B decays to open charm final states

The summits of the invariant mass distributions

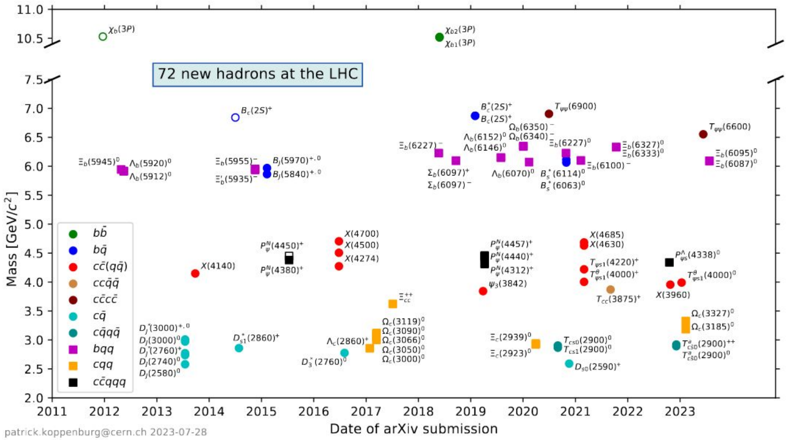
Bhagyashree Pagare
On behalf of LHCb collaboration

EPS - HEP 2023, Universität Hamburg, 20–25 Aug 2023

Introduction - The hunt for B decays

- More than 70 new hadrons discovered at LHC and more than 60 by LHCb
- More than 20 states are exotic
- Exotic states provide unique window to understand nature of strong force
- B decays to open charm final states provides a bountiful arena for finding such states and provides varieties of platforms for CPV measurements!
- b baryons not studied extensively compared to B mesons

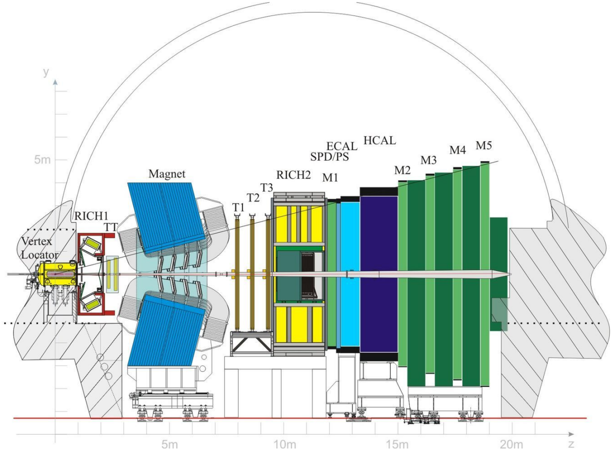
arXiv:2206.15233

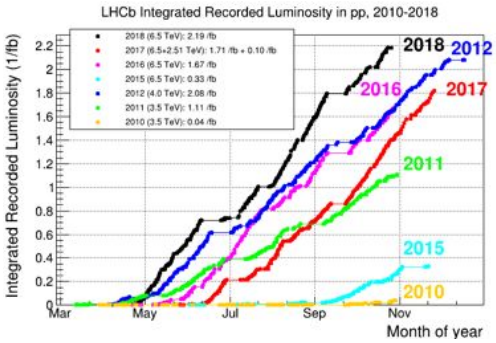


David Kirkby, APS, 2003

Where are we looking at ? —— LHCb!

- Forward arm spectrometer.
- Designed to study beauty and charm hadrons.
- Precise particle identification.
- Excellent mass, vertex and proper time resolution.
- VELO tracks the particles near the collision point.
- RICH provides identification for the particles.
- Trackers are located to track stable particles.
- Calorimeters further help to identify the particles from the energy deposits.
- Muon system
- Results presented today are from Run 1 (2011-2012) and Run 2 (2015-2018)



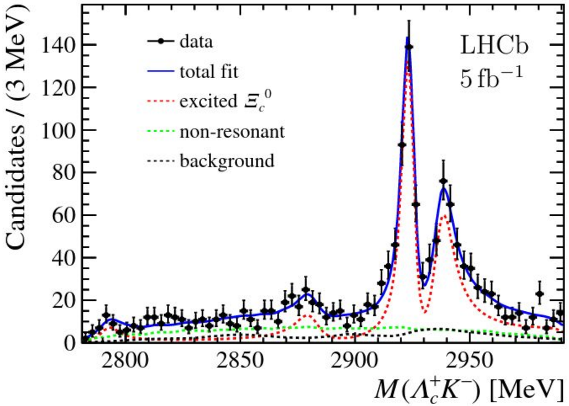


The B decays garden - Exploring the exotic flowers

- Studies of $B^- \to \Lambda_c^+ \bar{\Lambda}_c^- K^-$: Phys. Rev. D 108, 012020
- Amplitude analysis of $B^0 \to \bar{D}^0 D_s^+ \pi^-$ and $B^+ \to D^- D_s^+ \pi^+$ decays : Phys. Rev. D 108, 012017
- Resonant structures in $B^+ \to D_s^+ D_s^- K^+$: Phys. Rev. Lett. 131, 071901
- Studies of Ξ_b^- and Ω_b^- : LHCb-CONF-2023-001 NEW!

B meson decays studied last year

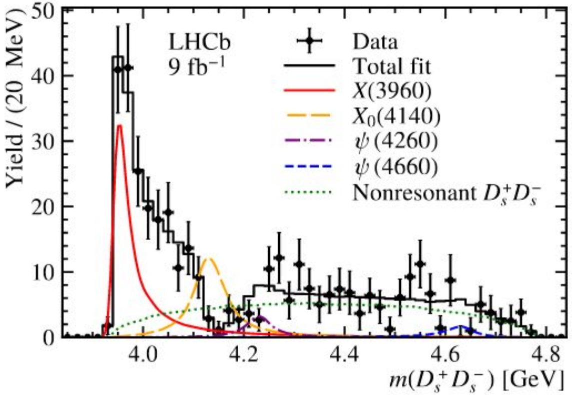
$B^- \to \Lambda_c^+ \bar{\Lambda}_c K^-$



$$m(\Xi_c(2923)^0) = 2924.5 \pm 0.4 \pm 1.1\,\mathrm{MeV},$$
$$m(\Xi_c(2939)^0) = 2938.5 \pm 0.9 \pm 2.3\,\mathrm{MeV},$$
$$\Gamma(\Xi_c(2923)^0) = 4.8 \pm 0.9 \pm 1.5\,\mathrm{MeV},$$
$$\Gamma(\Xi_c(2939)^0) = 11.0 \pm 1.9 \pm 7.5\,\mathrm{MeV},$$

Phys. Rev. D 108, 012020

$B^+ \to D_s^+ D_s^- K^+$



Component	J^{PC}	M_0 (MeV)	Γ_0 (MeV)	$\mathcal{F}$ (%)	$\mathcal{S}$ (σ)
$X(3960)$	0^{++}	$3956 \pm 5 \pm 10$	$43 \pm 13 \pm 8$	$25.4 \pm 7.7 \pm 5.0$	12.6 (14.6)
$X_0(4140)$	0^{++}	$4133 \pm 6 \pm 6$	$67 \pm 17 \pm 7$	$16.7 \pm 4.7 \pm 3.9$	3.8 (4.1)
$\psi(4260)$	1^{--}	4230 [59]	55 [59]	$3.6 \pm 0.4 \pm 3.2$	3.2 (3.6)
$\psi(4660)$	1^{--}	4633 [31]	64 [31]	$2.2 \pm 0.2 \pm 0.8$	3.0 (3.2)
NR	0^{++}	-	-	$46.1 \pm 13.2 \pm 11.3$	3.1 (3.4)

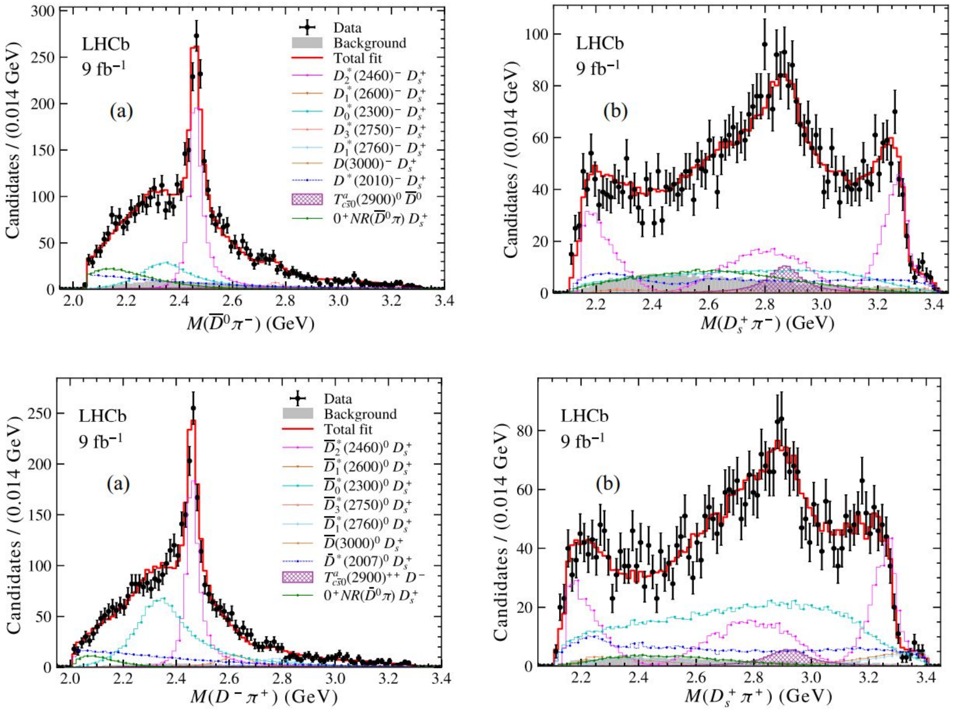
Phys. Rev. Lett. 131, 071901

B meson decays studied last year

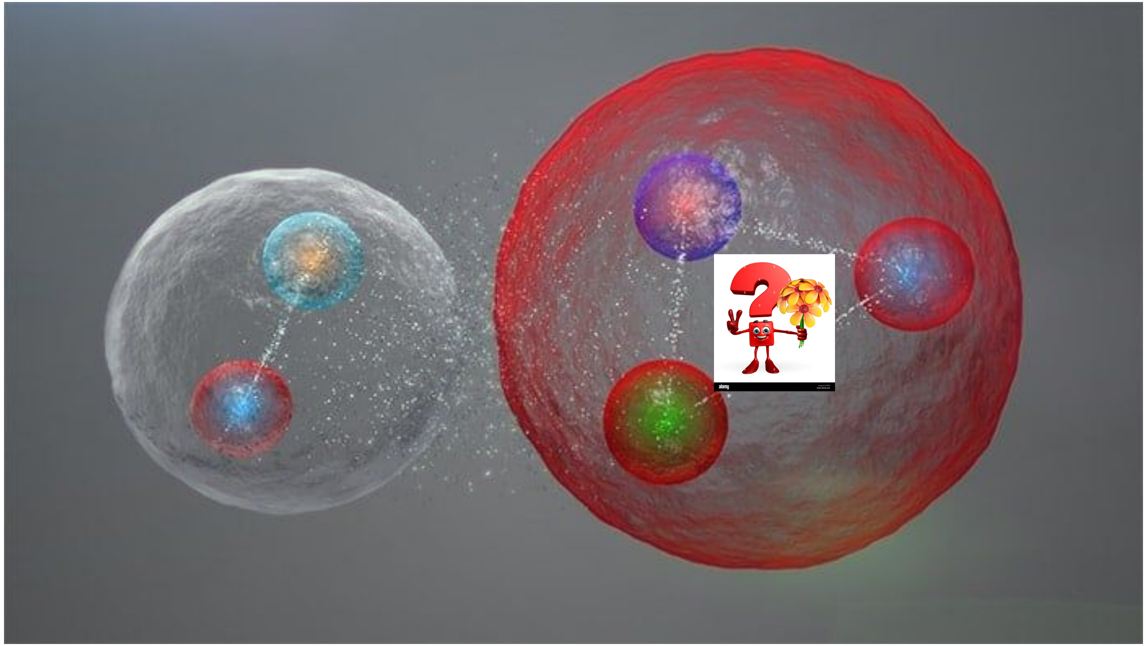
$B^0 \to \bar{D}^0 D_s^+ \pi^-$ and $B^+ \to D^- D_s^+ \pi^+$

$$
\begin{aligned}
T^a_{c\bar{s}0}(2900)^0 : M &= (2.892 \pm 0.014 \pm 0.015)\ \text{GeV}, \\
\Gamma &= (0.119 \pm 0.026 \pm 0.013)\ \text{GeV}, \\
T^a_{c\bar{s}0}(2900)^{++} : M &= (2.921 \pm 0.017 \pm 0.020)\ \text{GeV}, \\
\Gamma &= (0.137 \pm 0.032 \pm 0.017)\ \text{GeV},
\end{aligned}
$$

[Phys. Rev. D 108, 012017]



What about b baryons ?



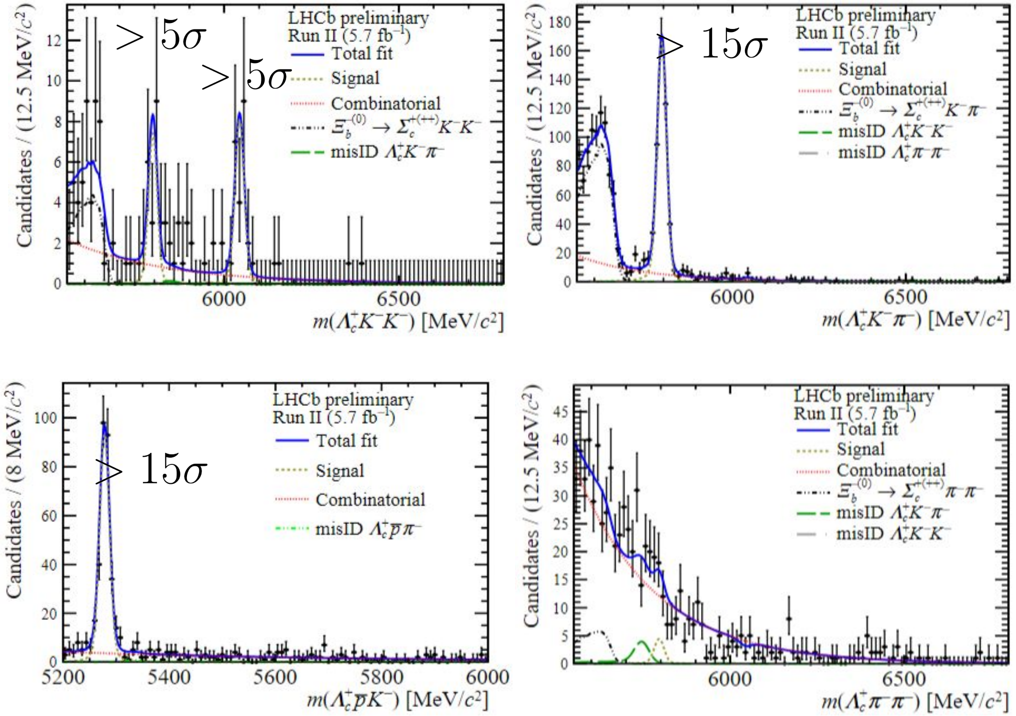
Studies of Ξ_b^- and Ω_b^- decays to $\Lambda_c^+ h^- h'^-$ $(h^{(')} = \pi, K)$ final states

NEW!

- Relatively few studies of Ξ_b^- and Ω_b^- decays to date.
  - Only 7 observed Ξ_b^- decays and 3 Ω_b^- observed !
- Little knowledge of their production rates in LHC collisions.
  - Knowledge of dependence on kinematics important for precise measurements.
  - Knowledge of production asymmetries essential for CP violation measurements
- Potential laboratory Ξ_c^0 and Σ_c^0 spectroscopy.
- Dataset - Run 1 and Run 2 data samples.
- Decay channels : $\Xi_b^-(\Omega_b^-) \to \Lambda_c^+ h^- h'^-$ and $B^- \to \Lambda_c^+ \bar{p} \pi^-$ as the control mode $\Lambda_c^+ \to p K^- \pi^+$
- Selection :
  - Consists of 2 MVA's - One for Λ_c particles and other for the b baryons
  - MVA receives topological, vertex and kinematics information.
  - Optimum working point is chosen for the 2 MVA's
  - PID requirements are optimised by minimising the mis-identified backgrounds.

Invariant mass distribution and its components

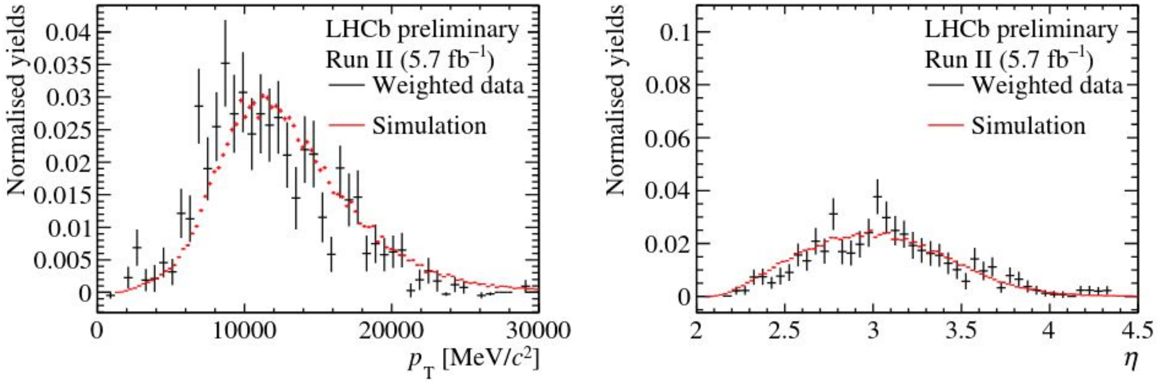
- Simultaneous fit
- Signal component
- Combinatorial background.
- Partially reconstructed backgrounds
  - With intermediate state corresponding to $\Sigma_c^{+(++)} \to \Lambda_c^+ \pi^{0(+)}$ with missing pion.
- Mis-identified backgrounds :
  - Kaons and pions can be misidentified.
  - Yields of misID backgrounds are constrained with respect to correctly identified channels.



First observation of: $B^- \to \Lambda_c^+ \bar{p} K^-$, $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$ with ; $\Xi_b^- \to \Lambda_c^+ K^- K^-$ and $\Omega_b^- \to \Lambda_c^+ K^- K^-$

Corrections to the phase space distributions

- Limited knowledge of b baryons.
- Kinematics of MC cannot be expected to match data, for these baryons.
- Results of this and similar analyses will be used to tune MC in future.
- Correction is applied to MC to get reliable efficiencies for computing the yields of modes.
- Efficiency computation - as a function of phase space distribution.
- Lifetime correction for Ω_b^- is also applied



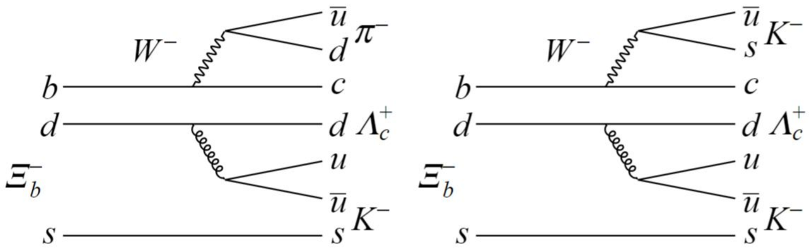
Results of the branching fractions

- Results of the branching fraction and production rate for Run 1 and and Run 2.
- Ratios of branching fractions of the same b hadron do not depend upon the pp collision energy.

	Run I	Run II	
$\frac{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}K^-)}{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}\pi^-)}$	$0.0404\pm0.0055\pm0.0021$	$0.0395\pm0.0025\pm0.0013$	$B^-\to\Lambda_c^+\bar{p}\pi^-$
$\frac{f_{\Xi_b^-}}{f_{B^-}}\cdot\frac{\mathcal{B}(\Xi_b^-\to\Lambda_c^+K^-K^-)}{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}\pi^-)}$	$0.0085\pm0.0037\pm0.0024$	$0.0032\pm0.0009\pm0.0003$	
$\frac{f_{\Xi_b^-}}{f_{B^-}}\cdot\frac{\mathcal{B}(\Xi_b^-\to\Lambda_c^+K^-\pi^-)}{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}\pi^-)}$	$0.1129\pm0.0116\pm0.0286$	$0.0763\pm0.0041\pm0.0062$	
$\frac{f_{\Xi_b^-}}{f_{B^-}}\cdot\frac{\mathcal{B}(\Xi_b^-\to\Lambda_c^+\pi^-\pi^-)}{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}\pi^-)}$	$0.0110\pm0.0054\pm0.0057$	$0.0015\pm0.0010\pm0.0014$	
$\frac{f_{\Omega_b^-}}{f_{B^-}}\cdot\frac{\mathcal{B}(\Omega_b^-\to\Lambda_c^+K^-K^-)}{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}\pi^-)}$	$0.0053\pm0.0023\pm0.0012$	$0.0037\pm0.0009\pm0.0004$	
$\frac{f_{\Omega_b^-}}{f_{B^-}}\cdot\frac{\mathcal{B}(\Omega_b^-\to\Lambda_c^+K^-\pi^-)}{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}\pi^-)}$	$0.0020\pm0.0021\pm0.00013$	$0.0006\pm0.0005\pm0.0004$	
$\frac{f_{\Omega_b^-}}{f_{B^-}}\cdot\frac{\mathcal{B}(\Omega_b^-\to\Lambda_c^+\pi^-\pi^-)}{\mathcal{B}(B^-\to\Lambda_c^+\bar{p}\pi^-)}$	$0.0013\pm0.0029\pm0.0027$	$-0.0003\pm0.0004\pm0.0005$	
$\frac{\mathcal{B}(\Xi_b^-\to\Lambda_c^+K^-K^-)}{\mathcal{B}(\Xi_b^-\to\Lambda_c^+K^-\pi^-)}$	$0.075\pm0.034\pm0.011$	$0.041\pm0.012\pm0.005$	$\Xi_b^-\to\Lambda_c^+K^-\pi^-$
$\frac{\mathcal{B}(\Xi_b^-\to\Lambda_c^+\pi^-\pi^-)}{\mathcal{B}(\Xi_b^-\to\Lambda_c^+K^-\pi^-)}$	$0.097\pm0.049\pm0.046$	$0.019\pm0.013\pm0.017$	
$\frac{\mathcal{B}(\Omega_b^-\to\Lambda_c^+K^-\pi^-)}{\mathcal{B}(\Omega_b^-\to\Lambda_c^+K^-K^-)}$	$0.38\pm0.43\pm0.24$	$0.17\pm0.13\pm0.09$	$\Omega_b^-\to\Lambda_c^+K^-K^-$
$\frac{\mathcal{B}(\Omega_b^-\to\Lambda_c^+\pi^-\pi^-)}{\mathcal{B}(\Omega_b^-\to\Lambda_c^+K^-K^-)}$	$0.24\pm0.57\pm0.53$	$-0.08\pm0.12\pm0.15$	

Combined Run1 and Run 2 results

- Results for Run 1 and Run 2 combined
- Combined accounting for correlations of systematic uncertainties
- Upper limits are obtained for modes $< 3\sigma$
- Results for the same b hadron decays are consistent with the Cabbibbo suppression factor



$$\frac{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} K^-)}{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)} = 0.0397 \pm 0.0023\,(\text{stat}) \pm 0.0012\,(\text{syst})\,,$$

$$\frac{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ K^- K^-)}{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ K^- \pi^-)} = 0.045 \pm 0.011\,(\text{stat}) \pm 0.005\,(\text{syst})\,,$$

$$\frac{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ \pi^- \pi^-)}{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ K^- \pi^-)} = 0.025 \pm 0.013\,(\text{stat}) \pm 0.019\,(\text{syst})\,,$$

$$\frac{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ K^- \pi^-)}{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ K^- K^-)} = 0.19 \pm 0.12\,(\text{stat}) \pm 0.10\,(\text{syst})\,,$$

$$\frac{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ \pi^- \pi^-)}{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ K^- K^-)} = -0.07 \pm 0.12\,(\text{stat}) \pm 0.16\,(\text{syst})\,.$$

$$\frac{f_{\Xi_b^-}}{f_{B^-}} \cdot \frac{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ \pi^- \pi^-)}{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)} < 0.0049\ (0.0057) \text{ at } 90\%\ (95\%) \text{ confidence level}\,,$$

$$\frac{f_{\Omega_b^-}}{f_{B^-}} \cdot \frac{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ K^- \pi^-)}{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)} < 0.0019\ (0.0022) \text{ at } 90\%\ (95\%) \text{ confidence level}\,,$$

$$\frac{f_{\Omega_b^-}}{f_{B^-}} \cdot \frac{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ \pi^- \pi^-)}{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)} < 0.0012\ (0.0015) \text{ at } 90\%\ (95\%) \text{ confidence level}\,,$$

$$\frac{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ \pi^- \pi^-)}{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ K^- \pi^-)} < 0.065\ (0.074) \text{ at } 90\%\ (95\%) \text{ confidence level}\,,$$

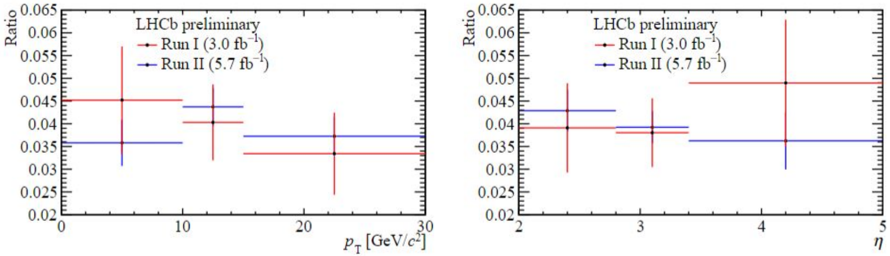
$$\frac{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ K^- \pi^-)}{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ K^- K^-)} < 0.56\ (0.64) \text{ at } 90\%\ (95\%) \text{ confidence level}\,,$$

$$\frac{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ \pi^- \pi^-)}{\mathcal{B}(\Omega_b^- \to \Lambda_c^+ K^- K^-)} < 0.37\ (0.45) \text{ at } 90\%\ (95\%) \text{ confidence level}\,.$$

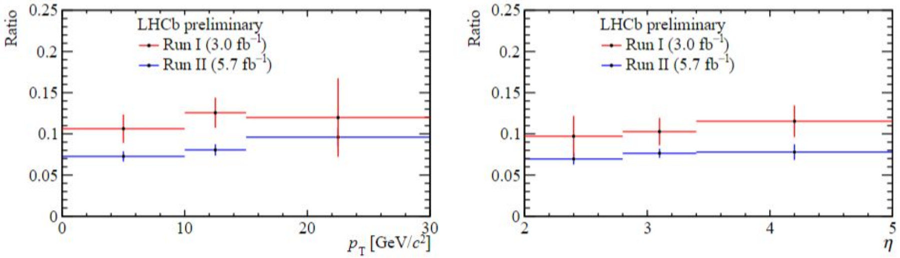
Kinematic dependence

- Cross-checks are performed by studying the branching branching of the meson modes with respect to kinematics
- Relative production rate of $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$ and $B^- \to \Lambda_c^+ \bar{p} \pi^-$ studied in bins of transverse momentum and pseudorapidity
- Appears to be consistent in different kinematic bins with current dataset.
- Uncertainty sare stat only

$$\frac{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} K^-)}{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)}$$

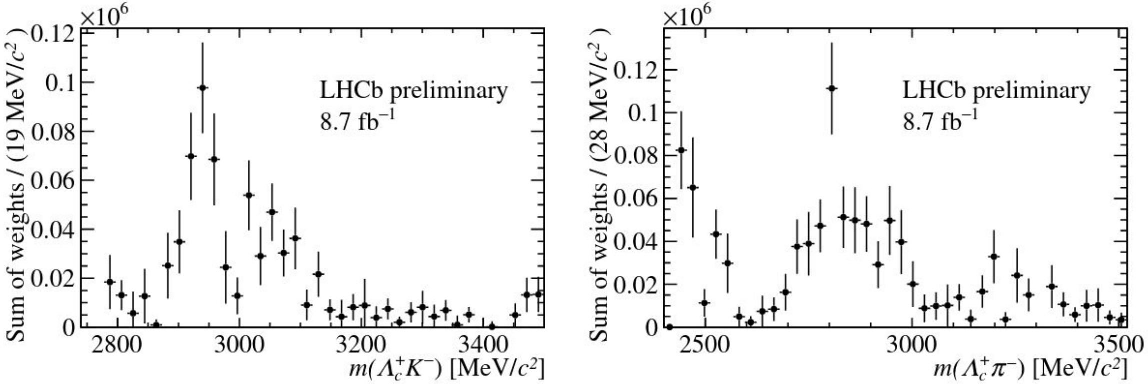


$$\frac{f_{\Xi_b^-}}{f_{B^-}} \cdot \frac{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ K^- \pi^-)}{\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)}$$



Studies of Ξ_b^- and Ω_b^-

- First look at the spectrum.
- Intermediate resonances corresponding to charmed states are seen in the mass distribution $m(\Lambda_c^+ K^-)$ and $m(\Lambda_c^+ \pi^-)$
- Structures appears consistent with Ξ_c *and* Σ_c states coming from $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$
- Full amplitude analysis left for future studies.



Summary

- Recents results about the B decays to open charm states were discussed.
- New observations in the b baryon sector have been presented
- Branching fractions of the b baryon decays have been measured
- Kinematic dependence of the b baryon production rate with respect be B meson have been computed.
- First look at the spectrum.
- Provides a laboratory for the charm spectroscopy.

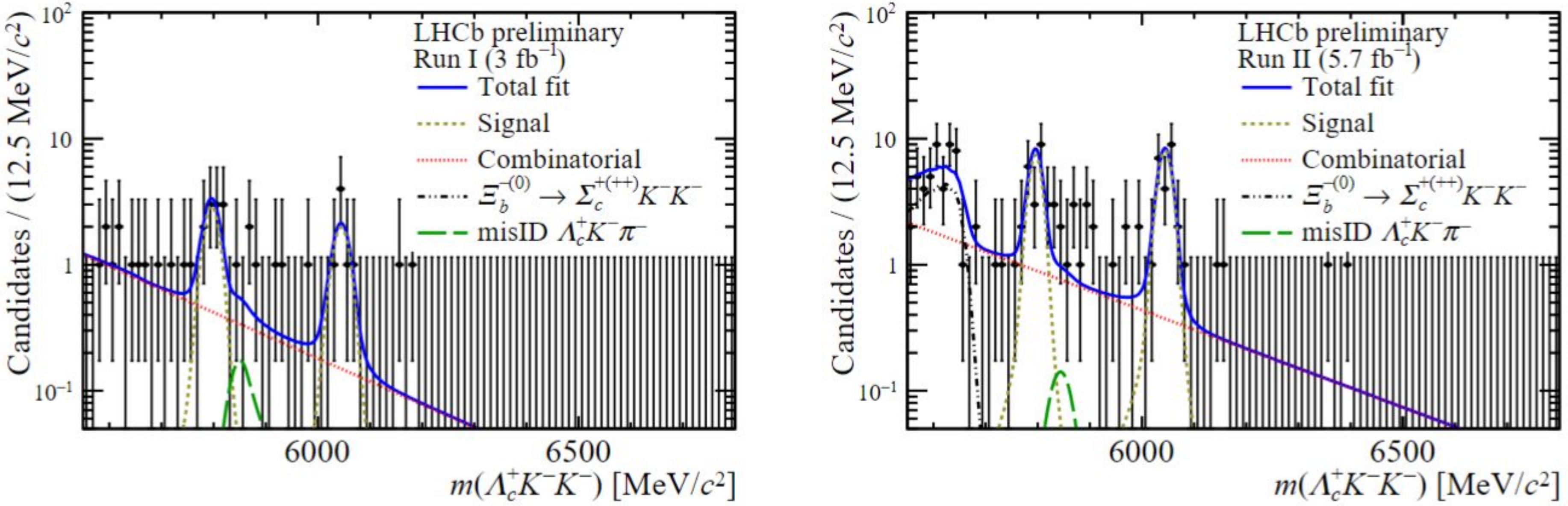
Thank you!

BackUp

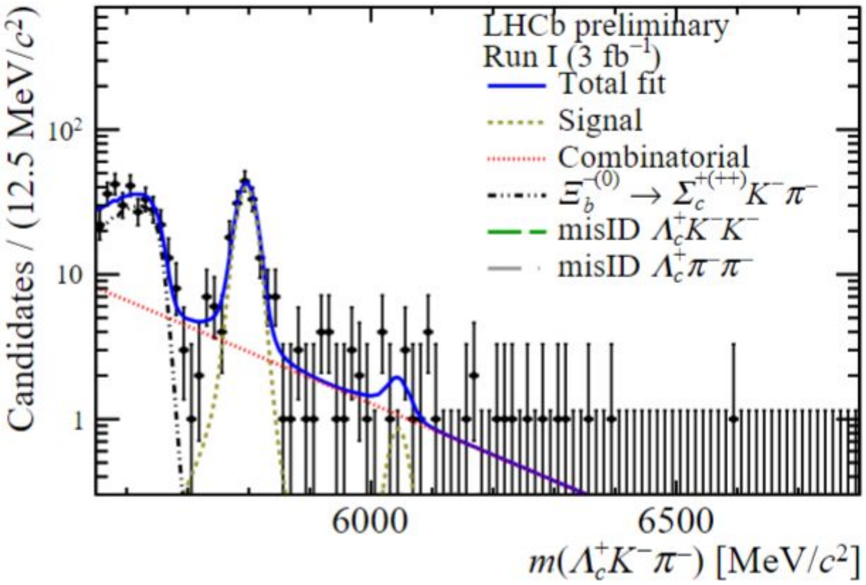
Systematic Uncertainties

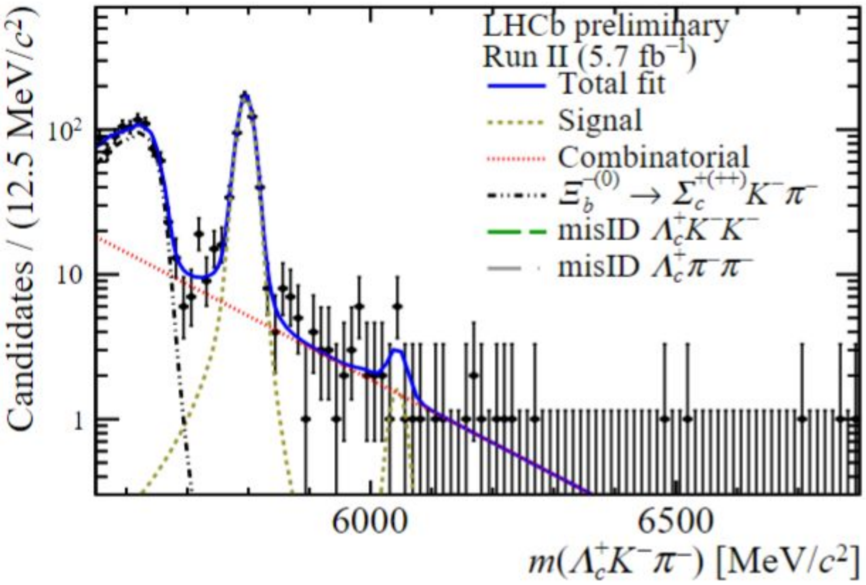
- Dominant systematic is the production kinematics for $\frac{f_{\Xi_b^-}}{f_{B^-}} \cdot \frac{\mathcal{B}(\Xi_b^- \to \Lambda_c^+ K^- \pi^-)}{\mathcal{B}(B^- \to \Lambda_c^+ \overline{p} \pi^-)}$
- Data-MC mismatch for the MVA variables
- Material budget
- Tracking corrections
- PID variable correction techniques
- Finite size of simulation samples
- Fit bias
- MC models

Run 1 and Run 2 fits for $\Lambda_c^+ K^- K^-$

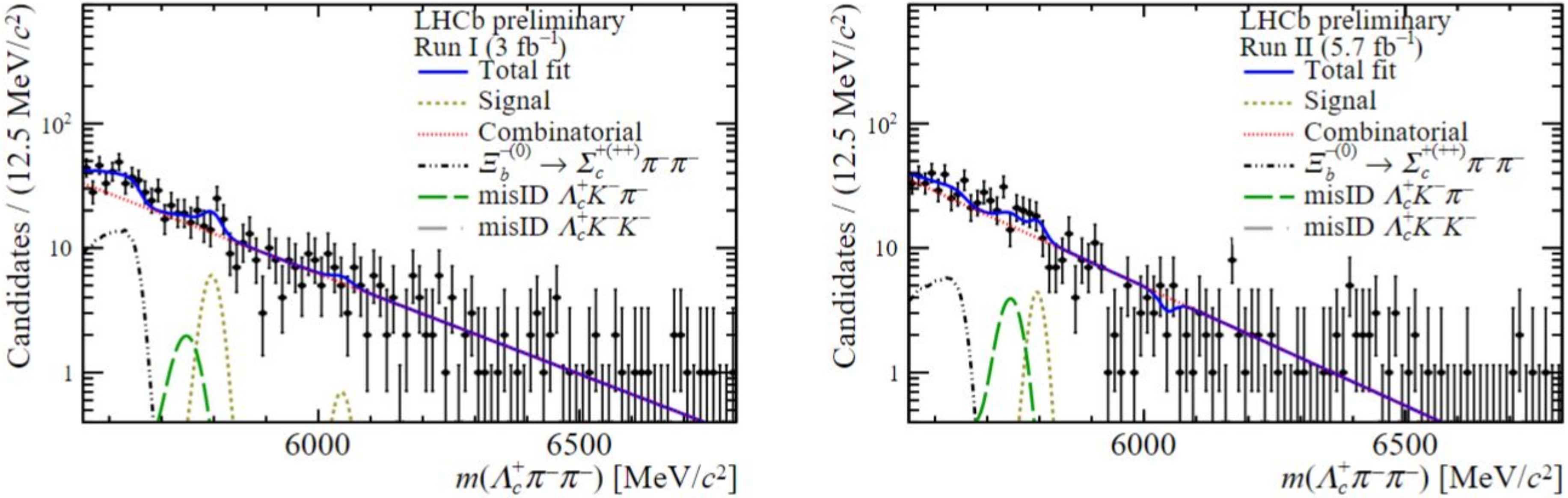


Run 1 and Run 2 fits for $\Lambda_c^+ K^- \pi^-$

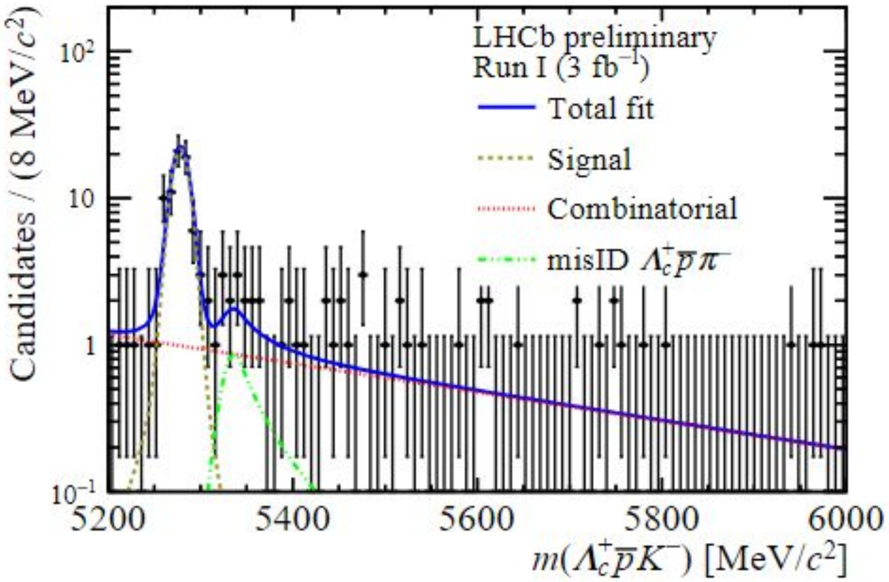


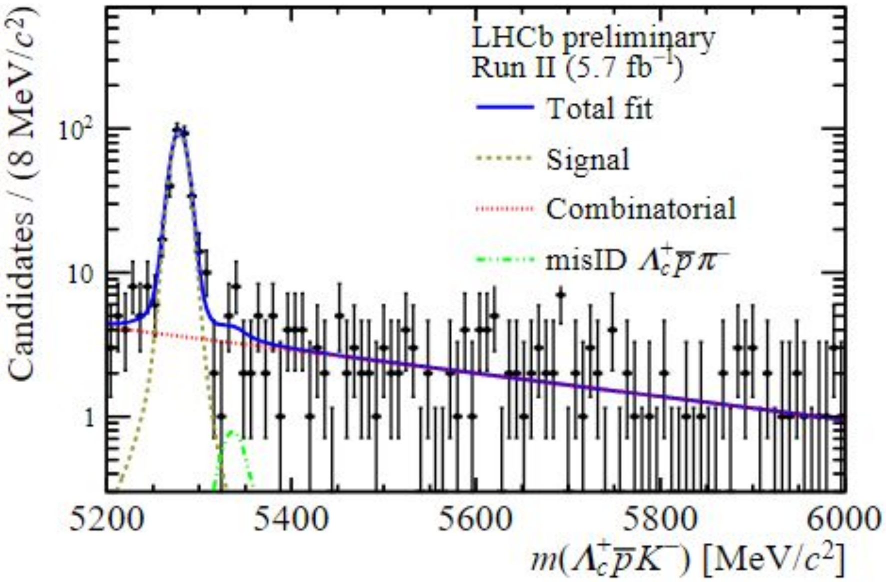


Run 1 and Run 2 fits for $\Lambda_c^+ \pi^- \pi^-$

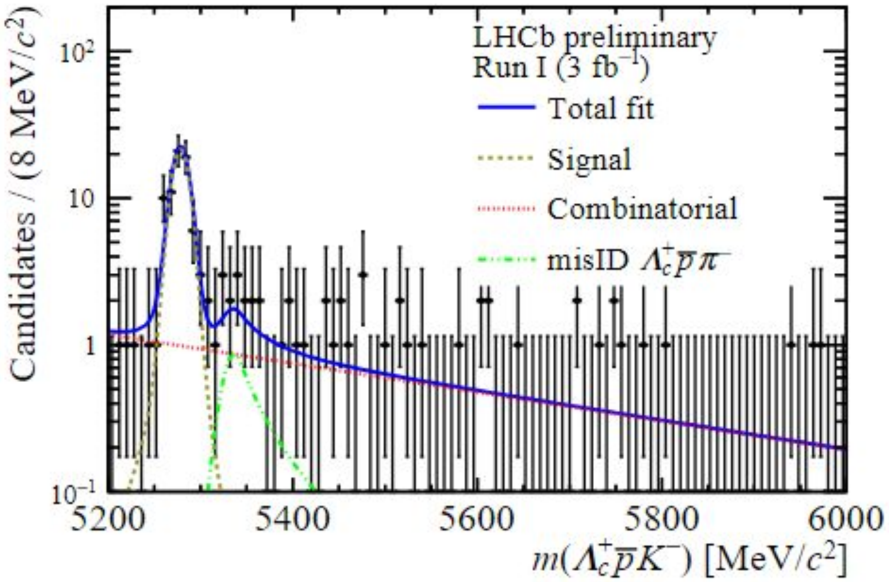


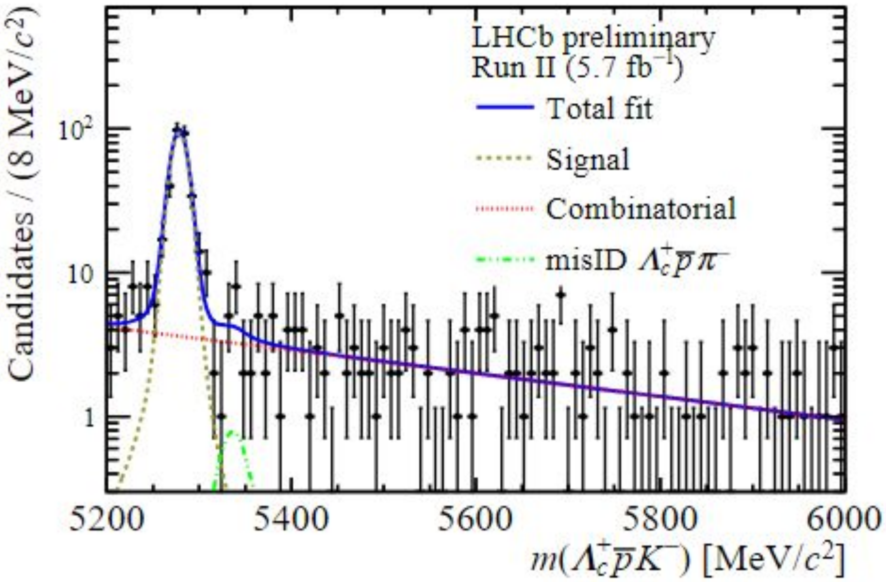
Run 1 and Run 2 fits for $\Lambda_c^+ \pi^- \pi^-$





Run 1 and Run 2 fits for $\Lambda_c^+ \overline{p} K^-$





Run 1 and Run 2 fits for $\Lambda_c^+ \overline{p} \pi^-$