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CROSS-SECTION MEASUREMENT OF $\pi^- p \rightarrow \pi^- \pi^+ n$ REACTION NEAR THRESHOLD

OMICRON Collaboration

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Abstract

Results of cross-section measurements for the reaction $\pi^- p \rightarrow \pi^- \pi^+ n$ are presented. They cover a range of incident pion momenta between 295 and 450 MeV/c. It is the first time that the cross-section has been measured so close to threshold. The experiment was performed with Omicron, a large-solid-angle spectrometer, which enables a measurement of the full set of kinematic variables.

In the region of overlap there is an excellent agreement with other experiments. The extracted value for the chiral-symmetry-breaking parameter is -1.1 ± 0.5. This value may be affected by a s-wave resonance which was observed.

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The $\pi p \rightarrow \pi\pi N$ reactions, as pointed out by Weinberg (1), provide a possibility to determine the $\pi\pi$ scattering lengths. In addition, one hopes to be able to determine transformation properties of chiral-symmetry-breaking part of the Lagrangian specified by a single parameter ξ. The symmetry breaking mechanism suggested by Weinberg (1) leads to a value of $\xi = 0$ while models put forward by Schwinger (2) attribute to ξ the values +1, +2 or -2.

The need to minimize the effect of resonances in the final-state suggests that measurements should be carried out close to the reaction threshold p_{TH} = 279 MeV/c. Previous experiments (3,4,5) were either performed too far above threshold or they did not provide the information about the full kinematics of the events (6).

To supplement the existing data we have performed a measurement of the reaction $\pi^- p \rightarrow \pi^-\pi^+ n$ using π^- beams at several momenta near threshold and we have studied angular and invariant-mass distributions from a knowledge of the complete kinematics of the events. The experiment was carried out with the Omicron spectrometer at the CERN Synchro-cyclotron. The apparatus and its performance were described in detail in refs (7,8). In this letter we present the results concerning the integrated cross-section.

The analysis of recorded data consisted of track-finding and fitting combined with vertex reconstruction and was followed by background rejection and kinematic analysis. Background processes with protons in the final state ($\pi^- p$ elastic scattering, neutral pion production and $\pi^- p$ bremsstrahlung) were rejected by applying kinematical cuts and proton identification criteria based on time of flight. Events originating in target walls were eliminated by restricting the fiducial target volume. Events with e^+e^- pairs in the final state arising from neutral pions via Dalitz-decays or external conversion were found to contribute significantly to background. At incoming pion momenta below 334 MeV/c secondary electrons were resolved from pions using pulse-height information from hodoscopes. At higher momenta subtraction of data obtained with the target at reduced hydrogen pressure was necessary to eliminate pairs produced by external conversion. Dalitz pairs were eliminated from the observed spectra of $\pi^-\pi^+$ events by subtraction of suitably scaled data obtained by simulation (8). The geometrical acceptance and efficiency of the detection system and analysis were determined by a Monte-Carlo simulation.

A normalization check was performed by evaluating the differential cross-section of $\pi^- p$ elastic scattering over the entire momentum range and comparing the results to the cross-sections obtained from phase shifts (9). The agreement between calculation and observation was found to be better than 5 %.

The result of the analysis shows the following features:

- the pion pairs are distributed isotropically in the $\pi^-\pi^+$ rest system at all energies, suggesting that the two pions are in a relative s-state (e.g. Fig. 1a),
- from these angular distributions and $\pi^\pm n$ invariant mass spectra we conclude that there is no significant evidence of ρ or Δ production,
- the invariant mass spectra of the $\pi^-\pi^+$ pairs show an enhancement of high-mass events when compared with phase space distributions (Fig. 1b) an effect that has also been observed in previous measurements (3).

Our data thus seem to indicate a strong $\pi^-\pi^+$ interaction, as supported by evidence from the process $pp \rightarrow pp\ \pi^-\pi^+$ (10) and the decay $J/\psi \rightarrow \omega\ \pi^-\pi^+$ (11) where again a strong two pion interaction in a relative s-state was observed and attributed to a resonant state.

The integrated cross-sections were computed for each incident beam momentum. To extrapolate to regions of phase space not covered by the apparatus we made use of the fact that the $\pi^-\pi^+$ invariant mass distribution was the only distribution to show considerable departure from phase space. Hence we integrated $d\sigma/dM_{\pi\pi}$ over the whole range taking into account the varying acceptance of the apparatus. The resulting cross-section (Table 1) is in good agreement with previous measurements at higher incident pion momenta as can be seen from Fig. 2.

One should note that the measured integrated cross-section at 16 MeV/c above threshold is probably at the limit of present experimental feasibility. This fact is best illustrated by the signal to background ratio being approximately 10^{-5}.

Theoretical calculations of the $\pi p \rightarrow \pi\pi N$ cross-section at low energies exploit the ideas of current algebra, PCAC and chiral symmetry. Following Weinberg's prediction (1) on $\pi\pi$ scattering lengths Olsson and Turner (12) used a threshold aproximation to calculate the $\pi p \rightarrow \pi\pi N$ amplitudes from a phenomenological Lagrangian and gave formulae for their dependence on the parameter ξ .

A difficulty on the extraction of ξ from data on the reaction $\pi^- p \rightarrow \pi^-\pi^+ n$ is imposed by the strong $I = 0$ $\pi\pi$ interaction which might be attributed to the tail of a broad resonance (ε) at about 500 MeV. Arndt et al. (13,14) estimated its contribution to the current algebra amplitude and found it to be negligible only up to a few MeV above threshold, at 10 MeV it should already account for 30 % and by 50 MeV above threshold it should be as large as the current algebra cross-section itself.

Bjork et al (5) tried to avoid this difficulty when analysing their data from a single-arm spectrometer measurement. Following the statement in ref (13) that the interference term between the current algebra and the strong $\pi\pi$ interaction correction should vanish linearly with kinetic energy they extrapolated the squared modulus of the matrix element to threshold. From a comparison with the prediction by Olsson and Turner (12) they arrive at $\xi = 0.05 \pm 0.26$. However, their linear extrapolation includes all their 7 data points at incoming pion momenta from 313 to 477 MeV/c . There is little justification for a linear dependence over such a range, and their fit indeed misses the point closest to the threshold by nearly two standard deviations. On the other hand, if one were to extrapolate only from the two or three measurements closest to the threshold (p_o = 313, 342, 369 MeV/c) one would deduce $\xi_{12} = -1.0 \pm 0.5$ and $\xi_{123} = -0.6 \pm 0.4$, respectively.

Aaron et al (14) analyse the data of Bjork et al. (5) by simultaneously fitting the coefficients in their parametrisation to the cross-section and to the PS11(εN) amplitude at higher energies. They extract for ξ a value of -0.2 ± 0.3. The most recent calculation has been performed by Oset and Vicente-Vaccas (15). In their analysis they found a non vanishing threshold contribution from the processes via N^* and ε in the intermediate state and from the same set of data they extract a value of -0.5 for ξ.

Our data cover the range of incident pion momenta from 295 to 450 MeV/c. Extrapolation of the square of the amplitude as a function of T_{CMS} to threshold using only the lowest four points (p_o = 295, 315, 334 and 354 MeV/c) would yield the value of $\xi = -1.1 \pm 0.5$ which is in a fair agreement with the value from the data of Bjork et al. for the corresponding energy range. However, it is not clear to what extent could the result be affected by the observed resonance in the $\pi^-\pi^+$ final state, so that an extraction of ξ from a straightforward threshold extrapolation may not be correct.

To conclude, we have performed a full-kinematics measurement of the $\pi^-p \rightarrow \pi^-\pi^+n$ reaction, covering the incident pion momentum range from 295 to 450 MeV/c. The lowest value (p_o = 295 MeV/c) provides the measurement closest to the threshold. The integrated cross-section is in excellent agreement with previous results. It is however difficult to extract the chiral-symmetry-breaking parameter ξ from the data in a straightforward manner due to presence of a strong $I = 0$ $\pi^-\pi^+$ interaction.

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TABLE CAPTION

Table 1. Integrated cross-section for the reaction $\pi^- p \rightarrow \pi^- \pi^+ n$ as a function of the incident pion momentum p_o. Δp_o indicates the r.m.s. beam momentum spread. The error represents a combination of statistical and systematical errors summed in squares.

FIGURE CAPTIONS

Figure 1. Acceptance corrected distributions of $\cos\theta_{\pi^-}$ in the $\pi^- \pi^+$ cms (a) and $\pi^- \pi^+$ invariant mass (b) at incoming pion momentum of 450 MeV/c. The solid line represents the phase space distribution.

Figure 2. Integrated cross-section for the reaction $\pi^- p \rightarrow \pi^- \pi^+ n$ as measured in this experiment (full circles) compared to previous experimental studies (3,4,5).

$p_0 \pm \Delta p_0$ [MeV/c]	CROSS-SECTION [μb]
295 ± 9	5.1 ± 1.2
315 ± 10	20 ± 3
334 ± 10	51 ± 12
354 ± 10	118 ± 20
375 ± 11	211 ± 36
394 ± 10	327 ± 41
413 ± 10	477 ± 56
432 ± 11	785 ± 104
450 ± 12	1052 ± 125

Table 1

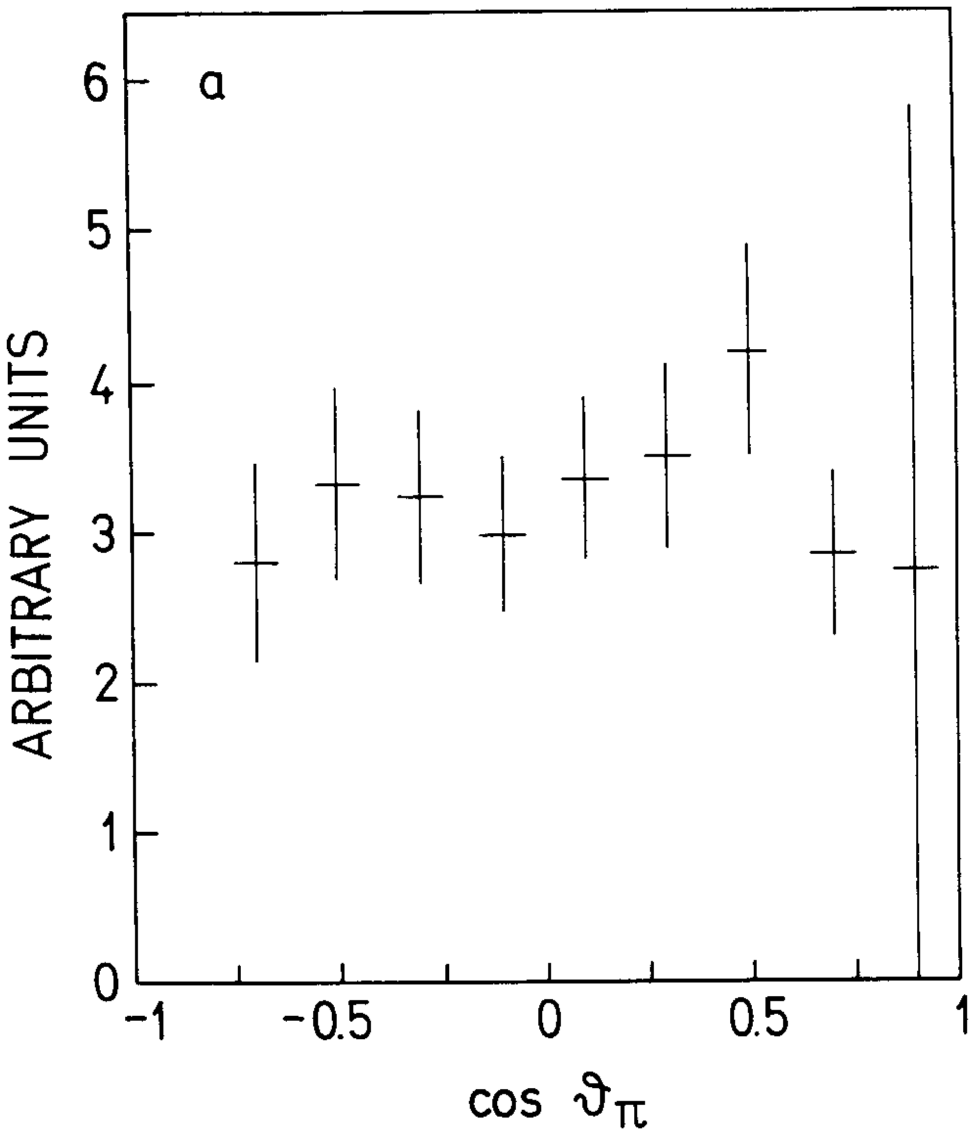
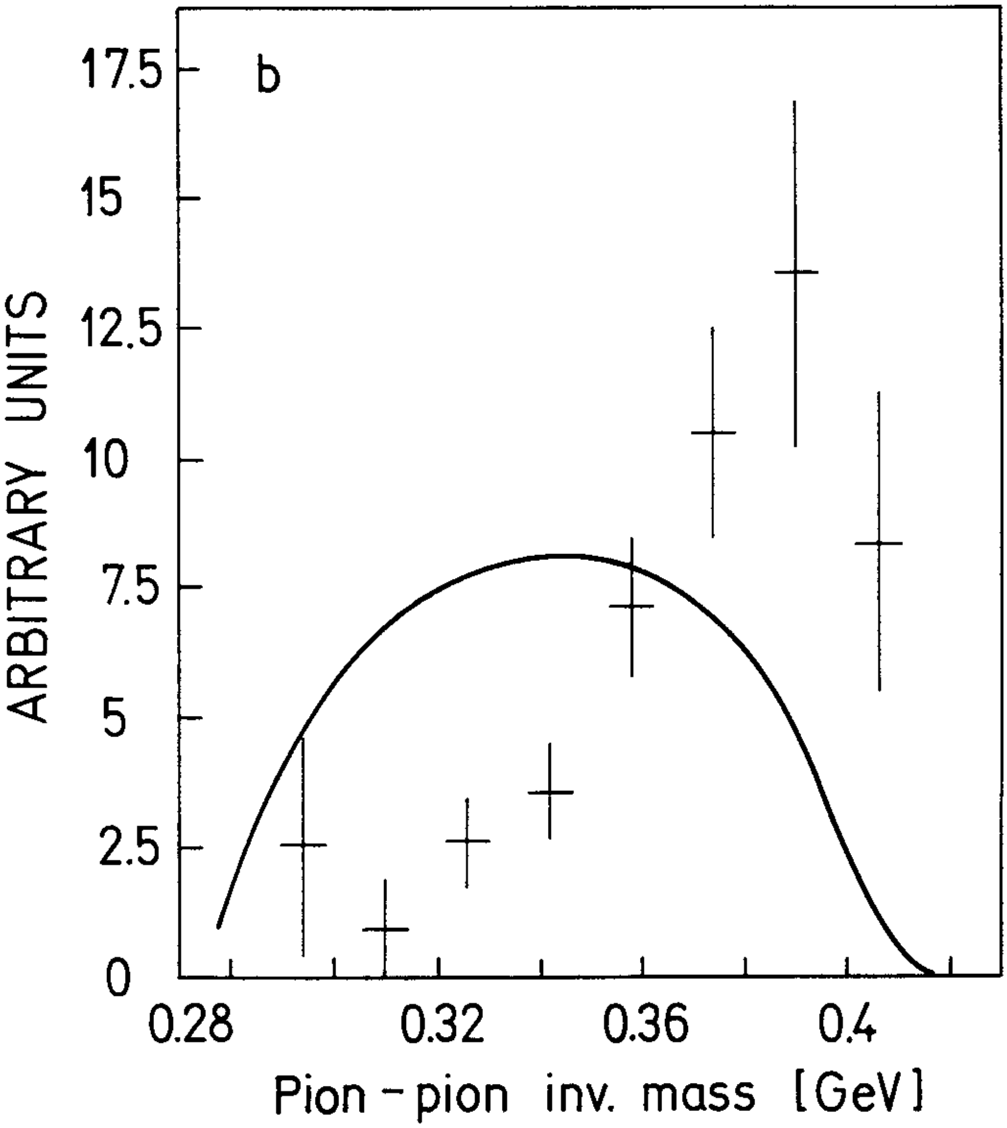


Figure 1



b
ARBITRARY UNITS
17.5
15
12.5
10
7.5
5
2.5
0
0.28
0.32
0.36
0.4
Pion - pion inv. mass [GeV]

Figure 1

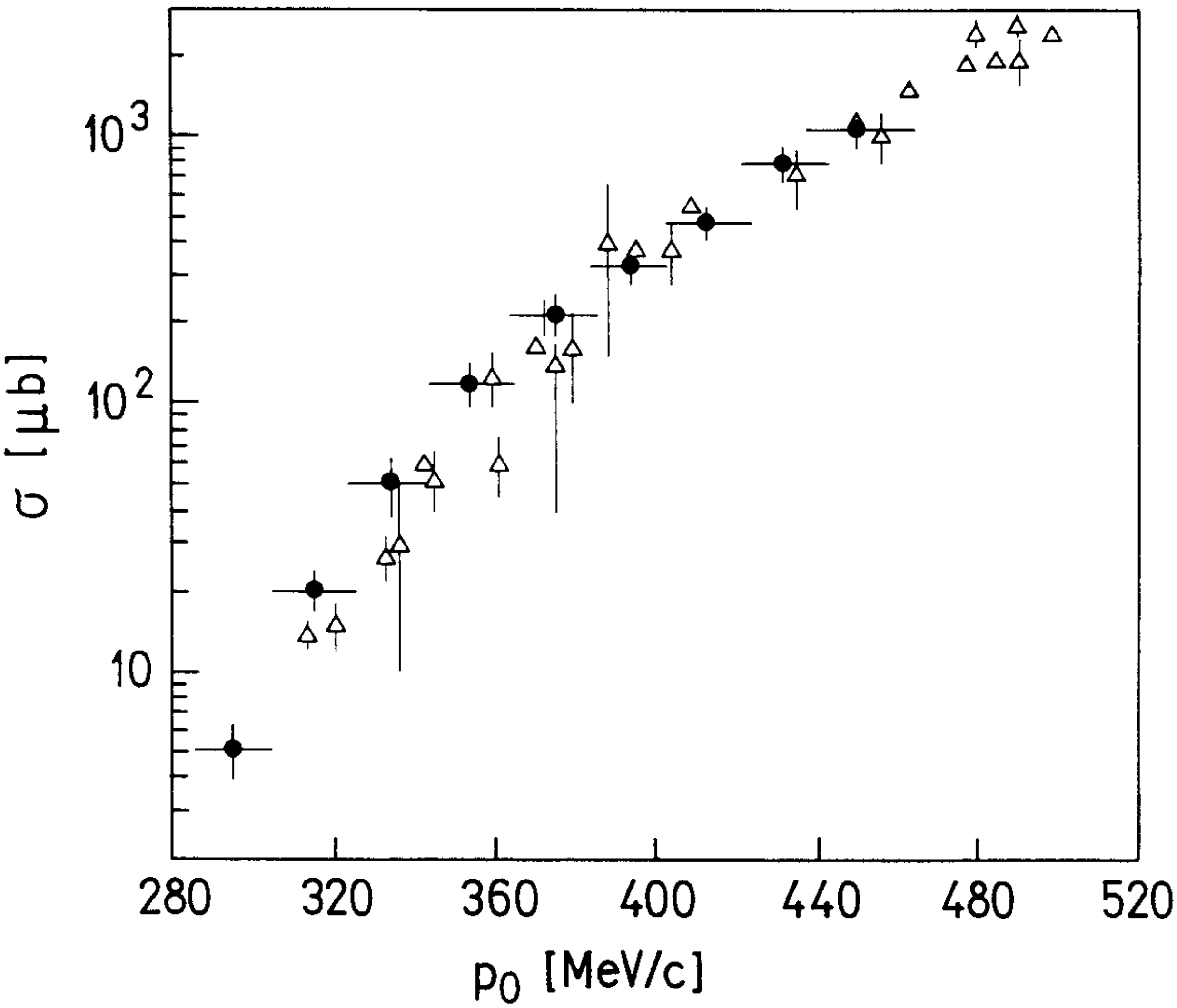


Figure 2