NEXT-HD, a tonne scale detector for neutrinoless double beta decay searches

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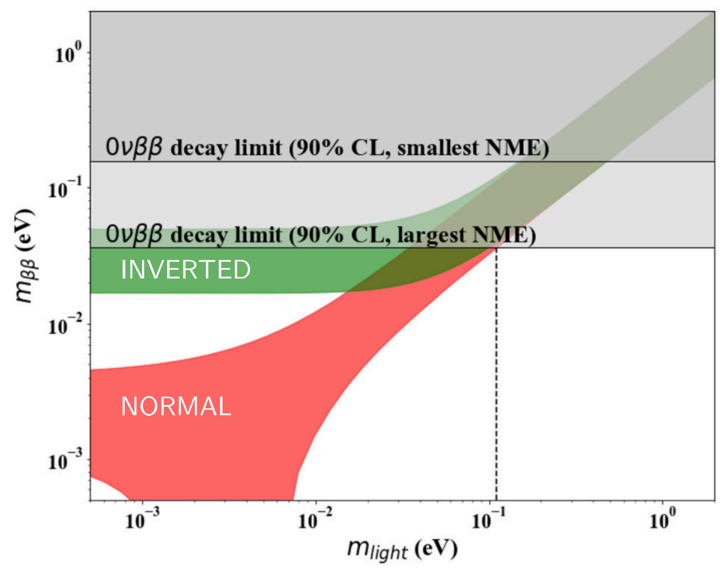
1 Sensitivity for future generation experiments

To explore the Inverted Hierarchy (IH) region **tonne-scale** detectors are needed.



For an experiment with background (c): an improvement of a factor **10 in $m_{\beta\beta}$** requires a factor of **10000 in isotope mass** (M) for the same running time (t). For a background-free experiment: $\mathbf{S(T^{0\nu}_{1/2}) \propto M}$

$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2\, m^2_{\beta\beta}$$

$$\mathcal{S}(T^{0\nu}_{1/2}) = K\,\epsilon\,\sqrt{\frac{Mt}{c\,\Delta E}}$$

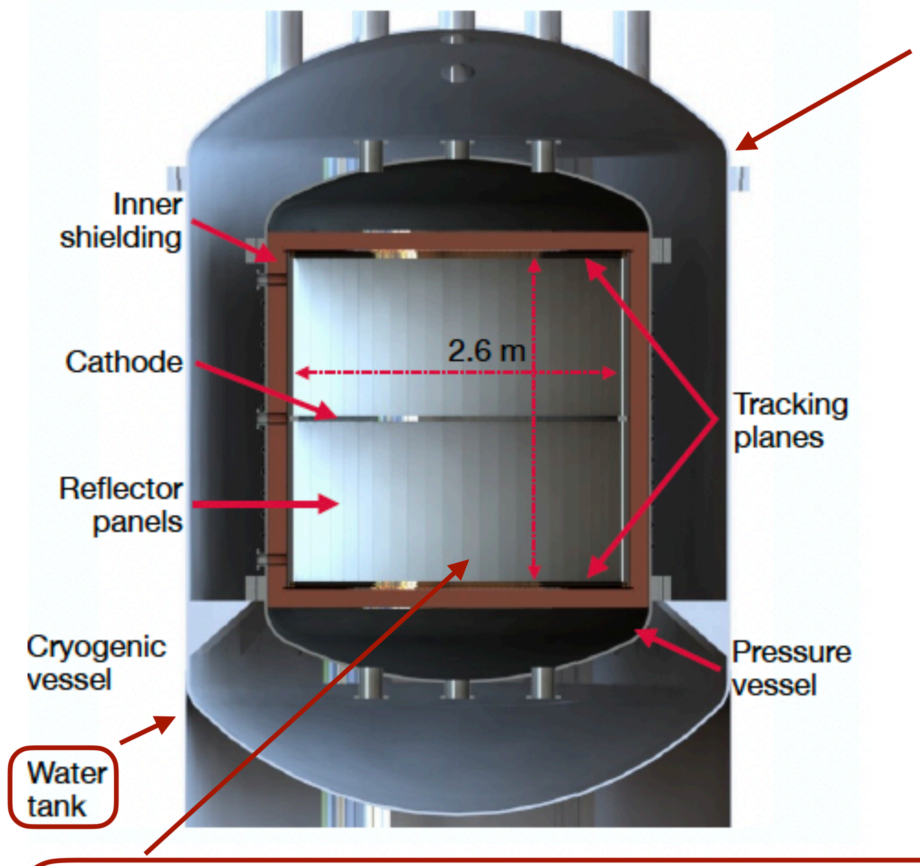
Effective Majorana Mass:

$$m_{\beta\beta} = |\sum_i m_i\, U^2_{ei}|$$

IH corresponds to a half-life sensitivity of $\sim 10^{27}$-10^{28} **yr**

2 NEXT-HD baseline Concept

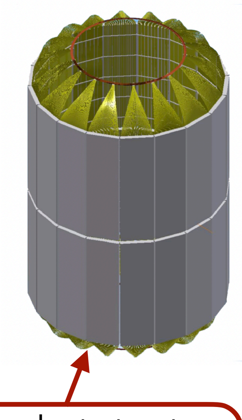
The NEXT-HD detector will explore the IH region with a **high-pressure electroluminescent (EL) TPC** cointaining 1 tonne of Xe enriched at 90% ^{136}Xe.



Symmetric TPC detector with two drift regions of 1.5 m and 2.2 m diameter holding **1 tonne a 15 bar.** With a:

1) barrel fiber detector made of wavelength-shifting optical fibers for the **energy measurement** (PMTs replaced to reduce background budget)

2) **high definition tracking plane** made of $\sim 10^5$ SiPMs with 5 (or 10) mm spacing, read out by in-vessel **ASICs**



Barrel fiber readout structure

Streched **photo-etched meshes** like the ones in NEXT-100 (parallel-wire grids as alternative solution), more on NEXT-100 see poster #622.

3) gas mixtures: low diffusion (Xe+He4) to improve track resolution [1] and He3 to mitigate cosmogenic backgrounds [2]

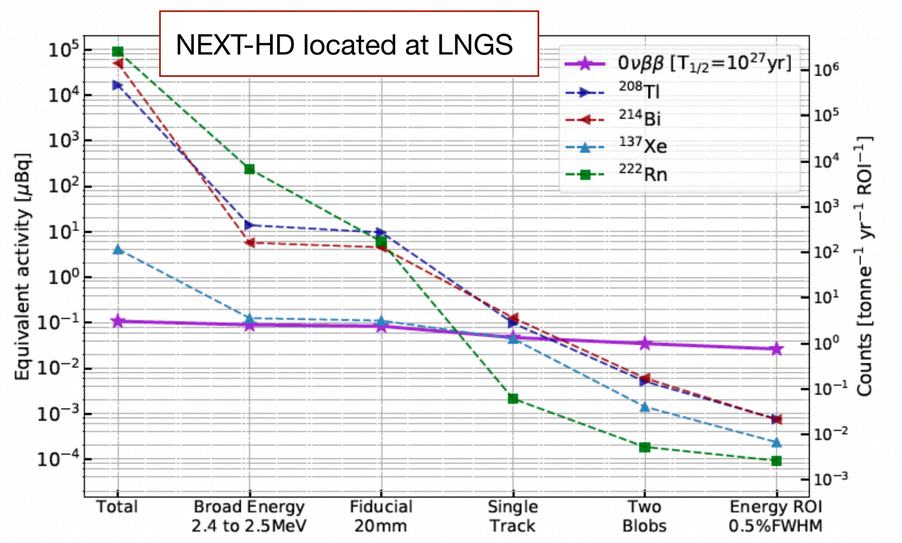
✓ **First module** to be installed at the Laboratorio Subterraneo de Canfranc (**LSC**), but collaboration open to a multi-modular approach to reach large exposures.

3 NEXT-HD background

To explore the IH the background index must be **< 1 count/tonne/year/ROI**

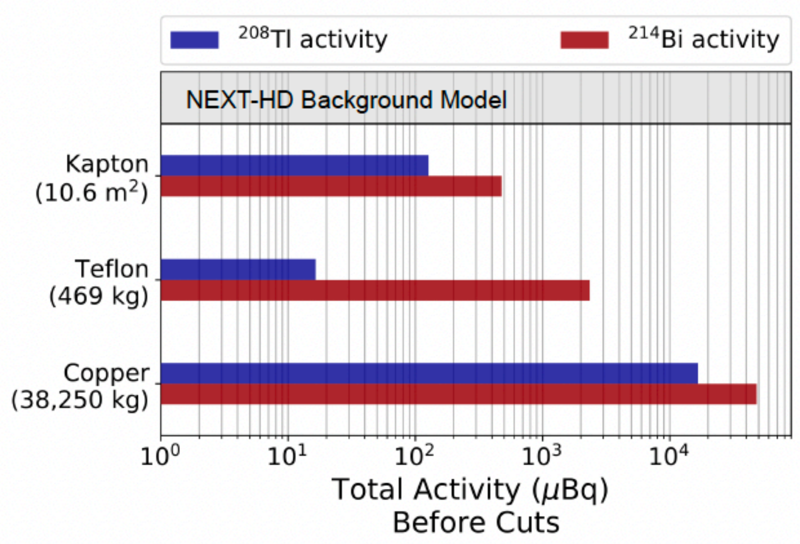
Background sources for the NEXT-HD detector include:

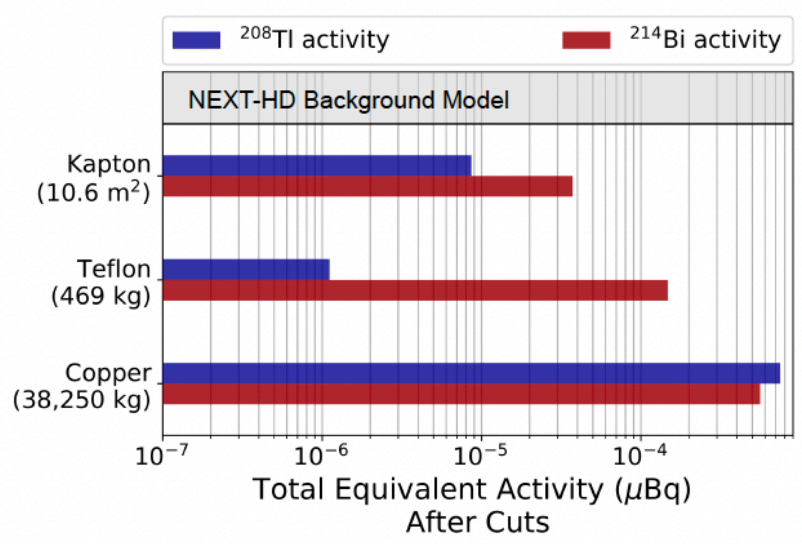
1) **natural radioactivity** in detector materials: ^{208}Tl (from ^{238}U) ^{214}Bi (from ^{232}Th) gamma-rays
2) **Radon** ^{220}Rn and ^{222}Rn diffuse from detector materials or gas system (subdominant)
3) **Cosmogenic background**: from neutron captures on detector materials (dominated by copper isotopes but also plastics and pressure vessel) and ^{136}Xe.



Det. system	Acceptance $[10^{-8}]$ ^{208}Tl	Acceptance $[10^{-8}]$ ^{214}Bi	Background index $[\mathrm{ton}^{-1}\,\mathrm{yr}^{-1}\,\mathrm{ROI}^{-1}]$
Field cage	6.80(90)	6.30(80)	4.25×10^{-3}
Readout planes	6.80(90)	7.80(80)	1.36×10^{-3}
Inner shielding	4.50(70)	1.20(70)	37.23×10^{-3}
Radon (cathode)	—	0.10(10)	2.72×10^{-3}

Source gas	Acceptance $[10^{-5}]$	Background index $[\mathrm{ton}^{-1}\,\mathrm{yr}^{-1}\,\mathrm{ROI}^{-1}]$
Pure xenon	5.68(17)	113.49×10^{-3}
0.1% ^{3}He doping		11.78×10^{-3}



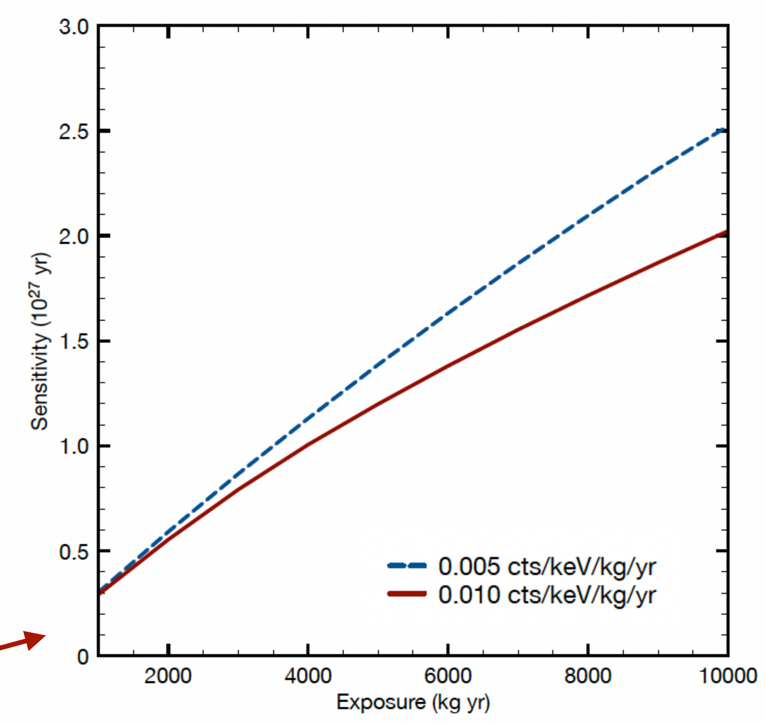


✓ Effectiveness of cut-based analysis and power in topological analysis in NEXT-HD leads to a background rate of **~0.17 count/tonne/year/ROI**

4 NEXT-HD sensitivity

Considering the total background index and the following experimental parameters for NEXT-HD:

Source mass (^{136}Xe)	1109 kg
Signal efficiency	24.6%
Background rate	$0.010\,\mathrm{keV}^{-1}\,\mathrm{t}^{-1}\,\mathrm{yr}^{-1}$
	$0.168\,\mathrm{ROI}^{-1}\,\mathrm{t}^{-1}\,\mathrm{yr}^{-1}$
Energy resolution	0.5% FWHM at 2458 keV
$\overline{T}_{1/2}$ (5 t yr)	1.2×10^{27} yr at 90% CL
$\overline{T}_{1/2}$ (10 t yr)	2.0×10^{27} yr at 90% CL



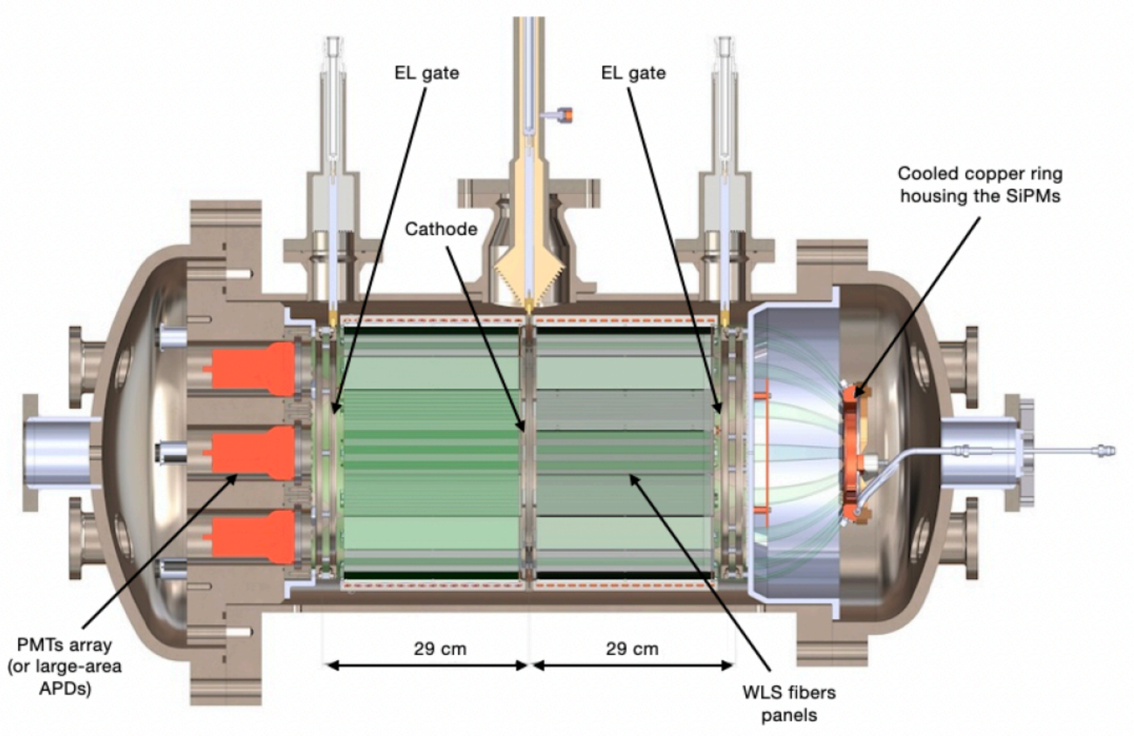
Projected sensitivity (90% CL) NEXT tonne-scale experiment located at LSC (solid red line) and LNGS (dashed blue line) [3]

✓ In less than 5 years of operation, the NEXT-HD detector could reach a half-life sensitivity of **1.2 x 10^{27} yr (90% CL)**

5 Towards NEXT-HD and beyond: ongoing R&D

Fiber Barrel R&D

The goal is to demonstrate an overall **photon detection efficiency (PDE) of 1-2%** (NEXT-White PDE is 1.4%) with the barrel fiber detector to maintain the energy resolution better than 1% FWHM and to detect the primary scintillation.



To validate the technology choice, the HD-DEMO [4] prototype is being built at DIPC with a barrel of WLS fibers covering the surface of the cylinder to detect Xe scintillation light, a symmetric design with a cathode in the middle and two anodes, and a readout using a PMT on one side and a cooled SiPM on the other side.

Camera Readout and Ba-Tagging (CRAB)

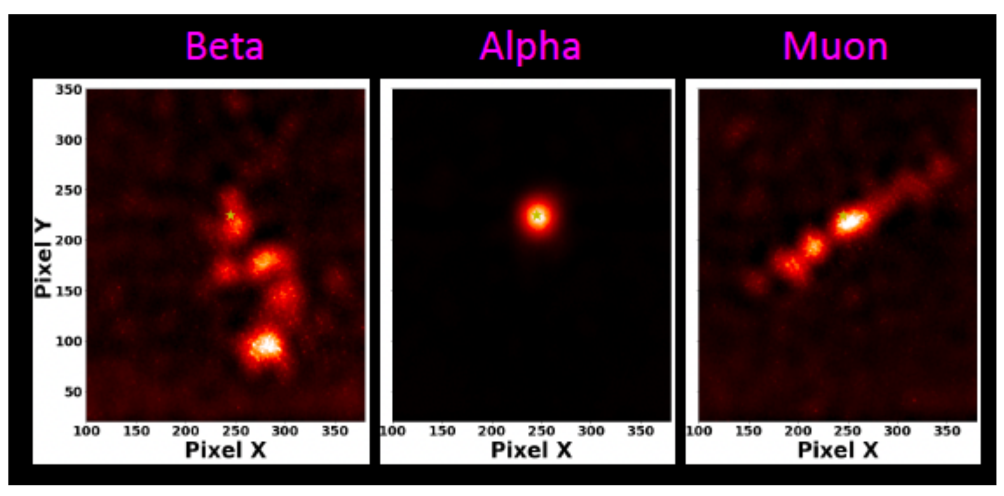
High-speed camera tracking is being pursued [5] to develop a detector with barium tagging (more in Ba-tagging in poster #909)

Advantages:

1) Entire redout system can be outside vessel, improving radiopurity and heat load within the detector
2) Simplified electronics
3) Focus from a distance rather than up close, freeing the cathode for Barium Tagging

Optical Readout System:

1) Image intensifier: amplifies light and converts into the visible with a gain of 3000
2) Camera: 3D tracks TPX2CAM with 1.6 ns resolution
3) Optics needed to focus onto the EL region



✓ **2D tracks**: Small scale optical TPC demonstrated proof-of-concept with an EMCCD camera coupled to an Image Intesifier

✓ **3D tracks:** Large scale optical TPC using TimePix3 camera, built at Argonne National Lab with first tracks expected soon

[1] Nucl.Instrum.Meth.A 905 (2018) 82-90
[2] J.Phys.G 47 (2020) 7, 075001
[3] JHEP 2021 (2021) 08, 164
[4] JINST 19 (2024) 04, C04042
[5] *JINST* 18 P08006 (2021)