Status of the NEXT project

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ON BEHALF OF THE NEXT COLLABORATION

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12-14 December 2018, Paris
$\beta\beta_{2\nu}$ vs. $\beta\beta_{0\nu}$

Counts

Total electron kinetic energy $Q_{\beta\beta}$

$\beta\beta_{2\nu}$

$T_{1/2} \sim 10^{19} - 10^{21}$ y

$\beta\beta_{0\nu}$

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

→ Need heroic background suppression at $Q_{\beta\beta}$
NEXT Neutrino Experiment with Xenon TPC

• Search for $\beta\beta 0\nu$ in $^{136}$Xe in a high pressure xenon gas time projection chamber (TPC)

• Working in gas allows:
  ◦ Excellent energy resolution (aiming at ~0.5% FWHM at $Q_{\beta\beta}=2.458$ MeV)
  ◦ Track topology enables discriminating $\gamma$-induced electrons from $\beta\beta$ events

• High pressure (10-15 bar) required to assemble enough mass in a reasonable volume

• Currently operating NEXT-White (~10 kg of depleted Xe), moving to NEXT-100 (100 kg of Xe enriched to 91% $^{136}$Xe)

• Radiopure detector, running at Canfranc Underground Laboratory
NEXT Concept

S1 (PMTs) gives $t_0$

S2 magnitude by proportional EL (PMTs) gives the event energy

S2 time-slice images (SiPMs) give the event topology

$E_{drift} \sim 0.4 \text{ kV/cm}$

$E_{EL} \sim 15 \text{ kV/cm}$
Energy resolution in Xe gas

The energy resolution, FWHM, is shown for $^{137}$Cs 662 keV $\gamma$-rays, as a function of xenon density, for the ionization signal only.

A. Bolotnikov, B. Ramsey, Nucl. Instr. and Meth. A 396 (1997) 360
Topological signature

Bragg peak – ‘blob’ of dense ionization at the end of electron track
Blob-based background rejection

Running prototype: NEXT-White (NEW) \(~10\) kg Xe

F. Monrabal et al. (NEXT collaboration), arXiv:1804.02409
Running prototype: NEXT-White (NEW) - 10 kg Xe
Online 3D calibration maps with $^{83}$mKr: point-like 41.5 keV events throughout TPC volume

Geometrical S2 map

Electron lifetime map

Average 3.7 ms, ~7.5 times larger than max drift time

NEW: Calibration with “high-energy” sources
$^{137}$Cs 662 keV
Extrapolates $(1/\sqrt{E})$ to 0.61% FWHM at $Q_{\beta\beta}$

$^{208}$Tl 1593 keV $e^+e^-$ escape peak
Extrapolates to 0.68% FWHM at $Q_{\beta\beta}$

$^{208}$Tl 2615 keV full absorption peak
Extrapolates to 0.85% FWHM at $Q_{\beta\beta}$

Track topology in NEW

Beta emission from the cathode

Signal/background discrimination using blobs

$^{208}$TI escape peak events: MC and data
NEW: low-background run

![Graph showing rate of activity over time with labels for Radon-free air and Inner lead castle.]

Graph: Rate (Hz) vs. Date
- Radon-free air
- Inner lead castle

Date: 29/07/18 to 26/11/18

December 12, 2018
NEW: low-background run

Data vs. expectation from nominal background model: overall rate ~2-fold larger than expected

Sources for discrepancy: lead castle paint and Rn-induced $^{214}$Bi on cathode
Discrepancy will go down when analyzing Run IVc

Expectation from best-fit to data with isotope-specific scaling
NEXT NEW step: enriched Xe for $\beta\beta_{2\nu}$

RGA spectrum confirms Xe enriched to 90% $^{136}\text{Xe}$...

**Enriched Xe run in January 2019**
NEXT-100 (construction in late 2019)

- **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:**
  - ~3,500 SiPMs, 15mm pitch

- **Outer shield:**
  - Lead, 20 cm thick

- **Inner shield:**
  - Copper, 12 cm thick
NEXT-100 expected sensitivity

Background: $4 \cdot 10^{-4}$ counts/keV/kg/yr
($\sim 0.5$-1 counts/100 kg/yr for 0.5-1% FWHM)

Dashed lines: largest and smallest estimations for the nuclear matrix elements

Similar sensitivity as KamLand-ZEN after $\sim 4$ years (remember NEXT-100 is a demonstrator for a ton-scale detector)

NEXT on the ton-scale: Exploring the Inverted Hierarchy

• Plot shows the sensitivity of a 100% efficient xenon experiment (with a reasonable NME set and $g_A = 1.27$)

• With a background $\sim 10$ counts/ton/year and a mass of 1 ton, 10 years of run are required (e.g., $\sim 30$ years for an efficiency of 30%).

• With a background count of $\sim 1$ counts/ton/year, only 2 years are required (6 years for an efficiency of 30%).

Barium Tagging: towards “background free” experiment

Drastic reduction in gamma-induced background achievable by identifying the $^{136}\text{Ba}$ daughter

Basic idea – single molecule fluorescence imaging (SMFI)

- coat cathode with chelating molecules selective for barium ions (but not Xe).
- The molecules are non fluorescent in isolation and become fluorescent upon chelation.
- Interrogate cathode surface with a laser: a single molecule holding Ba fluoresces at a longer wavelength and is readily identified.

A. D. McDonald et al. (NEXT Collaboration), PRL 120, 132504 (2018)

See talk by Ben Jones!
While barium tagging is being cooked, additional strategies must be developed to reduce background.

Two main problems to tackle:

- Electron diffusion smears out track features
- PMTs at the energy plane still contribute radioactive background

The collaboration will investigate operation with xenon-helium mixtures at cryogenic temperatures with high-resolution tracking:

- Transverse electron diffusion in Xe-He is 5-fold smaller than in Xe, with no degradation of energy resolution
- Low temperature operation will enable replacing PMTs with radiopure SiPMs for $t_0$ and energy measurement (impossible at room temperature because of SiPM DCR)
Electron diffusion in pure Xe: from “spaghetti with meatballs” to “sea cucumber”

Diffusion driven by elastic collisions with heavy xenon atoms
Electron diffusion in pure Xe-He (80/20)

Original track

1 m diffusion in Xe-He (80/20)

Diffusion dominated by elastic collisions with the much lighter He atoms

Summary and outlook

The high-pressure Xe TPC has unique advantages, making it a leading candidate for the ton-scale $0\nu\beta\beta$ search era.

NEXT-White demonstrated superb energy resolution and effective track reconstruction on the 10-kg scale. Background is low and well understood.

NEXT-100 will demonstrate the technology on the 100-kg scale, providing competitive limits within a few years.

The NEXT collaboration pursues promising directions for major background reduction, critical for the ton-scale detector: Ba tagging + topology improvement + higher radiopurity.
Backup slides
Largest source of uncertainty: the size of axial coupling $g_A$

$g_A = 1.269$ for weak interaction and decays of nucleons

Quenching effects inside the nucleus *may* considerably reduce $g_A$

**Conservatively** one should consider several options:

$$g_A = \begin{cases} 
  g_{\text{nucleon}} = 1.269 \\
  g_{\text{quark}} = 1 \\
  g_{\text{phen.}} = g_{\text{nucleon}} \cdot A^{-0.18}
\end{cases}$$

The degree of $g_A$ quenching is unknown. The expression for $g_{\text{phen.}}$ is based on $2\nu\beta\beta$ half-lives and may be different for $0\nu\beta\beta$
Effect of uncertainty in $g_A$

For $^{136}$Xe taking $g_A = g_{phen}$ pushes up the limit on $m_{\beta\beta}$ by a factor of $\gtrsim 5$