NEXT

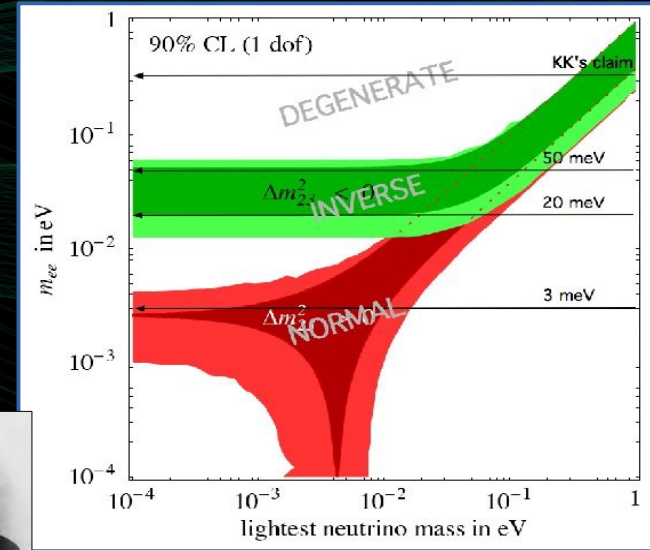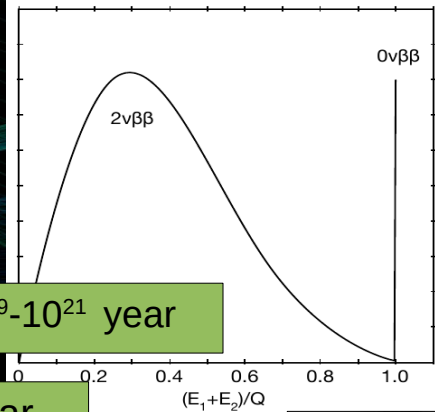*First searches of the ββ0ν decay in gaseous Xe*
And roadmap towards a ton-scale detector

Pau Novella (IFIC, CSIC & U. Valencia)
On behalf of the NEXT collaboration

Searching for the ββ0ν decay
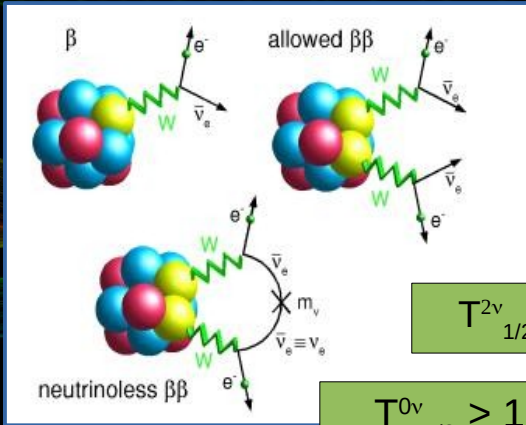
$T^{2\nu}_{1/2} \sim 10^{19}\text{-}10^{21}$ year

$T^{0\nu}_{1/2} > 10^{25}$ year

Searching for the ββ0ν decay
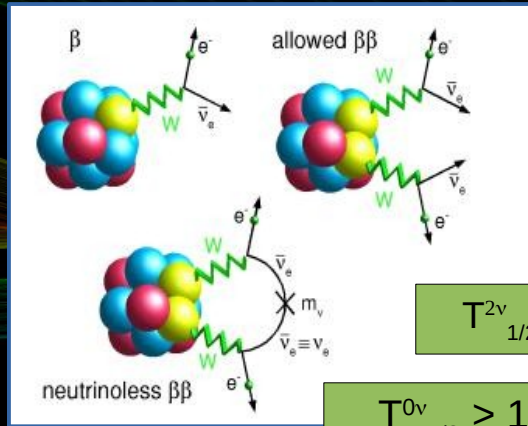
$T^{2\nu}_{1/2} \sim 10^{19}\text{-}10^{21}$ year

$T^{0\nu}_{1/2} > 10^{25}$ year
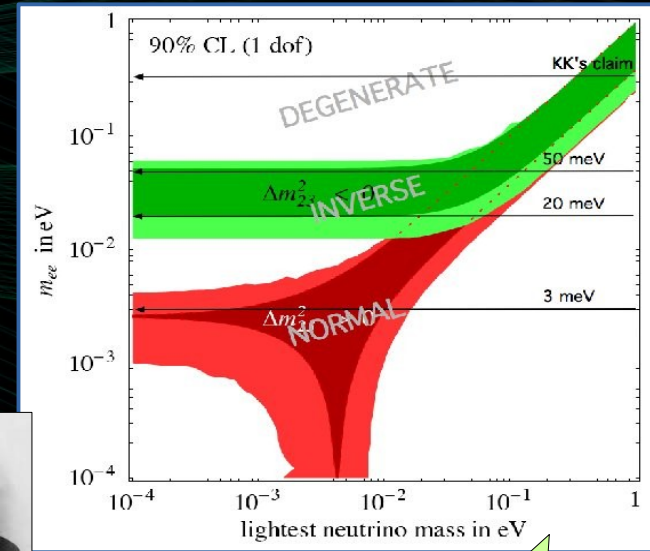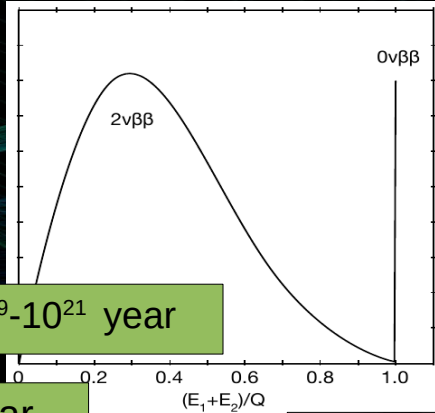
Detector requirements

- Energy resolution
- Background rejection
- Scalability

→ ββ0ν experiment

Calorimeters

Tracko-calos

Bolometers
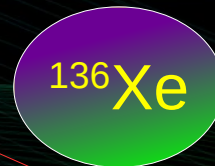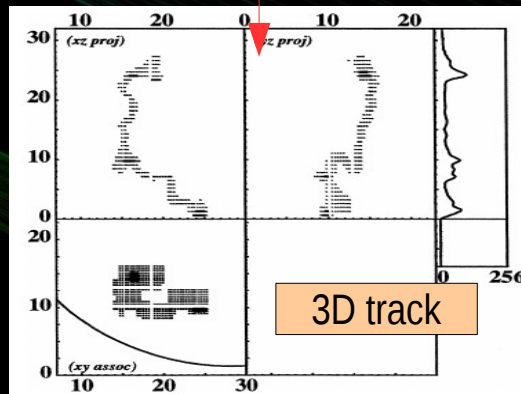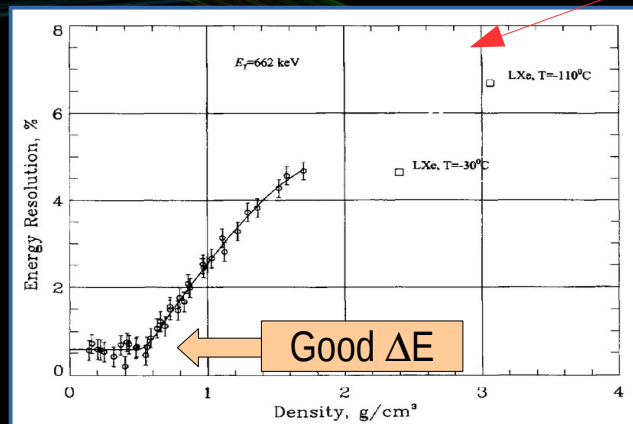
NEXT

NEXT: High-Pressure Gas-Xe TPC

- Sensitivity to the ββ0ν decay:

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

^{136}Xe
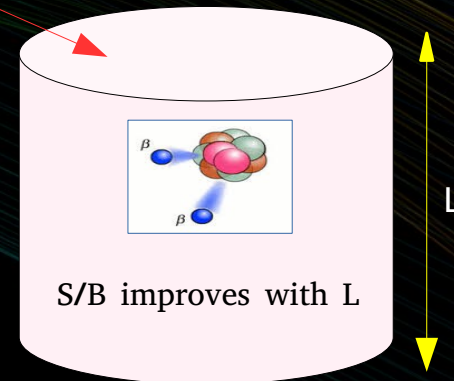
- $Q_{\beta\beta}$=2.458 MeV
- Scint/Ionization
- Cheap/Easy to enrich
- Long ββ2ν mode

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

E_γ=662 keV

LXe, T=-110°C

LXe, T=-30°C

Energy Resolution, %

Density, g/cm³

Good ΔE

(xz proj)

(yz proj)

(xy assoc)

3D track

R. Luescher et al, PLB 434 (1998)
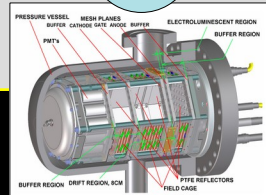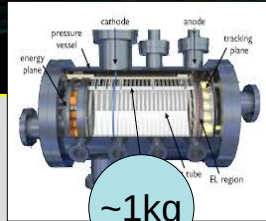
S/B improves with L

L

Source=Detector

The NEXT Project

- Search for the ββ0ν decay with a HPXe-TPC

R&D
Proof of Concept
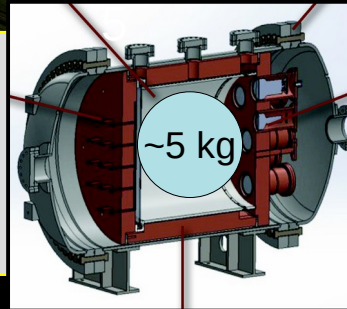
NEXT-White
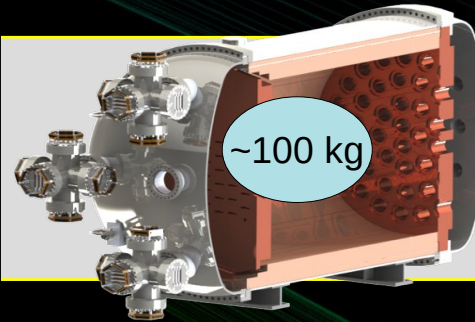Background+ββ2ν

NEXT-100 (+upgrades)
ββ0ν search

~1kg

~5 kg

~100 kg

Ton-scale +
Ba^{++} tagging:
ββ0ν search @ IH
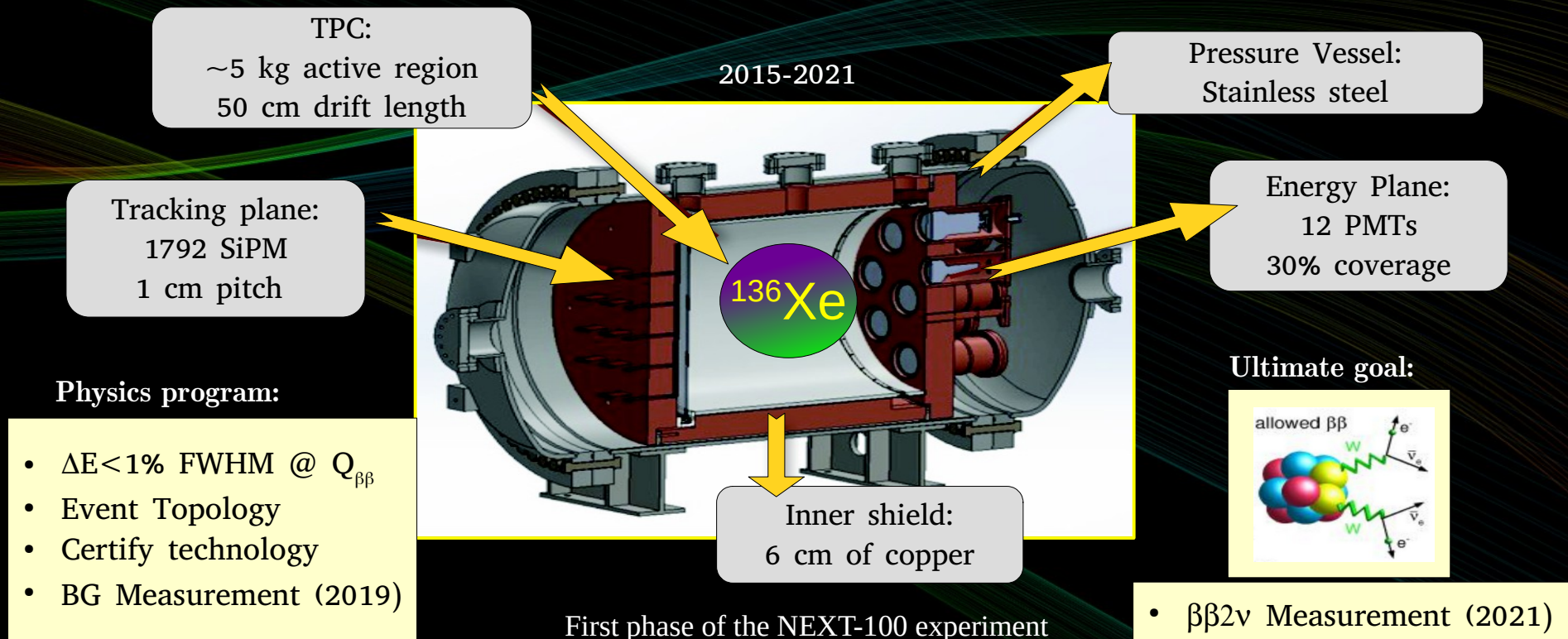
~1 Ton

2009-2014

2015-2021

2023-2026
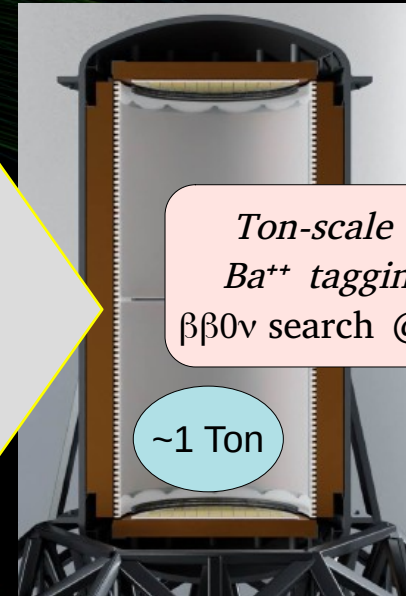
The NEXT TPC Concept

Gas TPC with 2 dedicated readout planes
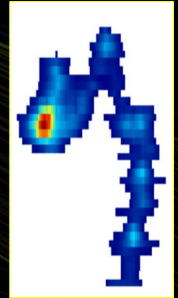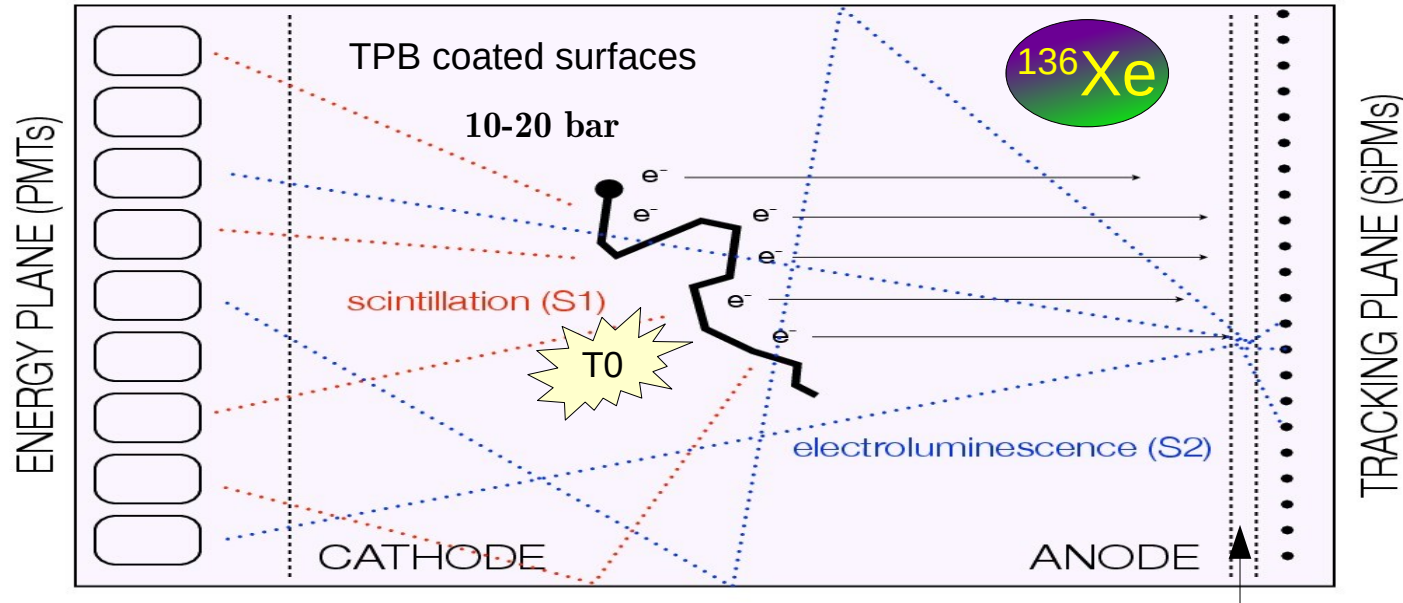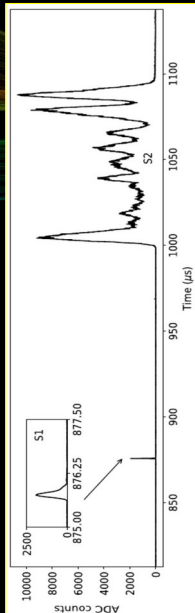
EL: linear gain, no avalanche fluctuations: optimize ΔE

NEXT-White: Physics @ LSC

TPC:
~5 kg active region
50 cm drift length

2015-2021

Pressure Vessel:
Stainless steel

Tracking plane:
1792 SiPM
1 cm pitch

Energy Plane:
12 PMTs
30% coverage

^{136}Xe

Ultimate goal:

allowed ββ

Physics program:

- $\Delta E < 1\%$ FWHM @ $Q_{\beta\beta}$
- Event Topology
- Certify technology
- BG Measurement (2019)

Inner shield:
6 cm of copper

First phase of the NEXT-100 experiment

- $\beta\beta2\nu$ Measurement (2021)
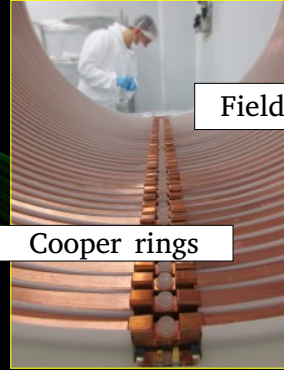
The NEXT-White Detector @ LSC

- First large-scale EL-based HPXe-TPC!

- Infrastructures @ LSC:
  - Gas system, seismic platform, lead castle, Rn abatement system
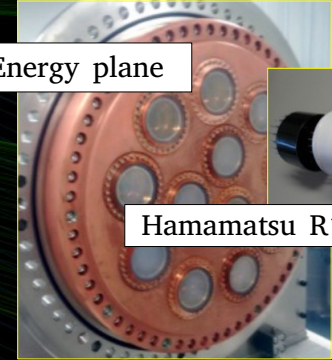
Steel vessel

6cm inner Cu shield

Energy plane

Hamamatsu R11410-10
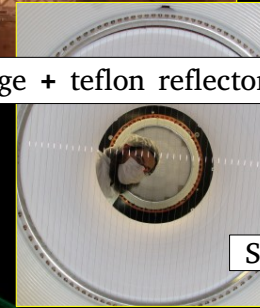
Field cage + teflon reflector
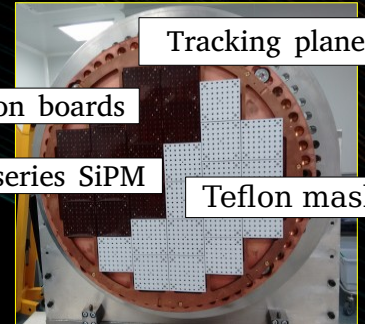
Cooper rings

Tracking plane
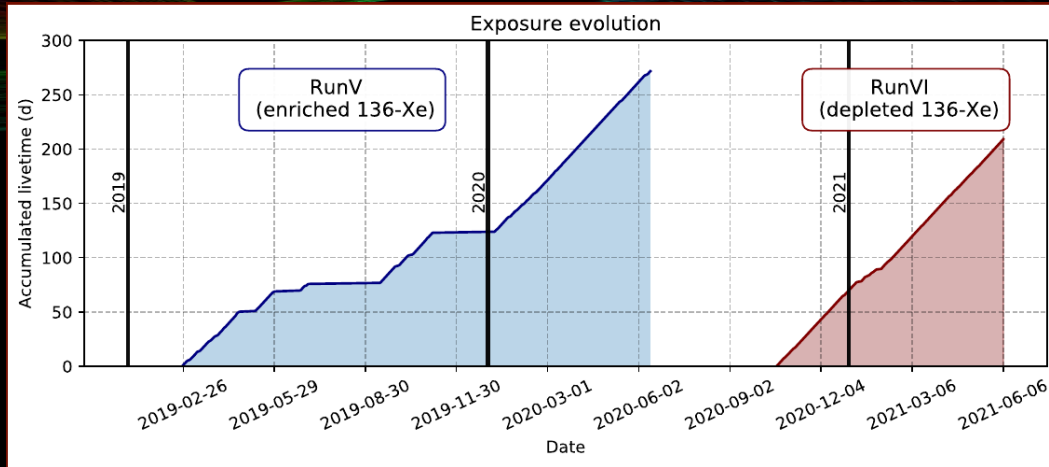
Kapton boards
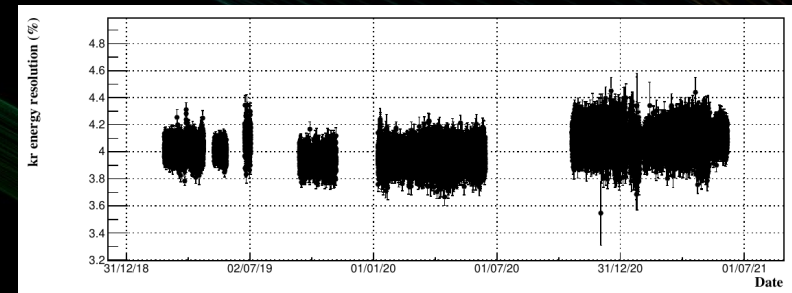
SensL C-series SiPM

Teflon masks
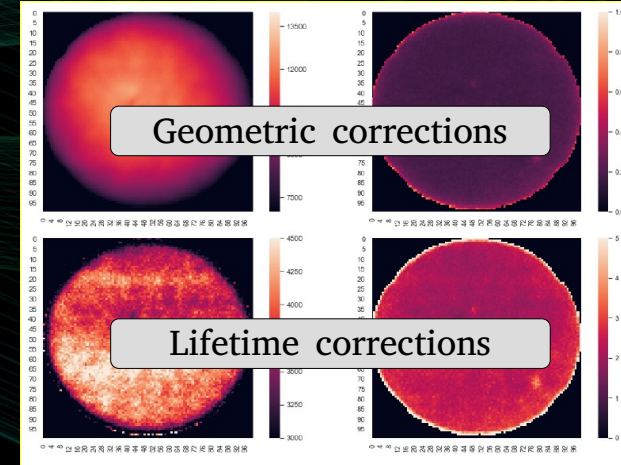
JINST 13 (2018) no.12, P12010

10.2 bar
Drift: 0.4 kV/cm
EL: 1.3 kV/(cm·bar)

NEXT-White Operation

- Stable operation from 2016 to 2021
- ^{83m}Kr → continuous calibration and monitoring
- ββ → ^{136}Xe-enriched and ^{136}Xe-depleted data:

Geometric corrections

Lifetime corrections

Total run-times: 271.6 day (Run-V) and 208.9 day (Run-VI)
DAQ dead time: ~3% @ Run-V and ~2% @ Run-VI

NEXT-White Calibration: ^{208}Tl/^{137}Cs

- ^{232}Th/^{137}Cs gamma-ray interactions from external sources

  - Energy scale
  - Energy resolution vs E
  - Energy resolution @ $Q_{\beta\beta}$

NEXT-White Calibration: ^{208}Tl/^{137}Cs

- ^{232}Th/^{137}Cs gamma-ray interactions from external sources

  - **Energy scale**
  - **Energy resolution vs E**
  - **Energy resolution @ Q$_{\beta\beta}$**

^{137}Cs photopeak

$\mu = 660.46 \pm 0.03$
$\sigma = 3.37 \pm 0.03$
$R~(\%) = 1.20 \pm 0.01$
$\chi^2/N_{dof} = 1.31$

^{208}Tl double-escape

$\mu = 1595.74 \pm 0.09$
$\sigma = 6.57 \pm 0.12$
$R~(\%) = 0.97 \pm 0.02$
$\chi^2/N_{dof} = 1.32$

- **JHEP 10 (2019) 230**
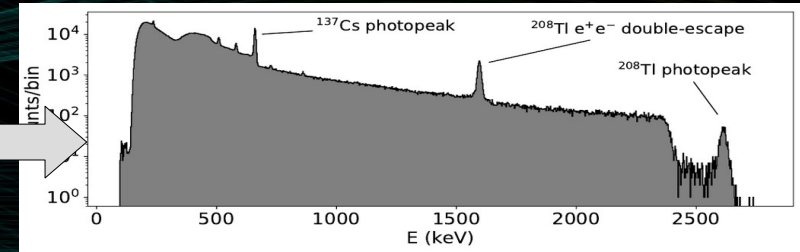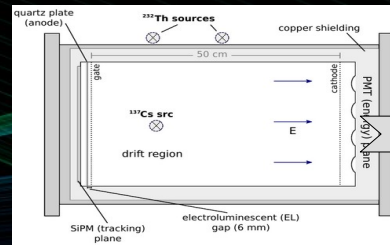- **JINST 13 (2018) no.10, P10020**
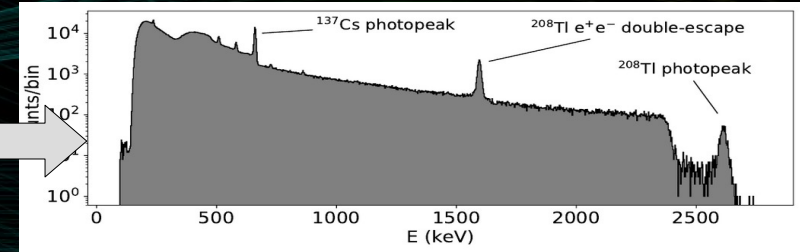
NEXT-White Calibration: ^{208}Tl/^{137}Cs

- ^{232}Th/^{137}Cs gamma-ray interactions from external sources

  - **Energy scale**
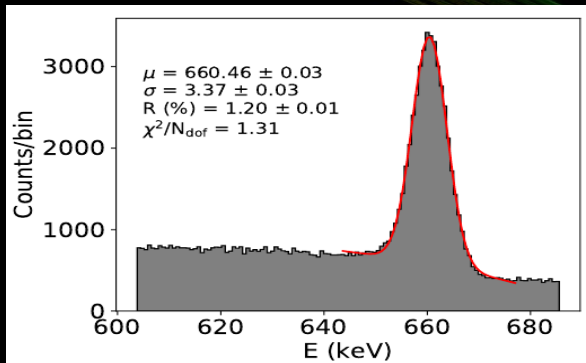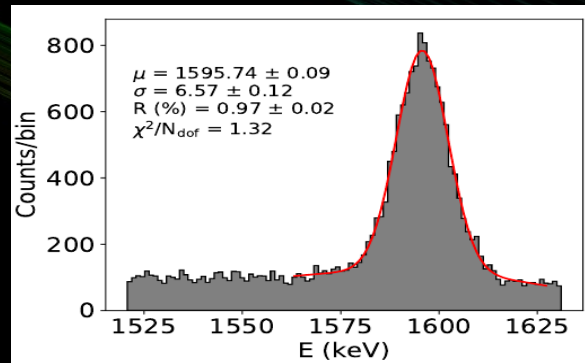 - **Energy resolution vs E**
  - **Energy resolution @ Q$_{\beta\beta}$**
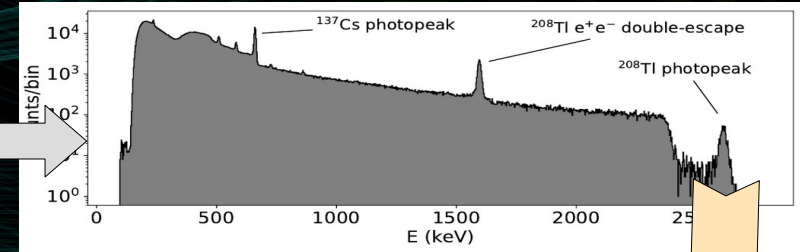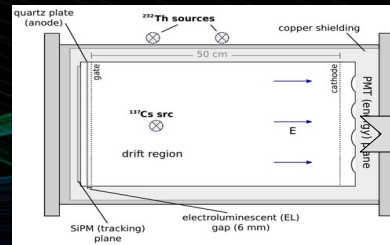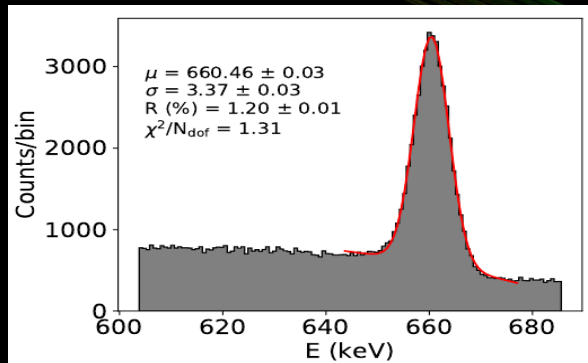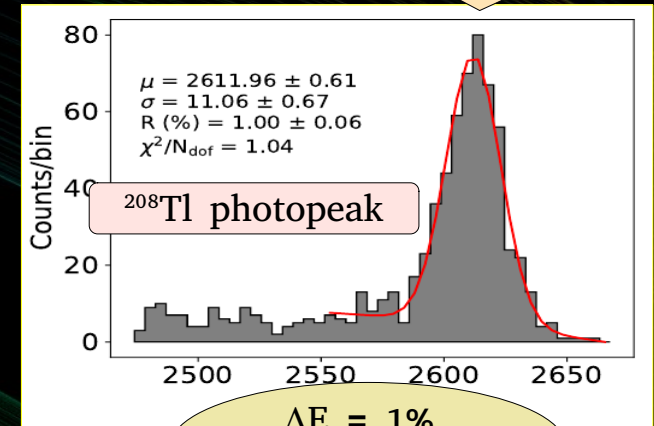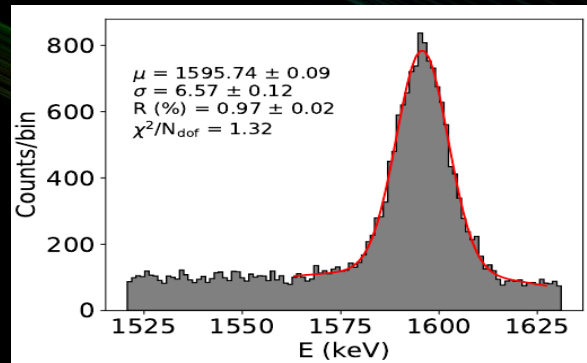

^{137}Cs photopeak

^{208}Tl double-escape

^{208}Tl photopeak

$$\Delta E = 1\%$$
$$FHWM \ @\sim Q_{\beta\beta}$$
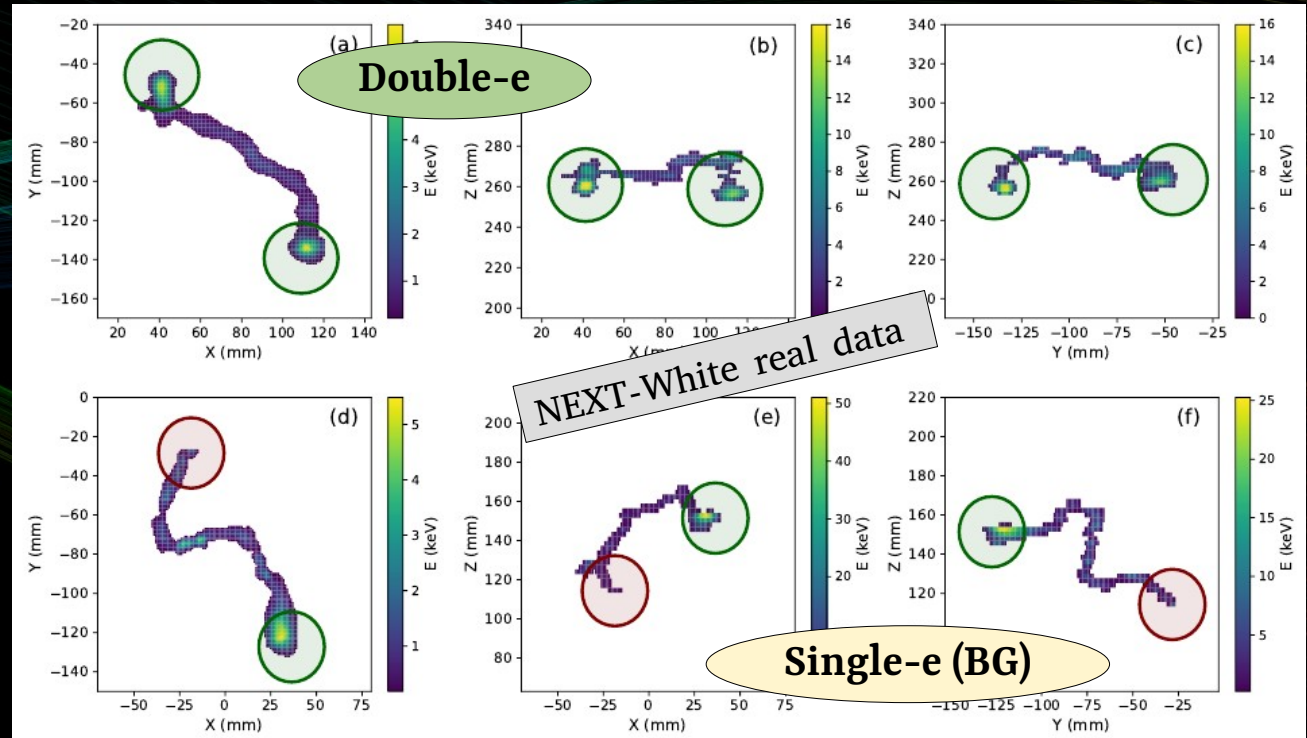
- **JHEP 10 (2019) 230**
- **JINST 13 (2018) no.10, P10020**

Best energy resolution in Xe!

NEXT-White: Topological reconstruction

- Track reconstruction based on SiPM signals **+** RL deconvolution

- Double-e (sig) vs Single-e (bg) discrimination based on "blob" energy
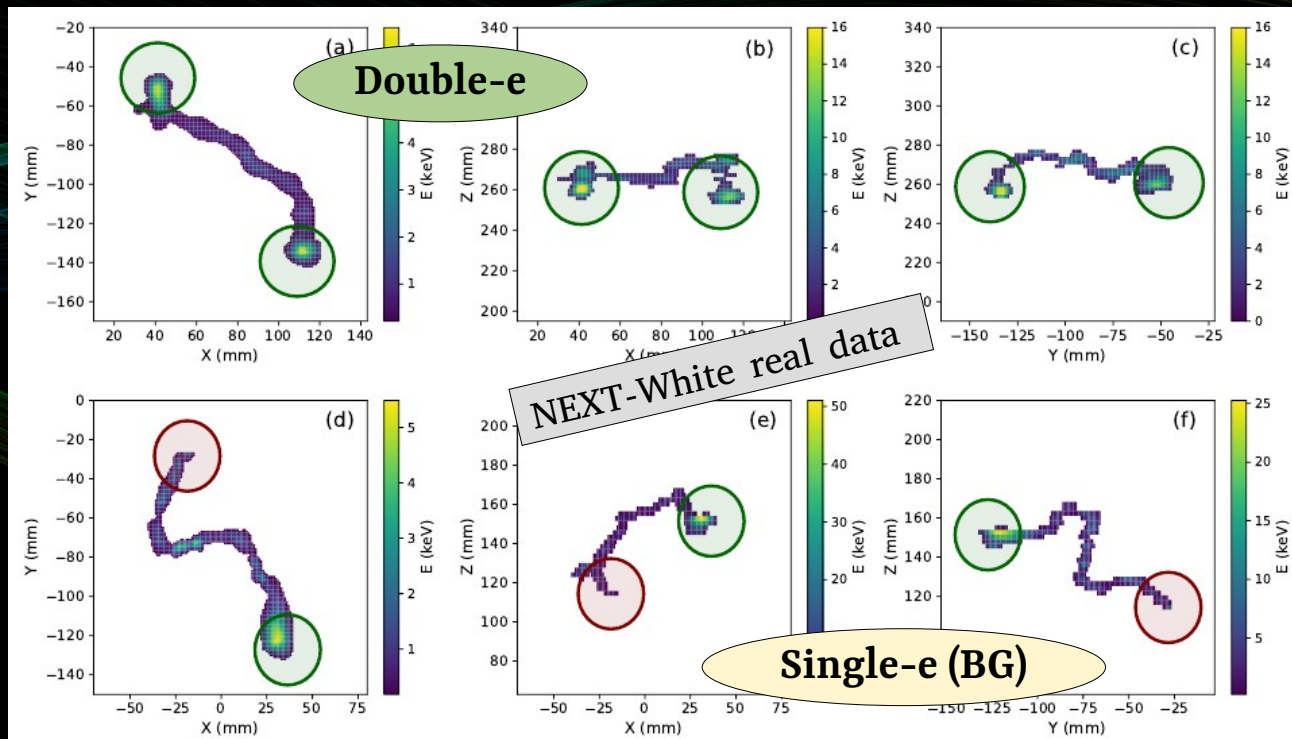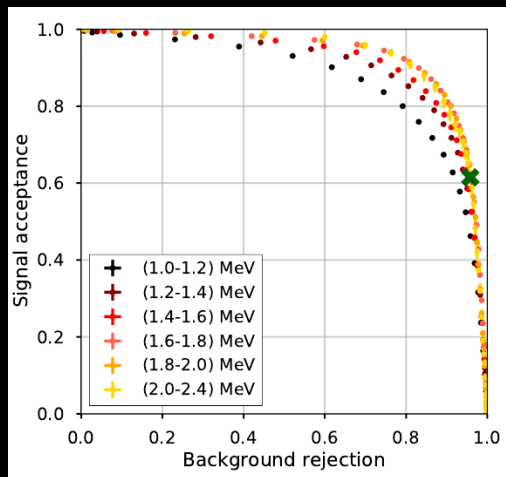
NEXT-White: Topological reconstruction

- Track reconstruction based on SiPM signals **+** RL deconvolution

- Double-e (sig) vs Single-e (bg) discrimination based on "blob" energy

- Sig. efficiency ~ 60% for BG acceptance of ~4% @ 1.6 MeV

JHEP 10 (2019) 052
JHEP 21 (2020) 146

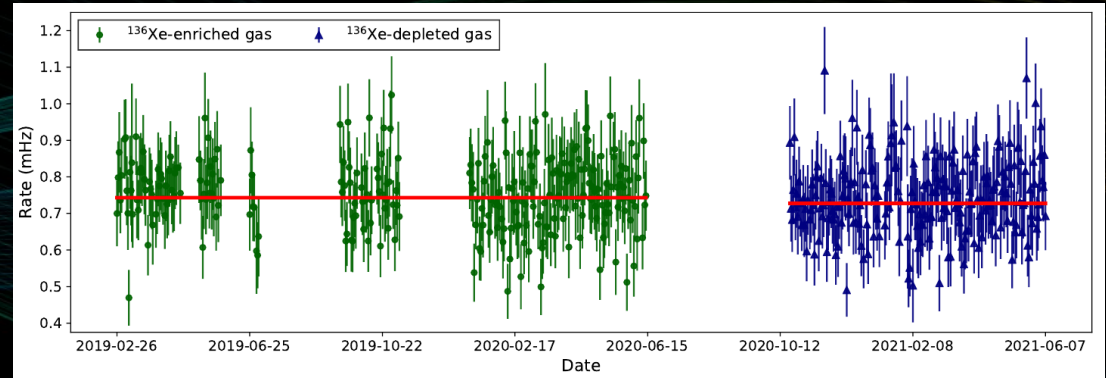

- Results to be improved with ML:

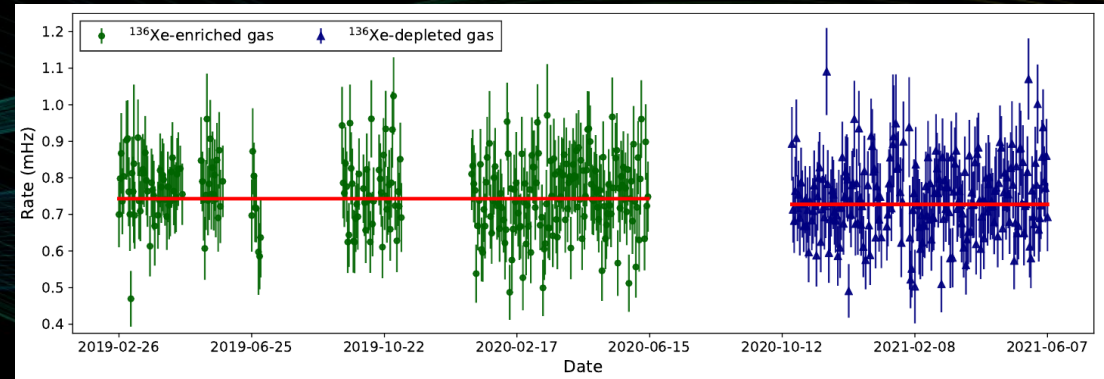DNNs: JINST 12 (2017) no.01, T01004
CNNs: JHEP 01 (2021) 189
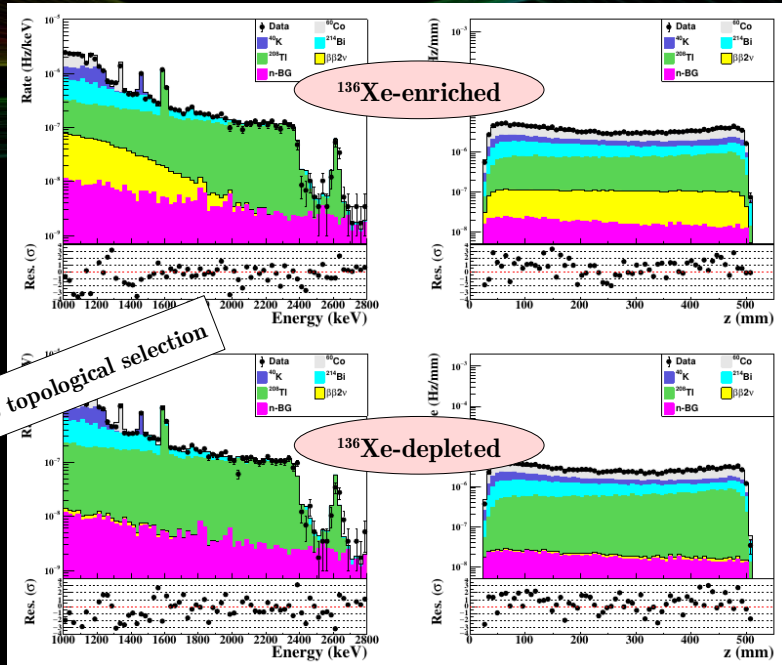
NEXT-White: Background Stability

- Fiducial Background rates per day:
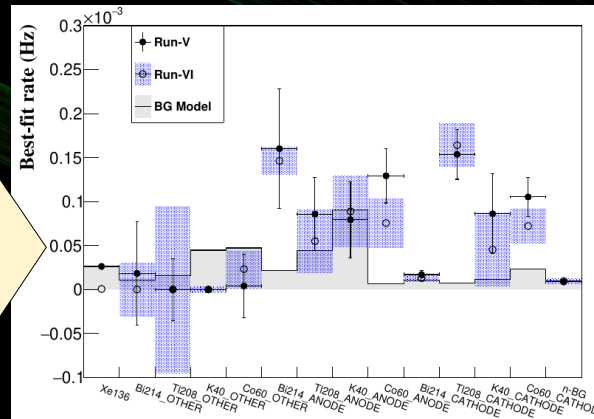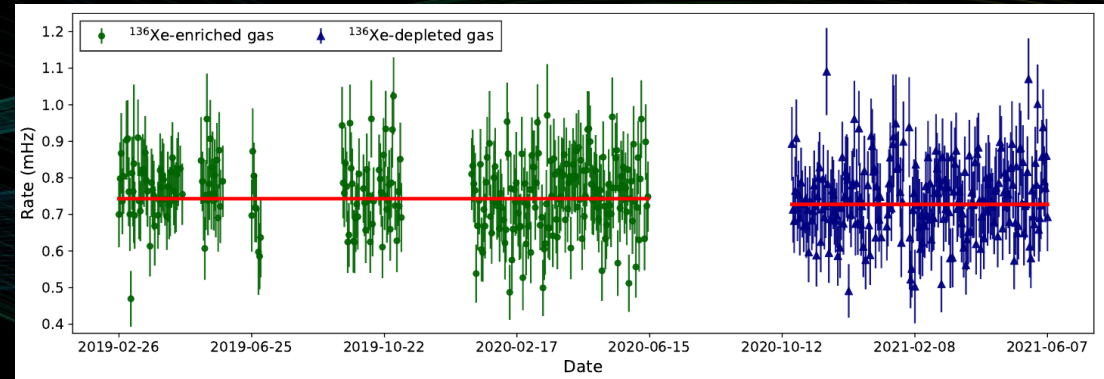
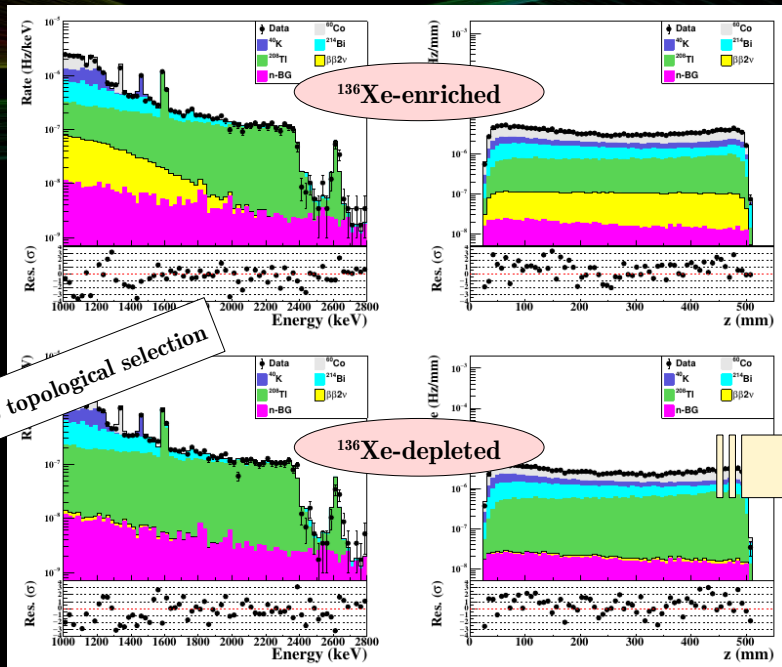# NEXT-White: Background Stability

- Fiducial Background rates per day:

- Run-V/Run-VI Background (E,Z) fit:

NEXT-White: Background Stability

- Fiducial Background rates per day:

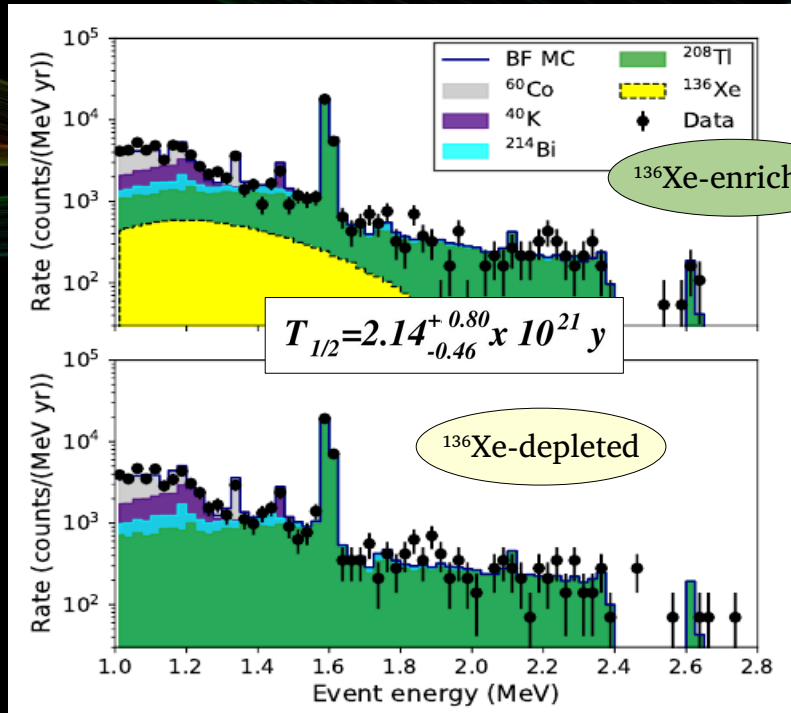- Run-V/Run-VI Background (E,Z) fit:

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

arXiv:2305.09435

- Specific radiogenic and cosmogenic background contributions consistent in Run-V and Run-VI

NEXT-White: ββ2ν Measurement

- Background-model-dependent method:

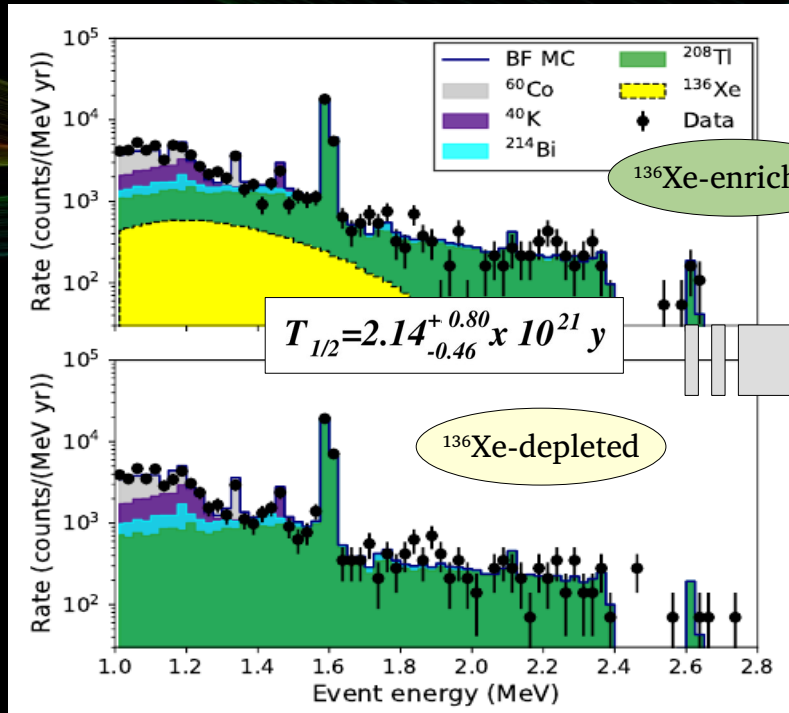$T_{1/2} = 2.14^{+0.80}_{-0.46} \times 10^{21}$ y

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

NEXT-White: ββ2ν Measurement

- Background-model-dependent method:

^{136}Xe-enriched

^{136}Xe-depleted

$T_{1/2} = 2.14^{+0.80}_{-0.46} \times 10^{21}\ y$

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

$T_{1/2} = 2.34^{+0.85}_{-0.49} \times 10^{21}\ y$
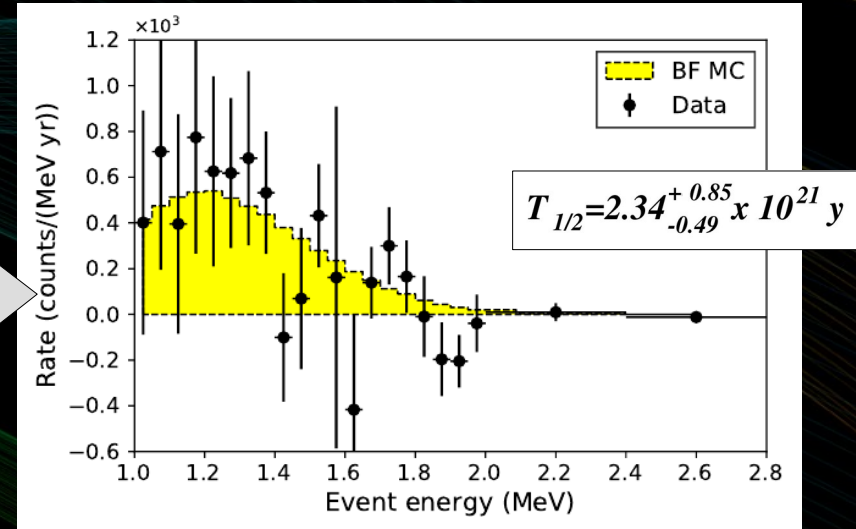
- Novel (so far unique in the field) technique possible due to the Xenon-based NEXT technology

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

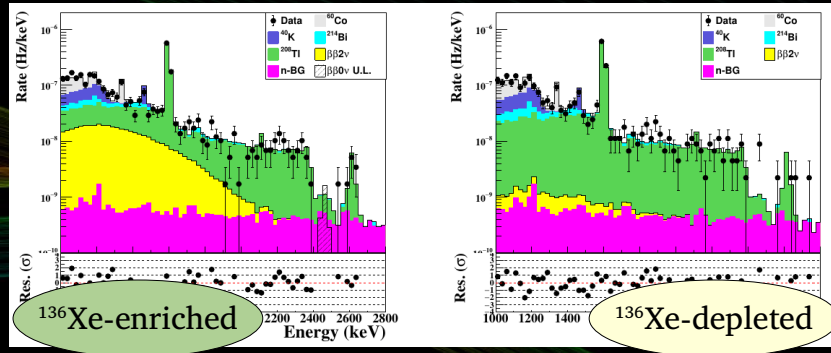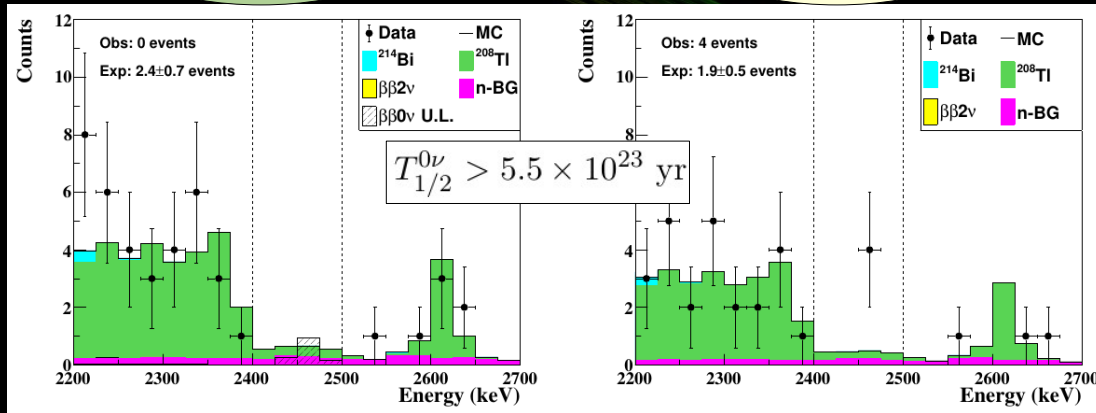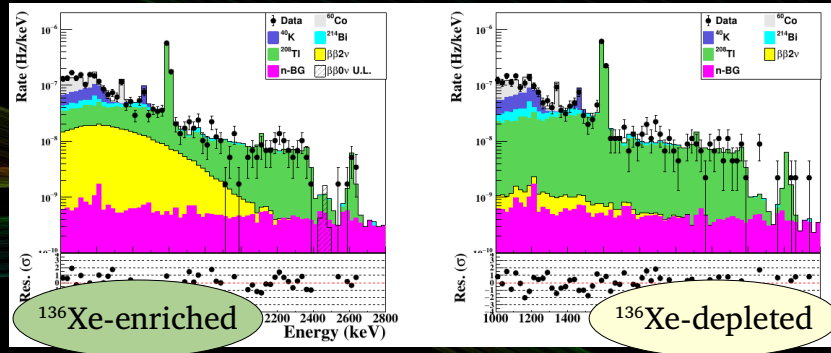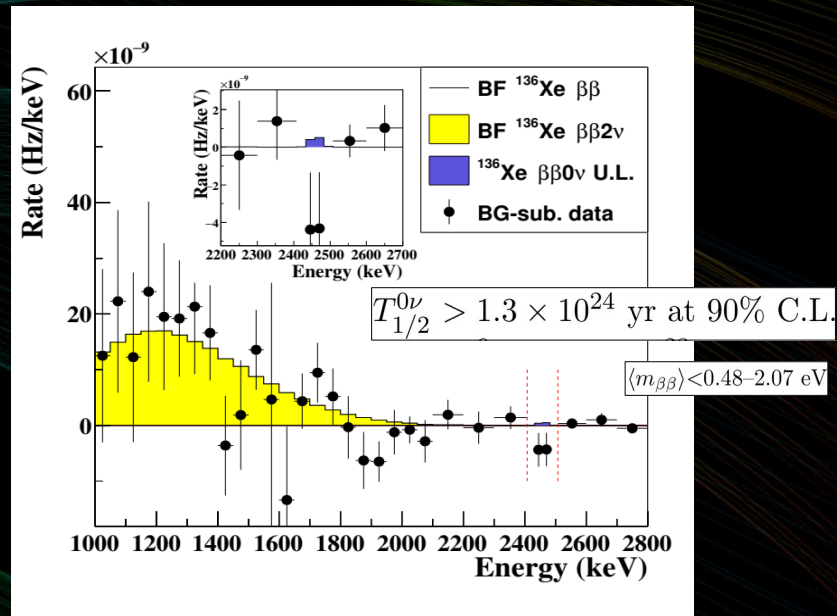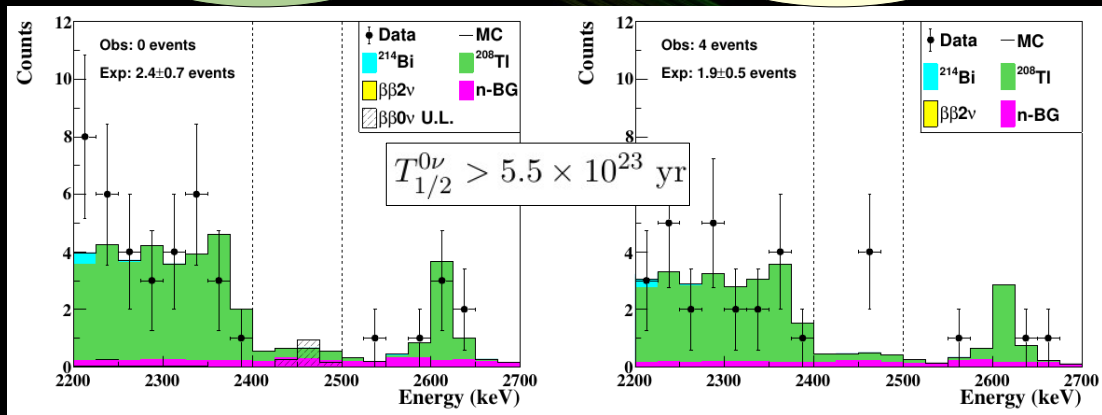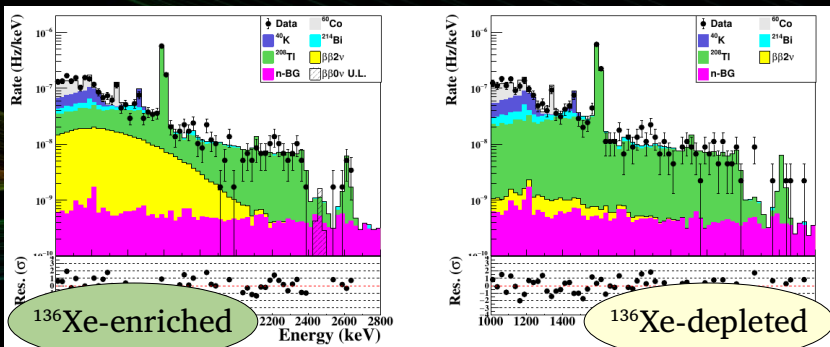Precision limited by exposure (3.5 kg of Xe)!

NEXT-White: Demonstration of ββ0ν searches

- Background-model-dependent:

NEXT-White: Demonstration of ββ0ν searches

- Background-model-dependent:

$$T_{1/2}^{0\nu} > 5.5 \times 10^{23} \text{ yr}$$

NEXT-White: Demonstration of ββ0ν searches

- Background-model-dependent:

^{136}Xe-enriched

^{136}Xe-depleted

Obs: 0 events
Exp: 2.4±0.7 events

$T_{1/2}^{0\nu} > 5.5 \times 10^{23}$ yr

Obs: 4 events
Exp: 1.9±0.5 events

- Background-subtraction (novel in the field):

$T_{1/2}^{0\nu} > 1.3 \times 10^{24}$ yr at 90% C.L.
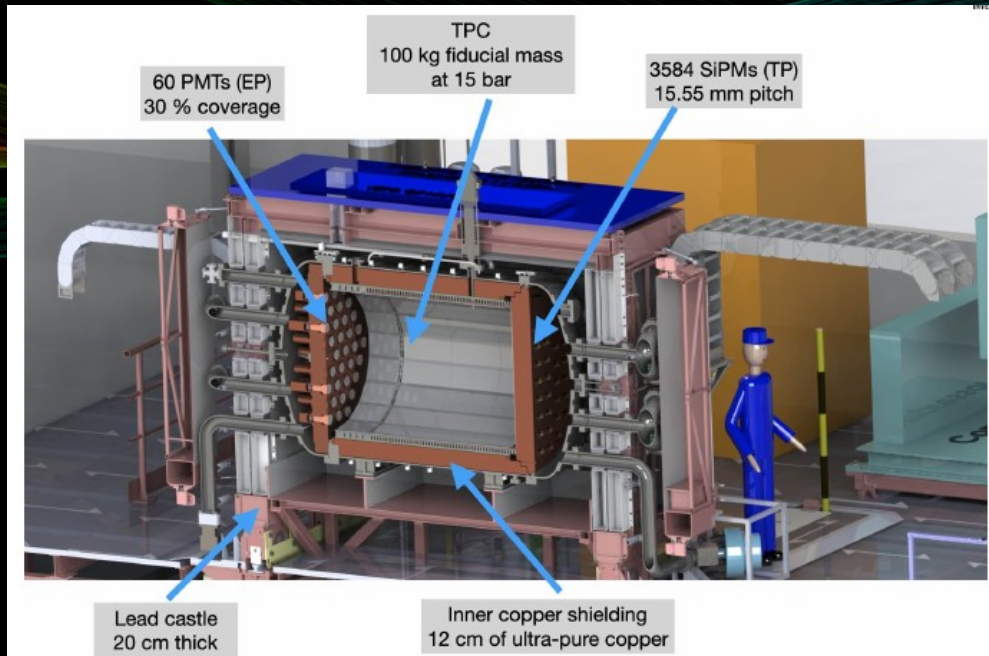
$\langle m_{\beta\beta} \rangle < 0.48$–2.07 eV

- ββ analyses demonstrate the capabilities of the NEXT technology with only 3.5 kg of Xe!

The NEXT-100 Detector

- Scales up the NEXT-White technology (~100 kg) to perform competitive ββ0ν searches

Muon veto covering the lead castle:

Goals of NEXT-100:

- Energy resolution <1% FWHM
- Improve radioactive budget
- Competitive Search of ββ0ν
- Prepare the ton-scale...

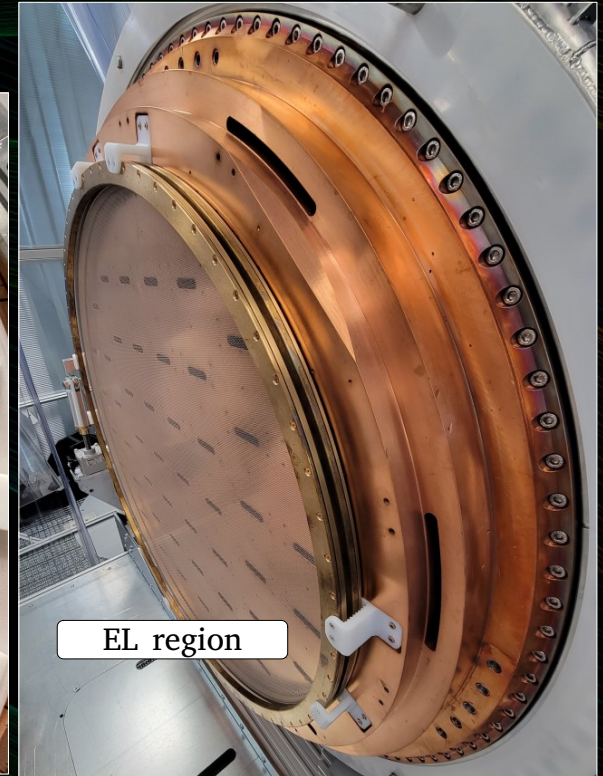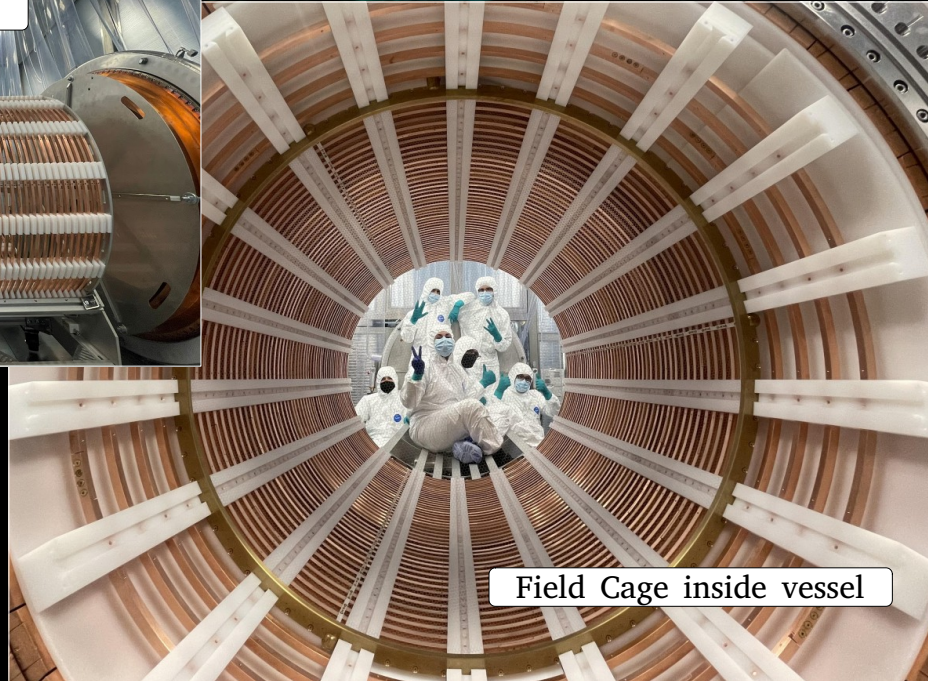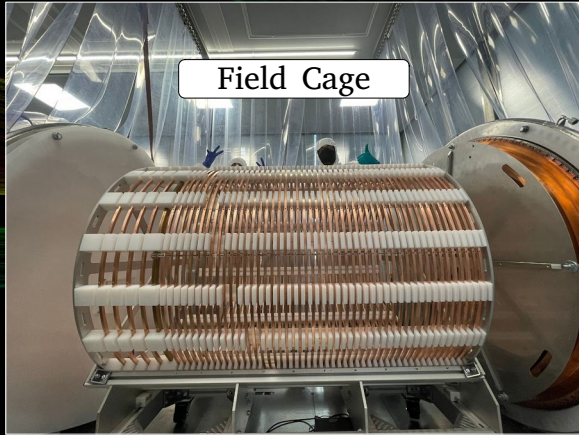- LSC infrastructures in place, detector being installed (2022-2023)

NEXT-100 @ LSC

Pressure Vessel

Gas System

Assembly of energy plate

PMT Window

NEXT-100 @ LSC

Field Cage

Field Cage inside vessel

EL region

NEXT-100 Physics Case

- Sensitivity study @ 2016:

Total BG:
$\sim 10^{-4}$ c/keV/kg/y
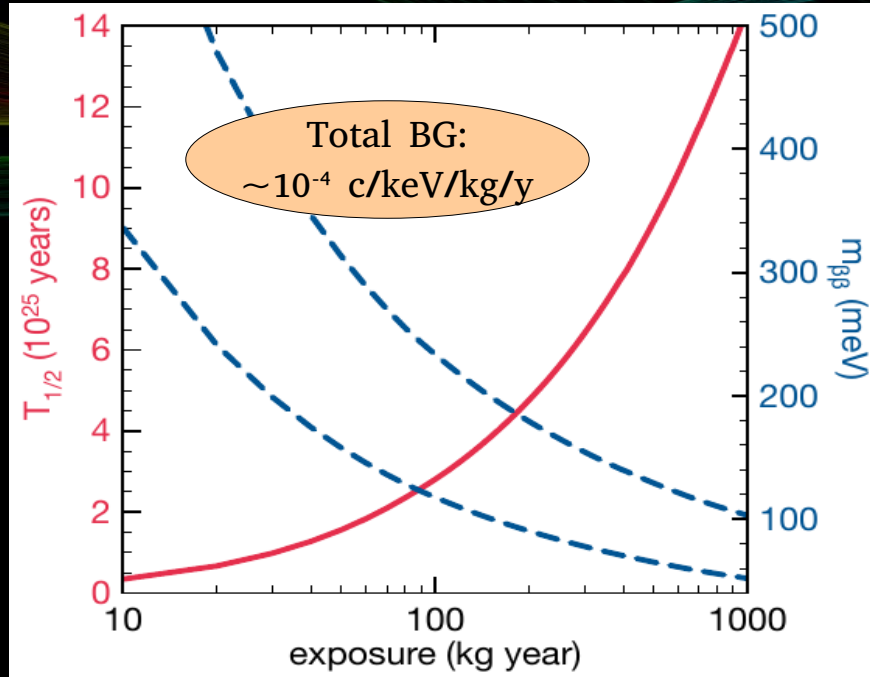
- New BG budget estimation: radiopurity screening campaign + MC

7.5×10^{-4} counts/(keV·kg·yr)

0.1 background events/yr
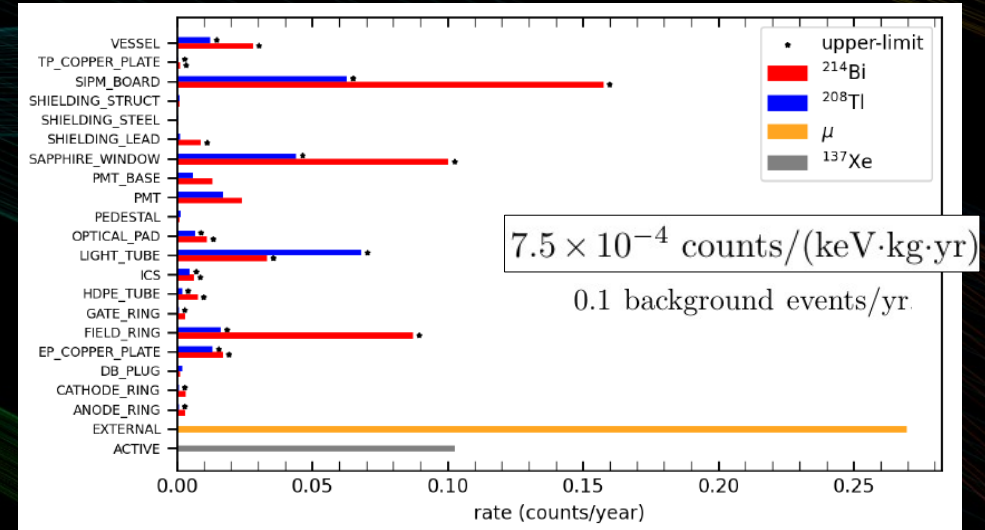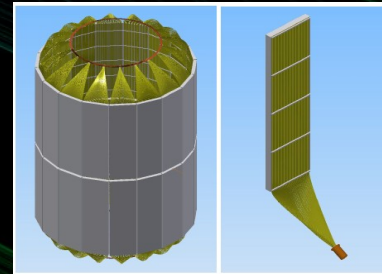
- Sensitivity: 4.1×10^{25} yr at 90% CL (3 years)

NEXT at the Ton-scale: NEXT-HD

- Next generation of ββ experiments: exposures >10^3 kg and BG index < 1 count/ton/yr
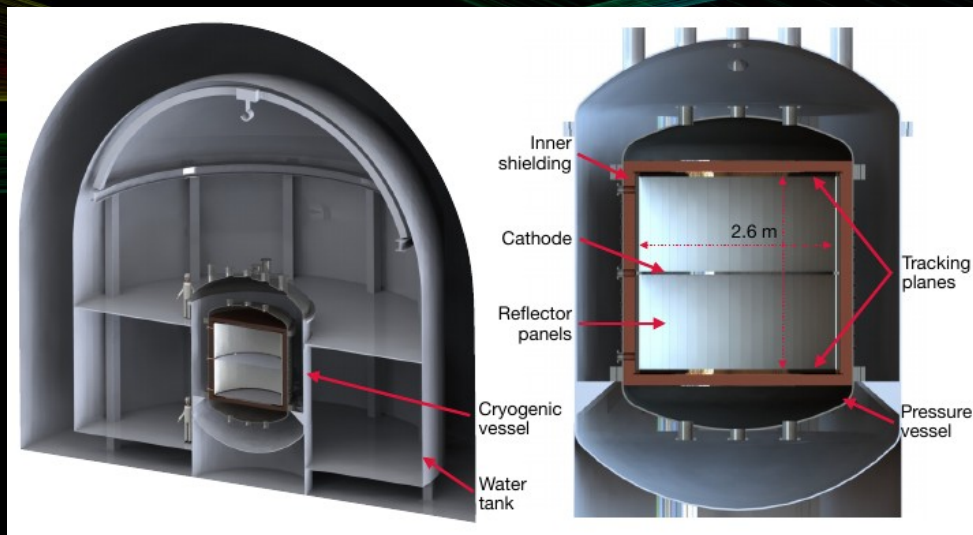- Conceptual design of a NEXT ton-scale detector: symmetric TPC, dense SiPM array, Barrel fiber detector (S1+S2)
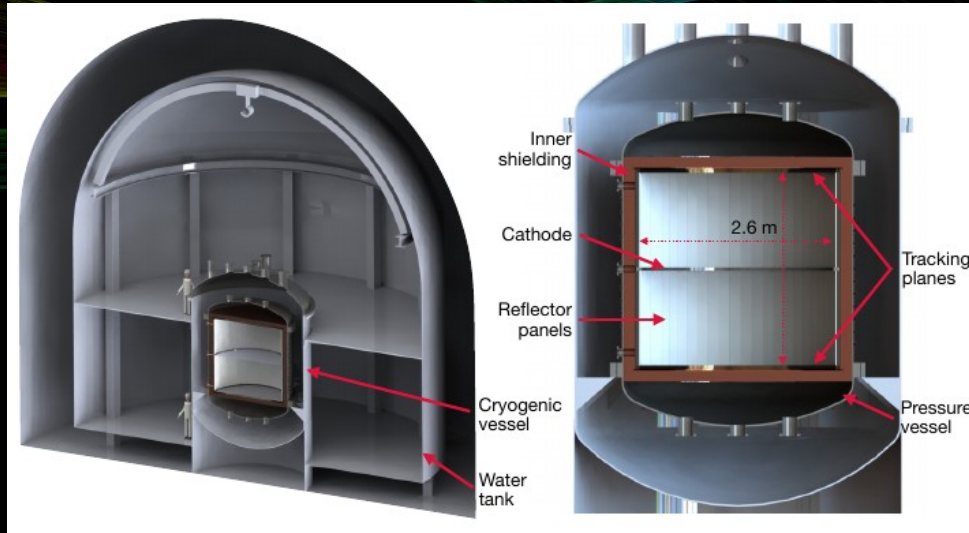
Energy resolution < 0.7% FWHM
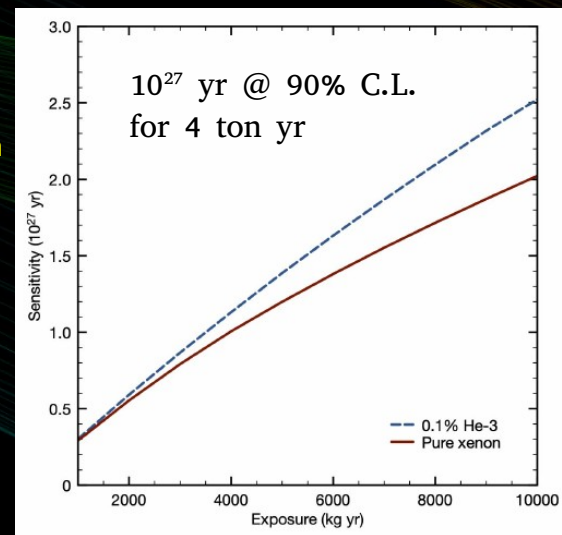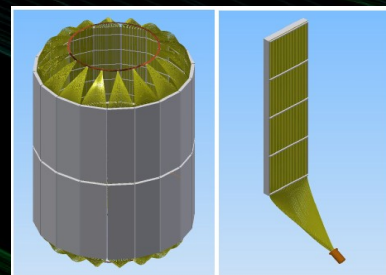due to improvement in light collection

- Gas mixtures: low diffusion (Xe+He4) to improve resolution and H3 (if possible) to mitigate cosmogenic BGs
- First module to be installed at LSC, but collaboration open to a multi-modular approach

NEXT at the Ton-scale: NEXT-HD

- Next generation of ββ experiments: exposures >10^3 kg and BG index < 1 count/ton/yr
- Conceptual design of a NEXT ton-scale detector: symmetric TPC, dense SiPM array, Barrel fiber detector (S1+S2)

Inner shielding
Cathode
Reflector panels
Cryogenic vessel
Water tank
Tracking planes
Pressure vessel
2.6 m

Energy resolution < 0.7% FWHM due to improvement in light collection

10^{27} yr @ 90% C.L. for 4 ton yr

Sensitivity (10^{27} yr)
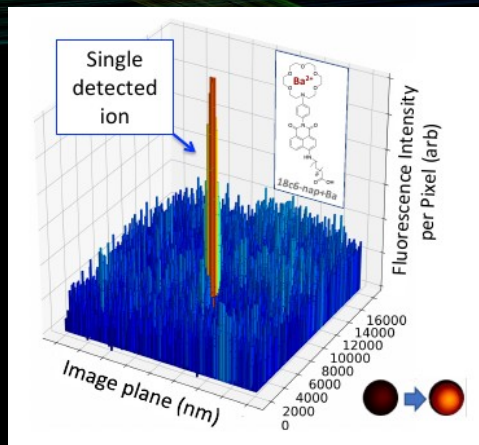
Exposure (kg yr)

0.1% He-3
Pure xenon

- Gas mixtures: low diffusion (Xe+He4) to improve resolution and H3 (if possible) to mitigate cosmogenic BGs
- First module to be installed at LSC, but collaboration open to a multi-modular approach
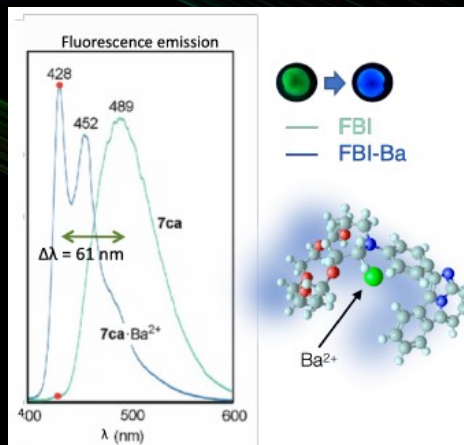
NEXT with Ba-tagging: BOLD

$$^{136}\text{Xe} \rightarrow {}^{136}\text{Ba}^{++} + 2e^- (+2\bar{\nu}_e)$$
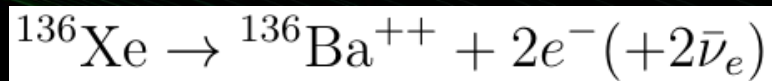
- Efficient ID of Ba²⁺ → BG-free experiment
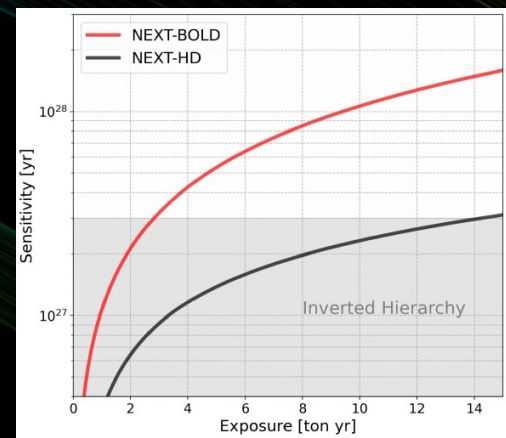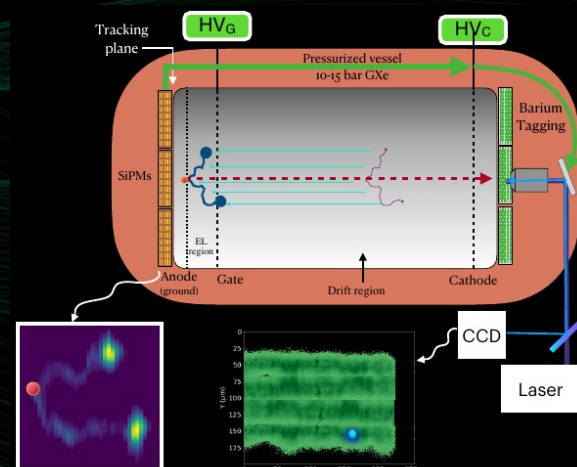- R&D on Single Molecule Fluorescent Imaging:

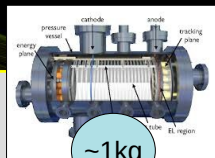
PRL 120 (2018) 132504

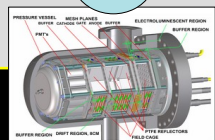Nature 583 (2020) 7814
Nature Commun. 13 (2022) 1, 7741

P. Novella, NEXT @ TAUP2023

Summary

R&D
Proof of Concept

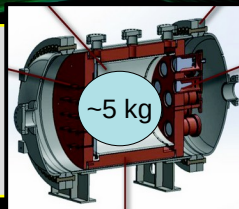~1kg

2009-2014

NEXT-White
Background+ββ2ν
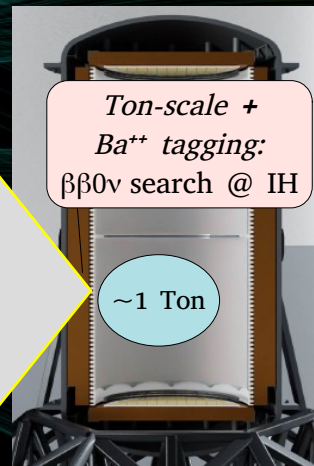
~5 kg

2015-2021

NEXT-100 (+upgrades)
ββ0ν search
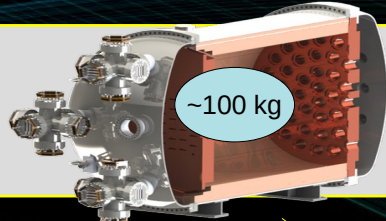
~100 kg

2022-2026

Ton-scale +
Ba++ tagging:
ββ0ν search @ IH

~1 Ton

90% CL (1 dof)

NEXT-100

NEXT-HD
NEXT-BOLD

m_{ee} in eV

lightest neutrino mass in eV

The NEXT Collaboration