

The Princeton Tritium Observatory for Light, Early Universe, Massive Neutrino Yield (PTOLEMY)

Tritium Focus Group Meeting
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Motivation

- Big bang relic neutrinos are predicted to be amongst the oldest and smallest particles in the universe. Information on their mass and density would significantly enhance our understanding of elementary particles, the ways in which mass is distributed, and the formation of the universe.
- PTOLEMY aims to gather information on neutrinos generated during the beta decay of tritium. To do this, a highly effective detector must be employed to detect the energy and position of electrons emitted during the beta decay.
- The first prototype of PTOLEMY aims to test this detector and use a MAC-E filter. Detected particles above the energy endpoint of electrons are indicative of neutrinos and allow for calculation of neutrino properties.
- The prototype of PTOLEMY currently assembled at PPPL will test principles and equipment while providing preliminary data on neutrinos before the next phase of the experiment.

Introduction

- In a matter of seconds after the Big Bang, neutrinos decoupled from matter. It is believed that these very neutrinos are still present in large numbers across the universe, making them one of the very few relics to have been produced before the creation of light elements. This, coupled with their extremely small mass, makes neutrinos of particular interest.
- Gaining information such as the mass and number density of relic neutrinos can give insight on how particles gain mass on a very small level, on how matter is distributed throughout the universe, and even on the birth of the universe itself.
- Understanding relic neutrinos is the ultimate goal of PTOLEMY.

Discussion

- The first prototype of the PTOLEMY experiment is meant to test various material components of the experiment. In particular, this prototype aims at developing a sub-keV calorimeter capable of detecting the energy of tritium beta particles.
- As is well known, during beta decay, a neutrino is released with an electron. By studying the energy of the electron, energy of the neutrino can be calculated. In this way, PTOLEMY provides a next step to the Karlsruhe Tritium Neutrino (KATRIN) Experiment. However, PTOLEMY has different goals, the majority of these revolving around the PTOLEMY focus on Big Bang neutrinos, as opposed to neutrinos in general.

KATRIN and PTOLEMY

- KATRIN is an experiment with the main goal of setting an upper mass limit on the neutrino. The first PTOLEMY prototype uses principles similar to KATRIN's. For example, both use a MAC-E filter to drive electrons to a Si-PIN diode detector.
- PTOLEMY is designed to study Big Bang relic neutrinos:
 - PTOLEMY is a considerably smaller size than KATRIN
 - Precision retained locally by extensive in situ calibration
 - Ultimate tritium mass goal is $\sim 100\text{g}$
 - Calorimeter which can measure the electron energy spectra of tritium betas to sub-keV precision

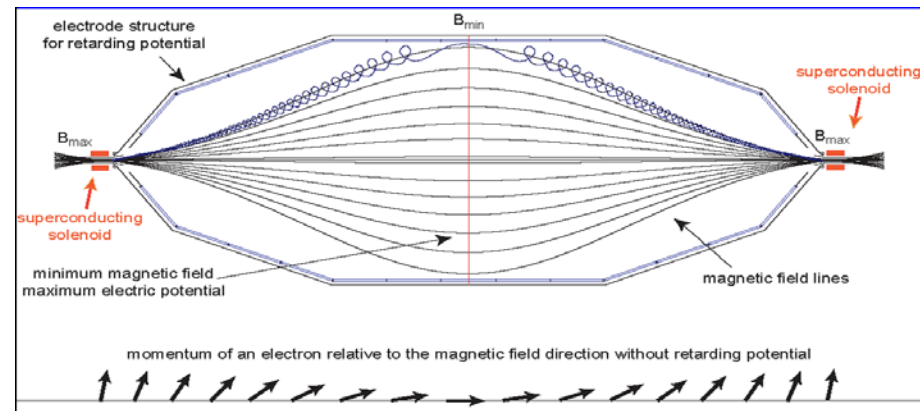
MAC-E Filter

- The MAC-E filter guides beta particles from the tritium source to the detector adiabatically using the magnetic field generated by superconducting solenoids while also applying an electrostatic barrier which allows only electrons of a sufficiently high energy to pass through the field.
- The orbital magnetic moment of the electron is conserved under adiabatic changes in the B field.

$$\mu = \frac{E_T}{B} \approx \text{constant}$$

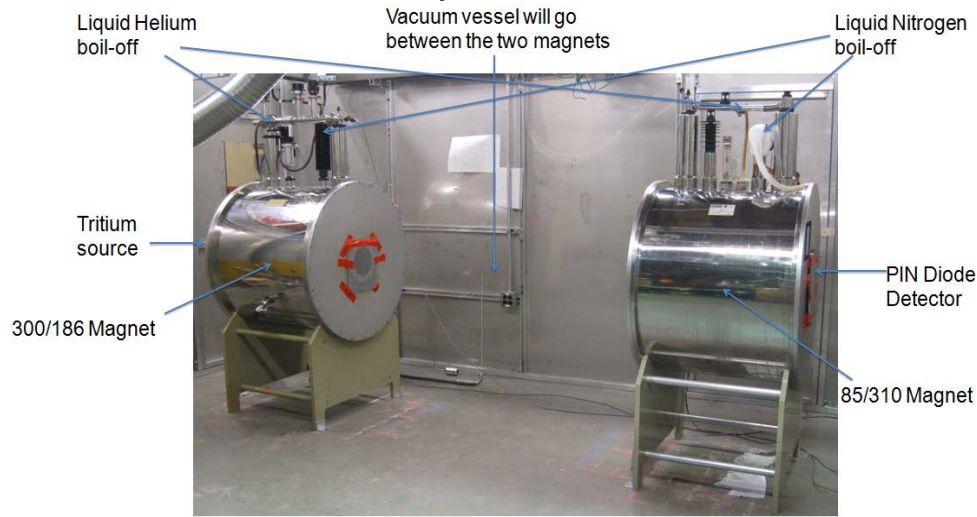
- The precision of the electrostatic cut-off is limited by the ratio of the source B field to the B field at the cut-off. The electrostatic cut-off needs to be uniform across the central region of the MAC-E filter.

$$\frac{\Delta E}{E} = \frac{B_{\text{cut-off}}}{B_{\text{source}}} = \frac{0.0003T}{6T} = 5 \times 10^{-5}$$



Experimental Set-up

- Currently, two superconducting magnets are being employed at PPPL to create the MAC-E filter.
- The source end magnet generates a field of approximately 3.35 T while the detector end magnet generates a field of just under 2 T.
- Both magnets are commercial, horizontal bore magnets manufactured by Oxford instruments.
- The detector magnet is a 300/186 model magnet while the source magnet is a 85/310 model. The former magnet is capable of being ramped up to 7 T but was limited to 3.35 T so that the magnetic field is at its lowest at the midpoint between the 2 magnets. In this same location, the electrical potential will be at its highest.



PIN Diode Detector

- The detector for the prototype is a Si-PIN diode, model XR-100CR from Amptek.
- Normally, the PIN diode is used as an X-ray detector. However, the basic function of the device is to detect electrons. Note: Early work done at LANL with PIN diodes for T detection.
- It is through the addition of the beryllium window that the diode detects X-rays. Therefore, the removal of the beryllium window enables the Si-PIN diode to be used for detecting electrons for the purposes of the experiment.
- The PX2CR Amplifier which is to be used with the PIN diode incorporates a Rise Time Discrimination circuit (RTD). Inclusion of the RTD is an important step towards reducing the amount of false data collected because it detects “noise” that is characterized by slow rise time and



Progress

- The superconducting magnets which comprise the MAC-E filter have been commissioned.
- The magnetic fields have been mapped and marked for areas of mechanical and medical significance. The PIN diode detector is currently operational in the lab.



PTOLEMY Infrastructure

- >\$1 million of PTOLEMY infrastructure currently in place.
- The addition of a dilution refrigerator planned for October 2014
- PTOLEMY lab extension underway

Collaborators

- Princeton University, PPPL, ARNL, SRNL, Columbia University, CERN, et. al.
- PTOLEMY is a growing project with opportunities available for additional collaborations.

Next Steps

- A vacuum pump and vessel are now in place.
- A set of tracks for the vacuum vessel have been installed.
- The PIN diode detector must be tested in the magnetic environment to ensure workability in high magnetic fields.
- Once everything has been completely secured and assembled, a source will be introduced and testing of the PTOLEMY concepts will commence with tritium. This is expected to occur in CY15.

