Heavy flavor production at LHCb

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on behalf of the LHCb Collaboration

LAL, Orsay

Selected measurements

- **Observation of new resonances in $\Lambda_b^0\pi^+\pi^-$** **NEW !**
  LHCb-PAPER-2019-025

- Observation of an excited B_c^+ state
  PRL 122 (2019) 232001

- Measurement of b-hadron fractions at 13 TeV
  arXiv:1902.06794

- Measurement of the mass and production rate of Ξ_b^- baryons
  PRD 99 (2019) 052006

- Measurement of Υ production at 13 TeV
  JHEP 07 (2018) 134

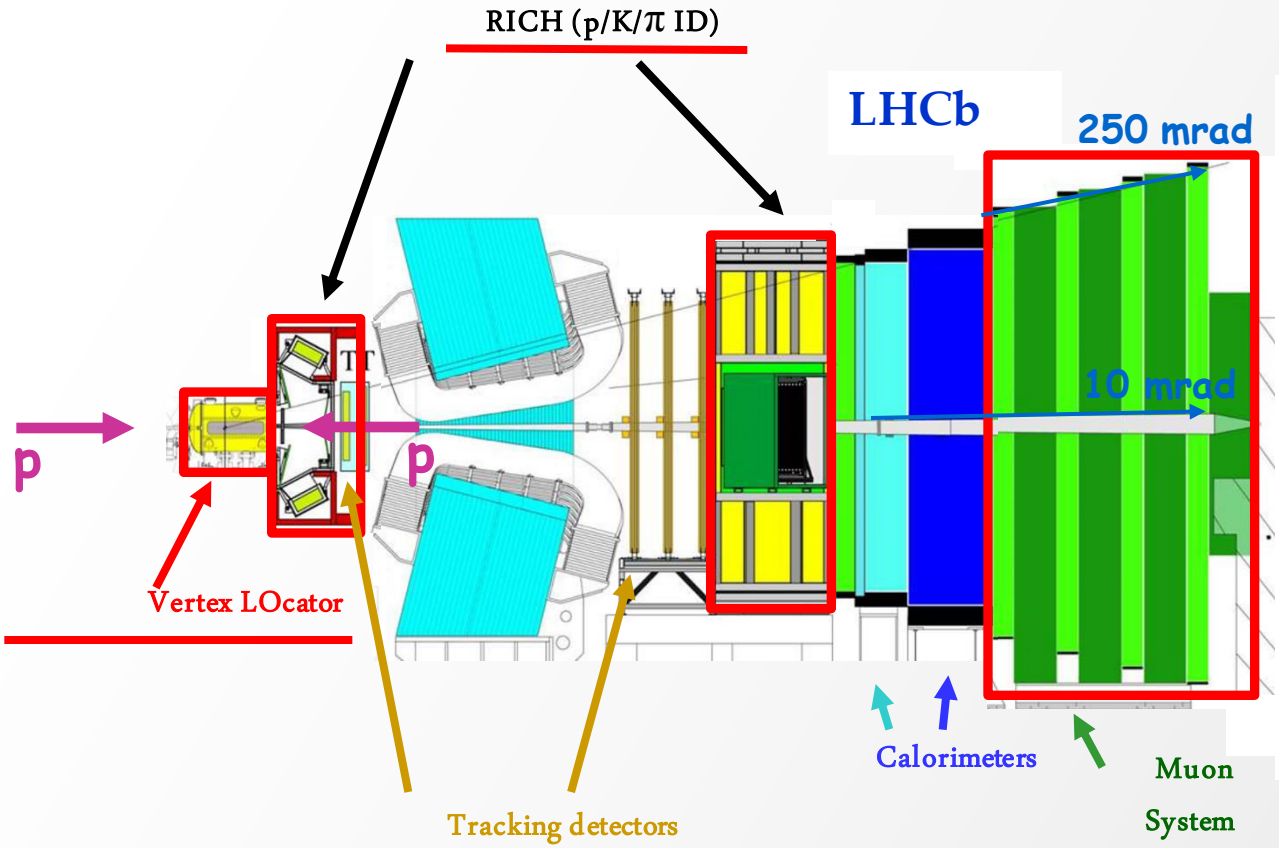
Recent, omitted in this talk:

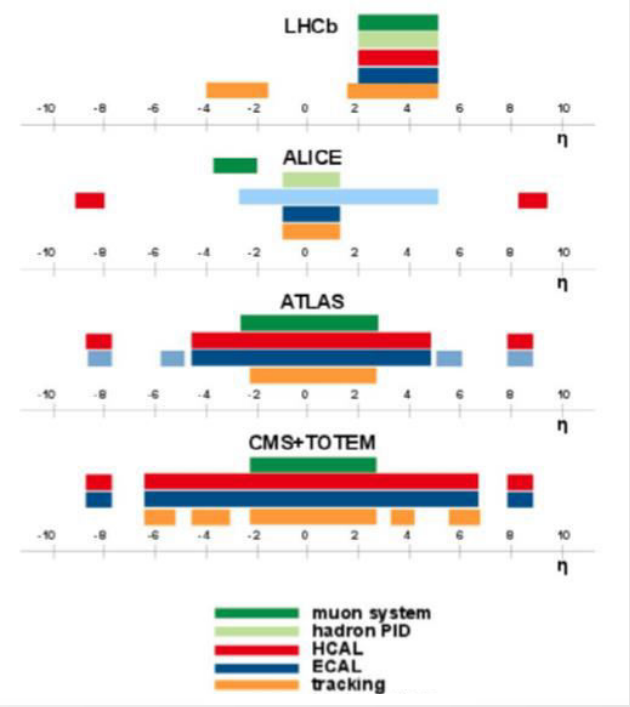
- Near-threshold $D\bar{D}$ spectroscopy and observation of a new charmonium state
  JHEP 07 (2019) 035

LHCb : single arm forward spectrometer

JINST 8 (2013) P08002, INT.J.MOD.PHYS.A30 (2015) 1530022

- **Forward HQ production** at the LHC
- Forward region $2 < \eta < 5$, **~4% of solid angle**, but **~40% of HQ production x-section**





- **Complementary cross-section measurements** and overlap in terms of rapidity and p_T
- Key detector systems for production measurements: **vertex reconstruction (VELO), particle identification (Muon detector, RICHs, Calorimeters), flexible trigger**

Heavy flavor production: motivation

- Variety of measurements
  - **Spectroscopy and production** of b-baryons
  - **Open heavy flavor** production and polarization
  - **Quarkonium** production and polarization
  - Associated production

- Important study for QCD, both perturbative and non-perturbative
  - **Tests of QCD** predictions
  - Determination of **non perturbative parameters**

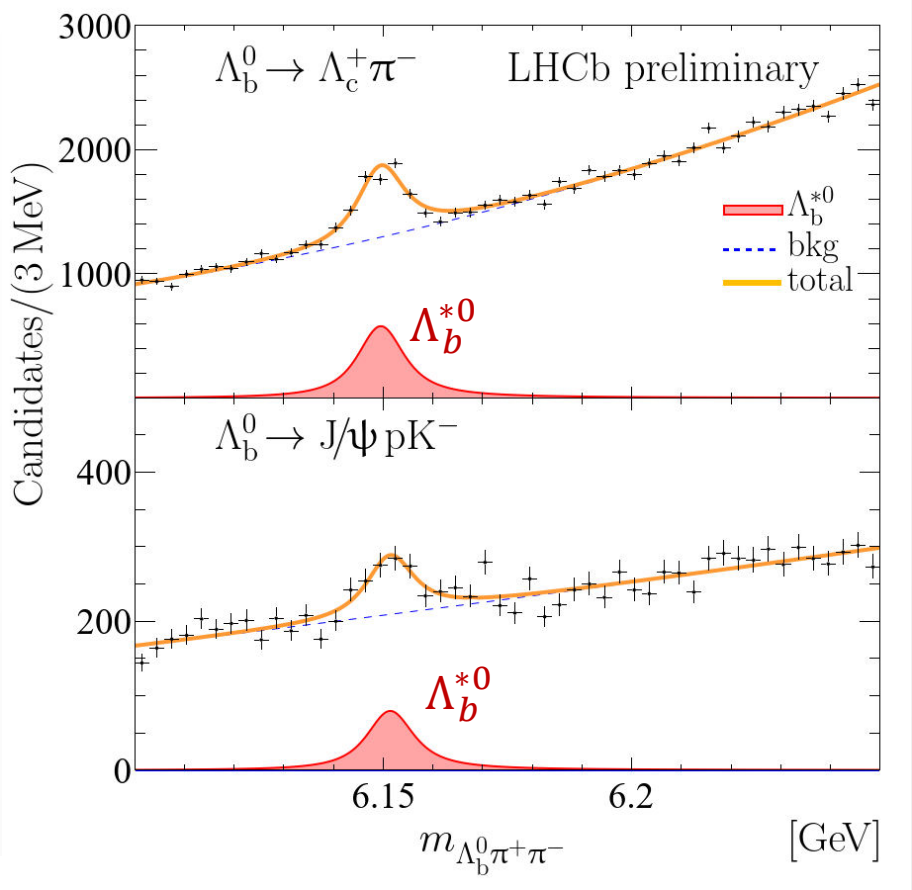
- Required for MC tuning ➜ inputs for precision flavor physics measurements

- Precise knowledge of SM background for New Physics searches

Observation of new resonances in $\Lambda_b^0 \pi^+ \pi^-$

- Previous study of Λ_b^0 spectrum at LHCb using data sample of $1\ fb^{-1}$ **LHCb-PAPER-2019-025**
  – discovery of $\Lambda_b(5912)^0$ and $\Lambda_b(5920)^0$ **PRL 109 (2012) 172003**
- Later confirmed by CDF **PRD 88 (2013) 071101**

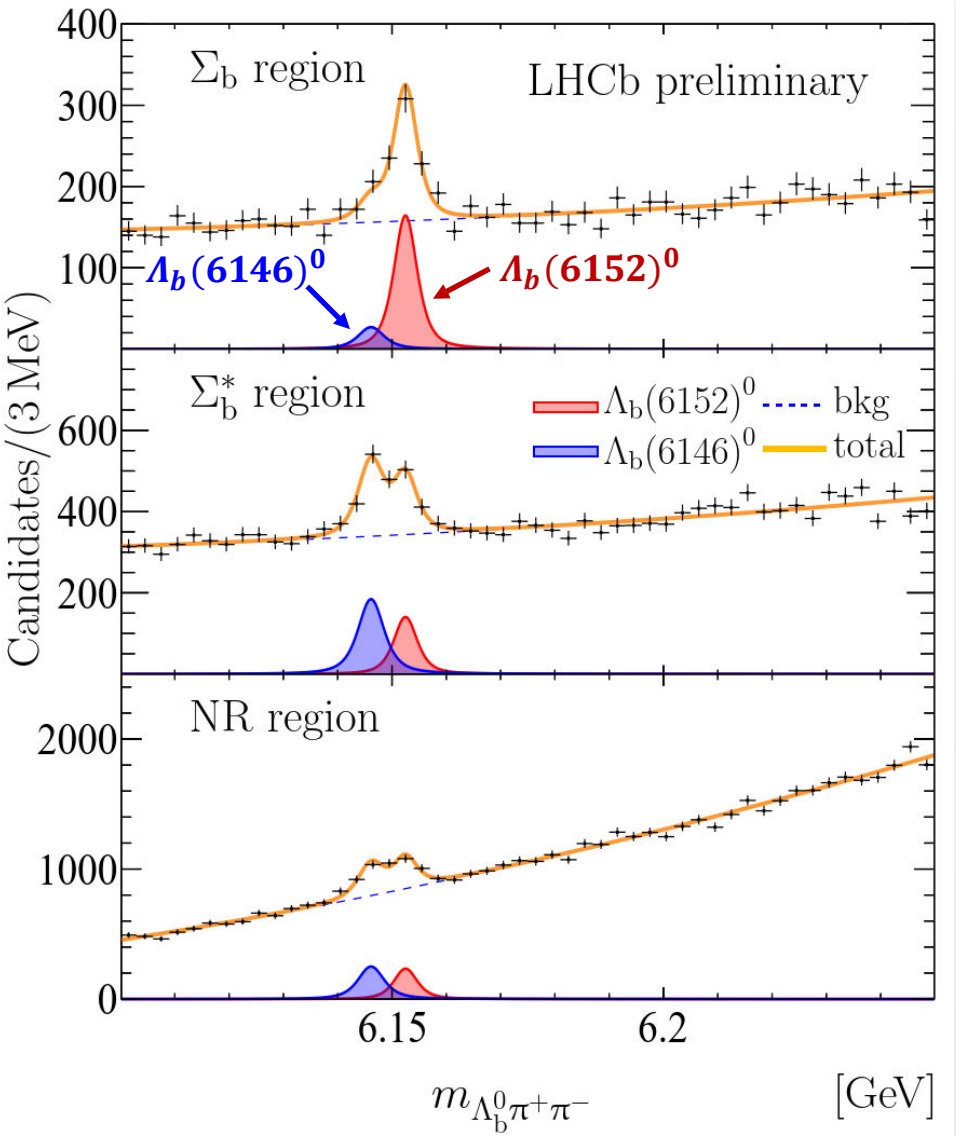
- **New results available with Run I+II data sample of $9\ fb^{-1}$**
- Two Λ_b^0 decay modes considered: $\boldsymbol{\Lambda_b^0 \to \Lambda_c^+ \pi^-}$ and $\boldsymbol{\Lambda_b^0 \to J/\psi\, p\, K}$



Clear excess around 6.15 GeV in both distributions

Observation of new resonances in $\Lambda_b^0\pi^+\pi^-$

- The $\Lambda_b^0\pi^+\pi^-$ inv. mass distribution is studied **LHCb-PAPER-2019-025**
  in regions of $\Lambda_b^0\pi^+$ inv. mass: resonant (Σ_b^+ and Σ_b^{*+}) and non-resonant



Two peaks hypothesis favoured with 7σ significance

Observation of new resonances in $\Lambda_b^0\pi^+\pi^-$

- **The mass distribution is studied in regions of $\Lambda_b^0\pi^+$ mass: resonant (Σ_b^+ and Σ_b^{*+}) and non-resonant**

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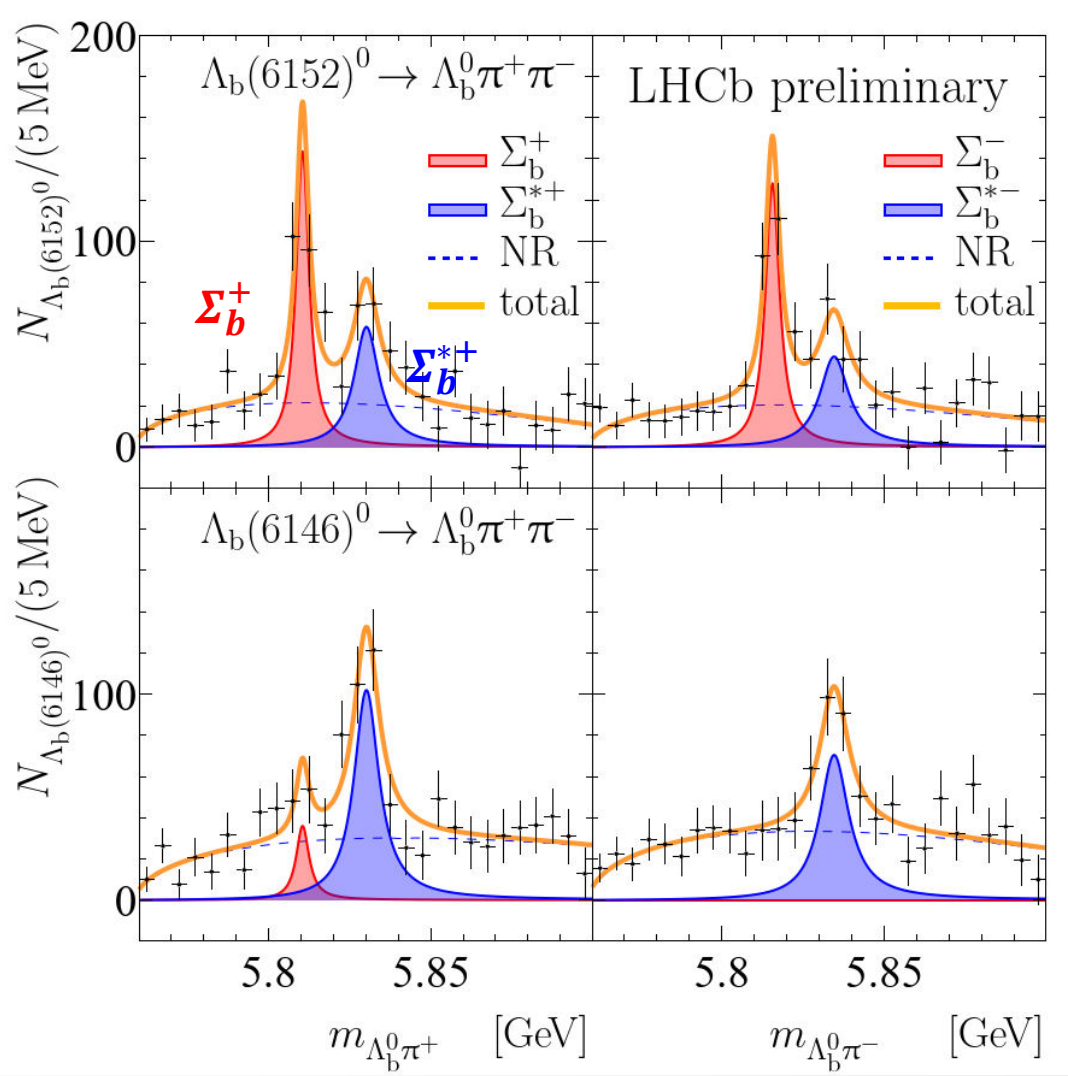
- **Background subtracted $\Lambda_b^0\pi^+$ inv. mass distributions:**



Different decay rates via Σ_b^+ and Σ_b^{*+} for observed states

Observation of new resonances in $\Lambda_b^0 \pi^+ \pi^-$

LHCb-PAPER-2019-025

- **Results:**

$$m_{\Lambda_b(6152)^0} = 6152.51 \pm 0.26\,\text{MeV}$$
$$m_{\Lambda_b(6146)^0} = 6146.17 \pm 0.33\,\text{MeV}$$
$$\Delta m = 6.34 \pm 0.32\,\text{MeV}$$

$$\Gamma_{\Lambda_b(6152)^0} = 2.11 \pm 0.81\,\text{MeV}$$
$$\Gamma_{\Lambda_b(6146)^0} = 2.90 \pm 1.28\,\text{MeV}$$

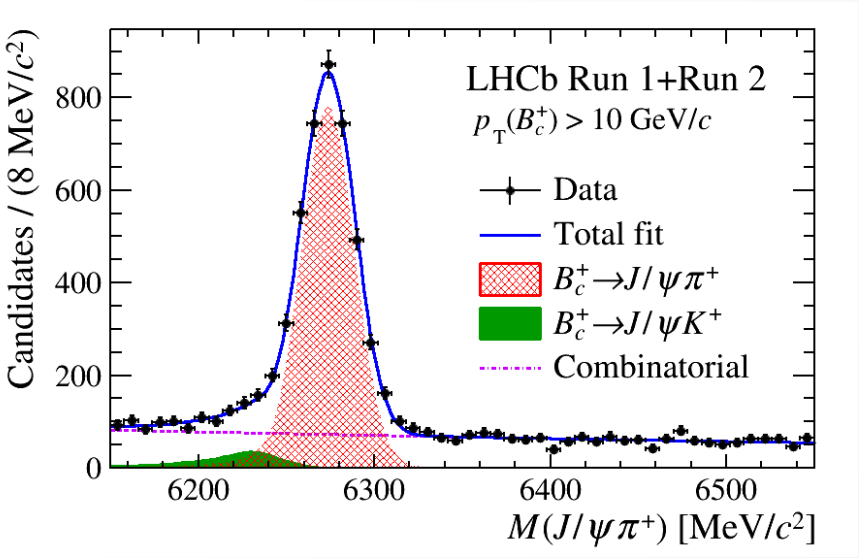
- Possible interpretation of the new states as a doublet of $\boldsymbol{\Lambda_b(1D)^0}$ states with $\boldsymbol{J^P} = \frac{3^+}{2}$ and $\frac{5^+}{2}$

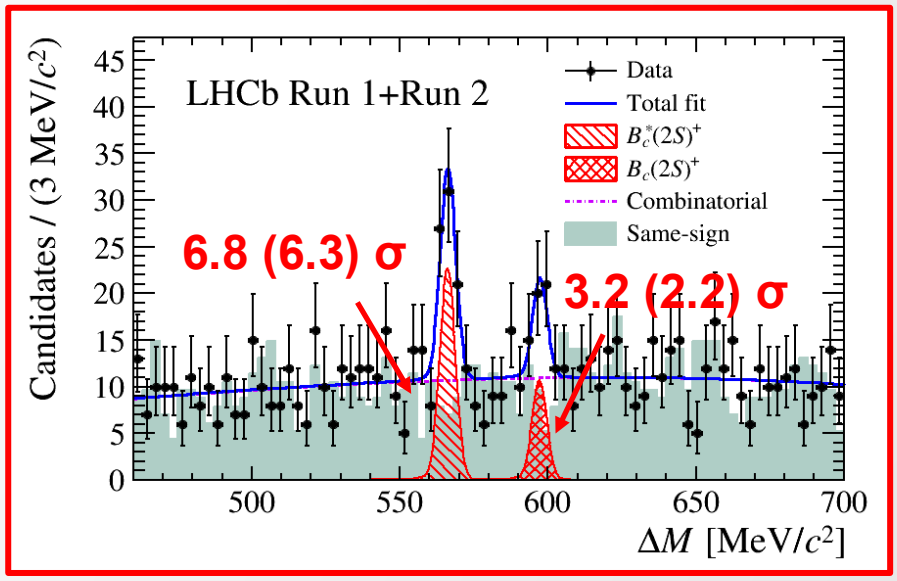
EPJA 51 (2015) 82
PRD 34 (1986) 2809

Observation of an excited B_c^+ state

PRL 122 (2019) 232001

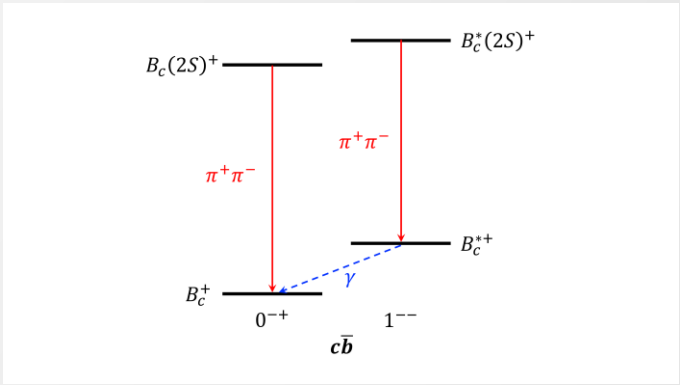
- Two states observed by CMS PRL122 (2019) 132001
- LHCb analysis: Run I+II data sample of 8.5 fb^{-1}
- Reconstructed via $\boldsymbol{B_c^{(*)}(2S) \to (B_c^+ \to J/\psi\,\pi^+)\pi^+\,\pi^-}$





- Masses are measured to be

$$6841.2 \pm 0.6\,(\text{stat}) \pm 0.1\,(\text{syst}) \pm 0.8\,(B_c^+)\ \text{MeV}/c^2$$
$$6872.1 \pm 1.3\,(\text{stat}) \pm 0.1\,(\text{syst}) \pm 0.8\,(B_c^+)\ \text{MeV}/c^2$$

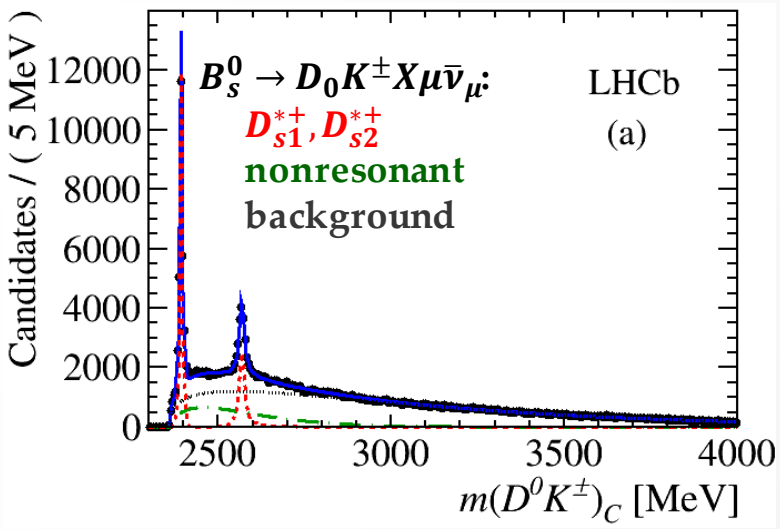


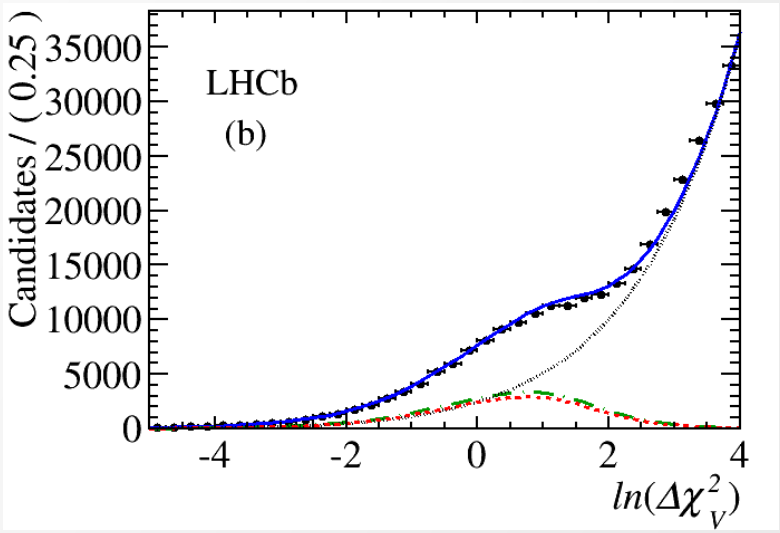
⇒ Consistent with expectations of $B_c(2^3S_1)$ and $B_c(2^1S_1)$ e.g. PRD 86 (2012) 094510

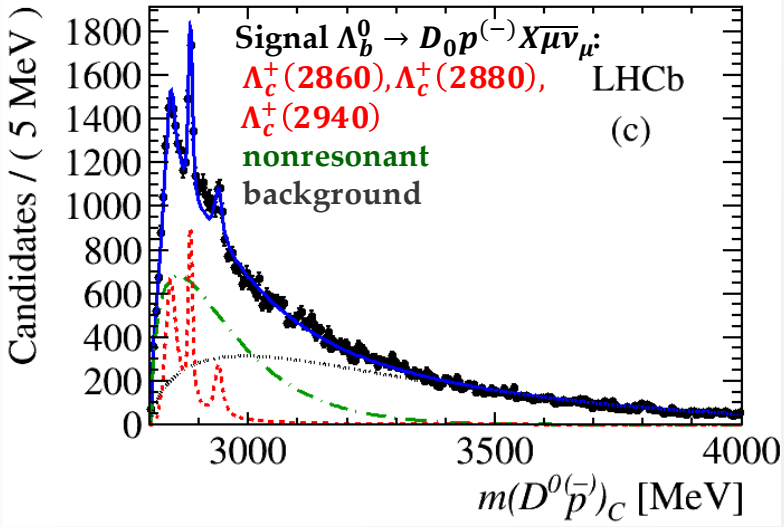
⇒ Confirms first observation by CMS

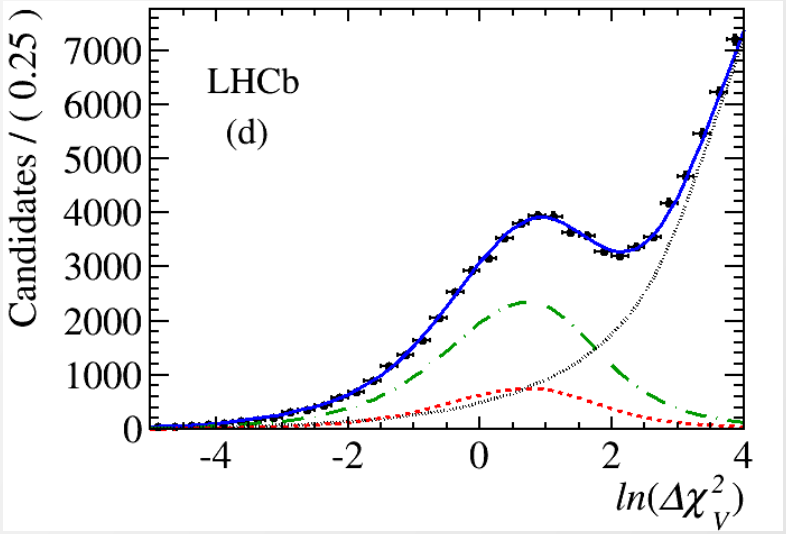
Measurement of b-hadron fractions at 13 TeV

- Data sample: part of Run II, $\mathbf{1.67\ fb^{-1}}$ **arXiv:1902.06794**
- Inclusive semileptonic decays to $H_c X\mu\bar{\nu}_\mu$ are used to reconstruct b-hadrons
- 2D fit to distinguish signal and background in decays to $H_c hX\mu\bar{\nu}_\mu$:









Measurement of *b*-hadron fractions at 13 TeV

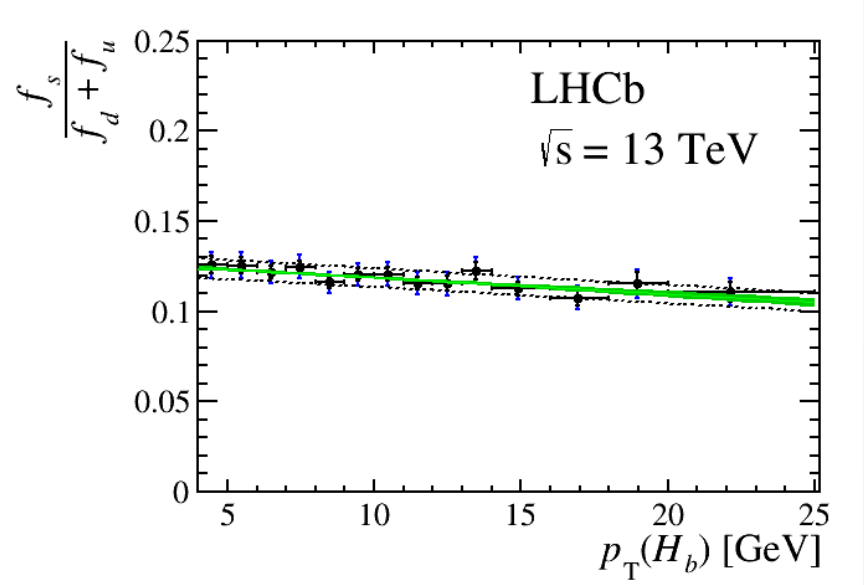
arXiv:1902.06794

- First measurement of *b*-hadron fractions at 13 TeV

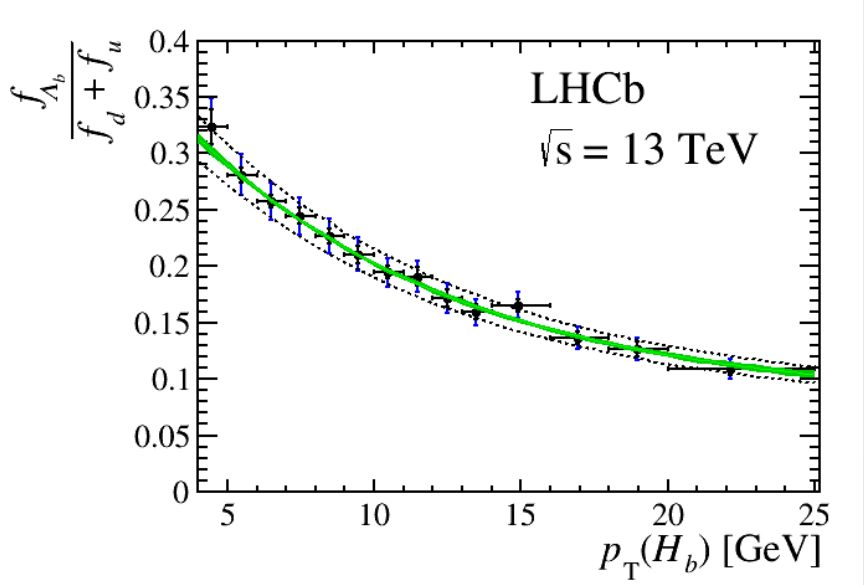
$$\frac{f_s}{f_u + f_d} = 0.122 \pm 0.006$$

$$\frac{f_{\Lambda_b^0}}{f_u + f_d} = 0.259 \pm 0.018$$

- Fragmentation fractions extracted as function of p_T



Fit by linear function

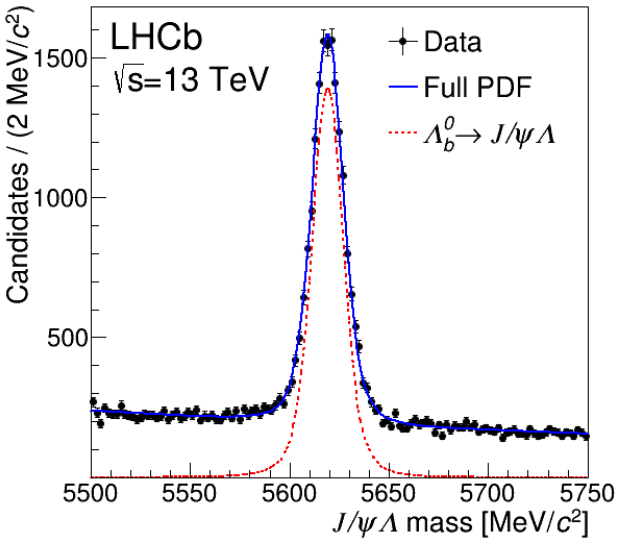


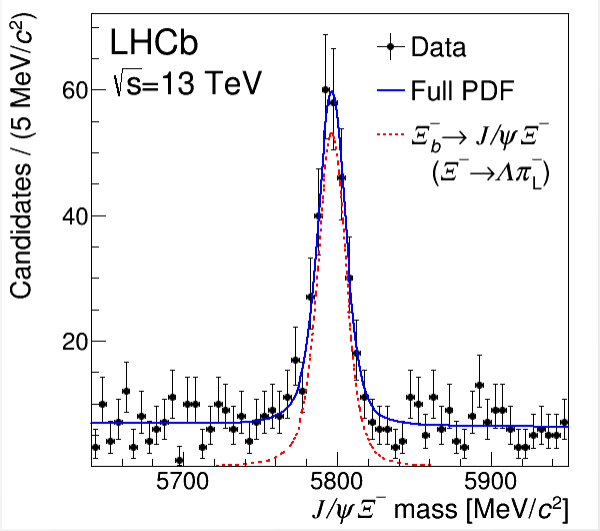
Fit by exponential function

Measurement of the mass and production rate of Ξ_b^- baryons

PRD 99 (2019) 052006

- Run I+II data sample of 1 fb^{-1} at 7 TeV, 2 fb^{-1} at 8 TeV and 1.6 fb^{-1} at 13 TeV
- Ξ_b^- reconstructed via $\Xi_b^- \to J/\psi\,\Xi^-$, normalization: $\Lambda_b^0 \to J/\psi\ \Lambda$





- Results – **first measurement of Ξ_b^- production**

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{\mathcal{B}(\Xi_b^- \to J/\psi\,\Xi^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\,\Lambda)} = (10.8 \pm 0.9 \pm 0.8) \times 10^{-2} \quad [\sqrt{s} = 7, 8\,\text{TeV}]$$

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{\mathcal{B}(\Xi_b^- \to J/\psi\,\Xi^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\,\Lambda)} = (13.1 \pm 1.1 \pm 1.0) \times 10^{-2} \quad [\sqrt{s} = 13\,\text{TeV}]$$

Measurement of the mass and production rate of Ξ_b^- baryons

PRD 99 (2019) 052006

- Assuming SU(3) symmetry, the fragmentation fraction is obtained

Nucl. PB326 (1989) 15
arXiv:1510.05568
PLB 751 (2015) 127

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} = (6.7 \pm 0.5 \pm 0.5 \pm 2.0) \times 10^{-2} \quad [\sqrt{s} = 7, 8\,\text{TeV}]$$

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} = (8.2 \pm 0.7 \pm 0.6 \pm \underbrace{2.5}_{\text{due to SU(3) symetry breaking}}) \times 10^{-2} \quad [\sqrt{s} = 13\,\text{TeV}]$$

- No significant production asymmetry observed

$$A_{\text{prod}}(\Xi_b^-) = (\ \ 1.1 \pm 5.6)\% \quad [\sqrt{s} = 7, 8\,\text{TeV}],$$
$$A_{\text{prod}}(\Xi_b^-) = (-3.9 \pm 4.9)\% \quad [\sqrt{s} = 13\,\text{TeV}].$$

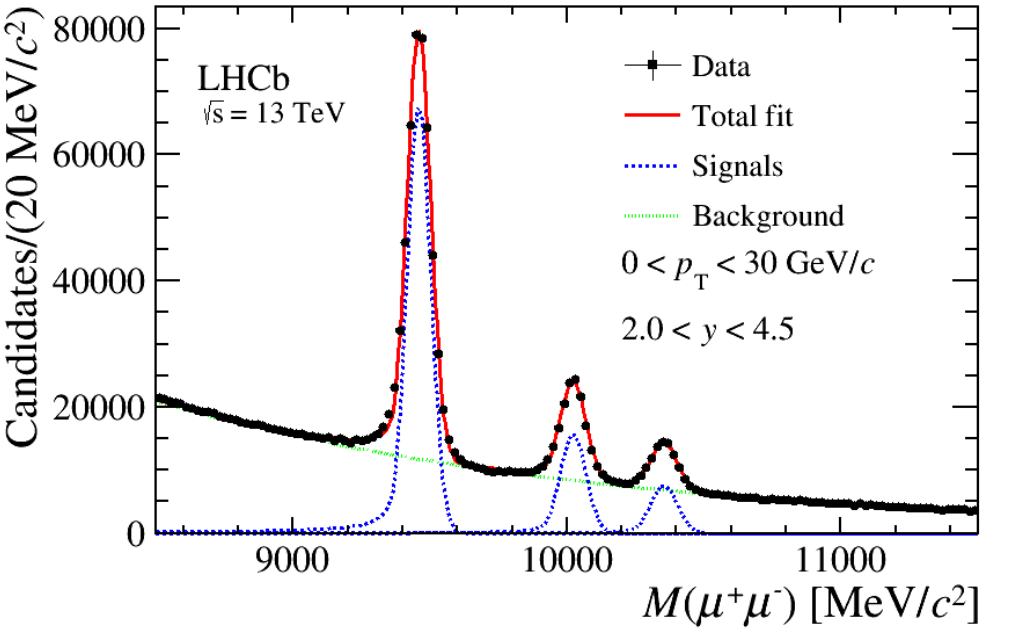
- The most precise measurement of Ξ_b^- mass

$$m(\Xi_b^-) = 5796.70 \pm 0.39 \pm 0.15 \pm 0.17\,\text{MeV}/c^2$$

Measurement of Υ production at 13 TeV

JHEP 07 (2018) 134

- Data sample **of 277 pb^{-1}** collected at $\sqrt{s} = 13$ TeV
- Clean signals from $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ using decays to $\mu^+\mu^-$



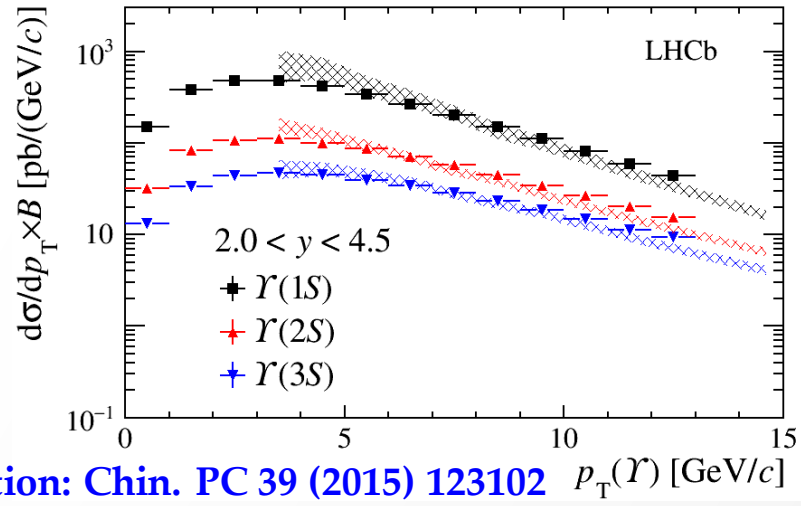
- Absolute production is measured

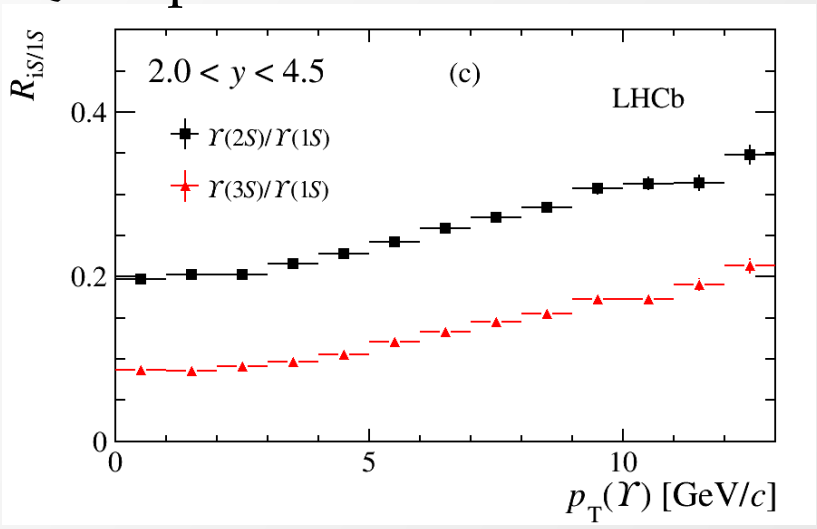
$$\mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) \times \sigma(\Upsilon(1S), 0 < p_{\rm T} < 15\,{\rm GeV}/c, 2 < y < 4.5) = 4687 \pm 10 \pm 294 \ {\rm pb}$$
$$\mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) \times \sigma(\Upsilon(2S), 0 < p_{\rm T} < 15\,{\rm GeV}/c, 2 < y < 4.5) = 1134 \pm 6 \pm 71 \ {\rm pb}$$
$$\mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) \times \sigma(\Upsilon(3S), 0 < p_{\rm T} < 15\,{\rm GeV}/c, 2 < y < 4.5) = 561 \pm 4 \pm 36 \ {\rm pb}$$

Measurement of Υ production at 13 TeV

JHEP 07 (2018) 134

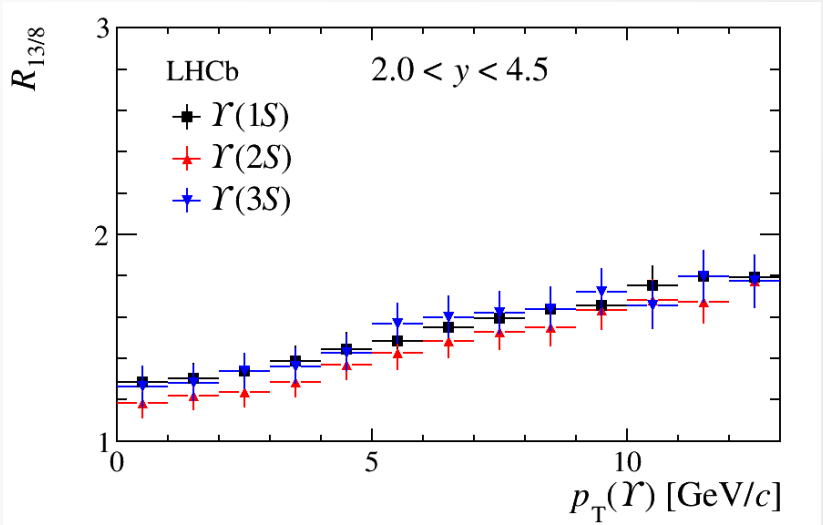
- p_T and y–differential and double differential cross-sections measured
- Results compared to Non Relativistic QCD prediction





Prediction: Chin. PC 39 (2015) 123102

- The 13/8 TeV ratios measured



Summary

Significant LHCb contribution to study heavy flavour production and spectroscopy:

- Observation of new excited $\boldsymbol{\Lambda_b^0}$ resonances
  provides tests of quark model

- Observation of excited B_c^+resonances
  precision tests of lattice predictions

- Measurement of $\boldsymbol{B_s^0}$ and $\boldsymbol{\Lambda_b^0}$ fractions
  important for measurements of BR of their decay modes

- First measurement of Ξ_b^- production and the most precise measurement of its mass

- Measurement of Υ production at 13 TeV
  provides tests of NRQCD

More results in progress with Run II data
Stay tuned!