Direct Neutrino Mass Measurement: Status, Recent Advances, and Future Prospects

Dr. Khushbakht Habib on behalf of the KATRIN Collaboration
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The determination of the absolute neutrino mass scale remains one of the central open questions in particle physics and cosmology. Several complementary approaches address this question, including direct kinematic measurements, searches for neutrinoless double-beta decay, and constraints from cosmological observations. Neutrinoless double-beta decay experiments aim to uncover whether neutrinos are their own antiparticles while probing the effective mass, whereas cosmological surveys provide independent constraints on the sum of neutrino masses. The KArlsruhe TRItium Neutrino (KATRIN) experiment currently provides the most sensitive direct kinematic probe of the neutrino mass by measuring the endpoint region of the tritium β-decay spectrum with high precision. The experimental setup employs a high-luminosity gaseous molecular tritium source in combination with a large high-resolution electrostatic spectrometer. Using the first 25% of its total dataset, KATRIN has achieved the most stringent direct upper limit of 0.45 eV/c² at a 90% CL on the neutrino mass[1]. With the full planned dataset, KATRIN aims to reach a final design sensitivity of better than 0.3 eV/c² (90% CL). Building on this success, the proposed upgrade, KATRIN++ aims to further improve the sensitivity and probe neutrino masses below the degenerate mass regime. Complementary efforts include the cyclotron radiation–based Project 8 and Quantum Tritium Neutrino Mass (QTNM) experiments, as well as calorimetric HOLMES and ECHo experiments using ^{163}Ho electron capture. Collectively, these efforts aim to reach the ultimate sensitivity required to explore the mass scale suggested by neutrino oscillation data. This talk will summarize the current global status of direct neutrino mass searches, highlight recent experimental progress, and discuss the prospects for future measurements aimed at determining the absolute neutrino mass scale.

[1] M. Aker et al. (KATRIN coll.), DOI: 10.1126/science.adq9592