next

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

The NEXT experiment

Status and prospects

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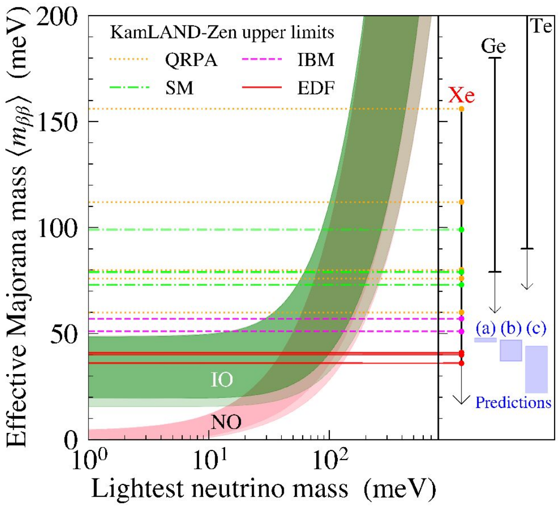
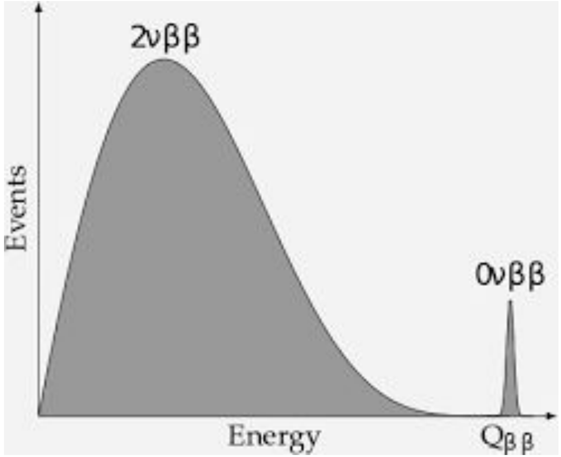
[1] Ben Gurion University of the Negev

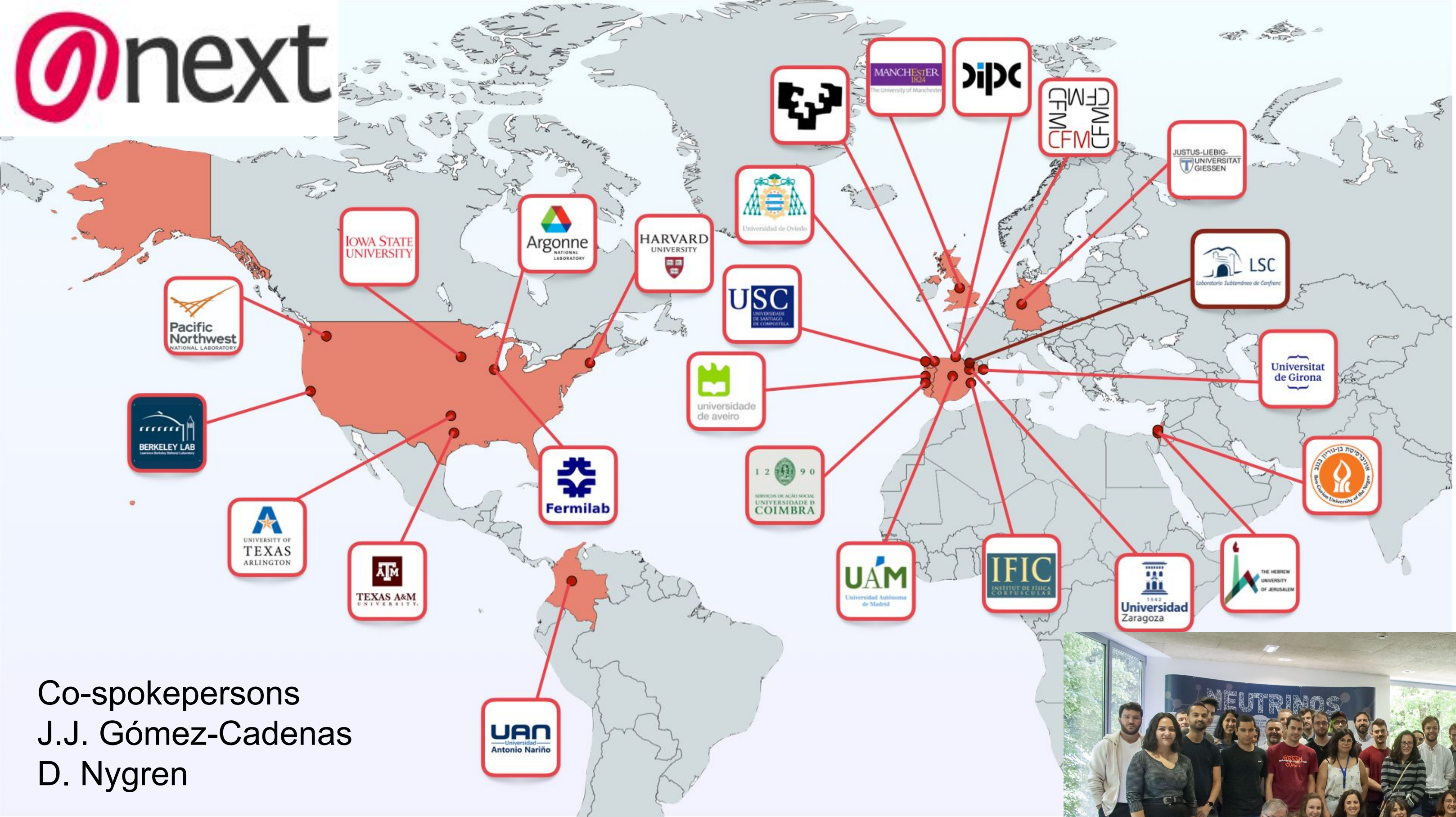
Double beta decay

- Second order weak process →$T_{1/2}$ ~ $10^{19\text{-}22}$ y
- Neutrinoless decay mode available if neutrinos are Majorana particles
  - $T_{1/2} > 10^{26}$ y
- Next generation of experiments will probe the **I**nverted **O**rdering
  - Expected signal in ^{136}Xe ~0.3 - 3 evt/tonne/y

KamLAND-Zen Collaboration 03/2022







Co-spokepersons
J.J. Gómez-Cadenas
D. Nygren

Neutrino **E**xperiment with a **X**enon **TPC**

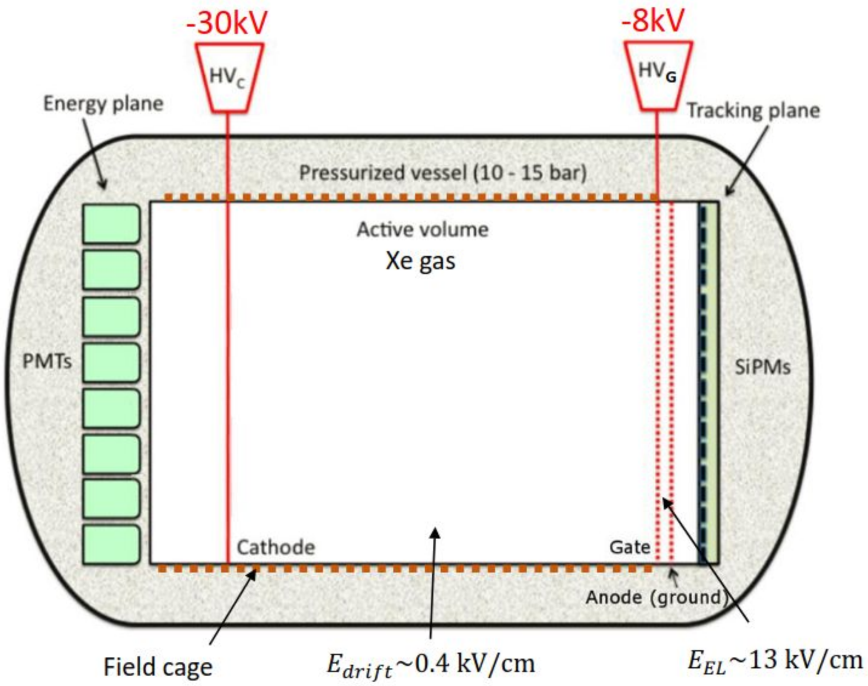
- Search for neutrinoless double beta decay (ββ0ν) in ^{136}Xe
- High pressure TPC with EL amplification
  - High density
  - **Excellent energy resolution** < 1% FWHM @ $Q_{\beta\beta}$
  - **Event topology** → background discrimination
- Installed @ Laboratorio Subterráneo de Canfranc, in Spain

NEXT: Status

- Concluded a 4-year physics program with the NEXT-White demonstrator
    - ~5 kg of ^{136}Xe-enriched gas @ 10 bar
    - Demonstrated **energy resolution < 1% FWHM @ $Q_{\beta\beta}$**
    - Demonstrated **topological background suppression capabilities**
    - Reported **competitive ββ2ν half life measurement** using an innovative method
- Beginning construction and commissioning of the NEXT-100 detector
    - ~100 kg of ^{136}Xe-enriched gas @ 15 bar
    - Aimed to demonstrate quasi-background free conditions and prepare for a tonne-scale detector
    - ββ0ν search
- Developing an R&D program for future detectors
    - Improved topology
    - **Background free** experiment using Barium Tagging

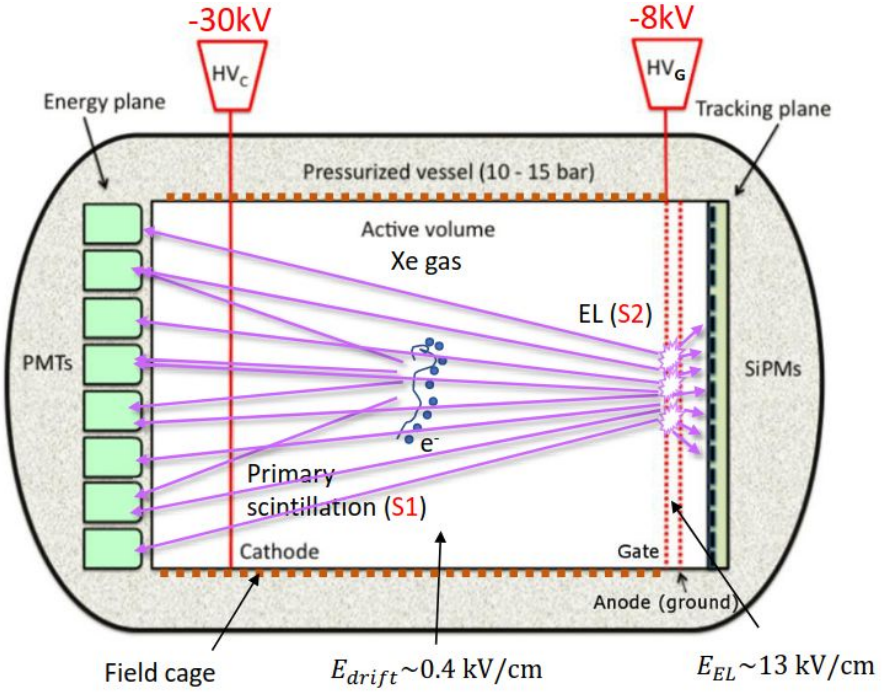
NEXT: design

- High pressure vessel
- Transparent electrodes
    - Drift region
    - EL region
- TPB on the walls
    - Shift VUV to blue
- Asymmetric detector
    - PMTs for t0 and calorimetry
    - SiPMs for tracking

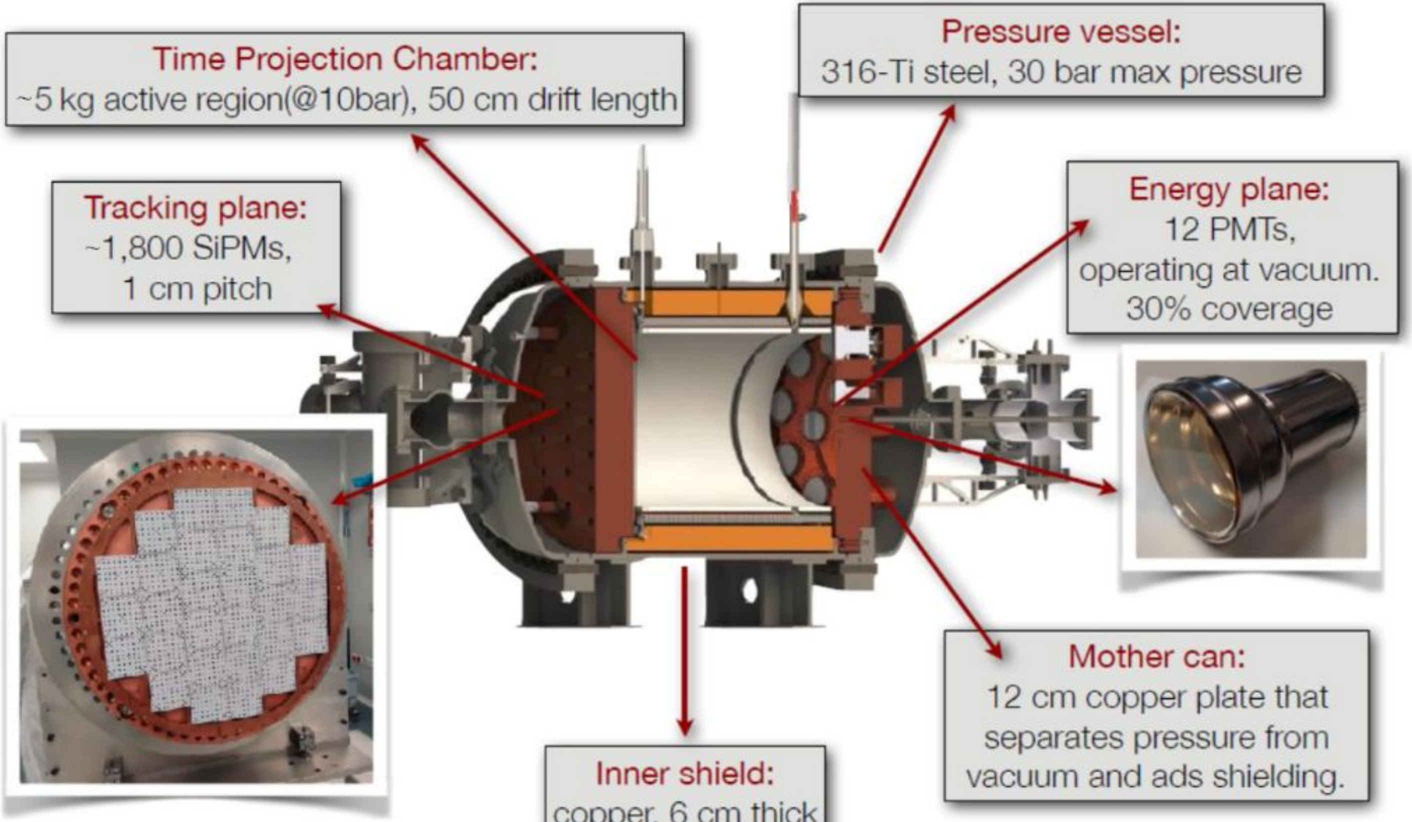


NEXT: principle of operation

- Interactions in the active volume produce scintillation photons and ionization electrons
  - Scintillation detected by PMTs →S1→t0
  - Electrons drift under a low electric field towards the EL region
- A strong field induces electroluminiscence (EL) →S2
  - EL photons collected by all PMTs provide a measurement of the deposited energy
  - EL photons collected by a small amount of SiPMs provide tracking →event topology



NEXT-White

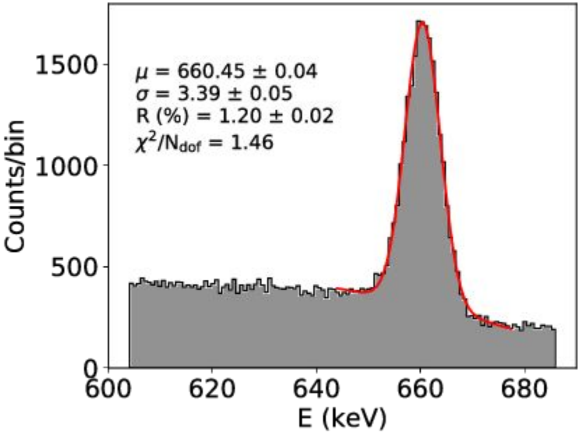

Time Projection Chamber:
~5 kg active region(@10bar), 50 cm drift length
Pressure vessel:
316-Ti steel, 30 bar max pressure
Tracking plane:
~1,800 SiPMs,
1 cm pitch
Energy plane:
12 PMTs,
operating at vacuum.
30% coverage
Mother can:
12 cm copper plate that
separates pressure from
vacuum and ads shielding.
Inner shield:
copper, 6 cm thick

NEXT-White

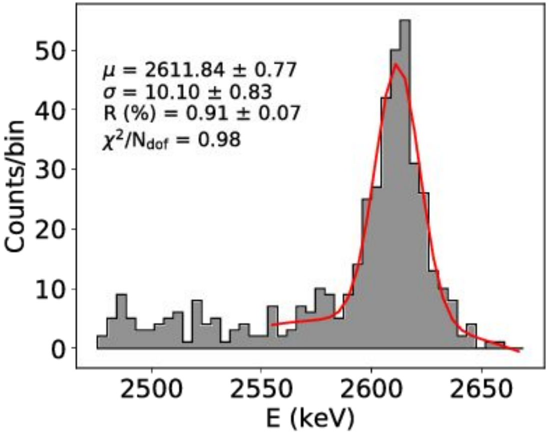
NEXT-White: energy resolution

- Demonstrated an **energy resolution < 1% FWHM @ $Q_{\beta\beta}$** using ^{137}Cs and ^{208}Tl γ sources
- Long tracks corrected using calibration maps produced with ^{83m}Kr decays

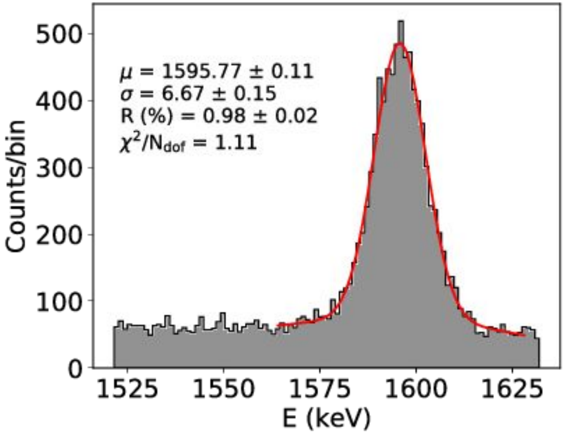
[J. Renner et al JHEP 2019 230](#)



^{137}Cs 662 keV photopeak



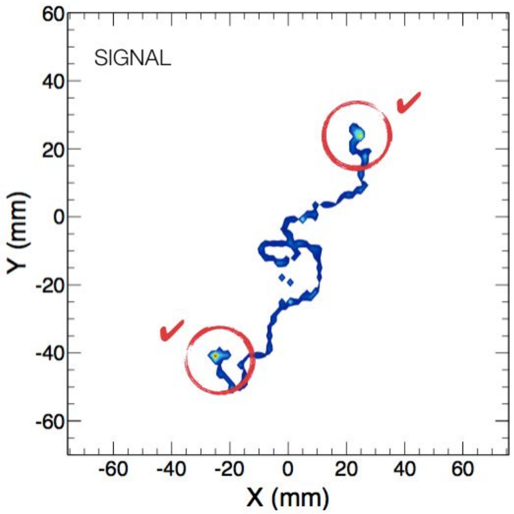
^{208}Tl 2612 keV photopeak

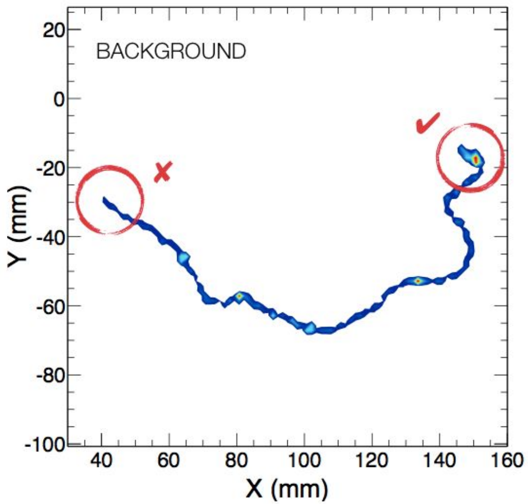


^{208}Tl 1592 keV double-escape peak

Topological background discrimination: principle

- An electron scattering through the gas deposites a large amount of energy at the end → bragg peak ("blob")
  - ββ events emit 2 electrons →**2 blobs**
  - Background events (γ) produce 1 electron →**1 blob**

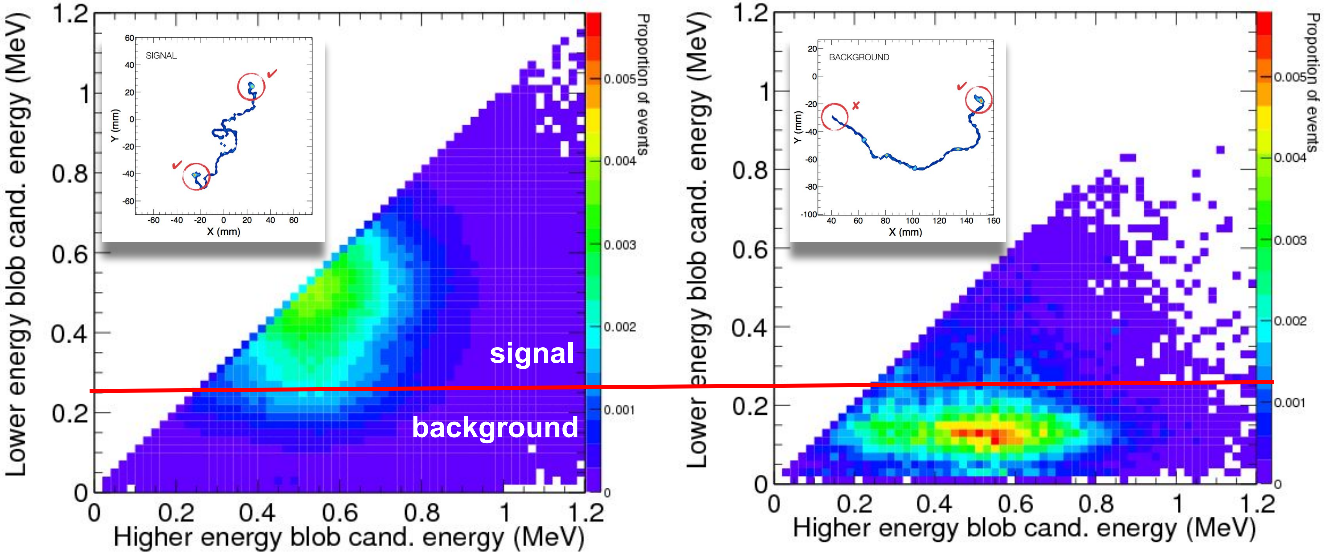




P. Ferrario et al JHEP 01 (2016) 104

Topological background discrimination: principle

- Measure energy within the two ends of the track
- Different distributions → Require a minimum energy for lower energy blob



MC

P. Ferrario et al JHEP 01 (2016) 104

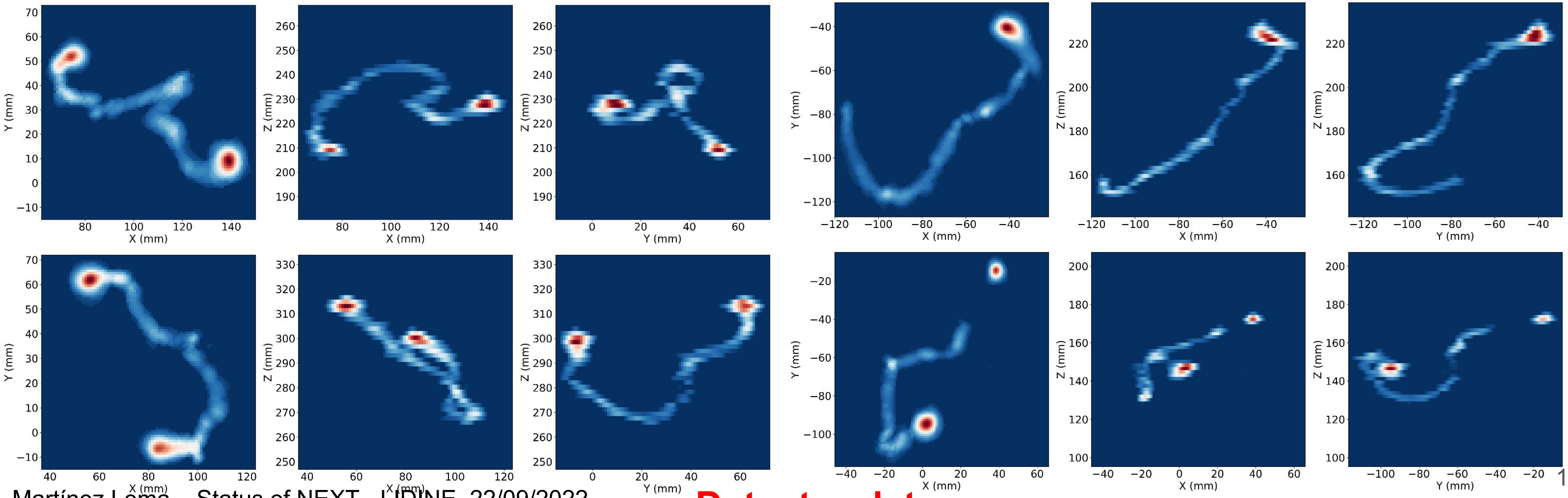
Track reconstruction

- New method based on the **Richardson-Lucy deconvolution**
  - Removal of diffusion and light emission effects
- Enhanced spatial resolving power

e^+e^- candidates

A. Simón et al JHEP 07 (2021) 146

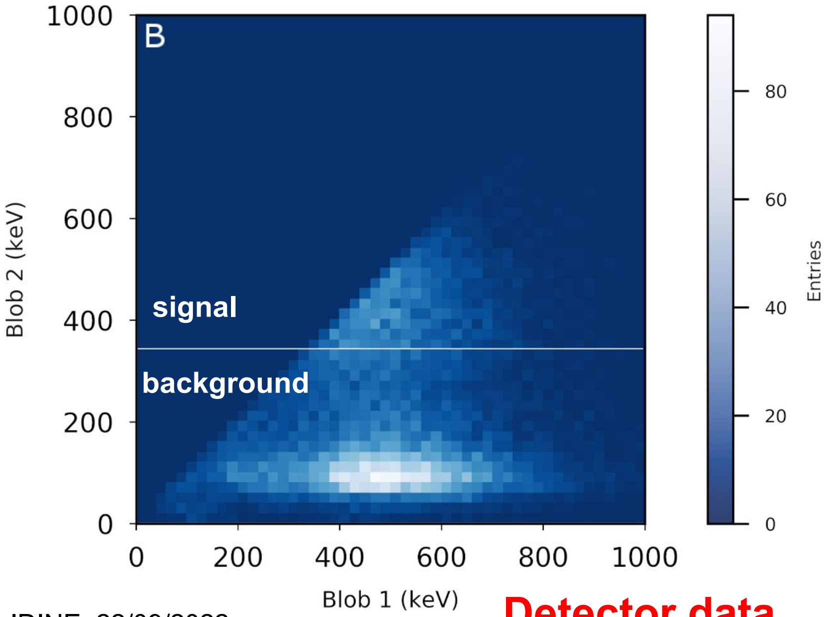
e^- candidates



Detector data

Topological background discrimination: performance

- **96% background rejection** (x27 reduction)
- **57% signal efficiency**



A. Simón et al JHEP 07 (2021) 146

Detector data

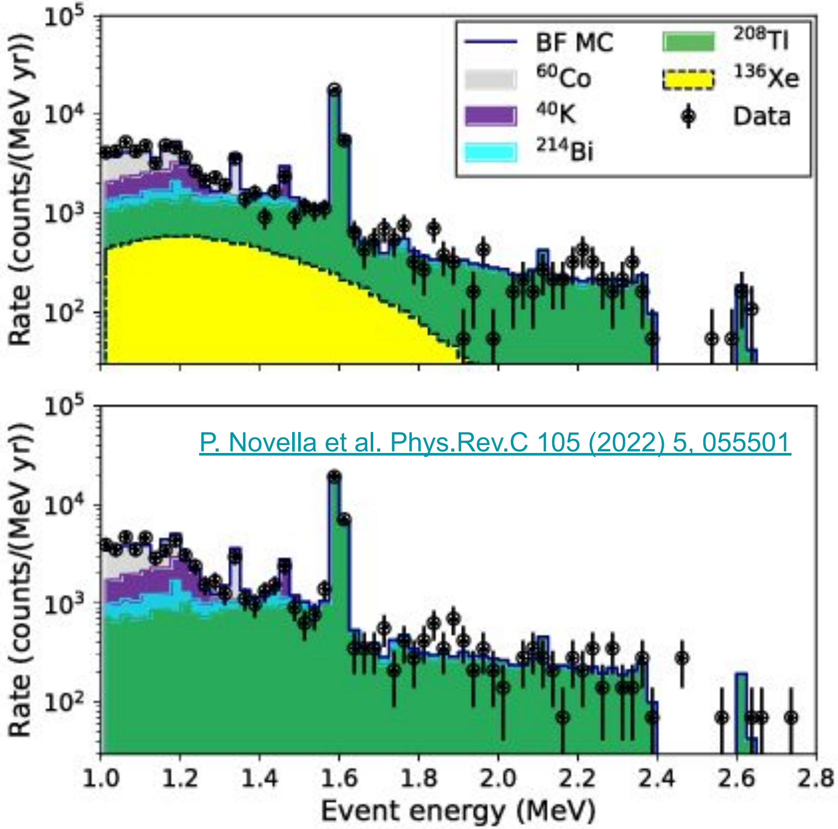
ββ2ν $T_{1/2}$ measurement

- Two runs of data
  - ^{136}Xe-depleted (2.6%) gas → Background characterization
  - ^{136}Xe-enriched (90%) gas →Signal analysis
- Same background rate on both runs
- Two approaches:
  - Background-model-based
    - Traditional method relying on characterization of backgrounds
  - Direct background substraction
    - **Unique method** in the field
    - Minimal dependence on background model
- Both yield competitive and compatible results

ββ2ν $T_{1/2}$ measurement: bkg-model-based analysis

- Energy spectra for the enriched and depleted runs
- Fitted both simultaneously with $T_{1/2}^{2\nu}$ and ^{60}Co, ^{40}K, ^{214}Bi and ^{208}Tl abundances as free parameters

$$T^{2\nu}_{1/2} = \left(2.14\ ^{+0.65}_{-0.38}(\mathrm{stat})\ ^{+0.46}_{-0.26}(\mathrm{sys})\right) \times 10^{21}\ \mathrm{y}$$



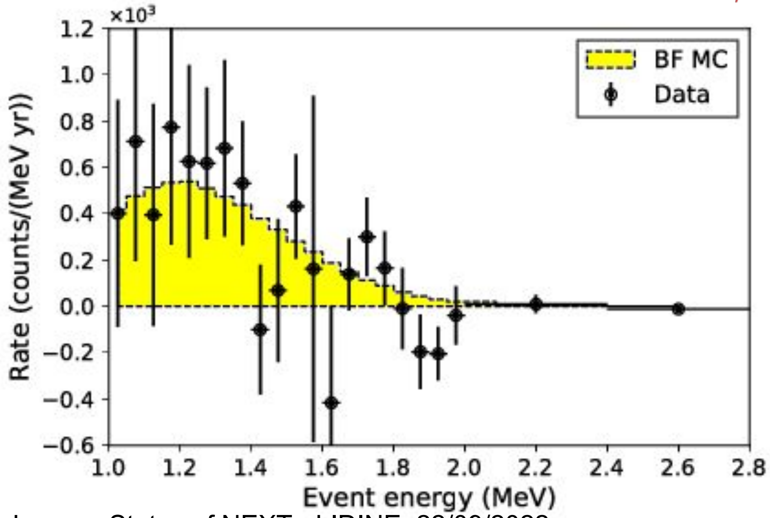
P. Novella et al. Phys.Rev.C 105 (2022) 5, 055501

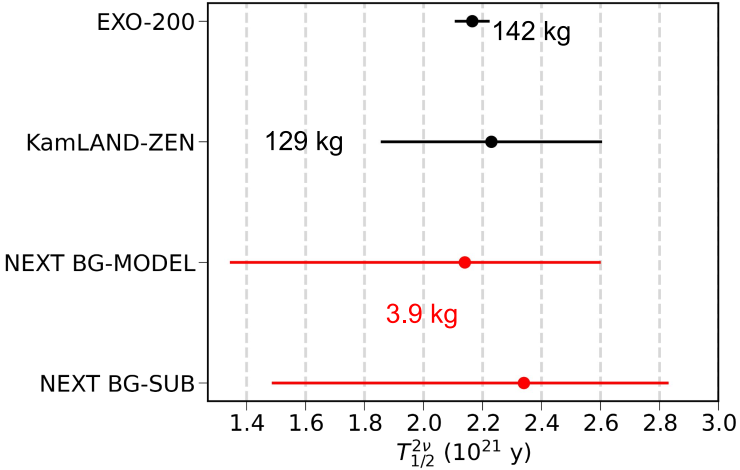
ββ2ν $T_{1/2}$ measurement: direct background subtraction

- Subtracted spectrum (enriched minus depleted)
  - **Minimal assumptions on background model**
- Fitted with $T_{1/2}^{2\nu}$ as the only free parameter

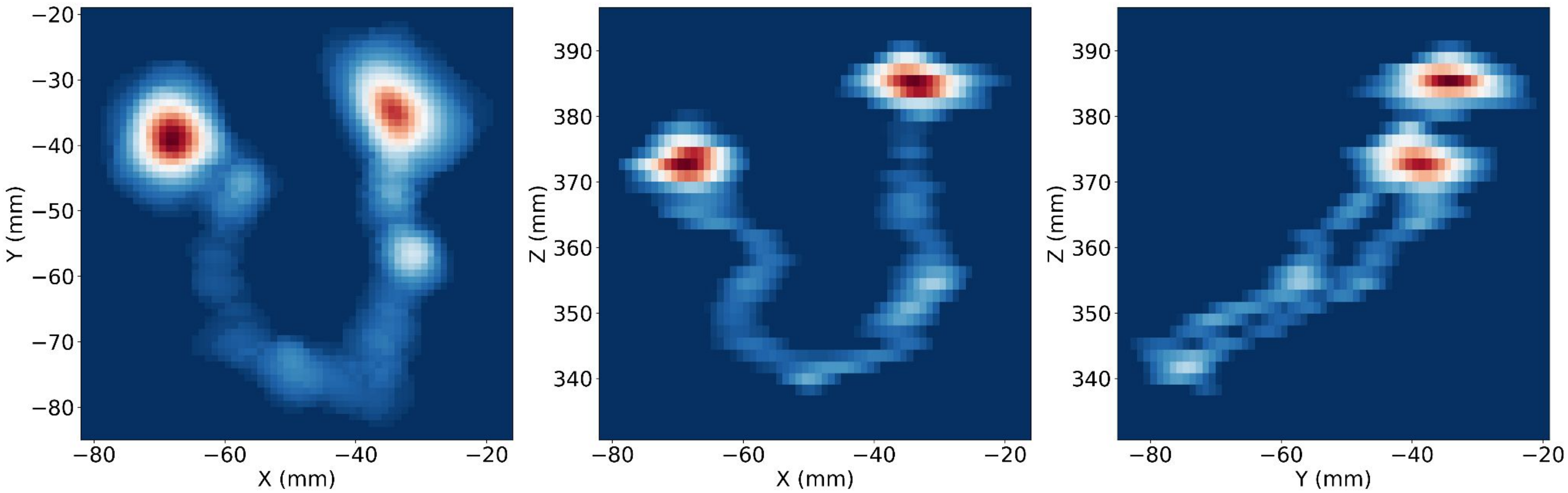
P. Novella et al. Phys.Rev.C 105 (2022) 5, 055501

$$T^{2\nu}_{1/2} = \left(2.34\ ^{+0.80}_{-0.46}(\text{stat})\ ^{+0.30}_{-0.17}(\text{sys})\right) \times 10^{21}\ \text{y}$$

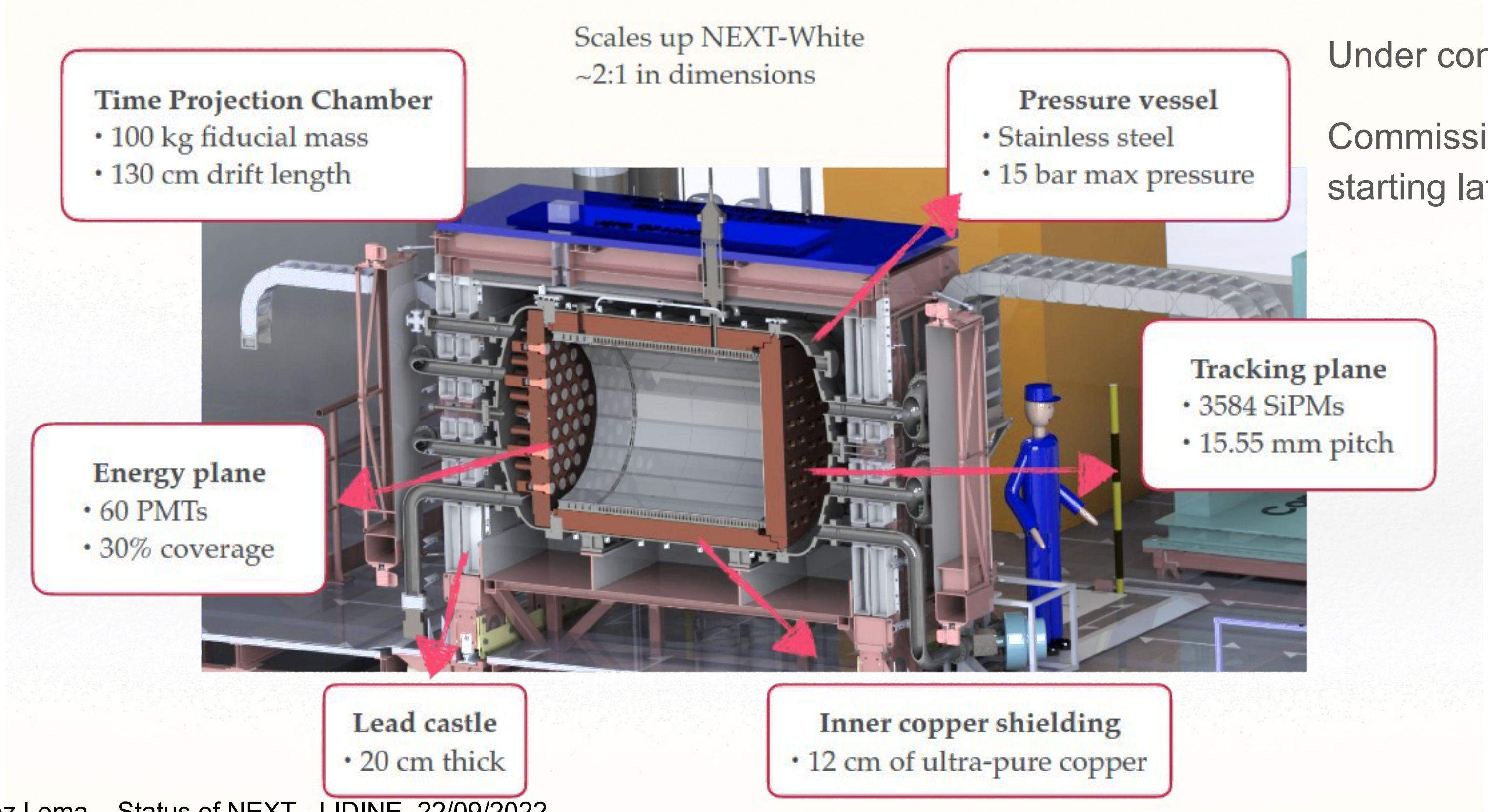




A ββ candidate



NEXT-100



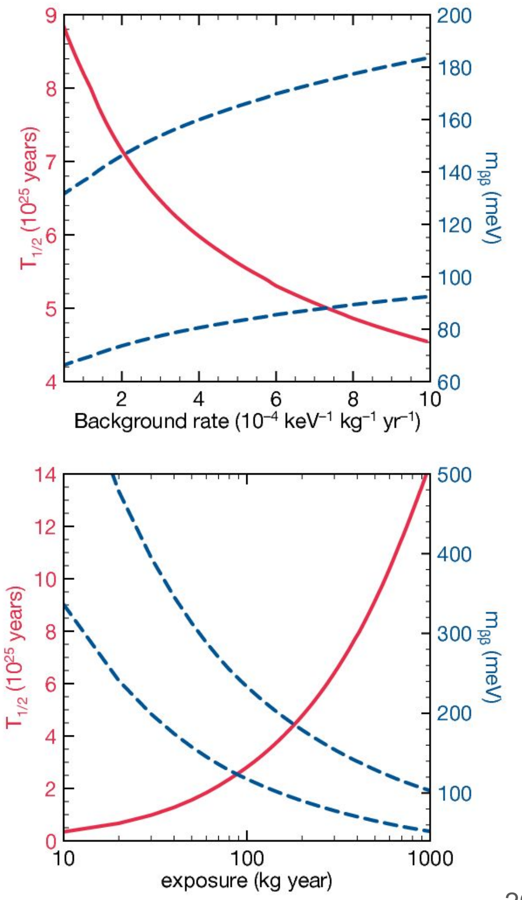
Under construction

Commissioning run starting late 2022

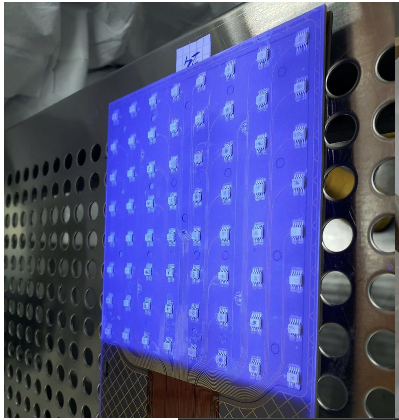
JHEP 05 (2016) 159

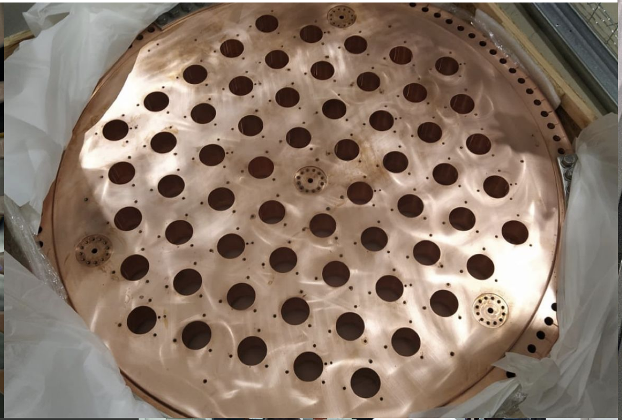
NEXT-100

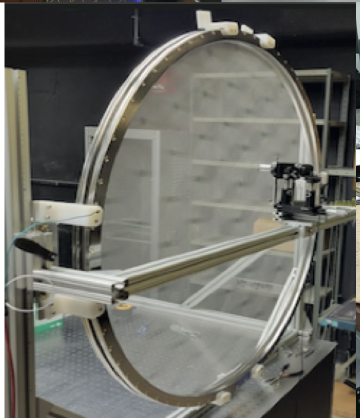
- Expected background rate $4x10^{-4}$ counts/keV/kg/year
- Goals
  - Improve E resolution closer to 0.5% FWHM @ $Q_{\beta\beta}$
  - Assess background model
  - Demonstrate quasi background-free conditions at the 100 kg scale (≲ 1 evt/year)
  - ββ0ν search
  - Prepare for a tonne-scale detector
- Main differences with respect to NEXT-White
  - Larger SiPM area by 60%
  - Teflon masks on tracking plane → improved topology
  - Thicker copper shield (x2)
  - Increased SiPM pitch



NEXT-100 @ LSC







The future: NEXT-HD

- Baseline concept for a tonne scale detector
- 1 tonne of ^{136}Xe-enriched gas
- Symmetric TPC with central cathode
- Dense SiPM plane readout
- Energy measurement through optical barrel fiber
  - Alternative R&D projects in development
- Low diffusion Xe/He mixtures→**better topology**
- Water tank
  - Muon veto
  - Neutron absorber
- Expected sensitivity **~10^{27} y**
- Estimated to start construction on ~2026

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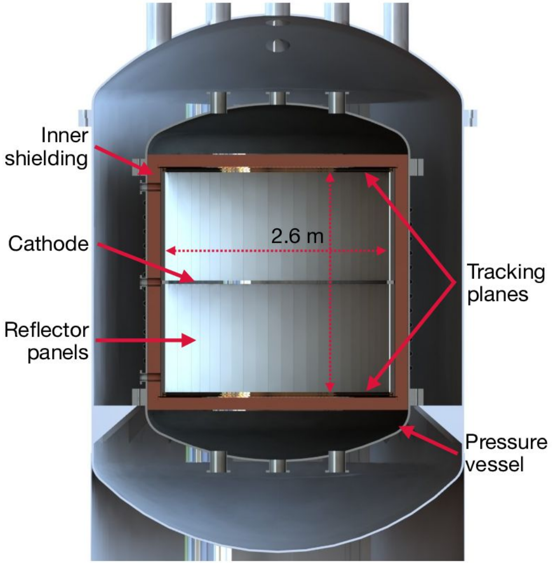
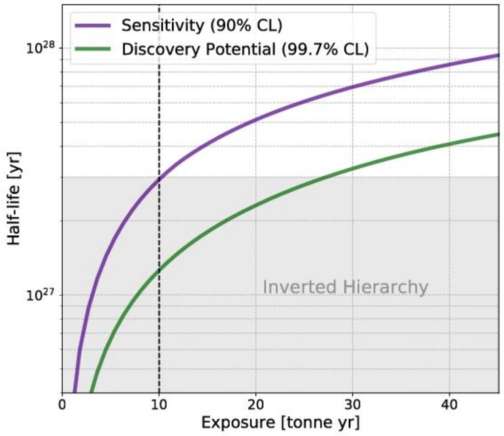
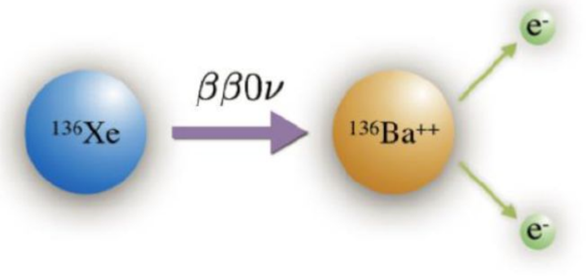
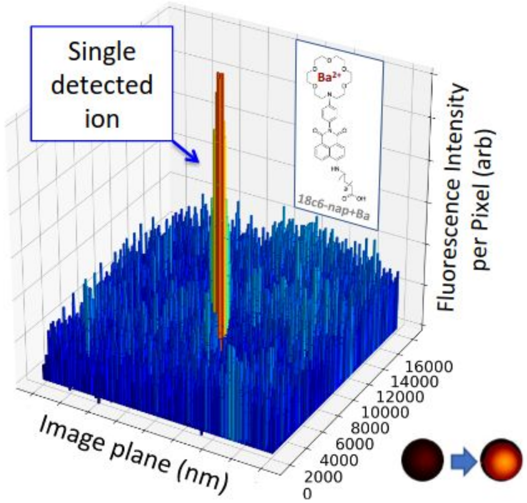




The future: NEXT-BOLD

- Barium tagging: identification of a ^{136}Ba atom in coincidence with a ββ candidate event in the ROI
  - Fluorescent molecules capture Ba^{++}
  - **In situ detection**
  - 100% background reduction → **Background-free experiment**
- ββ2ν rate within the ROI negligible
- The sensitivity of a tonne-scale NEXT detector with barium tagging **~10^{28} y**
- Active R&D program devoted to developing barium tagging techniques
  - Well funded
  - Multidisciplinary approach





Outlook

- NEXT concept demonstrated on a 5kg detector (NEXT-WHITE)
  - **E resolution < 1% FWHM @ $Q_{\beta\beta}$**
  - **96% background rejection** based on topology
  - Competitive **measurement of ββ2v half life** using a innovative method
- NEXT-100 in construction
  - Commissioning to start late 2022
- Tonne-scale detector in development
  - NEXT-HD: Baseline approach →continuation of known technology. Sensitivity ~10^{27} y
  - NEXT-BOLD: Aggresive approach with Ba tagging →**background free**. Sensitivity ~10^{28} y

Thank you for your attention

Backup

E resolution in GXe vs LXe

A. Bolotnikov, B. Ramsey / Nucl. Instr. and Meth. in Phys. Res. A 396 (1997) 360–370

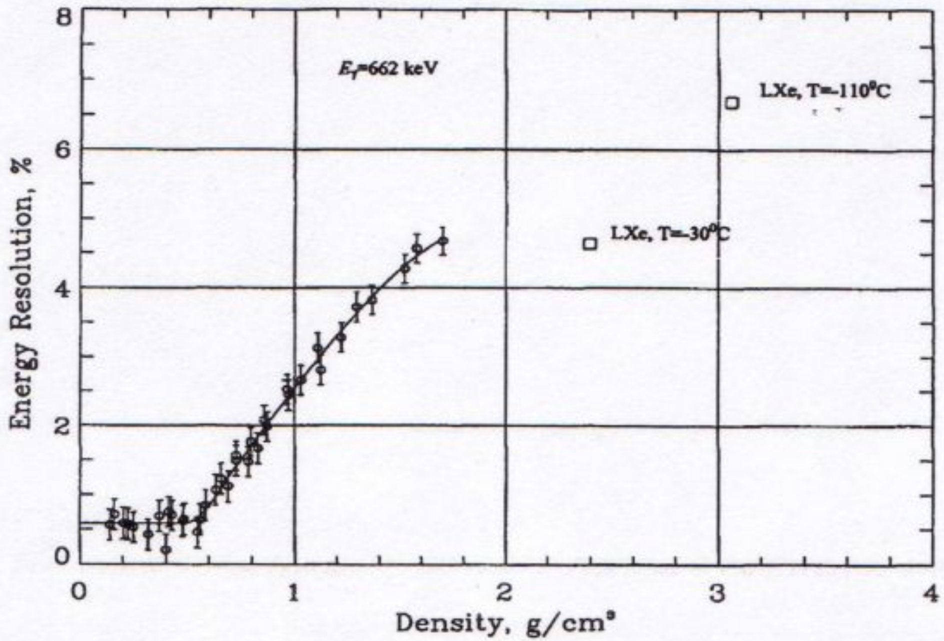
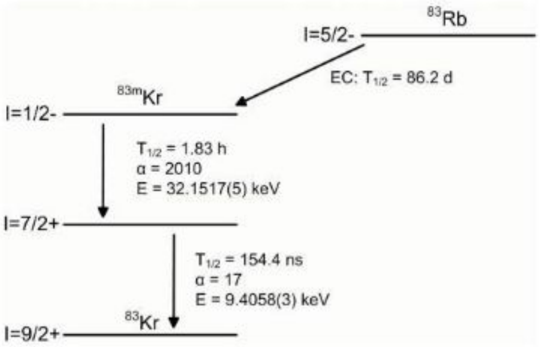


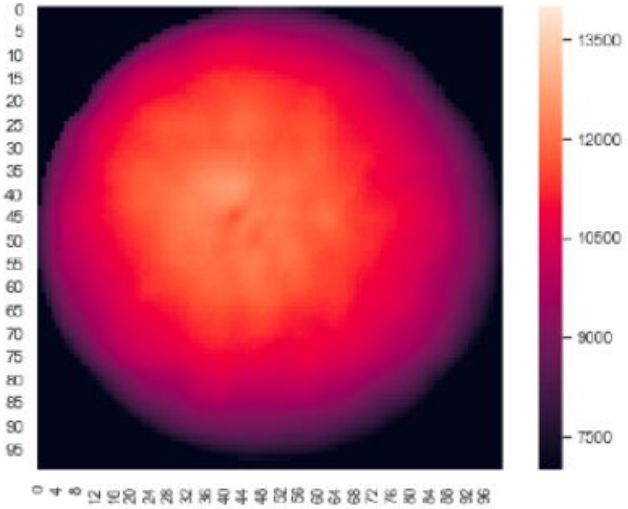
Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

^{83m}Kr calibration

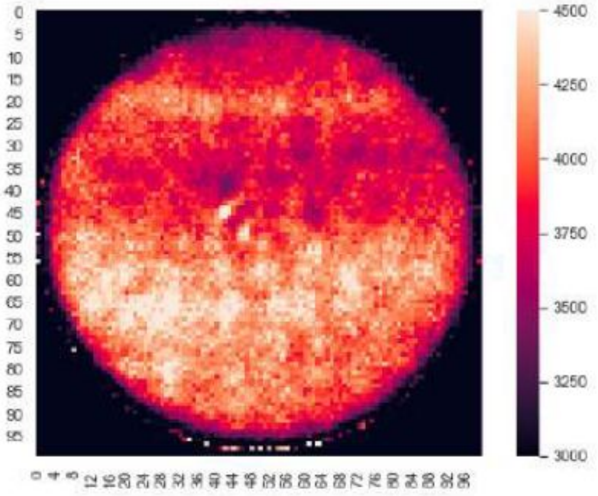
- Dual trigger: low E calibration + signal
- Continuous monitoring of the detector
- Corrections due to geometrical innefficiencies and lifetime



Light collection map

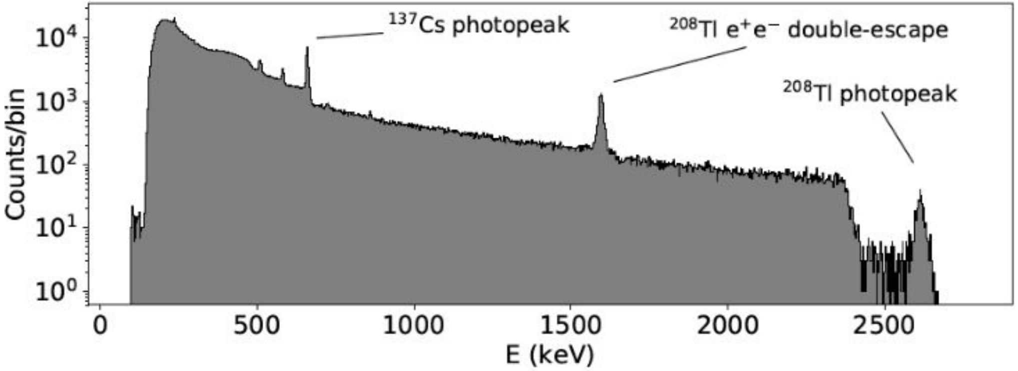


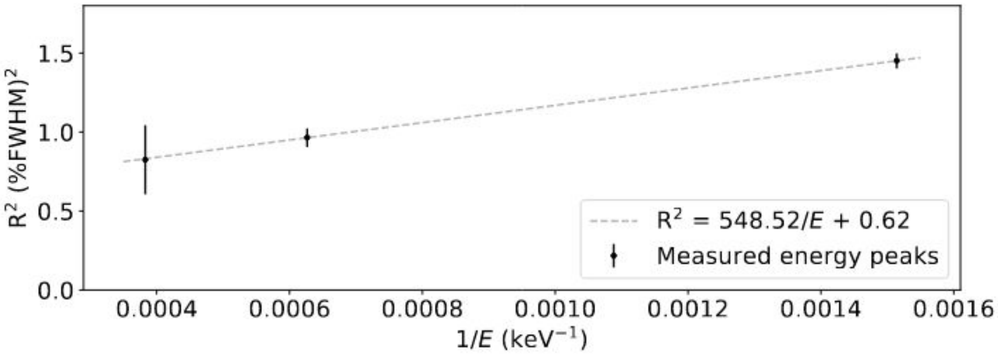
Lifetime map



High energy calibration

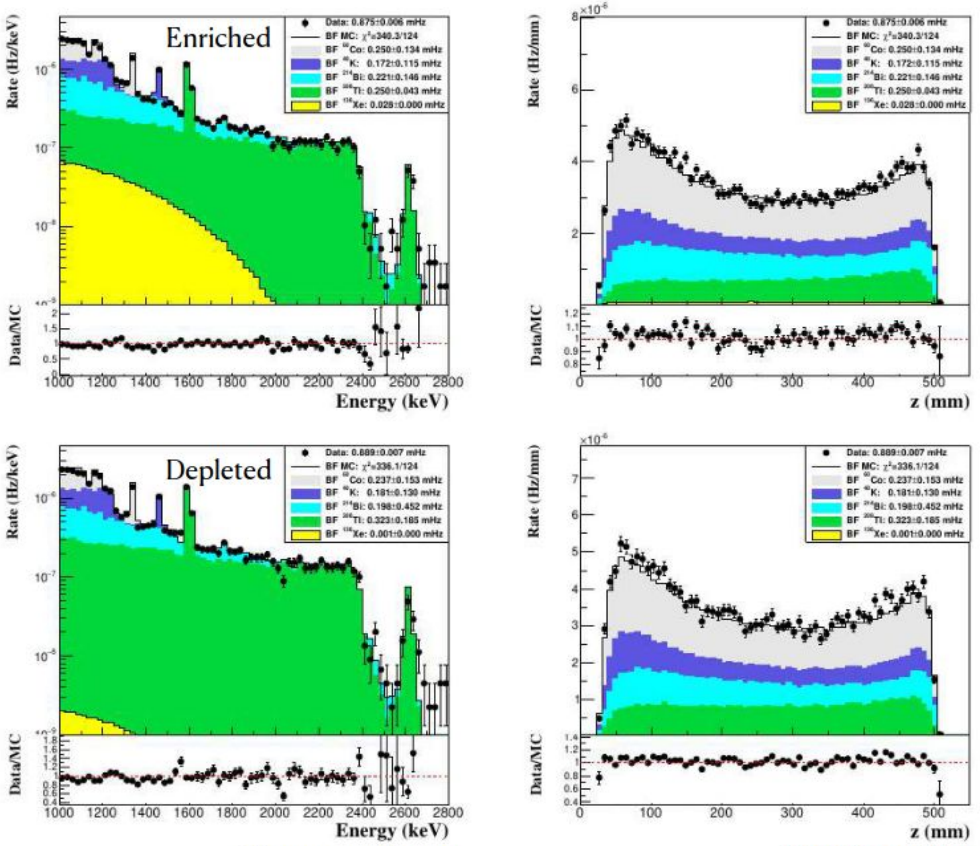
- ^{137}Cs and ^{208}Tl sources
  - 662 keV photopeak
  - 1592 keV double escape peak
  - 2614 keV photopeak
- Energy scale
- Energy resolution
- Topology
  - Double escape peak produces e^+e^- that have similar topology to ββ





Bkg model in NEXT-White

- 4 isotopes: ^{60}Co, ^{40}K, ^{214}Bi, ^{208}Tl
- 3 regions: anode, cathode, other
- 2 distributions: energy, drift pos
- Simultaneous fit to both distributions
- Measured spectrum in agreement with MC!

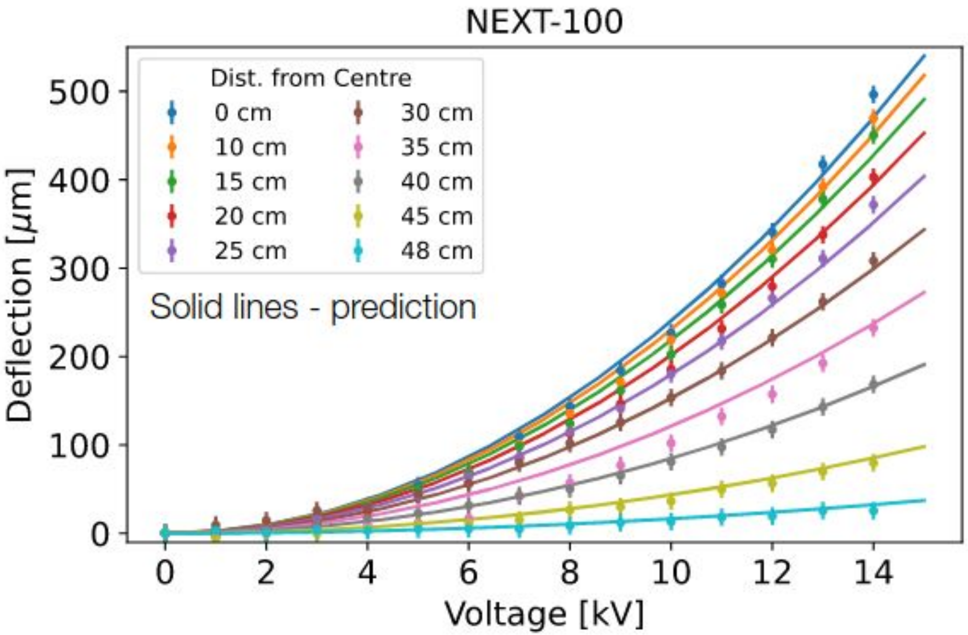


Energy spectrum

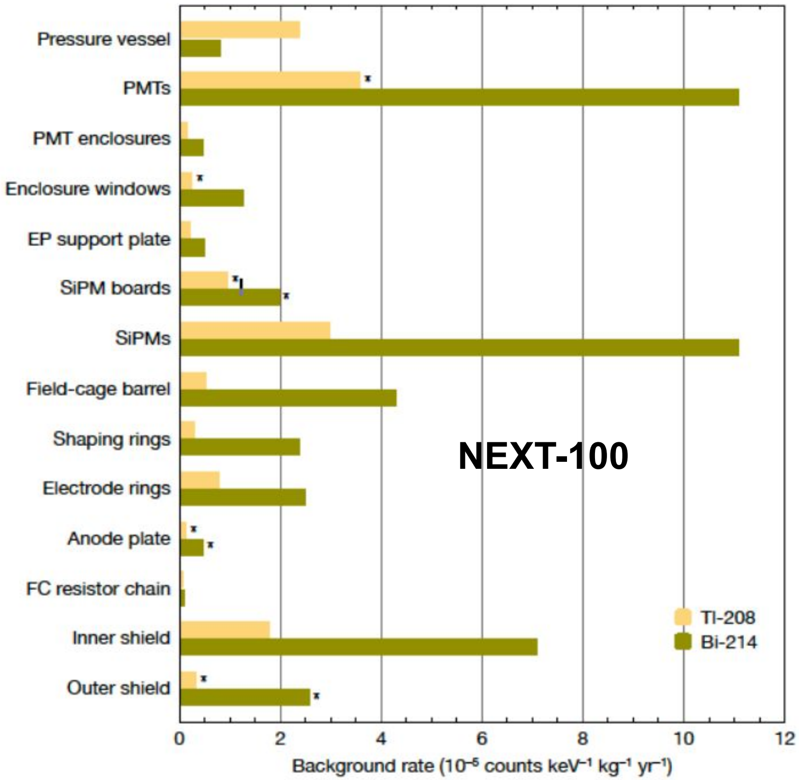
Z (drift) position

EL deflection

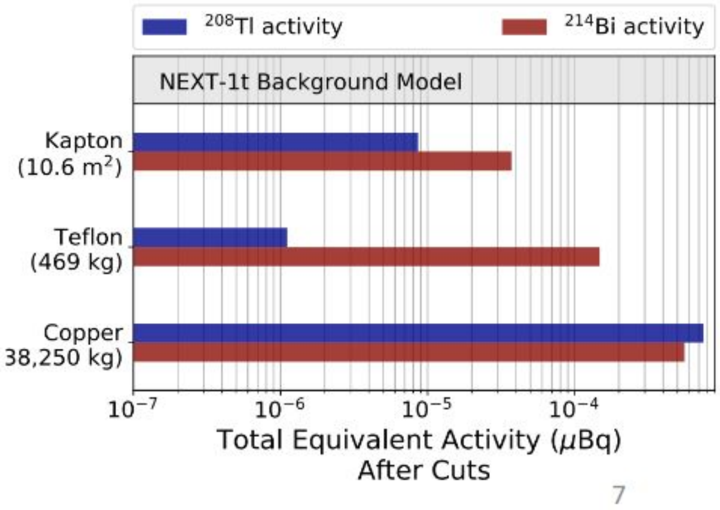
- Not an issue



Bkg budget in NEXT-100 & NEXT-tonne

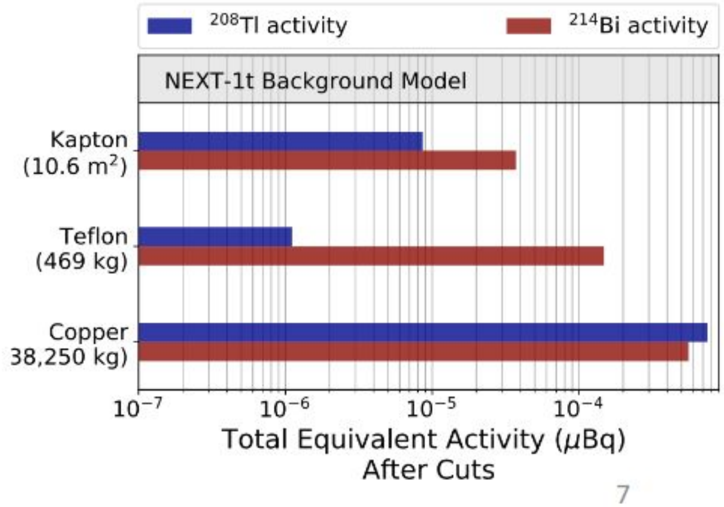


NEXT-tonne



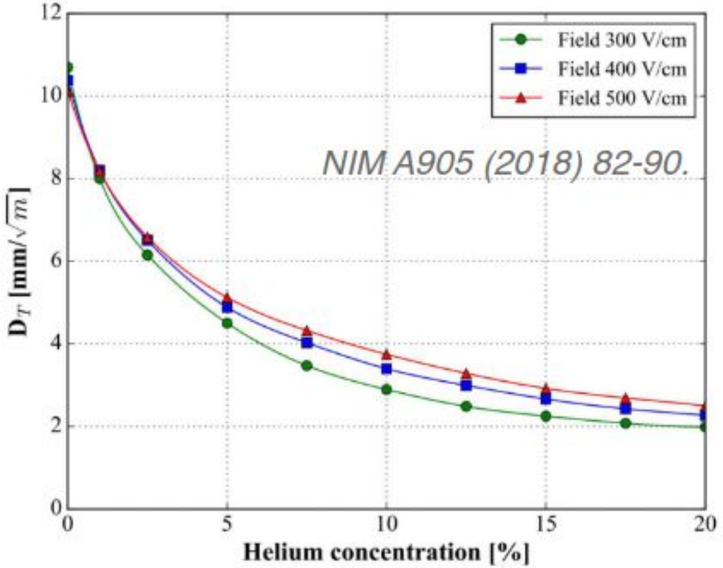
More on NEXT-tonne

- Modular approach. First module @ LSC
  - Subsequent modules locations TBD
- Gas adivitives
  - ^{4}He for Reduced diffussion →better topology
  - ^{3}He for cosmogenics ^{137}Xe backgrounds
- Estimated background 0.09 - 0.27 counts /ton/y/ROI
- Ongoing R&D projects
  - High speed cameras for tracking
  - Metalenses for enhanced VUV light collection
  - MCP-PMTs for energy measurement



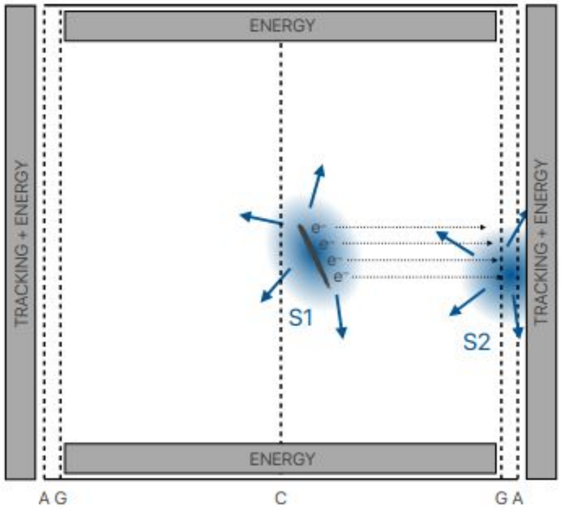
Low diff

- Transverse diffussion can be reduced ~x4 by adding 10 - 15 % of ^{4}He
- Minimal impact on energy resolution and light yield

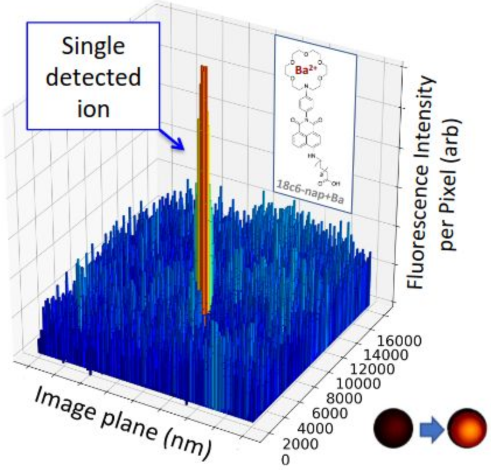


Optical fiber barrel

- Multi-clad wavelength-shifting fibers
- High coverage
- Similar PDE to PMTs in active volume



NEXT with Barium Tagging



- Single molecule fluorescent imaging employed to detect Ba^{2+} produced in double beta decay.

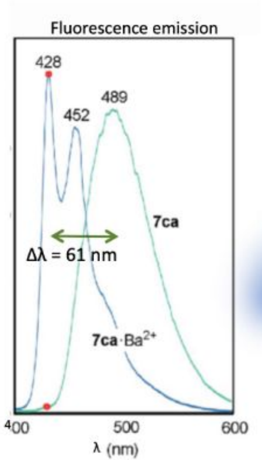
- NEXT has developed custom barium chemosensing molecules with demonstrated single ion response in dry environments.

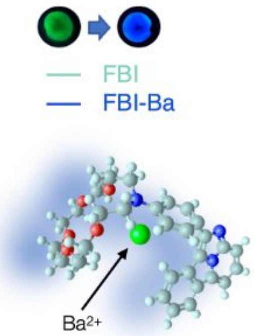
- Two approaches:
  - Turn-on

    JINST 11 (2016) 12, P12011; Phys.Rev.A 97 (2018) 6, 062509; Phys. Rev. Lett. 120 (2018) 13, 132504; JINST 15 (2020) 04, P04022; Sci.Rep. 9 (2019) 1, 15097; ACS Sens. 6 (2021) 1, 192–202; arXiv:2109.05902

  - Bi-color

    Nature 583 (2020) 7814, 48–54 , arXiv:2201.09099

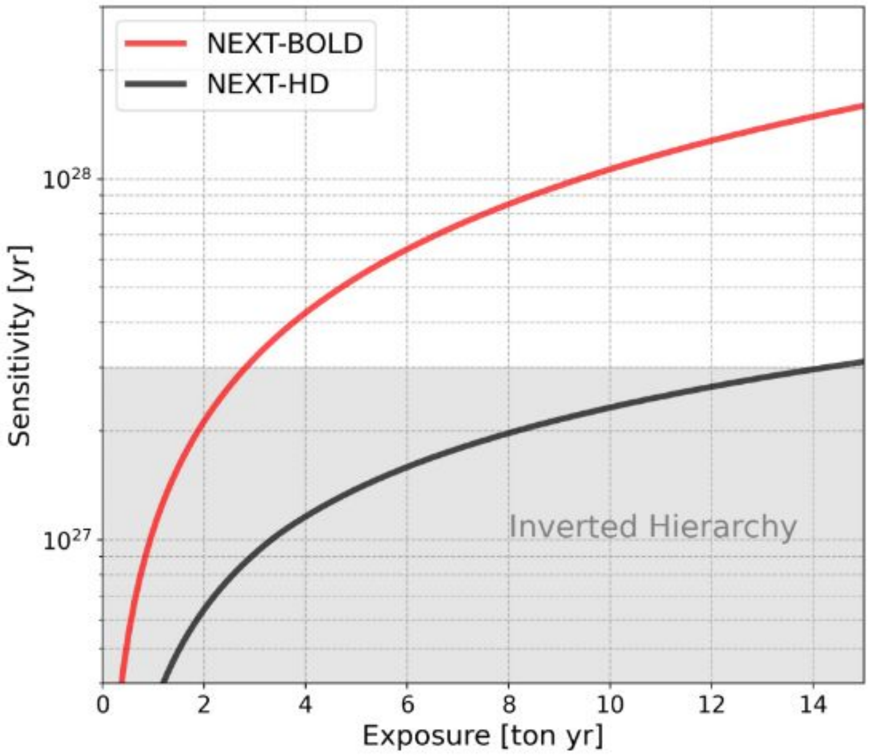




Realization of efficient, scalable barium tagging in high pressure xenon gas could enable truly a background-free tonne-scale technology.

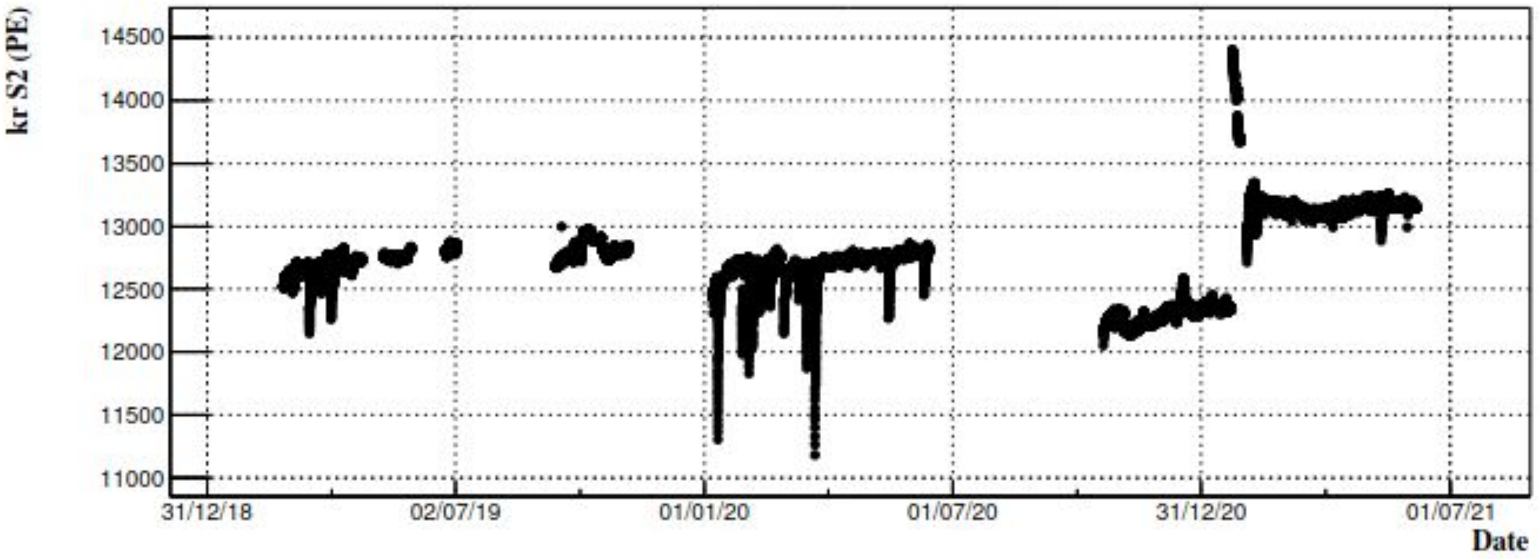
next

NEXT-tonne sensitivity



S2 light readout stability

- Data from ^{83m}Kr decays
- Complex dependence on pressure, temperature and electric stability of the EL region



S1 light readout stability

- Data from ^{83m}Kr decays
-