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Brief Reports

Observation of ψ production in e^+e^- annihilation at 29 GeV

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Inclusive ψ production in e^+e^- annihilation at 29 GeV has been measured with the Mark II detector. The ψ cross section is found to be $1.1\pm0.5\pm0.4$ pb. After subtraction of the expected contribution from B decay, an upper limit of $0.02\sigma_{\mu\mu}$ is obtained for other sources of ψ production.

INTRODUCTION

In this Brief Report, we present a search for inclusive ψ production in e^+e^- annihilation at 29 GeV, where the ψ is reconstructed via its leptonic decay modes e^+e^- and $\mu^+\mu^-$. The only known source of ψ production in high-energy e^+e^- annihilation is B-meson decay. The $B \rightarrow \psi$ branching ratio has been measured at the $\Upsilon(4S)$ resonance.[1] Therefore, a measurement of the ψ cross section at high energy can provide some information about other possible sources of ψ production.

The data sample was collected at the SLAC storage ring PEP at a center-of-mass energy of 29 GeV with the Mark II detector. The integrated luminosity is 208 pb^{-1}, corresponding to 100 000 hadronic events. This sample is 10 times larger than the one used in our previous search,[2] in which no ψ signal was found.

I. THE ψ SEARCH

For this measurement, the relevant parts of the Mark II detector, which is described in detail elsewhere,[3] are the drift-chamber tracking system, the central electromagnetic calorimeter, and the muon filter. The tracking system consists of an inner, high-resolution vertex drift chamber with seven concentric layers of sense wires, and an outer drift chamber with sixteen layers of sense wires. The system measures charged-particle momenta with a resolution of $\sigma_p/p=[(0.025)^2+(0.011p)^2]^{1/2}$ (p in GeV/c), in a 2.3-kG solenoidal magnetic field. The impact-parameter resolution of the vertex chamber is 85 μm. The calorimeter consists of eight lead–liquid-argon modules of 14 radiation lengths, which covers 65% of the solid angle and detect electromagnetic showers with an energy resolution of $\sigma_E/E=0.14/\sqrt{E}$ (E in GeV). The muon filter covers 45% of the solid angle and consists of four layers of steel plates, interlaced with proportional tubes.

The hadronic-event selection is based on the following criteria.

(1) There must be five or more charged particles, each with momentum $p>0.1$ GeV/c. Each charged track is considered only if $r<6$ cm and $z<10$ cm, where r and z are the distance of closest approach to the interaction point in a plane perpendicular to and along the beam axis, respectively. There must be at least two charged particles in each of the two hemispheres defined by a plane perpendicular to the thrust axis.

(2) The sum of the magnitudes of the charged-particle momenta must be greater than 7.5 GeV/c.

A track is identified as a muon if it traverses all four layers of the absorber and has a range consistent with that expected of a muon. In each layer the associated hits are required to be within 3 standard deviations of the extrapolated trajectory, including the effects of multiple scattering. This selection imposes a minimum muon momentum of 1.8 GeV/*c*. The probability that a hadron within the muon system solid angle fakes a muon by punchthrough or decay is less than 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 have been examined for each track.[4] 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 energy and proximity to the other jet fragments, and is typically 1%.

A pair of tracks is considered a candidate if both tracks are identified as electrons or muons. In addition, the following requirements are imposed.

(1) The two leptons must be in the same hemisphere. This cut is important since track pairs from back-to-back jets tend to have a large mass. It is, however, 97% efficient for ψ with momenta greater than 4 GeV/*c*, which represent, for instance, 90% of the ψ coming from *B* decays.

(2) In the electron channel, good spatial agreement between the shower and the extrapolation of the track is required.

(3) The momenta of both tracks must be less than 11 GeV/*c* to remove possible contamination from beam electrons and two-photon processes.

The distribution of invariant mass for unlike-sign lepton candidates is shown in Fig. 1(a), where the muon and the electron channels are combined. Four muon events are found in the ψ mass range, with a small background. The electron spectrum shows an accumulation of five events in the same mass range. When both channels are added, a clear excess of events can be seen in the 3-GeV region. The solid curve is our fit to the data of the sum of a Gaussian centered at the ψ mass and the predicted background contribution discussed below.

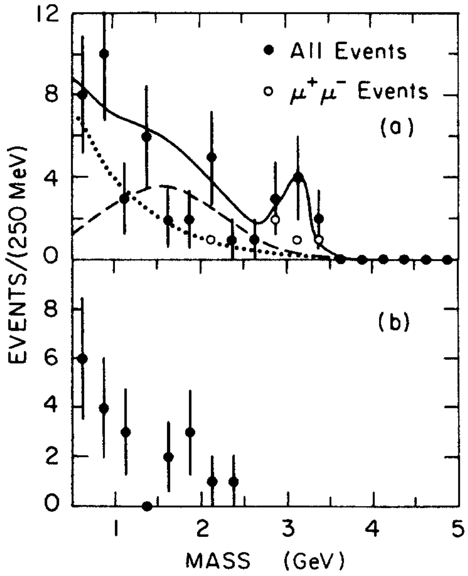

FIG. 1. (a) Unlike-sign dilepton mass distribution for all events (solid circles) and for $\mu^+\mu^-$ events (open circles). The dotted curve is the prediction of the misidentification background, the dashed curve is the estimated cascade contribution. The solid curve is the sum of these two contributions and of a Gaussian centered on the ψ mass. (b) Same-sign dilepton mass distribution.

II. BACKGROUND PREDICTIONS

The background prediction consists of the sum of a cascade contribution and a misidentification contribution. The cascade contribution [dashed curve in Fig. 1(a)] arises from events in which both the *b* quark and its *c*-quark decay product undergo semileptonic decays. It is the only sizable contribution to the production of two essentially true prompt leptons in the same jet. Its magnitude and shape are estimated with a Monte Carlo simulation whose luminosity corresponds to 40 times that of the data. The same Monte Carlo program was used in the Mark II analysis of the inclusive lepton production and the *b* lifetime measurement.[5] The characteristics of this simulation including *b* and *c* fragmentation functions, have been carefully checked against experimental data. The yield of e-μ pairs, to which only the backgrounds contribute, is also found to be compatible with expectations.[6]

The misidentification contribution [dotted curve in Fig. 1(a)] has been measured using the observed same-sign dilepton mass distribution, shown in Fig. 1(b), scaled by a factor of 1.2 to take into account the phase-space suppression of like-sign pairs compared to unlike-sign pairs. The precise shape of this background is determined by looking at the same-sign distribution obtained with slightly looser identification criteria because of the small numbers of events in Fig. 1(b). Here, we assume that the same-sign pairs in a single jet are all due to misidentification.

Since we have no same-sign candidate with a mass higher than 2.3 GeV, it is clear that the misidentification background is not dominant.

It can be seen from Fig. 1(a) that the predicted background is compatible both in shape and in magnitude with the observed event population at low masses and cannot explain the excess of events at high masses. The observation of a ψ signal is the most likely interpretation of this excess.

III. ψ CROSS-SECTION MEASUREMENT

The number of ψ is determined by fitting a Gaussian of fixed mass and width, obtained from the Monte Carlo estimate of our resolution, plus the fixed background to the experimental data, between 0.5 and 4 GeV. The fit has only one free parameter, the ψ yield, N_ψ. The result is $N_\psi = 5.8 \pm 2.7$.

The ψ detection efficiency has been determined by Monte Carlo simulation. It has already been shown[2] that this efficiency does not depend very much on the assumed production model because of the flat acceptance for ψ momenta between 4 and 12 GeV/*c*. The detection efficiency is 16% for dielectrons and 5% for dimuons. The dimuon efficiency is lower because of the reduced solid angle and the higher momentum imposed by the identification criteria. With these efficiencies, the muon and electron yields are compatible within the statistical errors. From the total dilepton sample, the ψ production cross section is, after having taken into account radiative corrections,

$$\sigma(e^+e^- \to \psi + X) = 1.1 \pm 0.5 \pm 0.4 \text{ pb} .$$

This result can also be expressed in terms of the muon-pair cross section:

$$\sigma(e^+e^- \to \psi + X) = (0.011 \pm 0.005 \pm 0.004)\sigma_{\mu\mu} .$$

The quoted systematic error includes the uncertainties associated with the production mechanism, the background estimate, the b fragmentation function, the identification efficiencies, the luminosity measurement, and the leptonic ψ branching ratio.

This number can be compared with the 0.8±0.08-pb cross section for ψ produced by B decays, assuming an average branching ratio of beauty particles to ψ of 1.08%±0.11% (Ref. 1).

The observed lifetime distribution of the ψ candidates is consistent with the hypothesis that all or most of the ψ are from B decays.

An upper limit can be derived for the production of ψ from sources other than B decays. The expected number of ψ coming from B decays is statistically subtracted from the number of observed ψ. The upper limit at 90% confidence level for ψ production from any other source than b decays is $0.02\sigma_{\mu\mu}$. This limit is not valid for models in which the fraction of ψ produced with a momentum below 4 GeV/c exceeds 20%.

CONCLUSION

The inclusive cross section for ψ production in e^+e^- annihilation at 29 GeV has been measured and found to be 1.1±0.5±0.4 pb or $(0.011 \pm 0.005 \pm 0.004)\sigma_{\mu\mu}$. This production rate should be compared with the 0.8±0.08-pb cross section expected from B decays. We set an upper limit of $0.02\sigma_{\mu\mu}$ on other possible sources.

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