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# STATUS OF THE MEG EXPERIMENT: TIMING COUNTER EXPERIMENTAL RESULTS

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## Abstract

The Timing Counter (TC) of the MEG experiment must achieve a time resolution equal or better than 100 ps FWHM ($\sigma$ = 42.5 ps). The results obtained, at the Beam Test Facility (BTF) of Frascati/Italy, on two TC prototypes elements, permitted the selection of the scintillator, providing the best timing resolution, achieving an average resolution of 92 ps FWHM ($\sigma$ = 39.2 ps) with a plastic scintillator.

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## 1 INTRODUCTION

The MEG experiment will proceed at the Paul Scherrer Institute (PSI) accelerator searching for the Lepton Flavour violation process $\mu \rightarrow e + \gamma$, with a sensitivity of $\sim 10^{13}$ - two orders of magnitude better than present existing limits [1,2]. The main background contribution to the process [3]:

$$\mu^+ \rightarrow e^+ + \gamma \qquad (1)$$

arises from an accidental combination of a positron, from reaction $\mu^+ \rightarrow e^+ + \nu_e + \nu_\mu$, and a $\gamma$ coming from $\mu^+ \rightarrow e^+ + \nu_e + \nu_\mu + \gamma$. The reduction of this background is achieved by precise measurements of the available experimental parameters [1]: the energy of the $\gamma$–ray, $E_\gamma$, and the positron momentum, $p_e$, that should be equal to $m_\mu /2$); the angle between the positron and photon, $\theta_{\gamma e}$, which should be 180°; and the time difference between photon and positron at the origin in the target, $\Delta t_{\gamma e}$, that should equal zero, within a resolution of 150 ps FWHM.

The TC is a system of scintillation bars with a photomultiplier (PMT) at both ends measuring the arrival time of the positrons. In this paper we present the experimental results on the performance of the TC for the MEG experiment [3,4], in particular, the tests performed on a single TC bar indicating that the desired resolution can be reached.

## 2 EXPERIMENTAL PROTOCOL

Each TC element consists of a scintillator bar connected at each end by two PMTs, PM1 and PM2, respectively. The quantity defining the arrival time of the particle at the bar is typically given by:

$$T = \frac{T_1 + T_2}{2}, \qquad (2)$$

where $T_1$ and $T_2$ are the arrival times of the scintillation light produced at the particle's impact point, on PM1 and PM2, respectively. The statistical uncertainty on the quantity $T$ is the same as for the quantity:

$$T' = \frac{T_1 - T_2}{2}. \qquad (3)$$

Therefore, one can determinate the uncertainty in $T$ by measuring the uncertainty of the difference in the arrival time, (T'), on PM1 and PM2, by employing a simple start-stop technique. In this configuration the signal from the PM1 furnishes the starting signal to a ramp generator that is stopped by the PM2 signal, delayed in order to insure its arrival after the one from PM1. After the STOP signal the resulting voltage is sampled and converted to a digital value which is proportional to the time between the two events. The timing resolution is given by the maximum time interval divided by the ADC resolution, providing 6.35 ps/digit resolution.

A problem can arise if large variations of a PM pulse-height generate significant time fluctuations when employing a fixed threshold discriminator. The method we have selected to overcome this difficulty is based on a simple double-threshold technique: a low-threshold discriminator, which is sensitive to the early arriving photons, introduces fewer time-fluctuations. The high-threshold is only used to validate the low-threshold signal, thus suppressing events produced by noise fluctuations. The rest of the electronic system is conventional, based of a Time to Amplitude Converter.

## 3 MECHANICS

An element of the TC consists on a scintillator bar with dimensions 800×40×40 $mm^3$. Two kinds of scintillating material have been tested: BC 408 and BC 404 produced by BICRON. Their main characteristics are resumed in Table 1.

**TAB. 1:** Main properties of scintillator bars.

| **Scintillation Properties** | **BC 404** | **BC 408** |
|---|---|---|
| Light Output, % Anthracene | 68 | 64 |
| Rise time, ns | 0.7 | 0.9 |
| Decay time, ns | 1.8 | 2.1 |
| Wavelenght of max. emission, nm | 408 | 425 |
| Light Attenuation Lenght, cm | 140 | 210 |

At each end of the bar there is directly coupled a 2 inch Hamamatsu fine-mesh PMT R5924, coupled with a standard Hamamatsu voltage divider. The photocathode diameter is 39 mm, thus optimally matching the bar cross dimension and eliminating the need of a light guide that might increase the time spread of the scintillation light.

A fine-mesh PMT was used since the PMTs will have to work in a magnetic field of the order of one Tesla.

The time resolution of the two scintillator bars (BC404 and BC408), performed in the Frascati Beam Test Facility (BTF), have been measured for several beam impact positions (along the bar) and for different impact angles (with respect to the normal to a bar surface). The impact angle covers a range, which corresponds to the most probable angles given by a Monte Carlo simulation of the reaction (1).

Due to the relatively large number of positions and angles in which measurements had to be carried on, a special mechanical chariot was built in Genoa, where the bar is mounted and moved by remote control. The bar can slide along the chariot's main axis so that all points along the bar can be brought to the beam spot with a precision of 5 mm. The chariot's axis can rotate around a horizontal axis and the bar can also rotate around the chariot axis. The precision for both rotations was measured to be 0.5 degrees. The chariot standing at the BTF with an inclination of about 45° is shown in Figure 1.

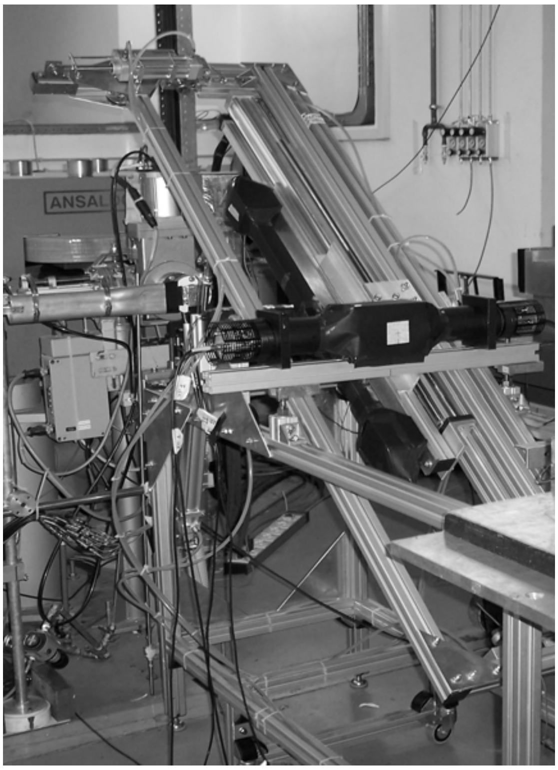

**FIG. 1:** The mechanical chariot standing at the BTF in Frascati.

## 4 TEST AT THE BTF

All tests were performed at the BTF in Frascati in November 2004. The BTF provides $e^-/e^+$ beams in the energy range of 25-750 MeV. The intensities available can range from a single particle per pulse (pulse length 1-10 ns) up to $10^{10}$ particles per pulse, with a repetition rate of 50 pulses/sec. However, the duty cycle at the present is limited to about 50%: particles are not available to the BTF when DAFNE is filled, which usually happens every 20 minutes, for a time interval of 20 minutes. The conditions chosen for the tests were: particles $e^+$ with an energy of 420 MeV, yielding a minimum beam spot size; one particle per pulse, in average, reducing the multi-hits events in the 10 ns spill. The layout of the tests is shown in Figure 2.

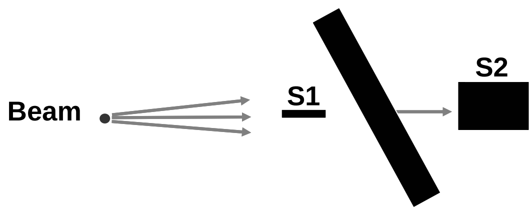


**FIG. 2:** Layout of the tests at the BTF of Frascati.

The bar under test is sandwiched between two scintillators, S1 and S2. S1 is a slab of $23\times12\times5$ mm$^3$ coupled by a single Hamamatsu R 647-01, and S2 a slab of $50\times50\times20$ mm$^3$, measured by two Philips XP2020.

The purpose of using S1 is to define the vertical beam spread, which could introduce an "apparent" time spread in the test bar. The beam spot size, as given by the BTF beam chambers, is shown in Figure 3.

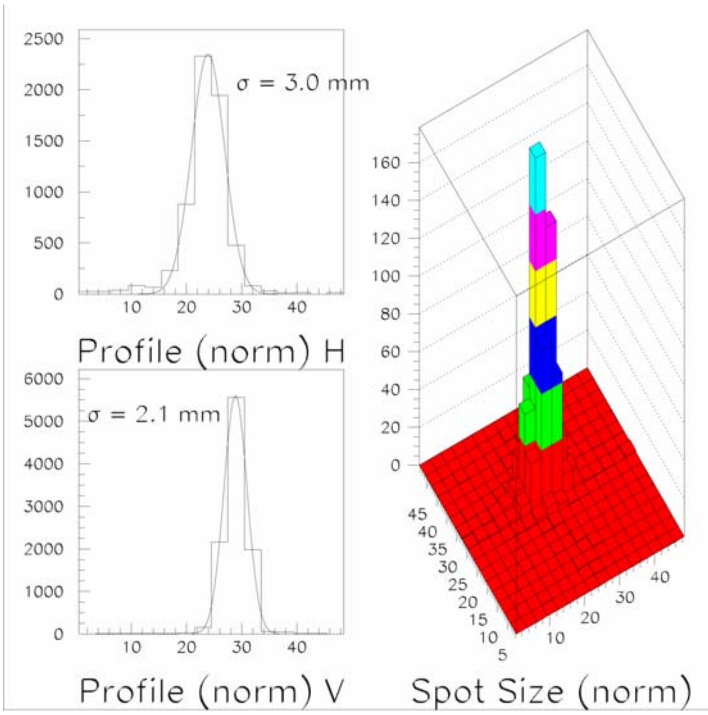


**FIG.3:** Vertical (Top) and horizontal (Bottom) profiles of the beam spot. The mean sizes (σ), obtained from Gaussian fit are 3.0 mm and 2.1 mm respectively.

The FWHM vertical spread is about 7 mm. However, the beam size and also its mean position were not stable. They were acceptable during each single run, but changes occurred occasionally when the BTF resumed operation, after the DAFNE refilling, and refocusing was time consuming, considering also the short times of each run (about 20 minutes).

The purpose of S2 is to discriminate between single particle and multi-particle events. The discrimination threshold depends on the energy deposited in S2. When the signal corresponds to multiple events, the TAC is inhibited during the acquisition. Figure 4 shows an energy spectrum measured by S2. Peaks corresponding to one, two and three simultaneous particles are clearly distinguished and separated.

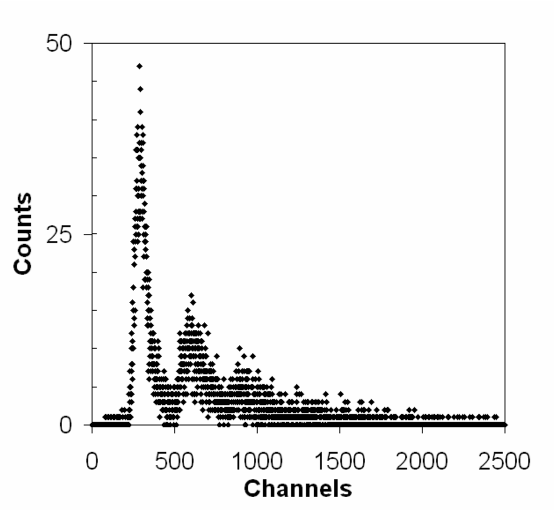


**FIG. 4:** Energy spectrum obtained by XP2020.

## 4 RESULTS

Data have been collected in the period 3-15 November 2004. For each scintillator bar, data have been taken at 11 positions along the bar itself and for 4 different impact angles, for a total of 38 points. After selection of single positron events, each point consists at least of 3500 events. Two time resolution curves (for BC408 and BC404) are displayed in Figure 5.

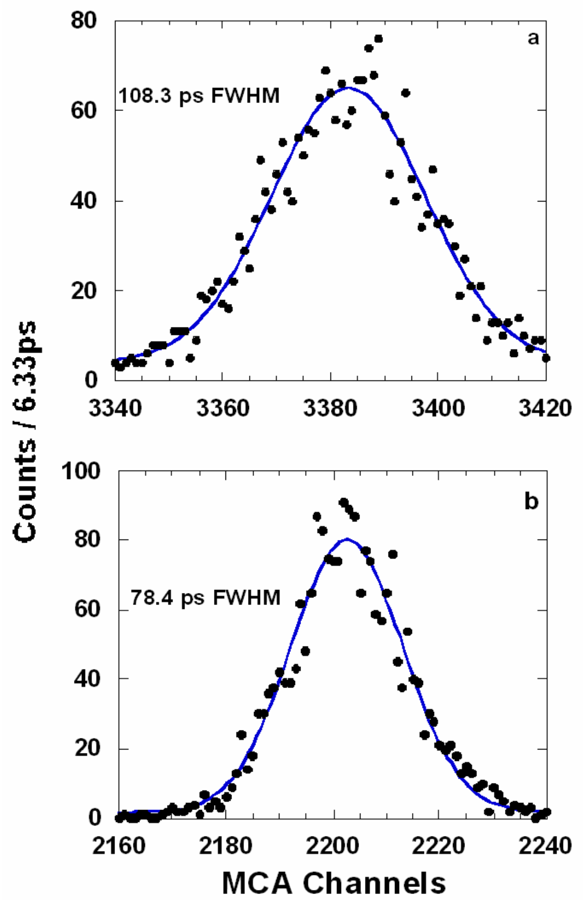


**FIG. 5:** Experimental data (Dots), and Gaussian best fit (Line) for BC408 (a) and BC404 (b).

Figure 6 shows the time resolution as a function of position at different angles for the BC408 and BC404 scintillators, respectively.

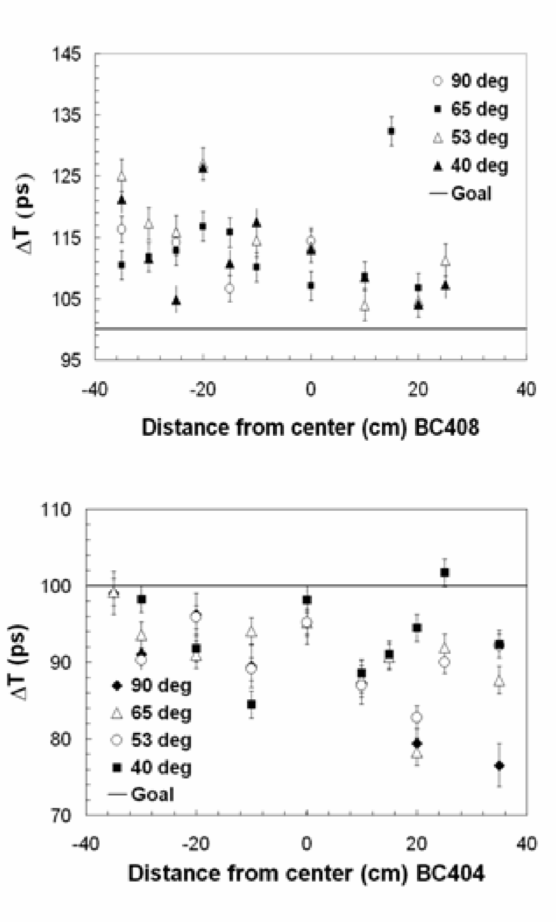


**FIG. 6:** The time resolution as a function of position (with respect to the center of the bar) at different impact angles, for BC408 (Top) and BC404 (Bottom). The solid line represents the expected limit resolution.

The same data averaged over the different angles is displayed in Figure 7.

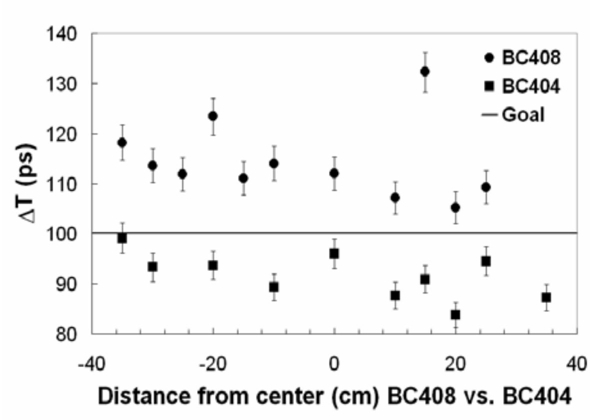


**FIG. 7**: Time resolution as a function of position, after averaging over the four impact angles for BC408 (dots) and BC404 (squares).

The results of Figures 6 and 7 clearly demonstrate that the scintillation type BC404 has better performance than BC408. Furthermore, for BC404, which has been chosen on this basis, the time resolution is rather insensitive to the impact position. It is worth noting that for the chosen scintillator, the average time resolution σ is ~39 ps, to be compared for instance to 100 ps reached by the BELL TOF system [5] and to 110 ps reached by CDF [6].

## 5 CONCLUSION

Next phase consists will consist in evaluating the time resolution between $\gamma$ and $e^+$ processes, in accordance to the MEG proposal [3,4]. The expected resolution is 150 ps FWHM.The present results indicate that the TC time resolution is about 92 ps FWHM, at the impact of the positron. In addition, one has to consider the uncertainty generated by the "swim back" of the positron track to the target. This has been estimated, by Monte Carlo generated events and by their reconstruction through the MEG chambers, to be about 40 ps FWHM, providing a total uncertainty of 100.3 ps FWHM. If a similar resolution is obtained also for the γ-rays, the predicted resolution can easily be reached. This is an order of magnitude better than the time resolution reached by the MEGA experiment [1,2].

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