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DUAL PROPERTIES OF STRANGENESS ANNIHILATION PROCESSES

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ABSTRACT

The dual properties of strangeness annihilation processes are studied. Experimental evidence is presented for such processes building up a low-lying Regge singularity. Quark-diagram arguments suggest that this singularity is the exchange degenerate $f'-\phi$ trajectory. The possibility of studying the factorization properties of strangeness annihilation processes using hyperon beams is pointed out.

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1. INTRODUCTION

Strangeness annihilation processes, such as

$$\bar{K} + K \rightarrow \text{pions} , \quad (1)$$

are expected to possess rather special dual properties. Naive quark-diagram arguments suggest that (a) such processes should always proceed via production and decay of resonances (i.e., there should be no non-resonant background) and (b) the produced resonances should be dual to a Regge singularity with the quark content of $\lambda\bar{\lambda}$ in the crossed channel of the elastic amplitude (see Fig. 1.a). The leading singularity with such an unusual quark content is the exchange degenerate $f'-\phi$ trajectory with intercept $\alpha_{\phi}(0) \approx 0$. Hence one expects the total annihilation cross-section to die away rapidly with increasing energy :

$$\sigma(\bar{K} + K \rightarrow \text{pions}) \sim s^{-1} . \quad (2)$$

Furthermore, (c) non-annihilation processes of the type ^{*})

$$\bar{K} + K \rightarrow \bar{K} + K + \text{pions} \quad (3)$$

are expected to obey normal duality, i.e., resonances being dual to the ordinary meson trajectories with intercept $\alpha_M(0) = 0.5$ and background to the Pomeron (see Fig. 1.b).

Such predictions for on-shell $\bar{K}$ -K scattering cannot, of course, be directly tested experimentally. However, it is possible to obtain information on the forward amplitude when one of the kaons is a Reggeon. For inclusive reactions in the appropriate Regge region, the cross-section is related, through the generalized optical theorem ¹⁾, to the Reggeon-particle forward scattering amplitude. Hence, by studying inclusive spectra one can learn about the properties of such amplitudes. In particular we can indirectly study the dual properties of $\bar{K}$ -K scattering by considering an inclusive process such as $K^-p \rightarrow \Lambda X$ which

^{*}) $K\bar{K}$ - pairs can also be produced in the annihilation process. This, however, is a minor effect and will be ignored in the present discussion.

is proportional to K^* (or K) Reggeon $-\bar{K}$ scattering which, in turn, should exhibit similar duality behaviour.

Our results provide good evidence in favour of the above predictions (b) and (c). Prediction (a) is hard to test but it is certainly not inconsistent with the data. The annihilation cross-sections turn out to be very large, which implies a particularly large contribution of the $f'\phi$ exchange.

2. REGGE DESCRIPTION OF INCLUSIVE STRANGENESS ANNIHILATION PROCESSES

Consider the process

$$K^- + p \rightarrow \Lambda + X, \quad (4)$$

for Λ in the proton fragmentation region, where X stands for anything. From Fig. 2 we see that, in this situation, the inclusive cross-section is proportional to the total cross-section for off-shell $"K^+"-K^-$ scattering. This is then related through the optical theorem to the forward $"K^+"-K^-$ scattering amplitude.

The generalized optical theorem requires a summation over a complete set of states X . In some special cases, however, the theorem may also be applicable to "semi-inclusive" processes in which the summation is performed over a certain limited set of states only, if proper care is exercised in the interpretation of the results. The strangeness annihilation process

$$K^- + p \rightarrow \Lambda + \text{pions} \quad (5)$$

provides an example.

Quark-diagram arguments illustrated in Fig. 1 strongly suggest that the annihilation process (5) builds up a Regge exchange contribution to process (4) which is different from that built up by the non-annihilation processes

$$K^- + p \rightarrow \Lambda + K\bar{K} + \text{pions} \quad (6)$$

which form the remainder of the inclusive process. Thus it is possible to discuss the energy dependence of semi-inclusive processes (5) and (6) separately in the Regge language, instead of their sum, process (4).

As discussed above, we assume that the process (5) exhibits the same dual properties as process (1). Thus we expect the cross-section of this semi-inclusive process (5) to be dominated by the $f'\text{-}\varphi$ exchange. Similarly, the non-annihilation processes (6) should exhibit the same dual properties as the processes (3) and build up the Pomeron ($\alpha_P(0) = 1$) and the leading ordinary meson f , ρ , ω and A_2 [$\alpha_M(0) = 0.5$] exchanges in the $\bar{K}K$ -channel.

Guided by the above consideration we write for the invariant cross-section of the process (4).

$$f(p \xrightarrow{K^-} \Lambda) = A_P\left(\frac{M^2}{s}, t\right) + A_M\left(\frac{M^2}{s}, t\right) \frac{1}{\sqrt{s}} + A_\phi\left(\frac{M^2}{s}, t\right) \frac{1}{s} \quad (7)$$

The first two terms correspond to the non-annihilation processes (6) and the third to the annihilation process (5).

3. ANALYSIS OF EXPERIMENTAL DATA

How can Eq. (7) be tested experimentally? A straightforward way would be to separate the annihilation and non-annihilation components directly from experimental data and to study their energy dependence at fixed values of M^2/s and t . At higher energies, however, a clear separation is impossible because of the difficulty in distinguishing fast kaons from fast pions in bubble chamber experiments ^{*}).

Another way to test the prediction Eq. (7) is to use factorization to estimate the contributions of the Pomeron and the ordinary meson trajectories from other Λ production processes such as

$$a + p \rightarrow \Lambda + X \quad ; \quad a = p, \pi^+, K^+ \quad (8)$$

$$a + p \rightarrow \Lambda + X \quad ; \quad a = \bar{p}, \pi^-, K^-. \quad (9)$$

^{*}) Existing estimates of these two components ²⁾ seem to be consistent with Eq. (7) within large uncertainties.

The processes (8) are so-called $(ab\bar{c})$ exotic ³⁾ and can be used to estimate the Pomeron contribution, while processes (8) and (9) together enable us to estimate the ordinary meson contribution. Combined with Regge pole model of residues in two-body scattering, the factorization of ρ and ω exchange predicts

$$\begin{aligned} f(p \xrightarrow{\pi^-} \Lambda) - f(p \xrightarrow{\pi^+} \Lambda) : f(p \xrightarrow{\bar{p}} \Lambda) - f(p \xrightarrow{p} \Lambda) : \\ \left[f(p \xrightarrow{K^-} \Lambda) - f(p \xrightarrow{K^+} \Lambda) \right]_{\rho+\omega} = 1 : 1.8 : 1 \end{aligned} \quad (10)$$

Figure 3 presents a compilation of cross-sections in the proton fragmentation region of the processes (4), (8) and (9) ⁴⁾. Approximate equality of cross-sections of the three exotic processes (8) ^{*}) when normalized by the asymptotic total cross-sections $\sigma_{ap}^{TOT}(\omega)$ ^{**)} shows the validity of Pomeron factorization. Comparison between the cross-sections of π^-p and $\bar{p}p$ processes also indicates that data are consistent with factorization of the ordinary meson trajectory exchange. We would normally expect normalized cross-sections in π^- , $\bar{p}$ and K^- induced processes to be approximately equal to each other. However, we see that the spectrum for process (4) lies considerably above the other processes (8) and (9). The difference between the measured spectrum of the K^-p process and the sum of the Pomeron and meson exchange contributions estimated from factorization is seen to decrease rapidly with increasing energy, indicating a low intercept of the corresponding trajectory in the $K\bar{K}$ channel. A quantitative estimate gives $\alpha(0) \approx 0$ in consistency with Eq. (7).

It seems to us safe to estimate cross-sections for non-annihilation processes (6) by putting $\sigma[\Lambda(K\bar{K})] \approx \sigma(\Lambda K_n) = 2\sigma[\Lambda(K^0\bar{K}^0)] + \sigma[\Lambda(K^+\bar{K}^0)] + \sigma[\Lambda(K^0\bar{K}^-)]$. The non-annihilation cross-section thus calculated (shown by a cross in Fig. 3) is in accord with the sum of the Pomeron and ordinary meson contributions estimated by factorization. This strongly supports the quark-diagram prediction (c) that the strangeness non-annihilation processes are dual to the Pomeron and ordinary meson trajectories f , ρ , ω , and A_2 .

^{*}) The cross-sections of these exotic processes are slowly rising with increasing energy. At low energies ($p_{lab} \lesssim 10$ GeV/c) this rise is presumably a threshold effect but at high energies we attribute it to the dynamics of the Pomeron contribution. Recall rising K^+p cross-sections in this connection.

^{**)} We take the following values $\sigma_{pp} = \sigma_{\bar{p}p} = 39$ mb, $\sigma_{\pi^\pm p} = 24$ mb and $\sigma_{K^\pm p} = 18$ mb.

Another process in which strangeness annihilation can be studied is

In the backward fragmentation region, the system $(p\bar{K}^0)$ forms an off-mass shell "Y". This "Y" collides with the beam particle K^+ forming a double-charged non-strange baryon state (Δ^{++}) . The process (11) is especially suitable for a study of the annihilation component because the ordinary meson exchanges are expected to be absent (this can easily be seen by enumerating legal quark-diagrams) ⁵⁾. On the other hand in other K^0 production processes like

one should expect no $f'-\varphi$ exchange. In the proton fragmentation region the K^0 production cross-section is presumably well approximated by twice the K_S^0 cross-section except for the K^-p process, where $\bar{K}^0$ production might be substantial and invalidate this approximation.

The experimental results ⁴⁾ on the energy dependence of the spectra of the processes (11) and (12) ($a = \pi^\pm, p, K^-$) are summarized in Fig. 4. Firstly, the spectra of the exotic processes, i.e., $a = \pi^+$ and p are consistent with weak energy dependence. Secondly, the cross-section for the process (11) is much larger than for the other processes at low energies and decreases rapidly as the energy increases. A quantitative estimate shows that the energy dependence of the spectra is consistent with the power law $\sim s^{-1}$. Altogether the data of the processes (11) and (12) provide good additional support for Eq. (7).

The test of prediction (a) that the annihilation occurs only via resonance formation is difficult. The reasons are the following : (i) The test involves a difficult experimental procedure of separating cross-sections into annihilation and non-annihilation components. (ii) Semi-local duality applied to inclusive reactions ⁶⁾ argues that the low intercept of the exchanged Reggeon, i.e., K or K^* in our case, favours excitations of heavy mass-resonances. Such resonances are considered to be broad and strongly overlapping and hence hard to observe. In the low missing mass region, however, resonances are relatively narrow and well separated. We have examined data ⁷⁾

relevant to the problem and find no apparent experimental contradiction to prediction (a).

4. DISCUSSION AND SUMMARY

We have had to rely on a rather indirect procedure to separate the strangeness annihilation component from the non-annihilation background in the processes studied. Although this might influence the quantitative side of our results, we believe that the qualitative picture emerging from our analysis is a correct one : The strangeness annihilation processes are dual to a low-lying Regge singularity different from the Pomeron and ordinary meson trajectories. It is tempting to follow the suggestion of the quark-diagrams and to identify this singularity with the exchange degenerate $f'-\phi$ trajectory.

This identification has an immediate consequence for the $SU(3)$ symmetry property of the nonet meson exchanges. $SU(3)$ symmetry plus the ideal mixing angle relates the ϕ coupling $g_{\phi K\bar{K}}$ to the ρ and ω couplings $g_{\rho K\bar{K}}$ and $g_{\omega K\bar{K}}$ so that $g_{\phi K\bar{K}}^2 = g_{\rho K\bar{K}}^2 + g_{\omega K\bar{K}}^2$. If the "K⁺" Reggeon exchanged in the $p\bar{\Lambda}$ -channel (see Fig.2) is also a member of an $SU(3)$ octet, such as K^{*+} or K^+ , one would expect that the ordinary meson contribution and the $f'-\phi$ contribution are similar in size. The large annihilation cross-sections shown in Fig. 3 and Fig. 4 imply that either $SU(3)$ is badly broken or that there is a substantial contribution from exotic "K⁺" exchange. A recent experiment ⁸⁾ finds a rather low intercept and a flat slope for the "K⁺" trajectory, which does not exclude the latter possibility.

Future hyperon beam experiments will provide information about the analyticity structure of the J -plane singularity dual to the strangeness annihilation processes. Factorization relations between the invariant annihilation cross-sections such as

$$f(p \xrightarrow{H} \Lambda) \cdot f(p \xrightarrow{K^+} K^0) = f(p \xrightarrow{K^-} \Lambda) \cdot f(p \xrightarrow{\bar{H}} K^0) \quad (13)$$

where H and $\bar{H}$ are hyperon and antihyperon beams, could be badly violated if exchanges other than the $f'-\phi$ pole contribute significantly.

Finally, let us remark on the importance of studying the behaviour of exclusive strangeness annihilation processes as well as the multiplicity structure of strangeness annihilation. The problem of building up smooth Regge

trajectories from strongly energy dependent exclusive processes is a very important problem in hadron physics. A careful study of such building of Regge trajectories in strangeness annihilation processes and comparison with other types of process might well shed new light on this difficult problem. Some hints in this direction are already given by recent results of the Athens-Democritus-Liverpool-Vienna Collaboration ⁹⁾ which indicate that multiplicity distributions of strangeness annihilation processes behave differently from those of most other processes.

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FIGURE CAPTIONS

Figure 1 : (a) Illustration of the strangeness annihilation process building up a Regge trajectory with $\lambda\bar{\lambda}$ quark content.
(b) Illustration of the non-annihilation processes building up ordinary meson and Pomeron trajectories.

Figure 2 : The inclusive strangeness annihilation process $K^- + p \rightarrow \Lambda + \text{pions}$.

Figure 3 : Normalized invariant cross-sections of various inclusive Λ production processes integrated over the x -interval $-0.9 \leq x \leq -0.5$ as a function of s^{-1} . Our theoretical interpretation of the data is indicated in the figure [the dash-dotted (dash-double dotted) line represents the sum of the Pomeron and meson contributions in K^-p (π^-p) process]. The errors shown include systematic uncertainties when available as well as statistical errors.

Figure 4 : Normalized invariant cross-sections of various inclusive K^0 production processes integrated over the x -interval $-0.7 \leq x \leq -0.5$ as a function of s^{-1} . Our theoretical interpretation of the data is indicated in the figure.

FIG.1a

FIG.1b

$$\sigma_p(K^- + K^+ \rightarrow \bar{K} K + \text{pions}) = \sum_{\bar{K} K \text{ pions}}$$

= Disc.

FIG.1b continued

FIG. 2

FIG. 3

FIG. 4