PROCEEDINGS OF SCIENCE

Search for Double Charm Production at Belle

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We report a study on double charm production, $e^+e^- \to cc + X$, using two charmed hadrons at a center-of-mass energy of 10.52 GeV. This result could be a basis of searches for doubly charmed hadron, for example, the doubly charmed tetra-quark state T_{cc}. Also it could clarify the discrepancy between experiment and theory in the double charmonia production. In this paper, we report on estimates for sensitivity of the measurement at the Belle experiment at KEK, based on a Monte Carlo simulation.

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1. Introduction

The high luminosity B-factory data provides opportunities to study a multi-charm production in e^+e^- collisions. We search for the process $e^+e^- \rightarrow cc+X$ (double charm event) with production of double open charmed hadrons which have not been measured yet in e^+e^- collisions. This process is shown in Figure 1. The perturbative QCD predicts $\sigma(e^+e^- \rightarrow cc+X) \approx 0.3$ pb [1] and $\sigma(e^+e^- \rightarrow DD+X)/\sigma(e^+e^- \rightarrow cc+X) \approx 1/16$, 6/16 and 9/16 for $DD = D^+D^+$, D^+D^0 and D^0D^0, respectively [2].

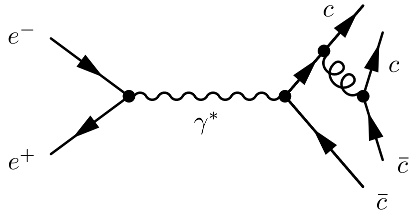

Figure 1: Feynman diagram of $e^+e^- \rightarrow cc\bar{c}\bar{c}$ production

Similarly, Belle and BABAR measured cross-section of double charmonium event using $J/\psi c\bar{c}$ decays and they obtained unexpectedly large results [3, 4]. Belle reported 0.74 pb for $e^+e^- \rightarrow J/\psi c\bar{c}$ and 1.17 pb for $e^+e^- \rightarrow J/\psi X$ cross-section in 2009 while theoretical predictions show that $\sigma(e^+e^- \rightarrow J/\psi c\bar{c})$ to be ~ 0.1 pb [5] and the ratio of $\sigma(e^+e^- \rightarrow J/\psi c\bar{c})/\sigma(e^+e^- \rightarrow J/\psi gg)$ to be $\sim 10\%$ [6]. If we also confirm $cc\bar{c}\bar{c}$ cross-section has a large discrepancy, that may mean that hadronization process is significantly violated or there is a new production mechanism.

Furthermore, an exotic hadron consisting of $cc\bar{u}\bar{d}$, named T_{cc}, can be generated from $cc\bar{c}\bar{c}$ production and is expected to have final states of open charmed hadron(s). Study on cross-section and momentum distribution of the $cc\bar{c}\bar{c}$ production will give us a guideline for T_{cc} search.

We search for two open charmed hadrons, D^0D^+, for the initial study, because this is the major final state expected when T_{cc} is produced. Other channels such as D^0D^0 and D^+D^+ will be added later. We use only continuum MC to avoid peaking background events through $B^0-\bar{B}^0$ mixing. In this paper we present the result of sensitivity study of double charm production using MC.

2. Analysis

2.1 MC

Presently, we use MC of 6 times larger than 89 fb^{-1} continuum data collected at $\sqrt{s} = 10.52$ GeV, just below the $\Upsilon(4S)$ resonance. We plan to add on-resonance event following study of peaking background from $B^0-\bar{B}^0$ mixing event. Continuum MC does not include double charm production, but include possible peaking background source of doubly Cabibbo-suppressed decay. One million of signal MC event are made by process of $e^+e^- \rightarrow \gamma^* \rightarrow D^0D^+\bar{D}^0D^-$ and sub-decays of D is fixed as $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$ and $\bar{D}$ decay generically.

Throughout this note, charge-conjugate processes are implied unless explicitly stated otherwise.

2.2 Event selection

All charged tracks are required to have less than 5 cm of the closest approach of a track to the interaction point in the z-direction and less than 2 cm in the transverse plane. To select a kaon and pion, we use likelihood ratio $\mathscr{R}_{K,\pi} = \mathscr{L}_{\mathrm{K}}/(\mathscr{L}_{\mathrm{K}} + \mathscr{L}_{\pi})$, where $\mathscr{L}_{K(\pi)}$ is a production of the likelihoods for $K^{\pm}(\pi^{\pm})$ from three detectors for hadron identification: Aerogel Cherenkov counter, Central drift chamber and Time-of-flight counter. We apply $\mathscr{R}_{K,\pi} > 0.6$ for kaon and $\mathscr{R}_{K,\pi} < 0.6$ for pion candidates. Particle selection criteria are summarized in Table 1.

We reconstruct D^0 using $K^-\pi^+$ and D^+ using $K^-\pi^+\pi^{+*}$. To improve the momentum determinations, daughter tracks from the D candidate are fitted to pass a common vertex. Multiple D^0D^+ combinations are allowed in a single event and its fraction is $\sim 50\%$ of number of reconstructed events.

	Selection Requirement
$K^{\pm}, \pi^{\pm}$	$dr < 2.0$ cm
	$dz < 5.0$ cm
	$\mathscr{R}_{K,\pi} > 0.6$ for $K^{\pm}$
	$\mathscr{R}_{K,\pi} < 0.6$ for $\pi^{\pm}$

Table 1: Summary of particle selection criteria.

2.3 Peaking background

The peaking background event came from $D\bar{D}$ event by doubly Cabibbo-suppressed decay of $\bar{D}^{0\dagger}$. Such $\bar{D}^0$ is reconstructed as Cabibbo-favored modes of D^0. This peaking background source is estimated using information of event generator in the MC simulation and subtracted from total number of events. Background from $D^0 - \bar{D}^0$ mixing is negligible.

2.4 2D fitting

We extract yield, $N_{D^0D^+}$, by two-dimensional binned maximum-likelihood fits on D^0 and D^+ mass plane. We assume double Gaussian function for signal shape ($\mathscr{S}_{D^0}$ and $\mathscr{S}_{D^+}$) and 1st order polynomial function for background shape ($\mathscr{B}_{D^0}$ and $\mathscr{B}_{D^+}$). Therefore, there are four components: D^0D^+ event ($\mathscr{S}_{D^0} \times \mathscr{S}_{D^+}$), D^0 with fake D^+ ($\mathscr{S}_{D^0} \times \mathscr{B}_{D^+}$), D^+ with fake D^0 ($\mathscr{B}_{D^0} \times \mathscr{S}_{D^+}$), and random background events ($\mathscr{B}_{D^0} \times \mathscr{B}_{D^+}$). We float all parameters of signal MC and fix them except for mean and magnitude of width of Gaussian when we fit on background MC using values from signal MC fit result. Figure 2 shows fit results on signal MC (top), continuum MC (middle), and peaking background (bottom).

* $\mathscr{B}(D^0 \to K^-\pi^+) = 3.89\%$ and $\mathscr{B}(D^+ \to K^-\pi^+\pi^+) = 9.4\%$ [7]
† $\mathscr{B}(D^0 \to K^+\pi^-) = 1.47 \times 10^{-4}$ [7]

2.5 Result

The efficiency of signal MC ($\varepsilon_{\rm sig}$) is 20.0% (199507 combinations are reconstructed from generated one million events). The results of fitting on background MC are scaled to size of continuum data and summarized in Table 2. $N_{D^0D^+}$ is a number of events under the $\mathscr{S}_{D^0} \times \mathscr{S}_{D^+}$ pdf and we subtract $N_{D^0D^+}$ in peaking background MC from that in MC including peaking background as we explained in Sec. 2.3. Estimated number of double charm events in MC is $-37.6\pm$ 114.0 and consistent with zero. We will do ensemble test for a further examination of this fit.

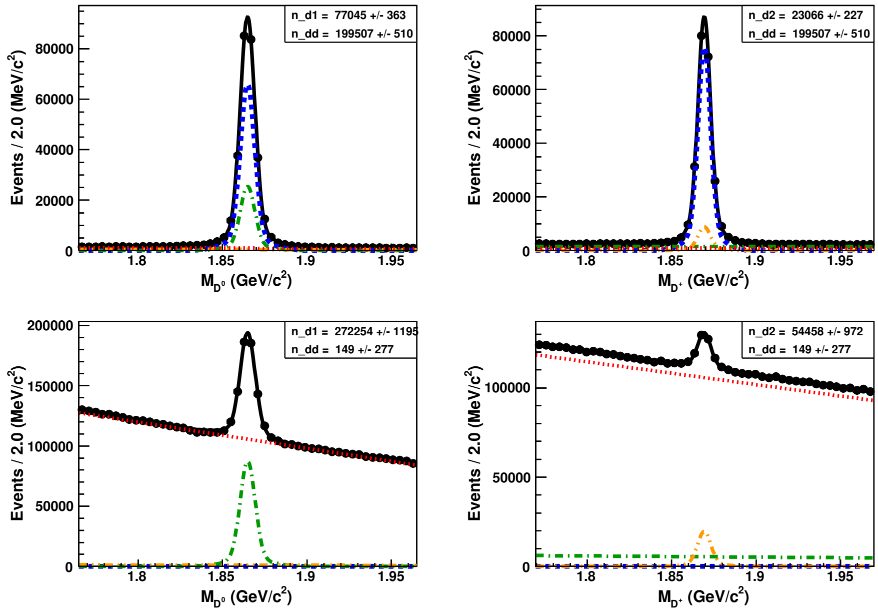

Figure 2: Projections onto the M_{D^0} (left) and M_{D^+} (right) of 2D fit of signal MC (top) and continuum MC 6 times larger size of data (bottom). D^0D^+ signal (dash), D^0 signal and D^+ background and it is opposite (dash-dot and dash-double-dot), combinatorial background (dot) and sum of all pdfs (line).

type of bkg MC	$N_{D^0D^+}$
including peaking bkg	24.8 $\pm$ 113.1
peaking bkg only	62.4 $\pm$ 14.1
double charm event in MC	-37.6 $\pm$ 114.0

Table 2: Fitted result of different MC sources.

The signal significance (Σ) can be evaluated as $\Sigma = N_{D^0D^+}/\sigma_{\rm bkg}$ where $\sigma_{\rm bkg}$ is the background fluctuation, that is 114.0 without taking account a systematic errors at this moment. We put off considering the systematic errors and assume that there are three times larger number of signal events in data than the error. The number of signal $N_{D^0D^+}$ can be estimated as,

$$N_{D^0D^+} = \mathscr{L}(e^+e^-) \times \sigma(e^+e^- \to cc+X) \times \frac{\sigma(e^+e^- \to DD+X)}{\sigma(e^+e^- \to cc+X)} \times \varepsilon_{\rm sig} \times \mathscr{B}(D^0 \to K^-\pi^+) \times \mathscr{B}(D^+ \to K^-\pi^+\pi^+).$$

Therefore, if we have 342 signal events of $N_{D^0D^+}$, which is 3 times of estimated $N_{D^0D^+}$ error using background MC in Table 2, we can estimate $\sigma(e^+e^- \to cc+X) \approx 13$ pb and $\sigma(e^+e^- \to DD+X) \approx 5$ pb which are equivalent to 3σ of significance.

3. Summary

We have estimated sensitivity to double charm production based on MC simulation. With 89fb^{-1} off-resonance data, the statistical significance for the $e^+e^- \to D^0D^+ + X$ is larger than 3σ if the cross-section is larger than 5 pb. To enhance the significance, we need to add other decay channels of D, use more data Belle stored at $\Upsilon(4S)$ resonance (711 fb^{-1}) and lower states of Υ energy (37 fb^{-1}), and suppress background events.

Belle has measured $J/\psi + c\bar{c}$ cross-section, which is larger than the theoretical calculation. We expect this doubly charmed hadron production study to be another test of pertubative or non-relativistic QCD prediction with more than 800 fb^{-1} of data stored in Belle.

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