A multiple reflection time of flight mass spectrometer for online isobar separation at TRIUMF

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Summary

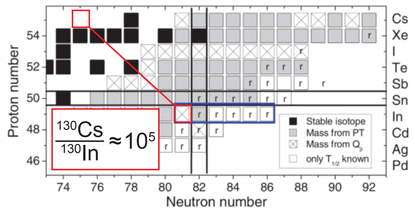
Penning trap mass measurements such as those carried out at TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) require pure samples of a single rare ion species. Distinguishing individual ion species becomes difficult when many species of similar mass are present in a sample.

The TITAN collaboration is currently commissioning a multiple reflection time of flight mass spectrometer, which will deliver high purity samples to the TITAN penning traps in a few milliseconds. The spectrometer was built in Giessen, Germany and it was recently shipped to TRIUMF in Vancouver; current work involves offline commissioning and simulation studies.

Motivation: isobar separation

- **Isobars are nuclei with the same number of nucleons but different proton/neutron ratios, resulting in mass differences of 10^{-4} to 10^{-6}. Isobaric contaminants can completely obscure ions of interest.**

- For instance, TITAN could help astrophysicists make better supernova models by measuring the mass of ^{130}In, but the facilities at TRIUMF produce 10^5 times more ^{130}Cs than ^{130}In [1,2]!



At left: chart of nuclides showing indium isotopes of interest along with ^{130}Cs background. The background is 10^5 times more abundant than ^{130}In. Figure adapted from [1].

- A multiple reflection time of flight (MRToF) spectrometer is a very high resolution device capable of isolating rare isobars like ^{130}In.

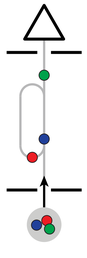
The multiple reflection technique

- **In time of flight (ToF) spectrometry, a cloud of ions flies with constant energy *E* over a distance *d*.**

- Light ions outpace heavy ions and reach the detector first, so we can calculate the mass and the mass resolving power from the flight time:

$$M = 2E\left(\frac{t}{d}\right)^2 \qquad \frac{M}{\Delta M} = \frac{t}{2\Delta t}$$

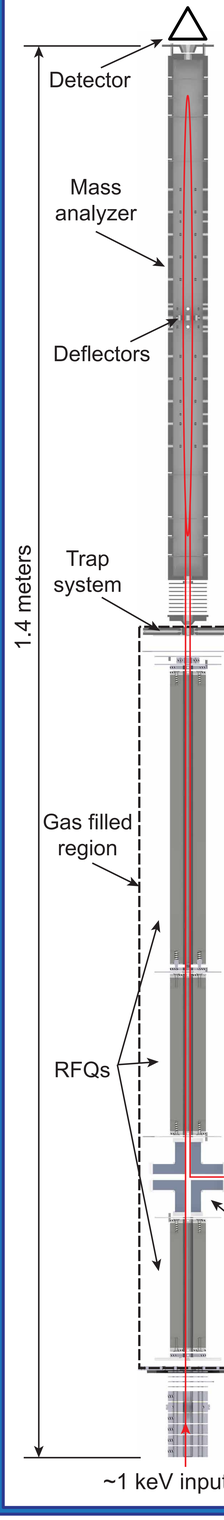
- The resolving power of a spectrometer measures how well the device can distinguish between similar masses. ToF resolving power can be increased by extending the ion flight path to increase the flight time *t*.



- **An MRToF spectrometer extends the flight path (to kilometers if necessary) by reflecting ions between two mirrors.**

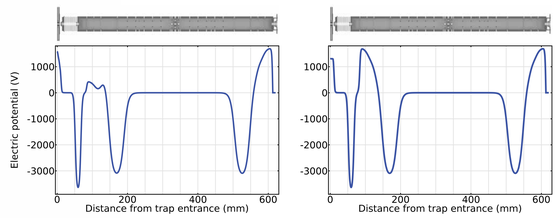
- With this technique we can achieve resolving power greater than 10^5 in a device the size of a refrigerator. For stable ions the resolving power is limited primarily by the accuracy and stability of control electronics.

The TITAN MRToF spectrometer



The mass analyzer

- Nine hollow stainless steel cylinders are stacked together to form the mass analyzer. The analyzer is mounted inside a vacuum chamber to prevent collisions with background gas during analysis.
- The nine analyzer electrodes generate fields which focus and reflect the ion beam to keep it contained in the analyzer.
- A detector at the top of the analyzer allows the user to rapidly generate a high resolution mass spectrum of the beam.



Electric potentials in the analyzer: loading a sample from the trap (left) and in multi-reflection mode (right).

The trap system

- A trap in front of the analyzer collects ions before analysis and allows them to cool via collisions with Helium gas. Cooled ions form a very small cloud in the center of the trap after many collisions (up to 1 ms), creating a well defined energy and starting point for the analysis.
- For samples which are ejected to the Penning traps, ions of interest are also recaptured in this trap in a novel process described at right.

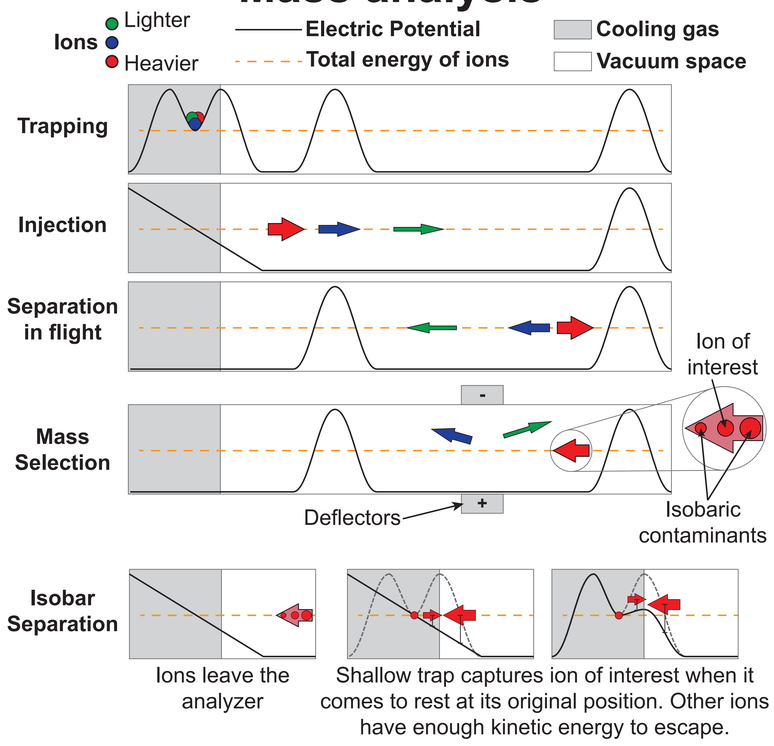
Beam transport

- The transport system to and from the mass analyzer is a series of gas-filled radio frequency quadrupoles (RFQs).
- Electrostatic optics at the input slow the 1 keV input beam to a few eV.

The Cube

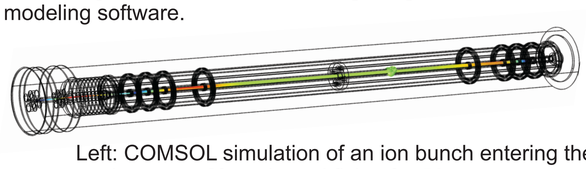
- A novel six-port switch sits at the center of the transport system. The cube can accept or transmit ions from any of its six faces.
- The space between the ports coupling the MRToF spectrometer to the existing TITAN system is too small for the mass analyzer, so this cubic switch is crucial to the project.

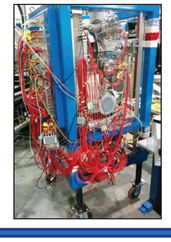
Mass analysis



Current Status

Preliminary testing of the mass analyzer in Giessen demonstrated a resolving power of greater than 50,000 in about 8 ms. The spectrometer arrived at TRIUMF in September and we expect to reach a mass resolving power of 100,000 by the end of November. Once high resolving power has been reached, a detailed study of the acceptance of the transport system will be conducted. The spectrometer will be installed on the TITAN beamline in winter 2015. In addition to offline commissioning, current work involves migrating simulation of ion trajectories to new modeling software.





Left: COMSOL simulation of an ion bunch entering the analyzer at a 2° angle and flying for 50 ns.
Right: The spectrometer unpacked at TRIUMF.

Acknowledgement and references

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[1] TRIUMF letter of intent for experiment S1415, https://mis.triumf.ca/science/experiment/view/S1415LOI
[2] ISAC yield database at http://mis.triumf.ca/science/planning/yield/target/U