Photoproduction of the π^0 meson from 1.1 - 5.5 GeV and a comparison to the CCR and Handbag model

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Exclusive neutral pion photoproduction ($\gamma p \to p\pi^0$) was measured in the CLAS detector at the Thomas Jefferson National Facility. The experiment employed a 1.1-5.5 GeV bremsstrahlung photon beam from 5.6 GeV electron beam created in the Continuous Electron Beam Accelerator Facility (CEBAF). The photon beam energy was impinged on a liquid hydrogen target. The neutral pions were detected via external conversion, $\pi^0 \to \gamma\gamma \to e^+e^-\gamma$, and subsequent Dalitz decay, $\pi^0 \to \gamma^*\gamma \to e^+e^-\gamma$. Measured differential cross-sections, $\frac{d\sigma}{dt}$ and $\frac{d\sigma}{d\cos\theta}$ are compared with the constituent counting rule, and handbag theoretical calculations. The results for the constituent counting rule agree well with the data. The handbag theoretical calculation significantly underestimates the data at center of mass energies, s $\sim$ 11 GeV.

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I. INTRODUCTION

In hadron physics, photoproduction of single pion is essential to understand the photon-nucleon vertex. At low energies, the photon-nucleon coupling establishes excited nucleon resonances which has been at the forefront of physics "missing resonances" search. At high energies single pion photoproduction can be used to test predictions of Regge theory, in which recent calculations [1] have shown to describe the presented data well. Furthermore, these measurements have shown that the differential cross section for single pion photoproduction at fixed c.m. angles, $\theta_{c.m.}$, of 70°, 90° and 110° seem to scale as $\frac{d\sigma}{dt} \sim s^{2-n} f(\theta_{c.m.})$, where s and t are the Mandelstam variables and n is the total number of interacting elementary fields in the initial and final state of the reaction. This is predicted by the constituent counting rule [2, 3] and exclusive measurements in pp and $\bar{p}p$ elastic scattering [4, 5], meson-baryon Mp reactions [5], and photoproduction γN [6–13] agree well with this rule. The following paper details the CLAS g12 experiment, the extraction of single neutral pion photoproduction from data, the differential cross-sections through the entire beam energy range of the g12 experiment, a comparison of the differential cross-section with existing world data, and a comparison to the constituent counting rule.

II. EXPERIMENTAL SETUP

The measurements used for this analysis was taken with the `CLAS` detector at Hall B at the Thomas Jefferson National Accelerator Facility `TJNAF` located in Newport News, Virginia. The *g12* experiment is a photoproduction experiment, it ran during March - June 2008 with a total of 44 days of good beam time. It collected over 128 TB of raw data that consisted of $26 \cdot 10^9$ events, with an integrated luminosity of 68 pb^{-1}. The photon beam was produced by impinging a 5.715 GeV electron beam, at 65nA, on a Au radiator of 10^{-4} radiation length. Photons in the energy range from 20% to 95% of the electron beam energy were tagged, resulting in a photon beam energy range of 1.1-5.5 GeV. This photon beam was then collimated before being introduced onto a ℓH_2 target 40 cm in length along the z-direction and 2 cm radius. The placement of the target was 90 cm upstream from `CLAS` center (toward Au radiator), this increased the acceptance of particles in the forward direction. During the runtime of *g12*, the Cherenkov detectors were filled with perfluorobutane (C_4F_{10}) allowing for electron/positron detection. The experiment had a dedicated trigger, amongst 9 other triggers, that consisted of `CC` and `EC` coincidence hits for the entire beam energy range. With proper cuts on the `CC` and `EC` a π/e rejection of 10^6 for $e^\pm$ pairs was established.

A. *g12* Run Summary

The *g12* experiment was divided into 626 production runs, 37 single-prong runs, 13 special calibration runs and numerous diagnostic runs which were not recorded. Each run consisted of approximately 50 million triggered events. If a run did not have at least 1M triggered events or if the run was corrupt, the run was discarded. The *g12* experiment had several special calibration runs. These runs consist of normalization, zero-field, and empty-target data runs. The normalization runs were used to calibrate the tagger for the measurement of the total photon flux and consistency of the left and right `TDC` signals of the tagger. The zero-field data

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was taken with the main torus magnet off. This was done to account for the position and orientation of the drift-chambers in the reconstruction. The empty target runs were used to investigate the contributions of the target wall to the data sample.

III. COMPARISON WITH THEORETICAL MODELS

There are several models that attempt to describe π^0 photoproduction in the low beam energy resonance region, while in the high beam energy regime there exists limited amount of theory. Described below are two theories.

1. *HandBag Model*

The production of the π^0 meson in photon-proton reactions, for incoming photon beam energies greater than 2.8 GeV, can considered to be a hard exclusive reaction. One approach to study the π^0 photoproduction, is use the handbag model. In the handbag approach, the reaction is factorized into two parts. The first part is when one quark from the incoming and one from the outgoing nucleon participate in the hard sub-process. This hard sub-process is achieved when the incident photon excites a quark, since quarks are bound quantum particles, the excited quark produces a jet of quarks that form the meson and then de-excites back into the nucleon. This is calculable using pQCD. The second part ,the soft part, consists of all the other quarks that are spectators and can be described in terms of GPDs [14–17]. The handbag mechanism is applicable when the Mandelstam variables, s, t, u, are large as compared to a hadronic scale of order 1 GeV . In Ref. [18] a model, derived from the handbag approach, has been applied to predict angular dependence of scaled photoproduction cross section of π^0 and is illustrated in Fig. 1. The handbag model calculations by Kroll *et al.* [18] does not agree with the measurement obtained by *g12*.

A. Constituent Counting Rule

The constituent counting rule (CCR) predicts the energy dependence of the differential cross-section at fixed center-of-mass angles for an exclusive two-body reactions. It validity is at high beam energies and large momentum transfer and the framework is similar to that of the handbag approach, in which the theory relies on the factorization of the exclusive process into a hard scattering amplitude and a soft quark amplitude inside the hadron. The prediction of CCR is:

$$\frac{d\sigma}{dt} \sim s^{2-n} f(\theta_{c.m.}) \tag{1}$$

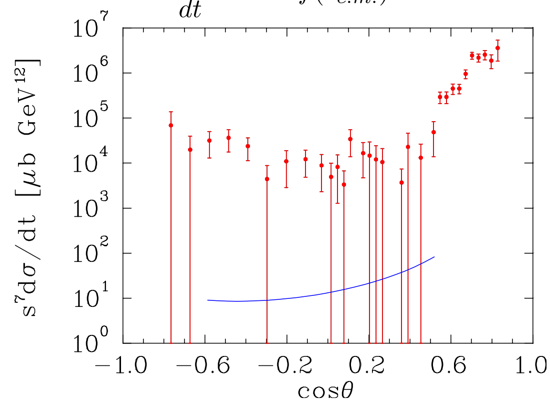

FIG. 1: Comparison of the π^0 differential cross section photoproduction data to GDP handbag model. Experimental data at $s = 11.08$ GeV^2 are from the current (red filled circles). The theoretical prediction at $s = 10$ GeV^2 by Kroll *et al.* [18] is given by blue solid line.

where s and t are the Mandelstam variables, n is the total number of interacting elementary fields in the initial and final state of the reaction and $f(\theta_{c.m.})$ depends on the dynamics of the process. Many exclusive measurements in pp and $\bar{p}p$ elastic scattering [4, 5], meson-baryon Mp reactions [5], and photoproduction γN [6–13] agree well with this rule. For π^0 photoproduction reactions CCR predicts that the differential cross-section $\frac{d\sigma}{dt}$ should scale as s^{-7}, where -7 was calculated from 4 elementary fields in the initial state, 1 for the photon, 3 for the number of quarks in a proton, and 5 elementary fields in the final state, 3 quarks from the proton and 2 quarks from the π^0 , 2-9 =-7. A comparison of this previous data along with the *g12* measurements can be seen in figure 2, at high energies and large angles the results are consistent with the s^7 scaling expected from the quark counting rule.

IV. SUMMARY

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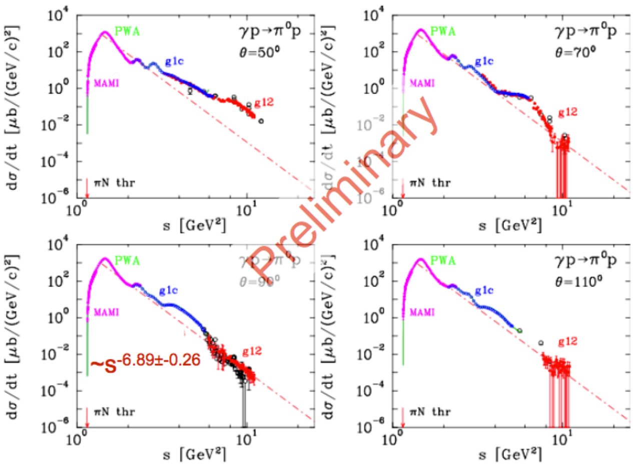

FIG. 2: The differential cross section for the $\gamma p \rightarrow p\pi^0$ reaction at $\theta_{c.m.} = 50°, 70°, 90°, 110°$, as a function of s (center of mass energy squared). Experimental data are from the current measurement (red filled circles), CLAS [19, 20] (blue circles), MAMI [21] (magenta circles), old measurements [22] (black open circle plus). The dash dotted line is a result of the fit performed at $\theta = 90°$ with power function $\sim s^n$ leading to n = 6.89 ± 0.26.

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