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MEASUREMENTS OF PION PRODUCTION IN $\pi^{\pm}p$ INTERACTIONS NEAR THRESHOLD

Omicron Collaboration

G. Kernel, D. Korbar, P. Križan, M. Mikuž, U. Seljak, F. Sever,[1] A. Stanovnik, M. Starič, D. Zavrtanik[2]
J. Stefan Institute and Department of Physics, University of Ljubljana, YU-61111 Ljubljana, Yugoslavia
C.W.E. van Eijk, R.W. Hollander, W. Lourens[3]
Delft University of Technology, Delft, The Netherlands
E.G. Michaelis[4]
CERN, CH-1211 Geneva 23, Switzerland
N.W. Tanner
Nuclear Physics laboratory, Oxford University, Oxford OX1 3RH, UK
S.A. Clark,[5]
Rutherford and Appleton Laboratory, Chilton, Didcot OX11 0QX, UK
J.V. Jovanovich
Department of Physics, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada
J.D. Davies, J. Lowe, S.M. Playfer[6]
Department of Physics, University of Birmingham B15 2TT, UK

Abstract

Results of full-kinematics measurements of $\pi^-p \to \pi^-\pi^+n$, $\pi^-p \to \pi^-\pi^0p$ and $\pi^+p \to \pi^+\pi^+n$ in the threshold region are compared with current-algebra calculations. Discrepancies can be largely attributed to isobar production, but even the threshold behaviour is not adequately described by existing calculations.

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[1]Present address: DPHN CEN-Saclay, F-91191 Gif-sur-Yvette, France
[2]Present address: CERN PPE, CH-1211 Geneva 23, Switzerland
[3]Present address: State University Utrecht, Utrecht, The Netherlands
[4]Deceased
[5]Present address: DEC, RDL 2B Queens House, Forbury road, Reading RG1 3JH, UK
[6]Present address: Institut für Mittelenergiephysik der ETH Zürich, CH-5232 Villigen PSI, Switzerland

1 Introduction

The low energy $\pi\pi$ scattering is in many respects one of the most interesting hadronic processes. Its simplicity and connection to chiral symmetry makes it a sensitive tool of low-energy QCD. As a means to study the pion-pion scattering the production of pions, $\pi p \to \pi\pi N$, close to the reaction threshold seems to be particularly suitable [1]. Historically, current algebra and PCAC made a number of firm predictions about the behaviour of the pion-nucleon and pion-pion interactions at low energy. Explicitly the amplitudes for $\pi p \to \pi\pi N$ at threshold were prescribed in terms of a single parameter ξ which is related to the structure of the chiral symmetry breaking term in the Lagrangian [2]. Weinberg's Lagrangian leads to a value of $\xi = 0$, whereas models put forward by Schwinger [1] attribute to ξ the values +1, +2, and -2. In QCD the chiral symmetry breaking occurs via the quark mass term ($\xi = 0$). A systematic non-perturbative QCD based description of low energy processes, has been developed as an expansion in powers of external momenta and of quark masses [3]. While pion-pion scattering has been examined in the framework of this theory and substantial corrections to the current algebra predictions were established, no calculation was performed to find the corresponding prediction for $\pi p \to \pi\pi N$ at threshold.

There exist a multiplicity of measurements of the cross-section of $\pi^- p \to \pi^-\pi^+ n$ and a few measurements of the other channels (see Ref. [4] for a review). The threshold behaviour of the amplitudes has been rendered uncertain by the lack of adequate statistics and complete kinematical information. To supplement the existing data we have performed good statistics, full kinematics measurements of the reactions $\pi p \to \pi\pi N$ using π^- and π^+ beams at several energies near threshold. The experiments were carried out with the Omicron spectrometer at the CERN SC. The apparatus and its performance were described in detail in Ref. [5]. Results of measurements of the reactions $\pi^- p \to \pi^-\pi^+ n$, $\pi^- p \to \pi^-\pi^0 p$ and $\pi^+ p \to \pi^+\pi^+ n$, were reported elsewhere [6]. In this contribution we compare our cross-sections with current-algebra calculations and give an account for discrepancies.

2 Results

From the many attempts to calculate cross-sections for $\pi p \rightarrow \pi\pi N$ reactions [2,7] within the framework of current algebra, the most elaborate is the one of Arndt et al. [8]. In their work, integrated cross-sections for all the $\pi p \rightarrow \pi\pi N$ reaction channels are calculated by summing diagrams up to the tree-level. The cases of $\xi = 0$ and $\xi = -2$ are evaluated. Comparison of our integrated cross-sections with their calculations is shown in Fig. 1.

The measured values for $\pi^- p \rightarrow \pi^-\pi^+ n$ are well above the $\xi = 0$ line which would result in a negative value of ξ. In our differential distributions we observed, however, the influence of a broad s-wave $\pi\pi$ resonance with a mass lying outside the invariant-mass region covered by our experiment. The fit of a relativistic Breit-Wigner resonance was very unstable and gave values around 600 MeV for the mass. The resulting width was comparable to the mass. On the other hand, we see no significant effects of Δ and ρ production in our data. Thus, we concluded that a broad s-wave resonance in the $\pi^-\pi^+$ system enhances the $\pi^- p \rightarrow \pi^-\pi^+ n$ cross-section even very close to threshold. Its influence makes this reaction unsuitable for simple studies neglecting isobar production.

The agreement of the measured $\pi^- p \rightarrow \pi^-\pi^0 p$ cross-section with the $\xi = 0$ tree-level calculation is remarkable. All the data points lie within 1σ from the prediction while the cross-section spans more than two orders of magnitude. No signs of isobar production were seen in the differential distributions, neither in the $\pi\pi$ nor in the πp systems, although the small number of events (up to 430) makes these statements somewhat weak. The absence of the structure in the $\pi^-\pi^0$ invariant-mass distributions fixes the $\pi\pi$ resonance isospin to $I = 0$.

The behaviour of the $\pi^+ p \rightarrow \pi^+\pi^+ n$ cross-section is twofold. Up to 360 MeV/c it lies above the $\xi = 0$ line, indicating a positive value for ξ. At higher momenta it flattens off and gets even below the $\xi = -2$ prediction. This kink in the cross-section we belive to be connected with the influence of the Δ^+ production in the final state, of which we see evidence in our differential distributions at momenta above 360 MeV/c. No other structure except for the reflection of the Δ^+ resonance is observed in the $\pi^+\pi^+$ system, confirming the isospin assignment to the $\pi\pi$ resonance.

3 Discussion

From the comparison made we conclude that the $\pi\pi$ system at low energies cannot be described by simple current-algebra calculations, the $\pi p \to \pi\pi N$ reaction bearing additional complications in terms of the πN isobars. A resonance-like behaviour is observed in the $\pi^-\pi^+$ system. We were unable to define precisely the mass and width of the resonance but the spin isospin and parity values of $I = 0, J = 0^+$ were determined. The absence of $\pi\pi$ resonances with $I = 1$ and $I = 2$ yields better agreement of $\pi^- p \to \pi^-\pi^+ n$ and $\pi^+ p \to \pi^+\pi^+ n$ cross-sections in the region where the influence of πN isobars is not significant. Even there, current algebra predictions differ for both reactions considered. As non-perturbative QCD calculations give substantial corrections to current-algebra $\pi\pi$ scattering-lengths, they might also clarify the threshold behaviours of the $\pi p \to \pi\pi N$ reaction cross-section. We hope that our data present enough motivation to theoreticians to perform the necessary calculations.

In order to clarify the behaviour of the $\pi\pi$ system in the $I = 0$ state a full kinematics measurement of $\pi^- p \to \pi^0\pi^0 n$ reaction in the threshold region would be highly appreciated. In addition, we have started to extract the fourth charged channel, $\pi^+ p \to \pi^+\pi^0 p$, for which we can quote a preliminary integrated cross-section of $(189 \pm 8 \pm 28)\mu b$ at $p_0 = 418\text{MeV/c}$.

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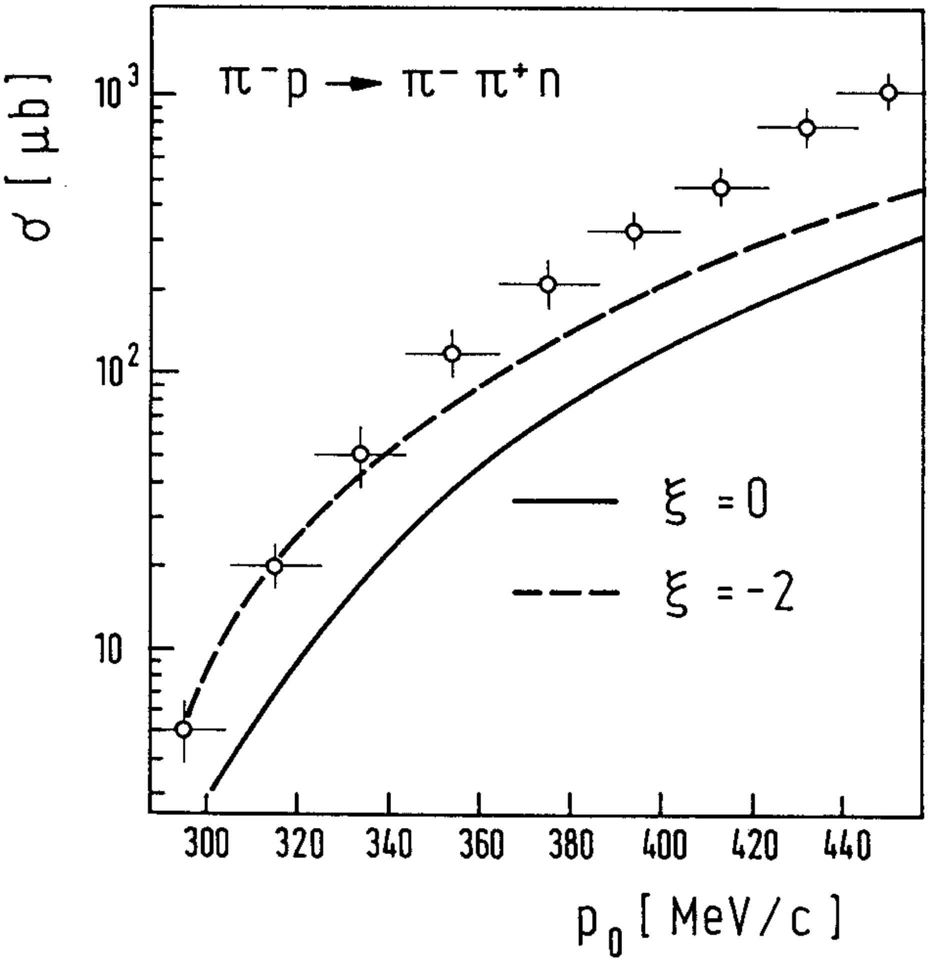
Figure captions

Figure 1 Measured integrated cross-sections for $\pi^- p \to \pi^- \pi^+ n$ (a), $\pi^- p \to \pi^- \pi^0 p$ (b) and $\pi^+ p \to \pi^+ \pi^+ n$ (c) in comparison with calculations of Arndt et al. [8].



π⁻p → π⁻ π⁺n
σ [μb]
10³
10²
10
ξ = 0
ξ = -2
300
320
340
360
380
400
420
440
p0 [MeV/c]

Fig. 1a

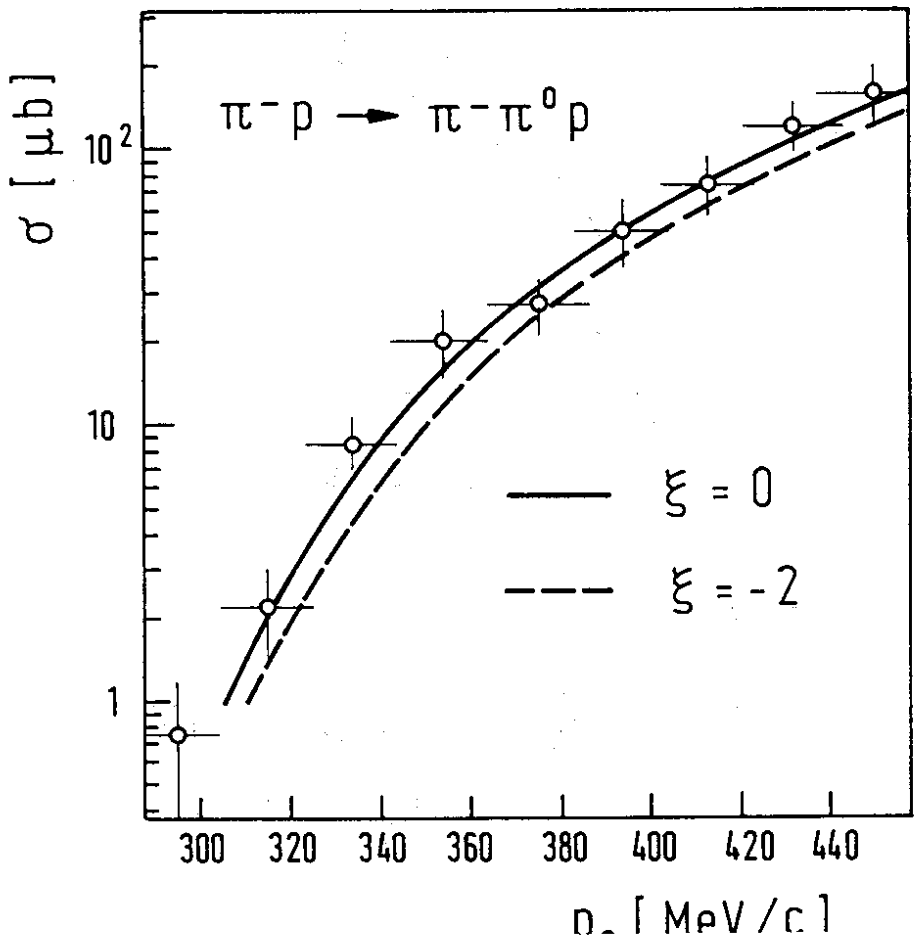


Fig. 1b

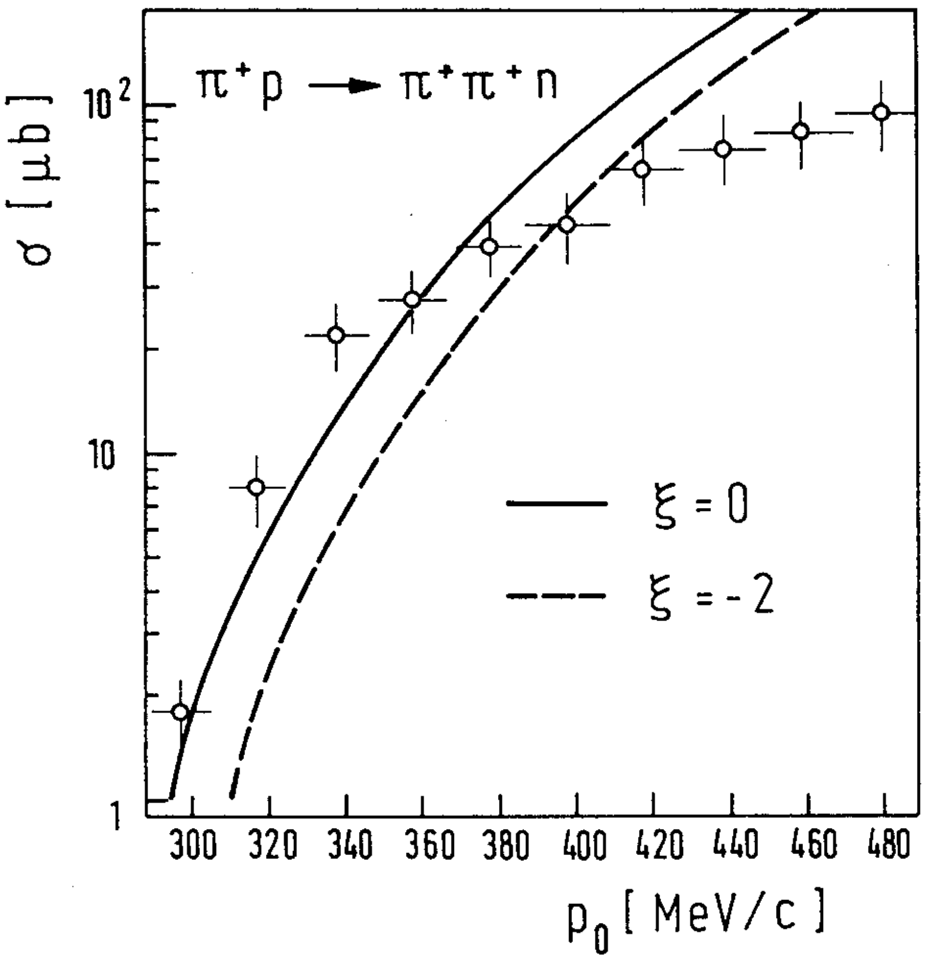


Fig. 1c

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