INCLUSIVE J/ψ PRODUCTION IN e^+e^- ANNIHILATION IN THE ENERGY RANGE FROM 4.0 TO 5.0 GeV

Pluto Collaboration

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We report on inclusive production of J/ψ (3.1)-mesons observed in e^+e^--annihilation in the energy range $\sqrt{s}$ = 4.0–5.0 GeV. After subtraction of the radiative tail of the ψ(3.7) direct production of the J/ψ (3.1) is found to be in the order of 0.1% of the total hadronic cross section. No enhancements are seen at $\sqrt{s}$ = 4.03 GeV and 4.4 GeV. The level is in agreement with expectations from violation of the Zweig-rule.

It has been suggested by several authors that "charm molecules", i.e. exotic bound-states of four quarks ($q\bar{q}\bar{c}c$) may exist and lead to a rich spectroscopy [1]. In particular the enhancements in the total hadronic cross section for e^+e^--annihilation at center of mass energies of 4.03 GeV and 4.4 GeV [2, 3] may be due to the formation of those four-quark-states. Some of the models predict sizeable branching-ratios (of the order of 10%) for the decay into J/ψ plus hadrons.

Direct J/ψ-production is also expected to appear via Zweig-rule violations but at a level < 1% of the total cross section [4].

We have searched for inclusive J/ψ-production via its decay into two muons

$$e^+e^- \to J/\psi + \text{charged hadrons} \qquad (1)$$
$$\hookrightarrow \mu^+\mu^-$$

using the magnetic detector PLUTO at the e^+e^--storage ring DORIS at DESY. The detector has been described elsewhere [5]. It has a superconducting solenoid producing a field of 20 kΓ. The field volume is filled with 14 cylindrical multiwire proportional chambers. Outside the flux-return-yoke are 25 proportional-tube-chambers which detect penetrating particles within 43% of the full solid angle. The chambers have a double layer of 180 parallel proportional tubes (108 cm long) resulting in a wire spacing of 1 cm.

A track is identified as a muon if it traverses the absorber, consisting of the coil and the yoke, and hits at least one muon-chamber within ±12.5 cm with respect to the extrapolated trajectory. This thickness

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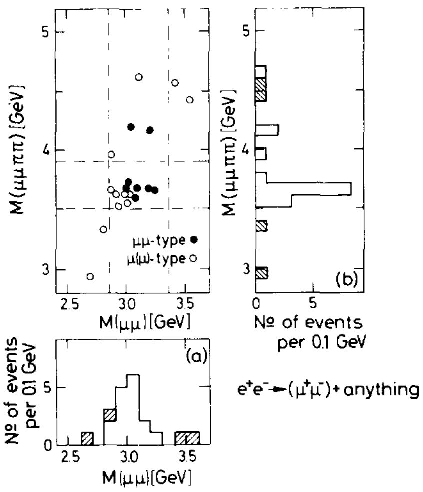

Fig. 1. Correlation between effective masses of muon pairs ($M(\mu\mu)$) and of ($\mu\mu\pi\pi$)-system (after fit) and related distribution for ($\mu\mu$) (a) and ($\mu\mu\pi\pi$) (b). The shaded in fig. (a) and (b) events are outside the muon-pair mass region from 2.85 to 3.35 GeV.

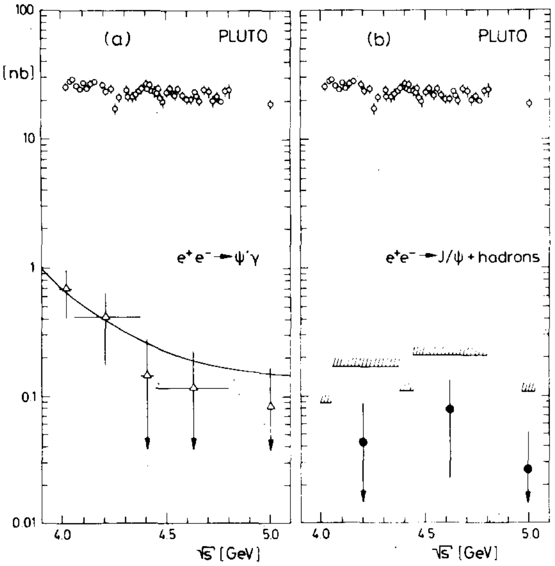

Fig. 2. (a) Production cross section for radiative $\psi(3.7)$ events (triangles) and the calculated cross section of the radiative tail of the $\psi(3.7)$ (full line). (b) Production cross section for direct J/ψ-production (closed circles) and upper limits (90% C.L.). In both figures the open circles are the total hadronic cross section without radiative corrections (taken from ref. [2] and from more recent unpublished data).

of material to be traversed by the muons depends on their direction and is on average about 68 cm of iron equivalent. Thus, to be accepted, the muons are required to have a minimum momentum of 1 GeV/c.

The probability $P(\mathrm{h}\to\mu)$ that a hadron penetrates the absorber by punch through or decay and is misidentified as a muon was measured by using tracks from multiprong events at the resonance $J/\psi(3.1)$ and tracks from hadronic events at $\sqrt{s} = 3.6$ GeV. We found for hadron momenta between 1.0 and 1.5 GeV/c

$$P(\mathrm{h}\to\mu) = (2.8 \pm 0.5)\%.$$

In the momentum range considered this probability is independent of momentum in accordance with a Monte-Carlo-study.

In order to search for reaction (1) we selected events of the type

$$e^+e^- \to \mu^\pm + T^\mp + (\geqslant 1 \text{ charged track})\,. \qquad (2)$$

Both the muon and the track T are required to have $|\cos\theta| < 0.752$, where θ is the angle between beam axis and track, and a momentum greater than 1 GeV/c. If T falls into the muon acceptance, it has to meet the criteria for muon identification. We have two types of events, (i) two muons identified ($\mu\mu$-type) and (ii) one muon identified and a track T which does not point to a muon chamber ($\mu(\mu)$-type).

We found 20 events from reaction (2) (8 of them of the $\mu\mu$-type) having effective masses of the ($\mu^\pm T^\mp$)-system (in the following called a muon pair) between 2.6 and 3.6 GeV. The effective mass distribution is shown in fig. 1a. The distribution peaks at the mass of the J/ψ-resonance. The width of the peak is compatible with the expected resolution. For further analysis we excluded events with muon pair masses outside a region of ±250 MeV around the J/ψ. The remaining sample contains 16 events.

There are three classes of events contributing to this sample: (i) radiative decays of the $\psi(3.7)$ resonance, (ii) directly produced $J/\psi(3.1)$ mesons and (iii) background.

We estimate the background from hadron punch through and decay to amount to about one event, contributing only to the $\mu(\mu)$-type events. For the $\mu\mu$-type the background is negligible (<0.5%).

For the 16 events of our sample we have tested the hypothesis whether they belong to the radiative tail of the $\psi(3.7)$ according to the cascade reaction:

Table 1
Details of kinematics of the directly produced J/ψ-events: $e^+e^- \to J/\psi + X$, $\hookrightarrow \mu^+\mu^-$

$\sqrt{s}$ (GeV)	$M(\pi\pi)$ (GeV)	$M(\mu\mu)$ after fit GeV	$M(\mu\mu\pi\pi)$ (GeV)	No. of prongs	No. of identified muons	X	M(X) (GeV)
4.20	3.02	0.92±0.02	4.20	4	2	$\pi^+\pi^-$	0.92±0.02
4.62	3.10	0.74±0.01	4.62	4	1	$\pi^+\pi^-$	0.74±0.01
4.72	2.86	0.44±0.06	3.97±0.10	4	1	$\pi^+\pi^-\gamma$	1.02±0.17
5.00	3.20	0.60±0.02	4.20±0.15	4	2	$\pi^+\pi^-\gamma$	1.12±0.05

$$e^+e^- \to (e^+e^-)\gamma \quad \hookrightarrow \psi' \quad \hookrightarrow J/\psi\pi^+\pi^- \quad \hookrightarrow \mu^+\mu^- . \qquad (3)$$

Events of this type allow kinematic fits with one or more constraints and thus can be identified event by event. If all four prongs are seen, the missing vector is required to be close to the beam direction. For 3-prong-events it was assumed that a photon was emitted from the initial state along the beam line. The missing momentum of the system of the three visible tracks plus the assumed photon must point in a direction which has no acceptance for charged tracks, being consistent with the momentum of an undetected charged pion.

Fig. 1 shows the correlation between the muon pair mass and the effective mass of the $(\mu\mu\pi\pi)$-system after the fit and the mass distribution of this system (fig. 1b) peaking at the $\psi(3.7)$ resonance. The 12 events of this peak fit the reaction (3), 6 of them are of the $\mu\mu$-type. The ratio of 4-prongs to 3-prongs (9 : 3) is in agreement with the geometric acceptance of our detector.

To calculate the number of events expected from the radiative tail of the $\psi(3.7)$-resonance, we used the standard procedure [6] with the branching ratios $\Gamma(\psi(3.7) \to J/\psi\,\pi^+\pi^-)/\Gamma_{\rm all} = 0.33 \pm 0.03$ and $\Gamma(J/\psi(3.1) \to \mu^+\mu^-)/\Gamma_{\rm all} = 0.07 \pm 0.01$ [7]. Taking into account the trigger efficiency for multiprongs and the acceptance of the detector we expect 14.1 events for an integrated luminosity of 5072 nb^{-1} in good agreement with our measurements.

Fig. 2a shows the energy dependence of the cross section for events of the reaction (3) (triangles). It is consistent with the radiative tail of the $\psi(3.7)$ (full line).

The remaining 4 events do not fit the reaction (3). We consider them as examples of direct $J/\psi(3.1)$ production (reaction (1)), because the effective mass of the $(\mu\mu\pi\pi)$-system is considerably greater than $\psi(3.7)$. Details of the kinematics of these events are given in table 1.

An upper limit (90% confidence level) for the cross section for direct J/ψ-production $\sigma(e^+e^- \to J/\psi$ + ($\geqslant$1 charged hadron)) was calculated and is shown in fig. 2b. For comparison the figure shows the total hadronic cross section without radiative corrections as measured by our detector [2].

The luminosity as a function of energy was not uniformly distributed. Especially at the 4.03 and 4.4 GeV resonance-like regions 850 and 1004 nb^{-1} respectively have been accumulated, but in these regions no events with directly produced $J/\psi(3.1)$ were found.

In order to calculate the cross section from a backgroundfree sample we used only the two events of the $\mu\mu$-type. We obtain for direct J/ψ-production in the energy range 4.0 to 5.0 GeV

$$e^+e^- \to J/\psi + (\geqslant 1 \text{ charged hadron}) = 31 \pm 21 \text{ pb} ,$$

which is 0.13% of the total hadronic cross section.

In conclusion direct J/ψ-production is found to be fairly small for center of mass energies 4.0 GeV $\leqslant \sqrt{s} \leqslant$ 5.0 GeV. No enhanced production at $\sqrt{s}$ = 4.03 GeV and $\sqrt{s}$ = 4.4 GeV is found.

The level at which we observe direct $J/\psi(3.1)$-production is compatible with the violation of Zweig-rule following from theoretical calculations.

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