Towards a New Lepton Flavour Universality Test with Baryons: First Evidence of $\Lambda_b^0 \rightarrow \Lambda_c^* D_s^{(*)}$

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Introduction

- The LHCb recently presented the Branching Ratio of the semi-leptonic decay $\Lambda_b^0 \rightarrow \Lambda_c^+ \tau^- \bar{\nu}_\tau$, where the τ^- was reconstructed in the $\pi^+\pi^-\pi^+\bar{\nu}_\tau$ decay mode.
- Another semi-leptonic decay $\Lambda_b^0 \rightarrow \Lambda_c^* \tau^- \bar{\nu}_\tau$ offers interesting observables, where, in this projects case, Λ_c^* can either be $\Lambda_c^+(2595)$ or $\Lambda_c^+(2625)$.
- To understand $\Lambda_b^0 \rightarrow \Lambda_c^* \tau^- \bar{\nu}_\tau$, it is of paramount importance that we understand the hadronic channels $\Lambda_b^0 \rightarrow \Lambda_c^* D_s^-$ and $\Lambda_b^0 \rightarrow \Lambda_c^* D_s^*$.

Why study $\Lambda_b^0 \rightarrow \Lambda_c^* D_s^-$ and $\Lambda_b^0 \rightarrow \Lambda_c^* D_s^*$???

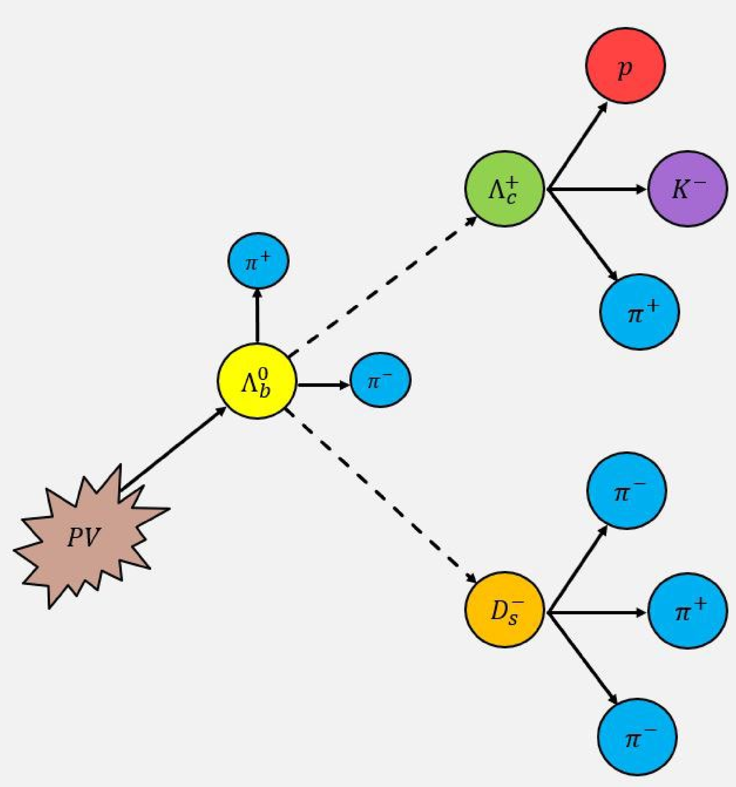
- They exist as a significant background in $\Lambda_b^0 \rightarrow \Lambda_c^* \tau^- \bar{\nu}_\tau$ decays
- They also have never been directly observed before!

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 $\Lambda_b^0 \rightarrow \Sigma_c \pi D_s$, where $\Sigma_c \rightarrow \Lambda_c^+ \pi$.
- 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 $\frac{\mathfrak{B}(\Lambda_b^0 \rightarrow \Lambda_c^+(2625) D_s)}{\mathfrak{B}(\Lambda_b^0 \rightarrow \Lambda_c^+(2595) D_s)}$ and $\frac{\mathfrak{B}(\Lambda_b^0 \rightarrow \Lambda_c^* D_s)}{\mathfrak{B}(\Lambda_b^0 \rightarrow \Lambda_c^* 3\pi)}$, where $\mathfrak{B}$ is the branching fraction.

The Decay Channel

Dataset: 2016, 2017, 2018 LHCb data, $\approx 6\ \text{fb}^{-1}$



Stripping & Trigger Lines

Cuts used in the stripping selection.

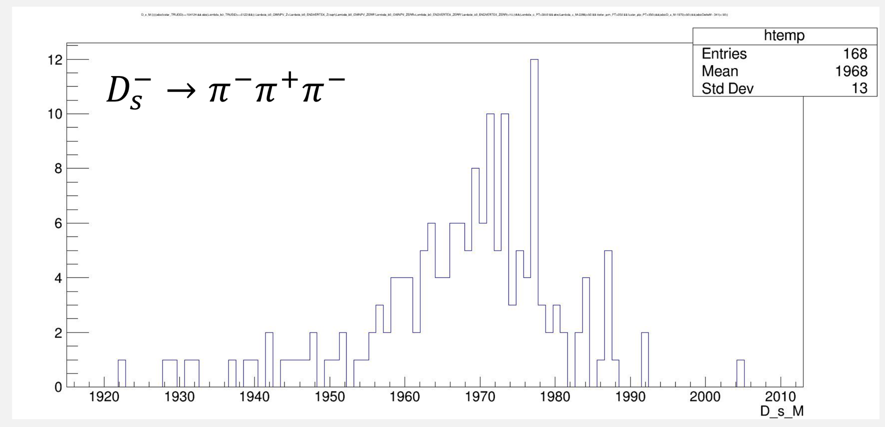
Cut	Value
Λ_b^0	
$m(\Lambda_c^+\pi\pi\pi)$	2500-5900 MeV/c^2
DIRA	> 0.995
Max. DOCA	< 0.15 mm
Λ_c^+	
p_T	> 1200 MeV/c
$m(pK^-\pi^+)$	2256.5-2316.5 MeV/c^2
Vertex Distance χ^2	> 36
IP χ^2	> 10
Vertex χ^2/DOF	< 10
Vertex χ^2	< 30
Max. DOCA	< 0.5 mm
DIRA	> 0.995
τ	
m($\pi\pi\pi$)	400-3500 MeV/c^2
min[m($\pi\pi$)]	< 1670 MeV/c^2
DIRA	> 0.99
Vertex χ^2	< 25
Max. DOCA	< 0.15 mm
At least two pions p_T	> 300 MeV/c^2
At least two pions IP χ^2	> 5
τ daughter pions	
p_T	> 250 MeV/c
IP χ^2	> 4
Track χ^2/DOF	< 3
PIDK	< 8
Ghost probability	< 0.4
Λ_c^+ daughters	
p_T	> 250 MeV/c
p	> 2000 MeV/c
Kaon PIDK	> 3
Pion PIDK	< 50
Proton PIDp	> 5
Track χ^2/DOF	< 3
IP χ^2	> 10
Ghost Probability	< 0.4

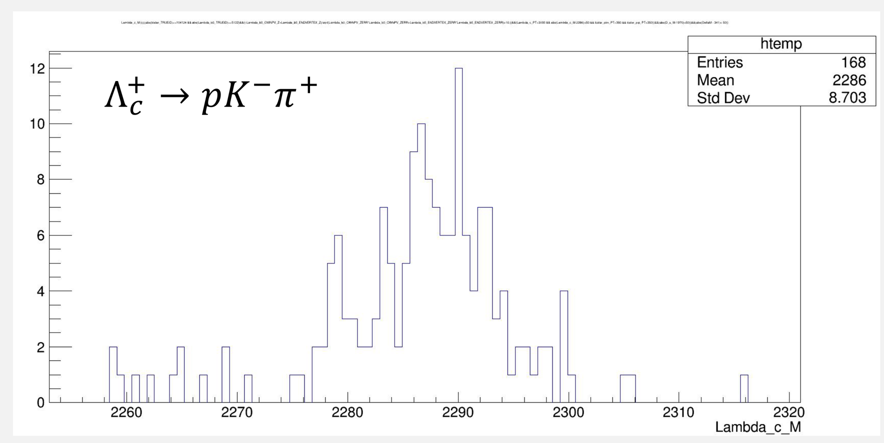
- The first stage of the selection, called stripping, is a set of loose cuts that selects events that are of interest to physics analyses. This method is employed during the central offline processing of the data samples to maintain computational inexpensiveness.

The trigger system is of crucial importance to discriminate the interesting b hadron decays against the dominant background from inelastic pp-scattering. The trigger is based on a two level system and exploits the fact that b-flavored hadrons are relatively heavy and long lived Furthermore, it is possible to select events where the trigger decision was made on signal (TOS) or on other particles present in the event (TIS).

(((Lambda_b0_L0Global_TIS) | | (Lambda_b0_L0HadronDecision_TOS))&&((Lambda_b0_Hlt1TwoTrackMVADecision_TOS) | (Lambda_b0_Hlt1TrackMVADecision_TOS)))" ((Lambda_b0_Hlt2Topo2BodyDecision_TOS) | | (Lambda_b0_Hlt2Topo3BodyDecision_TOS) | | (Lambda_b0_Hlt2Topo4BodyDecision_TOS))

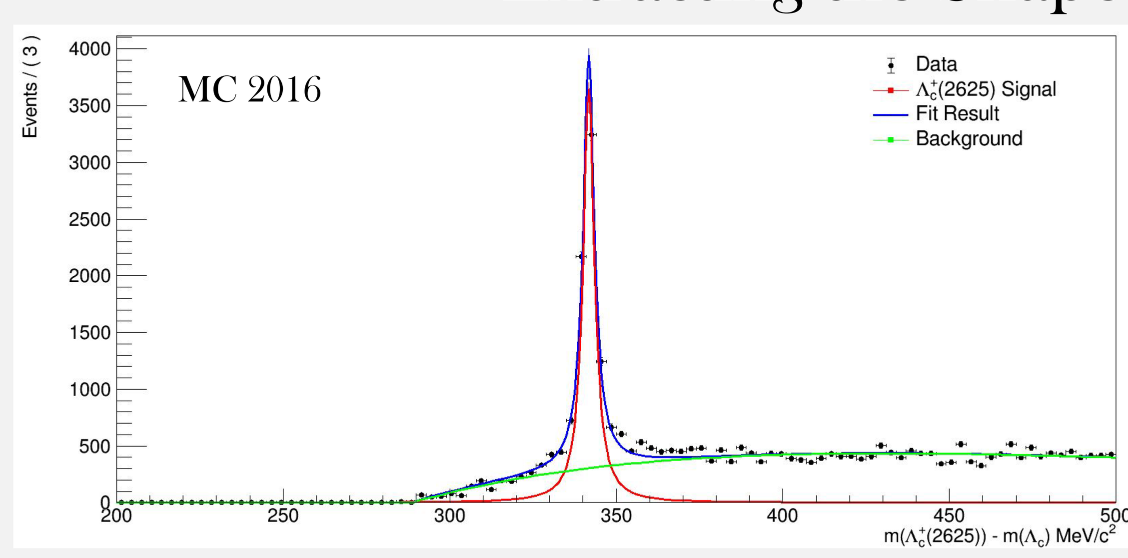
Selection

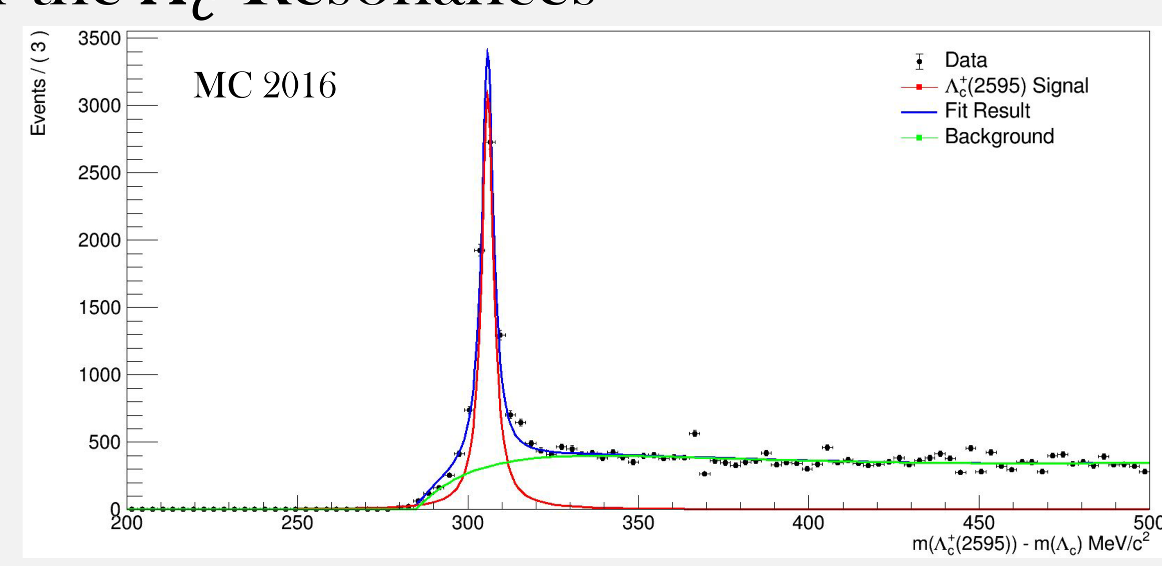




- Λ_b^0 Selection:
  - b quark hadron decays can be distinguished from other inelastic pp interactions, by the presence of a secondary vertex and particles with high transverse momentum p_T.
  - We require that the Λ_b^0 is downstream with respect to the primary vertex PV.
- D_s Selection:
  - We require that the D_s vertex is downstream with respect to the Λ_b^0 vertex along the beam direction with a significance of 4σ.
- Λ_c^+ and Λ_c^* Selection:
  - We require that the transverse momentum for the two pions that form the Λ_c^* is greater than 350 MeV/c.
  - We also require that Λ_c^+ has a high transverse momentum and with a mass that is reasonably near the known value.
- We defined these selections requiring on the simulated samples the Monte Carlo truth: these variables ensure that we have considered the correct simulated sample

Extracting the Shape of the Λ_c^* Resonances





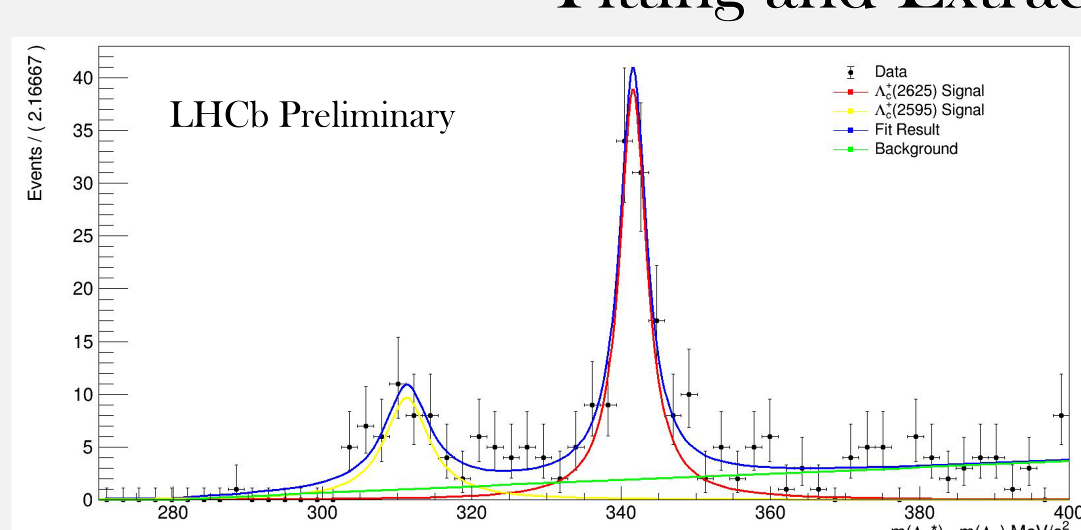
- As we can see in both plots above, the red line is a Breit-Wigner that represents the signal of the resonance in question. The blue line is the total fit. The green line is a threshold function that represents the background.

Efficiencies

- We rely on the Monte Carlo efficiencies to extract the ratio of the branching fraction.
- $\epsilon = \frac{Selection\ Events}{MC\ Truth\ Total\ Events}$
- $\epsilon = \epsilon_{selection}\epsilon_{trigger}\epsilon_{stripping}$

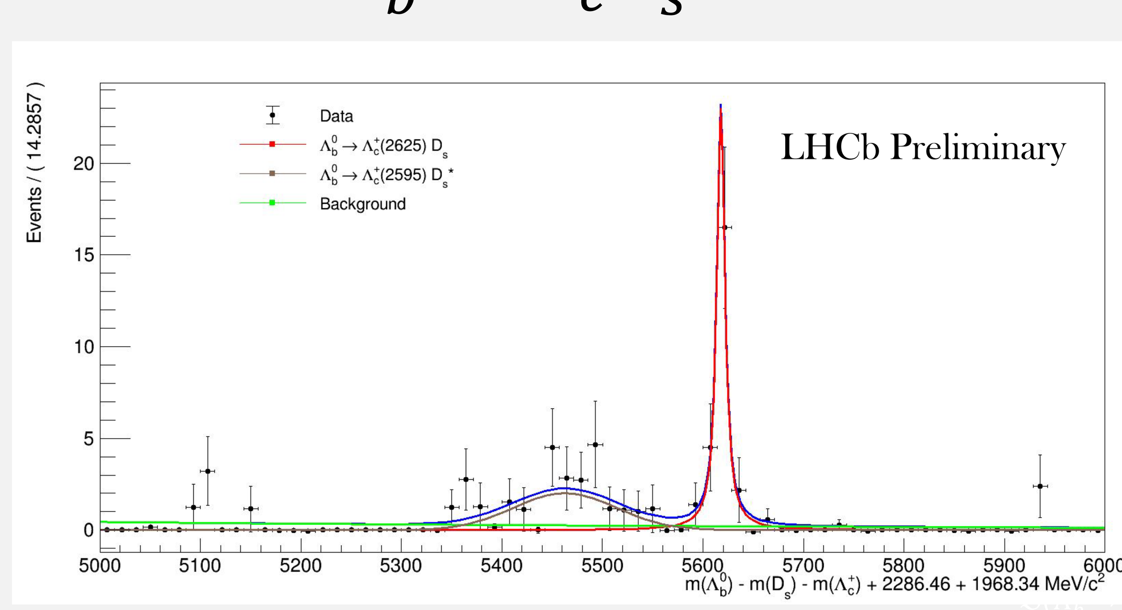
	$\Lambda_b^0 \rightarrow \Lambda_c^+(2625)\ D_s^-$	$\Lambda_b^0 \rightarrow \Lambda_c^+(2595)\ D_s^-$
$\epsilon_{selection}$	0.012	0.009
$\epsilon_{trigger}$	0.80	0.80

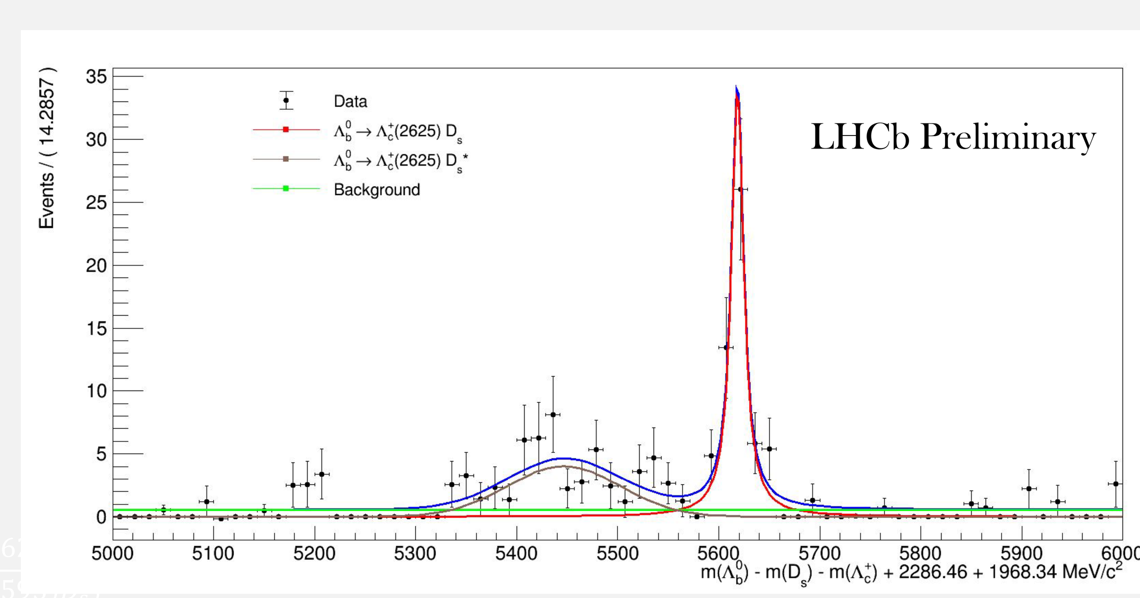
Fitting and Extracting Λ_c^* Yields



- Extracted number of signal events for $\Lambda_c^+(2625)$: N_{2625}
- Extracted number of signal events for $\Lambda_c^+(2595)$: N_{2595}

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





$$\frac{\mathfrak{B}(\Lambda_b^0 \rightarrow \Lambda_c^+(2625) D_s)}{\mathfrak{B}(\Lambda_b^0 \rightarrow \Lambda_c^+(2595) D_s)} = \frac{N(\Lambda_b^0 \rightarrow \Lambda_c^+(2625) D_s)}{N(\Lambda_b^0 \rightarrow \Lambda_c^+(2595) D_s)} * \frac{\epsilon(\Lambda_b^0 \rightarrow \Lambda_c^+(2595) D_s)}{\epsilon(\Lambda_b^0 \rightarrow \Lambda_c^+(2625) D_s)}$$

- This is the first evidence of the $\Lambda_b^0 \rightarrow \Lambda_c^* D_s^*$ and $\Lambda_b^0 \rightarrow \Lambda_c^* D_s$!
- It will be interesting to study these channels with the $D_s \rightarrow KK\pi$, due to the higher branching ratio.