Silicon photomultiplier readout system for the ECAL in the PEBS and test results from the system

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Abstract: Silicon photomultipliers (SiPMs) have remarkable advantages for use in photo-detection. Compared with PMT, SiPM shows advantages of high gain, excellent time resolution, insensitivity to magnetic fields and a lower operating voltage. SiPMs from Hamamatsu are used in the electromagnetic calorimeter (ECAL) sub-detector in the Positron Electron Balloon Spectrometer (PEBS) experiment, a balloon-borne spectrometer experiment aiming at the precise measurement of the cosmic-ray positron fraction. This paper introduces the evaluation and test results of several SiPM detector types, the dedicated front-end application specific integrated circuit (ASIC) electronics and the design of the data acquisition system (DAQ) system.

Key words: SiPM, PEBS, ECAL

PACS: 07.05.Hd **DOI:** 10.1088/1674-1137/35/12/011

1 Introduction

The PEBS [1] aims to observe the abnormal positron spectrum in cosmic rays. According to super-symmetric extensions, dark matter decay chains will finally generate an equal number of positrons and electrons. Since there is no other known source of positrons in the Galaxy, the value of $e^+/(e^++e^-)$ provides an excellent probe for the indirect detection of dark matter.

The PEBS has four sub-detectors: a TOF provides a fast trigger signal; a transition radiation detector (TRD) together with a high energy resolution ECAL provides the proton rejection capability that is critical for electron/positron measurement; and a tracker inside a magnetic field to distinguish electrons and positrons.

Considering that the main requirement for the space exploration is low power consumption, weight and volume, the technology of a scintillator with a embedded wavelength shift fiber readout by SiPM [2, 3] is applied for the ECAL sub-detector, the total number of readout channels is about 8000 [4].

This paper introduces the test of several SiPM [5] types and dedicated front-end ASICs, as well as the design of the ECAL DAQ system. The performance-test and beam-test results are also included.

2 Design of the readout system

Figure 1 shows the ECAL readout procedure. The front-end boards (orange part in Fig. 1) together with DAQ board (green part in Fig. 1) form the readout system.

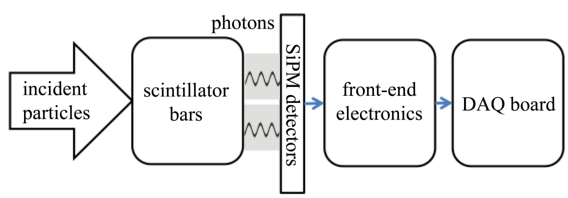

Fig. 1. ECAL system readout process.

Currently, there are several ASICs optimized for SiPM detector readout available, such as SPIROC-I/II, SPIROC- A [6] and VA32，VATA64. Front-end boards with similar structures, as shown in Fig. 2, are designed to evaluate and test the ASICs, which include the power-supply, amplification, the flexible

Received 14 March 2011

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re-programmable configuration circuit to fulfill the requirement of different ASICs and, finally, a common uplink connector for the acquisition system. All the front-end electronics have the same mechanical and electrical interface, so they can be connected to the same DAQ system and can easily replace each other.

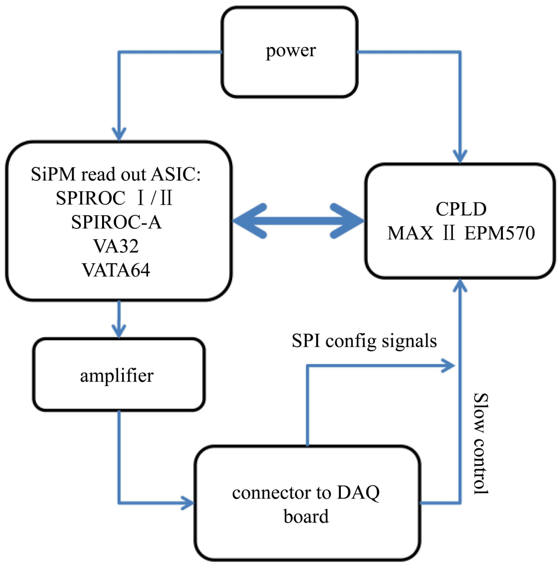

Fig. 2. The structure of the front-end board.

The DAQ system is designed to control the front-end, digitize the output signal from the ASIC and send data up to the computer [7]. The structure of the DAQ system is shown in Fig. 3.

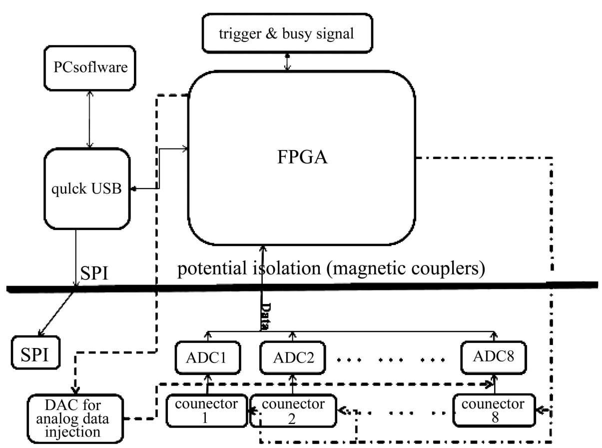

Fig. 3. The structure of ECAL's DAQ system.

3 SiPM detector performance result

With the readout system described before, several types of SiPM detector are tested. Fig. 4 shows the light emitting diode (LED) testing result. (X-axis: the charge amount calibrated by the output of ADC (e); Y-axis: the number of events. pe stands for photons and electrons detected by SiPM)

Five peaks can be seen in Fig. 4, The first peak indicates the pedestal signals. The adjacent peak represents the signals generated by the SiPM when only one pixel of the SiPM detector is fired. The next one shows the signals when two pixels are fired, and the next is three. At the X-axis, the ADC count between adjacent peaks gives the signal gain of the whole readout chain for one single photon or electron, this feature is very helpful for performing online calibration.

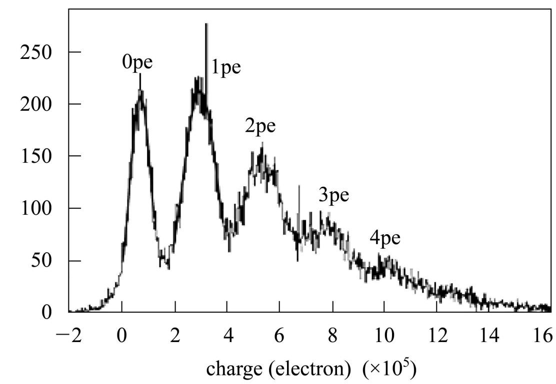

Fig. 4. The ADC distribution of SiPM output in LED testing.

ECAL is widely used in high energy physics to measure the energies of electrons and photons. The ECAL in the PEBS consists of 20 layers of 2 mm thick tungsten plates interleaved by scintillator layers. The SiPM combined with wavelength shift (WLS) fiber is used to collect and measure the light. As the sensitive wavelength range of the SiPM model S10943 [8] is 350–600 nm, ECAL selects the fiber WLSY11 (200) [9] as the delivery medium. This kind of fiber can highly and efficiently transfer the photons produced by the scintillator to the SiPM detectors.

The position dependency of the whole scintillator bar is tested with an experimental setup as shown in Fig. 5.

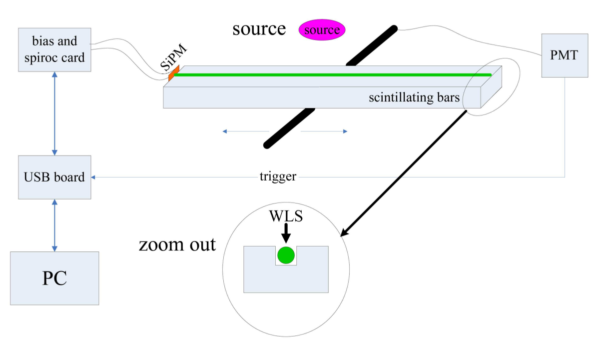

Fig. 5. The experimental equipment used in the position dependency test.

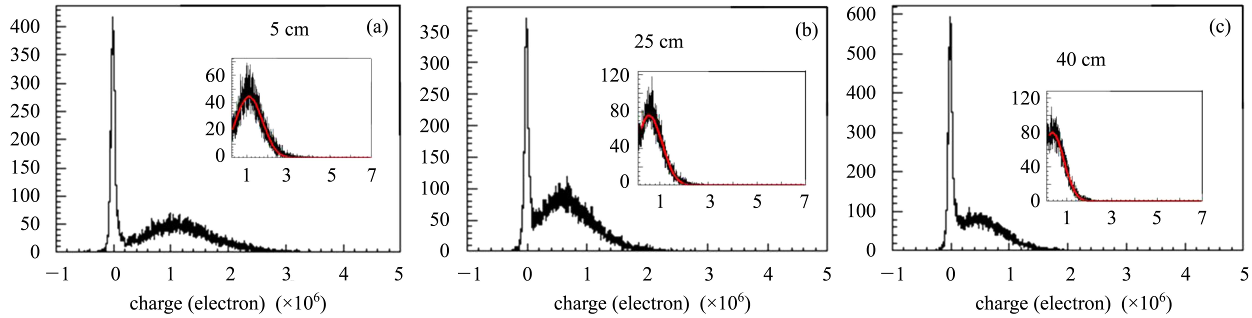

Fig. 6. The output of the readout system with different distances between the SiPM and the source (the main figure is the histogram of 10000 measured events and the inline image is the partial amplification of the peak). The distance between the SiPM and the source is (a) 5 cm, (b) 25 cm, (c) 40 cm.

In Fig. 5, a ^{90}Sr β source provides the electrons, the PMT detector generates a trigger to activate the readout system. The scintillator module and SiPM are protected in a light-tight box to remove noise. The SiPM output is studied while moving the radiation source and PMT along the module axis. The longer the distance that the light travels from the action point until it reaches the SiPM, the lower the photon flux is. The photon transport equation in the WLS is given in Eq. (1).

$$I_x = I_0 \cdot \mathrm{e}^{-l_x/l_0}, \tag{1}$$

here, I_x is the photon flux at position l_x, I_0 is the photon flux at the position where the photons enter the WLS, l_x is the distance between the photons and the SiPM detector, and l_0 is the length factor.

The testing results of different positions are shown in Fig. 6 (X-axis: the charge amount calibrated by the output of ADC (e); Y-axis: the number of events).

In Fig. 6, the ADC value of the pedestal peak is stabilized in all positions while the peak of the signal moves with the positions. With the result from LED testing, the ADC value of the signal peak is calculated to an equivalent number of photons, Fig. 7 gives the number of photons as a function of the corresponding source position (X-axis: the distance between the source and SiPM(cm); Y-axis: the number of photons detected by the SiPM).

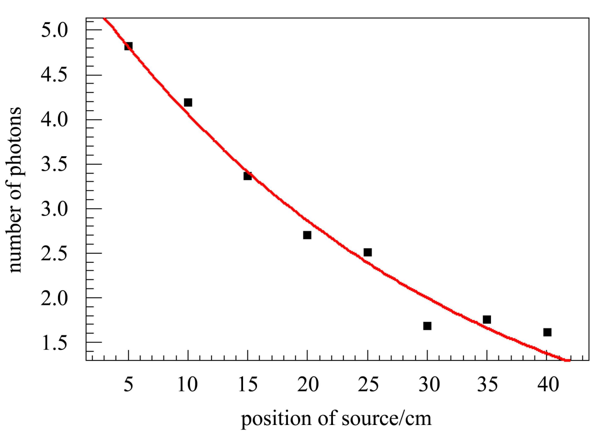

Fig. 7. The result of the scintillator bar propagation efficiency test.

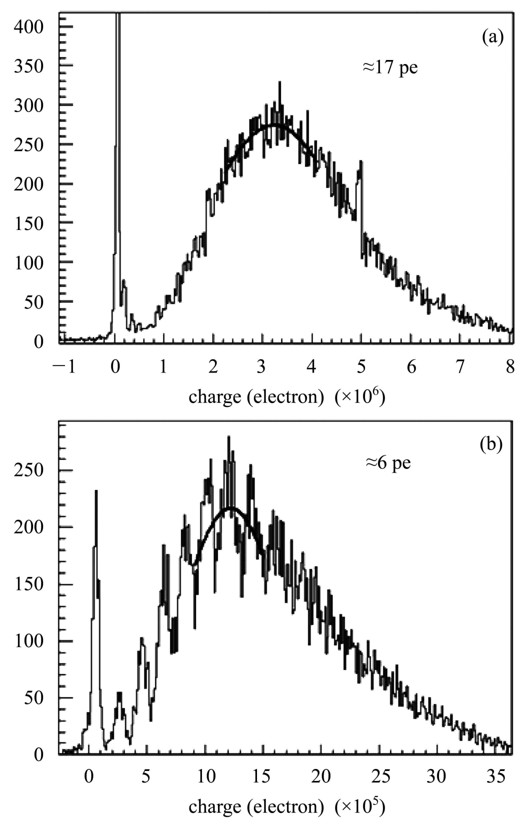

Fig. 8. The ADC distribution of SiPM output with different energy sources in the beam test, (a) light intensity is 17 pe, (b) light intensity is 6 pe.

Fitting the data with the photon transport curve, we can get the result Eq. (2), which is consistent with Eq. (1):

$$I_x = \mathrm{e}^{(1.76-3.54x)} = 5.81 \times \mathrm{e}^{-l_x/0.282}. \qquad (2)$$

4 The beam testing result

There is no single photon peak seen in the position dependency test as has been seen in the LED test, which is mainly due to the much greater number of photons generated by the radiation source. A beam-test gives an even clearer comparison. As the beam energy changes, the number of photons seen by the SiPM changes accordingly, as presented in Fig. 8. Fig. 8(a) shows the result when the light intensity is equal to 17 pe. Fig. 8(b) shows the result of light intensity equal to 6pe. In Fig. 8(b), we can see the single photon peaks, which are consistent with the result of the LED tests. The higher the photon number detected by the SiPM, the larger the uncertainty and the worse the energy resolution, there will be only one peak in the testing result. In addition, the position of the peak is varied with the photon intensity. That can explain why there is only one peak in Fig. 6.

5 Conclusion

This paper describes the design of the readout system, based on scintillating fibers and an SiPM detector, for an ECAL for the PEBS. The system is proved to fulfill the requirement in both the lab test and beam test. This DAQ system can also be used in other applications with the SiPM detector.

The first flight of the PEBS is scheduled to be made in mid 2012, and this system will be equipped with some mechanical and thermal optimization.

I would like to thank Guido Haefeli and Jean-Baptiste Mosset from the EPFL for discussions and providing material. I am also indebted to my colleagues for their help in preparing this paper.

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