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On recent data of branching ratios for $\psi(2S) \to J/\psi\pi\pi$ and $\psi(2S) \to J/\psi\eta$

Y. F. Gu[1*] and X. H. Li[2+]
[1]Institute of High Energy Physics, Beijing 100039, People's Republic of China
[2]Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
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Recent data on branching ratios for $\psi(2S)$ decays to $J/\psi\pi^+\pi^-$, $J/\psi\pi^0\pi^0$ and $J/\psi\eta$ are reviewed. An alternative treatment of data is proposed to get rid of the logical inconsistency which occurs in original computational procedure.

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There is a group of exclusive $\psi(2S)$ decays into J/ψ whose branching ratios are of importance to both charmonium and other (e.g. B and relativistic nuclear collision) physics, but were mostly measured two decades ago [1]. Recently, new results were reported on the branching ratios of $\psi(2S) \to J/\psi\pi^+\pi^-$, $\psi(2S) \to J/\psi\pi^0\pi^0$, and $\psi(2S) \to J/\psi\eta$ by the E760 experiment [2], and on the ratio of $B(\psi(2S) \to J/\psi\pi^+\pi^-)/B(\psi(2S) \to \mu^+\mu^-)$ by the E672/E706 experiment[3]. With these new entries, 9 branching ratios of the $\psi(2S)$ are reanalyzed by the Particle Data Group (PDG)[1]. In this letter, we comment on these recent data and propose, among other things, an alternative way of treating the data to get rid of the logical inconsistency which occurs in the computational procedure of ref. [2].

In determining the branching ratios of $\psi(2S) \to f$, where f is $J/\psi\pi^+\pi^-$, $J/\psi\pi^0\pi^0$, or $J/\psi\eta$, the authors of Ref.[2] used the expression

$$B(\psi(2S) \to f) = \frac{\varepsilon_{J/\psi X}}{\varepsilon_f} \frac{N_f}{N_{J/\psi X}} B(\psi(2S) \to J/\psi X), \tag{1}$$

where ε_f and $\varepsilon_{J/\psi X}$ include the geometrical acceptance and efficiencies for triggering and selection of the exclusive (f with π^0 or $\eta \to \gamma\gamma$) and inclusive ($J/\psi X$ with $J/\psi \to e^+e^-$) decays of the $\psi(2S)$, respectively; N_f and $N_{J/\psi X}$ are the numbers of exclusive and inclusive events selected, respectively. The authors claimed that, by determining $\frac{\varepsilon_{J/\psi X}}{\varepsilon_f} \frac{N_f}{N_{J/\psi X}}$ and using the branching ratio of $\psi(2S) \to J/\psi X$ in the PDG, they are able to make measurements of $B(\psi(2S) \to J/\psi\pi^+\pi^-)$ and $B(\psi(2S) \to J/\psi\pi^0\pi^0)$ with errors comparable to the world average. However, one notes that the method used by the authors to treat their data is questionable.

As a matter of fact, the PDG value of $B(\psi(2S) \to J/\psi X)$, 0.57 ± 0.04, on which the authors rely for determining the branching ratios of $B(\psi(2S) \to J/\psi\pi^+\pi^-)$, $B(\psi(2S) \to J/\psi\pi^0\pi^0)$, and $B(\psi(2S) \to J/\psi\eta)$, is not an independent, direct measurement, but is a value from a constrained fit to 7 branching ratios for the $\psi(2S)$ of 13 significant measurements including $B(\psi(2S) \to J/\psi\pi^+\pi^-)$, $B(\psi(2S) \to J/\psi\pi^0\pi^0)$ and $B(\psi(2S) \to J/\psi\eta)$[4], which are what the authors attempt to measure. One finds here an apparent logical inconsistency.

A correct way to make the measurements self-consistent would be to solve a linear equation of the form

$$x = a(x + b), \tag{2}$$

where $x \equiv B(\psi(2S) \to J/\psi\pi^+\pi^-) + B(\psi(2S) \to J/\psi\pi^0\pi^0) + B(\psi(2S) \to J/\psi\eta)$, $a \equiv \sum_{i=1}^{3} \frac{\varepsilon_{J/\psi X}}{\varepsilon_{fi}} \frac{N_{fi}}{N_{J/\psi X}}$, and $b \equiv 0.273B(\psi(2S) \to \gamma\chi_{c1}) + 0.135B(\psi(2S) \to \gamma\chi_{c2})$ using the PDG data which are irrelevant to x. The solutions of Eq.(2) for x with the addition of b give $B(\psi(2S) \to J/\psi X) = 0.315 \pm 0.226$ and 0.292 ± 0.136 for the two data sets (1990 and 1991) of the E760 experiment, respectively, which can now be applied to Eqs. (1) consistently. Table I gives the computed branching ratios for three exclusive decays. The same results can be achieved by using an iterative method of solving Eq. (2). However, the results thus obtained are much worse than the PDG world averages or fit values. Here the substantial errors are mainly due to the enlargement of the uncertainty by a factor of $\frac{1}{1-a} \approx 9$. Such an approach has practically nothing to recommend it.

We would thus propose that, as a natural and probably the best way to deal with the E760 data, its measured ratios $\frac{\varepsilon_{J/\psi X}}{\varepsilon_f}\frac{N_f}{N_{J/\psi X}}$ be used directly as the ratios of two branching ratios, $\Gamma(\psi(2S)\to f)/\Gamma(\psi(2S)\to J/\psi X)$ ($f=\pi^+\pi^-$, $\pi^0\pi^0$ or η). With these new entries, in addition to the previous 13 measurements [4], an overall fit as used by the PDG is redone with minor simplification [5]. In order to make the input data of E760 independent, two uncorrelated ratios (Table II),

$$\Gamma(\psi(2S)\to J/\psi\pi^0\pi^0)/\Gamma(\psi(2S)\to J/\psi\pi^+\pi^-)=\frac{\varepsilon_{J/\psi\pi^+\pi^-}}{\varepsilon_{J/\psi\pi^0\pi^0}}\frac{N_{J/\psi\pi^0\pi^0}}{N_{J/\psi\pi^+\pi^-}} \tag{3}$$

and

$$\Gamma(\psi(2S)\to J/\psi\eta)/\Gamma(\psi(2S)\to J/\psi X)=\frac{\varepsilon_{J/\psi X}}{\varepsilon_{J/\psi\eta}}\frac{N_{J/\psi\eta}}{N_{J/\psi X}}, \tag{4}$$

are in fact used in the fit instead of three ratios of $\Gamma(\psi(2S)\to J/\psi\ f)/\Gamma(\psi(2S)\to J/\psi X)$ ($f=\pi^+\pi^-$, $\pi^0\pi^0$ and η). Table III summarizes the fit results. The 1996 PDG fit values[4] and the E760 reporting values[1] are also included for comparison. Using the combined fit values in Table III, along with the 1998 PDG averages for $B(\chi_{c1}\to\gamma J/\psi)$, $B(\chi_{c2}\to\gamma J/\psi)$, $B(\pi^0\to\gamma\gamma)$, $B(\eta\to neutral\ modes)$ [6], and $B(J/\psi\to e^+e^-)$ [7], one may also compute $B(\psi(2S)\to J/\psi X)$ to be 0.57 ± 0.04, $B(\psi(2S)\to J/\psi\ neutrals)$ to be 0.235 ± 0.026, and $B(\psi(2S)\to e^+e^-)$ to be $(8.4\pm0.8)\times10^{-3}$.

We do not recommend using the 1998 PDG fit values of branching ratios for the $\psi(2S)$ decays to J/ψ and anything[1]. The ratio of the two $\psi(2S)$ decay partial widths, $B(\psi(2S)\to J/\psi\pi^+\pi^-)/B(\psi(2S)\to\mu\mu)$ [2], measured by the E672/E706 experiment was mistaken for $B(\psi(2S)\to J/\psi\pi^+\pi^-)/B(\psi(2S)\to J/\psi\mu^+\mu^-)$ in ref. [1]. In addition, the E760 data in their present form are inappropriate for such a fit by the above-mentioned argument.

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* E-mail: guyf@bepc5.ihep.ac.cn.
+ E-mail: lixh@sseos.lbl.gov. On leave from IHEP, Beijing.

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[5] We ignore the one constraint and fit to determine 5 parameters without the “other fit modes”. A check using 13 measurements contained in [4] shows no essential difference in fit quality, results and errors between the PDG fit and our simplification, except for $B(\psi(2S)\to J/\psi\eta)=0.027\pm0.003$ obtained by us compared with 0.027 ± 0.004 in ref. [4].
[6] We use the new fit value for $B(\eta\to neutral\ modes)$ given in ref. [1], 0.715 ± 0.006, instead of the previous fit value, 0.708 ± 0.008, which is still used by the PDG in calculating $B(\psi(2S)\to J/\psi\ neutral\ modes)$ in ref. [4].
[7] We use the new fit value for $B(J/\psi\to e^+e^-)$ given in ref. [1] or [4], $(6.02\pm0.19)\times10^{-2}$, instead of the previous fit value, $(5.99\pm0.25)\times10^{-2}$, which is still used by the E760 in calculating $B(\psi(2S)\to e^+e^-)$ in ref. [2].

TABLES

TABLE I. $\psi(2S)$ branching ratios determined by solving a linear equation of the form (2).

Channel	1990	1991
$\psi(2S) \to J/\psi\pi^+\pi^-$	0.136 ± 0.099	0.156 ± 0.074
$\psi(2S) \to J/\psi\pi^0\pi^0$	0.118 ± 0.087	0.084 ± 0.041
$\psi(2S) \to J/\psi\eta$	0.025 ± 0.021	0.017 ± 0.009

TABLE II. Ratios from the E760 measurement as input data of fit.

Ratio	1990	1991	Combined
$\Gamma(\psi(2S) \to J/\psi\pi^0\pi^0)/\Gamma(\psi(2S) \to J/\psi\pi^+\pi^-)$	0.868 ± 0.171	0.539 ± 0.089	0.609 ± 0.079
$\Gamma(\psi(2S) \to J/\psi\eta)/\Gamma(\psi(2S) \to J/\psi X)$	0.080 ± 0.033	0.056 ± 0.018	0.062 ± 0.016

TABLE III. $\psi(2S)$ branching ratios by a simutaneous least-square fit.

Channel	1990	1991	Combined	PDG96	E760
$\psi(2S) \to J/\psi\pi^+\pi^-$	0.318 ± 0.025	0.323 ± 0.025	0.318 ± 0.025	0.324 ± 0.026	0.283 ± 0.029
$\psi(2S) \to J/\psi\pi^0\pi^0$	0.196 ± 0.025	0.178 ± 0.022	0.186 ± 0.021	0.184 ± 0.027	0.184 ± 0.023
$\psi(2S) \to J/\psi\eta$	0.027 ± 0.003	0.027 ± 0.003	0.027 ± 0.003	0.027 ± 0.004	0.032 ± 0.010
$\psi(2S) \to \gamma\chi_{c1}$	0.086 ± 0.008	0.087 ± 0.008	0.087 ± 0.008	0.087 ± 0.008	
$\psi(2S) \to \gamma\chi_{c2}$	0.078 ± 0.008	0.078 ± 0.008	0.078 ± 0.008	0.078 ± 0.008	