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New Results on Double Charmonium Production in e^+e^- Annihilation at $\sqrt{s} \approx 10.6$ GeV with the Belle Detector

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Extending a previous analysis[1] the double charmonium production $e^+e^- \to J/\Psi(c\bar{c})$ and $e^+e^- \to \Psi(2S)(c\bar{c})$ has been investigated with a data set of 155 fb^{-1} with the Belle detector. Theoretical predictions for the cross section are one order of magnitude lower than the measured value and this discrepancy is still not understood. In a very recent update with a dataset of 285 fb^{-1} strong evidence for a new charmonium state at a mass of 3.940 GeV was found.

Keywords: charmonium production; double charmonium.

1. Analysis of $e^+e^- \to J/\Psi(c\bar{c})$

Details about the analysis can be found in a previous publication[2]. The J/Ψ is reconstructed in the leptonic decay channel. QED and $b\bar{b}$ events are suppressed and the invariant mass of the system recoiling against the J/Ψ is calculated from the kinematic information of the J/Ψ solely. The recoil mass $M_{recoil} = \sqrt{(E_{CM} - E^*_{J/\Psi})^2 - {p^*_{J/\Psi}}^2}$ is shown in Fig. 1. Three very distinct peaks are visible around the nominal masses of the η_c and χ_{c0}. The peak at 3.63 GeV/c^2 is identified as the $\eta_c(2S)$. The result of the fit, where the cross sections for all the known resonances are free parameters is shown in Table 1. The number of observed events for J/Ψ, χ_{c1}, χ_{c2} and $\Psi(2S)$ from the fit is compatible with 0 and the extracted upper limits on their cross sections are given. Table 1 shows also the measured cross sections for the other modes, which are one order of magnitude higher than the expectations in single virtual photon production from non-relativistic QCD (NRQCD) calculations[3]. However, theoretical calculations show, that the cross section might be significantly increased, when 2-virtual photon production is taken into account[4]. In this case also $J/\Psi J/\Psi$ production is possible, which is forbidden in single virtual photon production due to C conservation.

Using a control sample of $e^+e^- \to \Psi(2S)\gamma$ the bias on the $M_{\mathrm{r}ecoil}(J/\Psi)$ spec-

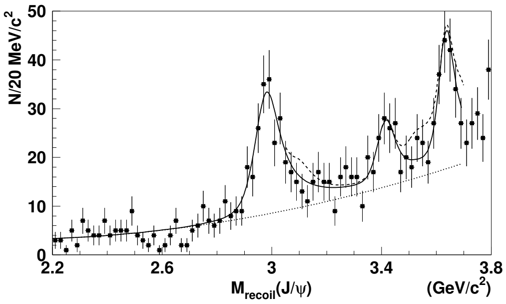

Fig. 1. The recoil mass spectrum for the process $e^+e^- \to J/\Psi(c\bar{c})$. Two fits are shown where the cross section for the J/Ψ, χ_{c1}, χ_{c2} and $\Psi(2S)$ modes are fixed at zero (solid line) or at their 90% C.L. upper limit (dashed line).

trum is measured and found to be < 3 MeV for J/Ψ. In addition 3 $J/\Psi\eta_c$ events were explicitely reconstructed in the data which is compatible with the number of expected events of 2.6 ± 0.8 from MC. This corresponds to a significance of more than 4 σ. No events were found in a search for fully reconstructed $J/\Psi J/\Psi$ events. We conclude that the η_c peak in the M_{recoil} spectrum does not include any significant fraction of $J/\Psi J/\Psi$ events and the large cross section can not be explained by 2-virtual-photon production where $J/\Psi J/\Psi$ events are misidentified as $J/\Psi\eta_c$.

For the three observed final states the production and J/Ψ helicity angles are measured and provide important information about the production process as well as the spin of the final states. The fit results to $A(1+\alpha\cos^2\theta)$ are presented in table 2 together with the expectations for the parameter α for pure P-wave production of $J/\Psi\eta_c$ and $J/\Psi\eta_c(2S)$ and pure S-wave production of $J/\Psi\chi_{c0}$. The numbers in the 2 left columns show the fit results when production and helicity angles are fitted independently. The right column shows the results of a simultaneous fit to the production and helicity angle distribution where $\alpha_{prod} = \alpha_{hel}$. The fit results are well compatible with the assumption and disfavour NRQCD calculations where $J/\Psi\chi_{c0}$ is produced in a mixture of a S- and D-wave where $\alpha_{prod} = \alpha_{hel} = +0.25$ is expected. Also associated glueball production[5,6] where $\alpha_{prod} = \alpha_{hel} \approx -0.9$ is unlikely.

Table 1. Summary of the signal yields from the fits to the M_{recoil} spectrum.

$(c\bar{c})_{res}$	N	M[GeV/c^2]	Signif.	$\sigma_{Born} \times B_{>2}$ [fb]
η_c	235 ± 26	2.972 ± 0.007	10.7	25.6 ± 2.8 ± 3.4
J/Ψ	-14 ± 20	fixed @ PDG value	—	< 9.1 at 90% C.L.
χ_{c0}	89 ± 24	3.407 ± 0.011	3.8	6.4 ± 1.7 ± 1.0
$\chi_{c1} + \chi_{c2}$	10 ± 27	fixed at PDG value	—	< 5.3 at 90% C.L.
$\eta_c(2S)$	164 ± 30	3.630 ± 0.008	6.0	16.5 ± 3.0 ± 2.4
$\Psi(2S)$	-26 ± 29	fixed @ PDG value	—	< 13.3 at 90% C.L.

Table 2. The α parameter obtained from fits to the production and J/Ψ helicity angle distributions for $e^+e^- \to J/\Psi(c\bar{c})_{res}$.

	Separate fits		Expectation		Simultaneous fits
$(c\bar{c})_{res}$	α_{prod}	α_{hel}	α_{prod}	α_{hel}	$\alpha_{hel} \equiv \alpha_{prod}$
η_c	$+1.4^{+1.1}_{-0.8}$	$+0.5^{+0.7}_{-0.5}$	$+1$	$+1$	$+0.93^{+0.57}_{-0.47}$
χ_{c0}	-1.7 ± 0.5	$-0.7^{+0.7}_{-0.5}$	-1	-1	$-1.01^{+0.38}_{-0.33}$
$\eta_c(2S)$	$+1.9^{+2.0}_{-1.2}$	$+0.3^{+1.0}_{-0.7}$	$+1$	$+1$	$+0.87^{+0.86}_{-0.63}$

2. Observation of the process $e^+e^- \to \Psi(2S)(c\bar{c})_{res}$

In this process the $\Psi(2S)$ is reconstructed in the decay channel $J/\Psi\pi^+\pi^-$. The $M_{recon}(\Psi(2S))$ distribution looks very similar as the one shown in Fig 1. The significance for $e^+e^- \to \Psi(2S)(c\bar{c})_{res}$ where $(c\bar{c})_{res}$ is the sum over η_c, χ_{c0} and $\eta_c(2S)$ is estimated to be 5.3 σ. The obtained cross sections have the same order of magnitude as the one given above for $e^+e^- \to J/\Psi(c\bar{c})_{res}$.

3. Evidence for a new charmonium state in $e^+e^- \to J/\Psi(c\bar{c})_{res}$

In a very recent update of the analysis on $e^+e^- \to J/\Psi(c\bar{c})$ the $M_{recoil}(J/\Psi)$ spectrum shows very clear evidence for a peak at 3.940 ± 0.011 GeV/c^2 with a significance of 4.5 σ. More detailed studies show that this new state decays primarily into $D^{(*)}D^{(*)}$ final states. No evidence for the known state X(3872) has been found.

4. Summary

The experimental measurement of the cross section for double charmonium production in e^+e^- annihilation is a factor 10 higher than the theoretical calculations and the difference still unexplained. The experimental results favour the single virtual photon production and no evidence for neither two virtual photon production nor associated glueball production is found in the data. More input from theory is needed to understand this discrepancy.

The process $e^+e^- \to \Psi(2S)(c\bar{c})$ was observed for the first time and shows a production cross section that has the same order of magnitude as the $e^+e^- \to J/\Psi(c\bar{c})$ production.

In a recent update strong evidence for a new charmonium state at a mass of 3.94 GeV/c^2 that decays into $D^{(*)}D^{(*)}$ is found. More data and the measurement of angular distributions for this final state will follow soon and help to understand the nature of this new charmonium state.

For detailed information on this analysis please refer to [2].

References

1. K. Abe, *et al.* (Belle Collaboration), *Phys. Rev. Lett.* **89**, 142001 (2002).
2. K. Abe, *et al.* (Belle Collaboration), *Further study of double charmonium production in* e^+e^- *annihilation at* $\sqrt{s} \approx 10.6$ *GeV*, hep-ex/0407009.

3. E. Braaten and J. Lee, Phys. Rev. **D67**, 054007 (2003).
4. G.T. Bodwin, J. Lee and E. Braaten, Phys. Rev. Lett. **90**, 162001 (2003).
5. S.J. Brodsky, A.S. Goldhaber and J. Lee, Phys. Rev. Lett. **91**, 112001 (2003).
6. S. Dulat, K. Hagiwara and Z.H. Lin, arXiv:hep-ph/04032230.