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Count rate capability of a ZnS:^{6}LiF based scintillation neutron detector read out with a SiPM

International Workshop on Position Sensitive Neutron Detectors 2018
Jülich, May 15th – 17th 2018

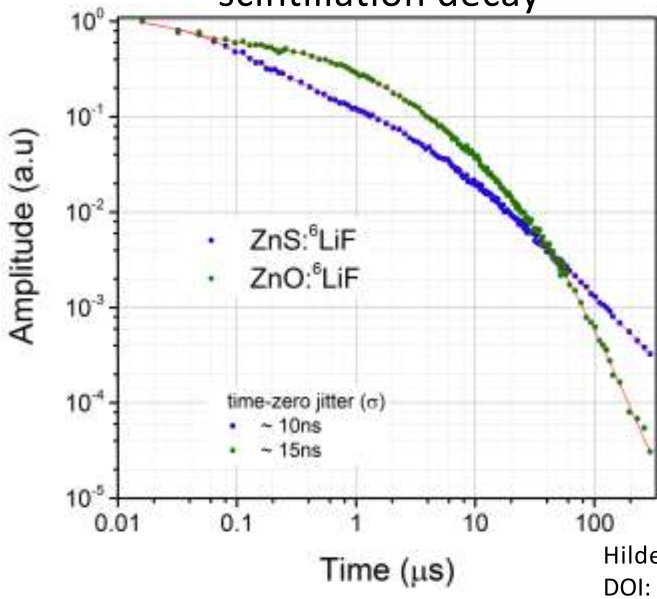
Motivation

- generally accepted that count rate capability of $ZnS{:}^{6}LiF$ neutron detectors is strongly limited due to the long afterglow of the scintillator
- solution of this problem was expected in the direction of faster scintillators, like e.g. $ZnO{:}^{6}LiF$ → triggered by J. Sykora *et al*. (2016, 2018)

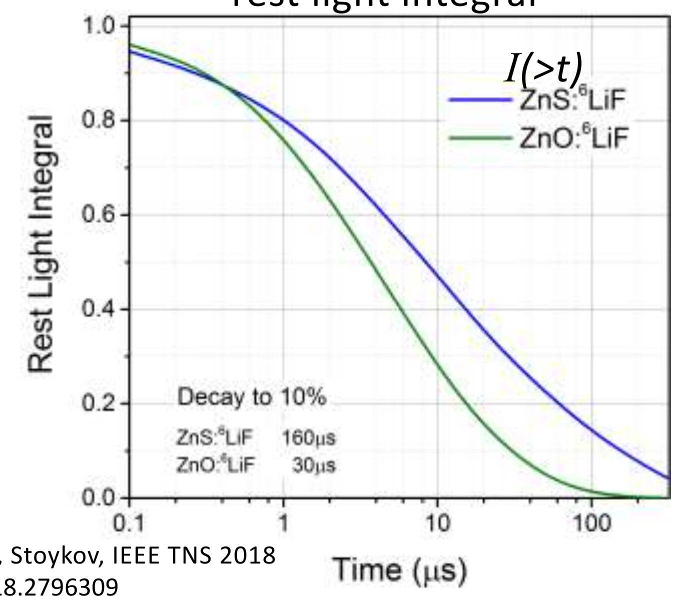
Motivation

- generally accepted that count rate capability of ZnS:^{6}LiF neutron detectors is strongly limited due to the long afterglow of the scintillator
- solution of this problem was expected in the direction of faster scintillators, like e.g. ZnO:^{6}LiF → triggered by J. Sykora *et al*. (2016, 2018)
- own measurements confirm decay curves and rest light integrals of ZnS and ZnO
  → in case of short integration or coincidence times: $I(>t)_{ZnS} \approx I(>t)_{ZnO}$
  → higher light yield of ZnS is advantageous for signal processing

scintillation decay



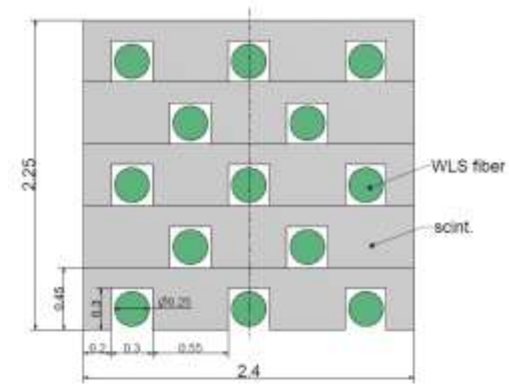
rest light integral

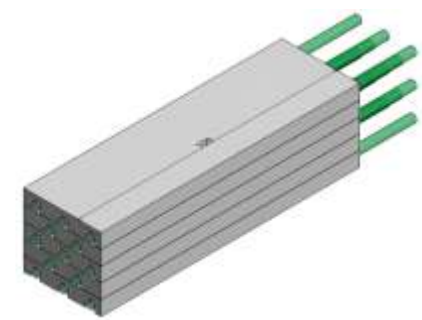


Hildebrandt, Mosset, Stoykov, IEEE TNS 2018
DOI: 10.1109/TNS.2018.2796309

ZnS:^{6}LiF Neutron Scintillation Detector

- pixelated approach
- ZnS(Ag):^{6}LiF (ND2:1) scintillation screen (Scintacor)
  - 0.45 mm thickness and machined grooves
- WLS fibres Y11(400)M (Kuraray)
  - Ø = 0.25 mm
  - embedded in grooves of scintillator
- Eljen EJ500 optical epoxy
- detection unit
  - front side: fibers polished and mirrored
  - rear end: 13 fibres bundled, polished and coupled to individual SiPM





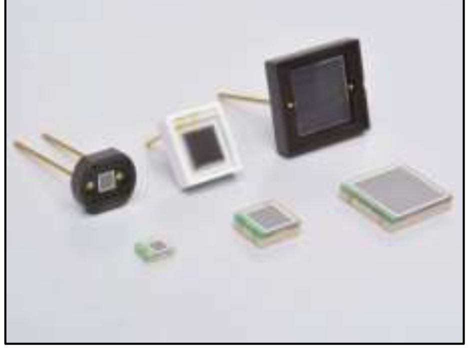
→ high neutron absorption efficiency

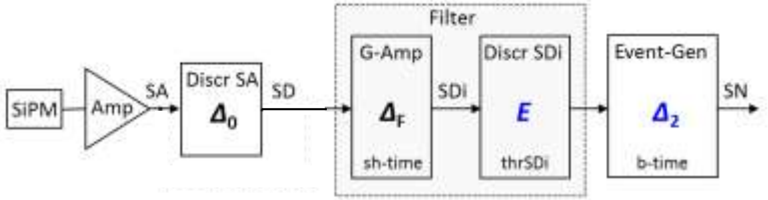
→ efficient, high and uniform light collection

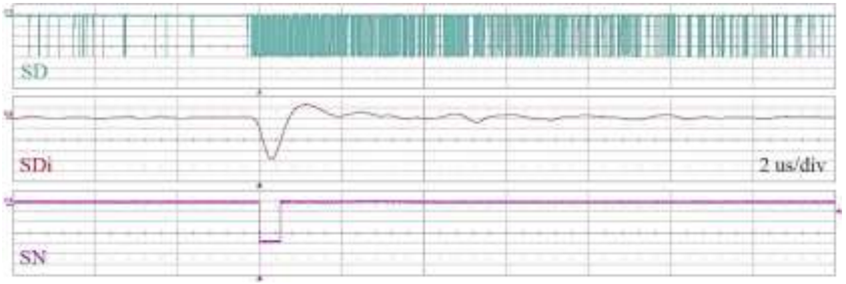
Photo Sensor and Signal Processing System

- SiPM used as photo sensor
  (Hamamatsu MPPC S13360-1350PE)
  → single photon counting capability
- each channel equipped with
  - individual SiPM
  - individual (FPGA-based) signal processing
  → individual channel readout, no coding
  → high count rate capability

Hamamatsu S13360 series







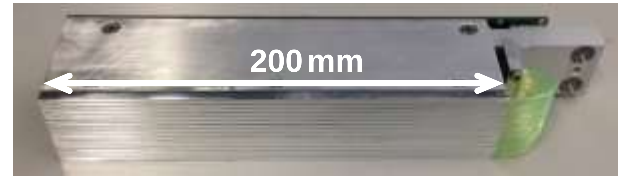
Discr SA input discriminator (dead time Δ_0 = 10 ns)
G-Amp Gaussian shaping amplifier (dead time Δ_F)
Discr SDi leading-edge discriminator (trigger efficiency E)
Event-Gen non-retriggerable mono-flop (dead time Δ_2)
n rate of detected events

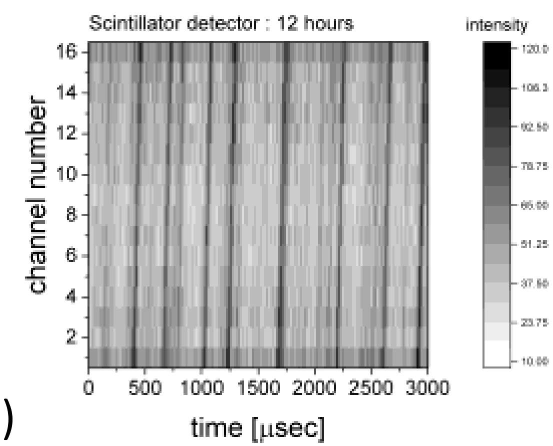
sh-time = 0.25 μs
b-time = 0.5 μs
n ≈ 10 Hz

Performance (1D Detector)

- achieved detector performance
  - 1D, gapless, individual pixel readout
  - individual long pixels (2.5 mm, 200 mm)
  - detection efficiency, 1 (8) Å — 65 (80) %
    - absorption probability, 1 (8) Å — 80 (100) %
    - trigger efficiency — 80 %
  - background count rate — ≤ 10^{-3} Hz
  - gamma-sensitivity (^{60}Co) — ≤ 10^{-7}
  - multi-count ratio — ≤ 10^{-3}
  - time resolution — < 1 μs
  - count rate capability — up to 10 kHz/ch
  - sustainable SiPM dark count rate — < 6 MHz
  - SiPM lifetime — > 10 years

Stoykov, Mosset, Hildebrandt, IEEE TNS 63(4), 2016, 2271-2277

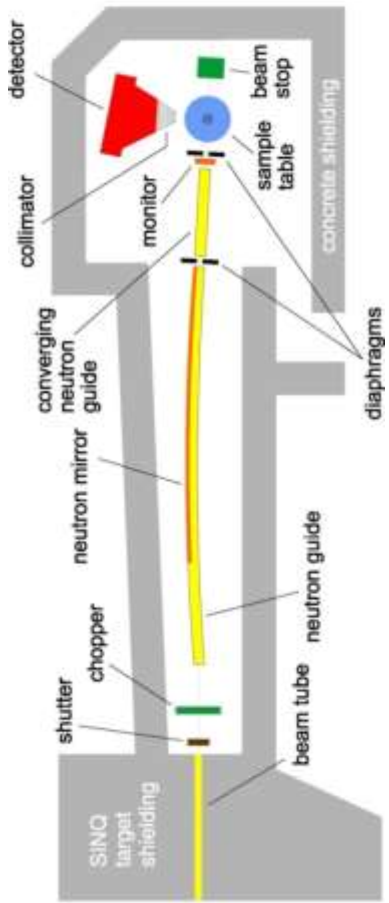


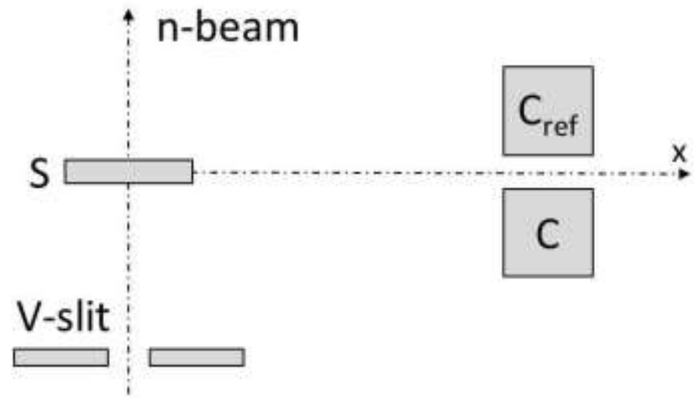


→ test of count rate capability (not yet constrained) with optimized electronics settings

Measurement Setup

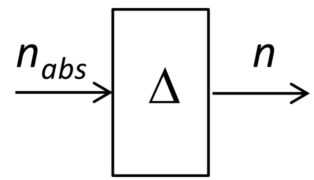
- POLDI beam line at Neutron Spallation Source SINQ (PSI)

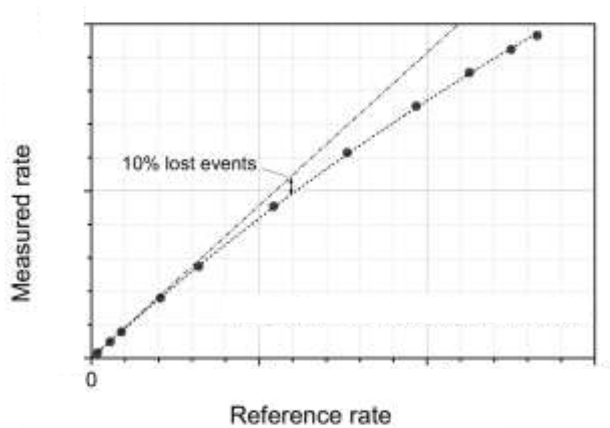




n-beam	neutron beam beam rates varied with vertical slits (V-slits)
S	Plexiglas sample
C_{ref}	reference detector: GS20 ^{6}Li-glass (Scintacor), $(2\times2\times50)$mm^3, SiPM
C	ZnS scintillation detector under test

Count Rate Capability



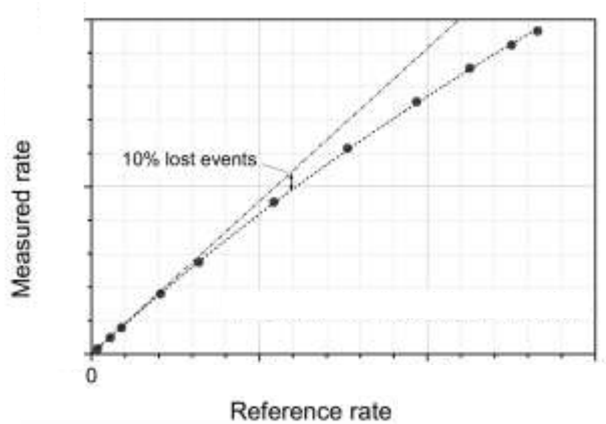


$$n = \frac{n_{abs}}{1 + n_{abs}\,\Delta}$$

n_{abs}	neutron absorption rate
n	rate of detected events

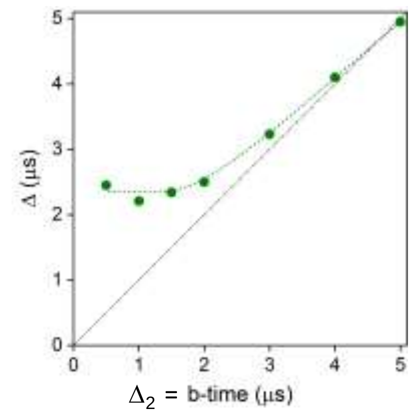
Count Rate Capability

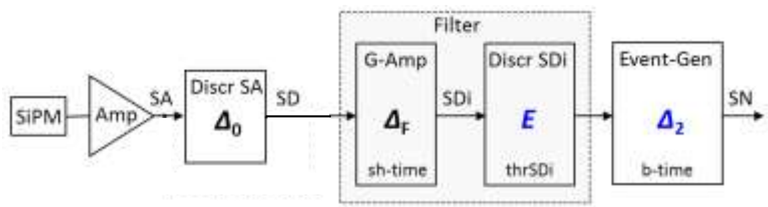
$$n_{abs} \longrightarrow \boxed{\Delta} \longrightarrow n$$



$$n = \frac{n_{abs}}{1 + n_{abs}\,\Delta}$$

but: $\Delta > \Delta_2$





Discr SA	input discriminator (dead time $\boldsymbol{\Delta_0}$ = 3 ns, instead of 10 ns)
G-Amp	Gaussian shaping amplifier (dead time $\boldsymbol{\Delta_F}$)
Discr SDi	leading-edge discriminator (trigger efficiency $\boldsymbol{E}$)
Event-Gen	non-retriggerable mono-flop (dead time $\boldsymbol{\Delta_2}$)
$\boldsymbol{n_{abs}}$	neutron absorption rate
$\boldsymbol{n}$	rate of detected events

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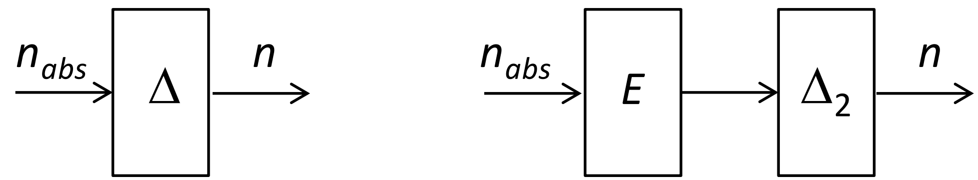
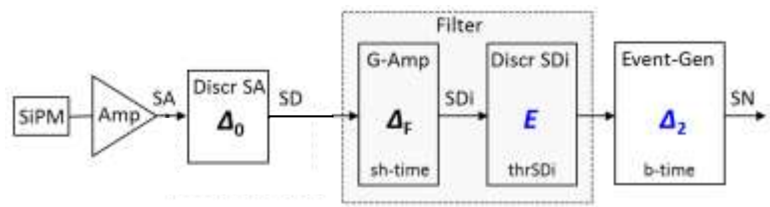
Count Rate Capability



$$n = \frac{n_{abs}}{1 + n_{abs}\,\Delta}$$

$$n = \frac{E\, n_{abs}}{1 + E\, n_{abs}\,\Delta_2}$$



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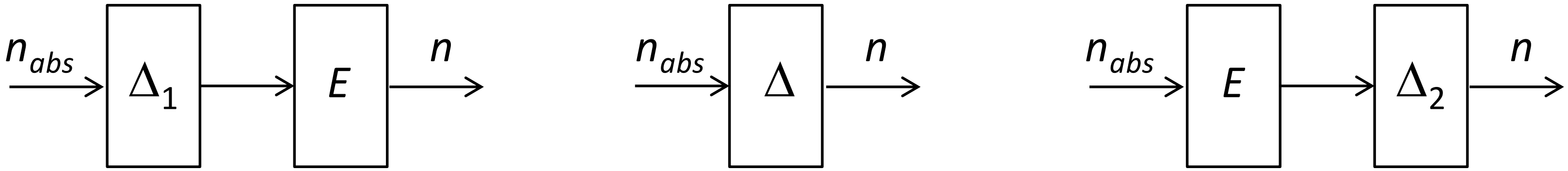
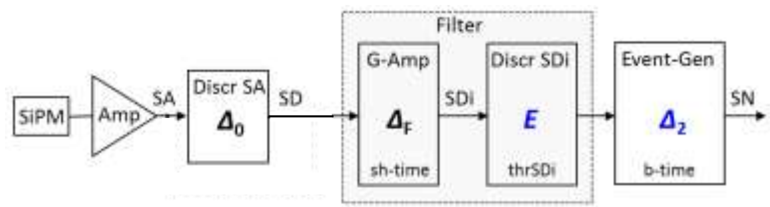
Count Rate Capability



$$n = E \frac{n_{abs}}{1 + n_{abs}\,\Delta_1}$$

$$n = \frac{n_{abs}}{1 + n_{abs}\,\Delta}$$

$$n = \frac{E\,n_{abs}}{1 + E\,n_{abs}\,\Delta_2}$$



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Event-Gen	non-retriggerable mono-flop (dead time $\boldsymbol{\Delta_2}$)
$\boldsymbol{n_{abs}}$	neutron absorption rate
$\boldsymbol{n}$	rate of detected events
Δ_1	$= \Delta_0 + \Delta_F$

Count Rate Capability

$$n_{abs} \longrightarrow \boxed{\Delta_1} \longrightarrow \boxed{E} \xrightarrow{\;n\;}$$

$$n_{abs} \longrightarrow \boxed{\Delta} \xrightarrow{\;n\;}$$

$$n_{abs} \longrightarrow \boxed{E} \longrightarrow \boxed{\Delta_2} \xrightarrow{\;n\;}$$

$$n = E \frac{n_{abs}}{1 + n_{abs}\,\Delta_1}$$

$$n = \frac{n_{abs}}{1 + n_{abs}\,\Delta}$$

$$n = \frac{E\,n_{abs}}{1 + E\,n_{abs}\,\Delta_2}$$

$$n_{max} = \frac{0.1\,E}{\Delta_1}$$

$$n = \frac{E\,n_{abs}}{1 + 0.1\,E\,n_{abs}/n_{max}}$$

$$n_{max} = \frac{0.1}{\Delta_2}$$

n_{abs}	neutron absorption rate, $n_{abs} = k\, n_{ref}$
n	rate of detected neutron
n_{max}	max. rate at 10% event losses
n_{ref}	rate in fast reference detector corrected for dead time

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Count Rate Capability

$$n_{abs} \longrightarrow \boxed{\Delta_1} \longrightarrow \boxed{E} \longrightarrow n$$

$$n_{abs} \longrightarrow \boxed{\Delta} \longrightarrow n$$

$$n_{abs} \longrightarrow \boxed{E} \longrightarrow \boxed{\Delta_2} \longrightarrow n$$

$$n = E \frac{n_{abs}}{1 + n_{abs}\,\Delta_1} \qquad n = \frac{n_{abs}}{1 + n_{abs}\,\Delta} \qquad n = \frac{E\,n_{abs}}{1 + E\,n_{abs}\,\Delta_2}$$

$$n_{max} = \frac{0.1\,E}{\Delta_1} \qquad n_{max} = \frac{0.1}{\Delta_2}$$

$$n = \frac{E\,n_{abs}}{1 + 0.1\,E\,n_{abs}/n_{max}}$$

$$\boxed{n = \frac{k\,E\,n_{ref}}{1 + 0.1\,k\,E\,n_{ref}/n_{max}}}$$

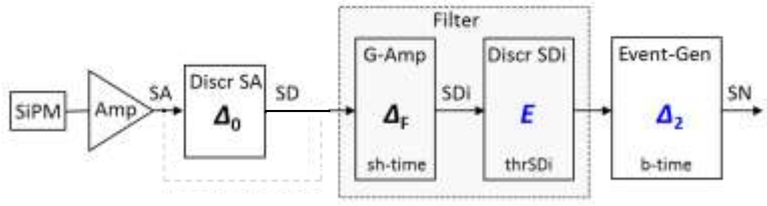
n_{abs} neutron absorption rate, $n_{abs} = k\,n_{ref}$

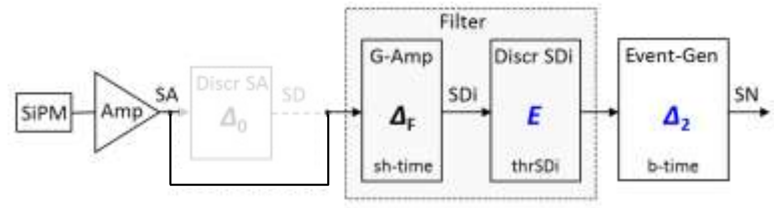
n rate of detected neutron

n_{max} max. rate at 10% event losses

n_{ref} rate in fast reference detector corrected for dead time

Measurements





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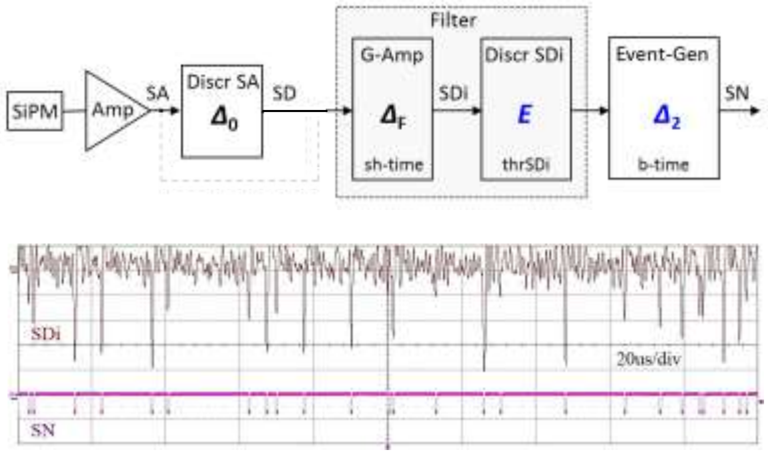
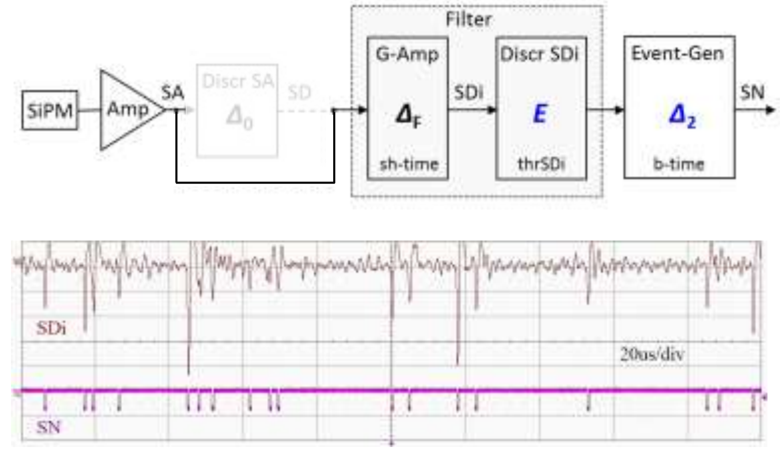
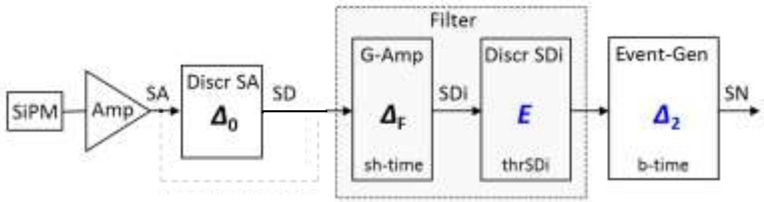


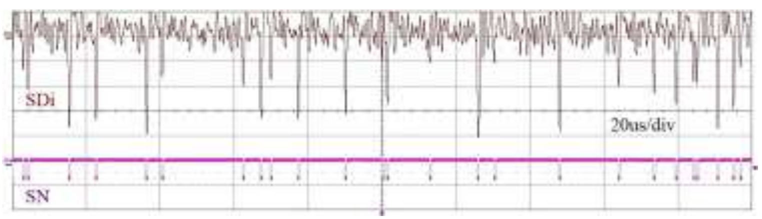
sh-time = 0.25 μs, b-time = 0.5 μs, n ≈ 95 kHz



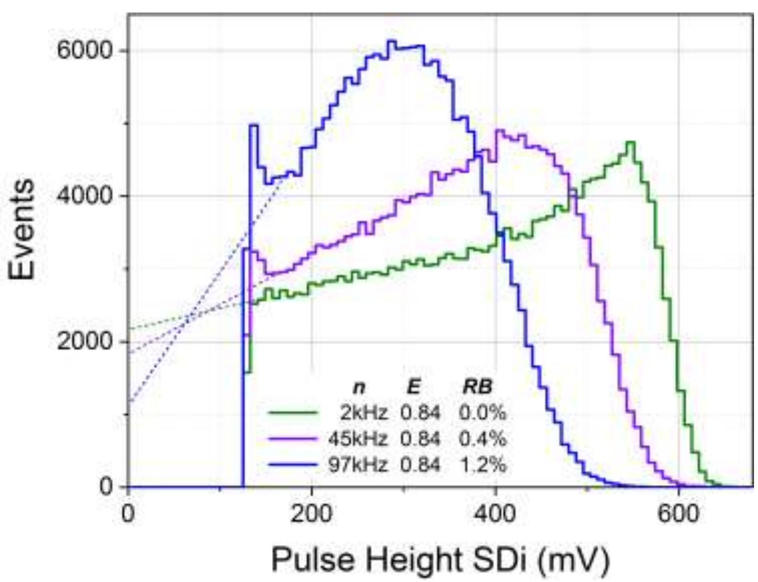
sh-time = 0.5 μs, b-time = 0.5 μs, n ≈ 80 kHz

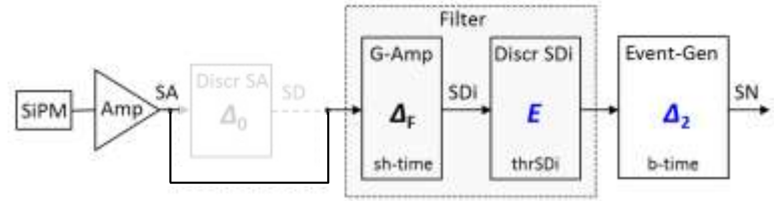
Measurements

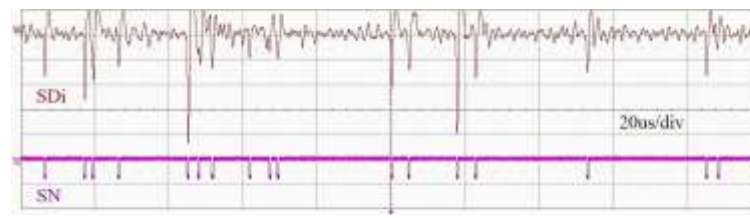




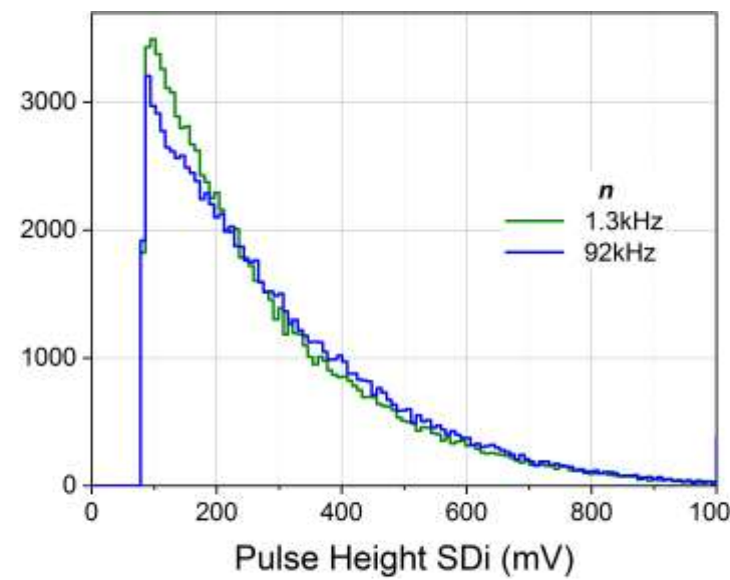
sh-time = 0.25 μs, b-time = 0.5 μs, n ≈ 95 kHz







sh-time = 0.5 μs, b-time = 0.5 μs, n ≈ 80 kHz



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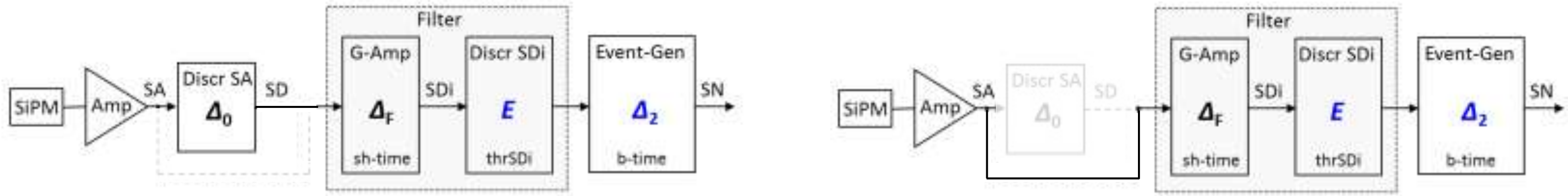

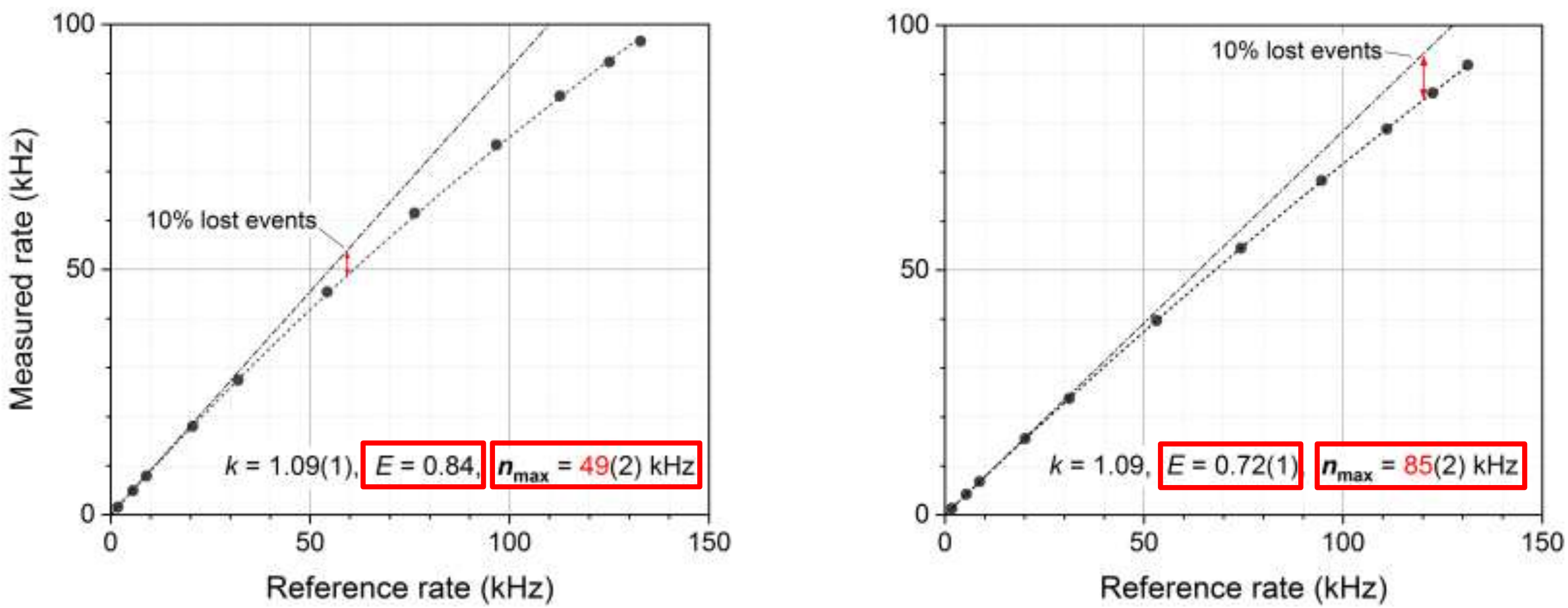

trigger efficiency ≈ 84 % n_{max} ≈ 50 kHz

Summary

- scintillation decay curves of ZnS and ZnO based neutron scintillators were measured
- count rate capability of a ZnS:^{6}LiF pixelated neutron scintillation detection unit was measured
- a maximum count rate of ~50 kHz (@10 event loss) could be achieved, still allowing a trigger efficiency above 80 %
- further studies and full characterisation, including e.g. γ-sensitivity, are still needed for high rate case

Teams and Support

detector

- Alexey Stoykov
- Jean-Baptiste Mosset
- M. H.
- Dieter Fahrni
- Andi Hofer

electronics

- Urs Greuter
- Alexey Gromov
- Nick Schlumpf

POLDI beamline scientist

- Tobias Panzner

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