where m_i ($i = 1, 2, 3$) are the masses of the mass eigenstates, and $U_{\alpha i}$ ($\alpha = e, \mu, \tau$) are the elements of the neutrino mixing matrix. The current limit is $m_\beta < 2.05 - 2.3\,\mathrm{eV}$ (at 95% CL) from the Troitsk and Mainz experiments, respectively.

Another possibility is to study the double beta decay of nuclei, looking for the process $(Z, A) \rightarrow (Z + 2, A) + 2e^-$, in which no neutrinos are present in the final state, the so-called neutrinoless double-beta decay (0νDBD) [2]. Such a process violates lepton number by two unit, and if it were observed, it would guarantee that neutrinos have a non-vanishing Majorana mass [3]. 0νDBD experiments are sensitive to the effective mass: $m_{\beta\beta} \equiv \left|\sum_i U_{ei}^2\, m_i\right|$. 0νDBD experiments offer the unique possibility to probe the Majorana nature of neutrinos. However, the interpretation of the results on the isotope lifetime (the actual outcome of the experiment) in terms of $m_{\beta\beta}$ is somewhat limited by the uncertainties related to the theoretical estimation of the appropriate nuclear matrix elements.

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Finally, cosmological observations, like for example those of the cosmic microwave background (CMB) and of large scale structures (LSS) can also probe the absolute neutrino mass scale, since massive neutrinos affect the evolution of the Universe at both the background and perturbation level [4]. At first order, cosmology is mainly sensitive to the total neutrino mass $M_\nu \equiv \sum_i m_i$. The limits on M_ν depend on the exact dataset combination that is considered; an analysis of the CMB data from the Planck satellite, complemented with data from other CMB experiments and with measurements of baryonic acoustic oscillations (BAO) yields $M_\nu < 0.23\,\text{eV}$ [15]. Cosmology currently offers the tightest limit on the absolute scale of neutrino masses, but this comes at the price of assumptions on the underlying cosmological model.

2. Beta decay

The hunt for extracting the neutrino mass m_β from the measurement of the end point of a beta spectrum has been an experimental challenge for many years. A review of the field can be found in the talk of **Hamish Robertson** at this conference. A very interesting experimental approach is described by **Matteo De Gerone**, who presents the HOLMES experiment [14]. This project based on the micro-bolometer technology aims to study the end point of the electron capture (EC) spectrum of ^{163}Ho. ^{163}Ho decays by EC to ^{163}Dy with the lowest known Q-value of about 2.55 KeV. HOLMES will deploy a large array of low temperature micro-calorimeters with implanted ^{163}Ho nuclei. The resulting sensitivity on m_β will be as low as 0.4 eV. This project is crucial in exploring the possibility of a complementary approach with respect to large mass spectrometers. It will also establish the potential of this approach to extend the sensitivity down to 0.1 eV.

3. Double beta decay

The hunt for 0νDBD is one of the most challenging research in recent years in the field of neutrino physics. This process is a unique tool to access lepton number violation and possibly the Majorana nature of neutrino (see the talk by **Fedor Šimkovic** in this conference for a theoretical review on the subject). Moreover, the lifetime for 0νDBD is related to the absolute value of the Majorana neutrino mass trough the relation:

$$[\tau^{1/2}_{0\nu}] = G_{0\nu}|M_{0\nu}|^2 \left|\frac{< m_{\beta\beta} >}{m_e}\right|^2 \qquad (1)$$

Where $G_{0\nu}$ is the phase-space factor, $M_{0\nu}$ the nuclear matrix element, and $m_{\beta\beta}$ the Majorana mass of the neutrino.

In his talk **Francesco Iachello** highlights some of the crucial aspects concerning the theoretical estimation of these parameters, focusing on the crucial uncertainties in the evaluation of $M_{0\nu}$. A first relevant update is that phase space factor $G_{0\nu}$ has been recently recalculated [5] with exact Dirac electron wave functions and including screening by the electron cloud, upgrading older results obtained with approximated electron wave functions. Recent results on $M_{0\nu}$ are reported for the $\beta\beta$ channel [6, 7] as well as for the ECEC channel. All these calculation are obtained using the Interacting Boson Model IBM-2. The main focus is on the axial vector coupling constant g_A. Most of the current results in nuclear matrix element (NME) estimation are done with an effective g_A =1.269. This value is in tension with the one obtained in the IB-2 model from the 2νDBD which gives a $g^{IBM-2}_{A,eff} = 1.269\,A^{-0.18}$. This gives rise to a factor 4-16 to the realistic estimates of expected half-lives, deeply impacting on the experimental approach in the field. The crucial question is whether or not g_A in 0νDBD is renormalized as much as in 2νDBD. This problem is currently attached experimentally by measuring the matrix elements to and from the intermediate odd-odd nucleus in 2νDBD decay.

Clementina Agodi illustrates how is possible to measure these matrix elements experimentally. The values of the NMEs could be checked by Heavy-Ion Double Charge Exchange (DCE), which is a transfer of two units of the isospin leaving the mass number unchanged. 0νDBD is a direct mechanism (i.e. a isospin-flip processes), while DCE is a sequential mechanism with two-proton plus two-neutron transfer or vice-versa. Nevertheless parent and daughter states of the are the same as those of the target/residual nuclei in the DCE and the results should provide good information on the transition. **Clementina Agodi** presents a proposal and a strategy plan to measure DCE for several DBD emitting nuclei at Laboratori Nazionali del Sud (LNS). The basic point is the coincidence of the initial and final state wave-functions in the two classes of processes and the similarity of the transition operators. This technique was demonstrated experimentally at LNS by the MAGNEX project for the ^{40}Ca(^{18}O,^{18}Ne)^{40}Ar reaction at 270 MeV, give encouraging indication on the capability of the proposed technique to access relevant quantitative information. The NUMEN project implies an upgrade of the current LNS facility to give high beam intensity and a new focal plane detector, suitable to resist to high rates.