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EXPERIMENTAL SETUP FOR THE STUDY OF ELASTIC π^-p SCATTERING AT SMALL ANGLES FOR ENERGIES OF 40 AND 50 GEV

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1. Introduction

An experiment was carried out at the accelerator of the Institute for High Energy Physics (Serpukhov) with the aim of investigating the elastic scattering of π^- mesons from protons, with incident pion momenta equal to 40 and 50 GeV/c.

The experiment was performed using a magnetic spectrometer with magnetostrictive spark chambers. Elastic interactions were identified with the help of the momentum measurement on the scattered π^- meson. The four-momentum transfer was determined from the scattering angle in the target. The obtained experimental data allow the determination of the slope of the differential cross section as a function of the four-momentum transfer t. In the region of small t, by taking into account the interference of the amplitudes of elastic and Coulomb scattering, it is possible to determine the ratio of the real and imaginary parts of the elastic scattering amplitude. The determination of these two parameters is important for verification of existing predictions about their asymptotic behaviour.

2. Experimental Setup

The experiment was performed in August 1971 with the help of the spectrometer used previously for measuring the radius of the π^- meson in the $\pi^- e$ scattering experiment /1/.

The experimental apparatus was located in beam channel Number 12 of the Serpukhov accelerator. The layout is shown in Figure I.

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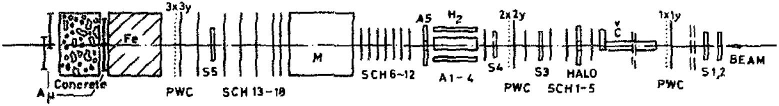

Fig. 1. Layout of the experimental setup.

The beam of π^- mesons fell on a liquid-hydrogen target. Trajectories of particles incident on the target were registered by the spark chambers SCH 1 - 5 located in front of the target. Their trajectories after scattering in the target were recorded in the spark chambers SCH 6 through 12 positioned between the target and the magnet. The momentum of these particles was determined through the measurement of the bending of their trajectories in the calibrated magnet. These trajectories were registered in the block of the chambers SCH 13 - 18 located behind the magnet.

The scintillation counters S1, S2, S3, S4, "HALO", A5, S5 and three pairs of the proportional chambers PWC1 - PWC3 triggered the spark chambers SCH1 - SCH18. The spark coordinates together with the information from the scintillation counters and the proportional chambers were transferred to the computer.

Except the counters already described which were included in the logical trigger setup, there were used other counters in the experiment:

a. Four large counters A1 - A4 surrounding the target. These counters could detect the recoil proton in the case of an elastic interaction.

b. Counters of the muon-filter A_μ . The filter consisted of 3.5 metres of iron and about two metres of concrete. Between the iron and the concrete and also behind the concrete, stood the counters working in coincidence scheme.

The beam of secondary negative particles was obtained from an aluminium target located in the 24th magnet of the accelerator and was extracted at zero angle through a limiting collimator. The beam was focused with a double quadrupole at the plane of the momentum collimator and analyzed in momentum in the field of the analyzing magnet and in the fringe field of the accelerator. The momentum dispersion of these fields was equal to 4.4 mm for 1% $\Delta p/p$. Because the width of the image of the internal target at the focus was equal to 2 mm, it was possible to use a beam with a momentum dispersion equal to $\pm 1\%$. After cutting out the desired momentum in the momentum collimator, the beam of π^- mesons was bent in the direction of the channel with the help of the next magnet. The size of the beam in the region of the hydrogen target was equal to 1.7 cm horizontally and 1 cm vertically (FWHM).

The adjustment of the beam as well as the checking in its momentum distribution was carried out with the aid of the spectrometer.

The 50 cm long hydrogen target /2/ used in the experiment guaranteed the constancy of the amount of atomic hydrogen in the interaction region with a precision of 0.05%. The external windows of a vacuum area of the target were extended to a distance of one metre from the region filled with hydrogen.

In order to measure the momentum of the π^- mesons, an SP-12, H-type magnet was used. The useful volume of the magnet was 50 cm horizontally x 20 cm vertically x 300 cm long. The magnetic field of this magnet was carefully measured /3/. It was found that the integrals of the field along the particle trajectories were equal with a precision of about 0.2%. The precision of determining the integral of the field was equal to 0.1%. However, the precision of the measurements of the incident particle momentum was basically determined by that of the measurement of the bending angle of its trajectory by the magnet and was equal to 0.5%. The magnet bent 50 GeV/c particles by 32.5 mrad.

3. Monitor

π^- mesons incident on the spectrometer were monitored with the aid of a system of counters and proportional chambers (Fig. 2).

The "BEAM COUNTERS" system included the scintillation counters S1, S2, S3, S4 and a threshold Čerenkov counter, Č, working in coincidence, and a scintillation counter with a circular opening, "HALO", working in anticoincidence.

The counters S1 and S2 were located at the beginning of the beam channel between the quadrupoles.

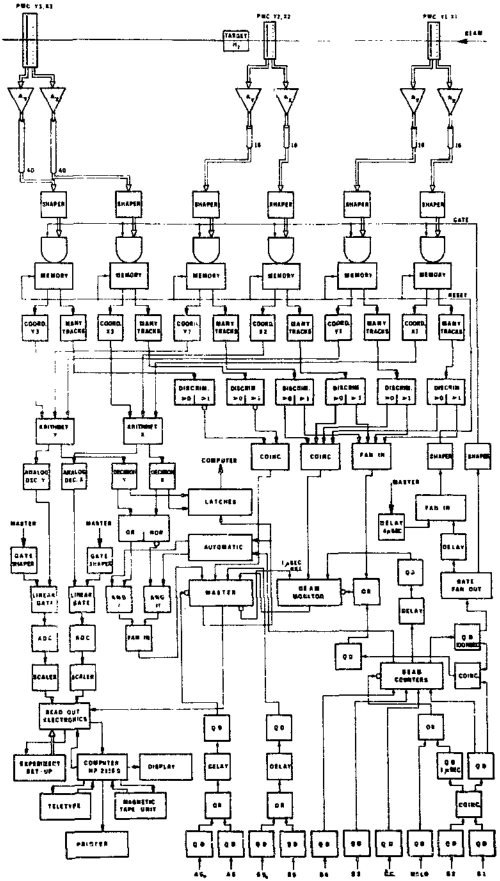

Fig. 2. Logical scheme of the trigger system.

The size of their scintillators was 15 cm x 15 cm x x 5mm.

The threshold Čerenkov counter $\check{C}$ was made of a tube 10 metre long. The air pressure inside the tube was regulated and adjusted to register π^- mesons and suppress K^- mesons and antiprotons.

The counters S3 and S4 were placed in front of the target. They limited the aperture of the beam. Their scintillators were in the form of discs 6 cm in diameter and 5 mm thick.

The beam-halo counter (''HALO'') was located in the first block of the spark chambers. Its scintillator has a size 40 cm x 40 cm and a thickness of 1 cm. The opening, with a radius of 4 cm, was made in the centre of the counter. It worked in anticoincidence with the other counters of the monitor and had the purpose of cutting the wings of the spatial distribution of the beam.

The ''BEAM COUNTERS'' circuit generated a gate pulse (''GATE'') of 100 nsec that caused the dumping of information from the proportional chambers into a fast intermediate memory. It also generated a late signal (''RESET'') that resetted this memory.

In order to ensure the working of the decision-making system, additional conditions were fulfilled in which it was efficient to carry out the analysis. The monitor signal was not generated if:

a. During 1 μ sec prior to the monitored particle there was another particle in the beam. A coincidence signal from S1 and S2 passed through the quad discriminator ''QD'' which formed an output pulse with the 1 μsec width. Each input signal which occured during the width of a given output pulse, extended the output pulse from each point of input threshold crossing, one full output signal width. The extended pulse entered then the anticoincidence input of the ''BEAM COUNTERS''.

b. During 100 nsec after the monitored particle another particle passed through the setup. The output signal from the ''QD'' circuit formed the ''GATE'' signal and could produce the input ''BEAM MONITOR'' signal from the proportional chambers only after about 300 nsec.

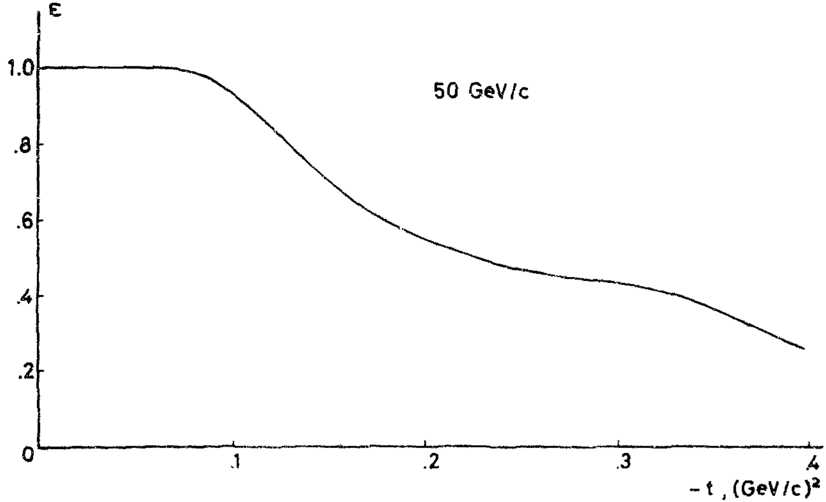

Fig. 3. Geometrical efficiency of the registration of scattered particles by S5 for a 50 GeV energy incident beam.

It allowed the inhibit signal to enter into the anticoincidence "BEAM MONITOR" input if there were signals from S1 and S2 in coincidence with the output signal (100 nsec width) from the same "QD" circuit.

c. In any of the proportional chambers PWC1X, PWC1Y, PWC2X, PWC2Y more than one wire fired. The firings of neighbouring wires were suppressed.

These conditions also reduced a probability of extra monitored particle during the spark chamber memory. It was important for a further off-line analysis of the recorded events.

The number of monitored particles was accumulated by the scalers and then was recorded on magnetic tapes for each trigger with the other information about the event.

4. Trigger

In addition to the counters of the monitor, the trigger system ("MASTER") for the spark chambers consisted of two additional counters.

The scintillation counter S5, located behind the magnet and in coincidence with the monitor output, limited the registration aperture. The counter with the monitor were entered into a special scaler and stored in the computer memory with each event.

The proportional chambers PWC3Y and PWC3X placed behind the magnet together with other proportional chambers and analogue decision-making electronics avoided the registration of events in which the π^- meson did not interact in the target.

The first two pairs of the chambers, PWC1 and PWC2, were located in front of the target on a 14 metre base line. They fixed the direction of the particles incident on the target. The last pair of the chambers PWC3 was located at a distance of 21 metres from PWC2, and registered the deviation of the particle trajectories from the direction determined by PWC1 and PWC2. The condition that this

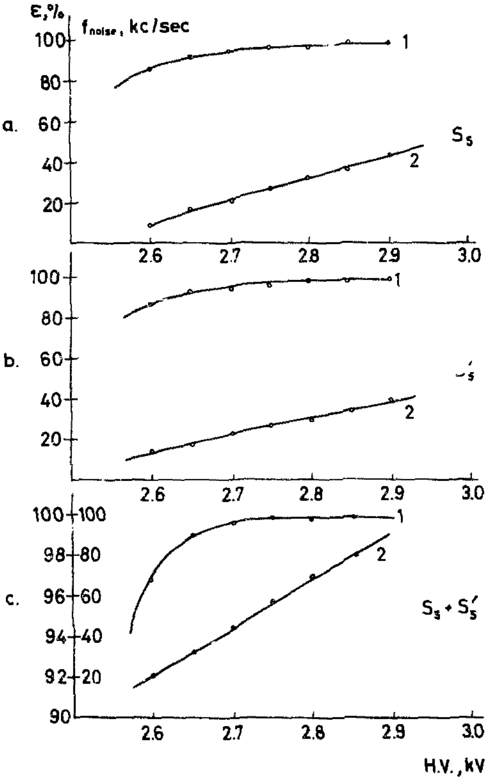

Fig. 4. Noise and the efficiency of the scintillation counter S5.

deviation is greater than a given amount can be formulated via the following inequality:

$$|AX1 + BX2 + X3 - C| > K , \qquad (1)$$

where the coefficients A and B depend only on the ratio of the distances between the chambers; C depends only on the wire spacing of the chambers and their relative alignment. The factor K determines the limit of angular deviation of the trajectory from the straight direction. This condition was tested with the analogue decision-making circuit described in /4/. It was checked independently for the vertical and horizontal planes (test was made in a time of 300 nsec). The setup was triggered even if the inequality was satisfied in only one of the planes, or at least one of the two last chambers was not fired. Multifirings of these chambers did not trigger the apparatus. Single events of this type were entered into a special scaler, and their number was stored with each registered event. As a check, a special run was carried out during which the spectrometer was triggered only from the events of this type. The rate of such events and their characteristics approximately corresponded to multifiring due to inelastic pion interactions in the matter of the second and third block.

For checking the working of the system during the experiment, the decision and the analogue decision pulses were entered into the computer. An ADC converter gives a signal with the amplitude proportional to the scattering angle of the particle.

A check of the cutoff angle K was carried out by measuring the scattering of the incident π^- mesons (trigger without decision) in a 5 cm thick lead target (multiple scattering of the incident beam in such a target was 1 mrad). This allowed the collection of a large statistical scattering of particle in a comparatively short time and checked the zeroing of the decision-making system. In such runs the angular distribution of all scattered π^- mesons was compared with the angular distribution of π^- mesons being in agreement with inequ-

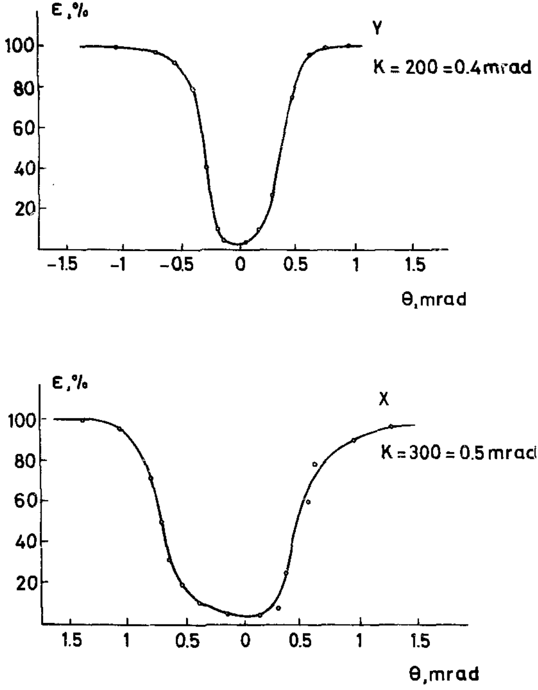

Fig. 5. Decision efficiency.

ality (1). The ratio of both the distributions for the selected quantity K in each plane is shown in Figure 5. In this experiment, the following cutoff angles were chosen: $K_x = 0.5$ mrad and $K_y = 0.4$ mrad; the obtained selection coefficient was 9 - 14.

The proportional chambers such as [5,6] had a sensitive area of 15 cm x 15 cm, a 3 mm wire spacing between the signal electrodes and a distance of 7 mm between the signal and high voltage electrodes. The signal electrode was a gold-plated tungsten wire of 20 μm in diameter.

The chambers were tested preliminarily in laboratory conditions. For the chambers use was made of the $Ar + 17\% CO_2 + 2\% C_2H_5OH$ gas mixture with 2% of Benzol vapour to decrease the noise rate of the chambers with an enough wide plateau of voltage [6]. With a selected cathode voltage of 3200 v, the chamber efficiency was from 99.4% to 99.5%, and the amount of multifirings did not exceed 2.5% provided the firing of neighbouring wires was suppressed.

5. Spark Chamber Blocks and Readout Electronics

The spark chambers [7] used in the experiment utilized a magnetostrictive system for the pickup of spark coordinates. The chambers were located in three blocks.

a. Five chambers in the first block located with a base line of six metres. All the chambers of this block had a size 25 cm x 25 cm, and spark coordinates were taken from one end of each of the two ("ground" and "high voltage") magnetostrictive wands. The trajectories of the particles incident on the spectrometer were recorded in this block.

b. In the second block there were seven chambers placed on a six metre base line. The size of these chambers was also 25 cm x 25 cm. Spark coordinates were picked up from both ends of each magnetostrictive wand. This block registered the particles leaving the target. The angle between the direction of the tracks in the first and second blocks of the chambers measured the scattering angle, and the point of intersection of these two tracks determined the point of interaction.

c. The third block, located behind the magnet, consisted of six chambers placed on a base line of four metres. They had a size 60 cm in the horizontal direction and 40 cm in the vertical one. Spark coordinates were taken from one end of the magnetostrictive wands. The block was placed in such a way that the particle with a momentum of 50 GeV/c passed through the centre of the chambers of the block.

A track reconstruction in space was provided by rotating one chamber in block 1 and two chambers in both blocks 2 and 3 by an angle of 45°. The chambers, with a full duty rate of the spectrometer, that went up to 120 firings per cycle of the accelerator, worked with an efficiency of the order of 95%. The spark coordinates of the chamber were measured with a precision of 0.2 - 0.4 mm. The spatial resolution of the single-ended magnetostrictive readout was equal to 5 mm, and for the double-ended readout it achieved 1.5 mm, but in the interval 1.5 to 5 mm the detection efficiency fell to 50%. The readout electronics permitted the recording of up to six sparks from each pickup coil.

The readout electronics /8/ synchronized the performance of the rest of the system with the work of the accelerator and the computer and provided the removal of data from the spectrometer to the computer. The HP 2116B computer was used to control the spectrometer. Except data processing from the spectrometer during the accelerator cycle, it recorded the data on magnetic tape and carried out a partial analysis of the obtained information /9/. The programs could analyze 10% of the data during the time between accelerator spills. The results of the analysis could be given out on a fast printer. During the running of the experiment, this system permitted a sufficient control of the performance of the spark chambers, decision-making system, counters and essential parts of the electronics. The on-line track reconstruction in the spark chamber blocks was used to select events in which the particle was scattered in the target region. In general, it allowed constant checking of the spectrometer operation.

6. Summary

In this experiment, data were collected under the following conditions of operation of the spectrometer:

a. Runs with full target. About 1.2×10^6 triggers were collected at an incident π^- meson energy of 50 GeV and about 0.9×10^6 triggers for an energy of 40 GeV.

b. Runs with empty target. About 0.6×10^6 triggers were taken at an energy of 50 GeV and about 0.4×10^6 triggers at an energy of 40 GeV.

c. 10 minute runs with the lead target were carried out every two hours during the collection of data. They were performed with the purpose of checking the decision-making electronics.

d. Runs were conducted to check the beam with the spectrometer trigger from the beam monitor.

e. A run was conducted where the spectrometer was triggered with multifirings of the two last proportional chambers.

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