A Search for the Neutrinoless Double Beta Decay of Xenon-136 with Improved Sensitivity from Waveform Denoising

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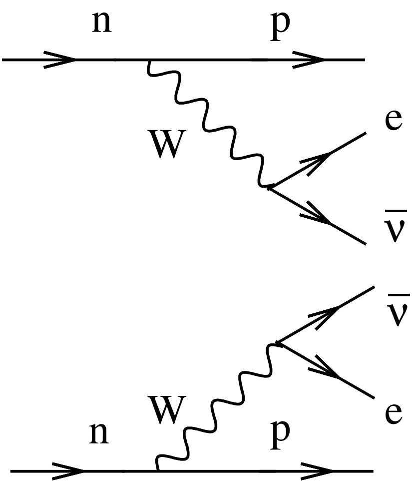
Outline

$\beta\beta 2\nu$ and $\beta\beta 0\nu$ Decay

The EXO-200 Detector

What is Double-Beta Decay?

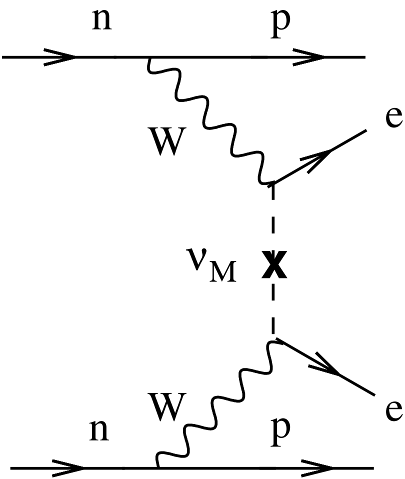


Avignone et al., RMP 2008.

Feynman diagram for $\beta\beta 2\nu$ decay. Equivalent to two single-β decays:

$$2n \to 2p + 2e^- + 2\bar{\nu}_e$$

What is Double-Beta Decay?



Avignone et al., RMP 2008.

Feynman diagram for $\beta\beta2\nu$ decay. Equivalent to two single-β decays:

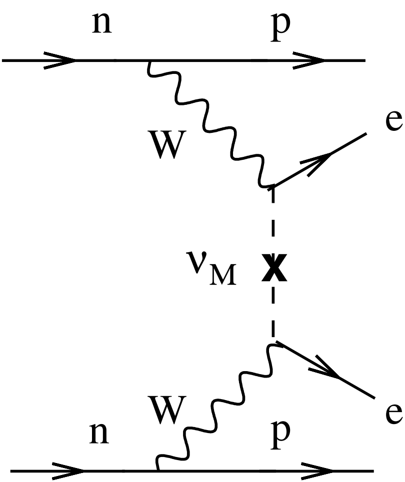
$$2n \to 2p + 2e^- + 2\bar{\nu}_e$$

Feynman diagram for $\beta\beta0\nu$ decay. Neutrinos annihilate each other:

$$2n \to 2p + 2e^-$$

$\beta\beta2\nu$ is allowed in the Standard Model; $\beta\beta0\nu$ is not.

Implications of Double-Beta Decay



Avignone et al., RMP 2008.

- Lepton number changes:

$$\Delta L = +2$$

- Neutrinos can convert to their own antiparticle:

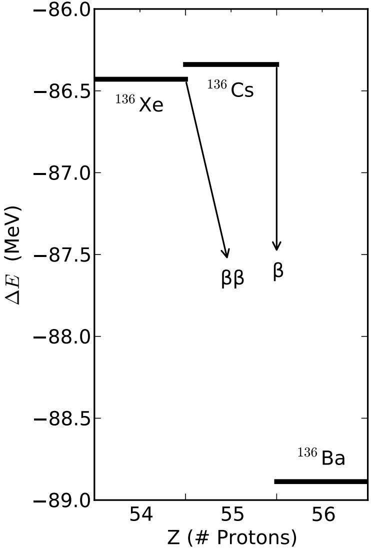
$$\bar{\nu}_R \to \nu_L$$

- Neutrinos have mass through a Majorana interaction:

$$-\frac{m_L}{2}\left(\overline{\Psi^c_L}\Psi_L + \overline{\Psi_L}\Psi^c_L\right)$$

$$-\frac{m_R}{2}\left(\overline{\Psi^c_R}\Psi_R + \overline{\Psi_R}\Psi^c_R\right)$$

The $A = 136$ Isobar



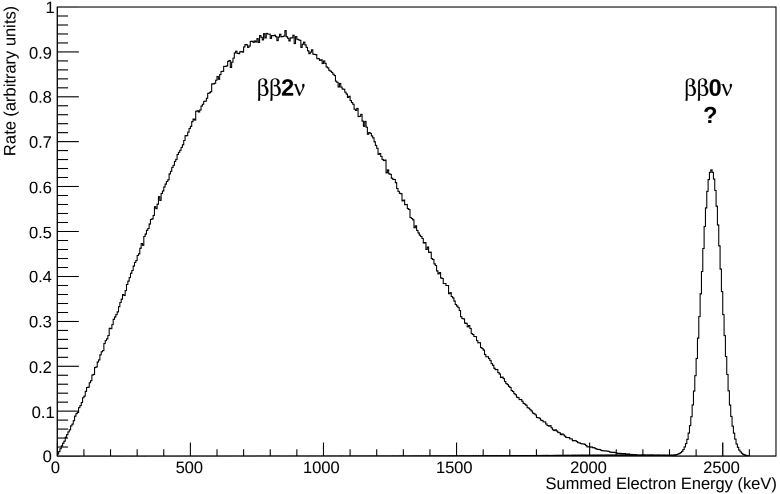
^{136}Cs undergoes single-β decay.

^{136}Xe cannot, due to energy conservation – but it can $\beta\beta$ decay through ^{136}Cs to ^{136}Ba.

The Q-value of $^{136}\text{Xe} \rightarrow ^{136}\text{Ba}$ is 2457.83 ± 0.37 keV, shared between all final products of the decay.

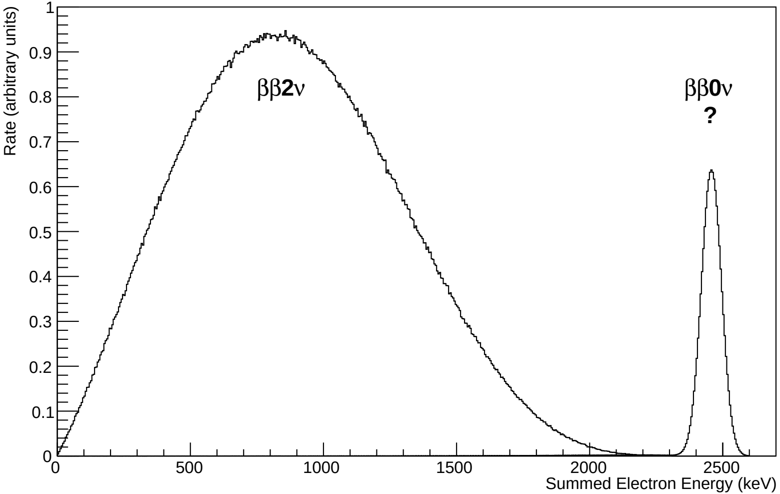
We observe energy in electrons; energy in neutrinos is lost.

Ideal Double-Beta Energy Spectrum



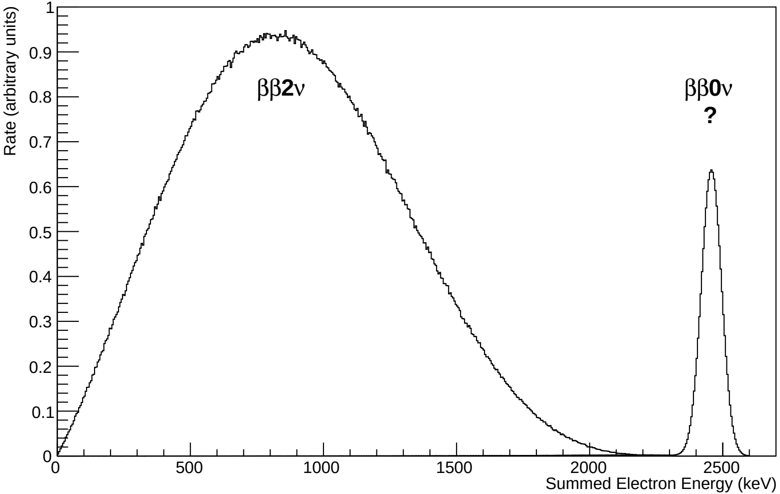
^{136}Xe $\beta\beta2\nu$ produces a smooth energy spectrum; "missing" energy carried off by neutrinos.

Ideal Double-Beta Energy Spectrum



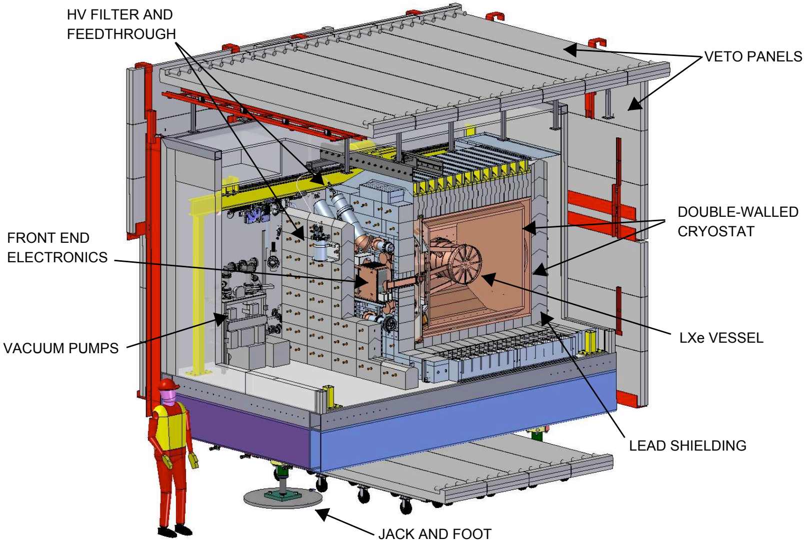
^{136}Xe $\beta\beta0\nu$ has no neutrinos, so no "missing" energy; mono-energetic peak at $Q = 2458$ keV.

Ideal Double-Beta Energy Spectrum

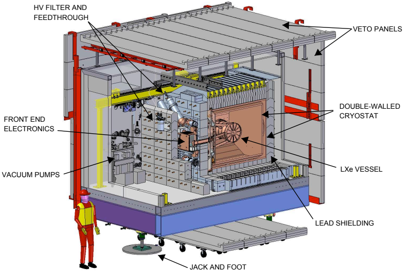


If the $\beta\beta0\nu$ peak exists, neutrinos have Majorana mass; peak height gives a measurement of that mass.

The EXO-200 Detector

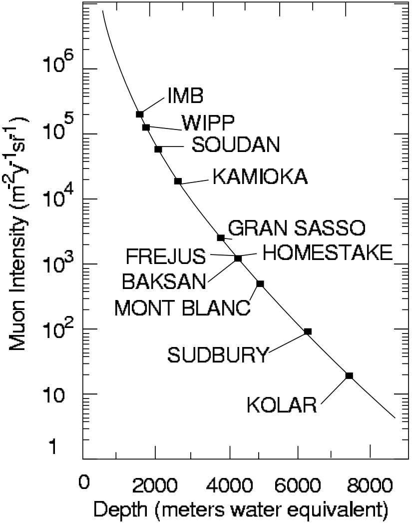


The EXO-200 Detector



To search for rare decays, low background is key:

- Clean (low-radioactivity) materials surrounding TPC.
- Deep underground to avoid cosmogenics.

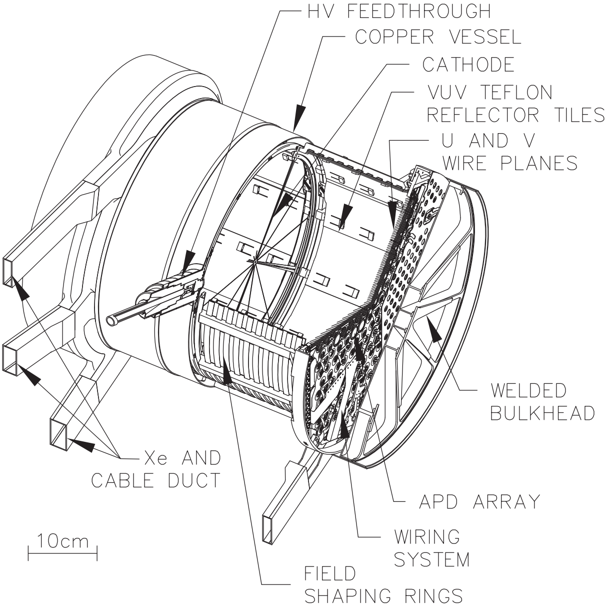


Esch et al., NIM A 2005.

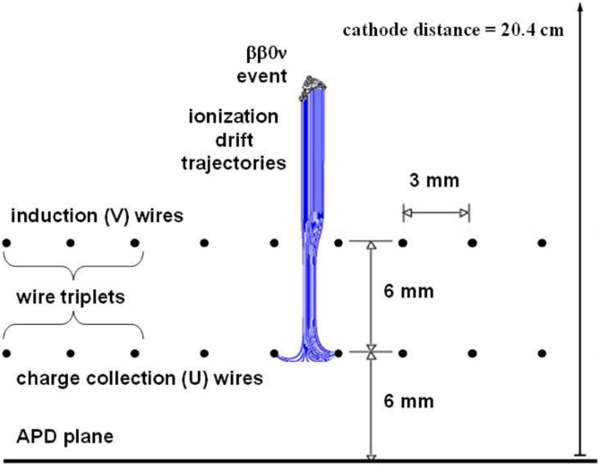
EXO-200 TPC

110 kg of liquid xenon in active volume, enriched to 80.6% in ^{136}Xe, contained in a time projection chamber (TPC).

Xenon continuously circulates through purifiers outside of the cryostat.

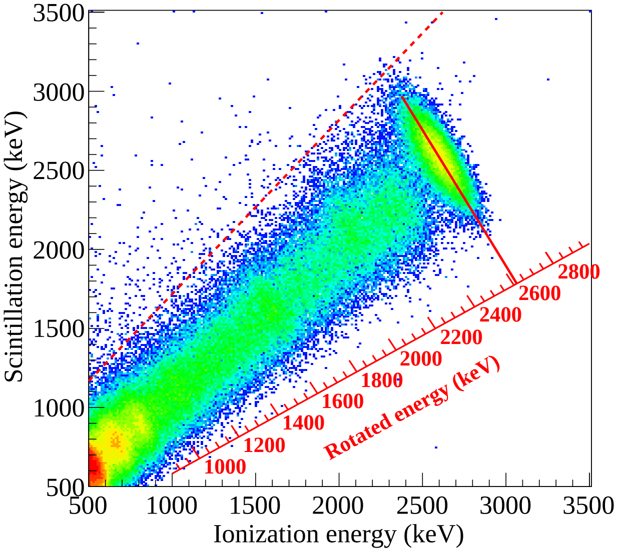


EXO-200 TPC



Charge drifts under an electric field and is collected by wires on the anodes. Light is observed by APDs behind the wires.

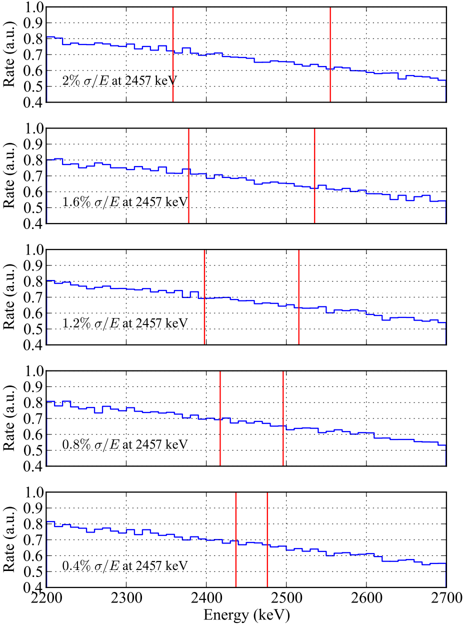
Energy from Ionization and Scintillation



Energy is independently measured from scintillation and ionization.

They are anticorrelated – better energy resolution from both together than either independently.

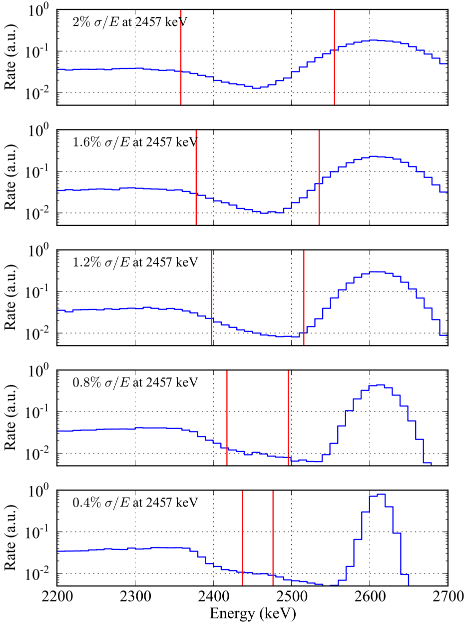
Primary Backgrounds: ^{137}Xe, ^{232}Th, and ^{238}U



Energy resolution is measured as $\sigma/$mean of a mono-energetic peak at the Q-value. Typically 1.5-2% for EXO-200.

Better resolution gives a sharper $\beta\beta0\nu$ peak, so less background in that energy window.

^{137}Xe spectrum is smooth around Q-value; background proportional to energy resolution.

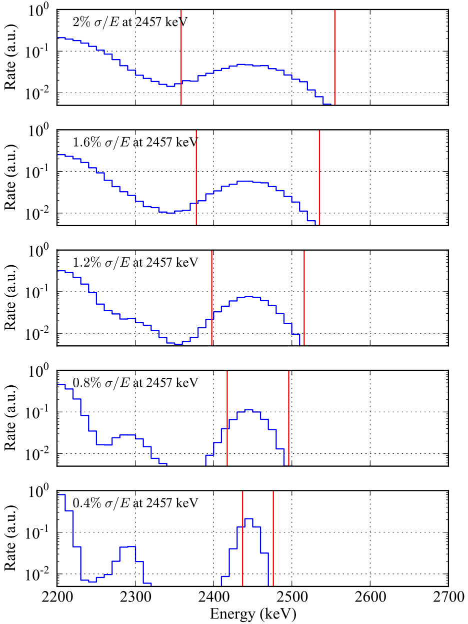


Primary Backgrounds: ^{137}Xe, ^{232}Th, and ^{238}U

Not all backgrounds are smooth. ^{232}Th has a gamma line at 2615 keV, so resolution reduces background sharply until 2457 and 2615 keV are well-separated around 1.2%.

Beyond that, resolution for ^{232}Th is less important (though still helpful).

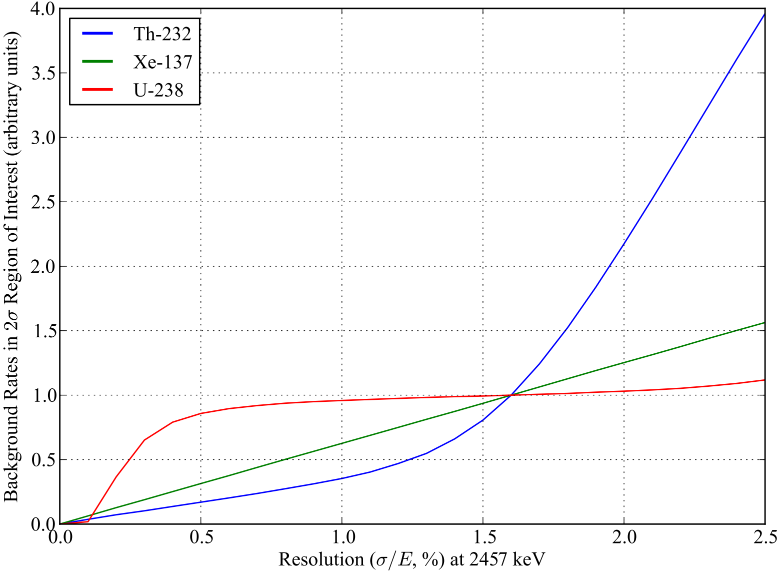
Primary Backgrounds: ^{137}Xe, ^{232}Th, and ^{238}U



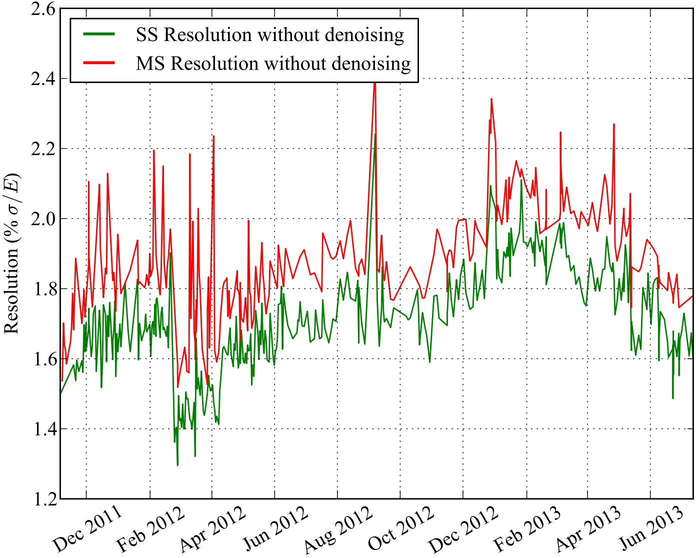
^{238}U has a 2448-keV gamma line, indistinguishable from 2457-keV Q-value except with extremely good resolution.

So, even down to 0.4% energy resolution, most of the ^{238}U peak at 2448 keV is still within our energy window. ^{238}U backgrounds aren't significantly reduced by resolution improvements.

Backgrounds vs. Resolution



Time Variation of Resolution



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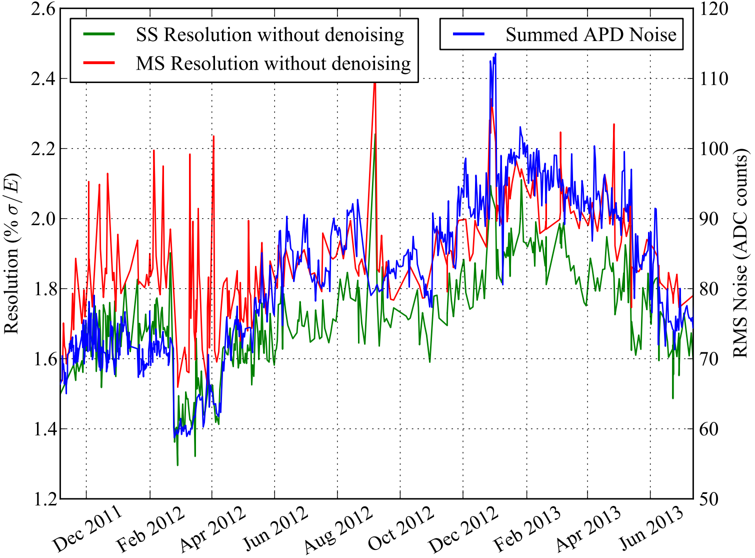

Backup Slides

Anticorrelated Scintillation/Charge