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SOME COMMENTS ON SSC PHYSICS

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Abstract

This talk discusses some topics of current interest with regard to SSC physics. Uncertainties in rate estimates are discussed as is the status of proposals to search for the Higgs boson.

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1. INTRODUCTION

In this talk I shall discuss some topics relevent to the physics of the SSC. I shall not give a review of the subject. Exhaustive reviews are provided by EHLQ[1] by the Proceedings of the Lausanne Workshop[2] and by the forthcoming Proceedings of the 1984 DPF Summer Study held at Snowmass.[3] I will first discuss the reliability of predictions for event rates at the SSC, then I shall discuss the status of proposals to search for the minimal Weinberg-Salam model Higgs boson.

2. UNCERTAINTIES IN RATE ESTIMATES

The QCD parton model underlies almost all of the estimates of signals and backgrounds relevant to the SSC and other hadron colliders. Fundamental interactions which are probed in the search for new physics involve the collisions of quarks and gluons and, in some specialized cases, other particles, such as W's, which can appear as constituents of the proton. The rate for some new particle production is given by the following parton model formula,

$$\sigma(s) = \sum_{i,j} \int f_i(x_1, Q^2)\, f_i(x_2, Q^2)\sigma_{i,j}(sx_1x_2)dx_1dx_2.$$

Here $\sqrt{\hat{s}} = \sqrt{sx_1x_2}$ is the invariant mass of the parton-parton system and $\sqrt{s}$ is that of the proton-proton system. In this formula, $f_i(x, Q^2)$ is the probability of a parton of type i being inside the proton with fraction x of the proton's momentum. $\sigma_{i,j}$ is the cross-section for the interaction of the two partons i and j. The scale Q appearing in the distribution functions is characteristic of the momentum transfers in the partonic process. In the case of jet production its value is somewhat ambiguous but is of order the jet transverse momentum. In the case of new particle production, the mass of the new particle is probably the appropriate value.

The distributions ($f_i(x, Q^2)$) are extracted from deep-inelastic scattering data at low Q^2 and then extrapolated to the higher Q^2 values appropriate to the SSC using the Altarelli-Parisi[4] equations of QCD. The kinematical range of the x_1 and x_2 integrals is $x_1 x_2 \geq \hat{s}_{min}/s$, where $\sqrt{\hat{s}_{min}}$ is the minimum, kinematically allowed, value of $\sqrt{\hat{s}}$. The distribution functions are rapidly falling functions of x, so that the dominant region of the integral comes from $x_1, x_2 \approx \sqrt{\hat{s}_{min}/s}$. At $\sqrt{s} = 40$ TeV, the production of a W boson is dominated by $x \approx .002$ and x as small as 4×10^{-6} is possible. These small values of x are not probed by current experiments which are confined to $x > 0.05$ and $Q^2 \leq 200\ \mathrm{GeV}^2$, so two problems arise.

Firstly, does the lack of data imply a very poor knowledge of the structure functions in this small x region? As Q^2 increases the uncertainties caused by the lack of data at small x wash out. This is illustrated in Fig. 1 which shows the behavior of the gluon distributions at small x as a function of Q^2. Three different gluon distributions were assumed at $Q^2 = 5$ GeV.[1]

(a) $x\,g(x, Q^2 = 5\ \mathrm{GeV}^2) = (2.12 + 9.17x)(1 - x)^{5.9}$
(b) $x\,g(x, Q^2 = 5\ \mathrm{GeV}^2) = \text{(a) for } x > 0.01$
$\qquad = 25.56\, x^{1/2} \text{ for } x < 0.01$
(c) $x\,g(x, Q^2 = 5\ \mathrm{GeV}^2) = \text{(a) for } x > 0.01$
$\qquad = 0.44x^{-1/2} - 1.886 \text{ for } x < 0.01$

The value of $g(x_0, Q^2)$ is controlled by that at $x > x_0$ at lower Q^2. The starting distributions were chosen to agree at $x > 0.01$, where data exist so that eventually they will agree at smaller x. It is surprising and encouraging that the differences wash out so rapidly.

Secondly, does QCD perturbation theory in the form of the Altarelli-Parisi equations continue to apply at these small values of x? This vital question occupied one of the physics groups at Snowmass and the report by John Collins[5] should be consulted for details.

The QCD perturbation theory does indeed break down at small x, but the appropriate values of x are extremely small. An easy way to see that something must go wrong is to compute the cross section for, say, single W production as a function of s. In the region of small x, the structure function $f_i(x, Q^2)$ is proportional to x^{-a} with a of order 1.3.[1] The cross section for W production will then behave as $s^{(a-1)}$logs. This behavior is unacceptable asymptotically and is an indication that the evolution of $f_i(x, Q^2)$ must ultimately change to cut off the growth at small x. This cut-off happens when the parton fraction, D, approaches 1, where D is defined by[6]

$$D(x, Q^2) = x f_i(x, Q^2) m_x{}^2/Q^2.$$

There is a region in the (x, Q^2) plane where D is of order one or larger. In this region, partons start to overlap, cease to act individually, collective effects become important and the simple parton model picture collapses. In his report, John Collins[5] has investigated this breakdown region. It is important not only that structure functions be used only when the fraction is small, but also that in the evolution of the Altarelli-Parisi equations from small Q^2 there are no sizeable contributions from regions of x and Q^2 where the equations are not valid. His conclusions are that the structure functions which are claimed to work for $x > 10^{-4}$ and 5 $GeV^2 \leq Q^2 \leq 10^8$ GeV^2 are indeed valid over that range, so that the results obtained using them are reasonably reliable.

One final word of caution about distribution functions. Some of the radically different results for rates at the SSC which have appeared in the literature are due to misuse of distribution functions, and do not represent some kind of extreme values showing the size of uncertainties. Care should be exercised when using a set of parameterizations of structure functions; these parameterizations usually have strictly limited ranges of applicability in x and Q^2 and can produce absurd results if used outside these ranges. Also, it is not legitimate to adjust the value of Λ_{QCD} in these parameterizations since they may not then agree with low energy data: Λ_{QCD} is usually strongly correlated with the gluon distribution, and these correlations are such as to tend to reduce differences at higher Q^2.

Another problem is the heavy flavor content of the proton at high Q^2. EHLQ include bottom and top quarks in their distributions. Unfortunately, there is some ambiguity in the method for dealing with thresholds. The simplest method is to ignore heavy quarks (of mass m_Q) below threshold, i.e. when $Q^2 \leq 4m_Q{}^2$ and then to allow them to evolve in the same way as massless quarks once the threshold has been crossed. EHLQ have not done this, but rather have included some mass effects in the heavy quark evolution,[7] which tend to slow their rate of growth above threshold. The ambiguity cannot be resolved completely since the different prescriptions are all equivalent up to higher order QCD corrections which were neglected.

The reliability at small x has an interesting consequence. The fraction of events at the SSC which can be understood in terms of perturbative QCD will be much greater than at the $Sp\bar{p}S$ collider. The cross-section for events in which there are two jets of transverse momentum greater than 10 GeV each of rapidity $|y| \leq 2.5$ is shown as a function of $\sqrt{s}$ in Figure 2. Estimated for the total cross section vary between 100 and 200 mb at SSC energies, the value at $\sqrt{s} = 540$ GeV being about 60 mb.[9] Of course as s gets very large the probability of a double parton scatter will increase and the jet mutiplicity will start to rise. The rate shown in this figure is very uncertain since it depends upon small x <u>and</u> Q^2.

Once we are certain that our predictions are free of small x disasters, the only uncertainty remaining concerns the accuracy of the evolved structure functions and the size of higher order QCD corrections to the parton-parton scattering cross-section $\sigma_{i,j}$. These corrections are often ignored in making estimates, but they can be significant and give some indication about the size of the error on these estimates. For example, there are expected to be corrections of order 30 percent which increase the cross section for single W production.[10] The inclusion of these corrections at the SppS collider improves the agreement between the predictions and the data.[11] For most processes these corrections are not known; it would be valuable to have more calculations. In the case of jet production the corrections are known only for a small fraction of the 2 → 2 processes.[12] The knowledge of these corrections helps to resolve the ambiguities in the choice of the scale Q^2 which appears in the distribution functions.

These corrections are sometimes incorporated into so-called K factors. It has become fashionable to multiply lowest order QCD predictions by a K factor of order 2 before comparing with data. Except for the few processes where the higher order corrections are known, there is absolutely no justification for this procedure. In any case, the corrections are very unlikely to be a simple multiplicative factor; for example in the case of jet production, the size of the correction will surely depend on the transverse momentum and the rapidity of the produced jet.

A very important issue concerns the mechanism for the production of new strongly interacting particles. In the estimates most widely available, the pair production of such particles proceeds via the annihilation of a pair of gluons (or a quark and an anti-quark), one from each of the incoming beams (see Fig. 3). This production is centered around zero rapidity. There has been much discussion in the literature[13] of the so-called intrinsic mechanism for such production. This mechanism exploits the possibility of exciting the pairs of heavy strongly interacting particles which are present in the proton's wavefunction (see Fig. 4). If this latter mechanism is dominant then the production of new, strongly interacting particles will be diffractive so that they will emerge at small angles to the beam (large rapidity).

Since the intrinsic mechanism is non-perturbative a clean QCD prediction is not possible. The cross-section has the following approximate form

$$\sigma \approx f(M/\sqrt{s})/M^b.$$

It is important to understand the parameter b and hence the dependence of the intrinsic rate upon the heavy particle's mass (M).

This will then allow an extrapolation from the existing upper bound on the intrinsic charm component at ISR energies to the intrinsic components of larger mass objects at the SSC. The fusion process has a mass dependence which corresponds to $b \approx 2$. Brodsky et al.[14] have concluded that the mass dependence of the intrinsic mechanism is $b \approx 4$. Since the charm production rate at the ISR from the intrinsic mechanism cannot be much greater than that from the fusion mechanism, this result would imply that the intrinsic mechanism will not be important for the production at the SSC of particles heavier than about 30 GeV.

Given the above discussion, it seems fair to conclude that the estimates given for production rates of new particles at the SSC should be good to a factor of two or so, at least for particles with masses greater than 100 GeV.

3. THE HIGGS BOSON

Several mechanisms have been proposed for the production of the Higgs boson at hadron colliders. Firstly it can be produced singly in gluon-gluon fusion via the diagram shown in Fig. 5. The rate depends on the number and masses of quark flavors which can appear inside the loop.[15] In the mass range $m_i << m_H$ the rate is roughly proportional to m_i^2 where m_i is the mass of the quark inside the loop. Thus the existence of extra generations will greatly enhance the rate. The process shown in Fig. 6 is less model dependent since it involves the coupling of the Higgs to the W and Z boson.[16] This coupling grows as the Higgs mass increases so that this mechanism will eventually dominate over the gluon-gluon fusion process. Although the final state consists of a Higgs and a quark pair, the quarks move almost parallel to the incoming hadrons so that this mechanism can also be considered a non-associated production of a Higgs.

Two associated mechanisms have also been considered. The production in association with a W or Z boson[17] will have a smaller rate but the presence of a W or Z in the final state could be used as a tag, so improving the signal to background ratio.[18] The production in association with a top quark pair is shown in Fig. 7. Again the rate is small but the presence of a heavy quark pair could be useful.

Figure 8 compares the production rate from all four mechanisms. The single production rates are always dominant. Notice that for $m_H \geq 400$ GeV the gauge boson fusion mechanism is dominant so that the rate is fairly model independent.

If the Higgs is lighter than about 70 GeV, it is likely to be found at the next generation of e^+e^- machines, either in the process $Z \rightarrow H\ e^+e^-$ [20] or via $e^+e^- \rightarrow Z + H$.[17] Consequently, I will only discuss Higgs masses larger than this. It is convenient to divide the discussion into three ranges of mass; (a) $m_H < 2\,m_W$; (b) $2\,m_W < m_H \leq 0(1)$TeV (c) $m_H \geq 0(1)$ TeV. I will discuss the second region first.

If the Higgs mass is greater than twice the W or Z mass then it will decay dominantly into W or Z pairs. The background in these channels from W or Z pair production via qq annihilation has been shown not to be a problem.[1,2] Even if the Z pair mode is detectable only via the leptonic decays of the Z's, it should still be possible to detect a Higgs boson if experiments are possible with an integrated luminosity of 10^{40}cm^{-2}. (See Fig. 9.) Figure 9 shows the signal and background for $H \rightarrow W^+W$. Here both of the W's are required to satisfy a rapidity cut of $|y_W| < 2.5$. The background has been estimated from $d\sigma/dM$ for the production of a pair of W's of invariant mass M, multipled by ΔM with ΔM the greater of 10 GeV or the Higgs width.

The observability of W and Z final states in their hadronic decay modes will greatly ease the detection of such a Higgs boson. If the W or Z bosons decay hadronically then the background will arise from final states with QCD jets in them. In the case of the WW final state where one W decays leptonically and the other decays hadronically, the background arises from the state W + jet.

The report of Fernandez et al.[22] discusses in great detail how the final state WW can be distinguished from that of W + jet(s). In the case where the W momentum is small, the two jets for $W \rightarrow q\bar{q}$ are widely separated, so that their invariant mass can be well measured. The UA2 group[23] working at the Sp$\bar{p}$S collider have attempted to detect the W in this manner. Their resolution is at present too poor and the statistics too low for the W to show up. Nevertheless the situation is not hopeless. The better resolution for proposed SSC detector should improve the situation and it should be possible to detect a slow W:[24] In her talk Ann Kernan,[25] discussed the possibility of detecting $W \rightarrow c\bar{b}$ via the semi-leptonic decay of the charm quark. The results give grounds for optimism.

If the W momentum is very large then the jets from its decay will coalesce. One now has to measure the invariant mass of a single jet. A typical QCD jet of the same energy will tend to have a larger invariant mass and a higher multiplicity. Roughly the probability of a jet of energy E having an invariant mass M is[26]

$$\frac{dN}{d\theta} = 0.25e^{-4\theta}$$

where $\theta = M/E$. At the SSC however is it unlikely that this latter, high momentum, regime can be reached.

Fernandez et al.[22] considered the more difficult case where the W pair have an invariant mass of 1 TeV, a region of critical interest. They require that one W should decay leptonically and that the other decay hadronically. The background now arises from the final state W +jet and is approximately 200 times the signal,[27] so a very strong background rejection is required. They find that such a rejection can be obtained by a series of cuts on the multiplicity, jet mass, distribution of particles within the jet, etc. A realistic detector simulation was used. Figure 10, reproduced from their article, shows the reconstructed jet mass from the W, assumed to have a mass of 80 GeV, and a QCD jet of the same energy. A calorimeter segmentation in rapidity of 0.03 units and in azimuth of .03 radians is used. The segmentation of the calorimeter is vital. It is not possible to produce the required rejection if the calorimeter ssegmentation is 0.1 in both rapidity and azimuth. Segmentations smaller than 0.03 do not significantly improve the situation.

A rejection factor of 200 corresponds to an efficiency of about 25 per cent for the $W \rightarrow q\bar{q}$ mode.[22] I have superimposed on the figure a peak corresponding to the decay of a 90 GeV object. The separation between this peak and the one at 80 GeV gives some idea how well a W could be distinguished from a Z if both decay hadronically. There is clearly some potential for separation.

In view of the large rejection factor obtained, it is reasonable to ask what are the uncertainties in their analysis. Undoubtedly the largest source of uncertainty is in the ISAJET Monte-Carlo which was used to simulate the background. After very strong cuts have been applied, one can become very sensitive to parts of the Monte-Carlo which are not normally tested. The background final state is really W +two jets and, the approximation used to generate these multi-jet states is not perfect.[28] In view of the importance of the result, a reanalysis using another Monte-Carlo is probably required.

I will now discuss the ramifications of this very important result. If we require that in the W pair mode 100 detected events are needed in an run of integrated luminosity of 10^{40} cm^{-2}, then we can only observe processes with a cross-section of more than 0.16 pb. For the production of a W pair via the decay of minimal Weinberg-Salam Higgs boson, the cross-section is larger than 0.3 pb for all values of the Higgs mass greater than $2M_W$ and less than 1 TeV. This rate corresponds to that where the W's are produced centrally with $|y| \leq 1.5$. If this is relaxed to $|y| \leq 2.5$ the cross-section is always larger than 0.8 pb.[1]

If the Higgs mass becomes very large then its couplings to itself and to longitudinally polarized W's and Z's become (case (c))very large. The width of the Higgs calculated perturbatively,

$$\Gamma_H \approx 58 \left(\frac{M_H}{500\ \text{GeV}} \right)^3 \text{GeV},$$

becomes very large and it is difficult to speak of a resonance. In this case, one is dealing with a strongly coupled system consisting of W's and Z's. The problems of predicting its behavior are similar to those of calculating hadron masses in QCD.

Several methods have been tried in order to make estimates of the consequences of such strong coupling. One method predicts the existence of a scalar bound state of mass below 1 TeV.[29] Such a bound state will behave in a similar way to the elementary Higgs.

There are several qualitative features which should occur.[30,31,32] Structure should appear in multi-W final states when the invariant mass of the multi-W system is of order 1 TeV. Examples of this structure include

(a) A larger ratio of 3W and 4W final states to 2W final states than is predicted on the basis of quark anti-quark annihilation.

(b) A ratio of Z pair to W pair cross sections which is larger than that expected from quark anti-quark annihilation. Furthermore this ratio should be larger at large pair masses.

(c) Variation of the W and Z pair cross-sections with the invariant mass of the pair which is different from the expected from production via quark anti-quark annihilation.

In the case of two and three gauge boson final states some estimates of the rates are possible by considering the production and decay of a 1 TeV Higgs boson produced either alone, which will generate a two gauge boson final state, or in association with a W or a Z, which will produce a three gauge boson final state. The ratio of cross sections with three and two gauge bosons obtained in this manner is similar to that obtained by using "soft W theorems"[31] which are analagous to the soft pion theorems of QCD. Estimates[32, 33] for the three boson final state yield about 200 fb in the interesting invariant mass region. The rates for final states with four gauge bosons will be less. Even if the W sector is not strongly interacting, there will be final states of three and four gauge bosons produced from $q\bar{q}$ annihilation. The rate will fall rapidly as the invariant mass of the multi-W system rises. This background is not known, however, it may not be relevant since the observability of these small rates is in doubt.

The effciency for detecting a 3W final state is difficult to assess. A detailed Monte-Carlo study is really required, but I will try to make an educated guess. I will assume that one W decays leptonically into either an electron or a muon, and that the others decay hadronically. The background now arises from final states with W + W + jet(s) and W + jets. The background rejection factor required is unknown. I will asume that the effciency in the lepton channel is 1.0 and that in the hadronic channel is 0.25. The fraction of WWW events detected is then 0.017. The efficiency for the other final states with three bosons should not be radically different. This implies that, in order to observe 20 events, 1200 must be produced. If the estimates presented earlier for the production rates are valid, this will require an integrated luminosity of order 10^{41}cm^{-2}, which is a seemingly impossible task. Using the same method I can estimate the efficiency for a 4W final state where one W decays leptonically to be .004. The same depressing conclusion concerning observability seems unavoidable.

The situation in case (a) is much more problematic. In this region the Higgs will decay dominantly into a $t\bar{t}$ pair. I will assume a t quark mass of order 45 GeV in what follows. There is a large background from the production of tt pairs via gluon fusion. This background totally overwhelms the signal making the observation exceedingly difficult.[1,33]

The associated production of a Higgs and a tt pair offers no more hope.[19] Here the background arises from $gg \to t\bar{t}\, t\bar{t}$. The presence of extra t quarks in the final state enhances the signal but the background still dominates.[19]

The best chance for detection seems to be by observing the final state HW, where the W is tagged from its leptonic decay. The background now comes from final states of W + tt, which is produced only by qq annihilation and is consequently smaller than backgrounds initiated by gluon fusion. Gunion et al.[18] have demonstrated that, given a resolution of order 0.1 on $\Delta M_{t\bar{t}}^2/M_{t\bar{t}}^2$, the signal exceeds the background. Unfortunately, the cross-section is rather small. If both the W and H are produced centrally, having $|y| \leq 2$, and the W has $p_T > 40$ GeV (both of these cuts enhance the signal to background ratio), then it is of order 120 fb, for Higgs masses around 130 GeV if the W is required to decay either to $e\nu$ or to $\mu\nu$.

There is a large background from the process with a final state of $Wt\bar{b}$, which a produced by gluon gluon fusion and which will be serious if good t/b rejection is not available. With the same cuts and resolution on ΔM^2, this rate is approximately 50 times the signal.[18] Good b quark rejection is therefore vital if this process is to be exploited; Figure 11 shows the signal and background as a function of m_H. In order to decide whether this method is feasible a detailed Monte-Carlo analysis is required.

F. Gilman and B. Cox[34], and G. Abrams and B. Cox[35] have carried out such an analysis for this case. The t and b quarks should be distinguishable by looking at the invarient mass of the jet formed by their hadronization. Figure 12 shows the reconstructed b and t quark masses from the ISAJET Monte-Carlo.[26] The long tail on the t quark distribution is caused by missing energy carried off by neutrinos. The t quarks from the decay of a 130 GeV Higgs boson are moving rather slowly so that the jet produced by their fragmentation is not very clear. In contrast, the background from the final state W tb has a clearer jet from the b quark. After cuts a signal to background ratio of 1/6 is obtained.[34,35] Having identified the tt pair, the Higgs is searched for by looking for a peak in the tt mass spectrum.

Since the top quarks are rather soft, the resolution on the tt pair mass depends critically on the ability to detect, and to corrrectly assign, low transverse momentum hadrons. If the hadrons with $p_t < 1$ GeV are excluded, the peak in the tt mass spectrum disappears. (See Figure 13.) The peak also vanishes if either detector resolution is included or fragments from the t jet which are moving backwards are rejected. The rather negative conclusion of there studies in disappointing for it means that we have no method with which we can confidently expect to find a minimal Higgs boson of mass less than $2M_W$.

The situation could be improved in non-minimal models of electroweak symmetry breaking with more than one Higgs doublet, such as, for example, models based on supersymmetry. In these models (see Ref. 36 for a recent review), there are several physical Higgs bosons, some of which can have enhanced couplings to quarks and leptons. The pro-duction rates could therefore be enhanced significantly over those discussed here.

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FIGURE CAPTIONS

Figure 1. The evolution of $xg(x, Q^2)$ as a function of Q^2 for various values of x. The solid lines correspond to the starting distribution (a), see text, the dashed to (b) and the dotted to (c).

Figure 2. The cross-section for producing a pair of jets each with transverse momentum greater that 10 GeV and with rapidity $|y| < 2.5$.

Figure 3. The gluon-gluon fusion mechanism for new particle production.

Figure 4. The intrinsic mechanism for new particle production.

Figure 5. The process gluon-gluon--> Higgs.

Figure 6. The process qq-->qqH via the gauge boson fusion process.

Figure 7. The associated production of a Higgs boson and a tt quark pair.

Figure 8. A comparison of the rate of Higgs boson production form the various mechanisms, from Ref. 19.

Figure 9. Cross section for the reaction $pp \rightarrow (H + W^+W^-)$ + anything with $m_t = 30$ GeV/c^2, for $\sqrt{s} = 40$ TeV. The intermediate bosons must satisfy $|y_W| < 2.5$. The contributions of gluon fusion (dashed line) are shown separately. Also shown (dotted line) is $\Gamma_H \, d\sigma(pp \rightarrow W^+W^- + X)/dM$ with $|y| < 1.5$ and $M = M_H$. With Γ_H = larger of the Higgs width and 10 GeV. From Ref. 1.

Figure 10. Reconstructed masses of $W \rightarrow qq$ and QCD jets produced for W-jet pairs of invariant mass 1 TeV. The W mass is assumed to be 80 GeV, and a calorimeter segmentation of $\Delta y = \Delta\phi = 0.03$ is used.[22] The figure also shows the W peak displaced and centered at 90 GeV, in order to give an indication of the W/Z separation which may be expected.

Figure 11. The rate $pp \rightarrow W + H$ at $\sqrt{s} = 40$ TeV (solid). Also shown is the background from $pp \rightarrow Wtt$ (dashed) and W tb (dotted). The backgrounds are estimated from $d\sigma/dM \, \Delta M$ where M is the mass of the quark fair and $\Delta M^2 = 0.1M^2$. the latter background has been divided by 100.

Figure 12. The reconstructed jet mass for a sample of b and t quark jets arising from the decay of a 130 GeV for Ref. 34.

Figure 13. The tt mass spectrum resulting from the decay $H^0 \rightarrow tt$ with $m_H = 120$ GeV. Fragments with energy less than 1 GeV are excluded. From Ref. 34.

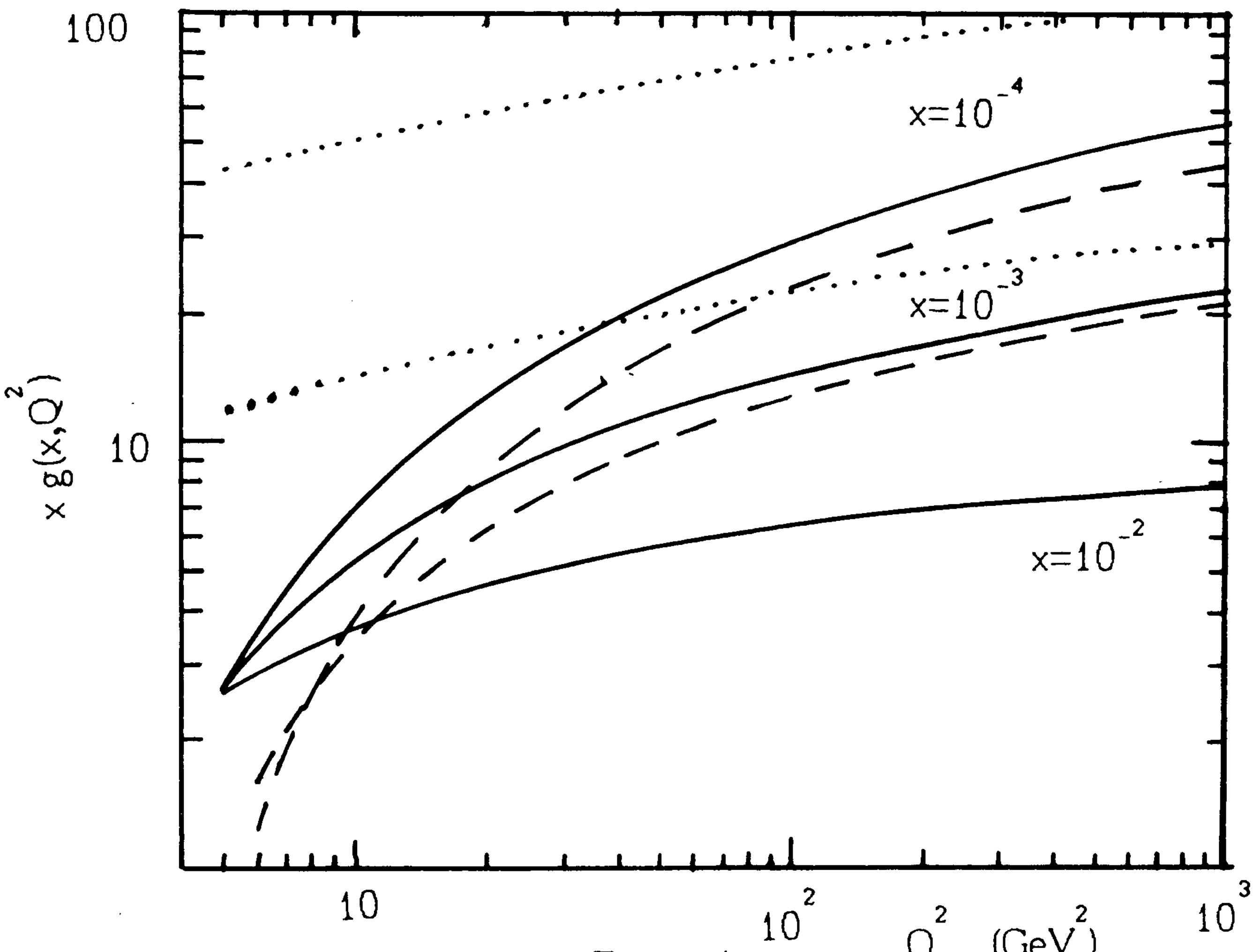


Figure 1.

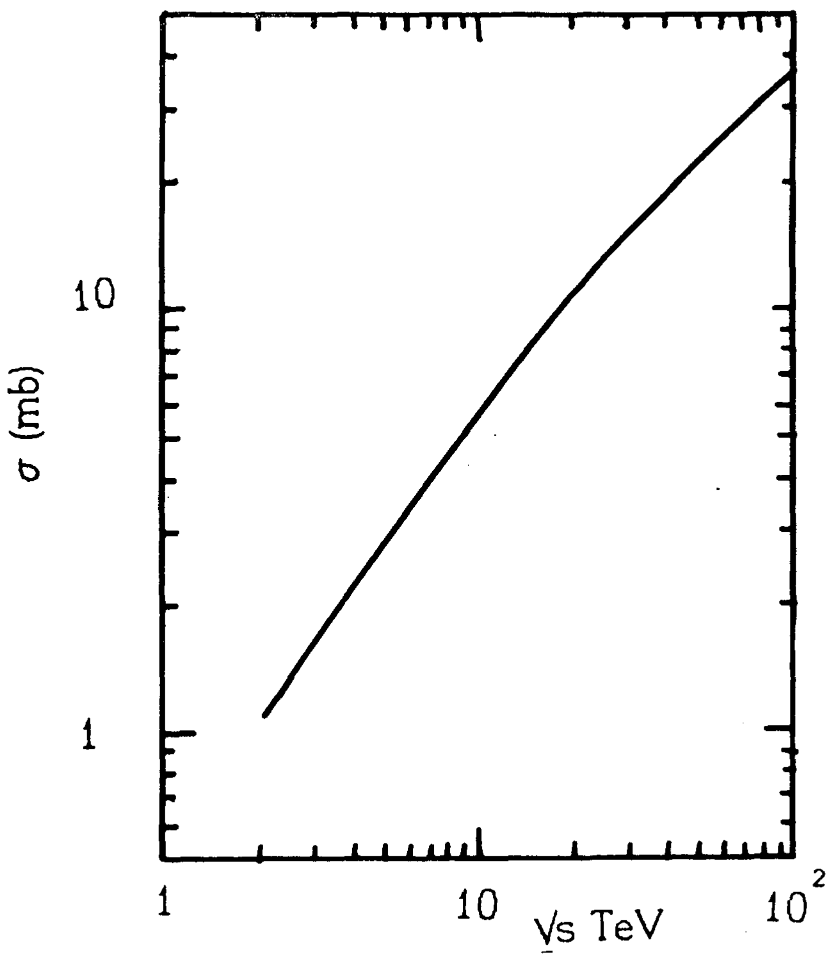
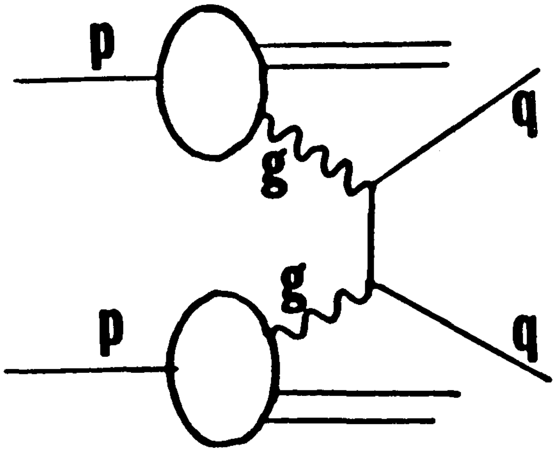


Figure 2.



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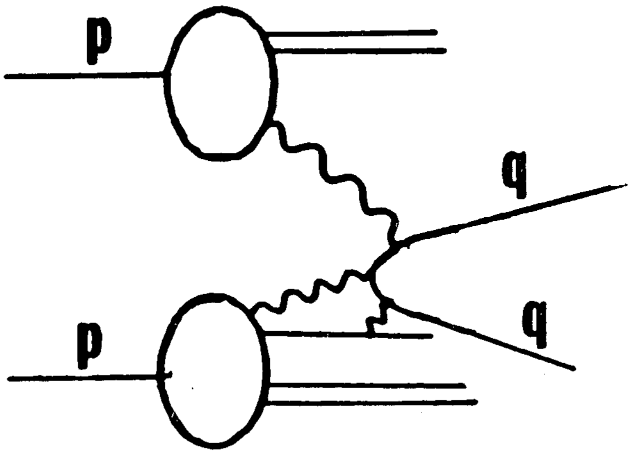

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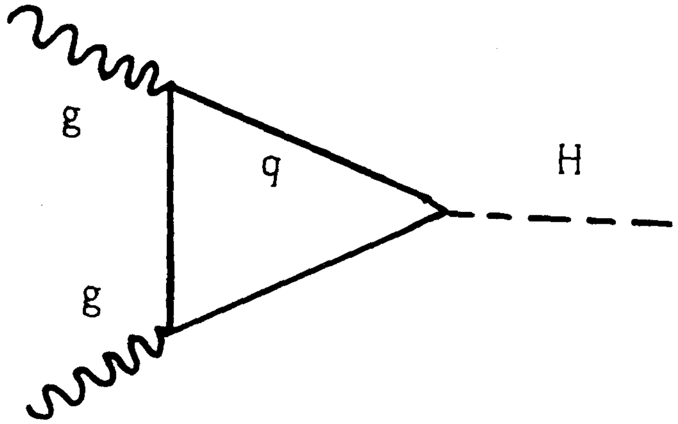

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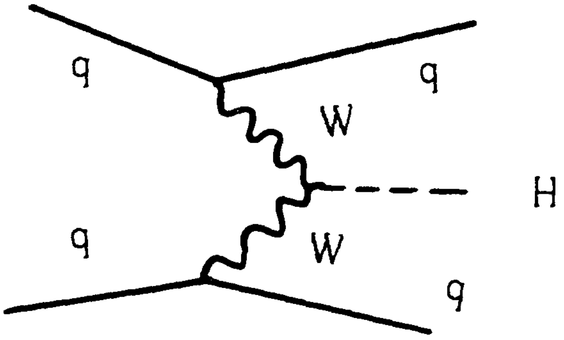

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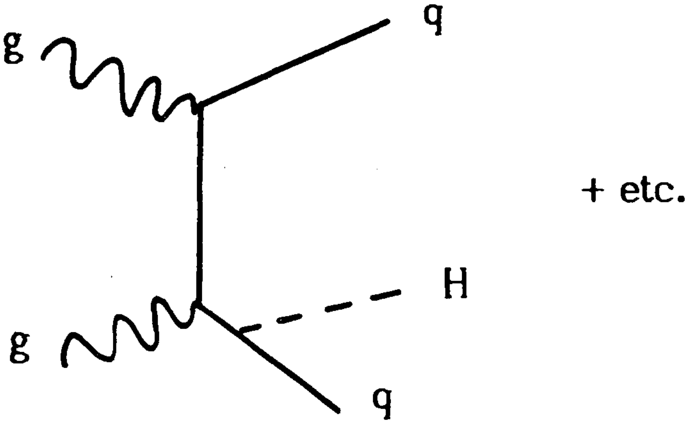

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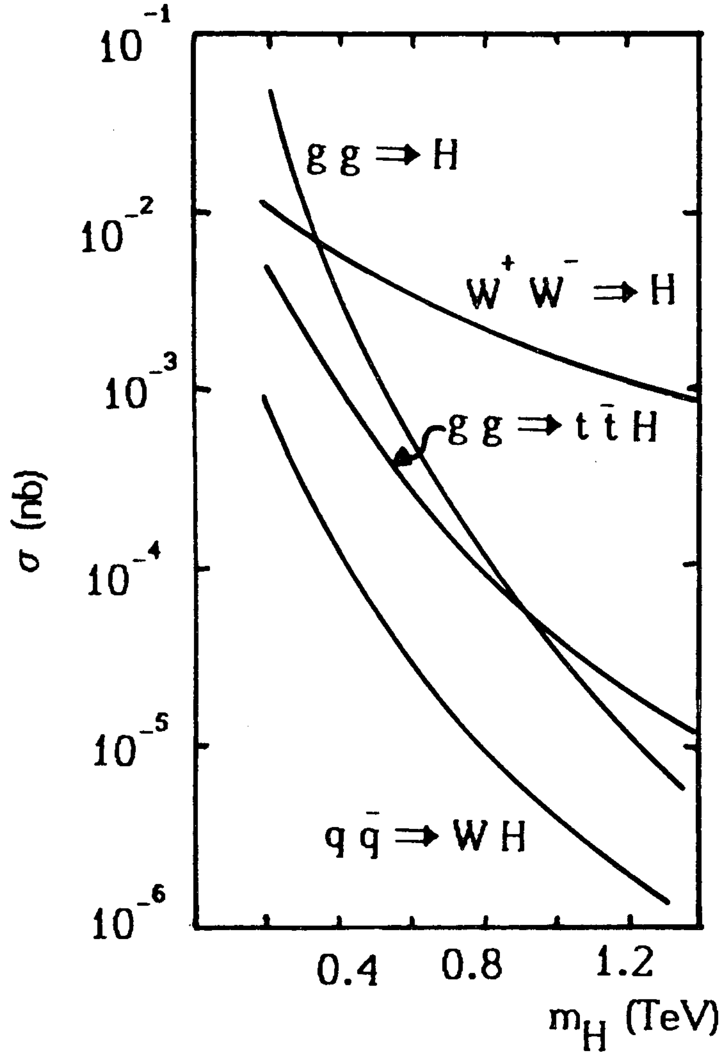
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
σ (nb)
$g\,g \Rightarrow H$
$W^+W^- \Rightarrow H$
$g\,g \Rightarrow t\,\bar{t}\,H$
$q\,\bar{q} \Rightarrow W\,H$
0.4
0.8
1.2
m_H (TeV)

Figure 8.

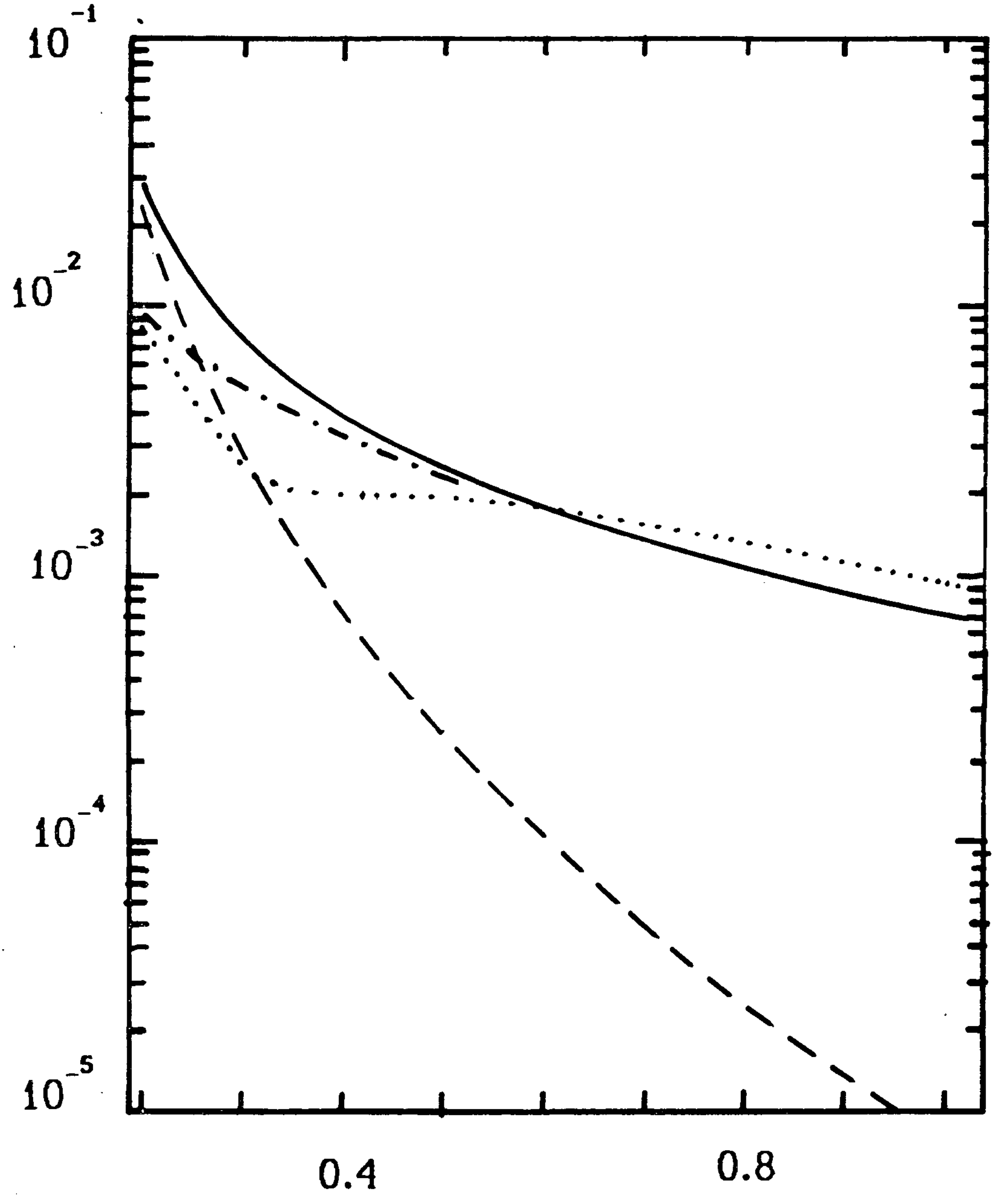

Figure 9.

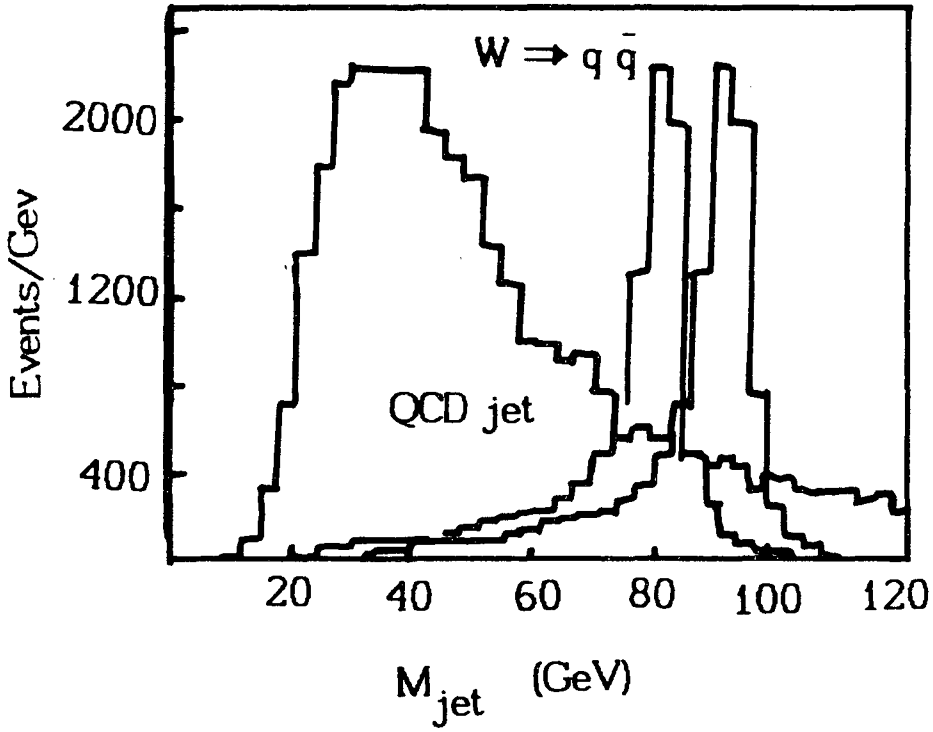
W ⇒ q $\bar{q}$
QCD jet
Events/Gev
2000
1200
400
20
40
60
80
100
120
M_{jet} (GeV)

Figure 10.

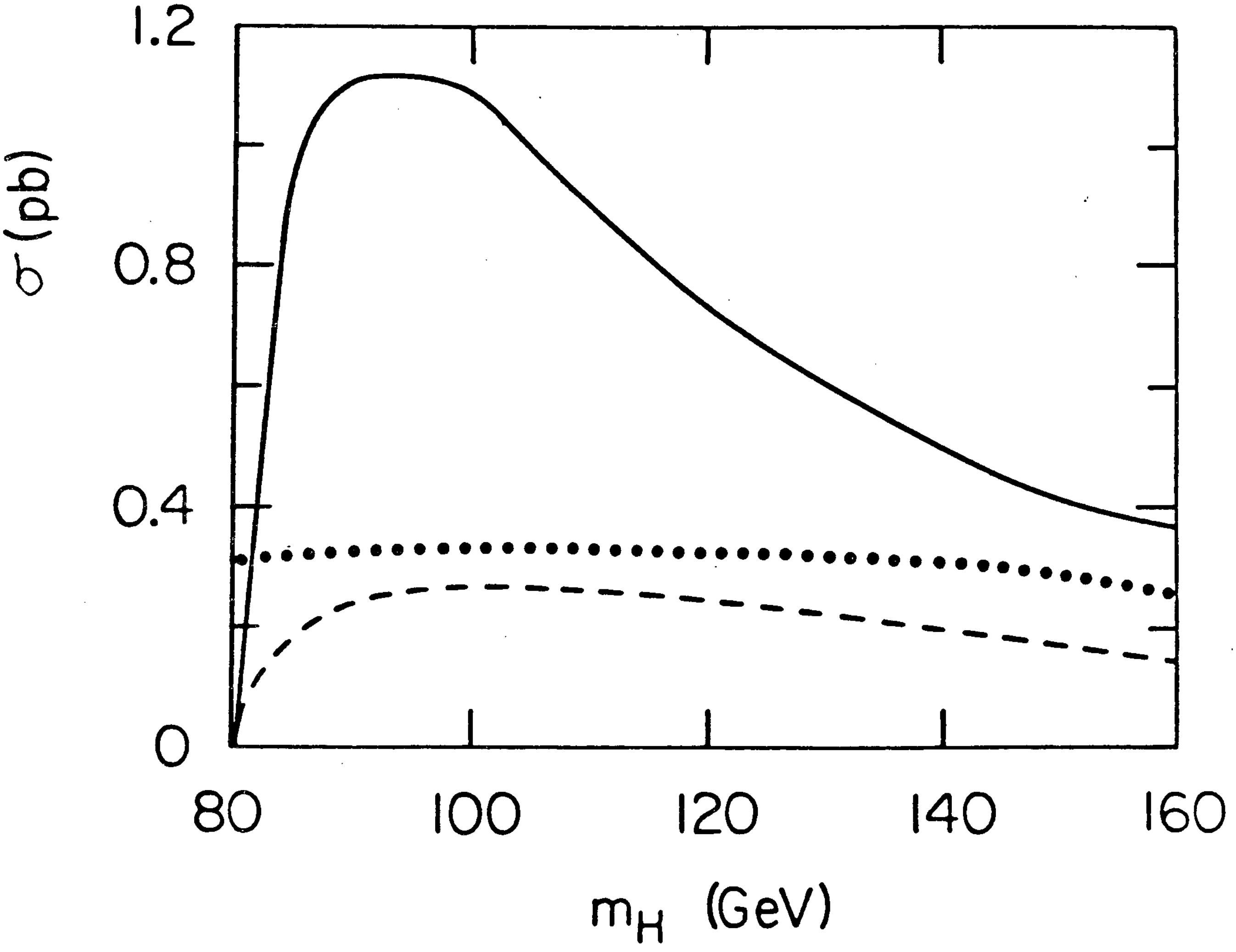

Figure 11.

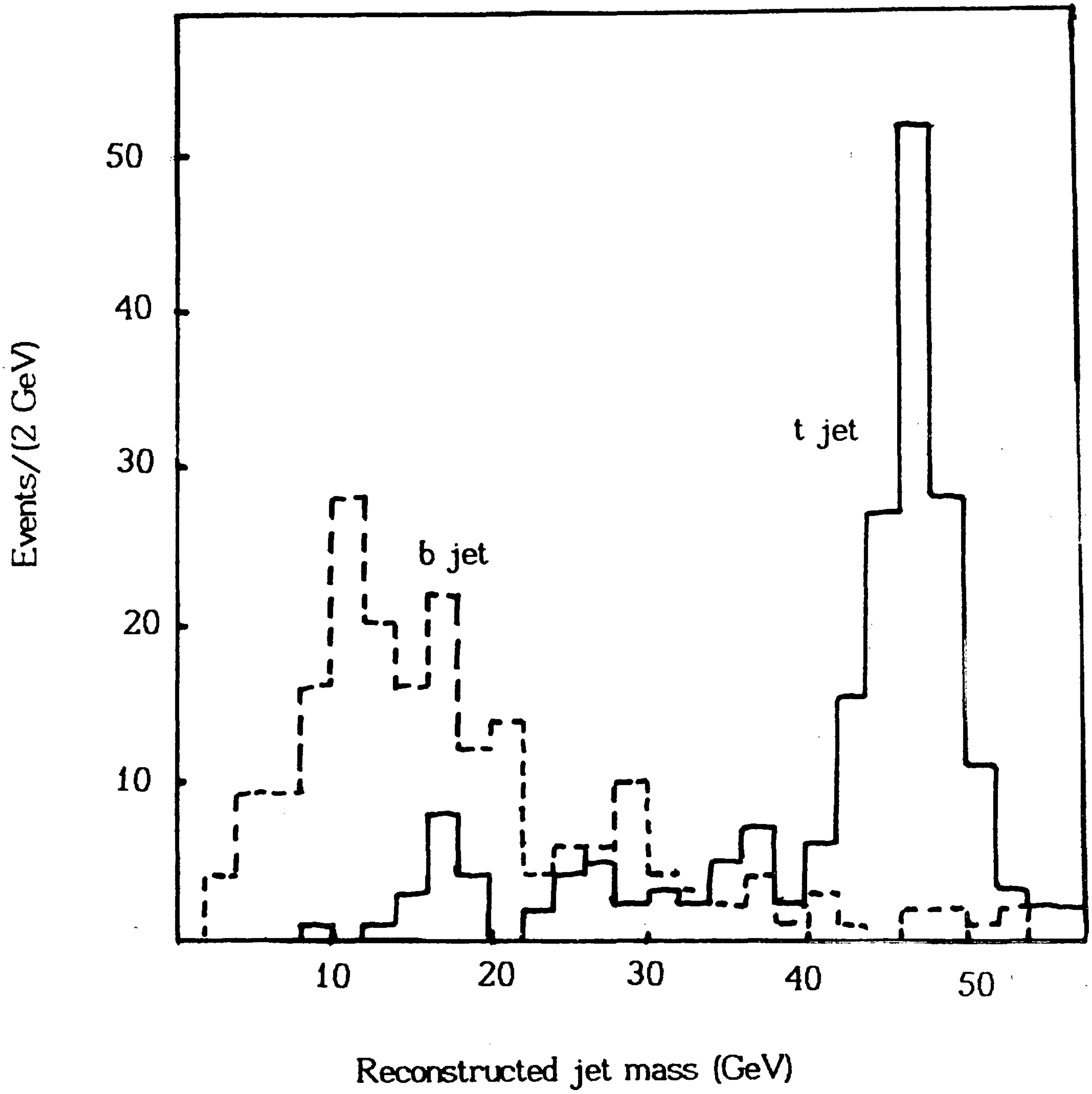
Events/(2 GeV)
50
40
30
20
10
b jet
t jet
10
20
30
40
50
Reconstructed jet mass (GeV)

Figure 12.

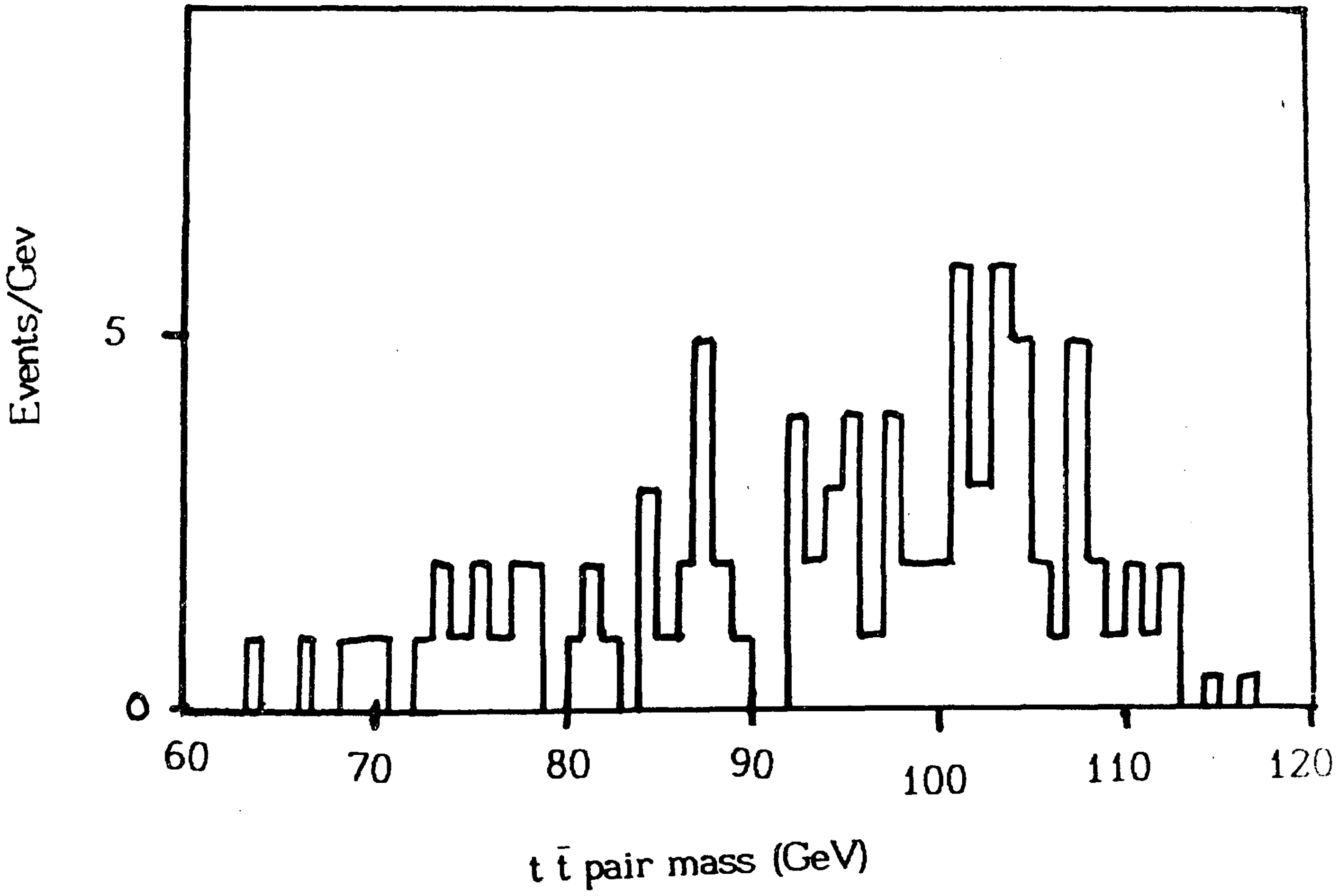

Figure 13.

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