TAMUTRAP—Design of the cylindrical Penning trap system

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The initial experimental program for the Texas A&M University Penning Trap facility (TAMUTRAP) will be centered on measuring the beta-neutrino correlation parameter, $a_{\beta\nu}$, in T=2, 0^+ to 0^+ superallowed β-delayed proton decays. In these experiments, $a_{\beta\nu}$ will be determined by observation of the proton energy distribution, which imposes three primary constraints on the design geometry of the apparatus: (i) the trap must provide a cold (few tens of eV), spatially localized source of ions with a minimal spread in time and energy; (ii) the geometry must allow for the full containment of the primary decay products of interest, in this case protons and positrons, which is facilitated by the Larmor precession of the particles within the trapping magnetic field; and (iii) provision should be made for flat disk-shaped position sensitive detectors held at arbitrary voltage to be placed at the ends of the measurement trap in order to detect the decay products.

In addition, the design of the TAMUTRAP facility has been optimized for precision mass measurements which requires that the trap geometry be both "tunable" and "orthogonalized" [1]. A quadrupole electric field is required for such measurements since the mass is related to the measured frequency of oscillation by the strength of the quadrupole component of the electric field. The geometry of a tunable trap includes compensation electrodes in order to produce the required quadrupole electric field at the trap center. An orthogonalized trap is one which employs a geometry in which adjustment of the voltages on the compensation electrodes does not affect the amplitude or shape of the quadrupole component of the electric field.

Additional measurement-independent constraints are also placed on the design of the trap geometry. The electrodes must be able to be machined and assembled taking into account real world fabrication precision. Furthermore, spacing should be allotted to prevent sparking between electrodes held at different voltages. And, finally, the entire trap must fit within the 210-mm diameter bore of the existing solenoidal magnet.

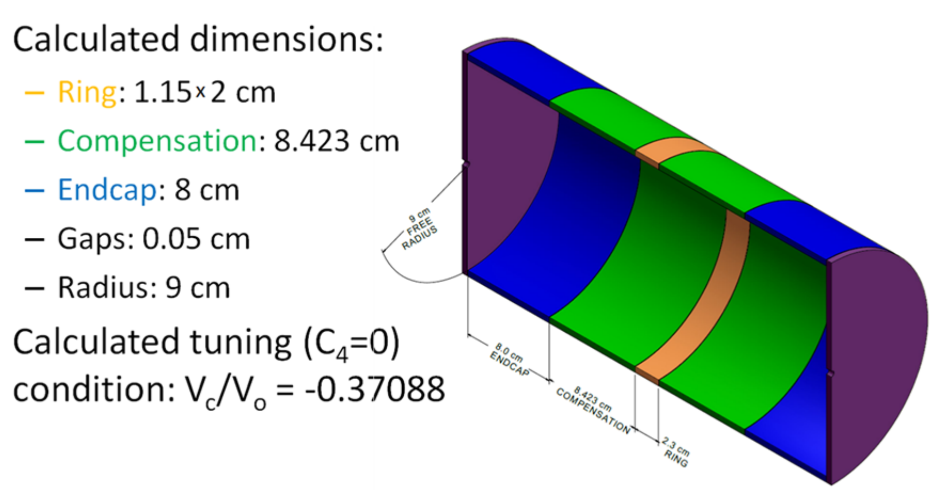

FIG. 1. Geometry of the large-bore cylindrical measurement trap.

Taking into account these constraints, the TAMUTRAP Penning trap system incorporates two cylindrical Penning traps within a large-bore superconducting solenoidal magnet having a field strength of 7 T. The first "purification" trap is similar to ISOLTRAP, and will be used optionally to further purify the incoming ion beam. The second "measurement" trap employs five electrodes with an inner radius of 90 mm. Since no existing Penning trap design could be modified or scaled to fulfill the design constraints for the measurement trap, the geometry was calculated from first principles. Using electrostatic techniques, an analytic description of a cylindrical, five electrode Penning trap of any electrode dimensions including gaps between electrodes, with endcaps of arbitrary voltage (to approximate detectors) was determined. Expanding the resulting potential at the trap center in Legendre polynomials and identifying the quadrupole term, the geometry was made both tunable and orthogonal. The trap design is shown in Fig. 1, and a cross section including the resulting field lines and the corresponding expansion coefficients can be found in Fig. 2. The 90 mm free radius of the measurement trap will be the largest of any existing Penning trap.

Coefficient of expansion	Calculated value for TAMUTRAP
C_0	-0.5728
C_2	0.4943
C_4	3×10^{-6}
C_6	0.02
C_8	-0.07

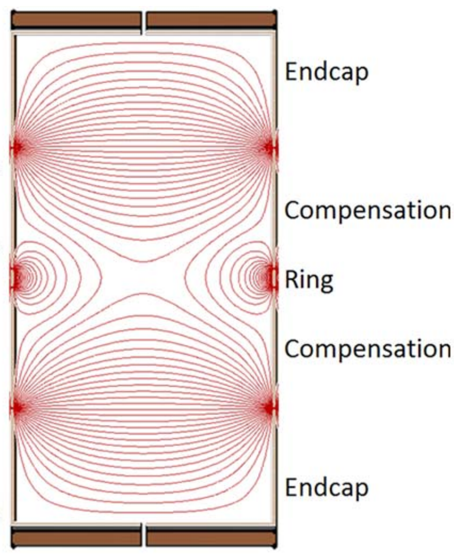

FIG. 2. Values of non-zero expansion coefficients (left) and a cross-sectional view of the measurement trap geometry with field lines superimposed (right).

[1] G. Gabrielse, L. Haarsma and S. Rolston, Int. J. Mass Spectrom. and Ion Processes **88**, 319 (1989).