First Production of the Σ* Nucleon Resonance using the LEPS Spectrometer

One of the primary objectives of subatomic physics is to understand the substructure of the proton and other baryons, which are composed of three valence quarks and many gluons. Quarks are the fundamental constituents of the theory of the strong interaction, called QCD, and gluons are particles that mediate the strong force. In other words, gluons play the same role for the strong interaction as photons do for the electromagnetic interaction.

By sending a beam of high-energy photons onto a target containing protons and neutrons, new particles can be produced. This is done at the LEPS detector, located at the SPring-8 facility. High-energy photons are produced by Compton scattering of laser light from the 8 GeV beam of stored electrons. Some of the electron energy is transferred to the laser light, which reflects back from the electron giving it an energy of several GeV. This beam of photons strikes a target, creating new particles.

Baryons containing strange quarks are particularly interesting. There are no strange quarks in the proton or neutron, but there are several baryons known with one strange quark. One of these is known as the Σ baryon, which comes in three charge states: Σ^-, Σ^0 and Σ^+. The Σ^0 is difficult to measure because it overlaps with a nearby baryon resonance with neutral charge called the Λ. However, the Σ^- resonance is easier to measure in the LEPS spectrometer due to its negative charge, beamline **BL33LEP**. An excited state of this resonance, the Σ^{*-}, was measured for the first time just recently using LEPS [1].

Shown in Fig. 1, the vertical axis is the cross section (representing the probability to create this particle) and the horizontal axis is the energy of the photon in the nuclear reaction $\gamma n \rightarrow K^+ \Sigma^*$. The K^+ particle contains an anti-strange quark, and is typically seen in coincidence with the Σ baryons. The Σ^{*-} particle is not observed directly, but its presence is deduced by measuring the K^+ and then using conservation of momentum and energy to calculated the unique mass of the Σ^*.

The four panels shown in Fig. 1 represent different center-of-mass (cm) angles, measured from the beam axis, of the K^+ as detected in the LEPS spectrometer. The points are the data and the curve represents the theoretical calculation. The theoretical model used here is based on quantum field theory, using Feynman graphs to calculate the probability to produce the above nuclear reaction. Details of the calculation are given in Ref. [2].

From comparison of the data and calculation, the value of the coupling constant (representing the overall strength of the nuclear reaction) between the neutron and the produced particles (the K^+ and Σ^{*-}). This, in turn, is proportional to the probability to produce a strange quark/anti-quark pair by the photon. Knowledge of these coupling constants enables theorists to make more quantitative predictions of the probability to produce other particles such as the Θ^+ pentaquark (see Ref. [3]).

Shown in Fig. 2, the vertical axis is the beam asymmetry (representing the probability of producing the reaction along the electric field of the photon) and the horizontal axis is the azimuthal angle around the beam axis, ϕ. The three panels on the left side are for detection of the ground-state Σ^- baryon and the three panels on the right are for detection of the excited-state Σ^{*-} baryon. In each case, the photon energy used increases in going from top to bottom panel. The curves are not theoretical predictions, but are simple fits to the function cos(2ϕ). Not only is the amplitude of the fitted function bigger for the left panel, the phase also changes sign for the right panel. This signifies that the reaction dynamics are sensitive

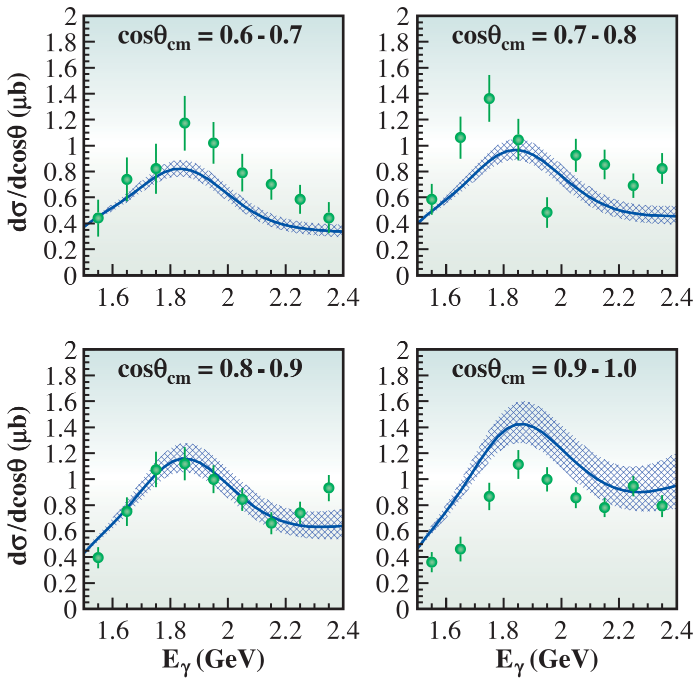

Fig. 1. Cross sections for the reaction $\gamma n \rightarrow K^+ \Sigma^{*-}$ as a function of photon energy. The curve is from the theoretical model of Ref. [2].

to the direction of the photon polarization. Hence, the Σ^- is produced in a different manner than the Σ^{*-} is produced. This is perhaps surprising since the primary difference between these two cases is simply the spin of the quarks.

Figure 3 summarizes the results presented in the previous figure. The vertical axis gives the amplitude of the fit at $\phi=0°$, and the horizontal axis is the beam energy. The top panel is for production of Σ^- and the bottom panel for Σ^{*-}. The curve in the lower panel is from the same theoretical model as for Fig. 1. Here, this model predicts that the beam asymmetry should be nearly zero, meaning that the reaction is predicted to have little sensitivity to the photon polarization. Clearly, the theoretical model needs to be improved, which is only possible now that the data are measured.

In summary, the LEPS Collaboration has measured for the first time with high precision the probability to produce a Σ^* baryon using the reaction $\gamma n \rightarrow K^+ \Sigma^{*-}$ using the photon beam (γ) incident on the neutron (n) at the SPring-8 facility. The beam asymmetry was also measured, which is the first time ever for a Σ^* baryon. The cross sections are in reasonable agreement with theory, but improvements in the theoretical model are necessary to get agreement with the beam asymmetry.

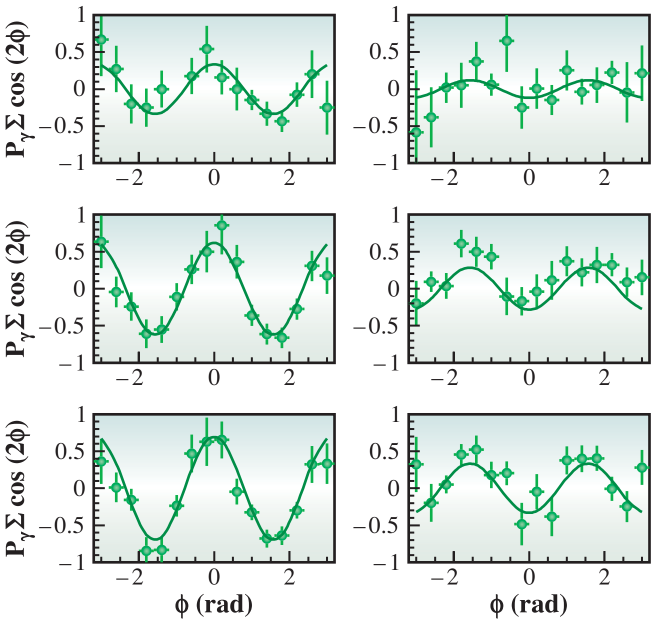

Fig. 2. Beam asymmetry as a function of the azimuthal angle ϕ for production of the Σ^- (left panels) and the Σ^{*-} (right panels). The beam energy increases from top panel to bottom panel.

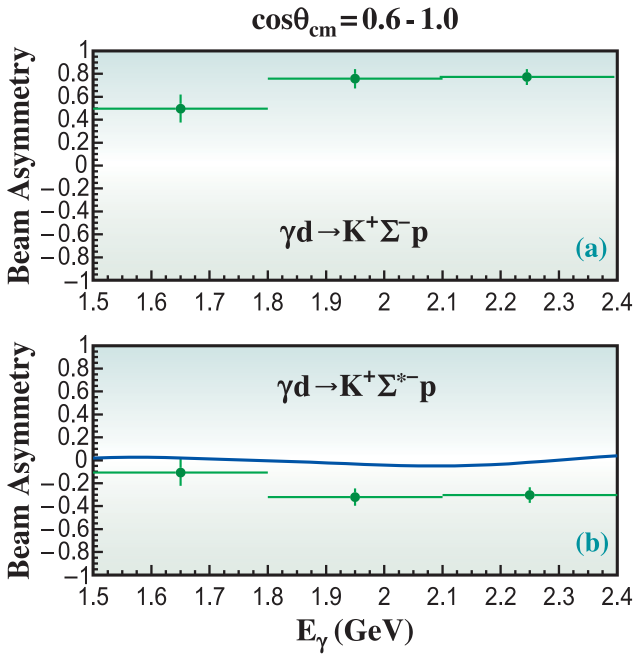

Fig. 3. Beam asymmetry as a function of photon energy for the Σ^- **(a)** and the Σ^{*-} **(b)**. The curve in the bottom panel is from the model of Ref. [2].

Ken Hicks for the LEPS Collaboration

Department of Physics and Astronomy,
Ohio University, USA

E-mail: hicks@ohioedu

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