MEASUREMENT OF THE DOUBLE DIFFERENTIAL JET PRODUCTION CROSS SECTION WITH RESPECT TO JET MASS AND TRANSVERSE MOMENTUM 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, with and without a jet grooming algorithm applied, using data collected by CMS experiment at LHC. The jet grooming used was the "Soft Drop" procedure

Softdrop iteratively declusters a jet j with distance parameter R into two subjets, j_1 and j_2. If the softdrop condition

$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \cdot (\frac{\Delta R_{12}}{R})^{\beta} \tag{1.1}$$

is met, then the procedure stops and j is the final jet. Otherwise, the declustering continues - the higher pt subjet is relabeled as j and the lower pt one is dropped. By design, this condition fails for wide-angle soft radiation, which is therefore removed by the soft drop procedure. The tunable parameters, β and z_{cut}, control the degree of jet grooming: β tunes the algorithm's sensitivity to wide-angle radiation, while z_{cut} sets the energy scale of the grooming. In the case of $\beta \to \infty$, an ungroomed jet is returned. In the $\beta = 0$ case, the soft drop procedure is identical to the "modified mass drop tagger" (MMDT) from Ref. from jets in a very theoretically controlled manner, making it suitable to separate the "hard" and "soft" parts of the jet. Specifically, the soft drop algorithm can remove non-global logarithms from correlations of radiation within and between jets, which are extremely difficult to compute theoretically

Comparing the production cross section for groomed and ungroomed jets separately allows us to gain sensitivity to both the "hard" and "soft" jet physics. The groomed cross section can be directly compared to theoretical calculations of the jet mass now and in the future, which is a very active area of theoretical research at this time allows a deeper understanding of the various effects involved in QCD groomed jet mass at next-to-next-to-leading order using soft colinear effective theory, matched to a provided a next-to-leading logarithm calculation with traditional perturbative QCD, matched to a parton shower at leading order, also using tt MCFM. We compare these theoretical predictions to our data in this paper for the first time in this channel at CMS. Both CMS and ATLAS have similar measurements in a dijet sample at

The analysis strategy is similar to that of However, there are several differences. As in that paper, the cross section is also unfolded in both jet mass and pt, however we also provide the measurement in jet ρ, dimensionless mass , and pt. While the previous measurement considered only one value for the soft drop parameter β, this analysis considers several. We apply the soft drop algorithm to compare directly to theoretical computations. Additionally, we not only measure the cross section as a function of mass, but also as a function of dimensionless mass, $\rho = 2log(m/(ptR))$, as is also done in the previously mentioned ATLAS measurement. The dimensionless mass ρ only weakly depends on pt, unlike mass, which is highly correlated. Additionally, the use of this variable aids in the separation of fixed order, perturbative and non-perturbative effects. Finally, we also present the normalized differential cross section. We compute the cross sections normalized per pt bin (the "normalized" cross section) with respect to the jet pt and jet mass by unfolding a binned two-dimensional distribution in pt and mass with widths Δpt and Δm, respectively.

The normalized differential cross section in two forms :

$$\frac{1}{d\sigma/dpt}\frac{d^2\sigma}{dpt\,dm} = \frac{1}{N/\Delta pt}R(\frac{N_{ij}}{\Delta pt\,\Delta m}) \tag{1.2}$$

as well as :

$$\frac{1}{d\sigma/dpt}\frac{d^2\sigma}{dpt\,d\rho} = \frac{1}{N/\Delta pt}R(\frac{N_{ij}}{\Delta pt\,\Delta \rho}) \tag{1.3}$$

where N is the total number of Z+jets events in our selection, N_{ij} is the number of such events in pt bin i and mass (ρ) bin j, and $R(\alpha)$ is the unfolding procedure applied to the two-dimensional distribution α.

The 2 above normalized distributions are provided within for ungroomed and groomed jets Anti-Kt Radious R= 0.8 jets. The groomed measurement is given in 9 configurations, one measurement is shown for jets groomed with every combination of 3 possible β and z_{cut} values (Where β = 0 and z_{cut} = 0 .1 is the current CMS default):

$\beta = [1, 0, -1]$

$z_{cut} = [0.15, 0.1, 0.05]$

These measurements currently represent humanity's highest energy measurement of a light quark enriched jet production cross section.

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 CMS Experiment

CMS stands for Compact Muon Solenoid, it 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 larger general purpose detectors, the other being ATLAS.

Chapter 3

Event Reconstruction

3.1 Particle Flow Algorithm

Particle Flow is an algorithm which combines information from various CMS subdetectors and allows for a determination of the particle type based on observed properties.

Chapter 4

Jet Clustering and Grooming

4.1 Jet Clustering Algorithms

Jet definitions IRC safe Anti-Kt, Cambridge-aachen...

4.2 Jet Grooming Algorithms

Jet grooming, soft drop explantion (PERHAOS MOVE DETAILS on soft drop FROM INTRO TO HERE)

Chapter 5

Conclusion

5.1 Conclusion

The measurement matches the theoretical calculations well, i hope.

The End.

Bibliography