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APPLICATION OF THE UNITARIZED VENEZIANO MODEL
TO THE VERY LOW ENERGY PION PRODUCTION

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A B S T R A C T

Lovelace's unitarized form of the $\pi\pi$ Veneziano amplitude predicts the behaviour of the S wave $I=0$ interaction. This is shown to give satisfactory agreement with the data for low energy $\pi N \rightarrow \pi\pi N$.

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In a previous paper ¹⁾, one of us presented a model for peripheral production of π in the momentum range 3-11 GeV/c. In this note we discuss the same reaction at very low energies (below $N^* \pi$ threshold). The production mechanisms in these two energy ranges are quite different. The former is dominated by π exchange and therefore many partial waves contribute to the initial πN state. In the latter case one knows, from πN phase shift analysis, which partial waves can contribute. Such information together with the assumption that higher angular momentum states are suppressed implies that the final $\pi \pi N$ state is dominated by the $\pi \pi S$ wave $I=0$ interaction. We shall show that the $\pi \pi$ phases resulting from a Veneziano model ^{2),3)} unitarized according to a prescription of Lovelace ⁴⁾ are compatible with experimental data.

In this context the most interesting feature of this model is the S wave $I=0$ phase shift. The main features are

- (i) a small scattering length $a_0 = 0.345 m_\pi^{-1}$
- (ii) ϵ resonance at 710 MeV with an enormous width ~ 500 MeV.

- (i) and (ii) inevitably imply
- (iii) a large effective range, $r_0 = -4.15 m_\pi^{-1}$.

The nature of the $\pi \pi$ interaction in the S wave $I=0$ state has, for a long time, been controversial. One explanation of the low energy anomaly was the proposed σ resonance ⁵⁾, a narrow width meson around 400-450 MeV while most analyses have favoured a broad resonance ϵ near the mass of the ρ ⁶⁾. Clearly, by property (ii), above the Veneziano-Lovelace model supports the ϵ . In this note we shall show how property (iii) is able to account for certain anomalies which previously had been attributed to the σ .

From πN phase shift analysis ⁷⁾, we know that up to $N^* \pi$ threshold the inelastic cross-section is dominated by the P_{11} wave which implies that the production of a $\pi \pi$ $J=I=0$

object is in an S wave relative to the nucleon. Furthermore, a $\pi\pi$ $J=I=1$ object and the nucleon would be in a relative P wave and would therefore be damped due to the centrifugal barrier. The threshold for $\pi N \rightarrow \pi N^*$ is approximately $T_\pi = 410$ MeV. In order to neglect πN final state interaction we should consider $T_\pi < 400$ MeV. Since πN^* must be in a relative P wave, this contribution is damped again by the angular momentum barrier. So we can compare our model with the data even beyond 400 MeV.

With this assumption about the S wave nature of the final state our amplitude becomes extremely simple and is just proportional to the $\pi\pi$ scattering amplitude ⁴⁾

$$A = \frac{2k}{\sqrt{s}} e^{i\delta_0^0} \cdot \sin\delta_0^0 \quad (1)$$

By assuming the cross-section for $\pi N \rightarrow \pi\pi N$ coming entirely from the inelastic $P_{11}\pi N$ wave then, in principle, the normalization is given by $\sigma = (\pi/q^2(1-\eta_0^0)^2)$ where q is the πN centre-of-mass momentum.

The very lowest energy data on $\pi N \rightarrow \pi\pi N$ are from emulsion experiments. In Fig. 1, we show a comparison with $\pi^-\pi^+$ mass distributions obtained by Batusov et al. ⁸⁾ for the process $\pi^-p \rightarrow \pi^-\pi^+n$ below 300 MeV. Kirz et al. ⁹⁾ carried out measurements on the same reaction in the range 360-780 MeV. They observed that at low energies the $\pi^-\pi^+$ mass peaked sharply around 400 MeV, but as the beam energy increased and the phase space correspondingly increased this peak moved upwards becoming less pronounced. This anomaly has often been believed to be evidence of the σ . The normalization in this case has been taken from the experimental $\pi N \rightarrow \pi\pi N$ cross-section.

In Fig. 2, we show the $\pi^-\pi^+$ mass distributions and our predictions at $T_\pi = 360, 430$ and 460 MeV. The characteristic features described above appear to be qualitatively well satisfied.

The "moving peak" can be explained by the rapid increase in δ_0^0 above threshold, i.e., large effective range. At 430 and 460 MeV, N^* production cannot be neglected since the $D_{13} \pi N$ partial wave is then inelastic, and we show improved fits corresponding to a coherent addition of a small background of πN^* in a relative S wave. In each case our curves are normalized to the experimental cross-section.

Figure 3 shows the results of a comparison with data by Barish et al.¹⁰⁾ at 374 MeV again for the process $\pi^- p \rightarrow \pi^- \pi^+ n$. At a fixed value of the lab. angle of the neutron θ_N the distribution in T_N , the kinetic energy of the neutron, shows a broad enhancement especially for small values of θ_N . This enhancement occurs at maximum values of $m_{\pi\pi}$ and therefore of $\sin^2 \delta_0^0$ in accordance with the model. Figure 4 shows the distribution in $\cos \theta_N$ which serves to determine the normalization of the curves in Fig. 3.

Thus the experimental evidence for supporting an S wave $I=0$ phase shift with properties given by the Veneziano-Lovelace model can be briefly listed as :

- a) - Peripheral pion production⁶⁾. In Ref. 1) it is shown that the unitarized Veneziano model describes the experimental data very well. Therefore the solutions⁶⁾ with broad ϵ are favoured by our model ;
- b) - Dispersion relation analysis of backward πN scattering^{7), 11)}. This is consistent with a broad ϵ ;
- c) - Analysis of $p\bar{p} \rightarrow 3\pi$ at rest. Hopkinson et al.¹²⁾ found evidence favouring the ϵ . Also Lovelace³⁾ has shown that the reaction $\bar{p}n \rightarrow 3\pi$ at rest is well fitted by the Veneziano formula ;

To this list we feel we can now add :

- d) - Pion production below πN^* threshold ;

- e) - $K\ell_4$ decay. It has been shown ¹³⁾ that this S wave phase shift is consistent with $K\ell_4$ decay but the data are not yet good enough to exclude other type of behaviour.

As far as we know, the only evidence against such a δ_0^0 is :

- 1) - The ABC ¹⁴⁾ effect. The experiment on $\pi d \rightarrow \text{He}^3 + 2\pi$ showed a significant enhancement near threshold which was thought to imply a large $\pi\pi$ scattering length ¹⁵⁾ if other final state interactions could be neglected ;
- 2) - A compilation now being undertaken at CERN in which a small but significant structure in $\pi^+\pi^-$ distributions is seen at 480 MeV ¹⁶⁾. Also Bunyatov et al. ¹⁷⁾ saw an enhancement around 500 MeV in $\pi^0\pi^0$.

Our conclusion which is based upon the results of Ref. ¹⁾ and those presented here together with the consistency of the phase shifts for $K\ell_4$ decay, is that the unitarized version of the $\pi\pi$ Veneziano amplitude is able to describe successfully a large range of experimental data.

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FIGURE CAPTIONS

- Figure 1 $\pi^- \pi^+$ mass distributions for the process $\pi^- p \rightarrow \pi^- \pi^+ n$. Data from Ref. ⁸⁾. Solid lines according to Eq. (1). Dashed curves represent phase space.
- Figure 2 $\pi^- \pi^+$ mass distributions for the process $\pi^- p \rightarrow \pi^- \pi^+ n$. Data from Ref. ⁹⁾. Solid curves according to Eq. (1). Dot-dashed curves correspond to addition of N^* background. Dashed curves represent phase space.
- Figure 3 Distributions in T_N , the kinetic energy of the neutron for various values of θ_N , the direction of the neutron, for the process $\pi^- p \rightarrow \pi^- \pi^+ n$ at 374 MeV. (Both quantities measured in lab. system.) Data from Ref. ¹⁰⁾. Solid curves according to Eq. (1). Normalization given by fitting the $\cos \theta_N$ distribution of Fig. 4. Dashed curves represent phase space.
- Figure 4 Distribution in $\cos \theta_N$, the direction of the neutron, for the process $\pi^- p \rightarrow \pi^- \pi^+ n$ at 374 MeV, measured in the lab. system. Data from Ref. ¹⁰⁾. Solid curve according to Eq. (1). Dashed curve represents phase space.

FIG. 3

FIG.4