Performance Studies of Microchannel Plate PMTs in High Magnetic Fields

Albert Lehmann [a,*] Alexander Britting [a] Wolfgang Eyrich [a] Matthias Hoek [c] Cecilia Pizzolotto [a] Carsten Schwarz [b] Björn Seitz [c] Andreas Teufel [a]

[a] *Physikalisches Institut IV, University of Erlangen-Nuremberg, Erlangen, Germany*

[b] *Gesellschaft für Schwerionenforschung, Darmstadt, Germany*

[c] *Department of Physics & Astronomy, Kelvin Building, University of Glasgow, Glasgow G12 8QQ, Scotland, UK*

Abstract

Microchannel plate (MCP) photomultipliers (PMT) are attractive photon sensors for the PANDA DIRC. The gain and the time resolution of different types of MCP-PMTs were studied as a function of the magnetic field and of the field orientation. It was found that for an efficient single photon detection a pore diameter of 10 μm or less will be needed in the 2 Tesla magnet field of PANDA. Both gain and time resolution are best with a pore size of 6 μm. In contrast to the gain the time resolution shows only a weak dependence on the magnetic field and its orientation. The best transit time resolution for single photons was evaluated to be $\sigma \approx 20$ ps with no magnetic field applied.

Key words: Photodetectors, MCP-PMT, Magnetic field, Single photon, Gain, Time resolution
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1. Introduction

The PANDA experiment [1] at the new FAIR facility at GSI in Darmstadt, Germany, will use antiproton beams of up to 15 GeV/c to perform high precision studies of QCD, among others charmonium spectroscopy and the search for exotic states. The fixed target will be surrounded by a 2 Tesla solenoid enclosing vertex, tracking and particle identification detectors (PID). To accomplish the ambitious goals of PANDA a high performance PID system is mandatory to reliably distinguish between pions and kaons over a large momentum range.

Due to space limitations inside the solenoid the DIRC (detection of internally reflected Cherenkov light) principle [2] will be applied for π/K separation. A barrel DIRC [3,4] will cover the central part of the PANDA detector, a disc DIRC [3,5] will cap the forward region. In both cases the measurement of the time of propagation (TOP) of the Cherenkov photons from the point of creation to the readout plane is foreseen. Dependent on the DIRC version the TOP will be used to reconstruct the Cherenkov angle [6,7] or to correct for dispersion effects in the radiator [8,9]. This puts serious constraints on the photon sensors: single photon detection inside the up to 2 Tesla magnetic field with a time resolution of $\sigma \leq 50$ ps. In addition, the dark count rate of the sensors must be low.

Microchannel plate photomultiplier tubes are promising candidates for the PANDA DIRC. Most of the commercially available MCP-PMTs offer a gain high enough for single photon detection combined with a sufficiently low dark count rate in the kHz regime. Their time resolution is excellent and

* Corresponding author
Email address: lehmann@physik.uni-erlangen.de (Albert Lehmann).

they stand high magnetic fields.

2. Setup

Three types of MCP-PMTs were investigated: two versions of the 64 pixel Photonis-Burle Planacon series, a 85011 with 25 μm pore size (Burle25) and a prototype with 10 μm (Burle10), and a 6 μm pore size single anode device from Budker Institute of Nuclear Physics (BINP) in Novosibirsk, Russia [10,11]. Some of their characteristics are listed in Table 1.

Table 1
Characteristics of the investigated MCP-PMTs

	Burle25	Burle10	BINP
pore diameter (μm)	25	10	6
active area (mm^2)	51x51	51x51	Ø 18
number of pixels	8x8	8x8	1
pixel size (mm^2)	5.9x5.9	5.9x5.9	Ø 18
cathode protection	none	none	5 nm Al_2O_3
active area ratio	0.44	0.47	0.34

The MCP-PMTs were mounted in a shielded box. They were irradiated with 14 ps (σ) wide light pulses of 372 nm wavelength using a PiLas [1] laser pulser. The light was guided into the box and focused onto the MCP-PMT with a system of glass fibers and microlenses. The intensity was reduced to the single photon level by employing appropriate neutral density filters.

This test system was placed between the 6 cm wide pole shoe gap of a dipole magnet at FZ Juelich, Germany, that delivered a field of up to 2.05 T. The strength of the magnetic field was controlled by a Hall probe during each measurement. For the two Photonis-Burle MCP-PMTs the window surface was always oriented perpendicularly to the magnetic field lines, while for the BINP MCP-PMT the angle between the field lines and the PMT axis could be varied in 15° steps.

The PMT signals were 200x amplified with an Ortec VT120A preamplifier of 350 MHz bandwidth. They were then passively split: one branch was sent directly to a LeCroy 2249A CAMAC ADC module to record the charge, while the other branch was shaped by a LeCroy 821 leading edge NIM discriminator. The discriminated signal was recorded by a LeCroy 2228A CAMAC TDC module. The reference time (ADC gate and TDC start) was obtained from the control unit of the laser pulser which has a time jitter of less than 4 ps.

Precision time resolution measurements without a magnetic field were performed using a 3 GHz / 20 Gs LeCroy WavePro7300A oscilloscope. This device allows accurate time measurements down to the picosecond regime. Using basically the same setup as above the delay between the time reference signal and the amplified MCP signal, both shaped with a discriminator, was measured with the oscilloscope. From the jitter of the delay the time resolution of the system could be deduced. Also the charge of the amplified MCP signal was integrated. The time delay and the signal area information were stored for each event to allow an offline time walk correction. Different types of discriminators and amplifiers were tested to tune the best time resolution.

3. Analysis

Gain and time resolution were analysed offline. The charge distributions were fitted with a discrete Poissonian distribution convoluted with Gaussian distributions. From the distance of the Gauss peaks the gain was calculated.

The time walk distribution was used to determine the time resolution. A two-dimensional histogram was sliced along the charge axis and projected to the time axis. The width of the resulting distribution reflects the time resolution dependent on the MCP anode charge. Using the width of the single electron peak as obtained with the fitting method mentioned above this technique allows a straightforward determination of the time resolution for single photons.

4. Results

The behaviour of the gain as a function of the magnetic field is shown in fig. 1 for different high voltage settings of the three studied MCP-PMTs. Clearly, the maximum gain reachable with the MCP-PMT depends on the pore diameter. The 25 μm device reaches just above 10^6 while with the MCP-PMT with 6 μm pore size a gain of almost 10^7 is possible. These results are compatible with earlier measurements [12].

The dashed line indicates the minimum gain of about 5 x 10^5 still acceptable for an efficient detection of single photons with the PANDA DIRC. From the plots it is obvious that the gain of the 25 μm

[1] The PiLas laser diode was delivered by Advanced Laser Diode Systems GmbH, D-12489 Berlin, Germany

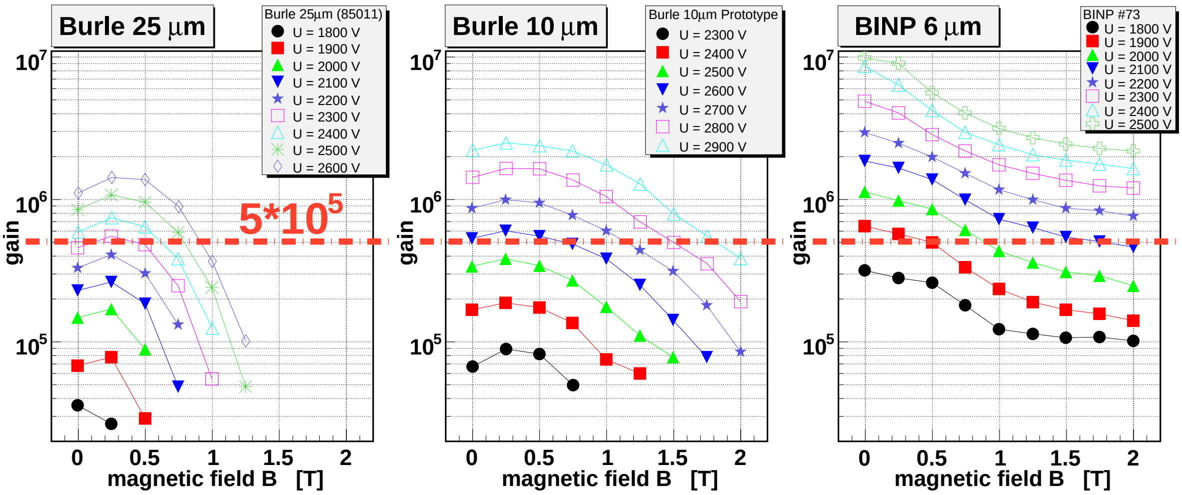

Fig. 1. Gain as a function of the magnetic field for different high voltage settings. Compared are MCP-PMTs of Photonis-Burle with 25 μm pore diameter (left), a Photonis-Burle prototype with 10 μm (middle) and a BINP device with 6 μm pore diameter (right). The minimum gain of 5 x 10^5 for an efficient single photon detection is indicated by the orange dashed line.

version of the Photonis-Burle Planacon reaches this limit only at large high voltage settings. Since the gain collapses completely just above 1 Tesla this device does not meet the requests for PANDA. The Photonis-Burle Planacon with the small pore diameter of 10 μm exhibits a larger gain and is still operable in the 2 Tesla field of the PANDA solenoid. Efficient single photon detection appears possible up to at least 1.75 T though a high voltage setting close to the recommended maximum for this device is needed. The best gain performance in a high magnetic field is observed for the BINP MCP-PMT with 6 μm pore diameter. The PANDA gain limit for single photon detection is reached at moderate operation voltages even in a 2 T field.

The time resolution of the investigated MCP-PMTs was measured in dependence of the magnetic field. For reasonably large high voltages the upper limits for the time resolution are 80 ps for the 25 μm Photonis-Burle Planacon, 60 ps for the 10 μm version and 50 ps for the BINP with 6 μm pores. Obviously, the smaller the pore size gets the better the time resolution becomes. Within the accuracy of our measurement we find – if at all – only a small deterioration of the time resolution towards higher magnetic fields.

For the BINP MCP-PMT the angle ϕ between the PMT axis and the orientation of the magnetic field was changed in 15° steps from 0° to 45°. Unfortunately, because of their geometrical size and the small gap between the pole shoes of the dipole magnet this was not possible for the Photonis-Burle devices. In fig. 2 the effect of the orientation of the field axis is shown for the gain and for the time resolution. For small tilt angles ϕ and 2 T the gain drops to about 30% of the gain without magnetic field. At $\phi = 45°$ the gain at 2 T drops to about one-tenth of the original gain. Nevertheless, single photon detection would still be possible if the high voltage were raised. The time resolution only moderately depends on ϕ. The large rise at 2 T and at 45° is a consequence of the small anode signals due to the significantly lower gain.

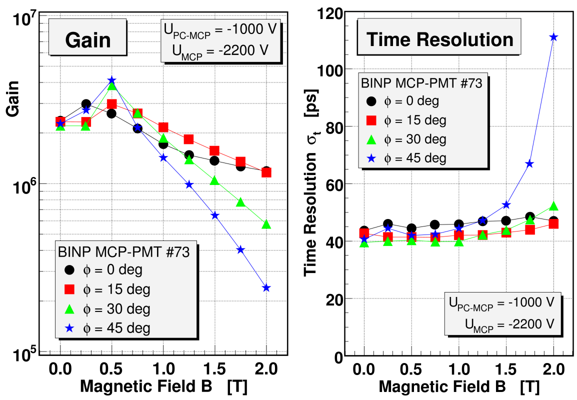

Fig. 2. Gain (left) and time resolution (right) for single photons as a function of the angle ϕ between the MCP axis (perpendicular to the window surface) and the field orientation. The data points are valid for the BINP MCP-PMT with 6 μm pore diameter.

The time resolution without a magnetic field was precisely measured using a fast oscilloscope.

For the BINP MCP-PMT the results for combinations of different amplifiers (Ortec VT120A [200x, 350 MHz], Ortec 9306 [100x, 1 GHz], Hamamatsu C5594 [63x, 1.5 GHz]) and discriminators (LeCroy 821, LeCroy 620CLR, EG&G CF4000, Ortec 934) were compared. All combinations showed a fair performance varying between 38 ps and 27 ps for a gain of 2.5 x 10^6. As expected, the best time resolution at a given pulse height was obtained with the high bandwidth C5594 amplifier. This was the case for all discriminators. However, the best performance for single photons, again for all discriminators, was obtained with the VT120A amplifier which has the highest amplification factor. This indicates that for a good time resolution measurement of single photons it is more important to apply a high amplification factor than to use a high bandwidth. Of the discriminators the EG&G CF4000 CFD showed the best performance.

In fig. 3 the time resolution measured for the Burle-Photonis with 25 μm pores is compared to that of the BINP MCP-PMT with 6 μm pores. For the latter a resolution of 27 ps was obtained. This result is still blurred by the finite time resolution of the electronics devices, the input channels of the oscilloscope, and in particular of the laser pulses. These resolutions were measured independently to be about 5-6 ps/channel for the oscilloscope channels and the same for the electronics devices used. The PiLas laser contributes 14 ps. Unfolding these contributions results in a net transit time resolution for single photons of $\sigma_t \approx 20$ ps for the BINP MCP-PMT. To our knowledge this is the best value determined for single photons so far.

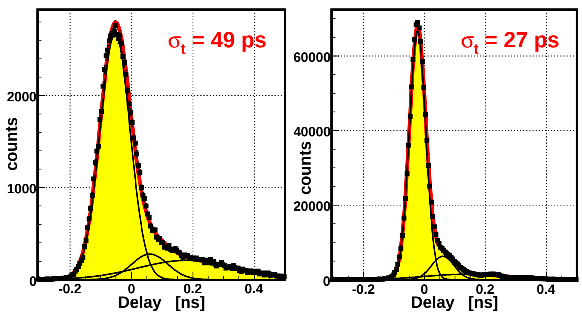

Fig. 3. Single photon time resolution for the Photonis-Burle MCP-PMT with 25 μm (left) and the BINP device with 6 μm (left) pore diameter measured with a 3 GHz / 20 Gs oscilloscope. A LeCroy 821 leading edge discriminator and an Ortec VT120A amplifier were used. The tails to the right stem from bouncing electrons at the MCP surface [13]. The resolution for the not shown Photonis-Burle device with 10 μm was 41 ps.

5. Conclusions

The behaviour of gain and time resolution of MCP-PMTs with different pore diameters were investigated in dependence of a magnetic field of up to 2 T. It was found that the Photonis-Burle device with 25 μm pores is not suitable for an operation at these high magnetic fields. A minimum of 10 μm pores is required for the PANDA DIRC. The best performance for both gain and time resolution was measured with the BINP MCP-PMT with 6 μm pores. However, further investigations concerning its rate stability and in particular its life time are needed. Still, MCP-PMTs with an appropriate design remain a high priority option for the PANDA DIRC.

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References

[1] PANDA Collaboration, Technical Progress Report, FAIR-ESAC/Pbar 2005
[2] P. Coyle et al., Nucl. Instr. Meth. A 343 (1994) 292
[3] K. Föhl, these proceedings
[4] C. Schwarz, these proceedings
[5] P. Schönmeier, these proceedings
[6] M. Akatsu et al., Nucl. Instr. Meth. A 440 (2000) 124
[7] Y. Enari et al., Nucl. Instr. Meth. A 494 (2002) 430
[8] B. N. Ratcliff, Nucl. Instr. Meth. A 502 (2003) 211
[9] C. Field et al., Nucl. Instr. Meth. A 518 (2004) 565
[10] V.V. Anashin et al., Nucl. Instr. Meth. A 357 (1995) 103
[11] A. Yu. Barnyakov et al., Nucl. Instr. Meth. A 567 (2006) 17
[12] M. Akatsu et al., Nucl. Instr. Meth. A 528 (2004) 763
[13] J. Va'vra et al., Nucl. Instr. Meth. A 572 (2007) 459