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p DOMINANCE AND REGGE COUPLINGS IN INCLUSIVE REACTIONS*

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ABSTRACT

The ρ Regge pole residues are calculated under the assumption of ρ dominance of the isovector, even G parity component of inclusive reactions. The calculated residues compare well with total cross section data and allow successful predictions of the charge dependence of pion production in the central region. Serious difficulties are encountered with the assumption of $P + f$ dominance of the isoscalar, even G parity component.

Recently data on pion production in the central or pionization region has become sufficient to allow tests of the Mueller double Regge analysis [1]. Surprisingly, even at low s , the squared center of mass energy, these data are consistent with an $s^{-1/4}$ approach toward the asymptotic scaling limit [2], where the P-P (double Pomeranchukon) term dominates [3]. This $s^{-1/4}$ behaviour is consistent with ρ -P dominance of the charge dependent component of pionization, and P-P plus f-P dominance of the charge independent component. In this paper we further investigate the former of these two hypotheses and find it to be remarkably successful. Throughout we assume that only the conventional (isolated and factorizable) Regge singularities are present, later we comment on the possible need for new isoscalar singularities.

The hypothesis of ρ -P dominance of the charge dependent component of pionization is an especially strong one, since, from it, expressions for the ρ Regge couplings can be derived. These expressions follow solely from ρ dominance and charge conservation; and, with the help of independent experimental data, allow the ρ Regge couplings to be calculated [4]. Thus the assumption of ρ dominance yields the magnitude, as well as the energy dependence, of the charge dependent component of pionization. Our procedure below is first to derive these expressions, and, then, to test the calculated couplings against experimental data.

First we consider the double Regge coupling $\gamma_{\rho P}^{\pi}$ for a produced pion with ρ and P exchanged. For any incident pair of particles ab , consider the cross section for simultaneous production of a π^+ at center of mass rapidity $y_1 = 0$ and a π^+ or π^- at a rapidity y_2 also in the central region, as shown in Fig. 1a. Form the difference

between these two cross sections:

$$\Delta_{\pi^+}(y_2) = \sigma_{\infty}^{-1} \left\{ \frac{d^2\sigma}{dy_1^{\pi^+} dy_2^{\pi^+}} \bigg|_{y_1=0} - \frac{d^2\sigma}{dy_1^{\pi^+} dy_2^{\pi^-}} \bigg|_{y_1=0} \right\} \quad (1)$$

where σ_{∞} is the asymptotic ab total cross section.

Since, to a good approximation, non-pions are rarely produced in the central region, $\Delta_{\pi^+}(y)$ is just the average charge emitted at y_2 given a π^+ at $y_1 = 0$. Thus charge conservation requires

$$\int_{-\infty}^{\infty} dy_2 \Delta_{\pi^+}(y_2) = -\gamma_{pp}^{\pi} \quad (2)$$

to insure no net production of charge in the central region. Here γ_{pp}^{π} is the double Regge coupling of a produced pion with two exchanged Pomeranchukons:

$$\frac{1}{\sigma_{\infty}} \frac{d\sigma}{dy} \bigg|_{y=0} \xrightarrow{s \rightarrow \infty} \gamma_{pp}^{\pi} \quad (3)$$

In Eq. (2) we are free to take infinite limits and still assume we remain in the central region, since we can choose the incoming energy arbitrarily high.

For $|y_2|$ large, $\Delta_{\pi^+}(y_2)$ is dominated by the P- ρ -P multiple Regge contribution shown in Fig. 1a:

$$\Delta_{\pi^+}(y_2) \bigg|_{|y_2| \text{ large}} = 2(\gamma_{\rho P}^{\pi})^2 \exp\left\{-(1-\alpha_{\rho})|y_2|\right\} \quad (4)$$

where α_{ρ} is the ρ Regge intercept. Eq. (4) is independent of a and b due to the σ_{∞}^{-1} in Eq. (1) and our assumption of a factorizable Pomeranchukon. We propose that this P- ρ -P term be taken as an approximation, in the sense of a finite energy sum rule, to $\Delta_{\pi^+}(y_2)$ for $|y_2|$

small as well as large. This assumption is just a definite formulation of what we mean by ρ dominance. Then

$$\int_{-\infty}^{\infty} dy_2 \Delta_{\pi^+}(y_2) = 2(\gamma_{\rho P}^{\pi})^2 \int_{-\infty}^{\infty} dy_2 \exp \left\{ -(1-\gamma_{\rho}) |y_2| \right\} \quad (5)$$

and, from Eqs. (2) and (5)

$$(\gamma_{\rho P}^{\pi})^2 = \frac{1-\alpha_{\rho}}{4} \gamma_{PP}^{\pi} \quad (6)$$

Eq. (6) is a specific test of our assumption of ρ dominance: given [3] $\gamma_{PP}^{\pi} = .76$ we predict, for $\alpha_{\rho} = .5$, $\gamma_{\rho P}^{\pi} = .31$. However, before explicit tests can be made, it is necessary to extend the argument further.

Next consider a target particle a^+ with rapidity y_a and an arbitrary beam particle b . As above, for $\Delta_{a^+}(y)$, the net charge produced in pions at a rapidity y (see Fig. 1b):

$$\Delta_{a^+}(y) = \sigma_{\infty}^{-1} \left\{ \frac{d\sigma}{dy^{\pi^+}} - \frac{ds}{dy^{\pi^-}} \right\} \quad (7)$$

Here charge conservation implies

$$\int_{-\infty}^{y_a} dy \Delta_{a^+}(y) + c_{a^+} = 1 \quad (8)$$

where c_{a^+} , which is the net charge for non-pion final states, must be included since non-pions frequently appear in the fragmentation region. Again, for $|y-y_a|$ large, the ρ -P double Regge term shown in Fig. 1b is dominant:

$$\Delta_{a^+}(y) \Big|_{|y-y_a| \text{ large}} = 2x_{\rho a} \gamma_{\rho P}^{\pi} \exp \left\{ -(1-\alpha_{\rho}) |y-y_a| \right\} \quad (9)$$

where

$$x_{\rho a} = \frac{\beta_{\rho aa}}{\beta_{Paa}} \quad (10)$$

and β_{Raa} ($R=P, \rho$) is the usual Regge-particle-particle factorized residue which appears also in expressions for the total cross section. (This is true in strong ordered multiperipheral models, e. g. [4].) Now our ρ dominance assumption yields

$$x_{\rho a} \gamma_{\rho P}^{\pi} = \frac{1-\alpha_{\rho}}{2} (1-c_{a+}) \quad (11)$$

Fortunately, it is easy to specify c_{a+} from experiment; the only non-pion present can be assumed to be the leading particle: $c_p = \langle n_p \rangle$, the expected number of protons emerging given an incident proton,

$c_{K^+} = \langle n_{K^+} \rangle$ and $c_{\pi^+} = 0$. With the experimental input [5,6] of $\langle n_p \rangle = .63$, $\langle n_{K^+} \rangle = .6$, we predict

$$x_{\rho p} = .31, \quad x_{\rho \pi} = .82, \quad x_{\rho K} = .30 \quad (\text{GeV}/c)^{1/4} \quad (12)$$

Taking a representative Regge fit for total cross sections [7]:

$$\frac{\sigma_{ab}^{ab}(s)}{\sigma_{\infty}^{ab}} = 1 + x_{\rho a} x_{\rho b} s^{-1/2} + x_{fa} x_{fb} s^{-1/2} + \dots \quad (13)$$

we can compare our predicted values for $x_{\rho \pi} x_{\rho p} = .25$ to the experimentally measured .21 and our prediction for $x_{\rho K} x_{\rho p} = .11$ to the measured (here we have added ρ - A_2 exchange degeneracy) .10. Thus, considering the experimental uncertainties involved in the specification of c , and our complete neglect of non-pion production, the assumption of ρ dominance is quite successful.

Further tests of Eqs. (6) and (12) can be made for pion production in the central region. For the inclusive reaction $a+b \rightarrow c+X$,

define $f_{ab \rightarrow c}$ by

$$f_{ab \rightarrow c} = \frac{1}{\sigma_{ab}^{\infty}} \frac{d\sigma}{dy_{ab \rightarrow c}} \Big|_{y=0} \quad (14)$$

and

$$\Delta_{ab} = f_{ab \rightarrow \pi^+} - f_{ab \rightarrow \pi^-} \quad (15)$$

Assuming ρ -P dominance,

$$\Delta_{ab} = A_{ab} p^{-1/4} \quad (16)$$

where p is the laboratory momentum of the projectile and

$$A_{ab} = (2M)^{-1/4} 2(x_{\rho a} + x_{\rho b}) \gamma_{\rho P}^{\pi} \quad (17)$$

Here M is the nucleon mass, and we assume a nucleon target. In Table 1, we list our predictions for A_{ab} . Similarly, for a and a' in the same isomultiplet, we can define

$$\Delta_{(a-a')b \rightarrow c} = f_{ab \rightarrow c} - f_{a'b \rightarrow c} \quad (18)$$

$$= B_{(a-a') \rightarrow c} p^{-1/4} \quad (19)$$

where

$$B_{(a-a') \rightarrow c} = (2M)^{-1/4} (x_{\rho a} - x_{\rho a'}) \gamma_{\rho P}^{\pi} \quad (20)$$

is independent of particle b as a consequence of factorization and our assumption of ρ -P dominance. We list our predictions for B in Table 2.

Data [8] on $\pi^{\pm} p \rightarrow \pi^{\pm}$ offer a clean test of these predictions, as $f_{ab \rightarrow c}$ has been measured for all four processes. To compare our predictions to these data, we have taken Ferbel's fit [3] for $f_{\pi^+ p \rightarrow \pi^-}$ as given; then $f_{\pi^+ p \rightarrow \pi^+}$ and $f_{\pi^- p \rightarrow \pi^{\pm}}$ are predicted from eqs. (17) and (18). As is evident in Fig. II, the predictions for all three are successful.

These predictions can also be tested against data [9] on $pp \rightarrow \pi^\pm$ and $pn \rightarrow \pi^\pm$. Here there are several data on $pp \rightarrow \pi^-$, for which we again take Ferbel's fit [3] as given. Our predictions for $pp \rightarrow \pi^+$ and $pn \rightarrow \pi^\pm$ are shown in Fig. 3, along with two extant data on $pp \rightarrow \pi^+$, which are in agreement with our predictions. For $K^+p \rightarrow \pi^\pm$ and $\gamma p \rightarrow \pi^\pm$, there is insufficient data to test the predictions given in Tables 1 and 2.

At a less ambitious level, the hypothesis of ρ -P dominance can be tested, independently of our coupling constant predictions, via the relations

$$f_{\pi^- b \rightarrow \pi^+} + f_{\pi^- b \rightarrow \pi^-} = f_{\pi^+ b \rightarrow \pi^+} + f_{\pi^+ b \rightarrow \pi^-} \quad (21)$$

$$f_{a p \rightarrow \pi^+} + f_{a p \rightarrow \pi^-} = f_{a n \rightarrow \pi^+} + f_{a n \rightarrow \pi^-} \quad (22)$$

which are violated if significant ρ - ρ or A_2 - A_2 double Regge contributions are present. Here a and b are arbitrary particles. For $b = p$, as is evident from Fig. 2, Eq. (21) is in good agreement with experimental data.

The further assumption of factorizable ρ and P Regge poles can also be tested by the relations

$$f_{pp \rightarrow \pi^+} - f_{pp \rightarrow \pi^-} = 2(f_{\pi^- p \rightarrow \pi^+} - f_{\pi^+ p \rightarrow \pi^-}) \quad (23)$$

$$= 2(f_{K^- p \rightarrow \pi^+} - f_{K^+ p \rightarrow \pi^-}) \quad (24)$$

$$= 2(f_{\gamma p \rightarrow \pi^+} - f_{\gamma p \rightarrow \pi^-}) \quad (25)$$

Again, as is evident from the success of our more stringent predictions in Figs. 2 and 3, the first of these relations is in good agreement with the data.

With the charge dependent component of pionization reasonably well understood, we have attempted to extend our analysis to the charge independent. Here we assumed P and f dominance as suggested by the $s^{-1/4}$ approach to scaling. Although there are no relations to determine the f couplings, this assumption can be tested at the factorization level. From the size of the charge independent $s^{-1/4}$ term in pp, π p, Kp and γ p pionization, the ratios of f couplings to p, π , K and γ can be calculated. The results thus obtained are in violent disagreement with the f couplings determined in total cross section Regge fits. As an example, consider $pp \rightarrow \pi^\pm$ and $\gamma p \rightarrow \pi^\pm$:

$$f_{pp \rightarrow \pi^\pm} = \gamma_{pp}^\pi + (2x_{fp} \gamma_{fp}^\pi \pm 2x_{pp} \gamma_{pp}^\pi) s^{-1/4} \quad (26)$$

$$= .76 + (.90 \pm .19) s^{-1/4} \quad (27)$$

$$f_{\gamma p \rightarrow \pi^\pm} = \gamma_{pp}^\pi + [(x_{fp} + x_{f\gamma}) \gamma_{fp}^\pi \pm x_{pp} \gamma_{pp}^\pi] s^{-1/4} \quad (28)$$

$$= .76 + (.33 \pm .09) s^{-1/4} \quad (29)$$

Here Eqs. 27 and 29 are the results of Ferbel's fits [2] and our ρ coupling predictions. From these four equations, we can derive

$$x_{f\gamma}/x_{fp} = -.27 \quad (30)$$

The negative sign in Eq. (30) implies that $\sigma_{\gamma p}$ should approach its limit from below. Similar violent disagreements with experiment occur if $pp \rightarrow \pi^\pm$ is compared to $\pi p \rightarrow \pi^\pm$ or $Kp \rightarrow \pi^\pm$. The strengths of the isoscalar f-P terms in pionization bear little or no resemblance to the strengths of the f in total cross sections.

This difficulty indicates either a strongly nonfactorizing f , in contradistinction to the P and ρ where nonfactorization of this order of magnitude can be ruled out, or the presence of important isoscalar singularities in addition to the P and f . In the latter event, the success of Ferbel's $s^{-1/4}$ fit indicates that these singularities should have a Regge intercept in the neighborhood of .5. For example, we have attempted to restore a factorizing f by the inclusion of f - f plus ω - ω double Regge terms; but the result was a strong $s^{-1/2}$ dependence for $f_{ab \rightarrow c}$ and a sizeable disagreement with the data of Figs. 2 and 3.

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TABLE I

ρ dominance predictions for $A_{ab} = p^{1/4} (f_{ab \rightarrow \pi^+} - f_{ab \rightarrow \pi^-})$ for different incident pairs of particles ab .

ab	$A_{ab} \text{ (GeV/c)}^{1/4}$
pp	.32
$\pi^+ p$	.59
$\pi^- p$	-.27
$K^+ p$	.33
$K^- p$	.01
γp	.16

TABLE II

ρ dominance predictions for $B_{(a-a')\rightarrow c} = p^{1/4}(f_{ab\rightarrow c} - f_{a'b\rightarrow c})$
for different particles a, a', c .

$(a-a')\rightarrow c$	$B_{(a-a')\rightarrow c} \text{ (GeV/c)}^{1/4}$
$(\pi^+ - \pi^-) \rightarrow \pi^\pm$	$\pm .43$
$(K^+ - K^-) \rightarrow \pi^\pm$	$\pm .17$
$(p-n) \rightarrow \pi^\pm$	$\pm .16$

CAPTIONS:

Fig. 1

a) P-p-P multiple-Regge Mueller diagram for $ab \rightarrow \pi^+ \pi^\pm X$. The subenergies across the Pomeranchukon exchanges can be taken arbitrarily large.

b) p-P double-Regge Mueller diagram for $a^+ b \rightarrow \pi^\pm X$.

Fig. 2

Comparison of experimental data [8] for $\sigma_\infty^{-1} \frac{d\sigma}{dy} \Big|_{y=0}$ for $\pi^+ p \rightarrow \pi^+$ and $\pi^- p \rightarrow \pi^\pm$ to our predictions (solid lines). The dashed line is a fit to $\pi^+ p \rightarrow \pi^-$ utilized, along with Table I, in making these predictions.

Fig. 3

Comparison of experimental data [9] for $\sigma_\infty^{-1} \frac{d\sigma}{dy} \Big|_{y=0}$ for $pp \rightarrow \pi^+$ to our prediction. Also included is our prediction for $pn \rightarrow \pi^\pm$, and the fit (dashed line) for $pp \rightarrow \pi^-$ utilized in our prediction.

Fig. 1

Fig. 2

Fig.3