Loss calculations for an ion trap update to ^{6}He CRES experiment

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In the Standard Model, the weak interaction is described by a *V–A* or vector minus axial-vector Lagrangian in which there are no scalar or tensor currents. This makes the weak interaction purely left-handed. In searching for physics beyond the standard model, we look for non-zero coupling coefficients for chirality-flipping interactions such as scalar or tensor interactions. We are able to see the decay rate is proportional to the following [1].

$$W(E_e)dE_e \propto \frac{F(\pm Z, E_e)}{2\pi^3} p_e E_e (E_0 - E_e)^2 dE_e \xi \left(1 + a_{\beta\nu} \frac{p_e \cdot p_\nu}{E_e E_\nu} + b_{\text{Fierz}} \frac{m_e}{E_e}\right).$$

From here we can see that the β spectrum depends on b_{Fierz} which, for a purely Gamow-Teller decay such as ^{6}He, is given as

$$b_{Fierz} \approx \left(\frac{C_T + C_T{}'}{C_A}\right),$$

where C_T and C'_T are exotic couplings which are set to zero in the standard model. Finding a non-zero b_{Fierz} via a precision measurement of the shape of the β spectrum would point to physics beyond the standard model. The cyclotron radiation emission spectroscopy (CRES) technique developed by the Project-8 collaboration [2] is being utilized to measure the β spectrum of ^{6}He from radiation emitted due to cyclotron radiation as a charged particle precesses in a magnetic field. The cyclotron frequency, *f*, of an electron is dependent on the kinetic energy E_e of the electron according to

$$f = \frac{1}{2\pi} \frac{eB}{m_e + E_e},$$

where *e* is electron charge, *B* is the magnetic field, and m_e is the rest mass of the electron. The incredible sensitivity of the CRES technique is this ability to use a frequency measurement to deduce the energy of the electron [3].

The experiment consists of a rectangular waveguide with a U-shape turn to read frequencies from either end to be able to cancel out the Doppler shift. The rectangular waveguide is split on one side of the U shape to include a circular waveguide that exists as a decay volume for the ^{6}He as shown in Fig. 1.

The current phase of the project involves pumping ^{6}He gas into a decay volume via 25 ȥ≈ 1 mm-diameter holes. The decay volume is ~ 10 cm in length and 1.156 cm in diameter. This radius propagates frequencies between 18-24 GHz well. The magnetic field can be varied from 0.5-7.0 T to shift our 18 - 24 GHz window to different energies and scan the whole β spectrum. The decay volume also has a coil around it creating a magnetic trap. This setup allows ^{6}He atoms to freely move about within the decay volume. The emitted βs of the ^{6}He nuclei that are near the walls are lost, and because of an increasing

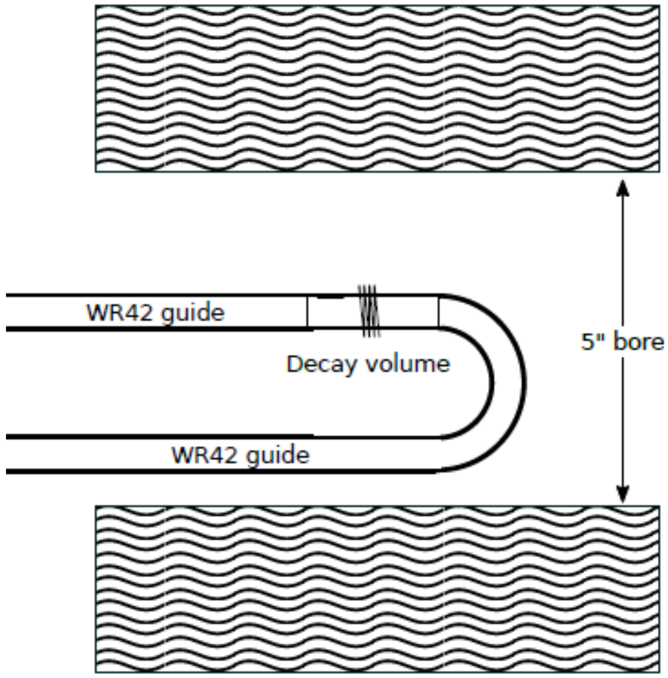

Fig. 1. Drawing of the U-shaped waveguide in the magnet.

cyclotron radius with higher energy; higher energy βs would be more likely to hit the wall, as show in Fig. 2, resulting a bias toward lower energies in our energy spectrum. With this issue it is still expected to get the uncertainty of $b_{\mathrm{Fierz}}<10^{-3}$ [4].

The next phase of the experiment involves the implementation of an ion trap to radially confine the ^{6}He ions and eliminate wall collisions, effectively bringing our expected precision to 10^{-4}. This

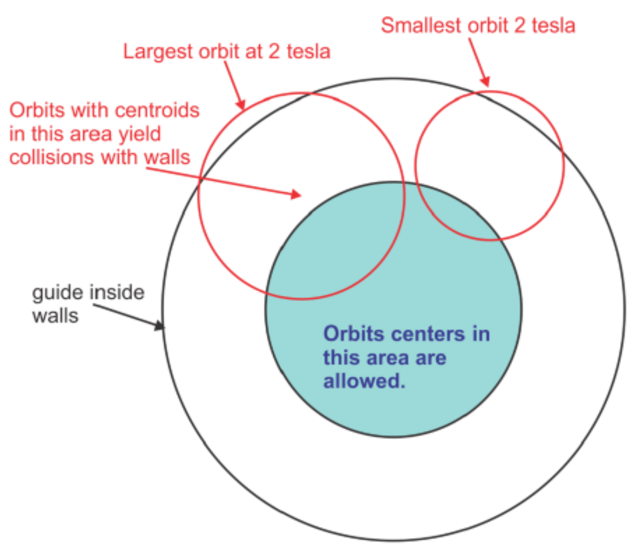

Fig. 2. The geometric effect of wall collisions in the case where there is no radial confinement of the ^{6}He.

however requires more modifications to the experimental setup as we would no longer be able to pump in neutral ^{6}He into holes within the trap. The waveguide will need to be modified to have a hole that allows a beam of ^{6}He ions to flow in and to the Penning trap. The issue here is making sure that the waveguide retains its ability to propagate the frequencies with minimal loss. Our goal is to remain below 1 dB of loss throughout the waveguide.

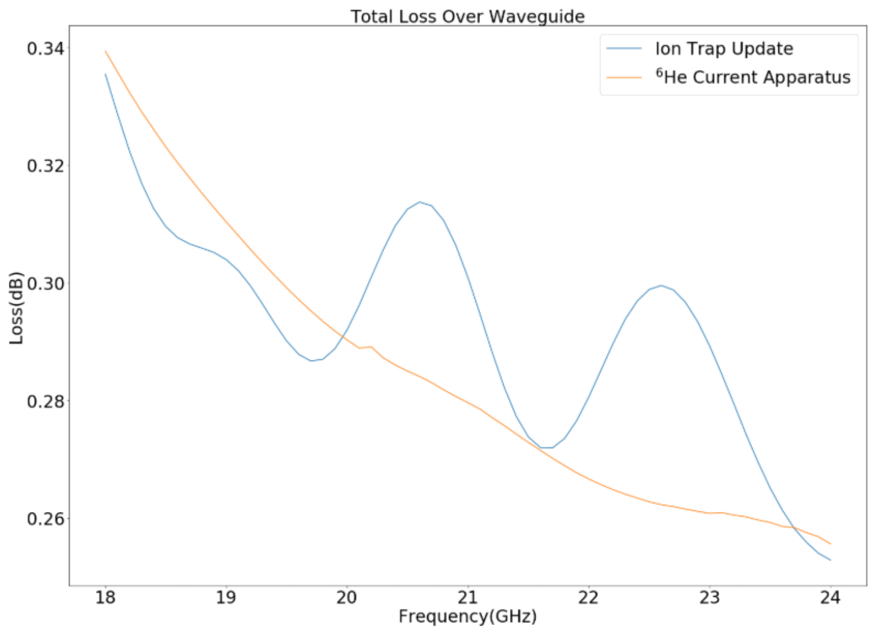

Fig. 3. The loss over the waveguide from the decay volume to the data collection waveport.

Using ANSYS' high-frequency structure simulator, HFSS, it was possible to create the waveguide within the environment and analyze the propagation of a given frequency band between two wave ports. Initially we attempted to minimize losses by testing different mesh densities over a hole cut into the waveguide. The results showed that there was no discernible difference between the different mesh densities. Next it was necessary to check how the loss over the Penning trap would differ from the loss of the current decay volume. Though the trap would not have the 25 holes for helium injection, it does contain Kapton spacers between each electrode. It was shown that the Kapton adds a small amount of loss to the system. Overall the system needs to remain below 1 dB of loss for the experiment to be viable, and though the loss of the system increased, we are still well below this threshold with the expected changes to the apparatus as shown in Fig. 3. From here, to update the experiment the Penning trap must be developed, along with an electron cyclotron resonance source and a radio-frequency quadrupole cooler buncher.

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