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Low Mass Dimuon Production at the CERN Proton-Antiproton Collider.

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Abstract

We present a study of low mass dimuon events ($m(\mu\mu) < 6$ GeV/c^2) from the UA1 experiment at the CERN $p\bar{p}$ collider. Contributions from semileptonic decays of heavy flavour particles, Drell-Yan type processes, J/ψ decays and leptonic decays of light mesons are extracted, and cross sections for high p_T beauty and Drell-Yan production are derived. A limit for the branching fraction for the exotic decay $B^o \rightarrow \mu^+\mu^-$ is also obtained. The cross section for low mass, high p_T Drell-Yan production is compared to the measured direct photon cross section using a QED and QCD derived relationship. This relationship is used to infer a measurement of the single photon cross section at lower values of transverse momentum, where photons cannot be unambiguously identified.

1. Introduction

Dimuon events at the CERN $p\bar{p}$ collider can originate from a large number of processes, including Z^0,Υ and J/ψ decays, Drell-Yan type processes, and semileptonic decays of heavy flavour particles. Due to the minimum transverse momentum required for muon identification in the UA1 detector ($p_T(\mu) \gtrsim 3$ GeV/c in the central rapidity region, where p_T is measured with respect to the beam direction), two classes of events can be naturally distinguished by their dimuon topology:

(i) high mass, predominantly low p_T muon pairs, where the muons are emitted essentially back-to-back in the transverse plane.

(ii) low mass, high p_T muon pairs, where the muons are emitted in a non-back-to-back configuration, or even parallel for very low masses.

From samples of high mass events we have obtained cross sections for Z^0, beauty, and high mass Drell-Yan production [1,2], and we found evidence for B^o-$\bar{B}^o$ mixing [3]. For the complementary low mass dimuon sample discussed in this paper, we expect contributions from heavy flavour production, J/ψ decays, leptonic decays of light mesons ($\rho, \omega, \phi, \eta, \eta\prime$), and from low mass, high p_T virtual photon production. The latter can proceed via processes of the type $q\bar{q} \to \gamma^* g$ and $qg \to \gamma^* q$, $\gamma^* \to \mu\mu$. We shall refer to such processes globally as 'Drell-Yan'. J/ψ production alone has already been studied in a separate analysis [4]. Here we study the contributions of *all* these processes to the low mass dimuon data. Emphasis is placed on low mass, high p_T Drell-Yan production and its implications within the framework of QCD.

The theory of QCD has been tested at the collider in a number of processes, including high p_T jets [5], weak bosons [6] and direct photons [7]. In the high p_T range these processes are well understood and calculable. For Drell-Yan type processes, the low p_T range has been investigated in the case of weak bosons. The main feature of the corresponding kinematical region, $m^2 \gg p_T^2$ (where m is the mass and p_T the transverse momentum of the intermediate boson), is that soft gluon emission dominates and perturbation theory is no longer valid [8]. Here we consider the complementary region, $m(\mu\mu)^2 \ll p_T(\mu\mu)^2$, by studying the production of low mass muon pairs. In this region the Drell-Yan process is related to high p_T direct photon production by the electromagnetic coupling α multiplied by a factor that is essentially a measure of the virtuality of the intermediate photon [9]. Applying this relationship to our low mass Drell-Yan cross section we can extend the measured direct photon cross section [7] down to lower transverse momentum values, i.e. below 17 GeV/c.

2. Data taking and event selection

The components of the UA1 detector and trigger used for dimuon studies, and the selection procedure for dimuon events, are described in [2] and references therein. The low mass dimuon data were recorded during two collider runs at $\sqrt{s} = 630$ GeV with a total integrated luminosity of 552 nb^{-1}. Events were selected if they contained at least two muons with transverse momentum $p_T(\mu) > 3$ GeV/c for each muon. A mass cut $m(\mu\mu) < 6$ GeV/c^2 is applied to separate the two dimuon event classes discussed above. The pseudo-rapidity range is restricted to $|\eta| \lesssim 1.7$ by the muon trigger acceptance. Requiring an inclusive single muon or dimuon trigger, a sample of 304 low mass dimuon events is obtained. Except for some overlap with the special J/ψ sample discussed in [4], this data sample is complementary to the samples studied in our previous dimuon publications [1,2,3].

3. Event topology

The simultaneous requirements of large transverse momentum ($p_T(\mu) > 3$ GeV/c) for each muon and a low dimuon mass ($m(\mu\mu) < 6$ GeV/c^2) imply a sizeable transverse momentum of the dimuon system. For very low masses the steep rise in acceptance above the $p_T(\mu\mu)$ threshold of about 6 GeV/c, shown in fig. 1, corresponds to an effective cut on $p_T(\mu\mu)$. This transverse momentum has to be balanced by hadronic activity opposite to the muons in the transverse plane, irrespective of the specific production process involved. On the other hand, the amount of hadronic energy emitted in the muon direction depends on the production mechanism. In ref. [2] it was shown that isolation of the muons is a powerful tool to distinguish between muons from heavy flavour and from Drell-Yan processes. In this analysis, a slightly different isolation criterion is used to account for the special topology of low mass muon pairs: If the two muons originate from the same parent (e.g. Drell-Yan, b cascade decays), the dimuon direction should be used to determine isolation. On the other hand, if they originate from different parents (e.g. semileptonic decays of two different b quarks), each muon should be treated separately. Since the two cases cannot be distinguished on an event by event basis, a combined criterion is used: A muon pair is classified as isolated, if

- $\Sigma E_T(\mu) < 3$ GeV for each muon *and*
- $\Sigma E_T(\mu\mu) < 3$ GeV for the dimuon system

where ΣE_T is defined as the scalar sum of the transverse energies measured in calorimeter cells in a cone of $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 0.7$ around the direction of the muon or dimuon momentum vector; η is the pseudo-rapidity and ϕ is the azimuthal angle measured in radians.

Classifying the data sample of 304 events according to charge and isolation we find the numbers quoted in table 1.

4. Background

The background sources for dimuon events are discussed in ref. [2] and the same background calculation methods, based on the data, are applied here. The largest background contribution (49±12 events) originates from kaon and pion decays in flight. The contributions from noninteracting hadrons and from misassociation of central detector and muon chamber tracks are 3±3 and 5±5 events respectively. Background from hadronic shower leakage and cosmic ray muons is found to be negligible. This yields a total background of 57 ± 14 events, where the error is systematic only. The breakdown according to charge and isolation is shown in table 1.

5. Monte Carlo calculations

The Monte Carlo calculations described in this section are needed to determine the shape of the expected mass and p_T distributions, to fix the relative normalization of various subprocesses, and to study the acceptance for the applied cuts.

The ISAJET Monte Carlo program [10] is used to obtain QCD-predictions for heavy flavour production. The application of this program for muons from heavy flavour processes has been extensively described in references [2] and [11]. Summing over all the subprocesses listed in table 2 yields an absolute prediction of 103 events from heavy flavour processes. The dominant contribution originates from cascade decays of single b quarks ($b \to c\mu\nu, c \to s\mu\nu$), resulting in unlike sign dimuons with masses around 2 GeV/c^2. As in the case of high mass dimuon production [2], and despite its higher production cross section, the contribution from $c\bar{c}$ production is suppressed due to the softer fragmentation of c quarks. Like sign events can arise from first generation b decays combined with B^o-$\bar{B}^o$ mixing, or from a second generation decay of one of the b quarks. Since muons from heavy flavour decays are accompanied by hadronic activity, they are expected to be nonisolated. Indeed, only 10 ± 5 % of the total heavy flavour contribution is predicted to satisfy our isolation cuts.

To calculate the expectation for the contribution from the light meson decays $\rho, \omega, \phi \to \mu^+\mu^-$, $\omega \to \mu^+\mu^-\pi^o$ and $\eta, \eta\prime \to \mu^+\mu^-\gamma$, a minimum bias data sample (data recorded with minimal trigger bias) is used. In these events, leading high p_T hadrons (mostly pions) are replaced by one of the listed mesons according to the following assumption for the relative frequency of occurrence of those mesons as leading particles: $\pi^{\pm} : \rho^{o} : \omega : \phi : \eta : \eta\prime = 2 : 1 : 1 : 1/6 : 1/2 : 1/4$ [12]. A pion to hadron ratio of $\pi^{\pm} : h^{\pm} = 0.58$ [13] is used. Then the leptonic decay of the meson is simulated using the branching ratios published by the particle data group [14] (typically 10^{-4}). Only events satisfying the dimuon selection cuts are kept. From this method a total contribution of 31 ± 12 events is expected, clustering in the mass region below 1 GeV/c^2. The fraction of these events satisfying the isolation cuts is estimated from the minimum bias data to be 13 ± 9 %.

To determine the properties of the expected Drell-Yan contribution, higher order processes of the type $q + \bar{q} \rightarrow \mu^+\mu^- + g$ (q$\bar{\text{q}}$ annihilation with gluon radiation) and $g + q \rightarrow \mu^+\mu^- + q$ (Compton diagrams) are generated with ISAJET. The contribution of the lowest order process $q + \bar{q} \rightarrow \mu^+\mu^-$ is negligible due to the low acceptance for low dimuon p_T. Applying the selection cuts and allowing for acceptance yields a prediction of 24 events from those processes, the majority of which (76%) originate from Compton type diagrams. Their mass spectrum peaks at very low masses, with a long tail extending up to 6 GeV/c^2. The shape of the generated $p_T(\mu\mu)$ distribution agrees very well with the 2^{nd} order QCD calculations of ref. [9]. In contrast to the processes discussed previously, the muons from Drell-Yan processes are expected to be isolated. From an analysis of the isolation of muons from W decays [2], we expect 80 ± 10 % of the Drell-Yan events to satisfy our isolation cuts; this fraction is confirmed by the Monte Carlo predictions. Therefore, muon isolation can be used to discriminate between Drell-Yan and other processes.

6. Heavy flavours and light mesons

We now turn to the interpretation of the data. The isolation properties and the characteristic mass spectra of the different processes will be used to study their respective contributions to the data sample. The contributions for all processes are extracted simultaneously from a fit to the mass distributions for isolated, nonisolated and all unlike sign dimuons, shown in fig. 2 [15]. The results of this fit are summarized in table 3, and will be discussed individually for each process.

Bound c$\bar{\text{c}}$ states are most easily identified through their well-defined mass. In the mass distribution for unlike sign events shown in fig. 2 a), a clear peak is seen at the J/ψ mass of 3.1 GeV/c^2. Fitting two Gaussians for the J/ψ and the $\psi\prime$ and treating the other contributions as described in table 3 (column III) yields a J/ψ contribution of 87 ± 10 events and a contribution of 7 ± 4 events for the $\psi\prime$, in agreement with expectations. Further details on these events are given in ref. [4].

Open heavy flavours ($b\bar{b}$ and $c\bar{c}$) and light mesons should contribute mainly to the subsample of nonisolated events. The light meson and background contributions are known from independent calculations based on the data, and the nonisolated Drell-Yan contribution is expected to be small. The number of dimuons from heavy flavour processes could hence be estimated by simply subtracting these contributions from the sample. A better estimate is obtained by performing a fit to the mass distribution for nonisolated unlike sign events (fig. 2 b) and table 3, column I), using the appropriate mass spectra as an additional constraint. To check the calculation for the light meson contribution, this contribution is also included in the fit. The resulting light meson contribution of 31 ± 8 events (table 3) is in good agreement with the absolute expectation for this subsample (27 ± 11 events), obtained from the minimum bias calculation.

From the same fit, a heavy flavour contribution of 48 ± 11 events is obtained. As can be seen from fig. 2 b), it is needed to fit the mass spectrum above 1.5 GeV/c^2. Its shape, which is dominated by the contribution from b cascade decays, is well described by the ISAJET prediction. A large fraction of these events is expected to result from higher order processes (table 2). However, the lowest and higher order contributions can not be distinguished in the mass spectrum in the dominant case of cascade decays, where both muons originate from the same parent b quark.

Comparing the measured number of events with the absolute ISAJET prediction for $b\bar{b}$ and $c\bar{c}$, the prediction has to be scaled by a factor of 0.6 ± 0.2 to explain the data. Since the $c\bar{c}$ contribution is small (table 2), we can apply this factor to the ISAJET cross section for beauty production in the relevant transverse momentum range to obtain a cross section for the production of high p_T *single* b quarks (including $\bar{b}$):

$$\sigma\,(p\bar{p} \rightarrow b + X, p_T(b) > 10\,GeV/c,\ |\eta(b)| < 1.5\,) = 0.7 \pm 0.1_{stat} \pm 0.4_{sys}\ \mu\text{b}.$$

The systematic error includes the errors of integrated luminosity, background subtraction, and detector acceptance, and the uncertainties of the parametrization of the fragmentation function and the decay branching ratios. Since the shapes of the $p_T(b)$ distributions for lowest order and higher order processes generated by ISAJET differ significantly in the low p_T range, the calculation of this cross section from the data is somewhat model dependent. However, in the high p_T range considered here, the sensitivity to the ratio of lowest and higher order contributions is greatly reduced. Even with the most extreme assumptions (100% lowest order or 100% higher orders) the cross section derived from the data would change by less than 30%.

Finally, the contribution from heavy flavour processes to the sample of 37 like sign events (from B^o-$\bar{B}^o$ mixing and second generation b decays) is consistent with expectations, taking into account the large background fraction (table 1).

7. Limit for the decay $B^o \to \mu^+\mu^-$

The large cross section for low p_T $b\bar{b}$ *pair* production obtained from an earlier analysis [2] ($1.1 \pm 0.4\,\mu$b for lowest order processes with $p_T(b) > 5$ GeV/c for both b's and $|\eta(b)| < 2$) allows us to search for rare B-meson decays with a clear signature. In the case of dimuons, the channel $B^o \to \mu^+\mu^-$ is a natural candidate to be considered. Such a decay is forbidden in the standard model, since it requires the presence of flavour changing neutral currents. Using the measured $b\bar{b}$ cross section and normalizing to the integrated luminosity of 552 nb^{-1}, about 10^6 B-mesons with $p_T > 5$ GeV/c are expected from flavour creation processes alone ($gg,q\bar{q} \to b\bar{b}$, including initial and final state gluon radiation). Contributions from other higher order processes like gluon splitting and flavour excitation are neglected. Of the 6 events in fig. 2 a) with $m(\mu\mu)$ between 4.8 and 6 GeV/c^2, where contributions from this decay would be expected, only one (with mass 5.39 ± 0.15 GeV/c^2) has $p_T(\mu\mu) > 5$ GeV/c. Assuming that a b quark picks up a light quark in the same way as a u quark, the measured K to π ratio for leading particles [13] suggests a corresponding B_s^o:B_d^o ratio of 1:2. Using a $B^\pm$:B_d^o ratio of 1:1, assuming a fraction of 10% baryons, and correcting for acceptance, we then obtain the following limits on the branching ratio for B^o decays into two muons:

$$Br(B^o \to \mu^+\mu^-) < 9 \times 10^{-5} \text{ at 90\% c.l., } B_d^o,B_s^o \text{ not separated, and}$$

$$Br(B_d^o \to \mu^+\mu^-) < 1.4 \times 10^{-4} \text{ at 90\% c.l.}$$

$$Br(B_s^o \to \mu^+\mu^-) < 3 \times 10^{-4} \text{ at 90\% c.l.}$$

The combined limit for B_d^o and B_s^o is of the same order of magnitude as the limits reported by the ARGUS and CLEO collaborations [16], who are however sensitive only to the B_d^o channel.

8. Drell-Yan

The Drell-Yan contribution is extracted from a fit to the mass distribution for isolated unlike sign muon pairs (fig. 2 c)). The residual contributions from light mesons and heavy flavours to this sample can be reliably extrapolated from the measured contributions to the nonisolated sample, since the small fractions of isolated events are known from the Monte Carlo and from other data samples. Using the shape of the Drell-Yan mass distribution as generated by ISAJET and fitting a Gaussian for the J/ψ, a Drell-Yan contribution of $36.2 \pm 5.8_{sys}$ events is obtained (table 3, column II). This translates into cross sections for high p_T, low mass Drell-Yan production:

$$\sigma^{DY}\left(p_T(\mu\mu) > 6\,GeV/c,\ m(\mu\mu) < 6\,GeV/c^2\right) = 1.3 \pm 0.2_{stat} \pm 0.4_{sys}\ \mathrm{nb}$$

and

$$\frac{d\sigma^{DY}}{dy}\left(p_T(\mu\mu) > 6\,GeV/c,\ m(\mu\mu) < 6\,GeV/c^2\right)\Big|_{y=0} = 0.26 \pm 0.04_{stat} \pm 0.08_{sys}\ \mathrm{nb}.$$

The systematic error reflects the errors of integrated luminosity, background subtraction and acceptance correction. The acceptance is calculated using the ISAJET Monte Carlo program including simulation of the detector and the muon trigger. Comparing this cross section to the cross section predicted by ISAJET, the ISAJET prediction must be scaled up by a factor of 1.9 ± 0.6 to reproduce the data.

About half of the Drell-Yan contribution (15.6 ± 1.6 events) lies in the mass region below 600 MeV, where the signal to background ratio is particularly favorable (fig. 2 c)). From these events, we obtain a differential cross section at m= 400 MeV/c^2 or $\sqrt{\tau} = m/\sqrt{s} = 6 \times 10^{-4}$:

$$\frac{d^2\sigma}{dm dy}(p_T(\mu\mu) > 6\,GeV/c)\Big|_{m(\mu\mu)=0.4\pm0.2\,GeV/c^2,\ y=0} = 0.25 \pm 0.06_{stat} \pm 0.06_{sys}\ \frac{\mathrm{nb}}{GeV/c^2}.$$

The invariant cross section as a function of transverse momentum for isolated Drell-Yan muon pairs with $m(\mu\mu) < 2.5$ GeV/c^2 is shown in fig. 3 and table 4. It is corrected for the 20% loss of events that do not satisfy the isolation cuts because of hadrons from the underlying event. The cut at 2.5 GeV/c^2 is chosen to eliminate the J/ψ contribution. All other contributions are subtracted using their individual p_T-distributions. A flat rapidity distribution within $|y| < 1.7$ is assumed. The measured cross section is compared to the QCD-predictions for isolated Drell-Yan events from Aurenche et al. [9], based on a calculation to second order in α_s. Since those predictions do not depend significantly on the choice of structure functions in the x range considered here (x $\gtrsim$ 0.02, where x=p_{parton}/p_{proton}), the good agreement, both in shape and normalization, shows that the proton structure at low x-values is adequately described.

Since no other measurements of Drell-Yan production in this new kinematical region (very low mass and high p_T) are known to us, and extrapolation towards lower transverse momenta is problematic from the theoretical point of view, it is difficult to compare our measurement with results from other experiments at lower energies [17]. However, since we are in the kinematical region $m(\mu\mu)^2 \ll p_T(\mu\mu)^2$, the intermediate virtual photon is "nearly real", so that a comparison with *direct photon production* can be made. In the case of isolated photons, the cross sections σ^γ for single photon and σ^{DY} for low mass, high p_T Drell-Yan production are related by the formula:

$$\int_{m^2_{min}}^{m^2_{max}} E\frac{d^4\sigma^{DY}}{dm^2 d^3p} \simeq C \times E\frac{d^3\sigma^\gamma}{d^3p}, \quad \text{where} \quad C = \frac{\alpha}{3\pi} ln \frac{m^2_{max}}{m^2_{min}}.$$

With $m_{min} = 2m_\mu$ and $m_{max} = 2.5$ GeV this gives a factor of $C = \alpha/1.91$. The invariant Drell-Yan cross section scaled according to this relation is compared to direct photon data [7] and theoretical predictions [9] in fig. 4. The good agreement shows that Drell-Yan muon pairs in this kinematical region can be effectively substituted for real photons. This allows us to infer a measurement of the single photon spectrum at lower values of transverse momentum, where photons cannot be unambiguously identified.

9. Conclusion

All significant contributions to the low mass dimuon sample ($m(\mu\mu) < 6$ GeV/c^2) are analyzed, including J/ψ, heavy flavour, and light meson production, and production of low mass, high p_T Drell-Yan muon pairs. From the subsample of nonisolated events we obtain a cross section for high p_T single b quark production (including $\bar{b}$) of $\sigma\,(p\bar{p} \rightarrow b + X, p_T(b) > 10\,GeV/c,\ |\eta(b)| < 1.5\,) = 0.7 \pm 0.1_{stat} \pm 0.4_{sys}$ μb. An upper limit for the branching fraction for the decay $B^o \rightarrow \mu^+\mu^-$ of 9×10^{-5} at 90% c.l. is also obtained. For the Drell-Yan contribution, the cross section for a new kinematical region $\frac{d\sigma^{DY}}{dy}\left(p_T(\mu\mu) > 6\,GeV/c,\ m(\mu\mu) < 6\,GeV/c^2\right)\Big|_{y=0} = 0.26 \pm 0.04_{stat} \pm 0.08_{sys}$ nb is derived from the subsample of isolated events. The invariant cross section $Ed^3\sigma/d^3p$ agrees well with QCD calculations and allows the extension of the measured single photon cross section towards a lower p_T range through replacement of the photon by a low mass muon pair.

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Tables

Table 1 : Event classification according to charge and isolation

Classification of the low mass dimuon data (304 events) according to charge and isolation. The number of background events expected for each subsample is also indicated. Errors are systematic only.

		nonisolated	isolated	total
unlike sign:	data	174	93	267
	background	27 ± 7	11 ± 5	38 ± 9
like sign:	data	32	5	37
	background	14 ± 4	5 ± 3	19 ± 5
total:	data	206	98	304
	background	41 ± 11	16 ± 8	57 ± 14

Table 2: Expected heavy flavour contributions

Relative contributions from various heavy flavour subprocesses to the low mass dimuon sample as predicted by ISAJET [10]. B^o-$\bar{B}^o$ mixing is included as measured by UA1 [3]. The processes generated include the lowest order process of flavour creation (gg,$q\bar{q} \to Q\bar{Q}$), and the higher order processes of flavour excitation ($gQ \to gQ$) and gluon splitting ($gg \to gg$, $g \to Q\bar{Q}$).

contributions to unlike sign dimuon sample:	%
$b\bar{b}$, μ's from same b ($b \to c\mu\nu$, $c \to s\mu\nu$):	
lowest order	26.1
higher orders	35.4
$b\bar{b}$, μ's from different b's:	
lowest order (suppressed by dimuon p_T requirement)	2.1
higher orders	21.5
$c\bar{c}$, μ's from different c's:	
all orders (suppressed by c quark fragmentation)	3.6
contributions to like sign dimuon sample:	
$b\bar{b}$, μ's from different b's:	
$b\bar{b}$, 2nd generation decay of one b	5.1
B^o-$\bar{B}^o$ mixing	5.9

Table 3 : Contributions to unlike sign dimuon sample

Number of events contributing to the sample of 267 unlike sign dimuon events obtained from fits to the data using the expected shape of the mass distributions. Contributions marked with an asterisk *) are normalized to the number of events observed in the neighbouring columns. The background contributions are fixed to the values expected from the background calculation. Errors are systematic only.

process	I nonisolated	II isolated	III all
J/ψ and ψ'	58 ± 12	36.8 ± 5.8	94 ± 11
$b\bar{b}/c\bar{c}$	48 ± 11	$5.3 \pm 2.7^{*)}$	$53 \pm 12^{*)}$
Drell-Yan	$9 \pm 4^{*)}$	36.2 ± 5.8	$45 \pm 9^{*)}$
$\rho, \omega, \phi, \eta, \eta'$	31 ± 8	$4.2 \pm 3.0^{*)}$	$35 \pm 9^{*)}$
background	27 ± 7	10.6 ± 5.4	38 ± 9

Table 4 : Invariant cross section for high p_T Drell-Yan production

Invariant cross section $Ed^3\sigma/d^3p$ for production of low mass ($m(\mu\mu) < 2.5$ GeV) high p_T Drell-Yan muon pairs. A flat rapidity distribution is assumed for $|\eta| < 1.7$. Errors are statistical only. A global systematic error of about 30% has to be added.

$p_T(\mu\mu)$ [GeV/c] range	average	$Ed^3\sigma/d^3p$, $\eta = 0$ [nb/GeV^2]
6- 8	6.75	$(1.2 \pm 0.9) * 10^{-3}$
8- 9	8.35	$(5.9 \pm 3.7) * 10^{-4}$
9-10	9.47	$(3.5 \pm 2.2) * 10^{-4}$
10-12	10.65	$(9.1 \pm 6.1) * 10^{-5}$
12-20	13.14	$(1.3 \pm 0.9) * 10^{-5}$
20-40	30.75	$(6.6 \pm 6.6) * 10^{-7}$

Figure captions

Fig. 1 Acceptance for the transverse momentum cut of $p_T(\mu) > 3$ GeV/c for each muon as a function of dimuon p_T for different masses of the dimuon system, assuming isotropic two body decay of the parent particle and 100% detection efficiency for the resulting muons.

Fig. 2 Dimuon mass distributions:

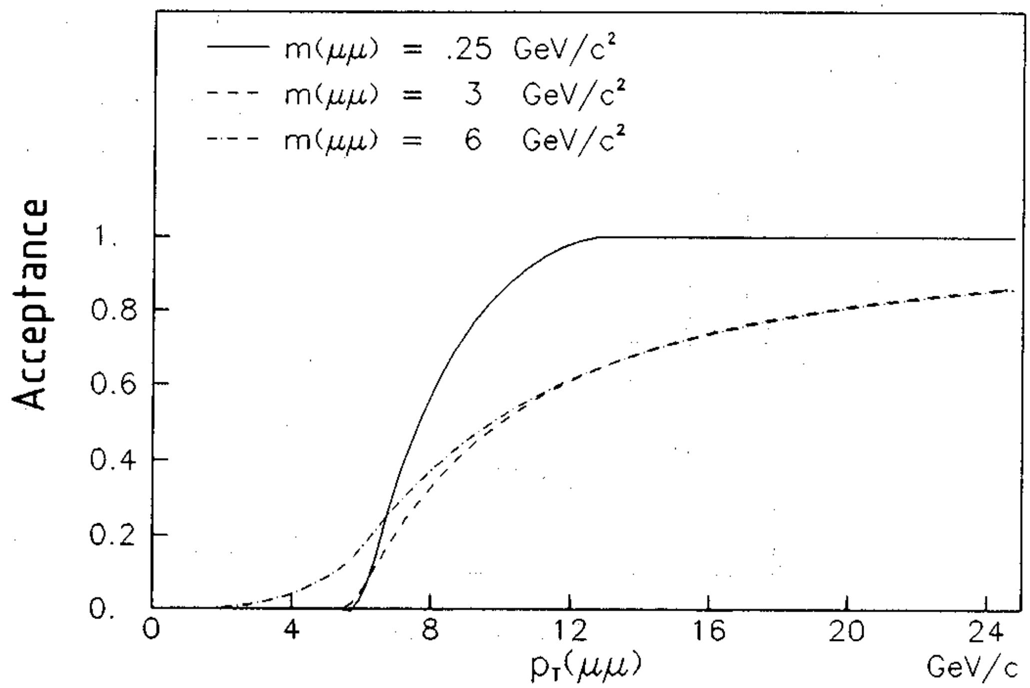
a) Mass distribution for all unlike sign muon pairs (267 events). The J/ψ,ψ' and background contributions are shown separately. The "other contributions" are listed in table 3, column III.

b) Mass distribution for 174 nonisolated unlike sign muon pairs. Also shown are the contributions from individual processes as listed in table 3, column I. In addition to the processes explicitly mentioned, the curve "all processes" includes contributions from J/ψ decay and decays of ρ, ω, ϕ, η and η'.

c) Mass distribution for 93 isolated unlike sign muon pairs. Also shown are the contributions from individual processes as listed in table 3, column II. In addition to the processes explicitly mentioned, the curve "all processes" includes contributions from J/ψ decay and decays of ρ, ω, ϕ, η and η'.

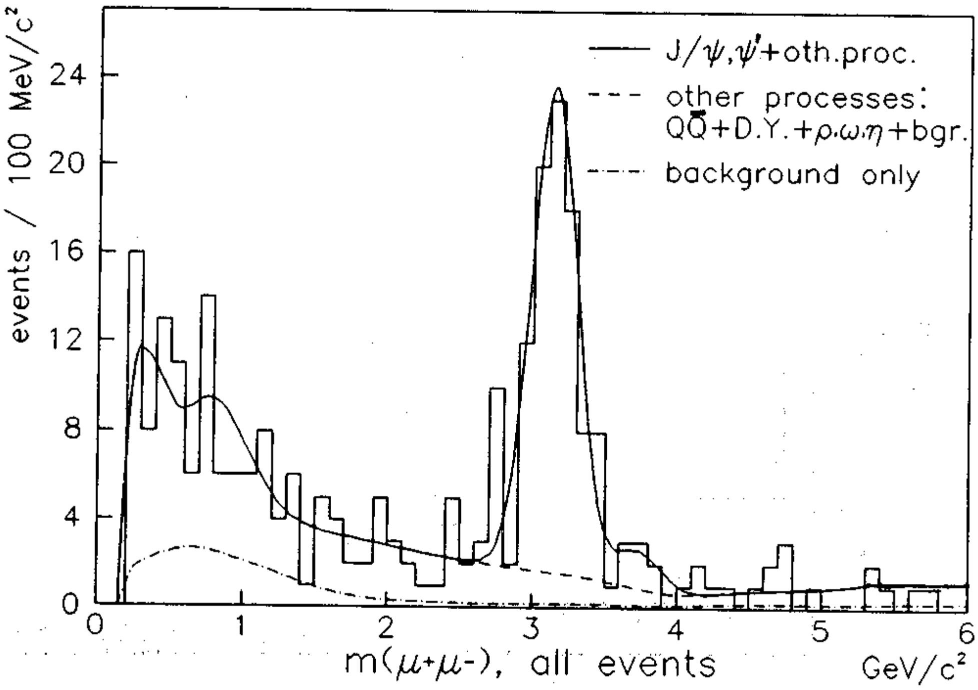
Fig. 3 Invariant cross section $Ed^3\sigma/d^3p$ for isolated Drell-Yan events with $m_{\mu\mu} < 2.5$ GeV/c^2. Only the statistical errors are shown. A global systematic error on the normalization of about 30% has to be added. Also shown are QCD predictions from Aurenche, Baier and Fontannaz [9] for two different values of the isolation cutoff $\delta/2$ (minimum angle between the virtual photon and the closest quark).

Fig. 4 Comparison of the Drell Yan and single photon cross sections. The Drell-Yan cross section is scaled by a factor $1.91/\alpha = 262$ derived from theory [9]. The single photon data are taken from reference [7]. The theoretical curves are from Aurenche et al. [9].



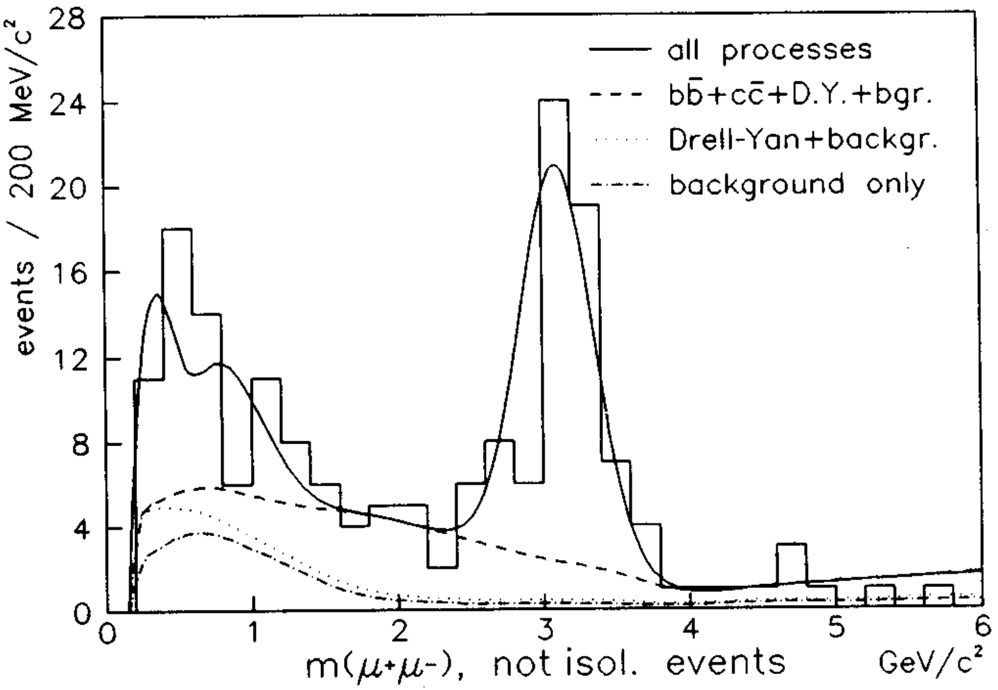
m(μμ) = .25 GeV/c²
m(μμ) = 3 GeV/c²
m(μμ) = 6 GeV/c²
Acceptance
1.
0.8
0.6
0.4
0.2
0.
0
4
8
12
16
20
24
p_T(μμ)
GeV/c

FIG. 1



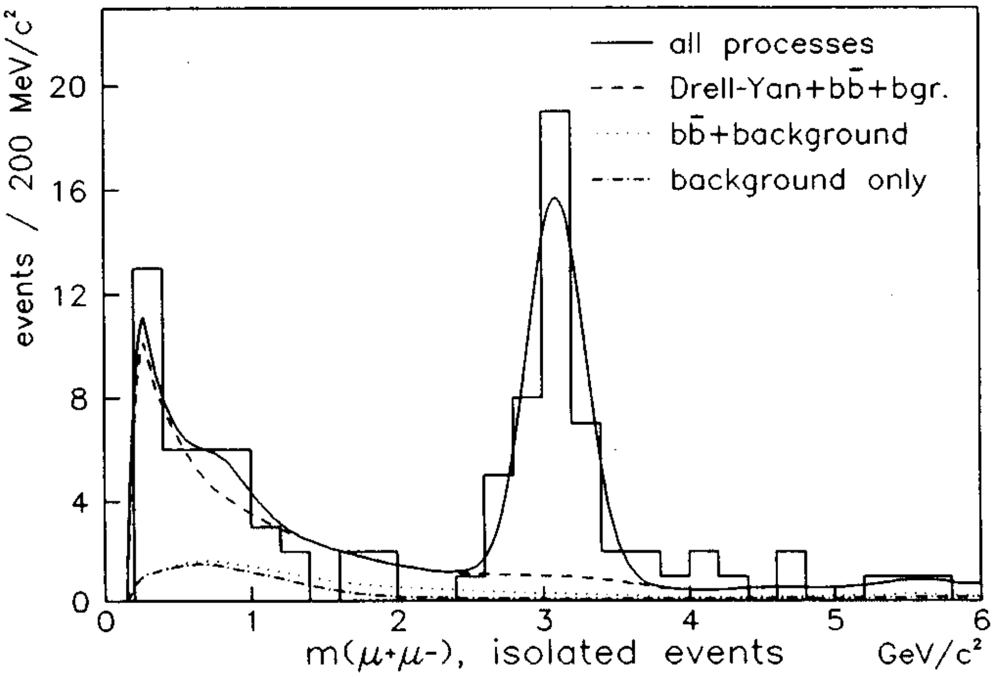
J/ψ,ψ'+oth.proc.
other processes:
QQ̄+D.Y.+ρ,ω,η+bgr.
background only
events / 100 MeV/c²
24
20
16
12
8
4
0
0
1
2
3
4
5
6
m(μ+μ-), all events
GeV/c²

FIG. 2a



events / 200 MeV/c²
28
24
20
16
12
8
4
0
0
1
2
3
4
5
6
all processes
bb̄+cc̄+D.Y.+bgr.
Drell-Yan+backgr.
background only
m(μ+μ-), not isol. events
GeV/c²

FIG. 2b



events / 200 MeV/c²
20
16
12
8
4
0
0
1
2
3
4
5
6
all processes
Drell-Yan+bb̄+bgr.
bb̄+background
background only
m(μ+μ-), isolated events
GeV/c²

FIG. 2c

Low mass Drell-Yan p_T-distribution

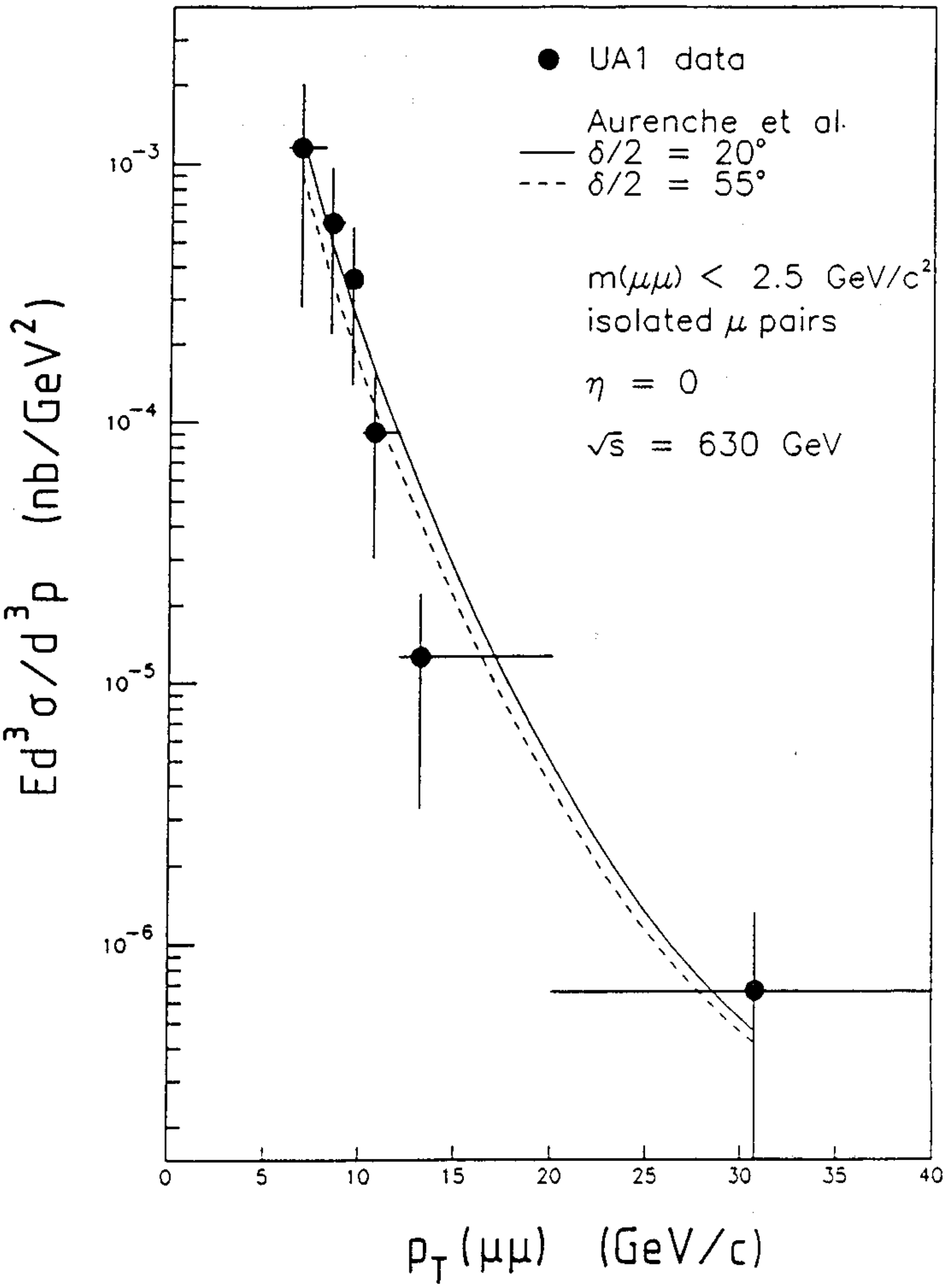


FIG. 3

Comparison of Drell-Yan and single photon cross sections

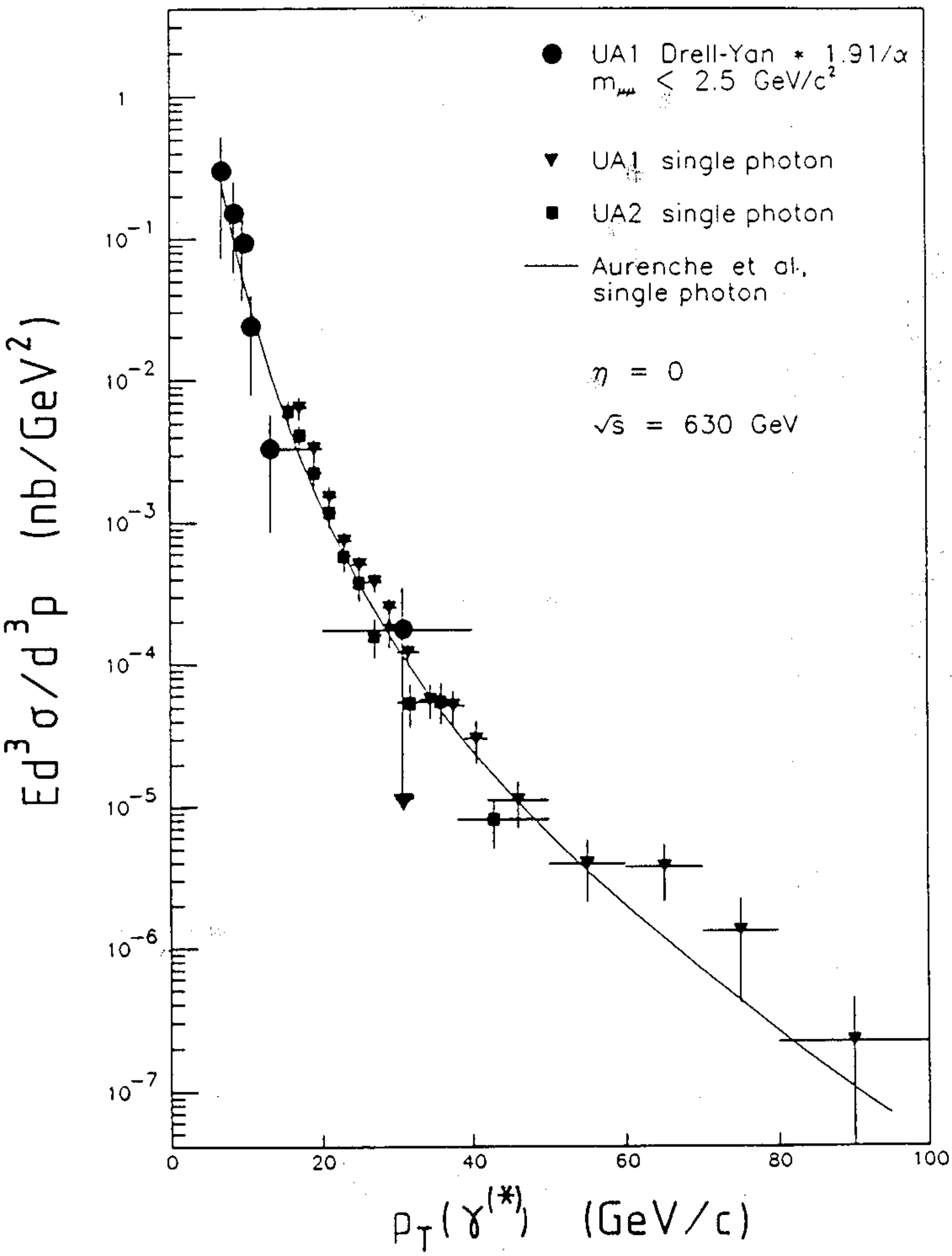


FIG. 4