

Branching Fractions of $\psi(2S)$, $\chi_{c0,1,2}$ and $\eta_c(1S)$

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Since 2002, the treatment of the branching ratios of the $\psi(2S)$ and $\chi_{c0,1,2}$ has undergone an important restructuring [1]. Since the 2023 online edition, the $\eta_c(1S)$ is now treated in a similar way.

When measuring a branching fraction experimentally, it is not always possible to normalize the number of events observed in the corresponding decay mode to the total number of particles produced. Therefore, the experimenters sometimes report the number of observed decays with respect to another decay mode of the same or another particle in the relevant decay chain. This is actually equivalent to measuring combinations of branching ratios of several decay modes.

To extract the branching fraction of a given decay mode, the collaborations use some previously reported measurements of the required branching ratios. However, the values are frequently taken from the *Review of Particle Physics* (RPP), which in turn uses the branching fraction reported by the experiment in the following edition, giving rise either to correlations or to plain vicious circles, as has been pointed out in several publications [2,3,4].

The way to avoid these dependencies and correlations is to extract the branching fractions through a fit that uses the truly measured combinations of branching ratios and partial widths.

In the case of the $\psi(2S)$, χ_{c0} , χ_{c1} , and χ_{c2} , such a fit involves decays from the four particles and, occasionally, some combinations of branching ratios of more than one of them. We tried to identify those branching ratios which can be correlated in a non-trivial way, and although we cannot preclude the existence of other cases, we are confident that the most relevant correlations have already been removed.

The $\eta_c(1S)$ can be produced in $\gamma\gamma$ collisions, in the radiative decays of vector and axial-vector charmonia (J/ψ , $\psi(2S)$ and $h_c(1P)$) or in B meson decays. As in the previous case, we now obtain the corresponding branching fractions using the products of branching ratios originally measured by the experiments, which sometimes involve several particles (cross-particle branching ratios) and performing an overall fit.

The PDG policy is to quote the results of the collaborations in a manner as close as possible to what appears in their original publications. However, in order to avoid the problems mentioned above, we had in some cases to work out the values originally measured, using the number of events and detection efficiencies given by the collaborations, or rescaling back the published results. The information was sometimes spread over several articles, and some articles referred to papers still unpublished, which in turn contained the relevant numbers in footnotes.

Even though the experimental collaborations are entitled to extract whatever branching ratios they consider appropriate by using other published results, we would like to encourage them to also quote explicitly in their articles the actual quantities measured, so that they can be used directly in averages and fits of different experimental

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determinations. For recent experiments our policy is not to use anymore extracted branching fractions, so that if the original measured quantity is missing in the relevant publication, the value will not be used by us in our averages and fits.

To inform the reader how we computed some of the values, we use footnotes to indicate the branching fractions actually given by the experiments and the quantities they use to derive them from the true combination of branching ratios actually measured. Likewise, we show the values of derived quantities even if they are not used in the fit, but to avoid confusion, we include in these measurements the footnote ‘Not used since the same experimental measurement has been used in another related quantity included elsewhere in the fit.

1. **Fit Information for the $\psi(2S)$ and $\chi_{c0,1,2}$**

This is an overall fit to 4 total widths, 1 partial width, 27 combinations of partial widths, 8 branching fractions, and 80 branching ratios or combinations thereof. Of the latter, 57 involve decays of more than one particle.

The overall fit uses 263 measurements to determine 50 parameters and gives a χ^2 of 435.4 for 213 degrees of freedom.

We have applied scaling factors in the final errors of the fitted values following the procedure described in section 5.2.3 of our Introduction. After rescaling, the total χ^2 is 156.1.

In the listing we provide the inter-particle correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the corresponding parameter x_j .

2. **Fit Information for the $\eta_c(1S)$**

This is an overall fit to 1 total width, 10 combinations of partial widths, 6 branching fractions and 32 branching ratios or combinations thereof. Of the latter, 29 involve decays of more than one particle.

The overall fit uses 115 measurements to determine 19 parameters and has a χ^2 of 215.4 for 96 degrees of freedom.

We have applied scaling factors in the final errors of the fitted values following the procedure described in section 5.2.3 of our Introduction. After rescaling, the total χ^2 is 78.4.

In the listing we provide the inter-particle correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the corresponding parameter x_i .

References:

1. K. Hagiwara *et al.* (Particle Data Group), Phys. Rev. **D68**, 010001 (2002).
2. Y.F. Gu and X.H. Li, Phys. Lett. **B449**, 361 (1999).
3. C. Patrignani, Phys. Rev. **D64**, 034017 (2001).
4. H. Wang and C.-Z. Yuan, Chin. Phys. **C46**, 071001 (2022).