The NEXT project

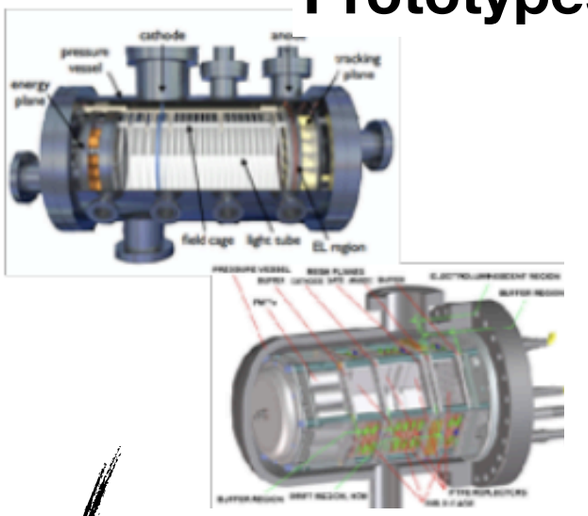
J.J. Gomez Cadenas on behalf The NEXT collaboration.

ikerbasque
Basque Foundation for Science

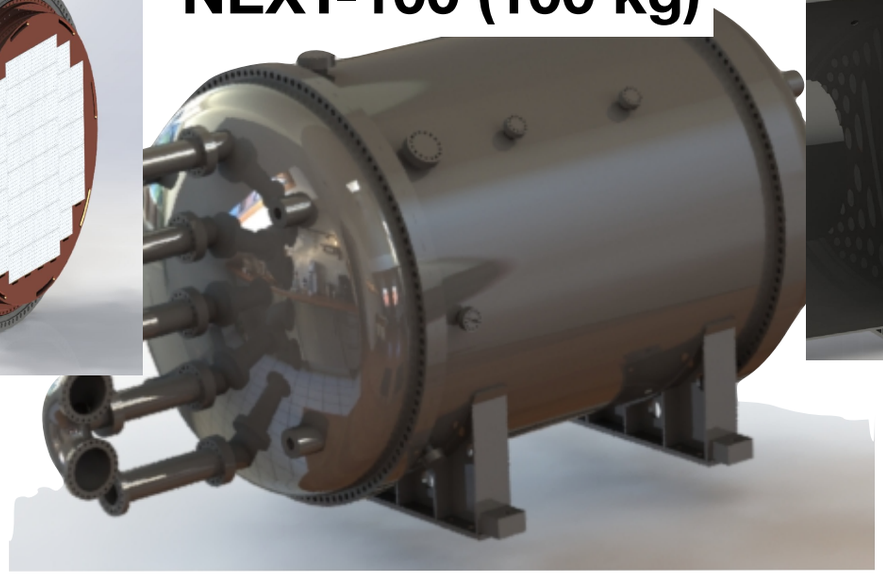
European Research Council
Established by the European Commission
Supporting top researchers from anywhere in the world

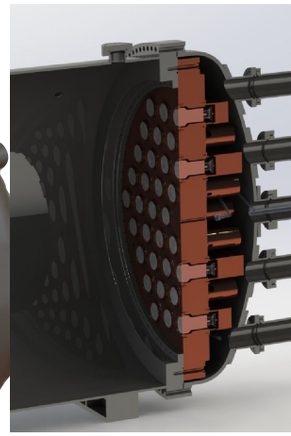
Gas phase detectors: NEXT

Prototypes



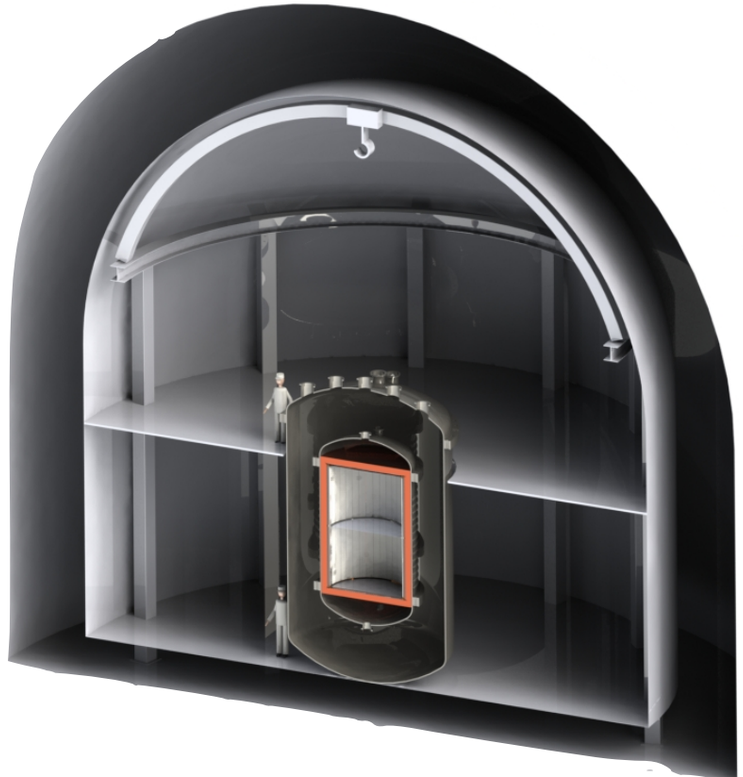
NEXT-100 (100 kg)



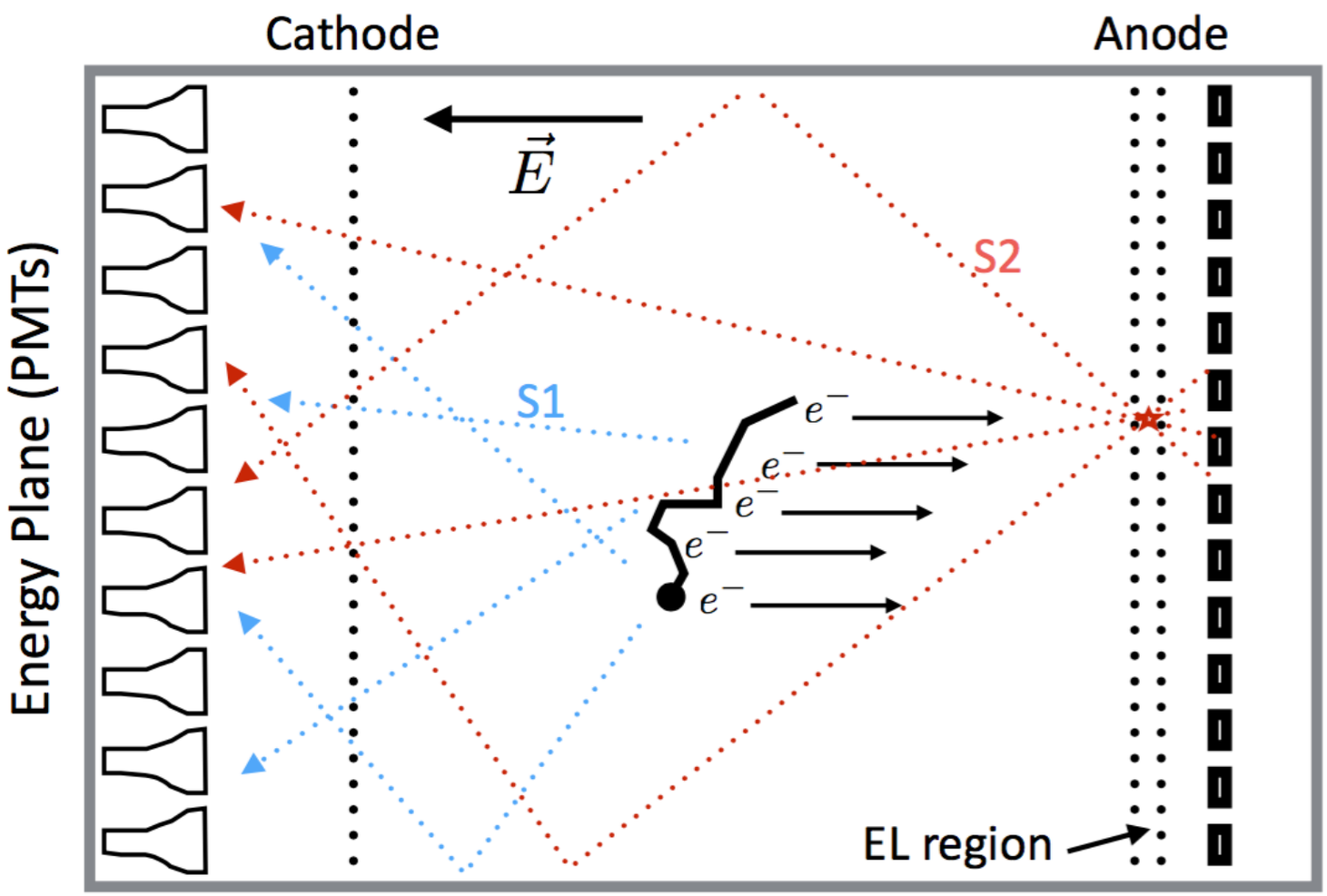


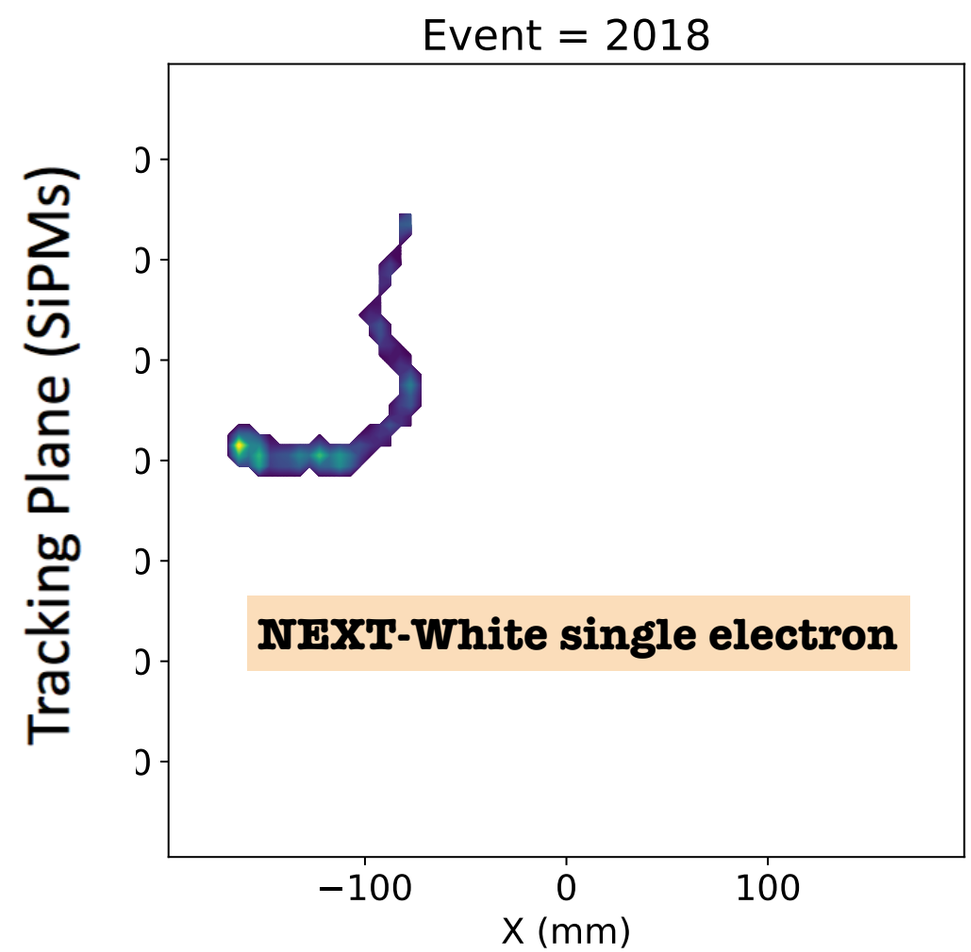
NEW (~10kg)

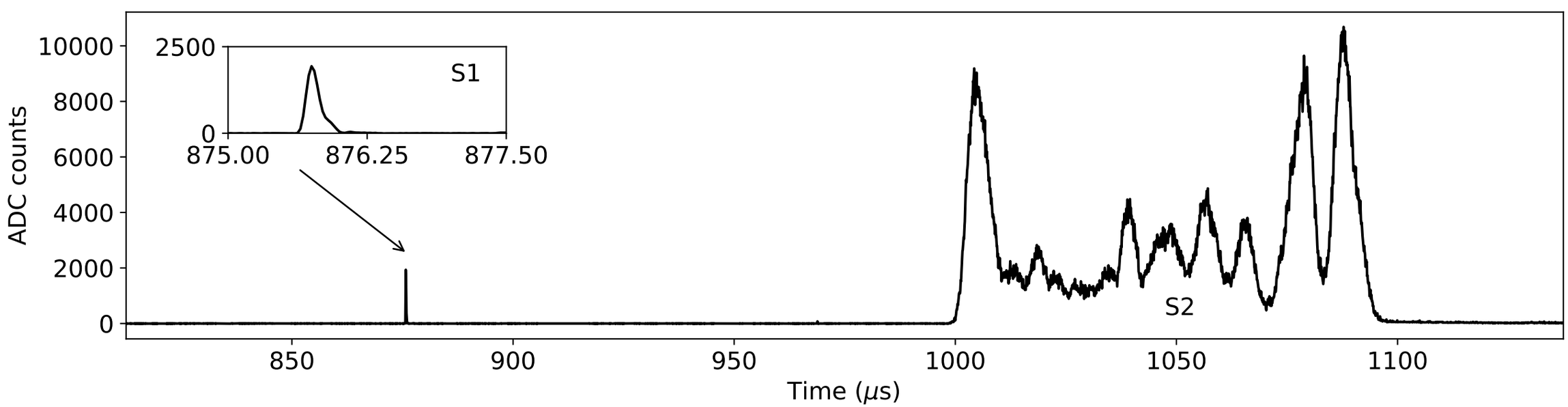
NEXT-HD/BOLD (~1000 kg)



Principle of operation

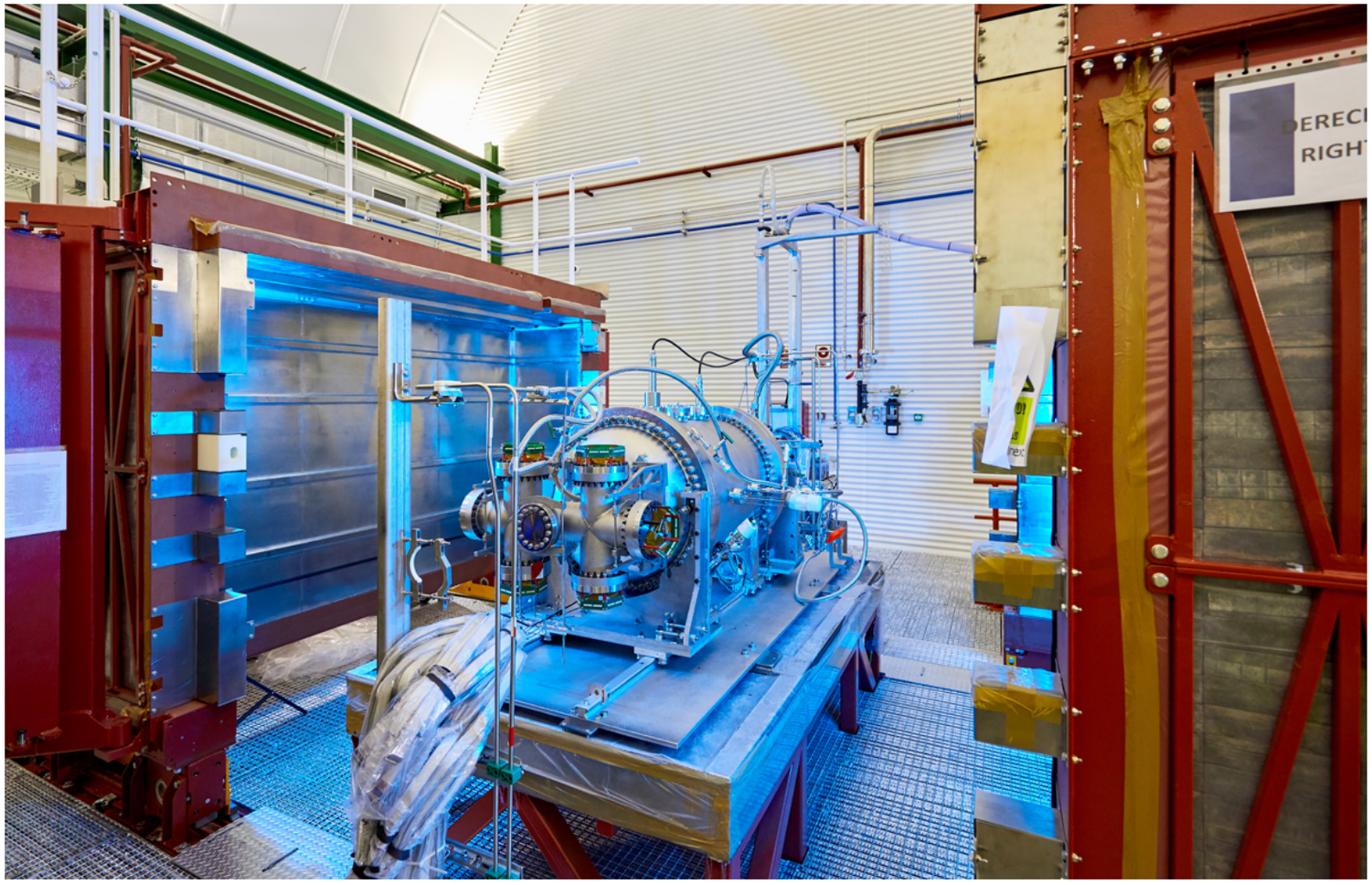






NEXT-White

JINST 13 (2018) no.12, P12010
e-Print: arXiv:1804.02409

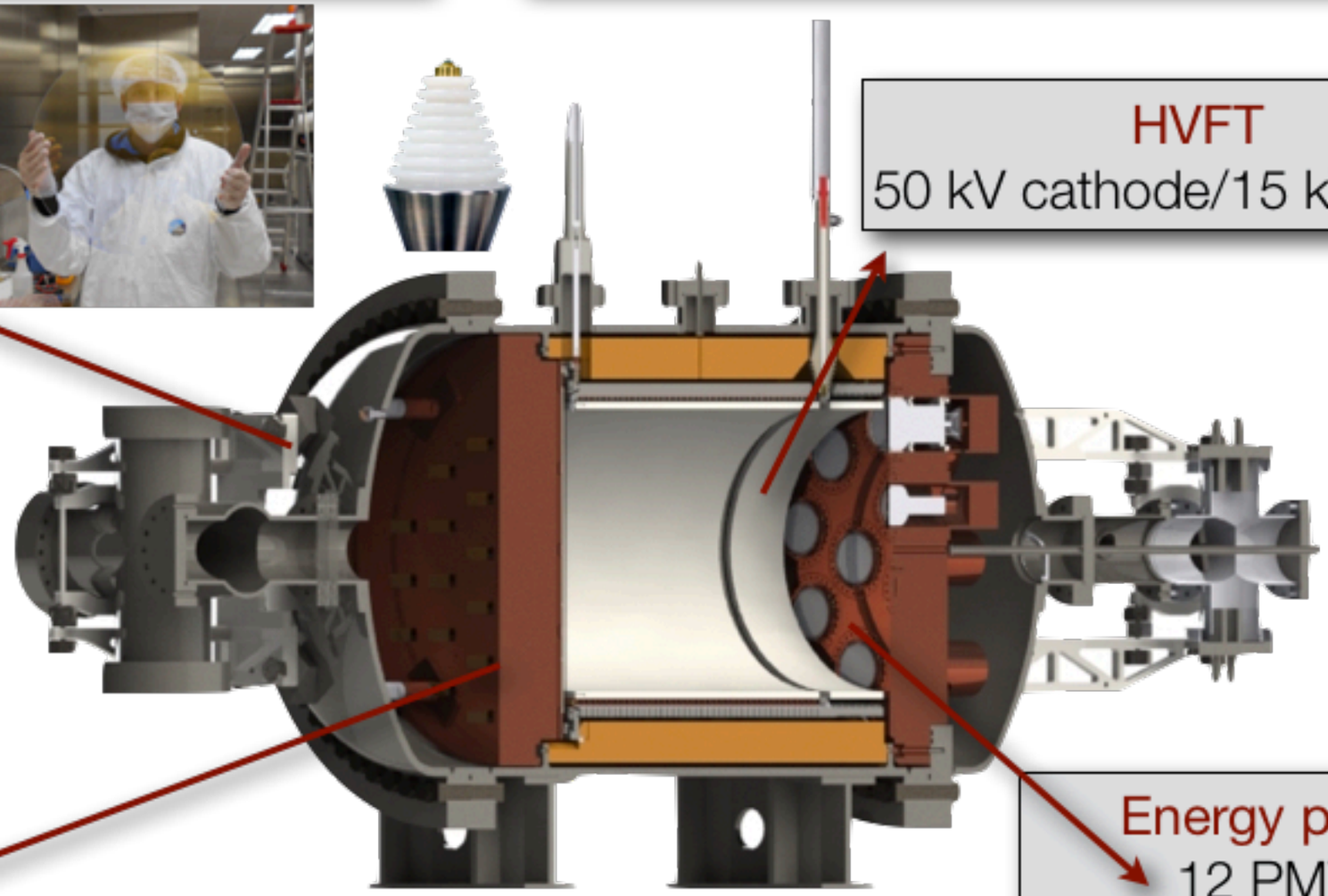


- A full scale demonstrator of the NEXT technology
- Technology development, radio purity, setting up infrastructures (shielding, gas system)
- Measures energy resolution, topological signature, background index, $\beta\beta2\nu$ mode. Running with enriched xenon since 2016.

NEXT-White at LSC

Time Projection Chamber:
5 kg active region(@15bar), 50 cm drift length

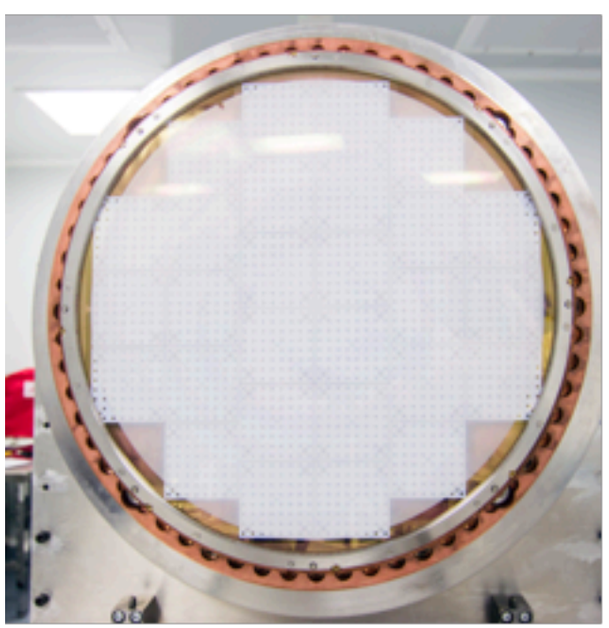
Pressure vessel:
316-Ti steel, 20 bar op pressure



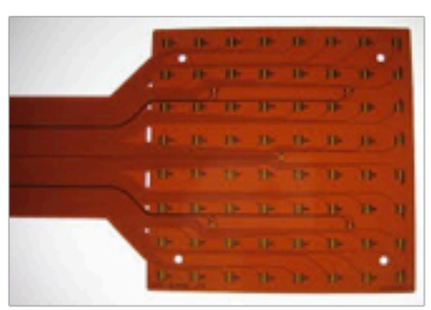
HVFT
50 kV cathode/15 kV anode

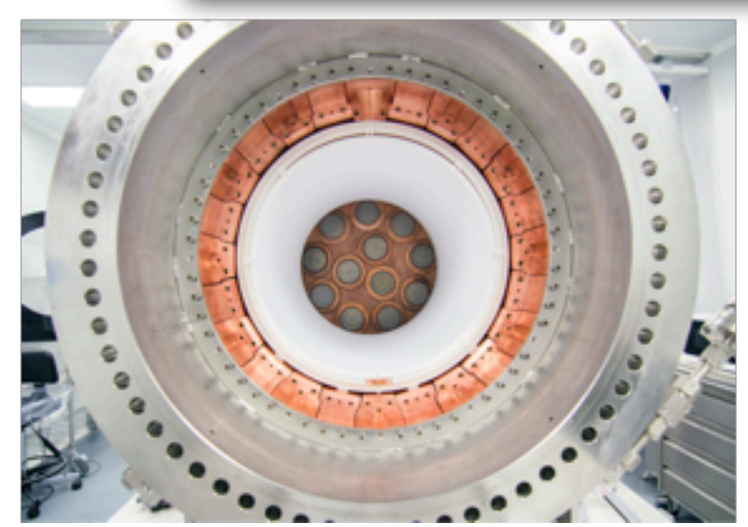
Tracking plane:
1792 SiPMs,
1 cm pitch

Energy plane:
12 PMTs,
30% coverage



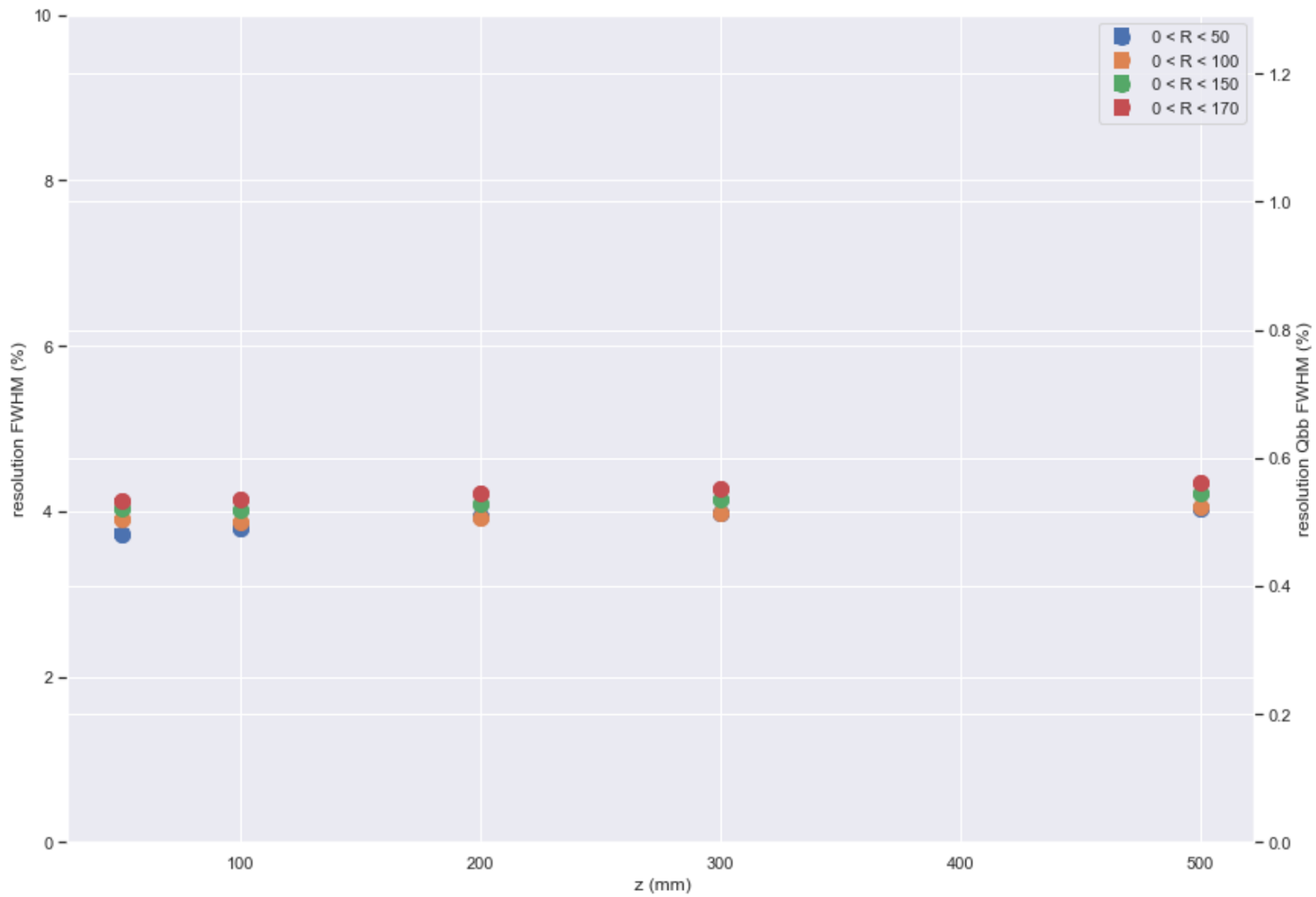
Inner shield:
copper, 6 cm thick





Energy resolution Krypton

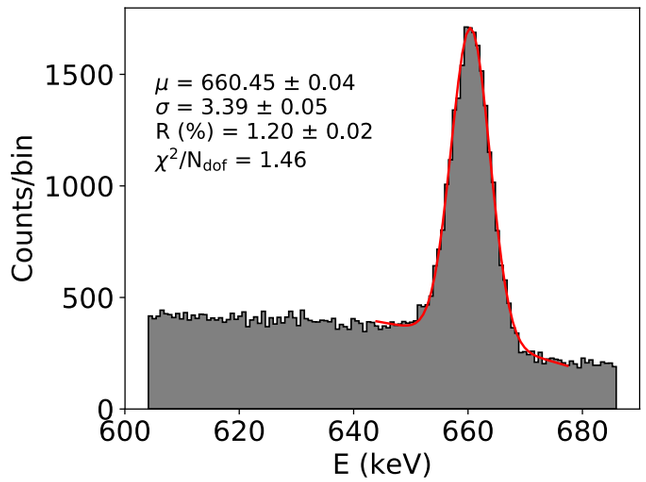
JINST 13 (2018) no.10, P10014
e-Print: **arXiv:1804.01780**

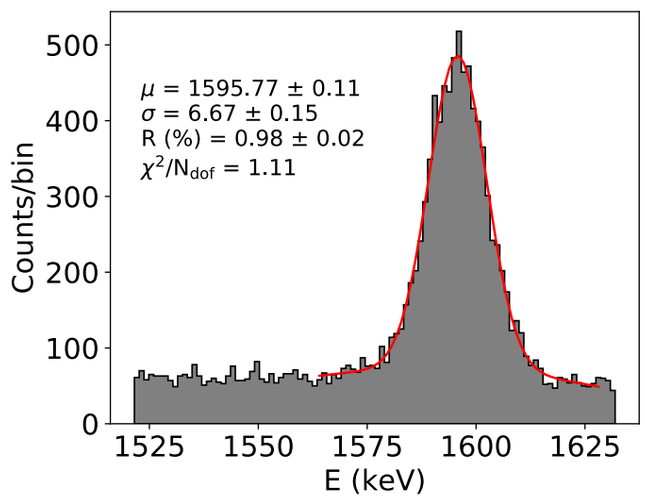


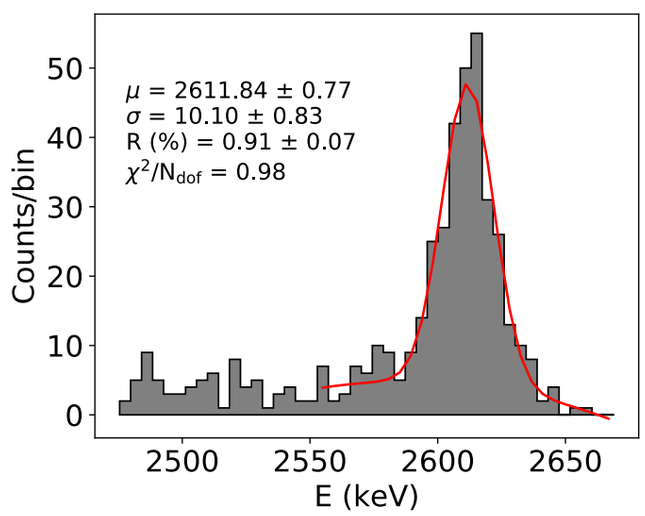
- Kr-83m, @ 41.5 keV.
- Energy resolution extrapolated at $Q_{\beta\beta}$ near 0.5 % in the full chamber.
- Energy resolution independent of Z and only softly dependent on R.

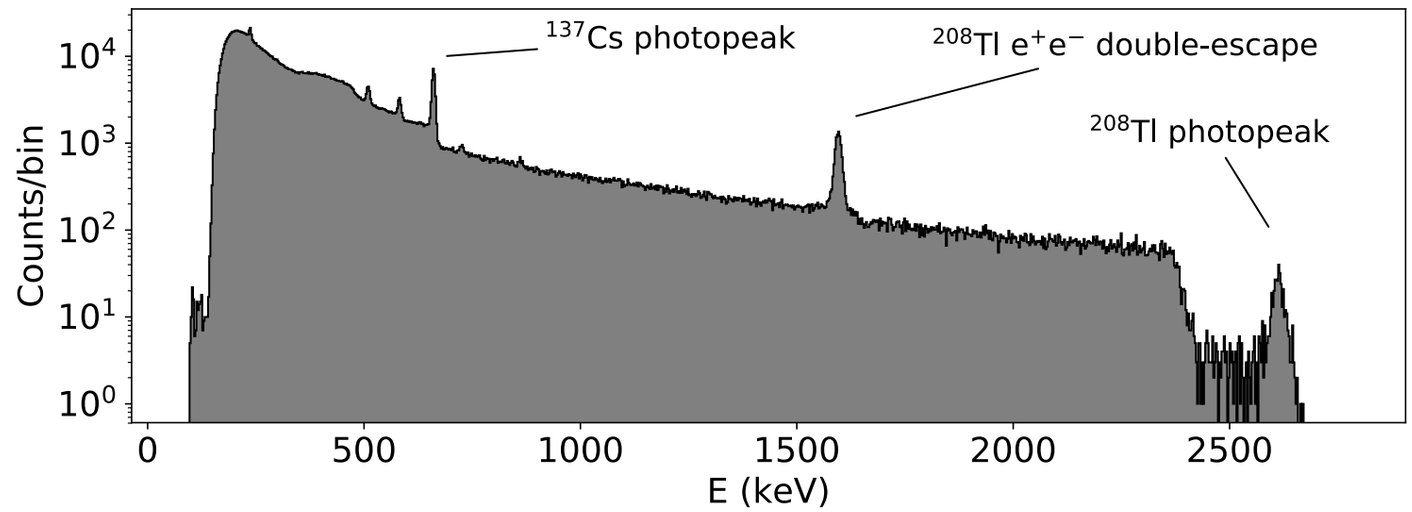
Resolution at high energy

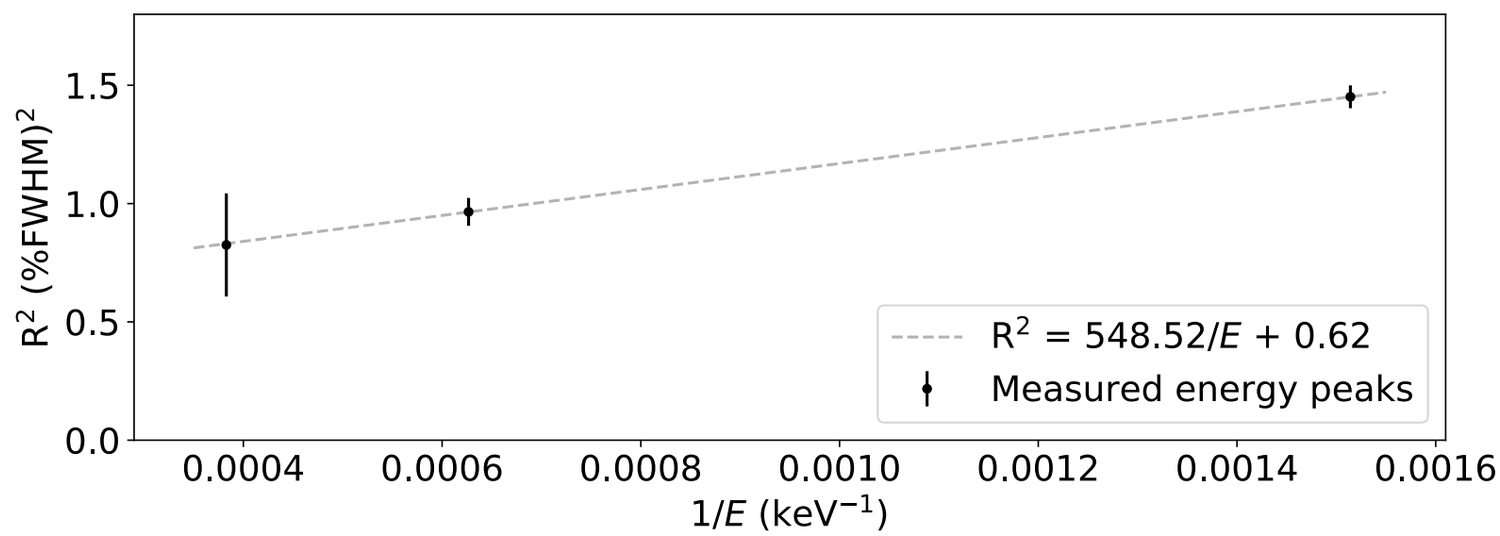
JHEP 1910 (2019) 230
e-Print: **arXiv:1905.13110**





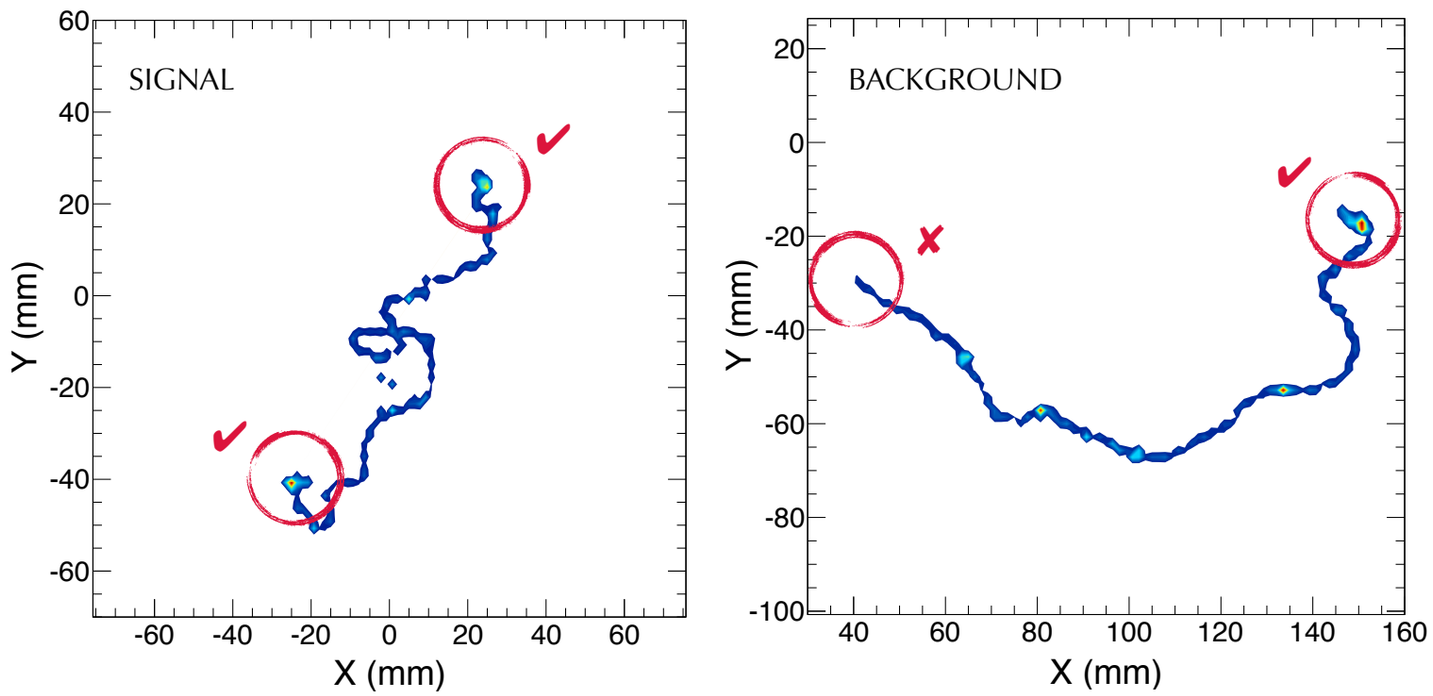






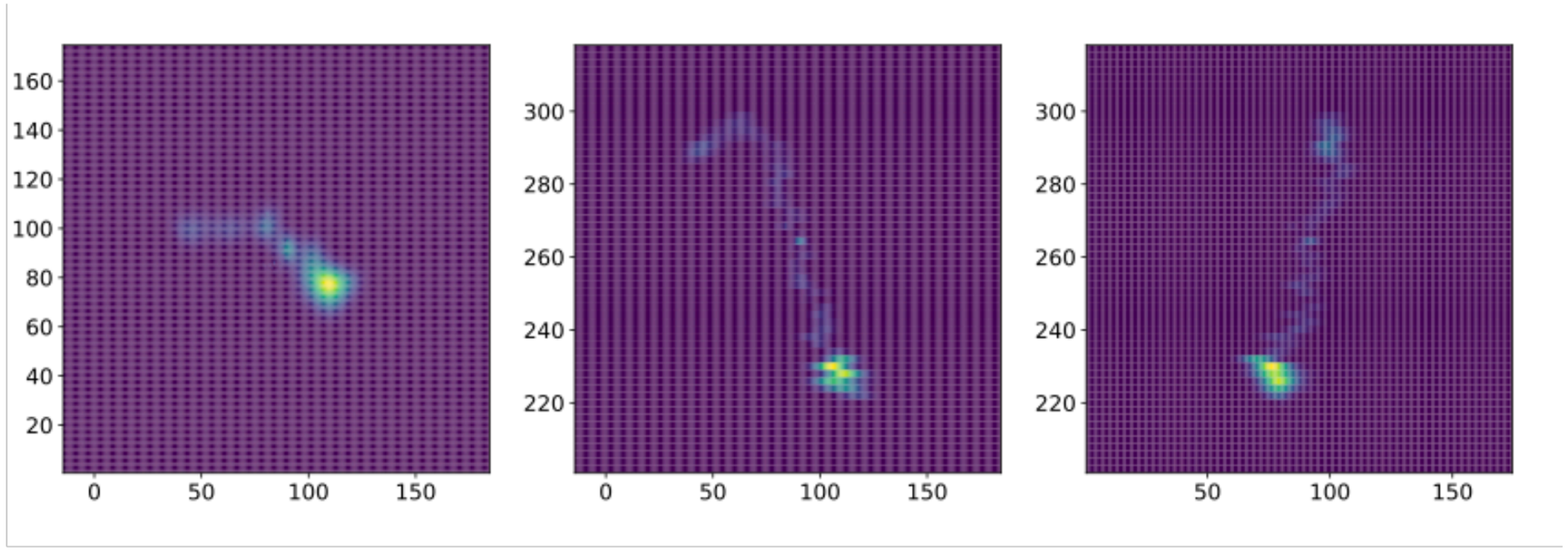
- Energy resolution at Qbb better than 1 % FWHM (target of NEXT-100)

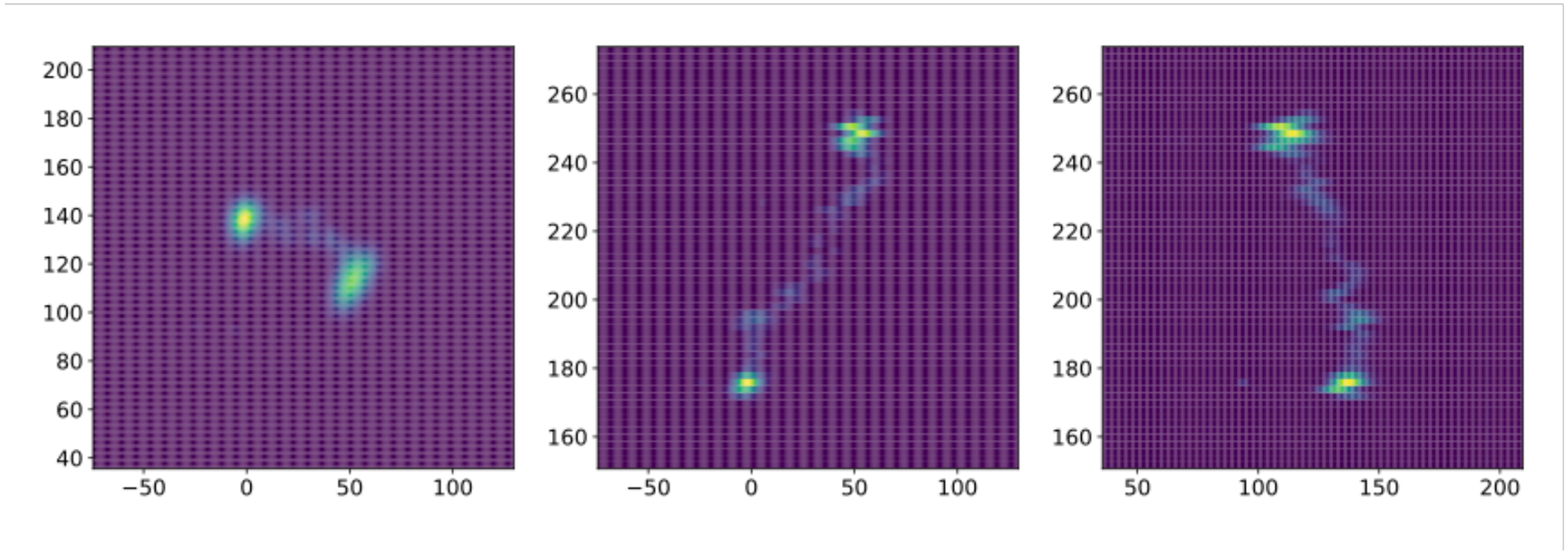
Topological signature



- Distinctive feature of NEXT technology.
- NEXT sensitivity paper: one order of magnitude background rejection with high signal selection efficiency.
- Needed for $\beta\beta2\nu$ and $\beta\beta0\nu$ searches.
- Our target: validate reconstruction machinery and Monte Carlo.

Double escape peak: single and double electrons

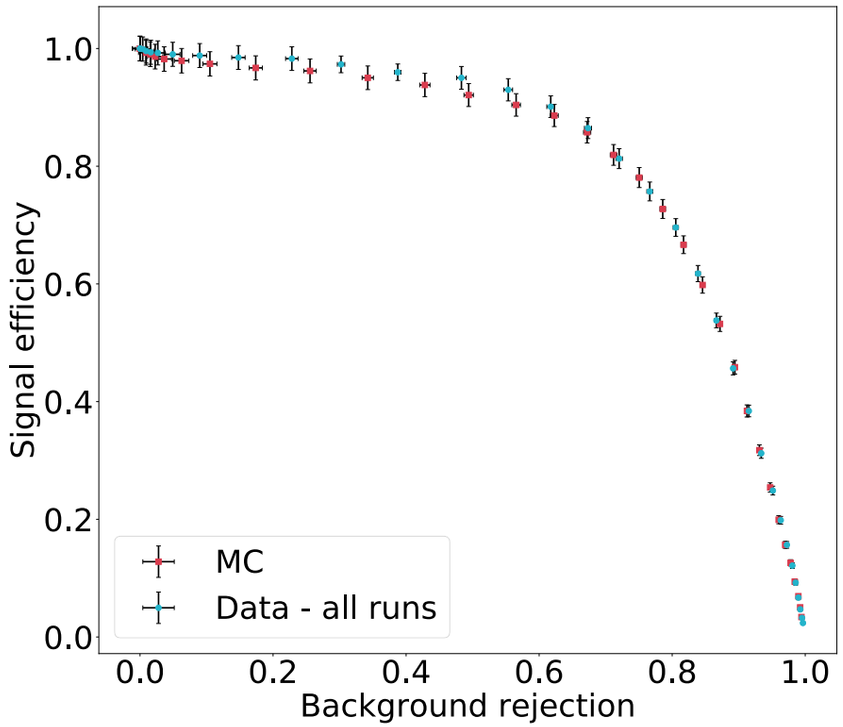




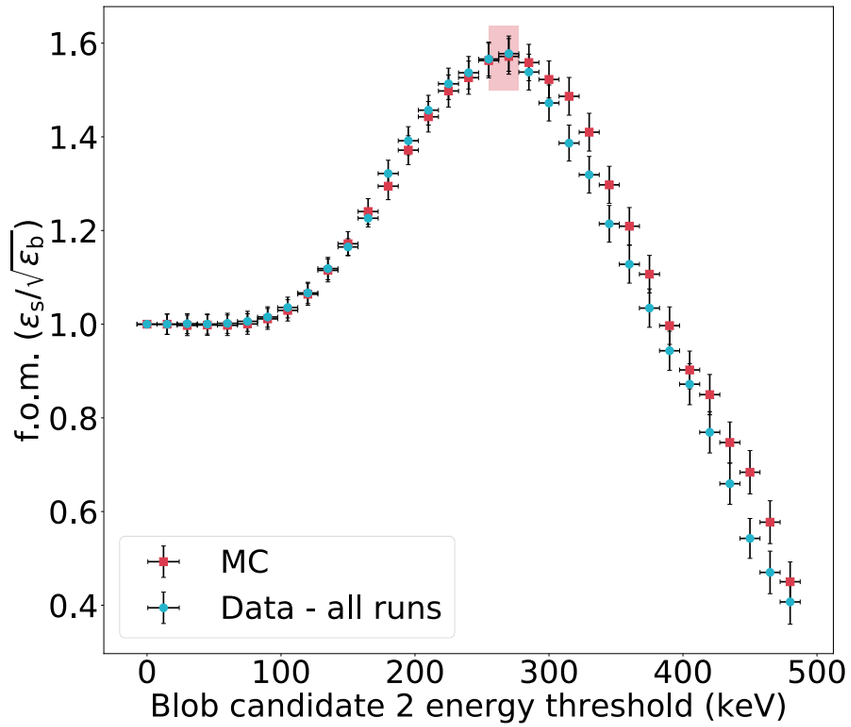
- Energy 1600 keV.
- Scale in mm.

Topological signature at Qbb using DNNs

DATA/MC comparison double escape peak

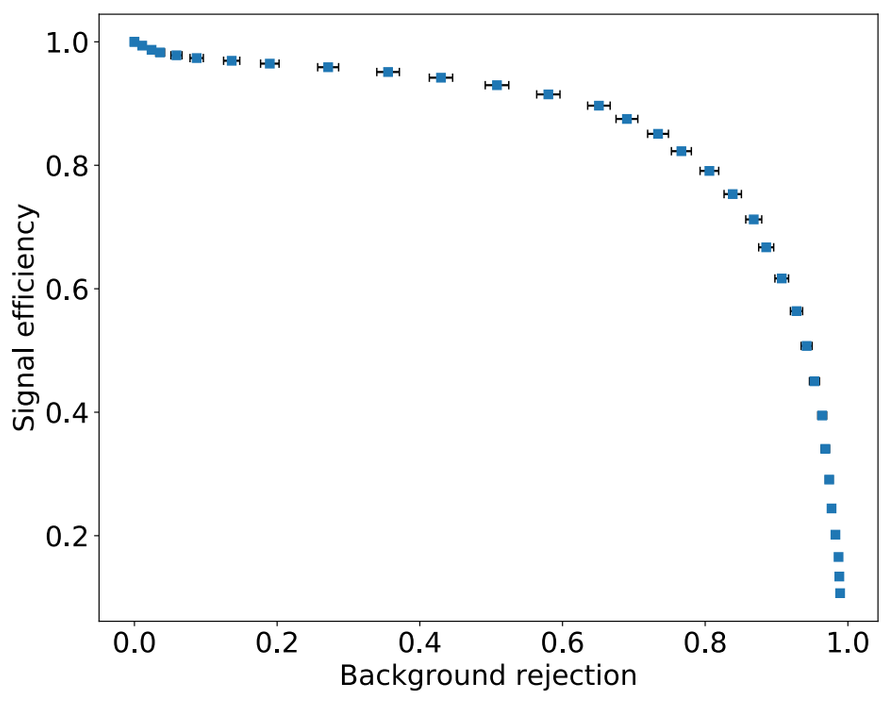


DATA/MC FOM two-blob cut.

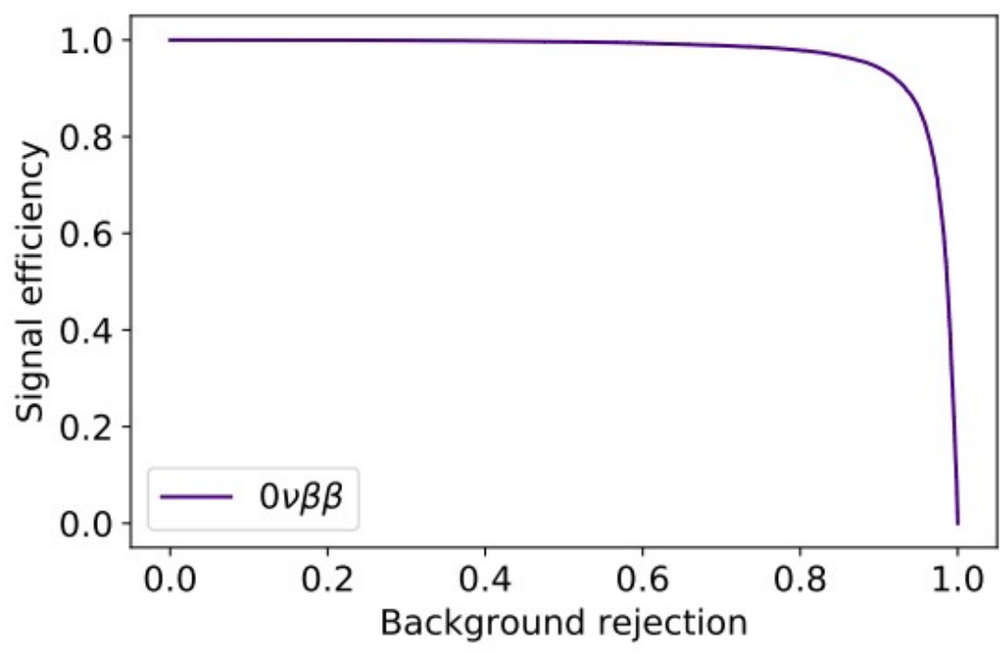


JHEP 1910 (2019) 052
arXiv:1905.13141

S/B at Qbb, classical analysis

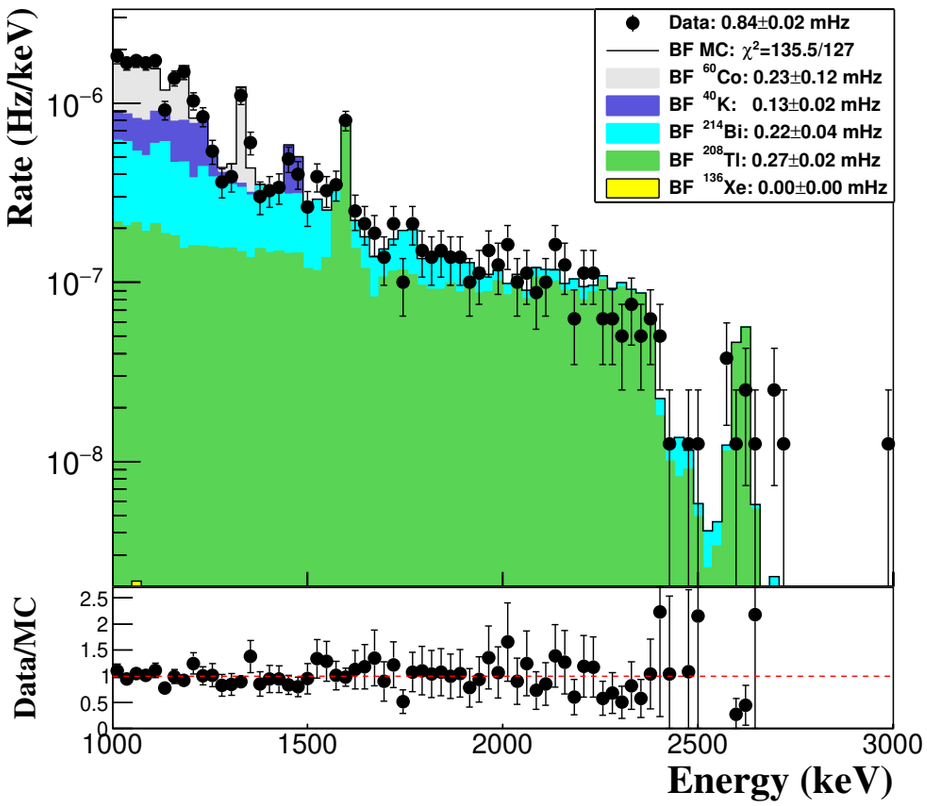


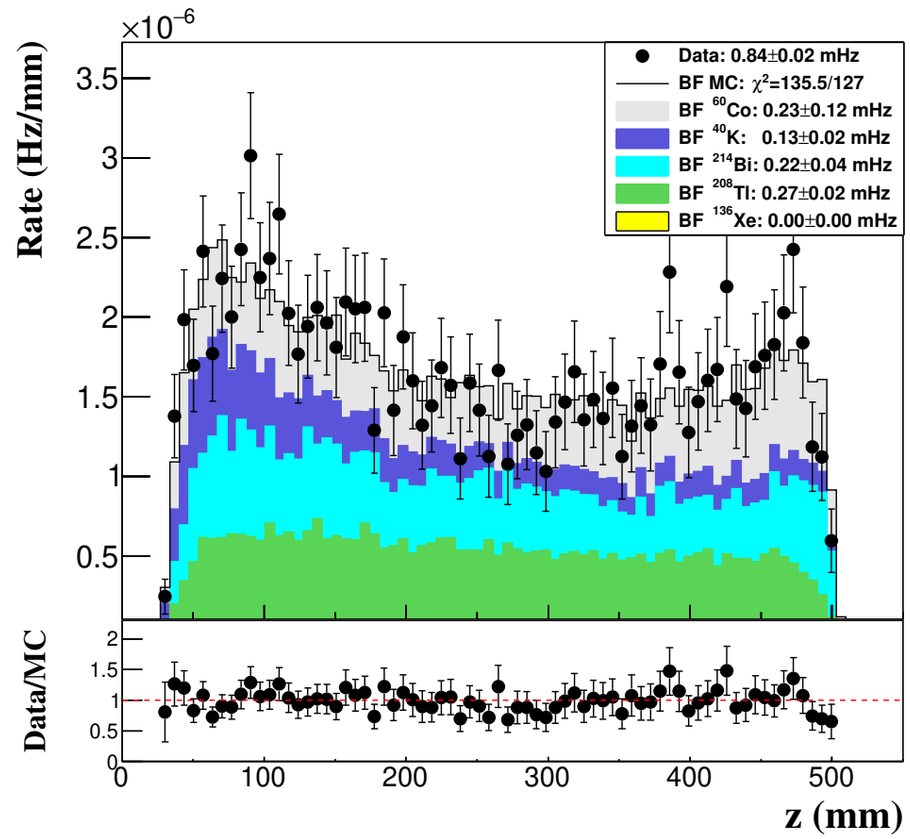
S/B at Qbb, DNN analysis



Run IV background model: tuning with data

- BG contributions per isotope/volume measured with a fit to the model.
- Signal + BG fit of energy and Z distributions. 4 isotopes x 3 volumes





- Background model validated: χ^2/ndof = 1.07, p-value = 29%
- Overall scale factor of 1.72 ± 0.04 to reproduce total BG rate
- In $Q_{\beta\beta}$±100 keV region and after topology cuts: 1 background event observed, (0.75±0.12) expected with 37.9 d exposure

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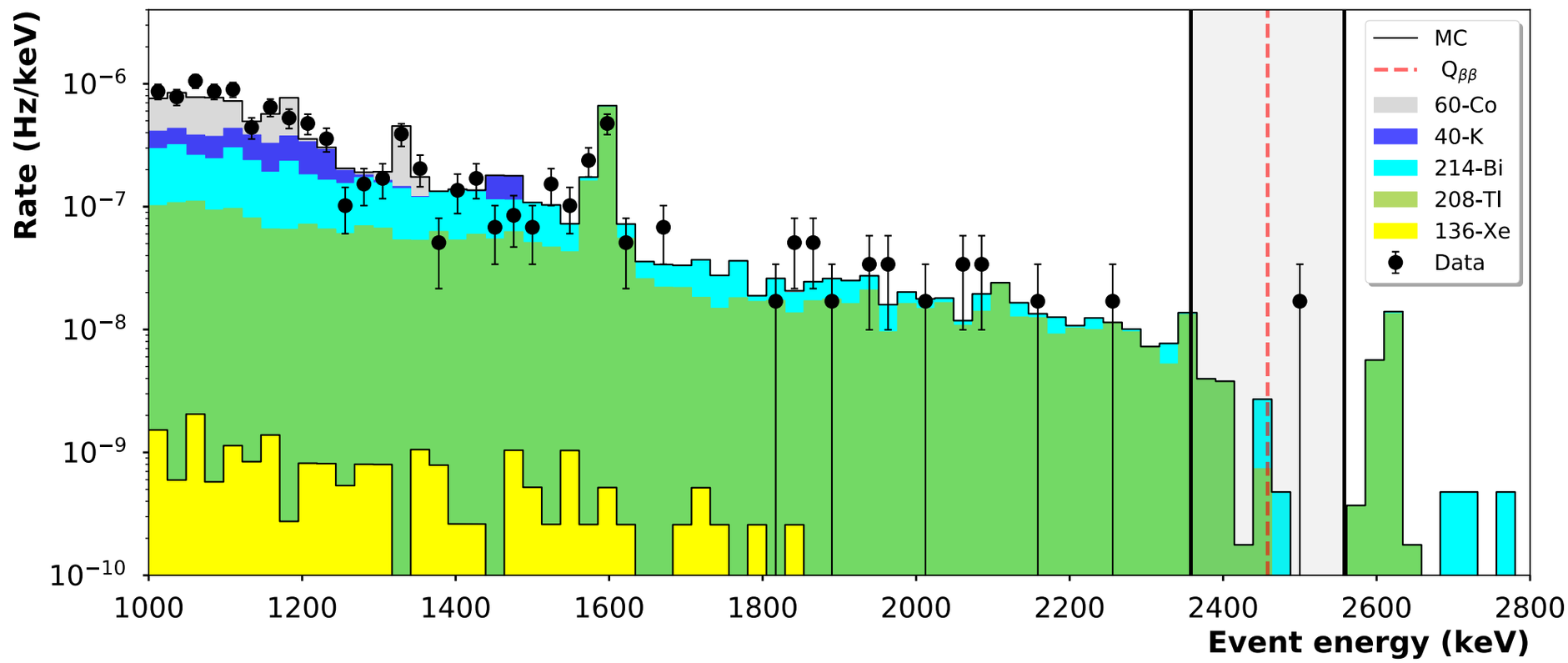
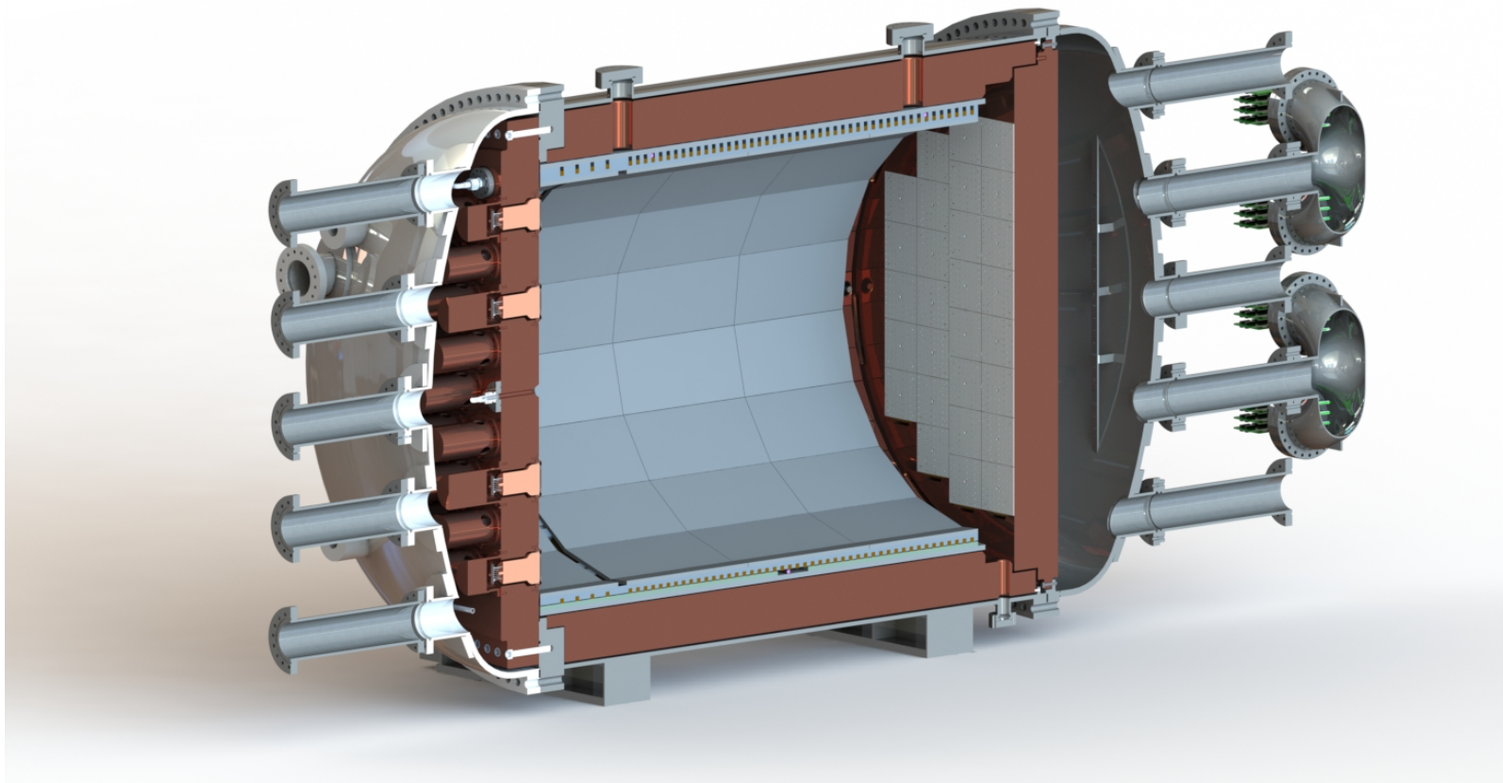


JHEP 1910 (2019) 051

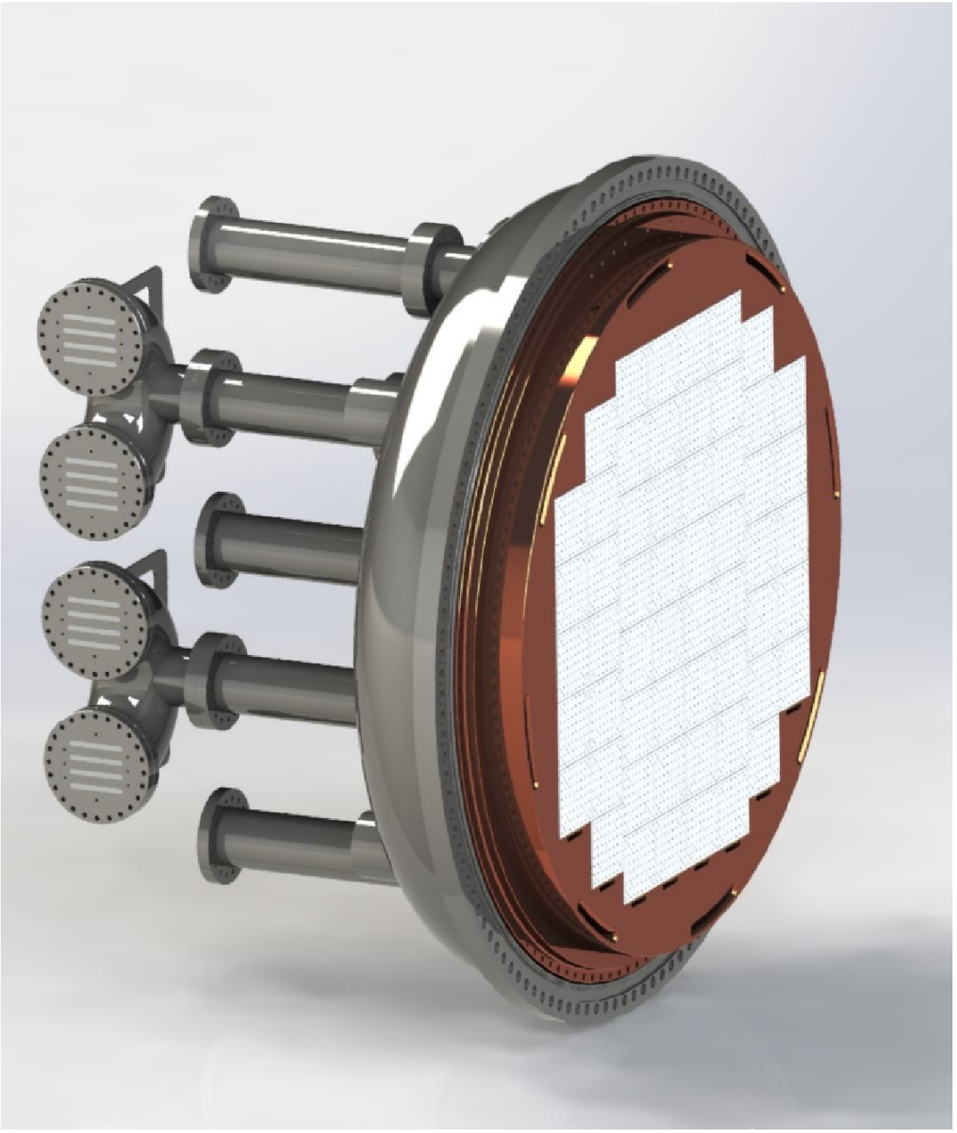
- Background model validated: χ^2/ndof = 1.07, p-value = 29%
- Overall scale factor of 1.72 ± 0.04 to reproduce total BG rate
- In $Q_{\beta\beta}$±100 keV region and after topology cuts: 1 background event observed, (0.75±0.12) expected with 37.9 d exposure

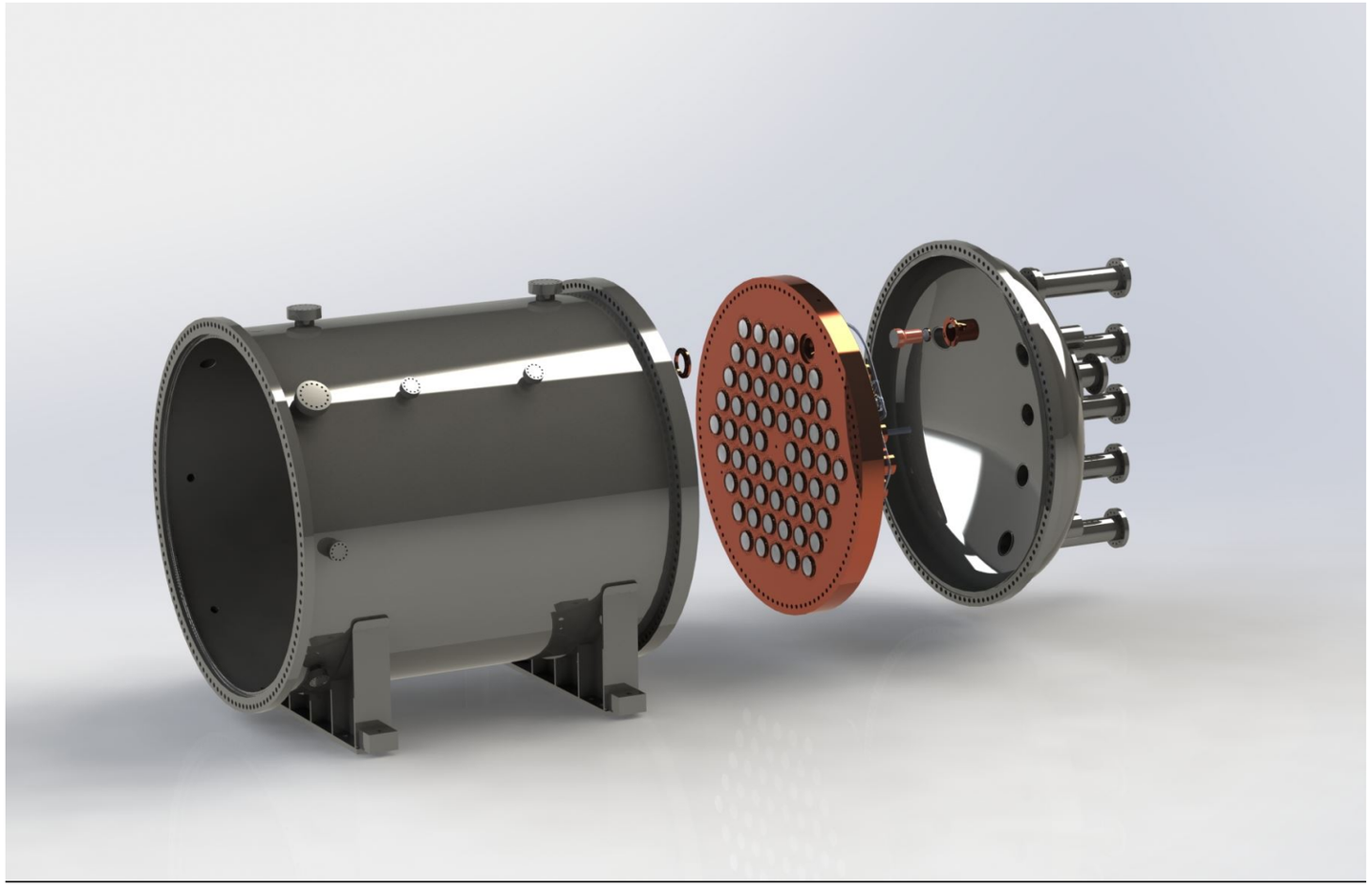
NEXT-100

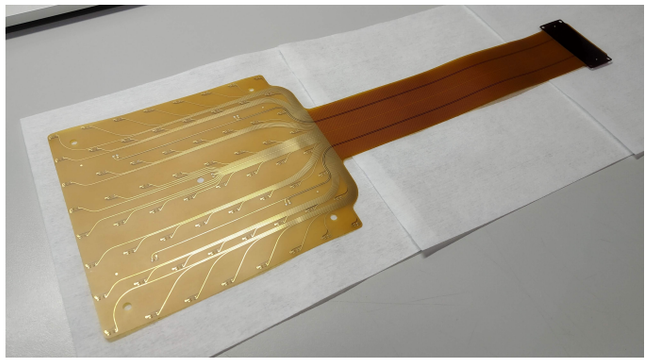


- 100 kg of enriched Xenon: Fiducial: 1.2 m long, 1 m diameter.
- Operates at 15 bar pressure.
- Schedule to start operations in 2020.

NEXT-100



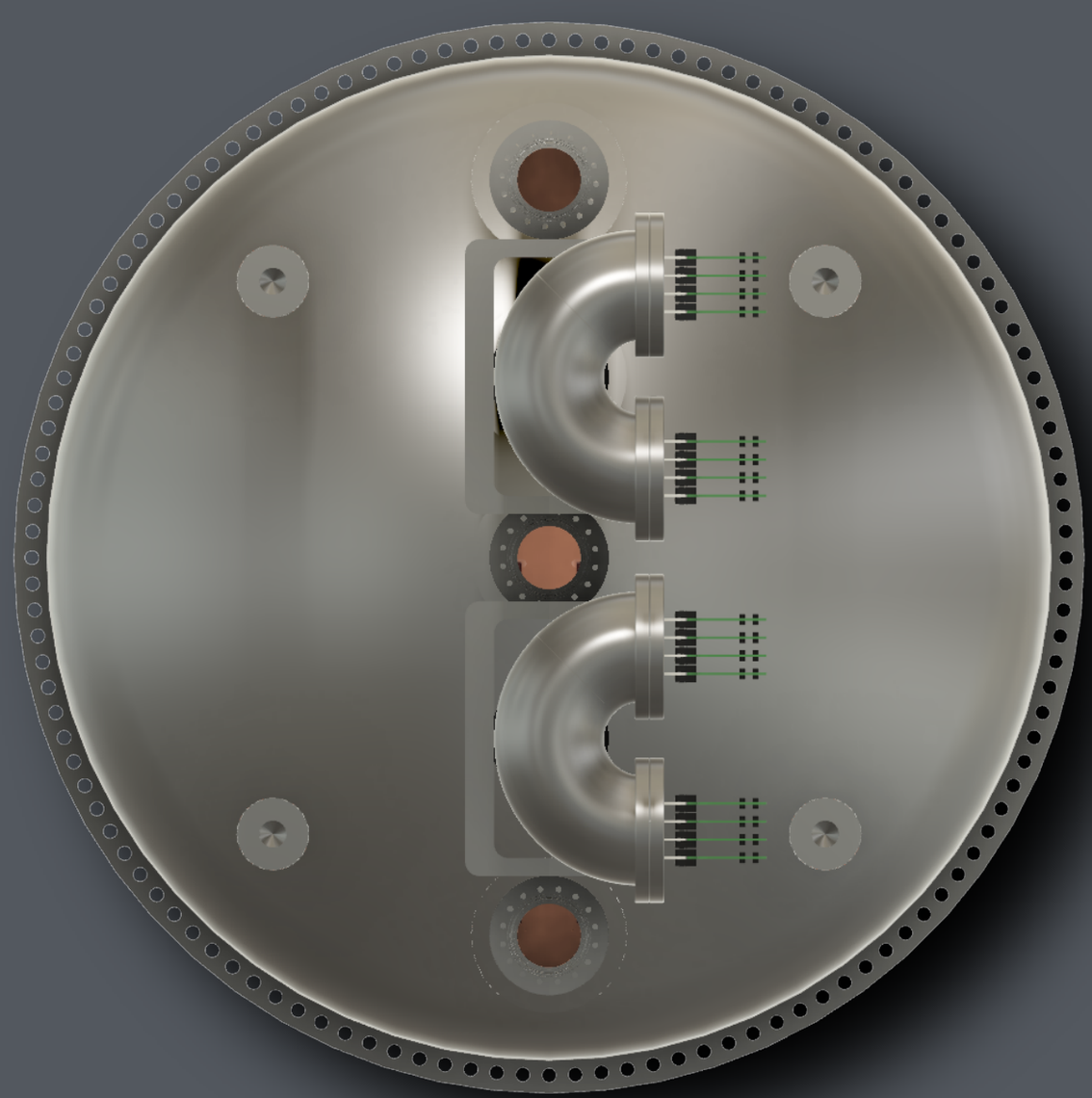


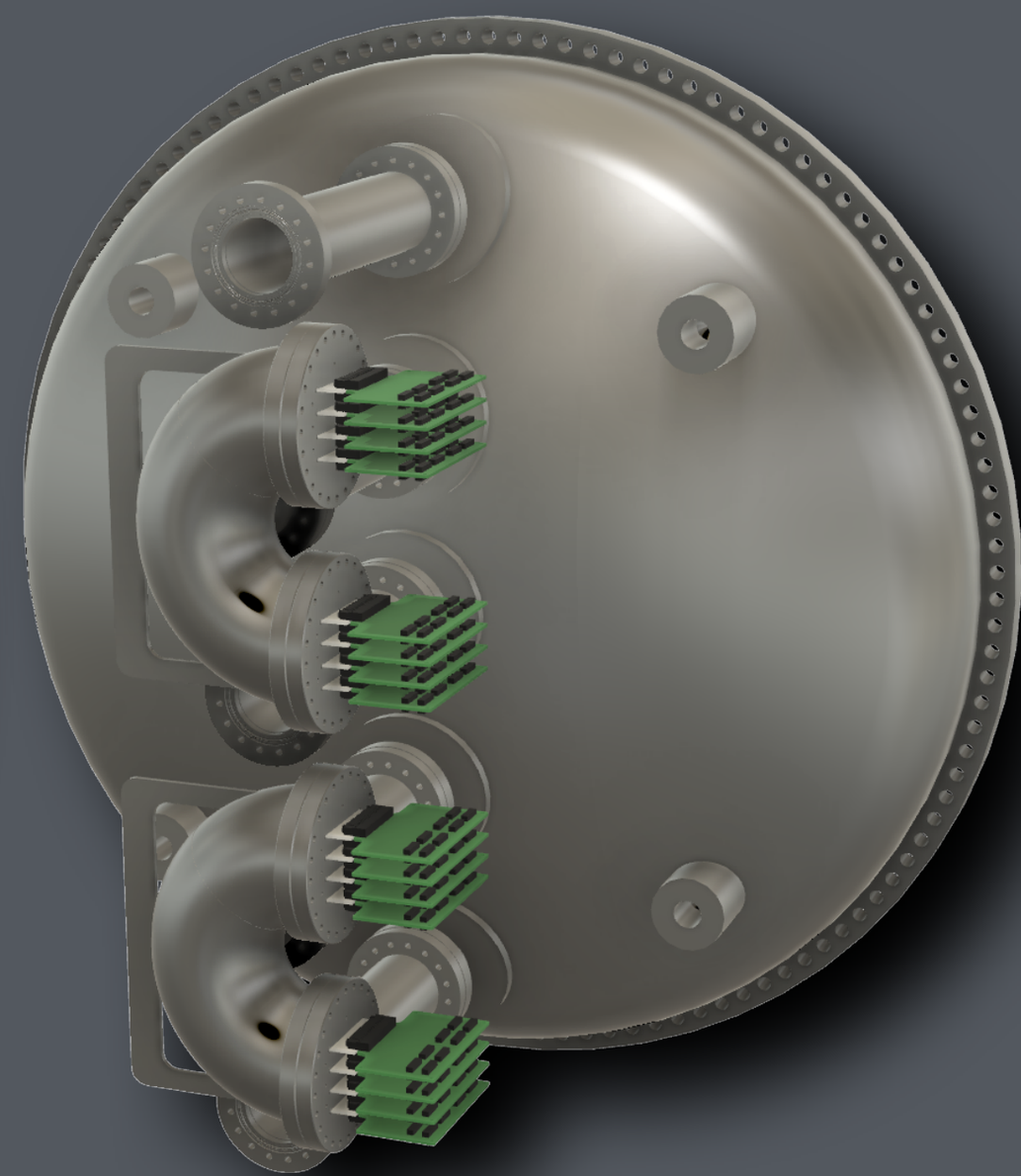


- 64 PMs, 5500 SiPMs.
- Improves radio purity of SiPM boards w.r.t. Next-White
- Schedule to start operations in 2020.

NEXT-100 TP

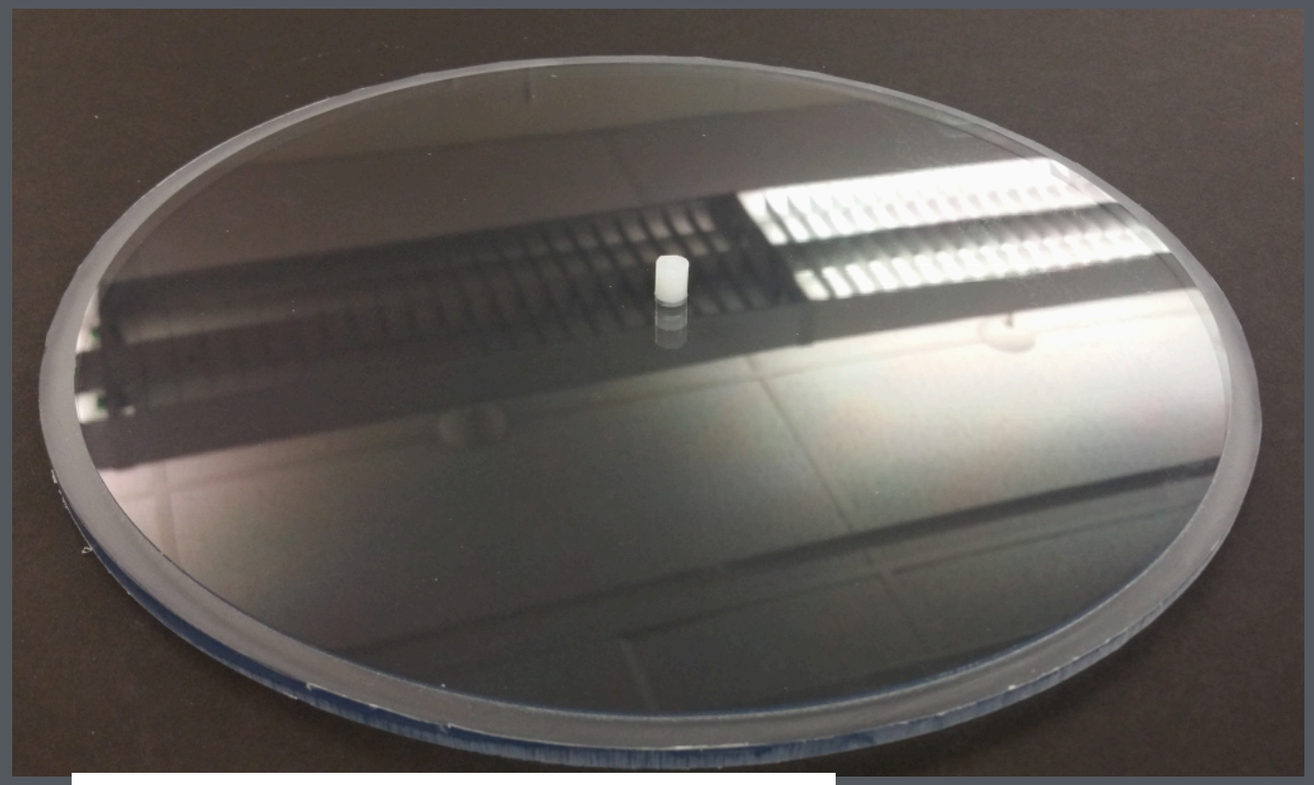
Potted Perpendicular Feedthrough

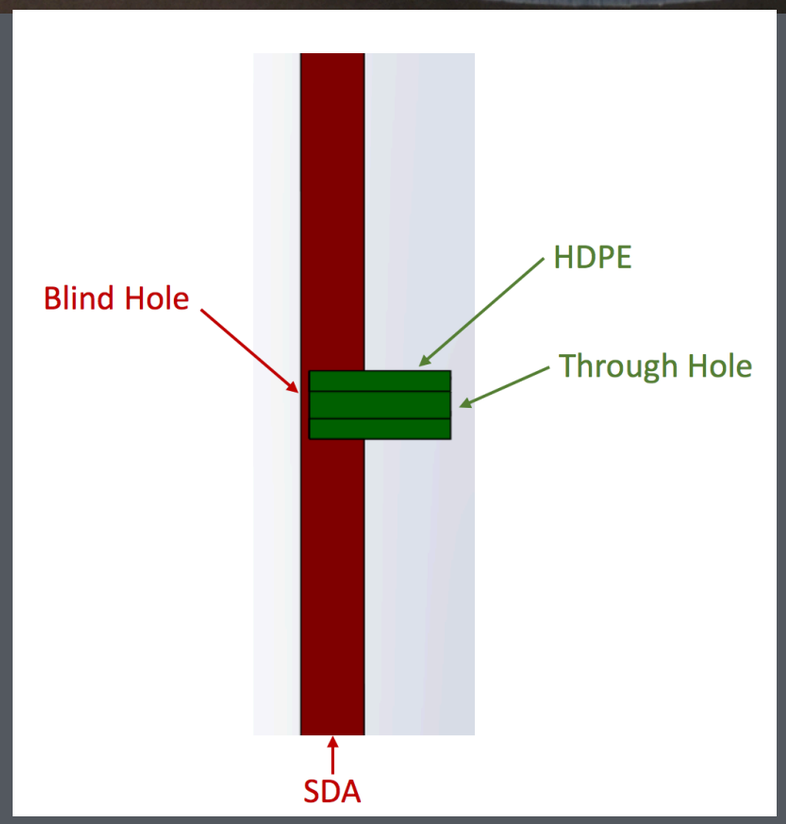


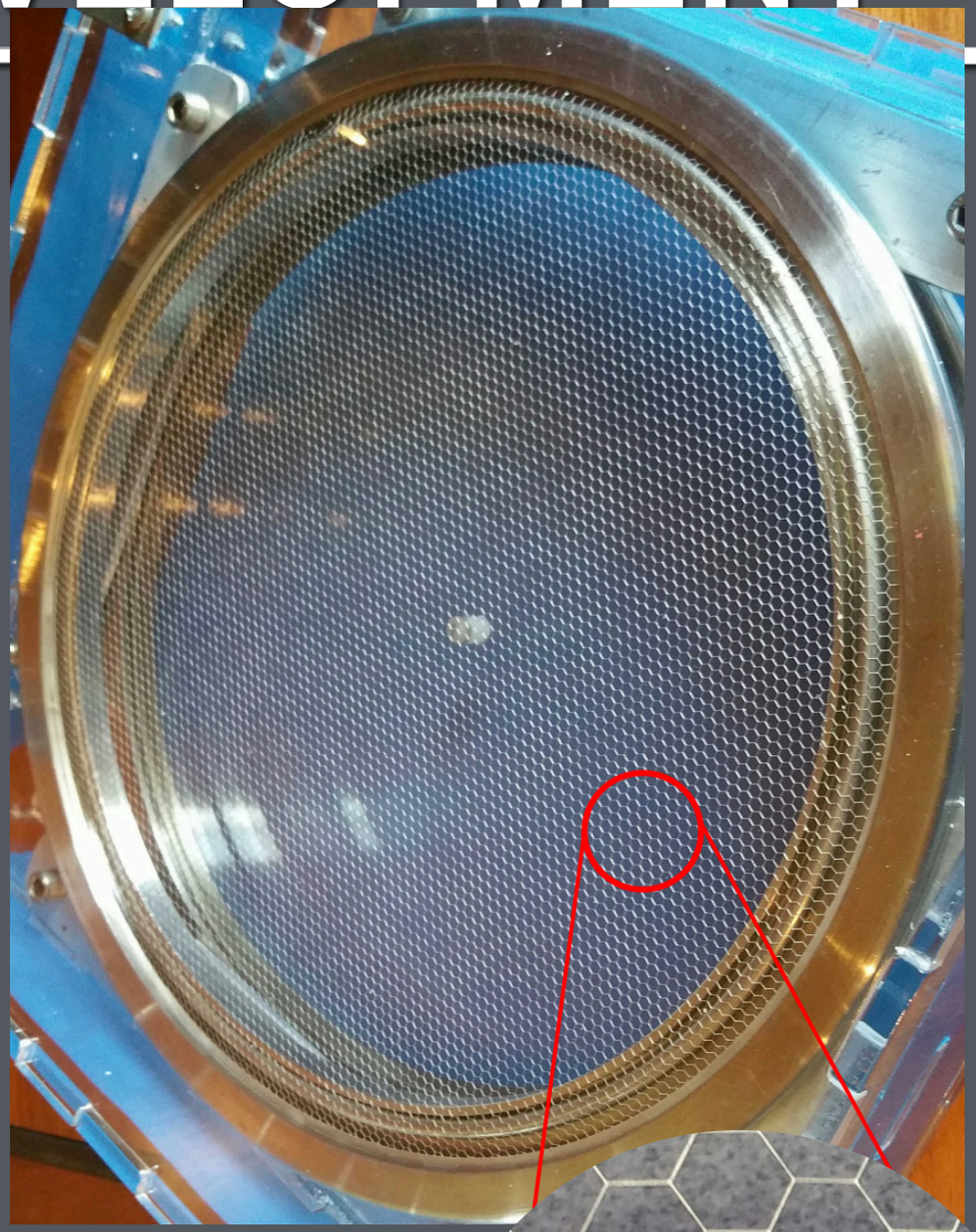


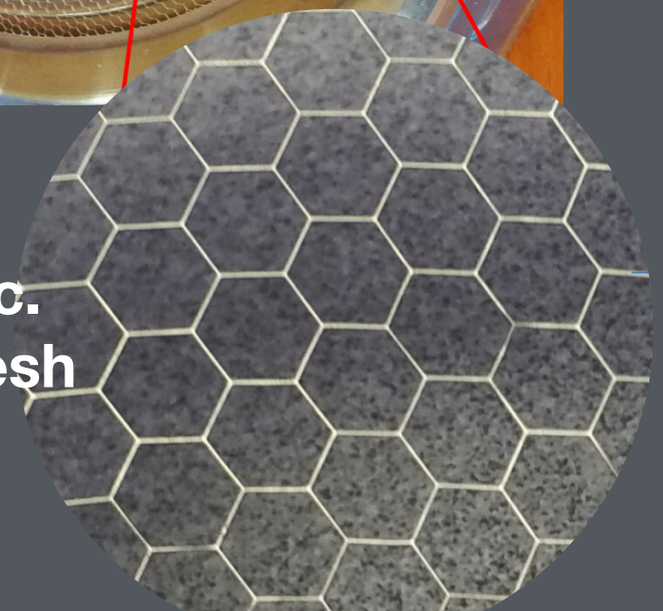
Using 2 ports we can extract all TP signals.
Each flange has 4 boards with 4 DICE-Board's signals each.

NEXT-100 EL DEVELOPMENT







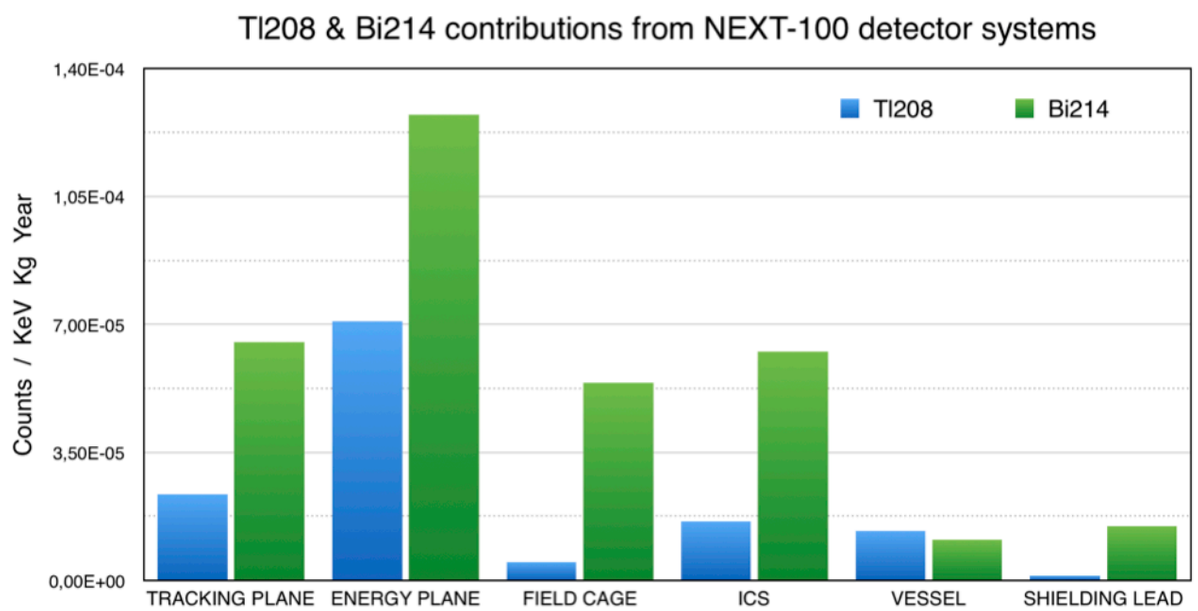


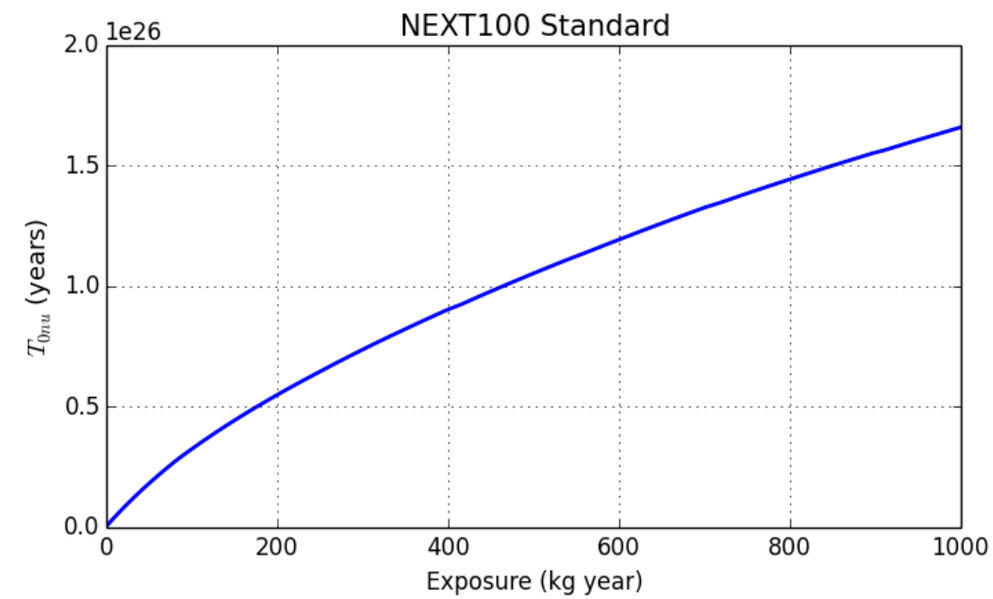
Anode made with resistive acrylic.
Gate made with electroformed mesh

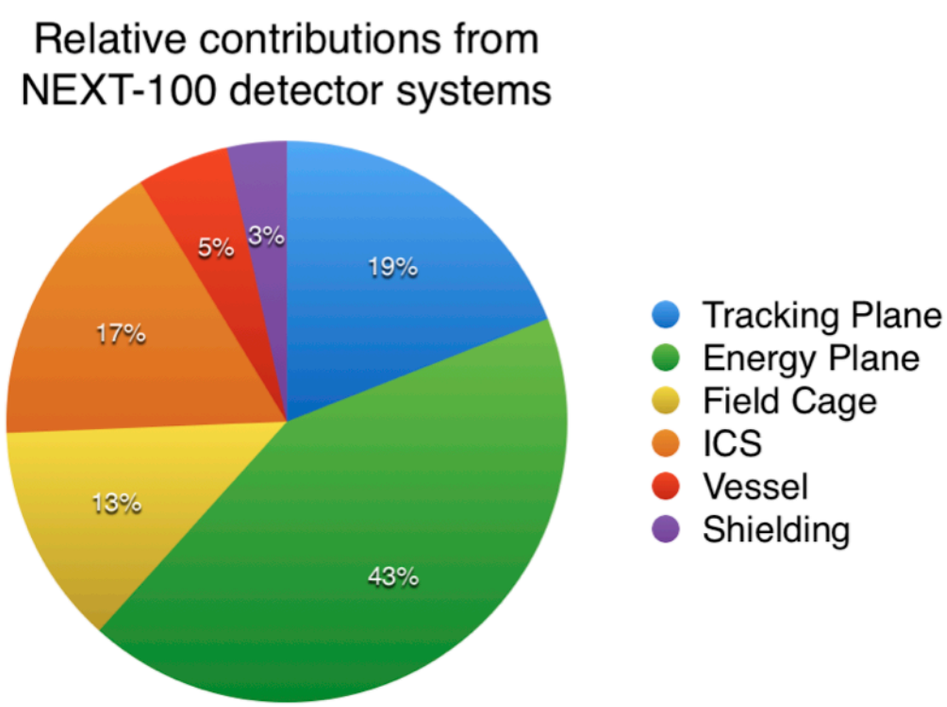
NEXT-100 Background model

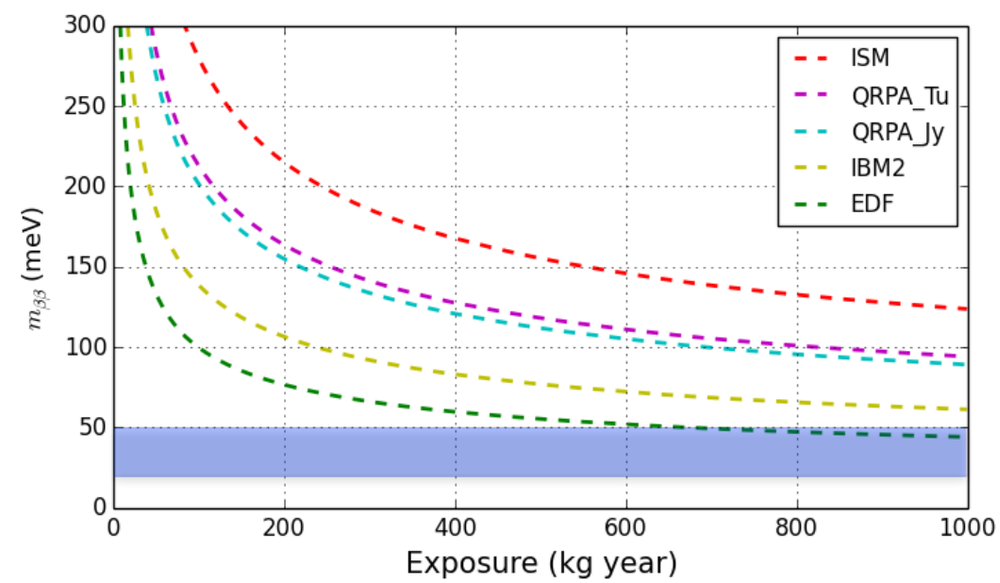
JHEP 1605 (2016) 159
e-Print: arXiv:1511.092

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

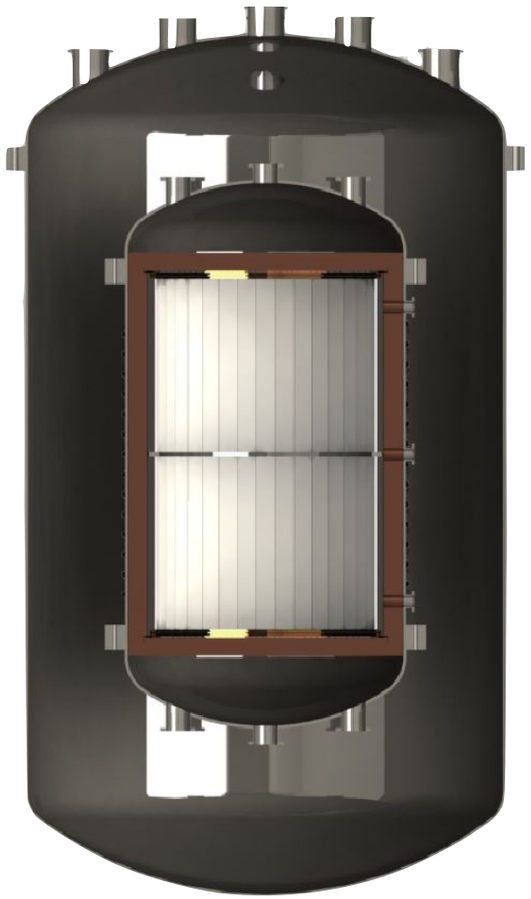


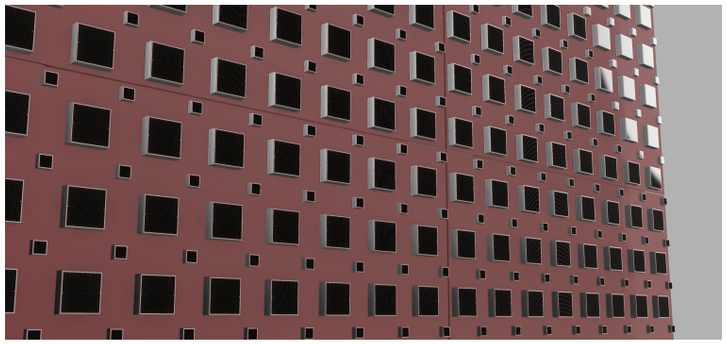




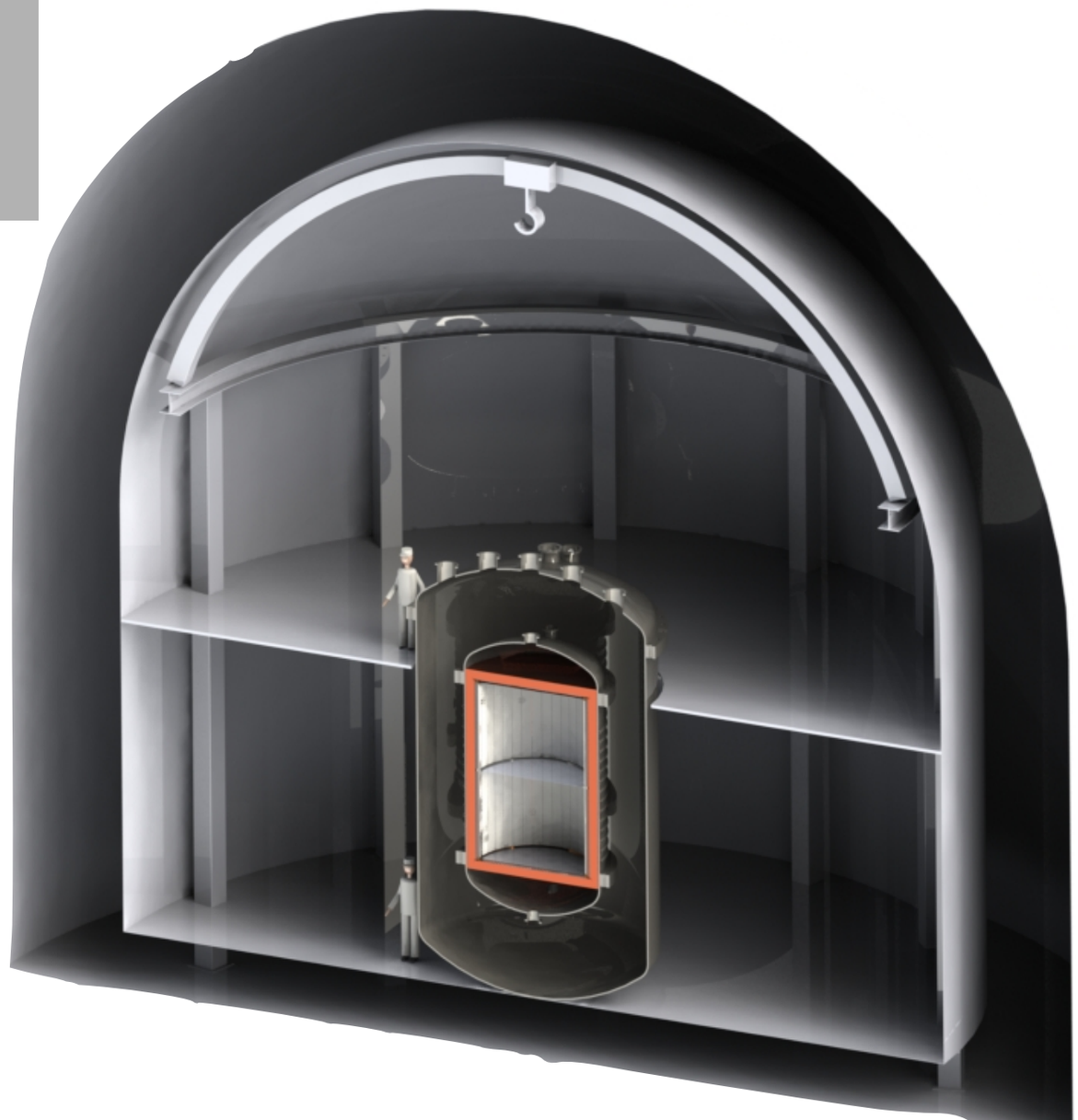


The NEXT incremental approach: NEXT-HD





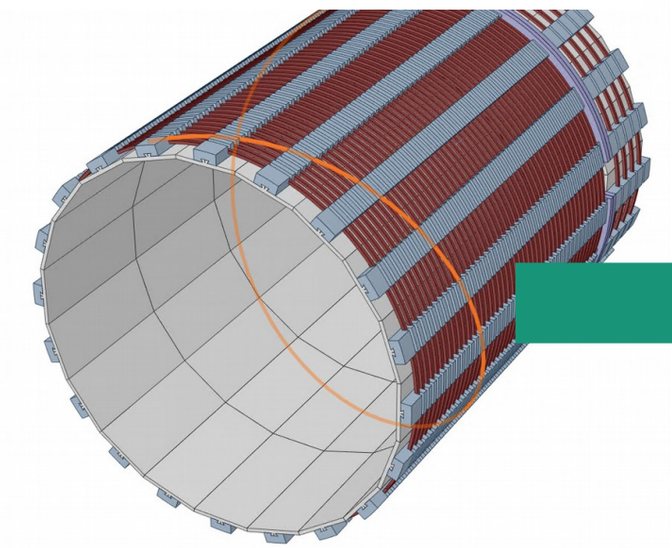
Symmetric detector:
Two sizes of SiPMs in the same plane, need to develop or borrow new integrated electronics.

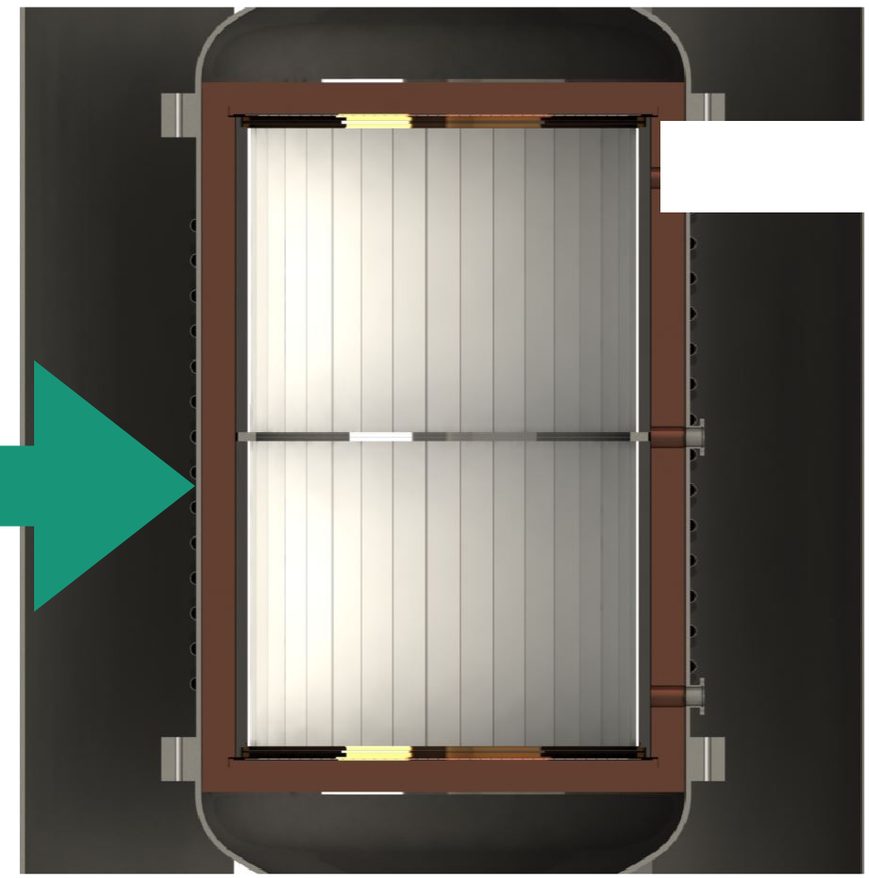


Operation with cold Xenon:
We need to reduce SiPM dark current

The NEXT incremental approach: NEXT-HD

Extrapolation of the current NEXT-100 concept

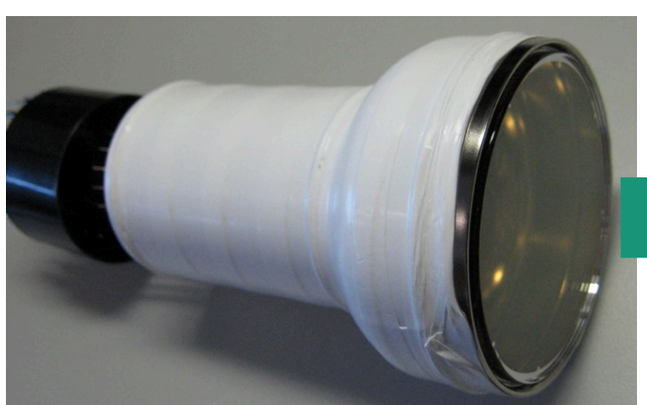


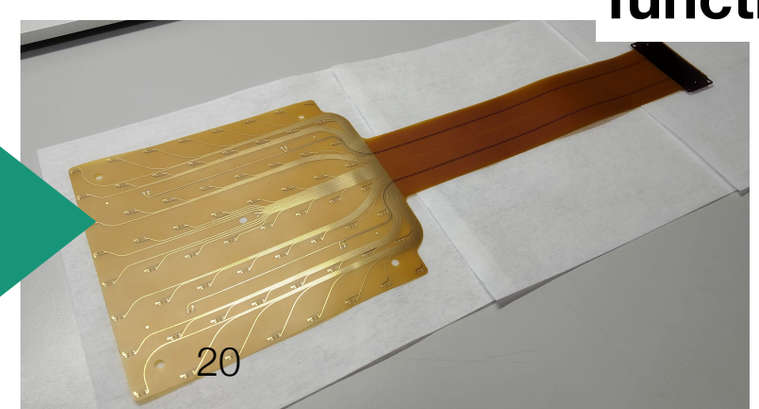


Symmetric TPC

Reduced radioactive budget by replacing the PMTs with SiPM.

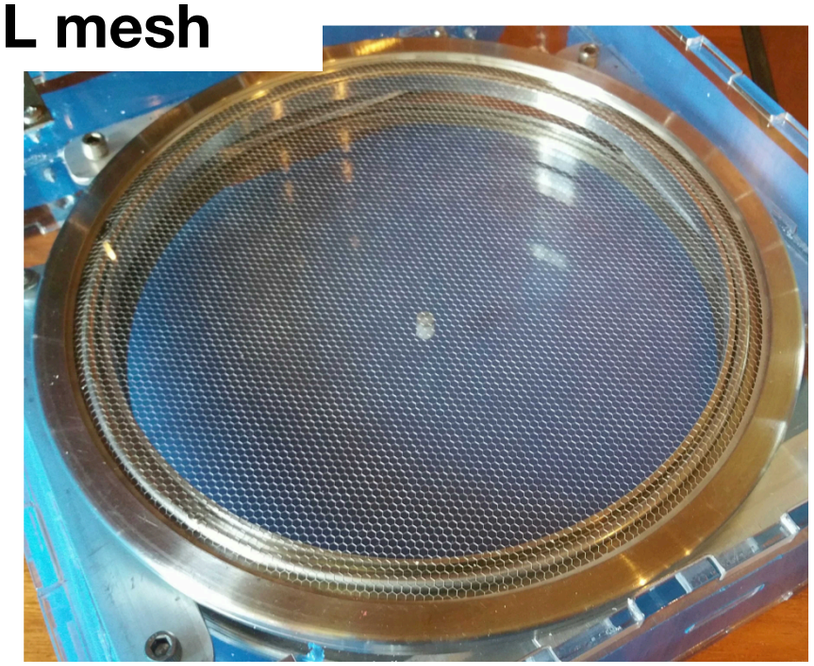
Energy and tracking functions remain independent



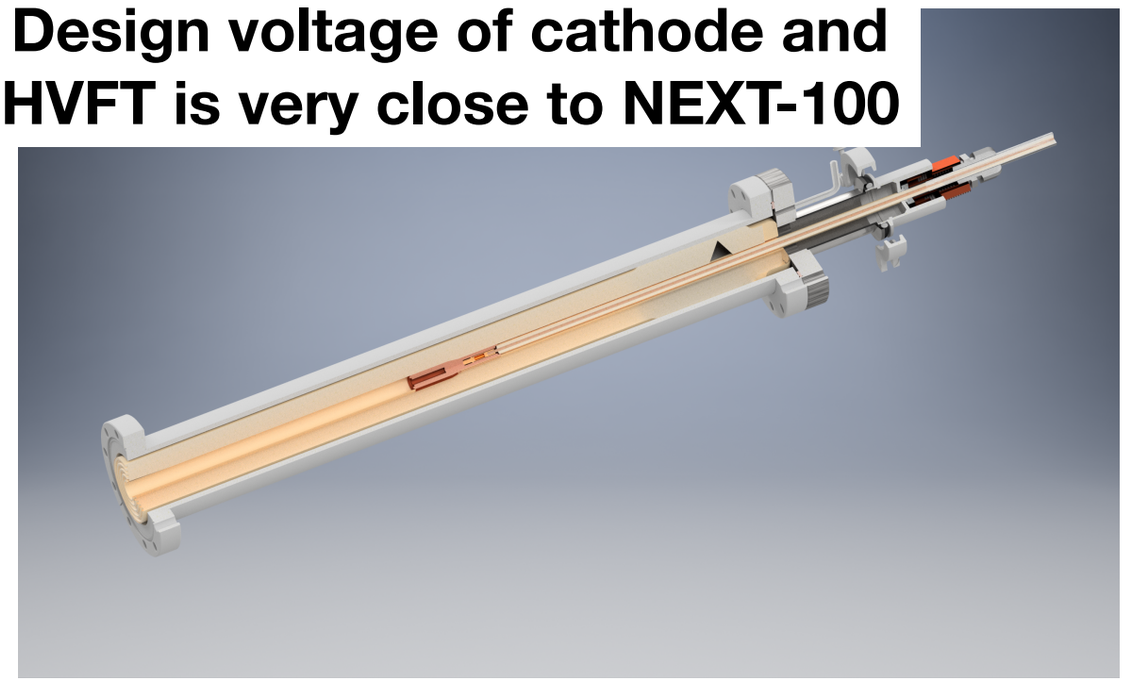


Solutions to be implemented in NEXT-HD

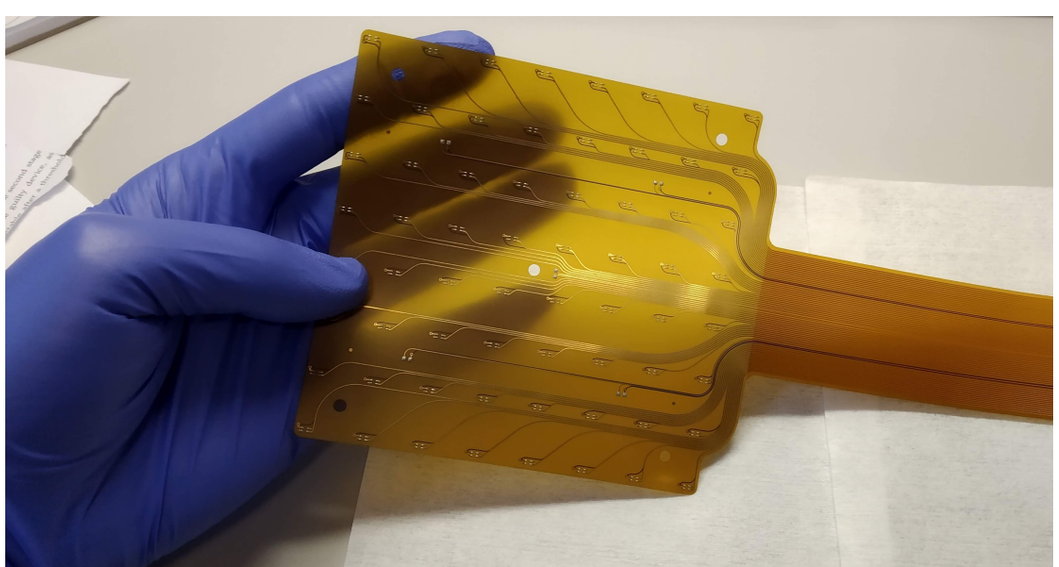
EL mesh

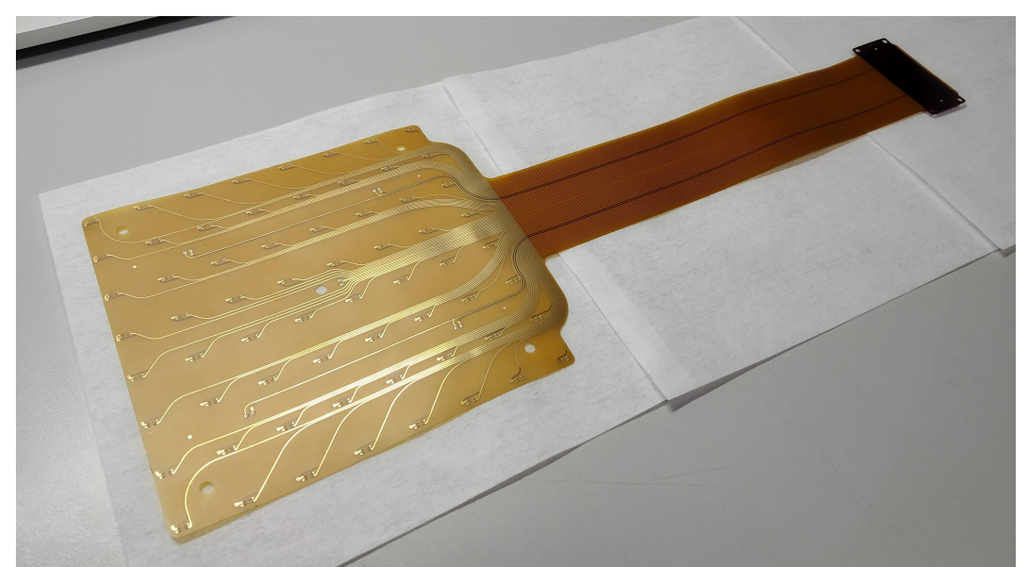


Design voltage of cathode and HVFT is very close to NEXT-100



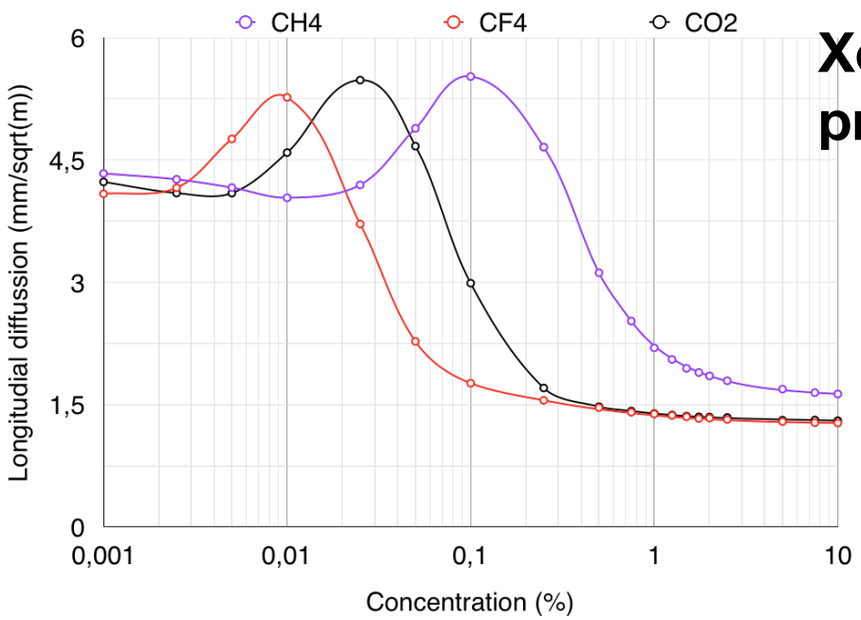
SiPM radio-pure substrates already in hand.





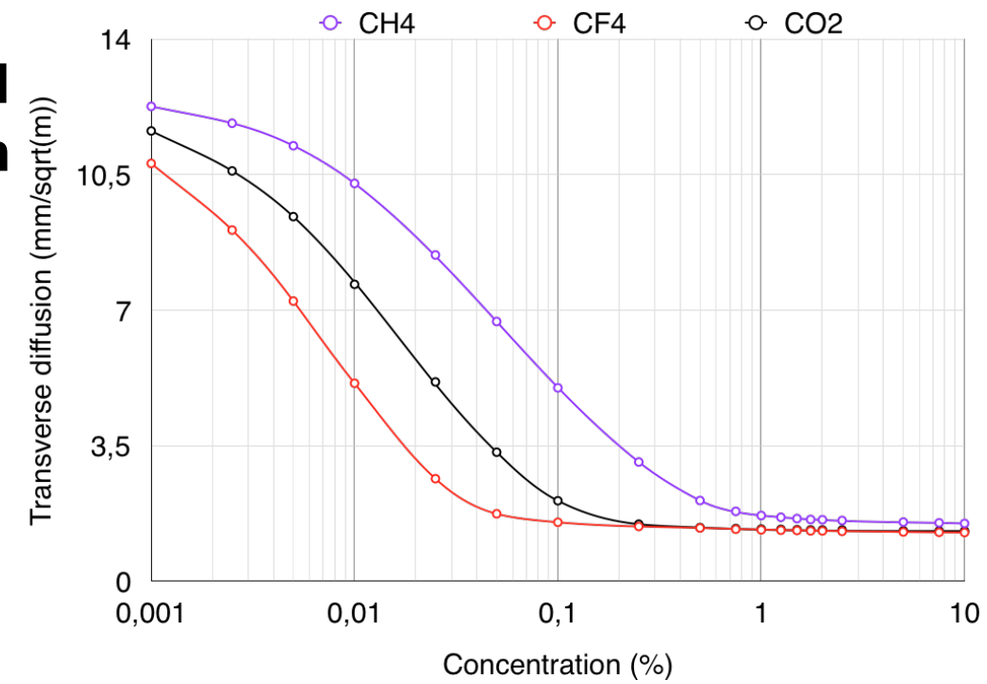
Current R&D: Gas mixtures

2016 JINST 11 C02007

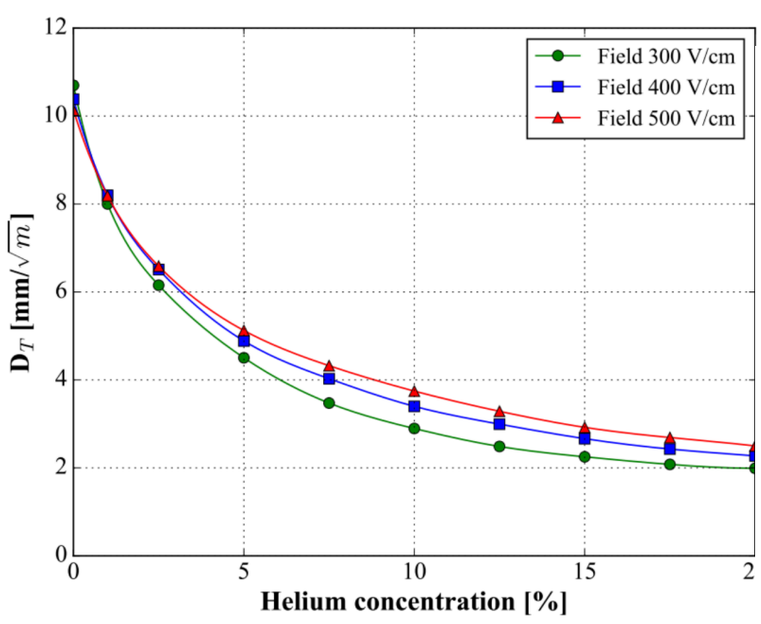


Xenon-CH4 mixtures could provide very small electron diffusion

At low concentrations (<1%) resolution is maintained

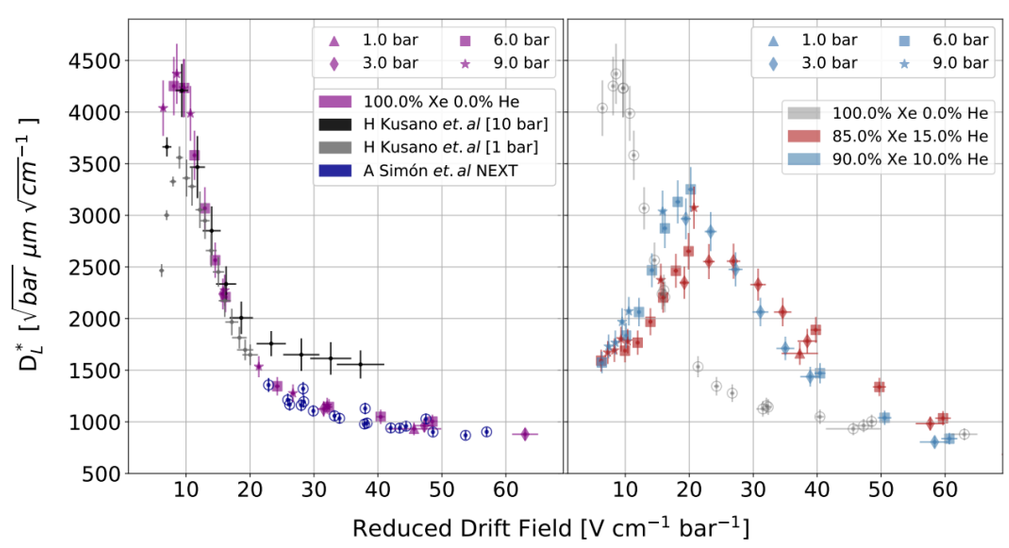


Xenon-Helium mixtures have a similar effect on diffusion but for a larger He concentrations.

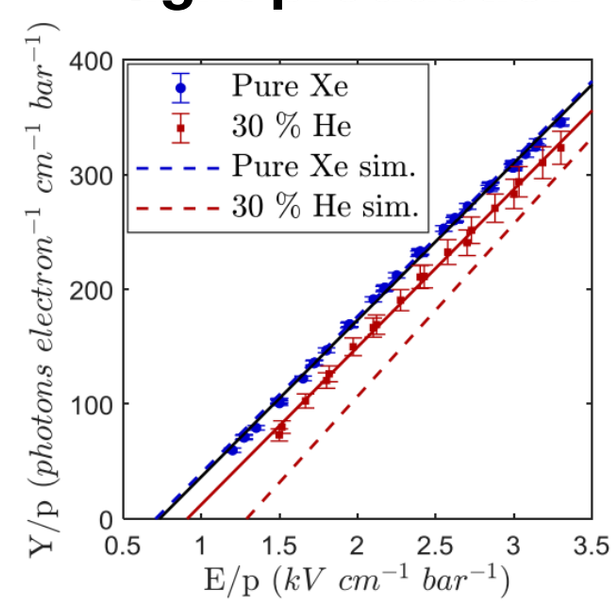


Nucl.Instrum.Meth. A905 (2018) 82-90.

JINST 14 (2019) no.08, P08009

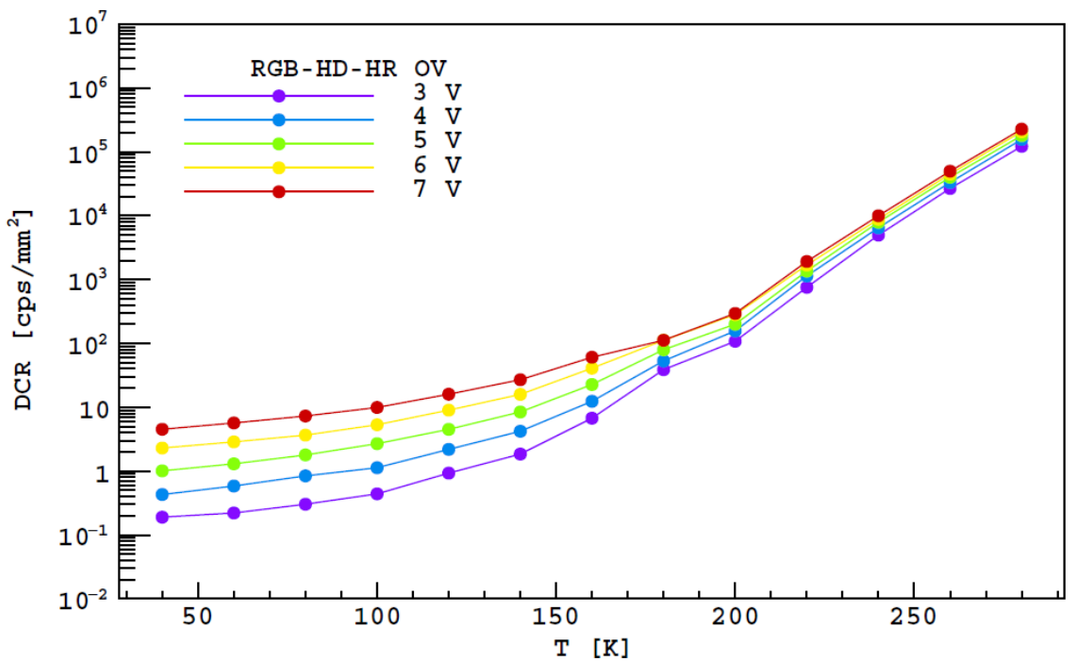


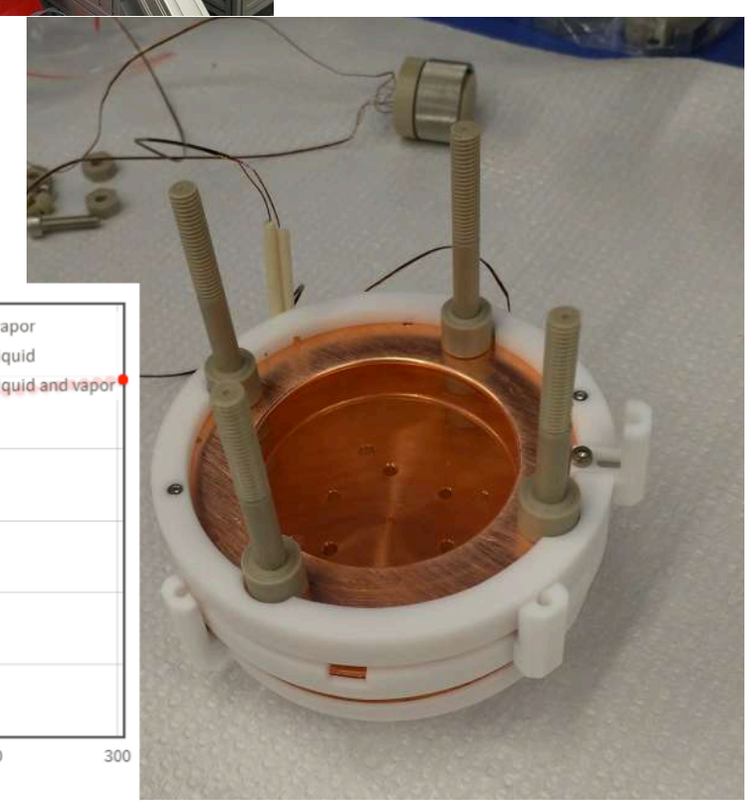
Much smaller effect on light production



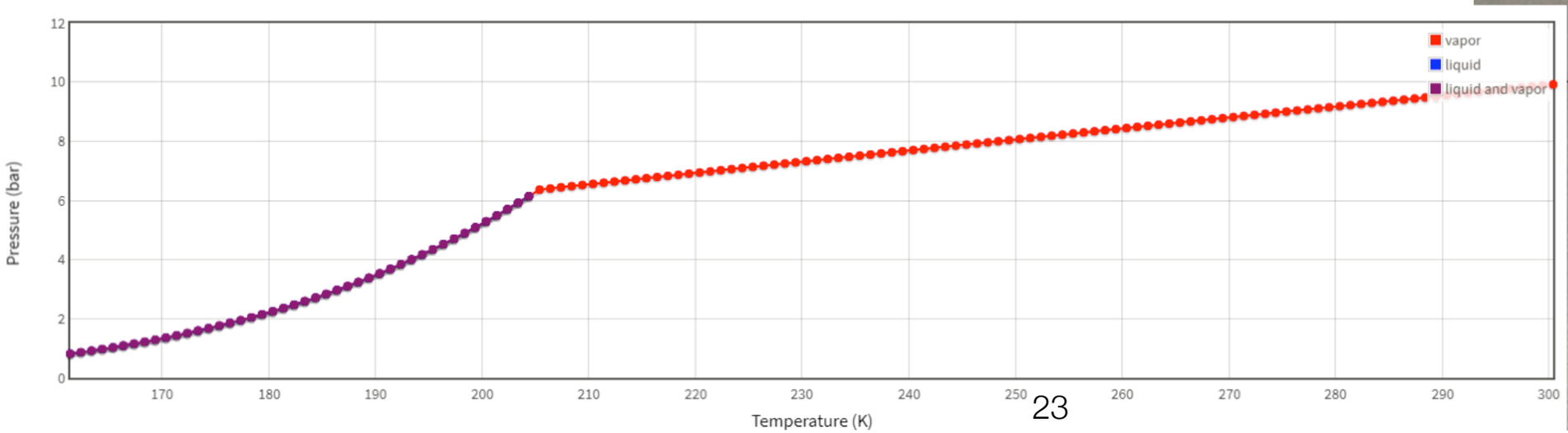
Current R&D: Cold Xenon

Cool gas to reduce DCR in SiPMs.



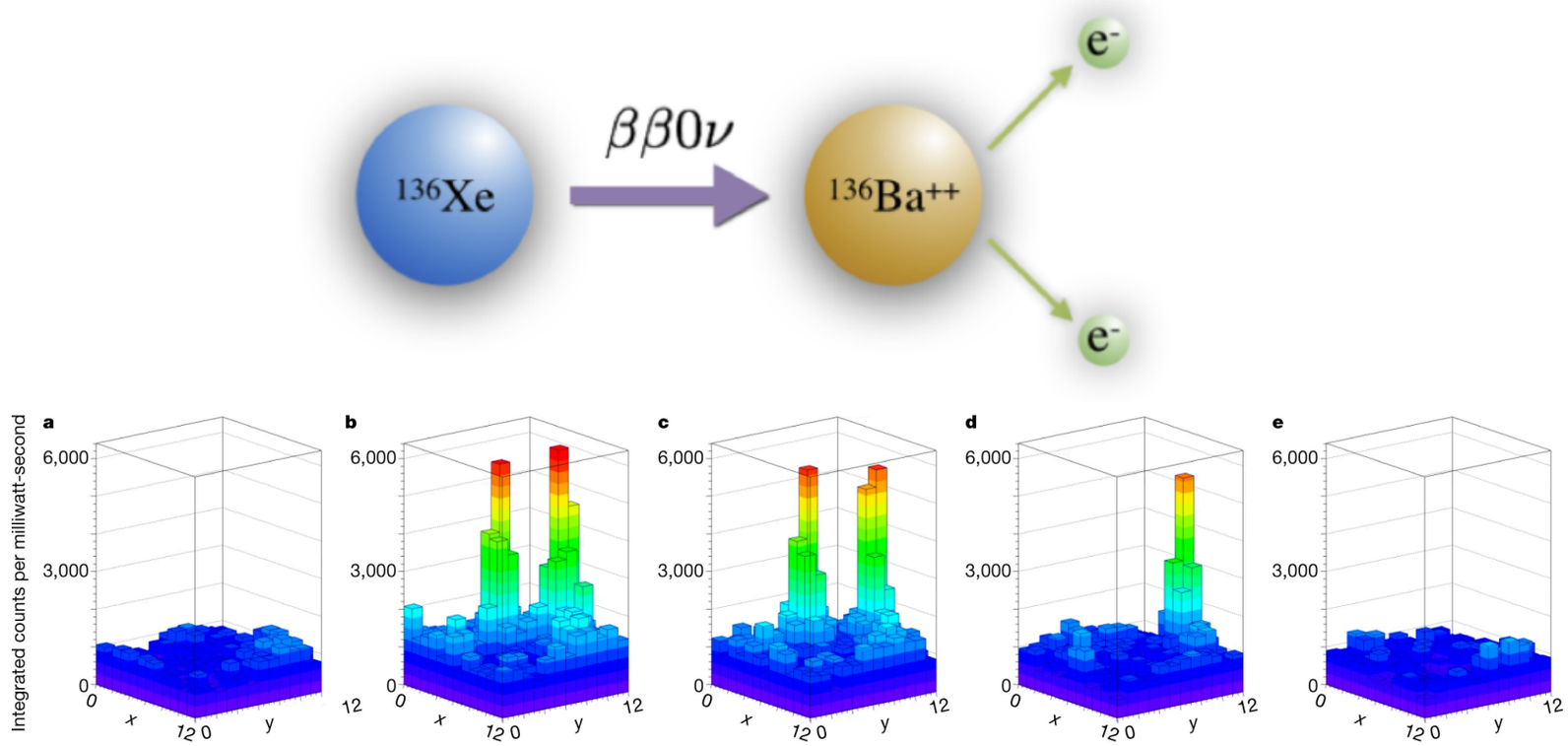


We still want to operate in the gas phase, and we have a large phase space for that!



NEXT-BOLD

Detecting "tagging" the Ba++ signaling a ββ0ν process has been a long sought holy grail of xenon chambers.

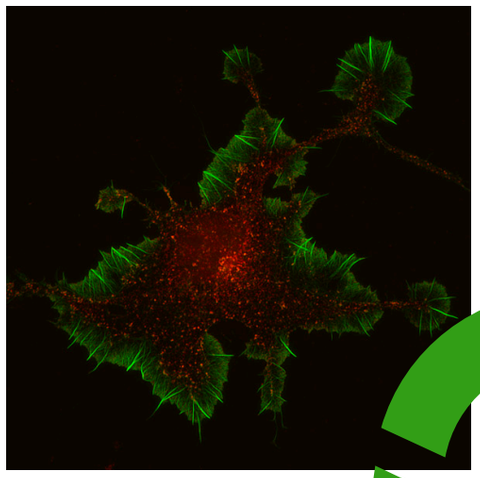


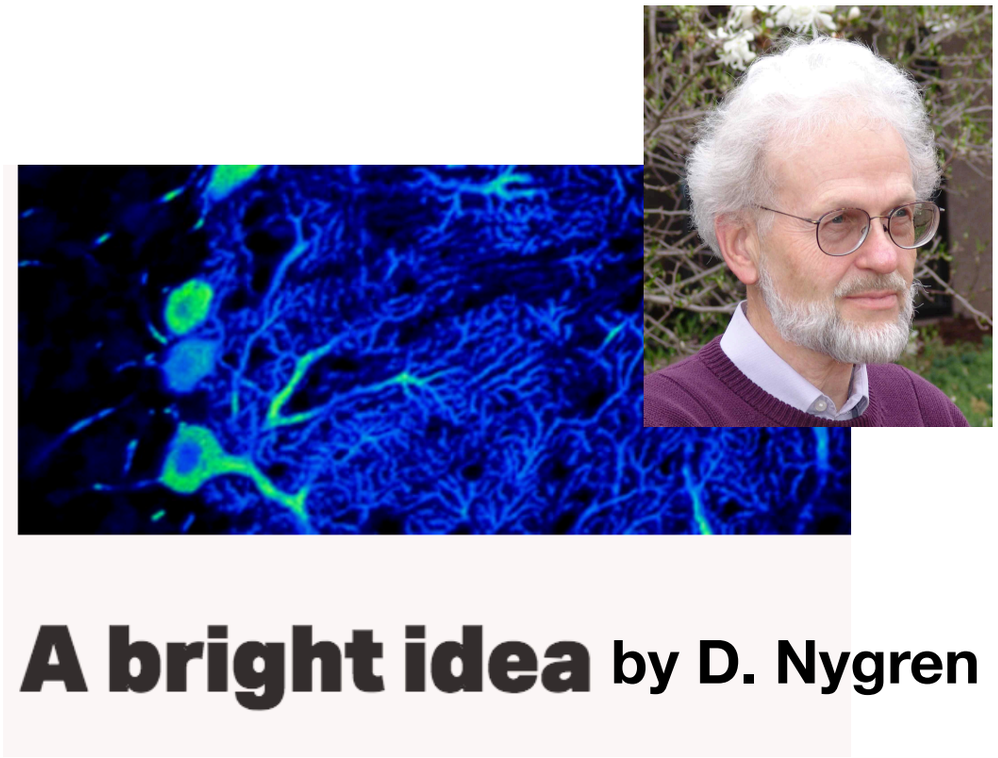
Barium identification in solid Xenon.

*Nature volume **569**, pages 203–207 (2019)*

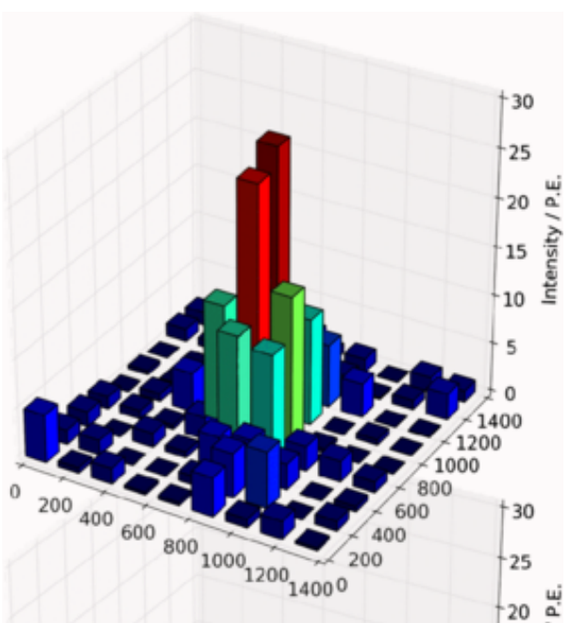
Single Molecule Imaging comes back to physics!

Noble prize in Chemistry 2014:
Development of super-resolved fluorescence microscopy





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

Phys. Rev. Lett. **120**, 132504

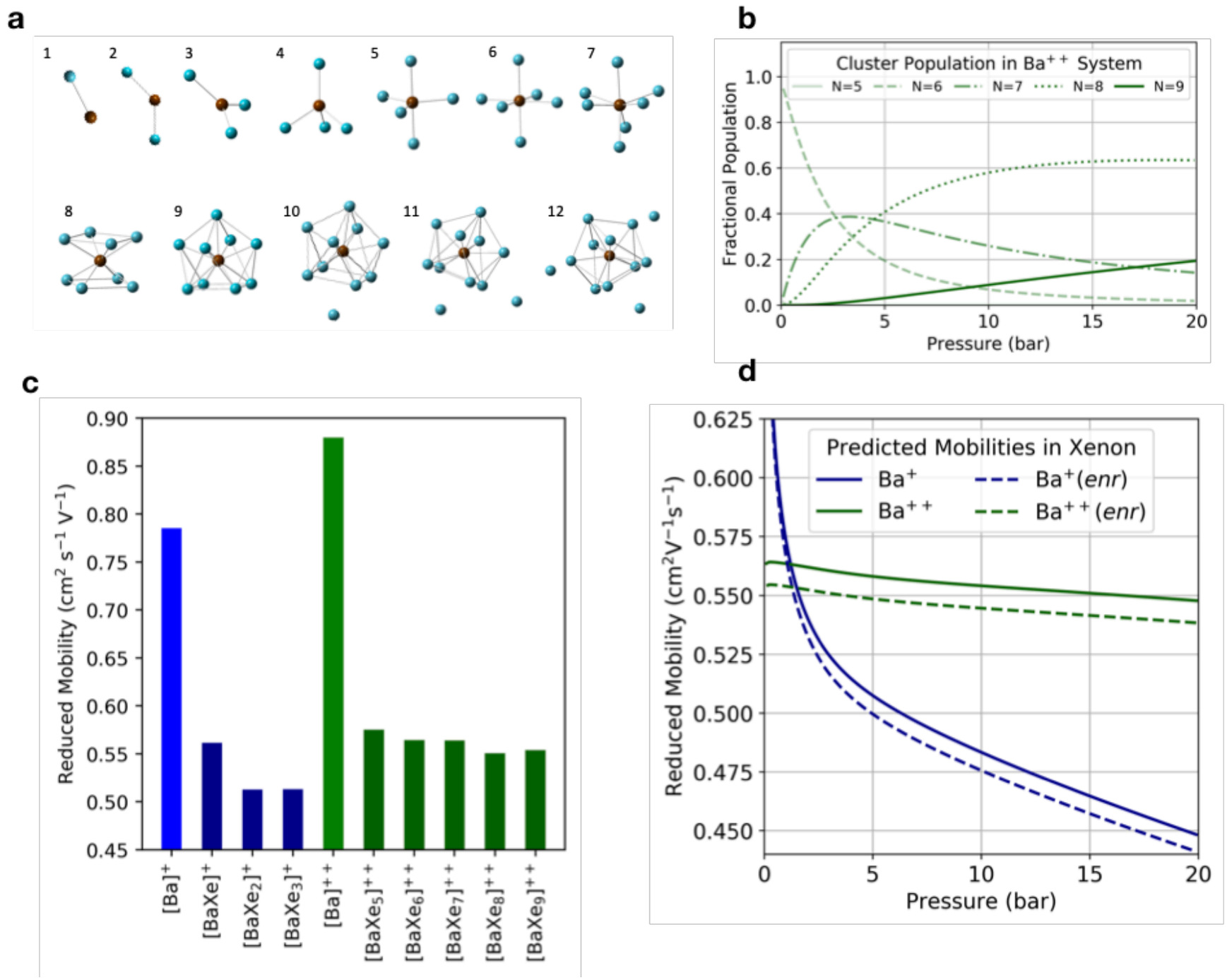
Biochemistry (NEXT proof of concept)	Physics (Detection of Ba^{++} in NEXT)
Wet medium (water)	Dry medium (xenon gas)
Indicators fluoresce in solution	Indicators fluoresce in interface between solid substrate and xenon gas
Efficiency of per-ion capture not quantified	Dense target to maximise Ba^{++} capture (10^4-10^6 molecules per micron)
Sparse but irregular target. Small but unpredictable background	Very high efficiency of ion detection required
Large NA, TIRF possible (immersion oil techniques)	No oil allowed. Solid immersion possible but difficult. Large NA feasible but challenging.
Conventional objectives	Pressure resistant objectives.
Selectivity not a concern due to controllable barium concentration	Selectivity against background ions (e.g. Xe+) required
Small detection area (~mm^2)	Large detection area (m^2)

Ba2+ road map and R&D

- Measure transport efficiency of Ba2+ in high pressure gas
- Molecular target: Preparing proof-of-concept experiments to demonstrate/measure ion capture by molecular sensor.
- Ion transport to the sensor: RF carpets, molecular sensor array.
- Target density
- Optical laser scanning techniques

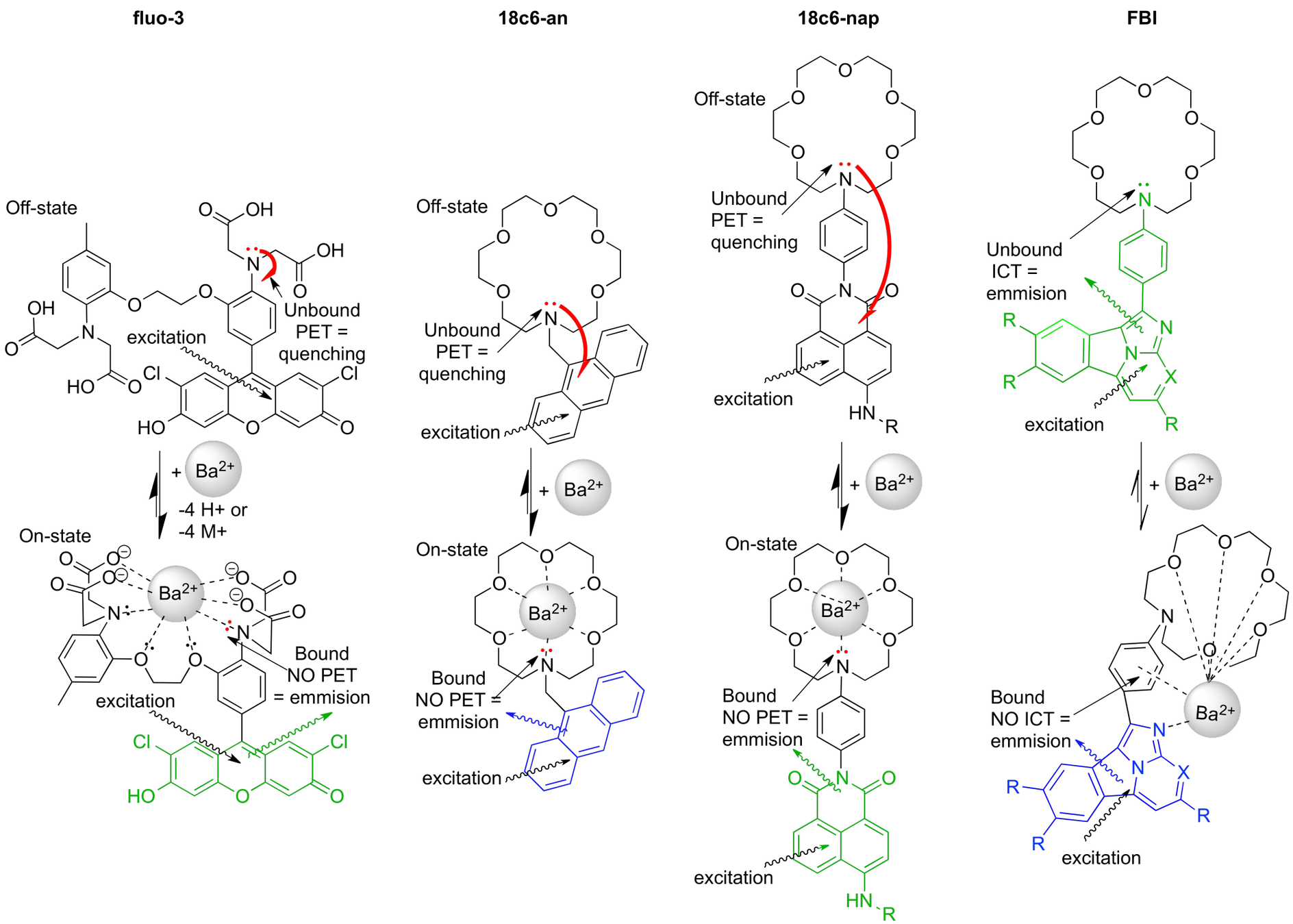
Solvation states

Phys.Rev. A97 (2018) no.6, 062509
arXiv:1804.01169

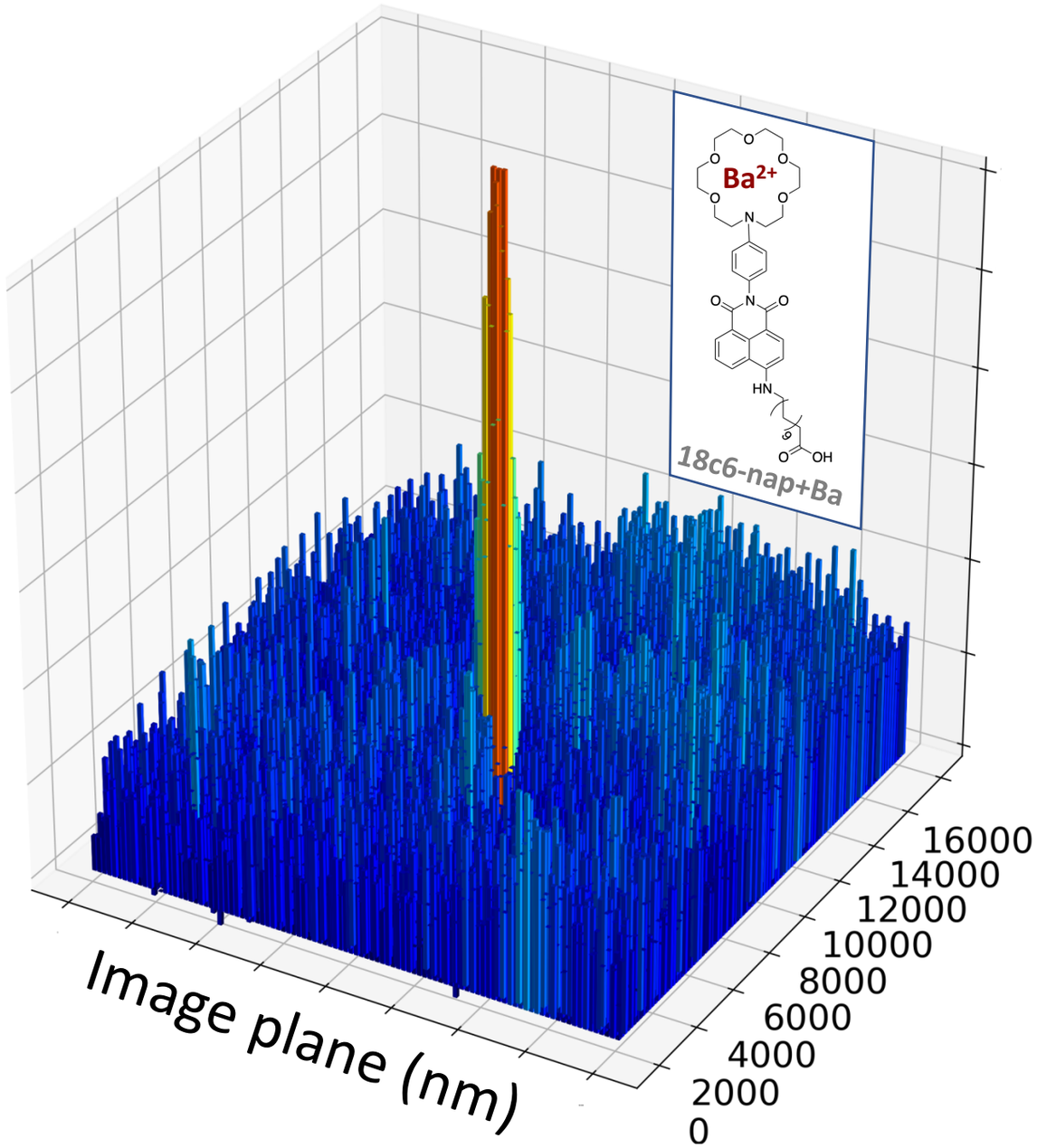


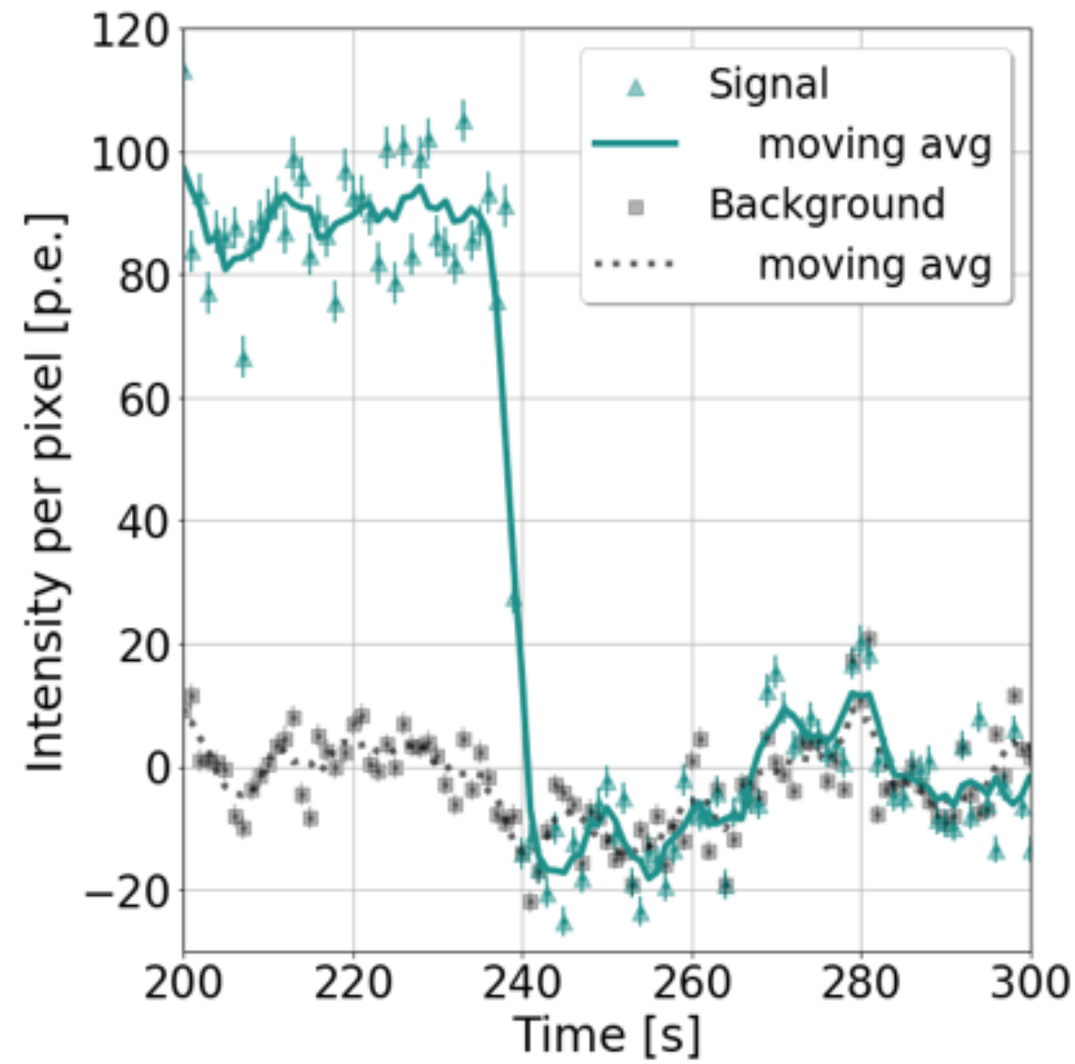
Transfer of Ba2+ to molecule entropically favourable

Dry molecules



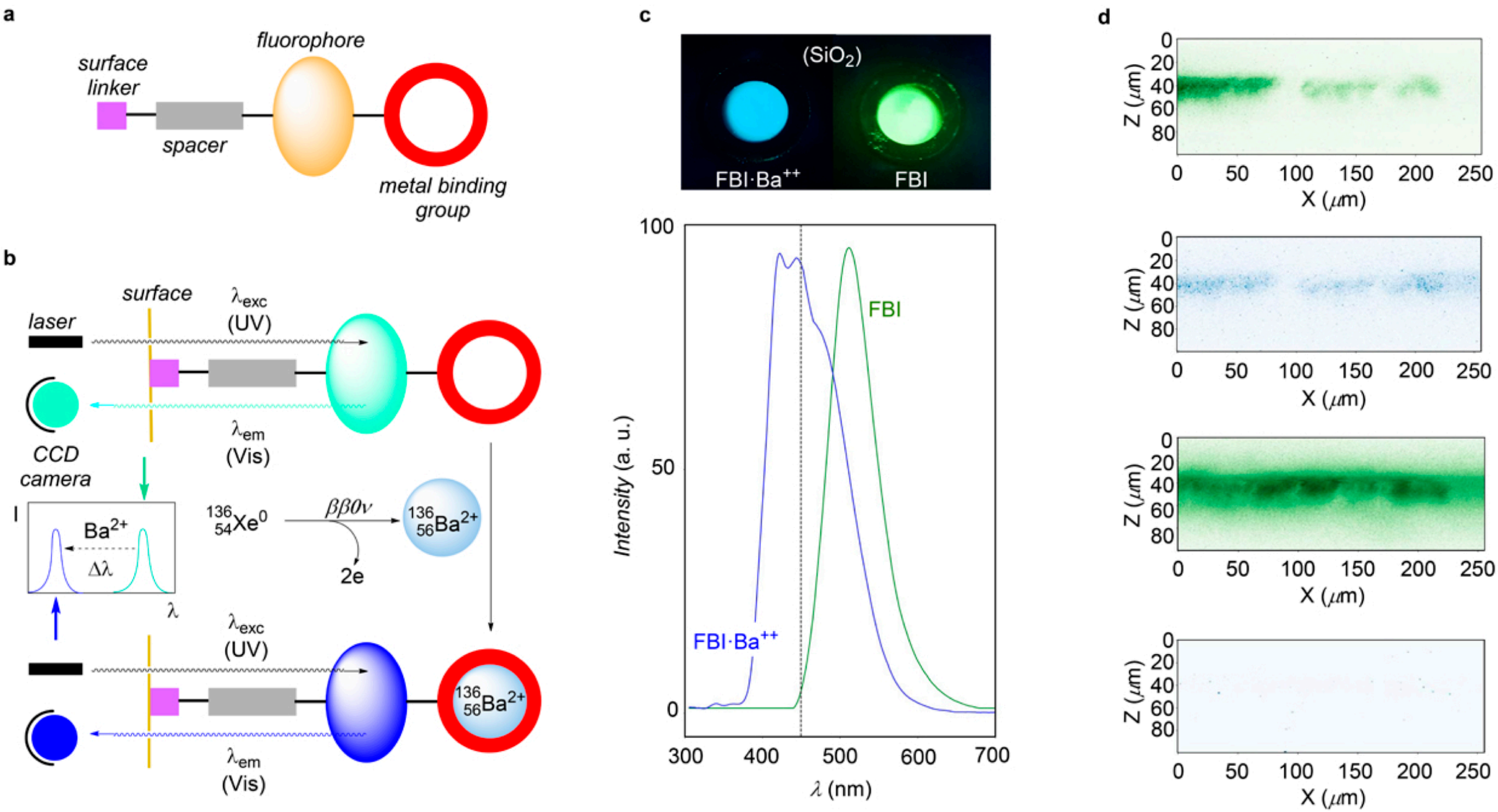
SMFI with photobleaching



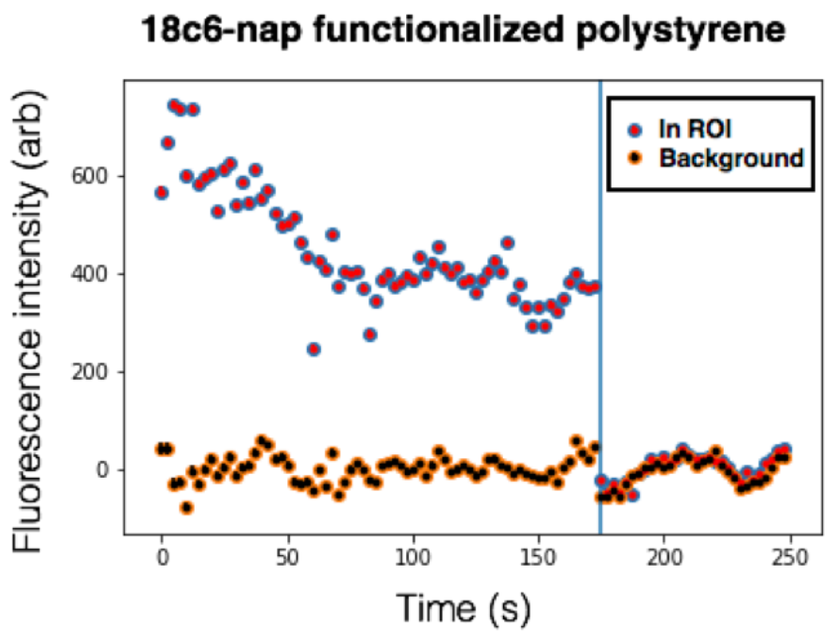


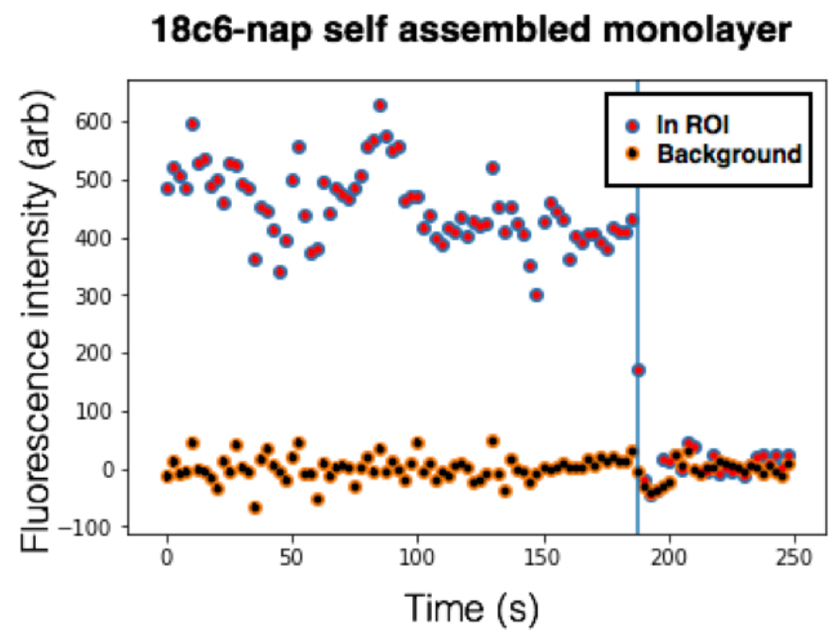
Bicolor molecules

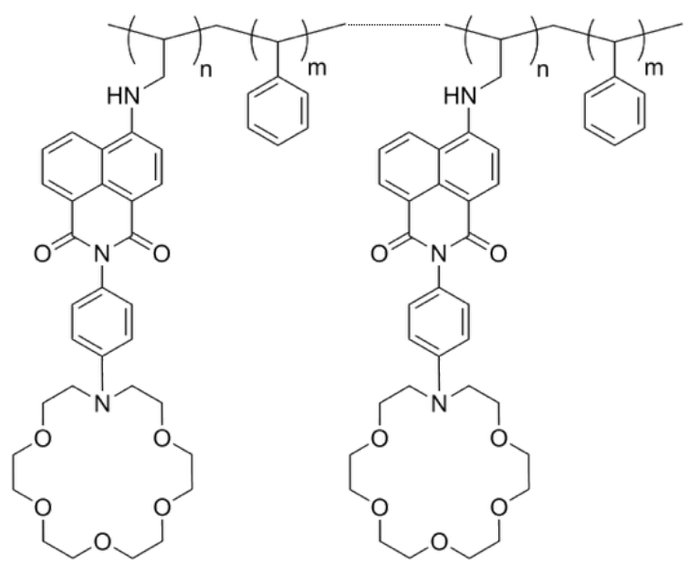
arXiv:1909.02782

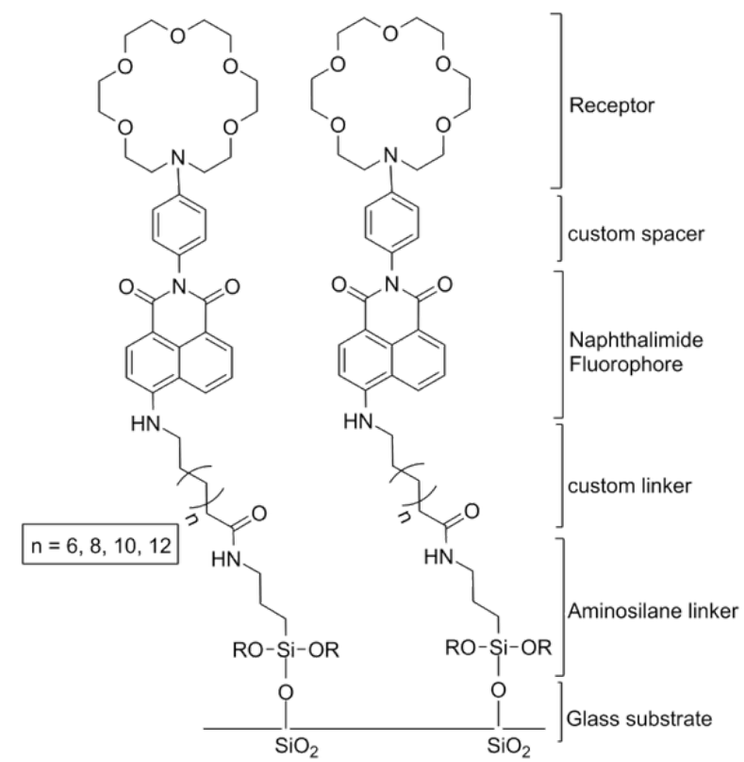


Monolayers


18c6-nap functionalized polystyrene
In ROI
Background
Fluorescence intensity (arb)
Time (s)


18c6-nap self assembled monolayer
In ROI
Background
Fluorescence intensity (arb)
Time (s)



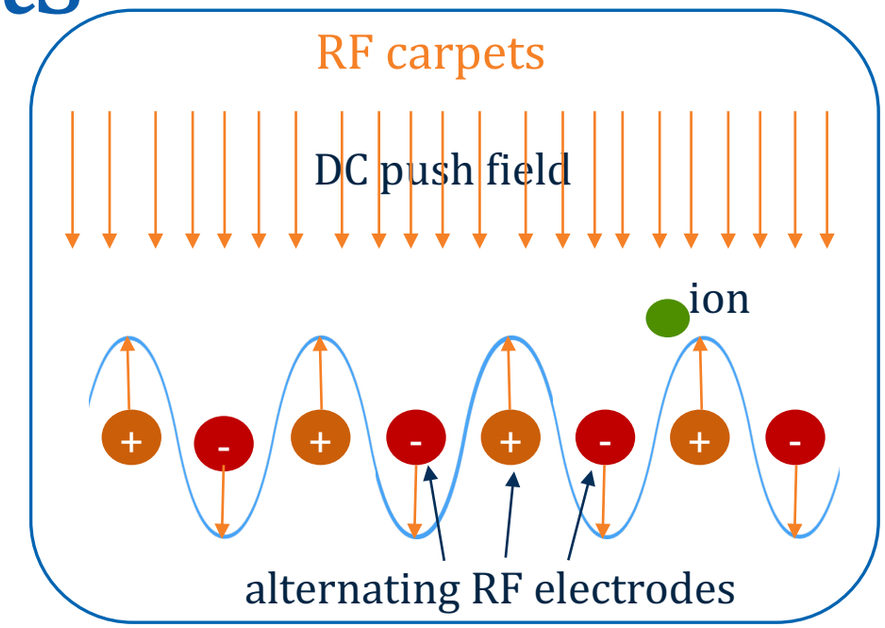

Receptor
custom spacer
Naphthalimide Fluorophore
custom linker
n = 6, 8, 10, 12
Aminosilane linker
Glass substrate

RF carpets

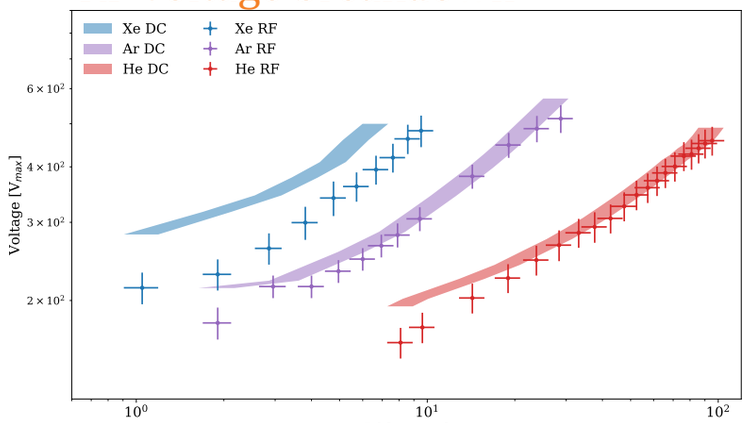
e-Print: arXiv:1909.05860

Ion transport using RF carpets

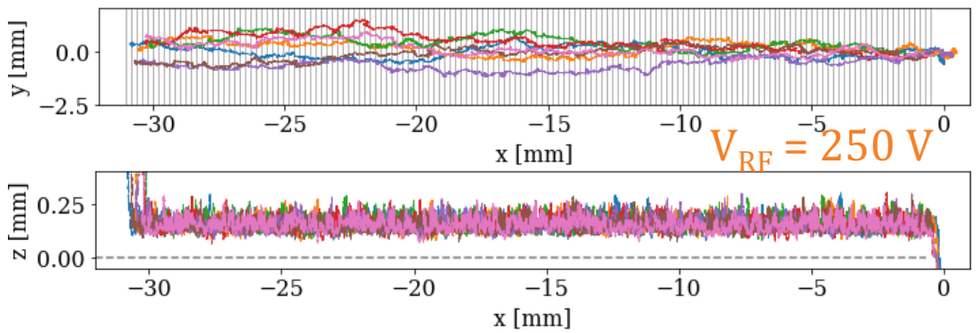
- Need to transport Ba^{++} ion to small (~cm^2) imaging region
  - RF carpets are being investigated for high pressure transport across the cathode
  - Commonly used for ion transport in low pressure helium
- Need to demonstrate they can work at 10 bar in xenon
  - A proposal has been accepted to test barium ion transport on an RF carpet in Xe gas at 1 bar in the CARIBU beam at ANL
  - Need high voltage and small inter-electrode distances
  - Tested high voltage RF breakdown across electrodes in high pressure noble gases
  - Preliminary simulations and calculations show RF carpet transport is possible at 10 bar



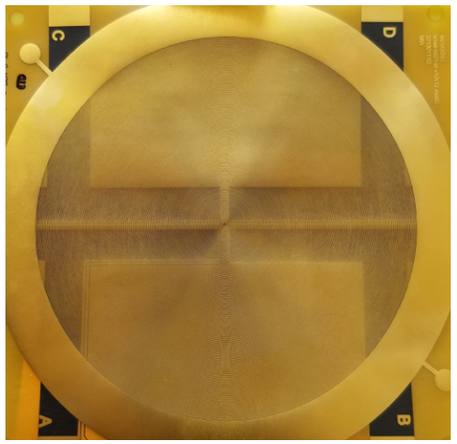
RF voltage breakdown arXiv: 1909.05860



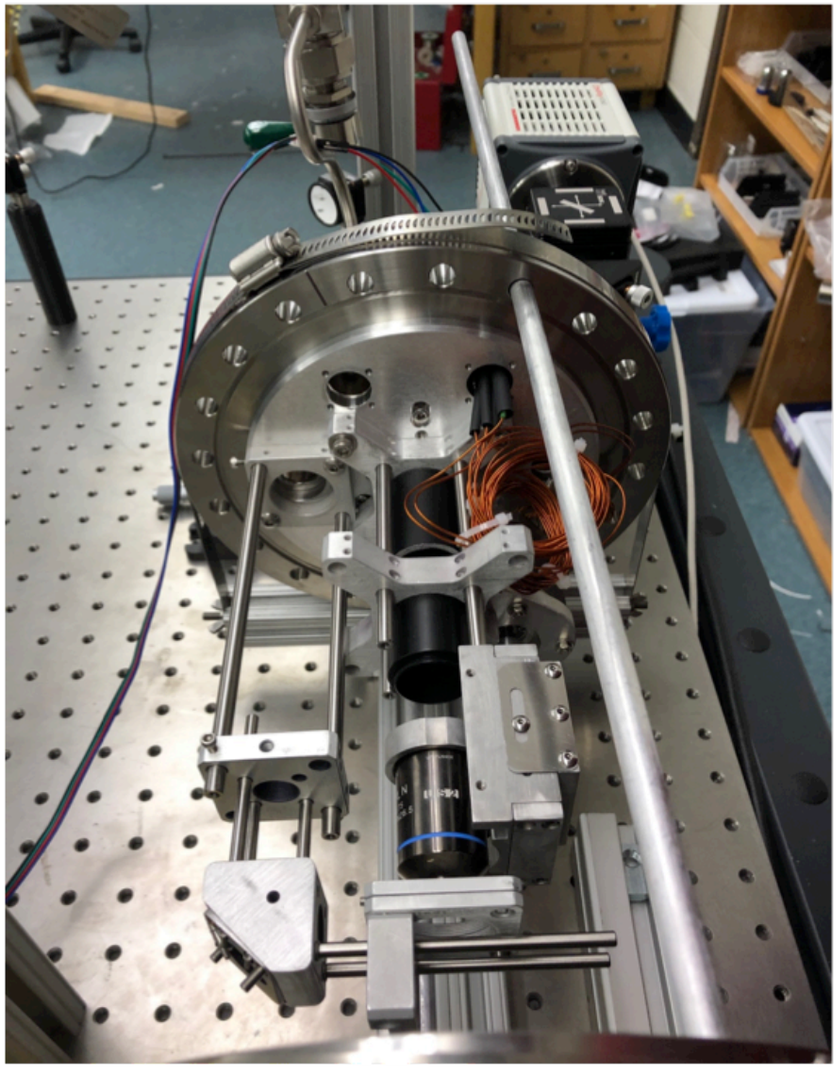
SIMION RF carpet simulations of Ba^{++} in 10 bar Xe

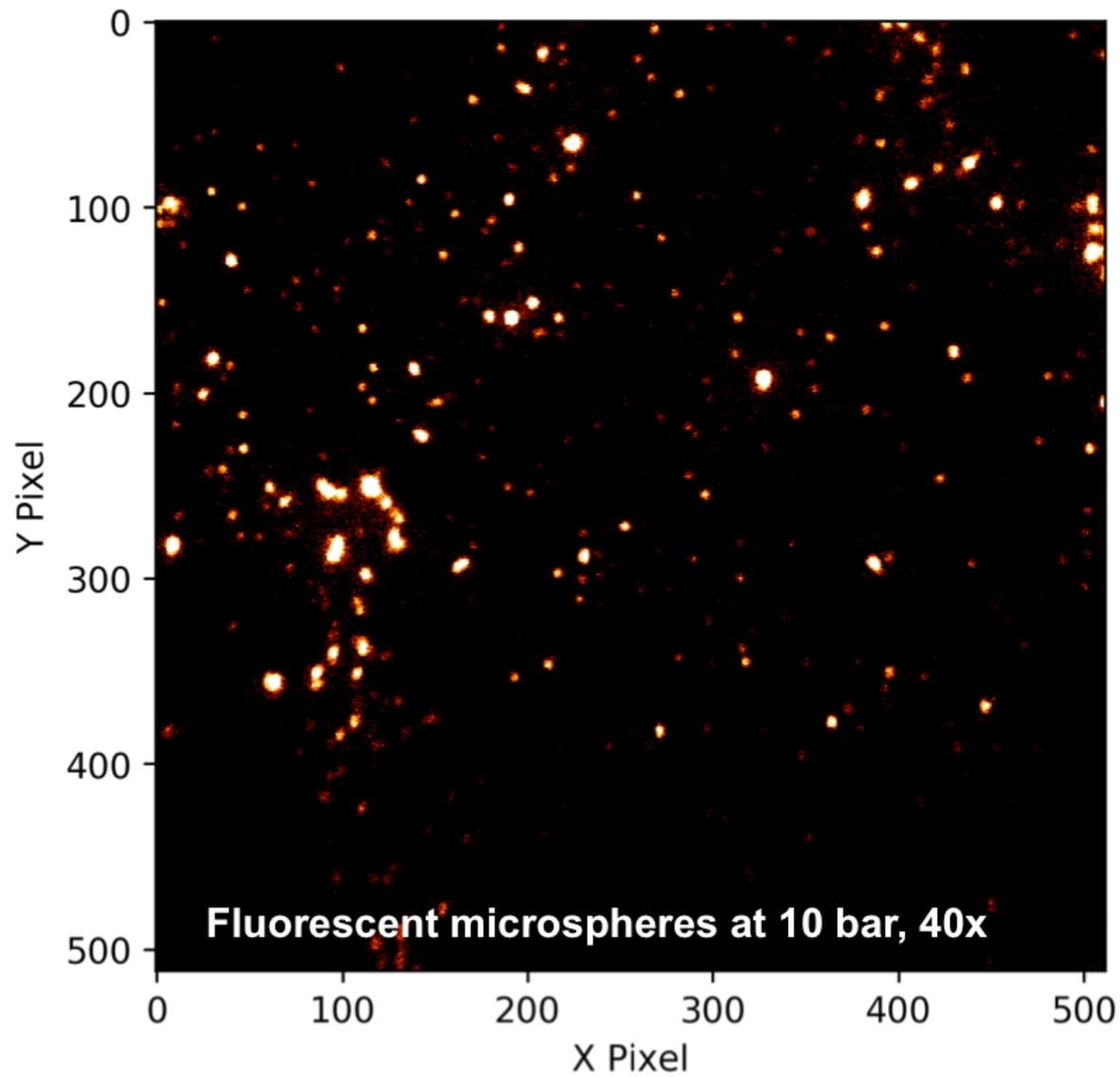


RF carpet for ANL tests

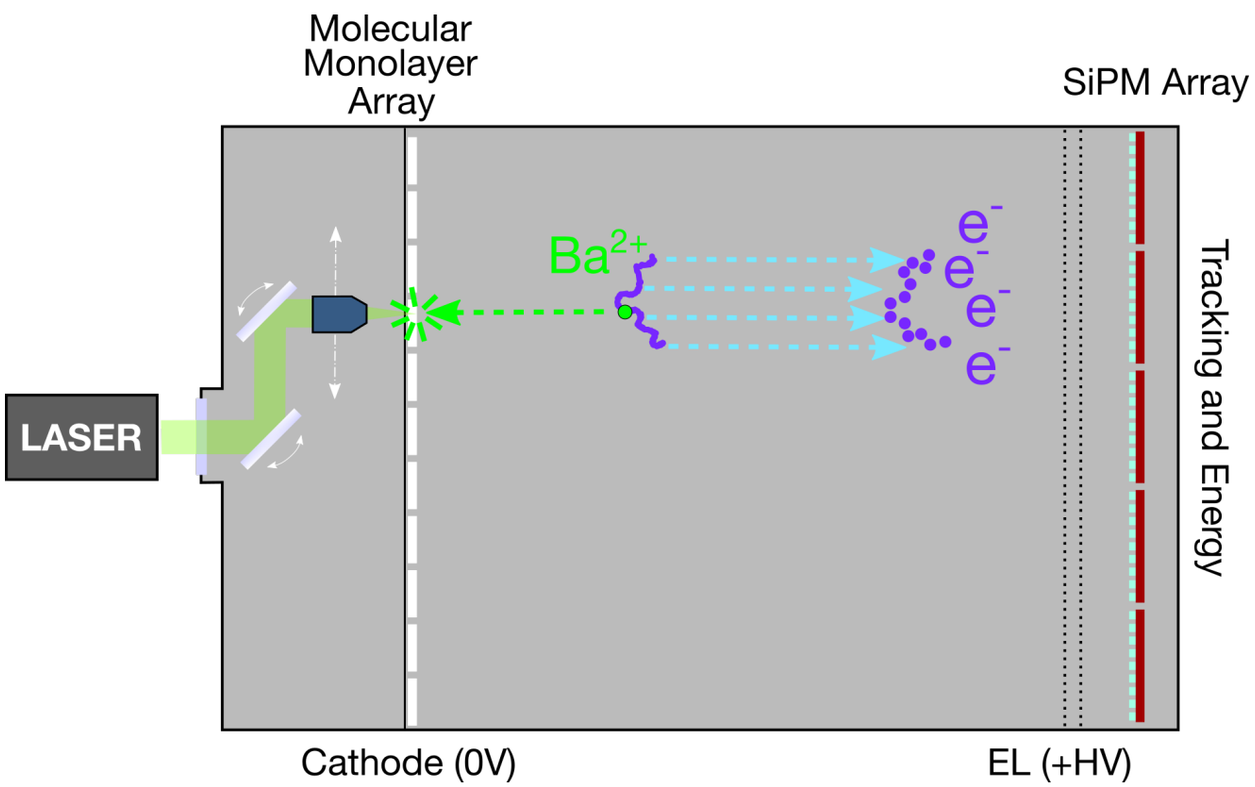


High pressure microscopy





NEXT-BOLD



- Asymmetric detector, SiPMs only, cathode at ground, high pressure/ cold gas (limit: resolution).
- Topology reconstruction only for calibration. Increased efficiency for signal.
- Cathode at V+ opens gate only on delayed bbonu trigger.
- RF carpet and/or Molecular Array
- Fast, high-pressure microscopy.
- Prototype: NEXT-White or NEXT-100

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

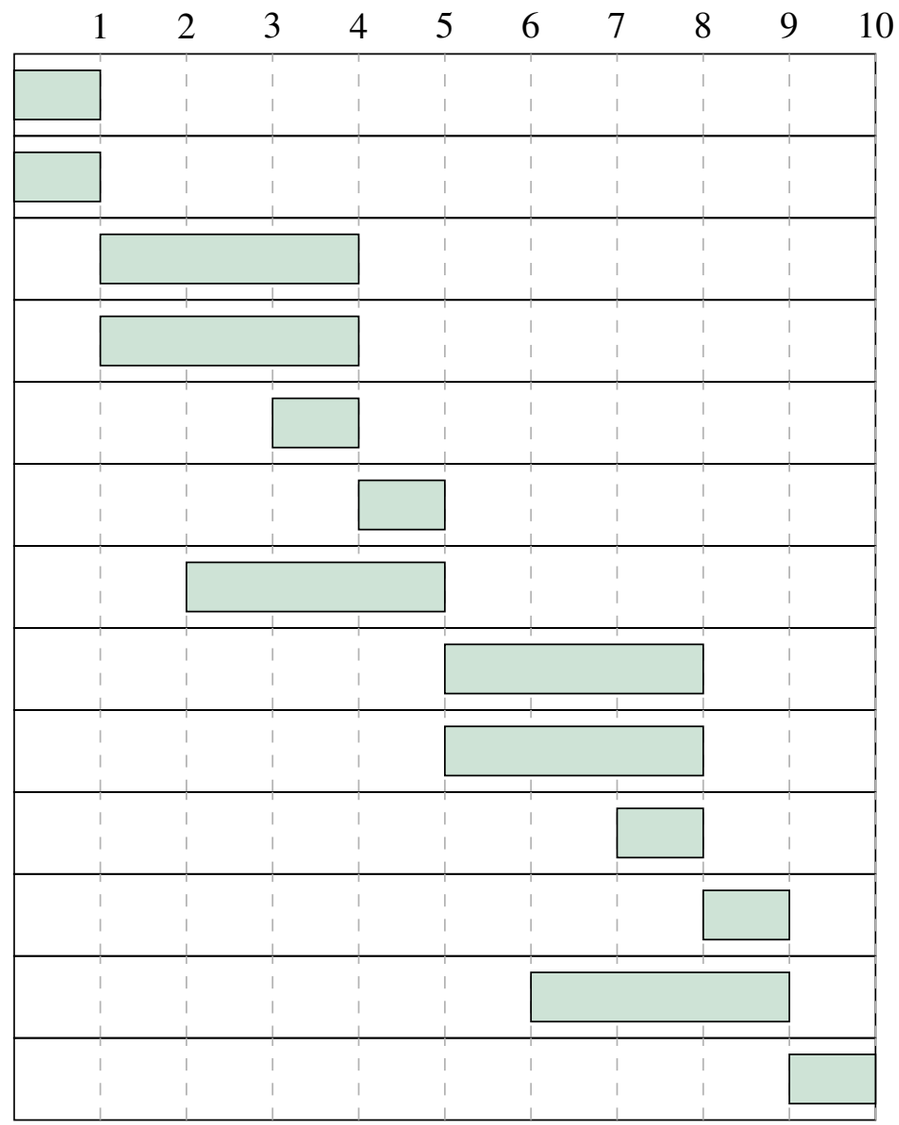
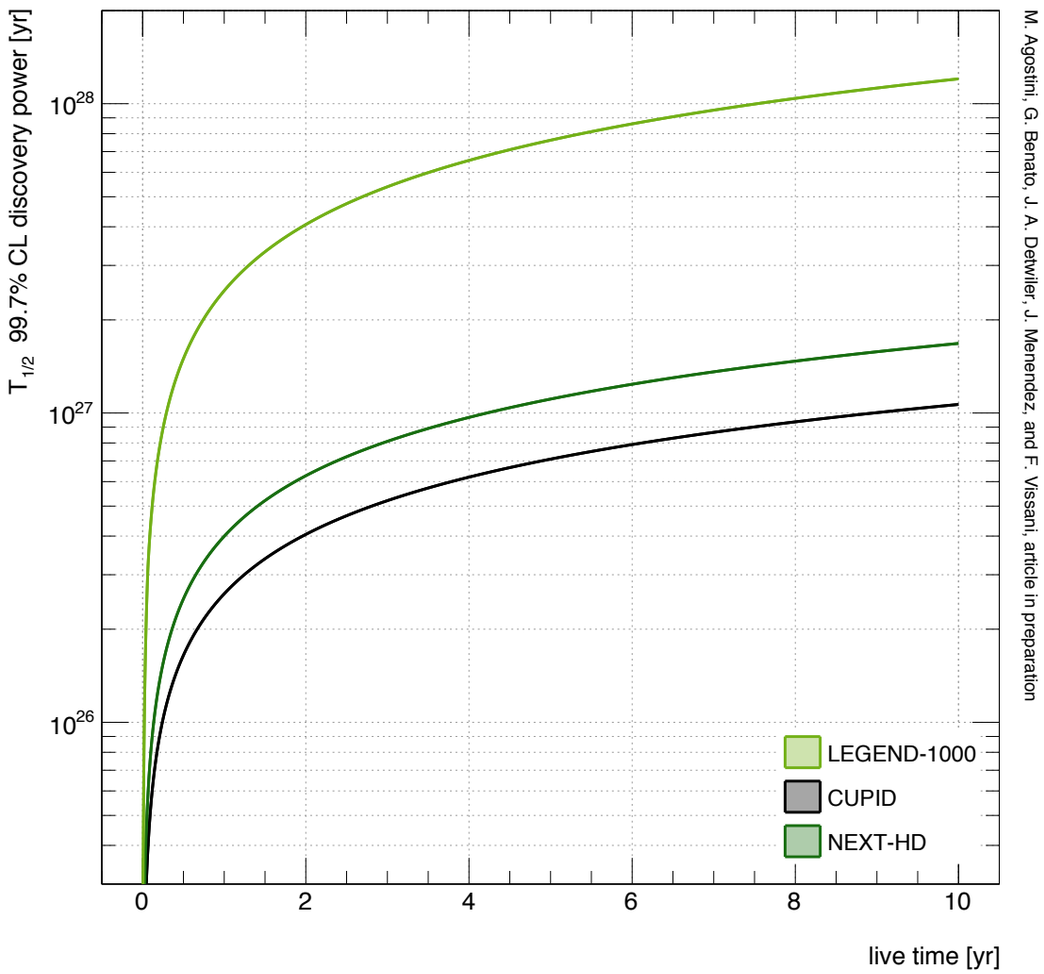
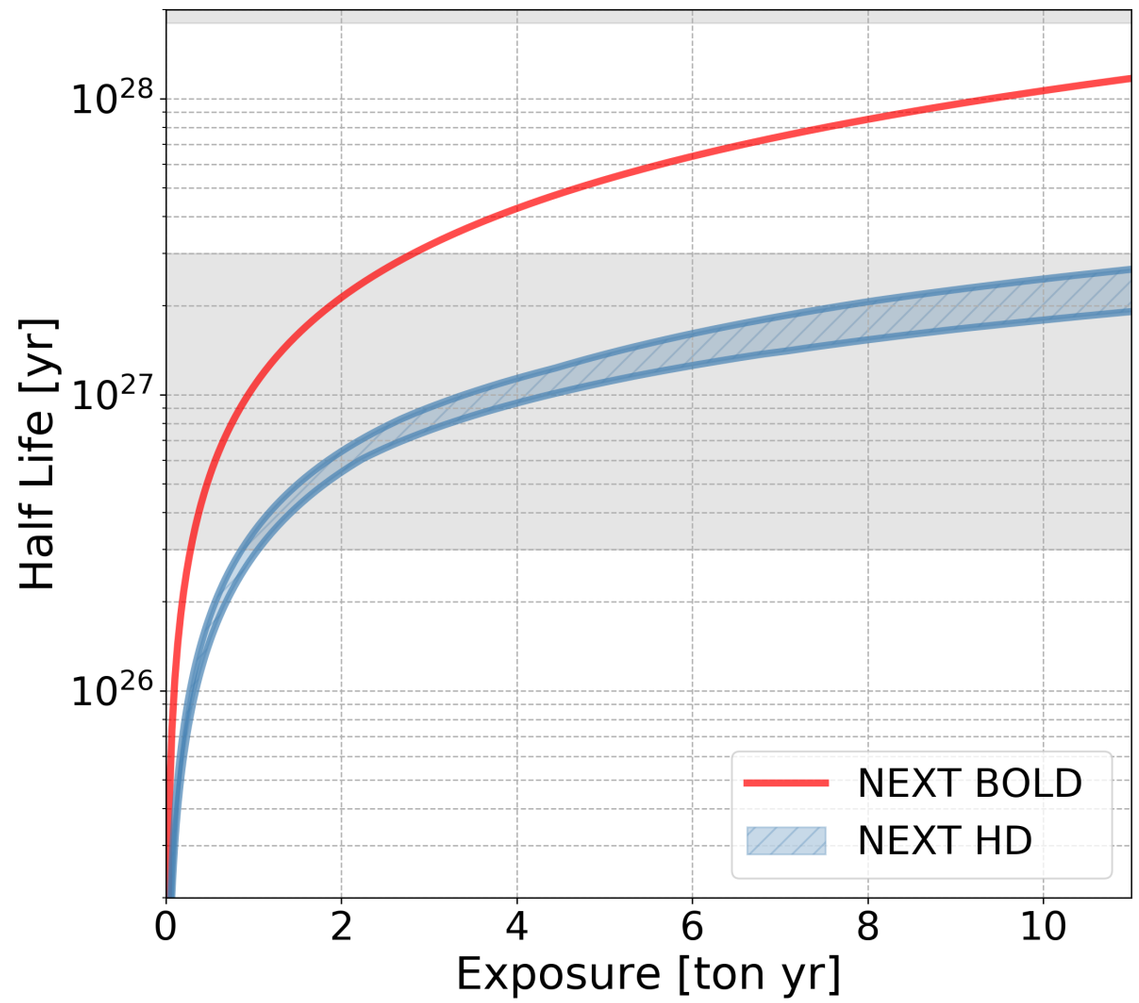


Figure 9: Time schedule of NEXT experiment including R&D program. Column numbers indicate years. Year 0 is 2019. Operation of two modules continue after year 10.

NEXT Sensitivity





Discovery potential NEXT-HD

Sensitivity NEXT (HD & BOLD)

NEXT-HD: BI. 0.39 counts/ton/year in ROI

NEXT-BOLD: “zero” counts, increased efficiency (relax topology ID)

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.
    - 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

Backup