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DISCLAIMER

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THE DECAY OF $\psi(3684)$ INTO $\psi(3095)$*

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ABSTRACT

We observe $\psi(3684)$ to decay into $\psi(3095)$ with a branching ratio of 0.57 ± 0.08. The branching ratio for the particular decay mode $\psi(3095) + \pi^+\pi^-$ is measured to be 0.32 ± 0.04. Remaining decays leading to $\psi(3095)$ are largely, but not entirely, accounted for by the mode $\psi(3095) + \pi^0\pi^0$ if the two pions in this decay are in a state of zero isotopic spin.

The discovery[1] of a second narrow resonance in electron-positron annihilation, the $\psi(3684)$, leads naturally to the question of the relationship of this state to the other recently discovered narrow resonance,[2,3] the $\psi(3095)$. In studying decay products of $\psi(3684)$, we have determined that the two states are indeed closely related, with approximately one-half of the decays of $\psi(3684)$ leading to $\psi(3095)$. In a majority of these decays, $\psi(3095)$ is accompanied by two pions.

The results presented here were obtained from a study of approximately 30,000 decays of $\psi(3684)$ detected by the SLAC-LBL magnetic detector at SPEAR. This detector and our general data analysis procedures have been described previously.[4,5] Data for the present analysis were taken on the peak of the ψ(3 [illegible]) total cross section.

The presence of $\psi(3095)$ among the decay products of $\psi(3684)$ is revealed in two different ways in our data. In the first of these, we observe the reaction,

$$\psi(3684) \rightarrow \psi(3095) + \text{anything} \qquad (1)$$

through the characteristic muon pair decay[6] of $\psi(3095)$. Figure 1 shows the invariant mass spectrum of the two oppositely charged particles of highest momenta for every event (muon rest masses are assumed in the calculation). Shower counter pulse height criteria were applied to reject electron pairs. The mass spectrum shown in Fig. 1 has two prominent peaks: one, at 3.7 GeV, corresponds to muon pairs produced with the full beam energy; the second, at 3.1 GeV, represents decays of $\psi(3095)$ and clearly establishes the decay mode (1).

Our second way of observing $\psi(3095)$ in the decay products of $\psi(3684)$ is through the reaction

$$\psi(3684) \rightarrow \pi^+ + \pi^- + \psi(3095) \; , \qquad (2)$$

where the identification of $\psi(3095)$ is made from its sharply defined mass. In Fig. 2a, we show the spectrum of missing masses recoiling against all pairs of oppositely charged particles, as determined from the incident energy and the measured momenta of the two particles in the pair. There is a clear enhancement at a missing mass of 3095 ± 5 MeV[7] having a width consistent with our measuring resolution. This peak, which we identify as $\psi(3095)$, is shifted to 3127 ± 5 MeV (3175 ± 5 MeV) if μ (e) masses are substituted for the pion mass in the calculation of the missing mass. Thus we unambiguously identify the decay mode (2).

A subset of our events have both a lepton pair from the decay of $\psi(3095)$ and the recoil pion pair. The missing mass spectrum for the pion pairs in these events is shown in Fig. 2b, where the very clean $\psi(3095)$ signal is apparent. A computer reconstruction of one of these events is given in Fig. 3. This event sample was used to study decay angular distributions for Monte-Carlo simulations of detection efficiency. Preliminary analysis showed the pions to have essentially isotropic angular distributions, while the leptons are consistent with either isotropy or $1 + \cos^2\theta$, relative to the beam axis.

There is no evidence for $\psi(3095)$ production at nonresonant energies in the vicinity of 3.7 GeV, except for a small signal, consistent with the radiative tail of $\psi(3684)$, at 3.8 GeV.

The number of $\psi(3684)$ decays leading to $\psi(3095)$ was determined from the data of Fig. 1, in which the two muons independently satisfy the trigger requirements. The background under the 3.1 GeV peak was estimated separately for events where only the two muon prongs were present and for events having additional prongs. In the first case, the radiative tail of the 3.7 GeV peak is the dominant source of background. In the higher multiplicity events, background arises from multihadron events satisfying muon pair selection criteria. A background subtraction of 9 ± 3% was applied to the data. To arrive at the branching ratio for reaction (1), the number of $\psi(3095)$ decays was normalized to the total number of detected events satisfying the multihadron selection criteria, and corrected for the branching ratio B_μ for $\psi(3095)$ to decay into muons,[8] the efficiency for detecting muon pairs and the average multihadron efficiency. Since we measure B_μ in the same apparatus with similar methods, systematic uncertainties in B_μ and multihadron efficiencies are strongly correlated and partially cancel in the determination of the branching ratio of reaction (1). Uncertainties in the muon pair angular distributions for $\psi(3095)$ decays from $\psi(3684)$ and the ratio of average hadron detection efficiencies at 3.1 and 3.7 GeV dominate over statistical errors and lead to an overall uncertainty of ±15% in the branching ratio. Our result for the branching ratio of reaction (1) is

$$\frac{\Gamma[\psi(3684) \rightarrow \psi(3095) + \text{anything}]}{\Gamma[\psi(3684) \rightarrow \text{all}]} = 0.57 \pm 0.08 \quad . \qquad (3)$$

The branching ratio for reaction (2) was determined from the $\pi^+\pi^-$ missing mass spectrum, Fig. 2a. Here the events chosen were such that the system recoiling against the $\pi^+\pi^-$ pair independently satisfied our trigger and event selection criteria. Background under the 3.1 GeV peak comes from the various possible two-particle missing mass combinations present in multiparticle events. A smooth curve was fit to the background to extract the 3.1 GeV signal. Corrections relating the true number of decays from reaction (2) to the number observed can be factored into the average triggering efficiency for the $\psi(3095)$ times the probability of observing the two recoil pions. As in the previous case, the systematic errors in the $\psi(3095)$ trigger efficiency largely cancel errors in the average efficiency for detecting all $\psi(3684)$ decays. The largest errors in the determination of the branching ratio for reaction (2) arise from uncertainties in the ratio of average hadron detection efficiencies at 3.1 and 3.7 GeV and in the efficiency for observing both recoil pions. After correction for all known inefficiencies, our value for this branching ratio is:

$$\frac{\Gamma[\psi(3684) \rightarrow \psi(3095) + \pi^+ + \pi^-]}{\Gamma[\psi(3684) \rightarrow \text{all}]} = 0.32 \pm 0.04 \quad . \qquad (4)$$

Finally, from the $\mu^+\mu^-$ events in the $\psi(3095)$ peak of Fig. 1, we determine the branching ratio

$$\frac{\Gamma[\psi(3684) \rightarrow \psi(3095) + \text{neutrals}]}{\Gamma[\psi(3684) \rightarrow \psi(3095) + \text{anything}]} = 0.44 \pm 0.03 \quad . \qquad (5)$$

The data sample in which no charged tracks are observed in conjunction with the $\psi(3095) \rightarrow \mu^+\mu^-$ is used to determine the numerator. These data are corrected for $\psi(3095)\pi^+\pi^-$ contamination due to both π^+ and π^- falling outside our visible acceptance [≅ 10% of all $\psi(3095)\pi^+\pi^-$], and for losses due to photon conversions [≅ 5% of all $\psi(3684) \rightarrow \psi(3095)$ + neutrals]. We note that the ratio of branching fraction (4) to that of (3), which measures the ratio

$$\frac{\Gamma[\psi(3684) \rightarrow \psi(3095) + \pi^+ + \pi^-]}{\Gamma[\psi(3684) \rightarrow \psi(3095) + \text{anything}]} ,$$

has the value 0.56, so that our data are quite consistent with the hypothesis that the $\psi(3684)$ decay to $\psi(3095)$ occurs mainly with emission of $\pi^+\pi^-$ or of neutrals.

If $\psi(3684) \rightarrow \psi(3095)$ decay proceeds entirely via the reaction $\psi(3684) \rightarrow \psi(3095)\pi\pi$, with the $\pi\pi$ system in a state of definite isospin, the ratio (5) would have the values 1/3 for $\pi\pi$ isospin-zero, 0 for $\pi\pi$ isospin-one, and 2/3 for $\pi\pi$ isospin-two.[9] Clearly isospin-zero is preferred. If we do assume $\pi\pi$ isospin-zero, the fact that our measured value of the ratio (5) is somewhat higher than the predicted value may result from the existence of decay modes

$$\psi(3684) \rightarrow \psi(3095) + \text{neutrals} ,$$

other than $\psi(3095)\pi^0\pi^0$ with branching ratios $\lesssim 10\%$ of the total.

In conclusion, the $\psi(3684) \rightarrow \psi(3095)$ decay is observed with a large branching ratio. Since phase space availability would favor a multitude of other decay modes at 3.7 GeV, one may suspect that a dynamical principle (or selection rule) is operative, suppressing not only the total widths of the $\psi(3095)$ and $\psi(3684)$, but also favoring the decay $\psi(3684) \rightarrow \psi(3095)$ over other processes.

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FOOTNOTES AND REFERENCES

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5. J.-E. Augustin et al., Total Cross Section for Hadron Production by Electron-Positron Annihilation Between 2.4 GeV and 5.0 GeV Center-of-Mass Energy, SLAC-PUB-1520 and LBL-3621, January 1975 (submitted to Phys. Rev. Letters).
6. The e^+e^- decay mode of the $\psi(3095)$ is not used in the study of the inclusive reaction (1) because of the large background contribution from the t-channel e^+e^- scattering diagram. This contribution is not present in the $\mu^+\mu^-$ final state.
7. In the mass range under consideration, the calculated value of the missing mass is approximately equal to $M[\psi(3684)] - E(\pi^+) - E(\pi^-)$; hence any translation of the beam energy scale would correspondingly translate the measured value of the missing mass. The mass values used here of 3.684 and 3.095 GeV have been determined by a flip-coil recalibration of the SPEAR magnetic guide field.
8. A. M. Boyarski et al., The Quantum Numbers and Decay Widths of the $\psi(3095)$, LBL-3695 (to be submitted for publication).
9. The mass differences between $\pi^\pm$ and π^0 modify these predictions slightly. If the expected rates are taken as just proportional to available phase

space, the predictions become 0.344 for isospin-zero and 0.677 for isospin-two.

FIGURE CAPTIONS

Fig. 1. Distribution of the $\mu^+\mu^-$ effective mass for highest momentum, low pulse-height, oppositely charged particle pairs from each event.

Fig. 2. (a) Distribution of missing mass, M_X, recoiling against all pairs of oppositely charged particles. (b) Same as (a) for those events in which the observed charged particles satisfy, within errors, conservation of total momentum and energy.

Fig. 3. An example of the decay $\psi(3684) \rightarrow \pi^+\pi^-\psi(3095)$, where $\psi(3095) \rightarrow e^+e^-$, from an off-line reconstruction of the data. The event is seen in the xy-projection where z is the beam (and magnetic field) direction. Also shown are the trigger and shower counters which detected the tracks. Tracks 3 and 4 are the slow pions and tracks 1 and 2 are the two leptons from $\psi(3095)$ decay.

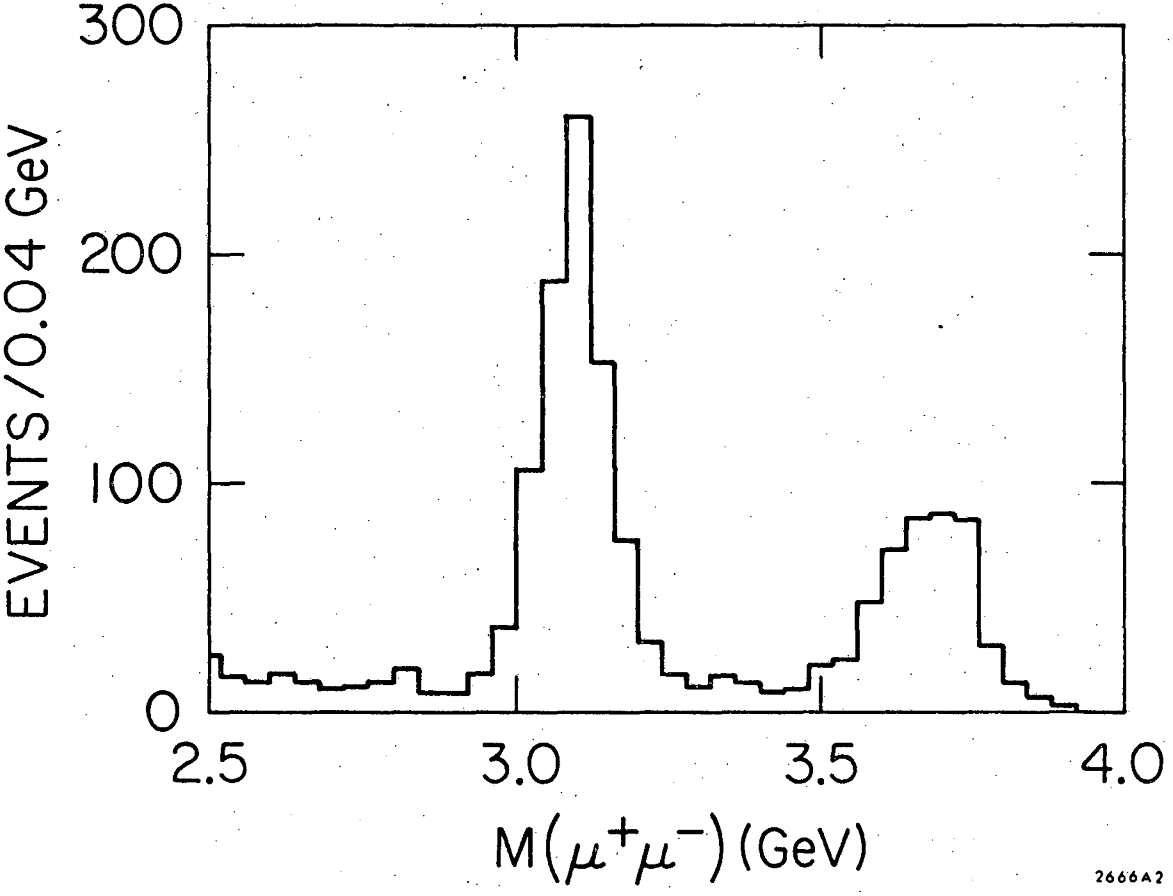

Fig. 1

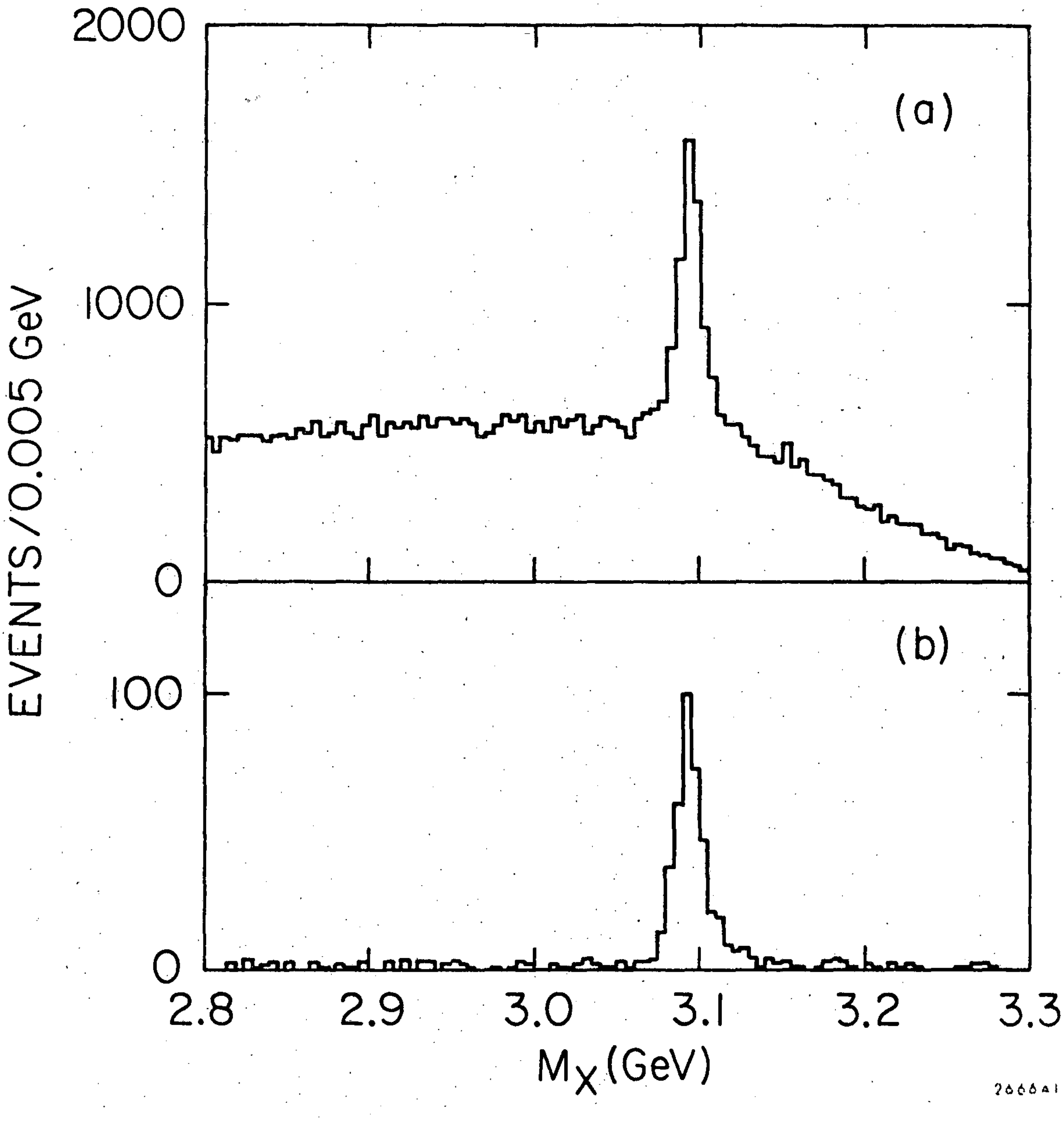
2000
1000
0
100
0
EVENTS/0.005 GeV
(a)
(b)
2.8
2.9
3.0
3.1
3.2
3.3
M_X (GeV)
266661

Fig. 2

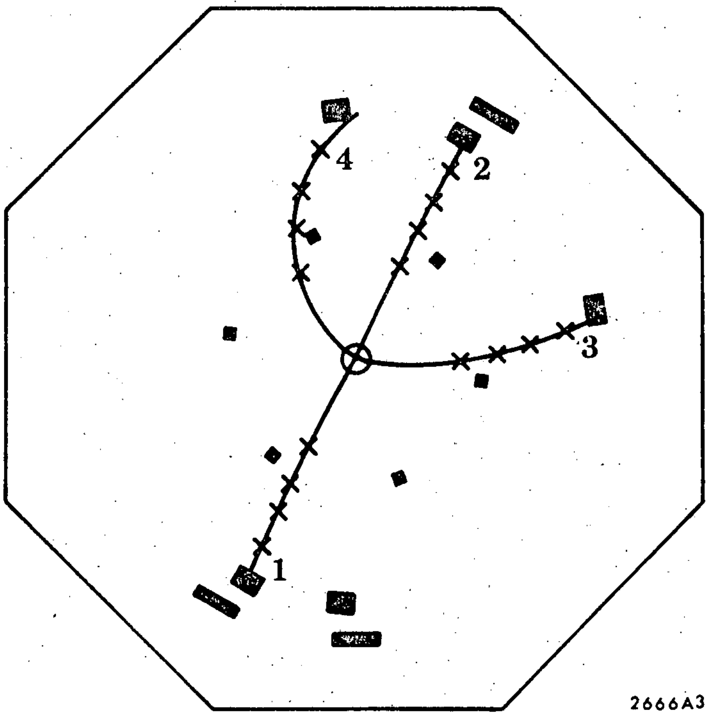

Fig. 3

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