High Precision Timing detectors for future experiments

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Precise Timing

Precise Timing has many applications in Physics. In particle physics a precise time measurement has always been the basic ingredient for fundamental discoveries.
Bologna Test Stand

We are studying the time resolution of various detectors by means of cosmic rays in a dedicated test stand.

![Diagram showing the time resolution study process]

- Trigger Detector
- Detector to Study
- Front End
- Read Out

Time variables:
- $T_{\text{trigger}}$
- $T_{\text{Detector}}$
- $\Delta T$

Histogram showing $\Delta T$ distribution.
Bologna R&D

A study of the timing properties of several new detectors is performed in Bologna INFN laboratories.

Detectors under study:

- **MCP-PMT**
  Micro Channel Plate
  PhotoMultipler

- **SiPM**
  Silicon PhotoMultiplier

- **UFSD**
  Ultra Fast Silicon Detector

A, C → trigger detector
B → detector to be studied
The readout electronics was composed by CAMAC modules: TDC and CIA, for time and charge measurements respectively. The charge was measured to apply time slewing corrections.

Developed for ALICE-TOF:
- Amplifier/Discriminator
- Ultrafast
- Low power
- $V=2.5\,\text{V}$
- Threshold $= 180\,\text{mV}$

We used different amplifier; in particular for the SiPM we used the NINO ASIC.
MCP-PMT

Main characteristics used detector:

- Insensitive to B
- Effective area (D) 17.5 mm
- Double MCP, channel 6 µm, 50:1 L:d
- Max voltage 2600 V

The MCP has been coupled to plastic scintillator 2x2x3 cm³

MCP time resolution: subtract from arrival time of MCP signal the mean time of the PMTs signals:

\[
\sigma_{MCP} = \sqrt{\sigma^2 - \sigma_{PM}^2} = (133\pm4) \text{ ps}
\]
SiPM: The Detector

Each pixel is independent and gives the same signal when fired by a photon. Output charge is proportional to the number of incident photons.

Main characteristic of SiPM detector used:
- Insensitive to B
- Effective area 3x3 mm$^2$
- Pixel 50x50 µm$^2$
- Low op. voltage
SiPM: Coupling to scintillator

Direct, by means of optical grease

By means of three optical plastic fibers I also studied the response varying the length of the fibers: 10 cm and 32 cm.
SiPM: Results

The data analysis was based on:

- All the time measurements were corrected for time slew effect

- SiPM time resolution obtained as difference of the two arrival times

\[
\sigma_{SiPM_{contact}} = \frac{\sigma}{\sqrt{2}}
\]

<table>
<thead>
<tr>
<th>Coupling</th>
<th>(\sigma_{SiPM}) (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>84±2</td>
</tr>
<tr>
<td>Fiber 10 cm</td>
<td>125 ± 2</td>
</tr>
<tr>
<td>Fiber 32 cm</td>
<td>139 ±2</td>
</tr>
</tbody>
</table>
Low Gain Avalanche Detector optimised for time applications

- Insensitive to B
- Compact and thin
- Radiation hard
- Uniform E

**UFSD**

Two different prototypes of UFSD, one from CNM one from FBK

First measurements with a cosmic rays setup: \( \sigma \sim 268 \text{ ps} \)

Large improvements are expected.
Conclusions

- **Precise timing has many applications** both in nuclear/subnuclear physics and in medical physics.

- In Bologna we prepared a Cosmic ray test facility to study the time resolution of different detectors: MCP-PMT, SiPM, UFSD.

- The obtained time resolution for **MCP-PMT** coupled to plastic scintillator is 133 ps.

- The **SiPM** was coupled both directly and by means of optical fibers to the scintillator. With the direct coupling the measured **time resolution** was **84 ps**.

- Tests on prototypes of **UFSD** are ongoing; **first results with cosmic rays**.
Backup
# MCP-PMT

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input window</td>
<td>Quartz</td>
</tr>
<tr>
<td>Photocatode type</td>
<td>S20</td>
</tr>
<tr>
<td>MCP</td>
<td>double, chevron, 6µm more size, 50:1 L:D</td>
</tr>
<tr>
<td>Output</td>
<td>single anode, SMA connector</td>
</tr>
<tr>
<td>Input usefull diameter</td>
<td>17.5 mm</td>
</tr>
<tr>
<td>Typical Gain</td>
<td>$7 \cdot 10^5$</td>
</tr>
<tr>
<td>Maximum voltage</td>
<td>2600 V</td>
</tr>
</tbody>
</table>
### SiPM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective photosensitive area</td>
<td>3x3 mm²</td>
</tr>
<tr>
<td>Pixel pitch</td>
<td>50x50 µm²</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>3600</td>
</tr>
<tr>
<td>Fill Factor</td>
<td>62%</td>
</tr>
<tr>
<td>Spectral response range</td>
<td>320-900 nm</td>
</tr>
<tr>
<td>Gain</td>
<td>$1.25 \times 10^6$</td>
</tr>
<tr>
<td>Time resolution (Single photon level FWHM)</td>
<td>250 ps</td>
</tr>
<tr>
<td>Recommended operating voltage</td>
<td>$67.6 \pm 10.0$</td>
</tr>
</tbody>
</table>
For technical reasons for the coupling by means of fibers we used this kind of configuration:

\[
\sigma_{\text{SiPM}_{\text{fiber}}} = \sqrt{\sigma^2 - \sigma^2_{\text{SiPM}_{\text{contact}}}}
\]
Plastic scintillator: BC-420

BC-420 plastic scintillator (2x2x3 cm³) are low self-absorption and are used for ultra-fast timing

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Polyvinyltoluene</td>
</tr>
<tr>
<td>Wavelength of Maximum Emission</td>
<td>391 nm</td>
</tr>
<tr>
<td>Refractive Index</td>
<td>1.58</td>
</tr>
<tr>
<td>Bulk Light Attenuation Length</td>
<td>110 cm</td>
</tr>
<tr>
<td>H:C Ratio</td>
<td>~ 1.1</td>
</tr>
<tr>
<td>Decay Constant</td>
<td>1.5 ns</td>
</tr>
</tbody>
</table>
Plastic Scintillating Fibers: WLS BCF-92, 2mm

WLS BCF-92 have the main characteristic to be fast blue to green shifter

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission Peak</td>
<td>492 nm</td>
</tr>
<tr>
<td>Decay Time</td>
<td>2.7 ns</td>
</tr>
<tr>
<td>Core material</td>
<td>Polystyrene</td>
</tr>
<tr>
<td>Core refractive index</td>
<td>1.60</td>
</tr>
<tr>
<td>Cladding material</td>
<td>Acrylic</td>
</tr>
<tr>
<td>Cladding refractive index</td>
<td>1.49</td>
</tr>
<tr>
<td>No. of H atoms per cc (core)</td>
<td>$4.82 \times 10^{22}$</td>
</tr>
<tr>
<td>No. of C atoms per cc (core)</td>
<td>$4.85 \times 10^{22}$</td>
</tr>
<tr>
<td>No. of electrons per cc (core)</td>
<td>$3.4 \times 10^{23}$</td>
</tr>
</tbody>
</table>
The NINO chip is an ultrafast low power Amplifier/Discriminator:

- IBM 0.25μm Si CMOS Technology
- 8 channel / chip (chip: 2x4 mm²)
- Differential input and all stage
- Low power (~ 40mW/chip)
- Intrinsic time jitter: 15-20 ps
- V= +2.5 V
- Output LVDS
Time Slewing

The time slewing correction is mandatory and is due to the transition of the signal form analogic to digital.
One MRPC stack is a chamber formed by two parallel resistive planes where the gap between the electrodes is divided in a given number of smaller gaps by electrically floating high-resistivity planes.

The 18 TOF supermodules (SM) are housed in the ALICE “space-frame” structure. Each SM is divided in 5 modules. We have a total of 91 MRPC per SM. The strip have 96 readout pads, divided in two row each of them with 48 pads. In total, the TOF has 152928 readout channels covering a total area of 141 m².