Analysis of $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$ with $\Lambda_c^+ \to p K^- \pi^+$ final state.

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1 Introduction

This report describes the project I worked on during my time as a summer student at CERN. For this project I worked in a team with two other people and we looked at decays of Λ_b^0 baryons at LHCb. More specifically, we looked at the decay $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$ where charge conjugated modes are included. The primary goal of studying beauty-baryon decays is that CP violation has not been observed yet in baryons. In addition, Precise measurements of beauty-baryon ground state masses are required to perform precision tests of various QCD models. Finally, the study of this decay is also useful for other studies in which it might be a source of background.

First a short description of the LHCb detector will be given. Then the analysis that we performed as a team will be described, but I will emphasize my personal contribution. This section will also contain the results of the analysis so far. Finally, the results will be discussed.

2 The LHCb detector

The primary goals of the LHCb detector are to study CP violation, rare decays of beauty- and charm-hadrons, and find evidence of new physics. Measurements of CP violation at B-factories and Tevatron are fully consistent with the CKM mechanism. However, the amount of CP violation is not enough to explain the matter/antimatter asymmetry that we see in the universe today and new effects that might be seen in heavy flavour physics could resolve this discrepancy [1].

The LHCb detector is build as a single-arm forward spectrometer, because it is designed to study particles containing b or c quarks which are mainly produced in the forward direction. It covers a pseudo-rapidity range of $2 < \eta < 5$ and has a momentum resolution of 0.4 % at 5 GeV/c and 0.6 % at 100 GeV/c. The impact parameter resolution for tracks with large transverse momentum is 20 μm [1].

The luminosity at the LHCb detector is regulated by defocusing the beam at the interaction point. This results in events that are dominated by a single pp collision per bunch crossing, and thus allow for precision measurements. LHCb, despite this lower luminosity, has the largest samples of B-mesons in the world. In addition, B_c mesons and b-baryons such as Λ_b are produced in large quantities [1].

3 Analysis

The procedures described in this section were performed on data with an integrated luminosity of $1.0\,\text{fb}^{-1}$ collected in 2011 with both polarities of the LHCb dipole magnet, and $2\,\text{fb}^{-1}$ in 2012 with the magnetic field pointing up. The Λ_c^+ candidates are reconstructed in the decay mode $\Lambda_c^+ \to pK^-\pi^+$. A "stripping" process selects events that have the proper decay topology. Additionally, the mass resolution of the Λ_b^0 candidates is improved by imposing kinematic and vertex constraints [2].

3.1 Pruning trees

To handle the large amounts of data, we remove unused branches from our Ntuples. In order to do this I developed a simple program called secateur. This program shows the user a dialog window (see figure 1) with a list of branches in the tree that needs to be pruned. The dialog also contains a search bar in order to quickly find branches. When the branches have been selected, a configuration file will be generated that contains information such as the input and output filenames, trees to prune, and the selected branches. Additionally, this program can also make simple selections. We use this functionality to implement the preselection.

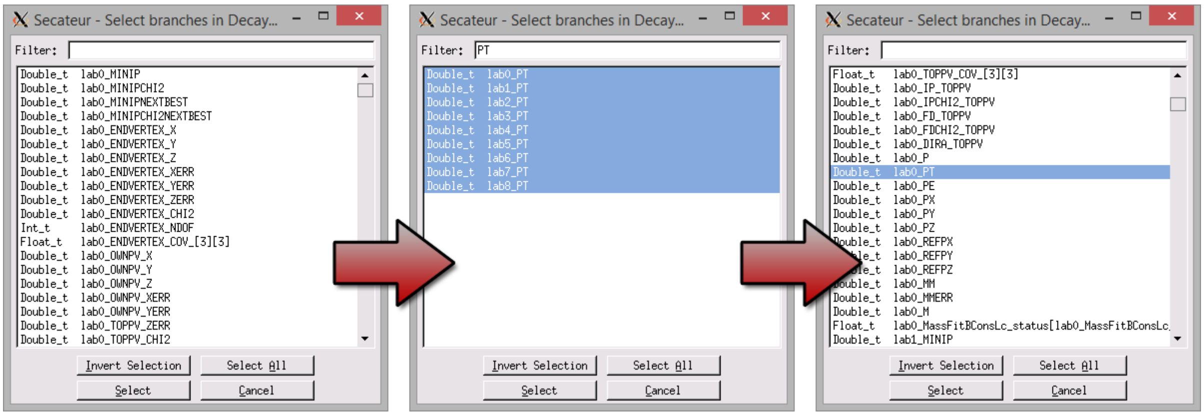


Figure 1: The branch selection dialog. In this example we find all transverse momentum variables by typing "PT" into the search bar and then select the branches we want. Then, the branches stay selected after clearing the search bar and we can select additional branches.

3.2 Preselection

We select Λ_c^+ candidates by requiring the $pK^-\pi^+$ mass to be within $20\,\mathrm{MeV/c^2}$ of the Λ_c^+ mass. In addition, we cut on the impact parameters (IPs) of the $K^+K^-\pi^-$ particles and particle identification (PID) requirements are applied to all final state particles. Figure 2a shows the $K^+K^-\pi^-$ mass distribution after the preselection and contains a clear peak at the D_s^- mass of $1968.49\,\mathrm{MeV/c^2}$. Figure 2b shows a scatter plot of the events. The horizontal axis contains the $\Lambda_c^+K^+K^-\pi^-$ mass and the vertical axis contains the $K^+K^-\pi^-$ mass. The peak at the intersection of the Λ_b^0 mass of $5619.4\,\mathrm{MeV/c^2}$ and the D_s^- mass is a result of the decay $\Lambda_b^0 \to \Lambda_c^+ D_s^-$ [3]. Since we are only interested in the non-resonant decays, we exclude events with a $K^+K^-\pi^-$ mass within $20\,\mathrm{MeV/c^2}$ of the D_s^- mass. The requirements that form the preselection are listed in table 1.

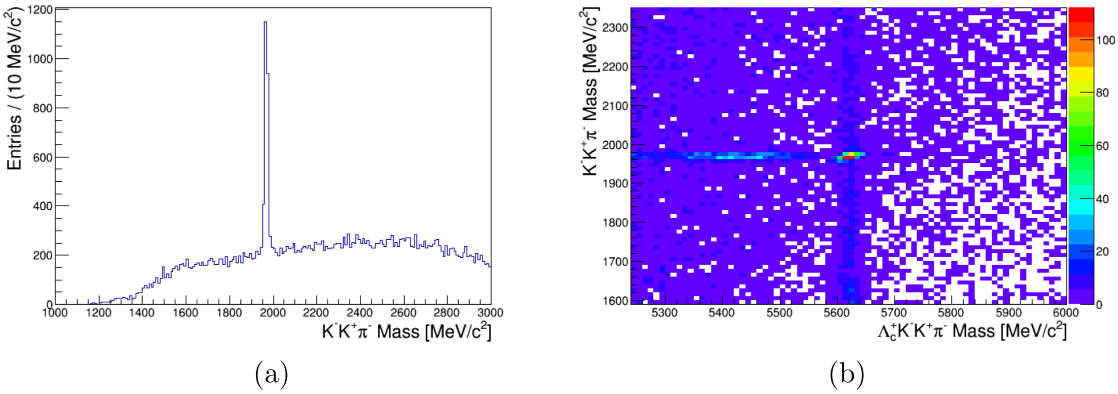


Figure 2: $K^+K^-\pi^-$ mass distribution containing a D_s^- mass peak (a) and a scatter plot showing the decay $\Lambda_b^0 \to \Lambda_c^+ D_s^-$ (b).

Table 1: Complete set of requirements for the preselection

Requirement	Variable description
$\lvert$`lab1_M` $- 2286\,\mathrm{MeV/c^2}\rvert < 20\,\mathrm{MeV/c^2}$	$pK^-\pi^+$ mass
$\lvert$`lab5_M` $- 1968\,\mathrm{MeV/c^2}\rvert > 20\,\mathrm{MeV/c^2}$	$K^+K^-\pi^-$ mass
`lab2_PIDp` > 10	Λ_c^+ daughter proton PID proton
`lab3_PIDK` > 10	Λ_c^+ daughter kaon PID kaon
`lab4_PIDK` < -3	Λ_c^+ daughter pion PID kaon
`lab4_PIDp` < -3	Λ_c^+ daughter pion PID proton
`lab6_PIDK` > 5	Λ_b^0 daughter kaon PID kaon
`lab7_PIDK` > 5	Λ_b^0 daughter kaon PID kaon
`lab6_IP_OWNPV` $> 0.1\,\mathrm{mm}$	Λ_b^0 daughter kaon IP w.r.t. the PV
`lab7_IP_OWNPV` $> 0.1\,\mathrm{mm}$	Λ_b^0 daughter kaon IP w.r.t. the PV
`lab1_IPCHI2_ORIVX` < 1	Quality of Λ_c^+ IP w.r.t. its origin vertex

3.3 Calculating sWeights

A boosted decision tree (BDT) will be used to further enhance our signal. In order to train the BDT without simulated events, we fit appropriate probability distribution functions to the Λ_b^0 candidate mass distribution and produce signal and background sWeights to use the ${}_s\mathcal{P}lot$ technique [4]. These weights can then be used to produce signal and background distributions of variables that are used to train the BDT.

In order to calculate the sWeights, I made a program for the team that uses RooFit to do an unbinned maximum likelihood fit. This program is called with a configuration file that specifies one or more root files that contain the data, which branches to fit, and signal and background pdfs.

The Λ_b^0 candidate mass distribution after preselection is shown in figure 3. In addition to the Λ_b^0 signal, the distribution also contains an unexpected signal at 5446 MeV/c^2. We modeled the distribution as two gaussian signals on top of an exponential background. The results of the fit are also included in figure 3.

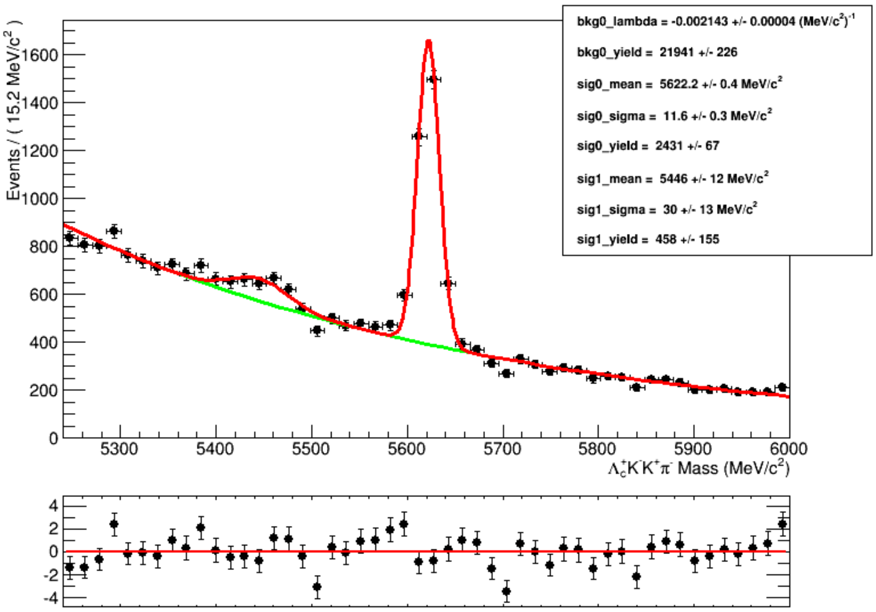
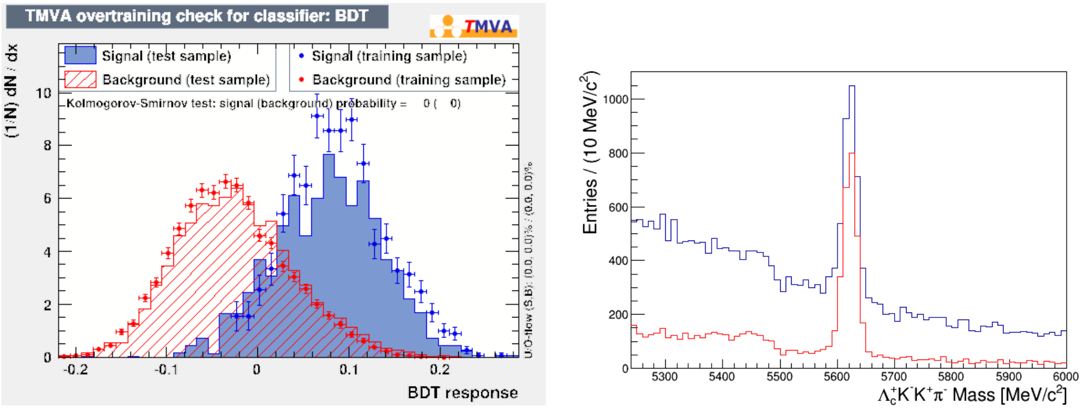


Figure 3: Λ_b^0 candidate mass distribution after preselection and a pull histogram. Two signals are visible on top of an exponential background.

3.4 Boosted decision tree

To train the BDT, data is randomly divided into training and testing samples of equal size. The variables used to train the BDT are listed in table 2. The current BDT training results are shown in figure 4a. The BDT response to the test and training samples appear to be different and this is an indication that the BDT is poorly trained. However, cutting on the BDT response already reduces the background significantly while keeping most of the signal, as can be seen in figure 4b.



(a) (b)

Figure 4: BDT training results (a) and Λ_b^0 candidate mass distribution (b) before (blue) and after (red) cutting on the BDT response.

Table 2: List of variables that are used to train the BDT

Variable type	Description	Particles
PT	Transverse momentum	Λ_b^0, all final state particles, and $pK^-\pi^+$ and $K^+K^-\pi^-$ systems
IP_OWNPV	IP w.r.t. PV	Λ_b^0, all final state particles, and $pK^-\pi^+$ and $K^+K^-\pi^-$ systems
IP_ORIVX	IP w.r.t. origin vertices	All final state particles, and $pK^-\pi^+$ and $K^+K^-\pi^-$ systems
IPCHI2_OWNPV	Quality of IP w.r.t. PV	Λ_b^0 and Λ_c^+
PIDp	PID proton	Λ_c^+ daughter proton
PIDK	PID kaon	Λ_c^+ daughter kaon and Λ_b^0 daughter kaons
FD_OWNPV	Flight distance w.r.t. PV	Λ_b^0
FD_ORIVX	Flight distance w.r.t. origin vertex	Λ_c^+
FDCHI2_OWNPV	Quality of flight distance w.r.t. PV	Λ_b^0
FDCHI2_ORIVX	Quality of flight distance w.r.t. origin vertex	Λ_c^+

4 Discussion

As can be seen in figure 3, two signal peaks are visible in the Λ_b^0 candidate mass distribution. The peak on the right-hand side is consistent with the Λ_b^0 mass. The location and width of the other peak are consistent with a partial reconstruction of the decay $\Lambda_b^0 \to \Sigma_c^+ K^+ K^- \pi^-$, where Σ_c^+ decays as $\Sigma_c^+ \to \Lambda_c^+ \pi^0$ and the π^0 is not reconstructed. From this we conclude that these might be two first observations of the decays $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$ and $\Lambda_b^0 \to \Sigma_c^+ K^+ K^- \pi^-$.

It is also important to point out that currently the BDT is only trained on the Λ_b^0 signal peak. As a result, the second peak is not enhanced by cutting on the BDT response (see figure 4). The following step in the analysis is to construct a pdf that describes the second peak better than a gaussian and to properly configure the BDT to reduce the overtraining.

References

[1] LHCb collaboration, A. A. Alves Jr. *et al.*, *The LHCb detector at the LHC*, JINST **3** (2008) S08005.

[2] W. D. Hulsbergen, *Decay chain fitting with a Kalman filter*, Nucl. Instrum. Meth. **A552** (2005) 566, `arXiv:physics/0503191`.

[3] LHCb collaboration, R. Aaij *et al.*, *Study of beauty hadron decays into pairs of charm hadrons*, Phys. Rev. Lett. **112** (2014) 202001, `arXiv:1403.3606`.

[4] M. Pivk and F. R. Le Diberder, *sPlot: a statistical tool to unfold data distributions*, Nucl. Instrum. Meth. **A555** (2005) 356, `arXiv:physics/0402083`.