The Key to a Background-Free Search in Liquid Xenon Ba-Tagging — Status and Prospects

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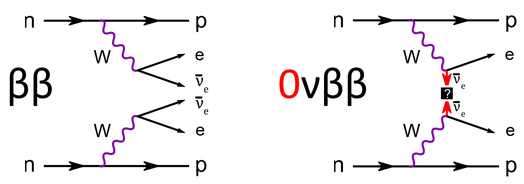
I: The search for 0νββ

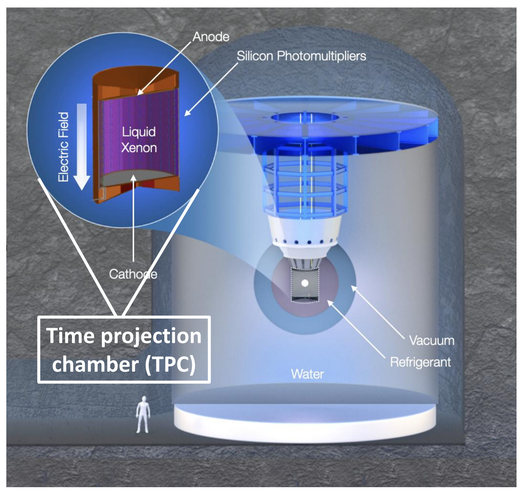
nEXO is a proposed experiment to search for neutrinoless double beta decay (**0νββ**) using 5 tonnes of liquid xenon (LXe) enriched to 90% in the double beta decay (**ββ**) isotope ^{136}Xe [1].



$$^{136}\mathrm{Xe} \rightarrow \boxed{^{136}\mathrm{Ba}^{++}} + 2e^- + 0\bar{\nu}_e$$

The current limit on ^{136}Xe 0νββ half-life is > 2.3 x 10^{26} years [2].

nEXO's projected sensitivity to ^{136}Xe 0νββ half-life is **1.35×10^{28} years** at 90% C.L. [3].

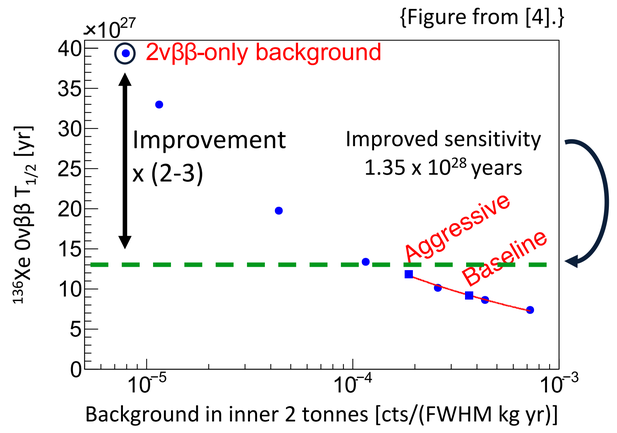


To further enhance the discovery potential, a proposed future upgrade involving a technique referred to as **Ba-tagging** is being explored for nEXO [4].

II: The Ba-tagging Technique

- Xe-based TPCs offer the unique capability to localize, extract, and identify the ^{136}Ba daughter produced in the ββ decay of ^{136}Xe.
- Ba-tagging has the potential to improve the sensitivity of a nEXO-like detector by a factor of **~2–3** for a 100% tagging efficiency [4].
- Several groups have successfully demonstrated single-barium atom/ion identification [5–6].

{Figure from [4].}

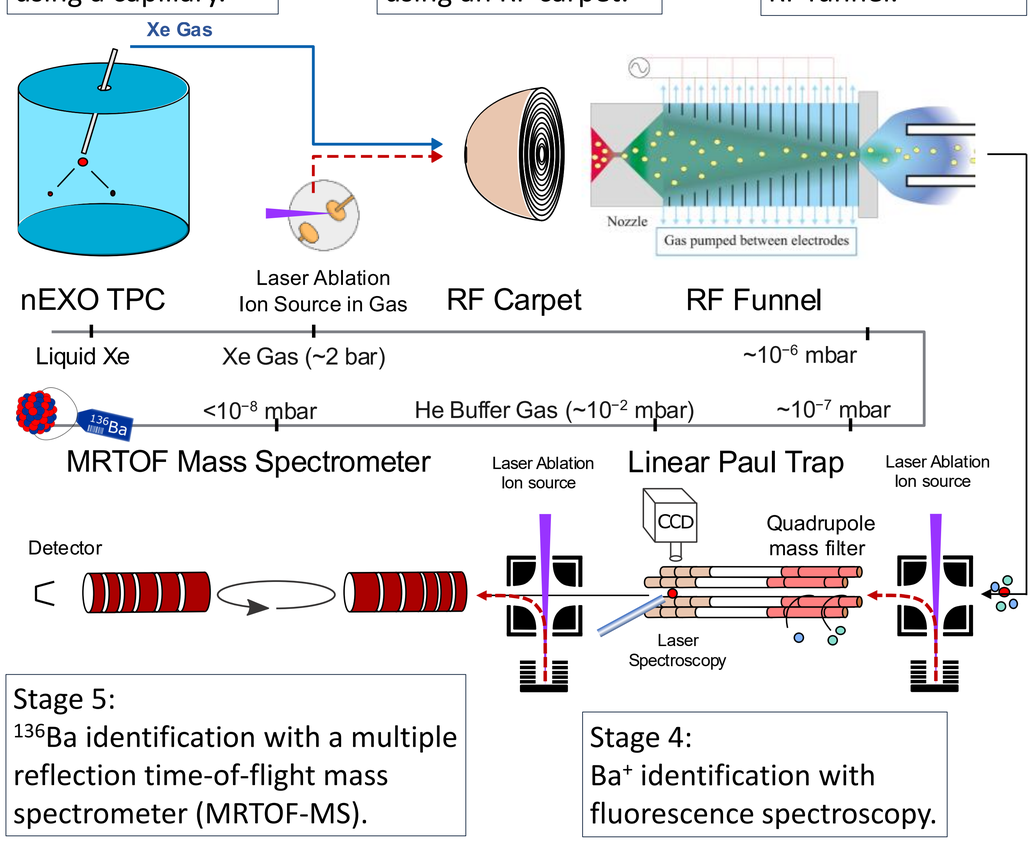


Our Goal: Extract and identify a **single ion** from tonnes of LXe!

Stage 1: Localization and extraction from LXe using a capillary.

Stage 2: Transport of xenon gas (GXe) and ^{136}Ba$^+$ using an RF carpet.

Stage 3: Extraction of ^{136}Ba$^+$ from GXe using an RF funnel.



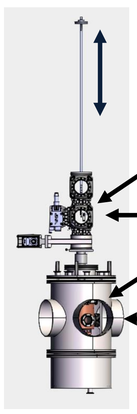
Stage 5: ^{136}Ba identification with a multiple reflection time-of-flight mass spectrometer (MRTOF-MS).

Stage 4: Ba$^+$ identification with fluorescence spectroscopy.

III: Current Status and Results

Stage 0: In-LXe ion source

An accelerator-driven in-LXe Ba ion source is being developed at TRIUMF to test the Ba-tagging scheme.

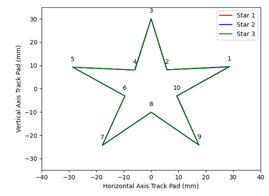


The initial approach involves implanting radioactive ^{139}Cs ions, which decays to ^{139}Ba, into an LXe vessel [7].

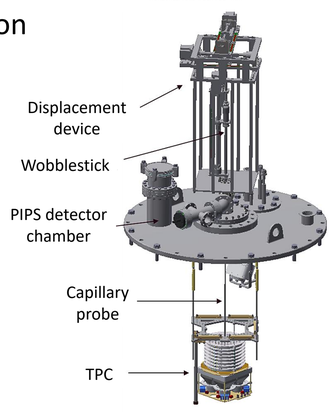
The decay signature will enable tagging of ^{139}Ba ions for subsequent extraction studies.

Stage 1: Capillary device demonstrator

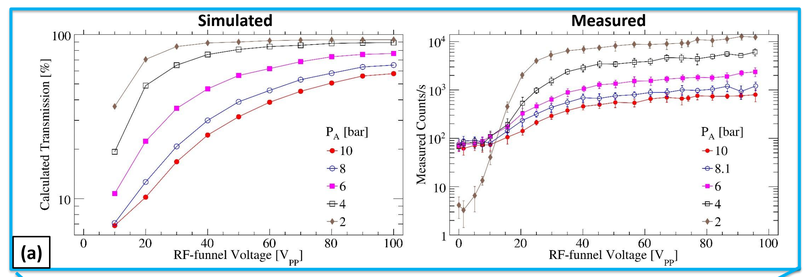
Capillary displacement device has been tested and demonstrated a position resolution of **0.1 mm** [8].

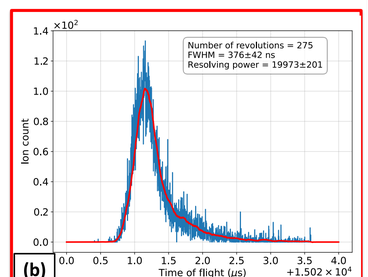


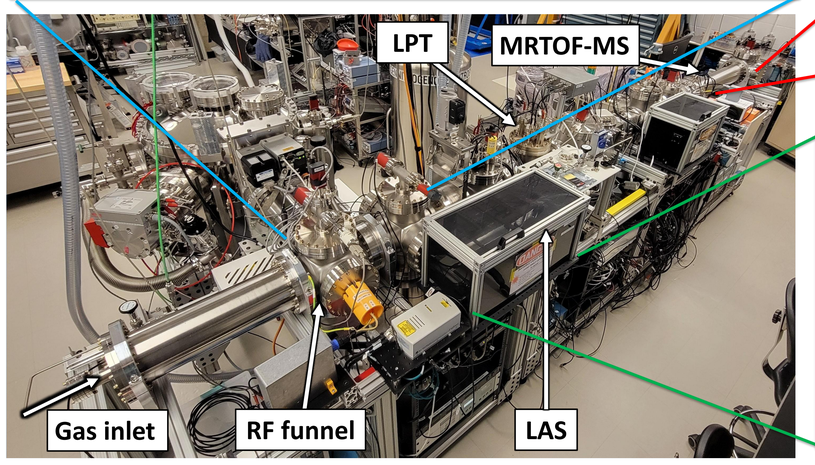
Transmission studies using **^{222}Rn** and argon gas (GAr) have demonstrated ion transport using a capillary.

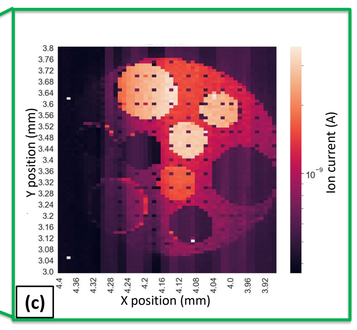


Stage 3–5: Ion extraction from GXe









a) Ion extraction from GXe using the RF funnel has been studied and shown to be in good agreement with simulations [9].
b) Bunched ions from the linear Paul trap (LPT) have been transported to the MRTOF-MS, achieving a mass resolving power (MRP) of **~20,000**.
c) A laser ablation ion source (LAS) was developed and used to demonstrate ion production over a wide mass-to-charge range using a multi-element target [10].

IV: Future roadmap

- ❖ Test the in-LXe ion source for ion implantation, initially in GAr and ultimately in LXe.
- ❖ Continue studies with the capillary demonstrator toward testing ion transport with LXe.
- ❖ Design and commission an RF carpet to transport Ba ions from the capillary to the RF funnel with high efficiency.
- ❖ Identify ions extracted from the RF funnel and study the extraction parameters.
- ❖ Achieve an MRP of ~50,000 to enable the separation of ^{136}Ba$^+$ from ^{136}Xe$^+$.
- ❖ Integrate all subsystems to carry out a benchmark study of the overall Ba-tagging efficiency.

References

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Refer to this review for more details on Ba-tagging.

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