UNIVERSITY OF CALIFORNIA
RIVERSIDE

MEASUREMENT OF THE LONGTIDUDIANL SINGLE SPIN ASYMMETRY, A_L, FOR POLARIZED PROTON-PROTON COLLISIONS IN THE $W \to \mu$ DECAY CHANNEL

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Physics

by

Michael J. Beaumier

August 2016

Dissertation Committee:

Professor Kenneth Barish , Chairperson
Professor Rich Seto
Professor John Ellison

The Dissertation of Michael J. Beaumier is approved:

Committee Chairperson

University of California, Riverside

Acknowledgments

In no particular order now, but say something nice about each person.

Advisors and Mentors

Ken Barish, Richard Hollis, K. Oleg Eyser, Ralf Seidl, Francesca Giordano, Joe Seele, Josh Perry, Martin Leitgab, Chris Pinkenburg, Martin Purschke, Collaborators, Sangwha Park, Daniel Jumper, Abraham Meles, Chong Kim,

Friends and Family

Bob Beaumier, Marian Beaumier, Joe Beaumier, David Beaumier, Emily Vance, Jackie Hubbard, Alexander Anderson-Natalie, Corey Kownacki, Chris Heidt, Pat Odenthal, Behnam Darvish Sarvestani, Oleg Martynov,

Some say that it takes a village to raise a child. The same can be said of raising a graduate student up to earning a PhD. This thesis is dedicated to the multitude who have helped me become the man I am today, and to students who struggle, and their mentors who do not give up on them.

ABSTRACT OF THE DISSERTATION

MEASUREMENT OF THE LONGTIDUDIANL SINGLE SPIN ASYMMETRY, A_L, FOR POLARIZED PROTON-PROTON COLLISIONS IN THE $W \rightarrow \mu$ DECAY CHANNEL

by

Michael J. Beaumier

Doctor of Philosophy, Graduate Program in Physics
University of California, Riverside, August 2016
Professor Kenneth Barish , Chairperson

This thesis discusses the process of extracting information about the spin structure of protons, specifically, spin contributions from the sea of quarks and antiquarks, which are kinematically distinct from the 'valence quarks'. We have known since the 'proton-spin crisis' [3] of the 1990s that proton spin does not entirely reside in the valence quarks, so the thurst of experimental efforts since then have been designed to determine both how to probe the proton spin structure, and how to validate models for proton spin structure. Here, I discuss one particular approach to understanding the sea-quark spin contribution, which utilizes the production of real W-bosons, and the W coupling with polarized spin structure in the proton sea, as produced from polarized protons collisions. Only one of the colliding protons is longitudinally spin polarized, in this analysis, and they are collided at an energy of $500GeV$. The expermental observable used is referred to as "A_L" which is expressed mathematically as a ratio of sums and differences of various helicity combinations of singly polarized interactions between two protons, i.e. $p + p^{\Rightarrow} :\rightarrow W \rightarrow \mu + \nu$. Once A_L has been experimentally measured, it can then be used to determine appropriate polarizations of proton sea-quarks, within a given uncertainty, if we write the cross-sections used in the calculation of A_L in terms of polarized parton distribution functions. Finally, this thesis will also include a discussion of my work experimentally determining the absolute luminosity of collisions at RHIC, which is needed as a normalization on any cross section used in the analysis. In particular, studying the cross section of the W interaction can help to validate our models for assigning a signal-to-background ratio to the $W \rightarrow \mu$ events.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 A Brief History of the Proton

The angular momentum of the proton has been a subject of study for the last 20 years**[CITATION NEEDED]**. One of the challenges of particle physics is to create a framework which can accurately describe matter, as well as predict the behavior of matter at all energy scales. The proton is a baryon which makes up the majority of the mass in the visible universe, yet fully understanding the origins of its properties - such as its mass and spin, still eludes us. However, through the applicaiton of the scientific method over many generations of physicists, we have magnificently described this important particle, and understood much of its properties. However, one property which still defies our descriptions is its fundamental angular momentum, spin.

Our understanding of the proton has evolved and sharpened since the first experiments in deep inelastic scattering showed that the proton is not a fundamental particle [4]. Gell-Mann later planted the seeds of a theoretical framework which could in part describe some of the structure of baryons, a class of hadrons which we may naively describe as composed of three 'valence quarks'**[CITATION NEEDED]**. We can apply well known spin-sum rules to the indivdual spins of the valence quarks which compose the proton in our naive valence-model to produce a correct prediction for the protons' spin $\frac{1}{2}$. When experimenters set out to measure the contribution of these valence quarks in 1988 at the EMC experiment [3], they were flabbergasted to find that the valence quarks carry only a small fraction of the proton's spin. Although recent papers [9] suggest that this 'spin crisis' is simple due to misattribution of spin, most literature to date has focused on understanding how to model the proton with parton distribution functions. These parton distribution functions come in many varieties, and probe different degrees of freedom within the proton, in both the case of unpolarized partion distribution funcitons, and polarized parton distribution functions.

1.2 Scope and Objectives of This Work

This thesis will describe the research I carried out between May of 2010 through August of 2016. I will

Chapter 2

Physics Background

2.1 How to Model Proton Spin

2.2 How to Measure Proton Spin

2.2.1 A Brief Description of Fixed Target Experiments

2.2.2 A Brief Description of Collider Experiments

2.3 How to Measure Beam Luminosity in Collider Experiments

Chapter 3

Experimental Apparatus

3.1 The Relativistic Heavy Ion Collider

3.1.1 Overview

3.1.2 Production of Polarized Proton Beams

3.2 The Pioneering High Energy Nuclear Interaction Experiment

3.2.1 Data Collection

3.2.2 The DAQ

3.2.3 Physics Triggers

Trigger 1

Trigger 2

Trigger 3

Trigger 4

3.2.4 Muon Trigger Upgrade

Chapter 4

Data Collection

4.1 Overview

4.2 Feature Engineering

4.2.1 Discriminating Kinematic Variables

4.2.2 Simulations

Chapter 5

Spin Analysis

5.1 Classification of Signal or Background Events

5.1.1 Naive Bayes Classification

5.1.2 Composition of Probability Distribution Functions

5.1.3 Labeling Data With Likliehood Ratio: W_{ness}

5.2 Extended Unbinned Maximum Likelihood Fits

5.2.1 Modeling The Hadronic Background

5.2.2 Modeling the Muon Background

5.2.3 Modeling the W-Signal

5.2.4 Overview

5.2.5 Fit Performance

5.2.6 S/BG and Muon Backgrounds

5.2.7 W_{ness} Dependence of S/BG

5.3 Data Validation

Mention Daniel's GPR, Ralf's PEPSI, Abraham's FVTX work, and Francesca's cross-checks.

5.3.1 Simulations and The Signal to Background Ratio

5.3.2 Gaussian Process Regression

5.3.3 Four Way Cross Validation

5.3.4 Asymmetry Consistency Check

5.3.5 Beam Polarization

5.3.6 Beam Luminosity

5.3.7 Code Cross Validation

5.4 Calculation of A_L for $W \to \mu$

5.4.1 Overview

5.4.2 Asymmetry Calculation

5.4.3 Discussion of Work Done By Analysis Team

Chapter 6

The Vernier Analysis

6.1 Overview

6.2 Analysis Note Here

6.3 W Cross Section

Chapter 7

Discussion and Conclusion

Bibliography

[1] Bazilevsky A., Bennett R., Deshpande A., and Goto Y. Absolute luminosity determination using the vernier scan technique: Run5-6 analysis and preliminary results at $\sqrt{s} = 62.4gev$. *PHENIX Analysis Note AN688*, 2008.

[2] Bazilevsky A., Bennett R., Deshpande A., Goto Y., Kawall D., and Seele J. Absolute luminosity determination using the vernier scan technique: Run4-6 analysis and preliminary results at $\sqrt{s} = 62.4gev$. *PHENIX Analysis Note AN597*, 2007.

[3] J. Ashman, B. Badelek, G. Baum, J. Beaufays, C. P. Bee, C. Benchouk, I. G. Bird, S. C. Brown, M. C. Caputo, H. W. K. Cheung, J. Chima, J. Ciborowski, R. W. Clifft, G. Coignet, F. Combley, G. Court, G. D'Agostini, J. Drees, M. Düren, N. Dyce, A. W. Edwards, M. Edwards, T. Ernst, M. I. Ferrero, D. Francis, E. Gabathuler, J. Gajewski, R. Gamet, V. Gibson, J. Gillies, P. Graftström, K. Hamacher, D. Von Harrach, P. Hayman, J. R. Holt, V. W. Hughes, A. Jacholkowska, T. Jones, E. M. Kabuss, B. Korzen, U. Krüner, S. Kullander, U. Landgraf, D. Lanske, F. Lettenström, T. Lindqvist, J. Loken, M. Matthews, Y. Mizuno, K. Mönig, F. Montanet, J. Nassalski, T. Niinikoski, P. R. Norton, G. Oakham, R. F. Oppenheim, A. M. Osborne, V. Papavassiliou, N. Pavel, C. Peroni, H. Peschel, R. Piegaia, B. Pietrzyk, U. Pietrzyk, B. Povh, P. Renton, J. M. Rieubland, A. Rijllart, K. Rith, E. Rondio, L. Ropelewski, D. Salmon, A. Sandacz, T. Schröder, K. P. Schüler, K. Schultze, T.-A. Shibata, T. Sloan, A. Staiano, H. Stier, J. Stock, G. N. Taylor, J. C. Thompson, T. Walcher, S. Wheeler, W. S. C. Williams, S. J. Wimpenny, R. Windmolders, W. J. Womersley, K. Ziemons, and European Muon Collaboration. A measurement of the spin asymmetry and determination of the structure function g_1 in deep inelastic muon-proton scattering. *Physics Letters B*, 206:364–370, May 1988.

[4] E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, G. Miller, L. W. Mo, R. E. Taylor, M. Breidenbach, J. I. Friedman, G. C. Hartmann, and H. W. Kendall. High-energy inelastic $e-p$ scattering. *Phys. Rev. Lett.*, 23:930–934, Oct 1969.

[5] A. Datta and D. Kawall. σ_{BBC} using vernier scans for 500 gev pp data in run09. *PHENIX Analysis Note AN888*, 2010.

[6] A. Drees. Analysis of vernier scans during rhic run-13 (pp at $255gev/beam$). *Collider Accelerator Department (RHIC) AP???*, 2013.

[7] Werner Herr and Bruno Muratori. Concept of luminosity. 2006.

[8] D. Kawall. How to measure absolute luminosity. *PHENIX Focus Seminar*, 2005.

[9] Bogdan Povh and Thomas Walcher. The end of the nucleon-spin crisis. 2016.

[10] Belikov S., Bunce G., Chiu M., Fox B., Goto Y., Kawabata T., Saito N., and Tannenbaum M. Determination of the absolute luminosity for the proton-proton data at $\sqrt{s} = 200gev$ recoreded by phenix during rhic run-02. *PHENIX Analysis Note AN184*, 2002.

[11] R Seidl, H Oide, R Hollis, M Sarsour, J Seele, M Leitgab, Y Imazu, and I Choi. Run 11 w analysis note. *PHENIX Analysis note: AN1024*, 99:403–422, 1992.