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CAN THE GLUINO BE LIGHT?

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A B S T R A C T

We refine our previous calculations of missing p_T cross-sections for light gluinos including the effects of p_T smearing at production, fragmentation, hadronization, E_T fluctuations in the surrounding event and measurement errors. Our new calculations agree with our previous ones to within a factor of 2, and hence we conclude that there is no "window of opportunity" for a light gluino.

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The CERN $p\bar{p}$ collider is the first accelerator to probe directly physics at energies of order 100 GeV, and either discover or set improved lower limits on the masses of conjectured new particles. Some time ago, theoretical calculations¹⁾ suggested that the collider would have sensitivity to strongly interacting supersymmetric particles, namely squarks $\tilde{q}$ and gluinos $\tilde{g}$, with masses up to $O(50)$ GeV. The UA1 collaboration has published²⁾ the results of a search for events with the missing transverse momentum signature expected from supersymmetry. From the relatively small number of monojet events they found and some calculations by the present authors³⁾, they inferred that the gluino mass was above $O(40)$ GeV. This lower limit was largely confirmed by other studies⁴⁾, and a similar lower limit on the squark mass was also deduced^{4),5)}. However, the range of gluino masses between the lower limits of $O(3)$ GeV established by beam dump experiments and a mass of 10 GeV was not studied in detail. This was essentially for computational reasons: the total cross-section for $\tilde{g}\tilde{g}$ pair production is so large, and the reduction imposed by the UA1 trigger and experimental cuts so severe, that a clear statement about the range $m_{\tilde{g}} = 3$ to 10 GeV required more careful analysis. Nevertheless we expressed⁵⁾ the belief that this low mass range could also be excluded. This belief has recently been questioned by two groups of authors^{6),7)} who wish to exploit a possible "window of opportunity" for $m_{\tilde{g}} = O(3)$ to $O(20)$ GeV. One claim⁶⁾ has been that fragmentation effects⁸⁾ reduce the missing p_T signal coming from light gluinos below the experimental upper limit. Another claim⁷⁾ has been that when a more realistic estimate is made of the transverse energy E_T produced in the rest of the event along with a $\tilde{g}\tilde{g}$ pair, the transverse energy resolution $\sigma = 0.7/E_T$ is so much increased that many fewer light $\tilde{g}\tilde{g}$ events survive the $p_T > 4\sigma$ cut applied by UA1, and gluinos up to 20 GeV could be tolerated.

In this paper we investigate this possible "window of opportunity" and conclude that it is closed. For our analysis we use a recently improved version⁸⁾ of our SUSY event generator which is better than our first version in the following three ways: it includes p_T smearing at production of the sparticle pair, takes into account supersymmetric parton fragmentation into a supersymmetric hadron, and hadronizes all final state jets. We have already shown⁸⁾ that this improved event generator yields cross-sections for larger $\tilde{g}$ and $\tilde{q}$ masses which are very similar to those calculated earlier at the elementary parton level. For this more detailed study of lighter gluinos we take account of three more effects which are not so important for heavier gluinos and squarks. We follow Ref. 7) in making a more realistic allowance for the average E_T and its

fluctuations ΔE_T . We also include the additional UA1 trigger²⁾ on total transverse energy $E_T \gtrsim 50$ to 60 GeV. Finally, we include the effects of fluctuations in energy measurement on the magnitude of p_T in SUSY events. The net result of all these improvements is to change our previous estimates of the SUSY monojet cross-sections for events between the 4σ cut and $p_T^2 = 1000 \text{ GeV}^2$ by less than a factor of 2 for $m_{\tilde{g}} > 10 \text{ GeV}$. Extending our results to $m_{\tilde{g}} = 5 \text{ GeV}$ we estimate a monojet p_T cross-section in this range which is about 3 times higher than the experimental upper limit. This is the basis for our claim that light gluinos are excluded, although we emphasize that the only people who can make a truly definitive statement are the members of UA1 themselves, after passing a SUSY event generator through their detector simulation.

We start by defining the arena of debate. As is seen in Fig. 2 of Ref. 5), for example, the SUSY cross-sections for monojet events with $p_T > 40 \text{ GeV}$ is almost independent of $m_{\tilde{g}}$ in the range 10 to 40 GeV. It is therefore clear that no meaningful lower limit⁷⁾ on $m_{\tilde{g}}$ can be extracted if one restricts one's attention to this range of p_T . The claimed^{3),5)} exclusion of light gluinos is based on the large number of monojet events predicted between the 4σ cut and $p_T^2 = 1000 \text{ GeV}^2$, and the experimental claim²⁾ that all observed monojet events in this range are explained by calculable backgrounds. We interpret the UA1 data as an observation of 0 ± 3 SUSY monojets in this range of p_T , from which we infer an upper limit of six SUSY monojet events between the 4σ cut and $p_T^2 = 1000 \text{ GeV}^2$. Figure 1 shows the calculated monojet cross-section in this p_T range as a function of $m_{\tilde{g}}$, calculated in the same way as in our previous work^{3),5),8)}, on the basis of which we believed $m_{\tilde{g}} < 40 \text{ GeV}$ could be excluded.

The first correction to these cross-sections comes from incorporating $\tilde{g}$ parton to $\tilde{g}$ hadron fragmentation^{6),8)} by convoluting the non-perturbative ansatz of Peterson et al.⁹⁾:

$$D(z) = \frac{N}{z(1-\frac{1}{2}z - \epsilon/(1-z))^2} : \epsilon = 0.15 \left(\frac{m_c}{\tilde{m}} \right)^2 \quad (1a)$$

with the perturbative QCD fragmentation function

$$F(z) = A(1-z)^{A-1} : A = c \ln \left(\frac{\alpha_s(\tilde{m})}{\alpha_s(E_{jet})} \right)$$

$$c = \begin{cases} \frac{36}{25} & \text{for } \tilde{g} \\ \frac{16}{25} & \text{for } \tilde{q} \end{cases} \quad (1b)$$

As seen in Fig. 2, the reduction in the p_T signal is less than a factor of 2 for $m_{\tilde{g}} > 10$ GeV, although it would be more important for lighter gluinos.

Next we turn to the E_T in the surrounding event accompanying $\tilde{g}\tilde{g}$ production. Previously we allowed^{3),5),8)} for an additional fixed $E_T^R = 20$ GeV in calculating

$$\sigma = 0.7 \sqrt{E_T(\text{susy debris}) + E_T^R} \quad (2)$$

This was based on the 1982 minimum bias data then available¹⁰⁾ which showed $\langle E_T \rangle = 24.4$ GeV after applying detector acceptance corrections. Although aware that E_T^R is higher in large p_T two-jet events, we were not convinced that this was a reliable guide to the E_T^R to be expected from $\tilde{g}\tilde{g}$ events, at least for $m_{\tilde{g}} \sim 40$ GeV which presumably do not bremsstrahl as many gluons as do light partons. We will see later that the total cross-section for p_T events in the range of interest is indeed somewhat reduced⁷⁾ when one makes a more realistic allowance for E_T^R . We allow E_T^R to fluctuate and parametrize it by a Poisson distribution in bins of $\Delta E_T^R = 8$ GeV with a mean $\langle E_T^R \rangle = 40$ GeV, which is presumably an overestimate of the $\langle E_T^R \rangle$ found in W production events during 1983, although compatible with the range of E_T^R found in 1984 W production events¹¹⁾. As already mentioned, one⁷⁾ effect of increasing $\langle E_T^R \rangle$ is to increase $\sigma(2)$, hence decreasing the range between $p_T = 4\sigma$ and $p_T^2 = 1000$ GeV² and hence also reducing the predicted monojet cross-section. This effect is shown clearly in Fig. 3, for the less realistic case of E_T^R fixed at 40 GeV as well as for E_T^R fluctuated according to Poisson with a mean of 40 GeV. However, this is not the only effect of increasing $\langle E_T^R \rangle$: there is also an effect on the trigger rate in UA1 as we now discuss.

In previous papers we have focused attention on the UA1 jet trigger, and have not discussed explicitly the other event triggers used by UA1²⁾ in 1983. These included a trigger to look for electrons with a nominal threshold of 10 to 12 GeV, and a trigger on total E_T above a nominal threshold of 50 (for 30% of the data) to 60 GeV (for 70% of the data). The addition to the cross-section picked up with the electron trigger is difficult to estimate reliably without a detailed detector simulation. Nevertheless, we have tried to estimate its order of magnitude in the following way. UA1 has measured¹²⁾ the ratio of the number of

events passing both their jet trigger and their electron trigger, divided by the total number of events passing their jet trigger. Jets in this biased sample pass the electron trigger with a probability of 0(10)% at $E_T = 15$ GeV, rising to 0(100)% above 40 GeV. If we assume without justification that the same would be true of jets from SUSY, the observable SUSY cross-section increases by up to 25% for $10 \text{ GeV} < \tilde{m}_g < 40 \text{ GeV}$. However, in view of the uncertainties in modelling it, we neglect the electron trigger hereafter.

The total $E_T \gtrsim 50$ to 60 GeV trigger²⁾ is now also potentially important. It had not been important previously^{3),5),8)} when we had taken E_T^R fixed at 20 GeV. In that case the vast majority of $\tilde{g}\tilde{g}$ events with $E_T \gtrsim 60$ GeV also had a jet satisfying the UA1 jet trigger. Therefore, although we had considered the effect of the total E_T trigger, we did not draw attention to it in our previous publications^{3),5),8)}. With $\langle E_T^R \rangle = 40$ GeV and with fluctuations ΔE_T^R , a SUSY event may satisfy the total E_T trigger even if it does not pass the jet trigger. However, this effect is not so important as might at first appear, for two reasons. One is that the so-called total E_T trigger actually uses only particles with $|\eta| < 1.4$, and the other is that the trigger is not very efficient until energies somewhat above the nominal trigger setting¹²⁾. The influence of the "total" E_T trigger is shown in Fig. 4: it increases the SUSY p_T cross-section only slightly above the level given by the jet trigger alone.

Finally we note that there are many ways in which measurement errors can cause some of the large number of SUSY events at low p_T to leak out beyond the experimental cuts. Two errors are known reliably and we compute their effects as representatives of this "leakage" phenomenon. First, SUSY events are subject to the same $\sigma = 0.7/E_T$ error in p_T as are the minimum bias and QCD backgrounds²⁾. Therefore one should convolute our previously calculated curves for $d\sigma/dp_T$ with a fluctuating energy-dependent error σ . It is clear that including this error will cause more low p_T events to migrate to larger p_T than high p_T events to migrate to smaller p_T . This is a particularly significant effect for small gluino masses, because their "naive" $d\sigma/dp_T$ curves fall most rapidly in the neighbourhood of the UA1 cuts on p_T . The effect is to enhance the predicted SUSY cross-section by 0(50)% for $\tilde{m}_g \sim 10$ to 30 GeV. A second measurement error which we have considered is the fluctuation in the measurement of the trigger jet E_T . By the same token as above, since the $d\sigma/dE_T$ cross-section for jets falls rapidly, the net effect of this error is to increase the p_T cross-section. Quantitatively, we use¹²⁾

$\Delta E_T = 1.2/E_T$ which is probably an underestimate of this error, and find an increase of 0(20)%. The influences of these two measurement errors are included in calculating the solid curve in Fig. 5.

Also shown in Fig. 5 are calculations for $m_{\tilde{g}} = 5$ GeV, incorporating all the improvements discussed above. Because the total cross-section for $\tilde{g}\tilde{g}$ production is so enormous for $m_{\tilde{g}} = 5$ GeV, and because such a small fraction of the events pass the UA1 triggers and cuts, it takes a lot of computer time to generate a statistically reliable point for $m_{\tilde{g}} = 5$ GeV. Therefore we have not attempted to present precise results for $m_{\tilde{g}} = 5$ GeV at all the intermediate stages of our analysis chronicled in Figs. 1 to 4, though we feel it is evident what the results would be. The best estimate that we can make of the likely range for apparent SUSY p_T cross-sections for $m_{\tilde{g}} = 5$ to 40 GeV is that in Fig. 5. The difference from our earlier calculations^{3),5),8)} is nowhere larger than a factor of 2. Calculations¹³⁾ of large p_T QCD jet cross-sections using the same q and g distributions in the proton agree with the data¹⁴⁾ to within a factor of 2, and are if anything lower than the data in the moderate p_T range. Therefore we believe our predicted SUSY cross-sections to within a factor of 2, and hence conclude from Fig. 5 that the "window of opportunity" for light gluinos is closed.

However, some words of caution are in order. The only way to be sure how a detector like UA1 would see any phenomenon is to put an event generator like ours⁸⁾ through the detector simulation. Only the UA1 experimentalists themselves can do this reliably and make the definitive statement about a lower limit on the gluino or squark mass. This would be a valuable output from the UA1 search for missing energy events, even if one cannot establish an upper limit on $m_{\tilde{g}}$ or $m_{\tilde{q}}$.

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FIGURE CAPTIONS

- Fig. 1 Cross-sections for monojets computed on the same basis as in Ref. 5), shown as a function of the gluino mass. The monojets were selected to have $p_T > 4\sigma$, $p_T^2 < 1000 \text{ GeV}^2$ and to pass the UA1 jet trigger.
- Fig. 2 The same cross-sections as in Fig. 1, after the fragmentation effects (1) are taken into account.
- Fig. 3 The monojet cross-sections of Fig. 1 with fragmentation and some effects of the surrounding event included. The surrounding event is modelled either with a fixed amount of additional transverse energy $E_T^R = 40 \text{ GeV}$, or with a fluctuating amount of transverse energy with $\langle E_T^R \rangle = 40 \text{ GeV}$, the latter being a more realistic model.
- Fig. 4 Monojet cross-sections with fragmentation and fluctuating surrounding event effects included. The solid curve shows the contribution of a "total" $E_T \gtrsim 50 \text{ GeV}$ trigger for 30% of the data, and $\gtrsim 60 \text{ GeV}$ for 70%, convoluted with a realistic¹²⁾ trigger efficiency curve.
- Fig. 5 Monojet cross-sections with all the above effects included, namely fragmentation, E_T from the surrounding event and its fluctuations, the total E_T trigger and measurement errors in p_T and in trigger jet E_T . The error bars from $m_g = 5 \text{ GeV}$ represent the Monte Carlo uncertainty in evaluating the cross-sections. The errors are negligible for larger m_g .

- Figure 1 -

- Figure 2 -

- Figure 3 -

- Figure 4 -

- Figure 5 -