The NEXT experiment

Gonzalo Díaz López

LPNHE since April 23
(IGFAE/USC until February 23)

International Research Network Neutrino
June 20th, Nantes

Overview

- Introduction: double beta decay
- NEXT, detection concept and phases
- Calibration and reconstruction in NEXT
- Main results: NEXT-White
- Near future prospects: NEXT-100
- Towards tonne scale

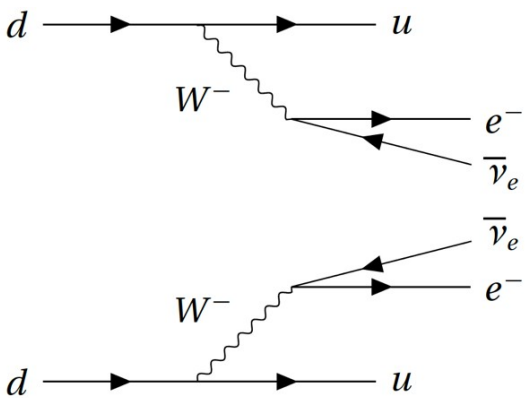
Overview

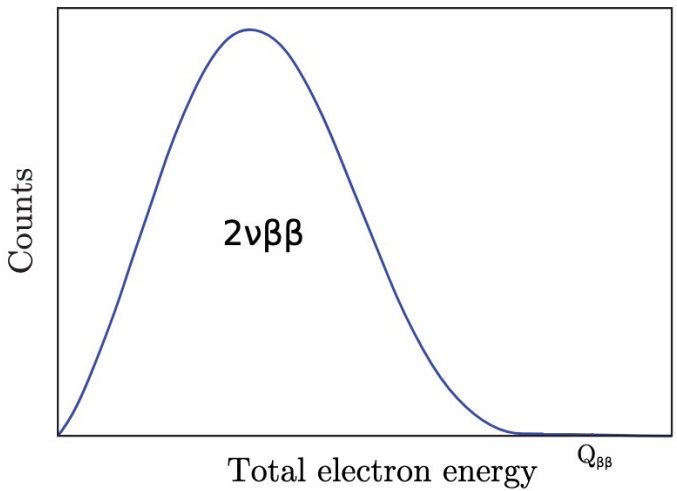
- Introduction: double beta decay
- NEXT, detection concept and phases
- Calibration and reconstruction in NEXT
- Main results: NEXT-White
- Near future prospects: NEXT-100
- Towards tonne scale

Double beta decay

- Double beta decay **with neutrinos**

$$N_Z \rightarrow N_{Z+2} + 2e^- + 2\overline{\nu}_e$$





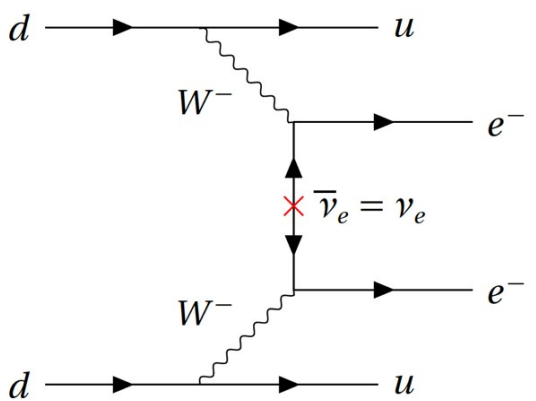
$T_{1/2} \sim 10^{20}$ years

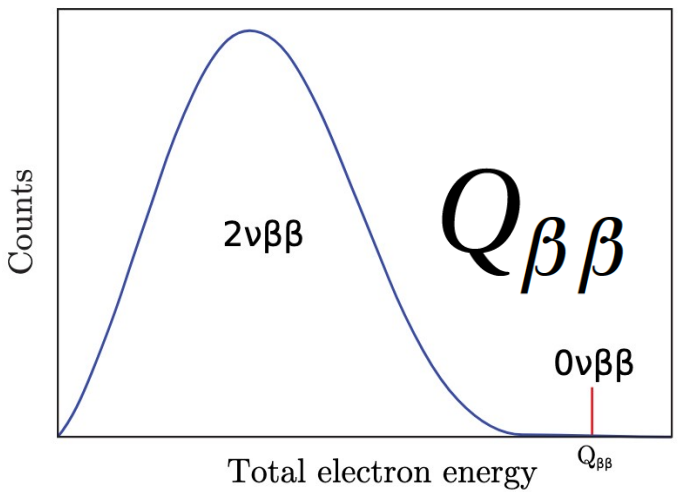
Double beta decay

- Double beta decay **without neutrinos**
- Neutrinos must be **Majorana** particles (neutrino = antineutrino)
- Sensitive to neutrino mass ordering and absolute scale

LEPTON NUMBER VIOLATION!!

$$N_Z \rightarrow N_{Z+2} + 2e^- + 2\bar{\nu}_e$$





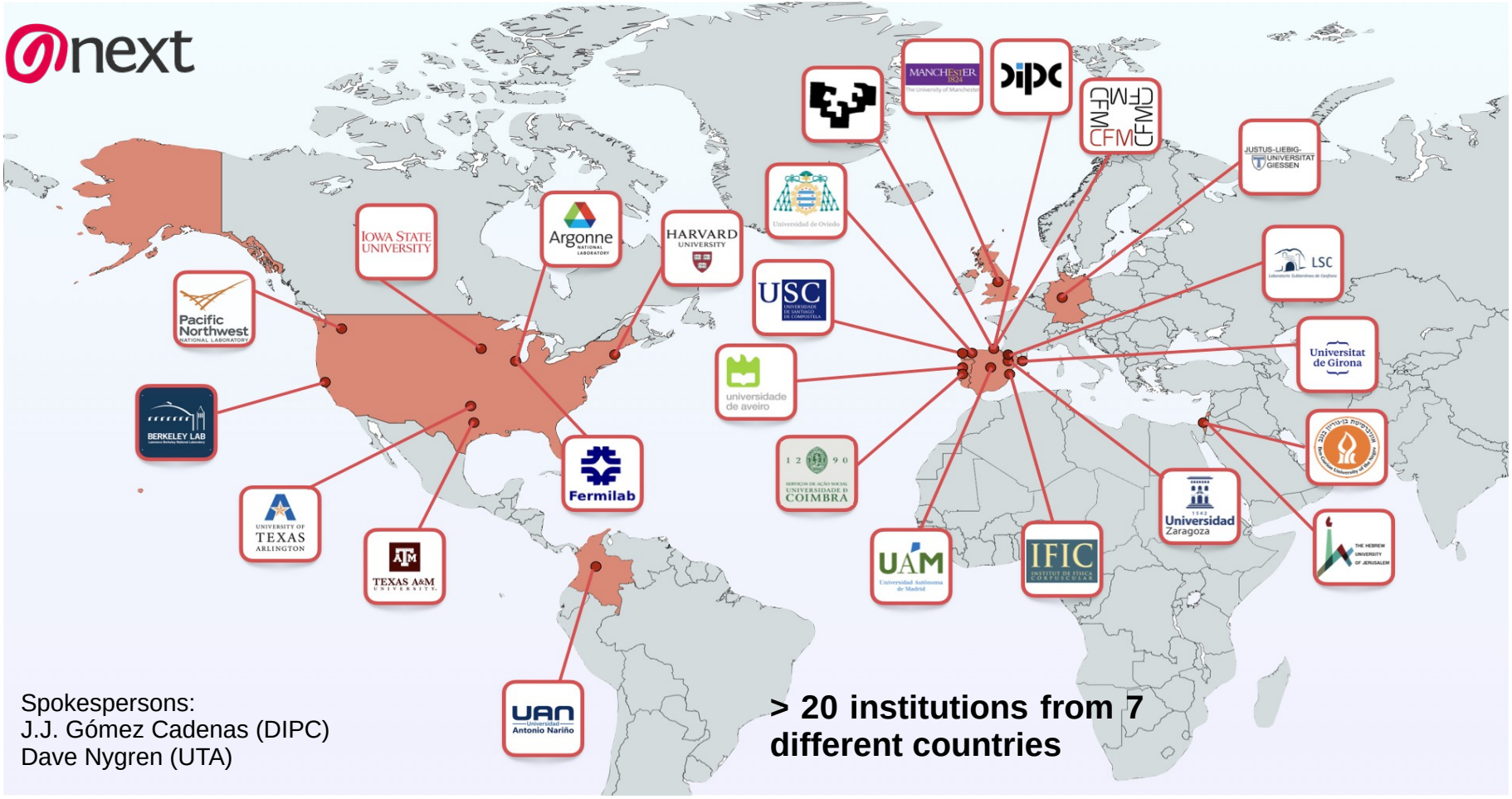
$T_{1/2} > 10^{26}$ years

Overview

- Introduction: double beta decay
- NEXT, detection concept and phases
- Calibration and reconstruction in NEXT
- Main results: NEXT-White
- Near future prospects: NEXT-100
- Towards tonne scale

NEXT Collaboration

Neutrino Experiment with a Xenon TPC

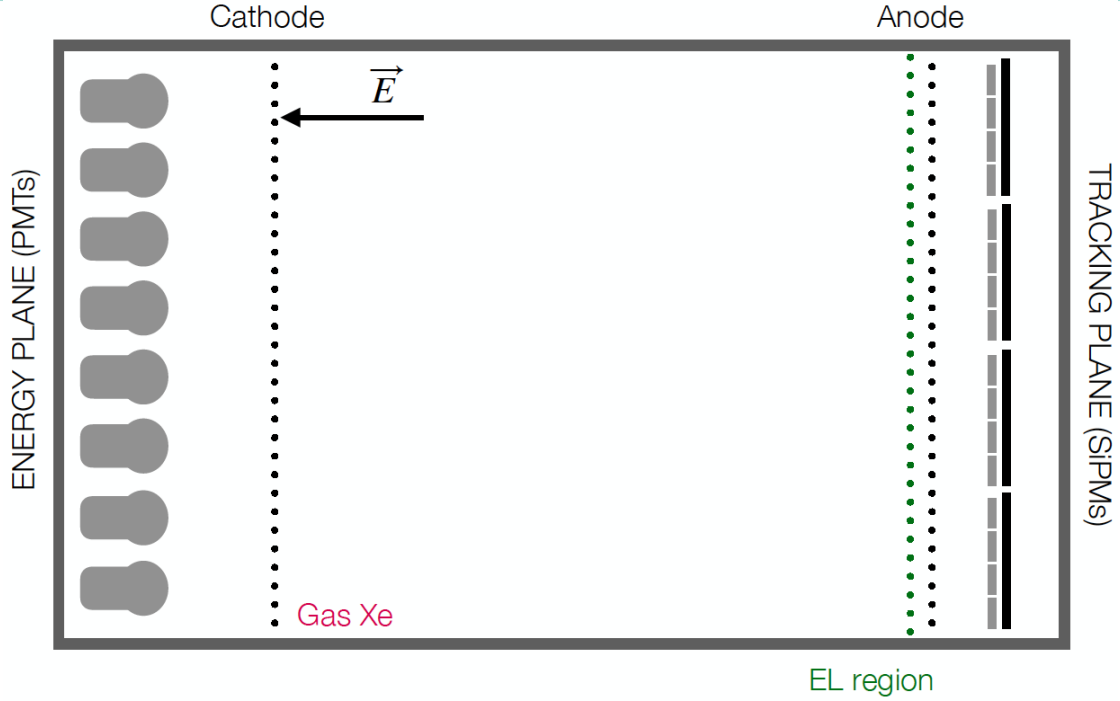


Spokespersons:
J.J. Gómez Cadenas (DIPC)
Dave Nygren (UTA)

> 20 institutions from 7 different countries

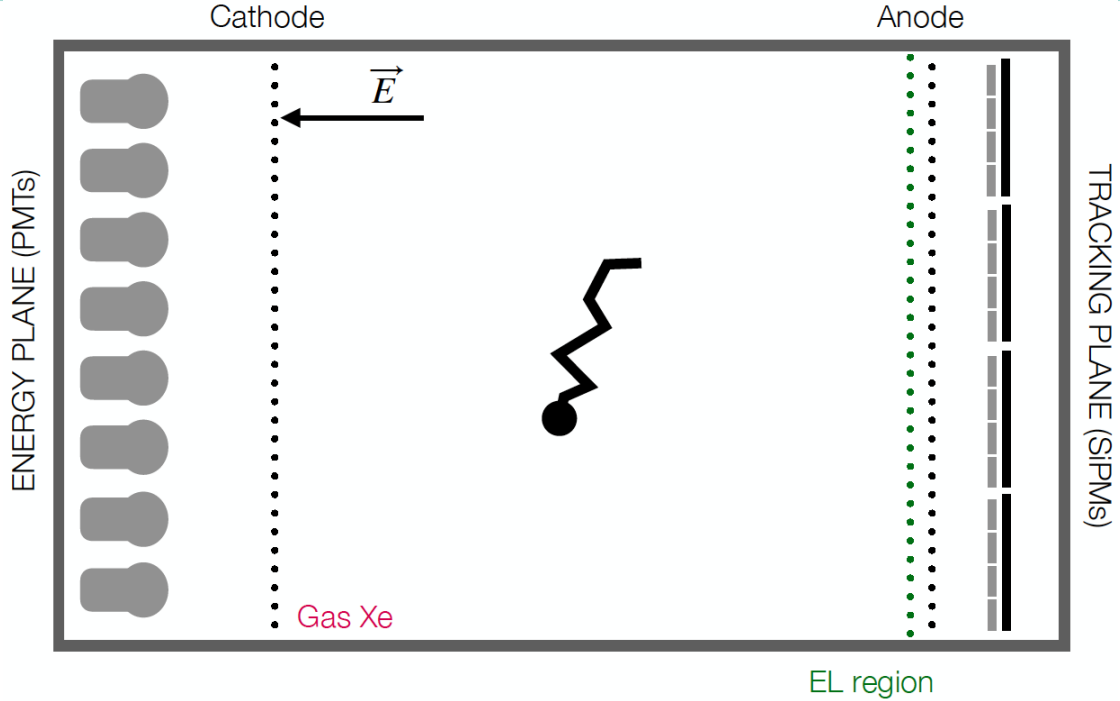
NEXT detection concept

- High pressure xenon (**enriched to ^{136}Xe**) TPC
- Asymmetric configuration:
  - Energy plane (PMTs)
  - Tracking plane (SiPMs)



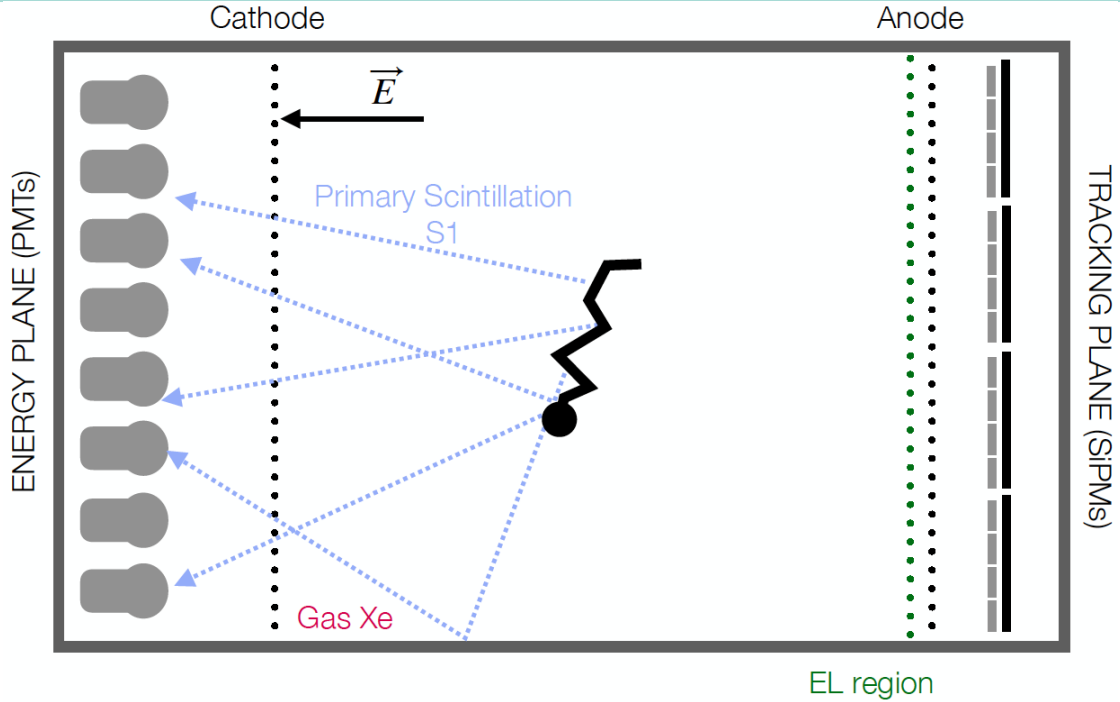
NEXT detection concept

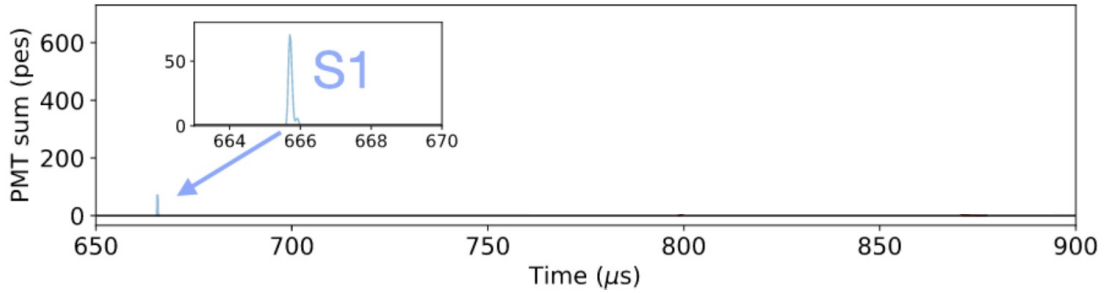
- High pressure xenon (enriched to ^{136}Xe) TPC
- Asymmetric configuration:
  - Energy plane (PMTs)
  - Tracking plane (SiPMs)
- Excitation + Ionization



NEXT detection concept

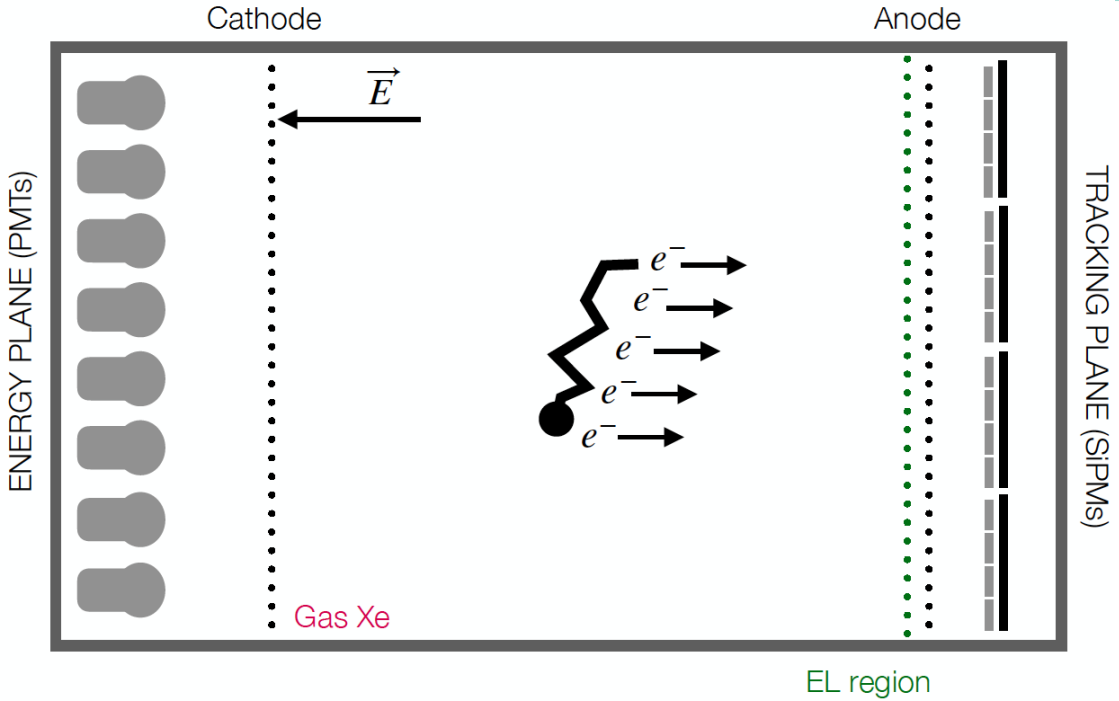
- High pressure xenon (enriched to ^{136}Xe) TPC
- Asymmetric configuration:
  - Energy plane (PMTs)
  - Tracking plane (SiPMs)
- Excitation + Ionization
- Scintillation light (S1)

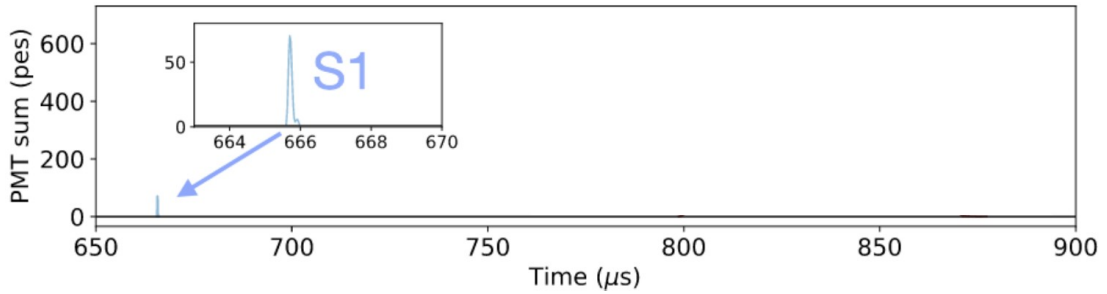




NEXT detection concept

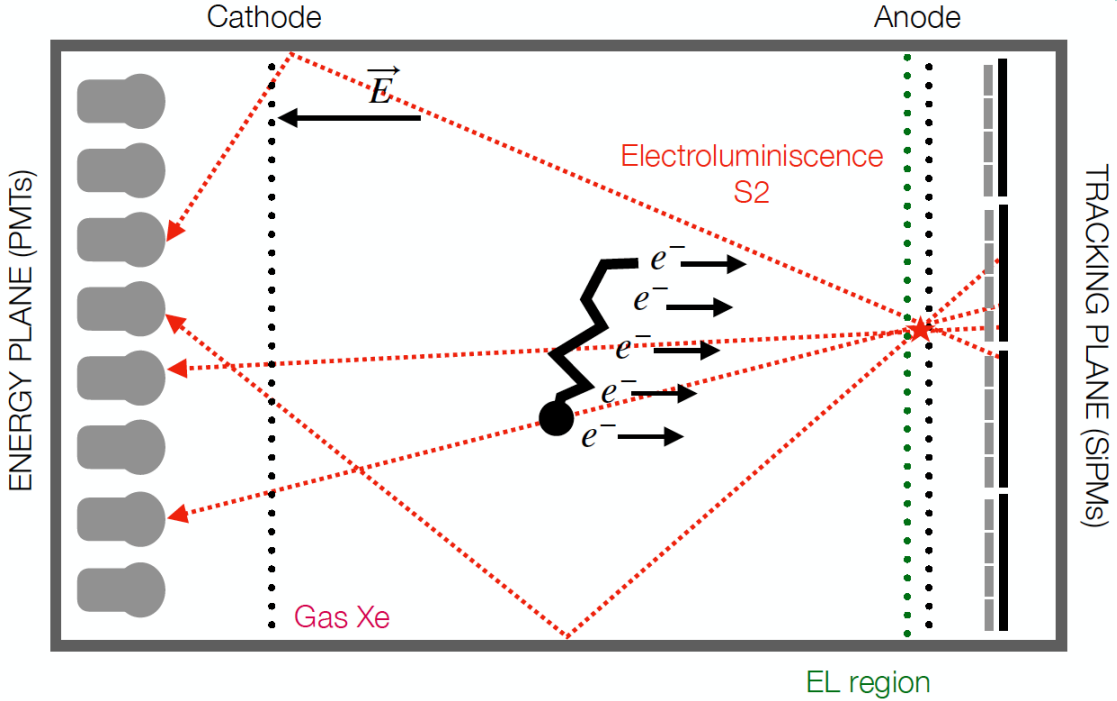
- High pressure xenon (enriched to ^{136}Xe) TPC
- Asymmetric configuration:
  - Energy plane (PMTs)
  - Tracking plane (SiPMs)
- Excitation + Ionization
- Scintillation light (S1)
- Drifting

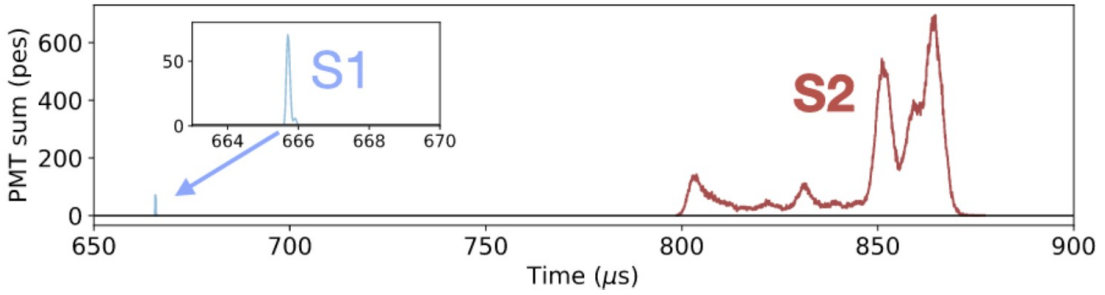




NEXT detection concept

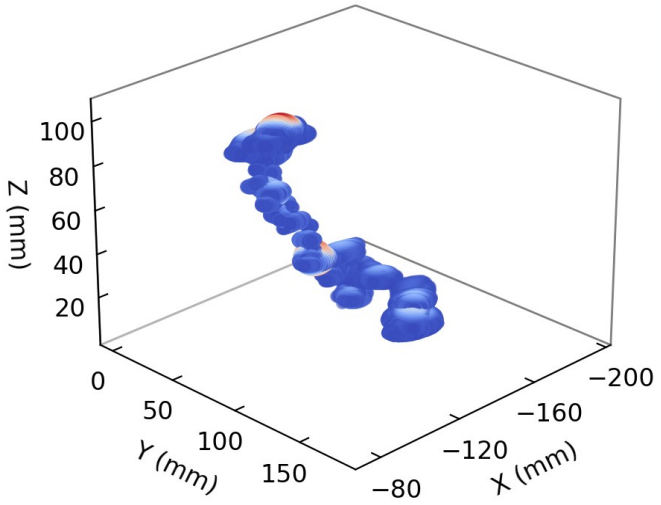
- High pressure xenon (enriched to ^{136}Xe) TPC
- Asymmetric configuration:
  - Energy plane (PMTs)
  - Tracking plane (SiPMs)
- Excitation + Ionization
- Scintillation light (S1)
- Drifting
- Electroluminescence light (S2)

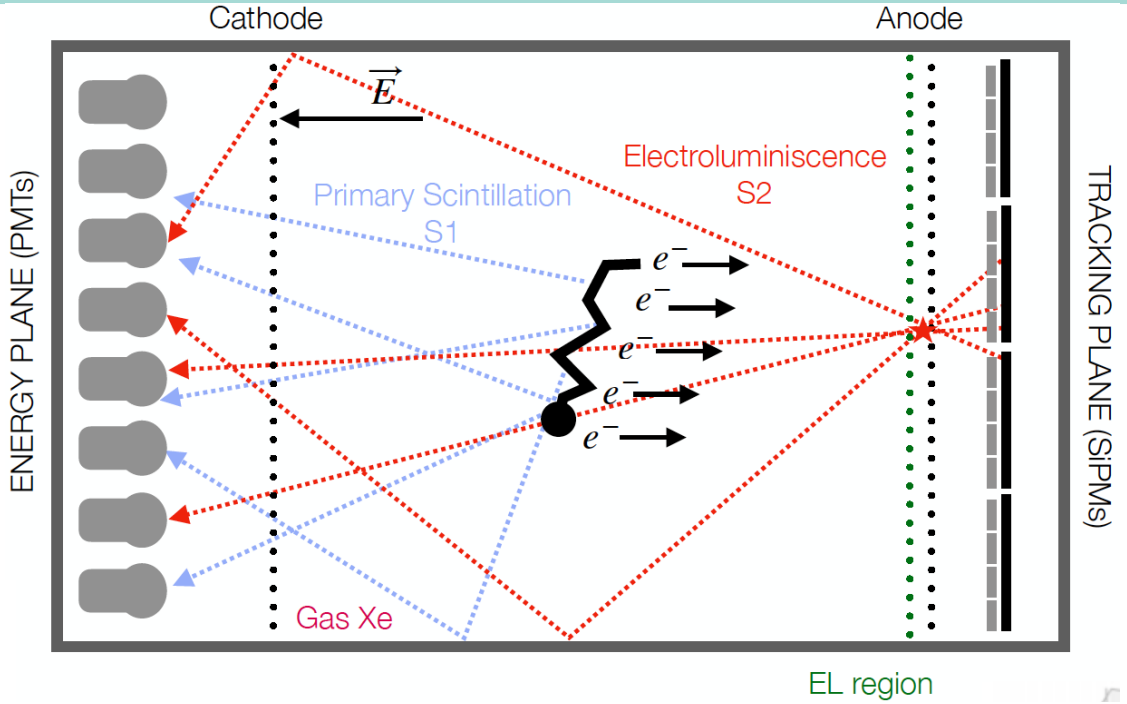




NEXT detection concept

- High pressure xenon (enriched to ^{136}Xe) TPC
- Asymmetric configuration:
  - Energy plane (PMTs)
  - Tracking plane (SiPMs)
- Excitation + Ionization
- Scintillation light (S1)
- Drifting
- Electroluminescence light (S2)
- 3D reconstruction

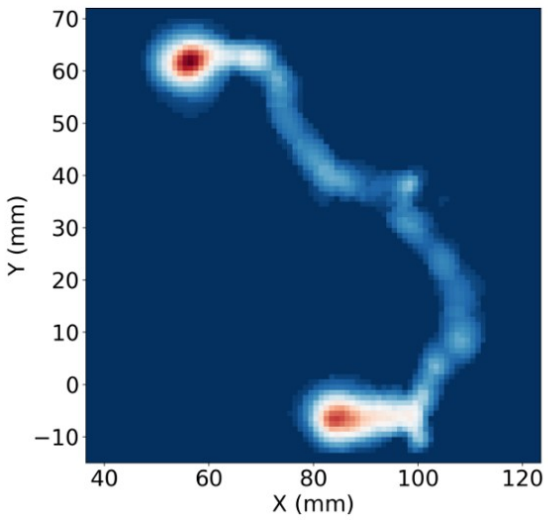




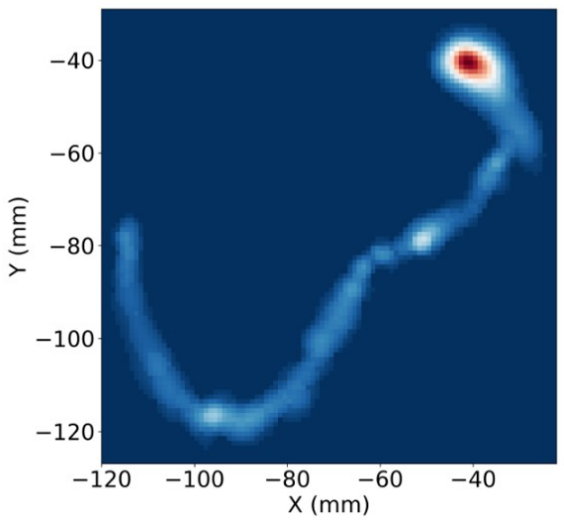
NEXT detection concept

- Gaseous Xenon: resolution + long tracks
- Long tracks: signal vs background discrimination! (Bragg's peak)

Signal



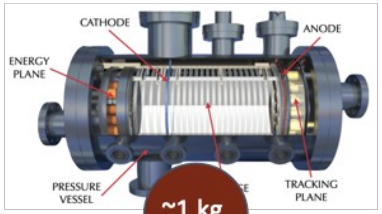
Background



(*event candidates in the 2νββ ROI from NEXT-White data, JINST 8 P05025)

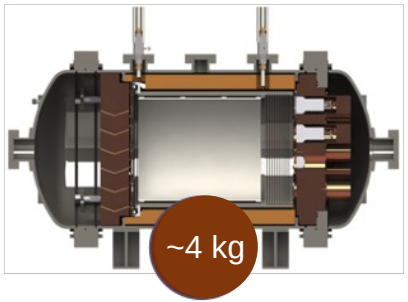
Timeline

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

We are here now
NEXT-100 under construction

Timeline

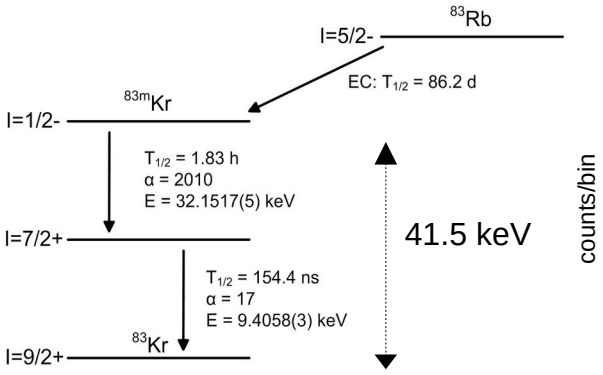

Paris
France
Portugal
Madrid
Spain
Lisbon
Tyrrhenian Sea
LSC
Laboratorio Subterráneo Canfranc

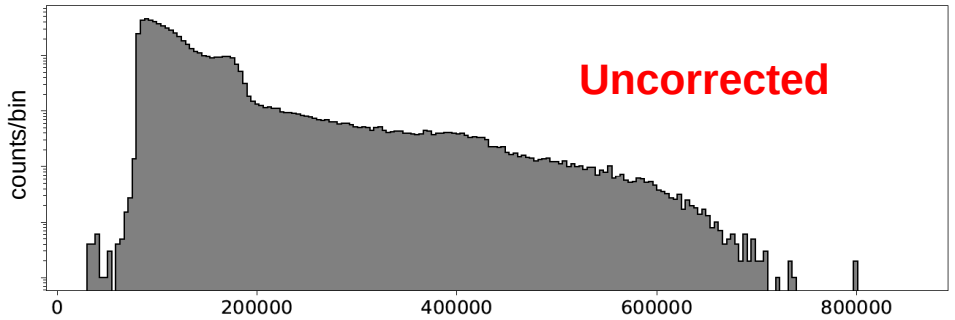
Overview

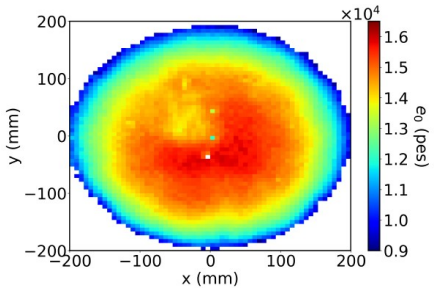
- Introduction: double beta decay
- NEXT, detection concept and phases
- Calibration and reconstruction in NEXT
- Main results: NEXT-White
- Near future prospects: NEXT-100
- Towards tonne scale

Calibration and reconstruction in NEXT

- ^{83m}Kr point-like depositions
- Geometrical + Attachment maps

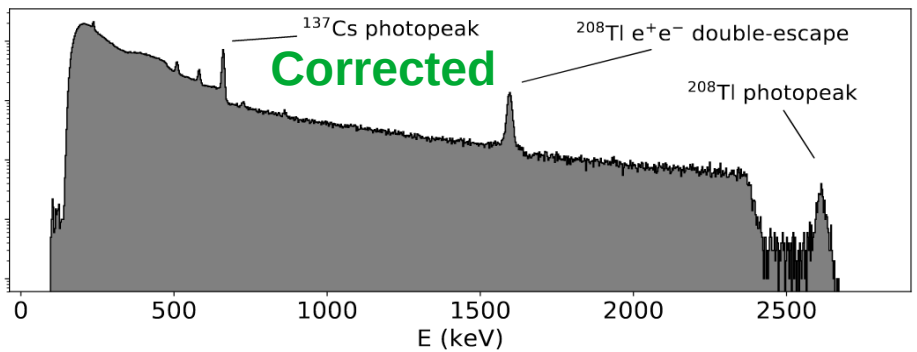






$$\overline{E}(x,y,z) = \overline{E}_0(x,y) \times e^{-z/\tau(x,y)}$$

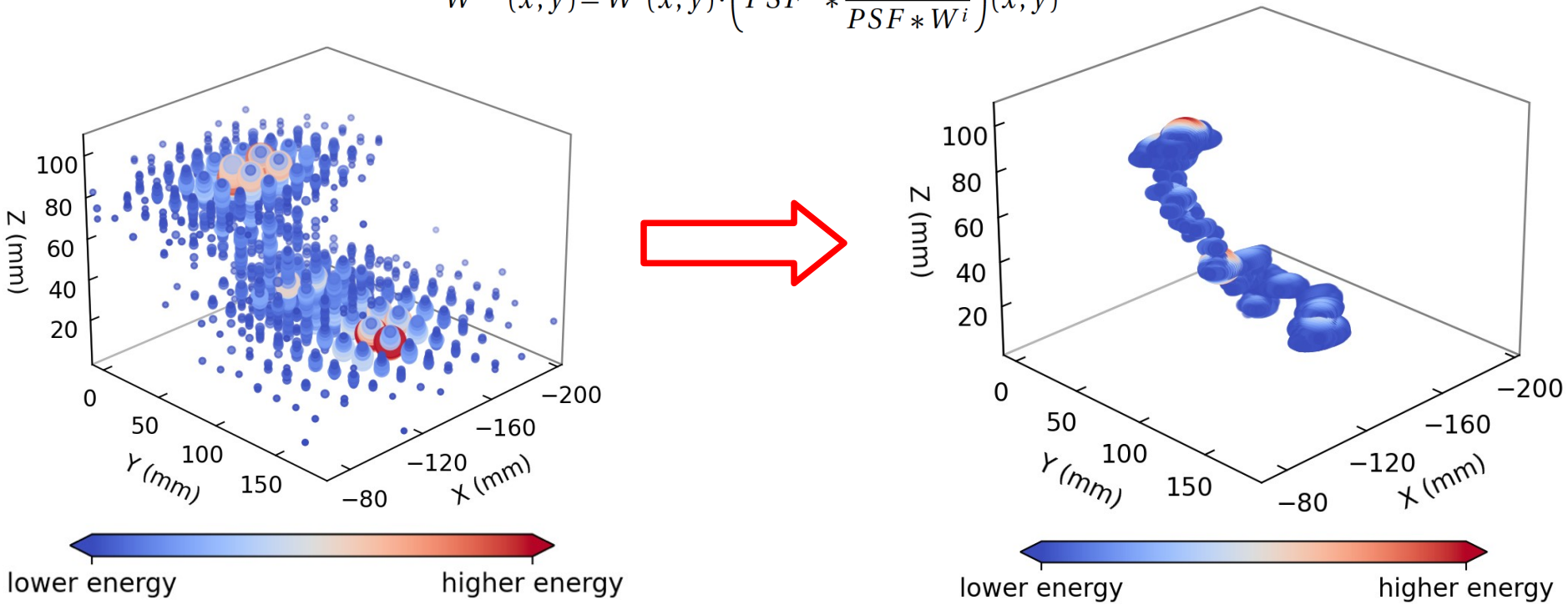
geometrical lifetime



Calibration and reconstruction in NEXT

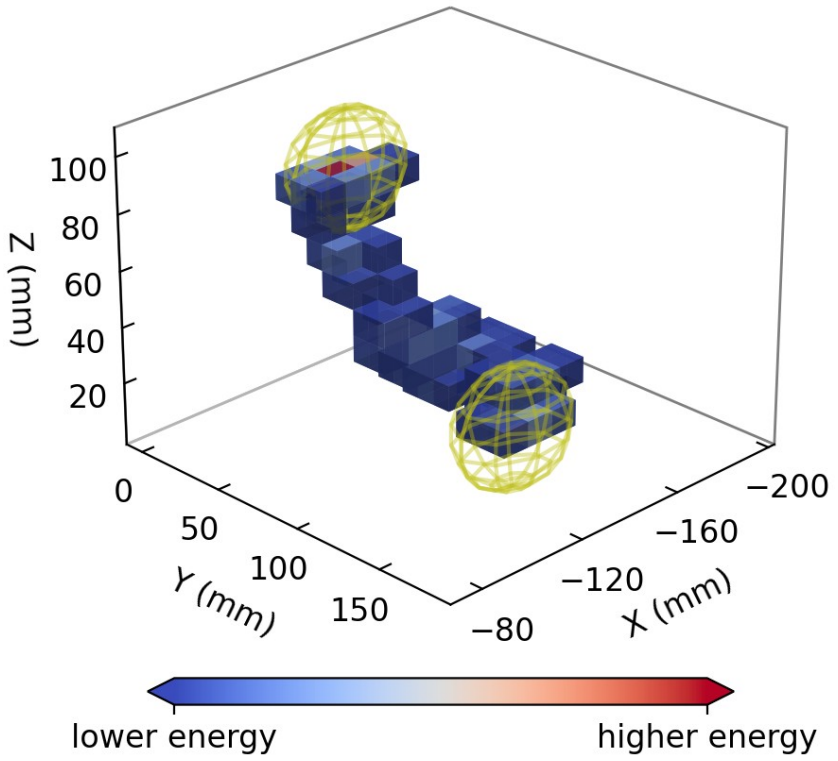
- Deconvolute diffusion and PSF effect
- Lucy-Richardson algorithm

$$W^{i+1}(x,y) = W^{i}(x,y) \cdot \left(PSF^{T} * \frac{H}{PSF * W^{i}} \right)(x,y)$$



Calibration and reconstruction in NEXT

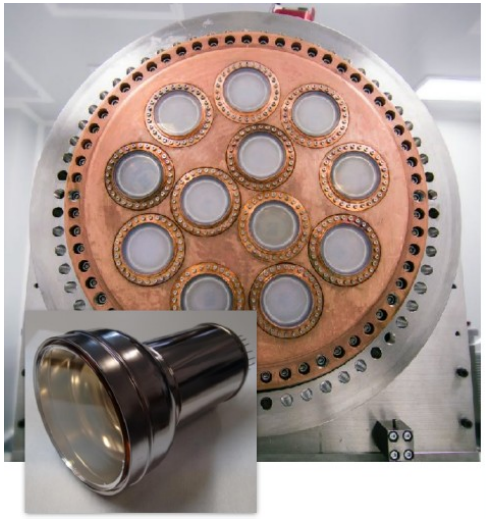
- Track voxelization
- Find extremes: BFS algorithm
- Define blobs

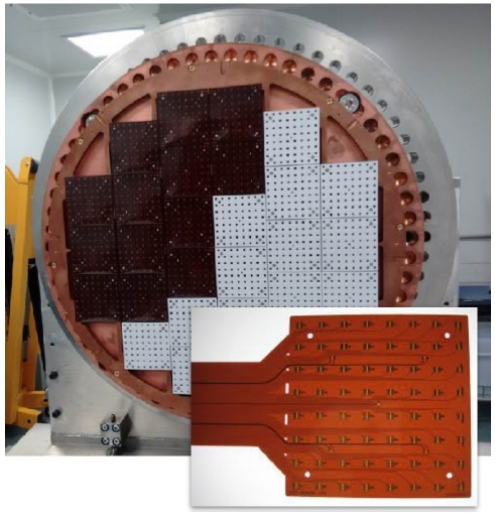


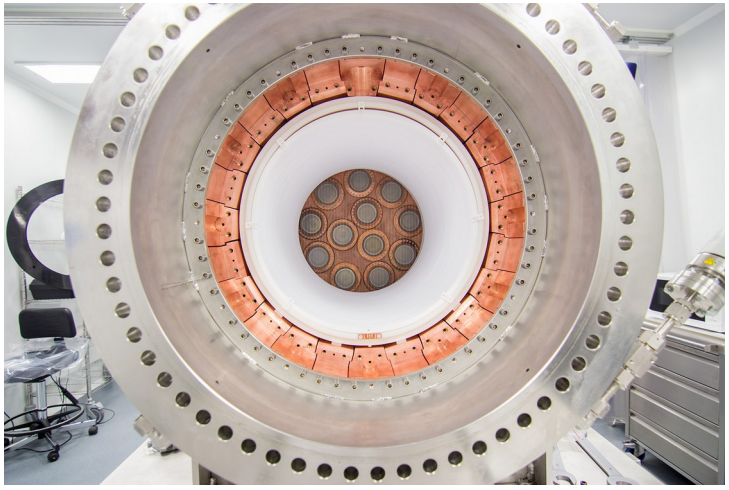
Overview

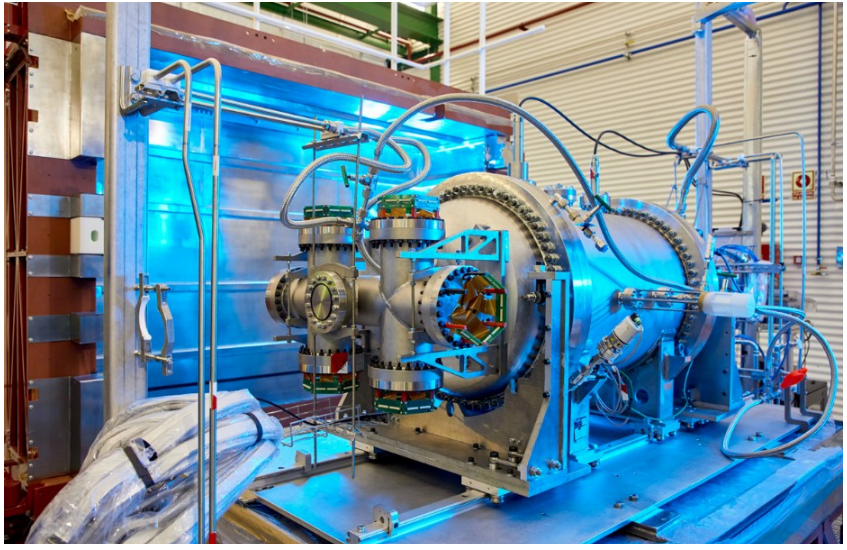
- Introduction: double beta decay
- NEXT, detection concept and phases
- Calibration and reconstruction in NEXT
- Main results: NEXT-White
- Near future prospects: NEXT-100
- Towards tonne scale

NEXT-White detector









- 4 kg Xe at 8.5 bar (90% ^{136}Xe)
- 50 cm (drift) x 40 cm (diam), 6 mm (EL)
- 12 PMTs (30% coverage)
- 1792 SiPMs at 1 cm pitch
- shielding: 20 cm (Pb), 6 cm (Cu)

NEXT-White main results

a) **Energy resolution** of (0.91 ± 0.07)% FWHM at 2.6 MeV (near Qββ)

JHEP 10 (2019) 230

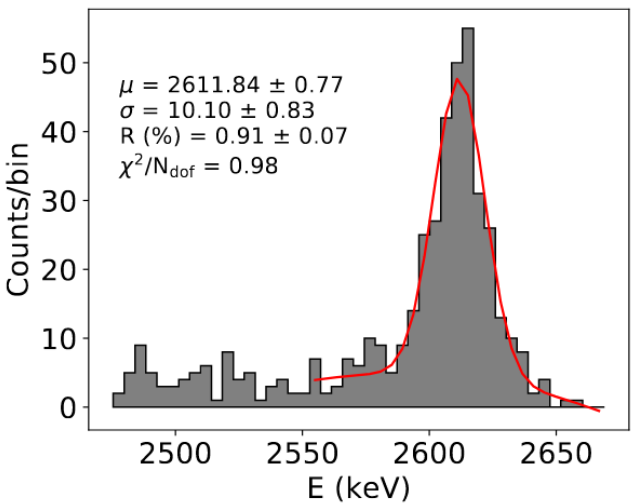
b) Demonstration of topological **signal vs background rejection**

JHEP 10 (2019) 52 || JHEP 01 (2021) 189 || JHEP 07 (2021) 146

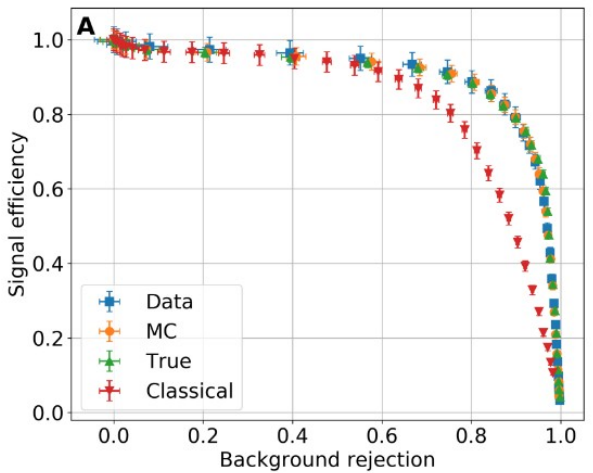
c) Measurement of **2νββ half-life**

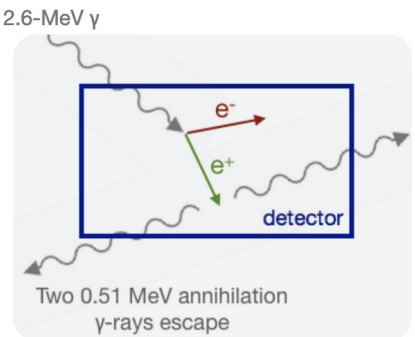
JHEP 10 (2019) 51 || **Phys. Rev. C 105, 055501 (2022)**

a) **0.9 % FWHM at 2.6 MeV**



b) **signal vs background discrimination**



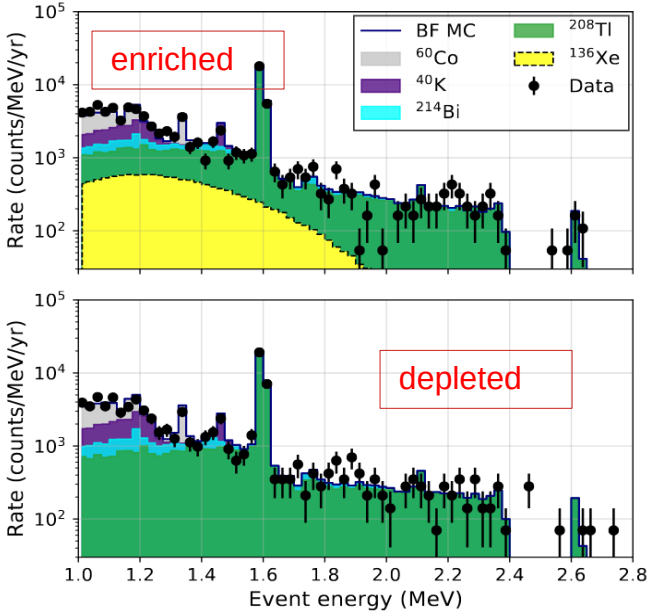


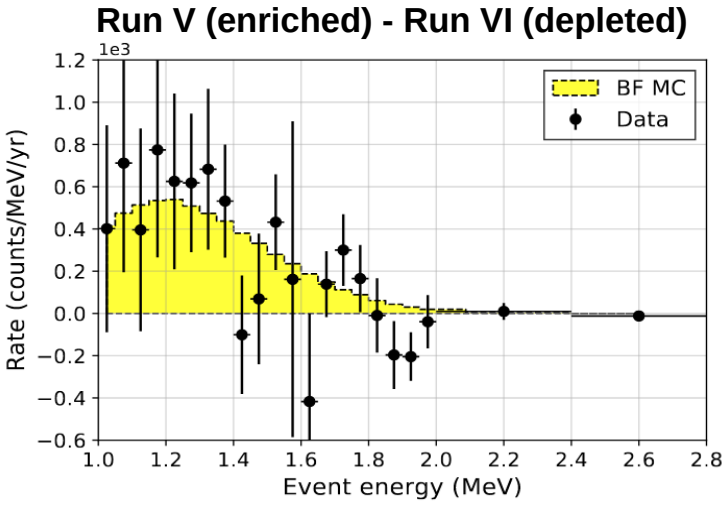
NEXT-White main results

c) **Measurement of 2νββ half-life**

- signal selection: single-track + topological
- new background subtraction technique
- ~4σ significance
- compatible with EXO-200 and KamLand-Zen

Phys. Rev. C 105, 055501 (2022)



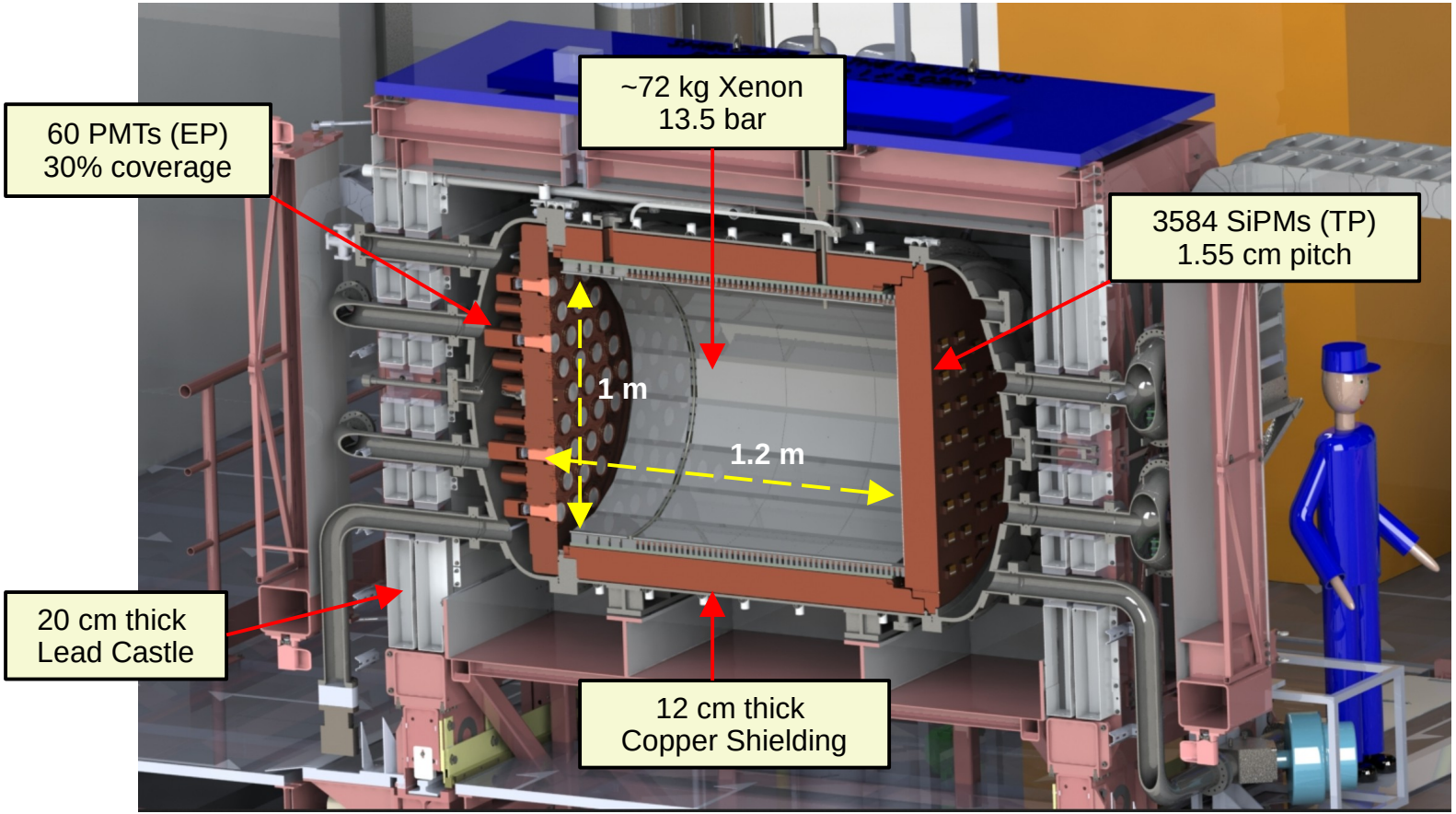


$$T_{1/2}^{2\nu\beta\beta} = 2.34^{+0.80}_{-0.46}(\text{stat.})^{+0.30}_{-0.17}(\text{sys.}) \times 10^{21} \text{ years}$$

Overview

- Introduction: double beta decay
- The NEXT detection concept and timeline
- Calibration and reconstruction in NEXT
- Main results: NEXT-White
- Near future prospects: NEXT-100
- Towards tonne scale

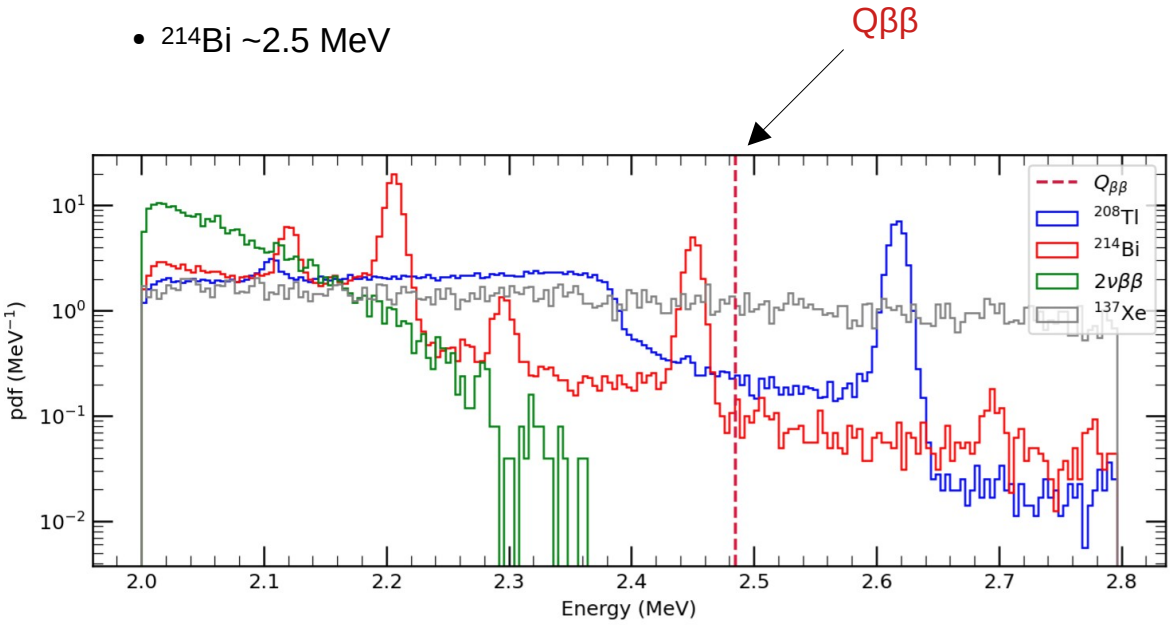
2 X NEXT-White!
Under construction at LSC!



NEXT-100 0νββ background model

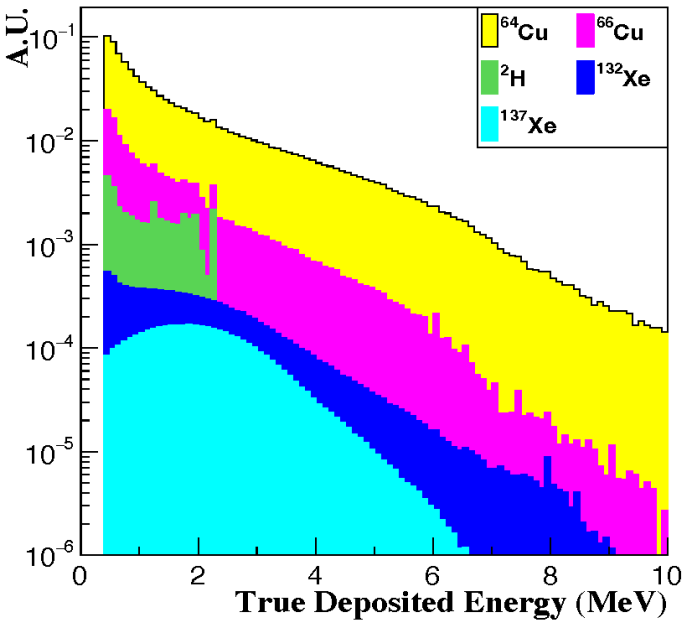
Radiogenics

- ^{208}Tl ~2.6 MeV
- ^{214}Bi ~2.5 MeV



Cosmogenics

- ^{137}Xe + prompt-γ (~95% Cu)
- >99% prompt-γ within 2 ms (**=> μ-veto**)



(from P. Novella)*

NEXT-100 0νββ sensitivity

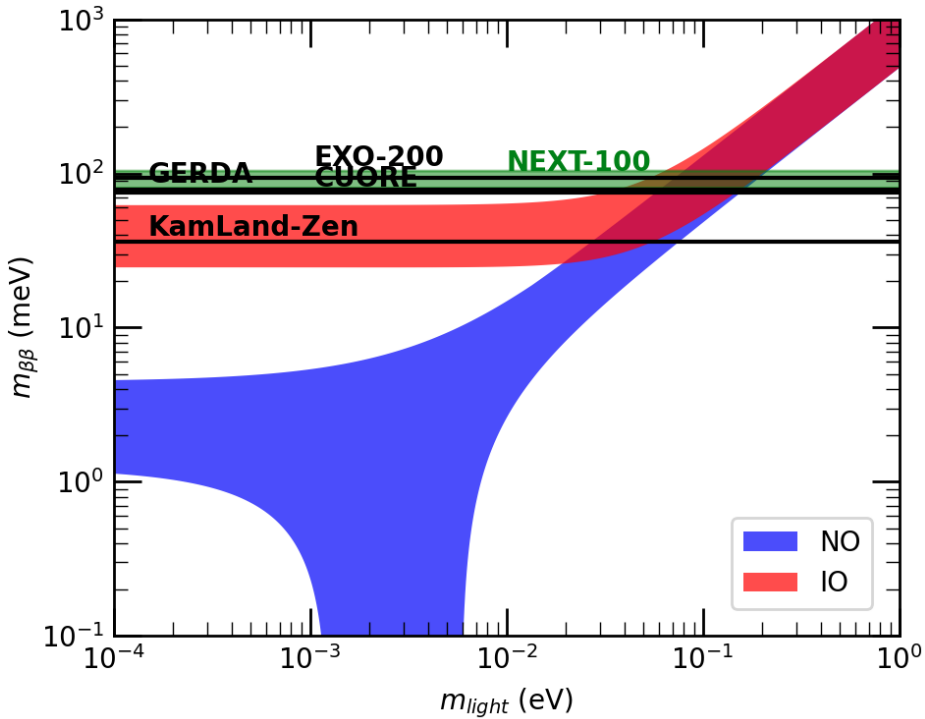
$$\left(T_{1/2}^{0\nu}\right)^{-1} = G_{0\nu} \cdot |M_{0\nu}| \cdot \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

$$m_{\beta\beta} = |c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 e^{i2\lambda_2} m_2 + s_{13}^2 e^{i2(\lambda_3 - \delta_{13})} m_3|$$

- Sensitivity estimated by a detailed detector simulation
- Radiogenic activities taken from the material screening campaign
- Cosmogenic contribution estimated from simulation of measured muon flux at LSC
- Expected background rate @ Qββ (with μ-veto):

0.9 (rad.) + 0.2 (cos.) counts/yr

$S(T_{1/2}^{0\nu\beta\beta}) > 2.4 \times 10^{25}$ years (90% CL)

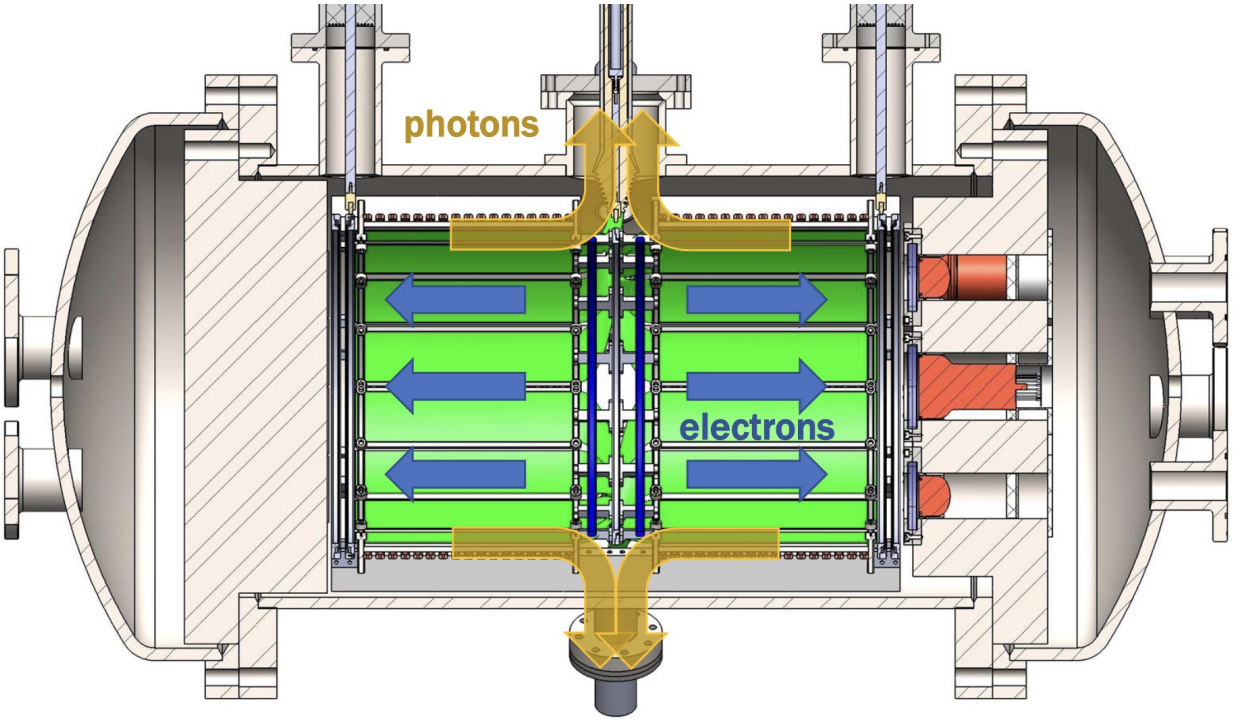


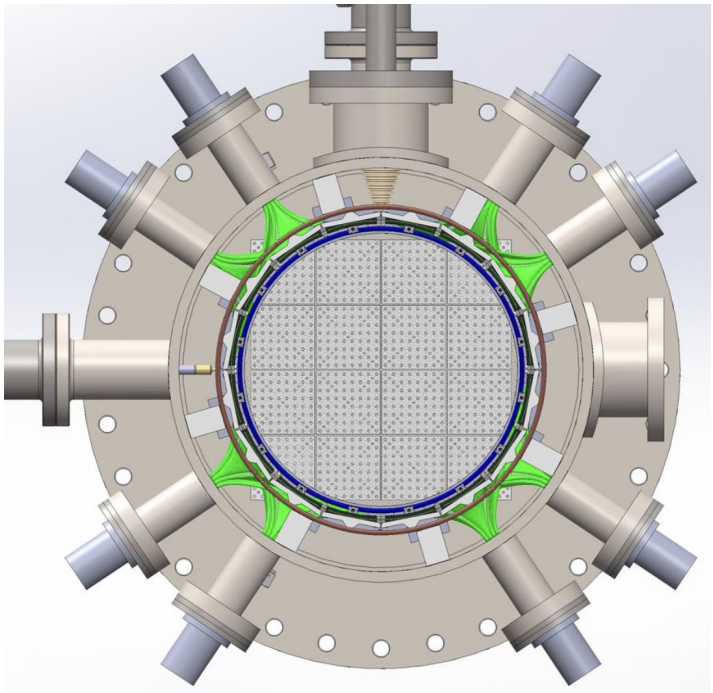
Overview

- Introduction: double beta decay
- The NEXT detection concept and timeline
- Calibration and reconstruction in NEXT
- Main results: NEXT-White
- Near future prospects: NEXT-100
- Towards tonne scale

Towards tonne scale

- Larger detector => lower photon CE
- **NEXT-HD**: symmetric + WLS fibers



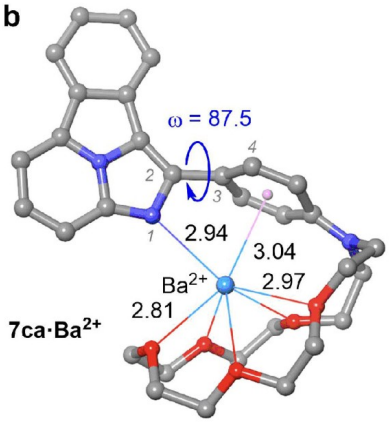


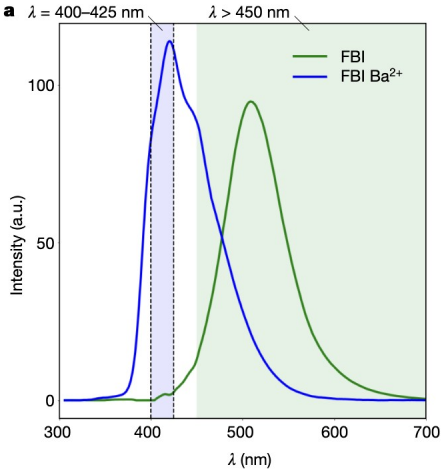
Towards tonne scale

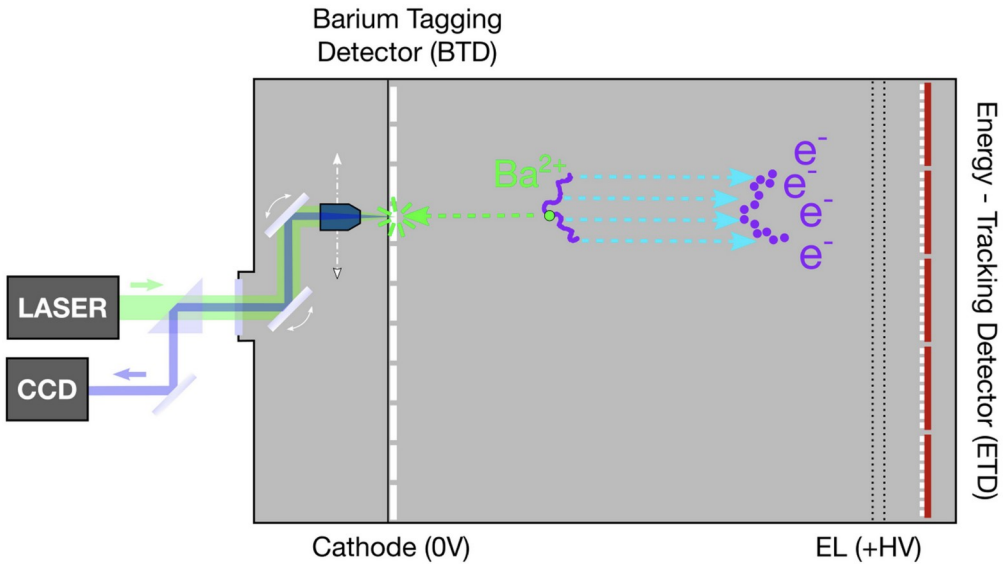
$$^{136}Xe \rightarrow {}^{136}Ba^{2+} + 2e^{-}$$

- Barium tagging => zero-background
- Development of FBI compounds

Nature 583, 48–54 (2020)

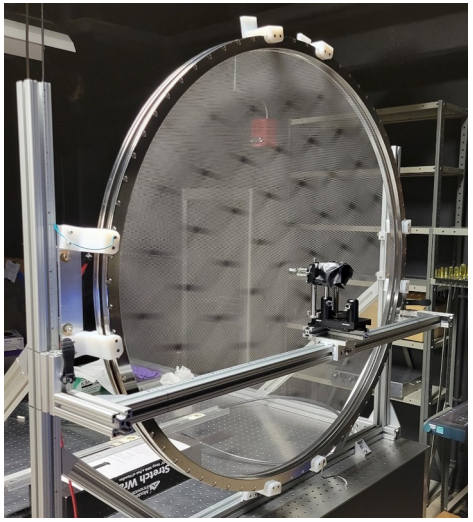


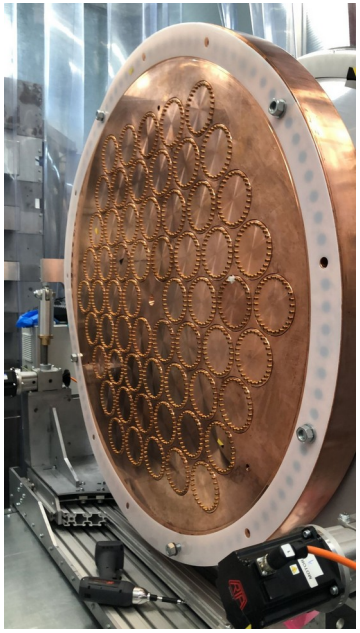


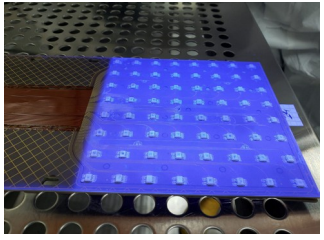


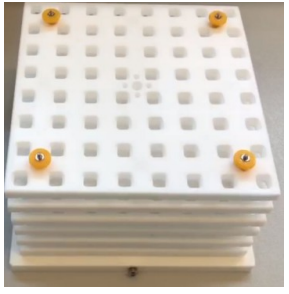
Thanks for your attention

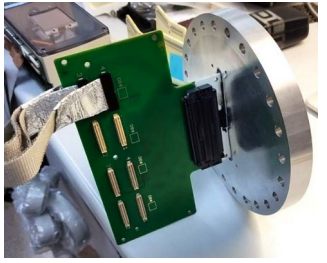
Ongoing NEXT-100 construction...







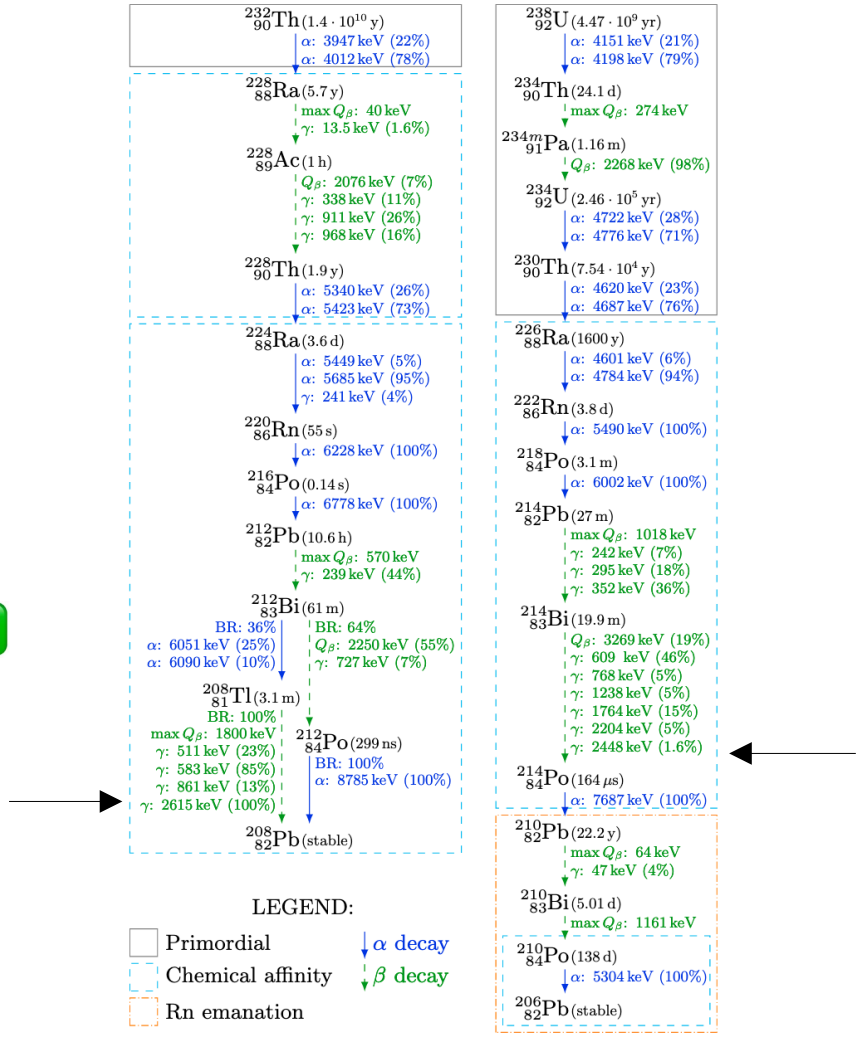




Backup

Background model

- Qββ ~ 2.5 MeV
- **Terrestial natural backgrounds**
  - Detector material impurities ✅
  - Airborne radon ❌
  - Radiation from rocks ❌
- **Cosmogenic backgrounds**
  - Prompt activations ✅
  - Long activations (^{137}Xe $T_{1/2}$~4 min) ✅
- **2νββ** ❌

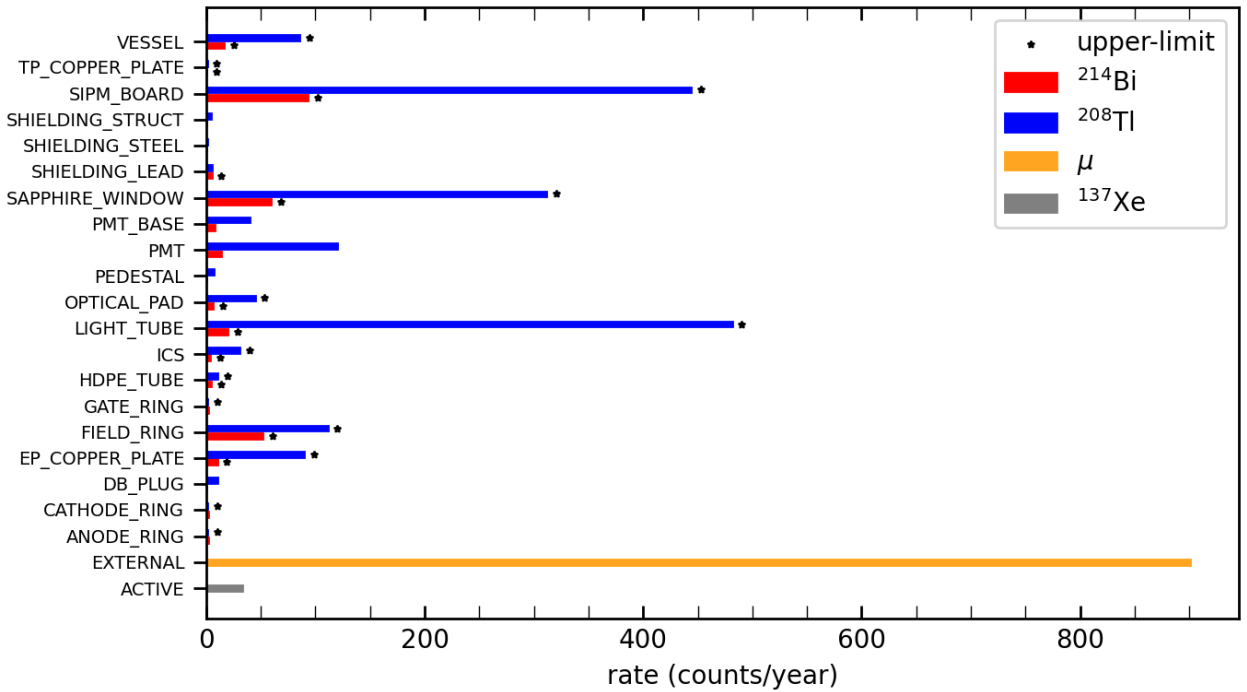


Background model

Volume	Material	Technique	A(^{208}Tl)	A(^{214}Bi)
LEAD-BOX	Lead	GDMS	$2.17 \cdot 10^{2}$	$< 5.32 \cdot 10^{3}$
STEEL-BOX	Steel	HPGe	8.74	$2.03 \cdot 10^{1}$
PEDESTAL	Steel	HPGe	$5.04 \cdot 10^{2}$	$3.58 \cdot 10^{2}$
BEAMS	Steel	HPGe	$7.08 \cdot 10^{2}$	$5.03 \cdot 10^{2}$
VESSEL	Steel	GDMS, HPGe	$< 8.82 \cdot 10^{2}$	$< 3.42 \cdot 10^{3}$
ICS	Copper	GDMS	< 7.87	$< 1.67 \cdot 10^{1}$
EP-COPPER-PLATE	Copper	GDMS	$< 4.73 \cdot 10^{1}$	$< 8.20 \cdot 10^{1}$
SAPPHIRE-WINDOW	Sapphire	HPGe	$< 2.16 \cdot 10^{1}$	$< 6.60 \cdot 10^{1}$
OPTICAL-PAD	Silicone	HPGe	$< 3.19^{*}$	$< 7.92^{*}$
PMT	Kovar	HPGe	$1.14 \cdot 10^{1}$	$2.10 \cdot 10^{1}$
PMT-BASE	Kapton	HPGe	$1.54 \cdot 10^{1}$	$4.09 \cdot 10^{1}$
TP-COPPER-PLATE	Copper	ICPMS	< 0.21	< 2.28
SIPM-BOARD	-	-	< 9.22	$< 3.56 \cdot 10^{1}$
BOARD-PLUGS	Peek	HPGe	$1.18 \cdot 10^{2}$	$1.55 \cdot 10^{2}$
LIGHT-TUBE	Teflon	ICPMS, HPGe	< 7.97	< 3.55
FIELD-RING	Copper	ICPMS	< 2.69	$< 2.69 \cdot 10^{1}$
CATHODE-RING	Steel	ICPMS	$< 5.03 \cdot 10^{-2}$	1.14
ANODE-RING	Steel	ICPMS	$< 5.19 \cdot 10^{-2}$	1.18
GATE-RING	Steel	ICPMS	$< 5.19 \cdot 10^{-2}$	1.18
HDPE-TUBE	HDPE	ICPMS, HPGe	$< 3.74 \cdot 10^{-1}$	< 3.07

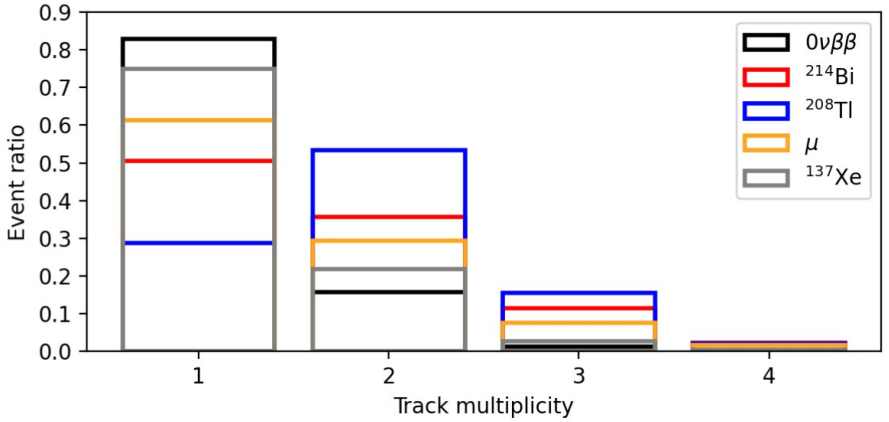
- Radiogenic screening campaign
- μ flux @ LSC ~ $3.44 \cdot 10^{-2}$ m^{-2} s^{-1}

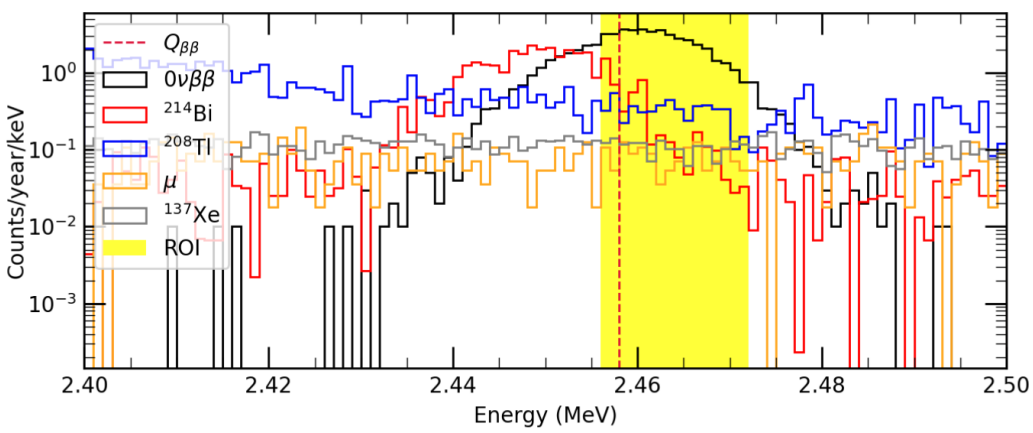
(γ >2.4 MeV) x (screening) x (nexus 2.4-2.5 MeV)



Sensitivity to 0νββ. Counting experiment

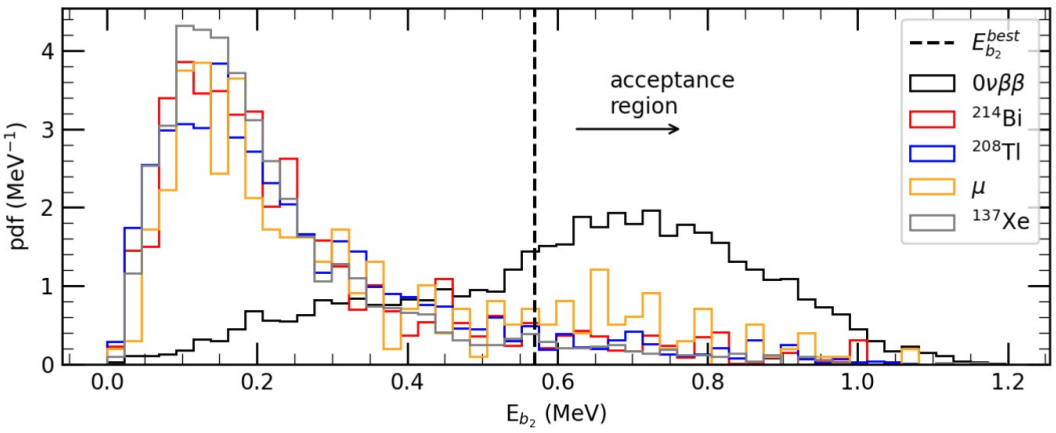
- *Analysis selections*
  - **nexus** (2.4 < E (MeV) < 2.5)
  - **reconstruction** (1S1 & 1S2)
  - **energy** (2.4 < E (MeV) < 2.5)
  - **fiducial** (R<45 cm & Z<2 cm)
  - **single track**
  - **blob overlap**
- *Signal selections*
  - **ROI**
  - **topological**



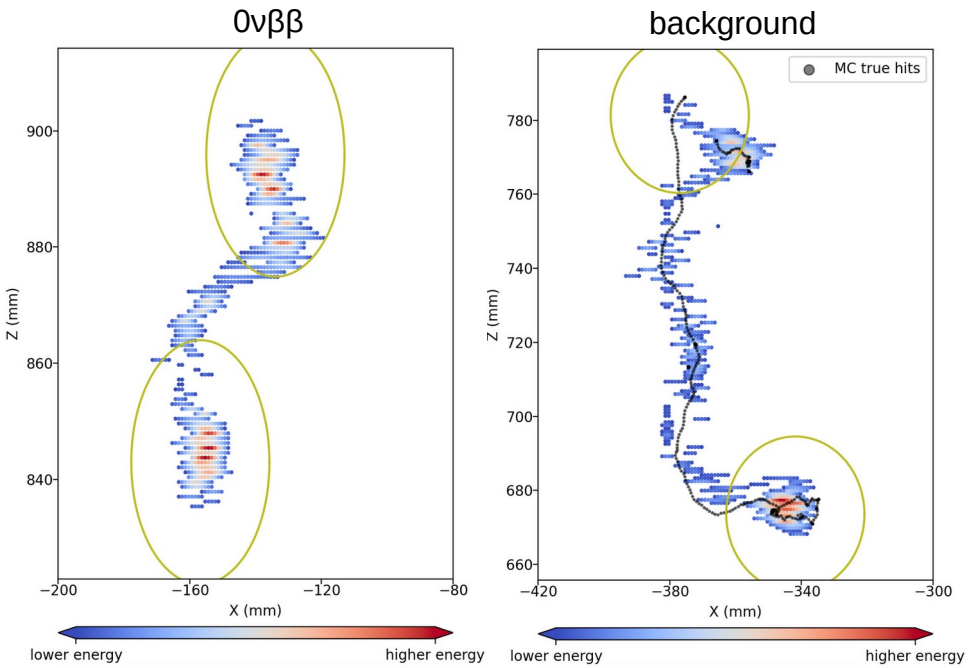


Sensitivity to 0νββ. Counting experiment

- **topological** selection (64% vs 9%)



Example of accepted events

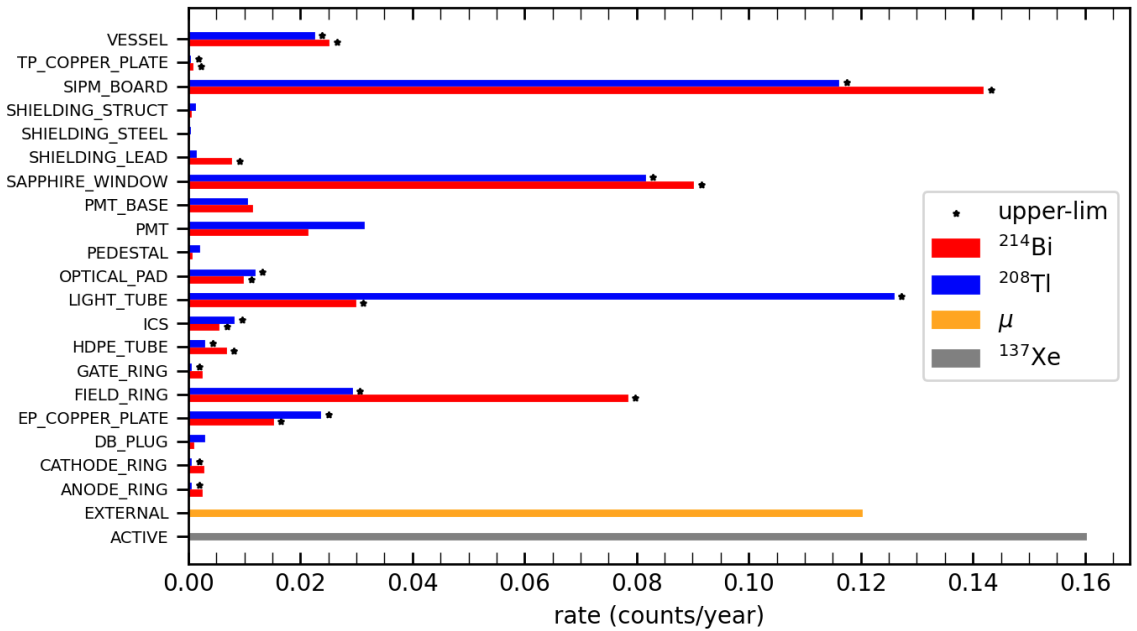


Sensitivity to 0νββ. Counting experiment

- Background rate (μ-veto) ~ **1.1 counts/year**
- Signal efficiency **18 %**

(counts/year)	nexus	reco	ene	fid	track	ovl	ROI	topo
^{214}Bi	296	94	76	71	35	35	4.9	0.45
^{208}Tl	1800	312	277	240	56	56	5.2	0.47
muons (μ)	900	50	15	13	7	7	1.32	0.12
^{137}Xe	33	25	19	15	11	11	1.73	0.16

efficiencies (%)	reco	ene	fid	track	ovl	ROI	topo
$0\nu\beta\beta$	83	54	50	42	42	28	18



Sensitivity to 0νββ. Counting experiment

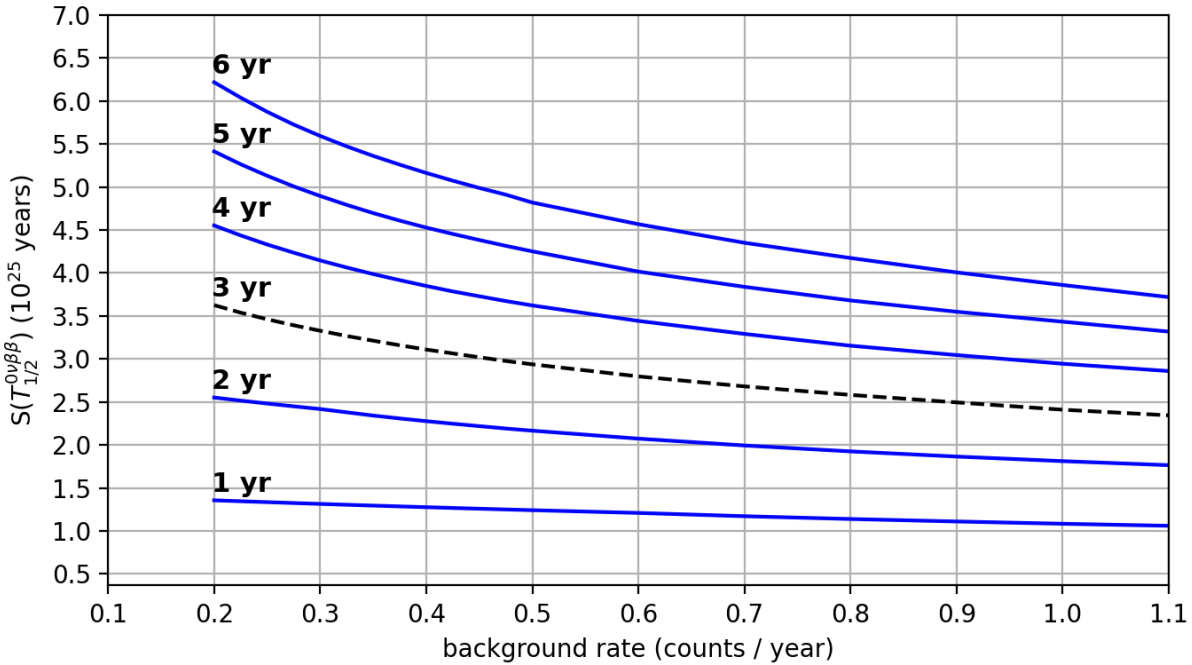
tentative NEXT-100
running time: **3 years**

^{136}Xe atoms:
72 kg @ 90%

$$S(T_{1/2}^{0\nu\beta\beta}) = \log(2) \cdot \epsilon_s \cdot \frac{t \cdot N_0}{S(b)}$$

signal eff.: **18 %**

background mean U.L.



$$S(T_{1/2}^{0\nu\beta\beta}) > 2.4 \times 10^{25} \text{ years (90\% CL)}$$