Snowmass2021 - Letter of Interest

White paper: Reaching 0.02 eV sensitivity on absolute neutrino mass using low energy electron capture and beta decay

NF Topical Groups: (check all that apply □/■)

□ (NF1) Neutrino oscillations
□ (NF2) Sterile neutrinos
□ (NF3) Beyond the Standard Model
□ (NF4) Neutrinos from natural sources
■ (NF5) Neutrino properties
□ (NF6) Neutrino cross sections
□ (NF7) Applications
□ (TF11) Theory of neutrino physics
□ (NF9) Artificial neutrino sources
□ (NF10) Neutrino detectors
■ (Other) *Instrumentation Frontier*

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Abstract: (maximum 200 words) The absolute neutrino mass scale could be the key for the theory beyond the Standard Model. Since the analysis of cosmological observations is approaching sensitivities close to the minimal allowed sum of neutrino masses and experiments searching for neutrinoless double beta decays are getting more sensitive, the quest for results from direct searches for the electron (anti-)neutrino effective mass by means of kinematic analysis is becoming very pressing. The proposed white paper aims to represent a complete picture of the present efforts. It will incorporate an outline of the results which are accessible in the near future as well as a critical discussion on plans for next-generation experiments, which will allow for achieving a mass sensitivity of the order of 0.02 eV, an order of magnitude better than presently running experiments. The aim is to present in a clear and honest way the challenges which need to be addressed, and to indicate ways to overcome them. For this, contributions from different communities will be of utmost importance.

The mass scale of neutrinos is one of the fundamental open questions in modern physics, having implications from cosmology to particle physics. The determination of this observable will pave the way to look beyond the Standard Model of particle physics. Precision measurements of the kinematics of weak decays in unstable nuclides are considered to be the approach to address this question which is least dependent on theoretical models. Nowadays two nuclides are considered to be suitable for the determination of the effective electron neutrino mass: ^{3}H, which undergoes beta decay, and ^{163}Ho, which decays through electron capture. Presently running experiments have been designed to reach sensitivities down to 0.2 eV. At the same time new ideas are under study for next-generation experiments which could improve the sensitivity by at least another order of magnitude.

Presently, two experiments using ^{3}H are taking data: KATRIN[1], in which the first neutrino-mass run led to an improved limit on the effective electron anti-neutrino mass of 1.1 eV at 90%C.L.[2], corresponding to a factor 2 with respect to the previous experiments at Mainz and Troisk[3;4], and Project 8[5] for which the proof of concept was successfully concluded. A third experiment, PTOLEMY[6], which has been actually conceived for the detection of the cosmic neutrino background using ^{3}H and is presently in the R&D phase, could in future play an important role. On the electron-capture side, two experiments have been proposed for the precise calorimetric measurement of the ^{163}Ho electron capture spectrum: ECHo[7] and HOLMES[8]. The ECHo collaboration already started data taking and is approaching a first data release. While Project 8 and PTOLEMY already have plans to investigate the neutrino mass region below 0.1 eV, for KATRIN, ECHo and HOLMES only plans for reaching 0.2 eV have been put forward.

In 2018, community members gathered at the ECT* workshop, *Determination of the absolute electron (anti-)neutrino mass*,[9] proposed to write a white paper with the aim of summarizing the present landscape of experiments dedicated at the direct determination of the effective electron (anti-)neutrino mass, and discussing the challenges which have to be addressed to reach a sensitivity as low as 0.02 eV. In particular, looking at the complexity of the proposed experiments, an important role of this paper is to spur interest in different physics communities to contribute to the development of next-generation experiments. The success of these experiments relies on a multidisciplinary approach in which particle physics, nuclear physics, atomic physics and statistical physics are strongly interconnected, and on the development of cutting-edge techniques for ultra-precise detector fabrication, identification and suppression of background, and data analysis. At the same time the availability of high-resolution and high-statistics ^{3}H and ^{163}Ho spectra allows for further interesting analysis, including the search for violation of Lorentz invariance or the existence of sterile neutrinos.

With this LOI we would like to reach the community interested and needed in the development of next-generation neutrino-mass determination experiments, going from particle physicists looking forwards to knowing the absolute neutrino-mass scale, to nuclear chemists and atomic physicists with ideas on the production of high-purity and high-intensity ^{3}H and ^{163}Ho sources, to experts in detector technologies and experts in low-background measurements, to theorists for the precise determination of the spectral shape at the level required for reaching 0.02 eV sensitivity. At the same time, phenomenologists are welcome to present their ideas on how to use coming data to understand more open questions. Their suggestions might shape the data acquisition of future experiments.

We aim to submit this text as contribution to the SNOWMASS process as well as publishing it as a separate work which should be a reference for our community. Anyone who is interested in contributing can find the draft of the outline in Appendix A.

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A Preliminary outline for planned contributed paper

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