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SCINTILLATION FACILITY FOR POSITIVE PION DETECTION

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Сцинтилляционная система для регистрации положительных пионов

Описывается установка для спектрометрических измерений заряженных частиц /пионы с энергиями до 100 МэВ и протоны - до 200 МэВ/ и их идентификации. Установка содержит время-пролетную систему и сцинтилляционный детектор полного поглощения. Приводятся блок-схема, принципиальная схема быстрого дифференциального дискриминатора и спектры, характеризующие работу установки.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1980

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Scintillation Facility for Positive Pion Detection

A set-up consisting of a time-of-flight system and a total absorption spectrometer with a system of identification of positive pions for the energies of 10-100 MeV is described. A method excluding extra information in two-dimensional spectra is discussed. The schematic diagram of electron circuits for selecting low amplitude pulses against the background of much higher pulses is presented.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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INTRODUCTION

The evolution of investigations of pion (with the energy of several tens MeV) interactions and production necessitates the development of effective facilities for pion registration. In a number of cases at such experiments there arises a necessity to identify pions of a wide energy range at the background level which is many times as high as the effect. The application of rather expensive magnetic spectrometers in these experiments is not always justified because of their usually low luminosity and of the impossibility of measuring simultaneously the particle energies of a wide range. Besides, relatively large sizes of magnetic spectrometers cause substantial efficiency losses for low-energy pions.

Recently, there appeared the descriptions of the so-called "π-detectors" [1,2]. They are total absorption scintillation detectors in which plastic scintillators are used. The described spectrometers have good energy resolution ($\sim$1 MeV) in the 10-100 MeV range and high enough efficiency ($\gtrsim$75%). The ΔE–E technique has been used in ref.[1] to identify the particles, and in ref.[2] the pion identification has been based on the stopped-pion decay detection.

The present paper describes a facility for spectrometric measurements of charged particles (pions of energies up to 100 MeV and protons - up to 200 MeV) and their identification. To perform the identification a two-dimensional analysis "velocity-energy" has been combined with a method analogous to the one described in ref.[2]. The time-of-flight system [3] has been used to determine particle velocity. The energy has been measured with a total absorption scintillation-detector. It should be noted that the use of the "time-of-flight" system combined with the use of total-absorption spectrometer for pions with energies of several tens MeV is more effective in type separation of particles than ΔE–E detectors-combination.

The described system has been used for an experimental study of meson production by protons on the nuclei at 200-300 MeV energies of incident protons. The pions generated in the experiment have a wide spectrum (practically from 0 to 100 MeV) and their number is considerably less (by several orders at small angles) than the number of elastically scattered protons at high general count rates.

FACILITY OPERATION AND PECULIARITIES OF PION REGISTRATION

The detection system consists of time-of-flight scintillation counters and a total absorption spectrometer positioned successively in the analysed particle beam.

The type separation of particles is performed by isolating the corresponding regions on the two-dimensional amplitude distributions of signals coming from the time-of-flight system and from the total absorption spectrometer. After this one should make the spectrum analysis of the interaction product component one is interested in. During the separation of pions from protons a logic system for pion identification (analogous to the one described in ref.[2]) can be switched on. The peculiarities of π^+-meson stopping and of its subsequent decay are used for spectroscopic measurements and pion identification in the total absorption counter. On its stopping in the scintillator a pion decays according to the scheme

$$\pi^+ \to \mu^+ + \nu_\mu$$

$$\to e + \nu_e + \tilde{\nu}_\mu$$

The muon emitted in the pion decay has a definite energy of 4.13 MeV and the energy of the positron emitted in the muon-decay is between 0 and 53 MeV. That is why to determine with the highest resolution the pion energy it is necessary to integrate the signals from both the pion and its decay muon but not that from the muon decay positrons. The probability that a pion has decayed but that its decay muon has not decayed reaches the maximum 94.8% for the time of 117 ns. The fixed contributions into the energy release made by the decayed muon are easily taken into account during the spectra processing. The presence of a constant amplitude signal from a 4.13 MeV muon in a given time interval after the pion pulse, is a flag used for pion identification.

BLOCK-DIAGRAMME OF THE FACILITY

The block-diagramme of the facility is shown in Fig.1.

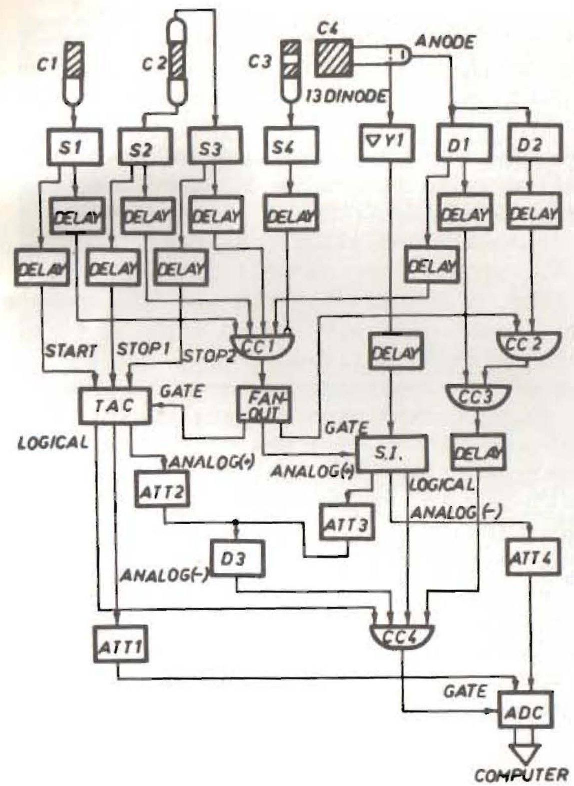

Fig.1. Block-diagram of the facility.

C-1 and C-2 are the base counters of the time-of-flight system, C-3 is a veto counter; C-4, a total absorption spectrometer (pion detector).

The counters C-1 and C-2 have the sizes 40 x 40 x 3 mm^3 and 80 x 80 x 5 mm^3, respectively. In the counter C-2 the scintillator is scanned by two photomultipliers (XP 2020) to compensate the spread in time caused by the uncertainty in the place of particle's entry into the scintillator.

The C-4 pion detector scintillator has the shape of a parallelepiped one end of which is changed into a cone. The side facing the beam has the sizes 180 x 180 mm^2 and the opposite one, turned to the PM (XP 2040), has the diameter 140 mm. The lenght of the scintillator has been chosen to be 250 mm so that it could fully home the range of 100 MeV pions. The signals are received from the PM anode and 13th dynode. The anode signal is used as a logical signal and the dynode signal is used for spectroscopic measurements.

The veto counter C-3 of the size 200 x 200 x 10 mm^3 with a hole (diameter 80 mm) in the center is used to exclude from consideration the particles passing through the edge of the scintillator and capable of leaving the detector without stopping in it.

Pulses from the counters C-1 and C-2 on passing through timing shapers (S1-S3) come to "start" and "stop" inputs of a time-to-amplitude converter (TAC) . A negative TAC signal comes to the analogue-to-digital converter (ADC). Signals from the S1-S3 outputs come as well into the coincidence circuit CC1. The output signal from the CC1 appears if there is no signal at the anticoincidence input and the signal from the C-4 has already arrived.

The discrimination of low amplitude background pulses from a pion detector is performed with a discriminator D1. The CC1 shaped-by-duration signals are the control signals for TAC, selector-integrator (SI)/4/ and coincidence circuit CC2.

The SI integrates a signal from the 13th dynode of the C-4 which passes first through the Y1 amplifier. To fit the peculiarities of pion registration the integration time has been 100 ns. A negative signal from the SI linear output comes to the ADC-2 and a positive signal is summed up with a TAC positive signal in the input of the differential discriminator D3. The amplitudes of these signals may be varied by attenuators ATT2 and ATT3.

The summed up signal is analysed by the D3 connected to the coincidence circuit CC4 which controls the ADCs. The purpose of ATT2, ATT3 and D3 units is to exclude extra information overloading the "on-line" operating computer. Figs. 2a and 2b show typical two-dimensional spectra (energy + time-of-flight) measured in the experimental study of pion production by protons. The events to be excluded from consideration at separating pions from protons are located in these Figures in the right-hand upper corner. The discrimination principle is the following. Let A and B denote the amplitudes of signals coming from ATT2 and ATT3; and C, a constant corresponding to the D3 upper threshold (the lower threshold equals 0). The coordinates of the two-dimensional spectrum points corresponding to the data coded by the ADC1 and ADC2 will be seen then in the left-hand part of the spectrum under the straight line $nA + kB = C$, where n and k are the attenuation coefficients.The angle can be easily changed by adjusting n and k attenuators. At $n=k$ the limiting straight line is equally inclined to both the

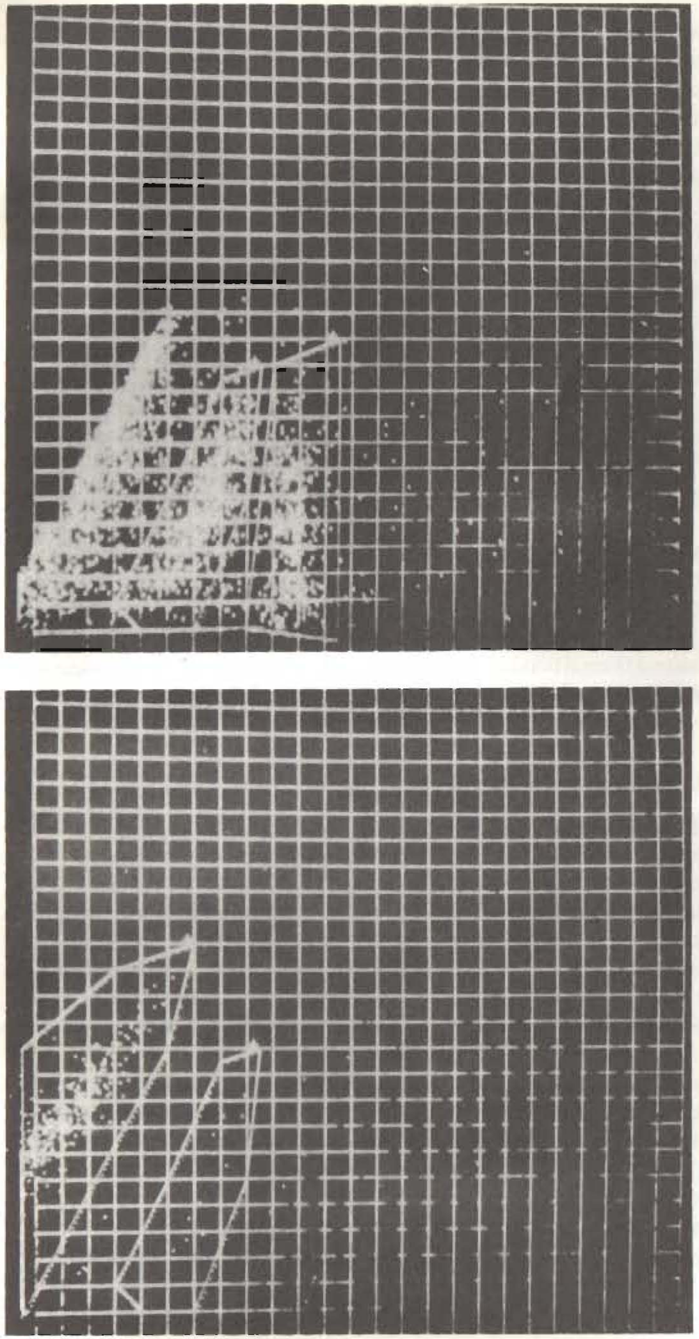

Fig.2. Two-dimensional spectra (energy + time-of-flight)
a) two-dimensional discriminator is off,
b) two-dimensional discriminator is on.

coordinate axes. Thus the necessary mode of two-dimensional discrimination is selected by varying C , n and k values.

Other units of the facility (fast differential discriminator D2 and coincidence circuits CC2, CC3) are used for pion identification and suppression of other particles. The signal appears in the D2 output only in case the input pulse amplitude penetrates into the window of the differential discriminator adjusted for 4.13 MeV decay muon pulses. This signal reaches the CC2 output if it arrives within the time T interval which is defined by a control pulse from the CC1 circuit. This time interval begins in ΔT time immediately after the pion signal. For T and ΔT the following values have been selected: T=80, ΔT=20 ns; 45% of the decay muon pulses get into the T interval. Since the time of the output signal arrival from CC2 circuit is defined by the arrival of the muon decay signal and has a probability character it is necessary to ensure the timing according to the pion pulse. The coincidence circuit CC3 is used for this purpose. The signal from the CC2 is a control signal for it and the timing is performed accoring to the signal from the D1 output. The ADCs used are built up in the CAMAC standard and are interfaced to a HP-2116C computer. The two-dimensional spectrum is of 256 x 256 channels. For data collection the associative technique has been used.

FAST DIFFERENTIAL DISCRIMINATOR

To separate the 4.13 MeV muon pulses a fast differential discriminator has been used. Its basic purpose is the selection of low amplitude pulses with a maximum of 0.5 V against the background of pulses the amplitudes of which are higher by one order. The schematic diagram of the circuit is shown in Fig.3. It includes an input emitter follower (T1÷T3), differentiating element (0.25 m cable and M1-1 differential receiver), discriminating elements M1-2,3; M2) and an output univibrator (M3).

The given circuit has a differentiating element in the input part which enables to get rid of the low-frequency background, clipp the input pulses and adjust just during the experiment the differentiation parameters to the input signal shape using the "Control" output.

The specifications of the circuit are as follows: the range of input signals is 0÷5 V; threshold adjustment, 8 mV ÷ 0.5 V for signals with τ_f =5 ns; maximum rate is not less than 100 MHz.

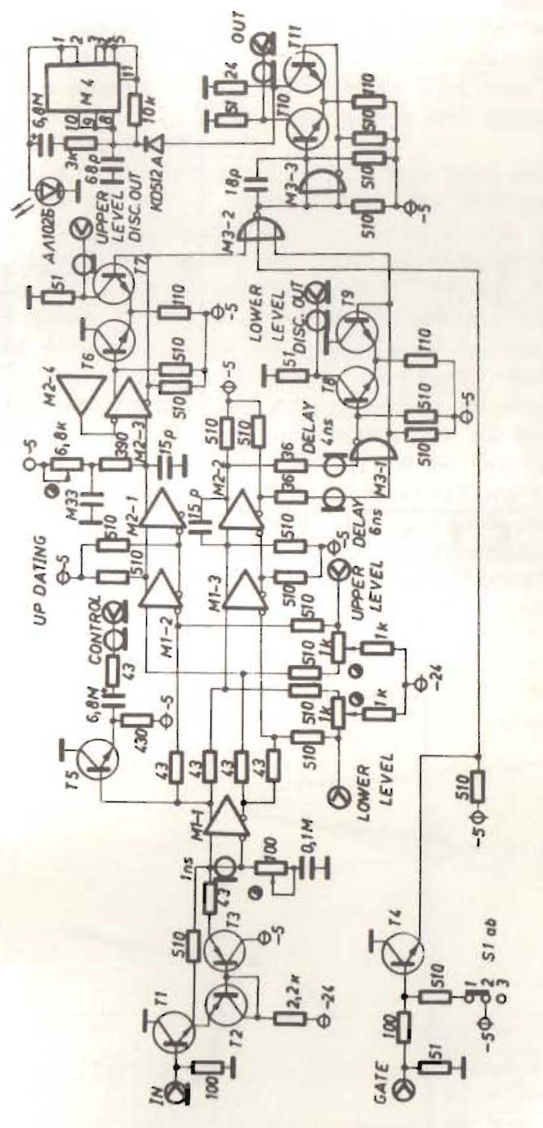

Fig.3. Schematic diagram of fast differential discriminator MI-IOII6; M2-IOIO5; TI, T4 ÷ T9-KT3I6D; T2÷T3-KT347B.

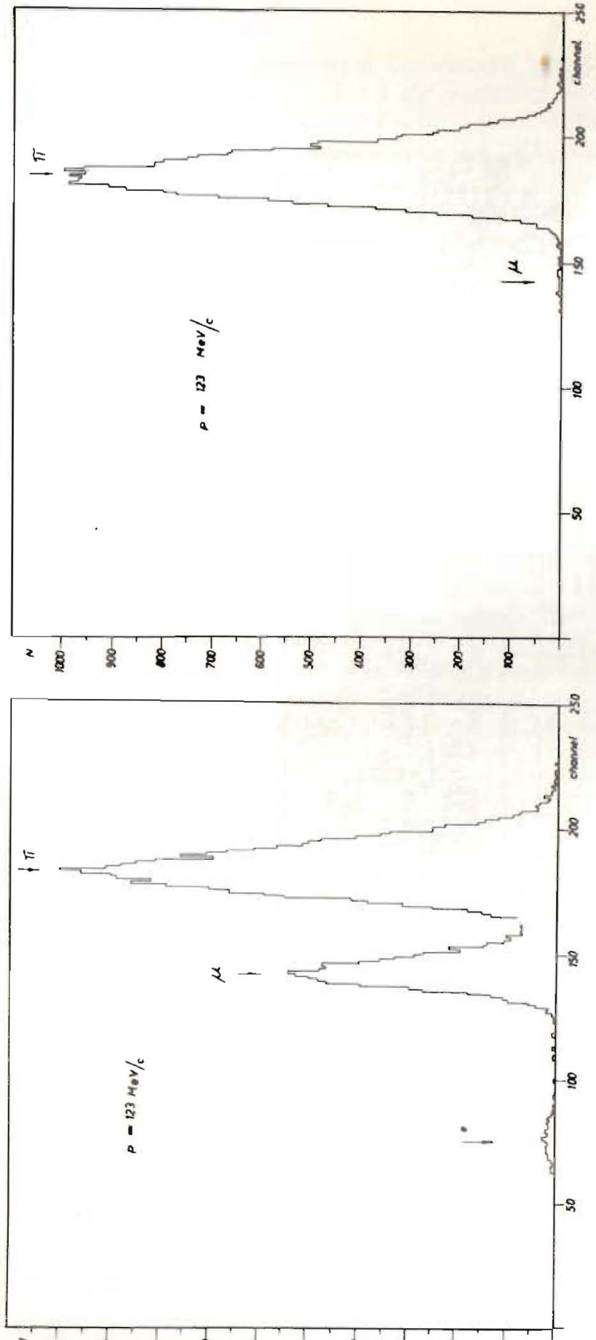

Fig.4. Operation of pion identification logic.

MEASUREMENT OF FACILITY CHARACTERISTICS

The adjustment of the facility and the measurement of its parameters has been performed on the meson channel of the JINR synchrocyclotron. Pion and proton beams have been used. The time-of-flight base in the measurements was 4.5 m. The measurements have shown that the pion detector has good energy linearity for pions and muons in the range 10-100 MeV for protons/5/.

The pion identification logic has been adjusted by selecting the D2 (Fig.1.)thresholds and differentiation parameter. Figure 4 demonstrates vividly the operation of the logic. Figure 4a shows the time-of-flight spectrum at the switched off pion identification logic and Fig.4b shows it at pion identification logic switched on. The energy dependence of pion registration efficiency at the switched on identification system is shown in Fig.5. The efficiency of muon suppression in this energy range exceeds 99%. An important factor affecting the operation of the pion identification logic is the quality of PM pulses shape. To achieve high efficiency the pulse trailing edge should be freed of "ringing" caused by oscillations in the spurious vibrational contours between the PM dynodes. We could not yet eliminate completely these oscillations in the used type

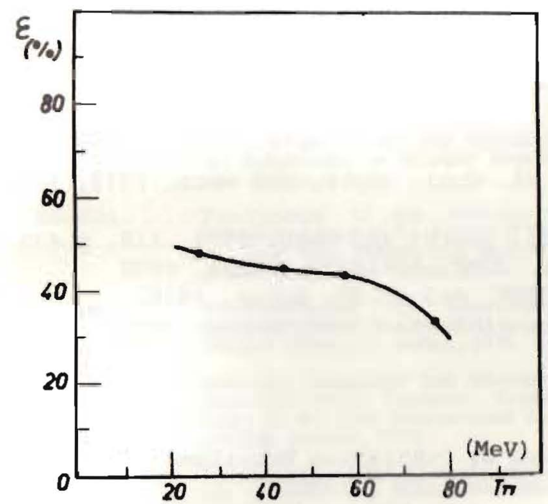

Fig.5. Energy dependence of pion registration efficiency at the switched on identification logic.

of PM.This hampers the reaching of equally high efficiency for pions of a wide energy range. Nevertheless it is possible to obtain higher effeciency for a narrower range of particle energies.

When analysing the spectra obtained with the total absorption counters it is necessary to take into account the distortions caused by the nuclear interaction of pions with the scintillator matter. The spectrum can be also distorted by positrons from the decay muons which get into the signal integrating interval. The calibration measurements at different pion energies make possible the spectra corrections. Simultaneously with the total absorption counter energy determination there arrives independent spectrometric information from the time-of-flight system. In actual experimental conditions the time-of-flight base was 1 M. The accuracy of time-of-flight system is comparable to the total absorption counter accuracy especially for the low-energy part of the spectra. Thus, for 500 ps time resolution of the time-of-flight system the accuracy of energy determination for 20 MeV pions is 1.7 MeV. The pion detector energy resolution is 1.5 MeV.In contrast to the energy spectra the time-of-flight spectra are free of these distortions. Due to this the comparison of time-of-flight spectra transformed into spectra with the total absorption counter spectra permits the evaluation and corresponding correction of the spectra under measurement. The fact that the facility parameters do not decrease at rather high count rates (up to 10^6 I/c) can be regarded as an advantage of the described facility.

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