The search for $0\nu\beta\beta$ with the NEXT time projection chamber

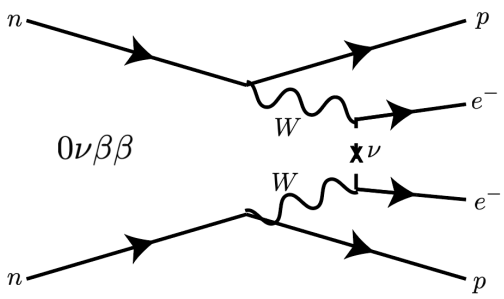
Krishan Mistry on behalf of the NEXT collaboration

5th August 2022

NuFACT 2022

Neutrino Experiment with a Xenon TPC (NEXT)

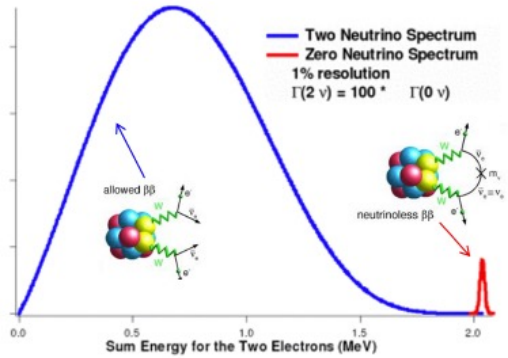
- NEXT is a $0\nu\beta\beta$ experiment that uses a high-pressure gaseous time projection chamber
  - ⇥ Xenon-136 $2\nu\beta\beta$ isotope - we can exploit its properties as a noble element



- Searching for tiny signal at end point of $2\nu\beta\beta$ spectrum
  - ⇥ To maximise discovery our potential, we must consider these four categories for our detector:

Energy Measurement

Topological Reconstruction



Scalability

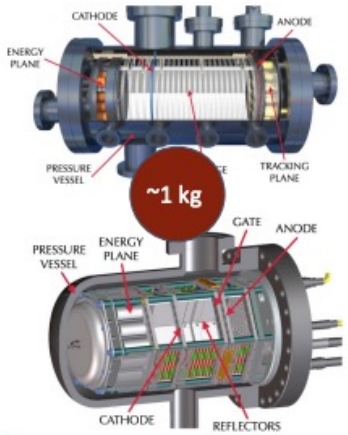
Low-background

The NEXT Program

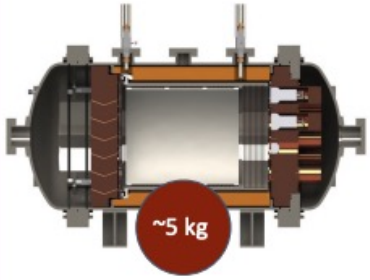
- Series of High Pressure Gaseous Xenon Time Projection Chambers with a rich R&D program
  - ⇥ NEXT-100 is the latest experiment and is in the final stages of construction!

We are here!

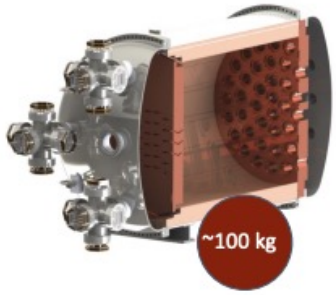
Prototypes
2008-2014
Demonstration of detector concept



NEXT-White
2015-2021
Background model assessment
$2\nu\beta\beta$ measurement for ^{136}Xe



NEXT-100
2022-2025
Background model assessment
Neutrinoless double beta decay search in ^{136}Xe



NEXT-HD
2026?
Neutrinoless double beta decay search through inverted neutrino mass ordering

NEXT-BOLD
Barium tagging for background-free experiment

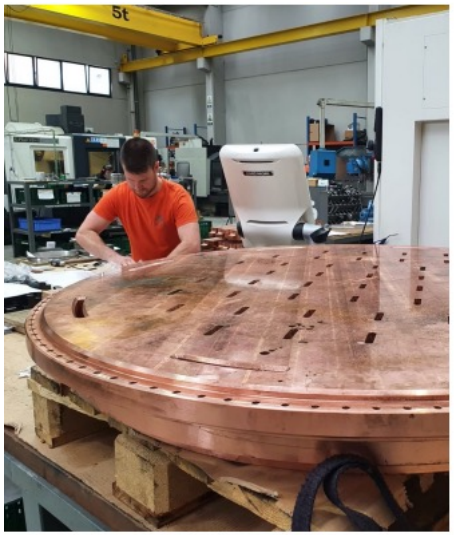
2009 2014 2015 2021 2022 2025 2026

NEXT-100 is coming soon!

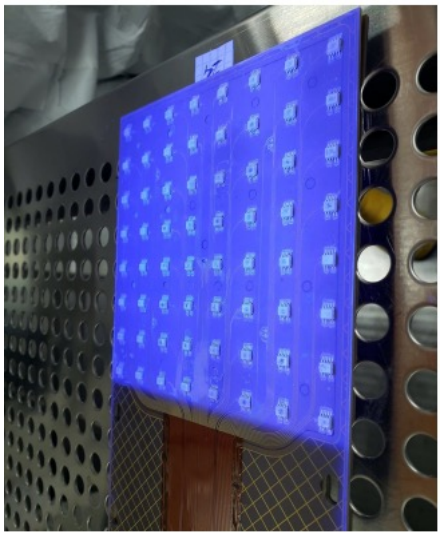
- Many of the TPC components of NEXT-100 have been completed and are ready to be installed

Pressure Vessel

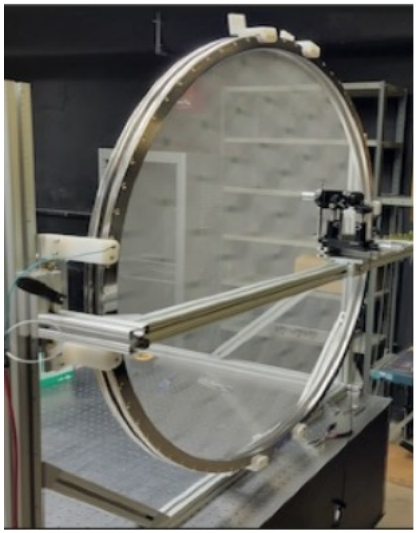
Copper Shielding



Tracking Plane SiPM boards

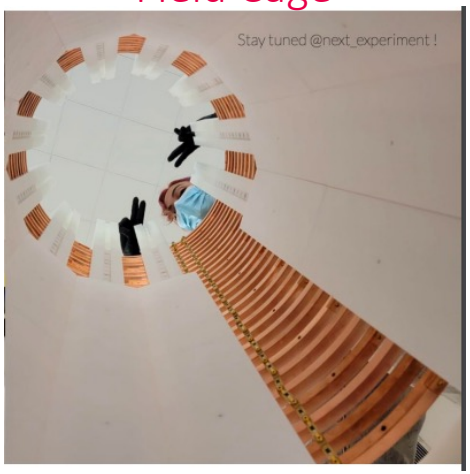


EL Region



Lead Castle

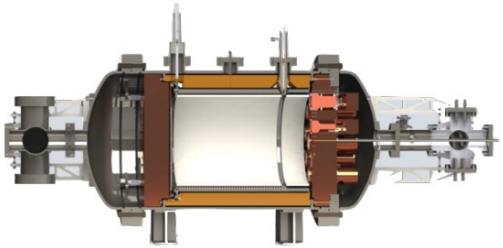
Field Cage



Asymmetric TPC Design

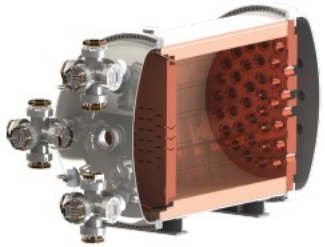
NEXT-White

~5 kg



LSC
Laboratorio Subterráneo Canfranc

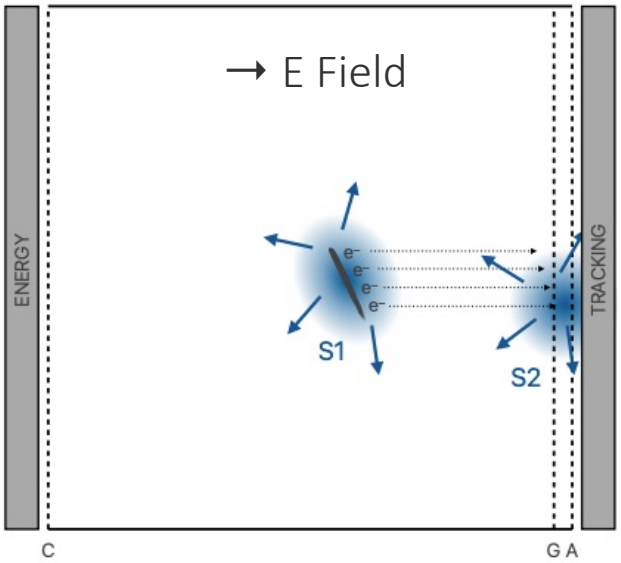
NEXT-100



~100 kg

- S1 (prompt) light used for triggering
- S2 (secondary) used for energy measurement and tracking

Asymmetric TPC design



- TPB used to wavelength shift the VUV light to visible
- Detectors are located at the Canfranc underground research facility

See talk from Gonzalo Diaz for more details on NEXT-White and NEXT-100!

Energy resolution

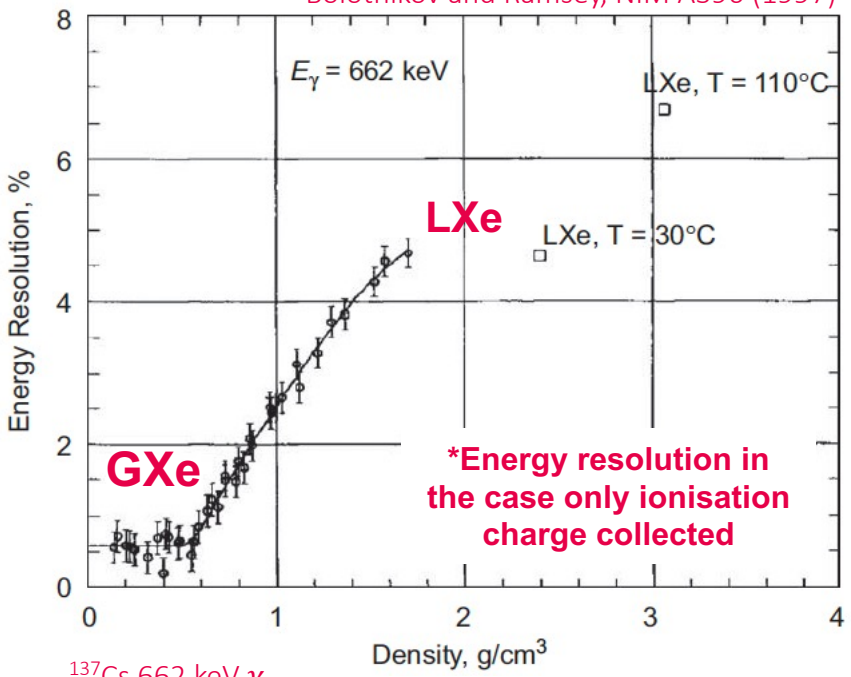
Require better than 2% energy resolution to effectively reject $2\nu\beta\beta$

- $0\nu\beta\beta$ decay: $^{136}Xe \rightarrow {}^{136}Ba^{2+} + 2e^-$
  - All energy transferred to the electrons which deposit their energy in the detector

- Gaseous phase: **energy resolution near the Fano limit**
  - Recombination is negligible
  - Sub-percent energy resolution at $Q_{\beta\beta}$ possible using only ionisation charge
  - NEXT-White has demonstrated 1% energy resolution

JINST 13 (2018) 10, P10020; JHEP 10 (2019) 230

Bolotnikov and Ramsey, NIM A396 (1997)



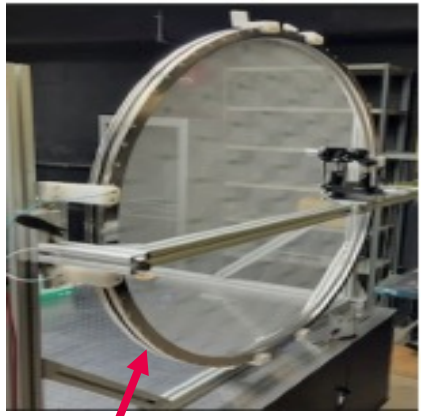
^{137}Cs 662 keV γ

Electroluminescence (EL)

- NEXT uses EL to amplify the ionisation charge

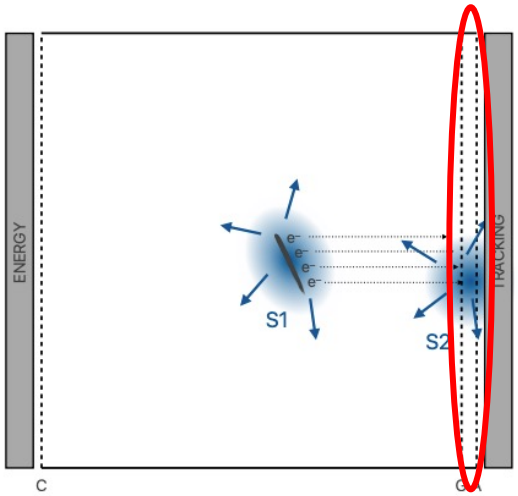
- Charges are accelerated and excite the xenon
  - Operated so that there is no ionisation
  - Scintillation emission (electroluminescence!) with gains from 10^3 - 10^5, proportional to initial charge
  - Near fluctuation-less gain - preserving good energy resolution

NEXT-100 EL Region!

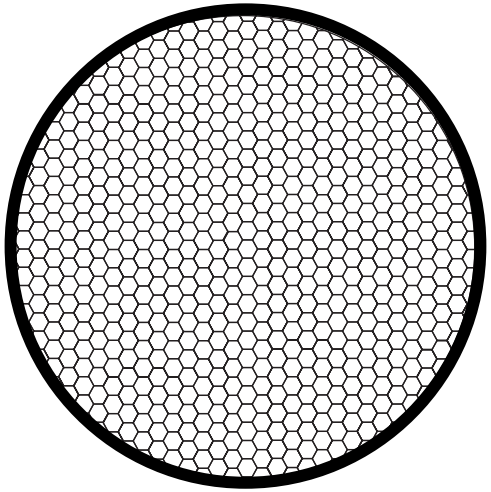


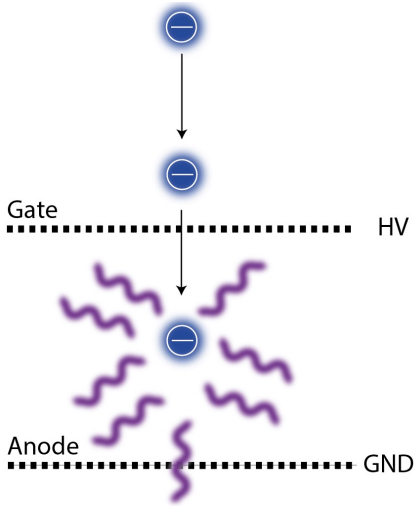
Two tensioned hexagonal meshes with front mesh biased to -HV

EL Region



EL Grid





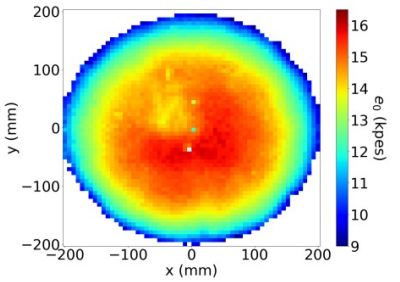
Calibration in NEXT

- NEXT uses several radioactive sources to calibrate the detector

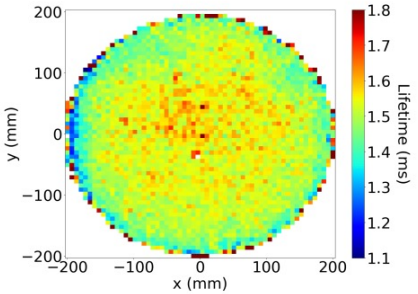
- Low energy: ^{83m}Kr (short half-life ~1hr)
  - Point-like depositions (41.5 keV) uniformly distributed throughout the active volume
  - Calibration maps generated for geometrical and lifetime corrections
  - Continuous monitoring of detector conditions

JINST 13 (2018) no.10, P10014

Geometric Corrections

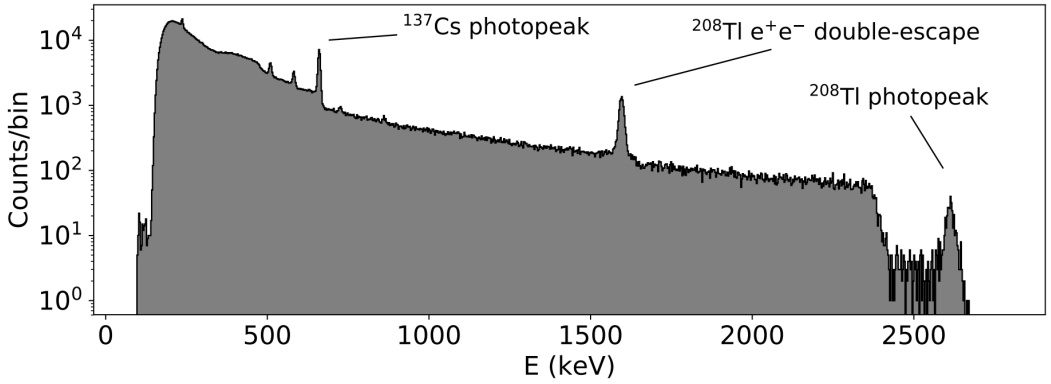


Lifetime Corrections



- High energy: ^{208}Tl (2615 keV) and ^{136}Cs (662 keV):
  - Energy resolution at Q value
  - Energy scale
  - Energy resolution vs E

JHEP 10 (2019) 230; JINST 13 (2018) no.10, P10020



Topology reconstruction

Gammas produced from natural radioactive decay chains can populate signal region (Q = 2.458 MeV)

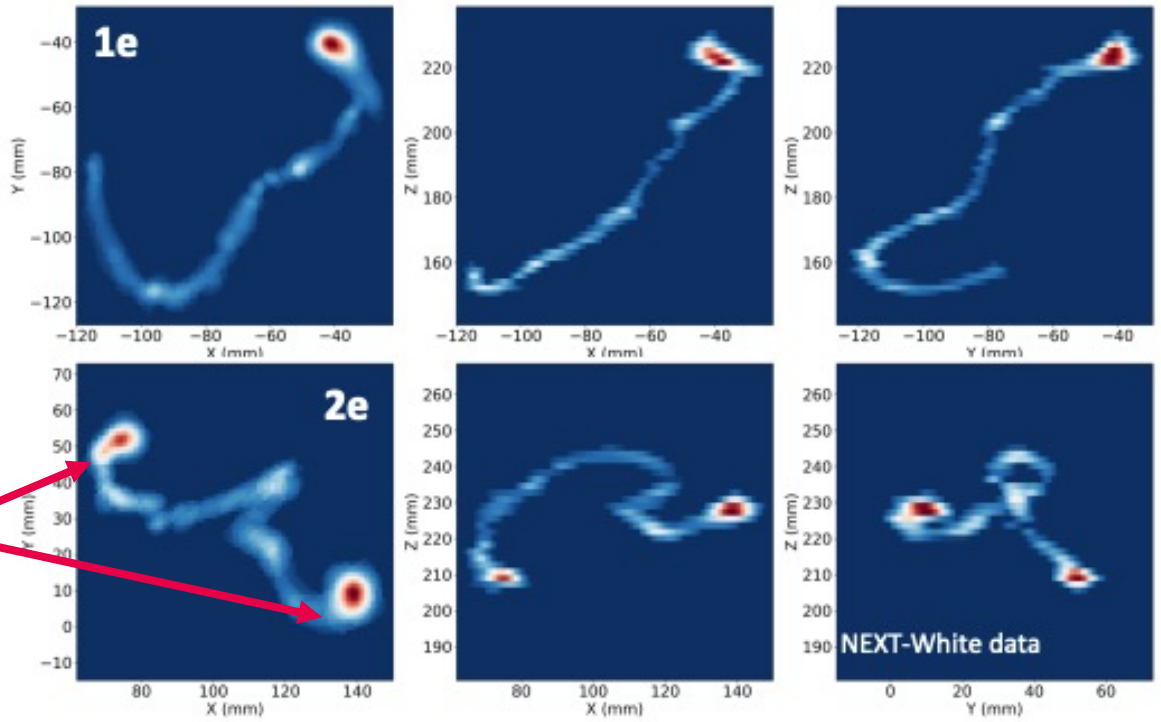
- ^{208}Tl decays to ^{208}Pb → de-excitation γ at 2.614 MeV
- ^{214}Bi decays to ^{214}Po → de-excitation γ at 2.447 MeV

} single electron events

Reconstruction of the topology allows for effective rejection of single electron events

- "blobs" at end of tracks used to identify $2e^-$ vs $1e^-$

NEXT-White Data

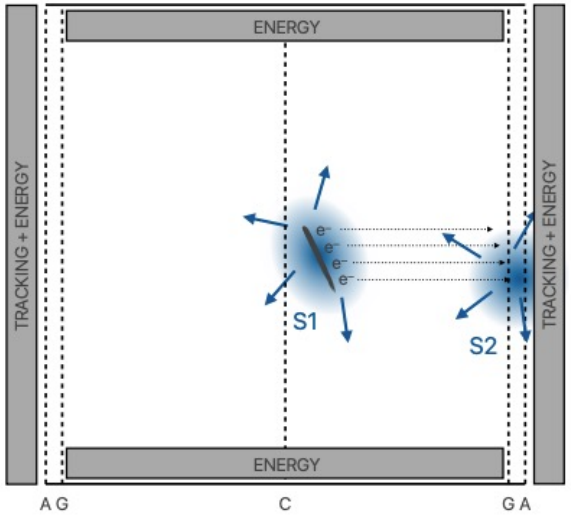


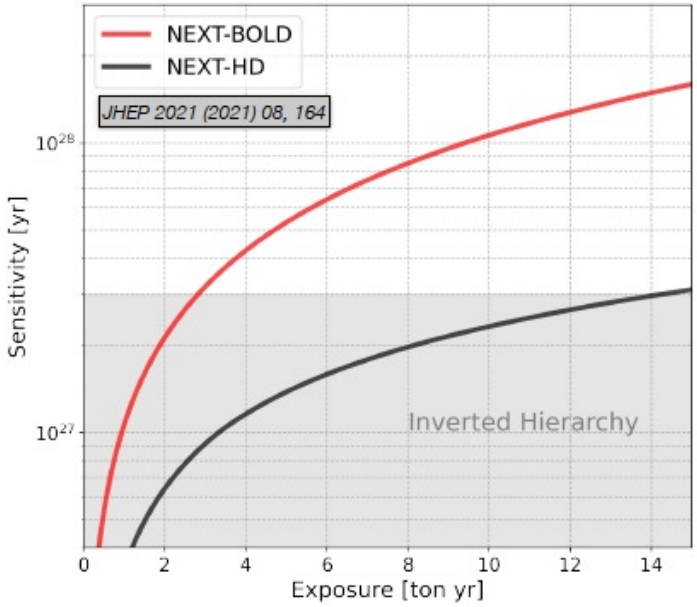
Scalability: towards the tonne scale

Tonne-scale detector required to reach target sensitivities towards $T_{1/2}$ ~10^{28} yr and cross the inverted hierarchy region

- Tonne scale TPCs required with minimal background acceptance
  - ⇥ Estimated background 0.09 to 0.27 count/(tonne year ROI)
- Symmetric TPC design helps reduce drift time (→ reduce diffusion)
- NEXT-tonne will be a multi-module system with ongoing R&D for future modules including barium tagging

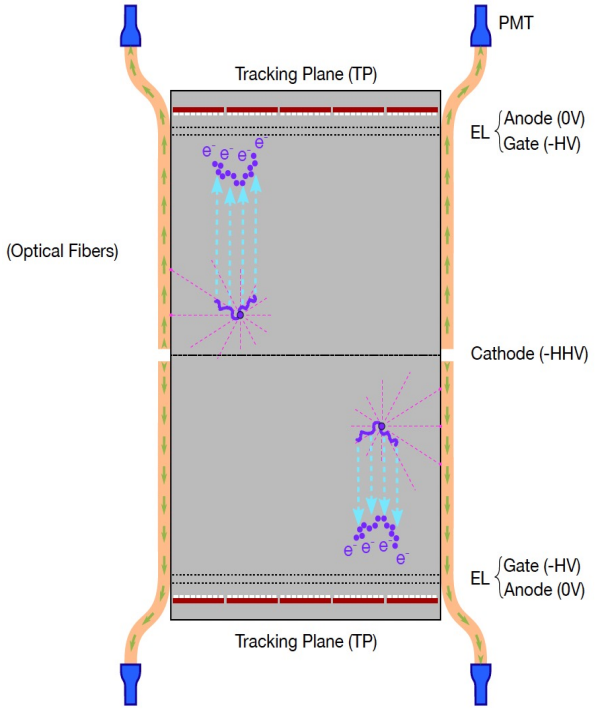
Symmetric TPC design

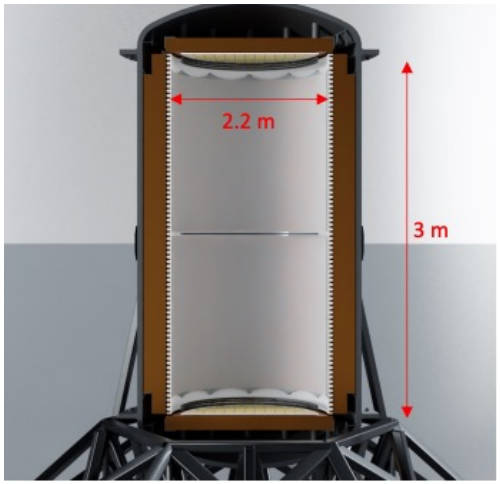




NEXT-HD: first tonne scale module

- Optical fibres around barrel of the TPC for energy measurement
  - ⇥ Detection via SiPM removing the use of PMTs which are a significant source of radioactivity
- Dense SiPM plane readout for high resolution tracking
- Potential use of additives:
  - ⇥ ^{4}He to reduce diffusion
  - ⇥ ^{3}He to reduce neutron capture on ^{136}Xe - which will be a significant background for NEXT at this scale J. Phys. G: Nucl. Part. Phys. 47 075001



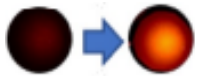


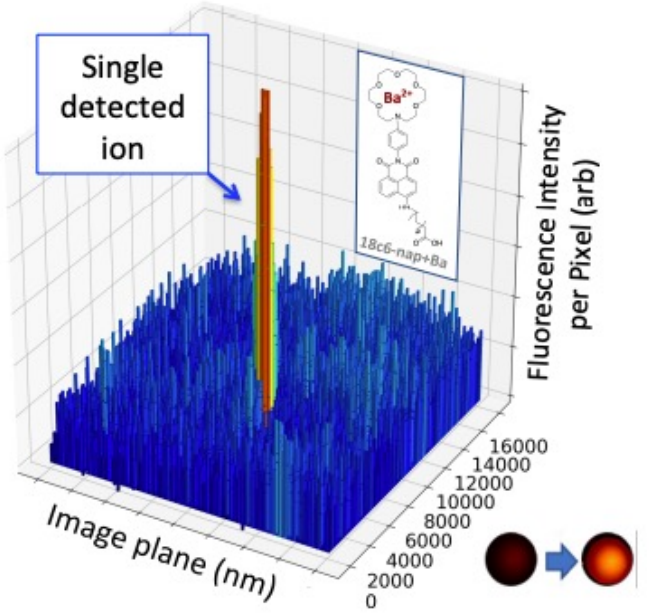
NEXT-BOLD: making barium shine

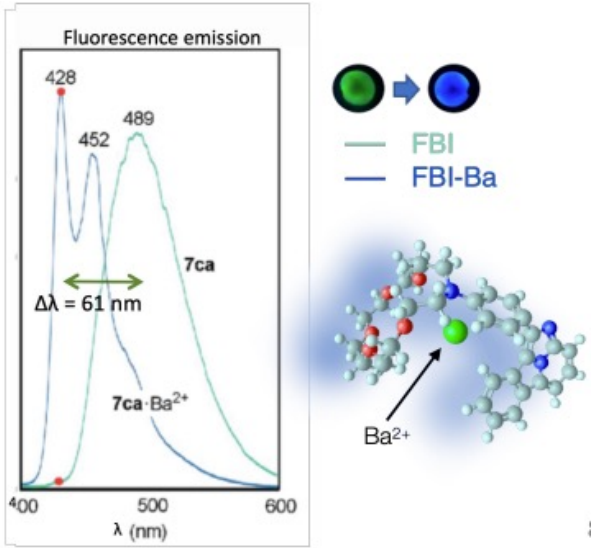
Tagging the barium ion in co-incidence with a two-electron signal in the ROI would yield a background free tonne-scale experiment

- Single molecule fluorescent imaging employed to detect the Ba^{2+} daughter

- NEXT has developed custom barium chemo-sensing molecules with demonstrated single ion response in dry environments

- Active R&D programme with two approaches:
  - Turn-on  JINST 11 (2016) 12, P12011; Phys. Rev. Lett. 120 (2018) 13, 132504; Sci.Rep. 9 (2019) 1, 15097
  - Bi-colour  Nature 583 (2020) 7814, 48–54 , arXiv:2201.09099

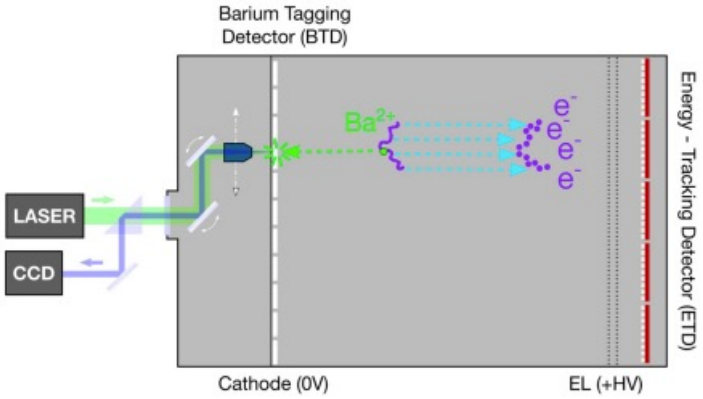




Ba tagging demonstrator phases

Demonstrator phases under intensive development under 2-3 yr time-scale

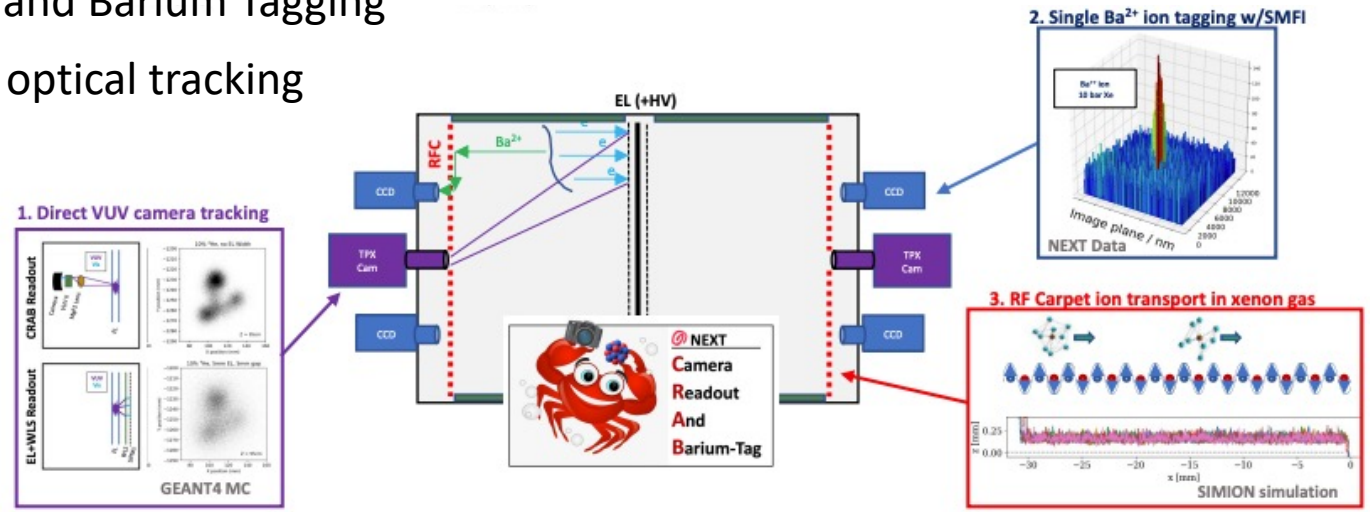
NEXT-BTD Concept



- BTD: Barium Tagging Detector
- Bring the sensor to the single-ion location

NEXT-CRAB Concept

- CRAB: Camera Readout and Barium Tagging
- High speed cameras for optical tracking
- MCP-PMT development for energy measurement
- Bring ion to sensor using RF-carpet



JINST 15 (2020) 04, P04022

Summary

- The NEXT experiment is a high-pressure xenon TPC searching for $0\nu\beta\beta$ decay with a phased program
- Sub-percent energy resolution is achievable using electroluminescent amplification
- Topological information is used to effectively reject single-electron backgrounds
- NEXT-100 experiment is in the final stages of construction
- Subsequent phases at the tonne scale aim to enter the inverted hierarchy region
- Barium tagging R&D program is making good progress with single ion sensitive compounds with demonstrator phases aiming for results in the next few years


Thank You!