Light Gluino Predictions for Jet Cross Sections in Tevatron Run II

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Abstract

The CDF inclusive jet transverse energy cross section at 1.8 TeV suggests anomalous behavior at both low and high transverse energies. In addition the scaled ratio of the 0.63 TeV to 1.8 TeV data lies significantly below the standard model prediction and suggests structure not attributable to standard model processes. These anomalies are in line with what would be expected in the light gluino scenario. We perform a unified fit and extrapolate to two TeV to predict the results at run II.

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The CDF collaboration at Fermilab has published [1] a study of the jet inclusive transverse energy cross section in \( p\bar{p} \) cross sections at 1.8\( TeV \) which suggest the possibility of anomalous behavior in both the low and high transverse energy regions. D0 has not published results in the low transverse energy region but has presented data at high transverse energy which appear to be consistent with either the CDF result or the standard model. The apparent anomaly at high \( E_T \) seen by CDF could, therefore, be a statistical fluctuation. It has also been suggested [2] that these results are compatible with the standard model if the gluon distribution at high \( x \) is appreciably higher than expected on the basis of previous fits. On the other hand, the anomalous behavior observed by CDF in both the low and high \( E_T \) regions is also consistent with that expected if the gluino of supersymmetry is light (below 10\( GeV \) in mass is sufficient) [3]. Although all direct searches for a light gluino have turned up negative, many indirect indications of such a light color octet parton have been noted. A partial list is contained in the references of [3].

The measured inclusive cross section at center of mass energy \( \sqrt{s} \) to produce a jet of transverse energy \( E_T \) averaged over a certain rapidity interval is theoretically expected to have the form

\[
d\sigma/dE_T = \alpha_s(\mu)^2 s^{-3/2} F(X_T, \Lambda, m) + \mathcal{O}(\alpha_s^3) \tag{1}
\]

Here \( \mu \) is the scale parameter, \( X_T = 2E_T/\sqrt{s}, \Lambda \) is the QCD dimensional transmutation parameter, and \( m \) represents any of the masses of the strongly interacting particles in the theory.Taken to all orders the cross section is independent of \( \mu \) but at finite order the theoretical result depends on \( \mu \) which must therefore be treated as a parameter of the theory. The CDF best fits correspond to \( \mu = E_T/2 \). At high energy the scaling function \( F \) depends only on \( X_T \). The CDF data for this cross section compared to the next-to-leading order (NLO) QCD predictions are below unity at low \( E_T \) and rise dramatically above unity at high \( E_T \). In the Supersymmetry (SUSY) treatment of [3] this behavior was attributed to three phenomena.

- With a light gluino the strong coupling constant runs more slowly being higher than the standard model at high \( \mu \) and lower at low \( \mu \).
- The production of gluino pairs increases \( F \) by a roughly uniform factor of 1.06 for all \( E_T \).
- A squark, if present, will cause a bump in the cross section at about \( m_{\tilde{Q}}/2 \).

The fit of [3] used the CDF suggested value of \( \mu \) and a value of \( \Lambda \) corresponding to \( \alpha_s(M_Z) = 0.113 \) and a squark mass of about 106\( GeV \). The theoretical ratio of the SUSY prediction relative to the standard model prediction is relatively insensitive to higher order corrections since both will have roughly equal higher order enhancements. In this work the CTEQ3 parton distribution functions (pdf’s) were used. In a later study [4], CDF considered the scaled ratio of the inclusive jet \( E_T \) cross sections at 630\( GeV \) and 1.8\( TeV \).
\[ r(X_T) = \frac{s^{3/2}d\sigma/dE_T}{s^{3/2}d\sigma/dE_T} \quad (\sqrt{s} = 630\text{GeV}) \]

\[ r(X_T) = \frac{s^{3/2}d\sigma/dE_T}{s^{3/2}d\sigma/dE_T} \quad (\sqrt{s} = 1800\text{GeV}) \]  

Since at both energies, \( \sqrt{s} \) is much greater than the QCD scale parameter \( \Lambda \) and all the quark masses of the standard model (except the top quark which contributes negligibly at these energies), the standard model prediction modulo residual corrections from higher order and from scaling violation in the pdf’s is just

\[ r(X_T) = \frac{\alpha_s^2(\lambda X_T \cdot 0.630\text{GeV}/2)}{\alpha_s^2(\lambda X_T \cdot 1.8\text{TeV}/2)} \]  

We have assumed here that the appropriate choice of \( \mu \) is \( \lambda E_T \) with \( \lambda = 1/2 \) being the result of the CDF best fit to the 1.8TeV data. The full standard model prediction with corrections incorporated seriously overestimates the CDF data. In addition there is a possible structure in \( r \) that, if real, might suggest the existence of a strongly interacting particle in the 100GeV region with a production cross section many times larger than that of top. As always, there is the possibility that the anomaly is due to systematic errors although it would be surprising if such errors induced structure in \( E_T \). In fact, the D0 experiment does not confirm the existence \[3\] of structure in \( r \) suggesting, therefore, an explanation in terms of systematic errors. Although the systematic errors could easily affect the normalization of the \( r \) parameter, it would be surprising if they affect the point to point errors. These systematic errors derive primarily from the lower energy (630 GeV) data and hence the existence or non-existence of structure should be definitively resolved by comparing the ratio of the 2TeV data which will be available beginning in the year 2000 with the 1.8TeV data. Although the energy step is small, the greatly increased luminosity in run II coupled with the small systematic errors in the 1.8TeV data should guarantee sufficient sensitivity to settle the question.

The features observed by CDF in the scaling ratio are those expected in the light gluino scenario \[3\]. The slower fall-off of \( \alpha_s \) predicts that the \( r \) parameter should be generally lower than the standard model expectations in agreement with the data. In addition a squark in the 100GeV mass range would provide a bump in each cross section at roughly fixed \( E_T = m_{\tilde{q}}/2 \). This would lead to a dip-bump structure separated by a factor of 1.8/0.63 in \( X_T \) in qualitative agreement with the CDF data. If the bump had occurred at lower \( X_T \) than the dip there would have been no possibility of a fit in any model where the structure was attributed to a new particle. Reference \[3\] provided two fits to the CDF data. The first used the CTEQ3 pdf’s and the scale choice \( \mu = E_T/2 \) with a squark mass of 130GeV. In the CTEQ3 pdf’s there are, of course, no initial state gluinos so the cross section bump derives from the reaction

\[ qg \rightarrow q\tilde{g}\tilde{g} \]  

(4)
with an intermediate squark in the $q\bar{g}$ channel. The dynamics are such that the initial state
 gluon splits into two dominantly collinear gluinos one of which interacts with the initial state
quark to produce the intermediate squark. Other non-resonant light gluino contributions to
the cross section come from the parton level processes

$$q\bar{q} \rightarrow \bar{\tilde{g}}\tilde{g}$$ (5)
$$gg \rightarrow \bar{\tilde{g}}\tilde{g}$$ (6)

If the gluino is light it should have a pronounced presence in the proton dynamically
generated from the gluon splitting discussed above. Two groups [7,8] have analyzed deep
inelastic scattering allowing for a light gluino and presented fits to the gluino pdf as well
as modifications of the other pdf’s due to the gluino presence. In ref. [6] we compared the
scaling violation using the Rückl-Vogt pdf’s with that using the CTEQ3 set. With intrinsic
gluinos there are extra contributions to the jet inclusive cross sections from the processes

$$g\bar{g} \rightarrow g\bar{g}$$ (7)
$$q\bar{g} \rightarrow q\bar{g}$$ (8)
$$g\bar{g} \rightarrow g\bar{g}$$ (9)
$$\tilde{g}\tilde{g} \rightarrow gg$$ (10)
$$\tilde{g}\tilde{g} \rightarrow q\bar{q}$$ (11)

The second process replaces the higher order reaction of Eq. (4) and provides a direct channel
pole at the mass of the squark leading to a peak in the transverse energy cross sections. We
treat the squark as a resonance in the quark-gluino channel. Each of these reactions of
course is subject to higher order corrections but these tend to cancel in the scaling ratio and
in the ratio of the SUSY transverse energy cross section to that of the standard model. In
this second fit the scale $\mu$ was chosen to be the parton-parton CM energy.

The purpose of the current work is to return to the inclusive jet transverse energy cross
section and seek a combined fit to this plus the scaling curve allowing for intrinsic gluinos in
the proton. Fitting both the scaling curve $r(X_T)$ and the 1.8TeV cross section is equivalent
to fitting the transverse energy cross section at both 1.8TeV and 0.63TeV. Using the parameters
of this combined best fit we then present the predictions for the $E_T$ cross section at
2TeV CM energy of run II and the scaling curve for 1.8TeV/2TeV. The primary parameters
of the combined fit are the scale $\mu$, the QCD $\Lambda$ parameter or equivalently $\alpha_s(M_Z)$, and the
squark mass $m_{\tilde{Q}}$. We find the optimal values

$$\mu = 0.6E_T$$ (12)
$$\alpha_s(M_Z) = 0.116$$ (13)
$$m_{\tilde{Q}} = 133GeV$$ (14)

In the fit we estimate NLO corrections by the K factor $1 + 10\alpha_s(\mu)/\pi$ and we simulate
resolution smearing by increasing the width of the squark by a factor of 2 from its SUSY
QCD prediction $2\alpha_s m_{\tilde{Q}}/3$. In addition it is known that the systematic errors in the 630GeV data form a fairly broad band [9]. We therefore allow the scaling data to float by a uniform factor near unity. The results are presented in figures 1-4.

Figure 1 shows the fit to the 1.8TeV jet inclusive $E_T$ cross section averaged over the CDF rapidity range $0.1 < |\eta| < 0.7$. In order to compare with the data of ref. [4], the light gluino prediction is plotted relative to the QCD prediction given to us in a private communication by the author of that reference. At high $E_T$ the fit goes through the lower range of the CDF errors which suggests it is also consistent with the D0 data. The fit qualitatively reproduces the dip at low $E_T$ and shows a peak at low $E_T$ due to the 133GeV squark. Figure 2 shows the scaling function $r(X_T)$ as given in the light gluino scenario with a 133GeV squark and as given by the standard model. The data has been moved up by a uniform factor of 1.2 which is consistent with the effect of systematic errors in the 630GeV data. The height and width of the dip-bump structure is in qualitative agreement with the expectations of the light gluino plus 133GeV squark model. One might expect that a full simulation including hadronization and detector acceptance could somewhat shift this mass.

If a squark exists at 133GeV it should be apparent in the $e^+e^-$ annihilation cross section through the quark-squark-gluino final state [10]. The L3 data [11] shows what is possibly an upward statistical fluctuation in the hadronic cross section in $e^+e^-$ annihilation in the 130GeV region. Since the gluino decays are expected to leave very little missing energy, the quark-squark-gluino final state might also explain an apparent surplus in the visible energy cross section at high $E_{vis}$ [12]. In addition, a SUSY symmetry breaking scale of 133GeV would, in the light gluino scenario, predict stop quarks in the region just above the top and could explain some anomalies in the top quark events [13] and lead to an enhancement in the deep inelastic cross section at high $Q^2$ and high hadronic mass [14]. If there is indeed a light gluino and a squark in the 100 ~ 135GeV region, a dip-bump structure should also be found at Lep II in the scaling ratio of the inclusive dijet cross section in $e^+e^-$ annihilation.

$$r(M^2/s) = \frac{s^2d\sigma/dM^2}{s^2d\sigma/dM^2} (\sqrt{s} = E_1) / (\sqrt{s} = E_2)$$

(15)

where both $E_1$ and $E_2$ are above the squark mass. Since the squark decays in the present model into quark plus gluino, the excess should be in the four-jet sample but should not appear in the pair production of two high mass states.

In Figure 3, we show the predictions for the jet inclusive $E_T$ cross section in $p\bar{p}$ collisions at the energy 2TeV relative to the standard model expectations. The curve shows a pronounced peak at $m_{\tilde{Q}}/2$ and is generally 5 to 10% below unity due to the slower running of $\alpha_s$ in the light gluino case and to the scaling violations in the parton distribution functions. In Figure 4 the scaling ratio

$$r(X_T) = \frac{s^{3/2}d\sigma/dE_T}{s^{3/2}d\sigma/dE_T} (\sqrt{s} = 1.8TeV)$$

(16)

\[\sqrt{s} = 2TeV\]
is plotted for the case of light gluino plus $133\, GeV$ squark and for the case of light gluino but no squark present (non-resonant solid line). The dash-dotted curve gives the prediction of the standard model.

Although we have not attempted to estimate hadronization corrections nor resolution smearing (apart from doubling the squark width), we expect that run II will be sensitive to the predicted peaks if they exist and will therefore either discover or rule out a squark in the $100\, GeV$ mass region in conjunction with a light gluino. With additional information on dijet mass and angular distributions [15–17], the Run II measurements are sensitive to a light gluino with a squark up to $1\, TeV$. Since most of the value of SUSY would be lost with squarks so high in mass, Run II should definitely settle the question as to whether the light gluino indications including those referenced in [3] are the first signs of SUSY or merely an amazing string of coincidences attributable to systematic errors.

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FIG. 1. Ratio of the inclusive jet transverse energy cross section with a light gluino and a 133$GeV$ squark to that of the standard model. CDF data at 1.8$TeV$ is superimposed.

FIG. 2. CDF data for the scaling ratio of the inclusive jet transverse energy cross section at 630$GeV$ relative to 1.8$TeV$ compared to the fit with a light gluino plus 133$GeV$ squark and to the standard model prediction (structureless curve). The data has been moved up by 20% consistent with the systematic errors in the 630$GeV$ data.
FIG. 3. Predicted ratio of the inclusive jet transverse energy cross section with a light gluino and a 133GeV squark to that of the standard model for 2TeV $p\bar{p}$ collisions.

FIG. 4. Predicted scaling ratio of the inclusive jet transverse energy cross section at 1.8TeV relative to 2TeV for a) light gluino only (no squark) and b) light gluino plus 133GeV squark. The dash-dotted curve shows the standard model prediction.