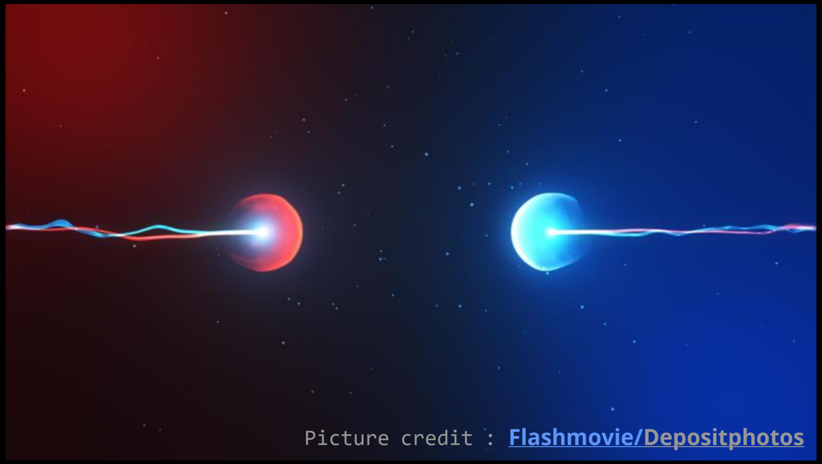
# *Unraveling the secrets of the Universe, one barium ion at a time.*

## *A barium tagging technique for nEXO*

**Hussain Rasiwala**
**Brunner's Neutrino Lab, McGill University**

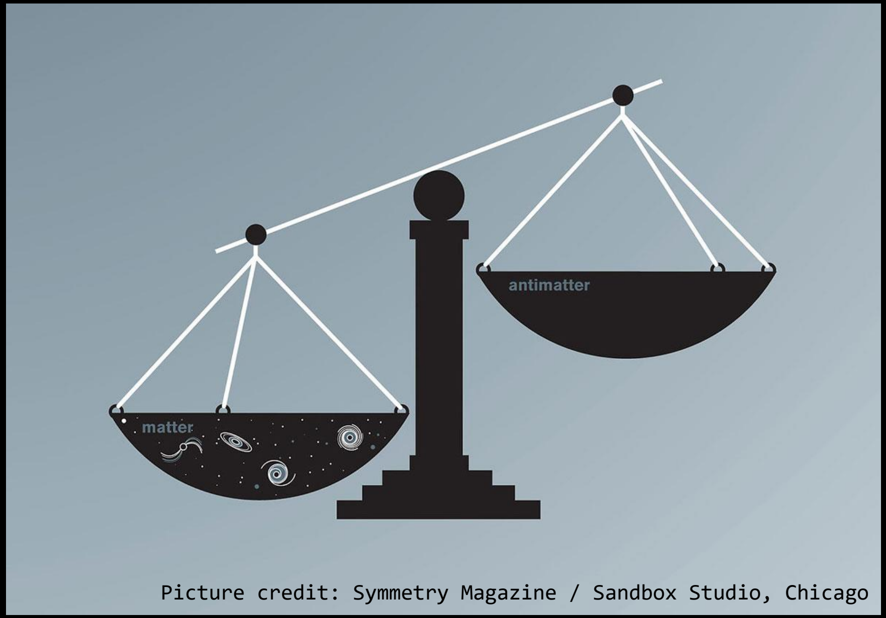
# Matter-antimatter asymmetry


Picture credit : Flashmovie/Depositphotos

A small asymmetry should have tip the scales in favor of matter to result in the current observable universe.

Big-bang is thought to have produced roughly equal amounts of matter and antimatter.

If that were the case, matter and antimatter should have annihilated, which is clearly not the case.



Picture credit: Symmetry Magazine / Sandbox Studio, Chicago

# Matter-antimatter asymmetry

- ~~Baryon number violation~~
- ~~CP violating process~~
- ~~Quark sector contribution isnt significant enough~~

- Neutrinos, maybe?

Matter-antimatter asymmetry

Neutrinos have mass


Weak interaction violates CP symmetry

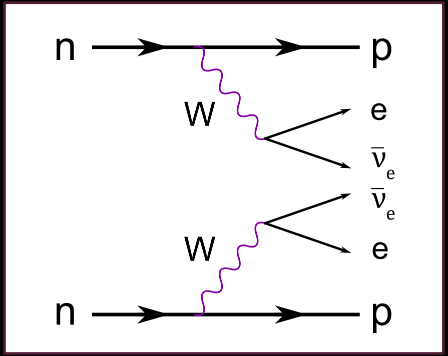
Neutrinos are chargeless

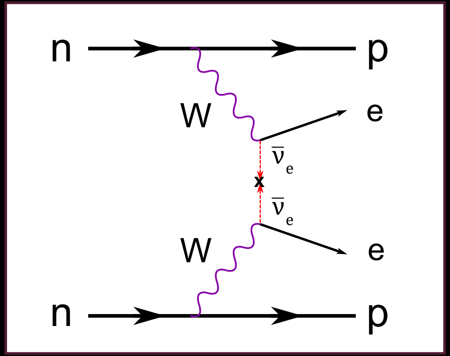
# nEXO Experiment

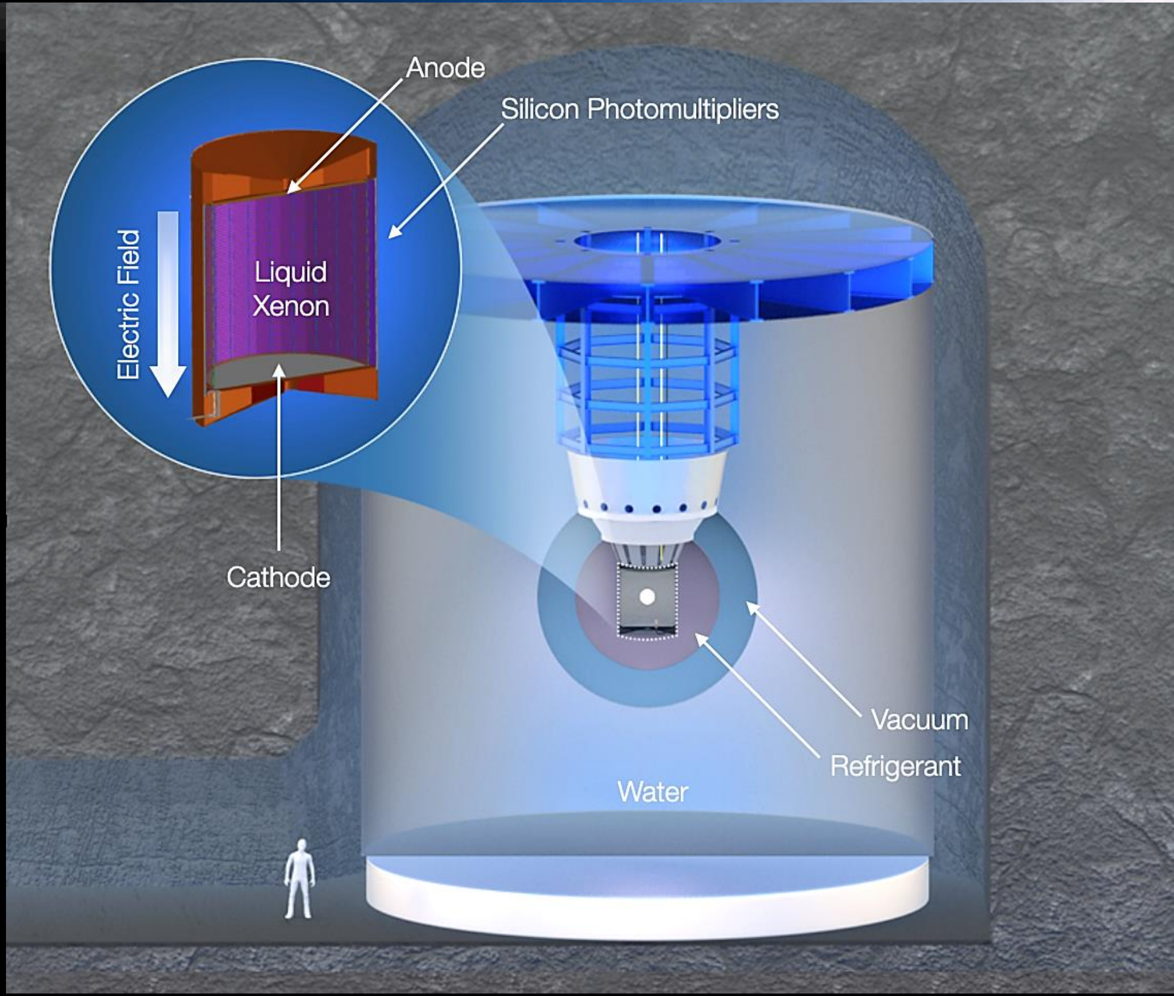
Searches for neutrinoless double beta decay (0νββ) events in liquid xenon (LXe) enriched in isotope Xe-136.

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

The current bound on Xe-136 0νββ half-life is 2.3 x $10^{26}$ years (KamLAND Zen 2022).




{nEXO pCDR, arXiv:1805.11142}

{Moe, M. K. *Physical Review C* 44.3 (1991) R931}

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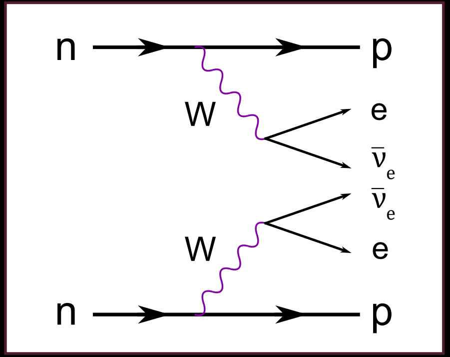
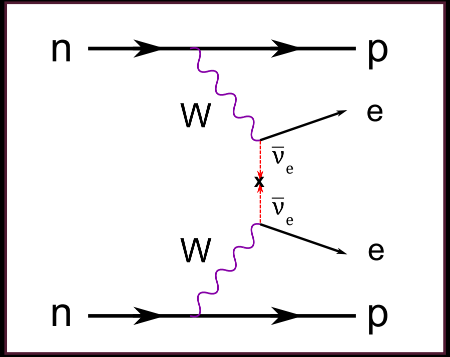
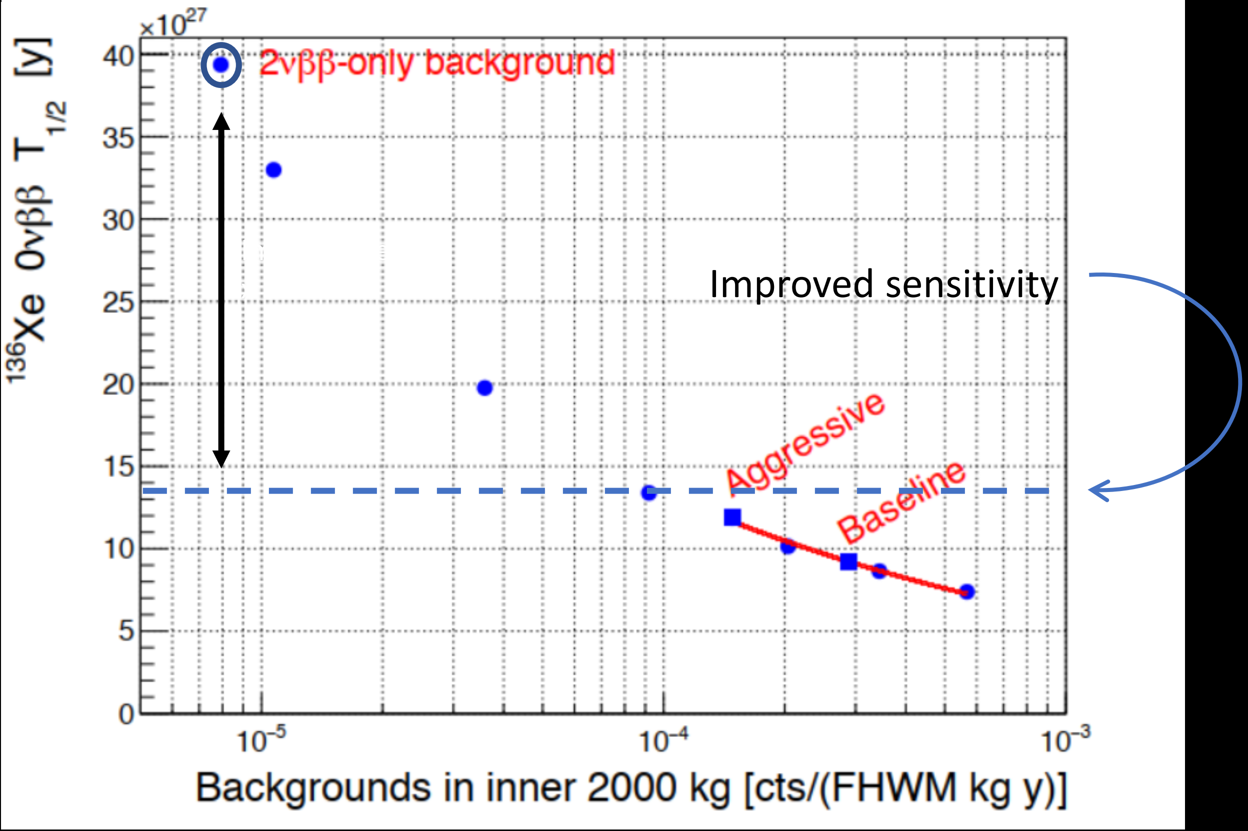



Asymptotic sensitivity for a potential upgrade using Ba tagging



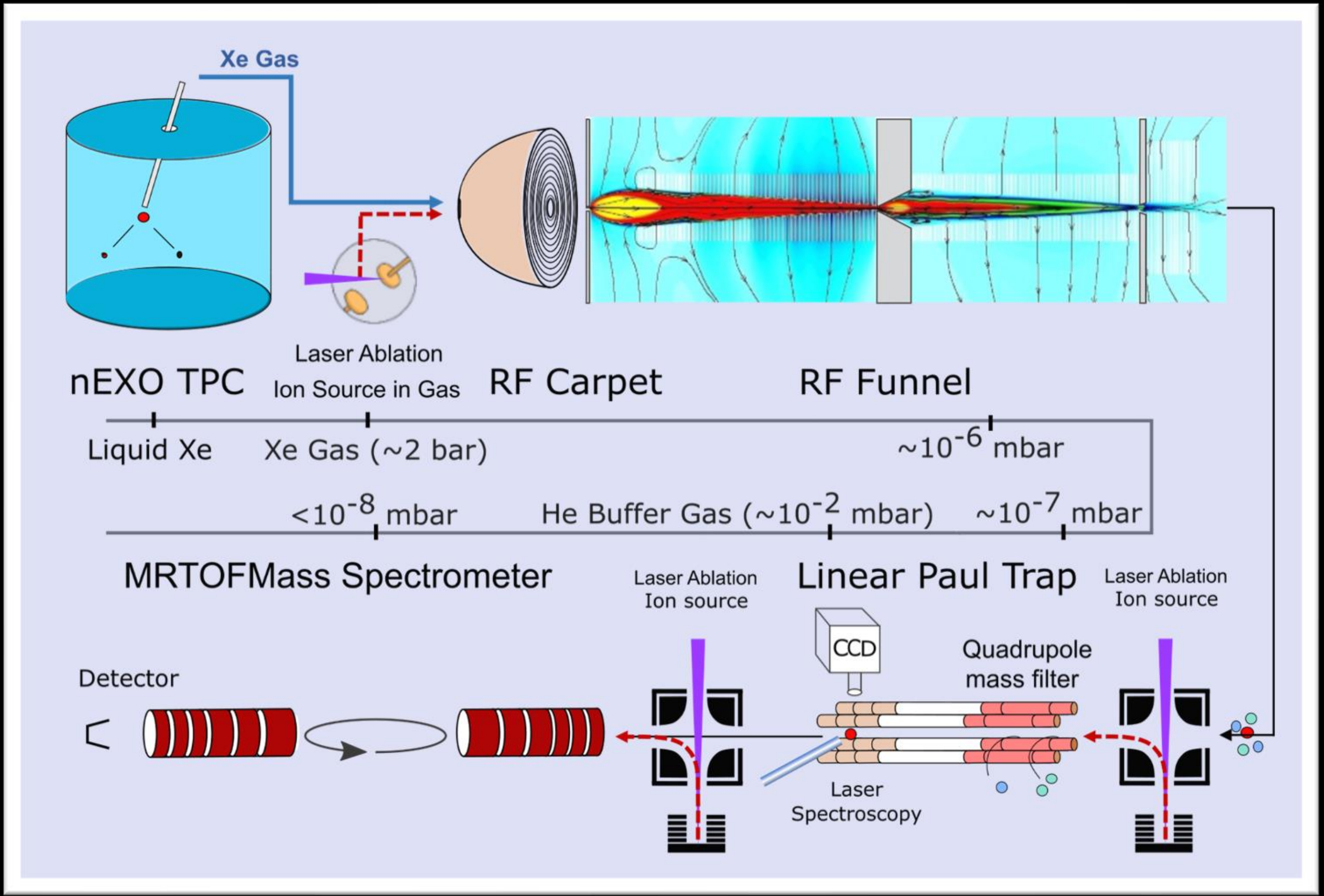


{Albert, J. B., & others. (2018). *Physical Review C*, *97*(6), 65503.}
{Adhikari, G., et al. Journal of Physics G: Nuclear and Particle Physics 49.1 (2021): 015104.}

# Ba-tagging Technique

**Stage 1:** Localization and extraction from liquid Xe

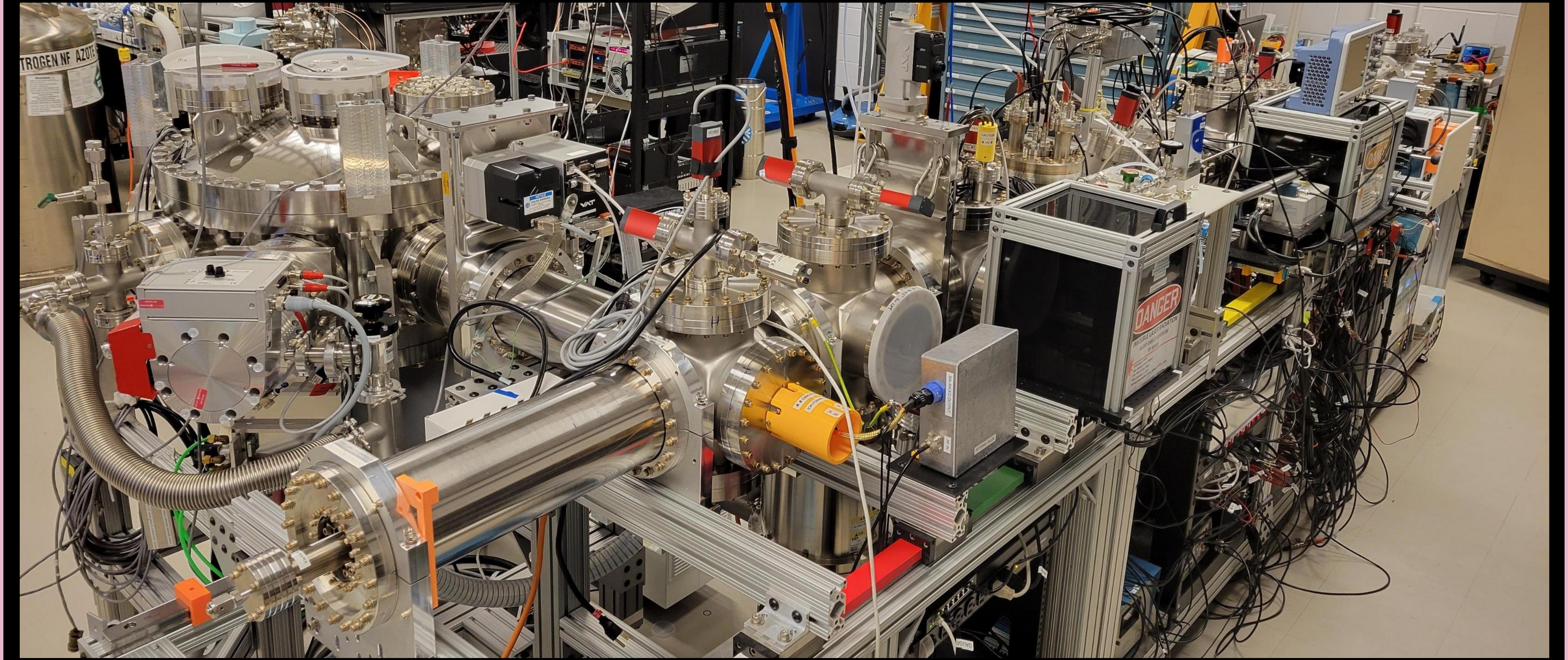
**Stage 2:** Transport and extraction from gaseous Xe




**Stage 4:** Barium-136 Identification with mass spectrometry

**Stage 3:** Barium element Identification with fluorescence spectroscopy

# Ion extraction from GXe



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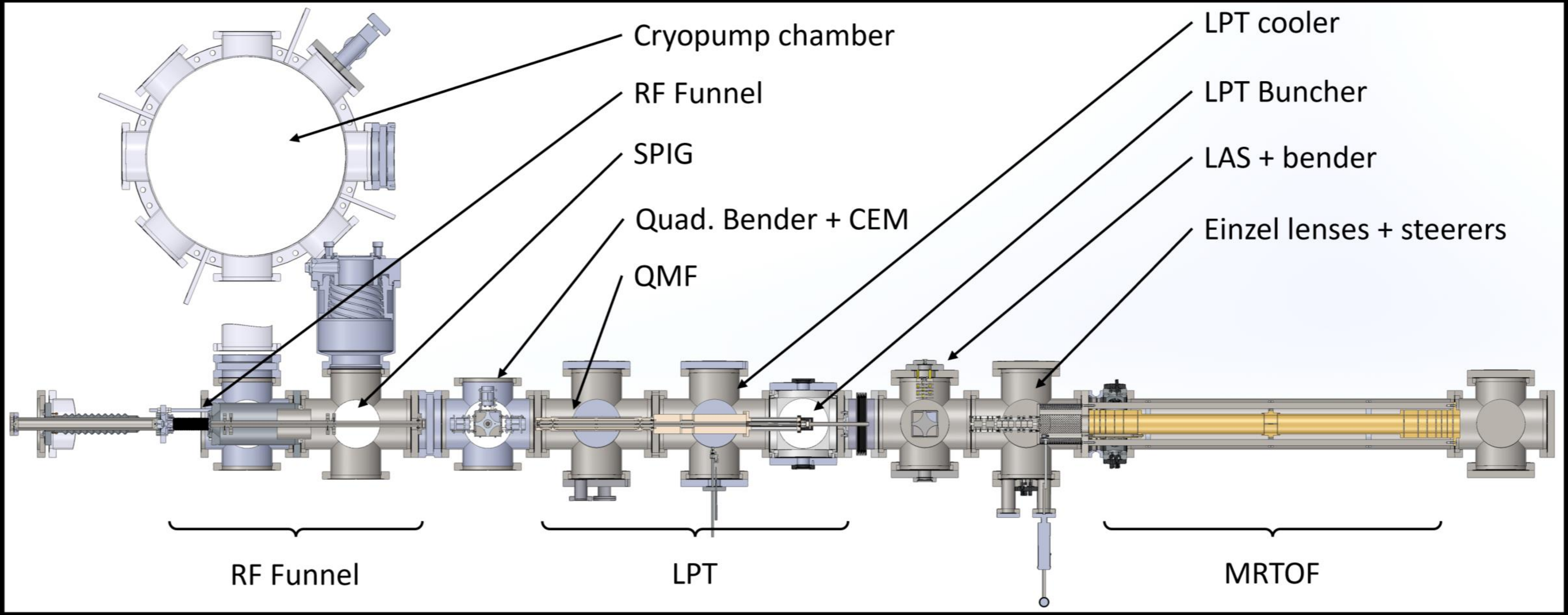

# Linear Paul Trap

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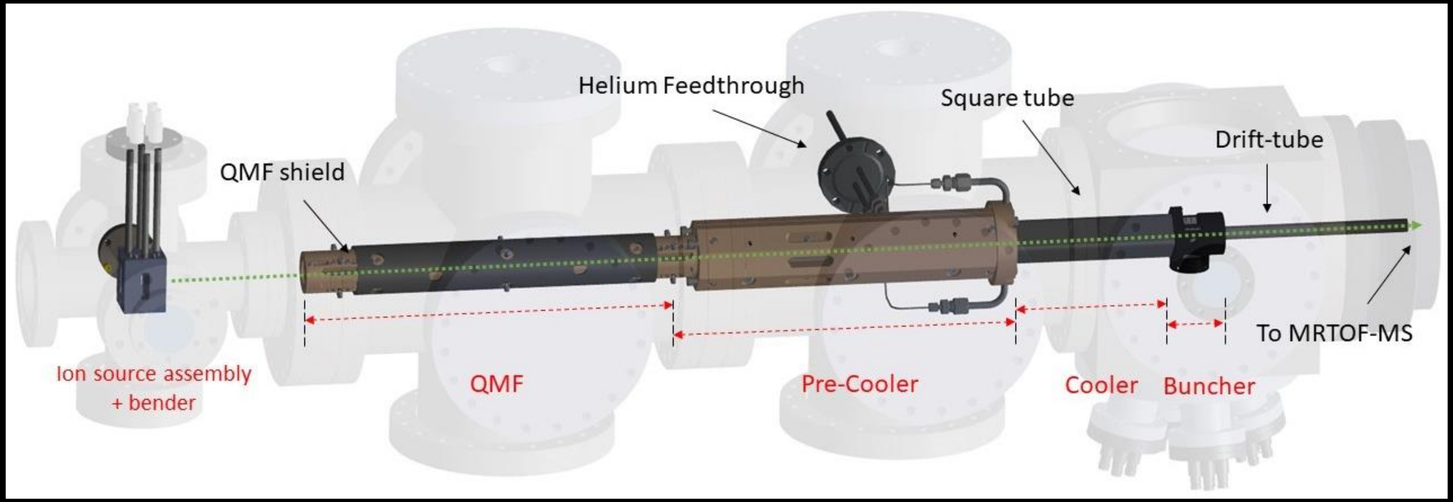


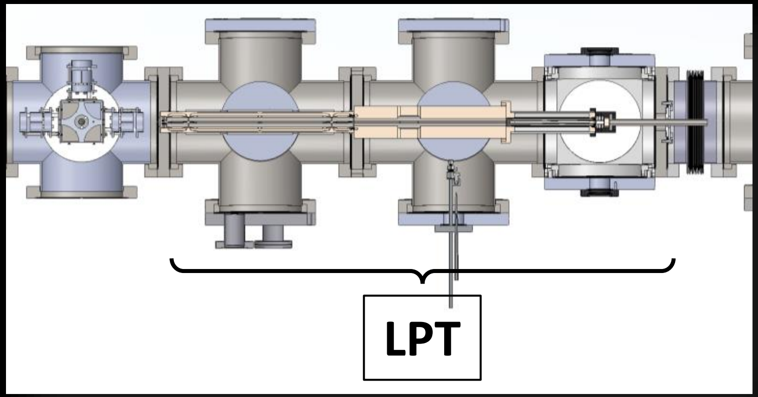


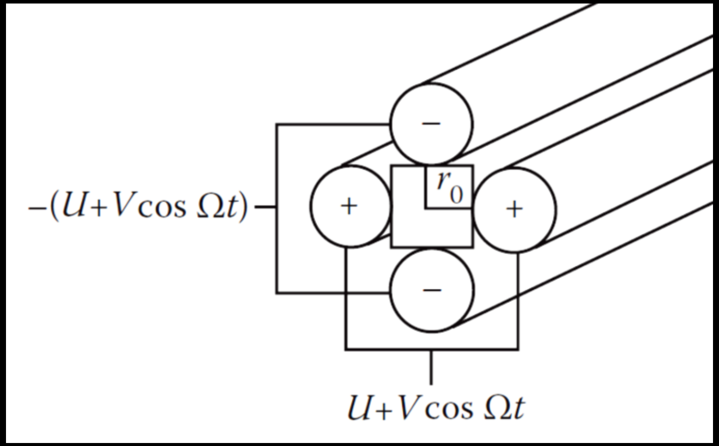


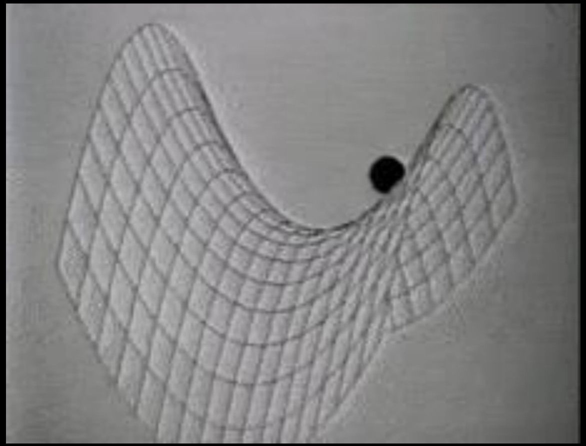

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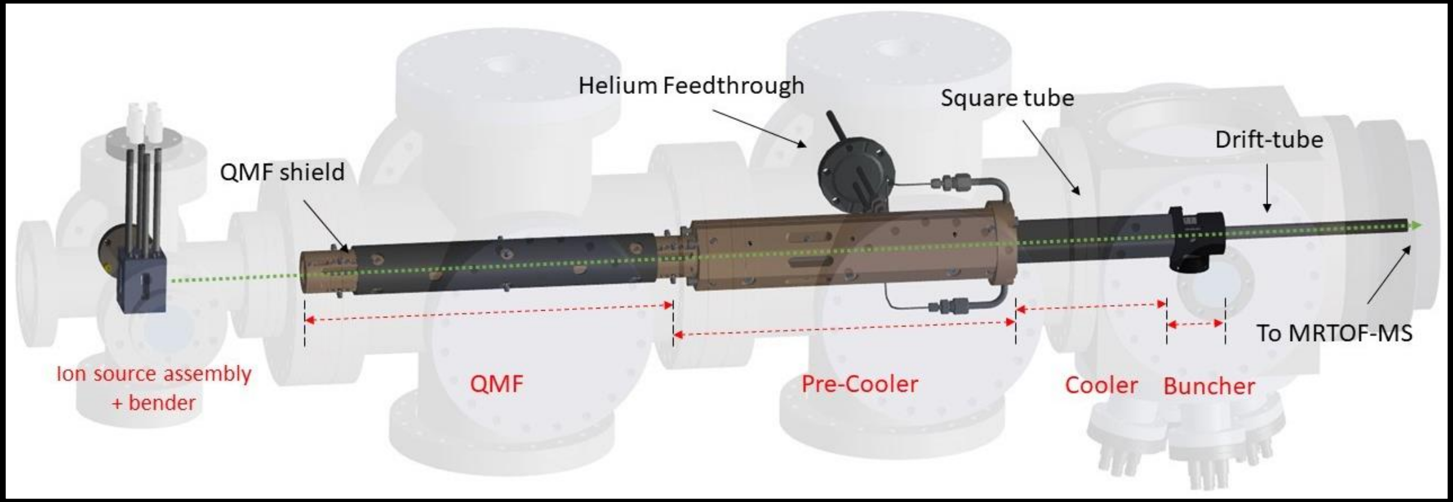


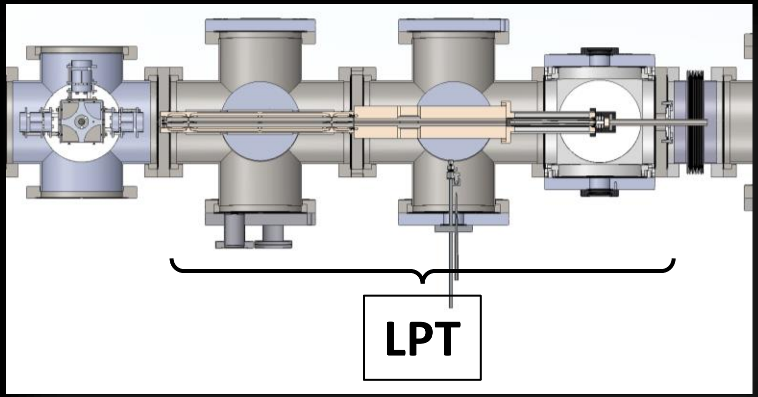


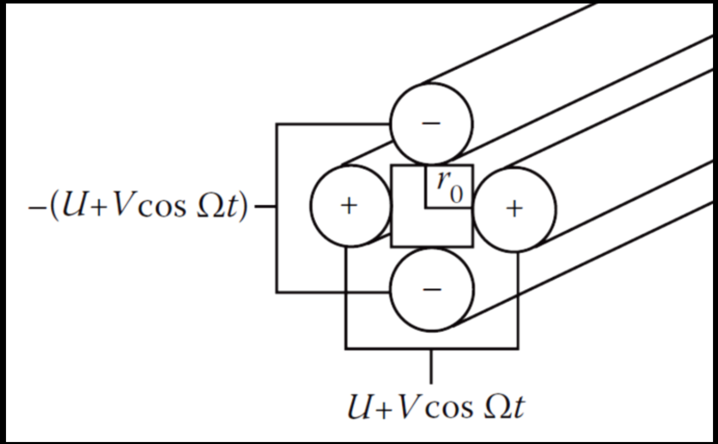


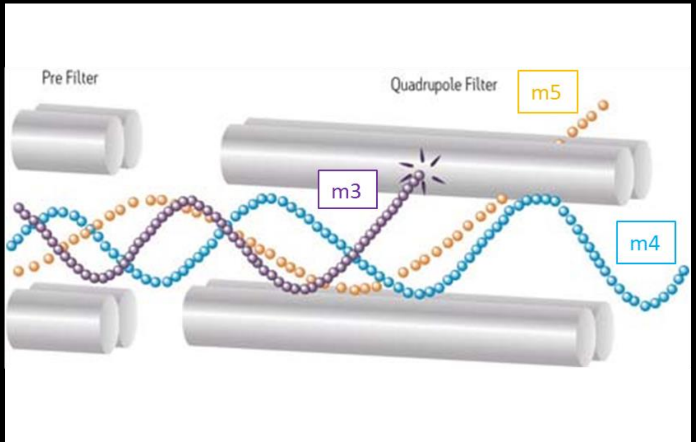

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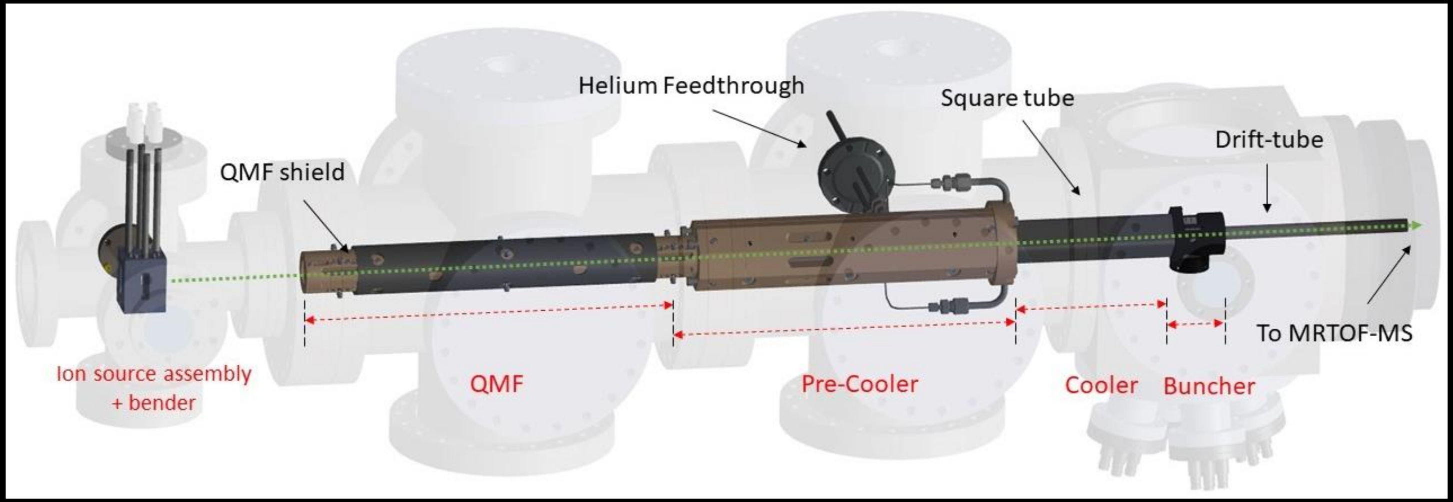


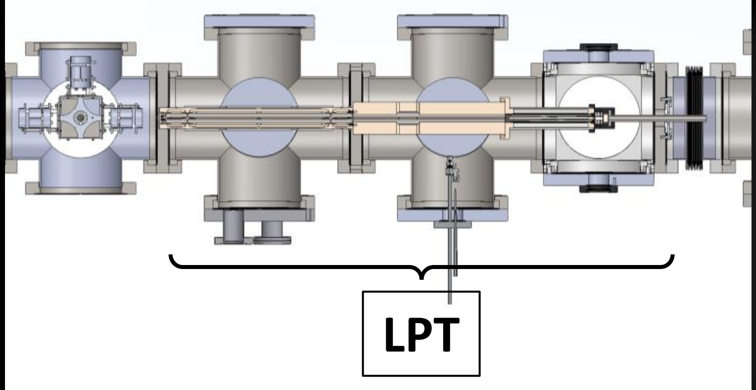


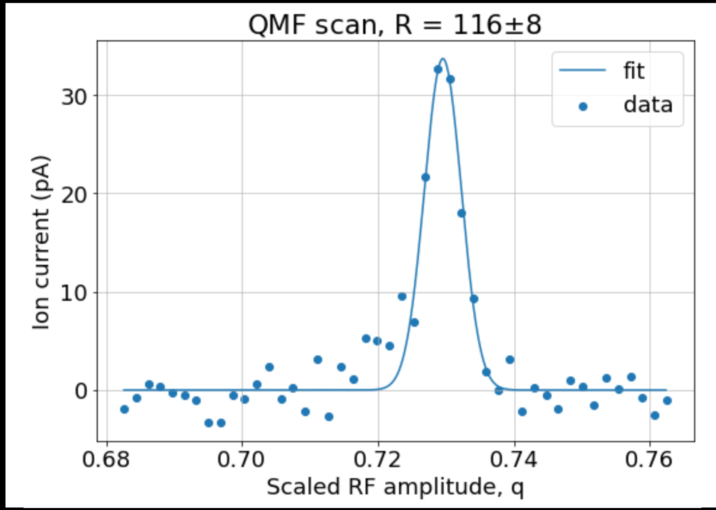


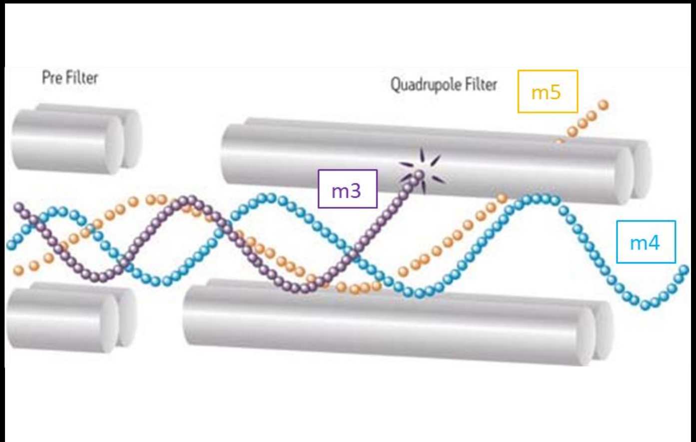

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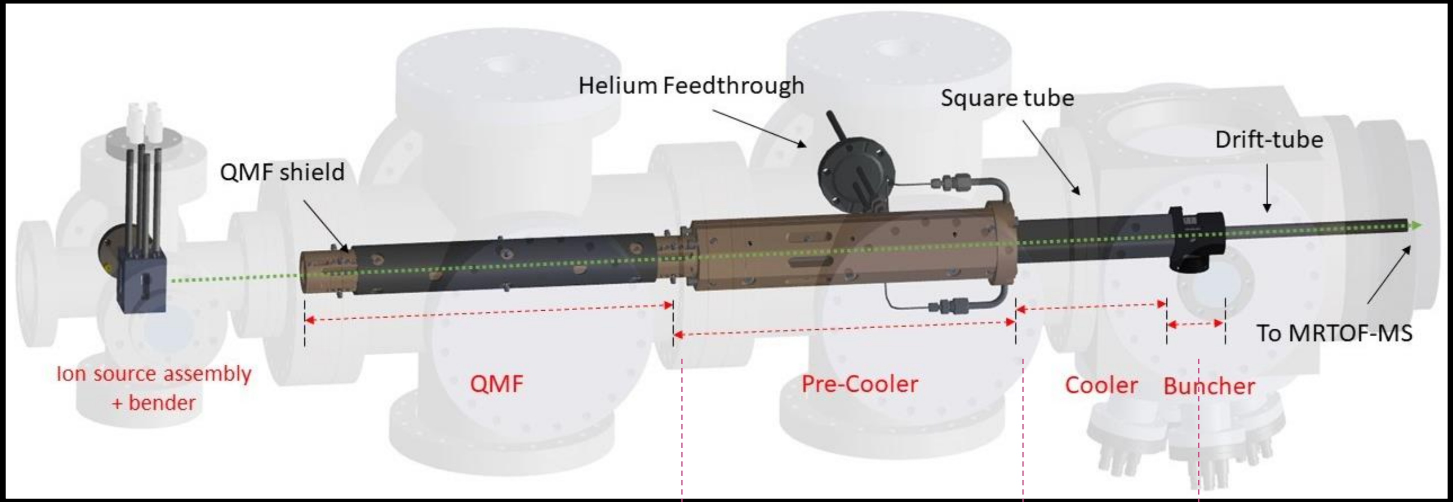


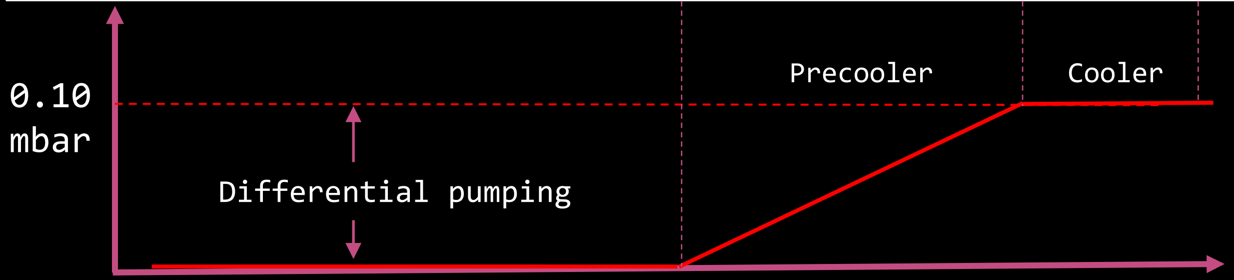


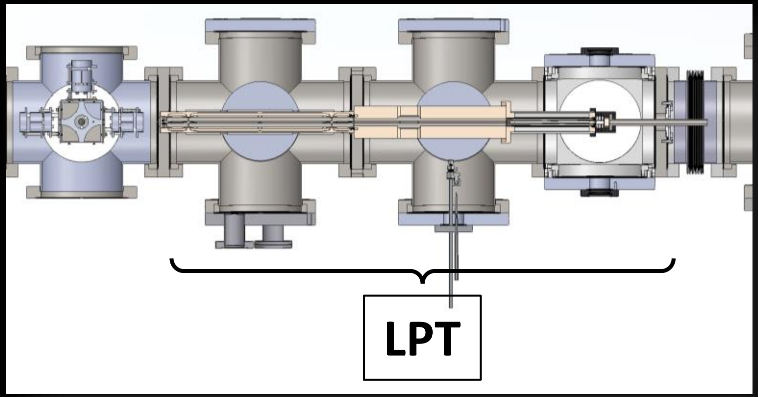


Helium gas with flowrate of 25 sccm is supplied to the cooler to cool incoming 50 eV to < 1 eV.

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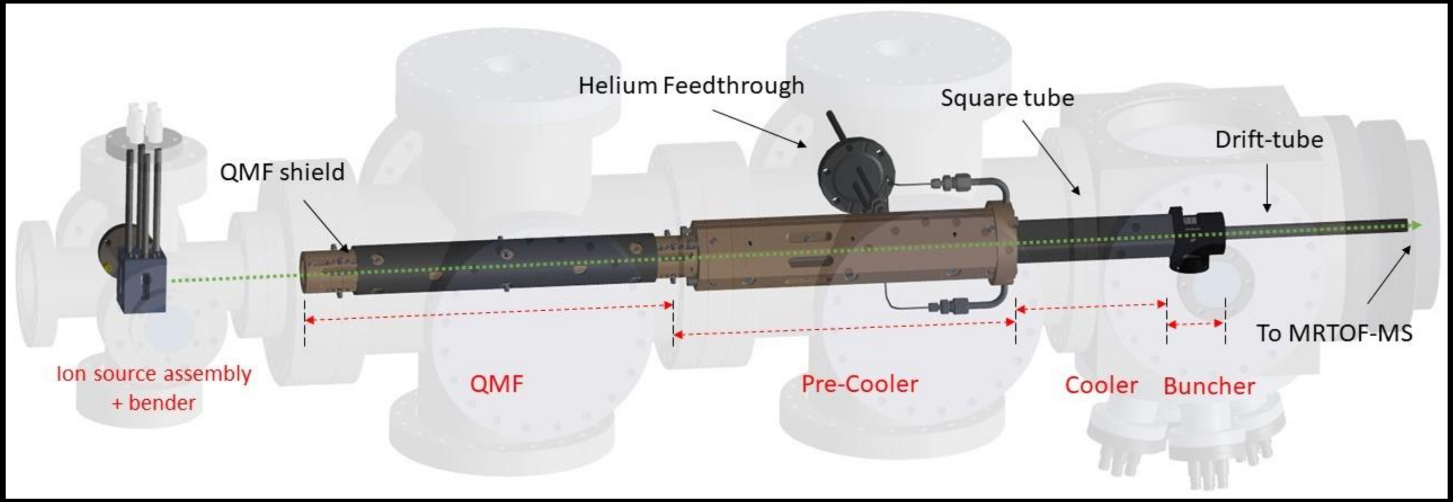


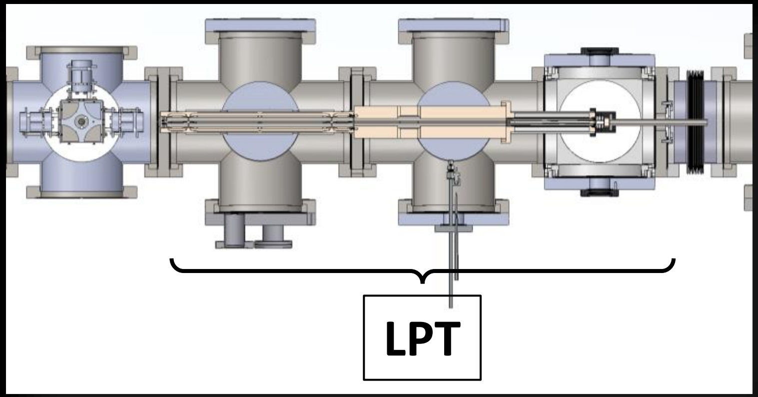


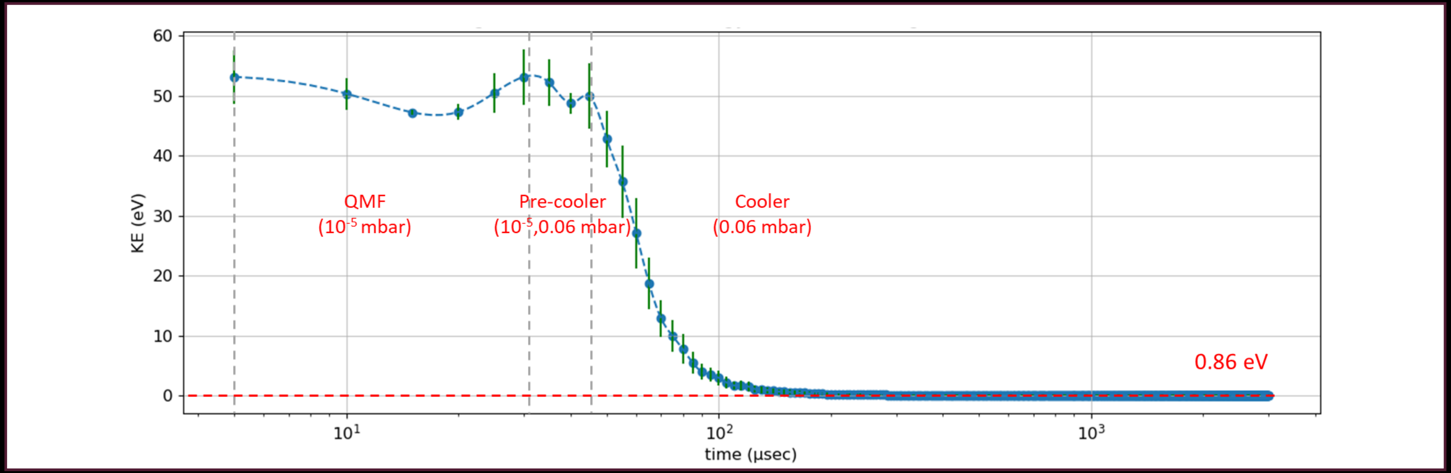

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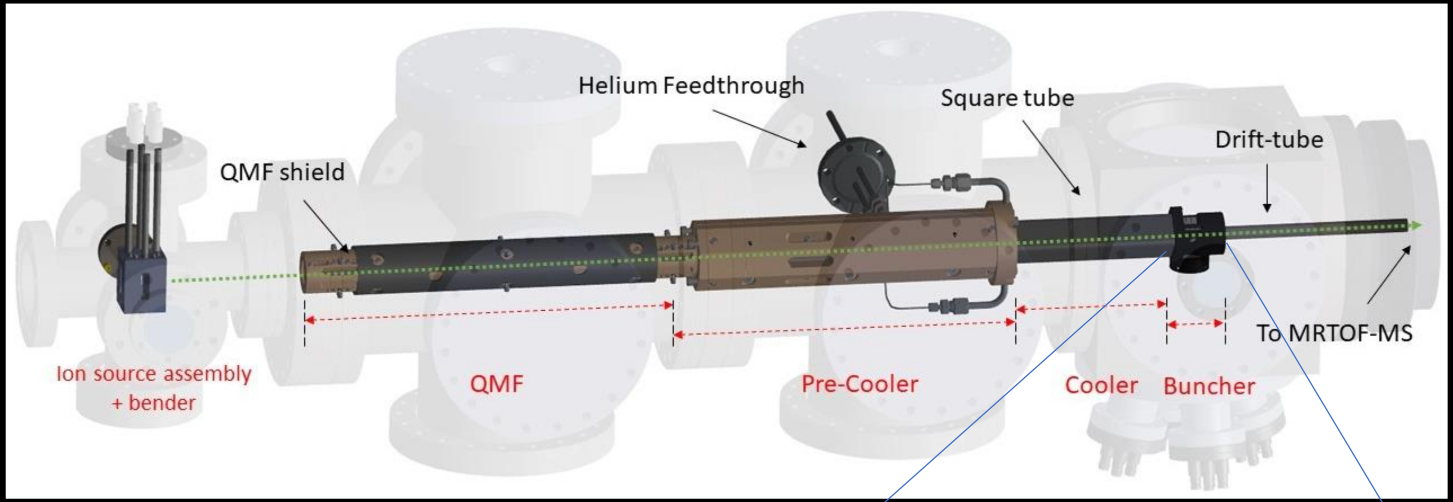


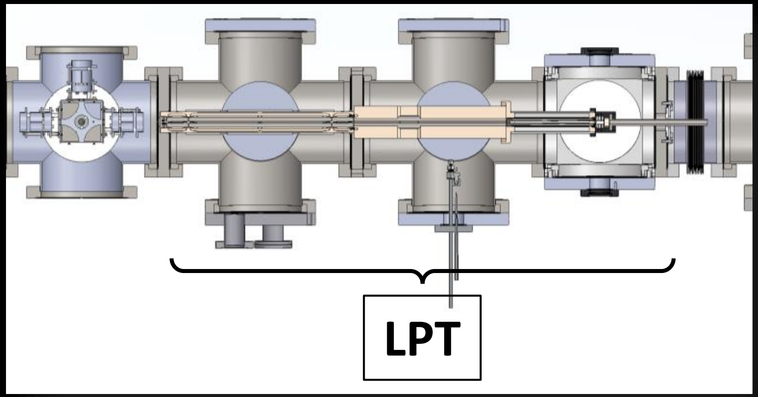


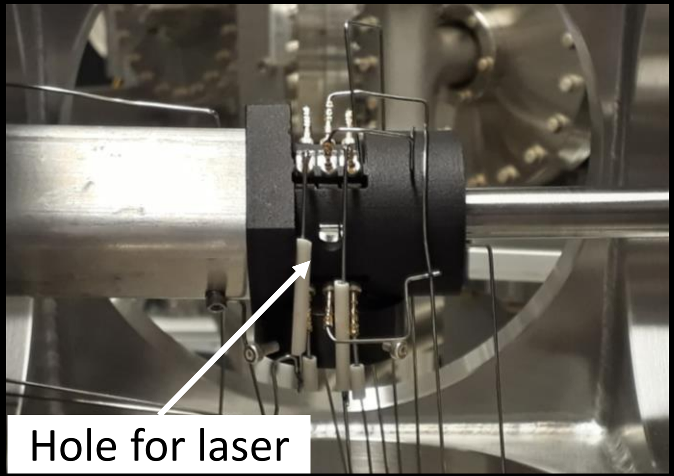


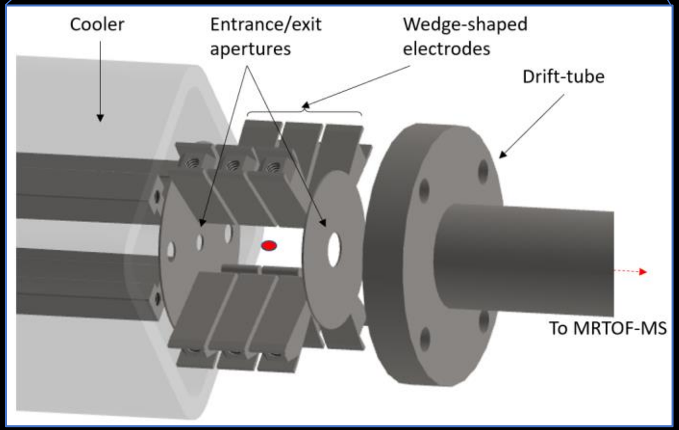

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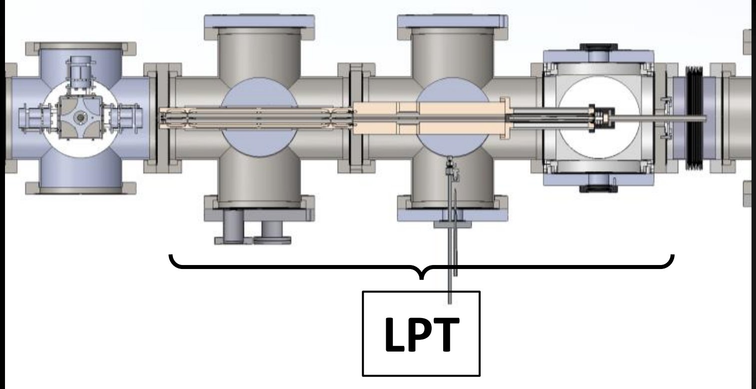


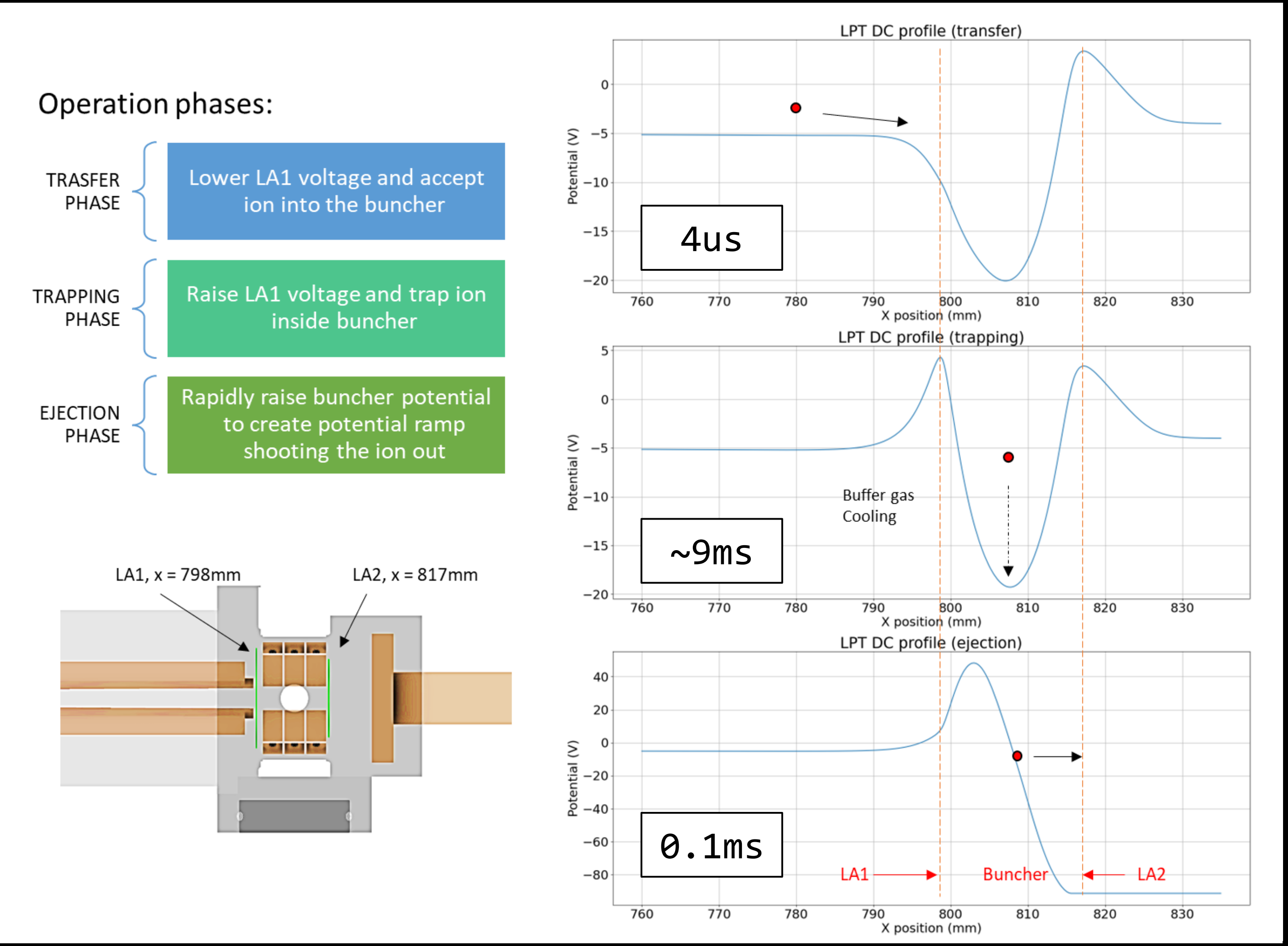

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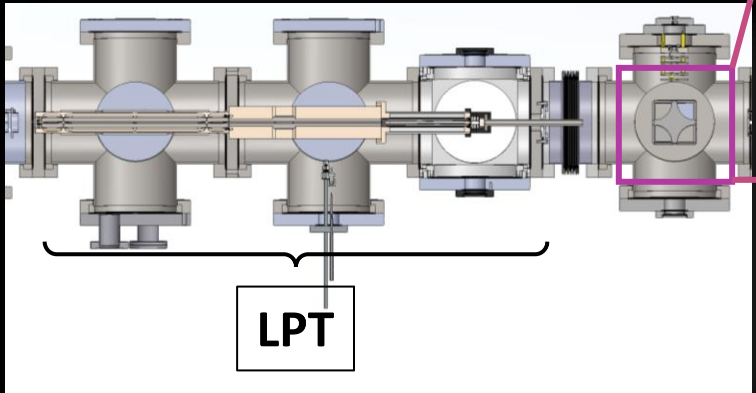
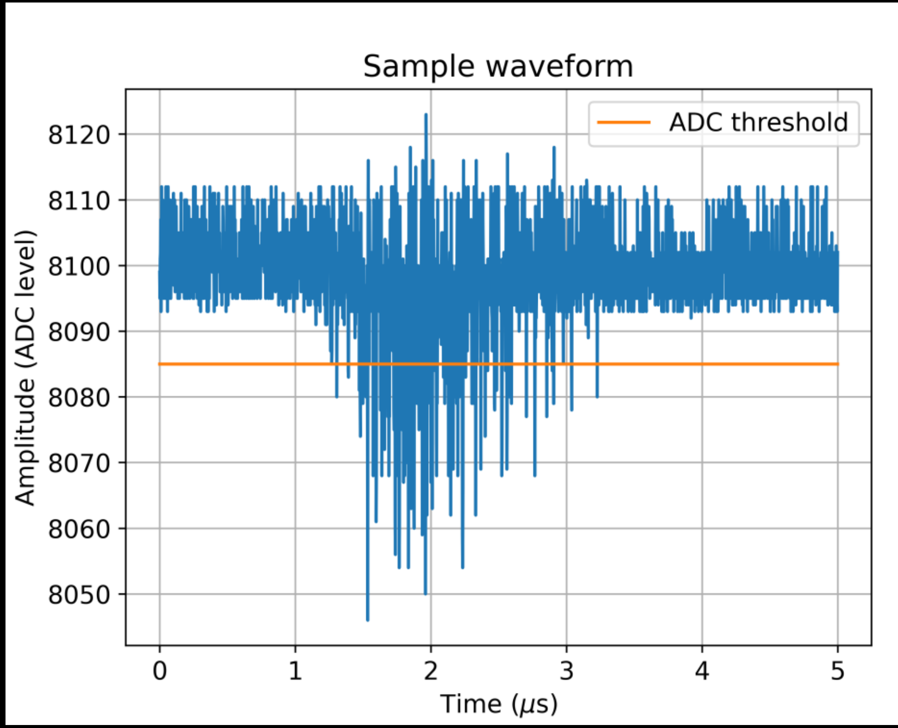



Channeltron detector



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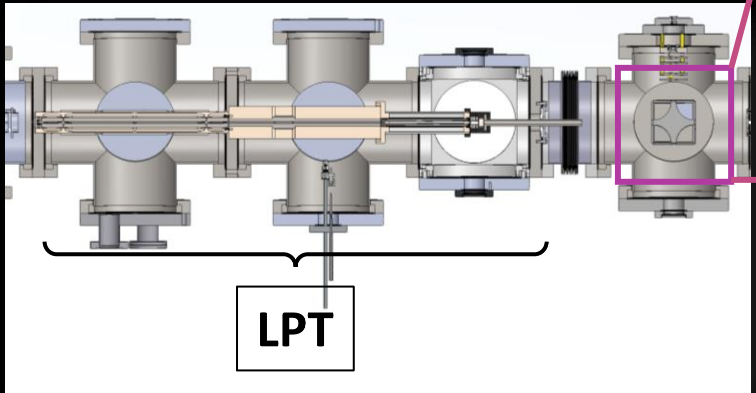


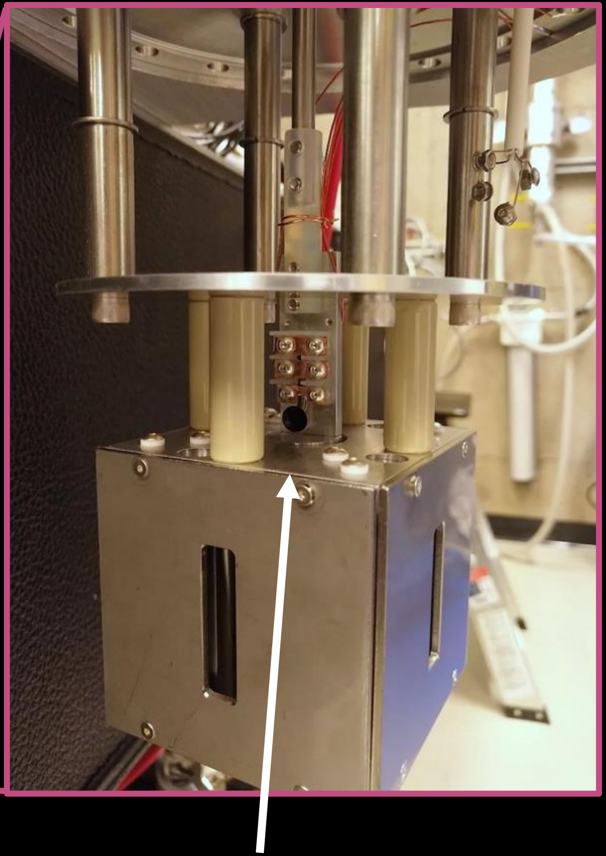

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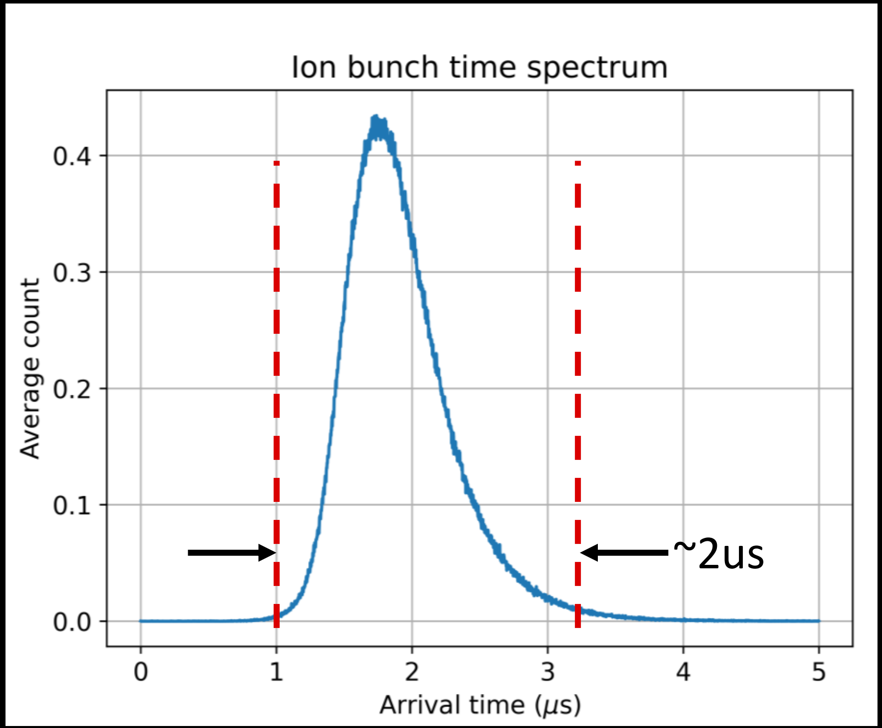
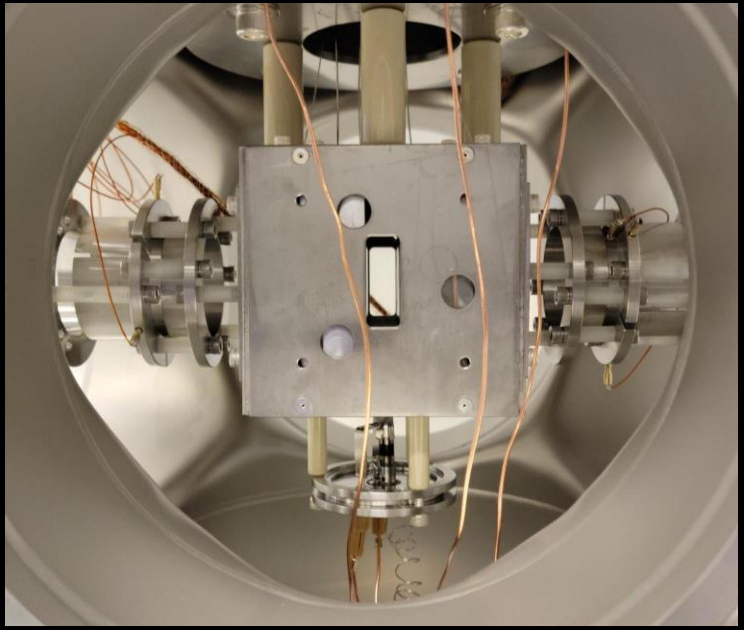
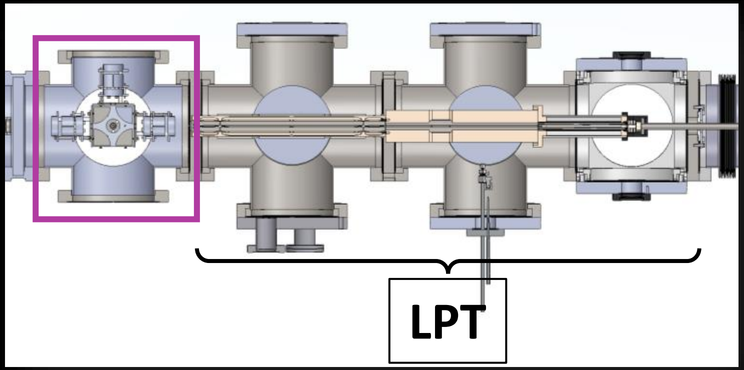


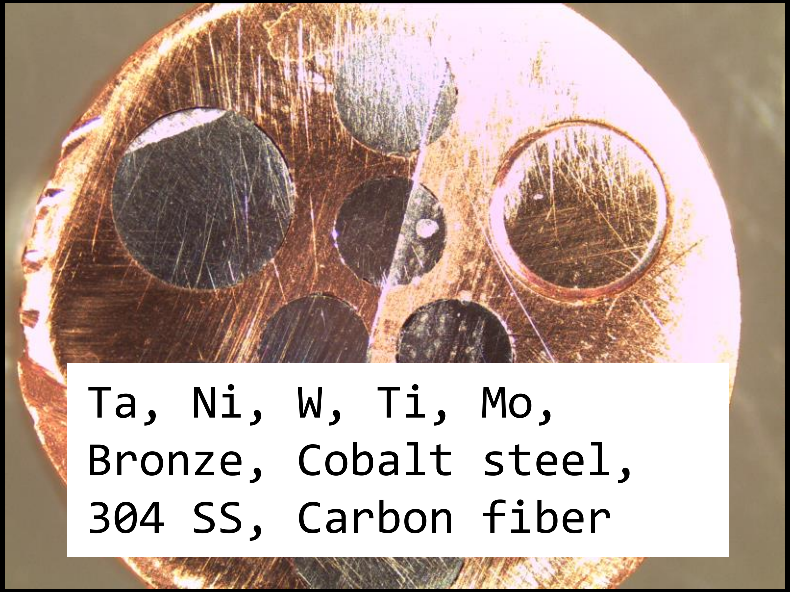

- Buffer gas pressure
- Potential well depth
- Trapping and transfer duration

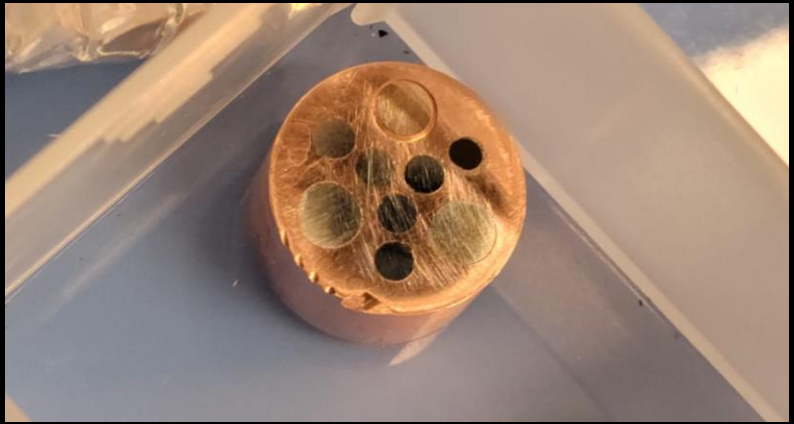
# Multi-element target for LPT






- 9 element/alloy rod pieces fitted into a Cu target to create a multi-element target.
- The target will then replace the thermal ion source as a laser ablation ion source.
- Possibility of selective ablation helps produce range of ions without requirement of swapping targets.



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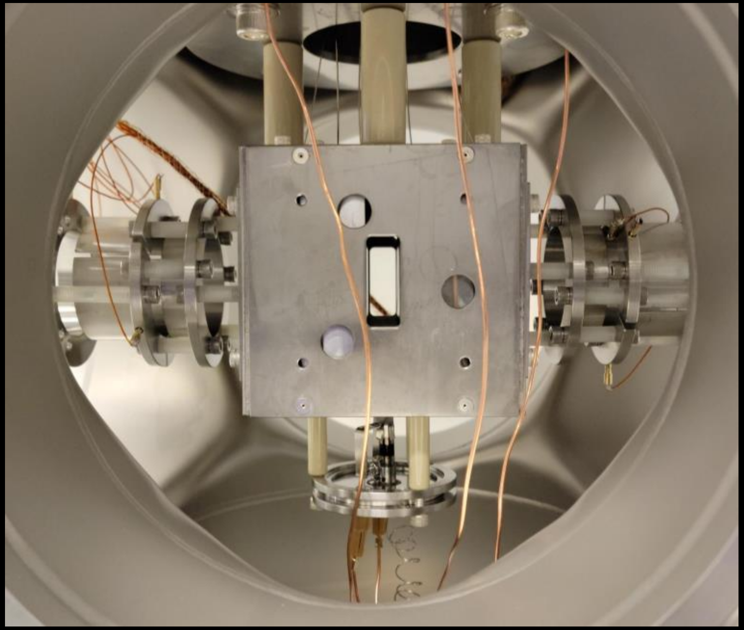

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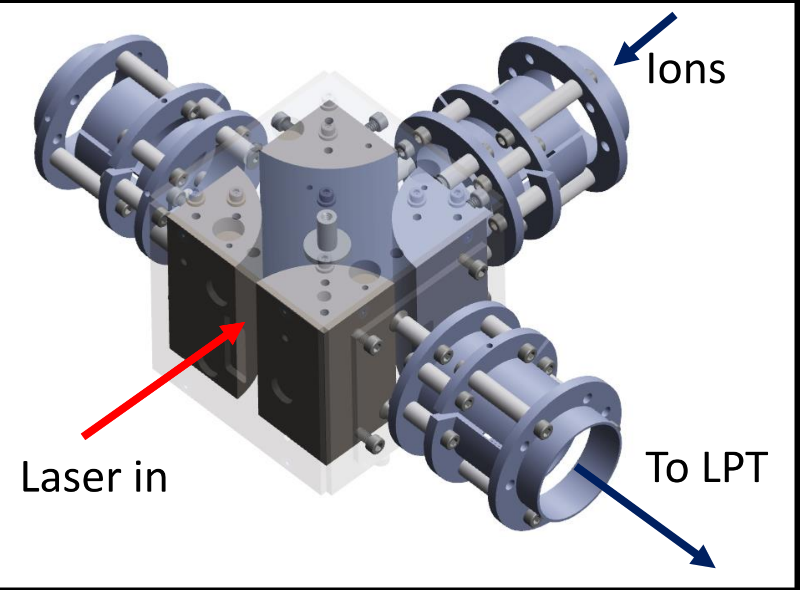


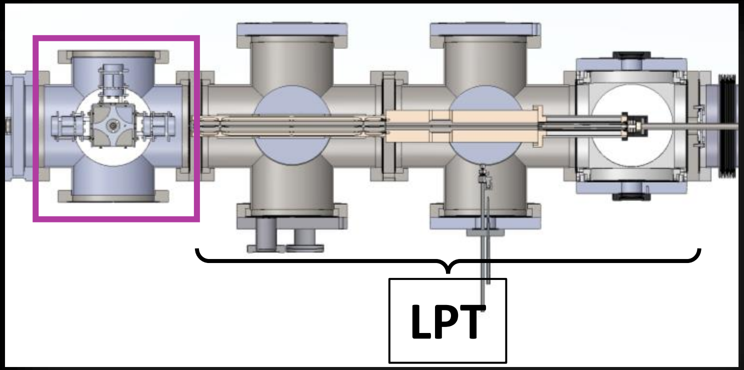


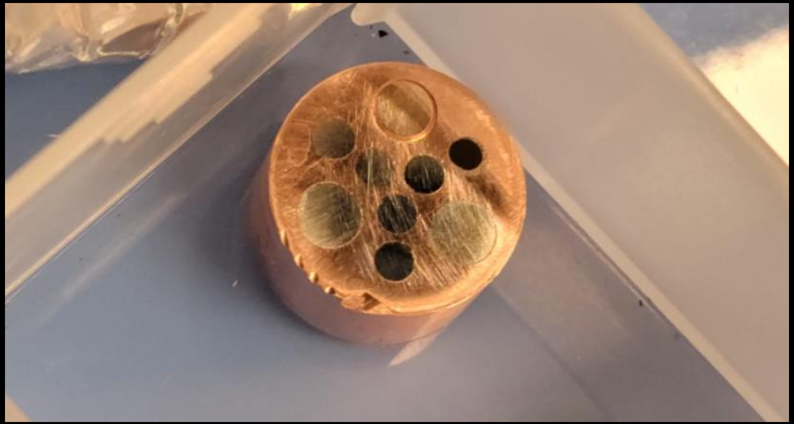

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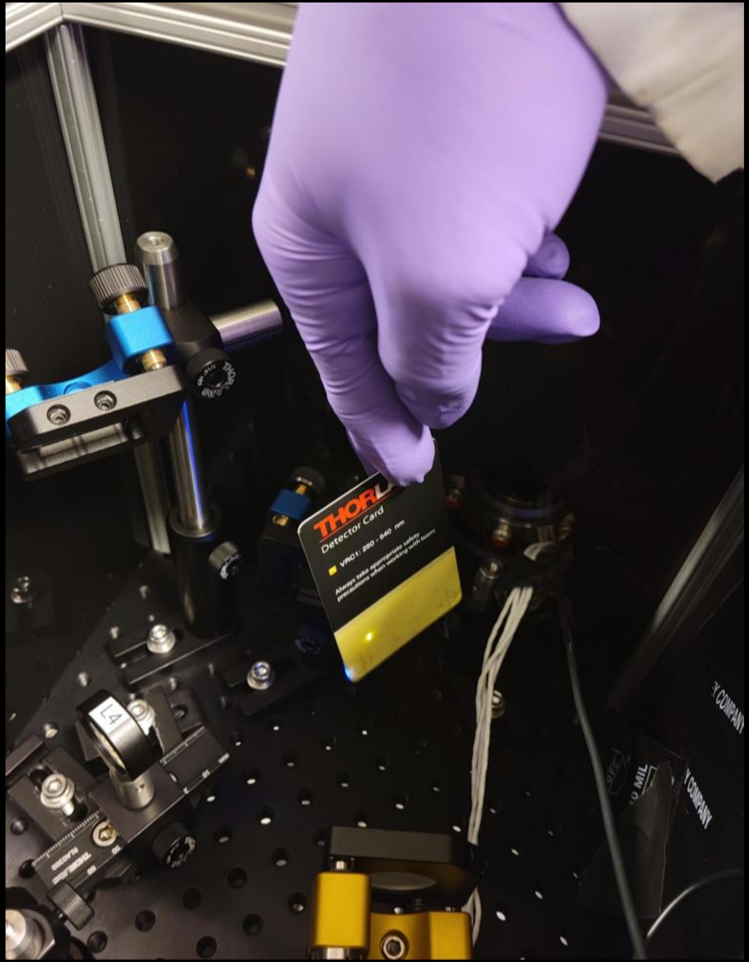

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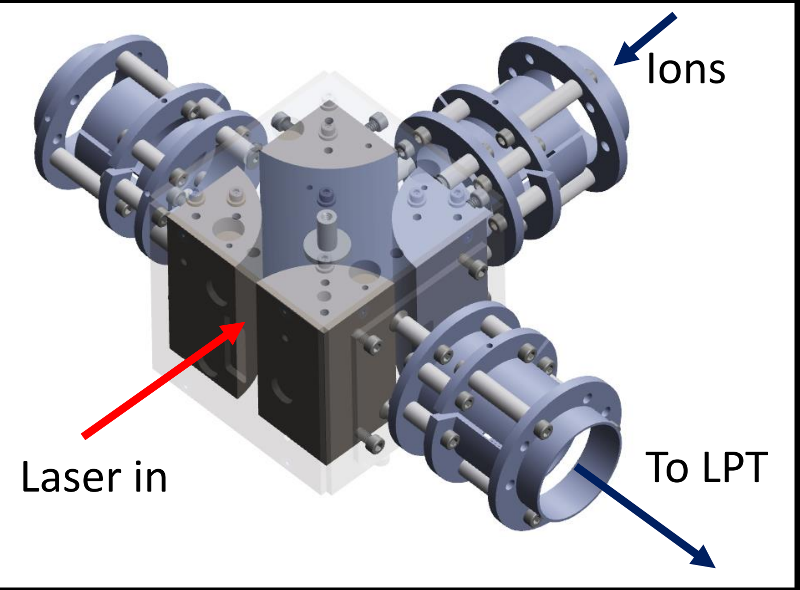
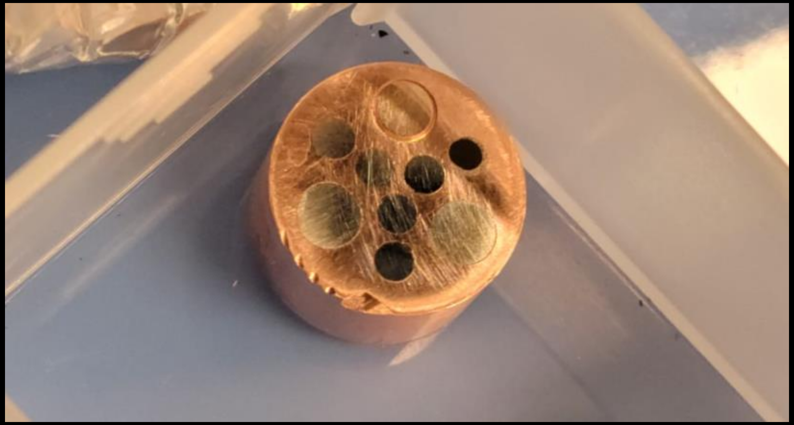


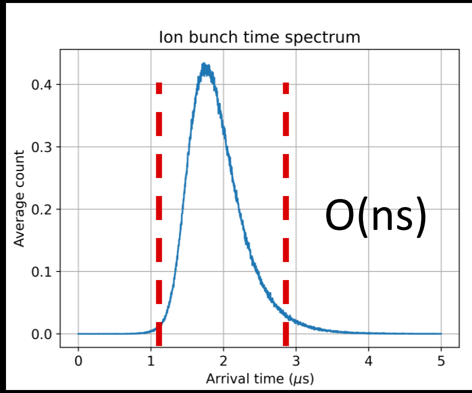
# Summary

Conclusion:

- $0\nu\beta\beta$ is an effective tool to search for BSM physics.
- nEXO Experiments will search for $0\nu\beta\beta$ in the isotope Xe-136.
- Ba-tagging technique is a potential upgrade for active background rejection in nEXO.
- Characterization of the gas extraction setup is currently under progress.

Next steps:

- Optimization of ion bunching.
- Determine MRTOF mass resolving power using bunched ions from LPT.
- Demonstrate ion production using the multi-element target.
- Perform ion extraction studies using RF Funnel with LPT and MRTOF.




MRP, m/Δm ~ 100,000

# Acknowledgement

Thanks to all the nEXO collaborator.

Special thanks to my colleagues and lab mates at McGill.

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NSERC CRSNG

Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

CINP ICPN
Canadian Institute of Nuclear Physics
Institut canadien de physique nucléaire

Fonds de recherche Nature et technologies
Québec

# Thank you for listening!

# nEXO Experiment

✓ To reduce non-double-beta decay backgrounds in the region of interest, **Barium tagging** is proposed as a potential future upgrade to nEXO.

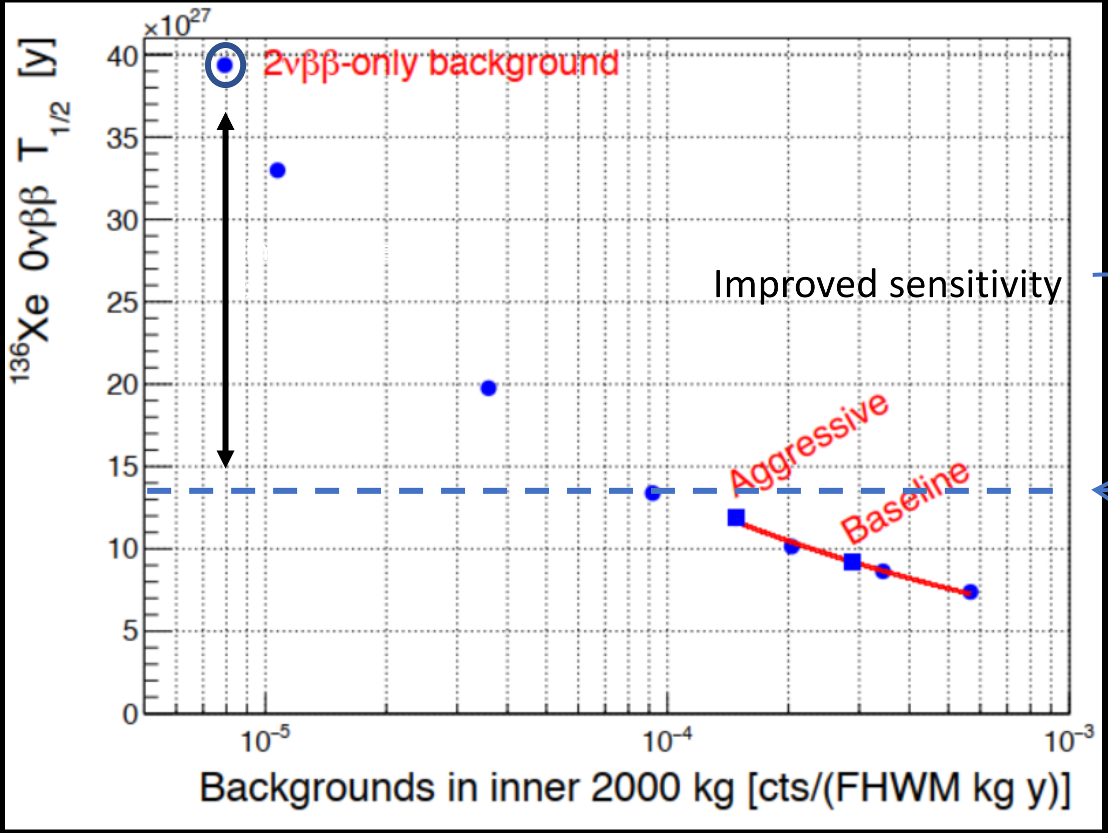
Detect Ba-136 ion at the position of potential $0\nu\beta\beta$ decay.

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

Boost to sensitivity of up to a factor of **2** to **3**.

{Moe, M. K. "Detection of neutrinoless double-beta decay." *Physical Review C* 44.3 (1991): R931.}

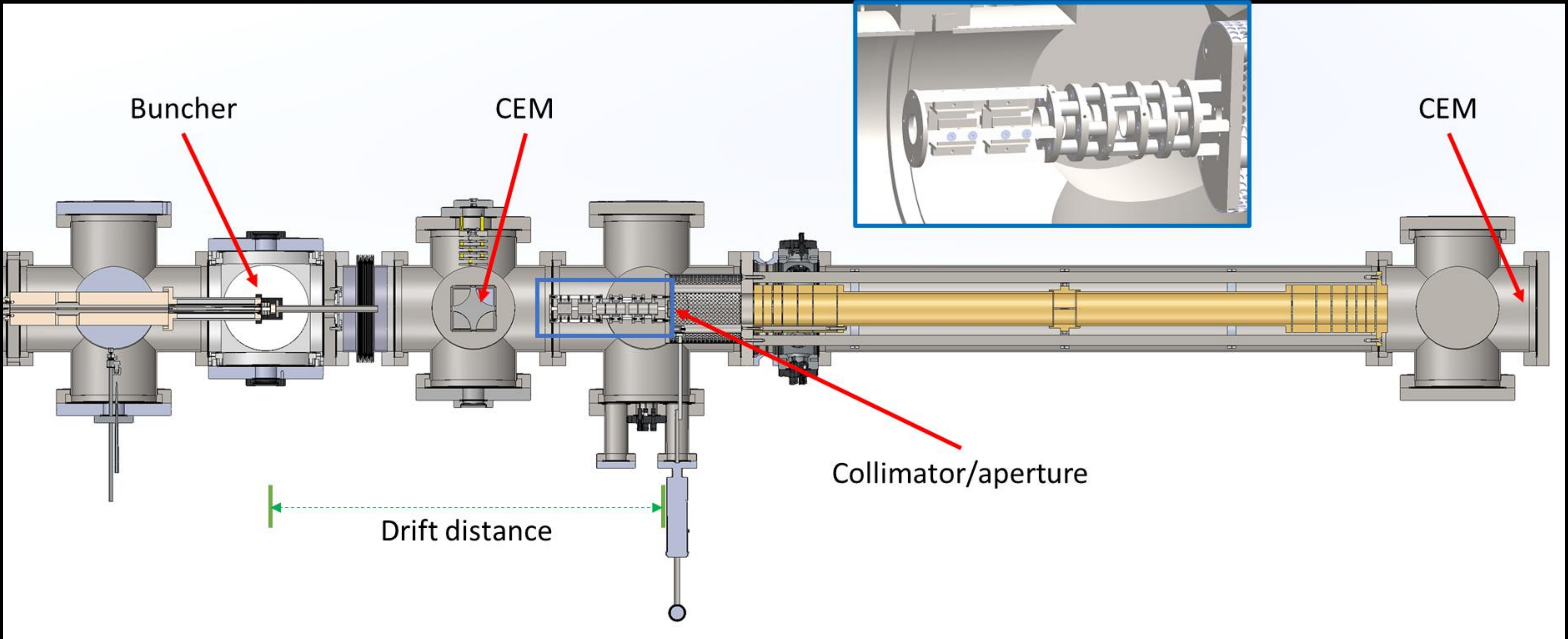
Asymptotic sensitivity for a potential upgrade using Ba tagging



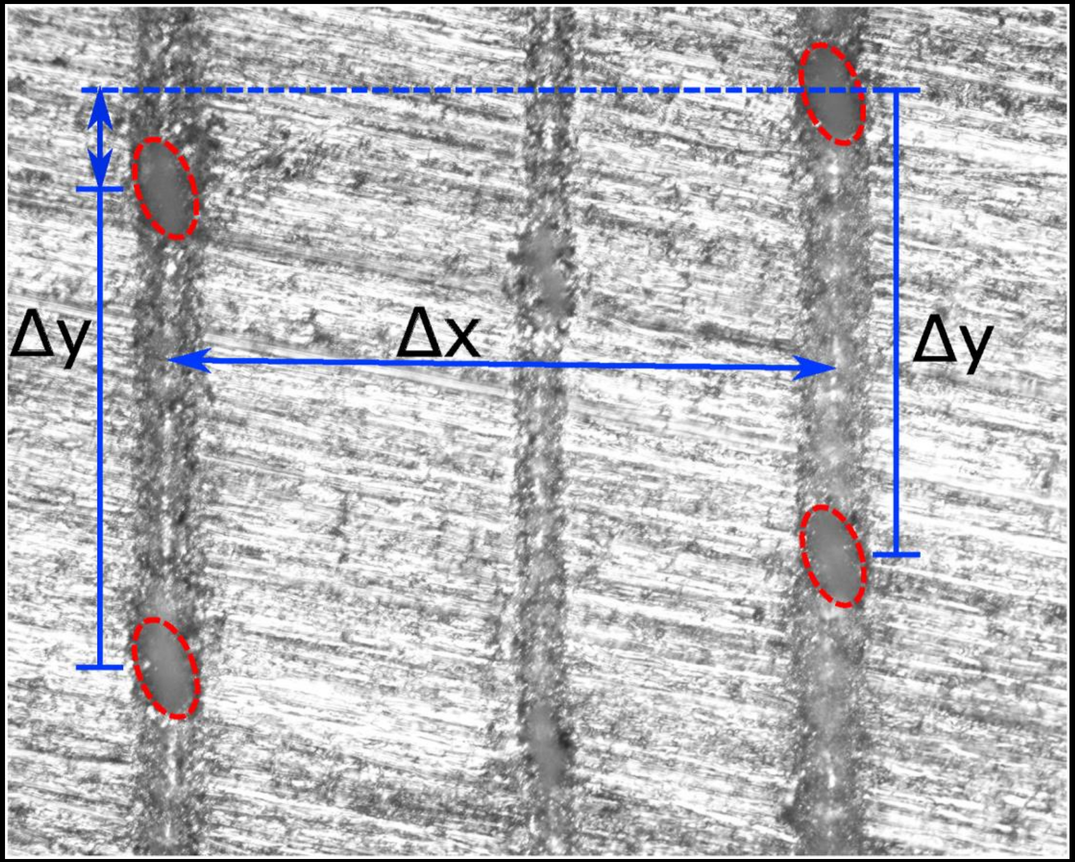

Improved sensitivity

{Albert, J. B., & others. (2018). *Physical Review C*, *97*(6), 65503.}
{Adhikari, G., et al. Journal of Physics G: Nuclear and Particle Physics 49.1 (2021): 015104.}

# Ion Bunching



# Laser ablation



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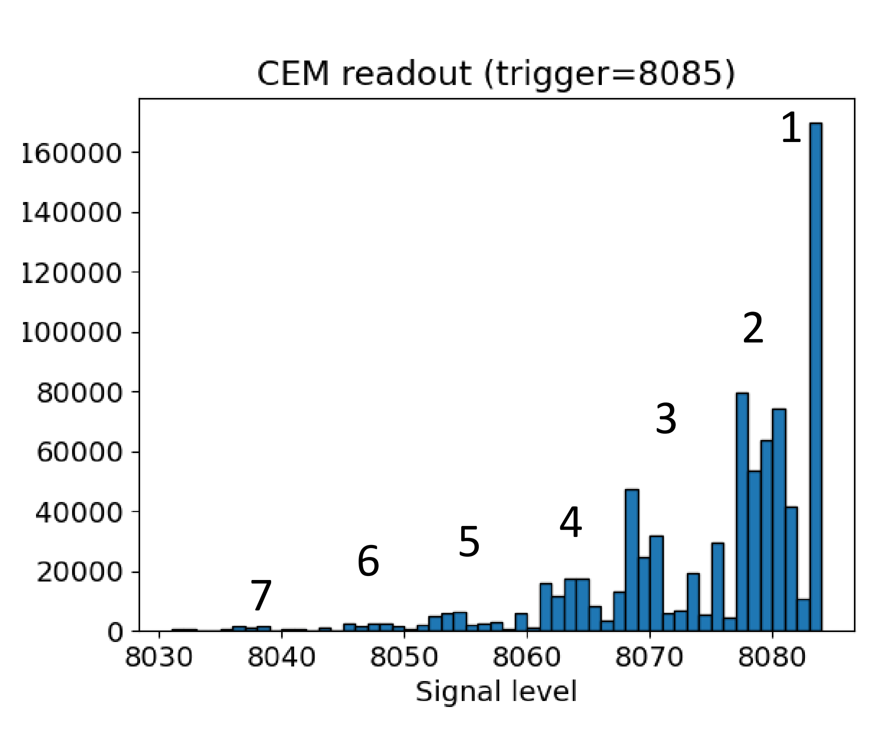


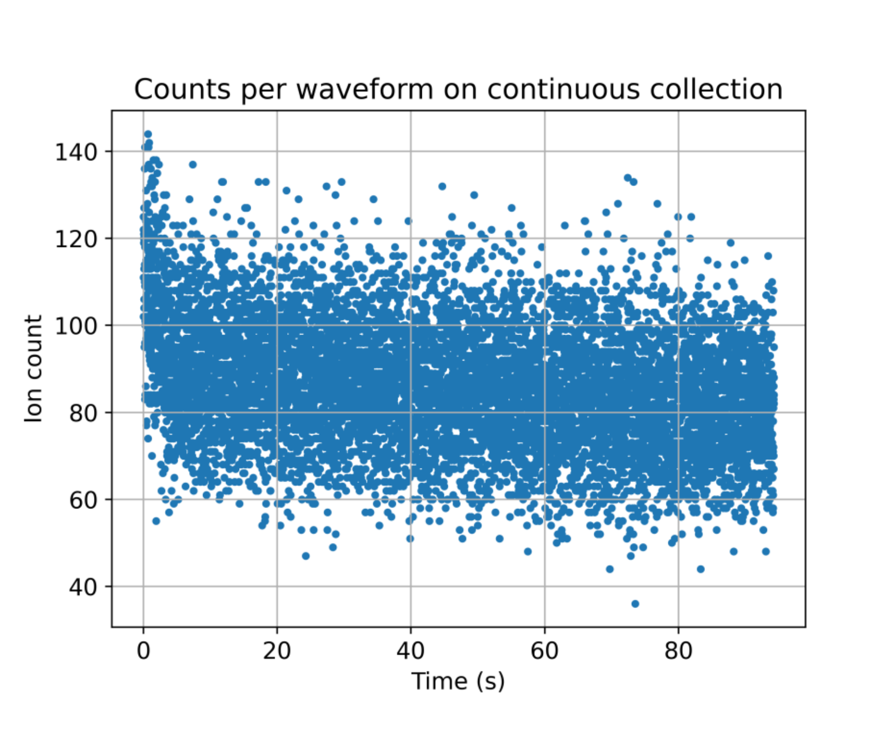

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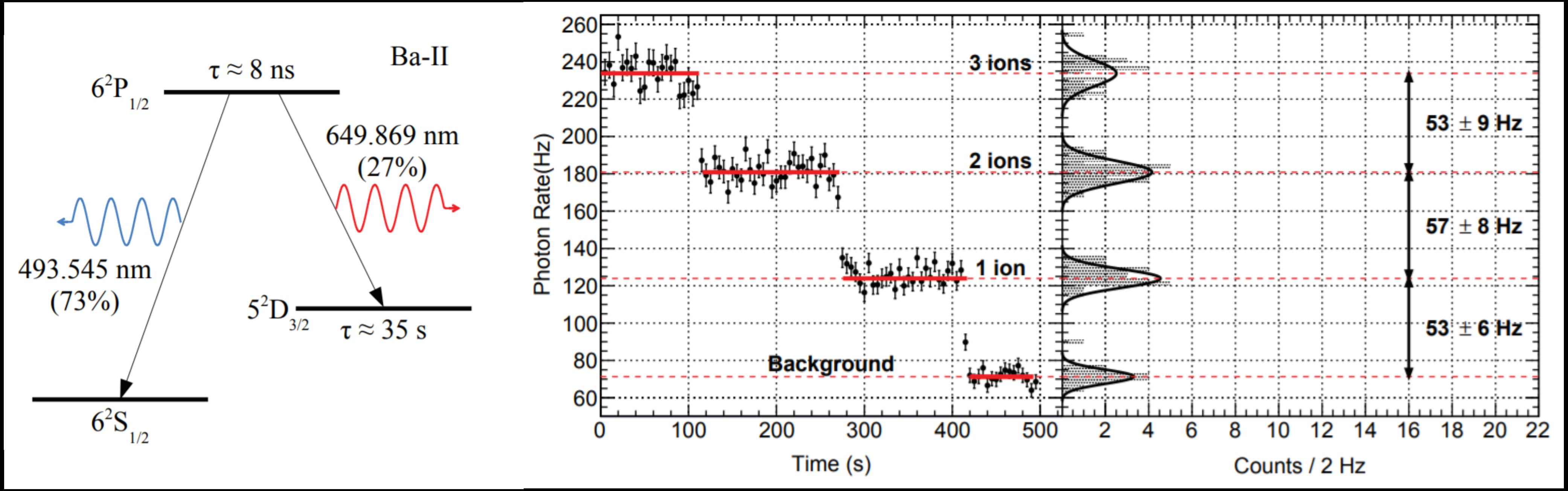
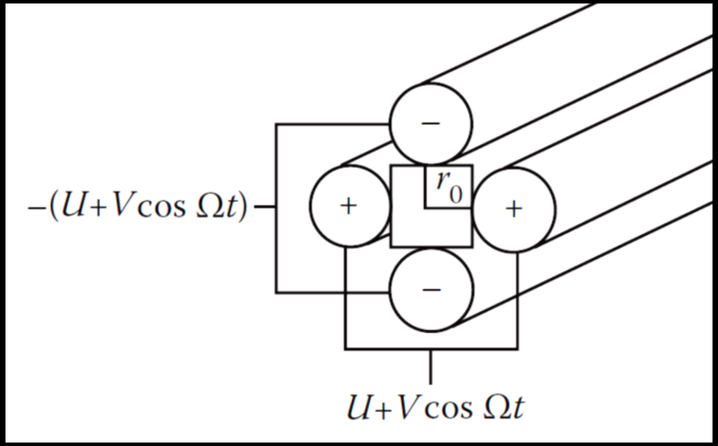


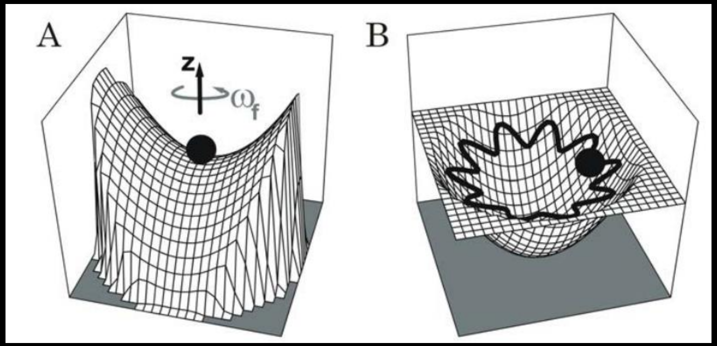

- Uses ion trap for confining ions and laser induced fluorescence for barium ion detection.
- This scheme was demonstrated first by M. Green et. al by studying 493nm florescence intensity from single barium ion.
- Single ion detection has been demonstrated by collaborators at Carleton University.

M.Green, et al., Phys.Rev.A 76 (2007) 023404

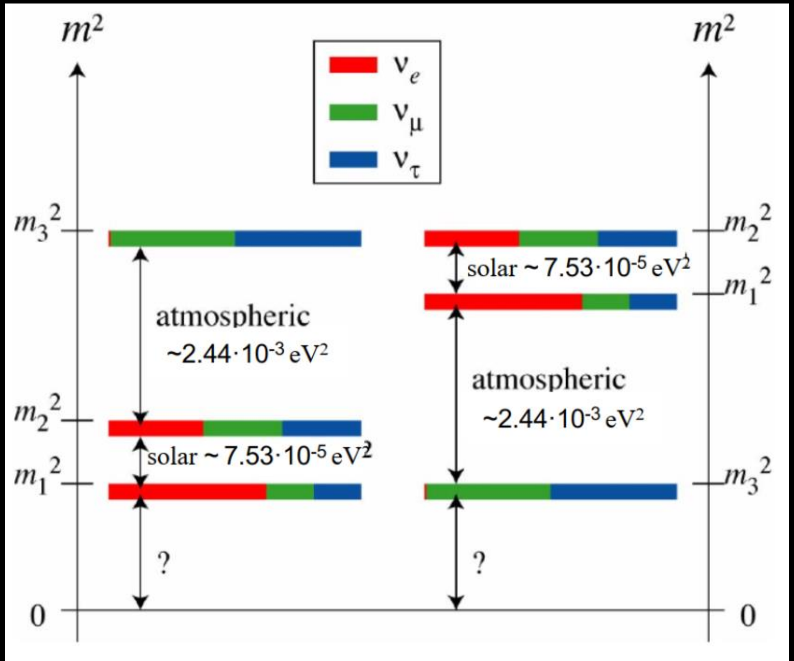
# Use of RF potentials

- Radio-frequency potentials are a useful tool for controlling ion motion.
- Net effect of a rapidly oscillating potential is restorative force that is proportional to distance from the axis.
- This effect forms the basis of the ion optics used in the Ba-tagging setup.



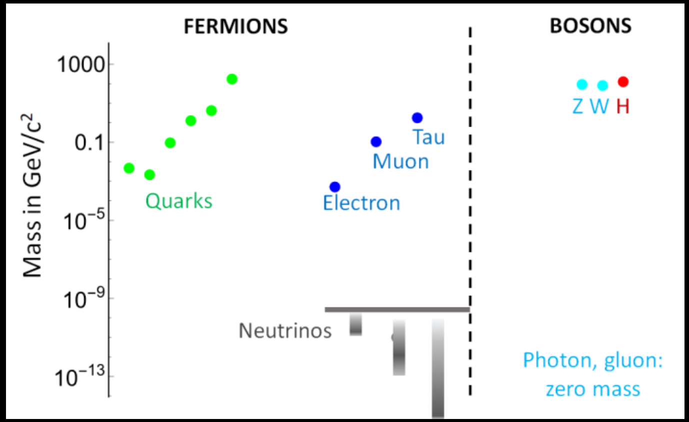




# What do we ***DON'T*** know about neutrinos?



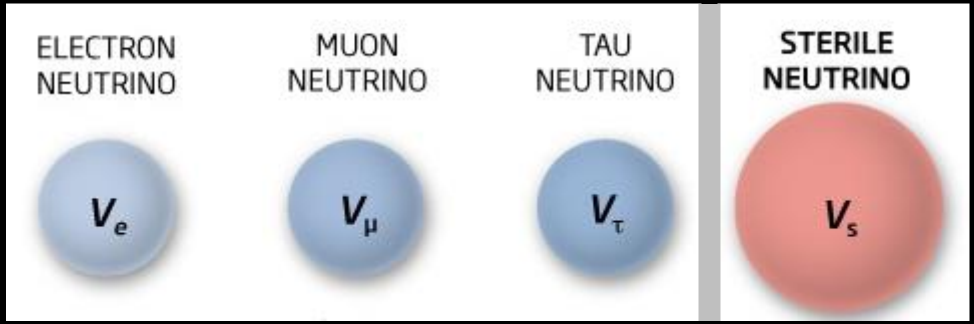

What is the mass hierarchy?
What is the absolute mass scale?

Why are their masses so small relative to the other Fermions?




Do neutrinos violate CP symmetry?

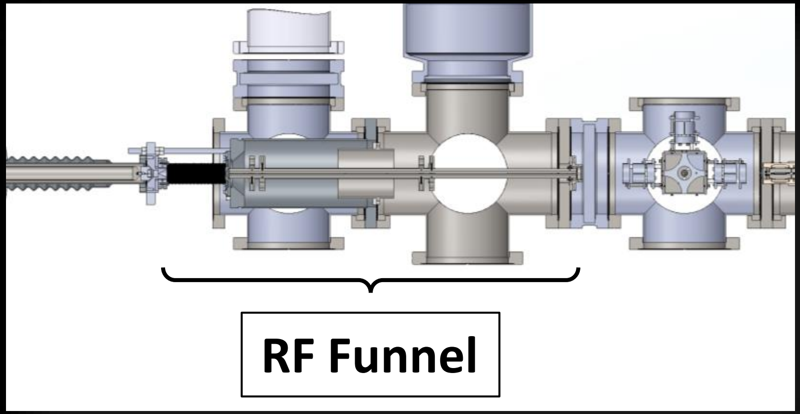
**Are neutrinos their own antiparticles?**

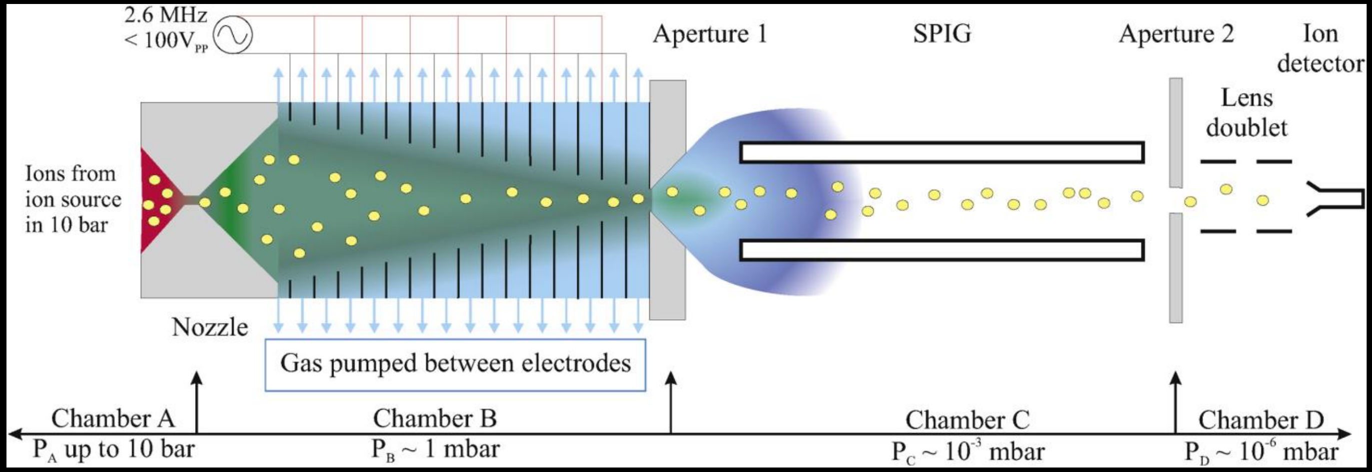



Are there other neutrino flavors?

# RF Funnel

- Radio frequency potential is applied to annular disc electrodes for radial confinement of ions.
- Residual flow of carrier gas is used to propagate ions along the axis.
- Gaps in between the disc electrodes allow the accompanying gas to be pumped out.

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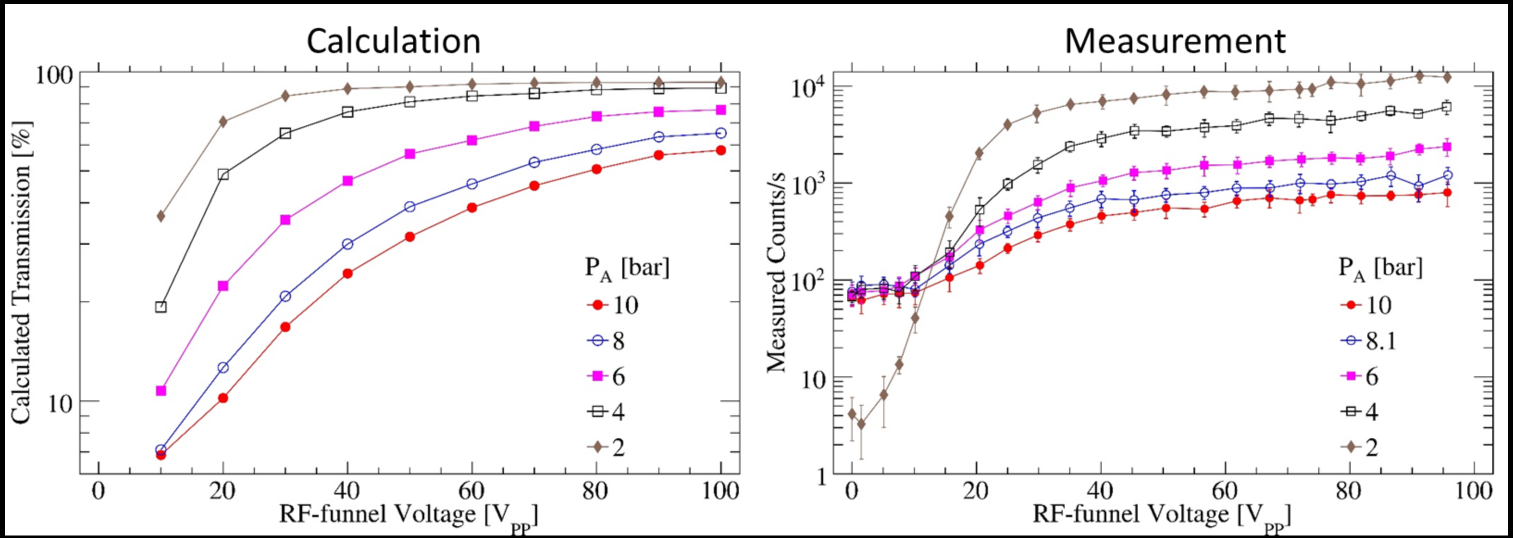


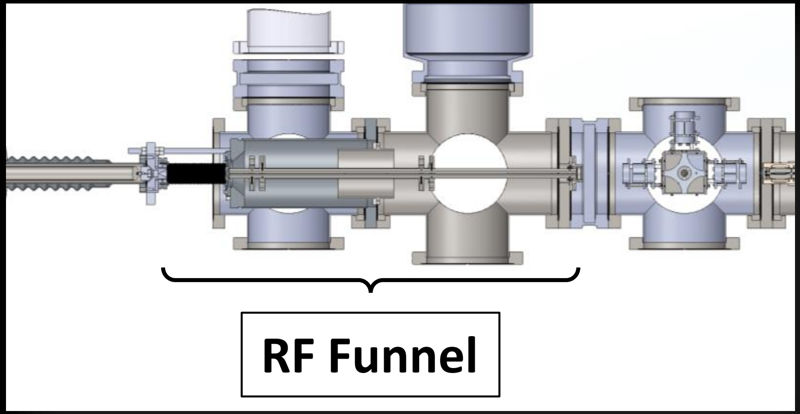


Initial study was successful in reproducing trend of the transmission curve obtained from calculation.

Despite that, there were some limitation:

- Ions not identified
- Extraction efficiency undertermined

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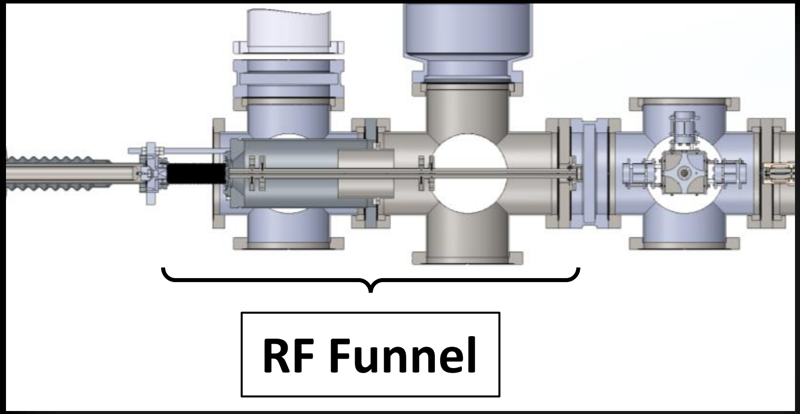


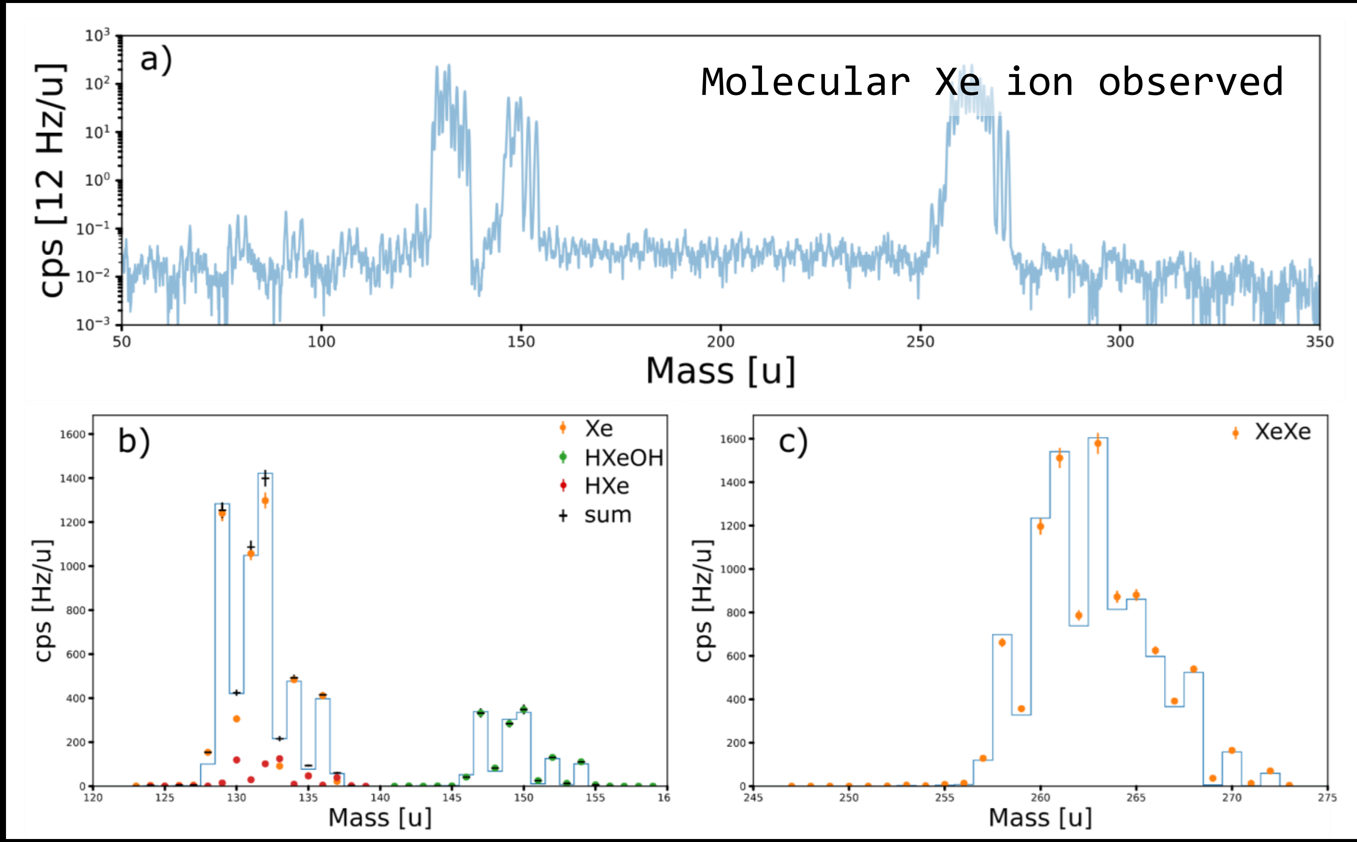


*{D. Fudenberg, *PhD Thesis* (2018), Stanford University}

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