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Beam test of the timing properties of 2 m long bars of BC408 plastic scintillator

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(for the ELETTRO[#] collaboration)

Abstract

The timing properties of BC408 scintillator bars 200 cm long, 4 cm wide, and thickness ranging from 4 down to 0.5 cm have been investigated for different distances from the read-out photomultiplier. The degradation of the timing performance with the distance from the read-out phototube was measured for increasing thickness.

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The time of flight (TOF) technique for particle identification in a magnetic spectrometer environment requires the use of long bars of plastic scintillators arranged in segmented hodoscopes. These further provide a fast trigger for event definition and the opening of gates for coincidence measurements. In such thin long scintillators the effect of the light attenuation along the path pointing to the read-out photomultiplier (PMT) has the consequence of spoiling the intrisic timing properties of the scintillator with increasing distances from the PMT and decreasing cross-sectional sizes of the bars. Studies concerning such a deterioration have been recently reported by a few authors [1,2,3,4]. In this report we present selected aspects of a beam test of the timing properties of a widely used plastic scintillator, the BC408.

We have carried out measurements at the East Hall PS T10 test area [5] at CERN, Geneva. A schematic diagram of the experimental set-up is shown in Fig. 1. The beam, composed by $2\ GeV/c$ positrons, pions and protons, was defined through three finger scintillating counters S1, S2 and S3, which were suitably aligned along the beam line. The signals from these counters were read by phototubes Hamamatsu H2431 (S1 and S3), and H1949 (S2) with a nanosecond risetime, through a short lightguide. The test counter (TC) was placed transverse to the beam line between S2 and S3, but very close to S2, with the $200x2\ cm^2$ side facing the incoming beam, so that the thickness was the only variable parameter. The impact position was easily changed by means of a moveable system of rails supporting the TC. The TCs had surfaces optically polished and tightly wrapped in a teflon layer followed by an outer light-proof layer of black tedlar. The ratio of the refraction indices of teflon ($n=1.29$) and scintillator ($n=1.58$) assures that the trapping angle for total internal reflection of photons is small, thus reducing the amount of light collected but improving the timing resolution of the counters [1,6].

The read-out of the TC signals was done by two PMTs Hamamatsu H2431 coupled directly to the TC with optical grease. The PMTs were not changed when testing the different TCs. The coupling was checked measuring the light output after successive assemblings, resulting in a reproducibility of the set-up conditions better than 95%. The high voltage settings were adjusted to equalize the output signals when the beam was impinging in the center of the TC. In order to provide energy and time information the signals from the finger counters and from the test counter were split through passive splitters. Timing was obtained using an Ortec 584 quadruple constant fraction discriminator (CFD), set to correct for time-walk effects in the dynamic range of the detected signals. The CFD thresholds were set just above the noise level of the phototubes. The coincident discriminated signals of S1, S2 and S3 were used to generate a main trigger gate, which provided the rejection of uncorrelated background, a common start for time measurement in the TDC modules, and a common gate for charge integration in the ADC modules, as shown schematically in Fig. 2. The nucleonics was based on a CAMAC Lecroy FERA-TFC system, with memories to hold the high rate of particles per beam burst. The memories were read out every time an overflow occurred, and the data were transferred to tape by a MacIntosh based DAQ code.

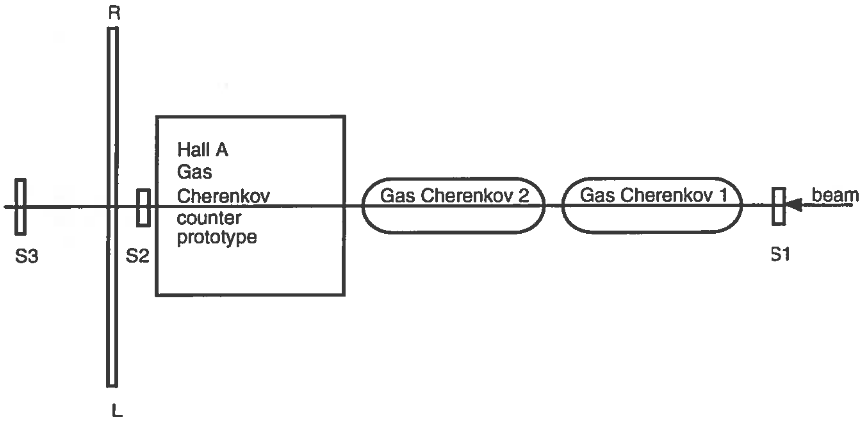


Fig. 1 *Diagrammatic view of the experimental set-up for the beam tests.*

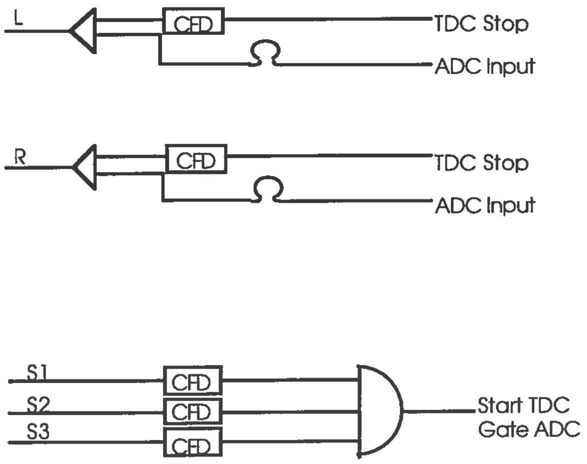


Fig. 2 *Trigger definition and diagram of the test counter signal handling.*

The data analysis was carried out off-line to extract the relevant observables for the different kinds of particles, namely the light yield from pulse height spectra and the time resolution from TDC stop peaks. The signals associated to positrons were determined using the response of the two CO_2 Cherenkov counters in the beam line, the protons were then separated through proper cuts on the TOF spectrum between S1 and S3. Fig. 3 well represents the particle ID capabilities at a beam momentum setting of $p = 2\ GeV/c$.

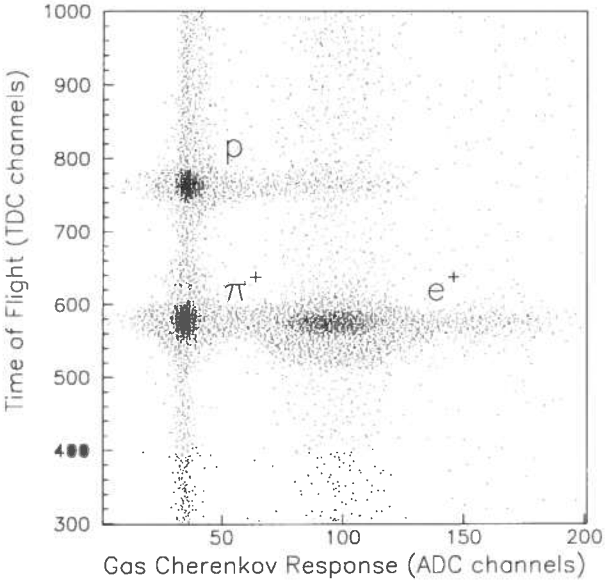
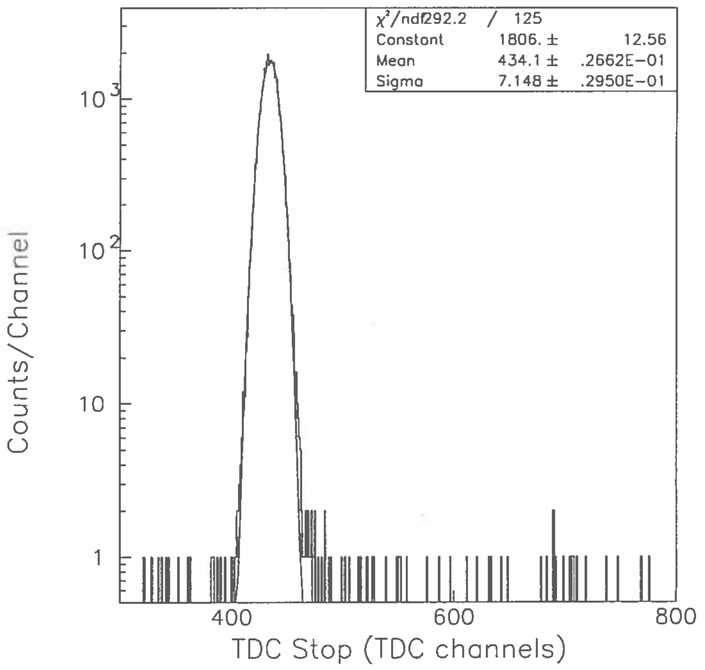


Fig. 3 *Beam particle ID during the present experiment for a momentum setting of 2 GeV/c.*

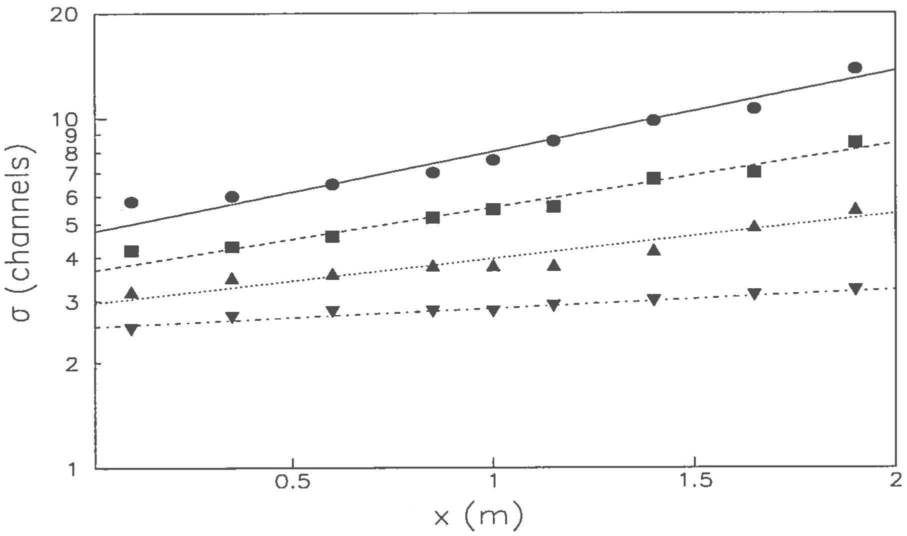
The time resolution of the left and right channels of the TC was derived as the width-parameter σ of the TDC stop peak for a given particle. An example of data for pions is showed in the spectrum of Fig. 4. The left-right weighted average value of σ has been retained as the quoted value for each distance x from the read-out PMT. These values have been represented in Fig. 5 as a function of distance. It is clear from Fig. 5 that we measure a worsening of the time resolution with increasing distance from the PMT. In addition this effect increases for decreasing scintillator thickness. The experimental points result to be well interpolated by an exponential curve with a degradation length λ_σ:

$$\sigma = \sigma_0 e^{x/\lambda_\sigma} \tag{1}$$

The values of the parameters σ_0 and λ_σ as from the fit of the data are given in Tab. I, and the corresponding curves are overlayed on the experimental points in Fig. 5.



<u>Fig. 4</u> *Example of timing data for thickness t=0.5 cm, gated on pion events from PID procedures.*



<u>Fig. 5</u> *Plot of the time resolution sigma as a function of position for different thickness. Dots are for t=0.5 cm, squares for t=1 cm, upward triangles for t=2 cm, downward triangles for t=4 cm.*

Tab. I *Thickness of the sample scintillating counters studied in the present work. Values of the parameters* σ_0 *and* λ_σ *used to fit the data in Fig. 5. Estimated errors are displayed in brackets.*

t [cm]	σ_0 [TDC channels]	λ_σ [m^{-1}]
0.5	4.7(3)	1.89(15)
1.0	3.7(2)	2.39(17)
2.0	3.0(1)	3.38(41)
4.0	2.5(1)	8.26(68)

Assuming that the time resolution is dominated by the photoelectron statistics, then the product $\sigma\sqrt{N_{pe}}$ should be approximately constant for a given counter, as a function of the longitudinal position x. A deviation from this behaviour for the different counter thicknesses here measured is displayed in Fig. 6, where the useful auxiliary quantity $\sqrt{\left(\sigma^2-\sigma_C^2\right)N_{pe}}$ has been considered. This is calculated from the measured time resolution σ, from the constant term $\sigma_C = 1.4$ TDC channels = 70±10 *ps*, which accounts for the average contribution of the other counters involved in the measurements and of the read-out electronics, and from the light yield converted into average number of photoelectrons N_{pe}. The thickness dependence is then derived as the quadratic difference with respect to the measured values of σ. This analysis leads to the following overall time resolution dependence from position x and thickness t of the test counter:

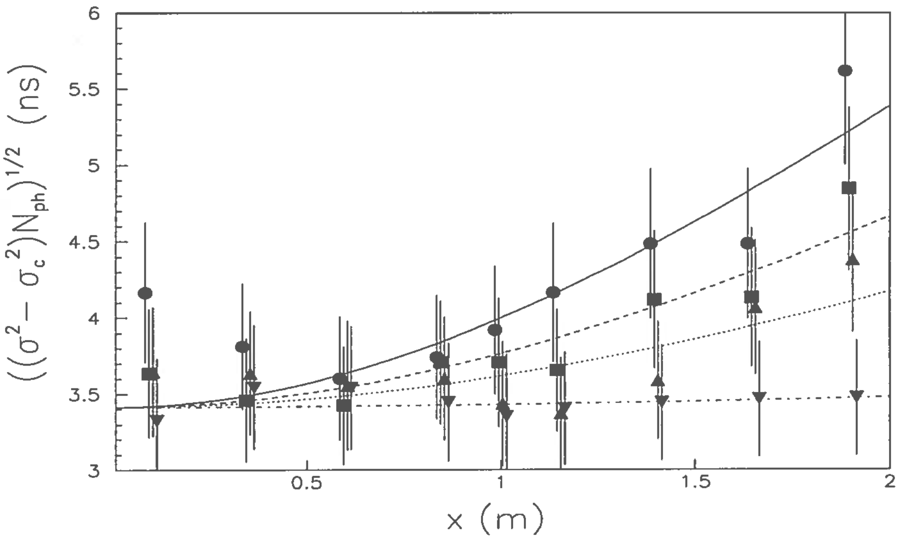
$$\sigma = \sqrt{\sigma_C^2 + \frac{\sigma_1^2}{N_{pe}} + \frac{x\sigma_2(t)}{N_{pe}}} \tag{2}$$

where the best fit to the data gives for the t-dependent term the following expression:

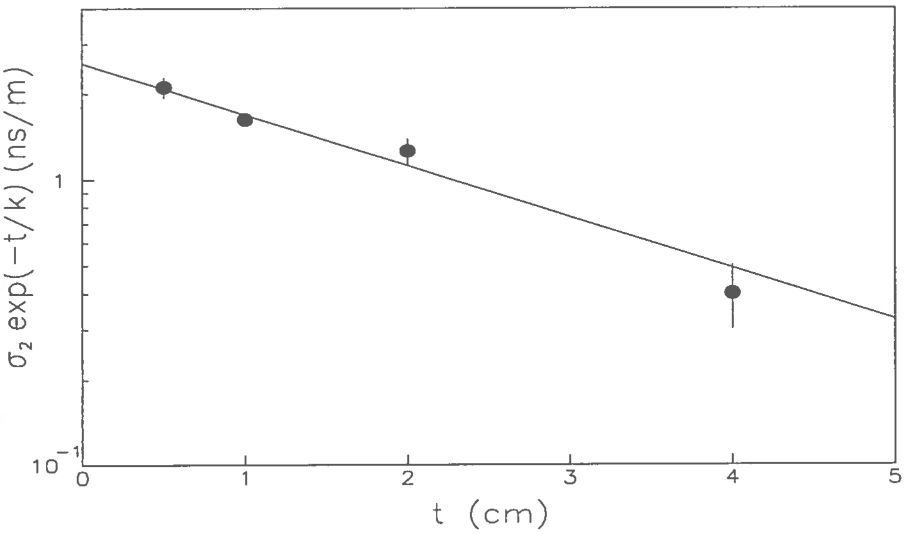
$$\sigma_2(t) = \sigma_2 e^{-t/k} \tag{3}$$

as shown in Fig. 7. The values quoted for the parameters are σ_1=3.4±0.1 *ns*, σ_2=2.6±0.2 *ns/m*, and k=2.3±0.3 *cm*. The measured trend of the t-dependent term demonstrates that a time degradation effect is confined to a thickness smaller than *4 cm*.

In summary, we have measured the time resolution for four bars of BC408 plastic scintillator *2 m* long, *4 cm* wide and *0.5*, *1.0*, *2.0* and *4.0 cm* thick at different impact positions along the bars. The time resolution shows a degradation with the distance. This result is mainly limited to the thinner test counters, whereas it tends to disappear for thickness around or larger than *4 cm*. This effect has been parametrized as a function of the light yield and of the counter thickness, and values for the parameters have been assigned.



<u>Fig. 6</u> Plot of the time resolution s as a function of position for different thickness, with a constant term quadratically subtracted, and multiplied by the light yields (see text for details). Curves are obtained applying Eq. (2).



<u>Fig. 7</u> Plot of the thickness-dependent term of the time resolution, according to Eq. (2).

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