Charmonium Physics in 1996/97 at BES

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OUTLINE

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1. INTRODUCTION

The BES has accumulated 3.7×10^6 $\psi(2S)$ events which is the largest sample in the world. Studies have been extended from $\psi(2S)$ to other charmonium states, J/ψ, χ_{cj} and η_c'.

2. Determination of the number of $\psi(2S)$ events

The number of $\psi(2S)$ events has been determined in two different ways. At first, inclusive J/ψ production from $\pi^+\pi^- J/\psi$ was measured by both IHEP and Univ. of Hawaii. The PDG (particle data group, 1996) value

$$B(\psi(2S) \to \pi^+\pi^- J/\psi) = 0.324 \pm 0.026$$

was used. Table 1 lists the results.

Table 1. Number of $\psi(2S)$ ($\times 10^6$)

	IHEP	Hawaii
93/94	$1.32 \pm 0.01 \pm 0.12$	$1.31 \pm 0.02 \pm 0.13$
1995	$2.41 \pm 0.01 \pm 0.21$	$2.36 \pm 0.02 \pm 0.23$
sum	$3.73 \pm 0.01 \pm 0.32$	$3.67 \pm 0.03 \pm 0.36$

A direct determination of the number of $\psi(2S)$ events is also tried for 1995 data set. The result $N_{\psi(2S)} = (2.39 \pm 0.12) \times 10^6$ agrees with the inclusive observation (see L.S.Zhang's talk).

E760 has recently reported a measurement of the decay rate (Phys. Rev. D, vol. 55, page 1153, 1997):

$$B(\psi(2S) \to \pi^+\pi^- J/\psi) = 0.283 \pm 0.029$$

using

$$B(\psi(2S) \to f) = \frac{\varepsilon_{J/\psi X}}{\varepsilon_f} \frac{N_f}{N_{J/\psi X}} B(\psi(2S) \to J/\psi X)$$

where $B(\psi(2S) \to J/\psi X)$ from the fitted value of PDG using data sample of $J/\psi\pi^+\pi^-$, $J/\psi\pi^o\pi^o$, $J/\psi\eta$, $\gamma\chi_{cj}$. However, the measurement procedure is inconsistent. Taking the measured ratios $B(\psi(2S) \to J/\psi\pi^+\pi^-)/B(\psi(2S) \to J/\psi X)$, $B(\psi(2S) \to J/\psi\pi^o\pi^o)/B(\psi(2S) \to J/\psi X)$, and $B(\psi(2S) \to J/\psi\eta)/B(\psi(2S) \to J/\psi X)$ of E760 group, we have made an overall fit following the procedure of PDG and got the result

$$B(\psi(2S) \to \pi^+\pi^- J/\psi) = 0.310 \pm 0.025.$$

If using this number, the total number of $\psi(2S)$ observed in the inclusive production of J/ψ in table 1 would be increased by 4% (See Y.F.Gu and X.H.Li's comment to PRD).

3. Particle ID package

Analysis of 1993/94 and 1995 $\psi(2S)$ data set at SLAC by B. Dunwoodie and X.H. Li has resulted in an understanding of the systematic shift behaviors of dE/dx and TOF at the BES detector. The ADC overflow decreases the dE/dx pulse height measurement for low β track which is critical for low momentum track of kaon or proton. Hadronic interactions in the 5cm-thick TOF counter delay the measured flight time for π, K and p tracks. Offline correction packages (dedxpsip.f, tofpsip.f and ttintsec.f) are available for 1993/94 and 95 $\psi(2S)$ data sets.

4. Physics

4.1 Leptonic decays

Based on C.Z.Yuan's work of 93/94 data set, both IHEP and Univ. of Hawaii have analyzed the J/ψ leptonic decays to e^+e^-, and $\mu^+\mu^-$ pairs for both 93/94 and 1995 data sets. Table 2 lists the results.

Table 2. $B(J/\psi \to e^+e^-)$ (in %)

	IHEP	Hawaii
93/94	$5.89 \pm 0.08 \pm 0.11$	$5.79 \pm 0.10 \pm 0.12$
1995	$5.89 \pm 0.06 \pm 0.09$	$6.02 \pm 0.08 \pm 0.13$
combined	$5.89 \pm 0.05 \pm 0.08$	$5.93 \pm 0.06 \pm 0.13$

$B(J/\psi \to \mu^+\mu^-)$ (in %)

	IHEP	Hawaii
93/94	$5.88 \pm 0.09 \pm 0.12$	$5.96 \pm 0.10 \pm 0.12$
1995	$5.86 \pm 0.06 \pm 0.11$	$5.90 \pm 0.08 \pm 0.16$
combined	$5.87 \pm 0.05 \pm 0.10$	$5.92 \pm 0.06 \pm 0.14$

The decay of $\psi(2S)$ to $\mu^+\mu^-$ has been observed in the following procedure

$$B(\psi(2S) \to \mu^+\mu^-) = \frac{N_{\mu\mu} - \sigma_{QED+I} \bullet L}{N_{\psi(2S)}}$$

where the term $\sigma_{QED+I} \bullet L$ of QED and its interference with the $\psi(2S)$ decay is from the prediction of QED. A preliminary result $B(\psi(2S) \to \mu^+\mu^-) = (7.6 \pm 0.3 \pm 1.5) \times 10^{-3}$ agrees with PDG within large error.

4.2 $\psi(2S)$ hadronic decays

Substantial progress has been achieved on $\psi(2S)$ hadronic decays. Not including $B\bar{B}$ pairs (see J. Panetta's talk), 26 channels have been observed in $\psi(2S)$ decays which are listed in table 3. Among them, 20 channels have not been reported in PDG, 10 channels has been renewed in last year, and 3 channels are measured for the first time.

Striking suppression still holds in VP mode

$$B(\psi(2S) \to \rho\pi) < 2.8 \times 10^{-5} \text{ (90\% C.L.)}$$

where the limit is at the level of electromagnetic decays. Comparing to the J/ψ decay, a suppression factor is > 60 relative to "15% rule".

Another VP mode $\omega\eta$ is also suppressed by a factor of > 3 in the $\psi(2S)$ decay (see S.W.Ye's talk)

$$B(\psi(2S) \to \omega\eta) < 7.1 \times 10^{-5} \text{ (90\% C.L.)}$$

However, "15% rule" holds for an isospin violated decay

$$B(\psi(2S) \to \omega\pi^o) = (4.4 \pm 1.7 \pm 0.9) \times 10^{-5}.$$

Table 3. $B(\psi(2S) \to X)$ $(\times 10^{-4})$**, limit at 90% C.L.**

Channel	1996 ($\times 10^{-4}$)	1997 ($\times 10^{-4}$)
$\rho\pi$	< 0.29	< 0.28
$K^+\bar{K}^*(892)^- + c.c$	< 0.32	< 0.30
$K^0\bar{K}^*(892)^0 + c.c.$	$0.84 \pm 0.24 \pm 0.16$	$0.81 \pm 0.24 \pm 0.16$
$\omega\eta$		< 0.71
$\omega\pi^0$		$0.44 \pm 0.17 \pm 0.09$
ωf_2	< 1.5	< 1.1
ρa_2	$3.1 \pm 1.5 \pm 1.1$	< 3.0
$K^*(892)^0\bar{K}_2^*(1430)^0 + c.c.$	< 1.8	
$\phi f_2'(1525)$	< 0.53	< 0.34
$K^*(892)^0\bar{K}_4^*(2045)^0 + c.c.$	$5.2 \pm 2.3 \pm 1.2$	
$\phi f_0(980)$	$0.77 \pm 0.24 \pm 0.15$	
$K^*(892)^0\bar{K}^*(892)^0$	$0.45 \pm 0.25 \pm 0.07$	
$\phi\phi$		< 0.26
$a_2\pi$	< 0.83	
$b_1\pi$	$4.1 \pm 0.6 \pm 1.0$	$3.0 \pm 0.5 \pm 0.7$
$K_1(1270)\bar{K}$	$7.6 \pm 0.9 \pm 1.5$	checking
$K_1(1400)\bar{K}$	< 2.7	checking
$\pi^+\pi^-K^+K^-$	$6.9 \pm 0.3 \pm 1.2$	
$K^+K^-K^+K^-$	$0.75 \pm 0.10 \pm 0.09$	$0.65 \pm 0.10 \pm 0.11$
$\pi^+\pi^-\pi^0$	$1.03 \pm 0.13 \pm 0.16$	
$K\bar{K}\pi$	$1.30 \pm 0.20 \pm 0.25$	
$K^*(892)^0K^-\pi^+ + c.c.$	$4.8 \pm 0.5 \pm 0.7$	
ϕK^+K^-	$0.57 \pm 0.21 \pm 0.10$	$0.51 \pm 0.13 \pm 0.09$
$\phi\pi^+\pi^-$	$1.3 \pm 0.2 \pm 0.2$	
$\omega\pi^+\pi^-$	$5.4 \pm 0.7 \pm 1.1$	$4.7 \pm 0.7 \pm 1.0$
$\rho^0\pi^+\pi^-$	$3.7 \pm 0.6 \pm 0.9$	

The vector-tensor modes in the $\psi(2S)$ decays have been reanalyzed using offline packages correcting dE/dx (dedxpsip.f) and TOF (tofpsip.f, ttintsec.f) and also simple event selection. Table 4 lists the results and the suppression of VT mode is still there.

Table 4. Limit at 90% C.L.

	$B(\psi(2S))$ $(\times 10^{-4})$	$B(\psi(2S))/B(J/\psi)$
ωf_2	< 1.1	< 0.029
ρa_2	< 3.0	< 0.028
$K^{*o}\bar{K}_2^{*^o} + c.c.$	< 1.8	< 0.028
$\phi f_2'$	< 0.34	< 0.045

Similar reanalysis has been made on the axial-vector pseudoscalar mode $b_1^{\pm}\pi^{\mp}$ and '15% *rule*" still holds. Check is still in process at Univ. of Hawaii on $K_1\bar{K}$.

Several models have been suggested to explain the above puzzle in the hadronic decays of $\psi(2S)$ but none is satisfactory. Two new suggestions appear in 1997.

- *Intrinsic charm of vector mesons: a possible solution of the "$\rho\pi$ puzzle"* (S.J.Brodsky et al., Phys. Rev. Lett. 78, 4682(1997));

- *Possible explanation of the "$\rho\pi$ puzzle" in J/ψ, $\psi(2S)$ decays* : final state interactions contribute to $\rho\pi$ with various intermediate physical channels (X.Q.Li et al., PRD 55, 1421(1997)).

4.3 $\psi(2S)$ radiative decays

The radiative decay $\psi(2S) \to \gamma\eta'$ has been done by both Univ. of Hawaii group and S.W.Ye from USTC (see S.W.Ye's talk). Table 5 lists the results and its suppression in $\psi(2S)$ decay still holds. Theoretical consideration of mixing of η, η' with $c\bar{c}$ states predicts $B(\psi(2S) \to \gamma\eta') \sim (1.0 - 2.7) \times 10^{-4}$ which is consistent with the above measurement.

Table 5. Branching fraction of $\psi(2S) \to \gamma\eta'$

	$B(\psi(2S))$ $(\times 10^{-4})$	$B(\psi(2S))/B(J/\psi)$
BES96	$1.45 \pm 0.37 \pm 0.36$	0.034 ± 0.012
Hawaii	1.7 ± 0.5	0.039 ± 0.012
USTC	$1.18 \pm 0.24 \pm 0.21$	0.027 ± 0.008

4.4 χ_{cj} state and η_c' search

The χ_{cj} states is with intensive theoretical interest. Substantial progress on χ_{cj} states have been achieved: better precision determination and first measurement on many branching fractions; significant difference found in χ_{c2} decays, $B(\chi_{c2} \to \pi^+\pi^-)/B(\chi_{c2} \to K^+K^-) \sim 3$.

The radiative decays of $\psi(2S)$ have been investigated for the η_c' state. A bump of 9.8 ± 3.8 events with mass $M = (3606.4 \pm 3.4)$MeV seen on $P\bar{P}$ mass plot besides χ_{cj} states. However, the statistics is poor. Shoulders on higher mass side of χ_{c2} are seen at $M = (3594 \pm 8)$MeV with a significance of 3.1σ on the $\pi^+\pi^-K^+K^-$ mass plot and again at $M = (3599 \pm 13)$MeV with a significance of 2.1σ on the $3(\pi^+\pi^-)$ mass plot. The mass is consistent with the Crystal Ball observation $M = (3594 \pm 5)$MeV. However, this candidate is not seen on the mass plots of $K^+K^-K^+K^-$, $\pi^+\pi^-P\bar{P}$, $\pi^+\pi^-\pi^+\pi^-$. Upper limits have been placed for the X(3594) production in the above three channels (see C.Z. Yuan's talk).

5. Publication status

9 analysis memos are available on the $\psi(2S)$ decays. However, there is only one paper draft completed and no paper has been submitted for publication. Table 6 lists the topics.

Table 6, Analyzed topics of $\psi(2S)$ physics

topic	memo	referee comm.	draft	subm.
$\psi(2S) \to \tau^+\tau^-$	$\surd$	$\surd$	$\surd$	$\times$
$J/\psi \to l^+l^-$	$\surd$	$\surd$	$\times$	$\times$
$\psi(2S) \to VT$	$\surd$	$\surd$	$\times$	$\times$
$\psi(2S) \to VP$	$\surd$	$\surd$	$\times$	$\times$
$\psi(2S) \to \gamma\chi_{cj}$	$\surd$	$\times$	$\times$	$\times$
$\psi(2S) \to \gamma\eta_c'$	$\surd$	$\times$	$\times$	$\times$
$\psi(2S) \to \gamma\eta', \gamma f_2$	$\surd$	$\times$	$\times$	$\times$
$\psi(2S) \to \omega\pi^0$, $\omega\eta$	$\times$	$\times$	$\times$	$\times$
$\psi(2S) \to AP$	$\surd$	$\surd$	$\times$	$\times$
$\psi(2S) \to B\overline{B}$	$\surd$	$\surd$	$\times$	$\times$

The $\psi(2S)$ results at BES are with intensive interest and have been quotated by many papers. The following lists some of the quotations before March of 1997.

- $\psi(2S)$ sample: preprint (2)
- VP/VT: preprint (4), Phys. Rev. (4)
- AP: Phys. Rev. (1)
- $\rho\pi$ scanning: preprint (4)

- χ_{cj}: preprint (1), Phys. Rev. (2)
- $B\overline{B}$: preprint (1)

6. Future plan

Further efforts will be made on the following topics.

- $\psi(2S)/J/\psi$: more hadronic and radiative decay modes
- χ_{cj}: decay amplitude, decays involving hadronic resonances
- More efforts on η_c', possibly η_c
- Search for $^1P_1$ state (Ph.D thesis)
- All-photon final states (Ph.D thesis)