Study of the $\Lambda/\Sigma^0$ electroproduction at JLab Hall A

Kazuki Okuyama

Graduate School of Science, Tohoku University, Japan
Graduate Program on Physics for the Universe (GP-PU), Tohoku University, Japan
Contents

JLab E12-17-003 (2018); I’m focusing on the \( p(e,e'K^+)\Lambda/\Sigma^0 \) reaction

- Introduction
- Experimental Setup
- Data Analysis: \( p(e,e'K^+)\Lambda/\Sigma^0 \) reaction
- Results & Summary

Electroproduction

Searching for \( nn\Lambda \) state
(I won’t talk about this.)

gas hydrogen target:
also available
as a calibration

Electroproduction

(\( \text{I won’t talk about this.} \))
JLab E12-17-003 (2018); I’m focusing on the $p(e,e'K^+)\Lambda/\Sigma^0$ reaction

- Introduction
- Experimental Setup
- Data Analysis: $p(e,e'K^+)\Lambda/\Sigma^0$ reaction
- Results & Summary

Electroproduction
Our group have been researching globally

I've been working on a research topic at JLab (I'll talk today)

We are performing experiments using electron accelerators all over the world.

I'm joining this school from here!
Strangeness Nuclear Physics

Hypernucleus

Hyperon

Hyperon/Hypernucleus Electroproduction has been performed at JLab.
Hyperon Electroproduction at JLab

Elementary Process of Hypernucleus Production!

HRS-L

$e^{-}$

$\sim 2.1$ GeV/c

HRS-R

$K^+$

$\sim 1.8$ GeV/c

$\Lambda$ or $\Sigma^0$

4.318 GeV

CEBAF

$E_{12}$-17-003

$\theta_{\gamma K}^{CM} = 8^\circ$, $Q^2 = 0.5$ (GeV/c)$^2$

Missing Mass $= \sqrt{\left\{ (E_e - E_{e'}) + M_p - E_K \right\}^2 - \left\{ (P_e - P_{e'}) - P_K \right\}^2}$
JLab E12-17-003 (2018); I’m focusing on the p(e,e’K+)Λ/Σ⁰ reaction

➢ Introduction
➢ Experimental Setup
➢ Data Analysis: p(e,e’K+)Λ/Σ⁰ reaction
➢ Results & Summary

Electroproduction
Continuous Electron Beam Accelerator Facility (CEBAF)

Linear accelerator

Injector

Refrigerator

$e^- \sim 4.3 \text{ GeV}, \sim 20 \mu\text{A} \text{ (this exp.)}$

Experimental Halls

Hall A

E12-17-003: at JLab Hall A in 2018
**Experimental Setup**

Electron beam

4.318 GeV

Hydrogen target

13.2 deg

K$^+$

Electron beam

13.2 deg

K$^+$

HRS-L

$\sim 2.1$ GeV/c

HRS-R

$\sim 1.8$ GeV/c

Detectors in HRS-R

- Drift Chamber (Tracking)
- Scintillators (Timing)
- Aerogel Cherenkov (K$^+$ identification)

HRS-L same as

- Drift Chamber (Tracking)
- Scintillators (Timing)
- Aerogel Cherenkov (K$^+$ identification)
Target Cell

Electron beam
4.318 GeV

HRS-L
~2.1 GeV/c

HRS-R
~1.8 GeV/c

13.2 deg

13.2 deg

Electron beam

Hydrogen target

Aluminum Cell thickness: 400 μm

S.N. Santiesteban et al., Nucl. Inst. and Meth. A 940, 351 (2019).
JLab E12-17-003 (2018); I’m focusing on the p(e,e’K+)Λ/Σ^0 reaction

➢ Introduction
➢ Experimental Setup
➢ Data Analysis: p(e,e’K+)Λ/Σ^0 reaction
➢ Results & Summary
Analysis flow

Hydrogen Data
- Target ID (Vertex Position)
- Kaon ID 1 (Aerogel Cherenkov)
- Kaon ID 2 (Coincidence Time)

Λ/Σ⁰ Missing Mass Spectrum
- Efficiency
- Acceptance

Event selection: 
\( p(e, e'K^+)\Lambda/\Sigma^0 \) reaction

The Differential Cross Sections (D.C.S.)

D.C.S. derivation of the hyperon electroproduction
Z-vertex (Target selection)

Electron beam

Hydrogen

|Z| < 10 cm

Z-vertex is derived from the tracking information.

- Gas region: 25 cm
- Used only 20 cm (80% of total)
Aerogel Cherenkov (Kaon identification)

AC1 (n=1.015): $\pi^+, K^+, p$
AC2 (n=1.055): $\pi^+, K^+, p$

$\beta > 1/n$ (Cherenkov light)

\begin{align*}
\text{Momentum Range (HRS-R)}
\end{align*}

$\beta$ vs $p$ [GeV/c]

AC1 ⊗ AC2
Coincidence Time (Kaon identification)

Event Selection
- Aerogel Cherenkov (AC1, AC2)
- $Z$-vertex (reaction point)

Target

$K^+ \rightarrow e^- HRS \rightarrow R HRS \rightarrow L$

Scintillator

Path Length $\sim 25$ m (S2 $\rightarrow$ Target)

Coincidence Time $= \text{Time difference at Target}$

$$t_{\text{Coin.}} := t_{\text{HRS-L}}(\text{Target}) - t_{\text{HRS-R}}(\text{Target})$$

Reaction timing at Target:

$$t(\text{Target}) := t(S2) - \frac{\text{Path Length}}{\beta c}$$

- $p$
- $K^+ \Pi^+$

Counts/0.066ns

Coincidence Time [ns]

HUGS2021 (June 18, 2021)
Missing Mass Spectrum

\[ p(e, e'K^+)\Lambda/\Sigma^0 \text{ reaction events are clearly seen} \]
Analysis flow

Hydrogen Data
- Target ID (Vertex Position)
- Kaon ID 1 (Aerogel Cherenkov)
- Kaon ID 2 (Coincidence Time)

Λ/Σ^0 Missing Mass Spectrum
- Efficiency
- Acceptance

Event selection: 
\[ p(e,e'K^+)\Lambda/\Sigma^0 \] reaction
I will briefly explain this part.

The Differential Cross Sections (D.C.S.)
D.C.S. derivation of the hyperon electroproduction
Derivation of the differential cross section

\[ \left( \frac{d\sigma_{\gamma^* p \to K^+ \Lambda(\Sigma^0)}}{d\Omega_{K^+}} \right)_{\text{HRS-R}} \approx \frac{1}{N_{\text{Target}}} \cdot \frac{1}{N_{\gamma^*}} \cdot \frac{1}{\varepsilon} \cdot \sum_{i=1}^{N_{\Lambda(\Sigma^0)}} \frac{1}{\varepsilon_i^{\text{DAQ}}} \cdot \Delta \Omega_{\text{HRS-R}}(p_K, \zeta) \]

- Num. of Target: 0.0375 b^{-1}
- Num. of Virtual Photon: 3.49x10^{13} (\Lambda), 5.23x10^{13} (\Sigma^0)
- Survival Ratios: 0.0680 (\Lambda), 0.0664 (\Sigma^0)
- DAQ efficiency: \approx 0.96
- Solid Angle: \approx 5.5 msr (Lab)
- Num. of Hyperons: \approx 1270 (\Lambda), \approx 350 (\Sigma^0)
JLab E12-17-003 (2018); I’m focusing on the $p(e,e'K^+){\Lambda}/\Sigma^0$ reaction

- Introduction
- Experimental Setup
- Data Analysis: $p(e,e'K^+){\Lambda}/\Sigma^0$ reaction
- Results & Summary
Results

➢ I deduced the differential cross sections at $Q^2 \sim 0.5 \text{ (GeV/c)}^2$

\[ W = 2.14 \text{ GeV}, \theta_{CM}^{\gamma K} < 15 \text{ degree} \]

\[ \Lambda \]

\[ \Sigma^0 \]

This Work

Preliminary

\[ \frac{d\sigma}{dQ_{CM}} \text{ [ub/str]} \]

\[ Q^2 \text{ [(GeV/c)}^2] \]

Kazuki Okuyama

HUGS2021 (June 18, 2021)
I deduced the differential cross sections in forward angles.

\[ W = 2.14 \text{ GeV} \]

Results: Comparison with Photoproduction

This Work

\[ Q^2 \sim 0.5 \text{ (GeV/c)}^2 \]
Summary

➢ We have been performing hypernuclear experiments around the world

➢ Our latest experiment: JLab E12-17-003 was performed in 2018

➢ $p(e,e'K^+)/\Lambda/\Sigma^0$ reaction is an elementary process of a hypernucleus production

➢ I deduced the differential cross section of the $\Lambda/\Sigma^0$ electroproduction

➢ I hope my work helps understanding about hyperon/hypernucleus production

Thank you for your attention!
Thank you for organizing such a wonderful school!
I’m having fun!!