

Data acquisition and analysis for the Milano neutrino mass experiment

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In a neutrino mass experiment it is crucial to achieve high energy and time resolutions together with a high statistics. It is also very important to distinguish between real beta decay events and various kind of spurious events. In this poster we describe the VXI-based data acquisition system used during about one year of measurement of the Milano neutrino mass experiment and the software tools employed to analyse the collected data. We consider in particular the event selection by means of Artificial Neuronal Networks and the pile-up recognition by means of Wiener Filtering. Moreover we give details about the complete procedure to obtain the ^{187}Re beta spectra. We describe also both the statistical approach applied to obtain the neutrino mass limit and the method to determine the ^{187}Re lifetime.

1. VXI data acquisition system

Hardware

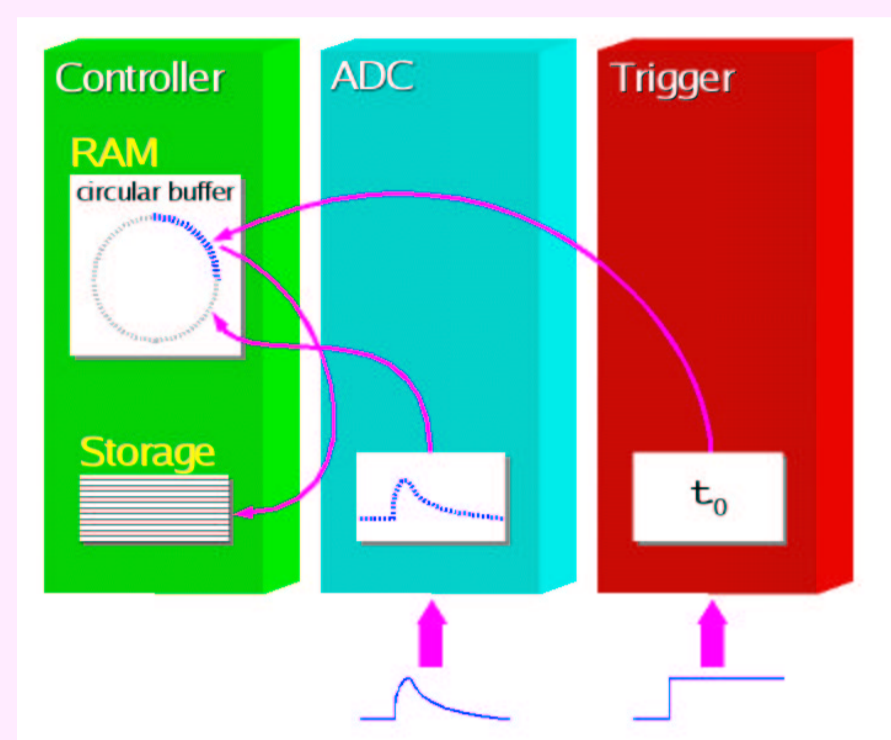
- A/D converter: Tektronix VX4244
- 16-channel 16-bit 100 ks/s per channel
- Trigger: Tektronix VX4286 16-channel analog comparator/interrupter

Software

- Labwindows/CVI
- multi-threaded acquisition code

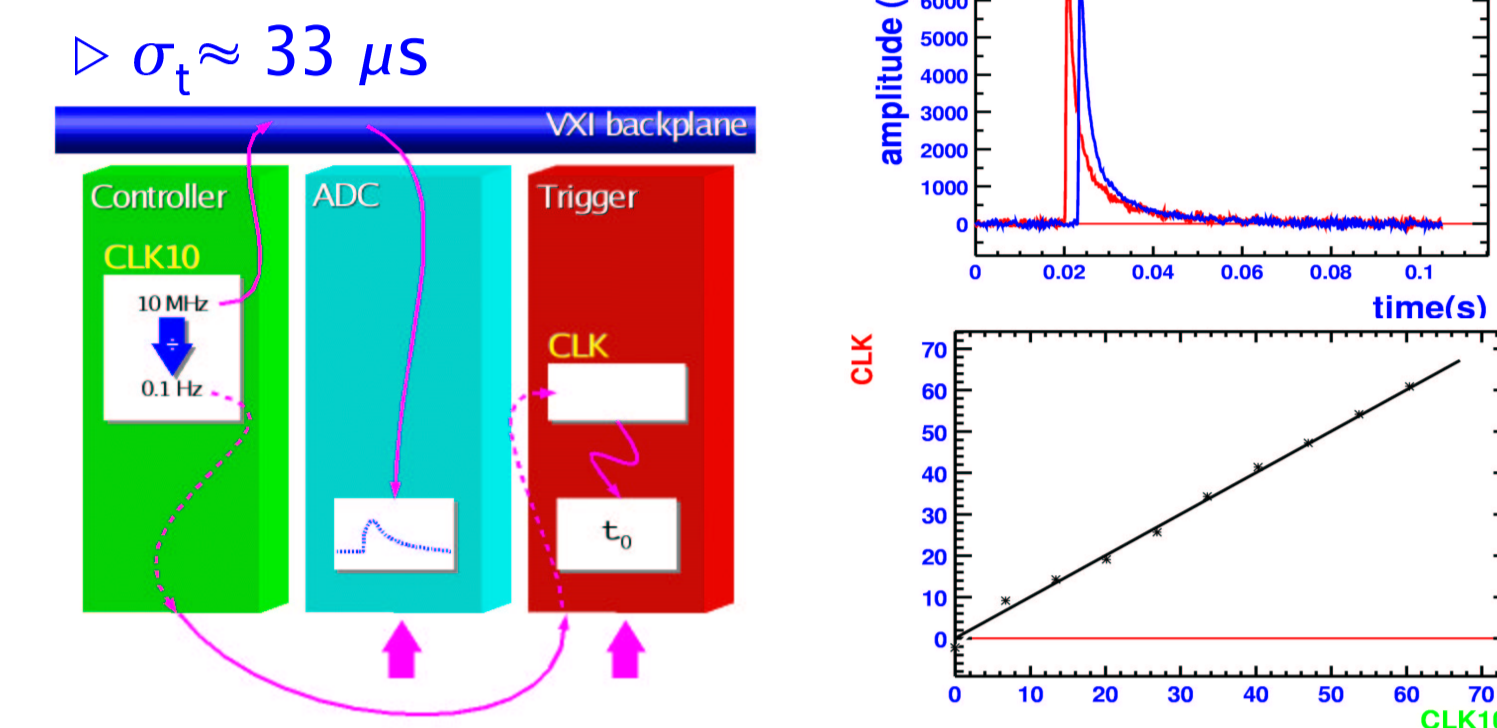
Daq set-up

- free-running ADC
- trigger time-tags to extract pulses



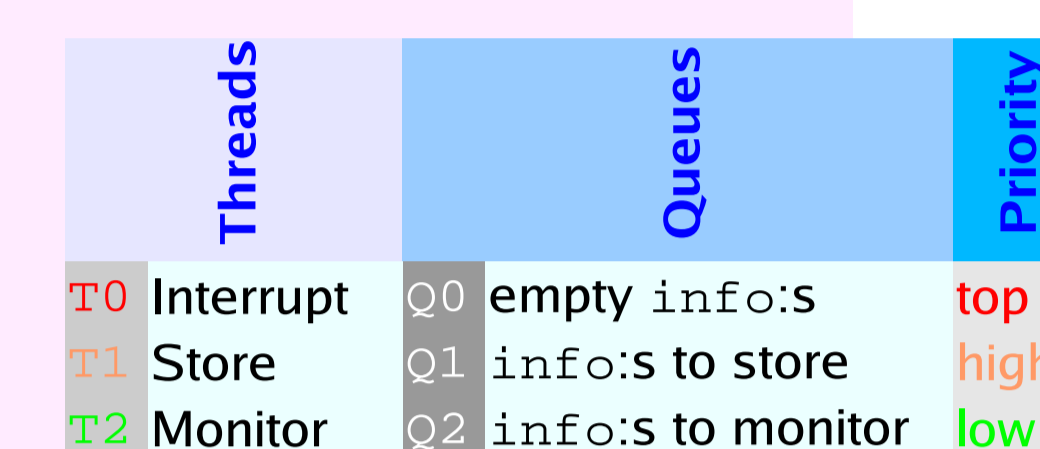
Pulse starting point t_0 stability in time

- continuous trigger clock CLK synchronization with controller clock CLK10
- $\sigma_t \approx 33 \mu\text{s}$



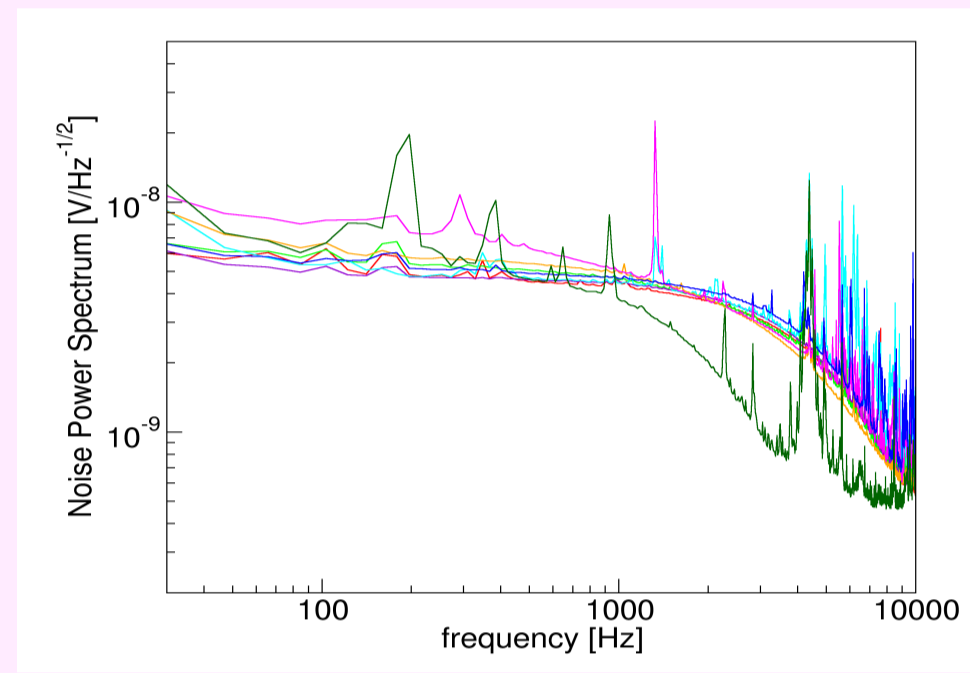
Threaded Daq

- Hardware module HW generates info:s
- Thread priorities
- with high trigger rates T2 executes less



2. Acquisition configuration

- pulse digitization
 - 2048 samples, 26 μs time base
- one-day measurements (for refrigerator service)
- acquisition cycles (see poster U09)
 - 25 min X-ray calibration (total rate ≈ 10 Hz)
 - 2 h pure β acquisition (total rate ≈ 1 Hz)
 - every one-day data set must begin and end with a calibration period
 - random records are acquired to build noise power spectra



3. Raw data reduction

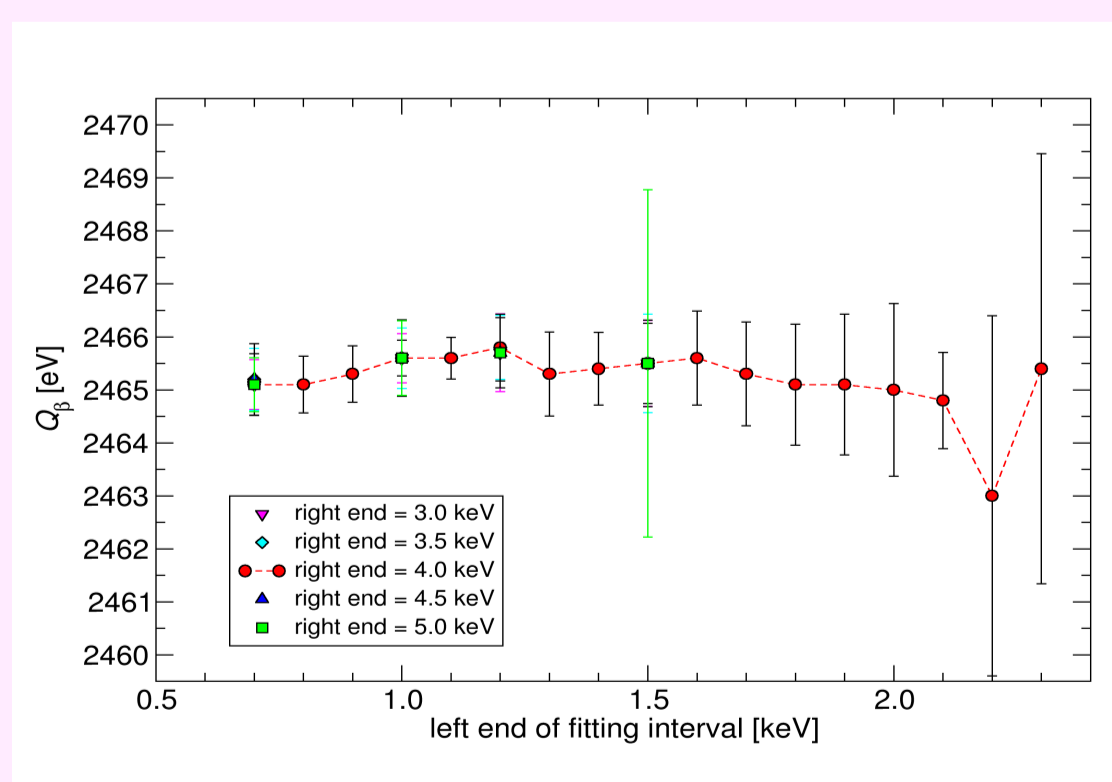
- average β pulse $s(t)$ and noise power spectra $\mathcal{N}(\omega)$ generation
- n-tuple generation**
 - 8 channel separation (events with multiplicity > 3 are discarded)
 - peak stabilization (gain drift correction) using Mn, Ti and Ca $K\alpha$ peaks
 - X-ray and pure β periods separation (see poster U09)
 - X-ray spectra calibration using 2nd order polynomials (see poster U09)
 - pulse shape analysis and pile-up recognition for β spectra generation
 - β spectra calibration using X-ray spectra calibration results
 - total X-ray and β spectra generation
- detector energy response function evaluation (see poster U09)
- β spectra analysis

4. n-tuple

- Optimal Filter (OF)** amplitude
 - $\mathcal{H}_{OF}(\omega) \propto S^*(\omega)/\mathcal{N}(\omega)$ for maximal signal-to-noise ratio
- Adaptive Filter (AF)** amplitude
- τ_{rise} rise and τ_{decay} decay times (10%-90%)
- shape parameters
 - root mean square deviation from $S_{OF}(t) = [\mathcal{H}_{OF}(\omega)S(\omega)]^{-1}$ left (TVL) and right (TVR) of $S_{OF}(t)$ maximum
 - root mean square deviation from template $s(t)$
 - Artificial Neuronal Network (ANN)** output
- amplitude and time delay of secondary pulses as found by **Wiener filtering (WF)**
 - $\mathcal{H}_{WF}(\omega) \propto S^*(\omega)/(|S(\omega)|^2 + |\mathcal{N}(\omega)|^2)$ transfer function for best least-square estimate of *uncorrupted* signal
- source open, source closed and random record tags

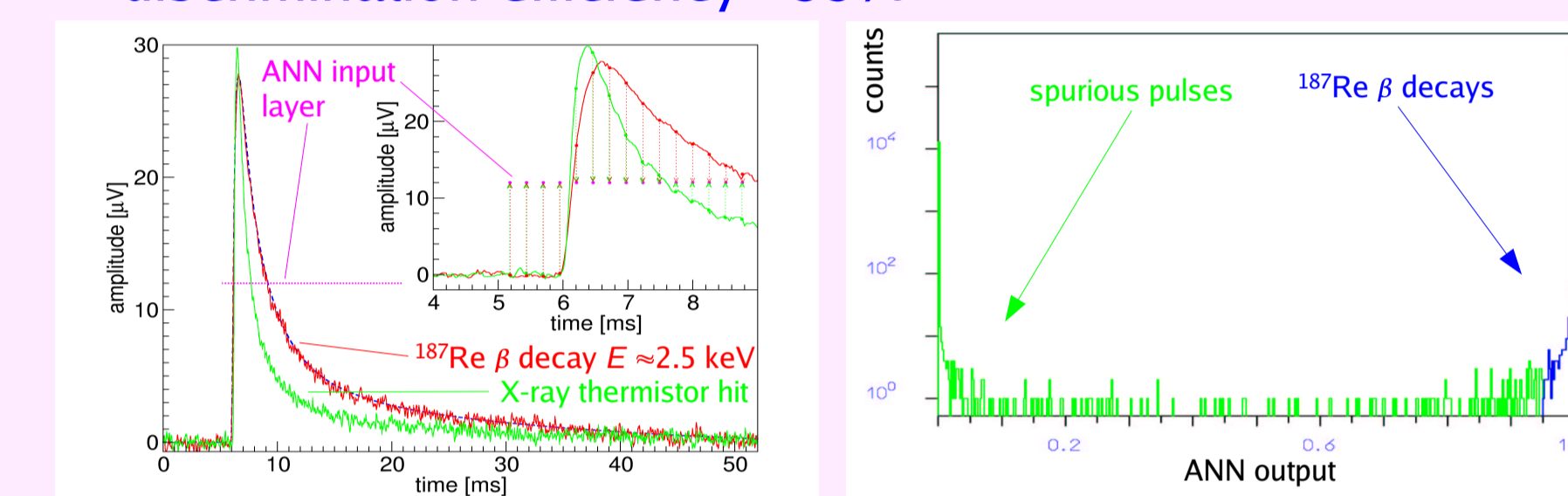
9. β spectrum analysis (listen to U02 presentation)

- fit function: $f(E) = [N_{\text{theo}}(E, m_\nu) + N_{\text{pile-up}}(E, m_\nu) + b(E)] \otimes R(E)$
 - $N_{\text{theo}}(E, m_\nu)$ first forbidden unique Buhring spectrum
 - $N_{\text{pile-up}}(E, m_\nu) = A_\beta \Delta t [N_{\text{theo}}(E, m_\nu) \otimes N_{\text{theo}}(E, m_\nu)]$ pile-up spectrum
 - $b(E)$ polynomial background spectrum
 - free parameters: N_{theo} and $N_{\text{pile-up}}$ normalizations, Q_β end-point, $b(E)$ parameters, m_ν^2
- estimator: $\chi^2 \cong 2 \sum_i [f_i - y_i - y_i \ln(f_i/y_i)]$ with f_i fit values, y_i measured data
- Bayesian approach for non physical regions
- $f(E)$ consistency tested varying the fitting interval ($E_{\text{min}} \geq 0.7$ keV, $E_{\text{max}} \leq 5$ keV)
 - best fitting interval: 0.9 ÷ 4.0 keV (for lowest statistical and systematic errors)



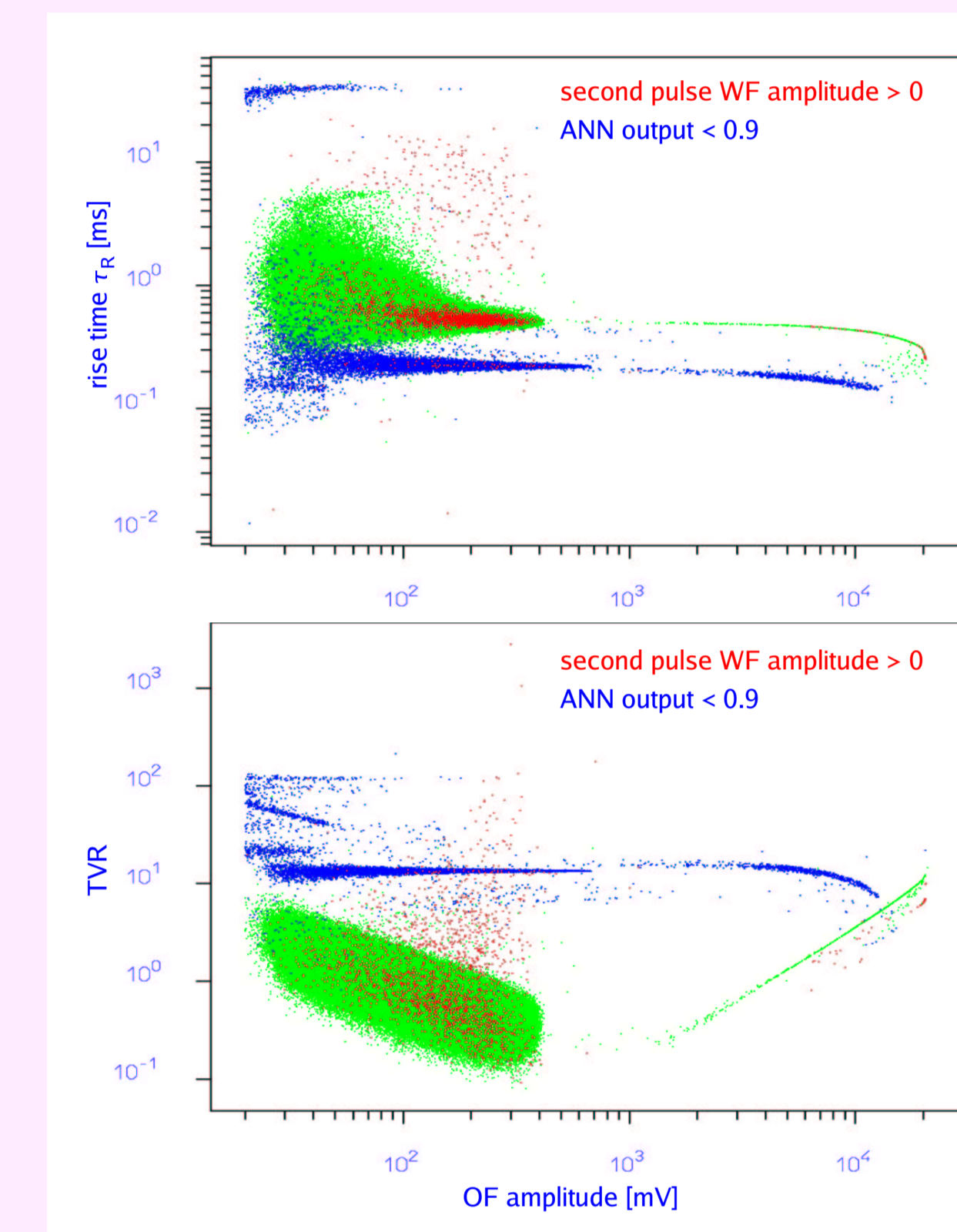
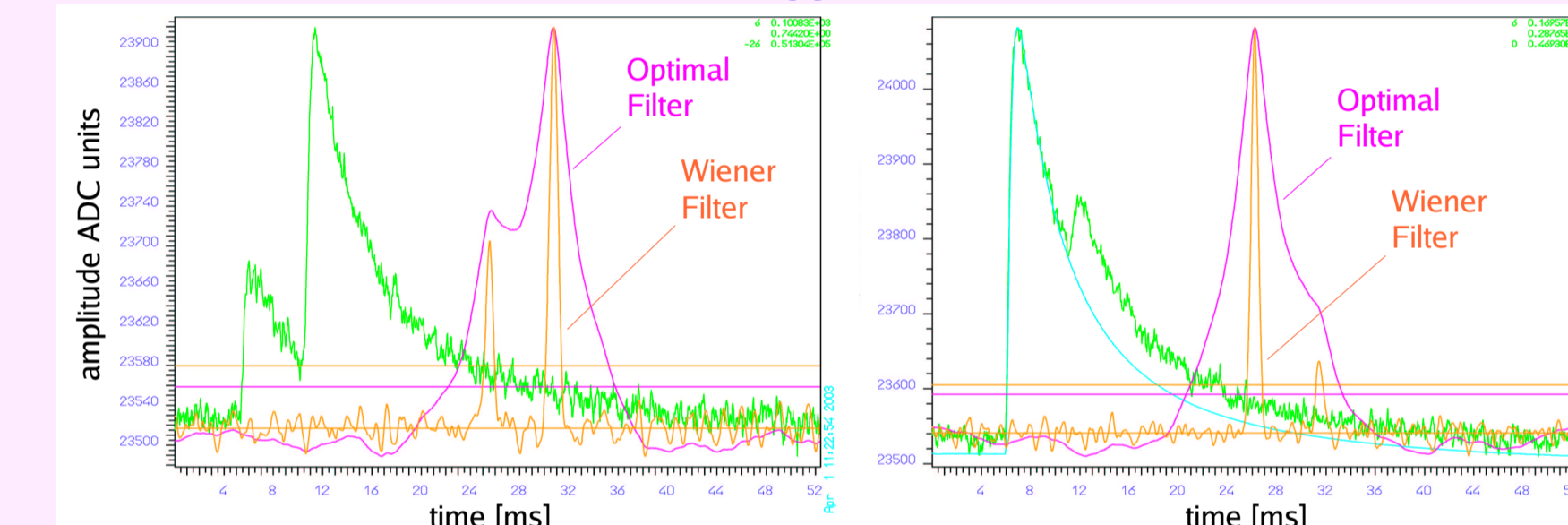
5. Pulse shape analysis

- aim: discriminate between true β and spurious events**
- tool: 3-layer Artificial Neuronal Network (ANN) applied to 10 ch. averaged pulses (60 input nodes)**
- discrimination efficiency >99%



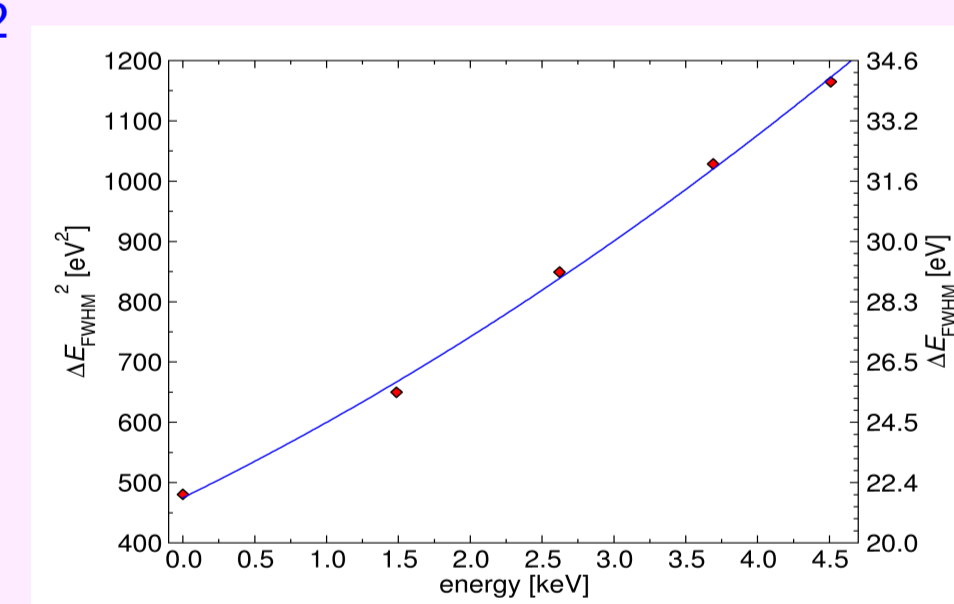
6. Pile-up recognition

- aim: resolve two β decays closely spaced in time**
- tool: Wiener Filter**
 - time resolution $\Delta t \approx 3 \tau_{\text{rise}}$



7. Detector energy response function

- asymmetric detector energy response function $R(E)$
 - two symmetric gaussians with equal FWHM, ≈ 40 eV separation and 4:100 area ratio (see poster U09)
- energy response function at β end-point for 8 detector sum spectrum
 - creation for each peak of a sum spectrum normalizing the peak area to detector mass and measuring time
- peak FWHMs depend on energy
 - $\Delta E^2_{\text{FWHM}} = a + bE + cE^2$
 - a noise
 - b thermalization statistical fluctuations
 - c uncorrected gain instabilities ($\approx 2\%$)
- extrapolation of $\Delta E^2_{\text{FWHM}}(E)$ at β spectrum end-point
- for β spectrum fitting: gaussian $R(E)$ with constant ΔE
 - $\Delta E = \Delta E_{\text{FWHM}}(Q_\beta)$



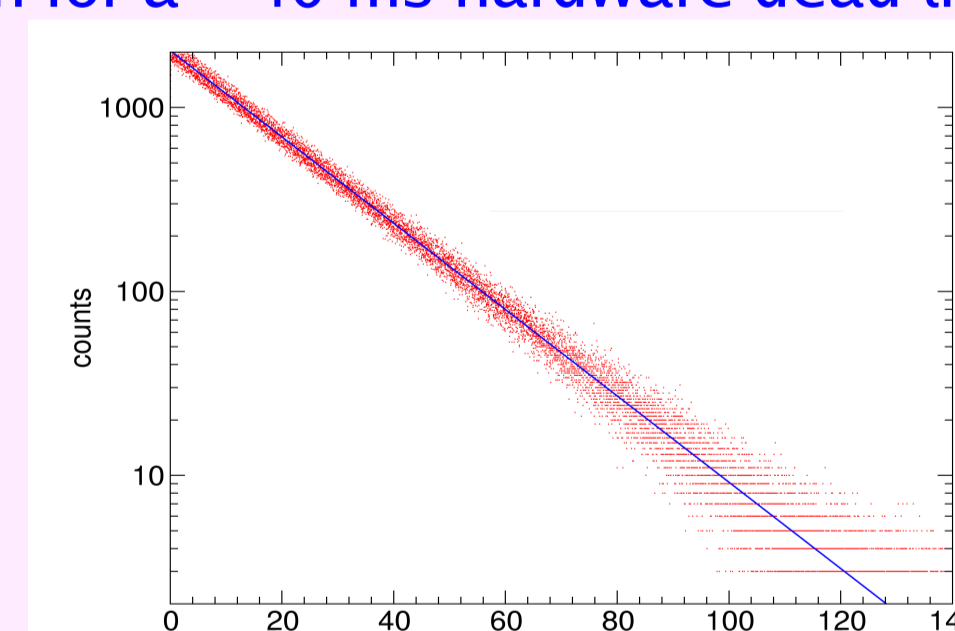
8. Summary of RUN 14 detector performances

see poster U11 and listen to presentation U02

detector	1	2	3	5	6	8	9	10	sum
mass [μg]	272	259	280	250	284	282	269	278	2174
T_{op} [mK]	104	91	104	107	87	72	97	101	
R_{op} [M Ω]	1.3	1.9	1.3	1.2	2.2	4.0	1.6	1.4	
threshold [eV]	350	350	350	470	350	400	400	700	700
ΔE_{FWHM} [eV]	0 keV	24	19	26	21	22	25	18	24
	1.5 keV	24	23	29	25	26	29	21	29
	3.4 keV	26	27	31	29	29	33	25	35
τ_{rise} [μs]	440	340	670	590	500	510	430	445	492

10. ^{187}Re lifetime τ measurement

- from distribution of time intervals Δt between two β decays
 - needs only a correction for a ≈ 40 ms hardware dead time
 - MC simulation
 - $\leq 1\%$ correction
- $N(\Delta t) = A e^{-r\Delta t}$, where $r \propto 1/\tau$ is the β decay rate



11. Systematic errors on m_ν^2

- perform fits under different hypotheses $\Rightarrow \Delta m_\nu^2 \Rightarrow$ systematic error ϵ_{sys}
- | Quantity | contribution to ϵ_{sys} |
|---|---|
| fit interval [keV] | 0.9 ÷ 4 2.1 ÷ 4 |
| alternative resolution functions $R(E)$ | 79% 14% |
| double gaussian $R(E)$ | 68% 6% |
| non-constant width $R(E)$ | 11% 8% |
| different order polynomials for $b(E)$: 1 st or 2 nd | 21% 8% |
| alternative β spectrum parametrizations | --- 78% |
| Total systematic error [eV²] | 90 125 |