

Studies of b-hadrons at LHCb

**Viacheslav Matiunin (NRC KI-ITEP, Moscow)
on behalf of the LHCb collaboration**

28 JULY - 6 AUGUST 2020
PRAGUE, CZECH REPUBLIC

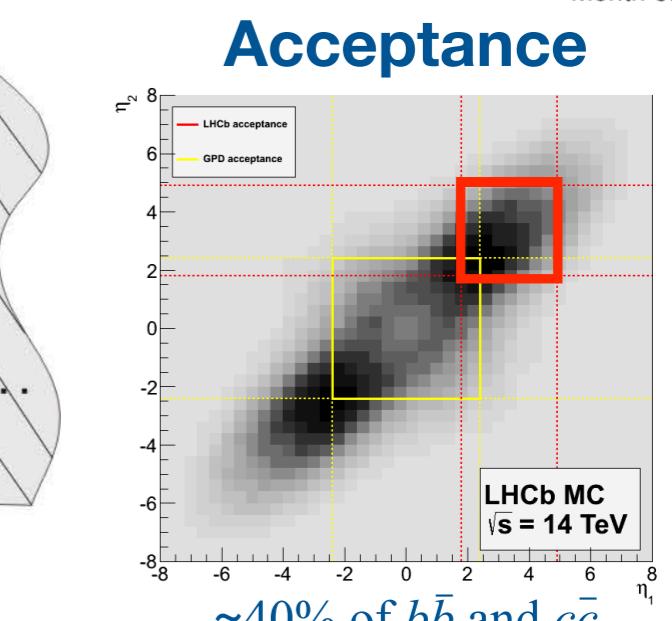
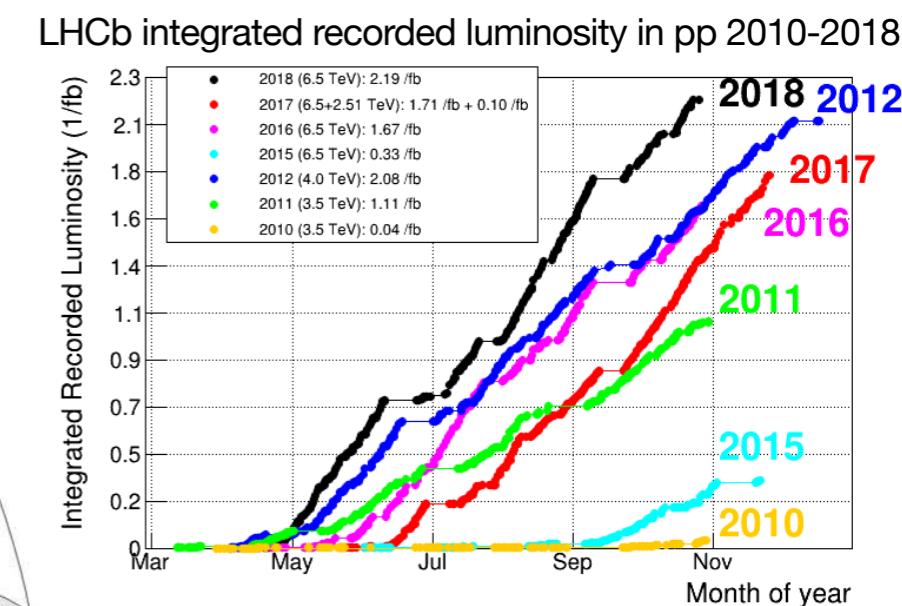
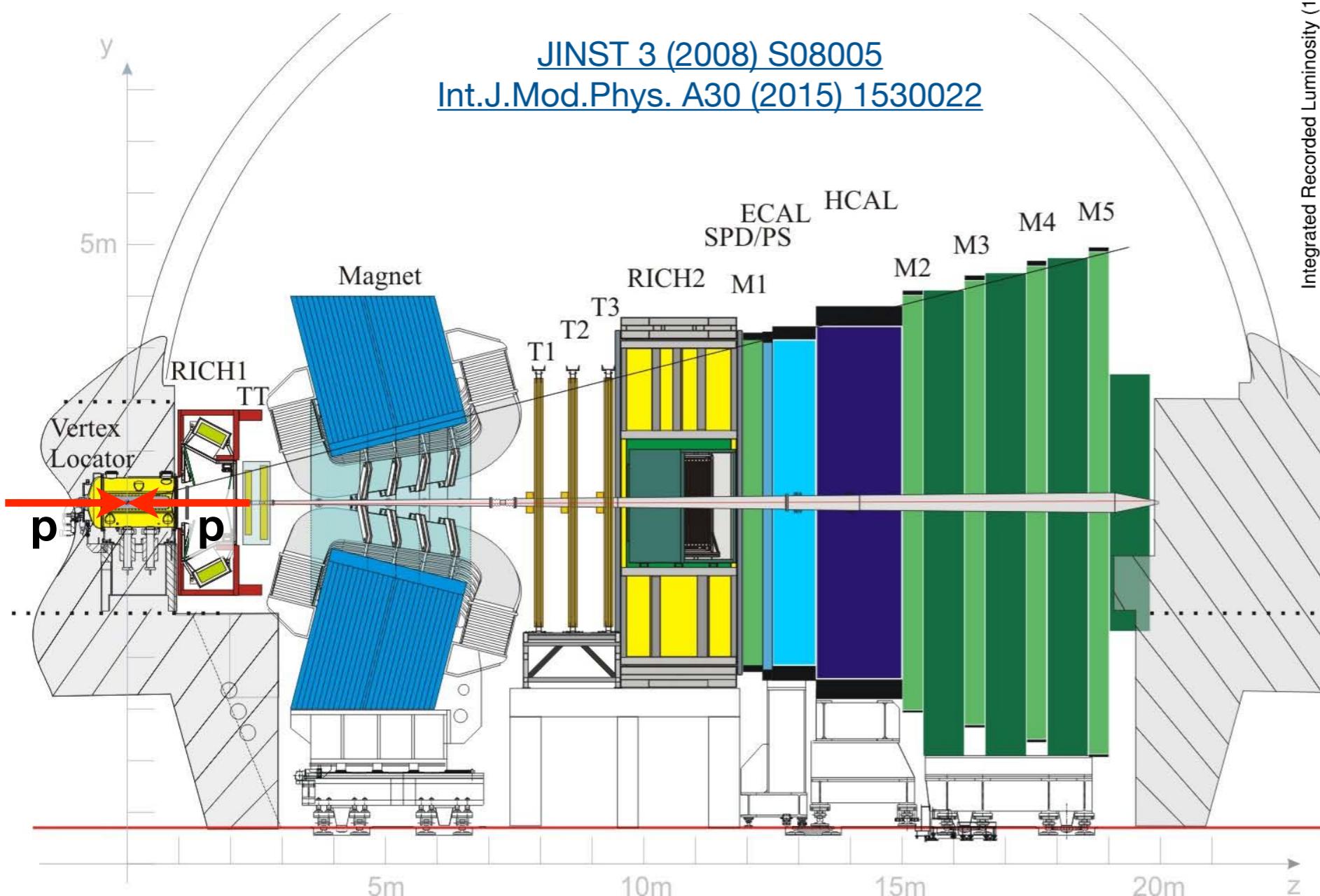
Outline

- The LHCb detector
- Recent results
 - First observation of excited Ω_b^- states
 - Excited Λ_b^0 baryons
 - Precise measurement of the mass and width of $\Lambda_b(5912)^0$ and $\Lambda_b(5920)^0$ states
 - Observation of two new narrow $\Lambda_b(5912)^0$ and $\Lambda_b(5920)^0$ states
 - Observation of new Λ_b^{**0} state consistent with $\Lambda_b(2S)^0$ prediction
 - Measurement of the B_c^- meson production fraction and asymmetry in 7 and 13 TeV pp collisions
- Summary

The LHCb detector

Details are given in the talk
by Martina Pili

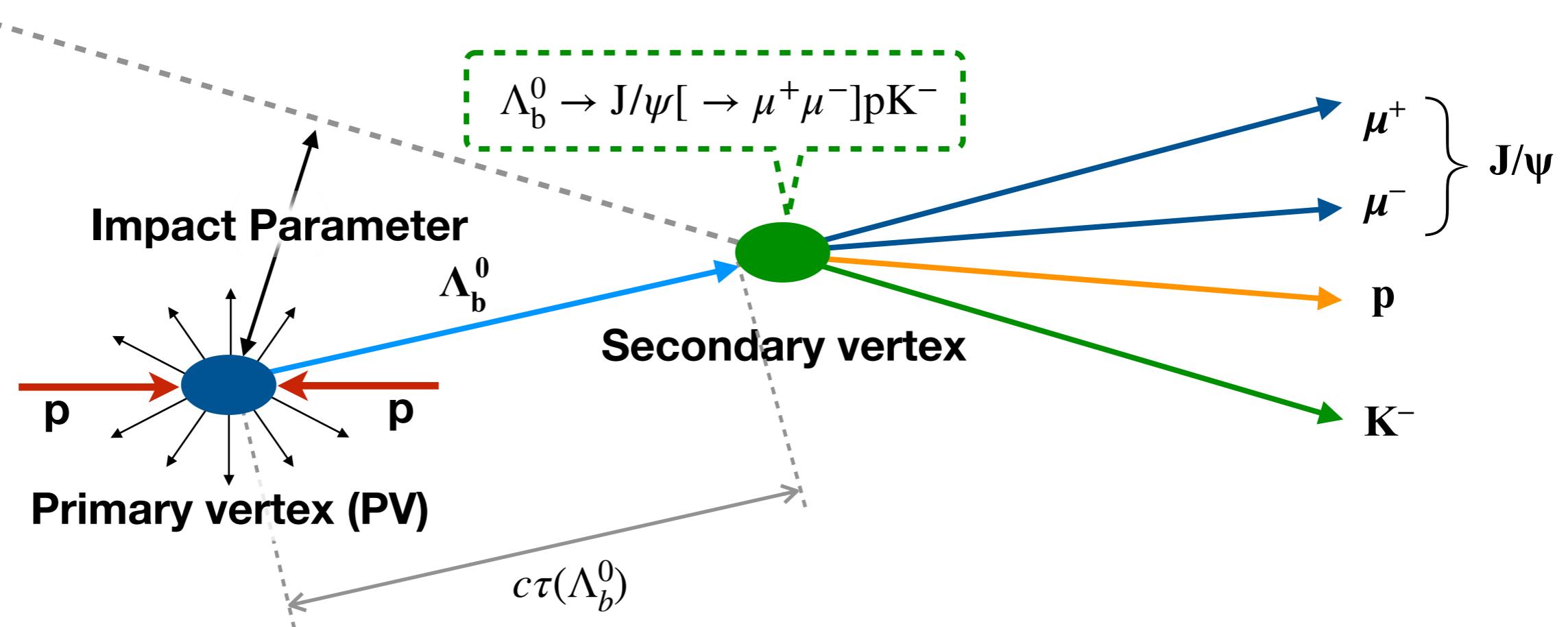
- **VELO**: **impact parameter** resolution $(15 + 29/p_T[\text{GeV}/c]) \mu\text{m}$, **decay time** resolution $\sim 45 \text{ fs}$
- **Tracking stations, Magnet**: **momentum** resolution $\Delta p/p = 0.4 \% \text{ at } 5 \text{ GeV}/c, 1.0 \% \text{ at } 200 \text{ GeV}/c$
- **PID efficiency**: for $e^- \sim 90\%$ with 5% $e \rightarrow h$ misID, for $K \sim 95\%$ with 5% $\pi \rightarrow K$ misID, for $\mu \sim 97\%$ with 1-3% $\pi \rightarrow \mu$ misID
- **Calorimetric system**: **ECAL** resolution $\sim 1\% \oplus 9\%/\sqrt{E[\text{GeV}]}$, **HCAL** resolution $\sim 9\% \oplus 69\%/\sqrt{E[\text{GeV}]}$
- **Trigger efficiency**: $\sim 90\%$ for **dimuon**, $\sim 30\%$ for multibody **hadronic**



Access to all species of b-hadrons

b-hadrons analysis strategy

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

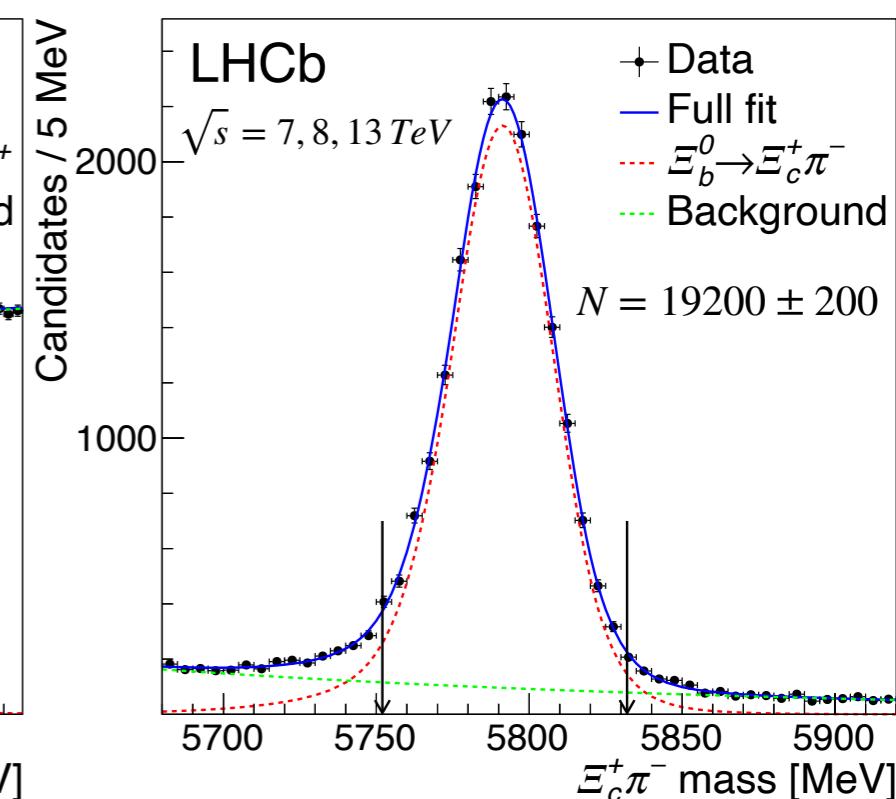
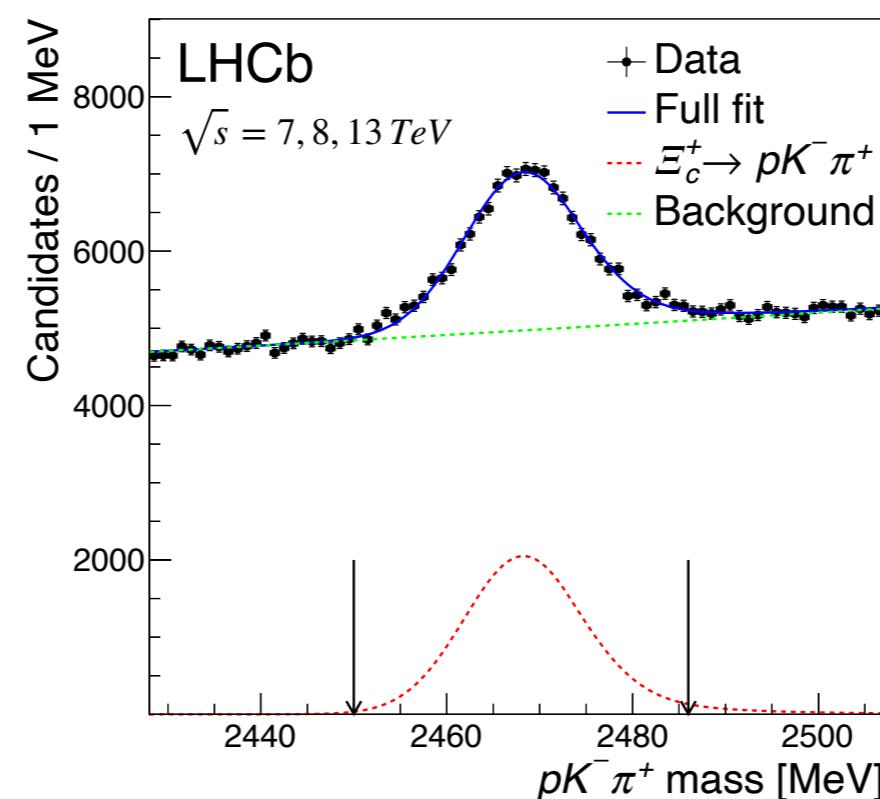
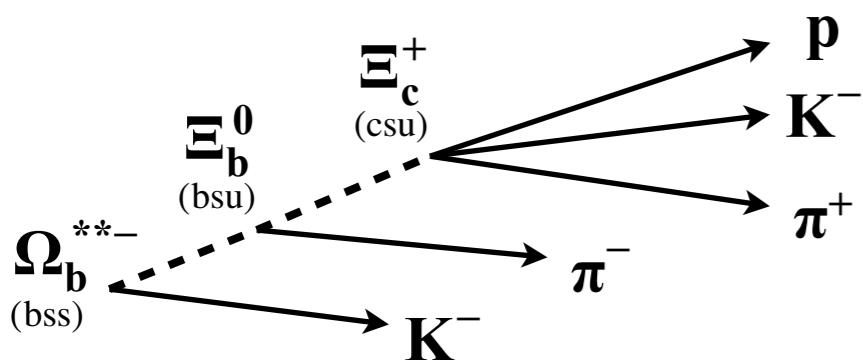
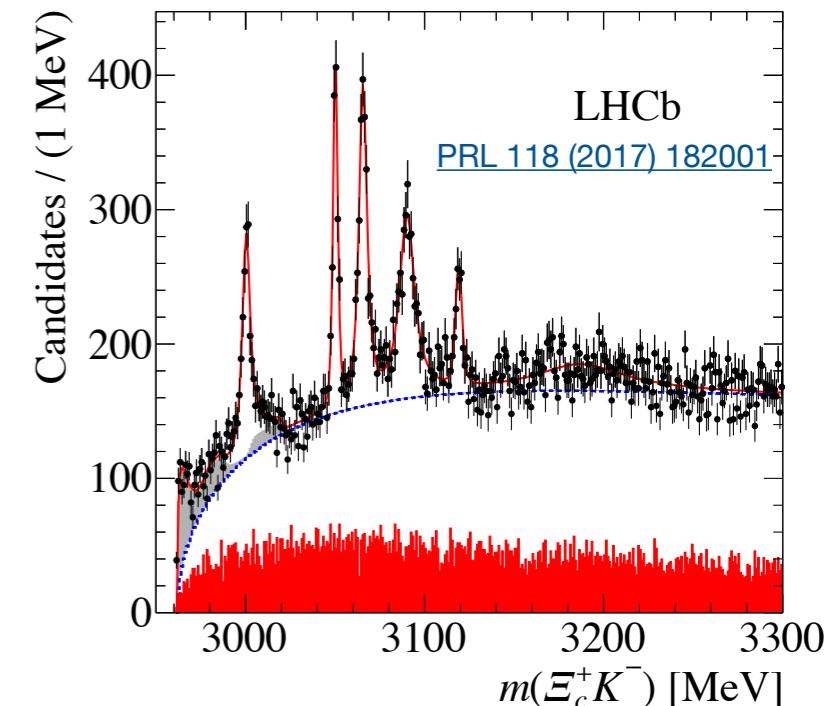


- Further selection to **suppress background**

First observation of excited Ω_b^- states

PRL 124 (2020) 082002

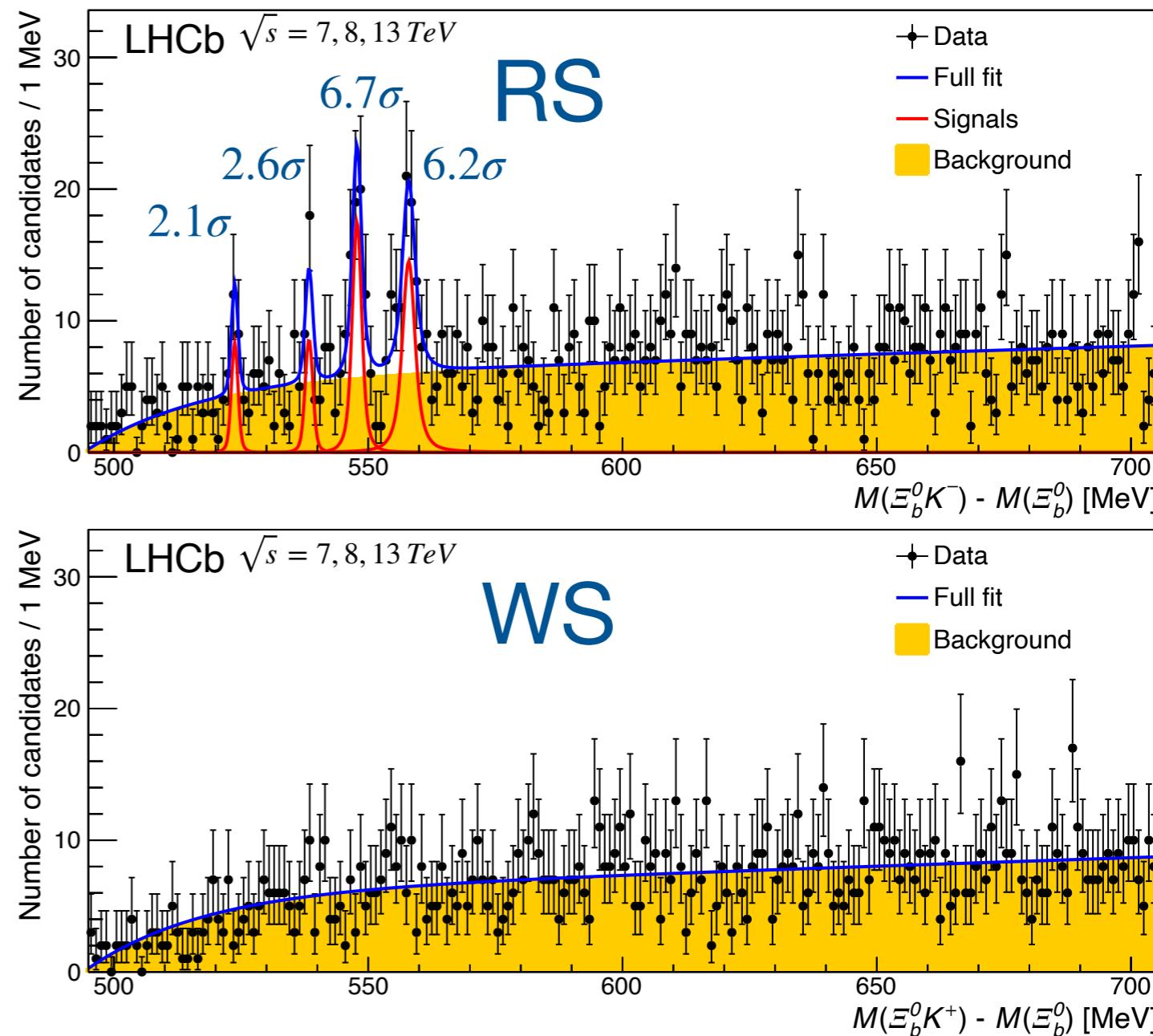
- Previous discovery of five narrow excited Ω_c^0 states
- Theoretical models describing observed Ω_c peaks also predict Ω_b states
- Search for analogous excited Ω_b^- states in the $\Xi_b^0 K^-$ spectrum
- Full Run1 + Run2 data sample (9 fb^{-1})
- Reconstruction: $\Omega_b^{**-} \rightarrow \Xi_b^0 K^-$, $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$, $\Xi_c^+ \rightarrow p K^- \pi^+$.
- Selection based on topology of the decays and particle identification requirements + boosted decision tree (BDT)



First observation of excited Ω_b^- states

PRL 124 (2020) 082002

- Simultaneous fit to wrong-sign (WS) and right-sign (RS) spectra with common background shape
- Four narrow peaks seen in RS distribution
- Signals modelled using S-wave relativistic Breit-Wigner convoluted with Gaussian resolution function
- Possible interpretations:
 - Excited Ω_b^- states with L=1 angular momentum excitations or n=2 radial excitations
 - Decay of higher mass excited Ω_b^- state:
 $\Omega_b^{**-} \rightarrow \Xi_b^{'0} (\rightarrow \Xi_b^0 \pi^0) K^-$, with missing π^0 and assuming $m(\Xi_b^{'0}) > m(\Xi_b^0) + m(\pi^0)$.



	δM_{peak} [MeV]	Mass [MeV]	Width [MeV]	
$\Omega_b(6316)^-$	$523.74 \pm 0.31 \pm 0.07$	$6315.64 \pm 0.31 \pm 0.07 \pm 0.50$	< 2.8 (4.2)	2.1σ
$\Omega_b(6330)^-$	$538.40 \pm 0.28 \pm 0.07$	$6330.30 \pm 0.28 \pm 0.07 \pm 0.50$	< 3.1 (4.7)	2.6σ
$\Omega_b(6340)^-$	$547.81 \pm 0.26 \pm 0.05$	$6339.71 \pm 0.26 \pm 0.05 \pm 0.50$	< 1.5 (1.8)	6.7σ
$\Omega_b(6350)^-$	$557.98 \pm 0.35 \pm 0.05$	$6349.88 \pm 0.35 \pm 0.05 \pm 0.50$	< 2.8 (3.2)	6.2σ
			$1.4^{+1.0}_{-0.8} \pm 0.1$	Global significances taking into account look-elsewhere effect

Excited Λ_b^0 baryons

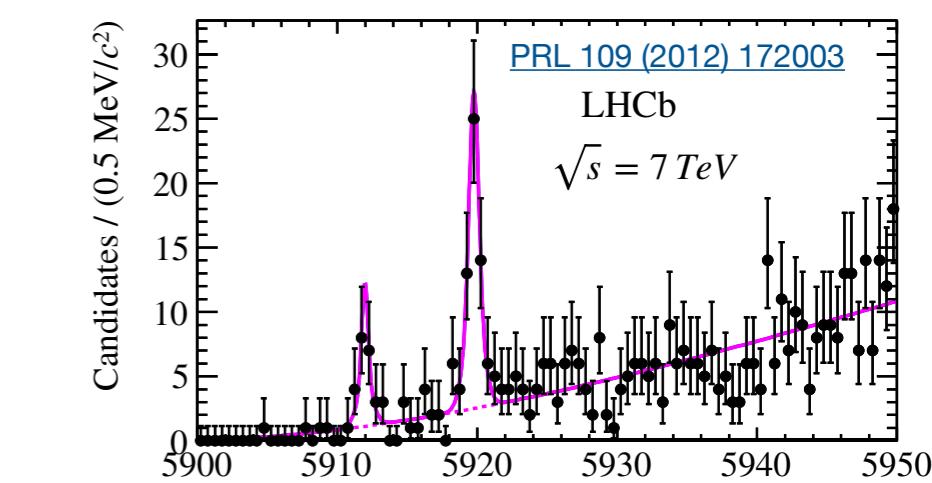
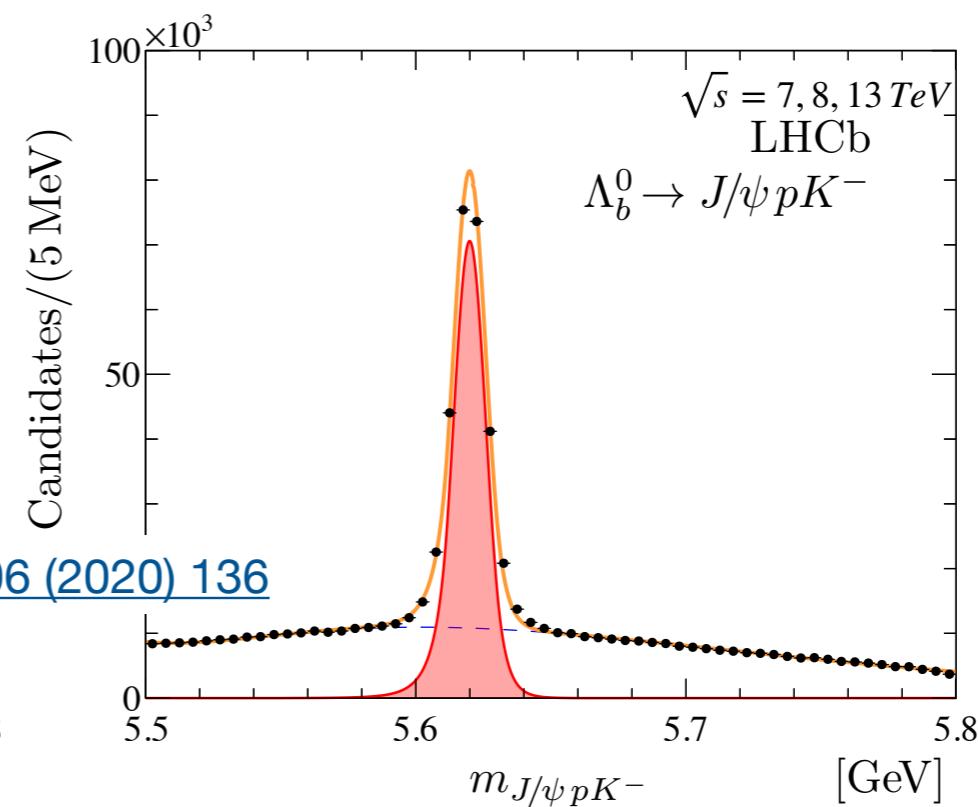
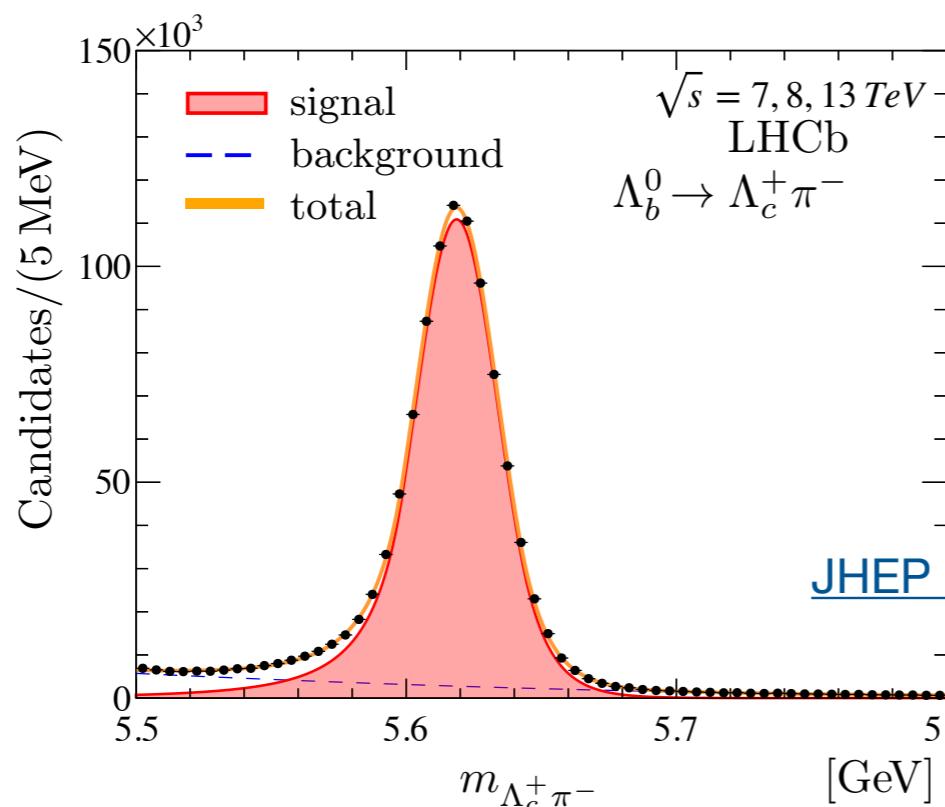
$m(\Lambda_b^{**0})$ predictions

[Int.J.Mod.Phys.A23:2817](#) [EPJA \(2015\) 51:82](#)
 ↓ ↓
PRD 34 (1986) 2809 PRD 84 (2011) 014025

- A number of excited Λ_b^0 baryon states are predicted
- In low mass region (near threshold) narrow $\Lambda_b(5912)^0$ and $\Lambda_b(5920)^0$ states reported by LHCb with 1 fb^{-1} [[PRL 109 \(2012\) 172003](#)], heavier state confirmed by CDF [[PRD 88 \(2013\) 071101](#)]
- High mass region studied by LHCb with 9 fb^{-1} [[PRL 123 \(2019\) 152001](#)]
- Intermediate mass region studied by LHCb with 9 fb^{-1} [[JHEP 06 \(2020\) 136](#)]

The two recent analyses by LHCb follow similar strategy

- Reconstruction: $\Lambda_b^{**0} \rightarrow \Lambda_b^0 \pi^+ \pi^-$, with $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ and $\Lambda_b^0 \rightarrow J/\psi p K^-$
- Selection using BDT

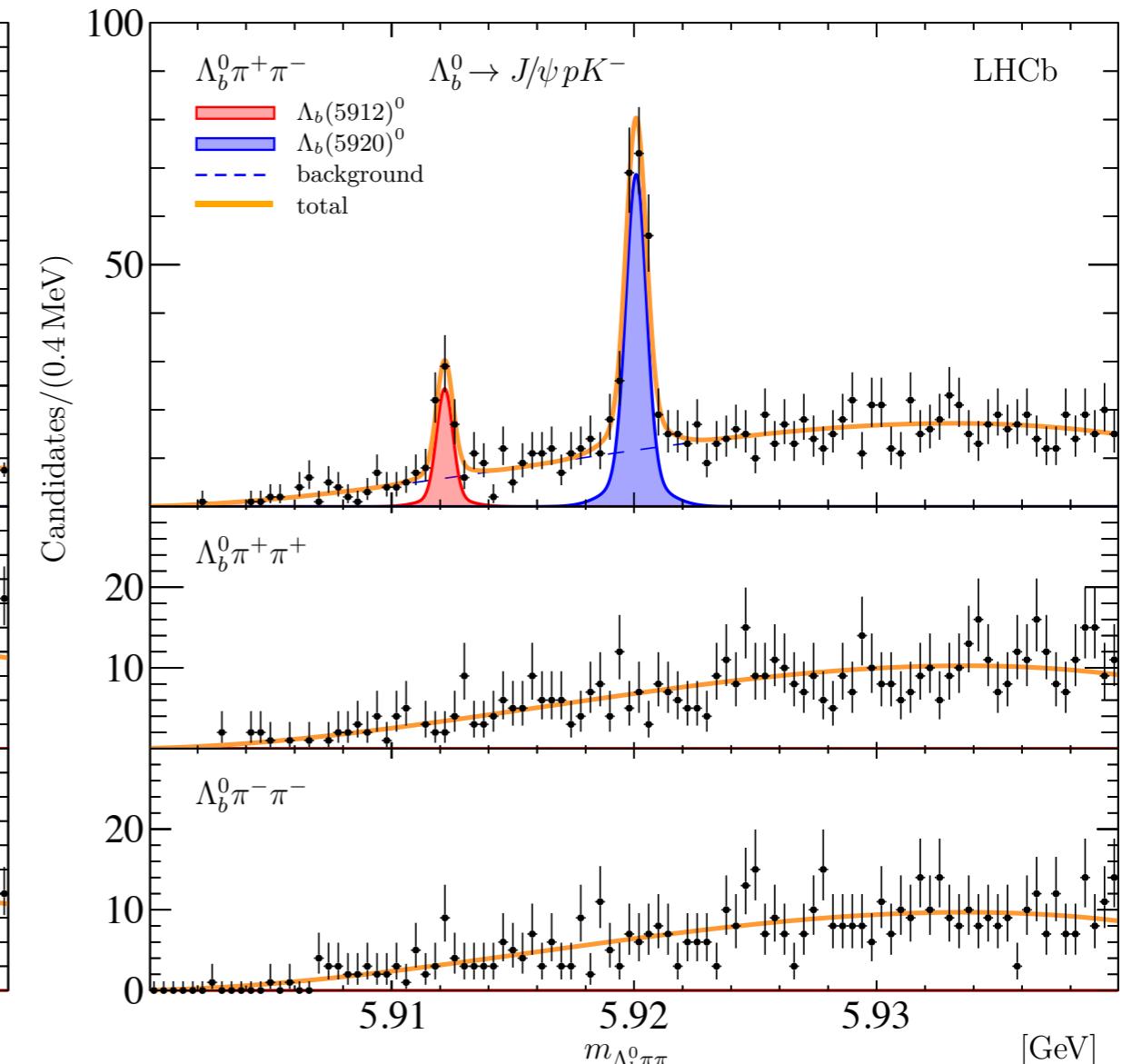
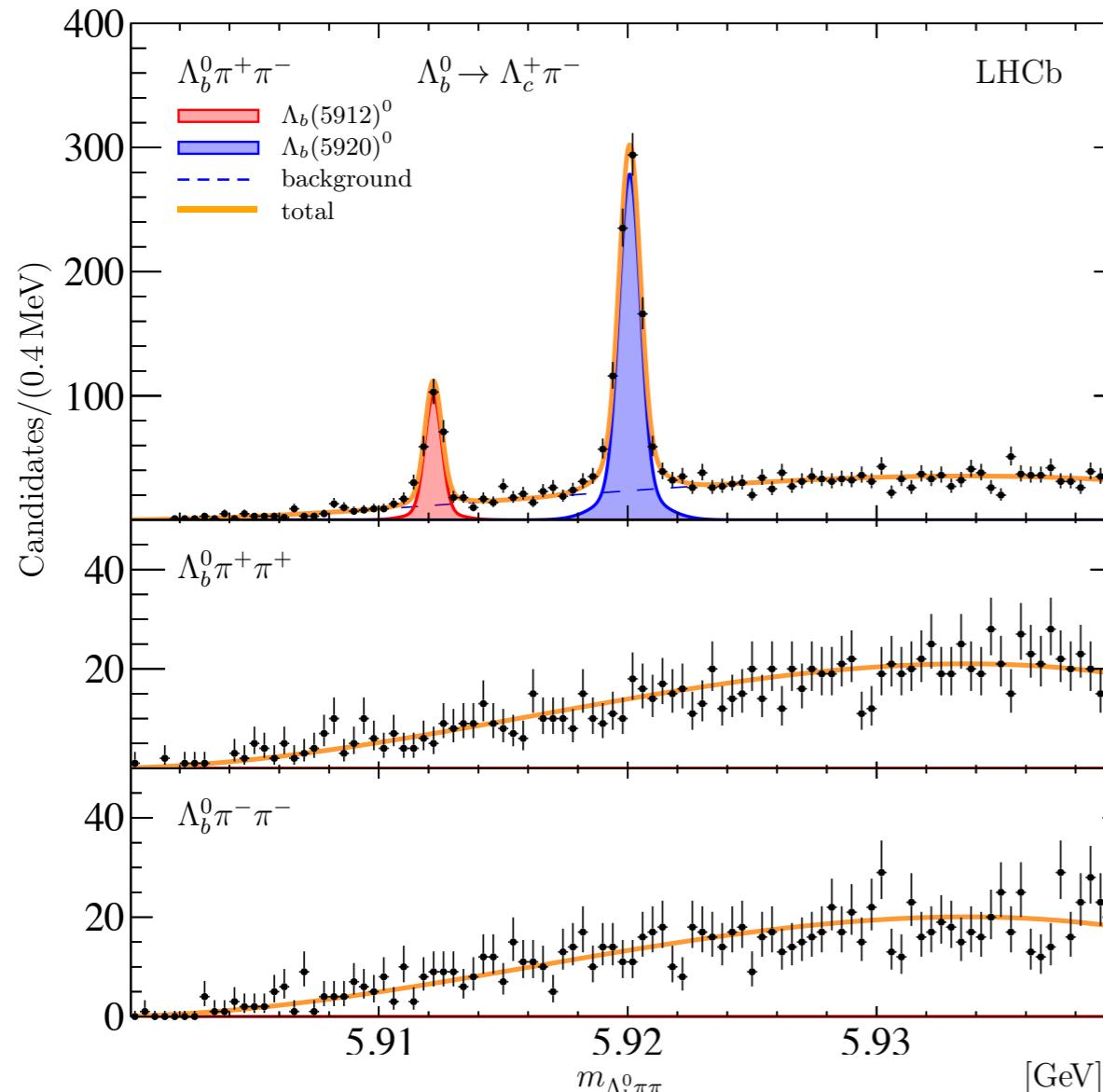


Excited Λ_b^0 baryons

[JHEP 06 \(2020\) 136](#)

Low mass region

- An update of the masses and widths measurements of low mass states
- Simultaneous fit of both $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ and $\Lambda_b^0 \rightarrow J/\psi p K^-$ (6 distributions in total)



Results

$$M_{\Lambda_b(5912)^0} = 5912.21 \pm 0.03 \pm 0.01 \pm 0.21 \text{ MeV}$$

$$M_{\Lambda_b(5920)^0} = 5920.11 \pm 0.02 \pm 0.01 \pm 0.21 \text{ MeV}$$

$$\Gamma_{\Lambda_b(5912)^0} < 0.28 \text{ MeV (95 \% CL)}$$

$$\Gamma_{\Lambda_b(5920)^0} < 0.20 \text{ MeV (95 \% CL)}$$

4 times more precise wrt first observation [[PRL 109 \(2012\) 172003](#)]

Excited Λ_b^0 baryons

High mass region

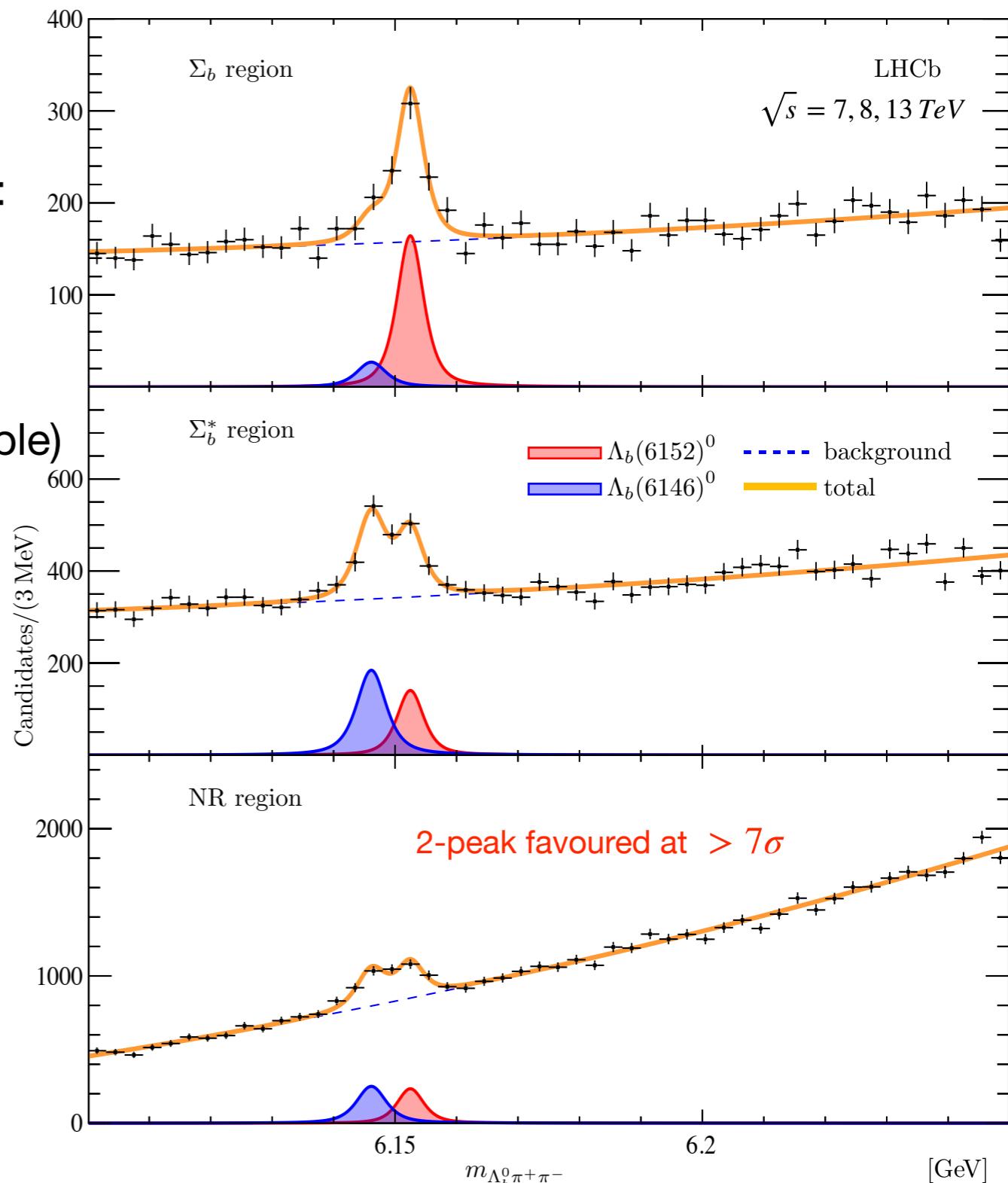
PRL 123 (2019) 152001

- Clear peaking structure at $\sim 6.15 \text{ GeV}/c^2$
- Peak is above $\Sigma_b^{(*)\mp}\pi^\pm$ hence spectrum is investigated in 3 nonoverlapping $m(\Lambda_b^0\pi^\pm)$ regions:
 - Σ_b^{\pm}
 - $\Sigma_b^{*\pm}$
 - nonresonant
- Simultaneous fit in 3 regions (only $\Lambda_b^0 \rightarrow \Lambda_c^+\pi^-$ sample)
- 7σ for 2-peak structure wrt 1-peak hypothesis

Results

$$\begin{aligned}
 m_{\Lambda_b(6146)^0} &= 6146.17 \pm 0.33 \pm 0.22 \pm 0.16 \text{ MeV}, \\
 m_{\Lambda_b(6152)^0} &= 6152.51 \pm 0.26 \pm 0.22 \pm 0.16 \text{ MeV}, \\
 \Gamma_{\Lambda_b(6146)^0} &= 2.9 \pm 1.3 \pm 0.3 \text{ MeV}, \\
 \Gamma_{\Lambda_b(6152)^0} &= 2.1 \pm 0.8 \pm 0.3 \text{ MeV},
 \end{aligned}$$

- Mass is consistent with the $\Lambda_b(1D)^0$ doublet with $J^P = 3/2^+$ and $5/2^+$ [[EPJA 51 \(2015\) 82](#), [PRD 34 \(1986\) 2809](#)]
- Interpretation as excited Σ_b^0 cannot be excluded

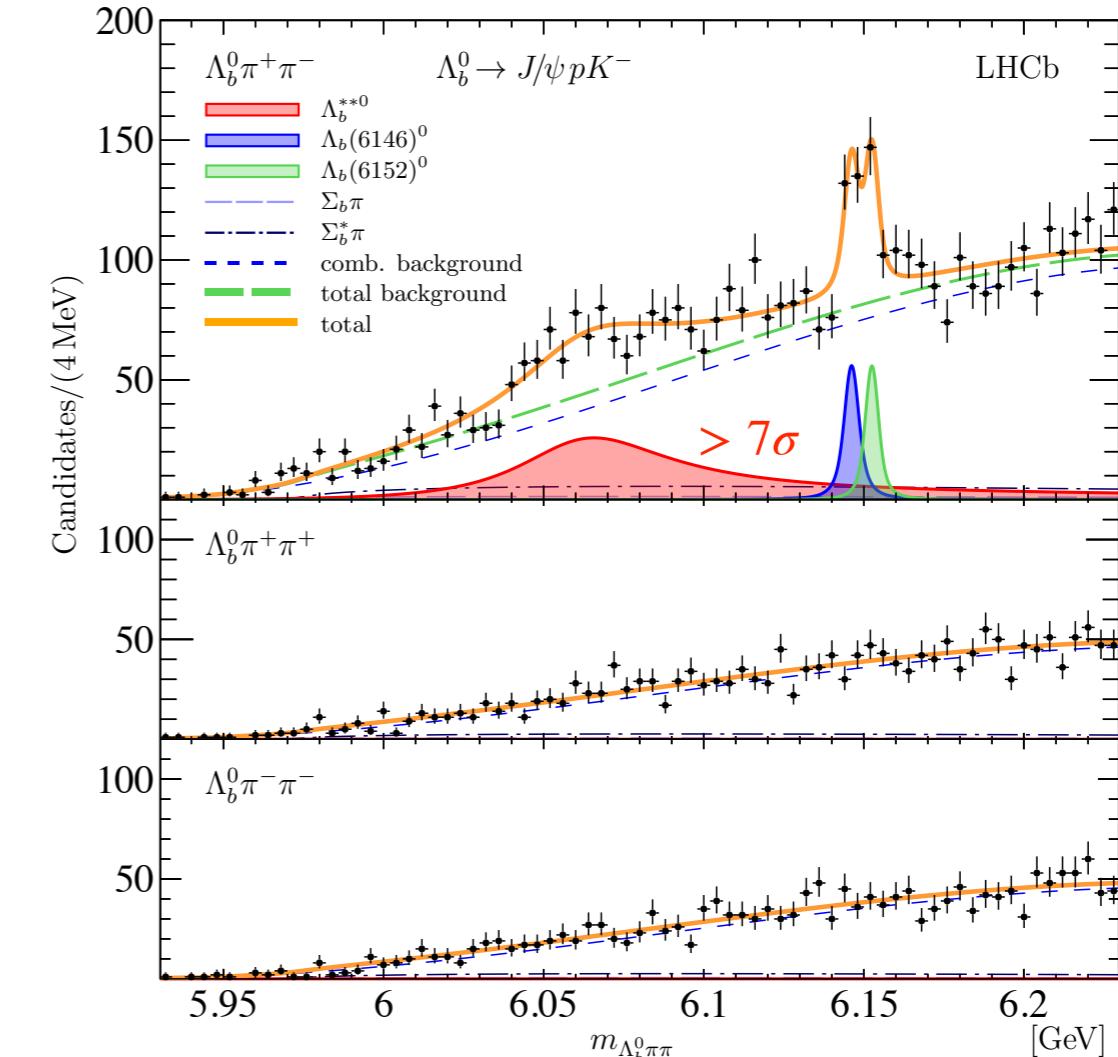
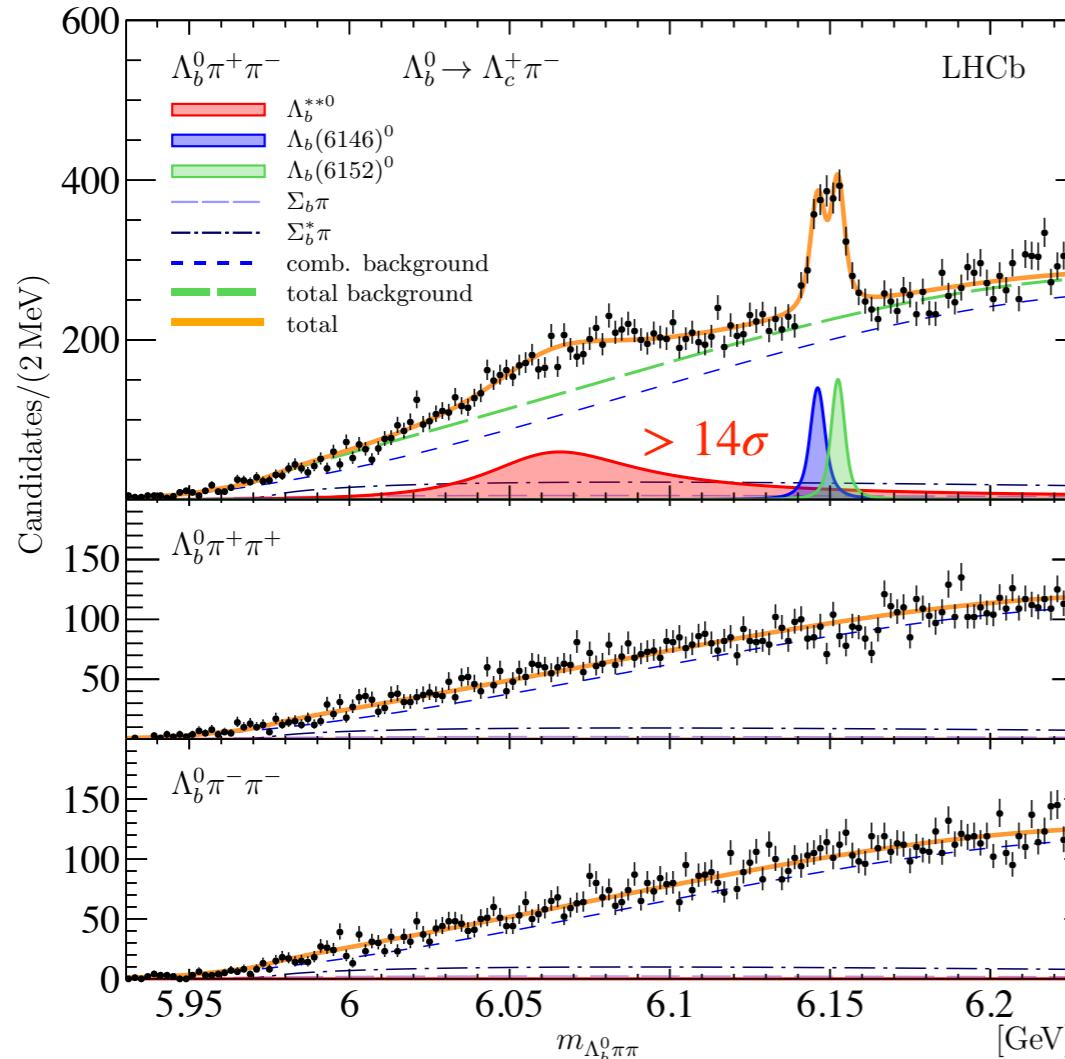


Excited Λ_b^0 baryons

Intermediate mass region

JHEP 06 (2020) 136

- Simultaneous fit of both $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ and $\Lambda_b^0 \rightarrow J/\psi p K^-$ (6 distributions in total)

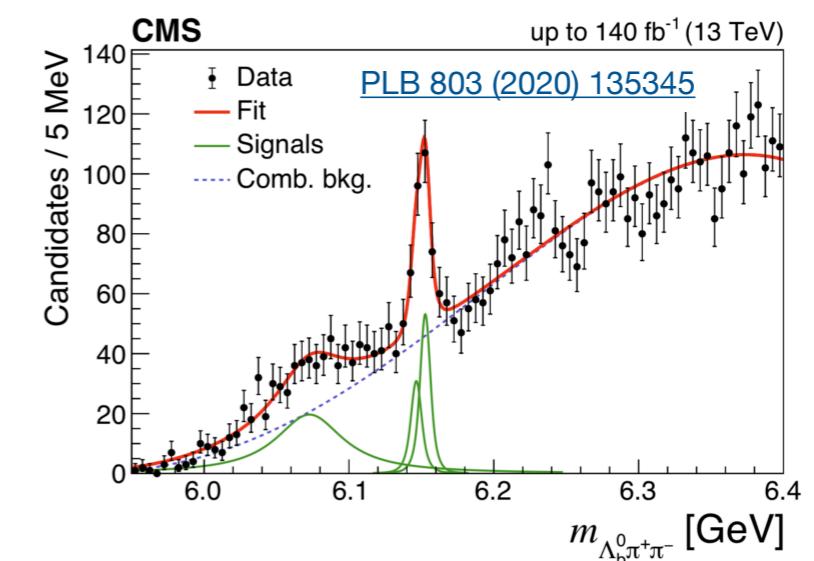


Results

$$M_{\Lambda_b^{**0}} = 6072.3 \pm 2.9 \pm 0.6 \pm 0.2 \text{ MeV}, \Gamma_{\Lambda_b^{**0}} = 72 \pm 11 \pm 2 \text{ MeV}$$

- Consistent with broad excess reported by CMS
- Mass and width are in agreement with $\Lambda_b(2S)^0$

[[PRD 34 \(1986\) 2809](#), [Int.J.Mod.Phys.A23:2817](#), [PRD 84 \(2011\) 014025](#),
[PRD 98 \(2018\) 074032](#), [Chin.Phys.C 38 \(2014\) 113101](#)]

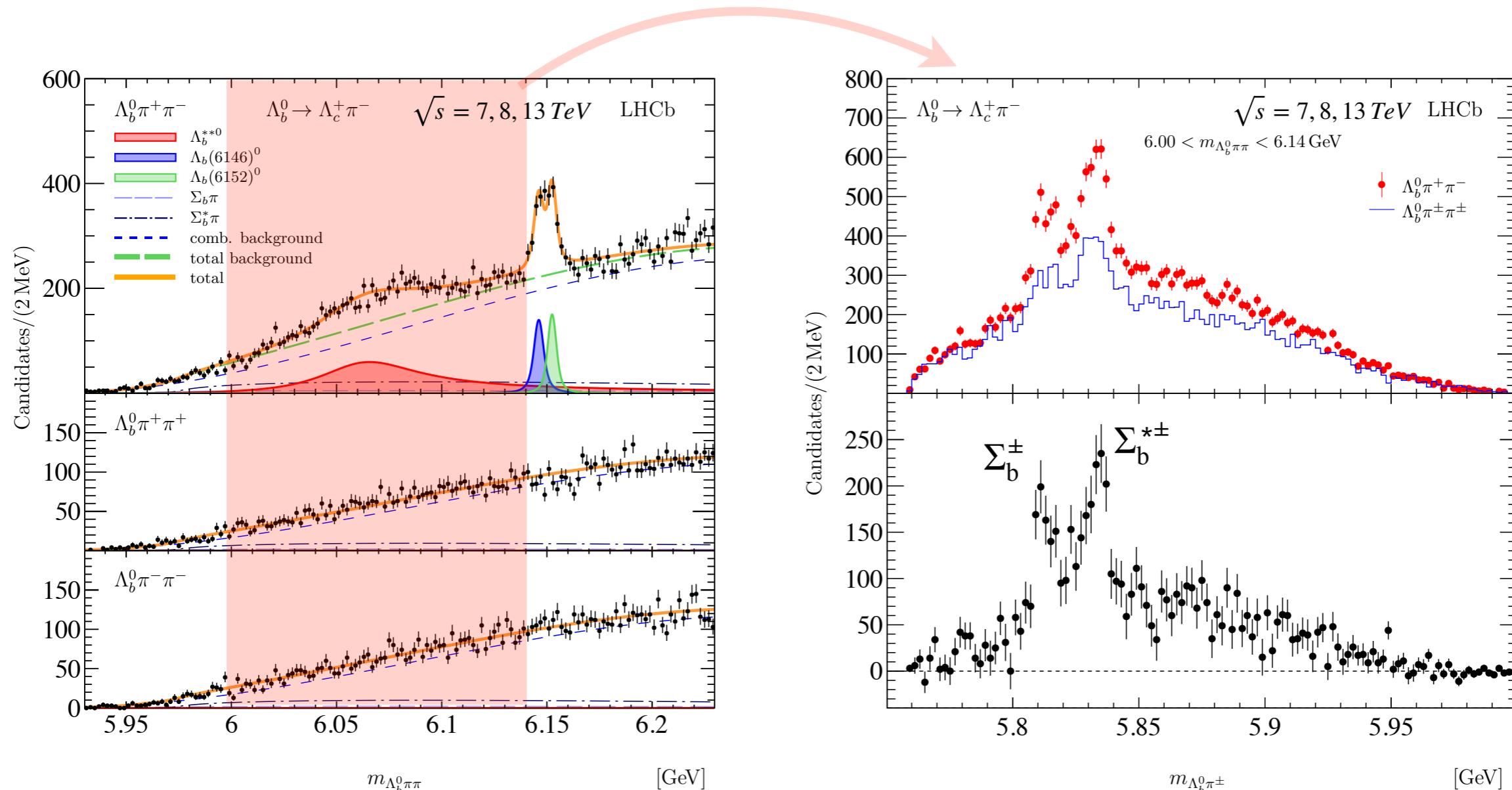


Excited Λ_b^0 baryons

Intermediate mass region

[JHEP 06 \(2020\) 136](#)

- Peak is above $\Sigma_b^{(*)\mp}\pi^\pm$ but in the Λ_b^{**0} mass region the $\Sigma_b^{(*)\pm}\pi^\mp$ and $\Sigma_b^{(*)\mp}\pi^\pm$ kinematic regions overlap.
- Hence, select signal region and use Wrong Sign samples as background proxy



- Small fraction of $\Lambda_b^{**0} \rightarrow \Sigma_b^\pm \pi^\mp$ and $\Lambda_b^{**0} \rightarrow \Sigma_b^{*\pm} \pi^\mp$ and dominant nonresonant contribution

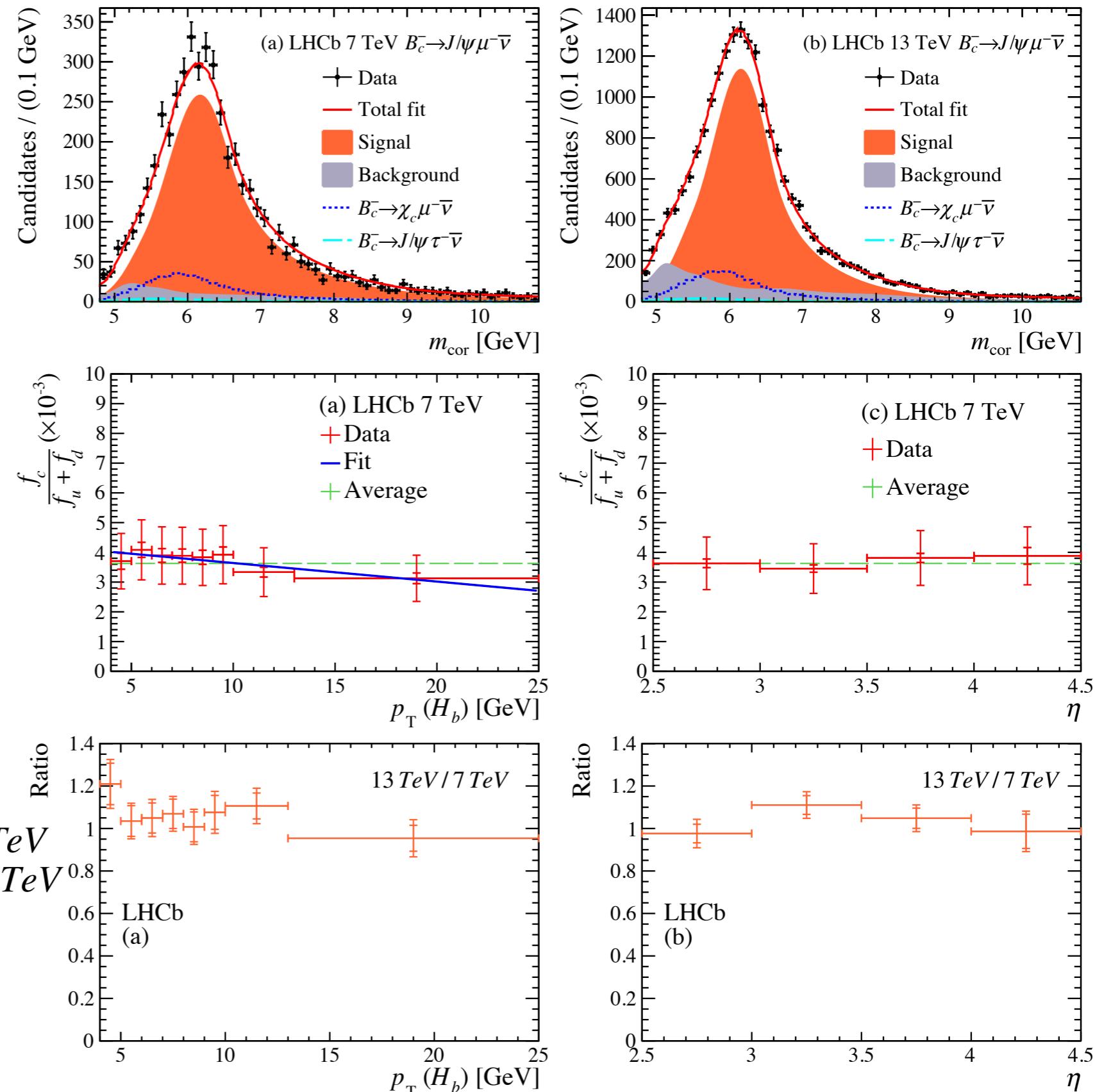
Measurement of the B_c^- meson production fraction and asymmetry

PRD 100 (2019) 112006

- Continue test of QCD by measurement of production fraction ratio $\frac{f_c}{f_u + f_d}$ and B_c^- production asymmetries
- Data samples: 7 TeV and 13 TeV
- Reconstruction: $B_c^- \rightarrow J/\psi \mu^-\bar{\nu}_\mu$, $B^0 \rightarrow D^+ X \mu^-\bar{\nu}_\mu$ and $B^- \rightarrow D^0 X \mu^-\bar{\nu}_\mu$

Results

- The rate does not change with energy, but shows a transverse momentum dependence
- Result of $\frac{f_c}{f_u + f_d}$ measurement:
 $(-3.63 \pm 0.08 \pm 0.12 \pm 0.86) \times 10^{-3}$ @ 7 TeV
 $(-3.78 \pm 0.04 \pm 0.15 \pm 0.89) \times 10^{-3}$ @ 13 TeV
- $B_c^- - B_c^+$ production asymmetry:
 $(-2.5 \pm 2.1 \pm 0.5)\%$ @ 7 TeV
 $(-0.5 \pm 1.1 \pm 0.4)\%$ @ 13 TeV



Conclusion

- The LHCb experiment provides a significant contribution to the knowledge of b-hadron spectroscopy:
 - First observation of excited Ω_b^- states
 - Excited Λ_b^0 baryons
 - Precise measurement of the mass and width of $\Lambda_b(5912)^0$ and $\Lambda_b(5920)^0$ states
 - Observation of two new narrow $\Lambda_b(5912)^0$ and $\Lambda_b(5920)^0$ states
 - Observation of new Λ_b^{**0} state consistent with $\Lambda_b(2S)^0$ prediction
 - Measurement of the B_c^- meson production fraction and asymmetry in 7 and 13 TeV pp collisions
- Looking forward to new results!

For more LHCb results on b-hadrons see:

- Precision measurement of the B_c^+ meson mass (talk by Zhiyu Xiang)
- First observation of the decay $\Lambda_b^0 \rightarrow \eta_c(1S)pK^-$ (talk by Daniel Johnson)

Acknowledgments



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