Studies of timing properties for a TOF counter at an external target facility*

YU Yu-Hong(余玉洪)[1,2;1)] XU Hua-Gen(徐华根)[1] XU Hu-Shan(徐瑚珊)[1;2)] ZHAN Wen-Long(詹文龙)[1]
SUN Zhi-Yu(孙志宇)[1] GUO Zhong-Yan(郭忠言)[1] HU Zheng-Guo(胡正国)[1]
CHEN Jun-Ling(陈俊岭)[1] TANG Shu-Wen(唐述文)[1,2]

1 (Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China)
2 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract Timing and amplitude properties of a prototype scintillator TOF counter at an external target facility are studied with a cosmic rays test. The dependence of signal pulse height and time resolution on the coordinate along the scintillator TOF counter is investigated with two different discriminators. A time resolution of 165 ps can be achieved at the center of the counter with a constant fraction discriminator. Time resolution better than 150 ps is obtained at the center with a leading edge discriminator after time walk correction is applied for off-line analysis.

Key words external target facility, scintillator, discriminator, time resolution

PACS 29.30.Aj

1 Introduction

With the Cooling Storage Ring of the Heavy Ion Research Facility in Lanzhou (HIRFL-CSR), an External Target Facility (ETF), also as a terminal of the second Radioactive Ion Beam in Lanzhou (RIBLL II), is under construction at the Institute of Modern Physics (IMP), CAS[1]. To make full use of the capabilities of the new RIB line, a sweeper magnet, a large area neutron detector with high detection efficiency and charged particle detectors are essential and under construction at ETF.

The time-of-flight (TOF) technique, employing a fast plastic scintillator, has often been used to study the charged fragments produced in a break-up reaction. A set of scintillator counter arrays with the same specification, called the “TOF-wall”, has been designed and constructed. The TOF-wall detectors will be located on both sides of the beam axis to measure either positively or negatively charged particles. Each TOF-wall detector is a high-efficiency, position-sensitive, double-layer detector system for measuring light charged particles with energies from several tens of MeV to ~1 GeV. This paper presents the design of the TOF-wall, and detailed studies of the timing properties for the prototype scintillator counter.

2 TOF-wall structure

Each TOF-wall detector, covering an overall active area of 120 cm × 120 cm, consists of 60 individual modules paralleled in two layers. Each layer is an assembly of 30 modules mounted with their long axis in the vertical direction. To avoid the presence of any ineffective detection area, there is a deliberate 2 cm misalignment between the two layers.

The single module consists of a 120 cm × 4 cm × 1 cm counter of the BC-408 plastic scintillator, which is manufactured by Saint Gobain Corporation[2]. Two photomultipliers (PMTs) R7525 (Hamamatsu) are employed as a read-out device[3] and coupled to a light guide 12 cm in length by two 2 mm thick silicone cushions on both ends, respectively. In order to reduce the light loss during propagation each counter is

Received 15 December 2008
* Supported by Knowledge Innovation Project of Chinese Academy of Sciences (CXTD-J2005-1, KJCX2-SW-N18), and NSFC (10635080, 10221003)
1) E-mail: yuyuhong@impcas.ac.cn
2) Corresponding author. E-mail: hushan@impcas.ac.cn, Tel.:+86-931-4969-325; Fax:+86-931-4969-329

wrapped with a 0.15 mm thick Tyvek 1056D [4], provided by Dupont Corporation, and light shielded with black plastic. The light guide is wrapped by Teflon due to its irregular shape. The voltage divider for PMT is designed with reference to the corresponding Hamamatsu manual, and the voltage distribution in dynodes is $4R:1R:1.5R:1R:1R:1R:1R:1R:1R$; here the adopted value of R is 200 kΩ.

3 Experimental setup

Timing measurements of a prototype scintillator TOF counter are studied with a cosmic rays test. The 2-fold coincidence of signals from two small BC-408 plastic scintillator detectors S1 and S2, with the dimension of 4.0 cm × 1.0 cm × 1.0 cm for each, are used to trigger the Data AcQuisition system (DAQ) as well as being used as a common start of TDC. A point-by-point measurement has been carried out to study the timing characteristic of the scintillator counter.

A typical PMT signal corresponding to a cosmic incident ray at the center of the scintillator counter is shown in Fig. 1. The PMT signals output from each end of the counter are sent into a Constant Fraction Discriminator (CFD) to eliminate time corrections associated with variation of amplitude. To make a time walk effect correction, measurements using a Leading Edge Discriminator (LED) and QDC are also made simultaneously.

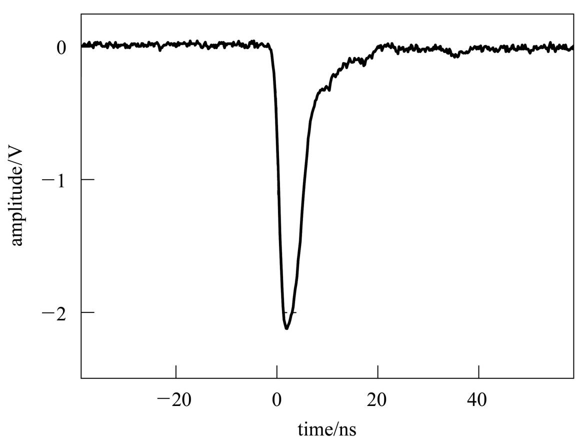

Fig. 1. A typical PMT pulse signal observed by a digital oscilloscope.

4 Analysis

The pulse height spectrum of one PMT, produced by minimum-ionizing muons crossing the counter at tested points, is well fitted by a Moyal[5] distribution. A similar result is obtained from the other phototube. In Fig. 2(a) the pulse heights of both PMTs and their geometrical mean are shown as a function of the coordinate along the counter axis. They exhibit a strong position dependence, which is described by a sum of two exponentials (see Fig. 2(b)). According to the pulse height geometric mean of the two PMTs, related to the total light collection efficiency, it is found that there is less total light at the center.

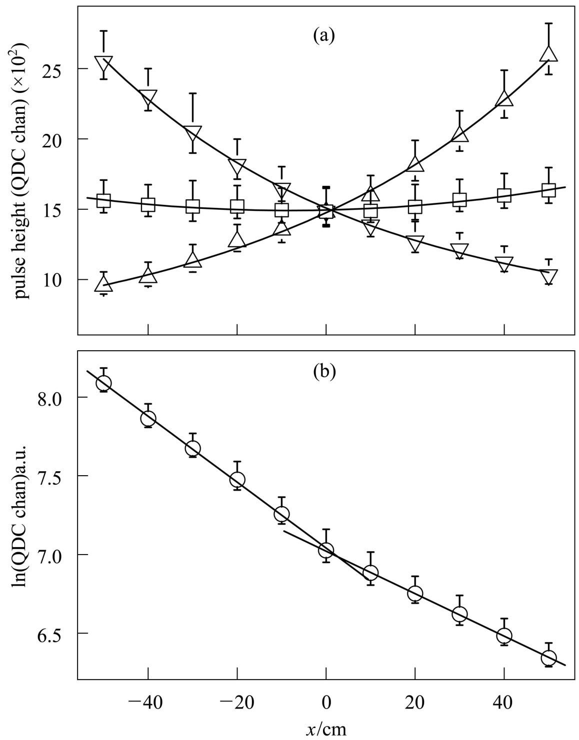

Fig. 2. (a) Charge pulse height distribution dependence on the hit position obtained from the scintillator counter. Open up-triangles and down-triangles are the results for PMT at each end along the x-axis, open squares are the results of the geometric mean of the two end PMTs. (b) Two components make a contribution into the light collection. The asymmetric error bar shows that a high-energy long tail exists caused by high-energy δ-rays, as cosmic rays penetrate the 1 cm thick scintillator counter. Lines show the fit to the experiment points.

For a double readout scintillator system, the weighted average time resolution for the crossing particle can be obtained by the relation

$$\sigma_{t_{\rm av}} = \sqrt{\left[\frac{1}{\sigma_{t_{\rm l}}^2}+\frac{1}{\sigma_{t_{\rm r}}^2}\right]^{-1}}\,, \tag{1}$$

where $\sigma_{t_{\rm l}}$, $\sigma_{t_{\rm r}}$ are the intrinsic time resolution of the two PMTs of a scintillator counter, $t_{\rm l}(t_{\rm r})$ is the measured time by TDC of the scintillator counter from the left (right) PMT, and $t_{\rm av}$ is the particle average crossing time using information from both ends of the tested counter. For each PMT output of the tested counter, the time interval, defined as the arrival time of the time signal from the PMT with respect to the common reference timing provided by S1 and S2[6], is recorded and analyzed. It is noted that the variance of the time interval includes the contribution from both the TOF start and stop detectors. To obtain the value of σ_{t_l} (σ_{t_r}), one of the methods is to solve three linear equations of the three time resolution between the start detector and the two ends of the counter: $\sigma(t_\mathrm{l}-t_\mathrm{s})$, $\sigma(t_\mathrm{r}-t_\mathrm{s})$ and $\sigma(t_\mathrm{l}-t_\mathrm{r})$.

Time distribution of the PMT signals from CFD are well fitted by a Gaussian distribution. The variance between the start detector and the two ends of the tested counter can be obtained easily, and used to calculate the intrinsic time resolution σ_{t_l} (σ_{t_r}).

In a scintillation timing system, the intrinsic timing jitter is inversely proportional to the square root of the pulse amplitude[7]. Without the time walk effect correction, LED generates "tails" on time distributions due to the variation of the pulse amplitudes. To remove this walk effect and obtain the variance between the start and the two PMTs, the correction was performed for each PMT of the test counters according to the equation

$$(t_{\mathrm{l(r)}}-t_\mathrm{s})'=t_{\mathrm{l(r)}}-t_\mathrm{s}+c_{\mathrm{l(r)}}+c_{\mathrm{l(r)}}/\sqrt{q_{\mathrm{l(r)}}}\ , \qquad (2)$$

where $c_{\mathrm{l(r)}}$ is the corrected parameter to be determined by the data; $q_{\mathrm{l(r)}}$ represents the integrated charge of the pulse, which is related to $t_{\mathrm{l(r)}}$ at the corresponding end, and t_s is the start time from the record of the start detector.

Figure 3(a) shows the time spread of $t_\mathrm{l}-t_\mathrm{s}$ signals versus signal pulse heights for $x=0$ measured with the CFD. The two dimensional scatter plot between $t_\mathrm{l}-t_\mathrm{s}$ pulse heights and measured times with the LED is shown in Fig. 3(b). It can be seen that the measured time is dependent on the signal pulse height (time walk effect). The walk effect is taken into account and the result is shown in Fig. 3(c). It is noted that the time distribution is more symmetric and close to the Gaussian after the walk effect correction for the results obtained with the LED. Except for $t_{\mathrm{l(r)}}-t_\mathrm{s}$, the correction is also used for $t_\mathrm{l}-t_\mathrm{r}$ since t_l and t_r can be considered as independent from each other.

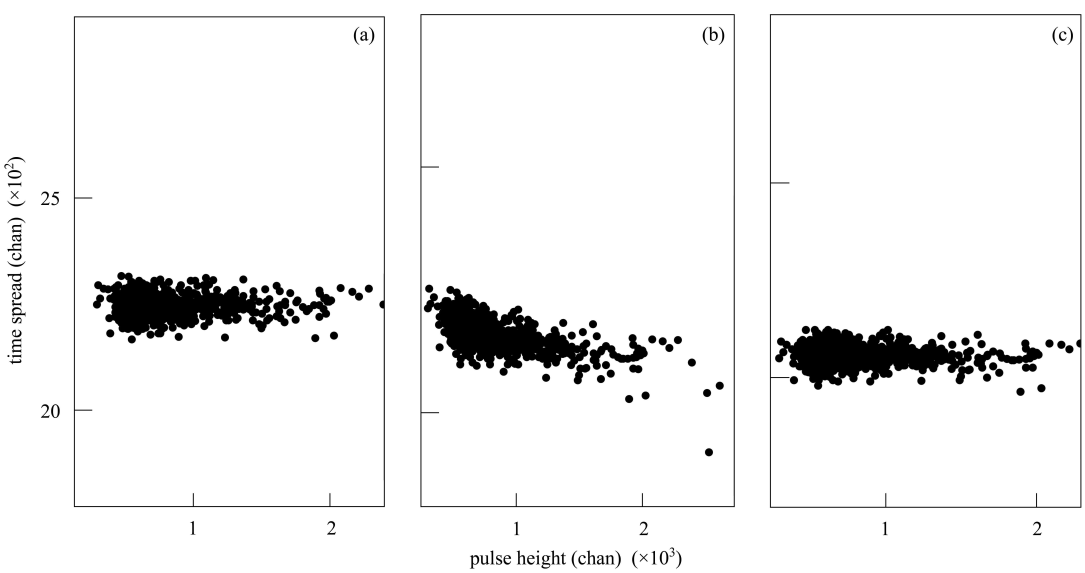

Fig. 3. $t_\mathrm{l}-t_\mathrm{s}$ signal time spread versus pulse height for $x=0$ (a) with the CFD; (b) with the LED without time walk effect corrections; (c) with the LED with time walk effect correction.

Figure 4(a) shows position x corresponding to the time resolution $\sigma_{t_\mathrm{l}}(\sigma_{t_\mathrm{r}})$, which is obtained using a single PMT at each end of the scintillator counter with two different discriminators. The time resolution for a single PMT is well fitted by an exponent function, and the weighted time resolution is given by[8]

$$\sigma_{t_\mathrm{av}}(x)=\sigma_0\frac{\mathrm{e}^{(L/4\lambda)}}{\sqrt{2\cosh(x/\lambda)}}\ , \qquad (3)$$

where L is the length of the counter, and σ_0 and λ are parameters. From Fig. 4(b), a time resolution of 165 ps can be achieved at the center of the counter with the CFD. The results obtained with the LED and corrected for time walk effect are also shown in Fig. 4(b). A time resolution of 150 ps is obtained at the same area as the former. For convenience, we defined a "near PMT" and a "far PMT" according to the distance between the hit point and the readout PMTs at each end. From these figures, it is found that the "near PMT" always has better time resolution than the "far PMT" and the worst weighted time resolution is obtained at the central area.

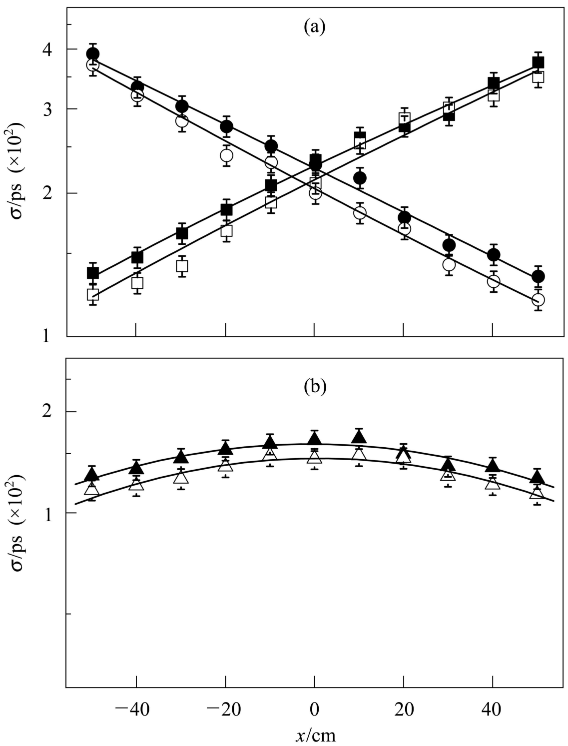

Fig. 4. Time resolutions of (a) σ_{t_l}, σ_{t_r} and (b) $\sigma_{t_{av}}$ versus x with two different discriminators. Solid symbols are the results for the CFD, and open symbols are the results for the LED corrected for the time walk effect.

Since each counter has two PMTs in equivalent condition to collect photons, it is possible to estimate the number of photoelectrons from their charge pulse height geometrical mean distributions. The width of this distribution depends mainly on photoelectron statistics. Assuming that the relative gains in two PMTs are matched one can estimate that the average number photoelectrons per PMT at different measured points from the distribution. It is found that there are less photoelectrons collected when the cosmic rays penetrate through the central hit point (also see Fig. 2(a)).

5 Conclusion

The TOF-walls with large area are designed to detect high-energy light charge particles in RIB experiments. Detailed studies of the timing and amplitude properties for a prototype TOF counter are performed with cosmic rays. The time resolution of 165 ps can be achieved at the center of the counter with a CFD. Compared with the CFD, a low-cost, high-performance discriminator with a leading-edge discrimination method can also meet our physics requirements. Further investigation of the timing using a LED with a simultaneous measurement of pulse is carried out as well. The result indicated that the time resolution of the TOF counter is about 10 percent better than using the CFD, after the time walk effect applied. The worst time resolution is obtained at the center of the counter because of less total light.

References

1 XIA J W, ZHAN W L, WEI B W et al. Nucl. Instrum. Methods A, 2002, **488**: 11
2 http://www.bicron.com
3 http://www.hamamatsu.com
4 http://www.MedicalPacking.dupont.com
5 Moyal J. Philos. Mag., 1955, **46**: 263
6 YU Yu-Hong, XU Hua-Gen, XU Hu-Shan et al. Chinese Physcics C (HEP & NP), 2009, **33**(7): 557
7 WANG Zhi-Ying. The Technical Princinple of Nuclear Electronics. Beijing: Atomic Energy Press, 1989. 194—195 (in Chinese)
8 Denisov S, Dzierba A, Heinz R et al. Nucl. Instrum. Methods A, 2002, **494**: 497