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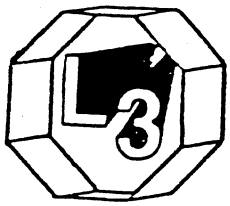

Search for Narrow High-Mass Resonances in Radiative Decays of the Z^0

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Abstract

We search for new resonances, Y, with mass, M_Y, in the range from 30 to 89 GeV, produced via the reaction $e^+e^- \to Z^0 \to \gamma Y$, where Y subsequently decays into e^+e^-, $\mu^+\mu^-$ or *hadrons*. We use 5.5 pb^{-1}of data collected in the energy range $88.2 \leq \sqrt{s} \leq 94.2$ GeV, near the Z^0 peak. We obtain the following upper limits, at the 95% confidence level, on the product of the branching ratios:

$$\begin{aligned} BR(Z^0 \to \gamma Y) \times BR(Y \to e^+e^-) &< 2.8\times10^{-4} \text{ for } 30 < M_Y < 89, \\ BR(Z^0 \to \gamma Y) \times BR(Y \to \mu^+\mu^-) &< 2.3\times10^{-4} \text{ for } 30 < M_Y < 89, \\ BR(Z^0 \to \gamma Y) \times BR(Y \to hadrons) &< 4.7\times10^{-4} \text{ for } 30 < M_Y < 86. \end{aligned}$$

These limits are valid for resonances with widths smaller than our mass resolution.

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1 Introduction

High energy e^+e^- collisions at LEP provide an ideal data sample in which to search for physics beyond the Standard Model [1]. We search for a high-mass resonance using data collected during a scan of the Z^0 resonance. The new resonance, Y, is produced via the following reaction:

$$e^+e^- \rightarrow Z^0 \rightarrow \gamma Y, \tag{1}$$

where

$$Y \rightarrow e^+e^-, \tag{2}$$

$$Y \rightarrow \mu^+\mu^-, \tag{3}$$

$$Y \rightarrow hadrons. \tag{4}$$

Some composite models [2,3] predict that high-mass resonances can be produced via reaction (1) with branching ratios as large as 10^{-2} [4], and the Standard Model predicts a branching ratio of order 10^{-6} for Higgs bosons produced in radiative decays of the Z^0 [5].

In our search, the high precision photon energy measurement of the L3 detector is used to obtain the mass spectrum of the system of particles recoiling against the photon. The recoil mass spectrum is then used to search for evidence of resonances with masses in the range from 30 to 89 GeV. Initial and final state photon bremsstrahlung in Z^0 decays constitutes the primary source of background in this search.

Limits on the production of such resonances have been reported by others [6,7]. Searches for another consequence of compositeness, excited leptons, have been performed by the L3 Collaboration [8] and others [9].

2 The L3 Detector

The L3 detector covers 99% of 4π [10]. It consists of a central tracking chamber (TEC), a high resolution electromagnetic calorimeter composed of bismuth germanium oxide (BGO) crystals, a ring of scintillation counters, a uranium and brass hadron calorimeter with proportional wire chamber readout, and a high precision muon spectrometer. These detectors are located in a 12 m diameter magnet which provides a uniform field of 0.5 T along the beam direction. Forward BGO arrays, on either side of the detector, measure the luminosity by detecting small angle Bhabha events.

For the present analysis, we use data collected in the following ranges of polar angle:

central tracking chamber:	$40° \leq \theta \leq 140°$,
electromagnetic calorimeter:	$42° \leq \theta \leq 138°$,
hadron calorimeter:	$5° \leq \theta \leq 175°$,
muon spectrometer:	$36° \leq \theta \leq 144°$,

where θ is defined with respect to the beam axis. The trigger efficiency exceeds 99.9% for the reactions under study. Details regarding the trigger conditions and the determination of the trigger efficiency can be found in reference [11].

The data were collected in 1990 at seven center of mass energies in the range from 88.2 GeV to 94.2 GeV, at intervals of 1 GeV. The integrated luminosity is 5.5 pb^{-1}which corresponds to approximately 115,000 hadronic Z^0 decays.

3 Event Selection

We search for high-mass resonances produced via reaction (1) and subsequently decaying via reactions (2-4). Therefore, we select three independent data samples for final states that consist of: $\gamma + e^+e^-$, $\gamma + \mu^+\mu^-$ and $\gamma + hadrons$.

In order to determine our acceptance, we have generated Monte Carlo events with resonances in the mass range from 35 to 87.5 GeV. The generator includes initial state radiation to lowest order. Parton showers are generated with the JETSET 7.2 Monte Carlo program [12]. We have generated events with both scalar and vector angular distributions for the resonance and find that our acceptance is about 2% higher for scalar particles. We conservatively use the smaller acceptance and furthermore reduce this acceptance by one standard deviation in order to account for systematic errors.

Initial and final state photon bremsstrahlung represents the primary source of background events. We use the following Monte Carlo generator programs in order to estimate this background: BABAMC [13] for the $\gamma+e^+e^-$ channel, KORALZ [14] for the $\gamma + \mu^+\mu^-$ channel and JETSET 7.2 for the $\gamma + hadrons$ channel.

The response of the L3 detector has been simulated with a program [15] which includes the effects of energy loss, multiple scattering and showering in the detector materials and the beam pipe. All generated events are tracked through the L3 detector by the simulation program and reconstructed by the same program that is used for the data.

The search is based on events containing an isolated energetic photon. Photons are observed as isolated clusters in the electromagnetic calorimeter. The energy of a cluster, E_9, is calculated by applying a position-dependent leakage correction to the energy deposited in a 3×3 array of crystals centered on the most energetic crystal in the cluster. The lateral energy spread of the shower is determined from the ratio E_9/E_{25}, where E_{25} is the corrected energy deposited in the 5×5 symmetric

extension of the 3 × 3 crystal array. An isolated photon or electron will have an E_9/E_{25} ratio very close to unity. For electromagnetic clusters we require an E_9/E_{25} ratio in the range from 0.90 and 1.04.

3.1 $\gamma + e^+e^-$ Final State

We select $e^+e^- \to \gamma + e^+e^-$ events using the following selection criteria:

- There must be 3 electromagnetic clusters with energy greater than 2 GeV in the BGO calorimeter. Two of the clusters must be tagged as charged by a TEC track which points to within 35 mrad of the cluster in the $R - \phi$ plane. No track must point to within 35 mrad of the third cluster.
- The total energy deposited in the BGO calorimeter must be greater than $0.8\sqrt{s}$.
- The angle between the photon candidate and the nearest $e^{\pm}$ candidate must be greater than 15°.

After applying the above selection requirements, we are left with 150 events, which correspond to an integrated luminosity of 5.5 pb^{-1}. Our acceptance varies linearly with the mass of the resonance from 0.31±0.02 at 40 GeV to 0.38±0.02 at 80 GeV.

Figure 1a shows the photon energy spectrum for the data collected at $\sqrt{s} =$ 91.2 GeV; also shown in the figure is the expected background normalized to the same luminosity. Good agreement between the data and background Monte Carlo is obtained.

3.2 $\gamma + \mu^+\mu^-$ Final State

We select events with two reconstructed tracks in the muon chambers using the selection criteria described in reference [11]. We further require that these events contain an isolated photon which satisfies the following criteria:

- The most energetic electromagnetic cluster in the BGO calorimeter, with an energy greater than 2 GeV, is chosen as the photon candidate.
- The angle between the photon candidate and the nearest muon must be greater than 15°.

A total of 104 events, corresponding to an integrated luminosity of 5.4 pb^{-1}, satisfy the above selection criteria. The acceptance increases linearly as a function of the resonance mass from 0.21±0.02 at 40 GeV to 0.33±0.02 at 80 GeV.

The photon energy spectrum for data collected at the Z^0 peak is shown in Figure 1b. Good agreement between the data and background Monte Carlo is obtained.

3.3 $\gamma + hadrons$ Final State

We select hadronic events that contain an isolated photon. In reference [11], the selection of $e^+e^- \rightarrow hadrons$ events is described in detail. For this search we require in addition that there be at least 5 charged tracks reconstructed in the TEC. The photon selection criteria have been tightened with respect to those of the leptonic channels in order to remove decay photons from π^0's and η's.

- The photon candidate must have an energy of at least 5 GeV and there must be no charged track pointing to within 100 mrad of the cluster in the $R-\phi$ plane.
- The cluster's E_9/E_{25} ratio must be greater than 0.97 and less than 1.04.
- The energy leakage into the hadron calorimeter must not exceed 25% of the energy of the cluster.
- The photon candidate must be separated by at least 45° from the nearest cluster of energy greater than 300 MeV in the electromagnetic calorimeter or greater than 2 GeV in the hadron calorimeter.

In total 178 events, corresponding to an integrated luminosity of 5.5 pb^{-1}, survive the above requirements. We estimate that $(6 \pm 2)\%$ of the photons in the final data sample come from the decays of π^0's and η's. The acceptance, in contrast to the leptonic channels, decreases linearly as a function of the resonance mass; for a mass of 40 GeV the acceptance is 0.40 ± 0.03 while at 80 GeV the acceptance is 0.20 ± 0.02. The sensitivity of the acceptance to the assumed $Y \rightarrow q\bar{q}$ couplings is observed to be small. The acceptance varies by less than 10% for Y decaying only to $b\bar{b}$ or only to light quarks.

Figure 1c shows the photon energy spectrum for data collected at $\sqrt{s} = 91.2$ GeV. We observe good agreement between the data and background Monte Carlo.

4 Results

We search for evidence of new high-mass resonances in the reaction $e^+e^- \rightarrow Z^0 \rightarrow \gamma Y$ using the mass spectrum of the particles recoiling against the photon.

The recoil mass, M_R, is given by:

$$M_R^2 = s - 2E_\gamma\sqrt{s}. \tag{5}$$

We use the recoil mass because of the high precision with which we measure the photon's energy, $\sigma(E_\gamma)/E_\gamma \approx 1\%$, and the small spread in the LEP center of mass energy, $\sigma(\sqrt{s}) = 50$ MeV [16]. The recoil mass spectra for all three channels are shown in Figure 2. The data and Monte Carlo background expectations are in good agreement and no indication of a resonance can be seen in any of the channels.

We search for resonances in the recoil mass spectrum using a mass window, ΔM_R, with a width corresponding to $\Delta E_\gamma/E_\gamma = 6\%$, given by:

$$\Delta M_R = (0.06)(s - M_R^2)/2M_R \tag{6}$$

About 80% of the signal from a resonance whose width is significantly less than ΔM_R will fall inside such a window. This efficiency is determined primarily by initial state radiation. For photon energies of less than 5 GeV the spread in the LEP center of mass energy becomes significant and less of the signal will be observed in the mass window.

We correct the number of events found in a given mass window for efficiency and compare to the number of expected background events. The mass spectrum is scanned in steps of $\Delta M_R/2$. We use our measured cross sections and Z^0 decay widths [11] to determine the total number of Z^0's which corresponds to the integrated luminosity of our data samples. We calculate the upper limit on the product of the branching ratios:

$$BR(Z^0 \to \gamma Y) \times BR(Y \to e^+e^-,\ \mu^+\mu^- \text{ or } hadrons).$$

at the 95% confidence level using Poisson statistics [17]. The resulting limits as a function of the recoil mass for each of the three decay channels are shown in Figure 3.

If the resonance has a width which is larger than ΔM_R our limits become less restrictive. For a mass of 85 GeV ΔM_R is 385 MeV, as given by eq. (6). Also shown in Figure 3 are upper limits on the branching ratio for a resonance with a Breit-Wigner line shape and a width of 1 GeV.

5 Conclusions

We have searched for evidence of production of new high-mass resonances in radiative decays of the Z^0. We find no evidence for such resonances in the mass

range from 30 to 89 GeV. We obtain the following upper limits, at the 95% confidence level, on the product of the branching ratios for narrow resonances, as seen in Figure 3:

$$\begin{aligned} BR(Z^0 \to \gamma Y) \times BR(Y \to e^+e^-) &< 2.8\times10^{-4} \text{ for } 30 < M_Y < 89, \\ BR(Z^0 \to \gamma Y) \times BR(Y \to \mu^+\mu^-) &< 2.3\times10^{-4} \text{ for } 30 < M_Y < 89, \\ BR(Z^0 \to \gamma Y) \times BR(Y \to \textit{hadrons}) &< 4.7\times10^{-4} \text{ for } 30 < M_Y < 86. \end{aligned}$$

The branching ratio limit in the hadronic channel is a factor of two smaller than earlier results [6]. The limits in the $Y \to e^+e^-$, $\mu^+\mu^-$ channels are new.

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Figure Captions

Figure 1: The photon energy distribution in (a) $\gamma + e^+e^-$, (b) $\gamma + \mu^+\mu^-$ and (c) $\gamma + hadrons$ events at $\sqrt{s} = 91.2$ GeV. The solid lines indicate expected background from Standard Model processes.

Figure 2: The distribution of the mass recoiling against the photon in $e^+e^- \to Z^0 \to \gamma Y$ events where Y decays into (a) e^+e^-, (b) $\mu^+\mu^-$ and (c) *hadrons*. The size of the bins is given by equation 6. The smoothed solid lines indicate expected background from Standard Model processes.

Figure 3: Upper limits, at the 95% CL, on the product of the branching ratio for $Z^0 \to \gamma Y$ times the branching ratio for (a) $Y \to e^+e^-$, (b) $Y \to \mu^+\mu^-$ and (c) $Y \to hadrons$. The solid line shows the upper limits for resonances with widths that are less than ΔM_R (eq. 6) and the dashed line shows upper limits for resonances with a width of 1 GeV.

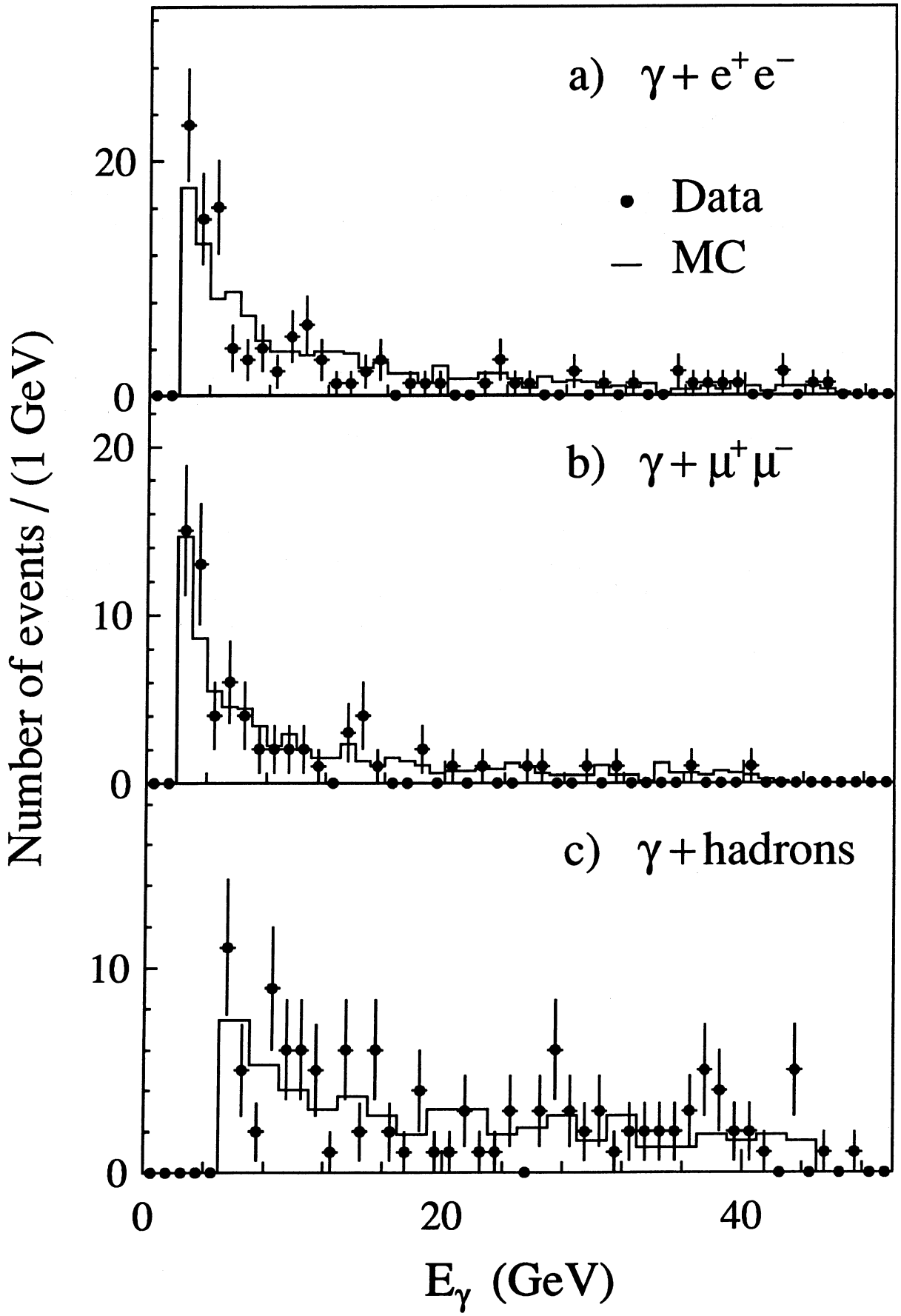
a) γ + e+e−
Data
MC
b) γ + μ+μ−
c) γ + hadrons
Number of events / (1 GeV)
20
0
20
10
0
10
0
0
20
40
Eγ (GeV)

Figure 1

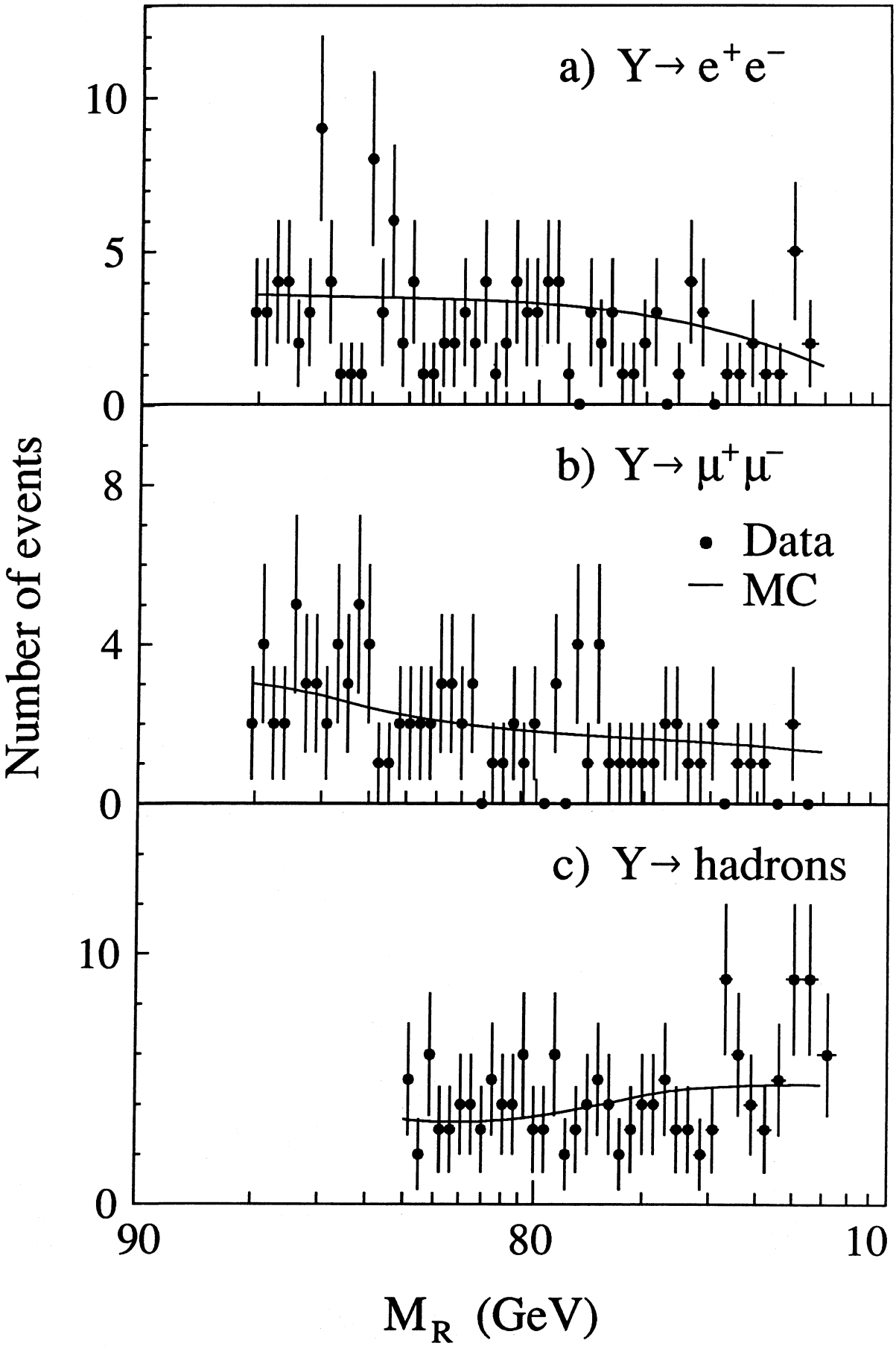
a) Υ→ e+e−
b) Υ→ μ+μ−
• Data
— MC
c) Υ→ hadrons
Number of events
10
5
0
8
4
0
10
0
90
80
10
MR (GeV)

Figure 2

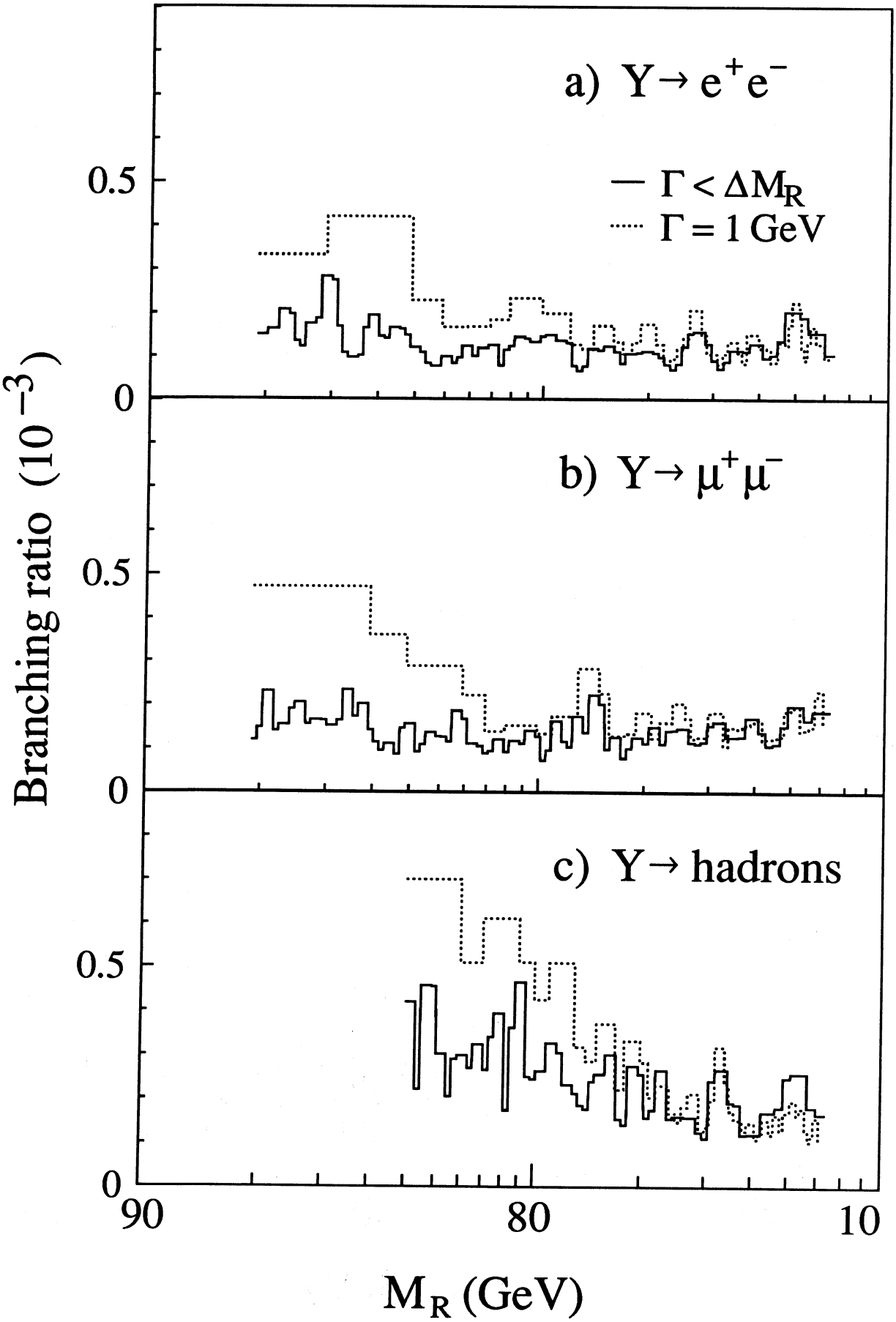

Figure 3

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