The NEXT Neutrinoless double beta decay experiment

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The experiment Rubik’s cube

radio-purity

scalability (mass, cost)

control of background

Resolution

Volume/Surface

extra handles
Why NEXT? — Advantages of HPXe technology

\[ T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{M t}{\Delta E \cdot B}} \]

**Cost**

Xenon is the cheapest and easiest to enrich of all $\beta\beta$ isotopes. No long lived radioactive isotopes. There is already 1 ton of enriched xenon in the World.

**Scalability**

Xenon is a noble gas suitable to build a TPC. No dead areas, S/N improves with L.

**$\Delta E$**

HPXe TPC is the only xenon detector that provides good energy resolution (better 1% FWHM at Qbb).

**Background**

HPXe TPC is the only xenon detector that provides topological signal.
Scalability

Economy of scale: Double L, signal increases 8 (L^3), background increases 4 (L^2), S/N improves by a factor 2
Energy resolution makes a difference

**Signal and background:**
- Signal: mv ~200 meV and an exposure of 5 ton year.
- Background 1 count/keV/ton/year.
Topological background reduction

- In xenon gas at 15 bar, a $\beta\beta$ event is a twisted track, 10 cm long, with two energy blobs at the two ends and no additional floating clusters.
- Instead the backgrounds are single electrons, accompanied 85% of the time by X-rays (Xenon de-excitation).
- HPXe TPC offers a signal that looks like a signal: two identified electrons with an energy within 10 keV of $Q_{\beta\beta}$.
Topological background reduction

*a MC simulated β0ν event*

![Image of a MC simulated β0ν event]

![Image of a MC simulated β0ν event with a legend specifying coordinates]

![Image of a MC simulated β0ν event with a legend specifying a 35 keV X-ray]

![Image of a MC simulated β0ν event with a legend specifying only one blob]

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**bb0nu - Blob1 & Blob2 Energy Histogram**

- **Blob1 Energy**
  - Mean: 0.1866
  - RMS: 0.01273

- **Blob2 Energy**
  - Mean: 0.1505
  - RMS: 0.01309

**Tl208 - Blob1 vs Blob2 Energy Histogram**

- **Blob1 Energy**
  - Mean: 0.524
  - RMS: 0.17816

- **Blob2 Energy**
  - Mean: 0.1866
  - RMS: 0.1101

**Bi214 - Blob1 vs Blob2 Energy Histogram**

- **Blob1 Energy**
  - Mean: 0.1101
  - RMS: 0.1611

- **Blob2 Energy**
  - Mean: 0.1737
  - RMS: 0.1611

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**X (MM)**

**Y (MM)**

**ONLY ONE BLOB**

**Xe 35 keV X-RAY**

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**Entries/bin**

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**Mean**

**RMS**

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**Track Length Histogram**

- **Track Length (mm)**
  - Mean: 107.8
  - RMS: 38.81

- **Entries**
  - 146,300

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**Event Energy Histogram**

- **Event Energy**
  - Mean: 2.431
  - RMS: 0.01273

- **Entries**
  - 18,000

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**Figure 36.**

Shows the number of time slices (hereafter simply as “slices”) in the y (mm) coordinate: a each slice represents an ordered time frame in the z coordinate: a
NEXT: A light TPC

- It is a High Pressure Xenon (HPXe) TPC operating in EL mode.
- It is filled with 100 kg of Xenon enriched at 90% in Xe-136 (in stock) at a pressure of 15 bar.
- The event energy is integrated by a plane of radiopure PMTs located behind a transparent cathode (energy plane), which also provide t0.
- The event topology is reconstructed by a plane of radiopure silicon pixels (MPPCs) (tracking plane).

EL mode is essential to get lineal gain, therefore avoiding avalanche fluctuations and fully exploiting the excellent Fano factor in gas.
NEXT R&D: detector performance achievements

- 1.8% FWHM energy resolution for 511 keV electrons over large fiducial volume
- Extrapolates to 0.75% FWHM at $Q_{\beta\beta}$ energy of 136Xe decay
- The DBDM prototype at LBNL extrapolates to 0.5% FWHM at $Q_{\beta\beta}$ using 660 Cs-137 electrons

![Energy Spectrum Graph]

[511 keV gammas in NEXT-DEMO (NEXT Coll., JINST 8 (2013) P09011)]

![S2 Charge Spectrum Graph]
The beauty of resolution

662 keV, ionization signal only

1.04% FWHM
Topography of the signal in \( \text{next} \)

- Higher energy deposition clearly visible at electron track end-point.
- Tracks reconstructed using SiPMs + PMTs

**Figure 13.** Examples of \( \text{Na}^{22} \) (top left) \( \text{Cs}^{137} \) (top right) and muon (bottom) track projections, \( \text{xy} \) plane projections, tracks reconstructed from NEXT.DEMO data, a large fiducial volume. The most important factors affecting the energy resolution of the NEXT.DEMO detector are geometrical inhomogeneities in response and any time variation of the detector gain.\(^6\)

6.1 Charge time dependence

As described in section \( \text{section} \), the calibration constants of the photodetectors were constantly monitored over the course of data taking so that any variation could be taken into account. Additionally, the temperature and pressure in the TPC have been monitored allowing for the study of the correlation between these physical factors and the detector response. A correlation between the measured pressure and charge is observed in the data as can be seen in figure (bottom left panel). The temperature of the vessel has a significantly smaller effect on the PMT charge. Both temperature and pressure oscillate at the level of \( \sim\)– every (– minutes due to the cycle of the hot getter which purified the gas and by up to (– due to air conditioning and activity in the laboratory over a timescale of (– hours. Other possible sources of time dependent variation are the occurrence of sparks in the TPC and variation of the gas purity. The increased light yield due to the TPB-coated tracking plane (see section \( \text{section} \) enabled the use of lower EL fields compared to previous analyses and improved gas...
**NEW (NEXT-WHITE) at glance**

- **Time Projection Chamber:**
  - 10 kg active region, 50 cm drift length

- **Pressure vessel:**
  - 316-Ti steel, 30 bar max pressure

- **Inner shield:**
  - Copper, 6 cm thick

- **Tracking plane:**
  - 1,800 SiPMs, 1 cm pitch

- **Energy plane:**
  - 12 PMTs, 30% coverage
Goals of NEW

• Measure the expected backgrounds from the different isotopes, but specially Bi-214 and Tl-208.
• Validate NEXT background model using measurement.
• Identify any unexpected source of background (correct if needed).
• Observe $\beta\beta^{2v}$ signal.
• Demonstrate energy resolution: our goal is to reach 0.5 % FWHM in the large detector.
• Demonstrate topological signature from data ($\beta\beta^{2v}$ and Tl-208 double escape peak).
• Certify technology and underground operation with enriched xenon.
NEXT 100 kg detector at LSC: main features

- **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
NEXT at LSC

Infrastructures: platform, lead castle, gas system, emergency recovery system, completed. First phase of experiment starts in 2015. In stock, 100 kg of enriched xenon and 100 kg of depleted xenon.
NEXT 100 kg radioactive budget

**Kapton Dice boards**
- Kapton and copper; 107 units
- Activity Ti-208: —0.040 mBq/unit
- Activity Bi-214: —0.030 mBq/unit

**PMTs**
- Hamamatsu R11410-10; 60 units
- Activity Ti-208: —0.140 mBq/unit
- Activity Bi-214: —0.500 mBq/unit

**Sensors:**
Activity level ~3 mBq per plane. Actual measurements. Not shielded.
NEXT 100 kg radioactive budget

**Vessel**
- Stainless steel 316Ti; 1121 kg
- Activity Tl-208: <0.150 mBq/kg
- Activity Bi-214: <0.460 mBq/kg

**Shielding**
- Lead; 13000 kg
- Activity Tl-208: <0.031 mBq/kg
- Activity Bi-214: <0.35 mBq/kg

Lead Castle and Pressure Vessel:
Activity shielded by ICS. Uncertainty related to upper limits has moderate impact in radioactive budget due to ICS suppression. (lead limits updated after GDMS measurement, March 1st)
NEXT 100 kg radioactive budget

ICS, and support plates
- Copper (CuA1); ~9500 kg
- Activity Tl-208: <0.001 mBq/kg
- Activity Bi-214: <0.012 mBq/kg

Copper
Electroformed commercial copper. Current measurements show our stock to be very radio pure, but only limits so far.

Residual radioactivity of ICS partially shielded (self-shielding)
NEXT100 rejection of backgrounds

A transparent target, away from surfaces

- Veto of effectively all charged backgrounds entering the detector (left). High-energy gammas have a long interaction length (>3 m) in HPXe.
The 2-electron signature

- Interaction of high-energy gammas (from TI-208 and Bi-214) in the HPXe can generate electron tracks with energies around the Q value of Xe-136. However, electron often accompanied of satellite clusters and single blob deposit
NEXT100 rejection of backgrounds

The 2-electron analysis

- Effect of the filters (cuts) defining an event with 2 electrons and energy in a ROI of $2\sigma$ around $Q_{\beta\beta}$.
- Efficiency for signal $\sim$35% for suppression factors $4-8 \times 10^{-7}$
- Topology rejection is the product of 1 track x 2 blobs conditions

<table>
<thead>
<tr>
<th></th>
<th>$0\nu\beta\beta$</th>
<th>TI-208</th>
<th>Bi-214</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiducial E&gt;2 MeV</td>
<td>67.86%</td>
<td>0.25%</td>
<td>0.01%</td>
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<tr>
<td>ROI</td>
<td>95.52%</td>
<td>8.99%</td>
<td>64.66%</td>
</tr>
<tr>
<td>1 track</td>
<td>74.60%</td>
<td>1.86%</td>
<td>12.54%</td>
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<tr>
<td>2 blobs</td>
<td>73.76%</td>
<td>9.60%</td>
<td>9.89%</td>
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</table>
## NEXT 100 expected background

<table>
<thead>
<tr>
<th></th>
<th>Activity (Bq)</th>
<th>Rejection Factors</th>
<th>Final rate (ckky)</th>
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<tbody>
<tr>
<td></td>
<td><em>Ti-208</em></td>
<td><em>Bi-214</em></td>
<td><em>Ti-208</em></td>
</tr>
<tr>
<td>Dice Boards</td>
<td>4,28E-03</td>
<td>3,21E-03</td>
<td>7,90E-07</td>
</tr>
<tr>
<td>PMTs</td>
<td>8,40E-03</td>
<td>3,00E-02</td>
<td>3,30E-07</td>
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<tr>
<td>Field Cage</td>
<td>4,38E-03</td>
<td>1,53E-02</td>
<td>5,30E-07</td>
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<td>ICS</td>
<td>1,326E-02</td>
<td>1,105E-01</td>
<td>1,100E-07</td>
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<td>Vessel</td>
<td>1,66E-01</td>
<td>5,16E-01</td>
<td>1,10E-08</td>
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<tr>
<td>Shielding Lead</td>
<td>6,266E-01</td>
<td>1,084E+00</td>
<td>2,000E-09</td>
</tr>
<tr>
<td>SUBTOTAL</td>
<td>8,23E-01</td>
<td>1,76E+00</td>
<td></td>
</tr>
<tr>
<td>TOTAL BKGND</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
• Reach $m_{\nu} < 100$ meV.
• Thus, NEXT has a chance of making a discovery or seeing a hint.

Inverted

Normal

$\sum_{i=1}^{3} m_i = 0.32 \pm 0.11$

$\Sigma m_\nu (\text{meV})$

$m_{\beta\beta} (\text{meV})$
1 kg

10 kg

100 kg

1 ton

R&D (2008-2013)

ββ2ν (2014-2016)

ββ0ν (100 meV) (2016-2020?)

ββ0ν (20 meV) (2020?)
What is NEXT-1ton

• It is a symmetric TPC filled with O(1 ton) of Xenon enriched at 90% in Xe-136 at a pressure of 15 bar
  • The drift length is 2 x 2 m (2 ms drift, DEMO measures lifetimes of > 10 ms)
  • The TPC radius is about 1 m.
  • The active volume is about 12 m$^3$ (1 ton at 15 bar)
  • The event energy is integrated by wavelength shifting light guides surrounding the gas and read by PMTs located outside the fiducial volume.
  • The event topology is reconstructed by two planes of radiopure silicon pixels (MPPCs by default).
Prospects

• Overall an HPXe detector may be the ultimate detector to discover the Majorana nature of the neutrino.
The NEXT Collaboration

Neutrino Experiment with a Xenon TPC