II.7 W' SIGNAL AND BACKGROUND AT LHC

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1 Introduction

Presented here is a feasibility study for W' production at LHC energies. The theoretical aspects of W' as well as Z' are already extensively discussed in these proceedings. The model used in this work is the Extended Gauge model of Altarelli et al. as described in ref. [1], and as implemented in the Pythia Monte Carlo by T.Sjöstrand [2]. Because of the difficulties expected in detecting hadronic decay channels of W' (very high luminosity and event pile up), in this work only leptonic channels are studied. In this analysis the electron decay channels are chosen. Switching to muons does not affect the branching ratios, but requires different detector smearing simulation.

The W' channels and their backgrounds are the following:

- the one electron channel $W' \to e\nu$
  with background from $W \to e\nu$
  and from the heavy top decay $t\bar{t} \to (Wb)X \to (e\nu b)X$.
- the three electron channel $W' \to WZ \to (e\nu)(ee)$
  where the continuum background $WZ \to (e\nu)(ee)$
  and the top decay chain $t\bar{t} \to (Wb)(Wb) \to (e\nu e\nu c)(e\nu b)$
  play an important role.

Before studying the processes in more detail, some remarks on the assumptions made in this analysis are listed in the next sections.

2 Detector aspects and general remarks

All processes have been studied under internally agreed assumptions on detector acceptance and smearing.

- Acceptance in pseudorapidity η is assumed to be $-2. < |\eta| < 2.$ for all particles.
- The electron resolution has been assumed to be $\Delta E/E = 0.15/\sqrt{E} + 0.02$.
- For the missing energy, reconstructed from the unsmeared momentum of the "detected" particles, $\Delta E/E = 0.7/\sqrt{E}$ has been used.

Cross sections have been converted to event rates assuming a luminosity $\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. This is equivalent to $\mathcal{L} = 10^5\ \mathrm{pbarn}^{-1}\ \mathrm{year}_{\mathrm{LHC}}^{-1}$ (with a year of 10^7 seconds of running).

The top quark mass is chosen to be $120\ \mathrm{GeV/c^2}$. This allows a top-hadron to decay into a real W and a bottom-hadron. The electron coming from the leptonic W decay is then as isolated as one originating from the W'. So, the single electron background cannot be reduced by applying an isolation cut. On the other hand it is shown that the three electron background from $t\bar{t}$ can be almost eliminated, since one of the electrons has to come from b-hadron decay. This electron will be surrounded by other particles, and can usually not fullfill the isolation requirement.

The Monte Carlo programs used are Pythia5.4 with Jetset7.3 .

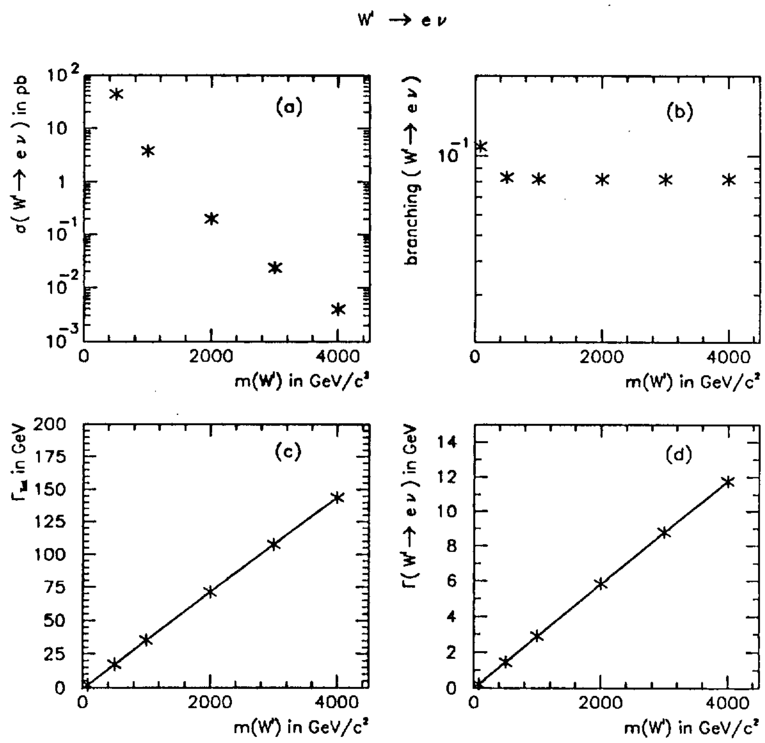

Figure 1: *(a) : cross section times branching ratio, (b) : branching ratio, (c) : total and (d) : partial width as a function of the* W′ *mass.*

3 The process $p\bar{p} \rightarrow W' \rightarrow e\nu$

In figure 1 some W′ characteristics are summarized. It is worthwhile noting that even for a very heavy W′($4\,\mathrm{TeV/c^2}$) the event rate is still 400, in the case of the high luminosity option for LHC. Furthermore it can be verified from figure 1 c and d that the total (and partial) width of the W (first point) lies nicely on the straight line connecting the W′ data. This is a consequence of the fact that in the Extended Gauge model the W′ and Z′ couple in the same way to leptons as the W and Z in the Standard Model.

3.1 Efficiency of η and p_T cuts

Since the detector has limited acceptance, and it may be necessary to apply transverse momentum cuts on electrons, it is instructive to look at the signal loss caused by these limitations. The efficiency as function of a minimum transverse electron momentum has been calculated, as follows:

$$\mathrm{Eff}(p_T^{\min}) = \int_{p_T^{\min}}^{\infty} \frac{d\sigma}{dp_T} dp_T \Big/ \int_0^{\infty} \frac{d\sigma}{dp_T} dp_T. \qquad (1)$$

Of all electrons in an event only the one with the largest p_T has been taken. No cut on missing momentum has been applied, but it should be noted that in the next section we do cut on missing p_T , so the efficiency will be lower there, as we shall see. The efficiency is shown in figure 2 as a function of p_T^{min} for a W′ of $500\,\mathrm{GeV/c^2}$ and $1\,\mathrm{TeV/c^2}$, for 4 π detection, with and without standard rapidity cut. It is encouraging to see that even after a 200 GeV/c cut about 80 % of the signal remains for the 1 TeV W′. Also the limited η region does not reduce the signal too much. The heavier the W′ the better the efficiency, but for a light W′ ($m = 500\mathrm{GeV/c^2}$) the efficiency drops to 40 % for a minimum electron p_T of 200 GeV/c .

3.2 The backgrounds considered

As already mentioned in the introduction, there are two serious background sources. The most obvious one is W $\rightarrow e\nu$. Since it is now generally assumed that the top quark mass should be at least 120

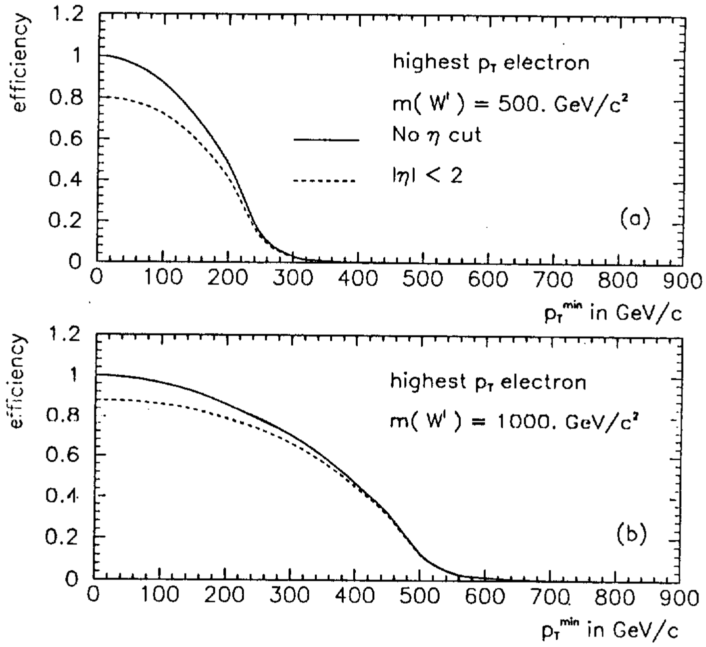

Figure 2: *Efficiency as a function of minimum electron p_T, for mass of* W$'$ *as indicated.*

GeV/c^2, this means that a top hadron decays into a real W and a bottom hadron. At LHC energies, the production cross section for a $t\bar{t}$ pair is rather large (5.8 nb, Pythia5.4), so the background coming from an electron of one of the W's, is non-negligible. Electrons coming from the b-hadrons have not been considered, since they will be surrounded by many particles, and are not isolated, so can be easily cut out.

Generating $t\bar{t}$ background turned out to be (computer)time consuming. To speed up the procedure, each generated $t\bar{t}$ event has been used ten times for further decay. In addition to that, several runs have been performed with different initial kinematical cuts (the invariant mass of the $t\bar{t}$ pair, and the range of allowed p_T of hard $2 \rightarrow 2$ processes *) to be able to reach the outer regions of phase space (which otherwise could be reached only by generating orders of magnitude more events). Finally the distributions of these runs have been combined, such that in each interval of e.g. transverse mass, only the statistically most relevant sample is taken. This yields as envelope the dotted line as shown in figure 3. For the $W \rightarrow e\nu$ background the same trick of kinematical cuts has been applied and also in that case each distribution is an envelope of many different ones. In figure 3 a the differential cross section as a function of the transverse mass of the electron and the missing momentum is shown. The numbers on top of the nice Jacobian peeks of the signal indicate the mass of the W$'$. The backgrounds are also shown, and it is clear that a light W$'$ suffers severely from $t\bar{t}$ production. The importance of the other background, $W \rightarrow e\nu$, grows with m_T compared to $t\bar{t}$, but for the heavier W$'$'s there is no serious background problem anymore, as shall become clear from the numbers in table 1. In this table 1 the following is listed :

The mass of the W$'$, the production cross section times branching ratio ($\sigma \cdot BR$) and the latter after the standard cut $|\eta| < 2$ (indicated by $\sigma_{|\eta|<2}$). The expected numbers of events per pbarn per LHC year ($\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}) are listed, for signal, as well as for both backgrounds. The indicated transverse mass cut is the value where the largest background signal cuts the W$'$signal. In addition a transverse momentum cut is applied, indicated by $+p_T > 100$. This cut holds for the electron *and* the missing transverse momentum. For the 2 , 3 and 4 TeV W$'$masses, the signal, nor background changes when a p_T cut is applied, so here only one row is presented.

*variables CKIN(1) and CKIN(3) in Pythia5.4 see [2]

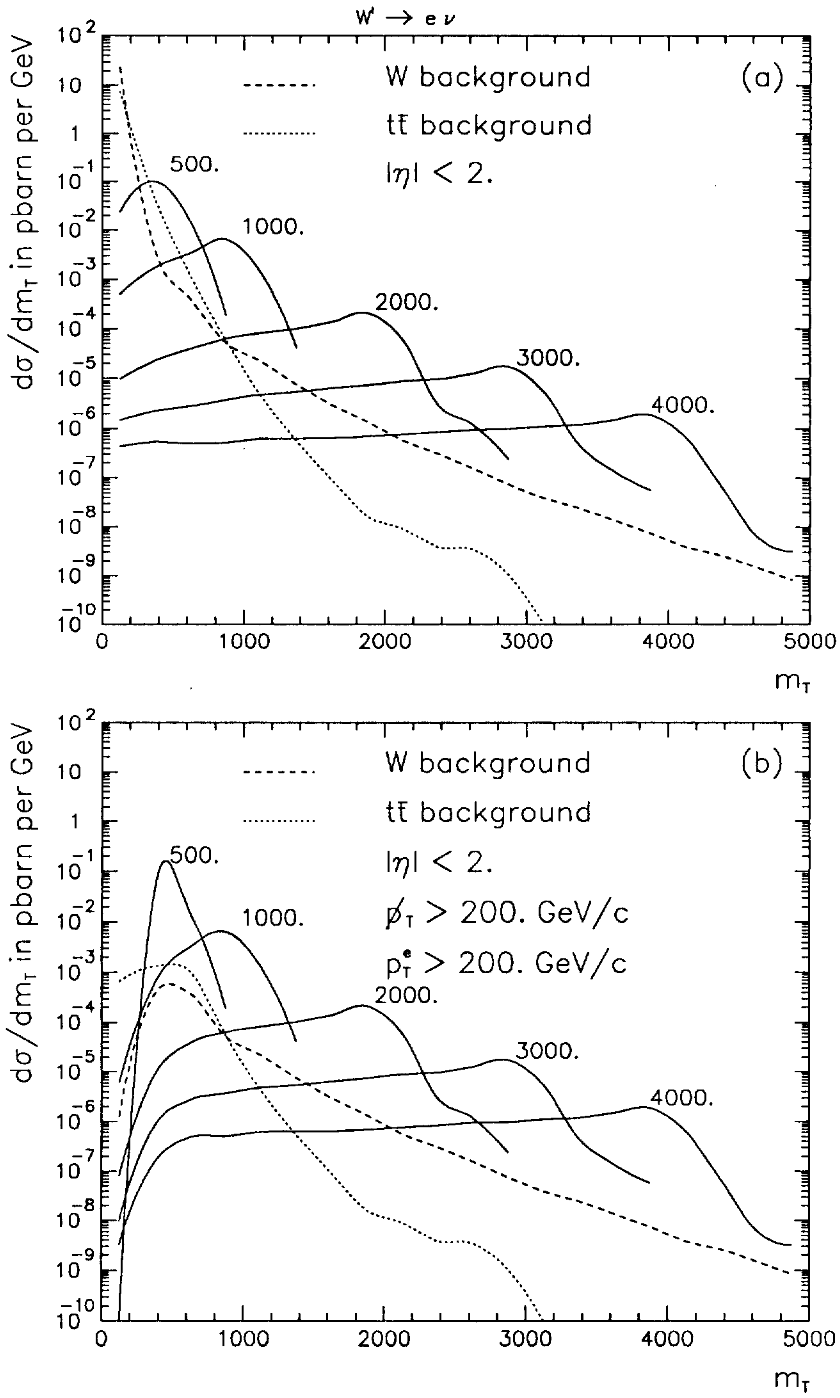

Figure 3: *Signal and Backgrounds for a: only η cut, b: η cut plus p_T cuts as indicated.*

$m_{W'} = 500$ GeV/c^2	$\sigma \cdot BR = 43.1$ pb $\sigma_{\lvert\eta\rvert<2} = 34.5$ pb		
$m_T > 300$	# $W' \to e\nu$	# $W \to e\nu$	# $t\bar{t}$
	25.6 10^5	0.519 10^5	4.85 10^5
$+p_T > 100$	25.6 10^5	0.516 10^5	4.34 10^5
$+p_T > 200$	14.8 10^5	0.208 10^5	0.60 10^5
$m_{W'} = 1000$ GeV/c^2	$\sigma \cdot BR = 3.68$ pb $\sigma_{\lvert\eta\rvert<2} = 3.34$ pb		
$m_T > 550$	# $W' \to e\nu$	# $W \to e\nu$	# $t\bar{t}$
	2.66 10^5	8.4 10^3	1.61 10^4
$+p_T > 100$	2.66 10^5	8.4 10^3	1.60 10^4
$+p_T > 200$	2.65 10^5	8.4 10^3	1.53 10^4
$m_{W'} = 2000$ GeV/c^2	$\sigma \cdot BR = .196$ pb $\sigma_{\lvert\eta\rvert<2} = .183$ pb		
$m_T > 900$	# $W' \to e\nu$	# $W \to e\nu$	# $t\bar{t}$
	1.57 10^4	1.35 10^3	3.26 10^2
$m_{W'} = 3000$ GeV/c^2	$\sigma \cdot BR = 0.0239$ pb $\sigma_{\lvert\eta\rvert<2} = 0.0222$ pb		
$m_T > 1450$	# $W' \to e\nu$	# $W \to e\nu$	# $t\bar{t}$
	1.74 10^3	1.63 10^2	3.59 10^2
$m_{W'} = 4000$ GeV/c^2	$\sigma \cdot BR = 0.0039$ pb $\sigma_{\lvert\eta\rvert<2} = 0.0036$ pb		
$m_T > 2000$	# $W' \to e\nu$	# $W \to e\nu$	# $t\bar{t}$
	2.49 10^2	30.	.5

Table 1: *Event rates for signal and background at one year running with* $\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}.

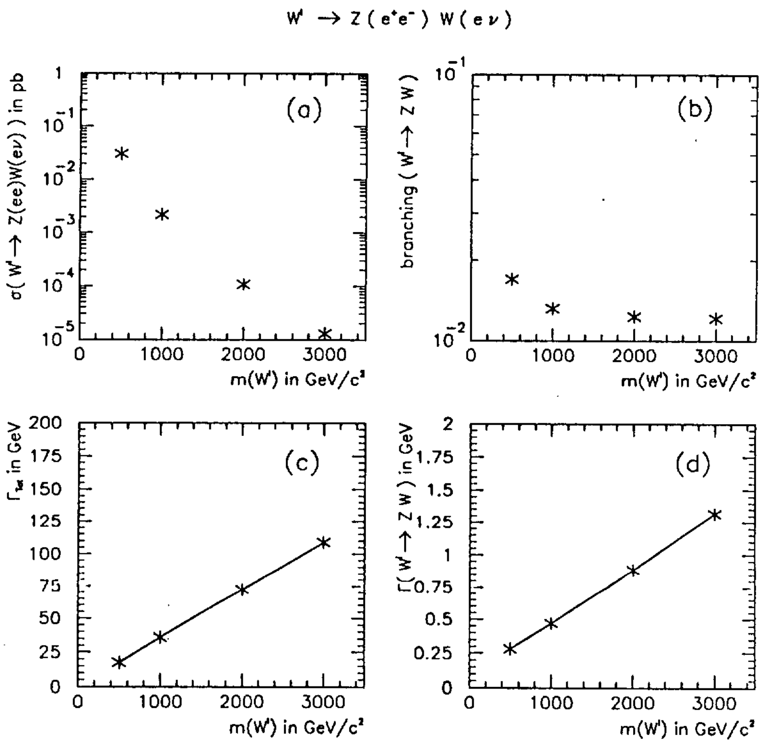

Figure 4: *(a) : cross section times branching ratio, (b) : branching ratio, (c) : total and (d) : partial width as function of* W$'$ *mass.*

4 The process $p\overline{p} \rightarrow W' \rightarrow WZ \rightarrow (e\nu)(ee)$

From a comparison of figure 1 and figure 4 it can be concluded that there is much less signal in this channel. A 500 GeV W$'$still gives 3000 events in an LHC-year, but it decreases rapidly with the increasing mass, and a 2 TeV W$'$ triggers only 10 times. It should be stressed that in the study of this channel, the charge of the leptons has not been used, so when speaking about electrons, both electrons and positrons are meant.

4.1 Efficiency of η and p_T cuts

Also for the 3 electron channel the efficiency has been plotted as a function of the p_T of the 3 highest p_T electrons. From figure 5 b it can be seen that more than 20% of the signal is lost after the rapidity cut for a W$'$mass of $1\,\mathrm{TeV/c^2}$. On the other hand, the loss due to an electron p_T cut of 25 GeV/c (which turns out to be a severe cut for the background) is negligible. For a W$'$mass of 500 $\mathrm{GeV/c^2}$ the efficiency after applying the same cuts is only about 60 %.

4.2 The backgrounds

It has been mentioned previously that there are two important backgrounds. The WZ continuum producing three electrons is a clear case and needs no further explanation. The $t\bar{t}$ case is more difficult since there are many ways to obtain 3 electrons. Considered here is only the decay chain :

$$t\bar{t} \rightarrow W^+(\rightarrow e^+\,\nu)b(\rightarrow e^-\,\overline{\nu}\,c)W^-(\rightarrow e^-\,\overline{\nu})\bar{b}(\rightarrow X) \tag{2}$$

Thus, only one electron comes from a b-hadron. The reason for leaving out the other possibilities, is that a cut on isolation would kill them anyway.

The electron isolation can be defined as the sum over the p_T of all particles within a cone ΔR of 0.2 around the electron (the latter not used):

$$\sum_{\Delta R<0.2} p_T < 5\,\mathrm{GeV/c} \tag{3}$$

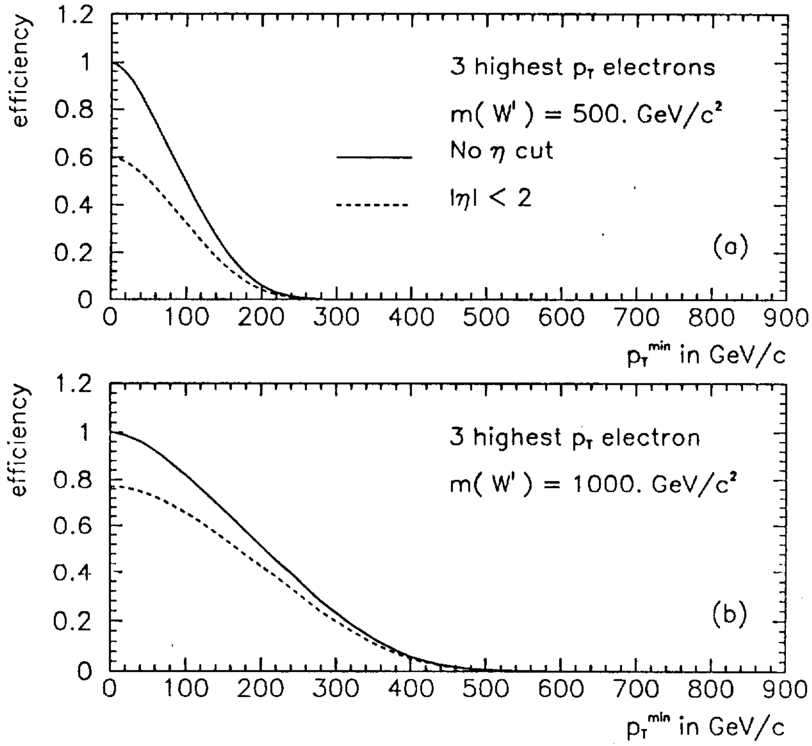

Figure 5: *Efficiency as a function of minimum electron p_T for W′ masses as indicated.*

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}. \tag{4}$$

Another way to get rid of the $t\bar{t}$ background, is to look at the invariant mass of all three two electron combinations. If the pair with mass closest to the Z mass does not lie in the interval:

$$m_Z - 3 \cdot \Gamma_{Tot}(Z) < m_{ee} < m_Z + 3 \cdot \Gamma_{Tot}(Z) \tag{5}$$

the event is rejected. This puts an enormous constraint on $t\bar{t}$ events, while the W′ signal, and the WZ background are hardly affected. In figure 6 the differential cross section is plotted as a function of p_T^Z. In all cases the "Z" momentum is reconstructed from the electron pair with mass closest to the Z mass. It is clear from figure 6 that the $t\bar{t}$ background is enormous when no cuts are applied, but that it drastically decreases after the electron p_T cut and the invariant mass cut. The numbers corresponding to the different cuts can be found in table 2. In each successive line the quoted cut is applied in addition to that of the previous lines. Thus in the fifth line all above mentioned cuts are applied. The cut on the invariant "Z" mass is clearly not suffient to get rid of the background. It's influence on $t\bar{t}$ background is large as can be expected, but not enough to kill it. The extra cut on the electron p_T is a good choice for both backgrounds, but the situation can be improved by imposing the isolation cut, and in addition a cut on the p_T of the "Z". The value of the p_T^Z cut is chosen in the same way as has been done for the transverse mass cut in table 1.

5 Conclusion

From tables 1 and 2 it can be seen that both channels are worthwhile studying, though for high mass W′'s the leptonic decay channel is the only possibility. Background is in both cases far less than the signal.

References

[1] G.Altarelli, B.Mele, M.Ruiz-Altaba ,Z.Phys. C45 (1989) 109

[2] T.Sjöstrand : Int.Journ.of Mod.Phys. A3 (1988) 75 and Pythia54 and Jetset73 on-line manual.

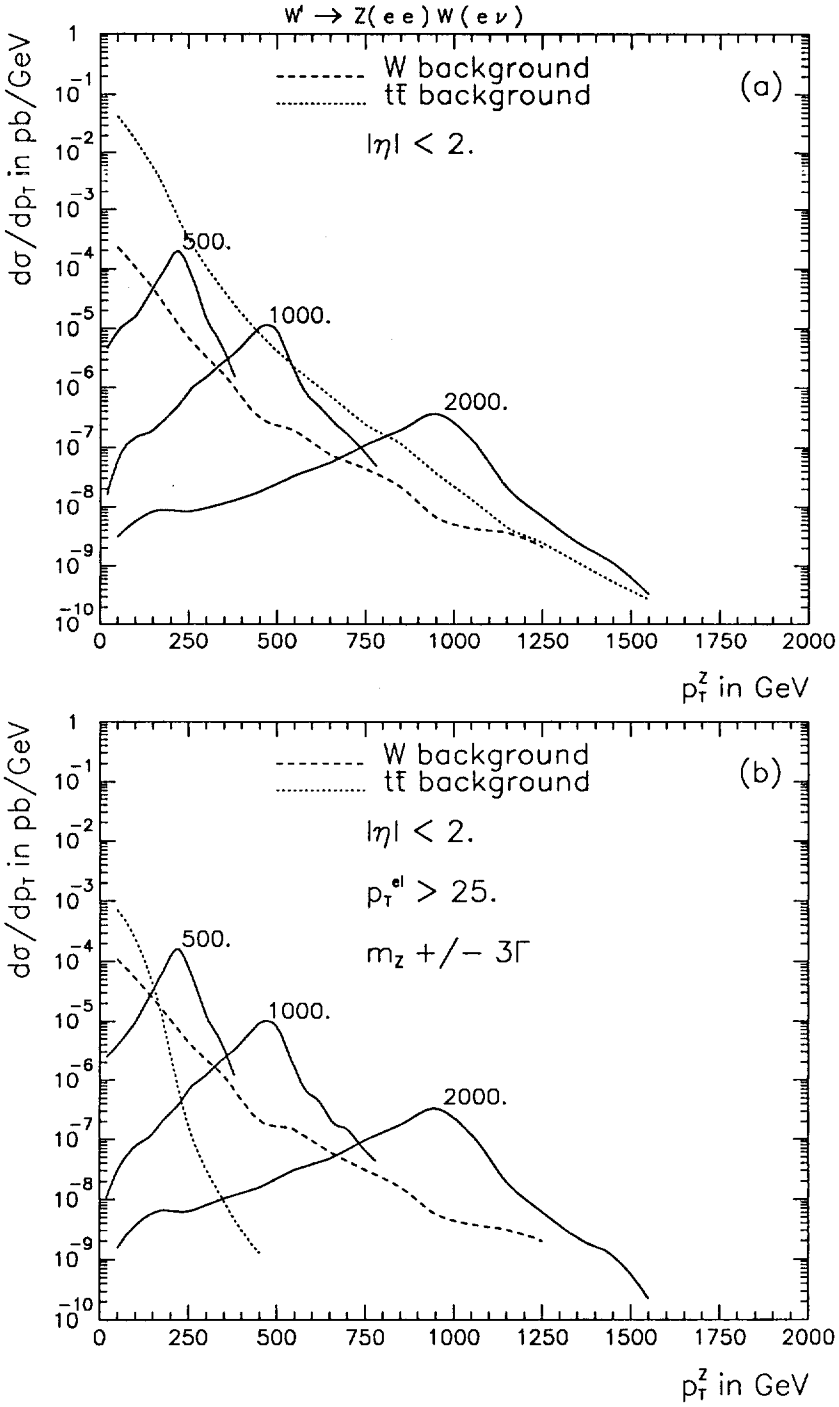

Figure 6: ***Signal and backgrounds for cuts as indicated.***

$m_{W'} = 500.\ \mathrm{GeV/c^2}$	$\sigma \cdot BR = 0.030$ pb $\sigma_{\|\eta\|<2} = 0.0181$ pb		
cuts:	# $W' \rightarrow WZ$	# WZ	# $t\bar{t}$
$\|\eta\| < 2.$	$1.81\ 10^3$	$2.85\ 10^3$	$4.76\ 10^5$
$+\ m_Z \pm 3 \cdot \Gamma$	$1.64\ 10^3$	$2.55\ 10^3$	$6.29\ 10^4$
$+p_T^e > 25$	$1.40\ 10^3$	$1.41\ 10^3$	$7.42\ 10^3$
+isolation	$1.36\ 10^3$	$1.38\ 10^3$	132
$+p_T^Z > 160$	1200	110	-
$m_{W'} = 1000.\ \mathrm{GeV/c^2}$	$\sigma \cdot BR = 0.0022$ pb $\sigma_{\|\eta\|<2} = 0.0017$ pb		
cuts:	# $W' \rightarrow WZ$	# WZ	# $t\bar{t}$
$\|\eta\| < 2.$	167	$2.85\ 10^3$	$4.76\ 10^5$
$+\ m_Z \pm 3 \cdot \Gamma$	149	$2.55\ 10^3$	$6.29\ 10^4$
$+p_T^e > 25$	143	$1.41\ 10^3$	$7.42\ 10^3$
+isolation	137	$1.38\ 10^3$	132
$+p_T^Z > 320$	127	12	-

Table 2: *Event rates for signal and background at one year running with* $\mathcal{L} = 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$.