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SDC-90-00113

SDC
SOLENOIDAL DETECTOR NOTES

PRODUCTION OF WH $\rightarrow$ W$\gamma\gamma \rightarrow$ e/$\mu\gamma\gamma$

M. L. Mangano

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PRODUCTION OF $WH \to W\gamma\gamma \to e/\mu\gamma\gamma$

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Pisa U

Perhaps the most critical mass-range for the discovery of the Higgs particle at the SSC is the intermediate range, *i.e.* values of the mass below the threshold for the production of a pair of real Z's. Various studies (see for instance the SDC EoI, the LoI, and the more specific SDC Note [1]) have shown that even below threshold, and for H masses above 130-140 GeV, the production and decay of the Higgs into a pair ZZ^* (Z^* being an off-shell virtual Z) is still detectable in the 4 charged lepton channel above backgrounds with the expected integrated luminosity. The possibility to discover the Higgs in the region between 80-90 GeV (reachable in principle at LEPII) and 130-140 GeV, however, still hasn't been fully explored. The best discovery channel, namely the production of Higgs and its decay into a pair of monochromatic photons, requires EM calorimeter resolution beyond what can be achieved by the SDC detector to provide the energy resolution necessary to separate the thin Higgs resonance from the continuum of the QCD background. This calls for alternative strategies to search for an intermediate Higgs with SDC.

The process I will consider here is the associated production of the Higgs with a W, the equivalent of the Bjorken process which in e^+e^- collisions gives rise to associated production of Higgs and Z. In the mass range we are interested in the production rate for this process is large enough to leave hopes for a discovery, provided one can find a good decay channel. Decay channels where hadrons are produced (like $HW \to b\bar{b}e/\mu$, $HW \to \tau\bar{\tau}e/\mu$ or $HW \to \gamma\gamma q\bar{q}'$), seem to be excluded by studies of the backgrounds [2]. The hadron-less decay $HW \to \gamma\gamma e/\mu$ is by far the cleanest and the one which has more chances of surviving possible backgrounds. Hence I will consider here this last possibility.

The signal we will be looking for, therefore, is a final state with two hard photons reconstructing the invariant mass of the Higgs, together with a charged lepton and missing transverse momentum. The spectrum of the lepton and of the missing energy should be consistent with the decay of a W boson with an average p_t of the order of half the W mass. The rest of the event should be relatively quiet, because there is no radiation from the final state. Since the initial state for the production of the WH pair is given by a $q\bar{q}$ pair, we also expect the initial state radiation to be sligthly suppressed with respect to a generic QCD event. So the structure of the underlying event will be the one typical of a Drell-Yan event, like the production of a W with small transverse momentum.

The possible sources of backgrounds that we considered belong to four categories; first of all we have the W *backgrounds*:

- Direct production of $W\gamma\gamma$ from ordinary Standard Model processes (like emission of two hard bremstrahlung photons from a $q\bar{q}'$ pair in the initial state, with subsequent fusion of the pair into a W boson). This is the only irreducible physics background.
- Standard Model production of $W\gamma j$, where the jet is misidentified as a photon.
- Standard Model production of Wjj, where both jets are misidentified as photons.

Then we have *b backgrounds* [3]:

- Production of a b quark with two hard bremstrahlung photons, where the b decays then semileptonically and the lepton is hard enough to fake a W.
- Production of $b+\gamma+jet$, where the b will fake the W and the jet will fake the second γ.
- Production of $b+\bar{b}+\gamma$, where one of the b's fakes the W and the other develops into a low-multiplicity jet which might occasionally fake the second γ.

In a third class we considered backgrounds coming from light quarks (*q backgrounds*):

- Production of three jets, where one of them fragments into a charged pion carrying most of the energy and faking the lepton, and where the other two jets fake the photons.
- Production of two jets and a photon, with one jet faking the lepton and the other faking the second γ.
- Production of one jet and two photons, with the jet faking the lepton.

Lastly we considered the backgrounds due to *top* quarks:

- Production of a $t\bar{t}$ pair, with one of the two W's decaying leptonically and two of the various jets of the event faking the photons.

In this note I will study these processes and show plots for the invariant mass distribution of the di-gamma system for the signal and the backgrounds. In the next Section I will describe the cuts used, the j-γ, b-W and b-γ rejection criteria and the matrix elements employed in the calculations. In the following Section I will present the results of the MC study and then the conclusions.

1 The Analysis Criteria

In this study all of the simulations were performed at the parton level, using exact matrix elements for the hard processes. All of the momenta and energies were smeared according to the LoI resolutions, as implemented in the Fortran routines provided by I. Hinchliffe and M. Shapiro [4].

The branching ratios for the radiative decay of the Higgs were taken from a very recent calculation which takes into account the QCD corrections to the $H \to b\bar{b}$ width [5]. Plots of the various BR's obtained from this work are given in Figure 2.

The cuts applied to both signal and backgrounds are the following:

- $p_t(\text{lepton}, \gamma) > 20\text{GeV}$
- $M_{\gamma\gamma} > 50\text{GeV}$
- $|\eta(\text{lepton}, \gamma)| < 2.5$
- $\Delta R(\gamma_1, \gamma_2) > 0.4$
- $\Delta R(\gamma, l) > 0.4$

where ΔR is the separation in the $\eta - \phi$ space between the two γ's and between the charged lepton and the γ's. These separation cuts, which do not significantly affect the signal, are imposed in order to isolate regions of phase space in which collinear partons are present in the final state of the fake-γ and fake-W backgrounds. Since two massless particles with an invariant mass larger than 50 GeV and p_t larger than 20 GeV cannot be too close in $\eta - \phi$ space, this singular region is partly screened by our cuts, and therefore the background cross sections change very slowly as a function of the $\Delta R(\gamma_1, \gamma_2)$ cut, provided this is not chosen to be too small.

In order to account for the misidentification of a jet, leading to the jet faking a photon, I multiplied the rates by a rejection factor R_{gj} per each jet. I will show plots using the following values of R_{gj}:

$$R_{gj} = 10^{-3}\,,\, 5 \times 10^{-4}\,,\, 3 \times 10^{-4}. \tag{1.1}$$

The use of the first two values can be justified on the basis of jet fragmentation data from CDF [7], these values representing a range for the probability of a jet fragmenting in such a way as to have a single π^0 carrying most of the energy. The third more optimistic value might be achieved by improving the π^0/γ discriminating power of the detector [8]. As will be clear at the end, the intermediate value R_{gj}=5×10^{-4} should be sufficient to allow a detection of the Higgs signal over the background with an integrated luminosity of the order of $10^5\, pb^{-1}$.

In the case of the q backgrounds we also have to account for the probability of a jet faking the charged lepton. We estimate this probability to be no larger than 10^{-4}, by

convoluting the probability of the jet fragmenting into a $\pi^{\pm}$ carrying most of the energy with the probability of misidentifying the charged pion with the charged lepton.

As for the probability of a b quark developing into a jet that will fake a γ, I used a rejection factor $R_{\gamma b} = 10^{-4}$. Although no data are available to justify this value, we believe this to be a conservative estimate, considering that even if the b quark were to evolve into a single isolated meson, still the decay of this B-meson should be easily distinguishable from a single isolated photon.

The momentum of the b quark was smeared using a Peterson-like fragmentation function before its decay into the lepton; in this procedure the weight of the events was multiplied by the following function [6]:

$$w_{pet}(z) = 0.238 \frac{z(1-z)^2}{(0.015z + (1-z)^2)^2}, \tag{1.2}$$

where z if the fraction of the b momentum carried by the B meson after fragmentation and where the overall coefficient normalizes the integral of the distribution to 1.

After the Peterson fragmentation, the b that should fake a W is decayed using the standard $V - A$ distribution into a $charm - lept - \nu$. Events where the lepton passes the cuts given above are considered as background events. In order to explore the effect of requiring the b-lepton to be isolated (like the W-lepton should be), I compared the p_t distribution of the lepton with and without the following isolation cut:

> $p_t(charm) \; < \; 2\,GeV$ if the *charm* quark is within 0.2 units in $\eta - \phi$ space from the lepton.

The two distributions are shown in Figure 1. After the other cuts on the γ's are imposed, only 1/20 of the leptons above 20 GeV satisfies the isolation criterion. Our isolation cut is conservative, because in a real event the B meson is accompanied by additional radiation, and there is more than just the c quark surrounding the lepton; on the other hand a high luminosity environment might require a softer isolation cut, in order not to affect the isolation of the real W-leptons. So we used in our study a rejection factor of 1/10, independent of the p_t of the lepton, in order to account for the probability of the b-lepton being isolated. Rejection factors of the order of 1/40 were found in a more detailed study of b semileptonic decays by K. Einsweiler [9], who studied the effect of gluon radiation, underlying event and minimum bias pile-up in a realistic detector simulation. Therefore we consider our choice a conservative one. Nevertheless – as will be clear from the results shown in the next Section – a factor of 1/10 is sufficient to push the b backgrounds below the level where they could interfere with our measurement. Additional rejection power might be provided by the use of the secondary vertex tagging, but we will not use this tool here.

The matrix elements for the signal are given in ref.[10]; those for the $W\gamma j$ and $W\gamma\gamma$ processes were calculated *ex-novo*. The results of the $W\gamma\gamma$ calculation were checked

against an independent calculation by Kleiss, Kunszt and Stirling [5]. I made many different technical checks (infrared behaviour, collinear factorization) on them and on those for the $W\gamma j$ process to make sure they are correct. The calculation of the Wjj background is based on calculations and a program developed with S. Parke [11], which was also compared against previous calculations and similar codes (like Papageno [12]).

The matrix elements for the processes involving the b quarks were calculated in [13]. I obtained the Fortran routines directly from the authors and implemented them in a parton level MC similar to the one used for the W processes.

The matrix elements for the q backgrounds have been known for a long time [14], and are implemented in many standard parton-level Monte-Carlos. Here they were added to the main program which was used for the study of the other backgrounds.

In all of the calculations the structure function set HMRSB was used.

2 Results

The signal distributions were generated for four values of the Higgs mass, namely:

$$M_H = 80, \quad 100, \quad 120, \quad 140 \text{ GeV}. \tag{2.1}$$

The γ-γ invariant mass distributions for the signals will be superimposed onto the various backgrounds. The backgrounds where the W or the photons are faked will be plotted after having been multiplied by the rejection factors described in the previous Section.

I will start from the comparison with the b backgrounds. In figure 3 I display the $\gamma\gamma$ invariant mass distribution for the following processes added in sequence: $b\gamma\gamma$ (dotted line), $b\gamma\gamma+ b\gamma j$ (dashed line) and finally $b\gamma\gamma+ b\gamma j + b\bar{b}\gamma + signal$ (solid line). In this plot the value R_{gj}=10^{-3} was used, as this rejection factor seems to be more than enough to give an acceptable signal-to-noise ratio. From this plot we conclude that the b quarks are not a dangerous background.

In figures 4, 5 and 6 I plot the W backgrounds, where the three values of R_{gj} given in Eq. (1.1) were used. The three lines correspond to the addition in sequence of the following processes: Wjj (dots), $W\gamma j$ (dashes) and $W\gamma\gamma+ signal$ (solid). The most serious background comes from $W\gamma j$, where the jet fakes the second γ. Several distributions were studied (like angular correlations between the photons, and between the lepton and the jets), but none of them showed relevant differences between the signal and the background so as to allow for additional cuts to be imposed without a serious loss in the signal as well.

The jjj and $jj\gamma$ backgrounds, with the cuts described earlier, give a total rate of 65μb and 36nb, respectively [15]. Using R_{gj}=5×10^{-4} and using the j/lepton rejection of 10^{-4} leaves a total rate of the order of few femtobarns (3.2fb and 1.8fb, respectively), which is almost irrelevant as these events have a m_{jj} spectrum which is smeared almost flatly

over the 50< m_{jj} <200 range. The $j\gamma\gamma$ background is a bit larger, but still sufficiently low as not to affect the signal (see figure 7).

Finally we come to the t backgrounds. Here the most serious concern comes from the possibility that the second W will decay into a pair of jets, with both jets fragmenting into isolated single π^0's faking a γ-γ peak with $m_{jj} \simeq M_W$.

Using current algebra and vector-dominance one can readily estimate the BR for the exclusive two-pion decay of the W to be smaller than 10^{-10}. Furthermore, the exclusive 2-pion decay would give rise to a $\pi^{\pm}\pi^0$ final state, which will be distinguishable from a $\pi^0\pi^0$ final state. Exclusive final states with higher multiplicity have larger BR's, but then the invariant mass of the π^0 pair possibly present in the final state will be far smaller than the W mass.

A precise estimate of these effects goes a bit beyond what can be calculated today from QCD, and only future data will provide us with the needed information. To get an order-of-magnitude estimate, I will therefore assume that the W will fake the photon pair with a probability of 2.5×10^{-7} (which would correspond to R_{gj}=5×10^{-4} for this process) and that the invariant mass of the pair will be spread over a 10 GeV range (let us notice that the natural width of this fake di-gamma resonance can't be smaller than the W-width).

With these assumptions the estimated area under the peak of a Higgs with $M_H \simeq M_W$ (integrating over a 4GeV bin) would be:

$$10^{-7} \times \sigma_{t\bar{t}} \times BR_{1l} \times (accept.), \tag{2.2}$$

where $\sigma_{t\bar{t}}$ is a function of the t mass, BR_{1l} is the branching ratio for one (and only one) W decaying into e/μ ($BR_{1l} = 2 \times 0.22 \times 0.78 \simeq 0.3$), and where we should also take into account some geometrical acceptance factor, easily computable with the MC.

To keep these rates below the 0.4 fb threshold (which is approximately the M_H = 80GeV signal in a 4GeV bin around the Higgs peak) requires $\sigma_{t\bar{t}}$ to be less than $10nb$, which implies $m_t > 150$GeV.

It is reasonable to assume that other handles can be used to reduce this fake H signal when m_t is smaller than the critical value, cutting for example on the presence of multiple additional jets or tagging at least one of the b's. A more detailed study, in particular understanding how much the peak of the W will be smeared in the case of decay to EM jets, will be needed to fully understand this problem.

As for the fake γ's coming from the other jets in the event, the total rate will be of the same order of magnitude given above, with the difference that now the m_{jj} spectrum will be smeared over a much wider range. Therefore this will not be a significant background.

3 Conclusions

To appreciate the effect of all of the backgrounds added together we display in figure 8, 9 and 10 the contributions of all the processes added in the following sequence: $b\gamma\gamma$, $b\gamma j$, $b\bar{b}\gamma$, $q\gamma\gamma$, Wjj, $W\gamma j$and finally $W\gamma\gamma+$ the signal.

The statistical significance of the four peaks as a function of the three values of R_{gj} is given in Table 1, where I display the ratio:

$$\frac{signal}{\sqrt{total}}, \tag{3.1}$$

evaluated by summing the events obtained with an integrated luminosity of $10^5 pb^{-1}$ over a 6GeV interval around the peak ($M_H \pm 3$GeV).

M_H	80	100	120	140
$R_{gj}=10^{-3}$	3.4	4.0	4.7	3.5
$R_{gj}=5 \times 10^{-4}$	3.9	4.7	5.4	4.0
$R_{gj}=3 \times 10^{-4}$	4.3	5.0	5.7	4.2

Table 1: Statistical significance as defined in Equation (3.1).

Even though further work is needed to understand the effects of the t backgrounds and to find what the real value of R_{gj} will be, I believe this analysis proves that the $WH \rightarrow l\gamma\gamma$ channel is a potentially interesting process to discover the Higgs in the $80 < M_H < 140$ range.

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FIGURE CAPTIONS

Fig.1: The Higgs branching ratios, taken from ref.[5].
Fig.2: p_t spectrum of the leptons from b-decay, with and without the isolation cut described in the text.
Fig.3: The b backgrounds, summed to one another in the following order: $b\gamma\gamma$, $b\gamma j$, $b\bar{b}\gamma+$ signal. We used $R_{gj}=10^{-3}$.
Fig.4: The W backgrounds, summed to one another in the following order: Wjj, $W\gamma j$, $W\gamma\gamma+$ signal. We used $R_{gj}=10^{-3}$.
Fig.5: The W backgrounds, summed to one another in the following order: Wjj, $W\gamma j$, $W\gamma\gamma+$ signal. We used $R_{gj}=5\times10^{-4}$.
Fig.6: The W backgrounds, summed to one another in the following order: Wjj, $W\gamma j$, $W\gamma\gamma+$ signal. We used $R_{gj}=3\times10^{-4}$.
Fig.7: The $q\gamma\gamma$ background.
Fig.8: All the backgrounds, summed to one another in the following order: $b\gamma\gamma$, $b\gamma j$, $b\bar{b}\gamma$, $q\gamma\gamma$, Wjj, $W\gamma j$, $W\gamma\gamma+$ signal. We used $R_{gj}=10^{-3}$.
Fig.9: All the backgrounds, summed to one another in the following order: $b\gamma\gamma$, $b\gamma j$, $b\bar{b}\gamma$, $q\gamma\gamma$, Wjj, $W\gamma j$, $W\gamma\gamma+$ signal. We used $R_{gj}=5\times10^{-4}$.
Fig.10: All the backgrounds, summed to one another in the following order: $b\gamma\gamma$, $b\gamma j$, $b\bar{b}\gamma$, $q\gamma\gamma$, Wjj, $W\gamma j$, $W\gamma\gamma+$ signal. We used $R_{gj}=3\times10^{-4}$.

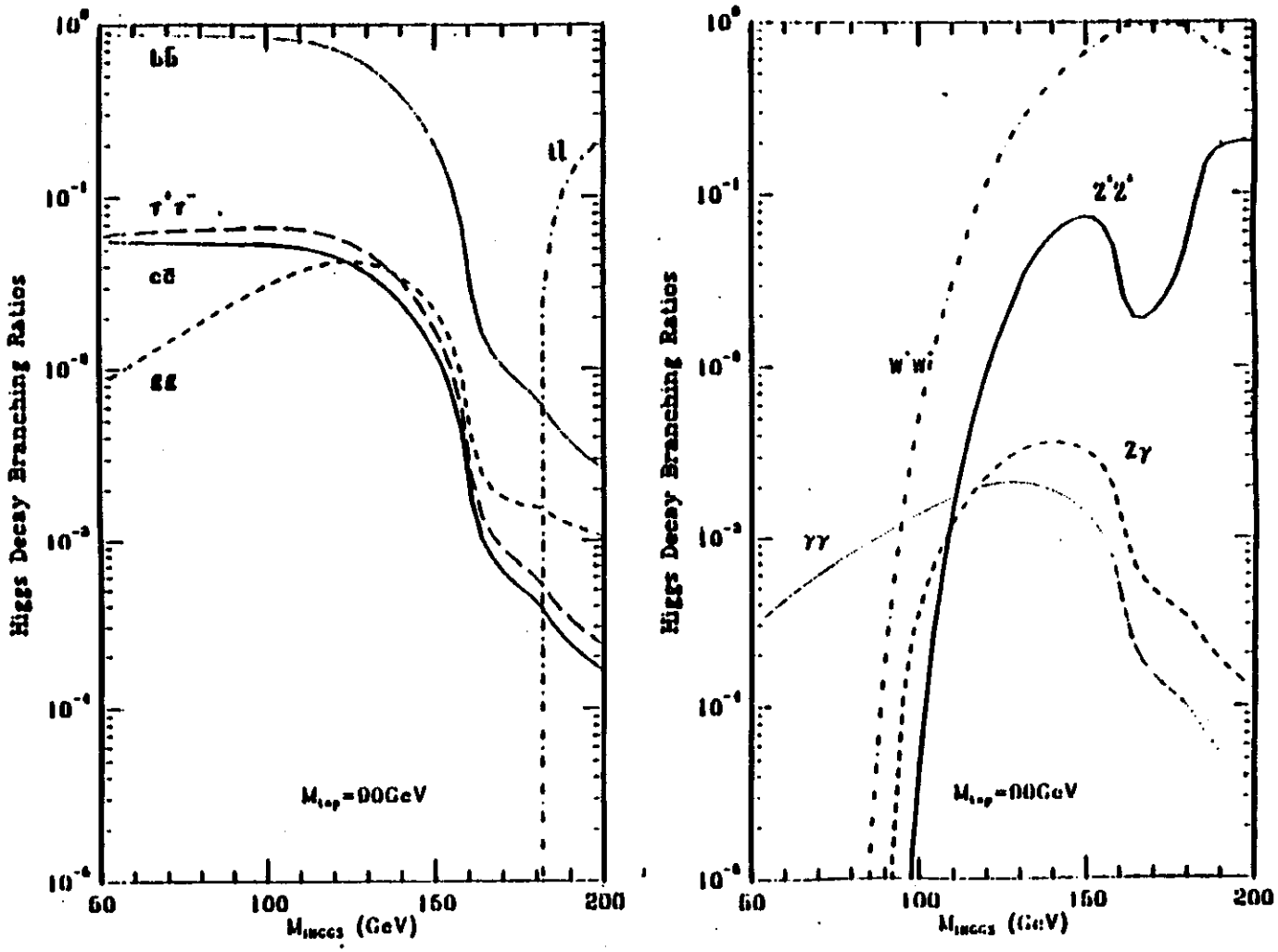

Higgs Decay Branching Ratios
$b\bar{b}$
$\tau^+\tau^-$
$c\bar{c}$
gg
$t\bar{t}$
M_{top}=90GeV
M_{Higgs} (GeV)
W^+W^-
Z^*Z^*
$Z\gamma$
$\gamma\gamma$

FIG 1

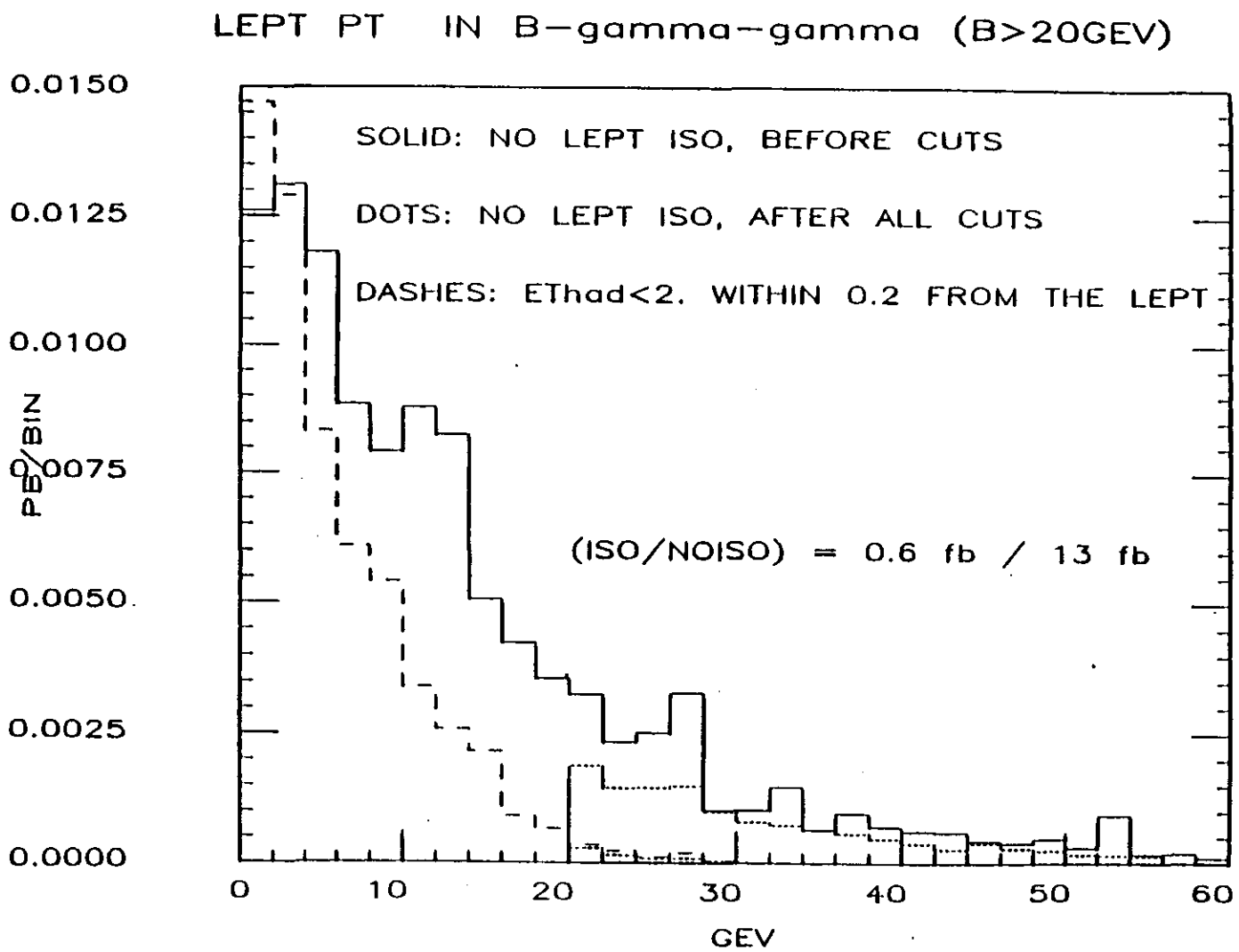

LEPT PT IN B-gamma-gamma (B>20GEV)
SOLID: NO LEPT ISO, BEFORE CUTS
DOTS: NO LEPT ISO, AFTER ALL CUTS
DASHES: EThad<2. WITHIN 0.2 FROM THE LEPT
(ISO/NOISO) = 0.6 fb / 13 fb
PB/BIN
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
0
10
20
30
40
50
60
GEV

FIG 2

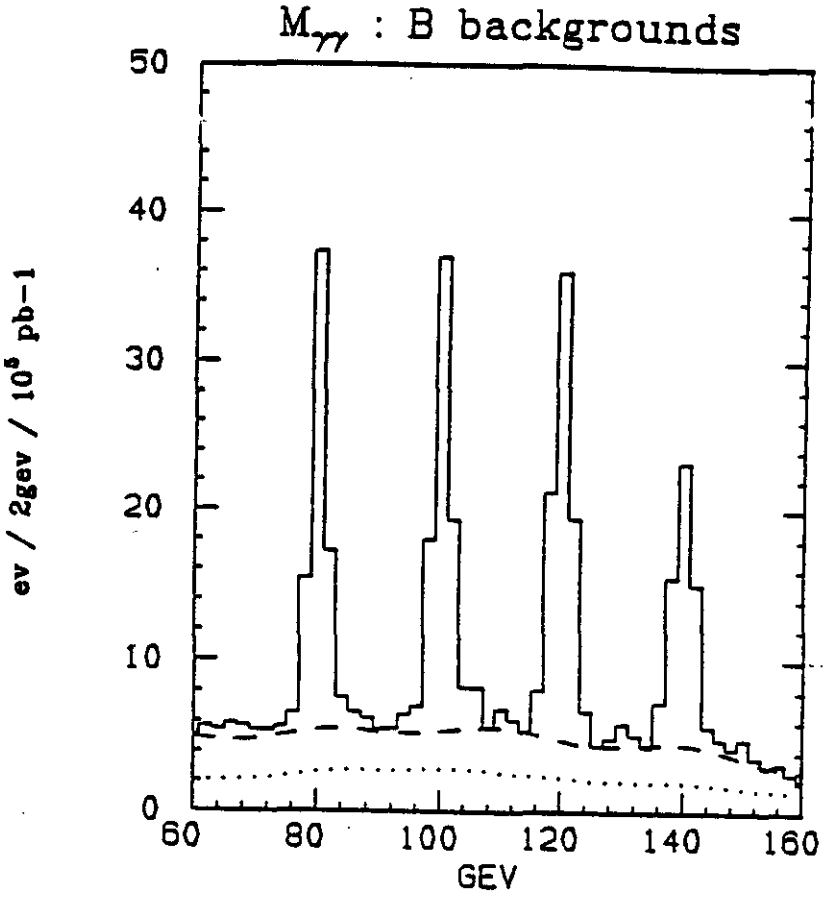

$M_{\gamma\gamma}$: B backgrounds
ev / 2gev / 10^5 pb-1
50
40
30
20
10
0
60
80
100
120
140
160
GEV

FIG 3

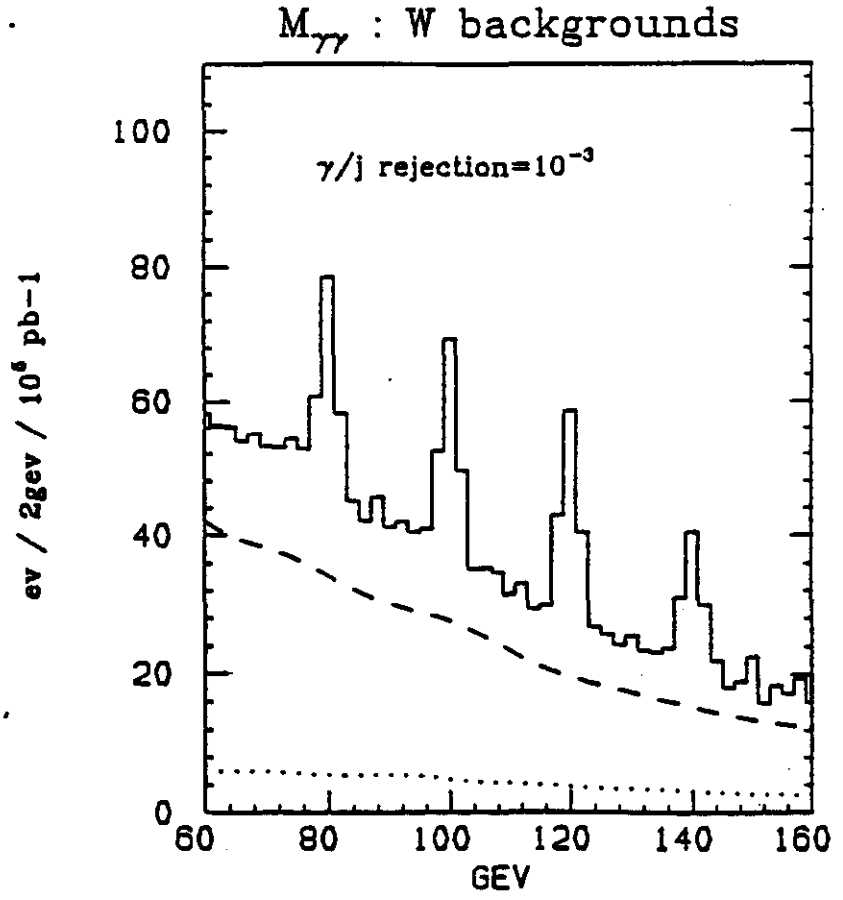

$M_{\gamma\gamma}$: W backgrounds
γ/j rejection=10^{-3}
ev / 2gev / 10^5 pb-1
100
80
60
40
20
0
60
80
100
120
140
160
GEV

FIG 4

FIG 5

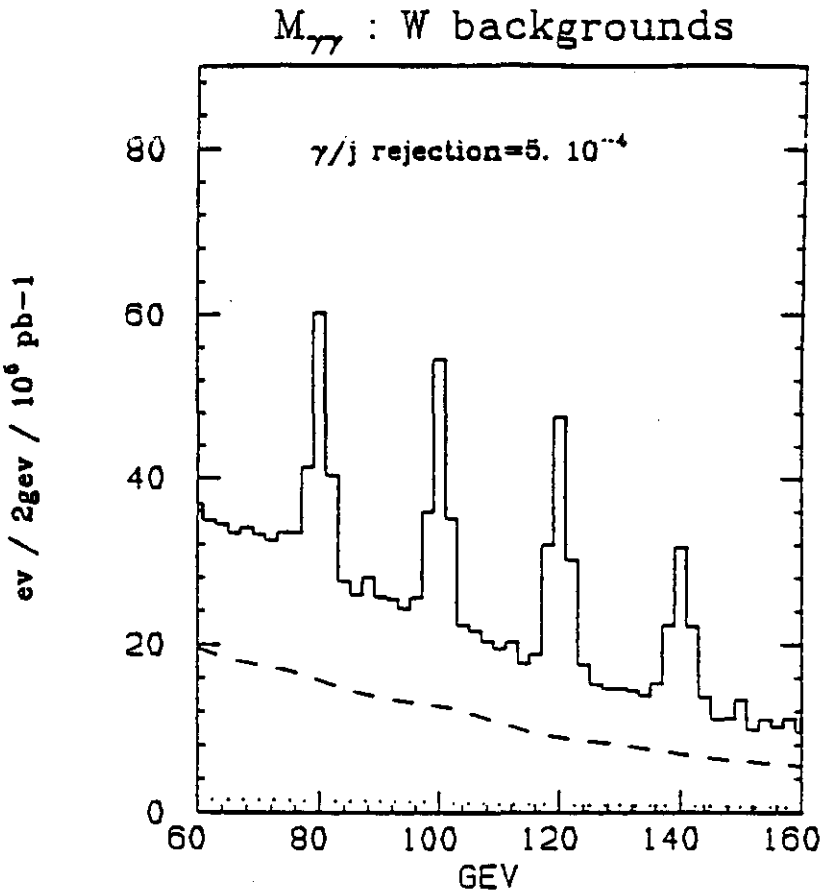

$M_{\gamma\gamma}$: W backgrounds
γ/j rejection=5. 10^{-4}
ev / 2gev / 10^6 pb-1
0
20
40
60
80
60
80
100
120
140
160
GEV

FIG 6

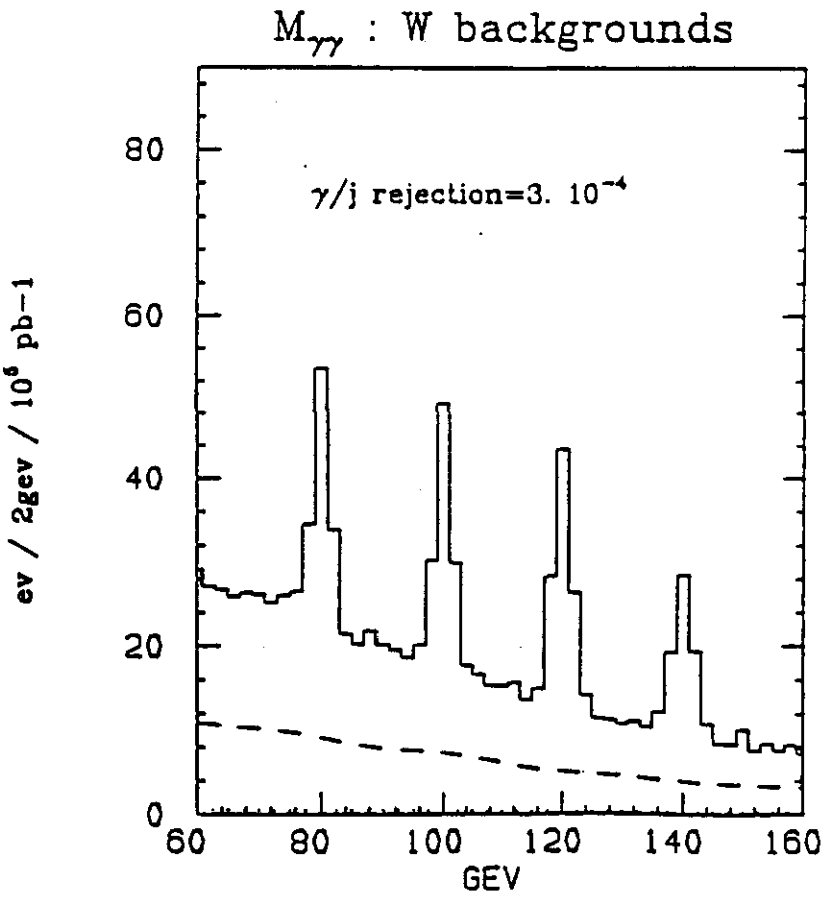

$M_{\gamma\gamma}$: W backgrounds
γ/j rejection=3. 10^{-4}
ev / 2gev / 10^6 pb-1
0
20
40
60
80
60
80
100
120
140
160
GEV

FIG 7

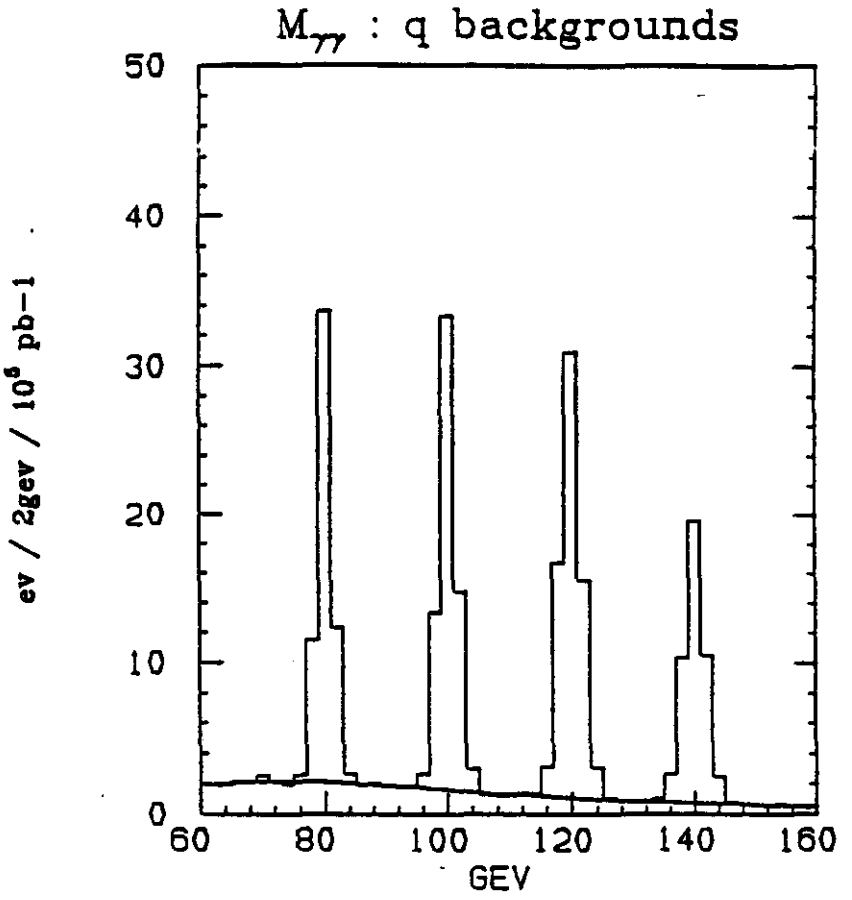

$M_{\gamma\gamma}$: q backgrounds
ev / 2gev / 10^6 pb-1
0
10
20
30
40
50
60
80
100
120
140
160
GEV

FIG 8

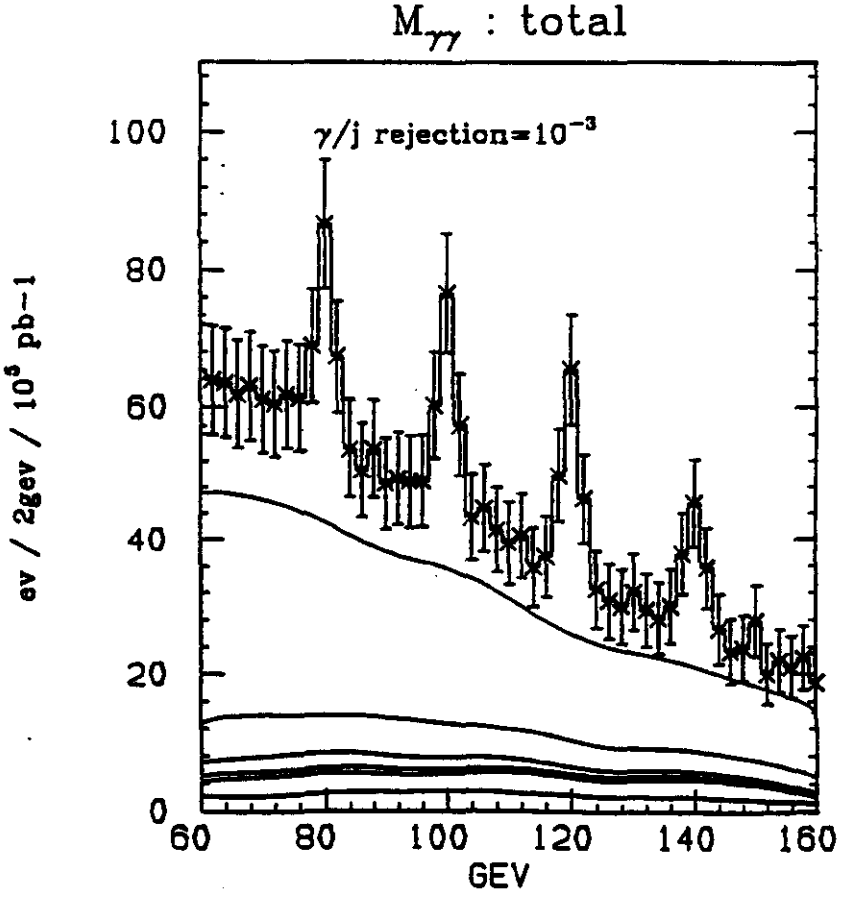

$M_{\gamma\gamma}$: total
γ/j rejection=10^{-3}
ev / 2gev / 10^6 pb-1
0
20
40
60
80
100
60
80
100
120
140
160
GEV

FIG 9

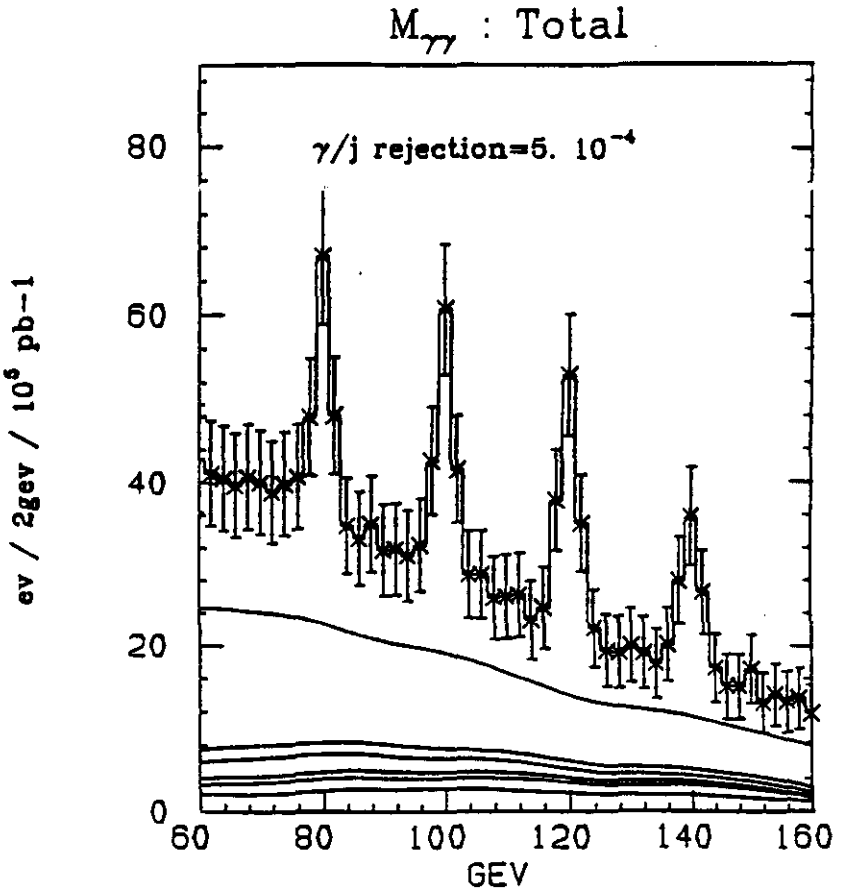
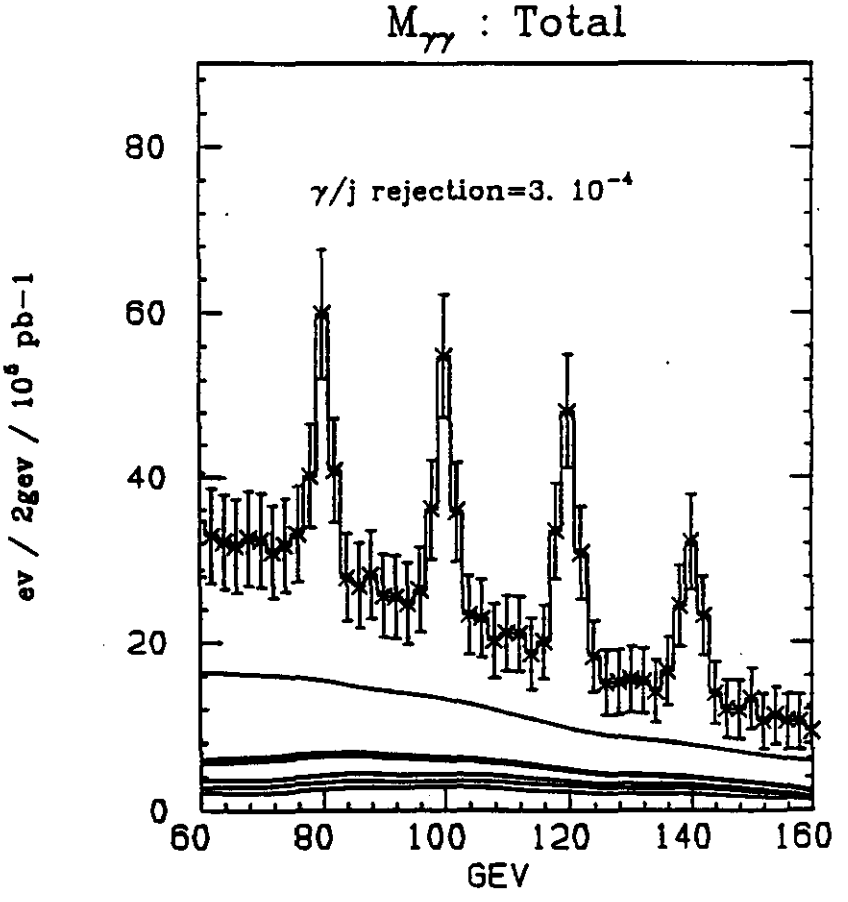

$M_{\gamma\gamma}$: Total
γ/j rejection=5. 10^{-4}
ev / 2gev / 10^5 pb-1
0
20
40
60
80
60
80
100
120
140
160
GEV

fig 10


$M_{\gamma\gamma}$: Total
γ/j rejection=3. 10^{-4}
ev / 2gev / 10^5 pb-1
0
20
40
60
80
60
80
100
120
140
160
GEV