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IMPLICATIONS OF MISSING MASS EXPERIMENTS FOR REGGE CUTS*

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ABSTRACT

The impact of the empirical features of missing mass spectra on Regge cuts is studied. The measured processes $a + p \to X + p$ $(a = \pi^-, p)$ indicate a large diffractive component in certain reggeon-particle amplitudes which may crucially affect the structure of the corresponding cuts. This diffractive term essentially measures the possible deviation from results for cuts derived in models with resonances only, such as the Finkelstein's selection rules which are based on duality diagrams considerations. Additional results for cuts are pointed out from the observed weak coupling of the pomeranchon to large masses.

I. INTRODUCTION

In the framework of Regge theory the natural objects to be studied after poles are Regge cuts. It is of importance therefore to investigate cuts both theoretically and phenomenologically.

Guided by field theoretic diagrams, Gribov[1] developed an interesting approach to Regge cuts. The general structure of Gribov's reggeon calculus was later confirmed from dual models calculations.[2] Although Gribov's theory is by no means complete, in particular because of the renormalization problem, it nevertheless provides a systematic way for exploring cuts. The reggeon-reggeon cut in this theory is determined by a new type of amplitude, namely the reggeon-particle amplitude, whose asymptotic behavior is determined by triple reggeon couplings. These new quantities are not merely mathematical objects, but do have a direct physical meaning since they are experimentally measurable in inclusive processes near the end of the spectrum.

Recently Muzinich et al.[3] studied the relation between the pomeranchon-pomeranchon (P-P) cut and the triple pomeranchon coupling (g_{PPP}). It was first shown by Arbabanel et al.[4] that g_{PPP} can be measured from single and double diffraction processes. Subsequently a rough estimate for g_{PPP} has been obtained[5] from available data which was used as an input in the work of Muzinich et al.[3]

Here we shall only discuss the contribution of double Regge (R-R) cuts to forward two-body scattering amplitudes. The restriction to "forward cuts" is needed since they are directly measurable from missing mass experiments. Hence the emerging picture is that a measurement of both the two-body and inclusive cross sections will, at

least in principle, determine both the poles and cuts. This fact strongly emphasizes the great importance of inclusive processes for understanding the structure of cuts.

We shall show that one can derive interesting results for R-R cuts by using some remarkable prominent features of the observed missing mass spectra. Explicitly it will be pointed out that the available inclusive data indicate the presence of a sizable diffractive component in the fixed pole residue of an elastic reggeon-particle scattering amplitude. Thus, in such amplitudes, one expects a considerable correction to a theory based on resonances only and exchange degeneracy. In particular, the Finkelstein's[6] selection rules for Regge cuts, with a nonzero reggeon-reggeon-pomeranchon vertex, may be violated. Actually a numerical estimate will be given for the deviation from the selection rules. We shall also study the implications of the empirical missing mass spectra on absorption models and the eikonal approximation.

II. DOUBLE REGGE CUTS AND TRIPLE REGGEON COUPLINGS

The discussion will be limited to R-R cuts in total cross sections (forward elastic amplitudes) from which cuts in processes with exchange of quantum numbers can be obtained through iso-spin and SU(3) relations.

The R_1-R_2 cut in the process

$$a + b \rightarrow a + b$$

is depicted in Fig. 1a. At high $s = (p_a + p_b)^2$ its contribution to the absorptive part of the forward elastic amplitude is given by;[1]

$$\mathrm{Im}\, F^{cut}(s,0) = \frac{1}{16\pi s}\int_{-\infty}^{0} dt\, \zeta_{R_1,R_2}(t)\, N_{R_1 a\rightarrow R_2 a}(t)\, N_{\bar{R}_1 b\rightarrow \bar{R}_2 b}(t) \left(\frac{s}{s_0}\right)^{\alpha_{R_1}(t)+\alpha_{R_2}(t)} . \quad (1)$$

Here t is the reggeons "mass", $s_0 = 1\ \mathrm{GeV}^2$ and the N's are fixed pole residues,[1] in the corresponding reggeon-particle amplitudes, defined by

$$N_{R_1 a\rightarrow R_2 a}(t) = \int_0^{\infty} dM^2\, A_{R_1 a\rightarrow R_2 a}(M^2,t) \quad (2)$$

where $A_{R_1 a\rightarrow R_2 a}(M^2,t)$ is the absorptive part of the amplitude of the process $R_1 + a \rightarrow R_2 + a$ shown in Fig. 1b, $M^2 = (p_a + q_1)^2$, and $N_{\bar{R}_1 b\rightarrow \bar{R}_2 b}(t)$ is treated in a similar way. The factor $\zeta_{R_1,R_2}(t)$

is $\mathrm{Re}\left(\xi_{R_1}(t)\,\xi^*_{R_2}(t)\right)$ for a "+" sign cut (unitarity cut) and is $\mathrm{Re}\left(\xi_{R_1}(t)\,\xi_{R_2}(t)\right)$ for a "-" sign cut (absorption cut or Gribov cut) with ξ_{R_i} $(i = 1,2)$ being the signature factors

$$\xi_{R_i}(t) = -\frac{e^{-i\pi\alpha_{R_i}(t)} + \tau_i}{\sin \pi\alpha_{R_i}(t)}$$

($\tau_i = +1,-1$ for a positive and negative signature respectively). The question of the "sign" of the cut will not be discussed[7] here as it is beyond the purpose of the present work. We shall rather focus on the fixed pole residues, given in Eq. (2), which are the basic elements for the R_1-R_2 cut.

The direct relation between cuts and inclusive reactions is now clear from Eqs. (2) and (1) since $A_{R_1 a\to R_2 a}(M^2,t)$ can be determined (at least in principle) from the interference of the R_1 and R_2 exchanges in the process $a + b \to X + b$ as indicated in Fig. 2. Of particular importance is the asymptotic behavior of $A_{R_1 a\to R_2 a}$;[8]

$$A_{R_1 a\to R_2 a}(M^2,t) \xrightarrow[\frac{M^2}{s_0}\gg 1]{} \sum_{R_3} \beta_{R_3 aa}(0)\, g_{R_1R_2R_3}(t) \times \left(\frac{M^2}{s_0}\right)^{\alpha_{R_3}(0)-\alpha_{R_1}(t)-\alpha_{R_2}(t)} \qquad (3)$$

This defines the triple-reggeon coupling $g_{R_1R_2R_3}$ (see Fig. 3) and furthermore shows the connection of $g_{R_1R_2R_3}$ to the R_1-R_2 cut.

One can see from Eq. (3) that for most cases of interest the asymptotic behavior of $A_{R_1 a\to R_2 a}$ is such that the integral in Eq. (2) is divergent. However, analytically continuing the integral, by subtracting the "bad" high M^2 limit of $A_{R_1 a\to R_2 a}$, a convergent expression for $N_{R_1 a\to R_2 a}$ can be derived.[9] In fact the analytic continuation procedure is automatically accomplished through the use of finite-energy-sum-rules for reggeon-particle amplitudes;[10]

$$\int_0^{\bar{M}^2} dM^2\, A_{R_1 a\to R_2 a}(M^2,t) = N_{R_1 a\to R_2 a}(t) + \sum_{R_3} \frac{\beta_{R_3 aa}(0)\, g_{R_1R_2R_3}(t)\, s_0}{\alpha_{R_3}(0) + 1 - \alpha_{R_1}(t) - \alpha_{R_2}(t)} \left(\frac{\bar{M}^2}{s_0}\right)^{\alpha_{R_3}(0)+1-\alpha_{R_1}(t)-\alpha_{R_2}(t)} \qquad (4)$$

where $\bar{M}^2$ is a properly chosen cut-off.

Later on we shall discuss in detail the case of $R_1 = R_2 = R$ for which Eq. (4) reduces to

$$N_{Ra\to Ra}(t) = \int_0^{\bar{M}^2} dM^2\, A_{Ra\to Ra}(M^2,t) - \sum_{R_3} \frac{\beta_{R_3 aa}(0)\, g_{RRR_3}(t)\, s_0}{\alpha_{R_3}(0) + 1 - 2\alpha_R(t)} \left(\frac{\bar{M}^2}{s_0}\right)^{\alpha_{R_3}(0)+1-2\alpha_R(t)} \qquad (4')$$

where $R_3 = P,R'$, $\alpha_P(0) = 1$, and $\alpha_{R'}(0) = 1/2$. In contrast with the first term in Eq. (4') being always positive definite the terms under

the sum contribute either positively or negatively to $N_{Ra\to Ra}$ depending on whether $\alpha_{R_3}(0) + 1 - 2\alpha_R(t)$ is, respectively, negative or positive. It was first pointed out by Muzinich et al.[3] that because the triple-pomeranchon coupling contributes a negative term to $N_{Pa\to Pa}$ the Gribov-Midgal[11] lower bound for the P-P cut might in fact be violated.

III. RESULTS FOR TRIPLE REGGEON COUPLINGS FROM MISSING MASS DATA

We shall now turn to the empirical prominent properties of the observed inclusive spectra. The kinematics of the processes to be studied is shown in Fig. 2b where $s = (p_a + p_b)^2$, $t = (p_b' - p_b)^2$, and $M^2 = (p_a + p_b - p_b')^2$. Note that in Fig. 2b the vacuum exchange is not forbidden. Such processes are $\pi^- + p \to X + p$ [12] ($a = \pi^-$ in Fig. 2b) and $p + p \to X + p$ [13,14] particularly for which interesting data have been accumulated.

The most remarkable features of these data, as observed from $(d^2\sigma/dtdM^2)$ at high s, small t, and M^2 above the resonance region ($s/M^2 \gtrsim 5$), are the rapid fall-off with the incident energy ($\sim 1/s$) and the flatness as a function of M^2.

What can one learn about Regge cuts from these experimental facts? Equivalently, what properties of reggeon-particle amplitudes are implied from the available inclusive data? To answer this the inclusive distribution will be written in the triple-Regge representation;[15]

$$\left.\frac{d^2\sigma}{dtdM^2}\right)_{a+b\to X+b} = \frac{1}{16\pi s^2} \sum_{R_1,R_2,R_3} \beta_{R_1bb}(t)\, \beta_{R_2bb}(t)\, \xi_{R_1}(t)\, \xi^*_{R_2}(t)$$

$$\times \left(\frac{s}{s_0}\right)^{\alpha_{R_1}(t)+\alpha_{R_2}(t)} \beta_{R_3aa}(0)\, g_{R_1R_2R_3}(t) \left(\frac{M^2}{s_0}\right)^{\alpha_{R_3}(0)-\alpha_{R_1}(t)-\alpha_{R_2}(t)} . \tag{5}$$

From the $\sim 1/s$ fall-off at $t \approx 0$ one obtains that the dominant exchanges in Fig. 2a have $\alpha_{R_1}(0) \approx \alpha_{R_2}(0) \approx 1/2$. That means that the

pomeranchon couples weakly to large masses. Now to obtain information on the R_3 trajectory (see Fig. 3) we exploit the flatness property in M^2 at $t \approx 0$ which implies $\alpha_{R_3}(0) \approx \alpha_{R_1}(0) + \alpha_{R_2}(0)$. When this result is coupled with the result for R_1 and R_2 derived from the s dependence of the spectrum, one concludes that $\alpha_{R_3}(0) \approx 1$. In other words although the pomeranchon couples weakly to large masses it is, however, dominant in the reggeon-particle amplitudes. Therefore the RRP term is stronger[16] that the PPP and PP'P ones (only these terms contribute in the scaling limit). Moreover it is important to emphasize that the RRP term is disfavored by the energy dependence, relative to PPP and PP'P, and hence the coupling relevant for the cut, namely g_{RRP} [see Eq. (4')] is even much stronger than g_{PPP} and $g_{PP'P}$ at least for small t.

We can summarize, just from the salient features of present missing mass experiments, that g_{RRP} is expected to be extremely crucial in R-R cuts and that g_{PPP} and $g_{PP'P}$ will be less important in the corresponding cuts. In fact a quantitative estimate for the importance of g_{RRP} in R-R cuts is derived below.

IV. A SUGGESTIVE ESTIMATE FOR THE g_{RRP} EFFECT IN R-R CUTS

For definiteness we consider the processes[12-14] $a + p \to X + p$, $a = \pi^-, p$ in Fig. 2a, where the dominant exchanges are P,P' and ω (the couplings of ρ and A_2 are small) as well as π exchange which will not be considered in the present context as it will not affect the essential conclusions.

As discussed above the inclusive data indicates that P' and ω are the dominant mechanisms for missing masses above the resonance region. Consequently for exchange degenerate P' and ω one obtains from Eq. (5), for $t \approx 0$, the following approximate relation;

$$\left.\frac{d^2\sigma}{dt\,dM^2}\right)_{a+p\to X+p} \approx \frac{1}{16\pi s^2}\, 2\, \beta^2_{RPP}(t)\,|\xi_R(t)|^2 \left(\frac{s}{s_0}\right)^{2\alpha_R(t)}$$

$$\times\ \beta_{Paa}(0)\, g_{RRP}(t) \left(\frac{M^2}{s_0}\right)^{\alpha_P(0)-2\alpha_R(t)} \tag{6}$$

where $R = P'$ or ω.

It will be instructive to split $N_{Ra\to Ra}$ into two pieces, the first contributed by resonances and the second by background (BG);

$$N_{Ra\to Ra} = N^{Res}_{Ra\to Ra} + N^{BG}_{Ra\to Ra} \tag{7}$$

From Eq. (4') one obtains

$$N^{Res}_{Ra\to Ra}(t) = \int_0^{\bar{M}^2} dM^2\, A^{Res}_{Ra\to Ra}(M^2,t) - \frac{\beta_{R'aa}(0)\, g_{RRR'}(t)\, s_0}{\alpha_{R'}(0) + 1 - 2\alpha_R(t)}$$

$$\times \left(\frac{\bar{M}^2}{s_0}\right)^{\alpha_{R'}(0)+1-2\alpha_R(t)} \tag{7'}$$

$$N^{BG}_{Ra\to Ra}(t) \approx -\frac{\beta_{Paa}(0)\, g_{RRP}(t)\, s_0}{\alpha_P(0)+1-2\alpha_R(t)} \left(\frac{M'^2}{s_0}\right)^{\alpha_P(0)+1-2\alpha_R(t)} \qquad (7'')$$

where[17] $M' \sim 1$ GeV is a mass below which the background contribution is negligible relative to the terms in Eqs. (7') and (7").

Our central goal is to study the role played by g_{RRP} in $N_{Ra\to Ra}$ and hence in R-R cuts. If indeed $N^{BG}_{Ra\to Ra}$ [Eq. (7")] turns out to be considerably large it might indicate a substantial correction to $N^{Res}_{Ra\to Ra}$, the latter being constructed from models based on resonances only, e:g., dual resonance models[2] and duality diagrams considerations.[6]

The data of Anderson et al.,[14] for $p + p \to X + p$ at $p_{LAB} = 15.1$ GeV/c and $t = -0.024$ (GeV/c)^2, will be used to estimate the coupling $\beta_{Ppp}(0)\, g_{RRP}(t)$ which is the one relevant to the R-R cut [see Eqs. (6) and (7")]. Using the above-mentioned data at $M^2 \approx 4$ GeV^2 and the empirical Regge residue function $\beta_{Rpp}(t)$,[18] one obtains

$$\beta_{Ppp}(0)\, g_{RRP}(0) \approx 53 \text{ GeV}^{-2} \qquad (8)$$

and from Eq. (7"), with $M'^2 \sim 1$ GeV^2,

$$N^{BG}_{Rp\to Rp}(0) \approx -53 \,. \qquad (8')$$

The last result should be compared with the Born term in $N^{Res}_{Rp\to Rp}$ which is[18] [from Eq. (7') with $a = p$] $\beta^2_{Rpp}(0) \approx 50$.

V. RESULTS FOR CUTS AND CONCLUSION

From the above estimates, based on inclusive data, one realizes that the negative term in $N_{Ra\to Ra}$, due to the triple-reggeon coupling g_{RRP}, can be comparable with the positive resonances contribution. Therefore it is possible that the R-R cut cannot be minorized by the eikonal approximation.[19]

It should be emphasized that the present discussion on R-R cuts hinges strongly on the very important role played by g_{RRP} in the structure of inclusive spectra.

An interesting rule for R-R cuts had been derived some time ago by Finkelstein.[6] The rule says that the R_1-R_2 cut (Fig. 1a) is negligible if there is no "s-u" duality diagram[20] for $R_1 + a \to R_2 + a$ and/or $\bar{R}_1 + b \to \bar{R}_2 + b$. However, this rule applies only to the resonance part of the fixed pole residue. Finkelstein[6] already remarked that the selection rule may not apply to cuts in which the reggeon-particle process has a diffractive component. However, it was not known how to estimate the diffractive contribution to the fixed pole residue. It is only recently, due to the developments in inclusive reactions, that we were able to control the vacuum exchange in the reggeon-particle amplitude. We have shown before, from inclusive data, that the g_{RRP} coupling may lead to a non-negligible deviation from the above-mentioned selection rule.

Phenomenologically the most important cuts are the so-called "absorptive cuts" namely a pomeranchon is exchanged with a reggeon. In most practical cases the P-R cuts appear in processes with a transfer of quantum numbers and therefore no vacuum exchange occurs in the relevant P + particle $\to$ R + particle amplitudes. However, one

may ask about the diffractive effects in the fixed pole residue which determines the P-P' cut. Again the answer comes from the observed features of missing mass spectra indicating very small effects. Although the present inclusive data do not allow a precise determination of the various triple reggeon couplings, we can nevertheless be confident that the data imply a very small $g_{PP'P}$ relative to g_{RRP}. Therefore the contribution to the P-P' cut arising from $g_{PP'P}$ is much smaller than the eikonal term and the resonance approximation to the fixed pole residue is expected to be a good one [compare with Eqs. (7)].

The present work has further emphasized the important impact of missing mass experiments on reggeon-reggeon cuts. It is extremely useful to have inclusive measurements at many values of the incident energy (low as well as high) and small momentum transfer ($\lesssim 1$ GeV^2) so as to allow a more precise determination of the various reggeon-particle amplitudes and hence a better insight into the structure of cuts.

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FOOTNOTES AND REFERENCES

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17. The significance of M' lies in the possible difference between the extrapolated pomeranchon exchange in the reggeon-particle amplitude and the background in the resonance region Strictly speaking the value of M' is not known a priori. However, for a rough estimate of $N^{BG}_{Ra\to Ra}$ in Eq. (7") the value $M' \sim 1$ GeV is reasonable.

18. The normalization and the evaluation of the various Regge residue functions are as follows; the trajectory R contributes

$$\frac{1}{16\pi s^2}\beta^4_{Rpp}(t)|\xi_R(t)|^2\left(\frac{s}{s_0}\right)^{2\alpha_R(t)}$$

to $(d\sigma/dt)$ and

$$\frac{1}{s}\beta^2_{Rpp}(0)\left(\frac{s}{s_0}\right)^{\alpha_R(t)}$$

to σ_T.

Assuming P' and ω to be exchange degenerate one obtains from the fall off $\sigma_T(\bar{p}p)$ (see E. Flaminio et al., Compilation of Cross-Sections II-Antiproton Induced Reactions, CERN-HERA 70-3, August 1970);

$$\beta^2_{Rpp}(0) \approx \frac{1}{2}\beta^2_{Ppp}(0) \approx 50 .$$

Furthermore from the differential cross-section data the cut-off in t for $\beta^2_{Rpp}(t)$ is roughly given by e^{4t}.

The result in Eq. (8) is then obtained by using the above value for $\beta^2_{Rpp}(t)$ and Ref. 14

$$\left.\frac{d^2\sigma}{dtdM^2}\right)_{t=-0.024,M^2\approx 4} \approx 3.5\ \frac{\text{mb}}{\text{GeV}^4}$$

at $p_{LAB} = 15.1$ GeV c.

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FIGURE CAPTIONS

Fig. 1. (a) The forward R_1-R_2 cut in the process $a + b \to a + b$. Note that the coupling of the external particles to the cut is through the fixed pole residues[1] $N_{R_1 a \to R_2 a}$ and $N_{\bar{R}_1 b \to \bar{R}_2 b}$ defined in Eq. (2). The "mass" of the reggeons is $t = q_1^2 = q_2^2$.

(b) The reggeon-particle process $R_1 + a \to R_2 + a$ relevant to the upper blob of the diagram in Fig. 1a.

Fig. 2. (a) The contribution of the R_1 and R_2 trajectories to the amplitude of $a + b \to X + b$ in the exchange region.

(b) The R_1 and R_2 interference term in the differential inclusive cross-section which determines the amplitude $A_{R_1 a \to R_2 a}(M^2, t)$ [see Eq. (2)].

Fig 3. A diagram which appears in the high M^2 limit of the process $R_1 + a \to R_2 + a$ (Fig. 1b) and serves to define the triple reggeon coupling $g_{R_1 R_2 R_3}(t)$.

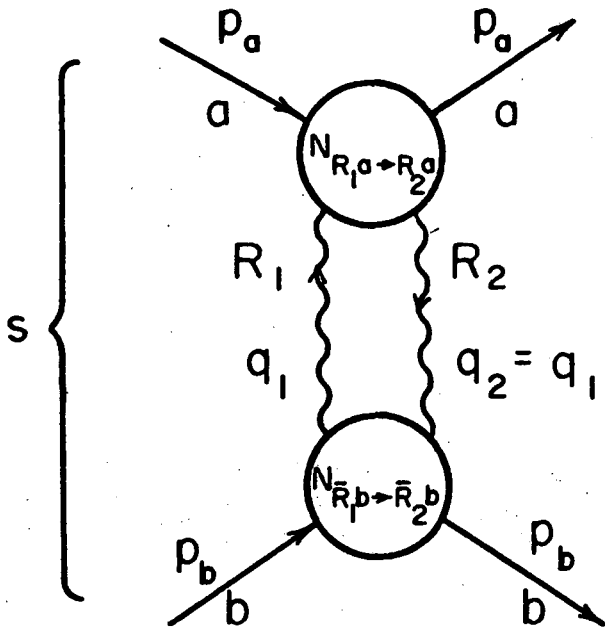

Fig. 1a

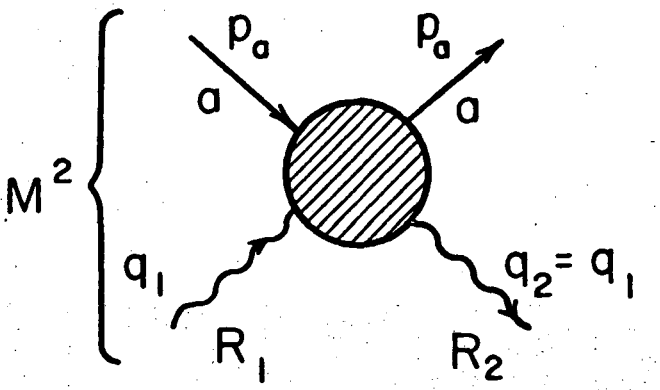

Fig. 1b

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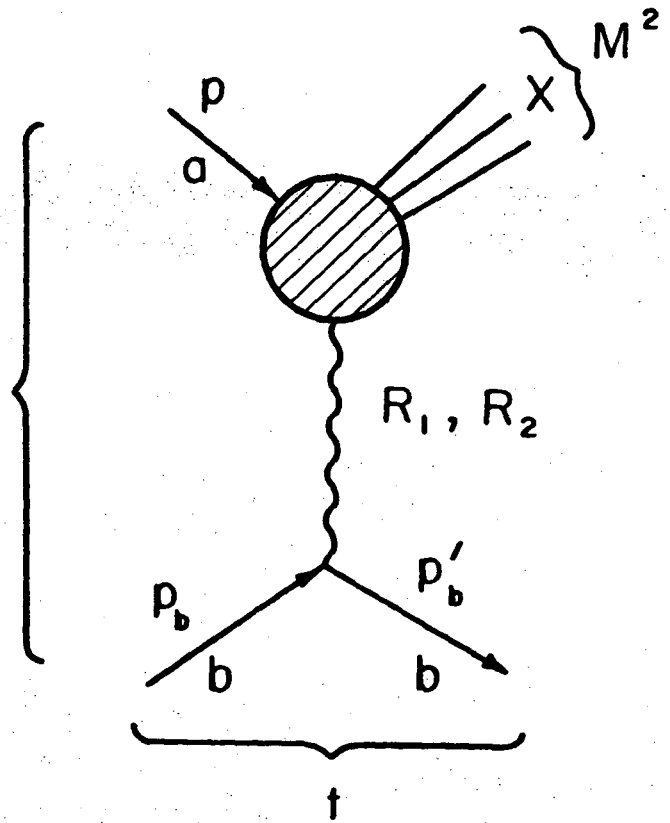

Fig. 2a

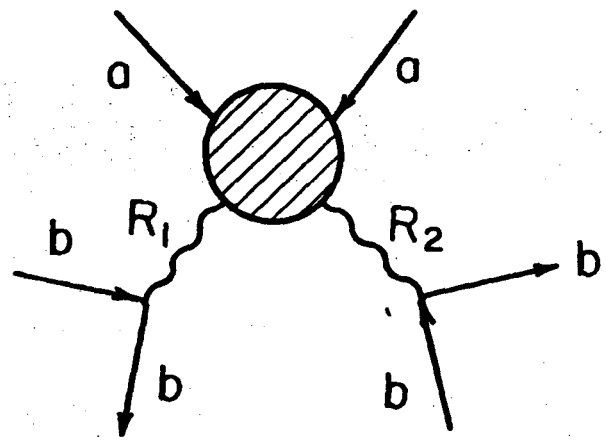

Fig. 2b

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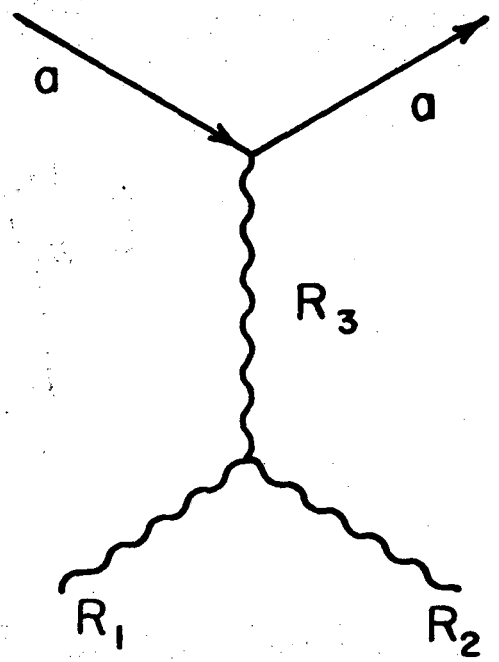

Fig. 3

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