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A module of silicon photo-multipliers for detection of Cherenkov radiation

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ABSTRACT

A module, consisting of 64 ($=8\times 8$) Hamamatsu MPPC S10362-11-100P silicon photomultipliers, has been constructed and tested as a position sensitive detector of Cherenkov photons. In order to increase the efficiency, i.e. the effective surface over which Cherenkov light is collected, we have manufactured and tested suitable light guides. In addition to the increase in efficiency, it is shown that such light guides considerably improve the signal-to-noise ratio. The results of our measurements indicate that the performance of such a Cherenkov counter with aerogel radiator could meet the requirements of particle identification at the foreseen upgraded Belle detector.

1. Introduction

The upgrade of the Belle particle identification system [1,2] will require a 4σ separation of kaons from pions up to a momentum of 4 GeV/c. The limited available space of approximately 20 cm has led to the decision for a proximity focusing ring imaging detector with aerogel radiator. Among the photon detector candidates that have been studied [3,4] none are completely immune to the high magnetic field (≈ 1.5 T) present inside the Belle spectrometer. The recent appearance of silicon photomultipliers (SiPMs) [5–8] may change the situation. In addition to their insensitivity to magnetic fields, silicon photomultipliers have other advantages: they are small and robust and do not require high voltages. Among their disadvantages is the relatively high dark count rate (≈ 1 MHz/mm^2) and, in the present state of technology and costs, a low fraction of sensitive surface compared to the full area covered by the photon detector. These deficiencies may be reduced with light concentrators, which would collect the light from a larger surface, thereby increasing the overall geometric acceptance of the detector as well as the signal-to-noise ratio. Silicon photomultipliers therefore represent a challenge and a promise in the area of ring imaging Cherenkov counters. The present measurements with a SiPM module follow the initial successful investigations of the performance of individual SiPM detectors, i.e. a smaller number of them, in a ring imaging Cherenkov counter [9].

2. Experimental set-up

A Cherenkov detector consisting of a 1 cm thick aerogel slab (with $n=1.03$ and 1.4 cm attenuation length at $\lambda=400$ nm) and a photon detector array of 64 ($=8\times 8$) Hamamatsu MPPC S10362-11-100P silicon photomultipliers has been assembled and tested in an 120 GeV/c pion beam at CERN. The arrival of a beam particle is triggered by a scintillation counter and its trajectory is registered with two multiwire proportional chambers (MWPCs). The incident particle hit coordinates are obtained by delay line readout of the cathode wire planes.

In a tile of aerogel, the pions radiate Cherenkov photons at an angle of ≈ 240 mrad relative to their track direction. These photons are detected by a photon detector plane at a distance of 115 mm from the aerogel upstream surface. The array of 64 SiPMs has been grouped into pads of 5.08 mm $\times$ 5.08 mm, consisting of 4 SiPMs each (Fig. 1), therefore requiring 16 signal lines per module. As the SiPM sensitive area is 1 mm^2, the geometric acceptance of a pad would be 15.5%. Additional inefficiency due to a 100 μm structure within the 1 mm^2 sensitive area of the MPPC S10362-11-100P is already included in the average photon detection efficiency given by the manufacturer (Fig. 2, [10]).

In order to increase the rather low geometric acceptance of the SiPM detectors within an array (15.5%), we have investigated the

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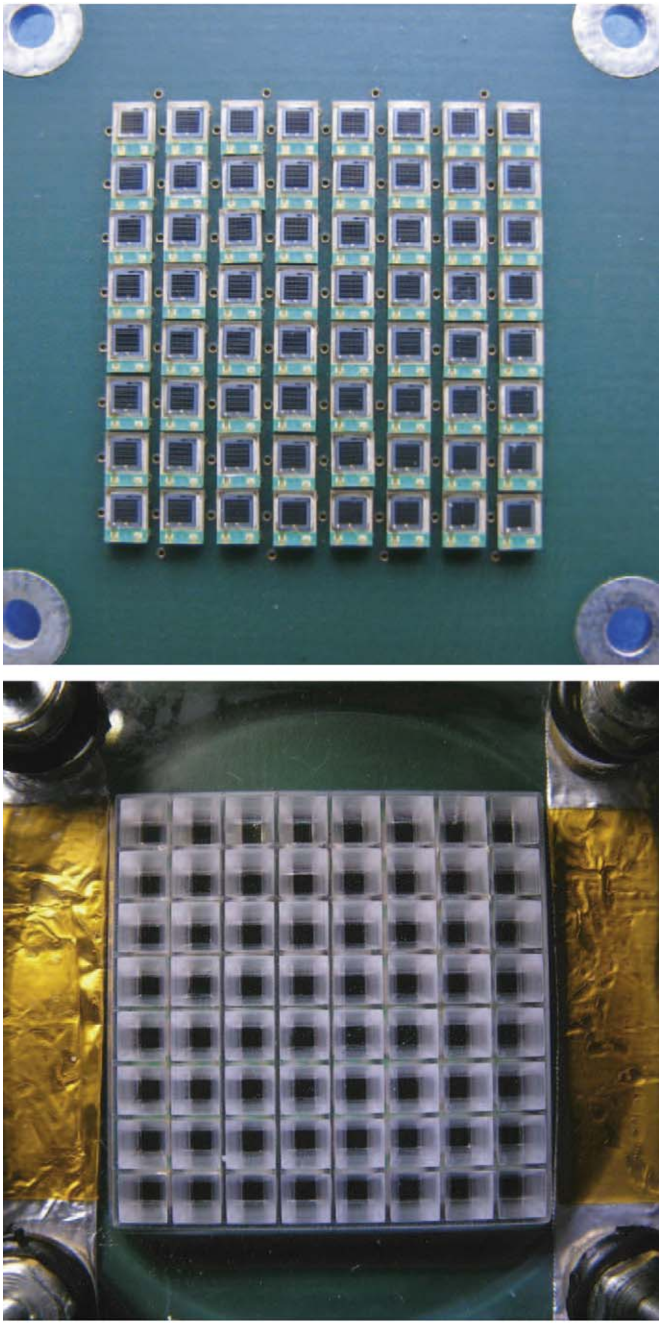

Fig. 1. The photon detector module consisting of 64 SiPMs without (above) and with (below) the pyramidal light guides. Four SiPMs are grouped into a single readout channel.

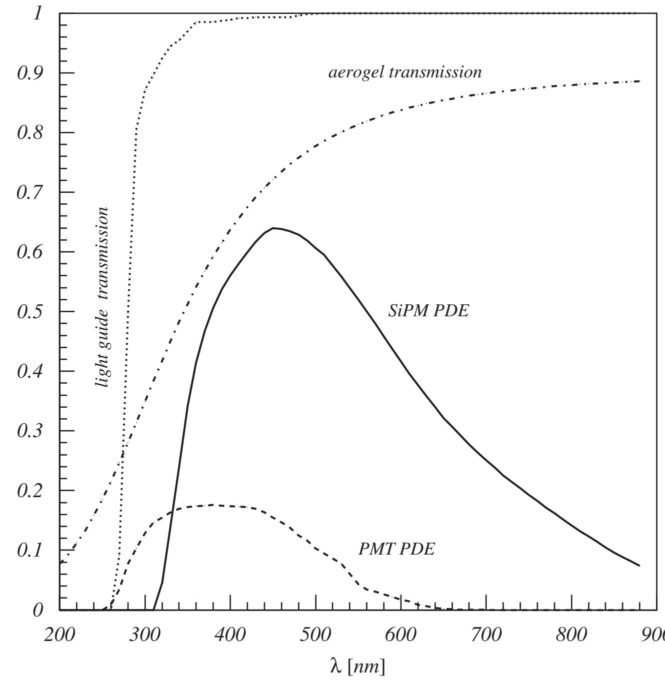

Fig. 2. The wavelength dependence of the photon detection efficiency (PDE) of one SiPM detector. Shown also is the efficiency for a typical bialkali multianode photomultiplier (PMT-PDE, including the photoelectron collection efficiency), the aerogel transmission and the light guide transmission.

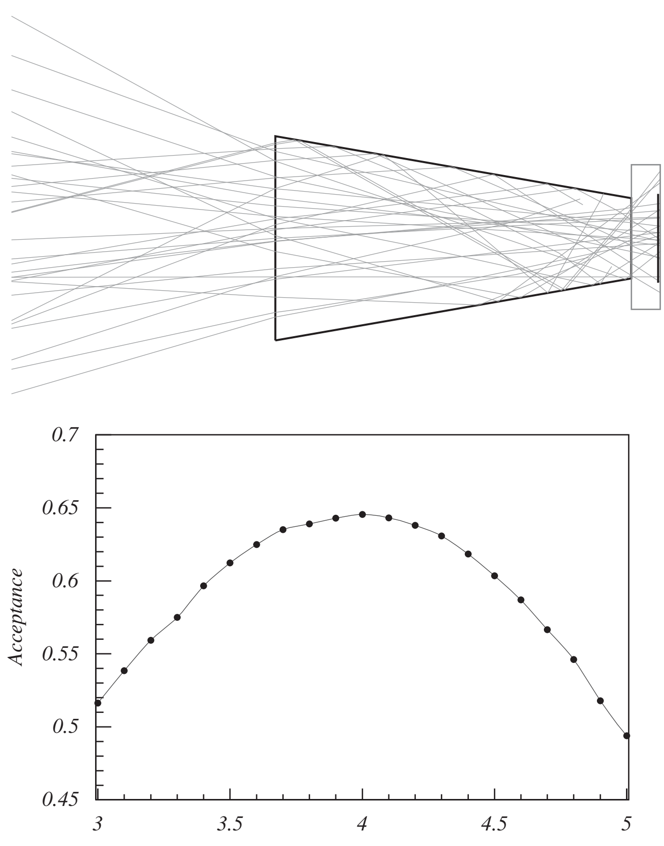

Fig. 3. (above) Trajectories of photons through the light guide and into the SiPM sensitive volume (shown as a thick line). (below) Acceptance, i.e. the fraction of generated photons that hit the SiPM volume, as a function of light guide length.

possibility of increasing the acceptance with light guides. Light guides in the form of truncated pyramids have been studied. The acceptance as a function of light guide length, at fixed, 10° inclination of the lateral planes, is shown in Fig. 3. Photons have been generated with isotropic incident angle distribution up to $\theta = 30^{\circ}$ and with uniform distribution over the $2.54\,\text{mm} \times 2.54\,\text{mm}$ surface of the light guide entry window. The loss of 35% of the photons is mainly due to the 0.3 mm gap between the light guide exit window and the sensitive volume of the SiPM and, to a lesser extent, also to refraction out of the light guide and to absorption. Therefore, the acceptance of an ideal light guide is about 65%, which is about 4 times larger than the bare geometric coverage of the SiPM sensitive surface in a module as described