$\Lambda(1405)_{\text{pn}}$ at J-PARC

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on behalf of the J-PARC E15 collaboration

“Strange Matter Workshop - Strangeness studies in Italy and Japan“
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We observed the “K-pp” Bound-State

We need further understanding

- **Spin/Parity of the “K⁻pp”**
  - New $4\pi$ detector system is needed  

Future plan

decay-angle measurement

(a) $\Lambda$-rest system

(b) $\Lambda p$-rest system
We need further understanding

- Spin/Parity of the “K⁻pp”
  - New 4π detector system is needed  ➜ Future plan

Recent results of the decay-angle measurement is consistent with J=0

**Paper in preparation**
We need further understanding

- Spin/Parity of the “K^-pp”
  - New $4\pi$ detector system is needed  \(\leftarrow\) *Future plan*

A new $4\pi$ detector with $\gamma$/n sensitive detectors
We need further understanding

• Spin/Parity of the “K-pp”
  – New $4\pi$ detector system is needed  ➡️ Future plan

• Other decay channels
  – $\pi\Sigma N$ mesonic decay is theoretically expected to be the dominant channel

• Only YN non-mesonic decays were reported

S. Ohnish et al., PRC 88(2013)025204

kaon absorption probability of $\Lambda^* N \rightarrow \pi\Sigma N / \Lambda N$
We need further understanding

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- Reaction mechanism
  - Relation between $\Lambda(1405)$ & "K-pp"
    - $\Lambda(1405)$ has been considered as "K-p"
    - Theoretically, "K-pp" is expected to be produced via $\Lambda(1405)+p\rightarrow"K-pp"$ door-way process

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$K^- \, ^3\text{He} \rightarrow \pi \Sigma p n$ Measurement

- Exclusive measurement of $\pi^\pm \Sigma^\mp p n$ final state in $K^- + ^3\text{He}$

- Experimental challenge of neutron detection with thin scintillation counter ($t = 3\text{cm}$)

  $n$ detection efficiency $\sim 3\% - 10\%$
Neutron ID with CDS

- $\pi^+\pi^-p$ events (3 tracks) in CDS with 4 CDH hits are selected
- A CDH hit with CDC-veto (outer-layer) is applied to identify the “neutral hit”

Neutron can be identified with CDS
\[ \pi \Sigma pn \text{ Events} \]

IM(\(n\pi^+\)) vs MM(\(\pi^+\pi^-pn\))

IM(\(n\pi^-\)) vs MM(\(\pi^+\pi^-pn\))
Selection of $\pi^\pm \Sigma^\mp pn$ Final State

- $\pi^\pm \Sigma^\mp$ events are separated using kinematical-fit
  - Constraints:
    - $M(\Sigma \rightarrow n\pi)$
    - 4-momentum conservation
  - Event selection by $\chi^2$ probability (0.01<p)

$\pi\pi pn\Lambda/\Sigma^0$ contribution can be seen
Selection of $\pi^\pm \Sigma^\mp pn$ Final State

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  - Constraints:
    - $M(\Sigma \to n\pi)$
    - 4-momentum conservation
  - Event selection by $\chi^2$ probability ($0.01 < p$)

- e.g. after acc/eff correction

- constraint: 4-momentum conservation = $n$ mass constraint

- measured
  - $K^-$
  - $1 \text{ GeV/c}$
  - $^3\text{He}$

- unmeasured
  - $p$
  - $n$

- measured
  - $\Sigma$

- measured
  - $\pi$

- measured
  - $n$

- measured
  - $\pi$

- constraint: $\Sigma$ mass

- CDS

- simple BG evaluation & subtraction
Selection of $\pi^{\pm} \Sigma^{\mp}pn$ Final State

- $\pi^{\pm} \Sigma^{\mp}$ events are separated using kinematical-fit
  - Constraints:
    - $M(\Sigma \rightarrow n\pi)$
    - 4-momentum conservation
  - Event selection by $\chi^2$ probability ($0.01<p$)

Trying to improve Exp. BG evaluation by introducing
- new analysis cuts
- loglikelihood function with DCA
- global fit with signal & BG’s
$\text{IM}(\pi^{\pm} \Sigma^{\mp})$ in $\pi^{\pm} \Sigma^{\mp} pn$ Final State

$\Lambda(1405)$ can be clearly seen in low $q_{Kn}$

$\Lambda(1520)$
**Y* pn Final State w/ simple BG subt.**

\[ \Lambda(1405) \sim 150 \text{ \(\mu\)b} \]

Fit w/ Flatté formula:  
\[ \text{Re}(z) \sim 1420 \text{ MeV} \]
\[ \text{-Im}(z) \sim 15 \text{ MeV} \]

\[ \Sigma^0(1385) \sim 20-100 \text{ \(\mu\)b} \]

[evaluated from  
\[ \Sigma^{+/–}(1385) \rightarrow \pi^{+/–}\Lambda \]
measurement]

\[ (\Sigma(1385) \rightarrow \pi\Lambda/\pi\Sigma : 87.0/11.7\%) \]
Select $\Lambda(1405)pn$ final state

- Below $\Lambda(1520)$
- Small contribution from $\Sigma(1385)$
$\text{IM}(\pi\Sigma p)$ in $\Lambda(1405)pn$ Final State

$0.2 < \cos\theta_{\text{CM}}^{\pi}$ selected

Dominant above the threshold

"Kpp" ROI

$\text{IM}(\pi^{\pm}\Sigma^{\mp} p)$ in $\Lambda(1405)pn$ Final State
$\text{IM}(\pi \Sigma p)$ in $\Lambda(1405)pn$ Final State

"Kpp" $\rightarrow \pi \Sigma N$ mesonic decay is theoretically expected to be the dominant channel

But, statistically, NO significant structure

This will be due to phase-space limitation of "K-pp" $\rightarrow \pi \Sigma N$ decay.
$\text{IM}(\pi^{\pm}\Sigma^{+}) \ vs. \ \text{IM}(\pi^{\pm}\Sigma^{+}p)$

Small phase-space of "K-pp" $\rightarrow \pi\Sigma N$
PS Limitation of “$K^{-}pp$” $\rightarrow \pi \Sigma p$ Decay

Phase space of $\pi \Sigma pn$

Kpp BW obtained with $\Lambda p$

$[\text{BW}] \ast [\text{phase space}]$

$0.2 < \cos \theta_{\text{CM}}^{\text{selected}}$

$\Lambda(1405)pn$
Comparison of $\Lambda pn$ & $\Lambda(1405)pn$

$0.35 < q_{Kn} < 0.65$ GeV/c

Large CS of the $\Lambda(1405)p$ compared to the “$K^-pp \rightarrow \Lambda p$”
Comparison of $\Lambda pn$ & $\Lambda(1405)pn$

$\Lambda(1405)pn$ production is dominant (energy-momentum mismatch is transferred to the proton).

$\Lambda(1405)="K'-p"$

$K' + (pp)_R \rightarrow "K'-p" + p$

Intrinsic $m_K < E_K$

$0.35 < q_{Kn} < 0.65 \text{ GeV/c}$

M(Kpp)
Comparison of $\Lambda pn$ & $\Lambda(1405)pn$

$\Lambda(1405)pn$ production is dominant ($E_K < intrinsic m_K$)

$'K' + (pp)_R \rightarrow "K-pp"$

$'K' + (pp)_R \rightarrow "K-p" + p$

$\Lambda(1405) = "K-p"$

$E_K < intrinsic m_K$

$'K-pp$ production is dominant

$\Lambda(1405)p$ production is dominant

(energy-momentum mismatch is transferred to the proton)

$0.35 < q_{Kn} < 0.65 \text{ GeV/c}$
Summary

• We observed the “K⁻pp” bound state in $^{3}{\text{He}}(K^{-},\Lambda p)n$
  – Binding energy: $\sim 50$ MeV
  – Width: $\sim 100$ MeV


• We found large CS of the $\Lambda(1405)p$ formation compared to the “K⁻pp”
  – quite important information on the production mechanism of the “K⁻pp”

← paper in preparation
Thank You!

J-PARC E15 Collaboration

Spares
Comparison of $\Lambda pn$ & $\Lambda(1405)pn$

- **No clear structure below $M(Kpp)$ in the $IM(\pi\Sigma p)$**
- **QF followed by $\Lambda(1405)p$ is dominant**
Detector Acceptance: $\Lambda p$ vs. $\pi\Sigma p$

- Detector acceptance is different between $\Lambda p$ and $\pi\Sigma p$
  - At $\cos\theta_n \sim 1$:
    - $\Lambda p$: flat acceptance
    - $\pi\Sigma p$: limited acceptance below the threshold

**cf. $\pi^\pm\Sigma^\mp pn$-PS MC w/ detector acceptance**
$K^- p \rightarrow \Sigma^+ \pi^- / \Sigma^- \pi^+$ Cross Section

(a) $\pi^- \Sigma^+$

(b) $\pi^+ \Sigma^-$

consistent with the references
Need further investigation

- More quantitative studies of the “K-pp”
  - J^p and other decay modes
- Systematic studies of other kaonic nuclei:
  - Single: “K-ppn” via [K^- + ^4He], “K-ppnn/K-pppnn” via [K^- + ^6Li]
  - Double: “K-K-pp” via [p^bar + ^3He]

A new 4π detector with γ/n sensitive detectors is required