Beauty baryons spectroscopy at LHCb

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on behalf of the LHCb collaboration

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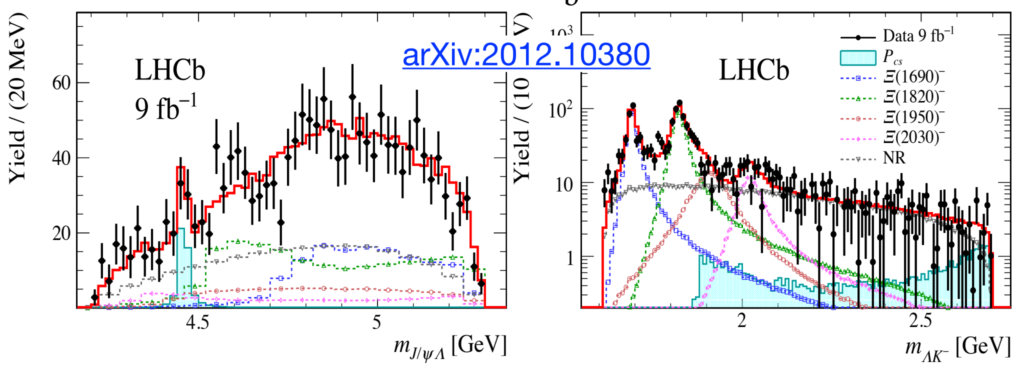
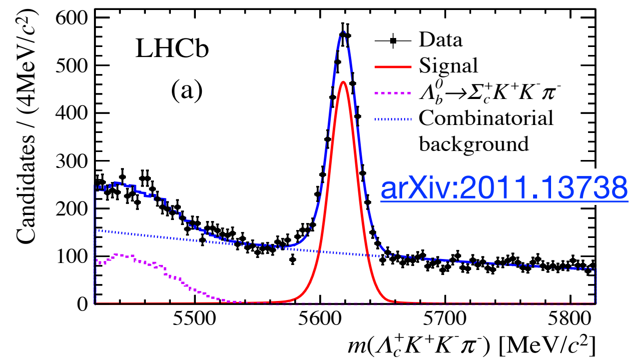
Les Rencontres de Physique de la Vallée d'Aoste (virtual)

Recent LHCb results on beauty baryons spectroscopy

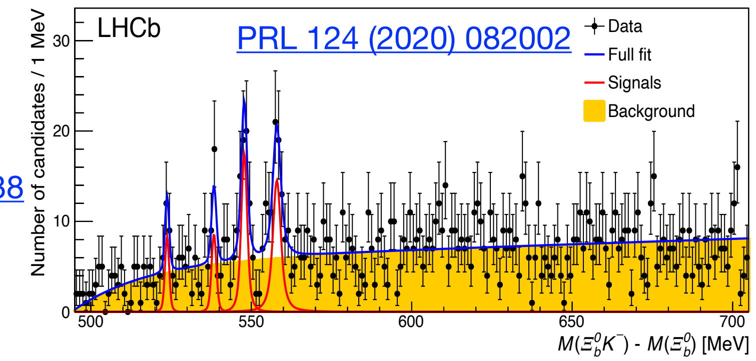
- Evidence of a $J/\psi\Lambda$ structure and observation of excited Ξ^- states in the $\Xi_b^- \to J/\psi\Lambda K^-$ decay



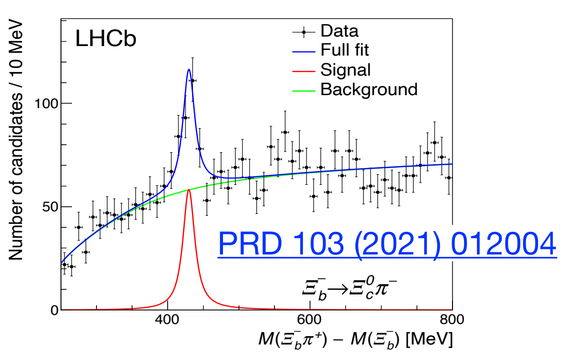
- Observation of $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$



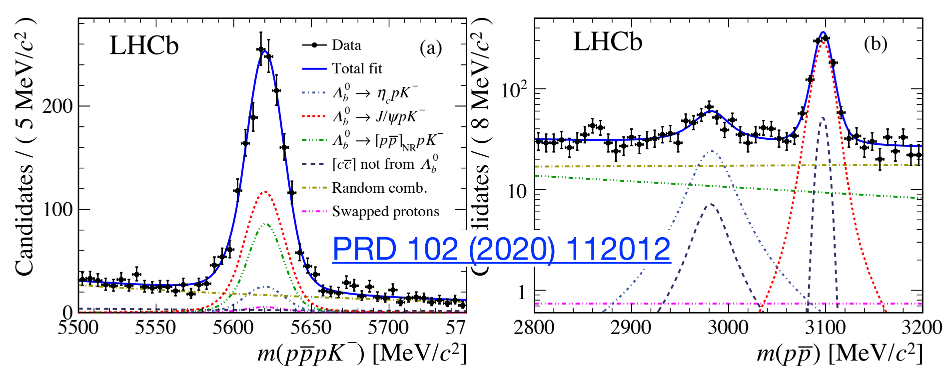
- Observation of excited Ω_b^- states



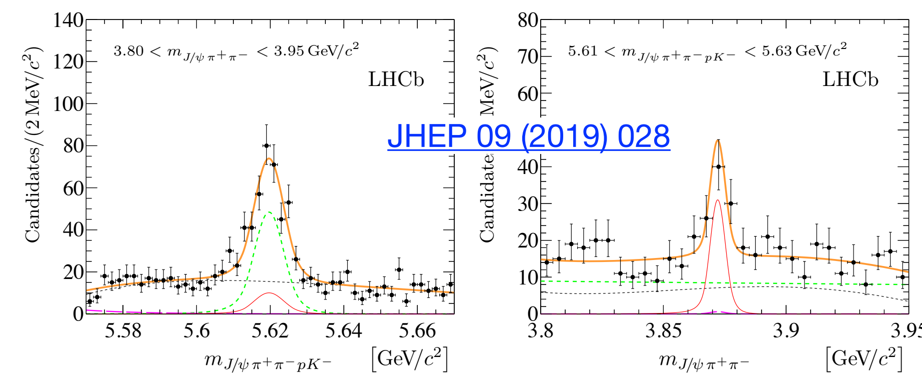
- Observation of a new Ξ_b^0 state



- First observation of the decay $\Lambda_b^0 \to \eta_c(1S) p K^-$



- Observation of $\Lambda_b^0 \to \chi_{c1}(3872) p K^-$



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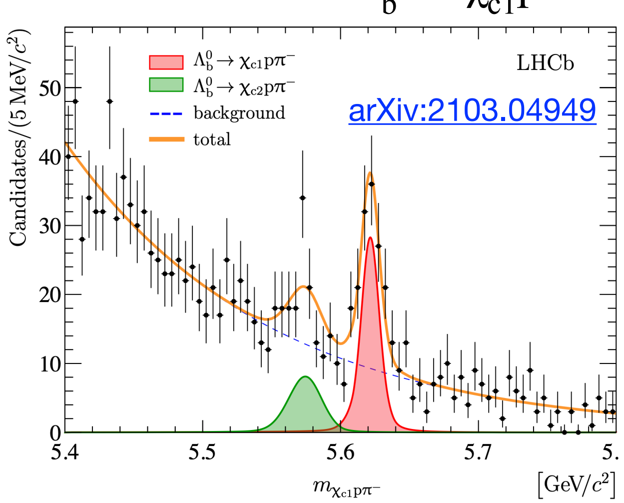
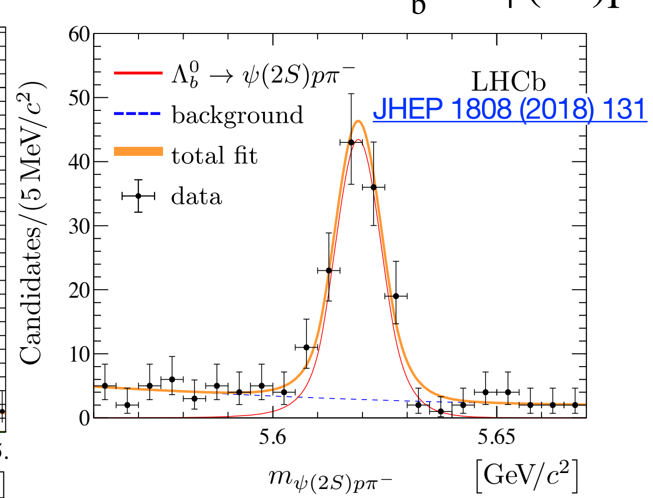
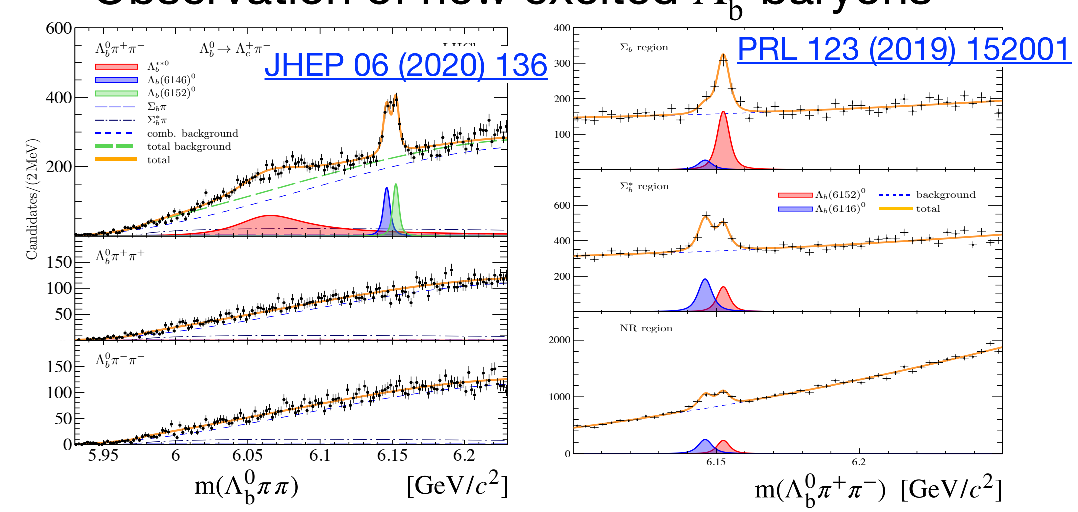


- Observation of $\Lambda_b^0 \to \psi(2S) p \pi^-$



- Observation of new excited Λ_b^0 baryons



Recent LHCb results on beauty baryons spectroscopy

See talk by Zehua Xu

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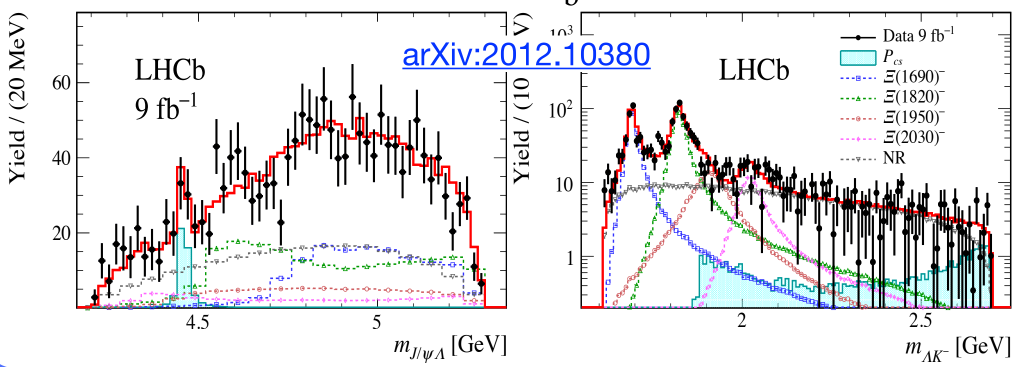

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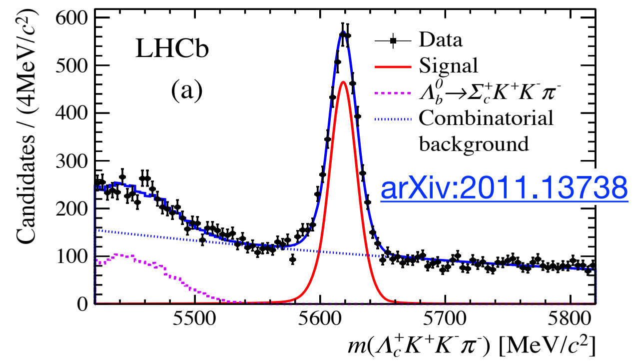

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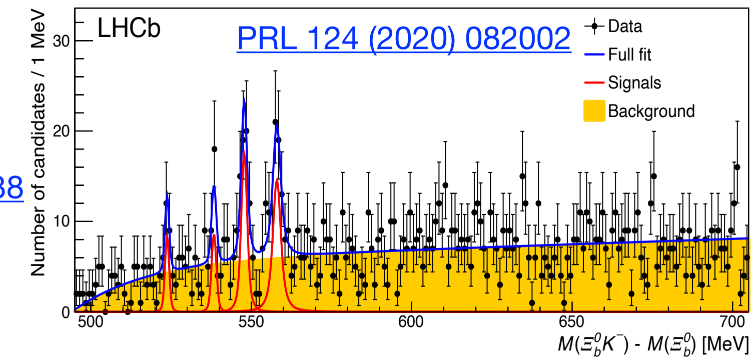

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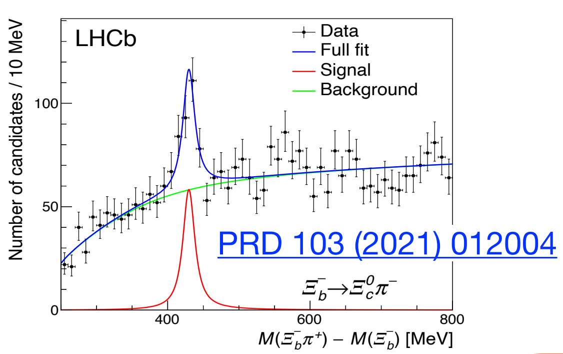

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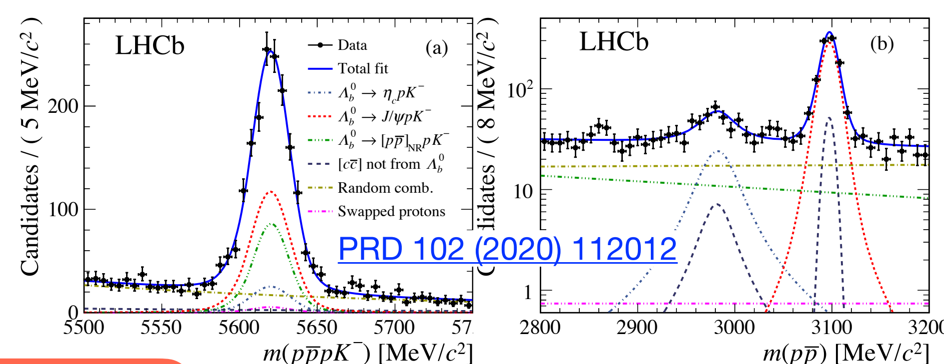
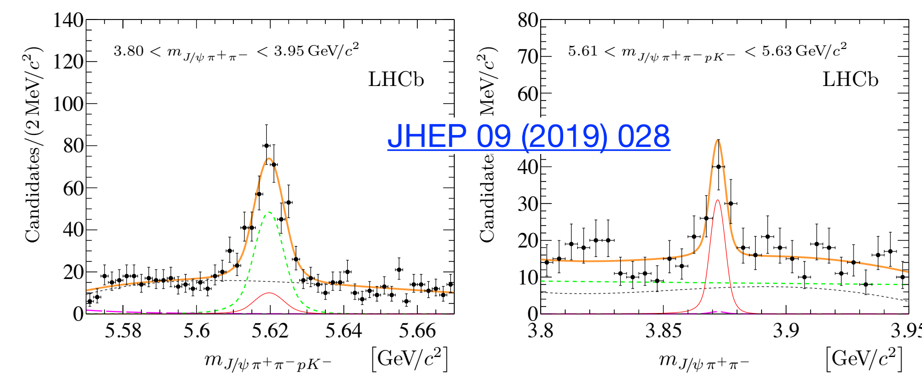
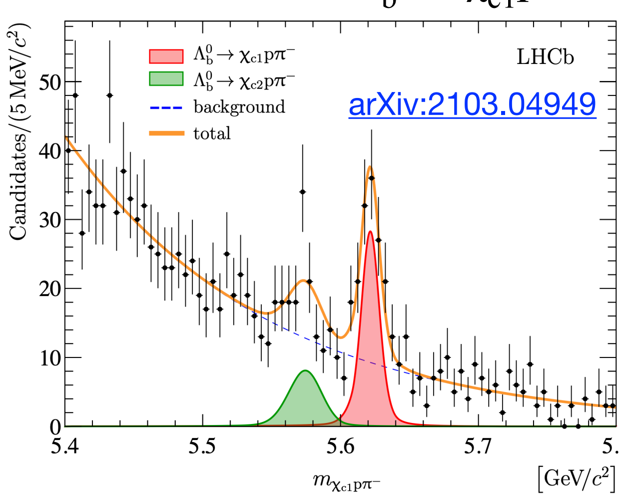


- Observation of $\Lambda_b^0 \to \chi_{c1}(3872) p K^-$

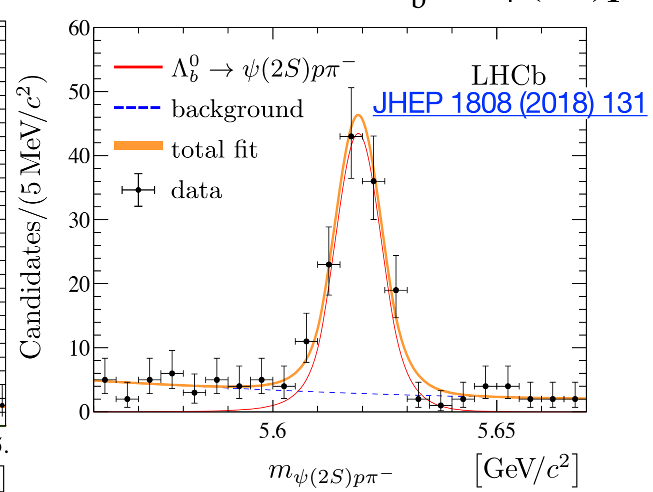


this talk

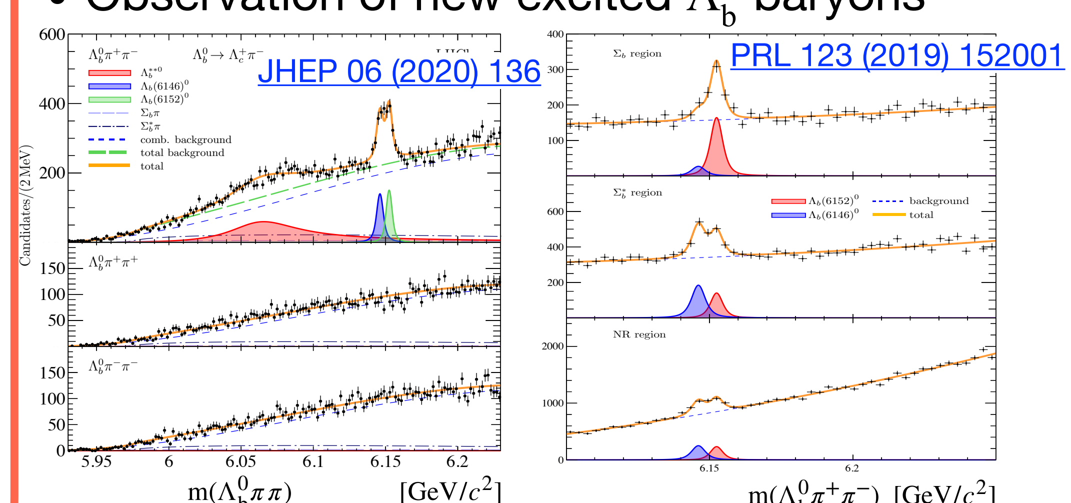
- Observation of $\Lambda_b^0 \to \chi_{c1} p \pi^-$



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

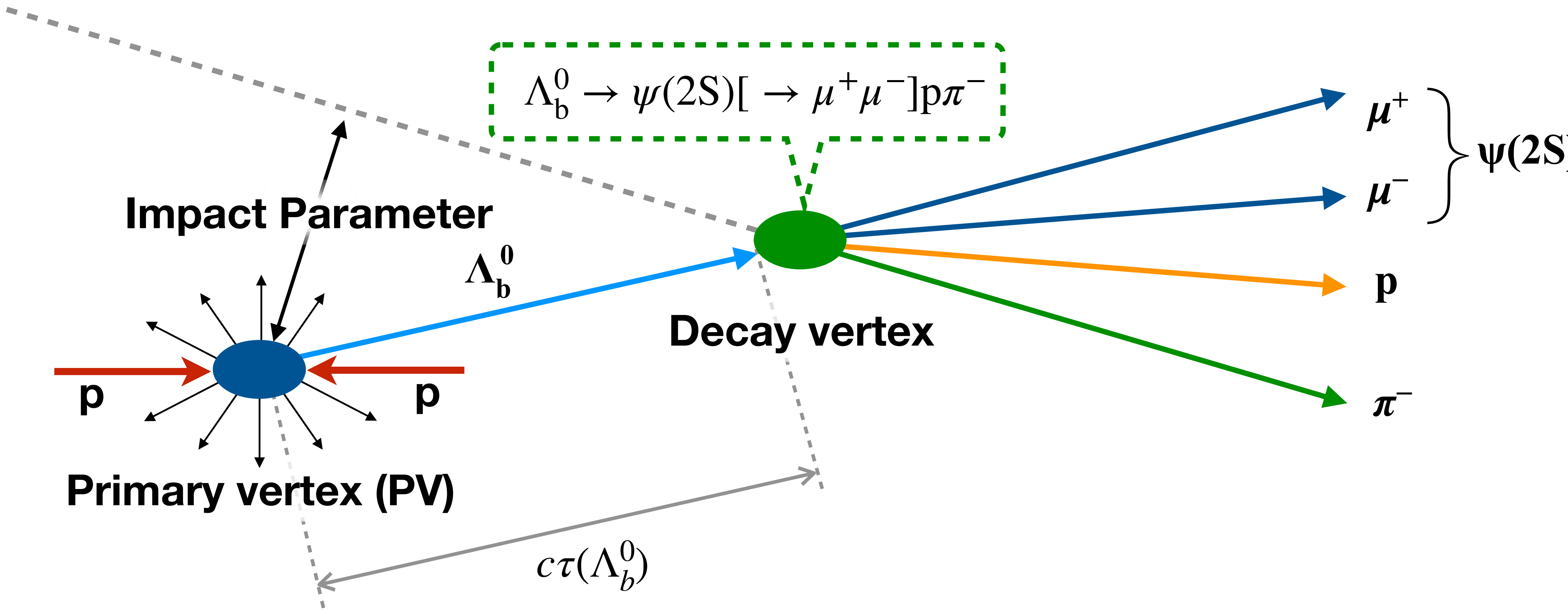


- Observation of new excited Λ_b^0 baryons



b-hadrons analysis strategy

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



Further selection to **suppress background**

- Track quality
- Particle identification
- Decay vertex separation from PV
- b-hadron pointing from PV
- Tracks not from PV
- Decay vertex quality
- Trigger on J/ψ and $\psi(2S)$

Motivation

Pentaquark resonances

Hidden-charm pentaquark resonances have been seen only in the $J/\psi p$ and $J/\psi\Lambda$ systems:

- $\Lambda_b^0 \to J/\psi p K^-$ [PRL 115 (2015) 072001, PRL 122 (2019) 222001, PRL 117 (2016) 082002]
- $\Lambda_b^0 \to J/\psi p \pi^-$ [PRL 117 (2016) 082003]
- $\Xi_b^- \to J/\psi \Lambda K^-$ [arXiv:2012.10380]

Interesting to search for resonances in other systems, like $\psi(2S)p$, $\chi_{c1}p$ and $\chi_{c2}p$.

Tetraquark resonances

Tetraquark resonances have been seen in the $\psi(2S)\pi^-$ and $\chi_{c1}\pi^-$ systems using following decays:

- $B^0 \to \psi(2S)K^+\pi^-$ [PRL 100 (2008) 142001, PRD 80 (2009) 031104, PRD 88 (2013) 074026, PRL 112 (2014) 222002, PRD 92 (2015) 112009]
- $B^0 \to \chi_{c1}K^+\pi^-$: two $Z_c^+ \to \chi_{c1}\pi^+$ observed by Belle [PRD 78 (2008) 072004], not confirmed by BaBar [PRD 85 (2012) 052003]

Interesting to search for same resonances $\psi(2S)\pi^-$ and $\chi_{c1}\pi^-$ with other decay channels.

Previous analysis of the $\Lambda_b^0 \to \chi_{c1,2} p K^-$ decays:

- $\dfrac{Br(\Lambda_b^0 \to \chi_{c2} p K^-)}{Br(\Lambda_b^0 \to \chi_{c1} p K^-)} = 1.02 \pm 0.10 \pm 0.02 \pm 0.05$ [PRL 119 (2017) 062001],

which is much higher than that for $B \to \chi_{c1,2}K^{(*)}$ measurements by Belle, BABAR and LHCb.

Such a suppression is expected within QCD factorisation approach.

For example, $\dfrac{Br(B^0 \to \chi_{c2}K^{*0})}{Br(B^0 \to \chi_{c1}K^{*0})} = (17.1 \pm 5.0 \pm 1.7 \pm 1.1) \times 10^{-2}$ [LHCb-PAPER-2013-024]

Observation of the decay $\Lambda_b^0 \rightarrow \chi_{c1} p \pi^-$

arXiv:2103.04949

Channels under study:

Signal: $\Lambda_b^0 \rightarrow \chi_{c1,2} p \pi^-$

Normalization: $\Lambda_b^0 \rightarrow \chi_{c1,2} p K^-$

$\Big\}\ \chi_{c1,2} \rightarrow \gamma J/\psi,\ J/\psi \rightarrow \mu^+\mu^-$

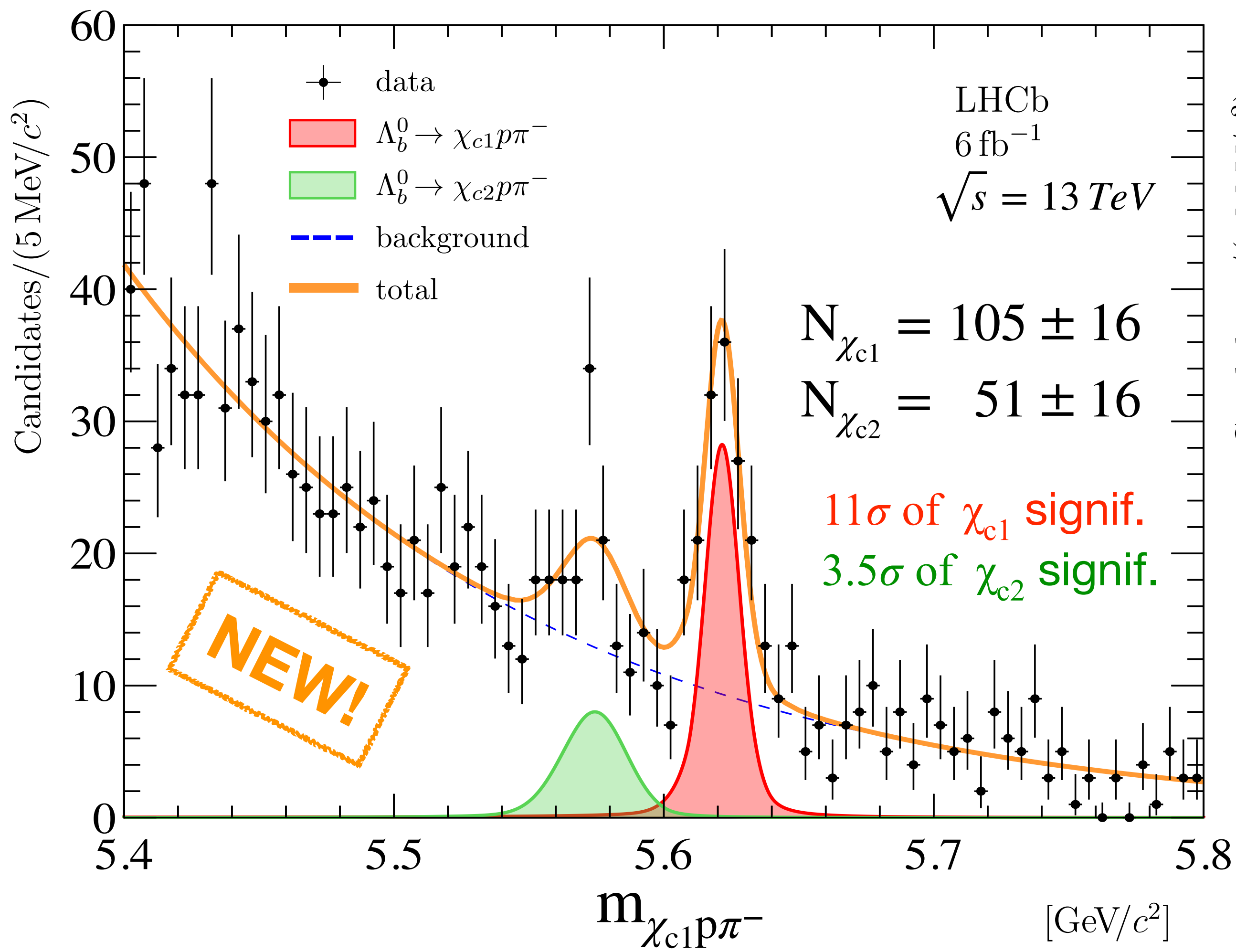
χ_{c0} contribution is not expected to give a sizeable contribution:

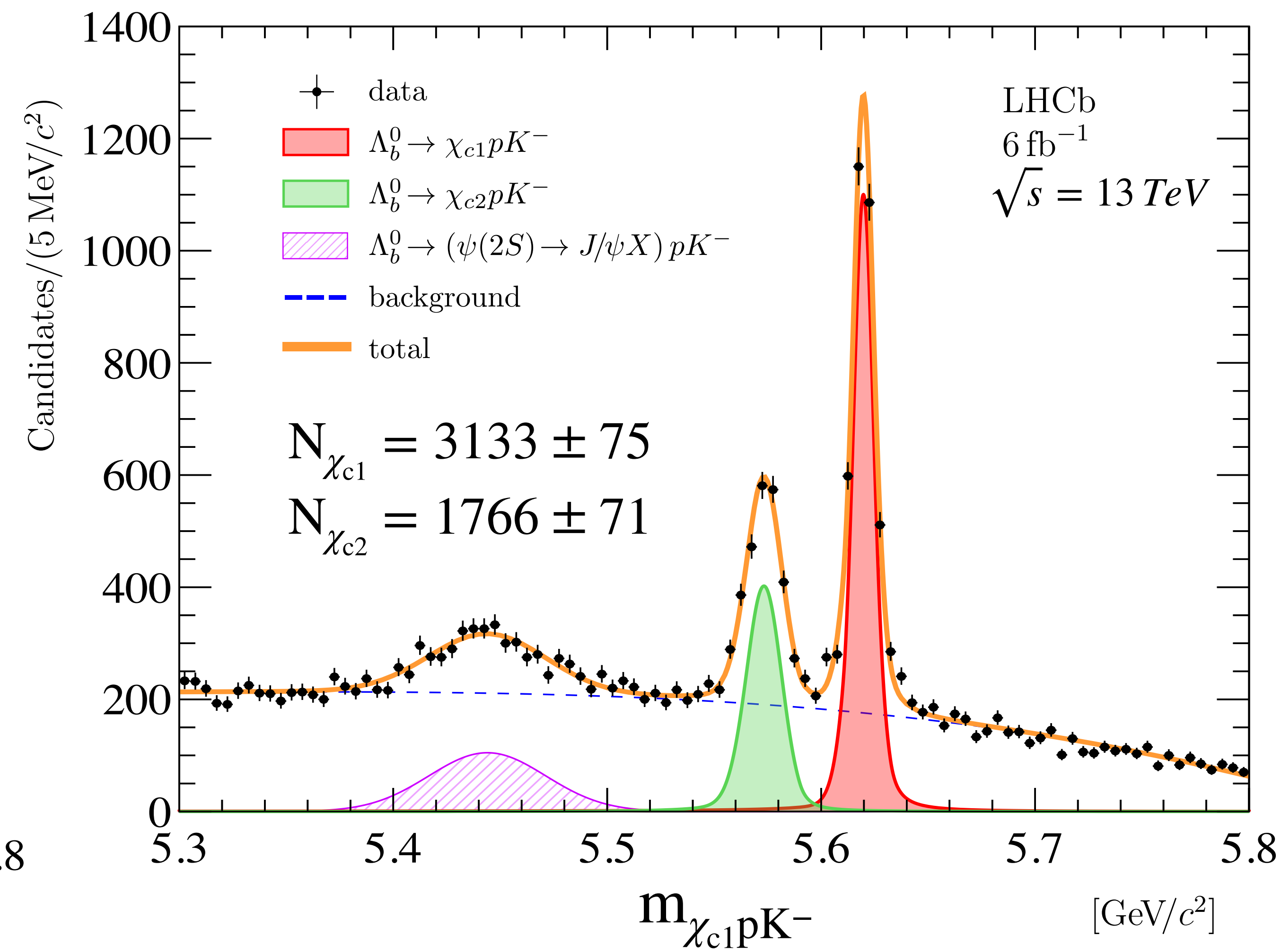
- suppressed within QCD factorisation approach (wrt χ_{c1})
- much smaller (wrt χ_{c1}) branching fraction to $\gamma J/\psi$

Background suppression:

Multivariate analysis: $c\tau(\Lambda_b^0)$, kinematics, particle identification

Data: 2015-2018, integrated luminosity $6.0\ \text{fb}^{-1}$





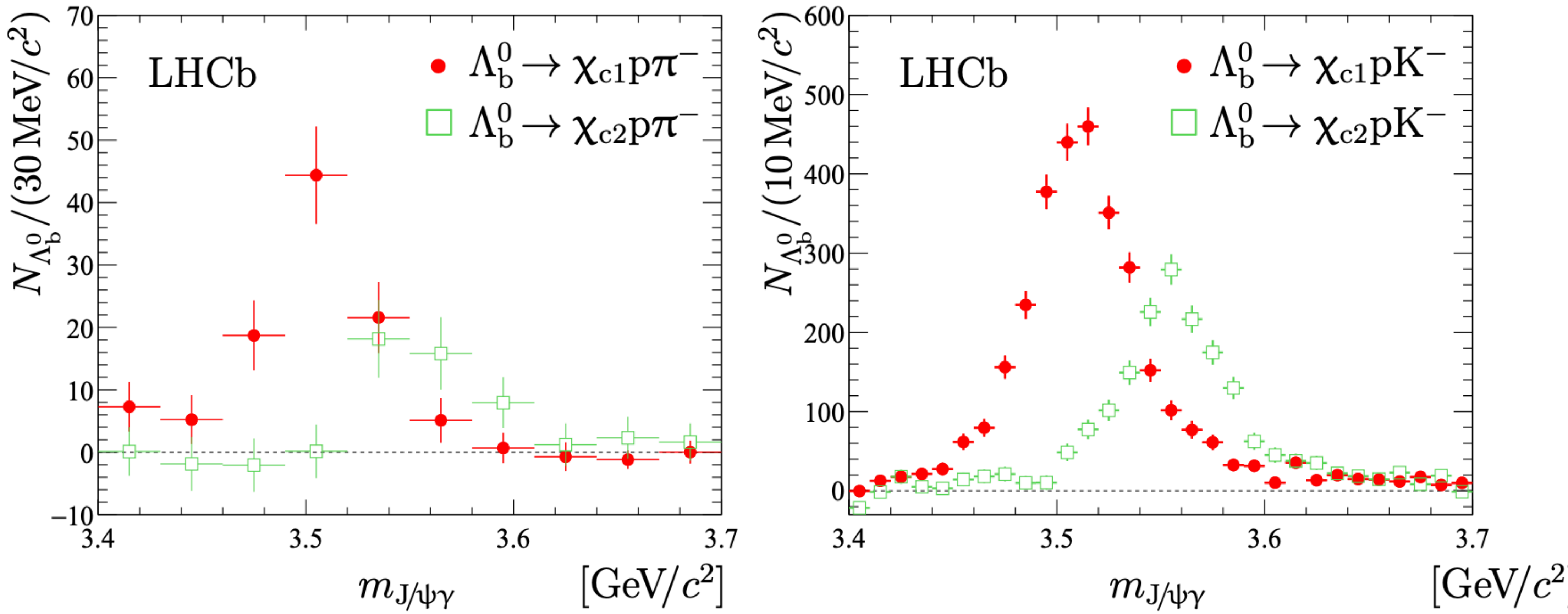
$M_{\chi c1} - M_{\chi c2}$ and $\sigma_{\chi c1}/\sigma_{\chi c2}$ fixed to MC

Mass is calculated with PV, J/ψ and χ_{c1} mass constraints

Observation of the decay $\Lambda_b^0 \to \chi_{c1} p \pi^-$

Background-subtracted $m(J/\psi\gamma)$ distributions

arXiv:2103.04949



Branching fraction ratios

Fit to data

$$R_{\pi/K} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} pK^-)} = \frac{N_{\chi_{c1}p\pi^-}}{N_{\chi_{c1}pK^-}} \times \frac{\varepsilon_{\chi_{c1}pK^-}}{\varepsilon_{\chi_{c1}p\pi^-}},$$

$$R^{\pi}_{2/1} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p\pi^-)} = \frac{N_{\chi_{c2}p\pi^-}}{N_{\chi_{c1}p\pi^-}} \times \frac{\varepsilon_{\chi_{c1}p\pi^-}}{\varepsilon_{\chi_{c2}p\pi^-}} \times \frac{\mathcal{B}(\chi_{c1} \to J/\psi\gamma)}{\mathcal{B}(\chi_{c2} \to J/\psi\gamma)},$$

$$R^{K}_{2/1} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} pK^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} pK^-)} = \frac{N_{\chi_{c2}pK^-}}{N_{\chi_{c1}pK^-}} \times \frac{\varepsilon_{\chi_{c1}pK^-}}{\varepsilon_{\chi_{c2}pK^-}} \times \frac{\mathcal{B}(\chi_{c1} \to J/\psi\gamma)}{\mathcal{B}(\chi_{c2} \to J/\psi\gamma)}$$

From MC samples corrected to Data/MC difference:

- Λ_b^0 kinematics
- PID variables
- Mean lifetime $c\tau\,(\Lambda_b^0)$
- Decay model of $\Lambda_b^0 \to \psi(2S)pK^-$

Values from PDG:

$\mathcal{B}(\chi_{c1} \to J/\psi\gamma) = (34.3 \pm 1.0)\%$

$\mathcal{B}(\chi_{c2} \to J/\psi\gamma) = (19.0 \pm 0.5)\%$

Observation of the decay $\Lambda_b^0 \to \chi_{c1} p \pi^-$

arXiv:2103.04949

Systematics

- Systematic uncertainties largely cancel for the ratios
- The remaining contributions are summarised in Table:

Source	$\mathcal{R}_{\pi/K}$	$\mathcal{R}^{\pi}_{2/1}$	$\mathcal{R}^{K}_{2/1}$
Fit model	2.4	3.7	3.7
Λ_b^0 production spectra	< 0.1		
$\Lambda_b^0 \to \chi_{cJ} p K^-$ decay models	< 0.1		< 0.1
Track reconstruction	< 0.1		
Hadron identification	0.3		
Trigger efficiency	1.1		
Data-simulation agreement	2.0		
Simulation sample size	0.4	0.6	0.7
Sum in quadrature	3.3	3.8	3.8

Alternative fit models:

- Maximum deviation of yields ratio is taken from fits of high-statistics pseudoexperiment samples with alternative models as a **systematics for $R_{\pi/K}$, $R^{\pi}_{2/1}$ and $R^{K}_{2/1}$**.
- Statistical significance of the $\Lambda_b^0 \to \chi_{c2} p \pi^-$ channel is calculated from fits of data with alternative models. The smallest significance of 3.5σ is taken as its **significance including systematic uncertainties**.

Resonant structure of $\Lambda_b^0 \to \chi_{c1} p \pi^-$

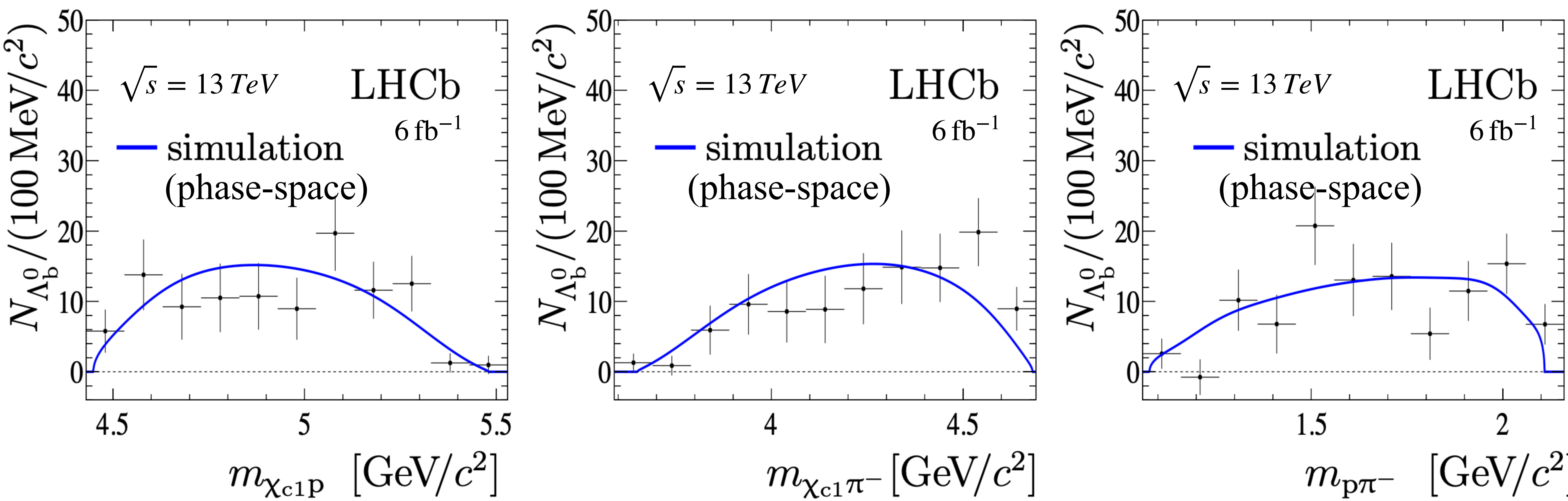
Results: branching fraction ratio

arXiv:2103.04949

$$\mathcal{R}_{\pi/K} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p K^-)} = (6.59 \pm 1.01 \pm 0.22)\%,$$

$$\mathcal{R}_{2/1}^{\pi} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} p \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p \pi^-)} = 0.95 \pm 0.30 \pm 0.04 \pm 0.04, \qquad \mathcal{R}_{2/1}^{K} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} p K^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p K^-)} = 1.06 \pm 0.05 \pm 0.04 \pm 0.04,$$

Background-subtracted distributions for the $\Lambda_b^0 \to \chi_{c1} p \pi^-$ decay



Overall, no evident peaking structure.

A search for small contributions from exotic states would be possible with a larger data sample.

Previous study of similar decay $\Lambda_b^0 \to \psi(2S) p \pi^-$

JHEP 1808 (2018) 131

Channels under study:

Signal: $\Lambda_b^0 \to \psi(2S) p \pi^-$

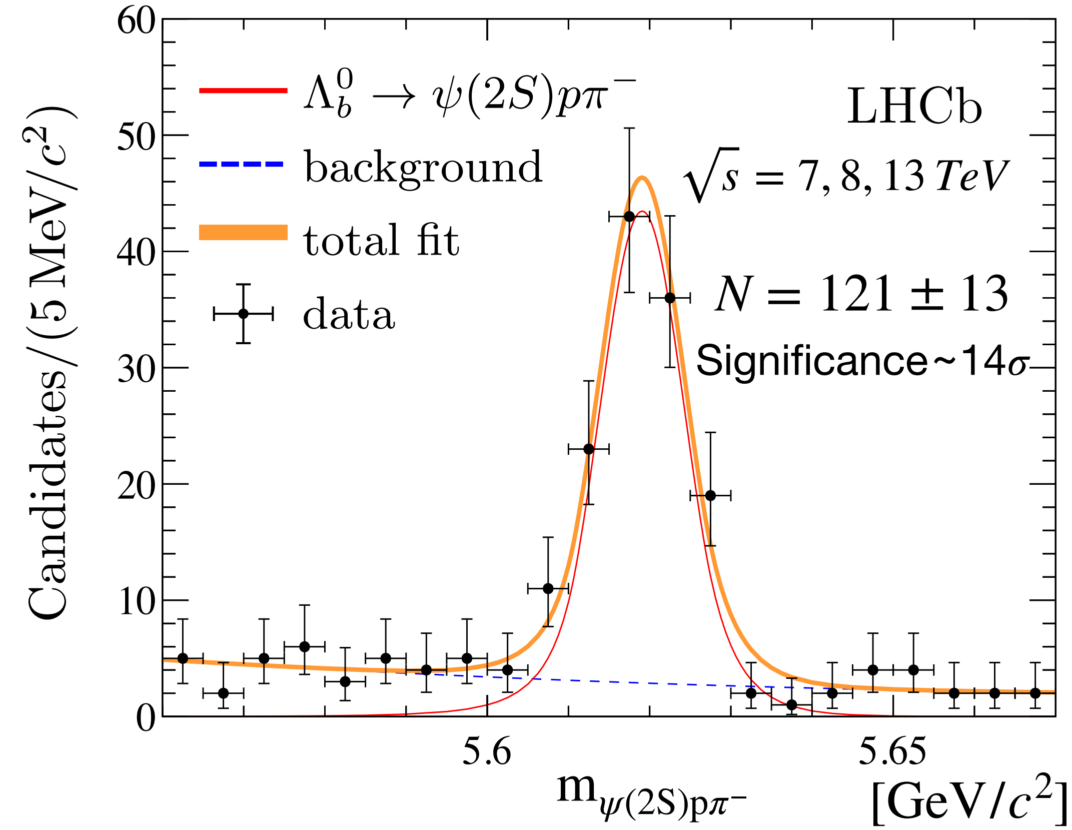
Normalization: $\Lambda_b^0 \to \psi(2S) p K^-$

(both with $\psi(2S) \to \mu^+ \mu^-$)

Data: 2011-2016, integrated luminosity $4.9\ \mathrm{fb}^{-1}$

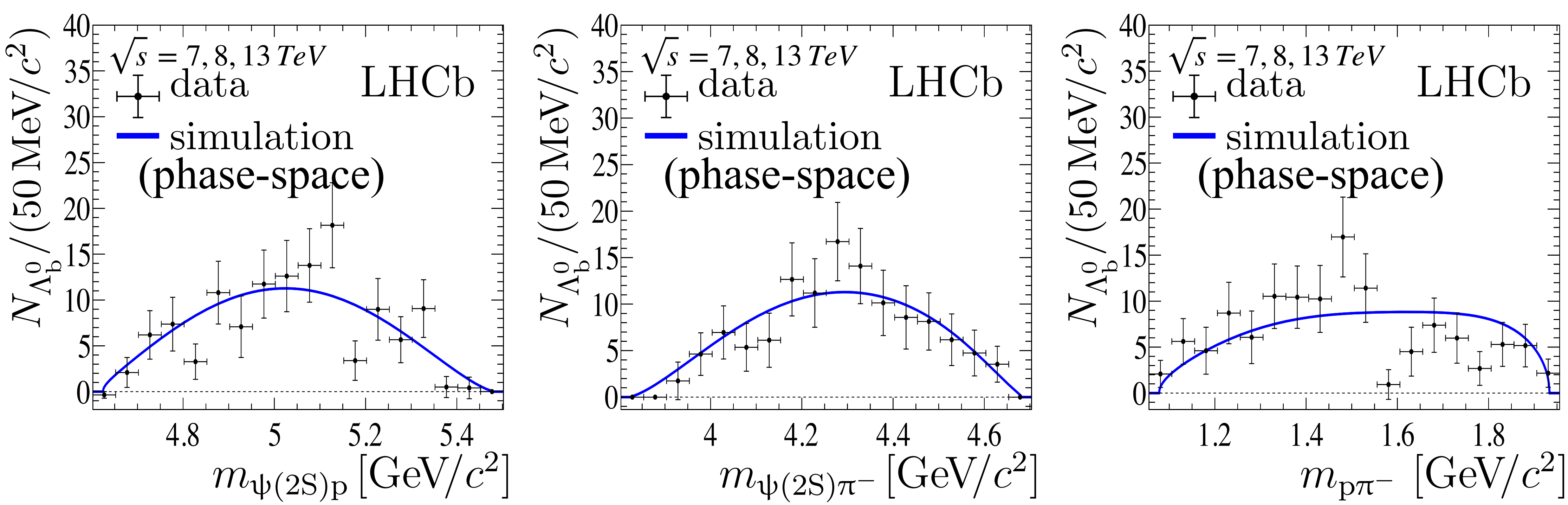
Branching fraction ratio:

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



Mass is calculated with PV and ψ(2S) mass constraints

Background-subtracted distributions:



no evident peaking structure

Comparison with analogous measurements

JHEP 1808 (2018) 131, arXiv:2103.04949

Results for χ_{c2}/χ_{c1}

$$\mathcal{R}^{\pi}_{2/1} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} p \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p \pi^-)} = 0.95 \pm 0.30 \pm 0.04 \pm 0.04\,,$$

Result shows also no suppression of χ_{c2} mode wrt χ_{c1}

$$\mathcal{R}^{K}_{2/1} = \frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} p K^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p K^-)} = 1.06 \pm 0.05 \pm 0.04 \pm 0.04\,,$$

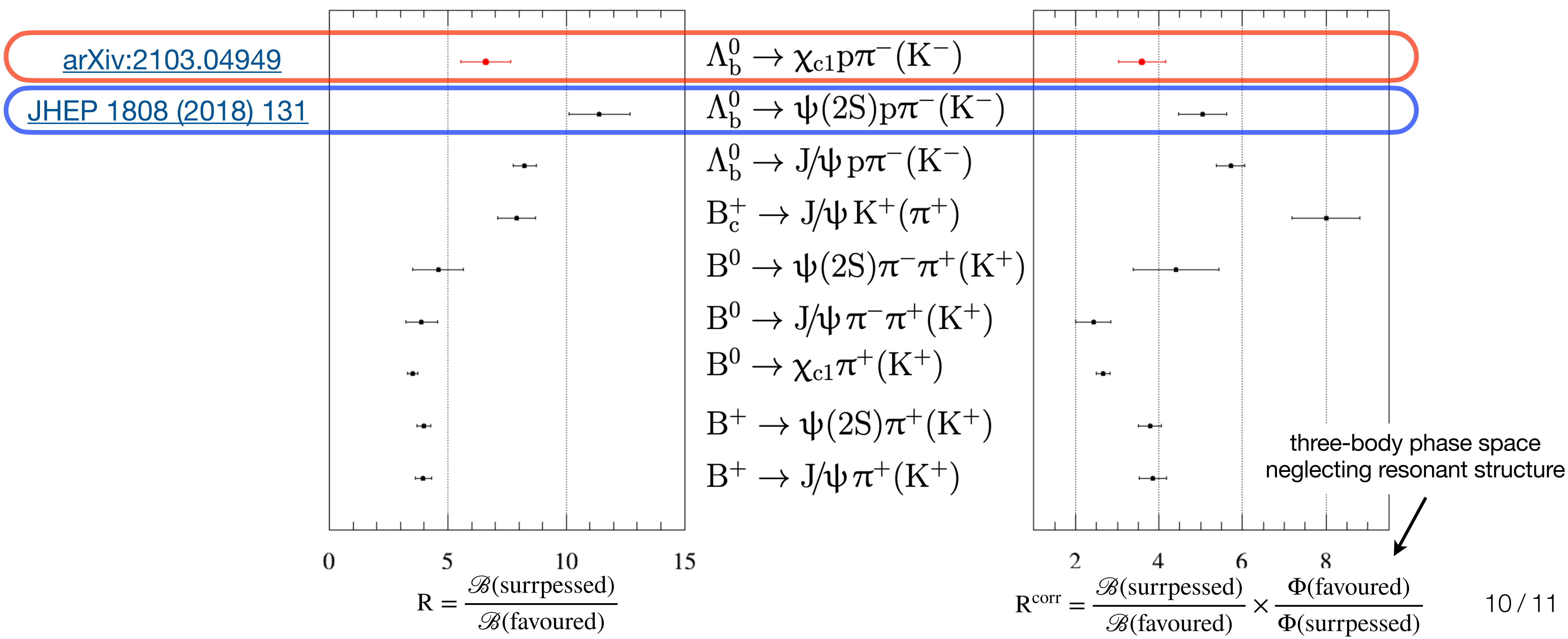
In agreement with previous measurement by LHCb $1.02 \pm 0.10 \pm 0.02 \pm 0.05$ [PRL 119 (2017) 062001]

Results for Cabibbo-suppression:

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

$$\frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p K^-)} = (6.59 \pm 1.01 \pm 0.22)\%$$

Comparison with previous measurements



Conclusion

- The LHCb experiment provides an excellent possibility for study of beauty baryons spectroscopy:
  - Observation of the decay $\Lambda_b^0 \to \chi_{c1} p \pi^-$ [arXiv:2103.04949]
  - Observation of the decay $\Lambda_b^0 \to \psi(2S) p \pi^-$ [JHEP 1808 (2018) 131]
- Looking forward to new results!

For more LHCb results see:

- Exotic hadrons: recent LHCb discoveries (talk by Zehua Xu)
- Rare Decays and Anomalies at LHCb (talk by Mick Mulder)
- Precision flavour physics at LHCb: CP violation and CKM constraints (talk by Sevda Esen)

Acknowledgments

Olga Igonkina Foundation

I would like to express my gratitude to the Olga Igonkina Foundation
for supporting this talk