Photoproduction of the π^0 meson from 3.9 - 5.5 GeV with a comparison to the Regge Model

Michael C. Kunkel*
Physics Department, Old Dominion University.

(CLAS Collaboration)

(Dated: February 12, 2016)

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 Regge theory. The Regge theoretical calculations underestimate the differential cross sections between 3.9 and 4.6 GeV, but agree with data at photon energies 4.6-5.4 GeV.

PACS numbers: 13.20.Cz, 13.25.Cq, 13.30.Ce, 13.60.Le, 14.40.0n

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.

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 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. EVENT SELECTION

Pions were skimmed initially and then re-identified as leptons by changing the mass of the pion. This method is sufficient when the decaying particle's mass, i.e. m_{π^0}, is less than that of pions. If the event satisfied the requirements listed in Table I, then all `TOF`, `ST`, momentum and vertex information was outputted as well as `CC` and `EC` information for the $\pi^\pm$ particles to be used to identify leptons, as discussed in Sec IV. To reduce the size

* Now at Forschungszentrum Jülich.

of the data set, a cut was placed on the total missing mass of $\gamma p \to p\pi^+\pi^-$ to be less than 275 MeV. This cut was broad enough to not interfere with π^0 selection from single π^0 production i.e. $\gamma p \to p\pi^0$ when assigned the pion the lighter mass of a electron/positron. This broad cut also does not interfere with π^0 production from light meson decay, i.e $\gamma p \to p\omega \to p\pi^+\pi^-\pi^0$.

TABLE I: Requirements of initial skim

Requirement
One in-time beam photon
One proton
One π^+ or *"unknown"* of q^+
One π^- or *"unknown"* of q^-

IV. PARTICLE IDENTIFICATION

Lepton identification was based on conservation of mass. Once the data is skimmed according to Table I, all particles that were π^+, π^-, unknown with q^+ or unknown with q^- were tentatively assigned to be electrons or positrons based on their charge. This meant that the mass term of the particle's 4-vector was set to be the mass of an electron instead of that of a pion. This technique works because the mass of the π^0 (0.135 GeV) is less than the mass of π^+ or π^- (0.139 GeV) and by laws of conservation of energy-momentum, a lighter particle cannot decay into heavier particle's.

A. Kinematic Cuts

First it should be noted that for the /g12 experiment, there was a two-prong trigger for events in which the photon beam energy was greater then 3.6 GeV, while for the entire data taking process there was a "lepton" trigger configuration. Therefore to measure the differential cross-section at photon beam energies less than 3.6 GeV this "lepton" trigger information was employed. Once particle section was achieved, it was necessary to reduce the background of the exclusive $\gamma p \to p\pi^+\pi^-$ reaction. For events of photon beam energy less than 3.6 GeV, a `CC` and `EC` "hit" must have been recorded for each charge track that was not the proton. For all events 3 kinematic fits were performed, a 1-C ($\gamma p \to pe^+e^-(\gamma)$) to identify the missing photon in the reaction, a 4-C ($\gamma p \to p\pi^+\pi^-$) as a discriminator and a 2-C ($\gamma p \to p\pi^0 \to pe^+e^-(\gamma)$) to identify the reaction. After the kinematic fit, a 1% confidence level cut was placed on the 1-C fit. The missing energy of the $\gamma p \to pe^+e^-$ spectrum versus the missing mass of $\gamma p \to pX$ was analyzed and shown that a 75 MeV cut on the missing energy was suitable to suppress the $\gamma p \to p\pi^+\pi^-$ reaction, see figure 1. After the missing energy cut, the signal to background ratio was $\sim 99.7\%$, see right figure 1, the other 4-C and 2-C fits were then used with a 1% confidence on each to suppress the background to $\sim 99.9\%$.

V. COMPARISON WITH THEORETICAL MODELS

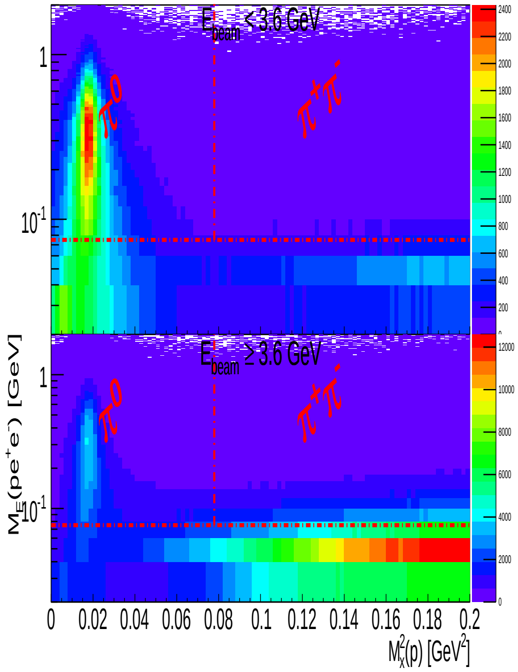
There are several models that attempt to describe π^0 photoproduction in the low beam energy resonance region, while in the high beam energy regime there exists limited amount of theory. Described below are two theories.

1. Regge Theory

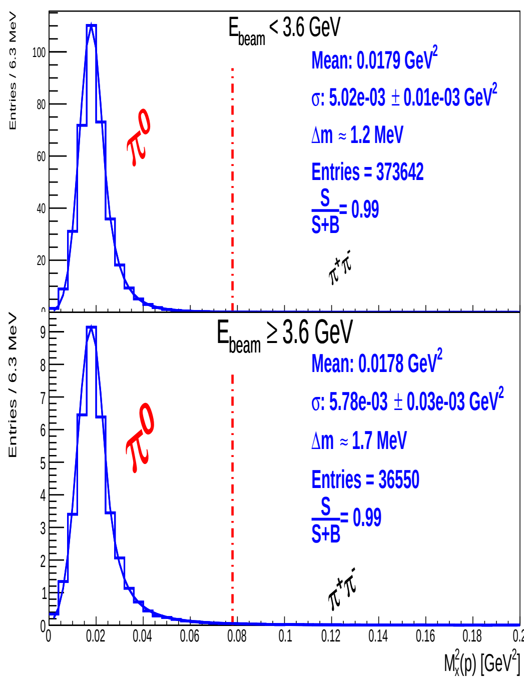
Regge theory can be used to describe the production of the π^0 meson in photoproduction. According to Regge theory the reaction amplitudes can be described by Regge poles in which the dominant Regge poles originate from t-channel exchange. This model has been developed over the years and is greatly described in [1]. Using this model along with the *g12* measurements, seen in figure 2, it is shown that this theory provides a good description of the data obtained by *g12* and a previous measurement [2].

VI. SUMMARY

[1] V. Mathieu *et al.*, Phys. Rev. **D92**, p. 074013 (2015), arXiv:1505.02321 [hep-ph].
[2] M. Braunschweig *et al.*, Physics Letters B **26**, 405 – 409 (1968).
[3] S. J. Brodsky and G. R. Farrar, Phys. Rev. Lett. **31**, 1153–1156 (1973).
[4] G. P. Lepage and S. J. Brodsky, Phys. Rev. D **22**, 2157–2198 (1980).
[5] W. Chen *et al.* (The CLAS Collaboration), Phys. Rev. Lett. **103**, p. 012301 (2009).
[6] L. Y. Zhu *et al.* (Jefferson Lab Hall A Collaboration), Phys. Rev. Lett. **91**, p. 022003 (2003).
[7] R. A. Schumacher and M. M. Sargsian, Phys. Rev. C **83** (2011).
[8] P. Landshoff and J. Polkinghorne, Physics Letters B **44**, 293 – 295 (1973).
[9] R. L. Anderson *et al.*, Phys. Rev. D **14**, 679–697 (1976).



(a)



(b)

FIG. 1: Left: $M_x^2(p)$ vs. $M_E(pe^+e^-)$. The horizontal red dashed-dotted line depicts the 75 MeV cut used in this analysis. The vertical red dashed-dotted line depicts the boundary of single π^0 to $\pi^+\pi^-$ production. Right: Final $M_x^2(p)$ data used in analysis. The horizontal red dashed-dotted line depicts the threshold of $\pi^+\pi^-$ production.

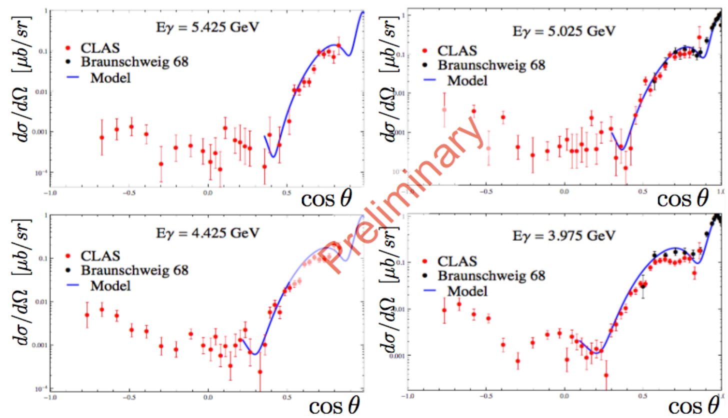


FIG. 2: Comparison with Regge model. Experimental data are from the current measurement (red filled circles) and previous bremsstrahlung measurements [2] (black open circles).

[10] R. L. Anderson *et al.*, Phys. Rev. D **49** (1994).
[11] J. Napolitano *et al.*, Phys. Rev. Lett. **61**, 2530–2533 (1988).
[12] J. E. Belz *et al.*, Phys. Rev. Lett. **74**, 646–649 (1995).
[13] C. Bochna *et al.*, Phys. Rev. Lett. **81**, 4576–4579 (1998).
[14] E. C. Schulte and others., Phys. Rev. Lett. **87** (2001).
[15] M. Dugger *et al.*, Phys.Rev. **C76**, p. 025211 (2007), 0705.0816.
[16] M. Dugger *et al.* (CLAS Collaboration), Phys.Rev. **C88**, p. 065203 (2013), 1308.4028.
[17] O. Bartholomy *et al.* (CB-ELSA Collaboration), Phys.Rev.Lett. **94**, p. 012003 (2005), hep-ex/0407022.
[18] V. Crede *et al.* (CBELSA/TAPS Collaboration), Phys.Rev. **C84**, p. 055203 (2011), 1107.2151.
[19] A. Anisovich *et al.*, Eur.Phys.J. **A44**, 203–220 (2010), 0911.5277.
[20] M. Sumihama *et al.*, Phys.Lett. **B657**, 32–37 (2007), 0708.1600.
[21] O. Bartalini *et al.* (GRAAL Collaboration), Eur.Phys.J. **A26**, 399–419 (2005).
[22] W. Briscoe *et al.*, Institute of Nuclear Studies of The George Washington University Database,.
[23] H. W. Huang and P. Kroll, Eur.Phys.J. **C17**, 423–435 (2000).
[24] A. Radyushkin, Phys.Lett. **B380**, 417–425 (1996).
[25] X.-D. Ji, Phys.Rev.Lett. **78**, 610–613 (1997).
[26] X. Ji, Phys. Rev. D **55**, 7114–7125 (1997).
[27] M. Diehl, T. Feldmann, R. Jakob, and P. Kroll, Eur.Phys.J. **C8**, 409–434 (1999).
[28] P. Joss, Compilation of photoproduction data above 1.2 gev, 1970.
[29] M. Fuchs *et al.*, Physics Letters B **368**, 20 – 25 (1996).
[30] R. Beck, Eur. Phys. J. A, **28**, 173–183 (2006).