Development a picosecond MCP based particle detector

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Outline

• Motivation
• Conception
• $N_{ph.e.}$ estimation
• Tests in magnetic field
• Prototyping
• Summary
Motivation

Time of flight measurement can provide:

- Momentum, GeV/c
- ΔTOF, ps

For different particle types and base distances:

- $K^-$, π, base = 1 m
- $\pi^-$, $\mu^-$, base = 2 m
- $K^-$, π, base = 2 m

Measurement of velocity ⇒ PID

(Flight distance is known)

$\sigma_t \approx 10\ ps$, 1 m distance

⇒ $\pi/K$ separation up to 3.5 GeV/c

Measurement of distance ⇒ VERTEX

(Velocity is known)

$\sigma_t \approx 10\ ps$, $\beta = 1$

⇒ Position resolution $\sim 3\ mm$

~140 int./bunch crossing @ HL-LHC
A 5 ps TOF counter


- Hamamatsu MCP PMT
- MCP channel dia. = 6 μm
- Photocathode dia. = 11 mm
- Multialkali photocathode
- Quartz radiator ~1 cm thick

\[
\sigma_{\text{TOF}} = 6.2 \text{ ps} \\
\text{while } \sigma_{\text{circuit}} = 4.1 \text{ ps} \\
\Rightarrow \sigma_{\text{intrinsic}} \approx 4.7 \text{ ps}
\]
Requirements to the detector
(for endcap EMC of CMS at HL-LHC)

- sensitive area ~ 10×10 cm
- 100% efficiency to MIP
- ~ 10 ps time resolution for single MIP
- anode segmentation ~ 1 cm
- operation in magnetic field ~ 4 T
- lifetime > $10^{14}$ MIPs/cm$^2$
- radiation hardness > $10^{15}$ n$_{eq}$/cm$^2$
Conceptual design

Photosensitivity is not needed:

=> metal entrance window
=> *Cherenkov radiator inside vacuum volume*
=> simpler design
=> more room for radiator optimization
Conceptual design

Lifetime:

\[ 10^{14} \text{ MIPs/cm}^2 \times 10 \text{ photoelectrons/MIP} \times 10^6 \text{ gain} \times e \]
\[ \approx 200 \text{ C/cm}^2 \]

Can ALD MCP provide such lifetime with alkali-antimonide photocathode?

What about more stable photocathode?

=> CsI

Another reason:
simpler production and manipulation on large area
Conceptual design

- Vacuum tight metal-ceramic body
- Semitransparent CsI photocathode
- VUV transparent Cherenkov radiator

VUV transparent materials:
- Fused silica SiO$_2$
- MgF$_2$
- CaF$_2$
- LiF
- Sapphire Al$_2$O$_3$
Conceptual design

Problem:
mechanical stability of large size MCP.

Solution:
array of «small» MCPs inside single vacuum volume.
Conceptual design

Vacuum tight metal-ceramic body

Semitransparent CsI photocathode

VUV transparent Cherenkov radiator

Array of small pore MCP chevrons

Segmented anode

~10 cm

Anode size should be small enough to avoid degradation of time resolution

~ 1 x 1 cm
Analytical calculation of the number of photoelectrons and duration of the light pulse

**QE of CsI photocathode**
from specification
of Hamamatsu R6835 PMT

**Refractive index**
from publications

**Internal transparency**
from publications
**Results of calculations**

**Charged particle**

![Diagram of charged particle and Cherenkov radiation](image)

**Table:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Total number of detected photons</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiF</td>
<td>23.1</td>
</tr>
<tr>
<td>MgF₂</td>
<td>19.3</td>
</tr>
<tr>
<td>CaF₂</td>
<td>16.5</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>14.0</td>
</tr>
<tr>
<td>Silica glass</td>
<td>1.3</td>
</tr>
</tbody>
</table>

MCP open area ratio = 60%

**MCP time resolution ~30 ps**

=>$\sigma < 30 \text{ ps}$

5 mm thick MgF₂ radiator provides

~ 20 ph.e. during first 50 ps

=>$\sigma_t < 10 \text{ ps}$ is expected
Magnetic test setup

SC solenoid with $B$ up to 4.5 T

PiLas laser:
- $\lambda = 823$ nm
- FWHM = 30 ps

MCP PMT
- multialkali ph.c. $\varnothing 18$ mm
- 2 or 3 MCPs
- 6, 8, 10 µm channel dia.

CAEN V1742 digitizer
- 12 bit ADC
- 5 GS/s
Magnetic test results

The relative gain of the different MCP PMTs as a function of magnetic field is presented for different MCPs exemplars. It is observed that the gain decreases with increasing magnetic field for all types of MCPs. The decrease is more pronounced for MCPs with larger pore diameters. The magnetic field dependency of the gain can be seen in the graph.

<table>
<thead>
<tr>
<th>MCP type</th>
<th>Gain degradation @ B=4T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two MCPs 6 μm</td>
<td>4 times</td>
</tr>
<tr>
<td>Two MCPs 8 μm</td>
<td>15 times</td>
</tr>
<tr>
<td>Two MCPs 10 μm</td>
<td>25 times</td>
</tr>
<tr>
<td>Three MCPs 8 μm</td>
<td>80 times</td>
</tr>
</tbody>
</table>

In order to separate effects of an eventual change of the photon detection efficiency in a magnetic field from a change of the gain, the relative gain of the MCP PMTs was measured as a function of magnetic field. The graph shows the decrease in gain with increasing magnetic field, with larger pore diameters experiencing a more significant decrease.

The magnetic field of up to 4.5 T a time resolution of 50 ps was obtained.

The high voltage on the PMTs was adjusted in zero magnetic field. The high voltage adjustment was performed using a PMT with two MCPs of 8 μm pore diameter (2MCP 8 μm) and a PMT with two MCPs of 10 μm pore diameter (2MCP 10 μm). The following exemplars were tested in a magnetic field of up to 4.5 T. All of them were produced in Novosibirsk and equipped with multi-alkali photocathodes. The photoelectron event could be evaluated from the PMT signal.

Several exemplars of MCP PMTs with different MCP stage designs were tested in magnetic fields up to 4.5 T. The gain degradation of the MCP PMTs as a function of magnetic field is shown in the graph.

In order to estimate the intrinsic time resolution of our circuit and to minimize the influence of the light source on the time resolution measurements in all data channels of the ADC, the gain was adjusted. The following exemplars were used: Subtraction of the electronics background and attenuator adjustment.

The evaluation of the gain were used. The time resolution was measured in the same way as a PMT signal goes to the other digitizer input. One part of the signal goes directly to the digitizer input, the second part through cable delay, amplifier, and attenuator adjustment. In the time restoring procedure we have split one pulse from the time-occupied event.

Fig. 1. Magnetic test results. Relative gain as a function of magnetic field for different MCP PMT types.

Fig. 2. Magnetic test results. Relative gain as a function of magnetic field for different MCP PMT types.

Fig. 3. Magnetic test results. Relative gain as a function of magnetic field for different MCP PMT types.
MCP 54x54-6

First sample of 5x5 cm MCP with 6 µm channel
developed by «Baspik» company (Vladikavkaz, Russia)

- MCP size 54.5 x 54.5 mm
- MCP thickness 390 µm
- channel diameter 6.3 µm
- open area ratio 67%
- gain >2000
- resistance 10 MΩ
“Small” prototype
for photocathode production mastering

- Upper part
- Bottom part
- O-ring sealing
- Electrical feedthrough
- Anode
- To pump
- MCP chevron
- Photocathode - MCP distance ≈ 10 mm
- Window (MgF₂)
- Indium sealing
- Output from photocathode
- Vacuum flange (for monochromator)
CsI photocathode production

Deposition of thin metal electrode and CsI photocathode in the same vacuum cycle.
Vacuum sealing of the prototype after photocathode deposition.
QE measurement setup

- Vacuum monochromator
- Deuterium lamp
- Pump station
- Tested prototype
- Reference detector
QE measurement results

Five CsI photocathodes on MgF$_2$ window have been produced so far.
Beam test setup

CAEN V1742 digitizer

1 GeV e⁻

Prototype under test

Trigger counters
Beam test results

Amplitude

\[ \langle N_{\text{ph.e.}} \rangle \approx 0.4 \]

Time

\( \sigma \approx 50 \text{ ps} \)
Summary

• Conceptual design of a "large area" MCP based TOF detector has been developed.
• According to calculations the time resolution < 10 ps is expected.
• The first sample of 5x5 cm MCP with 6 µm channel diameter has been produced.

Next steps:
• Optimization of CsI photocathode production
• "Large" prototype production and testing
Thank you!