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Time over threshold in the presence of noise

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ABSTRACT

The Time-over-Threshold (ToT) technique is a widely used quantity to measure the energy deposited in various detectors in particle physics. In this paper we present the studies of its behavior in the presence of noise. The ToT distributions from cosmic-ray data showed several equally spaced peaks that were successfully modeled due to a sinusoidal noise pick-up. The effects of that noise on the detection efficiency and energy resolution are also discussed.

1. Introduction

A common setup in particle physics is to couple a particle-sensitive material (e.g. scintillator, Cherenkov) to a photosensitive device like photomultiplier tube (PMT) or multipixel photon counter and measure the energy deposited in the material by reconstructing a given property of the output current pulse – the total charge collected, the pulse amplitude, etc. The measurement of the time over threshold (ToT), as shown in Fig. 1, is composed of two measurements of time for the signal going above (leading) and returning below (trailing) a given threshold [1]. This provides information about energy deposited by the interacting particle through the reconstruction of the difference between leading and trailing time $\Theta = t_{trail} - t_{lead}$. In addition the impact time could also be obtained from the leading time with a possible energy dependent correction. The dependence of the deposited energy on ToT (see Fig. 2) in the case of signals with fast rising time and exponential tail has an exponential form and could be parameterized by

$$E(\Theta) = \alpha Q(\Theta) = \beta A(\Theta) = E'_0 e^{k\Theta} + E_0 \quad (1)$$

due to the linear relation between energy E, charge at the anode Q of the photodetector and the signal amplitude A, where α, β, and k are constants and $(E'_0 + E_0)$ is related to the minimal detectable energy deposit corresponding to an amplitude equal to the threshold.

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The advantage of using the ToT instead of charge or amplitude measurement is the wider dynamic range accessible due to the logarithmic dependence on the energy. In addition the measurement of the time is performed using time to digital converters (TDCs) which provide less expensive solution per channel than the analog to digital converter (ADC) or charge to digital converter (QDC), especially where high signal rate and short signals are expected.

While the charge or amplitude measurements are a well established and mature technique, the ToT measurement became attractive in the late 90s with the development of the vertex detector for the BaBaR experiment [2]. Recently it is even more powerful due to the development of high precision time measurement devices, having a resolution of tens of picoseconds.

In the present paper we describe the observation of a peculiar structure in the reconstructed distribution of the ToT, which we explain by the superposition of a small-amplitude sinusoidal noise on top of the PMT signal. Such an effect was not observed in the previous studies of the noise in the Time-over-Threshold circuits [3].

Moreover, the much more common technique of the charge measurement done by the QDC is relatively immune to this noise as the integral over a long interval of time with respect to the period of a sinusoidal function is approximately zero.

2. Experimental setup

The present study was done at LNF-INFN as part of the development of the readout system of the Large Angle Photon Veto (LAV) system for the NA62 experiment at CERN SPS [4].

The NA62 experiment aims to perform a 10% measurement of the branching fraction of the extremely rare decay $K^+ \to \pi^+ \overline{\nu} \nu$ and subsequently to measure the V_{td} CKM matrix element. The theoretical prediction for the branching fraction is $Br(K^+ \to \pi^+ \overline{\nu} \nu) = (7.81 \pm 0.80) \cdot 10^{-11}$. The very low rate requires an efficient veto of all the other charged-kaon decay-modes, most of which contain photons in the final state. The use of a 75 GeV kaon beam increases the minimal photon energy at which high rejection factor is necessary but still an inefficiency less that 10^{-4} is required for photons with an energy of 200 MeV [5].

The Large Angle Photon Veto system [6] consists of blocks made of Schott SF57 lead glass coupled to a Hamamatsu R2238 (76 mm diameter) photomultiplier [7]. The blocks formerly used in the OPAL electromagnetic calorimeter barrel [8] are arranged in stations, each composed of four or five rings [4]. A total of 12 Large Angle Photon vetoes were produced, with 5 or 4 rings for a total of about 2500 analog channels. The signal from a 100-MeV photon in the lead glass after propagation through the cables to the front-end electronics can have an average amplitude as low as 10 mV at PMT gain of about 10^6. This signal is almost equivalent to the response to the energy deposited by a vertically incident cosmic ray. The efficiency for detection of such signals should be greater than 95%.

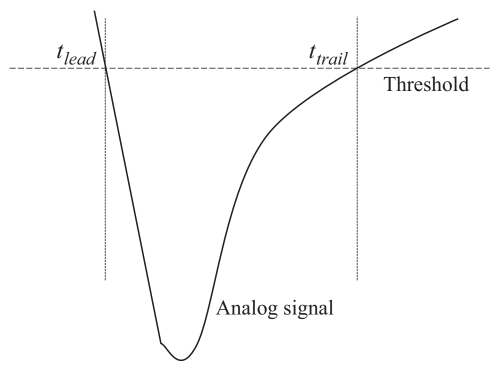

Fig. 1. The time over threshold is defined as the difference between the times when the analog signal goes above (t_{lead}) and below (t_{trail}) a certain threshold.

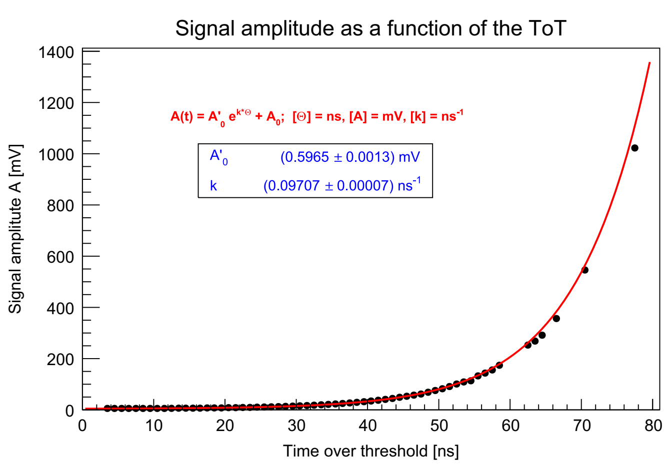

Fig. 2. Relation between the time over threshold and the amplitude of the signal derived from simulation and approximated with exponential function. The relation between the signal amplitude and the deposited energy is linear.

The LAV front end electronics (LAV FEE) was developed at the LNF [9,10]. It is based on a 9U VME mother board receiving 32 analog inputs. Each signal is clamped, amplified and split into two before being fed into a high-speed comparator with an LVDS output driver. This design allows the application of a time walk correction to improve the signal timing.

The comparator thresholds can be set through a board-controller mezzanine, which provides a serial USB and a CANopen communication [11]. The minimal threshold that could be set on the input signal for each of the channels was found to be less than 5 mV [12]. An additional negative feedback circuit was implemented to dynamically decrease the absolute value of the threshold just after the formation of the leading edge of the signal. Such a mechanism, referred to as hysteresis, provides a safety margin against fast changing signals which would cause the digital LVDS output to oscillate.

The experimental setup used during these studies is shown in Fig. 3. The lead-glass blocks were arranged in 4 columns of 5 blocks placed inside a light-tight metal box. The top and the bottom rows of blocks were used in the trigger logic to construct a cosmic ray telescope for vertical muons and only the three rows in the middle were studied. The signals coming from the lead-glass blocks, after the discrimination, were readout by a CAEN V1190B TDC module [13] which is based on the CERN HPTDC chip [14] and incorporates 2 times 32 input channels. The data is transferred to a PC for further analysis through a CAEN V1718 VME controller via a USB connection.

Some of the recorded data showed a peculiar shape of the ToT distribution. An explanation based on the addition of a sinusoidal noise was proposed and verified by means of a numerical signal simulation.

3. Signal and noise modeling

The general function describing the output signal is

$$A(t) = \int_0^t I(t-\theta) f(\theta)\, d\theta \qquad (2)$$

where $I(t)$ is the intensity of the light produced in the active material and $f(t)$ is the photodetector response function to single

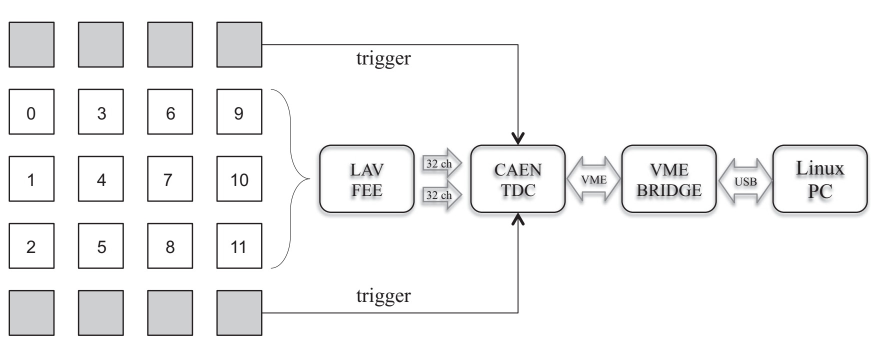

Fig. 3. Schematics of the experimental setup for the measurement of the ToT distribution for cosmic rays with lead-glass blocks. The top and bottom rows of blocks are used to form the trigger to select vertical cosmic rays.