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Intermediate Mass Higgs $\rightarrow$WW Decay

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Abstract

This Higgs decay mode, $H \rightarrow W^+W^-$, is very important in the Higgs mass range above the W^+W^- threshold and below the Z^0Z^0 threshold. In this note, the leptonic decays of this process, $H \rightarrow W^+W^- \rightarrow e^+\mu^-$, has been studied for various top mass, and it is shown that the background against this signalcan be reduced to the same size as the signal and that we can expect to have statistically significant signal.

1 Overview

For the Higgs particle with the mass above the W pair threshold, $H \rightarrow W^+W^-$ is the dominant decay mode. This mode is important below the ZZ pair threshold because this is the only mode which provides a descent event rate, although the background is fairly large and the signal does not show any clear structure. Another importance of this decay mode is that, combining with the ZZ^* measurement, the test can be done if the parent particle is consistent with the Higgs particle.

In this note, the decay mode of $H \rightarrow W^+ + W^- \rightarrow e^+ + \mu^-(+c.c.)$ has been studied for the Higgs particle with mass between the W pair threshold and the Z pair threshold. The total cross section of the signal is 1.56 pb (170 GeV Higgs, 140 GeV top), and the total evens/year is 1.56×10^4 with $L = 10^{33}$. So strong cut can be applied to reject backgrounds. As is shown in table 1, the net efficiency for the signal using the cuts in this note is around 5%.

It is shown that statistically significant signal can be observed, 900 Higgs signal with 1800 backgrounds per year with $L = 10^{33} cm^{-2} sec^{-1}$.

2 Monte Carlo

The following study has been done using PYTHIA 5.5 Monte Carlo without any detector simulations. All the cuts and results are not sensitive to the details of the detectors. It is assumed that the detector covers the rapidity region $\eta = \pm 2.5$ for leptons, hadrons and γs.

Only those leptons with $p_t > 20GeV$ coming from the W decays pass the isolation cut described below. In order to gain the statistics, all Ws and Zs are forced to decay into electrons and muons, and proper branching ratios are taken into account afterwards. This has been tested by generating 10^6 $q + g \rightarrow W + q'$ events. This test also proved that $b + g \rightarrow W + t$ is the dominant source of the background among the $q + g \rightarrow W + q'$ subprocess, so only $W + t$ production has been studied for this kind of subprocesses.

3 Isolated lepton selection

To reject those leptons contained in jets, especially charm and bottom jets, the leptons are required to pass the following isolation cut.

1. $p_t(e, \mu) > 20GeV$
2. $|\eta(e, \mu)| < 1.5$
3. $\Sigma E_t(dR < 0.3) < 5GeV$

The event is required to have a pair of opposite sign electron and muon. If the event has more than one electron or muon, the one with the largest pt is used. No explicit rejection using the number of electrons or muons are applied. After applying the following cuts, the cut using the number of same leptons is not necessary.

The p_t cut can be increased up to 30 GeV if necessary, e.g., if there were any problems in the single lepton trigger rate or decay muon problem. The signal rate decreases by 30 to 40 %, but the background rates also decrease and one can still retain significant signal. The signal rate increases by 10% or so by decreasing the p_t cut to 10 GeV, but backgrounds tend to get bigger and more complicated, and there is little overall gain.

The strong rapidity cut $|\eta(e, \mu)| < 1.5$ is necessary to reject those backgrounds which have small hadron activities. This is discussed later.

4 Background processes

The main backgrounds of the $H \rightarrow W + W \rightarrow e + \mu$ signal are

1. $q + \bar{q}, g + g \rightarrow t + \bar{t}$

2. $b + g \rightarrow W + t$

3. $q + \overline{q} \rightarrow W + W$

4. $\gamma^*, Z^* \rightarrow \tau + \overline{\tau}$

5. $q + \overline{q'} \rightarrow W + Z$

The cross sections of these processes are summarized in Table 1.

The cross section of $\tau + \overline{\tau}$ is large, but can be easily reduced by the acollinearity cut, cut 1 in the next section.

The total cross section of the $W + Z$ production is of comparable size as the signal, but the requirement on the sign of the lepton pair, acollinearity and ΣE_t can easily reduce this background to a negligible level.

5 Background rejection cuts

These backgrounds are reduced by the following cuts.

1. $|\phi_e - \phi_\mu| < \pi/2$

2. $|\eta_e - \eta_\mu| < 1.0$

3. $\Sigma E_t(same) < 35GeV$

4. $\Sigma E_t(opposite) < 35GeV$

In this section, 170 GeV Higgs and 140 GeV top quark are assumed. The mass dependence is summarized in Table.1. The event rates are calculated using $L = 10^{33} cm^{-2} sec^{-1}$.

In Fig.2 to 4, no cuts has been applied except for the isolated lepton selection,

- $p_t(e, \mu) > 10GeV$
- $|\eta(e, \mu)| < 2.5$
- $\Sigma E_t(dR < 0.3) < 5GeV$

Looser cuts are used to show the significance of various cuts. The cross sections of three backgrounds, $t + \overline{t}$, $W + \overline{t}$ and $\tau + \overline{\tau}$ are scaled by 0.01 in Fig.2 to 4, and by 0.2 in Fig.5.

In Fig.2, $|\phi_e - \phi_\mu|$ distributions of the signal ($H \rightarrow W + W$) and backgrounds listed above are compared. As can be seen from this plot, the cut using the ϕ difference reduces the $\tau + \overline{\tau}$ background to a negligible level. Also shown in this plot is the $W + Z$ background to present the overall comparison of the magnitudes of various processes. In

the following figures, $\tau + \overline{\tau}$ and $W + Z$ are not shown, because these backgrounds are negligible.

The second cut using the η difference selects $e\ \mu$ pairs coming from the same source, without explicitly imposing the mass of the $e\ \mu$ pair. In Fig.3, $|\eta_e - \eta_\mu|$ distributions of the signal and the three major backgrounds are compared.

In the third and fourth cuts, $\Sigma E_t(same)$ and $\Sigma E_t(opposite)$ are the sums of E_t of all particles except for neutrinos and two leptons used as the electron and muon pair for the signature of the signal, within $|\eta| < 2.5$ and in the same and opposite hemisphere of the direction of the electron and muon pair in the plane perpendicular to the beam axis. Fig. 1 shows the schematic view in the place perpendicular to the beam axis. These two cuts reduce the backgrounds with high hadron activities. Fig. 4 compares the $\Sigma E_t(same)$ distributions.

Fig. 5 shows the $\Sigma E_t(opposite)$ distribution after applying the above 3 cuts, in addition to tighter p_t cut, i.e.,

- $p_t(e, \mu) > 20GeV$
- $|\phi_e - \phi_\mu| < \pi/2$
- $|\eta_e - \eta_\mu| < 1.0$
- $\Sigma E_t(same) < 35GeV$

The cross sections of $t + \overline{t}$ and $W + \overline{t}$ are scaled by 0.2.

Fig. 6 shows the distribution of the rapidity of electron or muon, whichever is larger, after requiring $\Sigma E_t(opposite) < 35GeV$, in addition to the cuts for Fig.5. The tight rapidity cut, $|\eta(e, \mu)| < 1.5$, is necessary to reduce those backgrounds in which some jets are produced along the beam direction and thus the ΣE_t cut does not work.

6 Event rates and Mass dependence

Table 1 summarize the total cross sections of the signal and backgrounds, including the branching ratios to electrons and muons, and the event rates/year after all the selections mentioned in Section 3. and 5.. The event rates with three Higgs masses (162 GeV, 170 GeV and 180 GeV) and two top quark masses (140 GeV and 250 GeV) are included.

As can be seen from this table, the S/N ratio is 1/2 with top quark mass 140 GeV and 3/2 with top quark mass 250 GeV, with very large statistical significance. As the top quark mass becomes larger, the production rate of the backgrounds involving top quark production becomes smaller and the S/N ratio becomes better.

Although the signal shows no clear structure, as is shown below, the background estimation can be done by extrapolating the event rates given by using loose cuts when the experiment starts.

7 Signature of the Signal

This decay mode, $H \rightarrow W + W \rightarrow e^+ + \mu^- + \nu_e + \overline{\nu_\mu}$ does not have any clear signature because of the missing neutrino momentum. After the selection, the backgrounds have essentially the same structure as the signal, a W pair with small relative motion, decaying into a electron and muon, with small hadron activity. Consequently, there is no distribution which can clearly identify the Higgs signature.

Fig. 7 and 8 show the distributions of invariant mass and transverse mass of the lepton pair. In these figures, the solid line is the sum of the signal and all backgrounds, and the dotted line is the sum of all backgrounds. The statistical errors of the backgrounds are also shown. Some bumps are due to poor statistics of the Monte Carlo events, especially a few $t + \bar{t}$ backgrounds multiplied by 60.

The shapes of the distributions of the signal and background are quite similar. The significance of the signal strongly depends on the estimation of the background using the real data, but even if the background estimation done in this analysis is wrong by factor of 10, still the significance of the signal is 5σ.

Acknowledgements

I would like to thank B. Barsih for his financial support and giving me the opotunity to work at Caltech, and R-Y Zhu for his continuos supports and discussions.

Table 1: Cross sections and event rates of signal and backgrounds

Process	Higgs Mass (GeV)	Top Mass (GeV)	Cross Section(1) (pb)	Events/year(2) $L = 10^{33}$
$H \rightarrow W^+ + W^-$	162	140	1.58	1018
$H \rightarrow W^+ + W^-$	170	140	1.56	886
$H \rightarrow W^+ + W^-$	170	250	1.39	873
$H \rightarrow W^+ + W^-$	180	140	1.43	820
$q + \overline{q}, g + g \rightarrow t + \overline{t}$		140	320	448
$q + \overline{q}, g + g \rightarrow t + \overline{t}$		250	31.8	13
$b + g \rightarrow W + t$		140	95.5	1337
$b + g \rightarrow W + t$		250	30	234
$q + \overline{q} \rightarrow W + W$			2.37	330
$\gamma^*, Z^* \rightarrow \tau + \overline{\tau}$			137 (3)	0
$q + \overline{q'} \rightarrow W + Z$			1.07	5
Total background		140	556	1790
Total background		250	202	582

1. Total cross section including branching ratios.

2. Event rates after all cuts are applied.

3. $p_t(\tau) > 20GeV$

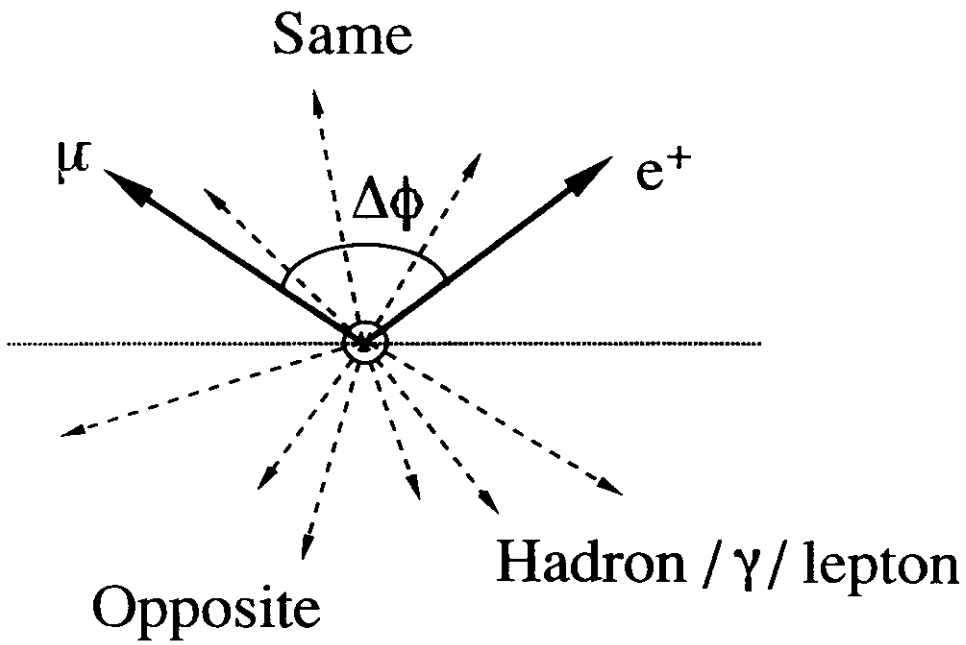

Fig. 1 Shematic view of the event
in the plane perpendicular to the beam axis.

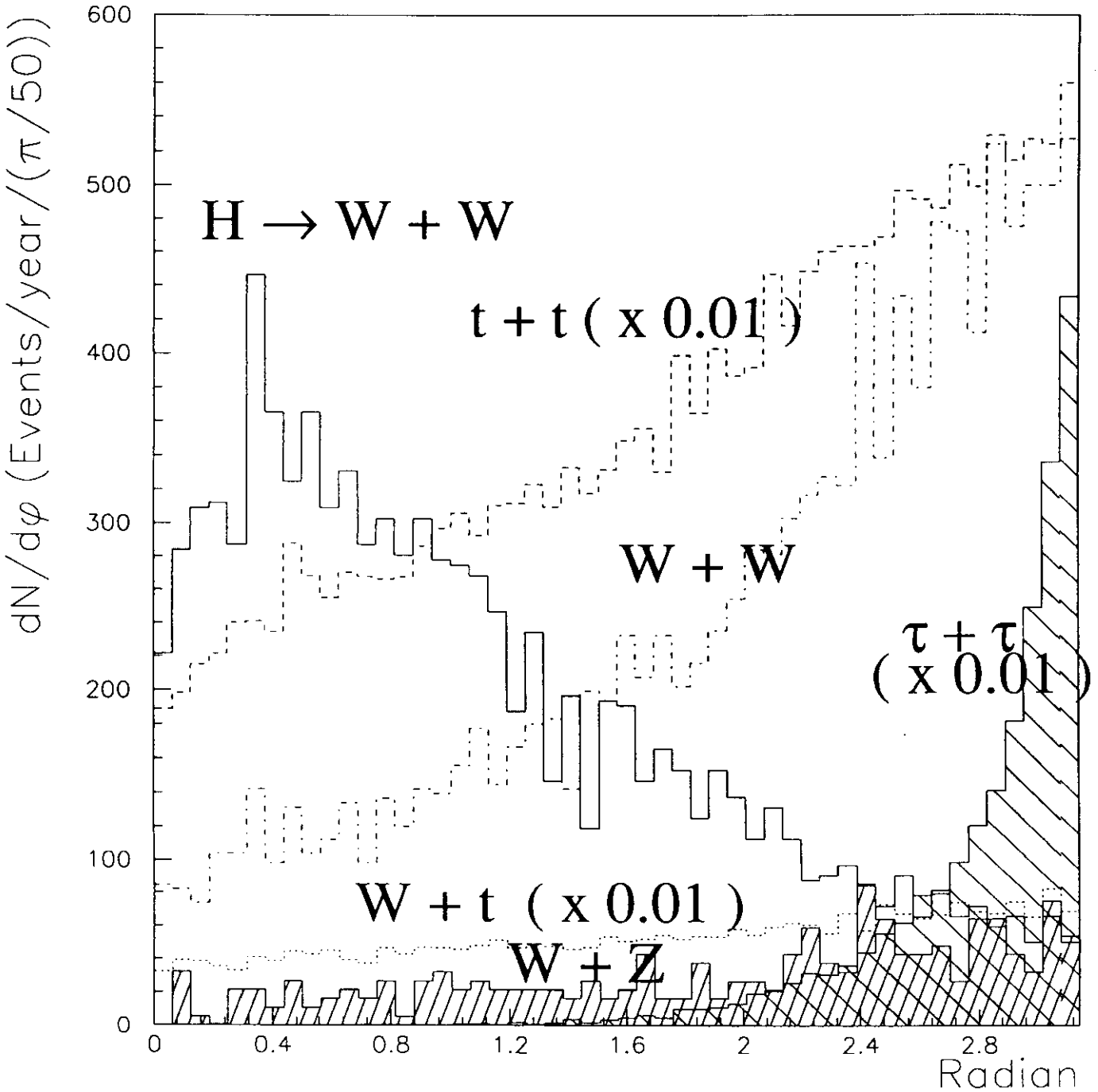

Fig.2 Phi(e) - Phi(mu)

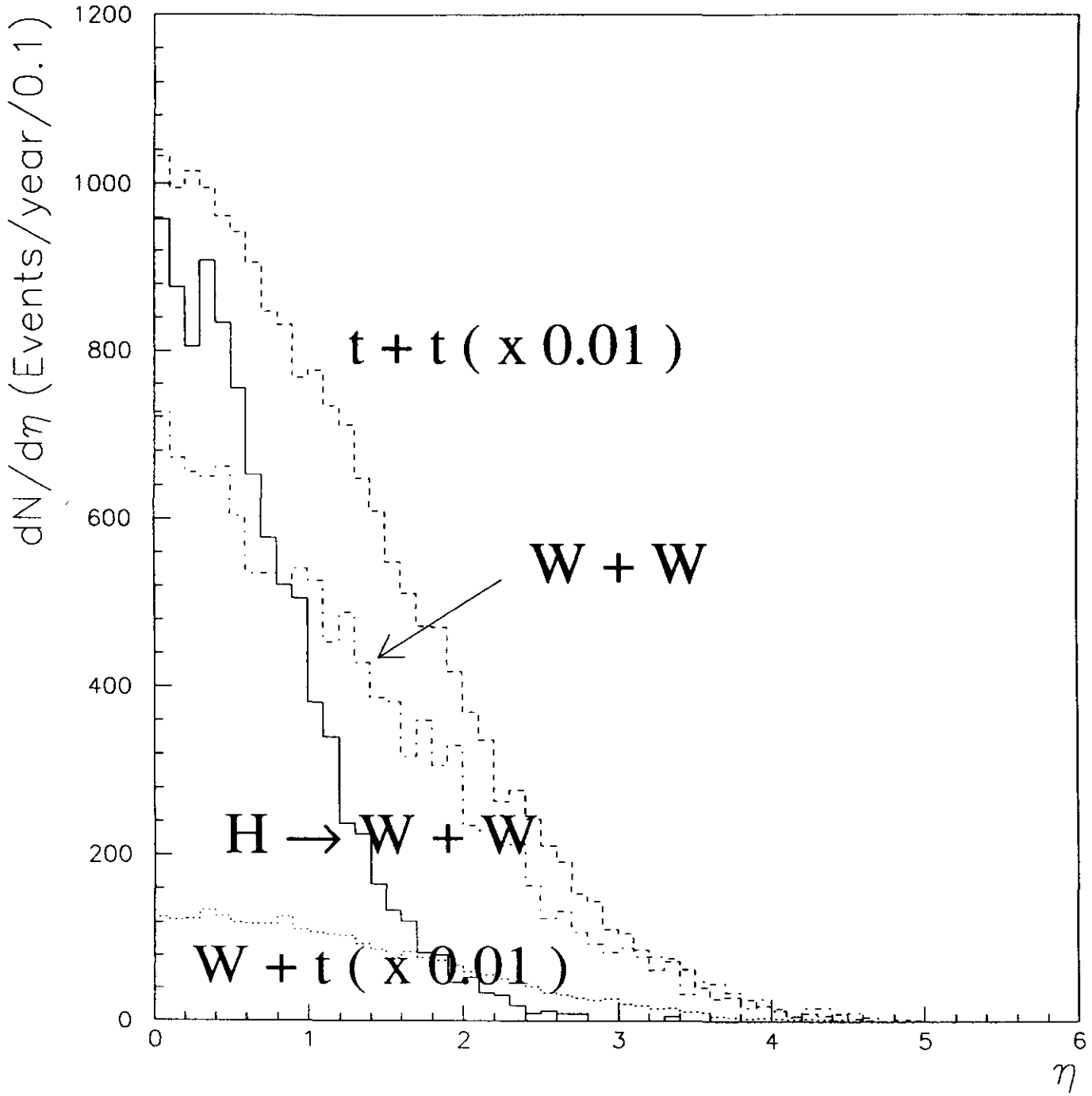

Fig.3 eta(e) - eta(mu)

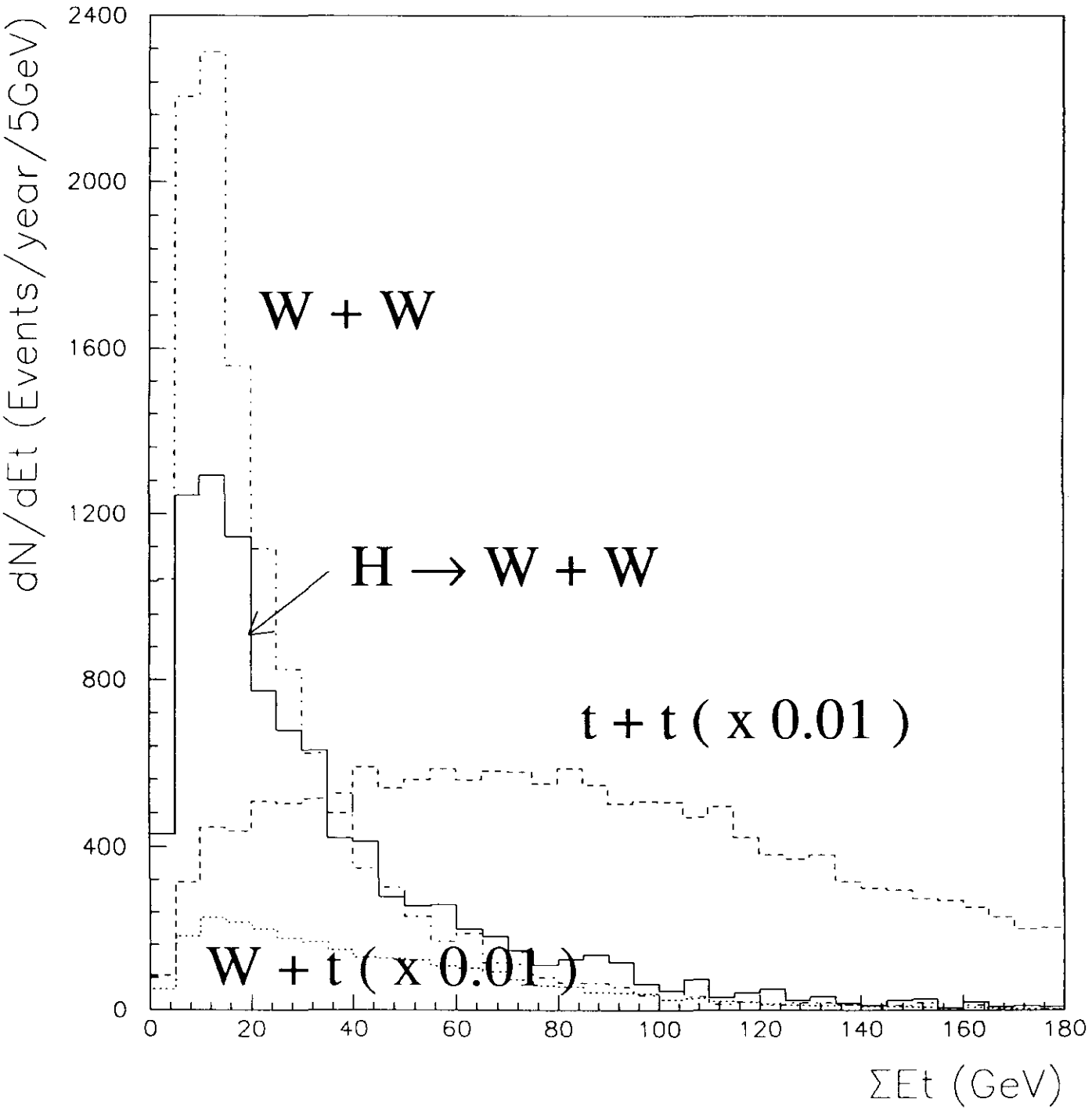

Fig.4 Et sum (same)

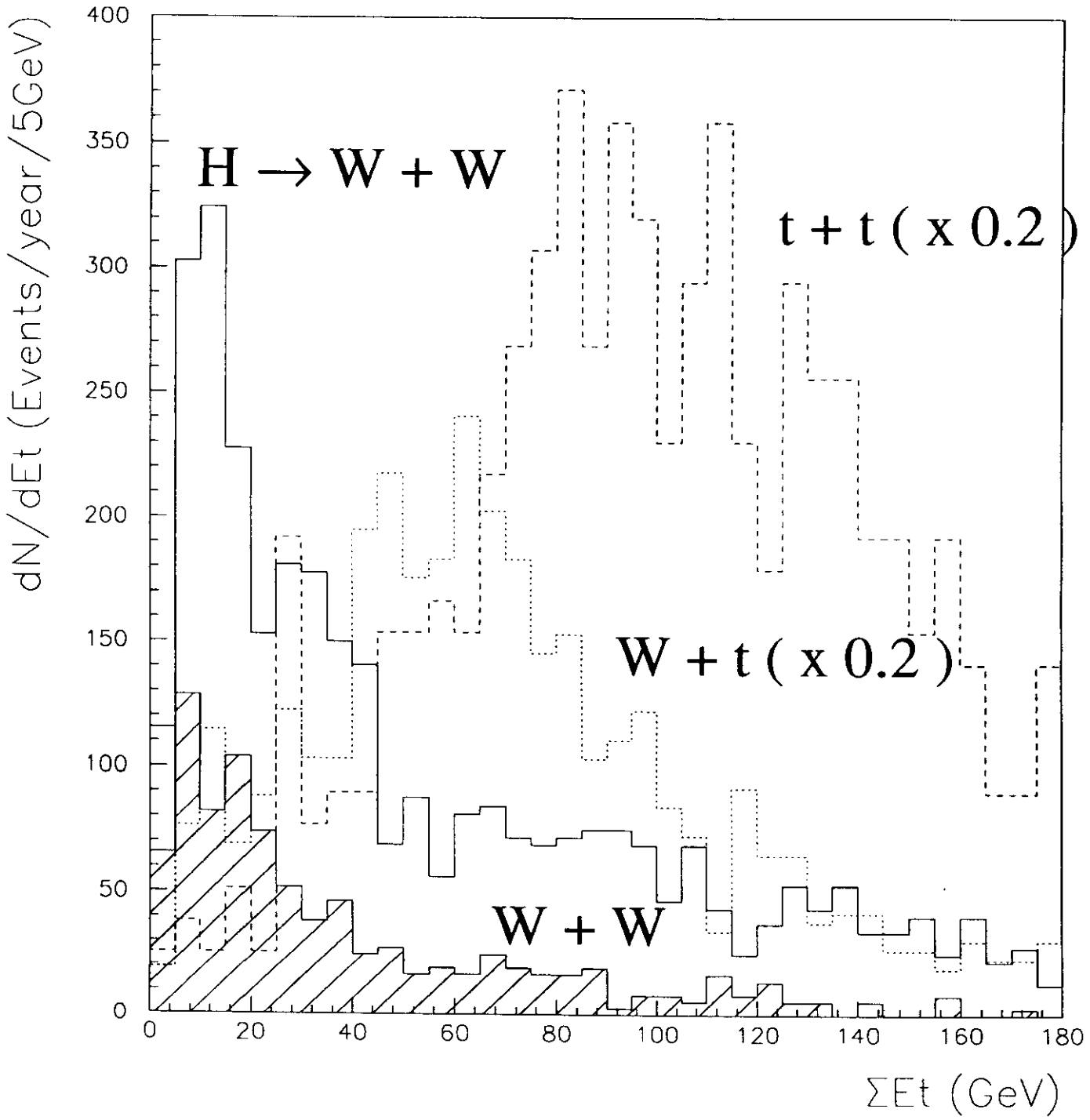

Fig.5 Et sum (opp) w/ other cuts

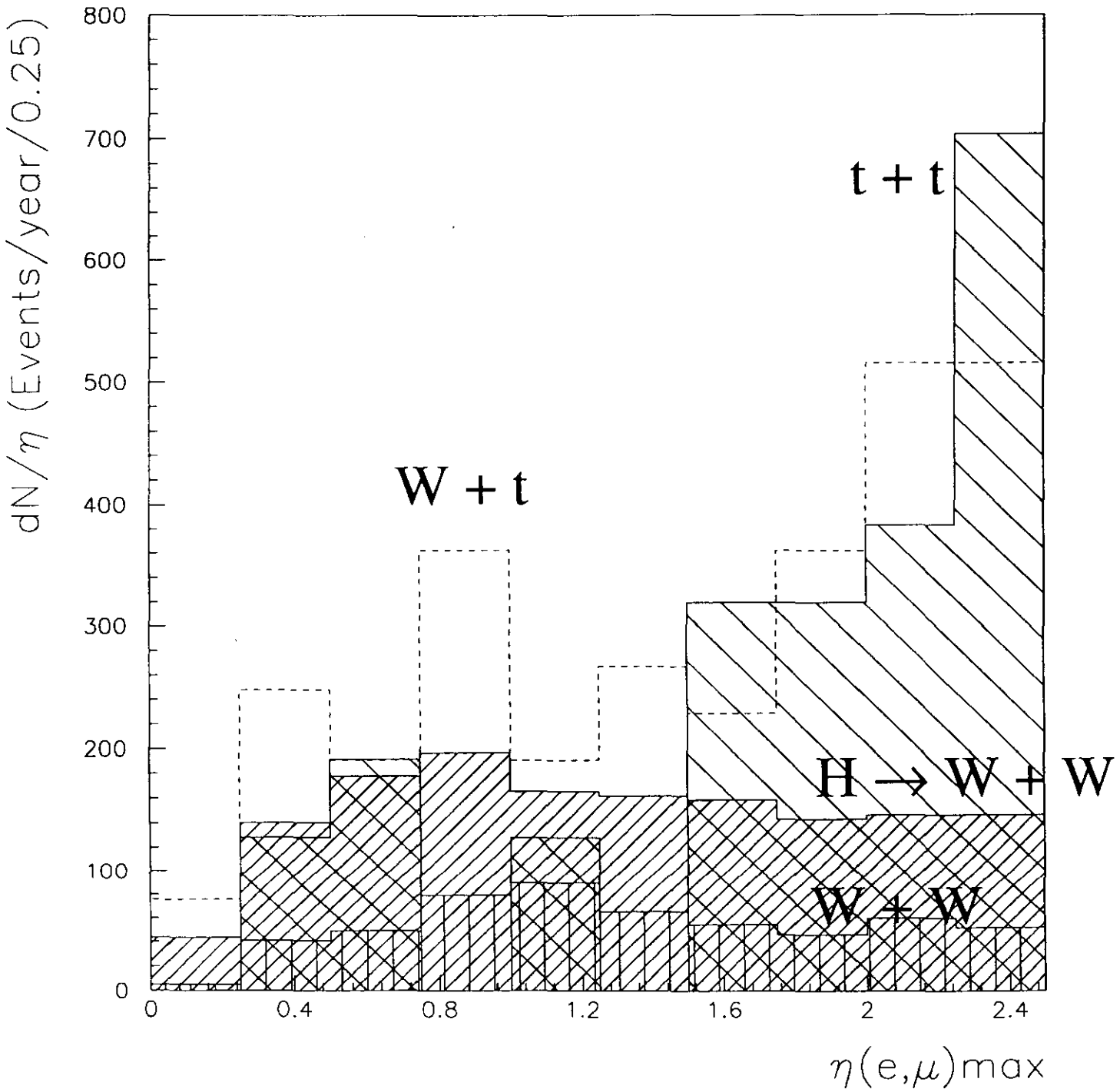

Fig.6 eta(e,mu) max w/ all cuts

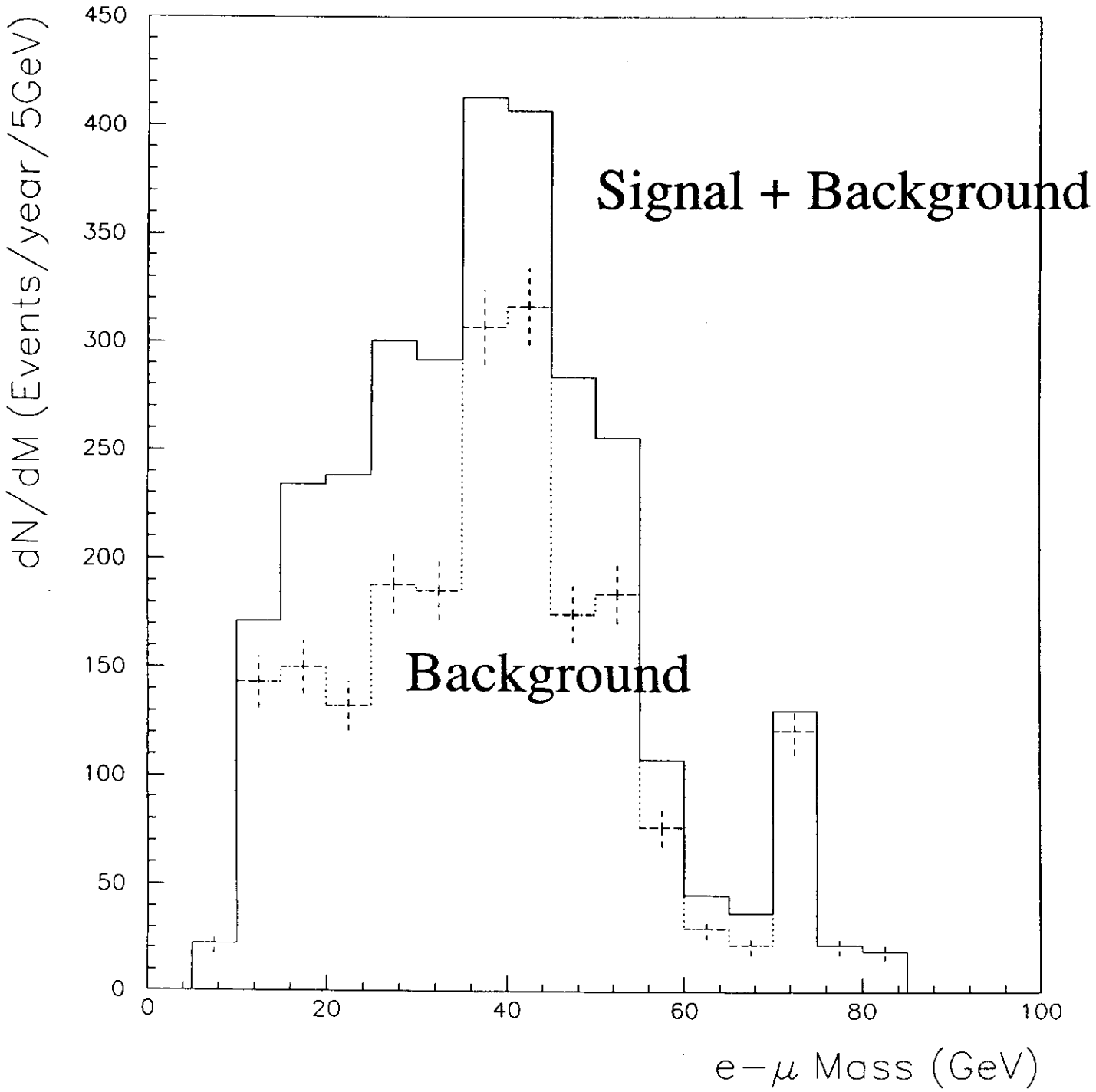

Fig.7 E-Mu Mass

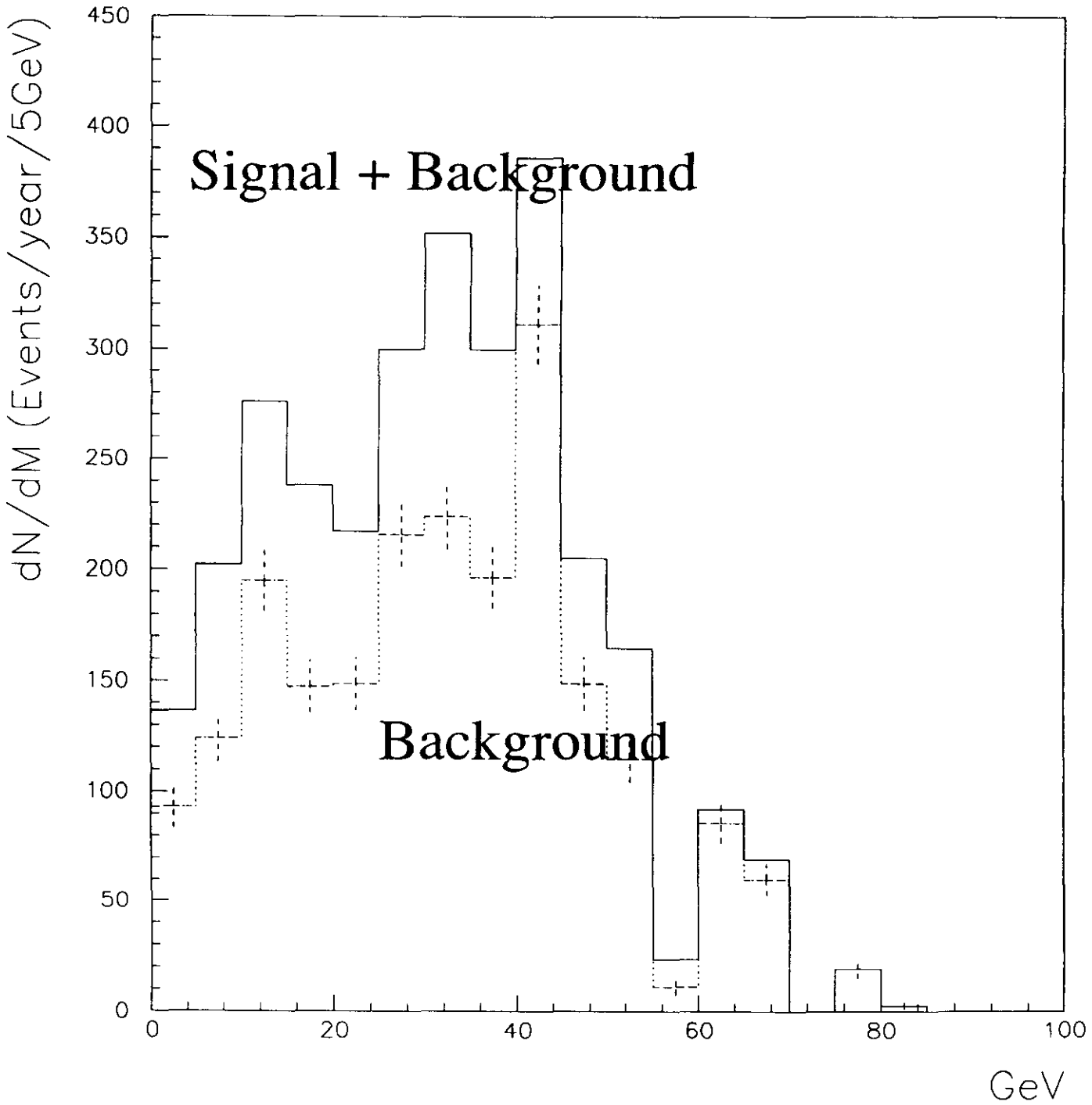

Fig.8 E-MU Tramsverse Mass