Observation of the charmless purely baryonic decay
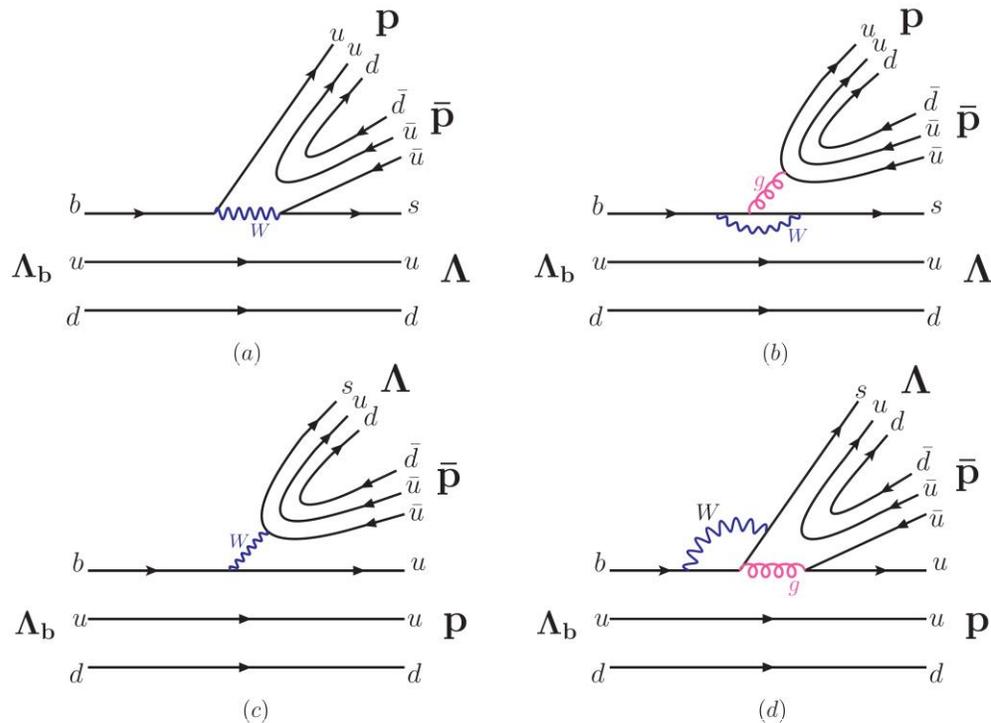
$$\boldsymbol{\Lambda_b^0 \rightarrow \Lambda\, p\, \overline{p}}$$

Alexandre Brea, on behalf of the LHCb collaboration

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16/03/2026

Purely baryonic charmless Λ_b^0 decays

- **Purely baryonic** baryon decays (PBD), involving only spin carrying particles, are largely unexplored.

  So far only two modes, both including charm baryons in the final state, have been observed.

- **Branching fraction predictions**[1].

  - $\mathcal{B}\,(\Lambda_b^0 \to \Lambda\,p\,\overline{p}) = (3.2^{+0.8}_{-0.3} \pm 0.4 \pm 0.7)\ \times\ 10^{-6}$

  - $\mathcal{B}\,(\Xi_b^0 \to \Lambda\,p\,\overline{p}) = (1.4 \pm 0.1 \pm 0.1 \pm 0.4)\ \times\ 10^{-7}$

- The **LHCb experiment** is the **only experiment capable** of examining these rare processes.

- **Direct CP asymmetry** (asymetry between matter-antimatter) predictions[1]:

  - $\mathcal{A}_{CP}\,(\Lambda_b^0 \to \Lambda\,p\,\overline{p}) = (3.4 \pm 0.1 \pm 0.1 \pm 1.0)\ \%$

  - $\mathcal{A}_{CP}\,(\Xi_b^0 \to \Lambda\,p\,\overline{p}) = (\text{-}13.0 \pm 0.5 \pm 1.5 \pm 1.1)\ \%$

Uncertainties associated with non-factorizable effects, CKM matrix elements, and hadronic form factors.

Analysis Strategy

Run 2 LHCb data: 2015+2016+2017+2018 (5.7 fb⁻¹).

- Perform a relative branching fraction measurement between signal channel and a topologically similar **normalisation channel** $\Lambda_b^0 \to \Lambda K^+ K^-$

- $\mathcal{B}(\Lambda_b^0 \to \Lambda K^+ K^-) = (15.9 \pm 1.2 \pm 1.2 \pm 2.0) \times 10^{-6}$ $\longrightarrow$ Measured without charm vetoes

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda p\overline{p})}{\mathcal{B}(\Lambda_b^0 \to \Lambda K^+ K^-)} = \frac{N(\Lambda_b^0 \to \Lambda p\overline{p})}{N(\Lambda_b^0 \to \Lambda K^+ K^-)} \cdot \frac{\epsilon_{\Lambda_b^0 \to \Lambda K^+ K^-}}{\epsilon_{\Lambda_b^0 \to \Lambda p\overline{p}}}$$

- Decay topology contains a Λ baryon which we detect up to 2 m.

- Track categories: 2 "long" tracks (**LL)** / 2 "downstream" tracks **(DD)**
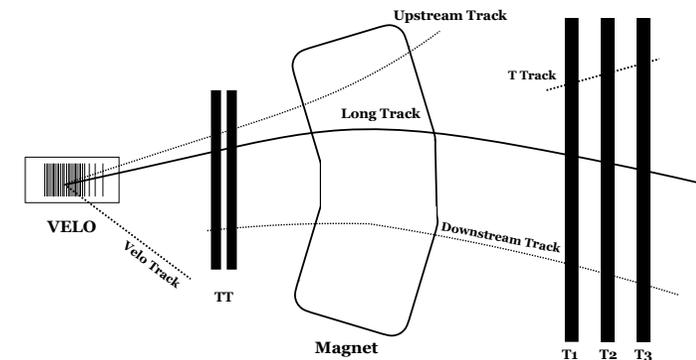
Signal yields from extended ML fit to $\Lambda h^+ h^-$ invariant mass.

Potential signal in the $\Xi_b^0 \to \Lambda p \overline{p}$ decay expected to be rather suppresed and out of reach.

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Event Selection

Trigger + Offline Selection + Preselection + MVA (XGBoost) + PID + Charm Vetoes

- **Common strategy for signal and normalisation**
  - Same trigger and closely related offline selections.

- **Topology of displaced $\Lambda_b^0 \to \Lambda\, h^+ h^-$ decays**
  - Good-quality tracks, displaced Λ_b^0 and Λ vertices.
  - Requirements on vertex quality, impact parameter, pointing, and flight distance.

- **Combinatorial-background suppression**
  - Dedicated **XGBoost** classifier.

- **Final purity requirements**
  - PID selections on bachelor hadrons.
  - charm-hadron vetoes in the normalisation mode.
  - m($h^+ h^-$)<2.85 GeV to exclude the charmonium region.
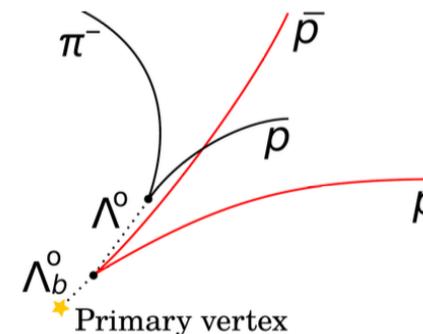
$\Lambda_b^0 \to \Lambda K^+ K^-$

$\left\| m_{K^+ K^-} - m_{D^0} \right\|$	$> 30\,\mathrm{MeV}$
$\left\| m_{\Lambda K^+} - m_{\Lambda_c^+} \right\|$	$> 30\,\mathrm{MeV}$
$\left\| m_{\Lambda K^+} - m_{\Xi_c^+} \right\|$	$> 30\,\mathrm{MeV}$
$\left\| m_{KK}^{K^\pm \pi^\mp} - m_{D^0} \right\|$	$> 30\,\mathrm{MeV}$
$m_{K^+ K^-}$	$< 2.85\,\mathrm{GeV}$

$\Lambda_b^0 \to \Lambda p\bar{p}$

|	
$m_{p\bar{p}}$	$< 2.85\,\mathrm{GeV}$

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Signal Extraction

Simultaneous unbinned maximum-likelihood fit
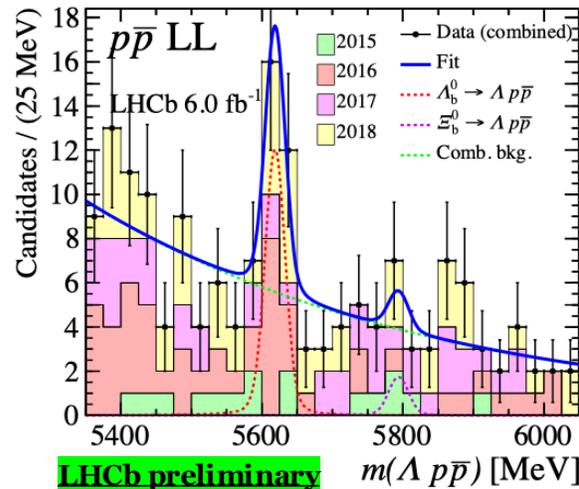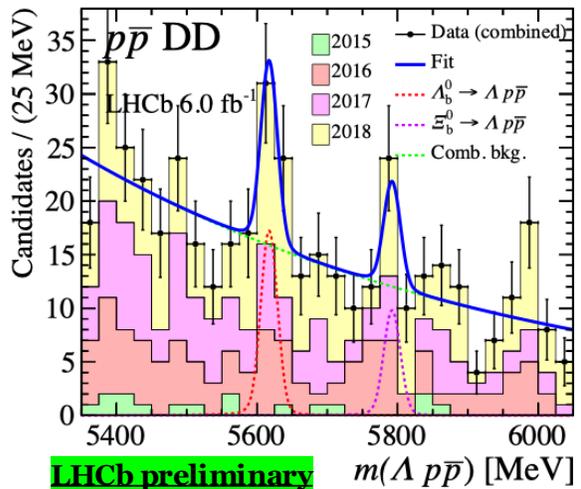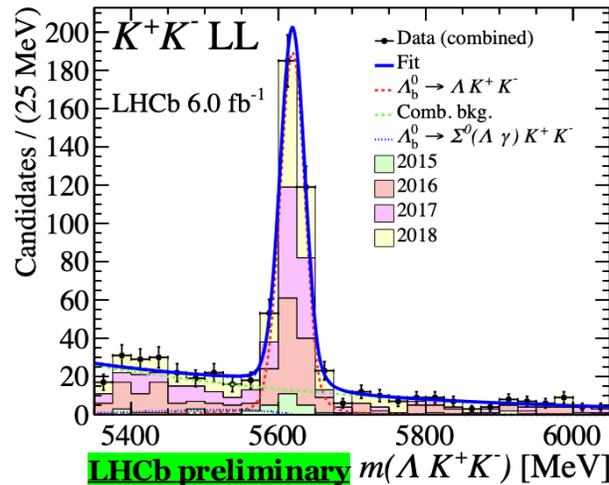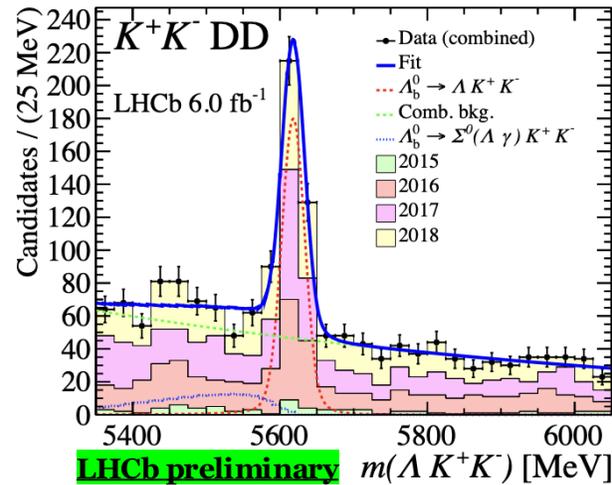
- Simultaneous fit, 4 invariant-mass spectra:
  - $\Lambda_b^0 \to \Lambda\, K^+ K^-$: **LL** and **DD**
  - $\Lambda_b^0 \to \Lambda\, p\, \overline{p}$: **LL** and **DD**

- Fit components:
  - Λ_b^0 peak in both modes
  - Combinatorial background in all categories
  - Partially reconstructed $\Lambda_b^0 \to \Sigma^0\, K^+ K^-$ only in the normalisation mode
  - $\Xi_b^0 \to \Lambda\, p\, \overline{p}$ included in the signal mode fit

- **Observe $\Lambda_b^0 \to \Lambda\, p\, \overline{p}$ with significance 5.1 σ**
  ($5.2\,\sigma$ statistical only)

- For $\Xi_b^0 \to \Lambda\, p\, \overline{p}$ no significant excess is observed

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Efficiency corrections and Results

- Efficiency maps are obtained from simulation in the 3-body Dalitz plane

- Background-subtracted data distributions are extracted with sWeights

- Phase-space-averaged efficiencies are computed separately for LL and DD
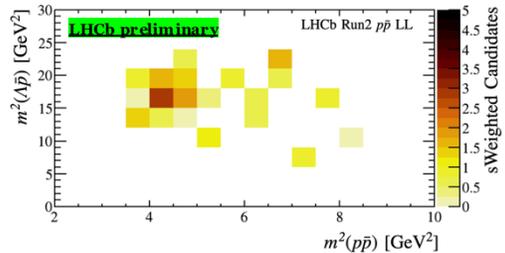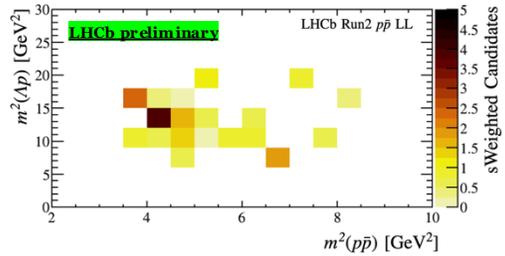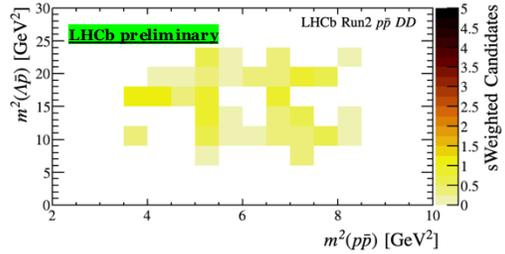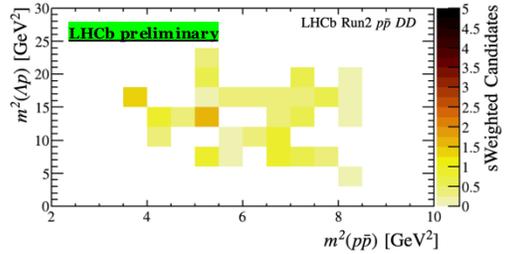
Source of uncertainty	Uncertainty [%]
Signal–fit modelling	2.8
Simulated-sample statistics	1.0
Tracking efficiency	4.3
PID efficiency	0.8
Truth-matching	0.2
Total systematic uncertainty	**5.3**

- Measured relative branching fraction:

$$R = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda p \bar{p})}{\mathcal{B}(\Lambda_b^0 \to \Lambda K^+ K^-)} = (5.13 \pm 1.28_{(\text{stat})} \pm 0.27_{(\text{syst})}) \times 10^{-2}$$

Observed $\Lambda_b^0 \to \Lambda\, p\, \bar{p}$ significance: 5.1 σ

First dedicated search of a baryon PBD, first charmless PBD observation!

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