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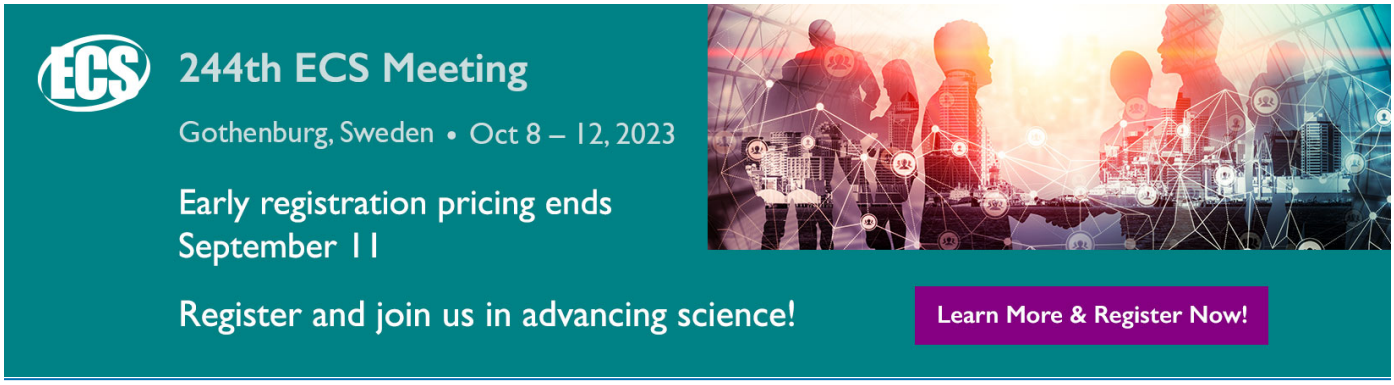
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To cite this article: M. Lisowska *et al* 2023 *JINST* **18** C07018

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Received: *March 31, 2023*
Accepted: *June 22, 2023*
Published: *July 28, 2023*

7th International Conference on Micro Pattern Gaseous Detectors
Rehovot, Israel
11–16 December 2022

2023 JINST 18 C07018

Towards robust PICOSEC Micromegas precise timing detectors

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https://doi.org/10.1088/1748-0221/18/07/C07018

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Abstract: The PICOSEC Micromegas (MM) detector is a precise timing gaseous detector consisting of a Cherenkov radiator combined with a photocathode and a MM amplifying structure. A 100-channel PICOSEC MM prototype with $10 \times 10\,\mathrm{cm}^2$ active area equipped with a Cesium Iodide (CsI) photocathode demonstrated a time resolution below $\sigma = 18\,\mathrm{ps}$. The objective of this work is to improve the PICOSEC MM detector robustness aspects, i.e. integration of resistive MM and carbon-based photocathodes, while maintaining good time resolution. The PICOSEC MM prototypes have been tested in laboratory conditions and successfully characterised with 150 GeV/c muon beams at the CERN SPS H4 beam line. The excellent timing performance below $\sigma = 20\,\mathrm{ps}$ for an individual pad obtained with the $10 \times 10\,\mathrm{cm}^2$ area resistive PICOSEC MM of 20 MΩ/□ showed no significant time resolution degradation as a result of adding a resistive layer. A single-pad prototype equipped with a 12 nm thick Boron Carbide (B_4C) photocathode presented a time resolution below $\sigma = 35\,\mathrm{ps}$, opening up new possibilities for detectors with robust photocathodes. The results made the concept more suitable for the experiments in need of robust detectors with good time resolution.

Keywords: Cherenkov detectors; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Timing detectors

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1 Introduction

The development of technologies for precise timing detectors has been driven by the demanding environments expected in future High Energy Physics experiments. The requirements of a time resolution of tens of picoseconds, stable long-term operation and a large area coverage must be met to make the device suitable. Within the PICOSEC Micromegas (MM) collaboration, a gaseous detector designed to achieve precise timing response is being developed [1–3]. First proof-of-concept single-pad prototypes demonstrated a time resolution below $\sigma = 25\,\text{ps}$ [1]. A recent multipad PICOSEC MM indicated how precise time resolution can be achieved with a 100-channel gaseous detector with $10 \times 10\,\text{cm}^2$ active area equipped with a CsI photocathode, showing a time resolution below $\sigma = 18\,\text{ps}$ [3]. Although the first tests of alternative, more robust approaches have been performed in the past (i.e. timing measurements of single-pad prototypes with resistive MM and Diamond-Like-Carbon (DLC) photocathodes [4]), new developments including the integration of resistive MM in 100-channel modules and robust Boron Carbide (B_4C) photocathodes have not been studied up to now. The objective of this work is to improve the PICOSEC MM detectors robustness aspects while maintaining a good time resolution.

2 Detection concept

The PICOSEC MM detection concept [1] is illustrated in figure 1(a). A charged particle passing through a Cherenkov radiator, creates a cone of ultraviolet (UV) photons which are converted into primary electrons on a photocathode coated directly on the radiator. Due to a high electric filed, the extracted electrons successively ionise the gas molecules, causing the multiplication of the electrons, first in the preamplification gap, and then, after passing through the MM mesh, in the amplification gap. A mixture of 80% Neon, 10% CF_4 and 10% Ethane at ambient pressure is used to fill the entire gas volume. The amplified electrons induce a signal on the anode which is passed through an

amplifier and read out by a digitizer. A typical PICOSEC MM waveform consists of a fast electron peak and a slow ion tail, as presented in figure 1(b). The rising edge of the electron peak is used to extract the time of arrival of the charged particle.

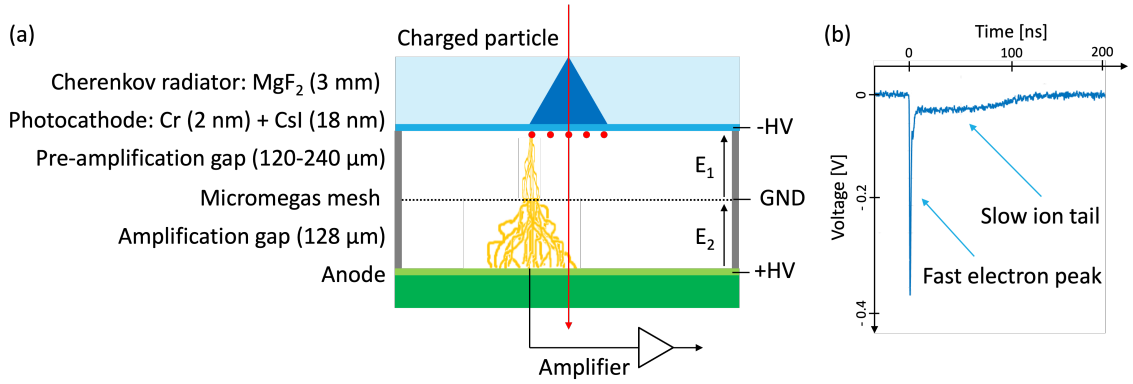


Figure 1. (a): PICOSEC MM detection concept. A charged particle passing through a Cherenkov radiator creates UV photons that are converted into electrons on a photocathode, then multiplied in the preamplification gap and afterwards in the amplification gap. (b): a typical PICOSEC MM waveform consisting of a fast electron peak with a rise time between 0.5 ns and 1 ns and a slow ion tail of ~100 ns.

3 Experimental setup

The PICOSEC MM prototypes have been tested for stable operation in laboratory conditions and successfully characterisied at the CERN SPS H4 beam line with 150 GeV/c muon beams during RD51 test beam campaigns. The main purpose of the muon beam characterisation was to measure the time resolution of the detectors. The experimental setup was based on a beam telescope with triggering, timing and tracking capabilities [1, 3]. Triple-GEMs were used to obtain the precise tracking of the particles, while a micro-channel plate photomultiplier tube (MCP-PMT, Hamamatsu R3809U50) was used as timing reference (time resolution in the inner part of the active area below $\sigma = 4$ ps [5]) and data acquisition trigger. As the new electronics dedicated for multipad device, custom-made RF pulse amplifier cards optimised for PICOSEC [6] and 128-channel SAMPIC Waveform Time to Digital Converter [7] with 8.5 GS/s sampling frequency were used.

4 Resistive Micromegas

Resistive MM [8] are essential to make the PICOSEC concept suitable for physics applications. The PICOSEC prototypes could benefit from the use of the resistive MM by protecting detectors from highly ionizing events and ensuring stable operation under particle beams, as well as achieving better position reconstruction and signal sharing. A possible risk of a resistive MM implementation may be to affect the shape of the signal, in particular the rising edge, by spreading the signal due to the resistive layer, which could result in a loss of the timing information. The objective is to profit from the advantages of the resistive MM while maintaining a good time resolution. To choose an optimal resistivity, two aspects must be considered. Firstly, the resistivity must be low enough to

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minimise the voltage drop during high-rate beam and improve the position reconstruction using the signal weighted average from neighbouring pads. Secondly, the resistivity needs to be high enough to ensure stable operation and not affect the rising edge of the signal. Simulations of rate capability and signal rising edge dependence were performed to select the resistivity for the new PICOSEC prototype. Informed by the simulations, a 100-channel detector with a $10 \times 10\,\mathrm{cm}^2$ area resistive MM with anode surface resistivity of $20\,\mathrm{M\Omega/\square}$ was produced. The production procedure was done in the same way as for a non-resistive multipad [3] with an additional step of adding a resistive layer of DLC that was placed on top of the readout pads with an insulating layer in between.

First test beam measurements of the multipad equipped with a resistive MM of $20\,\mathrm{M\Omega/\square}$, a CsI photocathode, 180 µm preamplification gap and RF pulse amplifiers were performed with an oscilloscope to compare the results with a non-resistive prototype [3]. The time resolution of the detector was calculated as the standard deviation of the signal arrival time (SAT) distribution. The results refer to events that were fully contained in individual $1 \times 1\,\mathrm{cm}^2$ pads, which was obtained by implementing a geometrical cut of a 4 mm diameter circle around center of each pad. The non-resistive prototype showed a time resolution below $\sigma = 18\,\mathrm{ps}$ for an individual pad [3]. The measurements of the $10 \times 10\,\mathrm{cm}^2$ resistive PICOSEC MM of $20\,\mathrm{M\Omega/\square}$ showed a time resolution below $\sigma = 20\,\mathrm{ps}$ for an individual pad, as can be seen in figure 2. The results confirm that adding a resistive layer does not affect the time resolution of the detector to a significant extent.

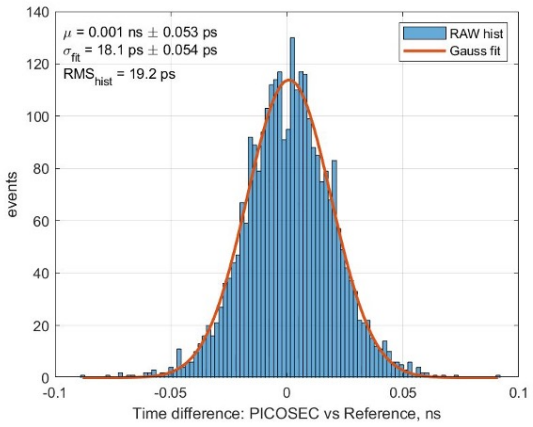


Figure 2. SAT distribution of a $1 \times 1\,\mathrm{cm}^2$ channel of the resistive PICOSEC MM. The cathode voltage was set at −490 V, the MM mesh at ground and the anode at +290 V. The histogram consists of the data after implementing a geometrical cut of a 4 mm diameter circle around the pad center to include only fully contained events. A Gaussian fit of the data gives a time resolution of the measured channel of $\sigma = 19.2\,\mathrm{ps}$.

To characterise the full detector, the SAMPIC digitiser was used [7]. The objective was to measure the timing precision. The measurements of the time resolution across the $10 \times 10\,\mathrm{cm}^2$ area resistive PICOSEC MM of $20\,\mathrm{M\Omega/\square}$ are presented in figure 3. First results obtained with the new digitizer showed uniform timing response within the pads and a narrow distribution of the time resolution across the channels with the mean value of $\sigma \approx 23\,\mathrm{ps}$, proving SAMPIC to be a suitable tool to study the response of 100-channel PICOSEC detector.

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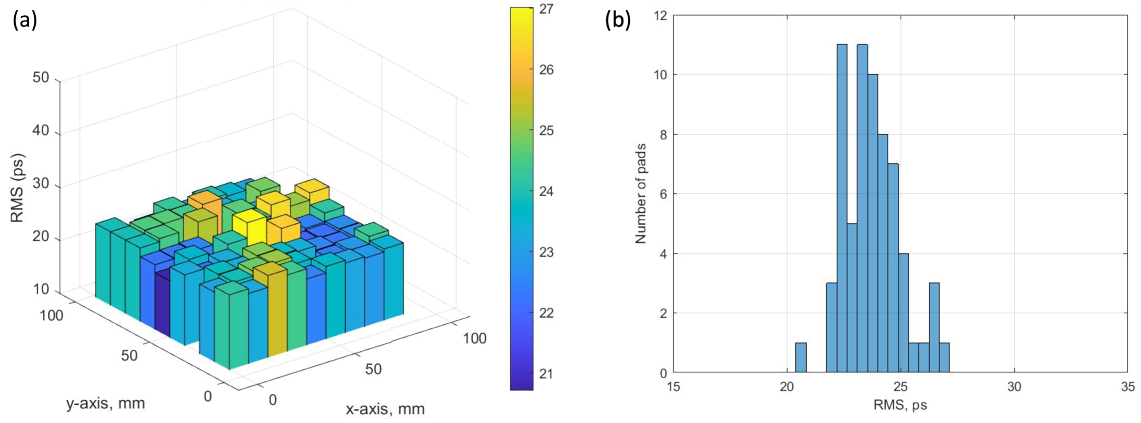


Figure 3. Time resolution for the $10 \times 10\,\mathrm{cm}^2$ area resistive PICOSEC MM measured using SAMPIC digitiser. Note that only 66 out of 100 pads were measured. (a): 3D plot of the timing response across the channels. (b): histogram of the time resolution RMS for all measured channels yields the mean value $\sigma \approx 23\,\mathrm{ps}$.

5 Robust photocathodes

The base UV-to-electron converter for the PICOSEC MM detector is a semi-transparent CsI photocathode. The high quantum efficiency of CsI leads to the production of around 10 photoelectrons per minimum ionizing particle (for a 3 mm thick MgF_2 radiator with a 3 nm Cr layer and a 18 nm CsI photocathode [1]). However, CsI photocathodes can be easily damaged by ion back flow, sparks, discharges and are sensitive to humidity. Therefore, there is a need to search for alternative, more robust photocathode materials. The most promising candidates are B_4C, DLC and nanodiamonds.

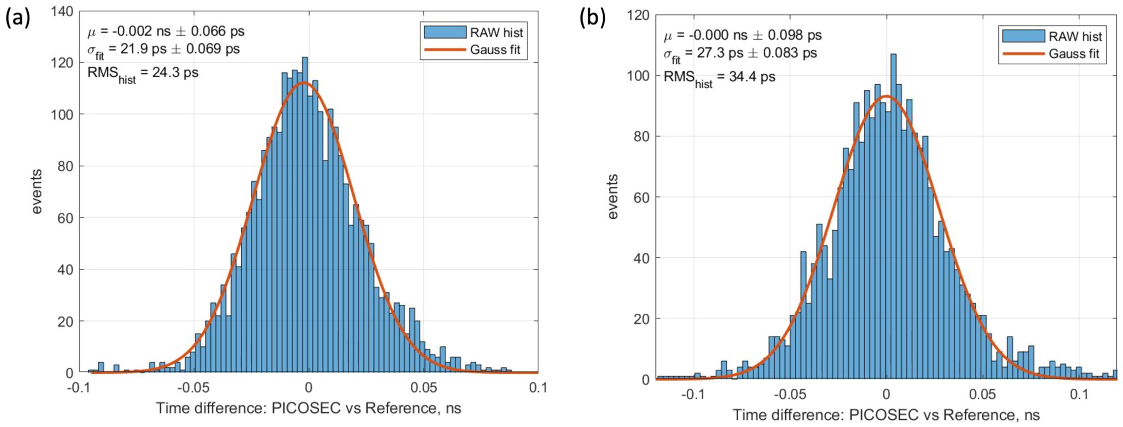


Figure 4. SAT distribution of a single-pad prototype equipped with a 12 nm thick B_4C photocathode. The voltage on the cathode was set at −490 V and on the anode at +275 V. A Gaussian fit yields a time resolution of $\sigma = 24.3\,\mathrm{ps}$ at the beginning (a) and $\sigma = 34.4\,\mathrm{ps}$ after 20 hours of operation with gas flushing (b), respectively.

The measurements of the time resolution for different thicknesses of B_4C photocathodes were performed during the RD51 test beam campaigns. A single-channel non-resistive PICOSEC MM prototype was used to test the samples. Different photocathode thicknesses ranging from 2 nm to 14 nm were tested. The time resolution improved as the thickness of the B_4C layer increased from

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2 nm to 12 nm, with the exception of the 10 nm sample which did not follow the trend. The 14 nm sample showed poorer time resolution than the 12 nm sample. First measurements from a single-pad detector with 120 µm preamplification gap equipped with a 12 nm thick B_4C photocathode, presented in figure 4, showed a time resolution below $\sigma = 25$ ps. The measurements performed 20 hours later presented a time resolution below $\sigma = 35$ ps. The 12 nm thick B_4C sample demonstrated the best time resolution achieved for robust photocathode materials studied up to now.

6 Conclusions

The work described in this paper focused on improving the robustness aspects of the PICOSEC MM detectors, including the integration of resistive MM and robust photocathodes, while maintaining good time resolution. The excellent timing performance below $\sigma = 20$ ps for an individual pad obtained with the $10 \times 10\,cm^2$ area resistive PICOSEC MM of 20 MΩ/□ equipped with a CsI photocathode showed no significant time resolution degradation as a result of adding a resistive layer. Measurements performed with a scalable readout chain including the SAMPIC digitiser resulted in a successful readout of a multi-channel detector. A single-pad prototype equipped with a 12 nm thick B_4C photocathode presented a time resolution below $\sigma = 35$ ps, opening up new possibilities for detectors with robust photocathodes. The results made the concept more suitable for the experiments in need of robust detectors with precise timing. Developments towards applicable detectors are ongoing. The challenges include stable operation in intense beams with resistive MM Multipad and operating a PICOSEC MM detector with a $10 \times 10\,cm^2$ area B_4C photocathode. Studies on the impact of the resistive layer on the signal sharing over adjacent channels are planned. Scaling up the PICOSEC MM detector by tiling $10 \times 10\,cm^2$ modules or the development of larger prototypes are potential next improvement steps.

Acknowledgments

We acknowledge the support of the CERN EP R&D Strategic Programme on Technologies for Future Experiments; the RD51 collaboration, in the framework of RD51 common projects; the Cross-Disciplinary Program on Instrumentation and Detection of CEA, the French Alternative Energies and Atomic Energy Commission; the PHENIICS Doctoral School Program of Université Paris-Saclay, France; the Program of National Natural Science Foundation of China (grant number 11935014); the COFUND-FP-CERN-2014 program (grant number 665779); the Fundação para a Ciência e a Tecnologia (FCT), Portugal (CERN/FIS-PAR/0005/2021); the Enhanced Eurotalents program (PCOFUND-GA-2013-600382); the US CMS program under DOE contract No. DE-AC02-07CH11359.

References

[1] J. Bortfeldt et al., *PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector*, *Nucl. Instrum. Meth. A* **903** (2018) 317 [arXiv:1712.05256].

[2] S. Aune et al., *Timing performance of a multi-pad PICOSEC-Micromegas detector prototype*, *Nucl. Instrum. Meth. A* **993** (2021) 165076 [arXiv:2012.00545].

2023 JINST 18 C07018

[3] M. Lisowska et al., *Sub-25 ps timing measurements with* $10 \times 10\,cm^2$ *PICOSEC Micromegas detectors*, *Nucl. Instrum. Meth. A* **1046** (2023) 167687.

[4] L. Sohl, *Development of PICOSEC-Micromegas for fast timing in high rate environments*, Ph.D. Thesis, Université Paris-Saclay (2020), available at https://hal-universite-paris-saclay.archives-ouvertes.fr/tel-03167728/ (accessed on March 31st, 2023).

[5] L. Sohl, *Spatial time resolution of MCP-PMTs as a* t_0*-reference*, *Nucl. Instrum. Meth. A* **936** (2019) 583.

[6] A. Utrobicic et al., *A large area 100 channel Picosec Micromegas detector with sub 20 ps time resolution*, in the proceedings of the 7^{th} *International Conference on Micro Pattern Gaseous Detectors*, Rehovot, Israel, 11–16 December 2022 [arXiv:2304.00056].

[7] D. Breton et al., *Measurements of timing resolution of ultra-fast silicon detectors with the SAMPIC waveform digitizer*, *Nucl. Instrum. Meth. A* **835** (2016) 51 [arXiv:1604.02385].

[8] I. Giomataris, *High rate applications of micromegas and prospects*, *eConf* **C0604032** (2006) 0023 [physics/0610153].

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