SLAC-PUB-3310
April 1984
(M)

NEW PARTICLES AND INTERACTIONS*

F. J. Gilman
SLAC, Stanford University
Stanford, CA 94305

P. D. Grannis
State University of New York
Stony Brook, L.I., NY 11794
and
Fermilab
Batavia, IL 60510

I. INTRODUCTION

The Working Group on New Particles and Interactions met as a whole at the beginning and at the end of the Workshop. However, much of what was accomplished was done in five subgroups. These were devoted to (1) new quarks and leptons, (2) technicolor, (3) supersymmetry, (4) rare decays and CP, and (5) substructure of quarks and leptons. Other aspects of new particles, e.g., Higgs, W', Z', fell to the Electroweak Working Group to consider.[1]

The central question of this Workshop of comparing $\bar{p}p$ (with $\mathscr{L} = 10^{32}/\text{cm}^2\text{-sec}$) with pp (with $\mathscr{L} = 10^{33}/\text{cm}^2\text{-sec}$) colliders carried through to all these subgroups. In addition there were several other aspects of hadron colliders which were considered: what does an increase in $\sqrt{s}$ gain in cross section and resultant sensitivity to new physics versus an increase in luminosity; will polarized beams or the use of asymmetries be essential in finding new interactions; where and at what level do rate limitations due to triggering or detection systems play a role; and how and where will the detection of particles with short, but detectable, lifetimes be important. A partial list of participants in each of the subgroups follows in Table I.

II. SOME BASICS

The calculation of cross sections for new particles follows the now standard procedure of considering an incident p or $\bar{p}$ as a broad-band parton beam and folding the parton flux with the cross section for a given parton subprocess. Thus

$$\frac{d\sigma}{d\tau}\,(pp \to X + \text{anything}) = \sum \tau \, \frac{d\mathscr{L}_{ij}}{d\tau}\, \hat{\sigma}_{ij\to X}(\hat{s}) \quad , \qquad (1)$$

(Invited talk presented at the DPF Workshop on Anti-P P Options for the Super Collider, Chicago, Illinois, February 13-17, 1984)

*Work supported in part by the Department of Energy, contract DE-AC03-76SF00515.

where the sum is over parton constituents in the incident ($p/\bar{p}$) beams, $\tau = \hat{s}/s$ is the ratio of the squares of the center-of-mass energies of the subprocess ($\hat{s}$) and overall process (s), and $\tau d\mathcal{L}_{ij}/d\tau$ plays the role of a differential luminosity for partons i and j. If X is a single particle $\hat{s} = M_X^2$.

In all the detailed comparisons of cross sections and rates the new structure functions (and corresponding to them, $\tau d\mathcal{L}_{ij}/d\tau$) of Eichten, Hinchliffe, Lane, and Quigg[2] were used. They have folded these in with the parton subprocess cross sections $\hat{\sigma}_{ij}(\hat{s})$ to get the corresponding $d\sigma/d\tau$ for pp or $\bar{p}p$ production of new particles. In general there seems to be fairly good agreement with the earlier calculations, particularly when the fractional momentum x is not small or the momentum squared which is characteristic of a given process is not very large. One place where differences with previous work does become apparent is in the gluon distributions at low x. We will see one particular manifestation of this later.

The parton subprocess cross sections $\hat{\sigma}_{ij}(\hat{s})$ are calculated from the $SU(3)_c \times SU(2) \times U(1)$ gauge theory, i.e., "the standard model." Thus it will have the form

$$\hat{\sigma}_{ij}(\hat{s}) = \frac{C_{ij}}{\hat{s}} \tag{2}$$

where the quantity C_{ij} will involve dimensionless gauge couplings (like α, α^2, α_s^2, depending on the process), and possibly dimensionless ratios like $M^2/\hat{s}$ where M is a heavy mass involved in the subprocess.

The fall of relevant cross sections as 1/s is a long-standing fact of life for those who live around lepton colliders. Recall that the "point" cross section $\sigma(e^+e^- \to \mu^+\mu^-) = 4\pi\alpha^2/3s$ has a size of about 10 pb, 0.1 pb and 1 femtobarn for $s = (0.1\ \text{TeV})^2$, $(1\ \text{TeV})^2$ and $(10\ \text{TeV})^2$, respectively. Now for some of the processes (e.g., $gg \to Q\bar{Q}$) relevant at a hadron machine $\alpha^2 \to \alpha_s^2$ and we gain a factor $\mathcal{O}(10^2)$, or $\alpha^2 \to \alpha$ (as in $u\bar{d} \to W$) and we also gain a factor $\mathcal{O}(10^2)$. Thus we often gain a large factor over σ_{pt} in the subprocess cross section, although it still needs to be folded with the parton luminosity $\tau d\mathcal{L}/d\tau$ to obtain the cross section for pp or $\bar{p}p$ collisions. But the point remains that Eq. (2) means that cross sections fall as 1/s and there is no way around this as long as dimensionless couplings of gauge bosons are involved in the calculation of $\hat{\sigma}(\hat{s})$. Of course, if we involve a coupling with dimensions, or calculate outside the framework of the parton model outlined above, it is possible to get around the small cross sections at high s. The ideas[3] related to intrinsic charm, top, technicolor,...which were well debated in the QCD Working Group are a particularly relevant example of this.

III. NEW QUARKS AND LEPTONS

We considered primarily quarks whose mass was greater than that of the W, leaving those at lower mass for discovery at other machines. For such a heavy quark, Q, its dominant decay is $Q \to W + q$, where q is a "light" quark, if such a decay is allowed at all by kinematics (or selection rules). In particular, if Q were the charge -e/3 member of a fourth generation, its main decay would likely be $Q \to W + t$.

Production will be by the subprocesses $gg \to Q\bar{Q}$ or $q\bar{q} \to Q\bar{Q}$. For the mass range that turns out to be accessible (see below) gluon-gluon fusion is the dominant production process and so the $\bar{p}p$ and pp cross sections differ only slightly. Figure 1 shows the Eichten et al.[2] calculation of the production cross section as a funtion of M_Q. The cross sections are much smaller than those of Snowmass,[4] presumably due to the different gluon distributions.

Since both produced heavy quarks decay, our signal involves two W's and two $(\text{jets})_q$. With a postulated single W detection efficiency ε_W of 0.15 (e.g., a "perfect detector" and the modes $W \to e\nu$, $W \to \mu\nu$), an integrated luminosity $\int \mathscr{L} dt = 10^{39}/\text{cm}^2$, plus a requirement that $\varepsilon_W^2(\int \mathscr{L} dt)(\sigma) > 200$ events (e.g., 50 events in a detector acceptance containing ¼ of the heavy quark pairs), the maximum mass of a quark that could be discovered[2] is 0.75 TeV/c^2. Raising the integrated luminosity to $10^{40}/\text{cm}^2$ increases this to 1.2 TeV.

Clearly the key to discovery of such quarks lies in the ability to detect W's in as background free way as possible. Here we could allow one W to decay to the relatively clean mode $\ell\nu_\ell$, while the other decays into quark jets. We have the additional constraint that the quarks are produced in pairs and we must have the same mass for Q and $\bar{Q}$. However the question of whether high energy W's decaying into quark jets can be picked out of the background is central to this and other new particle detection. Optimism and pessimism alternated through the Workshop on this question, with the outcome at best cloudy - this is clearly a question that deserves much more experimental attention. One needs to identify the four jet background from QCD to W^+W^- pair production followed by each W decaying to two quark jets, as well as look at W decay itself and the coalescence of the two jets into one as E_W increases. A plausible start in this direction might be to take analytic results for three jet production in QCD and use a Monte Carlo calculation to add a fourth jet. If detection and separation of $W \to$ (jets) at high E_W is feasible, the heavy quark decay signature, $Q \to W + q$, correspondingly looks good.

A similar approach to charged heavy leptons with $M_L > M_W$ appears much harder. First, the cross section produced by the generalized

Drell-Yan mechanism, is much smaller as shown in Fig. 2. Here the subprocess is $q\bar{q} \to \gamma, Z \to L^+L^-$ and we directly pay the price of the small values of σ_{pt} discussed in Section II. Second, we have a background from real W^+W^- pairs as well as fakes when one looks for

$$pp \to \underset{\hookrightarrow W^+\bar{\nu}_L}{L^+} \; \underset{\hookrightarrow W^-\nu_L}{L^-} + \text{anything}$$

If we ask for a 5σ effect, require $\epsilon_W^2 \int \mathscr{L}\, dt > \frac{1}{4} \times 10^{39}/\text{cm}^2$, and place a rapidity cut at ± 3, then the highest mass lepton discoverable[2] is at ~ 100 GeV. Increasing the luminosity an order of magnitude raises this to ~ 150 GeV. These masses are so "low" that the production by $q\bar{q}$ annihilation involves mostly "sea" quarks and $\sigma_{pp} \approx \sigma_{\bar{p}p}$. In any case with $M_L - M_W$ relatively small and a real W^+W^- pair background it seems hard to separate a clean signal for lepton pair production and decay from the background.

The case of neutral leptons is more involved and much more interesting. Again we can have an L^o that is heavy enough to permit $L^o \to W^+L^-$ through a real or virtual W, or through mixing we can have $L^o \to W^+\ell^-$. The whole question of masses and mixing angles for neutral leptons is a relatively open one and there are many interesting possibilities,[5] starting with particles that are stable or have long lifetimes. Their production is by a "generalized" Drell-Yan mechanism involving $q_1 \bar{q}_1 \to Z \to L^o\bar{L}^o$ or $q_1 \bar{q}_2 \to W^+ \to L^+L^o$. Unfortunately the cross sections are the same order as above, or smaller, and the accessible mass range does not extend much above 100 GeV.

IV. TECHNICOLOR

We regard technicolor as simply a representative of a class of theories which replaces the elementary Higgs field of the standard model with a dynamics, and in particular with a new strong interaction dynamics on a mass scale which therefore will be roughly comparable with the value of the vacuum expectation value of the standard Higgs field of ~ 250 GeV. Since in any case we do not have "the" technicolor model, it is most useful to examine a range of such models and the corresponding new physics possibilities.

At one extreme is a minimal mode with one extra weak doublet, U and D, whose members carry the new technicolor quantum number, but not ordinary color. The lowest mass technihadrons, the technipions $\pi_T^{+,-,o}$ are "eaten" to give the W^+, W^-, and Z their respective masses. There is no other "light" signal of the theory, and thus the first new physics to be encountered are the technirhos ρ_T^{+-o} and techniomega ω_T^o. Their mass is roughly estimated as 1.7 TeV and the ρ_T's decay in analogy to ordinary ρ's: $\rho_T \to \pi_T\pi_T$, i.e., $\rho_T^o \to W_L^+W_L^-$, $\rho^\pm \to W_L^\pm Z_L^o$, with a width of $\sim$ 0.3 TeV.

In parton collisions the ρ_T^o can be produced in a way reminiscent of producing the ρ^o in colliding beams: $q\bar{q} \to \gamma$, $Z \to \rho_T^o$. The cross section for ρ_T^o production in $\bar{p}p$ collisions is shown[2] in Fig. 3. Integrating over the peak due to $\rho_T^o \to W^+W^-$ gives a cross section of $\approx 25 \times 10^{-39}$ cm^2 on top of a comparable background from real W^+W^- non-resonant pairs. $\rho^\pm \to W^\pm Z^o$ has a bigger cross section and better signal to noise ratio, but it is clear that these are the kind of signals which strain the limits of both the luminosity of the machine and the experimental ability to detect "clean" W's. Even with an integrated luminosity of 10^{40}/cm^2, detecting the presence of such a ρ_T looks hard.

On the other hand, going to a nonminimal model[7] where the new doublet carries both technicolor and color, and there is also a doublet of technileptons (without ordinary color), gives us plenty of "low" mass particles to find. Aside from the 3 technipions which are "eaten," there are 60 other pseudoscalars: 4 other "technipions" ($P^\pm$, P^o, $P^{o\prime}$), 24 "leptoquarks" (P_3), and 32 color octet pseudoscalars ($P_8^\pm$, P_8^o, $P_8^{o\prime} \equiv \eta_T$). The "technipions" are expected below $\sim$ 40 GeV in mass, the "leptoquarks" at $\sim$ 160 GeV and the color octet pseudoscalars at $\sim$ 240 GeV.

Some of these particles may be produced singly by gluon fusion, e.g., $gg \to P^{o\prime}$, $P_8^{o\prime}$. Since color plays a role in the production mechanism, we expect sizable cross sections. This is seen to be the case in Fig. 4 where $\sigma(\bar{p}p \to P^{o\prime}$ + anything) is shown.[2] It is usually expected that the $P^{o\prime}$ and $P_8^{o\prime} \equiv \eta_T$ will decay dominantly into the highest mass pair of fermions possible. With the $P^{o\prime}$ mass below 40 GeV this is $\bar{b}b$ (possibly $\bar{\tau}\tau$), while for $P_8^{o\prime}$ it is $t\bar{t}$. In either case one needs flavor tagging. At the SSC the large $b\bar{b}$ pair background presumably excludes seeing $P^{o\prime}$. The situation for $t\bar{t}$ pairs and the η_T is less clear, although there is some feeling that with tagging of t quarks (not a small order in itself) one is likely to be able to see the η_T. The question of the viability of tagging t quarks at SSC energies is not one which was examined in any detail at this meeting, although the tagging of b quarks was discussed[8] and this is an important step toward doing the same for t quarks. From the point of view of studying the physics above, it deserves a thorough examination.

One is also able to pair produce many of these particles by quark or gluon fusion: $q\bar{q} \to P_3\bar{P}_3$, $P_8\bar{P}_8$ or $gg \to P_3\bar{P}_3$ or $P_8\bar{P}_8$. The ρ_T occurs as a direct channel pole in these subprocesses at $\sqrt{s} \approx 900$ GeV, enhancing their cross section. The particular cross section for

$\bar{p}p \to P_3\bar{P}_3$ + anything is shown in Fig. 5. Since the ordinary color quantum number is operative in the production mechanism and the masses are comparatively light, the cross sections still are big. There are plenty of these particles produced for $\mathscr{L} = 10^{32}/cm^2$-sec. The dominant mechanism involves gluon fusion, so the cross sections in pp and $\bar{p}p$ are nearly the same.

Detection of leptoquarks (P_3) involves one of the cleaner signals we have discussed so far. In fact they could even be stable,[9] resulting in them possibly "drilling" through the detection apparatus and coming out the other side. A more standard expectation is for decay into a lepton and $(jet)_q$. Seeing two high energy leptons and two quark jets where the lepton and jet on one side together have the same invariant mass as those on the other provides a clear and accessible signature.

In the case of the color octet pseudoscalars, the most likely decay modes involve the heaviest quark-antiquark pairs: $P_8^+ \to t\bar{b}$, $P_8^{o\prime} \equiv \eta_T \to \bar{t}t$, etc. Here a flavor tag, particularly for t quarks, is a necessity. We again can use the pair production to advantage by requiring that the reconstructed masses on each side be equal. But the primary burden in showing that these particles can be successfully identified falls on being able to distinguish events which contain t quarks a sizable fraction of the time and then to use these events (which involve several $(jets)_q$) to reconstruct masses of the decaying parent particles. As stressed previously, more experimental work is needed to clarify exactly what in fact is possible at the SSC.

V. SUPERSYMMETRY

It is widely believed that if the current ideas about supersymmetry are correct, the production of particles in its spectroscopy will be copious at the SSC. Thus it is fruitful to examine in some detail the various possible signatures available for the wide range of supersymmetric particles. This has been done by the supersymmetry subgroup of this Workshop. Its discussions are summarized in the report by Barnett[10] in these proceedings.

The phenomenology of supersymmetry has been widely reviewed.[11] For each of the known elementary fermions and gauge bosons, there are partners of the opposite statistics and spins differing by ½ unit. Thus, for example, we expect scalar leptons and quarks ($\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$...; $\tilde{u}$, $\tilde{d}$...), spin ½ gauge particles ($\tilde{\gamma}$, $\tilde{W}$, $\tilde{Z}$, $\tilde{g}$) and spin ½ Higgsinos and the Goldstino (or the gravitino). The mass scale for these new states is believed to be set by the electroweak mass scale ($m_{W,Z} \sim 10^2$ GeV). The hierarchy of masses among the supersymmetric particles is not clear, with many versions proposed. A popular conjecture adopted in the discussions of this Workshop is that the $\tilde{\gamma}$ is the lightest of the spectrum. In considering decay chains of supersymmetric objects, the $\tilde{\gamma}$ then appears at the end as a stable particle whose interactions with matter are typically of weak interaction strength. The masses of the remaining particles are uncertain but are predicted in local supersymmetric theories to lie in the vicinity of m_W, m_Z. The low end of the mass range is accessible to experiments at e^+e^- machines now under construction; thus it is appropriate to consider the range

$$100 \text{ GeV} \leqslant m \leqslant 1000 \text{ GeV}$$

as that which SSC experimentation may be in a position to explore uniquely.

The cross sections for producing supersymmetric particle pairs are straightforward analogs of the corresponding normal particles. Figure 6 shows these cross sections as a function of mass as computed by Eichten, Hinchliffe, Lane, and Quigg.[2] In this calculation the masses of all supersymmetric particles are taken to be equal and the energy is fixed at $\sqrt{s}$ = 40 TeV. The rates are quite large in many cases, even for $m = 1000$ GeV/c^2; the problem is clearly one of finding sufficiently clear signatures and ways to suppress the normal standard model backgrounds. It is useful to tabulate some of the main decay modes expected. In most cases, there are caveats to be borne in mind that the hierarchy of masses themselves are uncertain so that some modes may be forbidden simply by energy conservation. In Table II we list these decay modes, together with some decays of the usual W and Z.

The reactions in which pairs of supersymmetric particles are produced are categorized as two-sided or one-sided, depending upon the topology of the decays. One-sided events are characterized by having one hemisphere nearly empty of visible tracks due to an escaping $\tilde{\gamma}$ (or haps a $\tilde{\nu}$ which decays invisibly. Two sided events have tracks in both hemispheres but with missing E_T.

It should be pointed out however that the nomenclature as applied to reactions is simplified more than the actual events need be. For example, $\tilde{g}\tilde{g}$ production with both $\tilde{g}$ decays into $q\bar{q}\tilde{\gamma}$ <u>can</u> yield all four quark jets into a single hemisphere, balancing p_T with the pair of $\tilde{\gamma}$'s. Similarly, $\tilde{\gamma}\tilde{W}$ production with $\tilde{W} \rightarrow \bar{q}\tilde{q}(\tilde{q} \rightarrow q\tilde{g} = qq\bar{q}\tilde{\gamma})$ can give events which have jets that tend to balance p_T isotropically. The point is that the supersymmetric particles need not be produced with $p_T > m$, so that their decay products need not be strongly directed along the parent momentum vectors.

Detection strategies for these cases depend not only on the one-sided vs. two-sided topological categorization, but on whether leptons are included or not. For example, $\tilde{g}\tilde{g}$ production yields the final particles $(q\bar{q}\tilde{\gamma}) + (q\bar{q}\tilde{\gamma})$ so that vetos upon leptons may be of considerable help. Another two-sided pair, $\tilde{g}\tilde{W}$, can yield the final state

$(q\bar{q}\tilde{\gamma}) + (\tilde{e}\nu \to e\tilde{\gamma}\nu)$. Here the ability to identify the lepton is a major factor in the signature.

The general features of an experiment that can search for supersymmetry particles at the SSC are fairly clear. The main requirements which seem essential are:

1. Good resolution in missing p_T (MPT). All cases in Table II involve production of the non-interacting $\tilde{\gamma}$ in the decay chains (even if $\tilde{\gamma}$ is not lightest among supersymmetric particles, there is some lightest non-interacting object). Those cases where $\tilde{\gamma}$ is directly produced typically involve large missing p_T. Those for which several $\tilde{\gamma}$ appear in decays (e.g., $\tilde{g}\tilde{g}$) give less MPT owing to the lower momenta after decay and the tendency for $\tilde{\gamma}$ momenta to partially cancel. Even so, the explicit studies mentioned below show that measurement of MPT is an important ingredient.

   The necessity of measuring MPT places several requirements on the detectors. In order to limit the contribution to apparent MPT due to the beam exit holes, the angular coverage must extend to quite small angles. It is desirable to keep this contribution less than or equal to that arising from the contribution from hadronic energy resolution. At energies of $\sqrt{s}$ = 2 TeV, these two contributions are equal (for uranium calorimetry response) for hole sizes of about 1^o. The MPT due to particles through a hole of size θ_o scales like $(p_{beam}\ \theta_o)$, whereas the energy resolution term grows like $(\langle E\rangle)^{1/2}$, where <E> is the typical hadronic energy carried in jets. From an estimate that <E> may grow by a factor of 4 from 2 TeV to 40 TeV, we can find that the beam hole should be no bigger than 5 mrad.
2. Good jet recognition ability
   Many of the decay modes yield multiple jets which can lie reasonably close to each other. An example is $\tilde{g}\tilde{g} \to (q\bar{q}\tilde{\gamma}) + (q\bar{q}\tilde{\gamma})$. The backgrounds from two jet QCD processes then differ in jet multiplicity (or effective jet widths). The major detector requirement then is for fine transverse segmentation of calorimetry and dense calorimetry so as to limit the extent to which the hadron showers spread.
3. Good lepton identification
   The ability to recognize leptons is essential for many decays (e.g., $\tilde{W} \to \tilde{\ell}\nu \to (\ell\tilde{\gamma})\nu$). Lepton vetos are important for background suppression in other cases where heavy quark semileptonic decays can simulate the signals. In these cases it is of considerable importance to extend the lepton identification to as low momentum as possible and

to be able to sense both electrons and muons even near the core of jets. These are difficult requirements and may dictate special devices such as transition radiation detectors in addition to finely segmented calorimetry. The ability to veto leptons is ultimately limited by the presence of τ's which can decay with no visible electrons or muons.

The process which has been most carefully studied for hadron colliders is $\tilde{g}\tilde{g}$ production. Earlier studies[12,13] examined the main source of backgrounds and the kinematic variables which can be used to reject them. This reaction has been re-examined[10] during this Workshop for SSC energies.

A detector with uranium quality calorimetry was assumed to cover $|y| \leq 6$; the region $4 \leq |y| \leq 6$ was used as a veto region with less than 10% of the total transverse energy observed in these regions. Events were analyzed to find the eigenvectors of sphericity and divided into hemispheres along the direction of that eigenvector of largest eigenvalue. The magnitudes of the transverse momentum components in the two hemispheres, called $|p_T|$ and $|p_T'|$, were used to define two measures of momentum imbalance,

$$x_e = \frac{-\vec{p}_T \cdot \vec{p}_T'}{\left|p_T{}^2\right|} \qquad \text{and}$$

$$p_{out} = \left(\left|p_T'\right|^2 - x_E^2\left|p_T\right|^2\right)^{\frac{1}{2}} .$$

For the SSC study, cuts are placed at $x_E < 0.5$ and $p_{out} > 90$ GeV/c.

The dominant QCD backgrounds surviving these cuts are found in the ISAJET simulations to arise from high p_T gluon fragmentation into a pair of heavy quarks. The momentum imbalance cuts are satisfied in those events in which one of the quarks decays semi-leptonically yielding e, μ (or τ) and a ν. Thus events with visible leptons present can be used to study the properties of the background. For the earlier (CBA) studies, a cut at p_T(lepton) < 2 GeV/c yielded a good signal to background ratio for gluino masses of 100 GeV/c^2 (see Fig. 7).

The analysis for SSC gluino production has not yet been carried through to the same degree as the lower energy study. However the same general analysis looks promising in its ability to suppress background. Again the dominant background seems to be hard gluon fragmentation into heavy quarks. The distributions for $\tilde{g}$ pairs and backgrounds from QCD jet production are shown in Fig. 8. Both x_E and p_{out} distributions have been computed for the case of $m_{\tilde{g}} = 0.5$ TeV/c^2 and $\sqrt{s} = 40$ TeV. The appropriate cuts are $x_e < 0.5$ and $p_{out} > 90$ GeV in order to eliminate most of the background. However, the present study has quite limited statistics for the background sample. This, coupled with the steeply falling shape seen in Fig. 8b, means that the signal purity is not yet well understood. An additional cut on the backgrounds from QCD processes was investigated. Since the $\tilde{g}$ decays produce broad (massive) jets consisting of two rather closely spaced quark jets, it may be useful to require the effective jet mass to be large. Figure 9 shows the larger effective jet mass distributions in the gg events. The peak due to the assumed 0.5 TeV/c^2 $\tilde{g}$ mass is faintly visible, but the rms width is large. The inset to Fig. 9 shows the variation of effective mass and rms width with assumed $\tilde{g}$ mass. The effective mass of jets selected from the background sample (not shown) tends to be distributed rather uniformly. Presumably this is true because of the severe bias imposed on QCD jets by the cuts on x_E and p_{out}.

On the basis of the analysis for SSC $\tilde{g}\tilde{g}$ production, it appears that clean samples can be obtained with cuts which retain 10-20% of the signal (see Fig. 8). There are important uncertainties which remain to be investigated: the effect of multiple (3,4...) jet production could be severe and is not well handled in the ISAJET program. Potential backgrounds from W,Z production also require study. On the other hand, it may be useful to develop further the use of topological cuts which attempt to select the two jet pair signature typical of $\tilde{g}\tilde{g}$ decays at high energy.

The detection strategy for the production of $\tilde{q}\tilde{\gamma}$ has also been examined for lower energy.[13] Search for this process could be crucial if both $\tilde{q}$ and $\tilde{\ell}$ are more massive than $m_Z/2$ and the gluino is very heavy. In such a case, $\tilde{q} \to q\tilde{\gamma}$, which gives a rather distinctive final state of a single thin jet, large MPT and no leptons. A similar analysis to the $\tilde{g}\tilde{g}$ case was carried out; events now show pronounced peaking at very low x_E, but p_{out} is essentially useless (and undefined). Again lepton vetos and jet mass or shape cuts can be used to refine the sample; dominant backgrounds are again expected to come from high p_T gluons that fragment into heavy quark pairs. Analysis of this mode for SSC energies seems promising, since the intrinsic rates are large even for q masses up to 300 GeV/c^2.

Several other specific supersymmetric particle production modes seem particularly attractive for SSC, due to rather distinctive signatures involving leptons and reasonably high rates. The leptonic branching ratios, BR_ℓ, are dependent on masses and hence quite model dependent. A value of 10% is sometimes taken as representative. Among these we note:

1. $\tilde{\gamma}\tilde{W}$ with $\tilde{W} \to \tilde{\ell}\nu(\tilde{\ell} \to \ell\tilde{\gamma})$ $\quad (BR_\ell)$
   This event yields large MPT and a single high p_T lepton with no jets present. Rates, including branching ratio, are marginal (4000 BR_ℓ/year for $m_{\tilde{W}} = 100$ GeV/c^2).

2. $\tilde{g}\tilde{W}$; $\tilde{W} \to \tilde{\ell}\nu$ (BR_ℓ)

This analog has a higher rate, but more complexity in the final state. The typical signature is an isolated lepton opposite a (merged?) $q\bar{q}$ jet pair from $\tilde{g}$ decay. Missing p_T cuts will be less useful here, but the absence of leptons near the jets and jet shape cuts will be useful.

3. $\tilde{g}\tilde{Z}$; $\tilde{Z} \to \tilde{\ell}\bar{\tilde{\ell}}(\tilde{\ell} \to \ell\tilde{\gamma})$ (BR_ℓ)

This signature is similar to that for $\tilde{g}\tilde{W}$ above except that there are two (opposite sign) leptons opposite the jets. The lepton configuration will be charge symmetric, on average.

4. $\tilde{W}\tilde{Z}$; $\tilde{W} \to \tilde{\ell}\nu(\tilde{\ell} \to \ell\tilde{\gamma})$ (BR_ℓ^2)

$\tilde{Z} \to \tilde{\ell}\bar{\tilde{\ell}}(\tilde{\ell} \to \ell\tilde{\gamma})$

Rates are small after branching ratios (16,000 BR_ℓ^2 events for $m_{\tilde{W},\tilde{Z}} = 100$ GeV/c^2) but the signature of a single lepton opposite a massive lepton pair is distinctive. Moderate MPT is expected with no jet activity.

Each of these potential methods for detecting supersymmetric particles requires more study in Monte Carlo simulations of detectors and background processes. However, the rough guess is that signatures for $\tilde{g}$ can be found at the SSC for $m_{\tilde{g}} \lesssim 1$ TeV/c^2; for $\tilde{q}$, $\tilde{W}$, and $\tilde{Z}$ the rates are smaller but signatures perhaps cleaner so that searches up to a few hundred GeV/c^2 look possible.

It should be emphasized that the spectroscopy of supersymmetry is so rich and the hierarchy of masses so uncertain, that there are potential confusions upon observing peculiar events about their specific source. We assume that this pleasant dilemma can be unravelled through a combination of experiments and better theoretical understanding of the nature of supersymmetry.

Another potential supersymmetry signal which could be seen at the SSC is that from decays of $\tilde{g}\tilde{g}$ bound states.[14] Such states might provide an accurate measure of the $\tilde{g}$ mass, in contrast to continuum $\tilde{g}\tilde{g}$ production. As proposed by Goldman and Haber,[15] such states could form s-channel resonances in gluon-gluon scattering and thus produce bumps in the large p_T two-jet mass spectrum. Such states can be considered as analogs to the onium states formed by conjugate spin ½ quarks. The color octet character of the gluino gives a larger number of possible states than the usual $\bar{q}q$ bound states. Color singlets and symmetric color octets $\left(J^{PC} = 0^{++}, 1^{++}, 2^{++}\ldots\right)$ and antisymmetric color octets $(1^{-+}, 1^{++}\ldots)$ could be formed. The $\eta_{\tilde{g}}$ (the 0^{-+} lowest lying state) has its dominant decay into 2 gluons, with coupling enhanced by both color factors and wave function factors, relative to those for quarkonium states. Widths of the $\tilde{g}\tilde{g}$ states are estimated to be of the order of 300 MeV. Assuming a bound state mass of 100-300 GeV/c^2 and uranium calorimetry, we may expect dijet mass resolutions of no better than 3-5 GeV/c^2. Signal to noise ratios for isolated states would be in the range 1-10%. If there is a collection of bound states just below the threshold for free $\tilde{g}$ pair production, it appears that resolution broadening will smear these states across that threshold. In any case, demonstration of a peak requires high statistics (thousands of events per bin with a width a few GeV/c^2).

Consideration was given in this Workshop to the potential differences in pp and $\bar{p}p$ colliders for supersymmetry searches. Luminosity is the overriding consideration for most signatures, so that to first order a pp machine is favored over $\bar{p}p$. Production cross sections are dominated by gluon-gluon or quark-gluon scattering and thus differ little for the two cases. Some second generation experiments could benefit from study of asymmetries, but these in general are useful only for processes involving large x (valence) quarks and are thus very small rate. It could conceivably be of interest to study the asymmetry with polarized beams (++ vs. +- initial helicity) or to look for asymmetries signalling parity violation in $\bar{p}p$ production. Such experiments seem problematic and thus give only weak reasons for choosing $\bar{p}p$ over pp.

In summary, the SSC appears to be in an excellent position to search for a variety of supersymmetric particles in the mass range 0.1 to 1 TeV/c^2. The general requirements are high luminosity and full solid angle detectors with excellent jet and lepton identification properties.

VI. RARE DECAYS AND CP VIOLATION

The SSC will produce enormous numbers of heavy quarks, leptons and gauge bosons; for an integrated machine luminosity of 10^{40} cm^{-2}, one expects about 10^{12} b's, 10^{11} t's, 10^{10} τ's and 10^{9} W's. Therefore the possibility exists, with appropriate detection strategies, that interesting rare decay modes can be sought. Certainly the numbers of heavy flavor objects produced are large (and much greater than those anticipated in e^+e^- machines). The difficulties in identifying these states in hadronic collisions are also well known. Identification of t and b quarks, even through large decay modes, has proven to be hard, both in fixed target experiments and in colliders. It is clear that in the face of large backgrounds, new detection strategies are required to isolate relatively pure samples. The use of vertex detectors to tag the presence of long lived particles is the one promising new method for achieving this selection. Recent measurements[16] at PEP indicating a long b quark lifetime give impetus to the design of high resolution micro-vertex chambers.

Some of the motivations for designing experiments to measure rare decays of c, b, t or τ were summarized by Kane.[17] For example, flavor-changing neutral currents may well exist whose branching ratios depend upon the mass squared of the participating fermions. Such a hypothesis may give reasonable rates for decays such as $B \to \tau\mu$, $B \to \mu e$, $B \to K\mu e$; $T \to \tau\mu$, $T \to b\tau\mu$; and $\tau \to \mu\mu\mu$. Although these FCNC decays were not explicitly examined in this Workshop, it would seem that possibilities for detection are reasonably good. Combined use of vertex detection to signal the presence of heavy flavor and external calorimetry and particle identification should yield very good signals in two and three particle invariant mass peaks. Further study of these possibilities is warranted in order to take into consideration the real questions of geometric efficiencies (many heavy quarks at SSC are produced at small angles relative to the beams), the efficacy of separated vertex tagging, and the problems imposed by particle misidentifications. In this regard, present experiments which probe for the equivalent rare modes of K decay will give most useful information on both potential FCNC amplitudes and upon the experimental problems encountered.

An earlier analysis of an experiment which could tag b and c quark production was presented in the 1983 DPF Workshop in Berkeley.[18] This study, while made for a detector in a 1 TeV collider, contains a rather complete treatment of some of the background and triggering problems. It supports the conclusion above that signatures for FCNC processes such as $B \to Ke^+e^-$ or $\tau \to \mu ee$ are sufficiently good that backgrounds can be suppressed to the level of about 10^{-5} of all B or τ decays.

The detector simulation of Benenson et al.[18] studied in some detail the resolution achievable with a particular choice of vertex detector (four planes of silicon strips measuring azimuthal coordinates at radii of 1 to 4 cm from the beams). For intrinsic resolution in the strip planes of 10 μm, they find a resolution in the 1-dimensional vertex location of

$$\sigma_V = 5\ \mu m \oplus 3\ \mu m \oplus \frac{9}{p\beta}\ \mu m \quad , \qquad (5)$$

where the terms are due to position resolution, angular resolution, and multiple scattering respectively. Averaged over the spectrum of tracks near 90^o, they find $\langle\sigma_V\rangle = 10\ \mu m$. Some consideration was given to the possibility of using the vertex separation information at the trigger level. A scheme was discussed which could achieve the trigger level indication of a separated vertex within a few milliseconds and which would reduce the trigger rate by about a factor of 50. Even with this extra reduction, the total trigger rates tend to be rather large unless rather restrictive additional demands are made---for example the presence of two leptons in a single hemisphere.

The possibility of studying $B\bar{B}$ mixing and CP violation in the B system at the SSC has been examined in this Workshop and is the subject of a separate contribution[19] to these proceedings. The detector envisioned in this study is similar to that of the earlier study;[18] a silicon strip detector is used for vertex measurement, surrounded by conventional chambers and calorimetry. Electrons are assumed to be identified using transition radiator detectors; muons are tagged by their penetration of the full calorimeter. The useful luminosity is taken to be limited to 10^{31} cm^{-2} sec^{-1} due to the restriction of the interaction region to a $\pm$ 2 cm diamond and caution with respect to the radiation hardness of the silicon strip detector and associated electronics.

The study of both B^o-$\overline{B^o}$ mixing and CP violation could be made by studying the proper time dependence of the sign of the charge of the leptons produced in B^o and $\overline{B^o}$ semileptonic decays. Monte Carlo estimates for the rate were made using ISAJET. One starts with 1000 $b\overline{b}$ pairs produced per second, but after successive cuts for detecting a B^o and then having a semileptonic decay with p_T of the lepton greater than 3 GeV/c one comes down to a level[19] of 1/sec, i.e., 10^7/yr.

Such an event sample is clearly large enough to give good information first of all on mixing and hence on the B_L-B_S mass difference through observation of B^o and $\overline{B^o}$ decays to "wrong" sign leptons.

Second, a search for a CP violating effect outside of the neutral kaon system remains of very strong interest. Just as in the $K^o\overline{K^o}$ case, where the CP violation parameter ε_K allows $BR(K^o_L \to \mu^+) \neq BR(K^o_L \to \mu^-)$, there is a corresponding parameter ε_B which yields $BR(B^o_L \to \mu^-) \neq BR(B^o_L \to \mu^+)$. By following the neutral B^o and $\overline{B^o}$ decays out to large proper times, one can determine $Re\varepsilon_B$ from the difference between the initial $B^o \to \ell^+$ and initial $\overline{B^o} \to \ell^-$ rates.

The ability to make such a difficult measurement depends crucially on the B_L-B_S mass difference, and the size of $Re\varepsilon_B$ but given the potential sample of 10^7 $B \to \ell$ decays per year it would appear to be within the range of possibilities. Although also very difficult, such a large event sample would also make it possible to look for CP violation in the B decay amplitude itself (the equivalent of measuring ε' in the K^o system) by searching for different B and $\overline{B}$ decay rates into certain exclusive or semi-inclusive modes.

For the studies undertaken in this Workshop, no advantage is seen for $\overline{p}p$ collisions over pp. Indeed, for the case of the $B\overline{B}$ studies, the dc character of the pp machine gives about a factor 6 smaller pileup probability than the bunched $\overline{p}p$ machine (at the same luminosity for each).

More studies in this aread would be useful. Studies of simulated detectors covering the small angle region may show that the large flux of heavy flavors in these regions can be exploited. The ability of the microvertex detectors to unscramble multiple decays should be investigated, and detailed studies of backgrounds in the SSC environment for flavor changing neutral current decays remain to be made. Evaluation of the detector technologies for high precision position determination is essential and will likely come through experience with detectors now in preparation. In particular, radiation hardness, time resolution, and readout electronic packaging all pose rather severe constraints on the ability of the vertex chambers to isolate the long lived particles.

VII. SUBSTRUCTURE IN QUARKS OR LEPTONS

The notion that the elements of matter are composite structures has had well known historical sucess. Although present data are consistent with the idea that quarks and leptons are structureless, it is interesting to speculate that at smaller distance scales than probed so far they may begin to show evidence of compositeness. Once, and if, experiments reach the energy scale of the compositeness, the rich study of the detailed properties of the subelements (preons) can begin. Until that time, we should at least be sensitive to the ways that compositeness could manifest itself.

The discussion in the Workshop proceeded from the work of Eichten, Lane and Peskin[20] with calculations based on the new structure functions of Eichten et al.[2] The same general approach was discussed in the DPF Snowmass proceedings,[1] where consideration was also given to the properties of excited leptons and quarks.

For any compositeness pattern in quarks and/or leptons, it is necessarily true that two identical fermions share the same pool of preons. Therefore there is a term in the scattering amplitude for elastic scattering which arises from exchange of preons. This effect can be represented at low energy by an effective Hamiltonian involving a contact term, very much like the four-fermion interaction that represents the weak interaction at energies well below the W and Z mass. In particular $qq \to qq$ and $\bar{q}q \to \bar{q}q$ will possess this contact force. With composite leptons a similar effect would exist in Bhabba scattering. If quarks and leptons share at least one common constituent, then such forces arise in processes like Drell-Yan lepton pair production: $\bar{q}q \to \ell^+\ell^-$.

As argued in Ref. 20, the effective contact interaction for the helicity conserving part[21] at low energy is:

$$\mathscr{L}_I = \frac{g^2}{2\Lambda^2} \sum_{i,j=L,R} \eta_{ij}\left(\bar{f}_i\gamma_\mu f_i\right)\left(\bar{f}_j\gamma_\mu f_j\right) \tag{6}$$

where Λ is the scale of the new strong interactions characterizing the compositeness and $g^2/4\pi = \mathcal{O}(1)$. The computations of Ref. 2 are based upon taking only the left-left term in Eq. (6), but allowing both signs for $\eta_{LL} = \pm 1$. At energies comparable to Λ, this form must break down as the finite range of constituent effects becomes apparent. At lower energies, its effect can be most easily seen by observing its interference with a larger, known gauge interaction. Thus one can look for departures in expected behavior in such processes as large Q^2 qq scattering (i.e., large p_T jet production) or in high mass Drell-Yan production. Searches for equivalent departures in Bhabba scattering have already set limits[20] on Λ for electron structures which lie in the range 0.75 - 1.5 TeV (depending upon the specific V, A form for the effective Lagrangian).

In the case of quark jet experiments, the interference occurs between the usual QCD amplitude and the contact term. When the effect of the contact interaction is small, it may be characterized in the form of a multiplicative correction to the cross section,

$$1 \rightarrow 1 + \mathcal{O}\left(\frac{g^2}{\Lambda^2}\frac{\hat{s}}{g_s^2}\right) ,$$

where $\sqrt{\hat{s}}$ is the quark-quark subenergy and g_s is the QCD coupling constant. The actual computation must take into account the quark content of the colliding hadrons and their longitudinal momentum fractions.

Figures 10 and 11 show representative calculations with $g^2/4\pi = 1$ from Ref. 2 at $\sqrt{s} = 40$ TeV for pp and $\bar{p}p$ collisions respectively. Departures from the structureless cross sections ($\Lambda = \infty$) are clearly visible due to the interference between the contact term and QCD quark scattering. The jet cross sections also include terms due to gluon-quark and gluon-gluon scattering which dominate at low p_T and which do not contribute to the interference with the four-fermion contact term. The size of the effect depends upon the sign chosen for the contact term, particularly in the case of pp collisions. Different choices of V, A mixtures other than the left-handed fermions chosen here would presumably alter predictions by amounts similar to those from switching the sign of the contact term.

From the curves represented by Figs. 10 and 11 one must develop criteria for the observability of compositeness. There are two difficulties here: the first is the straightforward requirement of sufficient statistics. The second is the more delicate problem of predicting the shape of the pure QCD contribution from the observed lower p_T cross section and theoretical understanding of the extrapolation. On the latter issue we note that at the large p_T required for this study, the theoretical question is how well we know the quark distribution functions at moderate to large x ($x \gtrsim 0.1$). This region is perhaps the least troublesome in the sense that the very low x distributions with their less certain QCD corrections are unimportant. It is also worth pointing out that overall uncertainties on the magnitude of the cross section, such as arise in the K-factor for Drell-Yan production, are not at issue since extrapolation can be based upon the observed cross section at lower p_T. Finally, we note that the two different parameterizations of structure functions in Ref. 2 give expected jet cross sections from q-q subprocesses which are equal to within about 10%. Although these parameterizations may not be fully exhaustive, they do underscore the likelihood that the shape of large p_T jet cross sections in QCD will be well understood.

The criterion for observing compositeness effects used in Ref. 2 is that the interference effects yield a factor of two deviation from the $\Lambda = \infty$ case, and that the difference should give at least 100 events in a bin of size $\Delta p_T \Delta y$ = 200 GeV. Assuming an experiment with Δy coverage of 5 units, this implies Δp_T = 40 GeV/c -- a 1% p_T bin at 4 TeV/c. Figures 12 and 13 give the integrated luminosity required to sense compositeness in high p_T jets vs. the Λ characterizing the scale, for several values of machine energy. Both choices of contact interaction sign (η) are included. At $\sqrt{s}$ = 40 TeV a $\bar{p}p$ collider ($\int \mathscr{L} d = 10^{39}/cm^2$) is sensitive to Λ in the 10 to 12 TeV range, while pp (with $\int \mathscr{L} dt = 10^{40}/cm^2$) reaches scales between 15 and 20 TeV.

A similar procedure can be carried out searching for mutual compositeness in quarks and leptons using Drell-Yan dilepton production. Here the interference occurs between a contact interaction characterized by Λ and the Drell-Yan amplitude. Using the same technique,[22] the scales of Λ one is sensitive to are lower in this case than those for quark jets since the standard model subprocess cross section is much smaller. For example, the maximum observable Λ is about 10 TeV for a 40 TeV pp collider ($\int \mathscr{L} dt = 10^{40}/cm^2$) and about 5 TeV for a 40 TeV $\bar{p}p$ collider ($\int \mathscr{L} dt = 10^{39}/cm^2$). The main factor here is of course the luminosity difference assumed. The rule that a factor 2 (or e) in energy is worth a factor 10 in luminosity is approximately valid in these studies. These scales are reached through observation of the pair mass spectrum out to about 800-1000 GeV/c^2.

An interesting additional point to bear in mind in searching for compositeness is that the contact term may very well not be left-right symmetric; observable parity violation can be introduced by the interference of, e.g., the QCD and contact interactions. In the case that the interference is small and establishing an effect based on cross sections alone is difficult, it would be extremely useful to demonstrate a parity-violating asymmetry. Such a demonstration would be made possible if the beams could be polarized and study made of the rate dependence on beam helicity. Information on the structure of the contact term could also be obtained if pp and $\bar{p}p$ production could be compared.

Another approach[23] to establishing an effect is based on taking data at different values of s and looking at the jet-jet cross section ratio at a given $x_T = \sqrt{\hat{s}/s}$. The (logarithmic) dependence of the cross section ratio in QCD as a function of $\hat{s}$ is to be contrasted with the linear dependence expected from a contact term.

If there exists a mass scale at which quarks or leptons are composite, then clearly physics will enter a new regime once scattering subenergies reach this scale. The situation may be analogous to that for pp scattering around the pion threshold; excited states can be formed with subsequent strong decay. At energies around the scale Λ, processes such as $qq \rightarrow qq^*$, q^*q^*, qq + preon-antipreon bound states,... become prevalent. The fundamental parton subprocess cross sections are expected to be

$$\hat{\sigma} \approx \frac{4\pi}{\Lambda^2}$$

for saturation of s-wave unitarity. This corresponds to a cross section of $\sim$ 50 pb for Λ = 10 TeV. To obtain the cross section in hadron-hadron collisions one must fold in the proability of finding quarks in the appropriate x range, which yields a cross section for pp or $\bar{p}p$ collisions of $\sim$ 1 pb.

The signature for excited state detection depends on the nature of the substructure and the new strong interactions. If the excited states are exotic (higher color representations, etc.), they might even be moderately long lived[24] or stable. But in general we expect them to be unstable, decaying into ordinary fermions + possibly gauge bosons. As we are at an (s-wave) threshold we expect to see an isotropic distribution of several jets, in striking contrast to the two jet background at large $\hat{s}$ from QCD.

summary, the search for compositeness in quarks and leptons can be pushed to limits on Λ of 10 to 20 TeV with multi-TeV colliders. For this, $\bar{p}p$ colliders are not better than pp colliders. The reason this time is not that valence quarks do not play an important role, but that both $\bar{p}$ and p have them! Then the superior luminosity of a pp collider extends the range of sensitivity somewhat further. For the machines being discussed, the limits on Λ achievable by studying departures from QCD jet cross sections are themselves at energy scales within the kinematic range of the machine. Thus at a given $\hat{s}$, the observation of such departures would likely herald the onset of <u>observable</u> composite states at higher $\hat{s} < s$ at the same machine.

VIII. SUMMARY

The discussions in the Working Group on New Particles and Interactions have uncovered very little explicit benefit from the use of $\bar{p}p$ collisions in the SSC relative to pp. In much of the new physics considered, gluon-gluon scattering dominates the cross sections. In the few cases where valence quarks are of importance (e.g., in the studies of quark compositeness), either quark or antiquark can be used to establish the effect.

The tradeoff between luminosity and energy has been examined for several processes. At SSC energies, increasing the energy does not result in a proportional increase in the mass limit achieved for new particles. This is due to the fact that the relevant constituent cross sections typically fall like M^{-2} or $\hat{s}^{-1}$ and to the QCD non-scaling properties of the structure functions. Based on the calculations of cross sections from the structure functions of Eichten et al.,[2] we can determine the increase in cross section for specific new physics upon doubling $\sqrt{s}$ from 20 to 40 TeV. The factor by which σ increases is equivalent to the luminosity increase at the lower energy which would be required in order to have the same effect as doubling the energy -- assuming no experimental difficulties from the increased event rate.

Process	Increase in σ ($\sqrt{s}$ = 20 $\rightarrow$ 40 TeV)
$Q\bar{Q}$ (M_Q = 1 TeV)	7
$L\bar{L}$ (M_L = 0.3 TeV)	1.6
Minimal Technirho (M_{ρ_T} = 1.7 TeV)	3
$P^{o\prime}$ ($M_{Po}{}'$ = 40 GeV)	2
Leptoquark Pair (M_{LQ} = 0.2 TeV)	3.5
Gluino pair ($m_{\tilde{g}}$ = 0.5 TeV)	5
Gluino-Photino (m = 0.25 TeV)	1.5
Quark Compositeness (Λ = 10 TeV)	5

We see that doubling the energy at SSC is equivalent to a factor 1.5-7 increase in luminosity. Thus the nominal factor of ten increases in pp luminosity over $\bar{p}p$ is equivalent to an energy increase of around 3.

The need for special features of machine operation was identified for two studies. The search for a contact interaction signalling quark compositeness could benefit from having longitudinally polarized beams. Such an interaction may be parity violating and a study of the rate dependence on beam helicity could well be crucial in establishing the effect. Studies which involve measurement of separated decay vertices for b, c or τ tagging would benefit from special intersection regions in which the collision region is short (a few cm) along the beam coordinate.

The experimental signatures involved in the new physics studied at this Workshop are generally quite difficult and have been inadequately studied. The intrinsic widths of new states are often quite broad and dominant decay modes involve difficult detection modes such as W pairs, $t\bar{t}$, etc. More work is needed using detector simulations and improved Monte Carlo techniques for background simulation. For example the detection of W pairs with W $\rightarrow$ 2 jets is problematic: physics backgrounds from electroweak W^+W^- production are large. The QCD backgrounds from four jet production under a potential WW signal have not been calculated theoretically; work should be done to estimate these from Monte Carlo studies, using 3 jet production as a test bed for comparison of analytic calculations and Monte Carlos. The experimental signatures for W $\rightarrow$ 2 jet decays at large p_T also need study; to some extent these dijets will coalesce in a detector giving rise to a single broad jet.

Experimental study of high resolution vertex detectors is needed. Questions of rate capability, radiation damage, beam associated backgrounds, and the possibility of fast triggers are all crucial to exploitation of these devices for flavor tags at the SSC.

The question of how experiments will survive in high luminosity colliders ($\mathscr{L} = 10^{33}$ cm^{-2} sec^{-1}) was discussed, but deserves more study. On the hardware side there is the question of radiation hardness of the components. The effect of event pileup on physics signals has been studied[13,25] for some particular questions. These indicate that with about 10 events within a time resolution window, high p_T jet studies and gluino searches can still be performed with reasonable cleanliness. Further studies of pileup are in order. It is unclear how W pair signals (4 jets) suffer from multiple two-jet event overlaps. The utility of missing p_T signatures or lepton identification in the presence of several unresolved events needs study. The presence of multiple collision vertices may make life difficult for microvertex chambers searching for decays. There may be considerable help from good time resolution on calorimetric energy deposits in identifying pieces of distinct events. This technique deserves study to evaluate how well one can tag the showers from separate collisions; obviously the overlap of showers in a specific region of the detector gives an irreducible level of confusion. The problems associated with event pileup were estimated to be about 2-3 times worse for an equal luminosity $\bar{p}p$ (bunched) collider than for a pp (dc beams) collider as presented in this Workshop.

The potential for exciting discoveries opened by the SSC is clearly very great. The challenge posed by a new class of phenomena in which the decays are jets, leptons and non-interacting particles is great. The SSC environment is likely to be markedly different from present machines with the large production rates of gauge bosons and jets giving complex background topologies. The search for new phenomena will thus be an exciting and formidable task, with cleverness in building detectors and filtering procedures at a premium.

REFERENCES

1. The Working Group on New Particles and Interactions built on the large amount of work done at the Snowmass Meeting in 1982 and we often referred to and will refer to: Proceedings of the 1982 DPF Summer Study on Elementary Particle Physics and Future Facilities, edited by R. Donaldson, R. Gustafson, and F. Paige (American Physical Society, New York, 1983).
2. E. Eichten, I. Hinchliffe, K. Lane and C. Quigg, Fermilab preprint FERMILAB PUB 84-17-THY, 1984 (to be published in Rev. Mod. Phys.). We thank all four authors for presenting and explaining the input and results of this work.
3. S. Brodsky, J. Gunion, and H. Haber, these proceedings.
4. These cross sections are about two orders of magnitude smaller than those in Table 4.3 of G. L. Kane and M. L. Perl, Ref. 1, pg. 18, but within a factor of three of those in Fig. 5b of F. E. Paige, ibid., pg. 484.
5. See, for example, M. Gronau, C. N. Leung, and J. L. Rosner, Enrico Fermi Institute preprint EFI 83/63, 1983 (unpublished). We thank Jon Rosner for discussions of some of these possibilities in the subgroup on new quarks and leptons.
6. S. Weinberg, Phys. Rev. D13, 974 (1976) and D19, 1277 (1979); L. Susskind, Phys. Rev. D20, 2619 (1979).
7. E. Farhi and L. Susskind, Phys. Rev. D20, 3404 (1979).
8. See Section VI and the separate contribution to these proceedings of Ref. 19.
9. K. Lane emphasizes the possibility of weak hypercharge assignments which give exotic charges and do not permit decay to known particles. We thank him for his presentation of the results of Ref. 2 and many discussions in the subgroup on technicolor.
10. R. M. Barnett, contribution to these proceedings.
11. See, for example, the reviews by A. Savoy-Navarro, CERN-EP/83-132 (1983), to be published in Physics Reports; I. Hinchliffe and L. Littenberg, Ref. 1, pg. 242; H. E. Haber and G. L. Kane, University of Michigan preprint UMHE TH 83-17 (1984), to be published in Physics Reports.
12. S. Aronson et al., Ref. 1, pg. 505.
13. L. S. Littenberg et al., "Update to the CBA SUSY Studies," BNL internal note (1983).
14. H. E. Haber, contribution to these proceedings.
15. L. Goldman and H. E. Haber, Los Alamos preprint (1984), to appear in Proceedings of the 1983 Los Alamos Workshop: "Supersymmetry in Physics," to be published in Physica D.
16. E. Fernandez et al., Phys. Rev. Lett. 51, 1022 (1983) and N. S. Lockyer et al., ibid., 1316 (1983).
17. G. L. Kane, University of Michigan preprint UM TH 83-25 (1983), to be published in Proceedings of the Conference on the Physics of the XXI Century, Tucson, December 1983.
18. G. Benenson et al., Proceedings of the 1983 Workshop on Collider Detectors: Present Capabilities and Future Possibilities, pg. 143.

19. R. Loveless et al., contribution to these proceedings.
20. E. Eichten, K. Lane, and M. Peskin, Phys. Rev. Letters 50, 811 (1983).
21. The helicity flip portion does not interfere with the helicity conserving QCD amplitudes and adds to the cross section terms typically down by m^2/s.
22. After the Workshop a different technique (K. Lane, private communication) was suggested of looking directly for the effect of the contact term in the cross section, integrating over dilepton pair masses in the region (above ∿ 2 TeV) where the Drell-Yan contribution has become negligible. This allows one to be sensitive to Λ value of 20 TeV in $\bar{p}p$ (with integrated luminosity of $10^{39}/cm^2$) and 27 TeV in pp (with integrated luminosity of $10^{40}/cm^2$).
23. We thank J. Pilcher for this suggestion in the Working Group discussions.
24. M. Abolins et al., Ref. 1, pg. 274; see also L. Lyons, in Progress in Particle and Nuclear Physics 10, 27 (1983), and in Proceedings of the 1983 International Europhysics Conference on High Energy Physics, Brighton, July 1983.
25. H. A. Gordon et al., Ref. 1, pg. 357.

TABLE I

Participants in the Working Group on
New Particles and Interactions

New Quarks and Leptons

K. Lane
S. Meshkov
F. Paige
J. Pilcher
S. Pinsky
J. Rosner
W. Wenzel
A. B. Wicklund

Supersymmetry

R. M. Barnett
D. Burke
E. Eichten
H. Haber
L. Littenberg
X. Tata

Substructure

K. Lane
S. Meshkov
S. Mikamo
M. Mishina
F. Paige
J. Pilcher
S. Pinsky
W. Wenzel
A. B. Wicklund
F. Wilczek

Technicolor

K. Lane
S. Meshkov
S. Mikamo
M. Mishina
J. Pilcher
S. Pinsky
A. B. Wicklund

Rare Decays and CP

B. Gavela
G. Kane
R. Loveless
K. Nishikawa
F. Paige
S. Parker
D. Reeder
W. Wenzel
B. Winstein

Working Group Leaders

Theory: F. Gilman
Experiment: P. Grannis
Local Coordinator: C. Quigg

TABLE II

Decay Modes of Supersymmetric Particles

Particle	Decay
$\tilde{\gamma}$	Assumed to be stable (lightest mass supersymmetric particle)
$\tilde{g}$	$q\bar{q}\tilde{\gamma}$ dominant $g\tilde{\gamma}$ could occur through C-violating effects
$\tilde{q}$	$q\tilde{g}$ $q\tilde{\gamma}$
$\tilde{\ell}$	$\ell\tilde{\gamma}$
$\tilde{\nu}$	$\nu\tilde{\gamma}$ $\ell q_1\bar{q}_2\tilde{g}$ $\ell q_1 q_2\tilde{\gamma}$ $\nu q\bar{q}\tilde{g}$ $\nu q\bar{q}\tilde{\gamma}$ $\nu\ell\bar{\ell}\tilde{g}$ $\nu\ell\bar{\ell}\tilde{\gamma}$
$\tilde{W}$	$\bar{q}_1\tilde{q}_2$ $\tilde{Z}W$ (or virtual $W = W_v$) $\tilde{H}W$ (W_v) $\tilde{\gamma}W$ (W_v) $\tilde{\ell}\nu$ $\ell\tilde{\nu}$
$\tilde{Z}$	$\bar{q}\tilde{q}$ $\tilde{H}Z$ (Z_v) $\tilde{\ell}\bar{\ell}$ $\tilde{\gamma}Z$ (Z_v) $\tilde{\nu}\nu$

TABLE II (cont.)

Particle	Decay
W	$\tilde{W}\tilde{Z}$
	$\tilde{W}\tilde{H}$
	$\tilde{W}\tilde{\gamma}$
	$\tilde{\ell}\tilde{\nu}$
	$\tilde{q}_1\bar{\tilde{q}}_2$
Z	$\tilde{W}\tilde{W}$
	$\tilde{Z}\tilde{\gamma}$
	$\tilde{H}\tilde{\gamma}$
	$\tilde{\nu}\bar{\tilde{\nu}}$
	$\tilde{\ell}\bar{\tilde{\ell}}$
	$\tilde{q}\bar{\tilde{q}}$

FIGURE CAPTIONS

Fig. 1 - The cross section for heavy quark (mass = M_Q) pair production at several pp collider center-of-mass energies (from Ref. 2).

Fig. 2 - The differential cross section at rapidity = y = 0 for charged heavy lepton (mass = M_L) pair production at several $\bar{p}p$ collider center-of-mass energies (from Ref. 2).

Fig. 3 - The differential cross section for pp $\rightarrow W^+W^-$ + anything as a function of the W-pair mass in the minimal technicolor model including a technirho resonance at $\sim$ 1.7 TeV (solid line) (from Ref. 2).

Fig. 4 - The differential cross section at rapidity = y = 0 for $P^{o\prime}$ production at various $\bar{p}p$ collider center-of-mass energies (from Ref. 2).

Fig. 5 - The cross section for leptoquark pair ($P_3\bar{P}_3$) pair production at several $\bar{p}p$ collider center-of-mass energies. The solid lines indicate the cross section including the enhancement due to the technirho pole (from Ref. 2).

Fig. 6 - Cross sections for production of various supersymmetric particle pairs in pp collisions at $\sqrt{s}$ = 40 TeV (from Ref. 2).

Fig. 7 - The differential cross section for gluino pair production as a function of p_T for pp collisions at $\sqrt{s}$ = 800 GeV with a gluino mass, $m_{\tilde{g}}$ = 100 GeV. The variable p_T^{vis} is the larger visible p_T within one hemisphere, and cuts of $x_E < 0.5$, $p_{out} > 10$ GeV/c, and $p_T^{lepton} < 2$ GeV have been placed on both signal and background (from Ref. 13).

Fig. 8 - (a) The differential cross section versus x_E for gluino pairs and the two jet background. Note the vertical scale difference for the two distributions. The gluino mass is 500 GeV/c^2 and $\sqrt{s}$ = 40 TeV for pp collisions (from Ref. 10).
(b) The differential cross section versus p_{out} for gluino pairs and the two jet background after cuts $x_E < 0.5$ and visible $p_T > 50$ GeV/c. The gluino mass is 500 GeV/c^2 and $\sqrt{s}$ = 40 TeV for pp collisions (from Ref. 10).

Fig. 9 - The observed mass distribution for the decay products in the decay $\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$ in gluino pair production in pp collisions at $\sqrt{s}$ = 40 TeV with a gluino mass of 500 GeV/c^2, where only the larger observed mass in each event is plotted. The inset shows the dependence of average jet mass and rms width on the gluino mass (from Ref. 10).

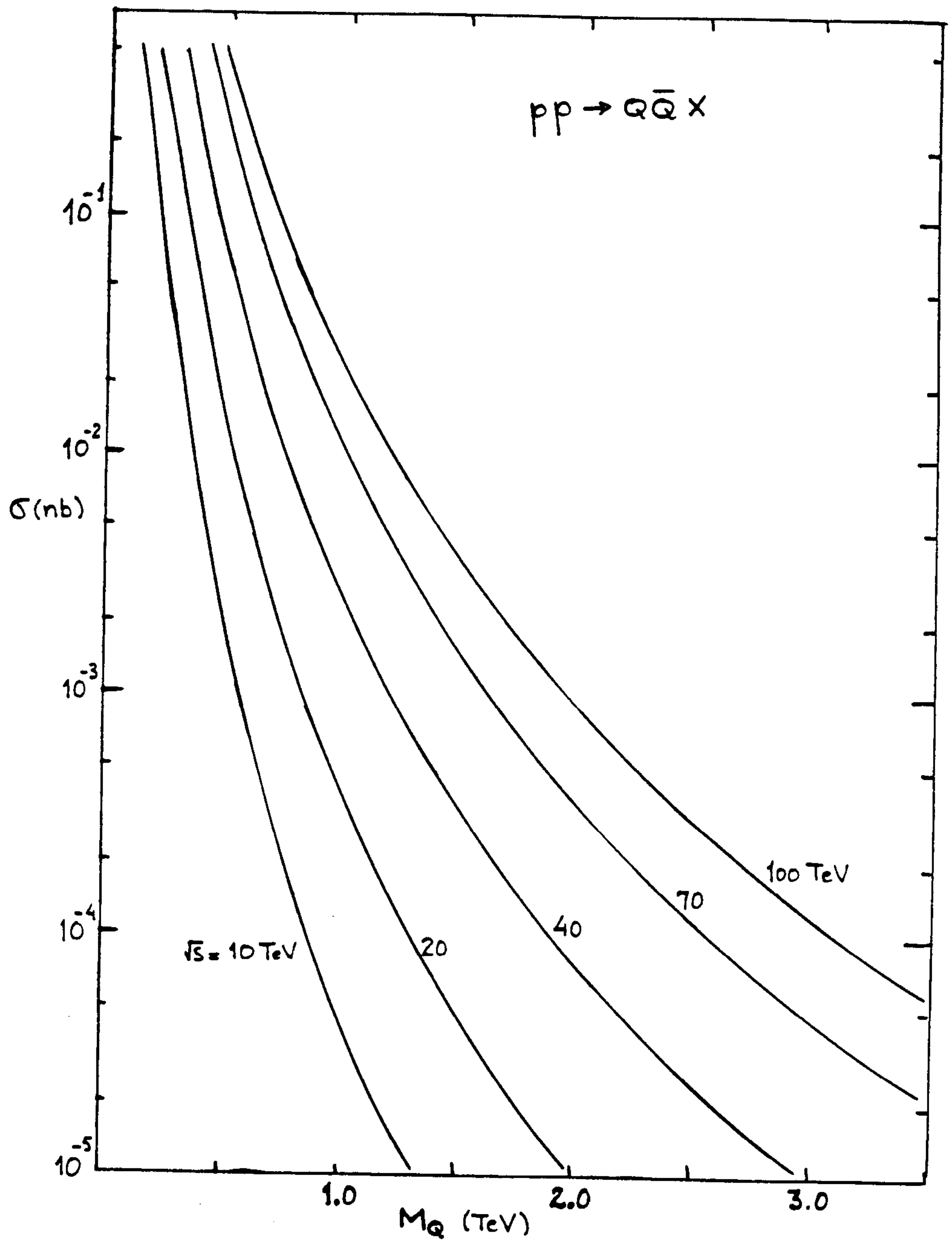
Fig. 10 - The differential cross section $d^2\sigma/dp_T dy$ at y = rapidity = 0 for jet production in a 40 TeV pp collider as a function of p_T. The effect of the contact interaction with both signs

and Λ = 15 TeV, 20 TeV, and ∞ is shown (from Ref. 2).

Fig. 11 - Same as Fig. 10, but for $\bar{p}p$ collisions.

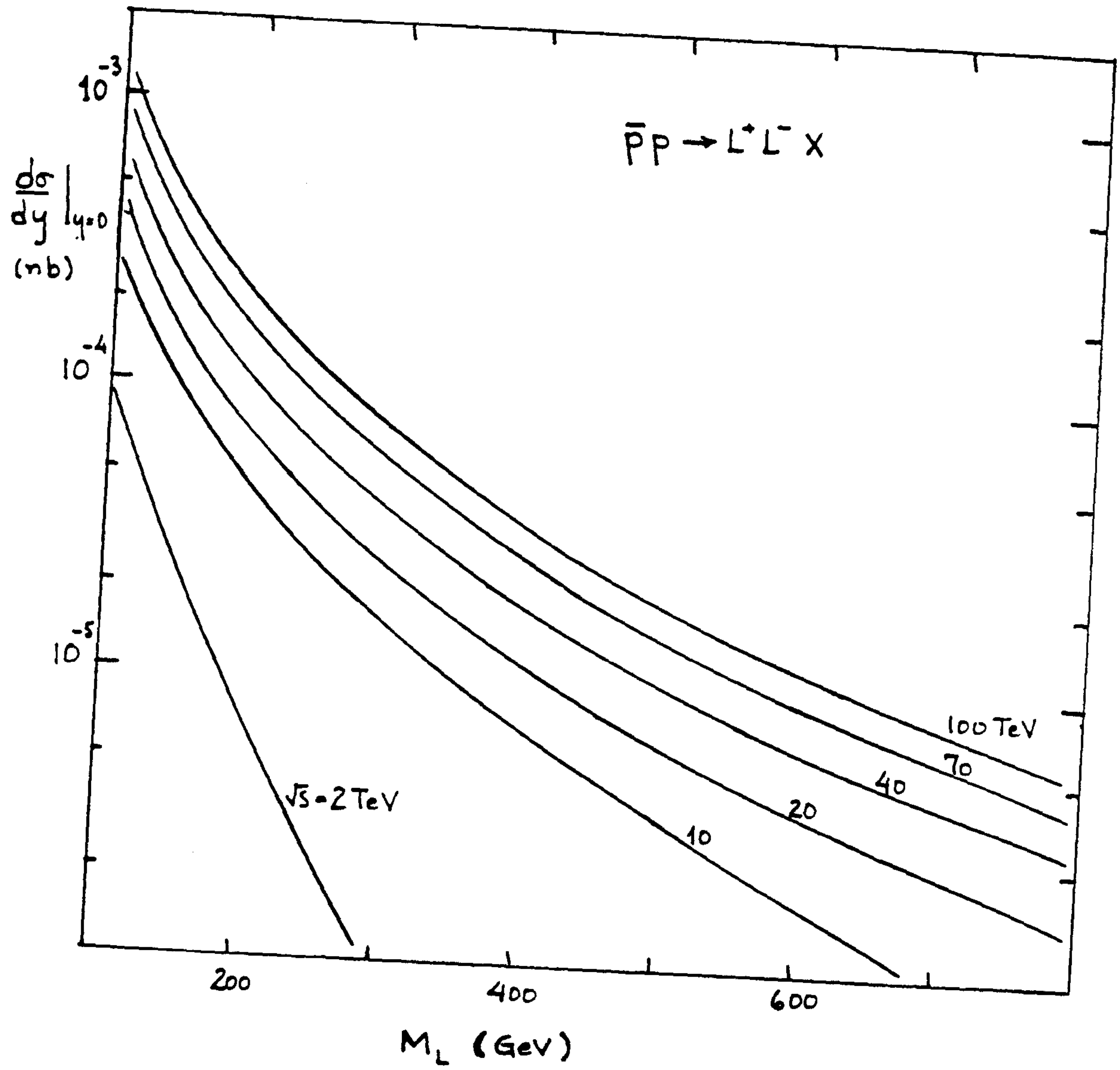
Fig. 12 - The integrated luminosity required to observe compositeness versus the compositeness mass scale Λ in a pp collider at several center-of-mass energies $\sqrt{s}$. The solid and dashed curves indicate positive and negative signs of the contact interaction, respectively (from Ref. 2).

Fig. 13 - Same as Fig. 12, but for $\bar{p}p$ collisions.



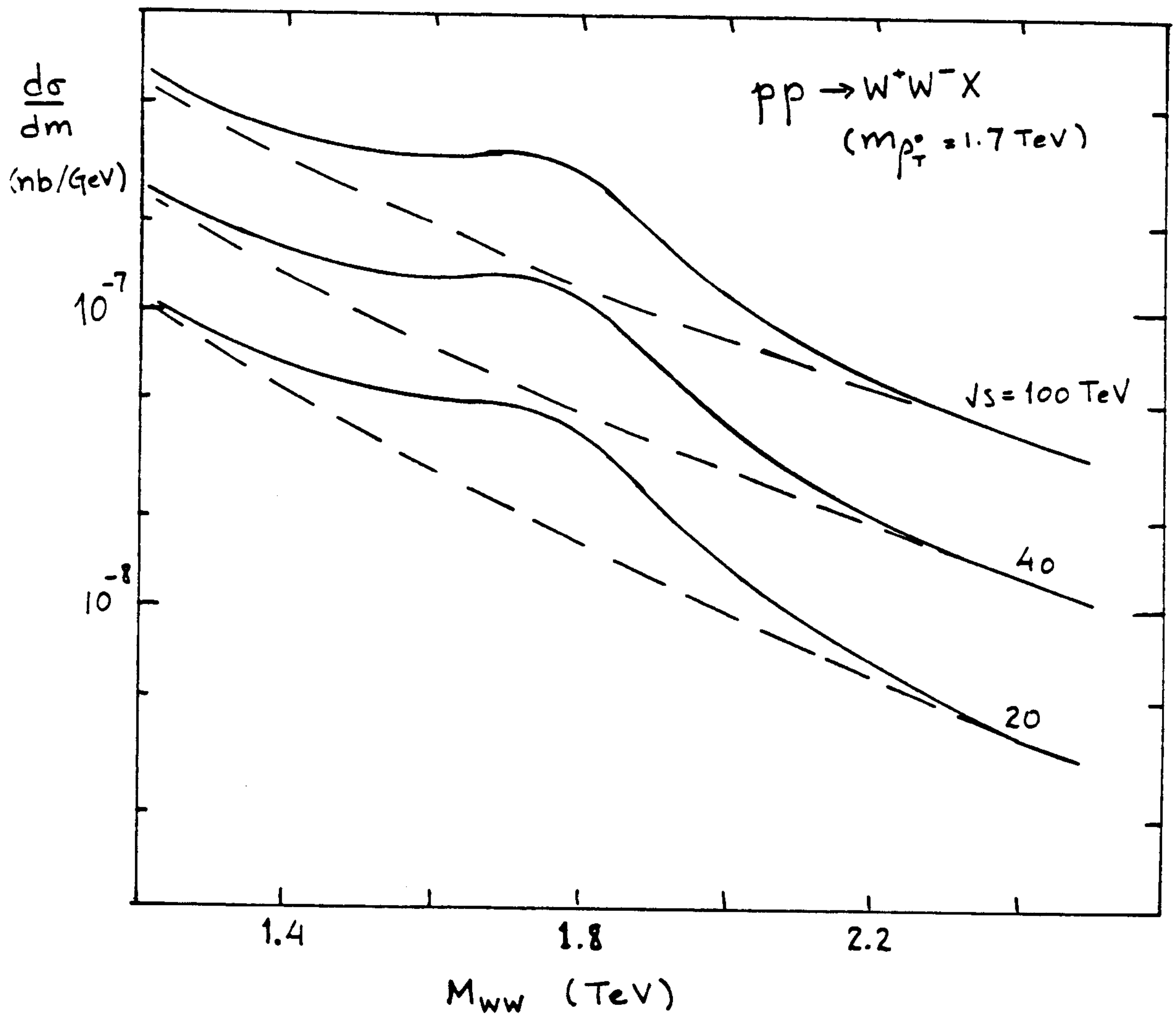
pp → $Q\bar{Q}$ X
10^{-1}
10^{-2}
σ(nb)
10^{-3}
10^{-4}
10^{-5}
√s = 10 TeV
20
40
70
100 TeV
1.0
2.0
3.0
M_Q (TeV)

Fig. 1



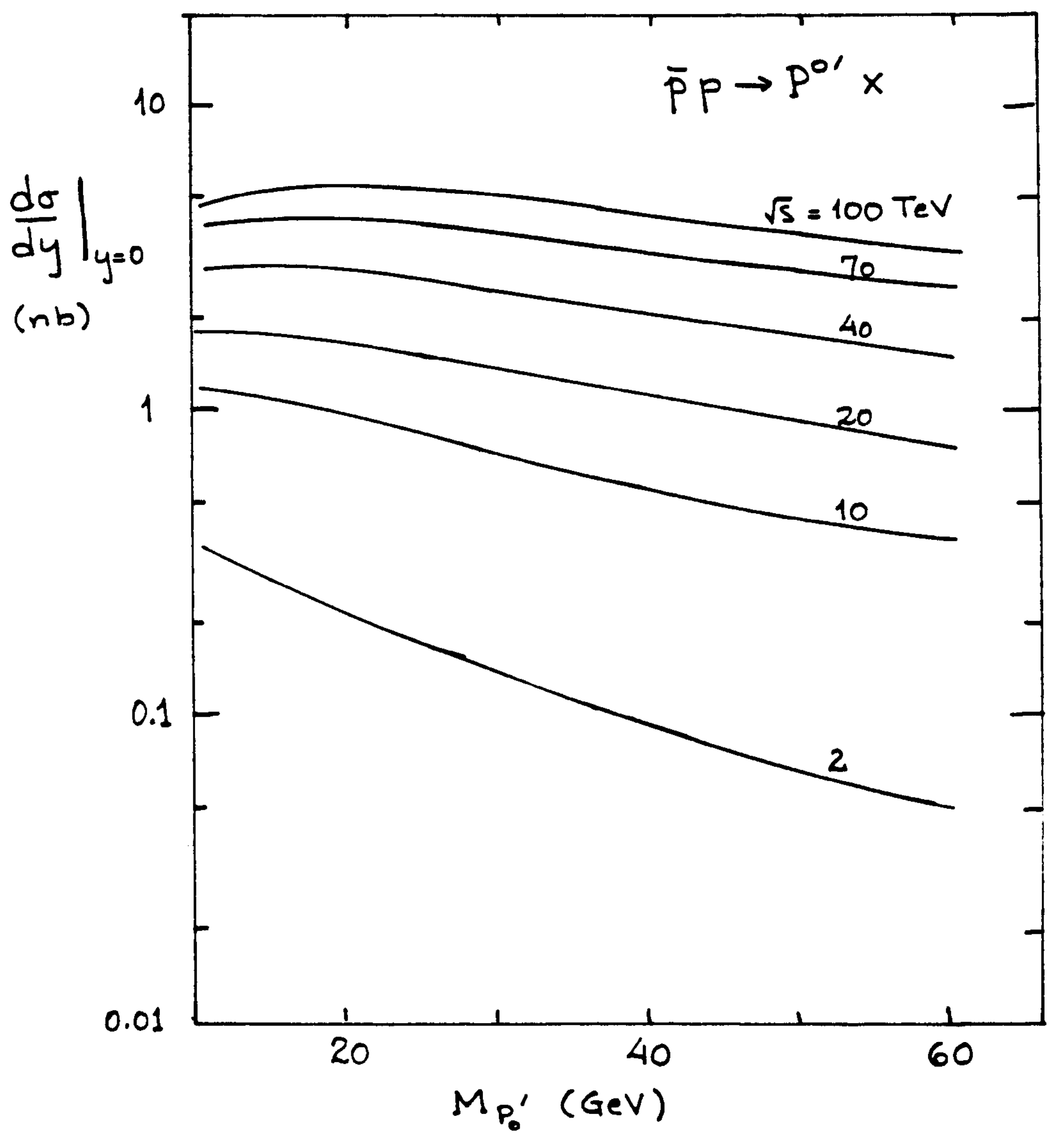
$\bar{p}p \to L^+L^-X$
$\frac{d\sigma}{dy}\Big|_{y=0}$ (nb)
10^{-3}
10^{-4}
10^{-5}
100 TeV
70
40
20
10
$\sqrt{s}=2$ TeV
200
400
600
M_L (GeV)

Fig. 2



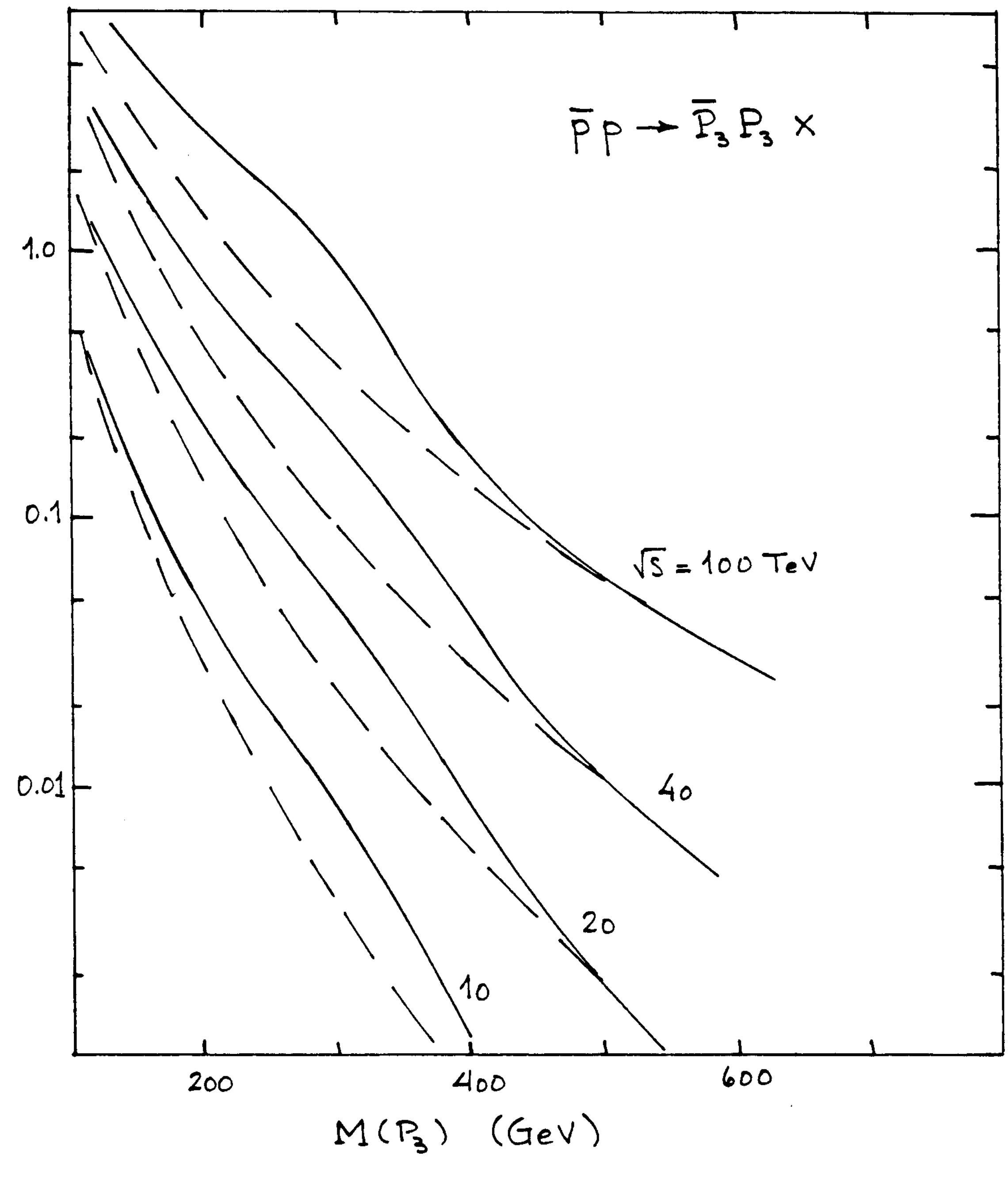
dσ/dm
(nb/GeV)
pp → W⁺W⁻X
(m_ρ_T° = 1.7 TeV)
√s = 100 TeV
40
20
10⁻⁷
10⁻⁸
1.4
1.8
2.2
M_WW (TeV)

Fig. 3



$\bar{p}p \to P^{0\prime} X$
$\frac{d\sigma}{dy}\Big|_{y=0}$
(nb)
10
1
0.1
0.01
$\sqrt{s}$ = 100 TeV
70
40
20
10
2
20
40
60
$M_{P_0'}$ (GeV)

Fig. 4



$\bar{p}p \to \bar{P}_3 P_3 X$
1.0
0.1
0.01
$\sqrt{s} = 100$ TeV
40
20
10
200
400
600
$M(P_3)$ (GeV)

Fig. 5

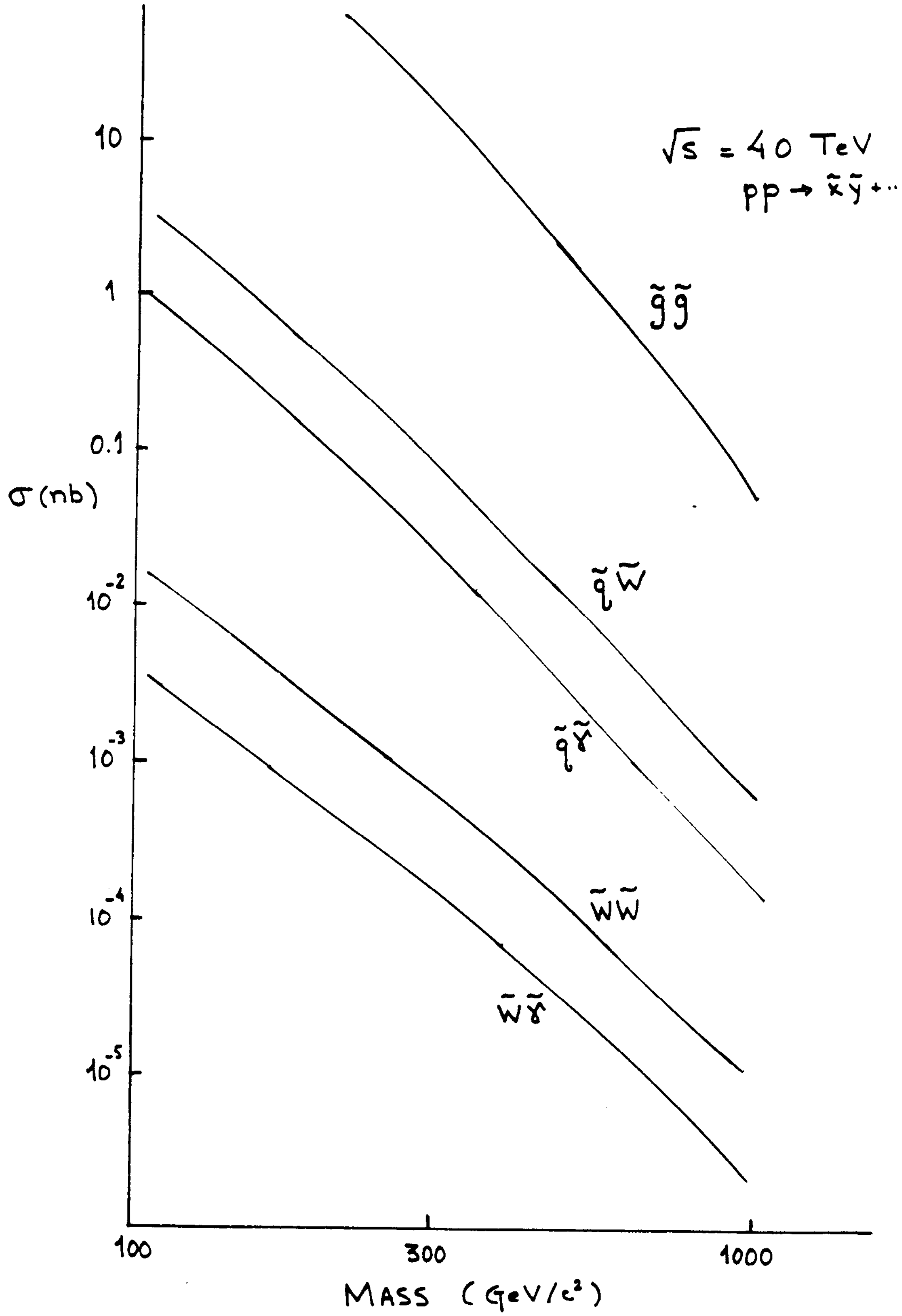
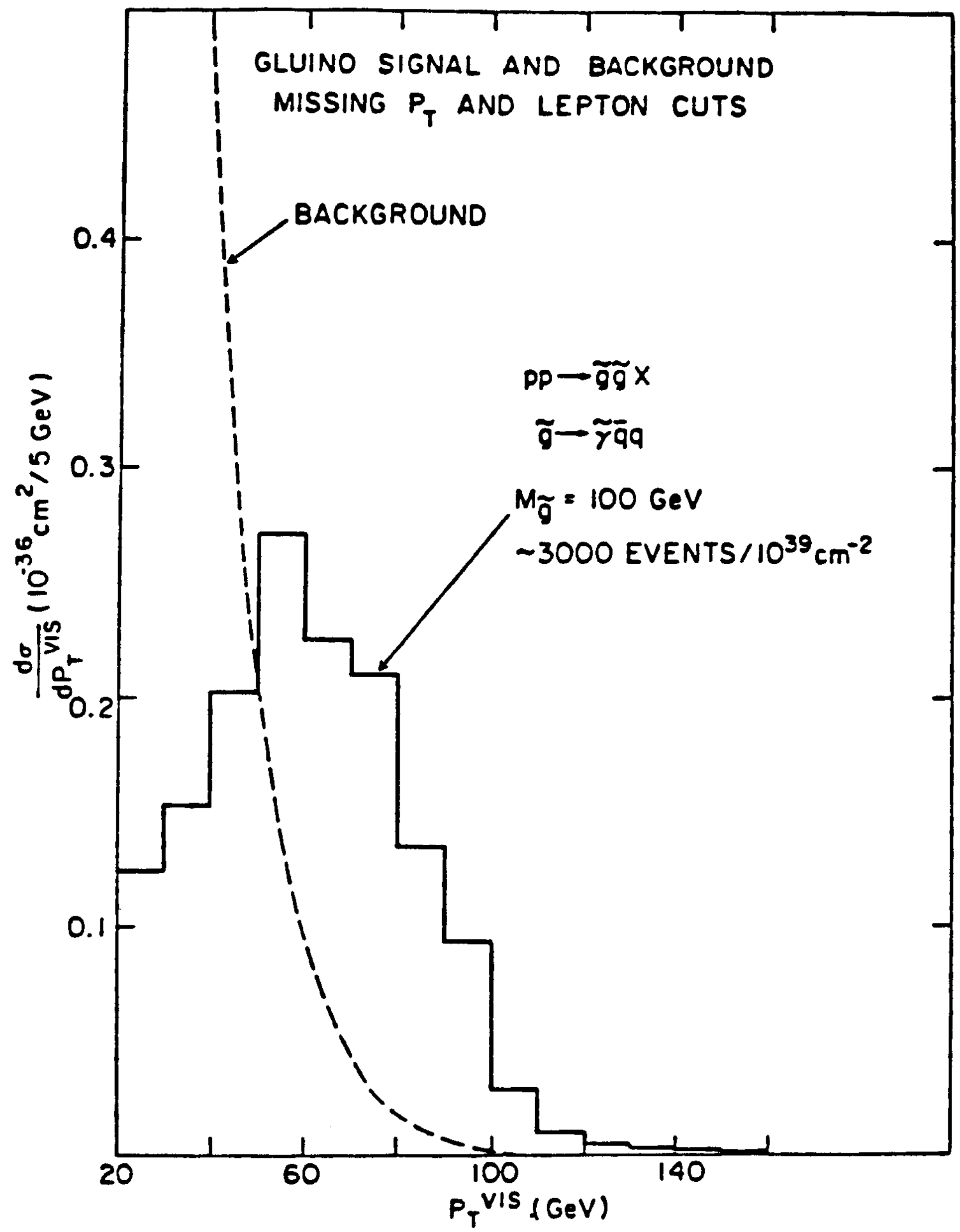
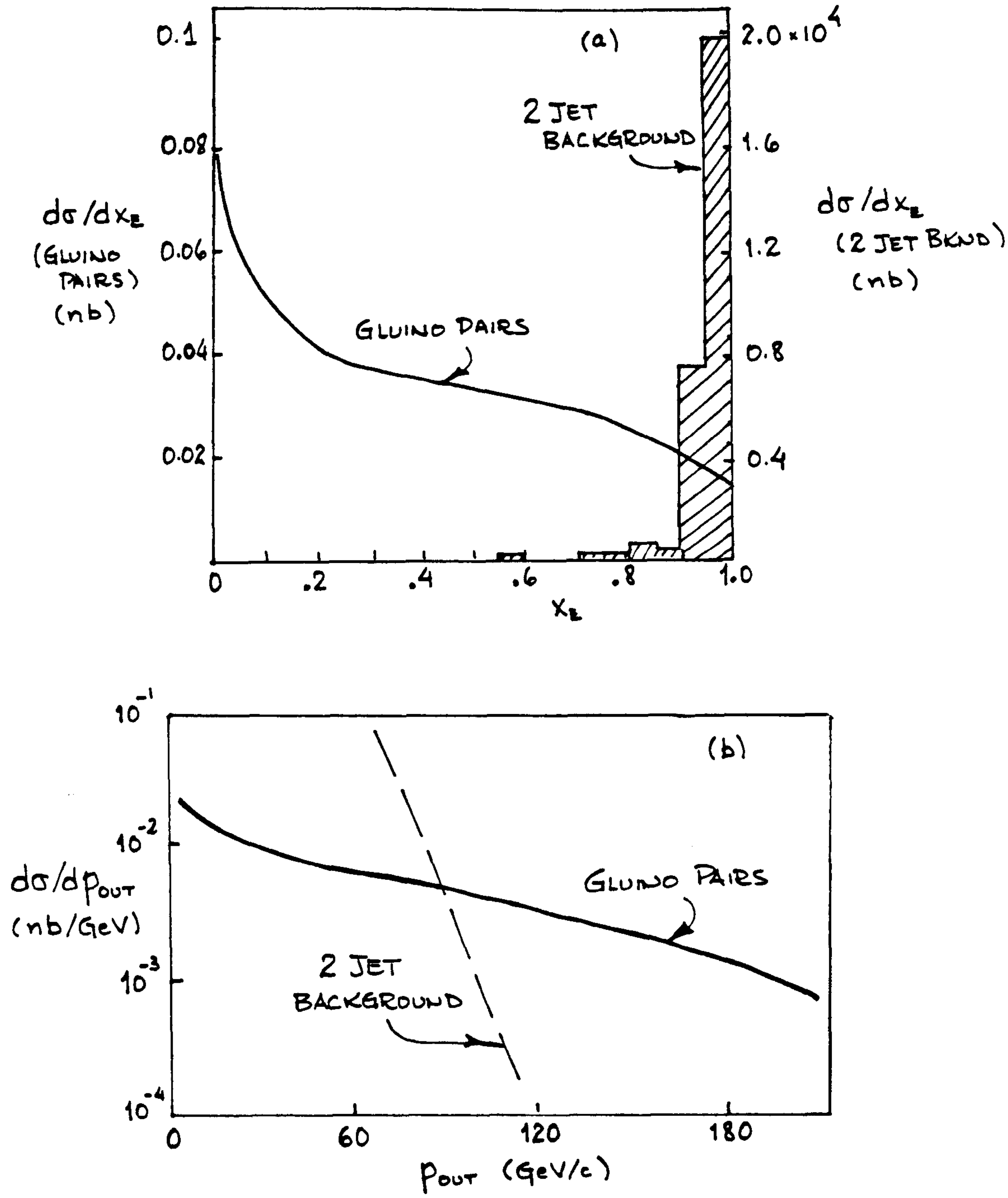

√s = 40 TeV
pp → x̃ỹ + ...
g̃g̃
q̃W̃
q̃γ̃
W̃W̃
W̃γ̃
σ (nb)
10
1
0.1
10^-2
10^-3
10^-4
10^-5
100
300
1000
MASS (GeV/c²)

Fig. 6



GLUINO SIGNAL AND BACKGROUND
MISSING P_T AND LEPTON CUTS
BACKGROUND
$pp \rightarrow \tilde{g}\tilde{g}X$
$\tilde{g} \rightarrow \tilde{\gamma}\bar{q}q$
$M_{\tilde{g}}$ = 100 GeV
~3000 EVENTS/10^{39}cm^{-2}
0.4
0.3
0.2
0.1
$\frac{d\sigma}{dP_T^{VIS}}$ (10^{-36}cm^2/5 GeV)
20
60
100
140
P_T^{VIS} (GeV)

Fig. 7



(a)
0.1
0.08
0.06
0.04
0.02
dσ/dx_E (GLUINO PAIRS) (nb)
2.0×10^4
1.6
1.2
0.8
0.4
dσ/dx_E (2 JET BKND) (nb)
2 JET BACKGROUND
GLUINO PAIRS
0
.2
.4
.6
.8
1.0
x_E
(b)
10^-1
10^-2
10^-3
10^-4
dσ/dp_OUT (nb/GeV)
GLUINO PAIRS
2 JET BACKGROUND
0
60
120
180
p_OUT (GeV/c)

Fig. 8

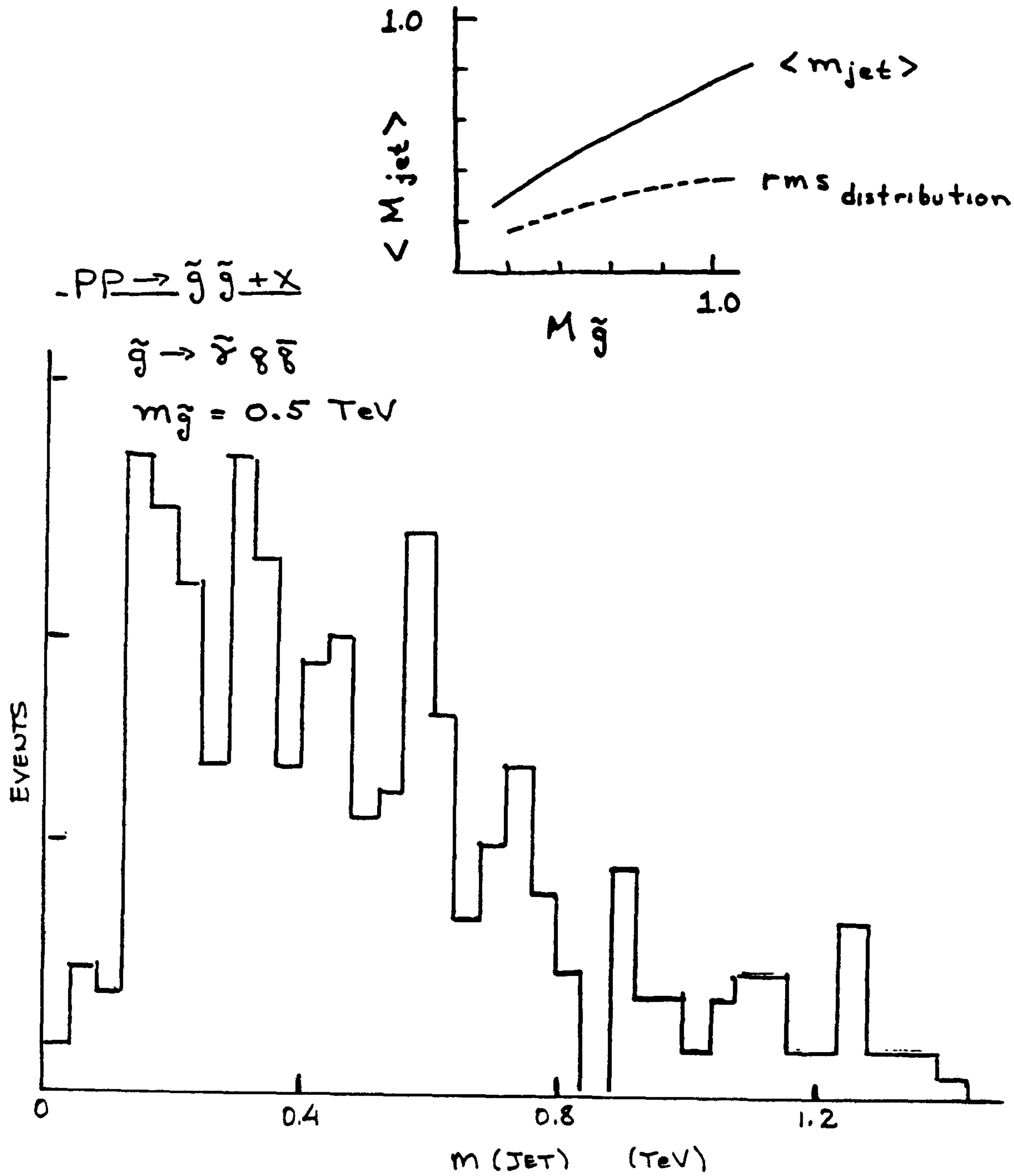

1.0
<mjet>
rms distribution
<Mjet>
1.0
M g̃
PP → g̃ g̃ + X
g̃ → γ̃ q q̄
mg̃ = 0.5 TeV
EVENTS
0
0.4
0.8
1.2
m (JET) (TeV)

Fig. 9

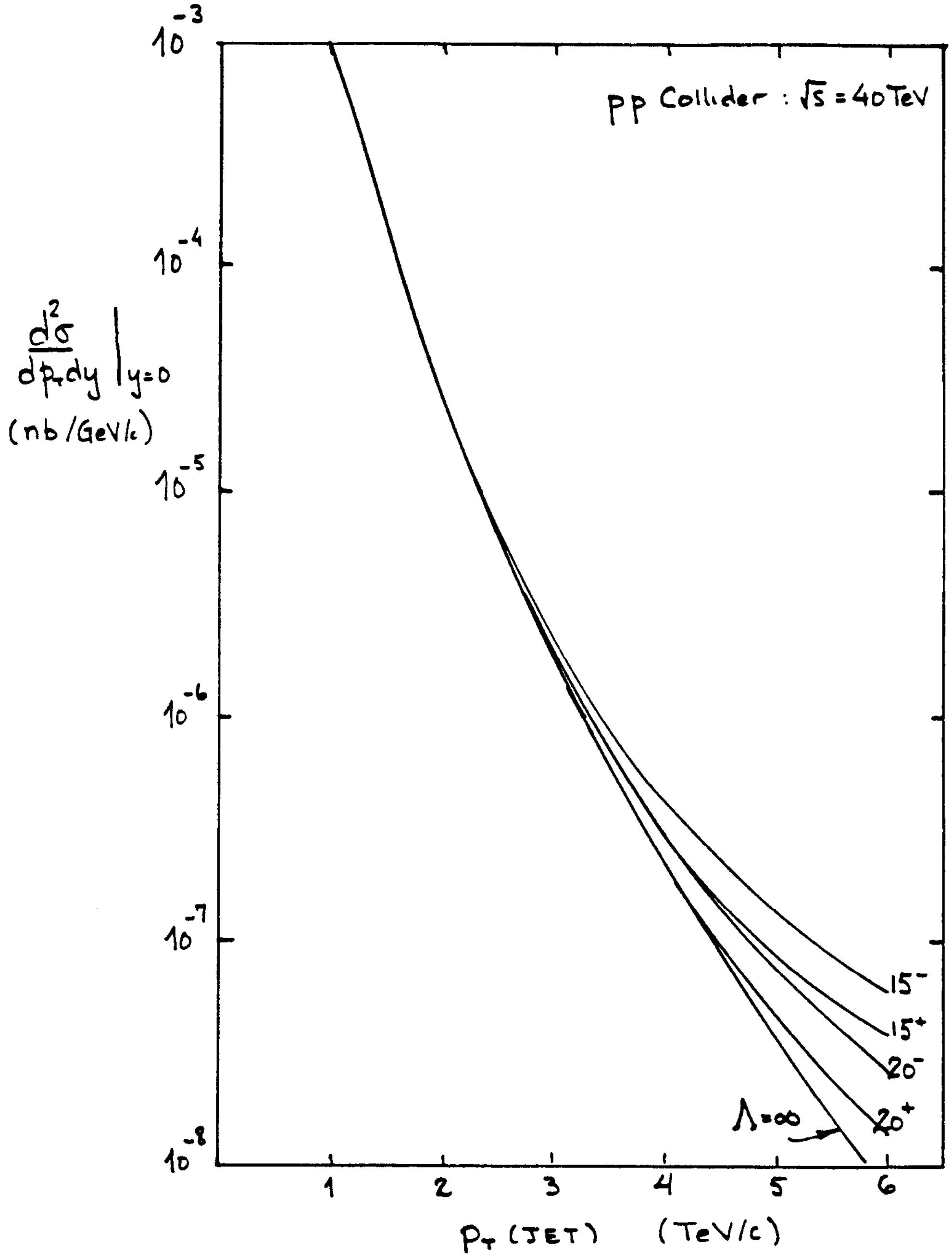
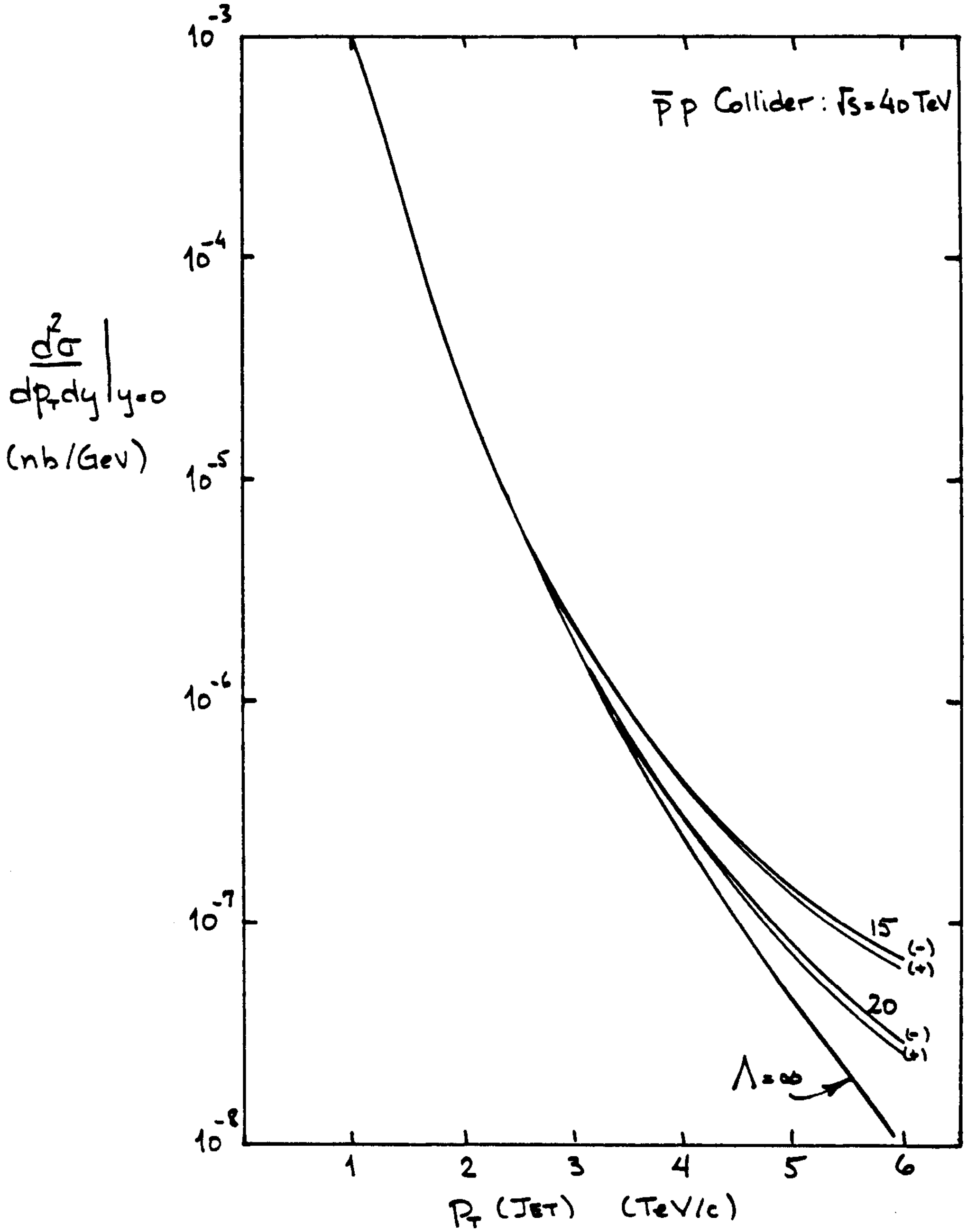

pp Collider : √s = 40 TeV
d²σ/dp_T dy |_{y=0} (nb/GeV/c)
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
15⁻
15⁺
20⁻
20⁺
Λ=∞
1
2
3
4
5
6
p_T (JET) (TeV/c)

Fig. 10



$\bar{p}p$ Collider : $\sqrt{s}$ = 40 TeV
$\left.\frac{d^2\sigma}{dp_T dy}\right|_{y=0}$
(nb/GeV)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1
2
3
4
5
6
p_T (JET) (TeV/c)
15
(-)
(+)
20
(-)
(+)
$\Lambda = \infty$

Fig. 11

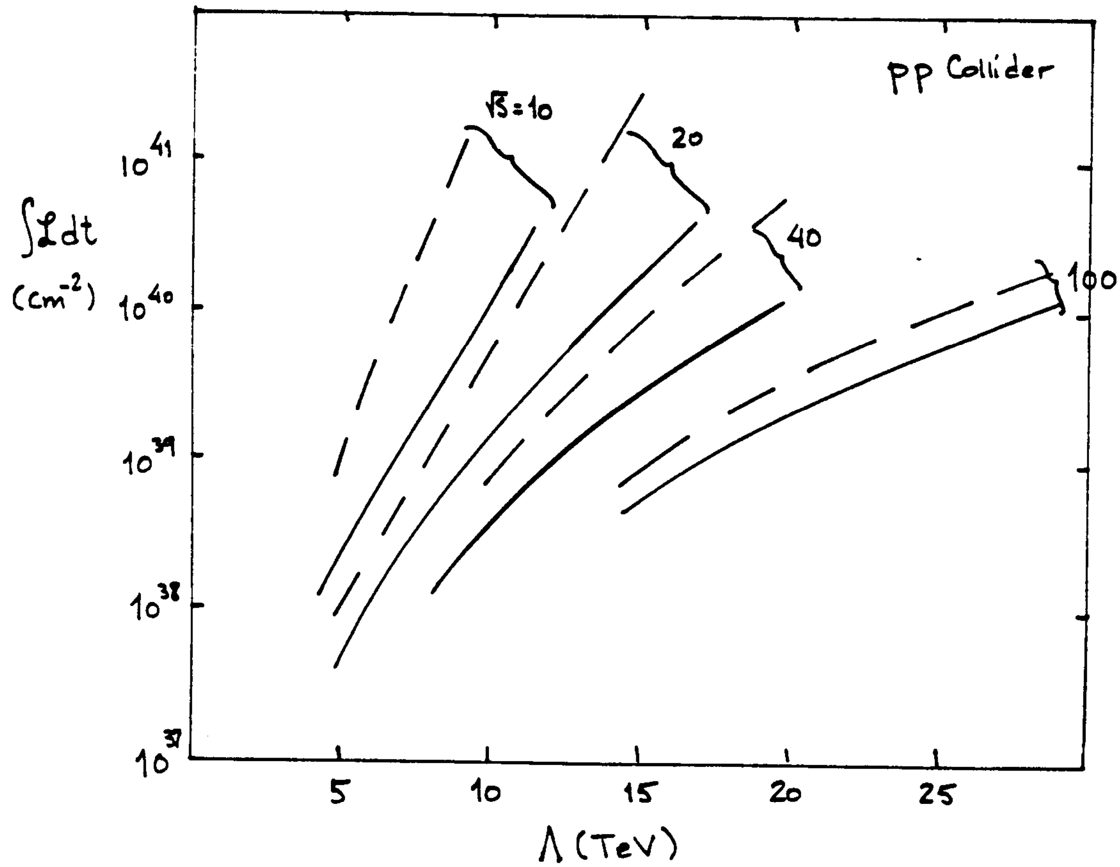

pp Collider
√s = 10
20
40
100
∫ℒdt
(cm⁻²)
10^41
10^40
10^39
10^38
10^37
5
10
15
20
25
Λ (TeV)

Fig. 12

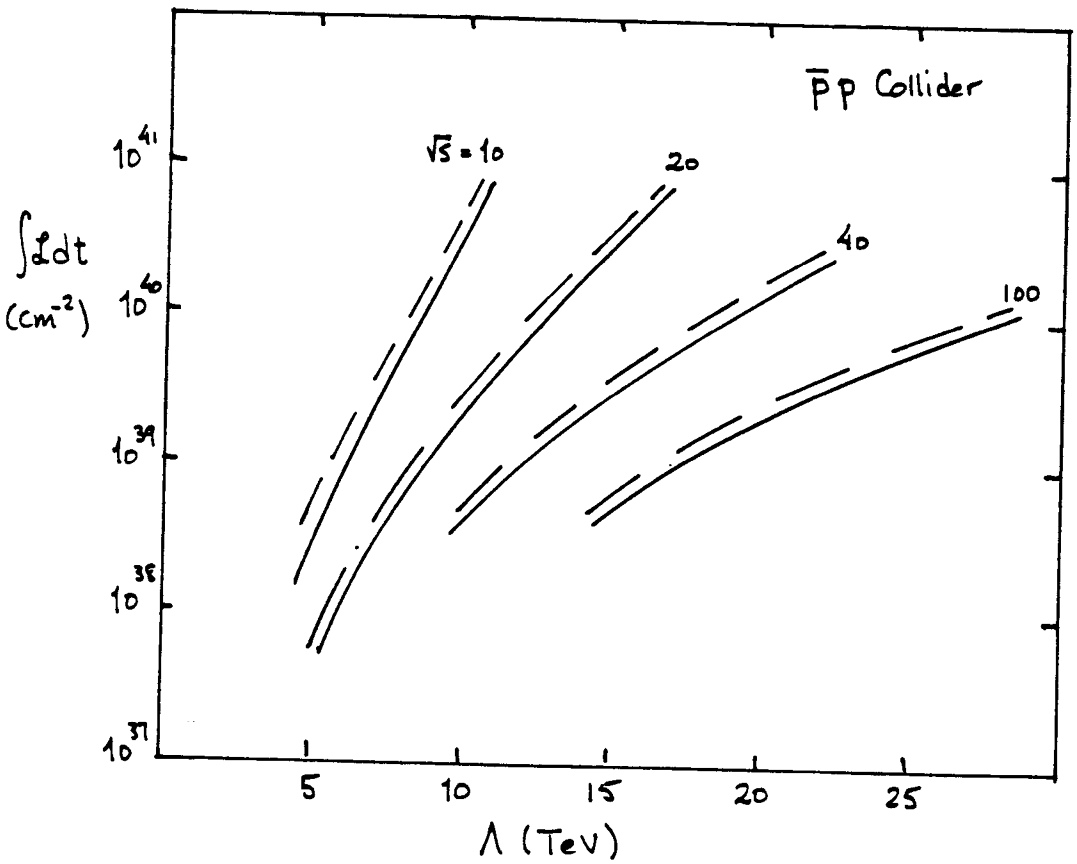

p̄p Collider
√s = 10
20
40
100
∫ℒdt
(cm⁻²)
10^41
10^40
10^39
10^38
10^37
5
10
15
20
25
Λ (Tev)

Fig. 13