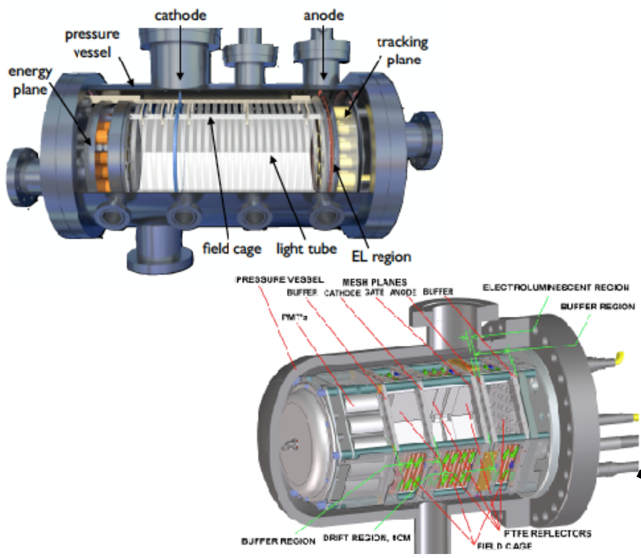
The NEXT project

J.J. Gomez Cadenas on behalf The NEXT collaboration.

ikerbasque
Basque Foundation for Science

European Research Council
Established by the European Commission
Supporting top researchers from anywhere in the world

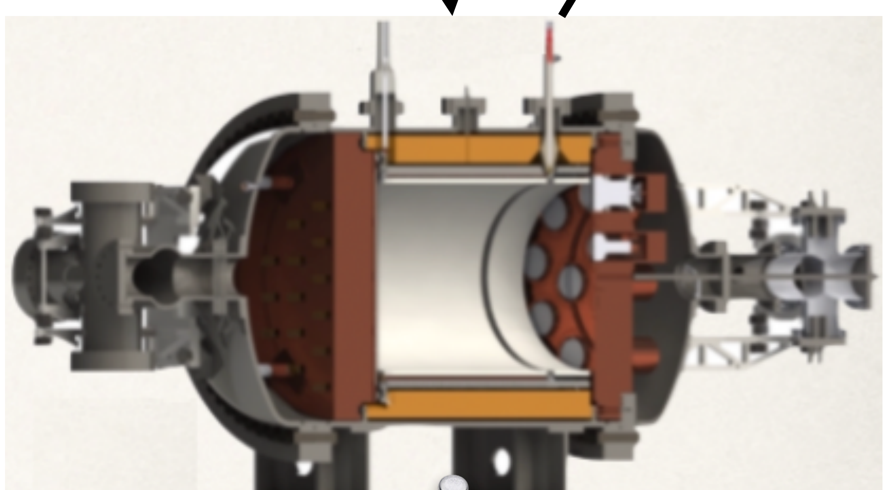
The NEXT program



Prototypes (~1 kg)
[2009 - 2014]

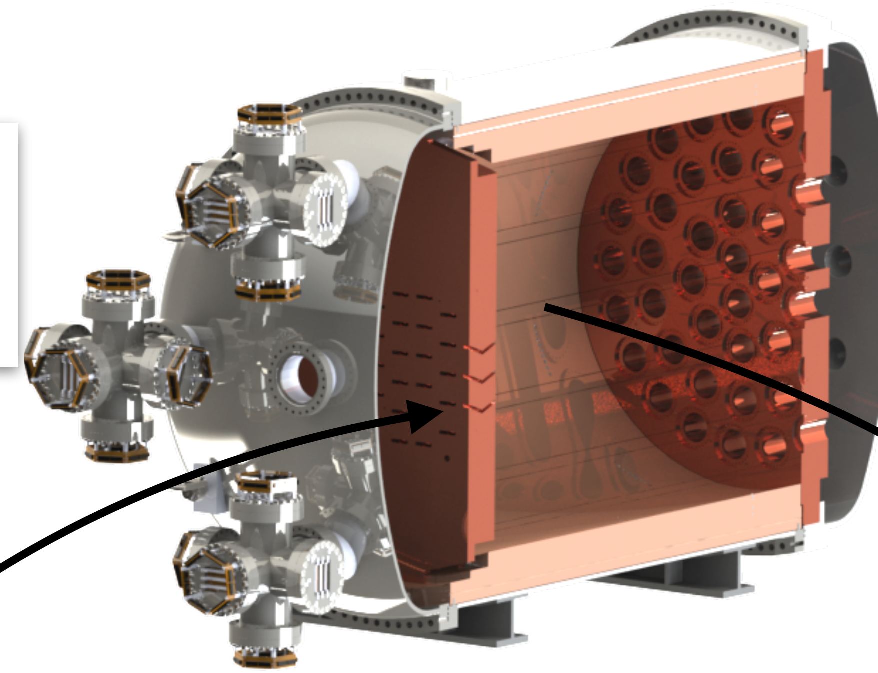
Demonstration of detector concept

NEXT-White (~5 kg)
[2015 - 2018]



Underground and radio-pure operations, background, ββ2ν

NEXT-100 (~100 kg)
[2020 - 2020's]

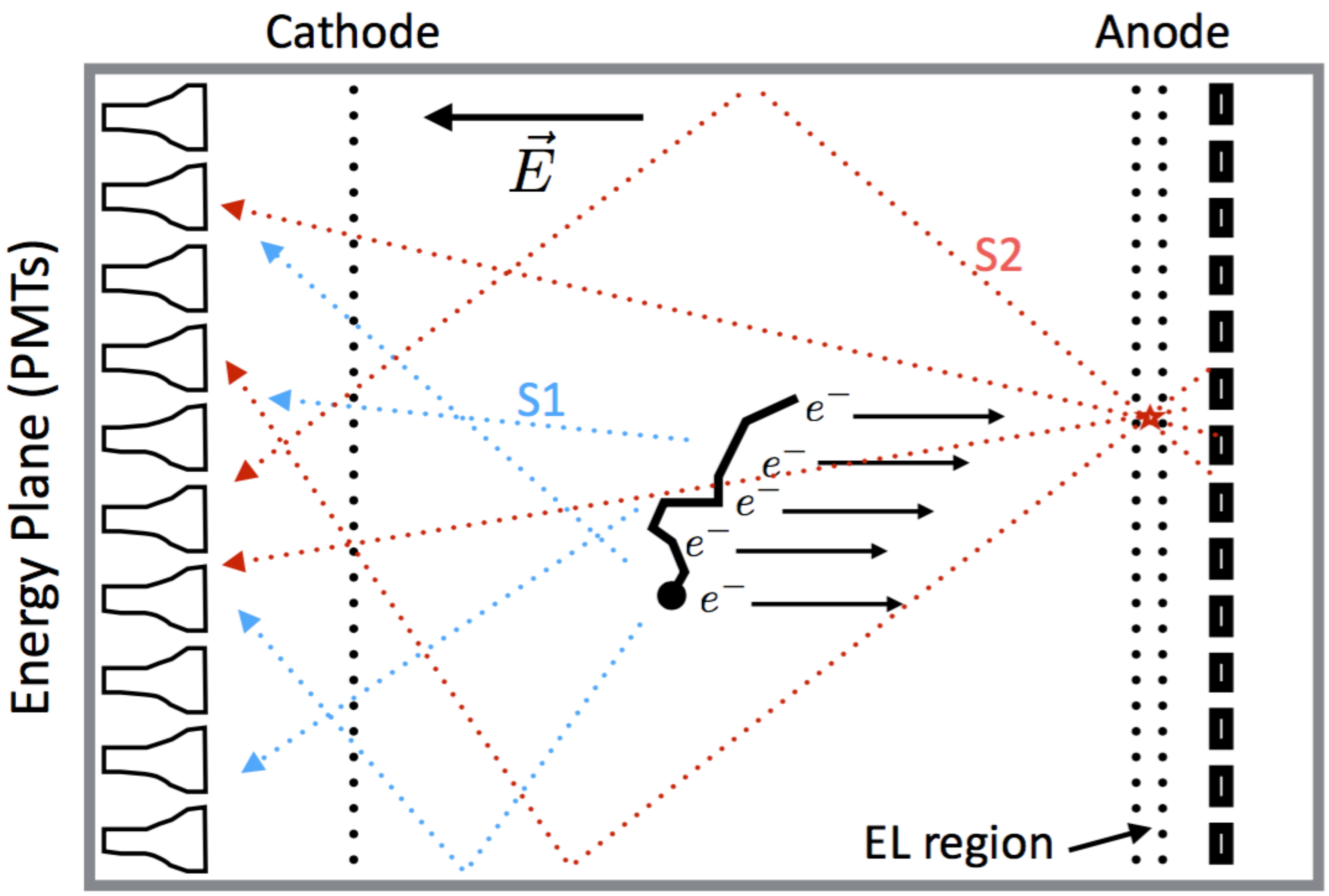


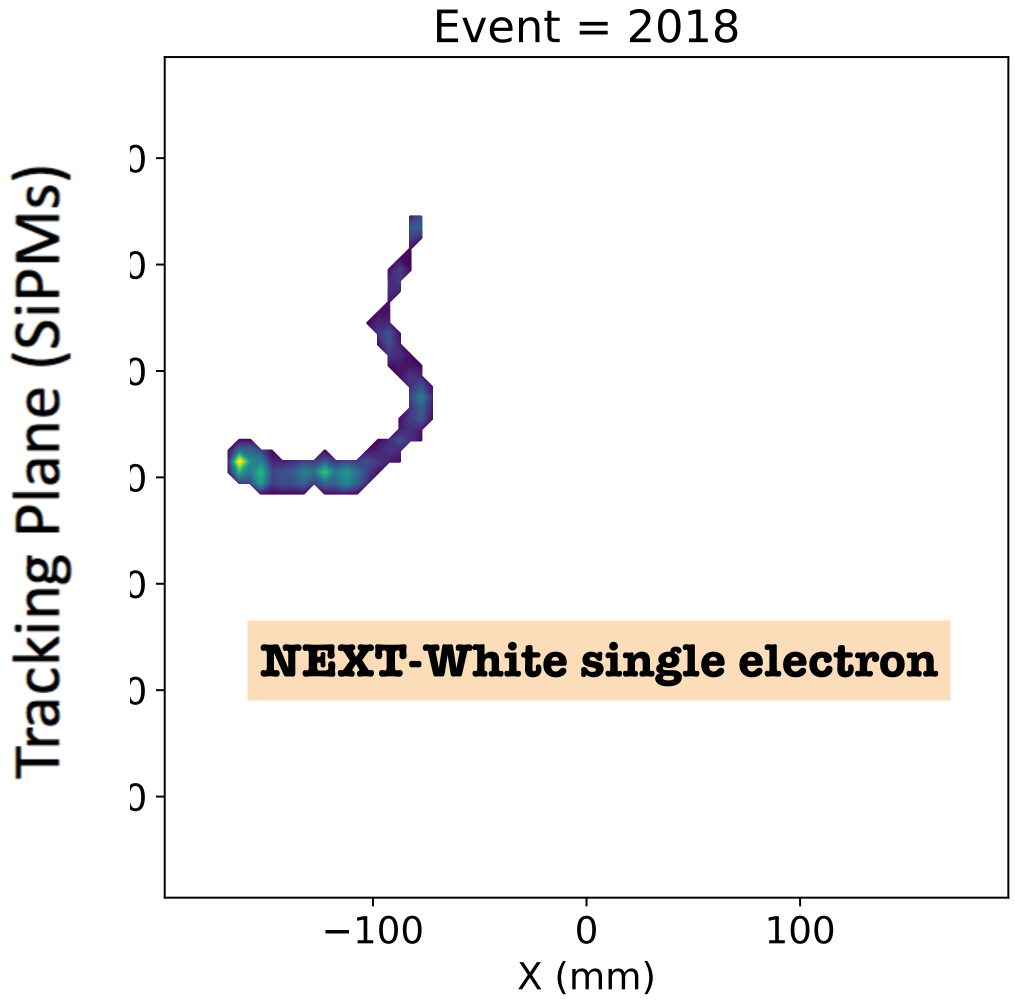
ββ0ν searches (10^{26} y)
Show extrapolation to ton scale

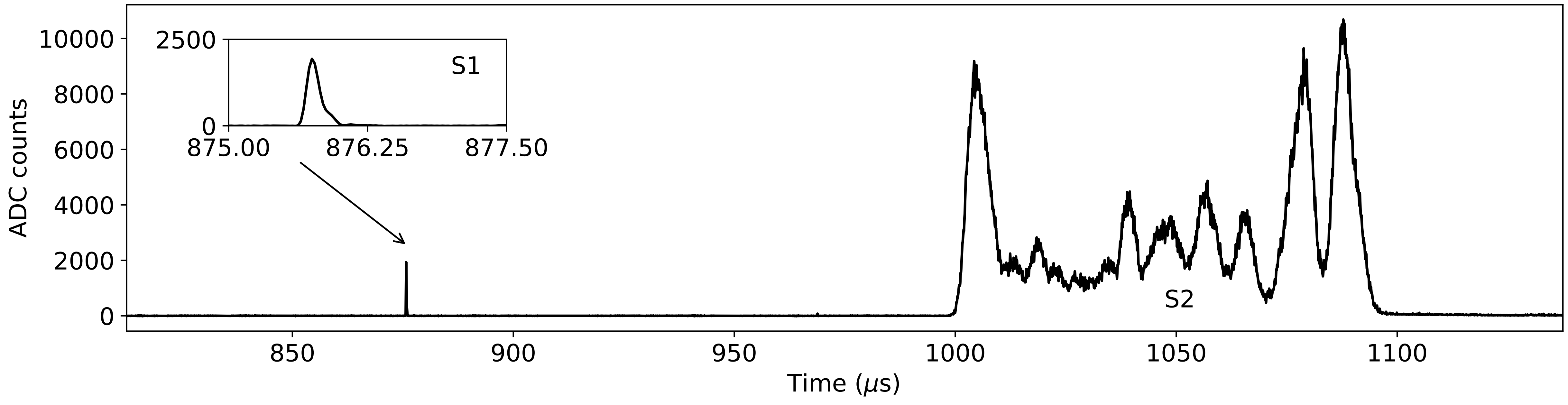
NEXT-HD/BOLD
[2020's]

ββ0ν searches (ββ0ν searches (10^{27}- 10^{28} y)

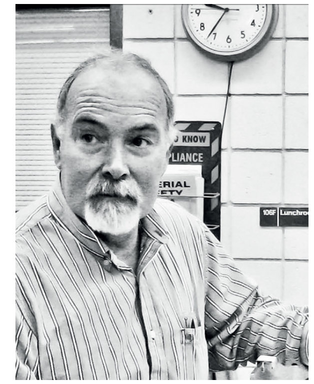
Principle of operation

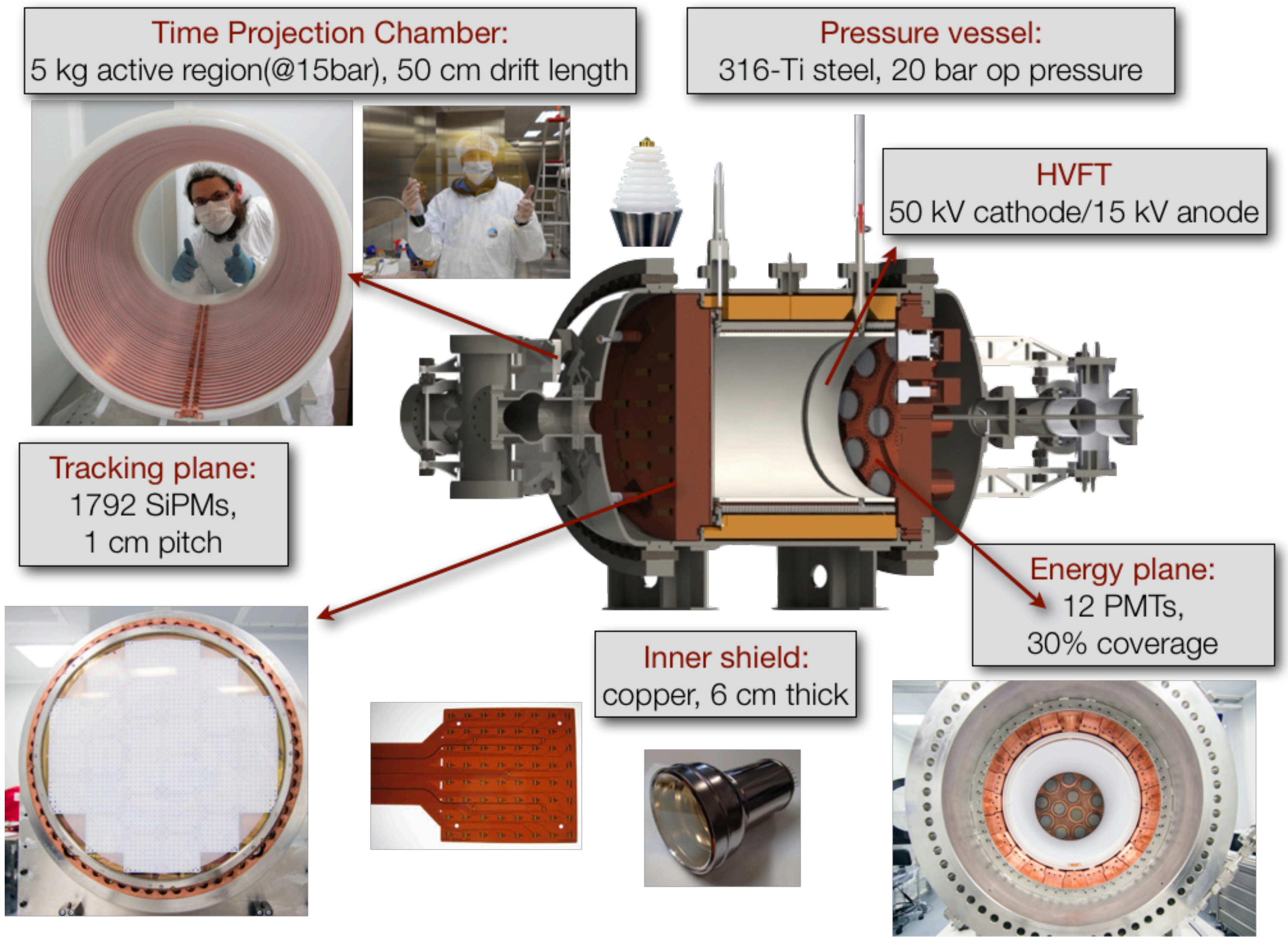






NEXT-White

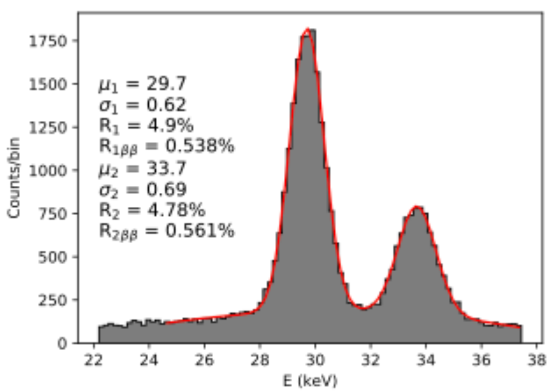


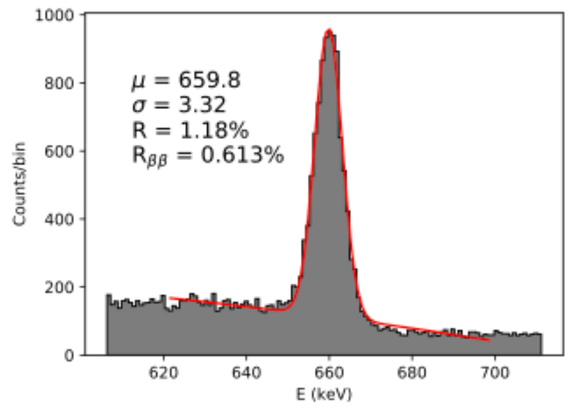


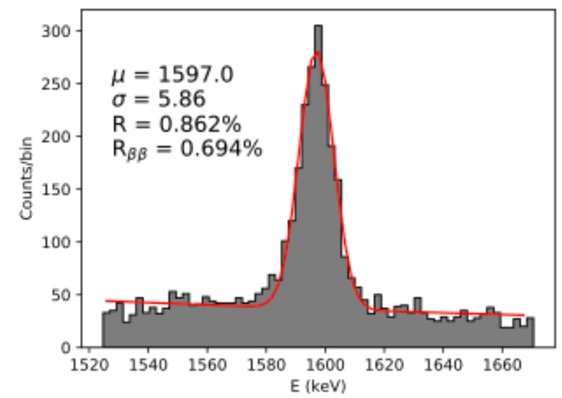
- A full scale demonstrator of the NEXT technology (started in 2016)

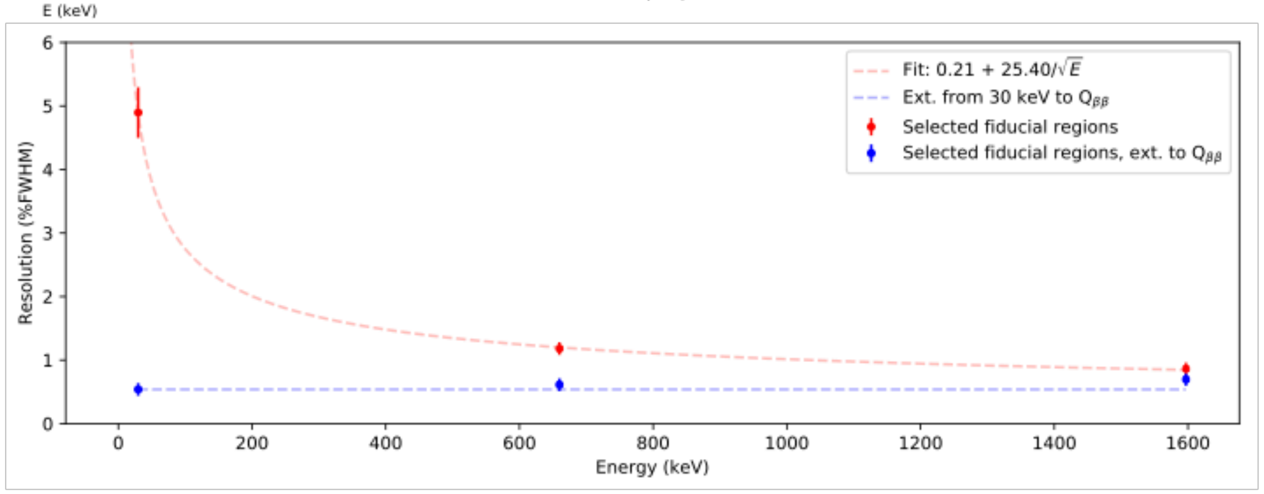
- Energy resolution, topology, lifetime, measured $\beta\beta2\nu$ mode

NEXT: Resolution

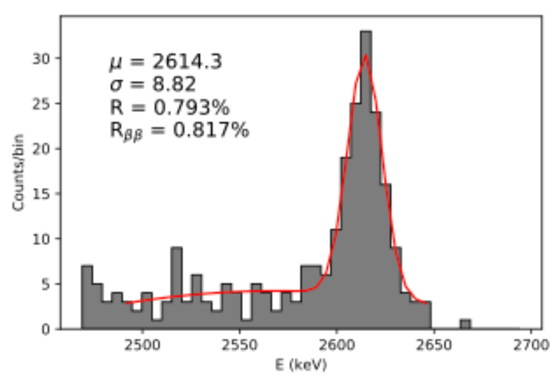








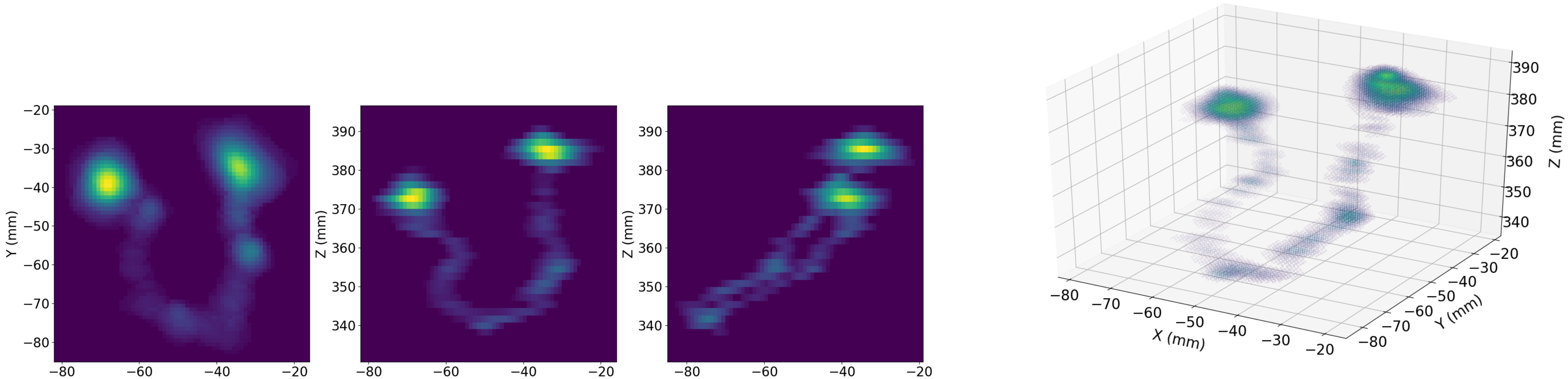
Energy resolution

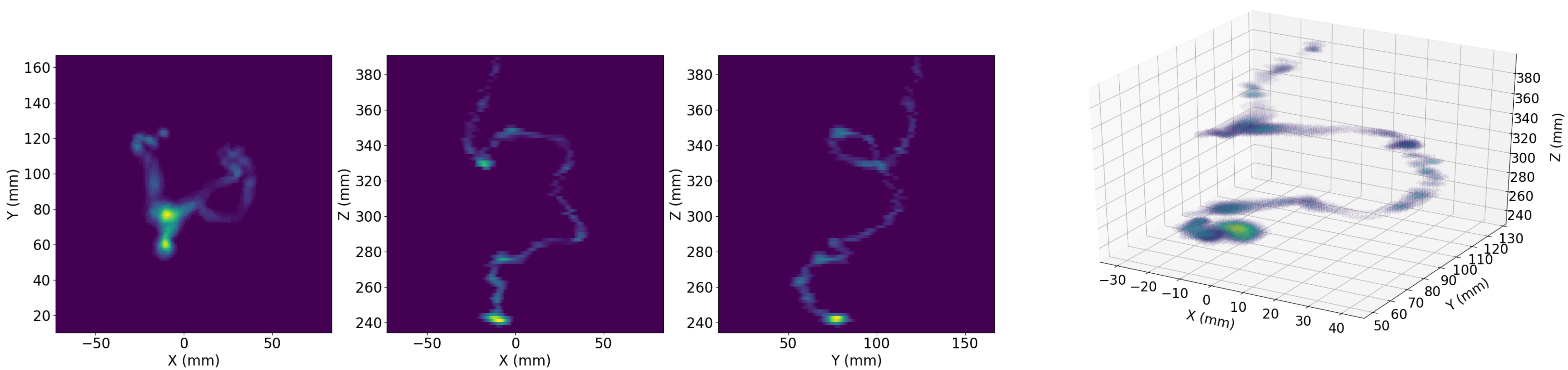


Energy resolution at $Q_{\beta\beta} \sim 0.8\,\%\,FWHM$ dominated by track corrections (0.5 % FWHM por point-like tracks). Room for improvement.

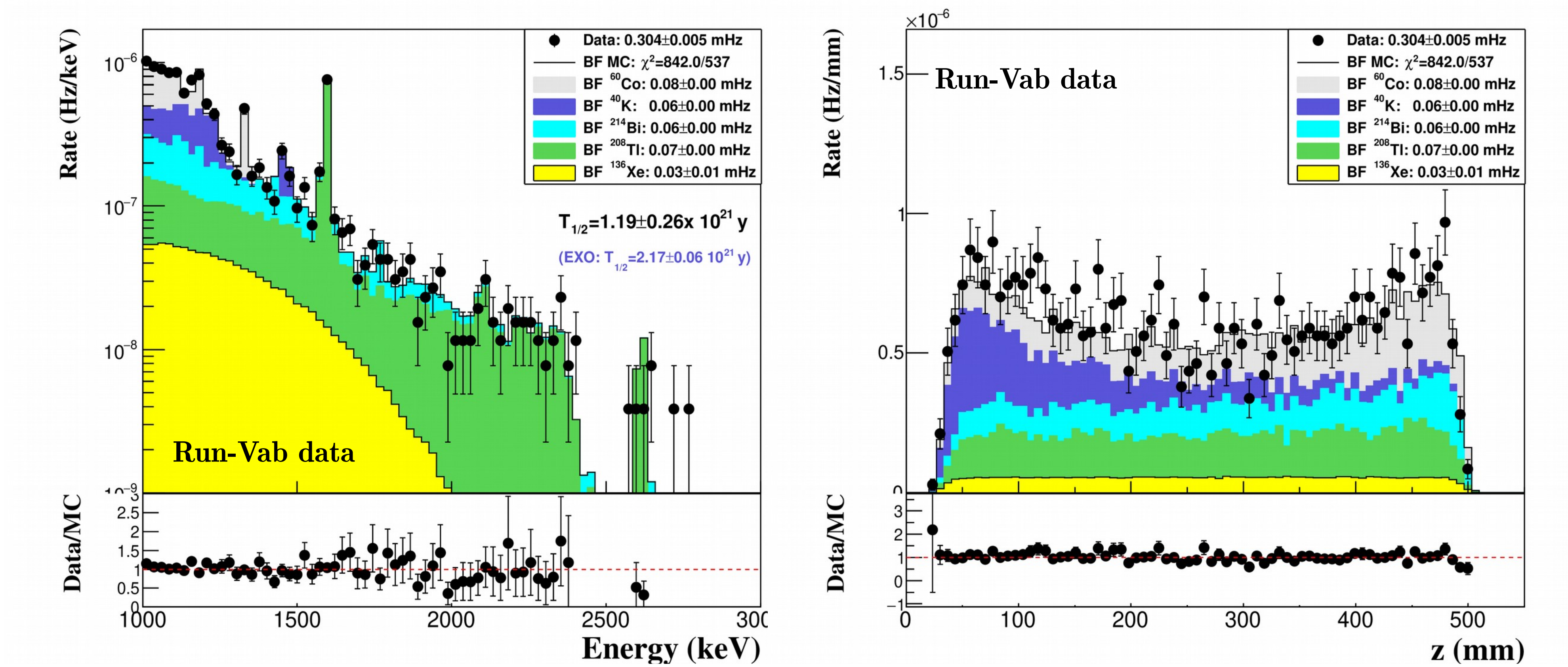
Topological signature

Single and double electrons from $\beta\beta2\nu$ analysis with energies near $Q_{\beta\beta}$



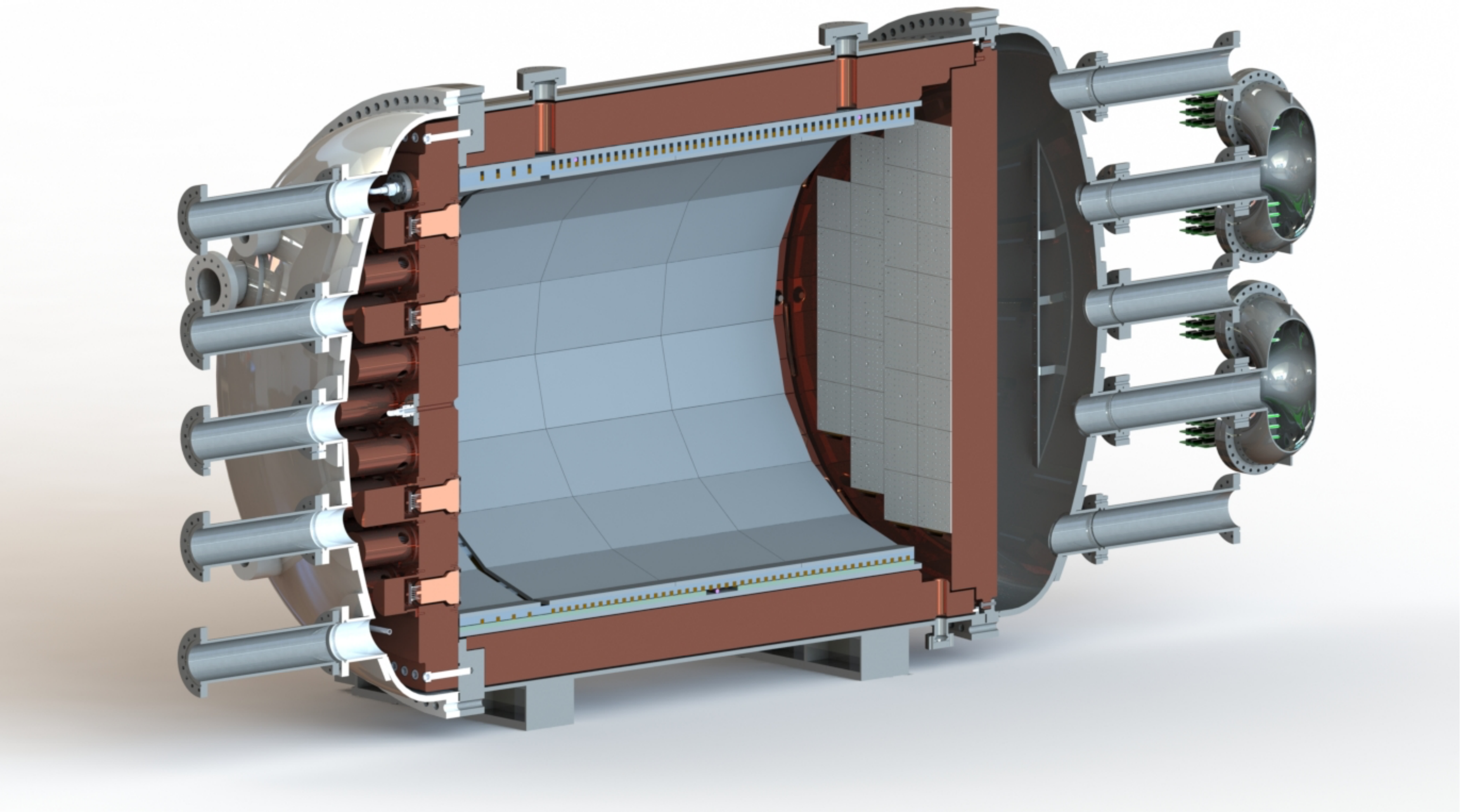


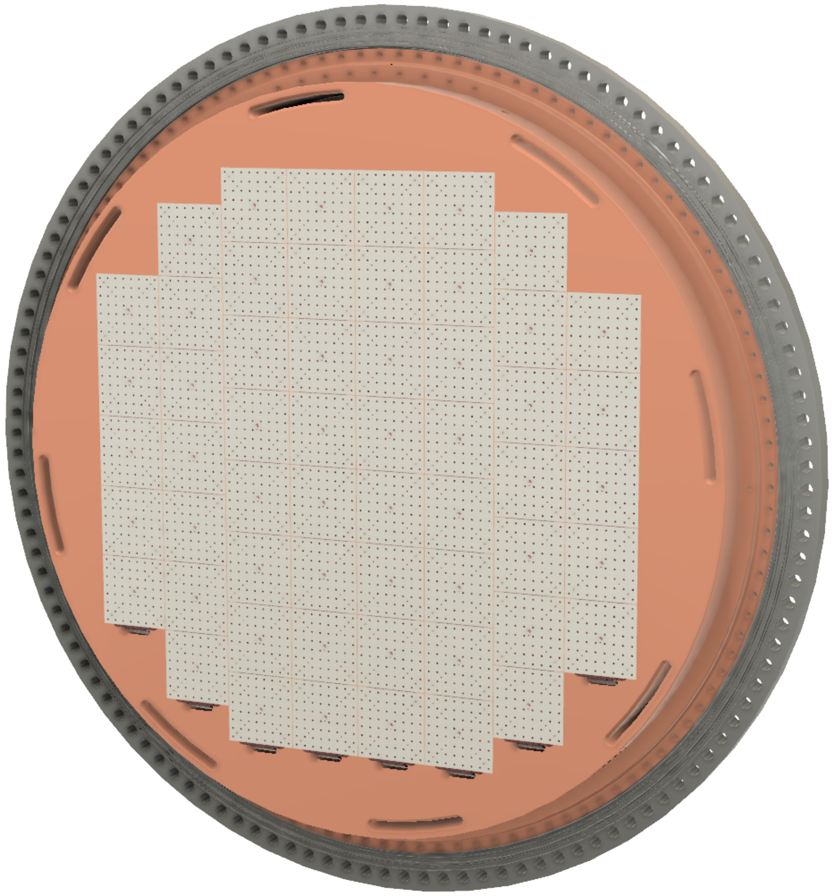
Measurement of $\beta\beta 2\nu$ mode

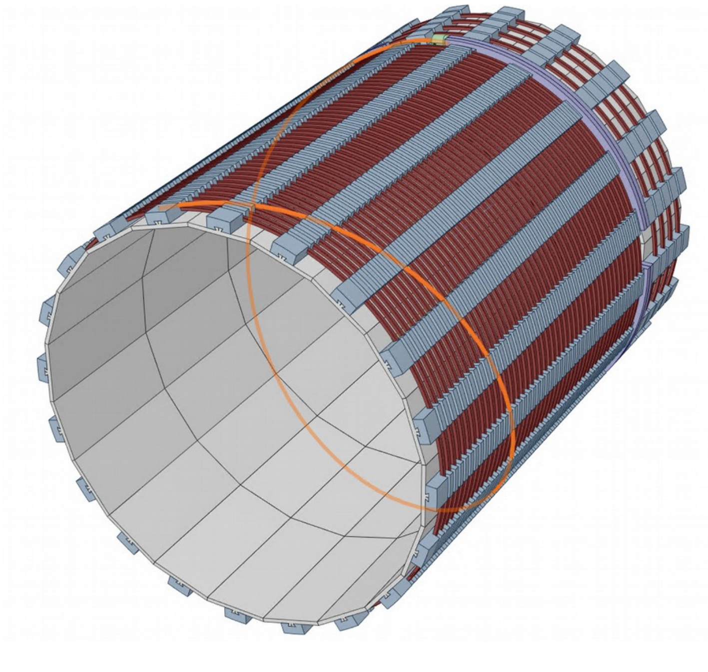


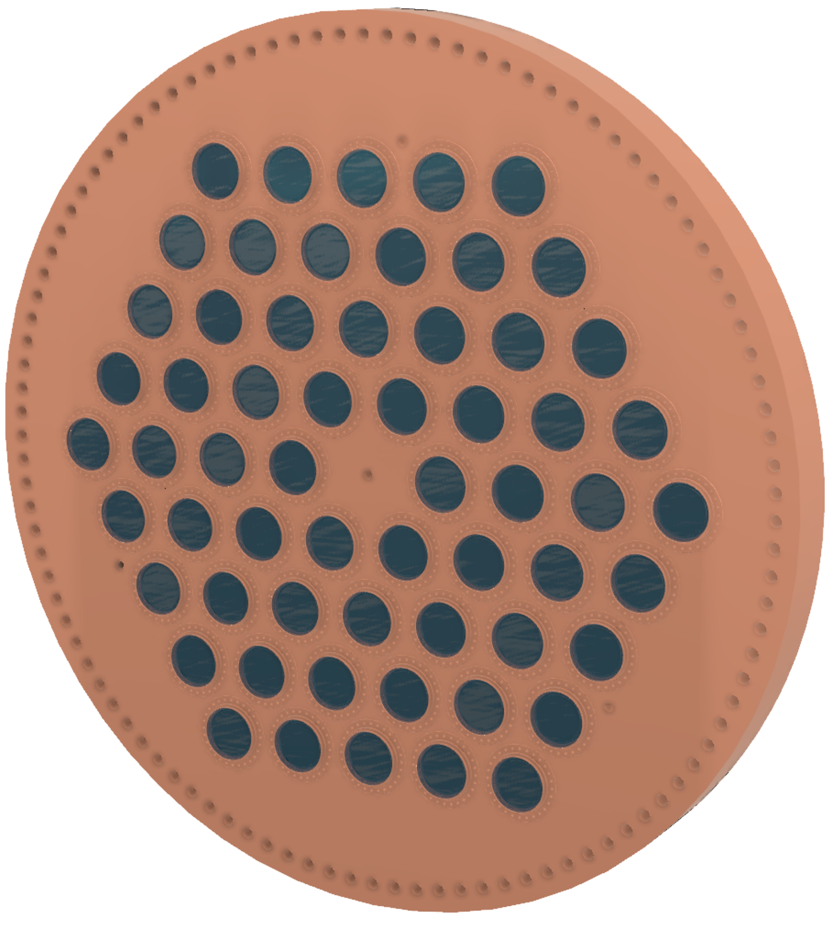
- ~4.5 σ error (3.8 σ difference w.r.t EXO-200)
- Improvements under way, including a new run with depleted xenon for precise background measurement

NEXT-100 (construction under way)



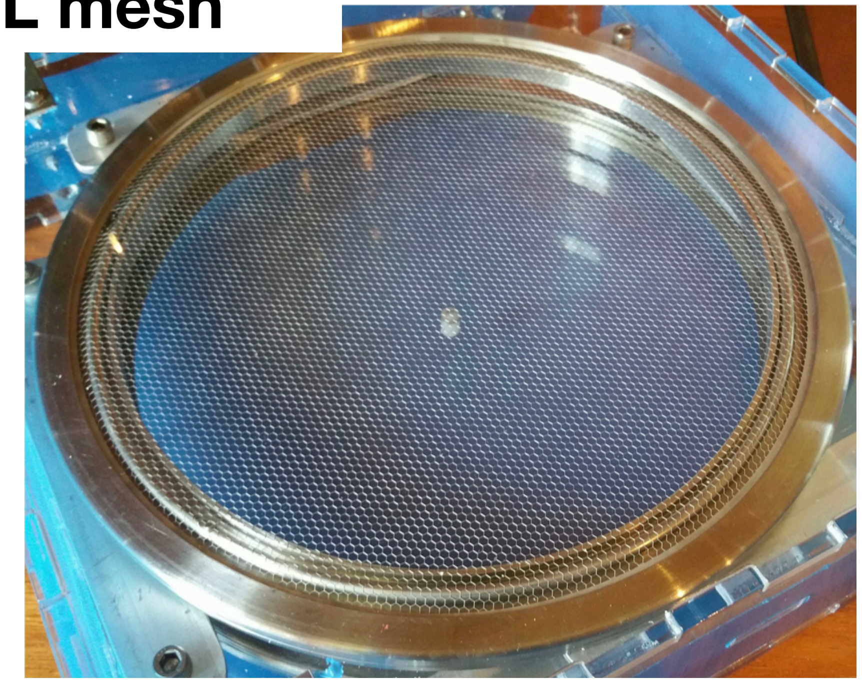




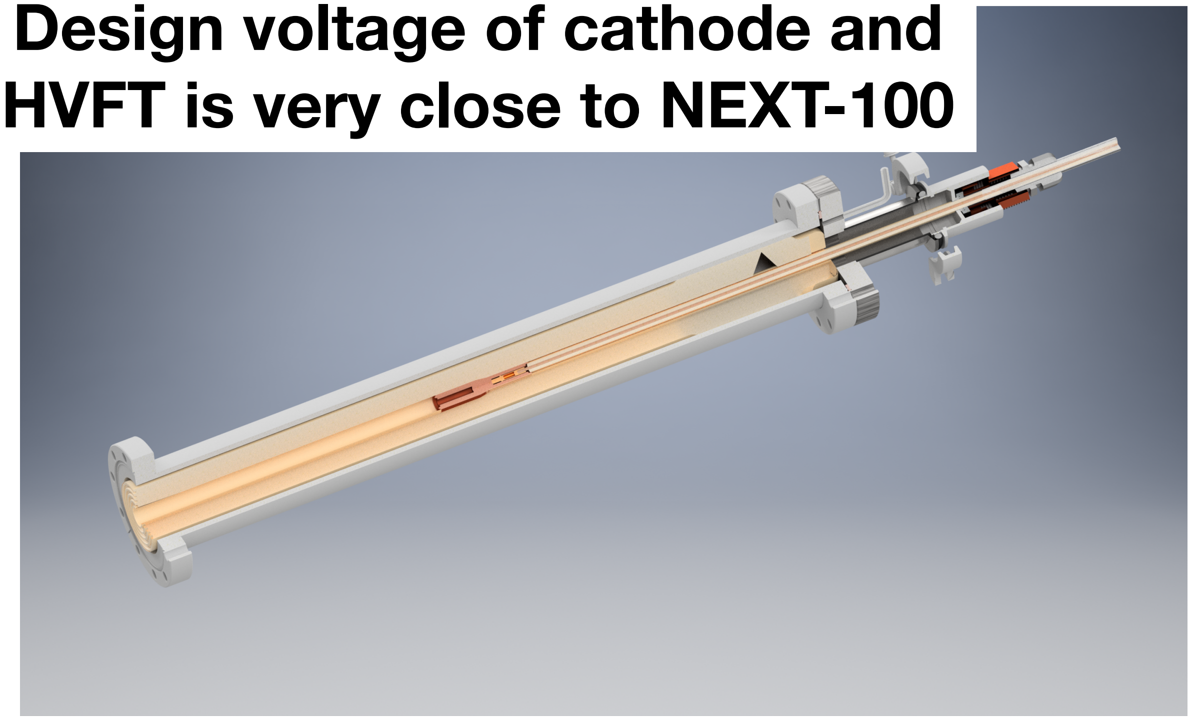


Solutions to be implemented in NEXT-100

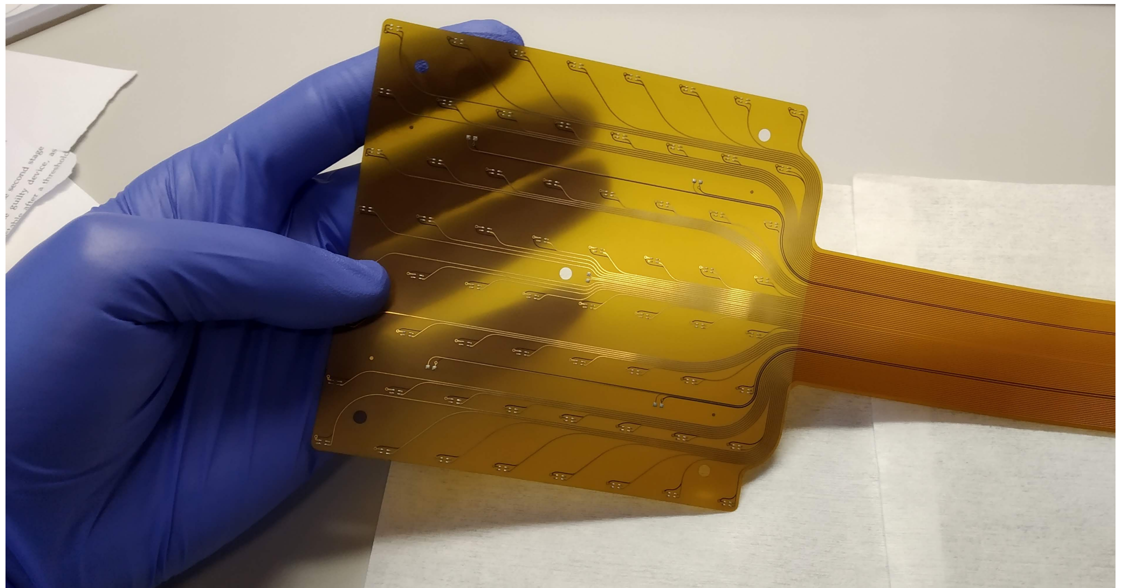
EL mesh

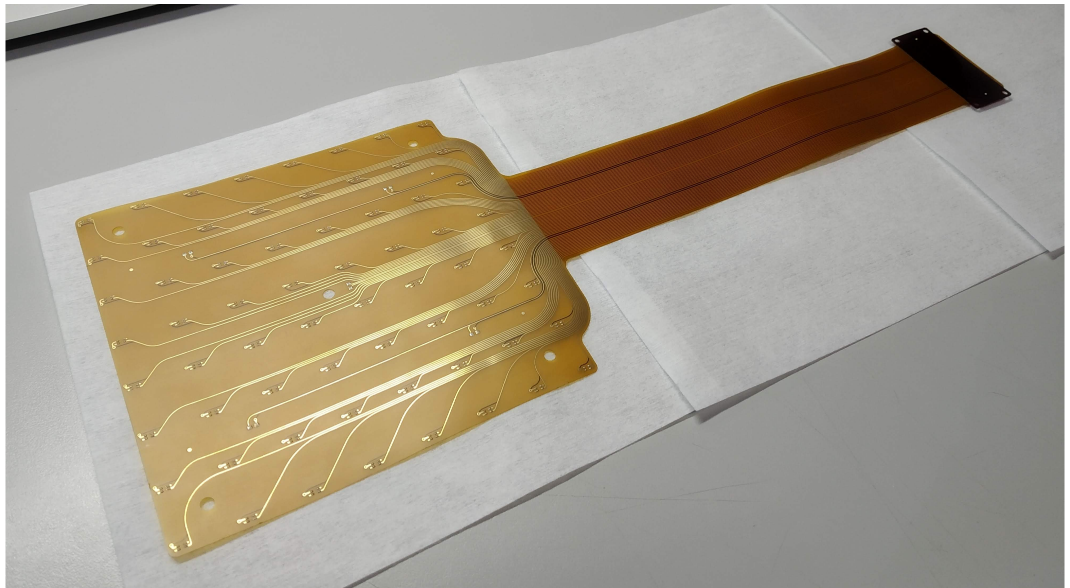


Design voltage of cathode and HVFT is very close to NEXT-100



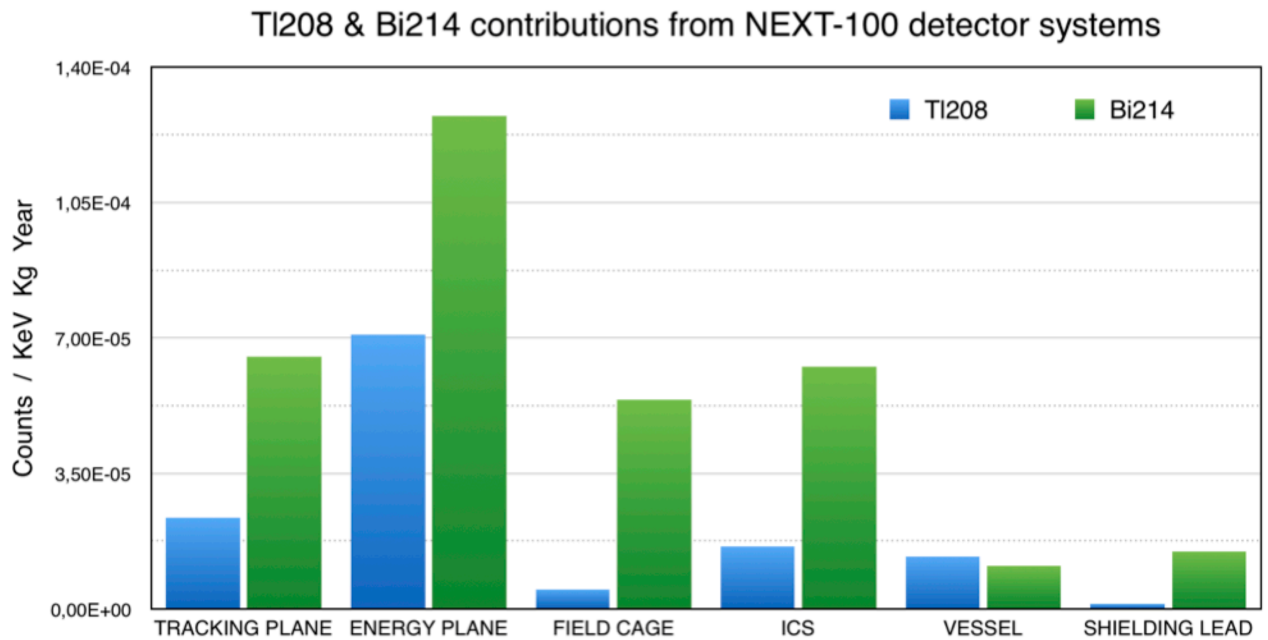
SiPM radio-pure substrates already in hand.

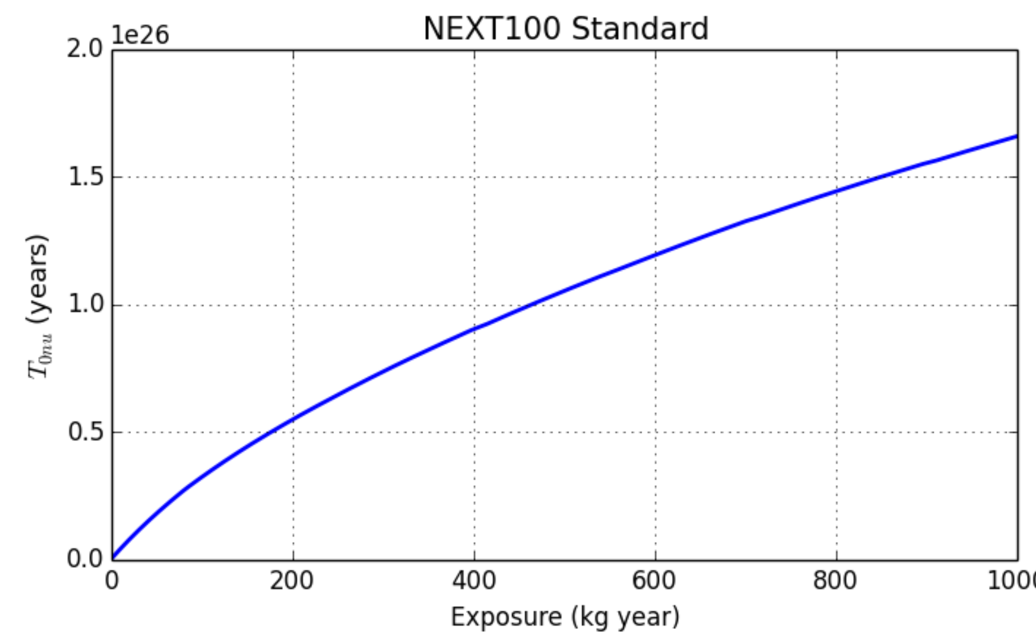


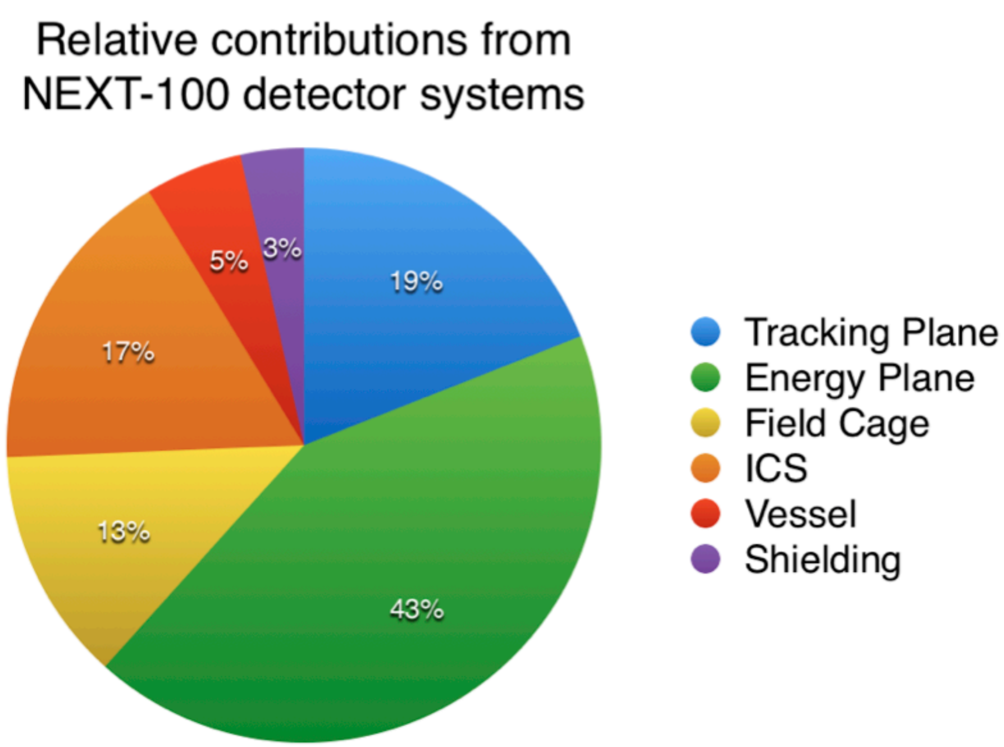


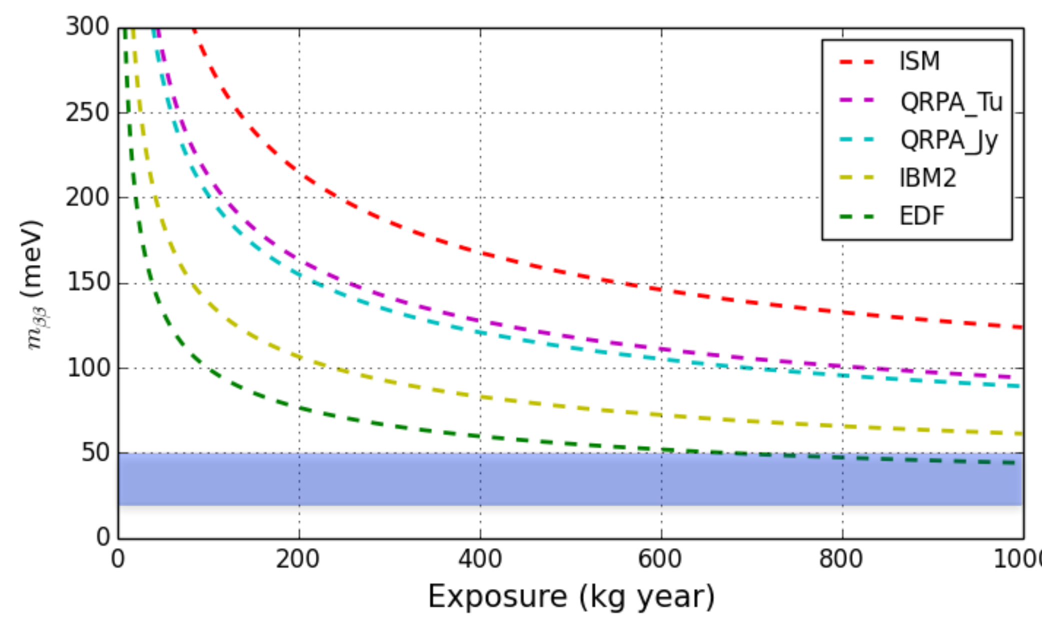
NEXT-100 Background model

1. Natural decay series: < 4.09 x 10^{-4} cts / keV kg year

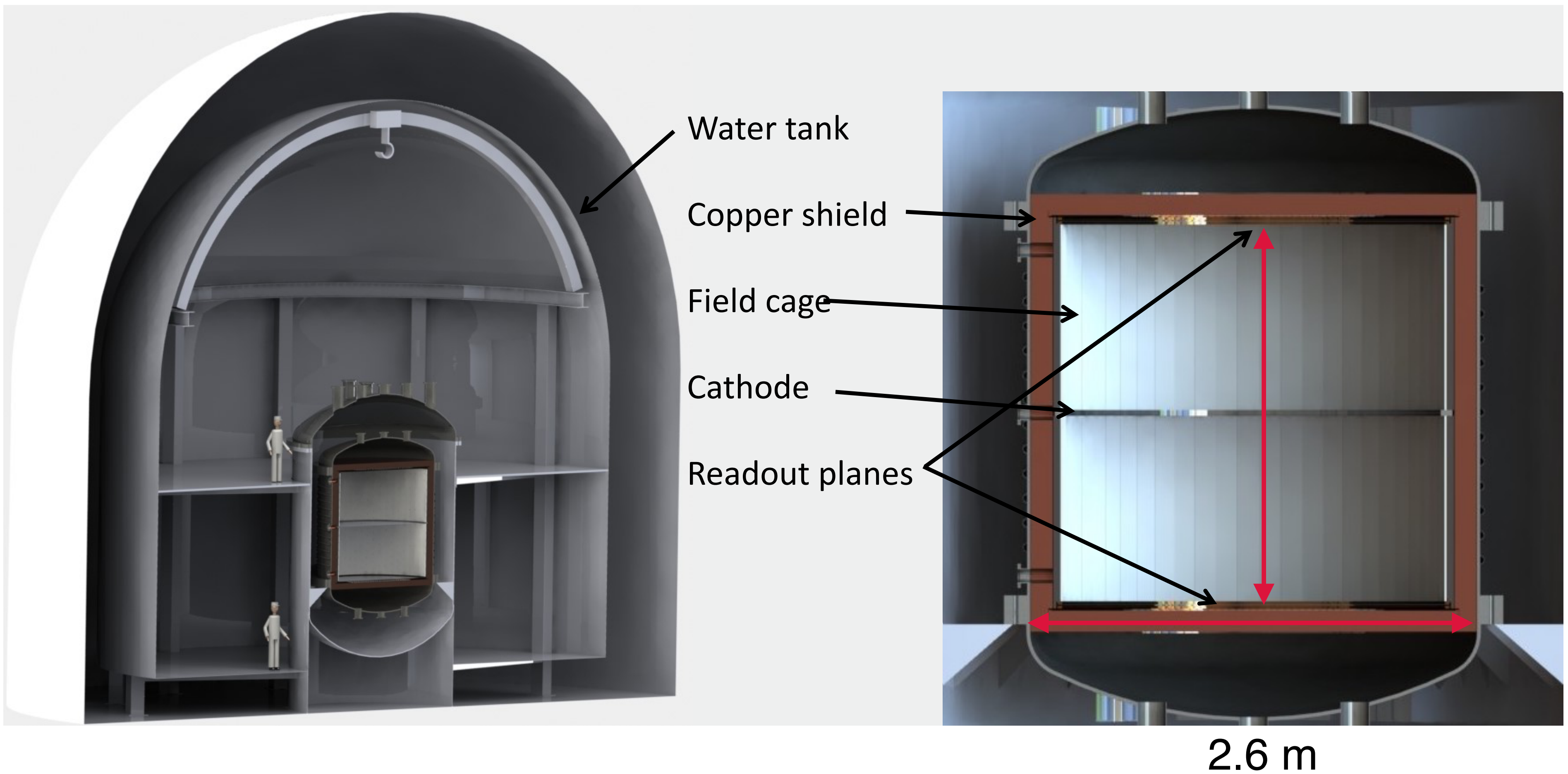








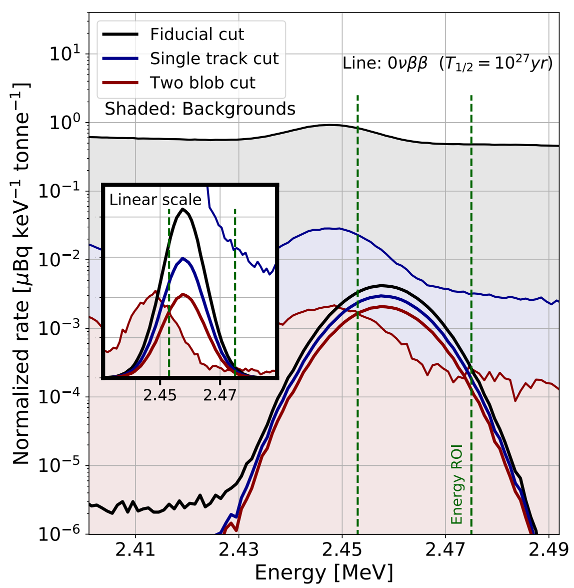
NEXT-HD

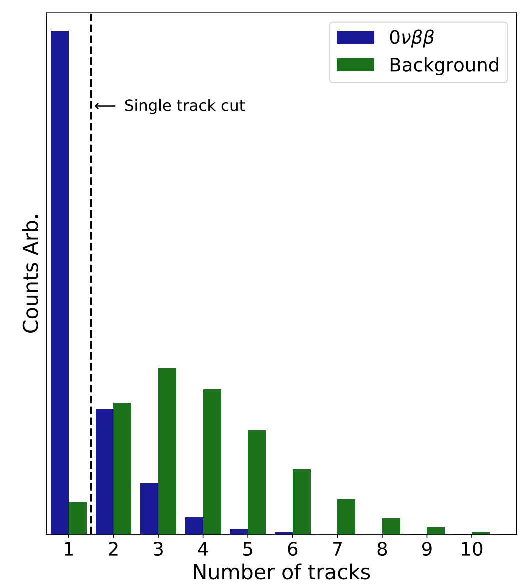


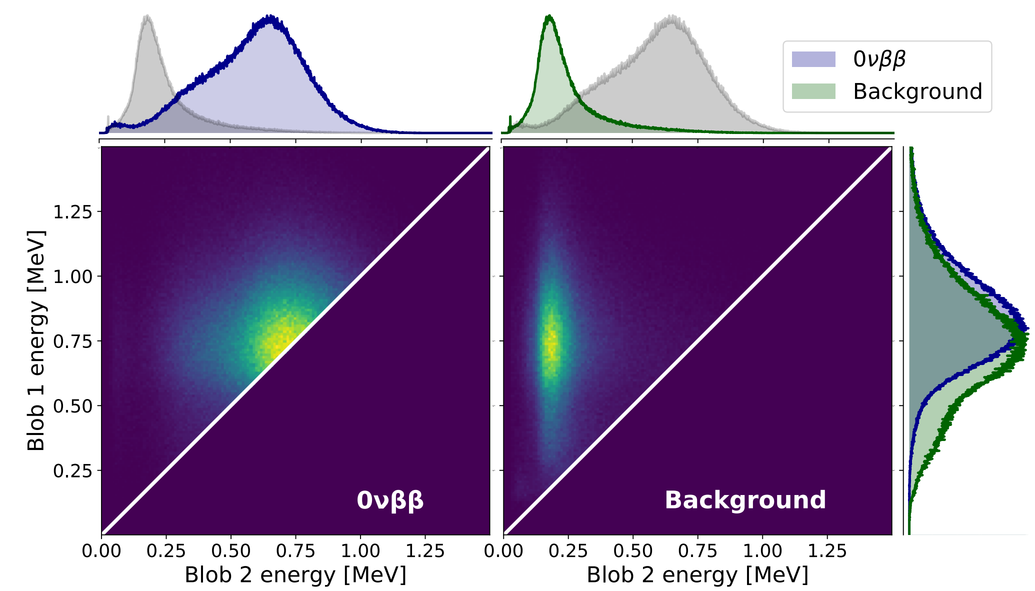
- Direct extrapolation of NEXT-100 with ~1 tonne of xenon at 15 bar.
- Symmetric design with a central cathode and two readout planes with SiPMs.
- Energy readout in a Barrel Energy Detector (double-clad fibres)

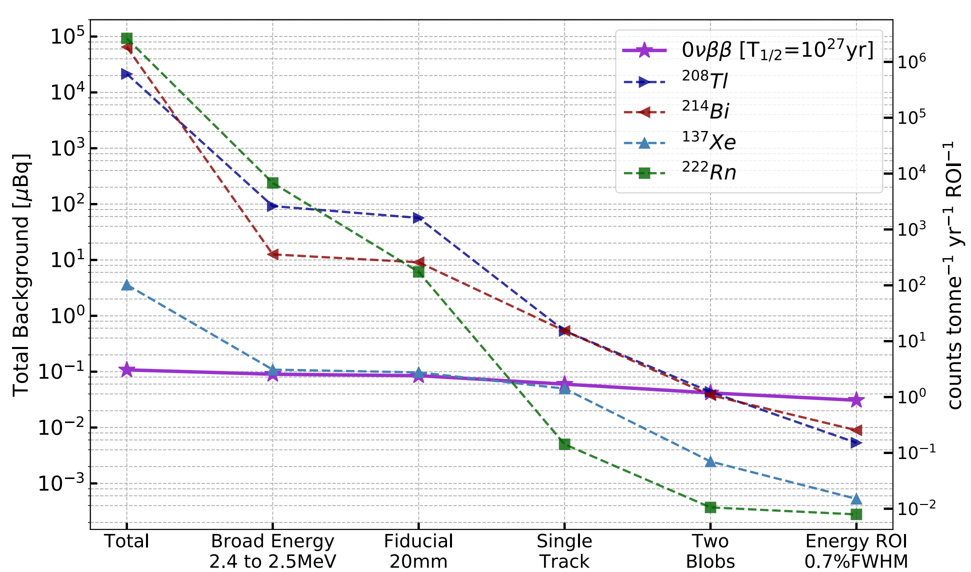
NEXT-HD

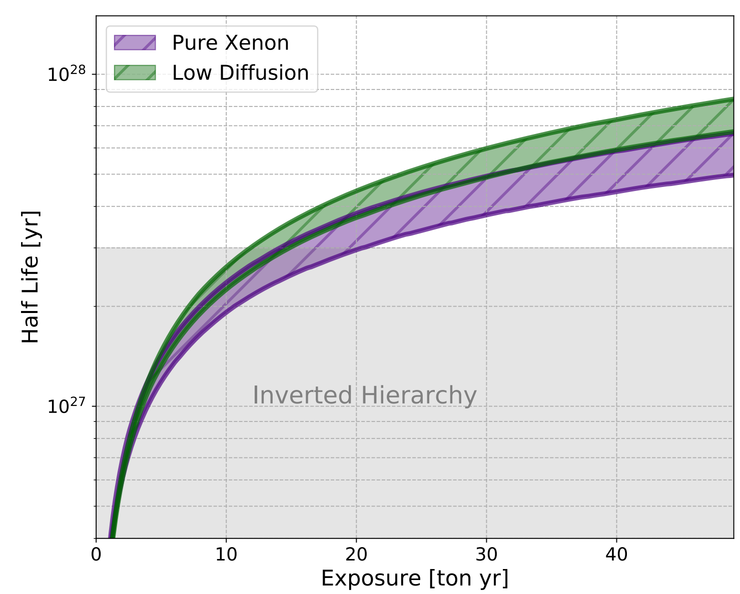
Reach: T $\sim 10^{27}$ year for 5 ton · year

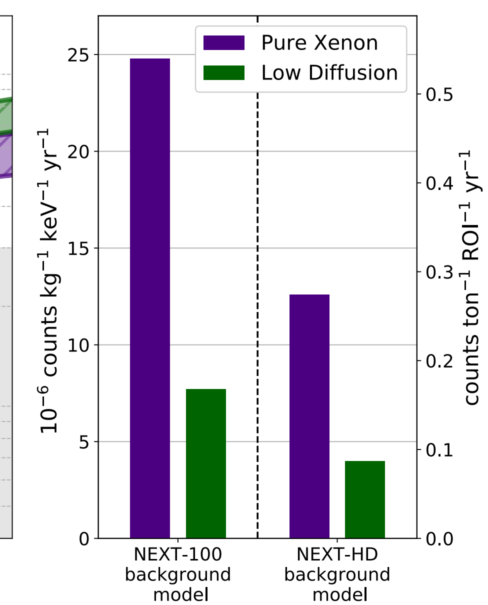




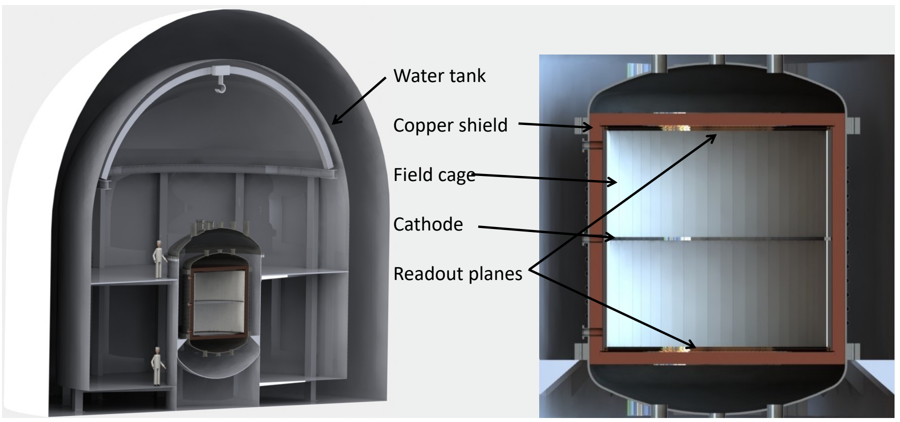






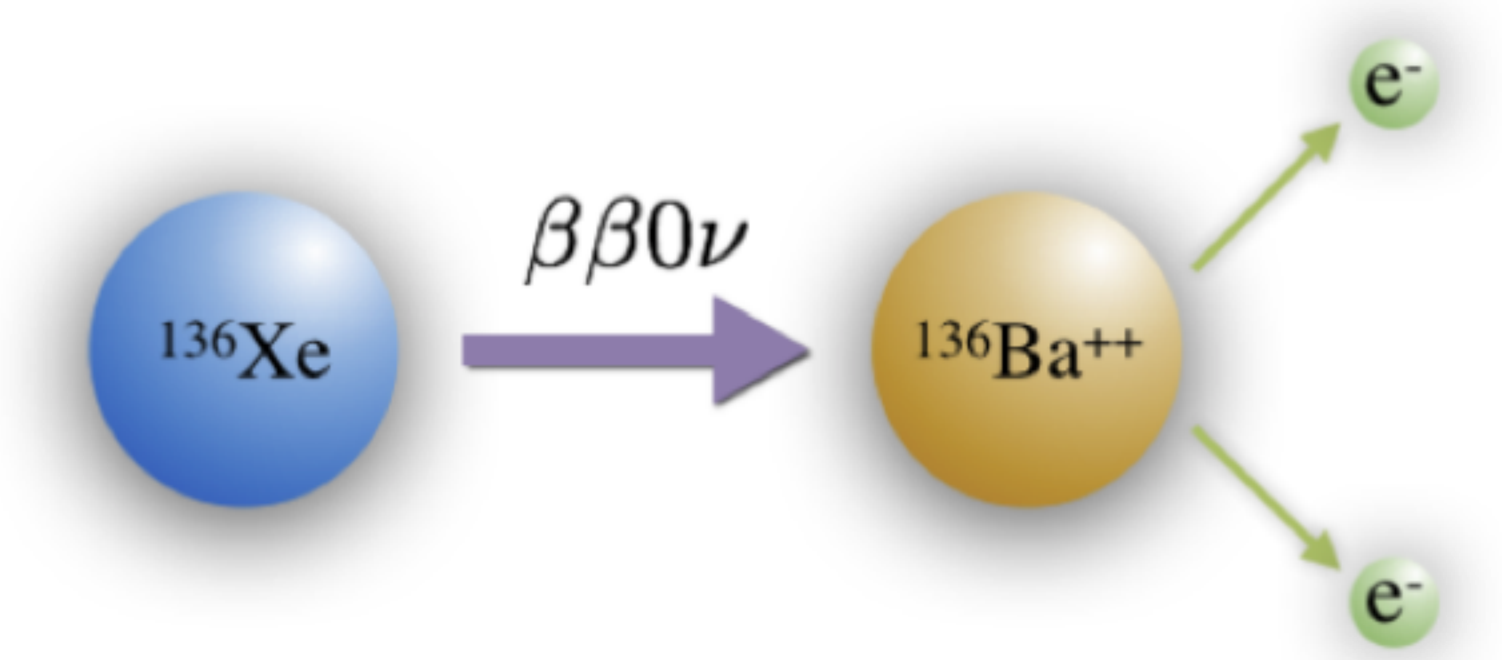


R&D for NEXT-HD



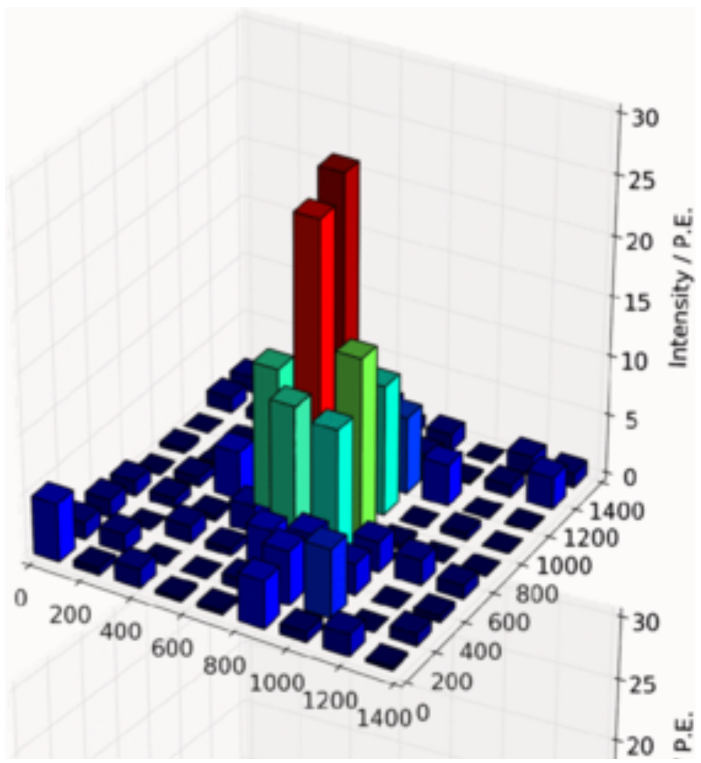
- EL amplification for large diameter grids.
- Barrel Energy Detector. Fibre readout PMTS/SiPMs?
- Cool Xenon (may be needed if fibres readout by PMTs)
- Handle dense tracking plane signals
- Reduce radioactive budget further w.r.t. NEXT-100
- Low diffusion gases

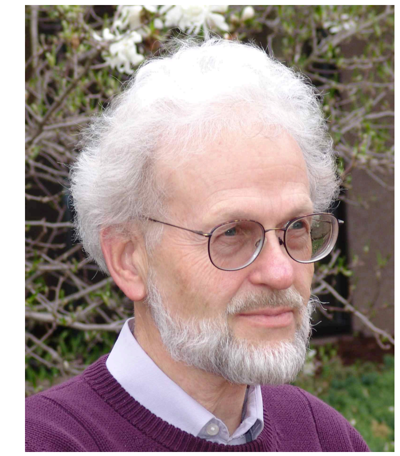
NEXT-BOLD



Detecting "tagging" the Ba++ signaling a ββ0v process has been a long sought holy grail of xenon chambers.

Ba2+ detection using molecular indicators



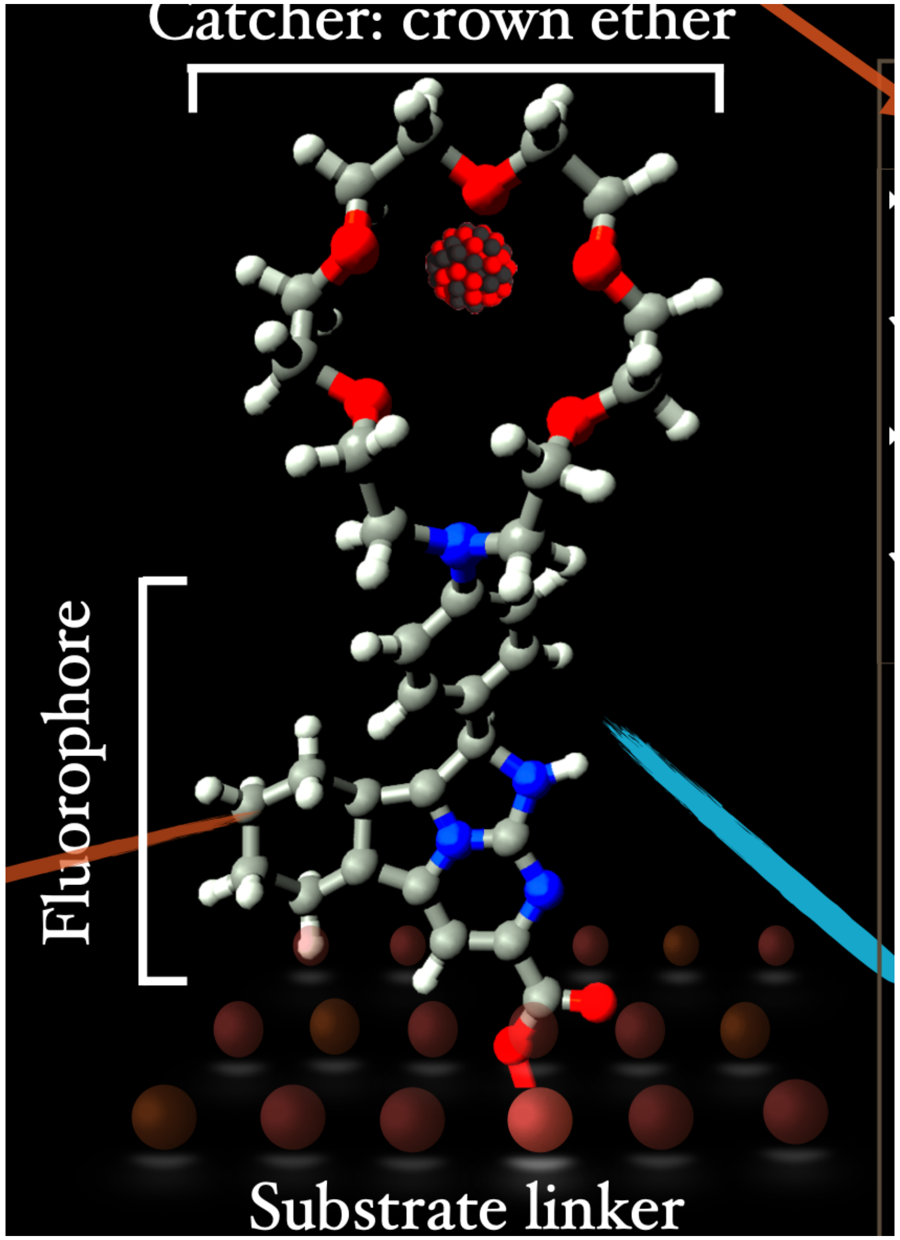


by D. Nygren

J.Phys.Conf.Ser. 650 (2015) no.1, 012002

Demonstration of Single-Barium-Ion Sensitivity for Neutrinoless Double-Beta Decay Using Single-Molecule Fluorescence Imaging

A.D. McDonald *et al.* (NEXT Collaboration)
Phys. Rev. Lett. **120**, 132504



The **NEXT** Collaboration's Big Idea:

Exploit *single molecule fluorescent imaging (SMFI)* to visualize a single barium ion as it arrives at the TPC cathode.

For ^{136}Xe, in gas phase, the daughter is ~100% $^{136}Ba^{++}$, perfect for using SMFI techniques.

Goal: develop custom molecules that change luminous response after chelating Ba dications.

Molecules must (and do!) display high specificity to Ba^{++}

Common elements: crown ether + fluorophore + linker

Complementary approaches explored in US and Spain
Spain: molecule changes color strongly: green → blue
Texas: molecule changes from non-luminous to luminous

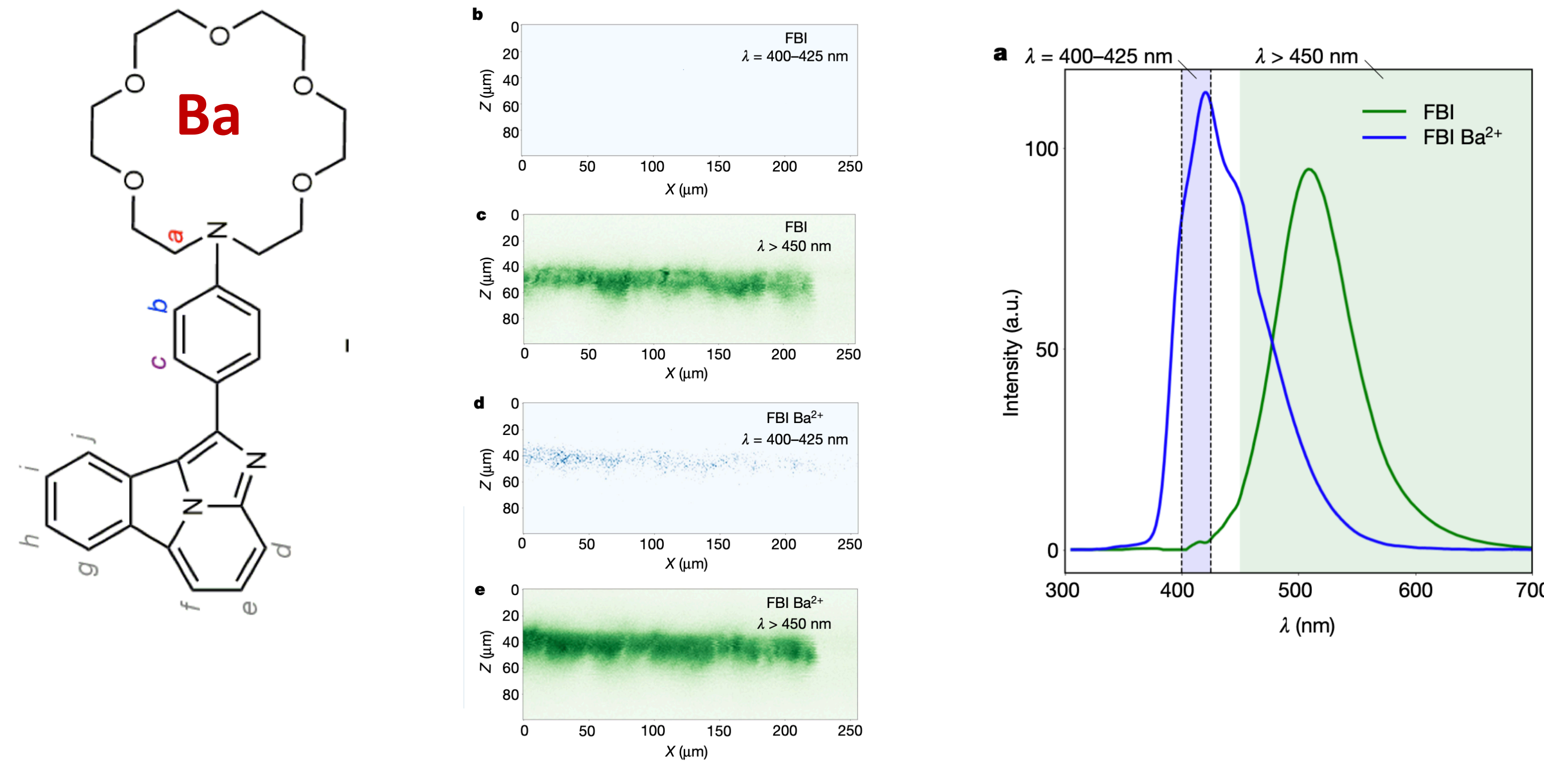
Molecular engineering: predictive computations too!

New Chemistry

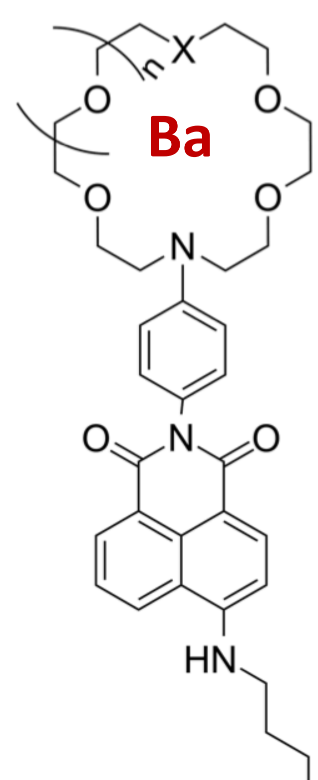
- Conventional ion chemosensors are not suitable for solventless (dry) imaging.
- NEXT has developed selective, dry-phase imaging of barium ions using crown ether derivatives.
- Ring receptor can be tuned to bind efficiently and selectively to barium.
- Computational chemistry is predictive for molecular fluorescence and binding.
- Two types have been developed: **on-off**, and **bi-color.**

Nature Sci Rep 9, 15097 (2019)
Nature 583, 48–54 (2020)
arXiv: 2006.09494 (submitted to JACS)

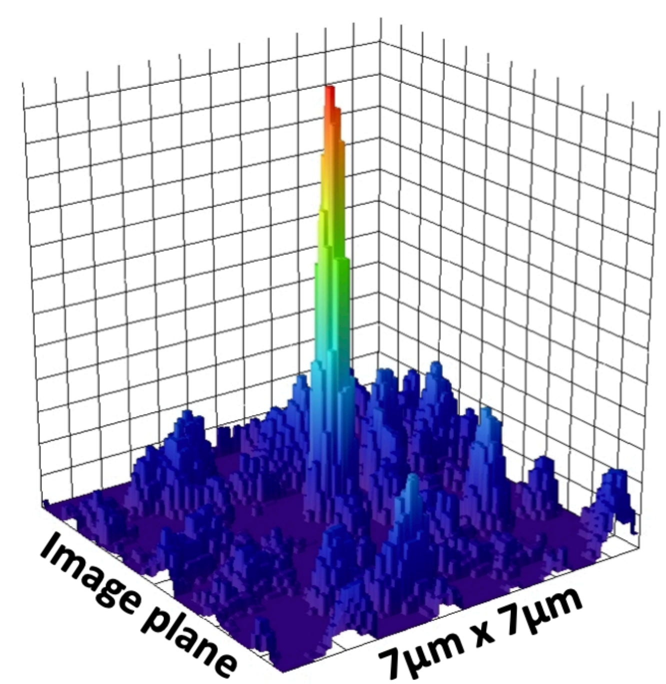
In-vacuo capture from $Ba(ClO_4)_2$ with bi-color response

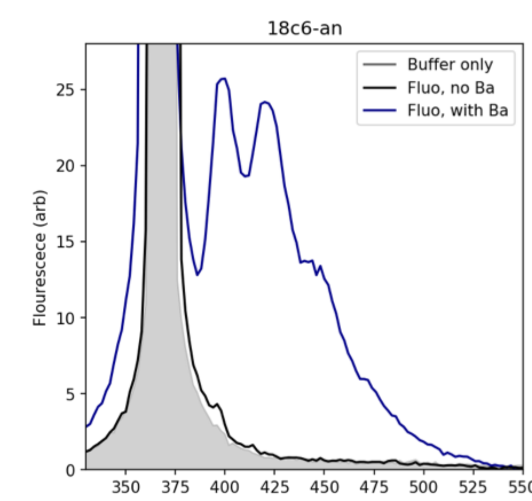


Dry single Ba++ ion detection with on-off fluorescence



1A-1E





Ba2+ expected to chelated indicators in high pressure gas

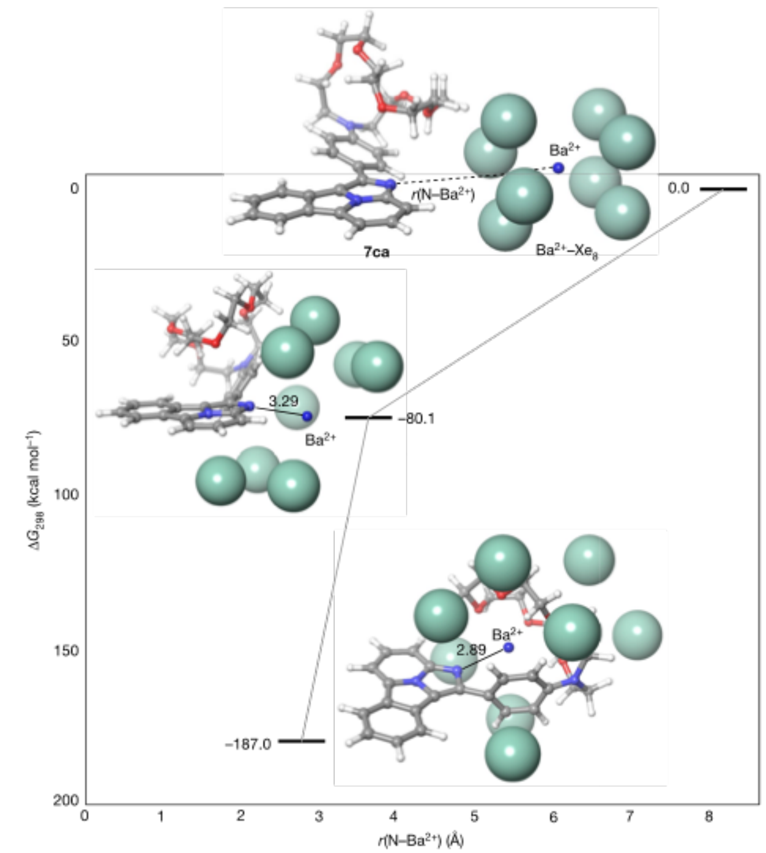
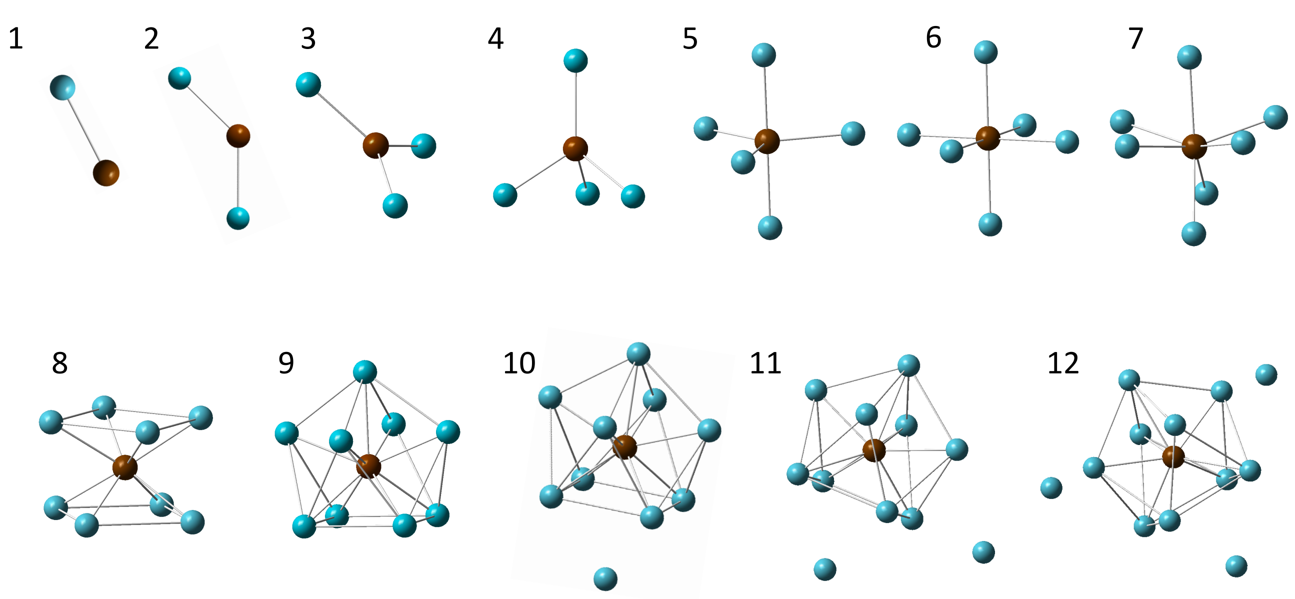
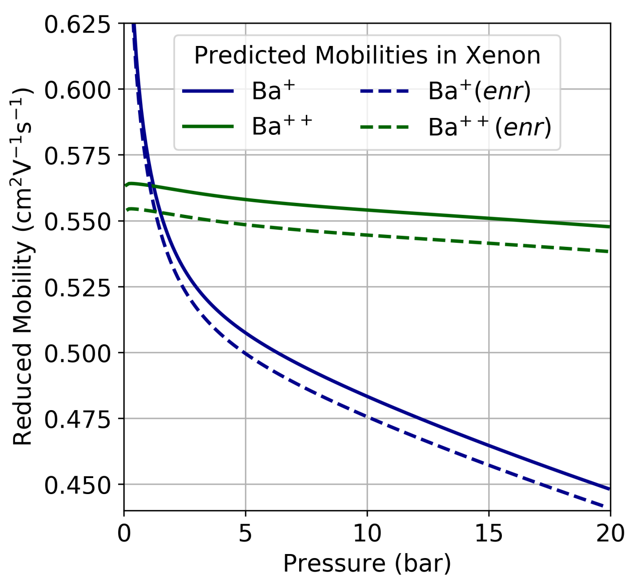


Fig. 4 | Computed structures of FBI (7ca) and a $Ba^{2+}Xe_8$ cluster at different N–Ba^{2+} distances. The geometries and energies shown were computed using DFT (see Methods for further details). Xenon atoms are represented using the Corey–Pauling–Koltun (CPK) space-filling model. The remaining atoms are represented using a ball-and-stick model and the CPK colouring code. Relative free energies (ΔG_{298}), have been computed at 25 °C (298 K).

Nature 583, 48–54 (2020)

Phys. Rev. A **97**, 062509





First demonstration of Ba2+ chelation in dry medium

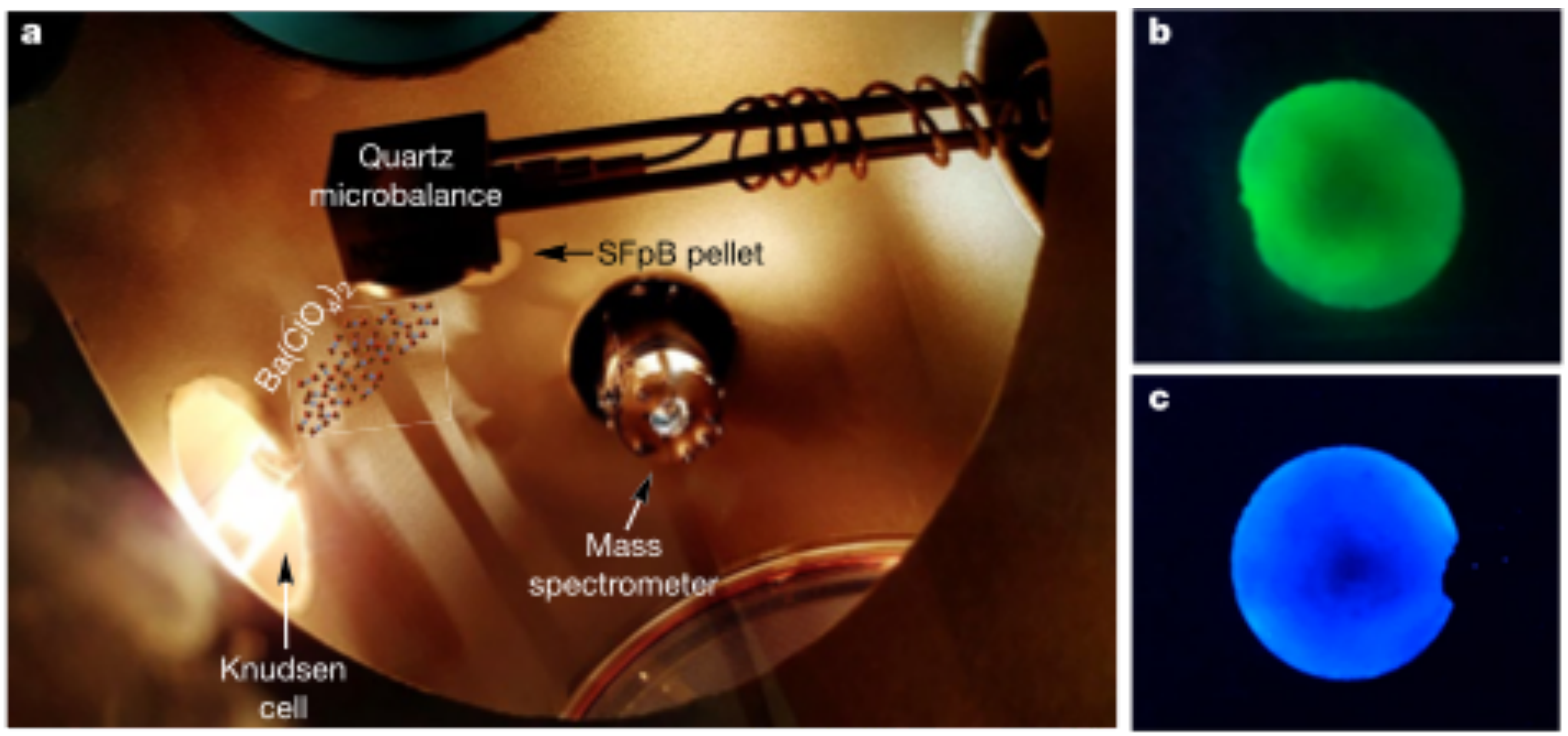


Fig. 3 | Sublimation of $Ba(ClO_4)_2$ on the FBI. a, Experimental setup. Photograph of the interior of the UHV chamber used for sublimation. The positions of the pellet, evaporator, quartz microbalance and mass spectrometer are indicated. **b**, **c**, Photographs of the pellet before (**b**) and after (**c**) the sublimation. In both cases, the excitation light is 365 nm. We note the characteristic green colour of unchelated FBI before the sublimation and the blue shift after the sublimation, which shows a large density of chelated molecules.

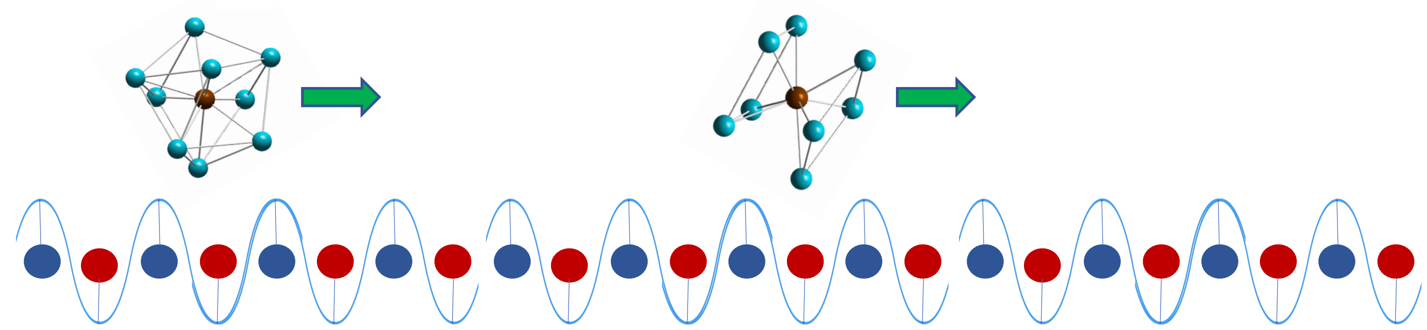
Nature 583, 48–54 (2020)

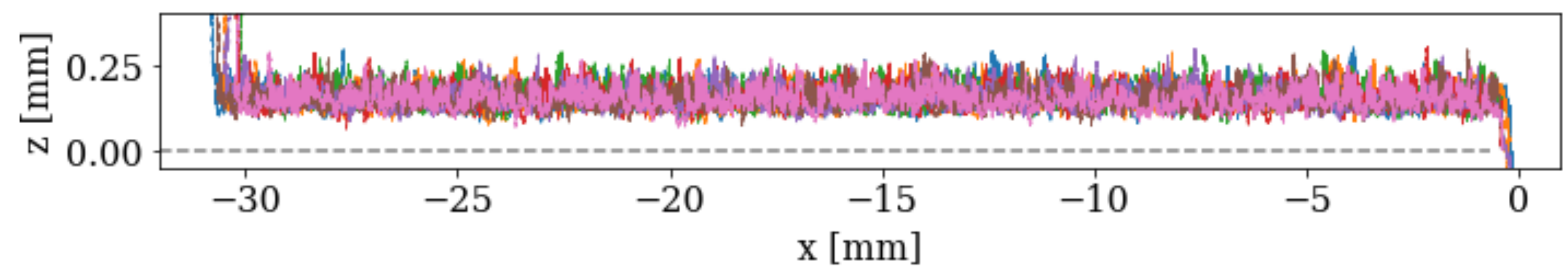
Ion Transport & Concentration

- One concept for ion collection from large volume is through concentration with RF carpets at 10 bar, onto 1mm^2 sensors.
- Simulations and HV tests suggest that efficient ion transport is achievable in principle at 10 bar.
- Dynamics of transport influenced by molecular ion formation with xenon – experiment is mandatory.
- Program of R&D at the CARIBU facility will test high pressure RF carpet, scheduled for 2020 (COVID permitting).

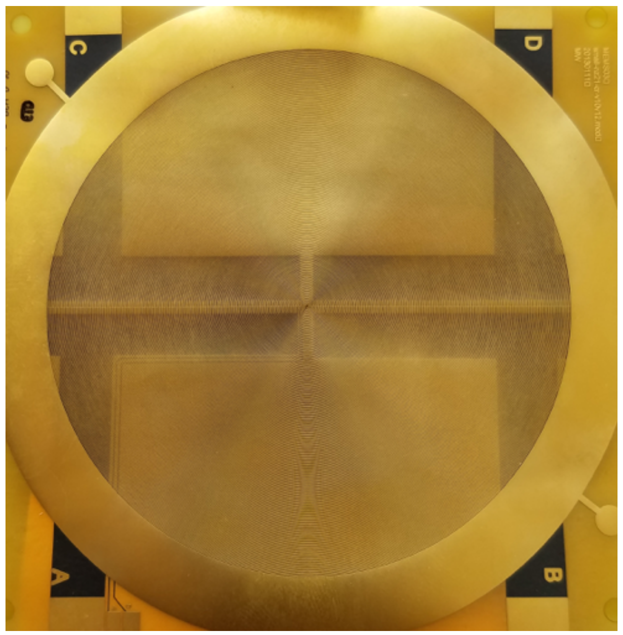
JINST 15 (2020) 04, P04022
Phys.Rev.A 97 (2018) 6, 062509

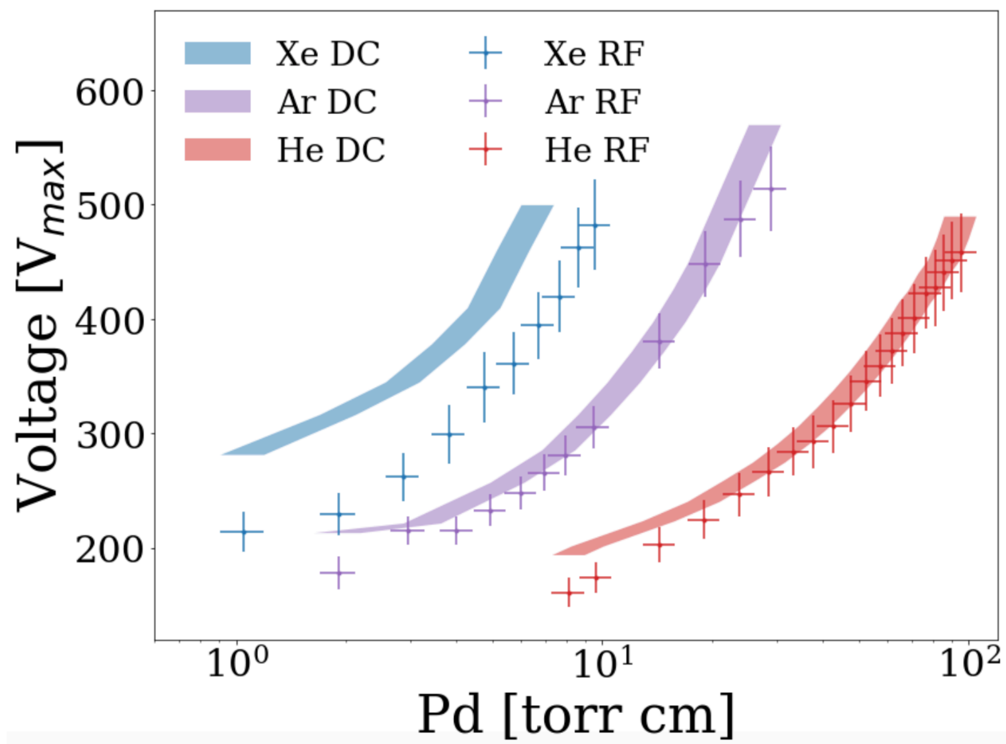
DFT calculations predict ion clustering and RF carpet simulations predict efficient transport.



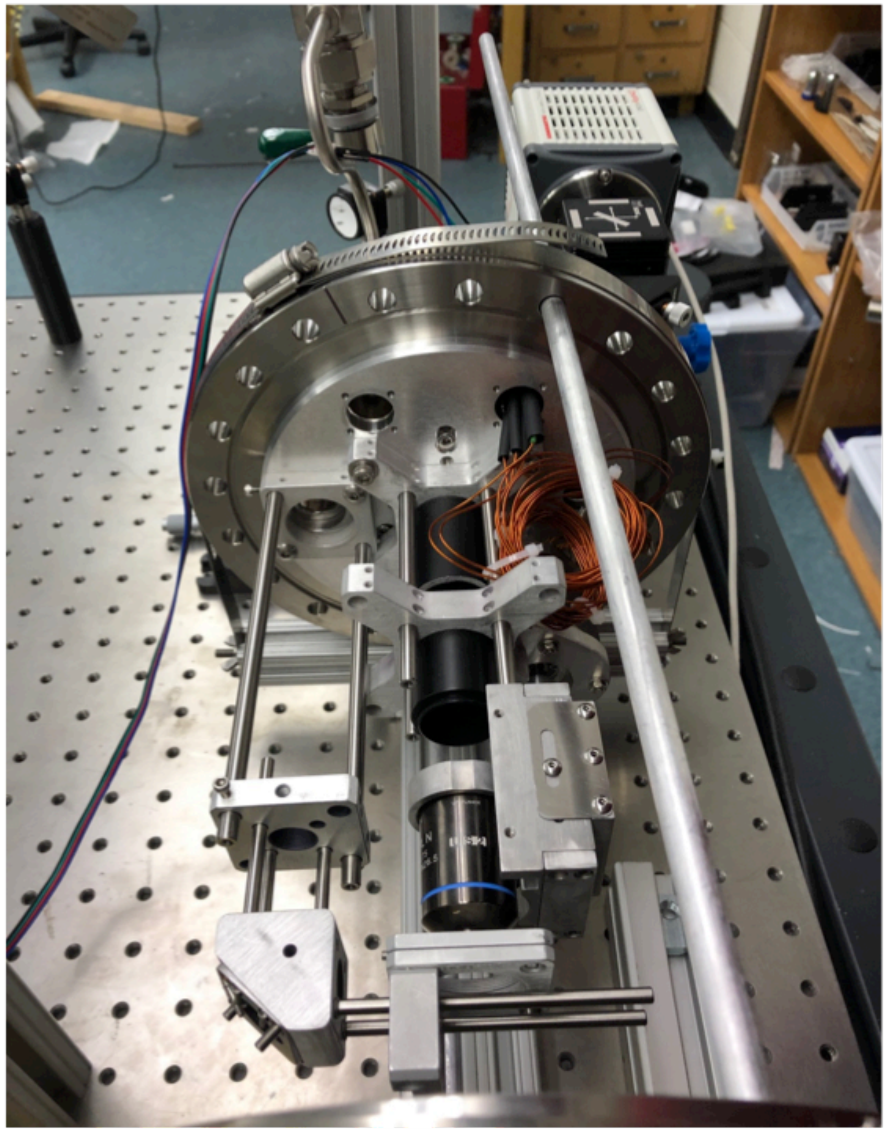


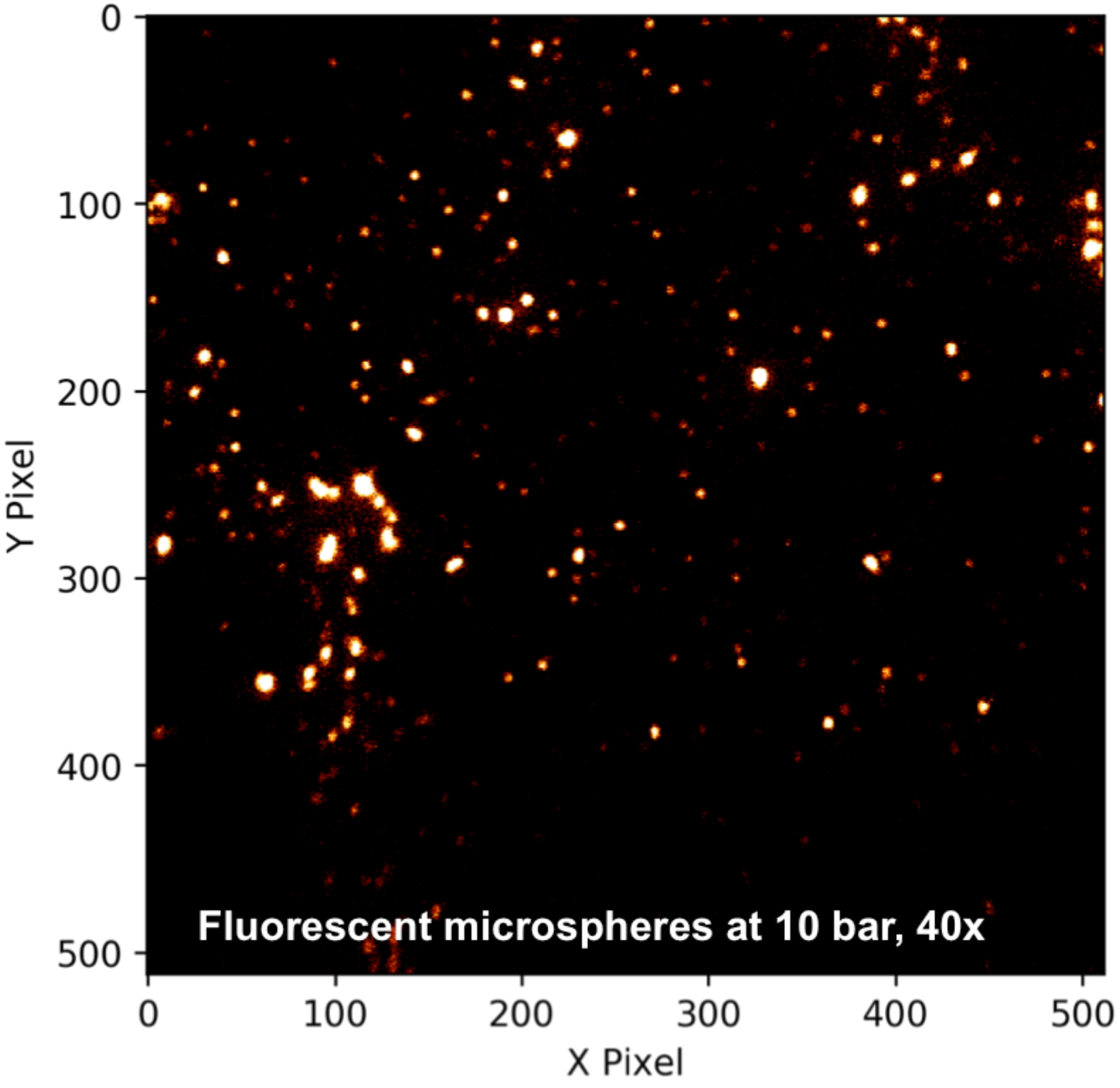
RF HV strength of Xe is sufficient for RF transport at 10bar.





High pressure microscopy

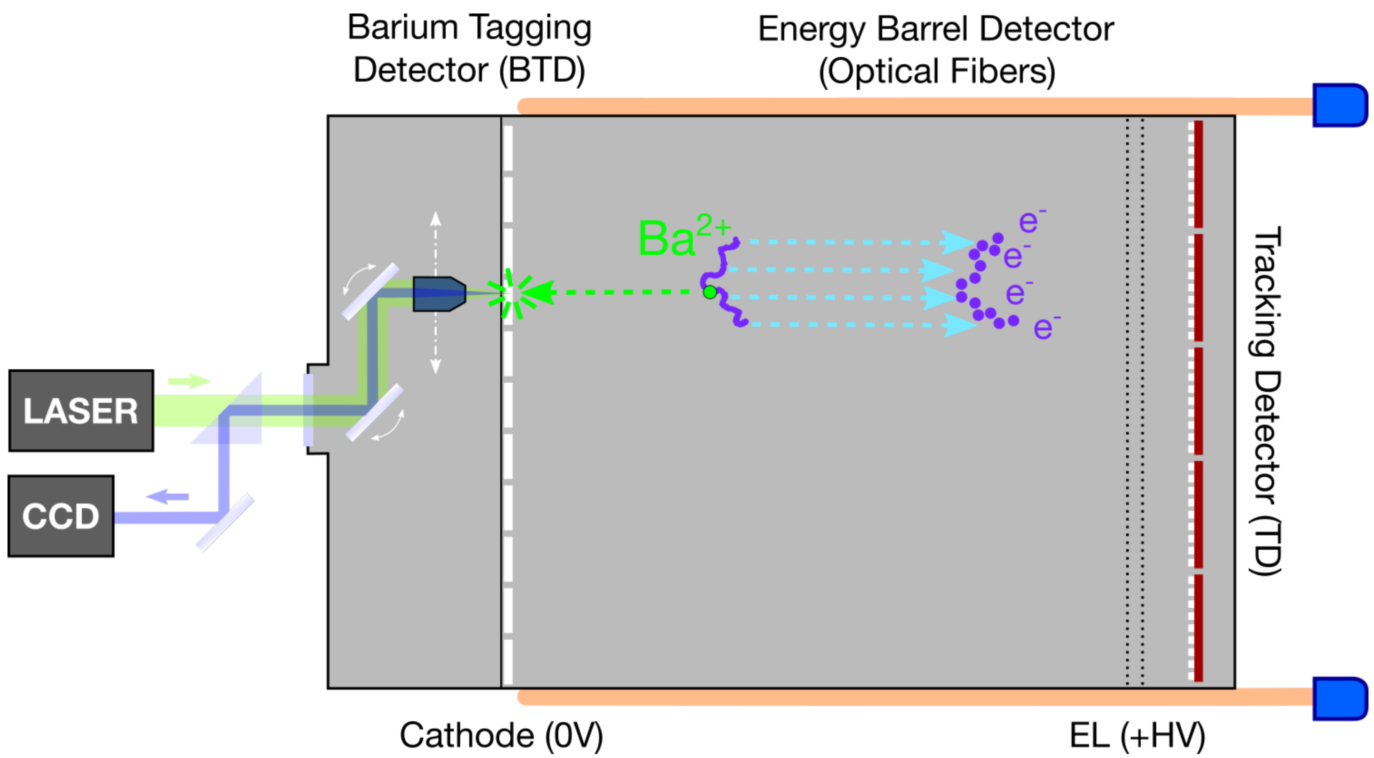




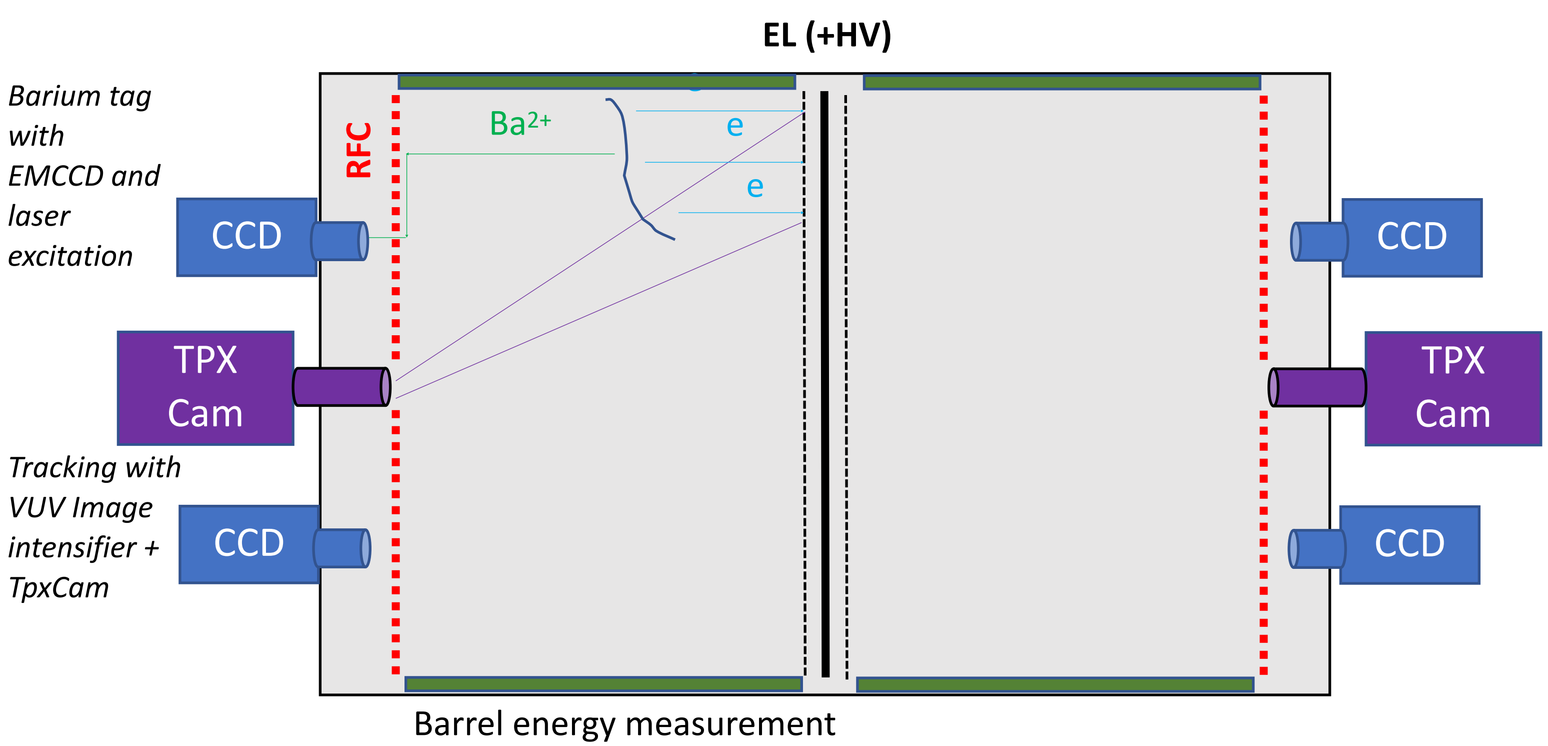
NEXT Steps

- Ion beams using $^{222}Rn^{2+}$ from thorium decay are under development for single ion test.
  (RITA/SABAT program, Spain)
- Beam tests also planned at ANL CARIBU with $^{144}Ba^{2+}$ mass-selected from ^{252}Cf fission.
  (GodXilla program, USA)
- The ultimate test-beam is ββ2ν !
- Demonstrator phases at 10kg-scale are being planned for ~2024-2025.
- Multiple full system concepts under exploration, to be guided by ongoing R&D.

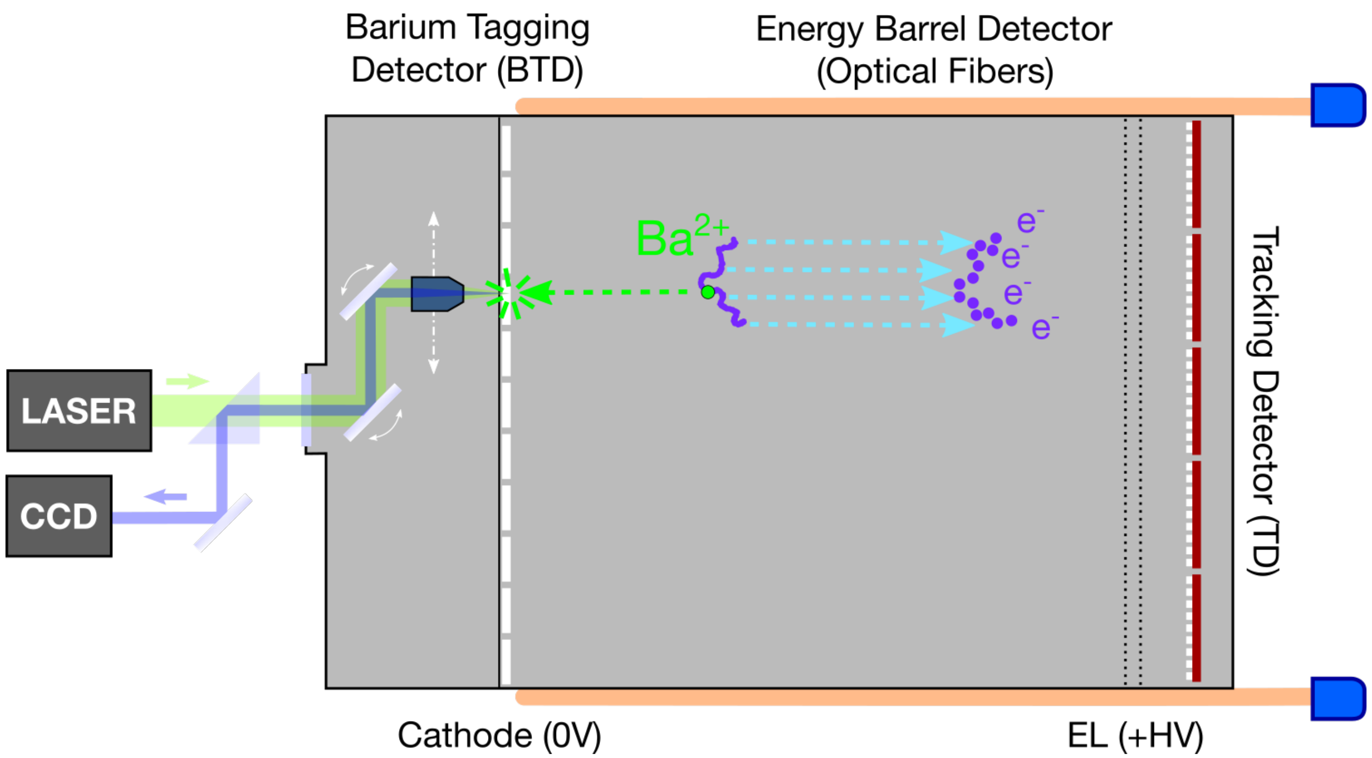
"SABAT" concept with fully active cathode, SiPM-based tracking and Energy Barrel Detector



"CRAB" concept with RF carpet concentrators and camera-based topology measurement



NEXT-BOLD (SABAT) concept



- Asymmetric detector.
- Energy measured by Barrel Detector (fibres).
- Topology reconstruction with SiPMs.
- High pressure to increase mass and decrease size of track (40 bars)
- Scanning region selected by predicted impact point.
- Cathode at V+ opens gate only on delayed bb0nu trigger.
- Fast, high-pressure microscopy.
- Prototype: NEXT-White or NEXT-100

- Delayed trigger:
- Single deposition with energy in ROI
- Opens gate at predicted arrival time
- Scans ~1cm around predicted arrival point

Funding for SABAT program requested to ERC (Synergy Grant).

Time line

	Tasks
1	Operation of NEXT-White
2	Assembly and commissioning of NEXT-100
3	Operation of NEXT-100
4	R&D for NEXT-HD and NEXT-BOLD
5	Choice of technology for ton-scale module
6	Construction of first ton-scale module
7	Procurement of isotope mass
8	Operation of first ton-scale module
9	R&D for second ton-scale module
10	Choice of technology
11	Construction of second ton-scale module
12	Procurement of isotope mass
13	Operation of two ton-scale modules

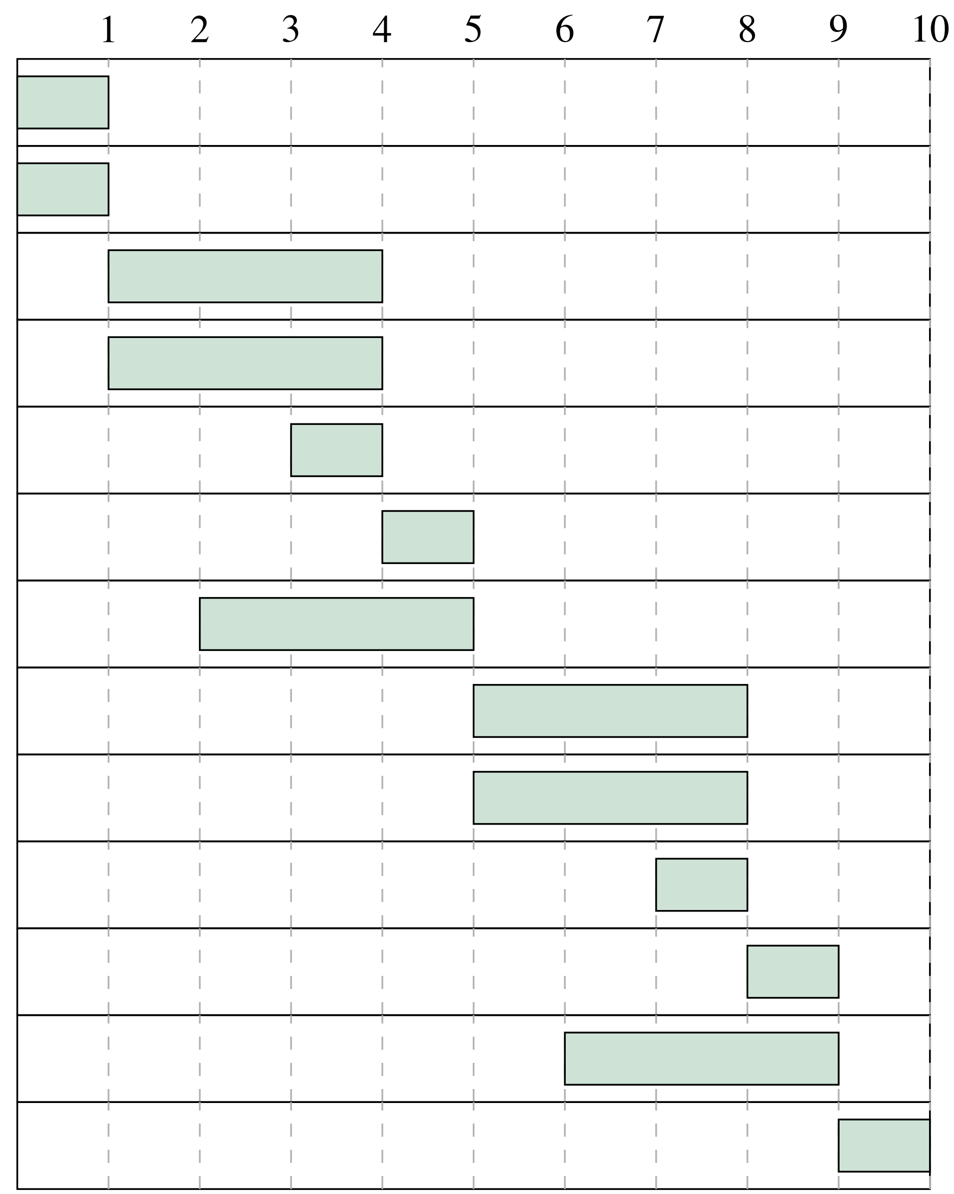


Figure 9: Time schedule of NEXT experiment including R&D program. Column numbers indicate years. Year 0 is 2019. Operation of two modules continue after year 10.

Conclusions

- Next generation of double beta experiments target to reach ~10^{27} years lifetime. Background rates at 1 evt/tonne·year.
  - NEXT-HD incremental approach. Some of the solutions also valid for BOLD.
  - R&D in the crucial parts already on-going.
- The next step (~10^{28} y) requires background rates at the 0.1 evt/tonne·year level.
  - NEXT-BOLD with barium tagging may be a background free experiment.
  - Very active R&D effort leading to a prototype in the next few years.

The NEXT Collaboration

co-spokespersons:
David Nygren
JJ Gomez Cadenas

LSC
Laboratorio Subterráneo Canfranc

USA

University of Texas Arlington
Argonne National Laboratory
Harvard
Fermilab
Texas A&M
Iowa State University
Pacific Northwest National Laboratory

Spain

DIPC
IFIC Institut de Física Corpuscular
Universitat de Girona
USC Universidade de Santiago de Compostela
Universidad de Zaragoza
Universitat Politècnica de València

Portugal, Israel, Russia, Columbia

U C
Ben-Gurion University of the Negev
UAN Universidad Antonio Nariño
JINR Dubna
universidade de aveiro