Commissioning of a Multiple-Reflection Time-of-Flight Mass-Spectrometer for Barium-tagging using a spatially resolved multi-element ion source

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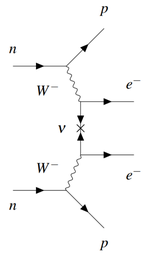
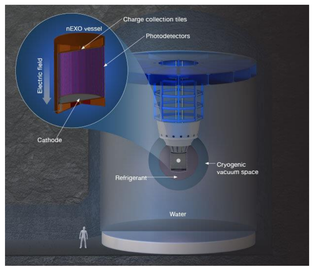
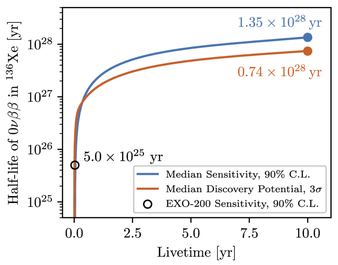
Searching for 0νββ

- The nEXO collaboration is searching for neutrinoless double-beta (0νββ) decay in the isotope ^{136}Xe.
- The observation of 0νββ decay would demonstrate the violation of lepton number conservation, providing evidence for physics beyond the Standard Model.
- nEXO plans to deploy 5 tonnes of liquid Xenon in a Time Projection Chamber (TPC) [1,2]. The detector is anticipated to be located in the cryopit at SNOLAB.





https://www.llnl.gov/news/understanding-universe-through-neutrinos (22/09/2018)



Projection of nEXO sensitivity as a function of livetime, reproduced from ref [2].

- Ba-tagging is a potential future upgrade to nEXO, to extract and identify the daughter Ba ion, eliminating all backgrounds to ββ decay.

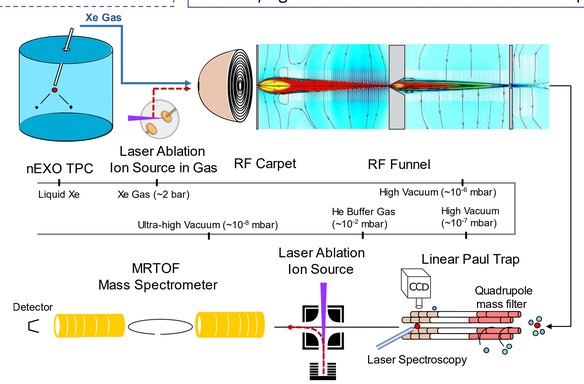
The Canadian Ba-tagging approach

Stage 1: The daughter ion of a potential ββ-event is extracted by a capillary with a small volume of LXe. The LXe undergoes a phase transition to GXe outside the TPC.

Stage 2: The RF Carpet transports the ion from the capillary to the RF Funnel.

Stage 3: The RF Funnel extracts the ion from Xe gas to vacuum [3].

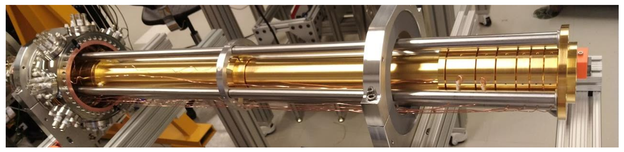
Laser Ablation Ion Sources (LAS') are used to create ions for studying the ion-extraction and identification process.



Stage 5: The multiple reflection time-of-flight mass spectrometer (MRTOF) is used for systematic studies of the extraction technique and mass determination of the Ba ion. Mass-Resolving Power (MRP) of 50k need to separate ^{136}Ba from ^{136}Xe.

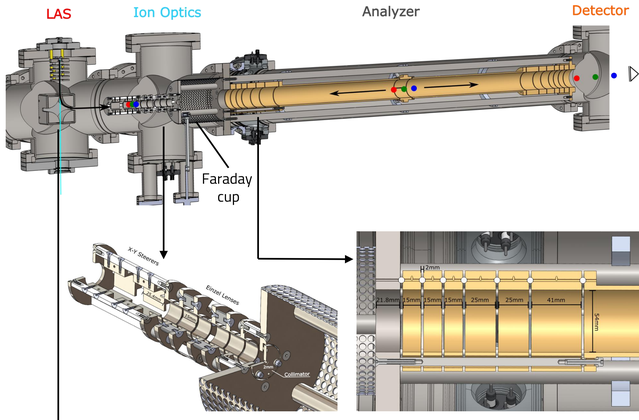
Stage 4: The Linear Paul Trap (LPT) detects the Ba ion with laser fluorescence spectroscopy, and cools and bunches ions for ejection to the MRTOF.

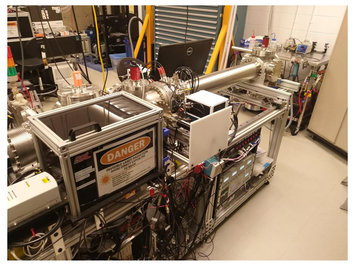
The MRTOF design and operation mode



Picture of the Au-plated electrodes during assembly.

Ions are reflected between two 6-electrode co-axial electrostatic mirrors, tuned to maximize the mass-resolving power. Based on the ISOLTRAP design [4].



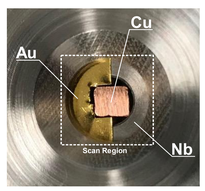


Picture of the assembled LAS and MRTOF.

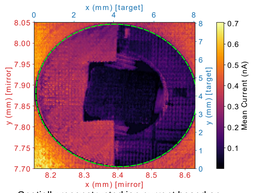
2 sets of x-y steerers and einzel lenses are used to steer and focus the beam onto the optical axis. A Faraday cup can be moved into the path of the ion beam for diagnostics of the ion optics.

The multi-element LAS

The LAS uses a reflection from a high-precision motorized mirror to position the laser spot on the surface of a multi-element target. Materials can be selectively ablated with a 349 nm laser for injection into the MRTOF, with a spatial resolution of ~50 μm [5].



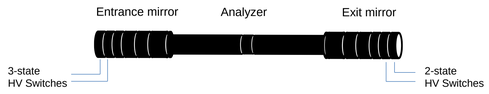
Picture of the multi-element target.



Spatially reconstructed ion current based on laser spot location on target.

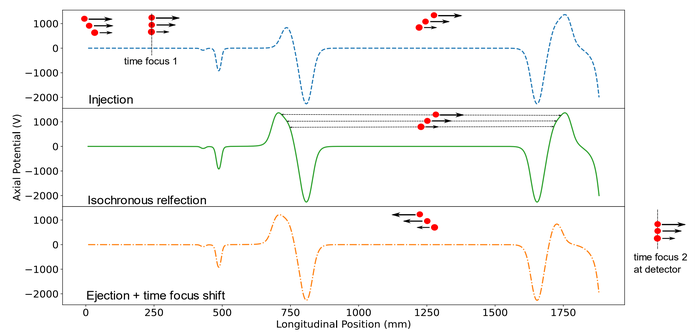
Operation Mode

All reflections are tuned to be isochronous relative to the analyzer mid-plane. Time focus is shifted to the detector with the final reflection [6].



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

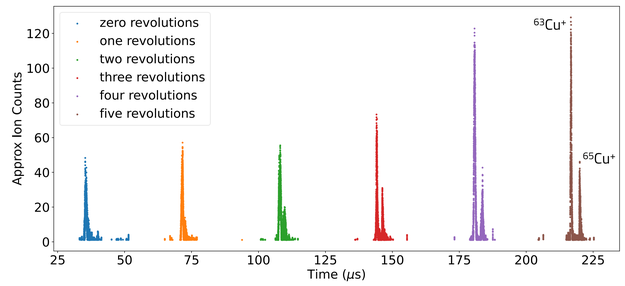
Timing System:
Timing controlled by FPGA bit-pattern generator, with t=0 synced to the laser pulse for operation with the LAS.



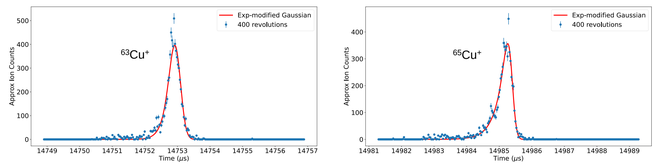
Plot of the simulated axial potential along the optical axis of the MRTOF.

Results

For initial tests, Cu was selectively ablated with the LAS and injected into the MRTOF. The TOF peak splits into ^{63}Cu and ^{65}Cu as the number of revolutions increases.



Using ^{63}Cu as a reference ion, the mass of ^{65}Cu was measured as **64.9281(9) amu**, agreeing with 64.9278 amu [7].



TOF extended to 15 ms for 400 revolutions, with 20k MRP using un-cooled ions from the LAS.

Conclusions

- The multi-element LAS can be used to selectively inject different ion species into the MRTOF.
- Stable ion trajectories have been demonstrated with the MRTOF up to 15 ms flight time.
- The MRTOF has demonstrated an MRP of up to 20k with ions from the LAS. The LPT is currently being commissioned, with cooled ions available 100k MRP is expected.
- Current setup has the potential to scan targets in time of flight!

ACKNOWLEDGEMENTS

Arthur B. McDonald Canadian Astroparticle Physics Research Institute

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NSERC CRSNG

Fonds de recherche sur la nature et les technologies Québec

References

[1] Kharusi, S.A. et al., 2018. nEXO Pre-Conceptual Design Report..., *arXiv preprint arXiv:1805.11142*.
[2] Adhikari, G. et al., 2021. nEXO: neutrinoless double beta decay..., Journal of Phys. G: Nucl and PP, 49
[3] Brunner, T. et al., 2015. An RF-only ion-funnel for extraction..., *Int. Journal of Mass Spec.*, *379*, pp.110-120.
[4] Wolf, R.N. et al., 2013. ISOLTRAP's multi-reflection time-of-flight..., *Int. Journal of Mass Spec.*, *349*, pp.123-133.
[5] Murray, K., et al., 2022. Characterization of a Spatially resolved..., *Int. Journal of Mass Spec.*, 472.
[6] Dickel, T. et al., 2017. Dynamical time focus shift in..., *Int. Journal of Mass Spec.*, *412*, pp.1-7.
[7] Coursey, J.S. et al., 2015. Atomic Weights and Isotopic..., NIST, v4.1, http://physics.nist.gov/Comp [19/09/2022]