Chapter 1

Introduction

The Standard Model (SM)

The SM predicts that all matter is composed of a combinations of particles called quarks or leptons and their anti-particles. The interactions between these particles are governed by the strong, weak and electromagnetic forces. There are total of 6 quarks and 6 anti-quarks in the SM that can interact via all three forces and there are 6 leptons and 6 anti-leptons however unlike quarks, no leptons can interact via the strong force.

The interactions of each force are described by the exchange of gauge bosons. The electromagnetic force is mediated by the photon, the weak force by the W and Z bosons and the strong force by 8 gluons.

This final particle in the SM is the Higgs boson. It is interactions with the field associated with this boson that are responsible for the intrinsic masses of the particles.

The SM can be used to predict how particles will interact and decay. These predictions have been tested in many different experiments over the past decades and so far no significant deviations from the predictions of the SM have been found.

Although the SM has been shown to be extremely successful there are a number of experimental observations that the SM does not explain. In its current form, the SM cannot explain the observed oscillation of neutrinos from one type into another

There exist many theories that go beyond to scope of the SM and seek to explain what the SM cannot. These theories predict the presence of new particles and phenomena that can collectively be called New Physics (NP). However at the moment there is no clear indication of which NP model gives the correct description of the universe and the search for NP effects is ongoing.

The Large Hadron Collider is the latest machine built to study of the predictions SM and to search for NP effects in high energy particle collisions. Two different approaches are used to There are two approaches used search for NP effects at the LHC; direct searches and indirect searches.

Direct searches involve looking for the direct production of on-shell NP particles and phenomena in the data collected from high energy collisions. This type of search is limited by the centre-of-mass energy of the collisions that dictates the energy available for the creation of new particles. The Higgs boson was found in 2012 by the ALTAS and CMS collaborations using this type of search

Indirect searches aim to precisely measure SM processes and look for deviations in the measured values from the predicted values. Deviations can be caused by the presence of NP effects that modify the SM process. Indirect searches are not as limited by the centre-of-mass energy of the collisions as direct searches because NP or SM particles influencing these processes are off-shell and therefore lower energy is needed to produce them. In a similar way to direct searches, indirect searches that do not reveal NP effects constraints the parameters space of the theoretical models. Although indirect searches are yet to reveal any significant deviations from SM predictions some interesting anomalies has been seen in the measured results of rare B-meson decays by the LHCb, BarBar and Belle experiments. In $b \to sll$ transitions deviations from the SM predictions have been seen in measurements of the angular distribution of $B^0 \to K^{*0}\mu^+\mu^-$ decays, the branching fraction of $B^0_s \to \phi\mu^+\mu^-$ decays and the ratios $R(K) = \frac{B^+ \to K^+\mu^+\mu^-}{B^+ \to K^+ e+e^-}$ and $R(K^*) = \frac{B^0 \to K^{0*}\mu^+\mu^-}{B^0 \to K^{0*} e+e^-}$. Also measurements of the ratios $R(D)$ and $R(D^*)$ for the branching fractions of $B^0 \to D^{(*)}\tau^-\nu_\tau$ and $B^0 \to D^{(*)}\mu^-\nu_\mu$ are differ from the expected SM values. The individual measurements of these processes are all within 3 standard deviations of the predicted values of the SM however combining the results increases the difference to ~ 4 standard deviations for $b \to sll$ transitions, $R(D)$ and $R(D^*)$. Although these deviations are far from conclusive evidence of NP effects, it will be very interesting to see if and how these measurements change in the future.

Particle decays and interactions that are highly suppressed in the SM offer excellent places for indirect searches for NP effects. The possible contributions from NP models can be at a similar order of magnitude to the SM contributions in these decays. The rare decays of B^0 and B^0_s mesons into two oppositely charged muons have long been interesting processes through which to test the SM. The purely leptonic final states produces precise theoretical predictions and the 2 muons lave a clearly identifiable signature in particle detectors. The search for $B^0 \to \mu^+\mu^-$ and $B^0_s \to \mu^+\mu^-$ decays began over 30 years ago and over that time the experimental sensitivity to these decays has dramatically increased as illustrated in Figure **??**. The latest experiments to join the search were ATLAS, CMS and the LHCb experiments

The data collected during Run 2 of the LHC, where the centre-of-mass energy of pp collisions is increased to 13 TeV, will enable more precise measurements of the branching fractions of these decays to be made. Furthermore the observation of $B_s^0 \to \mu^+\mu^-$ decays opens the way for other properties of this decay to be studied. In particular the effective lifetime of $B_s^0 \to \mu^+\mu^-$ decays provides a complementary search for NP effects to the branching fraction measurement, the presence of new physics effects could be revealed in either both or only one of these measurements. The search for $B_s^0 \to \mu^+\mu^-$ decays is over and the study of this decay has begun.

This dissertation documents the latest study of $B_{(s)}^0 \to \mu^+\mu^-$ decays at the LHCb experiment. The measurements of the $B_{(s)}^0 \to \mu^+\mu^-$ branching fraction and the $B_s^0 \to \mu^+\mu^-$ effective lifetime are presented using data collected during pp collisions with centre-of-mass energies of 7, 8 and 13 TeV. The theoretical motivation for studying these decays is given in Chapter 2 and the LHC and LHCb experiment are described in Chapter **??**. The criteria used to identify these decays in the data collected by the LHCb experiment are detailed in Chapter 3 and the measurement of the branching fraction is briefly covered in Chapter 4. The measurement of the effective lifetime is discussed in Chapter 5 and the systematic uncertainties on this measurement are given in Chapter 6. Finally a summary of the results and prospects for future measurements of $B_{(s)}^0 \to \mu^+\mu^-$ decays are given in Chapter 7.

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