ψ' Physics in 1997/1998

Li Xinhua
(Represent ψ' Group)

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I. Introduction

Below the open charm threshold, there are 8 charmonium members expected. The ψ' is with the highest mass and a unique laboratory to systematically study charmonium family members and investigate QCD. However, only meagre progress has been achieved on the ψ' study in the world due to low statistics ψ' data sample. There are 87 modes of $J/\psi \to hadrons$ in PDG [1]. However, for ψ', only 18 of them are there. While 22 modes have been measured in J/ψ radiative decays, no branching ratios have been reported in PDG for the ψ' radiative decays. There are still fundamental questions, such as the origin of suppression in $\psi' \to \rho\pi$ decays.

With the success of BEPC/BES, 3.8 million ψ' event sample has been collected at BES. There are 1.23 million J/ψ's in the process of $\psi' \to \pi^+\pi^- J/\psi$, and 0.95 million χ_{cJ} events in $\psi' \to \gamma\chi_{c0,1,2}$ at BES following the PDG branching fraction [1]. Studies have been extended from ψ' to other charmonium states, J/ψ, χ_{cJ}. This talk reviews the progresses achieved on the ψ' study since 1997 BES Meeting.

II. improve ψ' database

The neutral tracks are detected by shower counter at BES. Inadequent errors of momentum vector are saved in TRKLST in the neutral track reconstruction. We have done an investigation into samples of Bhabha and $e^+e^- \to \gamma\gamma(\gamma)$. Corrections to the errors of neutral tack measurements of both ψ' data and Monte Carlo simulation have been made for the first time at BES which improve kinematic fit to events of neutral tracks.

By combining the dE/dx and shower counter measurements in the selection of wide angle Bhabha events, we have calculated the integrated luminosity of 1993 - 1995 ψ' data sets. The result is $£_{int.} = 6.15\ pb^{-1}$ with an error down to 4%.

The total events of $J/\psi \to anything$ produced in the process of $\psi' \to \pi^+\pi^- J/\psi$ have been observed. By using the branching fraction of $\psi' \to \pi^+\pi^- J/\psi$ [1] the total number of $(3.788 \pm 0.009 \pm 0.309) \times 10^6$ ψ' events has been determined for the 1993 - 1995 ψ' data sets.

III. ψ' results ready for publication

A precise measurement for the branching fractions of $J/\psi \to l^+l^-$ has been performed in the process of $\psi' \to \pi^+\pi^- J/\psi$ which is free of QED background. The results are $B(J/\psi \to e^+e^-) =$ (5.903 $\pm$ 0.051 $\pm$ 0.103)% and $B(J/\psi \to \mu^+\mu^-) =$ (5.838 $\pm$ 0.055 $\pm$ 0.099)%, where the first error is statistical and the second systematic. These values are consistent with PDG [1] in much higher precision and also a verification of e–μ universality

$$\frac{B(J/\psi \to e^+e^-)}{B(J/\psi \to \mu^+\mu^-)} = 1.011 \pm 0.013 \pm 0.016.$$

The decays of ψ' into vector - tensor mesons, ωf_2, ρa_2, $K^{*0}\overline{K_2}^{*0}$ and $\phi f_2'$, are suppresed with respect to $''15\%\ rule''$ which poses an challenge to charmonium physics.

The decays of $\psi' \to \gamma\eta$ and $\gamma\eta'$ have been observed. Both are suppressed in ψ' decays relative to J/ψ but not as severely as hadronic $\psi' \to VP$ decays (e.g. $\psi' \to \rho\pi$). The η' - η_c' mixing has been proposed as the dominant mechanism for the OZI forbidden radiative charmonium decays such as $\psi(nS) \to \gamma\eta$ and $\gamma\eta'$ [2]. In this case, the branching fraction of $\psi' \to \gamma\eta'$ is estimated to be $(1.8 \pm 0.9) \times 10^{-4}$ which agrees with BES measurement. The ratio of the $\gamma\eta$ and $\gamma\eta'$ decay rates of the $J^{PC} = 1^{--}$ charmonium states is sensitive to the pseudoscalar octet-singlet mixing angle θ_p. Ignoring SU(3)-breaking effects, one has the simple relation [3]

$$\Gamma(\psi_{nS} \to \gamma\eta')/\Gamma(\psi_{nS} \to \gamma\eta) = \frac{p^3_{\eta'}}{p^3_\eta}\frac{1}{tan^2\theta_p}$$

where p_η $(p_{\eta'})$ is the momentum of the η (η') in the $\psi(nS)$ rest frame. The measured J/ψ branching fraction values [1] imply a mixing angle $\mid \theta_p \mid = 22^o \pm 1^o \pm 4^o$, which is consistent with $\mid \theta_p \mid = 28^{o}{}^{+7^o}_{-10^o}$ determined from the BES $\psi(2S)$ results.

The χ_{c0} state is observed in the $\pi^+\pi^-$ and K^+K^- modes. The measured full width $\Gamma_{\chi_{c0}} =$ 14.3 $\pm$ 2.0 $\pm$ 3.0 MeV agrees with PDG [1] at higher precision. We have also done a first measurement in the world

$$B(\chi_{c0} \to p\bar{p} = (16.3 \pm 4.4 \pm 5.4) \times 10^{-5}.$$

The color-octet contribution has been proposed to be crucial in the χ_{cJ} decays. A calculation to leading order in v^2/c^2 and next-to-leading order in α_s predicts $\Gamma_{\chi_{c0}} = 14.9 \pm 3.2$ MeV [4] which agrees with BES measurement. One expects that the decays $\chi_{cJ} \to gg \to light\ hadrons$ be similar to $J^{PC} = J^{++}$ glueballs and flavor symmetry. However, is there a trick in BES measurements?

$$B(\chi_{c0} \to \pi^+\pi^-)/B(\chi_{c0} \to K^+K^-) = 0.82 \pm 0.15$$

$$B(\chi_{c2} \to \pi^+\pi^-)/B(\chi_{c2} \to K^+K^-) = 1.88 \pm 0.51$$

IV. ψ' analyses soon ready for publication

There is intensive interest in the soft π process of $\psi' \to \pi^+\pi^- J/\psi$ to test nonperturbative QCD at low energy scale. Various theoretical models have been proposed for this process [5]. By selecting events $\psi' \to \pi^+\pi^- J/\psi$ with $J/\psi \to l^+l^-$, we have performed an analysis of $\pi\pi$ mass spectrum, correlation angle θ distributions. A visible small D-wave is revealed to contribute to decay amplitude.

An analysis of $\psi' \to K^{*\pm}\bar{K}^{\mp}$, $K^{*0}\bar{K}^0$ and $\omega\pi^0$ has been done. Another analysis of $\psi' \to \rho\pi$ will be completed soon. The decays of ψ' to vector - pseudoscalar mesons are suppresed to the level of electromagnetic process. Isospin violations in J/ψ, $\psi' \to VP$ decays are also observed

$$B(\psi' \to \omega\pi^0)/(\psi' \to \rho^0\pi^0) = 1.8 \pm 1.2 \text{ (preliminary)}$$

$$B(J/\psi \to \omega\pi^0)/(J/\psi \to \rho^0\pi^0) = 0.10 \pm 0.02$$

$$B(J/\psi \to K^{*0}\bar{K}^0)/B(J/\psi \to K^{*\pm}\bar{K}^{\mp}) = 0.84 \pm 0.12$$

$$B(\psi' \to K^{*0}\bar{K}^0)/B(\psi' \to K^{*\pm}\bar{K}^{\mp}) > 4.2$$

The decays of $\psi(nS) \to axial - vector\ pseudoscalar\ (AP)$ have been measured and the results are listed in table 1. It is noted that the AP is the dominant mode of ψ' hadronic decays. Flavor-SU(3)-violating is seen in $K_1(1270)\bar{K}$ and $K_1(1400)\bar{K}$ modes. An opposite character is also observed for ψ' and J/ψ decays.

Table 1, Branching fractions of $\psi(nS) \to AP$ (in 10^{-4}). $B(J/\psi \to b_1^{\pm}\pi^{\mp})$ is from PDG [1], the others are BES measurements. Limits are at 90% confidence level.

mode	$B(\psi')$	$B(J/\psi)$	$B(\psi')/B(J/\psi)$
$b_1^{\pm}\pi^{\mp}$	6.2 ± 1.3	30 ± 5	0.21 ± 0.06
$K_1(1270)^{\pm}K^{\mp}$	8.4 ± 2.5	< 27	> 0.31
$K_1(1400)^{\pm}K^{\mp}$	< 2.7	43 ± 22	< 0.06

First observations of χ_{cJ} hadronic decays to $K_s^0K^{\pm}\pi^{\mp}$, $K_s^0K_s^0$, $\phi\phi$ and $K^+K^-K^+K^-$ have been performed at BES. The branching fractions of $\chi_{cJ} \to 2(\pi^+\pi^-)$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$, $3(\pi^+\pi^-)$ are also measured at high precision.

V. new ψ' analysis notes

A first observation of ψ' decays to neutrals has been performed. The decays $\psi' \to \gamma\pi^0\pi^0$ have been analyzed in 5γ final states by using π^0 mass constrained kinematic fit. The $\pi^0\pi^0$ mass spectrum shows resonances $f_2(1270)$ and $\chi_{c0,2}$. The measured beanching fractions

$$B(\psi' \to \gamma f_2) = (2.01 \pm 1.12 \pm 0.79) \times 10^{-4}$$

$$B(\psi' \to \gamma\chi_{c0}) = (3.15 \pm 0.17 \pm 0.39) \times 10^{-3}$$
$$B(\psi' \to \gamma\chi_{c2}) = (1.02 \pm 0.17 \pm 0.12) \times 10^{-3}$$

are consistent with $\psi' \to \gamma\pi^+\pi^-$ analysis [6].

An explanation to $''\rho\pi\ puzzle''$ expects an 1^{--} glueball mixing with J/ψ [7]. A search in $\psi' \to \pi^+\pi^-\rho\pi$ found no evidence for the existence. Upper limits of the production rates in ψ' decays

$$B(\psi' \to \pi^+\pi^- X) \times B(X \to \rho\pi)$$

are obtained corresponding to assumed various masses and widths of the vector glueball.

VI. analyses still in process

1. decay of $\psi' \to \tau^+\tau^-$
2. ψ' decays to baryon anti-baryon pairs
3. study J/ψ, χ_{cJ} states in $\psi' \to \gamma\gamma e^+e^-$, $\gamma\gamma\mu^+\mu^-$
4. study $J/\psi \to \gamma\gamma\gamma$ in $\psi' \to \pi^+\pi^- J/\psi$
5. many pions decays of ψ'
6. look for $\eta(1440)$, $f_J(1710)$ states in ψ' radiative decays
7. develop Lund Model (Jetset 7.4) to build a generator of J/ψ, ψ' inclusive decays
8. precise measurement of $B(\psi' \to \pi^+\pi^- J/\psi)$

VII. Summary

ψ' is a unique laboratory to systematically study charmonium family members and investigate QCD.

3.8 million ψ' data have been collected at BES. 30 new modes of ψ' decays have been observed at BES compared to PDG [1]. The $''\rho\pi\ puzzle''$ still persists at much higher sensitivity and also extends to vector-tensor hadronic decays. The isospin violating is seen in J/ψ, ψ' decays.

There is still much to be done: more $\psi(nS)$ hadronic and radiative decays; χ_{cJ} decay amplitudes; publish ψ' research papers; put many ψ' results in PDG.

We hope to collect ψ' data at BES II, $\tau - C$ factory. Then we will have opportunity to precisely measure ψ' decay width and search for η_c', $^1P_1$ state.

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