December 28, 2009
Hiroyuki Noumi
RCNP, Osaka University
for the P31 collaboration

To the PAC chairperson and members:

I am writing to defend the P31 proposal, which has been deferred in the 8th PAC meeting. Below is the PAC recommendation for P31.

---

The PAC recognizes the importance of the physics of the proposed measurements. However, there are important questions which remain to be addressed by the proponent. The PAC recommends that this proposal be deferred and reconsidered after the following questions are answered:

1) How are the additional data going to accomplish the stated goals of the proposal? Can an I = 0 component of the spectra be extracted unambiguously?
2) Is the experimental setup suitable for the measurement of the Sigma0pi0 decay channel? Is it possible to discriminate the background of Sigma*(1385)–>Lambda pi0?

---

The proposed experiment is **aiming primarily to clarify whether 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]. This experiment will provide vital and most fundamental information on the longstanding argument of the deeply bound kaonic nuclear state. If the Λ(1405) is interpreted as a $\bar{K}N$ resonant state, we may have to re-consider a quark configuration of the baryon resonances and the classification of their excitation spectra.

Because Λ(1405) lies below the $\bar{K}N$ threshold, it is hard to realize direct coupling of $\bar{K}N$ to Λ(1405) in the $\bar{K}N$ scattering in free space. The $\bar{K}N$ to Λ(1405) coupling takes place only through a collision in a virtual state. The d($K^-$,n) reaction realizes $\bar{K}N$

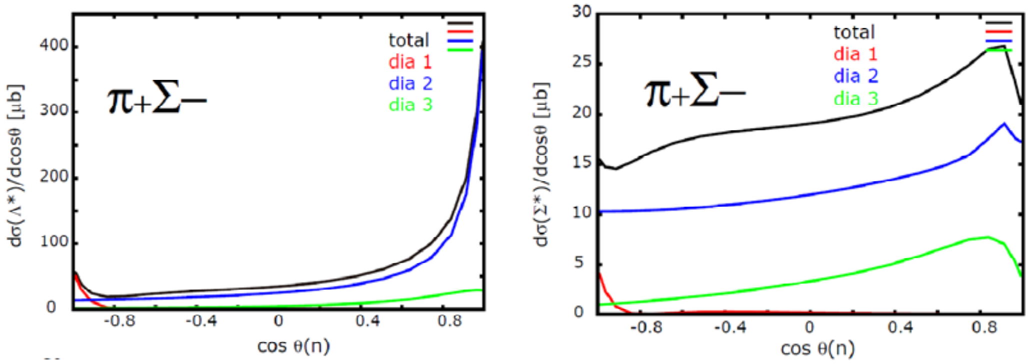


Fig.1: Calculated angular distributions of the Λ(1405) (left) and $\Sigma^*$(1385) (right) cross sections as a function of the neutron scattering angle in the center of mass system in the d($K^-$,n)$\Sigma^-\pi^+$ reactions at $p_{K^-}$ = 800 MeV/c, where the P-wave component in $\bar{K}$N scattering and explicit P-wave baryon components [3]. Diagrams 1, 2, and 3 correspond to those (c), (a), and (b) in Fig. 1 in the P31 proposal, respectively.

collision directly coupled to Λ(1405) in an ideal way.

Recently, we re-confirmed that **the ($K^-$,n) reaction is an ideal reaction to form the Λ(1405) state.** Fig. 1-left shows the differential cross section of the ($K^-$,n) reaction as a function of the neutron scattering angle, calculated by the chiral dynamics[3]. One can easily find that the cross section to produce **the Λ(1405) state is strongly enhanced in the forward direction of the neutron scattering angle.** This can be simply understood as follows. In the d(K-,n) reaction, the recoil momentum of the residual $\bar{K}$N system is as low as 250 MeV/*c* at the incident kaon momentum of 1 GeV/*c*, which corresponds to only 160 MeV/*c* in the center of mass system. Because of the typical baryon size of 1 fm, the angular momentum introduced in the residual $\bar{K}$N system is allowed to be less than $1 * 160/\hbar < 1$. Therefore, only the S-wave resonance, Λ(1405), can be formed in the reaction. On the other hand, as shown in Fig. 1-right, no enhancement of the cross section at a neutron forward angle can be seen in the angular distribution of the P-wave $\Sigma^*$(1385) resonance. In short, the d($K^-$,n) reaction at a neutron forward angle produces Λ(1405) dominantly.

The above-mentioned characteristic angular distributions of the hyperon resonances via the ($K^-$,N) reaction are worth of an additional comment. The d($K^-$,p) reaction populates the $\Sigma^{*-}$(1385) state. Comparison of the d($K^-$,p) spectrum with the d($K^-$,n) one, *i.e.* difference of the line shapes and the cross sections, at a nucleon forward angle would enhance a validity of the discussion. In the last PAC, Fujioka *et al.* proposed to place a proton TOF spectrometer system in the E15 setup in order to measure the $^3$He($K^-$,p) reaction [4]. The PAC considered that the proposed measurement is to be carried out as a part of E15. Therefore, we will take advantage of the existence of this detector and mix ($K^-$,p) triggered events in addition to ($K^-$,n) triggered ones.

Identification of each decay mode of the resonance produced is necessary. The identification of the final $\Sigma\pi$ states enriches the $\Lambda$(1405) component in the d($K^-$,n) spectrum because $\Lambda$(1405) to $\Sigma\pi$ decay branching ratio is 100% while $\Sigma^*$(1385) to $\Sigma\pi$ is only 12%.

Decomposition of the final $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ states is necessary to provide information on the difference of the line shapes and the magnitudes due to the interference term of the *I=0* amplitude to the *I=1* amplitude. The interference term is cancelled by adding the two spectra. The identification of the $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ states can be done by detecting two different charged pions in the CDS system of the E15 experiment. Therefore, we expect to **achieve the primary aim of measuring the position of the $\Lambda$(1405) state in the d($K^-$,n) spectra in coincidences with $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ decay modes.**

Identification of the final $\Sigma^0\pi^0$ state is necessary to provide information on the *I=0* amplitude in the d($K^-$,n)$\Sigma\pi$ reaction cross section. The identification of this decay mode will be done by detecting $p\pi^-$ in the decay chain of $\Sigma^0\pi^0$ –> $\Lambda\gamma\pi^0$ –> $p\pi^-\gamma\gamma\gamma$ in coincidence with the ($K^-$,n) reaction. $\Sigma^*$(1385) has a similar decay chain of $\Lambda\pi^0$ –> $p\pi^-\gamma\gamma$ and is a possible source of contamination to the $\Lambda$(1405) –> $\Sigma^0\pi^0$ mode. One needs to identify the two decay modes in the difference of the missing mass spectrum of $\gamma\pi^0$ from that of $\pi^0$. Due to the limited energy resolution, the $\Sigma^*$ decay mode is contaminating to the $\Lambda$(1405) one at the level of 1/3at around 1400~1420 MeV/$c^2$ in the missing mass spectrum if the production ratio of $\Lambda$(1405) to $\Sigma^*$ is comparable as is assumed in the proposal (Fig. 9 in the proposal). However, **once it is shown that the production ratio is very much enhanced in the d($K^-$,n) reaction as is described above, the contamination of the $\Sigma^*$ to $\Lambda\pi^0$ mode to the $\Lambda$(1405) to $\Sigma^0\pi^0$ mode would be very much reduced.**

As for the primary aim to fix the location of the $\Lambda$(1405) resonance produced via a $\bar{K}N$ collision, it will be accomplished by measuring the d($K^-$,n) spectra through the final $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ states. The result of the measurement would shed light on the structure of $\Lambda$(1405), and give a big impact to the arguments on the deeply bound kaonic nuclear states.

We discussed about identification of the $\Lambda$(1405) to $\Sigma^0\pi^0$ mode by measuring negative pion and proton through the d($K^-$,n) reaction. Particularly, **contamination of the $\Sigma^*$(1385) to $\Lambda\pi^0$ mode may be much reduced due to possible enhancement of $\Lambda$(1405) production by the d($K^-$,n) reaction at a neutron forward angle.** We will prepare to measure the $\Lambda(1405)$ to $\Sigma^0\pi^0$ mode in order to obtain decomposed information on the magnitude of the *I=0* amplitude in the d(K-,n) reaction.

In the d(K-,n) reaction, produced Y* is emitted backward with a recoil momentum of ~250 MeV/*c*. The decay proton is rather emitted to the backward direction. The simulation tells that the backward proton detector system (BPD) placed at 45 cm upstream from the center of the target cell to cover the beam entrance of the CDS earns a factor of 4 ~ 2 more efficiency for the proton than that of the CDH at the most interesting resonance mass region of 1400 ~ 1420 MeV/c². We are considering a simple scintillator hodoscopes with mppc readout as a candidate of BPD at present. We expect to make a compact BPD hodoscopes showing good performance in a strong magnetic field of 5 kGauss and to accommodate it without any serious interference with the current CDS components. The BPD system in combination of the current CDS system is the most efficient way to measure the $\Lambda(1405)\rightarrow\Sigma\pi^0$ decay mode.

In summary,

(1) The proposed experiment is aiming primarily to clarify whether $\Lambda(1405)$ is a $\bar{K}N$ resonant state as predicted by the chiral unitary model or not. To accomplish the aim, we will measure the $\Lambda(1405)$ state via the (K-,n) reaction to test whether the resonance appears at ~1420 MeV/c² or ~1405 MeV/c².

(2) We re-confirmed that the (K-,n) reaction is an ideal reaction to form the $\Lambda(1405)$ state dominantly at a neutron forward angle.

(3) We expect to achieve the primary aim of measuring the position of the $\Lambda(1405)$ state in the d(K-,n) spectra in coincidences with $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ decay modes in high statistics. We expect to obtain the combined information of the *I=0* and *I=1* amplitudes as well as the cross (interference) terms between the two amplitudes in the d(K-,n) reactions

(4) Contamination of the $\Sigma^*(1385)\rightarrow\Lambda\pi^0$ mode to the $\Lambda(1405)\rightarrow\Sigma\pi^0$ mode may be much reduced due to possible enhancement of $\Lambda(1405)$ production by the d(K-,n) reaction at a neutron forward angle. We will prepare to measure the $\Lambda(1405)$ to $\Sigma^0\pi^0$ mode together with the $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ modes in order to obtain the decomposed information on the different isospin amplitudes in the d(K-,n) reaction.

References:

[1] D. Jido, E. Oset, and T. Sekihara, “Kaonic production of $\Lambda(1405)$ off deuteron target in chiral dynamics”, Eur.Phys.J.A42:257-268,2009.

[2] R. H. Dalitz and A. Deloff, J. Phys. G17, 289(1991).

[3] J. Yamagata-Sekihara、T. Sekihara, and D. Jido, paper in preparation; D. Jido, T. Sekihara, J. Yamagata-Sekihara, and H. Fujioka, private communication, Autumn, 2009.

[4] H. Fujioka et al., J-PARC Proposal P28, July 2009