



IGFAE
Instituto Galego de Física de Altas Enerxías



**XUNTA
DE GALICIA**



The NEXT experiment at the Canfranc Underground Laboratory

Gonzalo Díaz López (St)

group: J. A. Hernando (PI), J. Renner (PD), C. Hervés (St), M. Pérez (St)

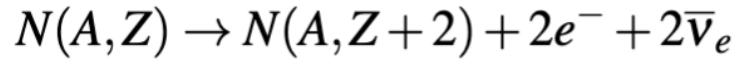
University of Santiago de Compostela, Spain

(on behalf of the NEXT Collaboration)

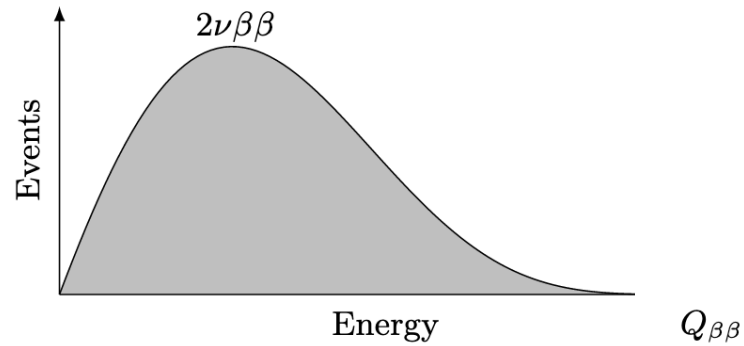
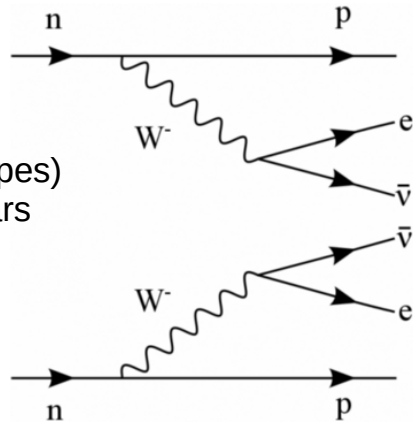
October 27th, EuNPC 2022 Conference

Santiago de Compostela, Spain

Double beta decay

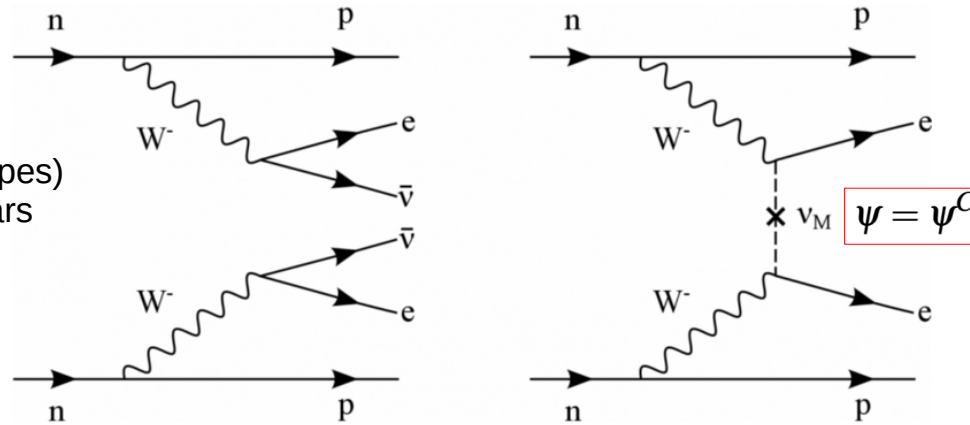


- Observed (11 isotopes)
- $T_{1/2} = 10^{19}$ - 10^{21} years



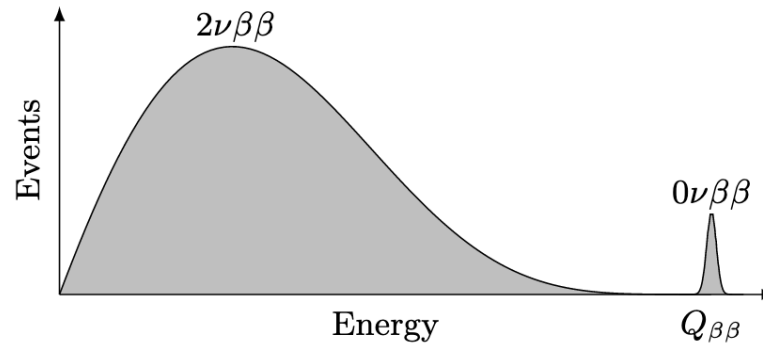
Majorana neutrinos and $0\nu\beta\beta$

$$N(A, Z) \rightarrow N(A, Z+2) + 2e^- + \cancel{2\bar{\nu}_e}$$

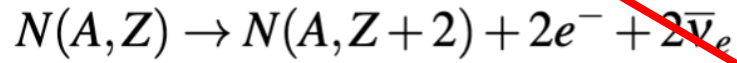


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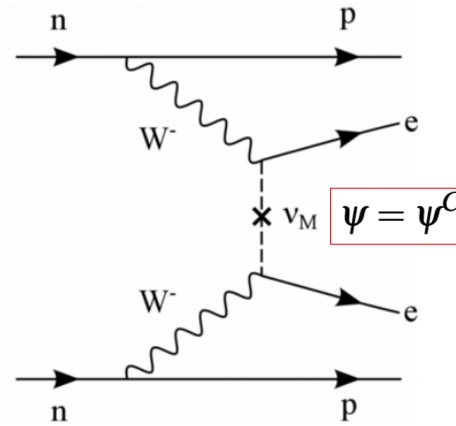
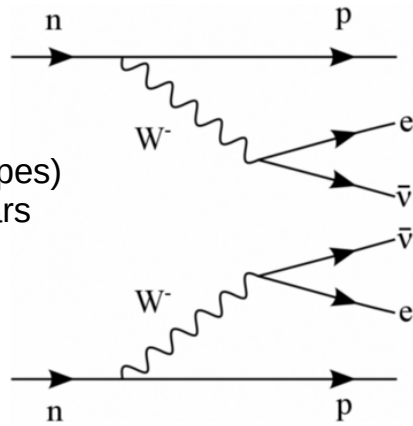
- Unobserved
- $T_{1/2} > 10^{26}$ years



Majorana neutrinos and $0\nu\beta\beta$

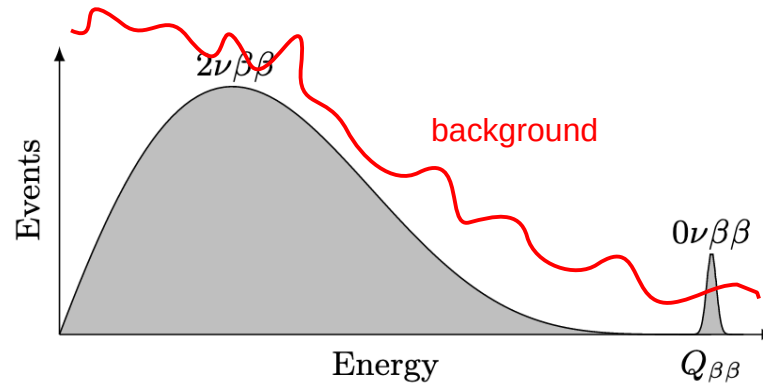


- Observed (11 isotopes)
- $T_{1/2} = 10^{19}$ - 10^{21} years



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

$$S(T_{1/2}^{0\nu\beta\beta}) \propto \epsilon_s \sqrt{\frac{t \cdot M}{b \cdot \Delta E}}$$

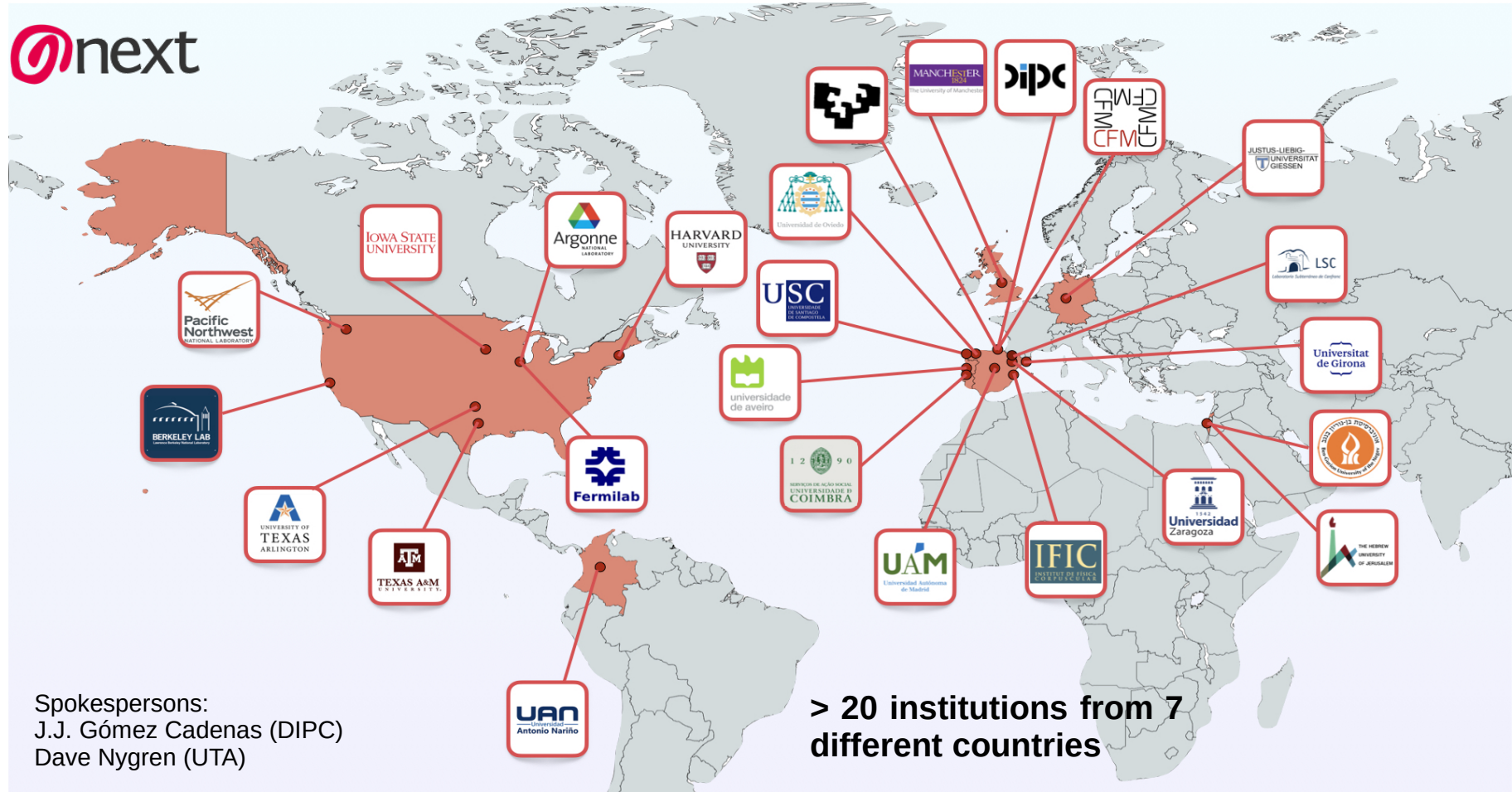


To improve sensitivity:

- Good energy resolution
- Active background discrimination
- Scalability

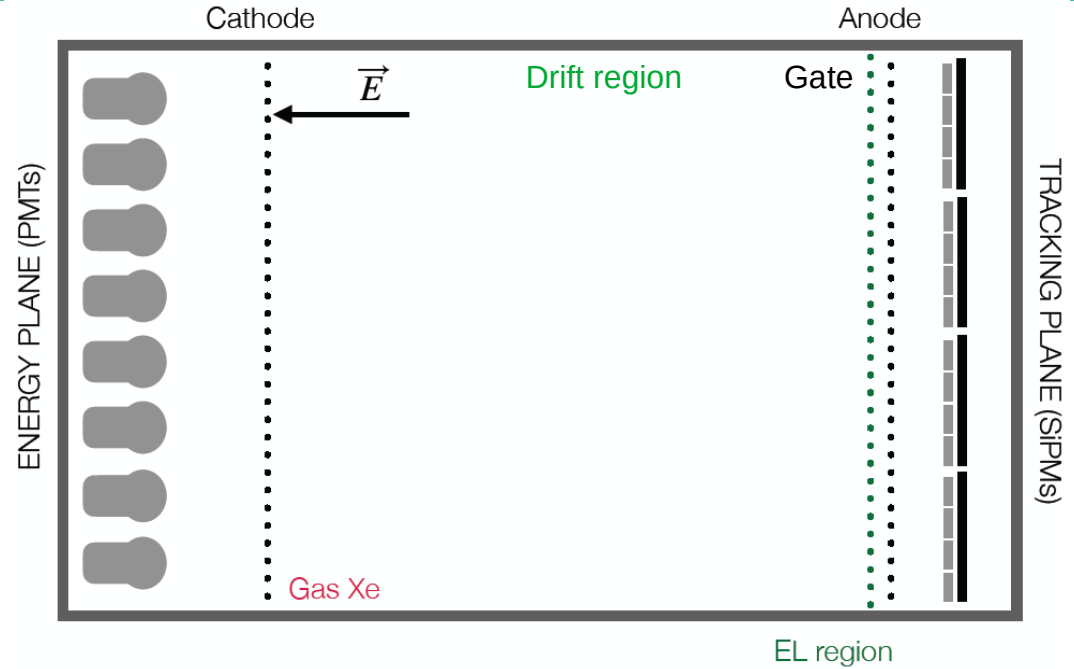
High pressure Xenon TPC!

Neutrino Experiment with a Xenon TPC



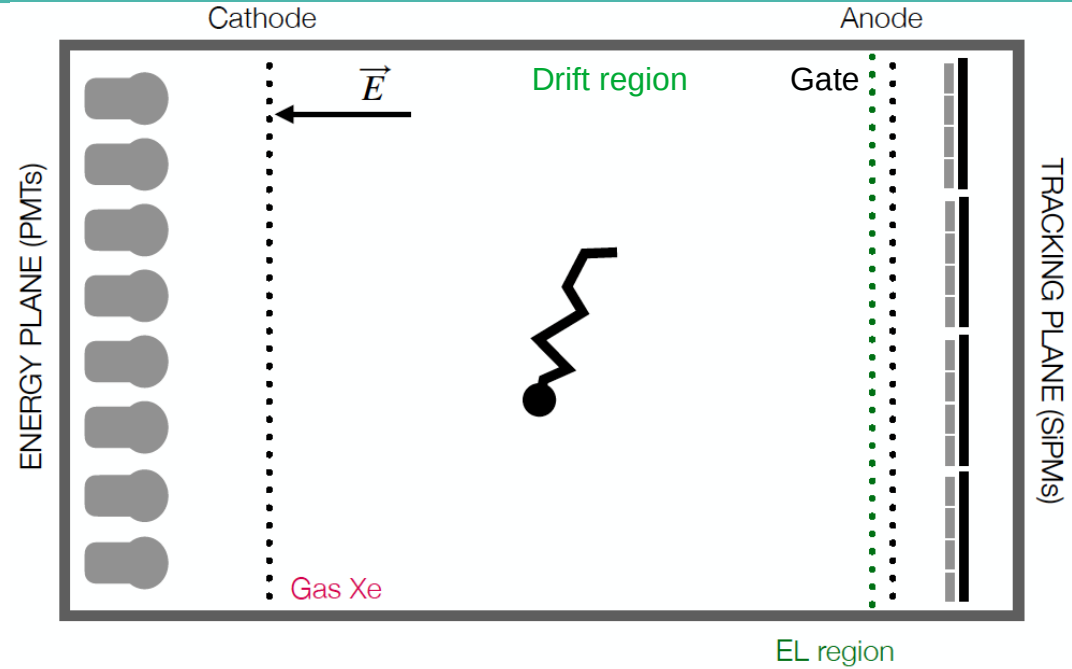
NEXT detection concept

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



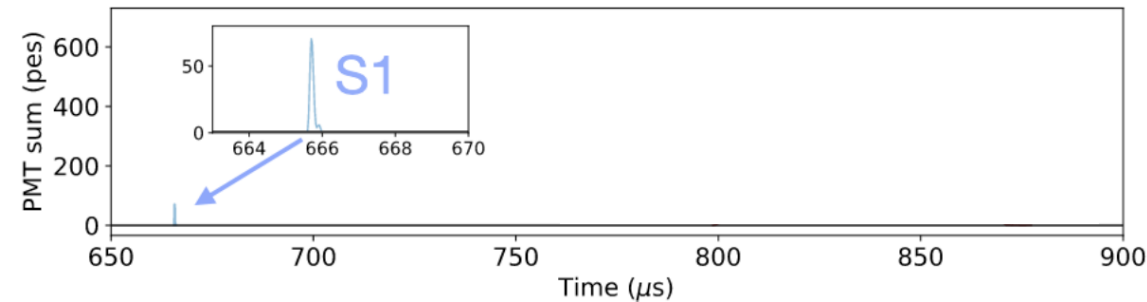
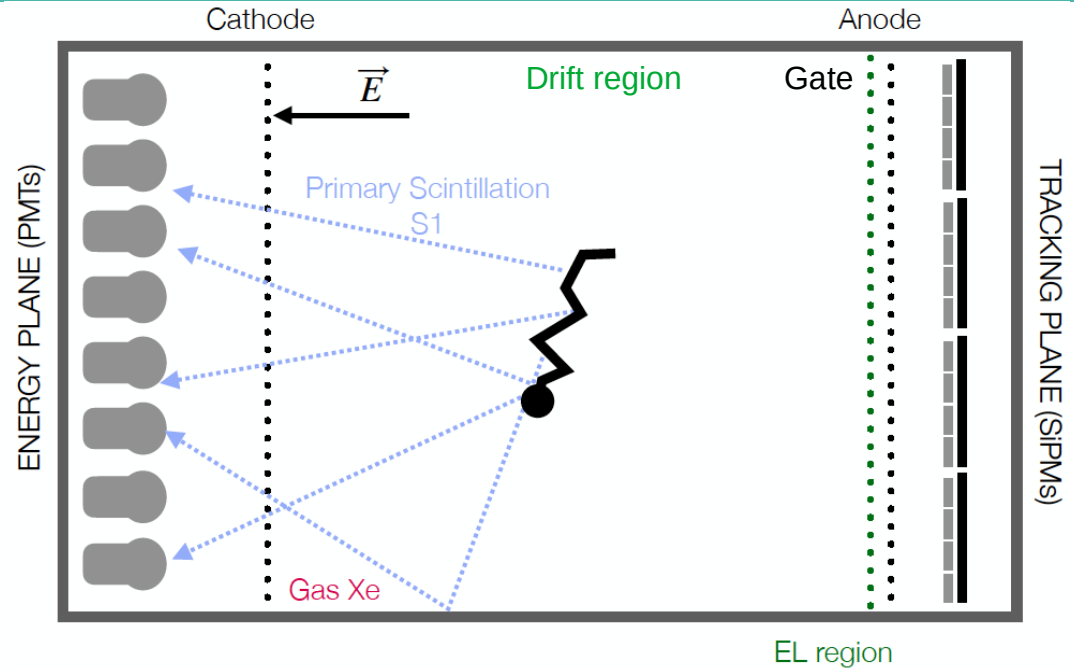
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- High pressure xenon (enriched to ^{136}Xe) TPC
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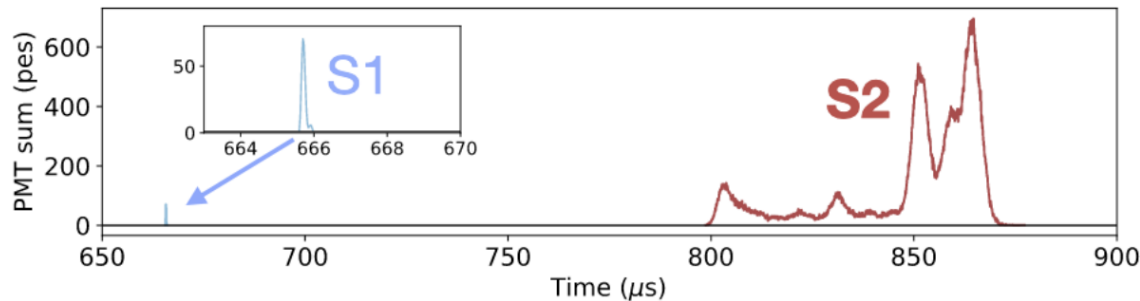
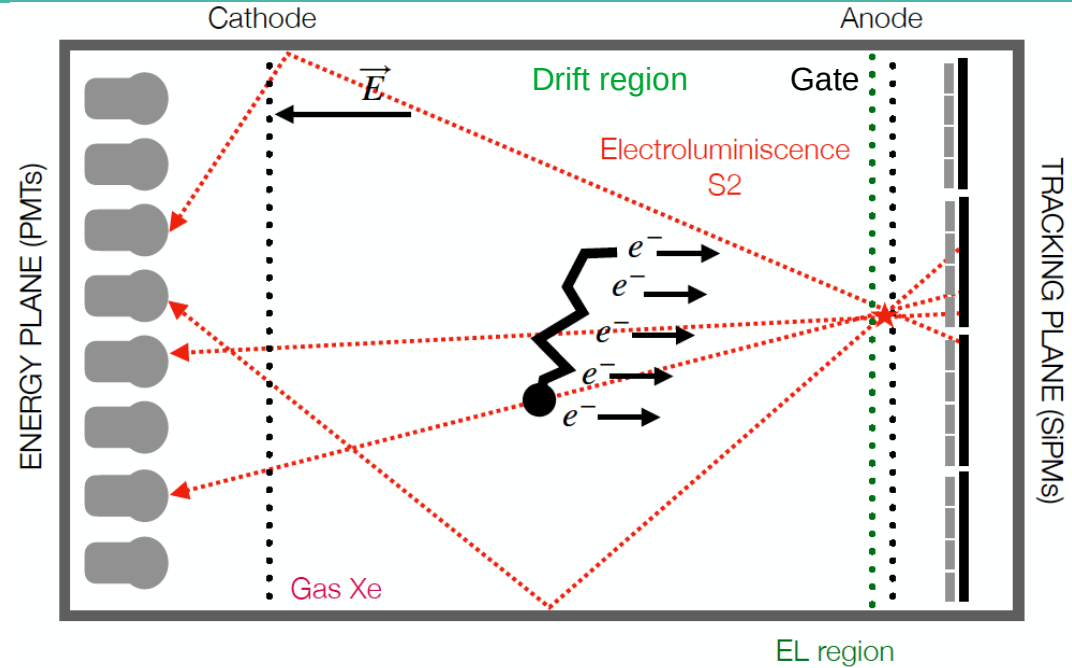
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- Scintillation light (S1) provides the start of event signal



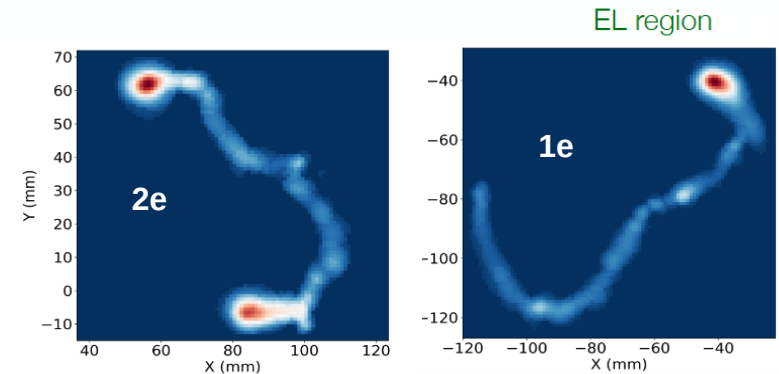
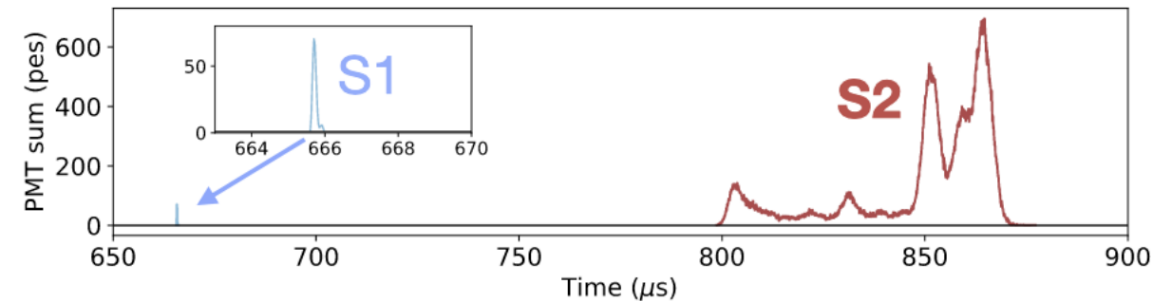
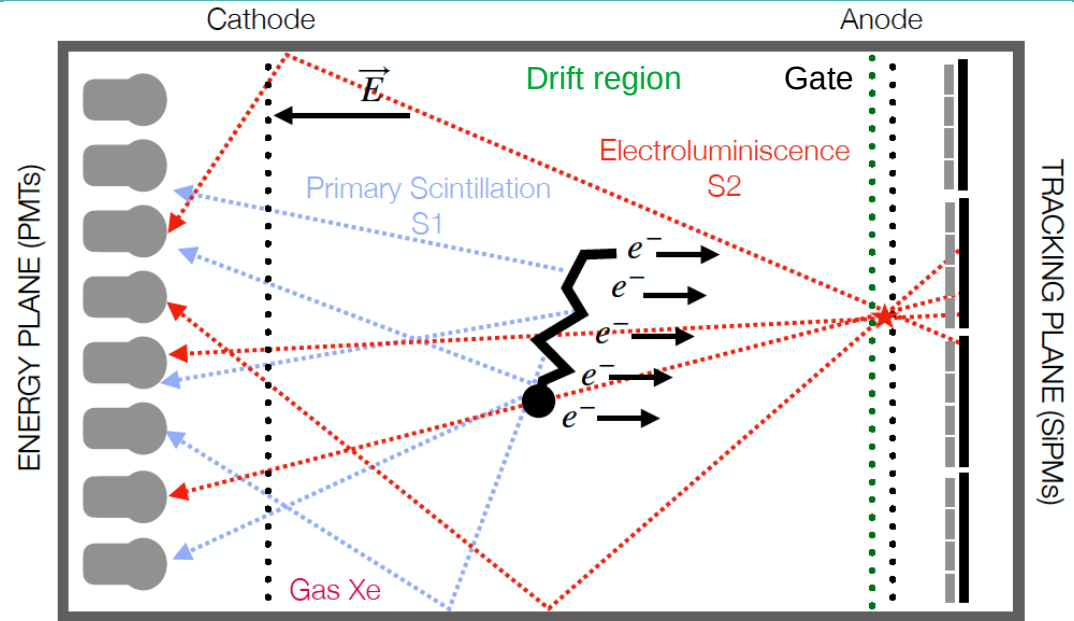
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- Ionization electrons are drifted towards the EL-region
- Electroluminescent light (S2) provides both energy and tracking measurements



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- Electroluminescent light (S2) provides both energy and tracking measurements
- 3D reconstruction
- Active background discrimination through Bragg peak



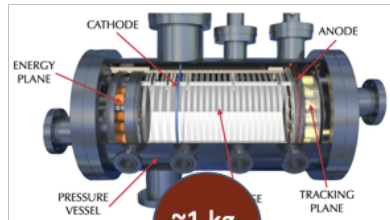
From NEXT-White data

NEXT experimental phases

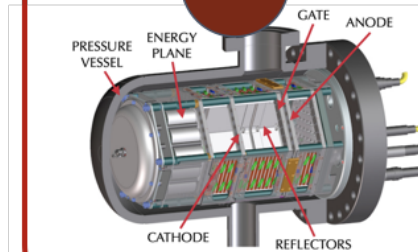
Prototypes

2008-2014

Demonstration of detector concept



~1 kg

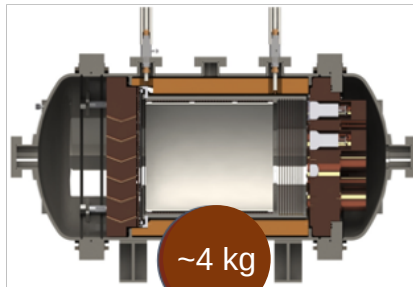


NEXT-White

2015-2021

Background model assessment

$2\nu\beta\beta$ measurement for ^{136}Xe



~4 kg

NEXT-100

2022-2025

Background model assessment

Neutrinoless double beta decay search in ^{136}Xe



~72 kg

NEXT-HD

2026?

Neutrinoless double beta decay search through inverted neutrino mass ordering

NEXT-BOLD

Barium tagging for background-free experiment



1 Tonne

2009

2014 2015

2021 2022

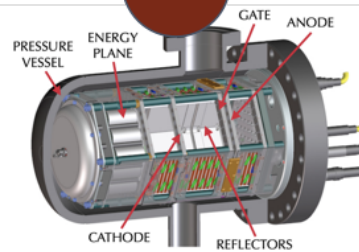
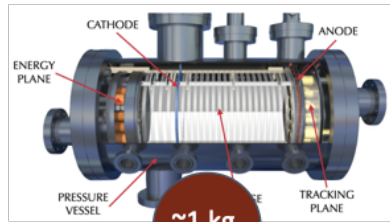
2025 2026

NEXT experimental phases

Prototypes

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NEXT-HD

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Neutrinoless double beta decay
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NEXT-BOLD

Barium tagging for background-free
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2009

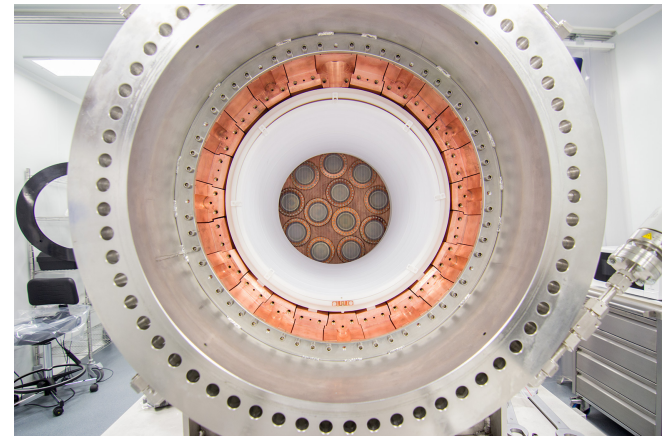
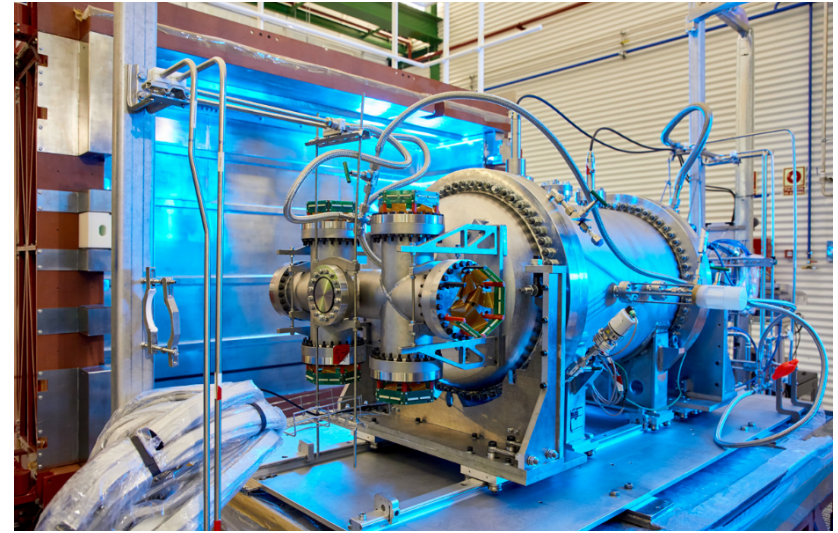
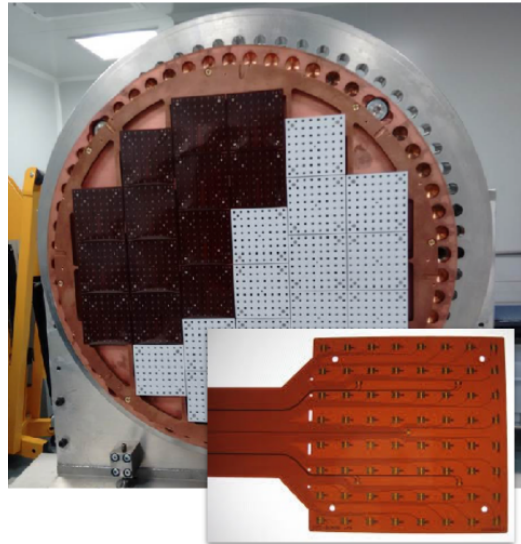
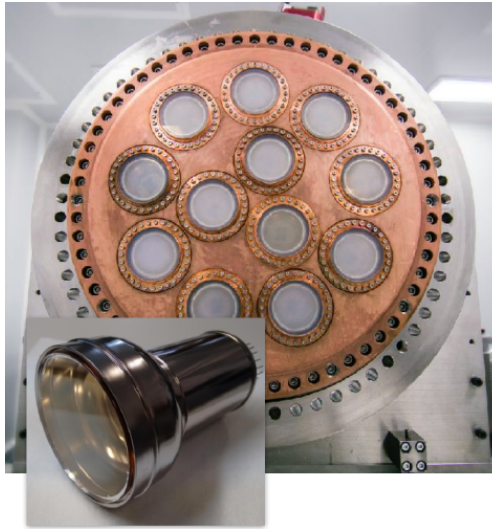
2014 2015

2021 2022

2025 2026

NEXT-White detector

- ~4 kg xenon (90% ^{136}Xe enrichment) at 10 bar
- ~50 cm length, ~20 cm radius, 6 mm EL-gap
- 12 Hamamatsu R11410-10 PMTs with 30% coverage
- 1792 (SensL) SiPMs at 1 cm pitch
- shielding: 20 cm thick lead castle, 6 cm thick inner copper



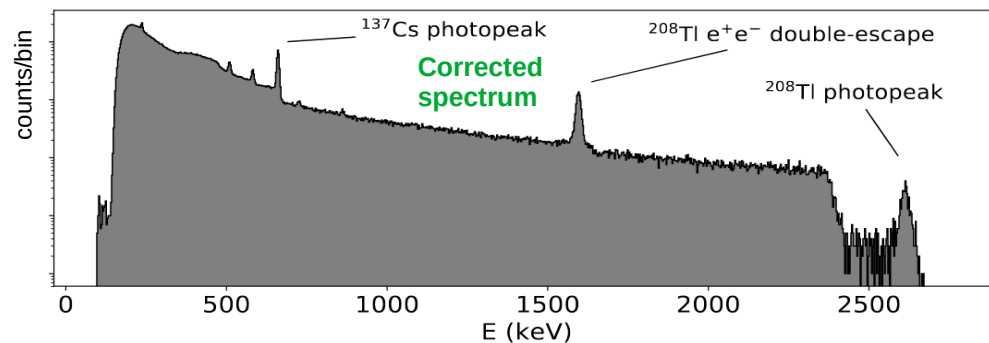
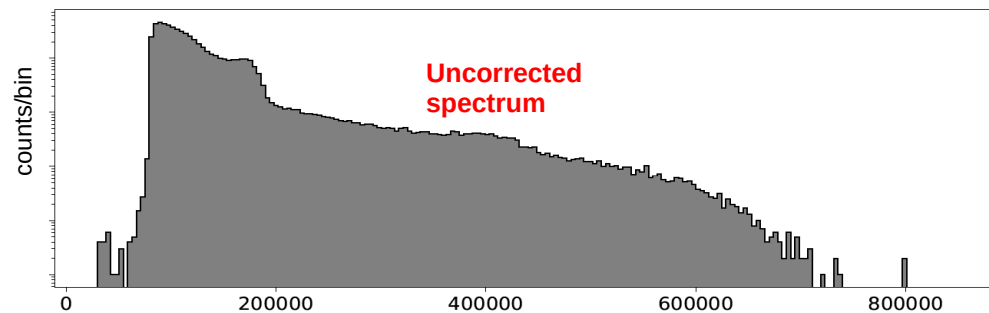
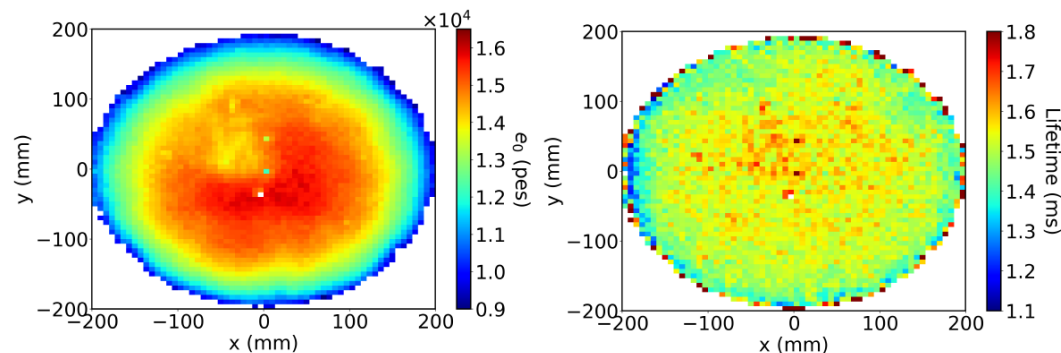
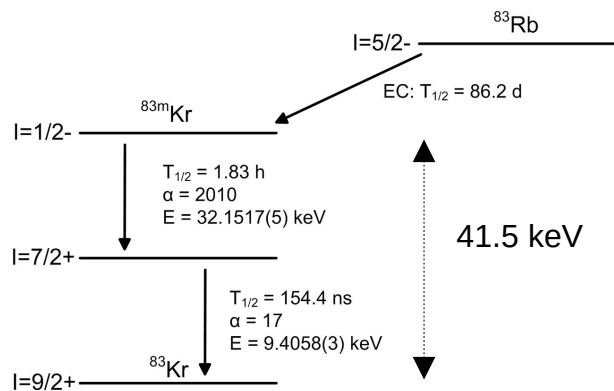
NEXT-White calibration and reconstruction

Low energy calibration

- Dual trigger DAQ ($E < 100$ keV) and ($E > 400$ keV)
- ^{83}mKr from ^{83}Rb decay is introduced in the chamber
- ^{83}mKr provides 41.5 keV point-like energy depositions, allowing the creation of:
 - Geometrical and lifetime **maps**: energy correction
 - Point spread function (**PSF**): diffusion deconvolution

Reconstruction

- Track hits are corrected using the ^{83}mKr maps
- Track diffusion is deconvoluted using the ^{83}mKr PSF



NEXT-White results

a) Energy resolution of $(0.91 \pm 0.07)\%$ FWHM at 2.6 MeV (near $Q\beta\beta$)

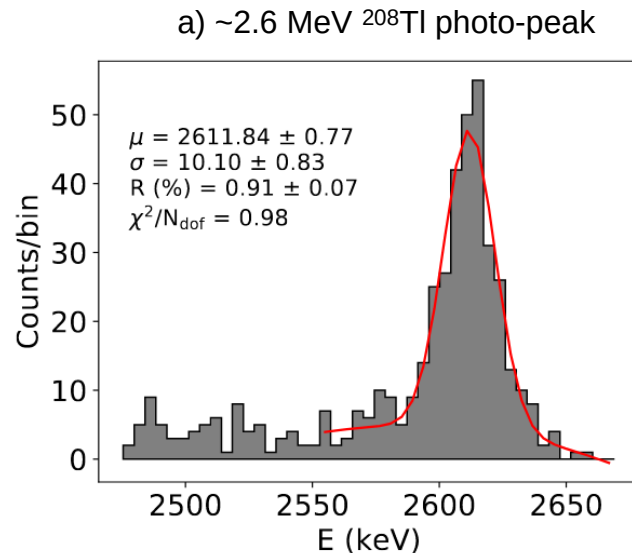
JHEP 10 (2019) 230

b) Demonstration of signal vs background rejection via topological discrimination in data using 1.6 MeV double escape peak of ^{208}Tl .

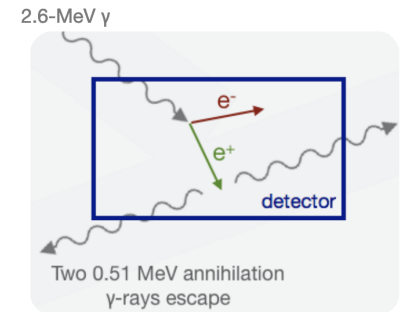
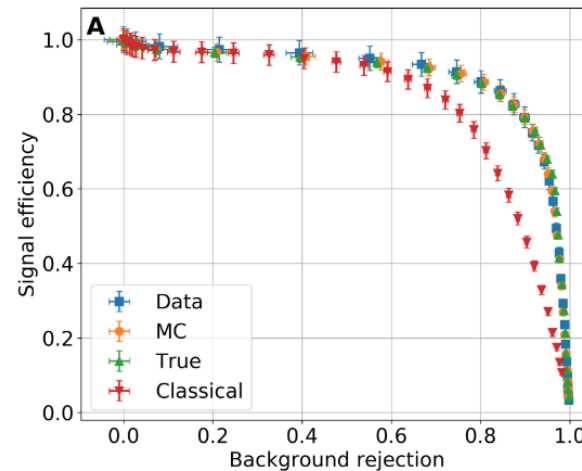
JHEP 10 (2019) 52; JHEP 01 (2021) 189; JHEP 07 (2021) 146

c) Validation of the background model and measurement of $2\nu\beta\beta$ half-life

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



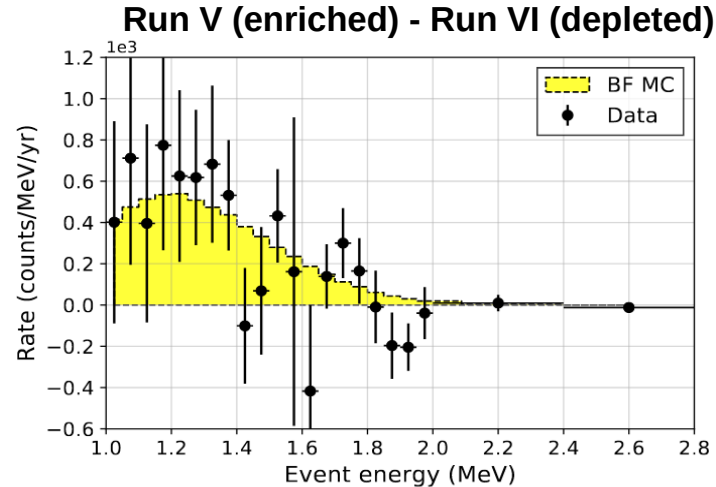
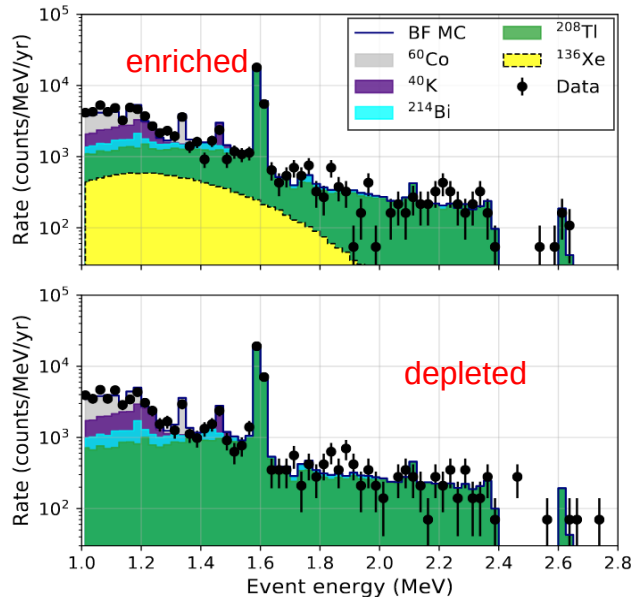
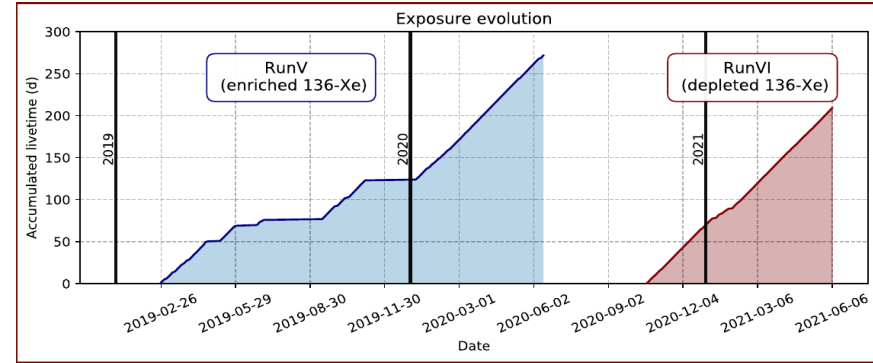
b) ROC curve for ^{208}Tl double-escape-peak



NEXT-White results

c) Measurement of $2\nu\beta\beta$ half-life

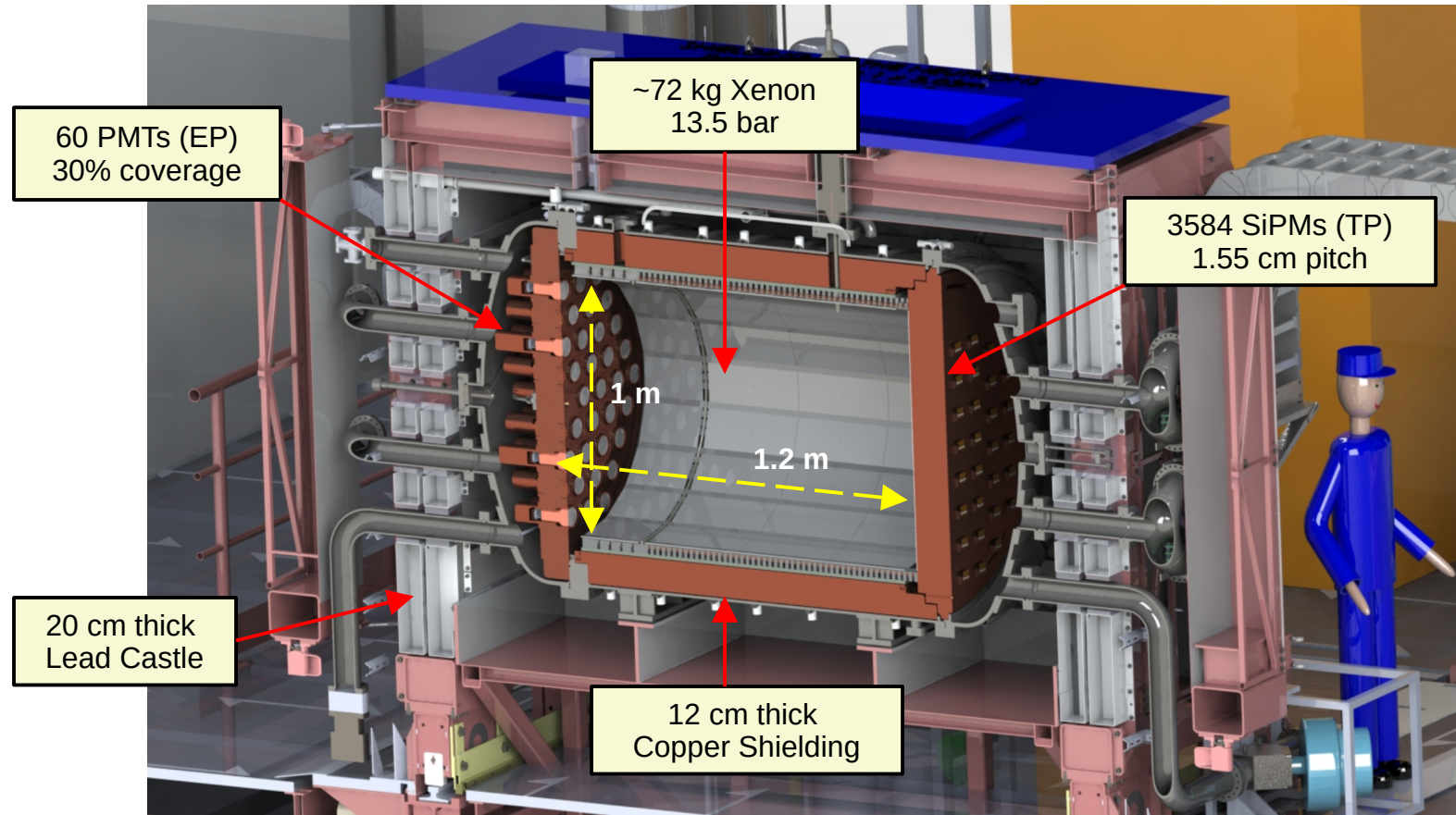
- signal selection: single-track + topological
- $\sim 4\sigma$ significance
- compatible with EXO-200 and KamLand-Zen
- new background subtraction technique between enriched and depleted runs



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

NEXT-100 detector

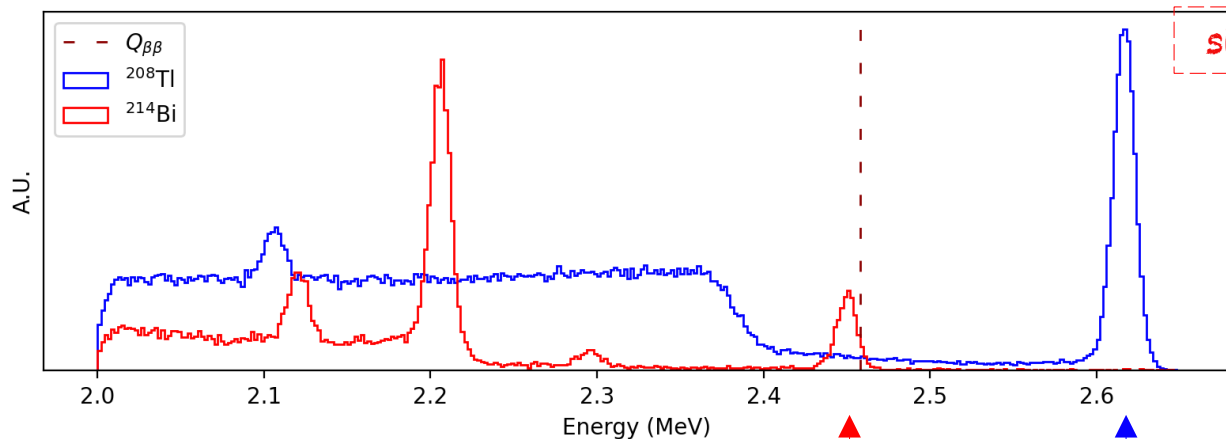
Under construction at LSC!



NEXT-100 background model components at ROI

- **Radiogenic from detector materials:** ^{208}Tl and ^{214}Bi from natural U and Th chains
- **Cosmogenics:** prompt-gammas from neutron activations in detector materials and long lived ^{137}Xe activations
- **External radon:** negligible, clean air fluxed from RAS system at LSC
- **External gammas from lab rocks:** negligible, lead castle shielding
- **External neutrons from lab rocks:** negligible (neutron absorber)
- **$2\nu\beta\beta$:** negligible (end-point at ~ 2.3 MeV)

Radiogenics

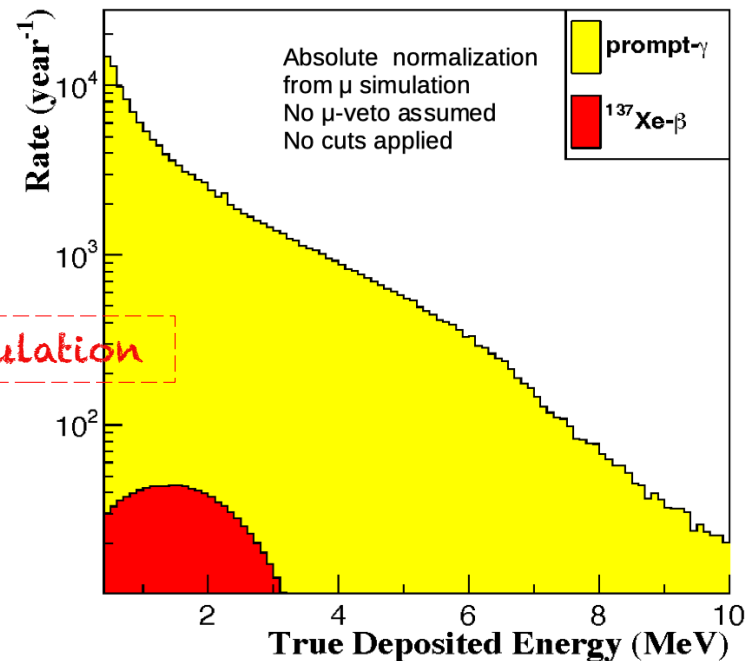


2.447 MeV
(^{214}Bi)

2.614 MeV
(^{208}Tl)

Cosmogenics

mostly ^{64}Cu (84%), ^{66}Cu (11%) activations

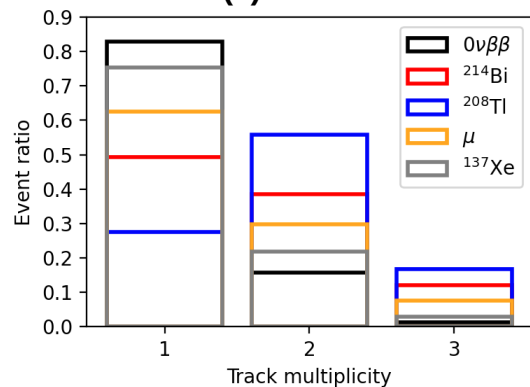


Muon veto to be installed on lead castle outer surface.

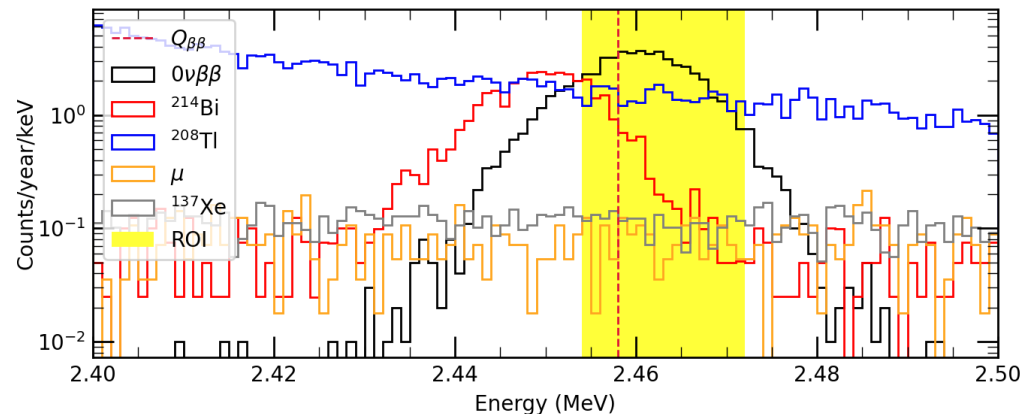
NEXT-100 sensitivity

- Simulation (GEANT4) of ^{208}Tl , ^{214}Bi , muons and $0\nu\beta\beta$ to estimate the NEXT-100 sensitivity (counting experiment)
- Signal selection cuts (after reconstruction and fiducialization): (1) single-track + (2) ROI + (3) topology

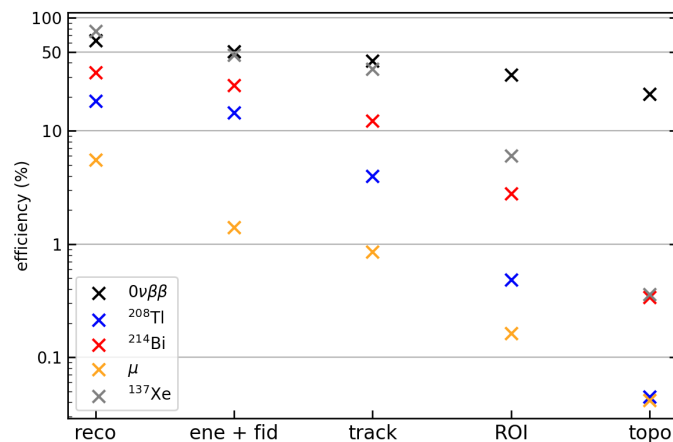
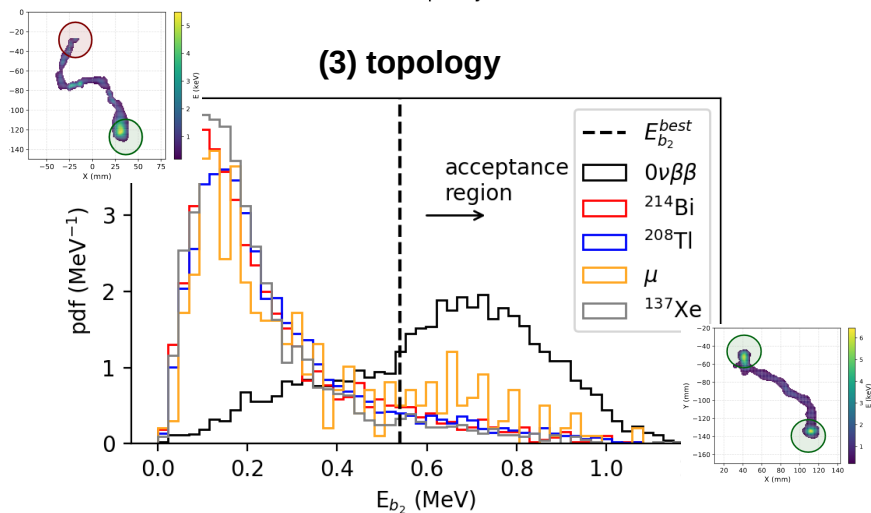
(1) 1-track



(2) ROI



(3) topology



Signal eff 21%
Background eff 0.1-1%

efficiencies w.r.t events that deposit a total energy in the 2.4-2.5 MeV window in the active volume

NEXT-100 sensitivity

- Simulation (GEANT4) of ^{208}Tl , ^{214}Bi , muons and $0\nu\beta\beta$ to estimate the NEXT-100 sensitivity (counting experiment)
- Estimated background rate from radiogenic origin (radiopurity measurements + simulation) **< 3.6 counts/year**
- Estimated background rate from cosmogenic origin (flux + simulation) ~ **0.04** (prompt- γ , 90% eff μ -veto) + **0.12** (^{137}Xe) **counts/year**

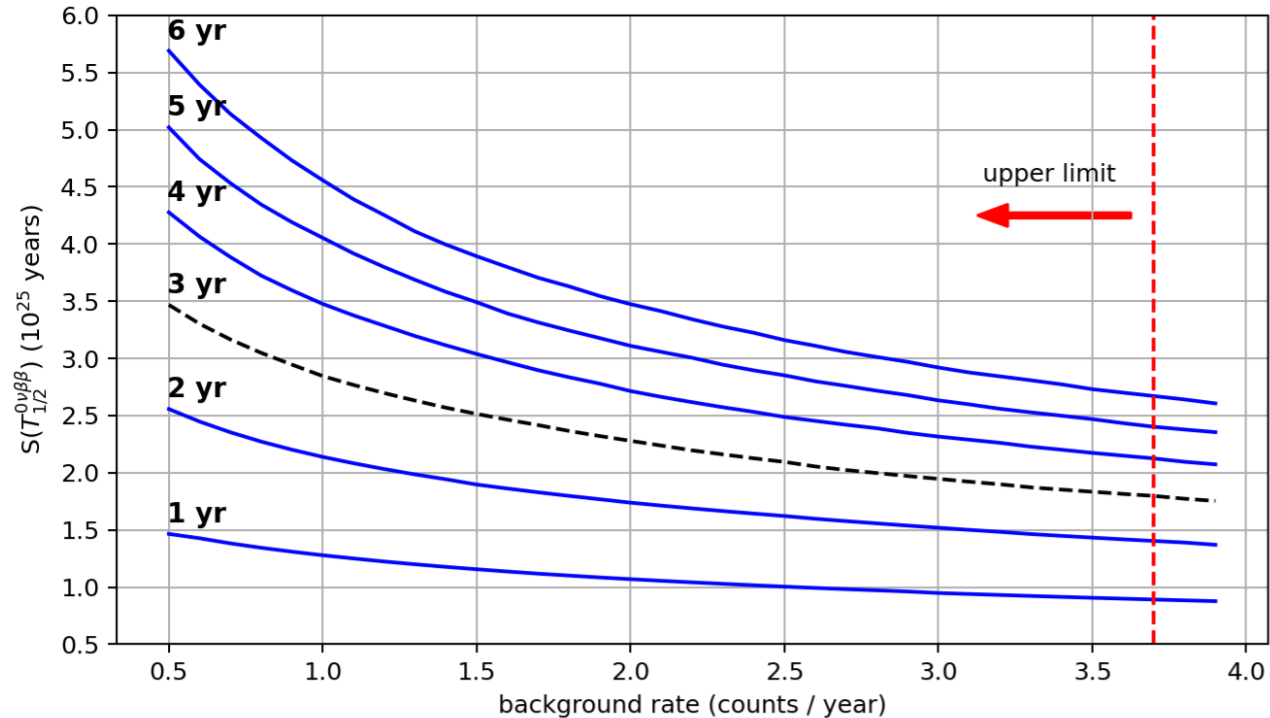
tentative NEXT-100
running time: **3 years**

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

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

signal eff: **21 %**

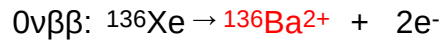
background mean C.I.



$$S(T_{1/2}^{0\nu\beta\beta}) > 1.8 \cdot 10^{25} \text{ years}$$

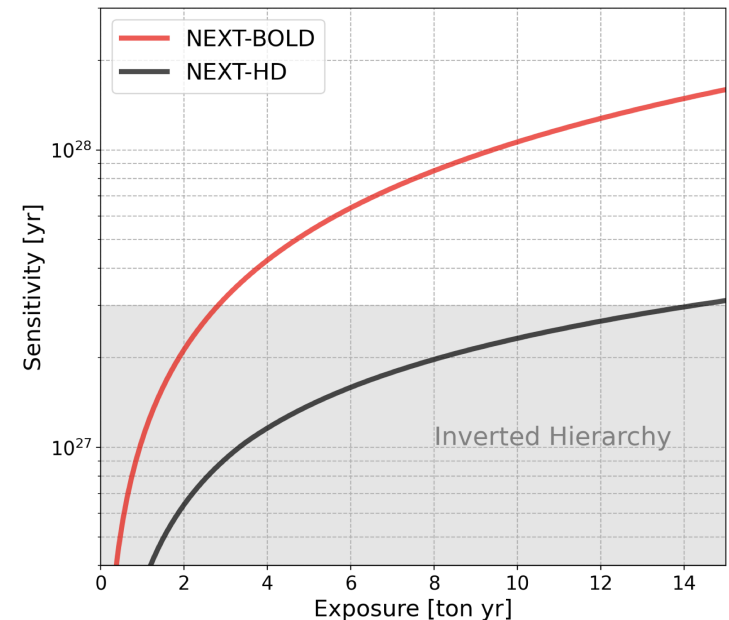
Summary and Future

- NEXT-White demonstration of main ingredients for a successful $0\nu\beta\beta$ experiment: calibration and reconstruction methods that provide the achievement of a good energy resolution and topological discrimination
- NEXT-100 in advanced construction state, to be finished at the end of this year 2022
- NEXT-100 background model current limit of **< 3.7 counts/year** ($2.9 \cdot 10^{-3}$ counts/(keV·kg·year))
- NEXT-100 sensitivity to $0\nu\beta\beta$ similar to closest ^{136}Xe TPC competitor EXO-200 ($> 3.5 \cdot 10^{25}$ years @ 90% C.L.)



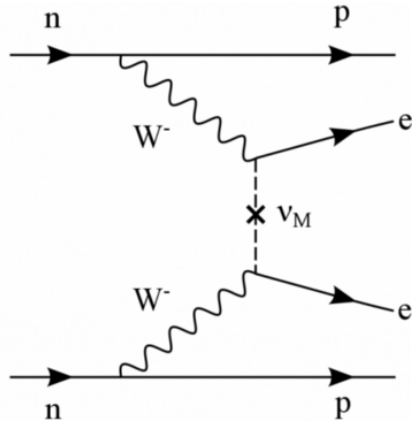
- NEXT-Collaboration has probed $^{136}\text{Ba}^{2+}$ tagging with the development of custom molecules
- NEXT Collaboration already in R&D for a future tonne scale detector NEXT-HD and NEXT-BOLD
 - NEXT-HD: tonne scale without Ba-tagging
 - NEXT-BOLD: tonne scale with Ba-tagging

Thanks for your attention



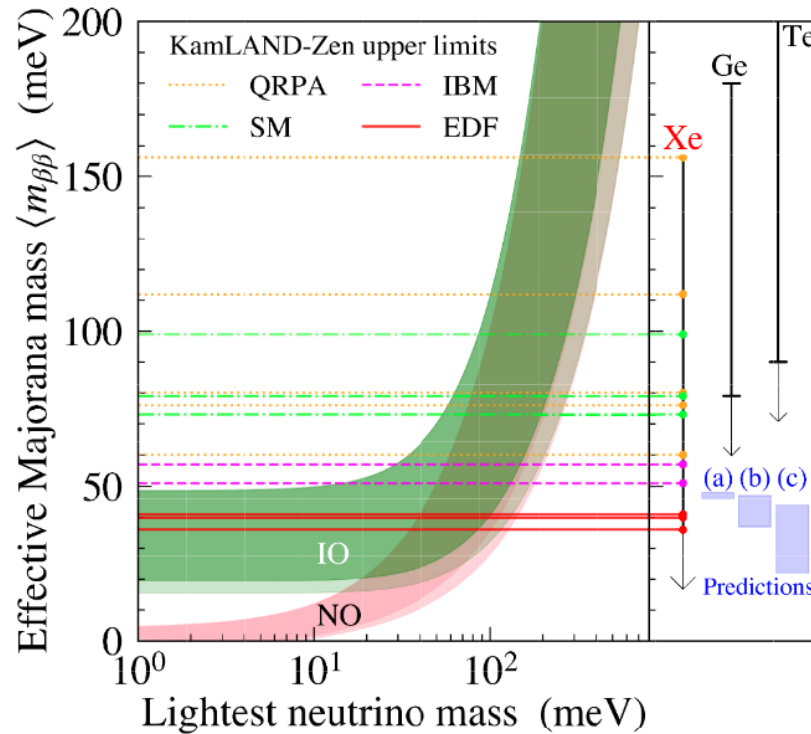
BACKUP

Majorana neutrinos and $0\nu\beta\beta$



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

$$m_{\beta\beta} \equiv \left| \sum_{k=0}^3 U_{ek}^2 m_k \right|$$



arXiv:2203.02139

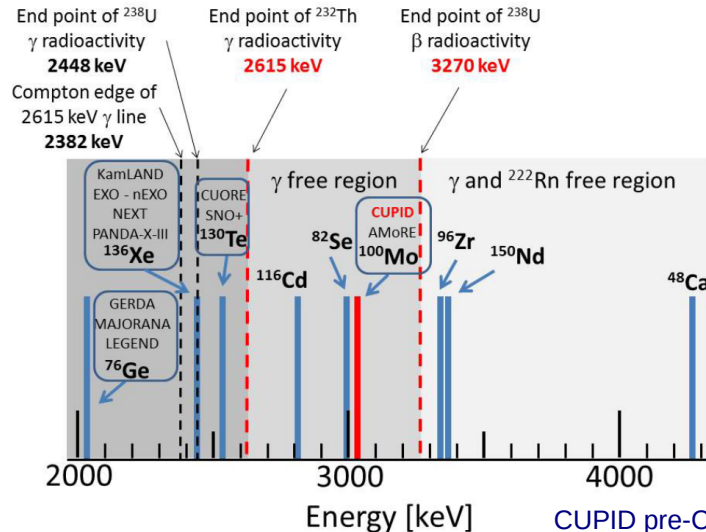
Current $0\nu\beta\beta$ generation of experiments

$$S(T_{1/2}^{0\nu\beta\beta}) \propto \epsilon_s \sqrt{\frac{t \cdot M}{b \cdot \Delta E}}$$

Requirements of a $0\nu\beta\beta$ experiment

- Good signal detection efficiency
- Large exposure (scalability)
- Good energy resolution
- Low background

9/11 possible isotopes with $Q\beta\beta \sim 2-3$ MeV



Large source mass
Easily scalable

**Fluid
embedded
source**

- ① **KamLAND-Zen 400** → **KamLAND-Zen 800** → KamLAND2-Zen
- ② **EXO-200** → nEXO
- ③ **NEXT-White** → **NEXT-100** → NEXT-HD/NEXT-BOLD
- ④ **SNO+** → **SNO+-phase II**

Completed
Data taking
Construction /
Commissioning
Advanced R&D
R&D

High energy resolution
/ efficiency

**Crystal
embedded
source**

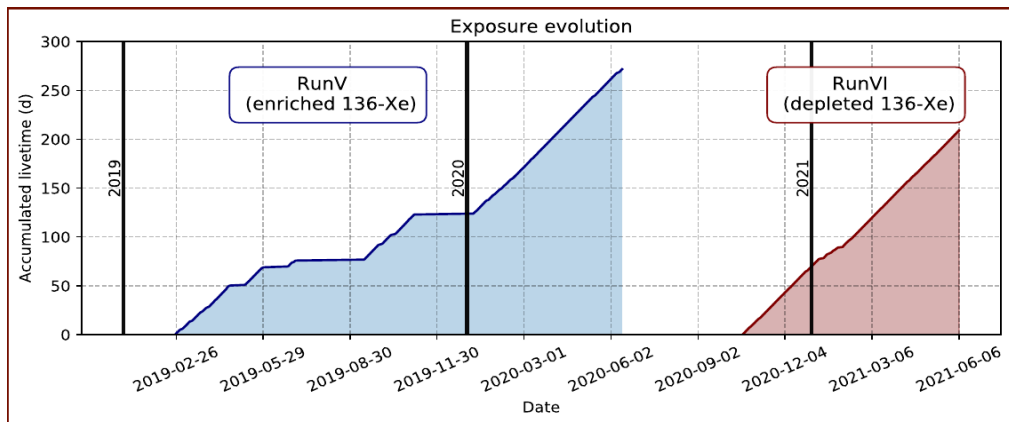
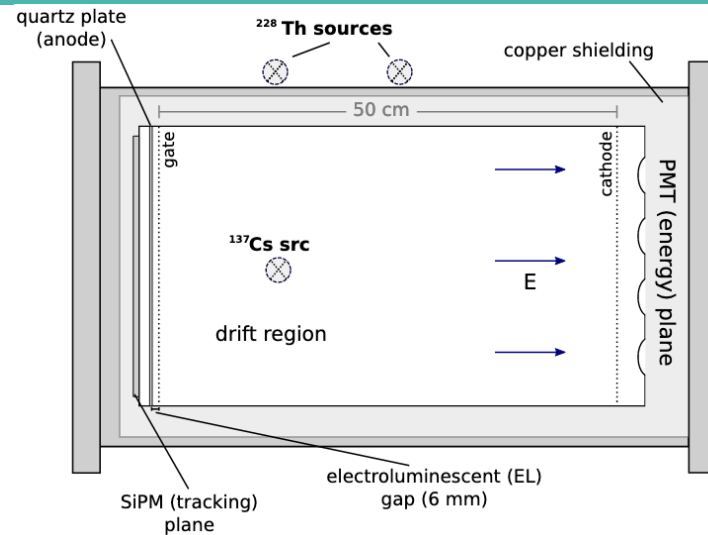
- ⑤ **GERDA**
MAJORANA dem. } → **LEGEND-200** → **LEGEND-1000**
- ⑥ **CUPID-Mo**
CUPID-0
CUORE } → **CUPID** → CUPID Reach / CUPID 1t
- ⑦ **AMORE-I** → **AMORE-II**

A. Giuliani, North America - Europe Workshop on Future of Double Beta Decay (9/2021)

NEXT-White operation

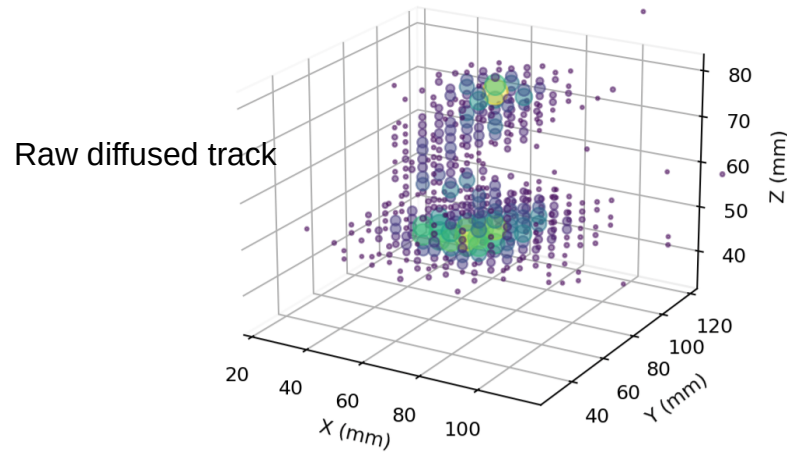
Data taking periods

- Calibration runs 2017-2018: energy resolution, energy scale and topological discrimination
 - Low energy calibration and monitoring using ^{83m}Kr
 - High energy calibration (energy scale) using ^{228}Th and ^{137}Cs
- Low background physics runs: background model and $2\nu\beta\beta$
 - **Run V** (2/19-6/20) Enriched: bkg + $2\nu\beta\beta$
 - **Run VI** (10/20-6/21) Depleted: bkg

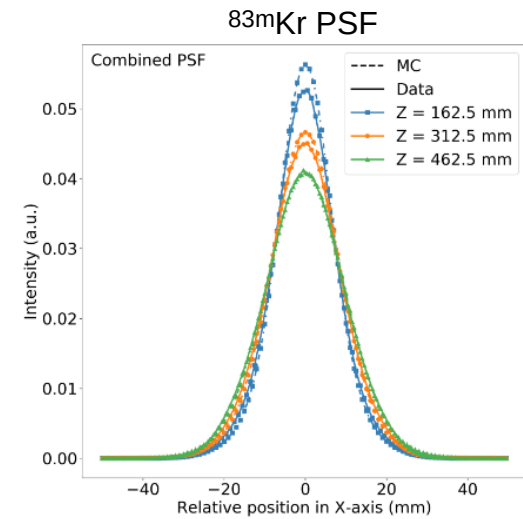
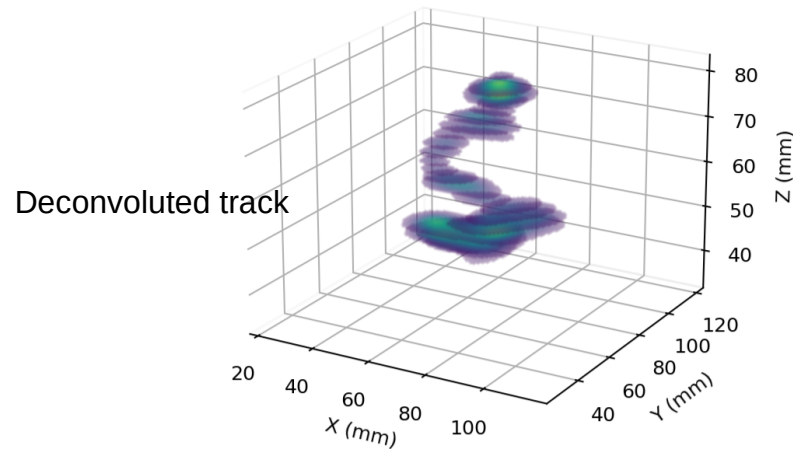


Run period	Start Date	Run time (day)	Triggers
Run-Va	25-02-2019	75.8	617,896
Run-Vb	13-09-2019	47.1	412,902
Run-Vc	08-01-2020	148.7	1,117,101
Run-V	25-02-2019	271.6	2,147,899
Run-VI	20-10-2020	208.9	1,646,501

NEXT-White calibration and reconstruction

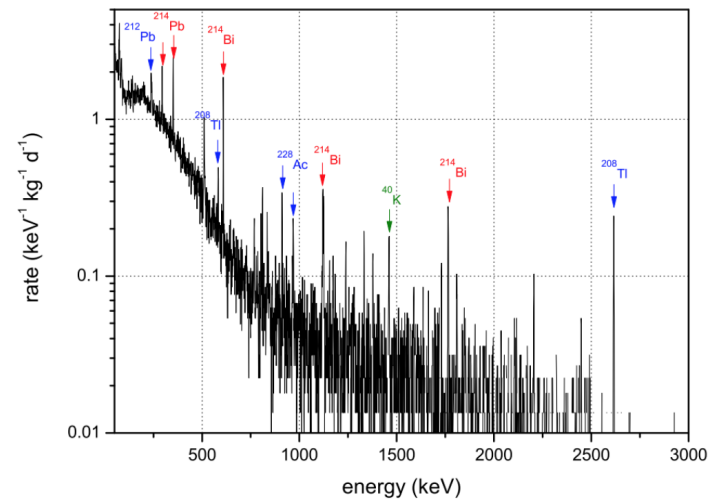
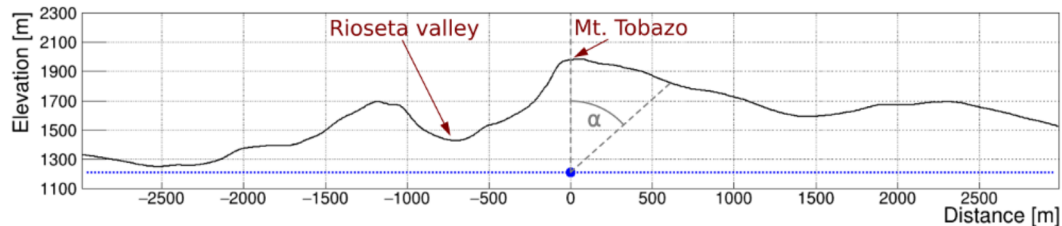
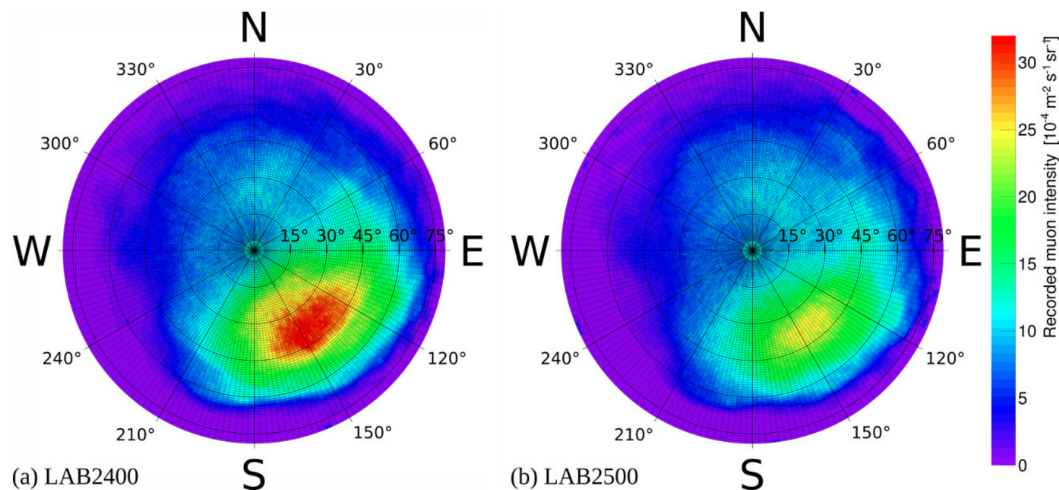


Lucy-Richardson
deconvolution algorithm



NEXT-100 background model components

- Detector's materials measurement campaign ongoing:
 - High resolution gamma spectroscopy: HPGe detector at LSC Radiopurity Service
 - Mass spectrometry (GDMS, ICPMS): external companies/institutions
- Angular muon flux at LSC known ([arXiv:1902.00868](https://arxiv.org/abs/1902.00868))



NEXT-100 sensitivity

Main differences between this update and 2016's paper:

- data-like (this) vs purely MC (2016) reconstruction
- final NEXT-100 detector design (this)
- extrapolated background rate from NEXT-White (2016)

Comparison with published	This preliminary update	2016 sensitivity paper (JHEP05(2016)159)
^{136}Xe mass (kg)	65 (90% enrichment)	91 (91% enrichment)
Signal efficiency (%)	21	28
Background rate (counts/year/kg/keV)	$< 2.9 \cdot 10^{-3}$	$4 \cdot 10^{-4}$
Half-life at 90% CL after 3 years	$> 1.8 \cdot 10^{25}$ years	$6.0 \cdot 10^{25}$ years