‘Searching for a needle in a haystack:’ A Ba-tagging approach for an upgraded nEXO experiment

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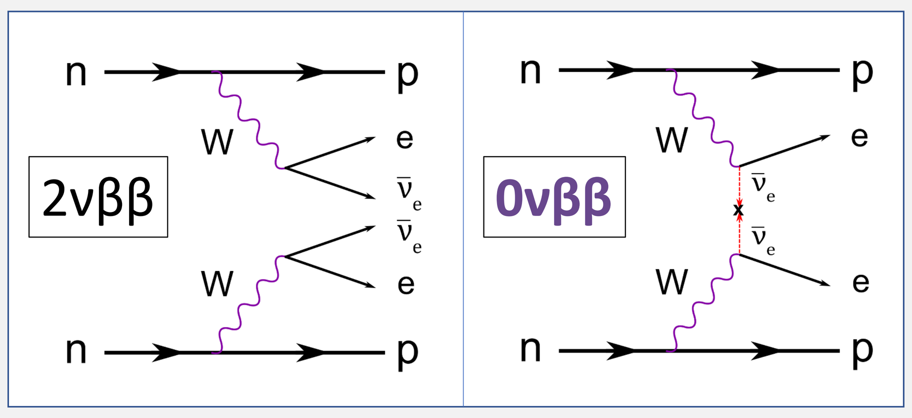
The search for 0νββ

The nEXO experiment will search for **neutrinoless double-beta decay (0νββ)** in 5 tonnes of liquid xenon (LXe) enriched to 90% in the isotope Xe-136 [1]:

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

nEXO’s projected sensitivity to ^{136}Xe 0νββ half-life is **1.35×10^{28} years** at 90% C.L. [2].



The observation of this event has implications on **physics beyond the Standard Model**:

- 0νββ is lepton-number violating.
- Could help explain the matter-antimatter asymmetry observed in the Universe.
- Demonstrate Majorana nature of neutrinos.

Ba-tagging upgrade for nEXO

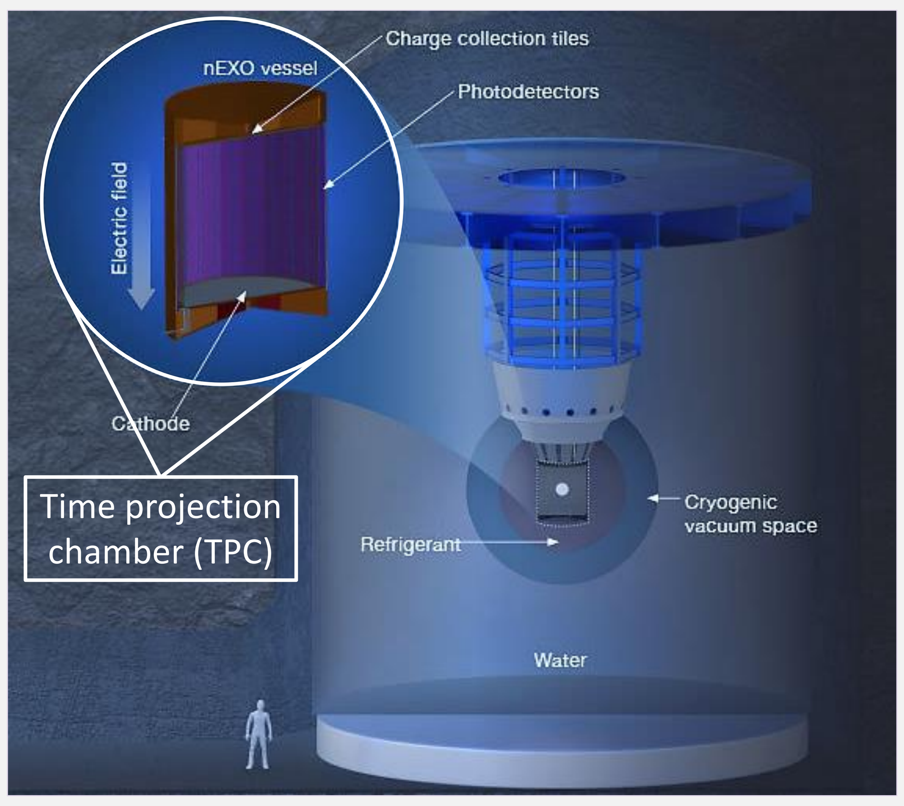
Liquid Xe TPC allows reconstruction of:

Energy | Event location | Event topology

→ Unique possibility to locate, extract and identify the ^{136}Xe double-beta decay daughter ^{136}Ba.
→ Only consider events of interest for 0νββ search with accompanying ^{136}Ba identification.

This technique is referred to as **Barium Tagging**, a proposed future upgrade for nEXO. Ba-tagging has the potential to increase the sensitivity of a nEXO-like detector by a factor of **~2-3** [3].

Various groups have demonstrated single barium identification [4-6]. The challenge of extracting the barium from large Xe detector volume remains.

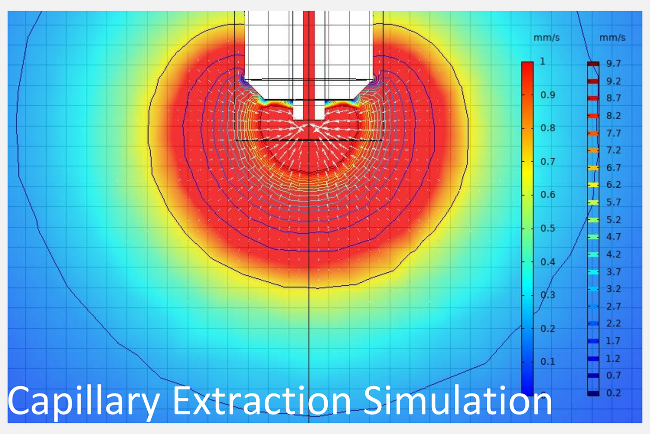


Goal: Extract and identify 1 ion from tonnes of LXe!!

Possible Ba-Tagging Scheme

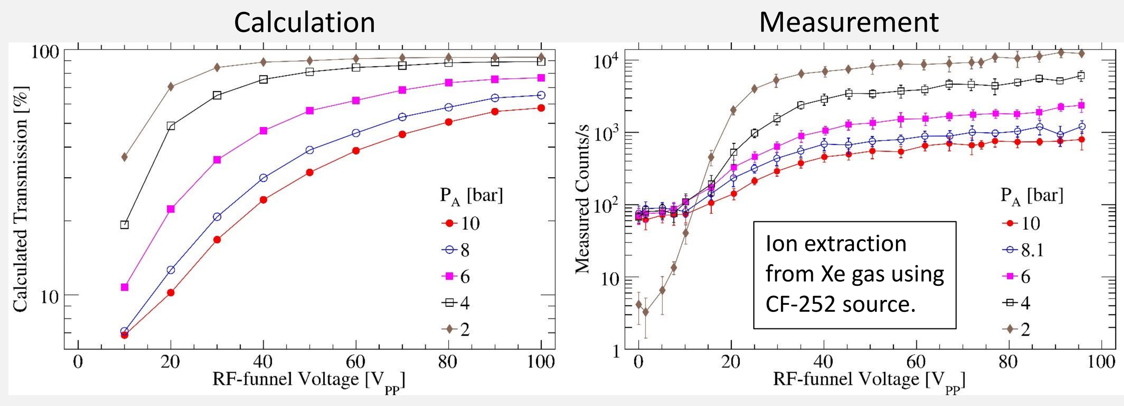
Stage1:
Move displacement device to event location and extract a certain LXe volume surrounding the event via a capillary. Once outside detector, LXe phase-transitions to GXe while transporting ion of interest

Capillary positioning apparatus is being developed at Carleton University.

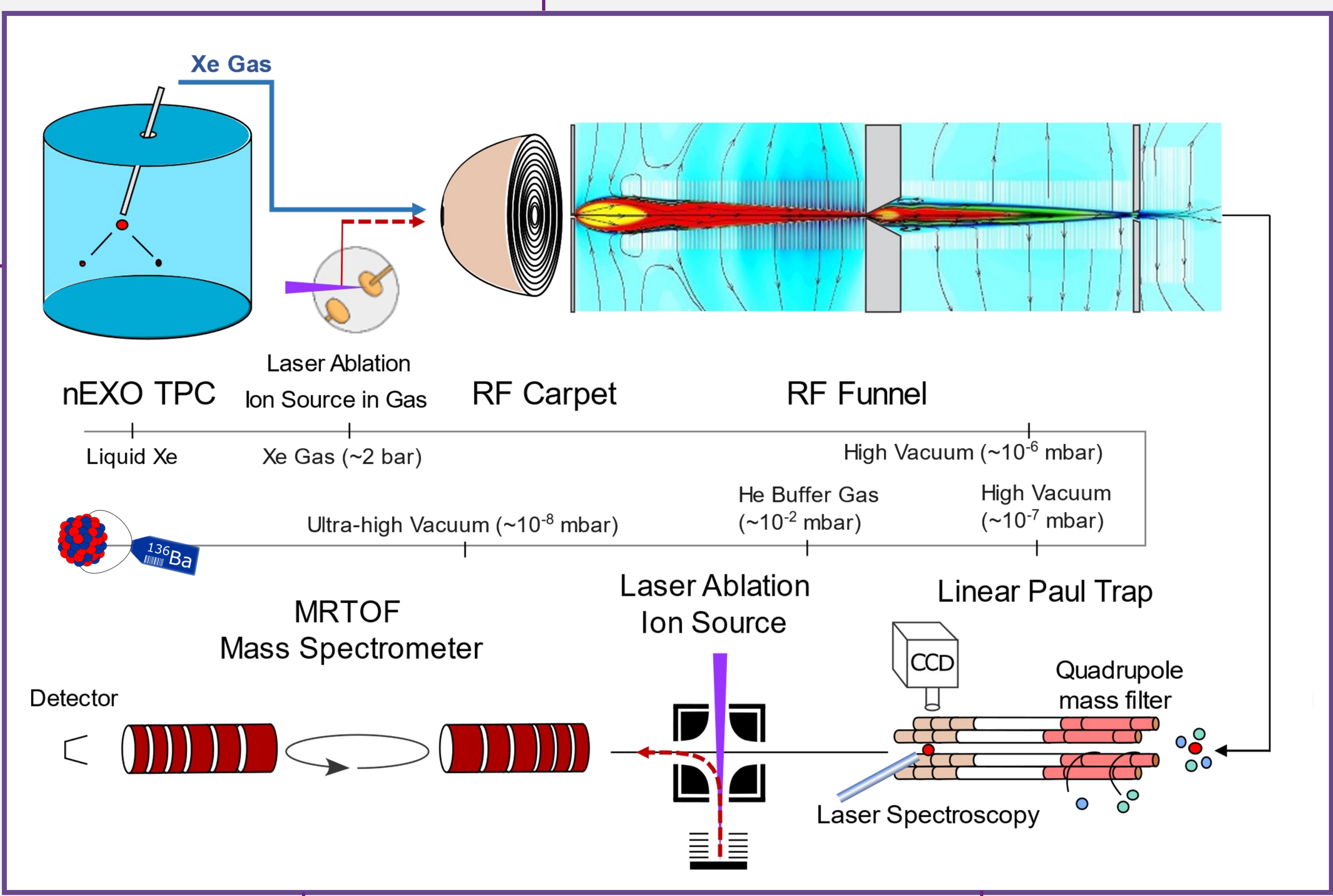


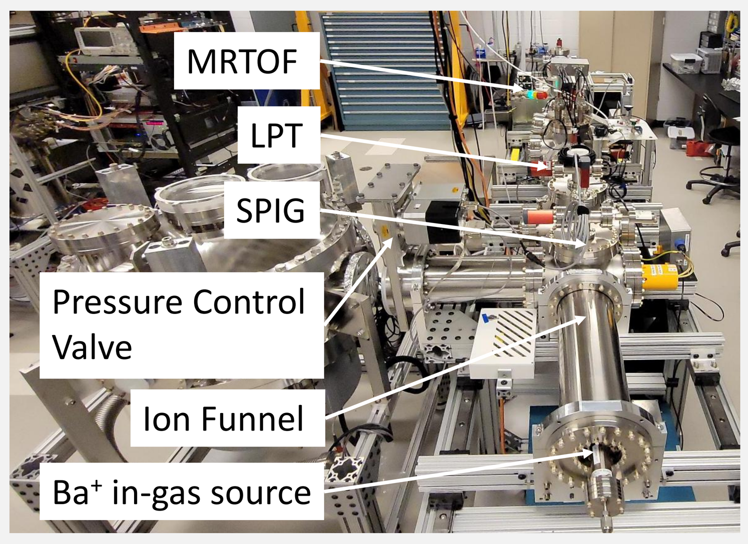
Stage2:
Radio-frequency (RF) carpet for efficient transfer of ion from capillary to **RF funnel.**

The RF funnel [7] transports the Ba ion from High-pressure Xe gas → High-vacuum



Transmission curves show agreement with calculations. Setup currently being re-commissioned at McGill University to further study ion extraction efficiency.

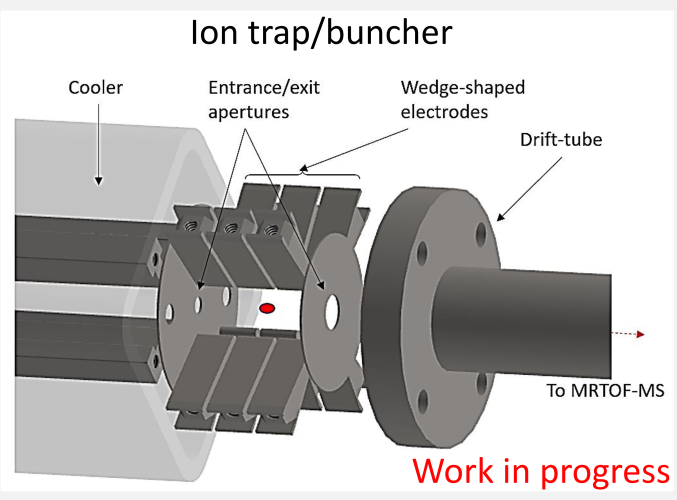




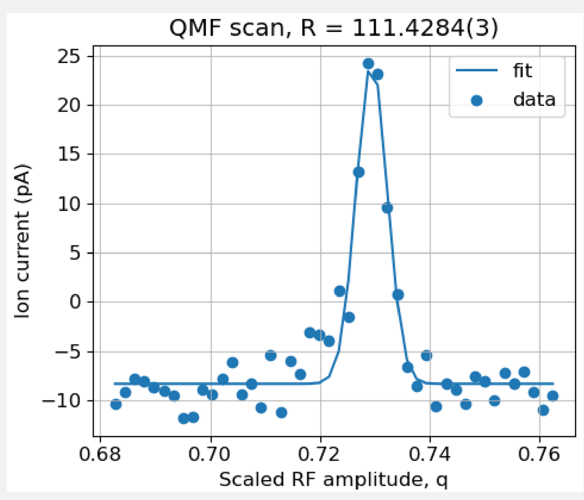
McGill setup with RF funnel, LPT and MRTOF (in sequence, from bottom of the image to the top).

Stage3:
Linear Paul trap for detection of barium ion via laser fluorescence spectroscopy. Ions are cooled and bunched to prepare for the next stage, time of flight mass spectrometry.

An additional quadrupole mass filter (QMF) facilitates removal of background ions.

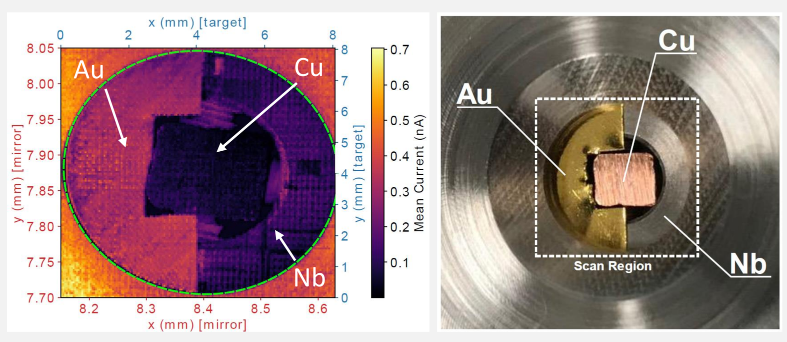


Ion cooling and bunching is expected to be achieved by end of year 2022.



QMF performance is characterized with ^{133}Cs ions, with mass resolving power R = m/Δm = q/ Δq > **100**

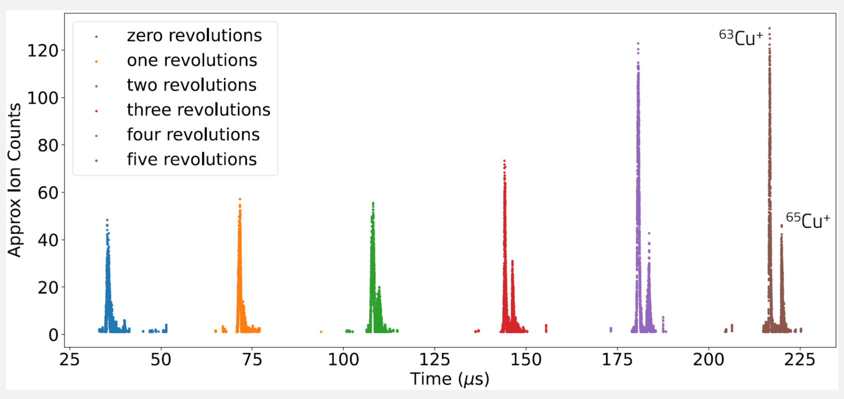
Laser ablation ion sources (LAS) [8], in gas and vacuum, are used to characterize the performance of the different stages (2-4).



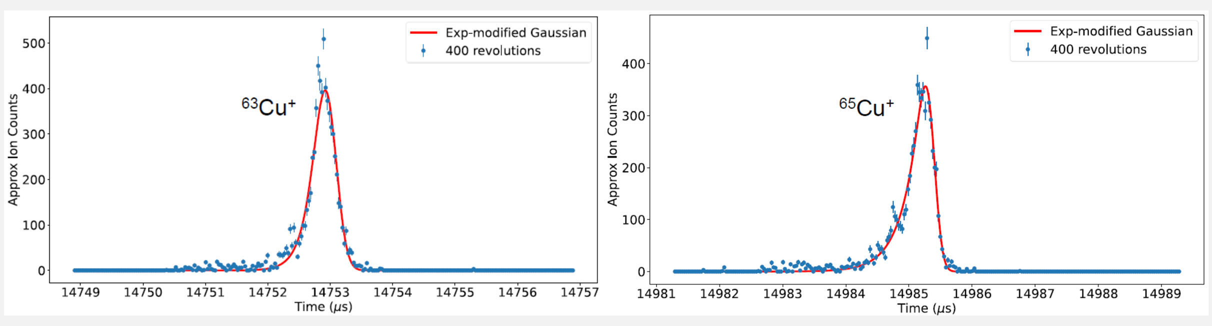
(Right) Multi-element LAS target, (Left) Ion current intensity map reconstructed from the ablation laser spot on the target.

Stage4:
Multiple Reflection TOF Spectrometer for systematic studies of extraction process and determination of ion mass [9].

Current resolving power of ions from LAS is **20k** and is expected to improve to **100k** with cooled ions from LPT.



Initial commissioning was done using Cu ions. Below plot shows the splitting of ^{63}Cu and ^{65}Cu peaks with successive revolutions.



Using ^{63}Cu as reference, ^{65}Cu mass was measured to be **64.9281(9) amu**, agreeing with 64.9278 amu.

Acknowledgements

Arthur B. McDonald Canadian Astroparticle Physics Research Institute
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TRIUMF
NSERC CRSNG
Fonds de recherche Nature et technologies Québec

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[9] Murray, K., et al., 2019. Hyperfine Interact 240, 97.