THE TIMING COUNTER OF THE MEG EXPERIMENT: DESIGN AND COMMISSIONING
(OR “HOW TO BUILD YOUR OWN HIGH TIMING RESOLUTION DETECTOR”)

S. DUSSONI
FRONTIER DETECTOR FOR FRONTIER PHYSICS – LA BIODOLA 2009
Fastest introduction to the MEG experiment you’ve ever seen
Q&A about the Timing Counter R&D
Final performance of the detector
The only thing of concern in this place is that in MEG we need to have a relative uncertainty in the photon-positron simultaneity as close as possible to zero. Our goal was to obtain 150 ps FWHM for $\Delta t_{p-\gamma}$. This corresponds to 100 ps FWHM for the positron alone. So the Timing Counter main goal is to obtain this time resolution, and more....
The TC has been studied to satisfy at least some minimum requirements:
© capability to deliver a fast signal with preliminary track information,
© high efficiency,
© high timing resolution $\sigma_t \sim 40$ ps,
© reliable operation.

Among these items, the first two are relevant for triggering purposes, the third is of paramount importance for our experiment while the latter is constrained by both the harsh environment in which the whole detector is working and the reduced redundancy allowed by the final setup.
The TC in its final shape is represented here, then we will review the R&D steps leading to this shape: we have two identical modules lying UpStream and DownStream the target, inside the COBRA magnet.

Each module has two layers: inner layer is built with scintillating fibers, 6 mm pitch, readout by APDs while outer layer is made by 15 scintillator bars with PMT transducing.

APD readout has two complementary implementations:
- analog signals from 16 fibers (i.e. 9.6 cm) are summed and acquired by the trigger boards
- each APD channel is discriminated and this output is sampled by an FPGA

A similar architecture is envisaged for the PMT signals.
Choice of scintillator: fast, with a high output and a sufficient absorption length: two candidates, BC404 and BC408
Which device to read out the light?
- fast
- low jitter
- robust against magnetic field
ideal candidates: fine-mesh PMTs from Hamamatsu

<table>
<thead>
<tr>
<th>parameter</th>
<th>BC404</th>
<th>BC408</th>
</tr>
</thead>
<tbody>
<tr>
<td>light yield</td>
<td>0.68</td>
<td>0.64</td>
</tr>
<tr>
<td>rise time</td>
<td>700ps</td>
<td>900ps</td>
</tr>
<tr>
<td>decay time</td>
<td>1.8ns</td>
<td>2.1ns</td>
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<tr>
<td>attenuation length</td>
<td>140cm</td>
<td>210cm</td>
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<tr>
<th>PM</th>
<th>TTS (FWHM) Typ.</th>
<th>TTS Measured</th>
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<tbody>
<tr>
<td>R7761-70 (1.5”)</td>
<td>350 ps</td>
<td>470 ps</td>
</tr>
<tr>
<td>R5924 (2”)</td>
<td>440 ps</td>
<td>650 ps</td>
</tr>
<tr>
<td>XP2020 UR (2”)</td>
<td>350 ps</td>
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Each bar has a slanted shape in order to minimize gain loss and timing worsening due to magnetic field: in our design the angle between the PMT axis and the field is around 20º which is optimum from this point of view.

No light guides used nor reflecting wrapping of the bars: using only photons from surface reflection improves timing by selecting photons with low spread in path length from the particle impact point to the PMT.

To obtain a sufficient amount of light and an optimum matching, bars have a squared 4x4 cm section (with some corner cut for mechanical constraints) and chosen PMTs are 2” fine-mesh R5924 from Hamamatsu equipped with custom-made voltage divider network.
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The most notable result for the Timing Counter is $\sigma_t \sim 40$ ps. Comparing it with other devices, it turns out that MEG TC is very good.

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<th>Exp. application</th>
<th>Counter size (cm)</th>
<th>Scintillator</th>
<th>PMT</th>
<th>$\lambda_{att}$ (cm)</th>
<th>$\sigma_t$(meas)</th>
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<td>G.D. Agostini</td>
<td>3 x 15 x 100</td>
<td>NE114</td>
<td>XP2020</td>
<td>200</td>
<td>120</td>
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<td>T. Tanimori</td>
<td>3 x 20 x 150</td>
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<td>5 x 10 x 280</td>
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<td>137</td>
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<tr>
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<tr>
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<td>420</td>
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<tr>
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TC PERFORMANCES - I

BTF test beam results

Timing resolution ps, FWHM
PSI final setup result, upper limit (measured with three bar telescope on Michel positrons)
most bars have $60\text{ps} < \sigma_t < 80\text{ps}$ (upper limit!)
The frontend electronics give a very important contribution to the final timing resolution. We designed a double threshold fast discriminator.

Low threshold gives the signal timing with very low intrinsic jitter (dominated by photoelectron statistics).

High threshold applies an energy cut selecting signals from positrons with good tracks (low energy background rejection).

Contribution to total timing resolution <10ps (σ) from intrinsic jitter.

Contribution from timing reconstruction algorithm is 7 ps (σ) @1.6 GS/s, ideal case (no noise, constant sampling speed).

Advantages of this approach is to have a reliable waveform to be digitized: even with a slower sampling speed timing resolution is not degraded significantly by the reconstruction algorithm: 13 ps (σ) @1.2 GS/s, real case (noise and sampling speed jittering).
FRONTEND ELECTRONICS

response of DTD with a PMT-like pulse at the input

nice signal with steep leading and trailing edges
Final setup: needed inter-bar equalization for a uniform detector response (all thresholds are set together).

Our choice was to use Michel and cosmics crossing the bar near the center, then find the landau peak and regulate HV for each PMT to obtain equal values for each couple.
A quite important issue is how much charge can be extracted from the PMTs without degrading their performances. We performed a long-term measurement with a continuous light source with a periodic check of PMT gain. Right, we have an older 1.5” PMT tested: after ~300 C have been drained the PMT performance degrades faster but with an acceptable rate, at least for a collected charge 5 times (approximately) larger. Left, the same measurement for a new 2” PMT like the ones used in the TC: degradation not yet observable after 2100 C of charge. Expected from our setup:
The reconstruction of the z-coordinate of the impact position, useful to determine the positron-photon collinearity already at the trigger level but also in the data analysis, is performed by a layer of scintillating fibers readout by APD.

Due to the length of the fibers and the reduced particle path inside them, we need to use APDs just below the breakdown, to achieve a gain of ~500. We obtained a nice separation between electrons and pions spectra at PSI.

A 8-channel board is the basic module of this detector. Each channel is discriminated onboard, while the analog signal from each APD is summed: in this way we can effectively reduce data amount by only digitizing one bit for each channel.

Then the hit map is reconstructed by associating “on” bits to their z position.
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DAQ SCHEMATIC

APD SIGNALS → PREAMPLIFIER → DISCRIMINATOR → ANALOG SUM OUTPUT

8X

TRIGGER SYSTEM

FPGA DIGITIZING

TRIGGER SIGNAL

IMPACT POSITION DETERMINATION, DZ~10CM

IMPACT POINT RECONSTRUCTION, DZ~1CM

SIGNAL FROZEN AND STORED