Branching Ratios of $\psi(2S)$, $\chi_{c0,1,2}$ and η_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. Since the 2023 online edition, the η_c(1S) is now treated in a similar way (see the end of this note).

When measuring a branching ratio 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 fractions of several decay modes.

To extract the branching ratio 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 ratio reported by the experiment in the following edition, giving rise either to correlations or to plain vicious circles, as discussed in more detail in earlier editions of this review [1,2].

The way to avoid these dependencies and correlations is to extract the branching ratios through a fit that uses the truly measured combinations of branching fractions and partial widths. This fit, in fact, should involve decays from the four concerned particles, $\psi(2S)$, χ_{c0}, χ_{c1}, and χ_{c2}, and occasionally some combinations of branching ratios of more than one of them. This is what is done since the 2002 edition [3].

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 The information was sometimes spread over several articles, and some articles referred to papers still unpublished, which in turn contained the relevant numbers in footnotes.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 determinations.

To inform the reader how we computed some of the values used in this edition of RPP, we use footnotes to indicate the branching ratios actually given by the experiments and the quantities they use to derive them from the true combination of branching ratios actually measured.

None of the branching ratios of the $\chi_{c0,1,2}$ are measured independently of the $\psi(2S)$ radiative decays. 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. Nevertheless, correlations in the errors of different quantities measured by the same experiment have not been taken into account.

The η_c(1S) can be produced in $\gamma\gamma$ collisions, in the radiative decays of vector and axial-vector charmonia (J/ψ, ψ(2S) and h$_c$(1P)) or in B meson decays. As for the ψ(2S) and $\chi_{c0,1,2}$, correlations can be introduced if the derived branching ratios are not properly extracted. We now obtain the corresponding branching ratios using the products of branching ratios originally measured by the experiments, sometimes among different particles (cross-particle branching ratios) and performing an overall fit. In some cases, we were obliged to infer the original product from the information given by the collaborations. However, for recent experiments our policy is not to use anymore extracted branching ratios, so that if the original measured quantity is missing in the relevant publication, the value will not be used in our averages and fits.

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

This is an overall fit to 4 total widths, 1 partial width, 25 combinations of partial widths, 10 branching fractions, and 76 branching ratios or combinations thereof. Of the latter, 58 involve decays of more than one particle.

The overall fit uses 253 measurements to determine 49 parameters and gives a χ^2 of 389.6 for 204 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 149.6.

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

2. Fit Information for the η_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, 31 involve decays of more than one particle.

The overall fit uses 113 measurements to determine 19 parameters and has a χ^2 of 184.6 for 94 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 74.1.

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

References:

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