THE NEXT EXPERIMENT FOR NEUTRINOLESS DOUBLE BETA DECAY SEARCHES

LATEST RESULTS

B. PALMEIRO (IFIC) ON BEHALF OF THE NEXT COLLABORATION
The NEXT collaboration

Ikerbasque • DIPC • Girona • UAM • IFIC • Santiago • UPV • Zaragoza
Iowa State • ANL • UTA • FNAL • PNNL • LBNL • Harvard • Texas A&M
Aveiro • Coimbra LIBPhys • Coimbra LIP • A. Nariño • BGU

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Funded by:
What is NEXT?
The NEXT program

- **Prototypes (~1 kg)**
  - [2009 - 2014]
  - Two neutrino double beta decay searches
  - Background model assessment

- **NEXT-White (~5 kg)**
  - [2015 - 2019]
  - Demonstration of detector concept

- **NEXT-100 (~100 kg)**
  - [2019 - 2020’s]
  - Neutrinoless double beta decay searches

- **NEXT-tonne (~1000 kg)**
  - [future generation]
The NEXT program

- Prototypes (~1 kg) [2009 - 2014]
  - Two neutrino double beta decay searches
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- NEXT-tonne (~1000 kg) [future generation]
NEXT-White (NEXT-10)

**Location:** LSC (Spain)  
**Status:** Running  
**Mass:** ~5 kg  
**Goals:**
- Demonstrate technology is robust.  
- Measure backgrounds to establish a reliable background model (and to improve it as needed).  
- Demonstrate energy resolution and topological signature in a large-scale detector.
### LATEST RESULTS FROM THE NEXT EXPERIMENT

#### NEXT-White data taking

<table>
<thead>
<tr>
<th>Run</th>
<th>Time</th>
<th>Goals</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>~03-11/2017</td>
<td>Depleted Xe</td>
<td>- No Radon abatement system&lt;br&gt;- No inner lead castle</td>
</tr>
<tr>
<td>IVa</td>
<td>~08/2018 (41 days)</td>
<td>Calibration</td>
<td>- Radiopurity improved&lt;br&gt;- No Radon abatement system&lt;br&gt;- No inner lead castle</td>
</tr>
<tr>
<td>IVb</td>
<td>~10/2018 (27 days)</td>
<td>Calibration and Background characterization</td>
<td>- Radon abatement system ON&lt;br&gt;- No inner lead castle</td>
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<tr>
<td>IVc</td>
<td>~11/2018 (40 days)</td>
<td>Enriched $^{136}$Xe</td>
<td>- Radon abatement system ON&lt;br&gt;- Inner lead castle</td>
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<tr>
<td>V</td>
<td>02/2019 (ongoing)</td>
<td>Double beta measurement</td>
<td>- Radon abatement system ON&lt;br&gt;- Inner lead castle</td>
</tr>
</tbody>
</table>
LATEST RESULTS FROM THE NEXT EXPERIMENT

Calibration of the NEXT-White detector using $^{83m}$Kr decays

Electron lifetime $\tau = (2049 \pm 44)$ $\mu$s

Raw spectrum

\[ \mu = 9395.0 \text{ pes} \]
\[ \sigma = 1174.1 \text{ pes} \]

Corrected spectrum

\[ \mu = (41.4707 \pm 0.0022) \text{ keV} \]
\[ \sigma = (0.6713 \pm 0.0024) \text{ keV} \]

R = (3.812±0.013) %FWHM
R_{GSS} = (0.4952±0.0017) %FWHM

Geometrical corrections
LATEST RESULTS FROM THE NEXT EXPERIMENT

Energy calibration of the NEXT-White detector with 1% resolution near $Q_{\beta\beta}$ of $^{136}$Xe

ARXIV:1905.13110

Raw spectrum

Corrected spectrum

$^{137}$Cs photopeak

$^{208}$Tl $e^+e^-$ double-escape

$^{208}$Tl photopeak
LATEST RESULTS FROM THE NEXT EXPERIMENT

Energy calibration of the NEXT-White detector with 1% resolution near $Q_{\beta\beta}$ of $^{136}$Xe

$^{208}$Tl: 1592 KeV

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

$^{208}$Tl: 2615 KeV

- $\mu = 2611.96 \pm 0.61$
- $\sigma = 11.06 \pm 0.67$
- $R (\%) = 1.00 \pm 0.06$
- $\chi^2/N_{dof} = 1.04$

Resolution is shown to be 1%FWHM @ $Q_{\beta\beta}$ matching NEXT expectations

Resolution vs. $1/\sqrt{E}$

$R = 15.98/\sqrt{E} + 0.58$

Measured energy peaks

ARXIV:1905.13110
Track reconstruction

Single-electron like

ββ-like electrons
LATEST RESULTS FROM THE NEXT EXPERIMENT

Efficiency of the topological signature in the NEXT-White detector

Signal efficiency signal-like events $71.3 \pm 1.5\%$ for a background acceptance of $20.3 \pm 0.4\%$ at Tl double escape peak (data).

Signal efficiency of $71.9 \pm 0.1 \text{ (stat.)}\%$, for a background acceptance of $13.2 \pm 1.1 \text{ (stat.)}\%$ at $Q_{BB} \text{ (MC)}$

Double escape peak events (signal-like) show a good performance of the topological reconstruction and blob characterization.
NEXT backgrounds

- **Radon:**
  - **Airborn:** radon gas in the air surrounding the detector.
  - **Internal:** emanation from the components inside the gas system external to the detector vessel or the inner detector components.

- **Radiogenic:** Inner materials are contaminated with different radioactive isotopes. Mainly $^{208}$Tl and $^{214}$Bi for $\beta\beta^0\nu$ searches and also $^{40}$K, $^{60}$Co for $\beta\beta^2\nu$ ones.

- **Cosmogenic:** Backgrounds induced by cosmic rays and their by-products.
LATEST RESULTS FROM THE NEXT EXPERIMENT

Measurement of radon-induced backgrounds in the NEXT double beta decay experiment

Internal radon has been characterized and measured. It is shown to be negligible for NEXT-100.
Measurement of radon-induced backgrounds in the NEXT double beta decay experiment

Backgrounds induced by airborne radon are eliminated by providing Rn-free air to the NEXT shielding structure surrounding the vessel.
Radiogenic backgrounds in the NEXT double beta decay experiment

The fit takes into account the 4 isotopes and 3 regions. It describes the data reasonably well in energy and $z$ showing that NEXT can also provide certain sensitivity to background origins!
Radiogenic backgrounds in the NEXT double beta decay experiment

The consistency between the rates in data and MC ensures the validity of the background model also after the topological selection. The overall background rejection factor, with respect to the fiducial sample, is found to be about 3.4 for $E > 1000$ keV and $16.8 \pm 2.2$ in a broad 200 keV region around $Q_{\beta\beta}$. 

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According to these results, a \((3.5 \pm 0.6)\sigma\) measurement of the \(2\nu\beta\beta\) half-life can be achieved in NEXT-White after 1 year with enriched xenon, applying topological cuts. The sensitivity deteriorates significantly if only fiducial cuts are applied.
The NEXT program

Prototypes (~1 kg) [2009 - 2014]

Two neutrino double beta decay searches
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NEXT-White (~5 kg) [2015 - 2019]

Demonstration of detector concept

NEXT-100 (~100 kg) [2019 - 2020’s]

NEXT-tonne (~1000 kg) [future generation]

Neutrinoless double beta decay searches
NEXT100

- Time Projection Chamber: 100 kg active region, 130 cm drift length
- Pressure vessel: stainless steel, 15 bar max pressure
- Energy plane: 60 PMTs, 30% coverage
- Tracking plane: 7,000 SiPMs, 1 cm pitch?
- Outer shield: lead, 20 cm thick
- Inner shield: copper, 12 cm thick

- Scales up NEXT-White by roughly 2:1 in dimensions.
Expected background rate:

- $4 \times 10^{-4}$ counts/(keV·kg·y)

Expected background:

- 1 event per year in ROI

Dominant source: PMTs
NEXT new ideas: Ba tagging

Single ion detectability has been demonstrated!

This can imply a background-free experiment!
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Two approaches developed in parallel:

- Phase 1, High Definition: incremental approach, using/improving existing technology.
- Phase 2, Barium Tagging: based on disruptive new concept (SMFI Ba\(^{++}\) tagging).

Phased approach:

- ~1 ton of 136Xe introduced per phase.
- Ultra pure materials.
- SiPMs as the only sensor
Future plans

- Physics campaign with NEXT-White: \( \beta \beta 2\nu \) measurement (ongoing) and \( \beta \beta 0\nu \) limits.
- NEXT-Ton studies under development.
- Ongoing R&D for NEXT upgrades: barium tagging for HPXe-TPC, gas mixtures (w/ molecular additives, helium), gas cooling, sensor plane upgrades...

Summary

- Late results from NEXT-White demonstrate the performance of the detector technology and sufficiently low background levels for NEXT-White and NEXT-100.
- NEXT is a recent competitor, but a promising one due to its great energy resolution, topological discrimination and potential Ba tagging capabilities.
New data is yet to come and next generation is knocking at the door

Stay turned!
Thanks!
Other 2018 and 2019 publications

- The Next White (NEW) Detector (arXiv:1804.02409)
- Initial results on energy resolution with the NEXT-White detector (JINST 13 (2018) no.10, P10020)
- Electroluminescence TPCs at the Thermal Diffusion Limit (arXiv:1806.05891)
- High Voltage Insulation and Gas Absorption of Polymers in High Pressure Argon and Xenon Gases (JINST 13 (2018) no.10, P10002)
- Electron drift properties in high pressure gaseous xenon (JINST 13 (2018) no.07, P07013)
• Electrons from the decay are emitted (yelling scintillation light, S1).
• These primary electrons lose energy while emitting secondary electrons until they are absorbed.
• Secondary electrons are drift by the electric field until the anode.
• When electrons reach the gate, they are highly accelerated by a stronger electric field and the gas is excited, generating electroluminescence light. Part of the light is recorded by PMTs (energy information) and some other is recorded by SiPM (tracking information).
Low-energy calibration of the NEXT-White detector

- $^{83}\text{Rb}$ decays 75% of the time to a metastable state of $^{83}\text{Kr}$ through internal conversion with a lifetime of 86 days.
- The metastable state decays to ground with a lifetime of 1.83 h emitting two conversion electrons of 32.1 and 9.4 keV.
- These low energy electrons create a very short signal, useful for calibration.
Low-energy calibration of the NEXT-White detector

**Objective:**
- Obtain a fine description of the detector response to account for the signal losses.
- Optimize energy resolution

**How:**
- $^{83}\text{Kr}^m$ decays
  - Uniform XYZ distribution
  - Monoenergetic (41.5 keV) pointlike events

**When:**
- Data taken with the detector from March to November 2017
NEXT-ton (~2025)

Phase 1:
- Improves topological signature, improves energy resolution
- Reduces radioactive budget (no PMTs)
- Energy plane made of large area SiPMs (design similar to that of Dark Side)
- Potential to reduce SiPM dark count by cooling detector
- $2.6 \times 10^{-6}$ cts / keV·kg·year total background rate

Phase 2:
- Tracking and energy measured in anode
- Cathode implements Barium Tagging System
- Virtually background free
LATEST RESULTS FROM THE NEXT EXPERIMENT

Event in the energy window
Life isn’t that easy. We found that the electron lifetime depends on the transverse position of the event. And it changes!
Light collection efficiency

The amount of light detected depends on the transverse position of the event. The simulations predict a smooth response with a steep drop at large R.
NEXT Background

<table>
<thead>
<tr>
<th>Part</th>
<th>40K</th>
<th>60Co</th>
<th>208Ti</th>
<th>214Bi</th>
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</thead>
<tbody>
<tr>
<td>ANODE_QUARTZ</td>
<td>4.26E-3</td>
<td>1.03E+0</td>
<td>38</td>
<td>3.935E-2</td>
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<tr>
<td>BUFFER_TUBE</td>
<td>1.04E-3</td>
<td>1.38E+1</td>
<td>124</td>
<td>1.782E-2</td>
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<tr>
<td>CARRIER_PLATE</td>
<td>1.68E-4</td>
<td>1.33E+1</td>
<td>19</td>
<td>2.663E-3</td>
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<tr>
<td>DB_PLUG</td>
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<td>9.52E+1</td>
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<td>6.00E-5</td>
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<td>DICE_BOARD</td>
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<td>1.554E-2</td>
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<td>PEDESTAL</td>
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<td>PMT_BASE</td>
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<td>SHIELDING_LEAD</td>
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<td>SHIELDING_STRUCT</td>
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<td>3.445E-6</td>
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<td>SUPPORT_PLATE</td>
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<td>VESSEL</td>
<td>3.10E-5</td>
<td>1.03E+2</td>
<td>28</td>
<td>4.620E-4</td>
</tr>
</tbody>
</table>
LATEST RESULTS FROM THE NEXT EXPERIMENT

Expected number of events

\[ E / Q_{\beta\beta} \]

- Background
- 1% FWHM
- 4% FWHM
- 10% FWHM