Contents

List of Figures **xvii**

List of Tables **xxiii**

---

1 Introduction **1**

2 Theoretical Background **7**

2.1 Standard Model 7

2.2 Quantum Chromodynamics 10

2.2.1 Perturbative Quantum Chromodynamics 14

2.2.2 Renormalization and Running of the Strong Coupling 15

2.3 Hadronic Collisions 18

2.3.1 Parton Shower and Hadronization 21

2.3.2 Underlying Event 24

2.4 Jets 25

2.4.1 Jet Algorithms 26

3 Experimental Setup **31**

3.1 The Large Hadron Collider 32

3.1.1 Luminosity Measurement 35

3.1.2 Pileup Interactions 36
3.2 The Compact Muon Solenoid 38
3.2.1 Coordinate System 39
3.2.2 Inner Tracker System 41
3.2.3 Electromagnetic Calorimeter 44
3.2.4 Hadronic Calorimeter 46
3.2.5 Superconducting Magnet 49
3.2.6 Muon System 49
3.2.7 Trigger and Data Acquisition System 51
3.2.7.1 Jet Triggers 53
3.2.7.2 Data Acquisition System 54
3.2.8 Data Management 54
3.3 Software Tools 55
3.3.1 CMSSW Framework 56
3.3.2 ROOT 57
3.3.3 NLOJet++ and fastNLO 57

4 Event Generation, Simulation and Reconstruction 59

4.1 Event Generation and Simulation Software 59
4.1.1 pythia 61
4.1.2 MadGraph5 61
4.1.3 herwig 62
4.1.4 powheg 62
4.2 Detector Simulation 62
4.3 Event Reconstruction 64
4.3.1 Particle Flow Algorithm 64

4.3.2 Jet Energy Corrections 69

5 Measurement of the Differential Inclusive Multijet Cross-sections and their Ratio 73

5.1 Data Samples 74

5.1.1 Monte Carlo Samples 75

5.2 Event Selection 76

5.2.1 Trigger Selection 76

5.2.2 Primary Vertex Selection 78

5.2.3 Missing Transverse Energy 80

5.2.4 Jet Identification 81

5.2.4.1 Jet ID Efficiency 82

5.2.5 Jet Selection 85

5.3 Comparison with Simulation 86

5.3.1 Pileup Reweighting 86

5.3.2 Comparison of Cross-sections and their Ratio 86

5.4 Jet Energy Resolution 89

5.5 Unfolding 95

5.5.1 Response Matrices 96

5.5.1.1 Inclusive Cross-sections 97

5.5.1.2 Cross-section Ratio, R_{32} 100

5.5.2 Closure Test 100

5.5.3 Unfolding of the Measurement 102

5.6 Experimental Uncertainties 103

5.6.1 Statistical Uncertainty 105

5.6.2 Jet Energy Corrections Uncertainty 105

5.6.3 Unfolding Uncertainty . . . 108
5.6.4 Luminosity Measurement Uncertainty . . . 110
5.6.5 Residual Uncertainty . . . 110
5.6.6 Total Experimental Uncertainty . . . 110

6 Theoretical Calculations 113
6.1 Fixed Order NLO Calculations . . . 113
6.1.1 NLO Correction Factors . . . 115
6.1.2 Non-perturbative Corrections . . . 116
6.1.3 Electroweak Corrections . . . 118
6.2 Theoretical Uncertainties . . . 120
6.2.1 Scale Uncertainty . . . 120
6.2.2 PDF Uncertainty . . . 121
6.2.3 Non-perturbative Uncertainty . . . 122
6.2.4 Total Theoretical Uncertainty . . . 123
6.3 Comparison of Theory to Data . . . 124

7 Determination of the Strong Coupling Constant 129
7.1 Sensitivity of Measurements to $\alpha_s(M_Z)$ . . . 130
7.2 Determination of $\alpha_s(M_Z)$ . . . 131
7.2.1 Fitting Procedure . . . 131
7.2.2 Fit Results . . . 137
7.3 Running of the Strong Coupling Constant . . . 140

8 Summary 145

9 Hardware and Software Activities Undertaken 149

9.1 Silicon Photo-Multipliers 150
9.2 MicroTCA 154
9.3 Other Activities 159

Appendix A **161**

A.1 Cross-section Ratio, R_{32} 162
A.2 Individual Sources of Jet Energy Correction Uncertainties 163
A.3 Experimental Uncertainties 167
A.4 Theoretical Uncertainties 170
A.5 Definitions 173

Bibliography **175**

List of Publications **191**

Reprints **197**