Measurement of the Deeply Virtual Neutral Pion Electroproduction Cross Section at the Thomas Jefferson National Accelerator Facility at 10.6 GeV

by

Robert Johnston

Submitted to the Department of Physics
in partial fulfillment of the requirements for the degree of

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Abstract

Deeply virtual exclusive reactions provide unique channels to study both transverse and longitudinal properties of the nucleon simultaneously, allowing for a 3D image of nucleon substructure. This presentation will discuss work towards extracting an absolute cross section for one such exclusive process, deeply virtual neutral pion production, using 10.6 GeV electron scattering data off a proton target from the CLAS12 experiment in Jefferson Lab Hall B . This measurement is important as exclusive meson production has unique access to the chiral odd GPDs, and is also a background for other exclusive processes such as DVCS, making the determination of this cross section crucial for other exclusive analyses.

Thesis Supervisor: Richard Milner
Title: Professor of Physics

Acknowledgments

To Be Completed. Currently this will serve as a to-do list:

input list of figures

input list of tables

Contents

Chapter 1

Introduction

1.1 Exploring Structure through Scattering

Humanity interested in the structure of reality, atomic theory, subatomic, subnuclear, structure of this thesis. The rest of this chapter discusses these advancments, and describes the theoretical background for this experiment. Chapter 2 descriptes the experiment, CHapter 5 the analysis, etc. Chapter 8 summarizes this work and discusses how this analysis will proceed in the near future and a path for future experiments. The appendix includes numerous technical details and upplemental plots.

As we increase the resolution (resolve features over smaller spatial distances), what we see is dependent on what resolution scale we are at. An exception to this case is if we are investigating point-like particles, which would have an identical response across all resolution scales

GPDs combine the kinematics of both elastic form factors and parton distributions. Andrey references 5, 6, and 7

1.1.1 Discovery of the Proton

Yimin has good references for this part

1.1.2 Electron as a Nucleon Probe

Include discussion of wavelength and momentum transfer (but in practice, limiting factor to resolution is lens system

1961 hofstadter nobel prize (Andrey reference 1) Andrey refrence 2 Friedman Kendall Tayleor scaling

Andrey thesis good write ups

Sangbaek: proton has properties Describe with QFT, words about QCD role of experiment in studying proton structure - proton discovery - neutron discovery - pointlike consitutents - development of quark model - scaling behavior and asymptotic freedom - details about scattering experiments from first principles - words about elastic scattering (mott scattering) - Plot of elastic form factors, discussion of Ge and Gm, Rosenbluth formula - Mention TPEX - discussion of inelastic scattering - Structure funcitons - Discussion of spin and sum rules

Now discussion of DVEP: GPDs, Wigner functions relationships all the way around some annoying math Handbag diagram Lepton hadron plane Status of experiments and future (EIC mapping)

invariant mass is W

Understanding the structure of matter has been a fundamental research pursuit for centuries.

Proton not a point mass - it has structure

1.1.3 Structure of our World

- atomic theory - discovery of proton / nucleon - proton structure measurements - lepton scattering experiments, HERA, etc

1.2 Theoretical Background

Discussion of Form Factors and genralized proton structure, Wigner Functions

1.2.1 GPDs and Deeply Virtual Scattering

The cross section for DVπ^0P has been theoretically linked to GPDs, which describe the 3D structure of the nucleon.

$$\frac{d^4\sigma_{\gamma^* p \to p' \pi^0}}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}\left\{\left(\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right) + \epsilon cos(2\phi)\frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)}cos(\phi)\frac{d\sigma_{LT}}{dt}\right\} \tag{1.1}$$

There are 8 GPDs, 4 correspond to helicity conserving (chiral even) processes and 4 correspond to are helicity flipping (chiral odd) processes: H, E, $\tilde{H}$, and $\tilde{E}$for chiral even, and H_T, E_T, $\tilde{H}_T$, and $\tilde{E}_T$

$\bar{E}_T$= 2*$\tilde{H}_T$+$E_T$is commonly used

Nucleon Polarization	Quark Polarization		
	U	L	T
U	H		$\bar{E}_T$
L		$\tilde{H}$	
T	E		H_T,$\tilde{H}_T$

Why do the scrtucture combine in the way they do with the coefficents of cos phi terms and epsilons?

And the structure functions can be written as:

$$\frac{d\sigma_L}{dt} = \frac{4\pi\alpha}{kQ^2}\left\{\left(1-\xi^2\right)|\langle\tilde{H}\rangle|^2 - 2\xi^2\Re\left[\langle\tilde{H}\rangle^*\langle\tilde{E}\rangle\right] - \frac{t'}{4m^2}\xi^2|\langle\tilde{E}\rangle|^2\right\} \tag{1.2}$$

$$\frac{d\sigma_T}{dt} = \frac{2\pi\alpha\mu_\pi^2}{kQ^4}\left\{\left(1-\xi^2\right)|\langle H_T\rangle|^2 - \frac{t'}{8m^2}|\langle\bar{E}_T\rangle|^2\right\} \tag{1.3}$$

$$\frac{d\sigma_{LT}}{dt} = \frac{4\pi\alpha\mu_\pi}{\sqrt{2}kQ^3}\xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\Re\left\{\langle H_T\rangle^*\langle\tilde{E}\rangle\right\} \tag{1.4}$$

$$\frac{d\sigma_{TT}}{dt} = \frac{4\pi\alpha\mu_\pi^2}{kQ^4}\frac{-t'}{16m^2}\langle\bar{E}_T\rangle^2 \tag{1.5}$$

and epsilon is...

and t' stands for.. t - t_0 where $t_0 = \frac{-4m^2\xi^2}{1-\xi^2}$

Where the skewness parameter is $\xi = \frac{x_B}{2-x_B}$ or whatever

The bracket $\langle\tilde{F}\rangle$ is the convolution of a GPD and an appropriate subprocess amplitude: $\langle\tilde{F}\rangle = \Sigma_\lambda \int_{-1}^{1} d\bar{x} H_{0\lambda,0\lambda}\left(\bar{x}, \xi, Q^2, t=0\right) \tilde{F}\left(\bar{x}, \xi, Q^2, t\right)$

Where λ is the unobserved helicites of the partons participaing in the subprocess

And k is the phase space factor given as $k = 16\pi\left(W^2 - m^2\right)\sqrt{\Lambda(W^2, -Q^2, m^2)}$

Where $\Lambda(W^2, -Q^2, m^2)$ is the Källén function and μ_{pi} is the reduced pion mass given as $\mu_{\pi^0} = \frac{m_{\pi^0}^2}{m_u+m_d}$ m_u and m_d are respective masses of up and down quarks.

Include proton pressure distribution plot

$$\Gamma(Q^2, x_B, E) = \frac{\alpha}{8\pi}\frac{Q^2}{m_p^2 E^2}\frac{1-x_B}{x_B^3}\frac{1}{1-\epsilon} \tag{1.6}$$

In addition to collinear momentum distribution of partons inside the nucleon, GPDs also encode the distribution of partons in the plane transverse to the nucleons momentum in the infinite momentum frame [58]. Moreover, their relation to energy-momentum tensor (EMT) form factors allow us to access the EMT densities, the distribution of energy, angular momentum, pressure, and shear forces inside the nucleon [15].

Only valence quarks contribute electroproduction of uncharged pions.

1.2.2 The Handbag Approach

DVMP is sensitive to chiral odd GPDs, distinguishing it from DVCS as a GDP probe because why? Because something involving photon helicity and pion helicity, I forget exactly though

1.2.3 The Goloskokov-Kroll Model

1.3 Overview of Experimental Status

1.3.1 Previous Experimental Results

1.3.2 Overview of this Analysis

Hi (Bedlinskiy et al., 2014) see more in section 1.1 just a test

References

Bedlinskiy, I., Kubarovsky, V., Niccolai, S., Stoler, P., Adhikari, K. P., Anderson, M. D., . . . Zonta, I. (2014). Exclusive π^0 electroproduction at w>2 gev with clas. *Physical Review C - Nuclear Physics*, *90*. Retrieved from https://arxiv.org/pdf/1405.0988.pdf doi: 10.1103/PhysRevC.90.025205

Appendix A

A.1 Full Cross Section Data

To be completed

Appendix B

B.1 Cross check between Andrey Kim and Bobby Johnston

As an additional cross check, Bobby calculated a $DV\pi^0P$ beam spin asymmetry and compared to Andrey Kim's results. This check will not comment on any acceptance, luminosity, or virtual photon flux factor calculations, but does validate exclusive event selection criteria. By examining figure B-1 we can see that agreement is reasonable, especially considering Bobby's calculation does not have sideband subtraction included.

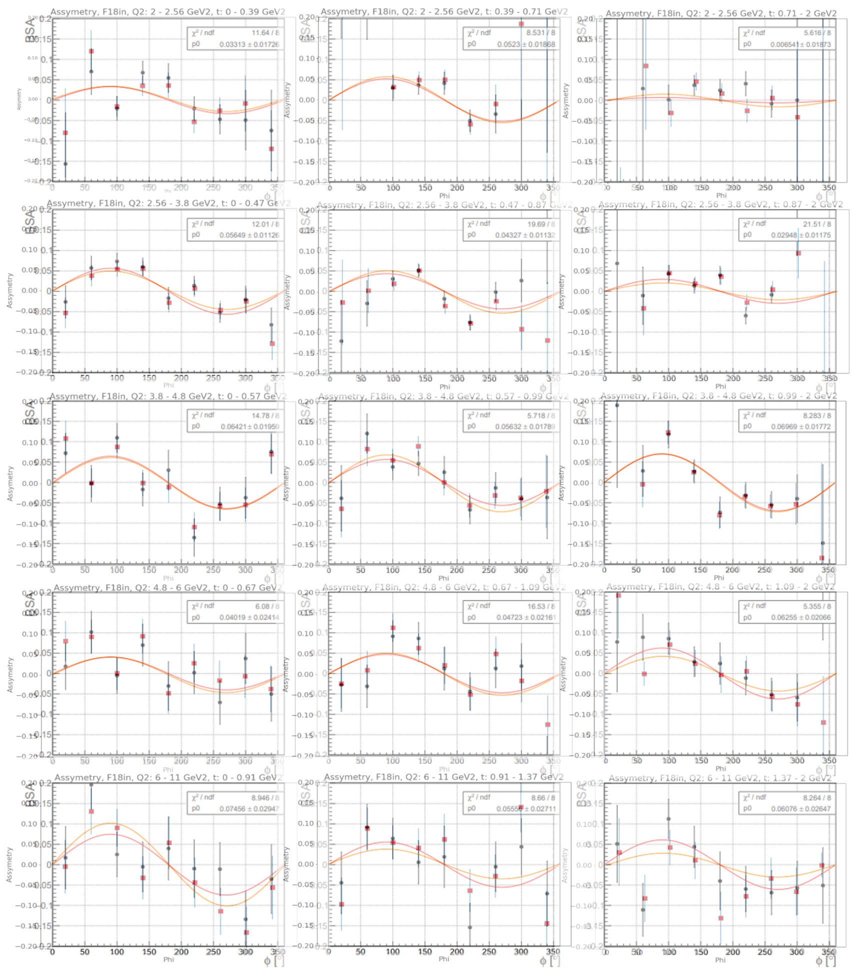

Figure B-1: Overlay comparison of Andrey Kim's results (black datapoints, red fit line) and Bobby's results (red datapoints, orange fit line).