Digital pulse processing of proton detector signals in the spectrometer *a*SPECT

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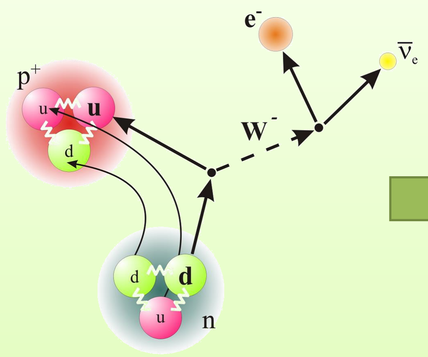
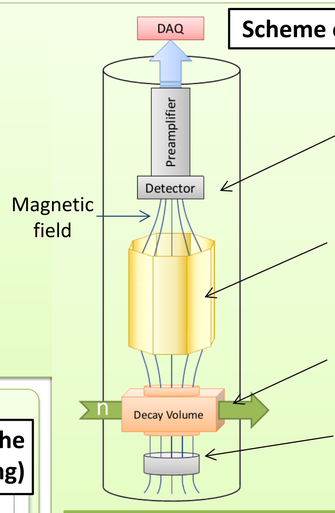
The *a*SPECT experiment

- Dedicated to the measurement of the electron-antineutrino angular correlation coefficient *a*
- *a* allows to test the Standard Model through the value of $\lambda = g_A/g_V$
- The value of *a* can be extracted from the proton recoil spectrum



- Protons: up to 751 eV
- Electrons: up to 780 keV

Scheme of the *a*SPECT spectrometer



Protons are post-accelerated by a high negative potential (-15 kV)

Analyzing plane: potential barrier to select protons depending on their energy

High cold neutron flux

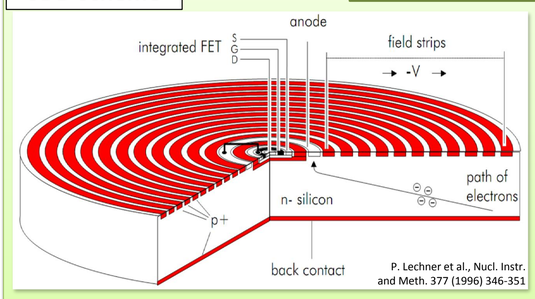
Electrostatic mirror to reflect protons

Some required characteristics of the *a*SPECT acquisition system:

- Sufficient energy resolution to treat the small proton signal
- Dead time < 5.2 µs, as this is the minimum time difference between an electron and its following correlated proton
- Good handling of low-energy proton events shortly following high-energy electrons, on both trigger conditions and energy calculation

Silicon Drift Detector & Preamplifier

SDD scheme

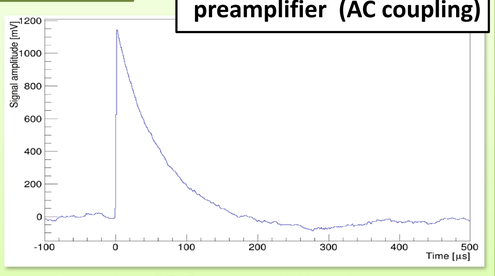


- Small readout anode compared to the detector volume
- First amplification FET directly onto the detector bulk

→ Greatly reduced thermal noise compared to a conventional PIN diode

- Inverts and amplifies the output signal of the detector

Pulse waveform after the preamplifier (AC coupling)

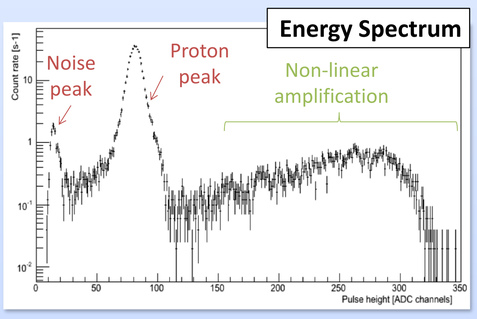


- Directly connected to the SDD to avoid noise coming from cables

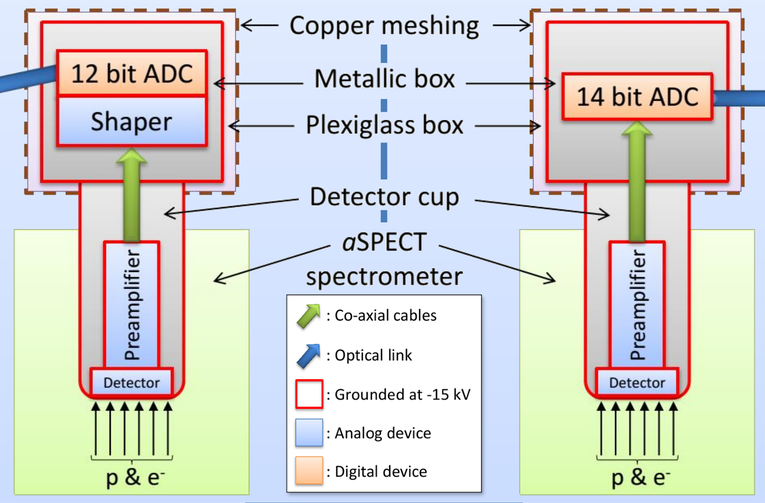
Comparison of 2 used DAQs

Preamp. → Shaper → 12 bit ADC

Energy Spectrum



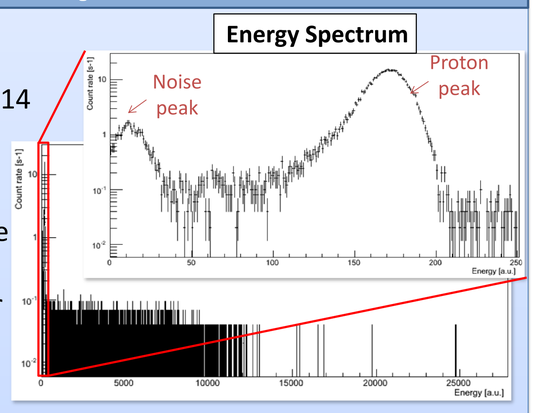
- The analog shaper applies a differentiation and integration filter on the input signal, resulting in a 2 µs long pulse for an event
- Non-linear amplification to avoid saturation from high-energy electrons
- The shaper output is then digitized by the 12 bit ADC



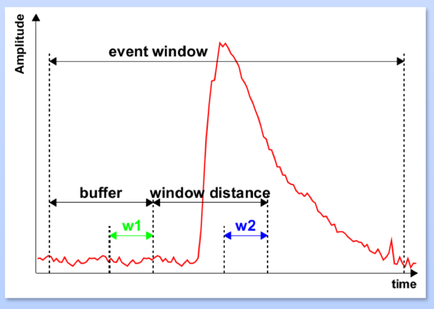
Preamp. → 14 bit ADC

- The signal is digitized by the 14 bit ADC just after the preamplifier
- The full dynamic range of the preamplifier can be covered with a sufficient resolution for the proton signal
- No saturation due to high-energy electrons

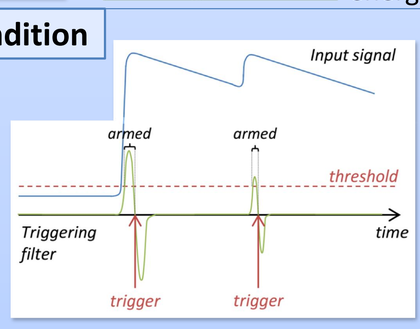
Energy Spectrum



Trigger condition



- Comparison between two windows (w1 & w2), separated by a certain distance
- The trigger condition is fulfilled if the mean value of w2 is higher than the one of w1 + threshold
- A delay can be set so the threshold condition has to be satisfied several times in a row before the trigger decision is made

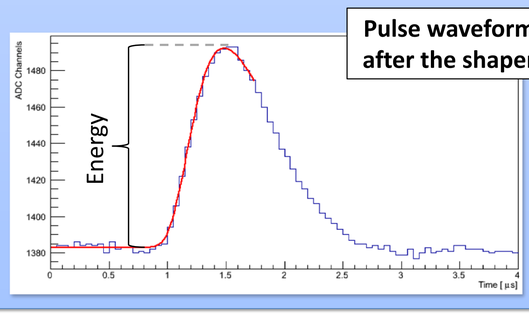


- The input signal is treated by a digital version of an analog RC-(CR)^2 (Low-pass and High-pass filter)
- The trigger is armed if the signal goes above the threshold and the trigger condition is only fulfilled if there is a zero-crossing occurring before a certain delay
- The resulting timestamp is independent of the pulse amplitude (same principle as a Constant Fraction Discriminator)

Energy calculation

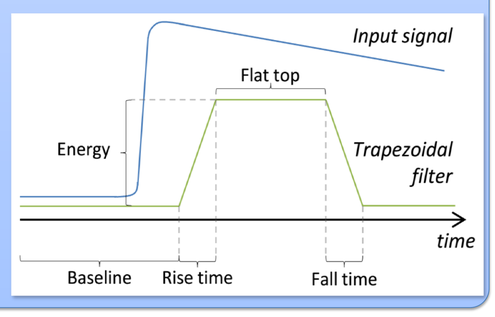
- The detected energy is directly proportional to the pulse-height for the linear part of the amplification
- The pulse-height is defined as the pulse maximum minus the baseline value and can be determined using a fit (in red)

Pulse waveform after the shaper



ADC resolution	
12 bit	14 bit
Sampling frequency	
20 MHz	100 MHz
Dead time + electronic latency	
4.0 µs + 0.2 µs	4.0 µs + 0.06 µs

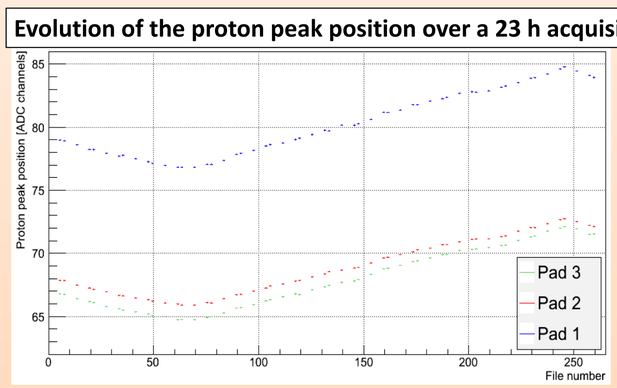
- A trapezoidal filter is used to determine the energy of an event
- It is mainly sensitive to the rising part of the input (≈0.6 µs): a 4 µs window is enough to get a sufficient energy resolution
- The energy is defined as the flat top value minus the baseline value



Online behavior of the two systems

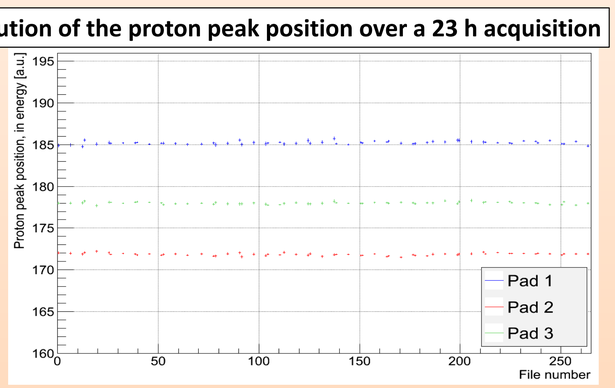
Proton peak position stability

Evolution of the proton peak position over a 23 h acquisition



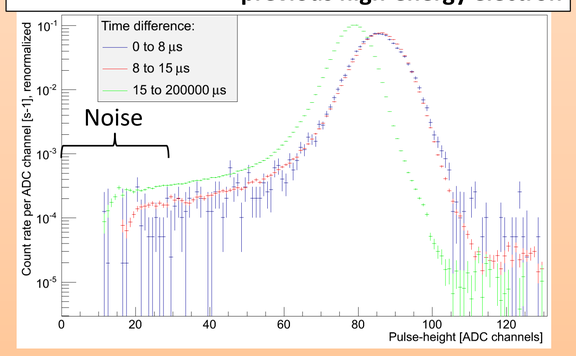
- Because of the analog components of the shaper, the pulse shaping is very sensitive to temperature
- A stabilized and cooled compressed air flow constantly blows on the shaper to reduce temperature effects
- The input signal is still dependent of analog devices (detector and preamp.) and thus to temperature, but this effect is small
- The energy is calculated through a digital filter: this process has a great reproducibility and no temperature dependency

Evolution of the proton peak position over a 23 h acquisition



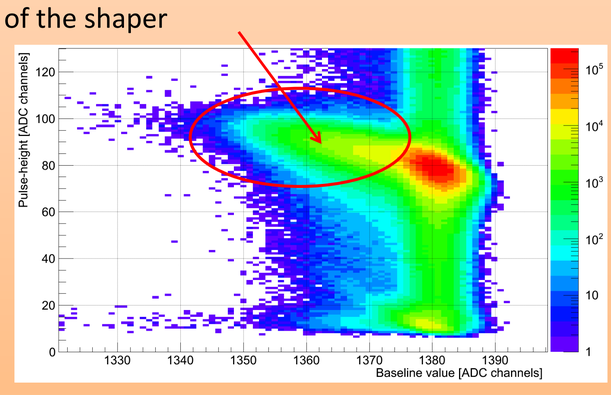
Behavior after high-energy electrons

Spectra depending on events time difference with previous high-energy electron



- No alteration of the trigger efficiency above the noise at low pulse-height (Pulse-height > 30 ADC channels): the three normalized spectrums have the same distribution

- Shift on the calculated energy for events coming shortly after an high-energy electron
- This effect is most certainly due to an overcompensation of a very sensitive parameter of the shaper



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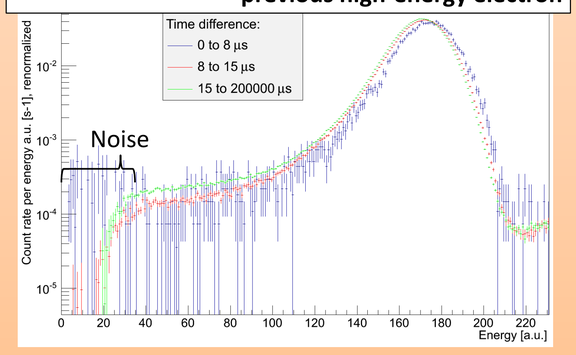
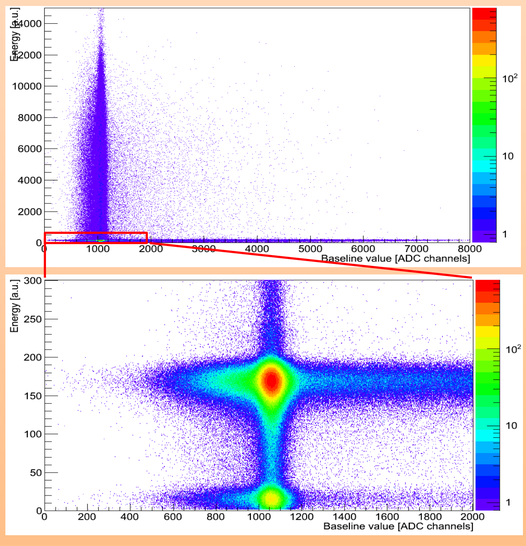


- Also no alteration of the trigger efficiency above the noise at low pulse-height (Energy > 35 a.u.)

- No evidence of energy miscalculation, whatever the baseline value is



Conclusion

- Over the last years, a lot of improvements were done on the shaper + 12 bit ADC setup. As a result this system performs globally well
- There are however a few imperfections left. Those are mainly due to the analog nature of the shaper
- The recent availability of high resolution and high sampling frequency flash ADC allowed us to test a 14 bit ADC without the need of an analog shaper
- This full digital treatment offers a great reproducibility and thus a very stable acquisition system
- The few left imperfections of the shaper + 12 bit ADC setup are no longer present with this solution