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Timing techniques with picosecond accuracy for novel gaseous detectors

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Introduction

The PICOSEC Micromegas detector has the potential for precise timing at the picosecond level [1, 2]. A simulation model is developed to train Artificial Neural Networks (ANN), for precise timing of PICOSEC [3] signals. This aims to a fast online timing, as well as in minimising the information to be saved during data acquisition. Two sets of waveforms were collected and digitized (20 GS/s) by a fast osciloscope during a femtosecond-laser test beam run, with the PICOSEC operating at the same conditions [2]. In both runs a fast photodiode was used to time the laser pulses, with <3 ps resolution, and provide accurate time-reference for each digitized waveform. The first set (SPE-set) comprises waveforms collected with attenuated laser beam intensity, eradicating the production of more than one photoelectrons (pes) on the PICOSEC photocathode. The SPE-set was utilised for generating simulated waveforms for training the ANN. In the second data set (EXP-set), the number of prompt pes produced by a laser pulse, found to follow a Poisson distribution with a mean value of ≈ 7.8. The EXP-set was used to evaluate the ANN performance in determining the PICOSEC Signal Arrival Time (SAT), relative to the photodiode time-reference. The ANN timing precision is compared to the results of a full offline timing analysis [4], i.e. the application of the Constant Fraction Discrimination (CFD) method to a logistic function that fits the leading edge of the digitised Electron Peak (Fig. 1). The ANN timing achieves the same precision as the one provided by the full offline analysis (i.e. 18.3±0.6 ps, Fig. 1).

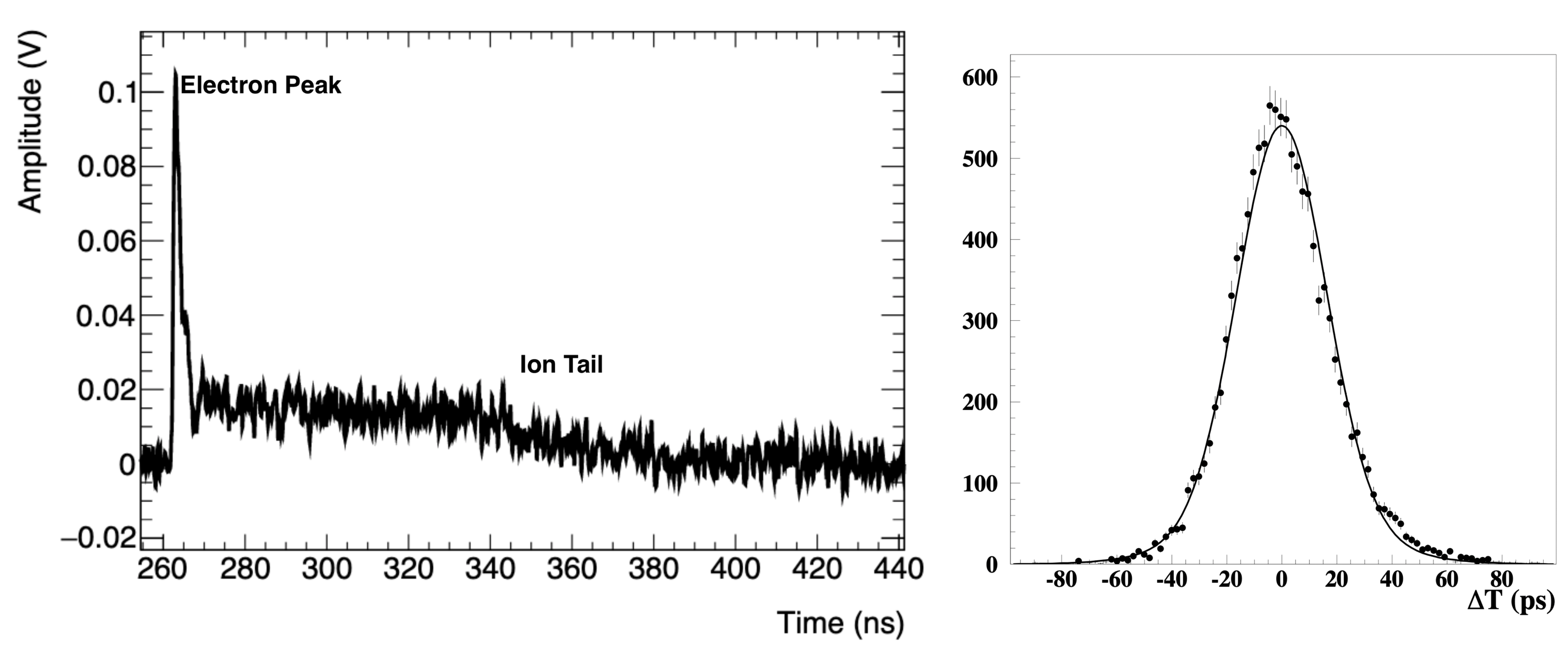

Figure 1. (left) A digitised (inverted) PICOSEC waveform, where the Electron Peak and the Ion Tail are indicated. (right) The distribution of the PICOSEC SAT, evaluated in the offline analysis, of all available pulses. The rms of this distribution determines the global timing resolution at 18.3±0.6 ps.

Simulation of multi-pe pulses using single-pe waveforms

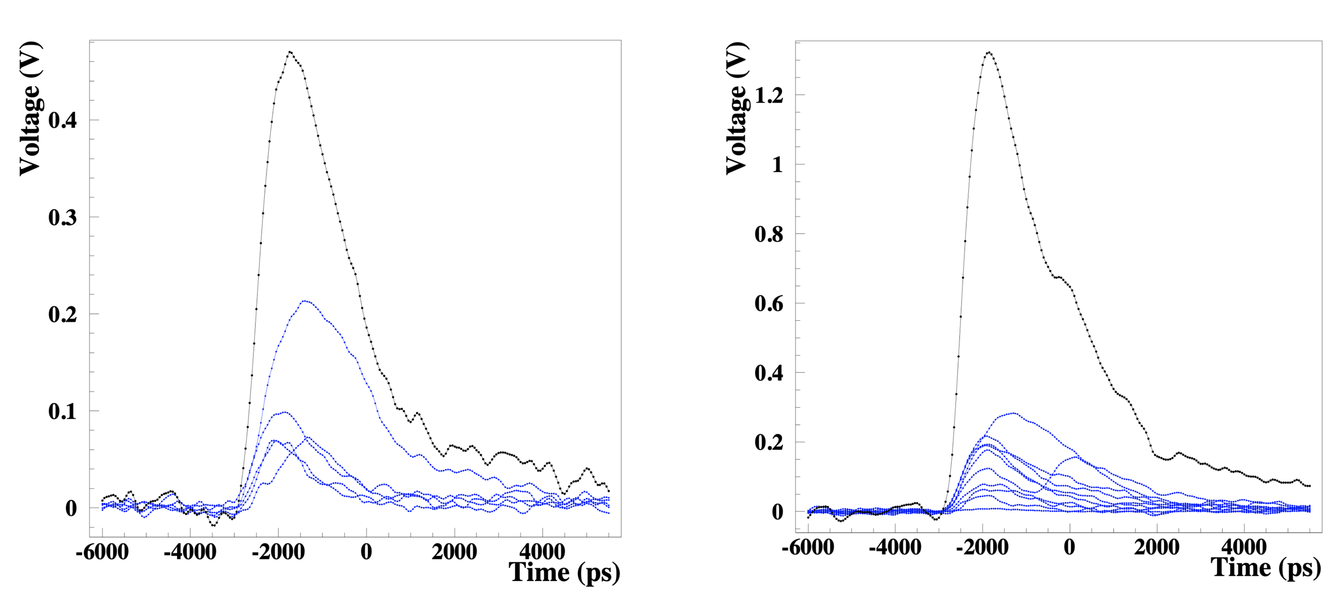

Figure 2. Simulation of the PICOSEC responce to 5 (left) and 10 (right) pes by summing SPE-set waveforms. The single-pe waveforms have been synchronised by using the respective time reference signals, provided by the photodiode, and a 3rd degree polynomial interpolation between digitizations.

The waveforms of the SPE-set are used to simulate signals corresponding to the PICOSEC response to many pes. Fig. 2 emulates the PICOSEC response to 5 and 10 pes. The deconvolution algorithm, described in [5], is used to estimate the number of pes producing the EXP-set waveforms. In the simulation, only SPE-set waveforms with Electron Peak charge >1 pC (>30 mV in amplitude) were used in order to reject noise. The EXP-set was then simulated by summing up N single-pe waveforms, chosen randomly, where N follows Poisson distribution. The simulated pulses were analysed as the real data. The charge distribution of the simulated pulses agrees very well with the respective EXP-set distribution, as shown in Fig. 3-left. Fig. 3-right presents results of the full timing analysis of the simulated pulses.

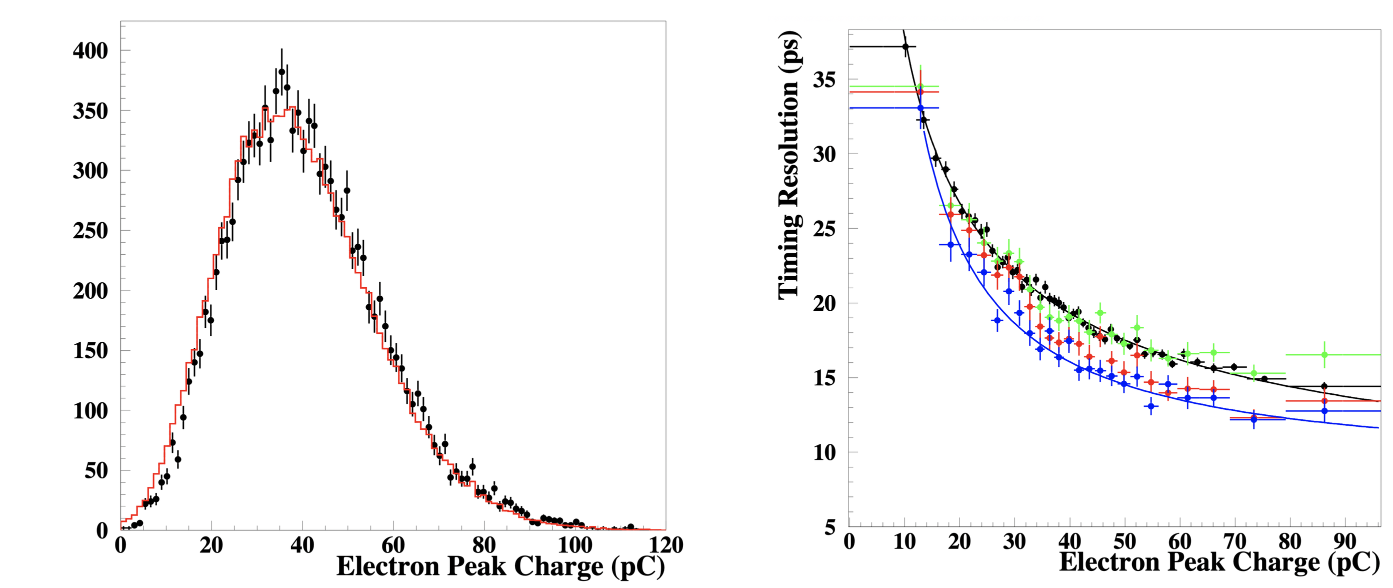

Figure 3. (left) The charge distribution of the EXP-set Electron Peaks (black points) and the simulation prediction (red histogram). (right) The timing resolution as a function of the Electron Peak charge of: (black) the simulated pulses, (blue) the original EXP-set waveforms, (red) after adding appropriately noise to the original EXP-set waveforms, and (green) after also adding appropriately the timing reference resolution (2.8 ps per single-pe pulse).

Timing with Artificial Neural Networks

A feedforward ANN has been employed to extract the timing information from the leading edge of the Electron Peak. It is assumed that a threshold trigger, at 100 mV, is used to select waveforms and to provide a timestamp with a time jitter of ±500 ps. This timestamp is used to select digitizations in a time window of 3.2 ns as shown in Fig. 4. In the training session, digitizations of simulated Electron Peak waveforms are presented as input to the ANN together with their respective reference times as target values. After learning the waveforms of the EXP-set are presented as inputs to the network, and its output is compared with the respective time-references to evaluate the ANN performance.

As shown in Fig. 5 the ANN timing achieves the same accuracy with the full signal processing analysis, even when presented with less inputs (lower sampling rate). Extensive tests have shown that the ANN performance is unbiased, e.g. does not depend on the precision of selecting the first digitization, does not depend on the charge distribution of the Electron Peaks, etc.

Conclusions

A model has been developed to simulate the PICOSEC response to many photoelectrons by using single photoelectron waveforms that have been collected and digitized in a laser test beam run. The simulation model is used to generate learning samples for an Artificial Neural Network. Although, the simulated waveforms are not completely mutually-uncorrelated, suffer of more noise and a small systematic timing error, they contain the necessary information that ANN needs to learn a precise timing procedure. Extensive tests demonstrated the ability of the ANN to time PICOSEC waveforms with the same precision as the one achieved with a full signal processing analysis.

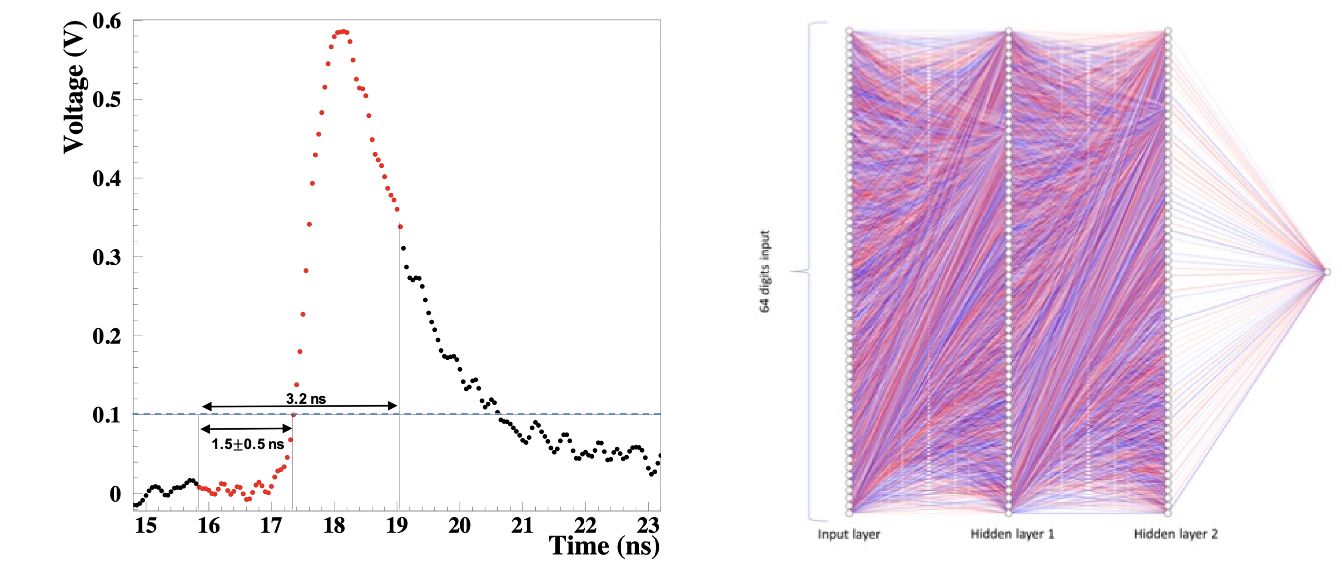

Figure 4. (left) A typical PICOSEC digitised waveform. The red points denote the digitised information that is presented to the ANN. In this example, the ANN is fed with 64 inputs. However, the ANN timing resolution remains the same when is fed with less inputs, as shown in Fig. 5. (right) The ANN architecture, used in this analysis, comprises one output node, one input and two hidden layers, with as many input and hidden nodes as the number of the selected Electron Peak digitisations.

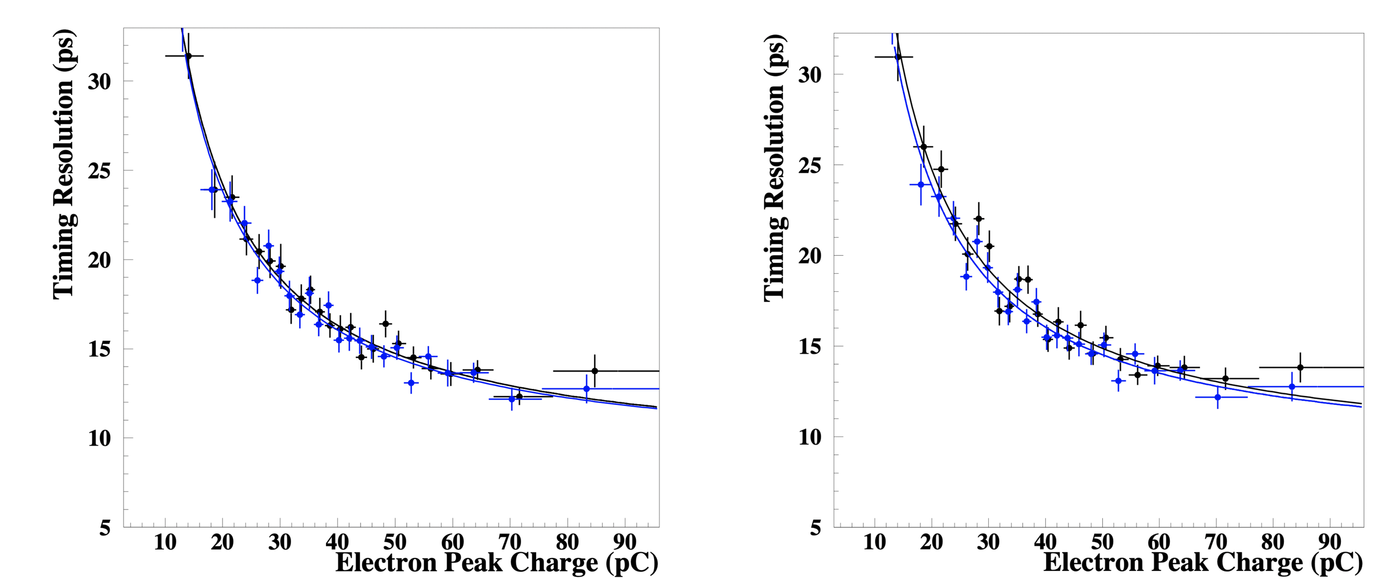

Figure 5. The timing resolution using ANN (black), as a function of the Electron Peak charge, in comparison with the timing resolution achieved by a full analysis of the digitized (with 20 GS/s sampling rate) Electron Peak waveforms (blue): (left) When the ANN is presented with 64 inputs (i.e. digitization at 20 GS/s) achieves 18.3±0.6 ps global timing resolution. (right) When the ANN is presented with 16 inputs (i.e. digitization at 5 GS/s sampling rate) achieves 19.2±0.8 ps global timing resolution.

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References

[1] J. Bortfeldt et al for the RD-51 PICOSEC Collaboration. Modeling the timing characteristics of the PICOSEC Micromegas detector. *Nucl. Instrum. Meth. A*, 993:165049, 2021.

[2] L. Sohl. *Development of PICOSEC-Micromegas for fast timing in high rate environments*. PhD thesis, U. Paris-Saclay, 2020.

[3] J. Bortfeldt et al for the RD-51 PICOSEC Collaboration. PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector. *Nucl. Instrum. Meth. A*, 903:317–325, 2018.

[4] S. Aune et al for the RD-51 PICOSEC Collaboration. Timing performance of a multi-pad PICOSEC-Micromegas detector prototype. *Nucl. Instrum. Meth. A*, 993:165076, 2021.

[5] I. Manthos et al for the RD-51 PICOSEC Collaboration. Recent developments on precise timing with the PICOSEC Micromegas detector. *J. Phys.: Conf. Ser.*, 1498:012014, 2020.

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