[6]HeCRES ion trap addition

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As described last year's report [1], the ^{6}He-CRES collaboration uses the cyclotron radiation emission spectroscopy (CRES) technique developed by the Project-8 collaboration [2] to measure the β spectrum of ^{6}He, ^{14}O, and ^{19}Ne from radiation emitted due to the 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 the electron charge, B is the magnetic field, and m_e is the rest mass of the electron. The incredible sensitivity of the CRES technique gives us the ability to use the frequency measurement to deduce the energy of the electron [3]. The use of this sensitivity is to measure distortions in the beta spectrum caused by a nonzero b_{Fierz} which is an indication of physics beyond the standard model. The experiment consists of a rectangular waveguide with a U-shape turn to read frequencies from either end to negate Doppler effects. 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 isotope of interes. This decay volume also has a coil around it creating a magnetic bottle to trap βs azimuthally.

The current limitation of the experiment is caused by a lack of radial confinement of the isotope of interest. Without this radial confinement, we expect an energy dependence on countable events within a region of our decay volume. In this case, the emitted betas of the 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. 1, resulting a bias toward lower energies in our energy spectrum.

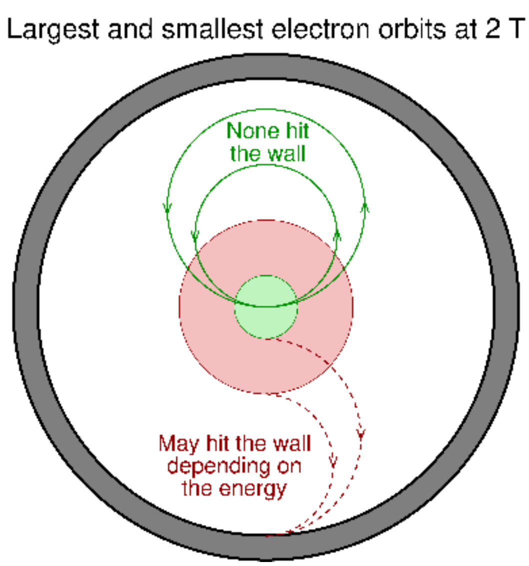

Fig. 1. The geometric effect of wall collisions in the case where there is no radial confinement of the isotopes.

With this issue it is still expected to get the uncertainty of $b_{\text{Fierz}} < 10^{-3}$ [4].

In order to resolve the issues of the wall effects, 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. With radially confinement effectively eliminating wall collisions, our expected precision on $b_{Fierz} < 10^{-4}$.

In order to accomplish this, SimION was used to simulate the radiofrequency quadrupole trap (RFQ) in cooling ^{6}He ions, as described in last year's report [1]. 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 2.89 eV which is used to plan the rest of the beamline after the RFQ. This timespread also defines the minimum width of our trapping region in the Penning trap. The RFQ design has been completed, though concerns of low count-rate caused by limited bunch sizes have held back development.

The Penning trap has similarly been tested with outputs from the RFQ simulation to confirm the hypothesis that we are able to radially confine ions from being within the danger zone where we see the energy dependence on our observed events. As seen in Fig. 2, the maximum radial position for ions in a bunch, we expect less than 0.24% of decays to occur within this region.

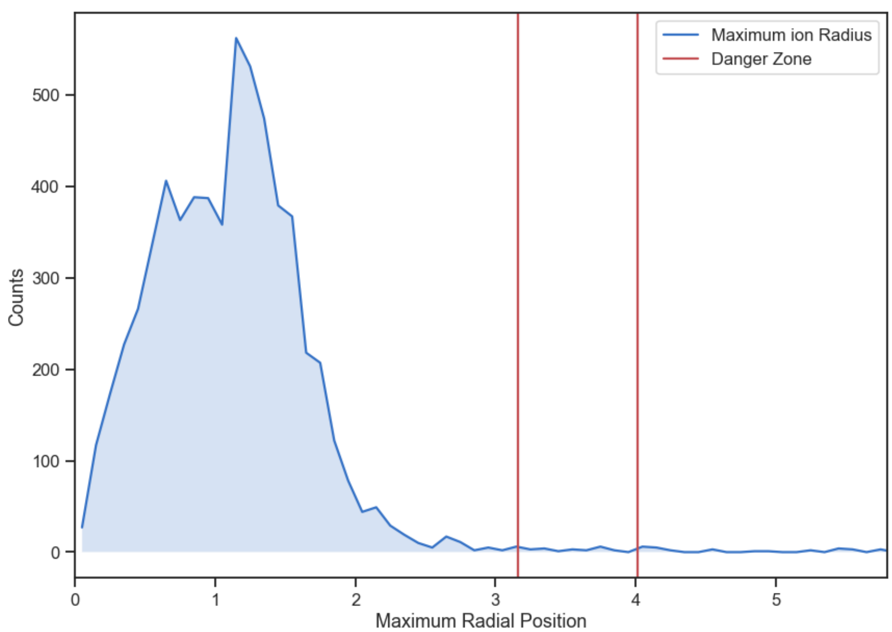

Fig. 2. A Plot of the maximum radial position in mm of every particle within a bunch during their time trapped within the Penning trap. The danger zone seen in Fig. 1 is represented as the region between the two vertical lines.

[1] D. McClain *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2020-2021), p V-68.
[2] D.M. Asner *et al.*, Phys. Rev. Lett. **114**, 162501 (2015).
[3] A.A. Esfahani *et al.*, J. Phys. G **44**, 054004 (2017).
[4] A. García, private communication.
[5] M.S. Mehlman, Ph.D. Thesis, Texas A & M University (2015).