High Precision Timing with the PICOSEC Micromegas Detector

The RD51 PICOSEC-Micromegas Collaboration[1]

Abstract

New challenges in current and future accelerator facilities have set stricter requirements on the timing and rate capabilities of particle detectors. The PICOSEC Micromegas detector has proven to time the arrival of Minimum Ionizing Particles with a sub-25 ps precision. Model predictions and laser beam tests demonstrated that an optimized PICOSEC design can time single photons with an accuracy of 45 ps which indicates an improved resolution in timing MIPs of the order of 15 ps. We propose the implementation of the PICOSEC detector for timing the arrival of EM showers with very high precision as well as for Time-of-Flight measurements for particle identification applications.

Keywords: MPGD, Micromegas, precise timing, PID

1. The PICOSEC Micromegas concept

The PICOSEC detector [1] consists of a two-stage Micromegas [2] coupled to a front window that acts as a Cherenkov radiator coated with a photocathode. The drift region is very thin (< 200 µm) minimizing the probability of direct gas ionization as well as diffusion effects on the signal timing. Due to the high electric field, photoelectrons (pes) undergo pre-amplification in the drift region. The readout is a bulk [3] Micromegas, which consists of a woven mesh and an anode plane separated by a gap of ~ 128 µm, mechanically defined by pillars. A relativistic charged particle traversing the radiator produces UV photons, which are simultaneously (RMS less than 10 ps) converted into primary pes at the photocathode. These primary pes produce pre-amplification avalanches in the drift region. A fraction of the pre-amplification electrons ($\sim 25\%$) traverse the mesh and are finally amplified in the amplification region. The arrival of the amplified electrons at the anode produces a fast signal (with a rise-time of ~ 0.5 ns) referred to as the electron-peak ("e-peak"), while the movement of the ions produced in the amplification gap generates a slower component ion-tail (~ 100 ns). This type of detector operated with Neon or CF_4 based gas

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mixtures can reach high enough gains to detect single pes.

2. Achievements in precise timing

The time response of a single-cell PICOSEC prototype detector (circular anode of 1 cm diameter) to single photons and to Minimum Ionizing Particles (MIPs) was extensively studied in laser and particle beams. The PICOSEC waveforms were fully digitized by a fast oscilloscope and analyzed offline to determine the e-peak charge and amplitude as well as the Signal Arrival Time (SAT), which is defined at 20% of the amplitude.
As reported in [1] the resolution for timing single photons was measured to be 76.0±0.4 ps, while the accuracy for timing the arrival of muons (MIPs) was measured to be 24.0±0.3 ps using CsI photocathodes (with an average value of $\sim$ 11 pes induced per MIP). Several technologies concerning photochathodes and resistive anodes have been evaluated, which guarantee radiation hardness and stability in operation while preserving the precise timing capability (28 - 34 ps) of the detector. Aiming at large area detectors, a multi-pad PICOSEC prototype was developed, which comprises a segmented anode divided into 19 hexagonal pads with a diameter of 1 cm each. Extensive tests in particle beams revealed that such a detector offers similar time resolution with the single-pad PICOSEC prototype even in the case that the incoming MIP induces signals in more than one neighboring pads [4].
The Garfield++ simulation package [5], complemented with a custom made simulation of the electronics response, reproduces [6] very well the PICOSEC timing characteristics. In addition a phenomenological model [7] was developed which describes stochastically the dynamics of the signal formation, in excellent agreement with the Garfield++ predictions and the experimental measurements. Recently, guided by the phenomenological model predictions, new PICOSEC designs were advanced that improve significantly the timing performance of the detector. As an example, PICOSEC prototypes with reduced drift gap size ($\sim$ 119 µm) reached a resolution of 45 ps (in comparison to 76 ps of the standard PICOSEC prototype) in timing single photons in laser beam tests [8]. It should be underlined that such a detector design maintains stable operation when irradiated with intense laser pulses, providing an excellent timing resolution of $\sim$ 6.8 ps for $\sim$ 70 pes.

Although the optimized PICOSEC, thin drift-gap design is yet to be tested in particle beams, a resolution of about 15 ps to measure the arrival time of MIPs can be reduced by scaling the observed performance in laser beam tests [8].

3. Potential applications

The ongoing R&D in advancing scalable, radiation hard, resistive PICOSEC Micromegas detectors is focused in evaluating new thin-gap Micromegas designs,

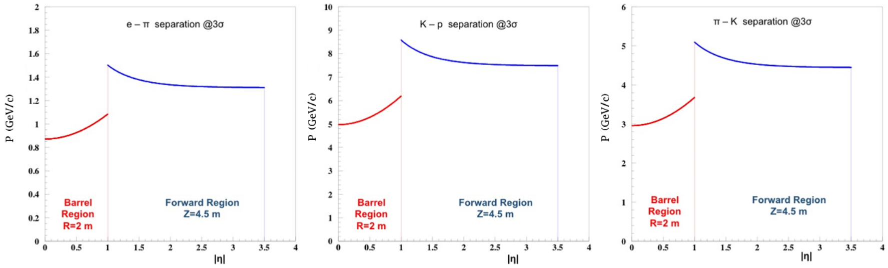

Figure 1: Limits, in the momentum-pseudorapidity plane, for separating e/π, π/K and K/p at the barrel and forward regions, as shown in the plots.

new photocathode materials, resistive-anode technologies as well as digitization electronics. However at this stage there are detector designs with proven operational virtues offering high timing precision.
As an example, a PICOSEC detector embedded in an EM calorimeter could offer an excellent resolution in timing the arrival of EM showers. Indeed the plethora of secondary relativistic electrons in the EM shower will induce a large number of pes even in the case that photocathodes (e.g. Al, Cr or Diamond Like Carbon-DLC) with very modest photon-yield are used. Moreover metallic or DLC photocathodes are almost immune to damage due to the ion back-flow in the Micromegas. According to simulations a PICOSEC detector can offer a timing resolution of approximately 14 ps for 5 GeV electrons, when the detector is embedded 2 radiation lengths inside the calorimeter. For higher energies the expected resolution is much less than 10 ps.

Another possible application concerns the use of PICOSEC as a TOF detector to provide particle identification at low momenta. We have considered the case of using PICOSEC detectors, with 20 ps timing resolution, to separate between e/π, π/K and K/p in the barrel and the forward region of a detector facility at the Electron Ion Collider [9]. Fig. 1 shows the limits, in the momentum-pseudorapidity plane, in separating at 3σ level (e.g. $3 \times \sqrt{2} \times 20ps$) between the above particles at the barrel and forward region. Although a better than 20 ps timing precision is needed in order to reach 3σ e/π separation at 4 GeV/c there is a wide momentum spectrum where the PICOSEC detector offers a good separation between π/K and K/p.

4. Concluding Remarks

The RD51 PICOSEC collaboration focuses in advancing scalable, radiation hard, resistive PICOSEC Micromegas detectors for very precise timing, by evaluating new thin-gap Micromegas designs, new photocathode materials, resistive-anode technologies as well as digitization electronics. These activities motivates collaboration between groups with diverse expertise, something we are hoping

to promote through this letter.
However, even at this stage of development, the currently designed detectors could offer valuable experimental information in physics projects. In this letter of interest we indicate two fields of potential application of the existing detector designs.

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