Photopion Production at Higher Energies

H. Gao and T. C. Black
Laboratory for Nuclear Science and Department of Physics
Massachusetts Institute of Technology
Cambridge, MA 02139

Abstract

Photopion production from a nucleon target is a fundamental process that is essential for studies of high-energy photoreactions in nuclei and for the study of quark models in the high energy regime. The approved JLab experiment E94-104 uses a 6 GeV beam to investigate the constituent quark counting rule for the $\gamma n \rightarrow \pi^- p$ differential cross section. This measurement can be extended to 8 GeV as JLab energies are upgraded. Quark model predictions for the momentum dependence of the ratio of π^- to π^+ photoproduction from the nucleon make their relative cross-section an important observable to investigate at high energies. Not only will it provide a decisive test of pion photoproduction models, but it is an excellent means of investigating the transition from a description based on nucleon-meson degrees of freedom to a QCD-based description in terms of quark-gluon degrees of freedom.

Introduction

For exclusive scattering processes at high energy and large transverse momentum, constituent counting rules predict the following scaling law for the differential cross section:

$$(d\sigma/dt)_{AB\rightarrow CD} \sim s^{2-n} f(cos\theta^*). \tag{1}$$

Here n is the total number of elementary fields and θ^* is the center of mass angle. The Mandelstam variables t and s are defined by

$$t = (p_A - p_C)^2 = (p_B - p_D)^2 \tag{2}$$
$$s = (p_A + p_B)^2 = (p_C + p_D)^2, \tag{3}$$

where p_A and p_B are the four-momenta of the incoming particles, and p_C and p_D are the four-momenta of the outgoing particles. For γ N $\rightarrow \pi$ N photo-pion production processes, $s = {M_N}^2 + 2M_N E_\gamma$, where M_N is the nucleon mass and E_γ is the photon energy.

The γn $\rightarrow \pi^-$p Process

For fundamental processes like $\gamma\ p \rightarrow \pi^+\ n$, $\gamma\ p \rightarrow \pi^0\ p$, and $\gamma\ n \rightarrow \pi^-\ p$, there are nine elementary fields. So constituent counting rules predict that

$$(d\sigma/dt)_{AB\rightarrow CD} \sim s^{-7} f(cos\theta^*). \tag{4}$$

Data from $\gamma\ p \rightarrow \pi^+\ n$ measurements [1] show that the cross section follows the quark counting rule prediction above a photon beam energy of 2.0 GeV (see Fig. 1). Fits of the data at a center of mass angle of 90° gives an $s^{-7.3\pm0.4}$ dependence for the $\gamma\ p \rightarrow \pi^+\ n$ cross section. It is not clear whether the $\gamma\ p \rightarrow \pi^0\ p$ reaction follows the same counting rule behavior, because discrepancies exist between different measurements. For the $\gamma\ n \rightarrow \pi^-\ p$ process, no scaling behavior in the cross section is seen for this reaction below a photon energy of 2.0 GeV, and no cross section data exist above 2.0 GeV.

As shown in Fig. 1, the approved JLab experiment E94-104 [2], which spans the photon energy range from 1.2 to 6.0 GeV, will overlap with the previous measurement at $s^{1/2} \sim 1.77$ GeV and will also test—for the first time, in the case of the π^- channel—the scaling behavior of the charged pion photoproduction processes at much higher energies. With future beam energy upgrades at JLab, this measurement can be extended to 8 GeV, which corresponds to a center-of-mass energy of $\sqrt{s} = 4.0$ GeV. Measurements at a pion center-of-mass angle of 90° can be performed within reasonable running time limits (100 hours).

The photopion Production Differential Cross Section Ratio $\pi^-\pi^+$

The quark model predicts that in the limit of $t \simeq 0$, the sea quark contribution dominates the photo-pion production reaction, so that the cross section ratio $\pi^-/\pi^+ \simeq 1$. As t/s and s increase, the valence quarks dominate and, since $f_d^{\pi^-} = f_u^{\pi^+}$, and the number of down quarks in the neutron is equal to the number of up quarks in the proton,

$$\frac{\frac{d\sigma}{dt}(\gamma\ n \to \pi^-\ p)}{\frac{d\sigma}{dt}(\gamma\ p \to \pi^+\ n)} = \frac{e_d^2 f_d^n f_d^{\pi^-}}{e_u^2 f_u^p f_u^{\pi^+}} = \frac{e_d^2}{e_u^2} = \frac{1}{4}. \tag{5}$$

This quark model prediction is consistent with data from the Drell-Yan process for an isoscalar carbon target [3]. There, the ratio

$$\frac{\sigma(\pi^+ C \to \mu^+\mu^- X)}{\sigma(\pi^- C \to \mu^+\mu^- X)} \tag{6}$$

is approximately unity for small values of t but falls off toward $\frac{1}{4}$ as t increases. Unfortunately, the errors are too large for the Drell-Yan experiment to confirm the quark model asymptotic limit of 1/4. Ito *et al.* [4] measured the forward angle photoproduction cross section ratio $R = \sigma(\pi^-)/\sigma(\pi^+)$ in deuterium to be $\sim 0.6 - 1$ for $0.6 \leq E_\gamma \leq 1.7$. Heide *et al.* [5] measured the singles π^- and π^+ photoproduction from deuterium at photon energies of 3.4 and 5.0 GeV and momentum transfer between 0.005 to 0.6 $(\mathrm{GeV/c})^2$; the π^-/π^+ ratio was found to be one for the forward direction, dropping to about 0.4 at larger angles. Both measurements agree, within experimental errors, with the quark model prediction for small values of t, and the measurements of Heide *et al.* [5] suggest a decrease of the π^-/π^+ ratio at large angles, i.e, larger values of t.

The approved JLab experiment E94-104 [2] will use a deuterium target to measure the ratio of π^-/π^+ singles production over the photon energy range from 1.2 to 6.0 GeV, at center of mass angles of 45°, 75°, and 90°. This corresponds to maximum values of t roughly six times greater than that of previous measurements [4] [5]. The data E94-104 will acquire on the $\gamma\ p \to \pi^+\ n$ cross section overlaps with the previous $\pi^+\ n$ data—whose maximum photon energy was 7.5 GeV [1]—in most of the energy regime, and at the center of mass angle of 90°, and will provide a cross-check on this data. The measurements of the $\gamma\ n \to \pi^-\ p$ cross section will explore a completely new kinematic region.

Because the $\gamma\ n \to \pi^-\ p$ and $\gamma\ p \to \pi^+\ n$ processes are related by isospin and time reversal, the π^-/π^+ ratio is fixed as soon as one has a model for π^+ photoproduction. Theoretically, this observable was found to be difficult to describe in various Regge absorption models [6]. Recently, Guidal, Laget and Vanderhaeghen [7] found that a good description of this observable for real photons is obtained by using degenerate π and ρ Regge trajectories with different phases, and by implementing gauge invariance. Measurement of the π^-/π^+ ratio thus decisively tests pion

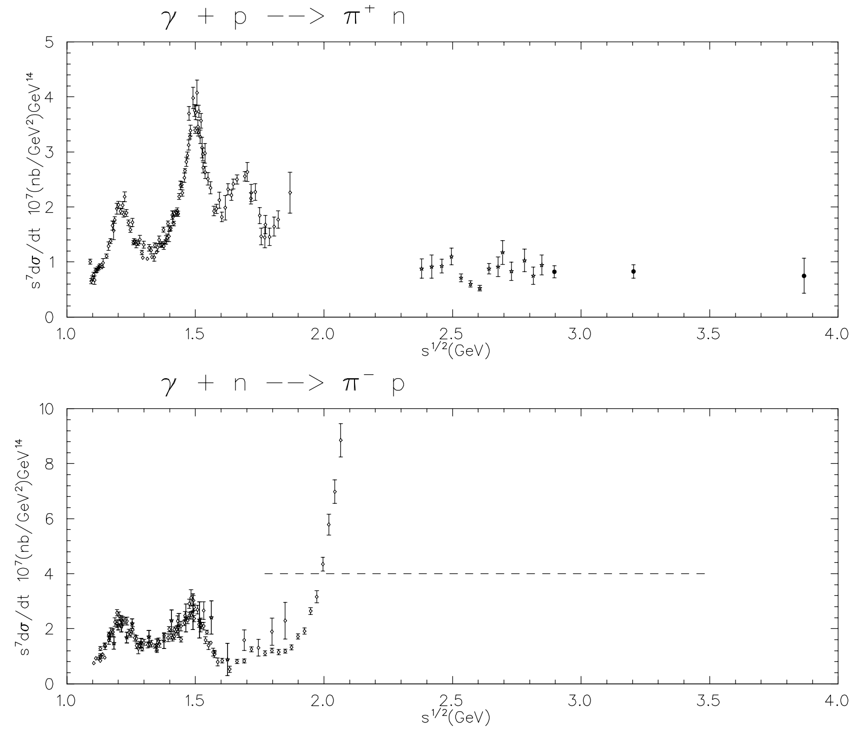

Figure 1: Existing data on the differential cross section for the $\gamma\ p \rightarrow \pi^+\ n$ and the $\gamma\ n \rightarrow \pi^-\ p$ processes as a function of the center of mass energy $s^{1/2}$, at the center of mass angle near 90°. The y axis is the differential cross section $d\sigma/dt$ multiplied by s^7. In the bottom figure, the dashed line indicates the $s^{1/2}$ range of the approved experiment E94-104: Its height is arbitrary.

photoproduction models. In addition, it is clear that measurements of the ratio of π^- to π^+ photoproduction from nucleons at high energies provide an important means of testing quark model predictions. Over the large range of t and s values probed by E94-104, measurement of the π^-/π^+ cross-section ratio provides an excellent means of investigating the transition from a nucleon-meson model of these processes to a description which uses quark-gluon degrees of freedom within the framework of QCD. With an 8 GeV electron beam expected from future JLab upgrades, this ratio measurement can be extended to the very large t region. Fig. 2 shows the projected measurement of this ratio as a function of t, at two different beam energies, with the errors given by the statistical uncertainties achievable with a total running time of 500 hours.

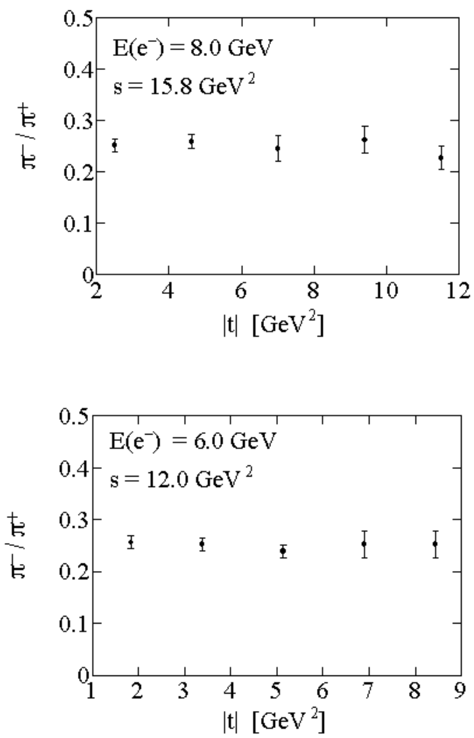

Figure 2: The projected measurement of the differential cross section ratio π^-/π^+ as a function of t at two different incident electron beam energies. The errors shown are the statistical errors for the ratio measurement.

Summary

With future upgraded JLab energies, photopion production from the nucleon will shed lights on very important questions in the intermediate energy region.

References

[1] R.L. Anderson *et al.*, Phys. Rev. **D14**, 679 (1976).

[2] JLab Experiment E94-104, Spokesperson: H. Gao, R.J. Holt.

[3] J.G. Branson *et al.*, Phys. Rev. Lett. **38**, 1334 (1977); K.J. Anderson, Hadronic Production of High-mass Muon Pairs, *19th International Conference on High-Energy Physics, Tokyo, 1978.*

[4] A. Ito *et al.*, Phys. Rev. Lett. **24**, 687 (1970).

[5] P. Heide *et al.*, Phys. Rev. Lett. **21**, 248 (1968).

[6] R. Worden, Nucl. Phys. **B37**, 253 (1972).

[7] M. Guidal, J.-M. Laget, and M. Vanderhaeghen, Phys. Lett. **B400**, 6 (1997).