

VU Research Portal

Measurement of CP Violation in Mixing and Decay of Strange Beauty Mesons

van Leerdam, J.

2016

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

van Leerdam, J. (2016). *Measurement of CP Violation in Mixing and Decay of Strange Beauty Mesons*.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Summary

Measurement of CP Violation in Mixing and Decay of Strange Beauty Mesons

Despite its precise and accurate description of elementary-particle interactions, the Standard Model of Particle Physics has several shortcomings. To find a more complete description of nature, particle interactions are tested for deviations from Standard Model predictions, which would indicate how to extend the model. The LHCb experiment at CERN's Large Hadron Collider searches for such deviations in the description of particle decays.

In particular, the LHCb experiment studies the decay of the bound states formed by beauty and strange quarks, or "strange beauty mesons". The combination of antibeauty and strange is a B_s^0 meson, beauty and antistrange form the corresponding antiparticle, denoted by \bar{B}_s^0 .

An important feature of these particles is that they can turn into each other, which creates a mixed system of a particle and its antiparticle. Starting with a B_s^0 meson, the particle evolves and can be either a B_s^0 or a \bar{B}_s^0 meson at the time it decays into other particles. Similarly, there is a probability that a particle created as a \bar{B}_s^0 meson decays as a B_s^0 meson.

A particularly interesting mode of decay is that into a J/ψ meson and a $\phi(1020)$ meson, which occurs for both B_s^0 and \bar{B}_s^0 . For this mode there are two possible decay paths for each of the two initial particles. In one path the initial particle first turns into its antiparticle and then decays into the $J/\psi \phi$ final state and in the other path the initial particle decays directly into this state.

This mixing and decay process is predicted to be almost identical for B_s^0 and \bar{B}_s^0 within the Standard Model framework. Measurements indicate that the difference in the rates for the transitions from B_s^0 to \bar{B}_s^0 and vice versa are

very small. Also the rates of the decays into the $J/\psi \phi$ state are expected to be nearly equal. This equivalence between matter and antimatter is known as *CP symmetry*.

Contributions from particle interactions that are not described by the Standard Model may increase the amount of violation of CP symmetry in the $B_s^0 \rightarrow J/\psi \phi$ process. In particular, a difference between the complex phases of the probability amplitudes for the B_s^0 – \bar{B}_s^0 mixing transitions may be introduced. In general this does not lead to CP violation, since the rate of a process only depends on the magnitude of the corresponding probability amplitude. In this case, however, the amplitude is a sum of the interfering contributions from the two decay paths. The relative phases of these contributions do affect the magnitude of the sum, leading to an observable difference between the $B_s^0 \rightarrow J/\psi \phi$ and $\bar{B}_s^0 \rightarrow J/\psi \phi$ processes.

This type of CP violation in the interference between decay paths with and without mixing is measured by examining the distribution of the time between the production and the decay of B_s^0 and/or \bar{B}_s^0 mesons. Without CP violation, this distribution is given by the sum of two exponential contributions with slightly different mean lifetimes. CP violation introduces an oscillation on top of this exponential shape with an amplitude of opposite sign for initial B_s^0 and \bar{B}_s^0 mesons.

In the LHCb experiment, B_s^0 and \bar{B}_s^0 mesons are abundantly produced in roughly equal amounts in the proton–proton collisions of the Large Hadron Collider. Decays into $J/\psi \phi$ followed by decays of the J/ψ meson into two muons and the ϕ meson into two kaons are selected by requiring the signature of these muons and kaons in the detector is compatible with this decay chain.

The produced B_s^0 and \bar{B}_s^0 mesons have a mean lifetime of about 1.5 ps, which means typical distances of several millimetres are covered before their decay. These distances are measured by determining the positions of the proton–proton collision and the common point of origin of the muons and kaons from the decay. Also including the measurement of the combined momentum of the decay particles, the time between production and decay of the original meson is inferred.

The shape of the decay-time distribution is modelled and the resulting model is fitted to the measured distribution to determine the values of its parameters. Parameters that describe CP violation determine the amplitude of the oscillation in decay time. The frequency of the oscillation and the lifetimes of the two exponential shapes are controlled by parameters that describe the

coupled $B_s^0 - \bar{B}_s^0$ system.

Different types of CP violation are included in the decay model, which are measured individually for the three different angular-momentum states of the $J/\psi \phi$ system for the first time in this measurement. Small differences between the contributions of these states are expected, which become important in a precision measurement of CP violation. The different contributions are separated by including the measurement of the angles between the momentum directions of the four final-state particles. This results in a four-dimensional distribution of the decay time and three decay angles.

To describe the measured distribution of these variables, experimental effects such as detection and selection efficiencies and finite measurement resolutions are included in the model. Also the fact that the measured distribution is a sum of B_s^0 and \bar{B}_s^0 decays is taken into account. Uncertainties in the estimates of these experimental effects lead to systematic uncertainties in the estimated decay-time and CP-violation parameters, in addition to the statistical uncertainties associated with the size of the sample of decays.

The measured distribution of time and angles is constructed from roughly ninety thousand decays, collected in the years 2011 and 2012. Estimates of the parameter values with these data are compatible with Standard Model predictions, given the experimental uncertainties. These results show that potential non-Standard Model contributions to the $B_s^0 \rightarrow J/\psi \phi$ mixing and decay process must be smaller than the current experimental precision.

An improvement in precision of an order of magnitude is expected with future data from the LHCb experiment, which provides new opportunities for measuring deviations from the Standard Model with $B_s^0 \rightarrow J/\psi \phi$ decays. The measurement with this larger sample of decays requires some improvements in the experimental procedure, to keep systematic uncertainties smaller than the statistical uncertainties.

Adopting the new strategy of measuring CP violation individually for the different angular-momentum states of the $J/\psi \phi$ system would enable interpretation of future precision measurements within a framework of measurements and theoretical calculations of several different meson decays. Such a combined analysis is likely to be required to overcome limitations in the theoretical predictions of CP-violation parameters. Combining these experimental and theoretical tools, the measurement of CP violation in mixing and decay of strange beauty mesons has the potential to continue playing an important role in the search for a more complete description of nature.

