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PROBING FOR PREON STRUCTURE VIA GLUONS

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Summary

Gluons form an important fraction of the partons at small x in $\overset{(-)}{p}p$ scattering at SSC energies ($\approx$ 40 TeV). Therefore, gluon reactions at the SSC may be expected to yield important signals for compositeness, if the preon scale is a few TeV. Here we develop a quantitative method for estimating many gluon scattering processes. Some of our estimates are model independent. We also propose explicit formulas for various scattering amplitudes based on a Veneziano-type beta function model that exhibits resonances and Regge behavior. Many interesting spectacular signatures are suggested in the resonance region, where massive vector bosons and/or excited and exotic quarks and leptons can be produced.

Introduction

If the preon scale can be reached or surpassed in the parton-parton center of mass at the SSC energies, we expect to find many signals of new physics indicating compositeness of quarks and/or leptons.

In the following, we shall use the mass, $M_V \geq 1$ TeV, of the first heavy composite vector meson (analog of rho) as a convenient characteristic scale of compositeness. The existing bounds on the preon scale and constraints that must be satisfied in models consistent with M_V of order 1 TeV are given in ref. 1.

In order to make quantitative estimates of the effects of compositeness and understand its characteristic signals, we must provide parton-parton scattering amplitudes which include the effects of the underlying strong precolor interactions. In analogy to ordinary strong interactions we need to account for massive ($\geq M_V$) resonances, Regge behavior and diffractive scattering. Quantative methods which are useful for this analysis were given in ref. 2. In particular, a spectrum of heavy composites lying on Regge trajectories was introduced, and a model for quark-(anti)quark scattering amplitudes was developed. These amplitudes were based on a string analogy (precolor flux tube) or Veneziano-type formulas (beta functions) which correspond to duality diagrams for preons.

Here we follow the approach of ref. 2 to take into account the contribution of gluons to the partons and jets in the context of compositeness: Gluons are important because, among the wee partons (small x) which dominate the parton distributions, they make the largest contribution to the pure QCD background[3]. We note that the role of gluons relative to composite colored quarks and color neutral leptons is analogous to the role of the photon relative to composite charged and neutral hadrons. This analogy helps a great deal to develop intuition and will guide us not only qualitatively but also quantitatively as shown below. In the same vein we introduce the vector meson dominance model to discuss spectacular signals of jets and leptons with energies of order M_V which are expected in the final states of $\overset{(-)}{p}p$ collisions.

Gluon Cross Sections

The parton differential cross sections for a+b→c+d, where at least two of the partons are gluons, can be expressed in the general form

$$\frac{d\sigma}{d\hat{t}} = -\frac{\pi\alpha^2_{QCD}}{\hat{s}^2}|M(\hat{s},\hat{t},\hat{u})|^2 \qquad (1)$$

in terms of the Mandelstoam variables $\hat{s},\hat{t},\hat{u}$ for the parton reaction. To obtain the cross sections for $\overset{(-)}{p}+p \rightarrow$ jets + anything, one must fold these, along with purely quark cross sections,[2] with parton distributions following the prescription of the parton model[3]. In what follows, we discuss $|M|^2$ for each basic process with explicit modifications to the QCD results taken into account.

<u>$gg\rightarrow q\bar{q}$</u> The preon duality diagrams that contribute to this process are depicted in Fig. 1, where the gluon is attached to the preon that carries color. The kinematic factors due to the spins of partons are identical to those appearing in the QCD amplitudes for elementary gluons and quarks. On the other hand, the pure QCD invariant amplitudes,[3] to lowest order, consist simply of poles $1/\hat{s}$, $1/\hat{t}$, $1/\hat{u}$, corresponding to the propagators of gluons or quarks. These must be replaced by composite amplitudes that have poles or Regge exchanges in the $\hat{s},\hat{t},\hat{u}$ channels as indicated by the duality diagrams. Furthermore, as $M_V\rightarrow\infty$, the composite amplitudes must reduce to the pure QCD amplitudes.

Thus, in a model-independent way we can write

$$|M|^2 = \frac{3}{8}\left\{(\hat{t}^2+\hat{u}^2)\left|\frac{A_{\hat{s}}}{\hat{s}}\right|^2 - \frac{4}{9}\,\hat{t}\hat{u}\left|A^{VF}_{\hat{s}\hat{t}}+P^{t}_{\hat{t}\hat{s}}\right|^2 - \frac{4}{9}\,\hat{t}\hat{u}\left|A^{VF}_{\hat{s}\hat{u}}+P^{u}_{\hat{u}\hat{s}}\right|^2\right\} \qquad (2)$$

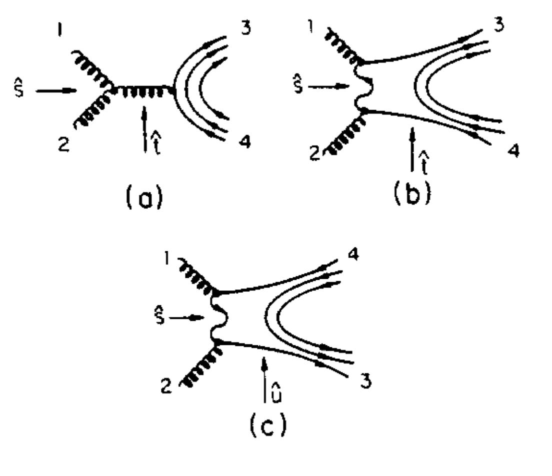

Figure 1
Preon duality diagrams for the $gg \rightarrow q\bar{q}$ process.

where the three terms correspond to Figs. 1a, b, and c respectively. No interference terms between the diagrams appear because they are proportional to $\hat{s}+\hat{t}+\hat{u}=0$ in the zero quark mass limit. Here $A_{\hat{s}}$ is a form factor for the vertex gqq which must reduce to 1 for a gluon on mass shell ($\hat{s}\to 0$) and must have power asymptotic falloff as $\hat{s}\to\infty$, in analogy to the electromagnetic form factors of hadrons. Similarly, $A_{\hat{s}\hat{t}}^{VF}(A_{\hat{s}\hat{u}}^{VF})$ is an amplitude with resonance poles or Regge exchanges in the $\hat{s}$channel ($\hat{V}$=vector) or the $\hat{t}(\hat{u})$-channel (F=fermion). In the limit $M_V\to\infty$ this amplitude must reduce to a simple $\hat{t}(\hat{u})$-channel pole, $1/\hat{t}(1/\hat{u})$, corresponding to quark exchange in pure QCD. Also, as $\hat{s}\to\infty$ it must reduce to a Regge exchange dominated by the quark Regge trajectory α_F. The function $P_{\hat{t}\hat{s}}^{t}(P_{\hat{u}\hat{s}}^{u})$ is the Pomeron contribution. Its presence will be better understood when we discuss gq→gq below.

As in ref. 2, we propose to construct these functions from ratios of gamma functions:

$$A_{\hat{s}} = \frac{1}{\sqrt{\pi}}\,\frac{\Gamma[1-\alpha^V(\hat{s})]}{\Gamma[5/2-\alpha^V(\hat{s})]} \tag{3a}$$

$$A_{\hat{s}\hat{t}}^{VF} = -\alpha'(1+i\Gamma_V/M_V)\,\frac{\Gamma[1-\alpha^V(\hat{s})]\;\Gamma[1/2-\alpha^F(\hat{t})]}{\Gamma[3/2-\alpha^V(\hat{s})-\alpha^F(\hat{t})]} \tag{3b}$$

where

$$\alpha^V(\hat{s}) = 1/2 + \alpha'\hat{s}(1+i\Gamma_V/M_V)$$
$$\alpha^F(\hat{t}) = 1/2 + \alpha'\hat{t}(1+i\Gamma_F/M_F) \tag{4}$$

Thus these amplitudes exhibit resonances that lie on Regge tragectories whose intercepts are chosen by analogy to hadrons (V ~ rho) and by taking unbroken chiral symmetry into account ($\alpha^F(0)=1/2$). The slope $\alpha'=(2M_V^2)^{-1}$ is required so that $\mathrm{Re}[\alpha^V(M_V^2)]=1$. An imaginary part $i\alpha'\hat{s}\Gamma/M$ is added to provide a width. We shall fix it such that $\Gamma/M=1/5$ for all resonances. The overall constants are chosen to reflect the correct QCD normalization as $M_V\to\infty$. The gamma functions in the denominators provide the correct assymptotic behavior as $\hat{s}\to\infty$ in lieu of kinematic factors in Eq. (2). The $\hat{s}^{-3/2}$ power fall-off of $A_{\hat{s}}$ could be increased by increasing the 5/2 in the gamma function; however, 5/2 should not be replaced by an integer, since this would cancel the poles of $A_{\hat{s}}$, except for the first few.

<u>$q\bar{q}$→gg</u> This process is the inverse of gg→$q\bar{q}$. Hence we have the same amplitudes, but the color factor is different in the initial state:

$$|M|^2 = \frac{8}{3}\left\{(\hat{t}^2+\hat{u}^2)\left|\frac{A_{\hat{s}}}{\hat{s}}\right|^2 - \frac{4}{9}\,\hat{t}\hat{u}\,|A_{\hat{s}\hat{t}}^{VF}+P_{\hat{t}\hat{s}}^{t}|^2 - \frac{4}{9}\,\hat{t}\hat{u}\,|A_{\hat{s}\hat{u}}^{VF}+P_{\hat{u}\hat{s}}^{u}|^2\right\} \tag{5}$$

<u>gq→gq</u> This process is obtained from gg→$q\bar{q}$ by crossing and changing the color factor in the initial state:

$$|M|^2 = (\hat{s}^2+\hat{u}^2)\left|\frac{A_{\hat{t}}}{\hat{t}}\right|^2 - \frac{4}{9}\hat{s}\hat{u}\,|A_{\hat{t}\hat{s}}^{VF}+P_{\hat{s}\hat{t}}^{s}|^2 - \frac{4}{9}\hat{s}\hat{u}\,|A_{\hat{t}\hat{u}}^{VF}+P_{\hat{u}\hat{t}}^{u}|^2 \tag{6}$$

Here, in a somewhat ad-hoc fashion, we have added the Pomeron exchange in the t-channel $P_{\hat{s}\hat{t}}^{s}$, $P_{\hat{u}\hat{t}}^{u}$. We choose this function as in ref. 2:

$$P_{\hat{s}\hat{t}}^{s} = \frac{2\pi g_P^2}{M_V^2}\;\frac{1+e^{i\pi\alpha_P(\hat{t})}}{\cos[\frac{\pi}{2}\alpha_P(\hat{t})]}\;\frac{\Gamma[\frac{1}{2}|\alpha_P(\hat{s})+\alpha_P(\hat{t})|]}{\Gamma[1+\frac{1}{2}|\alpha_P(\hat{s})-\alpha_P(\hat{t})|]} \tag{7}$$

where

$$\alpha_P(\hat{t}) = 1+\alpha'\hat{t}, \qquad g_P^2 = 9\text{-}25 \tag{8}$$

The asymptotic ratio of the Γ functions is

$$(\hat{s}/4M_V^2)^{\alpha_P(\hat{t})-1}$$

This form was chosen so that the unitarity bounds are not violated in crossing to the reaction gg→qq in Eq. (2) and (5).

<u>gg→gg</u> Because we now have 4 rather than 2 gluons, compositeness contributions to this process must be suppressed by a factor of α_{QCD} relative to the reactions considered above. Therefore, to lowest order the pure QCD contribution of ref. 3 is adequate for a reasonable estimate.

<u>Rescaling from Hadronic Cross Sections</u>

There are certain reactions among gluons and composite quarks whose diagrams are essentially in one-to-one correspondence to reactions among photons and composite protons. Using this correspoondence, we may estimate the cross sections by a simple rescaling prescription applied to the γp cross sections, as suggested below. As examples, we will discuss the total cross sections for gq → all composites, and gq → composite vector meson + composite fermion.

<u>σ^{tot}(gq)</u> According to the optical theorem the total cross section is given by

$$\sigma_{tot}(gq) = \frac{1}{s}\,\mathrm{Im}A(gq\to gq) \tag{9}$$

In lowest order QCD, the triple gluon vertex does not contribute to the imaginary part of the elastic amplitude, so that this process is analogous to γp → all hadrons. We can then estimate the new cross section by using the experimental data on $\sigma_{tot}(\gamma p)$ and applying the following rescaling formula

$$\sigma_{tot}^{gq}(\hat{s}) = \left(\frac{2\alpha_{QCD}}{9\alpha}\right)\frac{1}{s}\left[P_{CM}(s')\,\sqrt{s'}\,\sigma_{tot}^{\gamma p}(s')\right] \tag{10}$$

where the color factor $(2\alpha_{QCD}/9\alpha)\simeq 3$ takes into account color averaging and substitutes the coupling of the gluon instead of the photon. Here $P_{CM}(s')$ is the center of mass momentum of γ+p, and $\hat{s}$ is the CM energy squared of g+q. The dimensionless quantity in the square brackets is evaluated at s' rather than $\hat{s}$, where

$$s' = \frac{m_\rho^2}{M_V^2}(\hat{s} + 2M_V^2) \tag{11}$$

The factor m_ρ^2/M_V^2 allows us to rescale to the preon scale, instead of the QCD scale. The translation of s by $(m_\rho^2/M_V^2)(2M_V^2) = 2m_\rho^2 - m_{proton}^2$ takes into account the fact that chiral symmetry is exact in the preon theory (massless quarks). This is equivalent to shifting the proton Regge trajectory from intercept = -1/2 to intercept = 1/2.

Plots for the total cross section σ_{tot}(gq) as a function of $\sqrt{\hat{s}}$, at different values of M_V, are easily generated from known γp data but will not be given here for lack of space. At small $\hat{s}$ there are, of course, peaks corresponding to fermions on the same trajectory as the quark (see ref. 2) similar to the peaks for N^*, Δ, etc., in γp. In the resonance region, apart from peaks, the cross section drops from $\approx 1.0\ (1\text{TeV}/M_V)^2$nb to $0.2\ (1\text{TeV}/M_V)^2$nb. At larger values of $\sqrt{\hat{s}} (\geq 10\, M_V)$ the cross section settles to almost a constant (but slightly rising) value of $0.1\ (1\text{TeV}/M_V)^2$nb.

<u>$g+q \to V+q(\ell)$</u> In this process the final state may consist of either a quark plus an octet/singlet vector meson, or a lepton plus a lepto-quark vector meson. (See the next section for more details.) This is analogous to photoproduction of vector mesons such as $\gamma+p \to \rho^0+p$. By the scaling arguments given above we may write

$$\left[\frac{d\sigma}{d\hat{t}}(\hat{s},\hat{t},\hat{u})\right]_{gq\to V+g(\ell)} = \left(\frac{2\alpha^2_{QCD}}{9\alpha^2}\right)\frac{1}{\hat{s}^2}$$

$$\times \left[P_{CM}(s')\ s'\ \frac{d\sigma}{dt'}(s',t',u')\right]_{\gamma p \to \rho^0 p} \qquad (12)$$

with

$$s' = \frac{m_\rho^2}{M_V^2}(\hat{s}+2M_V^2);\quad t' = \frac{m_\rho^2}{M_V^2}\hat{t};\quad u' = \frac{m_\rho^2}{M_V^2}(\hat{u}+2M_V^2) \qquad (13)$$

Here $\hat{t}$ is not translated, since in the t-channel we expect the quantum numbers of vector mesons, not fermions. We have assumed that the intercepts of vector meson trajectories are not affected appreciably by chiral symmetry (see ref. 2). Note that $\hat{s}+\hat{t}+\hat{u}=M_V^2$ is consistent with $s'+t'+u'=m_\rho^2+2m_\rho^2$, so that the parametrization used for $\gamma p \to \rho^0 p$, i.e. (s',t') or (s',u') or (u',t') or (s',t',u') is not crucial to the rescaling. The rescaling could therefore be done from a theoretical expression or available photoproduction data for the differential cross section. Similar remarks apply to the production of heavy fermions instead of the quarks or leptons, if for example we compare the powers $g+q \to V+(\Delta,q^*)$ to $\gamma+p \to \rho^0+(\Delta,q^*)$.

Vector Meson Dominance

Vector meson production is also conveniently described by the Vector Meson Dominance model, provided the reaction takes place close enough to threshold, so that the preon quantum fluctuations are sufficiently "frozen" during the time of passage of the gluon. In this picture the gluon couples directly to the colored-octet preon bound state V_8 with coupling γ_V, in analogy to the ρ-γ mixing parameter γ_ρ.

Two duality diagrams of special interest for vector meson production are shown in Fig. 2, where the colored preon, labeled C, is explicitly indicated. In Fig. 2a the reactions

$$g(V_8)+q \to (V_8,V_1) + (q,\Delta_q,q^*) \qquad (14a)$$

or

$$g(V_8) + q \to V_3 + (\ell,\Delta_\ell,\ell^*) \qquad (14b)$$

occur depending on whether the X preon exchanged between the vector meson and fermion carries color or not. In the above reactions the Δ_q or q^* Regge trajectory is exchanged in the $\hat{s}$-channel with a V_8 or V_1 trajectory exchanged in the $\hat{t}$-channel for (14a) and a V_3 lepto-quark trajectory exchanged in reaction (14b). In Fig. 2b, reactions

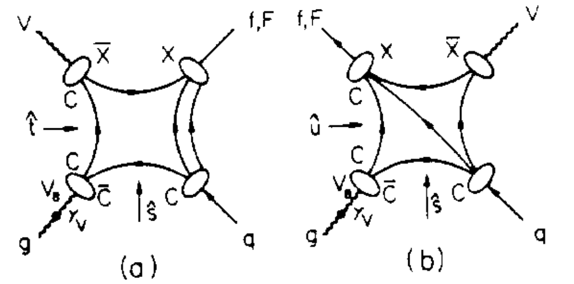

Figure 2
Preon duality diagrams for the $gq \to V(f,F)$ reaction of (14) and (15).

$$g(V_8) + q \to (q,\Delta_q,q^*) + V_1' \qquad (15a)$$

$$g(V_8) + q \to (Q_8,Q_1) + V_3 \qquad (15b)$$

or

$$g(V_8) + q \to (Q_6,Q_{\bar{3}}) + V_{\bar{3}} \qquad (15c)$$

take place, again dependent upon the type of X preon exchanged. The corresponding Regge exchanges are Δ_q and q^* trajectories in the $\hat{s}$-channel as well as the $\hat{u}$-channel for (15a), while exotic quark trajectories Q_8 and Q_1 or Q_6 and $Q_{\bar{3}}$ occur in the $\hat{u}$-channel for (15b). All these are model dependent.

If the colored octet meson V_8 in (14a) is only virtual and couples with strength γ_V directly to a gluon, reaction (14a) with light quark emission is just that discussed earlier for $gq \to gq$. In all other cases, massive vector meson production occurs followed by one of the decay channels listed below:

$$V_8 \to q\bar{q} \qquad (16a)$$

$$V_1^{(')} \to q\bar{q},\ell\bar{\ell} \qquad (16b)$$

$$V_3 \to q\bar{\ell} \qquad (16c)$$

Some Spectacular Signatures

Aside from the large deviations (magnitude, bumps, etc.) from QCD predictions expected in the pp or $\bar{p}p$ cross sections as a result of the preon structure discussed earlier and in ref. 2, some rather spectacular qualitative signature for compositeness arise with the production and decay of heavy fermions and/or vector bosons when $\sqrt{s} \geq M_V \sim (3\text{-}5)\Lambda_{HC}$. In particlular, we list the following:

1) Decay (16a) of V_8 into quark pairs leading to two quark jets nearly back-to-back with an invariant mass that resonates at $M_{V8} = M_V$. The momentum of each jet will be unusually large, roughly $M_V/2$.

2) Decay (16b) of $V_1^{(')}$ into high momentum ($\sim M_V/2$) quark or lepton pairs nearly back-to-back and in the ratio 3:1 with invariant mass resonating at $M_{V1} = M_V/2$. In general, the fermion pairs produced will belong to the same generation, but this need not be the case for V_1' in (15a), eg., if the color singlet boson is a bound state of preon pairs which carry the generation label. In this case, V_1' corresponds to one of the "horizontal" bosons discussed in ref. 4. In a composite model the mass of any horizontal boson is expected to be approximately M_V.

3) Decay (16c) of the V_3 lepto-quark into a quark jet and a lepton nearly back-to-back with momentum $M_V/2$ and invariant mass resonating at $M_{V3} \approx M_V$.

4) The above decays taken together with the production channels (14) and (15) result in three high momentum quark jets or a lepton pair and a quark jet with invariant masses peaked at the masses of the Δ_q or q^* resonances, $M_{\Delta q} \approx M_{q^*} \approx \sqrt{2}M_V$. The lepton pair reaction will then yield a large resonance contribution on top of the standard Drell-Yan background as discussed in ref. 5.

5) Production of excited quarks (Δ_q, q^*) and leptons (Δ_l, ℓ^*) with masses $\sim\sqrt{2}M_V$, as well as possibly some fermions with exotic quantum numbers, with decays into light fermions and heavy vector mesons.

6) Multiquark and multilepton production through multiperipheral graphs with Regge trajectories exchanged in the t-channel. Since the fermion and boson trajectories are nearly degenerate,[2] the light quarks and leptons can be emitted directly from the Regge exchange, without the production and decay of massive vector bosons. Hence a spray of quarks and leptons should signal the crossing of the preon threshold. The lepton-to-quark ratio should be just slightly smaller than 1/3 due to the unbalanced quark in the gq reaction.

Acknowledgments

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