CROSS SECTIONS AT HADRON COLLIDERS

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Summary

Some typical cross sections are given for pp colliders at $\sqrt{s}$ = .8, 2, 10, and 40 TeV.

Introduction

The hadron-hadron collider group[1] at this workshop has considered pp and $\bar{p}p$ colliders at energies $\sqrt{s}$ = .8, 2, 10, and 40 TeV and at luminosities up to $10^{34}cm^{-2}\ sec^{-1}$. In this note the predicted cross sections are given for new Z'^0 bosons, for the Drell-Yan continuum of $\mu^+\mu^-$ pairs, for high p_T hadron jets, for high p_T single photons, and for the associated production of heavy quarks. These processes have been selected not to cover the most interesting physics, but to provide a representative selection of cross sections for which to compare various energies and luminosities.

All of the cross sections given here are computed using leading-log perturbative QCD.[2-3] Such calculations agree with the available data to within about a factor of two for the Drell-Yan continuum[4] and for high p_T pions and single photons[5]. Some doubt about their reliability has resulted from the fact that experiments triggered on the total transverse energy

$$E_T = \sum_i E_i \sin\theta_i$$

observe a cross section much larger than the QCD jet cross section and no obvious jet structure. However, a recent ISR experiment[6] has shown that the transverse energy triggers are well described by a two-component model. One component has a high multiplicity of low p_T particles, the tail of the KNO distribution, and the other has a QCD jet character and about the predicted jet cross section. Thus the available evidence suggests that perturbative QCD calculations are at least approximately reliable.

All of the calculations are done using the Baier et al.[7] structure functions and a QCD scale parameter Λ = .1 GeV. Taking Λ = .2 GeV does not change the results very much, and values of Λ in this range are now generally favored[8]. For Λ = .5 GeV the scaling violations are significantly increased, so that the cross sections for large values of $m/\sqrt{s}$ are reduced. Also, all the cross sections are for a pp initial state. The results for $\bar{p}p$ would not be very different for small values of $m/\sqrt{s}$; large $m/\sqrt{s}$ requires very high luminosity, so pp is probably more appropriate.

Heavy Z Production

The masses and couplings of possible heavy $W'^{\pm}$ and Z'^0 are clearly model dependent. A reasonable assumption is that the dimensionless couplings are equal to those in the standard model, so that the effective low-Q^2 couplings are

$$G' = G_F \left(\frac{m_{standard}}{m}\right)^2$$

This is at least approximately true in most models and should probably provide a reasonable guide to the expected cross sections. The new Z'^0 cross sections as a function of the Z'^0 mass are shown in Fig. 1.

If the new Z'^0 decays only into quarks and leptons, then its branching ratio is given by

$$B = 3\% \left(\frac{3}{n_{gen}}\right)$$

where n_{gen} is the number of generations. Other modes such as $Z'^0 \to W^+W^-$ could decrease this branching ratio somewhat, but values of this order are still expected. Taking B = 3% and requiring 100 produced events for $L = 10^{34}cm^{-2}sec^{-1}$ and $T = 10^7 sec$ then gives

$$\sigma > 3.3 \times 10^{-11}\ mb$$

as the minimum observable cross section.

Drell-Yan Continuum

The $\mu^+\mu^-$ mass distribution from $q\bar{q} \to \mu^+\mu^-$ through a virtual photon or standard Z^0 is shown in Fig. 2. A reasonable criterion for an observable signal is 100 events produced in a bin $\Delta Q/Q$ = 10% and Δy = 2. Then for $L = 10^{34}cm^{-2}sec^{-1}$ and $T = 10^7 sec$

$$\frac{d\sigma}{dQdy} > (5 \times 10^{-12} mb/GeV) \left(\frac{1GeV}{Q}\right)$$

is observable.

High p_T Jets

The high p_T jet cross section is given by the sum of the parton cross sections for

$q+q \to q+q$, $q+g \to q+g$, $g+g \to g+g$, $g+g \to q+\bar{q}$, ...

weighted by the appropriate structure functions. The precise relation of this cross section to experimental observables is still in some doubt, but recent results from the ISR suggest that a hard scattering cross section can be extracted from a transverse energy trigger. In any event the QCD jet cross section should indicate the maximum observable momentum transfer to be used to look for quark substructure or similar effects. The cross sections are shown in Fig. 3.

A reasonable signal is 100 events produced in a bin $\Delta p_T/p_T \approx 10\%$ and $\Delta\Omega = 10$. Then for $L = 10^{34}$ $cm^{-2}sec^{-1}$ and $T = 10^7$ sec

$$\frac{d\sigma}{dp_T d\Omega} > (1 \times 10^{-12} mb/GeV) \left(\frac{1GeV}{p_T}\right)$$

can be observed.

High p_T Single Photons

The cross sections for high p_T single photons shown in Fig. 4 are based on the processes

$$g + q \to \gamma + q \quad \text{and} \quad q + \bar{q} \to \gamma + g$$

There are also significant contributions from $g + g \to \gamma + g$ and from the fragmentation of a jet into a photon. These are interesting but do not change the cross section by a large factor.

If it were possible to cover a large solid angle with a single-photon detector, then the observable cross section would be the same as for jets. In practice a single-photon detector must be much smaller; this is discussed by Palmer, Peoples, et al.[1]

Heavy Quarks

The cross sections for the associated production of heavy quarks through the processes $g + g \to Q + \bar{Q}$ and $q + \bar{q} \to Q + \bar{Q}$ are shown in Fig. 5. Detection of heavy quarks has not been studied in any detail as yet, but presumably one must observe a semileptonic decay into either e or μ. This has a branching ratio of about 10% unless there exists a lighter charged Higgs boson, in which case the decay $Q \to q + H$ is dominant. Given a semileptonic decay, one must then examine distributions involving the lepton and the associated hadrons. Thus a total of order 10^4 produced events is probably required, so that for $L = 10^{34} cm^{-2} sec^{-1}$ and $T = 10^7 sec$ the observable cross section is

$$\sigma > 10^{-10} mb.$$

Conclusion

All cross sections in perturbative QCD have the general form

$$\sigma = \frac{1}{m^2} F\left(\frac{m}{\sqrt{s}}, \ell n \frac{m^2}{\Lambda^2}\right)$$

where m is the relevant mass scale and F is related to a product of structure functions. The dependence of F on $\ell n\, m^2/\Lambda^2$ results from QCD scaling violations. As $m/\sqrt{s} \to 1$, F decreases rapidly, while as $m/\sqrt{s} \to 0$, it increases slowly. The fact that the scale of the cross section is set by $1/m^2$ is more general than QCD; it is true in any renormalizable field theory and indeed is just a reflection of the uncertainty principle. Thus to observe a given mass scale m requires both an energy $\sqrt{s}$ several times m and a sufficiently high luminosity. The tradeoff between energy and luminosity is process dependent; it is discussed in detail by Palmer, Peoples, et al[1].

Acknowledgment

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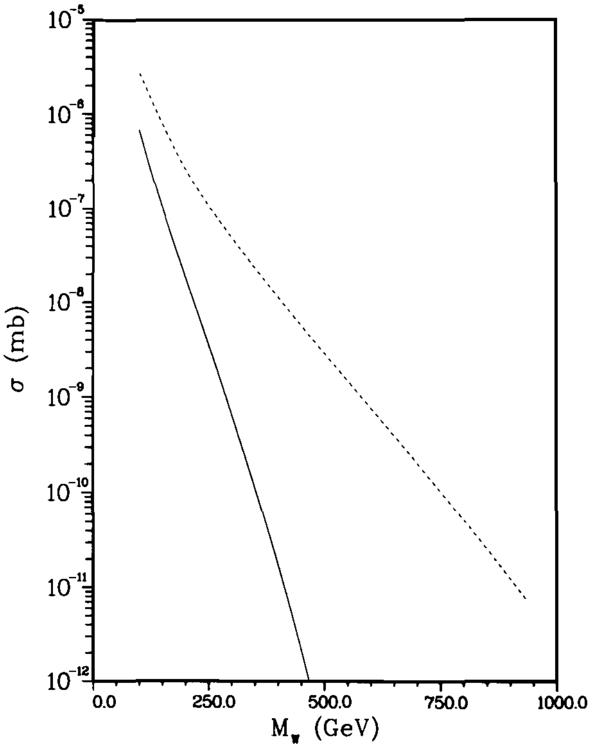

Fig. 1a: Total Z'^0 cross sections vs its mass. Solid curve: $\sqrt{s}$ = 800 GeV. Dashed curve: $\sqrt{s}$ = 2000 GeV.

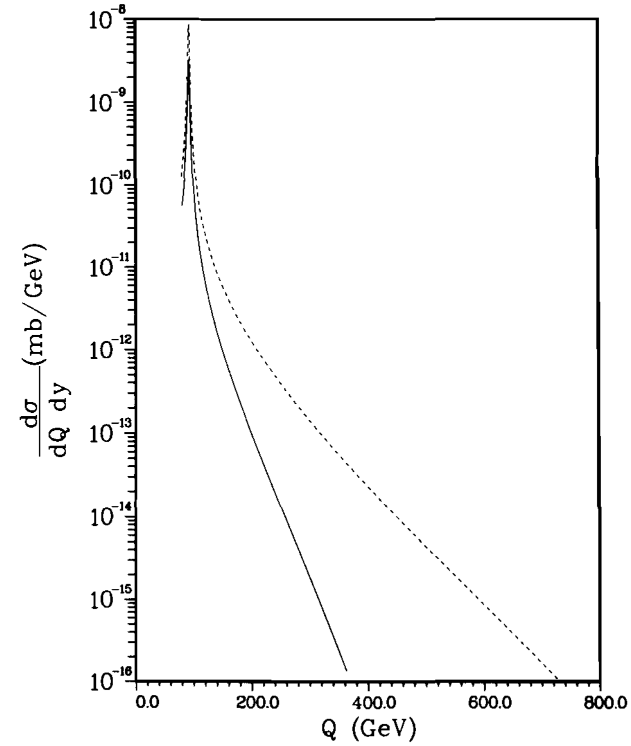

Fig. 2a: Drell-Yan cross section vs mass. Solid curve: $\sqrt{s}$ = 800 GeV. Dashed curve: $\sqrt{s}$ = 2000 GeV.

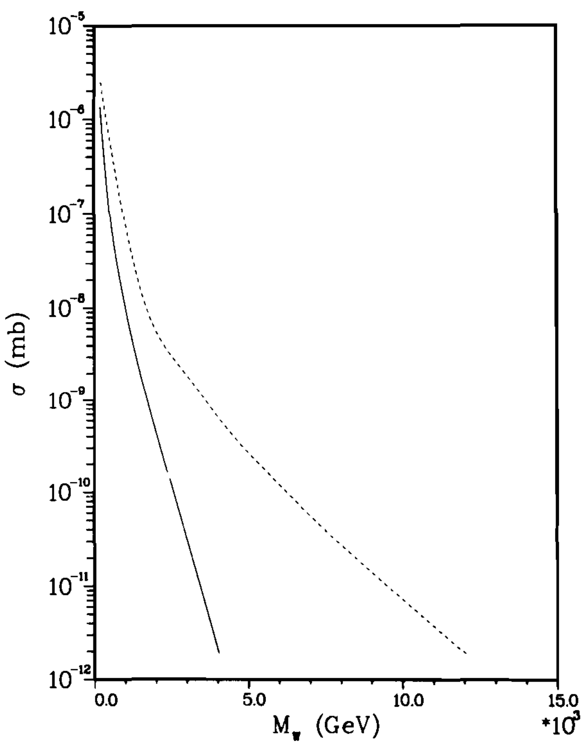

Fig. 1b: Same as Fig. 1a. Solid curve: $\sqrt{s}$ = 10 TeV. Dashed curve: $\sqrt{s}$ = 40 TeV.

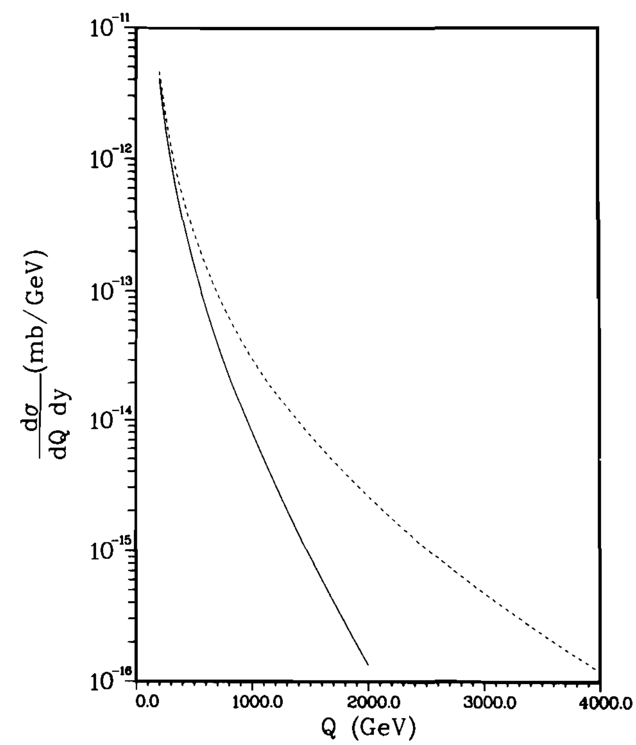

Fig. 2b: Same as Fig. 2a. Solid curve: $\sqrt{s}$ = 10 TeV. Dashed curve: $\sqrt{s}$ = 40 TeV.

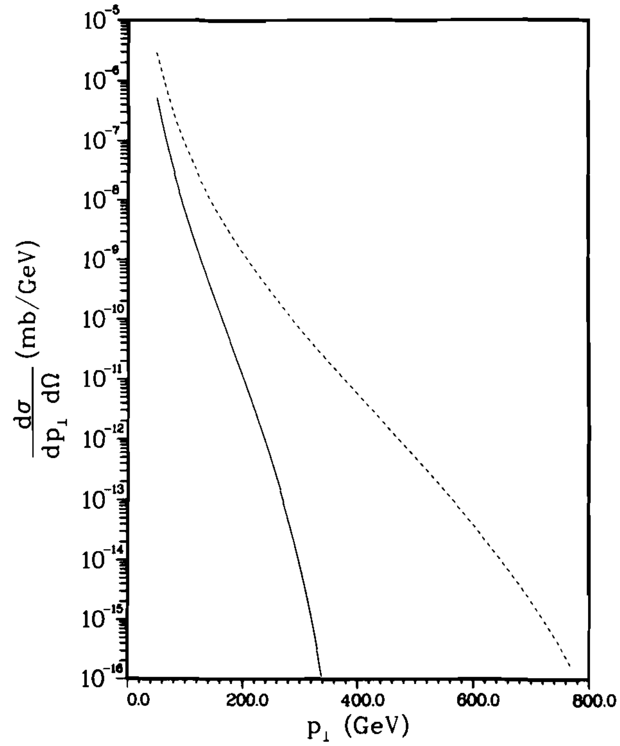

Fig. 3a: QCD jet cross section vs p_T. Solid curve: $\sqrt{s}$ = 800 GeV. Dotted curve: $\sqrt{s}$ = 2000 GeV.

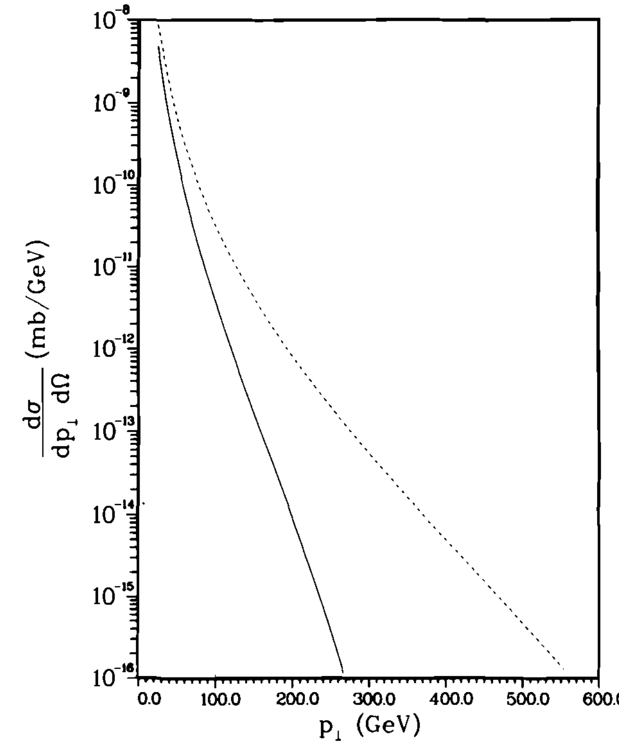

Fig. 4a: Single photon cross section vs p_T. Solid curve: $\sqrt{s}$ = 800 GeV. Dotted curve: $\sqrt{s}$ = 2000 GeV.

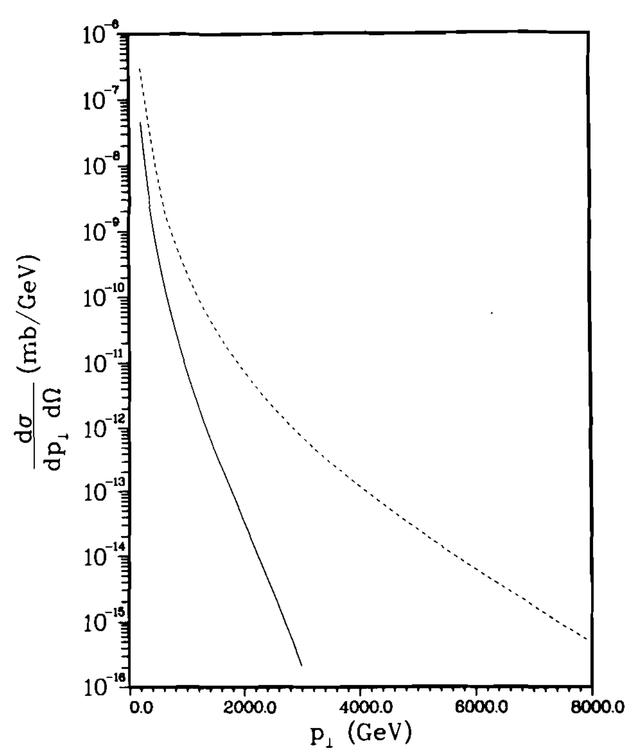

Fig. 3b: Same as Fig. 3a. Solid curve: $\sqrt{s}$ = 10 TeV. Dotted curve: $\sqrt{s}$ = 40 TeV.

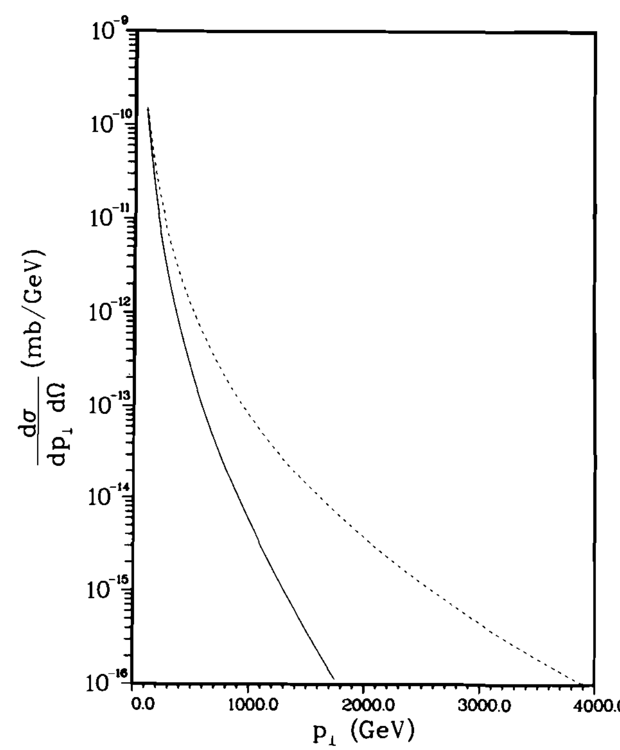

Fig. 4b: Same as Fig. 4a. Solid curve: $\sqrt{s}$ = 10 TeV. Dotted curve: $\sqrt{s}$ = 40 TeV.

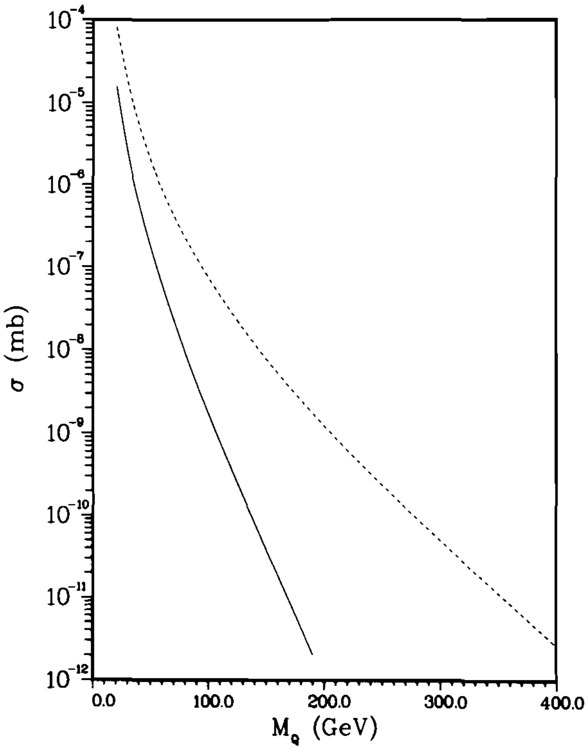

Fig. 5a: Heavy quark cross section vs quark mass. Solid curve: $\sqrt{s}$ = 800 GeV. Dotted curve: $\sqrt{s}$ = 2000 GeV.

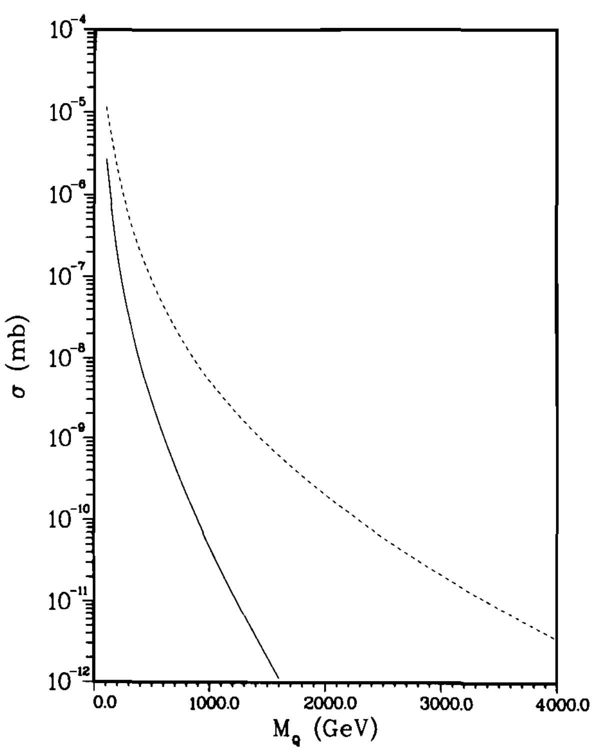

Fig. 5b: Same as Fig. 5a. Solid curve: $\sqrt{s}$ = 10 TeV. Dotted curve: $\sqrt{s}$ = 40 TeV.