Tyler Hague NUCLEAR PHYSICS

SUPER AWESOME MARATHON THESIS (pp.)

Director of Thesis/Dissertation: MK MP

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My research field is experimental nuclear physics. My work was ——

We present the details of the analysis, the obtained distributions, and their discussion.

MARATHON is a Deep Inelastic Scattering experiment in Jefferson Lab's Hall A. The experiment utilized Deuterium, Helium-3, and Tritium targets to extract the F_2^n/F_2^p structure function ratio and R. **Need to give an explanation of R. Talk about EMC and why we're looking at these things. Mention uniqueness of having Tritium target**

SUPER AWESOME MARATHON THESIS

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by

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Acknowledgments

This is the acknowledgements text.

Chapter 1

Introduction

As I chose a starting point for writing, this has become more of a theory chapter. It will likely be renamed and renumbered to reflect that soon.

1.1 The Quark-Parton Model

- Decide how "historical" to be
- Hadrons are composed of quarks
- Quarks are bound by gluons (strong force)
- Gluons create the "sea" via $g \to q\bar{q} \to g$
- Electric and Magnetic form factors?

The Quark-Parton Model describes the composition of hadrons, both baryons and mesons. Prior to 1964, it was believed that hadrons were as small as it got. However, the adherence of hadrons to the eight-fold way, a categorization of hadrons by charge and strangeness, suggested that there was some underlying mechanism that had yet to be discovered.

In 1964, Gell-Mann and Zweig independently suggested that hadrons could be composed smaller elementary particles. Gell-Mann offered the name "quarks" for these constituents.

Furthering the theory, in Novemeber 1974 two separate experiments published the discovery of the (now named) J/ψ particle. The long lifetime of the J/ψ suggested that new physics must be at play. The Quark-Parton Model predicted the existence of a quark symmetric to the strange quark, called the charm quark. It was determined that the J/ψ could be a meson comprised of a charm and anti-charm, suggesting the validity of the model.

1.2 Deep Inelastic Scattering

How does it work? Electron comes in, exchanges photon with nucleon. Boom.

At its most basic, Deep Inelastic Scattering (DIS) is the scattering of a lepton from a nucleon. The two participants exchange a virtual boson, the lepton scatters, and the nucleon is excited to a hadronic final state X with higher mass.

$$\ell + N \to \ell' + X$$

For the MARATHON experiment we will focus on electromagnetic DIS. In this case the lepton is charged and the exchanged virtual boson is a virtual photon. The JLab CEBAF accelerator provides an electron beam, so from here on the lepton will be written as an electron.

$$e^- + N \to e^- + X$$

PUT DIS FEYNMAN DIAGRAM HERE

By interacting with a single nucleon, DIS is a powerful tool for studying nucleon structure. By looking at the DIS cross section, we can see how the nuclear structure functions readily present themselves.

If we assume Lorentz invariance, **P** and **T** invariance, and conservation or lepton current, the cross section is

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{Q^4}\frac{E'}{E}L^{(s)^{\mu\nu}}W^{(s)}_{\mu\nu} \tag{1.1}$$

where Q^2 is the 4-momentum transfer, E is the beam energy, E' is the scattered electron energy, $L^{(s)^{\mu\nu}}$ is the lepton tensor, and $W^{(s)}_{\mu\nu}$ is the symmetric hadronic tensor.

When written explicitly in the laboratory frame, we arrive at

DIS Cross Section

(1.2)

$$\sigma \equiv \frac{d^2\sigma}{d\Omega dE'}\left(E, E', \theta\right) = \frac{4\alpha^2\left(E'\right)}{Q^4}\cos^2\left(\frac{\theta}{2}\right)\left[\frac{F_2\left(\nu, Q^2\right)}{\nu} + \frac{2F_1\left(\nu, Q^2\right)}{M}\tan^2\left(\frac{\theta}{2}\right)\right]$$

1.3 F_2 Structure Functions

"These two form factors, $F_{1,2}(q^2)$, parametrize our ignorance of the detailed structure of the proton". [9]

TALK MORE ABOUT THIS RELATION

The following relation allows the cross section to be written in terms of F_2 only.

$$F_1 = \frac{F_2\left(1 + Q^2/\nu^2\right)}{2x\left(1 + R\right)} \tag{1.3}$$

Here x is the bjorken scaling variable and R is the ratio of the longitudinal cross section to the transverse cross section, σ_L/σ_T.

Plugging this in we arrive at

$$\frac{d^2\sigma}{d\Omega dE'}\left(E, E', \theta\right) = \frac{4\alpha^2\left(E'\right)}{Q^4}\cos^2\left(\frac{\theta}{2}\right)F_2\left[\frac{1}{\nu} + \frac{\left(1 + Q^2/\nu^2\right)}{xM\left(1 + R\right)}\tan^2\left(\frac{\theta}{2}\right)\right] \tag{1.4}$$

1.4 $R = \sigma_L/\sigma_T$

$R = \sigma_L/\sigma_T$. R is independent of atomic number. This facilitates us taking ratios

If we instead approach DIS as the production and absorption of a virtual photon we can extract a different structure function $R = \sigma_L/\sigma_T$. That is, the ratio of the cross sections for absorbing longitudinal photons to transverse photons.

We can write the DIS cross section in terms of these cross sections as

$$\frac{d^2\sigma}{d\Omega dE'}\left(E, E', \theta\right) = \Gamma\left[\sigma_T\left(x, Q^2\right) + \epsilon\sigma_L\left(x, Q^2\right)\right] \tag{1.5}$$

In this equation Γ is the flux of transverse virtual photons and ϵ is the relative flux of longitudinal virtual photons. These are defined by

$$\Gamma = \frac{\alpha K E'}{2\pi^2 Q^2 E_0\left(1-\epsilon\right)} \tag{1.6}$$

$$\epsilon = \frac{1}{1 + 2\left(1 + \nu^2/Q^2\right)\tan^2\left(\frac{\theta}{2}\right)} \tag{1.7}$$

Here, K is the laboratory photon energy

$$K = \frac{W^2 - M^2}{2M} \tag{1.8}$$

1.5 EMC Ratios

Looking at the EMC-type ratios for Helium-3 and Tritium make it clear that we can extract the nucleon structure function ratio from the nuclear

structure function ratio. We will use a calculation of the super ratio to do this extraction.

Chapter 2

The Experiment

2.1 The Measurement

2.1.1 What are we measuring

2.1.2 How are we measuring it

2.1.3 Run Plan

2.2 The Apparatus

2.2.1 Hall A HRS Spectrometers

2.2.2 CEBAF Accelerator

2.3 Beamline Components

The Hall A Beamline has several measurement devices that allow the experimenter to fully understand the beam that is being delivered to the hall. For positioning, there are the Beam Position Monitors and the Harp. For beamspot sizing, there is the raster. For current and charge measurements, there are the Beam Current Monitors.

2.3.1 Beam Position Monitors

The Beam Position Monitors (BPMs) are a pair of measurement devices that consist of four sensing wires. By calibrating the signal received from each wire, the experimenter can reconstruct the position of the beam as it passed the BPM. Using both BPMs in conjunction allows the experimenter to determine the beam trajectory and where the electrons are incident on the target.

The BPMs are calibrated using a Harp fork. The Harp consists of three wires that

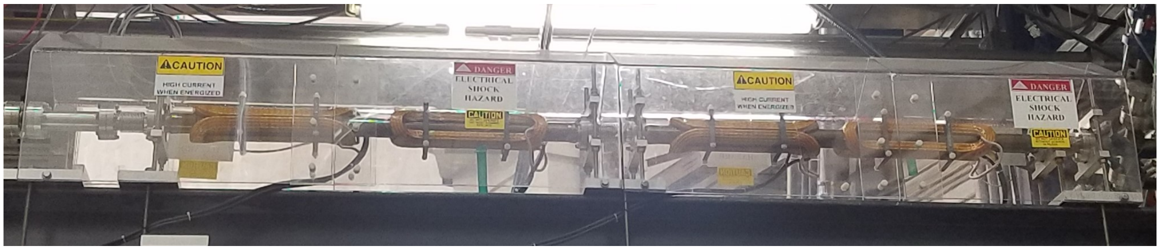

Figure 2.1: The Hall A raster consists of four dipole magnets on the beamline

are introduced sequentially into the path of the beam using a stepper motor. When the beam is incident on a wire, a charge is induced. By determining when each wire is struck by the beam, the experimenter can very accurately determine the position of the beam. This is an invasive (WRONG WORD - can't figure out right one right now) process.

2.3.2 Raster

The raster is a beamline apparatus in Hall A for spreading the beam onto the target, rather than being at a single point. This is done to prevent localized heating of the target. The raster consists of four dipole magnets, two for steering in the x-direction and two for steering in the y-direction.

Each raster magnet is powered by a triangle wave of different frequencies to minimize harmonics. The horizontal rasters are set to 24.5 kHz and the vertical rasters are set to 25 kHz. When running properly, the x-direction magnets will be synced and the y-direction magnets will be synced. This syncing ensures that the magnets are always working together to create the desired beam spread.

2.3.3 Beam Current Monitors

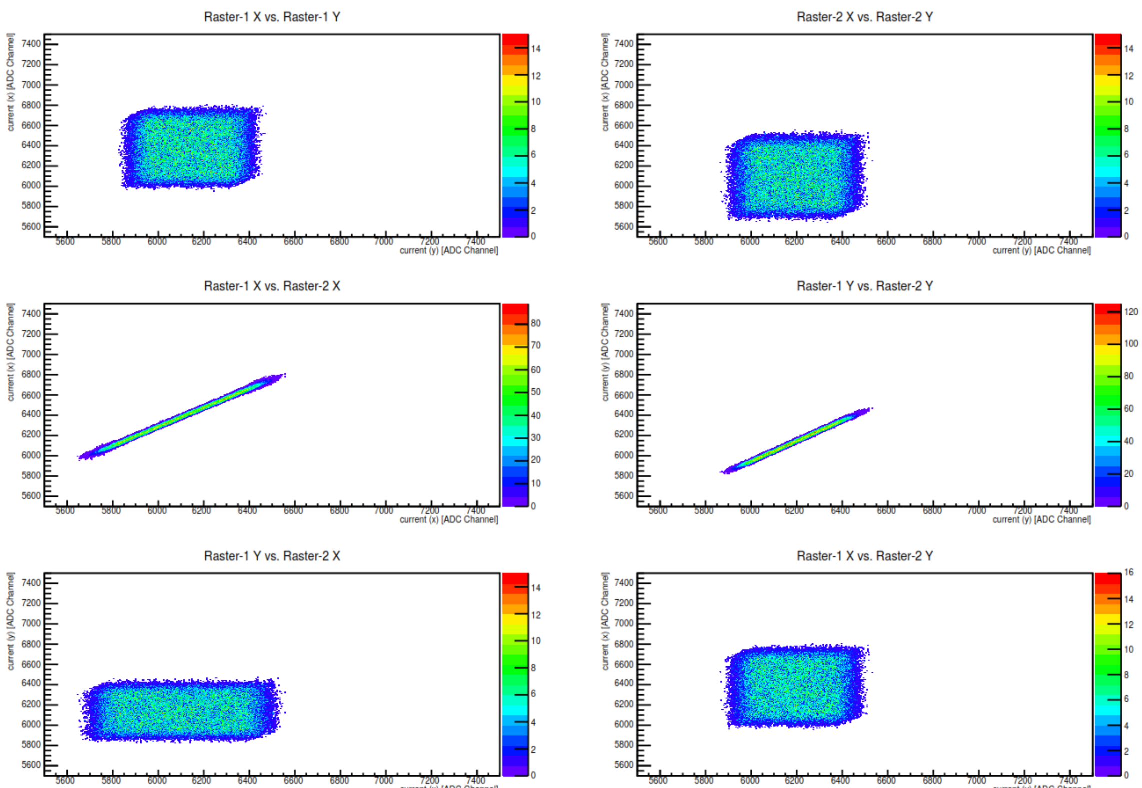

Figure 2.2: The X and Y raster pairs are each synced to produce the maximum kick. The X and Y directions are uncorrelated so that the beam travels uniformly over the target.

Chapter 3

Analysis

3.1 Calibration

3.1.1 Raster Calibration

In order to accurately determine the position of the beam, the raster needs to be calibrated to the BPMs. Reading out the BPMs gives an accurate position, but it has a phase lag which causes the readout to be uncorrelated with the events it is recorded with. The raster current is read instantaneously, which means it is an accurate for the event it is recorded with. However, the raster current does not directly tell us the position of the beam. Using these two systems together, the BPMs give the spread of the beam and the raster current can then be mapped to this spread. When the transformation between the raster current and position is found, it is easy to have an accurate beam position for every event that is recorded.

3.2 Analysis

3.2.1 Particle Identification

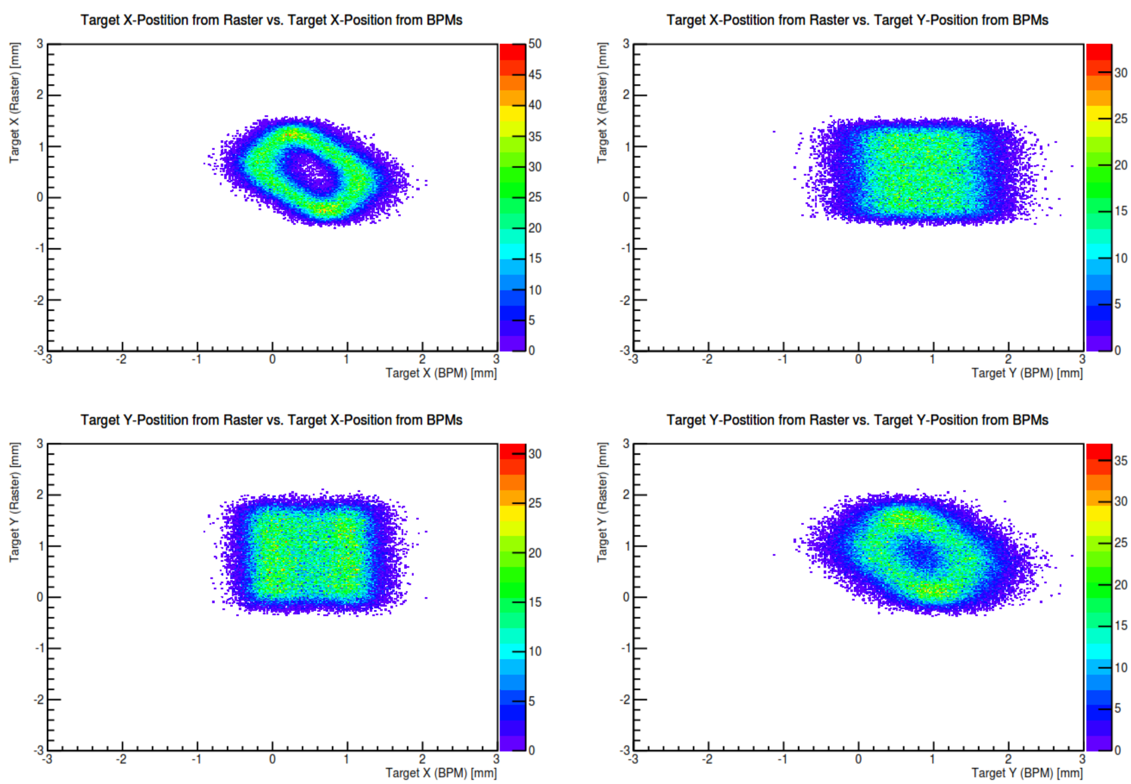

Figure 3.1: The BPM has a phase lag, causing the raster and BPMs to not be synced

Chapter 4

Results

Appendix A

Title of Appendix A

References

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