PROBING PARTON DISTRIBUTIONS IN PROTON WITH CHARMONIUM PRODUCTION WITH 120 GEV PROTON BEAM AT FERMILAB

BY

CHING HIM LEUNG

DISSERTATION

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Doctoral Committee:

Associate Professor Anne M Sickles , Chair
Professor Jen-Chieh Peng, Director of Research
Professor
Professor

[1]

Abstract

E906/SeaQuest is a fixed-target experiment at Fermilab with a 120 GeV proton beam. Muon pairs with mass between 2 to 9 GeV from the interaction of proton beam with various targets has been detected. The primary goal of the experiment is to study the partonic structure of the nucleon. In particular, the charmonium production data can be used to probe both the quark content as well as the gluon content. The preliminary result from the analysis of the SeaQuest charmonium production data will be presented. E1039/SpinQuest is a follow up experiment of SeaQuest. By utilizing a transversely polarized target,we could extend this study to the transverse momentum distribution of the partons.

To Father and Mother.

Acknowledgments

This thesis is a product of collaboration with a large number of talented individuals with whom I have had the privilege of working with over the past few years.

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Chapter 2

SeaQuest Experiment

2.1 Introduction

SeaQuest is a fixed-target experiment utilizing the 120 GeV proton beam from the Fermilab Main Injector. Details of the SeaQuest spectrometer can be found in Ref. [1]. A schematics of the spectrometer is shown in Fig. 2.1. The target system consists of seven interchangeable targets, including a flask with liquid hydrogen, a flask with liquid deuterium,an empty flask (vacuum), solid carbon, iron, and tungsten targets as well as a space with no target (air). The targets are interchanged periodically to reduce systematic uncertainties in the measured cross section ratios for different targets.

The spectrometer consists of two magnets and four tracking stations. FMag, placed 104 cm downstream the target, is a 5 m solid iron magnet that acts as the beam dump as well as a focusing magnet. It is then followed by the first tracking stations. Stations 1, 2 and 3 each consists of plastic scintillator hodoscopes and drift chambers. An open air dipole magnet (KMag) is placed between station 1 and station 2. The vertical magnetic field from both magnets bends the muons horizontally, allowing the measurement of the momentum of the muons. Downstream of station 3, there is a 1 m iron wall acting as a hadron absorber. Station 4 is located behind the hadron absorber and acts as a muon identifier. Station 4 consists of a hodoscope array and 4 layers of proportional tube planes. Tracks that pass through the hadron absorber and produce hits on station 4 are assumed to be from muons.

2.2 Beam

2.3 Target

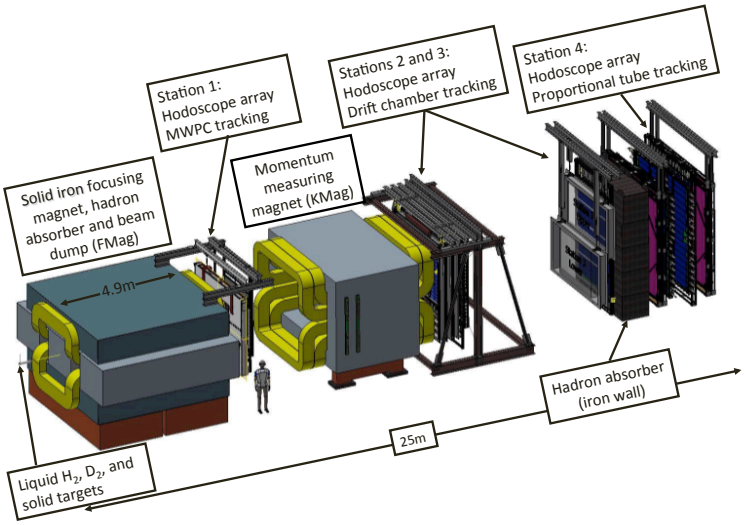


Figure 2.1: schematics of the SeaQuest spectrometer. Taken from Ref. [1]

Chapter 3

Analysis

3.1 Data Sets

Run	Experimental Conditions	Dates
2	Roadset 57	06/25/2014 to 08/20/2014
	Roadset 59	08/20/2014 to 09/03/2014
N/A	D3p and D3m moved	10//03/2014
3	Roadset 62	11/08/2014 to 01/14/2015
	Deuterium Change	11/13/2014
	Deuterium Change	12/02/2014
	Magnet Polarity flipped	01/14/2015
	Roadset 67	01/25/2015 to 06/19/2015
	Deuterium Change	04/24/2014
	D1 and H1 moved	05/13/2015
	Roadset 70	06/19/2015 to 07/03/2015
4	Constant adjustments	11/13/2015 to 03/06/2016
5	Roadset 78	03/06/2016 to 07/29/2016
6		01/14/2017 to 07/07/2017

Table 3.1: SeaQuest data sets and apparatus adjustments

3.2 Track Reconstruction

3.3 Event Selection

3.4 Target Contamination

3.5 Intensity Extrapolation

3.6 Mass Spectrum Fitting

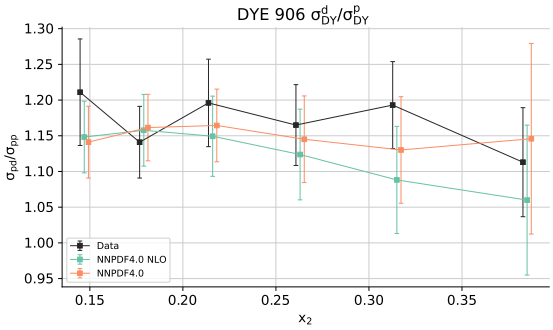
Chapter 4

Results

4.1 Drell-Yan Cross Section Ratio

4.1.1 Extraction of $\bar{d}/\bar{u}$

The $\sigma_{pd}/2\sigma_{pp}$ ratio is used by the NNPDF collaboration in their PDF extraction[2] and their result is shown in Fig.



(a) Calculated Drell-Yan cross section ratio.

(b) Extracted $\bar{d}/\bar{u}$ ratio.

Figure 4.1: Comparison of NNPDF4.0[2] with the SeaQuest result[3].

4.2 Charmonium Cross Section

4.2.1 Nuclear Dependence

Chapter 5

TMD with Transversely Polarized Target

5.1 Introduction

5.1.1 Transverse momentum dependent parton distributions

5.2 SpinQuest Experiment

5.2.1 Polarized Target

The polarized target used by SpinQuest has been rebuilt and tested by the University of Virginia. The target consists of a 5 T superconducting split coil magnet, a ^{4}He evaporation refrigerator, a 140 GHz microwave source and a 15 000 $\mathrm{m^3\,h^{-1}}$ pumping system. The target is polarized using Dynamic Nuclear Polarization(DNP)[4].

5.2.2 Data Acquisition System

5.3 Preliminary Result

Chapter 6

Conclusion and Future Prospects

References

[1] C. A. Aidala et al., "The SeaQuest spectrometer at Fermilab", Nucl. Instrum. Methods Phys. Res., Sect. A **930**, 49 (2019).

[2] R. D. Ball et al., "The Path to Proton Structure at One-Percent Accuracy", ArXiv210902653 Hep-Ex Physicshep-Ph (2021).

[3] J. Dove et al., "The asymmetry of antimatter in the proton", Nature **590**, 561 (2021).

[4] D. G. Crabb and D. B. Day, "The Virginia/Basel/SLAC polarized target: operation and performance during experiment E143 at SLAC", Nucl. Instrum. Methods Phys. Res., Sect. A, Proceedings of the Seventh International Workshop on Polarized Target Materials and Techniques **356**, 9 (1995).