Photodetection characterisation of SiPM technologies for their application in scintillator based neutron detectors

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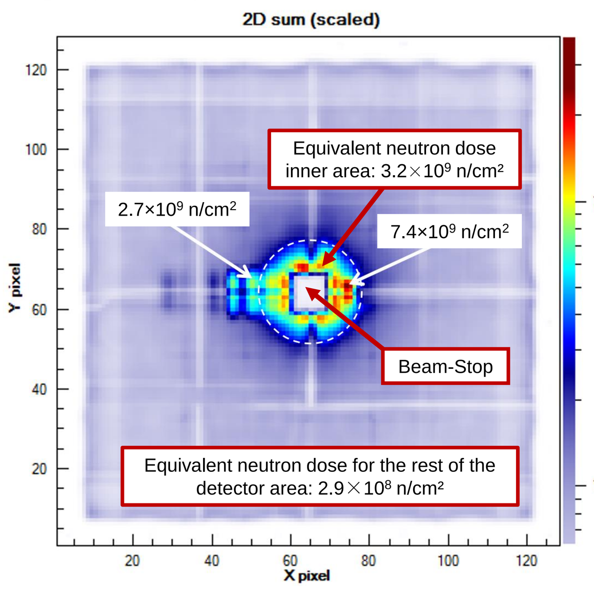
Motivation

The world-wide shortage of ^{3}He gas has triggered research on novel approaches for thermal and cold neutron detection. We propose using a pixelated solid-state scintillation detector consisting of a monolithic 1 mm thick Ce-doped ^{6}Li-glass scintillator covering a pixelated Silicon Photomultiplier (SiPM) based photodetector array [1] to detect the elastically scattered cold neutrons as used in *Small Angle Neutron Scattering* (SANS) experiments carried out at the KWS-1 instrument [2] of the *Heinz Maier Leibnitz Zentrum* (MLZ) in Garching, Germany. The main risk defined so far for using this technology is its performance under irradiation with thermal or cold neutrons. We quantified this issue based on photon detection efficiency (PDE).



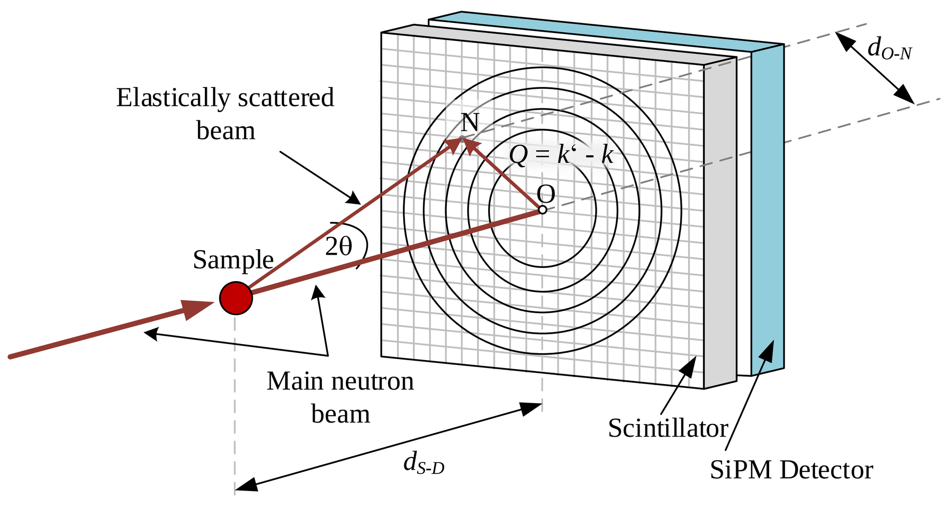


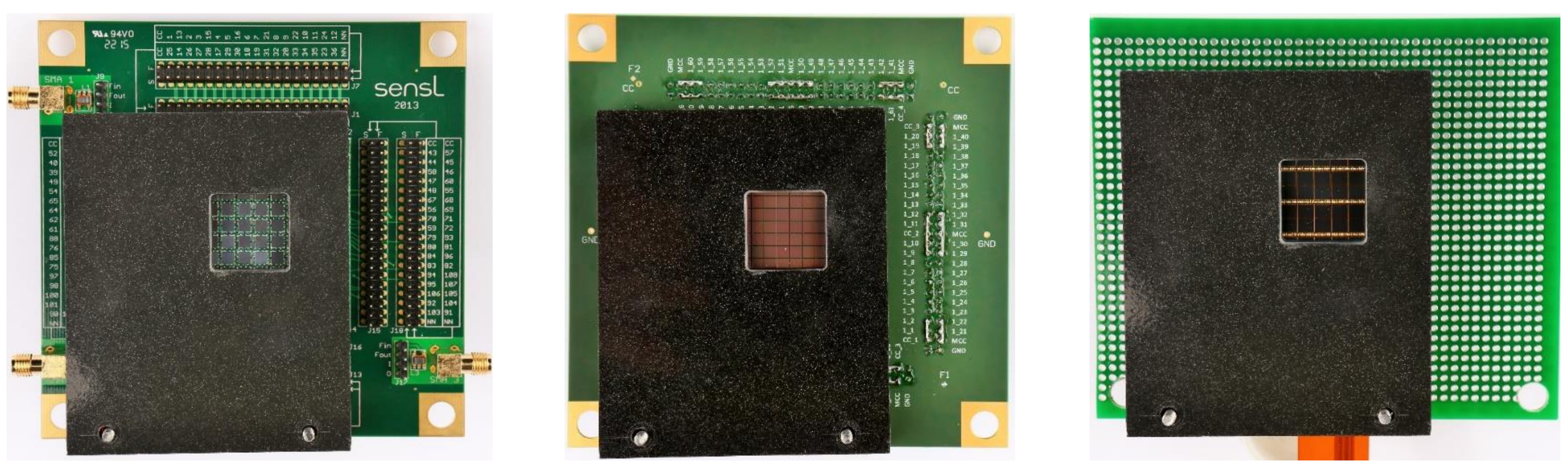
Fig. 1 Cold neutrons (λ_n = 5 Å) total dose detected during 240 days of constant operation (2014 – 2015) across different experiments by the 60 x 60 cm² active area PMT based scintillation *Anger* detector installed at the KWS-1 instrument (MLZ), scaled up with a factor of 14.2 for upper limit estimation, considering a source aperture of 5×5 cm² and shorter collimation distances [1].

Fig. 2 Schematic representation of a scintillation based solid-state detector proposed to be used in *Small Angle Neutron Scattering* (SANS) experiments [1].

Experimental Setup

Three different SiPM technologies (two analog and one digital) under test:

SiPM technology under study	(a) *SensL* Series-C array C-30035-144P-PCB	(b) *Hamamatsu* MPPC array S12642-0808PB-50	(c) *Philips* DPC3200-22-44
Array format	12 × 12	8 × 8	8 × 8
Pitch of each individual detector, mm	4.2	3.2	4.0
Array package size (4-side tileable), mm²	50.2 × 50.2	25.8 × 25.8	32.6 × 32.6
Active area of each individual sensor (pixel), mm²	3 × 3	3 × 3	3.2 × 3.8
Microcell size, µm	35	50	59.4 × 64
No. of micro-cells	4774	3464	3200
Micro-cell fill-factor, %	64	62	74
Detector fill-factor, %	51	87.9	76



(a) (b) (c)

Fig. 3 Photographs of the 3 chosen SiPM arrays covered by a 6 mm thick boron-carbide plate during exposure to neutron beams [1].

Measurement System

In order to evaluate the PDE of three technologies under study a customized measurement system was developed by aSpect Systems GmbH.

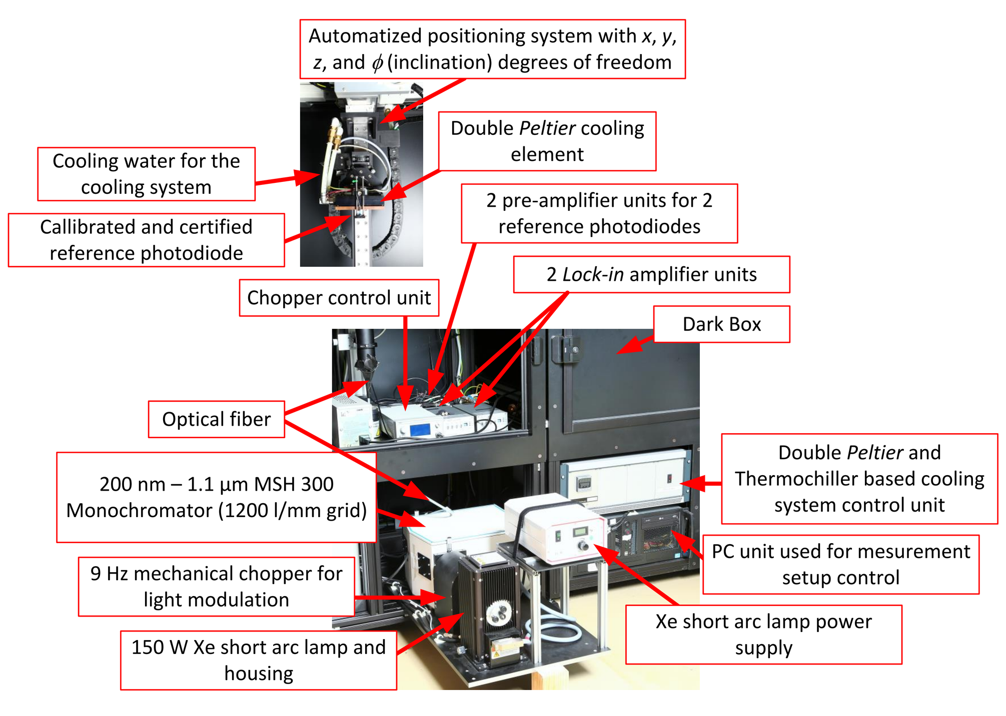


Fig. 4 Photograph of the different parts of the customized measurement system developed by the company *aSpect Systems GmbH* for monochromatic PDE evaluation in the wavelength range between 300 nm and 1.1 µm.

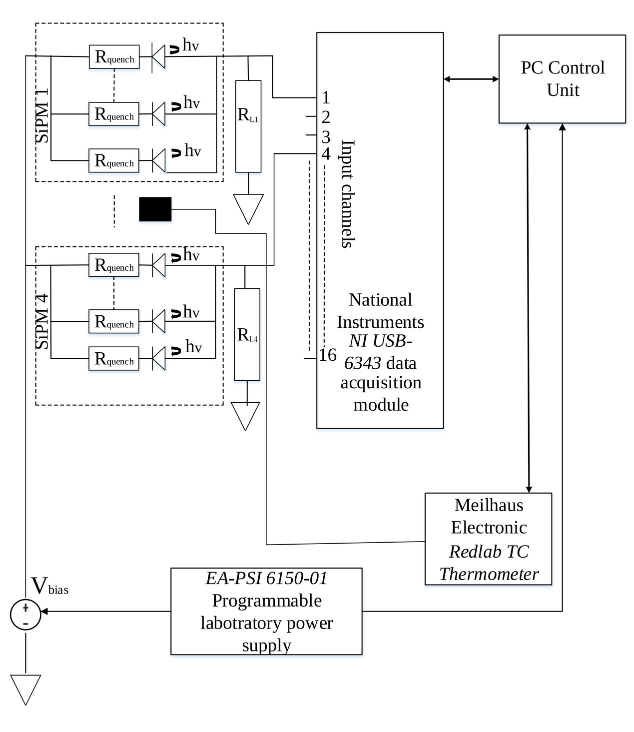


Fig. 5 Schematic of the experimental setup for current (I_{out}-V_{bias}) measurements for 4 SiPMs of analog photodetector modules.

Measurement Principle

By using certified spectral responsivity of a reference photodiode, irradiance was calculated by the measurement system and was correlated with the SiPM arrays.

$$PDE = \frac{Ph_i}{Ph_d}$$

Where Ph_i is the number of photons impinging on the SiPM arrays and Ph_d is the number of photons detected by the SiPM. For the determination of the number of detected photons, photon counting approach was used for the digital SiPM (PDPC) by using the tile evaluation kit (TEK) provided by the manufacturer along with the SiPM array, whereas the photocurrent method was performed for the analog SiPM arrays, in which Geiger mode current calculated via I-V curve was divided by the gain.

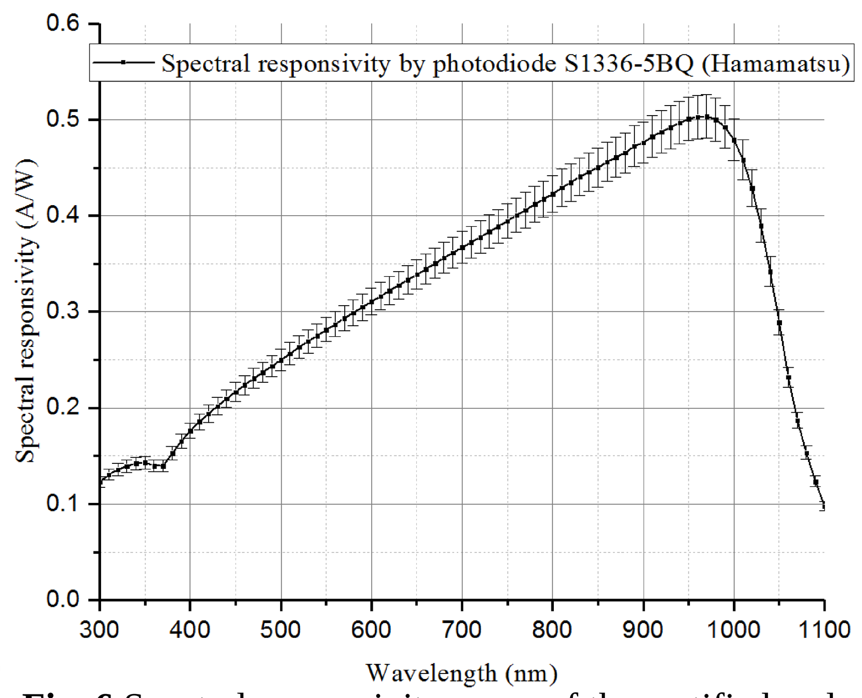


Fig. 6 Spectral responsivity curve of the certified and calibrated photodiode *S1336-5BQ (Hamamatsu)* for finding the incident photon flux on the SiPM arrays.

Photodetection Efficiency

We obtained the wavelength dependent PDE curve of all the non-irradiated SiPM arrays and compared it to the PDE curve of irradiated SiPM arrays under identical measuring conditions. In order to get better signal-to-noise ratio by reducing the dark currents, irradiated analog arrays were cooled down to -7°C. The plotted PDE curves constitutes the average of 4 SiPMs for all three technologies.

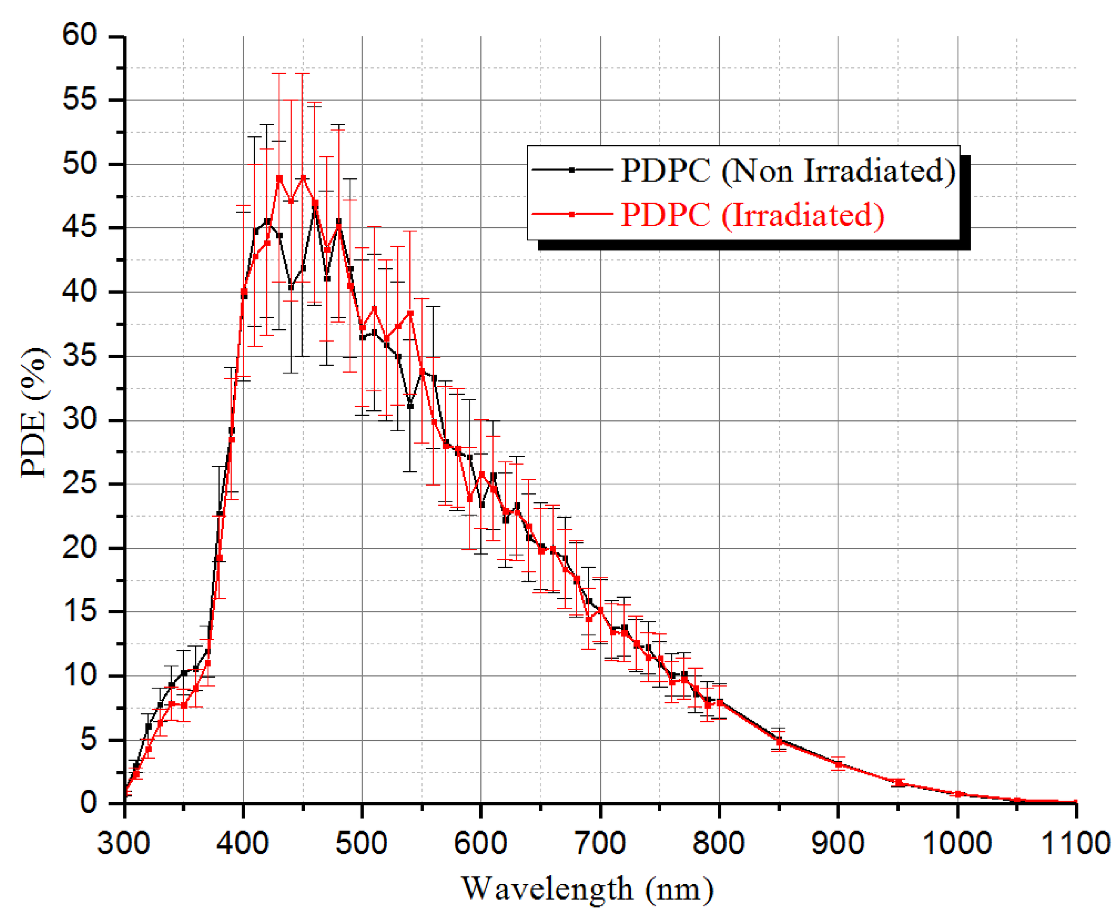


Fig. 7 Comparison of PDE curve between irradiated and non-irradiated digital SiPM (PDPC) array under identical condition @ 21°C.

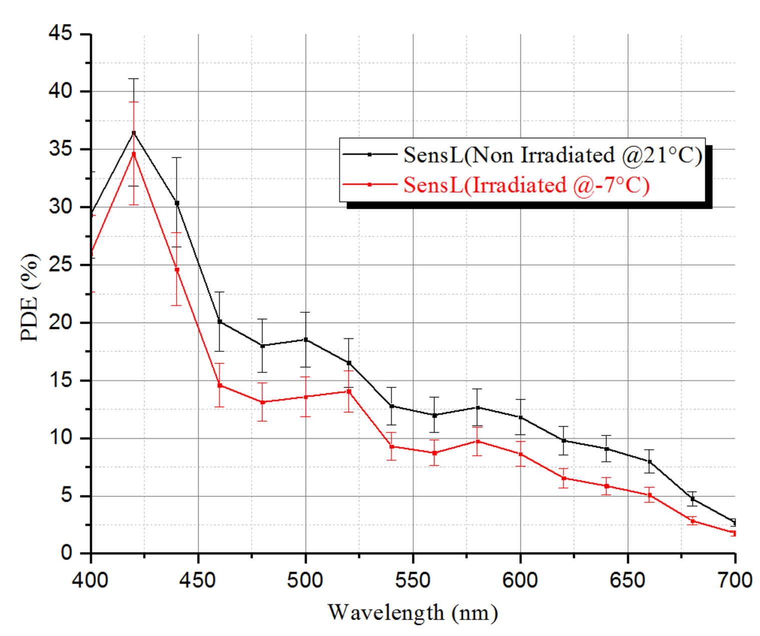


Fig. 8 Comparison of PDE curve between irradiated and non-irradiated analog SiPM array, *SensL*.

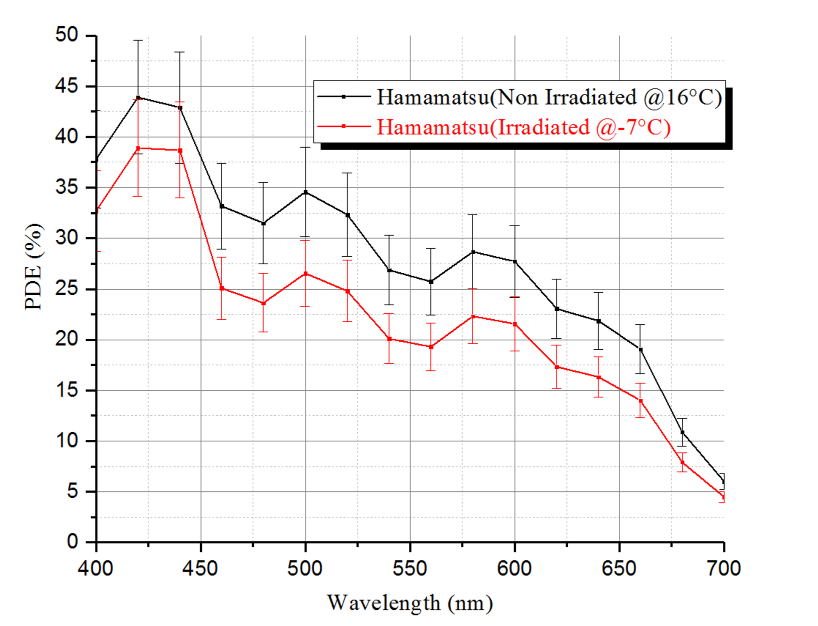


Fig. 9 Comparison of PDE curve between irradiated and non-irradiated analog SiPM array, *Hamamatsu*.

SiPM array	Relative change (%) in PDE @ 420nm	Received overall neutron doses
PDPC	3.8 ± 0.63	1.85×10^{12} n/cm²
SensL	4.9 ± 0.62	1.9×10^{12} n/cm²
Hamamatsu	11.3 ± 1.43	6×10^{12} n/cm²

Table 1: A comparative analysis of decrease in PDE for SiPM technologies due to the cold neutrons exposure.

References

[1] D. Durini et al. (2016) "Evaluation of the dark signal performance of different SiPM-technologies under irradiation with cold neutrons" *Nucl. Instr. and Meth. in Ph. Res.* A 835, pp. 99–109, http://dx.doi.org/10.1016/j.nima.2016.08.016
[2] A. V. Feoktystov et al. (2015) "KWS-1 high-resolution small-angle neutron scattering instrument at JCNS: current state", *J. Appl. Cryst.* 8, pp. 61-70, doi: http://dx.doi.org/10.1107/S1600576714025977