Studies of b-hadrons and quarkonia at LHCb

Zhiyu Xiang

(on behalf of the LHCb collaboration)

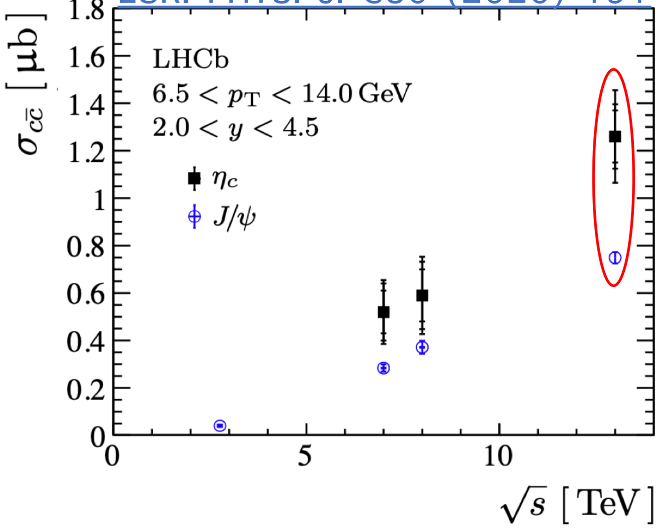
University of Chinese Academy of Sciences (UCAS)

DIS, April 2021

Shopping list

- $\eta_c(1S)$ production $@\sqrt{s} = 13$ TeV

EUR. PHYS. J. C80 (2020) 191



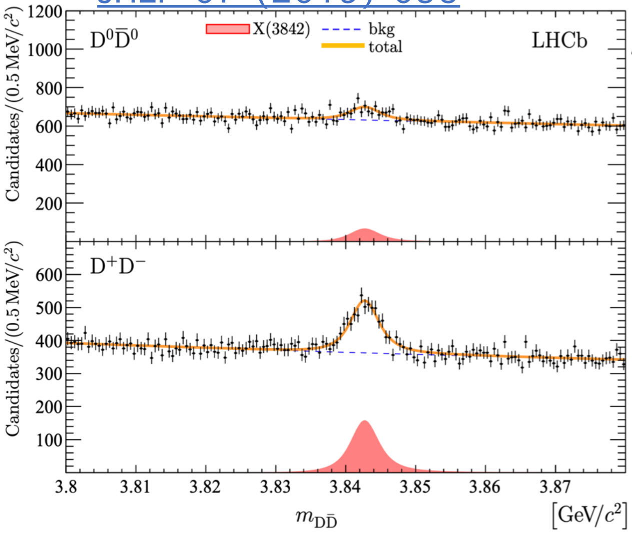
$$\left(\sigma_{\eta_c}^{\text{prompt}}\right)_{13\,\text{TeV}}^{6.5<p_T<14.0\,\text{GeV},\,2.0<y<4.5} = 1.26 \pm 0.11 \pm 0.08 \pm 0.14\ \mu\text{b}$$

Consistent with colour-singlet model prediction

NPB 945 (2019) 114662

- Observation of X(3842)

JHEP 07 (2019) 035

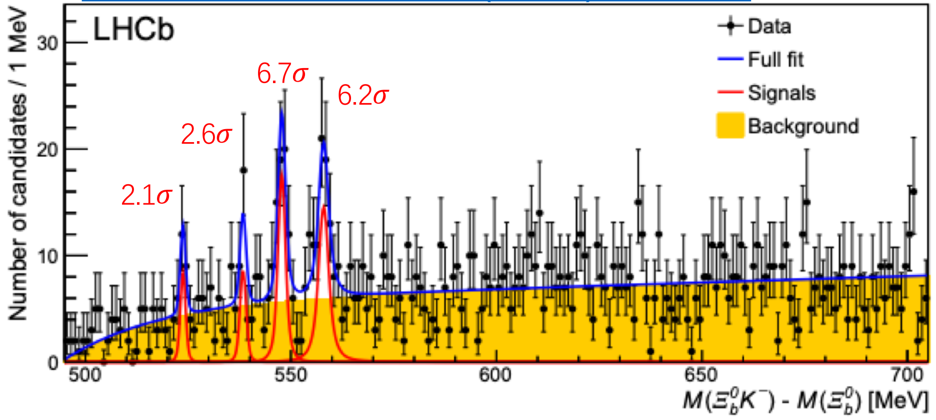


$$m_{X(3842)} = 3842.71 \pm 0.16 \pm 0.12\,\text{MeV}/c^2\,,$$
$$\Gamma_{X(3842)} = 2.79 \pm 0.51 \pm 0.35\,\text{MeV}\,,$$

Compatible with $\psi_3(1^3D_3)$

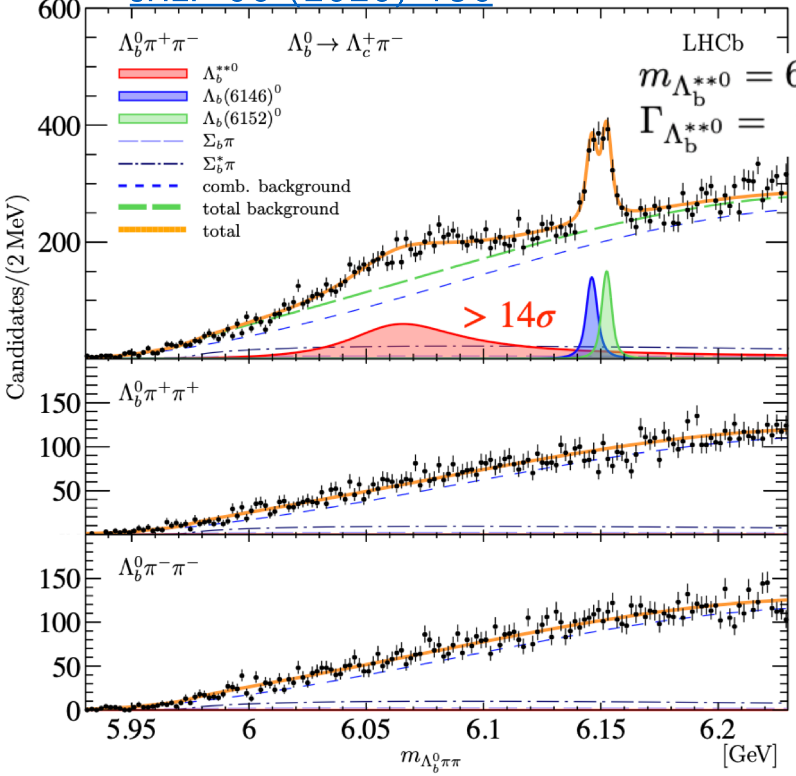
- Observation of excited Ω_b^-

PHYS. REV. LETT. 124 (2020) 082002



- Observation of excited Λ_b^0 baryon

JHEP 06 (2020) 136



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

Mass and width are in agreement with $\Lambda_b(2S)^0$

Shopping list (this talk)

- Observation of a new Ξ_b^0 state

  LHCB-PAPER-2020-032 , ARXIV:2010.14485 , PHYS. REV. D103 (2021) 012004

- Observation of new excited B_s^0 states

  LHCB-PAPER-2020-026 , ARXIV:2010.15931 , submitted to EPJC

- First observation of the decay $B_s^0 \to K^- \mu^+ \nu_\mu$ and measurement of $|V_{ub}|/|V_{cb}|$

  LHCB-PAPER-2020-038 , ARXIV:2012.05143 , PHYS. REV. LETT. 126 (2021) 081804

- First observation of the decay $B^0 \to D^0 \overline{D}^0 K^+ \pi^-$

  LHCB-PAPER-2020-015 , ARXIV:2007.04280 , PHYS. REV. D102 (2020) 0511022

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

  LHCB-PAPER-2021-003 , ARXIV:2103.04949 , submitted to JHEP

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

  LHCB-PAPER-2020-028 , ARXIV:2011.13738 , PHYS. LETT. B815 (2021) 136172

- Search for the doubly heavy baryons Ξ_{bc}^0 and Ω_{bc}^0 decaying to $\Lambda_c^+ \pi^-$ and $\Xi_c^+ \pi^-$

  LHCB-PAPER-2021-002 , ARXIV:2104.04759 , submitted to JHEP

PHYS. REV. D103 (2021) 012004

$\sqrt{s} = 7, 8, 13$ TeV $\int Ldt \sim 8.5$ fb^{-1}

New Ξ_b^0 state

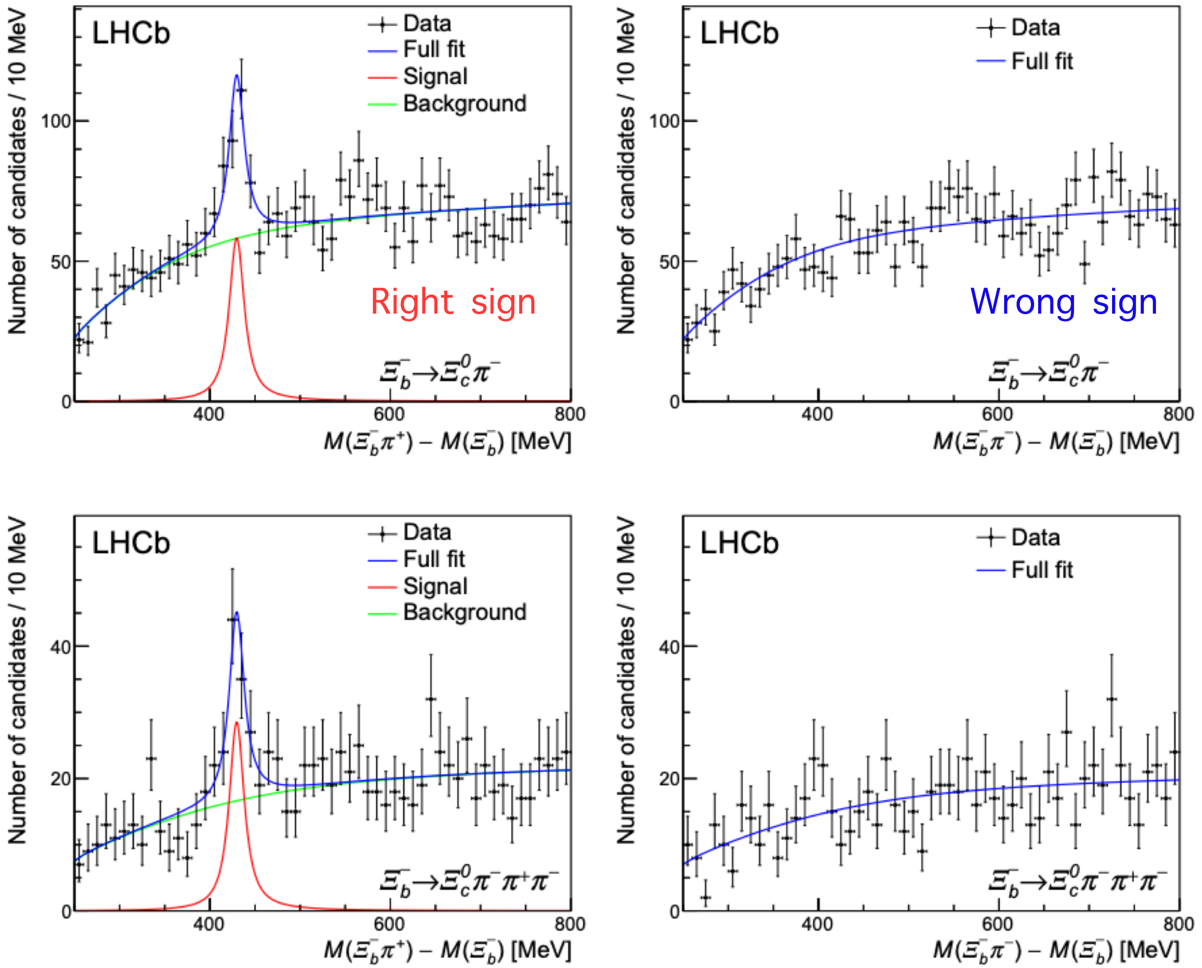
- Reconstruction: $\Xi_b^{*0} \to \Xi_b^- \pi^+$ ($\Xi_b^- \to \Xi_c^0 \pi^-, \Xi_b^- \to \Xi_c^0 \pi^- \pi^+ \pi^-$)
- A new $\Xi_b(6227)^0$ baryon observed with statistical significance of 10σ, mass and width are consistent with being isospin partner of $\Xi_b(6227)^-$

$$m(\Xi_b(6227)^0) = 6227.1\,^{+1.4}_{-1.5} \pm 0.5\,\text{MeV},$$
$$\Gamma(\Xi_b(6227)^0) = 18.6\,^{+5.0}_{-4.1} \pm 1.4\,\text{MeV},$$

- Branching ratio with the fragmentation fractions $b \to \Xi_b(6227)^0$ and $b \to \Xi_b^-$, also consistent with known $\Xi_b(6227)^-$

PHYS. REV. LETT. 121 (2018) 072002

$$\frac{f_{\Xi_b(6227)^0}}{f_{\Xi_b^-}} \mathcal{B}(\Xi_b(6227)^0 \to \Xi_b^- \pi^+) = 0.045 \pm 0.008 \pm 0.004$$

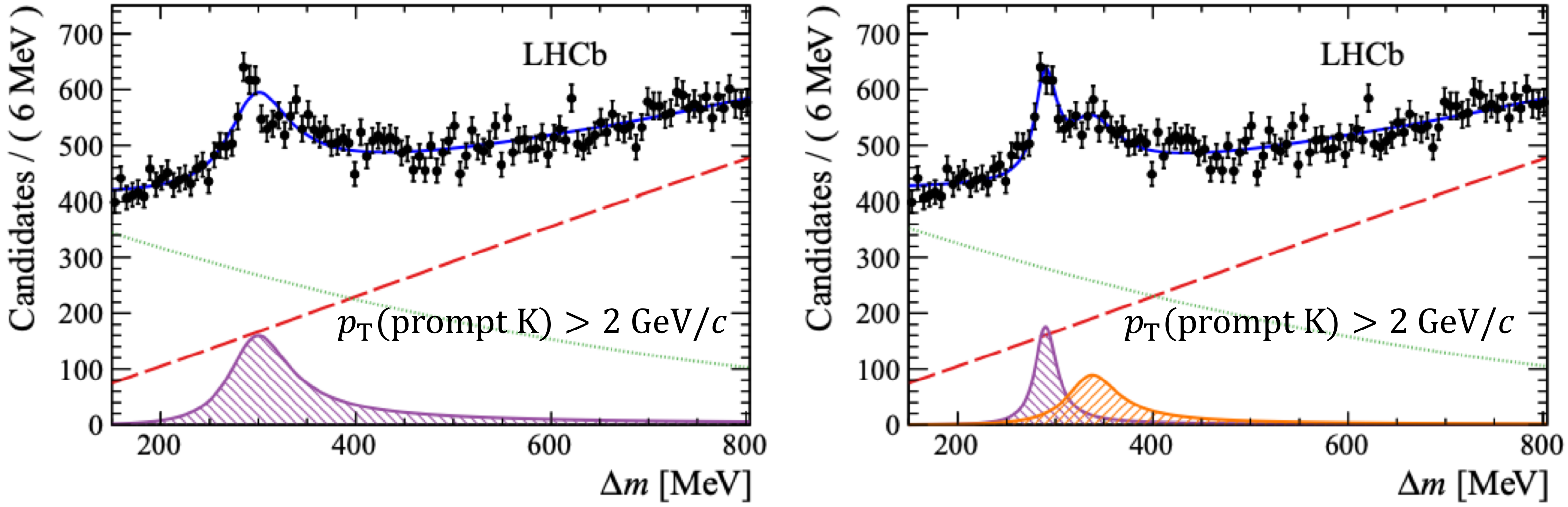


Excited B_s^0 states

ARXIV:2010.15931 submitted to EPJC

$\sqrt{s} = 7, 8, 13$ TeV $\int L dt \sim 9$ fb^{-1}

- Reconstruction: $B_s^0 \to B^+K^-$, with pure B^+ sample
- Peak structure around 300 MeV above B^+K^- threshold
- One-peak and two-peak fits performed in bins of $p_T(\text{prompt K})$
- Significance of two-peak structure relative to one-peak hypothesis above 7σ
- A single resonance decay through both B^+K^- and $B^{*+}K^-$ can not be excluded



$$m_1 = 6063.5 \pm 1.2\ (\text{stat}) \pm 0.8\ (\text{syst})\ \text{MeV},$$
$$\Gamma_1 = 26 \pm 4\ (\text{stat}) \pm 4\ (\text{syst})\ \text{MeV},$$
$$m_2 = 6114 \pm 3\ (\text{stat}) \pm 5\ (\text{syst})\ \text{MeV},$$
$$\Gamma_2 = 66 \pm 18\ (\text{stat}) \pm 21\ (\text{syst})\ \text{MeV}.$$

$$\Delta m \equiv m(B^+K^-) - m(B^+) - m(K^-)$$

Observation of $B_s^0 \to K^-\mu^+\nu_\mu$ and measurement of $|V_{ub}|/|V_{cb}|$

- First observation of suppressed decay $B_s^0 \to K^-\mu^+\nu_\mu$
- Normalization channel $B_s^0 \to D_s^-(\to K^+K^-\pi^-)\mu^+\nu_\mu$ to minimize systematic
- Corrected B_s^0 mass $m_{corr} = \sqrt{m^2(K\mu) + p_\perp^2(K\mu)} + p_\perp(K\mu)$ allows to discriminate between signal and different backgrounds

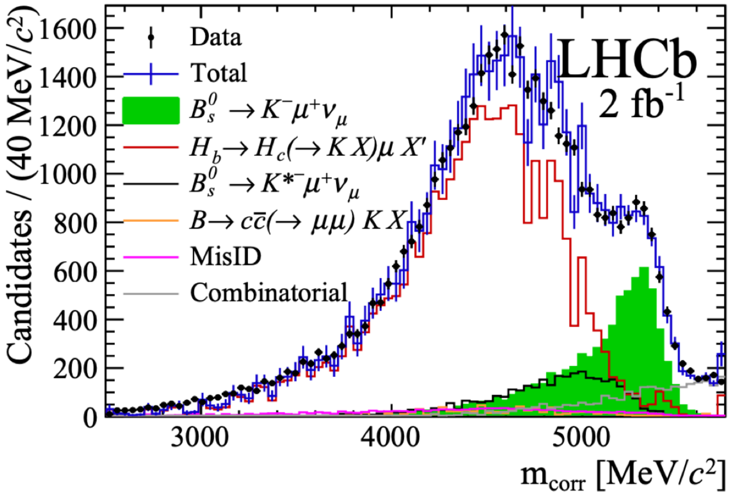
- Fit template from simulation
- $B_s^0 \to K^-\mu^+\nu_\mu$ yield:

  (low) $q^2 < 7\mathrm{GeV}^2/c^4$: 6922±285

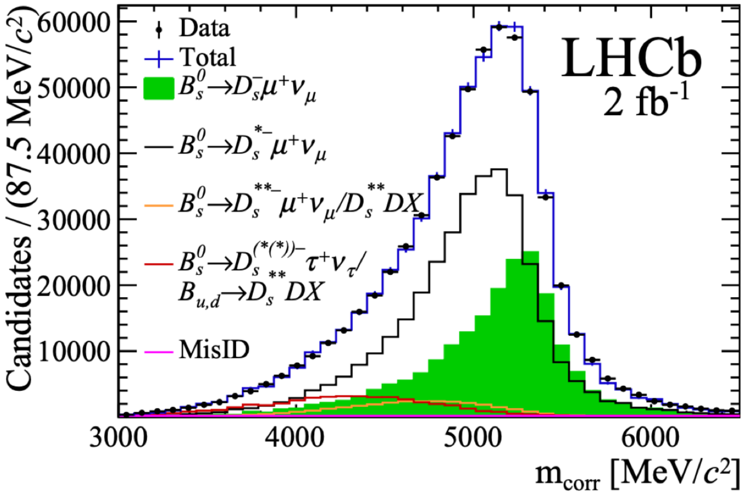
  (high) $q^2 > 7\mathrm{GeV}^2/c^4$: 6399±370
- $B_s^0 \to D_s^-(\to K^+K^-\pi^-)\mu^+\nu_\mu$

  yield: 201450±5200

Signal, $q^2 < 7\mathrm{GeV}^2/c^4$



Normalization



PHYS. REV. LETT. 126 (2021) 081804

$\sqrt{s} = 8\ \mathrm{TeV}\ \int L dt \sim 2\ \mathrm{fb}^{-1}$

Observation of $B_s^0 \to K^- \mu^+ \nu_\mu$ and measurement of $|V_{ub}|/|V_{cb}|$

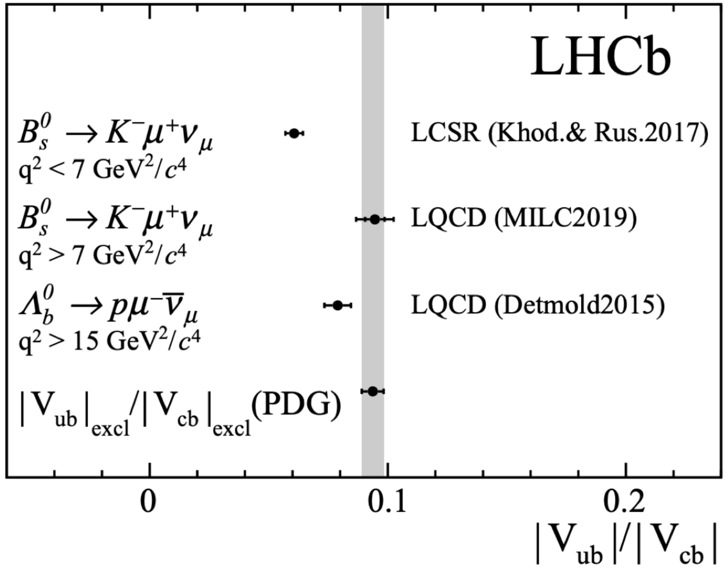
- Ratio of branching fractions: $R_{BF} \equiv \frac{\mathcal{B}(B_s^0 \to K^- \mu^+ \nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^- \mu^+ \nu_\mu)}$

$$R_{BF}(\text{low}) = (1.66 \pm 0.08\,(\text{stat}) \pm 0.07\,(\text{syst}) \pm 0.05\,(D_s)) \times 10^{-3},$$
$$R_{BF}(\text{high}) = (3.25 \pm 0.21\,(\text{stat})\,^{+0.16}_{-0.17}\,(\text{syst}) \pm 0.09\,(D_s)) \times 10^{-3},$$
$$R_{BF}(\text{all}) = (4.89 \pm 0.21\,(\text{stat})\,^{+0.20}_{-0.21}\,(\text{syst}) \pm 0.14\,(D_s)) \times 10^{-3},$$

- $|V_{ub}|/|V_{cb}|$:

$$|V_{ub}|/|V_{cb}|(\text{low}) = 0.0607 \pm 0.0015\,(\text{stat}) \pm 0.0013\,(\text{syst}) \pm 0.0008\,(D_s) \pm 0.0030\,(\text{FF}),$$
$$|V_{ub}|/|V_{cb}|(\text{high}) = 0.0946 \pm 0.0030\,(\text{stat})\,^{+0.0024}_{-0.0025}\,(\text{syst}) \pm 0.0013\,(D_s) \pm 0.0068\,(\text{FF}),$$

- Improve averages of the exclusive measurements



Discrepancy related to the difference in the theoretical calculations of the form factors

PHYS. REV. LETT. 126 (2021) 081804

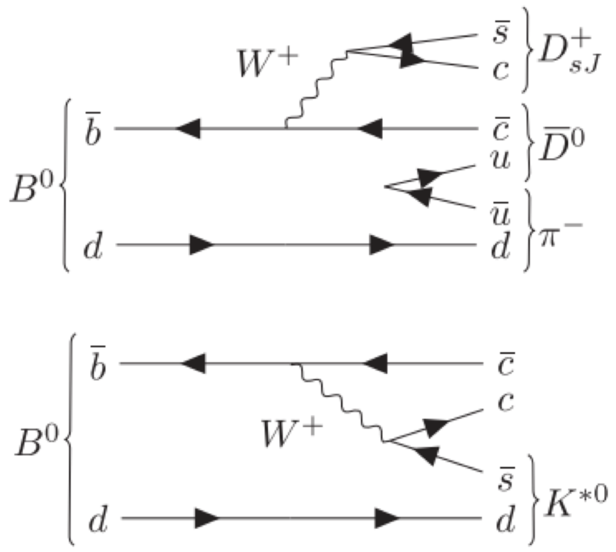
$\sqrt{s} = 8$ TeV $\int Ldt \sim 2$ fb^{-1}

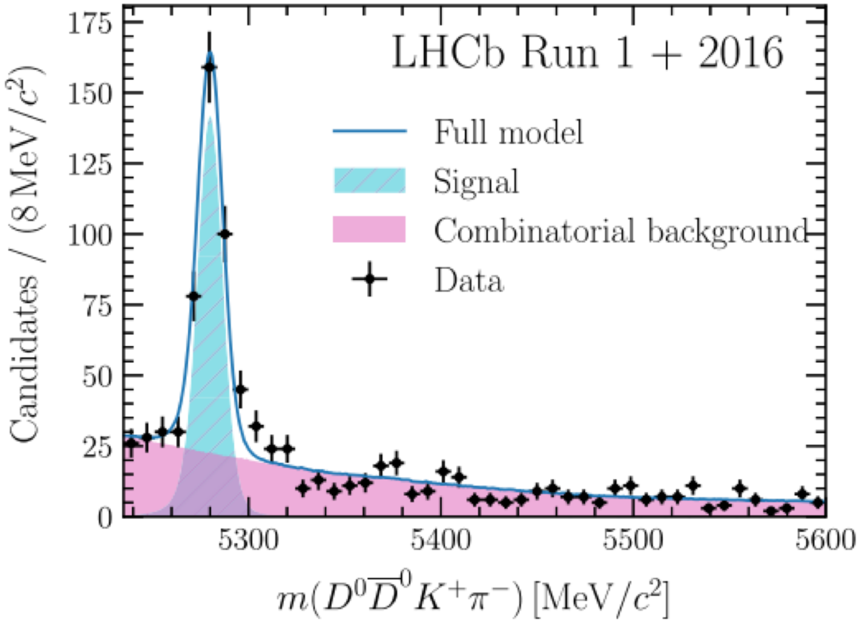
Observation of $B^0 \to D^0\overline{D}^0K^+\pi^-$

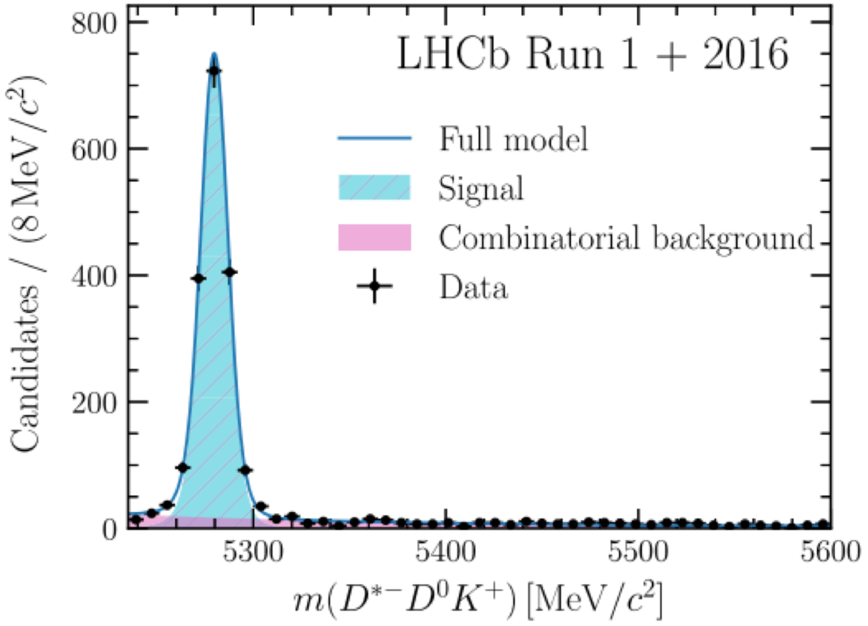
PHYS. REV. D102 (2020) 0511022

$\sqrt{s} = 7, 8, 13$ TeV $\int Ldt \sim 4.7$ fb^{-1}

- Use flight distance significance to reject charmless backgrounds
- D^0 mass constrained, neural networks further improve signal purity
- Split from $B^0 \to D^{*-}D^0K^+$: $|m(\overline{D}^0\pi^-) - m(\overline{D}^0) + m_{PDG}(\overline{D}^0) - m_{PDG}(D^{*-})| > 4\sigma_{D^{*-}}$







- Branching ratio: $$\frac{\mathcal{B}(B^0 \to D^0\overline{D}^0K^+\pi^-)}{\mathcal{B}(B^0 \to D^{*-}D^0K^+)} = (14.2 \pm 1.1 \pm 1.0)\%$$

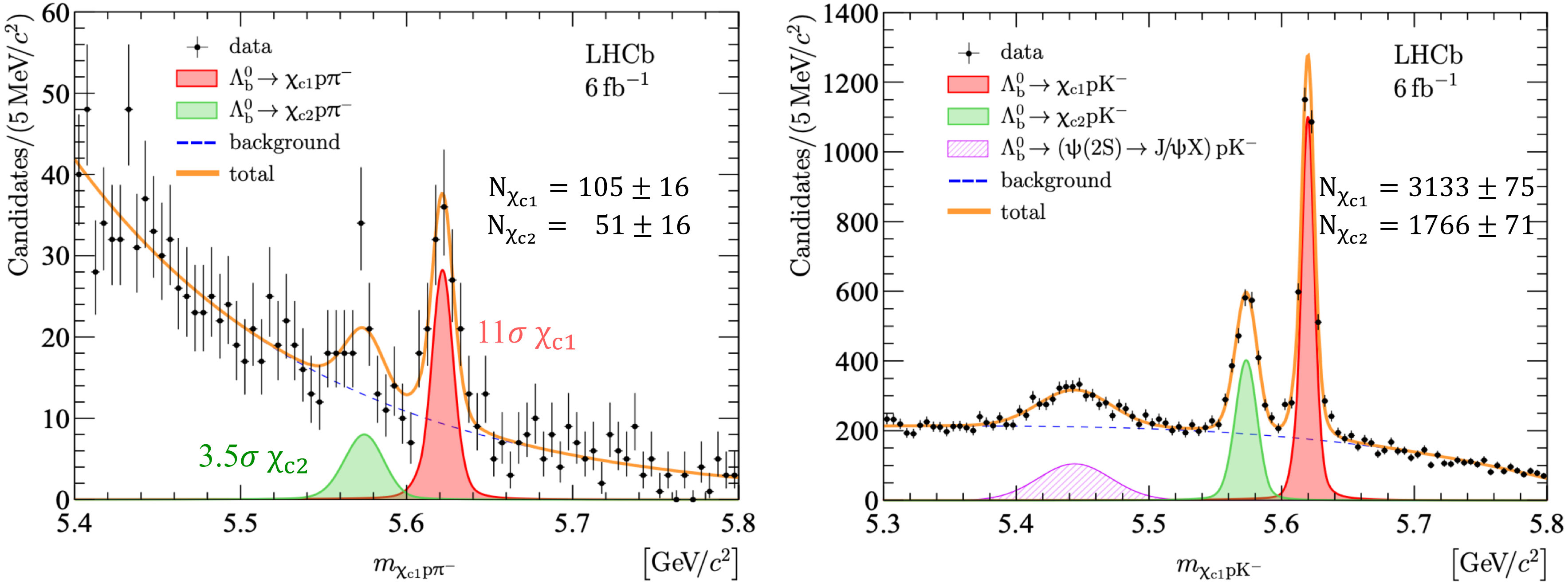
$$\mathcal{B}(B^0 \to D^0\overline{D}^0K^+\pi^-) = (3.50 \pm 0.27 \pm 0.26 \pm 0.30)\times 10^{-4}$$

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

ARXIV:2103.04949

$\sqrt{s} = 13$ TeV $\int Ldt \sim 6\ \mathrm{fb}^{-1}$

- Hidden-charm pentaquark only seen in $J/\psi p$ and $J/\psi\Lambda$ systems PRL 122 (2019) 222001, PRL 117 (2016) 082003, arXiv: 2012.10380
- What about $\chi_{c1,2}p$? search for $\Lambda_b^0 \to \chi_{c1,2}(\to \gamma J/\psi)p\pi^-$
- $\Lambda_b^0 \to \chi_{c1,2}pK^-$ taken as normalization



- χ_{c0} contribution is not expected sizeable: suppressed within QCD factorization approach and much smaller branching fraction to $\gamma J/\psi$ (wrt. χ_{c1})

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

ARXIV:2103.04949

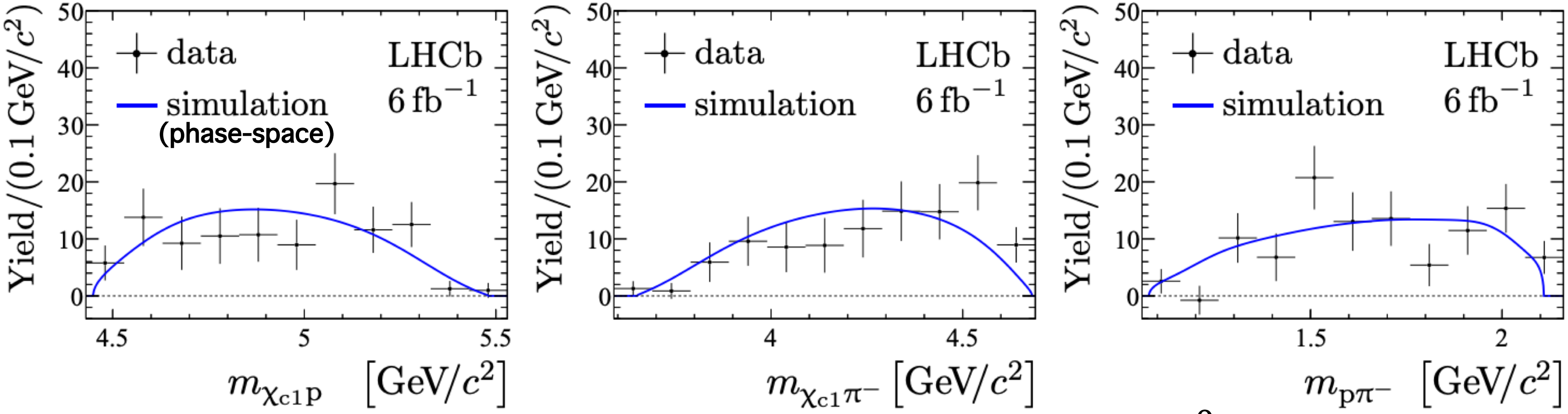
$\sqrt{s} = 13$ TeV $\int Ldt \sim 6\ \mathrm{fb}^{-1}$

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

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

  $R_{2/1}$ shows no suppression of χ_{c2} to χ_{c1}, which challenges the factorization approach for Λ_b^0 decay

- With the current statistics, no evidence for contributions from exotic states



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

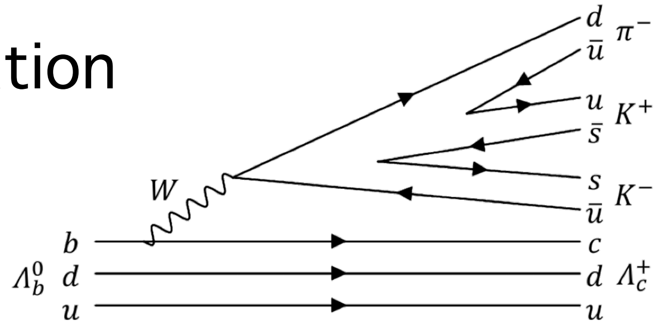
PHYS. LETT. B815 (2021) 136172

$\sqrt{s} = 7,8$ TeV $\int Ldt \sim 3$ fb^{-1}

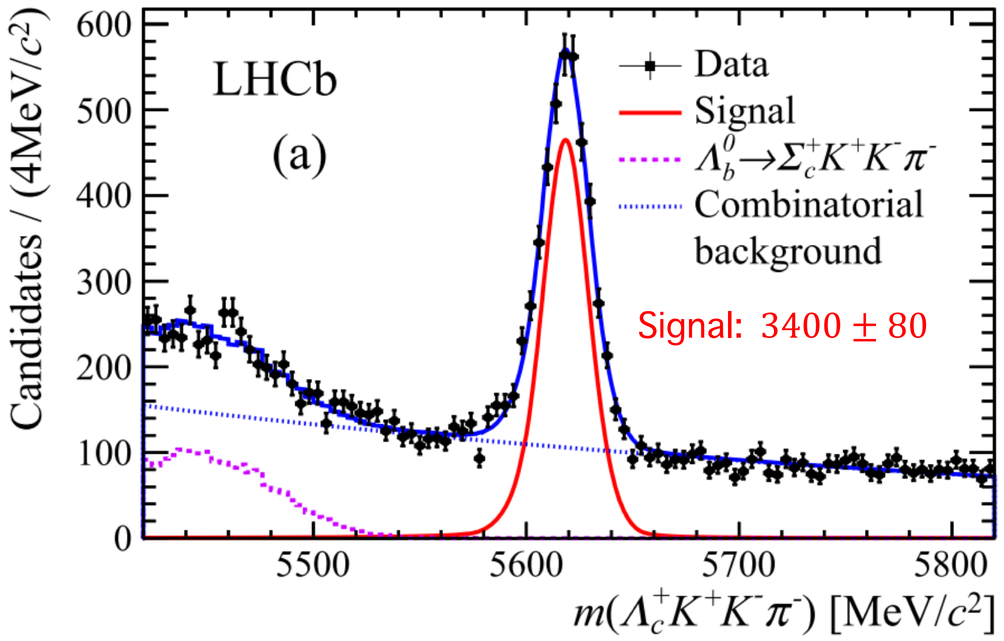
Observation of $\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-$

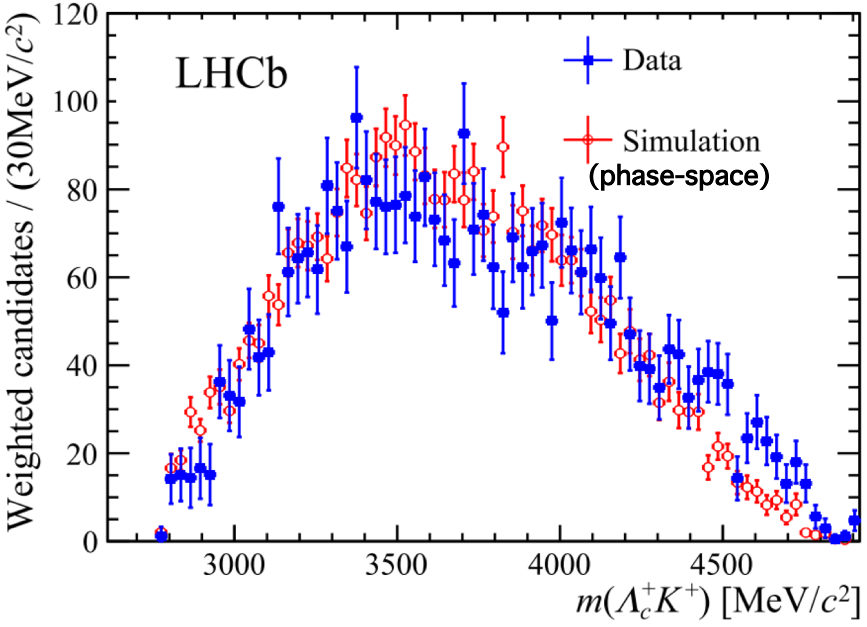
- $\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-$ provides a laboratory to search for open-charm pentaquarks
- Search for $\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-$, take $\Lambda_b^0 \to \Lambda_c^+ D_s^-$ as normalization
- Branching ratio: $\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)} = (9.26 \pm 0.29 \pm 0.46 \pm 0.26) \times 10^{-2}$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-) = (1.02 \pm 0.03 \pm 0.05 \pm 0.10) \times 10^{-3}$$



- No evidence for contributions from exotic states





Bkg.-subtracted data

vs

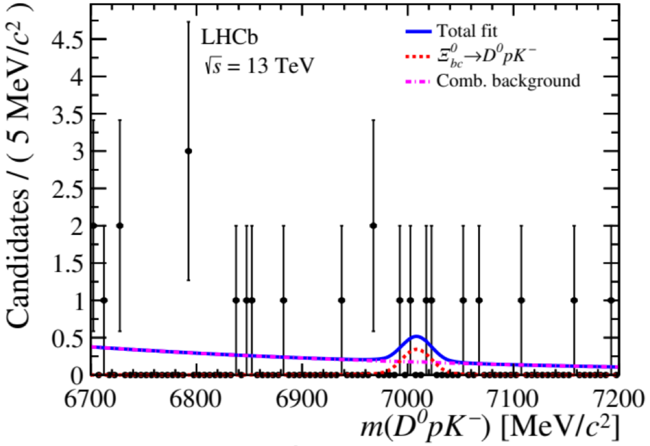
Simulation (PHSP)

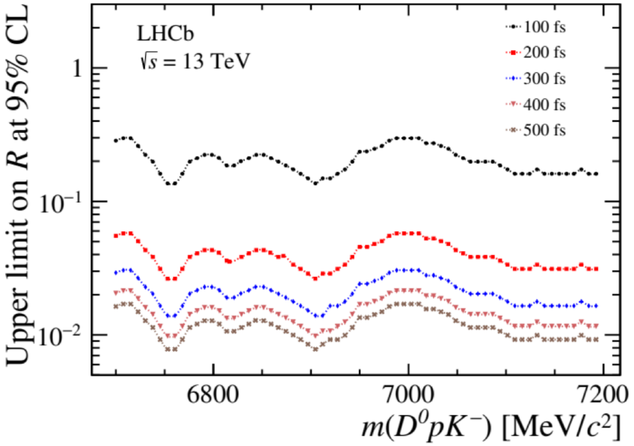
Search for Ξ_{bc}^0/Ω_{bc}^0

ARXIV:2104.04759

$\sqrt{s} = 13$ TeV $\int Ldt \sim 5.2\ \mathrm{fb}^{-1}$

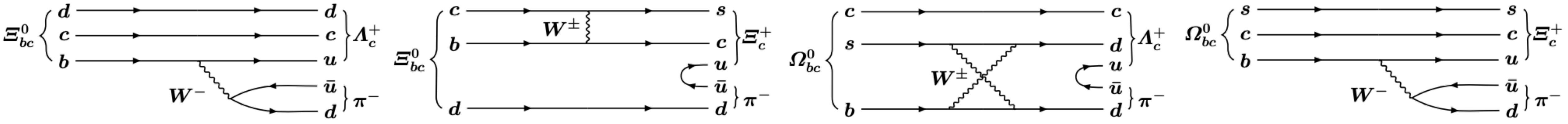
- The first search for doubly heavy baryon Ξ_{bc}^0 via $\mathrm{D^0pK^-}$ @ LHCb was reported recently, no significant signal excess is seen, upper limit set JHEP 11 (2020) 095





$$R = \frac{\sigma(\Xi_{bc}^0)\mathcal{B}(\Xi_{bc}^0 \to \mathrm{D^0pK^-})}{\sigma(\Lambda_b^0)\mathcal{B}(\Lambda_b^0 \to \mathrm{D^0pK^-})}$$

- New search for Ξ_{bc}^0 and first search for Ω_{bc}^0 both decay to $\Lambda_c^+\pi^-$ and $\Xi_c^+\pi^-$



- H_{bc}^0 $(\Xi_{bc}^0, \Omega_{bc}^0)$ production ratios:

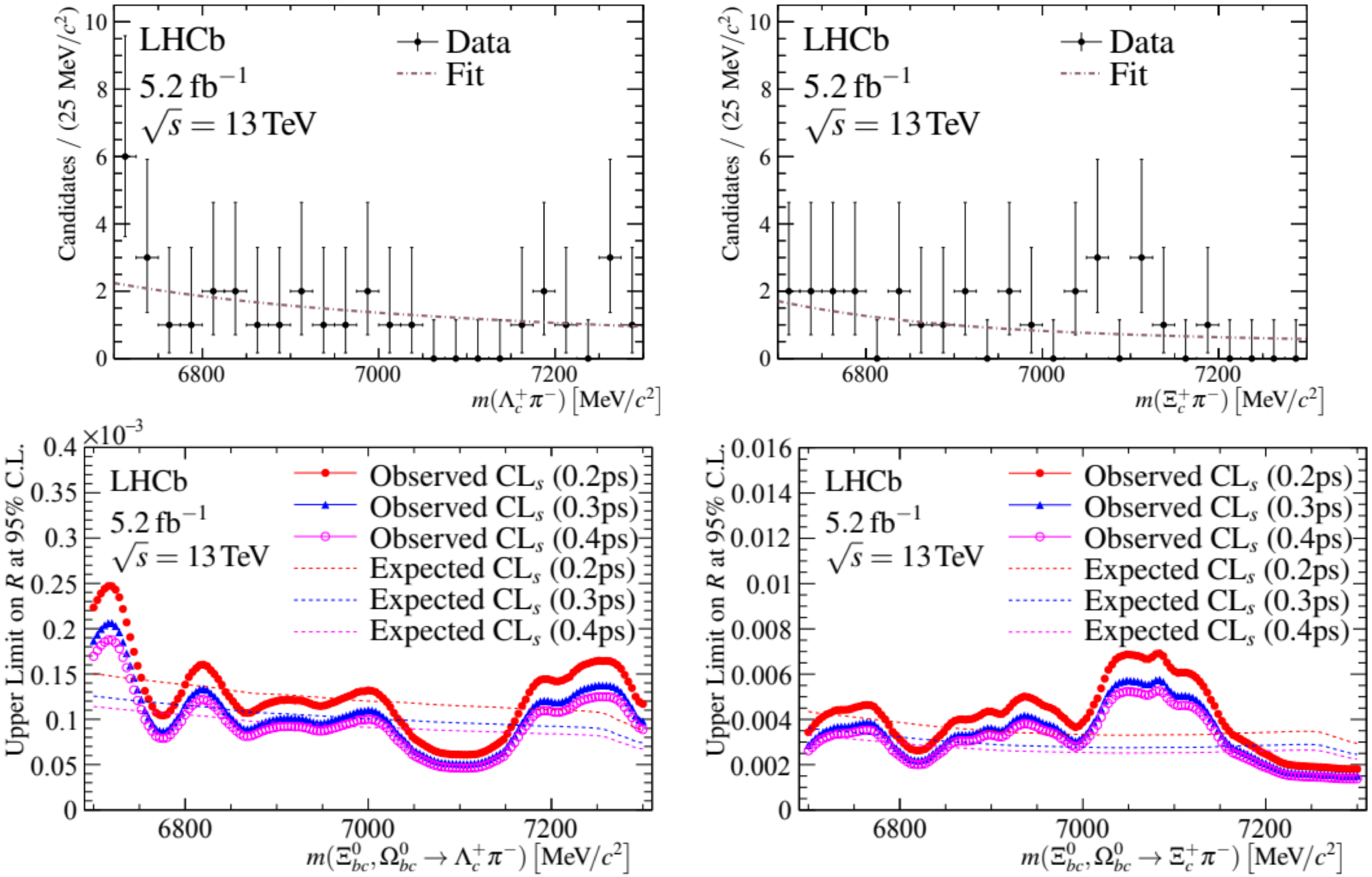
$$R(\Lambda_c^+\pi^-) = \frac{\sigma(\mathrm{H}_{bc}^0)\mathcal{B}(\mathrm{H}_{bc}^0\to\Lambda_c^+\pi^-)}{\sigma(\Lambda_b^0)\mathcal{B}(\Lambda_b^0\to\Lambda_c^+\pi^-)},\quad R(\Xi_c^+\pi^-) = \frac{\sigma(\mathrm{H}_{bc}^0)\mathcal{B}(\mathrm{H}_{bc}^0\to\Xi_c^+\pi^-)}{\sigma(\Xi_b^0)\mathcal{B}(\Xi_b^0\to\Xi_c^+\pi^-)}$$

Search for Ξ_{bc}^0/Ω_{bc}^0

ARXIV:2104.04759

$\sqrt{s} = 13$ TeV $\int Ldt \sim 5.2$ fb^{-1}

- No signal excess is seen, set upper limits on R at 95% confidence level under different mass ($6.7{\sim}7.3\ \mathrm{GeV}/c^2$) and lifetime ($0.2{\sim}0.4$ ps) hypotheses



fiducial region:

$2.0 < y < 4.5$

$2 < p_T < 25\ \mathrm{GeV}/c$

$R(\Lambda_c^+\pi^-)$:

$0.5\times10^{-4}{\sim}2.4\times10^{-4}$

$R(\Xi_c^+\pi^-)$:

$1.4\times10^{-3}{\sim}6.9\times10^{-3}$

Summary

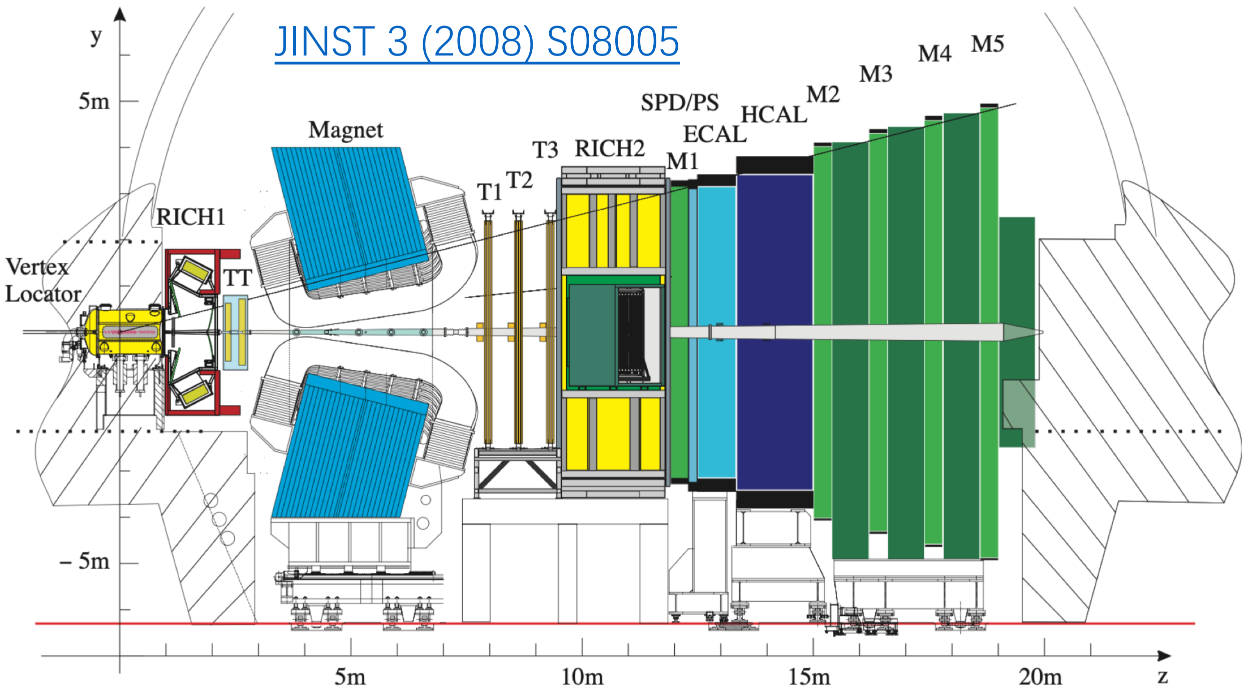
- LHCb has made great progress on studies of the b-hadrons & quarkonia
  - First $\eta_c(1S)$ production measurement @13 TeV, agree with theory
  - First search for doubly heavy baryons Ξ_{bc}^0/Ω_{bc}^0 , upper limit set
  - Observation of prompt production narrow $X(3842) \to D\bar{D}$ state, consistent with spin-3 $\psi_3(1^3D_3)$ charmonium
  - Observation of excited Ω_b^{**-}, $\Lambda_b(2S)^0$, $\Xi_b(6227)^0$, B_s^{**0} states…
  - Observation of new decay: $B^0 \to D^0\bar{D}^0K^+\pi^-$, $B_s^0 \to K^-\mu^+\nu_\mu$, $\Lambda_b^0 \to \chi_{c1}p\pi^-$, $\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-$
- More results can be found in [LHCb-publications]
- Upgrades I/II approaching $\int Ldt \sim 50/300\ \mathrm{fb}^{-1}$

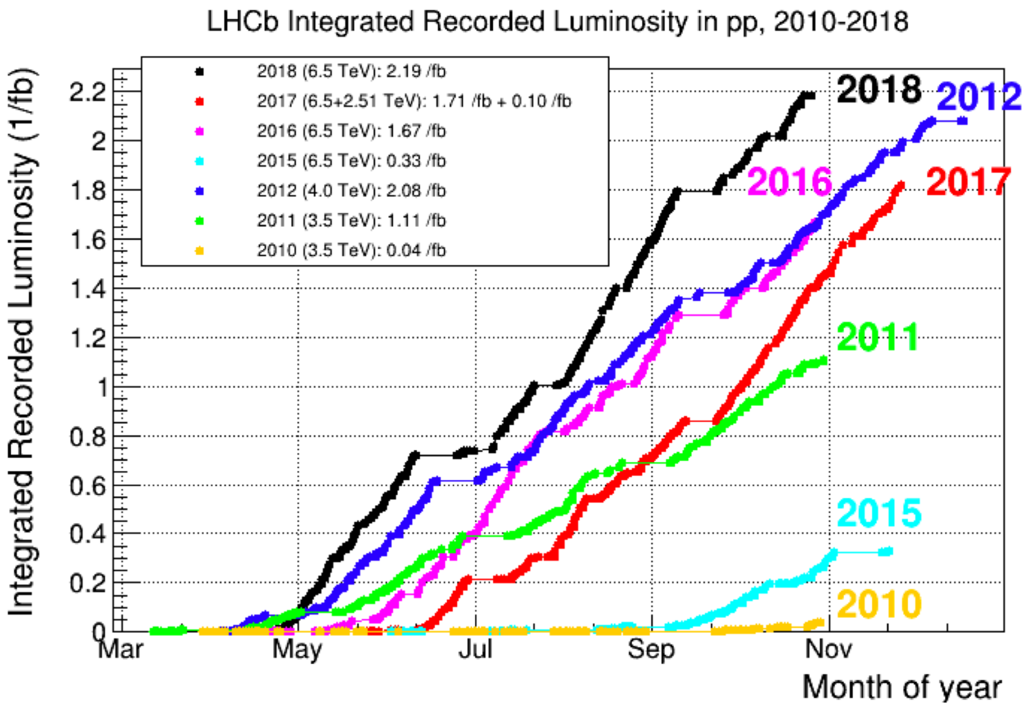
Thanks !

Backup

The LHCb detector and data-taking

- Acceptance $2 < \eta < 5$, with excellent vertexing, tracking, PID





- Run1 (2011-2012): $1\ \mathrm{fb}^{-1} @ \sqrt{s} = 7\ \mathrm{TeV},\ 2\ \mathrm{fb}^{-1} @ \sqrt{s} = 8\ \mathrm{TeV}$
- Run2 (2011-2012): $5.9\ \mathrm{fb}^{-1} @ \sqrt{s} = 13\ \mathrm{TeV}$

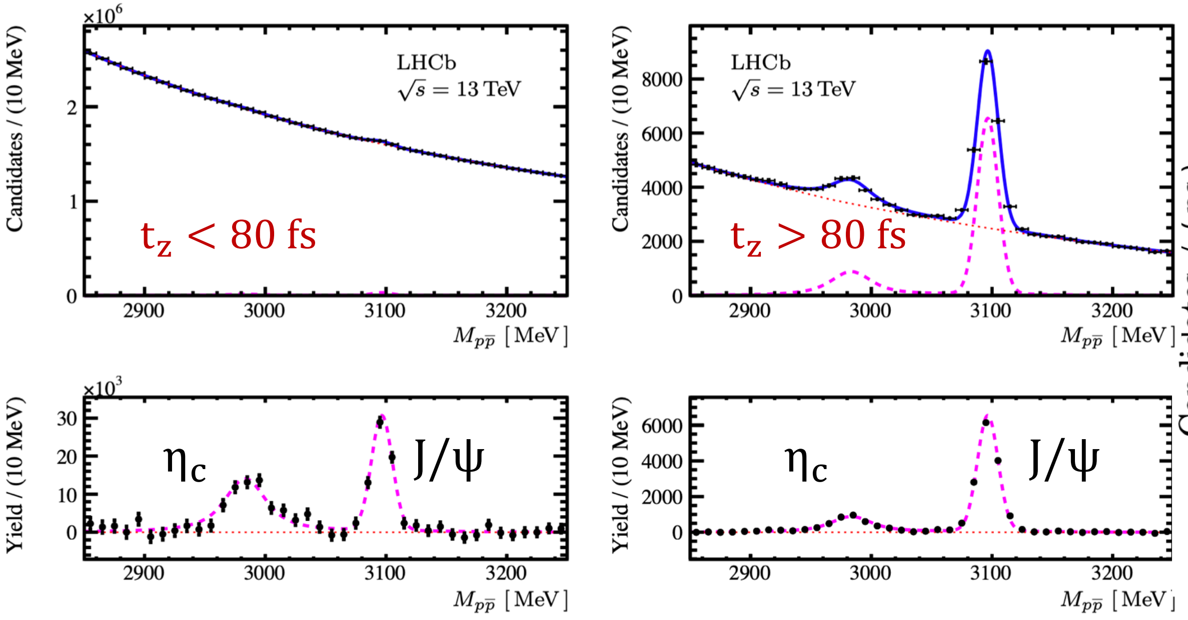
$\eta_c(1S)$ production at 13 TeV

EUR. PHYS. J. C80 (2020) 191

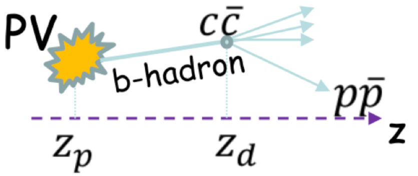
$\sqrt{s} = 13$ TeV $\int Ldt \sim 2$ fb^{-1}

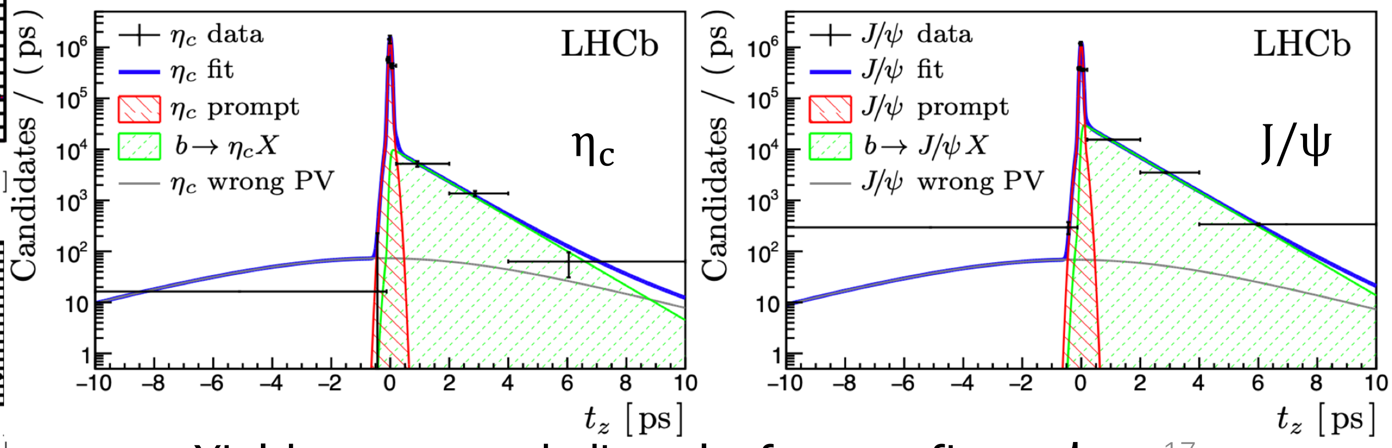
EUR. PHYS. J. C75 (2015) 311

- First $\eta_c(1S)$ prompt production measurement at 7,8 TeV, using $\eta_c(1S) \rightarrow p\bar{p}$
  - Colour-singlet leading order works well, below expected colour-octet contribution
  - Impressive progress in theory description, integrating LHCb result in calculations
- New analysis with 13 TeV data, measurement relative to J/ψ
  - Selection (as analysis with 7, 8 TeV) or pseudo-lifetime fit to separate prompt charmonium and charmonium from b-decays, consistent results



$$t_z = \frac{\Delta z \cdot M_{p\bar{p}}}{p_z}$$





Yields extracted directly from a fit to t_z

$\eta_c(1S)$ production at 13 TeV

EUR. PHYS. J. C80 (2020) 191

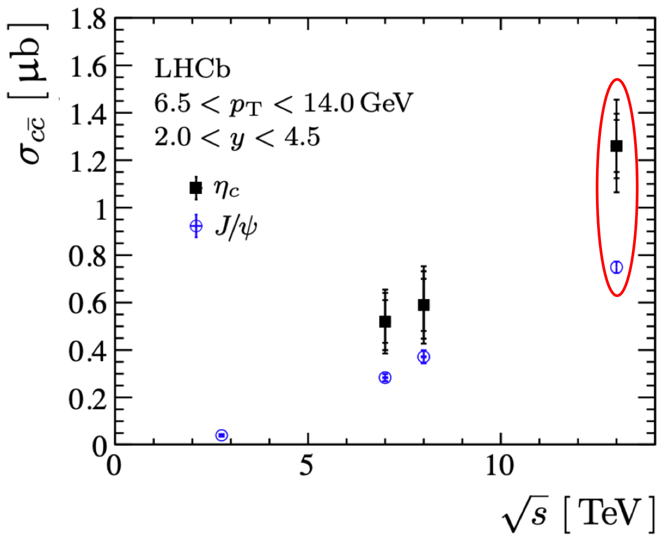
$\sqrt{s} = 13$ TeV $\int Ldt \sim 2\ \mathrm{fb}^{-1}$

- First $\eta_c(1S)$ production measurement at 13 TeV

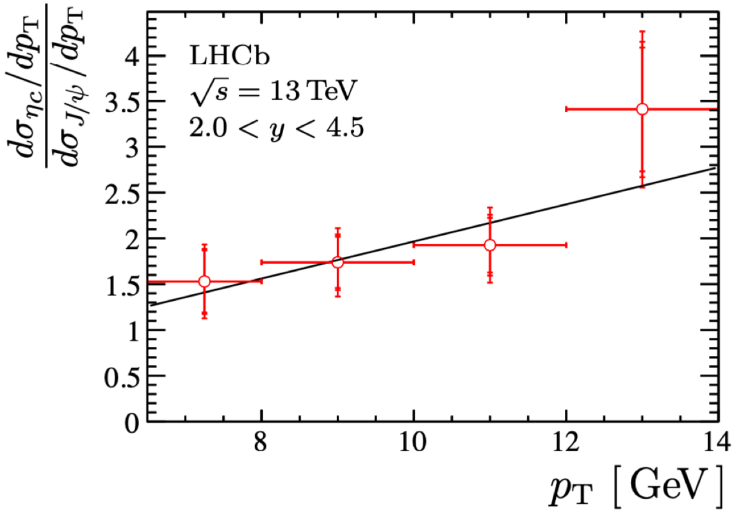
$$\left(\sigma_{\eta_c}^{\mathrm{prompt}}\right)_{13\,\mathrm{TeV}}^{6.5<p_T<14.0\,\mathrm{GeV},\,2.0<y<4.5} = 1.26 \pm 0.11 \pm 0.08 \pm 0.14\ \mu\mathrm{b}$$

  - Consistent with colour-singlet model prediction: $\sigma_{\eta_c} = 1.56^{+0.83+0.38}_{-0.49-0.17}$ NPB 945 (2019) 114662

✧ $\sqrt{s}$ cross-section dependence

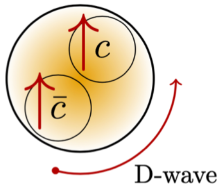


✧ p_T - differential prompt production



- Inclusive production in b-decays: $\mathcal{B}_{b\to\eta_c X} = (5.51 \pm 0.32 \pm 0.29 \pm 0.77) \times 10^{-3}$
  - Consistent and more precise than previous result

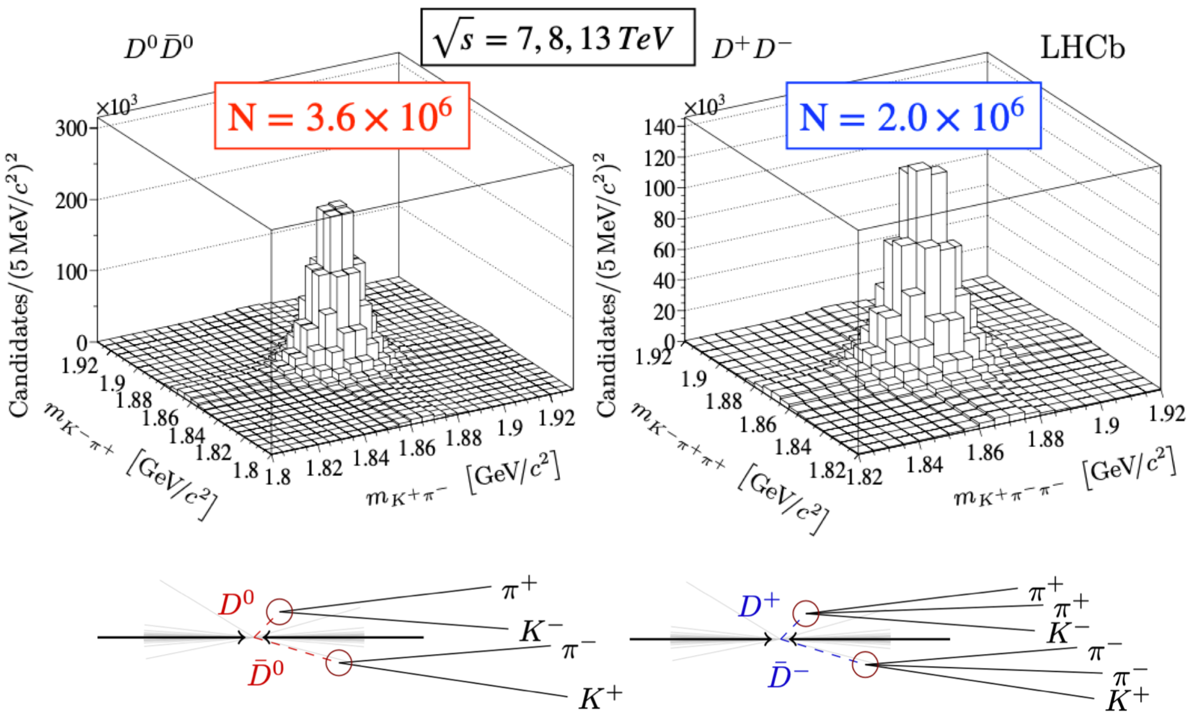
Observation of X(3842)

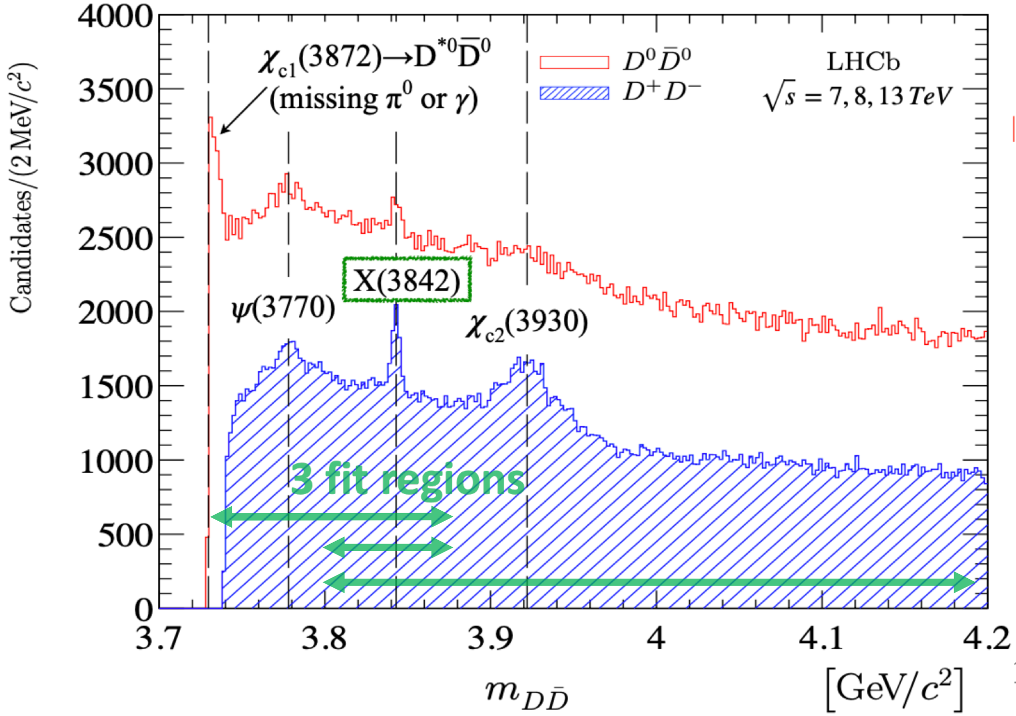


JHEP 07 (2019) 035

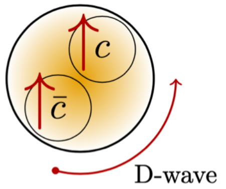
$\sqrt{s} = 7, 8, 13$ TeV $\int Ldt \sim 9\ \text{fb}^{-1}$

- Promptly production selection criteria, validate with pseudo-lifetime fit
- 80−90% purity in the D-meson mass window: ± 20 MeV of PDG value
- To improve $\mathrm{D\bar{D}}$ resolution: D-meson mass constrained to the known values
- Fits in three different mass region





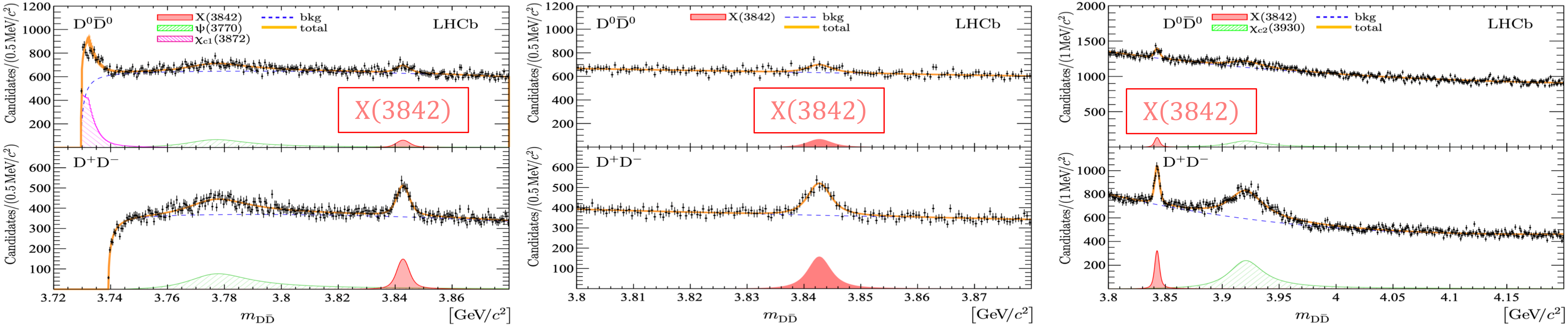
Observation of X(3842)



JHEP 07 (2019) 035

$\sqrt{s} = 7, 8, 13$ TeV $\int Ldt \sim 9$ fb^{-1}

- Simultaneous fit for $D\bar{D}$ candidates

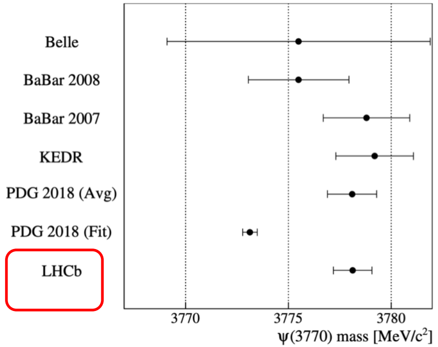


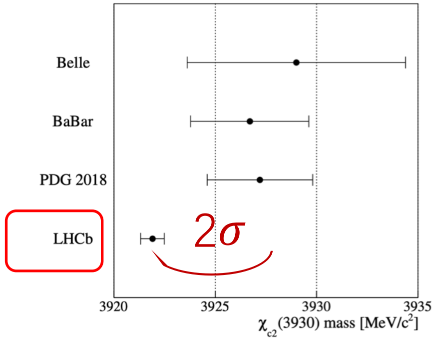
- Observation of X(3842) - new narrow charmonium state with measured parameters:

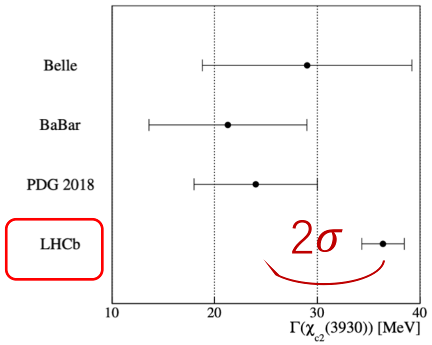
$$m_{X(3842)} = 3842.71 \pm 0.16 \pm 0.12\,\mathrm{MeV}/c^2\,, \quad \Gamma_{X(3842)} = 2.79 \pm 0.51 \pm 0.35\,\mathrm{MeV}\,,$$

- Mass and width are compatible with $\psi_3(1^3D_3)$ $\{n^{2s+1}\ell_J\}$ charmonium with $J^{PC} = 3^{--}$
- Prompt hadroproduction of the $\psi(3770)$ and $\chi_{c2}(3930)$ states are observed for the first time:

$$m_{\psi(3770)} = 3778.1 \pm 0.7 \pm 0.6\,\mathrm{MeV}/c^2 \quad m_{\chi_{c2}(3930)} = 3921.9 \pm 0.6 \pm 0.2\,\mathrm{MeV}/c^2 \quad \Gamma_{\chi_{c2}(3930)} = 36.6 \pm 1.9 \pm 0.9\,\mathrm{MeV}$$







PHYS. REV. LETT. 124 (2020) 082002

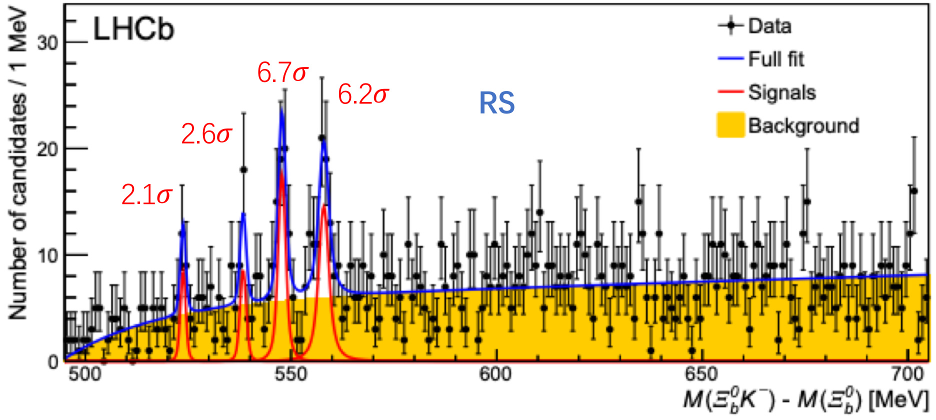
$\sqrt{s} = 7, 8, 13$ TeV $\int Ldt \sim 9\ \text{fb}^{-1}$

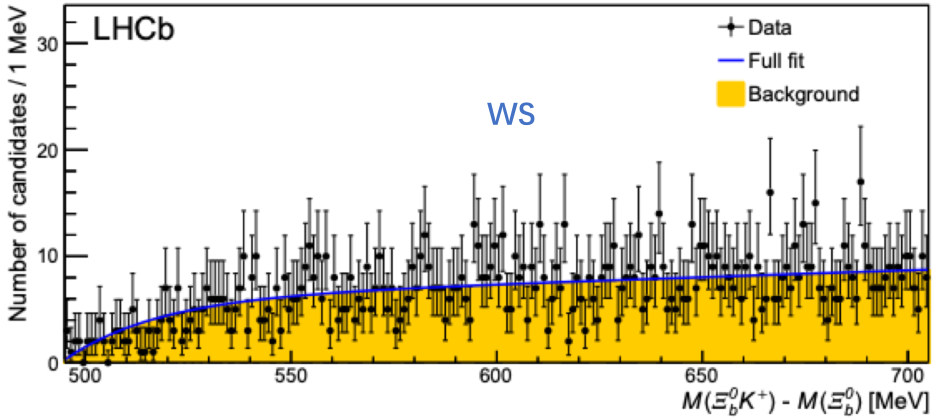
Excited Ω_b^- states

- Search for $\Omega_b^{**-} \to \Xi_b^0 K^-$ ($\Xi_b^0 \to \Xi_c^+\pi^-, \Xi_c^+ \to pK^+\pi^-$)
- Selection based on topology and PID, BDT further suppress background
- Simultaneous fit wrong-sign (WS) and right-sign (RS) spectra with shared background shape, 4 narrow peaks seen
- Signal shape: S-wave relativistic Breit-Wigner convoluted with Gaussian resolution function
- Possible interpretations:

➢ Excited Ω_b^- with L=1 angular momentum excitations or n=2 radial excitations

➢ Decay of higher mass excited state: $\Omega_b^{**-} \to \Xi_b'^0(\to \Xi_b^0\pi^0)K^-$, missing π^0





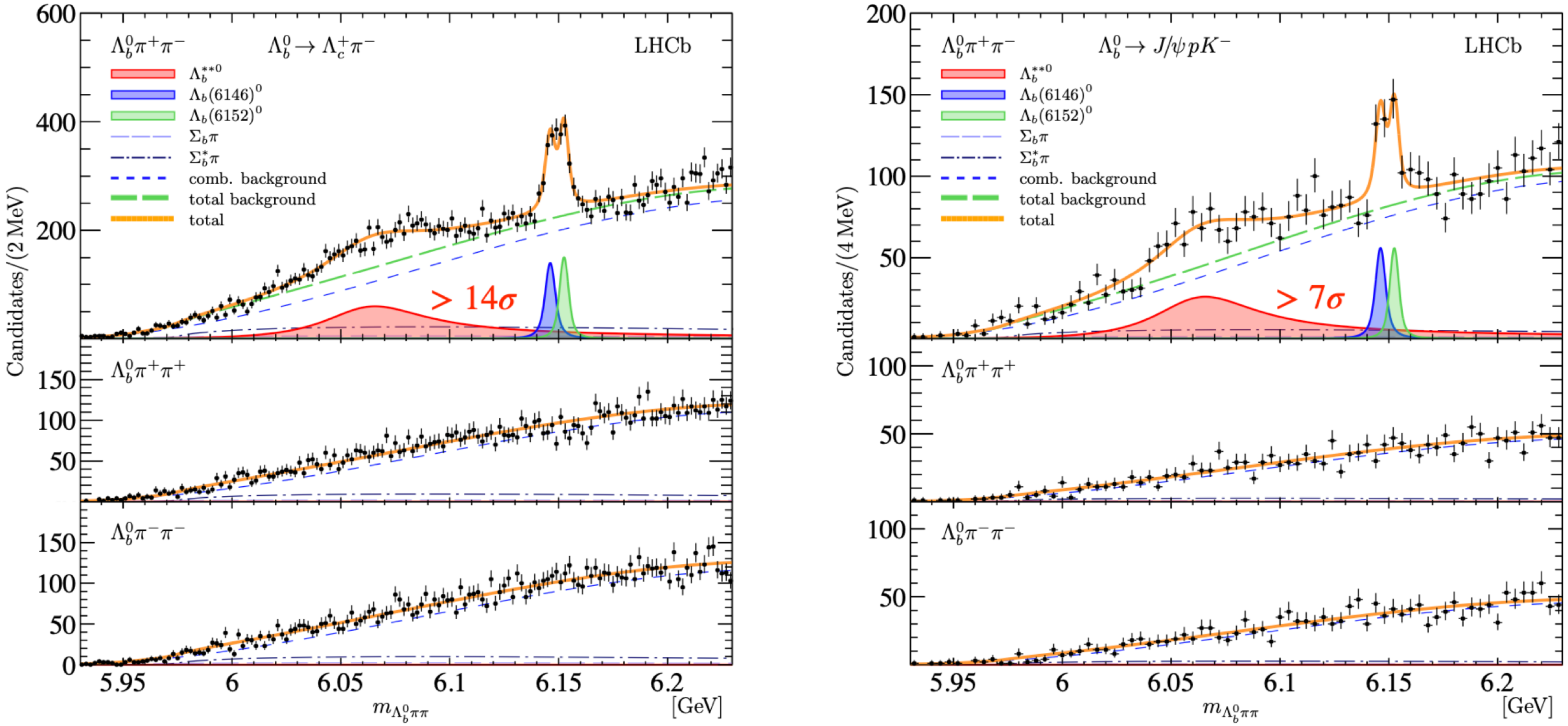
	$\delta M_{\rm peak}$ [MeV]	Mass [MeV]	Width [MeV]
$\Omega_b(6316)^-$	$523.74 \pm 0.31 \pm 0.07$	$6315.64 \pm 0.31 \pm 0.07 \pm 0.50$	$< 2.8\ (4.2)$
$\Omega_b(6330)^-$	$538.40 \pm 0.28 \pm 0.07$	$6330.30 \pm 0.28 \pm 0.07 \pm 0.50$	$< 3.1\ (4.7)$
$\Omega_b(6340)^-$	$547.81 \pm 0.26 \pm 0.05$	$6339.71 \pm 0.26 \pm 0.05 \pm 0.50$	$< 1.5\ (1.8)$
$\Omega_b(6350)^-$	$557.98 \pm 0.35 \pm 0.05$	$6349.88 \pm 0.35 \pm 0.05 \pm 0.50$	$< 2.8\ (3.2)$
			$1.4\,^{+1.0}_{-0.8} \pm 0.1$

Excited Λ_b^0 state

JHEP 06 (2020) 136

$\sqrt{s} = 7, 8, 13$ TeV $\int Ldt \sim 9$ fb^{-1}

- Reconstruction: $\Lambda_b^{**0} \to \Lambda_b^0 \pi^+ \pi^-$, with $\Lambda_b^0 \to \Lambda_c^+ \pi^-$ and $\Lambda_b^0 \to J/\psi p K^-$
- Simultaneous fit both $\Lambda_b^0 (\to \Lambda_c^+ \pi^-) \pi^+ \pi^-$ and $\Lambda_b^0 (\to J/\psi p K^-) \pi^+ \pi^-$
- Broad structure seen in addition to known narrow peaks
- Mass and width are in agreement with $\Lambda_b(2S)^0$ PRD 84 (2011) 014025, PRD 98 (2018) 074032, Chin.Phys.C 38 (2014) 113101…



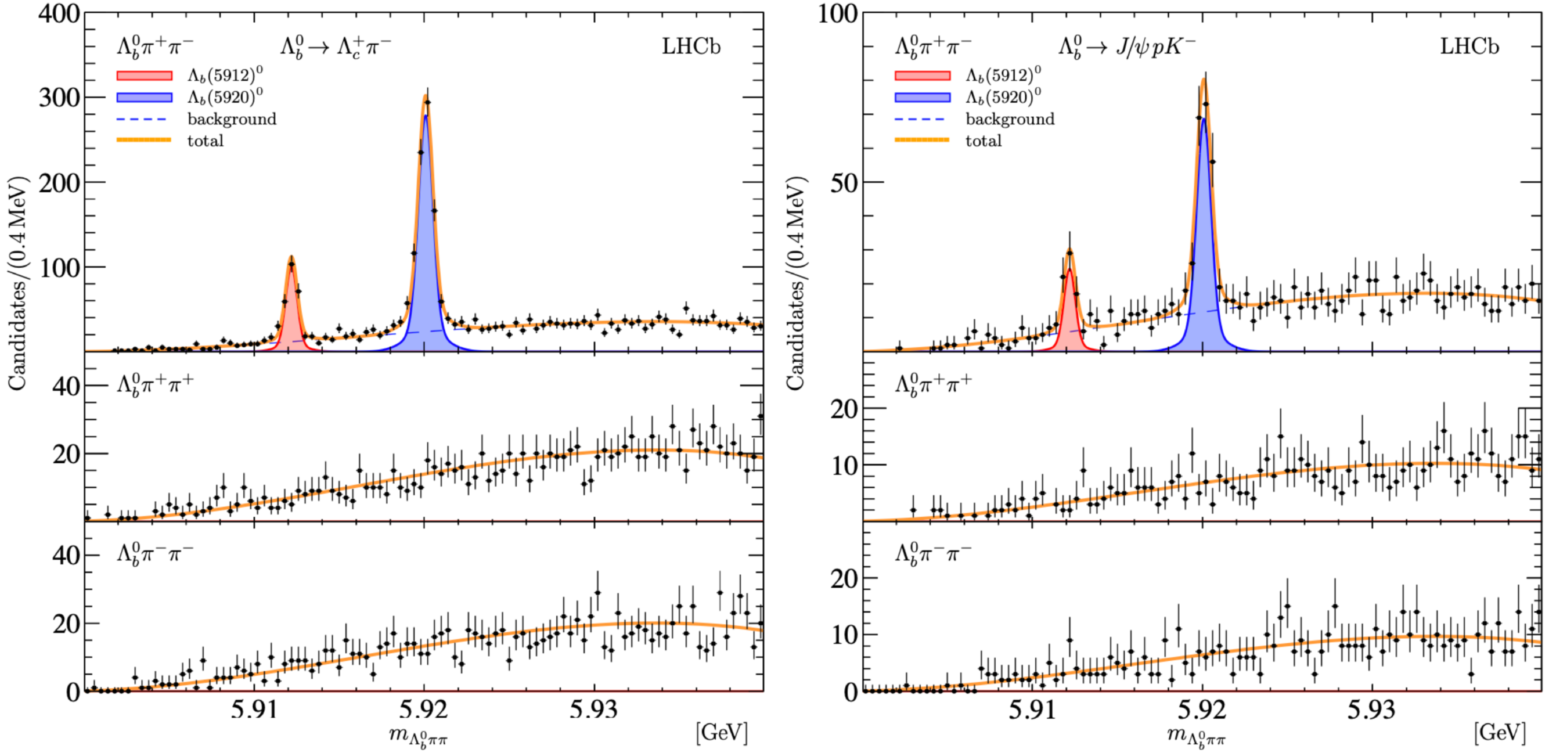
$$M_{\Lambda_b^{**0}} = 6072.3 \pm 2.9 \pm 0.6 \pm 0.2 \text{ MeV}$$
$$\Gamma_{\Lambda_b^{**0}} = 72 \pm 11 \pm 2 \text{ MeV}$$

Excited Λ_b^0 state

JHEP 06 (2020) 136

$\sqrt{s} = 7, 8, 13$ TeV $\int Ldt \sim 9\ \text{fb}^{-1}$

- Update of the masses and widths measurements of low mass states
  - 4 times more precise than first observation PRL 109 (2012) 172003
- Simultaneous fit both $\Lambda_b^0(\rightarrow \Lambda_c^+\pi^-)\pi^+\pi^-$ and $\Lambda_b^0(\rightarrow J/\psi p K^-)\pi^+\pi^-$



$$M_{\Lambda_b(5912)^0} = 5912.21 \pm 0.03 \pm 0.01 \pm 0.21\ \text{MeV}, \Gamma_{\Lambda_b(5912)^0} < 0.28\ \text{MeV (95\% CL)}$$
$$M_{\Lambda_b(5920)^0} = 5920.11 \pm 0.02 \pm 0.01 \pm 0.21\ \text{MeV}, \Gamma_{\Lambda_b(5920)^0} < 0.20\ \text{MeV (95\% CL)}$$