STAND FOR THE INVESTIGATION RADIATION HARDNESS OF THE PLASTIC SCINTILLATORS

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A universal stand for the measurements of scintillators has been developed. There were conducted the studies on the radiation hardness of organic plastic scintillators UPS-923A, SCSN-81, SC-301 and SC-307 based on polystyrene, and scintillators BC-408 and EJ-260 based on polyvinyl toluene on the stand.

Keywords: CMS, scintillators, SiPMs, radiation hardness

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Introduction

Modern spectrometers are designed to be operated under intense radiation field conditions. Elementary particle detectors included in these setups degrade under the influence of ionizing radiation. The determination of the radiation resistance of detector materials is the most important task that researches can come across. A wide variety of materials, which are used to develop such detectors requires numerous measurements. One of the most important aspects of these studies involves the establishment almost-real life operating conditions.

Experimental stand

Cosmic radiation is the only constant source of relativistic particles for the stand. To measure a numerous number of scintillators at a low flux density within short timeframes, we need to conduct simultaneous multiple measurements Therefore, a multi-channel universal stand was developed. The stand is constructed of nine-channel optical modules. The signals from the optical modules are sent directly to the 64-channel analog-to-digital converter (ADC), then digitized and recorded by the data acquisition system on a PC. Such a stand allowed using up to 7 such modules and measure up to 63 scintillators simultaneously.

The block-scheme of the measuring stand is shown in fig. 1 [1]. A nine-channel module represent circuit board with silicon photodetectors installed in it (fig. 2). Each module is placed in a dark-box. 3x3 mm^2 silicon photomultipliers (SiPM) S12572-015P [2] are used as photodetectors.

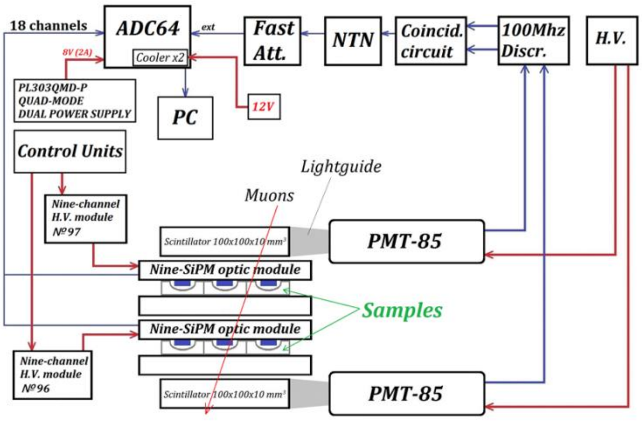

Figure 1. The block-scheme of the experimental stand

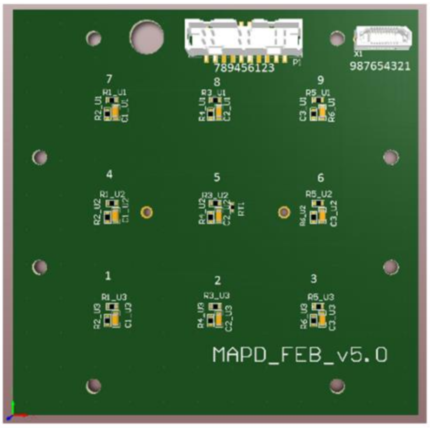

Figure 2. Nine-channel optic module

Each optical module is connected to a nine-channel high-voltage power supply board. Base voltages up to 90 V are supplied to the board via the system bus. There are nine voltage regulators on the board, which are controlled by a slow control system device. Tailored bias voltages are transmitted to all nine channels of the optical module through a short flat cable.

The temperature of the photodetectors is controlled by a thermal sensor installed on the module. It is used for the thermoregulation of the SiPM operating point displacement. The software of the system device changes the output voltage in accordance with the temperature change.

The triggering signal for the ADC is the coincidence of signals from two monitor counters that highlight the region of muon passage. Monitor counter is a 100x100x10 mm^3 scintillator, viewed with FEU-85. The scintillator is mated to the FEU-85 using a light guide.

Plastic scintillators

On the developed experimental stand it is possible to measure single plastic scintillators 30x30x3mm^3 (fig. 3, a) as well as block-samples (fig. 3, b). The block-scintillators are assembled out of nine single cells 30x30x3 mm^3, glued together with epoxy glue with a reflective additive TiO_2.

Each single scintillator sample has a dimple in the center. The dimple is a place for the photodetector and a lens which collects the light directly on the photodetector.

Scintillators based on polystyrene (SCSN-81 и UPS-923A) and scintillators based on polyvinyl toluene (BC-408 и EJ-260) were prepared by ISMA (Kharkiv) [3]. SC-301 and SC-307 samples based on polystyrene were made by IHEP (Protvino) [4]. Tyvek [5] and ESR [6] were used as reflectors for scintillators.

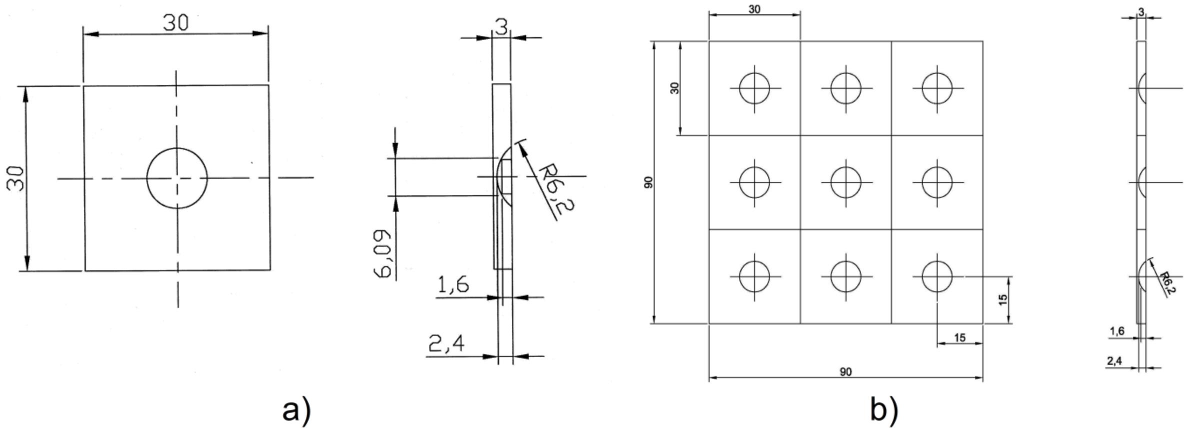

Figure 3. Drawing of scintillators: a) single samples, b) block-samples

Calibration of the measuring modules

To obtain the value of the output signal in absolute units – photoelectrons (p.e.), it is necessary to convert the values of the signal amplitude from relative units expressed in ADC channels. To do this, all channels were calibrated to a single level of light flux with a reference scintillator. The light yield (LY) of the reference scintillator was measured in fig. 5, b. Recalculation was tailored and performed using gauge coefficients for each channel of the measuring module (total 18 SiPMs).

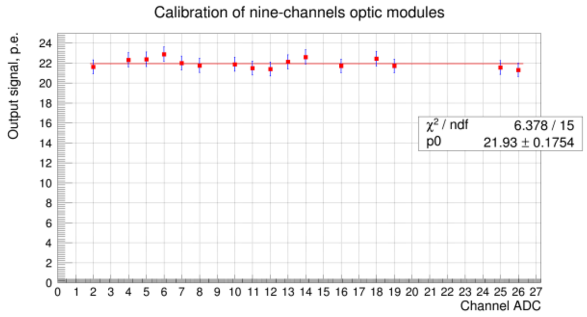

Figure 4. Calibration of measuring channels

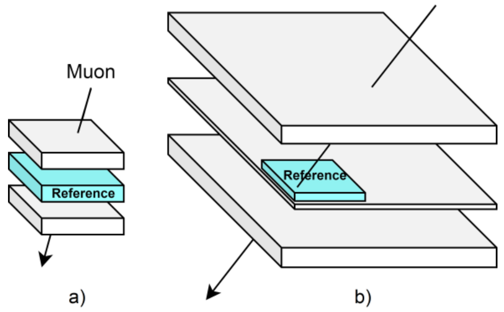

Figure 5. Transfer from single-channel module to multi-channel measuring module

A measurement error in this case includes reference scintillator calibration error δ_{ref}, sensitivity error of separate SiPMs δ_{9ch}, statistical error δ_{stat} and systematic error δ_{sys}. A systematic error is characterized by individual properties of SiPMs, which are used in the stand.

$$\delta = \delta_{ref} + \delta_{9ch} + \delta_{stat} + \delta_{sys} = 4.5\text{-}4.8\%$$

$$\delta_{ref} = 0.7\%, \ \delta_{9ch} = 0.3\text{-}1.2\%, \ \delta_{sys} = 3.2\%$$

The total error of all measurements does not exceed 5% (fig. 4).

Results of measurements on the stand

Measurements were carried out before and after irradiation of the studied scintillators. The measurement results of the scintillators before irradiation have a following form (Fig. 6, 7). The overall spread of absolute LY values is determined by the positioning of the scintillators relative to the SiPMs. It should be noted that the number of photoelectrons depends on the size of the SiPM and the size of the scintillator's dimple. For the 6.2 mm radius dimple, which we use (fig. 3, a), we had about 20 p.e. for UPS-923A samples (fig. 6) and about 22 p.e. for BC-408 samples (fig. 7).

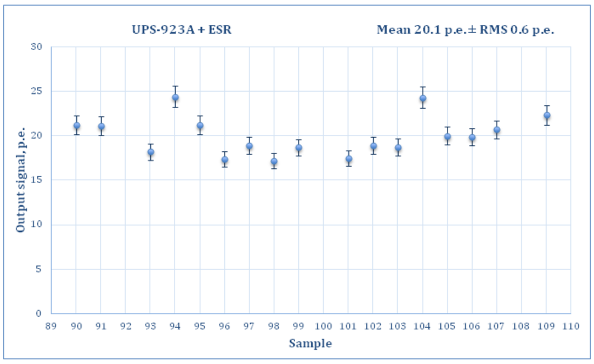

Figure 6. The absolute LY of UPS-923A samples

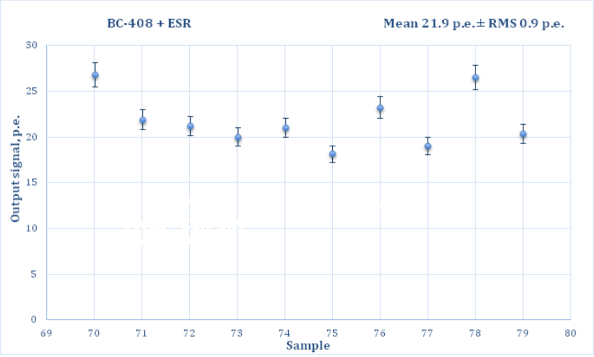

Figure 7. The absolute LY of BC-408 samples

The measurement results of the samples before and after irradiation are presented in tab. 1 (columns 4 and 7). The relative light yield (RLY) of all scintillators was normalized to the LY of BC-408 in the ESR reflector before irradiation (tab. 1, column 5) and after irradiation (tab. 1, column 9)

The irradiation was carried out in two different experiments: CMS at CERN [7] (irradiation on a scattered proton beam LHC took about 5 months) and at the IBR-2 reactor at JINR [8] (irradiation took about two weeks). The scintillators were irradiated to a dose of 0.8 Mrad.

Table 1. Measurement results of single scintillators before and after irradiation (at an irradiation dose of 0.8 Mrad)

№	1.	2.	3.	4.	5.	6.	7.	8.	9.
	Type	Reflector	#	Mean (G fit) ± RMS, p.e.	RLY	Irradiated on	Mean (G fit) ± RMS, p.e. (after irradiation)	Dose rate, kRad/h	Relative LY after irradiation
1.	BC-408	ESR	10	21.9 ± 0.9	**1.0**	IBR-2	9.3 ± 0.2	2.63	0.43
2.	EJ-260	ESR	9	25.3 ± 1.1	1.16	IBR-2	18.8 ± 0.8	2.55	0.75
3.	UPS-923A	ESR	17	20.1 ± 0.6	0.92	IBR-2	10.1 ± 0.1	2.88	0.51
4.	SC-301	ESR	10	26.7 ± 1.0	1.22	IBR-2	9.5 ± 0.2	2.64	0.36
5.	SC-307	ESR	10	24.4 ± 0.7	1.12	IBR-2	10.6 ± 0.8	2.93	0.43
6.	BC-408	Tyvek	10	11.2 ± 0.3	0.51	CMS	5.9 ± 0.1	1.28	0.53
7.	EJ-260	Tyvek	10	10.2 ± 0.2	0.47	CMS	10.2 ± 0.8	1.14	1.0
8.	UPS-923A	Tyvek	10	11.6 ± 0.5	0.53	CMS	7.3 ± 0.1	1.22	0.63
9.	SCSN-81	Tyvek	10	12.0 ± 0.3	0.55	CMS	9.7 ± 0.2	1.2	0.81

The LY of the Tyvek-wrapped scintillators (tab. 1, lines 6-8) are two times less than the equivalent ESR-wrapped scintillators (tab. 1, lines 1-3).

EJ-260 scintillators have the highest radiation hardness. The EJ-260 scintillators with a long-wavelength emission (490 nm) showed no changes of the LY at CMS experiment (table. 1, line 7). Meanwhile these scintillators irradiated in IBR-2 reactor had a small decrease of LY (table. 1, lines 2).

Scintillators with similar emission wavelength have the similar degradation behavior. So the scintillators with emission in blue area (420 nm), lose more than 50% of LY after the absorbed dose of 0.8 MRad (tab. 1, lines 1,3,4,5).

At the CMS experiment there is a similar behavior for blue scintillators. In contrast to the IBR-2, loss of LY at CMS is less. Irradiation conditions in the IBR-2 reactor are more aggressive than at CMS, which lead to an additional decrease in light output.

The LY for block-samples (tab. 2) does not differ from the LY of single samples (tab. 1, lines 1,3,6). Block-samples demonstrate similar radiation hardness relative to single scintillators.

Table 2. Measurement results of block scintillators before and after irradiation

Type	Reflector	#	Mean (G fit) ± RMS, p.e.	LY	Irradiated on	Mean (G fit) ± RMS, p.e.	Dose rate, kRad/h	Dose, MRad	Relative LY after irradiation
BC-408	ESR	16	21.4 ± 0.5	**0.98**	IBR-2	13.1 ± 0.8	1.8	0.6 *	0.6
UPS-923A	ESR	17	18.3 ± 0.6	0.91	IBR-2	10.7 ± 0.7	2.74	0.8	0.49
BC-408	Tyvek	9	11.6 ± 0.6	0.53	Not irradiated				

Conclusion

The developed stand allowed us to measure a large number of scintillators in a short-time period. Measurements were performed continuously before and after irradiation of scintillators. The stand is easy to operate, portable and reliable in operation. The obtained results are used to establish a radiation-resistant CMS Hadron Endcap Calorimeter at CERN.

References

[1] V. Ustinov, E. Sukhov, S. Afanasiev, D. Sakulin. The results of the study radiation resistance of organic scintillators based on polystyrene and polyvinyltoluene // Memories of the Faculty of Physics, Lomonosov Moscow State University, issue 6, 2019

[2] Silicon photomultiplier S12572-015P. Available at: www.hamamatsu.com/jp/en/S12572-015P (accessed 18.11.2019)

[3] Institute for Scintillation Materials. Available at: http://www.isma.kharkov.ua/about (accessed 18.11.2019)

[4] The Institute of High Energy Physics. Available at: http://www.ihep.su (accessed 18.11.2019)

[5] Tyvek reflector. Available at: http://www.dupont.ru/products-and-services/fabrics-fibersnonwovens/protective-fabrics/brands/tyvek (accessed 18.11.2019)

[6] ESR reflector. Available at http://multimedia.3m.com/mws/media/1389248O/application-guide-for-esr.pdf (accessed 18.11.2019)

[7] CMS experiment. Availed at: https://home.cern/science/experiments/cms (accessed 19.11.2019)

[8] IBR-2 Reactor. Available at: http://flnph.jinr.ru/en/facilities/ibr-2 (accessed 19.11.2019)