Bottom meson and baryon spectroscopy

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on behalf of the ATLAS, CMS and LHCb collaborations

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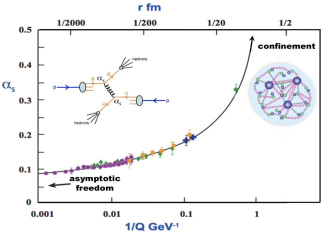
Outline

- b-hadrons at the LHC
- Observation of new excited B_s^0 states
  [arXiv:2010.15931]
- Observation of $\Xi_b(6227)^0$ and $\Xi_b(6100)^-$
  [Phys.Rev.D 103 (2021) 1, 012004], **[arXiv:2102.04524]**
- B_c^+ meson spectroscopy results
- Search for Ω_{bc}^0 and Ξ_{bc}^0 doubly heavy baryons
  [arXiv:2104.04759]

Motivations

- $\mathcal{L}_{\text{QCD}}$ is in principle expected to fully describe the spectrum and properties of hadrons

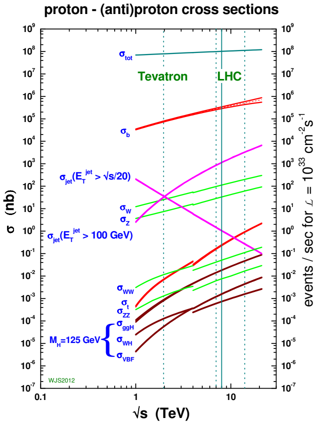


- the non-perturbative evolution of α_s does not allow to compute such predictions
- no confinement theorem exists to explain from first principles why and how quarks (and gluons?) bind together to form color-singlets

- lattice QCD simulations $\Rightarrow$ spectrum and properties of ground state hadrons
- QCD-inspired phenomenological models $\Rightarrow$ spectrum and decay properties of excited hadrons but with large model uncertainties
- experimental measurements $\Rightarrow$ crucial inputs to understand the **ways in which QCD forms bound states and about their internal structure**
- **many flavour physics observables are limited by hadron-related theoretical uncertainties**, either entering in measurements directly involving hadrons in the initial/final states or in hadronic contributions in loops

b-hadron production at the LHC

- all types of *b*-hadrons (and their excitations) can be produced at the LHC: $B^0 = |\bar{b}d\rangle$, $B^+ = |\bar{b}u\rangle$, $B^0_s = |\bar{b}s\rangle$, $B^+_c = |\bar{b}c\rangle$, $\Lambda^0_b = |udb\rangle$, $\Xi^-_b = |dsb\rangle$ ...
- $\sigma(pp \to b\bar{b}X) = 72.0 \pm 0.3 \pm 6.8\,\mu\mathrm{b}$ at 7 TeV in the forward region
  $\Rightarrow\sim$ **30*k* $b\bar{b}/s$ inside LHCb**
- $\sigma(pp \to b\bar{b}X) = 154.3 \pm 1.5 \pm 14.3\,\mu\mathrm{b}$ at 13 TeV in the forward region
  $\Rightarrow\sim$ **60*k* $b\bar{b}/s$ inside LHCb**
  [Phys.Rev.Lett. 118, 052002]
- ATLAS and CMS ran at larger luminosity and have larger geometrical acceptance
  $\Rightarrow\sim$ **40x $b\bar{b}/s$ inside ATLAS and CMS**



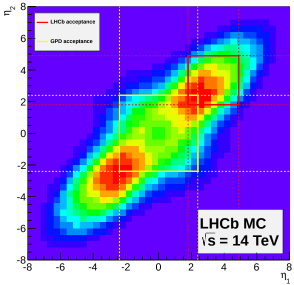
[W.J. Stirling, private communication]

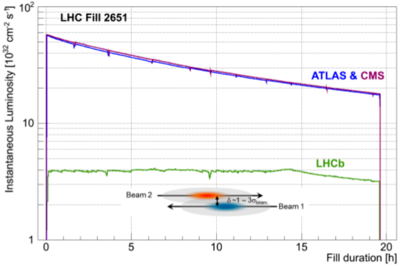
Unprecedented $b\bar{b}$ sample delivered by the LHC

The ATLAS, CMS and LHCb experiments

- complementary in *b*-hadron acceptance
- ATLAS and CMS cover high-p_T and $|\eta| < 2.4$
  $\Rightarrow\sim$ **40% of $b\bar{b}$ pairs inside acceptance at 14 TeV**
- LHCb covers low-p_T and $1.8 < \eta < 4.9$
  $\Rightarrow\sim$ **25% of $b\bar{b}$ pairs inside acceptance at 14 TeV**
- LHCb ran at $\mathcal{L} = 4 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ levelled luminosity to **optimise the triggering and reconstruction of *b*- and *c*-hadrons**
- ATLAS and CMS ran at about 25x instantaneous luminosity

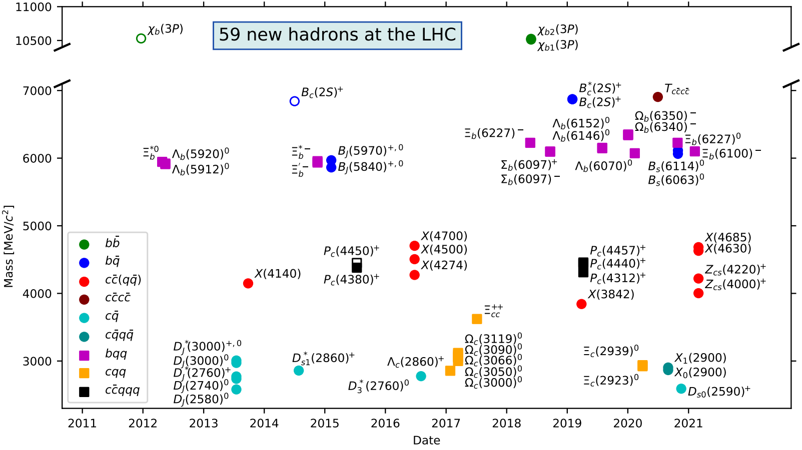
$\bar{b}b$ production angle plots





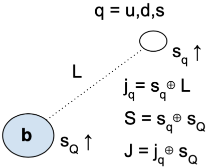
59 new hadrons at the LHC

[LHCb-FIGURE-2021-001]



... and many mass, lifetime, branching ratios and production measurements

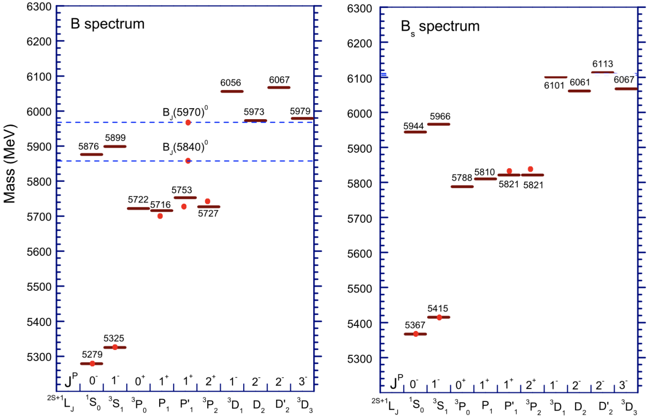
$B_{(s)J}$ spectroscopy



Status of $B_{(s)J}$ spectroscopy

[arXiv:2102.03694]

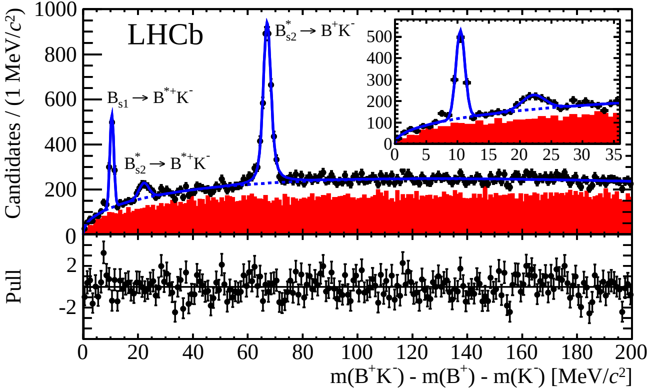
- significant progress since 2007 thanks to CDF, D0 and LHCb experiments
- still difficult to predict precise masses, widths and branching ratios of such states



Observation of new excited B_s states

[arXiv:2010.15931]

- study the high-mass B^+K^- region as an extension to the full LHCb $9\,\mathrm{fb}^{-1}$ dataset of [Phys.Rev.Lett. 110 (2013) 15, 151803] where the decay $B_{s2}^*(5840)^0 \to B^{*+}K^-$ was first observed favouring the $J^P = 2^+$ assignment



- $B_{s2}^*(5840)^0$ also observed to decay to the $B^0K_S^0$ final state by CMS [Eur. Phys. J. C 78 (2018) 939]

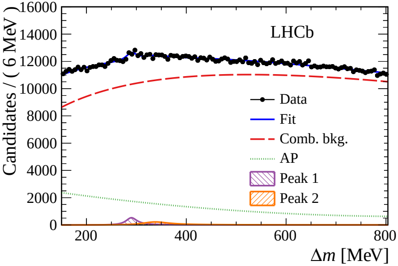
Observation of new excited B_s states

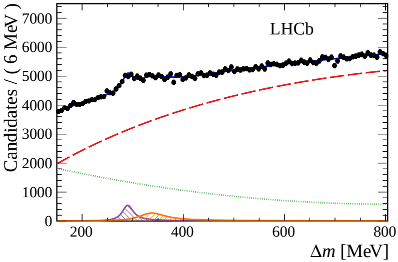
[arXiv:2010.15931]

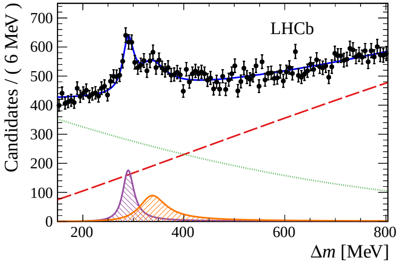
- $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ and $B^+ \to \bar{D}^0(K^+\pi^-)\pi^+$ candidates with topological, kinematical and particle identification requirements to obtain a purity $> 90\%$
- combine B^+ with a K^- consistent with being produced from the primary vertex (PV) with **tight particle identification requirements**
- same-sign B^+K^+ pairs to study combinatorial background shape
- kinematic fit with B^+ and J/ψ ($\bar{D}^0$) mass constraints and requiring the B^+ candidate to originate from the PV
- $p_T(K^-)$ as the strongest discriminant variable between resonant signals and background $\Rightarrow$ simultaneous fit in $0.5 < p_T < 1$ GeV, $1 < p_T < 2$ GeV and $p_T > 2$ GeV bins

Observation of new excited B_s states

[arXiv:2010.15931]







- B_s^{**0} signals described by two **not-interfering** relativistic Breit-Wigners convoluted with resolution functions determined from simulation
- 20σ local significance for one-peak hypothesis, **7.7σ for two peaks vs one peak hypothesis**

Observation of new excited B_s states

[arXiv:2010.15931]

$B_s^{**0} \to B^+ K^-$

$$m_1 = 6063.5 \pm 1.2\ (\text{stat}) \pm 0.8\ (\text{syst})\,\text{MeV},$$
$$\Gamma_1 = 26 \pm 4\ (\text{stat}) \pm 4\ (\text{syst})\,\text{MeV},$$
$$m_2 = 6114 \pm 3\ (\text{stat}) \pm 5\ (\text{syst})\,\text{MeV},$$
$$\Gamma_2 = 66 \pm 18\ (\text{stat}) \pm 21\ (\text{syst})\,\text{MeV},$$
$$f_1 = 0.47 \pm 0.11\ (\text{stat}) \pm 0.15\ (\text{syst}),$$

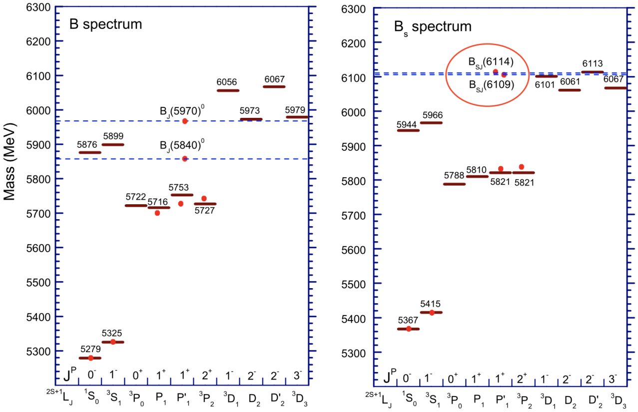
$B_s^{**0} \to B^{*+} K^- \to B^+ K^-$ with not-reconstructed γ

$$m_1 = 6108.8 \pm 1.1\ (\text{stat}) \pm 0.7\ (\text{syst})\,\text{MeV},$$
$$\Gamma_1 = 22 \pm 5\ (\text{stat}) \pm 4\ (\text{syst})\,\text{MeV},$$
$$m_2 = 6158 \pm 4\ (\text{stat}) \pm 5\ (\text{syst})\,\text{MeV},$$
$$\Gamma_2 = 72 \pm 18\ (\text{stat.}) \pm 25\ (\text{syst})\,\text{MeV},$$
$$f_1 = 0.42 \pm 0.11\ (\text{stat}) \pm 0.16\ (\text{syst}).$$

- single state decaying to both $B^+ K^-$ and $B^{*+} K^-$ channels is disfavoured but could not be excluded with the current data
- production ratio relative to the B_{s2}^{*0} only using $B^+ \to J/\psi K^+$ and requiring J/ψ triggers: $R = 0.87 \pm 0.15(\text{stat}) \pm 0.19(\text{syst})$

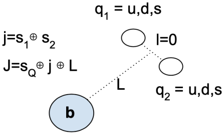
Interpretation of the new excited B_s states

[arXiv:2010.15931], [arXiv:2102.03694]



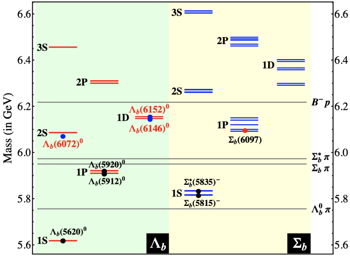
Consistent with $L = 2$ orbitally excited B_s mesons

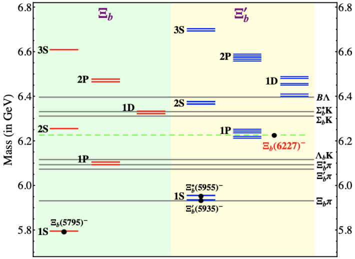
$|bqq'\rangle$ baryons spectroscopy

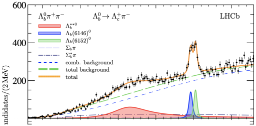


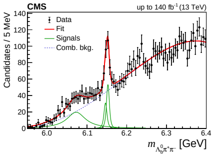
Status of *b*-baryons spectroscopy

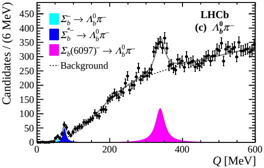
[Phys.Rev.D 98 (2018) 3, 031502], [JHEP 06 (2020) 136], [Phys.Lett.B 803 (2020) 135345], [Phys.Rev.Lett. 122 (2019) 012001], [Phys.Rev.Lett. 121 (2018) 7, 072002]

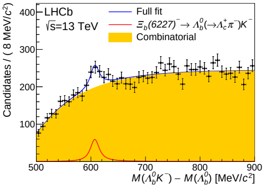








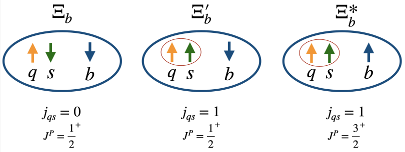




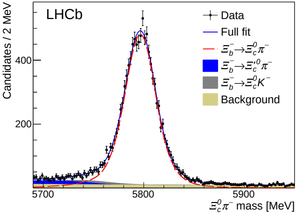
Observation of a new Ξ_b^0 state

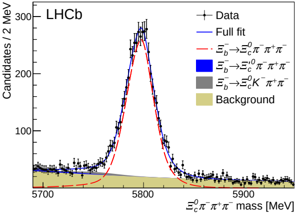
[Phys.Rev.D 103 (2021) 1, 012004]

- $\Xi_b^0 = |bsu\rangle$ and $\Xi_b^- = |bsd\rangle$ form three ground-state isodoublets



- a spectrum of either spatially or orbitally excited states is expected
- $8.5\,\mathrm{fb}^{-1}$ of *pp* collision data collected by the LHCb detector
- ground state Ξ_b^- reconstructed via its decays to $\Xi_c^0\pi^-$ and $\Xi_c^0\pi^-\pi^+\pi^-$ with $\Xi_c^0 \to pK^-K^-\pi^+$

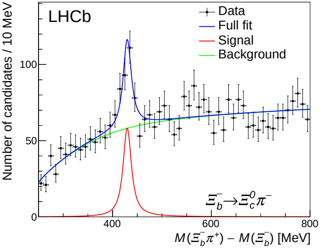


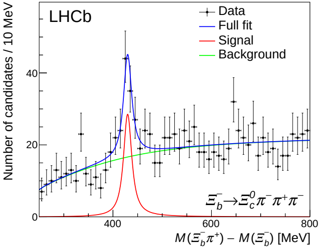


Observation of a new Ξ_b^0 state

[Phys.Rev.D 103 (2021) 1, 012004]

P-wave relativistic Breit-Wigner signal function





Improved mass and width precision of the charged isospin partner using $\Lambda_b^0 K^-$

$$\delta m_\pi^{\text{peak}} = 429.8\,^{+1.4}_{-1.5} \pm 0.3\,\text{MeV},$$
$$m(\Xi_b(6227)^0) = 6227.1\,^{+1.4}_{-1.5} \pm 0.5\,\text{MeV},$$
$$\Gamma(\Xi_b(6227)^0) = 18.6\,^{+5.0}_{-4.1} \pm 1.4\,\text{MeV},$$

$$\delta m_K^{\text{peak}} = 608.3 \pm 0.8 \pm 0.4\,\text{MeV},$$
$$m(\Xi_b(6227)^-) = 6227.9 \pm 0.8 \pm 0.5\,\text{MeV},$$
$$\Gamma(\Xi_b(6227)^-) = 19.9 \pm 2.1 \pm 1.5\,\text{MeV},$$

Production rate and most precise measurement of Ξ_b^- mass to date

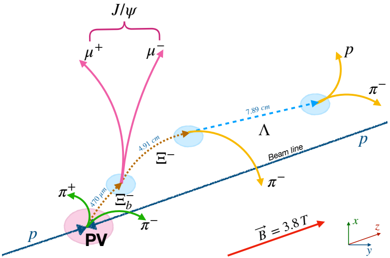
$$R(\Xi_b^- \pi^+) \equiv \frac{f_{\Xi_b(6227)^0}}{f_{\Xi_b^-}} \mathcal{B}(\Xi_b(6227)^0 \to \Xi_b^- \pi^+) = 0.045 \pm 0.008 \pm 0.004.$$

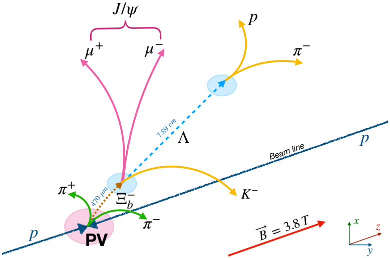
$$m(\Xi_b^-) = 5797.33 \pm 0.24 \pm 0.29\,\text{MeV}$$

Observation of a new excited beauty strange baryon decaying to $\Xi_b^- \pi^+ \pi^-$

[arXiv:2102.04524]

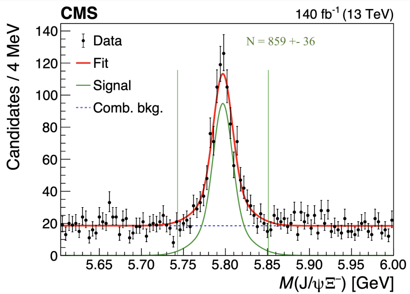
- $140\,\mathrm{fb}^{-1}$ of pp collision data collected at $\sqrt{s} = 13\,\mathrm{TeV}$ by the CMS detector
- ground state Ξ_b^- reconstructed via its decays to $J/\psi\Xi^-$ and $J/\psi\Lambda K^-$, the latter including the partially reconstructed $\Xi_b^- \to J/\psi\Sigma^0 K^-$ channel as in [Phys.Lett.B 772 (2017) 265-273]
- combine Ξ_b^- candidates with two opposite-sign tracks originating from the primary vertex refitting all the tracks to a common vertex

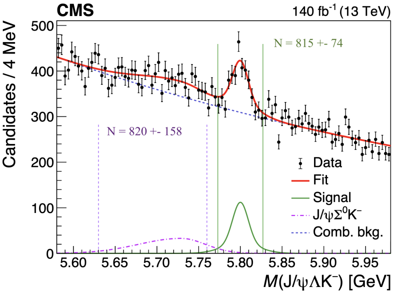




Observation of a new excited beauty strange baryon decaying to $\Xi_b^- \pi^+ \pi^-$

[arXiv:2102.04524]





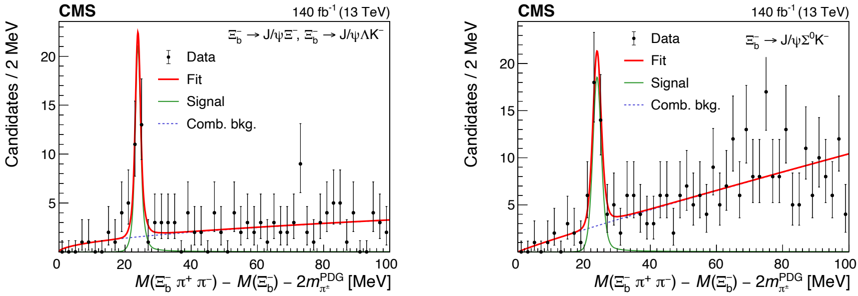
- use $\Delta M = M(\Xi_b^- \pi^+ \pi^-) - M(\Xi_b^-) - 2m_{\pi^\pm}^{\mathrm{PDG}}$ to achieve a better mass resolution and insensitive to the mass shift caused by the not-reconstructed photon in $\Sigma^0 \to \Lambda\gamma$ decays

- expect dominant $\Xi_b^{**-} \to \Xi_b^{*0}(\to \Xi_b^- \pi^+)\pi^-$ decay chain $\Rightarrow$ further require $M(\Xi_b^- \pi^+) - M(\Xi_b^-) - m_{\pi^+}^{\mathrm{PDG}} < 20.73$ MeV

Observation of a new excited beauty strange baryon decaying to $\Xi_b^- \pi^+ \pi^-$

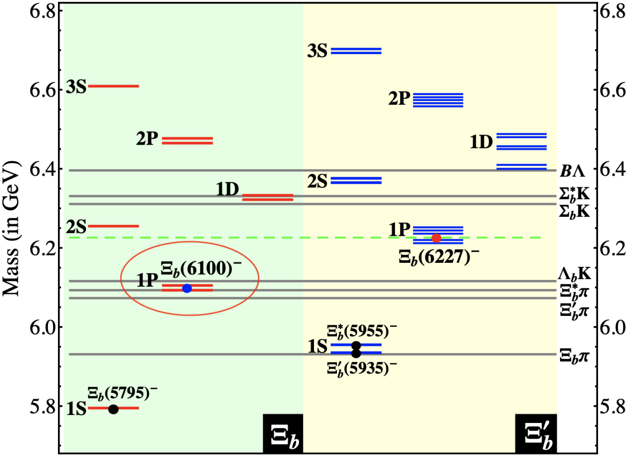
[arXiv:2102.04524]

- simultaneous unbinned extended maximum-likelihood fit on the fully and partially reconstructed data samples
- signal: relativistic Breit-Wigner convoluted with a double-Gaussian resolution function; background: threshold function
- $\Delta M_{\Xi_b(6100)^-} = 24.14 \pm 0.22(\text{stat}) \pm 0.05(\text{syst})$ MeV
  $\Rightarrow \boldsymbol{M(\Xi_b(6100)^-) = 6100.3 \pm 0.2(\text{stat}) \pm 0.1(\text{syst}) \pm 0.6(m_{\Xi_b^-})}$ **MeV**
- $\Gamma_{\Xi_b(6100)^-} < 1.9$ MeV at 95% confidence level



Interpretation of the $\Xi_b(6100)^-$ baryon

[arXiv:2102.04524], [Phys.Rev.D 98 (2018) 3, 031502]

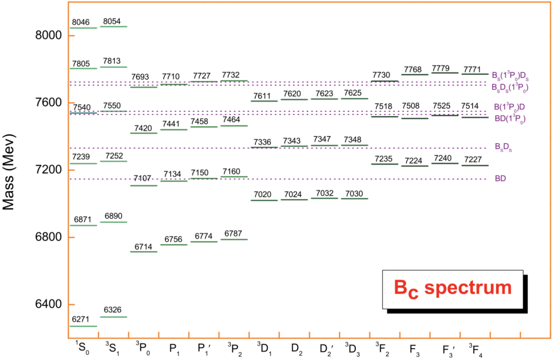


Consistent to belong to the $L = 1, j_q = 1, J^P = 3/2^-$ multiplet

B_c^+ spectroscopy

B_c^+ meson spectroscopy

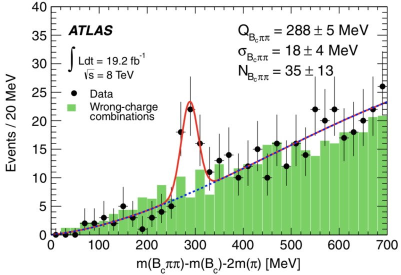
- the B_c^+ mesons are intermediate between charmonium and bottomonium states both in mass and size
- however, the **heavy-quark dynamics is richer** than $c\bar{c}$ and $b\bar{b}$ states and the examination of the B_c^+ spectrum may reveal where approximations used for quarkonium states break down
- both $c\bar{c}$ and $b\bar{b}$ pairs have to be produced in the same pp collision $\Rightarrow$ B_c^+ **production suppressed** by a factor $\alpha_s^2(Q^2)$



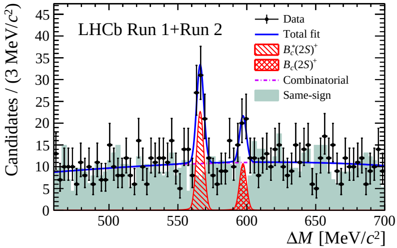
[Phys.Rev.D 99 (2019) 9, 096020]

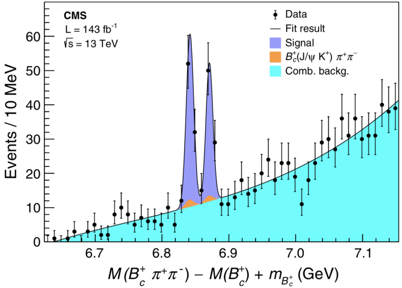
Radially excited B_c^+ states

[Phys.Rev.Lett. 113, 212004]

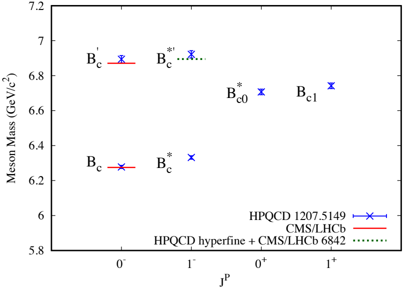


[Phys.Rev.Lett. 122 (2019) 23, 232001]





[Phys.Rev.Lett. 122, 132001]



[Phys.Rev.D 86, 094510]

Measurement of $B_c(2S)^+$ and $B_c^*(2S)^+$ cross-section ratios

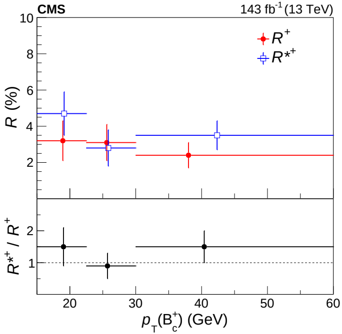
[Phys.Rev.D 102 (2020) 9, 092007]

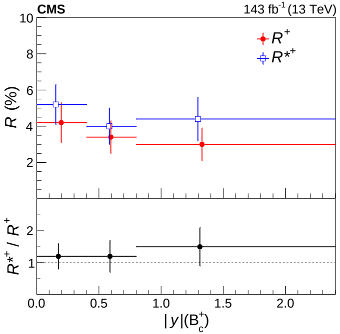
- $143\,\mathrm{fb}^{-1}$ of *pp* collision data collected at $\sqrt{s} = 13\,\mathrm{TeV}$ by the CMS detector
- fiducial region: $p_T(B_c^+) > 15$ GeV, $|\eta| < 2.4$

$$R^+ \equiv \frac{\sigma(\mathrm{B_c(2S)^+})}{\sigma(\mathrm{B_c^+})}\mathcal{B}(\mathrm{B_c(2S)^+} \to \mathrm{B_c^+}\pi^+\pi^-) = \frac{N(\mathrm{B_c(2S)^+})}{N(\mathrm{B_c^+})}\,\frac{\epsilon(\mathrm{B_c^+})}{\epsilon(\mathrm{B_c(2S)^+})},$$

$$R^{*+} \equiv \frac{\sigma(\mathrm{B_c^*(2S)^+})}{\sigma(\mathrm{B_c^+})}\mathcal{B}(\mathrm{B_c^*(2S)^+} \to \mathrm{B_c^{*+}}\pi^+\pi^-) = \frac{N(\mathrm{B_c^*(2S)^+})}{N(\mathrm{B_c^+})}\,\frac{\epsilon(\mathrm{B_c^+})}{\epsilon(\mathrm{B_c^*(2S)^+})},$$

$$R^{*+}/R^+ = \frac{\sigma(\mathrm{B_c^*(2S)^+})}{\sigma(\mathrm{B_c(2S)^+})}\,\frac{\mathcal{B}(\mathrm{B_c^*(2S)^+} \to \mathrm{B_c^{*+}}\pi^+\pi^-)}{\mathcal{B}(\mathrm{B_c(2S)^+} \to \mathrm{B_c^+}\pi^+\pi^-)} = \frac{N(\mathrm{B_c^*(2S)^+})}{N(\mathrm{B_c(2S)^+})}\,\frac{\epsilon(\mathrm{B_c(2S)^+})}{\epsilon(\mathrm{B_c^*(2S)^+})}.$$





Measurement of $B_c(2S)^+$ and $B_c^*(2S)^+$ cross-section ratios

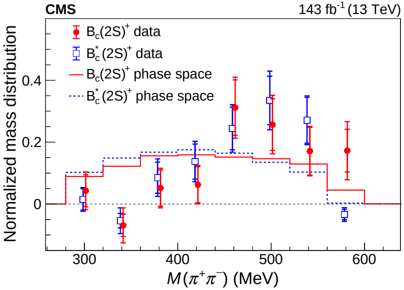
[Phys.Rev.D 102 (2020) 9, 092007]

$p_T(B_c^+) > 15$ GeV, $|\eta| < 2.4$

	Central	Stat.	Spread	Pions
$\epsilon(B_c(2S)^+)/\epsilon(B_c^+)$	0.196	1.1%	1.8%	4.2%
$\epsilon(B_c^*(2S)^+)/\epsilon(B_c^+)$	0.187	1.0%	1.6%	4.2%
$\epsilon(B_c^*(2S)^+)/\epsilon(B_c(2S)^+)$	0.955	1.4%	0.9%	—

$$R^+ = (3.47 \pm 0.63)\%,$$
$$R^{*+} = (4.69 \pm 0.71)\%,$$
$$R^{*+}/R^+ = 1.35 \pm 0.32.$$

invariant mass distribution of the dipion system



reconstruction efficiencies flat in $\pi^+\pi^- \Rightarrow$ not efficiency corrected

$\Xi_{bc}^{0,+}$ and Ω_{bc}^{0} spectroscopy

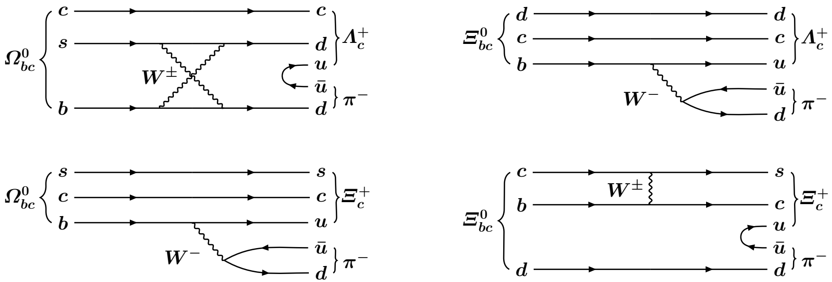
Spectroscopy of the ground-state doubly heavy baryons

- multiplet composed by $\Xi^0_{bc} = |dcb\rangle$, $\Xi^+_{bc} = |ucb\rangle$ and $\Omega^0_{bc} = |scb\rangle$
- most studies predict their masses in the 6700-7300 MeV range
- lifetime expectations: $\tau(\Omega^0_{bc}) \sim 0.2$ ps and $0.09 < \tau(\Xi^0_{bc}) < 0.28$
- production cross-section of Ξ^0_{bc} between 19 and 39 nb in LHCb acceptance at 14 TeV
- **very few theoretical predictions for their branching fractions**
- first null search for Ξ^0_{bc} in the $D^0 p K^-$ decay mode **[JHEP 11 (2020) 095]**

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

[arXiv:2104.04759]

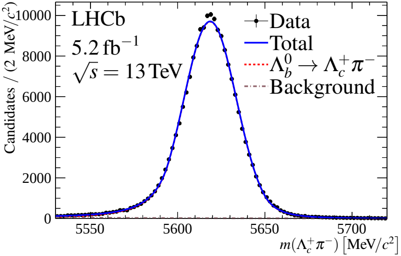
- $5\,\mathrm{fb}^{-1}$ of *pp* collision data collected at $\sqrt{s} = 13\,\mathrm{TeV}$ by the LHCb detector
- **first search for the Ω_{bc}^0 baryon**
- search for the Ξ_{bc}^0 baryon in a new final state
- **blind analysis**

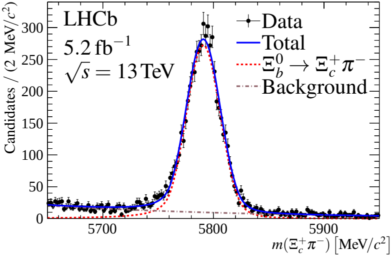


Search for Ξ_{bc}^0 and Ω_{bc}^0 baryons

[arXiv:2104.04759]

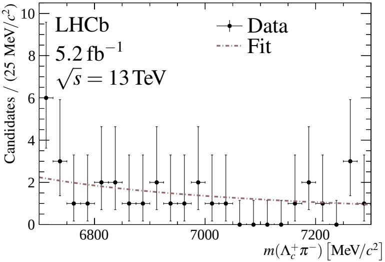
- Λ_c^+ and Ξ_c^+ baryons reconstructed in the $pK^-\pi^+$ decay mode are combined with a pion to form the doubly heavy baryon candidate (H_{bc})
- kinematic fit with constraints to the Λ_c^+ and Ξ_c^+ masses constraints and requiring H_{bc} to originate from the associated PV
- $\Lambda_b^0 \to \Lambda_c^+\pi^-$ and $\Xi_b^0 \to \Xi_c^+\pi^-$ as control modes: $\sim 190k$ and $6k$ candidates, respectively

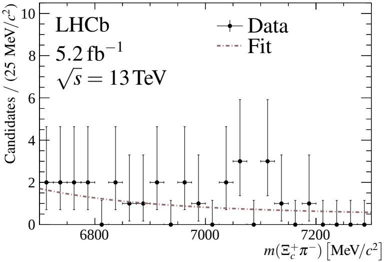




Search for Ξ_{bc}^0 and Ω_{bc}^0 baryons

[arXiv:2104.04759]



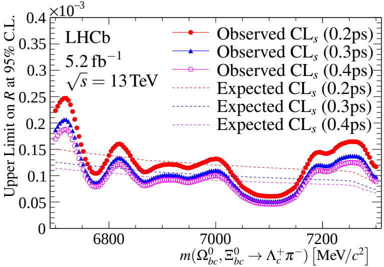


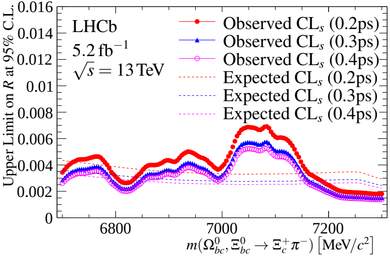
- no significant excess
- upper limit as a function of mass and lifetime hypothesis on the H_{bc} production cross-section relative to the Λ_b^0 and Ξ_b^0 modes
- $\epsilon(\Lambda_b^0, \Xi_b^0)/\epsilon(H_{bc}) \sim 3.0$ at $m(H_{bc}) = 6900$ MeV and $\tau(H_{bc}) = 0.4$ ps

Search for Ξ_{bc}^0 and Ω_{bc}^0 baryons

[arXiv:2104.04759]

- fiducial range: $2 < p_T < 20$ GeV and $2 < \eta < 4.5$
- upper limits at 95% confidence level using the asymptotic CL_s method with a 4 MeV step size
- results hold for the Ω_{bc}^0 and Ξ_{bc}^0 individually





Conclusions

- crucial interplay between experiments, QCD-inspired phenomenological models and Lattice QCD to improve our understanding of the non-perturbative regime of QCD
- "indirect" impact on the measurement of flavour physics observables and SM self-consistency checks
- 59 new hadrons observed by the LHC experiments **and more to come**
- **LHC Run 3 is approaching**: new results, exploiting the huge integrated luminosity collected by ATLAS and CMS and the *b*-hadron reconstruction capabilities of the **upgraded** LHCb, are expected in the near future

Thanks and stay tuned for new results!

Backup slides

Conventions and notations for excited heavy-light mesons

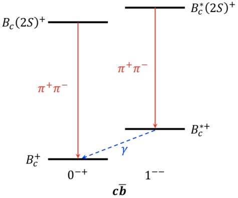
- L is the orbital angular momentum
- $j_q = L \oplus s_q$
- $S = s_q \oplus s_Q$
- $J = j_q \oplus s_Q$

- in the heavy-quark limit the properties of the heavy-light meson are determined by those of the light-quark
- the S_Q and j_q quantum numbers are separately conserved

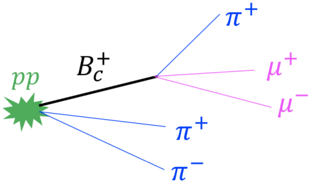
- **spectroscopy notation**: $n^{(2S+1)}L_J$
- states having $J^P = 0^+, 1^-, 2^+ ...$ are said to have *natural spin-parity*
- states having $J^P = 0^-, 1^+, 2^- ...$ are said to have *unnatural spin-parity*
- **PDG notation**: $D_{sJ}^{(*)}(m)^{0/\pm}$ or $B_{sJ}^{(*)}(m)^{0/\pm}$, where the $*$ subscript is used if the state has natural spin-parity

$B_c(2S)^+$ and/or $B_c^*(2S)^+$?

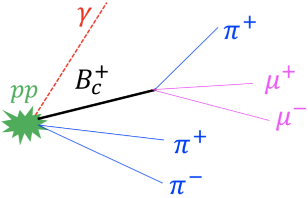
- ATLAS measurement could not distinguish between $B_c(2S)^+$ and $B_c^*(2S)^+$ because of the low yield and the Q-value resolution of $\sim 20\,\mathrm{MeV}$



$B_c(2S)^+ \to B_c^+\pi^+\pi^-$



$B_c^*(2S)^+ \to B_c^{*+}(\to B_c^+\gamma)\pi^+\pi^-$



- the photon energy is predicted to be $\sim 50\,\mathrm{MeV} \Rightarrow$ too soft to be reconstructed at the LHC (huge combinatorial background)
- most predictions give $m(B_c(2S)^+) > m(B_c^*(2S)^+)_{\text{reco}}$

Observation of two excited B_c^+ states at CMS: results

[Phys.Rev.Lett. 122, 132001]

- 67 ± 10 and 51 ± 10 events for the lower-mass and higher-mass peak
- $\Delta M = 29.1 \pm 1.5\,\mathrm{MeV}$
- the low-energy photon in the $B_c^*(2S)^+ \to B_c^*(\to B_c^+\gamma)\pi^+\pi^-$ decay chain has a reconstruction efficiency of the order of 1% (from simulation studies) $\Rightarrow$ the **$B_c^*(2S)^+$ mass can not be measured**
- dominant systematic uncertainties: modelling of the peaks replacing Gaussians with Breit-Wigners convolved with Gaussian resolution functions (natural widths consistent with zero), and world-average B_c^+ mass
- **observation of two peaks rather than one established at 6.5σ** accounting for systematic uncertainties (dominant one is the background model)

$\Delta M = 29.1 \pm 1.5(\text{stat}) \pm 0.7(\text{syst})\,\mathrm{MeV}$
$m(B_c(2S)^+) = 6871.0 \pm 1.2(\text{stat}) \pm 0.8(\text{syst}) \pm 0.8(B_c^+)\,\mathrm{MeV}$
$m(B_c(2S)^+) - m(B_c^+) = 596.1 \pm 1.2(\text{stat}) \pm 0.8(\text{syst})\,\mathrm{MeV}$
$m(B_c^*(2S)^+) - m(B_c^{*+}) = 567.0 \pm 1.0(\text{stat}) \pm 0.0(\text{syst})\,\mathrm{MeV}$

Observation of an excited B_c^+ state at LHCb: results

[arXiv:1904.00081 [hep-ex]]

- 51 ± 10 (6.8σ) and 24 ± 9 (3.2σ) events (local statistical significance)
- $\Delta M = 31.0 \pm 1.4\,\mathrm{MeV}$
- **global statistical significances: 6.3σ and 2.2σ**
- dominant systematic uncertainties: momentum scale and world-average B_c^+ mass
- assuming the hint for a second structure is due to the $B_c(2S)^+$ state

$\Delta M = 31.0 \pm 1.4(\text{stat}) \pm 0.0(\text{syst})\,\mathrm{MeV}$
$m(B_c(2S)^+) = 6872.1 \pm 1.3(\text{stat}) \pm 0.1(\text{syst}) \pm 0.8(B_c^+)\,\mathrm{MeV}$
$m(B_c^*(2S)^+)_{\text{reco}}) = 6841.2 \pm 0.6(\text{stat}) \pm 0.1(\text{syst}) \pm 0.8(B_c^+))\,\mathrm{MeV}$

Observation of a new excited beauty strange baryon decaying to $\Xi_b^- \pi^+ \pi^-$: selection of Ξ_b^- candidates

[arXiv:2102.04524]

- two well identified muons ($p_T > 3$ GeV) to form a good quality vertex and with $|m(\mu^+\mu^-) - m_{J/psi}^{\mathrm{PDG}}| < 100$
- Λ candidates ($p_T > 1$ GeV) from displaced two-prong vertices assuming the decay $\Lambda \to p\pi^-$ with $|m(p\pi^-) - m_{\Lambda}^{\mathrm{PDG}}| < 10$
- $p_T(\Xi_b^-) > 10(15)$ GeV for $J/\psi\Xi^-$ ($J/\psi\Lambda K^-$) and topological information, kinematic vertex fit with J/ψ mass constraint
- Unbinned maximum-likelihood fits with the Ξ_b^- signal described by a double-Gaussian with mean and yield as free parameters