Advancements in Single Barium Ion Capture and Imaging for Barium Tagging Sensors in NEXT Neutrinoless Double Beta Decay Searches

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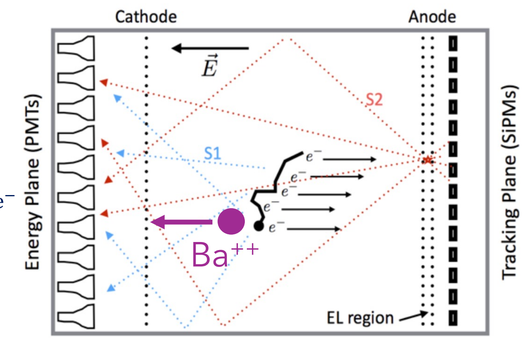
Neutrinoless Double Beta Decay 1

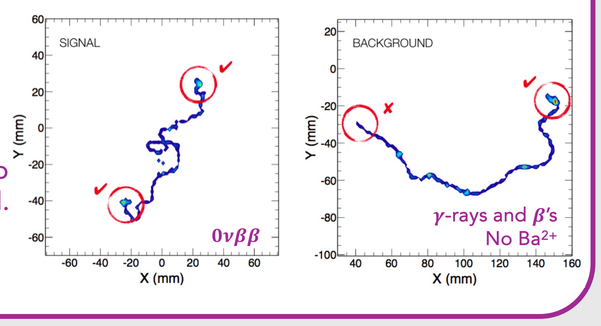
- Discovery of $0\nu\beta\beta$ would confirm neutrinos are Majorana fermions.
- In this process, lepton number is not conserved; probing physics beyond the Standard Model.



NEXT

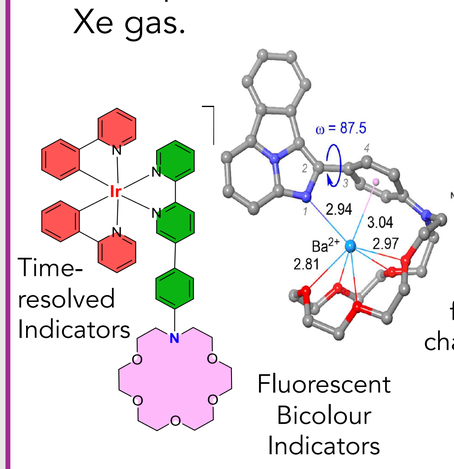
$^{136}_{54}Xe \rightarrow {}^{136}_{56}Ba^{2+} + 2e^-$

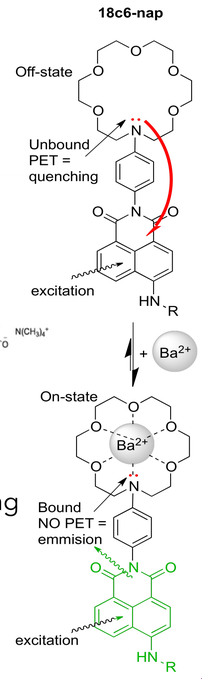
Ba tagging is a potential method to achieve zero background.



Barium Tagging for $0\nu\beta\beta$ 2

- Barium Tagging: ID of the daughter Ba ion made when 136Xe decays.
- Single Molecule Fluorescent Imaging (SMFI): Non-fluorescent molecule becomes fluorescent upon ion capture.
- The NEXT collaboration has developed novel organic fluorophores to detect Ba ions in Xe gas.

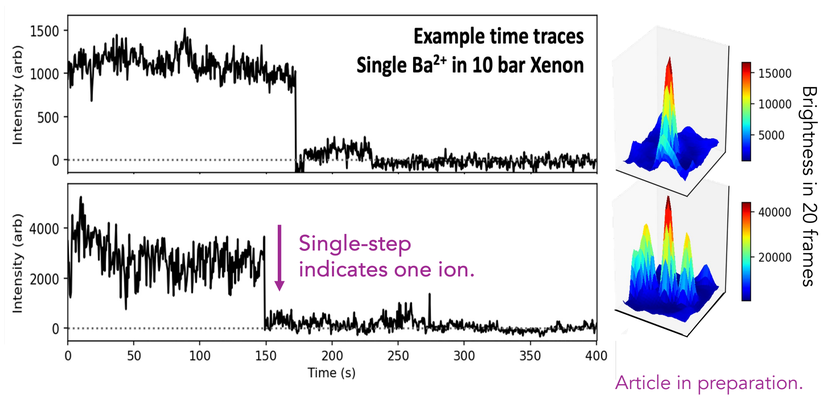




See poster by Pablo Herrero-Gómez #377

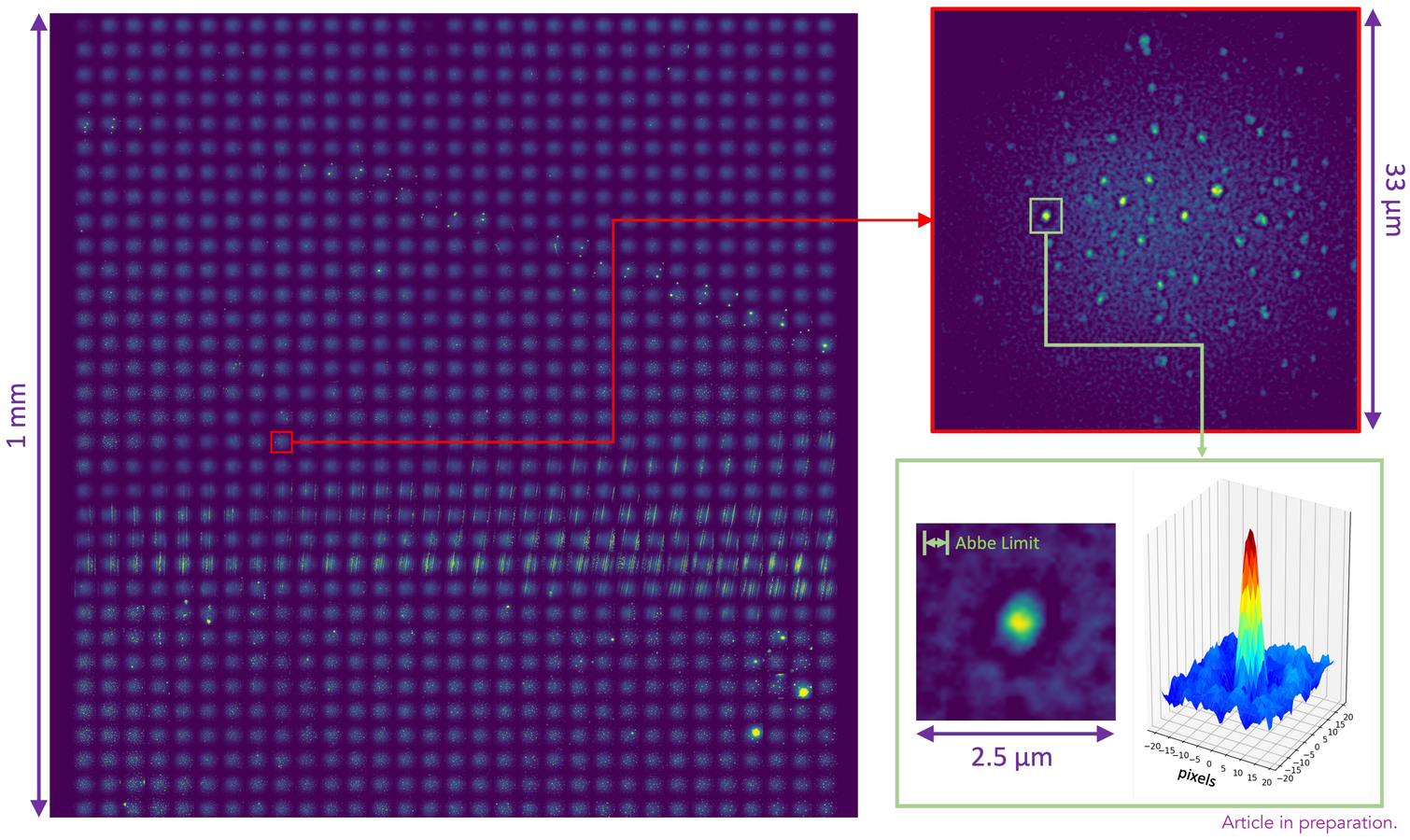
Single Ion Resolution 3

- Dry single-ion sensing was demonstrated with crown ether derivatives.
- A novel fluorescence microscope was developed with wide-field scanning and is operational in high-pressure gas.
- Single - molecule fluorescence and ion+chemosensor complexes are resolved.
- Imaging of single barium ions in 10 bar of Xe gas has been realized.



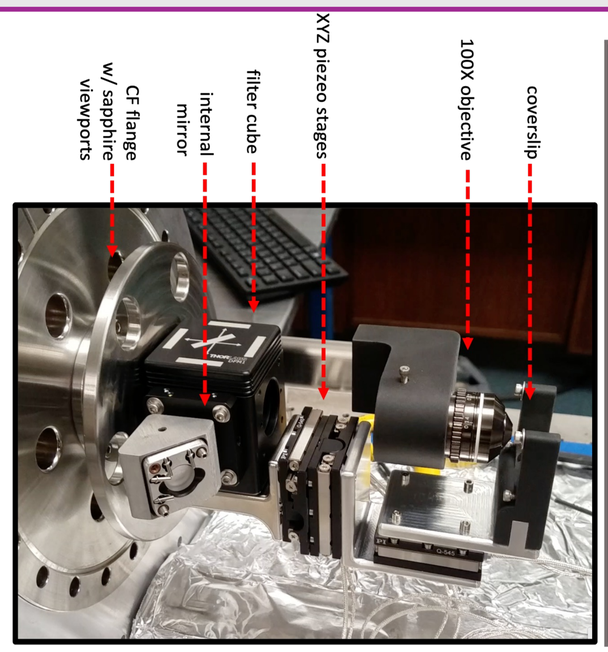
Article in preparation.

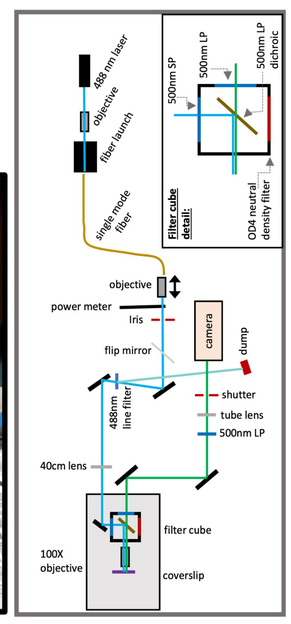
Single Molecule Microscopy 4



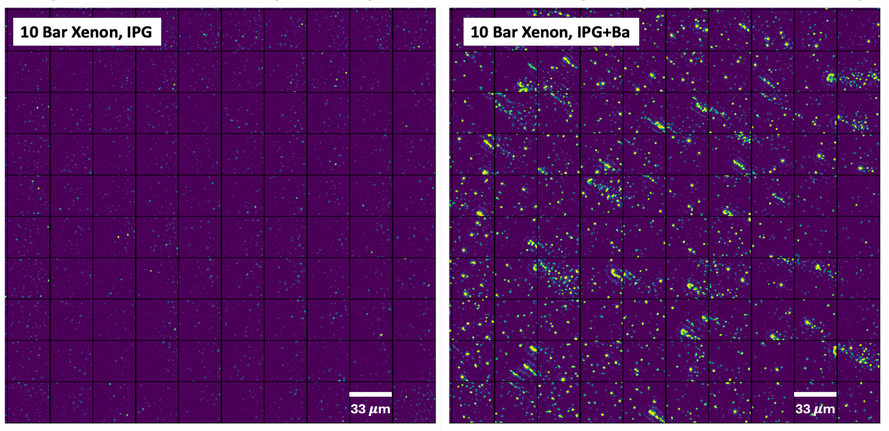
Article in preparation.

Molecular sensor with a 1 mm² scanning area used in a fluorescent microscope with XYZ stages for raster scanning. Advanced autofocus software ensures precise focal plane location. Consistent point-spread function close to the Abbe Diffraction Limit of single point-like emitters in air, vacuum, and pressurized gases.





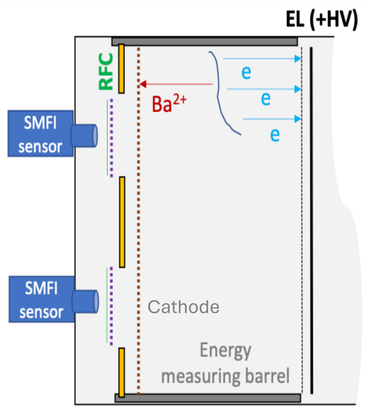
Components and optical paths of high-pressure microscope.



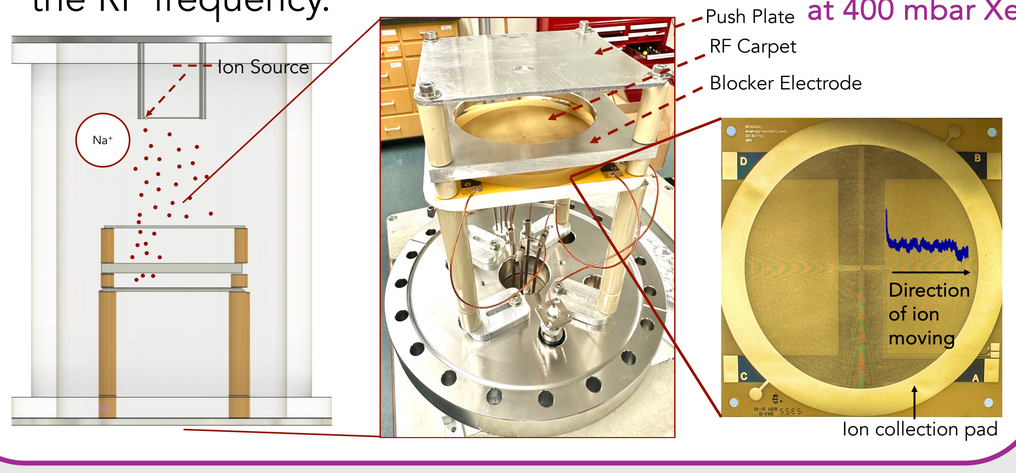
Chemosensor before and after addition of Ba^{2+}.

Ion Transport & Confinement 5

- One concept to integrate the system into a TPC is via the collection of ions and concentrating them using RF carpets (RFC).
- RFCs apply a rapidly switching voltage to generate ion levitation and transport in gaseous media.
- The applied voltage generates a micro-motion of the trapped ion at the RF frequency.



R&D: RFC test stand at 400 mbar Xe.

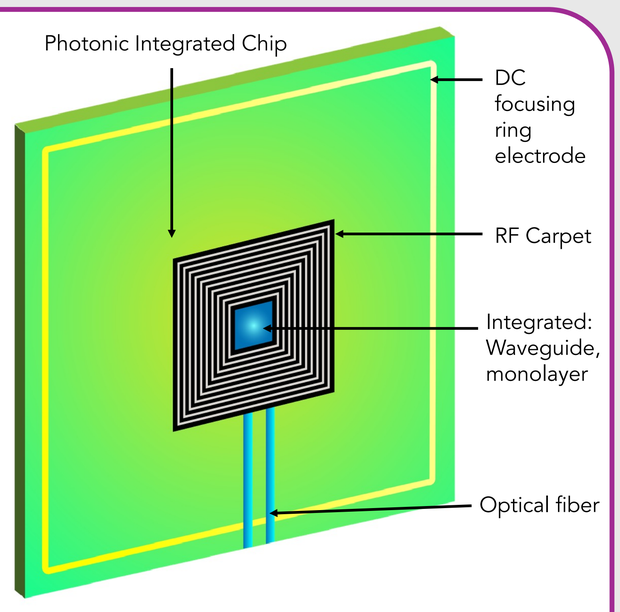


Novel Ion Sensor: νBIT 6

νBIT: Neutrinoless Barium Ion Tagging

- Compact ion detector that is selective, reliable, and scalable.
- Nanofabrication techniques to produce photonic integrated chips.
- Design elements:
  - Embedded waveguides + monolayer
  - Micron-pitch RF ion transport structures

Fused Silica and Silicon – 30nm of Cr – 100nm of Cu.



An integrated sensor with Ba^{2+} SMFI imaging and RF ion transport offers a promising solution for background-free barium tagging in next-gen large Xe gas detectors.

References:
[1]Nature Sci Rep 9,15097 [2]Phys. Rev. Lett. 120, 1352504 [3]arXiv:2109.05903 [4]ACS Sens. 2021,6,1,192-202 [5] Nature 583, 48–54 (2020) [6] ChemRxiv. 2023, 10.26434