January 4, 2013
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To the PAC chairperson and members:

I am writing to report the preparation status for the E31 experiment, "Spectroscopic study of hyperon resonances below $\bar{K}N$ threshold via the (K^-,n) reaction on Deuteron". In the 16th PAC, we demonstrated the readiness of the experimental apparatus for E31. Below, we report to show how we can determine the nature of the Λ(1405) such as a pole position of the $\bar{K}N$ bound state using the expected statistics of its spectra, as the PAC requests.

The E31 experiment is aiming to clarify whether the Λ(1405) is a $\bar{K}N$ resonant state as predicted by the chiral unitary model or not. To accomplish this aim, we will measure the Λ(1405) state via the (K^-,n) reaction to test whether the resonance appears at ~1420 MeV/c^2 as predicted by the chiral unitary model [1] or at ~1405 MeV/c^2 as deduced by Dalitz *et al.* [2] and a recent theoretical analysis by Esmaili *et al.* [3].

Below, recent arguments on the Λ(1405) are briefly summarized. A $\pi^0\Sigma^0$ invariant mass spectrum in the $pp \rightarrow pK^+\pi^0\Sigma^0$ reaction is presented by the COSY-ANKE collaboration [4] as an evidence against the two-pole model, although this is disputed by a theoretical calculation [5]. Very recently, Λ(1405) spectra in missing masses of the $pp \rightarrow pK^+\pi^{\mp}\Sigma^{\pm}$ reactions are reported by the HADES collaboration [6]. A theoretical analysis for the observed spectra is reported that the Λ(1405) is located at 1405^{+11}_{-9} MeV/c^2 with a width of 62±10 MeV [7], which is in agreement with the value obtained from a re-analysis of an old experimental data of stopped-K^- in ^{4}He [3].

Line shapes of Λ(1405) production in the p(γ, K^+)πΣ reactions are measured at LEPS [8,9] and CLAS [10]. The measured spectra show different shapes in the final $\pi^{\mp}\Sigma^{\pm}$ and $\pi^0\Sigma^0$ states, indicating that there is interference between the isospin I=0 and I=1 amplitudes. The effect of the interference is predicted by Ref. [11], although the observed shifts of spectra are not described by the models. Therefore, more experimental studies with different reactions are necessary in order to understand the Λ(1405) as a dynamically generated state. In particular, studies of Λ(1405) formation in kaon-induced reactions are strongly desired, through which one expects to access a $\bar{K}N$

channel coupled to the Λ(1405) directly. An experimental study of the Λ(1405) resonance below $\bar{K}N$ threshold via the d(K^-,n) reaction is expected to enhance an S-wave $\bar{K}N$ scattering process to form the Λ(1405) [12], where an energetic neutron is kicked at a forward angle.

Experimental setup for E31 is shown in Fig. 1. An incident kaon momentum is analyzed by the D5 magnet and a scattered neutron momentum is obtained from a time of flight measured between the deuteron target and the neutron counters (NC). Missing mass spectra of the d(K^-,n) reactions will be measured at an energy resolution of about 9 MeV. The Λ(1405) decays into $\pi^-\Sigma^+$, $\pi^+\Sigma^-$, or $\pi^0\Sigma^0$. Decay charged particles from the Λ(1405) will be detected by the Cylindrical Detector System (CDS) in order to identify the decay modes (Fig. 2). The $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ decay modes are identified by detecting 2 different charged pions, π^+ and π^-, with the Cylindrical Drift Chambers (CDC) and the Cylindrical plastic scintillator Hodoscopes (CDH). Since we measure a missing momentum of a produced hyperon resonance (Y^*) in the d(K^-,n) reaction, a missing mass of the Σ^+ (Σ^-) can be obtained from measured π^- (π^+) and Y^* momenta so that the $\pi^-\Sigma^+$ ($\pi^+\Sigma^-$) decay mode can be identified, which is demonstrated in a Monte-Carlo simulation, as shown in Fig. 3. In the simulation, energy straggling effects in materials, typical time and spatial resolutions of plastic scintillators and tracking chambers are taken into account. In the $\pi^0\Sigma^0$ decay, 2 charged particles, π^- and p, from the Λ are detected. The π^- can be detected by the CDC. Since the Λ(1405) is recoiled backward, the proton is boosted backward and detected by the backward proton detectors, plastic scintillator hodoscopes (BPD) and a small drift chamber (BPC) for backward emitted protons. A missing mass of a $\pi^0\gamma$ system is obtained from measured Λ and Y^* momenta so that the $\pi^0\Sigma^0$ decay mode is identified, demonstrated in a Monte-Carlo simulation, as shown in Fig. 4. The $\pi^0\Sigma^0$ mode is separated from the $\Sigma(1385)\rightarrow\pi^0\Lambda\rightarrow\pi^0\pi^-p$ or $\Lambda(1405)\rightarrow\pi^-\Sigma^+\rightarrow\pi^-\pi^0p$ background processes.

We simulated the Λ(1405) missing mass spectra produced in the d(K^-,n) reaction in the E31 experiment for the cases of two typical models. One is the case to simulate the measured spectrum shape calculated by the chiral unitary model [12]. The other is those reported by Hemingway [13]. Fig. 5 shows spectra with statistics expected in the requested beam time, where the acceptance of the detectors is corrected. We demonstrate the difference of the spectrum shapes to discriminate between the two models clearly. We further demonstrate the position and width dependences of the chi-squares in the statistically smallest case of the $\pi^0\Sigma^0$ decay mode, as shown in Fig. 6~9. We expect to determine the position and the width of the Λ(1405) at resolutions of better than 5 MeV and 10 MeV, respectively.

A deuteron target has been prepared for E31. Construction for the E15/31 setup was finished and commissioning run for E15 has been successfully completed. A negative kaon beam tuning was successfully done at 1.0 GeV/c. It is confirmed again in the last beam time for engineering run in December, 2012, that a kaon intensity of 10^4 per pulse per 1 kW primary proton beam can be obtained with keeping a kaon/pion ratio of as good as 0.3 at the primary beam power of 11 kW. This intensity corresponds to 2.7×10^5 kaons per pulse at a primary beam power of 27 kW assumed in the proposal, thanks to the 6.6 cm thick Au target used for the primary target.

We have finished hardware preparation for the E31 experiment, as already reported in the last PAC. We expect to start experiment within a several days to switch the target system after the E15 first stage run finishes. Then, it would be worthy to mention about milestones for E31. We request a beam time of 120 shifts at 27 kW (154 kW*week). However, we wish to first confirm an advantage of the $d(K^-,n)$ reaction that enhances S-wave $\bar{K}N$ scattering to form the $\Lambda(1405)$. To do it, we do not need much time. In the first 20 kW*week run, we expect to collect more than 1000 events of the $\Lambda(1405)\rightarrow\Sigma^-\pi^+$ decay modes, which exceeds more than twice the number of events of existing data in the $d(K^-,n)\Sigma^-\pi^+$ reaction [14]. At the same time, we expect to observe the $\Sigma^+\pi^-$ decay mode in the $d(K^-,n)$ reaction for the first time at a level of more than a few hundred events in statistics. We can accumulate data of $\Sigma^-(1385)$ production via the $d(K^-,p)$ reaction simultaneously. Comparison of the $d(K^-,p)$ spectrum with the $d(K^-,n)$ one, *i.e.* difference of the line shapes and the cross sections, is important. The $d(K^-,p)$ spectrum provides a magnitude of the I=1 amplitude in the reaction. The cross section ratio to the $d(K^-,n)$ spectrum gives an answer if an S-wave $\bar{K}N$ scattering process is enhanced.

We comment about a recent theoretical analysis [15] based on a Fadeev calculation in the $d(K^-,n)\pi\Sigma$ reaction that claims a spectrum shape near the $\bar{K}N$ threshold is distorted and the clear peak structure may not be observed if the peak is close to the threshold as the chiral unitary model predicted. This distortion effect is due to behavior of a Green's function characterized by the deuteron wave function. Since the Green's function rapidly decrease below the $\bar{K}N$ threshold, the distortion effect is expected to rapidly decrease if the peak position is apart from the $\bar{K}N$ threshold. Although the theoretical model calculation does not explain a measured spectrum in an old bubble chamber experiment of the $d(K^-,n)\pi\Sigma$ reaction [14], this spectrum has to be confirmed with larger statistics in E31.

In these respects, we strongly prefer to take data before the summer shutdown in 2013 even in a short period.

Data analysis for E15 (^{3}He target) is under progress. Particle identification in the CDS is successfully done (Fig. 10), and Λ and K^0 invariant mass spectra are reconstructed clearly from $p\pi^-$ and $\pi^\pm$ pairs identified by the CDS, respectively, as shown in Fig. 11. Fig. 12 shows a scattered neutron spectrum (1/β) with very low background events. A prominent peak of gamma is seen at 1/β=1. A peak of quasi-free kaon production can be seen at 1/β~1.3. Although nothing can be said about the kaonic bound state in this limited statistics, it is demonstrated that the experimental apparatus shows good performances as we expected.

We report briefly some developments to supplement the E15/31 setup from the last PAC.

(1) A backward proton detector system is fully installed.

(2) Beam veto counters (BV) installed behind the target are renewed so that they are operated for higher beam intensity.

(3) A set of drift chambers (FDC1) are installed at the entrance of the USHIWAKA beam sweeping magnet to reconstruct a trajectory of a scattered proton in the $d(K^-,p)\Sigma^{*-}$ reaction. This reaction mode is quite helpful to evaluate the spectrum shape for the isospin *I=1* channel.

(4) Beam defining counter hodoscopes (DEF) of 3 mm thin plastic scintillators with wave length shifter doped optical fiber read out are installed just in front of the target vacuum chamber to ensure the beam hit the target and easily remove stray beam events sneak into the online trigger.

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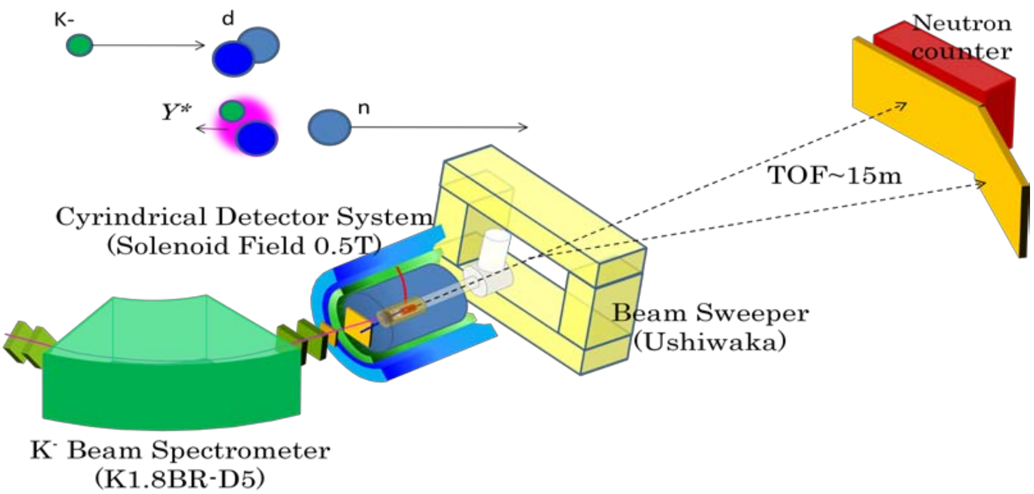

Fig. 1: Schematic layout of the E31 setup. A kaon beam at 1 GeV/c is irradiated on the deuteron target. A neutron is kicked at the forward angle to form Λ(1405).

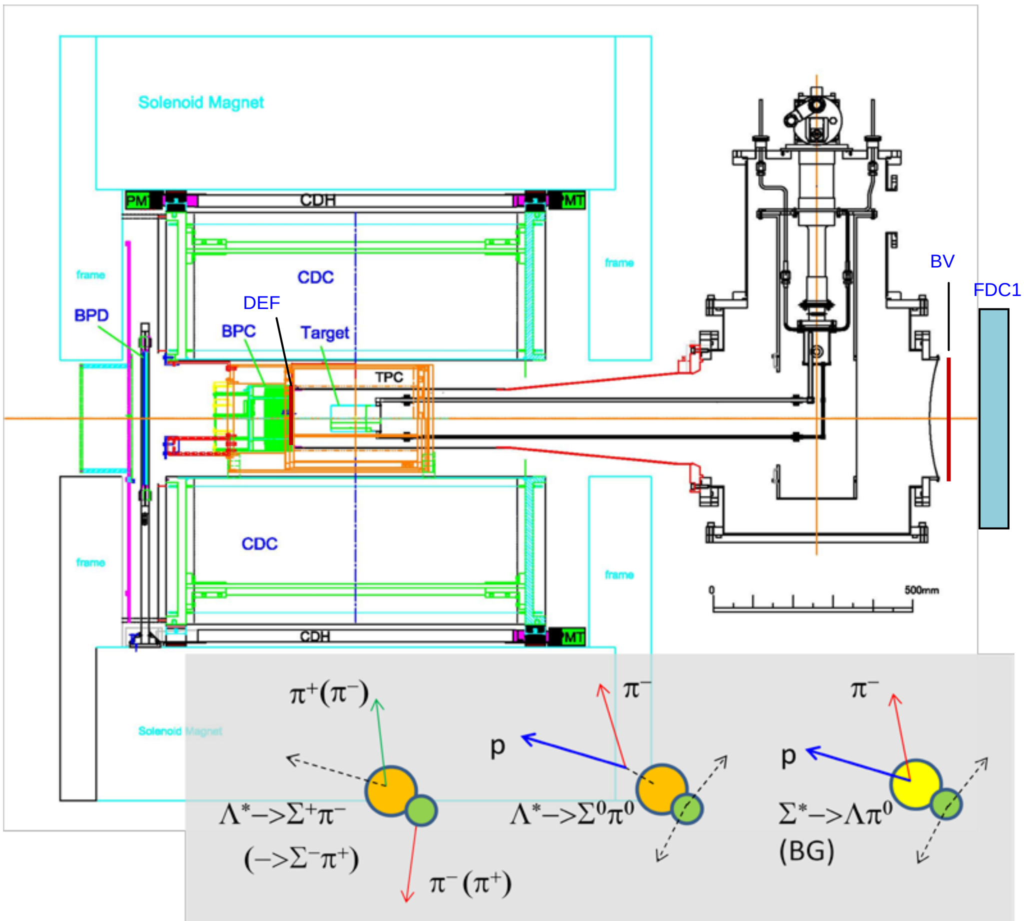

Fig. 2: Side view of the Cylindrical Detector System and the deuteron target. Typical decay topologies from produced hyperon resonances are also shown.

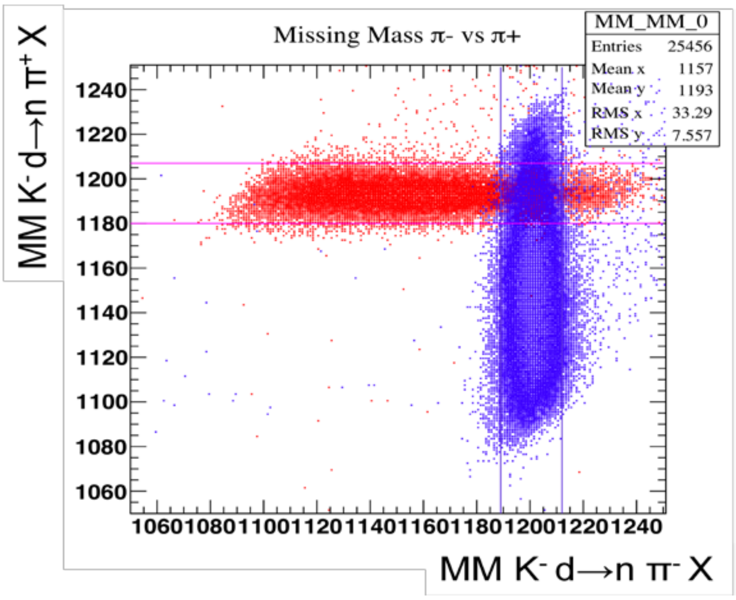

Fig. 3: Reconstructed missing masses in the d(K^-,n π^+) and d(K^-,n π^-) reactions. The neutron, n, is measured by the NC counters and the pions are detected by the CDS. The $\pi^-\Sigma^+$ ($\pi^+\Sigma^-$) mode is identified by gating in the Σ^+ (Σ^-) mass region.

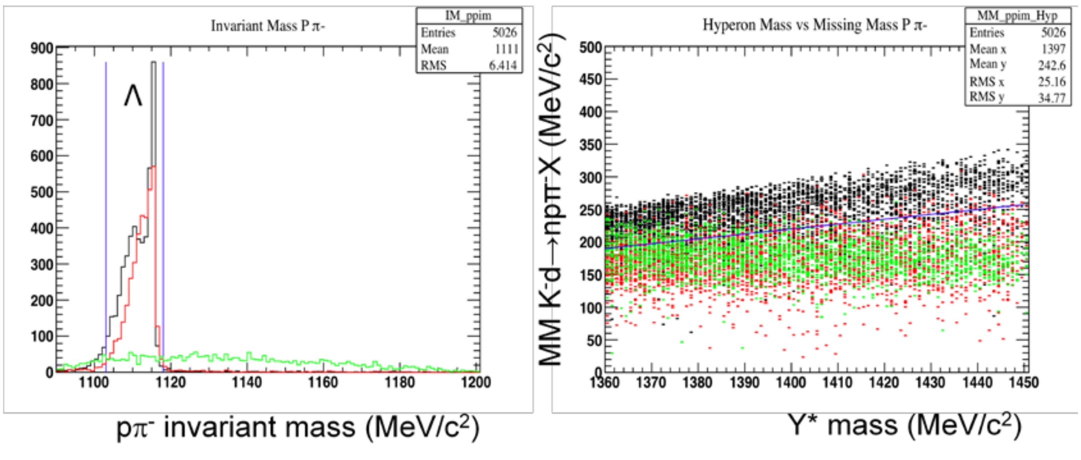

Fig. 4: Reconstructed invariant mass of $p\pi^-$ (left), and missing mass in the d(K^-,n$p\pi^-$) reaction as a function of a mass of produced hyperon resonance (right). In both figures, black, →red and green histograms/scatter plots correspond to the $\Lambda(1405)\to\pi^0\Sigma^0$, $\Sigma(1385)\to\pi^0\Lambda$, and $\Lambda(1405)\to\pi^-\Sigma^+$ modes, respectively. Lines to select the $\Lambda(1405)\to\pi^0\Sigma^0$ mode are shown in the figures.

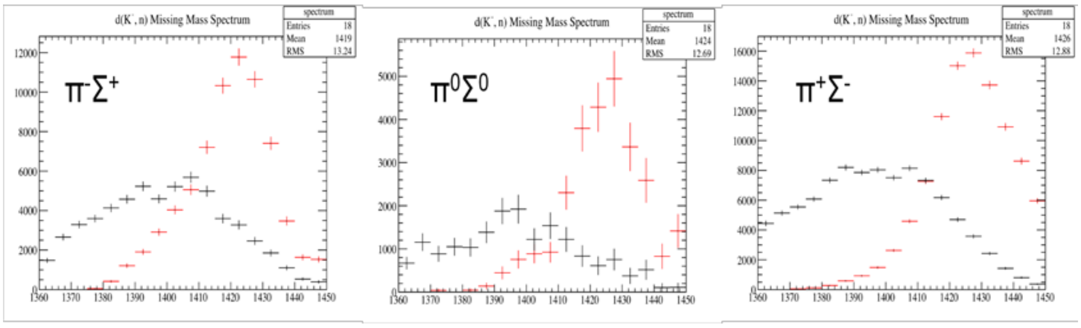

Fig. 5: Expected missing-mass spectra of the $\pi^-\Sigma^+$ (left), $\pi^0\Sigma^0$ (center), and $\pi^+\Sigma^-$ (right) decay modes, for which the detector acceptance is corrected. Expected statistics in the requested beam time are assumed to be 4800, 350, and 19200, respectively. Black points are simulated for Hemingway's data [13]. Red points are for calculations by the chiral unitary model [12].

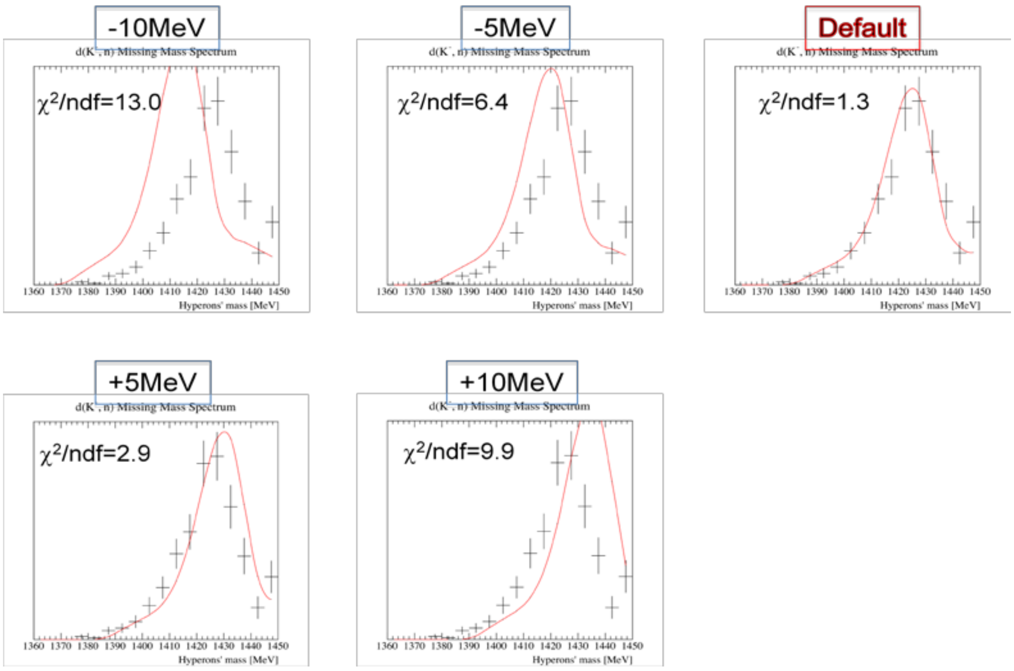

Fig. 6: Chi-square changes when a position of the fit function (chiral unitary model calculation) varies for the case of the $\pi^0\Sigma^0$ mode.

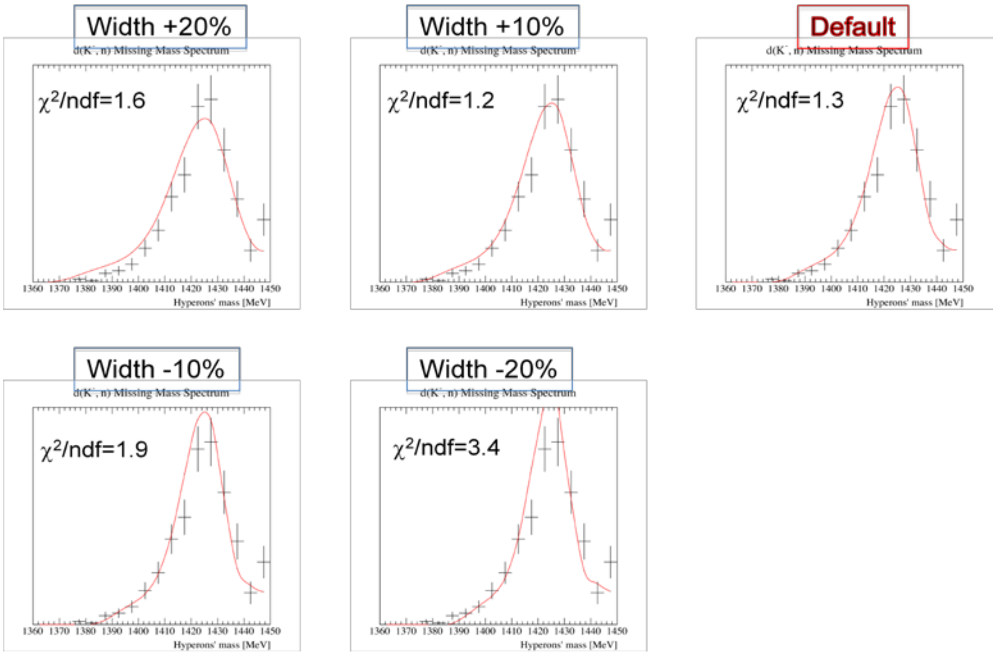

Fig. 7: Chi-square changes when a width of the fit function (chiral unitary model calculation) varies for the case of the $\pi^0\Sigma^0$ mode.

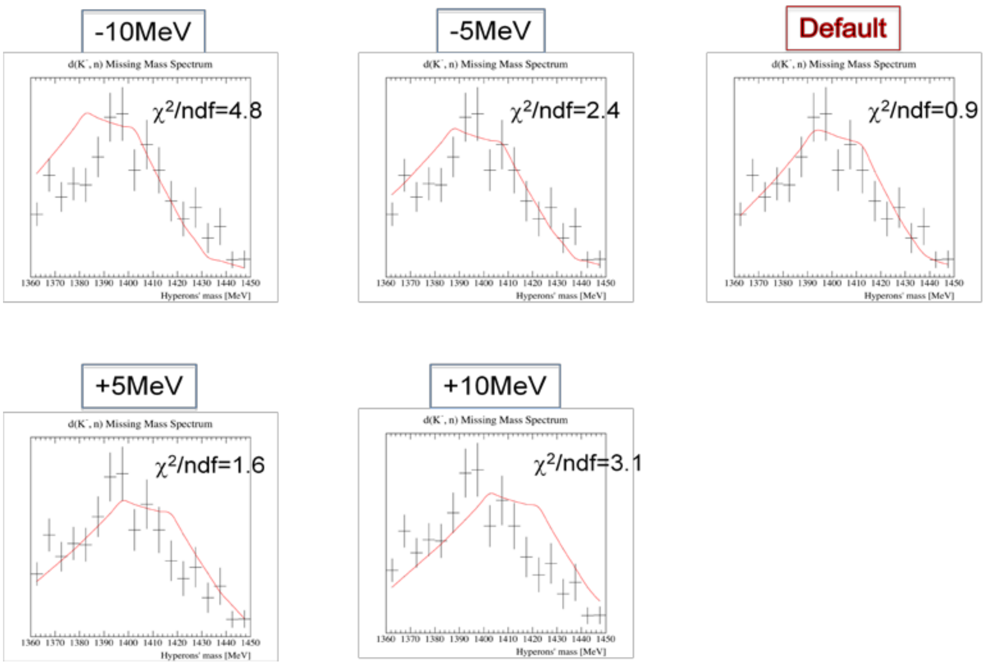

Fig. 8: Chi-square changes when a position of the fit function (Hemingway's data) varies for the case of the $\pi^0\Sigma^0$ mode.

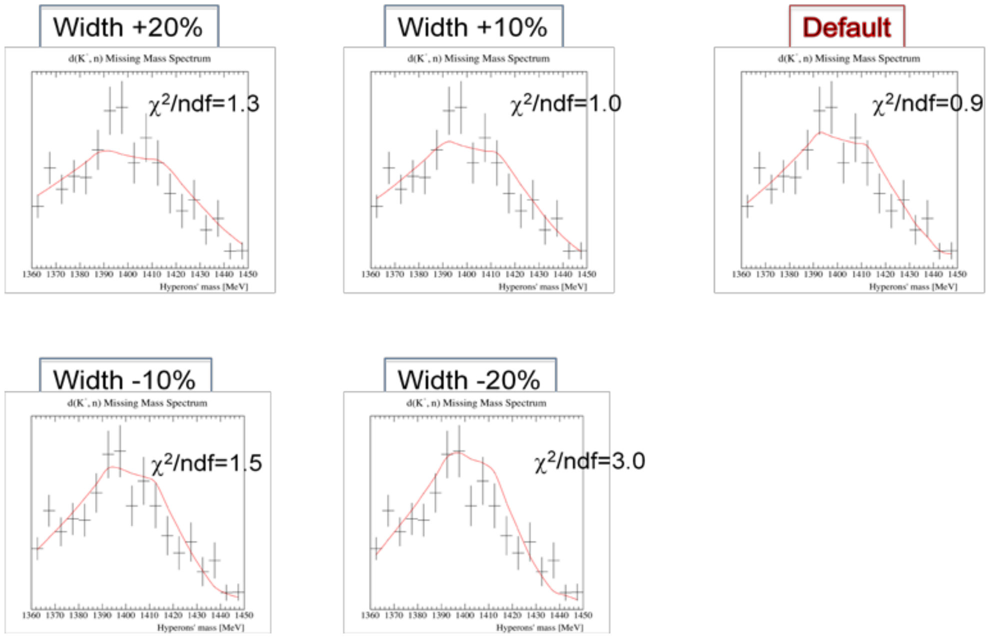

Fig. 9: Chi-square changes when a width of the fit function (Hemingway's data) varies for the case of the $\pi^0\Sigma^0$ mode.

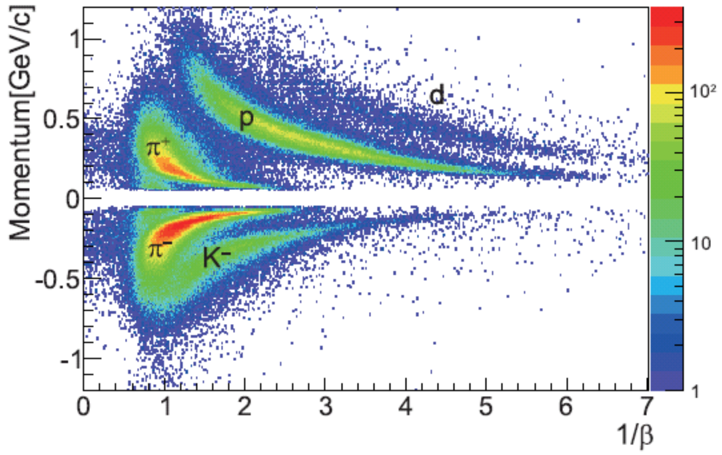

Fig. 10: Particle identification (left) and K⁰ invariant mass spectrum reconstructed from $\pi^{\pm}$ identified by CDC (right).

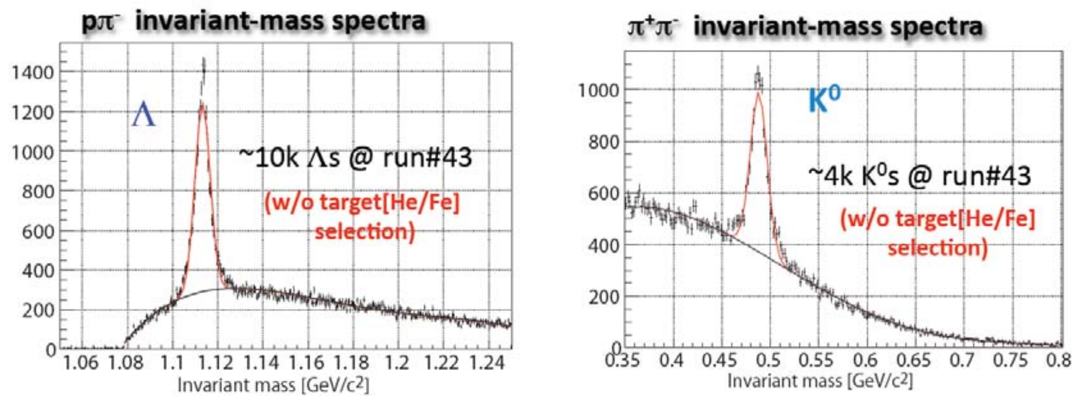

Fig. 11: Λ (left) and K⁰ (right) invariant mass spectra reconstructed from $p\pi^-$ and $\pi^{\pm}$ pairs identified by the CDS, respectively.

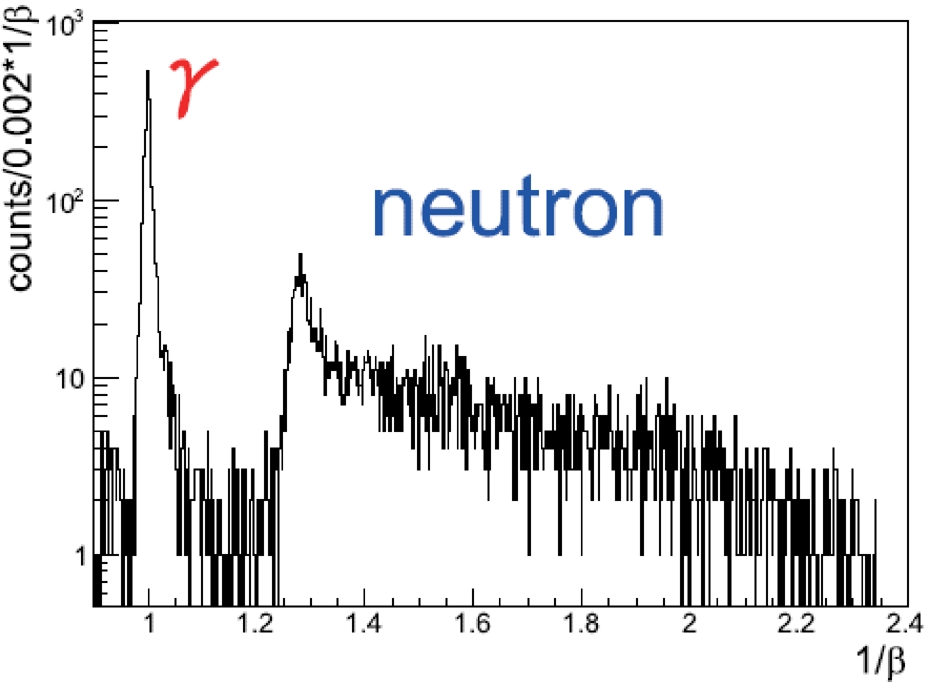

Fig. 12: Measured neutron spectrum (1/β). A prominent peak for gammas at 1/β~1 and a peak of kaon quasifree productions at 1/β~1.3 are clearly seen.