OBSERVATION OF B-MESON DECAY INTO J/ψ

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Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have observed the colour suppressed decay $B \to J/\psi\ X$, with a branching ratio of $(1.37^{+0.6}_{-0.5})\%$ for the mixture of charged and neutral B's produced on the $\Upsilon(4S)$. From the momentum distribution of the J/ψ we conclude that $Br(B \to J/\psi\ X) < 0.7\%$ (90% CL), for recoil masses, m_X, less than 1 GeV/c^2.

For footnotes see next page.

Inclusive decays of B mesons into J/ψ's are particularly suitable for the study of the interplay of weak and strong interactions in heavy meson decay. Accordingly, this reaction has already received considerable theoretical attention [1]. The decay is expected to proceed dominantly through the diagram shown in fig. 1. Such a process is called colour suppressed, because colour matching between the c quarks is required. This matching can however be accomplished by gluon exchange. Thus, a full description of the reaction requires the inclusion of QCD effects. If the light quark, q, can be considered as a pure spectator, the b quark would decay through a two-body process, $b \to (c\bar{c}) + s$. A measurement of the J/ψ momentum distribution allows one to test this picture and provides information on the distribution of recoil masses. So far, only an upper limit of 1.6% at the 90% CL for the branching ratio for $B \to J/\psi X$ has been published [2].

In this letter we report the observation of the decay $B \to J/\psi X$ using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The J/ψ were identified by their decays into $\mu^+\mu^-$ or e^+e^- pairs. The data sample used in this analysis corresponds to an integrated luminosity of 12 pb^{-1} collected on or near the peak of the Υ(4S) resonance. Throughout this paper, B is used to denote the mixture of neutral and charged B mesons produced in the Υ(4S) decays. The number of B mesons in the sample was calculated to be 17 400.

A short description of the detector and the trigger conditions is given in ref. [3]. The hadronic decays were selected by requiring at least 3 charged particles with transverse momentum larger than 80 MeV/c coming from the interaction region. In order to suppress the contribution of tau pair production at least 3 (5) photons with energy larger than 100 MeV were required in events with only 4 (3) charged particles. The selection criteria for hadronic events used in this analysis are sufficiently unrestrictive that corrections for unobserved decays of B mesons are expected to be negligibly small.

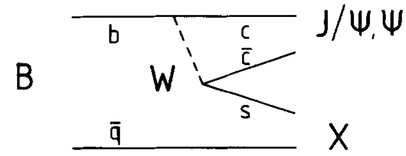

Fig. 1. Quark diagram for the weak decay $B \to J/\psi X_s$.

Muons are identified by requiring at least one hit in the outer layers of the muon chambers [4] and less than 0.6 GeV deposited energy in the electromagnetic calorimeter. This is 2.5 times the average energy deposited by a minimum ionizing particle. The muon identification efficiency is zero for momenta less than 0.7 GeV/c, rises to 60% at p = 1.0 GeV/c and reaches a plateau of 85% for momenta above 2.0 GeV/c. The probability for a pion to be misidentified as a muon is less than 4% for momenta below 2.0 GeV/c. The polar angle of the muons is restricted in most parts of this analysis by the requirement that $|\cos\theta| < 0.9$, in order to ensure good momentum resolution and to simplify the efficiency calculations. Muon momenta are required to be larger than 0.85 GeV/c. The efficiency for detection of two muons from J/ψ decays is about 50% for J/ψ momenta less than 2.0 GeV/c.

A short description of the electron identification procedure is given in ref. [5]. Essentially, it is based on calculating the likelihood functions for the electron hypothesis from three detector measurements: specific ionization in the drift chamber, time of flight and the energy deposition and shower shape in the electromagnetic calorimeter. In order to ensure good electron–hadron separation, the electrons are required to have a momentum larger than 0.85 GeV/c and a polar angle in the range $|\cos\theta| < 0.85$. A cut on the combined likelihood ratio for electron and hadron hypotheses yields a high efficiency of about 85%, with a hadron–electron rejection factor of more than 100. The overall efficiency for detection of an e^+e^- pair from J/ψ decays is about 30%.

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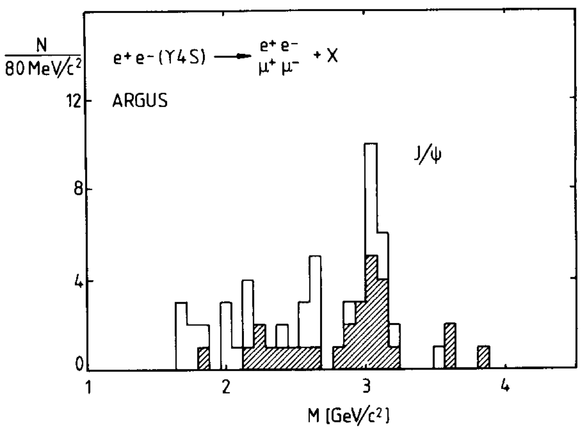

Fig. 2. Invariant mass distribution for lepton pairs from $e^+e^- \to \mu^+\mu^- X$ abd $e^+e^- \to e^+e^- X$ with $E_{CMS} \approx m_{\Upsilon 4S}$ and cuts as described in the text. The dashed distribution is the $\mu^+\mu^-$ channel only.

Fig. 2 shows the invariant mass spectrum of $\mu^+\mu^-$ pairs with total momentum less than 1.9 GeV/c, which is the maximum possible value for inclusive decays of B mesons into J/ψ. There is a peak of 12 events in the $\mu^+\mu^-$ spectrum within ±110 MeV/c^2 of the mass of the J/ψ. This interval corresponds to ±2 standard deviations for the mass resolution.

There are two sources of background, the first due to $\mu^+\mu^-$ pairs from the continuum, and the second due to semileptonic B decays. The combined contribution has been estimated by studying the $\mu^+\mu^-$ mass distribution outside the signal region. If the average background level within ±110 MeV/c^2 of the J/ψ mass is assumed to be equal to the level in a sideband interval from 2.0 to 2.95 GeV/c^2, an estimate of 2.3 ±0.7 background events in the J/ψ region of fig. 2 is obtained. The probability to observe 12 events with a background level of 2.3 ± 0.7 is 6×10^{-5}, which corresponds to more than 3.8 standard deviations.

The above background estimate is conservative, since the level of background decreases rapidly with increasing $\mu^+\mu^-$ mass. This dependence on the $\mu^+\mu^-$ mass has been confirmed using two additional methods for background estimation. The contribution from continuum sources can be directly estimated using data taken in the continuum near the Υ(4S) and at the Υ(1S), representing integrated luminosities of 7 pb^{-1} and 22 pb^{-1} respectively. This combined with a Monte Carlo estimate of the contribution of the semileptonic B decay reproduces the observed shape of the background in fig. 2. An event mixing procedure, where muons from different events containing $\mu^+\mu^-$ pairs are combined, gives the same result.

The amount of continuum background under the signal can separately be put on a quantitative basis. We have observed no candidates in the J/ψ mass band with momentum less than 1.9 GeV/c in the sample of continuum data. This leads to an upper limit of 3.7 events (90% CL) for the continuum contribution to the J/ψ region of fig. 2. From the combined continuum and Υ(1S) data sets, where three events were found, an improved upper limit of 1.7 events (90% CL) for the continuum contribution to the signal region is derived.

For J/ψ decays into e^+e^- pairs the background is higher and the efficiency is lower than for the $\mu^+\mu^-$ channel. In order to reduce the background, low multiplicity events were rejected by the requirement that $n_{ch} + (n_\gamma - 1)/2 \geqslant 8$, where n_{ch} and n_γ are the numbers of charged tracks and photons respectively. Electrons from converted photons were also rejected. We observe 7 events in the e^+e^- channel within ±110 MeV/c^2 of the J/ψ mass. The mass resolution for e^+e^- pairs is the same as for $\mu^+\mu^-$ pairs, except for a small radiative tail. The event mixing technique leads to a background estimate of 1.9 ± 0.3 events under the signal. The Monte Carlo calculation of the background from semileptonic decays of B mesons and continuum contribution estimation using combined continuum and Υ(1S) data gives a slightly higher value: 2.2 ± 0.3 events, which was used in obtaining the results reported below.

The probability to observe 7 events in the same mass interval as in the μ sample with a background of 2.2 ± 0.3 is less than 1%. The sum of the e^+e^- and $\mu^+\mu^-$ invariant mass spectra is also shown in fig. 2. The significance of the combined signal corresponds to more than 4.5 standard deviations.

The branching ratio for $B \to J/\psi X$ is found to be $(1.4^{+0.7}_{-0.6})\%$ in the muon channel and (1.3 ± 0.8)% in the electron case. The errors represent statistical and systematic uncertainties added in quadrature. The numbers are consistent, and the combined result is

$$\mathrm{Br}(B \to J/\psi X) = (1.37^{+0.6}_{-0.5})\%.$$

This result is evidence for the contribution of a so-called colour suppressed process to B meson decay.

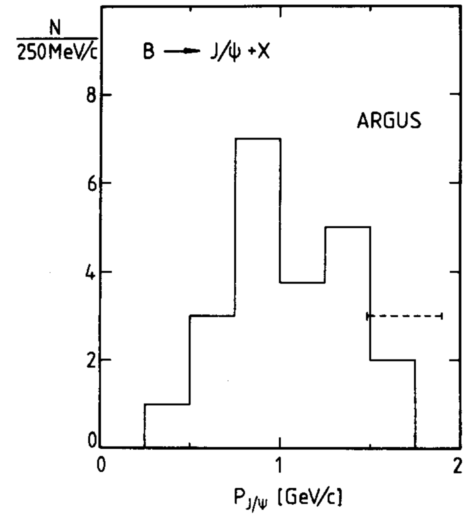

Fig. 3. Momentum distribution for J/ψ candidates from e^+e^- and $\mu^+\mu^-$ data combined. The cuts used are: $2.85 < m_{e^+e^-} < 3.25$ GeV/c^2 and $2.95 < m_{\mu^+\mu^-} < 3.25$ GeV/c^2 and $|\cos\theta_\mu| < 0.94$. The dashed line shows the momentum range for $B \to J/\psi K$.

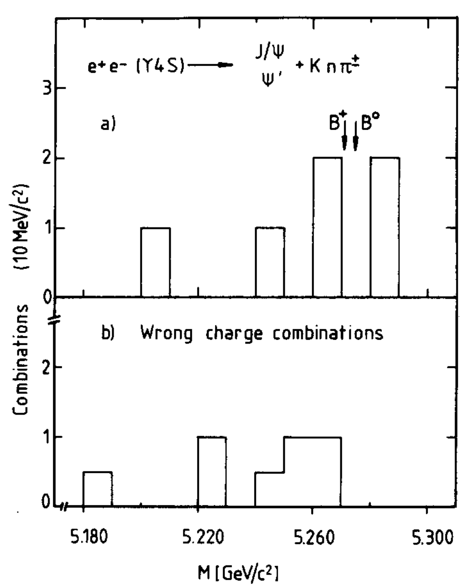

Fig. 4. (a) Invariant mass distribution for all combinations of J/ψ and ψ' candidates with $K^{\pm 0}$ and $n\pi^\pm$ ($n \leq 3$). $|\Sigma Q_l| \leq 1$ and χ^2 for the energy constrained fit < 9. (b) Same as (a) but with $|\Sigma Q_l| \geq 2$ (wrong sign combinations).

The data are consistent with a substantial ψ' production. There are two events where the lepton pair has a mass close to $M_{\psi'}$. Three J/ψ candidates can be combined with a $\pi^+\pi^-$ pair to form a ψ'.

Fig. 3 shows the momentum distribution of the J/ψ candidates lying in the mass range from 2.85 (2.95) to 3.25 GeV/c^2 for e^+e^- ($\mu^+\mu^-$) pairs. The spectrum is evidently dominated by recoil systems of high mass. Only two candidates are observed in the data sample with a momentum above 1.4 GeV/c, the region populated by the decays $B \to J/\psi K$ and 90% of $B \to J/\psi K^*$. We derive an upper limit for the branching ratio for B decays into a J/ψ and a low mass system, which at the 90% CL is

$$\mathrm{Br}(B \to J/\psi X) < 0.7\%, \qquad \text{where } m_X < 1 \text{ GeV}/c^2.$$

In the sample of inclusive $B \to J/\psi X$ events, we have searched for exclusive B decay channels. Fig. 4a shows the invariant mass distribution for J/ψ and ψ' candidates combined with 1 charged or neutral kaon and up to 3 charged pions. Charged particles are identified by use of dE/dx and time-of-flight measurements with a mass hypothesis probability cut of 5% [6]. K^0 candidates were required to form a secondary vertex [7]. Only combinations with total charge ±1 or 0 were considered. The ψ' candidates were required to have χ^2 for this hypothesis of less than 9. The plotted masses were obtained by a fit which constrained the energy of the candidates to be equal to $M_{\Upsilon(4S)}/2c^2$ [8]. Only combinations with χ^2 less than 9 are shown in the figure. The mass resolution of about $\sigma = 10$ MeV/c^2 is mainly determined by the beam energy spread.

Four combinations are clustered around the masses of B mesons [9]. The background was estimated by studying the mass distribution of wrong charge combinations with net charge larger than 1 (fig. 4b). This overestimates the background because B decays reconstructed with one missing pion can be shifted only slightly lower in mass, but still have a reasonable χ^2. For two events, there are two wrong charge combinations, and therefore each combination is weighted by 0.5 in the figure. The number of wrong and right charge combinations are approximately the same, so that the spectra can be compared directly. There is only one wrong charge combination close to the B meson mass. Thus, the four reconstructed B meson candidates include approximately one background event.

To conclude, we have observed the colour suppressed decay $B \to J/\psi X$. The statistical significance of the signal corresponds to 4.5 standard deviations. The branching ratio is $(1.37^{+0.6}_{-0.5})\%$, where errors include statistical and systematic uncertainties. The actual amount of colour suppression corresponding to this branching ratio still has to be evaluated. The momentum distribution of the J/ψ in this decay has been measured, and allows various theoretical models to be tested. An upper limit for $Br(B \to J/\psi X)$ of 0.7% (90% CL) has been obtained for all states with mass, m_X less than 1 GeV/c^2.

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