Comment on “$e^+e^-$ annihilation into $J/\psi + J/\psi$”

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The first observations of annihilation processes of the type $e^+e^- \rightarrow J/\psi \eta_c$ and $J/\psi (c\bar{c})_{\text{non-res}}$ were recently reported by Belle [1]. The measured cross-sections for both processes are an order-of-magnitude larger than theoretical predictions based on non-relativistic QCD (NRQCD) [2, 3]. In an attempt to explain at least part of this discrepancy, the authors of Ref. [4] suggest that processes proceeding via two virtual photons may be important. In particular, if the two-photon-mediated process $e^+e^- \rightarrow J/\psi J/\psi$ has a significant cross-section, the observed $e^+e^- \rightarrow J/\psi \eta_c$ signal, which is inferred from the $\eta_c$ peak in the recoil mass spectrum for the reconstructed $J/\psi$ in inclusive $e^+e^- \rightarrow J/\psi X$ events, might also include double $J/\psi$ events and, thus, produce an inflated cross-section measurement.

$e^+e^-$ annihilation to $J/\psi J/\psi$ via a single virtual photon is forbidden by charge conjugation symmetry and was ignored in our published analysis. Here, using a data sample of 101.8 fb$^{-1}$ collected by the Belle detector and the analysis procedure described in Ref. [1], we evaluate this possibility.

Since the $\eta_c$ and $J/\psi$ have similar masses ($M_{J/\psi} - M_{\eta_c} \simeq 116$ MeV/c$^2$), it is important to check for any momentum scale bias that may shift the recoil mass values. We use $e^+e^- \rightarrow \psi(2S)\gamma$, $\psi(2S) \rightarrow J/\psi \pi^+\pi^-$ events to calibrate and verify the recoil mass scale. We find that any shift in the recoil mass is less than 3 MeV/c$^2$.

The spectrum of recoil masses against the $J/\psi$ is presented in Fig. 1: a clear peak is observed around the $\eta_c$ nominal mass, and a smaller peak is seen around the $\chi_{c0}$ nominal mass; the large peak at $\sim 3.63$ GeV/c$^2$ is interpreted as the $\eta_c(2S)$. We performed a fit to this spectrum that includes all of the known narrow charmonium states. In this fit, the mass positions for the $\eta_c$, $\chi_{c0}$ and $\eta_c(2S)$ are treated as free parameters; those for the $J/\psi$, $\chi_{c1}$, $\chi_{c2}$ and $\psi(2S)$ are fixed at their nominal values. The expected line-shapes for these peaks are determined from a Monte Carlo simulation as described in our previous paper [1], the background is parametrized by a second order polynomial function, and only the region below the open charm threshold ($M_{\text{recoil}} < 3.7$ GeV/c$^2$) is included in the fit. The fit results, listed in Table I, give negative yields for the $J/\psi$, $\chi_{c1}$, $\chi_{c2}$ and $\psi(2S)$; the solid line in Fig. 1 is the result of a fit with all these contributions fixed at zero. The dotted line in the figure corresponds to the case where the contributions of the $J/\psi$, $\chi_{c1}$, $\chi_{c2}$ and $\psi(2S)$ are set at their 90% confidence level upper limit values. The dashed line is the background function. To set a conservative upper limit for $e^+e^- \rightarrow J/\psi J/\psi$, we use assumptions for the production and helicity angle distributions that correspond to the lowest detection efficiency.

In summary, using a larger data set we confirm our published observation of $e^+e^- \rightarrow J/\psi \eta_c$ and find no evidence for the process $e^+e^- \rightarrow J/\psi J/\psi$. We set an upper limit for $\sigma(e^+e^- \rightarrow J/\psi J/\psi) \times B(J/\psi \rightarrow > 2 \text{ charged})$ of less than 0.008 pb at the 90% CL.

Although the limit presented here is not inconsistent with the prediction for the $J/\psi J/\psi$ production rate given in Ref. [4], the suggestion that a significant fraction of the inferred $J/\psi \eta_c$ signal is actually $J/\psi J/\psi$ is ruled out. Therefore, the discrepancy between the Belle result and the NRQCD prediction remains.
Fig. 1: Distribution of masses recoiling against the reconstructed $J/\psi$ in inclusive $e^+e^- \rightarrow J/\psi X$ events. The curves are explained in the text.

Table I: Summary of the signal yields, charmonium masses and significances for $e^+e^- \rightarrow J/\psi (c\bar{c})_{\text{res}}$.

| $(c\bar{c})_{\text{res}}$ state | $N$        | $M$ [GeV/c$^2$] | $\sigma$ |
|-------------------------------|------------|----------------|----------|
| $\eta_c$                      | $175 \pm 23$ | $2.972 \pm 0.007$ | $9.9$ |
| $J/\psi$                      | $-9 \pm 17$  | fixed           | —        |
| $\chi_{c0}$                   | $61 \pm 21$  | $3.409 \pm 0.010$ | $2.9$ |
| $\chi_{c1} + \chi_{c2}$      | $-15 \pm 19$ | fixed           | —        |
| $\eta_c(2S)$                  | $107 \pm 24$ | $3.630 \pm 0.008$ | $4.4$ |
| $\psi(2S)$                    | $-38 \pm 21$ | fixed           | —        |

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