Search for new decays of the Λ_b^0 baryon at the LHCb experiment

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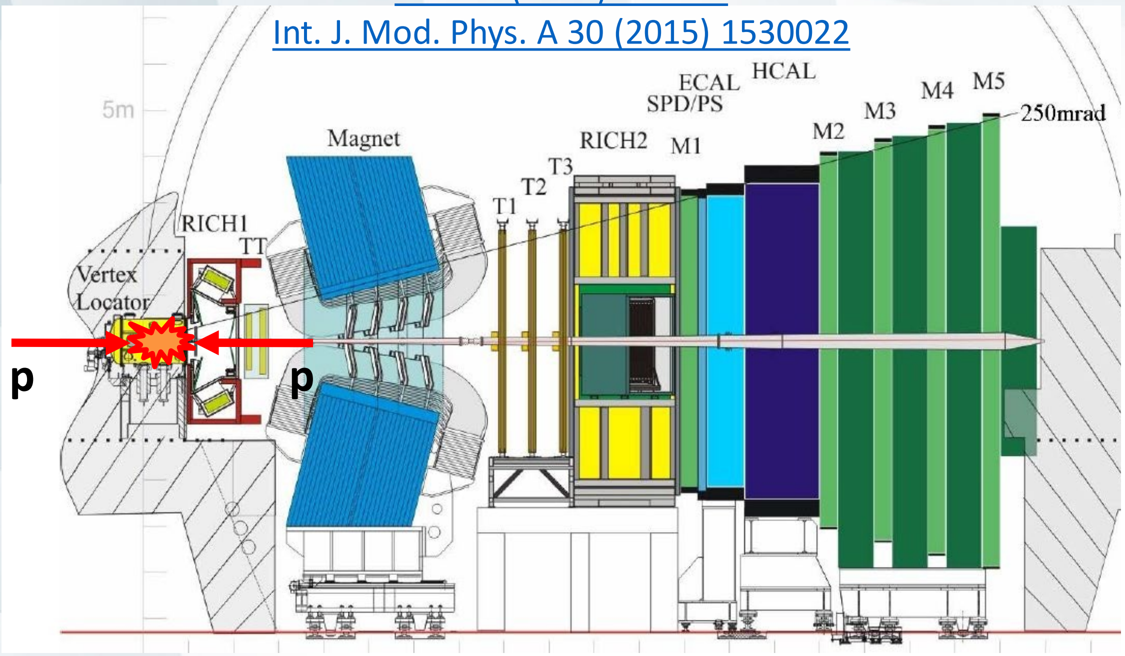
Outline

- **The LHCb detector**
- **New decays of the Λ_b^0 baryons:**
  - Observation of the decay $\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-$ ⇒ [integrated lumi ~3fb^{-1}, $\sqrt{s}$ = 7, 8 TeV]
  - Observation of the decays $\Lambda_b^0 \to J/\psi\Lambda$ and $\Lambda_b^0 \to \psi(2S)\Lambda$ ⇒ [integrated lumi ~3fb^{-1} , $\sqrt{s}$ = 7, 8 TeV]
  - Observation of the $\Lambda_b^0 \to \psi(2S)p\pi^-$ decay ⇒ [integrated lumi ~5fb^{-1} , $\sqrt{s}$ = 7, 8, 13 TeV]
  - Observation of the $\Lambda_b^0 \to \chi_{c1}(3872)pK^-$ decay ⇒ [integrated lumi ~5fb^{-1} , $\sqrt{s}$ = 7, 8, 13 TeV]
  - Observation of the $\Lambda_b^0 \to \Lambda\gamma$ ⇒ [integrated lumi ~1.7fb^{-1} , $\sqrt{s}$ = 13 TeV]
  - Observation of a new Λ_b^0 resonances in the $\Lambda_b^0\pi^+\pi^-$ systems ⇒ [integrated lumi ~9fb^{-1} , $\sqrt{s}$ = 7, 8, 13 TeV]
- **Summary**

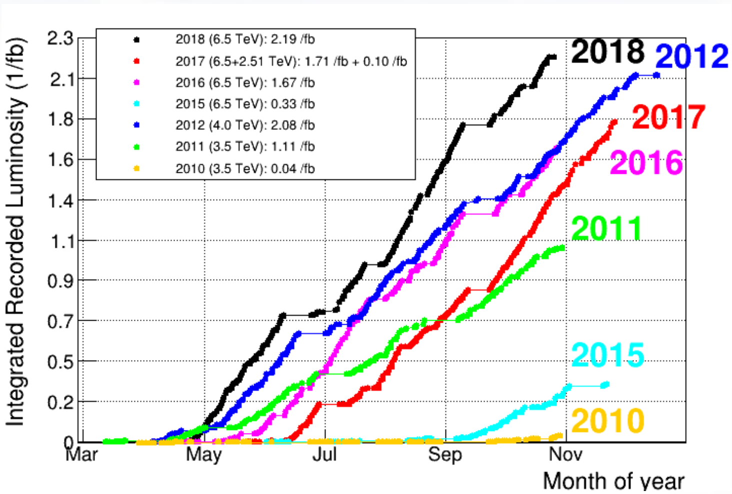
See also other LHCb news in talks from: V. Shevchenko, V.Matiunin, E.Kurbatov and P. Krokovny

The LHCb detector

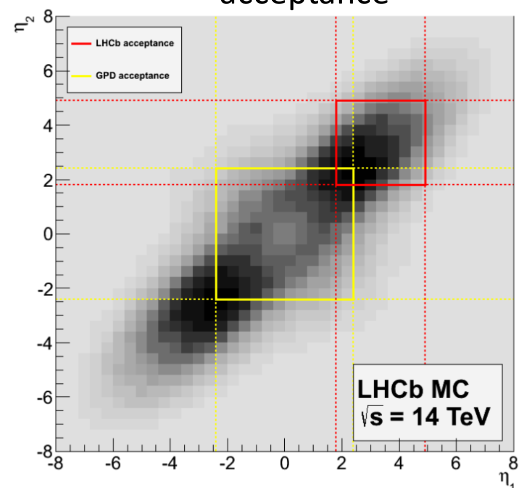
JINST 3 (2008) S08005
Int. J. Mod. Phys. A 30 (2015) 1530022



Total integrated lumi **~9 fb^{-1}**



~40% of **all produced $b\bar{b}$ and $c\bar{c}$ pairs** are in acceptance



Allow to study all kinds of beauty baryons

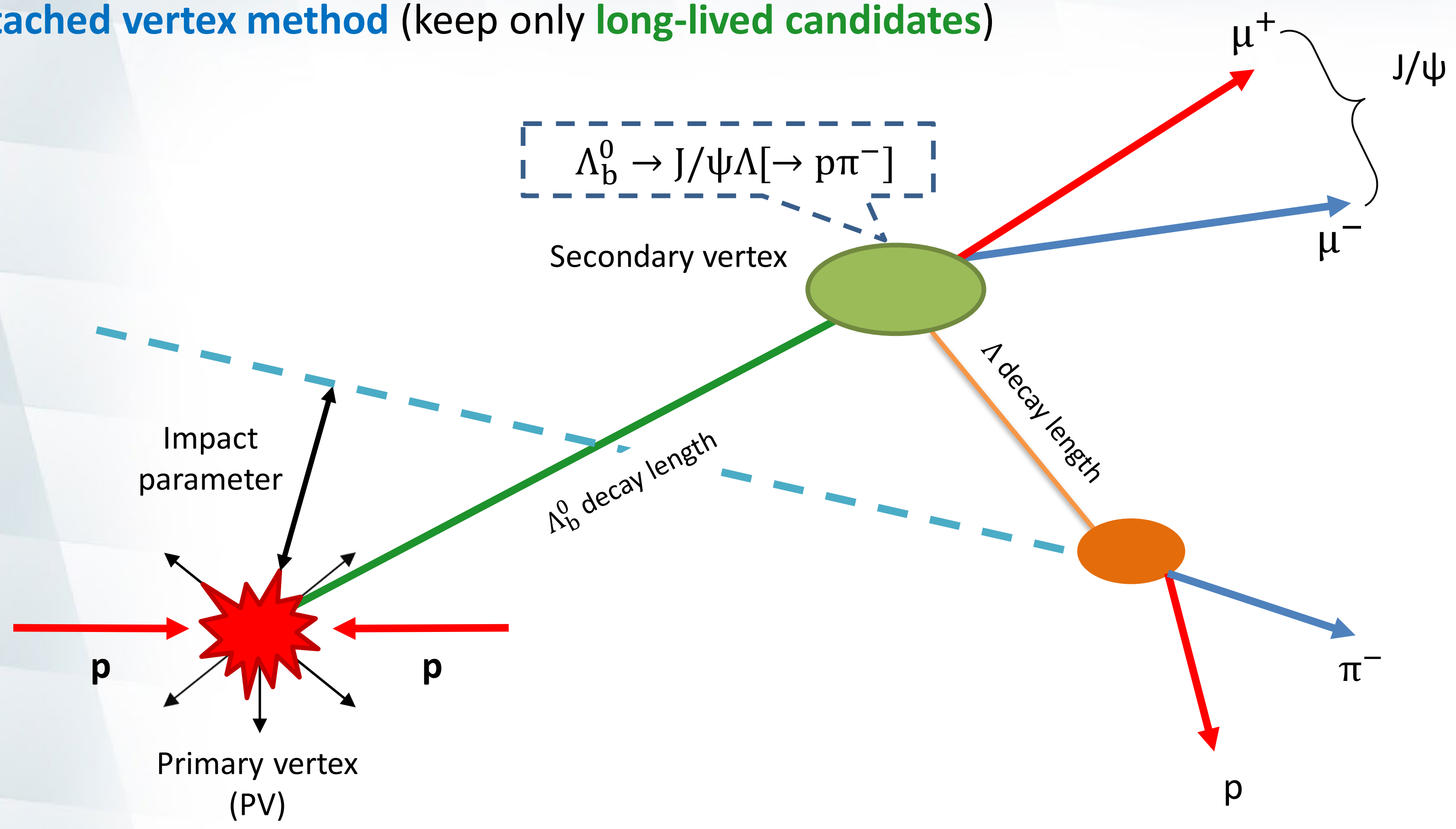
[see details in plenary talk from **V. Shevchenko**]

Main subsystems:

- **VErtex LOcator VELO:** for precise measurements of **vertices position**, **lifetime** and **impact parameter** resolutions;
- **Tracking stations TT, T1-T3 and dipole magnet:** provides measurement of high **momentum resolution** of charged particles
- **Identification system (RICH's, calorimeters)**: **K/p/π separation**, **trigger** on high p_T hadrons, **$e^{\pm}$, γ energy reconstruction**
- **Muon system (M1 – M5):** tracking stations for **muon identification**

Analysis strategy

- **Detached vertex method** (keep only **long-lived candidates**)



- Further selection **to suppress background: kinematics, particle identification, multivariate analysis**

Observation of the decay $\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-$

Motivation:

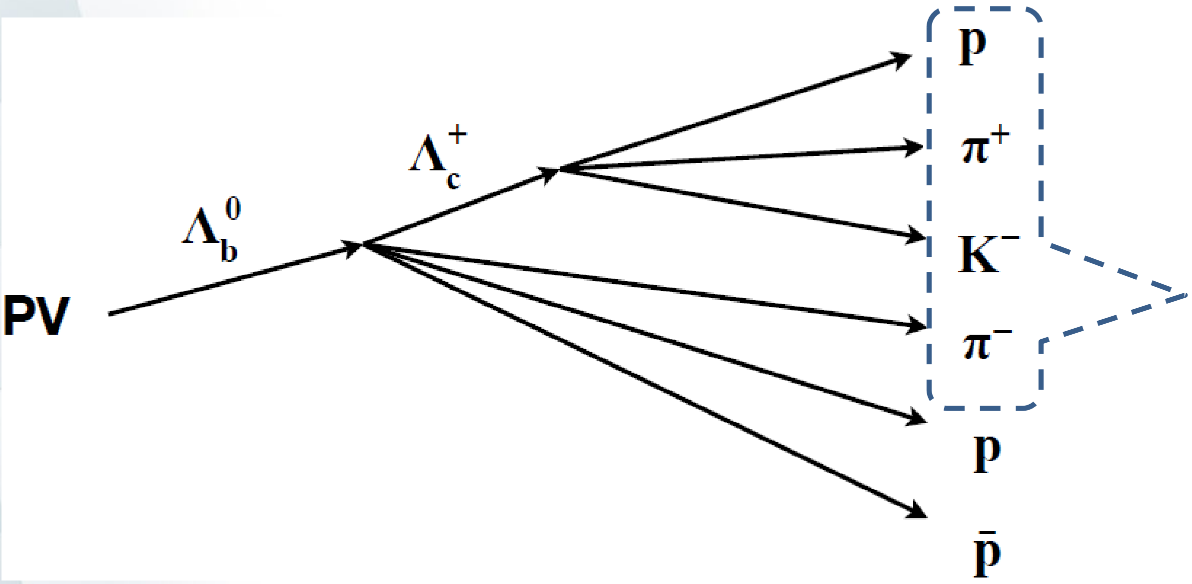
Search for dibaryon $\mathcal{D}_c^+ = [cd][ud][ud]$ with mass m($\mathcal{D}_c^+$) < 4682 MeV/c² could manifest $\Lambda_b^0 \to \bar{p}\mathcal{D}_c^+$, where:

1) $\mathcal{D}_c^+ \to p\Sigma_c^0$

2) $\mathcal{D}_c^+ \to p\mathcal{P}_c^0[\to \Lambda_c^+ \pi^-]$

$\mathcal{P}_c^0$ is a possible pentaquark state **Theory**: Phys. Lett. B 750 (2015) 37.

Decay scheme of the signal channel:



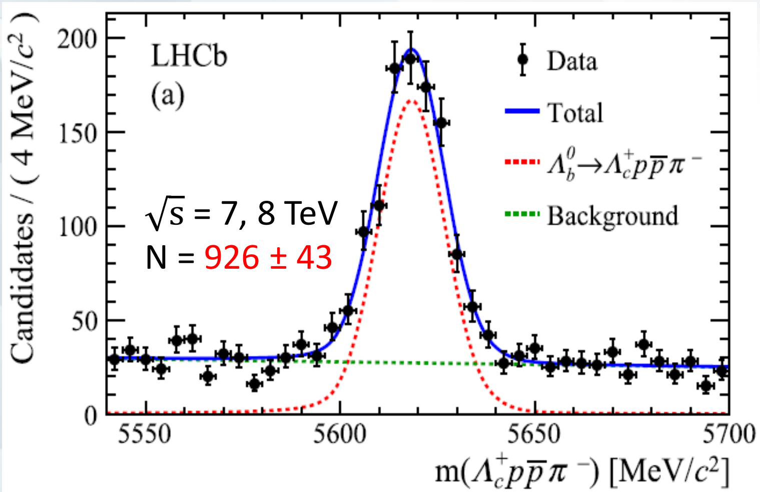
Normalization channel:
$\Lambda_b^0 \to \Lambda_c^+ \pi^-$

First! Λ_b^0 decay with three baryons in the final state

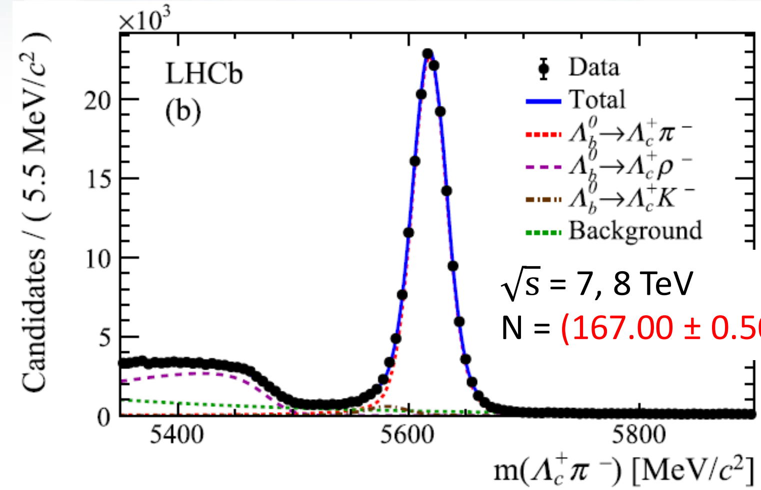
Observation of the decay $\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-$

LHCb: Phys. Lett. B 784 (2018) 101

Signal $\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-$ (**NEW!**)



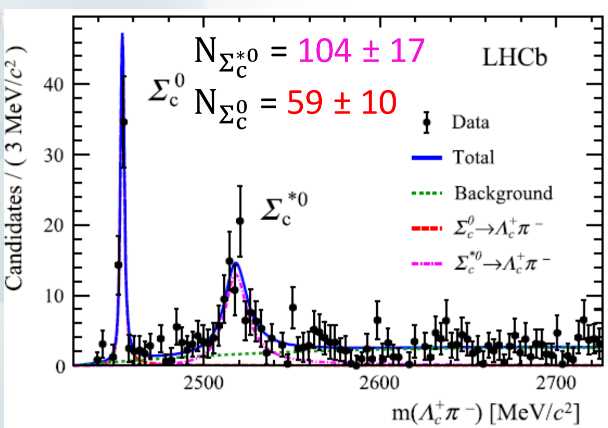
Normalization $\Lambda_b^0 \to \Lambda_c^+ \pi^-$



Relative branching fraction ratio:

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-)} = 0.0540 \pm 0.0023 \pm 0.0032$$

Dominant systematics: modelling of hadron interaction with the detector material



Contributions from $\Sigma_c(2455)^0$ and $\Sigma_c(2520)^0$ resonances are observed:

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Sigma_c^0 p\bar{p}) \times \mathcal{B}(\Sigma_c^0 \to \Lambda_c^+ \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-)} = 0.089 \pm 0.015 \pm 0.006,$$

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Sigma_c^{*0} p\bar{p}) \times \mathcal{B}(\Sigma_c^{*0} \to \Lambda_c^+ \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-)} = 0.119 \pm 0.020 \pm 0.014.$$

The mass spectra of the $\Lambda_c^+ p\pi^-$ final state is also inspected for possible dibaryon resonances, but no evidence of peaking structures is seen.

Observation of the decays $\Lambda_b^0 \to J/\psi\Lambda$ and $\Lambda_b^0 \to \psi(2S)\Lambda$

Motivation:

Ratios of branching fractions of b-hadrons decays into $[c\bar{c}]$+X provide useful information on the production of charmonia in b-hadron decays. These ratios can be used to test factorization of amplitudes.

Previous ATLAS measurements: $\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)/\mathcal{B}(\Lambda_b^0 \to J/\psi\,\Lambda) = 0.501 \pm 0.033\,(\mathrm{stat}) \pm 0.019\,(\mathrm{syst})$

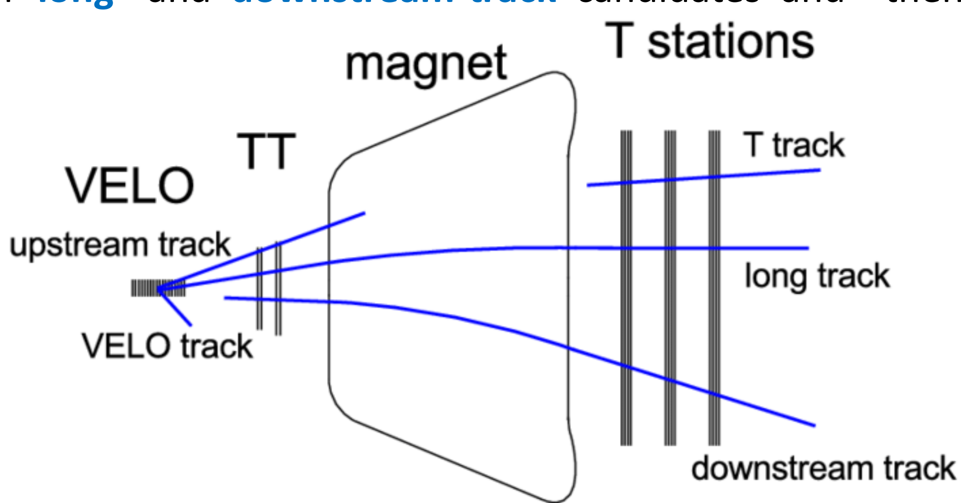
ATLAS: Phys. Lett. B 751 (2015) 63

differs by 2.8σ from a theoretical prediction: $\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)/\mathcal{B}(\Lambda_b^0 \to J/\psi\,\Lambda) = 0.8 \pm 0.1$

Theory: Phys. Rev. D 88 (2013) 114018
Theory: Phys. Rev. D 92 (2015) 114008

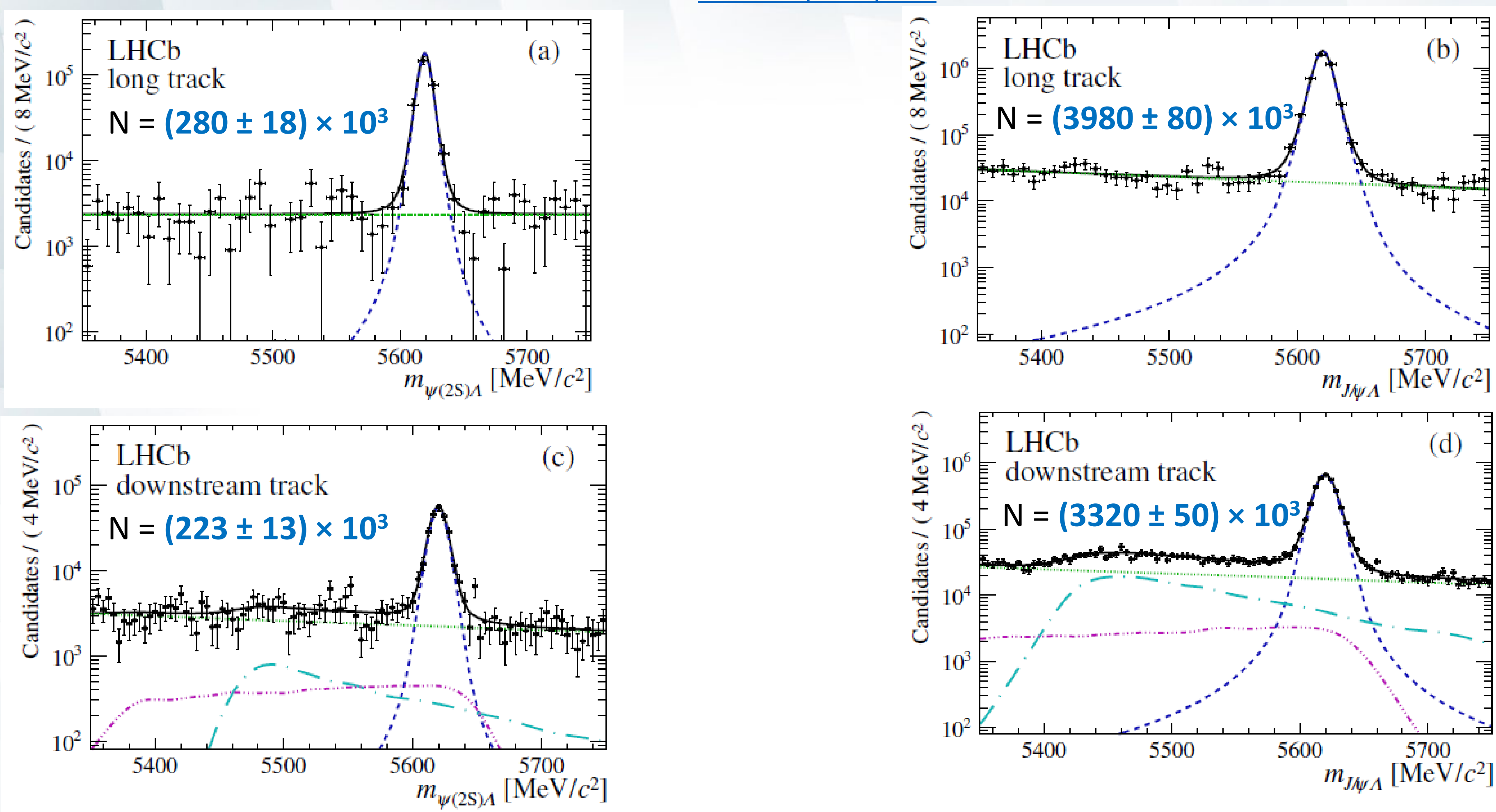
A measurement with improved precision helps to better understand this possible discrepancy

In both channels Λ hyperon is reconstructed using $p\pi^-$ final state. The ratio of branching fractions is determined **separately** for **long-** and **downstream-track** candidates and then combined into weighted average value.



Observation of the decays $\Lambda_b^0 \rightarrow J/\psi\Lambda$ and $\Lambda_b^0 \rightarrow \psi(2S)\Lambda$

LHCb: JHEP 03 (2019) 126



Weighted average value of branching fraction ratio:

$$\frac{\mathcal{B}(\Lambda_b^0 \rightarrow \psi(2S)\Lambda)}{\mathcal{B}(\Lambda_b^0 \rightarrow J/\psi\Lambda)} = 0.513 \pm 0.023\,(\text{stat}) \pm 0.016\,(\text{syst}) \pm 0.011\,(\mathcal{B})$$

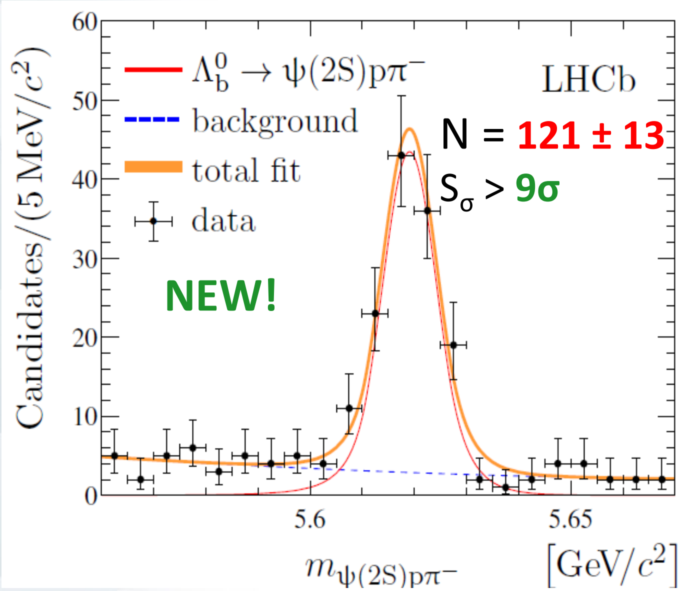
The measurement is compatible within **1σ** with ATLAS result and has a better precision. It confirms the discrepancy with the covariant quark model theory predictions

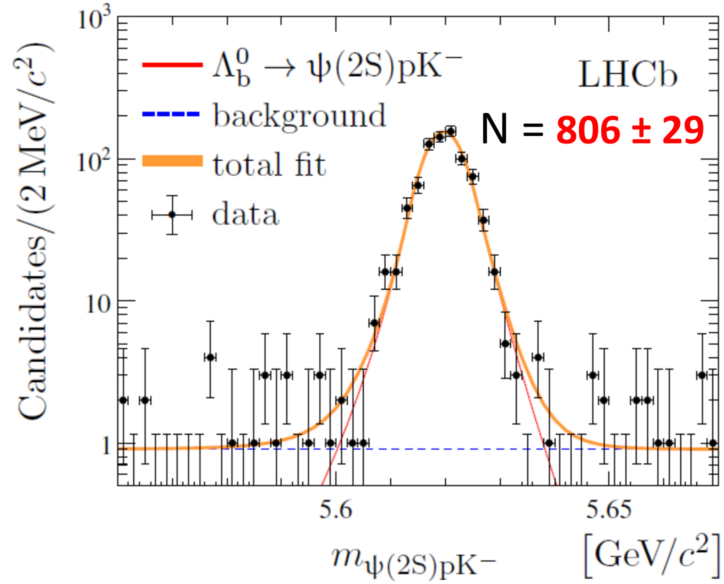
Observation of the $\Lambda_b^0 \to \psi(2S)p\pi^-$ decay

LHCb: JHEP 08 (2018) 131

Motivation:

The decay $\Lambda_b^0 \to \psi(2S)p\pi^-$ decay is of particular interest due to possible contributions from exotic states in both the $\psi(2S)p$ and $\psi(2S)\pi^-$ systems, similar to the $P_c(4380)^+$ and $P_c(4450)^+$ pentaquark states and to the charmonium-like state $Z_c(4430)^-$, respectively.





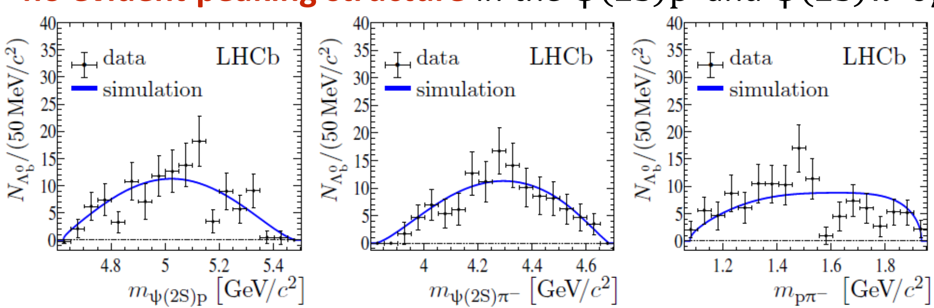
Branching fraction ratio

$$R_{\pi/K} = \frac{\mathcal{B}\left(\Lambda_b^0 \to \psi(2S)p\pi^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \psi(2S)pK^-\right)} = (11.4 \pm 1.3 \pm 0.2)\%$$

Absolute branching fraction

$$\mathcal{B}\left(\Lambda_b^0 \to \psi(2S)p\pi^-\right) = \left(7.17 \pm 0.82 \pm 0.33^{+1.30}_{-1.03}\right) \times 10^{-6}$$

no evident peaking structure in the $\psi(2S)p$ and $\psi(2S)\pi^-$ systems



Observation of the $\Lambda_b^0 \to \chi_{c1}(3872)pK^-$ decay

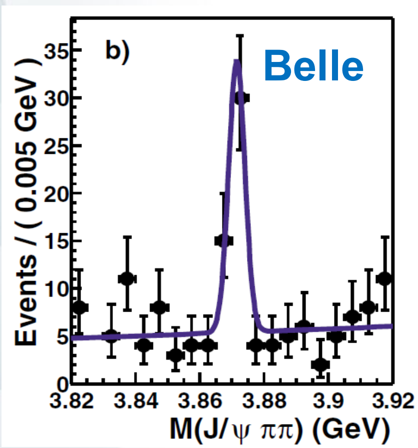
Motivation:

Several decays of the Λ_b^0 baryon to charmonium have been observed. This analysis is the **first observation** of the $\chi_{c1}(3872)$ state in beauty baryon decays.

The $\chi_{c1}(3872)$ state (a.k.a $X(3872)$) was discovered by the **Belle** collaboration at KEK in 2003 and subsequently confirmed by several other experiments (**BaBar**, **CDF**, **D0**, **LHCb**, **ATLAS**, **CMS**).

$B^\pm \to \chi_{c1}(3872)K^\pm$, $\chi_{c1}(3872) \to J/\psi\pi^+\pi^-$

Belle: Phys. Rev. Lett. 91 (2003) 262001



$\chi_{c1}(3872)$ $\quad I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 3871.69 \pm 0.17$ MeV
$m_{\chi_{c1}(3872)} - m_{J/\psi} = 775 \pm 4$ MeV
Full width $\Gamma < 1.2$ MeV, CL = 90%

$\chi_{c1}(3872)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi^+\pi^- J/\psi(1S)$	> 3.2 %	650
$\omega J/\psi(1S)$	> 2.3 %	†
$D^0 \overline{D}^0 \pi^0$	>40 %	117
$\overline{D}^{*0} D^0$	>30 %	3
$\gamma J/\psi$	$> 7 \times 10^{-3}$	697
$\gamma \psi(2S)$	> 4 %	181
$\pi^+\pi^- \eta_c(1S)$	not seen	746
$\pi^+\pi^- \chi_{c1}$	not seen	218
$p\overline{p}$	not seen	1693

Quantum numbers **$J^{PC} = 1^{++}$**, mass **$M(\chi_{c1}(3872)) = 3871.69 \pm 0.17$ MeV/c^2** [PDG] and dipion mass spectrum are measured. Despite significant experimental information the nature of the state is still uncertain.

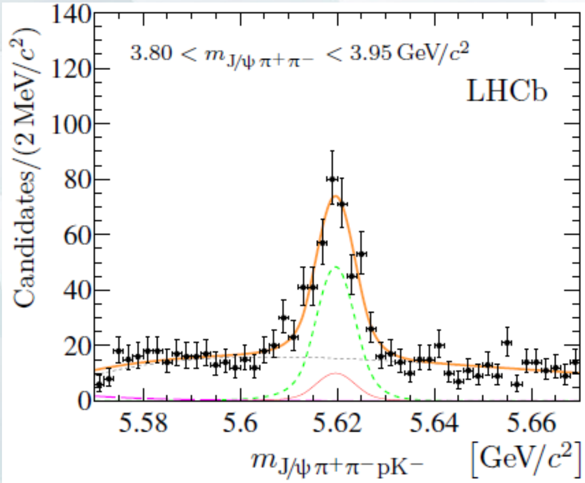
Possible interpretations: **$\chi_{c1}(2P)$ charomonium** state, **tetraquark**, … and their **mixtures**. The LHCb studies of radiative $\chi_{c1}(3872) \to \psi(2S)\gamma$ decays provide constraints to the interpretations of this state.

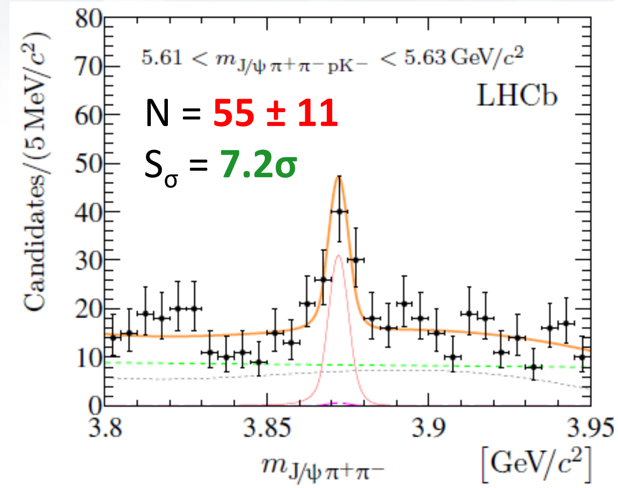
LHCb: Nucl. Phys. B (2014) 886

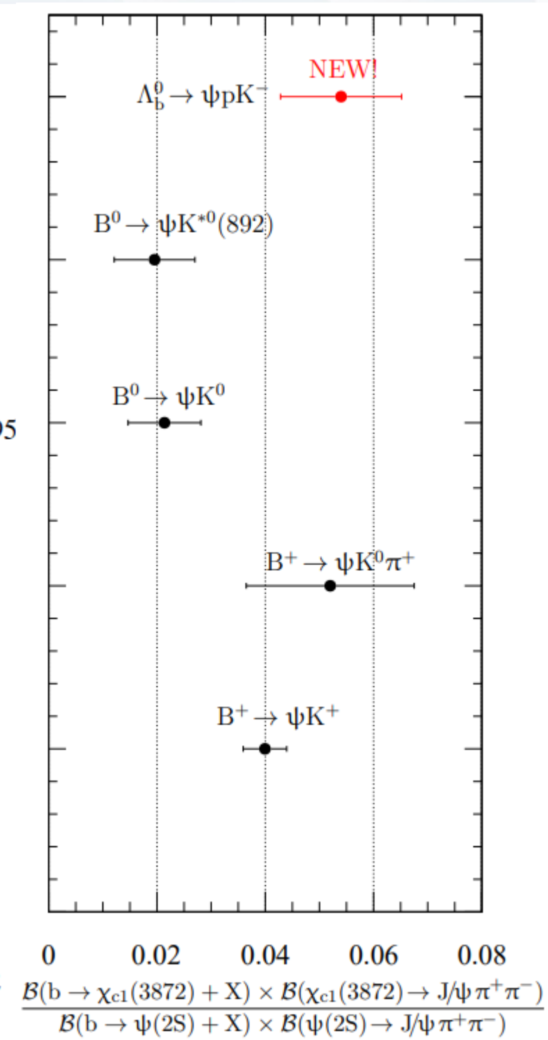
Observation of the $\Lambda_b^0 \to \chi_{c1}(3872)pK^-$ decay

Signal $\Lambda_b^0 \to \chi_{c1}(3872)pK^-$, $\chi_{c1}(3872) \to J/\psi\pi^+\pi^-$(**NEW!**)

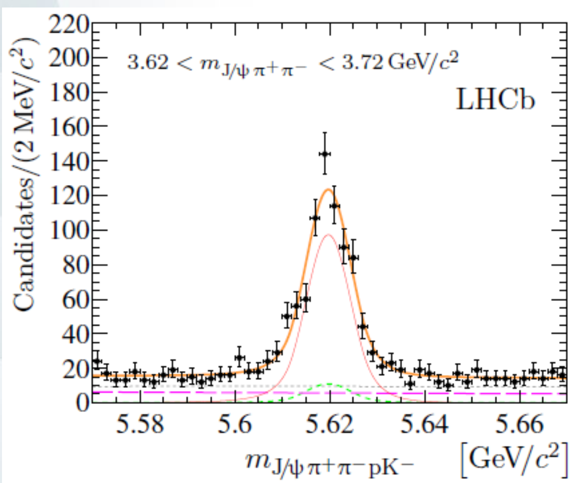
LHCb: JHEP 09 (2019) 028

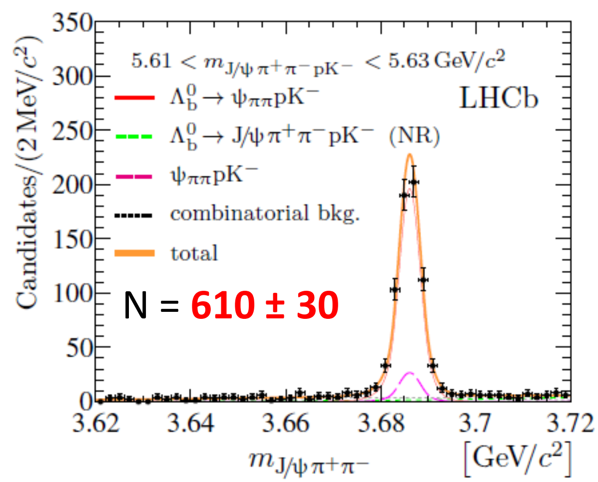






Normalization $\Lambda_b^0 \to \psi(2S)pK^-$, $\psi(2S) \to J/\psi\pi^+\pi^-$





Relative branching fraction ratio:

$$R = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c1}(3872)pK^-)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)pK^-)} \times \frac{\mathcal{B}(\chi_{c1}(3872) \to J/\psi\pi^+\pi^-)}{\mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)} = (5.4 \pm 1.1 \pm 0.2) \times 10^{-2}$$

Result is compatible with similar studies in B-meson decays

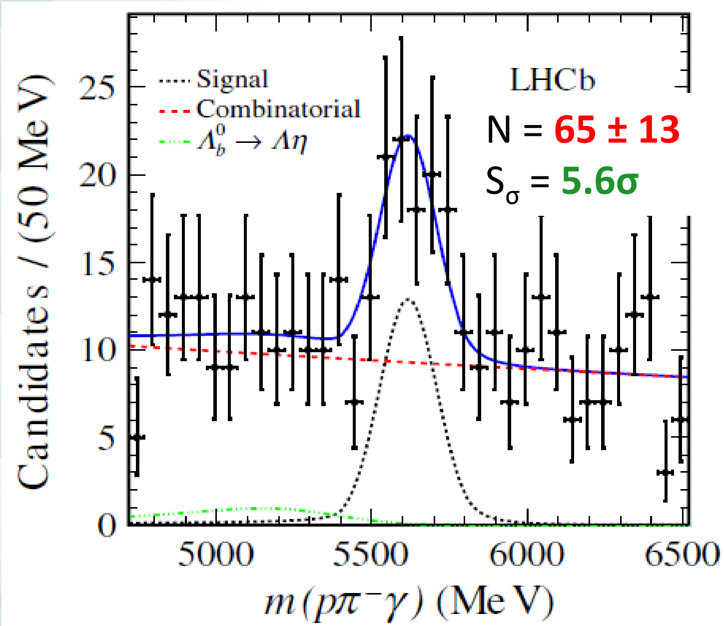
Observation of the $\Lambda_b^0 \to \Lambda\gamma$

LHCb: Phys. Rev. Lett. 123 (2019) 031801

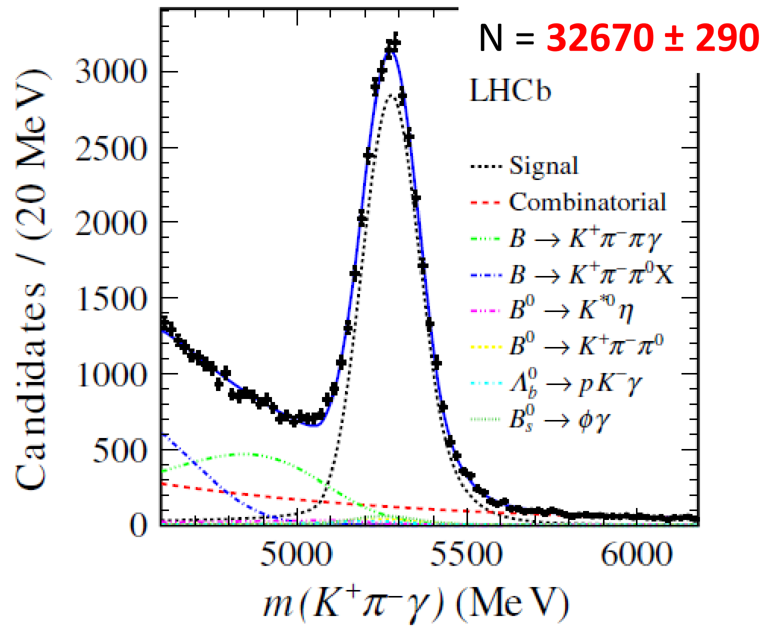
Motivation:

1) The decay $\Lambda_b^0 \to \Lambda[\to p\pi^-]\gamma$ proceeds via the $b \to s\gamma$ flavor-changing neutral-current transition. This process is sensitive to new particles, which can modify decay properties.
2) First observation of the radiative b-baryon decay

Signal: $\Lambda_b^0 \to \Lambda[\to p\pi^-]\gamma$



Normalization: $B^0 \to K^{*0}[\to K^+\pi^-]\gamma$



Measured branching fraction is found to be:

$$\mathcal{B}(\Lambda_b^0 \to \Lambda\gamma) = (7.1 \pm 1.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

In agreement with theoretical predictions:

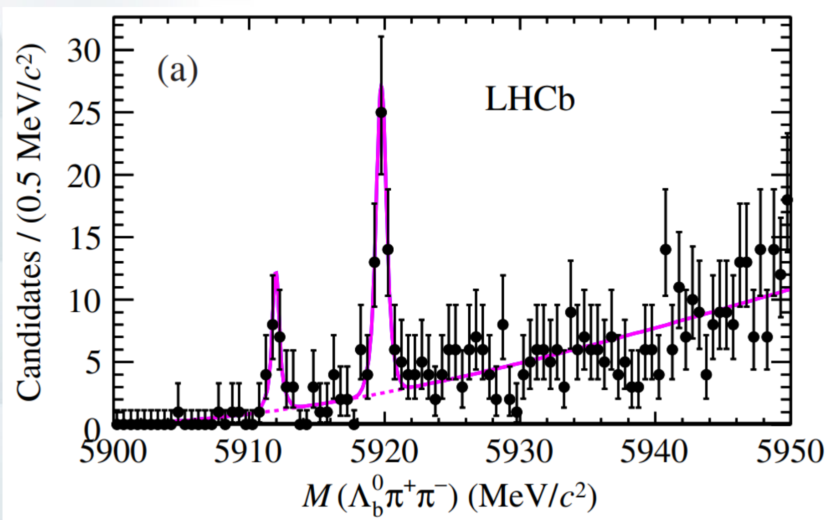
Theory: Eur. Phys. J. C 59 (2009) 861
Theory: JHEP 12 (2011) 067

Observation of a new Λ_b^0 resonances in the $\Lambda_b^0\pi^+\pi^-$ systems

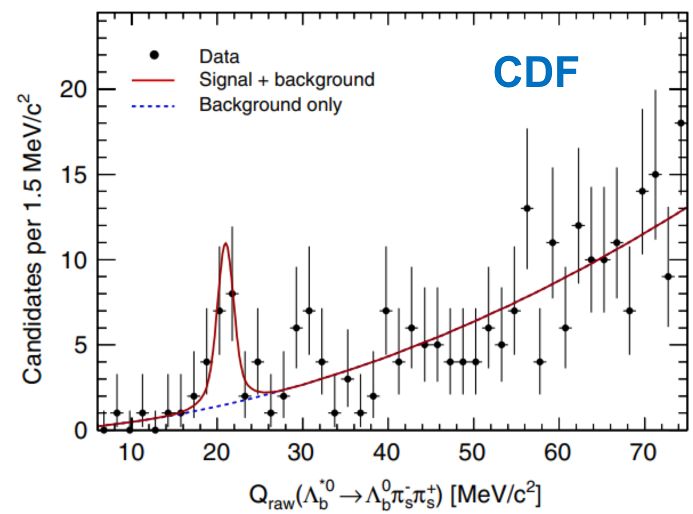
Motivation:

The spectrum of excited states decaying to the $\Lambda_b^0\pi^+\pi^-$ final state has already been studied by the LHCb experiment with the discovery of two narrow states, denoted $\Lambda_b^0(5912)$ and $\Lambda_b^0(5920)$ (**Confirmed** by CDF).

LHCb: Phys. Rev. Lett. 109 (2012) 172003



CDF: Phys. Rev. D 88 (2013) 071101(R)



In addition to the already observed doublet of first orbital excitations, more states in the mass region near 6.1 GeV/c^2 (or above) are expected.

Analysis strategy:

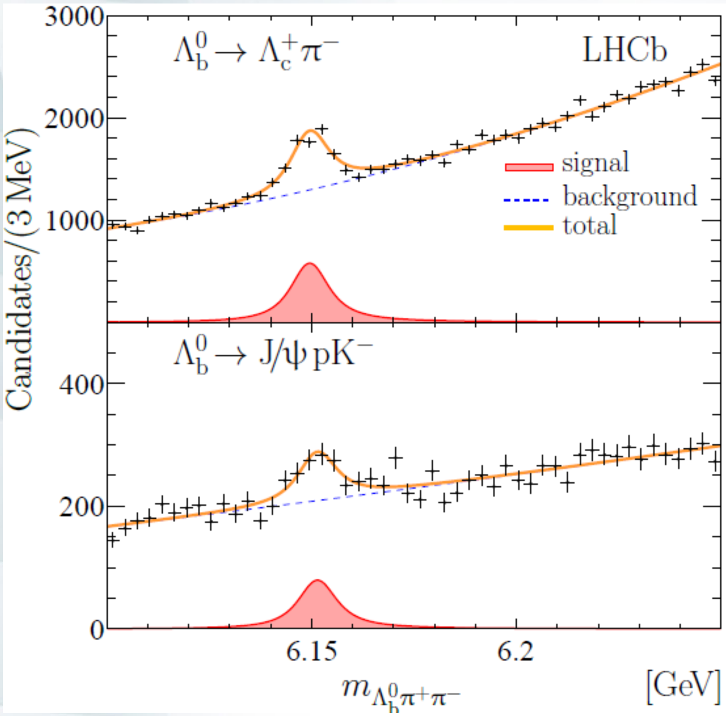
- Adding $\pi^+\pi^-$ pair to the reconstructed Λ_b^0 to probe excitations
- Λ_b^0 candidates are reconstructed in $\mathbf{\Lambda_b^0 \to \Lambda_c^+\pi^-}$ and $\mathbf{\Lambda_b^0 \to J/\psi p K^-}$
- Check structures near (above) 6.1 GeV/c^2
- Investigate substructure of decays: $X \to \Lambda_b^0\pi^+\pi^-$

$\Sigma_b^{(*)}$

Observation of a new Λ_b^0 resonances in the $\Lambda_b^0\pi^+\pi^-$ systems

LHCb: arXiv:1907.13598

Two **NEW** narrow states **Λ_b^0(6146)** and **Λ_b^0(6152)** are found:



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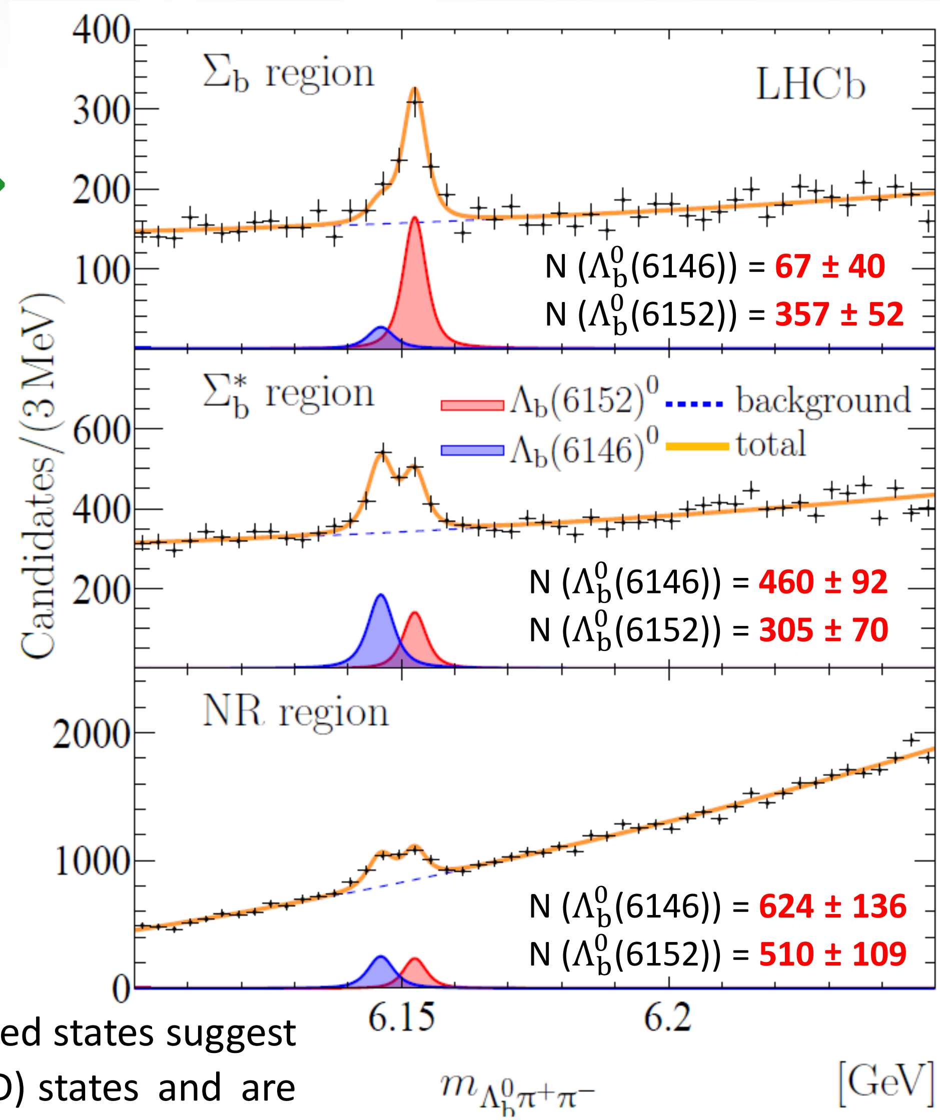

M(Λ_b^0(6146)) = 6146.17 ± 0.33 ± 0.22 ± 0.16 MeV/c^2

Γ(Λ_b^0(6146)) = 2.9 ± 1.3 ± 0.3 MeV

M(Λ_b^0(6152)) = 6151.51 ± 0.26 ± 0.22 ± 0.16 MeV/c^2

Γ(Λ_b^0(6152)) = 2.1 ± 0.8 ± 0.3 MeV

The measured masses and widths of these new excited states suggest their possible interpretation as a doublet of Λ_b^0(1D) states and are consistent with predictions.

Theory: Phys. Rev. D 34 (1986) 2809, Phys. Rev. Lett. 66 (1991) 1130, Eur. Phys. J. A (2015) 51: 82

Summary

The LHCb experiment provides a significant contribution to the knowledge of b-baryon spectroscopy

- Using data collected by the LHCb experiment during Run 1 (2011 - 2012) and Run 2 (2015 - 2018) number of new decays of the Λ_b^0 baryons were observed:
  - $\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-$, $\Lambda_b^0 \to J/\psi\Lambda$, $\Lambda_b^0 \to \psi(2S)\Lambda$, $\Lambda_b^0 \to \psi(2S)p\pi^-$, $\Lambda_b^0 \to \chi_{c1}(3872)pK^-$ and $\Lambda_b^0 \to \Lambda\gamma$
  - The existence of the $\chi_{c1}(3872)$ state in beauty baryon decays was confirmed
  - First observation of radiative b-baryon decay was done
  - New Λ_b^0 resonances $\Lambda_b^0(6146)$ and $\Lambda_b^0(6152)$ were observed in the $\Lambda_b^0\pi^+\pi^-$ systems
- Looking forward for new results!

Stay tuned with the news from LHCb!

Thank you for attention!

Backup #1

Λ_b^0 baryon quantum transitions