APD Denoising in EXO-200

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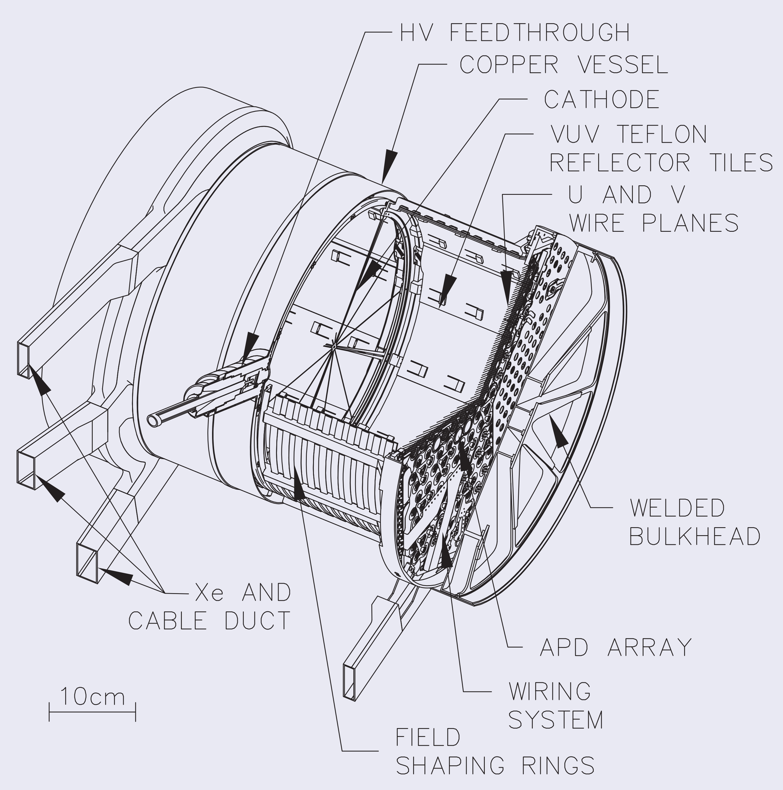
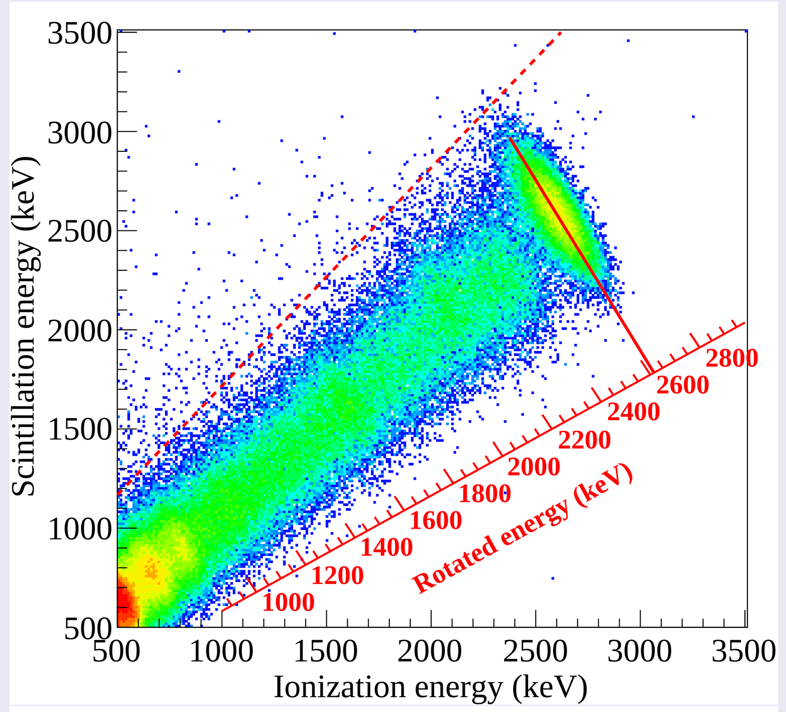
on behalf of the EXO-200 Collaboration

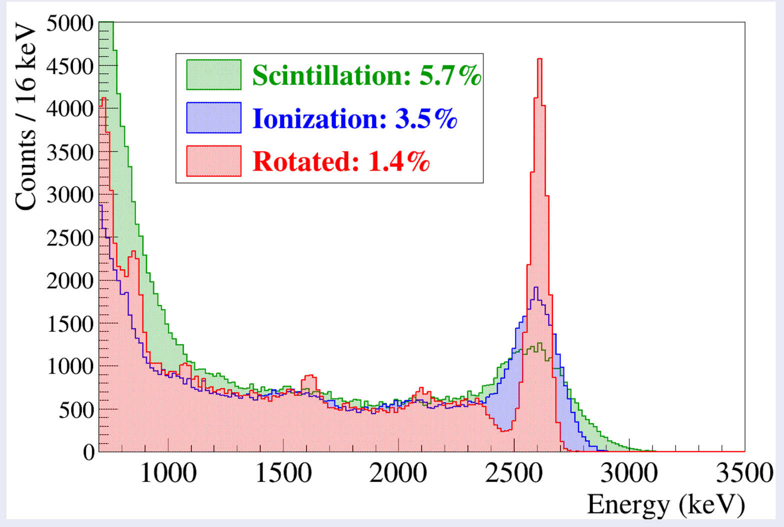
EXO-200

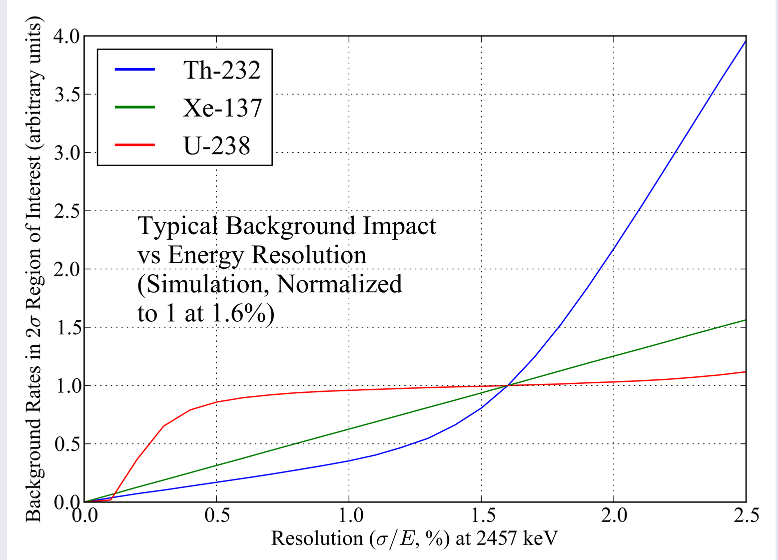


The EXO-200 TPC has 110 kg of liquid xenon, enriched to 80.6% in ^{136}Xe. The xenon is continuously purified. The TPC consists of a cathode in the middle and two anodes on the ends.

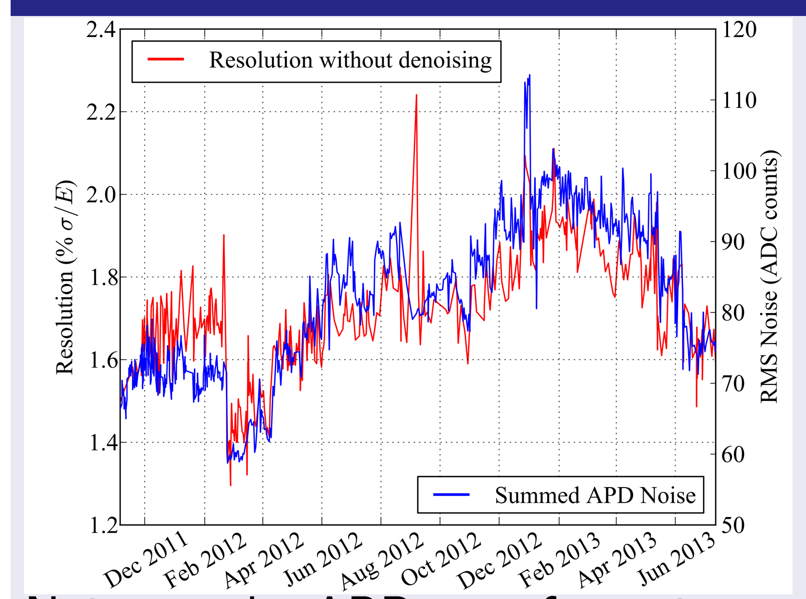
We measure light and charge independently; combining them leads to much better resolution than either can provide individually. Resolution is particularly important for us because small improvements in resolution can have a strong impact in thorium backgrounds from the 2615-keV gamma line of ^{208}Tl.







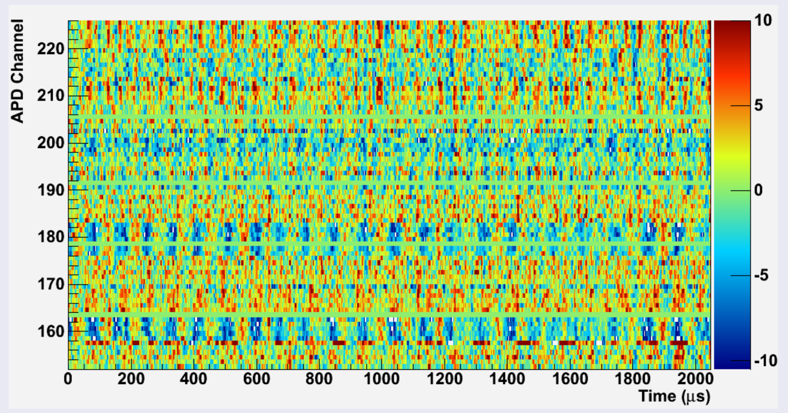
APD Noise Limits Resolution



Before denoising, energy resolution varies in time. The resolution varies in the range 1.5-2.0%, and the impact of thorium backgrounds depends strongly on resolution in this range.

We find that the resolution is highly correlated in time with RMS noise on the APDs.

Noise on the APD waveforms is highly correlated across channels. Individual channels are dominated by Poisson statistics on the signal; only when they are summed together does electronic noise become dominant. We want a denoising scheme which simultaneously minimizes signal fluctuations and electronic noise.



Model of a Waveform

When there is one energy deposit in the xenon, the APD waveform $X_i[f]$ (in frequency space) on channel i can be modeled:

$$X_i[f] = M_i Y_i[f] + N_i[f], \text{ where:}$$

- $Y_i[f]$ is the unit-magnitude template pulse for channel i.
- M_i is the pulse magnitude; it measures the scintillation energy, corrupted by Poisson fluctuations in photon statistics and gain.
- $N_i[f]$ is the additive (electronic) noise on channel i.

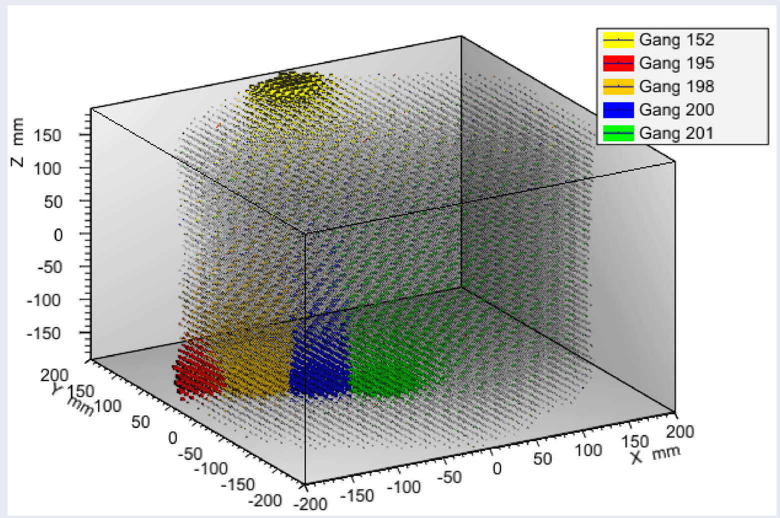
Characterizing the Lightmap

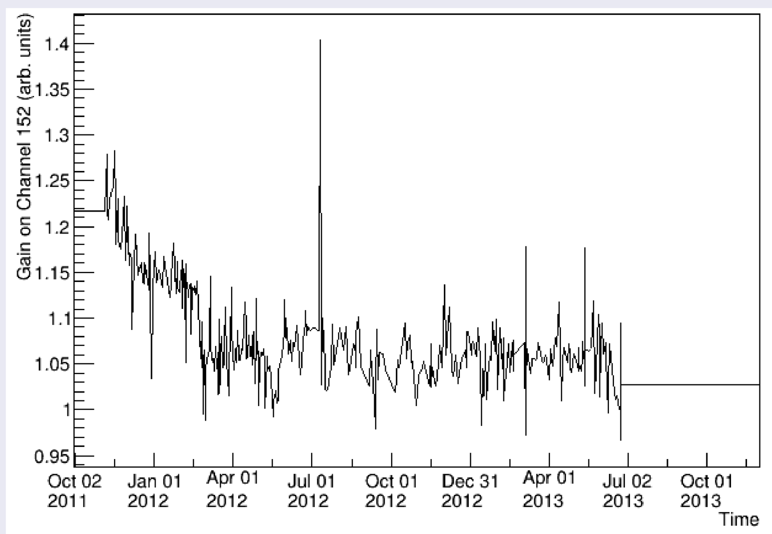
We need a map of light yield versus deposit position for each channel to model the dependence of M_i on energy. Channels have time-dependent gain, so each channel i needs a lightmap function $L_i(\vec{x}, t)$. Very difficult to measure this empirically with limited source statistics.

However, we can make a simplifying assumption that L_i is separable into a position-dependent and time-dependent component representing photon propagation through the detector and gain variations over time. This lets us simplify:

$$L_i(\vec{x}, t) = R_i(\vec{x}) S_i(t)$$

and we only need to empirically measure $R_i(\vec{x})$ and $S_i(t)$ for each channel – much easier.





Characterizing the Noise

In general, we could characterize the noise to lowest order by measuring the correlations:

$$\langle N_i[f] N_j[g] \rangle \text{ for each channel } i, j \text{ and frequency } f, g.$$

However, our noise is dominated by electronics and is relatively steady over short time periods; pairwise correlations will be zero when $f \neq g$. So, we only need to characterize correlations:

$$\langle N_i[f] N_j[f] \rangle \text{ for each channel } i, j \text{ and frequency } f.$$

Note that if we had significant dark current, we might be dominated by terms like $\langle N_i[f] N_i[g] \rangle$ instead.

The beauty of a low-background detector is that it collects lots of noise, so measuring noise empirically is relatively easy.

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