Nuclear Instruments and Methods in Physics Research A 595 (2008) 161–164

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Silicon photomultiplier as a detector of Cherenkov photons

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ARTICLE INFO

Available online 9 July 2008

Keywords:
Ring Imaging Cherenkov detector
Silica aerogel radiator
Geiger mode APD
Silicon photomultiplier

ABSTRACT

A novel photon detector—i.e. the silicon photomultiplier—whose main advantage over conventional photomultiplier tubes is the operation in high magnetic fields, has been tested as a photon detector in a proximity focusing RICH with aerogel radiator. This type of RICH counter is proposed for the upgrade of the Belle detector at the KEK B-factory. Recently produced silicon photomultipliers show less noise and have larger size, which are important issues for a large area photon detector. We measured the single photon pulse height distribution, the timing resolution and the position sensitivity for different silicon photomultipliers (Hamamatsu MPPC HC025, HC050, and HC100). The silicon photomultipliers were then used to detect Cherenkov photons emitted by cosmic ray particles in a proximity focusing aerogel RICH. Various light guides were investigated in order to increase the detection efficiency.

1. Introduction

Silicon photomultipliers are semiconductor photo-sensitive devices consisting of an avalanche photo diode (APD) matrix on a common silicon substrate, working in the limited Geiger mode [1–3]. The main benefit, if compared to other position sensitive detectors used in Ring Imaging Cherenkov (RICH) counters, is their insensitivity to high magnetic fields. They have several other advantages (i.e. lower operation voltage, less material) compared to conventional photomultiplier tubes. They have high peak photon detection efficiency (more than 50%), high gain of $\approx 10^6$ and good time response. Due to their small dimensions, they allow compact, light and robust mechanical designs. All these would have made them a very promising candidate for a detector of Cherenkov photons in a RICH counter. However, due to the serious disadvantage of a very high dark rate ($\approx 10^6\,\mathrm{Hz/mm^2}$), up to now they have not been used in Cherenkov detectors, where single photon detection is required.

One of the main issues of the present study was to verify the performance of this photo-sensor as single photon detector in a proximity focusing RICH [4,5], proposed for the upgrade of the Belle detector at the KEK B-factory [6].

2. Bench test results

The silicon photomultiplier mounted on a motorized two-dimensional stage (National Aperture XY-MM-3M-ST) was enclosed in a light tight box. It was illuminated by 635 nm light pulses from a laser head (Advanced Laser Diode System PiL063 with 35 ps FWHM pulse width) focused to a $\sigma \approx 6\,\mu\mathrm{m}$ diameter spot. Neutral density filters were used to reduce the light intensity to the single photon level. Signals from SiPM were first amplified (Ortec FTA 820) and then split into two branches. One was used to measure time (Ortec CF8000 discriminator in leading edge mode, CAEN V1290A multihit TDC with 25 ps LSB) and the other charge (LeCroy 2249A) of the signal.

First we have measured the single photon timing distribution (Fig. 1). As expected the silicon photomultiplier exhibits a narrow peak with rms of around 150 ps. By using a 3 ns coincidence time window to detect Cherenkov photons, the background hit probability is reduced to a 1% level.

In the charge distribution (Fig. 2), the peaks for different numbers of fired pixels are well separated from the noise level, thus offering the possibility for single photon detection.

We have also measured the position dependence of the silicon photomultiplier signal (Fig. 3) by scanning the light beam across the photosensitive surface of the silicon photomultiplier. The measured variation of the sensitivity reflects the structure of the device. We observe that there is little pixel-to-pixel variation, although there is somewhat more variation within individual pixels due to the dead areas (min/max ≈ 0.6).

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doi:10.1016/j.nima.2008.07.013

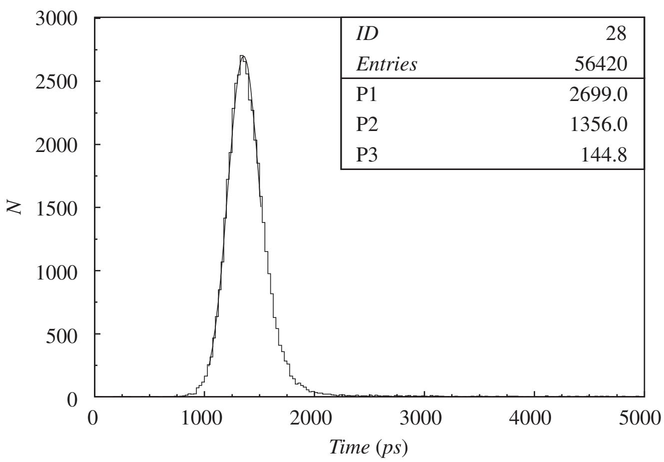

Fig. 1. Time distribution of the response of the Hamamatsu MPPC HC100 silicon photomultiplier to the $\lambda = 635\,\mathrm{nm}$ pulsed light source.

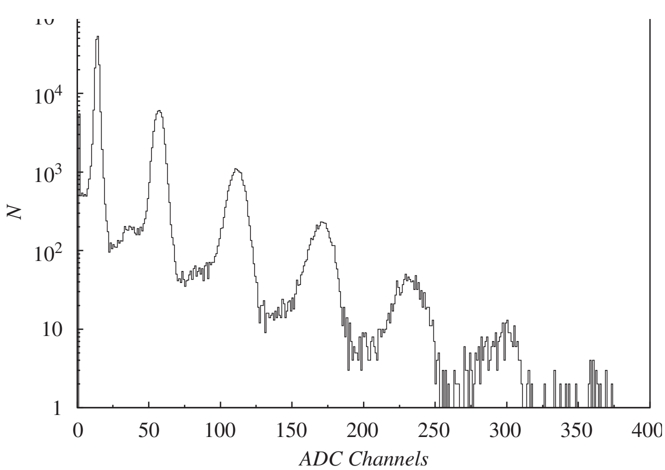

Fig. 2. Charge distribution of the response of the Hamamatsu MPPC HC100 silicon photomultiplier to the $\lambda = 635\,\mathrm{nm}$ pulsed light source. Single photons are well separated from noise.

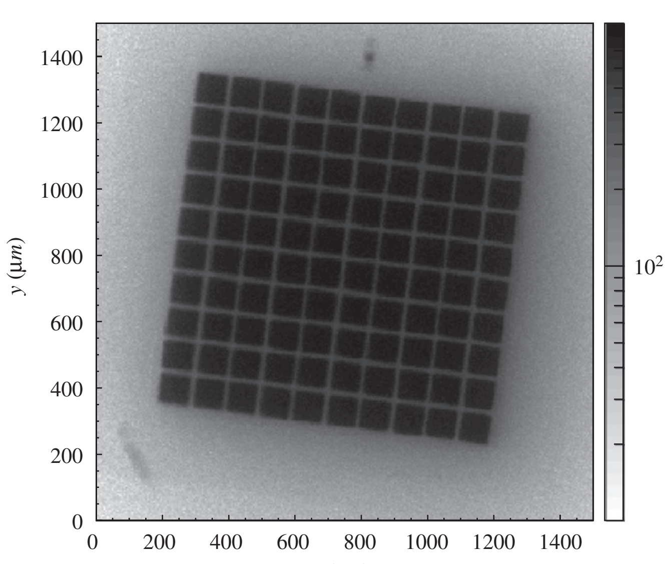

Fig. 3. Surface sensitivity to single photons for Hamamatsu MPPC with pixel size of $100\,\mu\mathrm{m}$.

3. Cosmic rays test

An array of silicon photomultipliers has been tested with Cherenkov photons from cosmic muons. To increase the efficiency of such a detector, different light guides have been machined and evaluated.

The cosmic charged particles are first registered by a scintillation counter. Their trajectory is measured by three layers of multiwire proportional chambers with a delay line cathode plane readout. The particles then enter a light tight box with the aerogel radiator and the photon detectors. The Cherenkov photons generated by the charged particles in the aerogel are registered by two types of photon counters, positioned 120 mm below the radiator. The first type of photon detector consists of six $1\,\mathrm{mm}^2$ Hamamatsu HC MPPCs: two of $25\,\mu\mathrm{m}$, two of $50\,\mu\mathrm{m}$ and two of $100\,\mu\mathrm{m}$ pixel size. We have chosen these silicon photomultiplier types due to their higher sensitivity in the blue wavelength region and lower noise if compared to other available types. In parallel to the array of silicon photomultipliers, an array of 12 multianode photomultipliers Hamamatsu R5900-M16 was used as a reference. Four neighboring channels in the multi anode photomultiplier tubes were connected to decrease the number of the electronic channels, resulting in a $9\,\mathrm{mm} \times 9\,\mathrm{mm}$ effective pad size.

The signals from silicon photomultipliers are first amplified (EG&G FTA820), discriminated (ORTEC CF8000) and then fed to a multihit VME TDC unit (CAEN V763A), which is controlled via Wiener PCIADA by the program running on the PC. The data acquisition is triggered by the scintillation counter signal.

4. The results

The Cherenkov angle distributions of photon hits are plotted in Fig. 4 for several 1 ns time intervals. It can be seen that the peak appears in the distribution only for time correlated hits (± 1 ns).

The distribution of hits as a function of their Cherenkov angle is shown for the MAPMTs in Fig. 5, in Fig. 6 for the SiPM signals that are out of the peak time window, and in Fig. 7 for the SiPM signals that fall within a 3 ns time window of the peak. The resolution of the Cherenkov angle is dominated by the uncertainty in determination of the charged particle track, so the widths of the Cherenkov photon peaks in both types of detectors should be about equal. Therefore, the fitting of the SiPM distribution (Fig. 7) has been performed by fixing the peak position and width to values obtained from the MAPMTs (Fig. 5) and by fixing the background shape to that of the out-of-time spectrum (Fig. 6), so only the normalization was allowed to vary. This procedure results in 146 photons detected by the SiPMs, while about 22 000 photons were detected by the MAPMTs. As the area covered by the SiPMs is only $6\,\mathrm{mm}^2$, whereas the area covered by the MAPMTs is $\approx 3900\,\mathrm{mm}^2$, this results in about four times more photons detected per unit area by the SiPMs than by the MAPMTs. This result agrees with expectations based on photon detection efficiencies provided by the manufacturer [7].

The small sensitive area of the single SiPM ($\approx 1\,\mathrm{mm}^2$) is a major limiting factor towards a higher photon detection efficiency. Light concentrators, collecting Cherenkov light from a larger area and concentrating it onto the SiPM sensitive surface, could increase the number of detected photons while conserving the dark count rate. Therefore, such light concentration would improve the signal-to-noise ratio.

For this purpose we have machined simple light guides (i.e. a truncated pyramid with planar entry and exit surfaces) from

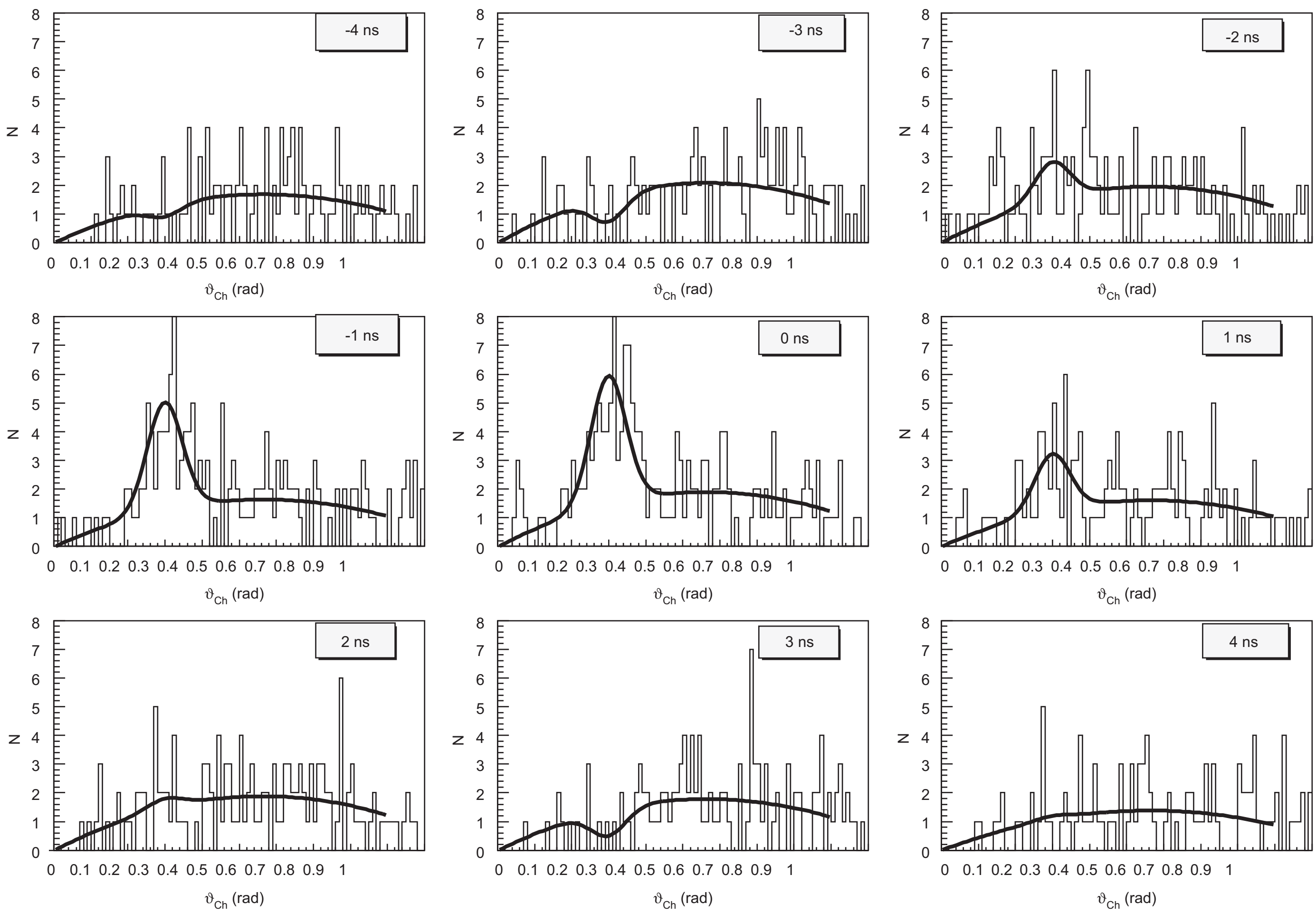

Fig. 4. Cherenkov angle distribution as measured with silicon photomultipliers for several 1 ns time intervals, centered at the indicated value.

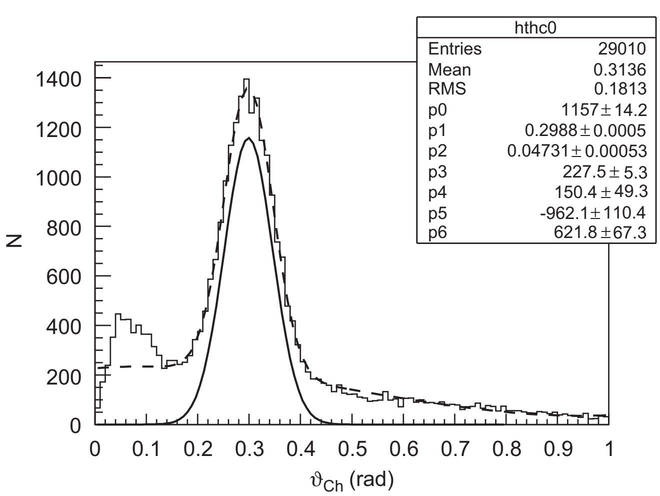

Fig. 5. Cherenkov angle distribution of the Hamamatsu R5900-M16 multi anode photomultiplier tubes array.

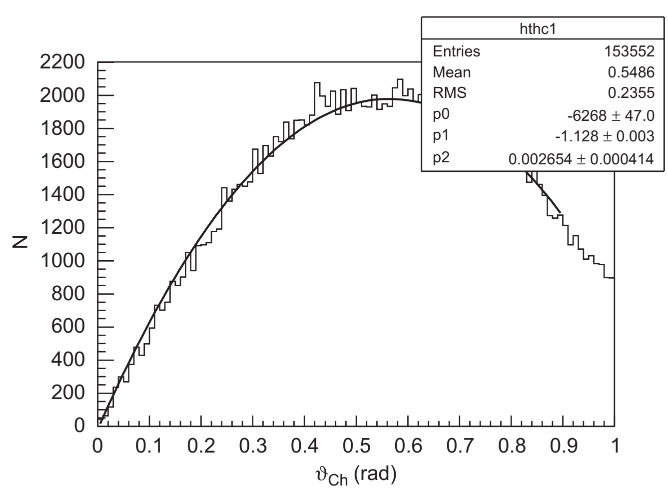

Fig. 6. Cherenkov angle distribution of the silicon photomultipliers array for off time hits.

UV grade perspex material used in the HERA-B RICH optical system [8], and mounted them in the cosmic rays test set-up. They have $3.5\,\mathrm{mm} \times 3.5\,\mathrm{mm}$ entrance window, $1\,\mathrm{mm} \times 1\,\mathrm{mm}$ exit window, and are 6 mm long.

The number of detected photons with the light guides increased by a factor of 2. From the ratio of photon entry and exit areas of the light guide alone ($3.5^2/1^2$), one would expect a 12-fold increase. The discrepancy can be attributed to the inefficiency of the light guide due to the angular spread of incoming photons (≈ 0.5 obtained by simulation) and to a gap ($\approx 1\,\mathrm{mm}$) between the light guide exit surface and the SiPM sensitive surface due to the SiPM enclosure.

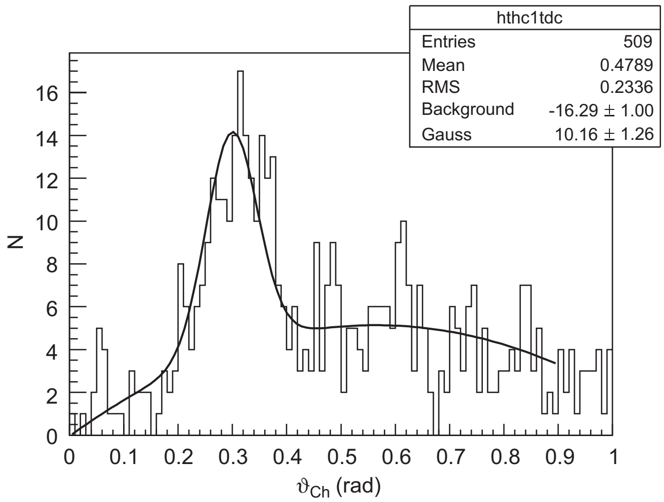

Fig. 7. Cherenkov angle distribution of the silicon photomultipliers array for hits within 3 ns time window.

5. Conclusions

We have detected Cherenkov photons radiated by cosmic particles in a 2.5 cm thick aerogel radiator with silicon photomultipliers.

An attempt has also been made to increase the SiPM detection efficiency by increasing the surface from which photons are collected by simple pyramidal light guides. Although an increased detection efficiency (factor 2) has been achieved, the limiting factor seems to be a gap between the light guide exit window and the SiPM sensitive layer due to the SiPM enclosure.

We believe that we have demonstrated that despite the relatively high dark noise rate of the SiPM detectors, they are promising as detectors of Cherenkov photons inside large magnetic spectrometers.

Acknowledgments

This work was supported in part by the Slovenian Research Agency under Grant nos. J1-9840 and J1-9339.

References

[1] P. Buzhan, et al., An advanced study of silicon photomultiplier, ICFA Instrumentation Bulletin.
[2] B. Dolgoshein, et al., Nucl. Instr. and Meth. A 563 (2006) 368.
[3] D. Renker, Nucl. Instr. and Meth. A 567 (2006) 48.
[4] T. Matsumoto, et al., Nucl. Instr. and Meth. A 518 (2004) 582.
[5] T. Iijima, S. Korpar, et al., Nucl. Instr. and Meth. A 548 (2005) 383; P. Križan, S. Korpar, T. Iijima, Nucl. Instr. and Meth. A 565 (2006) 457.
[6] K. Abe, et al., Letter of Intent for KEK Super B Factory, KEK Report 2004-4.
[7] MPPC data sheet, Hamamatsu Photonics.
[8] D. Broemmelsiek, Nucl. Instr. and Meth. A 433 (1999) 136.