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Quark Resonances and High Et Jets.

Permalink

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Journal

Physical review letters, 77(4)

ISSN

0031-9007

Author

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Publication Date

1996-07-01

DOI

10.1103/physrevlett.77.601

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Peer reviewed

Quark Resonances and High E_t Jets

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(Received 16 February 1996)

Possible spin-3/2 quark resonance would have a significant effect on high E_t jet production through their contribution to the subprocess $q + \bar{q} \rightarrow g + g$. Such enhancements are compared to a recently reported anomaly in inclusive jet production at the CDF detector. [S0031-9007(96)00738-7]

PACS numbers: 13.87.Ce, 14.80.-j

The possible existence of spin 1/2 quark resonances has been looked at, both theoretically [1] and experimentally [2]. In the latter two works excluded regions in the mass-coupling constant plane were obtained; these analyses were based on the absence of the direct production of such states. In this Letter we study the effect of a possible *spin-3/2* quark resonance, q^* , on the production rate of high E_t jets; the exchange of such a particle in the reaction $q + \bar{q} \rightarrow g + g$ will enhance high E_t gluon jet production. This study is motivated by the recently observed excess of such jets in 1.8 GeV $p\bar{p}$ collisions [3].

The q - q^* - g interaction Lagrangian with a minimum number of derivatives is

$$\mathcal{L} = \frac{g_s \kappa}{1M^*} (\bar{q}_\nu^* \gamma_\lambda - \bar{q}_\gamma^* \gamma_\nu) \frac{\lambda^\alpha}{2} q G_\alpha^{\nu\lambda} + \text{H.c.} \quad (1)$$

q_ν^* is the Rarita-Schwinger field for a spin-3/2 particle, $G_\alpha^{\nu\lambda}$ is the gluon field strength tensor, M^* is the resonance mass, g_s is the strong coupling constant, and κ parametrizes the strength of this interaction. The quark q and the corresponding q^* can represent either the u or the d quark. In subsequent discussion we shall take the masses of u^*, d^* to be degenerate. This Lagrangian assumes even relative q - q^* parity; for an odd relative parity an extra γ_5 would appear between the spinors. The cross sections discussed below are independent of this relative parity.

To order α_s , the amplitude for $q + \bar{q} \rightarrow g + g$ is given by the usual QCD diagrams, Fig. 1, and by the exchange of a q^* , Fig. 2. For a spin-3/2 q^* the amplitude due to the latter will grow by one power of $\hat{s}$, the quark-antiquark center of mass energy squared, faster than the amplitude described by Fig. 1. This is just a special case of the fact that an exchange of a spin- J particle yields an amplitude behaving as $\hat{s}^J$. Such growth cannot go on indefinitely as at high enough $\hat{s}$ an exchange of a spin-3/2 particle will violate unitarity. However, depending on the strengths of various couplings, this increase can persist to large values of $\hat{s}$ values, typically up to $\hat{s} \sim M^{*2}/\alpha_s \kappa^2$; this limit is well beyond the range of $\hat{s}$ needed at present.

The effect of such exchanges on E_t distributions can be seen in Fig. 3, where we show the transverse energy distribution, at rapidity $y = 0$, for gluon jets from the parton reactions $u + \bar{u} \rightarrow g + g$ plus $d + \bar{d} \rightarrow g + g$.

FIG. 1. QCD Feynman diagrams for the process $q + \bar{q} \rightarrow g + g$.

In all calculations presented here we used the MRSA' [4] parton distribution functions ($\Lambda_{\text{QCD}} = 231$ MeV) with renormalization scale $\mu = E_t/2$. Values for M^* , the mass of the spin-3/2 resonance and for its coupling strength, κ [cf. Eq. (1)], are the ones used below in comparing to the data of Ref. [3]. For $E_t < 200$ GeV the contribution of the exchange of the spin-3/2 resonances is small; this exchange rapidly dominates the QCD contributions for larger values of E_t .

In Fig. 4 we plot the sum of the square of the amplitude due to the exchange of a spin-3/2 particle (Fig. 2) and the interference of this and the QCD amplitude (Fig. 1) as a percentage of the corresponding next to leading order QCD calculation [5] of the single jet inclusive cross section and compare to the experimental results of Ref. [3]; the extra contribution is averaged over the pseudorapidity range $0.1 \leq \eta \leq 0.7$. We restricted the

FIG. 2. Feynman diagrams for the exchange of a spin-3/2 quark resonance in the process $q + \bar{q} \rightarrow g + g$.

FIG. 3. Transverse energy distribution for $p + \bar{p} \rightarrow g + g$, at 1.8 TeV center of mass energy and rapidity $y = 0$, from the subprocess $q + \bar{q} \rightarrow g + g$, for several values of the spin-3/2 quark resonance mass M^* and coupling strength κ [cf. Eq. (1)]; the solid line is for $\kappa = 0$, the dashed one for $\kappa = 0.13$, $M^* = 100$ GeV, and the dotted one for $\kappa = 1.0$, $M^* = 400$ GeV.

comparison to $\kappa \leq 1.0$. For $\kappa = 1.0$, $M = 400$ GeV is largest response mass that the data can accommodate; for smaller M^* we restricted the comparison to $M^* > 100$ GeV and for the latter we obtain a good fit with $\kappa = 0.13$. Fits can also be obtained for intermediate cases

FIG. 4. The percent difference between the experimental inclusive jet transverse energy distribution (Ref. [3]), the contributions due to the exchange of a spin-3/2 quark resonance, and pure QCD predictions used in Ref. [3]; solid curve is for $\kappa = 0.13$, $M^* = 100$ GeV, and the dashed one for $\kappa = 1.0$, $M^* = 400$ GeV.

of masses between 100 and 400 GeV, with couplings between 0.13 and 1.0. No best fit analysis was performed.

As mentioned earlier, restrictions on masses and couplings of spin-1/2 quark resonances exist [1,2]. As we are dealing with a spin-3/2 system these restrictions cannot be taken over directly; namely, restrictions on f_s of Refs. [1,2] do not translate into restrictions on κ . These analyses also assume that analogous couplings of spin-1/2 q^* 's to photons and W 's are proportional to f_s . The only unambiguous carryover of the spin-1/2 analysis to the spin-3/2 case is for the process of quark-gluon fusion where we find [6] $\sigma(g + q \rightarrow q_{s=3/2}^*) = 0.5\sigma(g + q \rightarrow q_{s=1/2}^*)$ and thus it is somewhat harder to produce the spin-3/2 state. Should we anyway make such a comparison, it is comforting that these are not far off; $M^* = 100$ GeV, $f_s = 0.13$ is in the allowed range, while for $f_s = 1.0$ the spin-1/2 analysis would limit M^* to $M^* > 560$ GeV, again not far away from the value $M^* = 400$ GeV used in this work. A reanalysis of the data of Ref. [2] using spin-3/2 excited quarks is needed.

A process, involving such excited quarks, that will contribute to high E_t is when this excited quark appears as an s -channel resonance; $qg \rightarrow q^* \rightarrow qg$. This exchange will be important for $\hat{s} \sim M^*$ and contribute in the region $E_t \sim M^*/2$; for our parameters it would have no effect on the distribution for $E_t \geq 200$ GeV. In this study we have shown that the t -channel exchange of spin-3/2 quark resonances can account for the observed large high E_t cross section.

I thank Dr. Walter Giele for discussions and for providing me with parton structure functions.

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