Neutrino Mass Measurements using TES Detectors to Cover the Inverted Hierarchy

Brian Mong[1,+], Josef Frisch[1], and Christopher Kenney[1]

[1]SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA
[+]bung@slac.stanford.edu

August 31, 2020

Abstract

Here we express an interest in a neutrino endpoint experiment (to measure the neutrino mass) that could cover the entire inverted hierarchy by using the latest developments in transition edge sensors (TES) and and recent investments in equipment to manufacture TES by U.S. based National Labs.

The absolute neutrino masses remain a mystery, although the fact that neutrino have mass is well known and for which the discovery was awarded the 2015 Nobel Prize in physics. Direct measurements are looking for the neutrino mass by measuring the missing energy in beta decays, carried away by the anti-neutrino, and the experiments fall into two broad categories: spectrometers and calorimeters. Perhaps the most well known experiment is KATRIN [1], which uses a large spectrometer to measure the kinetic energy of the electrons from tritium beta-decay (18.6 keV), with a neutrino mass sensitivity goal of 0.2 eV. Project8 is another tritium based spectrometer experiment where the decays occur in a magnetic trap, and the kinetic energy is measured from the electron's cyclotron frequency; this experiment hopes to reach the inverted hierarchy sensitivity in a Phase-4 experiment [2]. Project8 is currently analysing their Phase-2 run which represents the first tritium measurement using their technique, and developing Phase-3 which will demonstrate critical technology like the waveguide antennas required for the scale up to Phase-4. The remaining experiments are calorimeters, which have the additional advantage that they measure the total energy of the reaction (minus the neutrino) including the nuclear recoil, but these experiments suffer from lower energy resolution and other issues. The HOLMES experiment is using ^{163}Ho which has a low energy (2.6 keV) EC-reaction, which occurs in transition edge sensors (TES) that measure the reaction energy. ECHo is a similar experiment using ^{163}Ho but in metallic magnetic calorimeters (MMCs). The MARE experiment was considering two isotopes (^{163}Ho and ^{187}Re) and the both technologies TEC and MMCs. MARE finally abandoned ^{187}Re citing it is "not fully compatible with the technical requirements" [3]. With the exception of Project8, we are not aware of any other experiment with stated ambitions to cover the inverted hierarchy. Project8 is also the only U.S. based active neutrino endpoint experiment.

Caloriemeter detectors like TES appear to have a lot of potential in neutrino mass measurements, and recent developments and investments by and for CMB-S4 and SuperCDMS, using very similar detectors, may make make for a cost effective U.S. based neutrino mass measurement program. We are interested in investigating how these investments and recent developments in the technology can be used to create a next generation neutrino endpoint experiment. For example, since cryogenic calorimeter detectors are relatively slow to recover, a large number of separate detectors are required to get sufficient statistics without pileup. CMB-S4 expects to create an array of sensors with a total of $\tilde{6}$00k TES channels using one of a few possible multiplexing techniques [4]. This channel count seems to be sufficient for a neutrino mass measurement experiment. Understanding the recovery rates and statistics needed will dictate the needed channel count to prevent pileup. It is also worth investigating improvements in the energy resolution of TES detectors, and how this may help improve the mass sensitivity. The goal is to be able to observe a missing energy of < 0.04 eV on a 2.6 keV endpoint. HOLMES states a goal of $\approx$1 eV resolution [5], and ECHo has a goal of $<$5 eV [6]. We would like to investigate what energy resolution is achievable at the present and what might be possible, and understand the resolution relationship vs neutrino mass sensitivity.

References

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