Decoding beauty

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Summary

Imagine a tiny particle flying in a circle with almost the speed of light. Now imagine this with billions of particles. And, suddenly, these particles see another group of particles approaching at them at almost the speed of light from the opposite direction. A head-on collision occurs, and the particles are smashed into each other, producing many different particles. Luckily, we don't have to imagine this, as this is what happens in the Large Hadron Collider (LHC) at CERN. But why would we want to do this? The answer is simple yet complicated: to understand the fundamental building blocks of our universe, and the laws of nature that govern them.

Everything around us consists of atoms, which in turn consist of electrons, protons, and neutrons. Protons and neutrons are made even smaller particles, called quarks. The quarks, together with the leptons (electrons, muons, taus, and neutrino particles) are the fundamental building blocks of our universe. These particles interact with each other through the three fundamental interactions: electromagnetism, the weak force, and the strong force. The interactions are mediated by the force carriers, so-called bosons. Finally, there is the Higgs boson, which is responsible for giving mass to the particles. All of this is described by the Standard Model (SM) of particle physics.

The Standard Model is a very successful theory, and it has been tested to a very high precision. However, it is not a complete theory, as it does not describe gravity, it does not explain why there is more matter than antimatter in the universe, and has no explanation for dark matter. Therefore, physicists are looking for new physics beyond the Standard Model. One way to do this is to study the decays of particles containing a ”beauty” quark, so-called b-hadrons. Some decays of these particles are very rare in the Standard Model, and a contribution from possible new physics could have a sizable effect. One possible decay of interest are the $b \to s\ell\ell$ decays, where a beauty quark decays into a ”strange” quark and two leptons, either electrons or their heavier version called muons. Another interesting aspect of these decays is the same rate for muons and electrons, which is called lepton flavour universality (LFU). Experimentally, this can be tested by measuring the ratio of these decays to their electron and muon decay modes.

The measuring of these decays is done at the LHCb experiment at the LHC. The research carried out in this thesis focuses on the decays of the so-called Λ_b^0 baryon, consisting of a b-quark and two "light" quarks. By measuring the decays of the Λ_b^0 baryon, we can test the above-mentioned aspects of the Standard Model. Experimentally, it is beneficial to study the decays relative to other, well-known, decays. For these rare Λ_b^0 decays, a so-called resonant decay is used, where the electrons or muons originate from an intermediate particle. This thesis presents the measurement of the branching fraction of the resonant decay $\Lambda_b^0 \to J/\psi \Lambda$. The measured value is in agreement with theory predictions and previous measurements, and the uncertainty is reduced by a factor of three. The result is an important input in the study of the rare Λ_b^0 decays, and other b-particle decays at the LHCb detector.

The rare Λ_b^0 decays are studied to test for lepton flavour universality. To check the used analysis methods, ratios of the resonant Λ_b^0 decays are measured, as these decays are known to be lepton flavour universal. The ratios are expected to be equal to 1 in the Standard Model, however not all of them are in agreement. This indicates that there is potentially an issue in the analysis that needs to be addressed, and this thesis proposes possible solutions. The results are, however, promising and will lead to the first measurement of lepton flavour universality using the rare Λ_b^0 decays.

During the second long shutdown of the LHC, the LHCb detector has been upgraded to handle a higher data rate and collision rate. A large part of the detector was replaced, including the tracking stations. This thesis describes the working of the newly-installed SciFi detector, including the dataflow and data acquisition, the decoding of data, and the timing scans of the electronics. The timing scans are an essential part of the commissioning of the detector, as they are needed for a stable operation of the detector. Four clocks are scanned to find the optimal settings for the full detector, and the results are presented in this thesis. The SciFi detector is currently almost fully operational and data taking with the upgraded LHCb experiment is ongoing. The LHCb experiment is expected to collect a dataset of 50 fb^{-1} by the end of Run 4, which will allow for more accurate measurements of the rare $\Lambda_b^0 \to \Lambda \ell^+ \ell^-$ decays.