July 8, 2015
Hiroyuki Noumi
RCNP, Osaka University
for the E31 collaboration

To the PAC chairperson and members:

. I am writing to report a demonstration on the d(K-,n) spectrum obtained based on the calibration data for the E15 experiment. We clearly observed a missing mass spectrum of the $d(K^{-},n)$ reaction with identifying $\pi^{\pm}\Sigma^{\mp}$ production in the final states. The observed spectrum indicates interesting structure below the $\bar{K}N$ threshold. In order to increase statistical significance, we request beam time allocation for the E31 experiment at the earliest opportunity. Since we are always ready to run, we can flexibly accept beam time allocations, even though they are intermittent or a short term for each occasion.

According to a recent literature [1], two resonance poles appear between the $\bar{K}N$ and $\pi\Sigma$ thresholds for the case of an energy-dependent meson-baryon potential, as predicted by a chiral unitary model [2]. On the other hand, one resonance pole appears for the case of an energy-independent potential. Since available data are limited to the low-energy $\bar{K}N \rightarrow MB$ scattering data above the $\bar{K}N$ threshold and the $K^{-}p$ scattering length deduced from the kaonic hydrogen atom, experimental data to reach a $\bar{K}N$ pole below the $\bar{K}N$ threshold are strongly desired. Here, we remind again that the $d(K^{-},n)$ reaction enhances the S-wave $\bar{K}N$ scattering amplitude at the neutron forward angle [3].

In last April and May, beam time for the E15 experiment was allocated in order for taking calibration data of elementary $K^{-}p \rightarrow K^{0}n$ and $K^{-}n \rightarrow K^{-}n$ reactions by using H_2 and D_2 targets. This opportunity provided good data to evaluate feasibility for the E31 experiment. We demonstrate the $d(K^{-},n)X_{\pi\Sigma}$ spectrum, based on the D_2 data for 2.2 days (58 kW*days).

The experimental setup for the E15/31 experiment is shown in Fig. 1. Calibration and analysis procedures are almost the same as those established in the E15 experiment. We have selected a kaon beam by gating the time of flight between BHD and T0 timing counters, as shown in Fig. 2. The reaction vertex was determined by the closest distant approach between a kaon beam track reconstructed by beam line chambers (BLC2 and

BPC) and a charged track reconstructed by the cylindrical drift chamber (CDC). As shown in Fig. 3, the target deuterium was selected by applying a fiducial volume cut. Fig. 4 shows a $1/\beta$ distribution of a neutral particle deduced from the time of flight measured between the vertex point and the Neutron Counter (NC). The energy threshold of the neutron counter was set at 8 MeV. A peak corresponding to gamma rays is observed at $1/\beta=1$ with a resolution of σ_β about 0.003, which corresponds to the energy resolution of about 10 MeV/c^2. Scattered neutrons are identified in the region of $1/\beta>1.1$.

Particle identification of the charged particles detected by the Cylindrical Detector System (CDS) has successfully been made, as illustrated in Fig. 4. By identifying π^+ and π^- in the CDS, we selected event samples of the $d(K^-,n\pi^+\pi^-)X$ reactions. With these samples, invariant mass distributions of $\pi^+\pi^-$, π^+n, and π^-n were obtained, as shown in Fig. 6. The $\bar{K}^0$, Σ^+, and Σ^- particles can be clearly observed at the corresponding mass in each spectrum. Fig. 7 shows a missing mass spectrum of semi-inclusive $d(K^-,n)$ reaction. The $d(K^-,n)$ missing mass spectra selecting $\bar{K}^0$ and Σ^+/Σ^- are overlaid in Fig. 7. The $\bar{K}^0$-selected events raise at the $\bar{K}N$ threshold and show a peak at around the 1.47 GeV/c². This peak corresponds to the so-called quasi-$\bar{K}^0$ production. The Σ^+/Σ^--selected events are distributed over a wide range of the missing mass. These $\bar{K}^0$- and Σ^+/Σ^--associate events will be excluded from the event samples for further analysis.

The missing mass spectra of the $d(K^-,n\pi^+\pi^-)$ reaction are shown in Fig. 8. A peak at the neutron mass can be observed separately from events associate with another pion(s) above ~1.08 GeV/c². A reason why the neutron peak has a tail to the heavier side is not yet made clear at this moment, thus further studies are necessary. We gated a mass region from 0.90 to 0.98 GeV/c² in the missing mass spectrum so as to select the event samples of the $d(K^-,n\pi^+\pi^-)n_{\text{missing}}$ reaction.

In the event samples of the $d(K^-,n\pi^+\pi^-)n_{\text{missing}}$ reaction, we obtained missing masses of the $d(K^-,n\pi^+)$ and $d(K^-,n\pi^-)$ reactions, where the $\Sigma^\mp$ particles can be identified in Fig. 9. By selecting these $\Sigma^\mp$, as indicated in Fig. 9, we obtained event samples of the $d(K^-,n)\pi^\pm\Sigma^\mp$ reactions. Finally, we obtain a missing mass spectrum of the $d(K^-,n)$ reaction with $\pi^\pm\Sigma^\mp$ in the final state, as shown in Fig. 10.

Although the obtained results are still preliminary, we could find remarkable features in the spectrum.

1. Significant yields below the $\bar{K}N$ threshold are observed.
2. A bump (or shoulder) structure can be seen at around 1.42 GeV/c².
3. No peak structure is seen below 1.4 GeV/c².

We observed the $d(K^-,n)\pi^\pm\Sigma^\mp$ reaction at a neutron scattering angle of around 0 degree for the first time. This spectrum carries information on the $\bar{K}N \to \pi\Sigma$ scattering amplitude below the $\bar{K}N$ threshold. More statistics are necessary to distinguish the $\pi^\pm\Sigma^\mp$ final states and to accumulate the $\pi^0\Sigma^0$ final state in order to obtain complete information of the isospin I=0 and 1 amplitudes in the $\bar{K}N \to \pi\Sigma$ scattering.

We have found about 250 events in the mass region of 1.4 to 1.43 GeV/c^2 in the missing mass spectrum of the $d(K^-,n)\pi^\pm\Sigma^\mp$ reaction. Expected yield based on a theoretical calculation [3] was about 180. If we take data for proposed beam time (1080 kW*days), we expect about 19 times more statistics, about 4700 events for the $\pi^\pm\Sigma^\mp$ modes in total. Using the cross section ratio of $\sigma(\pi^0\Sigma^0)$ to $\sigma(\pi^\pm\Sigma^\mp)$ calculated in theory [3] and taking into account the detection efficiency, we expect about 180 events for the $\pi^0\Sigma^0$ mode.

In summary, we have demonstrated the missing mass spectrum of the $d(K^-,n)\pi^\pm\Sigma^\mp$ reaction based on the E15 calibration data for 2.2 days. The $d(K^-,n)$ reaction seems promising to provide $\bar{K}N \to \pi\Sigma$ scattering data, through which the pole of the $\bar{K}N$ state can be determined. Since the E31 experiment is always ready to run if the deuteron target is placed, we would like to request for beam time allocation at the earliest opportunity, even though they are intermittent or a short term for each occasion. For more flexible beam time coordination, we estimate expected achievement for allocated beam time. If we have 5 days with a 40 kW primary beam, expected yield of $\pi^\pm\Sigma^\mp$ is more than 800. Then, we could separate the $\pi^\pm\Sigma^\mp$ modes with reasonable statistics. For 10 days with the same power of primary beam, we may confirm a strength of the $\pi^0\Sigma^0$ mode as expected yield is about 60 events. For more than 20 days, we may have significant statistics for the $\pi^0\Sigma^0$ mode in order to decompose the I=0 and 1 amplitudes in the $\bar{K}N \to \pi\Sigma$ scattering.

References:

[1] S. Ohnishi, Y. Ikeda, H. Kamano, and T. Sato, Phys. Rev. C88, 025204 (2013).

[2] D. Jido, J. A. Oller, E. Oset, A. Ramos, and U. G. Meissner, Nucl. Phys. A 725, 181 (2003).

[3] Yamagata-Sekihara, J., Sekihara, T., and Jido, D., Prog. Theor. Exp. Phys., 2013, 043D02(2013).

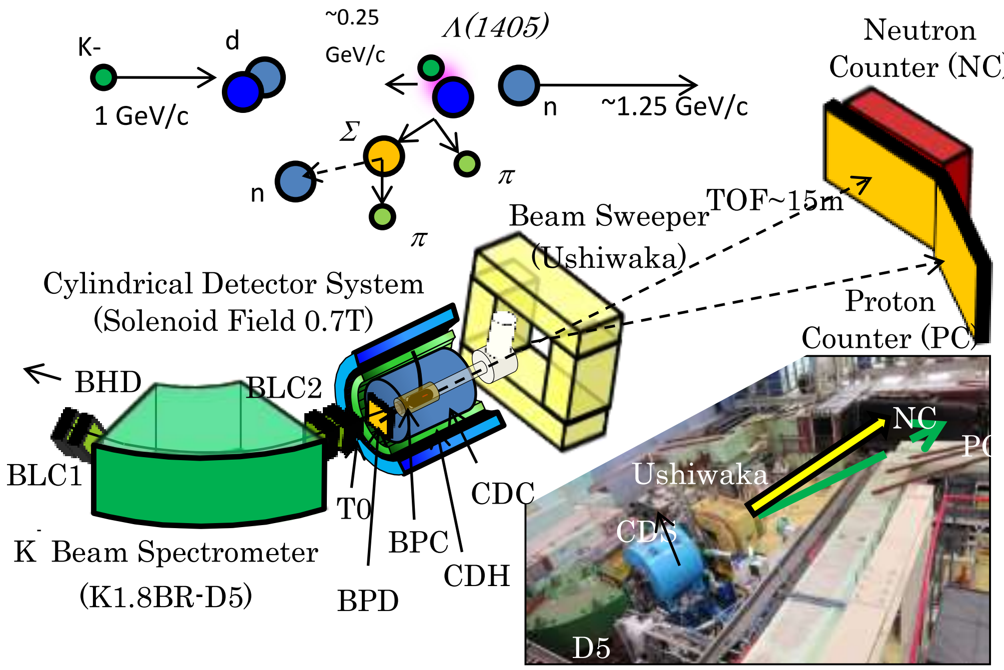

Fig. 1: Layout of the experimental setup for the E15/31 experiment

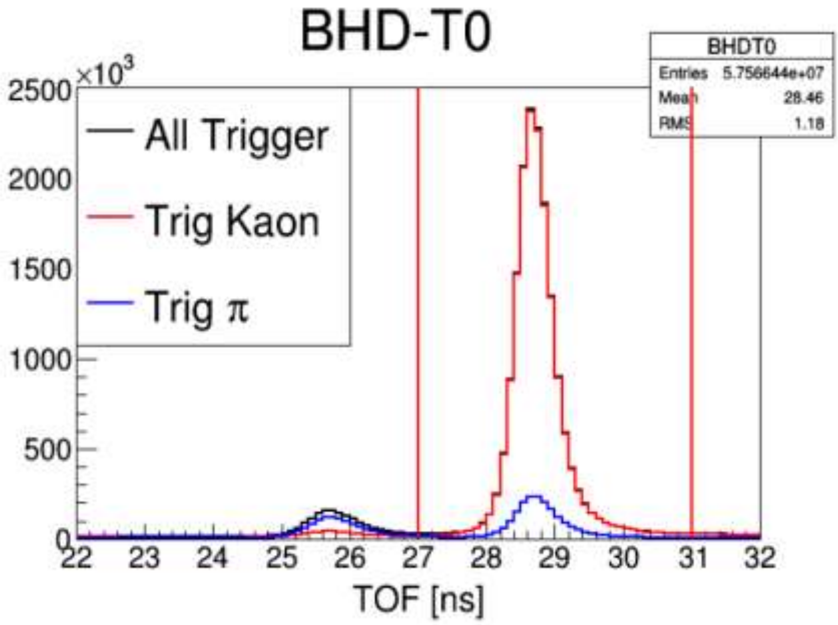

Fig. 2: Time of flight between BHD and T0 counters. BHD is beam hodoscopes located at the most upstream in the beam line of the K1.8BR experimental area. T0 is a time zero counter hodoscopes located upstream of the target. Vertical red lines indicate a time window for selecting kaon beam.

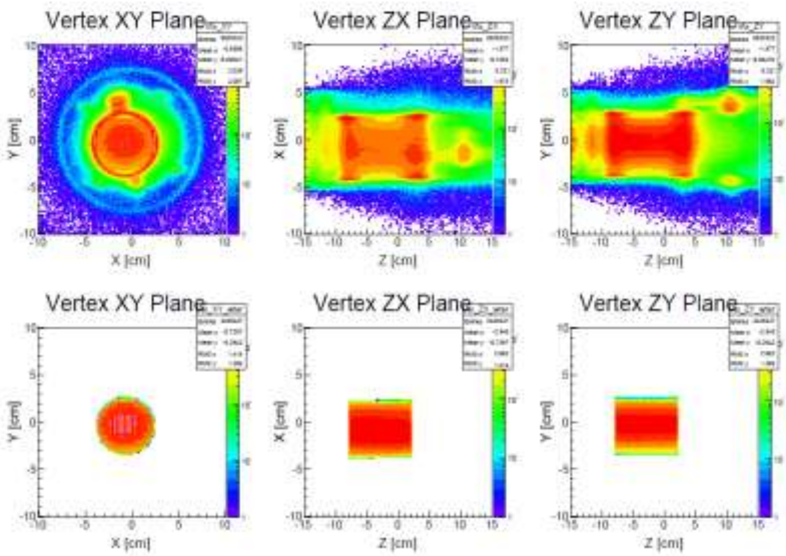

Fig. 3: Reaction vertex determined from a beam track and a charged track in CDC by means of the closest distance approach. An image of the target cell was clearly observed (upper). The target deuterium was selected by a fiducial volume cut (lower).

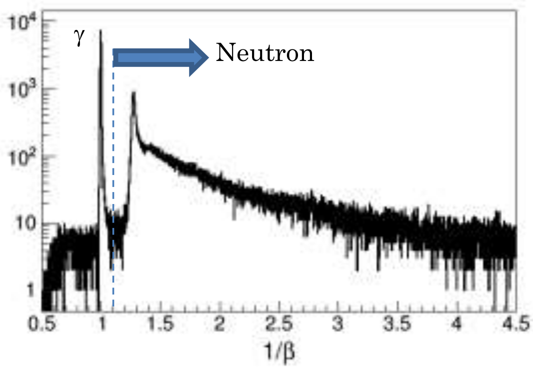

Fig. 4: 1/β spectrum obtained by the neutron time of flight counter located at a distance of 15 m from the target. A peak of gamma rays is located at 1/β=1. Neutrons are identified in the region of 1/β>1.1.

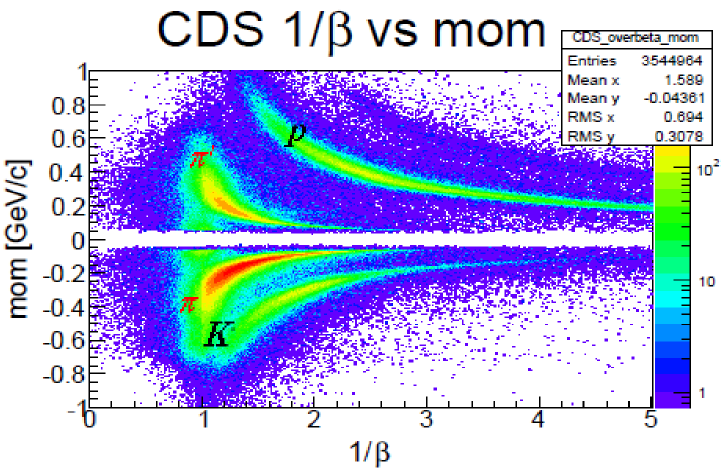

Fig. 5: Particle identification in the cylindrical detector system.

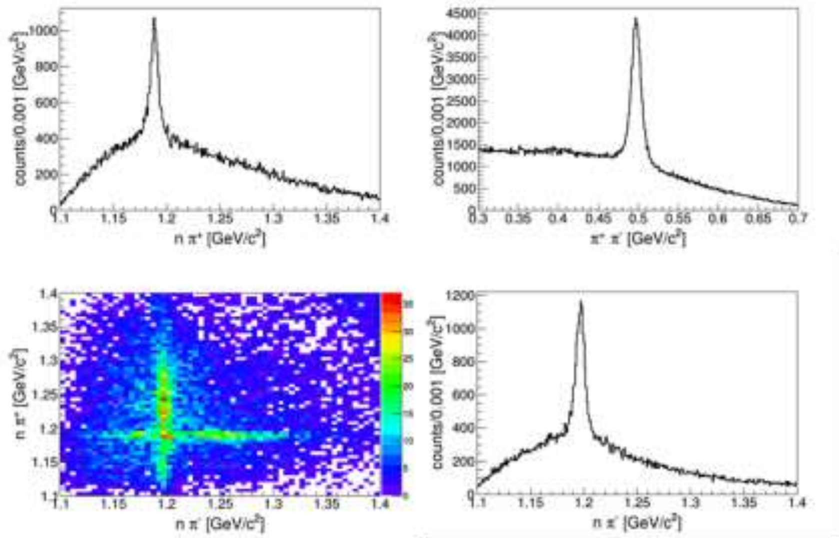

Fig. 6: Reconstructed invariant masses of n π^+, n π^-, and $\pi^+\pi^-$

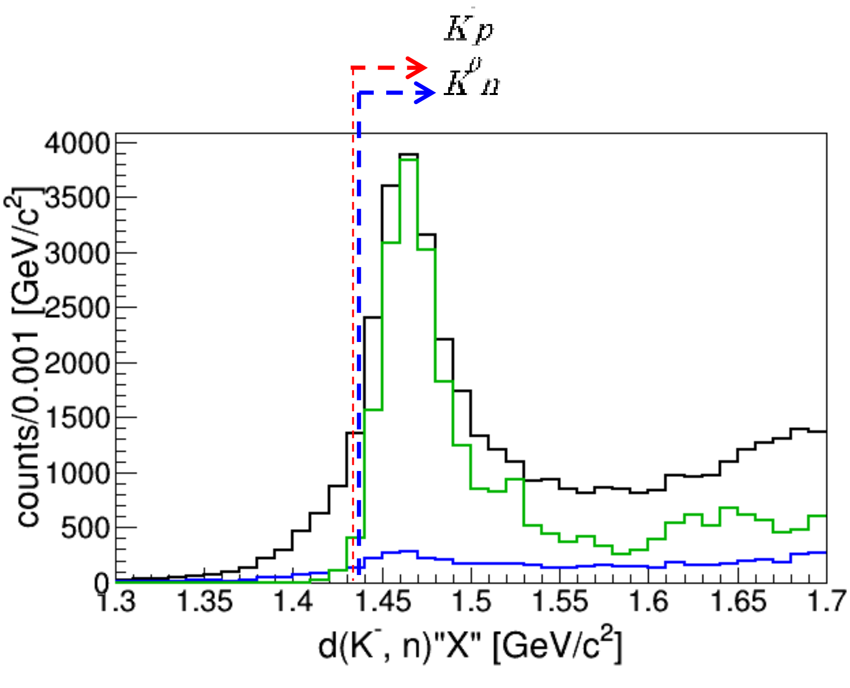

Fig. 7: Reconstructed semi-inclusive d(K$^-$,n) reactions, those selected K^0 (green: scaled 10 times) and forward emitted Σ^{+-} (blue: scaled 10 times).

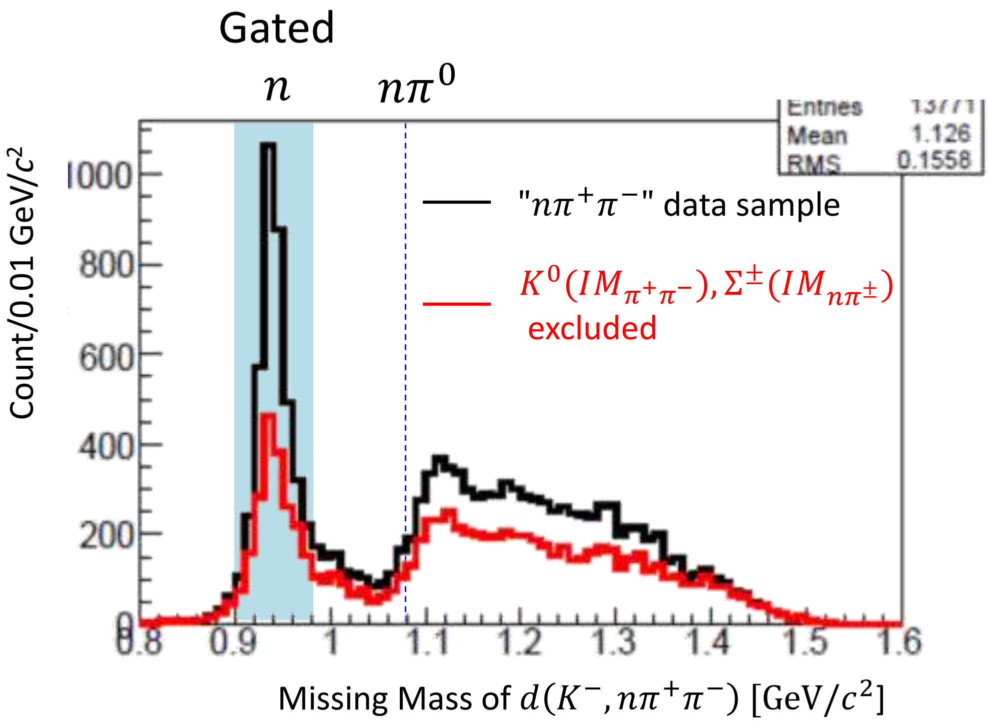

Fig. 8: .Missing neutrons were selected in the d(K-,nπ⁺π⁻).

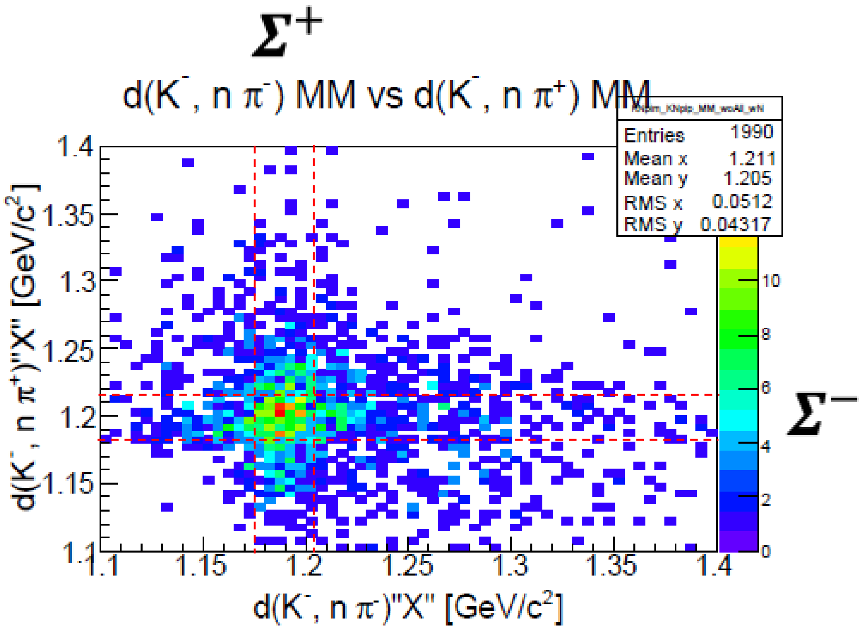

Fig. 9: .Missing Sigmas were selected in the d(K-,nπ^-), and. d(K-,nπ^+),

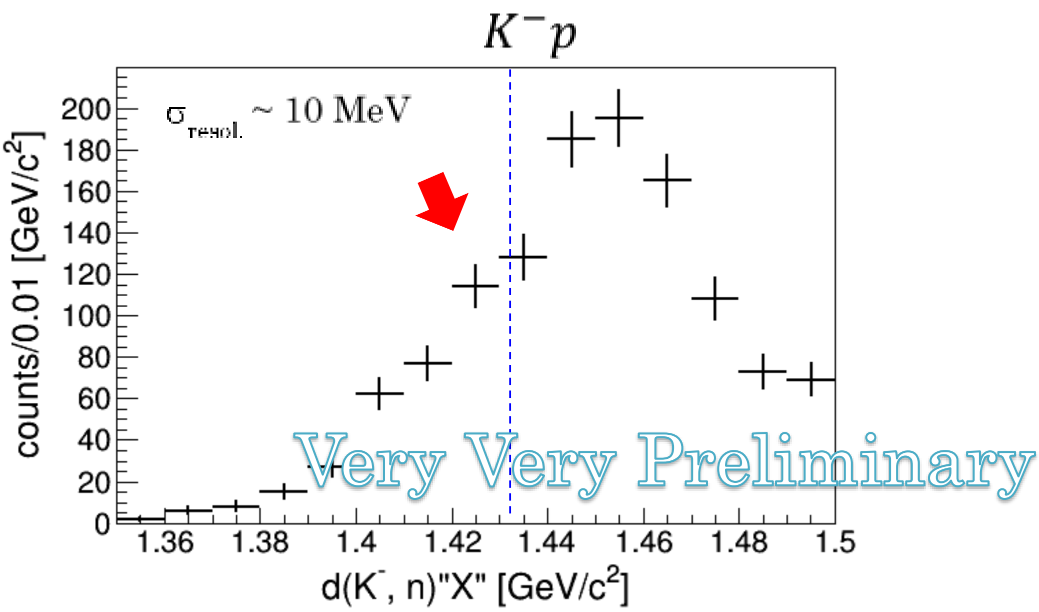

Fig. 10: .Missing mass spectrum of the d(K-,n)$\pi^{\pm}\Sigma^{\mp}$,