Status and prospects of the NEXT Experiment

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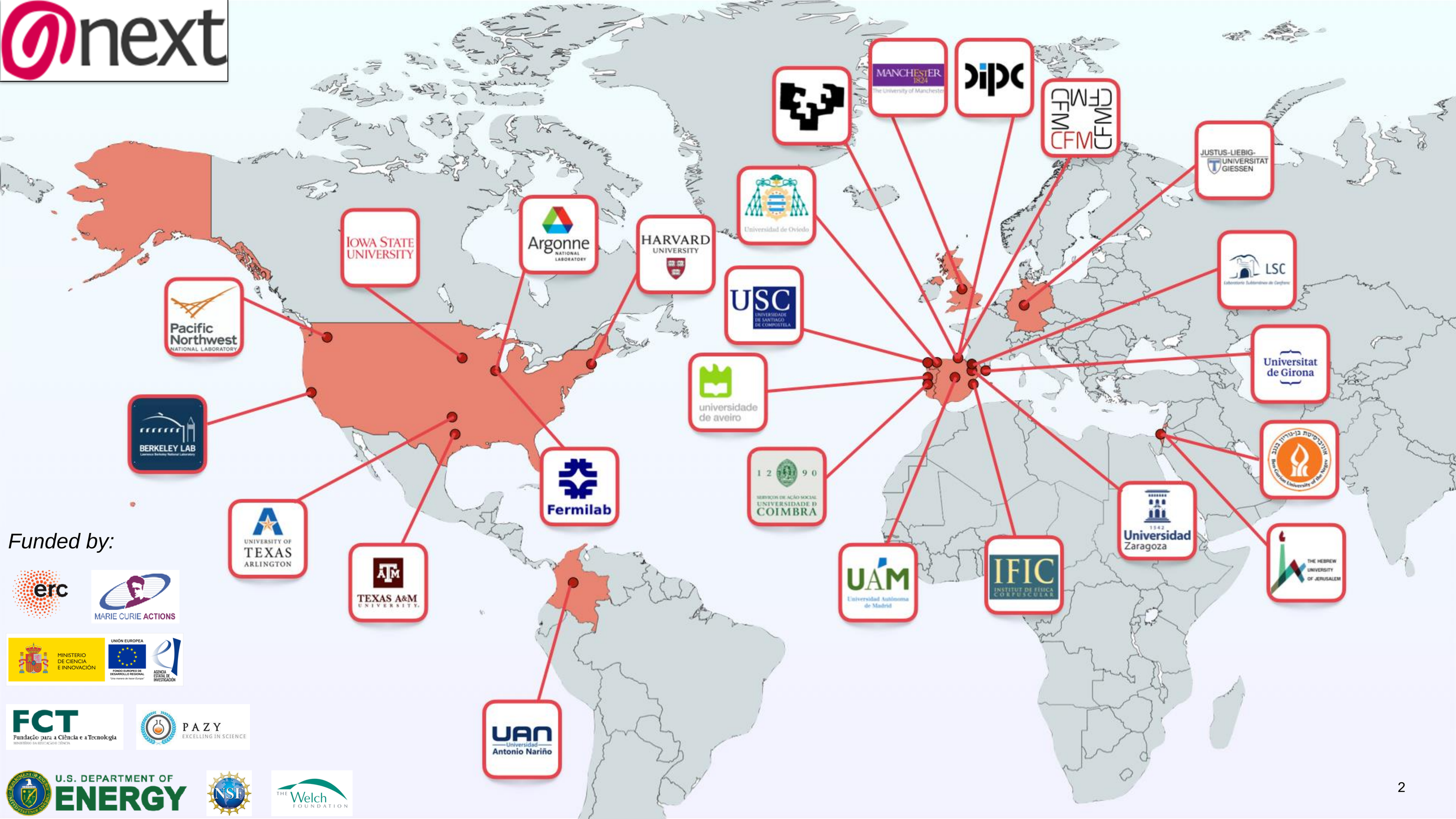
On behalf of the NEXT Collaboration

DOUBLE BETA DECAY: THE ROAD TO NORMAL HIERARCHY SENSITIVITY
6-7 June 2022 , Lisbon, Portugal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USC Universidade de Santiago de Compostela
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Manchester 1824 The University of Manchester
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Justus-Liebig-Universität Giessen
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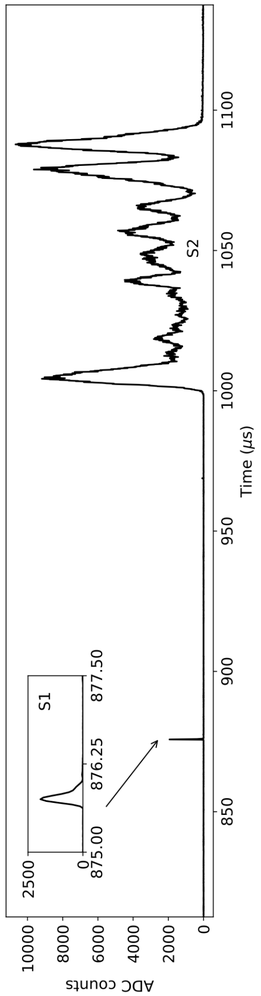
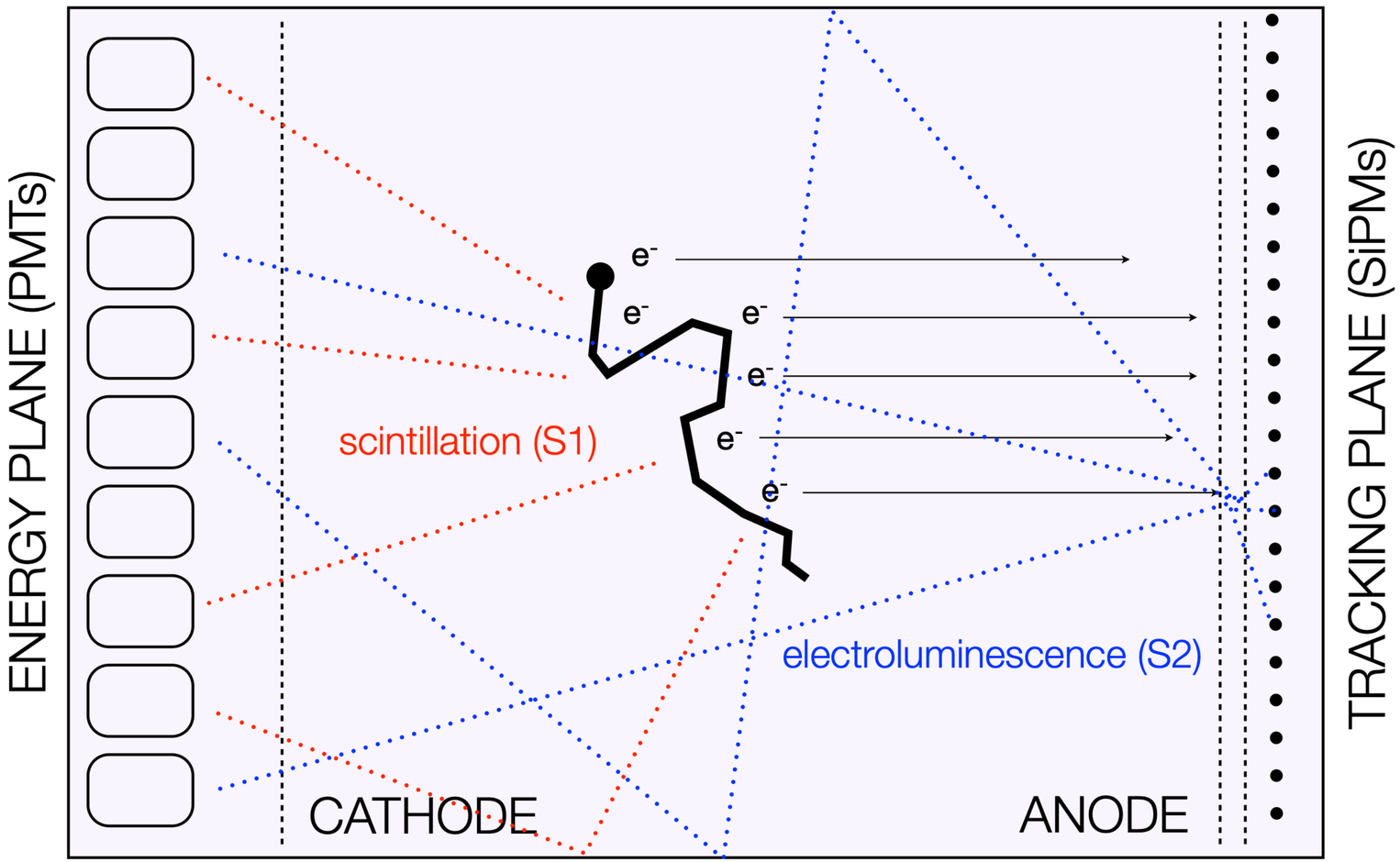
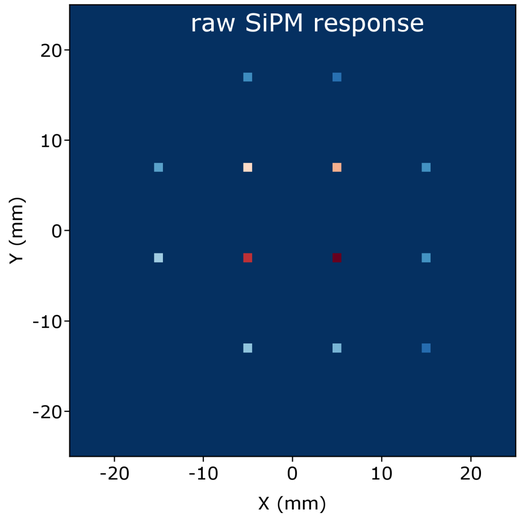
NEXT detection concept







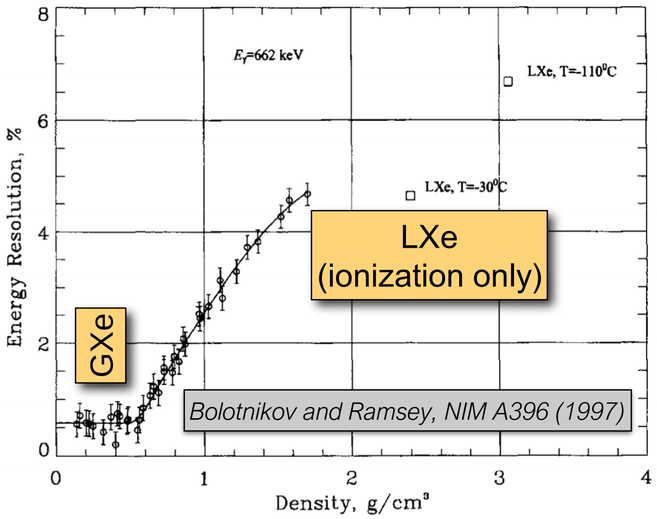
High-pressure xenon gas time projection chambers for 0νββ in ^{136}Xe

Precise energy resolution of <1% FWHM

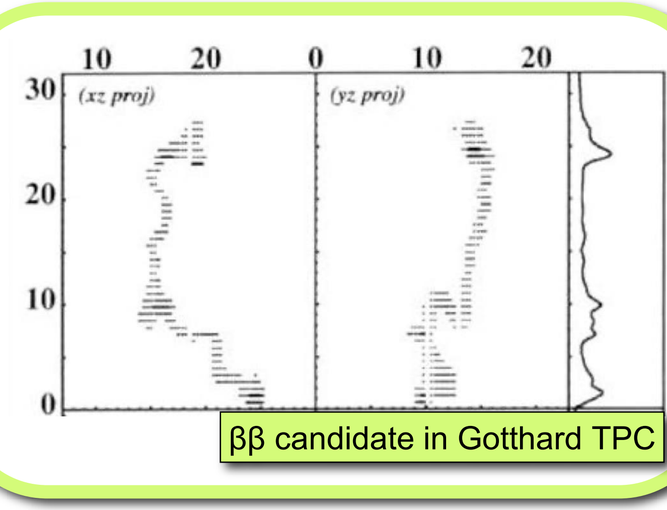
Topological event identification distinguishes 2e from 1e events

Scalability to large masses of isotopically-enriched ^{136}Xe

Possibility to detect $^{136}Ba^{++}$ daughter ion in coincidence with decay electrons



Bolotnikov and Ramsey, NIM A396 (1997)



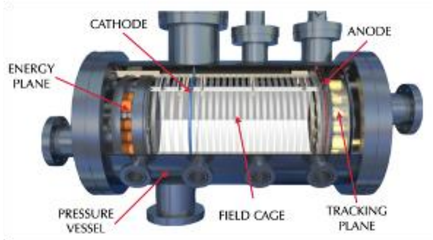
ββ candidate in Gotthard TPC

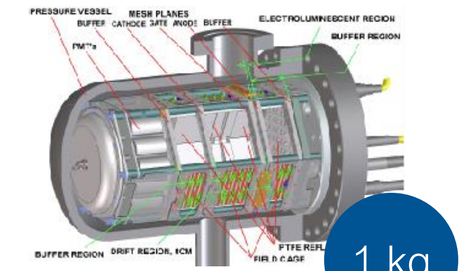
The NEXT program

Prototypes

2008-2015

- Demonstration of detector concept



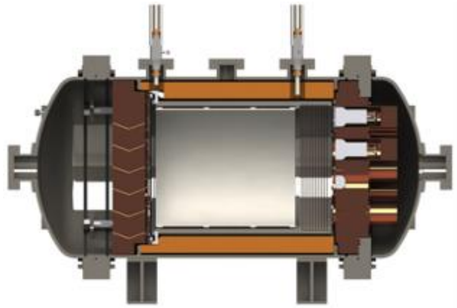


1 kg

NEXT-White

2016-2021

- Det. performance near $Q_{\beta\beta}$
- Background measurement
- 2νββ measurement

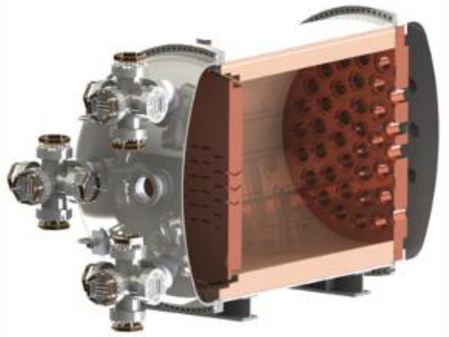


4 kg

NEXT-100

2022-2025

- Background measurement
- 0νββ search



100 kg

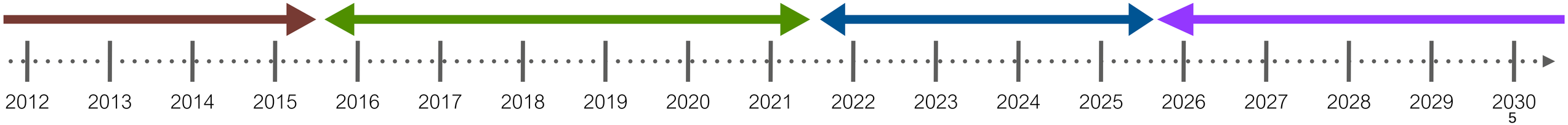
NEXT-HD

2026?

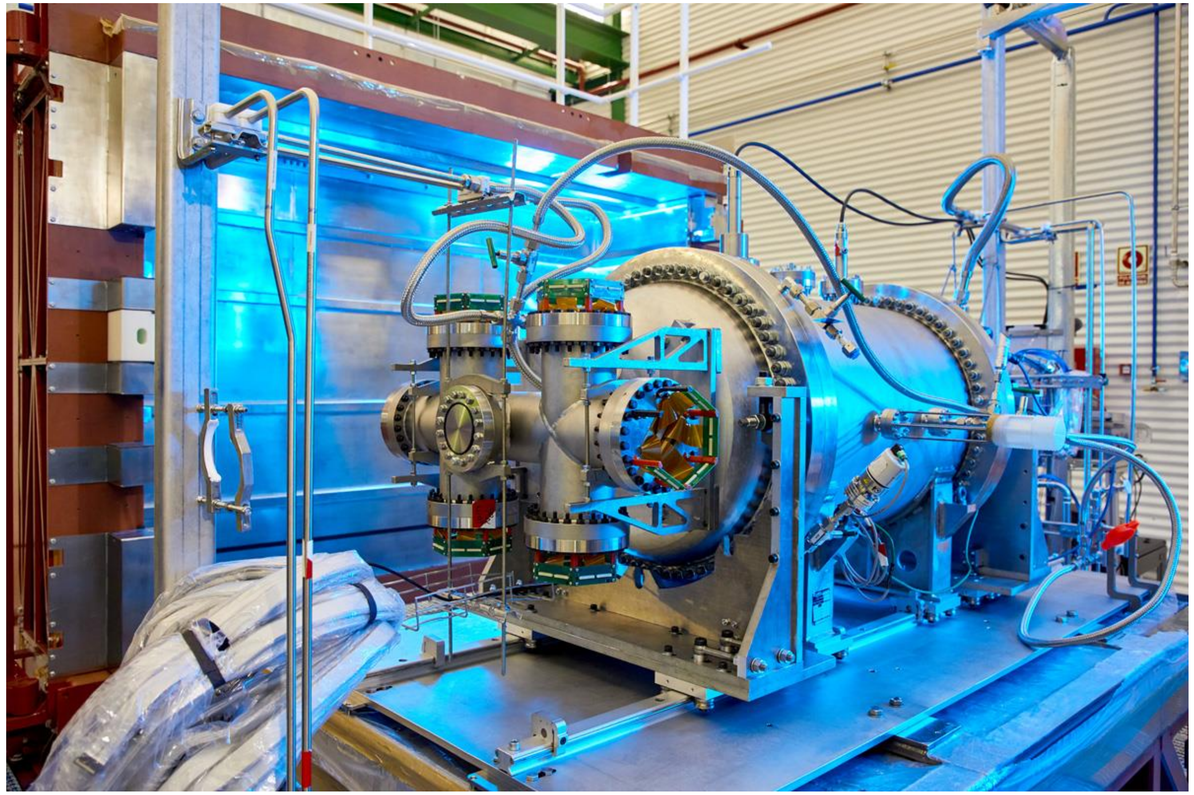
- 0νββ search through inverted ν mass ordering

NEXT-BOLD

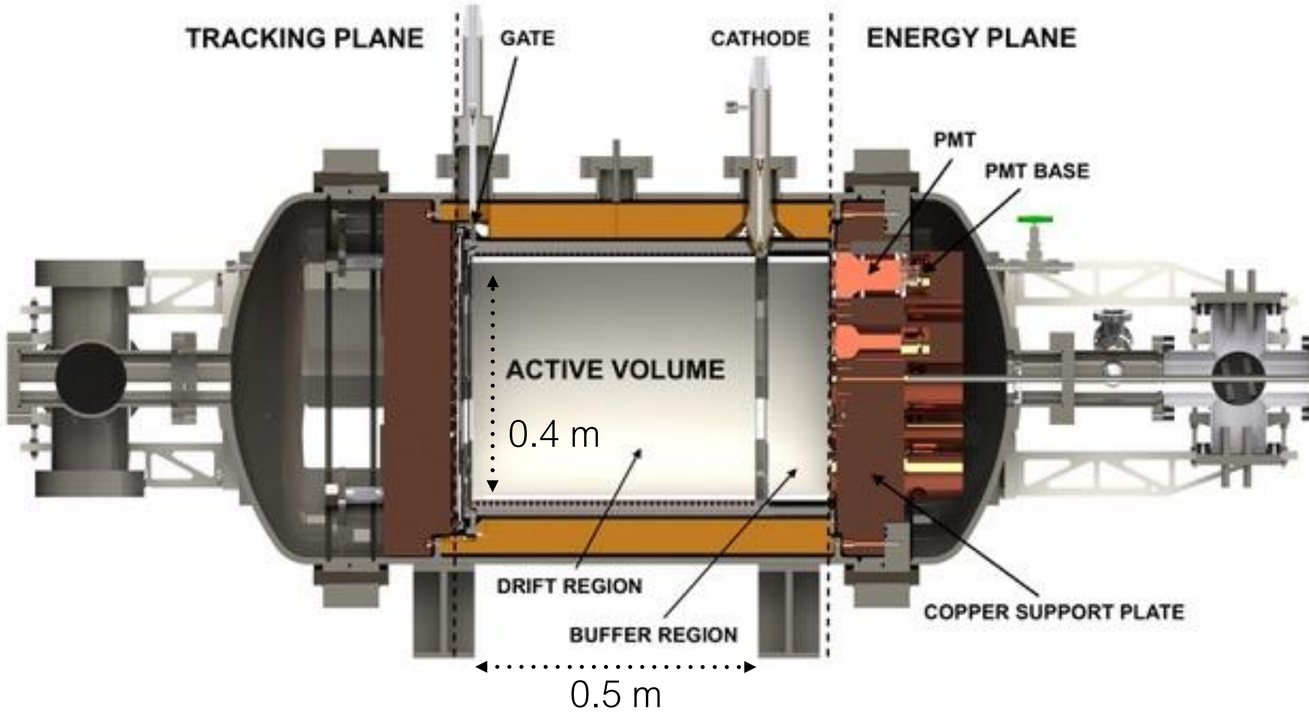
- Barium tagging for bgr-free experiment



NEXT-White



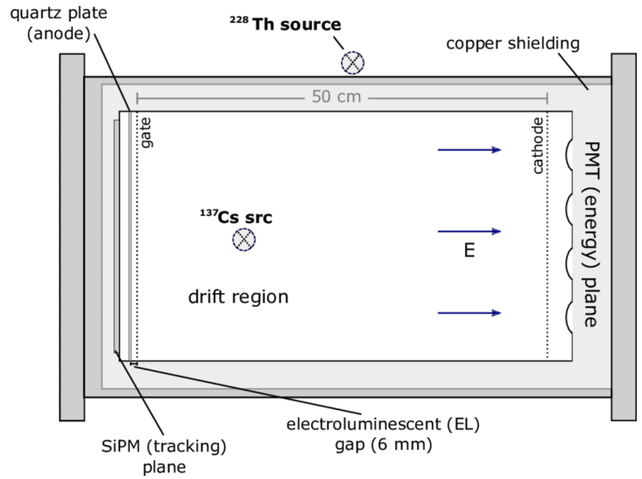
JINST 13 (2018) 12, P12010

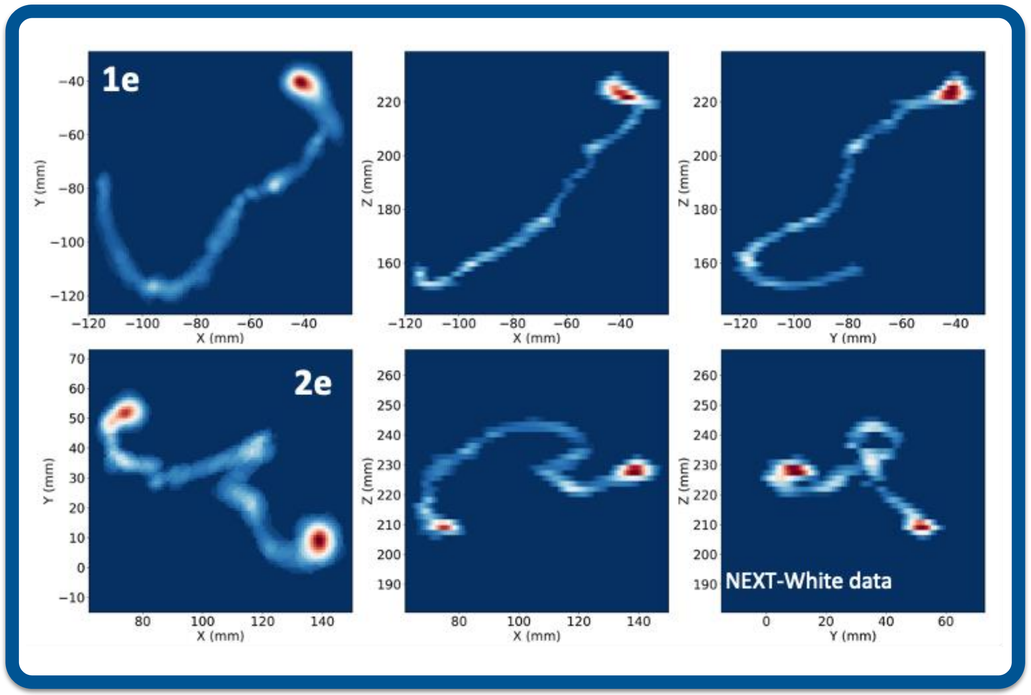


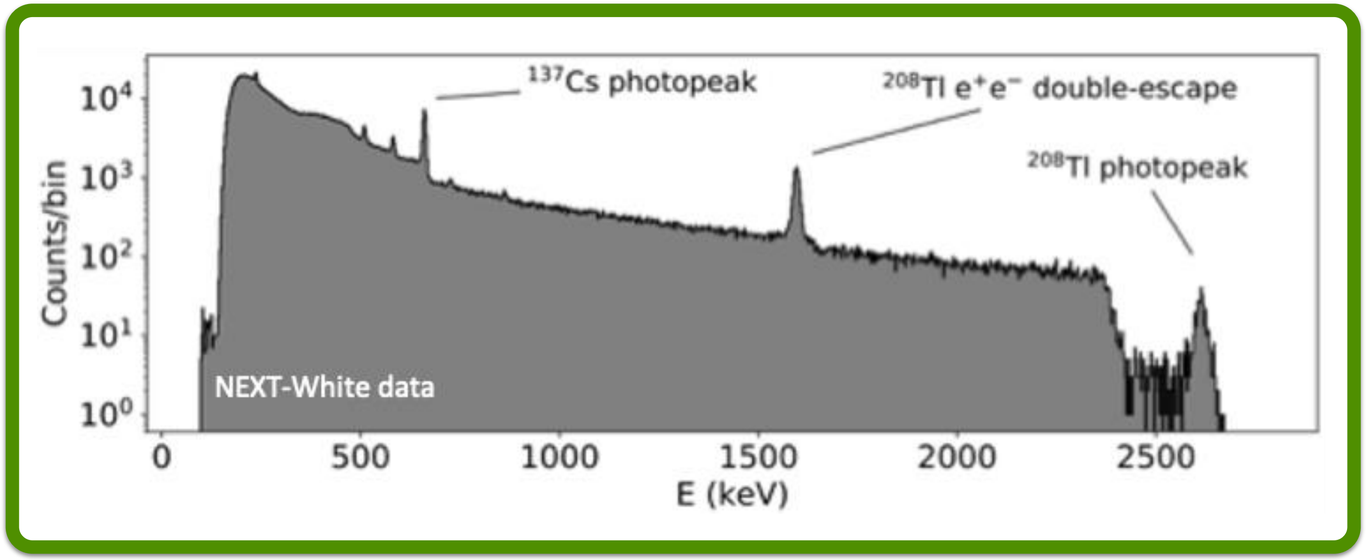
- Operated at the LSC, 2016-2021.
- ^{enr}Xe and ^{dep}Xe gas. Calibration and low-background data.

NEXT-White calibration data results

- ^{137}Cs (662 keV) and ^{228}Th (2615 keV) calibration gamma sources
- **Energy resolution**: **0.91±0.12%** FWHM at 2.6 MeV *JHEP 10 (2019) 230*
- **Topology**: 1e background rejection factor of **27** for 57% 2e signal efficiency at 1.6 MeV *JHEP 07 (2021) 146*

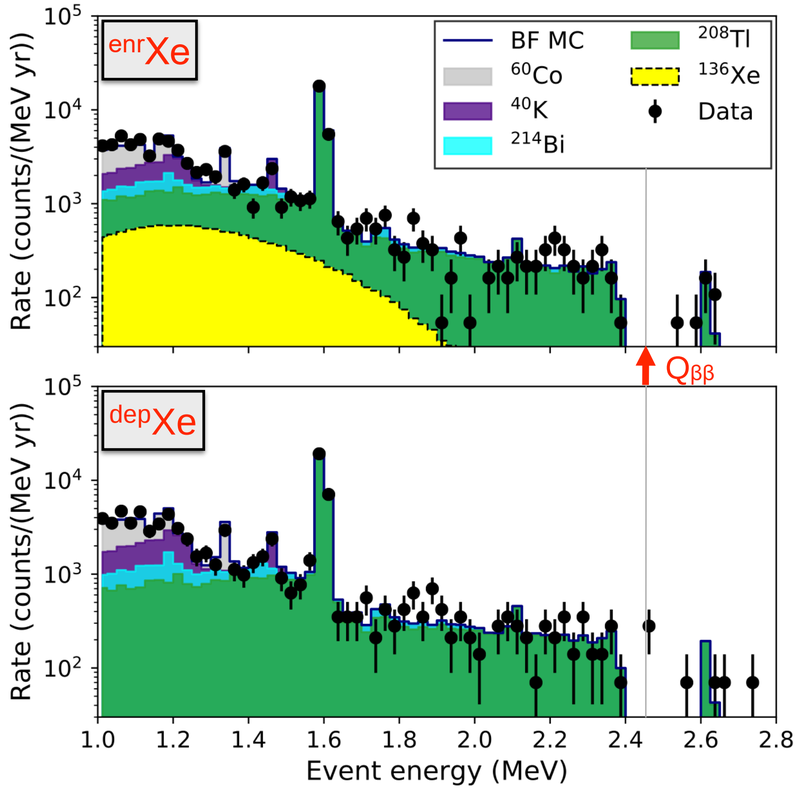


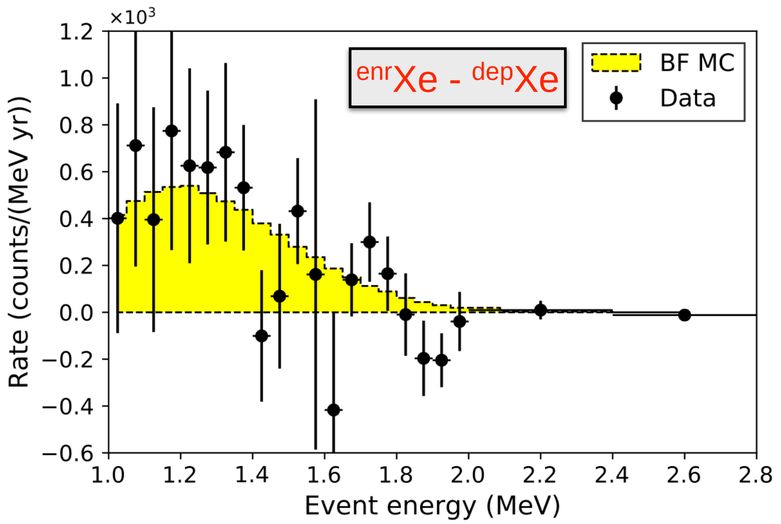




NEXT-White low-background data results

- Low-bgr data samples: **271.6 d** ^{136}Xe-enriched (90.9%), **208.9 d** ^{136}Xe-depleted (2.6%).
- Select 2e-like events in **3.5 kg** Xe fiducial mass.
- Direct background subtraction technique, ~independent of background model assumptions.





$T_{1/2}^{2\nu} = (2.34\ ^{+0.85}_{-0.49}) \times 10^{21}$ yr

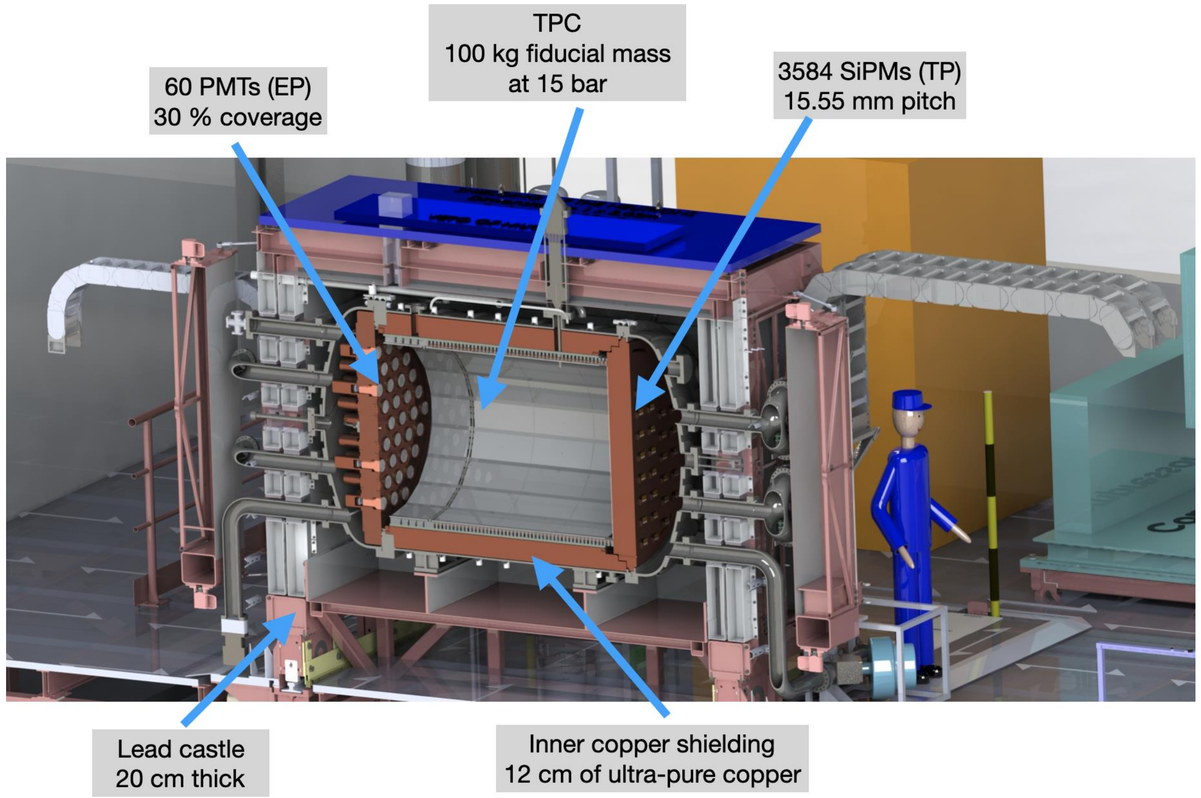
Phys.Rev.C 105 (2022) 5, 055501

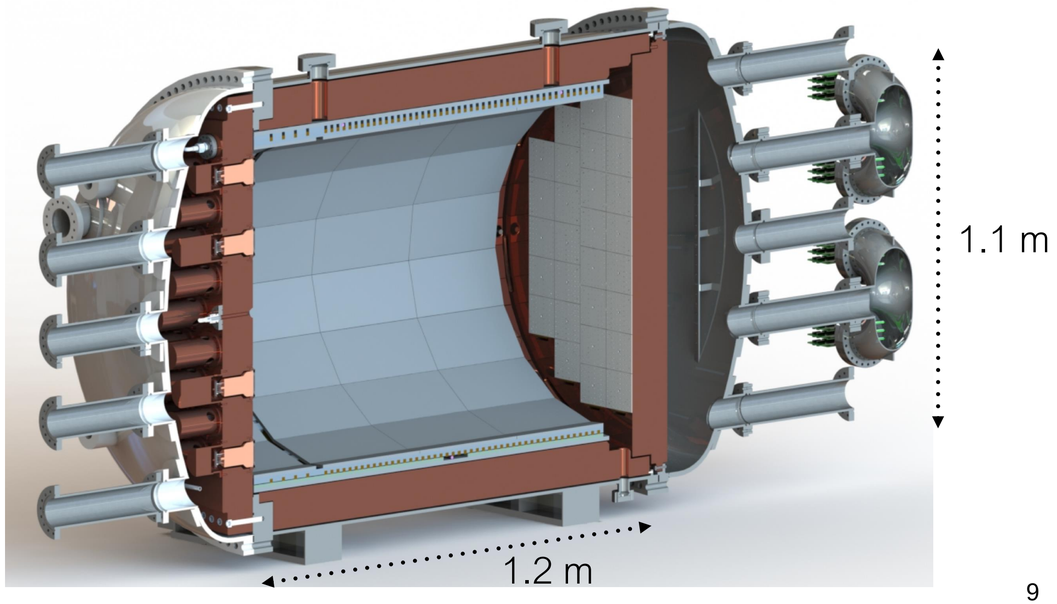
$T_{1/2}^{0\nu} > 0.6\text{-}1.3 \times 10^{24}$ yr at 90% CL

PRELIMINARY

NEXT-100

- Demonstrate ~bgr-free conditions at 100 kg scale, 0νββ search, tonne-scale demonstrator.
- Target background rate of 5×10^{-4} counts/(keV·kg·yr) or **1 count/(ROI·yr)** *JHEP 05 (2016) 159*
- Status: in advanced construction stage, to be installed at the LSC in late 2022.





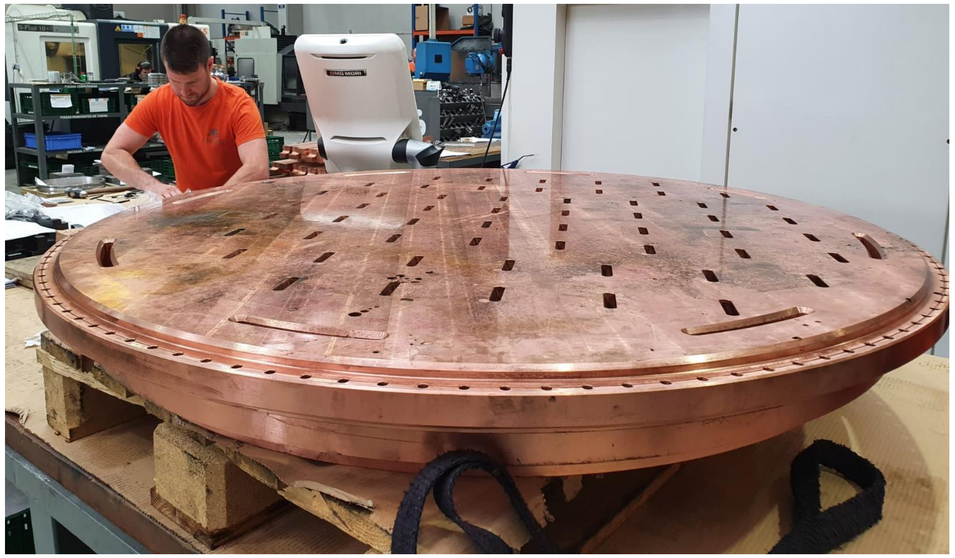
NEXT-100: external shield and gas system infrastructures

- **External shield**: refurbishing of lead castle completed. Now with more radiopure steel!

- **Gas system**: upgrades with respect to NEXT-White completed.

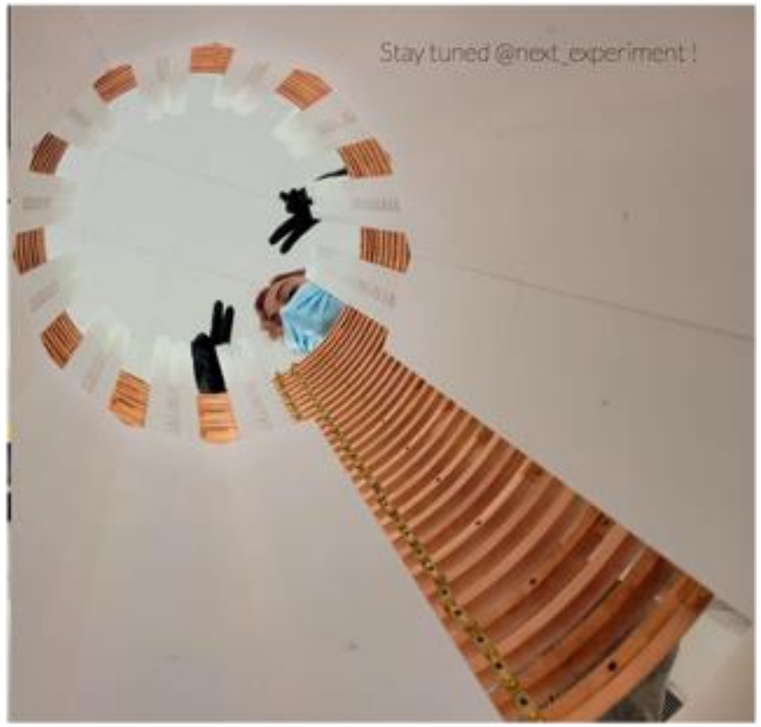
NEXT-100: pressure vessel and inner copper shield

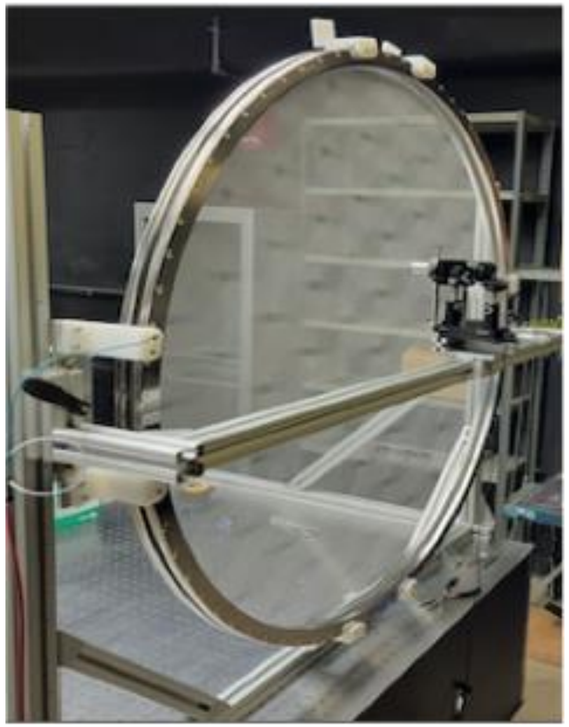
- **Pressure vessel**: stainless steel, **13.5 bar** operational pressure. Status: completed.
- **Inner shield**: radiopure copper, **12 cm** thick. Status: forged & machined, cleaning ongoing.



NEXT-100: time projection chamber

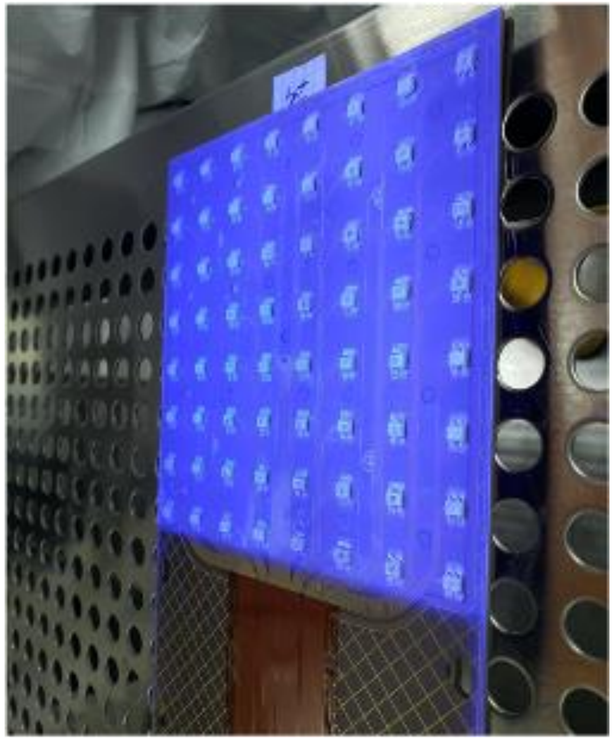
- **Field cage**: copper rings on HDPE staves, PTFE panels for increased light collection. Status: design and prototyping completed, production orders ongoing.
- **EL** (anode, gate) and **cathode**: stainless steel rings with wire meshes. Status: design and prototyping completed, production orders ongoing.

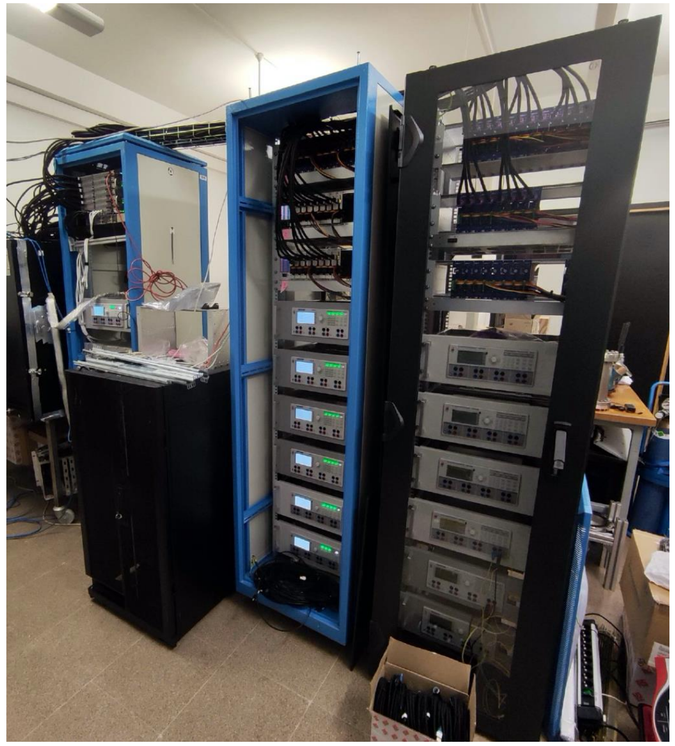




NEXT-100: readout planes and associated electronics

- **Energy plane**: **60** PMTs behind sapphire windows. Status: PMTs procured, PMT bases built, electronics completed, windows' coating ongoing.
- **Tracking plane**: 56 boards with 64 SiPMs each, for a total of **3584** SiPMs. Status: boards built and TPB-coated, electronics completed and tested.





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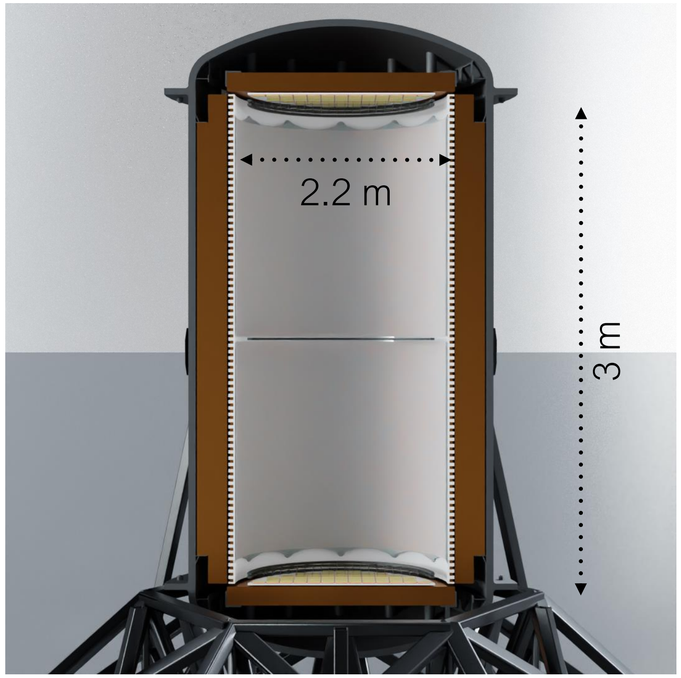
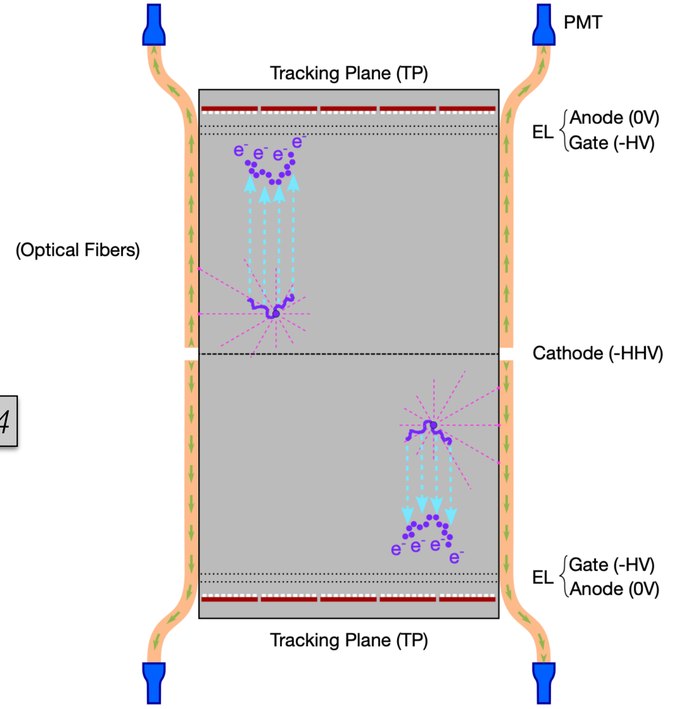
- Multi-module system with first module at Laboratorio Subterráneo de Canfranc (Spain)
- Baseline concept:
  - *Symmetric TPC with central cathode*
  - *Two dense SiPM tracking plane readouts*
  - *Barrel fibre detector for energy measurement*
  - *Gas additives (eg, ^{4}He) to reduce diffusion*
  - *Estimated background **0.09-0.27** counts/(ton·yr·ROI)*
- Other advanced readout options explored, and cosmogenic background mitigation using ^{3}He





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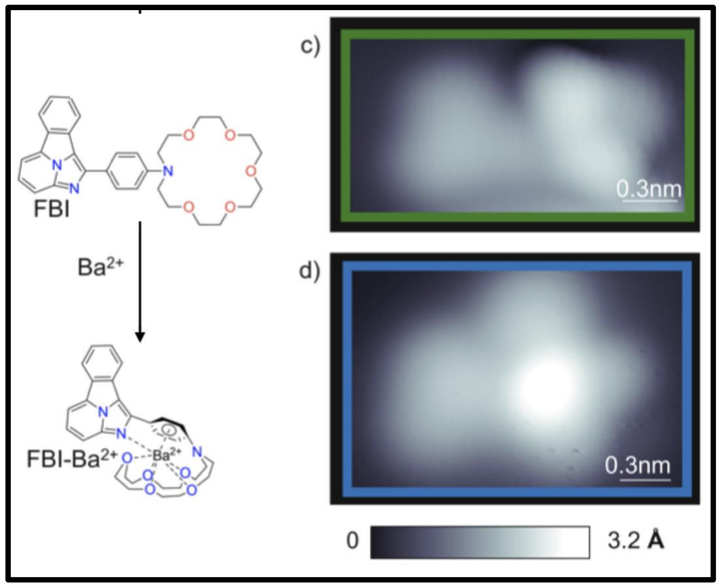
Barium Tagging at next

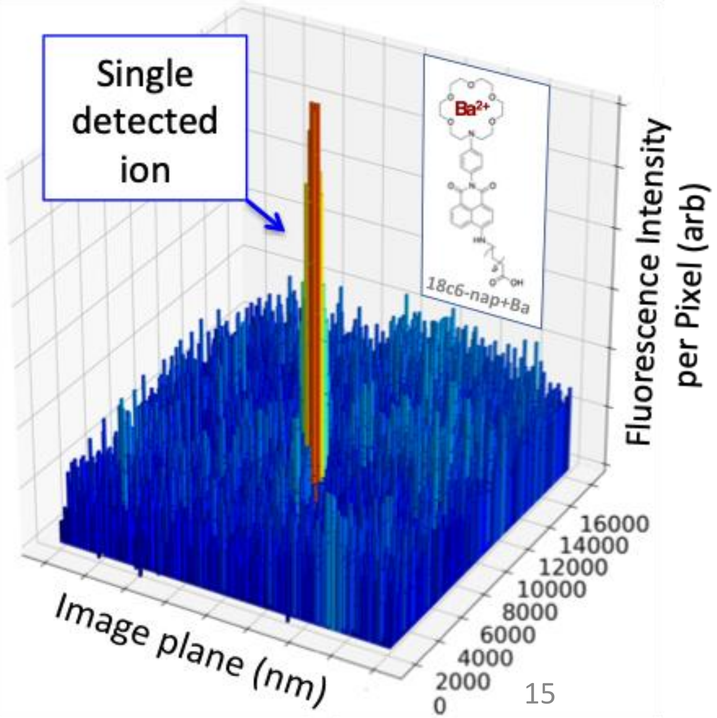
- Detection of **single barium ion** in coincidence with <1% FWHM energy resolution may be the path to a truly background free 0nubb search

- NEXT is pursuing single molecule fluorescent imaging (SMFI) based barium tagging sensors.

- R&D to date has realized molecular ion sensors that:
  - Exhibit **barium chelation** in vacuum &
  - Enable **single ion sensing** in xenon gas



STM shows barium location in molecule after chelation

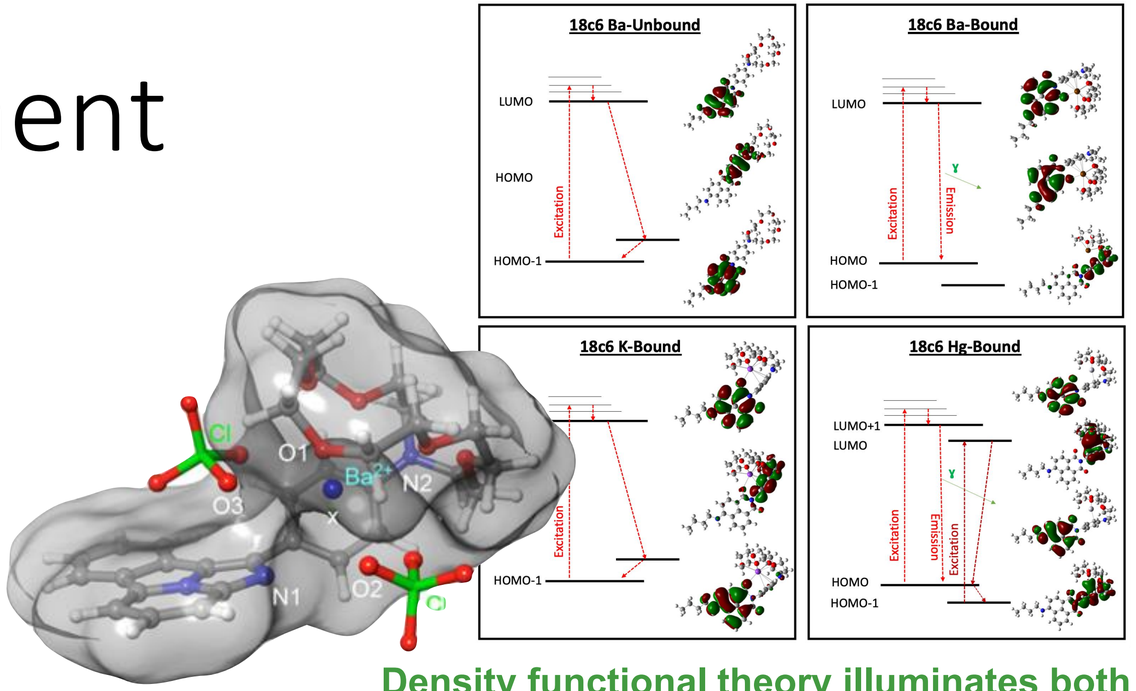


SMFI + high pressure microscopy enables Ba2+ detection in Xe gas

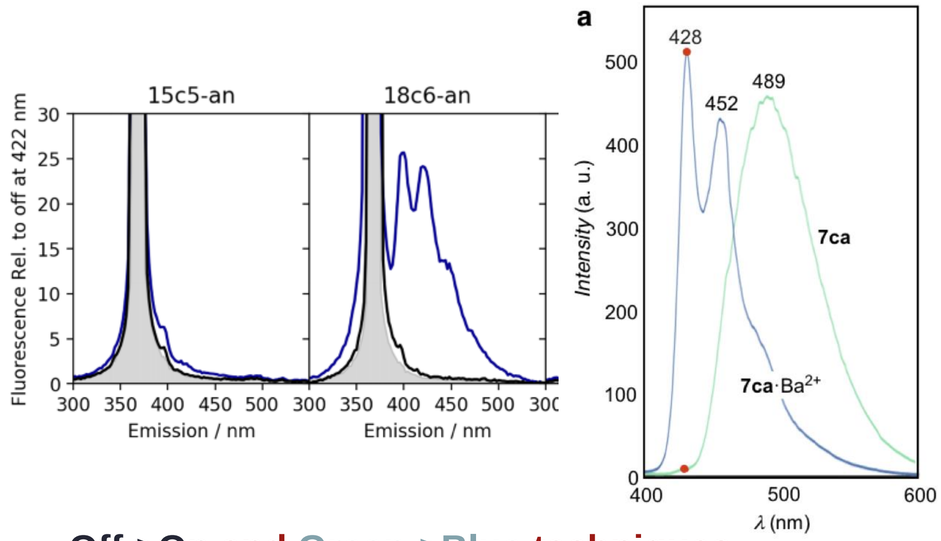
J.Phys.Conf.Ser. 650 (2015) 1, 012002;
JINST 11 (2016) 12, P12011;
Phys. Rev. Lett. 120 (2018) 13, 132504.
Sci.Rep. 9 (2019) 1, 15097;
Nature 583 (2020) 7814, 48–54;
ACS Sens. (2021) 6, 1, 192–202;
arXiv:2201.09099, arXiv:2109.05902

Molecular Sensor Development

- Sensing of Ba^{2+} at solid-gas interface via organic molecular monolayers is an entirely new technique, developed within NEXT.
- A rich R&D program is underway to explore space of possible molecules for single barium ion identification
- Both computational and experimental studies provide information for molecular optimization.
- NEXT's molecular arsenal now includes both:
  - Off-On fluorescence switching molecules
  - Bi-color emission wavelength switching molecules



Density functional theory illuminates both structure and function

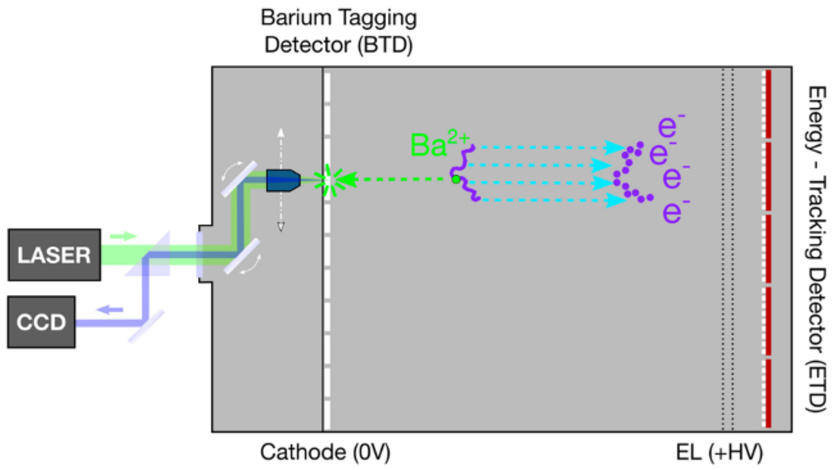


Off->On and Green->Blue techniques provide alternate sensing modalities

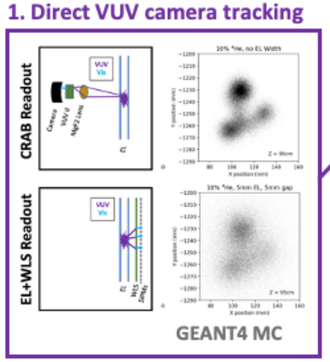
NEXT barium tagging demonstrator phases

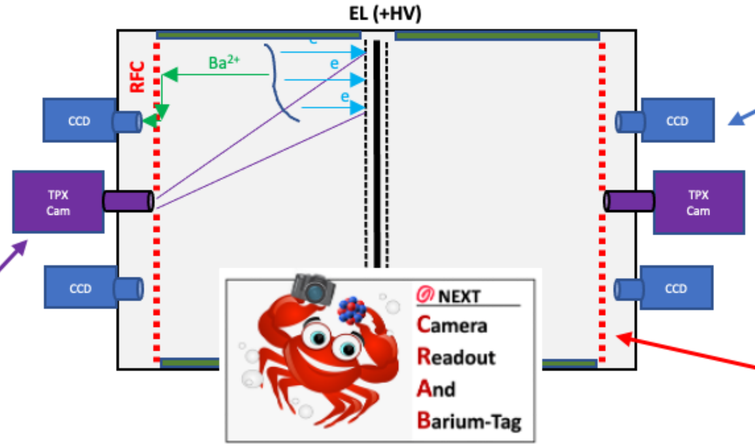
- Single ion sensor concepts fairly advanced
- Important R&D remains for ion concentration and collection

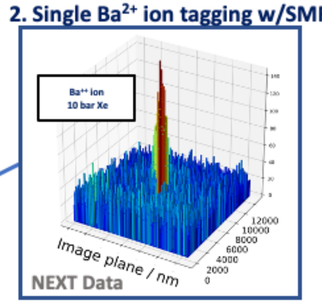
Sensor-to-ion (BTD concept)

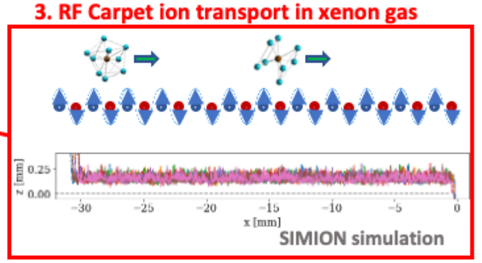


Ion-to-sensor (CRAB concept)



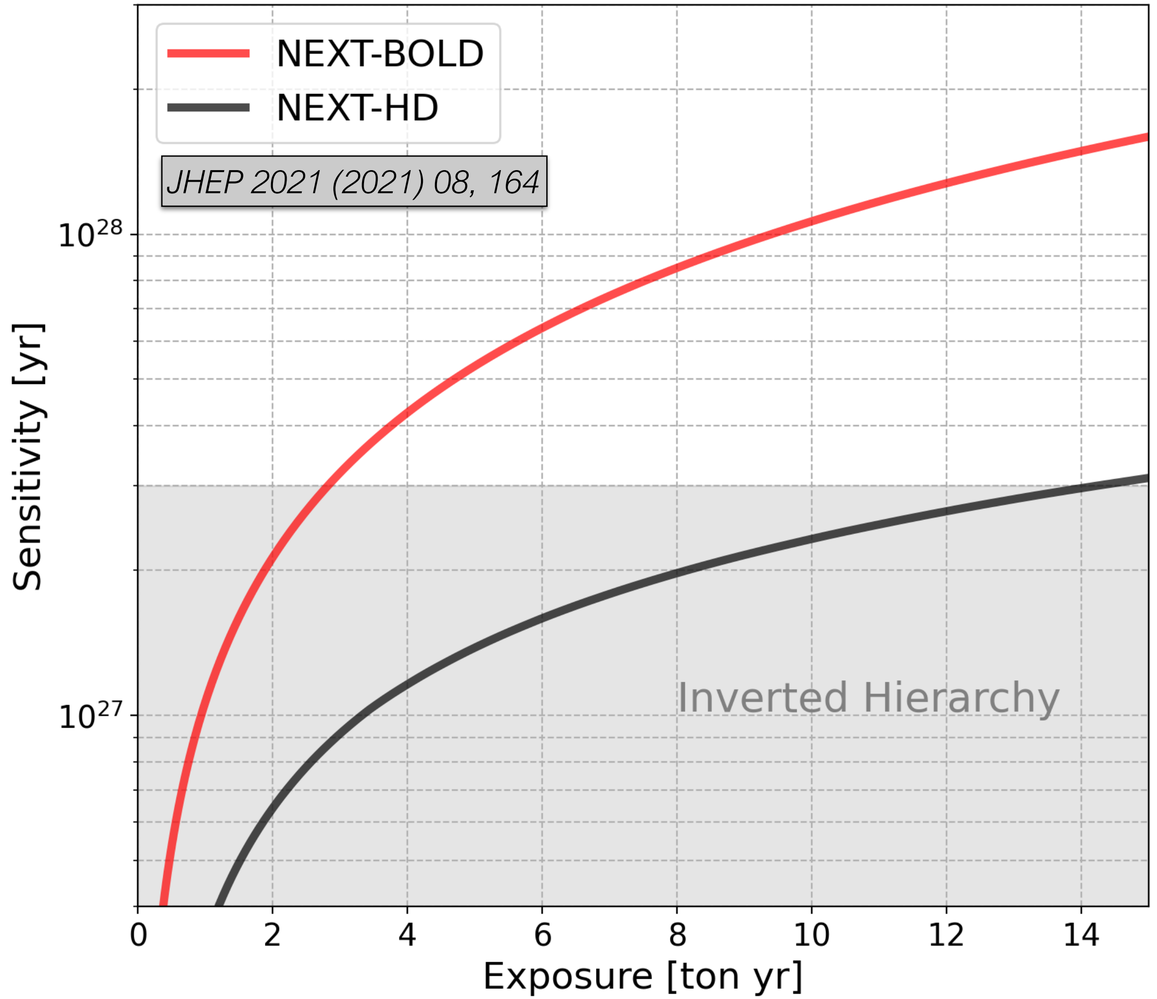






NEXT 0νββ sensitivity prospects at the tonne scale

- NEXT-HD first module can reach **10^{27} yr** sensitivity with **4 ton·yr** exposure.
- To explore **10^{28} yr** sensitivity, further background reduction and higher signal efficiency are essential.
- Both may be achieved with NEXT-BOLD, implementing Barium Tagging.



Summary

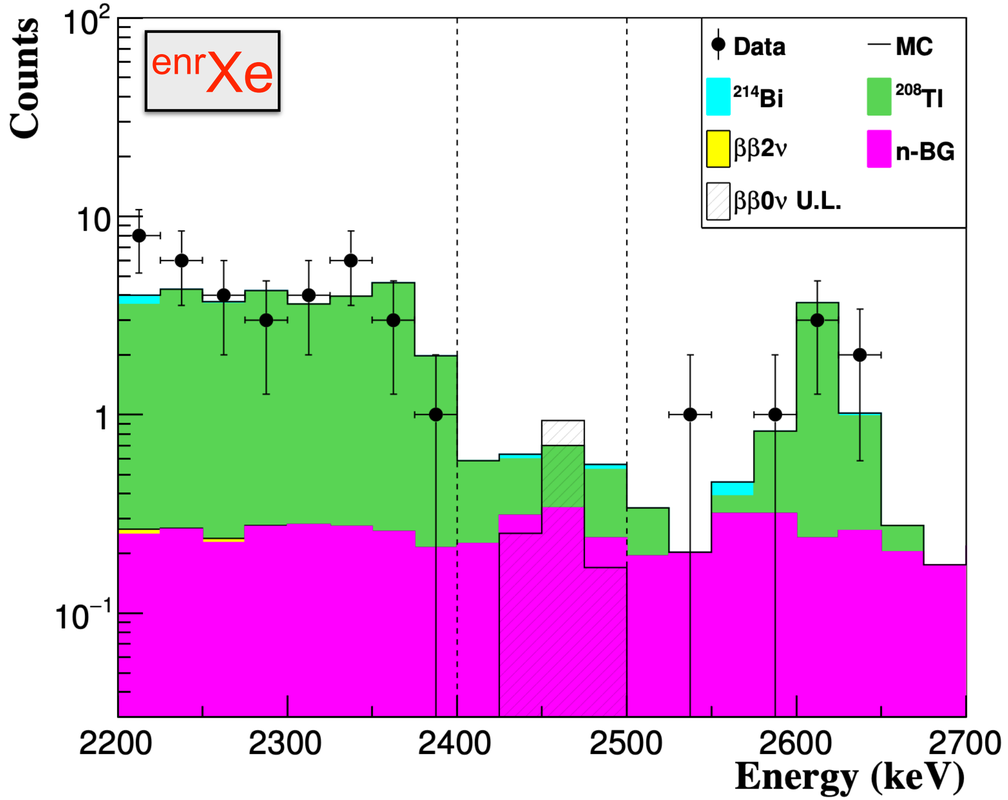
- The three aces and the joker up our sleeves for 0νββ searches in ^{136}Xe gas detectors:

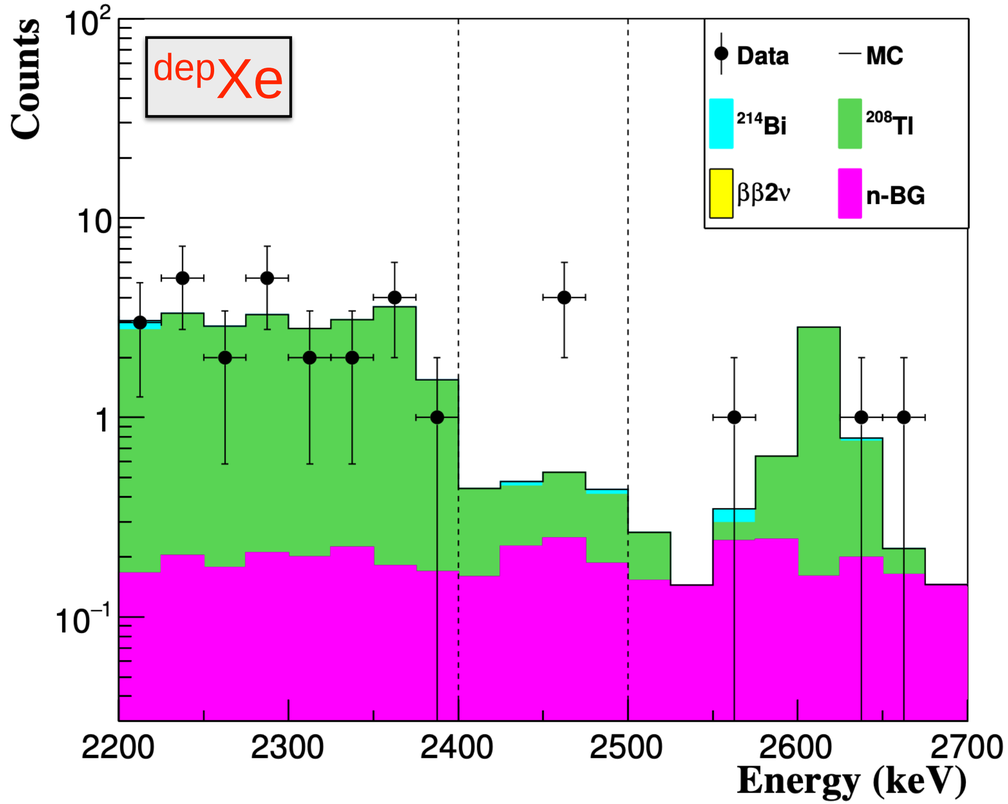
♠ energy resolution, ♦ topological identification, ♣ scalability,  barium tagging

- **Recent past**: detector performance, backgrounds and 2νββ with NEXT-White (~5 kg)
- **Short-term future**: 0νββ searches at the 100 kg scale with NEXT-100
- **Medium term**: 0νββ searches at the tonne scale with NEXT-HD
- **Longer term**: NEXT-BOLD, a tonne-scale detector implementing barium tagging

Backups

0νββ search in NEXT-White



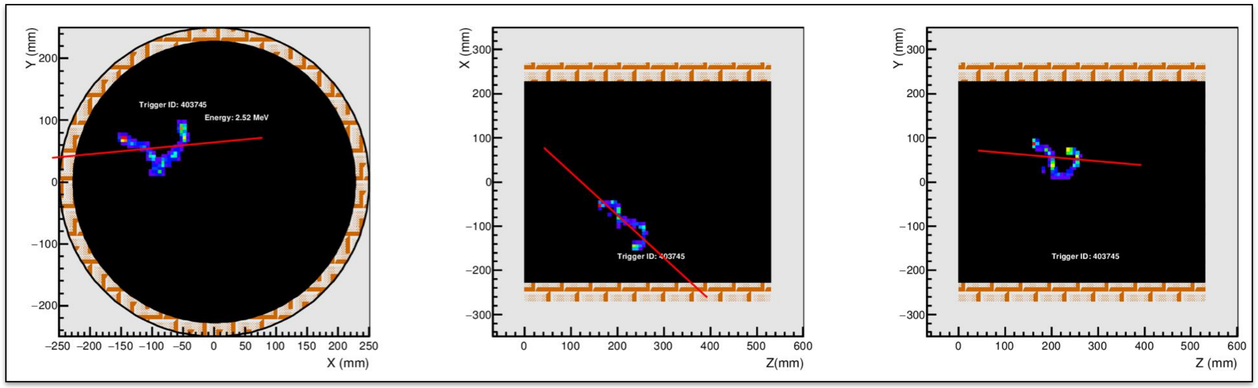


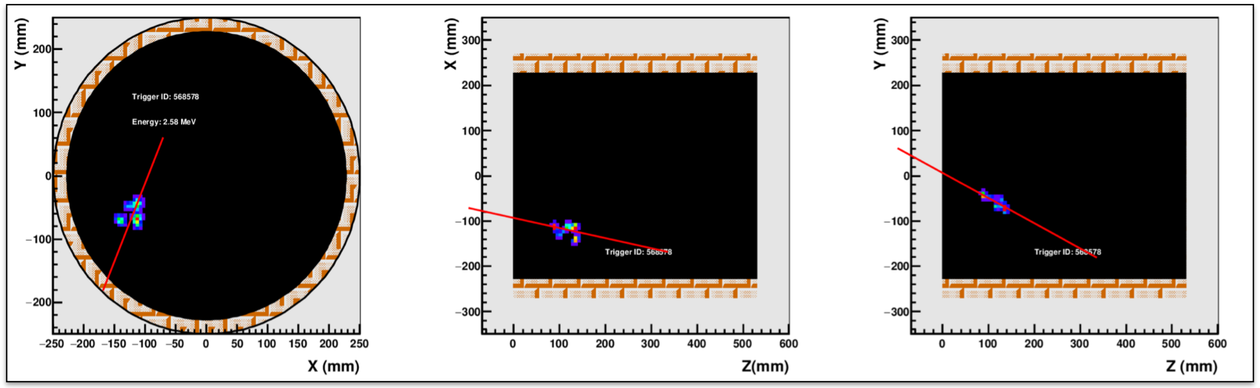
- In 100 keV wide energy ROI near $Q_{\beta\beta}$: **0** events in ^{enr}Xe run, **4** events in ^{dep}Xe run
- Background expectation: 1.8±0.3 yr^{-1} radiogenic, 1.5±0.9 yr^{-1} cosmogenic

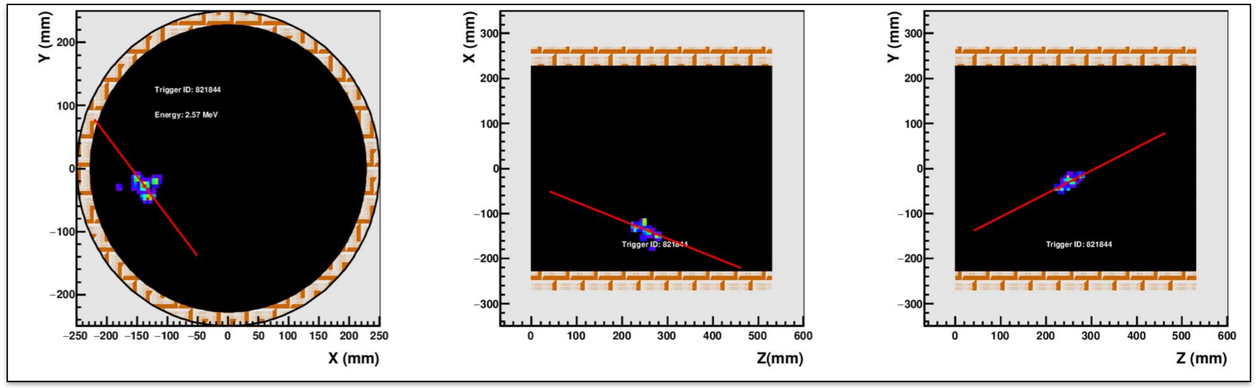
PRELIMINARY

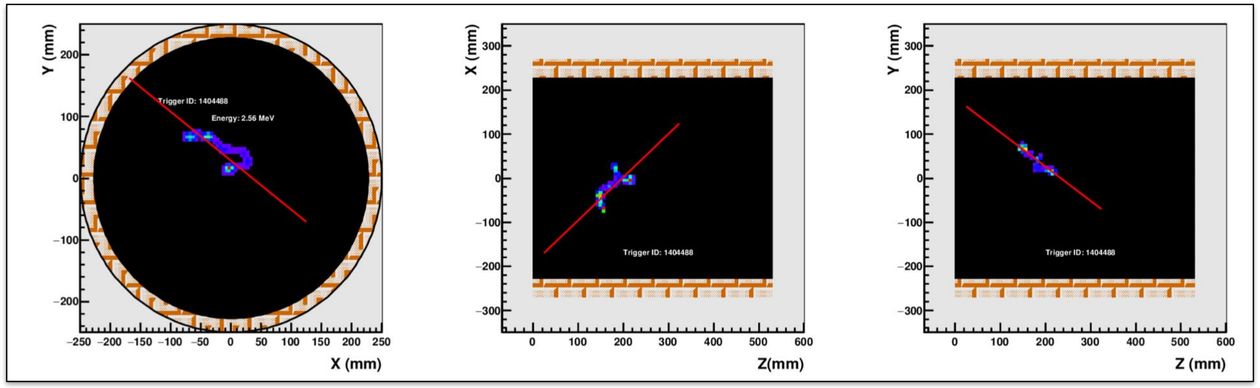
NEXT-White four ββ candidates in ROI, ^{dep}Xe run

PRELIMINARY









NEXT-100 projected sensitivity

- Target background budget: 5×10^{-4} counts/(keV·kg·yr), or 1 count/(ROI·yr)
  - *Estimated main contributors (preliminary): copper shield, tracking readout connectors, PMT bases*
- Global 0νββ efficiency: 28%
- For a 3-yr exposure and at 90% CL:
  - $T_{1/2} > 6\times10^{25}$ yr
  - $m_{\beta\beta} < 80\text{-}160$ meV

JHEP 05 (2016) 159