80 ps TIMING RESOLUTION
SCINTILLATION COUNTER WITH A PHOTOMULTIPLIER TUBE FEU-87

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We describe a TOF scintillator counter with a photomultiplier tube FEU-87 and a $2.4 \times 2.4 \times 6.0$ cm^3 scintillator. A time resolution (σ) of 84 ± 4 ps has been obtained from cosmic ray and deuteron beam tests. Possible timing improvements are discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Сцинтилляционный счетчик
с временным разрешением
80 пс на основе ФЭУ-87

Афанасьев С.В. и др.

Описан времяпролетный сцинтилляционный счетчик на основе фотоумножителя ФЭУ-87 и сцинтиллятора размером $2,4 \times 2,4 \times 6,0$ см^3. Временное разрешение (σ) 84 ± 4 пс было получено при проведении измерений на космических мюонах и в пучке релятивистских дейтронов. Возможные пути улучшения временных характеристик счетчика обсуждаются.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Introduction

The application of the time-of-flight (TOF) method with a typical TOF base of about 12—15 m requires detectors with 50—100 ps timing resolution to provide $\pi-K$ separation up to the momentum of 4—5 GeV/c. In this paper we describe a fast scintillation counter with a Russian photomultiplier tube (PMT) FEU-87 of relatively low cost and a LHE JINR produced scintillator. Our work was initiated by the proposal of the CERN NA-49 collaboration [1]. The described results allow us to improve $\pi-K$ and $K-p$ separation with the SPHERE forward spectrometer [2].

Description of the Counter

We have used a "standard" scintillation material based on polysty-rene doped with 1.5% p-terphenyl + 0.01% POPOP. The light pulse
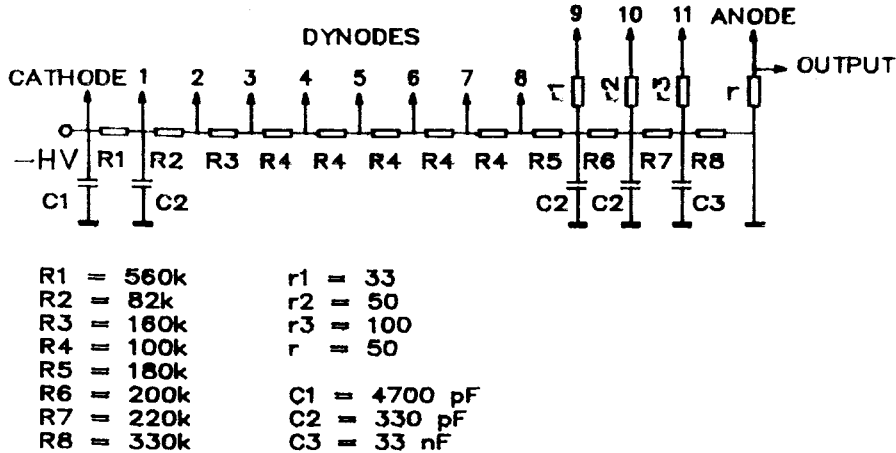
R1 = 560k   r1 = 33
R2 = 82k   r2 = 50
R3 = 160k   r3 = 100
R4 = 100k   r = 50
R5 = 180k
R6 = 200k   C1 = 4700 pF
R7 = 220k   C2 = 330 pF
R8 = 330k   C3 = 33 nF

Fig.1. Voltage divider used with the FEU-87 photomultiplier tube

500 mV/div. (vert.)
5 ns/div. (hor.)
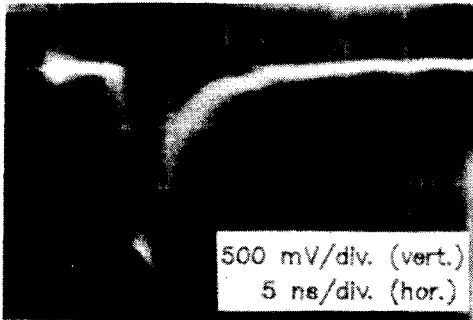
Fig.2. Typical output pulse of the counter

rise time (LPRT) of this scintillator is about 0.8 ns [3]. The scintillator $2.4 \times 2.4 \times \times 6.0$ cm^3 in size was wrapped in black paper without a reflector and viewed from one side (without a light guide) by a fast PMT of the FEU-87 type (2 cm diameter photocathode) with a certificate cathode luminous sensitivity of 95 μA/lm.

A voltage divider (see fig.1) is adjusted to a minimal timing resolution in response to a LED flash. This resolution has been improved by setting a significant voltage (> 700 V) between the protocathode and the first dynode, and thereafter between the last dynodes. No special stabilization is used because a low average working count rate (> 10^5 per second) is expected. The total high voltage is 2800 V. Figure 2 shows an output signal of the counter

(the scintillator is excited with a ^{90}Sr source). An amplitude of about 2 V corresponds to a minimum ionizing particle flash in the counter scintillator.

To estimate the PMT transit time jitter, we have measured the dispersion of time between a LED driving pulse and a PMT output signal for different output pulse amplitudes A (see fig.3). We should note that the observed dispersion behaviour differs significantly from the expected one for the transit time jitter ($\sim A^{-1/2}$ is the dashed line in fig.3). We explain this fact by the existence of a LED time jitter contribution with a more complicated behaviour. Over an amplitude range of about 2 V this contribution is more than 40 ps. On the other hand, in our measurements the photocathode is illuminated by a LED flash not quite uniformly. This fact means the existence of an additional unmeasured contribution to the PMT transit time dispersion (though its value should be not very significant because of the high voltage between the cathode and the first dynode). Finally, we estimate the PMT transit time jitter as about 50—60 ps.
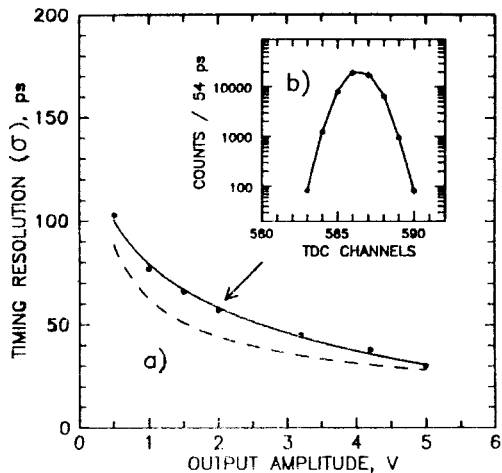
Fig.3. a) Dispersion of time between a LED driving pulse and a PMT output amplitude. The dashed line corresponds to the $A^{-1/2}$ dependence. b) Time spectrum for an amplitude of 2 V

Cosmic Ray Tests

A preliminary measurement of counter timing resolution was carried out with cosmic rays. A schematic drawing of the test arrangement is shown in fig.4. It includes:

— a test counter S;

— a cosmic muon telescope consisting of two 2.0 cm thick 1.0×1.0 cm^2 scintillators viewed by FEU-87 PMTs;

— constant fraction discriminators produced at LHE;

— a CAMAC readout system including TDCs (54 ps/channel), an ADC and a crate-controller with an IBM PC/XT compatible computer.
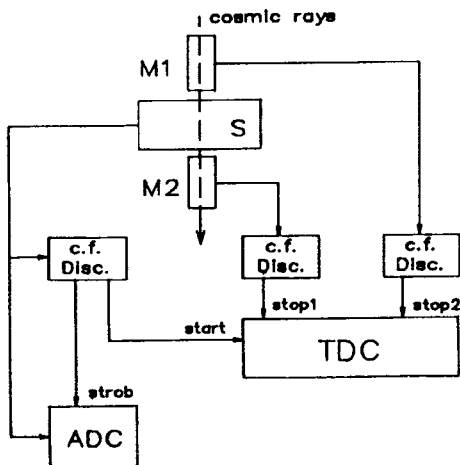
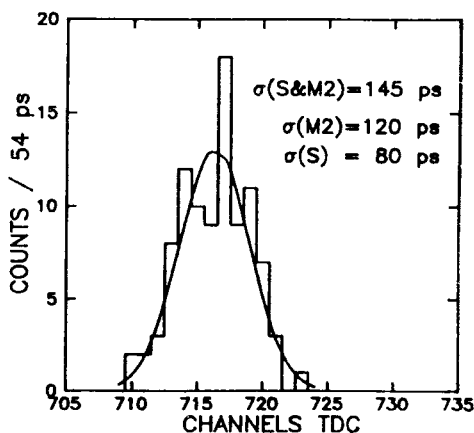Fig.4. Schematic drawing of the cosmic ray test arrangement

Fig.5. TOF spectrum for cosmic muons

Cosmic rays monitor rate was about 10 counts per hour and it took about 8 hours for one exposure.

Timing was done between S and $M1$, S and $M2$. Stop signals for TDCs were provided by both counters of the muon telescope and common start by the test counter S. The pulse charge of the counter S was also measured. A cut was set on this pulse charge in order to select minimum ionizing particles in cosmic radiation. The obtained $S — M2$ time spectrum corrected for residual amplitude dependence is presented in fig.5. The timing resolution σ_S of the counter S is obtained from $\sigma_{S\&M1}$, $\sigma_{S\&M2}$ and $\sigma_{M1\&M2}$. The last value is obtained from event-by-event subtraction $TOF_{S\&M1} — TOF_{S\&M2}$. The test counter time resolution derived from the corrected spectra is $\sigma_S \approx 80$ ps.

Deuteron Beam Tests

As a continuation of our study, we carried out tests on a 9 GeV/c deuteron beam. A layout of the test assembly is shown in fig.6. It includes:

— a test counter S;

— two monitor counters; the thickness of the forward one is 2.0 cm and its entrance area 1.0×1.0 cm^2; the thickness and diameter of the rear one is 10 cm and 1 cm, respectively; PMTs are FEU-87.
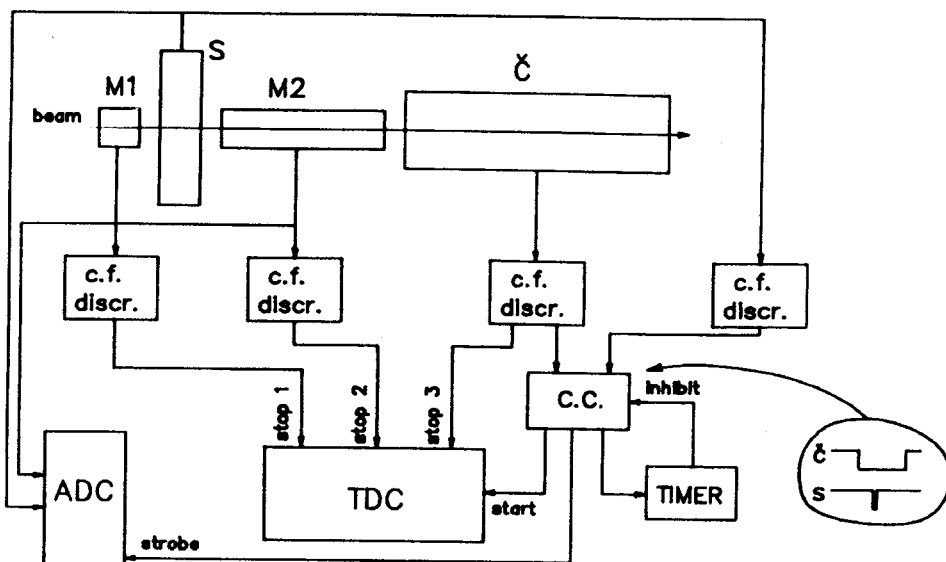
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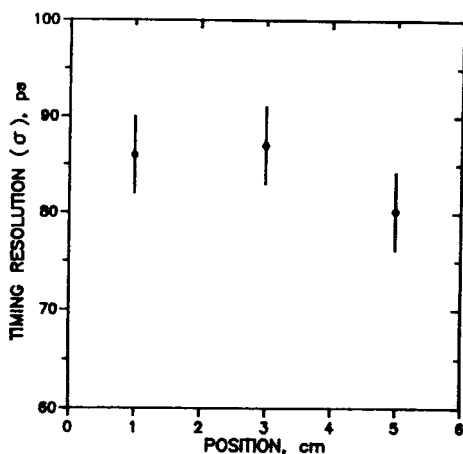Fig.6. Layout of the deuteron beam test assembly

Fig.7. Position dependence of the counter S timing resolution

— an additional Cherenkov plexiglass counter C 20 cm thick and 2.5 cm in diameter; its radiator is viewed by a FEU-85 type PMT (it has a higher gain than FEU-87);

— fast logic modules and a CAMAC readout system.

Data were read out in coincidence between the counters S and C. The output signal of the coincidence unit was timed with the pulse of the counter S pulse. Timing was done between S and $M1$, S and $M2$, S and C as well as charge measurements of $M2$ and S signals. A timer gate decreases a trigger rate down to 200—300 per spill. Deuterons having passed through the whole assembly are selected by applying cuts on TOF $(S-C)$ and ADC $(M2)$. The timing resolution σ_S of the counter S is obtained as shown above. The position dependence of σ_S is shown in fig.7 for a PMT with a cathode
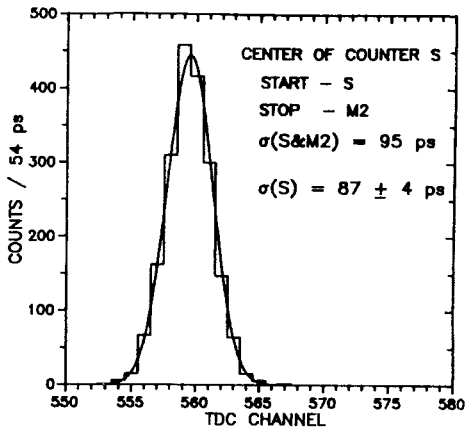
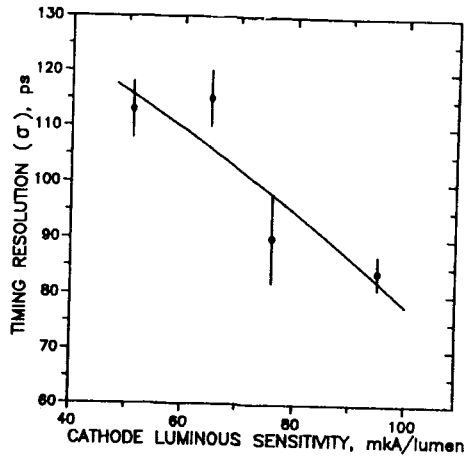Fig.8. TOF spectrum for 9GeV/c deuterons

Fig.9. Counter S timing resolution vs the cathode luminous sensitivity of PMT

luminous sensitivity of 95 μA/lm. The mean value of $<\sigma_S>$ is equal to 84 ± 1.5 (stat.) ± 4 (sys) ps. The systematic error is associated with PMT timing instability. The TOF $(S-M2)$ spectrum obtained at the center of the counter S is shown in fig.8.

Besides, the σ_S dependence on the cathode luminous sensitivity of PMT (see fig.9) was estimated. The value of sensitivity was taken from the PMT certificate. The 85 μA/lm lower limit can be put as a selection criterion of PMTs acceptability.

We note that the beam tests confirmed the conclusions derived from the cosmic ray run.

Some Possible Improvements

Here we would like to discuss possible ways to improve timing parameters of the counter.

One way to improve timing parameters of the scintillation counter is to use scintillation material with the shorter LPRT. For example, a scintillator based on polystyrene doped with 1.5—2.0% p-terphenyl (without any secondary dyes) has the LPRT of about 75 ps [3]. However the light yield obtained from this scintillator is only about 60% of that of our "standard" scintillator and additional tests to study this problem are needed.

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A possible improvement of PMT's timing parameters is due to employing an inverse pulse from a dynode as an outpot one. First, this operation provides smaller inner PMT's stray capacitance and a decrease of electron pulse widening [4] and, second, it eliminates the anode signal parasitic component induced by electrons travelling from the penultimate dynode to the last dynode [5]. In this way we hope to decrease significantly the PMT time jitter.

References

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