A study of time over threshold (TOT) technique for plastic scintillator counter*

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Abstract A new charge measurement method, time over threshold (TOT), has been used in some gas detectors lately. Here TOT is studied for TOF system, made of plastic scintillator counter, which can simplify the electronics of the system. The signal characteristics are measured and analyzed with a high quality oscilloscope, including noise, pedestal, signal amplitude, total charge, rise time and the correlation between them. The TOT and charge are related and can be fitted by some empirical formula. The charge measurement resolution by TOT is given and this will help the design of TOF electronics.

Key words scintillator counter, time over threshold (TOT), charge measurement, relative resolution

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1 Introduction

For fast signals, the pulse width is somewhat dependent on the pulse height. Thus the pulse height (charge) can be obtained by measuring the pulse width (i.e. the “Time over threshold”). Usually the front-end electronics of a time of flight (TOF) system is composed of the timing circuit and the charge circuit. The charge measurement is mainly used for time-amplitude correction to give a better time resolution and it generally doesn’t need very good precision. The TOT technique, transforming the charge measurement to time measurement, can combine two circuits. So it can simplify the electronics in some TOF systems and reduce the cost.

Lately the TOT technique has been used in several gas detectors. An ultra fast front-end preamplifier-discriminator chip called NINO has been developed and the TOT technique was applied to measure charge rather than amplitude in the ALICE TOF of Multi-gap Resistive Plate Chamber. Its correction of front edge time walk is done by TOT[1, 2]. The readout electronic of TOF of the Multi-gap Resistive Plate Chamber in STAR also uses the TOT technique to infer the input signal rise time for the slewing correction[3]. This technique has been studied by the Drift Chamber of CLEO-III also and it can achieve 10% charge resolution with 300 ns shaping time constant in the Drift Chamber with He-Propane gas mixture[4].

Then how about the use of the TOT in TOF of plastic scintillator? In this paper, this is studied and we try to answer how much of the relative charge resolution can be obtained by the TOT technology.

2 Experimental setup

Figure. 1(a) and Fig. 1(b) show the experimental setup for recording the pulse of the scintillator counter and the readout logic system. The plastic scintillator counter is made of a 2.3 m long EJ-200 scintillator and a fine-mesh PMT R5924. The EJ200 scintillator has a decay time of 2.1 ns, and a bulk attenuation length of 4 m. It is coupled with the R5924 PMT by air of gap at one end and wrapped with black paper to absorb the light at another end. The output of R5924 is fed into the oscilloscope Lecroy7100 to record this pulse. The oscilloscope has a 20 Gs/s

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sample rate to capture the signal details with 1 GHz bandwidth and 8 bits vertical resolution. The whole signal of TOF can be kept by the oscilloscope and then the TOT, the charge and the amplitude can be obtained offline.

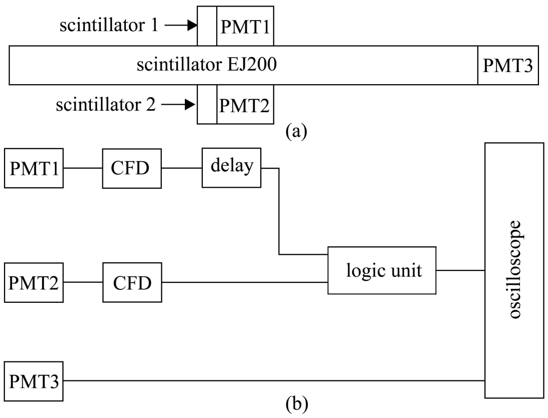

Fig. 1. (a) The experimental setup for recording the TOF pulse; (b) Schematics of the readout system.

The cosmic ray trigger consists of two small plastic scintillators coupled with photo-multiplier tubes (PMT). Plastics scintillators 1 and 2 of BC420 with a cross-section of 5.0 cm×5.0 cm are coupled with PMT1 and PMT2 with silicon grease which are Philips XP2020. The signals from PMT1 and PMT2 are discriminated by the Constant Fraction Discriminator (CFD). Then the channel from PMT1 is delayed a little before going into the coincident unit, so the timing of start signal from the coincident unit is determined by the leading edge of the signal of PMT1. The Output signal of this coincident unit is used as the oscilloscope common start gate signal.

3 Analyzing the oscilloscope signal of TOF

3.1 Noise, amplitude, charge and rise time

For every pulse recorded by the oscilloscope, the time width is 500 ns as shown in Fig. 2(a). And the data within the first 250 ns are noise without any particle passing through the scintillator counter. Fig. 2(b) shows the spectrum of noise which is fitted by using the normal distribution. The baseline has an offset of 2 mV.

To get the peak value of every pulse, 10 points near the peak are fitted with the normal distribution, because the oscilloscope records one point of pulse every 50 ps. Fig. 2(c) shows a fitting example. The peak value of this distribution minus offset of this pulse is the pulse height (i.e. the amplitude).

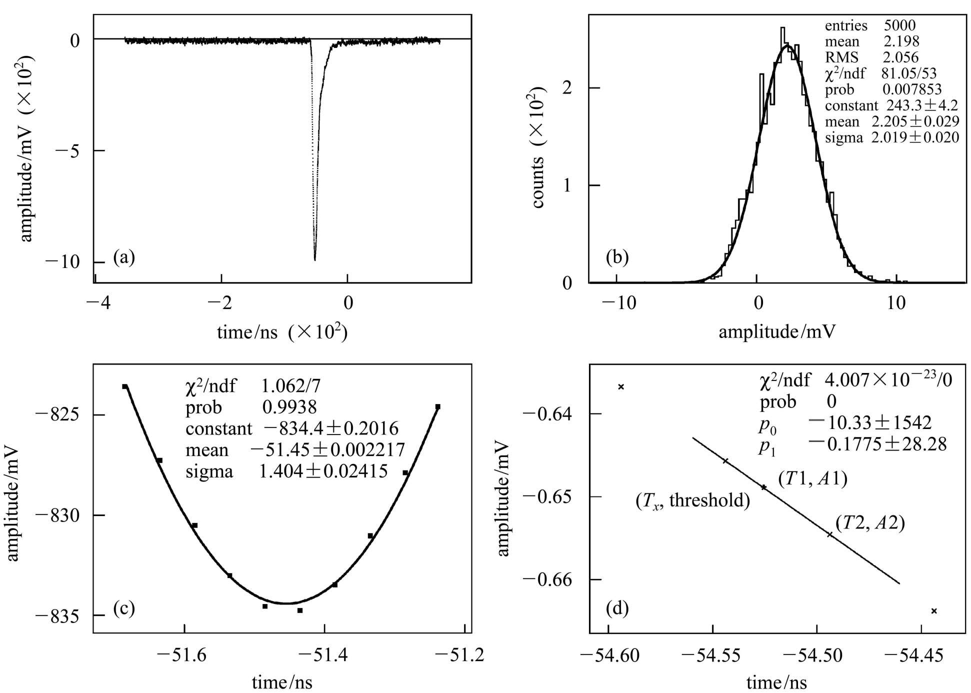

Fig. 2. (a) A wave shape of pulse; (b) The noise spectrum; (c) The peak of one pulse; (d) Illustration of calculating time at threshold.

The charge of every pulse is obtained from the time integral of the current pulse. The width of integral time is 100 ns which starts 40 ns before the time of peak to 60 ns after it. The charge of the pulse can be calculated with an equation

$$Q=\frac{50\ \text{ps}\times\sum\limits_{i=0}^{i<2000}V_i}{50\ \Omega}\ . \qquad (1)$$

When the oscilloscope is set at 200 mV/div, $\sigma_{\rm v}=\frac{0.2\times 8}{256}$=0.00625 V, the charge measurement precision can be obtained from the following equation:

$$\sigma_Q=\sqrt{\sum_{i=0}^{i<2000}(\sigma_{{\rm V}_i})^2}=\sqrt{2000\times(0.00625)^2}=0.28\ \text{pC}. \qquad (2)$$

If the charge changes from 60 to 200 pC, the relative precision of measurement can be achieved from 4.7‰ to 1.4‰.

The oscilloscope records the time and amplitude values of a signal per 50 ps. Given a threshold value, the time values can be obtained by the recorded data. Fig. 2(d) shows the method to calculate the time values by linearly fitting two nearby recorded points.

$$T_x=T_1+(T_2-T_1)\times\frac{\text{Threshold}-A_1}{A_2-A_1}\ , \qquad (3)$$

where A_1 and A_2 are the amplitude values of the nearby recorded data points, T_1 and T_2 are the arrival time of the two points near the threshold.

Figure 3 shows the distribution about offset, amplitude, charge and rise time of the pulse (The rise time is the time when the signal changes from 10% to 90% of the pulse height.). It is obvious that the offset of all pulses follows the normal distribution and the mean of the offset is 2 mV. The amplitude and charge follow Landau distribution.

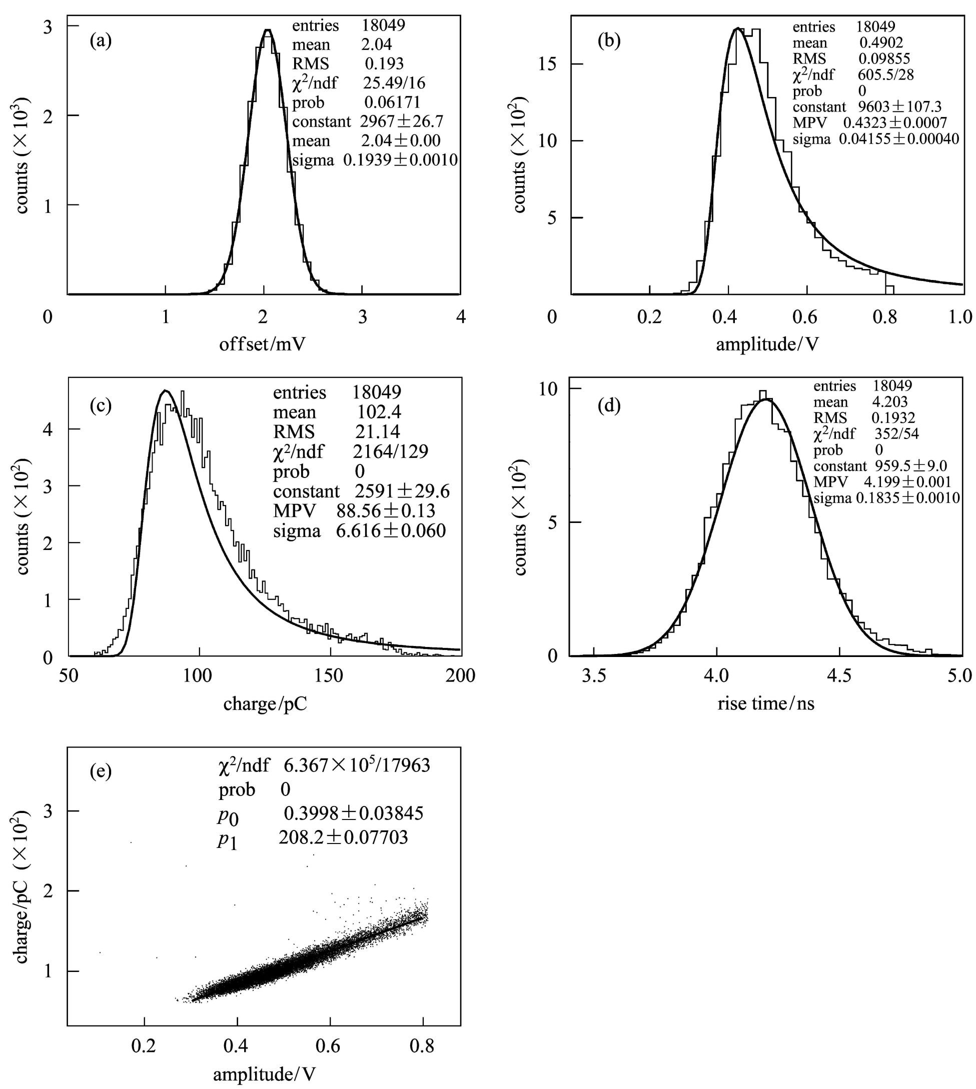

Fig. 3. (a) Spectrum of pulse offset; (b) Spectrum of amplitude; (c) Spectrum of charge; (d) Spectrum of rise time; (e) Charge versus amplitude.

Figure 3(d) demonstrates the histogram of rise time. It can be seen that when the light transfers from the center of bar to the end, the most probable value of rise time is 4.19 ns. Fig. 3(e) exhibits the approximately linear relation between charge and amplitude.

3.2 The correlation between TOT and charge

TOT has different spectrums as the threshold of TOT changes. The correlation between TOT and charge for two thresholds, 15% and 45% of the most probable value of amplitude, is shown in Fig. 4. In our situation, when the most probable value of the amplitude is 433 mV, the threshold of TOT is 65 mV and 195 mV. Fig. 4(a) and Fig. 4(b) show the spectra of TOT with different thresholds. TOT becomes small as the threshold increases. Fig. 4(c) and 4(d) exhibit the correlation between TOT and charge with different thresholds.

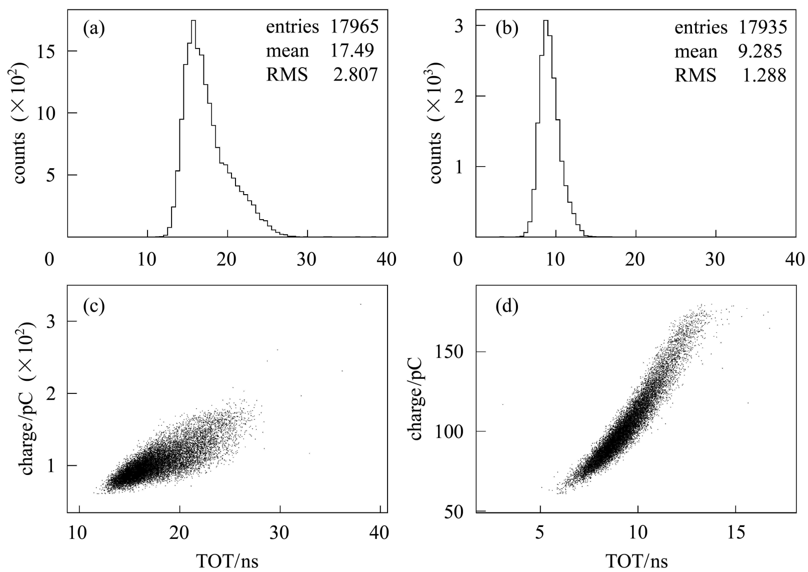

Fig. 4. (a) and (c) The distribution of TOT and the correlation between TOT and charge when the threshold is set to 65 mV; (b) and (d) The same as (a) and (c), but the threshold is set to 195 mV.

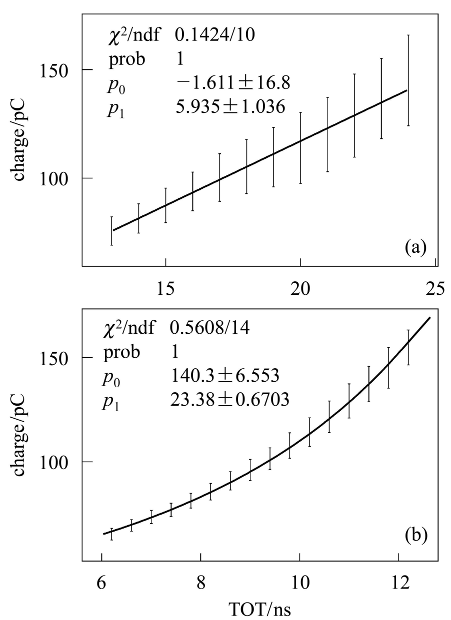

Fig. 5. TOT versus charge with different thresholds. The solid line show the best fit for mean charge value vs. TOT. (a) The threshold is set to 65 mV; (b) The threshold is set to 195 mV.

To study the correlation between TOT and charge, the TOT is grouped into bins. The spectrum of charge of every bin is fitted with the normal distribution. Its mean value and the standard deviation are obtained. Fig. 5 shows the correlation between TOT and charge with different thresholds. Fig. 5(a) exhibits the linear correlation between TOT and charge if the threshold is set to 65 mV. As the threshold of TOT increases to 195 mV, the correlation is not linear. It is shown in Fig. 5(b). This correlation can be fitted with the empirical equation $\mathrm{TOT}=A+B/\sqrt{Q}$, this equation can arrive at the best fit for mean charge.

With the above two fitted functions, the reconstructed Q by TOT can be obtained, the relative error of Q by TOT can be obtained by formula

$$\frac{\delta_Q}{Q}=\frac{Q_{\mathrm{TOT}}-Q_{\mathrm{actual}}}{Q_{\mathrm{actual}}}, \tag{4}$$

where Q_{actual} can be obtained by Eq. (2) and its precision as discussed above is better than 4.7‰ This is very precise and can be considered as the real value when considering the charge resolution by TOT. The distribution of $Q_{\mathrm{TOT}}-Q_{\mathrm{actual}}$ is fitted with the normal distribution.

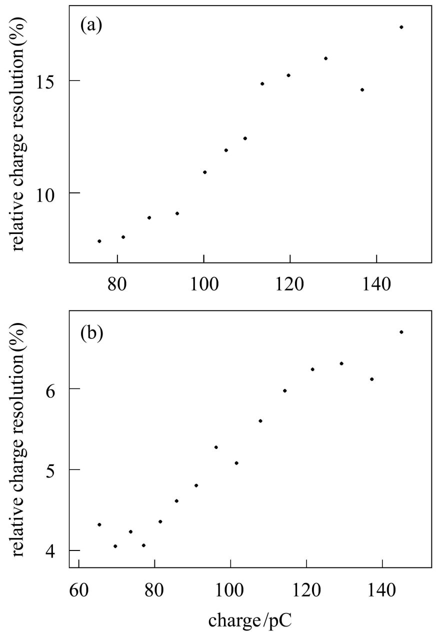

Fig. 6. The relative charge resolution versus charge. (a) The threshold is set to 65 mV; (b) The threshold is set to 195 mV.

Figure 6(a) and (b) show the relative charge resolution as the function of the measured charge, and the relative charge resolution tends to be worse as the charge increases. When the threshold of TOT increases from 65 mV to 195 mV, the relative charge resolution becomes better. The relative resolution by TOT can reach 4% to 7% when the threshold is set to 195 mV. This relative resolution relating to the jitter of pulse shape is due to the variation of the light emission in scintillation and electron multiplier in the photomultiplier tube.

4 Conclusions

The TOT technique for TOF made of plastic scintillator can be used for charge measurement and the above results will be useful for its electronics design. The charge could be reconstructed from TOT by some empirical formula. Our conclusions from the experiment are the following:

(1) When the threshold of TOT is set to be 15 percent of the most probable value of amplitude, which is the same as the threshold set to time measurement, the relation between TOT and charge is linearity and the relative charge resolution of this technique is only from 7% to 18%.

(2) When the threshold of TOT increases to 45 percent of the most probable value of amplitude, the resolution could be improved from 4% to 7%. The expense of increasing the threshold decreases the detection efficiency by a few percent. Also, as it is higher than the threshold of time measurement, the signal from PMT should be divided into two channels. One is sent to time measurement and another is sent to TOT measurement.

This TOT technique may simplify the development of the electronics and save its cost. Its disadvantage is that the precision of charge by TOT can not be very high for plastic scintillator since the TOT is not only the function of the charge, but also the function of the attenuation of light transmission, hit position, and transit time spread of photomultiplier tube.

References

1 ALICE Collaboration. Addendum to the Technical Design Report of the Time of Flight System, 2002. 20—25

2 Anghinolfi F et al. Nucl. Instrum. Methods A, 2004, **533**(1-2): 183—187

3 Schambach J et al. Proposed STAR Time of Flight Readout Electronics and DAQ, Proceedings of Computing in High Energy and Nuclear Physics Conference, 2003

4 Bebek C et al. Time over threshold technique for a drift chamber readout system, Proceedings of 5th Annual LeCroy Conference on Electronics for Particle Physics Conference, 1995