EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/91-208
18 November 1991

EXPERIMENTAL LIMIT ON THE DECAY $W^{\pm} \rightarrow \pi^{\pm}\gamma$ AT THE CERN $\bar{p}p$ COLLIDER

The UA2 Collaboration

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(Submitted to Physics Letters B)

ABSTRACT

Results are given on a search for the decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$ with the UA2 detector in $\bar{p}p$ collisions at $\sqrt{s}$ = 630 GeV. No signal for such a process is observed and upper limits on the ratio $R = \Gamma(W^{\pm} \rightarrow \pi^{\pm}\gamma)/\Gamma(W^{\pm} \rightarrow e^{\pm}\nu) < 4.9 \cdot 10^{-3}$ and on the branching ratio $Br(W^{\pm} \rightarrow \pi^{\pm}\gamma) < 5.4 \cdot 10^{-4}$ are derived at 95% confidence level.

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1. INTRODUCTION

The discovery of the Intermediate Vector Bosons (IVB) [1] at the CERN $\bar{p}p$ Collider has been a basic test of the Standard Model. For the charged IVB, the UA2 experiment has observed the decay $W^{\pm} \rightarrow e^{\pm}\nu$ and the hadronic decay in the quark-antiquark channel [2]. In the same experiment a search has also been made for the decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$. In the framework of the Standard Model this decay is highly suppressed and the partial width ratio is estimated to be [3]:

$$R = \frac{\Gamma(W^{\pm} \rightarrow \pi^{\pm}\gamma)}{\Gamma(W^{\pm} \rightarrow e^{\pm}\nu)} < 3 \cdot 10^{-8}$$

However, if one extends to W decay the method used to calculate the $\pi^{0} \rightarrow \gamma\gamma$ amplitude [4,5], much larger values of R are obtained, corresponding to a branching ratio of the order of 0.1 for the decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$.

Such a large value has been questioned by several theoretical papers [6]. Furthermore, the UA1 Collaboration has obtained the limit [7] $R < 5.8 \cdot 10^{-2}$ (95% CL). In this paper the experimental limit is improved by more than a factor ten. The analysis is based on a data sample collected between 1988 and 1990 at the CERN $\bar{p}p$ Collider ($\sqrt{s} = 630$ GeV), corresponding to an integrated luminosity of 13.0 ± 0.7 pb^{-1}. The simple final state topology for the $W^{\pm} \rightarrow \pi^{\pm}\gamma$ decay has been studied in order to isolate a possible signal. Selection criteria have been applied to these data in order to select a photon and a charged pion opposite in azimuth and with an invariant mass consistent with the W mass.

2. THE UA2 APPARATUS

The UA2 detector [8] provides full azimuthal coverage around the interaction region in the pseudorapidity range $-3 < \eta < 3$ and consists of a central tracking detector surrounded by electromagnetic and hadronic calorimeters [9]. The calorimeter is divided into a central part (CC) within $|\eta| < 1$ and two end cap regions (EC) reaching $|\eta| = 3$. All calorimeters use the sampling technique, with a tower structure and wavelength shifter readout. The granularity is $\Delta\theta \cdot \Delta\phi = 10° \cdot 15°$ in the CC and $\Delta\eta \cdot \Delta\phi = 0.2 \cdot 15°$ in the EC, except for the two cells closest to the beam axis where $\Delta\eta = 0.3$ and 0.5 respectively. The electromagnetic compartments are multi-layer lead-scintillator sandwiches with a total thickness of 17 radiation lengths (r.l.) in the CC and varying between 17.1 and 24.4 r.l. in the EC, depending on the polar angle θ. The hadronic compartments are multi-layer iron-scintillator sandwiches, 4 absorption lengths (a.l.) deep in the CC and 6.5 a.l. deep in the EC.

Clusters are reconstructed in the calorimeter by joining all cells with an energy greater than 400 MeV sharing a common edge. Clusters with a small lateral size and a small energy leakage into the hadronic compartments are marked as electromagnetic clusters.

The central detector, used to determine the position of the event vertex and to reconstruct charged particle tracks, consists of two silicon pad counter arrays [10] around the beam at radii of 2.9 cm and 14.8 cm. A cylindrical drift chamber [11] is located between the two silicon detectors. Beyond the outer silicon layer there is a transition radiation detector [12], consisting of two sets of radiators and proportional chambers, followed by a scintillating fibre detector [13] which provides track segments in the first six stereo triplets of fibres and localizes the beginning of electromagnetic showers in front of the CC in the last two stereo triplets, located after a 1.5 r.l. thick lead converter.

In the forward regions, $|\eta| > 1$, tracking and preshower measurements are provided by three stereo triplets of proportional tubes [14] placed in front of the end cap calorimeters. The first two triplets are used as a tracking device, while the last triplet, placed after a 2 r.l. thick iron and lead converter, acts as a preshower detector. Two sets of time-of-flight hodoscopes are located at small angles with respect to the beam. Their function is to define a minimum bias trigger and to provide an independent vertex measurement. Finally, two planes of large area scintillation counters cover the back sides of the end cap calorimeters. Events caused by beam halo particles are rejected in the analysis by detecting charged particles giving an early signal in these counters with respect to the beam crossing time.

3. MONTE CARLO SIMULATION

A Monte Carlo event sample has been generated using a special version of the PYTHIA 5.4 event generator [15] modified to include the decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$. The generated events have been processed through full calorimeter and silicon detector simulations. The detector response to the single pion in the final state was simulated using a parametrization obtained from single charged pions as measured in test beams. The Monte Carlo events have been analyzed requiring the presence of an azimuthally opposite cluster in the region $\Delta\phi > 150°$ with respect to the photon direction, a photon with transverse momentum $p_T^{\gamma} > 20$ GeV in the pseudorapidity region $|\eta_{\gamma}| < 0.76$ and a pion with $p_T^{\pi} > 20$ GeV and $|\eta_{\pi}| < 2.0$. This sample has been used for a qualitative comparison with the observed distributions and to compute the acceptance and the efficiencies of the selection criteria.

4. EVENT SELECTION

The online selection of the data was based on the trigger requirements for photon candidates [16] implemented in a three-level trigger system [17]. After removing events in which not all of the detector elements used in this analysis were functioning, the integrated luminosity is 13.0 ± 0.7 pb^{-1}. Only events in which there is a single reconstructed $\bar{p}p$ interaction vertex which is not displaced by more than 250 mm along the beam direction from the centre of the detector are retained.

The signature of the decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$ is given by a photon and a charged pion opposite in azimuth with an invariant mass compatible with the W mass. A sample of events containing a photon candidate has been selected [16] by requiring the presence of an isolated electromagnetic cluster with no associated charged track and with at most one preshower signal in a cone of radius $\sqrt{\Delta\phi^2 + \Delta\eta^2} < 0.265$ around the cluster axis, defined by the line joining the interaction vertex to the cluster centroid. The photon candidates are required to be contained in $|\eta| < 0.76$ and to have $p_T^{\gamma} > 20$ GeV. The associated pion is identified using the selection criteria given in the Monte Carlo section. The selected sample at this stage contains 4435 events with $p_T^{\pi} > 20$ GeV and $|\eta_{\pi}| < 2$.

The background in the $W^{\pm} \rightarrow \pi^{\pm}\gamma$ search is mainly due to two QCD processes : the first is direct photon production, where an associated jet is misidentified as a single charged pion, and the second is the production of two jet events in which one jet fakes the photon and the other is taken as a single pion. Calorimeter and silicon detector information, which are well understood from test beam studies, are used to distinguish QCD jets from single pions as follows :

a. A 40 GeV single pion is expected to induce a shower which is contained in a three-by-three group of calorimeter cells around the impact point. Figure 1 shows the distributions of the number of cells belonging to the pion candidate cluster (N_{cells}) in the data (full line) and in the Monte Carlo (dashed line) samples : the comparison indicates that the data still contain a large sample of QCD jets with more than one particle. These are partly removed by requiring $N_{cells} \leq 9$.
b. The *profile* ρ of a calorimeter cluster is defined as $\rho = (E_1 + E_2) / E_{tot}$, where the numerator corresponds to the sum of the energies of the two highest energy cells in the cluster and the denominator is the total energy of the cluster. Figure 2 (a) compares the profile distributions for the data (full line) and for the Monte Carlo (dashed line) samples after applying all the previous selection criteria. The shape of the distribution in the data sample is similar to that expected for jets from a two-jet sample. The distribution for jets (dashed line) is compared to that

from the data (full line) in Fig. 2 (b). Since single pions are expected to have high values of ρ, the requirement $\rho \geq 0.75$ is applied.

c. A charged pion is expected to appear as a "mono-track" jet. The presence of a single charged track pointing to the pion candidate cluster is ensured by pulse height requirements imposed on the silicon counters, within a window of $\Delta\eta < 0.2$ and $\Delta\phi < 15°$ around the cluster axis.

d. The invariant mass $M_{\gamma\pi}$ of the $\gamma\pi$ system must be consistent with the W mass. The $M_{\gamma\pi}$ distributions in the data and Monte Carlo samples are shown in Fig. 3 (a) and (b) respectively for the events passing all the previous criteria. A Gaussian fit to the Monte Carlo mass distribution gives $M_{\gamma\pi}^{MC} = 80.6$ GeV with $\sigma = 6.2$ GeV. The events from the data sample are therefore selected in the region 68 GeV $< M_{\gamma\pi} <$ 100 GeV corresponding to the range between -2σ and 3σ.

For the 12 events which remain at this stage of the analysis the full tracking information from the central detectors is used. By requiring the presence of one and only one track and no preshower signal in a cone of 10° around the pion candidate cluster, no events remain in the data sample.

The total efficiency, including geometrical acceptance, is evaluated to be $\varepsilon_{\gamma\pi}^{tot} = 0.072 \pm 0.004$, where the quoted error includes the statistical and systematic error added in quadrature. The latter comes mainly from the uncertainties on the photon and pion detection efficiencies (2.7% and 4.8%, respectively) and on the geometrical acceptance (1.4%).

5. LIMIT ON $W^{\pm} \rightarrow \pi^{\pm}\gamma$

No events compatible with the decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$ survive the selection criteria. An upper limit on the ratio of amplitudes

$$R = \frac{\Gamma(W^{\pm} \rightarrow \pi^{\pm}\gamma)}{\Gamma(W^{\pm} \rightarrow e^{\pm}\nu)} = \frac{N_{\gamma\pi}^{prod}}{N_{e\nu}^{prod}} = \frac{N_{\gamma\pi}^{obs}/\varepsilon_{\gamma\pi}^{tot}}{N_{e\nu}^{prod}}$$

can be calculated, where $N_{e\nu}^{prod} = 8539 \pm 444$ is given by the observed number of $W^{\pm} \rightarrow e^{\pm}\nu$ decays in UA2 [18], corrected for the measured efficiency and acceptance. The quoted error on $N_{e\nu}^{prod}$ takes into account the statistical error on the number of observed $W^{\pm} \rightarrow e^{\pm}\nu$ events and the systematic uncertainties on the $W^{\pm} \rightarrow e^{\pm}\nu$ efficiency and acceptance.

The upper limit on R has been computed with a simple Monte Carlo programme assuming that the 7.7 % uncertainty on $N_{e\nu}^{prod} \cdot \varepsilon_{\gamma\pi}^{tot}$ has a Gaussian distribution and taking into account the Poisson statistic on zero observed event. The values obtained are :

$$R < 4.9 \cdot 10^{-3} \quad (95\ \%\ CL)$$
$$R < 3.8 \cdot 10^{-3} \quad (90\ \%\ CL)$$

A limit on the branching ratio $Br(W^{\pm} \rightarrow \pi^{\pm}\gamma) = R \cdot Br(W^{\pm} \rightarrow e^{\pm}\nu)$ can be derived assuming the Standard Model value $Br(W^{\pm} \rightarrow e^{\pm}\nu) = 0.109$ as computed for $m_{top} > m_W - m_b$:

$$Br(W^{\pm} \rightarrow \pi^{\pm}\gamma) < 5.4 \cdot 10^{-4} \ (95\ \%\ CL)$$

This result is similar to the limit obtained by LEP experiments [19] for the branching ratio of the decay $Z \rightarrow \pi^{0}\gamma$ which is also suppressed in the Standard Model.

6. CONCLUSIONS

The data sample collected by the UA2 experiment between 1988 and 1990 at the CERN $\bar{p}p$ Collider, corresponding to an integrated luminosity of 13.0 pb^{-1}, shows no evidence for the decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$. Upper limits at the 95 % confidence level on the ratio of decay widths R into this channel and into $e\nu$, and on the branching ratio for such a decay are :

$$R < 4.9 \cdot 10^{-3}$$
$$Br(W^{\pm} \rightarrow \pi^{\pm}\gamma) < 5.4 \cdot 10^{-4}$$

ACKNOWLEDGEMENTS

We especially thank T. Sjöstrand for fruitful discussions and for the help in the Monte Carlo programme.

The technical staff of the institutes collaborating in UA2 have contributed substantially to the construction and operation of the experiment. We thank them deeply for their support. The experiment would not have been possible without the very succesful operation of the improved CERN $\bar{p}p$ Collider, whose staff and coordinators we sincerely thank for their collective effort. Financial support from the Schweizerischen Nationalfonds zur Förderung der Wissenschaftlichen Forschung to the Bern group, from the UK Science and Engineering Research Council to the Cambridge group, from the Bundesministerium für Forschung und Technologie to the Dortmund and Heidelberg groups, from the Australian Research Council, the CRA Pty Ltd, and the Victorian Education Foundation to the Melbourne group, from the Institut National de Physique Nucléaire et de Physique des Particules to the Orsay group, from the Istituto Nazionale di Fisica Nucleare to the Milano, Pavia, Perugia and Pisa groups and from the Institut de Recherche Fondamentale (CEA) to the Saclay group are acknowledged.

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FIGURE CAPTIONS

Fig. 1 N_{cells} distribution of the pion candidates in the data (full line) and Monte Carlo (dashed line) samples after selections (see text).

Fig. 2 (a) : The profile distribution of the pion candidates in the data (full line) and that of the Monte Carlo sample (dashed line).
(b) : The profile distributions for the same pion candidates (full line) and for jets from a two-jet data sample (dashed line).
In both figures (a) and (b) the distributions have been renormalized to the same number of events.

Fig. 3 Invariant mass of the $\gamma\pi$ system in the data (a) and Monte Carlo (b) samples after selections (see text). The superimposed curve in (b) is the result of a Gaussian fit to the Monte Carlo mass distribution.

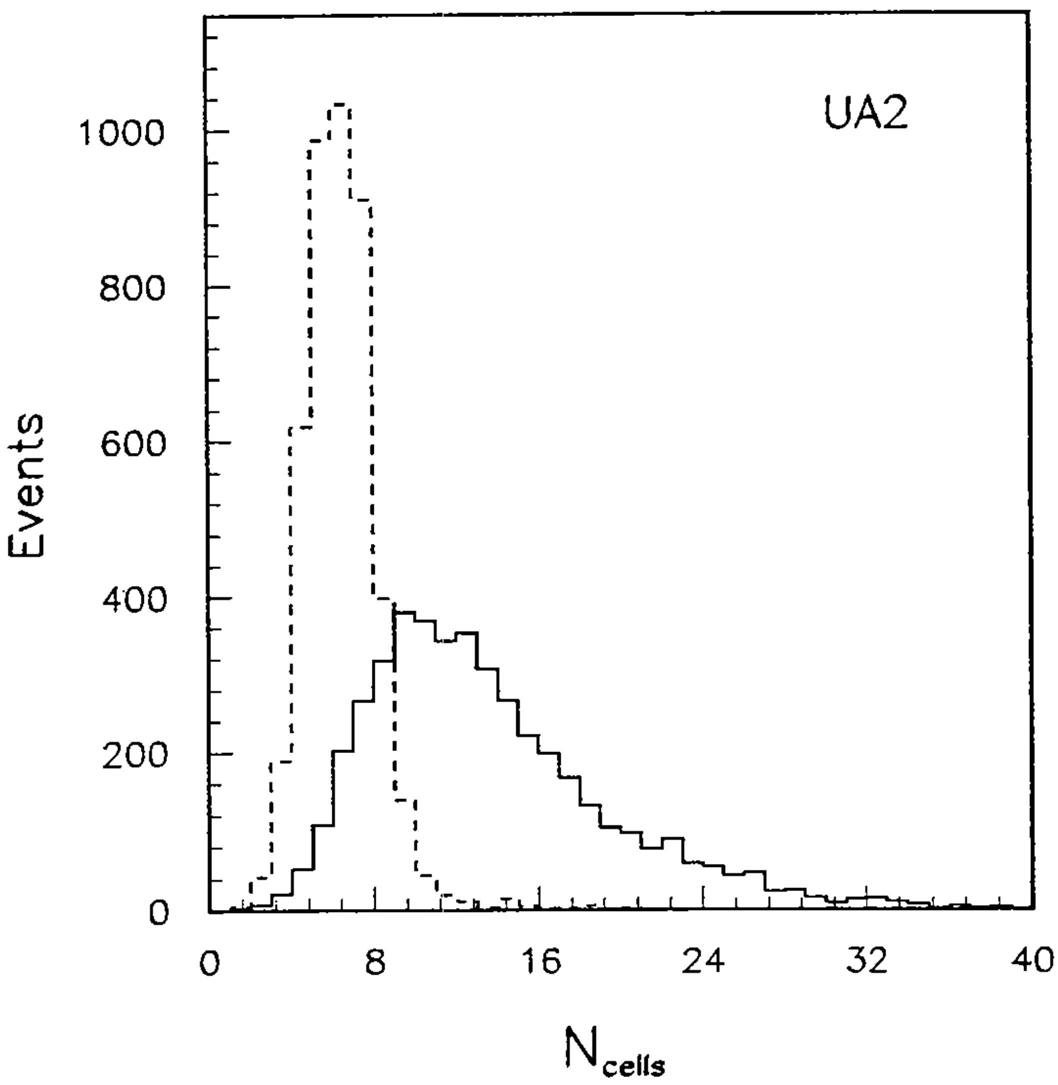
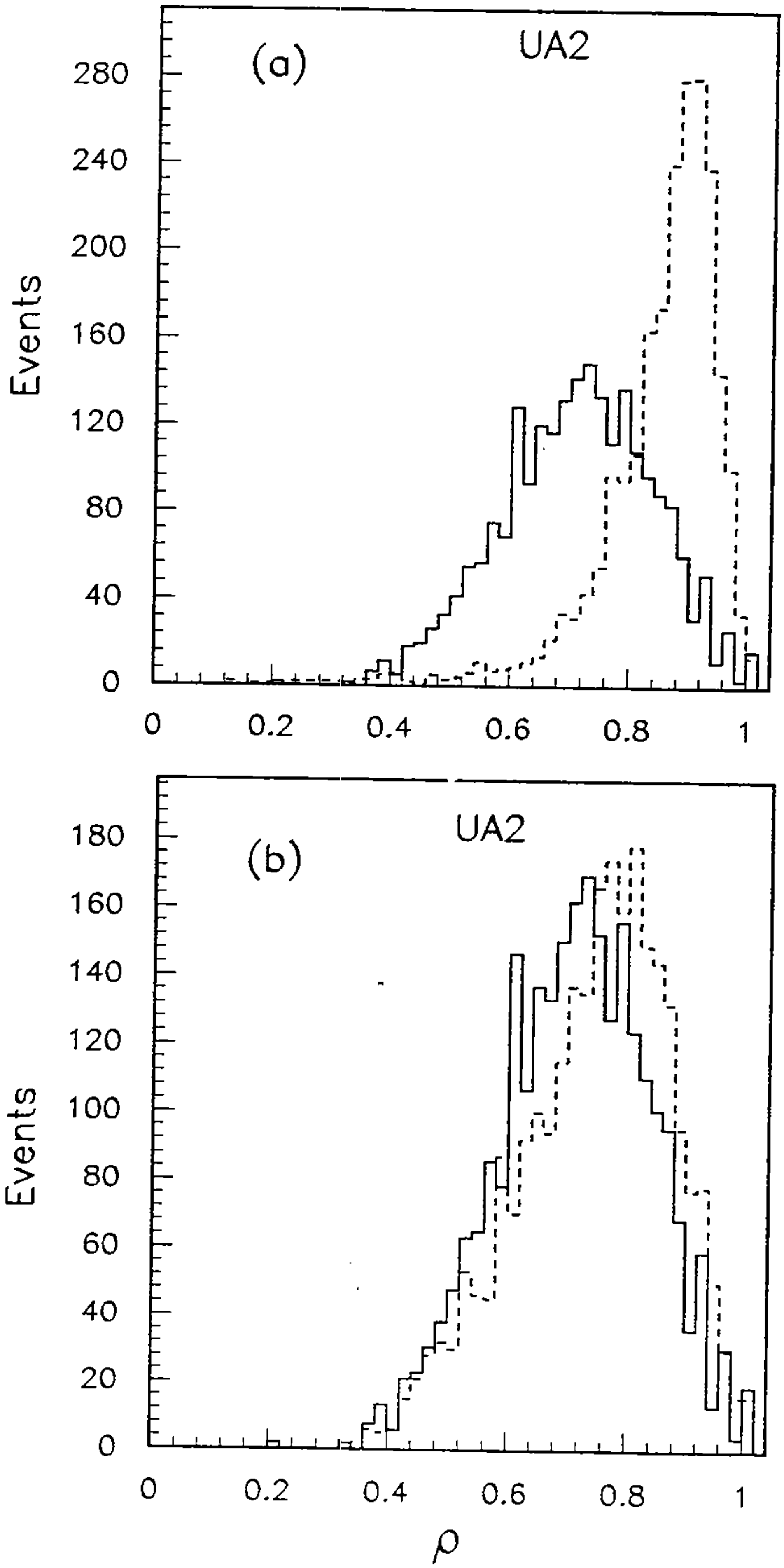


Figure 1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(a)
280
240
200
160
120
80
40
0
Events
0
0.2
0.4
0.6
0.8
1
UA2
(b)
180
160
140
120
100
80
60
40
20
0
Events
0
0.2
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0.8
1
ρ

Figure 2

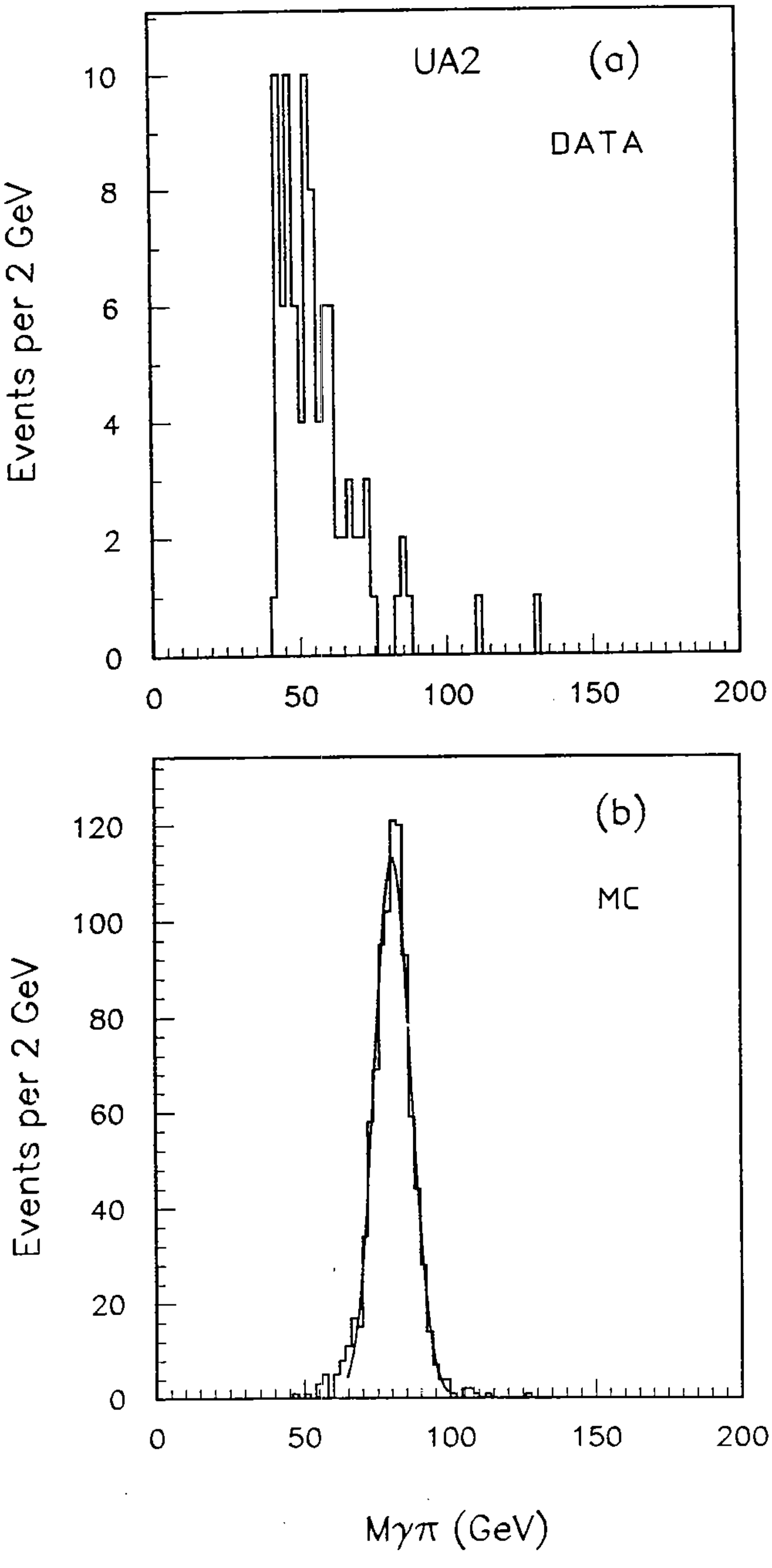

Figure 3

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