RICE UNIVERSITY

Search for Stop Quark via All-Hadronic Decay Channels with Heavy Object Tagging

by

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ABSTRACT

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Chapter 1

Introduction

1.1 Motivation

Chapter 2

Supersymmetry and the Standard Model

The fundamental theory of particle physics, known as the Standard Model (SM) can predict precise interactions between the fundamental particles in our universe. With these predictions we are able to confirm processes, but there are some aspects of the universe that have not yet been explained. In this chapter, we will analyze the Standard model and the respective models that cannot be explained.

2.1 The Standard Model

After decades of theoretical and experimental research the SM has been developed into a theory that explains the Electromagnetic (EM), Strong, and Weak force. The SM has not yet been able to include Gravity into the theory. With the robust theoretical and experimental methods used in the SM, we have discovered new elementary particles and predicted others.

2.2 The Fundamental Particles

All the matter can be explained by three kinds of elementary particles: leptons, quarks, and gauge bosons. Each of these can be distinguished by various respective properties. The leptons and quarks are fermions which are particles that have half-integer spin. The leptons are particles that only interact with the EM force, while quarks interact with the EM and Strong force. The gauge bosons are the force carries for each respective force and have integer spin.

There are three generations of leptons and quarks which are differentiated by a charge $\pm e$, the charge of an electron. The leptons have three different charged particle: electron (e), muon (μ), and tau (τ). With each charged particle having a corresponding neutrino (ν) of the same flavour, see fig 2.1. The quarks are also separated into three generations of doublets, the down-type ($-\frac{1}{3}e$): down (d), strange (s), and bottom (b) and up-type ($\frac{2}{3}e$): up (u), charm (c), and top (t). Each of the quarks has a color associated with it with is analogous to an electric charge, except there are three colors charges.

2.3 Quantum Field Theory

Since many of the elementary particles in the standard model, we are mainly interested in the interactions of fermions. This is described by the Dirac equation,

$$(i\gamma^\mu \partial_\mu - m)\psi(x) = 0, \tag{2.1}$$

where γ^μ are matrices and are invariant under rotations of vector and spinor indices, ∂_μ is the partial derivative, m is the mass of the particle, and $\psi(x)$ is the wave function of the particle. The combination of $\gamma^\mu \partial_\mu$ is a Lorentz-invariant differential operator. From this we are able to write down the Lagrangian for the Dirac particle as,

Figure 2.1 : The fundamental particle

$$\mathcal{L}_{Dirac} = \overline{\psi}(i\gamma^{\mu}\partial_{\mu} - m)\psi, \tag{2.2}$$

where $\overline{\psi}$ is the Hermitian conjugate of the wavefunction. This lagrangian describes the interactions of a particle moving through spacetime.

Why does the universe have to have this symmetry? Universe hase the inverse square law for gravity and EM.

More symmetry allows for a simpler description of the values.

2.4 Fundamental Problems in the standard model

Hierarchy problem? Dark Matter? Grand Unified Theory?

Support material for each of these unknowns and how SUSY can solve them. Fine Tuning

2.5 Superpartners

Initial assumption that every fermion has a boson partner and vice versa. These partners are exactly the same but differ by half integer spin. Changes Higgs mass divergence from quadratic to logrithmic (renormalizable)

Must be broken such that the masses of these partners are larger.

2.5.1 Chirality

Equal numbers of fermions and bosons. How does the spin change?

2.6 Minimal Supersymetric Standard Model

Soft supersymetry breaking.

2.6.1 R Parity

New conserved parameter known as R parity. With this is allows for a stable particle that is a dark matter candidate. Other consequences.

2.7 Mass Spectrums

Higgs boson corrections. spectrum of squarks.

Chapter 3

Compact Muon Solenoid

3.1 Introduction

Located near Geneva, switzerland as part of the CERN collaboration. LHC provides proton beams

General CMS facts. What kind of particles is it meant to detect? What are the subdetectors? Tracker, ECAL, HCAL, superconducting solenoid, muon chambers

3.2 Silicon Tracker

3.2.1 Pixel Detector

What is it? Newly installed pixel detector. Larger particle flux and data rate. What is the design of the modules? How do they work? Increased efficiency for B tagging.

3.2.2 Silicon Strips

How is it different from the pixels?

3.3 Electromagnetic Calorimeter

What kinds of particles does this detect? Mechanism?

3.4 Hadronic Calorimeter

What kinds of particles does this detect? Mechanism?

3.5 Superconducting solenoid

Iron yoke? how strong? Purpose?

3.6 Muon Chambers

What kinds of particles does this detect? Mechanism?

Chapter 4

Stop quark Production and Backgrounds

Why the stop quark? Also Stop quark or top squark?

4.1 Production and Decay Modes

Gluon fusion.

Main decay mode mode $\tilde{t} \to t + \tilde{\chi}_1^0$, $\tilde{t} \to b + \tilde{\chi}^+$. The top quark most likely decays into a b quark and W boson.

4.2 Standard Model Background

Signal events can be mimicked by SM events that have a large number of jets and missing energy.

Broken up into four major backgrounds, Lost Lepton (LL), Znunu, QCD, Rare decays

4.2.1 Lost Lepton

$t\bar{t}$ production of ttbar via the same mechanism as stop-antistop which can be gluon fusion. They then decay the same why as explained above.

W+jets: Production of W bosons plus jets. Jets can be tagged as b jets. W boson decay hadronically or leptonically (where the lepton is missed)

tW and ttW: Missed lepton

Transfer Factors

We want to suppress signal contamination by requiring $M_T(l, \not{E}_T) < 100$ GeV. This requirement confirms that it is orthogonal to the search reagions that are used in the search for direct top squark production in the single-lepton final state. Letting the two anaysis statistically combine the results in the future.

We are looking at the event count of data in each corresponding CR for the single-lepton sample. The prediction is allowed by means of a transfer factor (TF) which is obtained from simulation,

$$N_{pred}^{LL} = TF_{LL} \cdot N_{data}(1l). \tag{4.1}$$

This allows us to have the same selection for the single-lepton control sample and the zero-lepton sample. The only exception is the number of top and W-tagged candidates? what is the difference betweeen a candidate and a particle?

The LL estimation is dependent on the yield of data in the corresponding CR and the TF calculated by the single-lepton sample. The transfer factor is defined as,

$$TF_{LL} = \frac{N_{MC}(0l)}{N_{MC}(1l)}, \tag{4.2}$$

where $N_{MC}(1l)$ is the event count observed in the corresponding CR and $N_{MC}(0l)$

use the event count in the corresponding SR.

4.2.2 Z Boson Decay to Neutrinos

Znunu: production of a Z boson that decays into two nuetrinos which are then missed by the detector. Can have jets from other quarks/gluons in the interaction

4.2.3 Quantum Chromodynamic Events

QCD: Events that of jets produced by QCD processes. The missing energy from from a mismeasurement of the jets in the event causing missing energy

4.2.4 Rare Interactions

ttZ, ttH, WW, WZ, ZZ, tZq, tWZ: rare processed that can have jets plus MET. Expand upon these later

Chapter 5

Search Region Design

Using MC simulations that model the SM background for this process we want to reduce the number of events in our Search region. This is an all hadronic search so we are looking at event with zero tagged leptons. Unfortunately, some can get in by not passing the kinematic cuts or just by the non 100 % of the detector. There is a small nonzero inefficiency of mistagging a lepton as something else.

5.1 Minimizing the ttZ background

For the ttZ interactions, we produce two top quarks that can then decay to two b quarks and two W bosons. A possible way to mimick our search region is two have multiple jets, i.e. b quarks that hadronize and W bosons that decay hadronically, but we also need missing energy. This will be in addition to the Z boson decaying into two neutrinos and thus creating a large amount of missing energy.

We now try to look at the differing kinematic structure of the background, ttZ, and the signal region, stop quarks decaying. Under the assumption that the Z boson is created by radiated from the top quark the resulting decay to neutrinos should be close, small $\Delta\phi$, between the resulting jets. For the signal, the missing energy is produced by the neutralino. When the stop quark decays into top quark and neutralino the top quark should recoil off of neutralino to essentially be back-to-back. This will cause a large angle, $\Delta\phi$, between them. We then want to use the kinematic variable, $\Delta\phi(t_{1,2}, \not{E}_T)$, where

5.2 Lost Lepton Application

Can we apply this to other backgrounds. For boosted tops the the missing energy caused by missing the lepton in the W boson decay. The variable $\Delta\phi(t_{1,2}, \not{E}_T)$should also apply. Should work for wjts, tW, ttW.

5.3 Search Regions

The HM and LM Search regions should be defined and explained. Why are they defined the way they are?

5.4 Search Region Optimization

Look for an optimized cust for $\Delta\phi(t_{1,2}, \not{E}_T)$to maximize $\frac{S}{\sqrt{B}}$ in each SR. Could have a different cut for each region, but a combination to make it all the same would be nice. Since the signal can decay in multiple ways we need to optimize for all possible scenarios. Explain why we are maximizing $\frac{S}{\sqrt{B}}$

5.5 Limits

Looking at the significance and limits for the mass regions of the stop quark decay. Using the Higgs Combined tool, which includes statistics with a "maximal likelihood" fit? The cut, $\Delta\phi(t_{1,2}, \not{E}_T)$, would hopefully improve the values, but an optimized cut has not been chosen yet.