A Search for Lepton Flavor Violating Decays of the Higgs Boson and a Measurement of W Boson Production using the CMS Detector at the LHC

by

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Abstract

Abstract Goes Here

Acknowledgements

This is where any acknowledgements would go.

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Event Simulation

Particle interactions at CMS are very difficult to model. The strong nuclear force plays a very large role in proton-antiproton collisions, but calculations involving QCD are notoriously difficult. At short distances on the order of a femtometer, we can define the momentum scale Q to be much greater than Λ_{QCD}. This means that the effects of QCD can be calculated perturbatively (pQCD), which means that high order terms can be neglected and accurate predictions can be made. However, at Λ_{QCD} there are enormous amounts of soft radiation whose effects would be overwhelming to calculate by hand.

Additionally, the interactions of the collision products with the the detector components are very complicated and are effectively impossible to model by hand. Accurate models of physical processes at CMS are vital for testing existing theories and searching for new ones, so the difficulty of modelling these processes presents a significant challenge for CMS and for particle physics in general.

4.1 Monte Carlo Event Generation

Physical processes at CMS are simulated using a class of software called Monte Carlo generators. These programs are named after the famous casino because Monte Carlo software leans heavily on random number generation to simulate the kinematic distribution and decay chains of the event products. When using Monte Carlo software to simulate collisions, the user must specify the center of mass energy, the initial colliding particles, and the desired final products. Additional parameters can be defined by the user, such as the hadronization scale discussed in section 4.1. The three main components of Monte Carlo simulation are matrix element computation, parton showering, and hadronization.

Matrix Elements

Once the initial and final state particles are specified, a series of Feynman diagrams are created. By using Feynman rules as discussed in chapter 1 and averaging over helicity and color, production amplitudes are computed for the process. However, this calculation provides only a very basic picture of the event and neglects soft radiation at the pQCD scale.

Parton Showering

As discussed in chapter 2, in high energy collisions protons can be modeled as collections of partons where the partons are pointlike particles carrying a particular fraction of the proton's momentum. Parton distribution functions, as discussed in chapter 2, provide a model of how the protons will interact in a collision.

After the collision, Sudakov Form Factors[6] are computed, which represent the probablity of a parton splitting into multiple partons. A low momentum bound for splitting is defined, and all partons above this threshold are randomly split in accordance with the probability of splitting. Color is properly accounted for at each vertex. Parton showers simulate QCD radiation emitted by quarks in the form of gluons, or a gluon splitting into two quarks.

At this point it is necessary to reconcile the matrix element computation, which represents high energy hard scattering, with parton showers, which model soft radiation. Two methods are available. The matrix element and parton shower method (ME+PS) and the next to leading order and parton shower method (NLO+PS)[6]. In the ME+PS method, matrix elements are computed for the fundamental process with the addition of n partons. The additional partons are required to be separated by a specified transverse momentum threshold. The momentum threshold is chosen to be at the upper limit of pQCD. In this way, the event can be computed accurately at large angle via matrix element methods, and then parton showering algorithms can be applied to the additional partons in the event. The ME+PS method is good for simulating events with many hard jets that are well separated. These kind of jets are simulated much better with tree level computations rather than lower energy pQCD parton showering. The next to leading order and parton shower method (NLO+PS) extends to parton shower method to next to leading order to QCD.

Hadronization

After parton showering, the event consists of the hard final products and many soft partons. At this point, the partons must transform into color singlet final state hadrons. One way to the this is the Lund string model. In this model, quark and anti-quark pairs are connected by color "strings" with a potential $V(r) = \kappa r$ As the quarks and anti-quarks move apart, the string breaks and an additional quark anti-quark pair or a gluon is created. The p_T of the quark or anti-quark is $< p_T^2 >= \kappa/\pi$ and the Lund fragmentation function[6] defines the fraction of the longitudinal momentum of the endpoint particle that is imparted to its recently produced neighbor. In this fashion, the kinematic variables of the produced hadrons are known, and the shower continues until an energy scale cutoff is reached. This process is depicted in figure 4.1

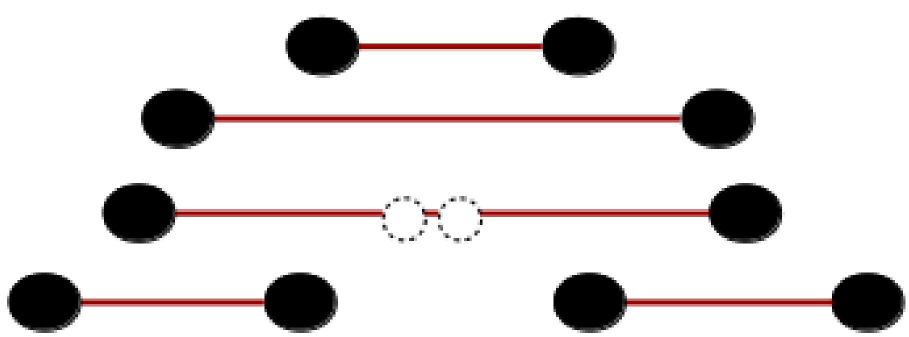

Figure 4.1: An illustration of the Lund string model. As the quark/anti-quark pair move further apart, the increase in potential energy creates an additional quark/anti-quark pair.

Monte Carlo Generator Software

A variety of different Monte Carlo generators are used at CMS. MADGRAPH [3] is used to compute leading order matrix elements. Its output is piped into PYTHIA[7], which models parton showers and hadronization using the Lund String Model. The combination of MADGRAPH and PYTHIA is an example of the ME+PS technique. Alternatively, NLO matrix elements can be computed with aMC@NLO[3] or POWHEG[1, 4, 5]. Parton showers and hadronization are once again simulated with pythia. This is an example of the NLO+PS technique.After hadronization, some heavy states may still need to decay. The τ lepton is too short lived to be directly observed in the detector, so any Monte Carlo simulation must decay the τ further. TAUOLA [8] is interfaced with

PYTHIA to provide an accurate view of τ decay by taking into account τ helicity and polarization.

4.2 Detector Simulation

After the simulation of the physical process, complete with parton showering and hadronization, it is necessary to model the interactions of the finale state particles with the CMS detector. This is done using GEANT4[2]. First, an accurate model of the CMS detector must be built in GEANT4, defining both the geometry and material components of the detector. The simulation is then carried out in two steps: tracking and detector response. The tracking step simulates the passage of particles through matter, modelling the energy lost based on the particles and the detector material. The next step is to model the detector response. This will simulate the signal that each event will create. Once the detector simulation is complete, we will have a very good idea of what a particular physical process at CMS will look like from the point of view of the detector. Now the challenge is the reconstruct the constituents of the event from the detector response, which is discussed in the next chapter.

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Event Reconstruction: Discuss how physics objects are reconstructed from detector deposits or lack thereof

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Analysis Methods: Summarize W+Jets and LFV Higgs ANs

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