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A STUDY OF THE LOW-ENERGY PION-PION INTERACTION WITH $\pi p \rightarrow \pi\pi N$ REACTIONS NEAR THRESHOLD

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Abstract

Results of full-kinematics measurements of $\pi^-p \rightarrow \pi^+\pi^-n$, $\pi^-p \rightarrow \pi^-p\pi^o$ and $\pi^+p \rightarrow \pi^+\pi^+n$ reactions are presented. The experiment covered the incident momentum region from 295 to 450 MeV/c in 20 MeV/c steps and was performed with the OMICRON spectrometer at the CERN SC. Integrated cross-sections as well as differential distributions are shown. Effects of a strong I=0, $J^P=0^+$ $\pi\pi$ interaction are observed. Comparison is made with theoretical predictions based on current algebra and chiral symmetry. Extraction of the chiral symmetry breaking parameter ξ is discussed and a straightforward threshold extrapolation is shown to be inadequate.

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The reactions $\pi p \rightarrow \pi\pi N$ near threshold have long been considered as one of the possible sources of information on low energy pion-pion scattering. In the framework of the soft-pion model and chiral dynamics, Weinberg [1] calculated the pion-pion scattering lengths, while Olson and Turner [2] extended the calculation to $\pi p \rightarrow \pi\pi N$ reactions near threshold. The scattering lengths are related with the $\pi p \rightarrow \pi\pi N$ cross-sections near threshold and are found to be dependent on a single parameter ξ, which describes the way a chiral symmetry breaking term is incorporated in the phenomenological Lagrangian. The only other parameter, which enters the calculation is the pion decay constant (f_π), for which values between 82 and 94 MeV have been used, the first one corresponding to the Goldberger-Treiman relation and the second obtained from pionic decay.

One should note that the chiral predictions on the pion-pion scattering lengths are valid only if there is no other strong pion-pion intereaction, say a broad reasonance. The same is true for the predictions on $\pi p \rightarrow \pi\pi N$ cross-sections, where one must be able to neglect isobar production. These facts suggest measurements as near to the threshold as experimentaly feasible. In addition a full kinematics measurement is essential to monitor departures from the chiral dynamics mechanism.

Despite the great theoretical interest experimental data in the threshold region existed only for the $\pi^- p \rightarrow \pi^+\pi^- n$ channel and even there experiments suffered either from poor statistics or were performed without full knowledge of kinematics. The reason for that are small cross-sections which are at energies about 10 MeV above threshold five orders of magnitude smaller than those for elastic scattering.

We have performed a set of full-kinematics measurements of $\pi^- p \rightarrow \pi^+\pi^- n$, $\pi^- p \rightarrow \pi^- p\pi^o$ and $\pi^+ p \rightarrow \pi^+\pi^+ n$ in the incident momentum region from 295 to 450 MeV/c using a large volume magnetic spectrometer OMICRON and pion beams from the CERN SC. MWPC's and drift chambers were used to track the primary pion and both charged secondaries. Together with particle identification, based on TOF and pulseheight criteria this enabled us to reconstruct the missing mass of the neutral particle of the reactions in question.

The number of $\pi p \rightarrow \pi\pi N$ events extracted from raw data varied with the reaction channel and beam momenta from 90 to 1600 for $\pi^- p \rightarrow \pi^+\pi^- n$, 6 to 400 for $\pi^- p \rightarrow \pi^- p\pi^o$ and 30 to 200 for $\pi^+ p \rightarrow \pi^+\pi^+ n$. From these events integrated crosss-sections and differential distributions were obtained.

Table 1 shows the integrated cross-sections which are in a good agreement with

previous values in the region where data existed. One should note that our lovest datum point is only 11 MeV CMS kinetic energy above threshold in the $\pi^-p \rightarrow \pi^+\pi^-n$ case (17 MeV for $\pi^-p \rightarrow \pi^-p\pi^o$, 12 MeV for $\pi^+p \rightarrow \pi^+\pi^+n$).

$p_o \pm \Delta p$ [MeV/c]	$\sigma(\pi^-p \rightarrow \pi^+\pi^-n)$ [μb]	$\sigma(\pi^-p \rightarrow \pi^-p\,\pi^o)$ [μb]	$p_o \pm \Delta p$ [MeV/c]	$\sigma(\pi^+p \rightarrow \pi^+\pi^+n)$ [μb]
295±9	5.1±1.2	0.75±0.40	297±4	2,5±0.5
315±10	20±3.1	2.2±0.7	317±4	7.9±1.3
334±10	51±12	8.5±1.6	338±5	30±5
354±10	118±20	19±5	358±5	38±5
375±11	211±36	27±6	378±5	38±5
394±10	327±41	50±13	398±5	59±7
413±11	477± 56	73±21	418±5	73±16
432±11	785±104	104±17		
450±12	1052±125	157±37		

Table1: Integrated cross-sections for all reaction channels measured. P_o indicates the mean momentum and Δp the momentum spread.

The differential distributions show the following features:

a) $\pi^- p \rightarrow \pi^+ \pi^- n$

The pion-pion invariant mass distributions show large departures from phase space; they are peaked towards larger masses (Fig. 1). This effect, which has been previously observed at higher energies does not seem to vanish even in the data nearest to the threshold, although it is less clear due to the poor resolution of the apparatus.

From distributions of $\pi^{\pm}n$ invariant masses we conclude, that there is no strong evidence of Δ production.

The spectra of the π^- angle in the $\pi\pi$ CMS are isotropic and show no forward-backward asymmetry (Fig. 2). This excludes ρ production, and suggests that the two pions are in a relative s-state.

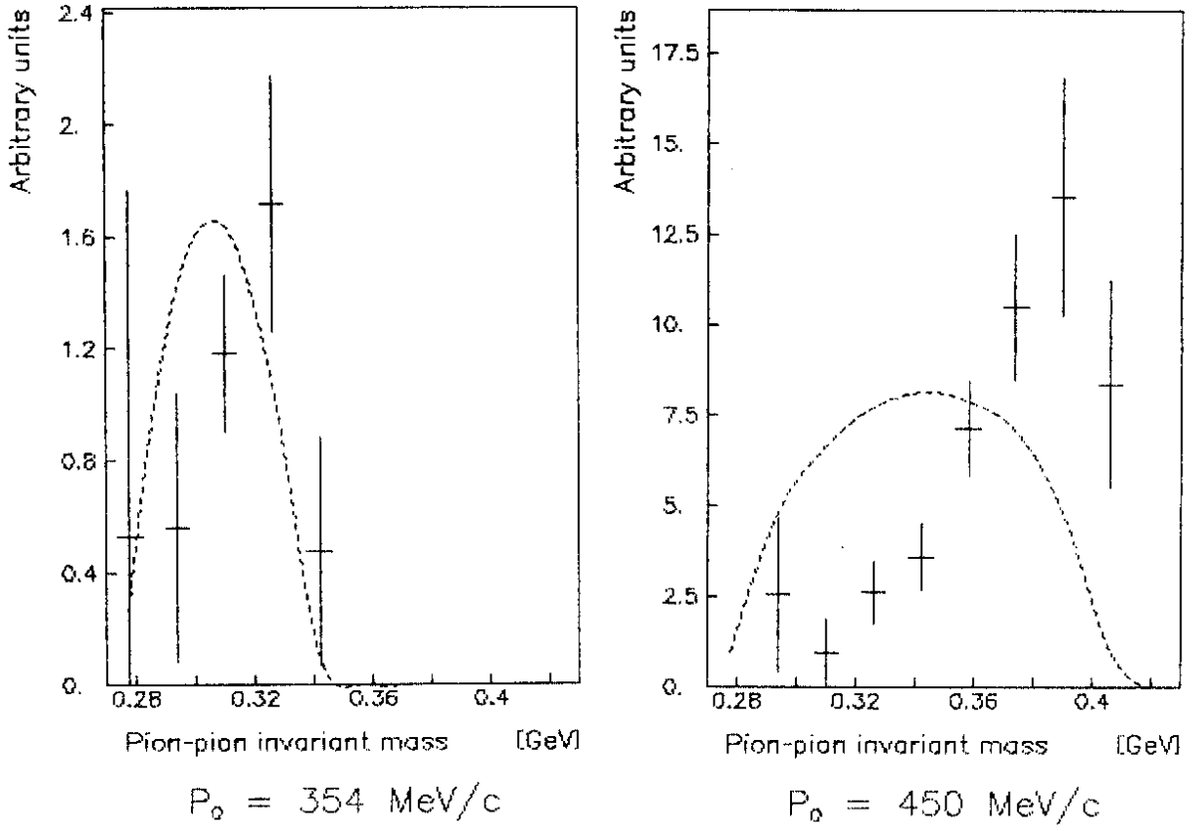

Figure 1: *$\pi^+\pi^-$ invariant mass spectra measured at 354 and 450 MeV/c. The dashed line represents the distribution according to phase space.*

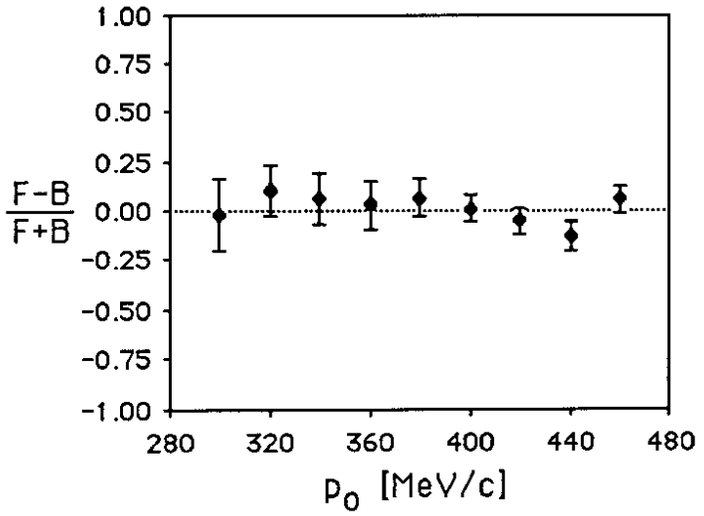

Figure 2: *The forward-backward assymetry of the π^- angle in the two-pion CMS.*

b) $\pi^- p \rightarrow \pi^- p \pi^o$ **and** $\pi^+ p \rightarrow \pi^+ \pi^+ n$

All differential distributions are consistent with phase space at lower energies. At higher enrgies effects of Δ production are observed in invariant mass distributions and they are more pronounced in the $\pi^+p \rightarrow \pi^+\pi^+n$ channel. In the pion-pion invariant mass spectra only the reflection of Δ production is observed at higher energies.

To summarize we conclude from diferential distributions that we see effects of a strong $I = 0$, $J^P = 0^+$ $\pi\pi$ interaction and that production of other isobars does not play an important role, especially not as energies approach the threshold.

To compare our data with theoretical threshold predictions, we divide our cross-sections with phase space x Q^2 (Q-CMS initial momentum) to obtain squares of reduced amplitudes (Fig. 3) which in the phenomenological Lagrangian framework are at threshold given by [2]

$$\begin{aligned} a(+-n) &= (82/f_\pi)^2 \mid 1.36 - 0.6\ \xi \mid \\ a(++n) &= (82/f_\pi)^2 \mid 1.51 + 0.6\ \xi \mid \\ a(+0p) &= (82/f_\pi)^2 \mid 0.53 + 0.21\ \xi \mid \end{aligned} \qquad (1)$$

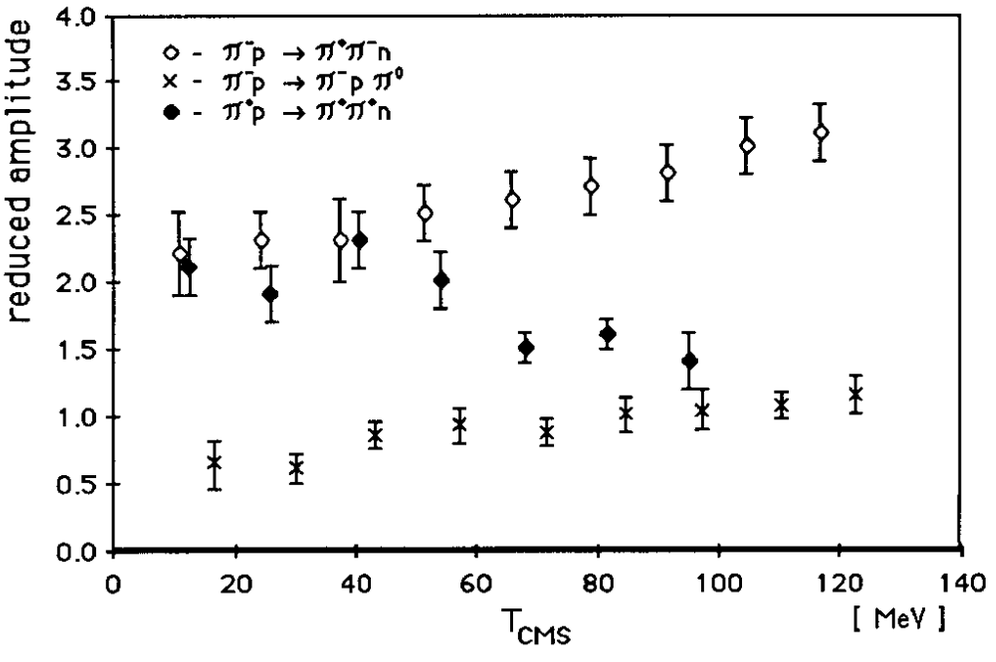

Figure 3: The plot of the reduced amplitude versus the total CMS kinetic energy for all three reaction channels measured.

This parametrisation should have its best application on the $\pi^+p \rightarrow \pi^+\pi^+n$ channel, where L = 1 relative angular momentum is forbiden by Bose statistics and a strong interaction with isospin at least two would be required to interfere. In Fig. 4 we see a band in the f_π - ξ plane which is consistent with the three datum points nearest to the threshold. We restrict ourselves to these points to minimize isobar production interference as we see from Fig. 3 that the a(++n) amplitude varies smoothly with the total CMS kinetic energy. We infer that for the value of ξ = 0 which has been proposed by Weinberg and found to be consistent with the quark model, an f_π value around 70 MeV would be required, while for accepted values of f_π we get for ξ values between 1 and 2. These values, together with ξ = - 2 have been proposed by Schwinger [3] as an alternative to ξ = 0.

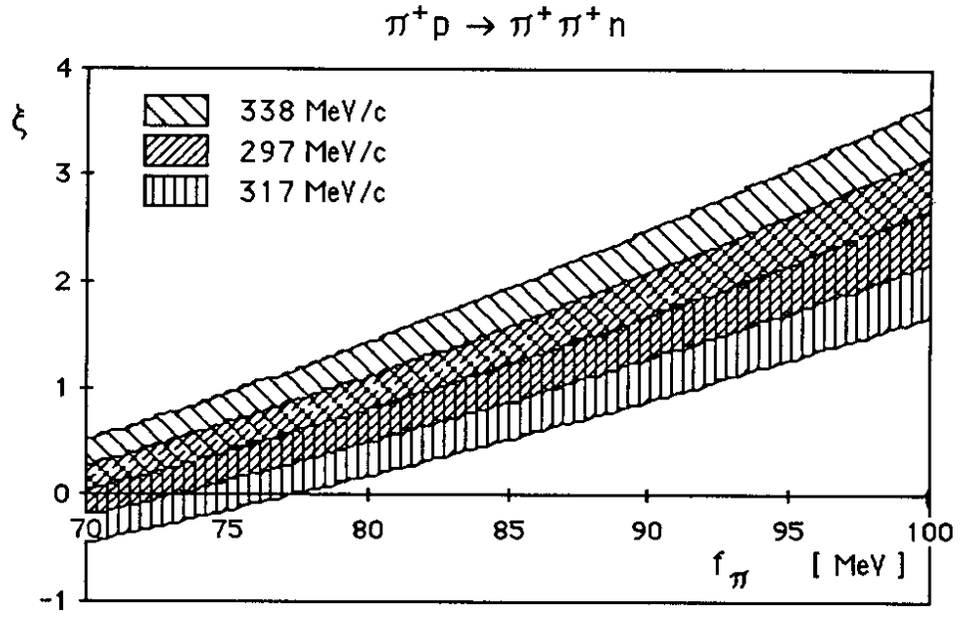

Figure 4: Bands in the f_π - ξ plane allowed by our lowest three datum points of the reaction $\pi^+p \rightarrow \pi^+\pi^+n$.

For the parametrization of the $\pi^-p \rightarrow \pi^-p\pi^o$ amplitude more care is needed because of the contribution of the asymmetric part of the amplitude ($I_{\pi\pi}$ = 1), which is not included in expresion 1. Its contribution to the cross section has been calculated by Arndt et al. [4] for ξ = 0 and found to be negligible at 295, 30 % at 315 and 50 % at 334 MeV/c. If we extract the symmetric part of the reduced amplitude and plot again in the f_π

- ξ plane the bands allowed by our lowest three datum points (Fig. 5), we find the value of $\xi = 0$ to coincide with f_π around the Goldberger-Treiman value of 82 MeV.

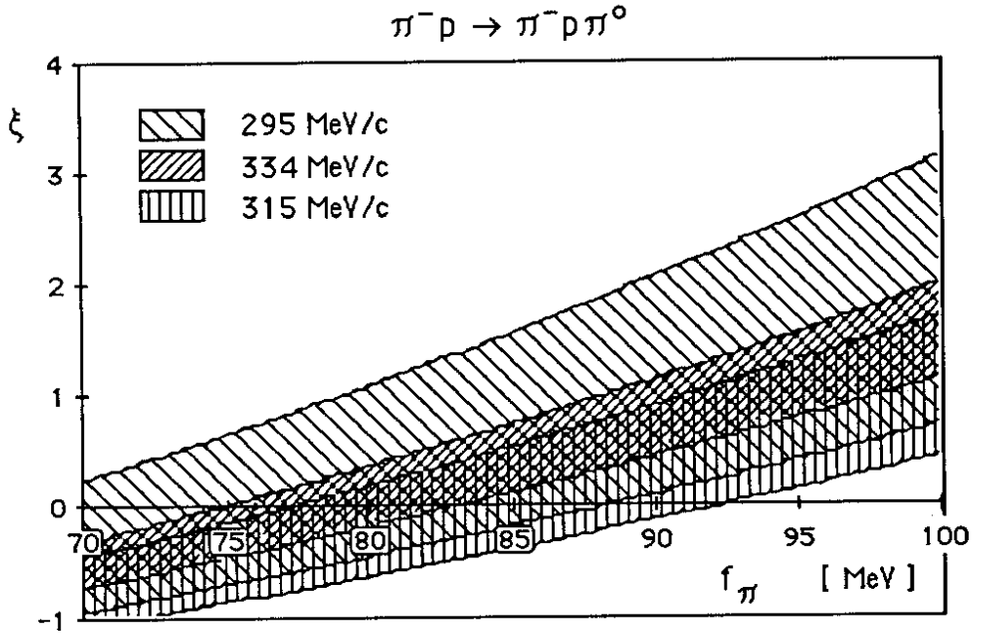

Figure 5: Bands in the f_π - ξ plane allowed by our lowest three datum points of the reaction $\pi^- p \to \pi^- p \pi^0$.

In the $\pi^- p \to \pi^+ \pi^- n$ channel we have observed a strong $\pi\pi$ interaction to contribute to the process. Several statements can be found in the literature about the threhsold behaviour of that contribution. In the latest calculation Oset and Vicente-Vacas [5] find a non-vanishing part of the threshold amplitude induced by the $\pi^- p \to N^* \varepsilon \to \pi^+ \pi^- n$ process. If ξ were 0 our data would require about half of the threshold amplitude being of non-chiral origin.

To conclude the data on $\pi^- p \to \pi^- p \pi^0$ and $\pi^+ p \to \pi^+ \pi^+ n$ cross-sections seem to be consistent with values of $\xi = 0$, although values of $\xi = 1$ or 2 are not excluded for some choices of f_π. In the $\pi^- p \to \pi^+ \pi^- n$ reaction effects of a strong $\pi\pi$ interaction are observed which enhance the cross-section even near threshold and inhibit a straightforward extraction of ξ.

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