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Performance study of the fast timing Cherenkov detector based on a microchannel plate PMT

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Performance study of the fast timing Cherenkov detector based on a microchannel plate PMT

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Abstract. Prototype of the fast timing Cherenkov detector, applicable in high-energy collider experiments, has been developed basing on the modified Planacon XP85012 MCP-PMT and fused silica radiators. We present the reasons and description of the MCP-PMT modification, timing and amplitude characteristics of the prototype including the summary of the detector's response on particle hits at oblique angles and MCP-PMT performance at high illumination rates.

1. Introduction

Modern comprehensive detection systems for the high-energy physics experiments often require relatively simple subdetectors able to generate trigger signals with the best timing in the shortest period of time. T0 and V0 detectors of the ALICE experiment at LHC are the good examples of such subdetectors [1-2]. They are used for the precise collision time measurement, the earliest trigger generation, online luminosity monitoring and multiplicity determination [3].

Future HEP projects could require radiation hard trigger detectors of much larger acceptance, smaller size along the beam axis and increased rate capability [4]. ALICE Fast Interaction Trigger (FIT) T0+ subsystem is being developed to meet these needs:

- acceptance for the detectors at different sides from the interaction point (IP): $3.8 \leq n \leq 5.4$, $-3.3 \leq n \leq -2.2$;
- time resolution better than 50 ps (sigma);
- thickness (size along the beam pipe) ≤8 cm;
- hadron fluence up to 10^{11} n_{eq}/cm^2;
- collision rates up to 40 MHz.

Such requirements could be satisfied with Cherenkov detector modules compiled into a single detector plane around the beam pipe with minimum gaps. We propose to use Planacon XP85012 photomultipliers [5], based on microchannel plates (MCP-PMTs) with 2 cm-thick fused silica bars

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acting as Cherenkov radiators. The radiators are optically coupled to the MCP-PMT window using the Dow Corning 200 fluid, which is optically transparent down to the photons' wavelength of 190 nm.

Since Planacon XP85012 is a multianode photomultiplier with 53x53 mm^2 sensitive area, one could reasonably increase the granularity of the detector by using four 26.5x26.5x20 mm^3 Cherenkov radiators and interconnecting the corresponding MCP-PMT anodes into four equal groups. The sides of each radiator should be covered with a light reflecting and a light absorbing layer, so that each Cherenkov module would represent four quasi-independent Cherenkov detectors with negligible gaps between the radiators. Such Cherenkov module has been produced and characterized with the help of relativistic particles and fast lasers. Results of these measurements are presented below.

2. Cross-talks in the MCP-PMT

The off-the-shelf version of XP85012 MCP-PMT features a common output of a positive polarity, along with the negative-polarity outputs of the individual anodes. As reported in [5], presence of the common output leads to positive cross-talks at the individual outputs when more than one quadrant is fired. This phenomenon leads to a significant distortion of the negative signal, as shown in fig.1 (a), compromising the possibility of precise timing measurements with this type of MCP-PMT.

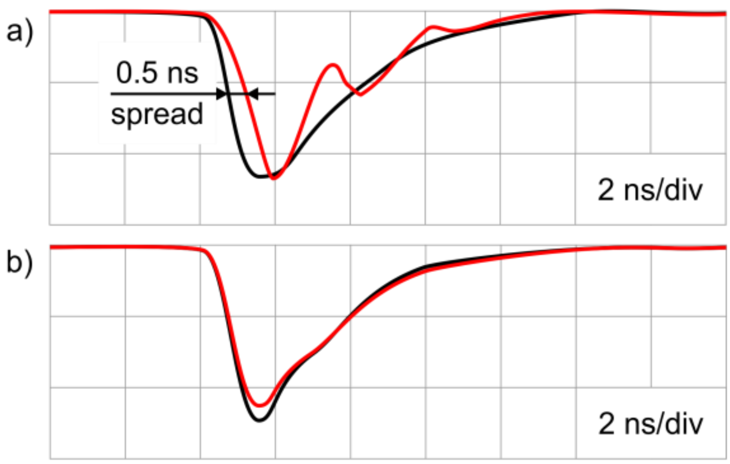

Figure 1. Averaged signal waveforms from one quadrant of the MCP-PMT before (a) and after (b) the readout PCB modernization: black curves – only one quadrant under illumination, red curves - all quadrants under illumination with short pulses of light of the same intensity.

To eliminate the positive cross-talk, in cooperation with the manufacturer, our group has designed and installed to a prototype MCP-PMT the new power supply and signal readout PCB with no common output connection and equalized connections lengths for the individual anodes. Waveforms from the modified MCP-PMT are shown in figure 1 (b).

There are some other inevitable sources of cross-talks in the tested MCP-PMT. Their detailed description is beyond the scope of this article, but none of them are characterized by positive polarity and they have no influence on the timing properties of the device.

3. Timing characteristics

Timing properties of the Cherenkov module with the modified MCP-PMT have been measured at CERN PS (Proton Synchrotron) with 6 GeV/c negative pion beam according to the technique, described earlier [6]. The experimental setup is shown in figure 2: time resolution of the tested device was measured relatively to the average timing of the two Cherenkov counters based on FEU-187 PMTs. The MCP-

PMT modules were biased to ~10^6 gain with their signals fed to CAEN DT5742 waveform digitizer with 5 GS/s sampling rate. Further details of the measurement technique could be found in [6].

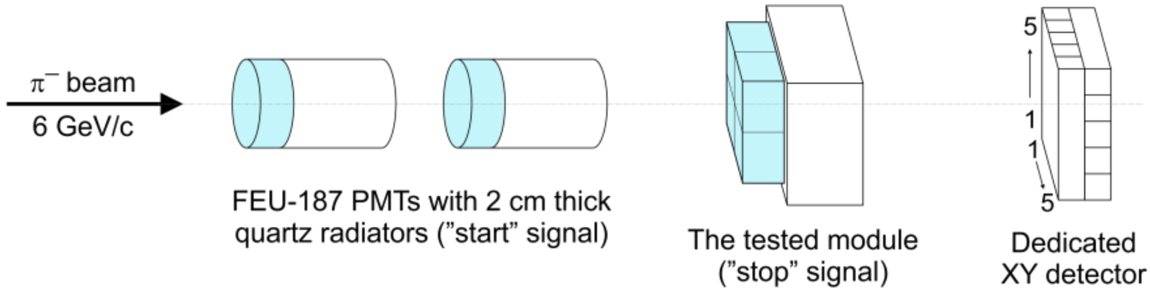

Figure 2. Experimental setup for measuring timing properties of the Cherenkov module at CERN Proton Synchrotron.

Time resolution of the Cherenkov counters serving as time trigger and the tested Cherenkov modules with the standard and modified versions of the XP85012 MCP-PMT is shown in figure 3.

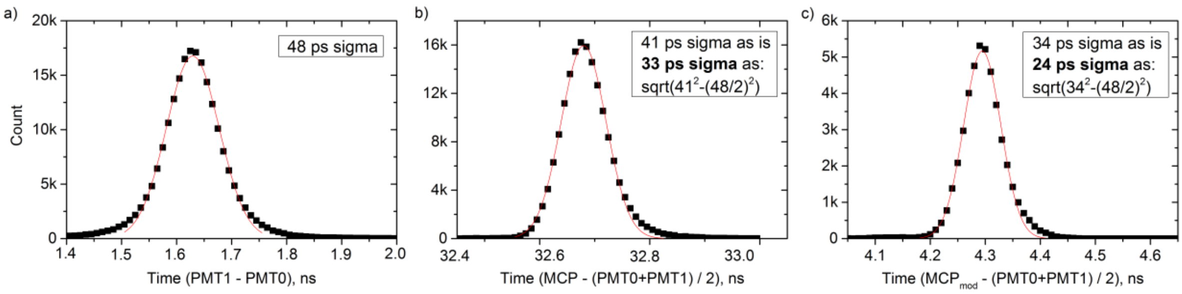

Figure 3. Time spectra, representing (a) the trigger Cherenkov counters time resolution, (b) time resolution of the tested Cherenkov module with the standard MCP-PMT, (c) time resolution of the tested Cherenkov module with the modified MCP-PMT.

Figure 3 (a, c) shows that the achievable time resolution of the Cherenkov module under study is 24 ps after the trigger error subtraction.

4. Amplitude characteristics

4.1. Particle hits at oblique angles

Some applications imply the possibility of irradiation of the proposed Cherenkov detector with particles hitting the device at different angles. For example, T0+C subsystem of the ALICE FIT T0+ detector is proposed to be placed 80 cm away from the IP. Taking into account the significant planar dimensions of the Cherenkov modules array (6x6 Cherenkov modules, or ~36x36 cm^2), it is obvious, that if the array were flat, particles would hit the radiators at the angles of up to 13.6° to the normal.

During the beam tests of Cherenkov module it was discovered, that unlikely the response of scintillation detectors to the particle hits at oblique angles, the mean signal amplitude of the detector under study decreases with the increase of the incidence angle (see figure 4).

Amplitude resolution of the device was also found to deteriorate from ~24% to ~33% from particle hits at the angles from 0° to 15°. Both of these phenomena could lead to a significant variation of the T0+C amplitude characteristics. Luckily, it is possible to avoid these effects by constructing the geometry, in which detector faces are perpendicular to the incoming particles. It is verified that optimal concave geometry with R≈80 cm fits in the allocated space along the beam pipe.

4.2. Rate capability of the MCP-PMT

In order to check the ability of the detector to cope with 40 MHz collision rate, at which LHC would operate during the Run 3 and 4, the tested prototype of the Cherenkov module was illuminated with

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bursts of up to 19 picosecond optical pulses of blue (λ=405 nm) laser light with 25 ns period. MCP-PMT was biased to a realistic gain of $1.5*10^4$ resulting in 10 mV/MIP average signal amplitude. The results are shown in figure 5.

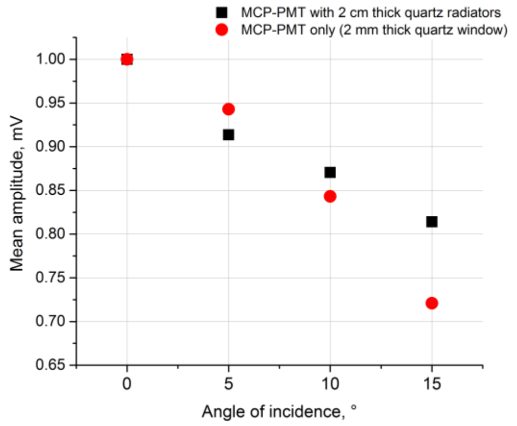

Figure 4. Dependence of mean amplitude of the signals from the tested Cherenkov module and the MCP-PMT itself on the angle of the particle incidence.

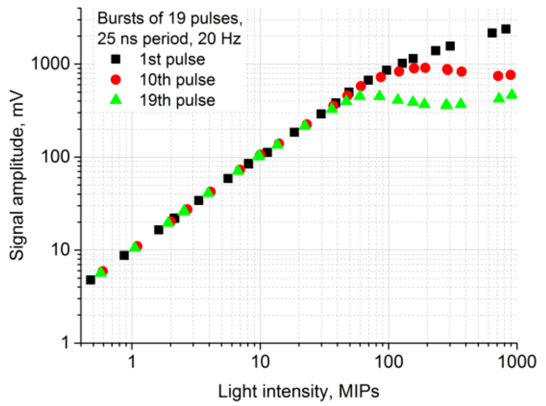

Figure 5. Dependence of the 1-st, 10-th and 19-th pulses of a burst of 19 pulses following with a 25 ns period on the intensity of light.

As could be seen from figure 5, an individual quadrant of the MCP-PMT is able to detect up to 10 consecutive 100 MIP pulses with 25 ns period with no significant decrease of the signals amplitude.

5. Conclusion

The possibility to build a compact high-precision timing Cherenkov detector for a high-energy and high-luminosity collider experiment is shown. Prototype of the Cherenkov module for the proposed detector is produced using the Planacon XP85012 MCP-PMT and 2 cm thick fused silica radiators. Common output connection removal from the signal readout and power supply PCB of this MCP-PMT enables one to eliminate the positive crosstalk between the anodes of the device, improving its time resolution.

Results of the in-beam test of the prototype demonstrate the possibility of achieving the time resolution of ~24 ps. It was also discovered, that particle hits at oblique angles significantly deteriorate amplitude resolution of the device. However, modular detector structure enables one to eliminate this problem with the help of the concave detector geometry appropriate when placed close to the interaction point.

It was confirmed, that the Planacon XP85012 MCP-PMT can cope with the bursts of not less than 10 consecutive signals with 100 MIP amplitude at 25 ns repetition rate at reasonable gain of $1.5*10^4$ (~10 mV/MIP) with no decrease in gain.

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