Mass Measurements of ^{23}Na and Beamline Upgrades to TAMUTRAP Facility

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Introduction

The Texas A&M University Penning Trap (TAMUTRAP) Facility, located at the Cyclotron Institute, is centered around a novel, large diameter cylindrical Penning Trap. Currently the facility is being commissioned by performing mass measurements on stable ions using a half – size prototype Penning trap.

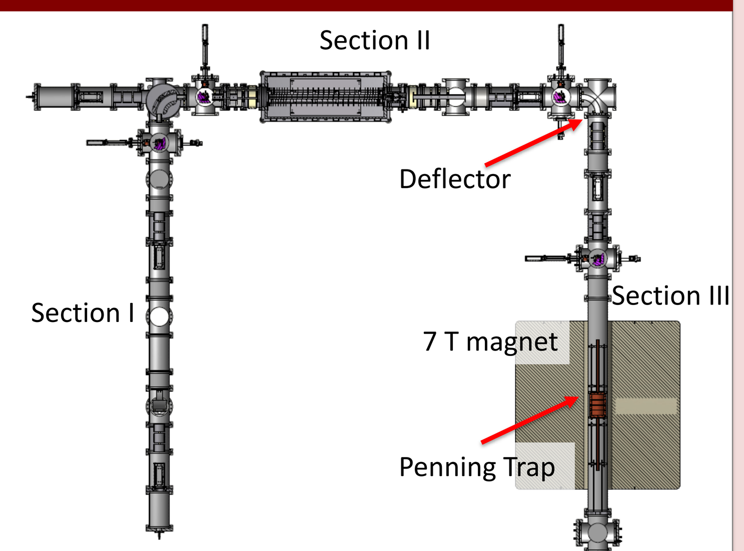

Figure 1: Graphic of TAMUTRAP beamline

Background & Motivation

Beta Decay

During beta decay, specifically beta plus decay, a proton is changed to a neutron through the exchange of a W^+ boson and the emission of a positron and an electron neutrino. The Standard Model predicts that the angle between the electron and anti-electron neutrino will be very small, with the β-v angular correlation parameter, $a_{\beta\nu} = 1$ (1). However, if anything other than a W^+ boson is exchanged, this parameter will be $a_{\beta\nu} < 1$. This will be an indication of physics beyond the Standard Model. TAMUTRAP will study this parameter for T=2, $0^+ \rightarrow 0^+$ superallowed beta delayed proton emitters(e.g. ^{32}Ar)(1).

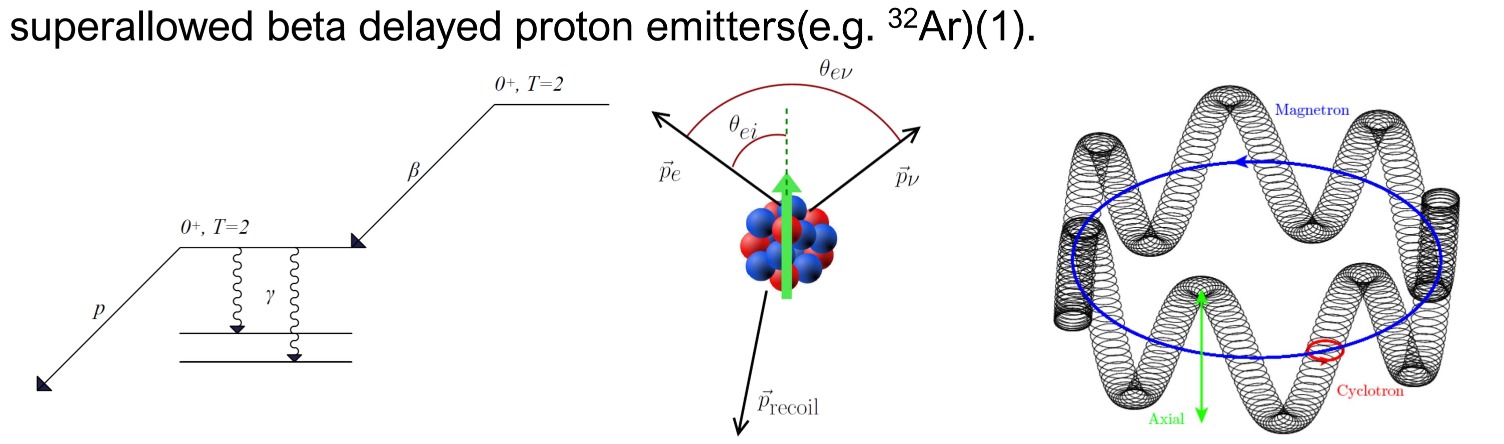

Figure 2-4: (From left to right) Diagram of the reaction to be studied(4), SM prediction of the relationship between decay products (4), and types of ion motion in a penning trap(3)

Ion Motion Inside a Penning Trap

A Penning trap is an ion trap that utilizes a static electric field and a linear magnetic field to confine ions to a small, well-known volume (2). When an ion is confined within the magnetic and electric fields of the Penning trap, it will undergo cyclotron motion. The cyclotron frequency (ω_c) can be found to determine the mass of the ion with the equation $\omega_c = \frac{qB}{m}$. This motion is a combination of three eigenmodes, each with a characteristic frequency. These modes are the magnetron(ω_-), reduced cyclotron(ω_+), and axial(ω_z) motions, where $\omega_- + \omega_+ = \omega_c$(5). Currently TAMUTRAP is performing mass measurements on stable isotopes such as ^{23}Na.

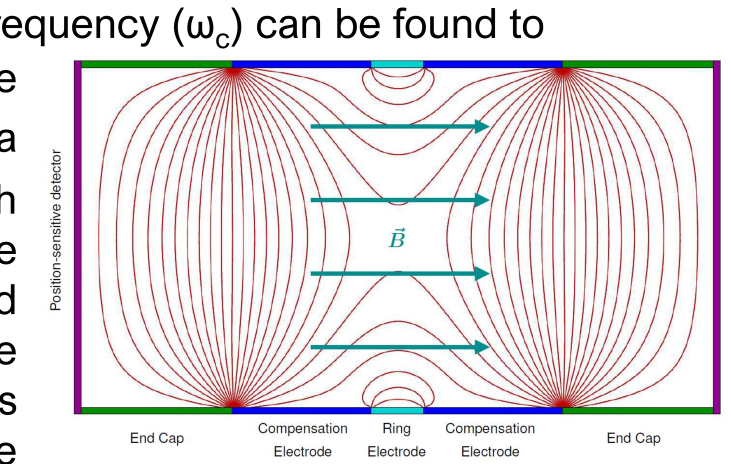

Figure 5: Trap geometry with electric and magnetic field lines(4)

Methods

Assembly and Cleaning

First, to ensure correct machining of all components, and that they all fit together, a preliminary assembly was done. In several instances pieces needed to be modified. Then, because TAMUTRAP will operate in a ultra-high vacuum of less than 10^{-8} mbar, all components are cleaned in an ultrasonic cleaner and rinsed with alcohol to ensure the removal of all contaminants.

Conductivity Testing

On the deflector, beam steerer, and Penning trap, voltages will be applied to certain components while others are held at ground. Therefore it was important to test that these components were electronically isolated.

Spherical Deflector & Beam Steerer

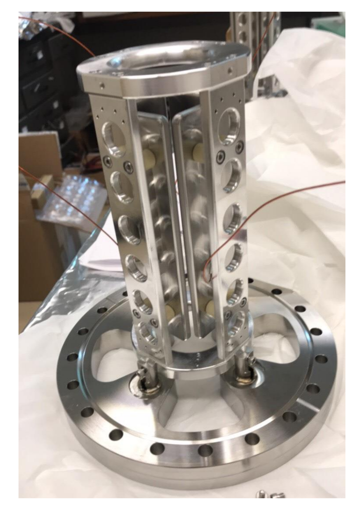

Figure 6: X-Y Beam Steerer

TAMUTRAP will operate at very a low radioactive beam current, so it is important that all beam-line components are efficient.

Beam Steerer

This beam steerer was installed in Section I of the beamline, and coupled with a gate valve.

Spherical Deflector

This spherical deflector replaced a previously used cylindrical deflector. Voltages applied to the inner spherically shaped electrodes bend the beam efficiently and, ideally, without beam aberrations (2).

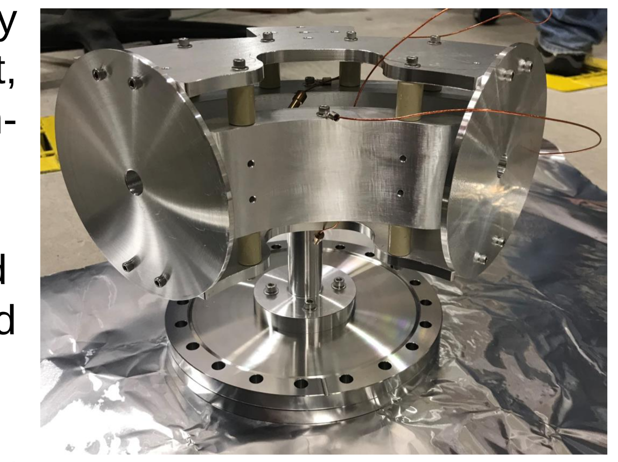

Figure 7: Spherical deflector

Penning Trap

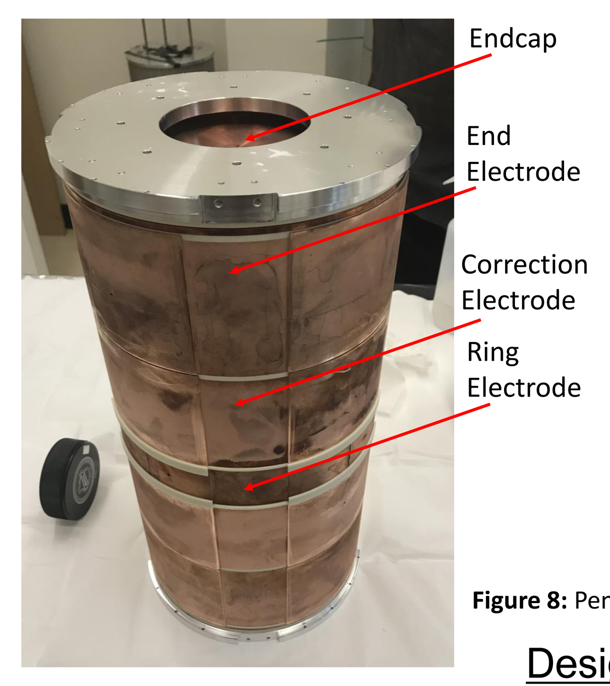

Figure 8: Penning Trap

Components and Dimensions

Inner Radius	90 mm
Length	335 mm
l/r_0	3.72

The length to radius ratio is much smaller than other traps such as ISOLTRAP, where l/r_0 = 11.75 (1). The large inner radii of the full size trap will allow us to study the decay of ions whose protons have even a large Larmor radii, up to 42.7mm in the case of ^{20}Mg (2).

Design Improvements

The extraction tube on the new, full sized Penning trap has been redesigned to have three segments to which different voltages can be applied, instead of one solid tube. This will allow us to reaccelerate the beam leaving the trap, decreasing beam loss.

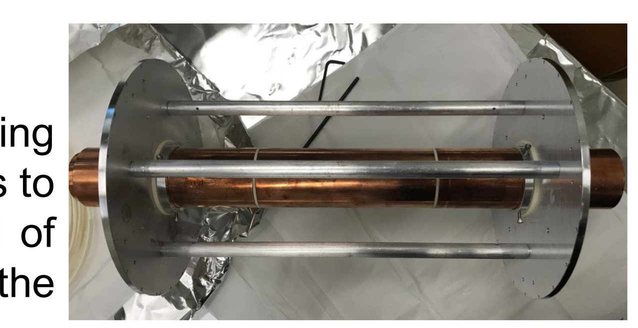

Figure 9: Extraction tube

Beamline Alignment

Currently, TAMUTRAP operates using stable isotopes from off-line ion sources. We attempted to realign Section I of the beamline to prepare the facility to receive radioactive beam from the K150 cyclotron.

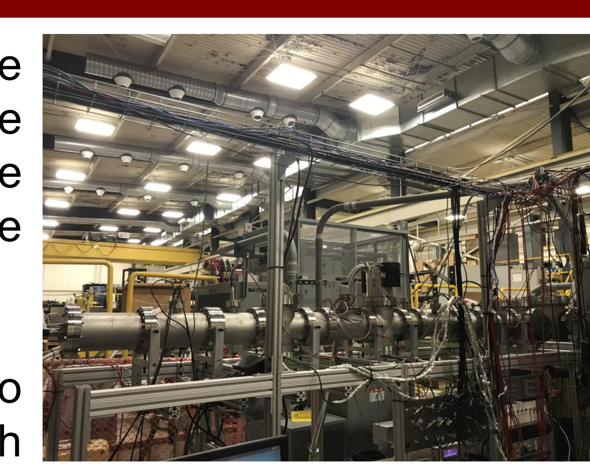

Figure 10: Section I of the TAMUTRAP beamline

Optical Transit Technique

Short range optical telescopes were aligned to previously set targets. The center of each flange is found using string and then aligned individually.

Figure 11: Bellow used in an attempt to couple Section I and II

Modifications

A gate valve and the new beam steerer were installed in the beamline. The gate valve will allow us to vent Section I of the beamline independently from Sections II and III.

Complications

There was a horizontal difference of 1” between Section I and II. Although it could be coupled using a bellow, it could not hold a vacuum.

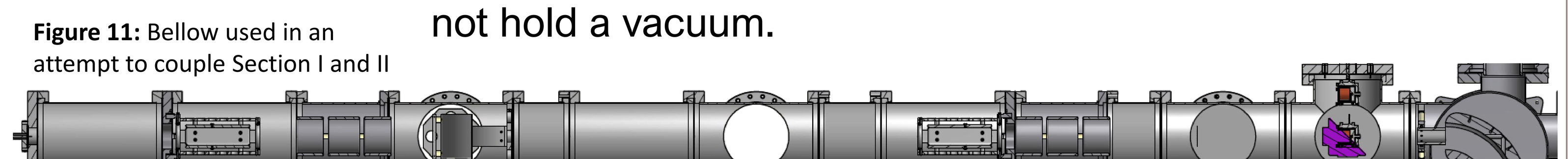

Figure 12: Graphic of Section I of the TAMUTRAP beamline

Mass Measurements

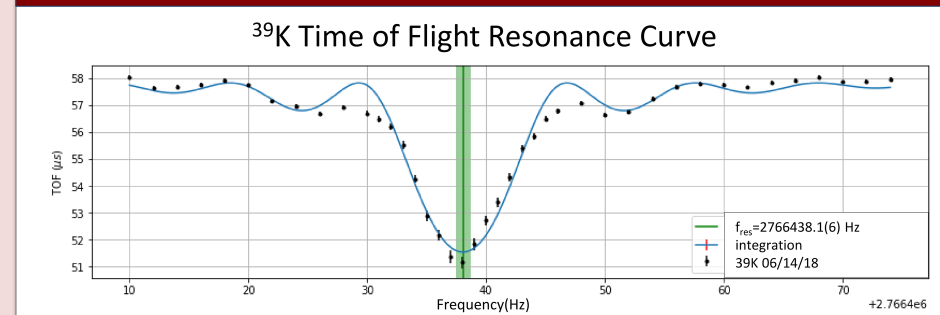

Figure 13: Graph of ^{39}K Time of Flight v Frequency

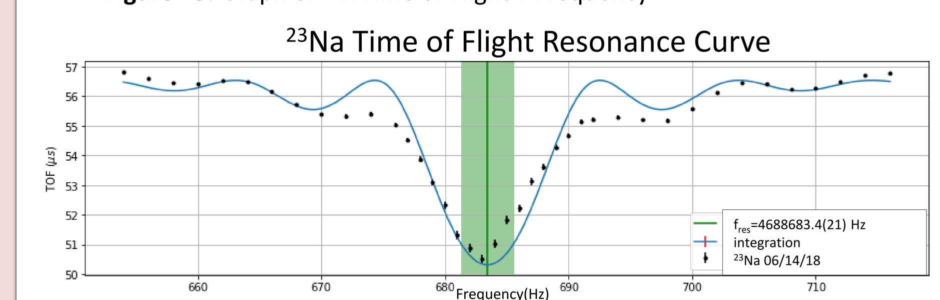

Figure 14: Graph of ^{23}Na Time of Flight v Frequency

When the ions are confined to the Penning trap, they are undergoing three modes of motion. To perform a mass measurement we must first couple this motion. This is done by first applying a RF to one segment of the trap ring electrode which increases the magnetron radius. Next, we apply a frequency to two segments of the electrode, near ω_c which increases the radial energy of the ion and leads to a coupling of ω_+ and ω_-. When the potential at the back of the trap is lowered, the radial energy is converted to axial energy and the ions leave the 7T field of the solenoid. They are then ejected towards the detector. Ions excited closer to the resonance frequency will have a shorter time of flight. Due to fluctuations in the magnetic field, we use a reference mass, ^{39}K, to calculate our target mass using the equation $m_{23Na} = \frac{f_{39K}}{f_{23Na}}(m_{39K} - m_e) + m_e$

Mass measurements were performed at a trapped ion energy of 115 eV and an excitation time of 100ms. We calculated the mass to be 22.989766(12) u with a precision better than $2x10^{-7}$. The literature value of the mass is 22.98976928u, and within the error of our measurement. Figures 13 and 14 display relatively large errors due to the asymmetry of the data.

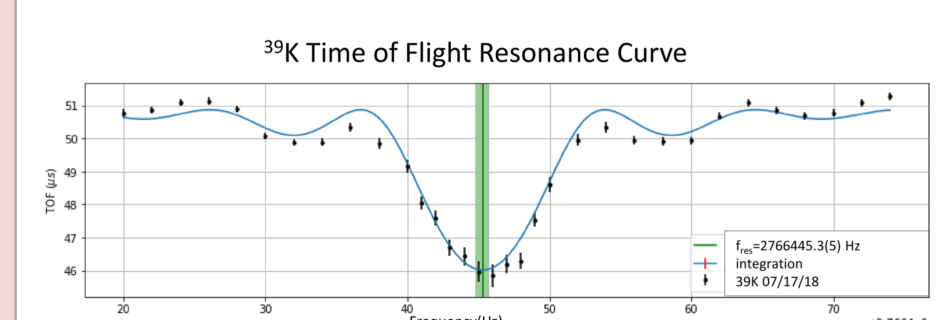

Figure 15: Graph of ^{39}K Time of Flight v Frequency

To demonstrate the functionality of the spherical deflector, scans were run on ^{39}K, with a trapped ion energy of 90 eV. A second mass measurement could not be run due to the delay in the alignment of Section I.

Conclusions and Future Work

Before the full size Penning trap can be installed, it must be gold coated to prevent oxidation and the support structure for the side of the penning trap needs to be machined. Additionally, Section I of the beamline needs to be realigned and coupled to Section II. The current plan is to disassemble Sections I and II of the beamline, and realign both. This will be beneficial because it will allow us to install an additional gate valve and replace Viton-O rings with copper gaskets.

From this work we found that we have the capabilities to measure the mass of ions to very high precisions. Furthermore, performing these mass measurements will allow us to characterize TAMUTRAP facility and thus better perform experiments in the future. Lastly, all hardware upgrades will facilitate the use of radioactive beam at TAMUTRAP.

References

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