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Characteristics of PMT used in prototype array of ED

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As a main component of ED, properties of PMT would affect the performance of the detector directly. Properties of XP2012B PMTs used in the prototype array of KM2A had been measured with the PMT test bench, which is built up for the test for more than 5200 PMTs will be used in ED array in LHAASO project. Most properties of PMT reach our requirement, which guarantee a good performance of ED in prototype array. Dual-readout of anode and dynode had been proved feasible to widen the dynamic range of ED. PMT with better TTS should be selected to guarantee a better time resolution of ED in future.

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1. Introduction

Large High Altitude Air Shower Observation (LHAASO) [1] is a proposed cosmic ray experiment which will be built in Daocheng, Sichuan Province of China, 4300m in altitude. As a main array of LHAASO, one square kilometer extensive air shower array (KM2A) focuses on the searching for origin of cosmic rays, exploring of radiation mechanism of gammas and studying of the 'knee' physics. It will cover the energy range from 10TeV to 100PeV [2] and consist of 5195 electromagnetic particle detectors(EDs) and 1171 muon detectors (MDs). ED have high detection efficiency (>95%), good time resolution (<2ns) and wide particle density range from 1 to 10 000/m^2. As Fig.1 shown, ED is a type of plastic scintillator detector [3, 4]. Wavelength shifting(WLS) fibers are used to collect the emitted light from the scintillator, convert it to 490nm and transfer it by total interval reflection to PMT. As an important part, PMT with suitable characteristics should be used to guarantee the performance of ED. PMT works under the gain of 4*10^5, whose uniformity should be better than 10% and dark noise rate should be lower than 200Hz with the electronic threshold of 1mV. To guarantee a good time resolution for ED, PMT with transit time spread(TTS) better than 4.5ns and cathode transit time difference(CTTD) better than 1ns is necessary. Especially, the maximum linear current should be larger than 1163mA for PMT to meet the dynamic range of ED, which will be realized by dual-readout of anode and dynode. Temperature coefficient less than 0.2%/°C is needed to guarantee the annual stabilities of PMT gain lower than 5%.

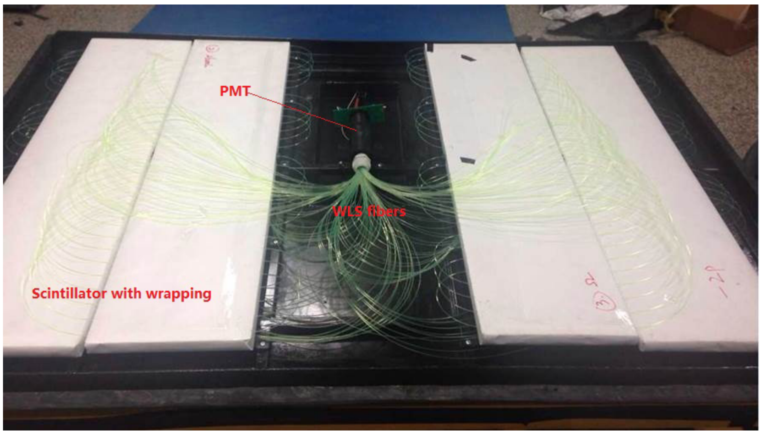

Figure 1: Structure of Electromagnetic Detector.

In the summer of 2004, a prototype array of KM2A, consisted of 40 EDs and 2 MDs, had been built at YBJ, Tibet of China. PMTs used in ED are XP2012B PMT produced by PHOTONIS [5] and all of them are measured with the PMT test bench in SDU, which is built up to fulfill the requirement for the test of more than 5200 PMTs in the future. According to the results, most properties of these PMTs reach our requirements except TTS, which result a time resolution of worse than 2ns for ED. PMT test bench and method are proved reaching our requirement for PMT test through this experiment. Method for dual-readout of anode and 6th dynode [6] is proved feasible to realise the wide dynamic range of PMT.

2. PMT Test Bench in SDU

A PMT test bench had been built up in Shan Dong University(SDU) to measure the properties of more than 5200 PMTs used in ED in the future. Fig.2 shows the scheme picture of the test bench. A light tight box with 3 stepper motors inside is used for the placement of 16 PMTs. Light of LED driven by the pulse generator is guided to 16 PMTs in the box by 16 optical fibers. Laser with a width of 70ps is used for the test of time characteristics. The pulse generator or laser also generates synchronous pulses to trigger the DAQ system, which is based on the VME bus. All the electronics used in the system, including QDC(v965),TDC(v775N),scaler(v560E), are produced by CAEN. The high voltage power supply supply power for 16 PMTs independently. All the equipment are controlled by the central workstation. Results of PMT are stored in the database, which will be benefit to the further data analysis. The application of batch and effective tests makes large quantity of PMTs calibration possible in future.

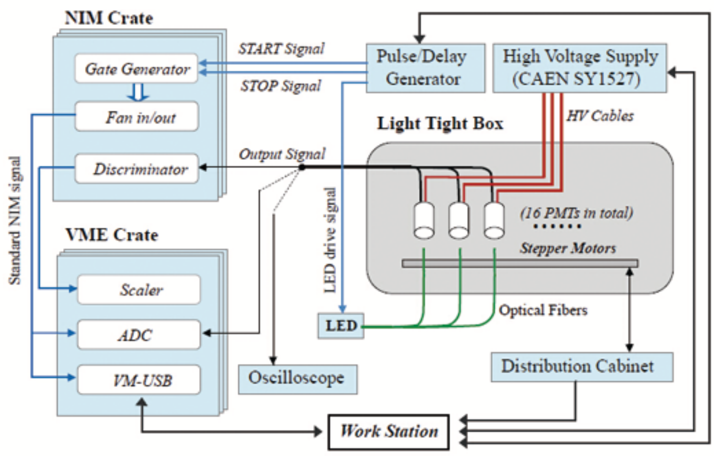

Figure 2: Block diagram of test scheme for the PMT test bench.

With this test bench, single photoelectron(SPE) spectrum, voltage response curve, uniformity, linearity, dark noise rate, temperature coefficient and time characteristics including transit time spread(TTS) and cathode transit time difference(CTTD) for PMTs can be measured.

3. Design of the high voltage divider circuit

Maximum linear current of PMTs should reach 1163mA, corresponding to the dynamic range from 1 to 10 000particles/m^2 of ED, with the amplitude of about 5mV for minimum iron particles(MIP). Method for dual-readout of anode and 6th dynode is applied for XP2012B, as shown in Fig.3. With the design, the maximum linear current of anode should be better than 23.3mA and maximum equivalent anode linear current of dynode, which is calculated with the maximum linear current and the ratio between anode and dynode output for the same signal, should be better than 1163mA. Output of anode and dynode is used for the test of 1 to 200 particles and 100 to 10 000particles separately, with an overlap from 100 to 200 particles, which is important for the connection of spectrum for anode and dynode. With this voltage divider, properties of XP2012B PMT had been measured.

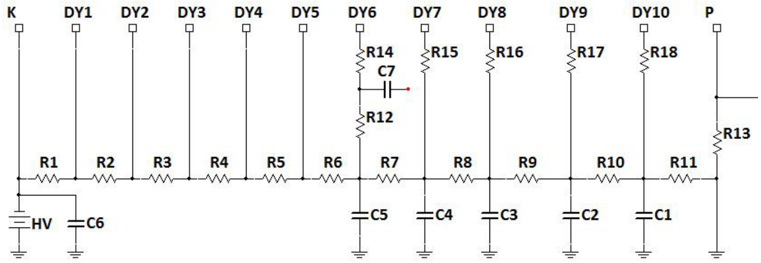

Figure 3: Circuit Design for Dual-Readout of Anode and 6th Dynode.

4. Results and Discussion

4.1 Calibration for Working Voltage

PMT used in ED is working with the gain of $4*10^5$. SPE spectrum and voltage response curve [7] are tested to calibrate the working voltage for each PMT. SPE spectrum is tested with voltage of 1800V. As shown in Fig.4a, peak value of SPE spectrum is used to calculate the absolute gain. Anode output under different voltage from 1000V to 1800V with a step of 100V is recorded, with constant LED driven level, to get the voltage response curve. As shown in Fig.4b, 50 000 events are recorded for each point to reduce the statistical error. With formula $G = AV^{\beta}$, working voltage could be calculated, with which other properties of PMT are measured.

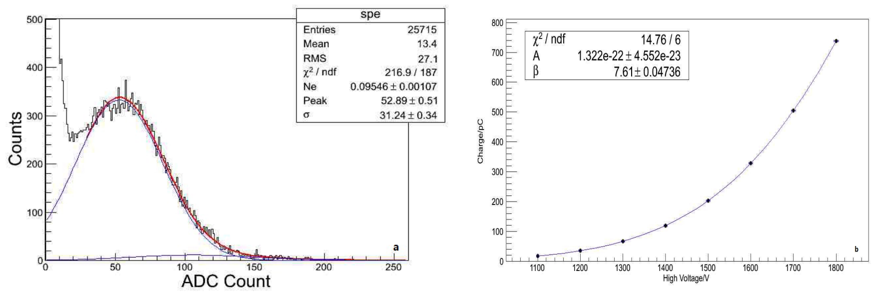

Figure 4: Calibration for working voltage. (a) Single Photoelectron Spectrum (b) High Voltage Response Curve

4.2 Uniformity

WLS fibers are coupled to the cathode in a disk area with diameter of 16mm. Uniformity in this area would affect the uniformity of ED when particles hit different area. Light source in light tight box is close to the cathode with a distance of 1mm and moves with the step monitor in a step of 1mm to scan the whole cathode in diameter of 38mm. As Fig.5a shows, anode output should be changed softly and no dead band should be found for the whole area. Data in diameter of 16mm are counted to plot the histograms as Fig.5 shown. RMS/Mean for distribution is used to represent the uniformity of PMT in statistics. Uniformity of XP2012B PMTs is 6% on average.

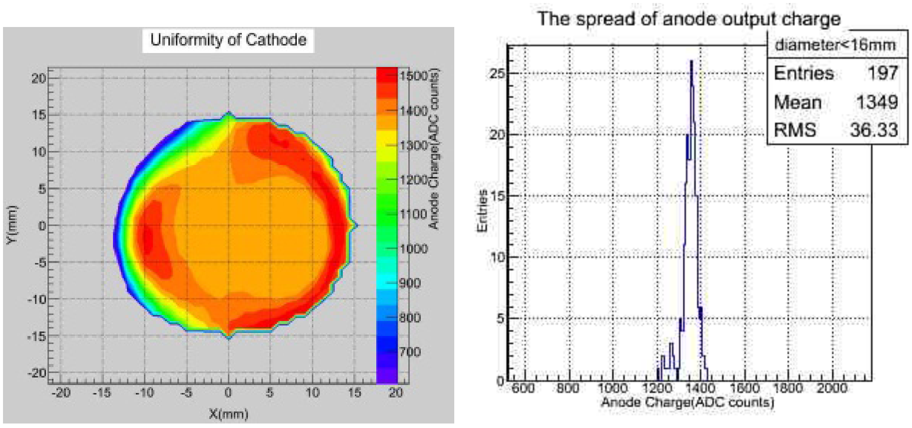

Figure 5: Uniformity. (a) Scan result for uniformity. (b)Anode output for different area in cathode.

4.3 Linearity

ED responds in a wide dynamic range covering from 1 to 10 000 particles/m^2, corresponding to a maximum anode linear current up to 1163mA, which is impossible to reach by anode readout of one PMT. So the design of dual-readout for both anode and dynode is put out for XP2012B. The method, named di-distance method, was developed to measure the linear dynamic range of PMT. The distance between the LED and PMT window can set to far and near position. The ratio of the light illuminating on the PMT will be a constant r for near and far distance. Increasing the intensity of LED light by adjusting the amplitude of driven pulse step by step, the ratio of PMT signal keeps at constant r for same far and near distance if the PMT works within linear range. Otherwise, the ratio will deviate from r, and linear range will be found. The non-linearity is defined as follows:

$$NL = (\frac{Q_{near}}{Q_{far}} - r)/r.$$

in which Q_{near} and Q_{far} represents the charge for near and far distance separately.

Fig.6a shows the linearity for both anode and dynode, in which output charge of dynode is multiplied by the ratio between anode and dynode output charge to get the equivalent anode output. The maximum equivalent anode current for dynode is recorded when the nonlinearity is worse than -5%. Maximum linear current for 33 out of 37 PMTs reach the requirement, as shown in Fig.6b.

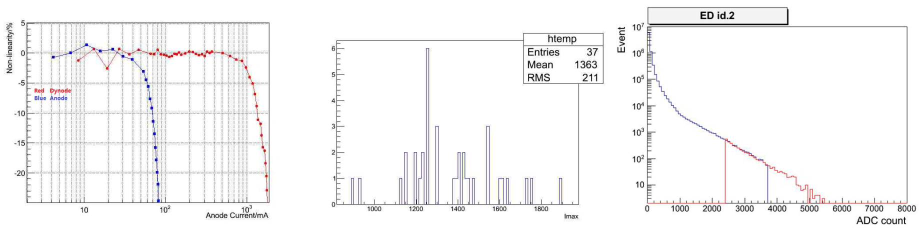

Figure 6: Linearity for PMT. (a) Linearity for anode and dynode. (b) Result for maximum linear current. (c) Connection for anode and dynode charge spectrum.

As Fig.6c shown, charge of anode and dynode for one PMT had been connected properly with the data from prototype array. And maximum linear current had been proved to reach our requirement, which means method for dual-readout of anode and dynode is feasible to widen the dynamic range of PMT.

4.4 Drak noise rate

Dark noise rate of PMT lower than 200Hz is needed for ED in consideration of the accidental coincidence rate. Signal for PMT is multiplied by a 10 times multiplier before entering the low threshold discriminator (LTD) with a threshold of 10mV. PMT is placed in the light tight box with power on for 12h before the test. All PMT has a dark noise rate lower than 200Hz and mean value is 13.4Hz for XP2012B, which has a tiny contribution to the noise of ED.

4.5 CTTD and TTS

TTS is the characteristic which represents the time resolution of PMT and CTTD contributes the time offset when particles path through different area of ED, both of which will affect time resolution of ED directly. Test and analysis for CTTD is same as test for uniformity, though the low threshold discriminator(LTD) and TDC is used for signal recording, As Fig.7a shown. As Fig.7b shown, RMS is used to represent the characteristic of CTTD in statistic. CTTD for XP2012B is 0.5ns on average. Gain for PMT is set to $5*10^6$ for TTS test. Fig.7c shows the result for one PMT, FHWM for TT distribution is defined as TTS. TTS for XP2012B with the gain of $5*10^6$ is 5.6ns on average. With these PMTs, time resolution of ED is 2ns to 2.2ns, which fail to reach the requirement that time resolution should be better than 2ns. With PMT of TTS 3.5ns, time resolution of ED is improved to 1.82ns. PMT with better TTS should be selected to guarantee a better time resolution for ED in future.

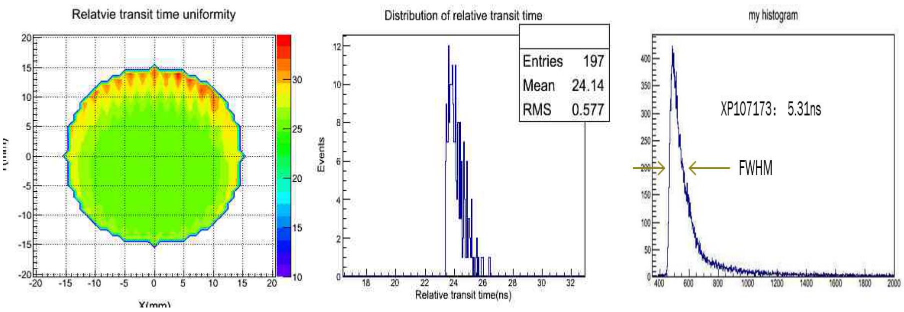

Figure 7: TTS and CTTD. (a) Scan result of CTTD. (b)Calculation for CTTD. (c) TT distribution for one XP2012 PMT.

5. Conclusion

PMT test bench has been built up in SDU to fulfill the requirement of measurement for more than 5200 PMTs in the future. Method for dual-readout of anode and dynode is proved feasible to realize the wide dynamic range of ED. Other properties of PMT used in prototype array also reach the requirements. All the characteristics of PMTs mentioned above guarantee a good performance of ED in the prototype array.

6. Acknowledgement

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