Commissioning of a Multiple-Reflection Time-of-Flight Mass-Spectrometer for Barium-tagging

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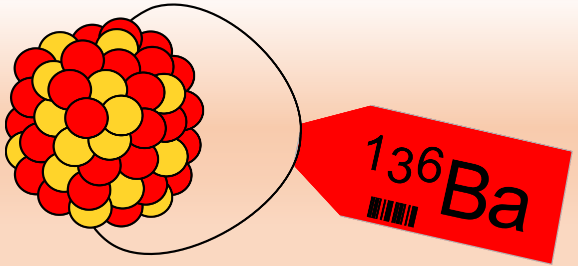
The nEXO Experiment

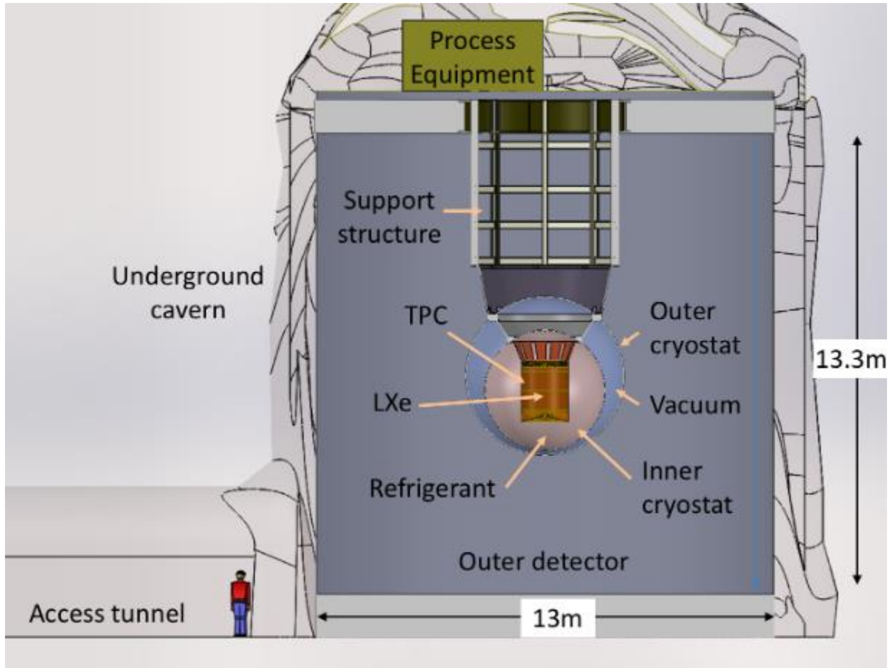


Context

- nEXO is a 0νββ experiment that uses a tonne-scale liquid Xe TPC.
- The ββ decay of ^{136}Xe produces ^{136}Ba, allowing for a unique opportunity.
- Ba-tagging is a potential future upgrade to nEXO, that aims to suppress backgrounds by extracting and identifying the daughter Ba ion of ββ decay.

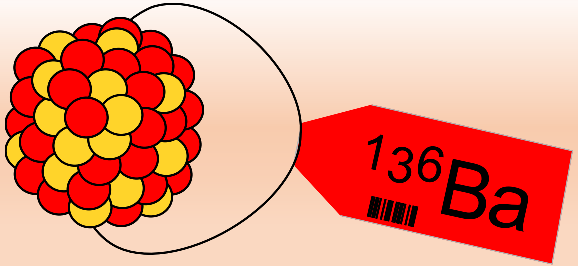
$$^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^{-}$$

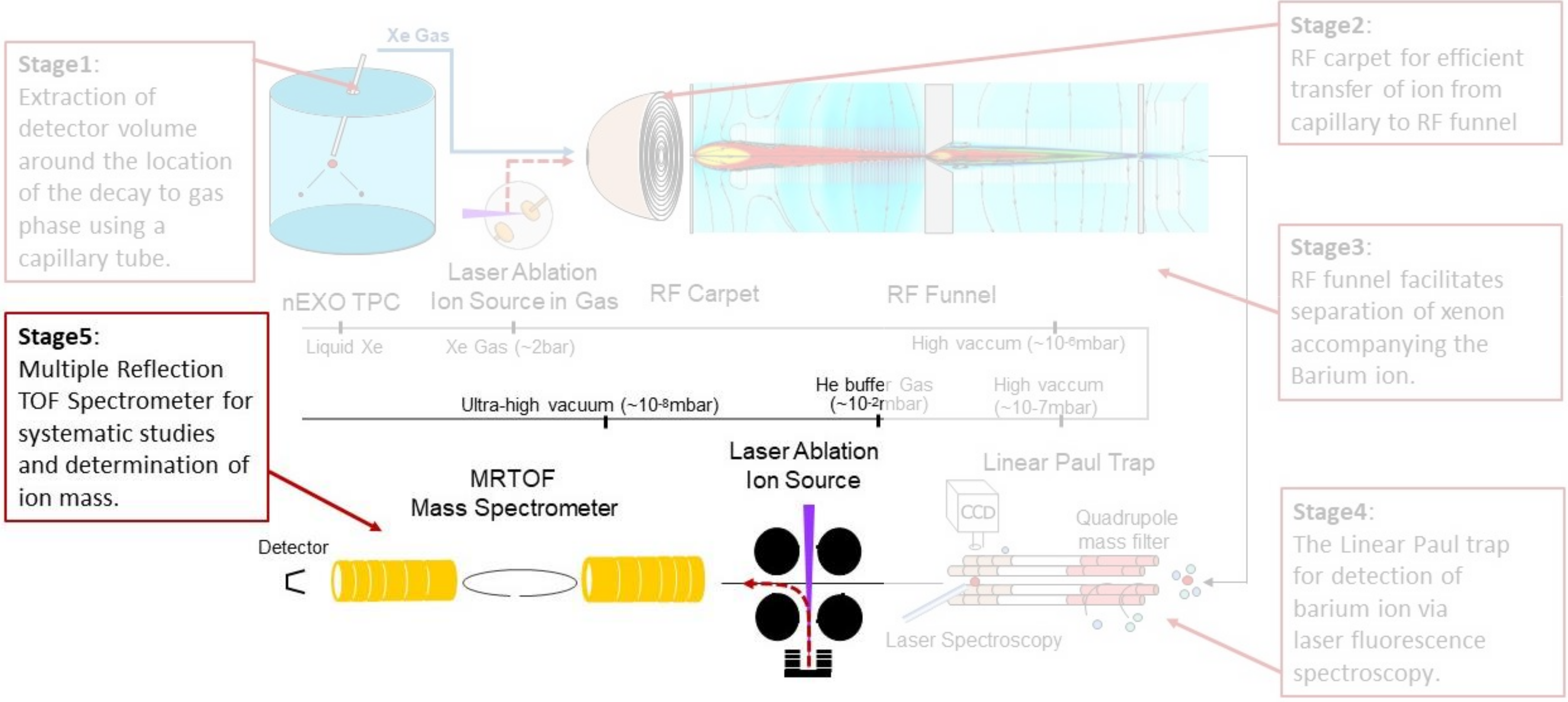
Extract from TPC volume and identify.



Source: nEXO Pre-Conceptual Design Report
arXiv:1805.11142

Barium Tagging in Canada





The MRTOF

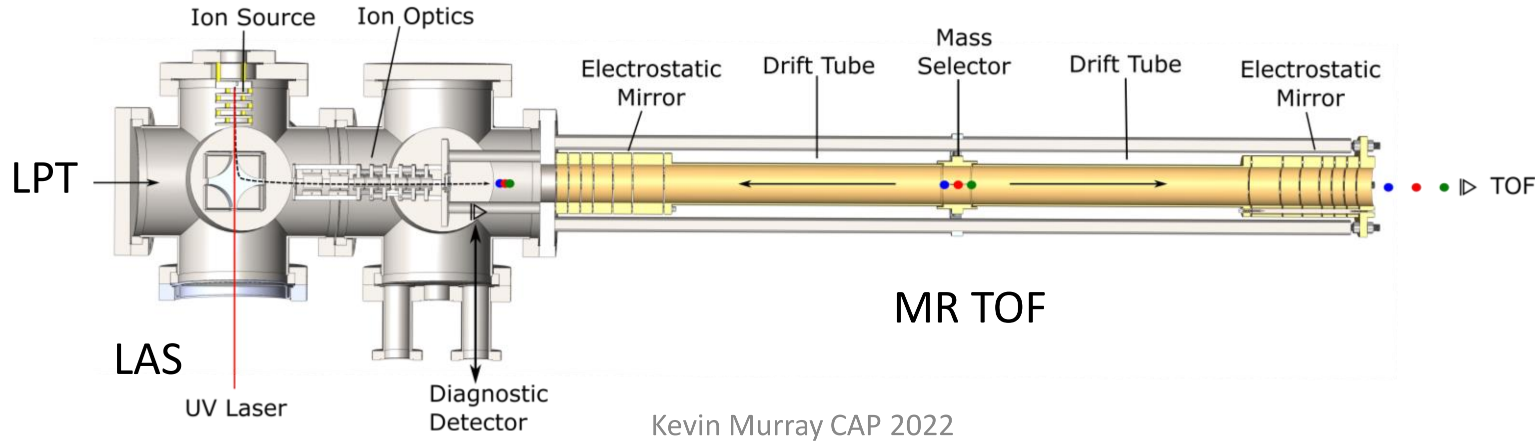
Operating Principle

- Ions accelerated by potential U gain kinetic energy $E_{kin} = z_i eU = \frac{m_i v_i^2}{2} \rightarrow t \propto \sqrt{m/q}$
- Ions with different mass-to-charge separate in time, and can be resolved if $\Delta t_{ij} > \Delta t_i, \Delta t_j$
- Calculated with mass-resolving power (MRP), $R = m/\Delta m = t/(2\,\Delta t)$

^{136}Xe mass = 135.907219(8) u, ^{136}Ba mass = 135.9045759(4) u , ∴ Δm =0.0026 and $R = m/\Delta m \approx$ 52000

Design

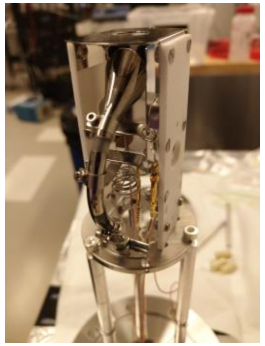
- Consists of central drift-tube and 2 electrostatic mirrors formed by 6 cylindrical electrodes.
- Ions are reflected between the mirrors to dramatically increase the MRP.

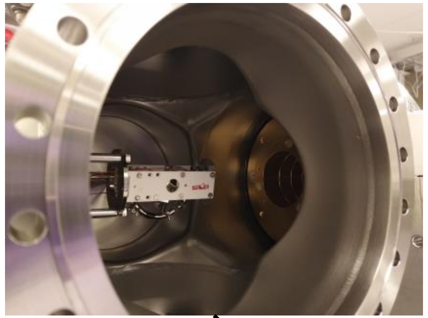


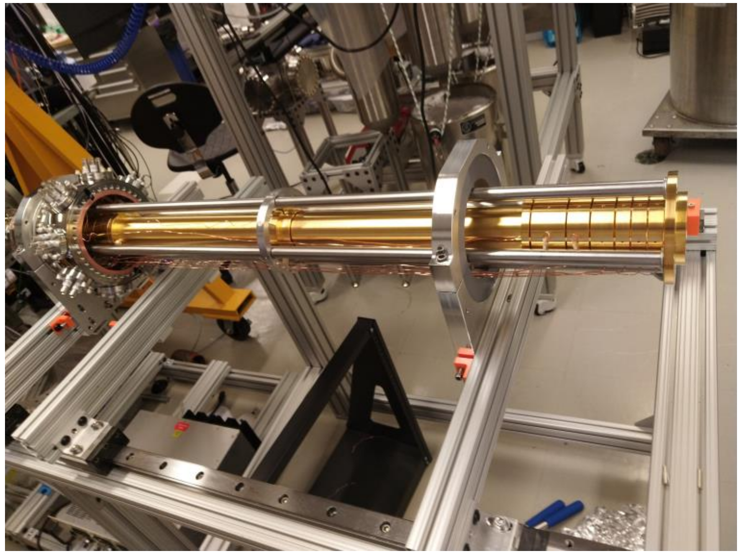
Assembling the MRTOF

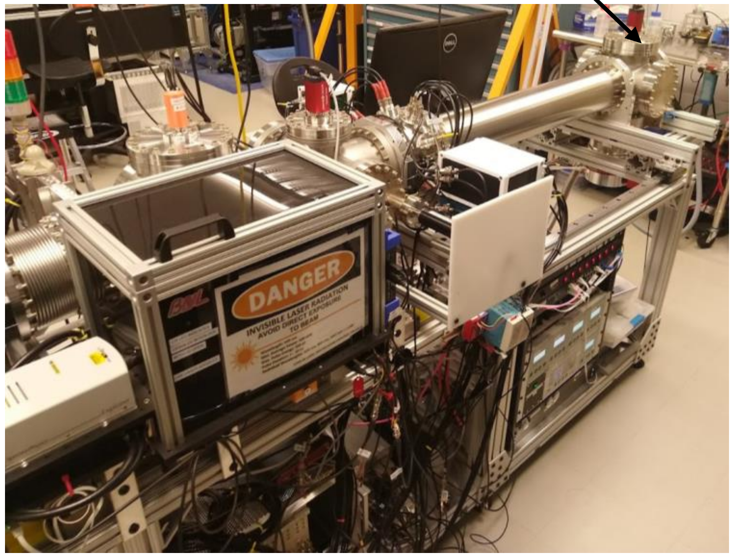
- MRTOF Analyzer is assembled as a stack of vacuum clean electrodes on a base flange.
- Analyzer is then mounted on a rail system, electrodes wired to feed thru's.
- Vacuum chamber is constructed around the analyzer.
- Chamber is sealed and pumped down to <1x10^{-9} Torr.

Ions detected with channeltron detector.



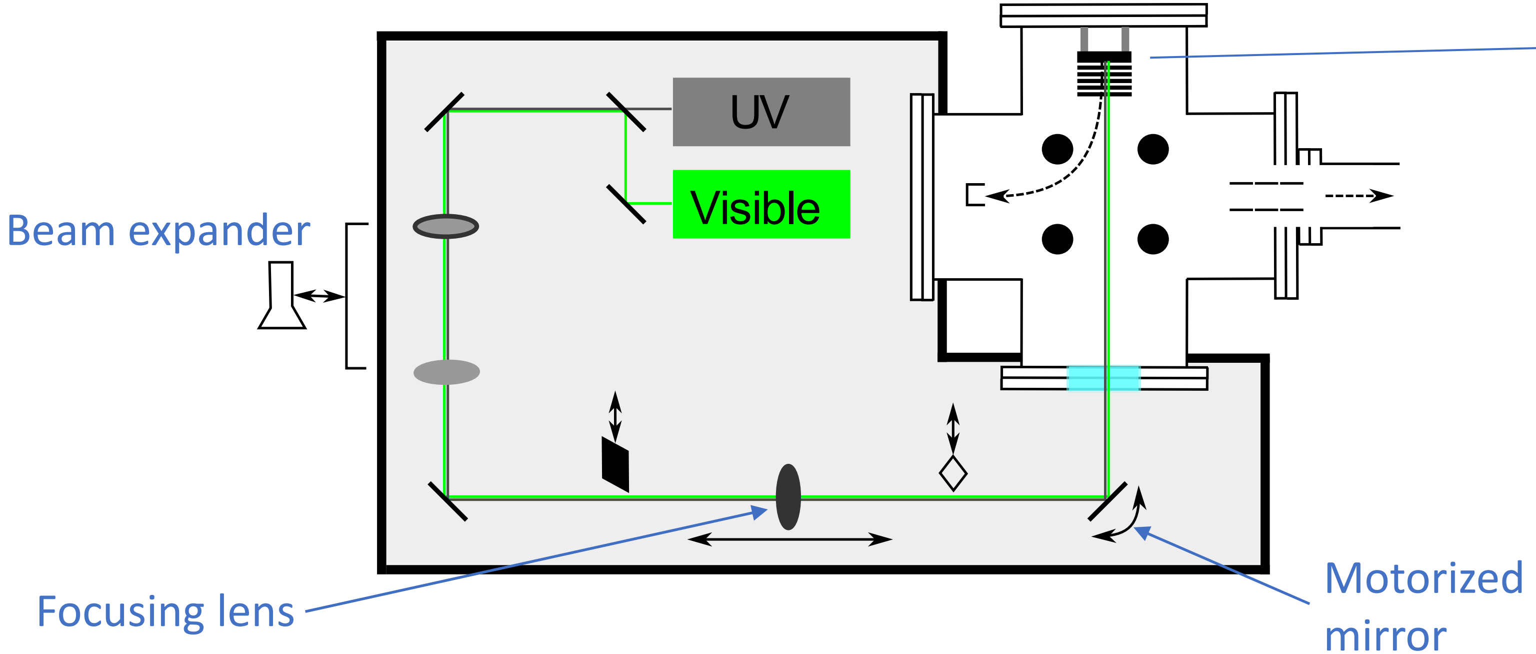


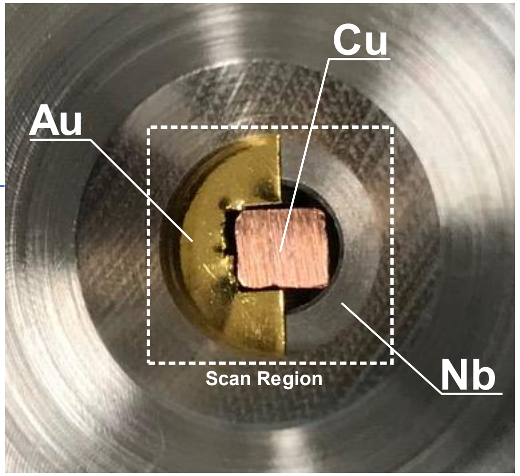


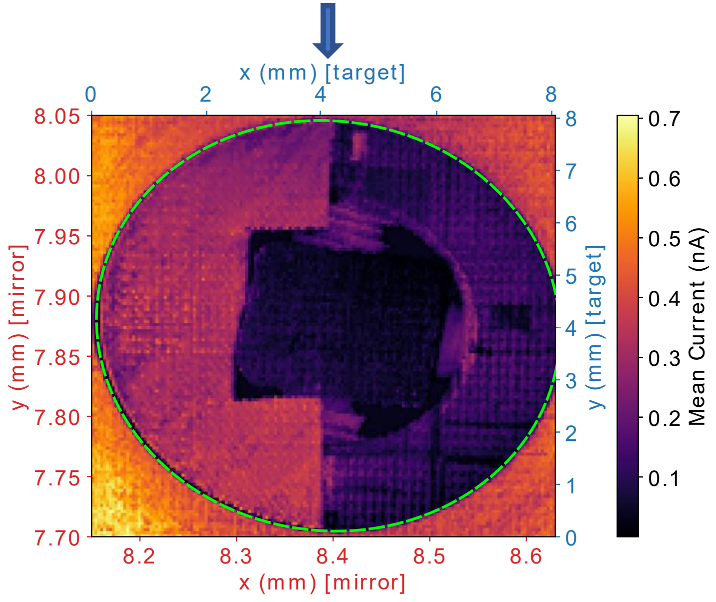


Laser Ablation Ion Source (LAS)

See publication: **Murray, K., et al. "Characterization of a Spatially resolved multi-element laser ablation ion source." *International Journal of Mass Spectrometry* 472 (2022): 116763.**

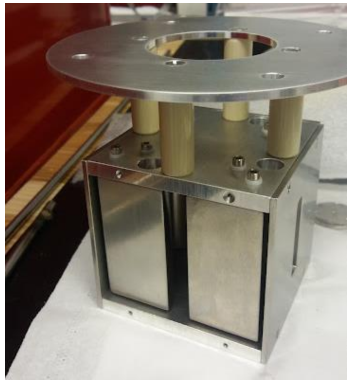


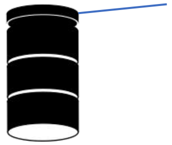


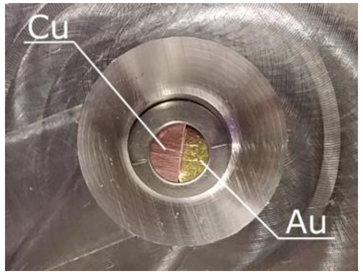


- Low kinetic energy ion source, ~100 eV.
- Forms 2D rasterized images of the target by measuring ion current.
- Can selectively ablate different materials on multi-element target (50 µm res).
- Up to 50 mm scanning range.

LAS for the MRTOF

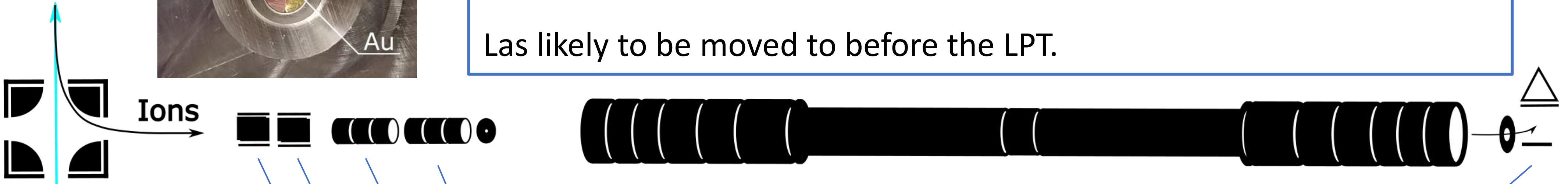




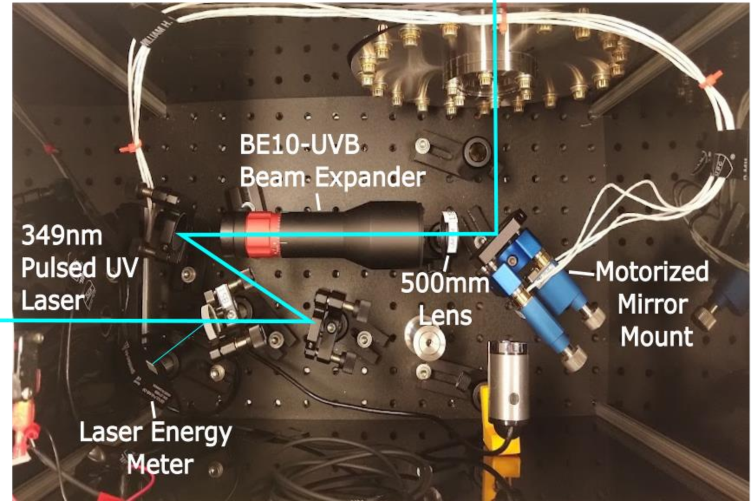


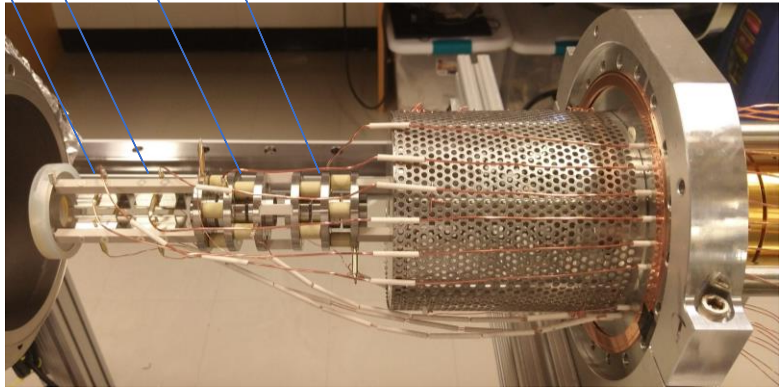
Ion source produces 1keV ion bunches, with relatively large emittance compared to cooled ions from the LPT, but useful for testing!

Las likely to be moved to before the LPT.



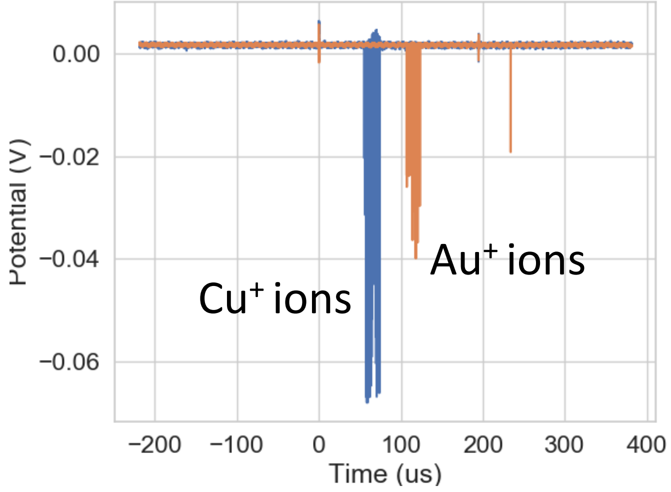
Quad Bender



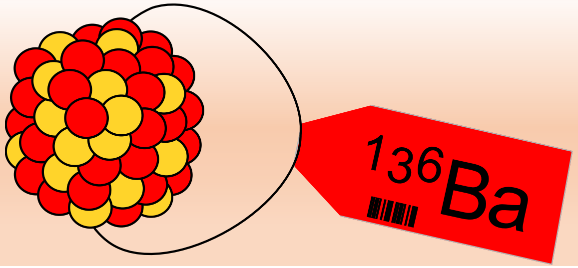


Steerers and lenses align and focus the beam.

Ion signal from the cem

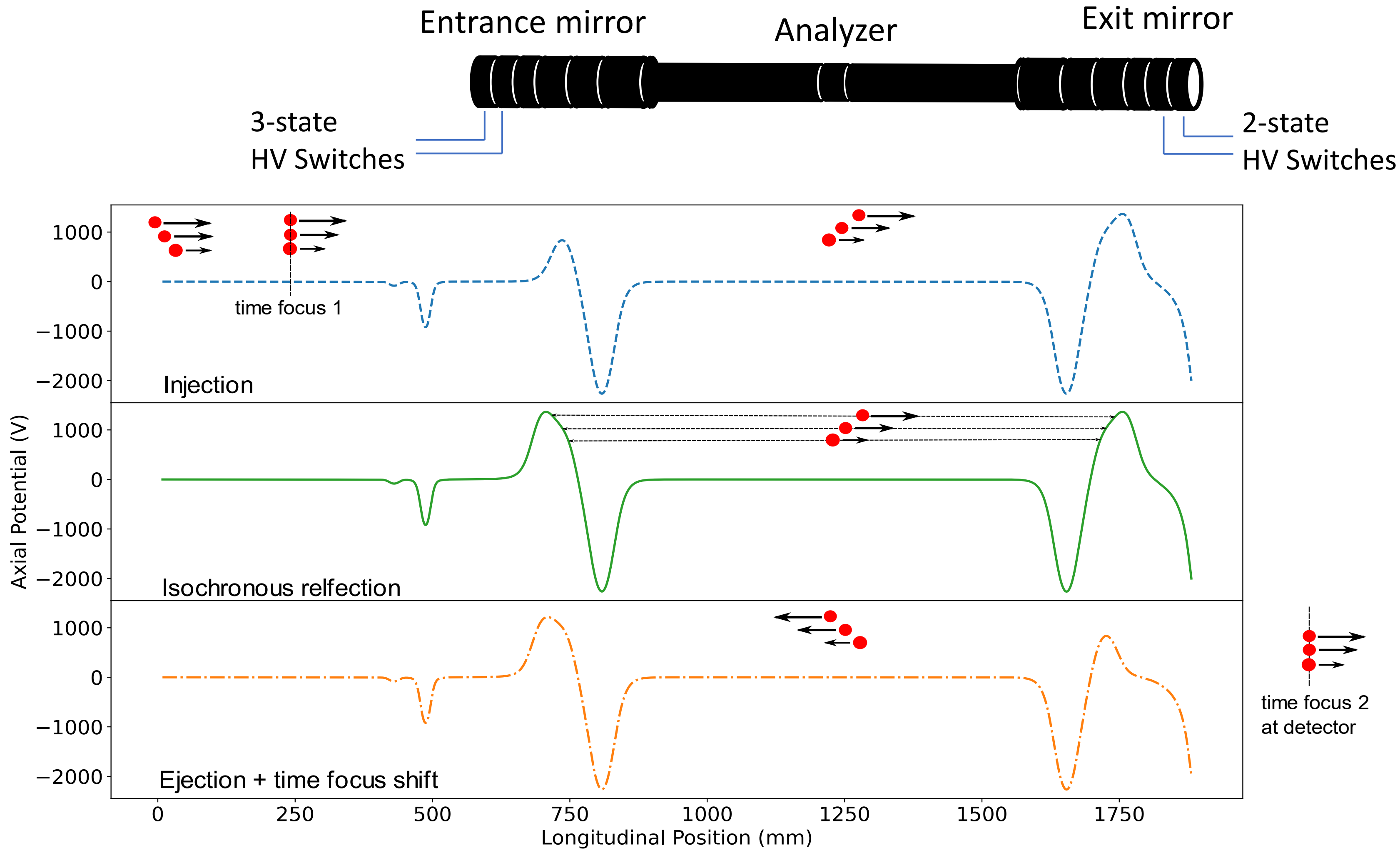


Reflections in the MRTOF



Time Focus:
Point in space at which ions with same m/q but slightly different KE arrive at the same time.

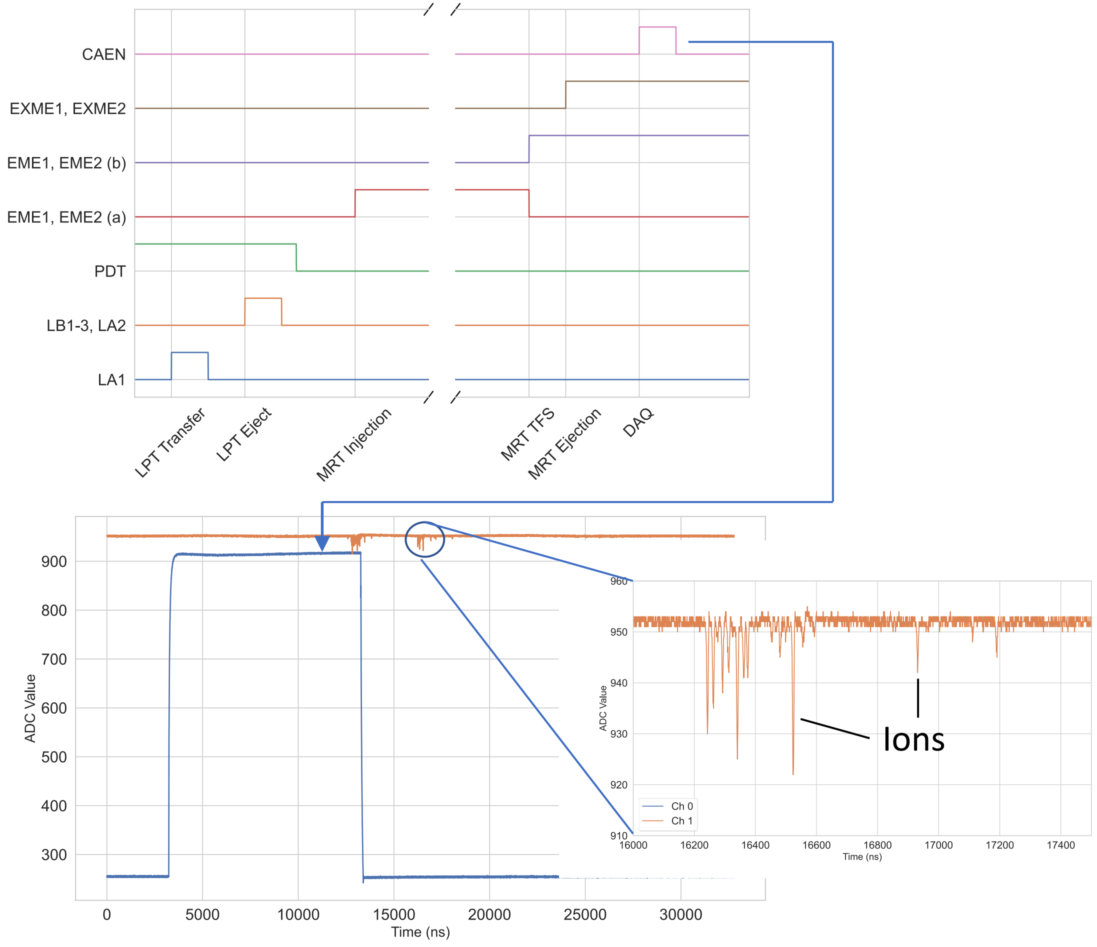
- HV switches let ions into and out of the analyzer.
- Mirrors of the MRTOF can be tuned to adjust the path lengths of ions with different KE.
- Time focus is shifted from the initial position to the detector with final reflection.



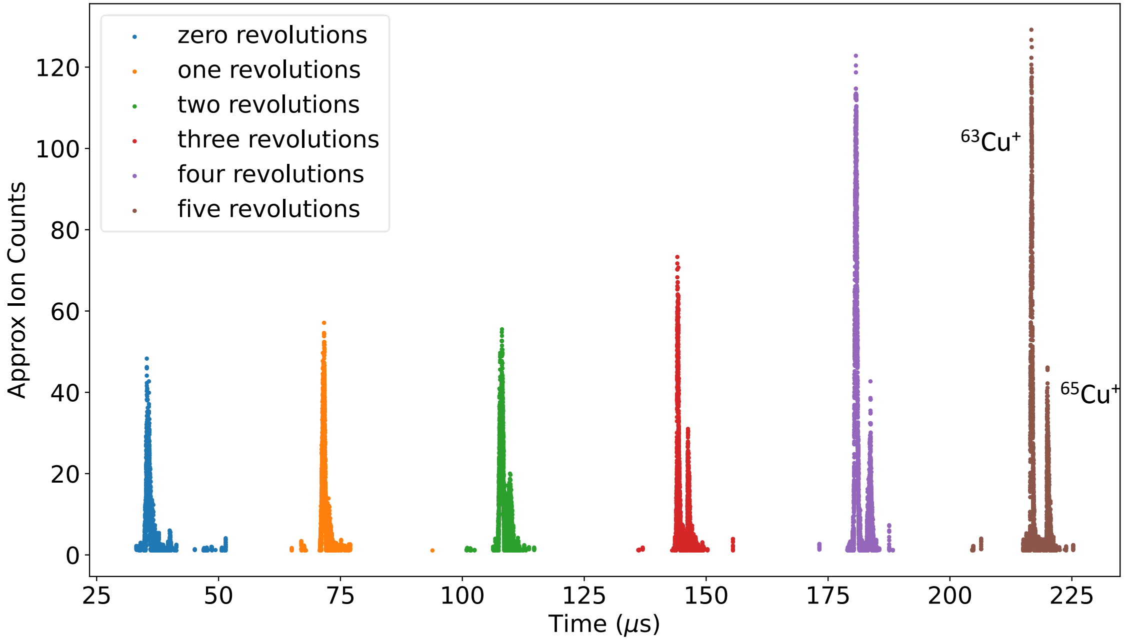
Rosenbusch, M., et al. "Delayed bunching for multi-reflection time-of-flight mass separation." *AIP Conference Proceedings*. Vol. 1668. No. 1. AIP Publishing LLC, 2015.

Cu Measurements

Timing controlled by FPGA bit-pattern generator, with t=0 synced to the laser pulse. ToF histograms formed with many wfms.



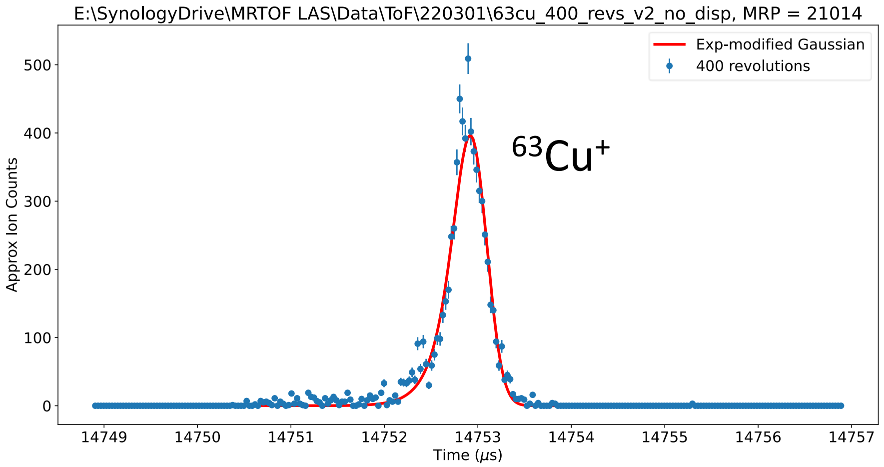
Select and inject Cu into MRTOF

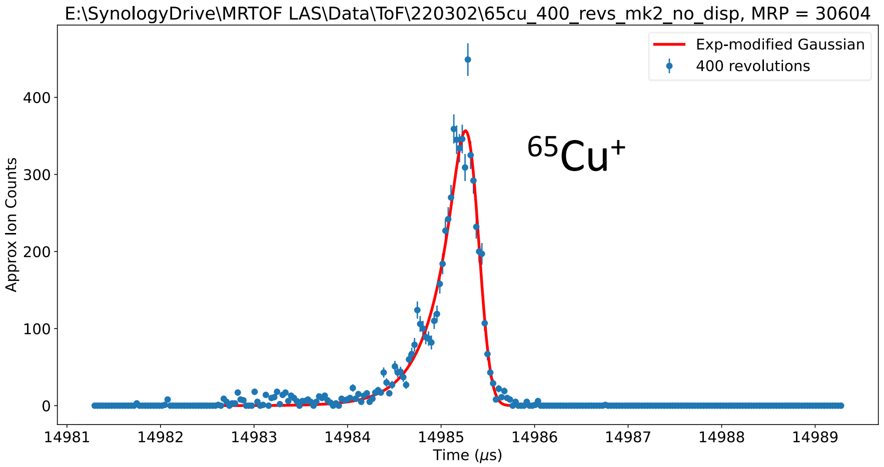


As revolutions increase, ToF peak splits! Cu has two stable isotopes…

Cu Measurements

Two visible ToF peaks are produced from the Cu region of the target, if the lighter peak is assumed to be ^{63}Cu, does the second peak measure correctly as ^{65}Cu?





ToF extended to 15ms, for 400 revolutions.

20-30k MRP

Mass of ^{65}Cu measured as **64.9281(9) amu**, agreeing with 64.9278 amu.

Conclusions

- The LAS can be used to selectively inject different ion species into the MRTOF.
- The MRTOF can form stable ion trajectories with up to 15ms flight time.
- The MRTOF has demonstrated a mass-resolving power up to 20-30k with ions from the LAS, can be improved with more tuning and cooled ions from the LPT, 100k MRP is expected.
- Current setup has the potential to scan targets in time of flight!

Thanks to the lab group at McGill!!

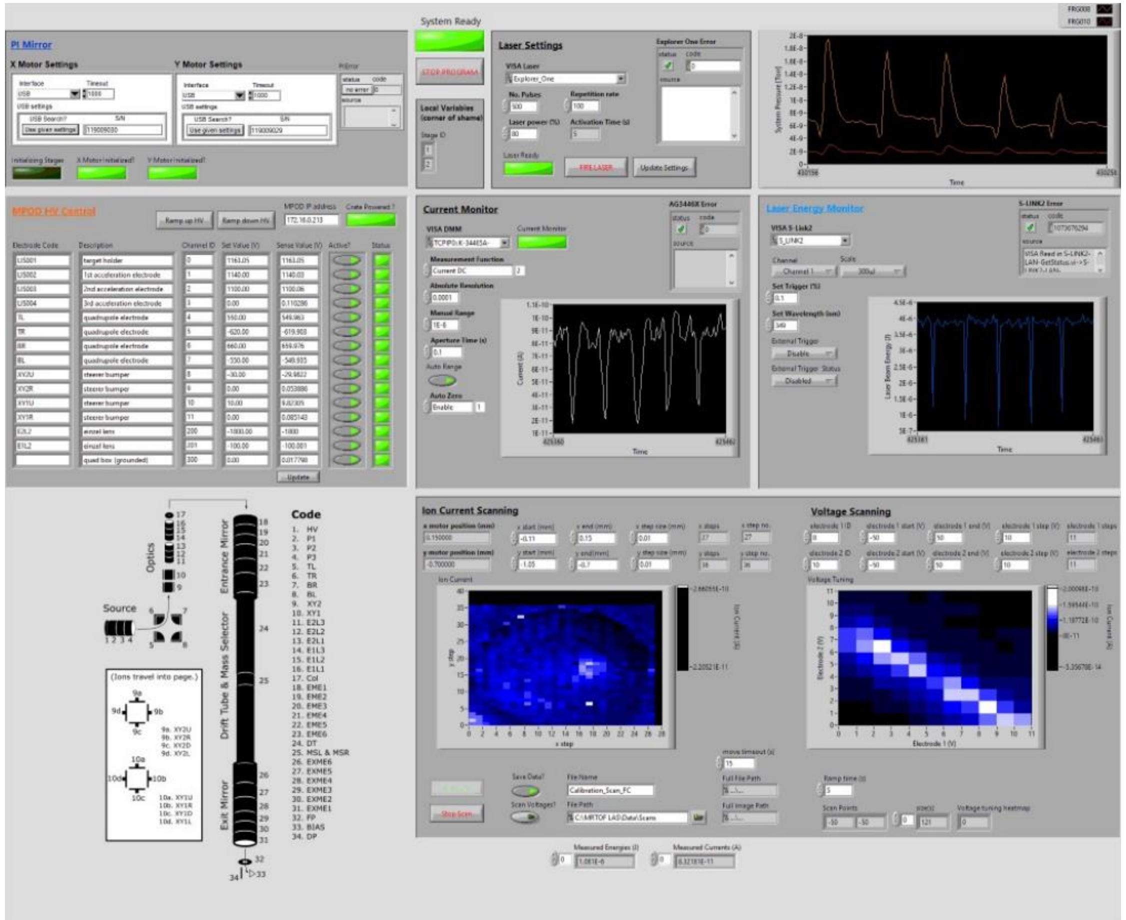
Special thanks to Chris and Hussain and all the ba-taggers!

Software

A labview vi is used to control the MRTOF components

mirror controls

laser controls



pressure monitor

HV DC controls

laser energy monitor

Voltage scanning