PROCEEDINGS OF SCIENCE

Angular analysis of the $e^+e^- \to D^{(*)}\bar{D}^*$ process near the open-charm threshold using initial-state radiation at Belle

Valentina Zhukova[*†]
Lebedev Physical Institute Of RAS
E-mail: zhukova.valentina07@gmail.com

We present the new results of measurements of the exclusive cross sections of the e^+e^- annihilation to charmed meson pairs as a function of the center-of-mass energy from the open-charm threshold up to $\sqrt{s} = 6$ GeV using initial state radiation technique. The analysis is based on the data sample collected by the Belle detector with an integrated luminosity of 951 fb^{-1}. The accuracy of the cross section measurement is increased by a factor of 2 in comparison with the first Belle study. We have performed the first angular analysis of the $e^+e^- \to D^{*\pm}D^{*\mp}$ process and decomposed this exclusive cross section into three components corresponding to the different D^* helicities.

ALPS 2019 An Alpine LHC Physics Summit
April 22 - 27, 2019
Obergurgl, Austria

[*]Speaker.
[†]A footnote may follow.

PoS(ALPS2019)013

1. Introduction

In spite of the numerous experimental and theoretical efforts, the nature and properties of vector charmonia lying above the open-charm threshold are not fully understood yet. For a long time, masses and widths of such resonances were determined from an analysis of the inclusive hadronic cross section of the e^+e^- annihilation. However, the parameters determined this way are model-dependent and suffer from large statistical uncertainties. On the contrary, measurements of exclusive cross sections allow one to determine the parameters of vector charmonia in a model-independent way thus opening a doorway to testing various phenomenological models for charmonia. The present analysis utilizes the 951 fb^{-1} data sample collected by the Belle detector [1] at the KEKB e^+e^- collider at the energies of the $\Upsilon(4S)$ and $\Upsilon(5S)$ resonances and the nearby continuum [2].

2. Method

We select signal events using the partial reconstruction method elaborated by Belle [3]. We fully reconstruct the ISR photon and only one charmed meson (D^{*+} or D^+). For the signal events, the spectrum of masses recoiling against the $D^{(*)+}\gamma_{\rm ISR}$ system,

$$M_{\rm rec}(D^{(*)+}\gamma_{\rm ISR}) = \sqrt{(E_{\rm c.m.} - E_{D^{(*)}\gamma_{\rm ISR}})^2 - p^2_{D^{(*)}\gamma_{\rm ISR}}}, \tag{2.1}$$

peaks at the D^{*-} mass. Here $E_{c.m.}$ is the e^+e^- center-of-mass energy while $E_{D^{(*)+}\gamma_{\rm ISR}}$ and $p_{D^{(*)+}\gamma_{\rm ISR}}$ are the center-of-mass energy and momentum of the reconstructed $D^{(*)+}\gamma_{\rm ISR}$ system, respectively. According to the Monte Carlo (MC) simulations, this peak is expected to be broad ($\sigma \sim 150$MeV/c^2) and asymmetric due to the asymmetric photon energy resolution function. Because of a poor $M_{\rm rec}(D^{(*)+}\gamma_{\rm ISR})$ resolution the signals for the D and D^* strongly overlap, so one cannot separate the two processes using this selective variable only. To resolve this problem we additionally reconstruct the slow pion from the decay of the D^{*-} meson. Then the recoil mass difference,

$$\Delta M_{\rm rec} = M_{\rm rec}(D^{(*)+}\gamma_{\rm ISR}) - M_{\rm rec}(D^{(*)+}\pi^-_{\rm slow}\gamma_{\rm ISR}), \tag{2.2}$$

has a narrow peak for the signal process around the $m_{D^{*+}} - m_{D^0}$ mass difference, since the uncertainty in the photon momentum is partially canceled.

To measure the exclusive cross sections as functions of $\sqrt{s}$ one needs to determine the $D^{(*)}\bar{D}^*$ mass spectrum. In the absence of higher-order QED processes, when one of the D^* mesons remains unreconstructed, the $D^{(*)}\bar{D}^*$ mass corresponds to the mass recoiling against the ISR photon, $M(D^{(*)}\bar{D}^*) \equiv M_{\rm rec}(\gamma_{\rm ISR})$. However, a poor $M_{\rm rec}(\gamma_{\rm ISR})$ resolution ($\sigma \sim 120$MeV/c^2) does not allow one to study relatively narrow charmonium states in the $D^{(*)}\bar{D}^*$ mass spectrum. To improve on the $M_{\rm rec}(\gamma_{\rm ISR})$ resolution we refit the recoil mass against the $D^{(*)+}\gamma_{\rm ISR}$ system constrained to the D^* mass thus utilizing a well-measured momentum of the reconstructed $D^{(*)+}$ meson to correct the momentum of the ISR photon. As a result, the $M_{\rm rec}(\gamma_{\rm ISR})$ resolution is improved drastically.

3. Analysis

The following background sources were considered: (1) combinatorial $D^{(*)+}$ candidate combined with a true slow pion from the D^{*-} decay; (2) real $D^{(*)+}$ mesons combined with a combi-

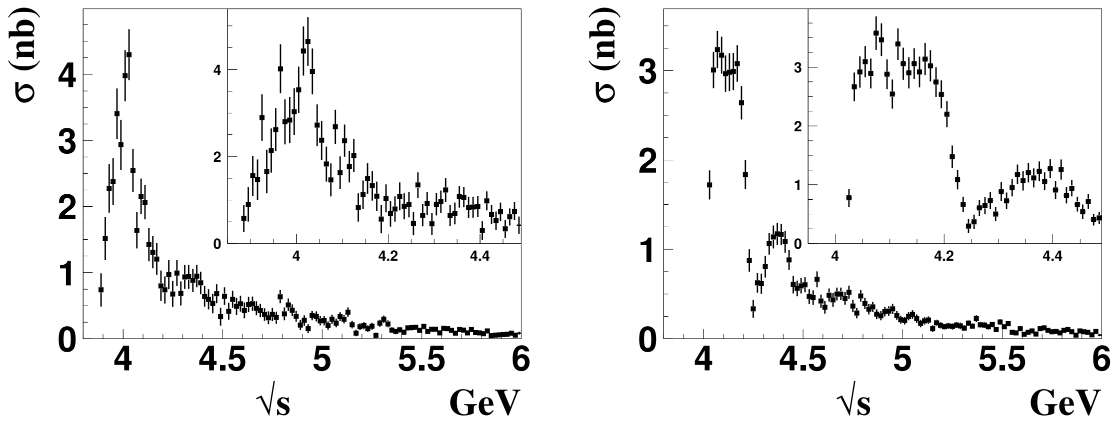

Figure 1: The exclusive cross sections as functions of $\sqrt{s}$ for $e^+e^- \to D^+D^{*-}$ (left) and $e^+e^- \to D^{*+}D^{*-}$ (right). The insets show the zoomed spectrum near the threshold with a half-size bin width.

natorial slow pion; (3) both $D^{(*)+}$ and $\pi^-_{\rm slow}$ are combinatorial; (4a) reflection from the processes $e^+e^- \to D^{(*)+}D^{*-}\pi^0_{miss}\gamma_{\rm ISR}$ with a lost π^0 in the final state, including $e^+e^- \to D^{*+}D^{*-}\gamma_{\rm ISR}$ followed by $D^{*+} \to D^+\pi^0$; (4b) reflection from $e^+e^- \to D^{*+}D^{*-}\gamma_{\rm ISR}$ followed by $D^{*+} \to D^+\gamma$; (5) contribution from $e^+e^- \to D^{(*)+}D^{*-}\pi^0_{\rm fast}$, where the fast $\pi^0_{\rm fast}$ is misidentified as $\gamma_{\rm ISR}$.

The contribution from the combinatorial backgrounds (1)-(3) is extracted using two-dimensional sideband regions of the $D^{(*)+}$ candidate mass versus the recoil mass difference. The dominant part of the background (4) is suppressed by a tight requirement on $M_{\rm rec}(D^{(*)+}\gamma_{\rm ISR})$. The remaining part is estimated from the data for the isospin-conjugated process $e^+e^- \to D^{(*)0}D^{*-}\pi^+\gamma_{\rm ISR}$ with a similar partial reconstruction method applied to the $D^{(*)0}$. Background (5) is estimated similarly to the study of $e^+e^- \to D^{(*)+}D^{*-}\gamma_{\rm ISR}$ and found to be negligibly small — its contribution is included into the systematic uncertainty.

The obtained exclusive $e^+e^- \to D^{(*)}\bar{D}^*$ cross sections are shown in Fig. 1.

4. Angular analysis

We analyzed, for the first time, the $D^{*\pm}$ helicities for both $e^+e^- \to D^{(*)+}D^{*-}$ processes. The $D^{*\pm}$ helicity angle is defined as the angle between the $\pi^\pm_{\rm slow}$ from the $D^{*\pm}$ decay and the $D^{(*)+}D^{*-}$ system seen from the $D^{*\pm}$ rest frame. In the $e^+e^- \to D\bar{D}^*$ process the helicity of the D^* meson is uniquely defined by the angular momentum and parity conservation — it should be transverse (T). Thus we perform the $D^{*\pm}$ angular analysis for this process to verify the method only. The longitudinal component (L) of the cross section is consistent with 0, as expected. The helicity composition of the $D^*\bar{D}^*$ final state is a mixture of TT, TL and LL components. We perform an analysis of the D^* helicity angle in each bin of $M(D^*\bar{D}^*)$. The results of the angular fit are presented in Fig. 2. The cross sections corresponding to different $D^*\bar{D}^*$ helicities have different $\sqrt{s}$-dependences. Near the threshold, the TT and TL components have a similar sharp rise while the LL component rises slowly. Only the TL component survives at high energies, $\sqrt{s} > 4.5$ GeV, that agrees with theoretical predictions [5].

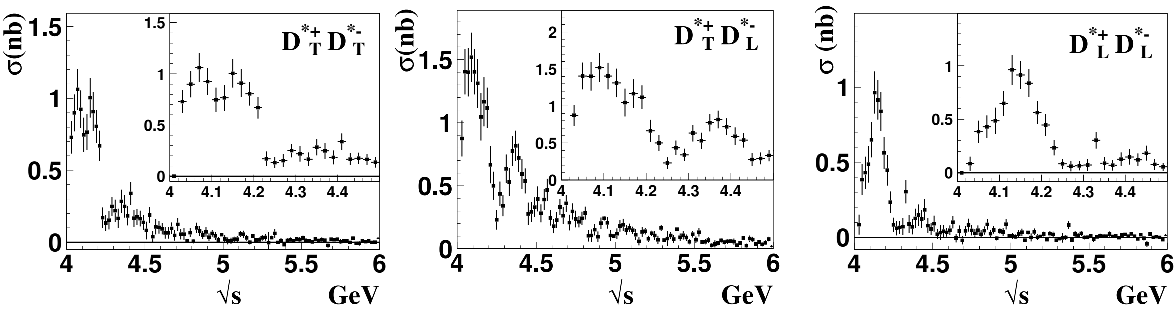

Figure 2: The components of the $e^+e^- \to D^*\bar{D}^*\gamma_{ISR}$ cross section corresponding to the different $D^{*\pm}$'s helicities. The insets show the zoomed spectrum near the threshold with a half-size bin width.

5. Summary

We present new measurements of the exclusive $e^+e^- \to D^{(*)+}D^{*-}$ cross sections at $\sqrt{s}$ near the $D^{(*)+}D^{*-}$ thresholds with initial state radiation. The accuracy of the measurements is increased by a factor of 2 in comparison with the previous Belle results [3] due to the increased data sample, improved track reconstruction efficiency and additional modes for the charmed meson reconstruction. The systematic uncertainties are significantly improved. We extend the energy region up to $\sqrt{s} = 6$ GeV and, due to the improved resolution and high statistics, decrease the step size in $\sqrt{s}$ near the threshold by a factor of two. We performed an angular analysis to decompose the corresponding exclusive cross sections into components for differently polarized $D^{*\pm}$ mesons. Such components have different behavior near the $D^{*+}D^{*-}$ threshold and only one of them (TL) survives at high energies. The measured decomposition can be used to extract the couplings of vector charmonia to open-charm channels, to identify their nature and to test the heavy quark symmetry [6].

6. Acknowledgement

Work is supported by Russian Foundation for Basic Research (18-32-00091 & 17-02-00485).

References

[1] A. Abashian *et al.* (Belle Collaboration), Nucl. Instr. and Meth. A **479**, 117 (2002).

[2] S. Kurokawa, E. Kikutani, Nucl. Instr. and Meth. A **499**, 1 (2003); and other papers included in this volume.

[3] K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **98**, 092001 (2007).

[4] C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C **40**, 100001 (2016).

[5] A.G. Grozin and M. Neubert, Phys. Rev. D **55**, 272 (1997).

[6] H. Georgi, “Heavy Quark Effective Field Theory”, in: Proc. of the Theoretical Advanced Study Institute 1991, eds. R. K. Ellis, C.T. Hill, and J.D. Lykken (World Scientific, Singapore, 1992) p. 589