Improvement of the Offline Event Reconstruction for the GERDA Experiment

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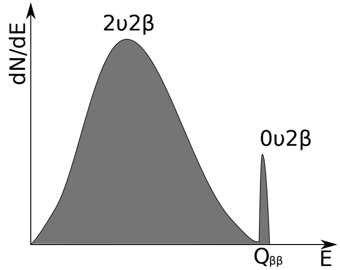
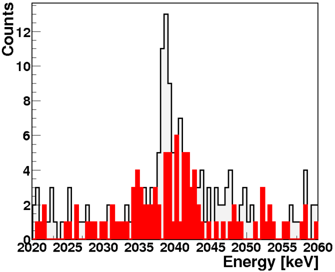
GERDA: a $0\nu2\beta$ decay experiment

Expected signal

- Continuum $2\nu2\beta$ spectrum
- Peak at $Q_{\beta\beta}$ for the $0\nu2\beta$ decay



Why do we need high resolution?

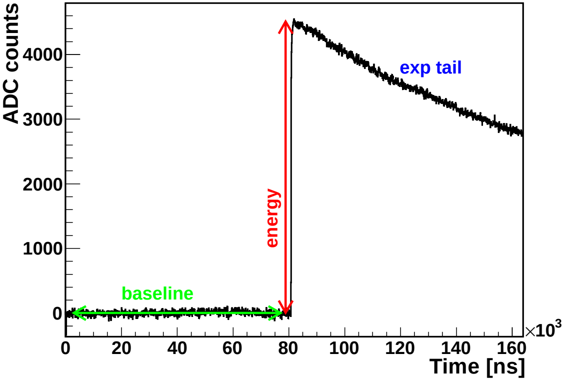


Flat background plus Gaussian peak with different sigma.

- $T_{1/2}^{0\nu2\beta} = 4.3 \cdot 10^{24} \varepsilon a \sqrt{\frac{Mt}{BI \cdot \Delta E}}$
- ε = efficiency, a = enrichment fraction, M = Ge mass, t = exposure, BI = Background Index, ΔE = resolution (FWHM).

Offline event Reconstruction

- Goal: take digitized waveform and extract energy and other physical quantities



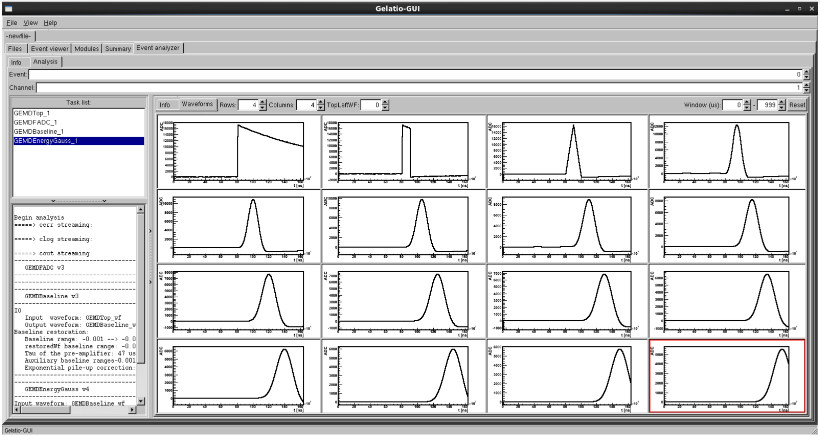
- Record charge pulse with FADC
- 160 μs window
- 40 s wide bins
- Flat baseline, sharp rise, exponential decay

Offline event Reconstruction

Gaussian shaping

- Reproduce digitally the signal shaping to extract the energy
- Standard method: semi-Gaussian shaping amplifier transforms the waveform to a pseudo-Gaussian shape using a $CR-(RC)^n$ circuit
- CR = differentiation, RC = integration of the signal
- Differentiate (CR) and recursively integrate (RC^n) the digitized signal using different time constants
- Take the height of the pseudo-Gaussian pulse as the deposited energy.

Standard GERDA offline event reconstruction



- Differentiate: $x[i] \rightarrow x[i] - x[i-k]$
- Integrate recursively with Moving Average (MA): $x[i] \rightarrow \sum_{j=i-k}^{i} x[j]/k$ if $i < k$, else $x[i] \rightarrow 0$

M. Agostini, L. Pandola, P. Zavarise and O. Volynets, JINST 6 (2011), P08013

Improvements of the Standard GERDA Algorithm

Limit of the standard reconstruction:

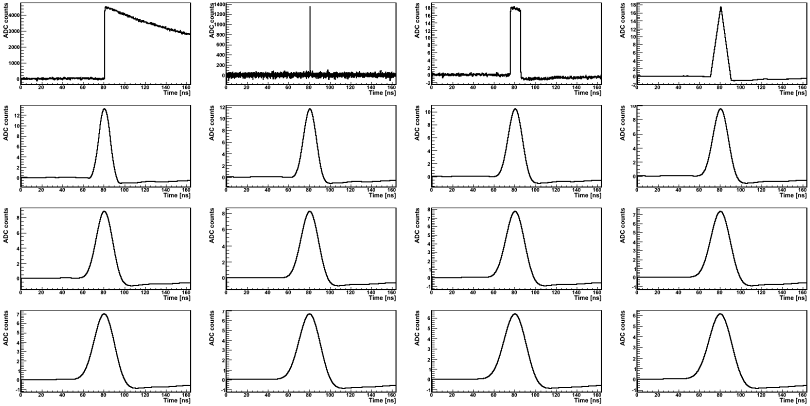
- The pseudo-Gaussian pulse moves towards right at each step and eventually exits the window.

Improvement # 1: Centered Moving Average (CMA)

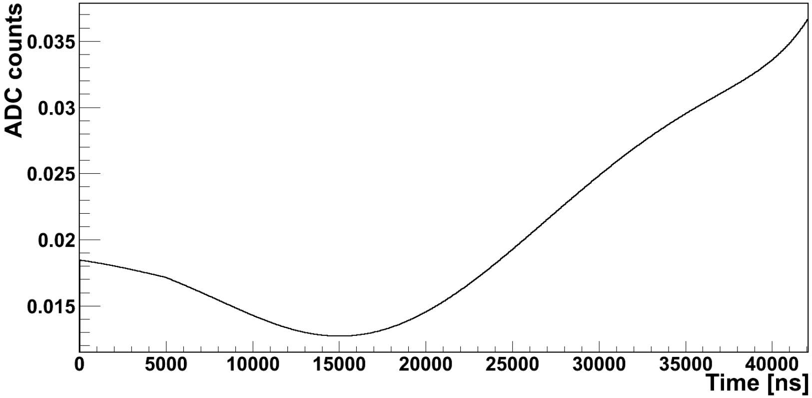
- Apply moving average on a window centered on the considered bin:

$$\begin{array}{lll} x[i] \rightarrow \sum_{j=i-L/2}^{i+L/2} x[j]/L & \text{if} & L/2 < i < N - L/2 \\ x[i] \rightarrow \sum_{j=0}^{i} x[j]/i & \text{if} & i < L/2 \\ x[i] \rightarrow \sum_{j=i}^{N} x[j]/(N-i) & \text{if} & i > N - L/2 \end{array}$$

- Advantage: the pseudo-Gaussian remains within the window $\longrightarrow$ an infinite number of iterations is possible.



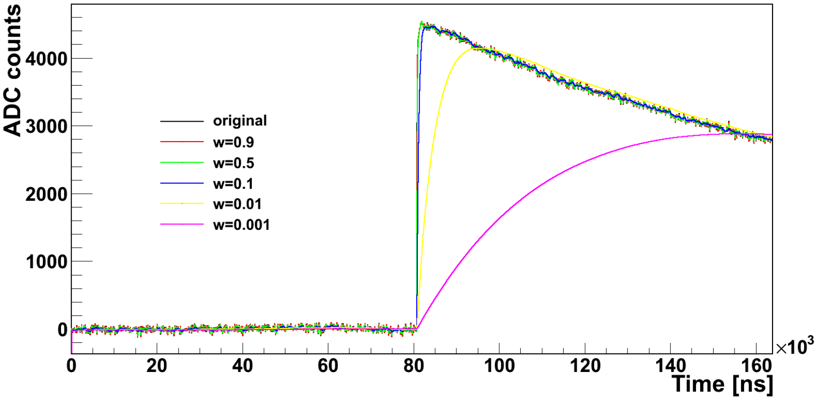
- Disadvantage: border effect due to non-uniform weighting
  $\rightarrow$ Low frequency modulation after high-number of iterations



Pseudo-Gaussian pulse (after 14 CMA iterations) zoomed in the first 40 μs.

Improvement # 2: Low Pass Filter (LPF)

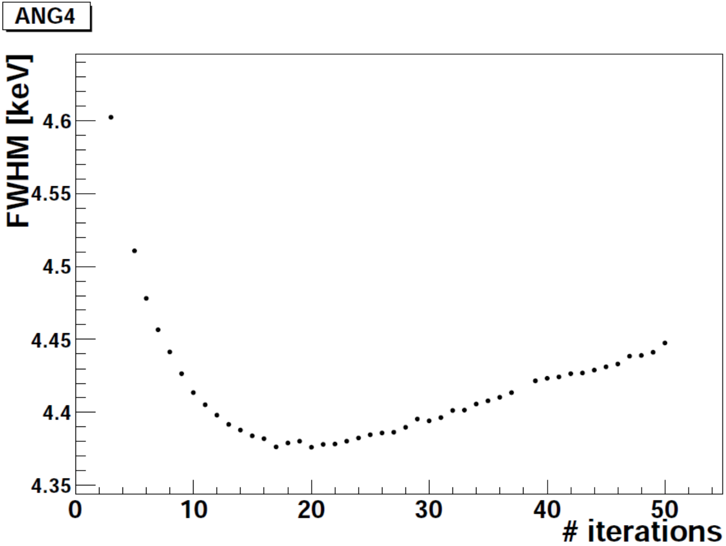
- Further reduce high frequency noise:
  $$x[i] \rightarrow wx[i] + (1-w)x[i-1] \quad \text{with} \quad w \in [0;1]$$
- $w = 1 \rightarrow$ no filter
- small $w \rightarrow$ waveform deformation



The Improved Semi-Gaussian Shaping

The new method step by step:

1. Select events around the 2614.5 keV peak of $^{208}\mathrm{Tl}$ ($^{228}\mathrm{Th}$ source used)
2. Apply low pass filter to the waveforms
3. Differentiate the waveform
4. Apply the CMA recursively
5. Fit the 2614.5 keV peak with proper function to extract FWHM
6. Plot FWHM as function of the number of CMA iterations applied.



FWHM vs number of CMA iterations for one of the detectors used in GERDA.

The search for the optimal reconstruction parameters:

- Process the data with different values of w and L
- Find the best parameter configuration for each detector separately
- Reconstruct the whole spectrum using the optimal parameters.

Det	GELATIO FWHM (keV)	Best case FWHM (keV)	w	L (μs)
ANG2	4.81	4.77	0.01	5
ANG3	4.68	4.60	0.01	5
ANG4	4.41	4.38	0.01	5
ANG4	4.29	4.16	0.005	5
RG1	4.51	4.44	0.005	5
RG2	4.83	4.77	0.01	6
GTF112	4.12	4.10	0.01	5
Agamennone	2.87	2.89	0.01	5
Andromeda	2.82	2.81	0.01	5
Anubis	2.96	2.95	0.01	3
Achilles	3.72	3.44	0.005	4
Aristoteles	3.08	3.08	0.01	6

Conclusion and outlook

Results

- Energy resolution improved for (almost) all the detectors
- The digital Semi-Gaussian shaping can be tuned for each detector separately
- Small improvement achievable through deeper estimation of the optimal reconstruction parameters

Further Possible Improvements

- Pole Zero Cancellation to subtract the decay tail
- Use of median filter to reduce random noise $x[i] \rightarrow Median(x[i-1], x[i], x[i+1])$
- Fourier transform to search for peculiar frequencies
- Trapezoidal Shaping.