$\Lambda_b^0 \to \Lambda_c^+ \overline{\Lambda}_c^- n$: A First Study of a Purely Baryonic Decay With a Neutron

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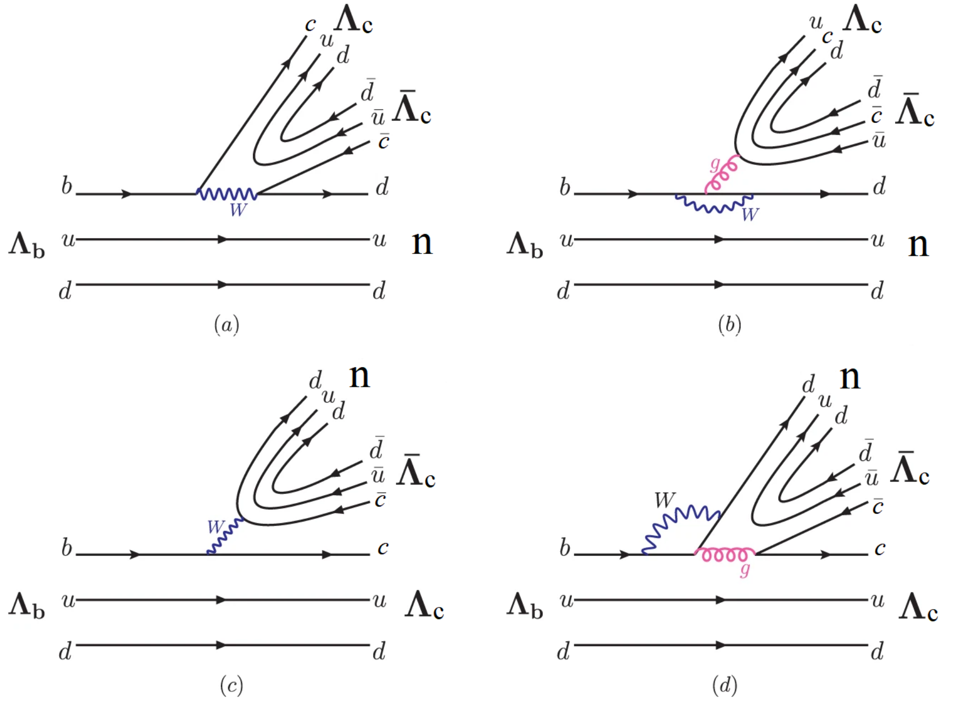
Introduction: Baryonic *b*-Decays

- Large *b*-mother masses allow for many different baryonic final states most of which are experimentally unknown.
- Theoretical description is a challenge and there are some phenomena such as the threshold enhancement that is not fully understood.
  [Ref: e.g. The Physics of the B Factories]
- First observation of a baryonic *b*-decay made in 1997: $B^0 \to \Lambda_c^+ \bar{p} \pi^+ \pi^-$.
  [Ref: Observation of Exclusive Decays to Final States Containing a Charmed Baryon]
- Currently the study of Purely Baryonic Decays (PBDs) i.e. a baryon decaying to only baryons is a very weakly probed region of Standard Model Physics.
- In addition, neutrons (lightest baryon alongside the proton) are difficult to observe at collider experiments.
- $D_s^0 \to p\bar{n}$ has been observed at CLEO
  [Ref: First Observation of the Decay D(s)+ ---> p anti-n]
- But currently no decay with final a state neutron observed yet at the LHC.

Introduction: $\Lambda_b^0 \to \Lambda_c^+ \overline{\Lambda}_c^- n$

- Motivation for the analysis is 2-fold:
  - Contribute to the emergent efforts towards measurements of Purely Baryonic Decays, of which only 1 so far has a completed dedicated study.
    - $\Lambda_b^0 \to p\bar{p}\Lambda$
      [Ref: First indication of the Lambda-b baryon decay to a charmless baryonic final state]
  - Hopefully, the first observation of a decay with a final state neutron at the LHC.

- Why $\Lambda_b^0 \to \Lambda_c^+ \overline{\Lambda}_c^- n$?
  - Reasonable predicted branching fraction $\sim 10^{-5}$.
  - Low Q value:
    $m(\Lambda_b^0) - 2m(\Lambda_c) - m(n) \approx 107\text{MeV}$
    (cleaner momentum resolution at source, phase-space suppression for backgrounds).
  - Excellent momentum resolution for Λ_c pair when reconstructed from $\Lambda_c^+ \to p^+ K^- \pi^+$ at LHCb.

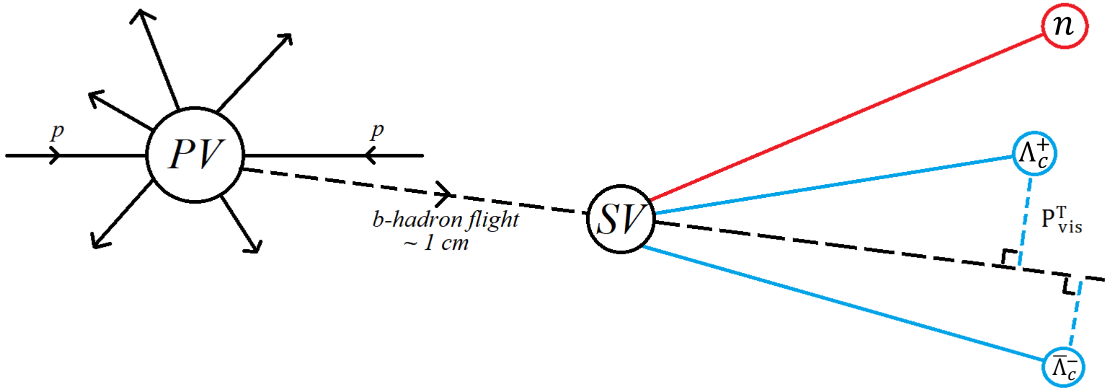


Leading order Feynman diagrams for $\Lambda_b^0 \to \Lambda_c^+ \overline{\Lambda}_c^- n$.

Analysis Outline

- My work is a search for $\Lambda_b^0 \to \Lambda_c^+ \overline{\Lambda}_c^- n$, this is done using the LHCb Run 2 dataset.
- Comparison and validation of signal channel against either:
  - $B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+$ [Ref: Study of the $B^\pm \to \Lambda_c^\pm \overline{\Lambda}_c^\mp K^\pm$ decay]
  - $B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_s^0$ [Analysis finalising]
  - Or Both…
- Both of the above decays have had dedicated analyses at LHCb.
- We have a glaring difference to these decays in that a neutron is not explicitly reconstructible.
- Therefore, a missing momentum approach is used (similar to that of neutrino analyses).
- We use a mass correction to account for the missing neutron using momentum transverse to b-mother flight.

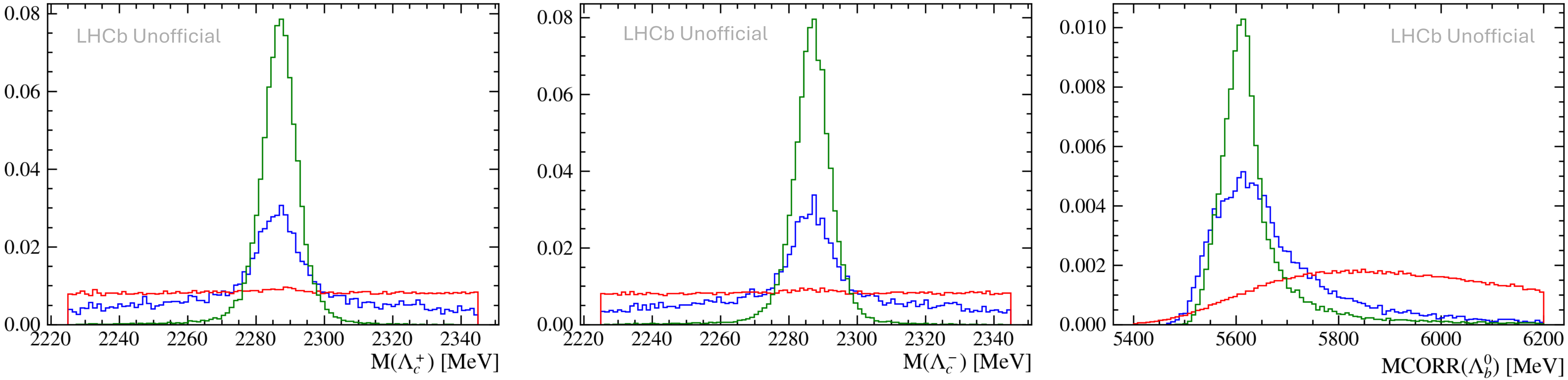
- $M_{CORR} = \sqrt{{P_{vis}^T}^2 + m_{vis}^2} + \sqrt{{P_{vis}^T}^2 + m_{invis}^2}$
- P_{vis}^T, visible transverse momentum to b-hadron flight.
- m_{vis}^2, visible mass squared.
- m_{invis}^2, invisible mass squared, i.e. neutron mass.



Event Selection

- We initially reconstruct $\Lambda_c^+ \rightarrow\ p^+K^-\pi^+$ (and charge conjugate) to form the $\Lambda_c^+\overline{\Lambda}_c^-$ pair using standard LHCb Λ_c^+ reconstruction.
- This accepts a large amount of background, so we make some additional manual selection cuts on neural net particle identification variables along with track momentum and some typical LHCb geometric parameters.
- Further selection will be made using a Multi-Variate Analysis (MVA).
- Data In plot bellow is a small subset of the 2016 sample, distributions are normalised.

Data with additional selection cuts
Data with initial $\Lambda_c^+\overline{\Lambda}_c^-$ reconstruction
Signal MC



Backgrounds

Allowed | Suppressed/Forbidden

- What we have done: reconstruct $\Lambda_c^+\overline{\Lambda}_c^-$ pairs and account for missing momentum via a mass correction.
- This is an inclusive selection and can allow some $\Lambda_c^+\overline{\Lambda}_c^-$ decays to pass.
- What is actually in that MCORR(Λ_b^0) blob? What are the backgrounds?
- Most prominent are kinematically allowed decays from b-mesons into $\Lambda_c^+\overline{\Lambda}_c^- X$, where X is some assortment of hadrons.
- $\Lambda_b^0 \to \Lambda_c^+\overline{\Lambda}_c^- B$ (B is a baryon) is not allowed as the next lightest neutral baryon after the neutron is the Λ which is too heavy at ~ 1116 MeV.
- B meson decays to $\Lambda_c^+\overline{\Lambda}_c^- X$ where X is a resonance such as $\rho(770)$ are either kinematically suppressed or forbidden.
- Decays to heavier excited charm baryons are usually supressed.
  - $B^0 \to \Sigma_c(\Lambda_c^+\pi^0)\overline{\Lambda}_c^- K_s^0$ is visible in the $\Lambda_c^+\overline{\Lambda}_c^- K_s^0$ extended spectrum although the Q-value is too small to be prominent in our corrected mass spectrum.
  - Higher excited states of the Λ_c^+ are subject to suppression from the additional units of orbital spin.

Backgrounds: $\Lambda_c^+\overline{\Lambda}_c^- X$

- Kinematically allowed $\Lambda_c^+\overline{\Lambda}_c^-$ background candidates:
  - $B^+ \to \Lambda_c^+\overline{\Lambda}_c^- K^+$
  - $B^0 \to \Lambda_c^+\overline{\Lambda}_c^- K_s^0$

  Category 1: B with 1 K | Known BFs | Q-value ~ 210 MeV

  - $B^+ \to \Lambda_c^+\overline{\Lambda}_c^- K^+\pi^0$
  - $B^+ \to \Lambda_c^+\overline{\Lambda}_c^- K_s^0\pi^+$
  - $B^0 \to \Lambda_c^+\overline{\Lambda}_c^- K^+\pi^-$
  - $B^0 \to \Lambda_c^+\overline{\Lambda}_c^- K_s^0\pi^0$

  Category 2: B with 1 K + 1 π | Unknown BFs | Q-value ~ 72 MeV

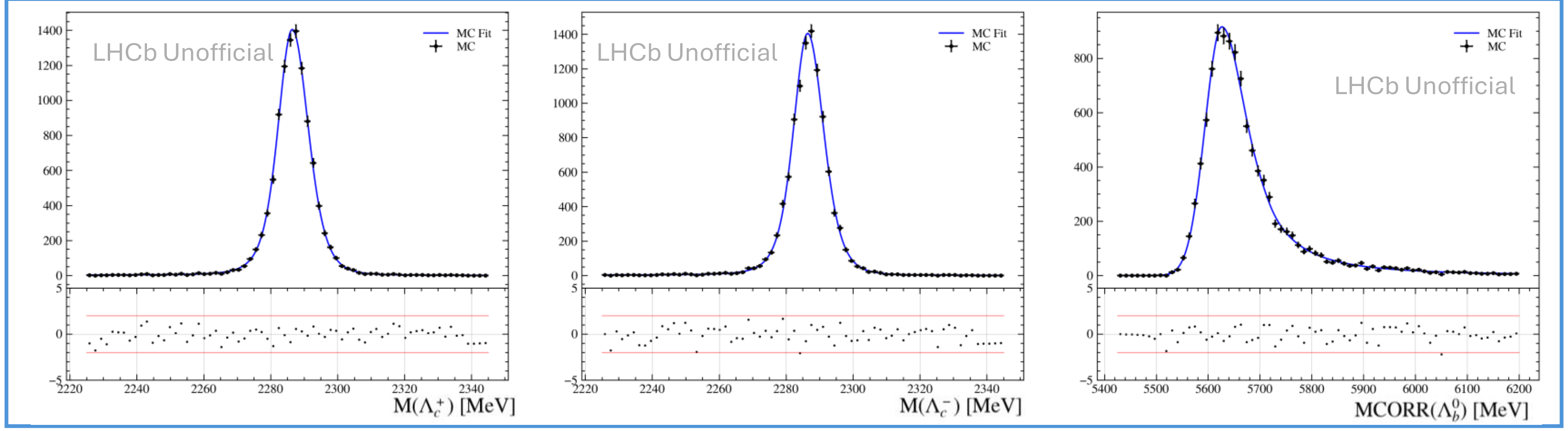
  - $B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^- K_s^0$

  Category 3: B_s^0 with 1 K | Unknown BFs | Q-value ~ 295 MeV

  - $B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^- K_s^0\pi^0$
  - $B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^- K^-\pi^+$

  Category 4: B_s^0 with 1 K + 1 π | Unknown BFs | Q-value ~ 160 MeV

Decays will be fit with MC category templates, e.g. Right: Category 1 (normalisation modes).



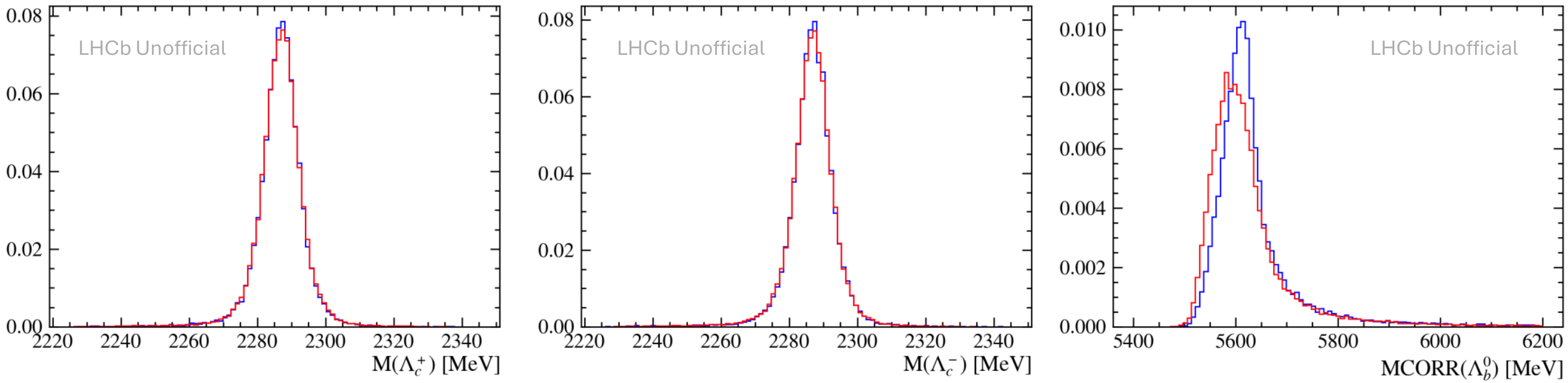
Backgrounds: $\Lambda_c^+\overline{\Lambda}_c^- X$ Constraints

- Some of these backgrounds are overlapping with signal in MCORR(Λ_b^0), e.g. category 4 (below).
  - $B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^- K_s^0\pi^0$
  - $B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^- K^-\pi^+$

  Category 4
- We are currently constraining the yields of $\Lambda_c^+\overline{\Lambda}_c^- X$ background categories to the known decays $B^+ \to \Lambda_c^+\overline{\Lambda}_c^- K^+$ and $B^0 \to \Lambda_c^+\overline{\Lambda}_c^- K_s^0$
- This gives us the opportunity to reconstruct and explore a number of $\Lambda_c^+\overline{\Lambda}_c^- X$ mass spectra.

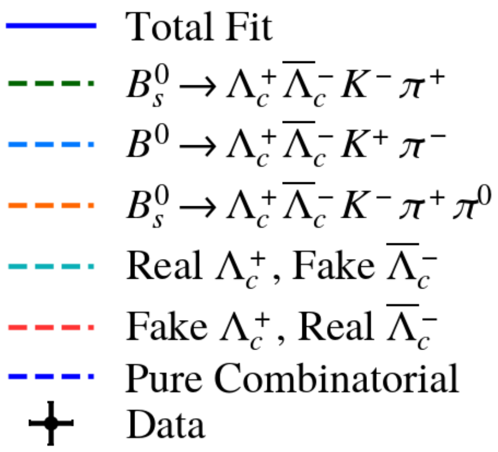
kgrounds are c

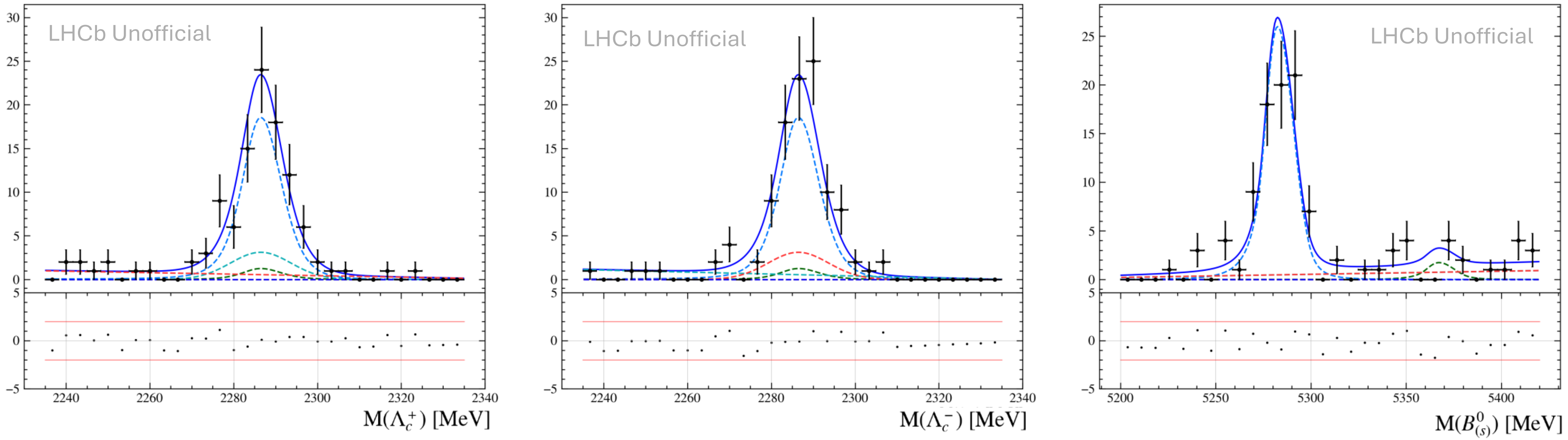
Distribution comparison of Signal MC to Category 4 MC



Backgrounds: $\Lambda_c^+\overline{\Lambda}_c^-K^-\pi^+$

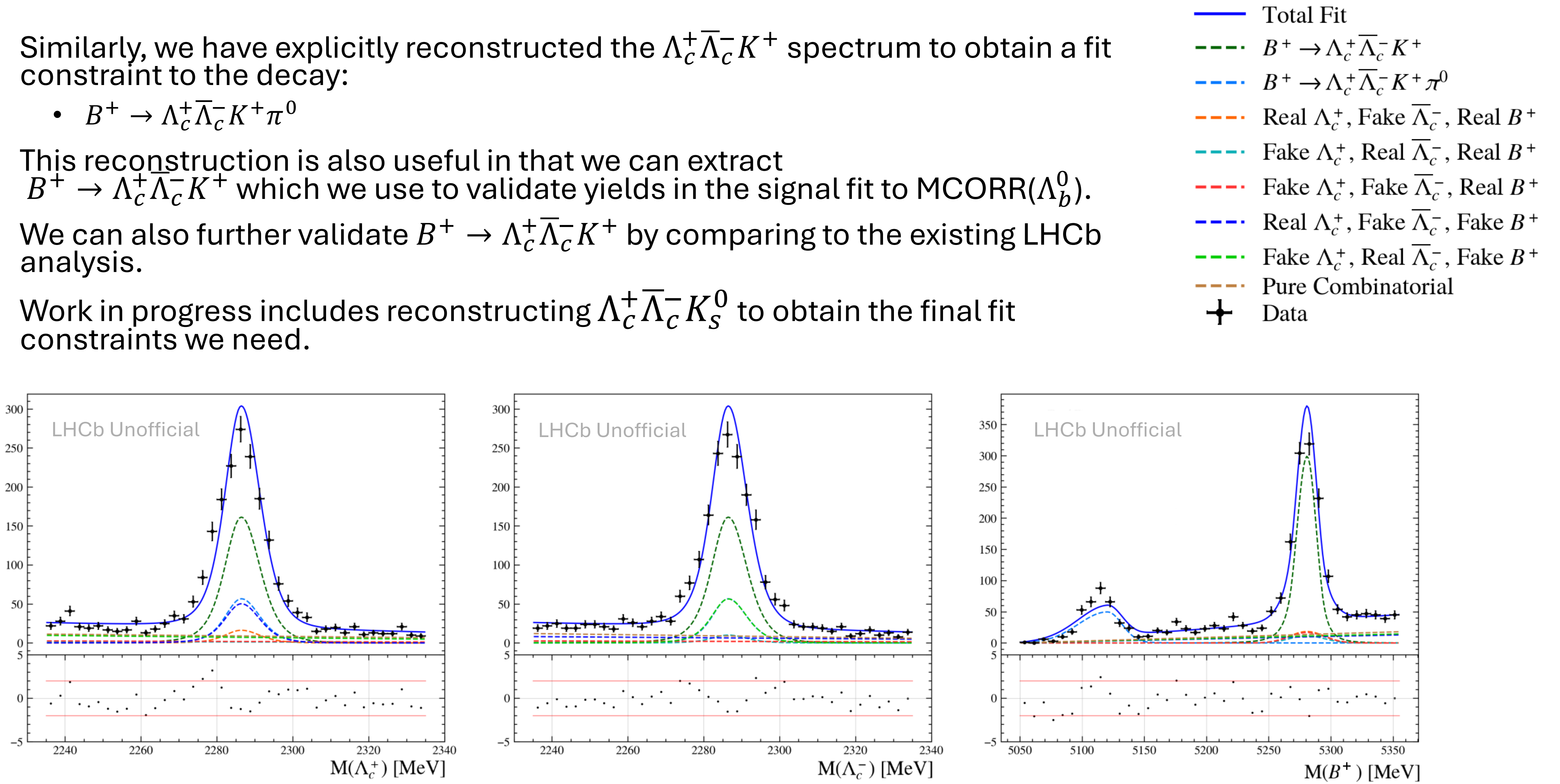
- We have explicitly reconstructed the $\Lambda_c^+\overline{\Lambda}_c^-K^-\pi^+$ spectrum and obtained fit constraints for the decays:
  - $B^0 \to \Lambda_c^+\overline{\Lambda}_c^-K^+\pi^-$
  - $B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^-K^-\pi^+$
- We can see from the mass spectra a clear peak at the B^0 mass.
- As $B^0 \to \Lambda_c^+\overline{\Lambda}_c^-K^-\pi^+$ is not yet experimentally observed we can consider this a first observation!
- Contribution from the B_s^0 mode is minimal.





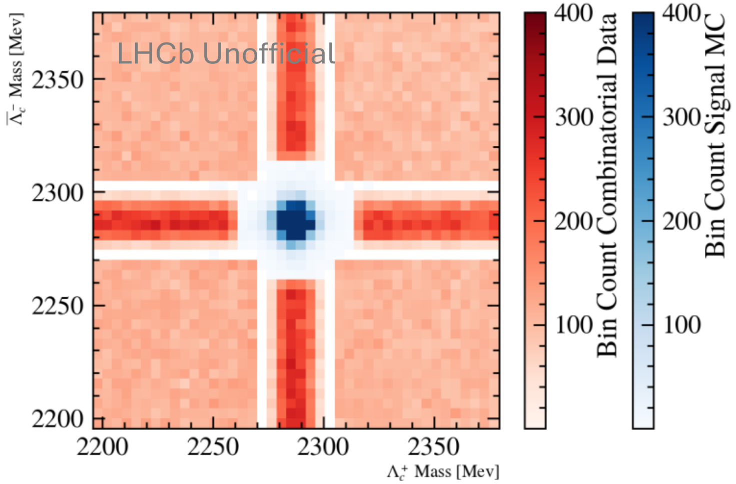
Backgrounds: $\Lambda_c^+\overline{\Lambda}_c^-K^+$

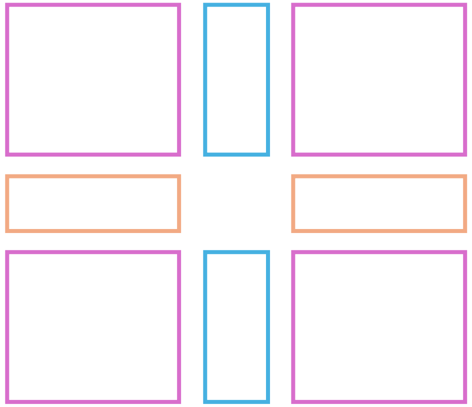
- Similarly, we have explicitly reconstructed the $\Lambda_c^+\overline{\Lambda}_c^-K^+$ spectrum to obtain a fit constraint to the decay:
  - $B^+ \to \Lambda_c^+\overline{\Lambda}_c^-K^+\pi^0$
- This reconstruction is also useful in that we can extract $B^+ \to \Lambda_c^+\overline{\Lambda}_c^-K^+$ which we use to validate yields in the signal fit to MCORR(Λ_b^0).
- We can also further validate $B^+ \to \Lambda_c^+\overline{\Lambda}_c^-K^+$ by comparing to the existing LHCb analysis.
- Work in progress includes reconstructing $\Lambda_c^+\overline{\Lambda}_c^-K_S^0$ to obtain the final fit constraints we need.



Backgrounds: Combinatorial

- We can model Combinatorial in MCORR(Λ_b^0) from 3 distinct contributions:
  - True Λ_c^+ & Fake $\overline{\Lambda}_c^-$
  - Fake Λ_c^+ & True $\overline{\Lambda}_c^-$
  - Fake Λ_c^+ & Fake $\overline{\Lambda}_c^-$
- Respectively they have shapes in $\Lambda_c^+\overline{\Lambda}_c^-$ Mass:
  - Peaking Λ_c^+ & Flat $\overline{\Lambda}_c^-$
  - Flat Λ_c^+ & Peaking $\overline{\Lambda}_c^-$
  - Flat Λ_c^+ & Flat $\overline{\Lambda}_c^-$
- The shape in Λ_b^0 corrected mass is non-trivial and is currently retrieved from a sideband proxy fitted with a double Crystal Ball.
- We leave the parameters in the final fit floating but check to see if they agree with sideband projections.

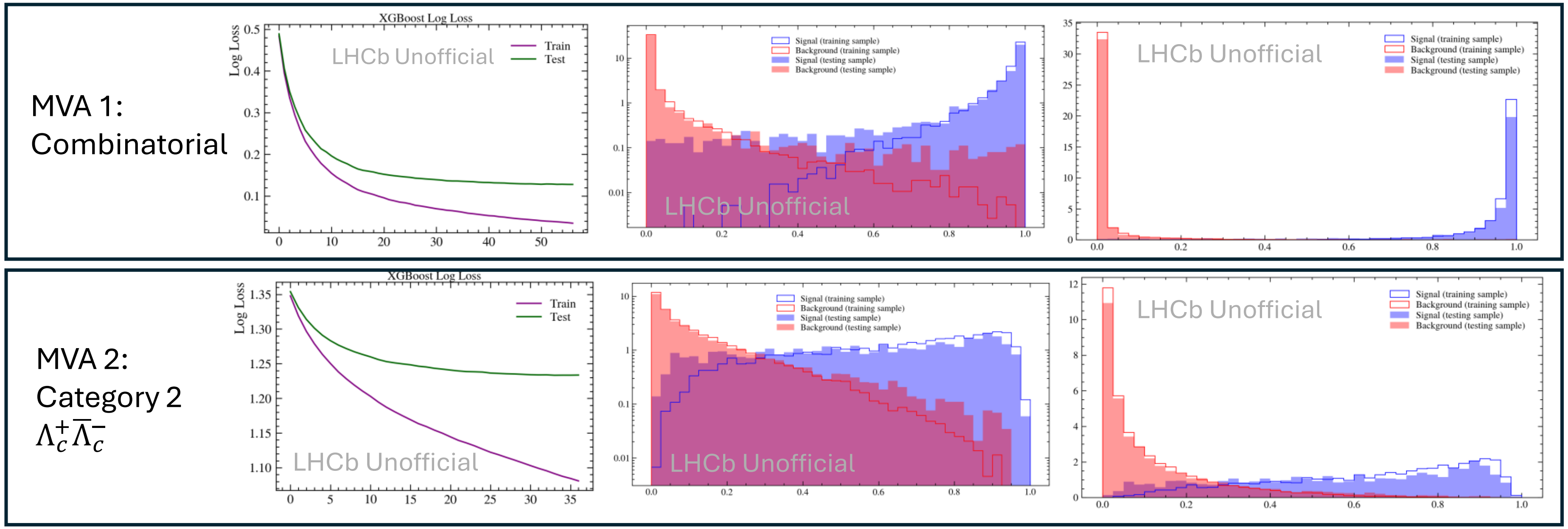




Multi-Variate XGBoost Selector

- To finalise the selection for our mass spectra we select candidates using 2 MVAs.
- Firstly, for combinatorial events, MC signal trained against a sideband in $\Lambda_c^+/\overline{\Lambda}_c^-$ mass.
- We introduce a second MVA to separate signal and category 2 decays.
  - $B^+ \to \Lambda_c^+\overline{\Lambda}_c^- \{K^+\pi^0, K_S^0\pi^+\}$
  - $B^0 \to \Lambda_c^+\overline{\Lambda}_c^- \{K^+\pi^-, K_S^0\pi^0\}$
- We take an optimal MVA working point using a Figure of Merit (FOM) study on the combined response from both MVAs. FOM metric is significance: S/sqrt(S+B).

Log Loss in training | XGBoost Separation, Log Scale | XGBoost Separation



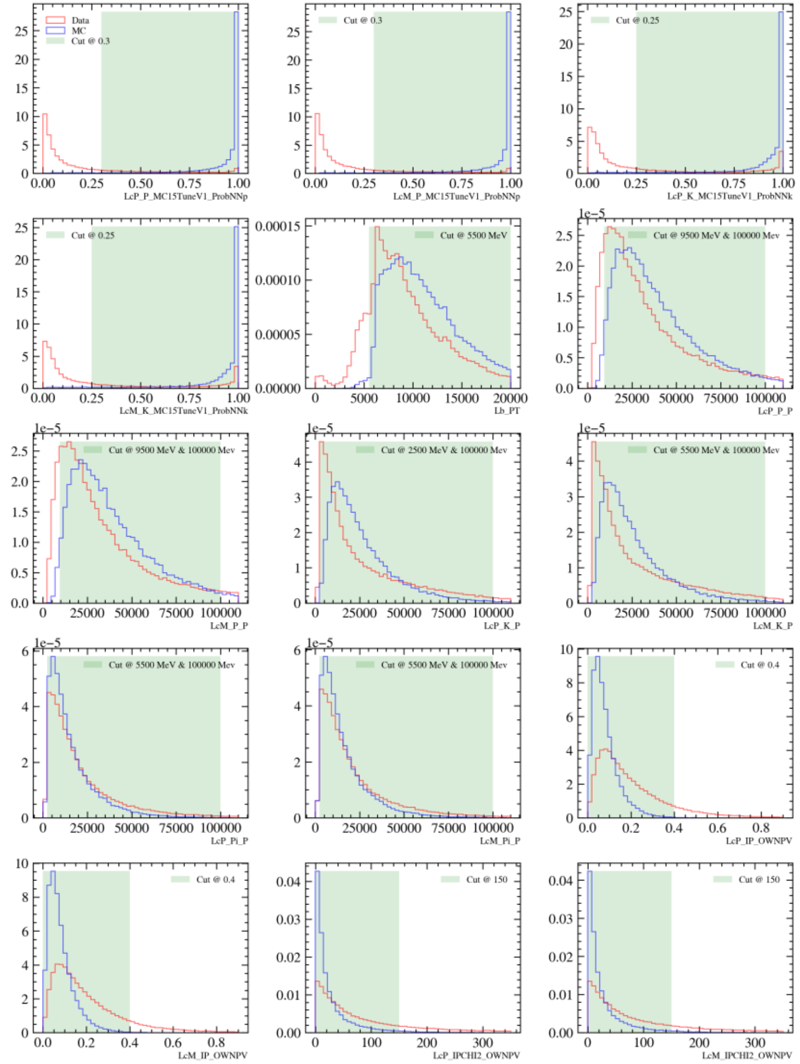
Summary

- The ongoing Run 2 analysis at LHCb of $\Lambda_b^0 \to \Lambda_c^+ \overline{\Lambda}_c^- n$ stands to be both:
  - One of the first studies and searches for a Purely Baryonic Decay.
  - The first observation of a decay mode with a final state neutron at the LHC.
- Progress on signal extraction:
  - Reconstruction and selection. [Finalised]
  - Final signal selection from 2 MVA selectors applied at optimal working points. [Finalising]
  - Mass fit component for Signal. [Finalised]
  - Mass fit components for combinatorial background. [Finalising]
  - Contributions from $\Lambda_c^+ \overline{\Lambda}_c^- X$ Backgrounds:

$B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+$ $B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_s^0$	[MC Templates and yield predictions calculated]	Category 1: B with 1 K
$B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+ \pi^0$	[Constraint calculated]	Category 2: B with 1 K + 1 π
$B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K_s^0 \pi^+$	[Constraint from $\Lambda_c^+ \overline{\Lambda}_c^- K_s^0$: Early Stages]	
$B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^+ \pi^-$		
$B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_s^0 \pi^0$		
$B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_s^0$		Category 3: B_s^0 with 1 K
$B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_s^0 \pi^0$		Category 4: B_s^0 with 1 K + 1 π
$B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+$		

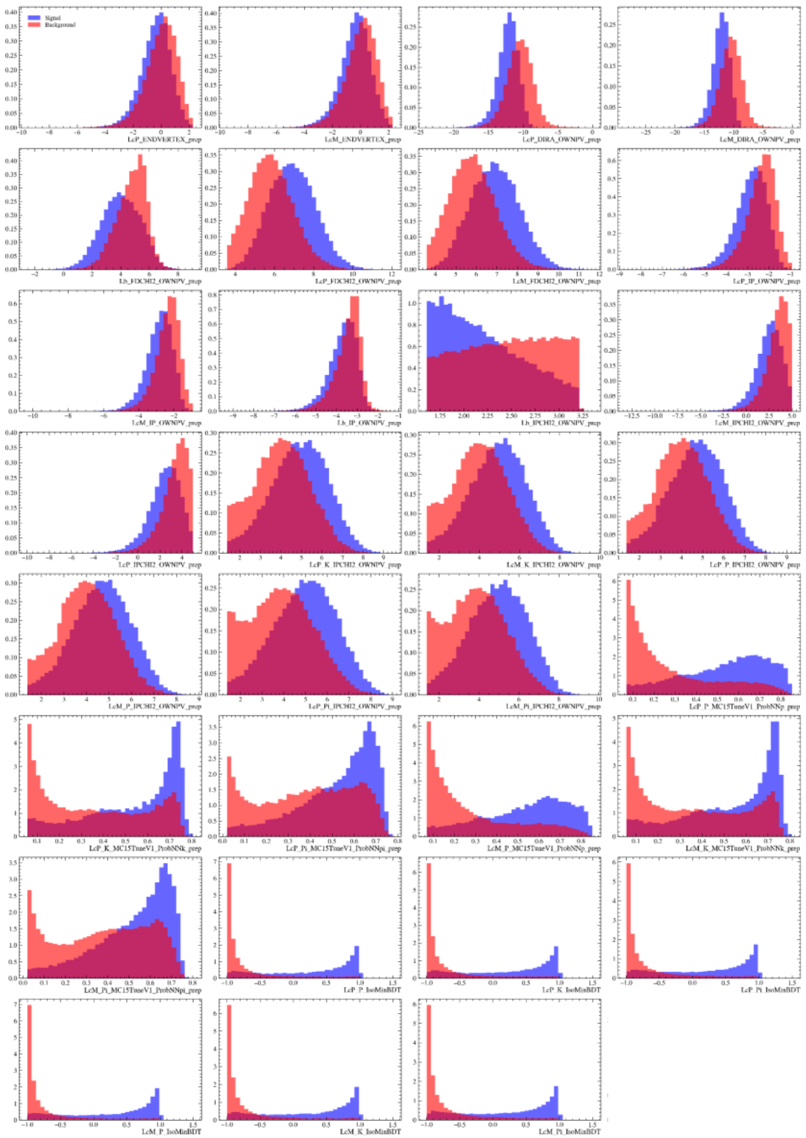
Backup: Selection Cuts made after $\Lambda_c^+\overline{\Lambda}_c^-$ Combination

- Cuts on final daughter PID ProbNN Variables.
- PT of the Λ_b^0.
- Momentum of the daughters.
- And IP variables of the $\Lambda_c^+\overline{\Lambda}_c^-$ pair.
- Data (red) subset of 2016 data.
- Signal MC (blue).



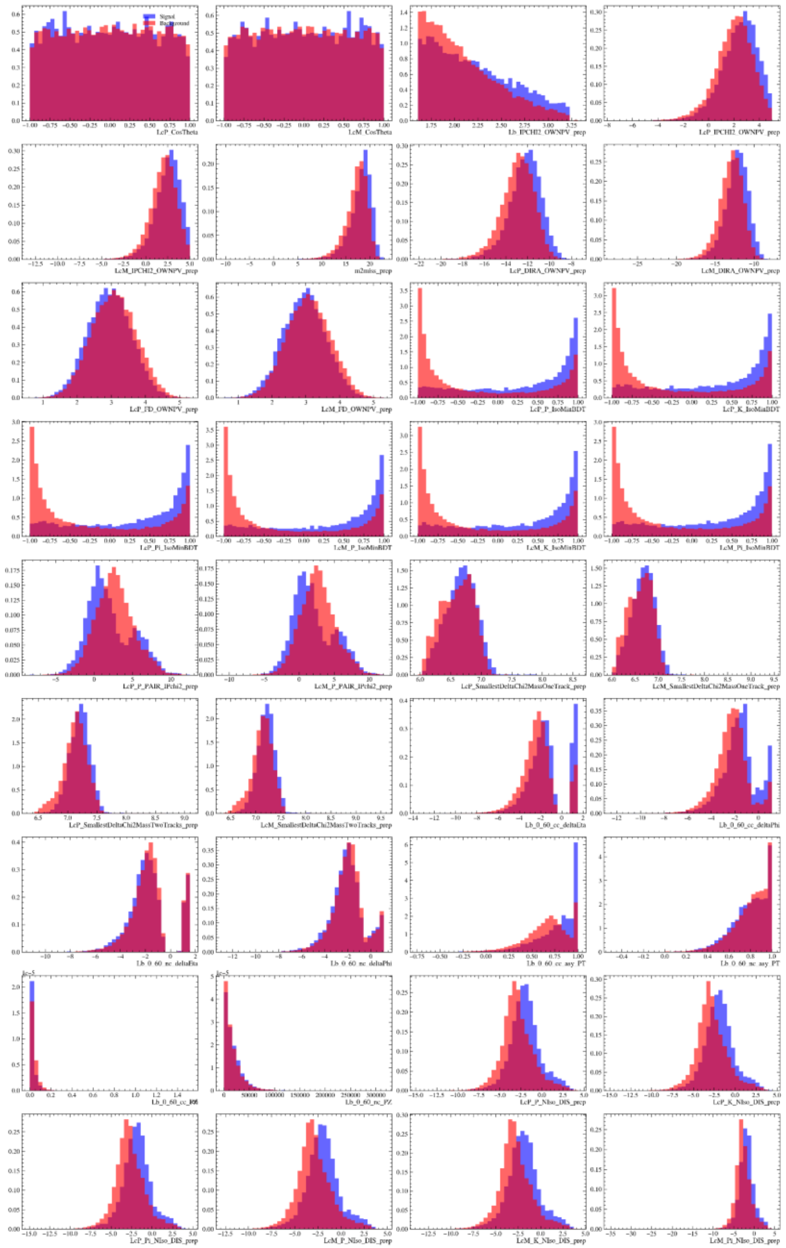
Backup: MVA 1 for Combinatorial

- MVA Variables:
  - Endvertex(chi2/ndf) for Λ_c^+ and $\overline{\Lambda}_c^-$.
  - Direction Angle for Λ_c^+ and $\overline{\Lambda}_c^-$
  - Flight distance chi2 for Λ_c^+, $\overline{\Lambda}_c^-$ and Λ_b^0
  - IP chi2 for Λ_c^+, $\overline{\Lambda}_c^-$, Λ_b^0 and daughters.
  - X prob NN X, where x is a final long track daughter, for all daughters.
  - Iso min BDT variables, for all daughters.
- Variables in plot have been pre-processed for both signal (blue) and bkg (red).



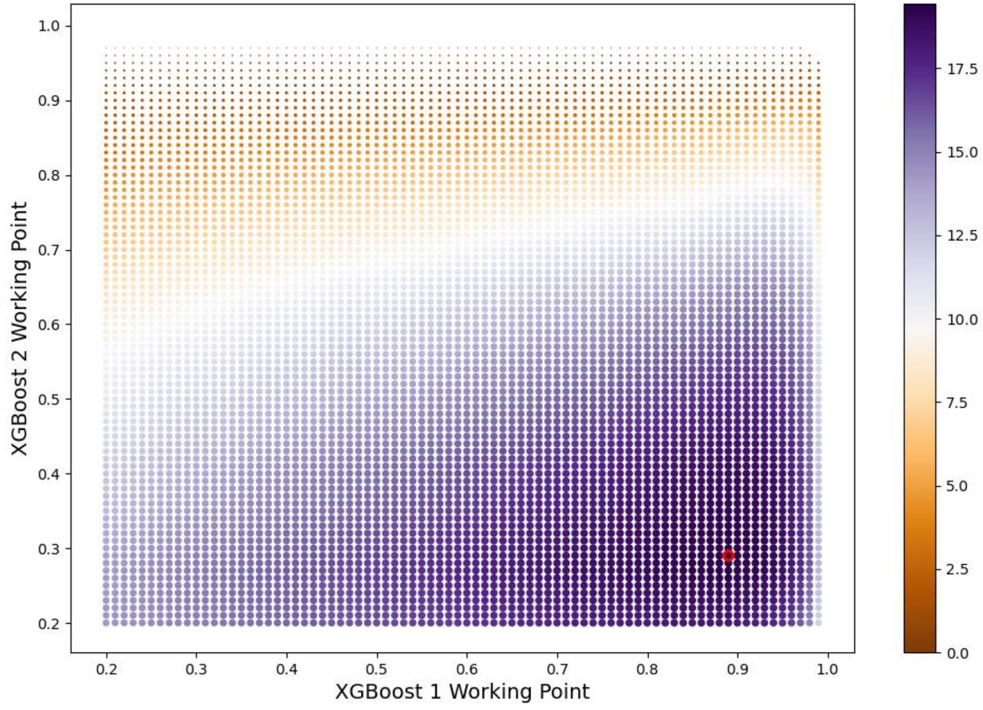
Backup: MVA 2 Category 2 Discriminant

- MVA Variables:
  - Cos theta for Λ_c^+ and $\overline{\Lambda}_c^-$.
  - IP chi2 for Λ_c^+, $\overline{\Lambda}_c^-$and Λ_b^0.
  - Missing mass squared
  - Direction angle, for Λ_c^+, $\overline{\Lambda}_c^-$.
  - Flight distance chi2, for Λ_c^+, $\overline{\Lambda}_c^-$.
  - Isolation variables:
    - Iso min BDT variables, for all daughters.
    - Pair IP chi2 for proton/ antiproton daughters of Λ_c^+, $\overline{\Lambda}_c^-$
    - Min delta chi2 mass one track), for Λ_c^+, $\overline{\Lambda}_c^-$.
    - Min delta chi2 mass two tracks), for Λ_c^+, $\overline{\Lambda}_c^-$.
    - Charged cone 0.6 radians, d_Eta, d_Phi, Pz, PT asymmetry.
    - Neutral cone at 0.6 radians, d_Eta, d_Phi, Pz, PT asymmetry.
    - N Iso DIS, for all daughters
- Some Isolation variables defined here: https://indico.cern.ch/event/533133/contributions/2172015/attachments/1277028/1895185/C_Isolation_BK.pdf
- Variables in plot have been pre-processed for both signal (blue) and bkg (red).



Backup: Selection of MVA Working Point(s)

- Best working point is determined from sampling the 2D space of responses to each MVA.
- The maximised criteria is determined by:
  - Performing a three-dimensional fit to the sample with XGBoost output > 0.20 (for both MVAs) to obtain the signal yields S(0.20,0.20) and background yields B(0.20,0.20)
  - The signal sample (MC) and background samples (Sideband,Cat2 MC) are used to calculate the signal efficiency ϵ_sig and background efficiency ϵ_bkg at different working points.
  - The total signal yield without MVA selection S_tot and background yield B_tot are estimated as: S_tot = S(0.20,0.20)/ ϵ_sig(0.20,0.20) and Btot = B(0.20,0.20)/ ϵ_bkg(0.20,0.20).
  - Finally, S(t1,t2) = S_tot* ϵ_sig(t1,t2) and B(t1,t2) = B_tot* ϵ_bkg(t1,t2) for any given pair of working points t1,t2.
  - FOM is given from max of S(t1,t2)/sqrt(S(t1,t2)+B(t1,t2)).



Constraint Formalism for $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+$

- We can use information from the explicit fits on the previous slides to obtain a fit constraint on the yield of $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+$ in the corrected Λ_b^0 mass fit.
- We want to link the fit yield of $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+$ to the yield of the PDF for category 1.

$$\frac{Y_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y_{\Lambda_b^0}(Cat1)} = \alpha$$

- We can untangle the 2 decay modes using the relative branching fraction measurement.

$$Y_{\Lambda_b^0}(Cat1) = Y_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+) \cdot \left[1 + \frac{\mathcal{B}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\mathcal{B}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot \frac{\varepsilon_{\Lambda_b^0}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}\right]$$

- Therefore, we can write:

$$\frac{Y_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot A = \alpha$$

where:

$$A = \frac{1}{\left[1 + \frac{\mathcal{B}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\mathcal{B}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot \frac{\varepsilon_{\Lambda_b^0}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}\right]}$$

Constraint Formalism for $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+$

- We have:

$$\frac{Y_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot A = \alpha$$

where:

$$A = \frac{1}{\left[1 + \frac{\mathcal{B}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\mathcal{B}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot \frac{\varepsilon_{\Lambda_b^0}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}\right]}$$

- Where α is now a ratio of yields between the decays $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+$ and $B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+$ in the corrected mass fit
- We can rewrite this ratio using quantities from the explicit reconstructions on slide 8 and 9. No Λ_b^0 subscript indicates quantities relate to the explicit reconstruction.

$$\frac{Y_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} = \frac{Y(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot \frac{\varepsilon(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}{\varepsilon(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)} \cdot \frac{\varepsilon_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}$$

- To finally get α in terms of known quantities.

$$\alpha = \frac{Y(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot \frac{\varepsilon(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}{\varepsilon(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)} \cdot \frac{\varepsilon_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot A$$

Constraint Formalism for $B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+$

- Using these quantities, we can calculate the constraint parameter α.

Parameter	Value
$Y(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)$	4.8 ± 3.1 [table 36]
$\varepsilon(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)$	$(5.0 \pm 0.1) \times 10^{-5}$ [table 36]
$Y(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)$	835 ± 33 [table 26]
$\varepsilon(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)$	$(2.96 \pm 0.04) \times 10^{-4}$ [table 26]
$\varepsilon_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)$	$(7.5 \pm 0.3) \times 10^{-5}$ *
$\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)$	$(8.9 \pm 0.3) \times 10^{-5}$ *
$\varepsilon_{\Lambda_b^0}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)$	$(3.01 \pm 0.02) \times 10^{-4}$ *
$\mathcal{B}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)/\mathcal{B}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)$	$0.53 \pm 0.05 \pm 0.04 \pm 0.01$ [7]

$$\frac{Y_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y_{\Lambda_b^0}(Cat1)} = \alpha$$

$$\alpha = \frac{Y(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{Y(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot \frac{\varepsilon(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}{\varepsilon(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)} \cdot \frac{\varepsilon_{\Lambda_b^0}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K^- \pi^+)}{\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot A$$

where:

$$A = \frac{1}{\left[1 + \frac{\mathcal{B}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\mathcal{B}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)} \cdot \frac{\varepsilon_{\Lambda_b^0}(B^0 \to \Lambda_c^+ \overline{\Lambda}_c^- K_S^0)}{\varepsilon_{\Lambda_b^0}(B^+ \to \Lambda_c^+ \overline{\Lambda}_c^- K^+)}\right]}$$

- MC efficiencies for the corrected mass selection is not finalised indicated with an * in table above, so this is a preliminary calculation.
- $\alpha = 0.010 \ \pm 0.007$