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COMPONENT FORMULAE FOR HADROPRODUCTION
OF LEFT- AND RIGHT-HANDED SQUARKS

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A B S T R A C T

We present differential cross-section formulae for left-left, right-right, and left-right squark pair production in hadronic collisions, for unequal left- and right-handed squark masses. These formulae are useful in calculations involving weak decays of squarks to winos and zinos.

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Hadroproduction of supersymmetric particles, in particular squarks and gluinos, has received considerable attention in the literature^{1),2)}. Harrison and Llewellyn Smith¹⁾ have provided explicit cross-section formulae for gluino pair production, squark pair production and gluino-squark production from quark and gluon collisions.

Squarks and gluinos, if sufficiently light, will be copiously produced in hadronic collisions. In fact, the monojet events reported by the UA1 collaboration³⁾ have led to the suggestion that these are the result of either (i) squark pair production with $m_{\tilde{q}} \approx 0(50 \text{ GeV})$ and $m_{\tilde{g}} > m_{\tilde{q}}$ ⁴⁾, (ii) gluino pair production with $m_{\tilde{g}} \approx 0(50 \text{ GeV})$ and $m_{\tilde{q}} > m_{\tilde{g}}$ ⁵⁾, or, squark-gluino production with $m_{\tilde{q}} \approx 0(100 \text{ GeV})$ and $m_{\tilde{g}} \approx 3-20 \text{ GeV}$ ⁶⁾. The missing transverse momentum (p_T) is carried away by the photino from the decay $\tilde{q} \rightarrow q\tilde{\gamma}$ or $\tilde{g} \rightarrow q\tilde{q}\tilde{\gamma}$. If the squarks and gluinos indeed decay 100% via these modes, the formulae of Ref. 1) are very useful in the computation of the final state distributions if the production and decay processes factorize. However, since the left- and right-handed squark masses are different in many models, separate formulae for $\tilde{q}_L\tilde{q}_L$, $\tilde{q}_R\tilde{q}_R$ and $\tilde{q}_R\tilde{q}_L$ production may prove useful^{*)}.

We note, moreover, that if the winos ($\tilde{W}$) and zinos ($\tilde{Z}$) are lighter than squarks, and squarks are pair produced, the decays $\tilde{q} \rightarrow q\tilde{W}$ and $\tilde{q} \rightarrow q\tilde{Z}$ would also be possible. In fact, since the wino (zino) are expected to have a mass smaller than that of the W (Z) boson (provided the photino mass is small)⁷⁾, squarks with $m_{\tilde{q}} > M_W (M_Z)$ would necessarily decay via these modes in addition to the decay $\tilde{q} \rightarrow q\tilde{\gamma}$. This could lead to rather striking signatures of the type $\bar{p}p \rightarrow n \text{ jets} + m \text{ leptons} + \cancel{E_T}$ since the winos and zinos would decay via $\tilde{W} \rightarrow q\tilde{q}\tilde{\gamma}$ or $l\nu\tilde{\gamma}$ and $\tilde{Z} \rightarrow q\tilde{q}\tilde{\gamma}$ or $l\bar{l}\tilde{\gamma}$ ⁸⁾. Such processes could be seen at the high energy hadron colliders such as the Fermilab tevatron, the LHC or the SSC. Other consequences of light winos and zinos have been considered in Ref. 9).

Since the vertices involving the wino and zino distinguish between helicities, the formulae of Ref. 1) cannot be directly used since only the sum of the left and right squark-(anti) squark pair production is given therein. The purpose of this paper is to present separately the cross-sections for left-left, left-right and right-right squark-(anti) squark pair production, without

*) By left-(right-)handed squark, we mean the scalar partner of the corresponding left-(right-)handed quark.

and

$$\frac{d\sigma}{dt}(qq \rightarrow \tilde{q}_L \tilde{q}_R) = \frac{2\pi\alpha_s^2}{9s^2} \left\{ \frac{1}{(t-m_{\tilde{q}}^2)^2} \left[-st - (t-m_{\tilde{q}_L}^2)(t-m_{\tilde{q}_R}^2) \right] + (t \leftrightarrow u) \right\}. \quad (21)$$

Here, s , t and u are the Mandelstam variables for the subprocess, and $\alpha_s \equiv g_s^2/4\pi$. In Eqs. (2a,b,e,f,g), t is the momentum transfer squared between q and $\tilde{q}$ whereas in Eqs. (2c,d,h,i) it is that between the particles of like flavours. Equation (2h) includes an additional factor of $\frac{1}{2}$ to take into account the identity of the final particles^{*}). We have checked that summing over both the left- and right-handed squarks (and taking into account the factor $\frac{1}{2}$ for identical particles referred to above), we reproduce the results of Ref. 1).

Finally, for the process $gq \rightarrow \tilde{g}q$, the results of Ref. 1) can once again be used taking care to (i) divide the result by two to separate the left- and right-handed squarks, and (ii) replacing the left- or right-handed squark mass, as the case may be.

The angular distributions obtained from Eqs. (2a-1) are shown in the Figure as a function of $\cos\theta^*$, the scattering angle in the centre-of-mass frame of the colliding partons. We have chosen $m_{\tilde{q}} = 50$ GeV and $m_{\tilde{g}} = 60$ GeV for illustrative purposes. The various flavours have been summed over (we allow for the production of five flavours of squarks) but the various combinations of the left- and right-handed squarks are shown separately [except that we have added together left-left and right-right squark-(anti-) squark production since these have identical distributions]. Also shown is the contribution to $\tilde{q}_R \tilde{q}_R$ and $\tilde{q}_L \tilde{q}_L$ pair production from gluon fusion¹⁾. When this is added on to the corresponding contribution from quarks, the resulting curve is peaked towards $\cos\theta^* = 1$. The fall-off of the like-handed $\tilde{q}\tilde{q}$ pairs and opposite handed $\tilde{q}\tilde{q}$ pair curves at the edges of the Figure is due to the characteristic $\sin^2\theta^*$ distribution. The favouring of the forward direction in these curves is the effect of the gluino propagator in the t -channel. (Note that for $\tilde{q}\tilde{q}$ production "forward" has been defined as in the direction of the same flavour antisquark.)

^{*}) This factor has not been written explicitly in Ref. 1) but the total cross-section agrees if we integrate (2h) and (2i) over the whole phase space.

In summary, we have presented explicit formulae for the differential cross-sections for left-left, right-right and left-right squark-(anti-) squark production by hadronic collisions. These are of importance since the decays of squarks into winos and zinos distinguish between the squark's handedness. It has been noted that if the squarks are heavier than the wino (zino), such decays would lead to multijet + multilepton + $\cancel{p}_T$ signatures¹¹⁾ which may manifest themselves at hadronic colliders such as the Fermilab tevatron, the LHC or the SSC.

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REFERENCES

- 1) P.R. Harrison and C.H. Llewellyn Smith - Nucl.Phys. B213 (1983) 223; E B223 (1983) 542.
- 2) G.R. Farrar and P. Fayet - Phys.Lett. 76B (1978) 575; *ibid* 79B (1978) 442; G.L. Kane and J.P. Lveill - Phys.Lett. 112B (1982) 227.
For a review, see: H.E. Haber and G.L. Kane - University of Michigan Preprint, UM-HE-TH 83-17 (1984).
- 3) UAl Collaboration, G. Arnison et al. - Phys.Lett. 139B (1984) 115.
- 4) J. Ellis and H. Kowalski - Phys.Lett. 142B (1984) 441; Nucl.Phys. B246 (1984) 189; CERN Preprint TH. 4072 (1985);
V. Barger, K. Hagiwara and W.-Y. Keung - Phys.Lett. 145B (1984) 147;
A.R. Allan, E. Glover and A.D. Martin - Phys.Lett. 146B (1984) 247.
- 5) E. Reya and D.P. Roy - Phys.Lett. 141B (1984) 442; Phys.Rev.Lett. 53 (1984) 381;
M. Glck, E. Reya and D.P. Roy - Dortmund Preprint 85/1 (1985);
V. Barger, K. Hagiwara, W.-Y. Keung and J. Woodside - Phys.Rev. D31 (1985) 528.
- 6) M.J. Herrero, L.E. Ibez, C. Lpez and F.J. Yndurin - Phys.Lett. 132B (1983) 199; 145B (1984) 430;
V. Barger, K. Hagiwara, W.-Y. Keung and J. Woodside - Phys.Rev.Lett. 53 (1984) 641;
R.M. Barnett, H.E. Haber and G.L. Kane - SLAC Preprint 3551 (1985).
- 7) S. Weinberg - Phys.Rev.Lett. 50 (1983) 387;
R. Arnowitt, A. Chamseddine and P. Nath - Phys.Rev.Lett. 49 (1982) 970; 50 (1983) 232;
J. Ellis, J. Hagelin, D.V. Nanopoulos and M. Srednicki - Phys.Lett. 127B (1983) 233.
- 8) P. Nath, R. Arnowitt and A. Chamseddine - Phys.Lett. 129B (1983) 445;
D.A. Dicus, S. Nandi and X. Tata - Phys.Lett. 129B (1983) 451.
- 9) H. Baer and X. Tata - CERN Preprint TH. 4099 (1985).
- 10) D.W. Duke and J. Owens - Phys.Rev. D30 (1984) 49.
- 11) H. Baer, J. Ellis, G. Gelmini, D.V. Nanopoulos and X. Tata - CERN Preprint (in preparation).

FIGURE CAPTION

Angular distributions of squarks from $p\bar{p}$ collisions at $\sqrt{s} = 630$ GeV in the parton c.m. frame. The squark mass $m_{\tilde{q}_L} = m_{\tilde{q}_R} = 50$ GeV and the gluino mass $m_{\tilde{g}} = 60$ GeV. The curves illustrated are: (i) same handed squark-antisquark pairs from gluon-gluon, and (ii) quark-(anti-) quark fusion, (iii) opposite handed squark-antisquark pairs, (iv) same-handed squark-squark pairs and (v) opposite-handed squark-squark pairs. The angle θ^* is the angle between quark and squark in (ii) and (iii), and the angle between like-flavour quark and squark in (iv) and (v). The curves (iv) and (v) also include antisquark-antisquark production in which case θ^* is the angle between the like-flavour antiquark and antisquark. The structure functions used are from Ref. 10).