PROCEEDINGS OF SCIENCE

Spectrometer for the charmed baryon spectroscopy experiment at the J-PARC high-momentum beam line

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The diquark correlation which is expectedly an essential degree of freedom to describe the hadron structure can be revealed from the study of charmed baryons. The experiment to observe and investigate the charmed baryon states was proposed at the J-PARC high-momentum beam line. The missing mass spectroscopy experiment via the $\pi^- p \to Y_c^{*+} D^{*-}$ reaction with 20 GeV/c is performed for the systematic measurement of the excitation energy, the production rate and the decay products of charmed baryons. The decay particles from the D^{*-} meson are detected by the forward magnetic spectrometer whose detection efficiency is $50-60$%. The excited charmed baryons can be measured with the missing mass resolution of 10 MeV. To reduce the background level, we apply the D^* tagging and several event selections by using kinematical conditions from the t-channel dominance of the production. The sensitivity of $0.1-0.2$ nb can be achieved. In addition, the decay measurement of the produced charmed baryons can also be performed to determine the branching ratio and identify the excited states from the analysis of the decay chain and angular distribution of decay products. The proposed experiment for the systematic measurement of the charmed baryons was found to be feasible.

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1. Introduction

The purposes of experiment are to observe and investigate the excited states of the charmed baryons. The goal is to reveal the diquark correlation [1] which is expected to be an essential degree of freedom to describe hadrons. The excitation energy and width are measured by the missing mass spectroscopy method by which all the excited states can be produced without any dependence of the final state. The measurement of the production rate which strongly related to the spin/isospin configuration of charmed baryons [2] can provide the unique information of the diquark correlation. In addition, the analysis of the decay particles and its decay chain which decays to the known states, the absolute decay branching ratio and the spin/parity of the excited states could also be determined. From the systematic measurement of the excitation energy, the production cross section and the decay properties, the charmed baryon states could completely be measured.

2. Experiment

The experiment is planned at the J-PARC hadron experimental facility [3] where the high-momentum beam line is being constructed by the beginning of 2016. The high-momentum beam line can provide the unseparated secondary beams with the high-intensity of more than 10^7 /spill up to the momentum of 20 GeV/c. The momentum resolution of less than 0.1% can be obtained by using the dispersive optical method. The high-momentum beam with both high-intensity and high-resolution can be delivered to the experimental area.

In the experiment, the $\pi^- \; p \to Y_c^{*+} \; D^{*-}$ reaction is used with the beam momentum of 20 GeV/c. The D^{*-} meson decays by the $D^{*-} \to \bar{D}^0 \; \pi^-$ channel (branching ratio of 67.7%). Then, the $\bar{D}^0$ meson decays by the $\bar{D}^0 \to K^+ \; \pi^-$ channel (branching ratio of 3.88%). The decay products of K^+ and π^- of 2$-$16 GeV/c from $\bar{D}^0$ and π^- of 0.5$-$1.7 GeV/c from D^{*-} are detected by the spectrometer. In addition, the decay measurement can be performed by detecting decay products from the produced Y_c^{*+}, such as as the $Y_c^{*+} \to \Sigma_c^{*++,0} \; \pi^{-,+}$, $Y_c^{*+} \to \Lambda_c^+ \; \pi^+ \; \pi^-$ and $Y_c^{*+} \to p \; D^0$ channels. The recoil momentum of Y_c^{*+} is measured by the missing mass method so that the mass of the decay products ($\Sigma_c^{*++,0}$ and D^0) can be obtained as a missing mass by only detecting the emitted pions and protons with the momentum of 0.2$-$1.5 GeV/c. In the case of the fixed target experiment with the high-momentum beam, all the generated particles, not only the scattered high-momentum particles from the D^{*-} decay but also the decay products from the produced Y_c^{*+}, are scattered to the forward direction. Therefore, the dipole magnet system which commonly measures both the particles from the D^{*-} decay for the missing mass method and the decay products from the produced Y_c^{*+} for the decay measurement is used for the charmed baryon spectrometer. For the spectrometer magnet, the FM cyclotron magnet which is used by the J-PARC E16 experiment [4] will be used.

Since the production cross section of charmed baryons is estimated to 10^{-4} smaller than that of the strangeness production (10$-$100 μb of the $\pi^- \; p \to Y^* \; K^*$ reaction), the charmed baryon production cross section of 1 nb was assumed for the experimental design. To obtain the production yield, the beam intensity of 6×10^7 /spill is used. The high-rate detectors such as scintillating fiber trackers will be installed for the measurements of the beam momentum and profiles at focal

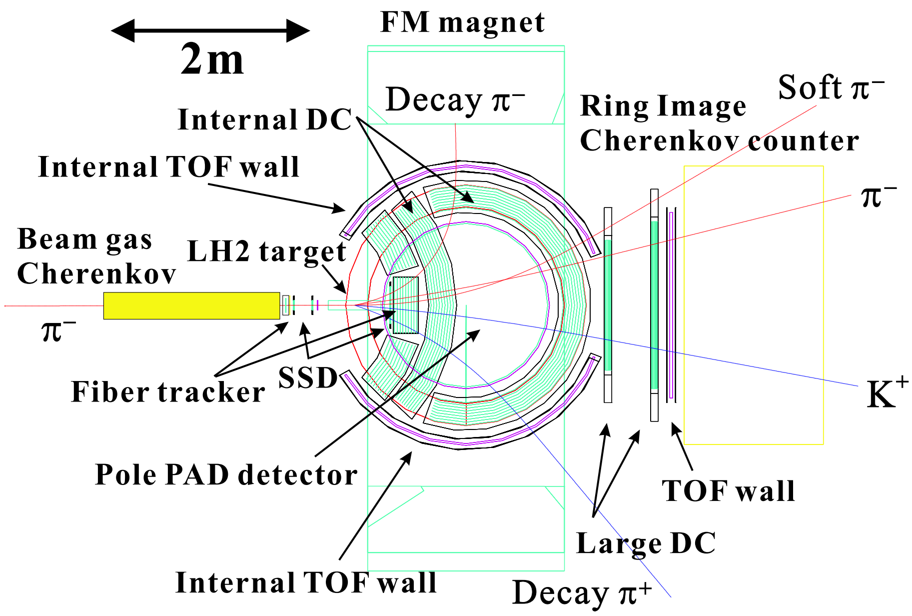

Figure 1: The schematic view of the charmed baryon spectrometer.

plane and at the upstream of the experimental target, respectively. For beam particle identification, the high-rate Ring-Image Čerenkov counter will be used. The D^{*-} meson is measured by the forward detector system, the scintillating fiber trackers at the downstream of the target, and the drift chambers and the Ring-Image Čerenkov counter for detecting the high-momentum K^+ and π^- from $\bar{D}^0$ at the exit of the magnet. For the measurements of the slow π^- from D^{*-} at the forward region and the decay particles from Y_c^* with the wide angular coverage, it is necessary to detect the particles inside of the magnet. The tracking detectors which have the larger angular acceptance were installed at the downstream of the target. The horizontal and vertical directions can be covered by using the detectors installed around the magnet pole and the pad-type detector on the magnet pole face are installed, respectively.

Figure 1 shows a concept design of the charmed baryon spectrometer. The acceptance for detecting the D^{*-} decay was estimated to be 50−60% for the excitation states up to 1 GeV by assuming the dominance of the t-channel process for the production. The momentum resolution of 0.2% was obtained at 5 GeV/c so that the invariant mass resolution for reconstructing the $\bar{D}^0$ and D^{*-} are estimated to be 5.5 MeV and 0.6 MeV, respectively. The missing mass resolution of excited states above 2.8 GeV/c^2 are estimated to be ∼10 MeV. For the decay measurement, both the polar and azimuthal angles are completely covered more than $\cos\theta_{CM} = -0.5$ for the $\Lambda_c(2940)^+ \rightarrow \Sigma_c(2455)^{++,0}\, \pi^{-,+}$ decay modes.

3. Simulation

The reduction of the background which is 10^6 times larger than that of the charmed baryon production is inseparable to design the experiment. There are the three kinds of the background processes, the multi-meson production including the strangeness production which includes the

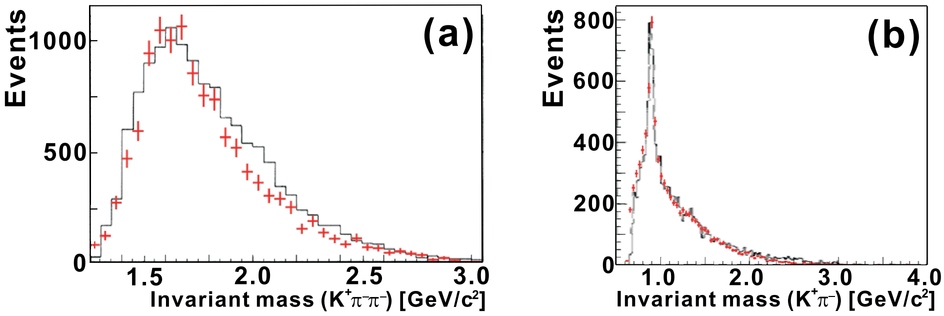

Figure 2: The simulation results of the invariant mass of $M(K^+\pi^-\pi^-)$ and $M(K^+\pi^-)$ of the BNL and CERN data by the JAM code,respectively. The black line and red crosses show the experimental data and simulations by JAM, respectively. The maximum positions are normalized to the data.

(K^+,π^-,π^-) final state, the wrong particle identification of K^+ from π^+ and proton and the associated charm productions which include the D^{*-} meson. The contribution from the wrong particle identification is estimated to be 30% of the main strangeness production by considering the 3% misidentification of K^+ from π^+ and proton by the particle identification counter. The contribution from the associated charm production events was minor compared with the other processes. In addition, it was found that the peaking background from the associated charm production can be checked by the analysis.

The main strangeness background processes were simulated by the JAM code [5], while the PYTHIA code [6] was also used for the comparison. The results of both simulators were checked by old experimental data of the $\pi^- p$ reaction in similar kinematical conditions, the BNL [7] and CERN experiments [8] with the beam momenta of 13 GeV/c and 19 GeV/c, respectively. It was found that both simulators have an ambiguity within only a factor from the experimental data. In particular, the JAM code well reproduced both background shapes and the absolute value as shown in Fig 2. The ambiguity of the absolute value around the $\bar{D}^*$ mass region ($\pm$20 MeV) and the K^{*0} production cross section were found to be 20$-$30%.

The main method of the background reduction is the D^* tagging. Both the mass region of the $\bar{D}^0$ mass and the Q-value ($Q = M(K^+\pi^-\pi^-) - M(K^+\pi^-) - M_{\pi^-}$) corresponded to the $\bar{D}^{*-}$ decay are selected. By using the D^* tagging, the background reduction of 2×10^6 can be achieved from the JAM simulation result. Although the background level is still high by only using the D^* tagging, the other background reduction methods such as $\bar{D}^0$ decay angle cut and the production angle cut are applied for the farther background reduction. Finally, the background reduction of 15 and the signal to noise ratio of 10 can be achieved. Figure 3 shows the missing mass spectrum simulated by the realistic experiment conditions. The sensitivity of the production cross section was found to be 0.1$-$0.2 nb in the missing mass region of $2.2-3.4$ GeV/c^2.

The feasibility of the decay measurement was checked by assuming the decay branch of $\Lambda_c(2940)^+$. In the missing mass spectra by tagging the decay products such as $\pi^\pm$ and proton, the clear peak structure whose mass resolution of 10 MeV can be observed with the continuum background level. The signal to noise ratio of the decay missing mass was estimated to be more than 10 so that the background level was small enough to analyze the decay events. The abso-

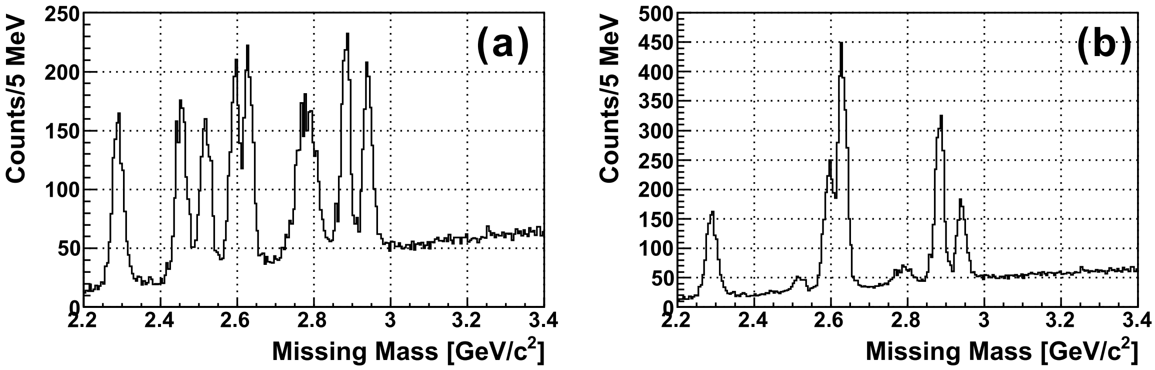

Figure 3: The missing mass spectra with the known charmed baryon states. (a) and (b) show the spectra with the cross section of 1 nb for each state and the production rate in the case of $\sigma(\Lambda_c^+) = 1$ nb, respectively.

lute branching ratio and the angular distribution with a wide angular range can be measured. To increase the signal events for the decay measurement, the $\bar{D}^0 \to K^+ \pi^- \pi^+ \pi^-$ mode (branching ratio = 8.08%) is measured for the D^{*-} detection as well as the $\bar{D}^0 \to K^+ \pi^-$ mode (branching ratio = 3.88%).

4. Summary

The goal of the charmed baryon spectroscopy experiment at the J-PARC high momentum beam line is to reveal the diquark correlation. The missing mass method is used for the systematic measurement of the excitation energy, the production rate and the decay products. The spectrometer system with the large acceptance and high missing mass resolution was designed by the Geant4 simulation. The background process was reproduced well by the JAM code. By applying the background reduction analysis, the achievable sensitivity was found to be $0.1-0.2$ nb in the missing mass region of $2.2-3.4$ GeV/c^2. The decay measurement can also be performed to help the missing mass measurement. It is feasible for the proposed experiment to perform the systematic measurement of the charmed baryons.

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