Toward measuring the Fierz parameter in ^{6}He: Cyclotron radio emission spectroscopy modeling with Kassiopeia

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An accurate determination of the absolute neutrino mass to < 0.2eV is at the forefront of modern physics, and this demanding measurement has necessarily developed novel and elegant detection techniques. The Cyclotron Radiation Emission Spectroscopy (CRES) technique has been demonstrated by Project-8 [1] – a next-generation tritium end-point experiment – to reach precisions as low as 0.05% in the β energy. The goal of the ^{6}He b collaboration is to utilize this technique to measure the energy spectrum of the pure Gamow-Teller β^- decay of ^{6}He. This will allow a very precise measurement of the Fierz interference parameter, b, which if non-zero would indicate the existence of tensor components to the weak interaction which is physics beyond the standard model. The ultimate goal is to observe the decay from ^{6}He ions confined in a Penning trap where our projected systematics are at the 10^{-4} level, representing an impact that far exceeds direct searches for tensor interactions at large-scale facilities such as the LHC. As part of this multi-institutional effort, we are simulating ^{6}He and its emitted radiation using the particle tracking package Kassiopeia.

The cyclotron frequency, f, of an electron in a strong uniform magnetic field, B, is dependent on the kinetic energy E_k of the electron according to

$$f = \frac{1}{2\pi}\frac{eB}{m_e+E_k/c^2}$$

where e is the electron charge, m_e is the rest mass of the electron, and c is the speed of light in a vacuum. CRES is a form of spectroscopy that turns the energy measurement into one of frequency; as we can measure frequencies very precisely, this is how we obtain such precise energy measurements: the energy resolution $\Delta E/E$ goes like $\Delta f/f$, and the resolution of the frequency is related to the time it is observed $t \sim 1/\Delta f$ [1]. For this reason it is important to observe the cyclotron frequency for ample time.

Kassiopeia is a particle-tracking simulation [2] that focuses on the low energy interactions in complex geometries and electromagnetic fields. Originally created for the Karlsruhe Tritium Neutrino (KATRIN) experiment, the current generation of tritium endpoint experiments, Kassiopeia is required to track particles and compute electromagnetic fields on site. Kassiopeia creates a ROOT file that contains physical quantities such as magnetic field, kinetic energy, time, position, etc. which can be used to show the cyclotron frequency and other qualities of the electron.

A Penning trap simulation in Kassiopeia has been created resembling SHIPTRAP's measurement trap [3]. For the simulation, electrons are currently being generated from the center of the trap reflecting the position and energies of ^{6}He β-decay within the trap. Helium gas will be implemented into the simulation to create special interactions. Future simulations will generate ^{6}He particles directly and allow it to decay and follow the primary particle as well as all of its descendants. From here wave guides will be added to the simulation and measure the cyclotron frequency from the beginning of the simulation until the electrons reach the waveguide to better interpret the endpoint and output of the simulation for further investigation.

[1] A.A. Esfahani *et al*., J. Phys. G **44**, 054004 (2017).

[2] D. Furse *et al*., New J. Phys. **19**, 053012 (2017).

[3] M.S. Rahaman. Ph.D. Thesis, Heidelberg University 2005; DOI: 10.11588/heidok.00005348.