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# Spatial time resolution of MCP–PMTs as a $t_0$ -reference

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## Abstract

A hyper-fast time reference is needed for characterisation measurements of fast-timing detector prototype. The time resolution of the reference detector, normally placed together with a device under test (DUT) in a beam telescope, should be considerably better than the time resolution of the DUT. Measurements with MCP–PMTs of the type R3809U-50 by Hamamatsu have been performed in order to characterise their spatial distribution of the time resolution and to validate them as a proper reference detector. These measurements were conducted during the tests of PICOSEC fast-timing Micromegas prototypes at the CERN/SPS-H4 beam line using a beam telescope consisting of three triple-GEM tracker and various trigger detectors. A time resolution of up to 3.8 ps has been obtained in the inner part of the active area. In the outer parts, the time resolution declines up to several ten picoseconds due to decreasing pulse amplitudes. In this region, the Cherenkov light cone is not fully projected onto the photocathode anymore. Finally, only diffuse reflected light is reaching the photocathode in the outermost parts. The pulse amplitude correlates with the number of generated photo electrons and therefore with the amount of light reaching the photocathode. This explains the strong spatial differences of the MCP–PMTs time resolution.

**Keywords:** MCP–PMT, time resolution, beam test, timing reference, MPGD, PICOSEC, Micromegas

**PACS:** 29.40.Gx, 29.40.Ka

## 1. Introduction

Reference detectors with a superb time resolution are necessary for various kinds of beam test studies in the field of R&D. One example is the time resolution study of the newly introduced PICOSEC Micromegas [1]. First prototypes has been tested in a muon beam at CERN/SPS-H4. MCP–PMTs of the type R3809U-50 [2] by Hamamatsu have been used as an absolute time reference for the PICOSEC studies. In this work the use of these MCP–PMTs as an absolute time reference will be justified. The spatial dependence in terms of efficiency and time resolution is studied for this justification.

## 2. Beam Measurement

Measurements have been performed with a beam telescope in a muon beam at CERN/SPS-H4. This beam telescope consists of triple-GEM detectors as tracking devices and scintillators with a coincidental PMT read-out as trigger devices. It additionally hosts two MCP–PMTs as time reference devices and

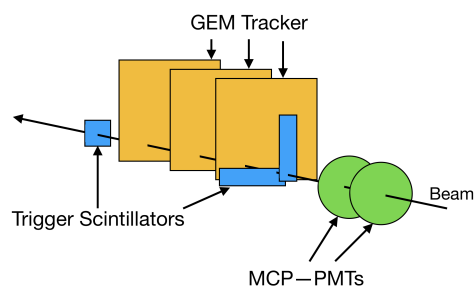


Figure 1: Scheme of the beam set-up. The GEMs are used as tracking devices and the scintillators are forming the trigger area by a coincidental read-out.

up to three mounting positions for various DUTs. The MCP–PMTs and DUTs are read out with sampling Oscilloscopes. The full waveforms are sampled and a pulse shape analysis has been performed off-line. The time jitter of the read-out has been measured to  $\sigma_{\text{DAQ}}=(2.18\pm 0.03)$  ps. A scheme of the telescope set-up is shown in Fig. 1.

The triple-GEM detectors are read out by a strip-segmented anode with strips in x- and y-direction. The tracks of the passing particles are reconstructed off-line based on the inclining points in the GEMs. The inclining point in the DUTs and the MCP–PMTs are extrapolated from these tracks with a precision better than  $40\ \mu\text{m}$ . The use of the tracking data is crucial for the analysis of spatial dependencies in the DUTs and MCP–PMTs.

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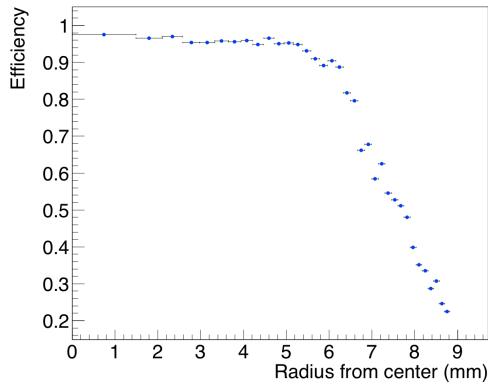


Figure 2: The radial dependency of the detector efficiency. An efficiency higher than 95 % is obtained for radii smaller than 5.5 mm.

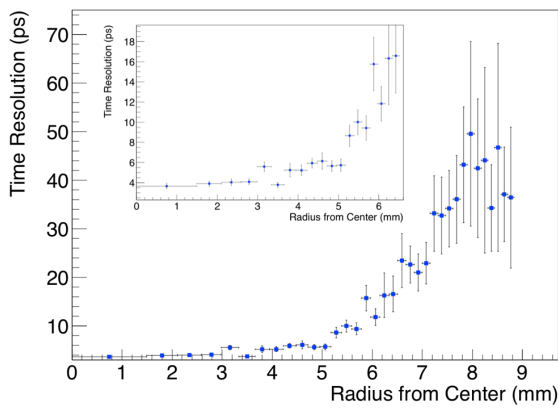


Figure 3: The spatial distribution of the time resolution shows a degrading resolution in the outer regions of the detector.

### 3. Efficiency

A most important feature of a reference detector is its detection efficiency which should be as high and uniform as possible over the active area.

Tracking data allow to measure the MCP-PMT efficiency as a function of impact position by calculating the ratio between the number of tracks hitting the MCP-PMTs active area and producing a signal and the total number of tracks hitting the same area. The distribution of this ratio along the radius of the MCP-PMT is shown in Fig. 2. This distribution show an equally distributed efficiency in the inner part of the MCP-PMT. An efficiency better than 95 % is obtained for radii smaller than 5.5 mm. This area is equal with the actual size of the photocathode. In the outer regions only partial and reflected light from the Cherenkov window can produce a signal. The efficiency drops rapidly in this area.

### 4. Time Resolution

The main study of this work is the spatial dependence of the time resolution. The time resolution is in general calculated by the time difference between the DUT and a  $t_0$ -reference detector. In this case the  $t_0$ -reference is equal to the DUT therefore

two identical MCP-PMTs are used and the time difference between both signals is calculated. The time difference follows a Gaussian distribution. The standard deviation of this distribution represents the total time resolution of this measurement. This includes the time resolution of both detectors and the resolution of the electronics and DAQ. It can be assumed that the contribution of the electronics and DAQ is small compared to the intrinsic time resolution of the detectors. The actual time resolution of an individual MCP-PMT is calculated by the following way:

$$\sigma_{\text{tot}} = \sqrt{\text{Var}_{\text{MCP1}}^2 + \text{Var}_{\text{MCP2}}^2} \Rightarrow \sigma_{\text{MCP}} = \frac{\sigma_{\text{tot}}}{\sqrt{2}}$$

This time resolution is calculated individually for tracks passing through the MCP-PMT at different radii from the center. Fig. 3 shows the time resolution along the MCP-PMT radius for the full active area and in the smaller plot a zoom on the time resolution for the inner radii. The distribution shows a time resolution of sub-4 ps for the innermost particle hitting the MCP-PMT. The time resolution stay at 6 ps or better for inner area up to 5.5 mm. This is equal to the radius up to which an efficiency of >95 % has been measured. In the outer parts the time resolution degrades rapidly and values equal to the expected time resolution of possible DUTs are reached. In this outer regions the light cone from the Cherenkov window is not any more projected fully on the photocathode. This loss of direct photo electrons on the photocathode results in a worse time resolution than in the inner parts.

### 5. Conclusion

With this work the usability of MCP-PMTs as a  $t_0$ -reference detector for DUTs with an expected time resolution >10 ps is shown. Nevertheless the necessary performances are only archived in the inner parts of the MCP-PMT up to an radius of 5.5 mm. In the outer parts only partial and/or reflected light reaches the photocathode. The lack of photo electrons affect the time resolution in this parts and the outer areas are not suitable as a  $t_0$ -reference.

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