

Status of the NEXT Experiment

And roadmap towards the ton-scale

2nd workshop on $\beta\beta 0\nu$ search in Xe: next-generation experiments

Pau Novella, IFIC (CSIC & U.V.)

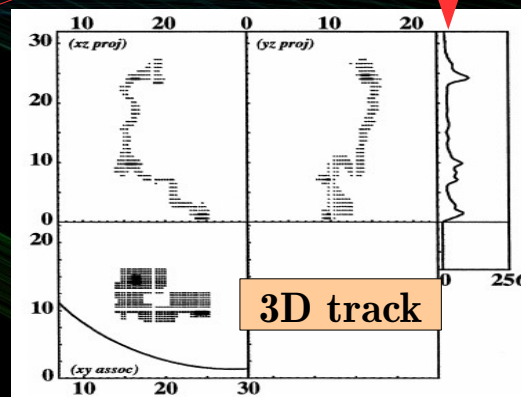
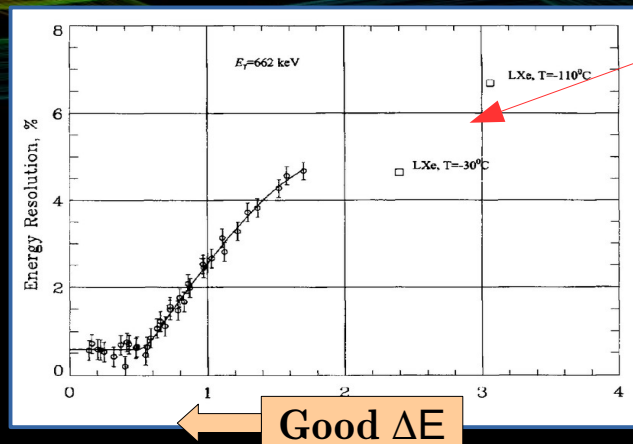
On behalf of the NEXT Collaboration

NEXT: HP Gas-Xe TPC Detectors

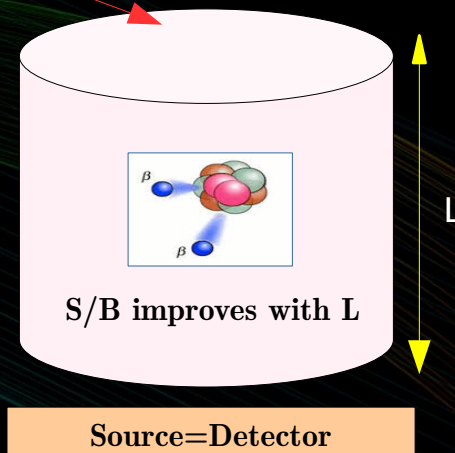
- Sensitivity to the $\beta\beta 0\nu$ decay:

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

Bolotnikov et al.
Nucl. Ins. Meth A 396 (1997)



R. Luescher et al, PLB 434 (1998)

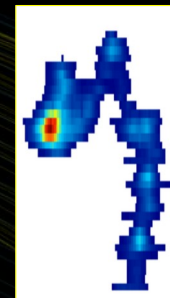
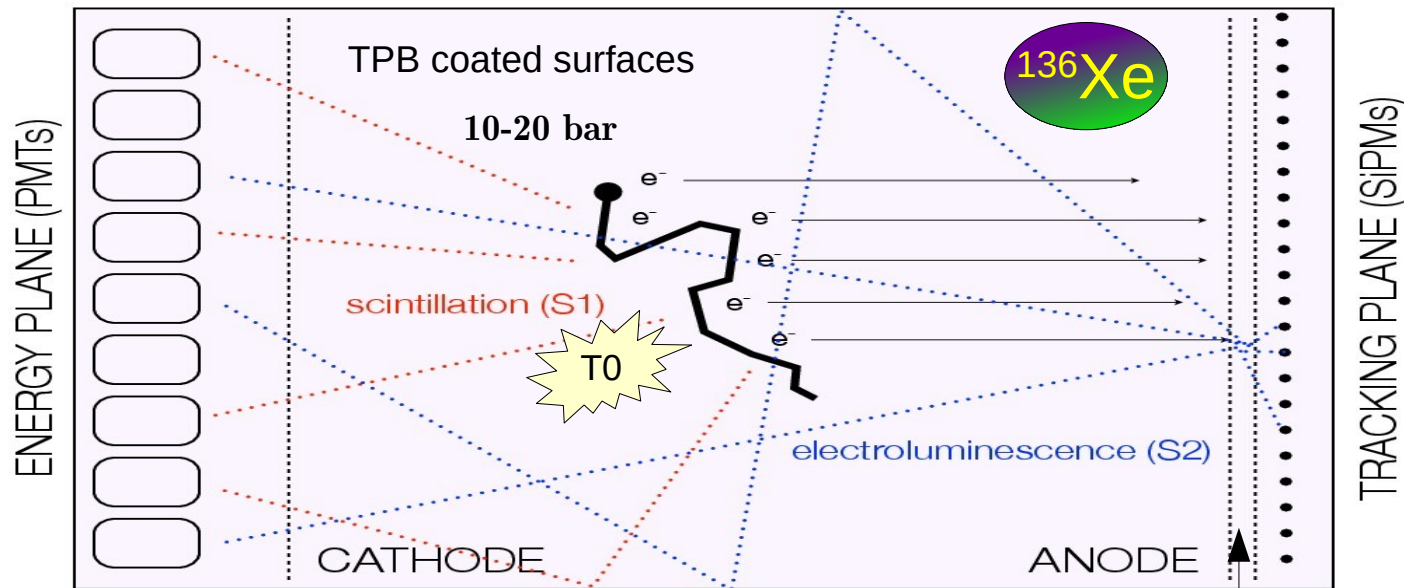
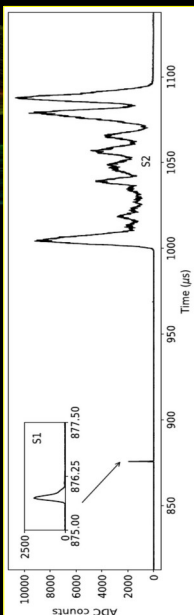


Gaseous
TPC

- Direct background measurement operating with Xe-136 depleted/natural xenon
- A given detector can be operated with different amounts of Xe (= different pressures)

The NEXT TPC Concept

Gas TPC with 2 dedicated readout planes

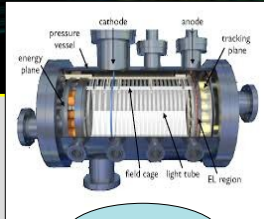


EL: linear gain, no avalanche fluctuations: optimize ΔE

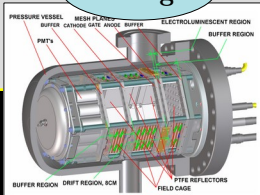
The NEXT Project

- Search for the $\beta\beta 0\nu$ decay with a HPXe-TPC

R&D
Proof of Concept

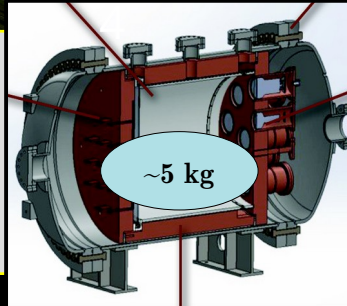


~1 kg



2009-2014

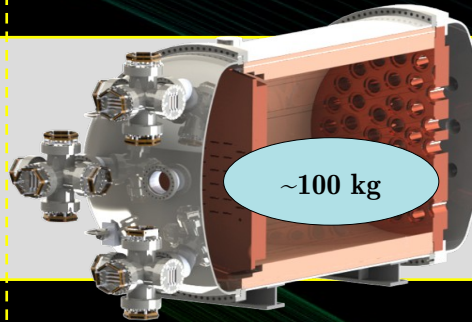
NEXT-White
Background+ $\beta\beta 2\nu$



~5 kg

2015-2021

NEXT-100 (+upgrades)
 $\beta\beta 0\nu$ search

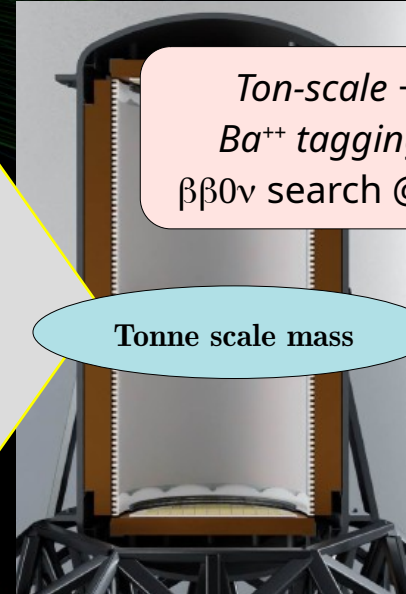


~100 kg

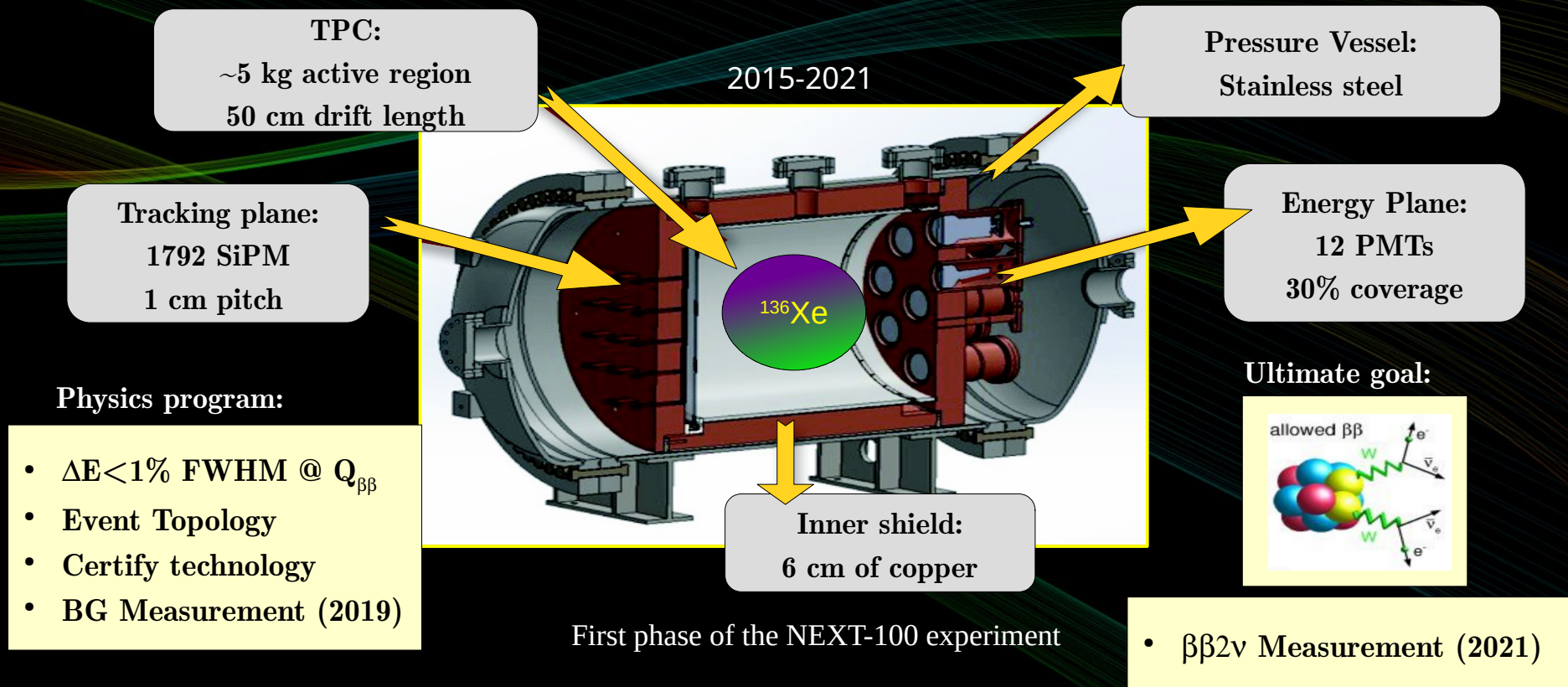
2024-2030

Ton-scale +
 Ba^{++} tagging:
 $\beta\beta 0\nu$ search @ IH

Tonne scale mass

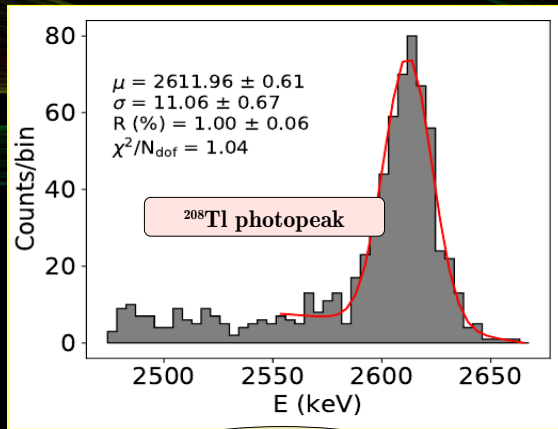


NEXT-White: Physics @ LSC

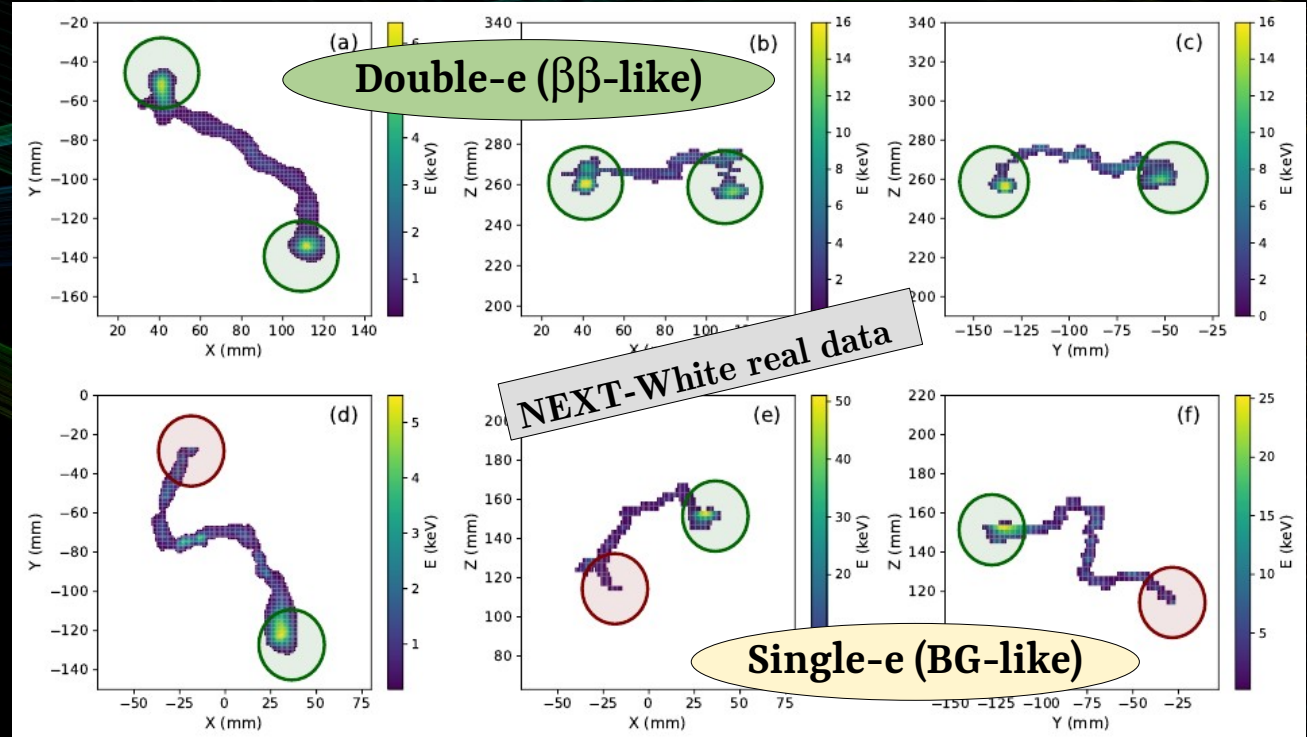


NEXT-White: Performance

JHEP 10 (2019) 230



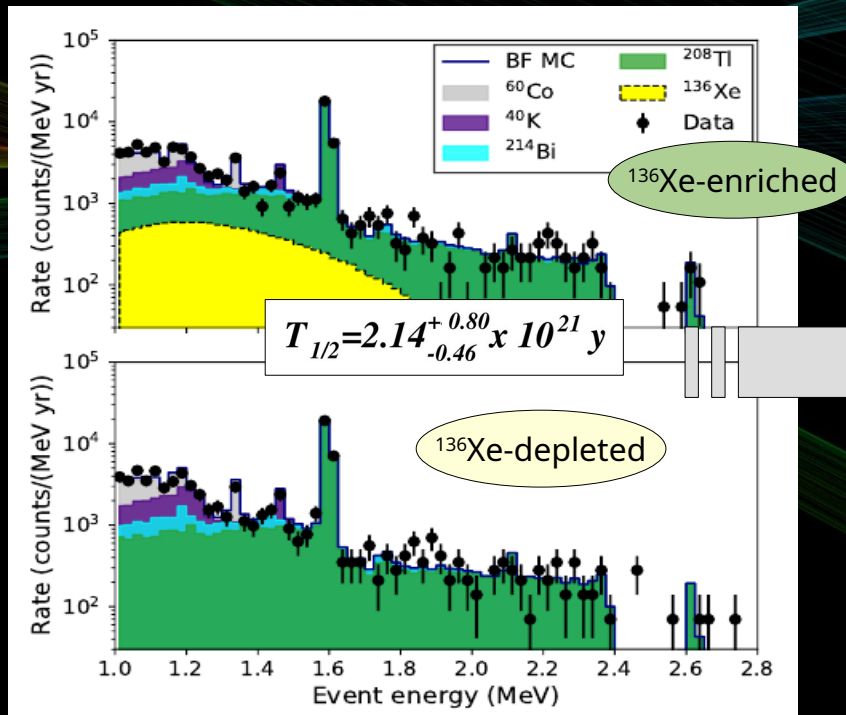
$\Delta E = 1\%$
 FWHM @ $\sim Q_{\beta\beta}$



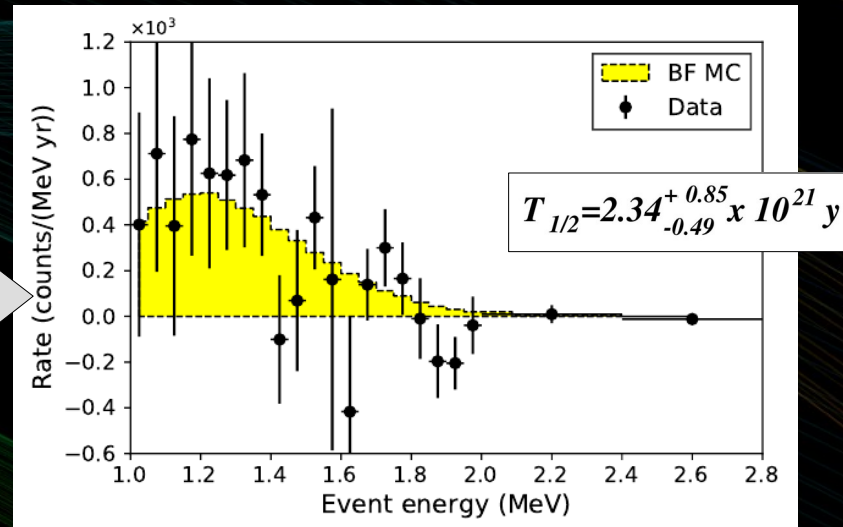
- $\beta\beta 0\nu$ candidate: events fully contained + one track with 2 blobs at the extremes + E within ROI

NEXT-White: $\beta\beta 2\nu$ Measurement

- Background-model-dependent method:



- Background-subtraction method, with little dependence on background model:



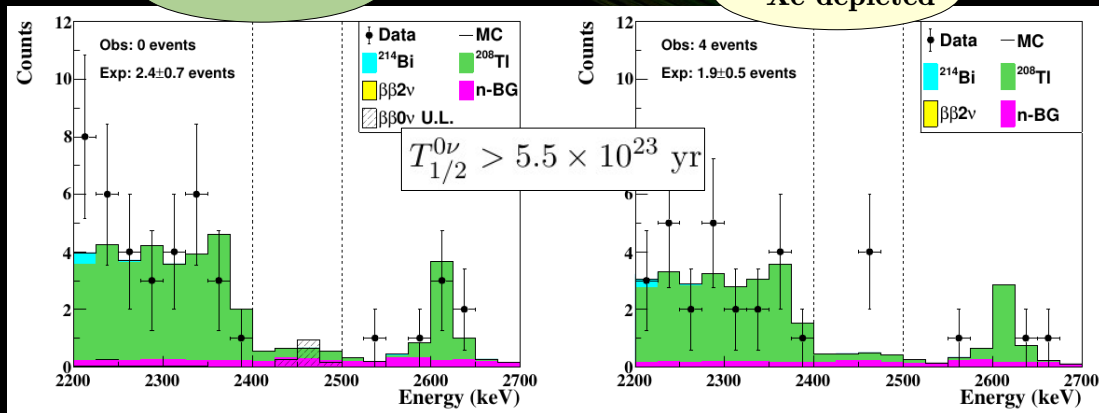
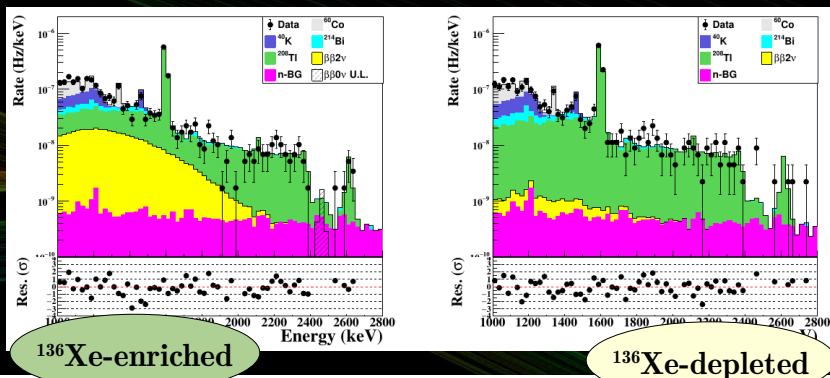
- Novel (so far unique in the field) technique possible due to the Xenon-based NEXT technology

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

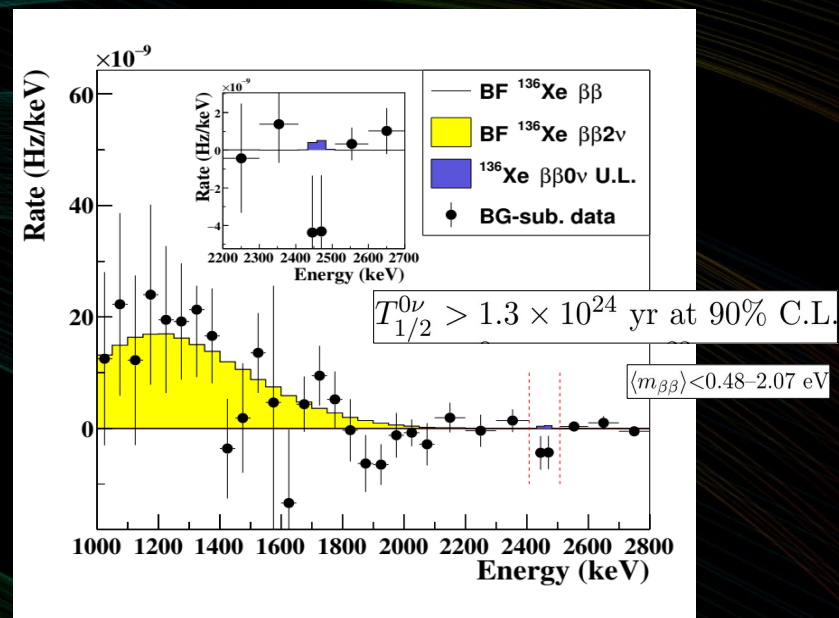
Precision limited by exposure (3.5 kg of Xe)!

NEXT-White: Demonstration of $\beta\beta 0\nu$ searches

- Background-model-dependent:



- Background-subtraction (novel in the field):

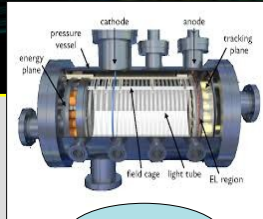


- $\beta\beta$ analyses demonstrate the capabilities of the NEXT technology with only 3.5 kg of Xe!

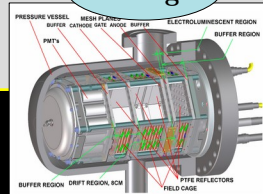
The NEXT Project

- Search for the $\beta\beta 0\nu$ decay with a HPXe-TPC

R&D
Proof of Concept

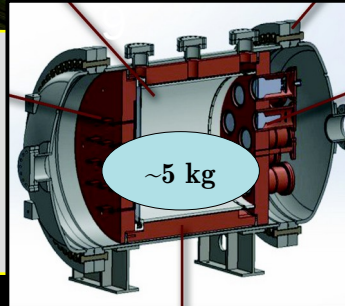


~1 kg



2009-2014

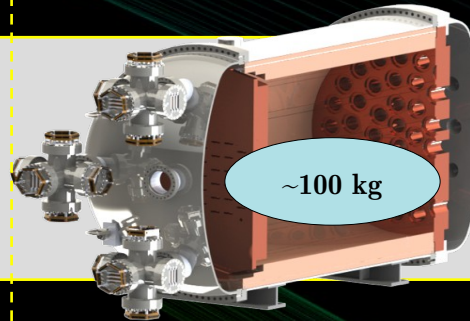
NEXT-White
Background+ $\beta\beta 2\nu$



~5 kg

2015-2021

NEXT-100 (+upgrades)
 $\beta\beta 0\nu$ search

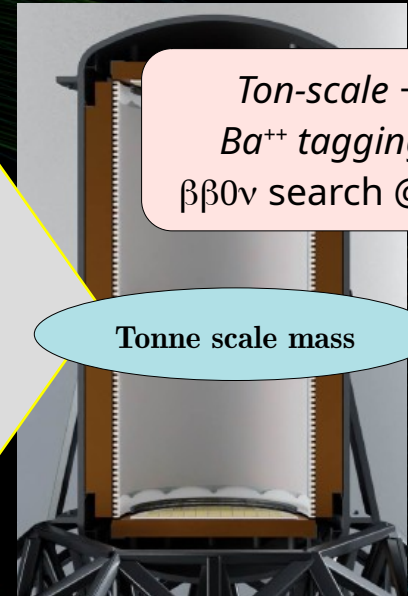


~100 kg

2024-2030

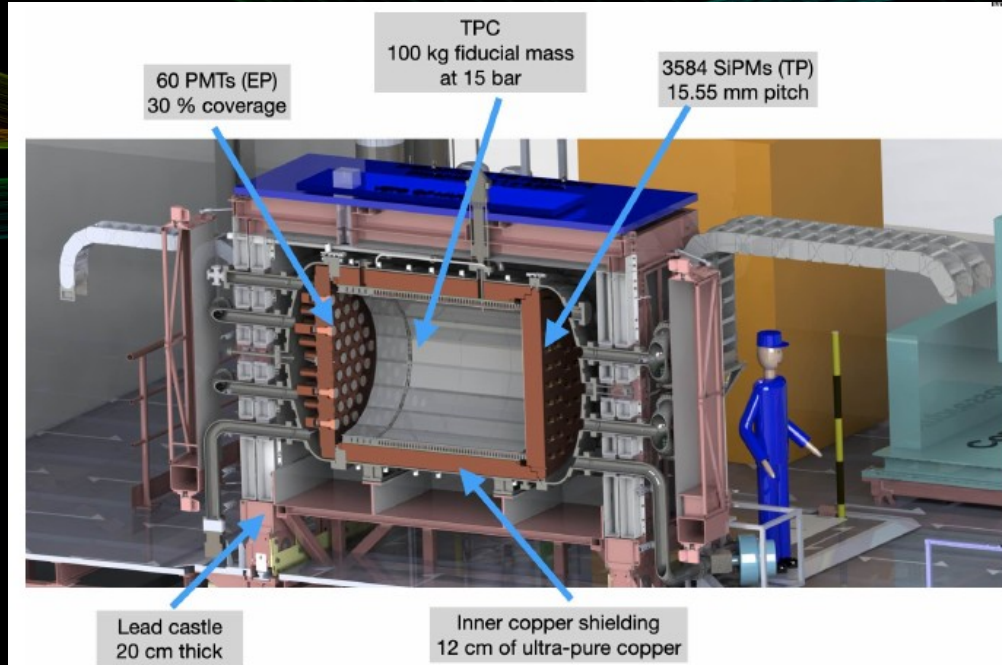
Ton-scale +
 Ba^{++} tagging:
 $\beta\beta 0\nu$ search @ IH

Tonne scale mass

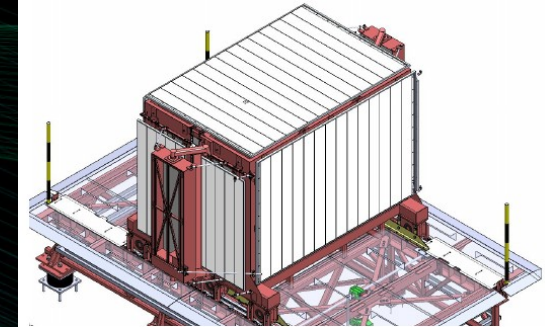


The NEXT-100 Detector

- Scales up the NEXT-White technology (~ 100 kg) to perform competitive $\beta\beta 0\nu$ searches



Muon veto covering the lead castle:

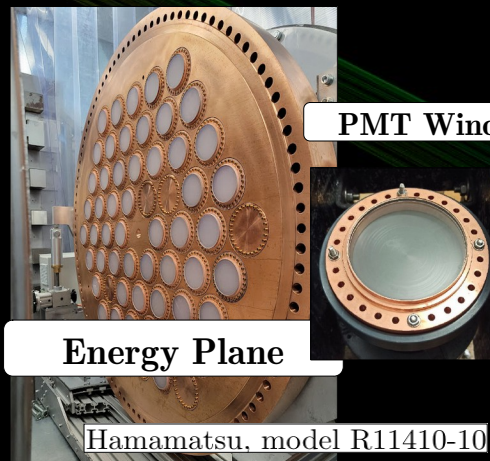
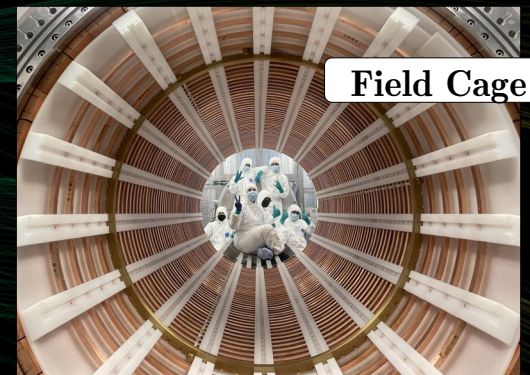
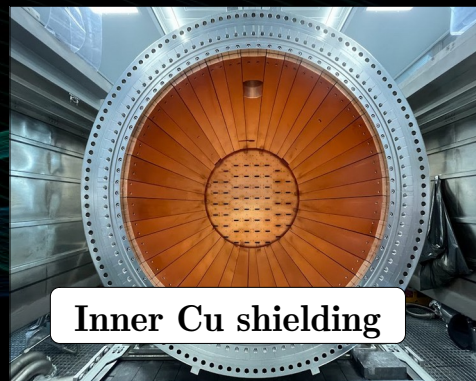
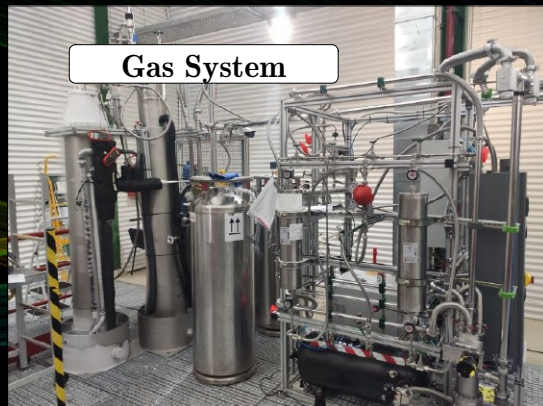


Goals of NEXT-100:

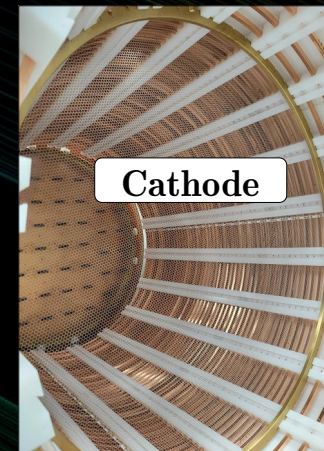
- Energy resolution $< 1\%$ FWHM
- Improve radioactive budget
- Competitive Search of $\beta\beta 0\nu$
- Prepare the ton-scale...

- Detector operating at the LSC since 2024

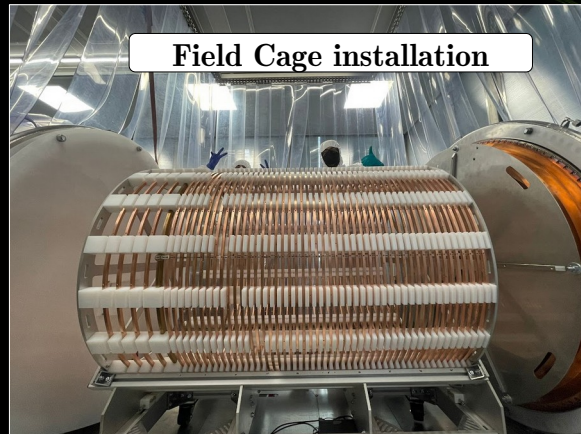
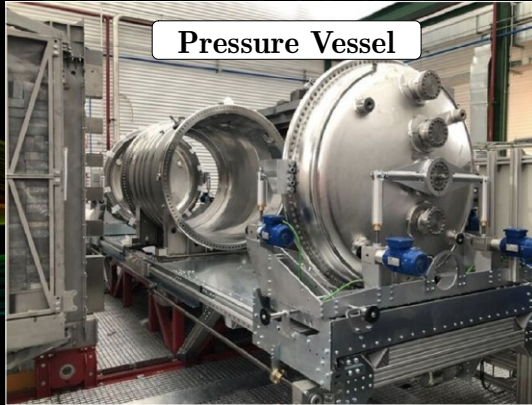
NEXT-100



PMT Window



NEXT-100 Installation @ LSC



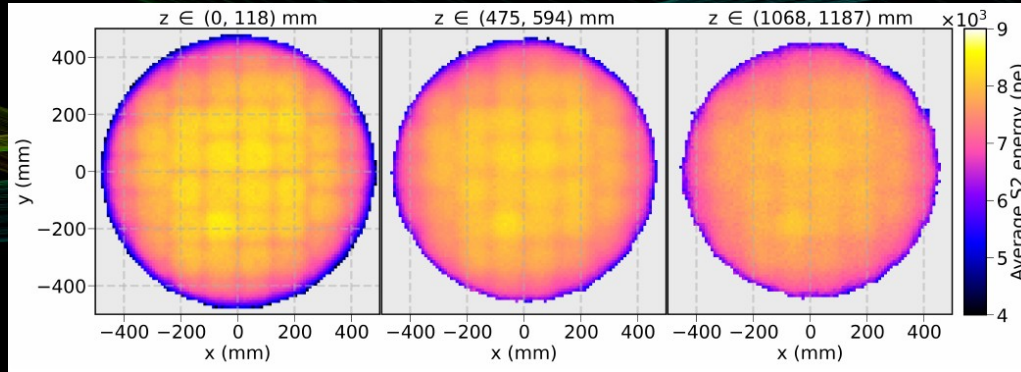
- NEXT ready since mid 2024

- 2024-2025: commissioning
- 2025: calibration/background @ 4 bar
- 2026-2029: $\beta\beta 0\nu$ search @ 10 bar

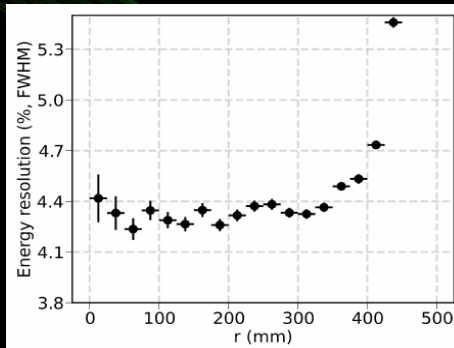
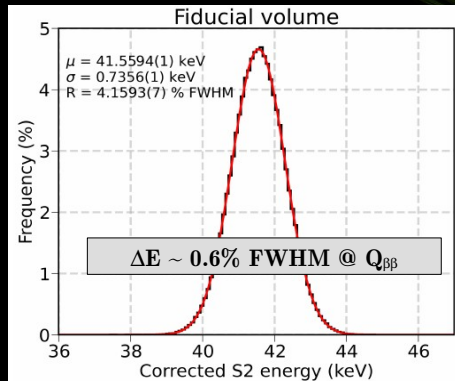
NEXT-100: Kr-83m Calibration

- Point-like 41.5 keV decays in the active volume

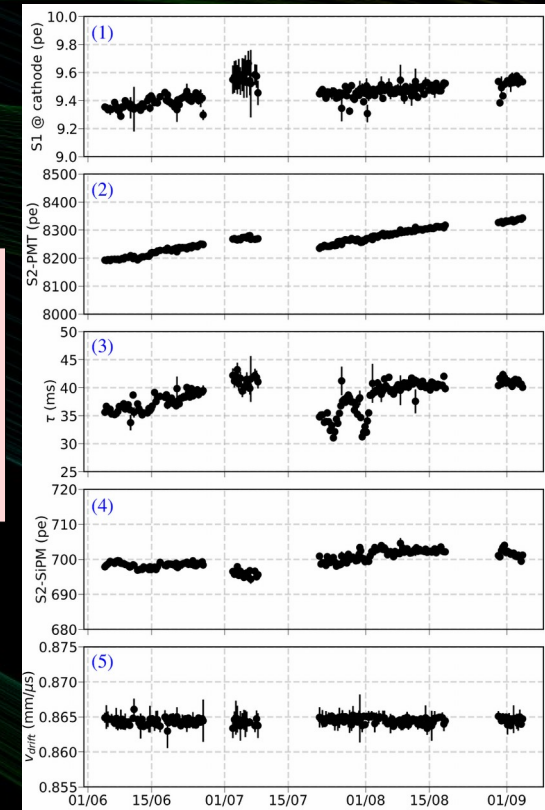
Geometrical and
lifetime corrections



Energy Resolution



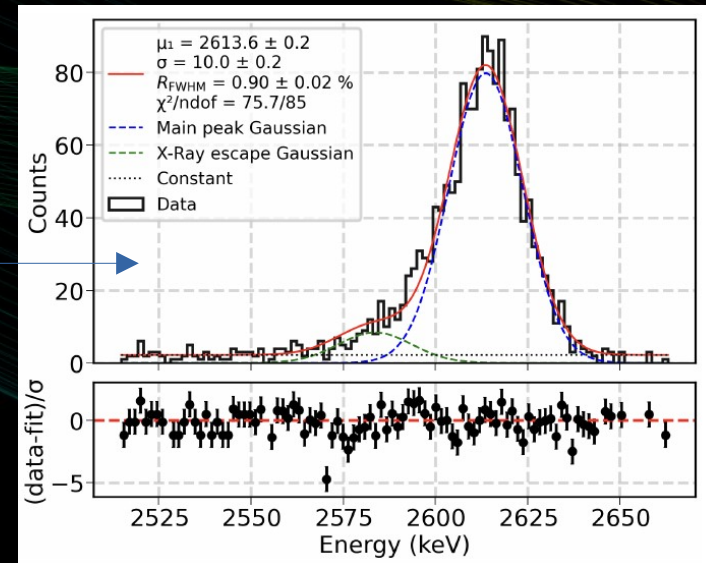
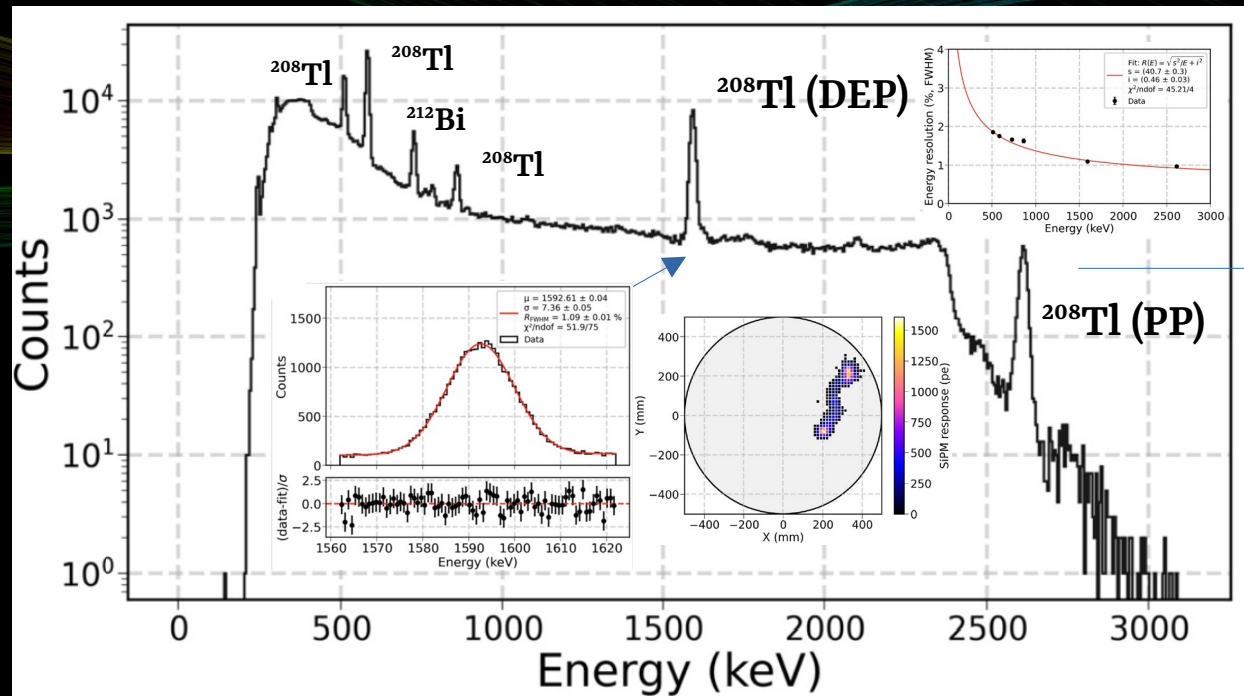
Monitoring



- Continuous calibration and monitoring of the detector

NEXT-100: Th-228 Calibration

- Th-228 calibration source deployed in dedicated port on the pressure vessel:



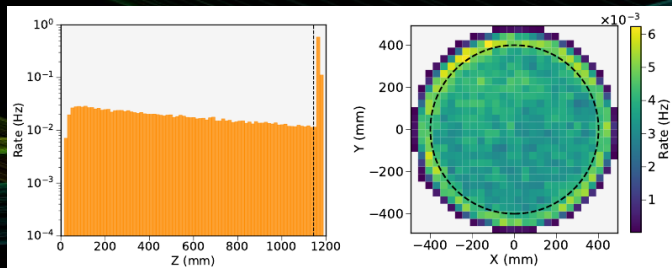
$\Delta E < 1\%$
FWHM @ $\sim Q_{\beta\beta}$

- Analysis of the energy scale and energy resolution versus energy

Rn-induced Background: Internal Rn

- Rn-induced Bi-214 @ Cathode estimated from α activity

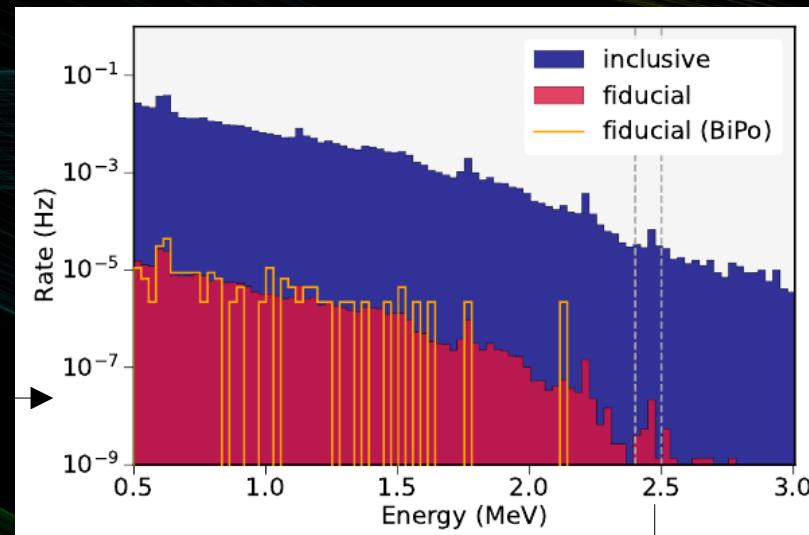
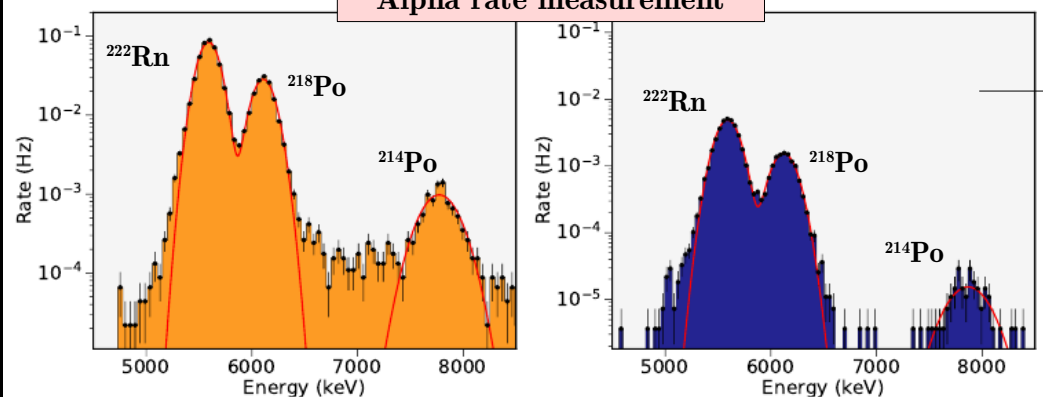
Bi-214 MC @ Cathode



cold-getter

Alpha rate measurement

hot-getter

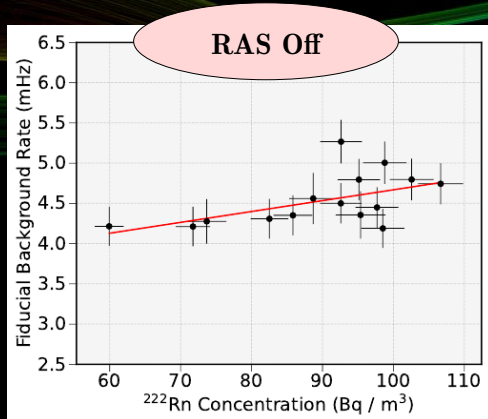


Selection	Rejection factor (%)	Background index (10^{-4} c/(keV·kg·yr))
Fiducial	99.979 ± 0.005	$6.2 \pm 1.3(\text{stat}) \pm 0.7(\text{sys})$
1 track	43.5 ± 10.3	$3.5 \pm 1.0(\text{stat}) \pm 0.4(\text{sys})$
double-e track	$\sim 90\%$	~ 0.4

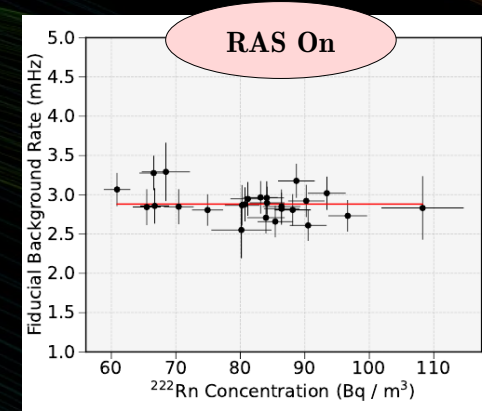
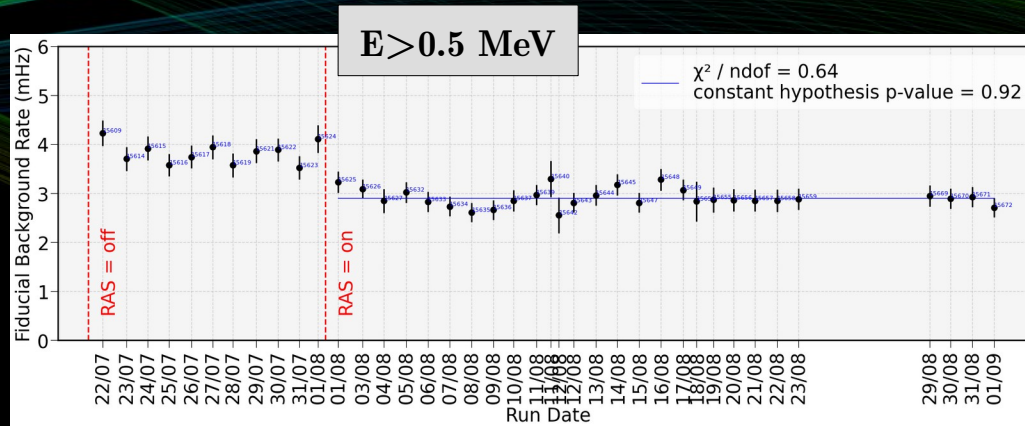
- Background index @ ROI 1 order of magnitude below radiogenic background expectation

Rn-induced Background: Airborne Rn

- Analysis of the background rate and correlation with the Rn-222 activity @ HALL A of the LSC
- Fiducial background = e-like events with 1 S2 and 1 S2, fully contained in the active volume, $E > 0.5$ MeV



$$R(\text{No-Rn}) = 3.32 \pm 0.47 \text{ mHz}$$

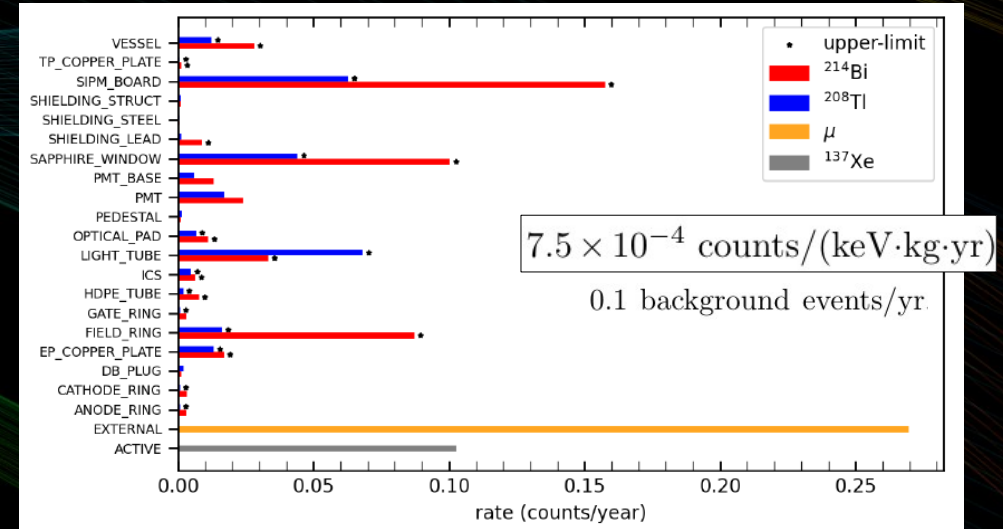
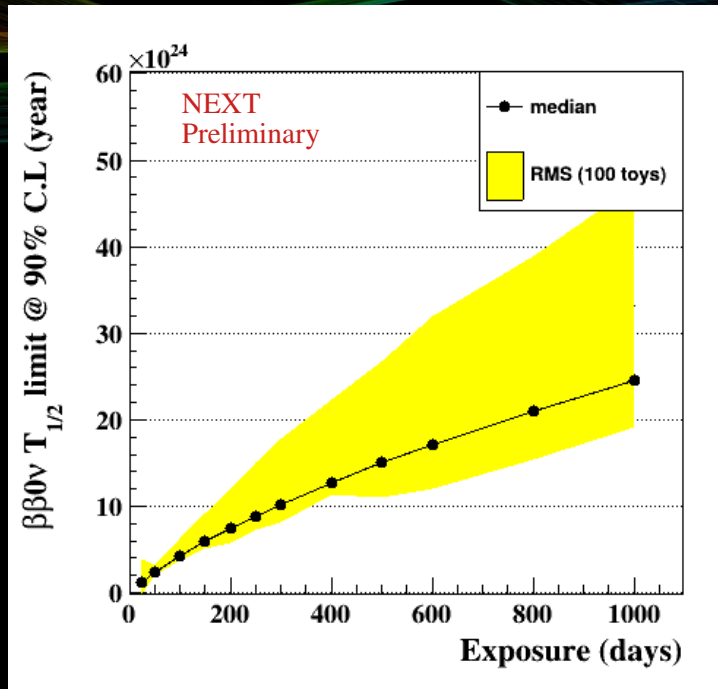


$$R = 2.88 \pm 0.04 \text{ mHz}$$

- NEXT-100 operates in a virtually Rn-free environment thanks to RAS @ LSC
- Rate of fiducial events constant in time: $R = 2.90 \pm 0.04 \text{ mHz}$

NEXT-100 Physics Case

- Sensitivity study @ 2016: Total BG:
 $\sim 10^{-4}$ c/keV/kg/y
- Updated sensitivity:
- New BG budget estimation: radiopurity screening + MC

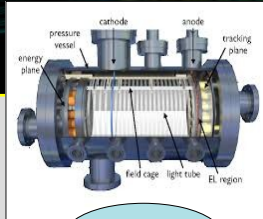


- Sensitivity: $> 10^{25}$ year at 90% C.L.
- Now measuring directly the BGs in NEXT-100...

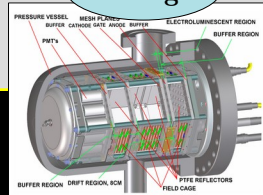
The NEXT Project

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R&D
Proof of Concept

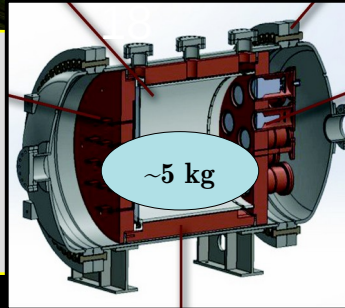


~1 kg



2009-2014

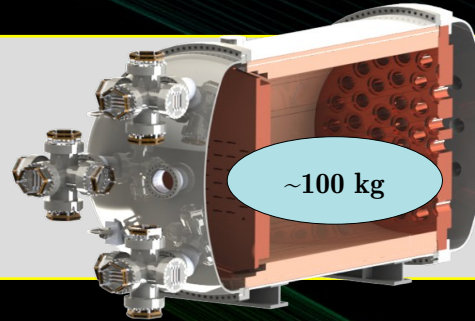
NEXT-White
Background+ $\beta\beta 2\nu$



~5 kg

2015-2021

NEXT-100 (+upgrades)
 $\beta\beta 0\nu$ search

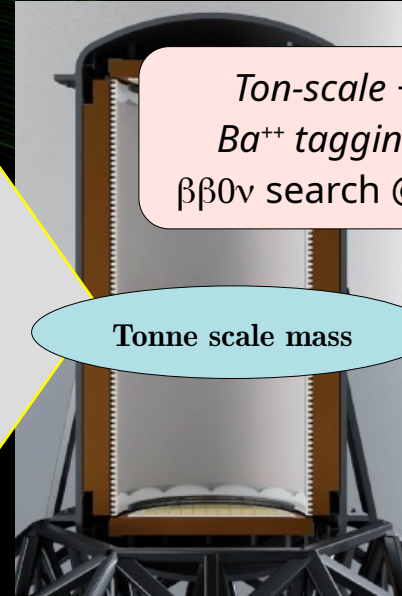


~100 kg

2024-2030

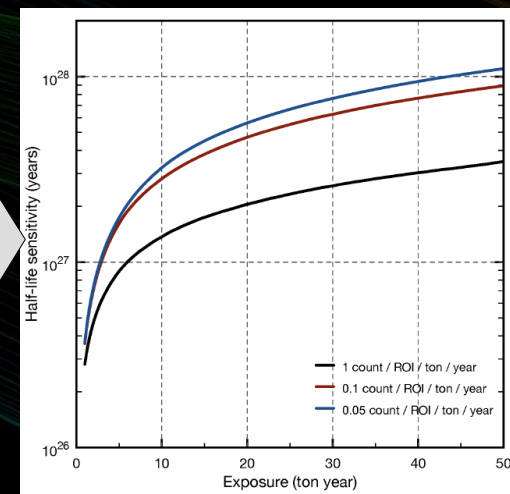
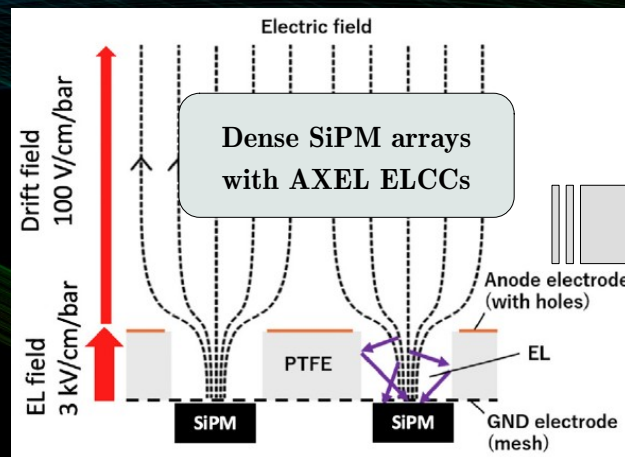
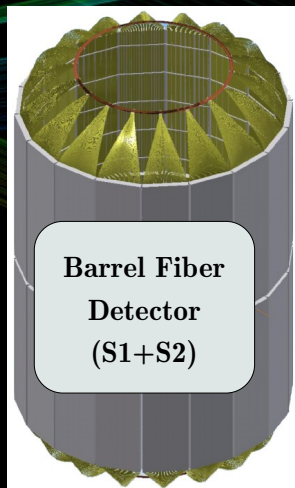
*Ton-scale +
 Ba^{++} tagging:
 $\beta\beta 0\nu$ search @ IH*

Tonne scale mass



NEXT at the Ton-scale: NEXT-HD

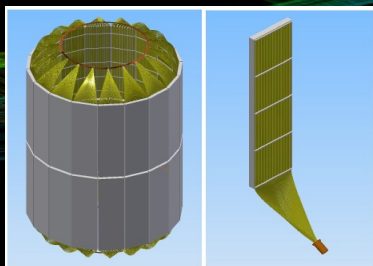
- Next generation of $\beta\beta$ experiments: exposures $>10^3$ kg and BG index < 1 count/ton/yr: $T_{1/2} > 10^{27}$ year
- Conceptual design of a NEXT ton-scale detector:



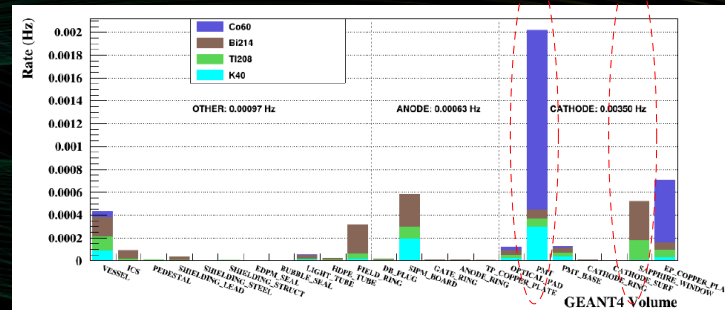
- Gas mixtures: low diffusion (Xe+He4) to improve resolution and He3 (if possible)
- First module to be installed at LSC (~ 2030) $\rightarrow$ open to a multi-site and multi-modular approach
 - 5 modules $\rightarrow \sim 10^{28}$ yr

NEXT-HD enhanced performance

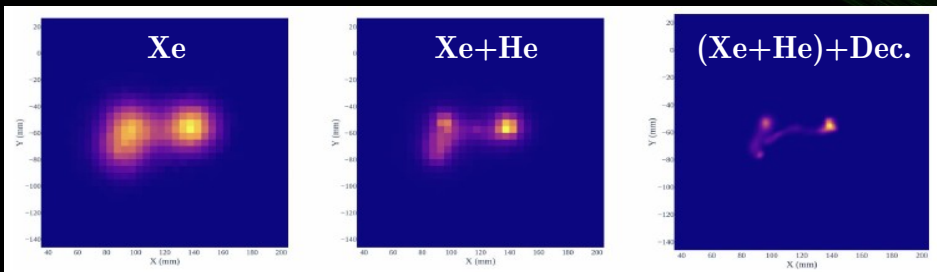
- **BFD: Improved energy resolution:**
 - light collection $\sim 2\%$ ($< 0.7\%$ FWHM)
 - Pressure-resistant system (unlike PMTs!)



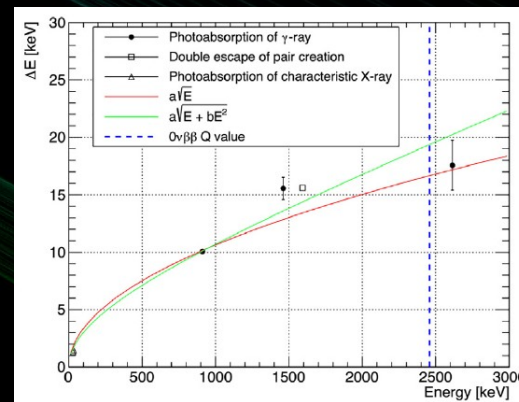
- Reduced background budget
- No PMTs and windows
- Better Cu shielding



- Gas mixtures: Improved background rejection power
 - Low diffusion (Xe+He) → better BG discrimination
 - He-3 → reduction of cosmogenic BG (Xe-137)



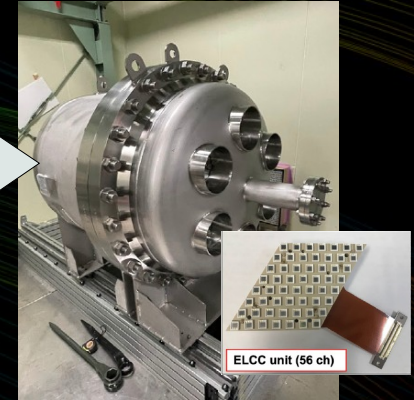
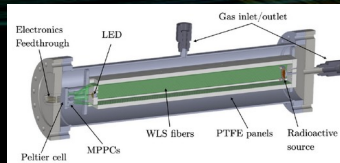
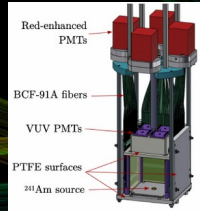
- Dense tracking planes + ELCCs
 - Independent energy measurement ($<0.6\%$ FWHM)
 - Scalable solution for large EL regions



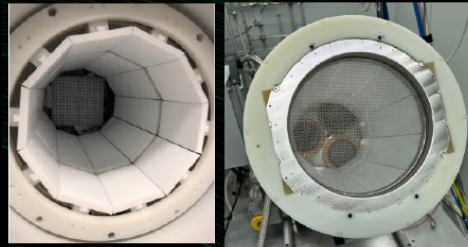
R&D Towards NEXT-HD

- HD-DEMO @ DIPIC: BFD + ASICS + ELCCs

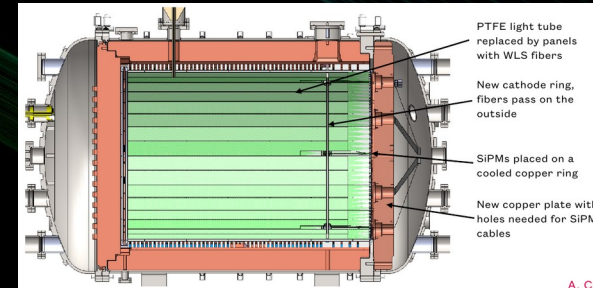
- AXEL @ Tohoku: ELCCs



- NEXT-DEMO++ @ IFIC: Xe/He + Dense TP + ASICS



NEXT-100 Upgrade with HD technologies (~2028)



~ 10^{26} year

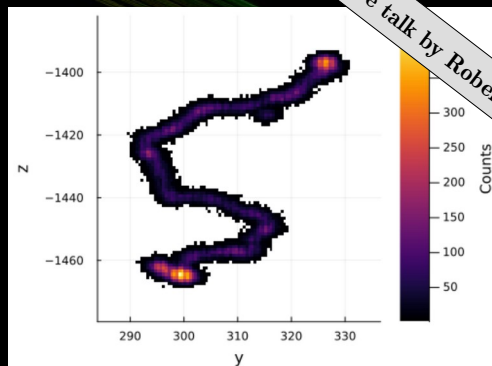
A Roadmap for NEXT-HD

- Conceptual design ~ready: CDR by 2027
- Start of construction: module @ LSC in 2030
 - Technology validated with NEXT-100 and HD-DEMO
- Detector ready by ~2032
- Depending on the available Xe (**only possible with gas!**):
 - Run with natural Xe: background index measurement
 - Run with world-wide available Xe-136: 500 kg @ 8 bar (**multi-collaboration**)
 - Run with 1-tone of Xe-136 (16 bar) whenever available $\rightarrow >10^{27}$ yr
 - **Multi-module/multi-site approach if new international partners $\rightarrow 10^{28}$ yr**

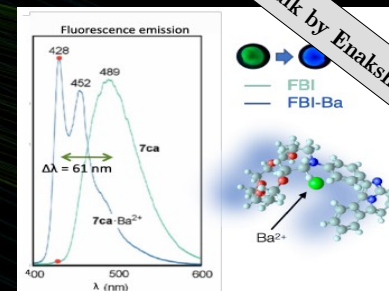
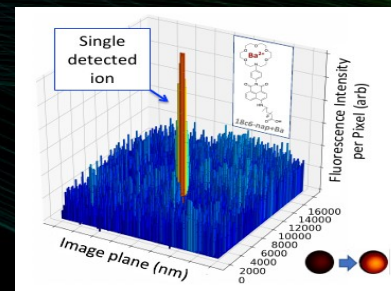
NEXT with Ions: BOLD & ITACA

- Next-to-Next generation of $\beta\beta$ experiments: exposures $>10^3$ kg and BG index < 0.1 count/ton/yr: $T_{1/2} > 10^{28}$ year
 - NEXT-BOLD: R&D on Single Molecule Fluorescent Imaging for Ba++ tagging
 - ITACA: R&D on *dual* electron-ion TPC
 - background rejection enhancement with ion tracks

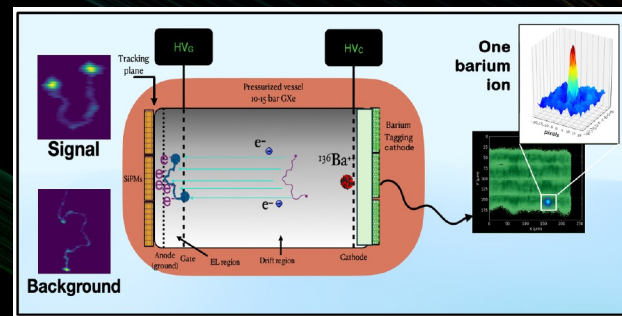
EPCJ 86 (2026) 3, 320
ArXiv:2604.02443



PRL 120 (2018) 132504
Nature 583 (2020) 7814
Nature Commun. 13 (2022) 1, 7741



See talk by Enakshi



- Unique gas-path to 10^{28} year and exploration of decay mechanism in case of discovery

Summary

- NEXT-100 physics program ongoing
 - Search for the $\beta\beta 0\nu$ decay at 10 bar ($>10^{25}$ year)
 - Future upgrades with solutions for the ton-scale ($\sim 10^{26}$ year)
- Conceptual design a ton-scale detector: NEXT-HD ($>10^{27} - 10^{28}$ year)
 - NEXT-HD technologically ready to be built in early 2030s @ LSC
 - Collaboration actively looking for new international partners and funding
 - Feasible, economic and staged roadmap for the next decade: physics early 2030s
 - If new international partners: multi-module/multi site approach $\rightarrow 10^{28}$ year
 - Gas community already working on possible synergies (NEXT, AXEL, R2D2)
- R&D towards future NEXT ion-TPCs: NEXT-BOLD & ITACA ($>10^{28}$ year)
 - Also a unique post-discovery option $\rightarrow$ decay mechanisms