Analysis of Monte Carlo simulations of $B \to K^* e^+ e^-$ and $B \to K^* J/\psi(\to e^+ e^-)$ decays

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Abstract

The LHCb collaboration published a measurement on lepton universality in $B^0 \to K^{*0} l^+ l^-$ and $B^0 \to K^{*0} J/\psi(\to l^+ l^-)$ decays, which might indicate hints of a possible violation. These processes were considered during my summer project, were I looked at Monte Carlo simulations of these topologies and their kinematics.

1 Introduction

In 2017 the LHCb collaboration performed a test of lepton universality by measuring the ratio of the branching fractions of the $B^0 \to K^{*0}\mu^+\mu^-$ and $B^0 \to K^{*0}e^+e^-$ decays [1]. Two regions of the dilepton invariant mass squared q^2 were considered in the analysis, one in the low mass region between 0.045 and 1.1 GeV^2/c^4 and one high mass region between 1.1 and 6.0 GeV^2/c^4 where the double ratio $R_{K^{*0}}$ of the branching fractions of $B^0 \to K^{*0} l^+ l^-$ and $B^0 \to K^{*0} J/\psi(\to l^+ l^-)$, where l are either the electrons or the muons, is measured.

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))} / \frac{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))} \tag{1}$$

To reduce the impact of systematic uncertainties, a double ratio is useful. The measure of $R_{K^{*0}}$ was compatible with the Standard Model prediction at the high q^2, but shows a 2.7σ deviation in the low mass q^2 bin, which might hint at the possibility of a violation of lepton universality. Due to this, the $B^0 \to K^{*0}\mu^+\mu^-$ and $B^0 \to K^{*0}e^+e^-$ decays might be well worth being looked at again by other experiments, and are what I have looked at during my summer project.

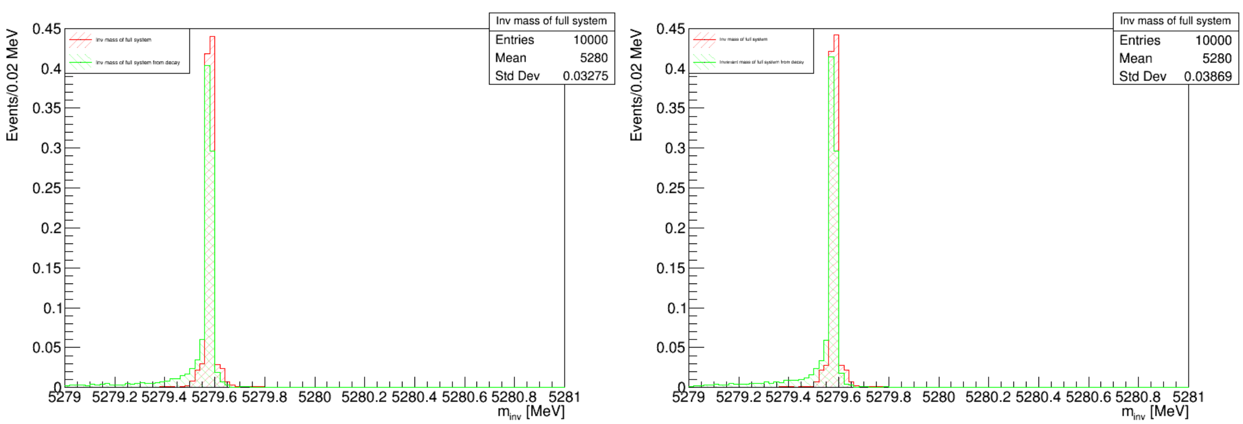
2 Project Outline

The generator used to produce the Monte Carlo samples that I have studied during the summer is PYTHIA 8, which is a standard tool for the generation of high-energy collisions and can simulate physics starting from a few-body hard process to a complex multihadronic final state [2].
There were several constraints put into the simulations, such as a 4 GeV cut on the electron transverse momentum p_T, as well as a 500 MeV cut on the transverse momenta of any final state hadrons. These cuts are useful to increase the effective statistics of the Monte Carlo sample in a phase space region close to what can be expected due to trigger selection.
During the analysis, photons which originate from Bremsstrahlung were ignored, since they cannot be reconstructed precisely in the detector. Furthermore, only final-state particles are taken into account. For example only electrons which no longer radiate photons are considered. This is ensured by calling on the status flag of the generated particle.
Furthermore, every particle's pdgID [1] has also been plotted, to check that the particles match to the expected decay. All of these were in accordance with the expectation.
The two decays that were analysed are :

$$B^0 \to K^{*0} e^- e^+ \tag{2}$$

$$B^0 \to K^{*0} J/\psi(\to e^- e^+) \tag{3}$$

3 Analysis



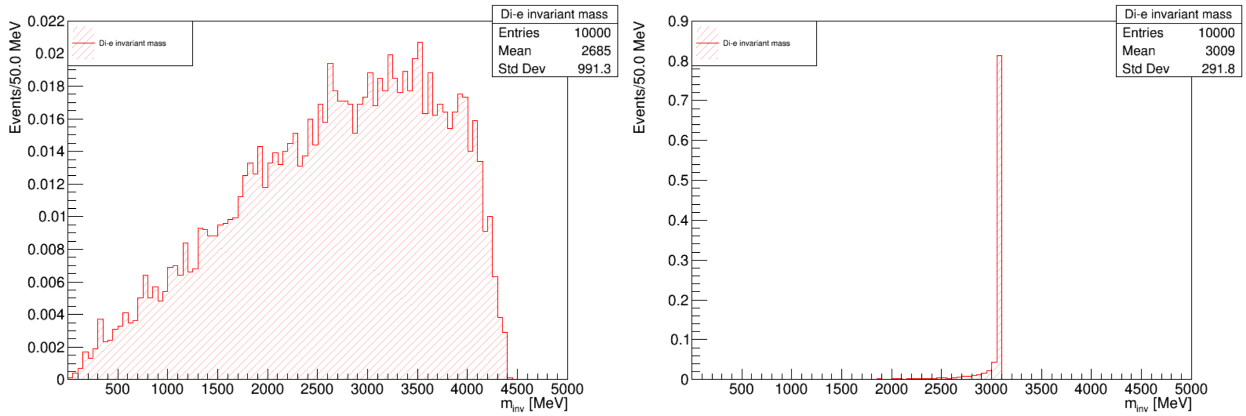
(a) Invariant mass of the $K^{*0}e^-e^+$ system

(b) Invariant mass of the $J/\psi K^{*0}$ system

Figure 1: In red the invariant mass of the B^0 meson is presented, while in green the reconstructed invariant mass from the decay particles of the B^0 through summing up their 4-momentum vectors is shown.

In Figure 1 the invariant masses of the full system is shown, in red the mass from the generated B meson, and in green, reconstructing the invariant mass from the 4-momenta of it's decay particles. Both of them peak at 5279.6 MeV which is in full accordance with the mass of a B^0 meson[3]. We can furthermore see that the peak of the invariant mass from the reconstruction of the decay is slightly shifted to the left. This is due to, as mentioned before, Bremsstrahlung not being accounted for and only taking into account final-state particles. For the decay there is furthermore a slightly larger tail to the left, which originates from electrons which have lost a significant amount of their energy due to Bremsstrahlung.

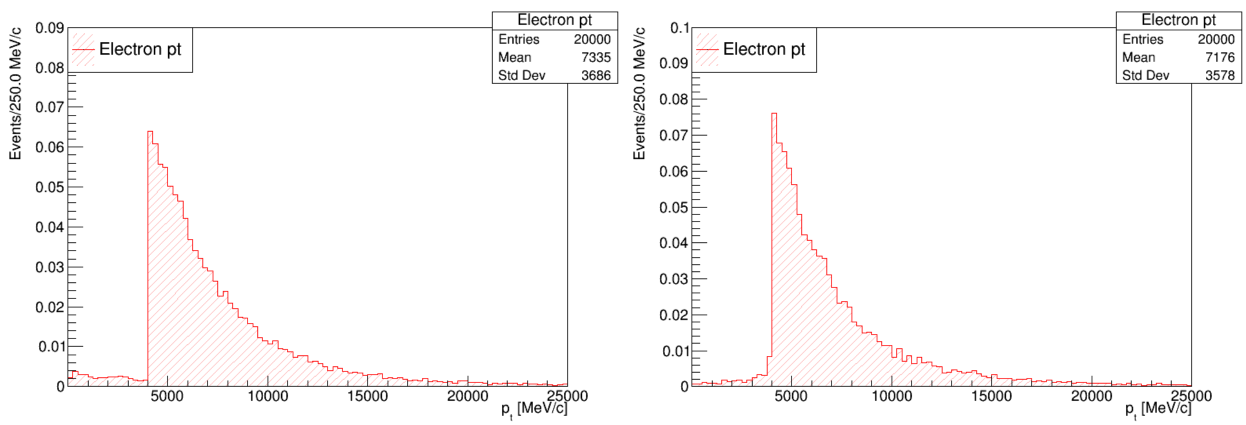
[1] A unique identifier for each generated particle



(a) Invariant mass of di-electron system in $B \to K^{*0}e^-e^+$ (b) Invariant mass of di-electron system in $B \to J/\psi K^{*0}$

Figure 2: Di-electron invariant masses, taken from final-state electrons

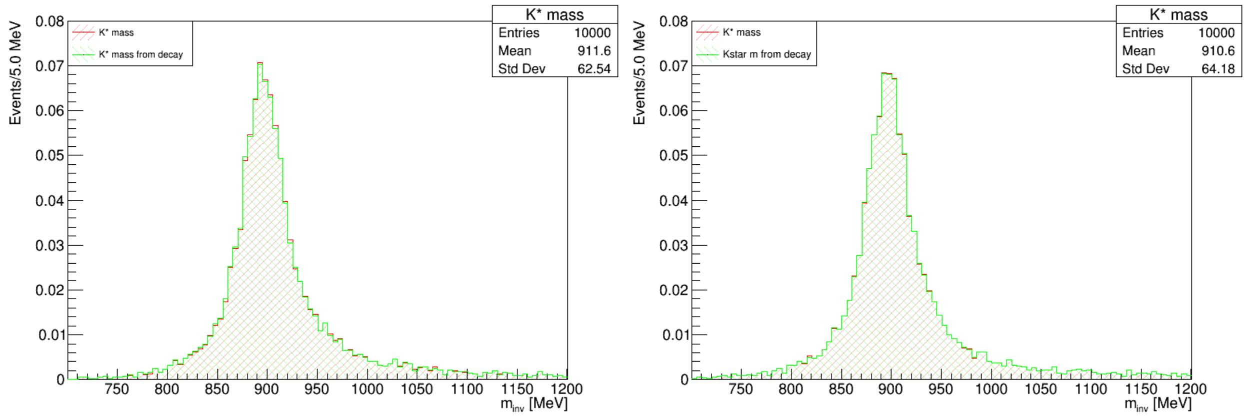
As seen in Figure 2, the invariant mass of the di-electron system for the $B \to K^{*0}e^-e^+$ is spread over a much wider range. However this is expected since in this topology, the di-electrons simply decay straight from the B^0 meson, which means that they can take on a wide range of values, while for the electrons which originally decay in the $B \to J/\psi K^{*0}$ topology from the J/ψ, the electrons are bound to the mass of the J/ψ. This explains that their invariant mass peaks around the mass of the J/ψ of 3096.900 ± 0.006 MeV[3].



(a) Transverse momenta of the $B \to K^{*0}e^-e^+$ electrons (b) Transverse momenta of the $B \to J/\psi K^{*0}$ electrons

Figure 3: Transverse momenta, taken from final-state electrons

Figure 3 shows the transverse momenta of the final-state electrons for each of the decays. What is important to note is that, even though there has been a cut put into the simulation at 4000 MeV, there are a small number of electrons which actually do have smaller transverse momenta. For the $B \to K^{*0}e^-e^+$, 3.73% of the electrons actually are below that cut, while for $B \to J/\psi K^{*0}$, 3.19% are below it. The reason for this is not quite understand and will have to be followed up on. One possible explanation would be that the cut is applied before the Bremsstrahlung has been accounted for.



(a) Invariant mass of K^{*0} for the the $B \to K^{*0}e^-e^+$ decay (b) Invariant mass of K^{*0} for the the $B \to J/\psi K^{*0}$ decay

Figure 4: Invariant masses of the K^{*0}

Shown in Figure 4, is the K^{*0} invariant mass, that does not show a sharp peak. The width stems from the exitations of a particle and are the direct inverse of the particle lifetime. The K^{*0} has an expected width of about 50.3 ± 0.8 MeV [3], and it can be seen that the width in the plots is probably slightly higher than this. As for the peak, this is in accordance with the expected K^{*0} mass of 892 MeV [3].

(a) Invariant mass of K^+ for the the $B \to K^{*0}e^-e^+$ decay (b) Invariant mass of K^+ for the the $B \to J/\psi K^{*0}$ decay

(a) Invariant mass of π^+ for the the $B \to e^-e^+$ decay (b) Invariant mass of π^+ for the the $B \to J/\psi K^{*0}$ decay

Figure 6: Invariant masses of the K^+ and π^+

In figure 6 the invariant masses of K^+ and π^+ in contrast to the invariant masses of K^{*0} are depicted, which have much sharper and well defined peaks.

4 Conclusion

Many more characteristics of the particles have been plotted, such as the pseudorapidity η, the azimuthal angle ϕ, their pdgID, as well as transverse momenta of the particles that have not been named here, however, to keep this report short and concentrated on the most important findings, these have been omitted.
Moreover, it would have been interesting further to look at the lifetime of the particles by looking at the absolute value of the length times the speed of light between the production and decay vectors of the the particles.
As for what has been found, most values agree with what was expected, with a big exception at the transverse momenta of the electrons, where the cut is not completely obeyed.
Furthermore, what has not been mentioned in the analysis, for the $B \to J/\psi K^{*0}$ decay, 0.07% of the π^- have a transverse momentum below 500 MeV/c, which should also not be the case due to the cut on final hadrons in the simulation.
Both of these factors will need to be followed up on, but apart from this, we can see that the particles are clearly identifiable and have mass peaks well within the expected ranges.

References

[1] LHCb collaboration (2017). Test of lepton universality with $B^0 \to K^{*0} l^+ l^-$ decays. *arXiv:hep-ex/1705.05802*.

[2] Sjöstrand, T., Mrenna, S. and Skands, P. (2008) A Brief Introduction to PYTHIA 8.1 *arXiv:hep-ph/0710.3820*

[3] The Review of Particle Physics (2018) M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018)