CLRC

Technical Report
RAL-TR-95-075

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V Barger M S Berger and R J N Phillips

January 1996

COUNCIL FOR THE CENTRAL LABORATORY OF THE RESEARCH COUNCILS

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ISSN 1358-6254

MADPH-95-920
RAL-TR-95-075
IUHET-324
December 1995

Thresholds in α_s evolution and the p_T dependence of jets

V. Barger[(a)], M.S. Berger[(b)], and R.J.N. Phillips[(c)]

[(a)] *Physics Department, University of Wisconsin, Madison, WI 53706, USA*
[(b)] *Physics Department, Indiana University, Bloomington, IN 47405, USA*
[(c)] *Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, UK*

Abstract

We point out that high-mass thresholds in the evolution of the strong-interaction coupling parameter α_s, due to gluinos, squarks and possible new heavy quarks, could introduce appreciable corrections to the transverse momentum dependence of jet production at the Tevatron. If the new thresholds were near scale $\mu =$ 200 GeV, then within the limits of asymptotic freedom they could introduce up to 11% increase in $\alpha_s(\mu)$ (and hence 23% increase in jet production) at scale $\mu = 500$ GeV, compared to Standard Model extrapolations.

The CDF experiment at the Fermilab Tevatron collider has recently reported that inclusive jet production in $p\bar{p}$ collisions appears to exceed next-to-leading order QCD expectations in the transverse momentum range $200 < p_T(j) < 420$ GeV [1]. It has been suggested that the discrepancy might be explained by a modified gluon distribution in the nucleon [2]. However, it is also possible that some new physics may be playing a significant role. In the present note we point out that high-mass thresholds due to gluinos ($\tilde{g}$) and squarks ($\tilde{q}$), plus possible new non-standard quarks (Q) and squarks ($\tilde{Q}$), would change the evolution of the QCD coupling parameter $\alpha_s(\mu)$ at large values of the scale $\mu \gtrsim m_{\tilde{g}}, m_{\tilde{q}}, m_Q, m_{\tilde{Q}}$. This effect could give a significant enhancement above standard expectations, both for $\alpha_s(\mu)$ at large μ and hence also for the jet production cross section at large p_T, although the relation between p_T and μ is an open question that can only be settled by higher order calculations.

The evolution equation for $\alpha_s(\mu)$ at one loop can be written

$$\frac{d}{dt}[\alpha_s(\mu)]^{-1} = \frac{b_3}{2\pi}, \tag{1}$$

with

$$b_3 = 11 - \frac{2}{3}n_f, \tag{2}$$

where $t = \ln\mu$ and n_f is the number of quark flavors that are active, i.e. that have $\mu > m_q$ [3]. In a supersymmetric (SUSY) model, b_3 reduces by two units above the gluino threshold and by $\frac{1}{3}$ above each successive squark threshold (assuming degenerate L- and R-chiral squarks), giving

$$b_3 = 9 - \frac{2}{3}n_f - \frac{1}{3}\tilde{n}_f, \tag{3}$$

where we assume the gluino is active and $\tilde{n}_f$ denotes the number of active squark flavors. It is clear that as the scale μ increases, successively more thresholds are crossed and the rate of evolution of $[\alpha_s(\mu)]^{-1}$ decreases. Accordingly, the rate of fall of $\alpha_s(\mu)$ as μ increases (asymptotic freedom) is reduced with each successive threshold. Further new physics, for example new iso-singlet quarks Q_i and their SUSY partners $\tilde{Q}_i$ (that appear naturally in the [27]-plet of E_6 symmetry [4, 5]) would reduce b_3 even more [6]; each counts the same as a conventional quark or squark in Eq.(3). Alternatively, a fourth generation would add two quark plus two squark flavors[7] (implications of α_s evolution for high-p_T jets are mentioned in Ref.[8]). With three new quarks plus squarks the value $b_3 = 0$ is reached and we can go no further without breaking asymptotic freedom (AF). Although AF is not necessarily an inviolable principle, it is an attractive feature that protects perturbative calculations at high energy; we therefore limit our present illustrations to cases up to the AF limit.

The solid curve in Fig.1 shows the one-loop evolution of $\alpha_s(\mu)$ versus μ for the standard model (SM) colored-particle content. The dotted curve shows the change to the minimum supersymmetric extension (MSSM), assuming for simplicity a common squark/gluino threshold at $\mu = m_{\tilde{q}} = m_{\tilde{g}} = 200$ GeV (which is just below the present Tevatron bound[9]). The dot-dashed curve shows the effect of adding three singlet quarks with the same threshold; the case of one or two singlet quarks can be obtained by interpolation between dotted and dot-dashed curves. Finally the horizontal dashed curve shows that adding three singlet squarks too, with the same threshold, brings us to the AF limit. The dashed curve lies above the solid SM curve by a factor 1.11 at scale $\mu = 500$ GeV.

The inclusive jet production cross section $\sigma(p\bar{p} \to jX)$ at the Tevatron is based on $2 \to 2$ QCD parton subprocesses that are proportional to $[\alpha_s(\mu)]^2$. A common choice for the scale μ here is $\mu = p_T(j)/2$, in terms of the jet transverse momentum p_T; in this case the new threshold effects of Fig.1 would only be felt for $p_T > 400$ GeV, i.e. mostly beyond the range of the reported Tevatron data[1]. However, for the choice $\mu = p_T(j)$ instead, the effects of Fig.1 would give an enhancement for $p_T > 200$ GeV; at $p_T = 500$ GeV this enhancement ranges between 12% (for the MSSM case) and 23% (for the AF limit case). The relationship between μ and p_T could be determined in principle by higher-order calculations of jet production, including the physics beyond the Standard Model in the loops, but for the present it remains an open question.

We conclude that new thresholds in the evolution of α_s are capable of providing substantial increases in the jet hadroproduction cross section at large $p_T(j)$, and may be significant contributors to the reported effect.

Acknowledgments

We thank Paul Grannis for drawing our attention to the latest D0 squark/gluon bounds. This research was supported in part by the U.S. Department of Energy under Grant Nos. DE-FG02-95ER40896 and DE-FG02-91ER40661 and in part by the University of Wisconsin Research Committee with funds granted by the Wisconsin Alumni Research

Foundation.

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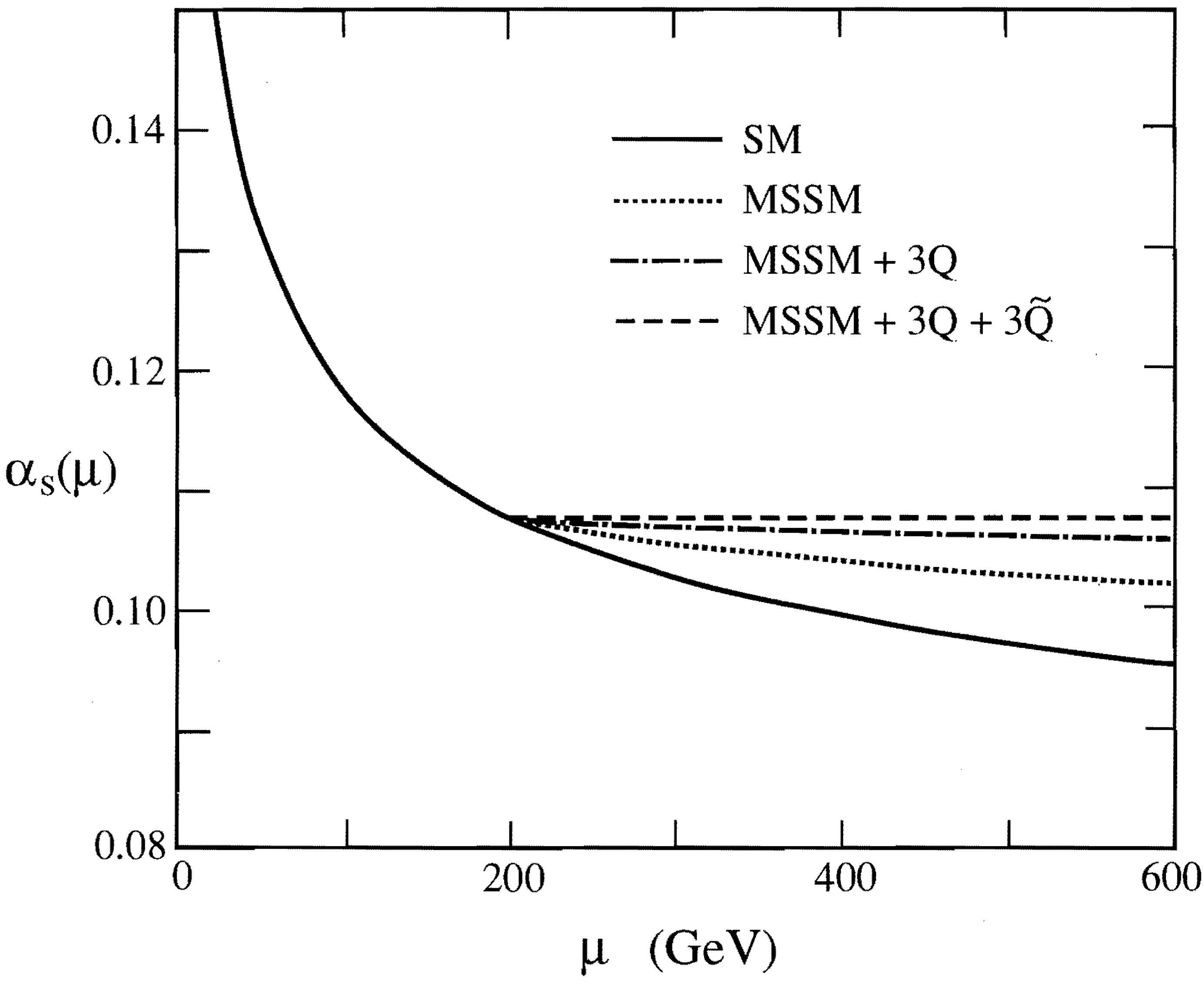
Figure captions

Fig.1. The one-loop evolution of $\alpha_s(\mu)$ versus μ is compared in various scenarios, normalized to $\alpha_s(M_Z) = 0.12$. The solid curve is the SM prediction, with $m_t = 175$ GeV. The dotted curve is the MSSM prediction, with a common squark/gluino threshold at $\mu = 200$ GeV. The dot-dashed curve shows the effect of three singlet quarks with common mass $m_Q = 200$ GeV. The dashed curve, which reached the AF limit, shows the further effect of three singlet squarks if $m_{\tilde{Q}} = 200$ GeV.



SM
MSSM
MSSM + 3Q
MSSM + 3Q + 3Q̃
0.14
0.12
0.10
0.08
$\alpha_s(\mu)$
0
200
400
600
μ (GeV)