$\psi(2S)$ Decay Studies in 1999/2000

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1 Completed or nearly completed studies in $\psi(2S)$ Decays

In 1999/2000, some subjects in $\psi(2S)$ decay studies have reached final stage and nearly got final results. They have passed the referee's inspection, the paper drafts have been prepared and ready (or almost ready) for submission. They are

(1) $\psi(2S) \to \omega, \phi + X$ hadronic decay
(2) $\psi(2S) \to B\overline{B}$
(3) Radiative decay of $\psi(2S)$ into two pseudo-scalars
(4) $\psi(2S) \to \tau^+\tau^-$

1.1 $\psi(2S) \to \omega, \phi + X$ hadronic decay

- **Br. of 12 $\psi(2S)$ hadronic decays measured for the 1st time**

  $\omega\pi^+\pi^-, \omega K^+K^-, \omega p\overline{p}, \phi\pi^+\pi^-, \phi K^+K^-, \phi p\overline{p},$

  $\phi f_0(980), \pi^0\pi^+\pi^- p\overline{p}, \eta\pi^+\pi^- p\overline{p},$

  $K^*K^-\pi^+ + c.c., K^*\overline{K}^* + c.c., K^*\overline{K_2}^* + c.c..$

  (see Table 1)

Table 1. BES measured branching ratios and 15% rule test

X	$B_{\psi'\to X}(10^{-5})$	$B_{J/\psi\to X}(10^{-4})$	Q_X
$\omega\pi^+\pi^-$	$44.7 \pm 5.7 \pm 5.4$	72 ± 10	$(6.3 \pm 1.4)\%$
ωK^+K^-	$13.1 \pm 4.4 \pm 3.9$	7.4 ± 2.4	$(17.7 \pm 9.8)\%$
$\omega p\overline{p}$	$6.7 \pm 2.3 \pm 1.4$	13.0 ± 2.5	$(5.2 \pm 2.3)\%$
$\phi\pi^+\pi^-$	$17.6 \pm 2.2 \pm 2.4$	8.0 ± 1.2	$(22.0 \pm 5.3)\%$
ϕK^+K^-	$6.1 \pm 1.8 \pm 1.5$	8.3 ± 1.3	$(7.3 \pm 3.0)\%$
$\phi p\overline{p}$	$0.86 \pm 0.50 \pm 0.20$	0.45 ± 0.15	$(18.9 \pm 13.4)\%$
ϕf_0	$6.6 \pm 1.7 \pm 0.8$	3.2 ± 0.9	$(20.5 \pm 8.1)\%$
$K^*K^-\pi^+ + c.c.$	$63.1 \pm 4.6 \pm 8.2$	no data	?
$K^*\overline{K}^* + c.c.$	$4.10 \pm 0.90 \pm 0.60$	2.9 ± 0.7	$(14.2 \pm 5.1)\%$
$K^*\overline{K_2}^* + c.c.$	$8.34 \pm 4.80 \pm 2.72$	67 ± 26	$(1.25 \pm 0.97)\%$
$\pi^0\pi^+\pi^- p\overline{p}$	$36.5 \pm 3.8 \pm 5.5$	23 ± 9	$(15.9 \pm 6.9)\%$
$\eta\pi^+\pi^- p\overline{p}$	$25.8 \pm 6.8 \pm 7.3$	no data	?
$\eta p\overline{p}$	$< 19.CL90\%$	20.9 ± 1.8	$< 9.0\%CL90\%$

- **PQCD 15% rule tested**

  4 channel are lower then PQCD by factor of 2 or more

  $(\omega\pi^+\pi^-, \phi K^+K^-, \omega p\overline{p}, K^*\overline{K_2}^* + c.c.)$,

  other channels agree with PQCD prediction.

  These data are hard to explain with existing theory

  Provide a clue to improve QCD theory

- **(D)OZI violation observed**

  – Definition of $R_{(\phi X/\omega X)}$ and $r_{(\phi X/\omega X)}$: $(X = \pi^+\pi^-, K^+K^-, p\overline{p})$

  $$R_{(\phi X/\omega X)} = \frac{B(\psi(2S) \to \phi X)}{B(\psi(2S) \to \omega X)} \qquad r_{(\phi X/\omega X)} = \frac{B((J/\psi) \to \phi X)}{B((J/\psi) \to \omega X)}$$

  The BES values of $R_{(\phi X/\omega X)}$ and corresponding values of $r_{(\phi X/\omega X)}$ from reference are listed in table 2.

  – $J/\psi(\psi(2S)) \to \phi\pi\pi$ is DOZI suppressed,
  $J/\psi(\psi(2S)) \to \phi K^+K^-, \omega\pi^+\pi^-, \omega K^+K^-$, SOZI process dominant
  but both SOZI and DOZI processes contribute.

  – Theories give different predictions for $R_{(\phi X/\omega X)}, r_{(\phi X/\omega X)}$.
  $\omega \sim \phi$ mixing model : $R_{(\phi X/\omega X)} \sim r_{(\phi X/\omega X)} \sim (1-4.2) \times 10^{-3}$
  PQCD : $R_{(\phi\pi^+\pi^-/\omega\pi^+\pi^-)} > r_{(\phi\pi^+\pi^-/\omega\pi^+\pi^-)} \approx 0.14$.
  Large N_C QCD : $R_{(\phi\pi^+\pi^-/\omega\pi^+\pi^-)}, r_{(\phi\pi^+\pi^-/\omega\pi^+\pi^-)}$ is $1/N_C^2 \sim 1/9$
  in limit $N_C \to \infty$.

- Strong (D)OZI violation observed

  BES $R_{(\phi X/\omega X)}$ data show a strong OZI violation (two orders of magnitude higher) than naive $\omega \sim \phi$ mixing model prediction observed.

  ϕ production not via $\omega \sim \phi$ mixing mechanism.

  PQCD and Large N_C QCD give semi-quantitative estimation to $R_{(\phi X/\omega X)}, r_{(\phi X/\omega X)}$

  DOZI violation in $\psi(2S)$ decays is stronger than in J/ψ decays.

These results have passed BES referee's inspection, the paper will be submitted to PRD.

Table 2. Ratio $R_{(\phi X/\omega X)}, r_{(\phi X/\omega X)}$

X	$R_{(\phi X/\omega X)}$	$r_{(\phi X/\omega X)}$
$\pi^+\pi^-$	$(39.3 \pm 7.0 \pm 6.0)\%$	$(11.4 \pm 2.4)\%$
K^+K^-	$(46.6 \pm 20.8 \pm 180)\%$	$(112.2 \pm 40.6)\%$
$p\overline{p}$	$(12.8 \pm 8.7 \pm 4.0)\%$	$(3.5 \pm 1.3)\%$

1.2 $\psi(2S) \to B\overline{B}$

- Long time researches by many persons.

  These channels studies reach the final stage, ready for submission.

- BES measured branching fractions

  8 channels measured, 5 for the 1st time, listed on Table 3,

  together with $Q_h = \frac{B(\psi(2S)\to h)}{B(J/\psi)\to h}$ (using the PDG values for J/ψ decays)

- PQCD 15% rule test

  Q_h are in reasonable agreement with PQCD 15% expectations.

- Flavor SU(3) symmetry test

  - Definition of phase-space-corrected reduced branching ratio $\mid M_i \mid^2$

    $$\mid M_i \mid^2 = \frac{B(\psi(2s) \to B_i\overline{B_i})}{\pi p^*/\sqrt{s}}$$

    (p^* is the momentum of the baryon in the $\psi(2s)$ rest frame).

  - SU(3) flavor symmetry

    In the context of flavor SU(3), a pure $c\overline{c}$ state is a flavor singlet

    In the limit of SU(3) flavor symmetry,$\mid M_i \mid^2$ should be the same for every baryon B_i in the same multiplet.

    Deviations from this rule would indicate a non- $c\overline{c}$ component of the charmonium wave function.

– The SU(3) relation works reasonably well for $J/\psi \to B\overline{B}$
  See Table 4. (although there may be some preference for $p\overline{p}$ mode).
  This relation has not been tested for the $\psi(2s)$.

– SU(3) flavor symmetry test in $\psi(2S) \to B\overline{B}$
  BES measured $\mid M_i \mid^2$ listed in Table 4.
  The results show a trend to smaller values for the higher masses, only marginally consistant to flavor-SU(3) symmetry prediction, similar to J/ψ case.

– Further studies needed
  Higher precision measurements both for the J/ψ and $\psi(2s)$ and the study of explicitly SU(3)-violating octet-decuplet modes, such as $\Sigma\overline{\Sigma^*}$ and $\Xi\overline{\Xi^*}$, might clarify this problem.

Table 3. Branching ratios of $J/\psi, \psi(2S) \to B\overline{B}$

(limits at 90% CL)

Decay	$B(\psi(2S))$ (10^{-4})		$B(J/\psi)$ (10^{-3})	Q_h (BES)
	BES	PDG98		
$p\overline{p}$	$2.62 \pm .58$	1.9 ± 0.5	2.14 ± 0.10	12.2 ± 2.8
$\Lambda\overline{\Lambda}$	$1.89 \pm .30$	< 4	1.35 ± 0.14	14.0 ± 2.7
$\Sigma^0\overline{\Sigma}^0$	$1.2 \pm .5$		1.27 ± 0.17	9.2 ± 4.1
$\Delta^{++}\overline{\Delta}^{--}$	$1.34 \pm .35$		1.10 ± 0.29	12.2 ± 4.5
$\Xi^-\overline{\Xi}^+$	$1.0 \pm .3$	< 2	0.9 ± 0.2	11 ± 4
$\Sigma^{*-}\overline{\Sigma}^{*+}$	$1.1 \pm .4$		1.03 ± 0.13	11 ± 4
$\Xi^{*0}\overline{\Xi}^{*0}$	$< .85$			
$\Omega^-\overline{\Omega}^+$	$< .77$			

Table 4. Reduced branching fractions $\mid M_i \mid^2$ for $J/\psi, \psi(2s) \to B_i\overline{B}_i$

(limits at 90% CL)

Decay	$\mid M_i \mid^2$ $(J/\psi)(10^{-3})$	$\mid M_i \mid^2$ $(\psi(2S))(10^{-5})$
$p\overline{p}$	2.23 ± 0.10	16.5 ± 3.7
$\Lambda\overline{\Lambda}$	1.24 ± 0.13	12.9 ± 2.0
$\Sigma^0\overline{\Sigma}^0$	1.26 ± 0.17	8.5 ± 3.6
$\Delta^{++}\overline{\Delta}^{--}$	1.16 ± 0.30	7.8 ± 2.3
$\Xi^-\overline{\Xi}^+$	1.1 ± 0.2	9.8 ± 2.6
$\Sigma^{*-}\overline{\Sigma}^{*+}$	1.47 ± 0.19	9.1 ± 3.3
$\Xi^{*0}\overline{\Xi}^{*0}$		< 8.3
$\Omega^-\overline{\Omega}^+$		< 9.9

1.3 Radiative decay of $\psi(2S)$ into two pseudo-scalars

Studied channel: $\psi(2S) \to \gamma(\pi\pi, K\overline{K}, \eta\eta) \to 5\gamma, \gamma 2P, \gamma 4P$.

- $\psi(2S) \to \gamma\pi\pi \to 5\gamma, \gamma 2P$ mode.

  $B(\psi(2S) \to \gamma f_2(1270))$,

  $B(\psi(2S) \to \gamma f_J(1710))$,

  $B(\chi_{c0} \to \pi^0\pi^0)$ measured

- $\psi(2S) \to \gamma K\overline{K} \to \gamma 2P, \gamma 4P$ mode.

  $B(\psi(2S) \to \gamma f_J(1710) \to \gamma K^+K^-)$

  $B(\psi(2S) \to \gamma f_J(1710) \to \gamma K^0_S K^0_S)$ measured

- $\psi(2S) \to \gamma\eta\eta \to 5\gamma$ mode.

  $B(\chi_{c0} \to \eta\eta)$, $B(\chi_{c2} \to \eta\eta)$ measured

Results summerized in Table 5.

- All branching ratios in Table 5 are the 1st measurement.
- $\frac{B(\chi_{c0}\to\eta\eta)}{B(\chi_{c0}\to\pi^0\pi^0)} = 0.73 \pm 0.31 \pm 0.23$

  is consistant with Flavor SU(3) symmetry prediction.
- Waiting for Referee's approval (who will continue?)

Table 5. Branching ratio measured from $\psi(2s) \to 5\gamma, \gamma 2P, \gamma 4P$

Process	Branching ratio
$\psi(2S) \to \gamma f_2(1270)$	$(2.37 \pm 0.26 \pm 0.37) \times 10^{-4}$
$\psi(2S) \to \gamma f_J(1710) \to \gamma\pi\pi$	$(3.51 \pm 0.90 \pm 1.46) \times 10^{-5}$
$\psi(2S) \to \gamma f_J(1710) \to \gamma K^+K^-$	$(5.8 \pm 2.0 \pm 1.0) \times 10^{-5}$
$\psi(2S) \to \gamma f_J(1710) \to \gamma K^0_S K^0_S$	$(2.2 \pm 1.0 \pm 1.2) \times 10^{-5}$
$\chi_{c0} \to \pi^0\pi^0$	$(2.80 \pm 0.32 \pm 0.60) \times 10^{-3}$
$\chi_{c2} \to \pi^0\pi^0$	$(9.2 \pm 2.7 \pm 5.3) \times 10^{-4}$
$\chi_{c0} \to \eta\eta$	$(2.03 \pm 0.84 \pm 0.61) \times 10^{-3}$
$\chi_{c2} \to \eta\eta$	$< 1.28 \times 10^{-3} (90\% CL)$

1.4 $\psi(2S) \to \tau^+\tau^-$

- Analysis almost finished
  (waiting for σ_{Q+I} - sum of cross sections of QED+Interference part)
- BES value satisfy $e - \mu - \tau$ universality within error (see Table 6)
- Paper draft needed

Table 6. $\psi(2S)$ **leptonic branching ratios**

PDG 98 (10^{-3})		BES (10^{-3})
$B(\psi(2S) \to e^+e^-)$	$B(\psi(2S) \to \mu^+\mu^-)$	$B(\psi(2S) \to \tau^+\tau^-)$
8.5 ± 0.7	7.7 ± 1.7	$7.26 \pm 1.16 \pm 1.44$

1.5 Model Independent Amplitude Analysis of $\psi(2S) \to \pi^+\pi^- J/\psi$

- Accepted BES paper – Shifman model
  (QCD Trace Anomaly)
  assume : $C_2 = g_1 + g_3/3 = 0$.
  fit parameter : $\kappa \sim (0.15 - 0.20)$
- MIAA -
  fit parameters : g_1, g_2, g_3
  no constraint for g_1, g_3
  g_2 – S and D wave components.
- Status
  Analysis – (nearly) completed
  Memo – Ready
  Referee – to be assigned
  possible publication – English or Chinese journal ?

2 Ongoing studies in $\psi(2S)$ Decays

2.1 Determination of $\psi(2S)$ decay widths

- **Purpose**

  Measure $\Gamma_t, B(h), B(\mu), B(\pi^+\pi^- J/\psi), B(J/\psi X)$

- **Need to know or prepare**:

  1. Code for selecting $\psi(2S) \to$ hadron,e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^- J/\psi$, $J/\psi X$ events
  2. Trigger efficiencies for hadron,e^+e^-, $\mu^+\mu^-$ evts.
  3. Acceptances $A_h^R, A_h^C, A_e^R, A_e^C, A_e^I, A_\mu^R, A_\mu^C, A_\mu^I, A(\pi^+\pi^- J/\psi), A(J/\psi X)$
  4. Vacuum polarization factor
  5. Luminosity determination
  6. Code for line-shape fit

- Mo Xiaohu will report the current situations.

- Fred uses $N_{\pi^+\pi^- J/\psi}/N_{\psi(2S)}$ of the $\psi(2S)$ scan data to determine $B_{\pi^+\pi^- J/\psi}$ which can make a cross check with line-shape fit results.

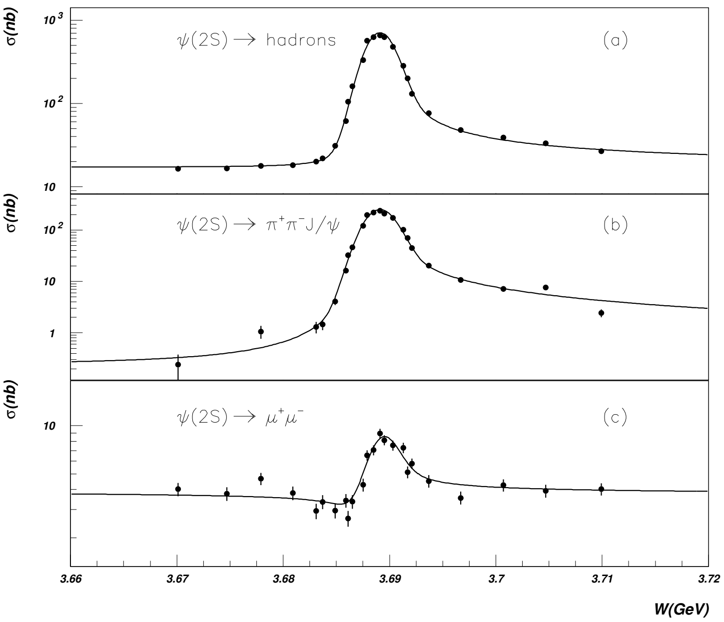

Figure 1: The total cross sections for $e^+e^- \to hadrons, \pi^+\pi^- J/\psi, \mu^+\mu^-$ in the vicinity of $\psi(2S)$ resonance. The solid curves represent the results of the fit to data

2.2 Measurement of $\psi(2S) \to J/\psi$ + neutrals

- 3 students contribute to this study: Liu Feng, Lu Feng, Zhang Lin.

  5 channels studied: $\psi(2S) \to J/\psi\pi^0\pi^0$, $\psi(2S) \to J/\psi\pi^0$

  $\psi(2S) \to J/\psi\eta$, $\psi(2S) \to \gamma\chi_{c1,2}, \chi_{c1,2} \to \gamma J/\psi$

- Differences

  Lu Feng – $J/\psi \to \mu^+\mu^-$ analyzed

  other two – use both $J/\psi \to \mu^+\mu^-, e^+e^-$ channels

  different generators (PPGEN, UGNT) and selection criteria are used

- Different results

  Lu Feng's results – (central values) basically agree with PDG96

  Liu Feng, Zhang Lin's – (central values) all higher than PDG96.

- Further detailed studies needed.

- Liu Feng will report his work.

Table 7. Branching ratios for $\psi(2S) \to J/\psi$ + neutrals

Decay $\psi' \to$	B% (Liu Feng)	B% (Lu Feng)	B% (Zhang Lin)	B% (PDG96)
$\pi^0\pi^0 J/\psi(\mu^+\mu^-)$	20.9 ± 2.5	$18.5^{+1.7}_{-1.8}$		18.4 ± 2.7*
$\pi^0\pi^0 J/\psi(e^+e^-)$	19.8 ± 2.2			
$\eta J/\psi(\mu^+\mu^-)$	3.51 ± 0.40	$2.92^{+0.35}_{-0.33}$	3.58 ± 0.15	2.7 ± 0.4*
$\eta J/\psi(e^+e^-)$	3.60 ± 0.47		3.57 ± 0.17	
$\pi^0 J/\psi(\mu^+\mu^-)$	0.21 ± 0.05*	$.133 \pm .041$	$.15 \pm .05$	$.097 \pm .021$*
$\pi^0 J/\psi(e^+e^-)$			$.17 \pm .06$	
$\gamma\chi_{c1} \to 2\gamma J/\psi(\mu^+\mu^-)$	12.0 ± 1.4	8.7 ± 1.2	10.4 ± 0.3	8.7 ± 0.8*
$\gamma\chi_{c1} \to 2\gamma J/\psi(e^+e^-)$	13.3 ± 1.5		12.9 ± 0.4	
$\gamma\chi_{c2} \to 2\gamma J/\psi(\mu^+\mu^-)$	12.8 ± 1.7	7.8 ± 1.3	11.3 ± 0.5	7.8 ± 0.8*
$\gamma\chi_{c2} \to 2\gamma J/\psi(e^+e^-)$	13.3 ± 1.9		12.2 ± 0.7	

Note: * data are for $J/\psi \to l^+l^-$
Zhang Lin's results include statistical error only

3 Studies need be continued or initialized

1. **PWA analysis of χ_c decays**

   - Current Researcher: ???
   - The statistics of $\chi_{cJ} \to 2(\pi^+\pi^-), 3(\pi^+\pi^-), \pi^+\pi^-K^+K^-$ large enough for PWA analysis.

- The results could supply the informations on glueball and hybrid exotic sector $H(J^{PC} = 1^{-+})$.
- J^{PC} of χ_c is well determined, the possible intermediate states in PWA analysis are restricted, therefore more reliable results can be expected.
- Yuan Changzheng and Hu Jingliang have done a preliminary analisis of $\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$, $f_0(980)f_0(980)$ is seen.
- No difficulties in deriving good results from these analysis.

2. **Systematic research of χ_c decays**

   - Current Researcher: ???
   - Varner has done a systematic researches on χ_c decays via $\psi(2S) \to \gamma nP, n = 2, 4, \cdots, \quad \gamma\pi^0\pi^0$.
   - Abundunt results getting out, (but preliminary!) some are already published, many are not.
   - With ordinary meathod, complementary to PWA analysis.
   - Many results are waiting for being checked and published !!!

3. $\psi(2S) \to VP$

   - Current Researcher: Lu Feng
   - The origin of $\rho\pi$ puzzel.
   - Long history, Many people worked for it.
   - Channels studied: $\rho(\pi, \eta, \eta')$,$\omega(\pi, \eta, \eta')$,$\phi(\pi, \eta, \eta')$, K^*K
   - Publication needed.

4. **Total number of $\psi(2S)$ events**

   - Current Researcher: Zhang Liangsheng
   - Globally decrease the systematic error caused by $N_{\psi'}$
   - Renewer BES previously published $\psi(2S)$ decay branching ratios.
   - Systematic error and background subtraction need be carefully studied.

5. **Search for h_c and Measurement of $B(\psi(2S) \to \eta J/\psi)$**

   - Current Researcher: Fred Harris
   - ${}^1P_1$ search via $\psi(2S) \to \pi^0 {}^1P_1, {}^1P_1 \to \pi^+\pi^- J/\psi(\pi^0$ missing). Interesting physics subject.
   - $\frac{B(\psi' \to \eta J/\psi)}{B(\psi' \to \pi^+\pi^- J/\psi)} \approx 0.146$. higher than PDG's, comparable with Liu Feng and Zhang Lin's results.

4 Summary

- BES $\psi(2S)$ studies have unique superiority in the world.
- BES $\psi(2S)$ studies have produced many interesting physics results.
- BES $\psi(2S)$ studies have published several papers.
- BES $\psi(2S)$ studies are still active currently.
- Some interesting topics need people to fill in.
- Collecting more $\psi(2S)$ events at BESII are still a good option.

  (in particular, searches for glueball and hibrid, as a complementary study for J/ψ decays)