Ageing and the Decay of Beauty

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Introduction

The two parts of the title and subtitle of my thesis, namely *Ageing: radiation hardness of the LHCb Outer Tracker* and *The decay of beauty: time-dependent CP violation using* $B_s^0 \to J/\psi\,\phi$ *decays* represent its two main subjects. In this introduction, I will first elaborate on the radiation hardness of the LHCb Outer Tracker. Next, I will discuss the subject of time-dependent CP violation in $B_s^0 \to J/\psi\,\phi$ decays. Finally, I will end the introduction with a brief chapter overview.

If you read this, there is a slight chance that you are a non-expert in particle physics. Since the main content of my thesis is quite technical, with this introduction, the summary and the acknowledgements, I aim to give the non-expert readers an impression of my research during the past four years. My hope is, naturally, that particle physicists will read these sections as well and will also find satisfaction in reading the physics chapters.

Ageing: Radiation Hardness of the LHCb Outer Tracker

LHCb is one of the four major experiments at the Large Hadron Collider (LHC) at CERN[1]. The Outer Tracker (OT) is a subdetector of the LHCb experiment. It is used to reconstruct the trajectories of particles through the detector originating from proton-proton collisions. To detect a traversing particle, the OT uses straw tubes filled with an ionization gas that act as cathodes with a central anode wire. It consists of three detection stations and each station comprises 4 detection layers. The OT has a modular design, meaning that it consists of 432 modules of 128 straw tubes, leading to a total of roughly 55 000 straw tubes in the entire OT. The modules are constructed by glueing the straws to the module panels.

After construction and prior to installation of the modules in the LHCb experiment, laboratory tests proved that outgassing of the glue that was used in the module construction reduced the performance of the detector modules. In the context of particle detector technology, effects that gradually reduce detector performance, such as malicious outgassing, are collectively called ageing effects.

The modules that were installed in the LHCb cavern were subjected to several beneficial treatments to reduce or prevent ageing effects. In this thesis, I will describe the results of tests that were performed to monitor the behavior of the OT modules during beam operation. Whereas this part of my thesis is hardware-oriented, the other part presents the analysis of

[1] CERN was founded as *Conseil Européen pour la Recherche Nucléaire*, but is known nowadays as the *European Organization for Nuclear Research*.

proton-proton collisions that contain B_s^0 particles and decay into J/ψ and ϕ particles, which I will explain below.

The Decay of Beauty: Time-Dependent CP Violation using $B_s^0 \to J/\psi\,\phi$ Decays

The main goal of the analysis of $B_s^0 \to J/\psi\,\phi$ decays is to measure a parameter, named the weak phase ϕ_s. The B_s^0 meson is sometimes called a beauty meson, since it consists of one s quark and one so-called beauty quark, $\overline{b}$. As I studied one particular decay mode of these beauty mesons, I decided to adopt the phrase *The Decay of Beauty* as the first part of my title.

The parameter ϕ_s is a measure of the amount of time-dependent CP violation in the interference between mixing and decay in $B_s^0 \to J/\psi\,\phi$ decays. In the Standard Model (SM), ϕ_s is estimated to be close to zero. New Physics models, however, predict that the value of ϕ_s can be enhanced due to so far unknown processes in B_s^0 mixing. Therefore, any significant deviation in ϕ_s from the SM prediction could be an indication of New Physics. The LHCb experiment is well suited to measure this parameter and I will present the most precise measurement of ϕ_s to date.

Chapter Overview

This thesis consists of six chapters. The first two chapters serve as a general introduction to the LHCb experiment (Chap. 2) and to parts of its physics program (Chap. 1). The final four chapters include my own research.

Chapter 1: CP Violation and Physics of B Mesons

This chapter is theoretically oriented and starts with a brief history of the discovery of CP violation and the appearance of CP violation in the Standard Model. Next, I will describe mixing and the decay of B mesons, and a classification of the different types of CP violation. Finally, more specific to $B_s^0 \to J/\psi\,\phi$ decays, I will discuss CP violation in the interference between decays with and without mixing in $b \to c(\overline{c}s)$ transitions.

Chapter 2: The LHCb Experiment

In the second chapter I will give an overview of the LHCb experiment and its various subdetectors. At the end of the chapter, I will discuss the performance of various subdetectors in relation to $B_s^0 \to J/\psi\,\phi$ decays.

Chapter 3: Operation and Performance of the Outer Tracker

This chapter focuses on the Outer Tracker, which is one of the LHCb subdetectors. I will discuss the working principle of the OT and its performance and will also introduce the

concept of hit efficiency. Hit efficiency is used to monitor possible ageing effects in the OT, which is the subject of the subsequent chapter.

Chapter 4: Radiation Hardness of the Outer Tracker

After a brief introduction, this chapter reproduces an article that was published in *Nuclear Instruments and Methods in Physics Research A*. It summarizes the results of methods to monitor ageing of the OT modules during beam operation.

Chapter 5: $B_s^0 \to J/\psi\,\phi$ Formalism

The remaining two chapters will cover the measurement of ϕ_s using $B_s^0 \to J/\psi\,\phi$ decays. This chapter is a continuation of the first chapter and focuses specifically on $B_s^0 \to J/\psi\,\phi$ decays.

Chapter 6: $B_s^0 \to J/\psi\,\phi$ Analysis

The final chapter presents the analysis of $B_s^0 \to J/\psi\,\phi$ decays. I will discuss the event selection and detector effects such as decay-time resolution and angular acceptance. Finally, after a study of systematic uncertainties, I will present a measurement of ϕ_s and other parameters of interest.