Asymmetries in mixed beauty decays

de Vries, J.A.

2018

Summary

The understanding of fundamental processes in nature has greatly improved over the last century. This has lead to the ambition to explain large-scale cosmological observations starting from the very small scale of particle interactions. In doing so, the Standard Model (SM) of particle physics is incomplete in describing these observations. It does not describe gravity, and in particular, it is unable to explain the large matter-over-antimatter dominance that we observe in our universe. Physics beyond the SM, in the form of additional particles and forces, may help to explain this difference. In this thesis, the search for new physics is done by precisely measuring processes that are sensitive to the contribution of unknown particles through quantum loops. If a deviation from the SM prediction is observed, new physics can explain the difference. In this thesis, the sensitive process that is measured is *CP* violation in the mixing of B^0 and B_s^0 mesons. These neutral mesons change into their own antipartner — $\overline{B}^0$ or $\overline{B}_s^0$— over time with a certain frequency, before they decay. This process is called mixing. After a certain time, these mesons decay to a lighter set of particles known as the final state. A final state is chosen such that it is specific for the state at the time of decay: $B_{(s)}^0 \to f$ and $\overline{B}_{(s)}^0 \to \overline{f}$.

A difference in the rate at which $B_{(s)}^0$ transforms to $\overline{B}_{(s)}^0$ and decays to $\overline{f}$, compared to the antimatter-equivalent process $\overline{B}_{(s)}^0 \to B_{(s)}^0 \to f$, is known as *CP* violation in the mixing. In the SM this difference is practically equal to zero. However, recent measurements by the D0 collaboration have hinted that these rates might be different at three standard deviations. This might indicate that new particles contribute to this process, and could help explain the matter-antimatter asymmetry in our universe.

In order to confirm or disprove these results, a new, more precise measurement is necessary. Exploiting the high energy and luminosity of the *pp* collisions at the Large Hadron Collider (LHC), the LHCb detector has collected data about millions of B^0 and B_s^0 meson decays. While this detector is specifically designed to perform such measurements, the level of precision allowed by this amount of data requires careful inspection of all possible sources of asymmetries in the detection; a higher detection efficiency for matter with respect to antimatter would artificially induce a non-zero measurement of the *CP* asymmetry. Possible sources of such asymmetries are due to interactions of particles with the detector material, misalignment, an asymmetry in the shape of the detector, particle identification and the online triggering of interesting events. These effects are calibrated to permille-level precision by using data from well-known decays of more abundant particles. In addition, there might be an asymmetry in the produced amount of $B_{(s)}^0$ and $\overline{B}_{(s)}^0$ mesons,

which could affect the measurement.

The asymmetry in the mixing of B^0 and $\overline{B}^0$ mesons is measured as a function of the decay time of the B^0 or $\overline{B}^0$. This allows to disentangle the amount of *CP* violation in mixing, known as $a_{\rm sl}^d$, from a possible production asymmetry: the latter only affects the offset of the observed mixing oscillation, while $a_{\rm sl}^d$ also affects the amplitude. The final state that is used to reconstruct the B^0 meson is the semileptonic decay $B^0 \to D^{(*)-}\mu^+\nu_\mu$. These decays have a large branching fraction, although the energy of the B^0 meson is not fully reconstructed due to the neutrino escaping detection. This biases and smears the reconstructed decay time of the B^0 meson, which is obtained from the measured B^0 decay length and momentum. The bias in the decay time is corrected by using simulated B^0 decays. The broad B^0 invariant mass peak resulting from the missing neutrino includes contributions from various backgrounds with a similar final state, in particular from B^+ mesons. These can be separated by their different decay-time behaviour, and the production asymmetry of B^+ mesons is taken from other measurements. The final result is

$$a_{\rm sl}^d = (-0.02 \pm 0.19 \pm 0.30)\%,$$

where the first uncertainty is statistical and the second systematic. This is the most precise measurement of $a_{\rm sl}^d$ to date.

In contrast, the asymmetry in the mixing of B_s^0 and $\overline{B}_s^0$ mesons, called $a_{\rm sl}^s$, is measured integrated over their decay time. This is similar to a counting experiment, and is possible due to the high mixing frequency in this system, which washes out any production asymmetry to negligible level. The semileptonic decay mode $B_s^0 \to D_s^-\mu^+\nu_\mu$ is used to reconstruct the B_s^0 meson. The contributing backgrounds are dominated by $B \to DD$-like decays, where B can be B^+, B^0, B_s^0 or Λ_b^0. The various contributions are determined from the known production- and branching fractions, and their efficiencies are studied using simulated events. These backgrounds dilute the measured asymmetry, and any production or *CP* asymmetry in these modes can bias the measurement. The size of these asymmetries is taken from earlier LHCb measurements. The final result is

$$a_{\rm sl}^s = (0.39 \pm 0.26 \pm 0.20)\%,$$

which is the most precise measurement of $a_{\rm sl}^s$ to date.

These results of $a_{\rm sl}^d$ and $a_{\rm sl}^s$ are compatible with the SM prediction, and only marginally compatible with the D0 result. The latter uses a different measurement strategy which allows for contributions other than just $a_{\rm sl}^d$ and $a_{\rm sl}^s$ which might explain the observed deviation from the SM. Since the precision of the measurements of $a_{\rm sl}^d$ and $a_{\rm sl}^s$ is limited by the amount of data, significant improvements are expected as LHCb collects more data in the near future. The role of these analyses in future searches for new physics is complementary to that of other measurements of *CP* violation, with ample room for a 5-standard-deviation discovery after the upgrade of the LHCb detector.