Digital signal processing for a thermal neutron detector using ZnS(Ag):^{6}LiF scintillating layers read out with WLS fibers and SiPMs

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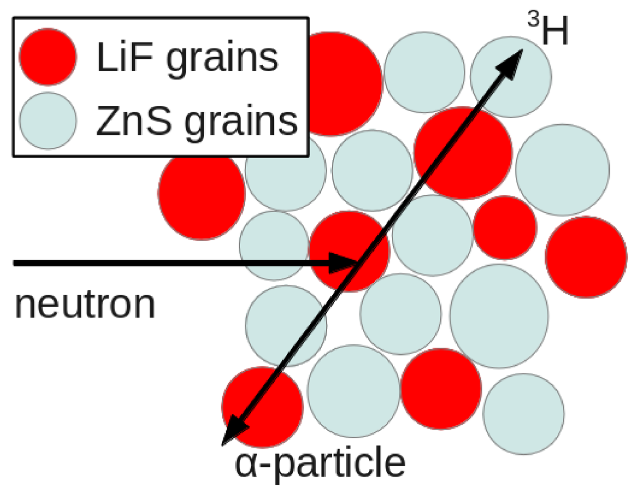
Introduction

A 1-D position sensitive detector for thermal neutrons is currently under development for upgrading the POLDI instrument [1-4], a strain scanning diffractometer installed at the Swiss neutron spallation source (SINQ) at PSI. This detector uses a ZnS(Ag):^{6}LiF scintillator which consists of a mixture of ZnS(Ag) scintillating grains and ^{6}LiF grains for capturing the neutrons.

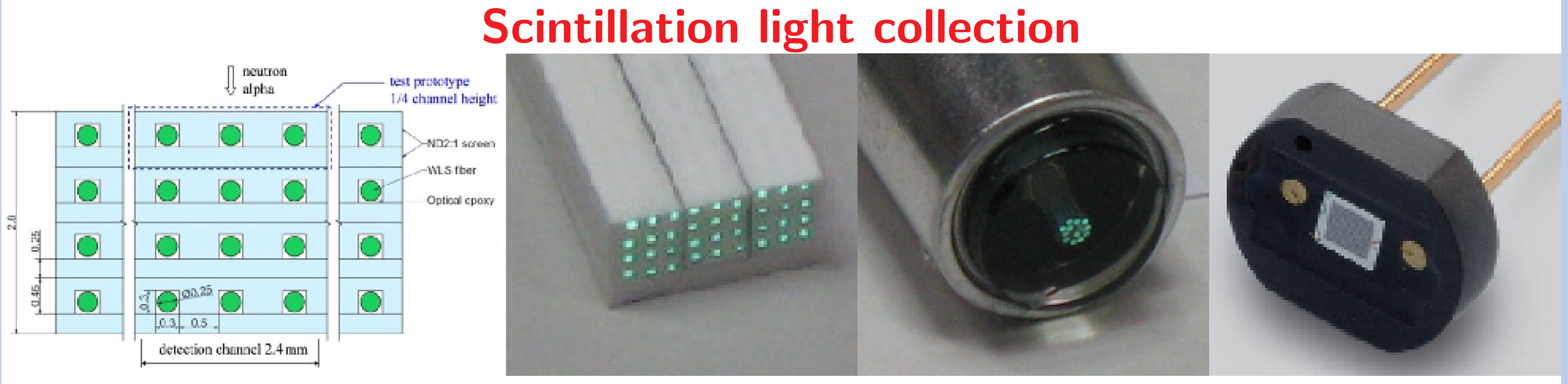
Description of the ZnS(Ag):^{6}LiF scintillator

- High ^{6}Li concentration: 1.4 x 10^{22} atoms/cm^3
  -> With a 3 mm thick scintillator, neutron absorption probability ~ 85% at 1.2 Å.
- High light yield: 160'000 photons / neutrons.
- Long emission time: 25% (60 %) of the photons are emitted in the first 1 μs (10 μs).
  -> Single photon counting is possible.
- 0.4 mm of scintillator is almost opaque.
  -> Embedded WLS fibres to collect the scintillation light.

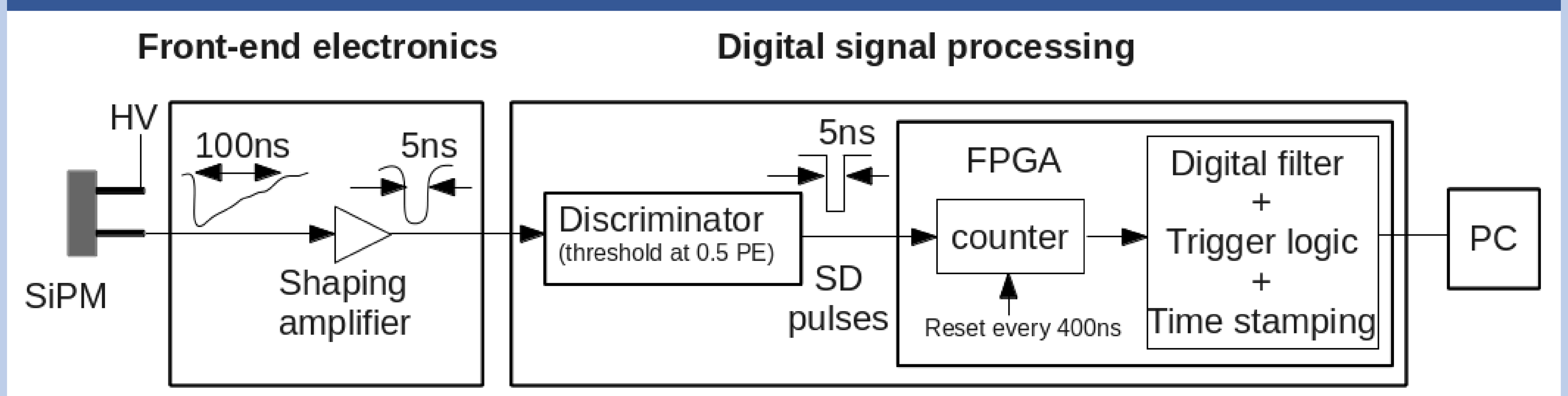


^{6}Li + n -> ^{3}H + α-particle
E_{triton} = 2.75 MeV, E_α = 2.05 MeV
$\sigma_{capture}$ = 940 barns at 1.8 Å

Scintillation light collection



Principle of the signal processing system (SPS)



The SPS is based on a photon counting approach. During each consecutive time slices of 400 ns (for example), the number of SD pulses is measured, i.e., the density in time of photons or SiPM dark counts is sampled. Once sampled, the signal is digitally filtered and the following triggering conditions are ANDed:

- The channel is ready. (After each trigger, an artificial dead time is introduced to prevent multiple triggers on same events.)
- The filter output is maximum. (maximum ->event time stamp)
- The filter output is higher than the threshold.

Digital filters under evaluation

x_i = filter input, z_i filter output

a) Moving sum $z_i = z_{i-1} + x_i - x_{i-M}$

b) Moving sum after differentiation
$y_i = x_i - x_{i-M}$ $z_i = z_{i-1} + y_i - y_{i-M}$

c) Discret-time implementation of a CR-RC^4 analog filter

$$y_i = b_1 y_{i-1} + b_2 y_{i-2} + b_3 y_{i-3} + b_4 y_{i-4} + b_5 y_{i-5} + a_1 x_{i-1} + a_2 x_{i-2} + a_3 x_{i-3} + a_4 x_{i-4}$$

a_i and b_i are non integer constants involving the time constant RC and the sampling interval [5].

Requirements for the filters:

- Background rate $< 10^{-3}$ Hz
- Prob. of multiple triggers $< 10^{-3}$
- Short dead time
- High trigger efficiency even for SiPM dark count rates up to ~ 2 MHz. (SiPM dark rate is expected to increase from ~ 100 kHz initially up to ~ 2 MHz after several years of operation due to radiation damage.)

Evaluation results of the difital filters

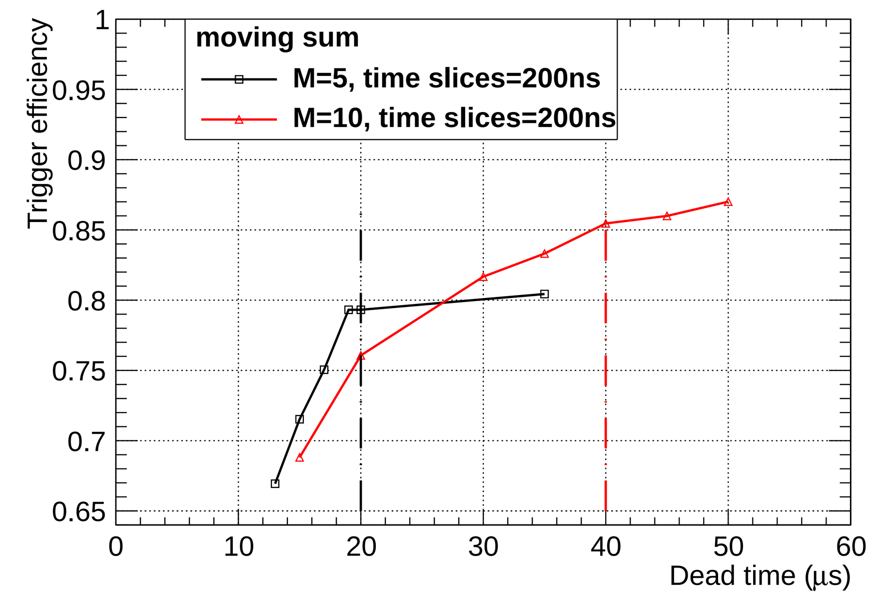
The evaluation uses real data:

- SiPM dark rate = 64kHz
- neutron rate = 20 Hz
- 10'000 events

The data provide, for each detected neutron, the temporal sequence of SD pulses produced during the 80 μs following the neutron capture.

In order to evaluate the performances at different SiPM dark rates, temporal sequences of dark counts are simulated and merged with the measured data.

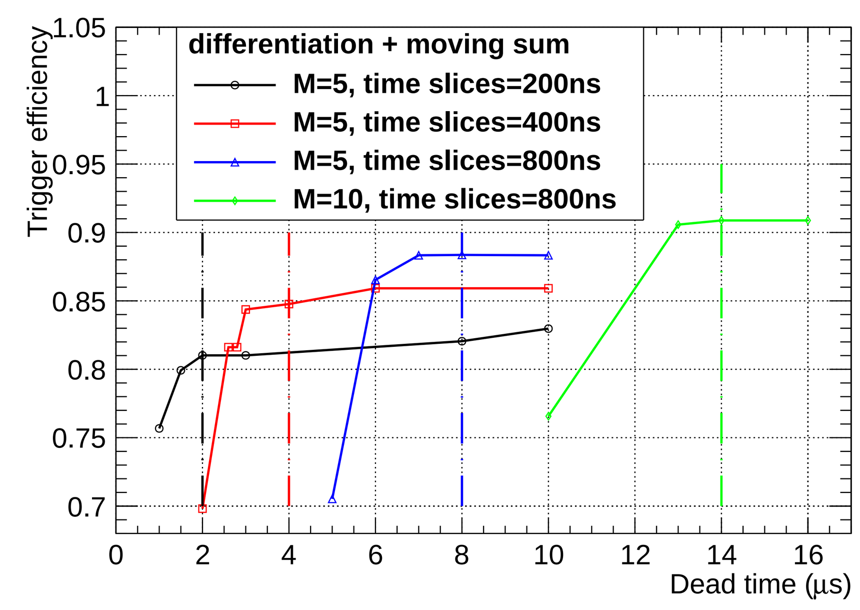
Dead time

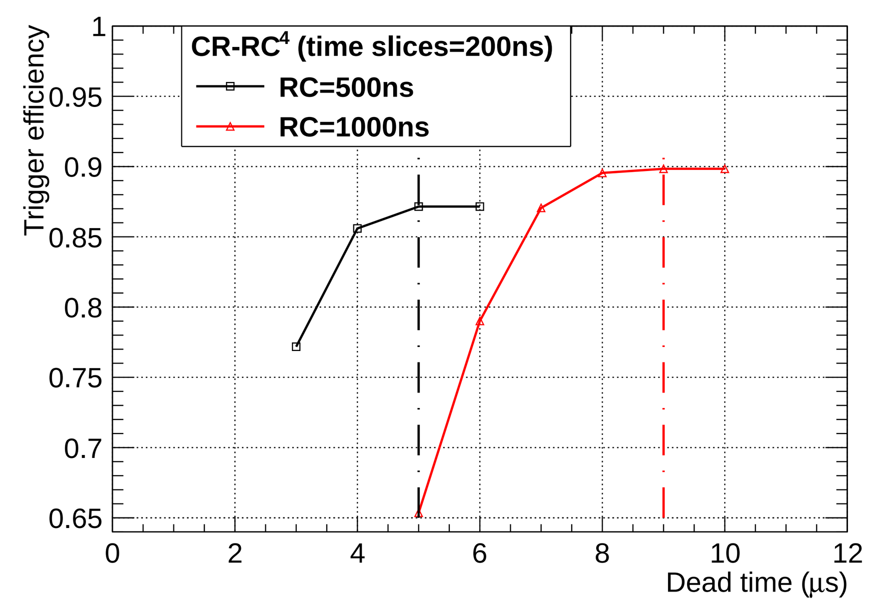


Conditions:

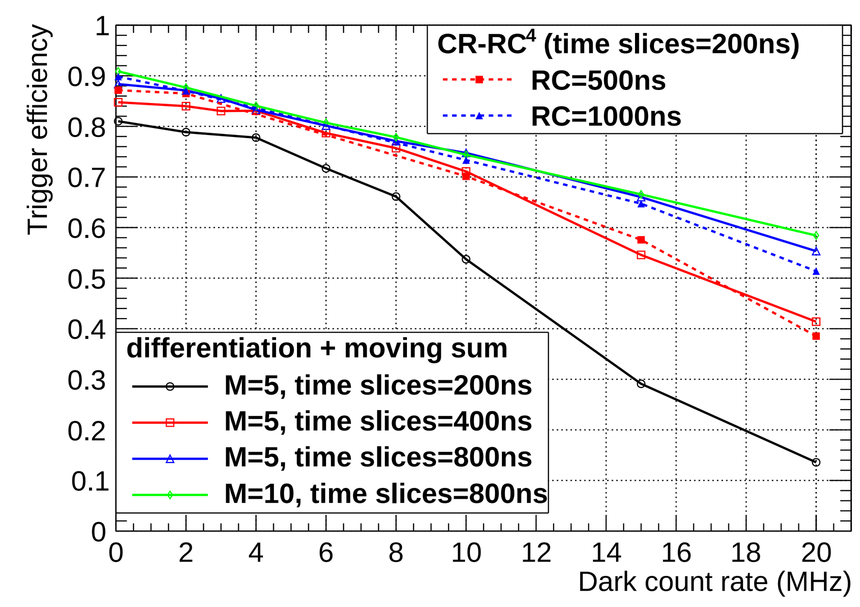
- SiPM dark rate = 63 kHz
- prob. of multiple triggers $< 10^{-3}$

The vertical lines denote the value of the dead time which is chosen for each filter.

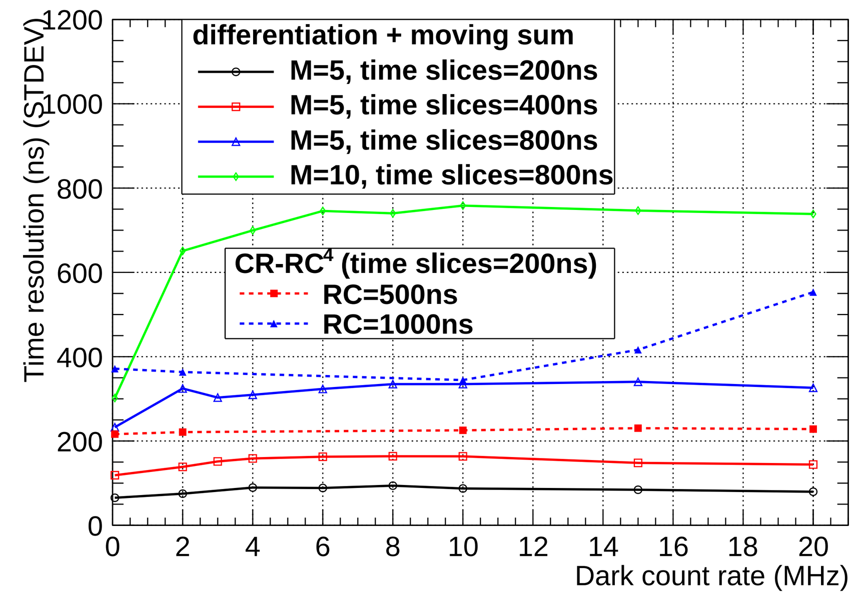


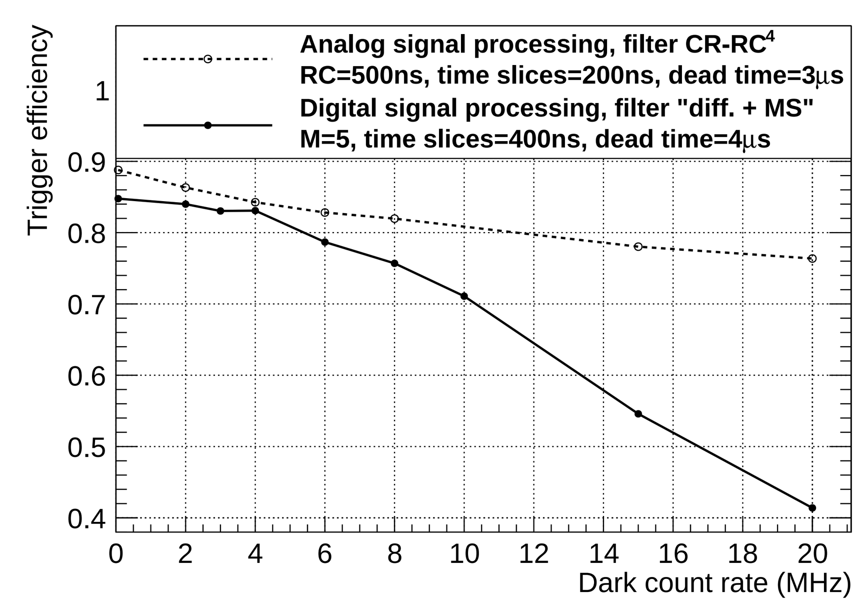


Trigger efficiency



Time resolution





Digital vs analog signal processing

To estimate the performances of an analog pulse processing, the measured data are corrected for the 12 ns dead time of the photon counting process and the effect of the SiPM crosstalk is added. The discret-time implementation of the CR-RC^4 filter is then used to mimic an analog readout with a CR-RC^4 filter.

Conditions: • Background rate $< 10^{-3}$ Hz • prob. of multiple triggers $< 10^{-3}$

Conclusion

The filter "moving sum" requires a too long dead time. The filter "moving sum after differentiation" has about the same performances as the digital filter "CR-RC^4" and it has the advantage to require much less computational ressources. The analog and digital signal processing have about the same performances up to a SiPM dark rate of ~ 6 MHz.

References

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[2] J.-B. Mosset, et al., *J. of Phys.: Conf. Series*, 528 (2014) 012041.
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