SiPM-based Neutron Monitors for CMS Experiment

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The 6Li-enriched scintillator coupled to the silicon photomultiplier (SiPM) was proposed to be exploited as a sensitive part of the detector dedicated to the monitoring of CMS neutron field. Four SiPM-based neutron detectors of different characteristics and vendors were commissioned at CERN lab and tested in CMS environment under full range of LHC instant luminosity conditions during Run2. Performed tests have demonstrated that all devices can potentially be used as thermal neutron detectors in harsh CMS environment.

KEYWORDS: SiPM, silicon photomultiplier, Bonner spectrometer, neutron detector

1. Introduction

Monitoring the neutron radiation field is an important task for the CMS experiment at CERN. Neutron background affects electronics situated in the experimental cavern inducing single event effect (SEU, SEL etc.). In addition, neutron flux is a main source of the background for the muon chambers, so affecting both performance and longevity of the detectors, especially for high luminosity operation.

The existing shield system of the beam pipe may have some imperfections due to mechanical constrains and necessity of the maintenance of beam pipe itself and associated equipment. Thus, there is a clear need for a distributed system of neutron monitors both around the beam shielding and in proximity to the radiation sensitive detector/electronics components.

The proposed neutron monitor is built using 6Li-enriched scintillator readout by SiPM. Recent development of SiPM, as well as experience in SiPM application in high energy physics experiments opens a possibility to use SiPM as photosensor for neutron detection [1–3].

It is essential that SiPM is insensitive to the magnetic field, what was experimentally proven up to 7 T [4]. Its compactness (order of few mm) allows to build an isotropic sensitive element of the Bonner sphere spectrometer capable to measure neutron energy from thermal to GeV range. The sensitive volume of the SiPM-based neutron detector is normally less than 1 cm3, which simplifies design and simulation of the Bonner spectrometer and allows direct comparison with passive detectors (e.g. TLD, gold foils). Low cost of the detection system (detector, readout electronics and infrastructure) gives a possibility to build an array of identical sensors, which could be easily relocated according to operational needs, and perform mapping of the neutron field.

The aim of this study was the test of existing SiPM-based neutron detectors with
different configuration to specify terms of reference for the future prototype and to spot possible issues.

We considered neutron detectors with SiPMs coupled to neutron sensitive scintillators ZnS(Ag)/\(^{6}\)LiF and LiI(Eu). In addition, Bonner spheres were used for neutron spectrum measurements.

It worth to note that SiPM itself is sensitive to radiation damages including neutron induced ones [5]. This effect should be taken into account, especially if the detector is used for a long term monitoring.

2. Devices under test

Several types of available neutron detectors based on \(^{6}\)Li-enriched scintillators coupled to SiPMs of different size and vendors were provided by SPC Doza [6], NPP KB Radar [7], Institute for Nuclear Research of the Russian Academy of Sciences INR [8] (Fig. 1). Characteristics of the tested neutron detectors are given in Table I, where MCA means a multichannel analyzer.

The detectors were commissioned at CERN lab with \(^{241}\)Am-Be and \(^{137}\)Cs (Fig. 2) sources, and installed on CMS HF platform during Run2 (Fig. 3). Experimental data were taken for full range of LHC instant luminosity – from 0 to \(\approx 20000 \mu b^{-1}s^{-1}\).

Table I. Characteristics of the tested neutron detectors.

| Prototype | #1 Doza | #2 Doza | #3 Radar | #4 INR |
|-----------|---------|---------|----------|--------|
| SiPM active area, mm\(^2\) | 6x6 | 3x3 | 3x3 | 6x6 |
| Pixel size, \(\mu m\) | 35 | 35 | 25 | 35 |
| Scintillator | LiI(Eu) | ZnS(Ag)/\(^{6}\)LiF | ZnS(Ag)/\(^{6}\)LiF | ZnS(Ag)/\(^{6}\)LiF |
| Scintillator area, cm\(^2\) | 0.127x0.3 | 0.5 | 0.1 | 10 |
| Readout | MCA | MCA | MCA, Counter | Counter |

Fig. 1. Tested neutron detectors.

Fig. 2. Test setup at the CERN lab.

Fig. 3. Detectors with and without moderators installed on CMS HF platform at \(R=2.2\) m and \(Z=14\) m.
3. Results

The figures below show preliminary results for the tested neutron detectors. Amplitude spectra were collected for the MCA-equipped devices. Spectra collected at CERN laboratory with Am-Be source are shown in green, pedestal/cosmic data are in red. Spectra collected in CMS experimental cavern are plotted in blue (Figs. 4 and 5).

The broad peak between 1700th and 2400th channels presented on Fig. 4 is caused by the interaction of the neutrons and the lithium-6 nuclei via the \(^{6}\text{Li}(n, \alpha)^{3}\text{H}\) reaction. To extract the neutron induced signals from \(\text{LiI(Eu)}\) spectrum it is then necessary to perform simultaneous measurements using identical sensor but covered by Cd-shielding or coupled to neutron-insensitive scintillator.

ZnS-based detectors (Fig.5) showed very low sensitivity to ionizing radiation, thus the neutron induced signals can be easily selected by pulse height discrimination.

![Figure 4. Amplitude spectra for the detector #1 (LiI(Eu)).](image1)

![Figure 5. Amplitude spectra for the detector #2 (ZnS(Ag)/6LiF ).](image2)

Neutron counting rate versus instantaneous luminosity for all detectors is presented on Figures 6-9. The best linearity was achieved using small area detector #3.

![Figure 6. Neutron counting rate versus instant luminosity for the detector #1.](image3)

![Figure 7. Neutron counting rate versus instant luminosity for the detector #2.](image4)
4. Conclusion

All four neutron detectors were successfully commissioned at the CERN lab and tested in CMS environment. Some preliminary results are presented, while other data are still under analysis. Technical requirements to the prototype will be formulated once data analysis will be finished.

In our opinion all devices can potentially be used as thermal neutron detectors in harsh CMS conditions. On-detector electronics has to be reduced to the bare minimum (scintillator, SiPM, analogue amplifier) and a digital part of read-out electronics should be moved to the less hostile area. Such a design allows easy replacement of the SiPM and/or scintillator in case their performance is substantially degraded due to integrated radiation damage.

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Fig. 8. Neutron counting rate per 10 seconds versus instantaneous luminosity for the detector #3.

Fig. 9. Neutron counting rate and instantaneous luminosity profile for the detector #4.