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A high dynamic range readout unit for a calorimeter[*]

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Abstract: A high dynamic range readout system, consisting of a multi-dynode readout PMT and a VA32 chip, is presented. An LED system is set up to calibrate the relative gains between the dynodes, and the ADC counts per MIPs from dynode 7 are determined under cosmic-ray calibration. A dynamic range from 0.5 MIPs to 1×10^5 MIPs is achieved.

Key words: BGO calorimeter, VA32 chip, PMT, LED, high dynamic readout

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1 Introduction

A BGO calorimeter for the space observation of high-energy electrons/positrons and gamma rays has been designed. It will be composed of 576 BGO crystal bars with dimensions of 2.5 cm×2.5 cm×30 cm. The BGO crystals form 12 layers with an area of about 60 cm×60 cm each. The response energy varies from 10 GeV to 10 TeV. From simulation with GEANT4 [1] codes, the maximum value of the deposited energy in one crystal is about 1.7 TeV for electrons of 10 TeV. For the identification of the EM shower from the hadron shower, based on shower profiles, a minimum measurable energy deposit per BGO bar down to 0.5 MIPs is required. So a dynamic readout range from 0.5 MIPs (about 11.5 MeV) to 1.7 TeV (about 1×10^5 MIPs) should be available. Several ways [2–4] to expand the readout dynamic range of the calorimeter were proposed. In this paper, a readout system that uses a PMT coupled with a front-end electronics circuit with a VA32 [5] chip will be reported.

2 Experimental setup

A) Since there is no electron test beam that could cover such a wide energy range, an LED source was designed to test the readout system. The right plot in Fig. 1 shows a block diagram of the LED source. The LED is driven by a pulse generator (GEN). A bunch of optical fibers is used to transmit the light from the diffuse cavity of the LED to a BGO crystal which disperses the light to the PMT that is going to be calibrated. Here, 64 lines of fibers are homogeneously distributed on the top of the BGO. The LED light intensity is tuned by changing the amplitude of the supply voltage from GEN, and monitored by the reference PMT R1166, which shares an amount of 1/64 from the bunch of fibers.

B) A Hamamastu PMT R5611 coupled with a BGO bar is supposed to readout the fluorescence from dynodes 7, 4 and 1 (marked as D7, D4 and D1), which correspond to low, medium and high energy ranges, respectively. The PMT base voltage divider is specially designed and carefully tuned in order to suppress the cross talk between the different dynodes.

C) VA32 is a chip that consists of a 32-channel charge amplifier combined with 14 bits -ADC. The sensitivity of each readout channel is about 1.14 fC per ADC count. Linearity up to about 12 pC could be reached. In order to avoid the cross talk between
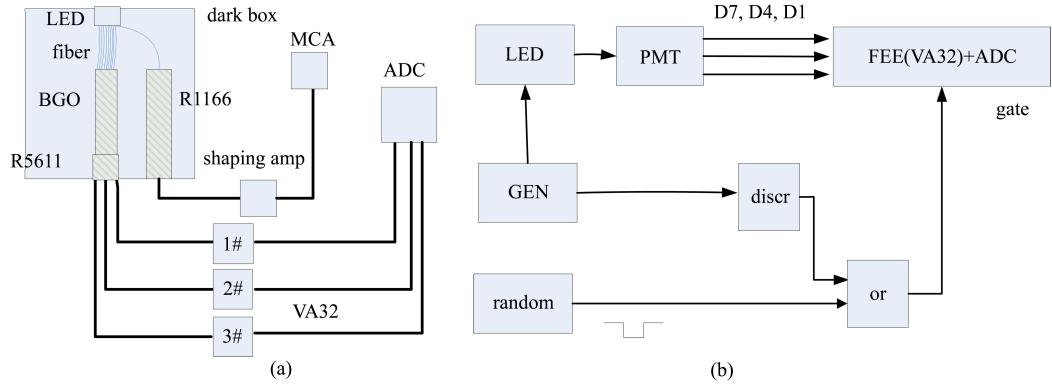
Fig. 1.   A block diagram showing the LED calibration measurement.

different channels on the chip, D7, D4 and D1 are put to their individual VA32 chips.

3   Results

The driven pulse was tuned to make the LED light pulse imitate the BGO fluorescence pulse. The amplitudes of the driven pulses were then increased step by step, and the ADC data of D7, D4 and D1 were taken. The "pedestal free" ADC-counts correlation between the readout dynodes was plotted, and the correlation between D4 and D7 is shown in Fig. 2(a). Linear correlation up to 12 pC (the upper limit of VA32) from D7 is obtained when the charge output reaches about 0.5 pC (this corresponds to 500 ADC counts). As the LED light intensity crosses over a given threshold, the D1 channel signal takes over its pedestal and data points appear in the plot of D4 vs. D1 (Fig. 2(b)). From the data fitting, the relative gains for D7/D4 and D4/D1 of 22 and 35 could be derived, respectively, at a 620 V PMT high voltage.

From Fig. 2, the charge collection of the high gain channel (D7 with D4 as reference) and medium gain channel (D4 with D1 as reference) both reach the maximum dynamic range of the VA32 chip (12 pC). For the low gain channel (D1), Fig. 2(b) indicates that when the ADC counts reach 360 (0.4 pC), the VA32 for the D4 channel is already saturated. Thus the ADC counts of the D4 channel cannot be used as a reference for D1 to check the upper limit of the D1-charge collection, since the upper limit of the D1-charge collection will directly determine the upper limit of the dynamic range of the energy measurement of the calorimeter and justify whether the PMT cathode is able to drive it in safety. For the determination of D1-charge collection capability, a reference PMT R1166 (shown in Fig. 1) is used as a monitor of the LED light intensity. The signal of R1166 is input to a readout chain, which contains a shaping amplifier

and a multichannel analyser. The charge spectrum of the anode outputs from R1166 is recorded. Both the spectra from R1166 and dynode 1 of R5611 are obtained under a given LED light pulse. Fig. 3 shows the peak ADC counts from D1/R5611 versus the peak channels from R1166. The charge collected by the D1 channel responds quite linearly up to 12 pC.
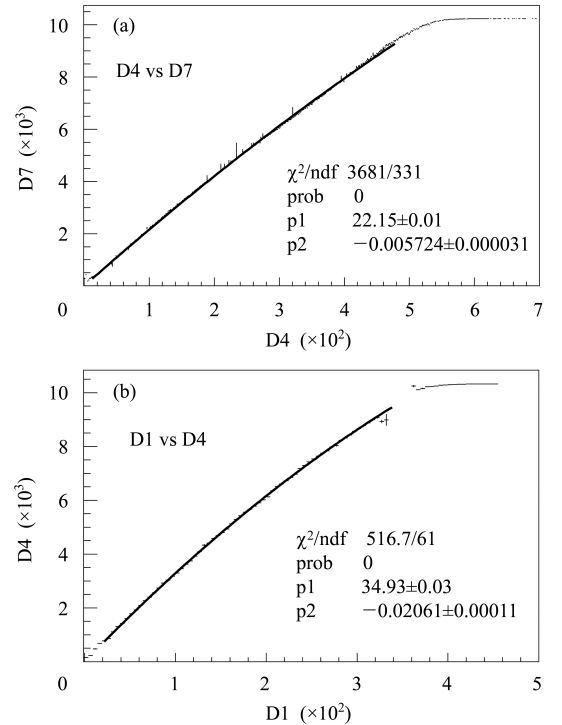

Fig. 2.   The correlation between the signals in (a) a low and medium energy range, and (b) a medium and high energy range (b).

The dynamic range of this readout system can be calculated from Eq. (1)

$$Dy_{nR} = k_e \times k_7 \times k_4 \qquad (1)$$

where k_e is the VA32 charge dynamic range, and k_7 and k_4 are the relative gains of D7 to D4 and D4 to D1 of R5611, respectively, obtained from Fig. 2. Ass-

ume the upper range of the VA32 chip is 12 pC and its minimum measurable charge is $q_{\min}$. The relationship between $q_{\min}$, k_e and Dy_{nR} is listed in Table 1.
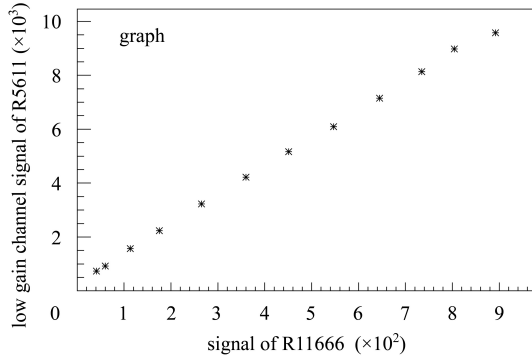

Fig. 3.   The low gain channel signal vs. that of R1166.

Table 1.   The correlation between $q_{\min}$, k_e and Dy_{nR}.

$q_{\min}$/fC	20	30	35	40	50
k_e	600	400	343	300	240
$Dy_{nR}(\times10^5$ MIPs)	4.6	3.0	2.6	2.3	1.8

If the fluorescence output of the BGO bar excited by a MIPs (cosmic muon) is well tuned, which makes the charge collected by the D7 of R5611 to be just 2 qmin, the D1 channel will be able to respond linearly to the MIPs numbers of $1/2 \times (Dy_{nR} \times 10^5)$.

Figure 4 shows the muon spectrum from the D7 channel with the BGO bar packaged by aluminum foil and air-coupled to R5611. The measured peak is shown, along with the fits by Landau distribution convoluted with Gaussian distribution based on the Minuit minimization package. The most possible value is 2413 channels, equal to about 2.8 pC, which is much higher than the $q_{\min}$ listed above. In this case, the VA32 dynamic range, k_e, is only 4.3 and the upper limit of the dynamics of the readout unit is 3311 MIPs.

Apparently the fluorescence output of a MIPs from BGO has to be suppressed to let the charge from the D7 drop down to $2 \times q_{mim} = 70$ fC. If the dynamic ranges of the readout unit from 0.5 to 1×10^5 MIPs is expected, the attenuation factor of the fluorescence output for a BGO bar has to be 40. Here we use black paper with an aperture to attenuate the fluorescence that was exited by the MIPs. The result is shown in Fig. 5. From the result, the cosmic signal of D7 is

about 25 fC, so 70 fC could be satisfied easily. The dynamic ranges of the three channels of the readout unit are shown in Table 2.
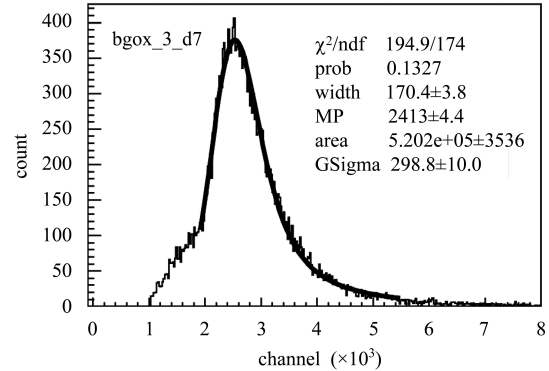

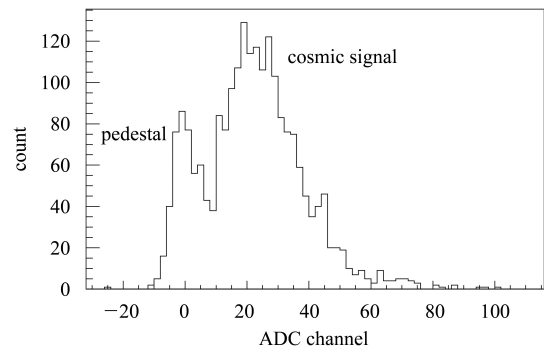Fig. 4.   The pulse height distribution of a high gain channel for cosmic rays.

Fig. 5.   The pulse height distribution of a high gain channel for cosmic rays (after light attenuation).

Table 2.   The dynamic range of D1, D4 and D7.

readout channel	D7	D4	D1
range (MIPs)	0.5 to 171	11 to 3762	385 to 131000
range/GeV	0.0115 to 3.9	0.25 to 86.5	8.8 to 3013.0

4   Conclusion

We presented a high dynamic range readout system, in which a PMT and a VA32 chip are used to measure the energy deposition in a BGO calorimeter. Through LED setup and cosmic-ray calibration, the performance of the dynamic range was shown to cover a range from 0.5 to 1×10^5 MIPs.

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