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Time resolution measurement of avalanche counters using digital signal processing technique

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A B S T R A C T

The application of digital sampling technique for extracting the timing properties of parallel-plate avalanche counter (PPAC) is described. The preamplifier output signals of two identical avalanche counters were simultaneously digitized by using a digital storage oscilloscope (sampling rate up to 10 GS/s, 8-bit resolution) and analyzed offline. The offline analysis includes signal and noise discrimination, noise filtration and determination of pulse arrival time. A time resolution better than 398 ps was obtained which matches the best literature results using analog electronics. The effect of sampling rate of signals on the achievable time resolution is studied as well. The results of the investigation lead to a simple and flexible method of data analysis in experiments dealing with avalanche counters.

1. Introduction

Parallel-plate avalanche counters (PPACs) are considered to be one of the most attractive and inexpensive tools in timing measurements (Martin and Stelzer, 1978; Stelzer, 1979). These detectors are frequently used in combination with other detectors such as drift chambers, Bragg ionization chambers or solid-state detectors for building multi-parameter detection systems (Tserruya et al., 1982; Kotov et al., 1999; Barbui et al., 2007; Beghini et al., 2005). PPACs are also the standard choice for detection of fission fragments in the fission experiments (see Nishio et al., 1997; Kotov et al., 2006; Bredeweg et al., 2007).

The analysis of PPAC signal is normally done online using standard analog timing electronics including fast amplifier, constant-fraction-discriminators (CFD) and a time-to-amplitude converter (TAC) whose output pulses are collected in a multi-channel analyzer (MCA). This chain of analog electronics performs well; however, if unexpected information in the detector signal is lost, there is no means of restoration.

Recent advances in high-speed signal digitization have presented new and exciting opportunities in many nuclear and particle physics measurements. High-speed signal digitization allows the acquisition and storage of the complete signal from the preamplifier output that enables offline analysis of signals. Such analysis would be free of the constraints of online processing, and could include repeated reanalysis to investigate alternative techniques. Moreover, the use of digital techniques greatly simplifies the electronics, as the preamplifier output is directly digitized and processed.

In this paper we have studied the potentials of digital sampling technique for exploiting the timing properties of avalanche counters. For this purpose, an experimental arrangement including two identical avalanche counters in conjunction with a digital storage oscilloscope (sampling rate up to 10 GS/s and 8-bit resolution) was used to obtain several thousands of coincident signals. The digitized signals are offline processed to extract the time resolution of avalanche counters by considering the effects of noise filtration and sampling rate of signals. The capability of digital techniques for improving the discrimination of the signals from noise at poor signal-to-noise conditions is explored as well.

2. Experimental setup

A PPAC simply consists of two thin parallel electrodes separated by a few millimeters with a uniform electric field between them and a suitable gas filling. Due to the strong electric field inside the detector gap, the primary electrons produced by the ionizing radiation initiate electron avalanches that leads to a detectable signal. The experimental arrangement used in this work consists of two identical avalanche counters of $5\times5\,cm^2$ (Fig. 1). The electrodes of the PPACs were made of 6-μm aluminized Mylar foil, well stretched over glass-epoxy frames. The interelectrode gap of each detector is 3-mm and is maintained by means of a highly machined spacer. The distance between the two PPACs is 5 mm. The tests were performed using an ^{241}Am α-source which emits 5.5 MeV α-particles. A collimator with an opening of 10 mm diameter is placed in front of the first counter to limit the time spread due to α-particles flight paths in the detectors electrodes. This helps to

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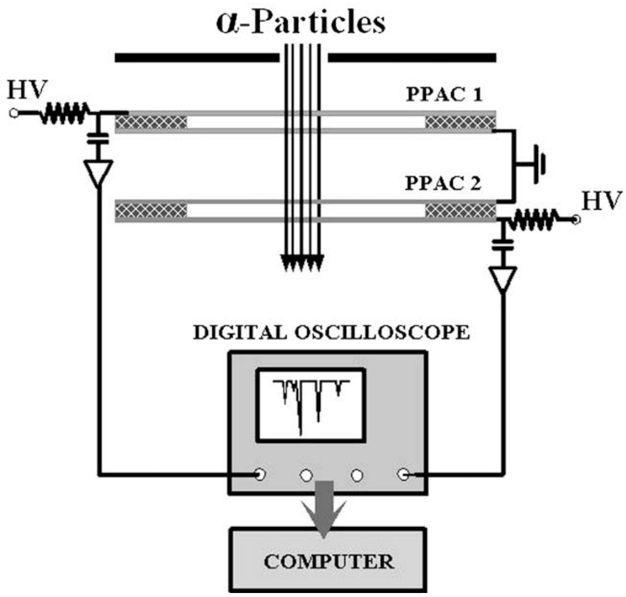

Fig. 1. Schematic view of the experimental arrangement and data taking system. A collimator, with an opening of 10 mm diameter, has been placed in front of the first counter to limit the time spread due to α-particles flight paths in the detectors electrodes. Both the detectors are operated at the same operating conditions.

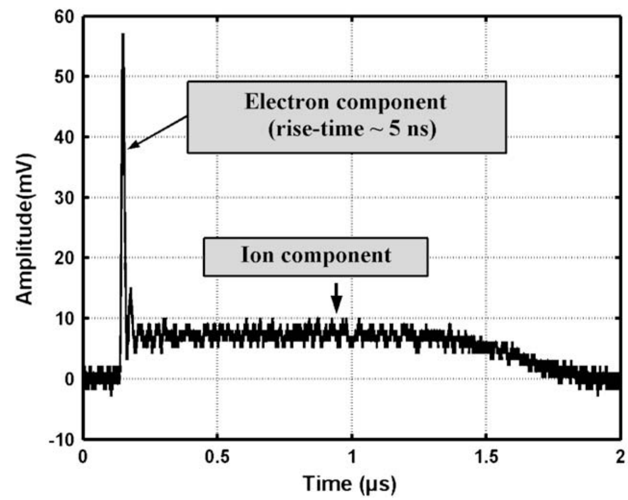

Fig. 2. A typical sample of preamplifier output, recorded by the digital sampling oscilloscope. The detector has been operated at 620 V.

reach the intrinsic time resolution of the avalanche counters by calculating the time differences between the coincidence pulses initiated by the α-particles passage through both the counters. The two counters together with the ^{241}Am α-source and collimator are enclosed in a vacuum chamber and the chamber is flushed with an isobutane (i-C_4H_{10}) gas at 8 ± 0.1 Torr of pressure.

The coincidence signals initiated by the passage of α-particles through both the avalanche counters are read out with fast current-sensitive preamplifiers[1] (risetime ≤ 1 ns).

The preamplifiers outputs are simultaneously digitized by means of the Lecroy WavePro7000 digital storage oscilloscope which has a maximum dual channel sampling rate of 10 GS/s and 8-bit resolution.

The tests were done at several operating voltages from 500 to 620 V and in each voltage, more than 20,000 of coincidence pulses were stored to the hard disk drive of the oscilloscope. Then, the digitized pulses were transferred to a personal computer for offline analysis. The offline analysis is performed using a program written in MATLAB language.

3. Results and discussion

An example of digitized pulses of the avalanche counters is shown in Fig. 2. The signal seen by the current-sensitive preamplifier is composed of two components. There is an initial very fast pulse from the electrons arriving at the anode that occurs in less than ∼5 ns. This is then followed by a much longer induced signal, typically of several microseconds duration, as the ions librated in the avalanche drift away from the anode to be neutralized on the cathode electrode. The fast electron component of the signal is used for timing measurements and the ion component is normally differentiated out in the input stage of preamplifier or amplifier.

To determine the time resolution of the PPACs shown in Fig. 1, the first step is to determine the arrival time of each PPAC output pulse. Then, the histogram of the differences in the arrival time of pulses from the two counters is plotted and fit with a Gaussian distribution. Assuming that the two detectors have the same resolution, the full-width at half-maximum (FWHM) of the fit divided by $\sqrt{2}$ gives the resolution of each counter.

A common method of pulse arrival time determination is the digital constant-fraction discrimination (d-CFD) method (Nelson et al., 2003; Nissilä et al., 2004; Bardelli et al., 2004). The d-CFD method searches for the maximum digitized value (MDV) and then set a threshold level based on a predefined fraction (f_{CFD}) of the MDV. The pulse is then analyzed to determine when it initially crossed this threshold. The time pick-off is linearly interpolated if the crossing of the threshold fell between two time steps.

Since the noise component of the signals can greatly affect the obtaining of information about time from a waveform, prior to determination of the pulse arrival time a filtering procedure is applied to suppress the harmful influence of the high frequency noise. For this purpose, two different noise filters were examined: the moving average filter and the cubic smoothing spline filter (Kurahashi et al., 1999). The moving average filter operates by replacing each data point with the average of a specified number of neighboring data points. The smoothing spline filter operates based on spline curve fitting. In the noise filtration using cubic smoothing spline, one searches for a piecewise cubic polynomial which attempts to minimize the residuals between the data and the model (Kurahashi et al., 1999). The degree of smoothing is a variable parameter. Since a noise filter can simultaneously remove the noise and signal data, the degree of smoothing should be optimized to reduce the noise while keeping the timing information of the signal. To determine the optimum degree of smoothing by each filter, we repeated the filters multiple times to reach the best time resolution.

The best results of time resolution calculations are shown in Fig. 3. The operating voltage of both the detectors has been 600 V and sampling rate was set to 10 GS/s. Fig. 3 shows three histograms corresponding to the signals filtered with moving average filter, cubic smoothing spline filter and without filtration. The best resolution is obtained with the signals filtered with the smoothing spline filter. The FWHM of the distribution related to the smoothing spline noise filter is ∼564 ps which corresponds to a time resolution of 398 ps for each counter. This FWHM is around 86 ps smaller than that obtained with moving average filter and 230 ps smaller than that of without filtration. The time resolution obtained with smoothing spline filter matches the best literature results using analog electronics which have been reported ∼400 ps for PPACs

[1] Made by Fuji Diamond Company, Japan.