Towards a New Lepton Flavour Universality Test with Baryons: $\Lambda_b^0 \to \Lambda_c^{*+} D_s^{(*)-}$

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Introduction

- The Standard Model predicts Lepton Flavour Universality (LFU), meaning all lepton flavors should interact with equal strength. Testing LFU involves comparing the ratios of branching fractions in leptonic and semi-leptonic decays, and any deviation from equality would indicate new physics beyond the Standard Model.

- Testing LFU with semileptonic $\Lambda_b \to \Lambda_c^*$ decays $\left(\Lambda_c^* \to \Lambda_c^+, \Lambda_c^+ = \Lambda_c(2595, 2625)^+\right)$ can help verify current anomalies observed in decays involving charmed mesons. This can be achieved by measuring the ratio $R(\Lambda_c^*) = \frac{B(\Lambda_b \to \Lambda_c^{*+} \tau \bar{\nu}_\tau)}{B(\Lambda_b \to \Lambda_c^{*+} \mu \bar{\nu}_\mu)}$.

- We can evaluate the $\Lambda_b \to \Lambda_c^{*+} \tau \bar{\nu}_\tau$ decay by studying its dominant background, which is the $\Lambda_b^0 \to \Lambda_c^{*+} D_s^{(*)-}$ channel, with the D_s decaying to $\kappa^+ \kappa^- \pi^-$.

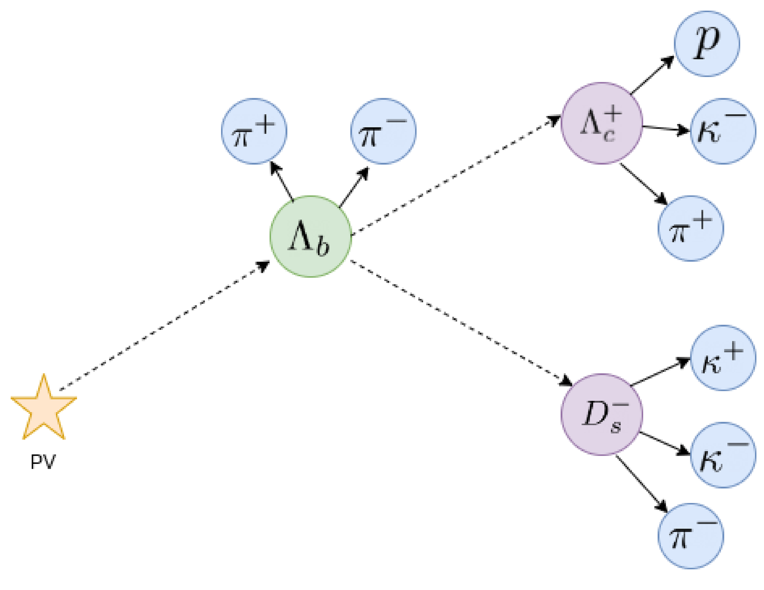


Figure 1. Decay channel.

- These decays are of interest as they provide an opportunity to study the nature of the $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$ states. Additionally, this branching ratio has never been calculated before.

Selection

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 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.

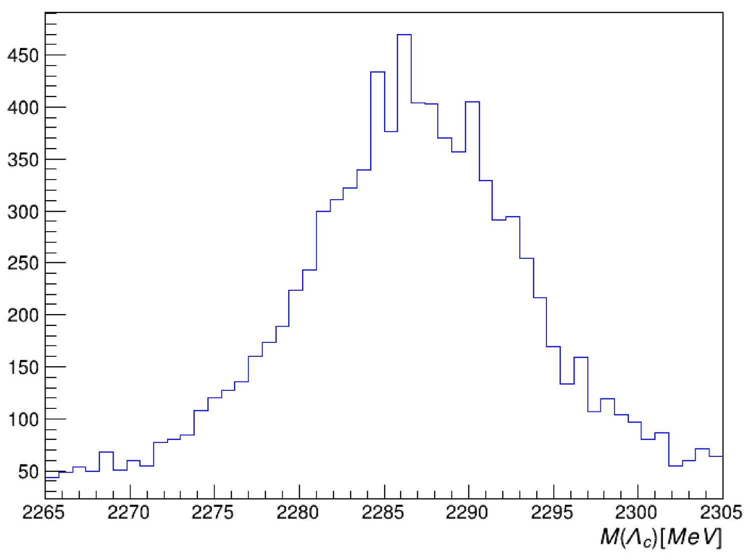
Stripping line and DaVinci selection

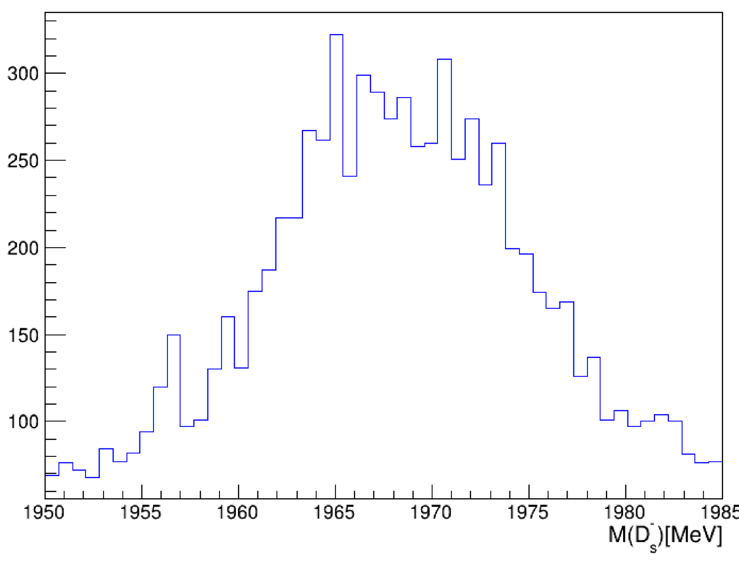
StrippingInclusiveCharmBaryons_LcLine selection

Particle	Stripping Selection
$p\ K^-$ Combination Cut	ADOCA(1,2) < 0.5 mm
$p\ K^- \pi^+$ Combination Cut	ASUM(PT)>1800 MeV ADAMASS(Λ_c^+) < 50 MeV ADOCA(p,π) < 0.5 mm ADOCA(K,π) < 0.5 mm Presence of daughter with: TRCHI2DOF < 4 PT > 500 MeV P > 5000 MeV
Λ_c^+ selection	CHI2VXNDF < 10 BPVVDCHI2 > 36 BPVDIRA > 0 ADMASS(Λ_c^+) < 32 MeV
Filter on Λ_c^+	Lc_BDT > 0.45

DaVinci selection

Particle	DaVinci Selection
$\pi^-/K^\pm$ from D_s^-	P> 1000 MeV PT> 100 MeV PROBNNpi> 0.2 / PROBNNk> 0.2 MIPCHI2DV(PRIMARY)> 4 TRCHI2DOF< 4 TRGHP< 0.4
K^+/K^- combination from D_s^-	AMASS< 2.1 GeV ACHI2DOCA< 20 ADOCA< 0.4 mm
$\pi^-/K^\pm$ combination from D_s^-	ACHI2DOCA< 20 ADOCA< 0.5 mm
$D_s^- \to K^+ K^- \pi^-$	ADAMASS(D_s)< 80 MeV PT> 600MeV P> 12GeV CHI2VXNDF< 40 BPVVDCHI2> 8 CHILDIP(K^-)< 3 mm CHILDIP(K^+)< 3 mm CHILDIP(π)< 5 mm
$\Lambda_c^+ \to pK^-\pi^+$	all from `InclusiveCharmBaryons_LcLine` stripping line
$\pi^\pm$ from Λ_c^{*+}	TRGHP< 0.6 PT> 100 MeV
$\Lambda_c^{*+} \to \Lambda_c^+ \pi^+ \pi^-$	ADAMASS($\Lambda_c(2625)$) < 500 MeV VFASPF(VCHI2/VDOF)< 10
$\Lambda_b^0 \to \Lambda_c^{*+} D_s^-$	AM$\in$ [4700; 6500] MeV VFASPF(VCHI2/VDOF)< 10 BPVIPCHI2()< 25 BPVDIRA> 0.999

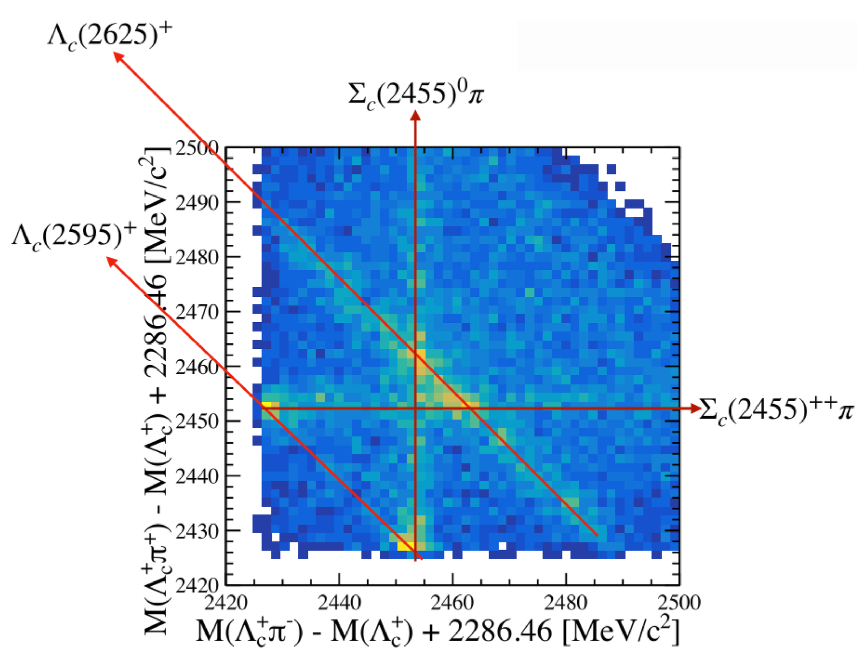




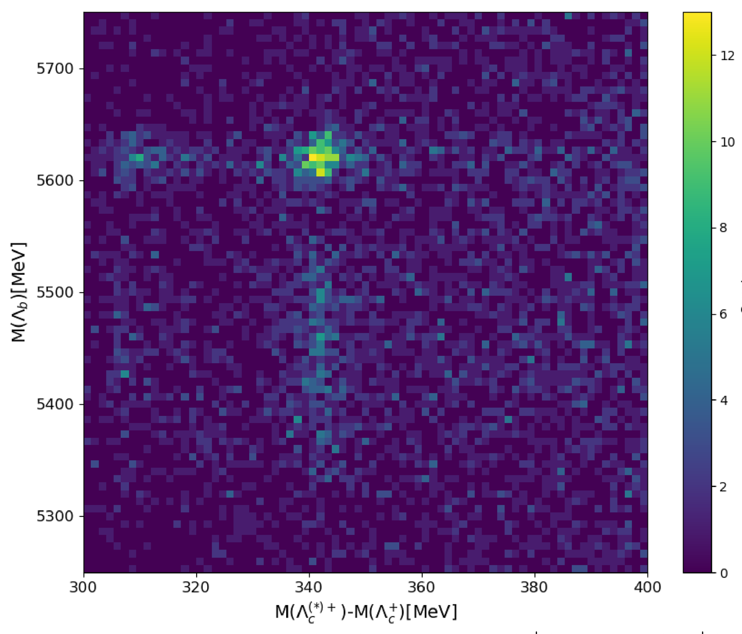
Project objectives

- Study the shape of the Λ_c^* system decaying into $\Lambda_c^+ \pi^+ \pi^-$.
- Understand the background due to other charmed baryons such as $\Lambda_b^0 \to \Sigma_c \pi D_s$, where $\Sigma_c \to \Lambda_c^+ \pi$.
- Develop an optimized Λ_b^0 and Λ_c^* selection.
- Create simultaneous fit that clearly distinguishes between the signal and the background of the two Λ_c^+ resonances.
- Extract the ratios $\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+(2625) D_s)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+(2595) D_s)}$ and $\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^* D_s)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^* \pi)}$, where $\mathcal{B}$ is the branching fraction.

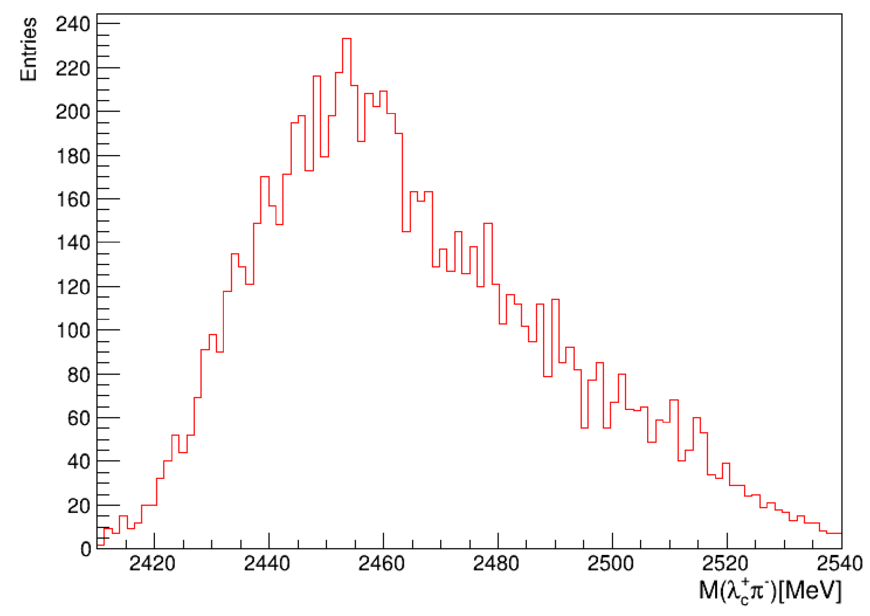
$\Lambda_c^+ \pi\pi$ structure



$\Lambda_c^+ \pi\pi$ structure



Histogram of $M(\Lambda_b)$ vs $M(\Lambda_c^{*+}) - M(\Lambda_c^+)$.



Histogram of $\Lambda_c^+ \pi^-$ invariant mass.

Extracting Λ_c^* Yields

A preliminary fit on $M(\Lambda_c^{*+}) - M(\Lambda_c^+)$ has been done. 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.

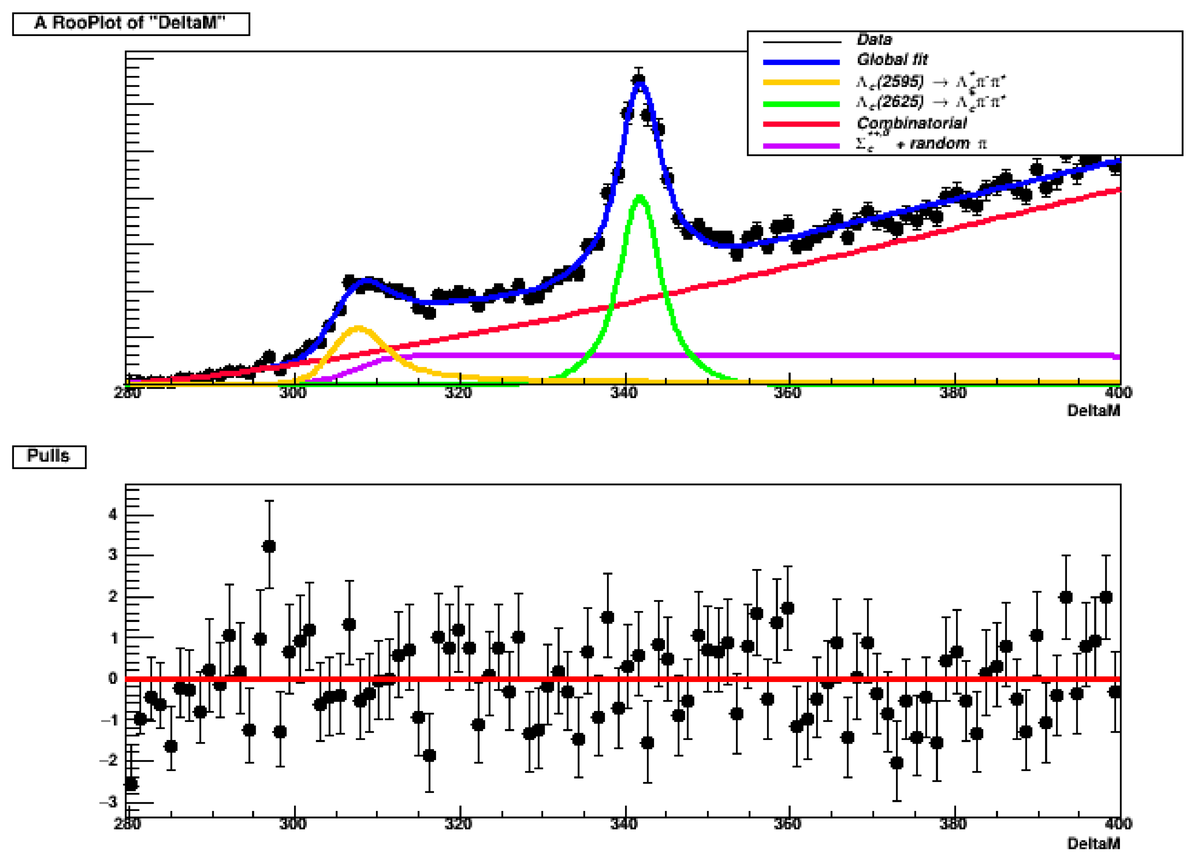
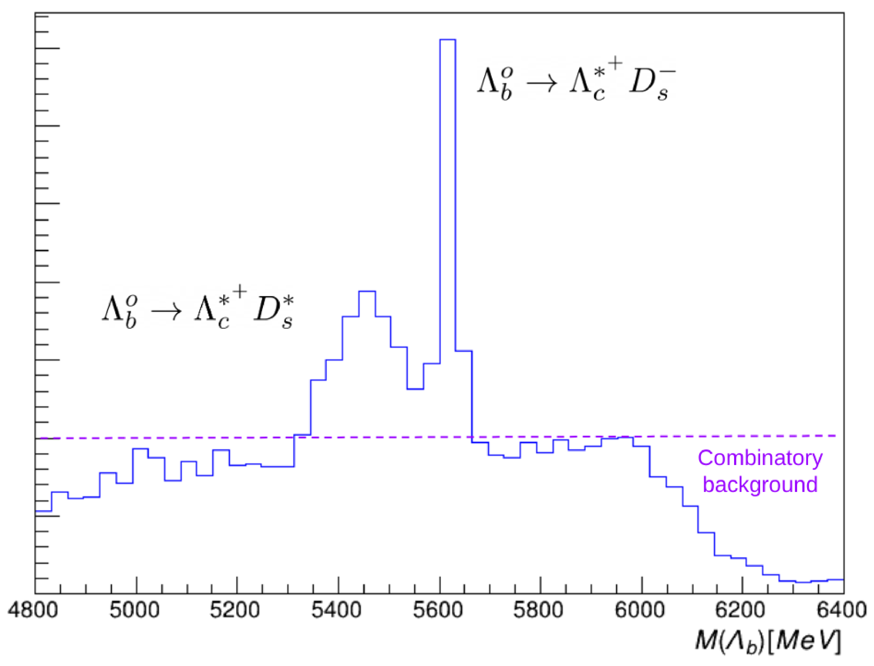


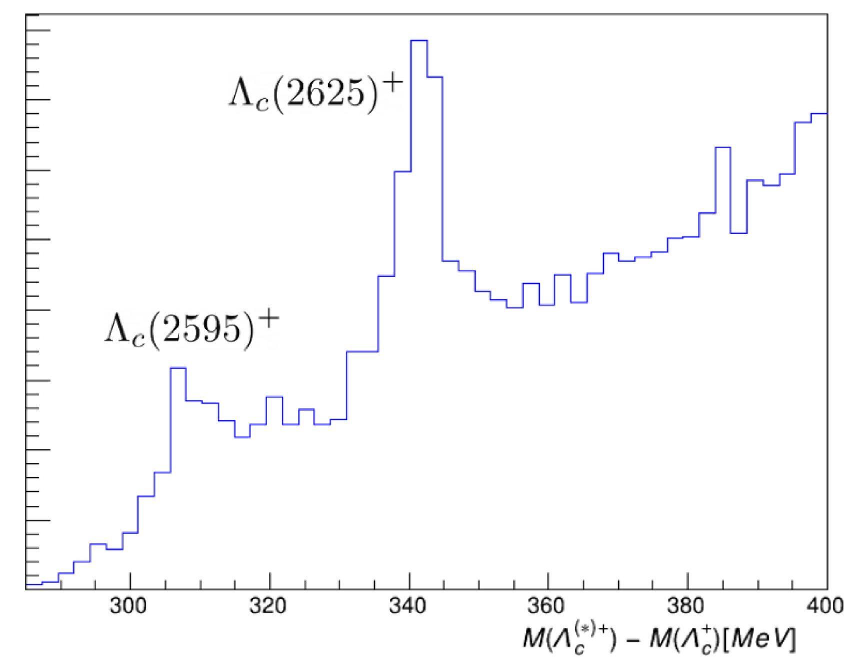
Figure 3. Fit of $M(\Lambda_c^{*+}) - M(\Lambda_c^+)$.

$\Lambda_b^0 \to \Lambda_c^* D_s^{(*)}$ Yields and Ratio of the Branching Fraction

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+(2625) D_s)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+(2595) D_s)} = \frac{N(\Lambda_b^0 \to \Lambda_c^+(2625) D_s)}{N(\Lambda_b^0 \to \Lambda_c^+(2595) D_s)} \times \frac{\epsilon(\Lambda_b^0 \to \Lambda_c^+(2595) D_s)}{\epsilon(\Lambda_b^0 \to \Lambda_c^+(2625) D_s)}$$



Histogram of Λ_b mass.



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

Conclusion

- We will continue our efforts on a two-dimensional fit involving $M(\Lambda_b)$ versus $M(\Lambda_c^{*+}) - M(\Lambda_c^+)$ to extract the event $\Lambda_b^0 \to \Lambda_c^{*+} D_s^{*-}$.
- For the fit of the Λ_b^0 invariant mass, a Breit-Wigner function or a double Crystal Ball function can be use to model the mass distribution of the event of interest.
- This is a work in progress, and further refinements will be made as the team continue with the analysis.

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