Nuclear Inst. and Methods in Physics Research, A 936 (2019) 563–564

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Optimal design of plastic scintillator counter with multiple SiPM readouts for best time resolution

R. Onda *, K. Ieki, T. Iwamoto, S. Kobayashi, N. Matsuzawa, Toshinori Mori, M. Nakao, M. Nishimura, S. Ogawa, W. Ootani, Y. Uchiyama

The University of Tokyo, Tokyo, Japan

ARTICLE INFO

Keywords:
Timing counter
SiPM

ABSTRACT

This study aimed to make a timing counter of the best time resolution with an about 10 cm square plastic scintillator read out by multiple SiPMs. To achieve this, SiPM connection scheme, counter geometry and difference of plastic scintillators were investigated. As a result, the best time resolution was achieved with a counter of $80 \times 175 \times 5$ mm^3 EJ-230 read out on each side by four readout channels of four SiPMs connected in series, marking $\sigma_t = 28$ ps with position dependence less than 5 ps.

Contents

1. Introduction

SiPM is widely used to read out scintillation counters. A time resolution gets better as more SiPMs are used because detected light yields increase. In order to suppress an increase in readout channels, it is desirable to readout multiple SiPMs with a single channel, and they should be connected in series rather than in parallel to get a better time resolution because smaller capacitance makes a rise time faster [1]. Series connection, however, requires higher bias voltage, and thus the number of SiPMs connected in series is limited. In this study, detailed investigations of SiPM connection scheme, counter geometry and difference of plastic scintillators were carried out to make an about 10 cm square counter using a plastic scintillator and multiple SiPMs.

2. Methods and results

A test counter was composed of a plastic scintillator and 36 SiPMs. Time resolutions were measured changing the number of SiPMs and their connection scheme. The plastic scintillator was BC-420 from Saint-Gobain and its size was $92 \times 92 \times 5$ mm^3. It was wrapped in a polyester reflector (ESR2 3M). The scintillator was read out on two sides, each by 18 SiPMs from Hamamatsu Photonics (MPPC S13360-3050PE). The 18 SiPMs were mounted on a PCB, on which each SiPM electrode is connected to a socket; the number of readout SiPMs and their connection can be flexibly changed by jumper pins. The SiPMs were coupled to the scintillator with optical grease (6262A OHYO KIKEN KOGYO). They have breakdown voltages about 52 V and were operated at 55 V per SiPM.

The counter was irradiated by beta-rays from ^{90}Sr. Events were triggered by a hit in a trigger counter. It was placed below the test counter under the RI (radioisotope). It was made of a $5 \times 5 \times 5$ mm^3 scintillator and a SiPM. The SiPM output signals were amplified and shaped using pole zero cancelation, and then recorded by a waveform digitizer (DRS4 [2]). The time resolution was defined as a half of the sigma of the distribution $\delta T = T_{\rm right} - T_{\rm left}$, where $T_{\rm right}$ and $T_{\rm left}$ were the averaged times measured by SiPMs attached to the right and left sides of the counter, respectively. In the present experimental setup, that time resolution is the same as the resolution of $(T_{\rm right} + T_{\rm left})/2$, the relevant quantity in an hypothetical experiment using this device. The times were extracted using a constant fraction method at 10% fraction. This method defines the pulse time as the time when the signal reaches a fraction of the maximum pulse height.

Three types of connection were examined to find an optimal connection scheme which realizes a better resolution with less readout channels

* Corresponding author.
E-mail address: onda@icepp.s.u-tokyo.ac.jp (R. Onda).

https://doi.org/10.1016/j.nima.2018.10.070
Received 29 June 2018; Received in revised form 9 October 2018; Accepted 10 October 2018
Available online 17 October 2018
0168-9002/

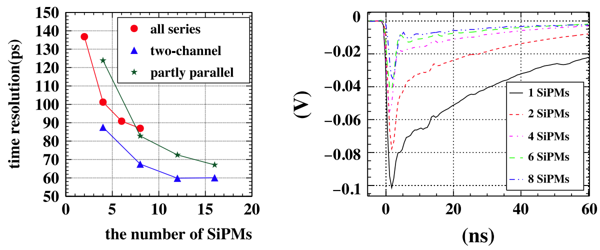

Fig. 1. (a) Comparison of time resolutions of three types of series connection scheme (left). The horizontal axis is the number of SiPMs attached on one side of the scintillator. The number of series connected SiPMs is equal to the total number of SiPMs as for all series connection (red), but a half of the total as for two-channel readout (blue) and partly parallel (green) connections. (b) Average waveforms of single photo-electron signals (right). The number of SiPMs connected in series was 1, 2, 4, 6 and 8 . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

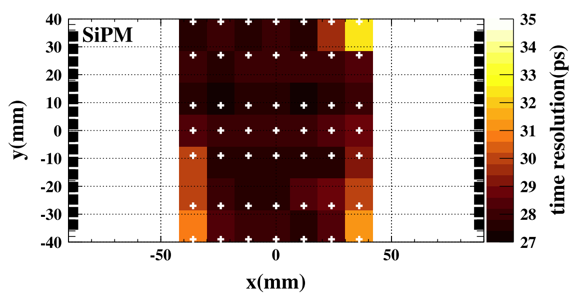

Fig. 2. Position dependence of a time resolution of a counter whose scintillator size is $80 \times 175 \times 5$ mm^3 with four readout channels of four series connection on each side (black boxes). RI was put on 7×7 positions (crosses), $x = -36, -24, -12, 0, 12, 24, 36$ mm and $y = -39, -27, -9, 0, 9, 27, 39$ mm, where $(x, y) = (0, 0)$ is the center. Colored 80×80 mm^2 area is effective for a timing measurement . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

as possible. The connection types are defined as all series, two-channel readout and partly parallel connection. The all series connection is the connection that all of the SiPMs used were connected in series and read out by a single channel. In the other cases, the SiPMs were divided into two groups and connected in series separately. Then, they were read out by two individual channels or by a single channel after being connected in parallel. The two-channel readout connection has twice the capacitance of that of the all series connection while the partly parallel connection has four times the capacitance when the total numbers of SiPMs used were equal.

Fig. 1(a) shows the time resolutions of the three types of connection as a function of the number of SiPMs. As expected, the time resolutions got better as more SiPMs were used. The improvement, however, started to saturate when four SiPMs were connected in series. As a result, the two-channel readout and the partly parallel connection gave better resolutions than the other when the number of SiPMs was eight. This can be explained by a change of waveform caused by series connection. Fig. 1(b) shows average waveforms of single photo-electron signals when 1, 2, 4, 6 and 8 SiPMs were connected in series. The rise time became faster as more SiPMs were connected in series, which resulted in a better time resolution. On the other hand, the pulse height decreased, which worsened a time resolution because of worse S/N. Therefore, the improvement saturated. For this test counter, optimal connection scheme was found to be four channel readouts with four series connected SiPMs per channel on each side considering the total number of SiPMs and the series connection effects. The time resolution, 48 ps, was obtained with this connection scheme.

The position dependence of a time resolution was measured using the counter with the optimized SiPM connection scheme. The over-voltage was set to 7 V in this measurement because the best time resolution was obtained with this bias voltage. The time resolution differed by 50% depending on the RI position and it was found that this was because of position dependence of light yields. When the RI was near to the side SiPMs were attached to, light yields of some SiPMs were too small because of their small solid angles, and thus the photon statistics and S/N of these channels were not enough.

One way to solve this problem is to use a longer scintillator. By making the distance between SiPMs and the irradiated region longer, light yield of each channel becomes more uniform. Fig. 2 shows position dependence of a time resolution measured using $80 \times 175 \times 5$ mm^3 sized scintillator. Thanks to smaller position dependence of light yield, difference of time resolution got much smaller, about 6%.

Two plastic scintillators were compared with each other. One was BC-420 (Saint-Gobain) used for $92 \times 92 \times 5$ mm^3 scintillator and the other was EJ-230 (Eljen Technology) for $80 \times 175 \times 5$ mm^3 scintillator. Their rise times are 0.5 ns according to the companies. However, the rise time of the latter scintillator was measured to be about 1 ns, which was twice faster than that of the former, 2 ns. As a result, the time resolution of EJ-230 was much better and it marked 28 ps while that of BC-420 was 42 ps when RI was placed on the center and over-voltage was 7 V.

3. Conclusion

A high time resolution counter with a plastic scintillator of multiple SiPM readouts was developed. It was found that series connection includes an effect to reduce signal height resulting in a worse time resolution while it also makes a rise time faster. Therefore, it is better to divide SiPMs into multiple readout channels rather than increase the number of SiPMs connected in series, taking these trade-off effects into account.

Multiple-channel readouts of each side were found to have a problem that their detected light yields varies among channels depending on their positions when incidence position of a particle is near the SiPMs, and this non-uniformity makes a time resolution worse. To solve this problem, it is effective to place SiPMs far from its irradiated region so that light yields become uniform resulting in improvement of a time resolution.

The optimal configuration was as follows: Readout scheme of SiPMs was four channel readouts of four series connection on each side. Plastic scintillator was EJ-230 and its size was $80 \times 175 \times 5$ mm^3. It marked 28 ps time resolution with position dependence less than 5 ps.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Numbers JP26000004, JP17J03308.

References

[1] M. Nishimura, et al., Pixelated positron timing counter with SiPM- readout scintillator for MEG II experiment, in: Proceedings 4th Int. Conf. on New Photo-Detectors, PoS(PhotoDet 2015), Moscow, Russia, 2016, p. 011.
[2] S. Ritt, R. Dinapoli, U. Hartmann, Nucl. Instrum. Methods A 623 (2010) 486–488.