Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Physics Division

LBL--23575

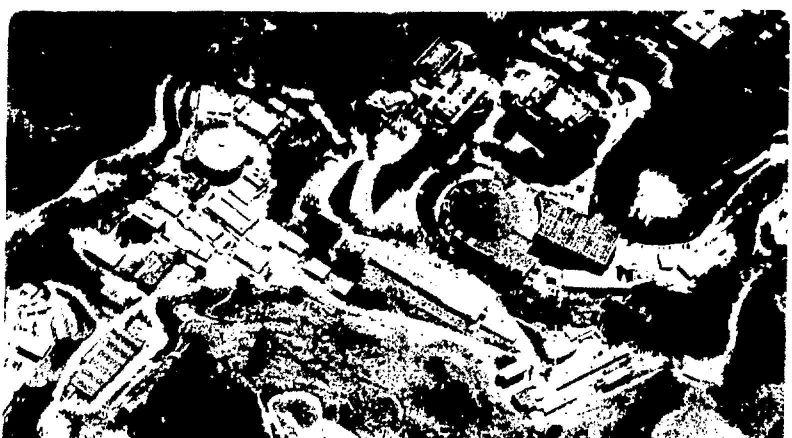
DE88 000464

Presented at the 1987 Madison SSC Workshop
"From Colliders to Supercolliders,"
Madison, WI, May 11-22, 1987, and
to be published in the Proceedings

Production of Heavy Squarkonium at the SSC

M.J. Herrero, A. Mendéz, and T.G. Rizzo

June 1987



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

June 1987 LBL-23575

PRODUCTION OF HEAVY SQUARKONIUM AT THE SSC*

M.J. Herrero[a], A. Méndez[b] and T.G. Rizzo[c]

[a]Theory Group, Lawrence Berkeley Laboratory, Univ. of California, Berkeley, CA 94720, U.S.A.

[b]Dept. Física Teòrica, Univ. Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain.

[c]Center for Particle Theory, University of Texas-Austin, Austin, TX 78712, U.S.A.

Abstract

We study the production of heavy bound states of squarks at the SSC and analyse their decays into longitudinal W's and Z's. In some situations a squarkonium state can be detected through its decay into a pair of W's.

1. Introduction

Supersymmetry (SUSY) is a very appealing extension of the standard model. It solves the hierarchy problem by introducing a fermion-boson symmetry and, as a consequence, many new degrees of freedom are predicted to exist. In addition, SUSY is the only known path towards the unification of all forces of nature. It is then of crucial interest to explore all the phenomenological implications of SUSY theories in order to eventually confront experiment.

New hadronic degrees of freedom have often been discovered in their hidden form and it might also happen that the first evidence of the supersymmetric partners of quarks (squarks) be in the form of bound states made of a squark and an anti-squark (squarkonium)[1,2].

The problem is that squarks tend to decay very rapidly into their fermionic partners emiting a gaugino

$$\text{squark} \rightarrow \text{quark} + \text{gaugino}$$

or into another (lighter) squark, by W emission,

$$\text{squark} \rightarrow \text{squark} + W$$

*To appear in the proceedings of the 1987 Madison SSC Workshop

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

All these processes are normally too fast to allow bound states to be formed. Nevertheless, there is an interesting possibility that all these decay modes might be suppressed either by phase space constraints and/or by the smallness of the intergeneration mixings.

This particular situation is probably excluded for the superpartners of the known quarks (u,d,s,c,b) unless the photino mass is exceedingly large. However, for the t-quark, the quarks of a possible fourth generation and the isosinglet charge -1/3 quarks of superstring inspired E_6 models there is a possibility that quarks are heavier than their scalar partners. In all such scenarios squarkonium states are expected to exist. In the case of the E_6 isosinglet squarks there are also Yukawa couplings that imply new decay modes into quark pairs or into a quark and a lepton. However these couplings can be small enough to allow the existence of the squark bound states and, at the same time, satisfy the cosmological constraints.

In this paper we shall assume that heavy squarkonium states exist and shall consider their production and subsequent decay in pp collisions at the energies of the SSC. We shall focus on the s-wave ground states $^1S_0$ which have $J^{PC} = 0^{++}$.

There are two interesting features in the production and decay of these squarkonium states:

1) 0^{++} squarkonium states can be strongly produced in pp collisions by gluon-gluon fusion. This would be, by large, the dominant production mechanism due to the high gluon luminosity at the SSC.

2) If $m_{sq} > M_W$, the decay of 0^{++} states in W pairs is enhanced by factors of type $(m_{sq}/M_W)^4$ due to the couplings of heavy squarks to the longitudinal components of the W's (i.e., to the Goldstone bosons)[3].

This is in contrast with the ordinary heavy quarkonium[4] s-wave states 0^{-+} and 1^{--}. The first one can also be produced by gluon-gluon fusion but, because it is a pseudoscalar, it can not decay into pairs of longitudinal W's or Z's. The opposite happens with the 1^{--} state where parity allows its decay into a pair of longitudinal W's or Z's since now they come out in p-wave; however the gluon-gluon fusion mechanism does not work here because of charge conjugation unless one requires the production of an extra gauge boson (a gluon or a photon) acompanying the vector bound state.

2. Production

As mentioned in the previous section, due to the high gluon luminosity at the SSC, the dominant production mechanism is gluon-gluon fusion. The production cross section is given in terms of the width of $0^{++} \to gg$, namely[4]

$$\sigma(pp \to gg \to 0^{++}) = \frac{\pi^2 \tau}{8M^3} \Gamma(0^{++} \to gg) \int_\tau^1 \frac{dx}{x} g(x, Q^2) g(\frac{\tau}{x}, Q^2), \tag{1}$$

where $M(\simeq 2m_{sq})$ is the squarkonium mass and $\tau = M^2/s$. The width is given by[1]

$$\Gamma(0^{++} \to gg) = \frac{16\pi\alpha_s^2}{3M^2} |\psi(0)|^2. \tag{2}$$

For numerical estimates we have taken the Coulomb type expression for the wave function at the origin.

$$|\psi(0)|^2 = \frac{1}{\pi} (\alpha_s \frac{M}{3})^3. \tag{3}$$

The values obtained for the production cross section are shown in fig. 1.

3. Decay

Since we assume that the single squark decays are supressed, the dominant decay modes of the 0^{++} squarkonium states are those with two gauge bosons in the final state. Particularly important are the channels $0^{++} \to gg$ and $0^{++} \to WW$ or ZZ. The first one involves the strong coupling constant and the other ones are enhanced due to the couplings of the squarks to the longitudinal components (Goldstone bosons) of the W's and Z's.

The widths can be computed using the standard procedure[2,5] consisting in taking the spin 0 projection of the non relativistic limit (NRL) of the cross section for $sq\ \overline{sq} \to VV$. The diagrams involved are shown in fig.2. The calculation leads to the following result

$$\Gamma(0^{++} \to VV) = |\psi(0)|^2 \frac{3}{32\pi} \frac{1}{m_{sq}} \sqrt{1 - \frac{M_V^2}{m_{sq}^2}} \quad |T|^2_{NRL} \tag{4}$$

where

$$|T|^2_{NRL} = \left[A(\frac{m_{sq}^2}{M_V^2} - 1) + C \right]^2 + 2C^2 \tag{5}$$

$$A = \frac{4m_{sq}^2(c_a^2 + c_b^2)}{M_V^2 - m_{sq}^2 - m_{sq'}^2} + 2C. \tag{6}$$

In eqs.(4-6) m_{sq} is the squark mass, $m_{sq'}$ is the mass of the t and/or u exchanged squark in diagrams (a) and (b), M_V is the mass of the gauge boson

(W or Z), c_a and c_b are the coupling constants involved in each one of the vertices of diagrams (a) and (b) respectively, and C is a function of the contact coupling of diagram (c) and the couplings and masses involved in the Higgs diagram (d).

Some interesting facts come out of the calculation:

1- Diagram (e) does not contribute to our calculation in the NRL. In the case of the transverse components of the Z this is expected because they are spin 1 objects whereas our bound state has spin 0. As far as the longitudinal component of the Z is concerned, it can not contribute since the Z Goldstone boson and the squarkonium state have opposite parities.

2- The enhancement factors come entirely from the $(\frac{m_{sq}^2}{M_V^2}-1)$ term of eq.(5) and therefore the existence of enhancement is correlated with the non-vanishing of A. Let us consider the following three situations:

a) Ignoring the Higgs contribution of diagram (d) and taking $m_{sq'} = m_{sq}$, A vanishes in the limit $m_{sq}^2 \gg M_V^2$ and there is no enhancement. This is shown in fig. 3a where the WW and ZZ decay modes are much below the gg mode.

b) Ignoring the Higgs contribution of diagram (d) and taking $m_{sq'} \neq m_{sq}$, the previous cancellation does not take place and the WW mode is enhanced (fig. 3b). The ZZ is not enhanced because the diagonal couplings of the Z require $m_{sq'} = m_{sq}$

c) The effect of including the Higgs diagram (d) is simply a change in the value of the quantity C that again destroys the cancellations taking place in case a). This is shown for the cases $m_{sq'} = m_{sq}$ and $m_{sq'} \neq m_{sq}$ in fig. 3c and 3d where the effective contribution (δC) of the Higgs diagram (d) to the quantity C has been taken to be 10 % of the contribution of the contact diagram (c). (From the couplings[7] of the squarks and gauge bosons to the neutral Higgs bosons, it can be argued[8] that this is a realistic value for δC.) Again, the WW mode is enhanced but so is the ZZ one. The fact that the ZZ mode is below the WW mode is due to the relative values of the Z and W couplings to the squarks.

4. Discussion

From the above results it is clear that the WW decay mode of a 0^{++} squarkonium can be comparable to the gg mode or may even be the dominant one. The relative branching ratio of $0^{++} \to WW/gg$ increases with the difference $m_{sq}^2 - m_{sq'}^2$ and also with the values of the Higgs couplings. The ZZ mode is less enhanced because in this case $m_{sq'} = m_{sq}$. It is interesting to to notice that this situation differs from the analogous case of the quarkonium where even in the case of degeneracy ($m_{sq'} = m_{sq}$) there is an enhancement through the axial couplings of the vector bosons to the quarks which are nonexistent in the squark case.

In figs. 4a and 4b we show the production cross section of fig. 1 multiplied by the branching ratio of $0^{++} \to W^+W^-$, for different choices of $\Delta m = m_{sq'} - m_{sq}$ and δC(Higgs contribution). The dashed curve shows the continuum W^+W^- production[6] which is the main background source. The signal is, in certain situations, well above the background. This is not the case[8] of the corresponding curves with ZZ in the final state (not shown here) where the signal hardly emerges from the background only at small values of m_{sq}. Nevertheless, it should be stressed that our signal has been probably underestimated by using the Coulomb type potential. Other choices[4] can increase substantially the signal/background ratio.

Therefore, it appears that the best signal for detecting the 0^{++} squarkonium states is through their decays into a pair of longitudinal W's. As a consequence, the bound states made of isodoubled squarks will be easier to detect than those made of isosinglet squarks (uncoupled to the W) which is the case of the right-handed squarks and of the E_6 new squarks.

Acknowledgments

We are grateful to the participants of the Madison SSC workshop for discussions. In particular, we would like to thank M.Barnett, J.F.Gunion, H.Haber and X.Tata for clarifying conversations. This work was supported in part by a Fulbright-MEC fellowship (Spain), the CAICYT (Spain) and the U.S. Department of Energy. One of us (M.J.H.) is grateful to the Theoretical Physics Group at LBL for their kind hospitality and to A.Dobado for introducing her into the subject.

References

[1] C.R.Nappi, Phys.Rev. **D25**, 84 (1982);
D.V.Nanopoulos, S.Ono and T.Yanagida, Phys.Lett. **137B**, 363 (1984);
J.A.Grifols and A.Méndez, Phys.Lett. **144B**, 123 (1984).

[2] H.E.Haber and G.L.Kane, Phys.Rep. **117**, 75 (1985).

[3] J.M.Cornwall,D.N.Levin and G.Tiktopoulos, Phys.Rev.**D10**, 1145 (1974);

C.E.Vayonakis, Lett.Nuovo Cim. **17**, 383 (1976);
B.W.Lee, C.Quigg and H.Thacker, Phys. Rev. **D16**, 1519 (1977);
M.S.Chanowitz, M.Furman and I.Hinchliffe, Nucl.Phys. **B153**,402 (1979);
G.J.Gounaris, R.Kogerler and H.Neufeld, Phys.Rev. **D34**, 3257 (1986);
M.S.Chanowitz and M.K.Gaillard, Nucl.Phys. **B261**, 379 (1985);
S.S.D.Willenbrock, Univ. of Wisconsin-Madison preprint MAD/PH/333 (1987).

[4] V.Barger *et al.*, Univ. of Wisconsin-Madison preprint MAD/PH/300.

[5] J.D.Jackson, Proc.SLAC Summer Inst. on Particle Physics, SLAC (1976);
B.Guberina *et al.*, Nucl.Phys. **B174**, 317 (1980).

[6] E.Eichten, I.Hinchliffe, K.Lane and C.Quigg, Rev.Mod.Phys. **56**, 247 (1984).

[7] J.F.Gunion and H.E.Haber, Nucl.Phys. **B272**, 1 (1986); **B278**, 449 (1986).

[8] M.J.Herrero, A.Méndez and T.G.Rizzo, in preparation.

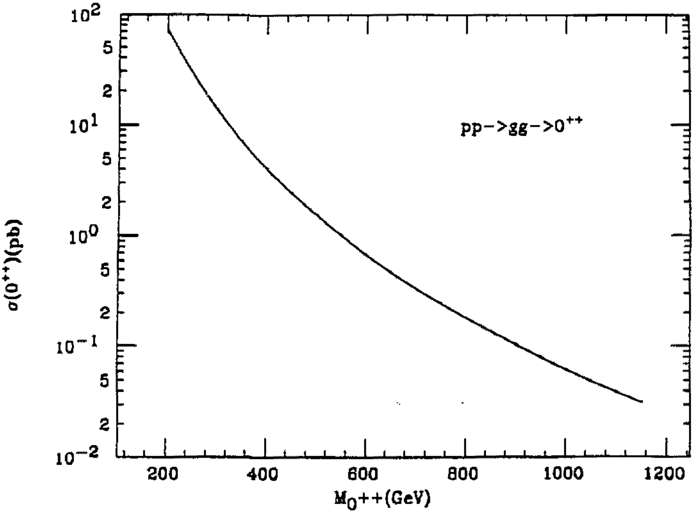


Fig.1.- Cross section of $pp \to 0^{++}X$ through gg fusion.

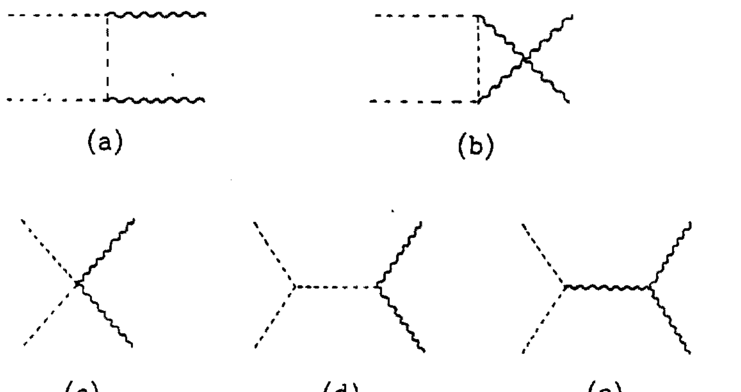


Fig.2.- Diagrams contributing to the decay of a 0^{++} squarkonium into two gauge bosons. The scalars exchanged in (d) are neutral Higgs bosons and the particle exchanged in (e) is a Z boson. The photon can not be exchanged because of charge conjugation.

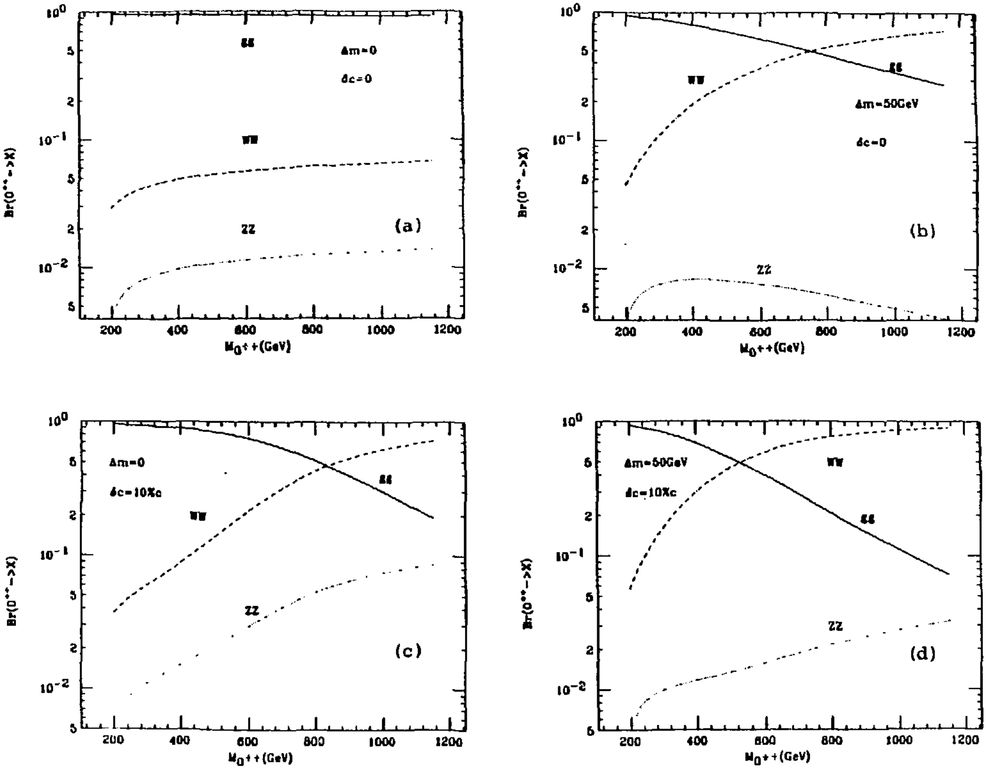


Fig.3.- Branching ratios for the dominant decay modes of the 0^{++} squarkonium

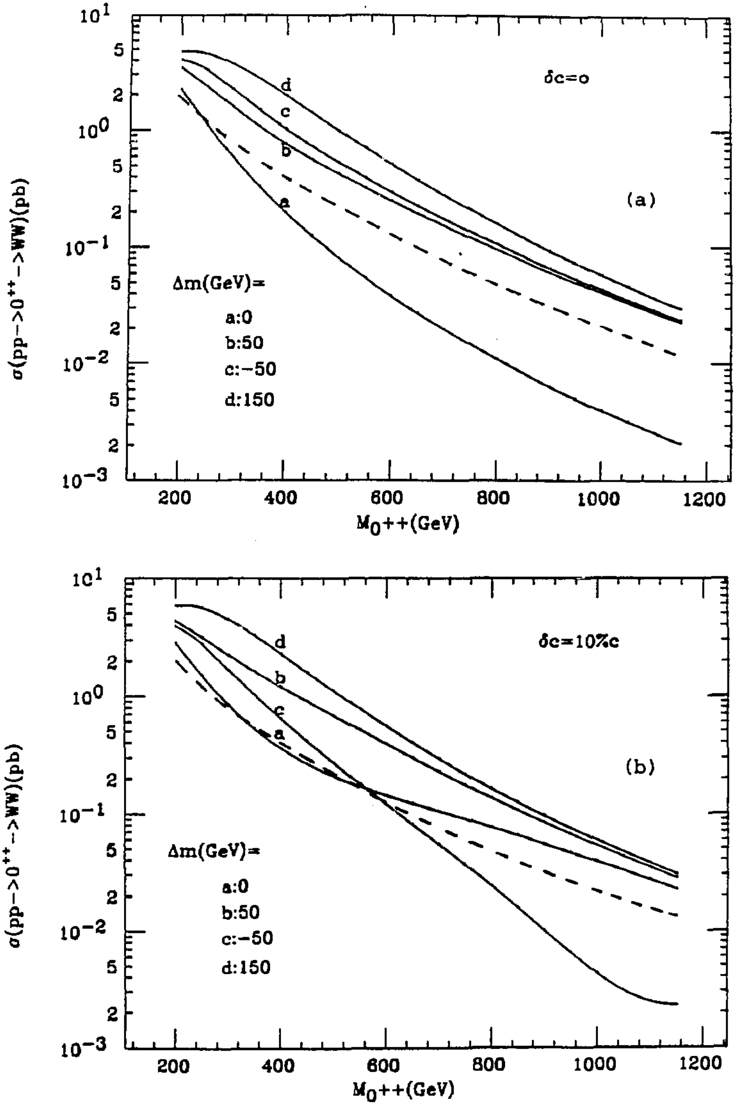


Fig.4.- Cross sections for $pp \to 0^{++} \to W^+W^-$ (solid) and the continuum W^+W^- production assuming $|y| < 2.5$ and $\delta M/M = 1\%$ (dashed).