E50 status report
(Executive Summary)

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I. EXECUTIVE SUMMARY

E50 has been approved as the stage-1 status at the 18th PAC. The PAC noted as follows.

i) The collaboration should not underestimate the difficulties posed by the detection of the tiny charmed-baryon signal via the missing-mass technique, which should remain the main goal of the experiment.

ii) The PAC emphasizes the importance of collaborative work with lattice QCD theorists to establish a coherent picture of excited hadrons with charm and strange quarks.

Keeping in mind these notes, we continuously keep close discussions with theorists and proceed preparation works on development of key detectors for the E50 experimental setup.

Recent progress for the theoretical estimations of the $\pi^- \, p \to \Lambda_c^+ \, D^{*-}$ reaction is briefly reported in section I A. Although it is still not easy to establish excited hadrons in Lattice QCD calculations, we follow a recent progress of the Lattice studies.

The above-mentioned theoretical estimation suggests that a production cross section of the $\pi^- \, p \to \Lambda_c^+ \, D^{*-}$ reaction is at a level of a few nb at a beam momentum of 20 GeV/c, as mentioned in section I A. In designing the detector system, we assume a typical production cross section of 1 nb in the $\pi^- \, p \to \Lambda_c^+ \, D^{*-}$ reaction. We have shown a sensitivity at a level of 0.1 nb in the proposal. However, we recognize key issues to develop a Ring-Image Čerenkov (RICH) counter for K/π identification in a range of 2∼16 GeV/c, high-rate trackers, and High-speed data acquisition (DAQ) system in order to achieve the design performance. Below in this document, the statuses of the preparation of the experimental apparatuses, the RICH counter, the high-rate tracking detectors, the choice of detectors for charmed baryon spectrometer and the DAQ system are summarized. More details for these detector developments are reported in a separate document.

A. Collaborations to theorists

We have refined the estimation of the cross section of the $\pi^- \, p \to \Lambda_c^+ \, D^{*-}$ reaction, based on two different theoretical frameworks, the reggeon exchange model and the effective Lagrangian method [1]. We refer to measured cross section data in the $\pi^- \, p \to \Lambda \, K^{*0}$ reaction. We have found in total that the reggeon exchange model excellently reproduces not only the energy dependence of the total cross section but also the differential cross sections as a function of t in the $\pi^- \, p \to \Lambda \, K^{*0}$ reaction, as shown in Figs. 1. The effective Lagrangian method substantially overestimates the cross section in the higher energy region. Assuming that the coupling constants of charmed meson and baryon vertices are the same as those for the strangeness production, we find that the total cross section for the charm production is about $10^3 \sim 10^6$ times smaller than the strangeness production depending on energy (s). Normalizing to the measured strangeness production cross section, we estimate

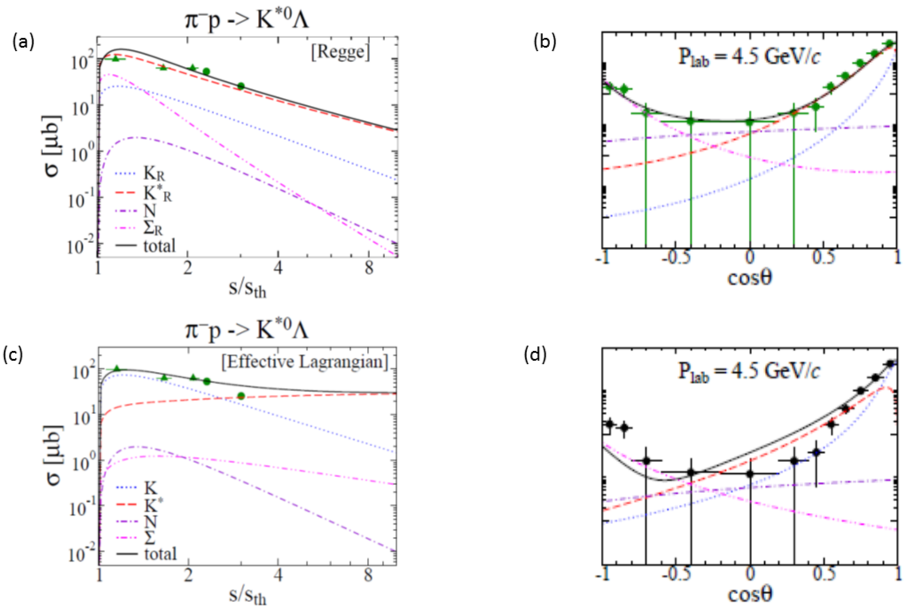

FIG. 1: Calculated total and differential cross sections of the $\pi^- \, p \to \Lambda \, K^{*0}$ reaction; (a) and (b) are total and differential cross sections calculated in the framework of the reggeon exchange model. (c) and (d) are those in the effective Lagrangian method. Here, s_{th} is the square of the threshold energy of the reaction.

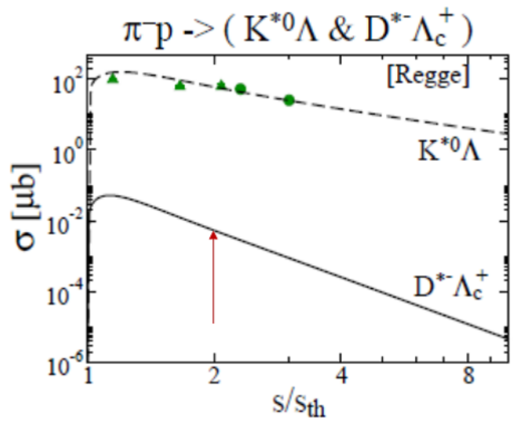

FIG. 2: Total cross sections of the $\pi^- \, p \to \Lambda_c \, D^{*-}$ reaction calculated in the framework of the reggeon exchange model. The quantity s/s_{th} is about 2 for the pion incident momentum of 20 GeV/c in the charm production, as indicated by an arrow.

that the charm production cross section is of order a few nb at a beam momentum of 20 GeV/c (Fig. 2), as consistent with the result of Ref. [2].

It is worthy to remark that there has been recently a progress on the hadron spectroscopy in Lattice QCD. By employing different types of interpolating fields for given quantum numbers, it is demonstrated that the calculated light flavor baryons are rather well classified by $SU(6) \times O(3)$ as predicted by the constituent quark model [3]. This suggests that low lying modes are well described by constituent quarks as effective degrees of freedom. This encourages further to explore the dynamics of a colored light quark pair though heavy baryon spectroscopy. We expect that the distinction of collective and relative motions of the diquark pair (the λ and ρ modes) is particularly useful.

B. Ring-Image Čerenkov counter

The cross section of the $\pi^- \, p \rightarrow Y_c^{*+} \, D^{*-}$ reaction is estimated to be at a level of nb [2], while the cross section to produce at least a kaon in the final state is a few mb. The wrong identification of those particles increases a background level drastically. Positive pions and protons increase the background level 2.4 times (240% increasing) in the inclusive $p\,(\pi^-, D^{*-})$ spectrum by assuming respectively only 3% of the wrong identifications of them. Therefore, a high performance of the PID counter is essential for the charmed baryon spectroscopy. Since the momentum range of scattered particles relevant to the charmed baryon productions is from 2 to 16 GeV/c, we designed a Ring Imaging Cherenkov (RICH) counter to identify π, K, and p for the scattered particles [4]. The performance of the designed RICH counter is evaluated by a Monte-Carlo simulation based on GEANT4. The PID performances for π, K and p are found that the particle detection efficiencies are 99% and the wrong identification ratios of pions and proton to kaons are 0.10% and 0.14%, respectively. The contribution to the background in the inclusive $p\,(\pi^-, D^{*-})$ spectrum from the wrong particle identification is estimated to be 5%. The obtained performances is satisfied to the requirements of the PID counter.

The PID performance of RICH counter is determined by angular resolution of the Cherenkov angle which depends on the position resolution of the photo-detection plane. In order to obtain enough resolution with a large acceptance, it is necessary for the spherical mirrors and 2 pieces of photo-detection plane which have size of 2.0×1.0 m constructed by more than 2000 photon sensors. We plan to use the multi-pixel photon counter(MPPC) as a photon sensor. The MPPC can detect 1 photon with good separation which is advantageous to detect feeble Cherenkov photons. In addition, it is not affected by a magnetic field as compared to the PMT. However, it is expected that a larger dark current rate of MPPC which is typically 100 kHz/mm^2 increases noise hit. Consequently, the PID performance may become worse. For studying the performance of the spherical mirrors and the MPPC detector plane, the test experiment was performed by using an electron beam at the GeV-γ experimental hall in the Research Center for Electron Photon Science (ELPH). The electron beam is suitable to study the response of the the spherical mirrors and the MPPC detector plane because the Cherenkov angle can be fixed as the same value due the particle velocity (β) which can be assumed to be 1. Electron beam which has momentum of up to 700 MeV/c

was induced to a prototype RICH counter. Air was used for radiators which have refractive indices of 1.000293. We used the S12642-0808 module made by Hamamatsu Photonics as a photo-detection plane which has 64 segments (8×8) and each segment size is 3.1×3.1 mm^2. Detail analysis is still on-going. However, we have already observed clear Cherenkov ring images with a typical angular resolution of 3.0 mrad, even at a preliminary result.

The details of the RICH counter are described in Sec.III of the separate report.

C. High-rate tracking detector

The intense π^- beam of 6.0×10^7/spill (30 MHz for the 2 sec extraction) is planned to be used in the experiment. The production cross section of the charmed baryon is expected to be small so that it is essential for the experiment to use the intense beam. For the beam measurement, a high-rate counters, such as a scintillating fiber tracker and a silicon strip detector, will be installed. Those counters is needed to be satisfied under the operation by assuming the beam with size of 100×100 mm^2 and expecting total counting rate of 30 MHz. For the experiments at the hadron facility, a uniform beam within an extraction period should be supplied to the experimental area. In the case of the present J-PARC, the beam orbit in MR is not stable and the extracted beam has a non-uniform time structure. We should take into account not only the high counting rate beam but also the bad time structure for the measurement of the high-rate beam. The high-rate pion beam was used for the past experiment, J-PARC E10 [5], at the K1.8 beam line. In the experiment, the intense pion beam of 12 M/spill (6 MHz) was used. For measuring the pion beam, we replaced the tracking detectors to the high-rate ones, in particular, at the places where the counting rate exceeded the limit of previously installed tracking detectors. Using those high-rate detector and tracking analysis method, we could use the beam intensity of more than 10 M/spill which could not be treated by using only the conventional tracking detectors such as MWPCs and drift chambers.

The most important point of the past E10 experiment is to measure the high-rate beam with a "narrow time gate". The drift chamber needed a time gate of $\sim$50 ns, while the scintillating fiber tracker was $\sim$1 ns. It is obvious for the rejecting power of the accidental beam hits. Therefore, it is a key to use a high-rate detector having a fast time response for a narrow time gate which enables us to measure the correct tracking events. In the E50 experiment, the counting rates on the beam line and at the downstream of the target are very high. We choose the scintillating fiber trackers for the beam line and the target downstream part. The researches and developments of the scintillating fiber trackers are planned.

The details of the high-rate tracking detectors are described in Sec.IV of the separate document.

D. Other detectors

For the charmed baryon spectrometer, we plan to install the timing counter for determining the reference timing (time zero), the tracking detectors having a large acceptance and the counter for the Time-Of-Flight measurement. The summaries of those counter are listed as follows. The details of the counters are described in Sec.V of the separate document.

- Reference timing should be determined by the time definition (time zero) counter. The counter is needed to be operated in the counting rate of 3 MHz per one segment, while it is required to have a good time resolution less than 100 ps(rms). We plan to develop the time zero counter which is the combination of a fine segmented plastic scintillator and MPPC.
- Tracking measurement at the downstream of the experimental target, the inside of the magnet and the downstream of the magnet is necessary to cover large acceptances. We chose wire chambers such as drift chamber and straw tube chamber as those large size trackers.
- TOF counter is installed at the downstream of spectrometer magnet between the drift chamber and scattered particle RICH. Because the particle identification by the Time-Of-Flight method is difficult for the high-momentum particle with 2-16 GeV/c, the role of the counter is to determine time reference for the downstream drift chamber and RICH.
- Internal TOF counter is installed inside of spectrometer magnet. The function of the counter is to identify scattered particles having a momentum of less than 1.7 GeV/c, and to determine the time reference for the internal drift chamber.
- Pole face TOF counter is installed on the magnet pole face for mainly detecting vertically scattered particle from the charmed baryon decay events.

E. DAQ

The DAQ system for the charmed baryon experiment is one of the big issues. Since the production rate of the hadronic events is so huge that the data acquisition system needs to have to tolerant such a severe experimental environment. The grand-design of the DAQ system is reported.

The conceptual schematic of the DAQ system is following. Detector signals are digitized on front-end electronics modules placed near the detectors. Those modules have a pipelined data transfer with a high-speed data link. The data of front-end modules are transferred by a self-trigger (or a periodic trigger) to buffer PCs. The PC nodes at the first stage plays as buffers and load balancers, which store the data and switch a destination of the data spill by spill. The PC nodes at the second stage plays as event filters. Each filter node performs the cellular automaton tracking, analyzes the RICH data, scaler counting and writes the data into the local storage device. A part of data are visualized on monitoring PCs. Since the price of several tens to a hundred GB memories becomes not so expensive nowadays, each node can be equipped with an enough memory to store the whole data of one spill. Then, the recorded data are forwarded to the KEKCC and the computing farm at RCNP.

For the trigger, we plan to construct a software trigger system including the tracking analysis such as a cellular automaton track finder and a Kalman filter based track fit, which uses a commercial CPU cluster for the on-line trigger decision in the similar way of the CBM on-line computing. The CBM experiment at FAIR demonstrates the performance of their first level event selection (FLES) package for simulation data, which utilizes a many-core CPU/GPU farm [6]. A cellular automaton track finder and a Kalman filter based track fit are massively parallelized in the FLES package. They achieved the track reconstruction rate of faster than 100 μsec/track/physical-CPU-core, with Intel Xeon E7-4860 CPUs. Assuming the same level of the track reconstruction performance, 60k tracks/core is expected for the 6-seconds spill of the J-PARC slow extraction. In order to satisfy the E50 requirement, where $1.1-2$ M$\times 4$ = $4.5-8$M tracks/spill must be reconstructed for the events, 100-200 CPU cores are needed. The feasibility and optimization including a utilization of the many-core hardware accelerators/co-processors (Intel Xeon Phi, NVIDIA Tesla GPU, etc.) will be studied.

For satisfying the request of the E50 data data taking system, the front-end electronics modules having a pipelined data transfer with a high-speed data link are being developed. Considerable number of MPPC will be used in E50 for readout of scintillation fiber trackers, ring imaging Čerenkov counters and timing counters, we are developing a modules for a multi-channel MPPC readout such as CITIROC and PETIROC [7], a upgraded EASIROC [7] which has been successfully used by many groups. For the readout of the other detectors, there are several R&D for the front-end electronics, a high resolution TDC for the timing counters, RPC readout electronics composed of discrete broadband preamplifiers, and wire chamber front-end electronics having a ASD chip and signal digitization with a TDC module.

The the software trigger technique and the front-end electronics modules having universal functions can satisfy the requirements of many experiments so that they can be standard techniques and modules for the hadron hall experiment and so on in the future. The collaboration with other groups is important for developing electronics modules. The details of the DAQ system are described in Sec.VI of the separate documents.

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