Charm physics at Belle

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Abstract. This talk reviews an unrepresentative selection of Belle's open-charm and charmonium analyses, focusing on new developments and topics of interest to the DIS community. Highlights include an \( X(3872) \) analysis favoring \( J_{PC} = 1^{++} \), and the \( D^0 \bar{D}^0 \) bound-state interpretation.

INTRODUCTION

A talk of this length does not allow even a representative survey of open-charm and charmonium analyses at Belle, so I’ve made a selection favoring the most interesting recent developments—concerning the exotic \( X(3872) \) state—and topics of interest to the deep inelastic scattering community. Due to length limitations, the writeup is even more cursory than the talk. Interested readers should consult the references.

The aim of the Belle collaboration is to study violation of the CP symmetry, using the time-dependence of decays of \( B \bar{B} \) pairs. Open-charm and charmonium studies are an active sideline. The KEKB collider [1] produces \( e^+ e^- \rightarrow \Upsilon(4S) \rightarrow B \bar{B} \) and \( e^+ e^- \rightarrow q \bar{q} \) continuum events with unprecedented luminosity: both \( B \)-decays and the continuum are copious sources of charmed and charmonium states. The Belle detector [2], at the KEKB interaction point, is a general-purpose detector with good particle ID capabilities.

THE \( X(3872) \): QUANTUM NUMBERS AND INTERPRETATION

The \( X(3872) \), a narrow state decaying to \( \pi^+ \pi^- J/\psi \), was discovered in \( B \rightarrow K \pi^+ \pi^- J/\psi \) decays by Belle [3], and confirmed by three other groups [4]. In subsequent analysis, it has not been possible to match the properties of the \( X \) with those of an expected \( c \bar{c} \) state [5]. Belle has recently reported the observation of \( X(3872) \rightarrow \gamma J/\psi \) and \( \omega J/\psi \) decays [6], confirming that the C-parity of the \( X \) must be even. An angular analysis of \( X(3872) \) decays has also been performed [7], exploiting zeroes in predicted distributions [8] to test various \( J_{PC} \) hypotheses. An example is shown in Fig. 1.

The \( X \rightarrow \pi^+ \pi^- J/\psi \) dipion mass distribution is shown in Fig. 2. The rate near the kinematic boundary is sensitive to the parity of the \( X \): for \( C = +1 \) and even parity, \( q_{J/\psi}^{*+} \) dependence is expected (\( \rho \) and \( J/\psi \) in S-wave, ignoring D-wave admixture); for odd parity, \( (q_{J/\psi}^+)^3 \) (P-wave; ignoring F-wave). Fits to the two cases find \( \chi^2 = 43.1 \) and 71.0, for 39 degrees of freedom, favoring \( J^{++} \) hypotheses. \( J^{PC} = 0^{++} \) is disfavored by angular distributions, and \( J^{PC} = 2^{++} \) by preliminary evidence for decays to \( D^0 \bar{D}^0 \pi^0 \) [2].
FIGURE 1. $X(3872) \to \pi^+\pi^- J/\psi$ angular distributions for data (points), and for the $J^{PC} = 0^{-+}$ hypothesis (histogram), including background estimated from $X$-mass sidebands (shaded). The definition of the angles is shown in the sketch on the left. The $\chi^2$ of the fits are (a) 17.7 and (b) 34.2 for 9 degrees of freedom, disfavoring $0^{-+}$. Note the concentration of events in the final bins, contrary to expectation.

FIGURE 2. $M(\pi^+\pi^-)$ distribution for events in the $X(3872)$ signal region (points) and sideband (shaded). Fits to $J^{++}$ (solid) and $J^{+-}$ (dashed) hypotheses are also shown: see the text.

The $J^{PC} = 1^{++}$ hypothesis is consistent with available data; all other assignments are disfavored by at least one test. However, the identification of the $X(3872)$ with the $1^{++}$ charmonium state $\chi'_{c1}$ is unlikely: potential model predictions for the $\chi'_{c1}$ mass are 3953–3990 MeV, and shift upward when coupling to open charm is taken into account [10]. The isospin-violating $\chi'_{c1} \to \pi^+\pi^- J/\psi$ decay would presumably have a small partial width, similar to $\Gamma(\psi(2S) \to \pi^0 J/\psi) = (0.27 \pm 0.06)$ keV [11], to be compared with a total width $\Gamma > 1$ MeV [10]. This contradicts BaBar’s 90% confidence limit $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) > 4.3\%$ [12]. The low ratio of radiative and hadronic partial widths $\Gamma(X \to \gamma \psi)/\Gamma(X \to \pi^+\pi^- \psi) = 0.14 \pm 0.05$ [8] also disfavors $\chi'_{c1}$.

By contrast, the observed properties of the $X(3872)$ are consistent with those of a $D^0\bar{D}^{*0}$ bound state [13]: the mass is within errors of $D^0\bar{D}^{*0}$ threshold, $(+0.6 \pm 1.1)$ MeV;
as the mass difference \( M(D^+D^{*-}) - M(D^0\bar{D}^0) = 8.1 \text{ MeV} \) is large by comparison, isospin violation is natural for such a state, explaining the observation of \( X(3872) \to \omega J/\psi \) and \( pJ/\psi \) decays. These decays are natural within the model of Swanson \cite{13}, where \( |\omega J/\psi\rangle \) and \( |pJ/\psi\rangle \) appear as admixtures to the \( |D^0\bar{D}^0\rangle \) wavefunction. A small branching ratio \( \Gamma(X \to \gamma J/\psi)/\Gamma(X \to \pi^+\pi^- J/\psi) \) is also expected for such a state.

**DOUBLE CHARMONIUM PRODUCTION AND THE \( X(3940) \)**

The process \( e^+e^- \to c\bar{c}c\bar{c}c\) was discovered by Belle in both double charmonium \( (J/\psi \eta_c) \) and associated charm \( (J/\psi D^{(*)}X) \) production; both processes have unexpectedly large rates \cite{15}. Various proposed alternative explanations of the data have been contradicted by further tests, including angular analysis and full reconstruction of \( e^+e^- \to J/\psi \eta_c \) events \cite{16}. The principal results have recently been confirmed by BaBar \cite{17}.

Evidence for a new state, \( X(3940) \), seen in the recoil mass \( (M_X) \) spectrum in \( e^+e^- \to J/\psi X \) events, was presented in 2004 at the Beijing conference \cite{18}. Decays of this state favor \( D\bar{D}^* \), based on a study of events with reconstructed \( J/\psi \) and \( D \) mesons. An updated analysis confirming these results is being prepared for publication this summer \cite{19}.

**OTHER RESULTS (MOSTLY SPECTROSCOPY)**

An enhancement at \( \omega J/\psi \) threshold has been seen in \( B \to K\omega J/\psi \) \cite{15}. Interpreted as a particle \( (M = (3943 \pm 11 \pm 13) \text{ MeV}, \Gamma = (87 \pm 22 \pm 26) \text{ MeV}) \), this \( "Y(3940)" \) would be exotic: a \( c\bar{c} \) state at this mass would be expected to decay to \( D\bar{D}^* \), with very small branching fractions for \( \omega J/\psi \) and other hadronic charmonium transitions.

Belle observed the \( D_{sJ}^+(2317) \) and \( D_{sJ}(2460) \) in both continuum production \cite{20} and \( B \) decays \cite{21}, confirming the observations by BaBar and CLEO \cite{22,23}, establishing the \( D_{sJ}(2460)^+ \to \gamma D_s^+ \) decay, and favoring \( J^P(D_{sJ}(2460)) = 1^+ \), based on the \( \gamma D_s^+ \) helicity angle distribution. Study of \( D_{sJ}^+(2317)^+ \to \pi^0D_s^+ \) \cite{24} likewise favors \( J^P = 0^+ \).

Searches for the \( D_{sJ}(2632)^+ \to D_s^+\eta \) and \( D^0K^+ \) state of SELEX \cite{25} find no evidence of production in \( B \) decays or the continuum at Belle \cite{26}.

Amongst other charmed baryon results, a new isospin triplet \( \Sigma_c(2800) \) decaying to \( \Lambda_c^+\pi^-,0,+ \) has been observed in the continuum \cite{27}. It is tentatively identified as the \( \Sigma_{c2} \) \( (J^P = 3/2) \), with some admixture of the \( \Sigma_{c1} \) (with the same quantum numbers).

Of the Belle pentaquark searches reported in 2004 \cite{28}, the most important uses interactions of kaons (from \( e^+e^- \) annihilation) with the material of the detector. This study placed a limit on production of the \( \Theta(1540) \) relative to the \( \Lambda(1520) \); an updated analysis, to be published in the summer of 2005 \cite{29}, also bounds the rate of exclusive production \( K^+n \to \Theta(1540)^+ \to pK^0 \), with similar sensitivity to that of DIANA \cite{30}.

A major study of charm fragmentation in \( e^+e^- \to c\bar{c} \) at \( \sqrt{s} \approx 10.6 \text{ GeV} \) will also be submitted for publication this summer \cite{31}. Fractional momentum distributions for \( D, D_s, \) and \( D^* \) mesons, and the \( \Lambda_c^+ \), are measured with much greater precision than in previous studies; a comparison of fragmentation functions is also presented.
SUMMARY

Recent Belle analyses include a study of $X(3872)$ decays and properties, favouring $J^{PC} = 1^{++}$ and the $D^0\bar{D}^0$ molecular model. Other contributions to spectroscopy include the $Y(3940)$, double charmonium production (including $e^+e^- \rightarrow J/\psi X(3940)$), and pentaquark searches. A study of charm fragmentation has also been performed. Many other results in charm and charmonium studies lie outside the scope of this talk.

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