A STUDY OF THE LOW MASS $\pi^-\pi^-$ SYSTEM PRODUCED IN THE REACTION $\pi^-p \to \pi^-\pi^- +$ ANYTHING AT 50 GeV/c

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The reaction $\pi^-p \to \pi^-\pi^- +$ anything was studied at 50 GeV/c using a multiwire spectrometer of the Dubna–Los Angeles collaboration. We have analysed 497 events at $m_{\pi\pi} < 0.7$ GeV, $|t| < 0.07$ GeV$^2/c^2$. Using a Chew–Low extrapolation the on-mass-shell cross sections and isospin $I = 2$, S wave phase shift were obtained. Our results, while consistent with earlier data, yield $a_0^2 = -(0.20 \pm 0.08)$ fm, and seem to disagree with the $a_0^0 = 0.37 \pm 0.07$ fm obtained from the K_{e_4} decay and the Show and Morgan curve.

1. Introduction

In this paper we present results of the experiment $\pi p \to \pi^-\pi^-...$ at 50 GeV/c. This experiment was performed during the "parasitic" run of π–e elastic scattering experiment in the Institute of High Energy Physics at Serpukhov in 1971. As the result of an analysis of the data we present extrapolated on-mass-shell cross sections of elastic scattering in a few mass bins very close to the $\pi\pi$ threshold. Our results on $I = 2$, S wave scattering length as well as some other results are discussed and compared with the dispersion relations predictions.

2. Apparatus and experimental procedure

The apparatus was originally designed to measure π-e elastic scattering. This is described in detail in paper [1]. Here we show only its schematic view (Fig. 1). Our reaction $\pi^-p \to \pi^-\pi^-...$ was triggered by the following logic:

$$\text{TRIGGER} = \text{UB} \times S_{\pi_1} \times S_{\pi_2} \times \bar{A}_5,$$

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where

$$UB = S_1 \times S_2 \times S_3 \times S_4 \times \overline{A}_H$$

defines a good beam particle. $S_{\pi_1} \times S_{\pi_2}$ signals two fast forward particles.

The anticoincidence counter A_5 was rather unfortunate for our reaction spoiling its inclusiveness. The events with large angle particles, being energetic enough to penetrate brass shim plate covering scintillator of the A_5 counter, were vetoed. This effect is accounted

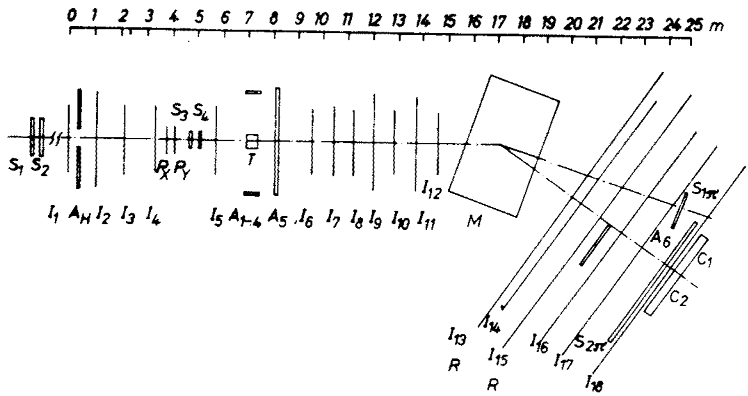

Fig. 1. A scheme of the spark chamber spectrometer: S — scintillation counters, —A — scintillation veto counters, I — spark chambers (R — rotated ones), T — hydrogen target, M — bending magnet

for in our analysis but leads to reduction of statistics. The geometrical acceptance of the apparatus for the two fast forward particles is confined to a very small mass ($m_{\pi\pi} < 0.7$ GeV) and a very small momentum transfer ($|t| < 0.07$ GeV^2). This is due to the fact that the experiment was originally designed to measure the elastic scattering on electrons.

3. *Reconstruction and selection of events*

Events recorded on tape were reconstructed using a modified pattern recognition program for the π-e scattering experiment (see Ref. [1]) and selected using the following criteria:

(*i*) the criteria for clean sample of two prong events: (a) both tracks originating from the target and hiting trigger counters S_{π_1} and S_{π_2}, (b) each track was required to have momentum in the range 13–34 GeV/*c*. Outside this interval momentum measurement was not reliable. At this level of selection we were left with 4309 events;

(*ii*) the criteria for rejection π-e pairs in our sample:

(a) coplanarity defined as

$$C = \{(\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_B\}^2 / (|\vec{p}_1 \times \vec{p}_2| \cdot |\vec{p}_B|)^2$$

larger than 2×10^{-7}, where $\vec{p}_1$, $\vec{p}_2$, and $\vec{p}_B$ are laboratory momenta of secondary pions and beam pions, respectively;

(b) the total momentum of fast secondaries $p_1 + p_2 < 47.4$ GeV;

(c) the transverse momenta of fast secondaries differ by more than 30 MeV/*c*.

These criteria have been chosen after examining the sample of π-e events and checked on the sample of 1315 events in which both particles fall into geometry of Č counters and could be identified as pions. At this level of selection we were left with 1801 events which we considered to be $\pi^-\pi^-X^{++}$ events. The estimated contamination of this sample by the π-e pairs is ~1.5%.

4. *Analysis of the data*

In Fig. 2 we show the missing mass distribution together with the OPE prediction (full line). This figure shows that our data are in full agreement with the model up to MM ≈ 2 GeV. Above this limit the model prediction is higher than the measured cross section and this fact is interpreted as loss of events due to an A_5 counter veto. To investigate

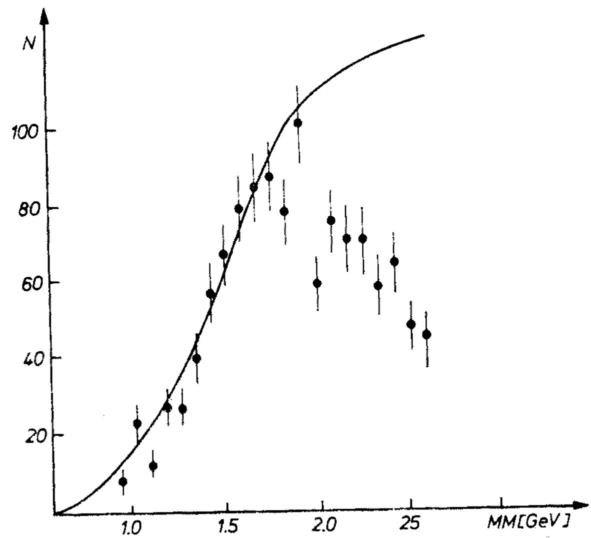

Fig. 2. Missing mass distribution. Full line represents the OPE predictions while points with errors refer to our results

this matter in more detail we have performed the additional Monte Carlo calculation using the measured π^+p scattering amplitudes up to MM = 1.5 GeV in order to imitate slow particles produced in the baryon vertex. We have found that the A_5 veto losses amount to 4–5%, uniformly distributed in the missing mass region up to 1.5 GeV. Since there is an agreement between the experimental MM-distribution and the model prediction also for 1.5–2.0 GeV, we believe that the A_5 losses remain small up to 2 GeV.

Therefore, we have decided to apply another kinematical cut to our data rejecting all events for MM > 1.9 GeV. This way we are left with 497 events.

In Figs 3 and 4 we show distributions of effective mass $m_{\pi\pi}$ of ππ system and of four-momentum transfer, respectively. Full line represents raw data, dotted line — data corrected for acceptance. Our results were analysed using the standard Chew–Low extrapolation method. At first we determine the quantity

$$F(m_{\pi\pi}, t) = \frac{\sigma_{\mathrm{exp}}(m_{\pi\pi}, t)}{\sigma_{\mathrm{OPE}}(m_{\pi\pi}, t)}$$

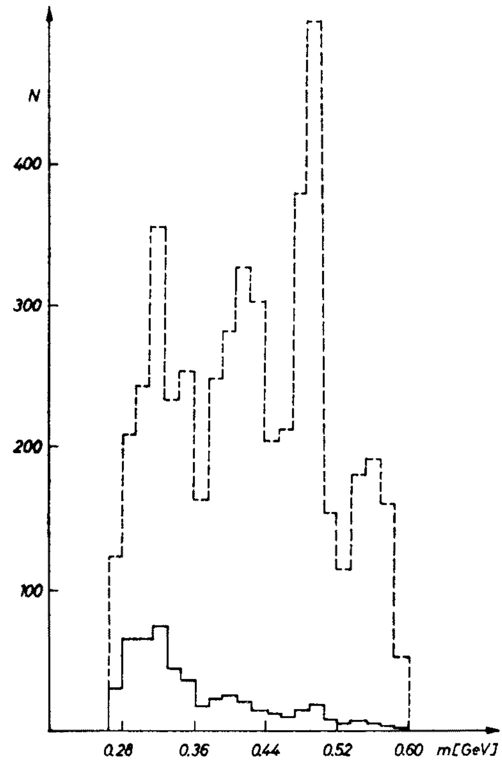

Fig. 3

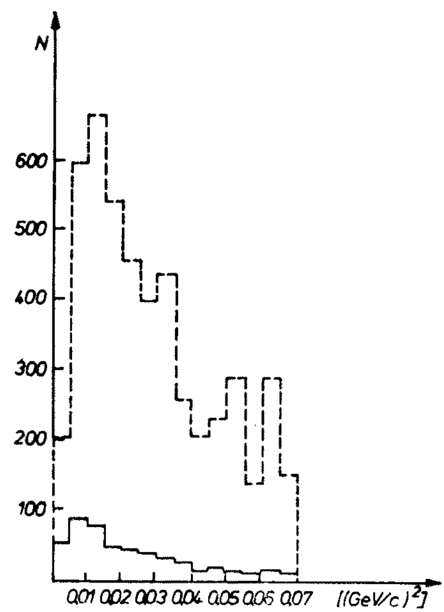

Fig. 4

Fig. 3. Effective mass distribution

Fig. 4. Four-momentum transfer distribution

in a few $m_{\pi\pi}$ and t bins. σ_{OPE} is a theoretical cross section for the reaction $\pi^- p \rightarrow \pi^- \pi^- X^{++}$ assuming one-pion-exchange in which we put

$$\sigma_{\pi\pi}(m_{\pi\pi}, t) = 1.$$

Therefore, by definition, $F(m_{\pi\pi}, t)$ is an off-shell $\pi^-\pi^-$ elastic scattering cross section. σ_{OPE} was calculated by integration over the three-body phase space of two pions and the missing mass MM with an OPE weight factor

$$W(p_{\pi_1}, p_{\pi_2}, \mathrm{MM}) = \frac{\mathrm{MM}\, m_{\pi\pi}^2 \sigma_{\pi^+ p}(\mathrm{MM}) \lambda^{1/2}(\mathrm{MM}^2, -t, m_p^2) \sigma_{\pi^-\pi^-} \lambda^{1/2}(m_{\pi\pi}^2, -t, \mu^2)}{2\pi^5 \lambda^{1/2}(s, m_p^2, \mu^2) \lambda^{1/2}(m_{\pi\pi}^2, \mu^2, \mu^2)\,(t-\mu^2)^2},$$

where $\sigma_{\pi+p}$ is a total π^+p cross section. The weight is 0 outside the kinematical cuts which were applied to the data.

Integrating over this range of missing mass we have determined $F(m_{\pi\pi}, t)$ in five bins of effective mass:

$$0.28 < m_1 \leqslant 0.32 \leqslant m_2 \leqslant 0.36 \leqslant m_3 \leqslant 0.42 \leqslant m_4 \leqslant 0.50 \leqslant m_5 \leqslant 0.70 \text{ GeV}$$

and five bins of momentum transfer

$$0.00 < t_1 \leqslant 0.01 \leqslant t_2 \leqslant 0.02 \leqslant t_3 \leqslant 0.035 \leqslant t_4 \leqslant 0.05 \leqslant t_5 \leqslant 0.07 \text{ GeV}^2/c^2.$$

On shell the $\pi\pi$ scattering cross section is, by definition, equal to

$$\sigma_{\pi\pi}(m_{\pi\pi}) = F(m_{\pi\pi}, t = \mu^2)$$

and can be determined by linear extrapolation (see Fig. 5 and Table I).

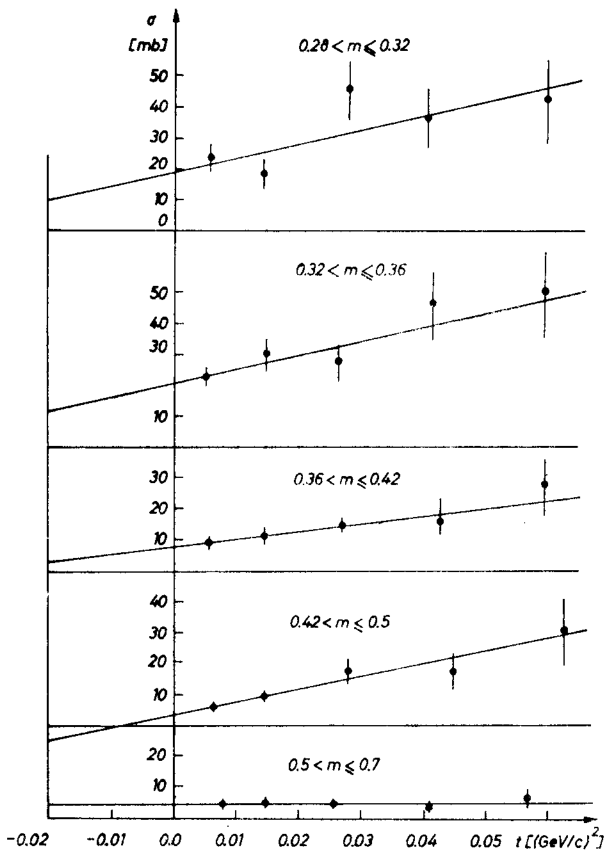

Fig. 5. Determination of $\sigma_{\pi\pi}$

TABLE I

$m_{\pi\pi}$ (GeV)	σ (mb)	δ_0^2 (deg)	a_0^2 (fm)
0.28—0.32	8.9 ± 5.5	-3.0 ± 2.0	-0.19 ± 0.12
0.32—0.36	11.3 ± 5.3	-01.8 ± 2.3	-0.21 ± 0.10
0.36—0.42	2.6 ± 2.8	-4.0 ± 4.2	-0.10 ± 0.11
0.42—0.50	-4.5 ± 2.9	—	—
0.50—0.70	4.5 ± 1.4	-10.4 ± 3.2	-0.13 ± 0.04

In Fig. 6 we show δ_0^2 phase shifts obtained from our measurement together with the phase shifts of Hoogland et al. [2] and Losty et al. [3]. We see a reasonable agreement between all these results. In particular, the results of the high-statistic experiment of Hoogland et al. [2] tend to confirm our low-mass data.

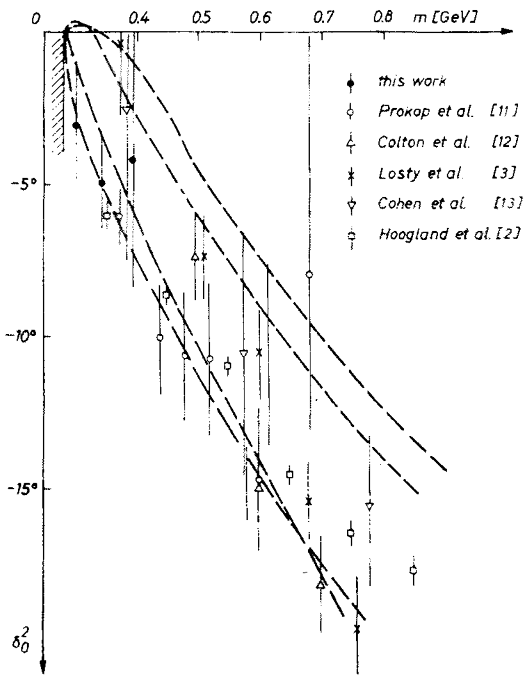

Fig. 6. Phase shifts δ_0^2 versus effective mass $m_{\pi\pi}$

The scattering length estimated from our data for $m_{\pi\pi} < 0.36$ GeV is $a_0^2 = -(0.20 \pm 0.08)$ fm. This should be compared with $a_0^2 = -(0.11 \pm 0.01)$ fm given by Hoogland et al. [2] and with $a_0^2 = -(0.15 \pm 0.02)$ fm obtained by Losty et al. [3]. In other experiments the errors on the data points close to threshold are too large for a meaningful determination of the scattering length.

5. Comparison of the universal curve of Show and Morgan with experimental data

We would like to point out that the following three pieces of information concerning the scattering length seem to be inconsistent:

(i) Assuming a weak coupling to the exotic channels and ϱ dominance of $I = 1$ absorptive part in $\pi\pi$ scattering, the analyticity and the crossing relate unambiguously a_0^0 and a_0^2 [4]. This relation can be represented as a curve on (a_0^2, a_0^0) plane. This curve is generally known as a universal curve of Show and Morgan [5][1].

(ii) a_0^0 was best measured in K_{e4} decay [6, 7] and the result $a_0^0 = 0.37 \pm 0.07$ fm is represented by a vertical band in (a_0^2, a_0^0) plane — see Fig. 7.

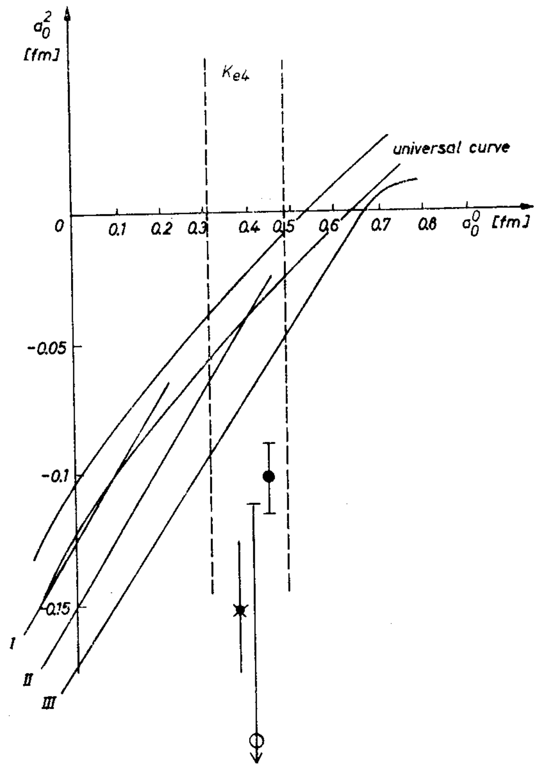

Fig. 7. The a_0^2, a_0^0 plane. a_0^2 results: × — Hoogland et al. [2], ● — Losty et al. [3], ○ — our result. Straight lines are Bonnier–Donohue bounds for $a_2^0 = 0.0017$ (I), 0.0027 (II), 0.037 (III) of Ref. [9]

(iii) The results of the measurement of a_0^2 in $\pi\pi$ production have been already discussed. They give $a_0^2 \leqslant -0.10$ fm.

We can see that the universal curve (i) cannot satisfy (ii) and (iii) simultaneously. It would have to be pushed down by at least 0.07 fm in order to touch the area of intersection. Such shift would need an exotic $I = 2$ exchange contribution to dispersion integral

[1] Actually the curve is really a narrow band. Uncertainty comes mainly from experimental errors of the ϱ parameters.

amounting to 60% of the ϱ contribution [8]. This possibility seems to be very unlike. Recently it was pointed out [9] that an increase in the $I = 2, l = 2$ scattering length a_2^0 results in pushing down Show–Morgan curve (see Fig. 7). The data would require $a_2^0 \approx 0.004$ (upper limit) i.e. around two times of the "canonical" value 0.0017 (see Ref. [10]). We conclude that the $\pi\pi$ results at low mass seem not to fit into a simple picture and further effort is needed in this field.

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REFERENCES

[1] G. T. Adylov et al., *Nucl. Phys.* **128B**, 461 (1977).
[2] W. Hoogland et al., *Nucl. Phys.* **126B**, 109 (1977).
[3] M. J. Losty et al., *Nucl. Phys.* **69B**, 185 (1974).
[4] J. L. Basdevant et al., *Nucl. Phys.* **72B**, 413 (1974).
[5] D. Morgan, G. Show, *Nucl. Phys.* **10B**, 261 (1968).
[6] L. Rosselet et al., *Phys. Rev.* **15D**, 574 (1977).
[7] J. L. Petersen, *The $\pi\pi$ Interaction*, CERN 77–04 (1977).
[8] M. R. Pennington, *Nuovo Cimento* **25A**, 149 (1975).
[9] B. Bonnier, J. T. Donohue, *Nucl. Phys.* **134B**, 351 (1978).
[10] A. M. Bincer, B. Sakita, *Phys. Rev.* **129**, 1905 (1963).
[11] J. P. Prokop et al., *Phys. Rev.* **D10**, 2055 (1974).
[12] E. C. Colton et al., *Phys. Rev.* **D3**, 2028 (1971).
[13] D. Cohen et al., *Phys. Rev.* **D7**, 661 (1973).