Optimization of a Multi-Reflection Time-of-Flight Mass-Spectrometer at the RIBF

Kevin Murray

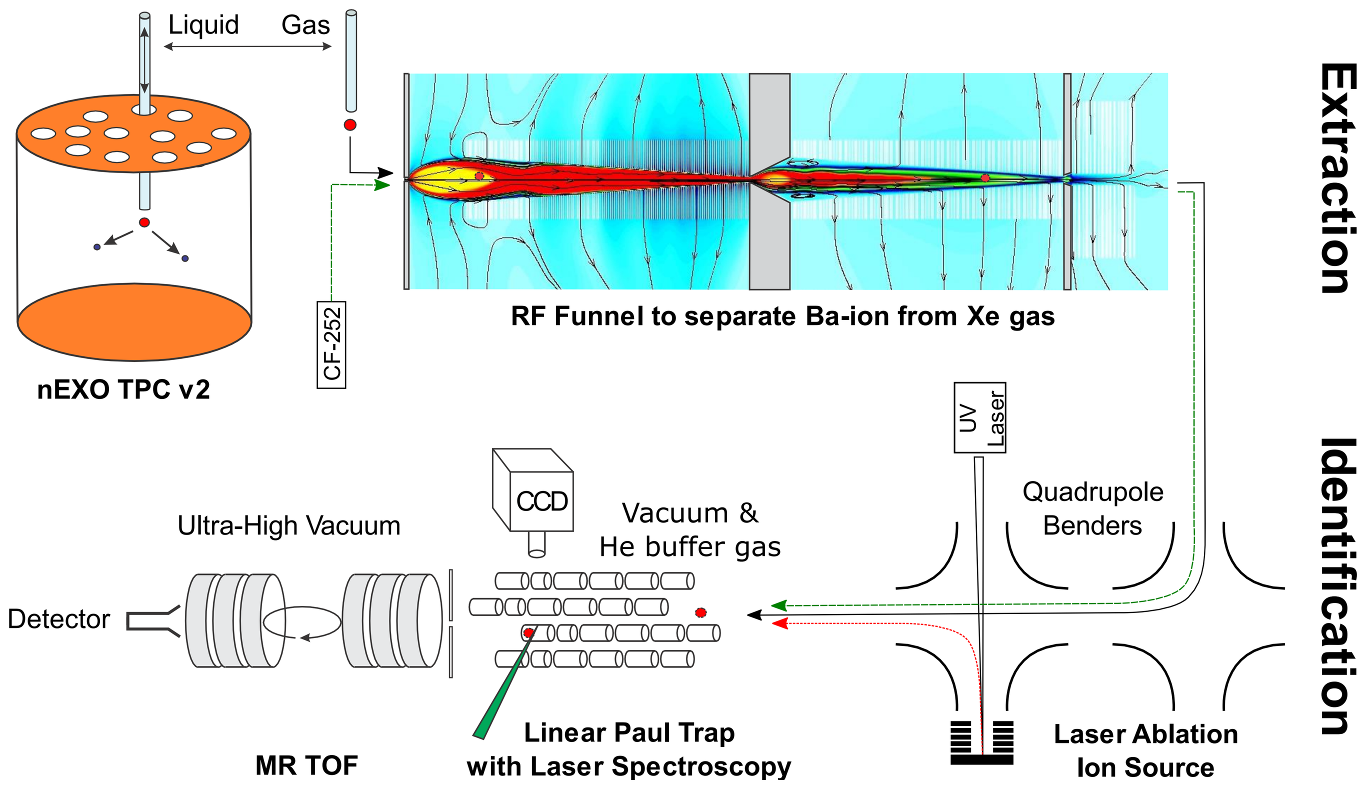
Introduction

nEXO

- The nEXO collaboration is searching for neutrinoless double-beta (0νββ) decay in the isotope Xe-136[1].
- 0νββ decay is only possible if the neutrino is a Majorana particle, i.e., the neutrino and antineutrino are the same particle.
- The nEXO experiment plans to deploy 5 tonnes of liquid Xe in a Time Projection Chamber (TPC). The detector is anticipated to be located in the cryopit at SNOLAB[2].

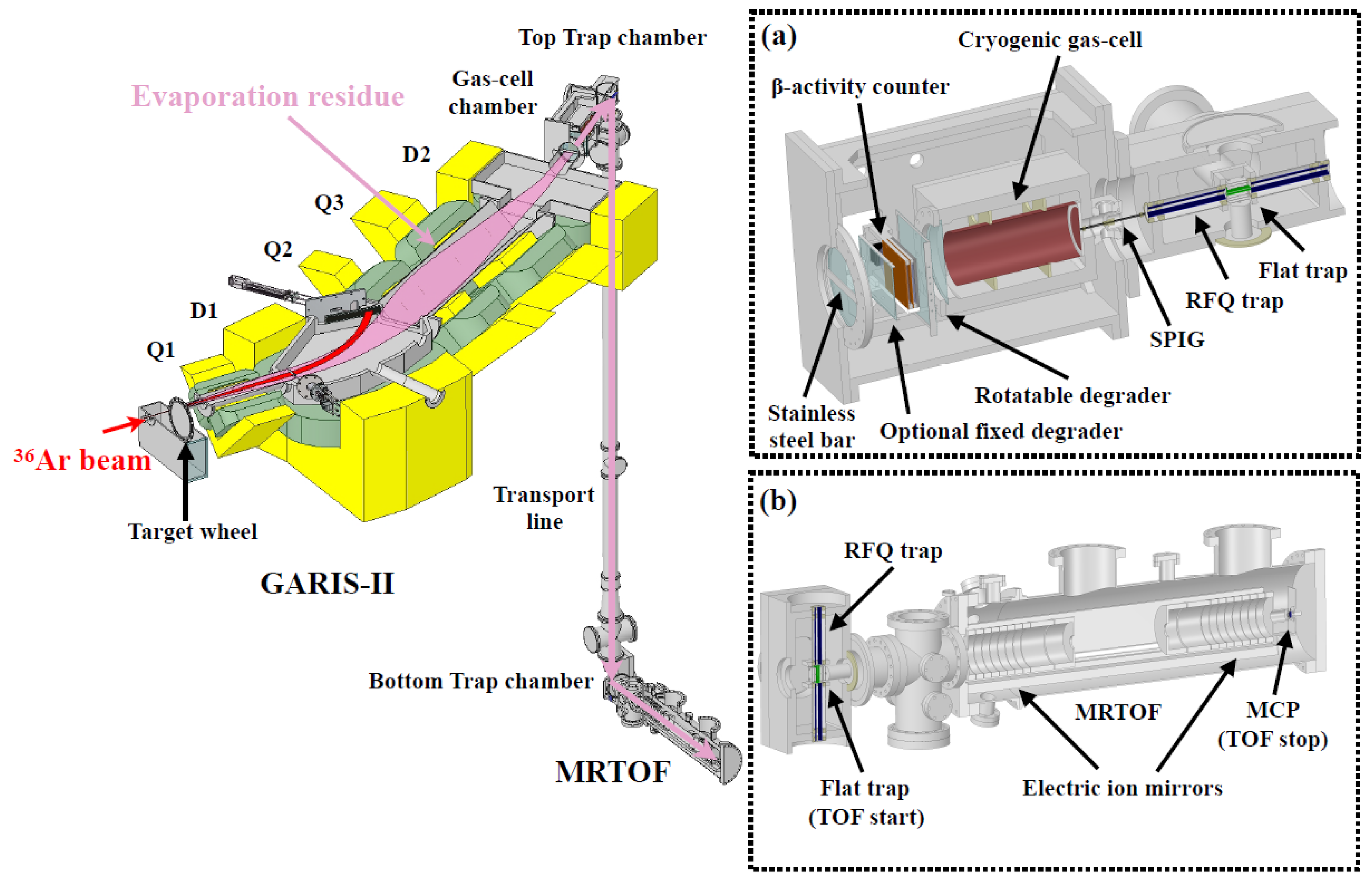
Barium-tagging

- Xe-136 double beta decays to Ba-136. The goal of Barium-tagging is to extract this Barium ion from the experiment vessel, and identify it. Eliminating all other backgrounds.
- After extraction from the TPC, ions are separated from the Xe gas with an RF-Funnel[3], then cooled and bunched with a Linear Paul Trap (LPT), in which the Ba ion can be identified with laser spectroscopy.
- Ion bunches are then injected into a Multi-Reflection Time-of-Flight Mass-Spectrometer (MR TOF) for further analysis.

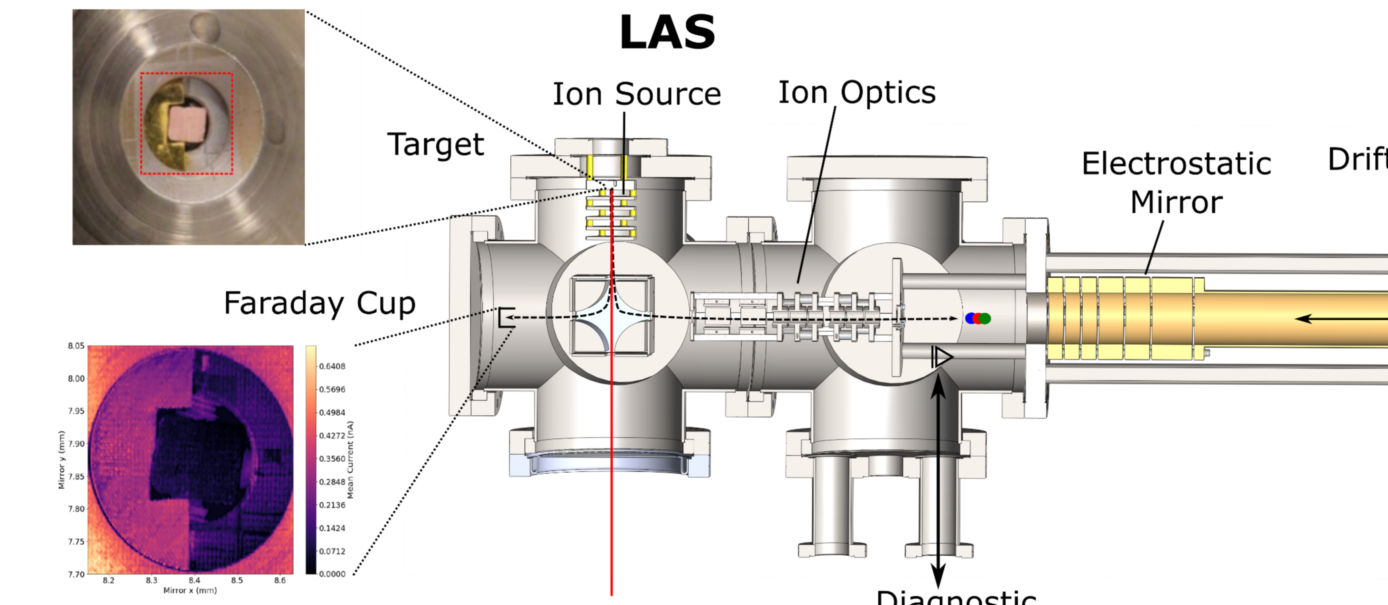


The RIBF

- The Radioactive Ion Beam Facility (RIBF), is host to the worlds largest superconducting ring cyclotron.
- The heavy-ion linear accelerator, that forms the first stage of the cyclotron, produces a beam which impinges on a rotating target.
- This interaction produces a beam of unstable isotopes, which are stopped in a gas cell, and cooled with a radio-frequency quadrupole (RFQ) trap[4].
- The masses of these nuclei can then be measured by an MR TOF.
- An MR TOF is used since it can provide a mass-resolving power in excess of 10^5, with only milliseconds of measurement time.
- These are the same qualities that make the MR TOF useful for Barium-tagging.



The MR TOF



- The MR TOF, reflects ion bunches between two electrostatic mirrors, with 6 electrodes in each, located on the ends of a drift-tube.
- All ions are given approximately the same kinetic energy and will separate in TOF by their mass.

The resolution can be calculated with[5]:

$$R = \frac{t}{2\Delta t} = \frac{t_0 + nT}{2\sqrt{(\Delta t)^2 + (n\Delta T)^2}}$$

- t_0 – Time of flight from the LPT to the center of the MR TOF.
- n – Number of revolutions.
- T – Time of flight for a single revolution.
- Δt – Turnaround time for ions leaving the LPT.
- ΔT – Time of flight spread due to mirror aberrations.

To maximize the resolution, the MR TOF's operational parameters must first be optimized.

Optimization

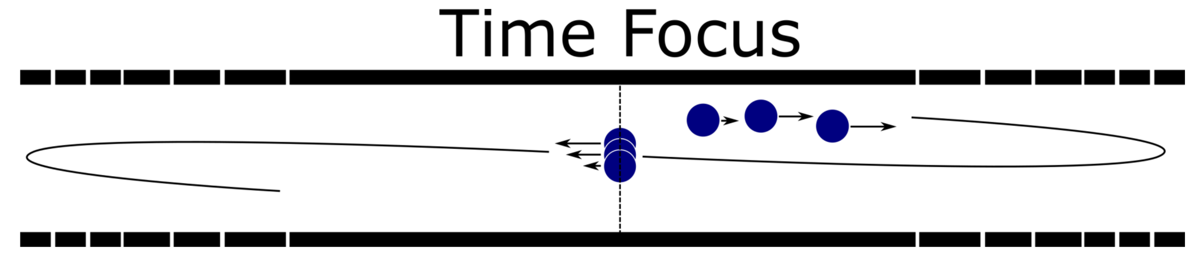
Requirements

The MR TOF needs to function as a:

- **High-resolution mass-spectrometer**, capable of isobaric separation.
- **Broad-range mass-spectrometer**, for systematic studies of the Barium ion extraction technique.

To achieve this it must be able to:

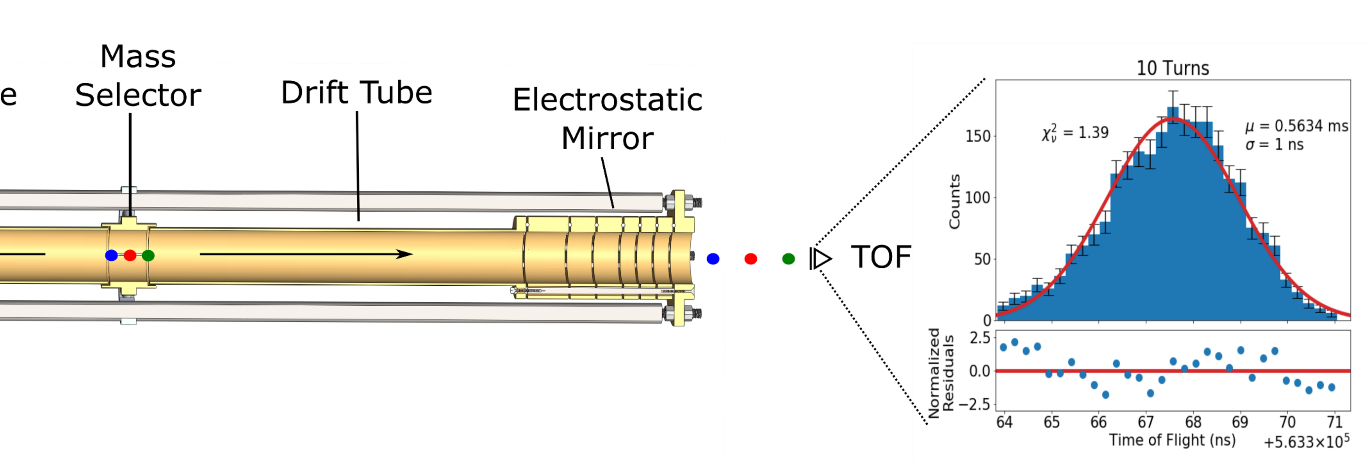
- Correct for time-of-flight aberrations.
- Eject unwanted ions with precision
- Switch easily between the number of revolutions.



Strategy

- The MR TOF has 6 potentials that must be tuned simultaneously.
- All ions of the same mass-to-charge ratio must reach the detector at the same time. This point in space is referred to as a time focus[6].
- A novel optimization program, based on a simplex algorithm, was developed with the ray-tracing simulation software SIMION 8.1.
- With this method, the MR TOF was optimized, and has an estimated mass-resolving power over 10^5.

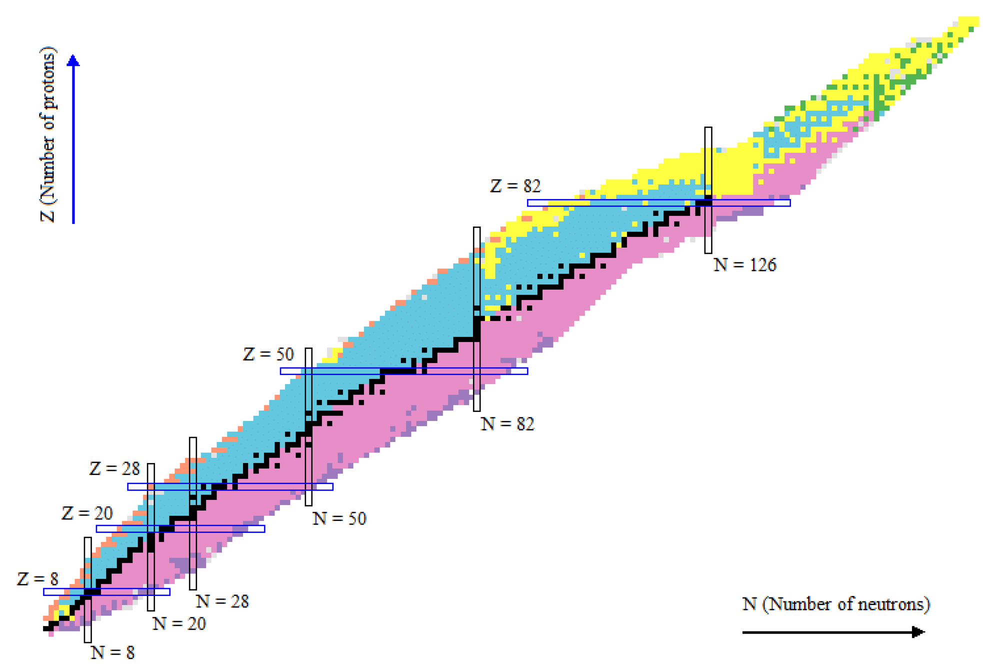
Commissioning the MR TOF



- The MR TOF will be machined and commissioned throughout 2019.
- The device is designed to operate with ion bunches produced by an LPT, which is being constructed at TRIUMF.
- To commission the MR TOF, while the LPT is under construction, a LAS will be used instead.
- The LAS produces ion bunches by pulsing a UV laser onto a target, and ablating the surface.
- The produced ions can either be measured with a Faraday Cup, or injected into the MR TOF, for time-of-flight measurements.

Research Goals

- Since no MR TOF exists currently at McGill University, conducting research with an MR TOF at the RIBF is a fantastic opportunity to gain expertise in the field.
- It also affords an opportunity to benchmark the optimization algorithm developed at McGill on a physical MR TOF. This can provide insight into ways in which the algorithm may be improved.
- It is likely that beam time access will be obtained during the research period, allowing for mass measurements on unstable isotopes.



Source: Tracy Jr, James. (2017). A Binding Energy Study of the Atomic Mass Evaluation 2012.

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