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Study of the Λ/Σ^0 electroproduction in the low-Q^2 region at JLab

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Abstract. We performed an experiment using tritium and hydrogen cryogenic gas targets at Thomas Jefferson National Accelerator Facility (JLab) in 2018 (E12-17-003)[1, 2]. In this article, we discuss the Λ/Σ^0 hyperon electroproduction from hydrogen target. Elementary Λ/Σ^0 hyperon production processes are important not only for an absolute mass scale calibration in our experiment, but also for the study of the electroproduction mechanisms themselves. In this article, we reported the results of the differential cross section for the $p(e, e'K^+)\Lambda/\Sigma^0$ reaction at $Q^2 \sim 0.5$ (GeV/c)^2.

1 Introduction

We have started and proceeded Λ hypernuclear experiments at JLab to understand the hyperon-nucleon interaction from the binding energy measurements of hypernuclei. Our experimental method enables us to investigate not only Λ hyperon but also Σ^0 hyperon production processes simultaneously as described later on. Λ/Σ^0 photoproduction $p(\gamma, K^+)\Lambda/\Sigma^0$ and electroproduction $p(e, e'K^+)\Lambda/\Sigma^0$ have been studied over several decades. In both reactions, protons are converted to hyperons. The only difference between them is that the photon involved in the reaction is real or virtual.

Experimentally, hyperon photoproduction has been studied very well and an abundance of data has been reported by many experimental groups[3–8]. Meanwhile, hyperon electroproduction can be associated with hyperon photoproduction and studied in a complementary manner under the same theoretical framework. The contribution from the virtual photon can be extracted by factorizing the triple differential cross section as follows[9]:

$$\frac{\mathrm{d}^3\sigma}{\mathrm{d}\omega \mathrm{d}\Omega_{e'} \mathrm{d}\Omega_{\mathrm{K}}^{\mathrm{c.m.}}} = \Gamma \frac{\mathrm{d}\sigma_{\gamma^*}}{\mathrm{d}\Omega_{\mathrm{K}}^{\mathrm{c.m.}}}, \tag{1}$$

where Γ is a so-called virtual photon flux. Through its definition, $\mathrm{d}\sigma_{\gamma^*}/\mathrm{d}\Omega_{\mathrm{K}}^{\mathrm{c.m.}}$ is regarded as a differential cross section for the kaon-hyperon production from virtual photons. Four-momentum of a virtual photon is denoted as $q^\mu := (\omega, \boldsymbol{q}) = (E_{\mathrm{e}} - E_{\mathrm{e}'}, \boldsymbol{P}_{\mathrm{e}} - \boldsymbol{P}_{\mathrm{e}'})$.

In the case of hyperon electroproduction, data can be taken at forward angles along the virtual photon direction, which are regions of interest for the photoproduction because it is missing. Besides that, $Q^2 := -q^2$ dependency appears in the electroproduction and this is also

interesting and promising. However, experimental data on electroproduction is less abundant than that on photoproduction. Thus, providing the results of the differential cross section for the hyperon electroproduction from experimental side is necessary.

2 Experiment

2.1 Missing mass method

We used 4.32-GeV electron beams provided by CEBAF (Continuous Electron Beam Accelerator Facility) at JLab and hydrogen gas as a fixed proton target. We measured momenta of the scattered final electrons (~ 2.10 GeV/c) and positively charged kaons (~ 1.82 GeV/c) associated with the neutral charged hyperon production in coincidence by using large magnetic spectrometers, HRS-L and HRS-R, respectively. Detailed descriptions of the experimental setup can be found in following papers[1, 10, 11]. Eventually, missing mass is calculated from the momentum-energy conservation for every coincidence event by

$$\text{Missing Mass} = \sqrt{E_{\text{miss}}^2 - \boldsymbol{P}_{\text{miss}}^2} = \sqrt{\left(E_{\text{e}} - E_{\text{e}'} + M_{\text{p}} - E_{\text{K}}\right)^2 - (\boldsymbol{P}_{\text{e}} - \boldsymbol{P}_{\text{e}'} - \boldsymbol{P}_{\text{K}})^2}. \quad (2)$$

With proton target, peaks at masses of Λ and Σ^0 are observed in the spectrum as shown in figure 1. Backgrounds come from the $\text{Al}(e, e'K^+)X$ reaction because of the target cell made of Aluminum and the $p(e, e'\pi^+)X$ reaction because of the high rate of pions. Amount and distribution of these background source are estimated and indicated by a yellow line in figure 1 even though they are very small. Therefore, remaining events are considered to be truly the hyperon production events. The tail structure from each peak is considered as a radiative tail. Radiative tail is well-understood phenomenon in the electron scattering experiment because electrons easily emit radiations. In this case, it was mainly caused from the scattered electrons when they pass through the Aluminum target cell obliquely. In order to derive the differential cross sections, radiative tail also needs to be taken into account as a hyperon production events. Those estimations were performed by fitting the distribution in some ways, combined with adequate simulation. The fluctuations of the fitting results are included as systematic uncertainties.

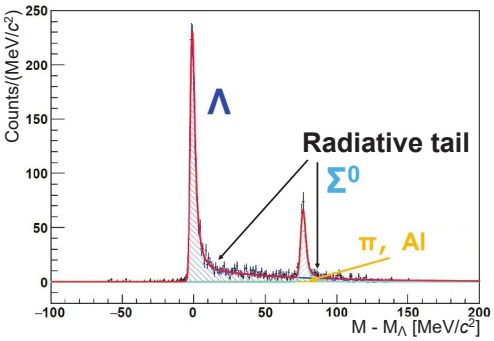

Figure 1. Missing mass spectrum obtained by the $p(e, e'K^+)X$ reaction. It was fitted to estimate number of hyperons including radiative tails (see text).

2.2 Differential cross section derivation

Differential cross sections are deduced using a following formula,

$$\overline{\left(\frac{\mathrm{d}\sigma_{\gamma^* p \to K^+\Lambda(\Sigma^0)}}{\mathrm{d}\Omega_{K^+}}\right)}_{\text{HRS-R}} = \frac{1}{N_{\text{T}}} \cdot \frac{1}{N_{\gamma^*}} \cdot \frac{1}{\bar{\varepsilon}} \cdot \sum_{i=1}^{N_{\Lambda(\Sigma^0)}} \frac{1}{\varepsilon_i^{\text{DAQ}} \cdot \varepsilon_i^{\text{Decay}} \cdot \Delta\Omega_{\text{HRS-R},i}}, \quad (3)$$

where, N_{T} is the number of proton targets per unit area, N_{γ^*} is the number of virtual photons contributing to the production, and $\bar{\varepsilon}$ is the cut efficiency in the event selection. In particular, data acquisition efficiency $\varepsilon_i^{\text{DAQ}}$, K^+'s survival ratio without any decay $\varepsilon_i^{\text{Decay}}$, and solid angle of HRS-R $\Delta\Omega_{\text{HRS-R},i}(p_{\text{K}}, Z)$ as a function of momentum and reaction point are applied every i-th event. Estimated quantities are summarized in table 1.

Table 1. Estimated quantities with statistical errors for deriving the differential cross sections

	Λ	Σ^0
$N_{\rm T}$	0.0375 ± 0.0013 [b^{-1}]	
$N_{\gamma^*}/10^{13}$	3.53 ± 0.01	4.95 ± 0.01
$\bar{\varepsilon}$	45.4 ± 1.2 [%]	44.3 ± 1.2 [%]
$N_{\rm Hyperon}/10^3$	1.36 ± 0.04	0.37 ± 0.02
$\varepsilon^{\rm Decay}$	~ 14 [%]	~ 14 [%]
$\varepsilon^{\rm DAQ}$	~ 96 [%]	~ 96 [%]
$\Delta\Omega^{\rm Lab}_{\rm HRS\text{-}R}$	~ 5.5 [msr]	

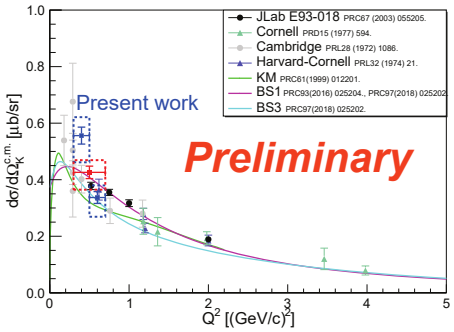

Figure 2. The Q^2 dependency of the differential cross sections for the Λ hyperon electroproduction (see text).

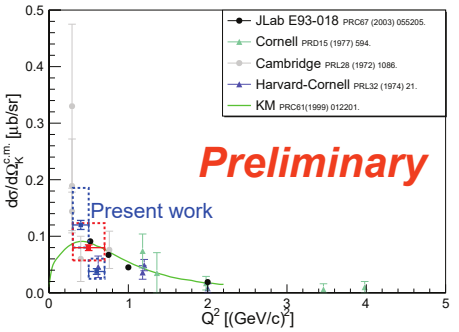

Figure 3. The Q^2 dependency of the differential cross sections for the Σ^0 hyperon electroproduction (see text).

3 Results

Using the dataset of our experiment ($W \sim 2.14$ GeV, $Q^2 \sim 0.5$ (GeV/c)^2, $\theta^{\rm c.m.}_{\gamma \rm K} \sim 8$ deg), we deduced the differential cross sections. In next subsections, we discuss these results comparing with other experimental data and theoretical calculations by showing the Q^2 dependency and angle dependency.

3.1 Q^2 dependency

The obtained results are shown with Q^2 dependency of the differential cross section in figure 2 and figure 3. Red points are the results using all data and blue points are the results with data divided into 2 sets based on Q^2 to see its dependency. Our results show the statistical error by the solid lines and the dotted boxes include systematic error. The other experimental results show only the statistical error[12–15]. Theoretical results are shown by curved lines[16–18]. As Q^2 decreases, our results tend to increase, which are similar to the other results, but with a higher slope.

3.2 Angle dependency

The obtained results are shown with angle dependency of the differential cross section in figure 4 and figure 5. Experimental data and theoretical calculations for the photoproductions are also shown without corrections[3–8, 16, 19, 20] . We deduced the differential cross section in low-Q^2 regions at forward angles which is missing data in the photoproductions. Our results tend to decrease as they approach to the forward angles in both reactions, but almost flat for Λ within statistical errors.

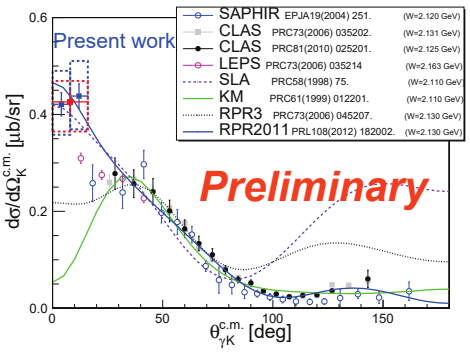

Figure 4. The $\theta_{\gamma K}^{c.m.}$ dependency of the differential cross sections for the Λ hyperon production. Our data is at $Q^2 \sim 0.5$ (GeV/c)^2, the others are at $Q^2 = 0$ (see text).

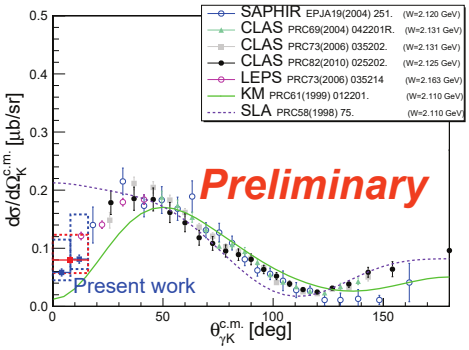

Figure 5. The $\theta_{\gamma K}^{c.m.}$ dependency of the differential cross sections for the Σ^0 hyperon production. Our data is at $Q^2 \sim 0.5$ (GeV/c)^2, the others are at $Q^2 = 0$ (see text).

4 Summary

We performed E12-17-003 experiment at JLab in 2018. This article described the results of the differential cross sections for the Λ/Σ^0 hyperon electroproduction at forward angles in low-Q^2 region. This is a region of interest where there was no data in the photoproduction so far. This work helps understanding hyperon photoproduction and electroproduction in the same theoretical framework.

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