PROCEEDINGS OF SCIENCE

Cross Section Measurements at Belle

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The unprecedented integrated luminosity of the KEKB electron-positron collider enables the study of rare particle production processes and the high statistics analysis of particle properties in hithereto inaccesable detail. Three such analyses by the Belle collaboration examplary for the opportunities opening up at the *B*-factories will be described in this article : The Measurement of cross sections of exclusive $e^+e^- \to VP$ processes at $\sqrt{s} = 10.58\,\mathrm{GeV}$, the study of the $e^+e^- \to D^0D^{*-}\pi^+$ cross section in events with initial-state radiation, and the measurement of $\eta\pi^0$ production in two-photon collisions.

The 2009 Europhysics Conference on High Energy Physics,
July 16 - 22 2009
Krakow, Poland

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[†]Presentation on behalf of the Belle collaboration [1]

PoS(EPS-HEP 2009)055

1. Exclusive Vector-Pseudoscalar-Meson Production

The high integrated luminosity delivered by the KEKB asymmetric-energy electron-positron collider enables the Belle Collaboration [2] to study rare exclusive two-body processes in e^+e^- annihilation. An example of such highly suppressed processes are reactions of the type $e^+e^- \to VP$ [3], where V and P stand for a Vector and Pseudoscalar meson respectively. It has been observed [4, 5] that double charm production in $e^+e^- \to J/\psi\eta_c$ has an unexpectedly high cross section. The basic diagram for double charm production is very similar to the one describing $e^+e^- \to \phi\eta(\eta')$ where the c quarks are replaced by s quarks. Thus considering both reactions together may contribute to a better understanding of the underlying physics. In addition, Belle has also measured the reaction $e^+e^- \to \rho\eta(\eta')$, which also belongs to the VP class with a different isospin configuration and light quarks only.

The vector mesons, ϕ and ρ, are reconstructed in their charged decays, $\phi \to K^+K^-$ and $\rho \to \pi^+\pi^-$. For the pseudoscalar mesons the following decay modes are considered: $\eta \to \gamma\gamma$, $\eta' \to \pi^+\pi^-\gamma$ and $\eta' \to \eta\pi^+\pi^-$. For all reconstructed VP combinations clear signals are observed with significances ranging from 7.6 to 30.0 allowing for an extraction of the production cross sections. The two decay modes of the η' have been combined for the final results, shown in Fig. 1. Also shown are measurements of the same VP final states at different centre-of-mass (CM) energies from CLEO [6] and BaBar [7], the latter using initial state radiation.

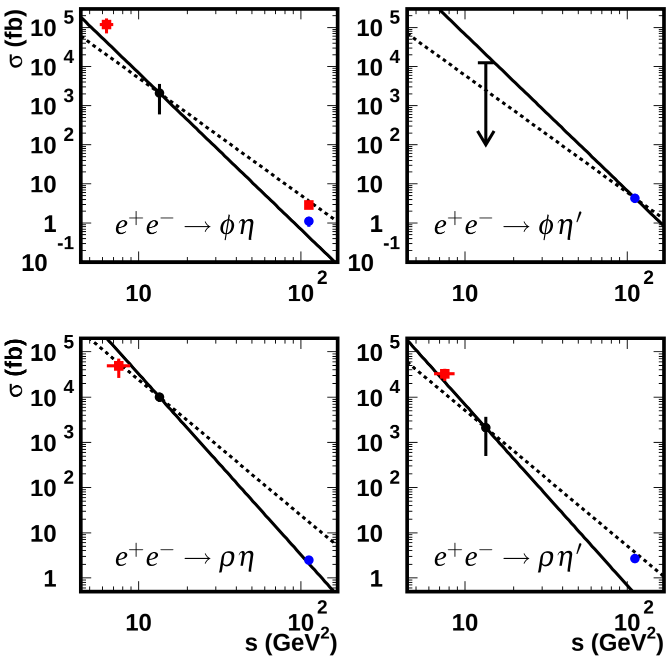

Figure 1: The $e^+e^- \to VP$ cross sections as a function of centre-of-mass energy squared. The Belle measurements (blue) are shown together with results from CLEO (black) and BaBar (red). The solid lines indicate a $1/s^4$ dependence, the dashed lines a $1/s^3$.

Most QCD-based models predict the energy dependence of the process $e^+e^- \to VP$ to be $1/s^4$ [8, 9] while the comparison of the measured cross section of the process $e^+e^- \to \phi\eta$ by CLEO and BaBar favours the $1/s^3$ dependence. The $1/s^3$ dependence of the process $e^+e^- \to VP$ is predicted in [10]. Recently theoretical calculations of the $e^+e^- \to VP$ cross sections have been published, which use the light cone approach [11, 12]. The authors of Ref. [11] claim that their results favour a $1/s^3$ dependence. In Ref. [12] an asymptotic behaviour of $\sigma \sim 1/s^4$ is expected in the limit $s \to \infty$. The $1/s^3$ and $1/s^4$ dependences are indicated in Fig. 1, however at present no definite conclusion about the energy dependence of the $e^+e^- \to VP$ reaction can be drawn.

2. Exclusive $D^0D^{*-}\pi^+$-Resonance Production ISR events

Using a data sample collected at the $\Upsilon(4S)$ resonance and nearby continuum with an integrated luminosity of 695 fb^{-1}, the Belle collaboration studies open charm production near threshold via the measurement of exclusive $e^+e^- \to D^0D^{*-}\pi^+$ cross section as a function of centre-of-mass energy from the $D^0D^{*-}\pi^+$ threshold to 5.2 GeV [13].

This study is motivated by the existence of a mysterious family of charmonium-like states with masses above the open charm threshold and quantum numbers $J^{PC} = 1^{--}$. Although these states have been known now for several years, the nature of these states, first found in $e^+e^- \to \pi^+\pi^-J/\psi(\psi(2S))\gamma_{\text{ISR}}$ processes, remains unclear. Among them are the $Y(4260)$ state observed by BaBar [14], confirmed by CLEO [15] and Belle [16]; the $Y(4350)$ discovered by BaBar [17] and Belle [18] as well as the the $Y(4660)$ [18] and $X(4630)$ [19] both observed by Belle.

In this most recent study, the D^0 candidates are reconstructed using five decay modes: $K^-\pi^+$, K^+K^-, $K^-\pi^-\pi^+\pi^+$, $K^0_S\pi^+\pi-$ and $K^-\pi+\pi^0$. To improve the momentum resolution of the D meson candidates, final tracks are fitted to a common vertex with a mass constraint on the nominal D^0 mass. D^{*+} candidates are selected via the $D^{*+} \to D^0\pi^+$ decay mode with a $D^{*+} - D^0$ mass-difference window of $\pm 2\,\mathrm{MeV}/c^2$ around the nominal value. The obtained $D^0D^{*-}\pi^+$ mass spectrum is shown in Fig. 2 (left). The hatched histogram indicates the contribution from combinatorial background. Other background sources are found to be negligible. The $e^+e^- \to D^0D^{*-}\pi^+$ cross section is extracted from the background subtracted $D^0D^{*-}\pi^+$ mass distribution. The resulting $e^+e^- \to D^0D^{*-}\pi^+$ exclusive cross section averaged over the bin width is shown in 2 (right) with statistical uncertainties only. The total systematic uncertainty, comprised of contributions from background subtraction, cross section calculation, the D branching fractions, the signal reconstruction and Kaon identification, amounts to 10%.

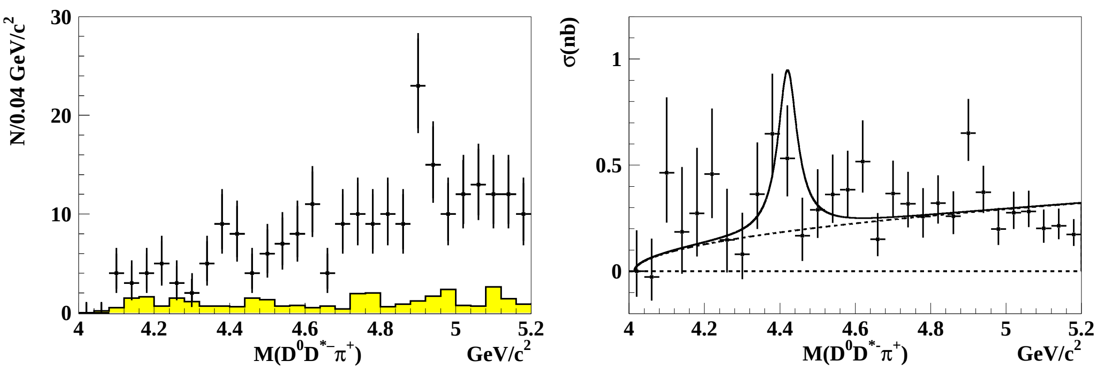

Figure 2: Event yields (left) and cross section (right) as a function of the $D^0D^{*-}\pi^+$ mass.

A likelihood fit to the $M_{D^0D^{*-}\pi^+}$ distribution is performed where a possible $\psi(4415)$ signal contribution is parameterised by an s-wave relativistic Breit-Wigner (RBW) function with a free normalisation. Its mass and width are fixed to the PDG values [20]. To take a non-resonant $D^0D^{*-}\pi^+$ contribution into account a threshold function $\sqrt{M - m_{D^0} - m_{D^{*-}} - m_{\pi^+}}$ with a free normalisation is used. Finally, the sum of the signal and non-resonant functions is multiplied by a mass-dependent second order polynomial efficiency function and differential ISR luminosity. The

	Y(4260)	Y(4350)	Y(4660)	X(4630)
$\sigma(e^+e^- \to X) \times \mathscr{B}(X \to D^0 D^{*-}\pi^+)$, [nb]	0.36	0.55	0.25	0.45
$\mathscr{B}_{ee} \times \mathscr{B}((X \to D^0 D^{*-}\pi^+)$, $[\times 10^{-6}]$	0.42	0.72	0.37	0.66
$\mathscr{B}(X \to D^0 D^{*-}\pi^+)/\mathscr{B}(X \to \pi^+\pi^- J/\psi)$	9			
$\mathscr{B}(X \to D^0 D^{*-}\pi^+)/\mathscr{B}(X \to \pi^+\pi^- \psi(2S))$		8	10	

Table 1: The upper limits on the peak cross sections for the processes $e^+e^- \to X \to D^0 D^{*-}\pi^+$ at $E_{\text{c.m.}} = m_X$, $\mathscr{B}_{ee} \times \mathscr{B}(X \to D^0 D^{*-}\pi^+)$ and $\mathscr{B}(X \to D^0 D^{*-}\pi^+)/\mathscr{B}(X \to \pi^+\pi^- J/\psi(\psi(2S))$ at 90% C.L., where $X = Y(4260), Y(4350), Y(4660), X(4630)$.

fit yields $14.4 \pm 6.2(\text{stat.})^{+1.0}_{-9.5}(\text{sys.})$ signal events for the $\psi(4415)$ state with a statistical significance of 3.1 σ.

To obtain limits on the decays $X \to D^0 D^{*-}\pi^+$, where X denotes $Y(4260)$, $Y(4350)$, $Y(4660)$ or $X(4630)$ four likelihood fits to the $M_{D^0 D^{*-}\pi}$ spectrum are performed, each with one of the X states, the $\psi(4415)$ state and a non-resonant contribution. The same fit function as before is used except an additional RBW with free normalisation for the given X state. The width and mass of the X state is fixed to the values of previous measurements or – where available – to the PDG value. The values of the amplitude of the $Y(4260)$, $Y(4350)$, $Y(4660)$ and $X(4630)$ signal function are found to be consistent with zero within errors. The calculated upper limits (at the 90% C.L.) on the peak cross sections for $e^+e^- \to X \to D^0 D^{*-}\pi^+$ processes at $E_{\text{c.m.}} = m_X$ are presented in Tab. 1. In particular no evidence for $Y(4260) \to D^0 D^{*-}\pi^+$ decays as predicted by hybrid models are found within the present data sample.

No clear evidence for open charm production associated with any of these states has been observed, neither in this most recent work nor in previous analysis. The absence of open charm decay channels for Y states, large partial widths for decay channels to charmonium plus light hadrons and the lack of available $J^{PC} = 1^{--}$ charmonium levels are inconsistent with the interpretation of the Y states as conventional charmonia. Further studies will be needed to clarify the nature of these states.

3. Exclusive $\eta\pi^0$-Production in Two-Photon events

The high statistics data samples accumulated by the Belle detector permit the detailed investigation of the exclusive production of $\eta\pi^0$ in collisions of two photons radiated off the incoming electron and positron. The results [21] are based on a data sample of 223 fb^{-1}.

Both the η and π^0 are decaying to $\gamma\gamma$, therefore the process $\gamma\gamma \to \eta\pi^0$ is reconstructed as an all neutral final state. Each of the four γ's is required to have a minimum energy of $E_\gamma > 100\,\text{MeV}$ each, while the total energy is less than 5.7 GeV accounting for the beam electron and positron escaping undetected along the beam line. The π^0 candidate is required to have $p_T > 0.15\,\text{GeV}/c$ and balanced by the η such that the combined p_T of the π^0 and η is less than $0.05\,\text{GeV}/c$. The raw yields of $\eta\pi^0$ as a function of the $\gamma\gamma$ centre-of-mass energy, W, is shown in Fig. 3a, together with the estimated background. The resonance structures of the $a_0(980)$, $a_2(1320)$ and the less prominent $a_2(1700)$ are visible.

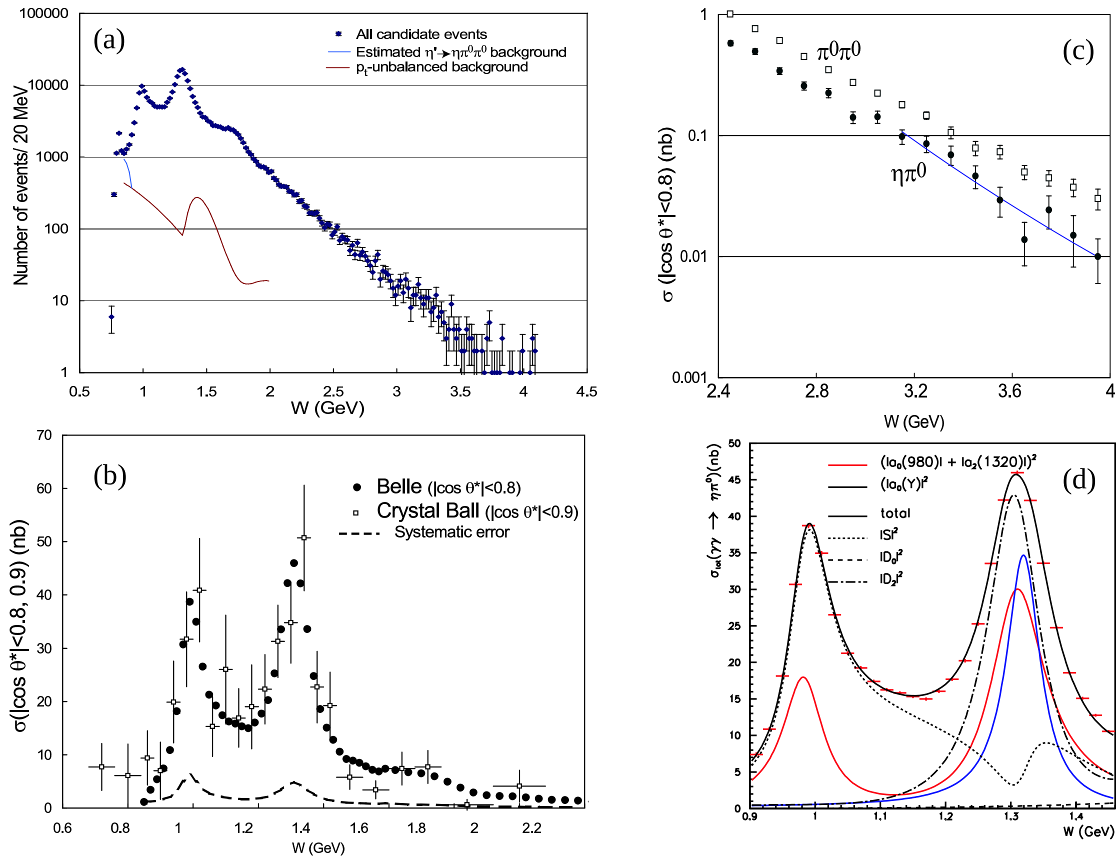

Figure 3: The raw event yield (a) and cross sections (b, c, d) of the exclusive $\eta\pi^0$ production in two-poton collsions. For more details see text.

Parameter	Unit	$a_0(980)$	PDG: $a_0(980)$	$a_0(Y)$	PDG: $a_0(1450)$
Mass	MeV/c^2	$982.3^{+0.6}_{-0.7}{}^{+3.1}_{-4.7}$	984.7 ± 1.2	$1316.8^{+0.7}_{-1.0}{}^{+24.7}_{-4.6}$	1472 ± 19
Γ_{tot}	MeV	$75.6 \pm 1.6^{+17.4}_{-10.0}$	$50 - 100$	$65.0^{+2.1}_{-5.4}{}^{+99.1}_{-32.6}$	265 ± 13
$\Gamma_{\gamma\gamma}\mathscr{B}(\eta\pi^0)$	eV	$128^{+3}_{-2}{}^{+502}_{-43}$	240^{+80}_{-70}	$432 \pm 6^{+1073}_{-256}$	unknown

Table 2: The parameters of the $a_0(980)$ and $a_0(Y)$ of the Belle analysis compared to the world averages.

The data has been corrected for efficiencies and resolutions to extract the differential cross section in the kinematic range $0.84 < W < 4.0\,$GeV, $|cos\theta^*| < 0.8$, where θ^* is π^0 (or η) scattering angle in the $\gamma\gamma$ centre-of-mass system. Figure 3b shows the cross section in the resonance region $0.9 < W < 2.3\,$GeV compared to the previous measurement by Crystal Ball [22]. Both measurements are found to be consistent, with a much improved precision for the Belle measurement thanks to the almost two orders of magnitude larger data sample. A dedicated partial wave analysis, illustrated in Fig. 3d, is performed to extract the parameters of the resonances reported in Tab. 3.

The energy and angular dependence above 3.1 GeV are compared with those measured in the $\pi^0\pi^0$ channel. The measured cross section ratio is consistent with QCD predictions. The W-dependence of the integrated $\eta\pi^0$ cross section follows a power law W^{-n} with $n = 10.5 \pm 1.2 \pm 0.5$, in agreement with the result found for $K^0_S K^0_S$ pairs, $n = 10.5 \pm 0.6 \pm 0.5$ ($|cos\theta^*| < 0.6$) [23], close to the expected value of 10. In Fig. 3c the W dependence of the $\eta\pi^0$ shown together with the $\pi^0\pi^0$ cross section for which $n = 8.0 \pm 0.5 \pm 0.4$ has been reported [24].

Acknowledgments

The measurements reported here became possible thanks to the engagement and competence of the KEKB machine crew pushing for ever increasing instantaneous luminosities while maintaining stable running conditions for the Belle experiment. I am indebted to my colleagues at Belle who's excellent results I had the pleasure to present at the EPS09 conference. Especially I would like to mention S. Uehara and Y. Watanabe for the vector-pseudoscalar-meson analysis, K. Belous and M. Shapkin for the $D^0 D^{*-} \pi^+$ analysis, and G. Pkhlova for the exclusive $\eta\pi^0$ analysis.

References

[1] URL to the slides of the presentation at EPS09:
`http://indico.ifj.edu.pl/MaKaC/contributionDisplay.py?contribId=834&sessionId=19&confId=11`

[2] Belle Collaboration, A. Abashian, Nucl. Instrum. Meth. **A479** (2002) 117.

[3] Belle Collaboration, K. Belous *et al.*, submitted to Phys. Lett. B, arXiv:0906.4214 [hep-ex].

[4] Belle Collaboration, K. Abe *et al.*, Phys. Rev. Lett. **89** (2002) 142001;
ibid. Phys. Rev. **D70** (2004) 071102.

[5] BaBar Collaboration, B. Aubert *et al.*, Phys. Rev **D72** (2005) 031101.

[6] CLEO Collaboration, G.S.Adams *et al.*, Phys. Rev. **D73** (2006) 012002.

[7] BaBar Collaboration, B. Aubert *et al.*, Phys. Rev **D76** (2007) 092005;
Phys. Rev **D74** (2006) 111103(R).

[8] G.P. Lepage and S.J. Brodsky, Phys. Rev. **D22**, (1980) 2157;
S.J. Brodsky and G.P. Lepage, Phys. Rev. **D24**, (1981) 2848.

[9] V. Chernyak arXiv:9906387 [hep-ph];
V.L. Chernyak and A.R. Zhitnitsky, Phys. Rep. **112**, (1984) 173.

[10] J.M Gérard and G. López Castro, Phys. Lett. **B425** (1998) 365.

[11] Cai-Dian Lü, Wei Wang and Yu-Ming Wang, Phys. Rev. **D75** (2007) 094020.

[12] V.V. Braguta, A.K. Likhoded, A.V. Luchinsky, Phys. Rev. **D78** (2008) 074032.

[13] Belle Collaboration, G. Pakhlova *et al.* arXiv:0908.0231 [hep-ex].

[14] BaBar Collaboration, B. Aubert *et al.* , Phys. Rev. Lett. 95, (2005) 142001;
BaBar Collaboration, B. Aubert *et al.* , arXiv:0808.1543 [hep-ex], (2008).

[15] CLEO Collaboration, T.E. Coan *et al.* , Phys. Rev. Lett. **96** (2006) 162003;
CLEO Collaboration, Q. He *et al.* , Phys. Rev. **D74** (2006) 091104.

[16] Belle Collaboration, C.Z. Yuan *et al.*, Phys. Rev. Lett. **99** (2007) 182004.

[17] BaBar Collaboration, B. Aubert *et al.* , Phys. Rev. Lett. **98** (2007) 212001.

[18] Belle Collaboration, X.L. Wang *et al.*, Phys. Rev. Lett. **99** (2007) 142002.

[19] Belle Collaboration, G. Pakhlova *et al.*, Phys. Rev. Lett. **101**, 172001 (2008).

[20] Particle Data Group, C. Amsler *et al.*, Phys. Lett **B667** (2008) 1.

[21] Belle Collaboration, S. Uehara *et al.*, submitted to Phys. Rev. D, arXiv:0906.1464 [hep-ex].

[22] Crystal Ball Collaboration, D. Antreasyan *et al.*, Phys. Rev. **D33** (1986) 1847.

[23] Belle Collaboration, W.T. Chen *et al.*, Phys. Lett. **B651** (2007) 15.

[24] Belle Collaboration, S. Uehara *et al.*, Phys. Rev. **B79** (2009) 052009.