DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 85-137
December 1985

IS A LIGHT GLUINO STILL COMPATIBLE WITH THE CERN COLLIDER DATA?

by

K. Hagiwara

Deutsches Elektronen-Synchrotron DESY, Hamburg

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 85-137
December 1985

ISSN 0418-9833

IS A LIGHT GLUINO STILL COMPATIBLE WITH THE CERN COLLIDER DATA?

K. Hagiwara

DESY, D-2000 Hamburg 52, Fed. Rep. Germany

ABSTRACT

The QCD $2 \rightarrow 3$ contribution to large missing transverse momentum events from light gluinos of mass 3-5 GeV is estimated by using the gluon-to-gluino splitting approximation to the squared matrix elements and the scale dependent gluino fragmentation function. The $2 \rightarrow 3$ processes give the dominant contribution over the $2 \rightarrow 2$ contribution, confirming the trend observed by Herzog and Kunszt for heavier gluinos. Most events have back-to-back jet configurations in both mono- and dijet events and would appear as an excess of jet-jet fluctuation at the CERN collider. Nonobservation of such effects in the 1984 data would rule out $m_{\tilde{g}}$ down to 5 GeV but probably not below 3 GeV.

INTRODUCTION

The light gluino scenario [1,2] has received much attention [3-9] as a possible supersymmetric interpretation [10] of the observed [11] unusually large missing transverse momentum ($\not{p}_T$) events associated mainly with a single jet at the CERN $p\bar{p}$ collider. The scenario assumes squarks of mass $\sim$100 GeV whose two-body decay into a quark and a photino gives the monojet events with large $\not{p}_T$ clustering around $\not{p}_T \sim 50$ GeV (Jacobian peak). The light gluino ($m_{\tilde{g}} = 3$-5 GeV) is then needed to obtain sufficient production rate via the process $qg \rightarrow \tilde{q}\tilde{g}$.

An invited talk given at the Quark Structure of Matter Meeting, Strasbourg-Karlsruhe (September, 1985).

Recently, the UA1 Collaboration reported [12] new results on large $\not{p}_T$ events from the 1984 run of the CERN collider at $\sqrt{s}$ = 630 GeV with an integrated luminosity of 263 nb^{-1}. With the four triggers

$$\begin{aligned}
&\text{1a:} \quad E_T(\text{'E.M. cluster'}) > 10 \text{ GeV} \\
&\text{1b:} \quad E_T(\text{'jet'}) > 25 \text{ GeV} \qquad\qquad (1)\\
&\text{1c:} \quad \Sigma E_T > 80 \text{ GeV} \\
&\text{1d:} \quad \left|\Sigma E_T^L - \Sigma E_T^R\right| > 17 \text{ GeV and } E_T(\text{jet}) > 15 \text{ GeV}
\end{aligned}$$

and the selection criteria which include

$$\begin{aligned}
&\text{2a:} \quad \not{p}_T > \max\{4\sigma, 15 \text{ GeV}\} \\
&\text{2b:} \quad p_T(\text{jet}) > 12 \text{ GeV} \qquad\qquad (2)\\
&\text{2c:} \quad \text{No jet with } p_T > 8 \text{ GeV back-to-back to monojet } (\pm 30^0) \text{ or} \\
&\qquad\quad \text{within } \pm 30^0 \text{ of } \not{p}_T \text{ vector}
\end{aligned}$$

they observed 29 monojet events by combining both the '83 and '84 data. The last trigger condition (1d) was introduced in the '84 run to trigger on the events with transverse momentum imbalance with respect to the vertical plane which includes the colliding beams. The last selection criterion (2c), which we call $\not{p}_T$ isolation cut, rejects events which come from fluctuation of the normal (QCD) dijet events.

Shown in Fig. 1 are these 29 monojet events [12] plotted against

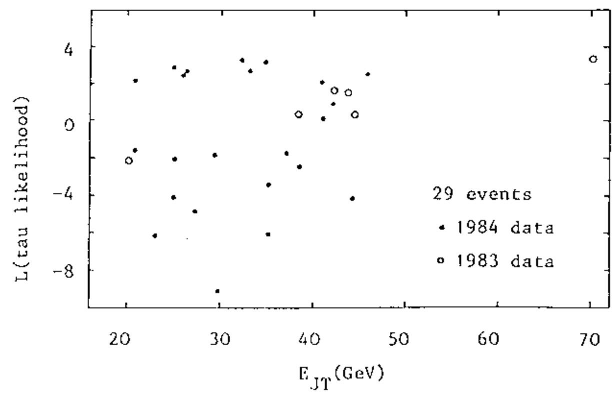

Fig. 1

the likelihood of being a tau, L (vertical axis), and the jet transverse energy (horizontal axis). Open circles show the '83 data [11] and the closed circles show the '84 data [12]. The events with $L > 0$ and $E_{JT} < 40$ GeV are the $W \to \tau\nu$ candidates. The standard model contributions to the monojet events [13] are expected to populate in the $L < 0$ region. A most striking feature in this plott is the clean separation of the τ-like ($L > 2$) and the non τ-like ($L < -1$) events below E_{JT} = 35 GeV. Above this value of E_{JT}, such a clean distinction disappears and a cluster of eight events appears in the region $0 < L < 3$, 38 GeV $< E_{JT} <$ 46 GeV. These events are somewhat isolated from the others in the E_{JT}-L plane and might signal new physics [12]. If we interpret this as a signal of the light gluino scenario, then we should regard it as a first clean evidence of the Jacobian peak predicted by the two-body $\tilde{q} \to q\tilde{\gamma}$ decay. Although the relative production rate (4 from the '83 data and 4 from the '84 data) is not as expected from the naive luminosity consisting, which implies 2.3 times more events in the '84 run, the absolute rates are both not far from the naive prediction [2]: 2~3 events in the '83 data and 5~6 events in the '84 data for $(m_{\tilde{q}}, m_{\tilde{g}})$ = (100,3) GeV.

It is still an open question whether the scenario provides an explanation of the narrowness ($L > 0$) of the observed jets. All we have at hand are qualitative expectations that the jets from $\tilde{q} \to q\tilde{\gamma}$ decays are narrower than ordinary jets at hadron colliders. First of all quark jets should be narrower than gluon jets and second, there is an indication from the first order QCD radiative correction [2,3] that the q-jets from the $\tilde{q} \to q\tilde{\gamma}$ decay may be even narrower than those observed in e^+e^- annihilation.

Hence it is even more important to investigate the consequences of the light gluinos seriously at hadron colliders and at beam dump experiments [14].

QCD $2 \to 3$ CONTRIBUTIONS TO LARGE $\not{p}_T$ EVENTS

If the light gluino exists, then not only the $\tilde{q}\tilde{g}$ production which leads to desired signals but also copious production of a $\tilde{g}$-pair is expected from the subprocesses, $gg \to \tilde{g}\tilde{g}$ and $q\bar{q} \to \tilde{g}\tilde{g}$. The two gluinos produced back to back in the transverse plane each hadronize into gluino-hadrons ($\tilde{g}_h$) and then decay into $\tilde{\gamma}$'s. The imbalance of the two (unobservable) $\tilde{\gamma}$ transverse momenta is then measured as $\not{p}_T$. This contribution was estimated by various authors [3-7] and they generally agree that such a contribution does not rule out the scenario because of the large ambiguity in theoretical estimates, with the one exception of Ref. 6 where similar results were interpreted as evidence against light gluinos by allowing less ambiguity in theoretical estimates.

However, Herzog and Kunszt [8] pointed out that the QCD $2 \to 3$ processes, $gg \to \tilde{g}\tilde{g}g$ and $qg \to q\tilde{g}\tilde{g}$, give rise to large $\not{p}_T$ events with the rate larger than the $2 \to 2$ ($gg \to \tilde{g}\tilde{g}$ and $q\bar{q} \to \tilde{g}\tilde{g}$) contributions for smaller gluino masses ($m_{\tilde{g}}$ = 10 to 20 GeV). Fig. 2 shows schematically

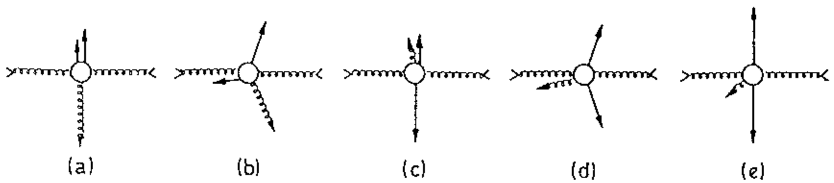

Fig. 2

the five typical momentum configurations for the process $gg \to g\tilde{g}\tilde{g}$ where the matrix element becomes large. Curly lines and solid lines denote gluon and gluino three-momentum vectors, respectively, in the colliding gluon c.m. frame. The configurations may be labelled as (a) $g \to \tilde{g}$ splitting, (b) $\tilde{g}$-excitation, (c) gluon emission colinear to a gluino, (d) gluon emission colinear to initial gluons, and (e) soft gluon emission. Among these, the latter three configurations give similar final states to the leading order one, i.e. a back-to-back gluino pair. Hence the loop correction in the same order is required to know the actual magnitude of the correction. In particular, the leading logarithmic terms in the configuration (c) and (d) are already taken into account by the scaling violations of the $\tilde{g}$ fragmentation function and the g distribution in a nucleon, respectively. On the other hand, the configurations (a) and (b) appear only in the α_s^3 or higher orders. The $2 \to 3$ processes hence give the leading contributions to these two configurations where two high p_T gluinos are almost collinear (a) or only one gluino has high p_T (b). In fact, Herzog and Kunszt observed that the collinear gluino configuration (a) gives the dominant source of large $\not{p}_T$ for lighter gluinos because the magnitudes of two photino transverse momenta add up to give large $\not{p}_T$ in this collinear configuration whereas they tend to cancel out in the $2 \to 2$ contributions where only the difference of the two photino transverse momenta gives $\not{p}_T$ in the back-to-back configuration.

To examine this $g \to \tilde{g}$ splitting effect quantitatively for the relevant mass range, $m_{\tilde{g}}$ = 3-5 GeV, we introduce an approximation which makes use of the universality of collinear singularities. The simplest source for two gluons is a scalar source (ϕ), which can be expressed by the effective Lagrangian [15)]

$$\mathcal{L} = \frac{1}{4\Lambda}\, \phi\, F^{a\mu\nu} F^{a}_{\mu\nu} \tag{3}$$

where $F^a_{\mu\nu}$ denotes the usual gauge covariant gluon field strength. By attaching a gluino-pair to a gluon leg emitted from the source, we find

$$dD = \frac{d\Gamma(\phi \to g\tilde{g}\tilde{g})}{2\,\Gamma(\phi \to gg)} = \frac{\alpha_s}{8\pi}\, T_A \left(1 - \frac{q^2}{\hat{s}}\right)^3 \beta\left[2 - \beta^2 \sin^2\theta\right] \frac{dq^2}{q^2}\, d\cos\theta \tag{4}$$

where T_A = 3, q^2 denotes the mass squared of the $\tilde{g}$-pair, $\hat{s} = m_\phi^2$, $\beta = (1 - 4m_{\tilde{g}}^2/q^2)^{1/2}$, and θ is the polar angle of the $\tilde{g}$ momentum in the $\tilde{g}$-pair rest frame where the ϕ momentum direction is chosen as the

polaraxis. This distribution reduces to the universal $g \to \tilde{g}$ splitting function in the $q^2/\hat{s} \to 0$ limit. I retain the $(1-q^2/\hat{s})^3$ factor to suppress the contribution from the region where our approximation is not valid. (Recently, it was found [16)] that our approximation overestimates the exact $2 \to 3$ cross section by a factor of 20 % in the relevant region.)

By aligning the jet axis to those of the dominant $2 \to 2$ subprocesses ($gg \to gg$ and $qg \to qg$) in the formula

$$d\hat{\sigma}(ab \to c\tilde{g}\tilde{g}) = d\hat{\sigma}(ab \to cg)\, dD(g \to \tilde{g}\tilde{g}) \tag{5}$$

with the decay function as defined by Eq. (4), we obtain a simple $2 \to 3$ subprocess cross section which simulates the exact $2 \to 3$ cross section in the collinear $\tilde{g}$-pair configuration (Fig. 2a) but gives negligible contributions in all the other configurations shown in Fig. 2.

NUMERICAL ESTIMATES

In the following numerical estimates we use the standard $2 \to 2$ fusion cross sections [17)] for $q\bar{q} \to \tilde{g}\tilde{g}$ and $gg \to \tilde{g}\tilde{g}$ with $m_{\tilde{q}}$ set to infinite and the approximation (5) for the $2 \to 3$ processes ($gg \to g\tilde{g}\tilde{g}$, $qg \to q\tilde{g}\tilde{g}$, $q\bar{q} \to g\tilde{g}\tilde{g}$). We employ a running coupling constant, the scale-dependent $\tilde{g} \to \tilde{g}_h$ decay function with $\epsilon_{\tilde{g}} = \epsilon_b (m_b/m_{\tilde{g}})^2$, the collinear $\tilde{g}_h \to \tilde{\gamma}$ decay function and the jet selection algorithm of Refs. 2 and 5, and the parton distributions of Duke and Owens [18)] with Λ = 0.2 GeV (set-I). Only the three selection criteria (2a,b,c) are imposed on the cluster transverse momenta in the parton level where the $\not{p}_T$ resolution of the UA1 detector is approximated by

$$\sigma = 0.7\left[\sum_{\text{partons}} |\vec{p}_T| + \langle E_T \rangle_{sp}\right]^{1/2} (\mathrm{GeV})^{1/2} \tag{6}$$

with a constant scalar transverse energy contribution from the spectator fragmentation, $\langle E_T \rangle_{sp}$ = 25 GeV or 40 GeV.

Shown in Figs. 3a and b are the $2 \to 2$ and the $2 \to 3$ subprocess

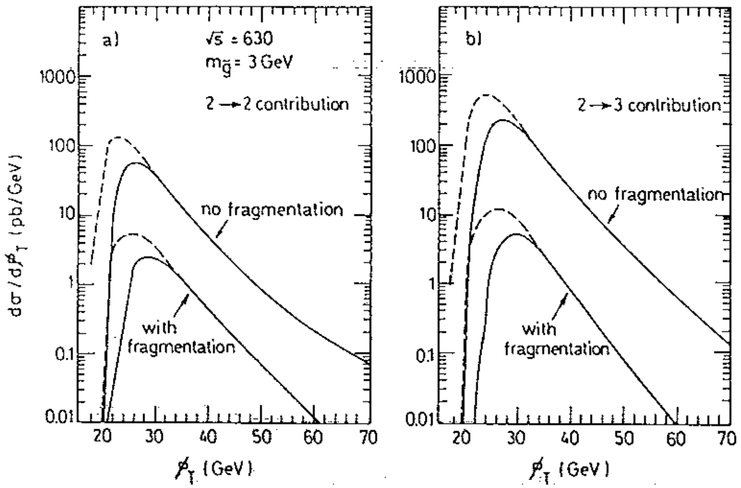

Fig. 3 Missinbg p_T distributions from the $2 \to 2$ (a) and the $2 \to 3$ (b) processes for $m_{\tilde{g}}$ = 3 GeV in $p\bar{p}$ collisions at $\sqrt{s}$ = 630 GeV. Dashed and solid lines are obtained by imposing the cuts (2a) and (2b) with $\langle E_T \rangle_{sp}$ = 25 GeV and 40 GeV, respectively

contributions to the $\not{p}_T$ distributions without the $\not{p}_T$ isolation cut (2c) for $m_{\tilde{g}}$ = 3 GeV at $\sqrt{s}$ = 630 GeV. The importance of the $\tilde{g} \to \tilde{g}_h$ fragmentation effect is clearly seen in the figures. Also shown is the significance of the 4σ cut (2a); dashed and solid lines denote the results obtained by imposing the 4σ cut with spectator E_T = 25 GeV and 40 GeV, respectively. In minimum bias events [19] one finds $\langle E_T \rangle_{sp} \simeq (20\text{-}30)$ GeV while in W/Z production it is considerably larger [20]: $\langle E_T \rangle_{sp}$ = (35-40) GeV. The typical mass scale of the $\tilde{g}$-pair production processes which give rise to the large $\not{p}_T$ signal is around 50-70 GeV. Although it is slightly smaller than the W/Z masses, it is certain that the gluon initiated processes as $gg \to \tilde{g}\tilde{g}$ should give more spectator E_T from initial state bremsstrahlung than the $q\bar{q}$ annihilation process at the same mass scale. Hence the solid curves with $\langle E_T \rangle_{sp}$ = 40 GeV would provide more realistic estimates. By comparing Fig. 3a and 3b, it is clear that the $2 \to 3$ processes give the dominant source of large $\not{p}_T$ events.

We show in Figs. 4a and b the same distributions as in Figs. 3a

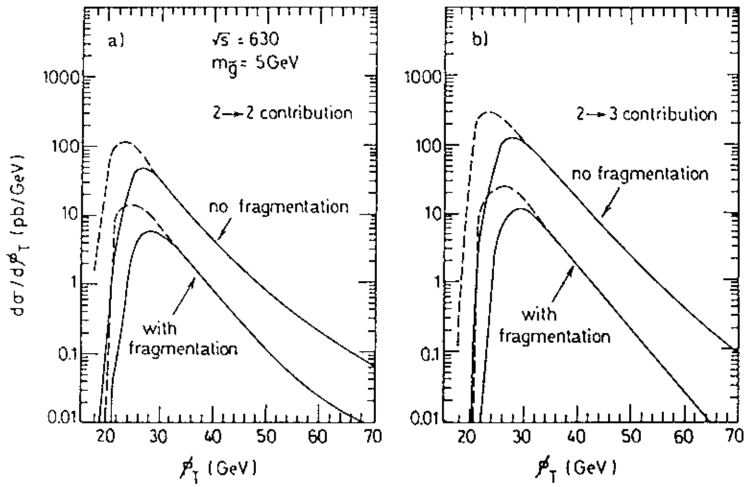

Fig. 4 Same as Fig. 3 but for $m_{\tilde{g}}$ = 5 GeV

and b but for $m_{\tilde{g}}$ = 5 GeV. All the qualitative features remain unchanged. A notable difference is that although the cross sections for $m_{\tilde{g}}$ = 5 GeV is the same ($2 \to 2$) or smaller ($2 \to 3$) than those for $m_{\tilde{g}}$ = 3 GeV, the $\not{p}_T$ distributions after fragmentation is substantially larger at $m_{\tilde{g}}$ = 5 GeV. As $m_{\tilde{g}}$ decreases, the fragmentation effect becomes more important and the collider experiments eventually loose their sensitivity to detect $\tilde{g}$'s through the $\not{p}_T$ signal. As we shall see in the following, the present collider experiment is sentitive down to $m_{\tilde{g}}$ = (3-5) GeV, which is at the border of the sensitibe region of beam dump experiments [14].

Shown in Figs. 5a and b are the monojet and dijet $\not{p}_T$ distributions summed over the $2 \to 2$ and $2 \to 3$ contributions with $\langle E_T \rangle_{sp}$ = 40 GeV for $m_{\tilde{g}}$ = 3 GeV and 5 GeV, respectively. Also shown are the distributions after imposing the $\not{p}_T$ isolation cut (2c). It is clearly seen

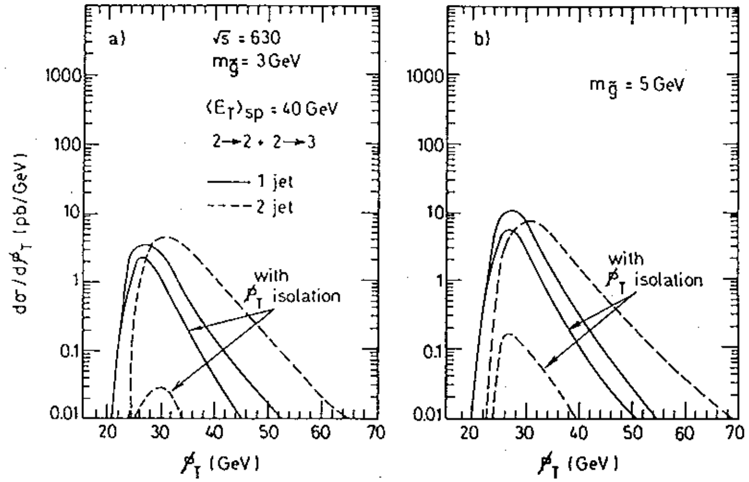

Fig. 5 Missing p_T distributions of monojet (solid lines) and dijet (dashed lines) events summed over 2→2 and 2→3 contributions calculated with the gluino fragmentation effects and with the cuts (Eqs. (2) for $m_{\tilde{g}}$ = 3 GeV (a) and 5 GeV (b) in $p\bar{p}$ collisions at $\sqrt{s}$ = 630 GeV. Results with and without the $\not{p}_T$ isolation cut (2c) are shown separately. $\langle E_T \rangle_{sp}$ = 40 GeV.

that this cut gets rid of dijet events almost completely. Only part of the monojet signal survives the cut with the distribution peaked around $\not{p}_T$ = 25 - 30 GeV. It should be remarked that even after the $\not{p}_T$ isolation cut the remaining monojet events from this source should have substantial minijet (p_T < 8 GeV) activity in the back-to-back of monojet direction. Hence if significant numbers of monojet signal survive all the cuts, one should find evidence for light gluinos. The integrated cross sections with $\langle E_T \rangle_{sp}$ = 40 GeV at $\sqrt{s}$ = 630 GeV are tabulated below. The cross sections with $\langle E_T \rangle_{sp}$ = 25 GeV are typically a factor of two larger.

Table. Integrated cross sections of $\not{p}_T$ events for $m_{\tilde{g}}$ = 3 GeV (5 GeV) satisfying the cuts (2a) and (2b) with $\langle E_T \rangle_{sp}$ = 40 GeV in $p\bar{p}$ collisions at $\sqrt{s}$ = 630 GeV.

	σ(1 jet + p_T) in pb	σ(2 jets + p_T) in pb
2→2 contribution	12.0 (36.7)	14.0 (25.7)
2→3 contribution	18.8 (52.8)	33.5 (66.4)
sum	30.8 (89.5)	47.5 (92.1)
after $\not{p}_T$ isolation (2c)	16.6 (47.6)	0.3 (1.6)

CONCLUSIONS

With an integrated luminosity of 263 nb^{-1} at $\sqrt{s}$ = 630 GeV and by taking into account the azimuthal angle acceptance factor of 7/9 for the $\not{p}_T$ events [11], we expect 3.4 (9.7) monojets for $m_{\tilde{g}}$ = 3 GeV (5 GeV) which satisfy all the selection criteria (the trigger condition (1b) is almost automatically satisfied). From Fig. 1, the UA1 Collaboration observed only 10 monojet events in the region L < 0 and E_{JT} < 40 GeV where the light gluino signal is expected. The above numbers imply that a significant fraction of the 10 monojet events in this region should come from gluinos if $m_{\tilde{g}}$ = 5 GeV. Our estimate is rather conservative by using a large $\langle E_T \rangle_{sp}$ (= 40 GeV), small running coupling constant (Λ = 0.2 GeV), a soft gluon distribution, no K-factor, and by neglecting $\tilde{g}$-excitation contributions (see Fig. 2b). Hence it is probably safe to conclude that the present collider data rule out light gluinos down to $m_{\tilde{g}} \sim 5$ GeV as long as $m_{\tilde{\gamma}}/m_{\tilde{g}} < 0.9$. [2]

On the other hand, light gluinos with $m_{\tilde{g}} < 3$ GeV would be difficult to rule out at hadron colliders at present due to the increasing sensitivity of the $\not{p}_T$ signal cross sections to the details of the $\tilde{g}$ fragmentation and $\tilde{g}_h$ decay distributions. This gives an excellent opportunity for future beam dump experiments to rule out or find a signature of light gluinos. This is not as easy a job as it seems because the present gluino mass bounds [14] were obtained under several naive assumptions which may or may not be realized in nature.

ACKNOWLEDGEMENTS

I would like to thank S. Jacobs for valuable help in preparing this talk. I enjoyed discussions with J. Colas, E. Reya and D. Zeppenfeld, and learned a lot from collaborations with V. Barger, E.W.N. Glover, S. Jacobs, W.-Y. Keung, A.D. Martin, R.J.N. Phillips and J. Woodside.

REFERENCES

1. Herrero, M.J., Ibáñez, L.E., López, C. and Yndurain, F.J., Phys. Lett. 132B, 199 (1983); ibid. 145B, 430 (1984)

2. Barger, V., Hagiwara, K., Keung, W.-Y. and Woodside, J., Phys. Rev. Lett. 53, 641 (1984); Phys. Rev. D31, 528 (1985)

3. De Rújula, A. and Petronzio, R., CERN report TH-4070 (1984)

4. Barnett, R.M., Haber, H.E. and Kane, G.L., Phys. Rev. Lett. 54, 1983 (1985); LBL report 20102 (1985)

5. Barger, V., Jacobs, S., Woodside, J. and Hagiwara, K., DESY report 85-032 (1985)

6. Ellis, J. and Kowalski, H., Phys. Lett. 157B, 437 (1985); CERN report TH-4072 (1984)

7. Altarelli, G., Mele, B. and Petrarca, S., Phys. Lett. 160B, 317 (1985)

8. Herzog, F. and Kunszt, Z., Phys. Lett. 157B, 430 (1985)

9. Haber, H.E., Kane, G.L. and Quiros, M., Phys. Lett. 160B, 297 (1985)

10. For a recent review, see e.g. Hagiwara, K., talk at the "New Particle '85" Conference (Madison, 1985), DESY report 85-101 (1985)

11. Arnison, G. et al. (UA1 Collaboration), Phys. Lett. 139B, 115 (1984)

12. UA1 Collaboration: Rohlf, J., talk at the American Physical Society Meeting (Eugene, August, 1985); Rubbia, C., talk at the 1985 International Symposium on Lepton and Photon Interactions at High Energies (Kyoto, August, 1985); Geer, S., talk at the 6th UK Institute for High Energy Theoretical Physicists (St. Andrew, September, 1985); Colas, J., talk at the Quark Structure of Matter Meeting (Strasbourg-Karlsruhe, September, 1985), in these proceedings

13. For a recent review, see e.g., Hikasa, K., talk at the "New Particle '85" Conference (Madison, 1985), University of Wisconsin preprint MAD/PH/261 (1985)

14. Bergsma, F. et al. (CHARM Collaboration), Phys. Lett. 121B, 429 (1983); Ball, R.C. et al., Phys. Rev. Lett. 149B, 253 (1984)

15. Shizuya, K. and Tye, S.-H.H., Phys. Rev. Lett. 41, 787 (1978)

16. Glover, E.W.N., Hagiwara, K. and Martin, A.D., DESY report 85-134 (1985)

17. Harrison, P.R. and Llewellyn Smith, C.H., Nucl. Phys. B213, 223 (1983); E, B223, 542 (1983)

18. Duke, D.W. and Owens, J.F., Phys. Rev. D30, 49 (1984)

19. Kernan, A., in Proton-Antiproton Collider Physics - 1981, Madison, edited by V. Barger, D. Cline and F. Halzen (AIP, New York, 1982), p. 325

20. Levi, M. and Ciapetti, G., talks at the 5th Topical Workshop on $p\bar{p}$ Collider Physics (St. Vincent, Italy, 1985)