# First steps towards the experimental observation of purely baryonic decay processes

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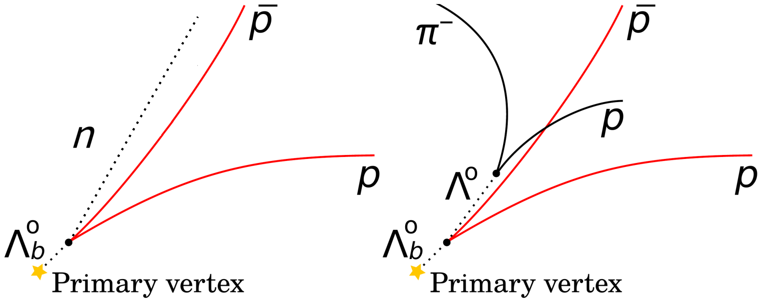
[1] *EPFL, Lausanne*
*SPS/CHIPP Annual meeting Lausanne 2018*

29 August 2018

# Purely baryonic decays of baryons

- Decays of baryons into final states containing *only* baryons
- Predicted by the Standard Model[1,2], examples:

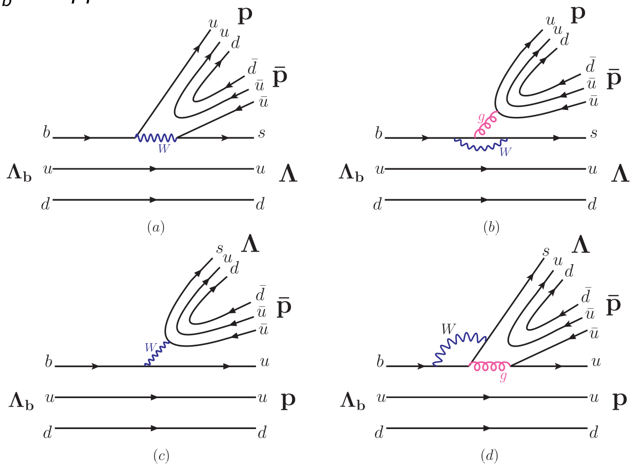



- Yet, **none of these modes has ever been experimentally observed**
- They constitute an unexplored class of decays...
- **Measurements of purely baryonic decays** represent valuable tests of theoretical predictions and can validate the factorization approach used.

[1] Purely baryonic decay processes by C. Q. Geng, Y.K. Hsiao, E. Rodrigues [1806.00861]
[2] Exploring the simplest purely baryonic decay processes by C. Q. Geng, Y.K. Hsiao, E. Rodrigues [1603.05602]

# Objectives

- Study purely baryonic decays in modes:
  - $\Lambda_b^0 \to \Lambda p \bar{p}$
  - $\Xi_b^0 \to \Lambda p \bar{p}$



# Objectives

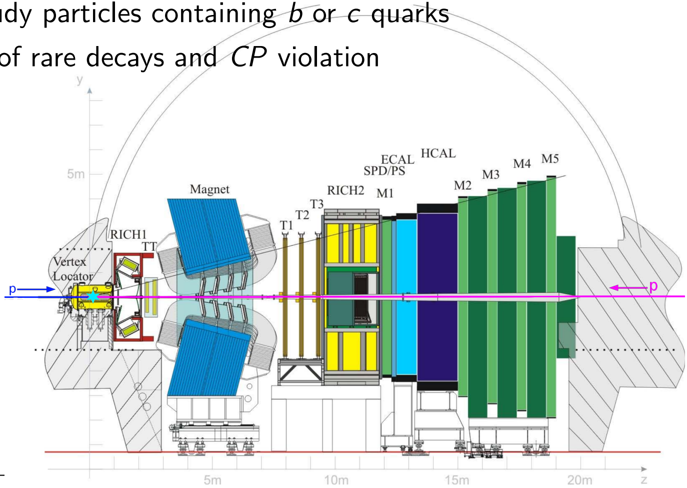
- Study purely baryonic decays in modes:
  - $\Lambda_b^0 \to \Lambda p \bar{p}$
  - $\Xi_b^0 \to \Lambda p \bar{p}$
- Measure the branching fractions; Theoretical predictions[1]:
  - $B(\Lambda_b^0 \to \Lambda p \bar{p}) = (3.2^{+0.8}_{-0.3} \pm 0.4 \pm 0.7) \times 10^{-6}$
  - $B(\Xi_b^0 \to \Lambda p \bar{p}) = (1.4 \pm 0.1 \pm 0.1 \pm 0.4) \times 10^{-7}$
    (uncertainties from non-factorisable effects, CKM matrix elements, and hadronic form factors)

- Depending on the successful observation and the available statistics: Carry out the first *CP* violation measurement for these decay modes; Theoretical prediction of direct *CP* violation:
  - $\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda p \bar{p}) = (3.4 \pm 0.1 \pm 0.1 \pm 0.1)\%$
  - $\mathcal{A}_{CP}(\Xi_b^0 \to \Lambda p \bar{p}) = (-13.0 \pm 0.5 \pm 1.5 \pm 1.1)\%$

[1] Purely baryonic decay processes by C. Q. Geng, Y.K. Hsiao, E. Rodrigues [1806.00861]

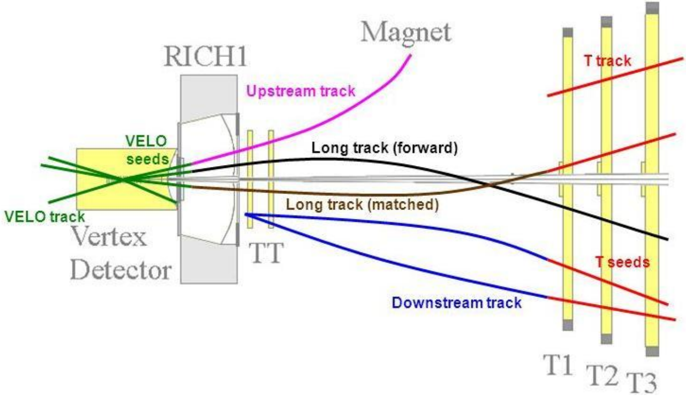
# LHCb detector

- Single-arm forward spectrometer[1]
- Covers the pseudorapidity range $2 < \eta < 5$
- Designed to study particles containing $b$ or $c$ quarks
- Measurements of rare decays and $CP$ violation




[1] A. A. Alves Jr *et al.* LHCb Collaboration, **The LHCb Detector at the LHC**, 2008 JINST **3** S08005

# Tracks at LHCb




Decays $\Lambda_b^0 \to \Lambda p\bar{p}$, $\Xi_b^0 \to \Lambda p\bar{p}$ contain $\Lambda$

In LHCb conditions $\Lambda$ can travel up to $\sim$2 m

- If $\Lambda$ decays in VELO $\to$ Two Long tracks
- If $\Lambda$ decays after traversing VELO $\to$ Two Downstream tracks

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Figure taken from Jeroen van Hunen, NIKHEF B-physics meeting June 4, 2004

# Expected yields

- According to a Run 1 study[1]:
  $N_{\Lambda_b^0 \to \Lambda^0 p\bar{p}} = 27.5 \pm 9.6_{(stat.)} \pm 3.0_{(sys.)}$

**Results for the free parameters of the simultaneous fit of the selected Run-1 data**

| $N_{\Lambda_b^0 \to \Lambda^0 p\bar{p}}(11\mathrm{LL})$ | $N_{\Lambda_b^0 \to \Lambda^0 p\bar{p}}(12\mathrm{LL})$ | $N_{\mathrm{DD}}/N_{\mathrm{LL}}(11)$ | $N_{\mathrm{DD}}/N_{\mathrm{LL}}(12)$ |
|---|---|---|---|
| $3{,}4^{+1{,}8}_{-1{,}4}$ | $9{,}7^{+3{,}4}_{-2{,}8}$ | $1{,}6^{+1{,}3}_{-0{,}7}$ | $0{,}9^{+0{,}5}_{-0{,}4}$ |
| $N_{komb.}(11\mathrm{LL})$ | $N_{komb.}(12\mathrm{LL})$ | $N_{komb.}(11\mathrm{DD})$ | $N_{komb.}(12\mathrm{DD})$ |
| $7{,}9^{+4{,}8}_{-3{,}7}$ | $34{,}6^{+10{,}3}_{-9{,}0}$ | $14{,}4^{+6{,}1}_{-5{,}2}$ | $38{,}8^{+8{,}8}_{-7{,}9}$ |

- With Run 2 luminosity and improvements in reconstruction, trigger and event selection, $\sim$**100** $\Lambda_b^0 \to \Lambda p\bar{p}$ **signal events** are expected.

[1] R. Zillmer, Master Thesis, University of Rostock

# Analysis steps:

- **Trigger selection**
- Event reconstruction
- Signal MC study
- Backgrounds
- Event Selection
- *Hypothesis testing*
- *Systematic uncertainty studies*

**LHCb Trigger**

- Level 0 (Hardware trigger):
  A hadron from signal detected or triggered independently of signal
- High Level Trigger 1 (Software trigger):
  One or two good quality tracks of interest reconstructed
- High Level Trigger 2 (Software trigger):
  2-or-3-body decay of interest reconstructed

Trigger $\varepsilon$[%]

| | 2015 *LL* | 2015 *DD* | 2016 *LL* | 2016 *DD* |
|---|---|---|---|---|
| $\Lambda_b^0 \to \Lambda p\bar{p}$ | 34.07 $\pm$0.66 | 29.22$\pm$0.31 | 37.22$\pm$0.40 | 33.05$\pm$0.20 |

# Analysis steps:

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- Look for events containing decay chain $\Lambda_b^0 \to \Lambda h\bar{h}$
  $\hookrightarrow \Lambda \to p\pi^-$
  with constraints on the decay product properties ($p_T$, angles,...)
- Apply proton mass ($h = p$) hypothesis and refit with constraints on $m_\Lambda$ and decay topology

Combined trigger and reconstruction $\varepsilon$[%]

| | 2015 *LL* | 2015 *DD* | 2016 *LL* | 2016 *DD* |
|---|---|---|---|---|
| $\Lambda_b^0 \to \Lambda p\bar{p}$ | $\sim$0.16 | $\sim$0.50 | $\sim$0.19 | $\sim$0.56 |

# Analysis steps:

- Trigger selection
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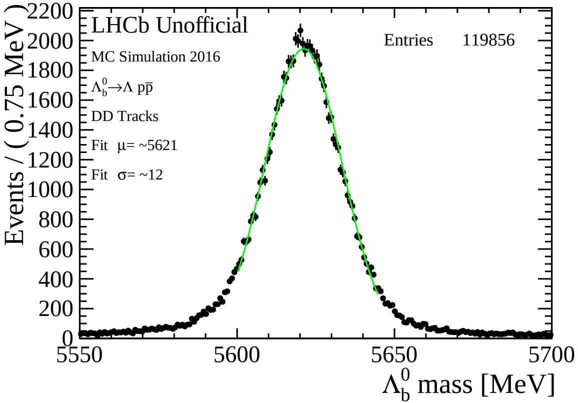
**Signal regions:**

- $\Lambda_b^0 \to \Lambda p\bar{p}$ : $m_{\Lambda_b} \pm 50\mathrm{MeV}$
- $\Xi_b^0 \to \Lambda p\bar{p}$ : $m_{\Xi_b^0} \pm 50\mathrm{MeV}$



# Analysis steps:

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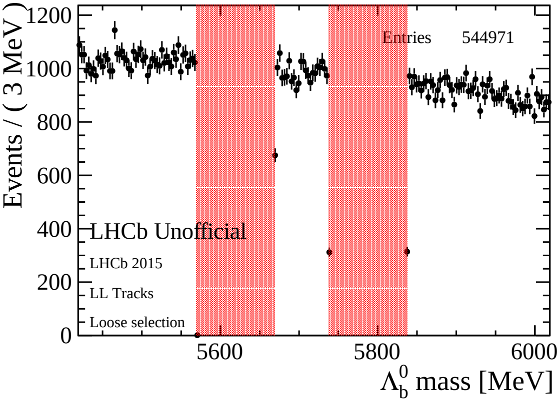
**Blind regions:**

$m_{\Lambda_b^0}$ = 5619.60 ± 0.17 MeV

- $\Lambda_b^0$: [5569,5669] MeV

$m_{\Xi_b^0}$ = 5794.5 ± 1.4 MeV

- $\Xi_b^0$: [5738,5838] MeV



# Analysis steps:

- Trigger selection
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**Backgrounds considered (1/2):**

- Combinatorial
- Cross-feed: a double meson misidentification in $\Lambda_b^0 \to \Lambda h h'$
  - $h \in \{K, \pi\}$
- $K_s^0$ cross-feeds: proton-pion misidentification:
  - $B_{(s)}^0 \to K_s^0 h h'$
  - $B_{(s)}^0 \to K_s^0 p \bar{p}$
  - $\Lambda_b^0 \to K_s^0 p h$
- other (Relevant for LL tracks, unlike modes above):
  - $B^0 \to p \bar{p} h h'$ [$B^0 \to p \bar{p} K \pi$]

# Analysis steps:

- Trigger selection
- Event reconstruction
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**Backgrounds considered (2/2):**

- Partially reconstructed (not observed) $\rightarrow$ toy simulation:
  - $\Lambda_b^0 \rightarrow \Lambda p \bar{p} \pi^0$
  - $\Xi_b^0 \rightarrow \Lambda p \bar{p} \pi^0$
- Modes like $\Lambda_b^0 \rightarrow \Sigma^0 p \bar{p}$ (not observed) with a decay $\Sigma^0 \rightarrow \Lambda\gamma$ where the $\gamma$ is not reconstructed:
  $\Delta m_{(\Sigma^0 - \Lambda)} = (76.959 \pm 0.023)\mathrm{MeV}$
  and $\mathcal{B}_{\Sigma^0 \rightarrow \Lambda\gamma} = 100\%$

# Analysis steps:

- Trigger selection
- Event reconstruction
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**Selection optimization**

- Multivariate approach utilizing machine learning tools to optimize signal event selection

**Examples of input variables for optimization:**

- $\Lambda_b^0$ transverse momentum
- $\Lambda_b^0$ pseudorapidity
- $\Lambda_b^0$ IP significance w.r.t PV
- $\Lambda_b^0$ pointing angle
- Daughter $\Lambda$ displacement
- ...

# Summary

- **Purely baryonic decays of baryons** are predicted by SM yet **not observed**, therefore constitute an unexplored class of decays
- **Measurements of purely baryonic decays** will test theoretical predictions and validate theoretical assumptions
- Selected signal channels $\Lambda_b^0 \to \Lambda p\bar{p}$, $\Xi_b^0 \to \Lambda p\bar{p}$ and associated backgrounds are analyzed
- Study aims at **first observation** of purely baryonic decays, branching fraction measurement and if the signal yield allows, $CP$ violation will be studied