SLAC-R-726

A Precise Measurement of the Proton Elastic Form Factors for $1.75 \leq Q^2 \leq 8.83$ (GeV/c)^2

Lisa Clogher

Stanford Linear Accelerator Center
Stanford University
Stanford, CA 94309

SLAC-Report-726

Prepared for the Department of Energy
under contract number DE-AC03-76SF00515

Printed in the United States of America. Available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

*Ph.D. thesis, The American University, Washington, DC 20016

Order Number 9505489

A precise measurement of the proton elastic form factors for $1.75 \leq Q^2 \leq 8.83$ $(GeV/c)^2$

Clogher, Lisa, Ph.D.

The American University, 1993

U·M·I

300 N. Zeeb Rd.
Ann Arbor, MI 48106

A PRECISE MEASUREMENT OF THE PROTON ELASTIC FORM FACTORS FOR $1.75 \leq Q^2 \leq 8.83$ $(GeV/c)^2$

by

Lisa Clogher

submitted to the

Faculty of the College of Arts and Sciences

of The American University

in Partial Fulfillment of

the Requirements for the Degree

of

Doctor of Philosophy

in

Physics

Signatures of the Committee:

Chair: Peter Bosted

Ben M. Szalata

Stephen Rock

Raymond G. Arnold

Betty Hennett

Dean of the College

8-20-93

Date

1993
The American University
Washington D.C. 20016

7513

THE AMERICAN UNIVERSITY LIBRARY

To my grandfather, Eaton James Clogher, who told me time and time again:
"The important thing is to learn *how* to think, not *what* to think".

A PRECISE MEASUREMENT OF THE PROTON ELASTIC FORM FACTORS FOR $1.75 \leq Q^2 \leq 8.83$ (GeV/c)^2.

BY

Lisa Clogher

ABSTRACT

The proton elastic electric and magnetic form factors, $G_{Ep}(Q^2)$ and $G_{Mp}(Q^2)$, have been separated out to Q^2 of 8.83 (GeV/c)^2, more than doubling the Q^2 range of previous data. The results for $G_{Mp}(Q^2)/\mu_p G_D(Q^2)$ decrease smoothly from 1.05 to 0.92, while $G_{Ep}(Q^2)/G_D(Q^2)$ is consistent with unity. Comparisons are made to QCD Sum Rule, diquark, constituent quark, and VMD models, none of which agree with all of the new data. The ratio Q^2F_2/F_1 approaches a constant value for $Q^2 > 3$ (GeV/c)^2.

ACKNOWLEDGMENTS

Experiment NE11 was the collective effort of twenty-seven physicists from thirteen institutions. I wish to extend my appreciation for the hard work and commitment each member gave to the experiment, and for the spirit they brought with them to the group. Three members to whom particular thanks should be given for their untiring efforts and tremendous contributions during both the data-taking and analysis stages of the experiment are, Dr. Peter Bosted, spokesperson for the experiment, and then students, now doctors, Allison Lung and Linda Stuart.

In addition to the physicists, this experiment could not have gotten off the ground, much less been a success, without the skill and dedication of the many SLAC technicians and support staff. I would like to personally thank Gerry Davis, Bob Eisele, Carl Hudspeth, and Bill O'Hanlon for their efforts, and for the opportunity I had to work with them and dabble in the arts of their trades.

There are several people whose help and influence I have greatly benefitted from. To Ray Arnold, I owe a particular gratitude for first introducing me to the physics going on at SLAC, and then encouraging me to join the group and supporting me during my stay at SLAC. Frank Dietrich, with whom I can say it was a pleasure to work, deserves a standing ovation for his guidance and patience during the many, long months of the floating wire calibration and ensuing analysis. His tidbits of wisdom and his scientific dogma will remain with me for quite some time. Special thanks goes to Larry Whitlow who made my early years out at SLAC quite an

enlightening experience. I am grateful for his help and continual encouragement over the years. Lastly, I wish to thank Bruce Flanders for his help in the final stage of this thesis.

To those who traveled this path before me, and whose insightful conversations and friendship helped make my road less burdensome, I thank Marc Frodyma, Javier Gomez, Mina Katramatou and Makis Petratos. And yes, I do agree with Javier: A thesis is something one does only once.

And to those who have traveled this path with me, by virtue of their unfailing support, love and understanding, I thank Rosemari and Paul Clogher, my parents; Sue Williams and Paula Clogher, my sisters; Michael Clogher, my brother; and Dimitri Andivahis, my husband. In many respects this thesis is as much a product of their efforts as it is of mine.

TABLE OF CONTENTS

ABSTRACT ii

ACKNOWLEDGMENTS iii

LIST OF TABLES ix

LIST OF ILLUSTRATIONS x

1. INTRODUCTION 1

Elastic Electron-Proton Scattering 3
Interpretation of the Form Factors 6
Form Factor Measurement 8
Experiment NE11 10

2. EXPERIMENTAL APPARATUS AND DATA SAMPLE 13

Overview 13
The Electron Beam 16
A-Line Beam Transport 16
Toroidal Charge Monitors 19
Toroid Calibration Runs 21
Targets 21
Spectrometers and Detectors 25
The 8 GeV Spectrometer 25
Optics 27
Detector Hut 29
Čerenkov Counter 29
Lead Glass Shower Counter 32
Multiwire Proportional Chambers 35
Hodoscope and Scintillators 37
The 1.6 GeV Spectrometer 37

Optics 39
Detector Hut 40
Čerenkov Counter 40
Lead Glass Shower Counter 43
Drift Chambers 43
Scintillators 44
Electronics 45
8 GeV Electronics 45
Trigger 47
Coincidence Circuits 48
1.6 GeV Electronics 49
Trigger 49
Data Acquisition and Storage 50
Hydrogen Data Set 52

3. DATA ANALYSIS 54

Bad Data Elimination 54
Event Analysis: Electron and Pion Classification 56
Particle Identification 56
The Lead Glass Shower Counters 56
The Čerenkov Counters 62
Particle Tracking 64
8 GeV Tracking Procedure 64
Track Reconstruction 68
Spectrometer Coordinate Systems 69
Particle Definitions and Histogramming 71
Obtaining the Differential Cross Section 76
Run-by-Run Corrections to the Cross Section 79
Efficiency Corrections 79
Dead–Time Corrections 83
Target Density Fluctuations 86
Incident Charge Determination 89
Corrections to E, E'_o, and Θ 91

Ionization Losses 96
Kinematic Point Corrections to the Cross Section 97
Pion Subtraction 98
Aluminum End-Cap Subtraction 99
The Acceptance Functions 100
Conversion From P, Θ to W^2 105
Integrating the Elastic Peak 108
Radiative Corrections 110
Resolution Correction 117
Conversion to Nominal Kinematics 118

4. RESULTS AND COMPARISONS WITH THEORY 120

Reduced Cross Sections 120
The 1.6 GeV Normalization 120
Systematic Errors 123
Point–to–Point Errors 123
Overall Normalization Error 124
Extracting the Form Factors 124
Errors on the Form Factors 126
Elastic Form Factor Results 126
Form Factor Scaling and the Dipole Form 127
Comparison with Theory 129
Vector Meson Dominance Models 133
Höhler *et al.* 134
Iachello, Jackson, and Lande 136
Dimensional Scaling 137
Hybrid Models 139
QCD Sum Rules 141
Constituent Quark Model 143
Diquark Model 145
Conclusions 149

APPENDIX A. ELASTIC PEAK CALIBRATION 151

Deradiating the Elastic Peaks 152
Deviations in Kinematic Variables 157
A Check for Super-elastic Events 160
APPENDIX B. THE 8 GeV MONTE-CARLO 162
The Monte Carlo Code 162
Correction Factors 166
The Total 8 GeV Acceptance Function 167
Comparisons with Data 168
APPENDIX C. TABLES OF RESULTS 173
REFERENCES 177

LIST OF TABLES

1. Target Cell and Scattering Chamber Dimensions 24
2. Hydrogen Elastic Kinematic Points 51
3. Special Kinematic Points 53
4. Čerenkov and Lead Glass Performance 61
5. 8 GeV Reconstruction Coefficients 70
6. 1.6 GeV Reconstruction Coefficients 72
7. Reconstructed Variables 73
8. Electron Definitions 75
9. $(\Delta P, \Delta\Theta)$ Histograms 77
10. Electron Efficiencies 80
11. Choice of ΔP and $\Delta\Theta$ Cuts 108
12. Radiative Correction Factors 113
13. Variation of Radiative Correction Parameters 117
14. Summary of Errors 125
15. TRANSPORT Model for Monte Carlo 164
16. Measured Cross Sections 174
17. Sachs Form Factors 175
18. Pauli and Dirac Form Factors 176

LIST OF ILLUSTRATIONS

1. Feynman Diagram for Elastic Electron Proton Scattering 4
2. The Dipole Form 9
3. Previous Form Factor Data 11
4. Top view of ESA Spectrometers and Target 14
5. The A-Line Beam Transport System 17
6. Toroid Electronics 20
7. The Target Assembly 23
8. Side view of the 8 GeV Spectrometer 26
9. The 8 GeV Horizontal Plane Optics 28
10. The 8 GeV Vertical Plane Optics 29
11. The 8 GeV Detector Hut 32
12. The 8 GeV Shower Counter 34
13. Schematic of 8 GeV Wire Chambers 36
14. Side view of the 1.6 GeV Spectrometer 38
15. The 1.6 GeV Horizontal Plane Optics 40
16. The 1.6 GeV Vertical Plane Optics 41
17. The 1.6 GeV Detector Hut 42
18. 8 GeV Trigger Electronics 46
19. 1.6 GeV Trigger Electronics 50
20. Normalized Shower Energy Electron Spectra 59
21. Normalized Shower Energy Pion Spectra 60
22. 8 GeV Čerenkov Spectra 63
23. Dead-Time Corrections 85
24. Target Density Fluctuations 88
25. Ratio of Corrected Toroid Values 92
26. Survey Comparison of 8 GeV Scattering Angle 94
27. The 8 GeV Acceptance Function 103

28. The 1.6 GeV Acceptance Function 105
29. The Raw Cross Section vs W^2 110
30. Radiative Correction Diagrams 112
31. The Q^2 Dependence of the 1.6 GeV Normalization 121
32. Reduced Cross Sections vs ϵ for $Q^2 = 1.00$ to 4.00 $(\mathrm{GeV/c})^2$ 122
33. Reduced Cross Sections vs ϵ for $Q^2 = 5.00$ to 8.83 $(\mathrm{GeV/c})^2$ 123
34. G_{E_p}/G_D 127
35. $G_{M_p}/\mu_p G_D$ 128
36. Form Factor Scaling – $G_{E_p}\mu_p/G_{M_p}$ 130
37. The Vector Meson Dominance Interaction 133
38. Dimensional Scaling – Q^2F_2/F_1 138
39. QCD Factorization Diagrams for Form Factors 142
40. Subprocess Diagrams for the Diquark Model 147
41. W^2 Peaks Before and After Deradiating 156
42. Shifts Needed to Center 8 GeV Peaks 158
43. Shift in $E'_{1.6}$ Needed to Center Peaks 159
44. Check for Super-Elastic Events 160
45. The 8 GeV Total Acceptance 169
46. Efficiency Function for the 8 GeV Acceptance 170
47. Checks for $\Delta\Theta$ and $\Delta\Phi$ Dependence 171
48. ΔP Overlap Spectra 172