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Limits on J/ψ and T Production in e^+e^- Interactions at $\sqrt{s}$ = 29 GeV*

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ABSTRACT

A search has been made for the inclusive production of J/ψ (3.1) and T (9.4) mesons in e^+e^- interactions at 29 GeV, via their decay into two leptons. No signal is observed in the J/ψ region, nor in the T region. The limits on the cross sections are $\sigma(e^+e^- \to \psi X) < 4.4 \times 10^{-36}$ cm^2, and $\sigma(e^+e^- \to TX) < 4.7 \times 10^{-36}$ cm^2. The same data yield limits on the branching ratios for the b quark $Br(b \to \psi X) < 4.9\%$ and $Br(b \to \ell^+\ell^- X) < 0.8\%$.

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In this Letter we present a search for inclusive ψ production by detection of the dilepton decay mode:

$$e^+e^- \longrightarrow \psi X \qquad (1)$$
$$\hookrightarrow \mu^+\mu^-,\ e^+e^-$$

at a center-of-mass energy of 29 GeV using the SLAC-LBL Mark II detector at the PEP storage ring. Both leptons in (1) were identified either by the muon system or by the electromagnetic shower calorimeter, exploiting the good efficiency of the apparatus for detecting both muons and electrons. A similar search was carried out for Υ production. No signal for the J/ψ or Υ was found and we give upper limits on the inclusive production cross sections.

Various dynamical mechanisms suggest that observation of the ψ may be a good signal for underlying new physics. For example, in heavy quark decay, a decay sequence leading through charm may provide a $c\bar{c}$ bound state some reasonable fraction of the time[1]. The initial heavy quark could result either from direct coupling to the intermediate virtual photon, or be coupled to a Higgs particle or to some other exotic system. Several QCD predictions have also been made for ψ production[2]. The perturbative calculations for the inclusive process $e^+e^- \to \psi X$ yield cross sections between 10^{-3} and 10^{-4} $\sigma_{\mu\mu}$ for $E_{c.m.} > 15$ GeV. Very high statistics experiments are needed in order to check these calculations and to identify the different mechanisms which are involved. The perturbative calculations are however the minimal expected contribution to ψ inclusive production: a large uncertainty comes from possible

non-perturbative contributions. Some calculations[3] predict a cross section larger than $10^{-1}\ \sigma_{\mu\mu}$, which would imply a large probability to observe ψ's at energies $E_{c.m.} > 15$ GeV. In the inclusive ψ production $e^+e^- \to \psi X$, the ψ leptonic decay modes should stand out relatively cleanly above a background of uncorrelated e^+e^- or $\mu^+\mu^-$ pairs.

The detector has been described elsewhere[4]. Charged particles are detected over 80% of the solid angle with a cylindrical, 16 layers, drift chamber. The solenoidal magnetic field is 4.6 Kgauss for 43% of the data sample and 2.3 Kgauss for the remaining 57%. The average momentum resolution is $\Delta p/p = \sqrt{(0.015)^2 + (0.007p)^2}$ (where p is in GeV) when the particle is constrained to pass through the beam interaction point. The smaller magnetic field was compensated for by the installation of a vertex detector in the summer 1981, which provides improved spatial resolution for charged particle tracking. Outside the magnet coil there are 8 lead-liquid argon shower counters which serve to identify and measure photons and electrons over 65% of the solid angle. The detector is surrounded by four layers of steel plate absorbers and proportional tubes, used to identify muons over 55% of the solid angle.

A particle is identified as a muon if it traverses at least three layers of the absorber and has a range consistent with that expected for a μ. At each layer the associated hits must be within 3 standard deviations of the extrapolated trajectory. This selection requires a minimum muon momentum of 1.4 GeV/c. The probability that a hadron

within the muon system solid angle fakes a muon by decay or punch through within these criteria is less than 1.1%. An electron is identified from the amount of energy deposited in each layer of the liquid argon calorimeter. The total energy and the shape of the shower inside the calorimeter is examined for each track[5]. The identification efficiency is ~ 76% at 1 GeV and increases with the electron energy. The probability of misidentifying a hadron as an electron depends on its position inside a jet of particles, and is typically 1%.

In the search for ψ's, a sample of 9411 hadronic events is selected out of a total luminosity of 34617 nb^{-1} with the following cuts. Each particle must have R < 5 cm and Z < 10 cm, where R and Z are the distances of closest approach to the interaction point in a plane perpendicular to and along the beam axis respectively. Each event has the following properties:

1) There must be 5 or more charged particles each with momentum p > 0.1 GeV/c. Dividing the event in two hemispheres with respect to a plane perpendicular to the sphericity axis, there must be at least 2 charged particles in each hemisphere;
2) The sum of the magnitudes of the charged particle momenta must be greater than 7.5 GeV/c;
3) The sphericity[6] axis must form an angle θ_s with the beam such that $|\cos\theta_s| < 0.7$.

Requiring that two leptons be detected, we are left with a sample of 250 events.

The invariant mass is computed for all neutral pairs of leptons of the same type, if at least one of them has a transverse momentum with respect to the sphericity axis larger than 1 GeV and both leptons have momenta ranging between 1.4 and 11 GeV/c. Figure 1 shows the invariant mass distribution for opposite charge e^+e^- and $\mu^+\mu^-$ combinations. There are no events in the region between 2.5 and 3.3 GeV, corresponding to the position of the ψ.

The background is estimated by a Monte Carlo method. A simulation of $e^+e^- \to q\bar{q}$ and $e^+e^- \to qqg$, including radiative effects, was used to describe the data from $e^+e^- \to$ hadrons. The Monte Carlo simulation agrees well with the data for the distributions in momentum and transverse momentum of the leptons, for the charged multiplicity, etc. The source of leptons in the Monte Carlo is mostly the semileptonic decay of c and b quarks, with a small contribution from π and K decay and from γ's converting in the material close to the interaction point. The Monte Carlo simulation does not include ψ production, and yields no $\ell^+\ell^-$ event in the ψ region.

The ψ detection efficiency ranges between 1.5% and 2.1% depending on which model of production is assumed (including the leptonic branching ratio of 14%). The less favorable mechanism is the "non-perturbative model" of ref. 3. Using the value of 1.5%, the corresponding 90% C.L. upper limit is:

$$\sigma(e^+e^- \to \psi X) < 4.4 \times 10^{-36} \text{ cm}^2$$

Note that this upper limit corresponds to $4.3 \times 10^{-2}\ \sigma_{\mu\mu}$. This limit is a factor of 10 to 100 above the values calculated in perturbative QCD models[2], but it excludes the large cross section expected from the non-perturbative model of Kane et al[3] which would yield ~ 15 events in the plot of Fig. 1 in the region 2.5 - 3.3 GeV. Previous measurements were made of inclusive ψ production in e^+e^- at $\sqrt{s}$ = 4.0 - 5.0 GeV[7].

We used similar methods to search for Υ production. There are no e^+e^- and $\mu^+\mu^-$ combinations with an invariant mass compatible with an Υ (9.4) mass. To estimate the detection efficiency we employed a perturbative QCD matrix element based on the process $e^+e^- \to \Upsilon gg$ and simulated events by Monte Carlo method. We find $\varepsilon_\Upsilon = 1.4\%$. The corresponding 90% C.L. upper limit is $\sigma(e^+e^- \to \Upsilon X) < 4.7 \times 10^{-36}\ cm^2$, or $4.6 \times 10^{-2}\ \sigma_{\mu\mu}$.

Our data may also be used to set an upper limit on the branching ratio $Br(b \to \psi X)$ of b quarks into ψ's and on the flavor-changing neutral current process $b \to \ell^+\ell^- X$. We use the conventional model of the B meson, assuming that the decay is controlled by the decay of the b quark, the other quark (u,d, or s) having a spectator role. The efficiency to detect $\psi \to \ell^+\ell^-$ from B meson decay is 2.5%. The total number of $b\bar{b}$ events is computed to be 10% of the 9411 selected hadronic events. This leads to a 90% C.L. upper limit of:

$$Br(b \to \psi X) < 4.9\%$$

in agreement with the limit of 1.4% measured by CLEO collaboration[8] at CESR. A simple theoretical calculation[1] predicts a value of $Br(b \to \psi X)/Br(b \to \text{all}) \simeq 3 - 5\%$.

In the case of the decay $b \to \ell^+\ell^- X$, the invariant mass of the leptons is expected to be rather large (Fig. 2). A cut is therefore applied at $M_{\ell^+\ell^-} > 1.6$ GeV. Only pairs of leptons in the same hemisphere are considered with no cut in the lepton transverse momenta. One candidate is left in the data, and 2 events are expected from the background Monte Carlo calculation described previously. The acceptance for this neutral current decay mode is found by the Monte Carlo methods to be 13%, which leads to

$$Br(b \to \ell^+\ell^- X) < 0.8\% \text{ at } 90\% \text{ C.L.}$$

Along with similar limits obtained by MARK J at PETRA[9] and by CLEO at CESR[10], this result supports the assignment of the b quark to a weak iso-doublet, implying therefore the existence of a t quark[11].

In summary, we have searched for inclusive production of $J/\psi(3.1)$ and $\Upsilon(9.4)$ via their decay into two leptons. No signals are observed. At the 90% C.L., we determine $\sigma(e^+e^- \to \psi X) < 4.3 \times 10^{-2}\ \sigma_{\mu\mu}$ and $\sigma(e^+e^- \to \Upsilon X) < 4.6 \times 10^{-2}\ \sigma_{\mu\mu}$. The same data yield limits on the branching ratios for the b quark $Br(b \to \psi X) < 4.9\%$ and $Br(b \to \ell^+\ell^- X) < 0.8\%$.

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Figure Captions

Fig. 1 Invariant mass spectra of e^+e^-, $\mu^+\mu^-$ lepton pairs:

a) in the range 2.6 - 4.6 GeV

b) in the range 6 - 18 GeV.

The shaded events correspond to the expected invariant mass distribution from a Monte Carlo calculation with 5 quark flavors.

The dotted curve is the ψ signal expected from the "non-perturbative model."

Fig. 2 Invariant mass $M_{\ell^+\ell^-}$ distribution: the solid curve corresponds to a Monte Carlo calculation with 5 quark flavors, the dotted curve corresponds to decay $B \to \ell^+\ell^- X$ assuming that 10% of B mesons present in the data sample undergo this decay mode.

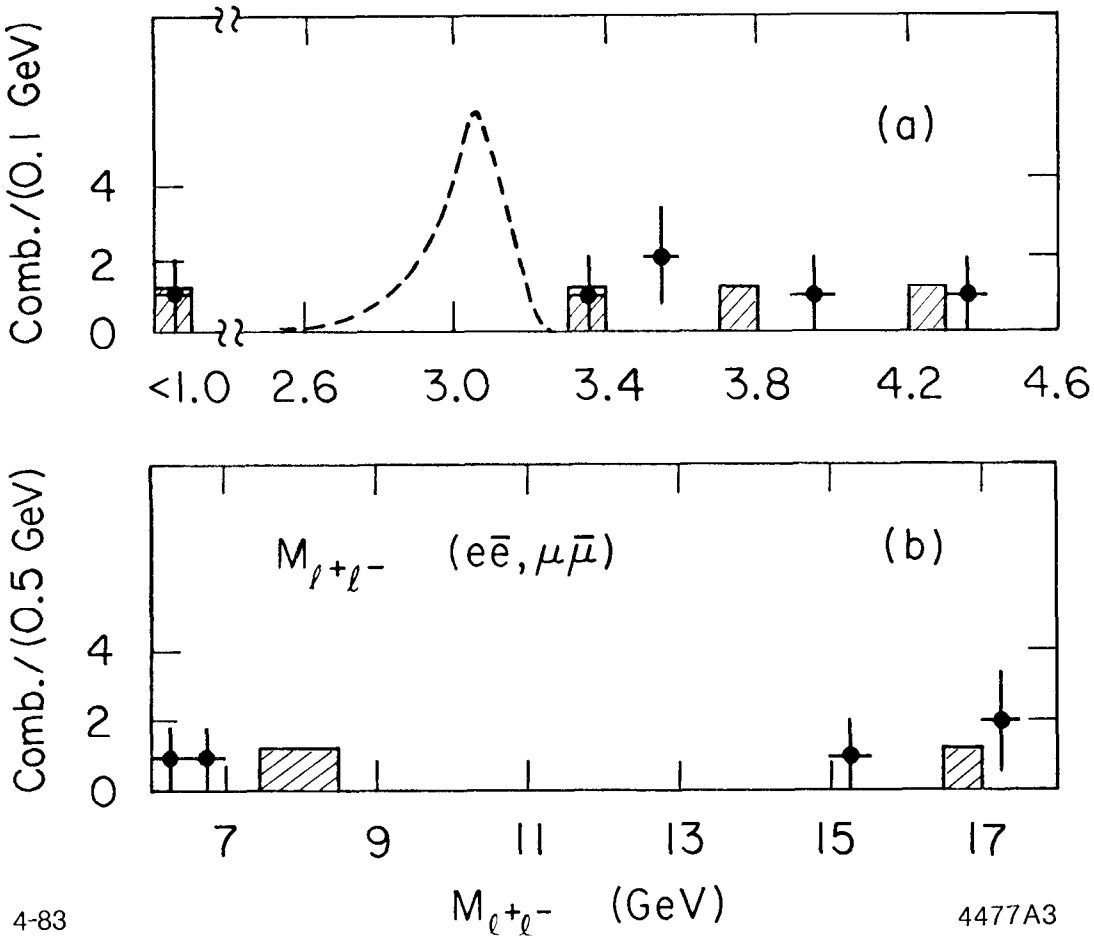
Comb./(0.1 GeV)
4
2
0
(a)
<1.0
2.6
3.0
3.4
3.8
4.2
4.6
Comb./(0.5 GeV)
$M_{\ell^+\ell^-}$ $(e\bar{e}, \mu\bar{\mu})$
(b)
4
2
0
7
9
11
13
15
17
$M_{\ell^+\ell^-}$ (GeV)
4-83
4477A3

Fig. 1

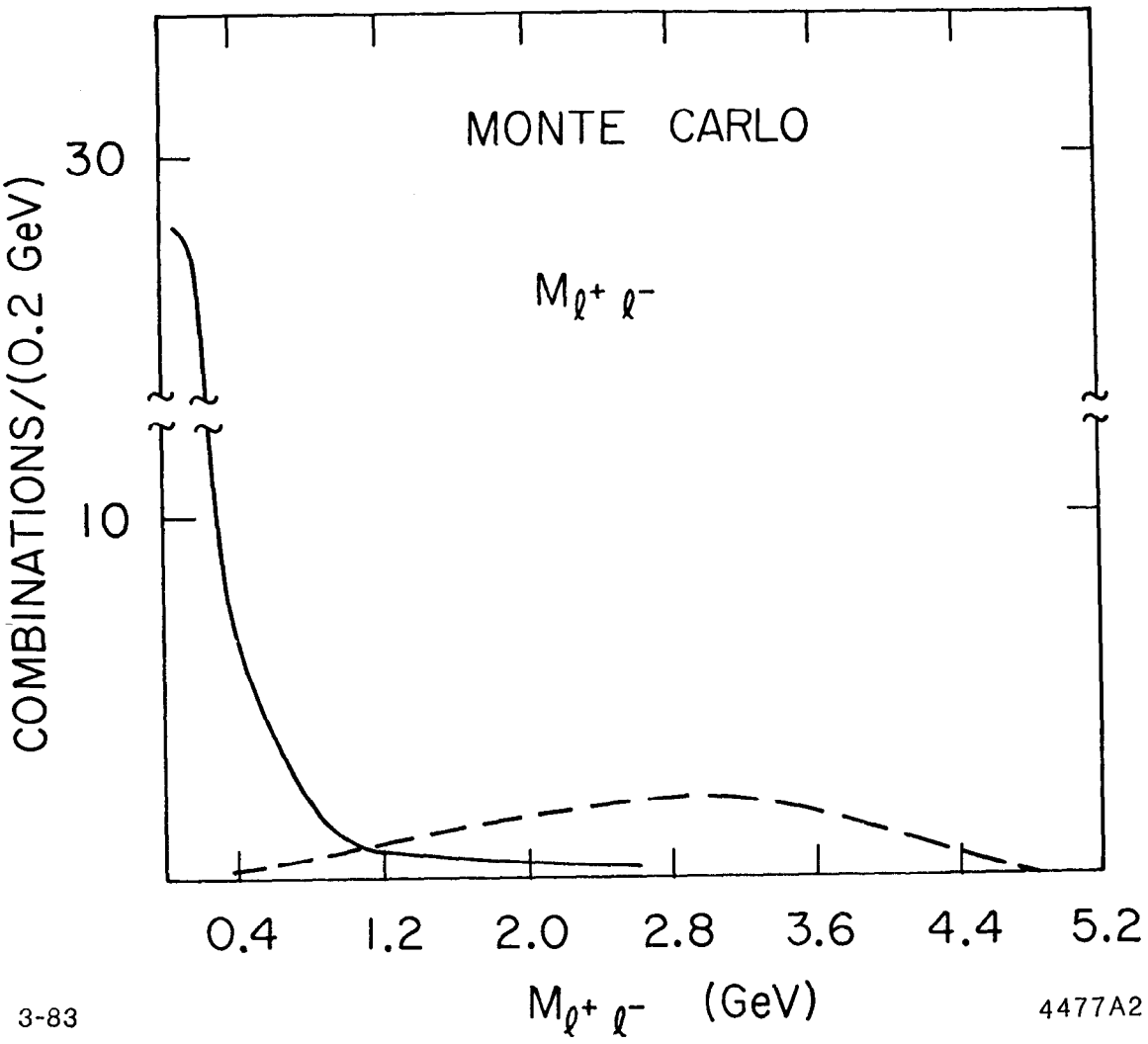
MONTE CARLO
$M_{\ell^+\ell^-}$
COMBINATIONS/(0.2 GeV)
30
10
0.4
1.2
2.0
2.8
3.6
4.4
5.2
$M_{\ell^+\ell^-}$ (GeV)
3-83
4477A2

Fig. 2