第28卷 第4期
2004年4月

高 能 物 理 与 核 物 理
HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS

Vol.28, No.4
Apr., 2004

First Evidence of $\psi(3770)$ Hadronic Transition to $J/\psi\pi^+\pi^-$ *

BES Collaboration

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Received 16 February 2004

* Supported by NSFC (19991480, 10175060), National Natural Science Funds for Distinguished Young Scholar(10225524, 10225525), Major Subject of CAS(KJ95T-03), the 100 Talaents Program of CAS(U-11, U-24, U-25), Knowledge Innovation Project of CAS(U-602, U-34)

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Abstract Evidence of $\psi(3770)$ decays to a non-$D\bar{D}$ final state is observed. A total of 6.8 ± 3.0 $\psi(3770)\to J/\psi\pi^+\pi^-$ events are obtained from a data sample of $8.0\pm0.5\ \mathrm{pb}^{-1}$ taken at center-of-mass energies around 3.773GeV using the BES-Ⅱ detector at the BEPC. The branching fraction is determined to be $BF(\psi(3770)\to J/\psi\pi^+\pi^-)=(0.59\pm0.26\pm0.16)\%$, corresponding to the partial width of $\Gamma(\psi(3770)\to J/\psi\pi^+\pi^-)=(139\pm61\pm41)\mathrm{keV}$.

Key words $\psi(3770)$, hadronic transition, non-$D\bar{D}$ decay, branching fraction, BES, BEPC

1 Introduction

The $\psi(3770)$ resonance is believed to be a mixture of the 1^3D_1 and 2^3S_1 states of the $c\bar{c}$ system[1]. Since its mass is above open charm-pair threshold and its width is two orders of magnitude larger than that of the $\psi(2S)$, it is thought to decay almost entirely to pure $D\bar{D}$[2]. However, Lipkin pointed out that the $\psi(3770)$ could decay to non-$D\bar{D}$ final states with a large branching fraction[3]. There are theoretical calculations[4—7] that estimate the partial width for hadronic transition of the $\psi(3770)\to J/\psi\pi^+\pi^-$ based on the multipole expansion in QCD. Recently Kuang[7] used the Chen-Kuang potential model to obtain a partial width for $\psi(3770)\to J/\psi\pi\pi$ in the range from 37 to 170keV, corresponding to 25 to 113keV for $\psi(3770)\to J/\psi\pi^+\pi^-$ from isospin symmetry. In this paper, we report evidence for $\psi(3770)\to J/\psi\pi^+\pi^-$ based on $1.4\pm0.1\mathrm{pb}^{-1}$ of data taken in the center-of-mass(c.m.) energy region from 3.738GeV to 3.885GeV and $6.6\pm0.4\mathrm{pb}^{-1}$ of data taken at 3.773GeV using the upgraded Beijing spectrometer (BES-Ⅱ) at the Beijing Electron Positron Collider (BEPC).

2 The BES-Ⅱ detector

BES-Ⅱ is a conventional cylindrical magnetic detector that is described in detail in Ref.[8]. A 12-layer Vertex Chamber (VC) surrounding the beryllium beam pipe provides input to the event trigger, as well as coordinate information. A forty-layer main drift chamber (MDC) located just outside the VC yields precise measurements of charged particle trajectories with a solid angle coverage of 85% of 4π; it also provides ionization energy loss (dE/dx) measurements which are used for particle identification. Momentum resolution of $1.7\%\sqrt{1+p^2}$ (p in GeV/c) and dE/dx resolution of 8.5% for Bhabha scattering electrons are obtained for the data taken at $\sqrt{s}=3.773\mathrm{GeV}$. An array of 48 scintillation counters surrounding the MDC measures the time of flight (TOF) of charged particles with a resolution of about 180 ps for electrons. Outside the TOF, a 12 radiation length, leadgas barrel shower counter (BSC), operating in limited streamer mode, measures the energies of electrons and photons over 80% of the total solid angle with an energy resolution of $\sigma_E/E=0.22/\sqrt{E}$ (E in GeV) and spatial resolutions of $\sigma_\phi=7.9$ mrad and $\sigma_Z=2.3$ cm for electrons. A solenoidal magnet outside the BSC provides a 0.4 T magnetic field in the central tracking region of the detector. Three double-layer muon counters instrument the magnet flux return and serve to identify muons with momentum greater than 500MeV/c. They cover 68 % of the total solid angle.

3 Data analysis

3.1 Events selection

To search for the decay of $\psi(3770)\to J/\psi\pi^+\pi^-$, $J/\psi\to e^+e^-$ or $\mu^+\mu^-$, $\mu^+\mu^-\pi^+\pi^-$ and $e^+e^-\pi^+\pi^-$ candidate events are selected. These are required to have four charged tracks with zero total charge. Each track is required to have a good helix fit, to be consistent with originating from the primary event vertex, and to satisfy $|\cos\theta| < 0.85$, where θ is the polar angle.

Pions and leptons must satisfy particle identification requirements. For pions, the combined confidence level (CL), calculated for the π hypothesis using the dE/dx and TOF measurements, is required to be greater than 0.1 %. In order to reduce γ conversion background, in which the e^+ and e^- from a converted γ are misidentified as π^+ and π^-, an opening angle cut, $\theta_{\pi^+\pi^-} > 20°$, is imposed. For electron identification, the combined confidence level, calculated for the e hypothesis using the dE/dx, TOF and BSC measurements, is required to be greater than 1 %, and the ratio $CL_e/(CL_e + CL_\mu + CL_\pi + CL_K)$ is required to be greater than 0.7. If a charged track hits the muon counter, and the z and $r\phi$ positions of the hit match with the extrapolated positions of the reconstructed MDC track, the charged track is identified as a muon.

3.2 Analysis of the $\pi^+\pi^-$ recoile mass

The mass recoiling from the $\pi^+\pi^-$ system are calculated using

$$M_{REC}(\pi^+\pi^-) = \sqrt{(E_{cm} - E_{\pi^+\pi^-})^2 - |\boldsymbol{P}_{\pi^+\pi^-}|^2},$$

where E_{cm} is the c.m. energy, $E_{\pi^+\pi^-}$ and $\boldsymbol{P}_{\pi^+\pi^-}$ are the total energy and momentum of the $\pi^+\pi^-$ system, respectively.

Fig.1(a) shows the distribution of mass recoiling from the $\pi^+\pi^-$ system for candidate events with total energy within $\pm 2.5\sigma_{E_{\pi^+\pi^-l^+l^-}}$ of the nominal c.m. energy at which the events were obtained and with a dilepton invariant mass within ± 150MeV of the J/ψ mass. Two peaks are observed. The higher one is from $\psi(2S)$ events produced by radiative return to the peak of the $\psi(2S)$, while the small enhancement around 3.1GeV is mostly from $\psi(3770)$ decays. Fig.1(b) shows a Monte Carlo simulation events of $\psi(2S)$ production and decay to

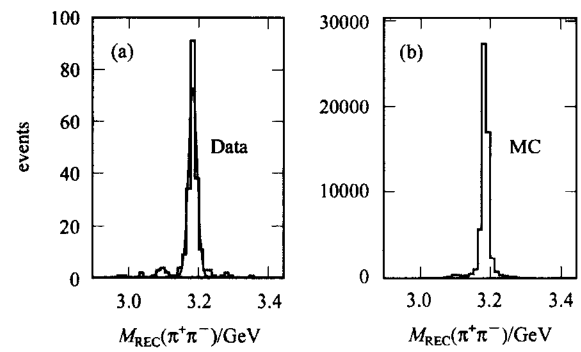

Fig.1. Distribution of mass recoiling from the $\pi^+\pi^-$ system for(a) $l^+l^-\pi^+\pi^-$ events (data) and (b) Monte Carlo $\psi(2S)\to J/\psi\pi^+\pi^-$. In(a), the curve gives the best fit (see section IV).

$J/\psi\pi^+\pi^-$ at the c.m. energies of the data from 3.738 to 3.885GeV, where the higher peak is from $\psi(2S)$ events produced by radiative return to the peak of the $\psi(2S)$, and the small enhancement around 3.1GeV also is from $\psi(2S)$ events produced by radiative return to the tail of $\psi(2S)$. The Monte Carlo simulation includes leading-log-order initial state radiation (ISR), in which the center-of-mass energies after ISR are generated according to Ref. [9]. The $\psi(2S)$ is generated using energy dependent Breit-Wigner functions, and the beam energy spread is taken into account. In the Monte Carlo study, $\psi(3770)$ is also generated using energy dependent Breit-Wigner functions. Fig.2 shows the distribution of $J/\psi\pi^+\pi^-$ events with $J/\psi\to l^+l^-$ ($l = e$ or μ) as a function of the energy remaining after photon radiation, as determined by our Monte Carlo simulation, where the branching fraction for $\psi(3770)\to J/\psi\pi^+\pi^-$ (solid histogram) is set to be 0.4 %, while the branching fractions for $\psi(2S)\to J/\psi\pi^+\pi^-$ (dotted histogram) and $J/\psi\to l^+l^-$ are taken from the Particle Data Group (PDG)[10].

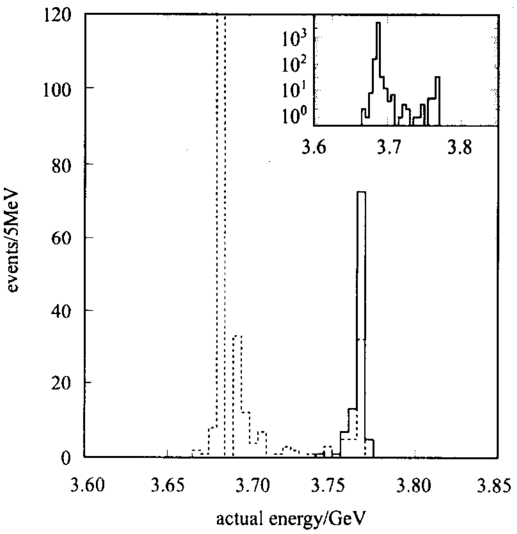

Fig.2. The distribution of $\psi(3770)$ (solid line) and $\psi(2S)$ (dotted line) events decaying to $J/\psi\pi^+\pi^-$ with $J/\psi \to l^+l^-$ versus energy remaining after ISR determined from Monte Carlo simulation at the c.m. energy 3.773GeV. The insert on the right-top shows the energy distribution of $\psi(2S)$ events.

3.3 Kinematic fit

In order to reduce background and improve momentum resolution, events are subjected to four-constraint kinematic fits to either the $e^+e^- \to \mu^+\mu^-\pi^+\pi^-$ or the $e^+e^- \to e^+e^-\pi^+\pi^-$ hypothesis. Events with a confidence level greater than 1 % are accepted. Fig.3(a) shows the scatter plot of $\pi^+\pi^-$ energies versus the fitted mass of lepton pairs, where the $\pi^+\pi^-$ energies are calculated using only the measured momenta. There are clearly two clusters, whose energies are around 0.57 and 0.65GeV and fitted masses around 3.18 and 3.10GeV, corresponding to $\psi(2S) \to J/\psi\pi^+\pi^-$ and $\psi(3770) \to J/\psi\pi^+\pi^-$, respectively. Projecting the events in Fig.3(a) onto the horizontal scale, two fitted dilepton mass peaks are observed around 3.10 and 3.18GeV, as shown in Fig.3(b). There are 9 ± 3 events in the lower mass peak. Since the higher mass peak is due to $\psi(2S)$, which is produced by radiative return to the $\psi(2S)$ peak, its energy will be approximately 3.686GeV, while the c.m. energy is set to the nominal energy in the kinematic fitting. Therefore, the dilepton masses calculated based on the fitted momenta from the J/ψ coming from $\psi(2S) \to J/\psi\pi^+\pi^-$ are shifted upward to about 3.18GeV.

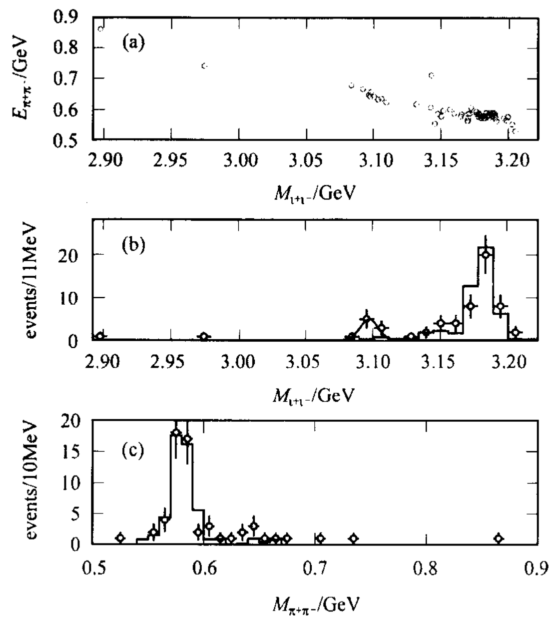

Fig.3. (a) The scatter plot of the measured $\pi^+\pi^-$ energies versus the fitted dilepton masses. There are two clusters. The cluster whose energy is around 0.65 GeV is mostly composed of signal events from $\psi(3770) \to J/\psi\pi^+\pi^-$, while the events with energies around 0.57GeV are due to $\psi(2S) \to J/\psi\pi^+\pi^-$ events. (b) The fitted masses of the l^+l^-. (c) The $\pi^+\pi^-$ energies. In (b) and (c), the open circles are data, and the histograms are the results of the Monte Carlo simulation for $\psi(2S) \to J/\psi\pi^+\pi^-$. Shown in (b) is the fit to the data using the Monte Carlo background shape (histogram), a small constant background term, and a Gaussian to represent the signal.

3.4 Background

Backgrounds from QED radiative processes with γ conversion, two-photon backgrounds, such as $e^+e^- \to e^+e^-\mu^+\mu^-$ (where the slow muons are misidentified as pions) and $e^+e^- \to e^+e^-\pi^+\pi^-$, and $e^+e^- \to \tau^+\tau^-$, are negligibly small. Candidate $J/\psi\pi^+\pi^-$ events could also be produced in the continuum process, $e^+e^- \to l^+l^-\pi^+\pi^-$. From a sample of 5.1$pb^{-1}$ taken in the energy region from 3.544 to 3.600GeV and 22.3pb^{-1} taken at 4.03GeV with the BES-Ⅰ detector, no $J/\psi\pi^+\pi^-$, $J/\psi \to l^+l^-$ events are observed[11]. This data sample is about 3.4 times larger than that of the $\psi(3770)$ sample. Hence the continuum background is also negligible.

However, due to radiative return and the tail of the $\psi(2S)$ under the $\psi(3770)$, there is $\psi(2S) \to J/\psi\pi^+\pi^-$ background produced around the center-of-mass energy of

3.770GeV that can pass the event selection criteria and yield fitted dilepton masses around 3.097GeV. This background, the main background to the $\psi(3770)\to J/\psi\pi^+\pi^-$ signal, can be seen in Fig.3(b), that also shows the distribution of Monte Carlo $\psi(2S)\to J/\psi\pi^+\pi^-$ events (solid histogram) that have passed selection. To estimate the amount of background under the signal, we have fit the data in Fig.3(b) with the Monte Carlo background shape (with normalization floating), a small constant background term, and a Gaussian to represent the signal with Mn_fit[12]. The fit yields a total of 2.2 ± 0.4 (stat) ±0.4(sys) background events out of the 9.0 ± 3.0 (stat) events near 3.097GeV, where the systematic error arise from the uncertainty in estimation of the background. For example, removing the constant background or using a polynomial background of first degree in the fit changes the background estimate by 0.4 events. The probability that the 9 events observed are due to a fluctuation of the $2.2\pm0.4\pm0.4$ background events is 1.2×10^{-3}, which gives the $\psi(3770)\to J/\psi\pi^+\pi^-$ signal significance to be 3σ. After background subtraction, 6.8 ± 3.0 signal events remain. In this analysis, possible interference between the $\psi(2S)$ background and the $\psi(3770)$ is neglected since the interference term cancels after integrating over the pion momenta[6].

3.5 The number of ψ(3770) produced

The total number of $\psi(3770)$ events is obtained from our measured luminosities and the cross sections for $\psi(3770)$ production at the center-of-mass energies. The Born level cross section at same energy E is given by

$$\sigma_{\psi(3770)}(E)=\frac{12\pi\Gamma_{ee}\Gamma_{tot}(E)}{(E^2-M^2)^2+M^2\Gamma_{tot}^2(E)},$$

where the $\psi(3770)$ resonance parameters, Γ_{ee} and M are taken from the PDG[10], $\Gamma_{tot}(E)$ is chosen to be energy dependent and normalized to the total width Γ_{tot} at the peak of the resonance[10,13]. In order to obtain the observed cross section, it is necessary to take into account the ISR correction. The observed $\psi(3770)$ cross section, $\sigma^{obs}_{\psi(3770)}$, is reduced by a factor $g(s_{nom})=\sigma^{obs}_{\psi(3770)}(s_{nom})/\sigma^{B}_{\psi(3770)}(s_{nom})$, where s_{nom} is the nominal c.m. energy squared. The ISR correction for $\psi(3770)$ production is calculated using a Breit-Wigner function and the radiative photon energy spectrum[9]. With the calculated cross sections for $\psi(3770)$ production at each energy point around 3.773GeV and the corresponding luminosities, the total number of $\psi(3770)$ events in the data sample is determined to be $N^{prod}_{\psi(3770)}=(5.7\pm1.3)\times10^4$, where the error is mainly due to the uncertainty in the observed cross section for $\psi(3770)$ production.

4 Result

The detection efficiency for the decay channel is determined to be $\epsilon_{\psi(3770)\to J/\psi\pi^+\pi^-, J/\psi\to l^+l^-}=0.171\pm0.002$, where the error is statistical. Using these numbers and the known branching fractions for $J/\psi\to e^+e^-$ and $\mu^+\mu^-$[10], the branching fraction for the non-$D\bar{D}$ decay $\psi(3770)\to J/\psi\pi^+\pi^-$ is measured to be

$BF(\psi(3770)\to J/\psi\pi^+\pi^-)=(0.59\pm0.26\pm0.16)\%$,

where the first error is statistical and the second systematic. Using Γ_{tot} from the PDG[10], this branching fraction corresponds to a partial width of

$\Gamma(\psi(3770)\to J/\psi\pi^+\pi^-)=(139\pm61\pm41)\text{keV}$.

The dominant systematic uncertainty is due to the uncertainty in the total number of $\psi(3770)$ produced ($\pm24\%$). Other systematic uncertainties are due to the uncertainties in the efficiency ($\pm10\%$) and the background shape ($\pm6\%$). All systematic uncertainties are added in quadrature.

Fitting the recoil mass distribution in Fig.1(a) with two Gaussian functions plus a first order polynomial yields 8.8 ± 3.3 events in the small peak. The Monte Carlo study shows that 1.9 ± 0.6 out of 8.8 ± 3.3 events are due to $\psi(2S)\to J/\psi\pi^+\pi^-$. The detection efficiency is $\epsilon_{\psi(3770)\to J/\psi\pi^+\pi^-, J/\psi\to l^+l^-}=0.18$. These numbers yield a branching fraction $BF(\psi(3770)\to J/\psi\pi^+\pi^-)=(0.57\pm0.27\pm0.015)\%$, which is in good agreement with the value obtained above.

5 Summary

In summary, the branching fraction for $\psi(3770)\to J/\psi\pi^+\pi^-$ has been measured. From a total of $(5.7\pm1.3)\times10^4\psi(3770)$ events, 6.8 ± 3.0 non-$D\bar{D}$ decays of $\psi(3770)\to J/\psi\pi^+\pi^-$ events are observed, leading to a branching fraction of $BF(\psi(3770)\to J/\psi\pi^+\pi^-)=(0.59$

$\pm 0.26 \pm 0.16)\%$, and a partial width $\Gamma(\psi(3770) \to J/\psi \pi^+ \pi^-) = (139 \pm 61 \pm 41)$keV.

We would like to thank the BEPC staff for their strong efforts and the members of the IHEP computing center for their helpful assistance. We acknowledge Professor Yu-Ping Kuang and Professor Kuang-Ta Chao for many helpful discussions on the non-$D\overline{D}$ decay of $\psi(3770)$.

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$\psi(3770) \to J/\psi \pi^+ \pi^-$强跃迁过程的首次观测*

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2004-02-16收稿
* 国家自然科学基金(19991480,10175060),国家杰出青年科学基金(10225524,10225525),中国科学院九五重大项目(KJ95T-03),中国科学院百人计划基金(U-11,U-24,U-25),中国科学院知识创新基金(U-602,U-34)资助

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摘要　观测到$\psi(3770)$衰变到$J/\psi\pi^+\pi^-$非$D\bar{D}$末态迹象．利用工作在北京正负电子对撞机上的北京谱仪探测器在质心系能量3.773GeV附近获取的$8.0\pm0.5\mathrm{pb}^{-1}$数据样本，共观测到$6.8\pm3.0$个$\psi(3770)\to J/\psi\pi^+\pi^-$事例．由此得到的分支比为

$BF(\psi(3770)\to J/\psi\pi^+\pi^-)=(0.59\pm0.26\pm0.16)\%$，其对应的分宽度为

$\Gamma(\psi(3770)\to J/\psi\pi^+\pi^-)=(139\pm61\pm41)\mathrm{keV}$．

关键词　$\psi(3770)$　强跃迁　非$D\bar{D}$衰变　分支比　BES　BEPC

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