Spectroscopic study of hyperon resonances below $\bar{K}N$ threshold via the (K^-, n) reaction on Deuteron

P-307

We have been planning to study of the Λ(1405) resonance, which locates below the $\bar{K}N$ threshold, via the $d(K^-, n)$ reaction. In the presented reaction, Λ(1405) can be produced dynamically from meson-baryon resonant state. The preparation of experimental setup had been done. The counters worked as expected.

A physics motivations and recent status of the E31 is presented in this contribution.

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Introduction

|| WHAT IS Λ(1405) ? ||

► **Property**
- $S = -1, I = 0$
- Negative parity baryon
- lightest excited state

TABLE 1, Properties from PDG

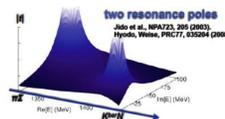|	
$I(J^P)$	$0\left(\frac{1}{2}^-\right)$
Mass	$1405.1^{+1.3}_{-1.0}$ MeV
Full width Γ	50 ± 2 MeV
Decay mode	$\Sigma^\pm \pi^\mp, \Sigma^0 \pi^0$

► **Structure**

Based on the constituent quark model
- 3-quark system (uds)
  → **Can NOT** explain its light mass
  and large Spin-Orbit splitting energy to Λ(1520)

Based on $\bar{K}N$ interaction
- $\bar{K}N$ deeply bound state (single-pole)
  B.E. : as deep as 27 MeV
- Two-pole ($\bar{K}N - \pi\Sigma$) structure

two resonance poles
Jido et al., NPA723, 205 (2003).
Hyodo, Weise, PRC77, 035204 2008).

► **Strongly attractive $\bar{K}N$ interaction?**
- A deeply bound kaonic nuclei

► **Meson-baryon molecule state?**
- A new building block of hadron
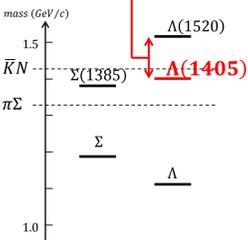
Important information for these discussions

|| RECENT STUDIES ||

► **HADES** (Agakishiev et al., Phys. Rev. C87, **2013**, 055202)
- $pp \to K^+p''\Sigma\pi''$

► **LEPS** (M. Niiyama et al., Phys. Rev. C78, **2008**, 035202)
- $\gamma p \to K^+ "\Sigma^\pm \pi^\mp"$

► **CLAS** (K. Moriya et al., Phys. Rev. C87, **2013**, 035206)
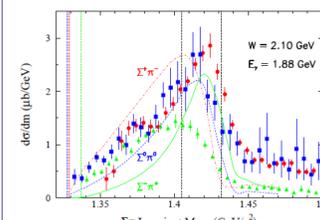- $\gamma p \to K^+ "\Sigma^{\pm,0} \pi^{\mp,0}"$

Λ(1405) is expected to be
a dynamically generated state.
→ **The line shape depends on the reaction.**

Line shape by CLAS

W = 2.10 GeV
E_γ = 1.88 GeV

Different line shapes in the final $\Sigma\pi$ states are indicating existences of interference term between I=0 and I=1 amplitudes.

※ These measurements of line shape
could NOT pin down Single / Double - pole structure of Λ(1405).
⇓
Study of $\bar{K}N$ scattering coupled to Λ(1405) is necessary.
→ *Using $d(K^-, n)$ reaction*

Experiment

J-PARC E31 experiment
Noumi et al., J-PARC E31 proposal.

|| PRODUCTION ||

► $d(K^-, n)$ reaction
- $\bar{K}N$ scattering to form Λ(1405)
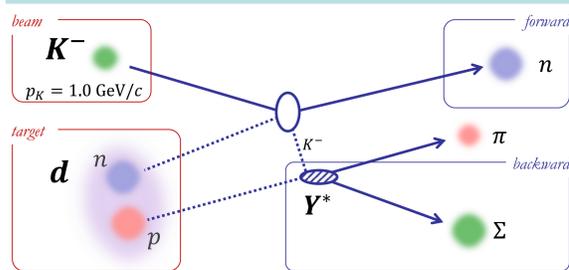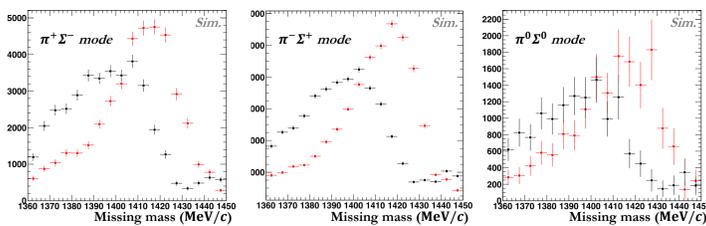 below $\bar{K}N$ threshold is realized.

beam K^- $p_K = 1.0$ GeV/c *forward* n
target d n p K^- *backward* Y^* π Σ

FIGURE 1, The reaction diagram that is expected to be dominant

|| EXPECTED SPECTRA ||

► Simulated $d(K^-, n)$ missing mass spectra

$\pi^+\Sigma^-$ mode   *Sim.*
$\pi^-\Sigma^+$ mode   *Sim.*
$\pi^0\Sigma^0$ mode   *Sim.*

Missing mass (MeV/c)

Black plots : The line shap is calculated by R. H. Dalitz et al. (one-pole) (R. H. Dalitz et al., J. Phys. G: Nucl. Part., 17, **1991**, 289)
Red plots : The line shape is calculated on Chiral unitary model by D. Jido et al. (two-pole) (D. Jido et al., Eur. Phys. J A, 42, **2009**, 257)

|| DETECTORS ||

► **Beam line detectors**
- BHD, T0 — Plastic scintillator
- BLC1, BLC2 — Drift chamber
- AC — Aerogel Cherenkov counter

► **Forward detectors**
- NC, PC, BVC, CVC — Plastic scintillator
- FDC — Drift chamber

► **Backward detectors**
- BPD — Plastic scintillator
- BDC — Drift chamber
  → *detects the decay proton*

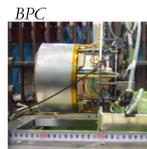### || LD2 TARGET ||

► **Liquid deuteron**
- Density is 0.17 g/cm²

► **G-M refrigerator**
- Temperature is controlled ∼ 20 K.

BPD 350 mm × 340 mm
BPC φ 168 mm Effective : φ111 mm

|| MEASUREMENT ||

► **Missing mass spectra in the $d(K^-, n)$ reaction**
- Reconstructing mass of produced hyperon resonances

► **Identifying all the decay final states of Λ(1405)**
- *Decomposing isospin amplitudes*
  $\pi^\pm\Sigma^\mp$, $\underline{\pi^0\Sigma^0}$ *Purely I=0*

Λ(1405):
$\pi^+\Sigma^- \to \pi^+ \boxed{\pi^- n}$
$\pi^-\Sigma^+ \to \pi^- \boxed{\pi^+ n}$, $\pi^- \boxed{\pi^0 p}$
$\pi^0\Sigma^0 \to \pi^0 \boxed{\gamma \Lambda} \to \pi^0 \gamma \boxed{\pi^- p}$

background
$\Sigma(1385) \to \pi^\pm\Sigma^\mp$, $\pi^0 \boxed{\Lambda} \to \pi^0 \boxed{\pi^- p}$
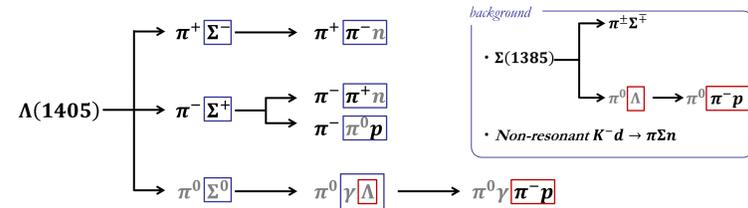Non-resonant $K^- d \to \pi\Sigma n$

FIGURE 2, Main decay modes of the hyperon resonances

$K^- d \to n$ Λ(1405)   *Detected by NC*
Kicked neutron
Decay π   Decay π   Decay π
Decay proton in $\pi^0\Sigma^0$ mode
Λ(1405) → $\pi\pi N(\gamma)$ *Detected by CDS*
All decay mode of Λ(1405) can be measured.

Target cell   BPC   BPD   Solenoid magnet
Angular distribution of decay proton
←Backward   Forward→
cos θ
Beam K^- 1 GeV/c
CDH   CDC   IH   DEF

Cylindrical Detector System

Vapor pressure monitor & safty valve   GM refrigerator
1st stage cold head (35W@50K) D_2 Inlet
Radiation shield box   Pumping to RP & TMP
2nd stage cold head (1.5W@4.2K)
Cold finger   Heat exchanger
Target cell (D_2)   Kaon beam K
CFRP vessel   Large cross chamber
Target system

NC   CDS   D5

Neutron Counter
Forward neutrons
Trajectory of the neutron
Beam sweeping magnet   CDS & target system   Beam line spectrometer
Decay particles
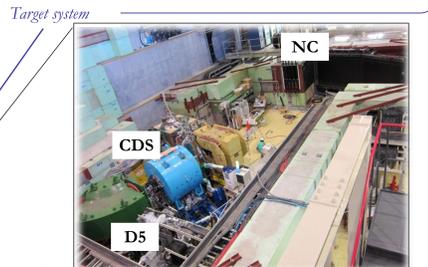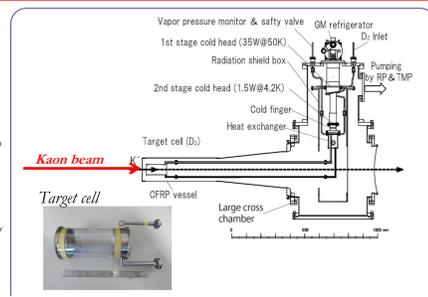Trajectory of the beam center

PC   NC   CVC
BVC, FDC
BLC2, T0, AC
BLC1
BHD

FIGURE 3, Experimental setup

K1.8BR beam line
D: dipole magnet
Q: quadrupole magnet
S: sextupole magnet
O: octupole magnet
T1: production target
IF: intermediate focus
MS: mass slit
ES: electrostatic separator
CM: correction magnet
FF: final focus
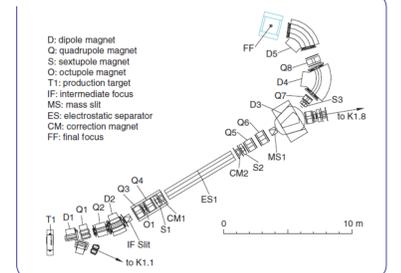
K. Agari et al., Prog. Theor. Exp. Phys. **2012**, 02B011

Status

► **Preparation of detectors**
- All detectors were installed and in operation.
  → *Detector performances were demonstrated in good shape in the previous beam time (E15 1st physics run, May, 2013)*

*Almost setup of E15 is same as E31.
Only target is different (Helium - 3).*

TABLE 2, Typical performances

$MM_{^3He(K^-,n)X}$ resolution	10 MeV/c
BPD time resolution	< 200 ns

The E31 pilot run will be held on the next beam time of HD
→ A data of $\pi^\pm\Sigma^\mp$ mode in $d(K^-, n)$ reaction will come…

Conclusion

► **We plan to study the hyperon resonances via the $d(K^-, n)$ reaction.**
- Λ(1405) will be studied with decomposing isospin structure.

► **instrumentation for the experiment (detectors, LD2 target) was demonstrated well in the previous beam time.**
- E31 experiment is ready to run.

► **The E31 pilot run will start in the next beam time.**
- $\pi^\pm\Sigma^\mp$ mode will be analyzed first.