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TOWARD A STUDY OF Λ(1405) VIA THE D(K-, ΠΣ) REACTION

There is a long-standing argument if Λ(1405) is a KbarN bound system. Theoretical analyses of Chiral Unitary model, suggests a double-pole structure of Λ(1405): Σϖ and KbarN. The theoretical statement about the double pole structure of Λ(1405) shows a new picture of Λ(1405) as a resonant meson-baryon state, which is different from the so-called traditional picture of Λ(1405). In order to solve above-mentioned questions, it is necessary to clarify how Λ(1405) is coupled to KbarN. Therefore, we have conducted an experiment to study Λ(1405) in KbarN scattering (E31). Since Λ (1405) cannot be formed directly from the K-p reaction in free space, we use the d(K-, n)Σϖ reactions at a kaon momentum of 1GeV / c, where we expect the incident kaon to knock out a neutron in the deuteron and the recoiled Kbar reacts with the residual nucleon with the formation of Λ(1405).

We have finished a beam time for the second run of E31 in January and February, 2018. The E31 experiment is performed at the K1.8BR beam line in the Hadron Experiment Hall of J-PARC. In the second run, by increasing statistics to several times, we expect to measure Λ(1405) in the Σ+ϖ-/Σ-ϖ+ invariant mass spectra in the d(K^-, Σϖ)"n". In particular, we expect to measure angular dependence of widely production of Λ(1405) in the d(K^-, Σϖ) reaction.

Key words: kaon,E31, invariant mass spectrum.

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d(K- ,ϖΣ) реакциясы арқылы Λ(1405) зерттеу

Λ(1405) гипероны KbarN жүйесімен байланысты деген бұрыннан келе жатқан теория бар. Хиральды жалпы модель теориясы, Λ(1405) гипероны екіполюсті құрылымға ие екендігін көрсетеді: Σϖ и KbarN. Бұл теория бойынша, Λ(1405) мезон- барионды күйдің резонансы ретінде жаңашылдық тудырады. Жоғарыда аталып өтілген сұрақтардың шешімін табу үшін, Λ(1405) гипероны KbarN жүйесімен қалай байланысқанын анықтау қажет. Сол себепті, KbarN шашырауындағы Λ(1405)-ты зерттеу үшін эксперимент жүргіздік (E31). Λ(1405) резонансы Kp реакциясында ашық немесе бос күйде алынбайтындықтан, (K-, n) Σϖ сатылы реакциясын пайдаландық. Бұл аталмыш реакциядан, каон дейтронның ішіндегі нейтронды ұшып шығарып, ал реакция нәтижесндегі Kbar қалған бір нуклонмен әрекеттесіп Λ(1405) резонансын тудырады.

Жоғарыда аталып өтілген E31 эксперимен үстіміздегі жылдың қаңтар және ақпан айларында K1.8BR тізгініндегі J-PARC эксперименттік алаңында жүргізілді (Жапония). Эксперименттің екінші бөлігінің негізгі мақсаты, статистиканы бірнеше есе өсіріп, d (K-, Σϖ) «n» реакциясындағы Σ + ϖ- / Σ-ϖ + инвариантты массаның спектрлерін анықтау арқылы Λ (1405)-ты зерттеу. Сонымен қатар, Λ (1405)-тың қалыптасуының бұрыштық тәуелділігін анықтау.

Түйін сөздер: каон, E31, инвариантты масса спектрлері.

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Изучение Λ(1405) с помощью реакции d(K-, ϖΣ)

Существует теория, что Λ(1405) является связанной с KbarN системой. Теоретический анализ хиральной общей модели предполагает двуполюсную структуру Λ(1405): Σϖ и KbarN. Теоретическое утверждение о двухполюсной структуре Λ(1405) показывает новую картину Λ(1405) как резонансное мезон-барионное состояние, которое отличается от так называемой традиционной картины Λ (1405). Чтобы решить вышеупомянутые вопросы, необходимо выяснить, как Λ(1405) связан с KbarN. Поэтому мы провели эксперимент по изучению Λ(1405) в рассеянии KbarN (E31). Так как Λ(1405) не может быть образовано непосредственно из реакции Kp в свободном пространстве, мы использовали реакцию d(K-, n) Σϖ при импульсе каона 1GeV/c, где мы предполагаем, что инсидентный каон выбивает нейтрон из дейтрона и отбитый Kbar реагируют с другим нуклоном с образованием Λ (1405).

В январе-феврале 2018 года был закончен эксперимент для второго запуска E31. Данный эксперимент E31 был запушен на линии пучка K1.8BR в экспериментальном зале J-PARC в Японии. Во второй части эксперимента E31, увеличивая статистику до нескольких раз, мы ожидаем измерение Λ (1405) в Σ + ϖ- / Σ-ϖ + спектр инвариантных масс в d (K-, Σϖ) «n». В частности мы хотим измерить угловую зависимость образования Λ (1405) в реакции d (K-, Σϖ).

Ключевые слова: каон, E31, спектр инвариантной массы.

Introduction

Λ(1405) is one of well-known hyperon resonances, which has a mass, width and spin-parity of 1405.1+1.3-1.0 MeV/c2, 50±2MeV, and 1/2-, respectively [1]. But, the review of particle physics [2] adopted the mass and width of the Λ(1405) state obtained by analyzing the invariant mass spectrum of Λ(1405) in the final Σ + π- state via the 4.2 Gev/c K- induced reaction on hydrogen [3, 4]. It has the lightest mass in negative parity baryons, which is hardly explained by the simple quark model [5]. Since the Λ(1405) is located just below the KbarN threshold, there are longstanding argument if it is a KbarN bound state. Theoretical analysis of Chiral Unitary model [6], suggests a double-pole structure of Λ(1405): Σπ and KbarN [7]. The theoretical statement about the double pole structure of Λ(1405) shows a new picture of Λ(1405) as a resonant meson-baryon state, which is different from the so-called traditional picture of Λ(1405). Unfortunately, statistics in experimental data seems poor and 2 π0 in the final state cannot be distinguished kinematically each other. Recently, the γp → K+π+Σ− and K+π−Σ+ reactions were measured at LEPS/SPring-8 [8]. Although the statistics is limited, they claimed the interference between the I=1 and I=0 amplitudes. The K-d → π+Σ−n reaction was reported [9], which shows a clear peak at the Λ(1405) mass region. This reaction seems promising to study Λ(1405). In experimental situation, some reports about Λ(1405) show its spectrum shape depending on the reaction process. Therefore experimental study of KbarN coupled to the Λ(1405) is desired.

A repulsive shift of K-p atomic state at 1st energy region [10] arises an interesting discussion of deeply bound kaonic nuclear states [11], where Λ (1405) is interpreted as a bound state of KbarN system with the binding energy of as deep as 27 MeV [12]. On the other hand, a chiral unitary model calculation claims that Λ (1405) may consist of two components in the coupled-channel KbarN-πΣ system [13]. Namely, poles coupled to the πΣ state and KbarN state are suggested at different positions, (1390 – 132i) MeV and (1426 –32i) MeV, respectively [14]. As a consequence, the resonance position of the KbarN → πΣ channel sits at about 1420 MeV and the binding energy is as shallow as 15 MeV. This situation obviously affects the property of the deeply bound kaonic nuclear states. In order to clarify which picture is valid, decomposition of Λ (1405) states coupled to KbarN is of essentially importance. Since Λ (1405) lies below the KbarN threshold and has no decaying channel coupled to KbarN, it is vital to investigate a KbarN collision process in a virtual state.

The E31 experiment is performed at the K1.8BR beam line in the Hadron Experiment Hall of J-PARC [15, 16]. Since Λ (1405) cannot be formed directly from the K-p reaction in free space, we used the KbarN scattering process [17] as a d(K-, n)Σπ two steps reactions at a kaon momentum of 1GeV / c, where we expect the incident kaon to knock out a neutron in the deuteron and the recoiled Kbar reacts with the residual nucleon with the formation of Λ(1405) (Fig. 1). We will measure the Λ(1405) spectrum shape in a Σ + π- / Σ-π + invariant mass spectrum of the d (K-, Σπ) «n» reaction.

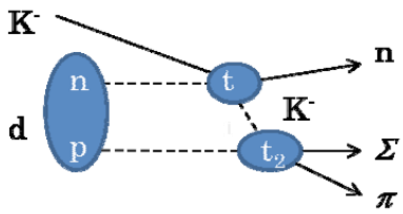


Figure 1 – (K-,n) Reaction Diagram

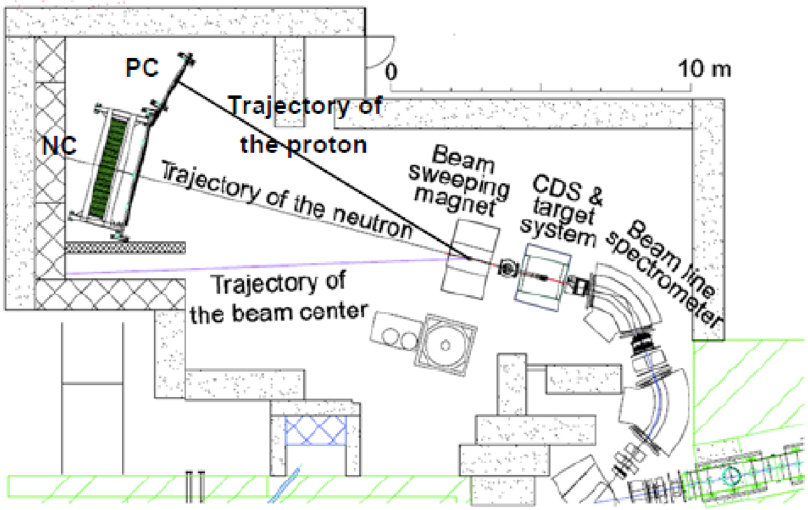


Figure 2 – Schematic view of the K1.8BR spectrometer

E31 experimental setup

The E31 experiment is performed at the K1.8BR beamline in the Hadron Experiment Hall of the J-PARC. The schematic drawing of the K1.8BR spectrometer and E31 setup is shown in Fig. 2 [18]. The beam momentum is analyzed by a beam-line spectrometer with a resolution of 2.2 MeV/c at 1.0 GeV/c. Decay charged particles associated with the d(Kbar ,n) reaction are measured by the cylindrical detector system (CDS) surrounding the target to obtain those of momentum and TOF, which also make it's particle identification possible. CDS operates in a magnetic field of 0.7 T. The Neutron Counter (NC) and Proton Counter (PC) which detects forward scattered neutron and proton are placed 15 m ahead in the forward direction. Since Λ(1405) is recoiled backward, the decay proton from Σ0π0 mode (0π0 → Λγπ0 → pπ-γπ0) [19] is emitted backward, which is detected by backward proton detector (BPD) and chamber (BPC) placed in the upstream of the target.

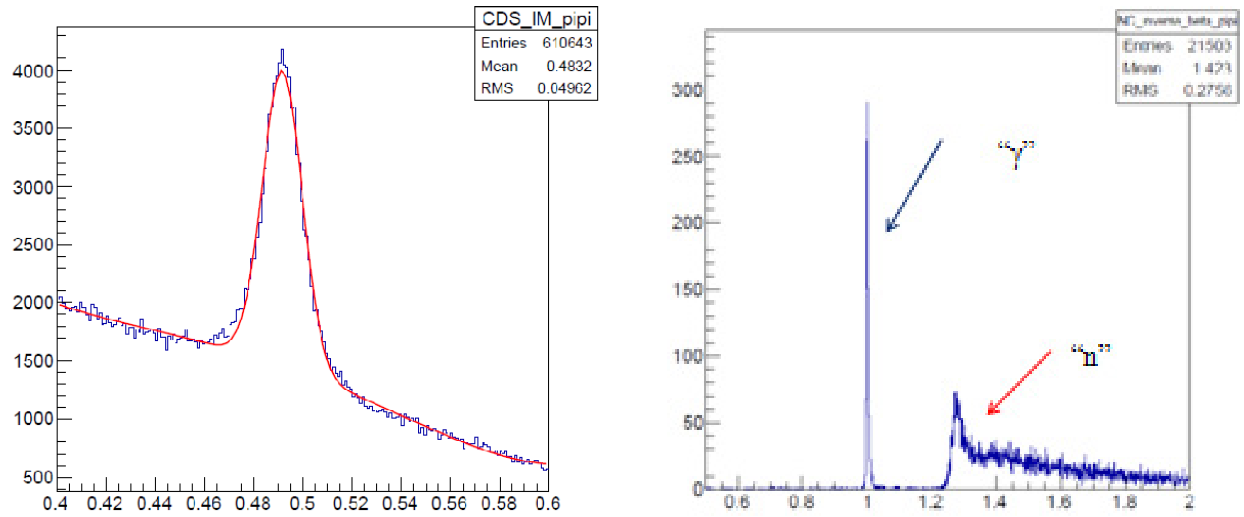
Preliminary results

The second E31 physics run was performed in January and February, 2018. About 40GeV kaons were used. π- / π + and neutrons particles are detected by CDS and NC, respectively (Fig. 3). Among these events X="n" is identified in the missing-mass spectrum of the d (K-, Σπ) «X» reaction, as shown in Fig.4.

Also, for investigation of Λ(1405), we have to identify Σ+ and Σ-. By using the information and data, which mentioned in the Fig. 3 and Fig. 4., we can easily define Σ+ and Σ- spectrums, as shown in Fig. 5.

We decomposed the d (K⁻, Σπ)"n" spectrum into d (K⁻, Σ+π-)"n" and d (K⁻, Σ-π+)"n". The decomposed Invariant Mass of the $\Sigma\text{-}\pi^+$ and $\Sigma\text{+}\pi^-$ in the d (K⁻, Σπ)"n" reaction are shown in Fig. 6. The difference of the two spectra is observed clearly. Also, we can clearly see the peaks, which correspond to Λ(1405) and Λ(1520).

But, we have to noticed that Λ(1520) is used as a reference, actually we are interested in Λ(1405).



Invariant Mass of $\pi^+\pi^-$ (GeV/ c²) 1/β

Figure 3 – (left) Identification of π- / π + by using CDS detector. (right) 1/ β distribution of the forward neutral particles detected with the NC

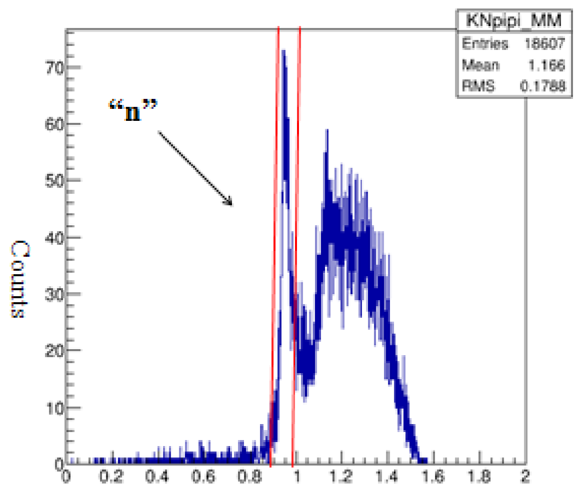


Figure 4 – Missing Mass of d(K⁻, $n\pi^+\pi^-$)"X" (GeV/c²)

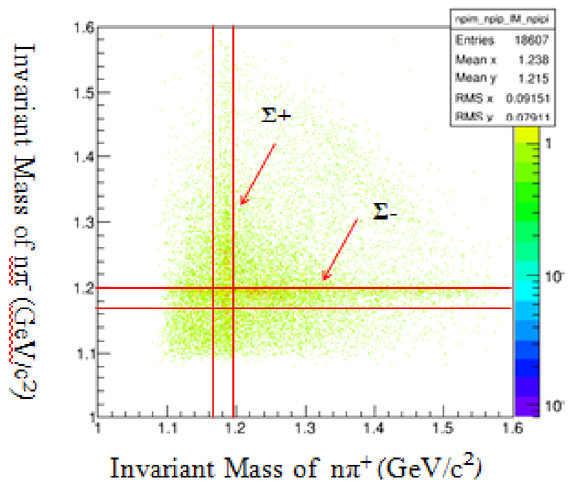


Figure 5 – Invariant Mass of $n\pi^+$ and $n\pi^-$.
The strong focusing cross-image corresponds to Σ-decay event

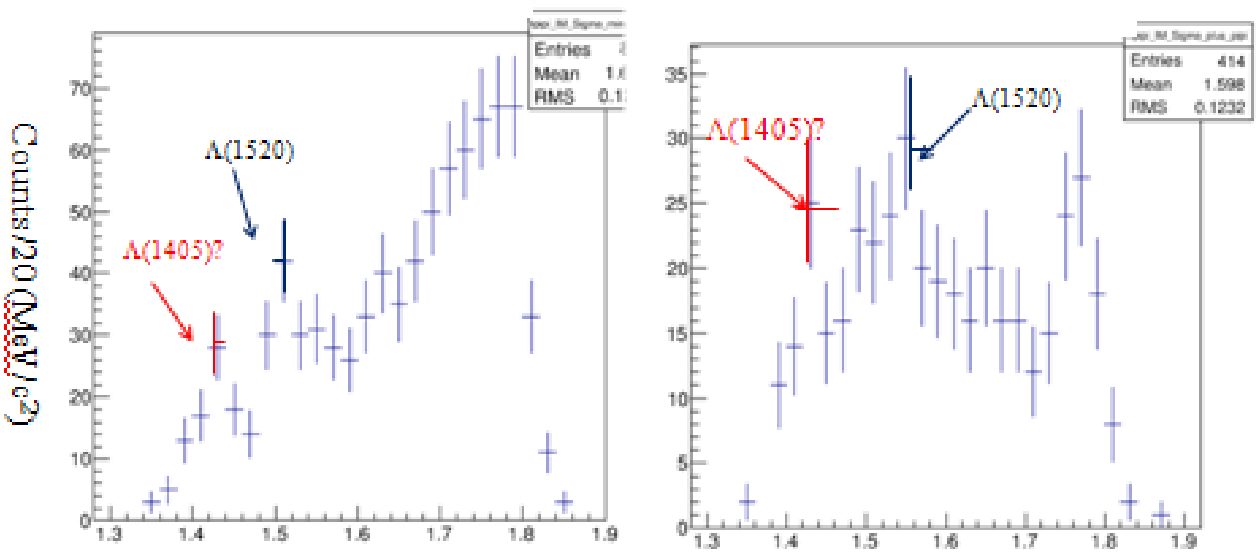


Figure 6 – Invariant Mass of Σ-π^{+} and Σ+π^{-}(GeV/c²) in the d (K⁻, Σπ)”n” reaction

Conclusion

The J-PARC E31 experiment was performed to investigate the spectrum shape of Λ(1405) directly generated in KbarN → Σπ by the d (K⁻, Σπ)”n” reaction at the incident kaon momentum of 1.0 GeV/c. The second E31 physics run was performed in January and February, 2018. The experiment for E31 second physics run is performed at the K1.8BR beamline in the Hadron Experiment Hall of the J-PARC [20]. About 40GeV kaons were used. The difference of the d (K⁻, Σ+π-)”n” and d (K⁻, Σ-π+)”n” spectrums shown clearly. We have to noticed that these preliminary results based on the first E31 physics run. We could increase 10 times more statistics and measure angular dependence of widely production of Λ(1405) in the d (K⁻, Σπ)”n” reaction.

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