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EXPERIMENTAL STUDY OF Λ(1405) VIA THE D(K- ,ΠΣ) REACTION AT J-PARC K1.8BR

The Λ(1405) baryon resonance plays an outstanding role in various aspects of hadron and nuclear physics. It has been considered that the Λ(1405) resonance is generated by the attractive interaction of the antikaon and the nucleon as a quasi-bound state below its threshold decaying into the ϖΣ channel. Thus, the structure of Λ(1405) is closely related to KbarN interaction. In this paper, after reviewing the basic properties of the Λ(1405) resonance and introduction to the experiment, which is performed at the K1.8BR beamline in the Hadron Experimental Hall of J-PARC, Tokai, Japan in January and February 2018, we introduce the spectral shapes which are taken by the data analysis. We have finished a beam time and data taking for the second run of E31. In the second run, we could increase the statistics several times. Based on the second run data, we analyzed the Σ+ϖ- and Σ-ϖ+ invariant mass spectra in the d(K-, Σ+ϖ-)»n» and d(K-, Σ-ϖ+)»n» reactions, respectively, where «n» is clearly identified in the missing mass spectrum of each reaction. Also, we considered the background events to estimate the sideband and get the correct peak structure of Λ(1405).

We summarize the recent progress in the investigation of the Λ(1405) structure and discuss the future perspective of the physics of the Λ(1405) resonance.

Key words: kaon, E31, invariant mass spectrum.

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J-PARC K1.8BR- ДА d(K- ,ϖΣ) реакциясы арқылы экспериментте Λ(1405) зерттеу

Во второй части эксперименте E31, увеличивая статистику до нескольких раз, мы ожидаем измерение Λ(1405) в Σ+ϖ-/Σ-ϖ+ спектр инвариантных масс в d(K-, Σϖ) «n». Кроме того, мы рассмотрели фоновые события, чтобы оценить боковую полосу и получить правильную структуру спектрального пика (1405).

Λ (1405) барионды резонансы адрондар және ядролық физиканың әр түрлі салаларында маңызды рөл атқарады. Λ (1405) резонансы тартылу күші арқылы антикаон және нуклон түрінде квази байланысқан күйдің төменгі табалдырығында ϖΣ-каналына ыдырайды. Осылайша, Λ (1405) құрылымы KbarN әсерлесуімен тығыз байланысты. Бұл мақалада, Λ (1405) негізгі қасиеттеріне және 2018 жылдың қаңтар және ақпан айларында K1.8BR тізгініндегі J-PARC, Токай, Жапония экспериментальды алаңында жүргізілген тәжірибеге кіріспе жасаймыз және деректерді анализ жасау барысында алынған спектрлермен танысамыз. 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, бүйірлік жағдайларды бағалау және дұрыс спектрлік шыңдық құрылымды алу үшін спектрлердегі фондық жағдайларды қарастырдық (1405).

Түйін сөздер: каон, E31, инвариантты масса спектрлері.

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Экспериментальное изучение Λ(1405) с помощью реакции d(K- ,ϖΣ) В J-PARC K1.8BR

Барионный резонанс Λ(1405) играет главную роль в различных разделах физики адронов и ядерной физики. Cчиталось, что резонанс Λ(1405) генерируется притягивающим взаимодействием антикаона и нуклона в виде квазисвязанного состояния ниже его порога, распадающегося в ϖΣ-канале. Таким образом, структура Λ(1405) тесно связана с взаимодействием KbarN. В этой статье, после обзора основных свойств резонанса Λ(1405) и введения в эксперимент E31, который был запушен на линии пучка K1.8BR в экспериментальном зале J-PARC в г.Токай, Япония в январе и феврале 2018 года и мы познакомилист со спектральными формами, которые были получены анализом данных. 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». Кроме того, мы рассмотрели фоновые события, чтобы оценить боковую полосу и получить правильную структуру спектрального пика (1405).

Мы суммируем недавние прогрессы в исследовании структуры (1405) и обсудим будущие перспективы физики резонанса (1405).

Ключевые слова: каон, E31, спектр инвариантной массы.

Introduction

The Λ(1405) resonance is a negative parity baryon resonance with spin 1/2, isospin I = 0, mass m=1405.1+1.3-1.0 MeV/c2, width 50±2MeV, and strangeness S = −1 [1]. The resonance is located slightly below the KbarN threshold and decays into the πΣ channel through the strong interaction. The existence of Λ(1405) was theoretically predicted in 1959 by Dalitz and Tuan [2,3], based on the analysis of the experimental data of the KbarN scattering length. It is shown that the unitarity in coupled-channel KbarN–πΣ system leads to a resonance pole in the πΣ amplitude.

There is a long-standing discussion on the interpretation of theΛ(1405) resonance. It is known to be difficult to describe Λ(1405) as an ordinary three-quark state in simple constituent quark models [4], because Λ(1405) has a lighter mass than the nucleon counterpart, the N(1535) resonance. Moreover, the mass difference from the Λ(1520) resonance with J =3/2−, which is supposed to be the spin–orbit partner ofΛ(1405), is too large in comparison with the splitting in the nucleon sector. According to these difficulties of the simple three-quark picture, the meson–baryon quasi-bound picture ofΛ(1405) attracts much attention. In fact, the Λ(1405) resonance can be naturally described as a quasi-bound KbarN state embedded in the πΣ continuum in coupled-channel meson–baryon scattering models, for instance, by the phenomenological vector meson exchange potential with flavor SU(3) symmetry [5]. 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).

But, the review of particle physics [8] 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 [9,10]. It has the lightest mass in negative parity baryons, which is hardly explained by the simple quark model [11]. 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 [12]. 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 [13], 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 [114] arises an interesting discussion of deeply bound kaonic nuclear states [15], where Λ (1405) is interpreted as a bound state of KbarN system with the binding energy of as deep as 27 MeV [16]. 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 [17]. Namely, poles coupled to the πΣ state and KbarN state are suggested at different positions, (1390 – 132i) MeV and (1426 –32i) MeV, respectively [18]. 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.

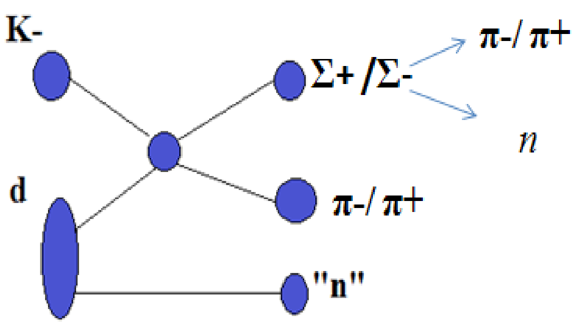

Figure 1 – (K-,n) Reaction Diagram

The E31 experiment is performed at the K1.8BR beam line in the Hadron Experiment Hall of J-PARC [19,20]. Since Λ (1405) cannot be formed directly from the K-p reaction in free space, we used the KbarN scattering process [21] as a d(K-, n)Σπ one step reactions at a kaon momentum of 1GeV / c, where the incident kaon knock-out a bound nucleon in the deuteron, become to be an off-shell Kbar and forms Λ(1405) followed by a Σπ decay (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.

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 [22]. 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 (Σ0π0 → Λγπ0 → pπ-γπ0) [23] is emitted backward, which is detected by backward proton detector (BPD) and chamber (BPC) placed in the upstream of the target.

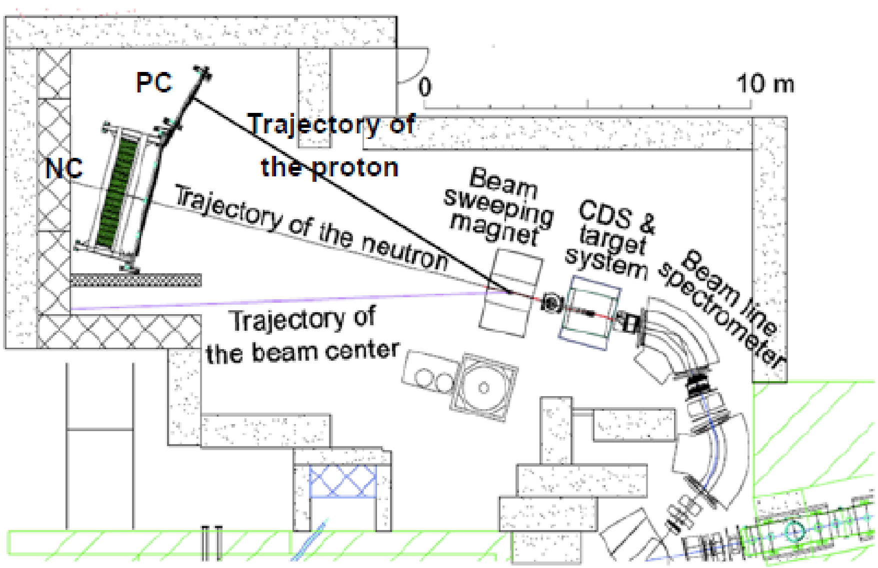

Figure 2 – Schematic view of the K1.8BR spectrometer

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.

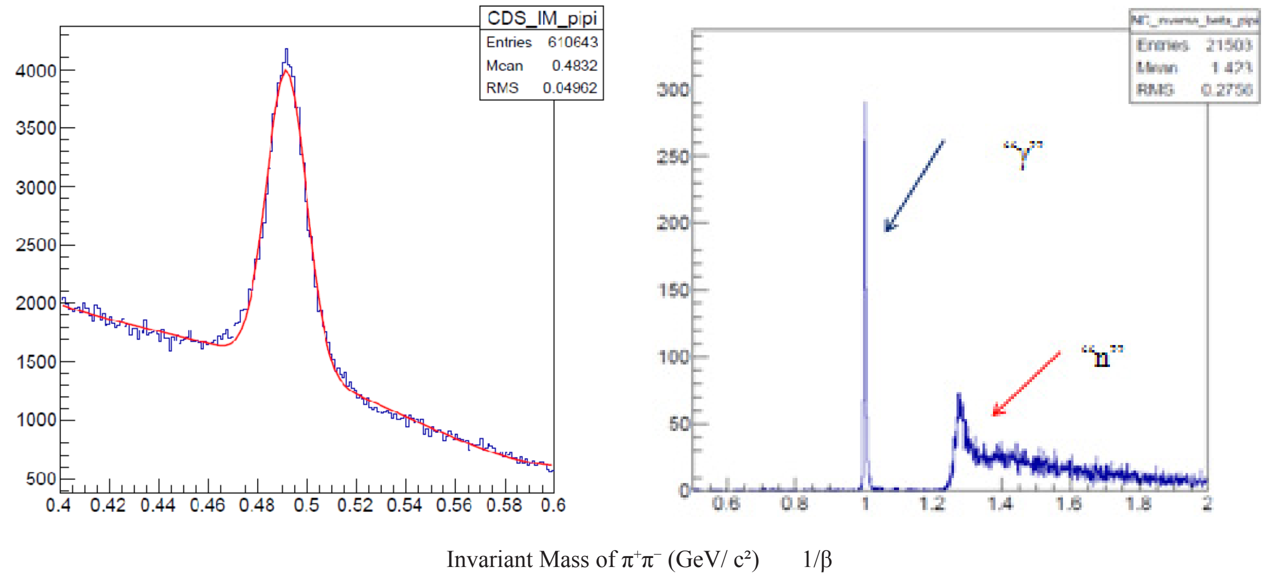

Figure 3 – (left) Identification of π-/π + by using CDS detector. (right) 1/β distribution of the forward neutral particles detected with the NC

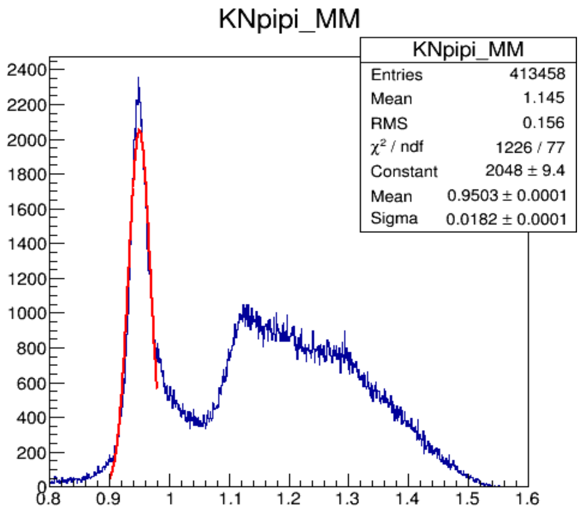

Figure 4 – Missing Mass of d(K⁻, nπ⁺π⁻)”X” (GeV/c²). The fitted region between 0.9 and 0.98 is selected as a neutron mass

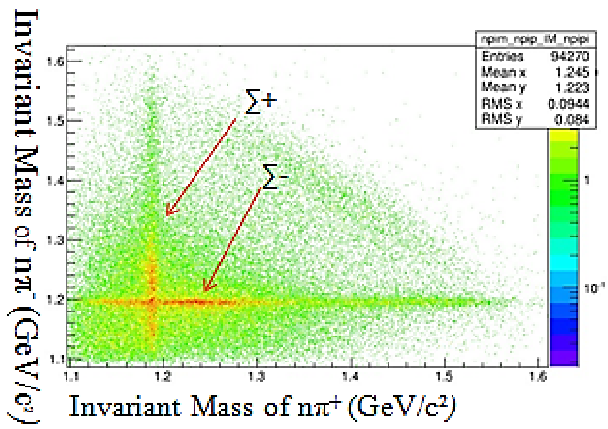

Figure 5 – Invariant Mass of nπ⁺ and nπ ⁻. The strong focusing cross-image corresponds to Σ-decay event

We decomposed the d (K⁻, Σπ)"n" spectrum into d (K⁻, Σ+π-)"n" and d (K⁻, Σ-π+)"n". To evaluate the background distribution in the piSigma, we defined sideband region in the n π-/n π+ IM spectrums. "Side-band" is taken as a mass region just beside the selected Sigma mass peak window, as shown in Fig 6.

Then, by using the side- and events and calculate the event number of each side, we reconstruct the follwing histograms. Fig. 7.

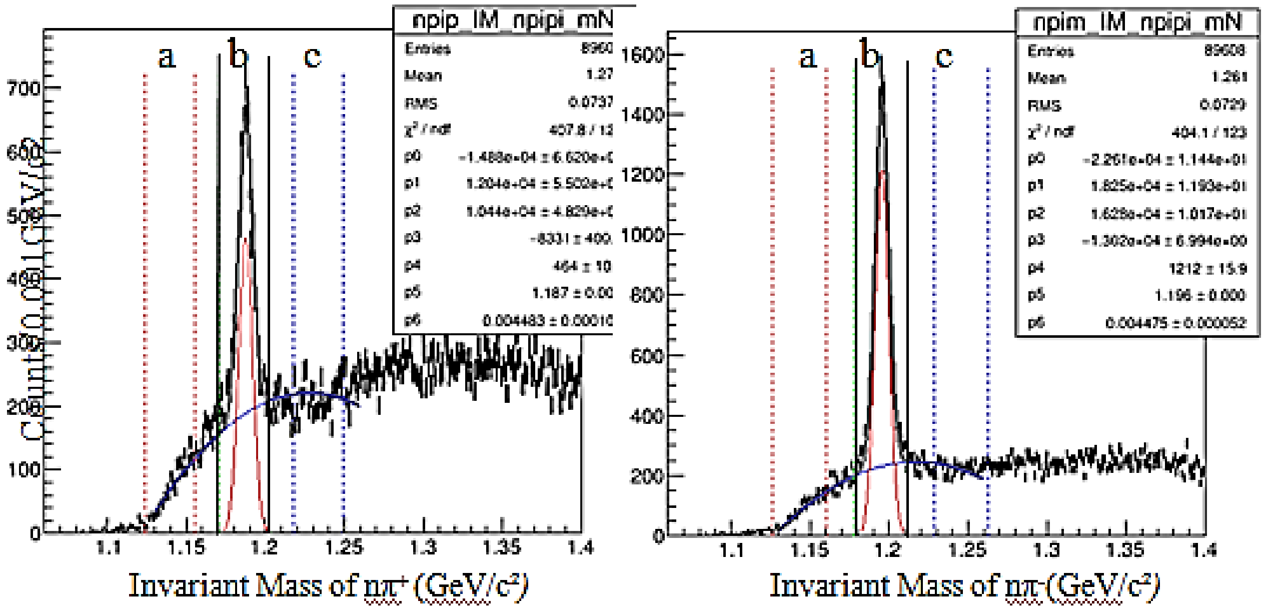

Figure 6 – Invariant Mass of nπ⁺ and nπ ⁻. The Σ- and Σ+ selections are shown with black hatch, while sideband regions are defined as the red and the blue hatches

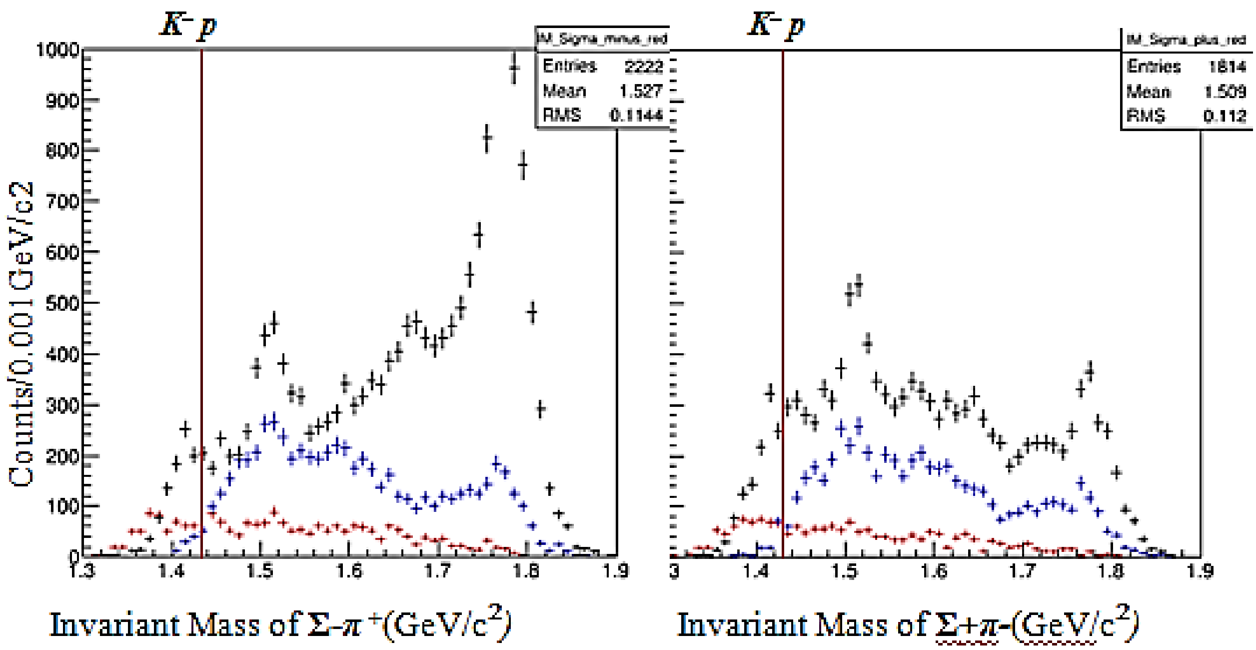

Figure 7 – Invariant Mass of Σ+π- and Σ-π+ with side- band events.
The black histogram represents the Σ+π- and Σ-π+ and the red and the blue histograms represent sideband events

Then, compare the "side-band" spectra and IM(Σπ) spectra by normalizing the vertical scales. The normalization can be done by the following formulas: b/(a+c). Finally, we got the decomposed Invariant Mass of the Σ-π^+ and Σ+π^- in the d (K^-, Σπ)"n" reaction are shown in Fig. 8. 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).

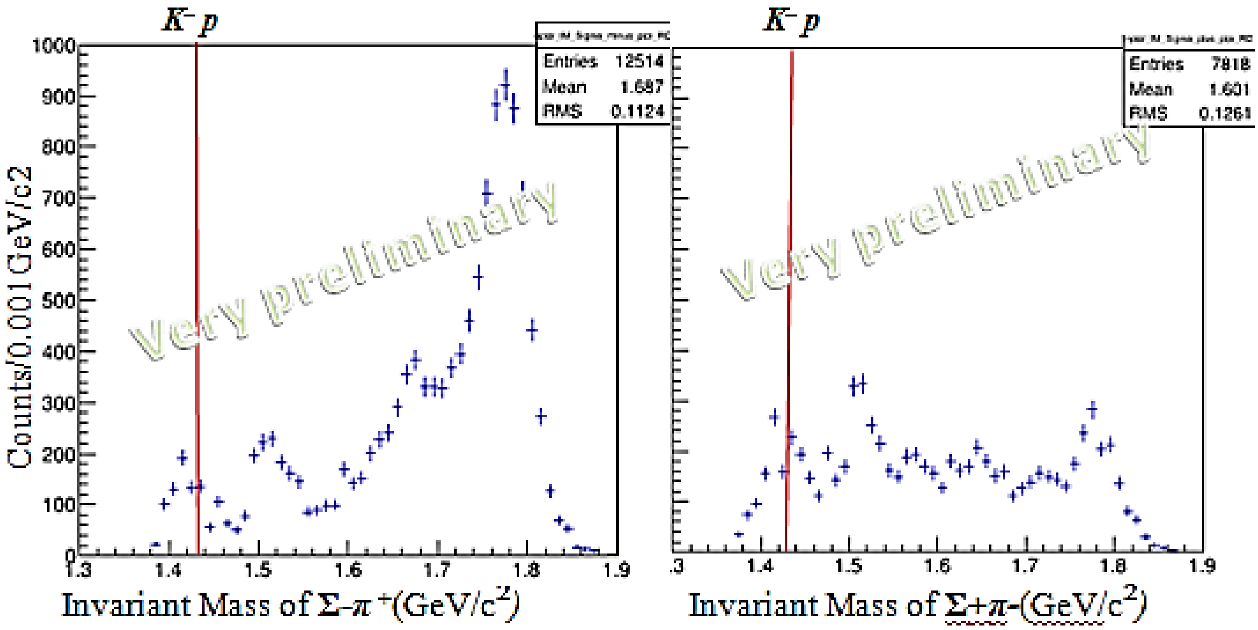

Figure 8 – Subtruction between two histograms of invariant Mass of Σ-π^+ and Σ+π^-(GeV/c²) in the d (K^-, Σπ)"n" reaction

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 [24]. 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 very preliminary results based on the second E31 physics run. All the related behaviors of the d(K-, Σπ)"n" reaction are explained by one step process. By using background estimation we have obtained the clear Λ(1405) peak position. The next step of the analysis will be Monte Carlo simulation. Monte Carlo simulations will be performed by using Geant4.9.5.p01 toolkit [25]. The purposes of the Monte Carlo simulations were to produce dummy data with speci_c processes and to evaluate all the detector effects, such as energy losses of particles, multiple scatterings, the detector acceptance, and the tracking performance with the chamber position resolution.

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