Proposal for $\psi(2S)$ Scan Experiment on BES

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1 Why $\psi(2S)$ scan?

Since the discovery of the $\psi(2S)$ particle in 1974 [1],a few measurements for its total decay width have been carried out[2-4]. The results show the big deviation of their central values ranging from 202 to 306 keV. Also their relative errors are rather large ranging from 13% to 28%. The branching ratio of $\psi(2S) \to \pi^+\pi^- J/\psi$ is of particular importance because of its easy tagging and large fraction. However, its central values have been changed from 0.32[5], 0.36[3] to 0.283[6], by a factor of 27%. And its relative error is not sufficiently accurate ranging from 0.10 to 0.17. Due to the measurement of this branching ratio by E760 collaboration[6], its PDG value varied from 0.324 ± 0.026 (yr. 1996[7]) to 0.302 ± 0.019 (yr. 1998[8]). In the branching ratio measurement of any $\psi(2S)$ decay channel, the total number of produced $\psi(2S)$ events are usually calculated based on the number of $\psi(2S) \to \pi^+\pi^- J/\psi$ events and its branching ratio, therefore its relative error will be directly accounted into the error of the branching ratio of being studied channel.

Similar situation happend for the branching ratios of $\psi(2S) \to J/\psi$+anything and $\psi(2S) \to \mu^+\mu^-$. The central value of $B(\mu)$ ranges from 0.0077[9] to 0.0099[3] and its relative error ranges from 0.17[2] to 0.32[3]. For the $B(J/\psi X)$, the central value ranges from 0.51 to 0.57 and its relative error ranges from 0.14 to 0.24[2,3].

Table 1 summarizes the results of these measurements together with corresponding values of PDG96 and PDG98. It is certainly interesting to measure the total decay width of $\psi(2S)$ and its branching ratios to $\pi^+\pi^- J/\psi$, $J/\psi X$, $\mu^+\mu^-$ decay channels with better accuracy. We propose making a scan in the vicinity of $\psi(2S)$ to reach this goal.

2 What will we do in $\psi(2S)$ scan?

At 18 energy points (center-of-mass energy W_i = 3.67, 3.675, 3.68, 3.682 to 3.692 with step of 1 MeV, 3.695, 3.700, 3.705, 3.710), we will collect 23 nb^{-1} integrated luminosity for each point, measure the cross sections for final states of hadrons, e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^- J/\psi$ and $J/\psi X$ (J/ψ tagged by lepton pairs invariance mass cut). As the branching ratio of $\psi(2S)$ to e^+e^- is small, the cross section of e^+e^- final state is dominated by QED process, therefore it can be used to calculate the integrated luminosity at each energy point. The contribution of $\psi(2S)$ to e^+e^- can be corrected by a recursive iteration procedure (see section 4). By fitting these data simultaneously with the

Table 1. $\psi(2S)$ **decay width and some branching ratios**

Group	yr.	Γ (keV)	$B(\mu\mu)$ (10^{-3})	$B(\pi^+\pi^- J/\psi)$	$B(J/\psi X)$
MARKI	75	228±56(0.25)	9.3±1.6(0.17)	0.32±0.04(0.13)	0.57±0.08(0.14)
SPEC	75		7.7±1.7(0.22)		
DASP	79	202±57(0.28)	9.9±3.2(0.32)	0.36±0.06(0.17)	0.51±0.12(0.24)
E760	92	306 ± 39(0.13)			
	97			0.283 ± 0.029(0.10)	
PDG	96	277±31(0.11)		*0.324±0.026(0.08)	*0.57±0.04(0.07)
PDG	98	277±31(0.11)		*0.302±0.019(0.063)	*0.542±0.030(0.055)

note: numbers in pararences denote the relative error.
* : fit value.

theoretical cross sections (taking into account the beam energy spread and the radiative correction effect) for above processes, $\Gamma(t)$, $B(\mu\mu)$, $B(\pi^+\pi^- J/\psi)$ and $B(J/\psi X)$ of $\psi(2S)$ resonance can be deduced.

3 Can BES improve the existing accuracies?

In 1995, BES collaboration had published the paper with title of "A measurement of J/ψ decay widths"[10], it means that BES has all the necessary experience to do the same measurement for $\psi(2S)$ resonance. Actually, BES has already made a preliminary study for $\psi(2S)$ total width measurement[11] with bad quality $\psi(2S)$ scan data, which consists of several times rough scan in the vicinity of $\psi(2S)$ resonance in different runs aiming at the determination of peak position of $\psi(2S)$ rather than a careful study of $\psi(2S)$ line shape[12]. Eventhough, a reasonable result for the total width has been obtained to be 252 ± 45 keV, based on selected $\psi(2S) \to \pi^+\pi^- J/\psi$ events and its branching ratio value(PDG96) . The excitation curve for $\psi(2S)$ is shown in Fig. 1.

Recently BES Collaboration is measuring R value in the range 2-5 GeV[13]. This experiment also needs $\psi(2S)$ scan but with integrated luminosities and energy points in the vicinity of $\psi(2S)$ resonance less than those needed by our purpose. Therefore, we just need add some additional energy points and increase the integrated luminosity at each points to an appropriate quantity, the goal of improving the accuracies for exsisting values of $\Gamma(t)$, $B(\mu\mu)$, $B(\pi^+\pi^- J/\psi)$ and $B(J/\psi X)$ of $\psi(2S)$ resonance can be reached. As all the principal key questions for our purpose have been solved in R measurement, such as the subtraction of beam-gas background, the determination of hadron events selection effeciency, the trigger efficiency, etc., our task becomes very simple: collect the events number of e^+e^-, $\mu^+\mu^-$ and hadron final states at certain energy points in the vicinity of $\psi(2S)$ resonance, fit them with theoretical cross sections simultaneously and deduce the Γ, Γ_h and Γ_μ. If we collect also the events of $\pi^+\pi^- J/\psi$ and $J/\psi X$ final states, $B(\pi^+\pi^- J/\psi)$ and $B(J/\psi X)$ can also be determined.

Now we analyze which kind of accuracies BES can reach for these quantities. To determine these errors accurately is very difficult, however, to give an approximate estimation is possible. Define $f_i = \Gamma_i \Gamma_e / \Gamma$, $i = e, \mu, \tau, h, \pi, X$, here Γ is total decay width and Γ_i is patial width of process i. For $i = \pi, X$, it represents the process of $\psi(2s)$ decaying to $\pi^+\pi^- J/\psi$, $J/\psi X$ respectively. For

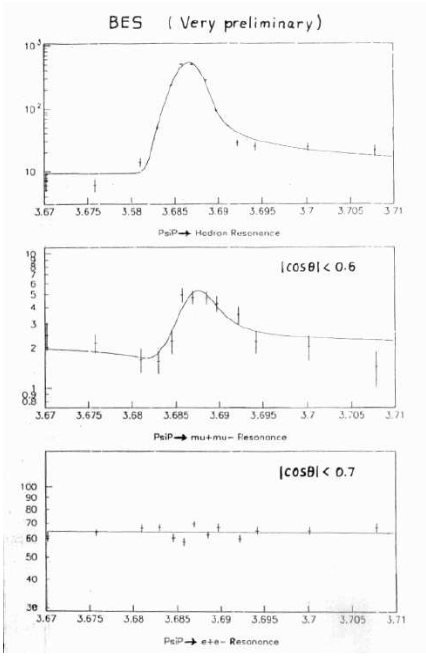

Figure 1: The $\psi(2S)$ excitation curves

$\psi(2s)$, since $\Gamma \gg \Gamma_{e,\mu,\tau}$, assuming lepton universality, we have $\Gamma \sim \Gamma_h \sim f_h^2/f_e, \Gamma_\mu \sim f_h, B_i \sim f_i/f_h, i = \mu, \pi, X$. By simple calculation, we can deduce that

$$(\frac{d\Gamma}{\Gamma})^2 = 4(\frac{df_h}{f_h})^2 + (\frac{df_\mu}{f_\mu})^2 \tag{1}$$

$$(\frac{dB_\mu}{B_\mu})^2 = (\frac{df_h}{f_h})^2 + (\frac{df_\mu}{f_\mu})^2 \tag{2}$$

$$(\frac{dB_\pi}{B_\pi})^2 = (\frac{df_h}{f_h})^2 + (\frac{df_\pi}{f_\pi})^2 \tag{3}$$

$$(\frac{dB_X}{B_X})^2 = (\frac{df_h}{f_h})^2 + (\frac{df_X}{f_X})^2 \tag{4}$$

Without considering the radiative correction, $f_i \propto S_i, i = e, \mu, \tau, h, \pi, X$, S_i stands for the area under the energy-cross section exitation curve for process $\psi(2S)$ decaying to final state i. For hadron final state, we have:

$$\sigma_h(W) = \frac{N_h(W)}{L(W)\epsilon_h} \tag{5}$$

$$N_h = N_h(obs) - N_{bg} \tag{6}$$

Here,L stands for integrated luminosity,$N_h(obs)$ for observed number of hadron events,ϵ_h for detection efficiency of hadron events, and N_{bg} for background events number including beam gas, $\tau^+\tau^-$ hadronic final states, and two photon processes hadronic final states. Easy to get

$$[\frac{d\sigma_h}{\sigma_h}]^2 = [\frac{N_h(obs)}{N_h}]^2[\frac{dN_h(obs)}{N_h(obs)}]^2 + [\frac{N_{bg}}{N_h}]^2[\frac{dN_{bg}}{N_{bg}}]^2 + [\frac{dL}{L}]^2 + [\frac{d\epsilon_h}{\epsilon_h}]^2 \tag{7}$$

In above equation, as N_{bg} is much smaller than N_h, especially in resonance region, hence $N_h \sim N_h(obs)$,then we have approximately:

$$[\frac{d\sigma_h}{\sigma_h}]^2 \simeq [\frac{dN_h(obs)}{N_h(obs)}]^2 + [\frac{dL}{L}]^2 + [\frac{d\epsilon_h}{\epsilon_h}]^2 \tag{8}$$

Similary we have

$$[\frac{d\sigma_i}{\sigma_i}]^2 \simeq [\frac{dN_i(obs)}{N_i(obs)}]^2 + [\frac{dL}{L}]^2 + [\frac{d\epsilon_i}{\epsilon_i}]^2,\ i = h, \mu, \pi, X \tag{9}$$

In right side of above equation, the 2nd and 3rd terms are equal for all the scan energy points and can be considered as systematic error, while the 1st term is statistical error, varying with cross section value, therefore the 1st term need to be taken into account as a whole in the line-shape fitting.

In terms of equation (1-4,9), we have error estimation as follows:

$$\frac{d\Gamma}{\Gamma} \simeq [5(\frac{dL}{L})^2 + 4(\frac{d\epsilon_h}{\epsilon_h})^2 + 4(\frac{d\epsilon_\mu}{\epsilon_\mu})^2 + \frac{4}{N_h(t)} + \frac{1}{N_\mu(t)}]^{1/2} \tag{10}$$

$$\frac{dB_\mu}{B_\mu} \simeq [2(\frac{dL}{L})^2 + (\frac{d\epsilon_h}{\epsilon_h})^2 + (\frac{d\epsilon_\mu}{\epsilon_\mu})^2 + \frac{1}{N_h(t)} + \frac{1}{N_\mu(t)}]^{1/2} \tag{11}$$

$$\frac{dB_\pi}{B_\pi} \simeq [2(\frac{dL}{L})^2 + (\frac{d\epsilon_h}{\epsilon_h})^2 + (\frac{d\epsilon_\pi}{\epsilon_\pi})^2 + \frac{1}{N_h(t)} + \frac{1}{N_\pi(t)} + \frac{dB(J/\psi \to l^+l^-)}{B(J/\psi \to l^+l^-)}]^{1/2} \tag{12}$$

$$\frac{dB_X}{B_X} \simeq [2(\frac{dL}{L})^2 + (\frac{d\epsilon_h}{\epsilon_h})^2 + (\frac{d\epsilon_X}{\epsilon_X})^2 + \frac{1}{N_h(t)} + \frac{1}{N_X(t)} + \frac{dB(J/\psi \to l^+l^-)}{B(J/\psi \to l^+l^-)}]^{1/2} \tag{13}$$

In above expressions, $N_i(t)$ is the total number of observed events for process $\psi(2S)$ decaying to final state i, $\frac{dB(J/\psi \to l^+l^-)}{B(J/\psi \to l^+l^-)}$ is the error introduced by l^+l^- invariant mass cut to tag J/ψ in the processes of $\psi(2S)$ decaying to $\pi^+\pi^-J/\psi$ and $J/\psi X$. In our $\psi(2S)$ scan plan, we will take 23 nb^{-1} data at each of 18 energy points, wherein 11 points are in the resonance area. Hence $N_i(t)$ now is the sum of the total number of observed events for process $\psi(2S)$ decaying to final state i at these 11 energy points. We will collect events in the scope of $|cos\theta| < 0.6$ for di-muon final state and $|cos\theta| < 0.8$ for hadron, $\pi^+\pi^-J/\psi$ and $J/\psi X$ final states. Based on experiences obtained in J/ψ and $\psi(2S)$ decay widths and R value experiments, $\epsilon_h \sim 0.6$, $\epsilon_\pi \sim 0.5$, $\epsilon_X \sim 0.5$, $\epsilon_\mu \sim 0.85$, and

$$\frac{d\epsilon_h}{\epsilon_h} \simeq 4\%,\ \frac{d\epsilon_\mu}{\epsilon_\mu} \simeq 2\%,\ \frac{d\epsilon_\pi}{\epsilon_\pi} \simeq 2\%,\ \frac{d\epsilon_X}{\epsilon_X} \simeq 2\%. \tag{14}$$

We require dL/L $\cong 3.3\%$ (see next section). Considering the center-of- mass energy spread of BEPC is about 1.3 MeV at $\psi(2S)$ energy region, the number of $N_i(t)$ are estimated to be :

$$N_h(t) \simeq 31600,\ N_\mu(t) \simeq 1230,\ N_\pi(t) \simeq 1060,\ N_X(t) \simeq 1700. \tag{15}$$

Using these numbers, we obtain the error estimation for Γ, $B(\mu\mu)$, $B(\pi^+\pi^- J/\psi)$ and $B(J/\psi X)$ in our $\psi(2S)$ scan experiment listed in Table 2 together with those of existing measurements. From this table we can see, BES will reach the best accuracies for Γ, Γ_μ, $B(\pi^+\pi^- J/\psi)$ and $B(J/\psi X)$ for the $\psi(2S)$ resonance in a single experiment.

Table 2. Relative errors of $\psi(2S)$ decay width and some branching ratios

	Group	yr.	Γ	$B(\mu\mu)$	$B(\pi^+\pi^- J/\psi)$	$B(J/\psi X)$
$\psi(2S)$ scan	BES		0.115	0.071	0.074	0.072
Existing measurement	MarkI	75	0.25	0.17	0.13	0.14
	SPEC	75		0.22		
	DASP	79	0.28	0.32	0.17	0.24
	E760	92,97	0.13			0.10

4 How to reach 3.3% relative accuracy for luminosity

In this experiment, wide angle Bhabha events will be used to calculate the integrated luminosity at each energy point. The error of e^+e^- events efficiency is 2.2%[10], which is the systematic error. To require total error of 3.3%, the statistical error need to be less than 2.5%, which requires number of Bhabha events in solid angle $|cos\theta| < 0.7$ should be $N_{ee}(W) > 1600$ at each energy point for non-resonant (QED) cross section, which corresponds to $L_{int}(3.686GeV) = 23nb^{-1}$ as $\sigma_{QED}(|cos\theta| < 0.7) \simeq 69.5nb$. BEPC can reach peak luminosity $L_p(3.55GeV) \simeq 4 \times 10^{30}$. Very conservatively the average luminosity L_{av} for all $\psi(2S)$ scan energy points can be taken as $L_{av} = 1.44 \times 10^{30}/cm^2s = 1.44 \times 10^{-3}nb^{-1}s^{-1}$. Number of energy points in the visinity of $\psi(2S)$ will be 18 in this experiment, hence the total pure running time will be $18 \times L_{int}/L_{av} \simeq 80$ hours. The whole experiment can be completed in 5-6 days.

One thing should be mentioned here. In the resonant region, e^+e^- final states are produced through both QED process and $\psi(2S)$ decay, which are unidentified in experiment. However the cross section from $\psi(2S)$ decay is roughly 1/10 of that of QED process in the solid angle of $|cos\theta| < 0.7$ at the $\psi(2S)$ peak energy. To cope with this problem, we first take total number of e^+e^- events as Bhabha events to calculate luminosity to determine $\Gamma(t)$ and $B(\mu^+\mu^-)$. Then assumining e-μ universality, namely ,$B(\mu^+\mu^-) = B(e^+e^-)$, splitting the e^+e^- events into QED part and resonant part, re-calculate the integrated luminosity for each energy point and re-do the fitting procedures to get new values for $\Gamma(t)$ and $B(\mu^+\mu^-)$. Such a recursive iteration is repetedly carried out untill the values of $\Gamma(t)$ and $B(\mu^+\mu^-)$ are converged in two succesive iterations.

5 Summary

In the occasion of BES R ratio measurement being implemented, which has solved almost all the problems for $\psi(2S)$ scan experiment, it needs only 5-6 days BEPC running to reach $11.5\%, 7.1\%, 7.4\%, 7.2\%$ accuracy for $\Gamma, \Gamma_{\mu}, B(\pi^{+}\pi^{-}J/\psi), B(J/\psi X)$, respectively, which are the best results for these parameters in a single experiment. Hence we can say, this is a "pay less and gain more" deal.

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