

Direct measurement of the  $\bar{K}N \rightarrow \pi\Sigma$  scattering  
amplitude below the  $\bar{K}N$  threshold employing the  
 $d(K^-, N)''\pi\Sigma''$  reaction

Kentaro Inoue

January 20, 2023

# Contents

|          |                                  |          |
|----------|----------------------------------|----------|
| <b>1</b> | <b>Introduction</b>              | <b>3</b> |
| <b>2</b> | <b>Experimental setup</b>        | <b>4</b> |
| <b>3</b> | <b>Analysis</b>                  | <b>5</b> |
| <b>4</b> | <b>Discussion and conclusion</b> | <b>6</b> |
| <b>A</b> | <b>Appendix Title.1</b>          | <b>7</b> |
| <b>B</b> | <b>Appendix Title.2</b>          | <b>8</b> |

# Chapter 1

## Introduction

## Chapter 2

# Experimental setup

## Chapter 3

# Analysis

## Chapter 4

# Discussion and conclusion

Appendix A

Appendix Title.1

**Appendix B**

**Appendix Title.2**

# Bibliography

- [1] R. H. Dalitz and S. F. Tuan, Phys. Rev. Lett. **2** (1959).  
"Possible Resonant State in Pion-Hyperon Scattering"
- [2] M. H. Alston, L. W. Alvarez, P. Eberhard and M. L. Good,  
Phys. Rev. Lett. **6**, 698 (1961).  
"Study of Resonances of the  $\Sigma - \pi$  System"
- [3] R. H. Dalitz, T. C. Wong and G. Rajasekaran,  
Phys Rev. **153**, 1617 (1967)  
"Model Calculation for the  $Y^*(1405)$  Resonance State"
- [4] R. J. Hemingway, Nucl Phys B **253**, 742 (1985).  
"Production of  $\Lambda(1405)$  in  $K^-p$  Reactions at  $4.2\text{GeV}/c$ "
- [5] R. H. Dalitz and A. Deloff, J. Phys. G17, 281 (1991).  
"The Shape and Parameters of the  $\Lambda(1405)$  Resonance"
- [6] N.KaiserP.B.Siegel and W.Weise, Nucl Phys A **594**, 325 (1995).  
"Chiral Dynamics and the Low-Energy Kaon-Nucleon Interaction"
- [7] D. Jido et al., Nucl. Phys. A **725**, 181 (2003).  
"Chiral Dynamics of the Two  $\Lambda(1405)$  States"
- [8] M. Niiyama et al., Phys. Rev. C **78**, 035202 (2008).  
"Photoproduction of  $\Lambda(1405)$  and  $\Sigma(1385)$  on the proton at  $E_\gamma = 1.5$ - $2.4\text{GeV}/c$ "
- [9] K. Moria for the CLAS Collaboration,  
Phys. Rev. C **87**, 035206 (2013).  
"Measurement of the  $\pi\Sigma$  photoproduction line shapes near the  $\Lambda(1405)$ "
- [10] K. Moria for the CLAS Collaboration,  
Phys. Rev. Lett. **112**, 082004 (2014).  
"Spin and parity measurement of the  $\Lambda(1405)$  baryon"
- [11] S. X. Nakamura and D. Jido, Phys. Theor. Exp. Phys., **2014**, 023D01 (2014).  
"Lambda (1405) photoproduction based on the chiral unitary model"

- [12] L. Roca and E. Oset, Phys. Rev. C **87**, 055201 (2013).  
"Λ(1405) poles obtained from  $\pi^0\Sigma^0$  photoproduction data"
- [13] G. Agakishiev for the HADES Collaboration,  
Phys. Rev C **87**, 025201 (2013).  
"Baryonic Resonances to the  $\bar{K}N$  threshold: The case of Λ(1405) in  $pp$  collisions"
- [14] M. Hassanvand et al., Phys. Rev. C **87**, 055202 (2013)  
"Theoretical analysis of  $\Lambda(1405) \rightarrow (\pi\Sigma)^0$  mass spectra produced in  $p + p \rightarrow p + \Lambda(1405) + p$  reactions"
- [15] J. Siebenson and L. Fabbietti, Phys. Rev. C **88**, 055201 (2013)  
"Investigation of the Λ(1405) line shape observed in  $pp$  collisions"
- [16] M. Iwasaki et al., Phys. Rev. Lett. **78**, 3067 (1997).  
"Observation of Kaonic Hydrogen  $K_\alpha$  X Rays"
- [17] M. Bazzi et al., Phys. Lett. B **704**, 113 (2011).  
"A New Measurement of Kaonic Hydrogen X-Rays"
- [18] T. Hyodo and U.-G. Meißner, PDG Review, Tables and Plots, Section.83  
"Pole Structure of the Λ(1405) Region"
- [19] O. Braun et al., Nucl. Phys. B **129**, 1 (1977).  
"New Information About the Kaon-Nucleon-Hyperon Coupling Constants  $g(KN\Sigma(1197))$ ,  $g(KN\Sigma(1385))$  and  $g(KN\Lambda(1405))$ "
- [20] D. Jido, E. Oset and T. Sekihara, Eur. Phys. J. A **42**, 257 (2009).  
"Kaonic Production of Λ(1405) off deuteron target in chiral dynamics"
- [21] J. Yamagata-Sekihara, T. Sekihara, and D. Jido, Prog. Theor. Exp. Phys.**2013**, 043D02 (2013).  
"Production of hyperon resonances induced by kaons on a deuteron target"
- [22] A. D. Martin, Nucl. Phys. B **179**, 33 (1981).  
"Kaon-Nucleon Parameters"
- [23] J. D. Davies et al., Phys. Lett. B **83**, 55 (1979).  
"Observation of Kaonic Hydrogen Atom X-rays"
- [24] M. Izycki et al., Z. Phys. A **297**, 11 (1980).  
"Results of the Search for K-series X-rays from Kaonic Hydrogen"
- [25] H. Zhang et al., Phys. Rev. C **88**, 035204 (2013).  
"Partial-wave analysis of  $\bar{K}N$  scattering reactions"

- [26] H. Zhang et al., Phys. Rev. C **88**, 035205 (2013).  
"Multichannel parametrization of  $\bar{K}N$  scattering amplitudes and extraction of resonance parameters"
- [27] P. M. Bird et al., Nucl. Phys. A **404**, 482 (1983).  
"Kaonic Hydrogen Atom X-rays"
- [28] H. Noumi et al., Proposals for the 15th PAC meeting  
"Spectroscopic study of hyperon resonances below  $\bar{K}N$  threshold via the  $(K^-, n)$  reaction on Deuteron"
- [29] Y. Ikeda, T. Hyodo, and W. Weise, Nucl. Phys. A **881**, 98 (2012)  
"Chiral SU(3) theory of antikaon–nucleon interactions with improved threshold constraints"
- [30] T. Hashimoto et al., Phys. Rev. Lett. **128**, 112503 (2022).  
"Measurements of Strong-Interaction Effects in Kaonic-Helium Isotopes at Sub-eV Precision with X-Ray Microcalorimeters"
- [31] J. Zmeskal et al., J-PARC P57 Proposal  
"Measurement of the Strong Interaction Induced Shift and Width of the 1s State of Kaonic Deuterium at J-PARC"
- [32] G. P. Gopal et al., Nucl. Phys. B **119**, 362 (1977).  
"Partial-wave analyses of KN two-body reactions between 1480 and 2170 MeV"
- [33] Jonathan M. M. Hall et al., Phys. Rev. Lett. **114**, 132002 (2016).  
"Lattice QCD Evidence that the  $\Lambda(1405)$  Resonance is an Antikaon-Nucleon Molecule"
- [34] H. Kamano et al., Phys. Rev. C **90**, 065202 (2014).  
"Dynamical Coupled-Channels Model of  $K^-p$  Reactions: Determination of  $P$ -partial-wave amplitudes"  
Phys. Rev. C **92**, 025205 (2015).  
"Dynamical Coupled-Channels Model of  $K^-p$  Reactions. Extraction of  $\Lambda^*$  and  $\Sigma^*$  Hyperon Resonances"  
Phys. Rev. C **95**, 044903(E) (2015).
- [35] J. Esmaili, Y. Akaishi, and T. Yamazaki, Phys. Lett. B **686**, 23 (2010)  
"Experimental confirmation of the  $\Lambda(1405)$  ansatz from resonant formation of a  $K^-p$  quasi-bound state in  $K^-$  absorption by  $^3\text{He}$  and  $^4\text{He}$ "
- [36] M. Niiyama et al., Phys. Rev. C **78**, 035202 (2008).  
"Photoproduction of  $\Lambda(1405)$  and  $\Sigma(1385)$  on the proton at  $E_\gamma = 1.5$ - $2.4\text{GeV}/c$ "

- J. K. Ahn, Nucl. Phys. A **721**, 715c (2002).  
 "Λ(1405) photoproduction at Spring-8/LEPS"
- [37] J.C.Nacher et al., Phys. Lett. B **455**, 55 (1999).  
 "Photoproduction of the Λ(1405) on the proton and nuclei"
- [38] A. Cieplý and J. Smejkal, Nucl. Phys. A **881**, 115 (2012).  
 "Chirally motivated  $\bar{K}N$  amplitudes for in-medium applications"
- [39] L.Fabbietti et al., Nucl. Phys. A **914**, 60 (2013).
- [40] K. Miyagawa, J. Haidenbauer, and H. Kamada Phys. Rev. C **97**, 055209 (2018)  
 "Faddev approach to the reaction  $K - d \rightarrow \pi \Sigma n$  at  $p_K = 1.0 \text{ GeV}/c$ "
- [41] S. Kawasaki et al., JPS Conf. Proc. **13**, 020018 (2017).  
 "Spectroscopic Experiment of Λ(1405) via the In-flight  $d(K^-, n)n$  Reaction at J-PARC K1BR.8"
- [42] E. Oset, A. Ramos, and C. Bennhold, Phys. Lett. B **527**, 99 (2002); **530**, 260(E) (2002).  
 "Low lying  $S = -1$  excited baryons and chiral symmetry"
- [43] H. Zhang, et al., Phys. Rev. C **88**, 035204 (2013). "Partial-wave analysis of  $\bar{K}N$  scattering reactions"
- [44] S. Ohnishi et al, Phys. Rev. C **93**, 025207 (2016).  
 "Structure of the Λ(1405) and the  $K^-d \rightarrow \pi \Sigma n$  reaction"
- [45] H. Kamano et al., Phys. Rev. C **94**, 065205 (2016).  
 "Toward Establishing Low-Lying Λ and Σ Hyperon Resonances with the  $\bar{K} + d \rightarrow \pi + Y + N$  Reaction"
- [46] T. Hyodo and D. Jido, Prog. Part. Nucl. Phys. **67**, 55 (2012).  
 "The Nature of the Λ(1405) Resonance in Chiral Dynamics"
- [47] K. Agari et al, Prog. Theor. Exp. Phys., 02B009 (2012)
- [48] K. Agari et al, Prog. Theor. Exp. Phys., 02B011 (2012)
- [49] TRANSPORT <http://linac96.web.cern.ch/Linac96/Proceedings/Thursday/THP72/Paper.1>
- [50] T. K. Ohnska et al., Nuclear Science, IEEE Transactions on 33, 98 (1986).
- [51] M. Shiozawa and et al., A new TKO system manager board for a dead-time-free data acquisition system, in 1994 IEEE Nuclear Science Symposium-NSS'94, pages 632–635, (1994)
- [52] M. Iio et al., Nucl. Instrum. Methods Phys. Res., Sect. A **687**, 1 (2012).

- [53] S. Agostinelli et al., Nucl. Instrum. Methods Phys. Res., Sect. **A** 506, 250 (2003)  
J. Allison et al., IEEE Transactions on Phys. Sci. 53, 207 (2006)  
J.Allison et al., Nucl. Instrum. Methods Phys. Res., Sect. **A** 835, 186 (2016)
- [54] K. Fuji, [https://www-jlc.kek.jp/subg/offl/lib/docs/helix\\_manip/node3.html](https://www-jlc.kek.jp/subg/offl/lib/docs/helix_manip/node3.html) (1968).
- [55] Opera Electromagnetic FEA Solution Software
- [56] V. Flaminio et al., CERN-HARA-87-01, 121 (1983).
- [57] M.Jones et el, Nucl. Phys. B **90**, 349 (1975)
- [58] R. Barlow and C. Beeston, Comp. Phys. Comm. **77**, 219 (1993).
- [59] A. Nappi, Comp. Phys. Comm. **180**, 269 (2009).
- [60] M. jones, R. Levi, Setti, D. Merrill and R. D. Tripp, Phys. Rev. B**90**, 349 (1975).
- [61] M. Bernheim and et. el., Nucl. Phys. A**365**, 349, (1981).
- [62] R. Machleidt, Phys. Rev. C**63**, 024001 (2001).
- [63] S. Agostinelli et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **506**, 250 (2003).  
J.Allison et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **835**, 186 (2016).