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The Physics Potential of the CBA

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THE PHYSICS POTENTIAL AT CBA

INTRODUCTION

Brookhaven is presently updating its plans for a proton-proton colliding beam accelerator and will make presentations to the DOE in a major review this spring. Subsequently, a special subpanel of HEPAP will also review the project, culminating in a June meeting at Woods Hole and a written recommendation to DOE. If the results of these deliberations are favorable, construction of the CBA can go forward rapidly beginning in FY 1985, and be completed in FY 1988. As described in previous issues, much work has already been done.

This issue will discuss some of the physics opportunities offered by such a facility. The proton-proton collider will have a center-of-mass energy of 800 GeV and a standard luminosity of 2×10^{32} cm^{-2} sec^{-1}; low beta interaction regions with luminosities of 10^{33} cm^{-2} sec^{-1} and regions with shortened interaction diamonds and luminosities of 10^{32} cm^{-2} sec^{-1} will be available. Since CBA will have six interaction regions, it will be possible to run a number of quite different experiments requiring different luminosities and/or interaction diamond configurations simultaneously. CBA is a fully dedicated collider, so it is expected that it will run for $\approx 10^7$ sec per year. In evaluating the physics potential of this machine, it is assumed that rate limited experiments will obtain annual integrated luminosities of $10^{40}/cm^2$ at $\sqrt{s}$ = 800 GeV with instantaneous luminosities of 10^{33} cm^{-2} sec^{-1}. Polarized protons will also be available, possibly at the full luminosity.

The great discoveries of the past year at the CERN Collider have demonstrated once again the strength of hadron machines in discovering new physics. The striking clarity of the jets[1] and how plainly the W events stand out from the background[2] reenforce our optimism regarding how much important physics a team of talented experimentalists with well-instrumented apparatus can obtain from hadron-hadron collisions. That the standard electroweak model and the QCD-parton model for hadron dynamics seem to be approximately correct supports the estimates that have been made in the past and gives us confidence in making estimates for the future. These results encourage us to look more closely at the mass region around 100 GeV while pressing on to break new ground in the higher mass region. Looking back over the history of K-meson physics, one must expect that there is a rich lode to mine in the study of W and Z physics. At the same time, we are mindful that there are unsolved problems in our understanding of particle physics that require studies of masses above 100 GeV: Is there further unification of the various interactions? How do the particles get their mass? What are the origins of CP violation and the families of fermions? Are the quarks elementary?

We expect that very soon both the $W^{\pm}$ and Z° intermediate vector bosons will have been discovered and their masses approximately determined to be about 83 and 94 GeV, respectively. But at what scale will new physics reveal itself? Do we have any hints as to where or what we should be looking for?

Besides ordinary intuition, there are indications of new physics. For example, consider grand unified theories (GUTS). The simplest SU(5) Georgi-Glashow model assumes a "great desert hypothesis" - no new mass scales between m_Z and m_X, the unification mass. This hypothesis is testable via proton decay experiments, since $\tau_p \propto m_X^4$ is very sensitive to the actual value of m_X. The theory predicts $\tau_p \approx 2 \times 10^{29 \pm 1.7}$ yr.[3] The present experimental bound, $\tau_p > 3 \times 10^{31}$ yr[4], implies that something is wrong with the above scenario. New mass scales between m_Z and m_X would affect the evolution of the coupling constants and could increase the value of m_X and thus τ_p. The lower the mass scale of this new physics, the bigger the effect on the value of m_X.

While the fundamental theory of symmetry breaking and mass generation is as yet unknown, for very general reasons there should be "low-energy" manifestations of it. These are expected to be below about 300 GeV because color and electroweak interactions give mass to light particles of that order or less. Furthermore, the theory must account for the mass scale of weak interactions, $G_F^{-1/2} \approx 300$ GeV, and for the vacuum expectation value of the Higgs scalar which breaks the electroweak symmetry and has about the same value. A number of familiar models do give effects in this mass range. For example, technicolor models suggest the occurrence of many of pseudo-goldstone bosons at about 200 GeV. Such particles, together with their color excitations, would lead to a rich new spectroscopy. Similarly, supersymmetric theories generally predict large numbers of new particles well below 300 GeV. Most likely the new physics will be something as yet unthought of, but these new arguments provide a very strong indication that 100-300 GeV is a region where thorough exploration will be rewarded.

The CBA with its high energy and very high luminosity is ideally suited to study this physics. On the one hand, it will be a copious source of W's and Z's and all of the rich phenomena associated with them. On the other hand, it will provide the highest sensitivity to a large variety of new phenomena in the mass range up to around 300 GeV. Viewed in the context of the world program, the CBA is the correct next step in the construction of high energy accelerators. The e^+e^- machines, LEP and SLC, are probably the ideal machines for studying the Z° and its decay products, but they do not have the energy to go much above 100 GeV. The $\bar{p}p$ colliders at CERN and Fermilab will have the first look at phenomena in this region and may be expected to make many important discoveries; indeed, they have already begun to do so. The Tevatron, with energy twice that of CBA, will be able to study large cross section processes, especially QCD jets, to higher mass values. The fact that the CBA will have 10^3 times higher luminosity is its real strength. The important point to bear in mind is that interesting cross sections are generally very small, even at very high energy, and so high luminosity is needed to study them. Calculations which explicitly support this point are presented in many contributions to the Snowmass Proceedings. See, in particular, the summary paper by the Hadron-Hadron Collider Group.[5]

The range of physics possible with the CBA is enormous. This has been studied and documented repeatedly over the past years in major summer studies, mini workshops, working groups, and notably, last year's DPF Summer Study at Snowmass. During the last few months, several groups made up of Brookhaven scientists and scientists from the universities have been working together, studying the physics possibilities once more and considering how the experiments might be done. This report is a summary of that work. Reports of the individual groups will soon be issued so that details will be available to the interested scientist. Necessarily, some of the possibilities are more well-developed than others; some are based on more speculative notions and some are contingent on other yet-to-be made discoveries such as the top quark. In some cases we think we know how to do the experiment; in others we don't. We expect that there are those amongst our readers who will know how to fill in some of these gaps. Obviously, we will be delighted to hear of any physics potential which we have overlooked. It is important to emphasize that the examples that follow are chosen to demonstrate the broad range of capability for experimentation made possible by the energy and luminosity of the CBA. Obviously the specific experimental proposals will come from the high energy physics community and will reflect developments in theory and experiment not at present foreseen. However, we believe that the physics presented below makes a convincing case that the CBA will play an essential role in the future of high energy physics in the United States and in the world.

Most of the physics considered here involves either the production of heavy particles or the hard scattering of partons.

Thus the cross sections can be calculated fairly reliably using perturbative QCD. (This is true even for new types of particles, eg. supersymmetric ones, once their masses are specified.) An important question is how to separate the signal from the potentially large background. In many cases we have carried out a detailed analysis of this question. Both the signal and the background events have been simulated using ISAJET, a Monte Carlo event generator based on perturbative QCD and phenomenological models for parton and beam jet fragmentation.[6] It is in reasonable agreement with data from the ISR and SPS Collider: indeed it is striking how closely the SPS Collider events resemble theoretical expectations. The response of an appropriate detector has also been simulated quite realistically. The details vary from case to case, but generally the effects of energy resolution, finite spatial segmentation, and high rates have been included.

We begin by discussing some of the physics that can be done with the enormous number of W's and Z's that will be produced at the CBA. To put this in perspective, the total number of W's produced at $L = 10^{33}$ cm^{-2} sec^{-1} will be about 5 per second; the rate of Z° production will be comparable to that expected at LEP, about 1 per second.

$W^{\pm}$ AND Z° PROPERTIES

Precise measurement of the $W^{\pm}$ and Z° masses is of the highest priority in testing the standard model. Indeed, inclusion of quantum corrections increases the mass predictions for the $W^{\pm}$ and Z° from 78.3 GeV and 89 GeV to 83 and 93.8, respectively. Small deviations from these corrected values would signal new unanticipated effects. However, it is not enough to measure M_Z with high precision; to infer new physics, M_W must also be precisely determined. For example, a measurement of M_Z

to within 0.1 GeV at e^+e^- colliders combined with a ±0.5 GeV measurement of M_W at CBA would determine the ρ parameter to within 1%. Deviations from the prediction $\rho = M_W^2/M_Z^2\cos^2\theta_W = 1$ would indicate new physics such as heavy fermions or additional scalars in the electroweak theory.

The determination of the W mass requires an accurate measurement of the Jacobian peak in the p_T distribution of the leptons from the W-decay.[7] Ideally, this peak is at $M_W/2$. In fact, there are significant corrections coming from the transverse motion of the W. One can make use of the fact that the p_T distribution of the W should be similar to that of the Z and thus the mass of the W relative to the Z can be inferred from the shape of the p_T distributions of the observed ℓ's. While the interpretation of such a distribution for the absolute mass of the parent particle would be difficult, comparing it to a distribution from a particle of known mass, the Z°, with kinematically similar production and decay mechanisms, will allow (statistics permitting) a very accurate relative mass determination. A careful study of this approach has been carried out in which p_T distributions of ℓ's corresponding to W and Z decays were produced at different masses allowing for initial W and Z p_T distributions as predicted by QCD.[8] The backgrounds to this process include semileptonic heavy quark decays and high p_T π^0's. Demanding a very small energy deposit in the neighborhood of the identified $\ell^\pm$ and requiring that there be missing transverse momentum due to the missing energetic neutrino result in a p_T distribution almost completely free of background beyond 20 GeV/c. A chi-squared minimization procedure was used to find the best value of a linear p_T scaling parameter which mapped the Z° Jacobian peak onto the W peak. This scaling parameter was then interpreted as the mass ratio. The Jacobian peak region is shown in detail in Fig. 1. The dependence of χ^2 on the ratio of M_W/M_Z is shown in Fig. 2, for a realistic number of events and a mass difference of 10 GeV, for a fit to the peak between 35 GeV and 43 GeV. This method produces a W-Z mass difference determination with an uncertainty of 0.26 GeV.

Large samples of W's and Z's allow many other studies which address the structure of electroweak interactions, the structure of the proton, and hadron dynamics. For example; the study of the W and Z decays into hadrons is of fundamental importance but it must overcome large backgrounds and so will need high statistics to allow severe cuts. Detailed angular distribution measurements give important direct information on the V,A structure of the W coupling to quarks and to leptons. This is illustrated clearly in Fig. 3 where the standard model predicts very different distributions for ℓ^+ and ℓ^-.[9] The production distributions are measurements of the proton structure functions and QCD tests which can be used in conjunction with the Drell-Yan measurements, discussed below, to sort out the various components of the proton. Up-down asymmetries of W-decay with regard to the production plane are direct parity violating effects which arise only from higher order QCD loops; the effect is expected to be small and so requires many W's.

Polarized proton beams present obvious physics opportunities for studying W physics. Because of the V-A coupling, left-handed protons produce W's far more copiously than right-handed protons do. Thus, when the difference between rates with left- and right-handed protons for various processes involving W's is measured a very substantial parity violating signal should be seen. This would be spectacular in the leptonic decay modes and can be used as a tool in extracting the hadronic decay modes from the large, parity-conserving background.[7] Indeed, this unique capability of the CBA will prove a valuable tool in studying a variety of physics.

W^+W^- PRODUCTION

This is a very exciting process to study because it involves in a direct way the $W^+W^-Z^\circ$ coupling which is characteristic of the non-Abelian gauge theory. No other accelerator, until LEPII, can study this process: the rates are very small[10] - see the cross section in Fig. 4 - and it is only CBA's high luminosity which makes it feasible. The favored way to search for W pair production is by looking for the leptonic decay of one W and the hadronic decay of the other. The principal background to this is a W produced in conjunction with ordinary hadronic jets. This has been estimated using the leading - log approximation for jet evolution and the results are shown in Fig. 5. Here it is assumed that the lepton from one W has been observed and that recoiling hadronic jets of mass M are observed in conjunction with it. It is seen that there is a clear signal at $M = M_W$ above background.[11]

$W^+ \gamma$ X FINAL STATES

An advantage of the open geometry, $e^\pm$ -signature methods of studying the W is that one is capable of detecting other electromagnetic particles in the final state. Final states which include a W and an isolated energetic γ are of special interest.[12] These states, like those containing W^+W^- or $Z^\circ Z^\circ$,allow one to study the couplings between the gauge bosons themselves. Final states containing W and γ are produced more strongly and have been studied in more detail. In these reactions the W and γ are regarded as the result of a quark-antiquark annihilation. Assuming the quarks have no transverse momentum and a fixed W mass, it is possible to determine, with zero constraints, the momentum of the missing neutrino and thus to fully reconstruct the kinematics of the quark-antiquark induced reaction. Since the cross section is sensitive to the trilinear gauge coupling, its measurement tests the predictions of the non-Abelian gauge theory. The final state including a $W^{\pm}$ and a γ with $p_T > 10$ GeV has been calculated to have a cross section of 6×10^{-36} cm^2 which, when combined with the 8.5% branching ratio of $W^{\pm} \to e^{\pm}\nu$, yields 4000 such events for the canonical integrated luminosity of 10^{40} cm^{-2} in a detector of 80% acceptance. The major physics background in this kinematic region is W + high p_T jet, where the jet contains a leading high p_T π°. While this background is initially 250 times larger than the signal, simple topological cuts on energy deposited near the γ reduce this to a signal to background ratio of 1 to 1. The resulting simulated angular distribution in the W+γ center-of-mass is shown in Fig. 6.[13] Included in this calculation are the effects of quark transverse momentum and of electromagnetic energy resolution on the $e^{\pm}$ and γ measurements. The minimum provides a direct measurement of the quark charge.

For both W^+W^- and for $W^{\pm}\gamma$ an important aspect of checking the standard model prediction is that deviations could show up as a signal of, for example, a new state which decays into these channels.

HIGGS BOSON

The Higgs boson plays a central role in the standard model, but unlike the W and Z, theory gives us very little guidance regarding its mass. The rates for producing it and the favored ways of searching for it depend very strongly not only on its mass but on the total number of heavy flavors. If its mass is less than about 40 GeV there are good signatures for searching for it at SLC or LEP. For masses above that the luminosity of CBA is needed to produce enough of them to have any hope of discovery. One potential technique would be to use the vertex detector described below to search for pairs of heavy quark jets.

One signature that looks promising if the mass of the Higgs is above $2m_W$ or $2m_Z$ is $H \rightarrow W^+W^-$, or $Z°Z°$. The rate for this is small but it may be detectable if there is more than one heavy flavor. The branching ratio for one W going to jets and the other to leptons is about 1/7. The momentum of the missing neutrino can be determined by a one-constraint fit using transverse momentum balance and the constraint of the W mass, thus allowing a determination of the W^+W^- pair mass.[14] Estimates of the rates at this high mass are still somewhat uncertain, but it seems reasonable to hope for several hundred Higgs of mass 200 GeV per year.

MASSIVE LEPTON-PAIR PRODUCTION[15]

In our present view a proton-proton collision is not an elementary process. Rather the protons contain more fundamental constituents, the quarks and gluons, which appear to be permanently confined inside the hadrons, at least at energies presently investigated. Thus our study of proton-proton collisions requires understanding of three features: the distribution of the constituents within the protons; the fundamental interaction of the constituents; and the "decay" of the final state constituents into the observable hadrons which confine them. The present theory of the constituents, QCD, has not yet yielded well-defined predictions for all three aspects of the general proton-proton collision. Likewise, experimental studies which must confront all three complexities at once have not yielded a set of unambiguous data to compare with theory.

There is a type of proton-proton interaction which isolates the question of the distribution of quarks inside the proton - the so-called Drell-Yan process. In this the fundamental interaction of the constituents is the annihilation of quark-antiquark pairs into a virtual photon and is presumably well understood. Likewise, the final state is restricted to virtual photon decay into electron or muon pairs, which is again well understood. As such, the Drell-Yan process is the simplest proton-proton interaction from the point of view of the constituent theory. The quark and gluon distributions obtained by analysis of the Drell-Yan process at lower energies (as well as from deep-inelastic lepton-nucleon scattering) have provided the means of estimating the rates of various processes at the CBA.

However, study of the Drell-Yan process is by no means a closed issue. The use of a virtual photon to probe the constituent distributions is subject to the usual restrictions of quantum mechanics - the method of probing modifies the results of the experiment. The measured distributions depend on the mass of the virtual photon. This dependence is one of the few relatively clear-cut predictions of the QCD theory - but it is a very weak dependence - varying as a fractional power of the log of the mass. The high energy available at the CBA will significantly enlarge the scale over which data confronts theory. But energy alone is not enough. The Drell-Yan process involves an electromagnetic interaction and so has relatively low rate. Hence the high luminosity of the CBA is critical in order to obtain sufficient data to extend our confidence in the QCD theory.[16]

A possible variation on the constituent theory is that the quarks and gluons themselves contain constituents.[17] This possibility would manifest itself most clearly in the Drell-Yan process involving very high mass photons. Dramatic departures from the QCD expectations would be noted - in a high luminosity, high energy experiment. High mass lepton pairs and high transverse momentum processes, to be discussed next, provide important complementary information for testing QCD. An experimental program aimed at detailed studies of the strong interaction at high energies must have the capability of measuring the lepton pair production with good accuracy. The expected cross section including the Z° peak is shown in Fig. 7. Note that $\ell^+\ell^-$ pairs can be studied to a mass considerably above that available at e^+e^- machines until LEPII is in operation.

Other, more technical aspects of the Drell-Yan process can be well studied in high luminosity experiments at the CBA. Most prominent is the transverse momentum dependence of the virtual photon.[18] Very high transverse momentum photons are mainly produced by a particular QCD mechanism in which a gluon strikes a quark, and the photon is radiated as a kind of Bremsstrahlung. This process probes the gluon distributions as well as quark distributions. But the rate of this process is low and little data on it will be obtainable except at the CBA. The predicted p_T for the pair is shown in Fig. 8, at the Z peak. The variation of this distribution with mass is also predicted and important to measure. Roughly speaking, the peak becomes lower and moves to higher p_T as the mass of the pair increases. Other types of measurements which round out the testing of the QCD theory include the question of corrections to the total rate of the Drell-Yan process (the K factor), possible departures from the simple $(1 + \cos^2\theta)$ distribution due to "higher twist" events,[19] as well as electroweak interference terms. There are also striking asymmetry predictions made by QCD for pair production using polarized protons: a very large (parity-conserving) asymmetry between the rates for parallel and anti-parallel helicities is possible and is a direct measurement of the polarization of the sea quarks in the proton.[20]

HIGH TRANSVERSE MOMENTA[21]

Past experience and many open questions, such as the origin of families of fermions, lead to speculations regarding the compositeness of quarks. Processes involving large transfer of momentum have a proven track-record in uncovering substructure and so it is natural to look to particles or jets produced at large transverse momentum to study this question. Experiments at CBA are expected to be feasible for jets up to 250 GeV, π^0's up to 170 GeV and prompt γ's up to 75 GeV in transverse momentum.

The Tevatron can reach higher p_T for jets, but for π°'s and prompt γ's its limit is below that for CBA.[5]. Furthermore, it may be mentioned that CBA will yield results at larger values of the scaling variable $2p_T/\sqrt{s}$ than will be accessible to the Tevatron and so will be sensitive to different parts of the proton substructure as well as to different subprocesses. These cross sections will be compared with the predictions of QCD, which involves studying QCD evolution of structure function, the fragmentation function for quarks and gluons, as well as the basic interaction. This will probably require extensive and systematic studies, including energy dependence, jet-jet correlations, and jet and single particle studies with different types of triggers.[22] Deviations from these expectations will be the classic indication of compositeness: in particular, inclusive rates that fall more slowly with increasing p_T are a sure indication of substructure. Estimates based on the ideas studied at Snowmass indicate CBA will yield sensitivity up to substructure scale of 1000 GeV.[17] Polarized protons provide a novel twist to this: substructure need not give rise to a parity conserving interaction.[17] Thus, taking the difference between right- and left-handed polarized protons is expected to give interesting information. On the one hand, it enables one to measure the form of the constituent coupling. On the other hand, if the constituent coupling violates parity, this difference will increase the sensitivity to a substructure. This is illustrated in Fig. 9 where maximal parity violation and a substructure scale $\Lambda = 2000$ GeV have been assumed.[23]

b QUARKS - RARE DECAYS[24]

The production rate of B-mesons at CBA at a luminosity of 10^{33} is 10^4/sec yielding 10^{11}/year. Thus CBA offers the potential of studying a variety of B related phenomena with substantially better statistics than e^+e^- machines. Rare decays of the

B are of interest because they could signal new interactions. For example, the decay $B^+ \to K^+e^+e^-$ is a flavor changing neutral current process which has a branching ratio of order 10^{-6} for the standard model but 10^{-4} for some horizontal gauge symmetric models. The rate for $b \to s + \gamma$ depends on the t mass and the flavor-mixing matrix. It is probably fairly rare, but detectable with this large number of b's. Another interesting aspect of the B is that in analogy to the K system it is expected that there is strong $B^\circ\bar{B}^\circ$ mixing. Such mixing would result in back-to-back jets containing bb or $\bar{b}\bar{b}$ rather than $b\bar{b}$. In addition to the directly produced b's, heavier quarks, t and above, are expected to decay into b's as they cascade down to charmed particles. The potential for studies of CP violation is also significant.

In order to see whether such a potential might be realized, a detector has been designed using silicon microstrip detectors to tag D-mesons by their decays. Since $b \to c$ is dominant this is a good tag for b events. The resolutions of such new detectors are in the range of 10 microns while the $c\tau$ for charmed particles is 100-250 microns. With the high readout density, it would be efficient to use small area detectors which would require a small diamond configuration. One of the options available at CBA, an interaction region with a 2 cm long diamond and resulting luminosity of 10^{32}, is well matched in both physical dimensions and rate to such a detector. Figure 10 shows such an interaction region and detector. Figure 11 shows an event containing a decaying D, first macroscopically and then as seen by the vertex detector. Detailed study has shown that such vertex detectors can be used in a trigger and can reject events without secondary vertices at the level of 98%. This trigger system, composed of two stages, utilizes data-flow hardware processor techniques for track finding ($\approx$ 100 μsec) and microprocessors operating in parallel for vertex reconstruction ($\approx$ 2 msec). A pretrigger requiring a p_T of 15 GeV in a calorimeter reduces the initial rate to one which can be handled by this vertex trigger.

Offline, using only the vertex detector information, one can reduce the light quark background by another factor of 20 resulting in a sample containing 1/3 to 1/2 b jets to be subjected to full analysis. One could operate a vertex detector based apparatus in such a way as to accumulate at least 10^6 events with fully resolved B going to D each year. A configuration using two vertex detectors and more complex trigger logic would allow one to reduce the initial p_T cut to 8 GeV and produce a more unbiased sample of b jets.

It may not be idle to note that these b-decays alone will produce about 10^9 τ's per year. Thus the CBA can be a very rich source of τ's and one might speculate about searching for its rare decays such as $\mu^+\mu^+e^-$ or other unusual possibilities.

HEAVY QUARKS

A. New Hidden Flavors ('onia)

It is expected that there will be additional heavy quarks in the kinematic range covered by CBA. The t quark is predicted by the standard model and it is reasonable to anticipate further generations. The lepton-lepton decay of the quark-antiquark state which was used to discover the J/ψ and the Υ remains the clearest signature of such new quarks. It is possible to estimate the production rate for such states from scaling considerations and to calculate their leptonic branching ratios. In Fig. 12 are plotted the signal and the background for a number of possible masses of a new $q\bar{q}$ state, assuming a detector of 1% energy resolution with the canonical CBA center-of-mass energy and annual luminosity.[25] This signature is expected to be useful only up to masses in the region of the $Z°$. Weak decays of the heavy quarks to lighter quarks become dominant beyond this point and other signatures must be sought. Although e^+e^- colliders are the machines of choice in studying the detailed properties of new 'onia, the rates at CBA are comparable with those at LEP throughout the range between 40 GeV and the Z, and experience with the J/ψ and T indicates that the discovery may very well take place at the CBA.

B. New Bare Flavors

Quarks more massive than 40 GeV or so will more likely be seen in their "bare" form. It is expected that CBA will produce them at detectable rates for masses well above this limit. The cross section as a function of mass is shown in Fig. 13.[26] This cross section yields more than 10,000 bare quarks at mass of 100 GeV/c^2 per year. The large masses of these new flavors, be they top quarks or members of a fourth generation, lead to characteristic decay distributions that should make them easier to pull out of the background than for the lighter flavors. For example, there is a strategy[27] for detecting heavy flavors based on trigger schemes which rely on the lepton(s) from decays of the type

$$Q \to q + \ell + \nu$$

where Q is the heavy quark under study and q is an accessible lighter quark, as in

$$t \to b + \mu^+ + \nu_\mu$$

The high CBA luminosity is important in allowing triggering schemes which depend on small branching ratios.

We have found that lepton-based triggers can be devised which are both reasonably efficient for heavy flavors and quite selective against known states (b and lighter). The trigger is based on looking for jets accompanied by two leptons, one of which has a high transverse momentum both with respect to the beam and with respect to the jet axis. Reasonable numbers of heavy quark events survive this cut while the signal to background ratio is greatly improved, by a factor of 500 for M_Q = 50 GeV/c^2, better for higher masses. This does not include the use of vertex detectors, or any off-line jet shape analyses, which show promise for distinguishing the heavy quarks from light ones.

It is worth pointing out that if the t quark mass is higher than 40 GeV, more t's are produced from W-decays than in pairs so, for example, if $m_t = 50$ GeV more than 5×10^6 t jets will be produced in this way in the standard year.

In addition to new flavor searches, the production characteristics of any new flavors are also of obvious interest. For example, diffractive production of heavy flavors, based on the large cross section for charm production, may be substantial.

HEAVY Z's AND W's

While the standard model has been very successful, there are alternatives which predict several Z's and W's. If the lightest Z and W have exactly the masses predicted by the standard model it is likely that there will be no other Z's or W's. However, even slight deviations from the standard model allow the existence of additional Z's and W's at masses accessible at the CBA. There are several ways that the theory can be extended which remain consistent with present knowledge. Until we have a better understanding of grand unification, the value of $\sin^2\theta_W$, the origin of CP violation and the like, we should keep an open mind toward this question. In Fig. 14 we show as an example an $SU_L(2) \times SU_R(2) \times U(1)$ based gauge theory prediction of a second higher lying Z states.[28] From an experimental point of view as one goes to higher masses, the overall rate decreases rapidly putting a premium on luminosity. For the theory illustrated in Fig. 14, using the annual $10^{40}/\text{cm}^2$ luminosity, experiments looking for Z's with masses up to 250 GeV could be expected to produce a significant signal within one year.

Should higher mass W's and Z's be discovered, the use of polarized proton beams will tell us in a very direct way whether the heavy W's couple to left- or right-handed currents and will enable us to measure the analogue of $\sin^2\theta_W$ for the heavy Z.

An especially striking signal for a right-handed W^+ occurs in some theories which lead to final states containing two μ^+'s and no missing neutrinos. Figure 15 shows the distribution of transverse momentum for the two μ^+'s for a W_R^+ with mass 200 GeV. This curious phenomenon results from the decay of the W_R^+ into a heavy Majorana neutrino and, incidentally, gives a measure of the Majorana neutrino mass. (In the example shown in Fig. 14 it is taken to be 100 GeV/c^2.)[29]

STABLE HEAVY QUARKS

A possible explanation for the existence of several generations of quarks and leptons is that they are the bound states of more basic constituents. This explanation suggests the possibility that there might be excited states in different color representations. If so, the lightest excited quark in a triality zero color representation is probably stable. In Fig. 16 the annual production rate at CBA of an excited color 10 quark as a function of its mass is given.[17] It is expected that such excited quarks will be produced in pairs each contained within a heavy stable hadron carrying most of the momentum of a jet. The rate of high p_T pairs of single tracks produced by conventional processes is very small. Thus, assuming that the q* have a mass in excess of 50 GeV, time of flight is an effective strategy for identifying them. The augmentation of a general purpose detector containing calorimeters and central drift chambers in a magnetic field by a high resolution time of flight system is a possible approach. Using a pretrigger requiring at least 15 GeV of energy deposited in each of two calorimeter cells in the region $|y| < 1$ together with the requirement that the tracking system see two corresponding high momentum tracks reduces the rate to about 3 triggers per second. Offline, the requirement that each p_T exceed 42 GeV reduces the residual background sample to about 2000. Time of flight would then resolve the massive particles such as the excited quarks from the other particles with $\beta = 1$. Depending on the mass, the overall yield for a year of running ranges from 2 x 10^7 at 50 GeV to 500 at 200 GeV. Even in the worst case at 200 GeV, this is a sufficient number of events to allow a relatively good mass determination.[30] Alternatively, the large CBA luminosity will allow the use of a small aperture, special purpose detector featuring high momentum and time of flight resolution.

SUPERSYMMETRIC PARTICLES

Supersymmetric theories[31] are of very great interest for several reasons. In particular, they offer a possible explanation for the vast disparity between the mass scale of the weak interactions (10^2 GeV) and the mass scale of grand unification (10^{15} GeV). In addition, a generalization of supersymmetric theories currently seems to offer the best hope of including gravity in a manner which could allow unification with the other forces. The essential property of such theories is the symmetry between the fermions and the bosons. For each of the familiar particles, there is a corresponding particle whose spin is different by 1/2. The particles corresponding to the quark, the gluon, and the photon are called, respectively, the scalar quark ($\tilde{q}$), the gluino ($\tilde{g}$), and the photino ($\tilde{\gamma}$). The scalar quark and gluino, like their familiar analogs, carry color and are thus strongly produced. The supersymmetric quality is likely to be conserved and thus there will be only associated production of such particles. The theoretically preferred mass scale for these particles is that of the W. Indeed, models based on super gravity predict supersymmetric partners of the W with mass below 80 GeV/c^2.[32]

The gluino is believed to decay into a final state containing either a photino or a Goldstino (the Goldstino is the spin 1/2 analog of the Goldstone boson). Since both of these particles are neutral non-interacting particles, the experimental signature is a final state with significant missing p_T.[33] As a result of associated production, there are typically two particles contributing missing p_T. Just how striking the missing p_T signature will be for any particular event depends on the relative direction of these two particles. The scalar quark, masses permitting, should decay into quark plus gluino, which then decays as described above. The relative ease of seeing a gluino signal from a $\tilde{g}\tilde{g}X$ final state compared to a scalar quark signal from a $\tilde{q}\tilde{g}X$ or $\tilde{q}\tilde{q}X$ final state depends strongly on the relative masses. This mass dependence relates to both the production mechanism and the strength of the transverse momentum imbalance signature produced by the decay.

A study has been made of the feasibility of extracting a gluino signal at CBA using a detector based on established calorimeter techniques. A set of variables based on the symmetry of the momentum distribution in the final state can be defined which effectively selects for gluinos in a background composed of light constituents scattered at high p_T and heavy quark final state decays. This selection can also be augmented by a lepton veto design to remove those events having a transverse momentum imbalance resulting from a missing neutrino. The signal to background ratio is greater than 1.0 at large values of p_T up to gluino masses of 70 GeV using only transverse momentum imbalance criteria. As shown in Fig. 17, this mass range can be extended to 100 GeV by including a lepton veto. Assuming an integrated luminosity of 10^{39} cm^2, the signal for gluinos of 100 GeV, having $p_T > 50$ GeV, would be 2000 events. These would be superimposed on a background of 300 events. Study of the details of these events may allow one to further reduce this background and to address the question of contributions to the signal from scalar quark events.

Although the Snowmass work on gluino detection assumed a luminosity of 10^{32} cm^{-2} sec^{-1}, methods of using higher intensity have recently been studied. It is found that tightening the cuts on p_T imbalance allows adequate background rejection even at the full CBA luminosity of 10^{33} cm^{-2} sec^{-1}. Moreover, for the high gluino masses relevant here ($M \leq 100$ GeV/c^2 can be detected for $L = 10^{32}$) such cuts make only small inroads into the signal. It thus seems possible to detect gluino pairs for $M_{\tilde{g}} \leq 125$ GeV/c^2.

Another possibility is the detection of scalar quarks through the reaction $pp \to \tilde{\gamma}\tilde{q}X$. This process is most interesting if the mass of the gluino is greater than that of the scalar quark. The scalar quark would then decay to a photino and a normal quark. Although the cross section is small compared to that of the corresponding gluino plus scalar quark production mode, the signature, a single quark jet whose p_T is completely unbalanced, is extremely powerful and allows the background to be satisfactorily rejected. Fig. 18 shows the p_T imbalance distribution for 60 and 100 GeV scalar quarks as well as that of the QCD background for $p_T > 35$ GeV. Cuts on the event shape and the presence of leptons have also been imposed. For an integrated luminosity of 10^{39} one accumulates 3000 events for a scalar quark mass of 60 GeV and 700 events for a mass of 100 GeV. If the mass of the gluino is high, $\geq$200 GeV, while the scalar quarks and leptons are in the mass range 50 to 100 GeV, such a scalar quark signal is likely to be the only supersymmetric signal which can be observed at the next generation of machines. Since the cross section is low, this places a premium on luminosity.

The supersymmetric partner of the W can be searched for by the same methods used for the gluino or scalar quark search,[32,34] but the signal is not as strong. For $m_{\tilde{W}} \approx 40$ GeV, after cuts the signal and background are each about 20,000 events. For $m_{\tilde{W}} \approx 60$ GeV the signal is reduced to about 2,300 events. However, since the $\tilde{W}$ will be produced via W-decay, the polarized proton asymmetry should allow the signal to be extracted from the background.

TECHNICOLOR IDEAS

Another theoretical approach to understanding the origin of mass is the class of technicolor theories. The particles suggested by these ideas illustrate further the kinds of objects that could be discovered at CBA, whatever their real origin. Although the intrinsic scale of these theories is around 1 TeV, they predict numerous particles with mass below 300 GeV. The pseudo-Goldstone, pseudoscalar η_T would be produced in substantial numbers up to mass 300 $\mathrm{GeV/c^2}$ and beyond at CBA (see Fig. 19). It is expected that it will decay most strongly into the heaviest fermions allowed and there is hope that the ability to detect bare heavy flavors, as discussed above, will make the signal observable. A detector designed to study the $t\bar{t}$ decay is described in the Snowmass proceedings and the expected signal is shown in Fig. 20.[35]

Another particle that occurs in technicolor theories is the leptoquark. It is expected to be somewhat lighter than the η_T and to decay into a lepton and a quark jet, e.g. $\mu + c, \tau+t, \tau+b$. This very characteristic signal is quite distinct from the semileptonic decay of a normal quark which ordinarily involves an energetic neutrino which escapes detection. The production cross section for leptoquarks is shown in Fig. 21. The p_T distribution for the μ is extremely hard as shown in Fig. 22, for the μ+c decay.[36]

OTHER POSSIBILITIES

Many experiments related to strong interaction dynamics are also possible. They include measurements of total cross sections, detailed studies of multiparticle production, tests of dispersion relations, study of elastic scattering and diffraction dissociation.[37] With the exception of elastic scattering at high momentum transfer, these do not require high luminosity, but they can make use of special intersection configurations available at CBA.

The design of the CBA makes it possible to incorporate into the facility at some stage the other two options which have been considered. There is a lot of potentially very important physics that can be done with a relativistic heavy ion collider or with an ep collider. The addition of either of these to the pp colliding beams would extend the research capability of the facility in very exciting and unique ways. Detailed reports on the physics of both of these are presently available from Brookhaven.

A. RELATIVISTIC HEAVY ION PHYSICS[38]

The energy of the CBA is comfortably above that needed to reach the temperature and density inside colliding nuclei in order to achieve the expected phase transition into quark-gluon matter. The production and detection of this new state of matter will be the primary aim of experiments with relativistic heavy ions. Once achieved, it offers a means of studying color confinement and the structure of the QCD vacuum over large distances which cannot be attained with single particle beams. Several signatures have been suggested to study this new form of matter: observation of low-mass lepton pairs, changes in strange particle production, correlation of π's or γ's, unusual jet distribution, and large fluctuations in rapidity distributions.

The CBA is the only facility planned for the forseeable future in which truly high energy heavy ion collisions can be realized. It has been established that ions of atomic mass number up to $A \approx 130$ can be injected at modest cost and accelerated in the standard magnet lattice with luminosity of about 10^{28} cm^{-2} sec^{-1}. At full energy the energy-per-nucleon would be about 400 GeV/nucleon.

Detectors and measurement strategies for such a program will be similar in many ways to what is required for high luminosity proton-proton physics. While the event rate ($\approx 10^4$/sec) is modest by CBA standards, it is high enough to warrant very selective triggers, and as in proton-proton physics, the required measurements place a premium on high resolution calorimetry and lepton detection. The level of complexity in selected events will be extreme, but the density of particles per unit solid angle is similar to that seen in high p_T jets. Thus, detector systems developed for high-rate experiments with proton beams should serve well for a program of heavy ion measurements.

B. ep COLLIDER[39]

An ep collider with 20 GeV electrons on 400 GeV protons capable of an average luminosity of 5×10^{31} cm^{-2} sec^{-1} can be built at the CBA. Such a facility can be designed to be compatible with p-p running at the other areas and so would allow integrated ep luminosities of about 5×10^{38} cm^{-2} per year. The spin manipulations required to achieve longitudinal polarization for the electrons is straightforward and compatible with the proton beam in polarized or unpolarized conditions.

A high energy ep collider will provide tests of both electro-weak theory and QCD at greatly increased values of Q^2. Fig. 23 shows that Q^2 up to about 15,000 GeV^2 should be measurable in deep inelastic electron scattering. This gives sensitivity to a compositeness scale of about 4 TeV.[17] Measurements of the proton structure functions, both for polarized and unpolarized protons, will provide valuable information for the interpretation of many p-p induced phenomena.

An ep collider is an especially powerful tool for searching for right-handed currents. By controlling the electron polarization this collider would be sensitive to a right-handed W with mass up to about 400 GeV. It is also well suited to search for heavy electron-type leptons which could be detected with masses up to about 100 GeV.

The physics that can be studied at an ep collider is in many ways complementary to the hadron-hadron and electron-positron collider programs. It would provide a very attractive extension to the capabilities of the CBA.

CONCLUDING REMARKS

The purpose of this summary is to bring to the attention of the high energy physics community the wide variety of new physics experiments that the high luminosity and high energy of CBA will make possible. These examples are intended to illustrate the power and flexibility of the machine. It will provide the facilities for a very large number of experimentalists to pursue a broad range of physics. The high luminosity allows not only the study of rare processes but also the use of small, special purpose detectors. The six interaction regions can be arranged in different configurations, so, for example, one can be at very high luminosity for a $\mu^+\mu^-$ experiment, another can have a small diamond for use with a vertex detector, and so on. There is the possibility of polarized protons, heavy ions and variable energies in the two rings. The machine will be dedicated solely to colliding beam physics. There is a great deal of very important physics that will clearly be done if CBA is built: detailed studies of the W and its interactions, extensive studies of the properties of the b-quark, systematic studies of QCD and proton structure through the Drell-Yan and high p_T processes, new flavor searches in a significant mass range. In the more speculative area, supersymmetry, technicolor, composite models and alternatives to the standard electroweak theory have been considered, not so much as tests of these theories as tests of the capabilities of the machine.[40] We believe that these examples demonstrate the power of the CBA to probe deeply into Nature's secrets and to move nearer an understanding of the fundamental theory, whatever it may be. The CBA would provide the world's high energy physics community with a unique and valuable resource.

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Because this summary covers such a wide range of physics, it is not practical in general to give references to primary sources. The purpose of these references is to allow the interested reader to follow up on the discussion given here; proper references should be found in these secondary sources. Reports of the Brookhaven working groups are referred to below as "BNL Report (in preparation)". They can be obtained in the near future by writing to the first-named author c/o the Physics Department at BNL or by calling Mrs. Patricia Valli at 516-282-5377.

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FIGURE CAPTIONS

1. Transverse momentum distribution for lepton from $W \to \ell + \nu$, showing the Jacobian peak in detail.
2. χ^2 for the fit to the Jacobian peak in the lepton p_T spectrum as a function of $\beta = m_W/m_Z$.
3. Angular distributions of e^+ and e^- from W decays offer sensitive tests of the V-A structure of the W coupling to quarks and leptons. The figures assumes a coupling, which leads to a strong difference between the angular distributions of positrons and electrons. This figure shows the angular distribution for an electron with $p_T = 20$ GeV.
4. Cross sections expected from the standard model for production of W^+W^- by pp collisions at 800 GeV center-of-mass energy, as a function of the pair mass.
5. W^+W^- signal and background. The trigger is an isolated lepton in one hemisphere and a pair of hadronic jets in the other hemisphere. The cross section is shown as a function of the mass of the jet pair.
6. Angular distribution of W from $q\bar{q} \to W\gamma X$. The striking dip is determined by the d quark charge.
7. Cross section for lepton pair production by the Drell-Yan process, including the Z° peak, as a function of the mass of the pair.
8. Transverse momentum distribution of the Z° as predicted by QCD corrections to the Drell-Yan process
9. Transverse momentum distributions of hadron jets for polarized and unpolarized pp collisions at 800 GeV. A quark substructure at a mass scale of 2 TeV would cause deviations at high p_T as shown. Polarized beams allow much more sensitivity to such constituents, if their interactions violate parity.

10. Vertex detector layout for use with a 2 cm proton interaction diamond, viewed from the one side (upper figure) and along the beam direction (lower figure). Silicon microstrip detectors with 10 μ resolution would find D mesons as a tag for b decays.

11. A simulated event containing $c\bar{c}$ jets. The upper figure shows the full event and lower figure shows an expanded view of only the tracks reconstructed with the vertex detector of Fig. 9. (The small circle in the upper figure indicates the part that is blown up in the lower figure.) A million or more $B \rightarrow D$ events per year could be obtained in this way at the CBA.

12. Lepton pair mass distributions from new hidden flavors ('onia) of mass 10, 25, 30, 35 or 40 GeV. This signature is useful up to the Z°, i.e., for quark masses up to about 40 GeV. A mass resolution of 1% is assumed.

13. Cross section for production of new bare flavors as a function of the quark mass.

14. Lepton pair mass distribution for the standard model (dashed line) and for a left-right symmetric model (solid line) which predicts two Z°'s, one near the standard model prediction and one at a higher mass.

15. Transverse momentum distributions of the two ℓ^+'s from a right-handed heavy W^+ which decays through a heavy Majorana neutrino. This signature for a heavy W would be particularly striking, since there are no missing neutrinos.

16. Cross section for producing color decuplet fermion pairs. Some models of composite quarks predict such stable excited states in addition to the usual quark generations.

17. A gluino signal can be extracted by using cuts based on missing transverse momentum and by vetoing leptons to eliminate missing neutrinos. Once a cut is made to select events with large missing p_T and no hard charged leptons, it is more likely to find a large visible p_T from gluino production than from the normal two jet background.
18. Extraction of a scalar quark signal. The variable x_E measures the transverse momentum imbalance of the event and ranges from 0 for a single jet event to 1 for a perfectly balanced two-jet event.
19. Cross section for production of technicolor η_T. If these pseudo-scalars exist, they should be copiously produced at the CBA, up to masses of 300 GeV and beyond.
20. The upper figure shows the expected signals for η_T of mass 200 GeV and 300 GeV decaying into $t\bar{t}$ along with the background from other processes. The lower figure shows result of making cuts, primarily utilizing a high resolution vertex detector for the signal at 300 GeV.
21. Leptoquark pair production cross section as a function of the leptoquark mass.
22. The characteristic hard muon signal from a leptoquark decay should be quite distinctive, especially since there will be no missing neutrino.
23. The number of events per day produced with momentum transfer greater than $\sqrt{Q^2}$ at an ep collider addition to CBA.

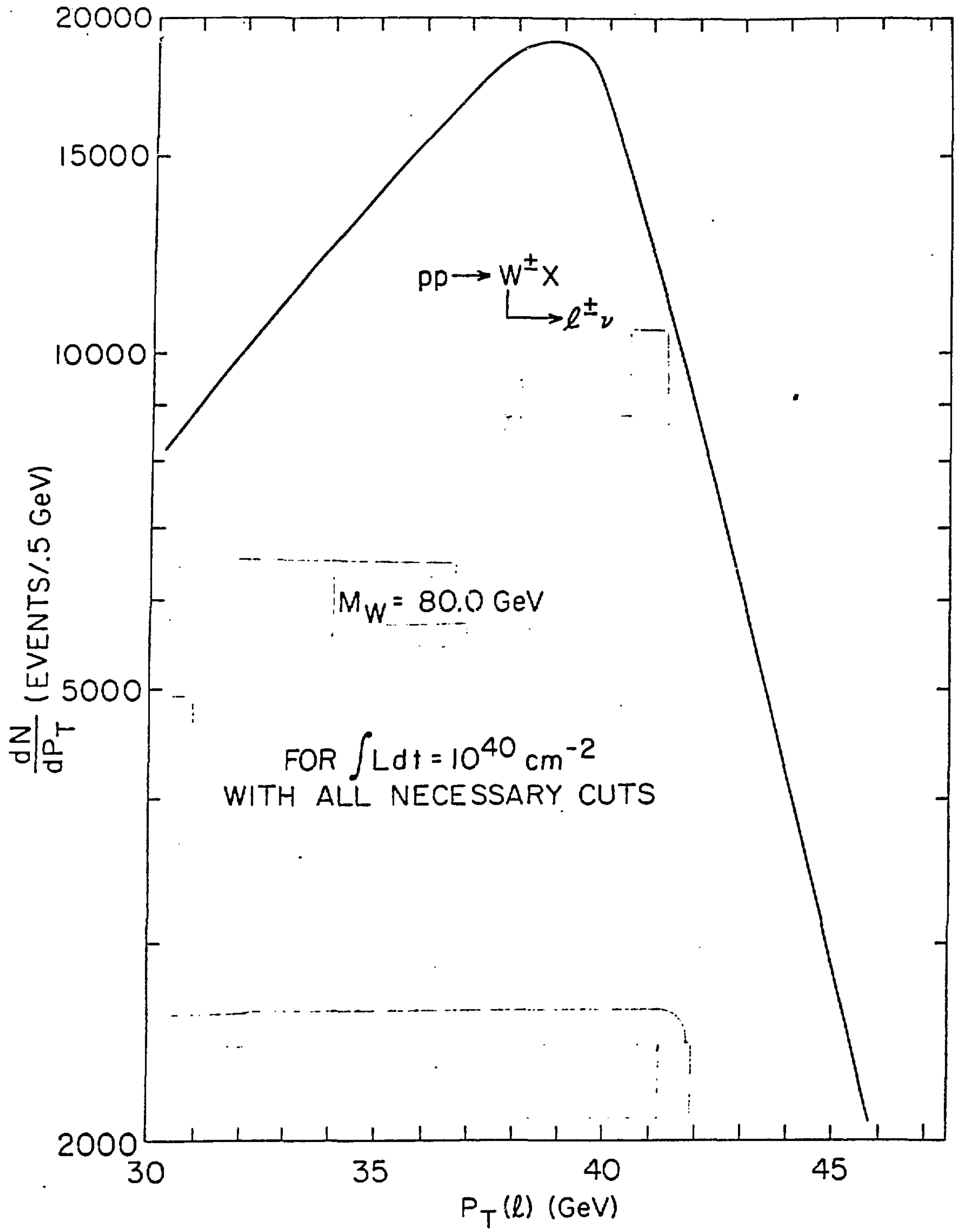

20000
15000
10000
5000
2000
$\frac{dN}{dP_T}$ (EVENTS/.5 GeV)
pp → W±X
→ ℓ±ν
MW = 80.0 GeV
FOR ∫Ldt = 10^40 cm^-2
WITH ALL NECESSARY CUTS
30
35
40
45
PT(ℓ) (GeV)

Figure 1

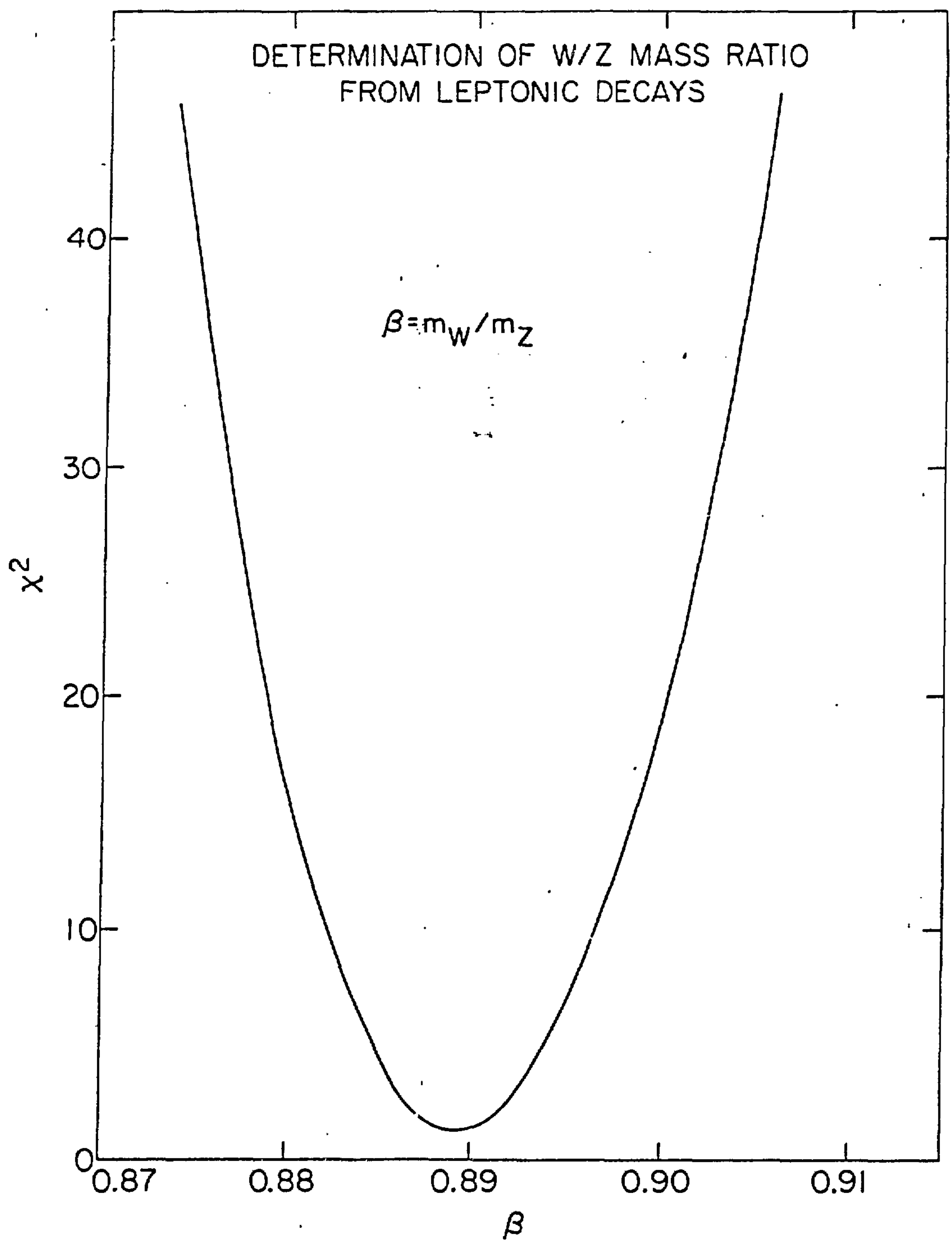
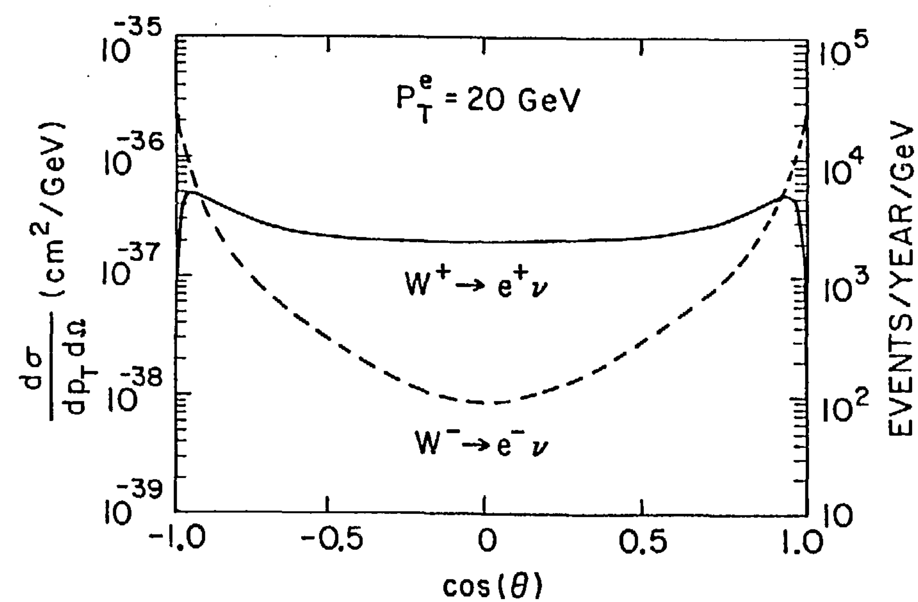
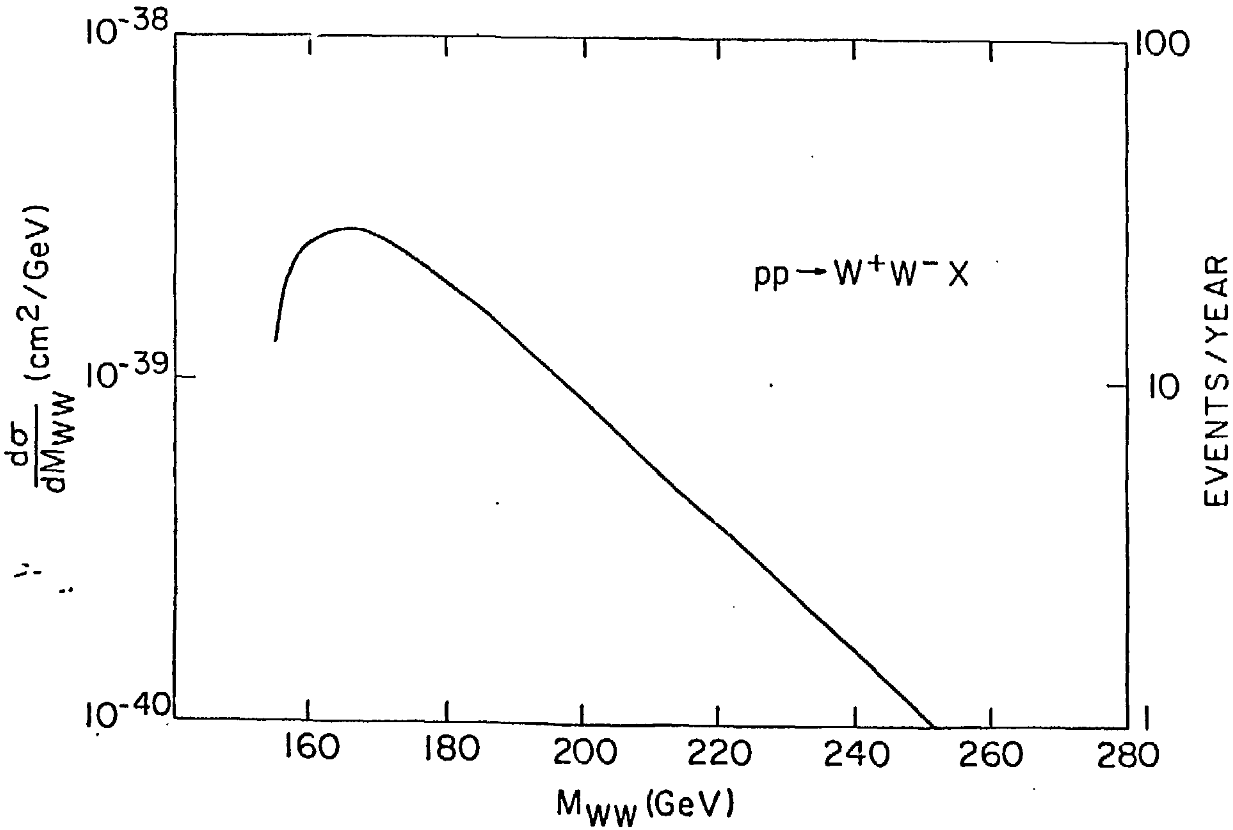

DETERMINATION OF W/Z MASS RATIO
FROM LEPTONIC DECAYS
$\beta = m_W/m_Z$
χ^2
40
30
20
10
0
0.87
0.88
0.89
0.90
0.91
β

Figure 2



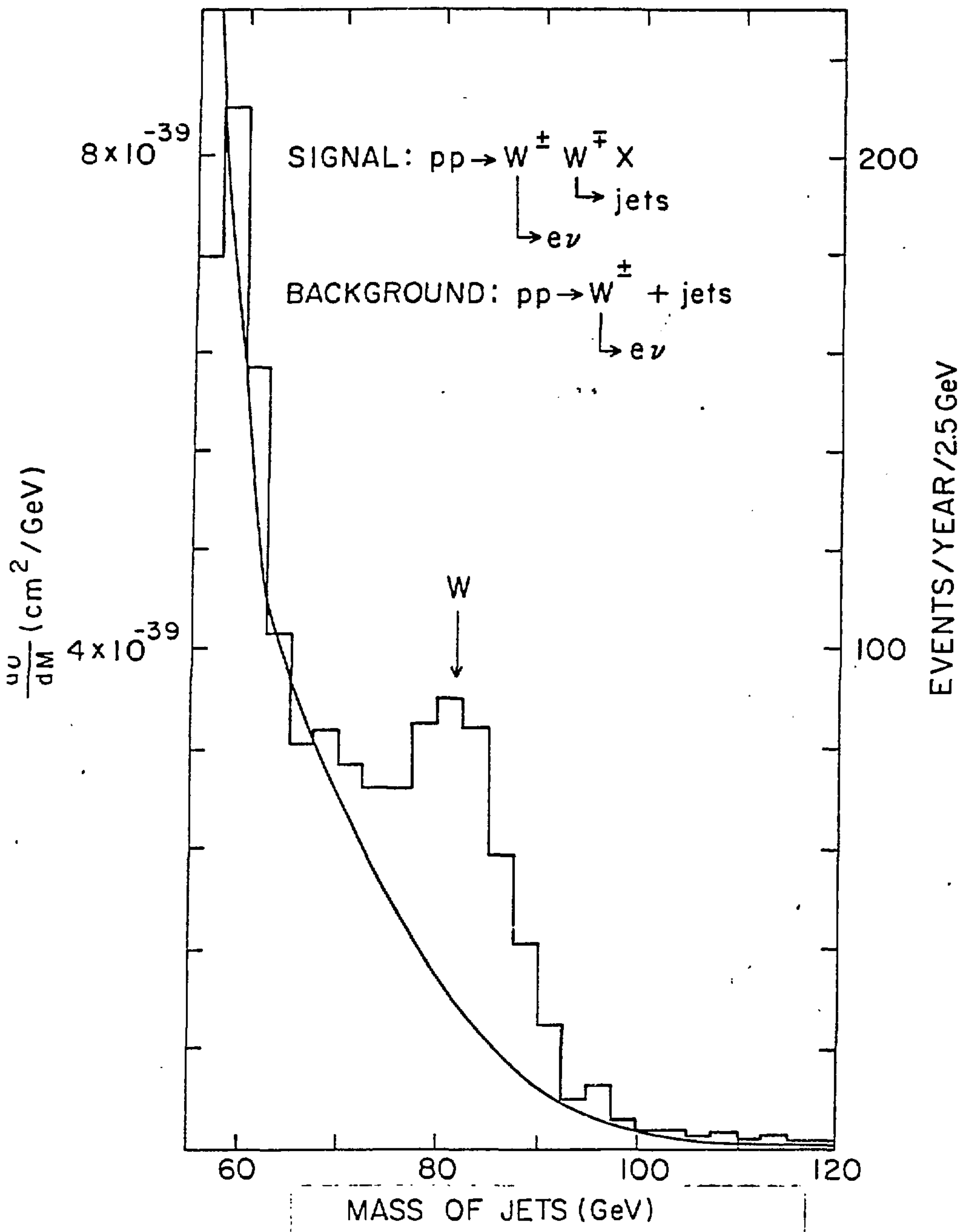
$P_T^e = 20$ GeV
$W^+ \to e^+ \nu$
$W^- \to e^- \nu$
$\frac{d\sigma}{dp_T d\Omega}$ (cm^2/GeV)
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
EVENTS/YEAR/GeV
10^5
10^4
10^3
10^2
10
-1.0
-0.5
0
0.5
1.0
cos(θ)

Figure 3



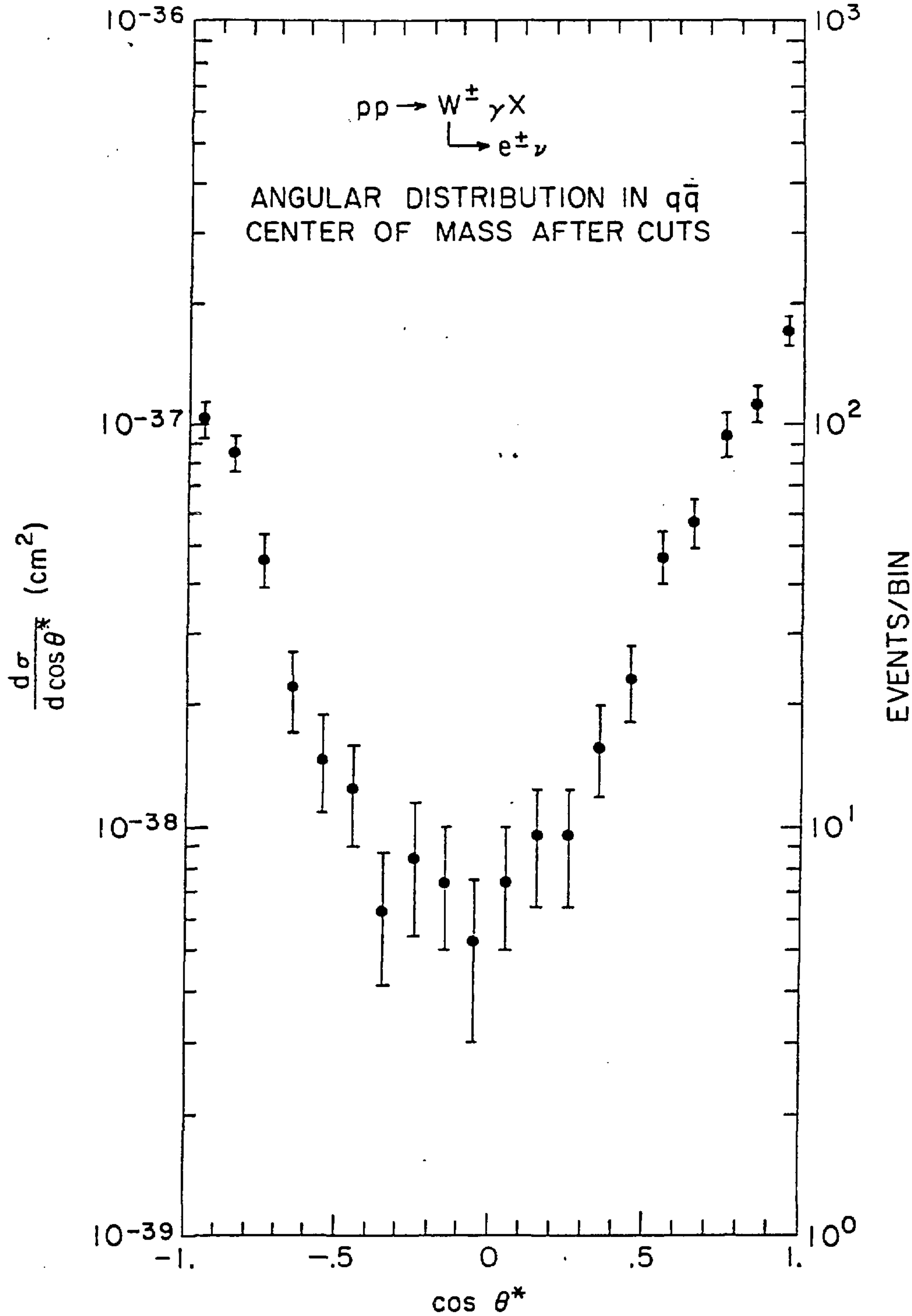
10-38
10-39
10-40
dσ/dMWW (cm2/GeV)
pp → W+W- X
100
10
1
EVENTS/YEAR
160
180
200
220
240
260
280
MWW (GeV)

Figure 4



SIGNAL: pp → $W^{\pm}$ $W^{\mp}$ X
→ jets
→ eν
BACKGROUND: pp → $W^{\pm}$ + jets
→ eν
W
8×10^{-39}
4×10^{-39}
$\frac{d\sigma}{dM}$ (cm^2/GeV)
200
100
EVENTS/YEAR/2.5 GeV
60
80
100
120
MASS OF JETS (GeV)

Figure 5



pp → W± γX
└→ e± ν
ANGULAR DISTRIBUTION IN qq̄
CENTER OF MASS AFTER CUTS
10-36
10-37
10-38
10-39
10³
10²
10¹
10⁰
dσ/d cos θ* (cm²)
EVENTS/BIN
-1.
-.5
0
.5
1.
cos θ*

Figure 6

65%

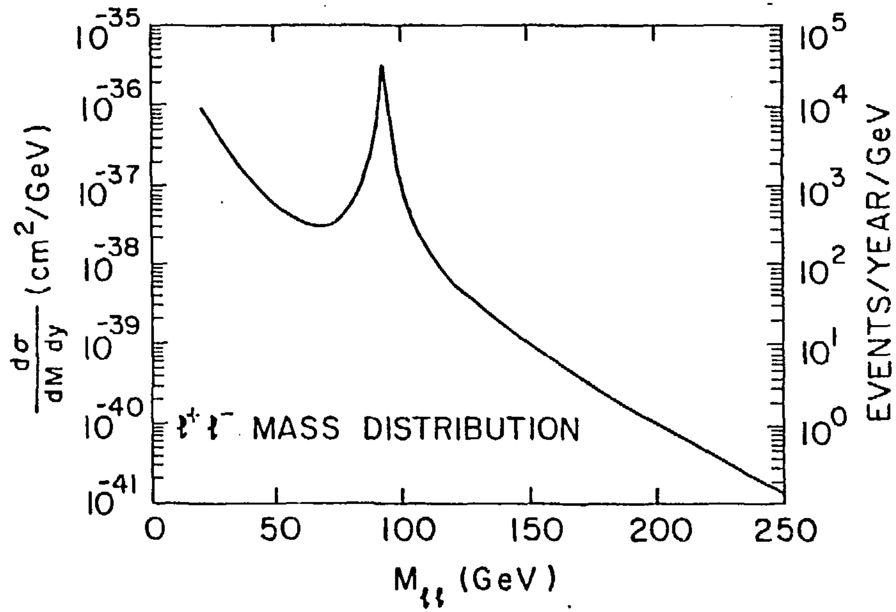
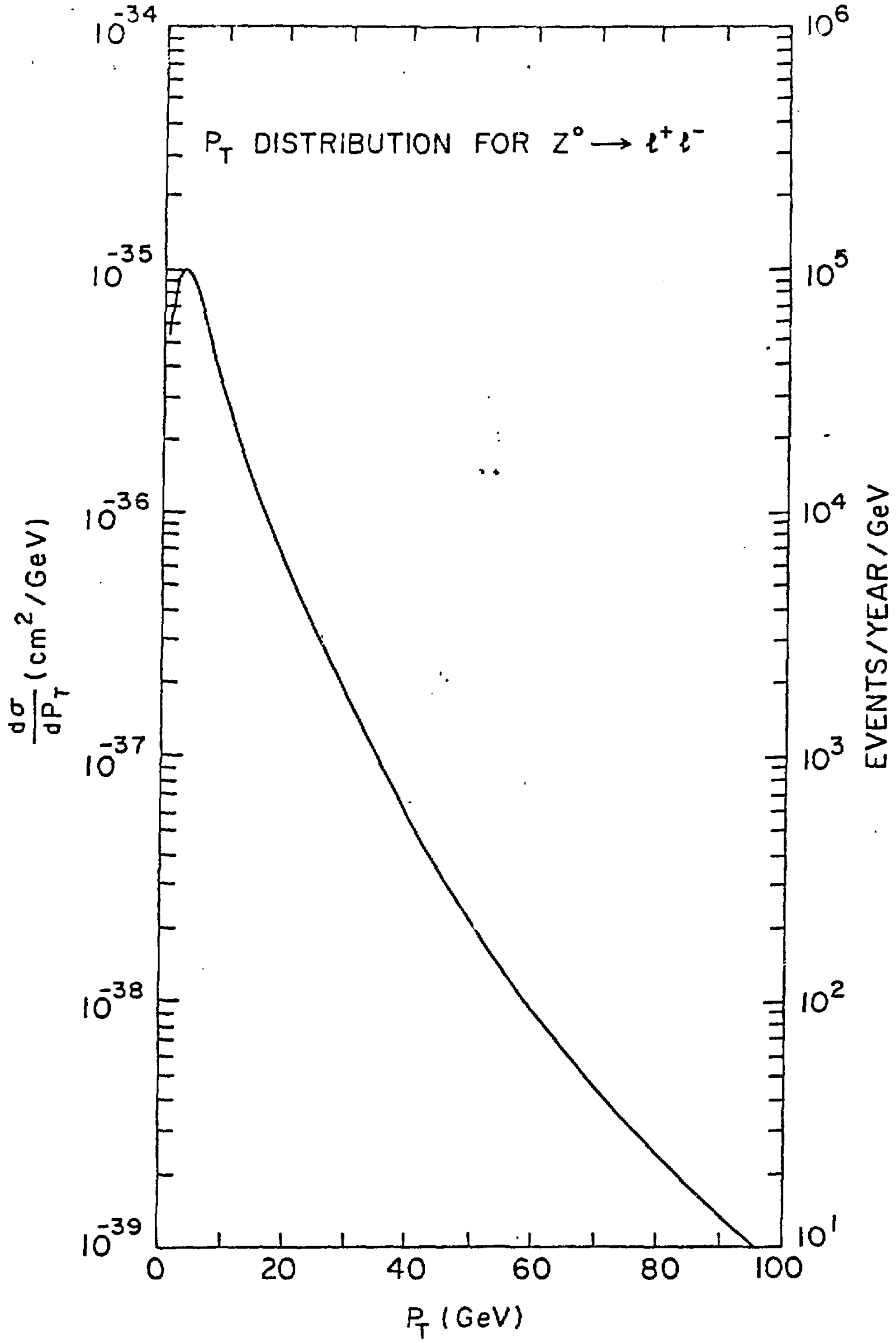

10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
$\frac{d\sigma}{dM\,dy}$ (cm^2/GeV)
$\ell^+\ell^-$ MASS DISTRIBUTION
0
50
100
150
200
250
$M_{\ell\ell}$ (GeV)
10^5
10^4
10^3
10^2
10^1
10^0
EVENTS/YEAR/GeV

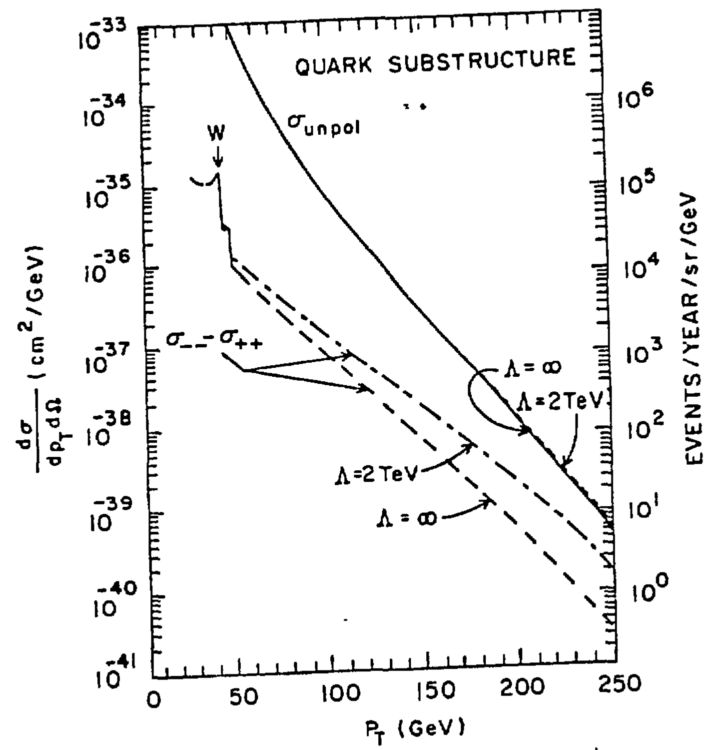
Figure 7



P_T DISTRIBUTION FOR $Z^\circ \longrightarrow \ell^+\ell^-$
$\frac{d\sigma}{dP_T}$ (cm^2/GeV)
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
EVENTS/YEAR/GeV
10^6
10^5
10^4
10^3
10^2
10^1
0
20
40
60
80
100
P_T (GeV)

Figure 8

95%



QUARK SUBSTRUCTURE
σ_{unpol}
W
$\sigma_{--} - \sigma_{++}$
$\Lambda = \infty$
$\Lambda = 2$ TeV
$\Lambda = 2$ TeV
$\Lambda = \infty$
$\frac{d\sigma}{dp_T d\Omega}$ (cm^2/GeV)
EVENTS/YEAR/sr/GeV
P_T (GeV)
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0
50
100
150
200
250

Figure 9

VERTEX DETECTOR FOR D's AT SHORT INTERACTION DIAMOND

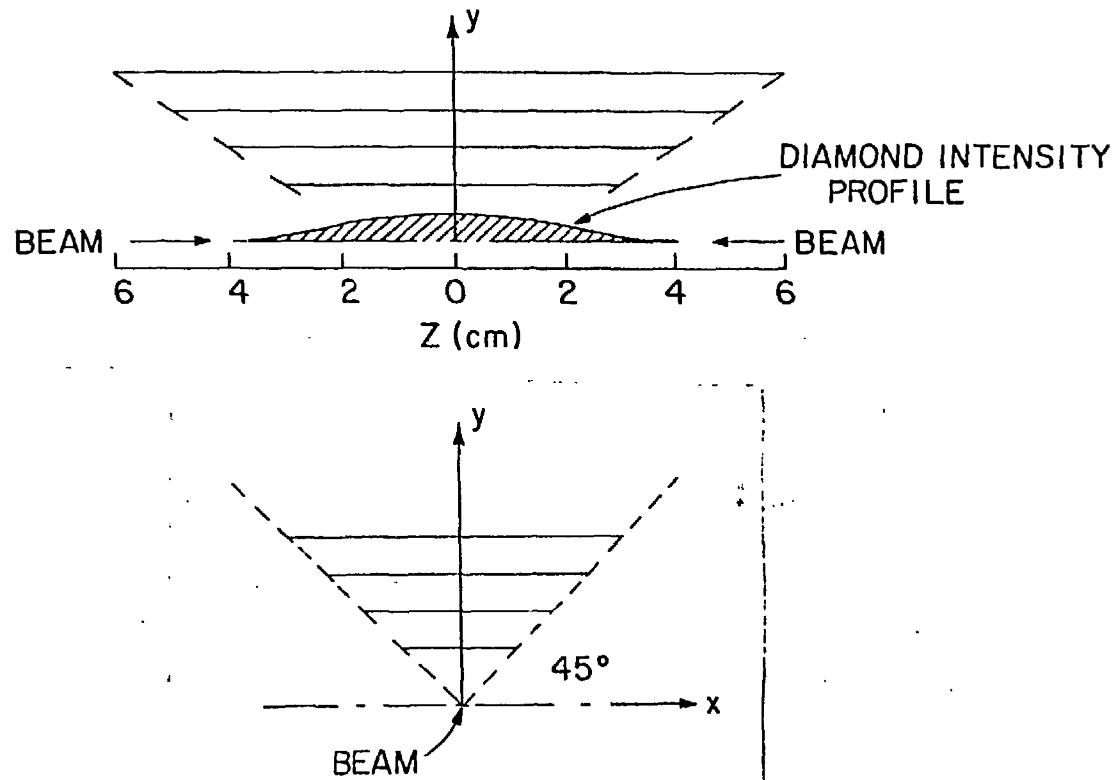
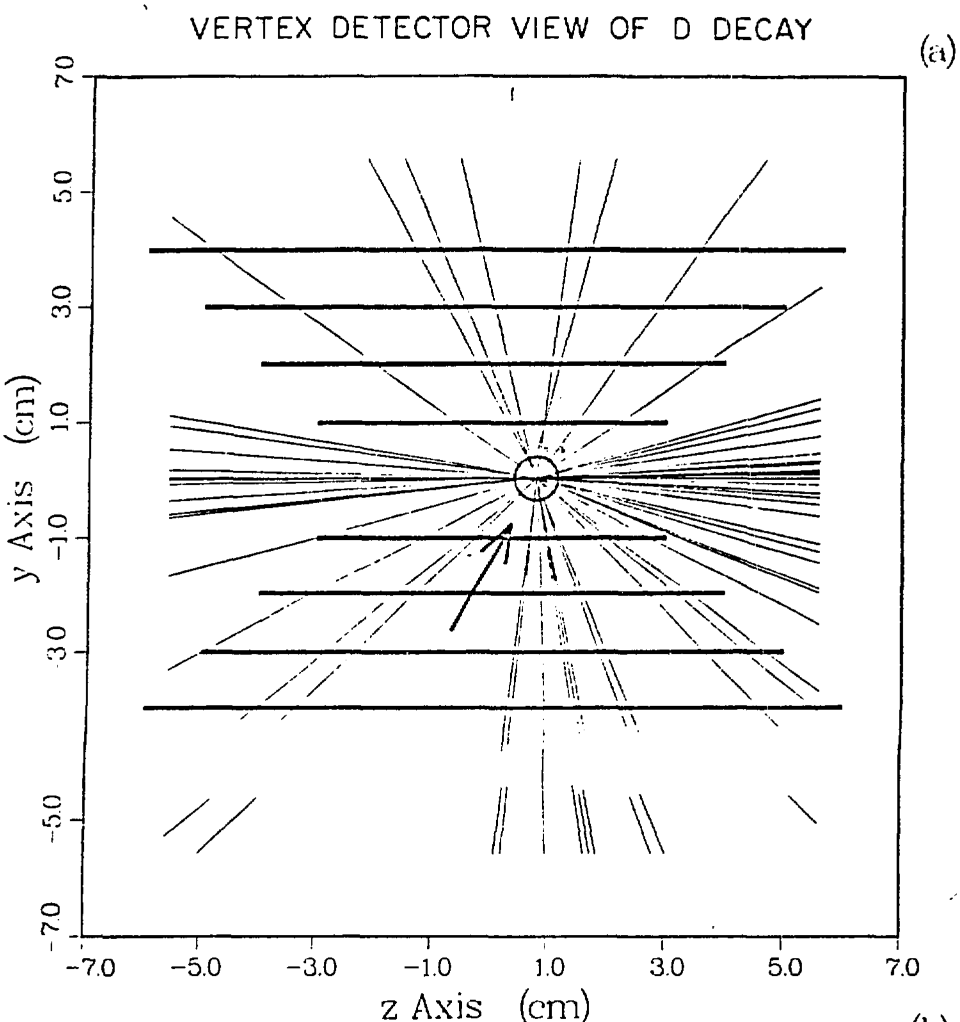
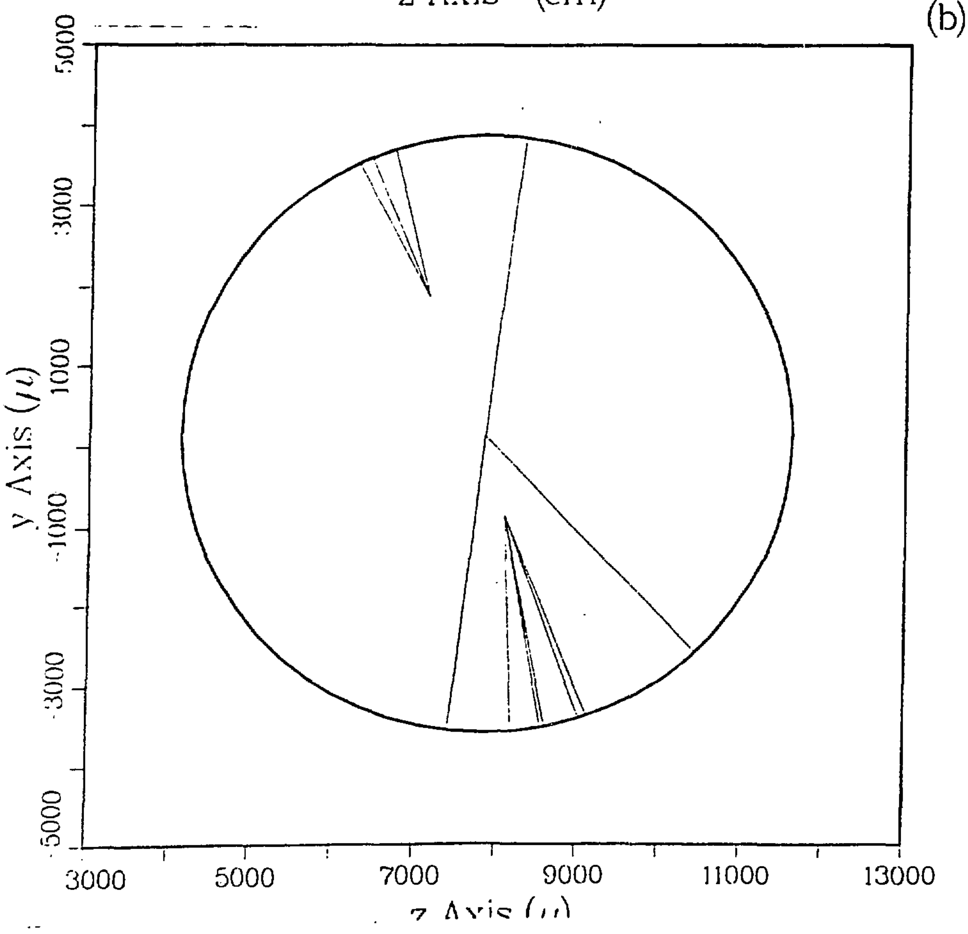


Figure 10


VERTEX DETECTOR VIEW OF D DECAY
(a)
y Axis (cm)
z Axis (cm)
7.0
5.0
3.0
1.0
-1.0
-3.0
-5.0
-7.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0


(b)
y Axis (μ)
5000
3000
1000
-1000
-3000
-5000
3000
5000
7000
9000
11000
13000

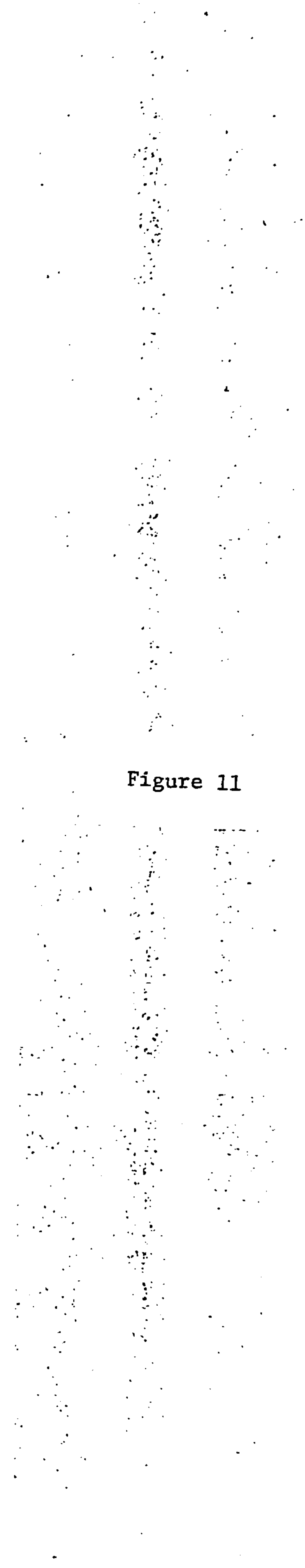


Figure 11

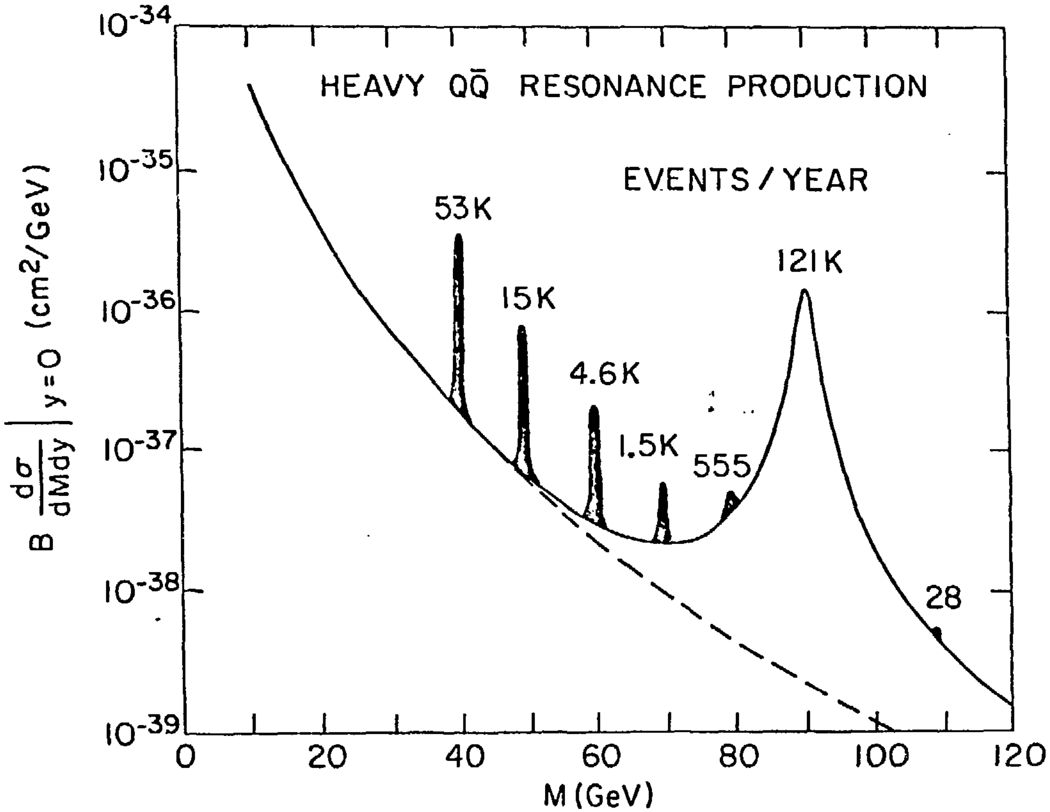
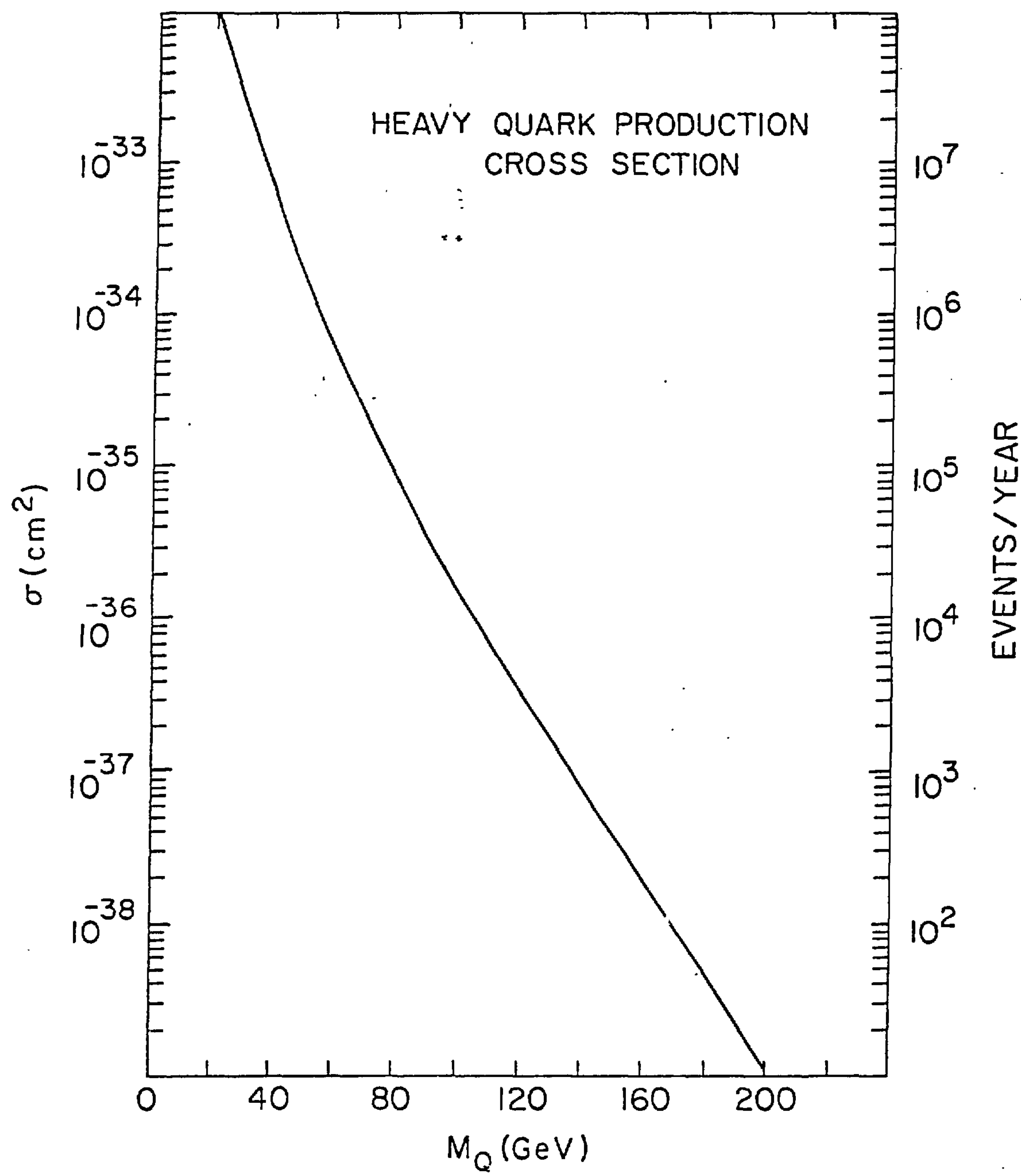

HEAVY QQ̄ RESONANCE PRODUCTION
EVENTS / YEAR
53K
15K
4.6K
1.5K
555
121K
28
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
0
20
40
60
80
100
120
M (GeV)
$B \frac{d\sigma}{dMdy}\Big|_{y=0}$ (cm^2/GeV)

Figure 12



HEAVY QUARK PRODUCTION
CROSS SECTION
σ (cm^2)
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
EVENTS / YEAR
10^7
10^6
10^5
10^4
10^3
10^2
0
40
80
120
160
200
M_Q (GeV)

Figure 13

65%

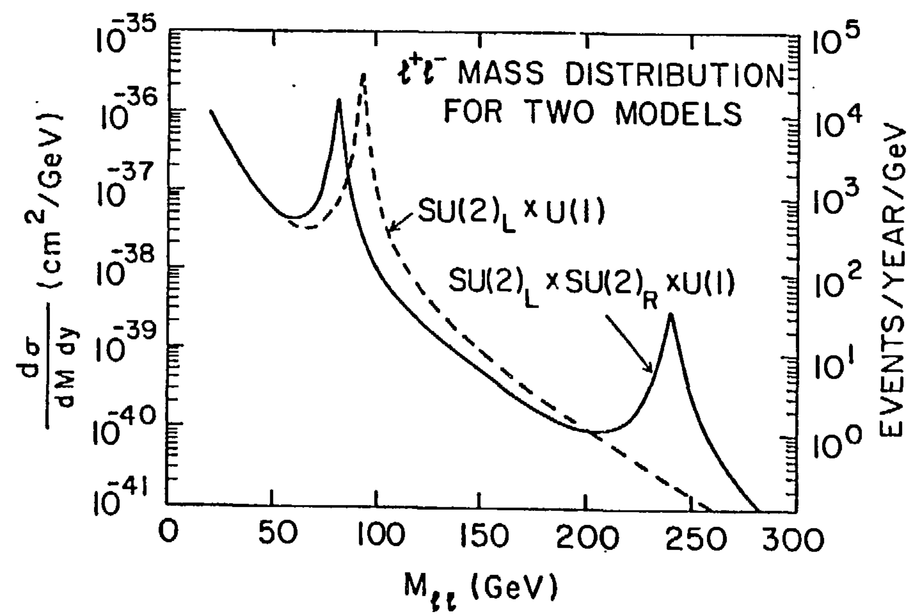
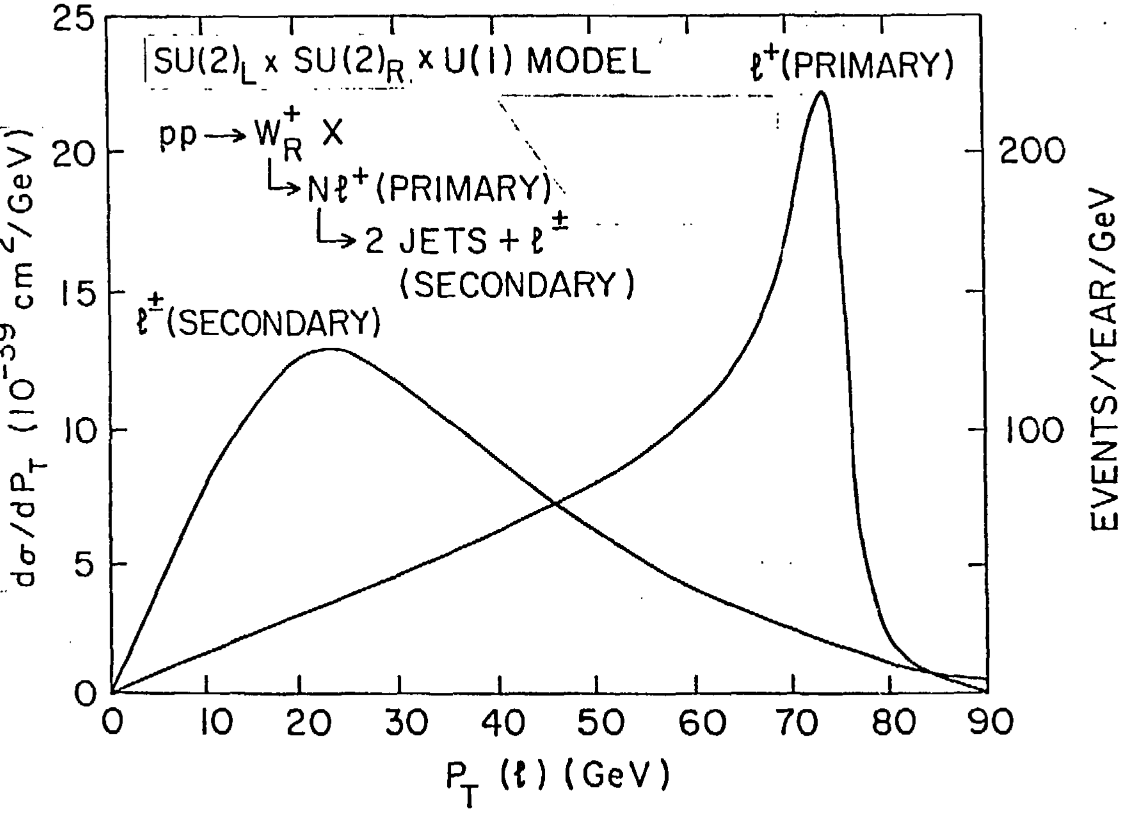
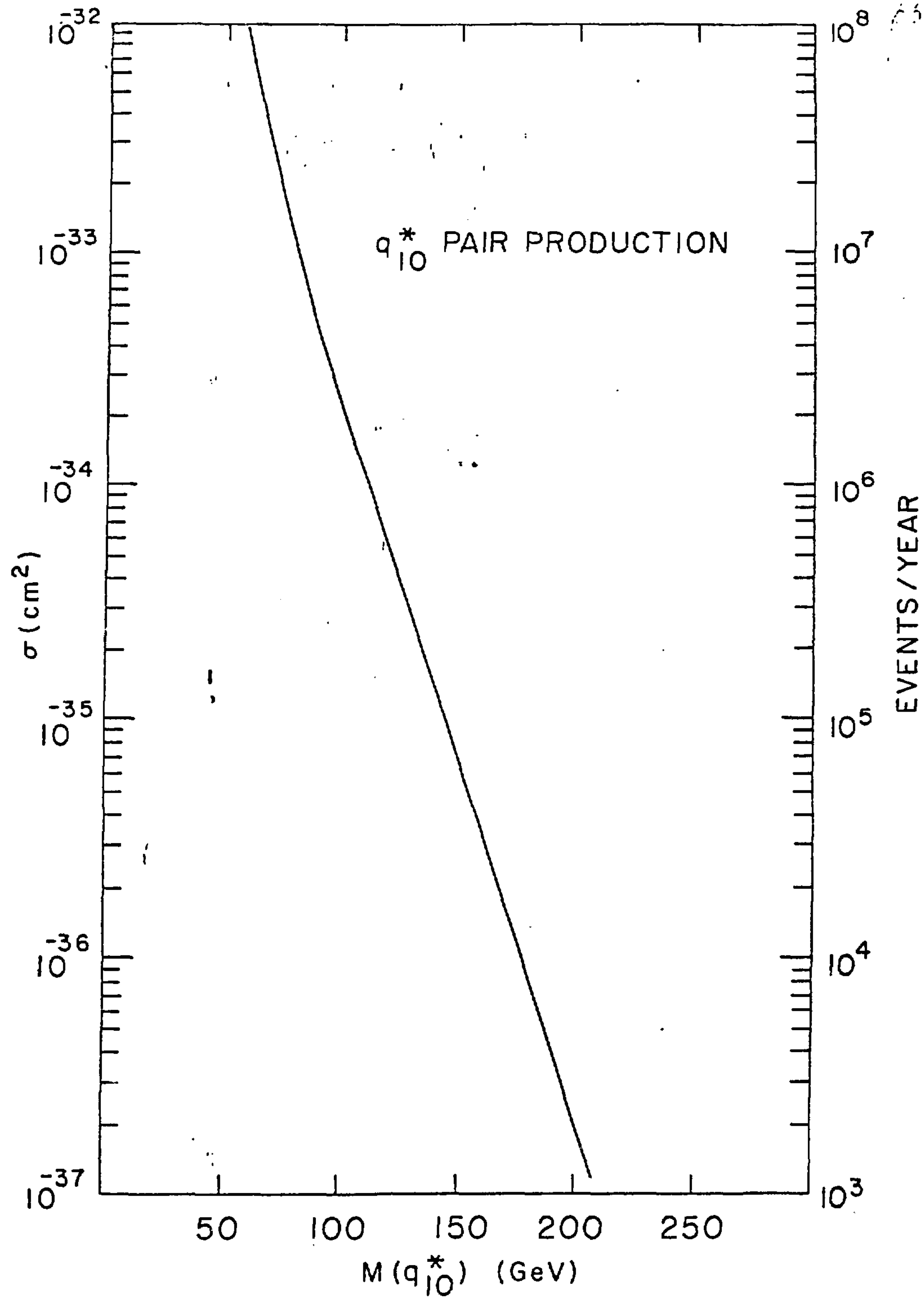

$\ell^+\ell^-$ MASS DISTRIBUTION
FOR TWO MODELS
SU(2)$_L$ x U(1)
SU(2)$_L$ x SU(2)$_R$ x U(1)
$\frac{d\sigma}{dM\,dy}$ (cm^2/GeV)
EVENTS/YEAR/GeV
$M_{\ell\ell}$ (GeV)
0
50
100
150
200
250
300
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^5
10^4
10^3
10^2
10^1
10^0

Figure 14

60%



SU(2)L x SU(2)R x U(1) MODEL
ℓ+(PRIMARY)
pp → W+R X
→ Nℓ+ (PRIMARY)
→ 2 JETS + ℓ±
(SECONDARY)
ℓ± (SECONDARY)
dσ/dPT (10^-39 cm^2/GeV)
EVENTS/YEAR/GeV
PT (ℓ) (GeV)
0
5
10
15
20
25
100
200
30
40
50
60
70
80
90



10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
$\sigma\ (cm^2)$
10^8
10^7
10^6
10^5
10^4
10^3
EVENTS/YEAR
q^*_{10} PAIR PRODUCTION
50
100
150
200
250
$M(q^*_{10})$ (GeV)

Figure 16

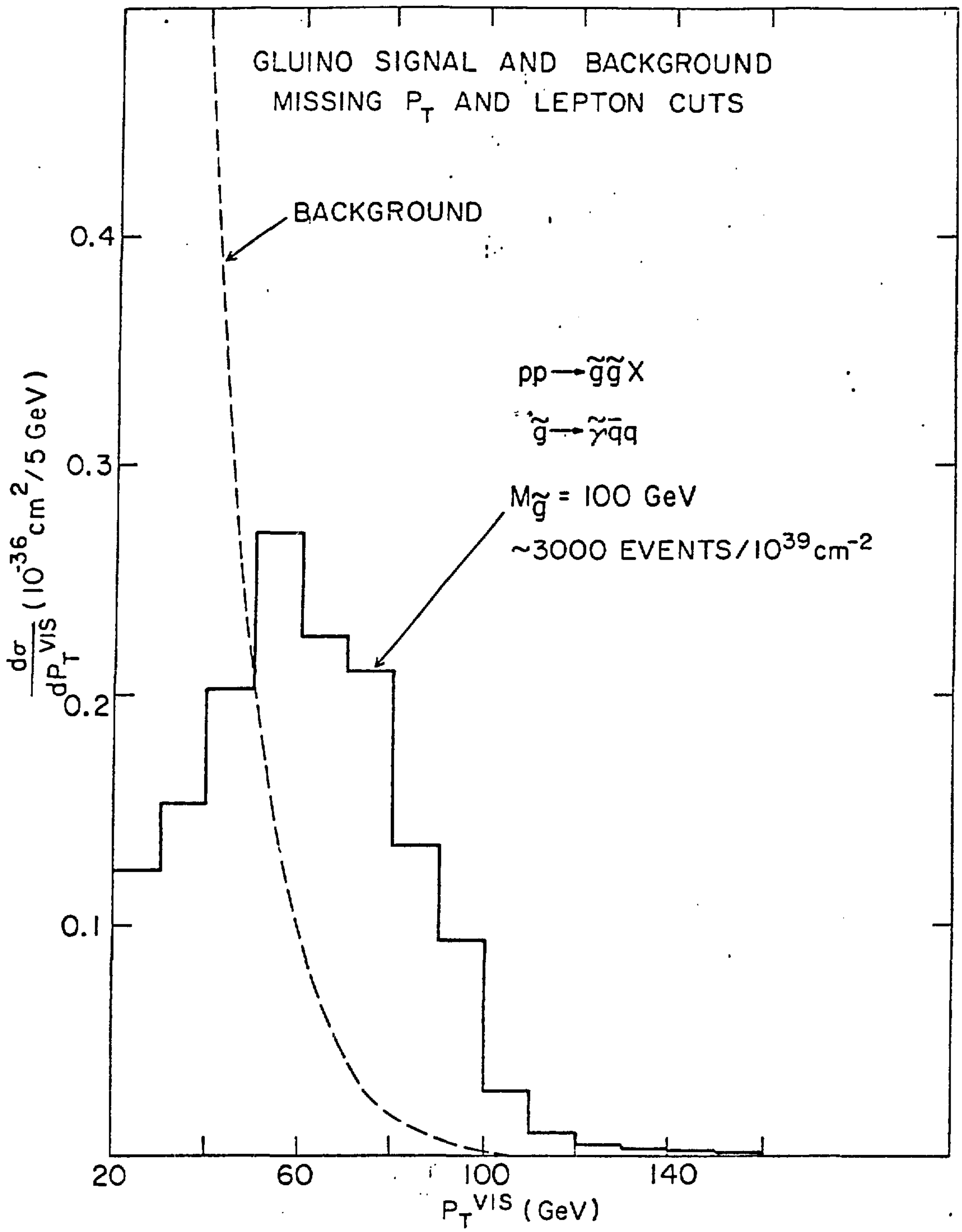

GLUINO SIGNAL AND BACKGROUND
MISSING P_T AND LEPTON CUTS
BACKGROUND
$pp \rightarrow \tilde{g}\tilde{g}X$
$\tilde{g} \rightarrow \tilde{\gamma}\bar{q}q$
$M_{\tilde{g}}$ = 100 GeV
~3000 EVENTS/10^{39}cm^{-2}
0.4
0.3
0.2
0.1
$\frac{d\sigma}{dP_T^{VIS}}$ (10^{-36}cm^2/5 GeV)
20
60
100
140
P_T^{VIS} (GeV)

Figure 17

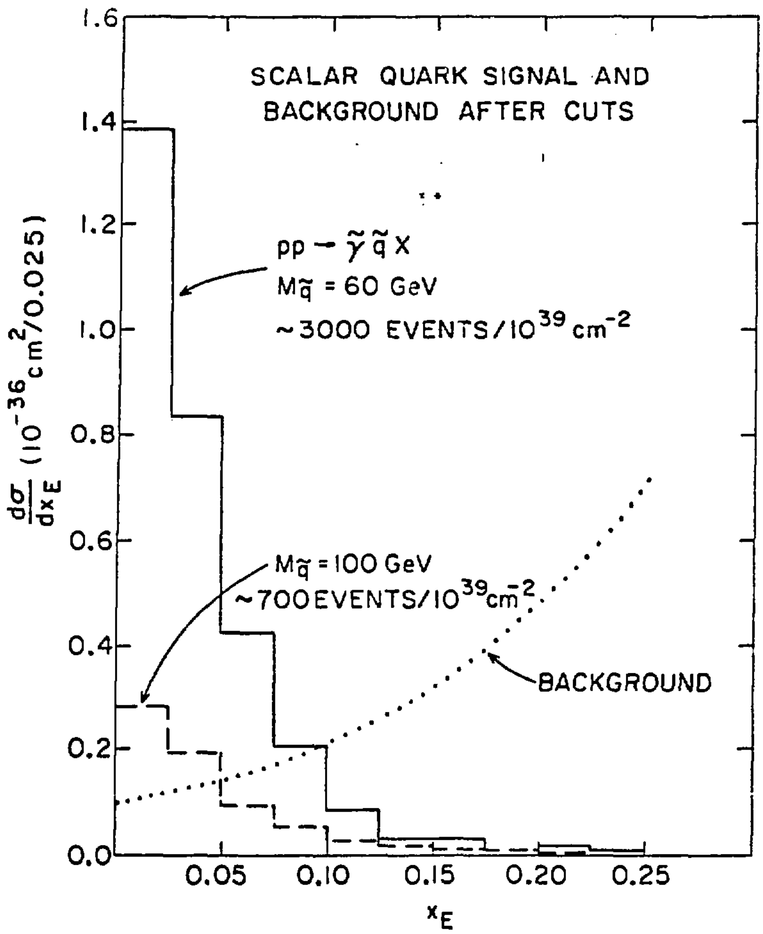
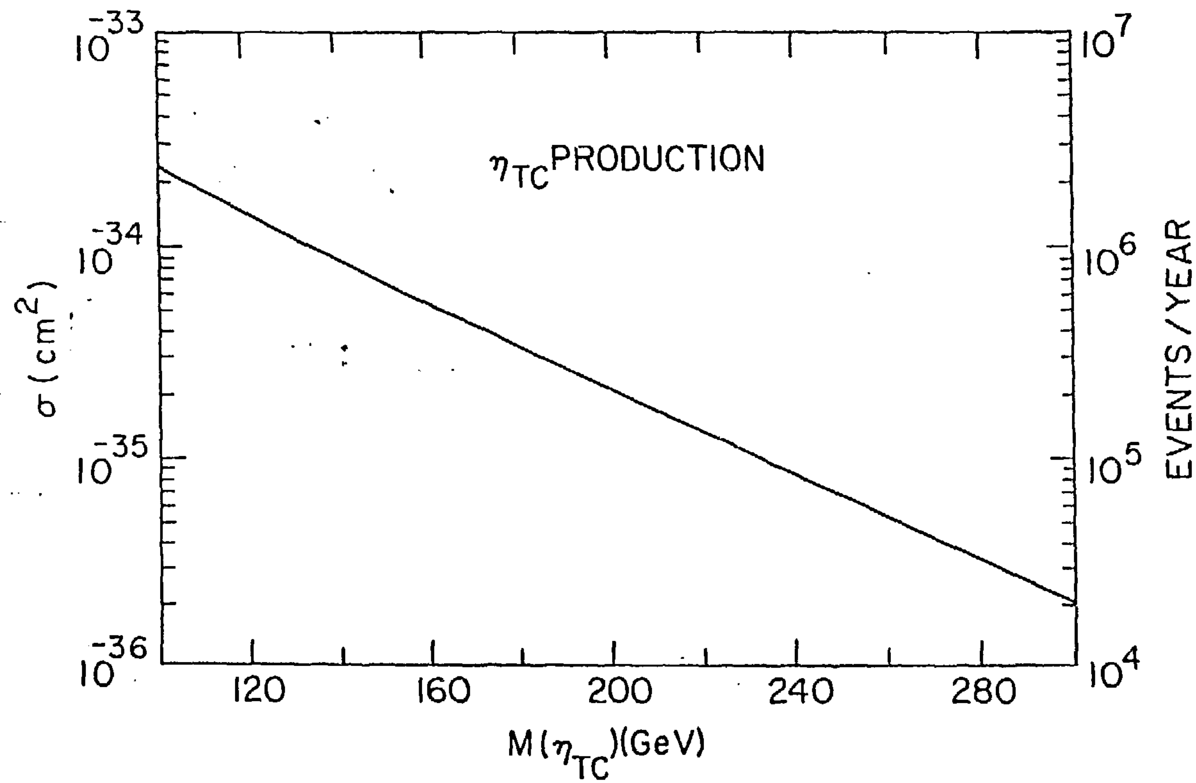

SCALAR QUARK SIGNAL AND BACKGROUND AFTER CUTS
pp → γ̃ q̃ X
Mq̃ = 60 GeV
~3000 EVENTS/10^39 cm^-2
Mq̃ = 100 GeV
~700 EVENTS/10^39 cm^-2
BACKGROUND
dσ/dx_E (10^-36 cm^2/0.025)
x_E
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.05
0.10
0.15
0.20
0.25

Figure 18

55%



10^{-33}
10^{-34}
10^{-35}
10^{-36}
σ (cm^2)
η_{TC} PRODUCTION
120
160
200
240
280
M(η_{TC})(GeV)
10^7
10^6
10^5
10^4
EVENTS / YEAR

Figure 19

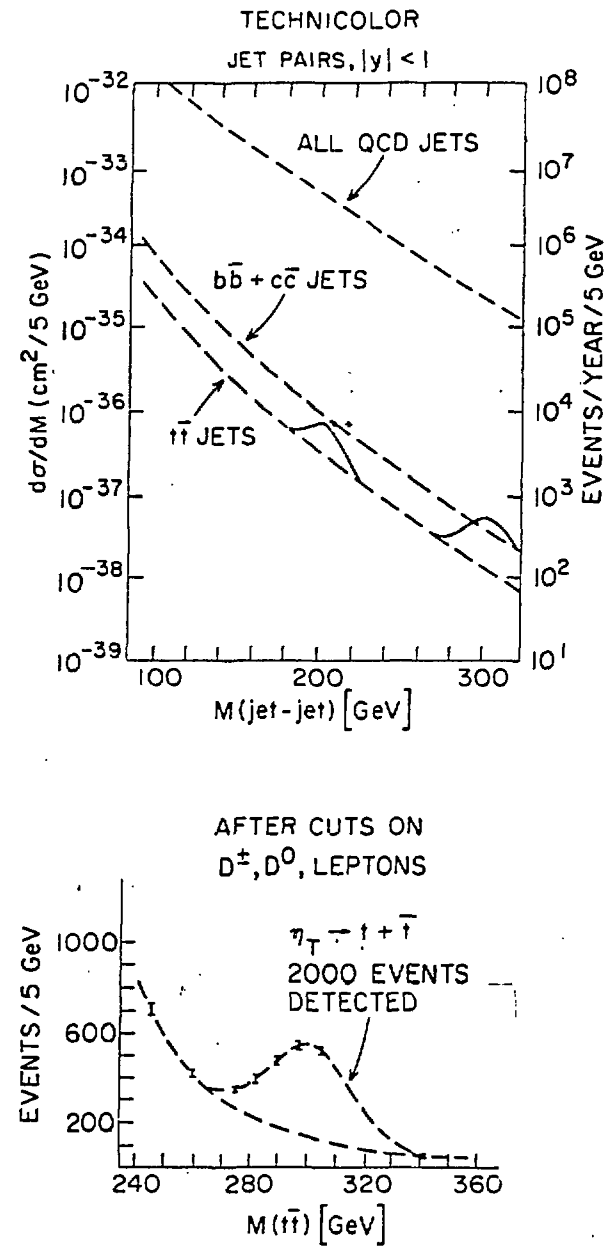

TECHNICOLOR
JET PAIRS, |y| < 1
ALL QCD JETS
$b\bar{b} + c\bar{c}$ JETS
$t\bar{t}$ JETS
$d\sigma/dM$ (cm^2/5 GeV)
EVENTS/YEAR/5 GeV
M(jet-jet) [GeV]
AFTER CUTS ON
$D^{\pm}, D^0$, LEPTONS
$\eta_T \to t + \bar{t}$
2000 EVENTS
DETECTED
EVENTS/5 GeV
M($t\bar{t}$) [GeV]

Figure 20

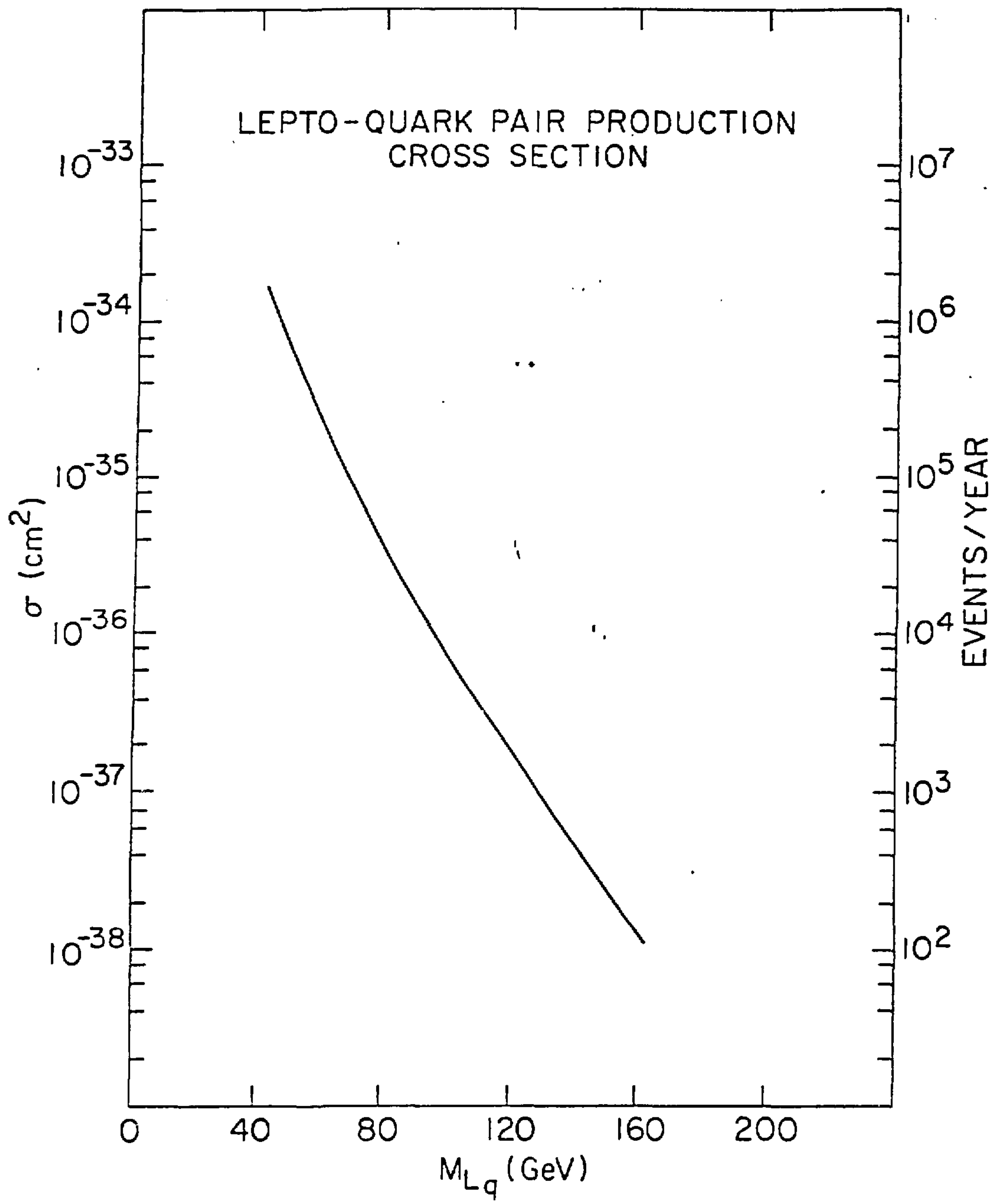

LEPTO-QUARK PAIR PRODUCTION
CROSS SECTION
σ (cm^2)
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
EVENTS/YEAR
10^7
10^6
10^5
10^4
10^3
10^2
0
40
80
120
160
200
M_{L_q} (GeV)

Figure 21

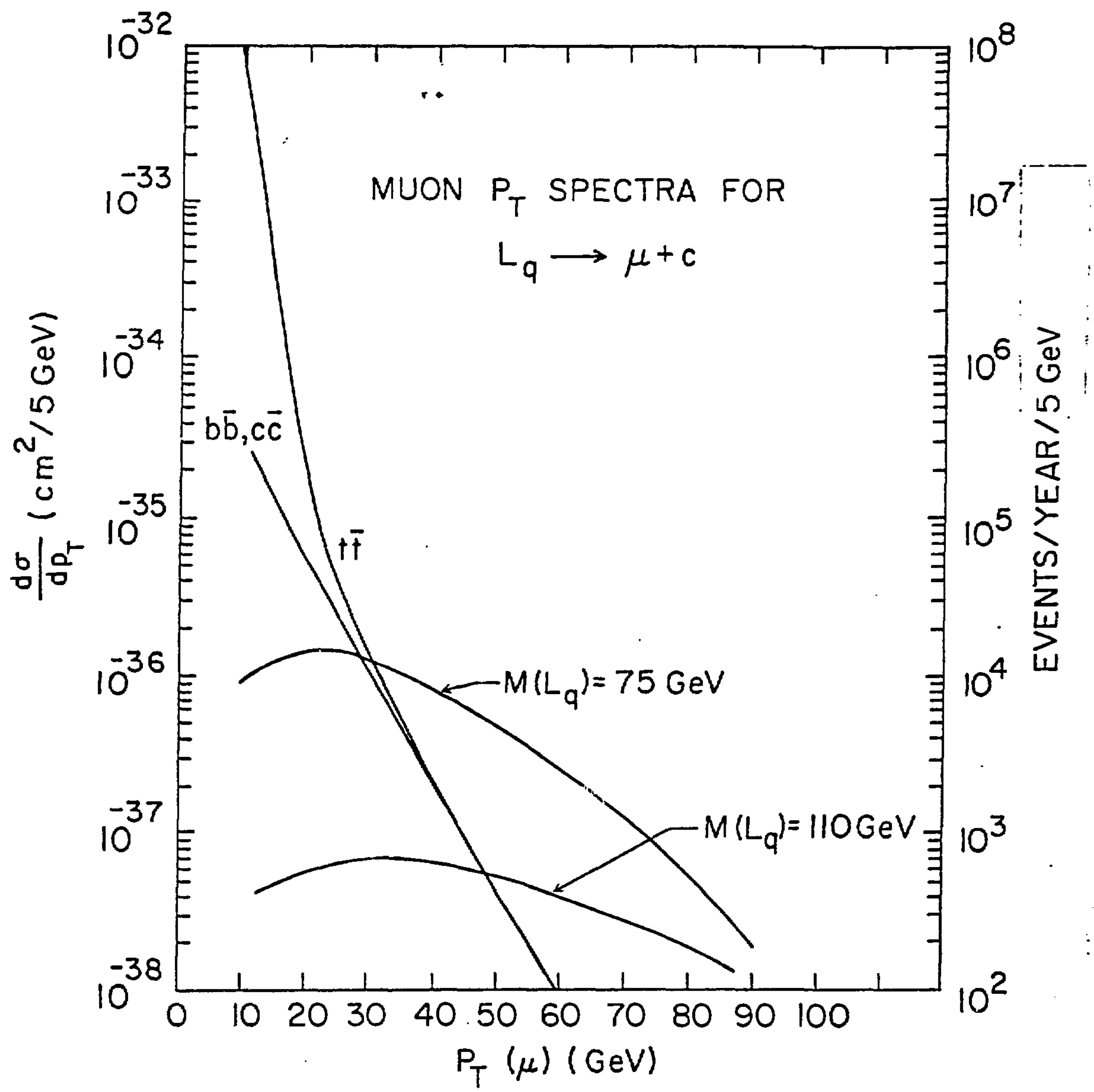

MUON P_T SPECTRA FOR
L_q ⟶ μ + c
b b̄, c c̄
t t̄
M(L_q) = 75 GeV
M(L_q) = 110 GeV
dσ/dp_T (cm²/5 GeV)
EVENTS/YEAR/5 GeV
P_T (μ) (GeV)
10^-32
10^-33
10^-34
10^-35
10^-36
10^-37
10^-38
10^8
10^7
10^6
10^5
10^4
10^3
10^2
0 10 20 30 40 50 60 70 80 90 100

Figure 22

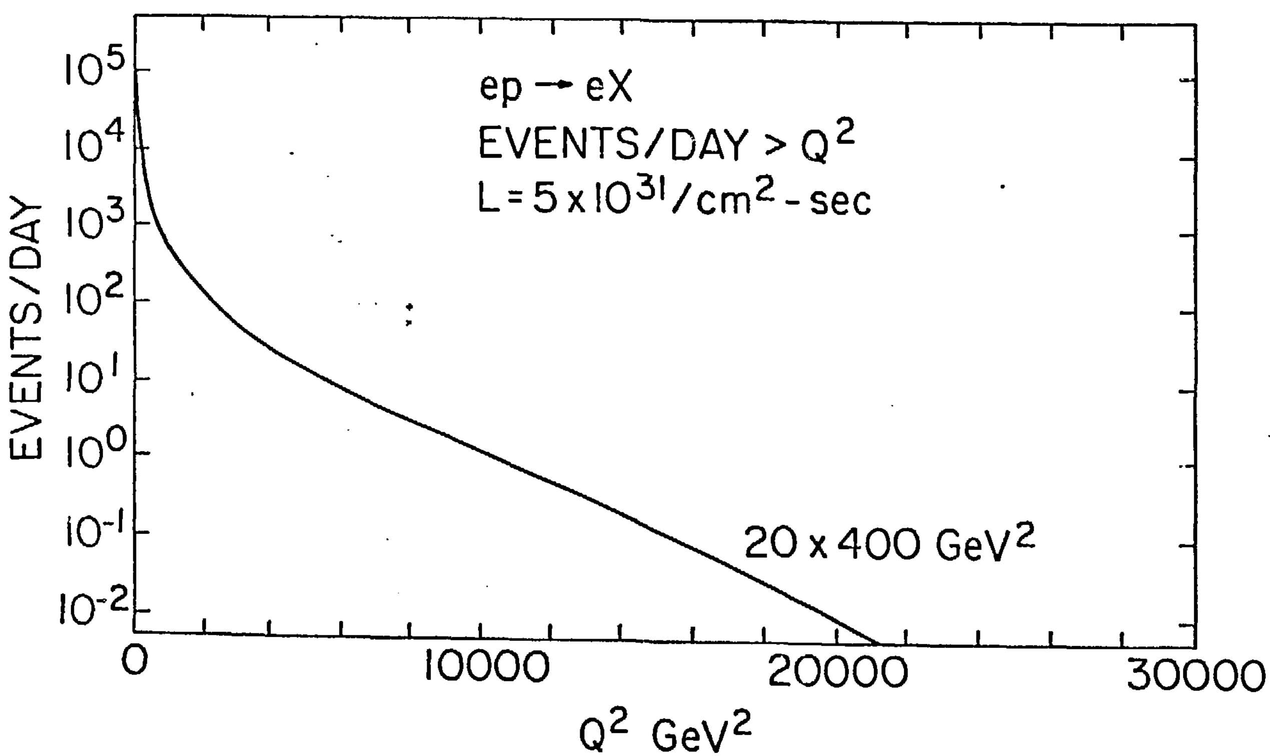

ep → eX
EVENTS/DAY > Q2
L=5x10^31/cm2-sec
20 x 400 GeV2
EVENTS/DAY
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
0
10000
20000
30000
Q2 GeV2

Figure 23