He6CRES experiment and ion trap addition update

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Through the use of the cyclotron radiation emission spectroscopy (CRES) technique developed by the Project-8 collaboration [1] to measure the β spectrum of ^{6}He, ^{14}O, and ^{19}Ne, the He6-CRES collaboration seeks to test the standard model (SM) by searching for scalar and tensor currents. The CRES technique gives a uniquely precise window to view the β energy E_e through the cyclotron frequency, f of the electron according to

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

where e is the electron charge, B is the magnetic field, and m_e is the rest mass of the β. This non-destructive technique allows incredible sensitivity the energy of the β [2]. The goal is to apply the CRES technique to search for distortions to the β spectrum caused by an interference of SM and beyond-the-SM scalar and/or tensor currents, described by the Fierz parameter, b_{Fierz}. This parameter, which is zero in the SM, is linearly sensitive to new physics and has discovery potential if measured to $\leq 1 \times 10^{-3}$ [3].

The experiment originally consisted of a rectangular waveguide with a U-shape turn to read frequencies from either end to cancel Doppler effects from the betas confined in the magnetic bottle (see Fig. 1). However, due to frequency-dependent abberations within the data we have terminated the I-side of the waveguide, *i.e.* the side that does not include the U-bend.

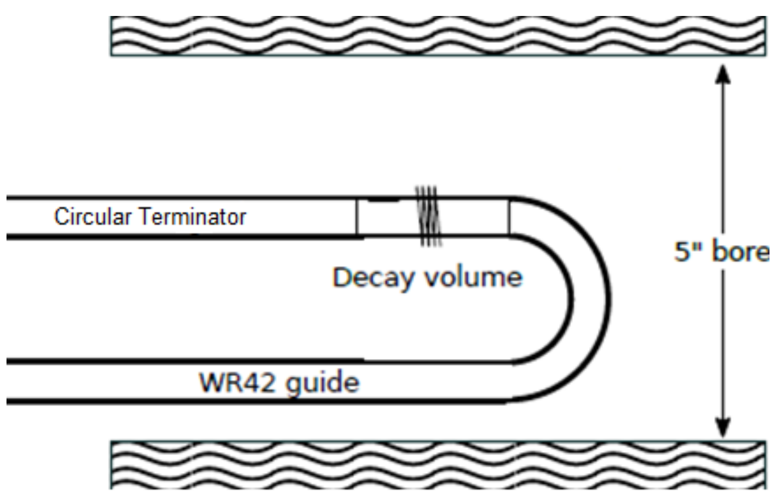

Fig. 1. Drawing of the U-shaped waveguide in the magnet.

A current limitation of the experiment is caused by a lack of radial confinement of the isotope of interest. As gaseous atoms are pumped into the system we expect an energy dependence on countable events within a region of our decay volume. In this case, the emitted betas of the ^{6}He nuclei that are near the walls are lost, and because of an increasing cyclotron radius with higher energy, higher energy betas 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 $b_{Fierz}{}^{6} < 10^{-3}$ [4].

To negate the issues of the wall effects, we have opted for measurements on the ratio between the beta spectra of two nuclei, ^{6}He and ^{19}Ne, where the ratio will wash out the energy-based efficiency effects. Also, given that effect of a non-zero b_{Fierz} on β^{+} to β^{-} energies is opposite, we double our sensitivity on the measurement. Over the last year two measurements were performed, one with the original waveguide and another with the updated, terminated waveguide.

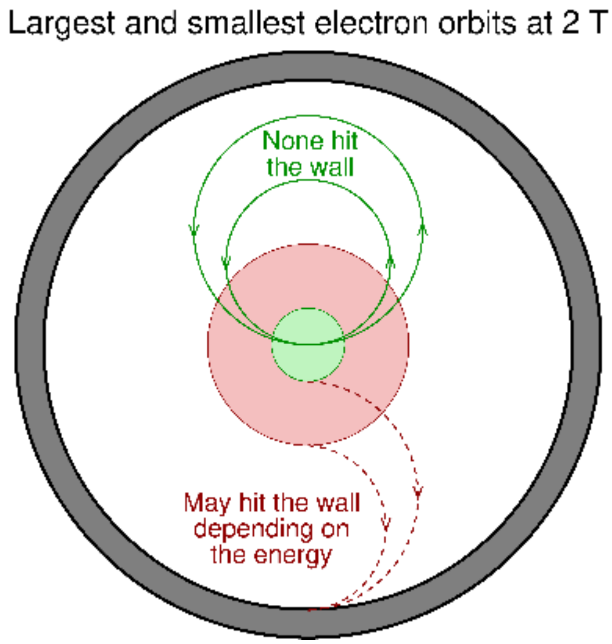

Fig. 2. The geometric effect of wall collisions in the case where there is no radial confinement of the isotopes.

However, to reach the desired precisions we must greatly increase our statistics, and eliminate the wall effects as well. To this end, two ion traps have been in development. The first, a radiofrequency quadrupole trap, will be used to cool and bunch a beam of ions before passing it to the second, a Penning trap, which will axially confine the ions while the magnetic field holds radially confines them. The Penning trap is designed with the same dimensions as the current decay volume being ~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 0.5-6 T to shift our 18 - 24 GHz window to different energies and scan the whole β spectrum.

SimION simulations have shown that the radiofrequency quadrupole trap (RFQ) is able to cool $^{6}He^{+}$ ions to allow for efficient injection and radial confinement within the small Penning trap. For this experiment we have rescaled a version of the TAMUTRAP RFQ [5] from $r_0 = 6$ mm to $r_0 = 12$ mm, which allows us to operate with $V_{RF} = 200$ V, and frequencies between 0.5-1.5 MHz. These parameters in the simulation gives us a time spread of 0.84 μs and an energy spread of 2.9 eV which is used to plan the rest of the beamline after the RFQ.

The limiting factor then became the maximum bunch size, as the CRES technique already has an extremely low efficiency due to the fact the magnetic bottle only confines one in 10^3 betas long enough to observe a CRES signal And in order to reach the desired precision, we expect to require 10^9 counts. Rate limitations of RFQs have not been studied in great detail since mass-measurements require low (single-ion) counting rates, with most RFQs presumed to be limited to 10^4/bunch. This rate would, however, result in months of counting for the shortest lived isotope of interest, and years to reach 10^9 for longer-lived isotopes. Along with other studies, such as for the General Purpose Ion Buncher [6], SIMION simulations have been performed which indicate it should be possible for the RFQ we designed for He6-CRES to reach $10^5 - 10^6$ ions per bunch without space-charge effects overloading the RFQ. This hypothesis, if true would greatly increase our count rate and lower our counting time to the point of making experiments with ^{19}Ne and even ^{14}O accessible, as shown in Fig. 3.

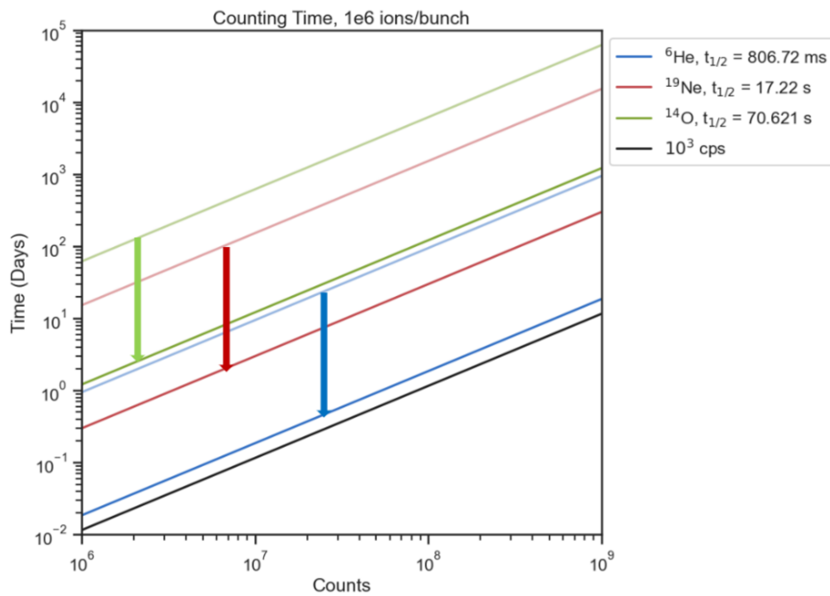

Fig. 3. The expected time to count in days to reach a given number of counts. The more transparent lines are for 10^4 particles per bunch, where the opaque lines represent 10^6 particles per bunch.

Testing the RFQ limits on bunch size will be occurring over the next year. First with the TAMUTRAP RFQ while the new RFQ is ordered, then with the new RFQ. Once the RFQ has shown that it is able to successfully transport large bunches with time and energy spreads allowing for efficient trapping within the Penning trap, it will be transported to the University of Washington where we will begin the Penning-trap upgrade to the He6-CRES experiment.

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