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Precision Timing with shower maximum detectors based on pixelated micro-channel plates

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Abstract. Future calorimeters and shower maximum detectors at high luminosity colliders need to be highly radiation resistant and very fast. One exciting option for such a detector is a calorimeter composed of a secondary emitter as the active element. In this report we outline the study and development of a secondary emission calorimeter prototype using micro-channel plates (MCP) as the active element, which directly amplify the electromagnetic shower signal. We demonstrate the feasibility of using a bare MCP within an inexpensive and robust housing without the need for any photo cathode, which is a key requirement for high radiation tolerance. Test beam measurements of the prototype were performed with 120 GeV primary protons and secondary beams at the Fermilab Test Beam Facility, demonstrating basic calorimetric measurements and precision timing capabilities. Using multiple pixel readout on the MCP, we demonstrate a transverse spatial resolution of 0.8 mm, and time resolution better than 40 ps for electromagnetic showers.

1. Introduction

In this paper we discuss our studies on the usage of micro-channel plates (MCP) as precision timing sensors in high energy physics. MCPs have been suggested as the active element in a sampling calorimeter for a long time [1] where the charged shower particles induce signals in the MCP structure which we shall refer to as secondary emission (SE). MCPs are also commonly used in combination with a photo cathod as MCP-PMTs. They feature excellent timing performance due to the very fast signal rise time of order 100 ps. Commercial MCP-PMTs with photo cathode may also be used to detect relativistic charged particles [2]. The particles create Cherenkov radiation as they pass through the window of the MCP which ensures high detection efficiency. SE induced signals enhance this signal further. We use MCP-PMTs in this fashion as timing reference counters [3]. Our studies with MCPs cover several aspects of precision timing measurements in high energy physics : MCPs as very precise reference timing detectors, as tools to study the timing properties of showers in calorimeters and MCPs as active elements in precision timing calorimeter. Precision timing calorimeters promise to be a very powerful tools for physics at the energy and intensity frontier [4]. The studies presented here focus on the timing performance of MCPs measuring electromagnetic showers. As we have discussed previously, the temporal evolution of electromagnetic showers is very coherent [5], allowing multiple measurements on a single shower, increasing the precision of the combined measurements.

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2. Experimental Setup

We use a Photek MCP-PMT 240 as our main sensor both for the reference timing measurements as well as for shower timing measurements. As data acquisition system we use a Domino Ring Sampler (DRS) [6] either in the evaluation board available from PSI or as implemented in the CAEN V1742 digitizer board [7]. We record data with 5 GS/s. The DRS4 evaluation board is rated at an analog bandwidth of 700 MHz with a noise level of 0.35 mV. Our studies of the transverse shower evolution are performed with a Photonis MCP model XP85012 with segmented readout. It has 8 times 8 pixels on a area of about 5 by 5 cm, resulting in a pixel size of about $(6\text{mm})^2$. Further details on the setups and the performance of its individual components can be found in the references [3, 8, 9].
In Fig. 1 we show the experimental setup with two Photek MCP-PMTs as start and stop counter and a Photonis MCP as the test vehicle. Tungsten absorber was used to induce a shower. The beam impact point is defined with a scintillator trigger counter with a lateral size of $(2\text{mm})^2$. Beam was provided from the FNAL M-test facility. A 120 GeV proton beam was used for calibration and alignment purposes. Electron beams of 4, 8, 16 and 32 GeV are used to perform the shower timing measurements. The time of arrival is extracted from the signal

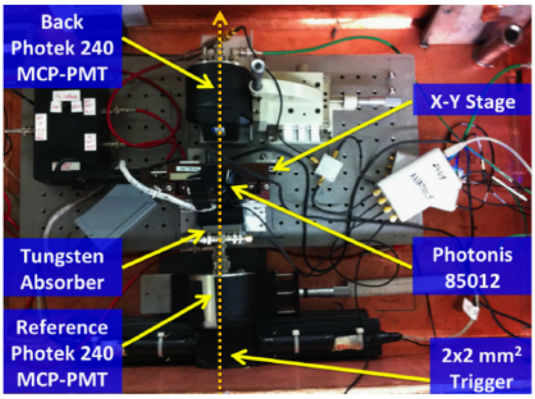

Figure 1. Experimental setup with two Photek MCP-PMTs and a Photonis MCP with segmented readout. Here the setup to test the pixelated readout of the Photonis is shown. For this a motorized stager allows to shift the Photonis without changing the alignment of the trigger with respect to the Photek. The setup testing the shower timing with the more precise Photek is equivalent.

pulses by performing a Gaussian fit to the peak of the reference MCPs spanning 8 to 10 bins, corresponding to 1.6 to 2.0 ns at an equivalent bin width of 0.2 ns at 5 GS/s. The differential time resolution between two Photek MCP-PMT was measured to be 10 ps in response to 120 GeV protons. No additional radiator was used for this measurement. This corresponds to a single device resolution of around 6 ps. The time resolution of the DRS wiht typical MIP signal amplitude from the Photek MCP-PMT was measured to be around 5 ps from split signals feeding the DRS. We conclude that the time resolution of the Photek MCP-PMT when measuring the time of arrival of charged particles in our setup is dominated by the readout system.
Electromagnetic showers are induced by inserting tungsten absorber of varying thickness into the beam. The absorber was placed as closely as possible to the sensor under study to avoid spreading of the shower.

3. Experimental Results

In Fig.: 2 we show the signal amplitude in a Photek MCP at various shower depths for a 32 GeV electron beam. We find the signal amplitude to scale in the expected way with the shower depth, increasing to a depth of about 5 radiation length and then decreasing. This demonstrates that the MCP may serve as a calorimetric device. In Fig.: 3 we show the time resolution between the reference MCP and the MCP behind the tungsten absorber, measuring the shower time of arrival. We find the time resolution to be around 13 ps, only slightly worse than for the bare MCP in response to a 120 GeV proton. The time resolution is largely independent of the shower depth. This confirms our statement, based on earlier studies and simulations, that the

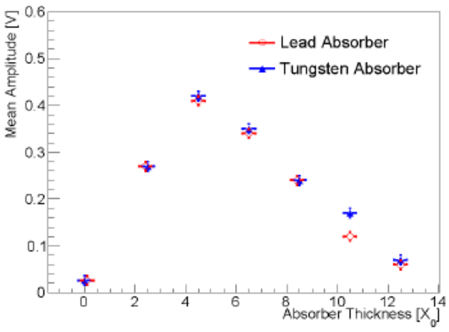

Figure 2. Signal amplitude in a Photek MCP at various shower depth for a 32 GeV electron beam. We find the signal amplitude to scale in the expected way with the shower depth, increasing to a depth of about 5 radiation length and the decreasing. We use tungsten as absorber. With a Moliere radius of 0.93 cm the shower is largely contained transversely in the entrance window of the Photek MCP-PMT which has a diameter of 4 cm.

temporal evolution of electromagnetic showers is very coherent. To further study the feasibility

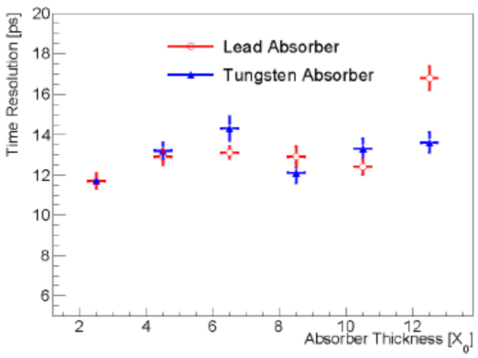

Figure 3. Time resolution between the reference MCP and the MCP behind the tungsten absorber, measuring the shower time of arrival. The time resolution is independent of the depth it is measured at. Note that the signal amplitude varies as a function of the shower depth as shown in Fig.: 2.

to MCPs as an active element in a precision timing calorimeter we perform measurements with a segmented MCP. Transverse segmentation allows to measure the lateral position of a shower. It also allows to perform multiple measurements across the shower which can be exploited to enhance the timing performance. In Fig.: 4 we show the time resolution of the Photonis MCP

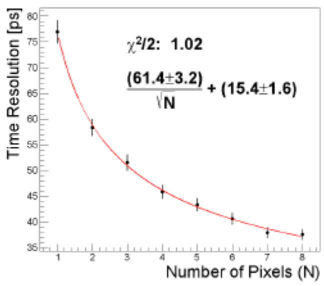

Figure 4. Time resolution for electromagnetic shower measured with the Photonis MCP. Combining the measured time from up to 8 pixels one improves the time resolution down to around 37 ps for 8 pixels. This allows to achieve a very good resolution despite a modest single channel resolution.

as a function of the number of pixels used in a combined timing measurement. Here, a time stamp is reconstructed for each pixel and the results are combined in quadrature. The single pixel timing performance of the Photonis MCP is worse than for the Photek MCP. However combining 8 pixels, the maximum we could read out in this setup, we achieve a timing resolution of around 37 ps. A further improvement seems achievable with combining more pixels. With the information of multiple pixels we also are able to reconstruct the lateral position of the showers. We achieved a spatial resolution of 0.9 mm with the pixel size of the Photonis MCP of 6 mm. In Fig.: 4 we show the time resolution of the Photonis MCP with the photo cathode switched on or off. We find the timing resolution to be independent of the photo cathode bias. This illustrates that the signal in showers is dominated by SE induced signals.

Operating MCPs in SE mode is crucial for their application in a calorimeter, in particular in a high energy proton collider. In such an application the device will be exposed to very significant

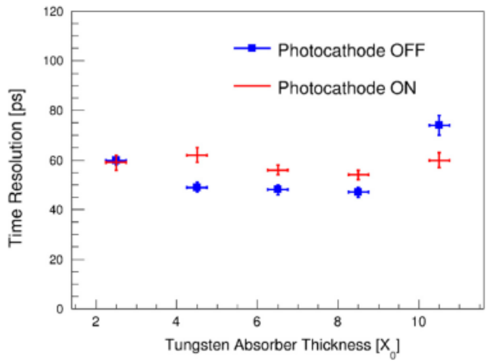

Figure 5. Time resolution per pixel of the Photonis MCP as a function of the shower depth. The data recorded with the photo cathode on is compared with data recorded with photo cahtode off. The time resolution is identical within the uncertainties. This demostrates that MCPs operated in SE mode are capable to provide precise timing in a calorimetric application.

radiation levels which are challenging conditions for a photo cathode. Bare MCPs however may exhibit much higher tolerance to radiation.

4. Summary

We demonstrate that MCPs are well suited to be used as an active elements in a precision timing calorimeter. Timing precision of around 13 ps can be achieved for electromagentic showers. With this we also demonstrate that the temporal evolution of electromagnetic showers is coherent on the level of a few ps. Transverseley segmented MCPs allow to measure the position of showers and utilize multiple measurements on the same shower to improve the timing resolution beyond the single pixel performance.

4.1. Acknowledgments

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