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SOLENOIDAL DETECTOR NOTES

THE IMPACT OF RESOLUTION, CRACKS
AND BEAM HOLES ON DETECTION OF PROCESSES
WITH MISSING ENERGY: HIGGS DECAY TO $l^+l^-\nu\bar{\nu}$

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The Impact of Resolution, Cracks and Beam Holes on Detection of Processes with Missing Energy: Higgs decay to $l^+l^-\nu\bar{\nu}$ *

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Abstract

We have examined detector characteristics which can lead to backgrounds for Higgs boson decay into Z pairs and subsequently to a charged lepton pair and neutrinos. We believe that mismeasurement (smearing) can be effectively handled even if resolution is relatively poor, cracks exist, and there are non-Gaussian tails. We also discuss the η coverage (and resolution at large $|\eta|$) required to restrict backgrounds to a level that allow detection of this missing-energy signature. We find that a detector that covers $|\eta| < 4.5$ is adequate.

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The total production cross-section for Higgs bosons at the SSC is rather small. [1]. In view of this, it is important that as many decay channels as possible are exploited in its search. The cleanest decay channel is $H^0 \rightarrow ZZ \rightarrow l^+l^-l^+l^-$ where l denotes either e or μ. Here the background arises only from the production of Z pairs by $q\bar{q}$ or gg annihilation and is small.[1] This channel in which the Higgs mass can be fully reconstructed, has a combined branching ratio of order 1.5×10^{-3}. In an SSC experiment with an integrated luminosity of $10^{40}cm^{-2}$, the search in this channel is limited by statistics if the Higgs mass is greater than 600 GeV.

The next cleanest channel is $H \rightarrow ZZ \rightarrow l^+l^-\nu\bar{\nu}$. Here the effective branching ratio is larger: 0.8% . In this case the signal consists of a pair of leptons that have an invariant mass equal to the Z mass and missing E_T[4]. There is a physics background from the production of Z pairs by $q\bar{q}$ [5]or gg[6] annihilation. This is smaller than the signal at large enough missing E_T. An additional source of background can arise in the case of an imperfect detector. A Z boson can be produced at large transverse momentum in conjunction with QCD jets. Mismeasurement of the jet energies or loss of jets in cracks or in the beam hole can give rise to missing E_T. In this note we will consider the requirements that must be placed on detector hermiticity if this background is to be reduced below that from Z pairs.

It has been suggested[7] that it may be advantageous in isolating this signal to look for the presence of additional jets at large rapidity. This is because the dominant process for Higgs production for large Higgs masses is $qq \rightarrow qqH$ via the so-called W fusion process [8]. In this case the Higgs has E_T of order M_W. The other source of Higgs bosons, namely, $gg \rightarrow H$ [9] produces, at lowest order in α_s, Higgs bosons with no E_T. However higher-order QCD effects modify this and produce an average transverse momentum which is similar to that from the W fusion process [10]. We shall not include this process in our discussion; its rate depends on the top quark mass. It will increase the rates shown by at most a factor of 2.

Here we shall define a jet to be a parton with E_T greater than 50 GeV and a separation from other partons of $\Delta R = \sqrt{((\Delta\eta)^2 + (\Delta\phi)^2)} > 0.7$. Some of the quark jets from the process $qq \rightarrow Hqq$ have too small a E_T to appear as jets. Figure 1 shows the cross section as a function of missing E_T where we have not required that there be a fixed number of jets. Here we have required that the Z that decays to l^+l^- have a transverse momentum of more than 200 GeV and that l^+ and l^- both have $|\eta| < 2.5$. Two cases are assumed where the Higgs mass has been taken to be 700 GeV and 900

[1]There is a potential background from final states such as $Zt\bar{t}$ where the top quarks decay semileptonically. This background is negligible if the resolution in the dilepton pair mass is 10% or better.[3]

GeV. The figure shows the Higgs signal (solid curves) as an excess of events over the background (dashed curve) from the $q\bar{q} \to ZZ$ process at large missing E_T.[2]

Our goal in detector design should not be to reduce any detector backgrounds to some minimal level but only to less than physics backgrounds. Hence in this case we should aim to be in the situation where the background from the $Z + jets$ final state is below that of the dashed curve in Figure 1. In generating this background we encounter a familiar problem. The rate for $Z + jets$ is very large, but since missing energy arises from the rather improbable events where a substantial mismeasurement of the jet energy is made or a jet is lost down the beam hole, it is can be difficult to obtain a statistically reliable background estimate. The techniques used for obtaining good statistics from the background have been discussed elsewhere [11].

We used the following form for the energy resolution of a jet:

$$\frac{\sigma}{p} = \frac{B}{\sqrt{E}} + C$$

where we chose $B = 0.8$ and $C = 0.015$. This corresponds to the worst case discussed in the supersymmetry study [11]. The calorimeter is assumed to cover the range $|\eta| < 4.5$; jets outside this range are lost and contribute missing E_T. To account for cracks which degrade resolution we chose what may be a worst case scenario. We chose two cracks centered at $|\eta| = 1.775$ and at 3.025. The factor B above was modified such that $B \to B + 0.7$ at $|\eta| = 1.775$ and 3.025, and fell linearly to the original B at a distance of 0.125 (in η) on either side of the center position. The resolution peak at $|\eta| = 1.775$ is somewhat worse than that shown in the a recent study of detector hermeticity[12]. Since we use a parton Monte Carlo,[13] a "jet" is either completely in the crack or completely out (so we may exaggerate the effects of cracks).

The final resolution effect we considered was the possible existence of non-Gaussian tails. The CDF collaboration at the Tevatron Collider has seen no evidence of such tails[14] in the region away from cracks, but the SSC will have much higher luminosity and jets with much higher E_T. To mock this effect, we have added a second wider Gaussian on top of the original Gaussian; this second Gaussian was taken to have a resolution (σ) 3 times that of the original and 5% the magnitude of the original. Anything much larger would probably be inconsistent with the CDF results.[14]

We produce missing-energy Monte Carlo events by generating Z+2-jet events and smearing their momenta. The cut offs on jet p_t and separation are adjusted so that the total rate for inclusive Z production as a function of the transverse momentum of

[2]The process $gg \to ZZ$ occurs at a smaller rate than $q\bar{q} \to ZZ$[6]

the Z is in agreement with the QCD prediction.

In Figure 1 we have superimposed the background from $Z + jets$ as a dot-dashed curve. It can be seen that this background is below that from the ZZ final state. Figure 2 shows the transverse mass distribution, *i.e.* the invariant mass of the ZZ system computed from the energy and transverse momentum of the Z that decayed to l^+l^- and the missing E_T. It is not clear that this variable produces a better signal/background than the missing E_T signal itself does. Again, one can see how far the $Z + jets$ background falls below the signal.

The elimination of the physics background due to the continuum production of ZZ pairs (see Figure 1) requires a missing E_T cut at 300 GeV. This immediately shows that a beam hole of $|\eta| > 4.5$ can pose no problem, since a 14 TeV jet would be required to escape the detector to obtain missing E_T of 300 GeV. It should be emphasized that the magnitude of the "detector" background (dot-dashed curve) is dominated by the non-Gaussian tails, not by the beam holes, not by the cracks and not by the Gaussian resolution. Also poor resolution for $|\eta| > 3$ has no impact on these results.

Other variables can be used to separate signal and "detector" background. For example, Figure 3 shows the azimuthal angle between the reconstructed Z, and the jet with the largest E_T. In this figure we have required that the missing E_T be greater than 200 GeV. The Higgs process produces events that are flat in this variable (solid curve) while the $Z + jets$ background peaks near $\phi = 180^0$. This occurs because one way to obtain large apparent missing E_T is to mismeasure a jet which is balancing the transverse momentum of the observed Z.

The rapidity distribution of jets can also be used as a discriminator. In the Higgs process the jets, if they are observed, appear at large rapidity. Figure 4 shows the rapidity distribution of the jet with the largest rapidity. More than 50% of the Higgs events have a jet in the range $2 < |\eta| < 4$. Whereas most of the "detector" background has jets at $|\eta| < 2$. Hence the ability to tag jets in the region $2 < |\eta| < 4$ may be useful in eliminating the $Z + jets$ background. It is not, however, very effective in reducing the background from ZZ pairs [7].

If the resolution in the dilepton invariant mass is poor, then there is a possible additional source of background. The production and decay of $t\bar{t}$ pairs followed by semileptonic decays can give rise to two charged leptons and missing energy. We have added onto Figure 1 a dotted curve showing the missing E_T from this source. To obtain this curve we have required that there be a pair of isolated leptons of opposite charge whose invariant mass is between 70 and 110 GeV. The transverse momentum of the lepton pair is required to be more than 200 GeV and the leptons are again required to have $|\eta| < 2.5$. Here isolated means that there is no parton within $\Delta R = 0.2$ of the lepton if the parton has more than 5 GeV of E_T. In addition we have required that the events do not contain an additional isolated charged lepton with $|\eta| < 2.5$ and $p_t > 15$ GeV. We have assumed a top quark mass of 250 GeV. A top quark of mass 150 GeV produces a similar background. It can be seen that the missing energy from this source is far below the signal and hence we do not regard it as a potential problem. We have also checked that the final states $Z + t\bar{t}$ and $Z + b\bar{b}$ produce negligible backgrounds.

In conclusion, we have looked at a process with missing E_T that occurs rarely, namely the production of a Higgs boson followed by its decay to $l^+l^-\nu\bar{\nu}$. We have demonstrated that a detector with calorimeter coverage of $|\eta| < 4.5$ with relatively poor resolution is able to reduce the "detector" background below the physics background. We believe that this missing energy process is not very demanding on the detector in the SSC environment.

Acknowledgment

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Figure 1

The distribution in missing E_T from the production and decay to $l^+l^-\nu\bar{\nu}$ of a Higgs boson of mass 700 GeV (heavy solid curve) and 900 GeV (light solid curve). The leptons l which can be either e or μ are required to have $|\eta| < 2.5$, and the Z that decays to l^+l^- is required to have transverse momentum of at least 200 GeV. The dashed curve shows the same distribution from the process $q\bar{q} \to ZZ \to l^+l^-\nu\bar{\nu}$. The dot-dashed curve shows the missing E_T that arises from the final state $Z + jets$ with the detector resolution described in the text. Finally the dotted histogram shows the missing transverse energy spectrum from the production and decay of a $t\bar{t}$ pair, for a top quark mass of 250 GeV. The events are required to give rise to an l^+l^- pair which has invariant mass between 70 GeV and 110 GeV and transverse momentum greater than 200 GeV. Again the leptons are required to have $|\eta| < 2.5$ and they are required to be isolated *i.e.*there are no jets with transverse momentum of more that 5 GeV in a cone about the lepton of radius $\Delta R = 0.2$. In addition we require that there be no additional isolated charged leptons with $p_t < 15$ GeV.

Figure 2

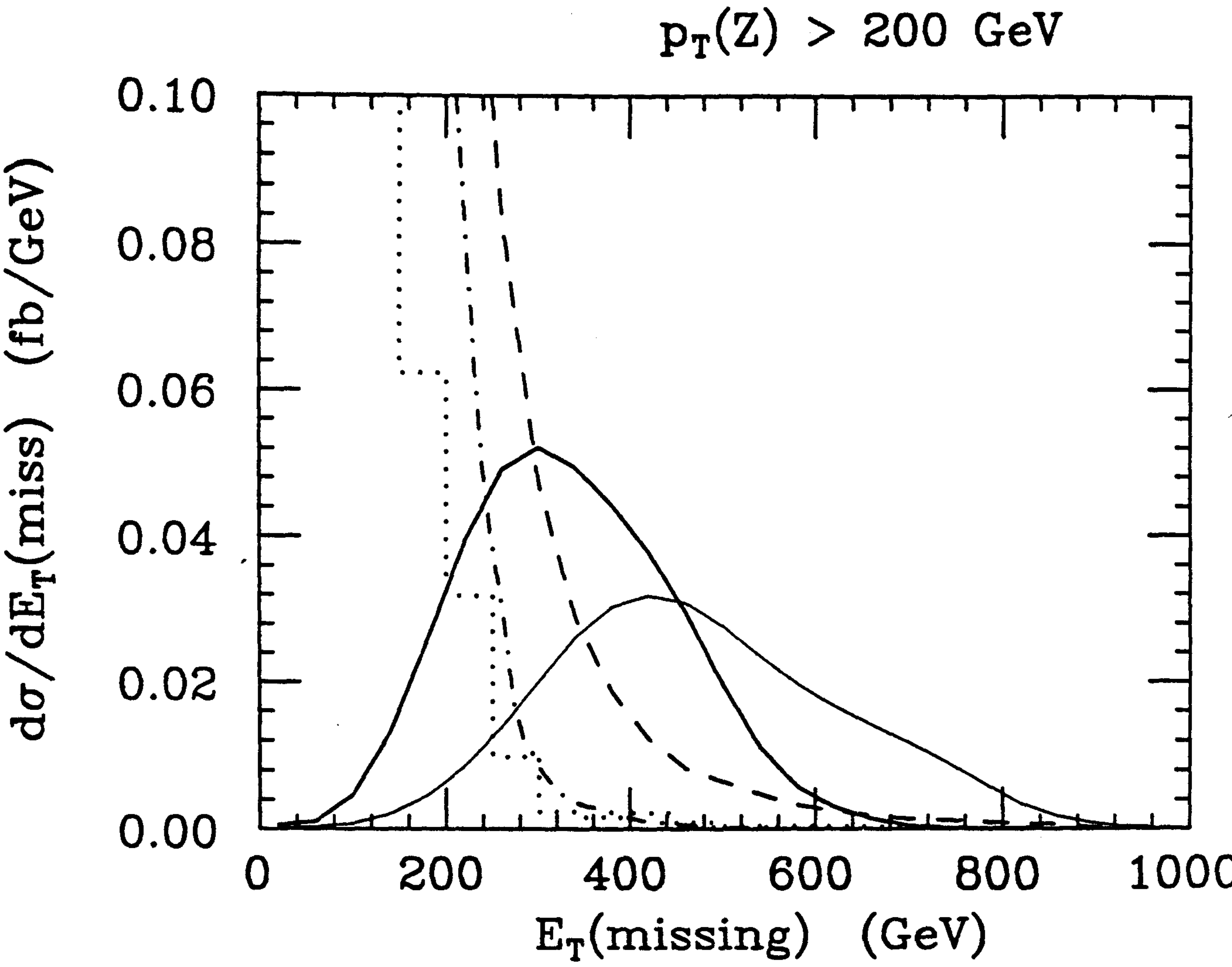
As Figure 1 except that the transverse mass distribution is plotted and the missing E_T is required to be more than 200 GeV.

Figure 3

The distribution in azimuthal angle ϕ between the Z that decays to l^+l^- and the jet with the largest transverse momentum. The cuts are as described in Figure 2. The solid curve is the Higgs process and the dashed the $Z + jets$ background process.

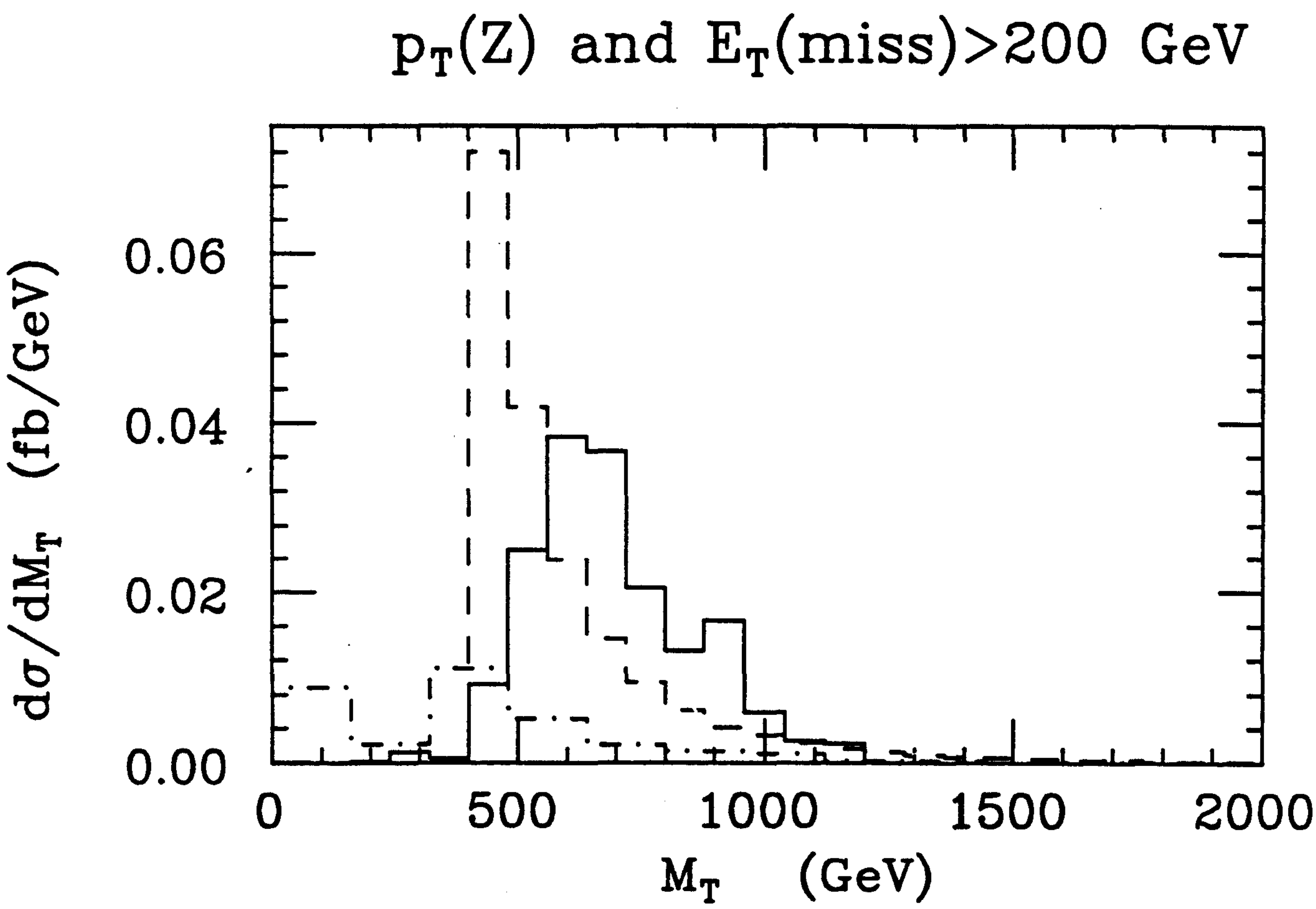
Figure 4

The rapidity distribution of the jet with largest rapidity. The cuts are as described in Figure 2.



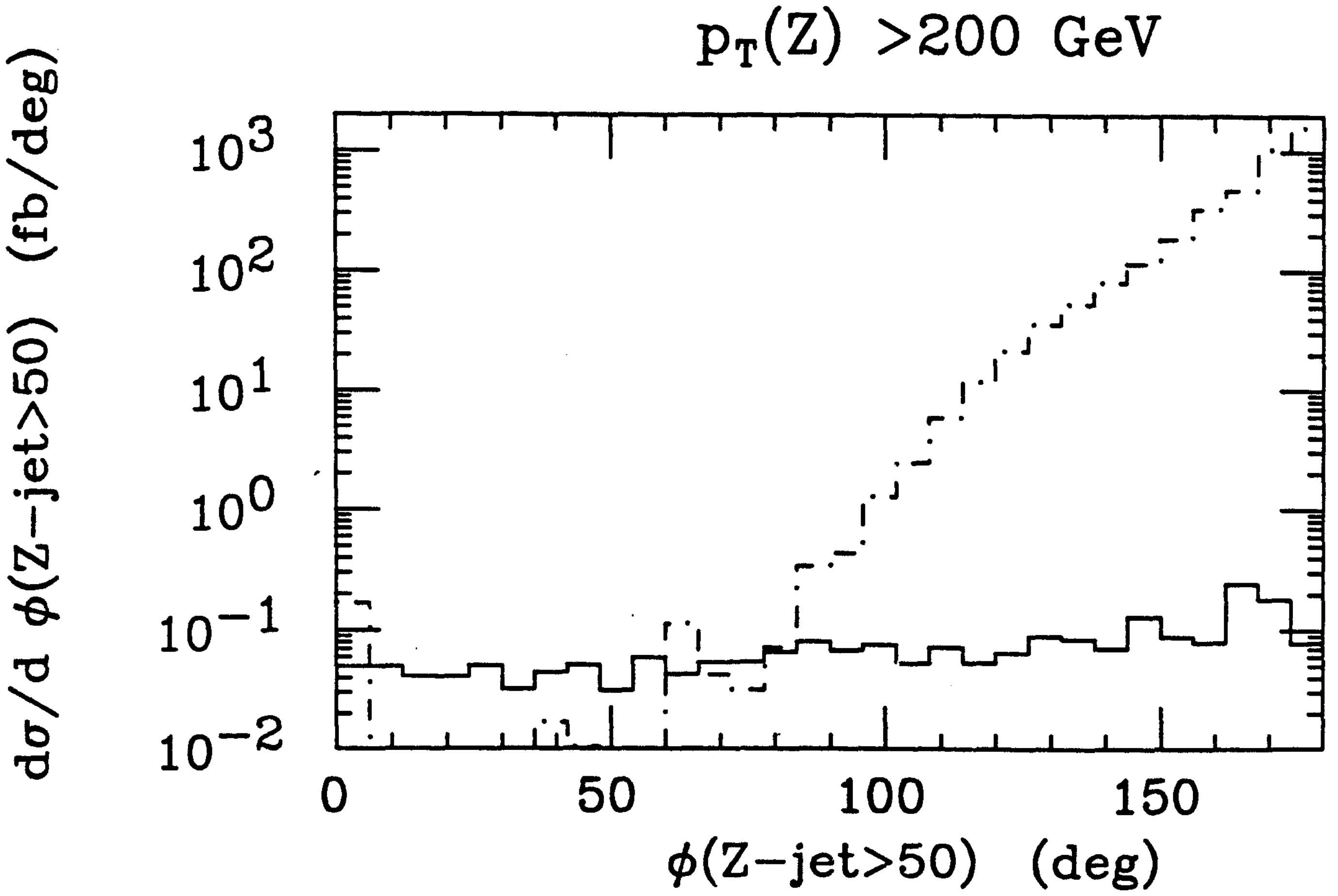
$p_T(Z) > 200$ GeV
0.10
0.08
0.06
0.04
0.02
0.00
$d\sigma/dE_T$(miss) (fb/GeV)
0
200
400
600
800
1000
E_T(missing) (GeV)

Fig. 1



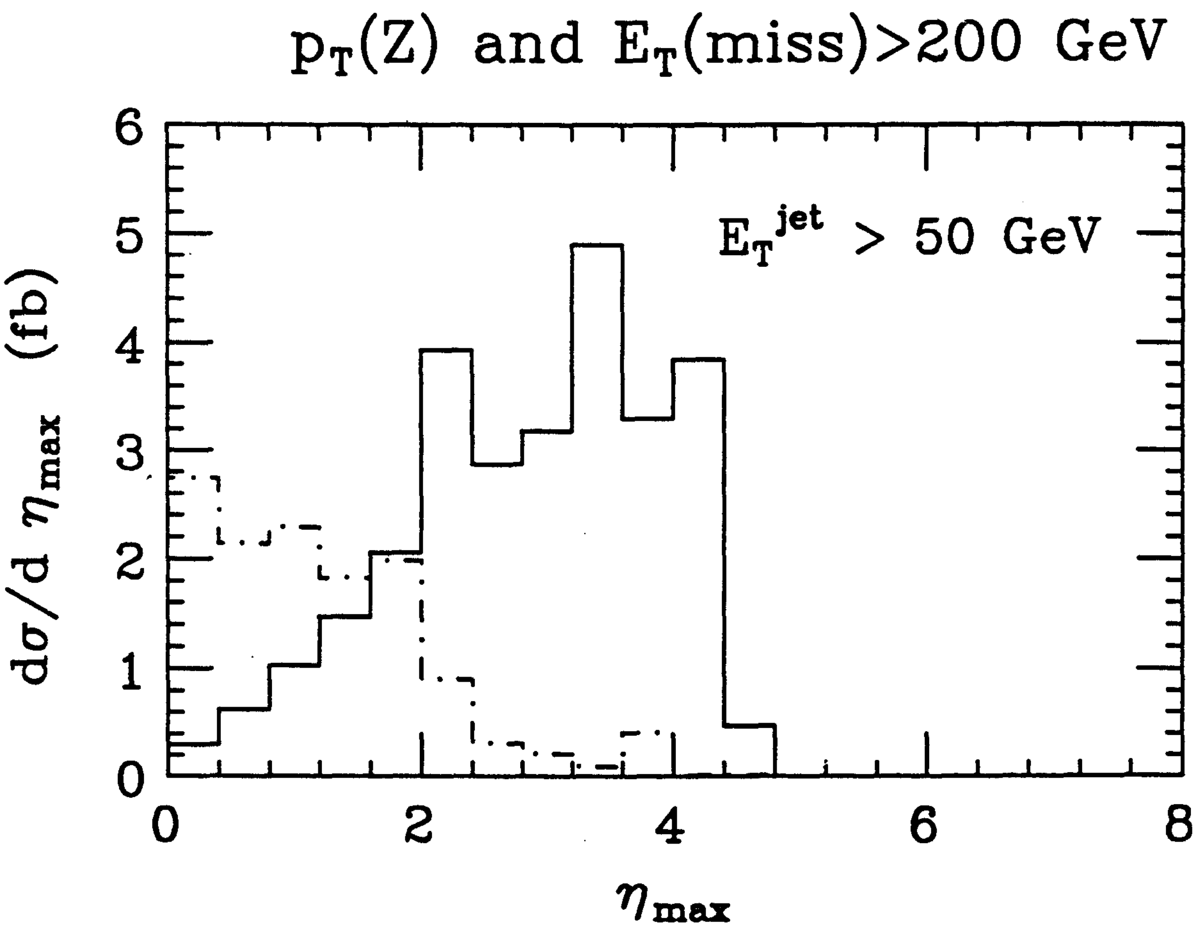
$p_T(Z)$ and E_T(miss)>200 GeV
0.06
0.04
0.02
0.00
$d\sigma/dM_T$ (fb/GeV)
0
500
1000
1500
2000
M_T (GeV)

Fig. 2



$p_T(Z)$ >200 GeV
$d\sigma/d\ \phi(Z-jet>50)$ (fb/deg)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0
50
100
150
$\phi(Z-jet>50)$ (deg)

Fig. 3



$p_T(Z)$ and E_T(miss)>200 GeV
E_T^{jet} > 50 GeV
$d\sigma/d\,\eta_{max}$ (fb)
η_{max}
0
1
2
3
4
5
6
0
2
4
6
8

Fig. 4