Title: 'Measurements of $B \to \mu^+\mu^-$ decays using the LHCb experiment'

Introduction

- Including current experimental status, summary of the CMS-LHCb combination and the ATLAS results for the branching fractions. The observation of $B_S{}^0 \to \mu^+\mu^-$ enables other variables such as the effective lifetime to be measured.

Theory of $B_S{}^0 \to \mu^+\mu^-$ decays; the Standard Model and Beyond

- The Standard Model
    - brief introduction to the SM
    - limitations of the SM/why we are studying it
    - the use of rare decays as indirect searches for new physics phenomena
- $B(s)^0 \to \mu^+\mu^-$ decays - how these occurring with in the SM
- the $B(s)^0 \to \mu^+\mu^-$ branching fractions - the effective hamiltonian, what it is in the SM and how new physics theories can enter it
- Effective lifetime of $B_S{}^0 \to \mu^+\mu^-$ - definition of the effective lifetime and its SM value, the dependance on A_deltaGamma and the precision needed to see new physics through the effective lifetime
- New physics and $B(s)^0 \to \mu^+\mu^-$ - the branching fraction and the effective lifetime of $B_S{}^0 \to \mu^+\mu^-$ offer complementary proves for new physics

The LHC and LHCb Experiment

The LHC

- Brief overview of the LHC including;
    - how protons start as hydrogen gas and pass through a chain of accelerators into the LHC
    - the luminosity and centre of mass energy of the LHC and how it can achieve the designed values
    - running of the LHC so far (Run 1, LS1 and Run 2)
    - summary of experiment on the LHC

LHCb

- Introduction to LHCb, its physics goals and general structure
- Tracking systems;
    - the VELO - how it works and the resolution it achieves
    - the Tracking stations - the TT and T1-3 stations, how they work and the resolution it achieves
    - the dipole magnet
    - Track reconstruction - the different types of reconstructed tracks (VELO, upstream, long etc.) and efficiency of the track reconstruction
- Particle identification;
    - RICH - the purpose of the RICH detectors and the different momentum ranges they cover, how the detectors work, the removal of the aerogel for Run 2
    - Calorimeters - the different functions of SPD, PS, ECAL and HCAL and their composition
    - Muon stations - location and design of the muon stations
    - PID variables and performance - brief explanation of DLL and ProbNN PID variables and their performance
- The Trigger;
    - Overview of the structure of the trigger
    - L0 - runs at LHC bunch crossing rate and uses limited information to make decisions

- HLT - runs in L0 output and more detailed reconstruction allowed in the HLT due to the lower rate
- trigger decision - TIS, TOS etc.

- LHCb software and simulation;
    - overview of the overview of software used at LHCb and how data goes from hits in the detector to ROOT files to be used in physics analyses
    - description of simulation of particle decays
- Data collected so far at LHCb;
    - data collected by LHCb and what is used for the analysis

Event Selection

Backgrounds

- The backgrounds that are relevant to $B(s)^0 \rightarrow \mu^+\mu^-$ decays and need to be removed in the selection

MC

- decay samples needed for studies that are detailed in my thesis

Selection used in the $B(s)^0 \rightarrow \mu^+\mu^-$ branching fraction measurements

- Trigger requirements
- Cut based selection
    - stripping selection - stripping selection used to Run 1 Branching Fraction analysis and the studies I did to improve the stripping selection efficiency for $B(s)^0 \rightarrow \mu^+\mu^-$ decays in preparation for stripping 21
    - offline selection cuts - stripping selection and offline cuts used to select $B(s)^0 \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow h^+h^-$ decays in Run 1 and Run 2 data
- Particle Identification requirements
    - Choice of PID requirements

- Multivariate classifiers
    - Two classifiers are used to select events for the analysis both are BDTs
    - Boosted Decision trees - description of how BDTs work
    - BDTS - description of initial BDT used to remove candidates very unlikely to be signal and its performance at removing background
    - Global BDT (same BDT as the Branching Fraction analysis) - variables included in the BDT and the importance of isolation variables, how the BDT was developed and its performance on data from each year

Selection used for the effective lifetime measurement

- Focusing on the differences between the selections
    - Different trigger requirements
    - Mass cut at 5320 MeV
    - The selection of $Bs^0 \rightarrow \mu^+\mu^-$ decays uses the same linear combination of ProbNN variables developed for the Branching fraction analysis but a looser selection requirement.
    - The same BDT is used although others were investigated - BDT cut optimised using toy experiments to find the cut that gives the lowest expected uncertainty on the effective lifetime measurement.

Measurement of the $Bs^0 \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow \mu^+\mu^-$ Branching Fractions

Overview of the Branching Fraction analysis covering the main areas but not too detailed.

Measurement of the $B_s^0 \rightarrow \mu^+\mu^-$ Effective Lifetime

- Overview of the analysis strategy - fit the mass distribution to extract sWeights then fit the sWeighted decay time distribution to obtain the lifetime, the fit has been optimised using toy studies. Also sWeights method assumes that the mass and decay time are not correlated which has been shown to be true
- Mass PDFs - these are the same PDFs used for the Branching Fraction analysis
- Decay time PDFs
    - $B_s^0 \rightarrow \mu^+\mu^-$ signal uses decay time acceptance and an exponential, the acceptance models the bias in the decay time distribution caused by the selection. The parameterised acceptance is taken from MC which is weighted using the nTracks distribution from $B^0 \rightarrow K^+\pi^-$ decays in data and MC to compensate for data-MC differences.
    - describe the decay time PDFs used for the background needed for the toy studies
- Optimising the fit;
    - outline the procedure for toy studies
    - To fit for tau or 1/tau - during development of the analysis with low statistics (Run 1 only) fitting for tau produced incorrect estimations of the uncertainties due to the likelihood function. However with the data set used (Run 1 + Run 2) the coverage for fitting for tau is good.
    - details of the different toy experiments performed looking at different mass ranges and including different background components in the mass fit. The conclusion to fit in the mass range 5320 - 6000 MeV/c2 and only include the Bs2MuMu peak and combinatorial background.
    - expected sensitivity
- Results for the effective lifetime

Systematic Uncertainties and Cross checks

(Keeping the same structure as the analysis note)

- Fit accuracy - biases arising form the fit choice, this is evaluated given the number of events we observed
- Contamination from exclusive backgrounds - the change in the lifetime measurement because these backgrounds are not included in the mass fit
- Effect of the production asymmetry on the result
- Mass model - sensitivity of the final result to the PDF used to fit the $B_s^0 \rightarrow \mu^+\mu^-$ mass
- Effect of the decay time acceptance on the mix of light and heavy mass eigenstates
- Decay time acceptance - measuring both $B^0 \rightarrow K^+\pi^-$ and $B_s^0 \rightarrow K^+K^-$ acceptance testing the analysis strategy and the determination of the acceptance function
- Combinatorial background decay time distribution - investigating how well combinatorial background in $B^0 \rightarrow h^+h^-$ decays described that in Bs2MuMu decays
- Incorrect assignment of primary vertices cross check - there is no fit component to account of incorrectly assigned PVs, however for this measurement it has no impact on the result
- Total systematic uncertainty on the final result

Summary and Outlook

- Summary of the results
- Including future predictions for the effective lifetime measurement and expected sensitivities at the end of Run 2 and with 50^-1 and 300 fb^-1 with the current analysis strategy