Hyperon-nucleon interaction through the $K^- d \to \pi \Lambda N$ reaction

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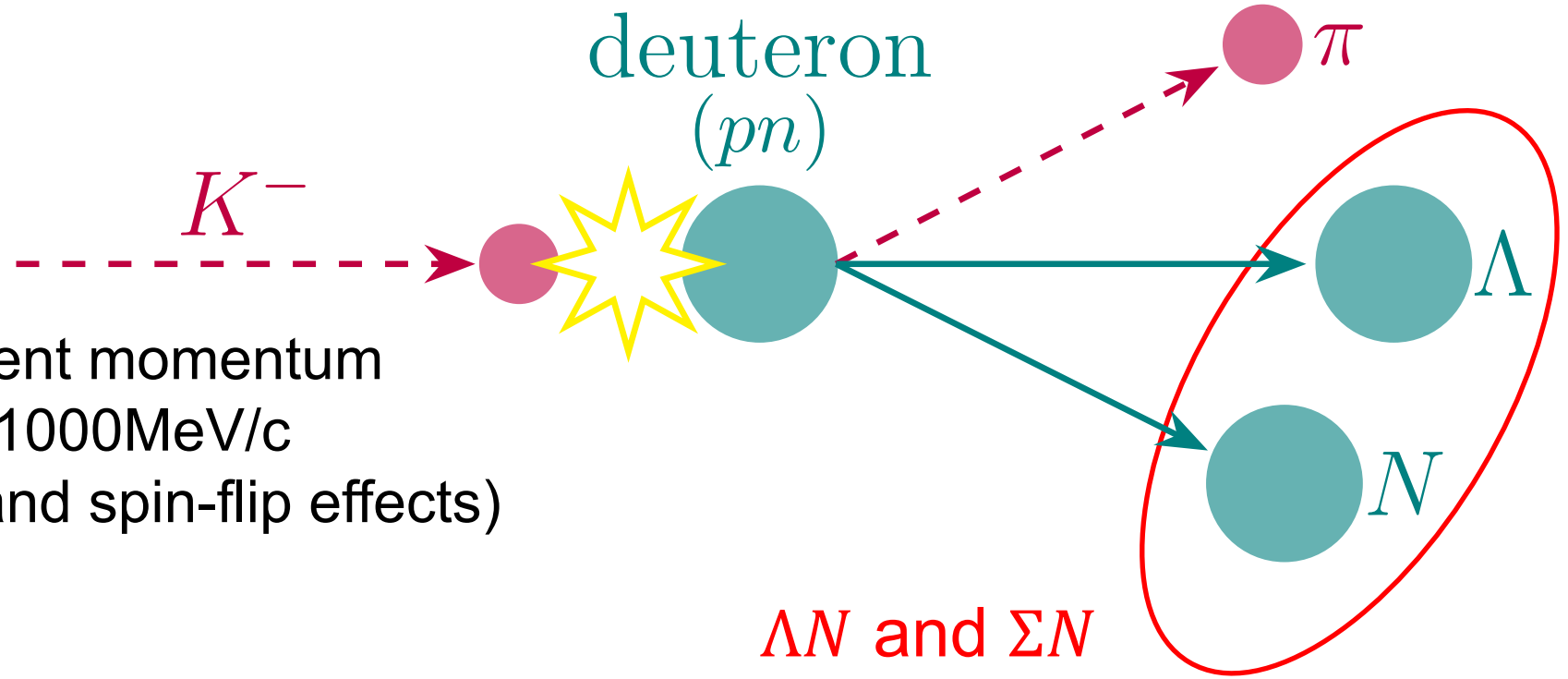
$K^- d \to \pi \Lambda N$ reaction

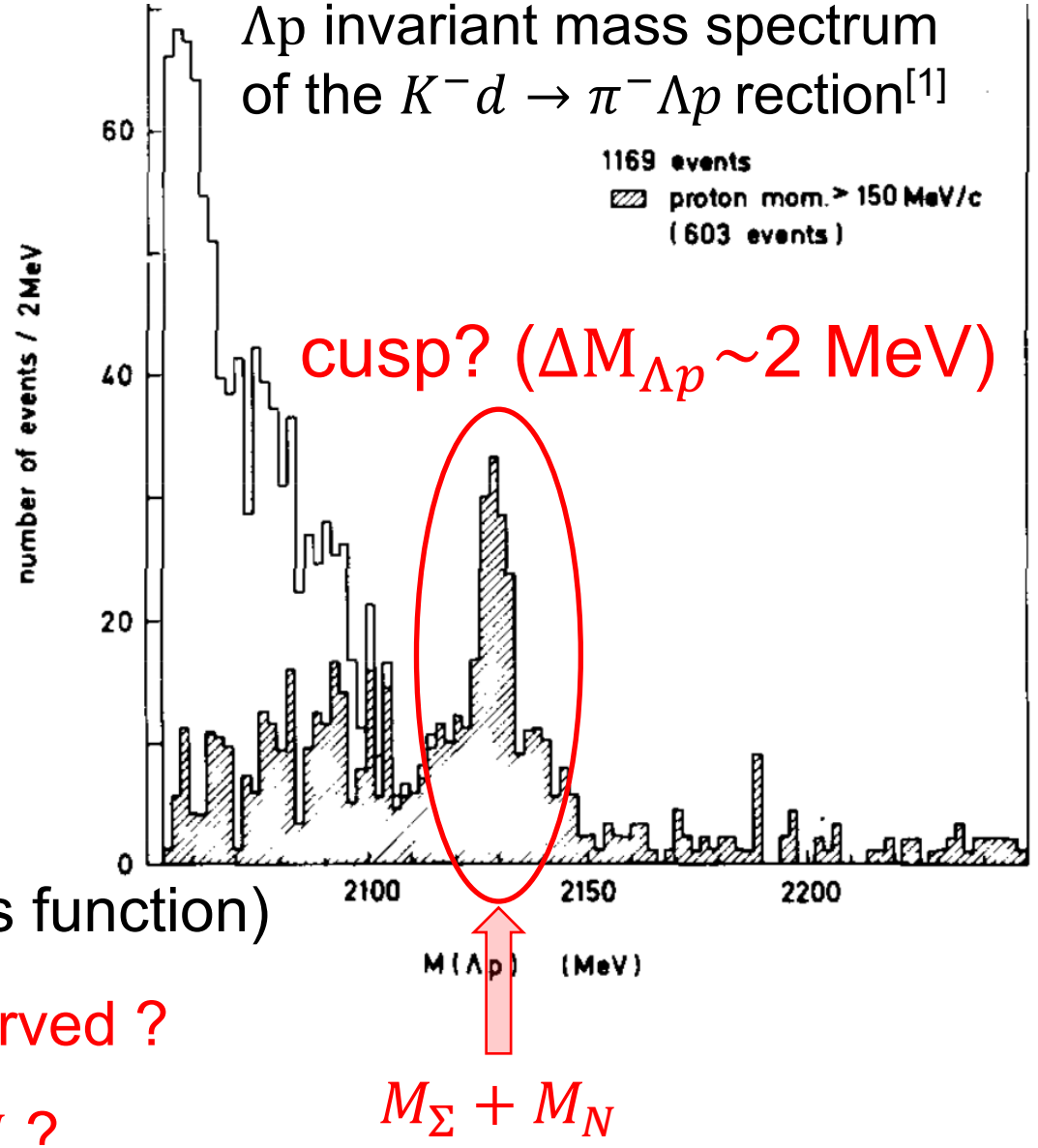


ΣN cusp structure

- Threshold cusp is general feature in spectra representing the sharp peak at thresholds.
- Two factors on the ΣN threshold:
  1. ΣN is coupled to lower channel ΛN
  2. Intermediate Σ (imaginary part of Green's function)

Is cusp structure (sharpness) really observed ?

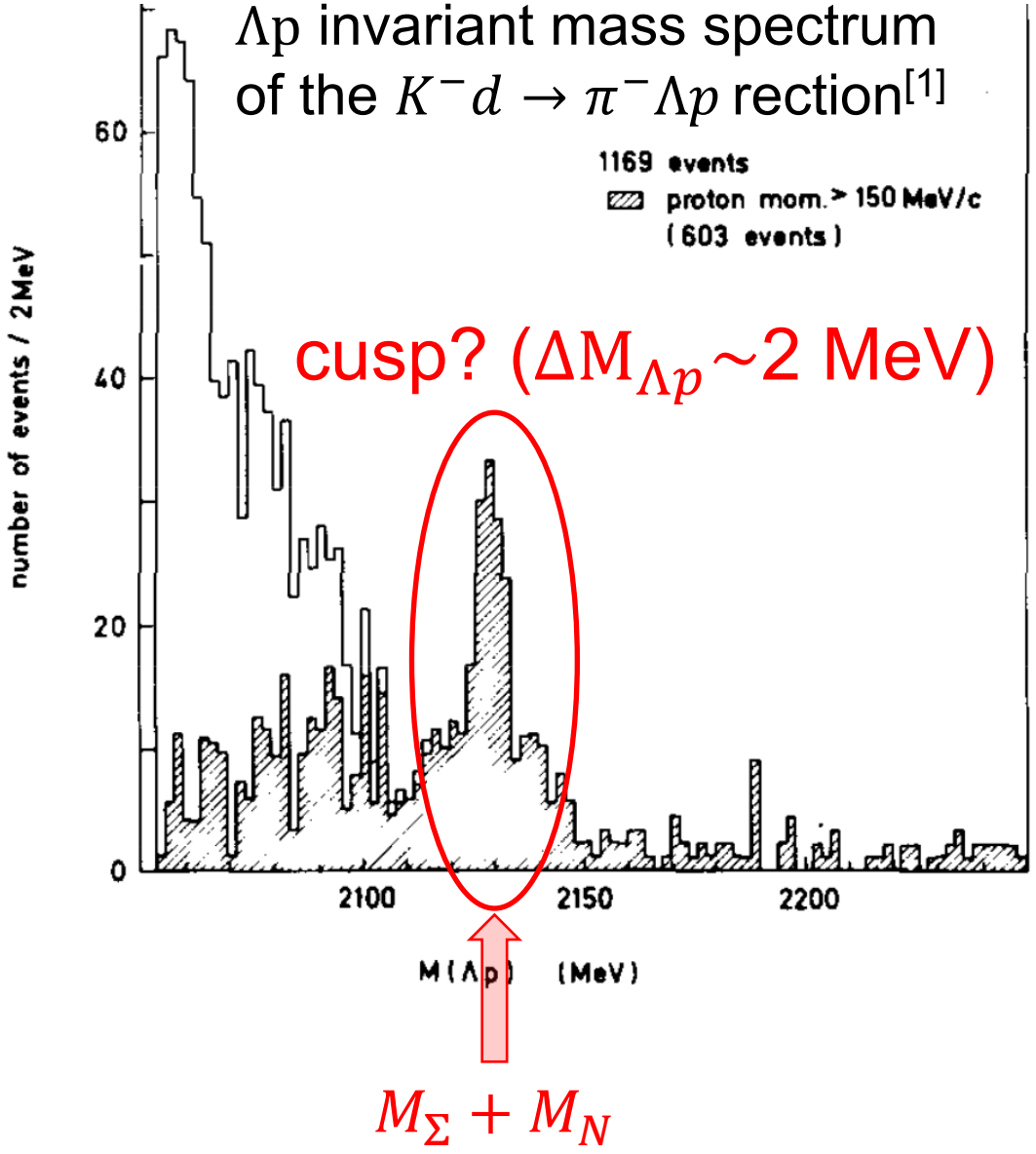
Can we obtain the amplitude of $\Sigma N \to \Lambda N$?



[1] O. Braun, et al, Nuclear Physics B 124, 45 (1977).

ΣN cusp structure

- Ongoing experiment J-PARC E90[2]:
  incident kaon momentum 1.4 GeV/c
  expected resolution $\Delta M_{\Lambda \mathrm{p}} = 0.4$ MeV
- This study is focused on the theoretical analysis of the ΛN invariant mass spectrum near the ΣN threshold.



[1] O. Braun, et al, Nuclear Physics B 124, 45 (1977).
[2]Y. Ichikawa et al. (J-PARC E90 Collaboration), EPJ Web Conf. 271, 02012 (2022).

Isospin symmetry breaking of ΛN

- There are some experimental data of the scattering length $a_{\Lambda p}$.

  However, $a_{\Lambda n}$ is not measured due to the experimental difficulties.

  Thus, its isospin symmetry breaking ($a_{\Lambda n}/a_{\Lambda p}$) is unknown.

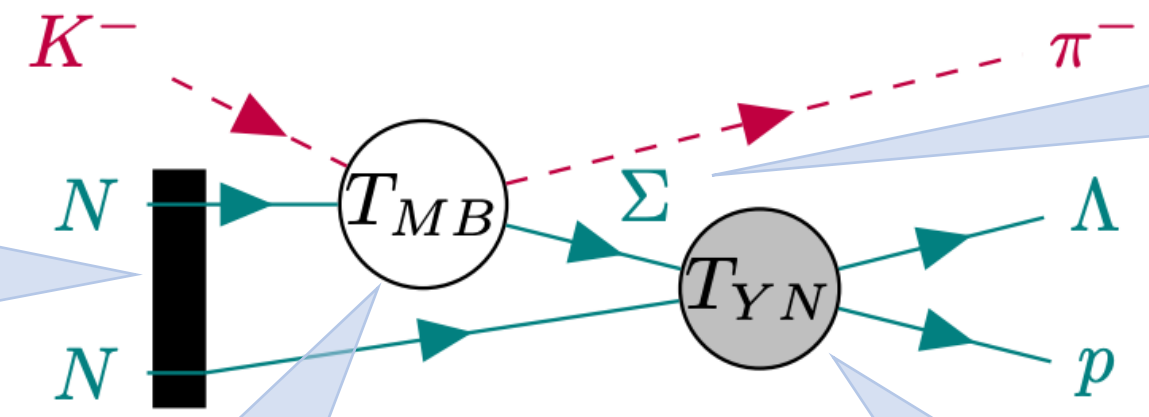
- We calculated ΛN invariant mass spectra for the $K^- d \to \pi^0 \Lambda n$, $\pi^- \Lambda p$ and concluded that ratios of them can be extracted from that of the spectra[3].

$$a_{\Lambda n}^{\mathrm{spin}=1} / a_{\Lambda p}^{\mathrm{spin}=1} \approx 2 \frac{d\sigma(\pi^0 \Lambda n)}{dM_{\Lambda n}} \Big/ \frac{d\sigma(\pi^- \Lambda p)}{dM_{\Lambda p}}$$

[3] S.Y. and D. Jido, T. Ishikawa, Phys. Rev. C **112**, 015208 (2025)

Scattering process (Foreground)

Σ exchange diagram for the $K^- d \to \pi^- \Lambda p$ reaction



Deuteron (wave function[4], spin of deuteron)

Propagator

Meson-baryon amplitude

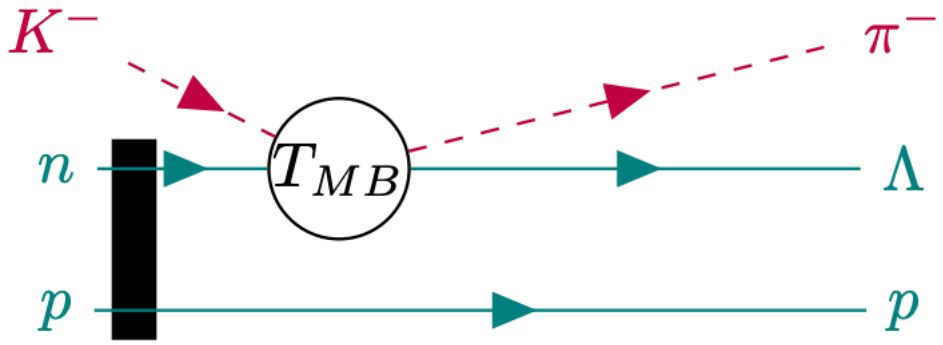
Σ exchange

Hyperon-nucleon amplitude

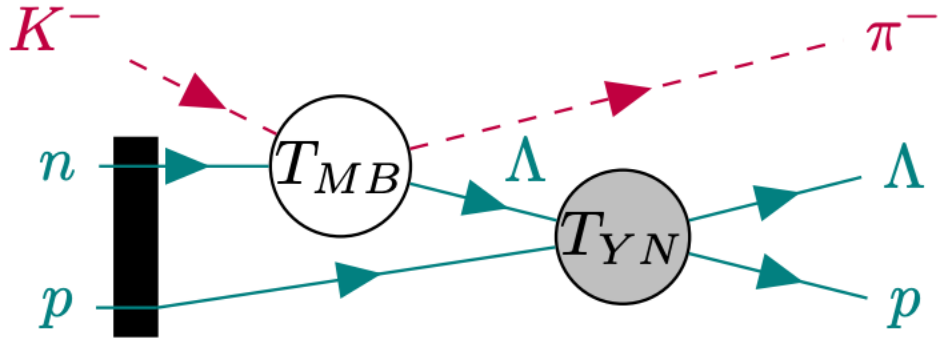
[4] R. Machleidt, Phys. Rev. C 63, 024001 (2001).

Scattering processes (Backgrounds)

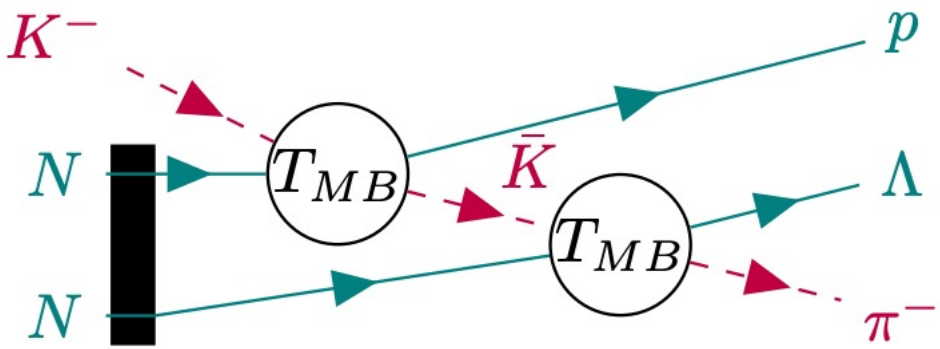
Background diagrams for the $K^- d \to \pi^- \Lambda p$ reaction



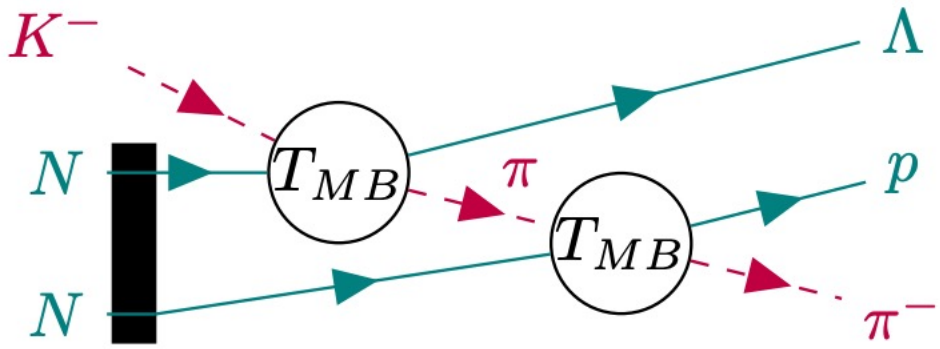
impulse



Λ exchange

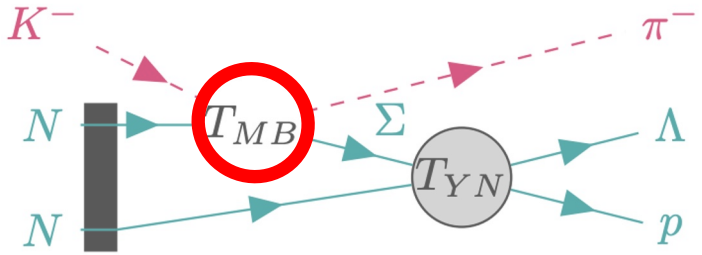


$\bar{K}$ exchange



π exchange

Meson-Baryon amplitude: T_{MB}



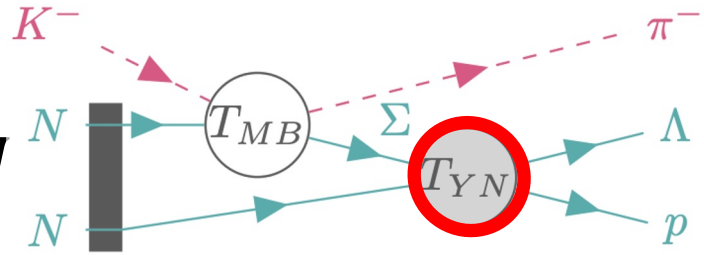
- Partial wave expansion (up to f-wave, $l = 4$)
- $\bar{K}N$ amplitudes ($\bar{K}N \to \bar{K}N, \pi\mathrm{Y}$):

  ANL-Osaka DCC model[4] (amplitude for each channel)

- πN amplitudes: experimental data[5]

[5] H. Kamano, S. X. Nakamura, T.-S. H. Lee, T. Sato, Phys. Rev. C **90**, 065204 (2014)
[6] R. L. Workman, R. A. Arndt, W. J. Briscoe, M. W. Paris, and I. I. Strakovsky, Phys. Rev. C 86, 035202 (2012).

Hyperon-nucleon amplitude: T_{YN}



- K-matrix parametrization (3×3 matrix, $\Lambda p, \Sigma^+ n, \Sigma^0 p$ channel)

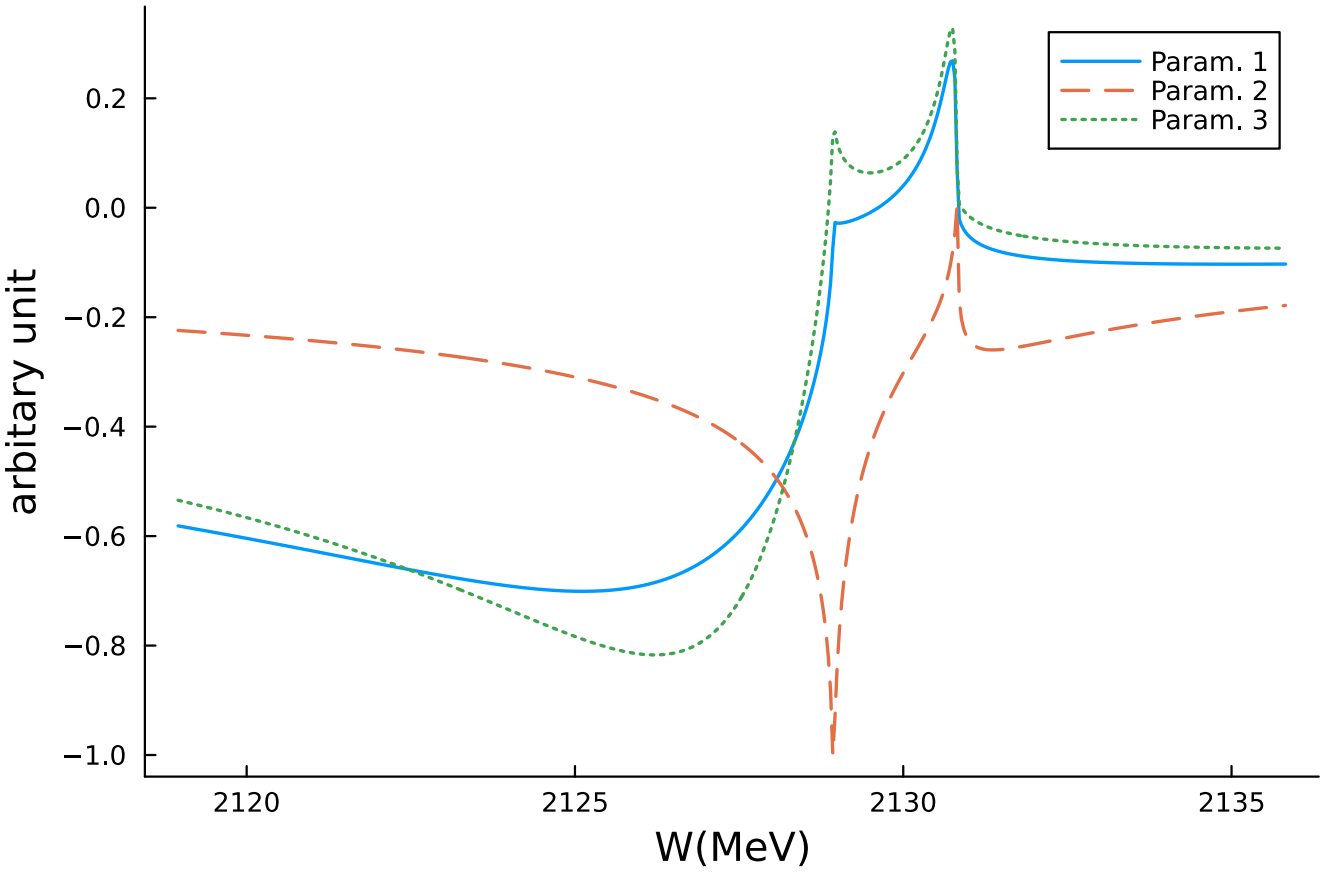
$$T(W) = (K^{-1} - iP(W))^{-1}$$

- K is real and constant. Three components for

$$K_2 = \begin{pmatrix} K_{\Lambda\Lambda} & K_{\Lambda\Sigma} \\ K_{\Sigma\Lambda} = K_{\Lambda\Sigma} & K_{\Sigma\Sigma} \end{pmatrix}, K = \begin{pmatrix} 1 & 0 \\ 0 & -\sqrt{2/3} \\ 0 & \sqrt{1/3} \end{pmatrix} K_2 \begin{pmatrix} 1 & 0 & 0 \\ 0 & -\sqrt{2/3} & \sqrt{1/3} \end{pmatrix}$$

are fixed by the value of $a_{\Lambda p}$ and $a_{\Sigma N(I=1/2)}$.

Hyperon-nucleon amplitude

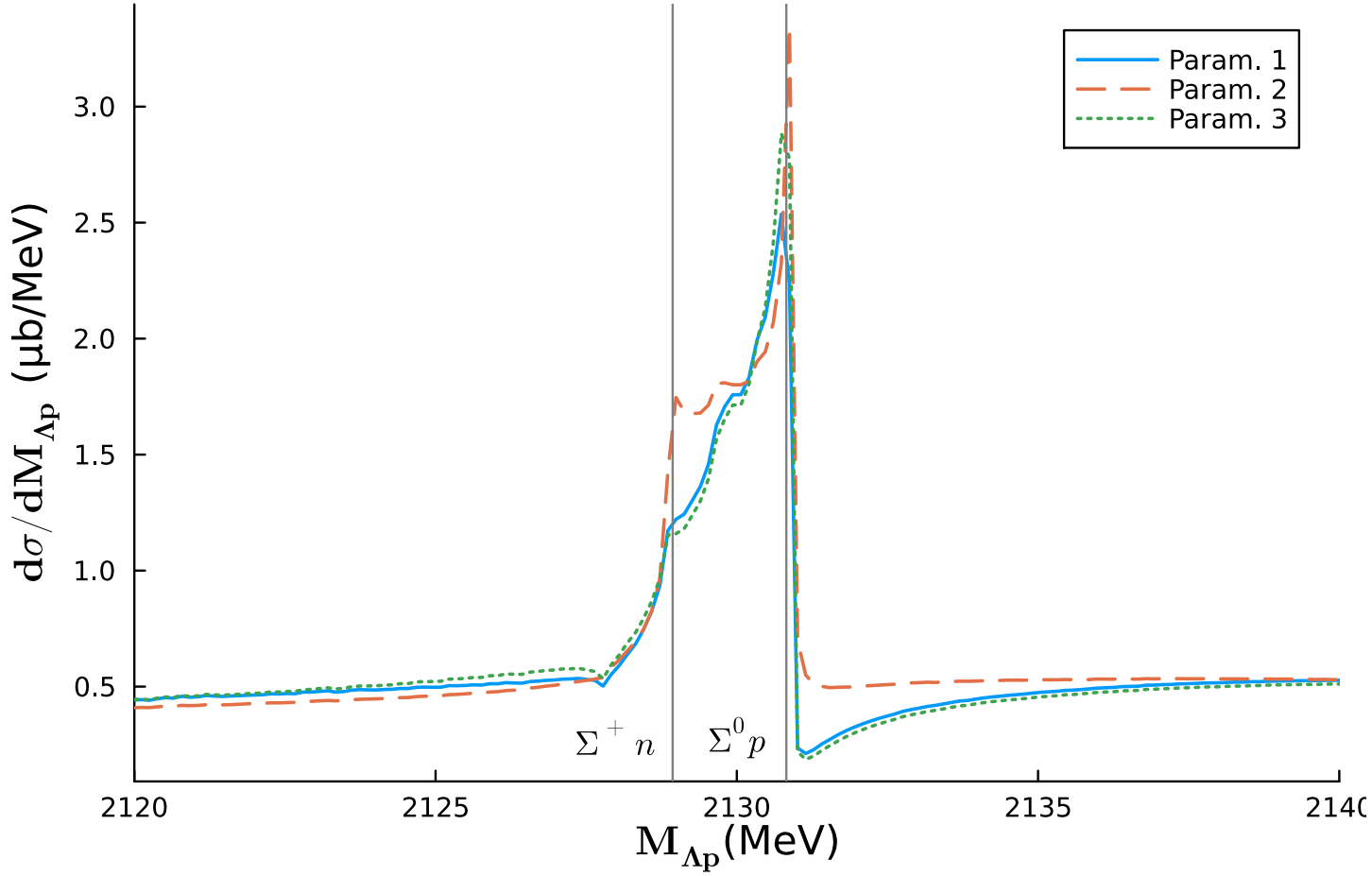


- Imaginary part of the $\Sigma^+ n \to \Lambda \mathrm{p}$ amplitude (as an example)

Param. 1	$1.68 - 2.35i$[7]
Param. 2	$-3.83 - 3.01i$[8]
Param. 3	$2.53 - 2.64i$[9]

[7] Th. A. Rijken, V. G. J. Stoks, and Y. Yamamoto, Phys. Rev. C 59, 21 (1999).
[8] J. Haidenbauer and U.-G. Meißner, Phys. Rev. C 72, 044005 (2005).
[9] J. Haidenbauer, U.-G. Meißner, A. Nogga, and H. Le, Eur. Phys. J. A 59, 63 (2023).

ΣN cusp with some parameters



- Λp invariant mass spectra for the $K^- d \to \pi^- \Lambda p$ reaction (include background processes)
- Incident kaon: 1000 MeV/c

  Pion angle $\cos\theta_\pi > 0.9$

Param. 1	$1.68 - 2.35i$
Param. 2	$-3.83 - 3.01i$
Param. 3	$2.53 - 2.64i$

Summary

- The cusp (sharp peak) structure at ΣN threshold in the ΛN invariant mass spectrum for $K^- d \to \pi \Lambda N$ is numerically observed.
- There is mainly two factors that causes threshold peak:
  ① propagator with deuteron wave function
  ② two body amplitude of the final state interaction
- The shape of the spectrum varies depending on the value of $a_{\Sigma N}^{\mathrm{spin}=1}$.
  ⇒ possibility of detecting the amplitude of $\Sigma N \to \Lambda N$