CERN Summer School

Towards the First measument of: $\Lambda_b^0 \to \Lambda_c^{*+} D_s^{(*)-}$

Summer Project Report

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1 Introduction

The Standard Model states that all three lepton flavours (electron e^-, muon μ, tau τ) have the same electroweak coupling with the gauge bosons Z and W^{+-}. This implies that for decays involving different lepton families, the branching fractions are not affected by the type of lepton but vary only due to differences in phase space and contributions suppressed by helicity. This principle is known as Lepton Flavour Universality (LFU). LFU tests involves comparing the ratios of branching fractions in leptonic and semi-leptonic decays. If these ratios are consistent with the predictions of the Standard Model, it supports the validity of LFU. However, if discrepancies are observed, it could indicate new physics beyond the Standard Model (BSM) [1][2].

Testing LFU with semileptonic $\Lambda_b \rightarrow \Lambda_c^*$ decays can help verify current anomalies observed in decays involving charmed mesons. This can be achieved by measuring the ratio $R(\Lambda_c^*)$, where

$$R(\Lambda_c^*) = \frac{B(\Lambda_b \rightarrow \Lambda_c^{*+} \tau \bar{\nu}_\tau)}{B(\Lambda_b \rightarrow \Lambda_c^{*+} \mu \bar{\nu}_\mu)}$$

We can evaluate the $\Lambda_b \rightarrow \Lambda_c^{*+} \tau \bar{\nu}_\tau$ decay by studying its dominant background, which is the $\Lambda_b^0 \rightarrow \Lambda_c^{*+} D_s^{(*)-}$ channel. In particular, we are interested in processes where D_s decays to $\kappa^+ \kappa^- \pi^-$, as it shows in Figure 1. This process is something that has never been measured before, and is also a good opportunity to study the nature of the Λ_c^+ resonances, as we have that $\Lambda_c^{*+} \rightarrow \Lambda_c^+ \pi^+ \pi^-$ and $\Lambda_c^+ = \Lambda_c\,(2595, 2625)^+$.

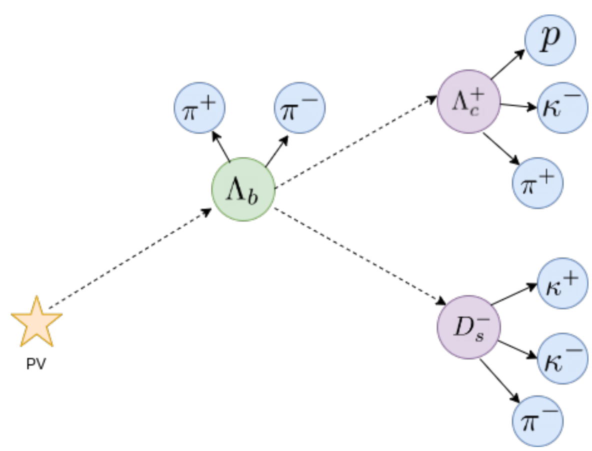

Figure 1: Decay channel.

2 Selection

For the data sample of 2016, 2017 and 2018, we require the following selection. The plots of variables of interest, such as the mass of Λ_c and D_s^- are shown below.

Λ_b^0 **Selection**:

- The decays of b quark hadrons can be identified from other inelastic pp interactions by detecting a secondary vertex and particles with high transverse momentum (p_T).

- The Λ_b^0 must be located downstream from the primary vertex (PPV).

D_s **Selection**:

- The D_s vertex must be positioned downstream of the Λ_b^0 vertex along the beam direction, with a significance of 4σ.

Λ_c^+ **and** Λ_c^* **Selection**:

- The transverse momentum of the two pions forming the Λ_c^* must exceed $350\,\mathrm{MeV}/c$.

- The Λ_c^+ must have a high transverse momentum and a mass close to its known value.

- These selection criteria were defined based on the Monte Carlo truth from simulated samples, ensuring the correct simulated sample was used.

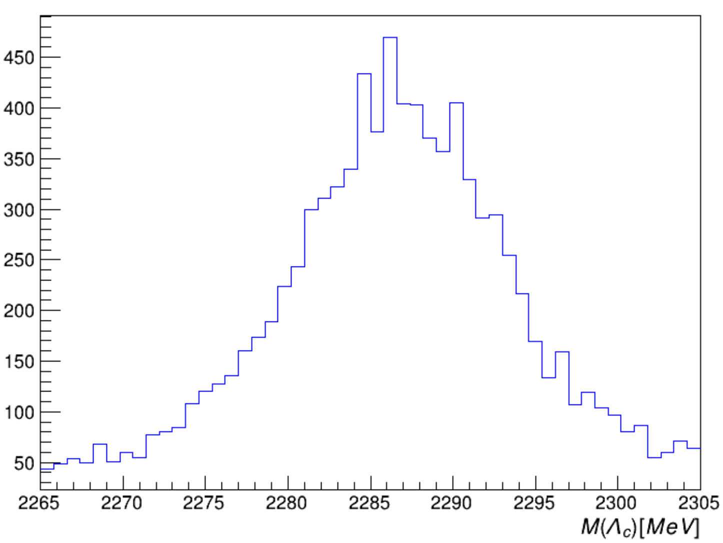

Figure 2: Mass distribution of Λ_c.

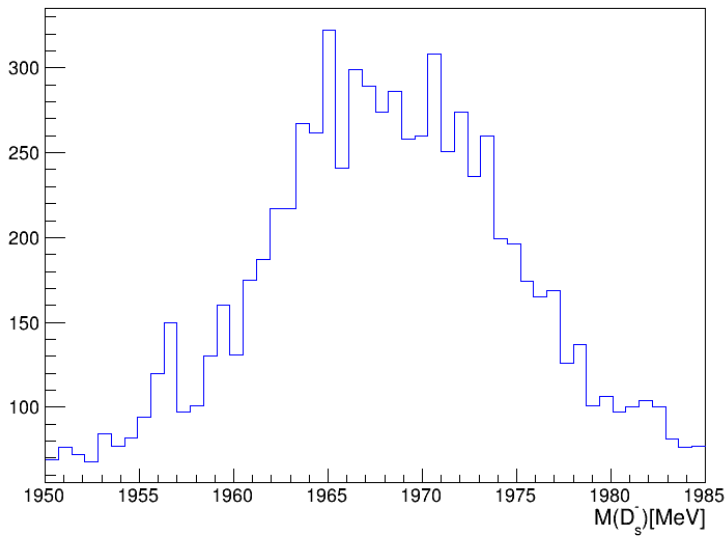

Figure 3: Mass distribution of D_s^-.

3 $\Lambda_c^+\pi\pi$ structure

The mass distribution graph for ΔM (i.e., $M(\Lambda_c^{*+}) - M(\Lambda_c^+)$) from the 2016 data sample is shown in Figure 4. This graph indicates the presence of the $\Lambda_c(2625)$ and $\Lambda_c(2595)$ resonances. Figure 5 presents the mass distribution of Λ_b. The primary peak corresponds to the decay mode $\Lambda_b^0 \to \Lambda_c^{*+} D_s^-$. Additionally, a smaller peak on the left indicates another possible decay mode, $\Lambda_b^0 \to \Lambda_c^{*+} D_s^{*-}$. While the rest corresponds to a combinatorial background. Additionally, a 2D plot of ΔM versus the mass of Λ_b was created to study the correlation between these variables. The resulting plot shown on Figure 6 provides a detailed view of a highlighting primary peak corresponding to the decay mode $\Lambda_b^0 \to \Lambda_c^{*+} D_s^-$ near 340 MeV, where the $\Lambda_c(2625)$ resonance is. This combined analysis enhances our understanding of the resonance structures and decay channels.

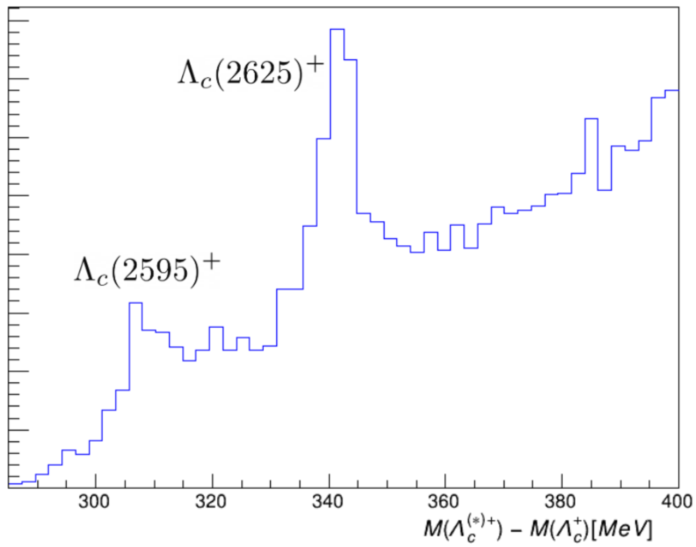

Figure 4: Histogram of $\mathrm{M}(\Lambda_c^{*+}) - M(\Lambda_c^+)$ mass.

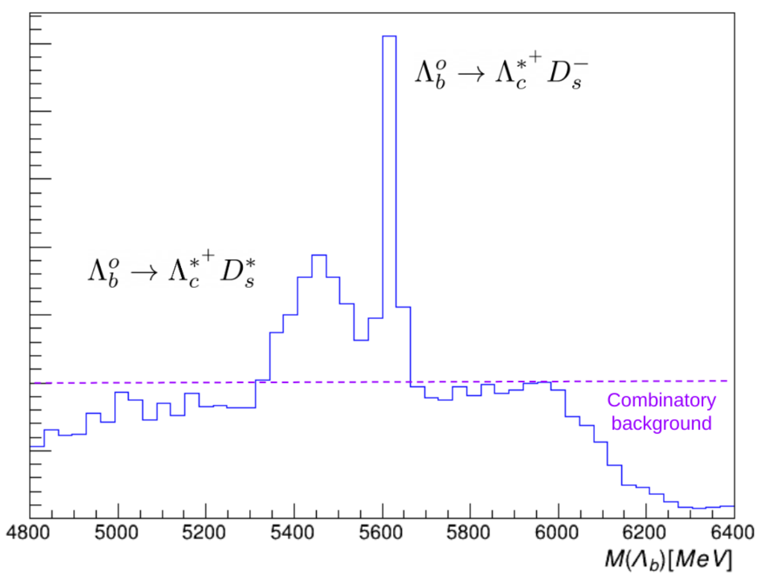

Figure 5: Histogram of Λ_b mass.

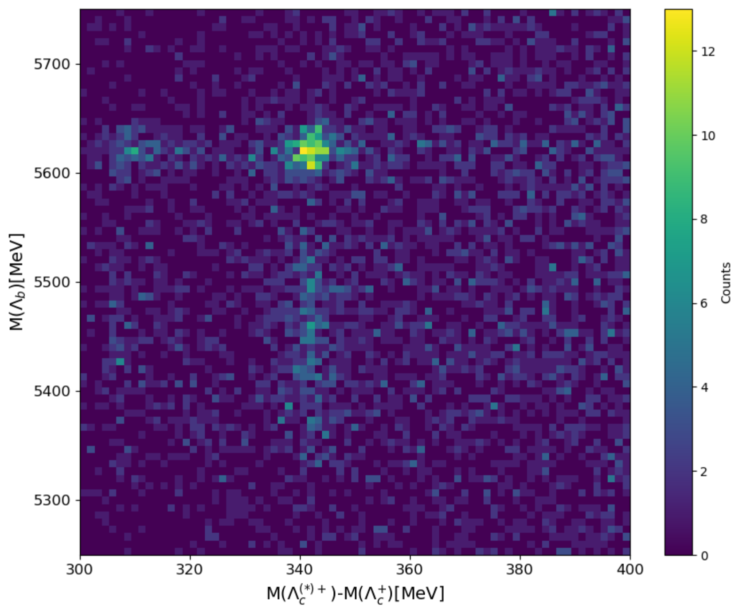

Figure 6: Bidimensional plot of Λ_b mass vs M(Λ_c^{*+}) $- M(\Lambda_c^+)$.

4 Extracting Λ_c^* Yields

A preliminary fit on $M(\Lambda_c^{*+}) - M(\Lambda_c^+)$ was done, as shown on Figure 7. We used the 2016, 2017, and 2018 LHCb data sample. The blue line represents the overall fit to the data. The green curve shows the fit for the $\Lambda_c(2625)$ signal, modeled with a double Gaussian. The yellow one is the fit for the $\Lambda_c(2595)$ signal modeled as a Gaussian convoluted with resolution effects. The red curve shows the background, modeled with the Argus PDF for random combinations, while the purple curve represents the real Σ_c with a pion.

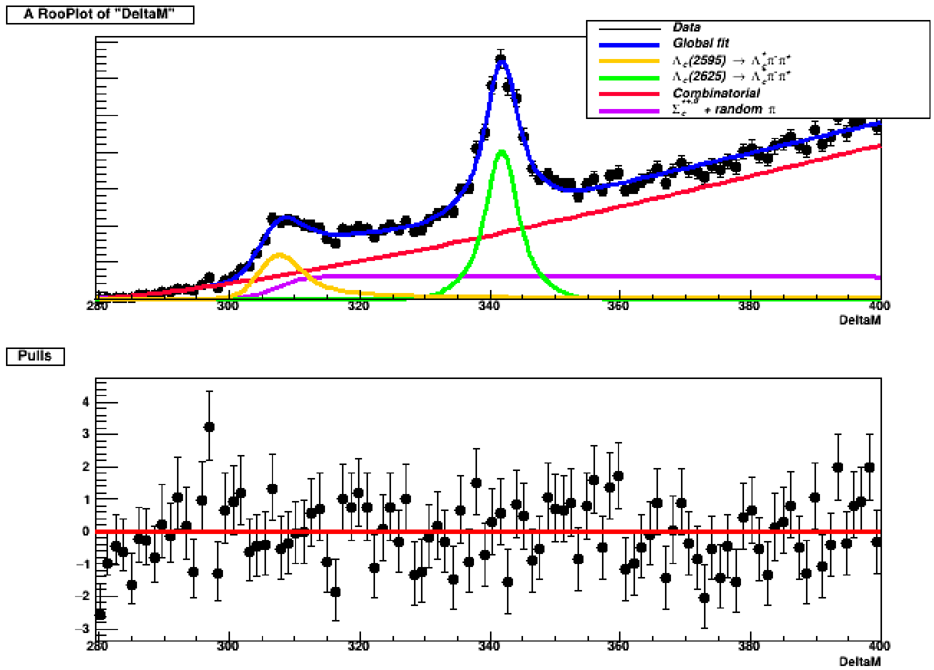

Figure 7: Fit of $M(\Lambda_c^{*+}) - M(\Lambda_c^+)$.

The fit for the signal was re-done using a Breit-Wigner function, in which we got favorable results. As mentioned before, the purple line represents the background due to Σ_c. As we have $\Lambda_c^+\pi^+\pi^-$, two possible combinations are possible: Σ_c^{++} when considering Λ_c^+ and π^+, or Σ_c^0 with the combinantion Λ_c^+ and π^-. The number of events containing Σ_c can be calculated by fitting the distribution of these two variables, Σ_c^0 and Σ_c^{++},in the sidebands $DeltaM > 360$ MeV.

Figures 8 and 9 show the fit for each variable. The model consists of a Gaussian PDF for the signal and an exponential PDF for the background.

From these fits, we can determine the number of Σ_c events for each variable. By integrating the ΔM distribution in the sideband region, we can estimate the total number of true non-resonant Σ_c events. This results are shown below. N_1 and N_2 corrrespond to the number of signal events in the first fit and second fit respectively.

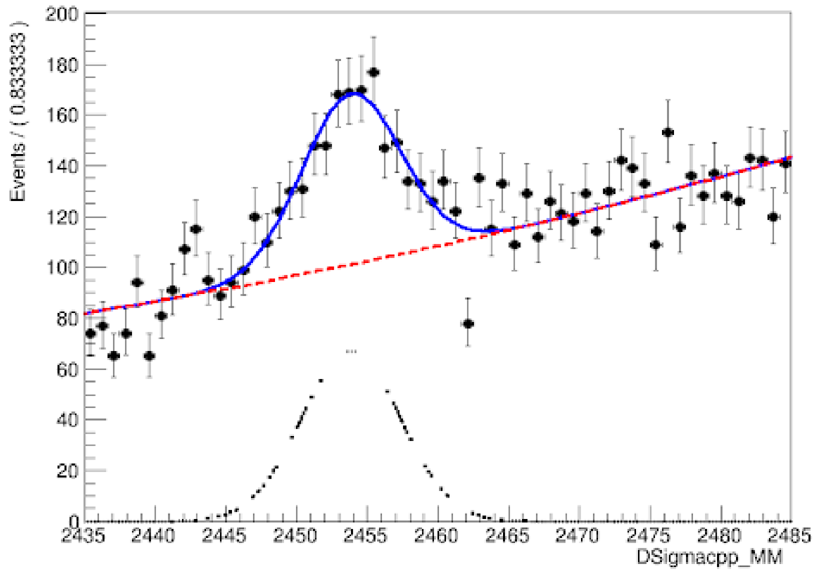

Figure 8: Fit of $M(\Sigma_c^{++})$.

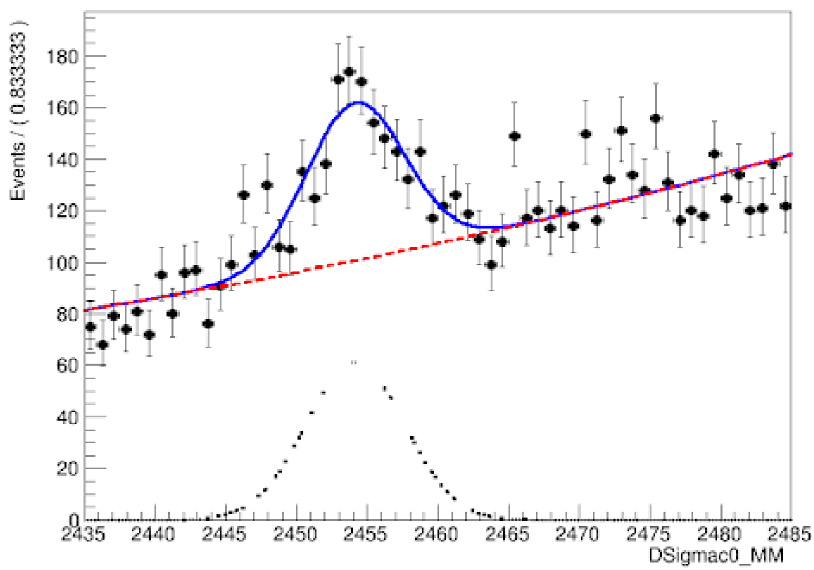

Figure 9: Fit of $M(\Sigma_c^{0})$.

$$Integral\,(DeltaM > 360) = 0.4\,(normalized)$$

$$New\, value\, of\, \Sigma_c = (N_1 + N_2)/0.4 = 3370.405$$

5 Conclusion

During my project, I focused on studying the Λ_c^* system decaying into $\Lambda_c^+\pi\pi$, with $\Lambda_c^+ = \Lambda_c(2595, 2625)^+$. We examined the background contributions such as $\Lambda_b \to \Lambda_c^+ D_s^-$ with $D_s^- \to K^- K^+ \pi^-$. A Breit-Wigner fit for the signal in the ΔM distribution was made. A 2D plot of ΔM versus Λ_b showed an acumulation of events $\Lambda_b^0 \to \Lambda_c^{*+} D_s^-$ and another for $\Lambda_b^0 \to \Lambda_c^* Ds^*$. Sideband fitting and ΔM integration provided estimates for Σ_c events. The exact number of non-resonant Σ_c events was succesfully calculated and will hopefully be used in future fits for ΔM. This is still a work in progress for the team. I want to extend my gratitude to my supervisors for their support throughout this summer project. Not only did encouraging me to work, but also motivated me to attend lectures and learn as much as I could.

References

[1] Katharina Müller and on behalf of the LHCb Collaboration. “Tests of Lepton Flavour Universality at LHCb”. In: *Journal of Physics: Conference Series* 1271.1 (July 2019), p. 012009. DOI: 10.1088/1742-6596/1271/1/012009. URL: https://dx.doi.org/10.1088/1742-6596/1271/1/012009.

[2] Sara Celani. *Lepton Flavour Universality tests and Lepton Flavour Violation searches at LHCb*. 2021. arXiv: 2111.11105 [hep-ex]. URL: https://arxiv.org/abs/2111.11105.