Summary of the P50 status report

the P50 collaboration

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In this document, we report a summary of the studies for the PAC's concerns listed below. We separately prepare another two documents, where the studies of the production cross section and the background evaluation, the main concerns of the PAC, are described more in details.

The main concerns of the PAC for P50 are summarized as follows.

i) over all level of the signal, and

ii) Reliability of the background.

The PAC recommends further studies and shows possible strategies as listed below.

1. The background simulation should be tested against existing πN data in similar kinematical conditions. In particular, detailed comparisons of all the available kinematical distributions should be presented. Moreover, an attempt to estimate the MC uncertainty (for the background) should be made using different MC codes and/or different tuning of the MC codes. This uncertainty should be taken into account when estimating the S/B ratio.

2. In order to validate the estimation of the signal cross section, and its uncertainty, alternative models to describe the $\pi N \to D^* Y_c$ reaction should be analysed (in addition to the Reggeon model). Attempts should also be made to validate the theoretical models against related processes with available data, such as J/ψ production or inclusive charm production in πN and γN reactions (even if this comparison requires non-trivial extrapolations). The dependence of $\sigma(\pi N \to D^* Y_c)$ on the Y_c structure (with the unavoidable suppression of the production cross section for the highly excited states) should be taken into account in estimating the S/B ratio.

3. In order to further increase the S/B ratio, more extensive studies about the impact of a more complete detection of the Y_c decay products should be performed, even taking into account possible modifications of the proposed experimental set-up.

4. In order to establish the physics potential of this new proposal, P50 should provide a detailed comparison of the results expected on each Y_c state relative to those already available from the B factories.

Executive Summary

I. Estimation of the production cross section

Firstly, we estimate a level of the cross section of the $p(\pi^-, D^{*-})\Lambda_c$ reaction, based on the available measurements of the inclusive J/ψ productions in $\pi^- N$ collisions and of the semi-inclusive $\bar{D}$, D^{*-}, and/or Λ_c productions in the photon-induced reaction on a proton. Secondly, we estimate the cross section based on the theoretical models. Here, we revisit the Regge theory in addition to an estimation based on a naive t-channel D meson exchange model and a consideration on an application of the perturbative QCD. We also calculate the relative production rates of the excited states to that of the ground state Λ_c. We found interesting features of the production rates, which could provide information on the spin/isospin configuration of the charmed baryons.

(1) The measurement of the inclusive J/ψ production in a collision of a pion to a nucleus at p_π=16 GeV/c and 22 GeV/c shows the cross sections of (1.0±0.6) nb/nucleon and (3.1±0.6) nb, respectively [1]. Assuming that the ratio of the exclusive to the inclusive J/ψ production is 1/10 and the ratio of the associate to the hidden charm production is ∼20, which are estimated in the corresponding ϕ [2, 3] and associate $K^*\Lambda$ [4] productions, it is estimated that the cross section of the $p(\pi^-, D^{*-})\Lambda_c$ reaction could be a few nb.

(2) The cross section of the $\gamma(p, \Lambda_c D^{*-})X$ reaction is estimated as ∼18 nb by using the measurements of the $\Lambda_c\bar{D}X$, $D\bar{D}X$, $\bar{D}X$, and $\bar{D}^*X$ productions [5].

(3) We considered theoretical estimations.under consultations with several theorists.

- Considering the effective Lagrangians of the t-channel pseudoscalar (PS) meson exchange in the $\pi N \rightarrow VBreaction$, the cross section is calculated, where V and B represent a scattered vector meson and a baryon. Compared with the ρN production, the $\bar{D}^*\Lambda_c$ production cross section is reduced the 4th order of magnitude.
- We also considered if the perturbative approach in QCD (pQCD) is applicable. However, many difficulties are expected. Namely, the soft-QCD effects would be large at the J-PARC kinematics. Knowledge of the distribution amplitude of the charmed hadrons is necessary. It is challenging to obtain a reliable theoretical prediction even for the inclusive production because We still keep discussions so that pQCD could give us some reasonable order estimation of the cross section. In particular, the pQCD might work at a larger scattering angle region, where $|t|$ is as large as s and the hard process is expected to be more dominant.

(4) We revisited the Regge model to obtain a plausible theoretical estimation. Taking into account unknown factors of the transition form factors and the coupling constants in the $p(\pi^-, D^{*-})\Lambda_c$ reaction, a few nb for the cross section seems reasonable as an estimation for the present experiment.

(5) In order to evaluate the excitation energy dependence of the production rate, we demonstrated an yield estimation based on the t-channel $D*$ exchange scattering at a forward angle with harmonic oscillator wave functions for the initial and final quark states.

(6) The production rate is proportional to the spin and isospin dependent part and the overlap of the spatial distribution of the relevant waves. The spin/isospin dependent part, expressed by the product of the Clebsh-Gordan coefficients, carries information on the spin/isospin configuration of the charmed baryons. The overlap of the relevant waves are expressed as $\sim (q_{eff}/A)^L e^{-(q_{eff}/A)^2}$, where q_{eff} and A represent the effective momentum transfer and the oscillator parameters of relevant baryon's wave functions, respectively. See the attached report on the production cross section in more details. Taking the ratios of the production rates of the excited states to that of the ground state, the exponential part, $e^{-(q_{eff}/A)^2}$, is almost canceled. Thus, the spin/isospin configuration part can be extracted without depending on details of the spatial distribution of the baryon wave functions very much.

(7) The present model calculation suggests that the production rate is kept even at the higher L states, depending on spin/isospin structures of baryons. We expect the signal level of ∼nb for the Λ_c states even at the higher L states, On the other hand, ∼0.1 nb or less for some Σ_c states.

(8) We point out that the measurements of the production rates provide rich physics information;

   - The magnitudes of the coupling strength at the $Y_c N D^*$ and $Y_c N D$ vertices will be given by the production cross section.
   - The production rates of excited states with different isospin and orbital angular momentum will provide the information on the spin and radial wave functions of charmed baryons.

II. Background studies and detection of the Y_c decay products

Firstly, we report results of Monte-Carlo simulations if the background shapes of available data are reproduced with employing two hadron interaction codes, JAM and PYTHIA. Then, we report the studies of background reductions to improve the S/B ratios. At the recommendation of the PAC, we improve the spectrometer design to cover the decay products from populated excited charmed baryon states. We consider to use the pion beam at 20 GeV/c. This improve the acceptance of the scattered D^{*-} and the decaying particles from excited charmed baryon states very much, while the missing mass resolution is sacrificed by only about 10 %, as the contribution for the resolution is described in Appendix E of the attached document on the background studies. We demonstrate that the measurements of the decay products are feasible, identifying an excited state and an associate decay particle (a pion or a proton), where a corresponding daughter state (a low-lying charmed baryon state or the D meson) is also identified in the missing mass spectrum of the $p(\pi^-, D^{*-}a)$ reaction. Here a represents the associate decay particle.

(1) The background simulators of JAM and PYTHIA were checked by old experimental data in similar kinematical conditions. There are little available experimental data which clearly include the experimental information. As for the π^- p reaction, the BNL experiment [6] with the beam momentum of 13 GeV/c and the CERN experiment [7] with that of 19 GeV/c can be available. The absolute value of the background around the D^{*-} mass region (±20 MeV) can be checked by the BNL data. In addition, there are the cross section data of the charged track multiplicity [8, 9]. We found that the JAM code well reproduced not only the background shape but also the absolute value in the invariant mass spectrum reconstructed from $K^+, \pi^-\pi^-$. The ambiguity of the absolute value around the D^{*-} mass region (±20 MeV) was found to be 20−30%. The PYTHIA code showed a different shape, where the background event distribution is shifted more in the higher mass region. As a result, PYTHIA overestimated the number of background events at around the D^{*-} mass region by a factor of 4 although the overall background shape was not reproduced very well, as shown in Fig. 1 in the attached report on the background studies. For both simulator, the Lund string model was used for the hadronization process of which the parameterization of the input resonances were essential to reproduce the background shape. On the other hand, it was found that the contribution of the hard processes can be neglected.

(2) The background reductions were studied, taking into account the three kinds of possible background processes, multi-meson production including the strangeness production, wrong particle identification, and associated charm production. The strangeness production background is the main contribution of the background. By using the D^* tagging, the reduction of background events was found to be 2×10^6. Although the background level is still high by only using the D^* tagging, the other background reduction methods are applied for the farther background reduction. One method is the angular selection of K^+ and π^- which reconstruct the $\bar{D}^0$ mass in the center-of-mass system. The other is the event selections by using the kinematical conditions from the t-channel dominance of the $\pi^- + p \to Y_c^{*+} + D^{*-}$ reaction. By taking into the reduction by the D^* tagging and the possible event selections, the average background level

can be reduced to be 5 counts/MeV in the missing mass region of $2.2 - 3.4$ GeV/c^2 for a beam time of 100 days. The background from the wrong particle identification by considering the performance of the PID detector was checked. The contribution of the missing mass spectrum was the same level as of the strangeness production. The associated charm production events were simulated by the EvtGen code. The contribution was found to be minor compared with the strangeness production and the wrong particle identification events. Finally, we estimate that the average background level was 11 counts/MeV in the missing mass region of $2.2 - 3.4$ GeV/c^2. From the comparison of the JAM and PYTHIA code, the error of the background level by using the different MC codes was estimated to be a factor of 2. The sensitivity of the production cross section was found to be 0.1−0.3 nb from the simulation results.

(3) From the missing mass measurement, the recoil momentum vector of the produced Y_c^{*+} is measured so that the decay daughters such as $\Sigma_c(2455)$ and D^0 can be identified by only detecting the emitted π and proton from Y_c^{*+}. The setup of the spectrometer was modified for both the missing mass method and the decay measurement. Mainly, the internal detectors installed in the magnet gap were modified for measuring the wider angular distribution of the decay products. The original performances for the missing mass measurement was kept after the modification. The acceptance of detecting D^{*-} was more than 50% by assuming the production angle of $exp(bt)$ while the mass resolution of ∼10 MeV for excited charmed baryon states. From the modification of the internal detector system, the coverage of the decay products are increased to be ∼85% with both the polar and azimuthal angle completely covered more than $\cos\theta_{CM} = -0.5$ for the $\Lambda_c(2940)^+ \to \Sigma_c(2455)^{++,0} + \pi^{-,+}$ decay mode. The mass resolution for the decay products was estimated to be ∼10 MeV.

(4) The feasibility of the decay measurement was checked by using the EvtGen code 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 can be observed with the continuum background level. The background level was small enough to analyze the decay events. 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%). The 3 times larger signal events can be obtained. The number of decay events combined with both 2-body and 4-body mode are found to be more than 500 counts so that the branching ratios can be determined with the statistical error of less than 5% with the assuming branching ratio in the case of 1 nb production cross section. The sensitivities of the decay measurement for the $\Sigma_c + \pi$ and $p + D^0$ modes were estimated to be $\Gamma_{\Sigma_c\pi}$ =0.03 and Γ_{pD^0} =0.05, respectively. The angular distribution can be also measured by using those number of events with wide angular range. The information of the decay products can be obtained from the experiment.

III. Comment on the B-factories

(1) Typical statistics of the charmed baryons measured in the B-factories reported in literatures:

Belle:

* $\Lambda_c(2880)$, $\Lambda_c(2940) \rightarrow \Sigma_c \pi$ ~690 and ~220/553 fb^{-1} [10]
  c.f. :Babar($\Lambda_c(2880)$, $\Lambda_c(2940) \rightarrow Dp$ ~2800 and ~2280/287 fb^{-1} [11])
* $\Sigma_c(2800)^{0,+,++} \rightarrow \Lambda_c \pi^{-,0,+}$ ~2240, ~1540, and ~2810/281 fb^{-1} [12].
* Inclusively reconstructed Λ_c may be a several x10^4.

LHCb:

* $\Lambda_b \rightarrow \Lambda_c \pi$ ~70540/1 fb^{-4} [13]

(2) In Belle-II, they will increase two orders of magnitude. P50 may not be a rival in statistics. However the spectroscopic studies via the missing mass methods can provide unique/valuable information on the structure of charmed baryons.

* The production rates of excited states with different isospin and orbital angular momentum will provide information on the spin/isospin configurations of charmed baryons.
* We found that the production rate may not be suppressed very much because of the $(q_{eff}/A)^L$ dependence, as mentioned above. It is therefore interesting to compare the production rate of charmed baryons in different processes.
* The improved design of the spectrometer system could cover a wide angular acceptance for decay particles from excited states. Taking an advantage of the missing mass spectroscopy, we could provide the partial decay width easily from the yields of parent and daughter charmed baryons identified in the missing mass spectra.

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