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INTRINSIC CHEVROLETS AT THE SSC

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Summary

The possibility of the production at high energy of heavy quarks, supersymmetric particles and other large mass colored systems via the intrinsic twist-six components in the proton wave function is discussed. While the existing data do not rule out the possible relevance of intrinsic charm production at present energies, the extrapolation of such intrinsic contributions to very high masses and energies suggests that they will not play an important role at the SSC.

Discussion

Some time ago[1] it was suggested that various features of the data on charm production at the ISR[2] might be indicative of the presence of a new production mechanism corresponding to the excitation of intrinsic charm components of the proton wave function. The experimental features of particular interest were the apparently weak dependence of the production cross section on the longitudinal momentum of the charmed system and the apparently large magnitude of the cross section, as compared with the conventional expectations from perturbative QCD. In the usual QCD production mechanism of (extrinsic) gluon fusion[3], $GG \to Q\overline{Q}$, the charmed system is produced predominantly at small momentum in the overall CM system and with considerably smaller total cross section than inferred from many of the early ISR results. In contrast, the intrinsic charm component was argued[1] to exhibit a fairly flat distribution in the momentum fraction carried by the charmed quarks and to have a normalization which is inaccessible to perturbative QCD and therefore perhaps sufficiently large. The data from the EMC collaboration[4] on deep-inelastic muon scattering could also be intepreted as suggesting an unexpectedly large charm structure function in the region $x > 0.3$.

The possible existence of such a new production mechanism is of great importance for design considerations at the SSC[5,6]. An example of the importance of this issue is that, if intrinsic large x production is dominant, experiments and, perhaps, even the machine should be designed to focus on the forward "diffractive" regime[5]. The question of the present experimental evidence for the role of intrinsic charm is reviewed elsewhere in these proceedings[7]. For the present purposes a brief summary is sufficient. The data vary considerably from experiment to experiment and their interpretation is sufficiently model dependent to yield only the conclusion that the data do *not* rule out the possibility that intrinsic charm is playing a role in the ISR data. In the following discussion the focus will be rather on the issue of how the basic intrinsic-production picture extrapolates to the very large mass systems accessible at the SSC (the production of intrinsic "Chevrolets"[6]).

The basic picture of heavy $Q\overline{Q}$ pairs (or pairs of any heavy colored objects, e.g., Chevrolets) as intrinsic constituents of the proton arises by analogy with the presence of virtual heavy lepton pairs in atomic systems in QED. Such contributions can be ascribed to the Serber-Uehling vacuum polarization contribution to the mass shift[8] corresponding to the twist-six term $e^2(\partial_\alpha F_{\mu\nu})^2/60\pi^2 m_\ell^2$ in the effective QED Lagrangian. The corresponding $1/M_Q^2$, twist-six terms in the effective QCD Lagrangian have the

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form[5]

$$L_{QCD}^{eff} = -\frac{1}{4} F_{\mu\nu a} F^{\mu\nu a} - \frac{g^2 N_C}{120\pi^2 M_Q^2} D_\alpha F_{\mu\nu a} D^\alpha F^{\mu\nu a} + C \frac{g^3}{\pi^2 M_Q^2} F_\mu^{a\nu} F_\nu^{b\tau} F_\tau^{c\mu} f_{abc} + O\left(\frac{1}{M_Q^4}\right) \tag{1}$$

(Our notation will be small m for the mass of a light quark and capital M for the mass of a heavy quark or Chevrolet.) The second term in Eq. 1, in analogy to case of QED, can yield a heavy quark contribution to the proton wave function corresponding to between two and six gluon attachments to the ordinary, light nucleon constituents as illustrated in Fig. 1. Note also that, as in the atomic case, the *running* coupling $\alpha_s(k^2)$ is evaluated at the soft momentum scale of the bound state, not the heavy scale. Thus this is not a problem for which QCD perturbation theory is completely reliable. For the present purposes *this means simply* that a sizeable normalization for the production cross section ($\leq 1\%$) cannot be ruled out theoretically but must be determined experimentally. *However*, we may still use perturbation theory as a guide. The structure of the *perturbative* diagrams (i.e., of the denominators) suggests[3,4] *that, if these intrinsic* terms make important contributions to the overall wave functions, then the important kinematic configurations for these contributions will correspond to when all constituents have similar velocity or rapidity. Thus characteristic momentum fractions are given by

$$x_i \equiv \frac{(k^0 + k^z)_i}{p^0 + p^z} \quad \alpha \quad \sqrt{(k_\perp^2 + m^2)_i}\,. \tag{2}$$

Hence these naive perturbative considerations alone suggest that the heaviest objects, when present, will carry the largest momentum fractions. Whether a more detailed analysis including the nonperturbative dynamics of the ordinary light constituents will yield this same result is presently *unknown*. While single gluons carry on average only a small momentum fraction, the multi-gluon nature (see Fig. 1) of the intrinsic component makes it at least plausible that a sizeable *momentum* fraction can be transferred *from* the valence quarks to the heavy quarks. For the moment we will simply assume that the experimental features (large x values, large cross sections) noted above for the ISR data might be characteristic of intrinsic charm. Even with this assumption, the details of the hadronic production process remain to be specified. It has been argued[5] that this process might be simply a piece of the usual hadronic cross-section at low momentum transfer, corresponding, perhaps, to forward, diffractive excitation of the intrinsic wave function components. This again *is consistent* with a sizeable cross section and, more importantly for the present purposes, it is suggestive[5] that the production mechanism itself introduces no further suppression of large-mass states beyond the $1/M_Q^2$ factor present in the wave function (recall Eq. 1). If all this were true, then the fraction of heavy particle production that is due to the intrinsic mechanism would be approximately independent of M_Q, for the ordinary gluon fusion mechanism also gives a $1/M_Q^2$ cross-section.

This then is the central issue to be studied in this note. Assuming that the intrinsic contribution can be normalized to charm production at the ISR, how is it extrapolated to the large masses accessible at the SSC? If we assume that the total energy is sufficiently large that threshold effects are irrelevant, does the production cross section for intrinsic heavy particles fall off only as $1/M^2$ as suggested above, or does it fall more rapidly, for example like $1/M^4$, as more conservative ideas might suggest? As an illustrative example consider the production of 1 TeV quarks at the SSC. If the intrinsic process is (optimistically) normalized to 0.5 mb for charm at the ISR, a $1/M^2$ behavior yields a production cross section of order 1 nb at the SSC while $1/M^4$ suggests 2×10^{-6} nb instead. For comparison a typical gluon fusion cross-section for this energy and mass is 10^{-2} nb.

In an attempt to clarify this issue, we will use perturbation theory as a guide. Our procedure will be to begin by analysing a diagram corresponding to the usual extrinsic gluon fusion contribution and then study how the M dependence of the contribution *changes* when we include the extra gluon exchanges characteristic of the intrinsic component. Consider first (light) $q - q$ scattering leading

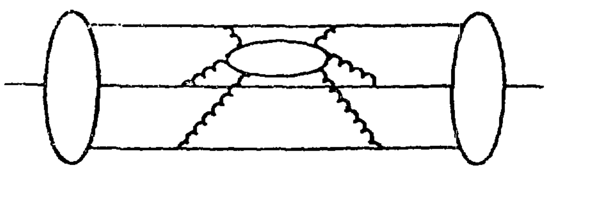

Fig. 1. *Example of intrinsic heavy quark contribution to the proton wave function in QCD.*

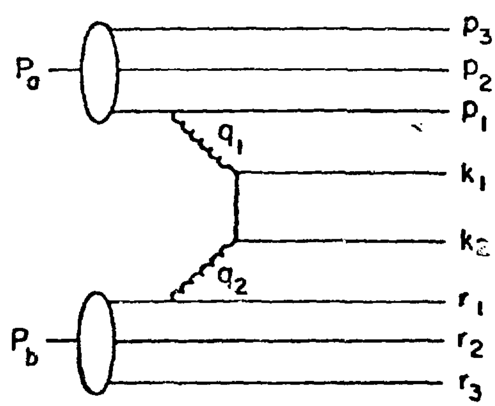

Fig. 2. *Typical diagram for heavy quark production by gluon fusion.*

to heavy $Q\overline{Q}$ pair production as illustrated in Fig. 2. The fact that the initial quarks are confined inside the incident hadrons will play no role here except to supply implicit cutoffs in various phase space integrals. Let us use light cone notation:

$$p^\mu \equiv (p^+, p^-, p_T), p^+ \equiv p^0 + p^z, \quad p^- \equiv p^0 \pm p^z, \quad p^2 = p^+p^- - p_T^2. \tag{3}$$

Then the magnitudes of the components of the momenta in Fig. 2 are given by (assuming that the initial quarks have momentum fractions of order 1 and that $\sqrt{s} \gg M$)

$$p_1 \simeq (\sqrt{s}, (m^2 + m_h^2)/\sqrt{s}, m_h)\,, \tag{4a}$$

$$r_1 \simeq ((m^2 + m_h^2)/\sqrt{s}, \sqrt{s}, m_h)\,, \tag{4b}$$

$$q_1 \simeq (e^y M, m_h^2/\sqrt{s}, m_h)\,, \tag{4c}$$

and

$$q_2 \simeq (m_h^2/\sqrt{s}, e^{-y} M, m_h)\,. \tag{4d}$$

Here m_h is intended to represent a typical hadronic scale. Thus the m_h term for the tranverse momenta explicitly represents the fact that this is to be a small momentum transfer process (i.e., that the exchanged gluons are only off shell by order m_h^2). The $Q\overline{Q}$ system is to be characterized by rapidity y and small total transverse momentum,

$$k_1 + k_2 \simeq (e^y M, e^{-y} M, m_h) \tag{5}$$

while the individual k_i may exhibit transverse momenta of order M (such that the overall invariant mass of the $Q\overline{Q}$ system remains of order M).

The essential step in rendering the analysis of such diagrams reasonably easy is to choose an appropriate gauge. A helpful choice here is an axial gauge with gauge-fixing vector

$$n^\mu = (1, -1, 0) \tag{6a}$$

so that the gluon propagators have numerators of the form

$$D^{\mu\nu}(q_i) \quad \alpha \quad -g^{\mu\nu} + \frac{n^\mu q_i^\nu + q_i^\mu n^\nu}{n \cdot q_i} - \frac{q_i^\mu q_i^\nu n^2}{(n \cdot q_i)^2}\,. \tag{6b}$$

With this choice, the large M behavior of each individual graph in perturbation theory is the same as that of the cross-section after summing over graphs, whereas in Feynman gauge, for example, the actual behavior of the cross-section is only obtained after considerable cancellation between graphs. Given that the phase space of the $Q\overline{Q}$ system is constrained as noted above, it is straightforward to verify that, in our axial gauge, the cross section resulting from Fig. 2 alone exhibits the behavior

$$\frac{d\sigma}{dydt} \quad \alpha \quad \frac{1}{M^2 m_h^2}\,. \tag{7}$$

This is exactly the expected $1/M^2$ behavior for the gluon fusion contribution. It is probably worth noting that in

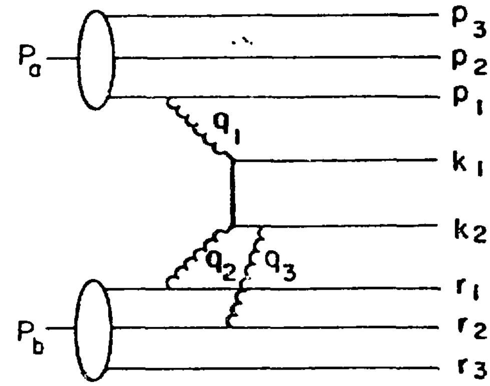

Fig. 3. Typical diagram for heavy quark production with extra gluon corresponding to intrinsic production.

Feynman gauge the corresponding quantity scales as M^{+2} instead of M^{-2}. To calculate all the relevant diagrams and establish the cancellation is nontrivial.

Now let us ask what happens when further (approximately on-shell) gluons are included such that the $Q\overline{Q}$ system now carries a sizeable momentum fraction – i.e., it is in the intrinsic regime. A sample diagram is given in Fig. 3. We define the appropriate (intrinsic) kinematic region by Eqs. 4 and 5 above plus the constraint of large rapidity y such that

$$q_2 \simeq (m_h^2/x_2\sqrt{s}, x_2\sqrt{s}, m_h) \tag{8a}$$

and

$$q_3 \simeq (m_h^2/x_3\sqrt{s}, x_3\sqrt{s}, m_h) \tag{8b}$$

where $x_2 + x_3$ is a finite fraction of 1 and neither individual fraction is vanishingly small. Another straightforward calculation, in the specified gauge, yields an intrinsic contribution with behavior

$$\frac{d\sigma}{dydt}\Big|_{Int} \quad \alpha \quad \frac{1}{M^4}\,. \tag{9}$$

Thus the inclusion of one (or more) extra gluon with a large momentum fraction has resulted in a further suppression of the production process at large M values by an extra factor of $1/M^2$. The interested reader is encouraged to evaluate any other diagram of a similar nature and establish that they all have this $1/M^4$ behavior. One case which is particularly interesting arises from the interference term in Fig. 2 *plus* Fig. 3 squared. The leading part of this term naively (and actually) behaves as $1/M^3$, but vanishes when the transverse part of final-state phase space is *symmetrically* integrated over, so that a $1/M^4$ term remains.

Conclusion

These results lead to the conclusion that the hadronic production process via the intrinsic component is actually more suppressed at large quark masses than the extrinsic gluon fusion process. The extra factor of $1/M^2$ can be easily (if only qualitatively) understood as the result of the extra hard scattering (hard at a scale M^2) which is necessary in order to put the intrinsic, virtual heavy quarks on shell. Thus, independently of the possible role for intrinsic charm at the ISR, the production of truly heavy intrinsic objects at the SSC is unlikely to play a substantial role. It should be noted, however, that our analysis of both the intrinsic and extrinsic processes does not include the confinement effects which organize the final state into color singlet hadrons. While such, presumably soft, dynamical effects cannot change the relative scaling laws discussed above, there remains the possibilty that they might tend to bias the final state toward the production of large x heavy flavor hadrons (perhaps containing some of the initial state valence quarks). Thus, even though the dominant extrinsic perturbative process is central, large x heavy flavor hadrons might still be produced. A well known example in the context of QED is the effect due to multiple scattering which biases the negative lepton produced in Bethe-Heitler pair production toward having the same velocity as the target nucleus[9]. The question of whether such effects might be important at the SSC deserves further study including a careful phenomenological analysis of the ISR data on charm production[7] which exhibit some indication of leading charm effects.

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