Status of TITAN's Penning Trap Upgrades

A. Czihaly[1,2], S. Kakkar[1,3], E. M. Lykiardopoulou[1,4], A. P. Weaver[1] , A. A. Kwiatkowski[1,2]
[1]TRIUMF, BC, Canada, [2]University of Victoria, BC, Canada, [3]University of Manitoba, MB, Canada, [4]University of British Columbia, BC, Canada

Introduction

How do you measure the mass of a charged atom that lives for less than one second? That is the task of the Penning trap at TITAN, TRIUMF's Ion Trap for Atomic and Nuclear science. Penning traps confine ions using a magnetic field and an electric field, allowing for mass determinations. These high-precision mass measurements help us understand nuclear reactions that govern stars and fundamental interactions. In order to increase the precision of the trap, it has undergone a cryogenic upgrade, and a novel mass measurement technique, the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) method is being commissioned.

Upgrade Motivation

In Penning traps, the mass is determined the cyclotron frequency (Eq.1), with the precision of measurements scaling inversely with the charge state of the ion (q). TITAN utilizes an electron beam ion trap, making it the only facility in the world to use highly charged short-lived isotopes for this purpose. Highly charged ions have a higher probability to charge exchange with gas in the trap, diminishing the quality of the measurement. To prevent this, background gas can be reduced by improving the vacuum of the system by freezing out residual gas at cryogenic temperatures.

$$\nu_c = \frac{qB}{2\pi m}$$

Eq.1: Cyclotron frequency as a function of ion charge (q), magnetic field strength (B), and mass of the ion of interest (m)

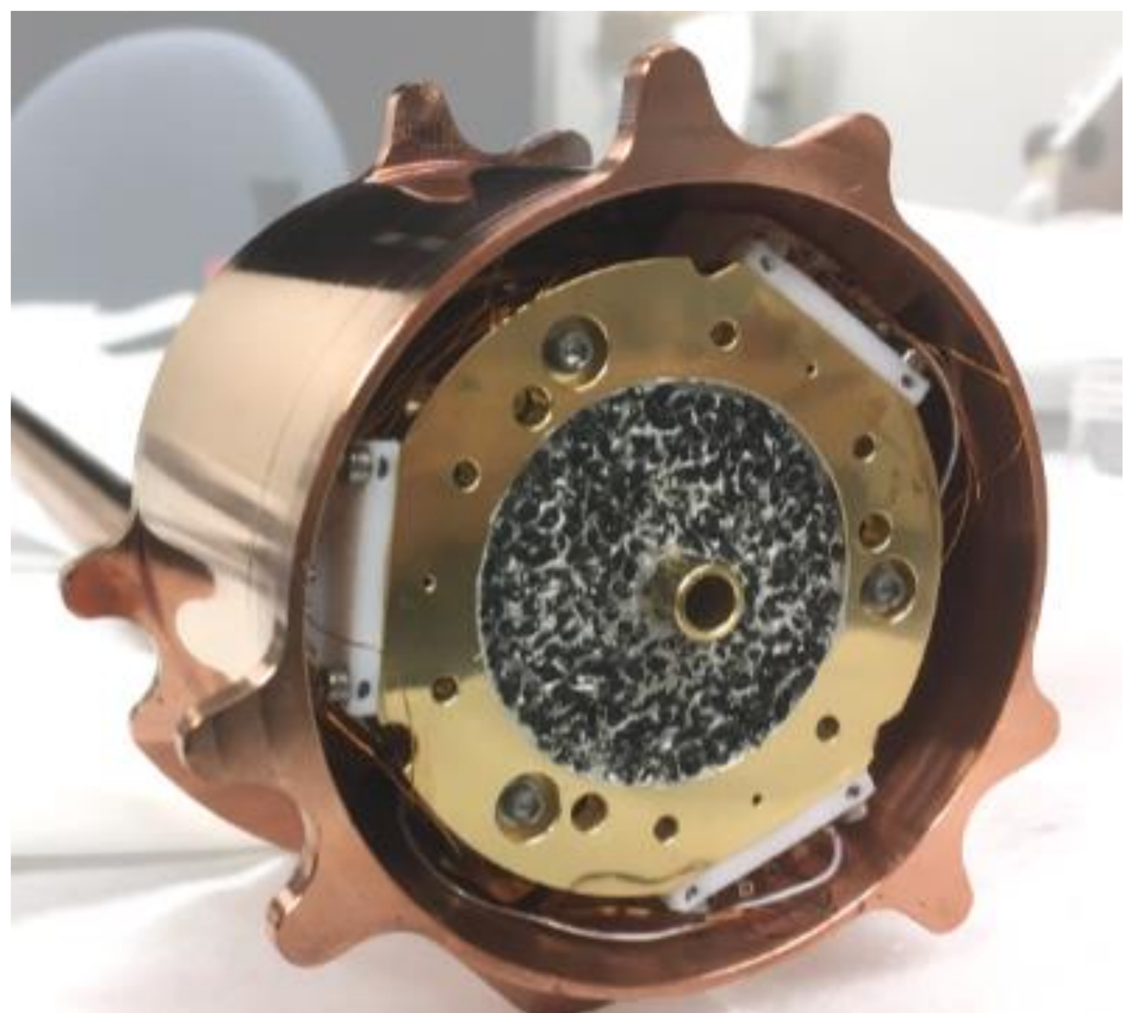
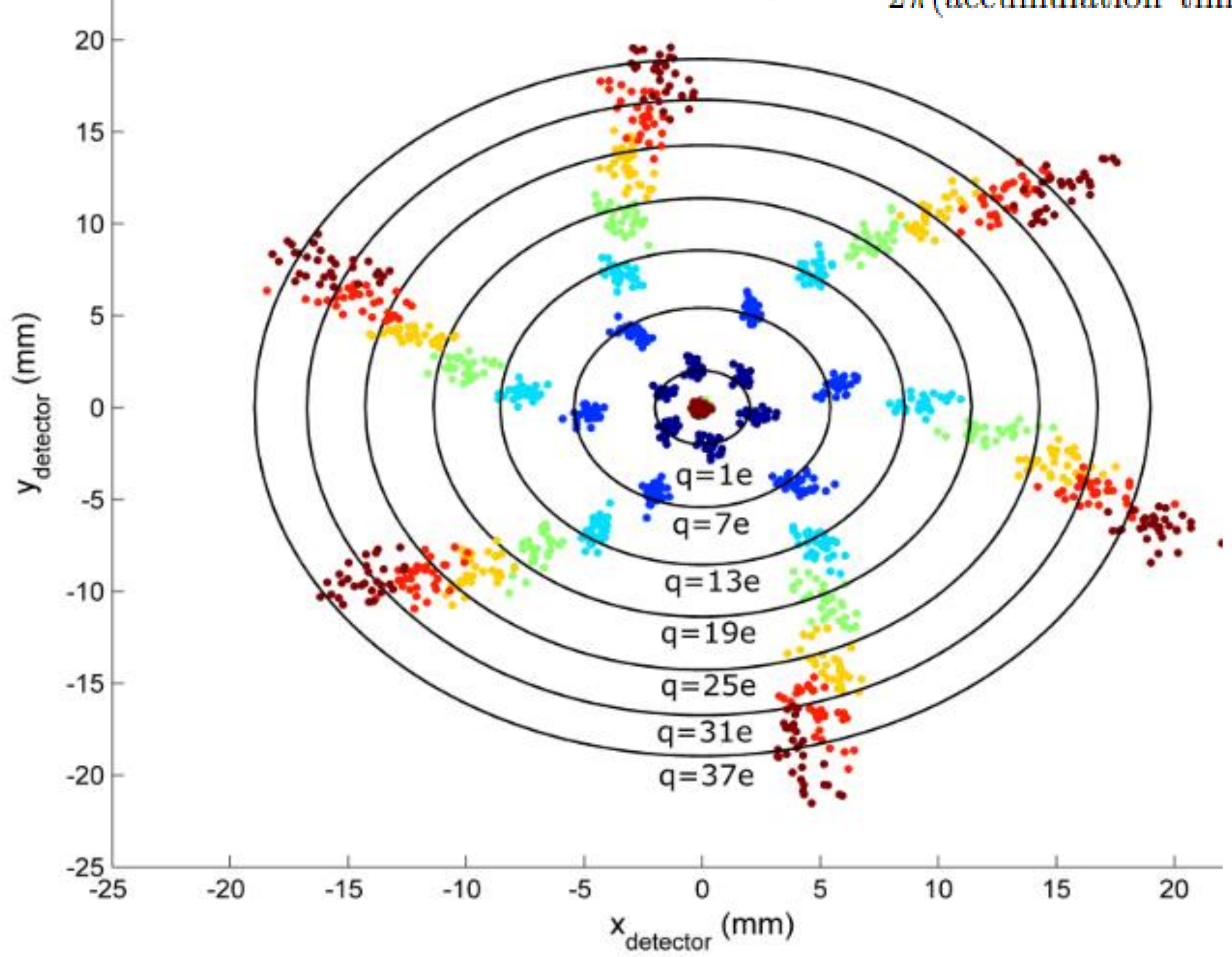


Fig.1: Trap with coconut-based carbon getter (black) on trap surface, gold-plated trap, copper shield

Cryogenic Upgrade

In order to be more compatible with highly charged ions, the trap has undergone a cryogenic upgrade. The update comprises the addition of a cryocooler to freeze background gasses on the trap surfaces and the redesign of the trap and surrounding optics. Since the cryocooler was expected to reduce the temperature of the trap to 11K, lighter gasses were trapped in a carbon getter (see Fig.1). As required, the cryogenic upgrade lowered the pressure of the trap by three orders of magnitude as compared to the room-temperature Penning trap [1]. A beamtime was completed on August 1, 2023 to commission the cryogenic trap using TRIUMF's stable beam source.

$$\text{frequency} = \frac{\phi + 2\pi(\#\ \text{of revolutions})}{2\pi(\text{accumulation time})}$$



Phase-imaging Technique

Thus far, we have relied on a robust time-of-flight based technique for mass determination. In 2013, a new methodology was developed which can improve precision by a factor of five for singly charged ions though simulations indicate higher gains as charge state increases. This new technique, PI-ICR, is currently being implemented and is expected to be complete within the next year.

PI-ICR Implementation Status

- ✓ Simulations of new technique to achieve radially symmetric optics
- ✓ Redesign, install, and tune through new optics
- ✓ Acquisition of RoentDek 40mm position sensitive detector
- ✓ Modification of DAQ for new detector for increased position resolution
- ✓ Development of an analysis tool
- ❑ Optimize beam spot and voltages
- ❑ Implementation and troubleshooting of new technique with stable ions
- ❑ Measure all systematic errors
- ❑ Commission technique with radioactive ions

Outlook

The cryogenic system upgrade was successfully commissioned in a summer 2023 experiment with a stable ion beam. PI-ICR implementation is anticipated to be completed between fall 2023 and spring 2024 with the expectation to test in 2024 with radioactive ion beam. In summary, this combination will provide more precision information for studies of nuclear astrophysics and fundamental symmetries.

References

[1] Lykiardopoulou, E. M. (2023), *Resurrecting the N = 20 island of inversion and upgrades to the TITAN measurement Penning trap,* PhD Thesis, UBC
[2] Leistenschneider, E. (2019), *Dawning of Nuclear Magicity in N=32 Seen Through Precision Mass Spectrometry,* PhD Thesis, UBC

Discovery, accelerated