DIFFERENTIAL JET PRODUCTION CROSS SECTION MEASUREMENT IN Z + JET EVENTS FROM PROTON - PROTON COLLISIONS AT $\sqrt{S}$ = 13 TEV USING THE CMS DETECTOR AT LHC

by

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Table of Contents

List of Tables

List of Figures

Abstract

In The standard model of particle physics, while describing our universe well on many scales, has yet to be precisely measured in all energy regimes. Recent theoretical advances in higher order QCD calculations have provided a way to compare the standard model's predictions to precision measurements of data and monte carlo simulation. Within this dissertation, I present a measurement of the double differential jet production cross section as a function of the jet mass and transverse momentum, in events with a Z + Jet topology, with and without a jet grooming algorithm applied. Studying Z + jet events will yeild a light quark enriched jet sample, which has not yet been studied at $\sqrt{s} = 13$ TeV.

Furthermore, comparing groomed and ungroomed jets will allow us the better understand the jet mass in all energy regimes since the groomed jets will have varying amounts of soft and collinear radiation with respect to the ungroomed counterpart.For ungroomed jets, leading-order and next-to-leading order QCD Monte Carlo programs are found to predect the jet mass spectrum in the data reasonably well, with some disagreement at very low and very high masses. For groomed jets, the agreement between the Monte Carlo programs and the data improves overall, and extends lower in jet mass due to the removal of soft and colinear portions of the jet.First-principles theoretical calculations of the groomed jet mass are also compared to the data, and agree with the data

within the range of acceptability of the calculations.

Ultimately these measurements will be used to tune Monte Carlo generators, producing more accurate parton showering simulations, leading to tighter constraint of backgrounds in future searchs for new physics.

Chapter 1

Introduction

1.1 Motivation

Within this dissertation, I provide a measurement of the differential jet cross section, as a function of the jet mass and transverse momentum, in events with a Z + Jet topology using data collected by CMS experiment at LHC.

1.2 The Standard Model

”Fortunately, nature is as generous with its problems as Nobel with his fortune. The more we know, the more aware we are of what we know not.”- David Gross

The Standard Model, SM, of particle physics constitues humanity’s latest attempt at describing our universe in a calculable way. The basic premise being, the entire universe is compised solely of; 6 types of quark and 6 types of lepton, which comprise matter, and the guage bosons, which mediate the 3 (this theory does not yet encompass gravitaion) fundamental forces; The strong and weak nuclear interactions and electromagnetism.

Various attempts have been made to unify the fundamental forces under one theory, thusfar the electromagnetic and weak interactions have been united by electro-weak theory.

The Standard electroweak model can be described $SU(2)xU(1)$ mathematically.

The $SU(2)xU(1)$ guage group is a convolution ($< -$That is not the right word...) of the special unitary symmetry group $SU(2)$ describing 3 mixed massive vector bosons, W_{-} W_{+} Z_0, carriers of the weak nuclear force and the unitary gauge group $U(1)$, describing the lonely massless chargeless photon, of the electromagnetic interaction.

The standard model of the strong interaction is known as quatum chromodynamics, QCD, described by the special unitary group $(SU(3)_f)$, where the flavours of quark are the physical manifestation of the symmetry group. This force is mediated by the 8 massless gluons which carry color charge, making QCD more complicated mathematically than QED.

The SM also contains a Higgs boson, an excitation of a scalar Higg's field, which gives rise to spantaneous symmetry breaking of the electroweak theory, providing the particles with mass, but I won't get into that.

The quarks and leptons are arranged in generations according to their relative masses, as shown in Figure 1.1. The table also shows the spins of the particles, the leptons and quarks have half-integer spin, fermions, that obey the fermi exclusion principle, conversely the bosons have half integer spin and therefore obey bose-einstein statitics. Through the SM we interpret the observed hadronic particles, mesons (baryons) , as 2 quark (3 quark) bound states. The existence of spin $\frac{3}{2}$ baryons, which are symmetric bound states in space, spin and flavour and the need to obey Fermi-Dirac statistics, by maintaining total assymmetry of the wavefunction,implies there is another degree of freedom, called color, so that each quark is either red, green or blue. Granted only color singlet, containing either all 3 or 1 and it's anti color, states exist. Furthermore there exists a property of asymptotic freedom where the QCD coupling between quarks and gluons increases as they asymptotically approach one another. There exists a wealth of experiemental data to support the concept of asymptotic freedom despite the fact that rigorous mathematical proof of the exlusion of free quark and gluon states has yet to be acheived.

Assymptotic freedom is a useful property as it allows for perturbative calculations of QCD observables, this is discussed in section XXX.

Nuclei in ordinary matter are composed solely of 1^{st} generation particles, up and down quarks, bound by gluons. Neutral atoms contain an equal number of protons (composed of 2 up quarks and a down quark) and electrons, 1^{st} generation leptons. The main distinction between leptons and quarks, both fermions (particles of $\frac{1}{2}$ integer spin), being that leptons do not experience the color interaction $(SU(3)_f)$ like their quark friends. In each generation there is a quark with charge $Q = +\frac{2}{3}$ (up, charm, top) and another of charge $Q = -\frac{1}{3}$ (down, strange, bottom).

1.2.1 Quantum Chromodynamics

For the purpose of this thesis, in order to emphasize the relevance to jet substructure measurements, I will discuss the theory of Quantum Chromodynamics from a kinematic (¡- better word?) rather than Lagrangian perspective. This is useful as the jet studies presented here help probe QCD in the soft and collinear limits. Jets are formed by the hadronization of quarks and gluons. In this thesis

I present a measurement of a light quark enriched jet samples. Consider the simplest process that could produce a quark initiated jet, a quark of energy E_q emitting a gluon of energy E_g. The probability that this will occur is a function of the gluon's energy fraction, z, and the emission angle , θ.

$z = \frac{E_g}{E_q+E_g}$

$1 - cos\theta = \frac{m^2}{2E_qE_g}$

Then the probability of gluon emission from the quark is :

$P_q(z, cos\theta)dzdcos\theta = \frac{\alpha_s C_F}{\pi}\frac{dz}{z}\frac{dcos\theta}{1-cos\theta}$

It is useful to assume the small angle approximation, $\theta << 1$, giving:

$P_q(z, \theta^2)dzd\theta^2 = \frac{\alpha_s C_F}{\pi}\frac{dz}{z}\frac{d\theta^2}{\theta^2}$

Notice that the probability of emission diverges for very soft (small z) or very collinear (small θ) gluons.

It is elucidating to rewite the probability in terms of inverse logarithms in the and intruduce the "Lund Diagram" in order to visualize the uniform distribution of soft and collinear gluons in the $log\frac{1}{\theta^2}, log\frac{1}{z}$ space.

$P_q(z, \theta^2)dzd\theta^2 = \frac{\alpha_s C_F}{\pi}d(log\frac{1}{z})d(log\frac{1}{\theta^2})$

Jets can also be initiated by gluons and this probability is incredibly similar :

$P_q(z, \theta^2)dzd\theta^2 = \frac{\alpha_s C_A}{\pi}d(log\frac{1}{z})d(log\frac{1}{\theta^2})$

This similarity allows us to interpret the variations in quark enriched and gluon enriched jet samples in terms of the C_F and C_A, in $SU(3)$, $C_F = \frac{4}{3}$ and $C_A = 3$.

1.3 Theoretical Calculations

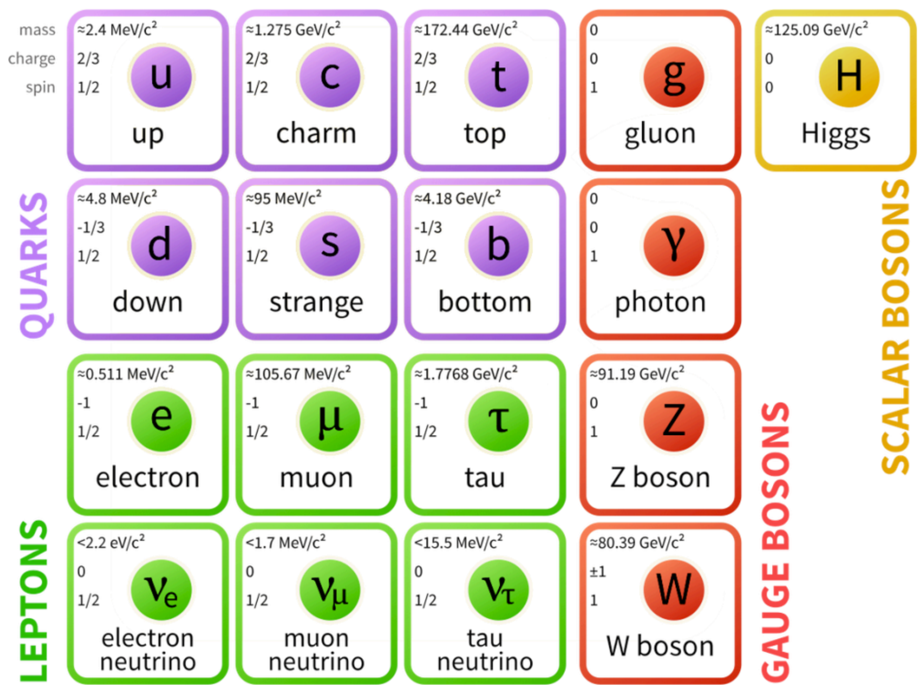

Figure 1.1: Fundamental particles of the Standard Model [1].

Chapter 2

CMS Experiment at LHC

2.1 The Large Hadron Collider

The Large Hadron Collider, LHC, is the largest machine created my mankind.

2.2 The Compact Muon Solenoid

The Compact Muon Solenoid, CMS, is one of 4 detectors that measure collisions of protons and lead ions produced by the Large Hadron Collider, LHC, at CERN. CMS is the smaller of the 2 large general-purpose detectors, the other being ATLAS. The most notable feature of the detector is it's powerful 3.8 Tesla solenoid magnet, the largest superconducting magnet ever built, as of the year 2011.

Chapter 3

Measurement of the differential jet production cross section with respect to jet mass and transverse momentum in Z + Jet events from pp collisions at $\sqrt{s} = 13$ TeV

Chapter 4

Identification and Calibration of Boosted Hadronic W Bosons within Fully Merged Top Quark Jets at 13 TeV

Chapter 5

Conclusion

5.1 Conclusion

The measurement matches the theoretical calculations well, i hope.

The End.

Bibliography

[1] modellinginvisible.org standard model description. `https://www.modellinginvisible.org/standard-model/`. Accessed: 2019-08-06.