PROCEEDINGS OF SCIENCE

Baryon spectroscopy in (π,2π) reactions with 10^6Hz pion beams at J-PARC

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Although baryon resonances (N* and Δ*) have been studied for a long time, our knowledge on their mass spectra and properties are still limited due to their overlapping spectra with large widths. Recently a Dynamical-Couple Channel model shows there are significant contributions of (π, 2π) reactions to high mass baryon resonances. However, there are only 240 thousand events of (π, 2π) reaction data which was mainly measured in 1970's. Thus, we proposed an experiment E45 to study baryon resonances in (π, 2π) reaction utilizing 10^6 Hz $\pi^\pm$ beams at J-PARC. We aim at clarifying most of baryon mass levels with (π, 2π) data with the increased statistics by two orders of magnitude. We also search for exotic baryons such as hybrid baryons predicted by lattice QCD calculations. We measure reactions of $\pi^-p\to\pi^+\pi^-n$, $\pi^0\pi^-p$ and $\pi^+p\to\pi^0\pi^+p$, $\pi^+\pi^+n$, as well as $\pi^-p\to K^0\Lambda$ and $\pi^+p\to K^+\Sigma^+$ in a large acceptance Time Projection Chamber (HypTPC) inside a Helmholtz dipole magnet. We trigger these reactions by requiring two charged particles in the hodoscope counters surrounding HypTPC. HypTPC is placed inside a superconducting Helmholtz type dipole magnet with the magnetic field of 1.5 T. We will measure these reactions in small momentum steps over a large beam momentum range and perform partial wave analysis to extract properties of each resonance. In this work, we will show the experimental design, expected results in simulations, and the status of the detectors.

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1. Introduction

There are still many missing light baryon resonances (N* and Δ*) and those which have not been established well experimentally in Particle Data Group (PDG). It is difficult to resolve these resonances clearly due to overlapping mass spectra of wide resonances. To cope with this problem, a Dynamical-Couple Channel (DCC) model has been developed [1,2], which includes ππN channels such as ηN, πΔ, σN, and ρN. The model shows baryon resonances up to 2 GeV/c^2 have large contributions of ππN decay channels. On the other hand, the resonances in PDG have been measured mostly from (γN→πN and πN→πN) reactions only. There exist only 240 thousand events of (π, 2π) reaction data which was measured mostly in 1970's [1]. Thus, we proposed an experiment E45 to study baryon resonances in (π, 2π) reaction utilizing 10^6 Hz $\pi^\pm$ beams at J-PARC. Our goal is to determine most of baryon mass levels by increasing (π, 2π) data with the increased statistics by two orders of magnitude. We also search for exotic baryons such as hybrid baryons (*qqqγ*) predicted by lattice QCD calculations [3].

2. J-PARC E45 experiment

The goal of E45 is to measure (π,2π) reactions in large acceptance TPC (HypTPC) in wide range acceptance and beam energies for partial wave analyses. At the J-PARC K1.8 secondary beam line, we inject 10^6Hz $\pi^\pm$ beams on the liquid hydrogen (proton) target. We measure 4 reaction channels of $\pi^- p\to\pi^+\pi^- n$, $\pi^- p\to\pi^0\pi^- p$, $\pi^+ p\to\pi^0\pi^+ p$, and $\pi^+ p\to\pi^+\pi^+ n$. In these reactions, there are commonly two charged particles and a neutral particle in the final state. To trigger these reactions, we require two charged particles hits in the TPC hodoscope which surrounds the TPC. By using this trigger, we can also measure the two additional channels includes hyperons; $\pi^- p\to K^0\Lambda$, and $\pi^+ p\to K^+\Sigma^+$. The latter is particularly important since it is sensitive to $\Delta*$ of $I=3/2$.

The E45 setup is shown as Fig. 1. The main detector of the experiment is HypTPC, which is installed inside a superconducting Helmholtz dipole magnet with a vertical magnetic field. The magnetic field is for momentum analysis. The HypTPC contains a liquid hydrogen target inside the drift volume, which is inserted inside the cylindrical target holder from the top of the TPC, as shown in Fig. 2. HypTPC, as shown in Fig. 2, has an octagonal-prism shape. The vertical electric field of 180V/cm is applied in the drift volume, which is filled with P-10 gas (Ar-CH_4 90:10). The drift velocity is around 5cm/us. Due to also vertical magnetic field, the transvers diffusion side is reduced so that we have good position resolution. The electrons along particle trajectories drift downward and pass through the gating grid wire plane, and reach GEMs for amplification. The pad plane at the bottom consists of concentrally arranged approximately rectangular pads of 2.5 mm width and 10-12 mm length typically. A designed Typical hit position resolution is 200-300 μm with the magnetic field of 1 T. The configuration of GEMs is three layer stack, with 100um thick GEM at the top and two 50um thick GEMs in the middle and the bottom layers. The gain is around 10^4.

HypTPC is a high-rate capable TPC, which accepts pion beams of 10^6Hz directly in the drift volume. The TPC was constructed and is under performance evaluation. The most crucial problem for high rate beams is electric field distortion due to ion backflow from GEMs. To copy with this, we adopt double absorption of position ions with GEMs and the gating grid.

In the prototype TPC test up to a 10^6Hz proton beam, the hit position distortion with gating grid operation was measured to be within ±100 μm, which is good enough compared to the position resolution [4]. We also evaluated efficiency which was more than 95% at the beam rate up to 10^6 Hz.

The Helmholtz dipole magnet wad fabricated in Korea and was delivered to KEK in 2016. It was designed to produce vertical magnetic field up to 1.5 T. The transverse field component is at most 3% in the TPC sensitive volume.

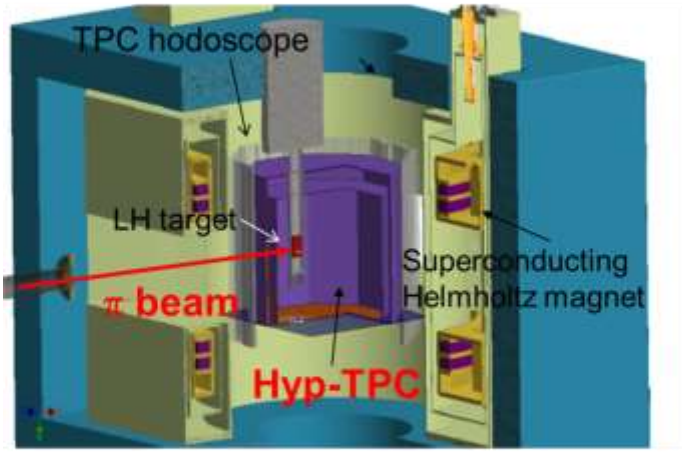

Figure 1: J-PARC-E45 experimental setup.

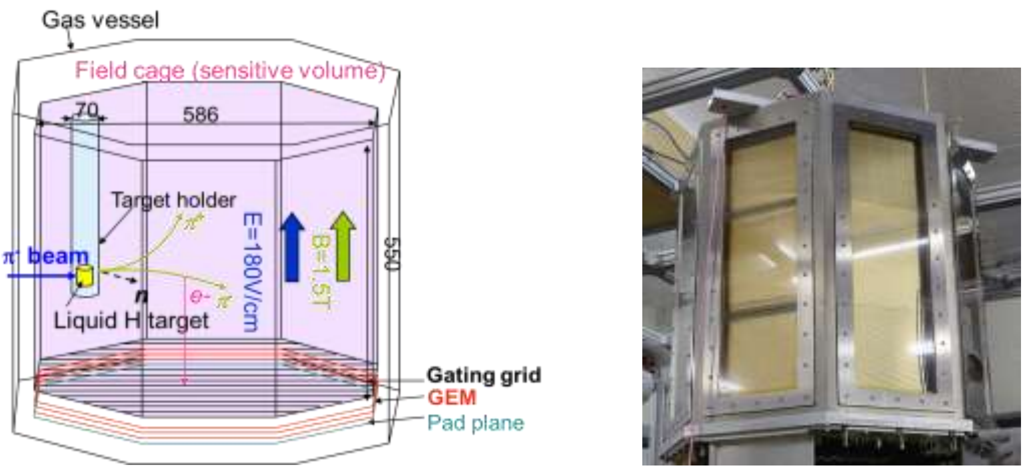

Figure 2: A schematic view (left) and a photograph of HypTPC (right).

1.1 Expected performance of the experiment with simulation

We have evaluated performance of the E45 spectrometer. The solid angle of HypTPC is close to 4π, since the target is inside the TPC. The TPC hodoscope only covers the side of the TPC as shown in Fig. 1, so that the acceptance is limited. The acceptance of $\pi^+p\rightarrow\pi^+\pi^0p$ reaction is shown in Fig. 3 (left). The acceptance depends on the π^+ beam energy, but almost uniform in the proton center of mass angle. It ranges from 40% to 80%.

The separation among π, K, p is crucial to identify (π,2π) reactions, which will be done using energy loss in the HypTPC. The simulated energy loss as a function of rigidity is shon in Fig. 3 (right). π and p can be separation is up to 1.1 GeV/c, and π and K can be separated up to 0.5 GeV/c.

The major background of (π,2π) reactions is elastic scatterings (πp→πp). They can be suppressed offline by requiring that an incident beam momentum vector and the sum of the momentum vectors of two produced charged particles are not aligned.

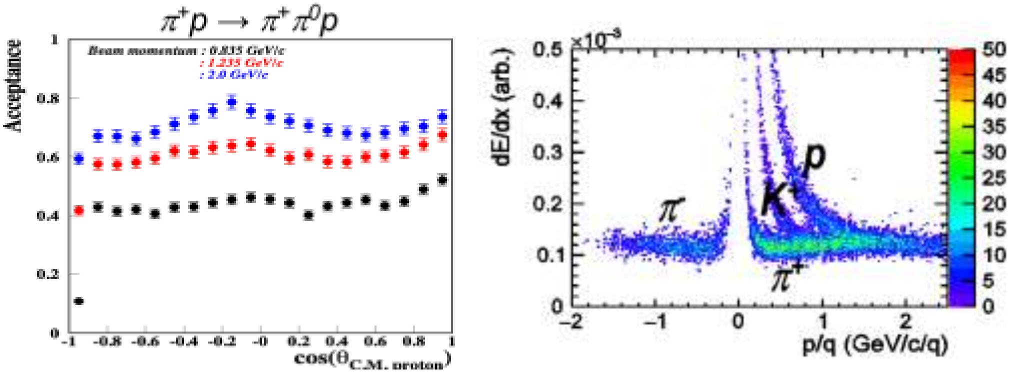

Figure 3: Acceptance with the TPC hodoscope for $\pi^+p\rightarrow\pi^+\pi^0p$ reaction (left). Particle sepatation performance with dE/dx and momentum.

1.2 Expected statistics

Expected statistics of E45 is summarized here. Assuming the π beam rate of 10^6 / spill of 6s, the thickness of the liquid hydrogen target of 5 cm, the HypTPC acceptance of 40%, and (π,2π) cross sections of 2 mb, the event rate is 160 events / 6s. The rate of elastic scattering background is 3200 events / 6s, assuming its cross section of 40 mb.

In E45 experiment, we cover the center-of-mass kinetic energy range from 1.50 to 2.15 GeV. We separate the energy range and the proton-center-of-mass angle into 24 for π^- (or 23 for π^+) and 20, respectively. The total number of events in the experimental period of 15 days will be 30 million events, which corresponds to 32 thousand events per energy-angle bin. The statistics exceeds the world's ππN reaction data of 240 thousand by factor of 130.

3. Summary

In order to resolve most of nucleon and delta resonances up to 2 GeV/c^2, we proposed (π, 2π) experiment at J-PARC with the statistics with two-orders of magnitude higher than previous experiments. The experiment is based on a large acceptance TPC which can accept extremely high rate π beams of 10^6 Hz. The TPC and the superconducting Helmholtz magnet were already constructed and its final performance evaluation at high rate will be performed in 2017. The liquid hydrogen target will also be constructed in 2017. The experiment will be ready in 2018.

References

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