Heavy exotic mesons at LHC*b*

recent results

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on behalf of the LHC*b* Collaboration

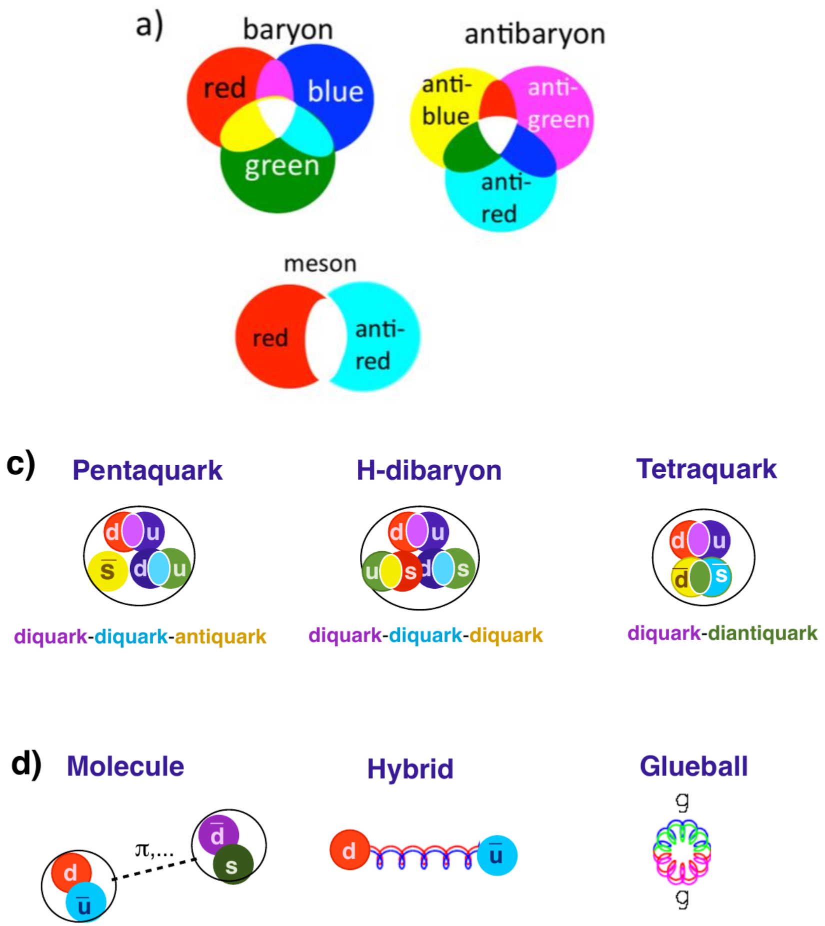
The XXXIII Workshop on «Hard Problems of Hadron Physics» (online)

November 9, 2021

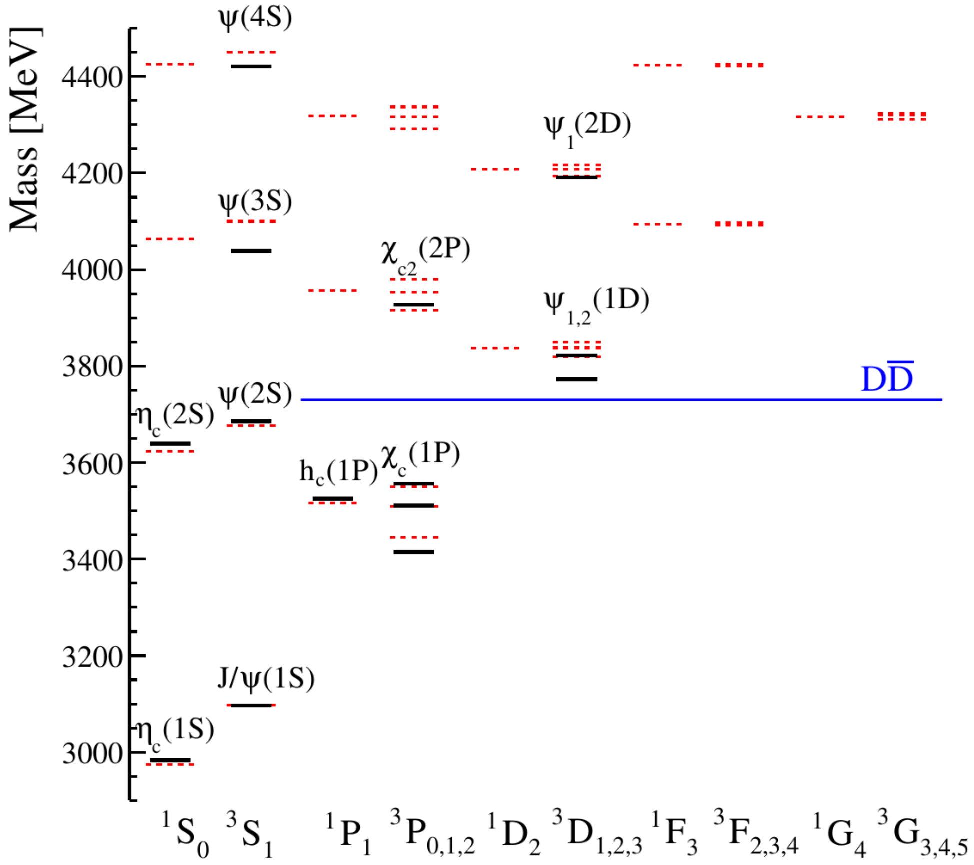
In memory of Simon Eidelman
(1948 – 2021)

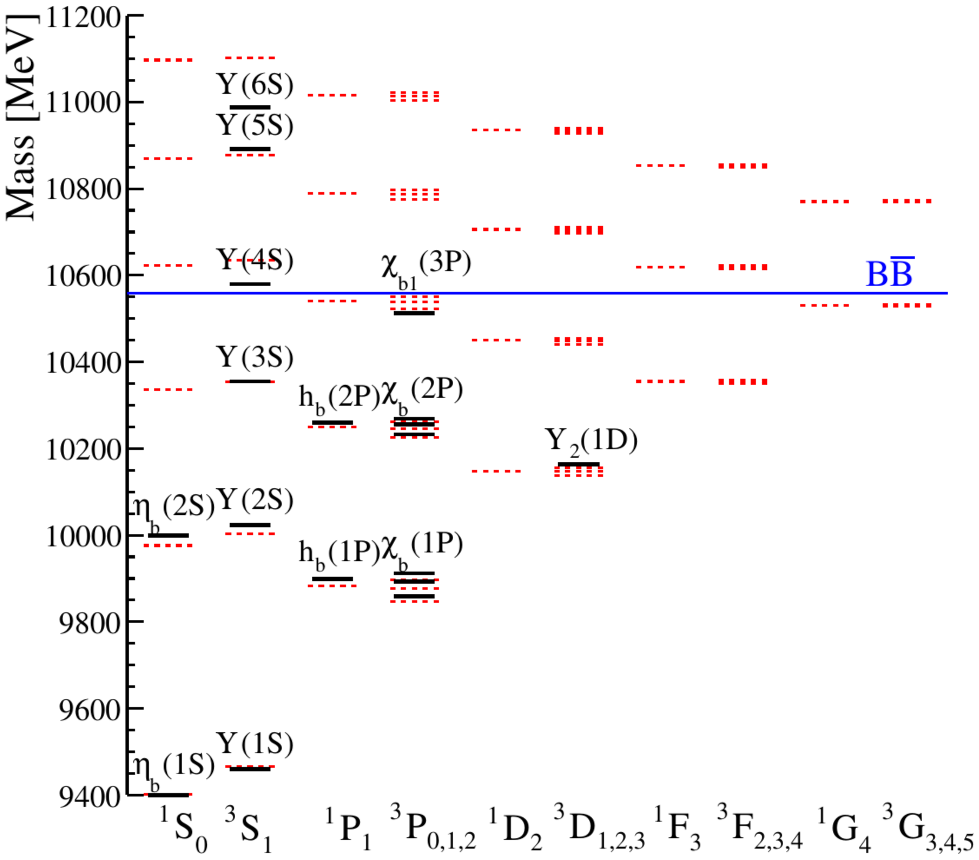
What are exotic states?

- The QCD has difficulties describing the interactions of quarks in hadrons from the first principles
- Conventional states: $q_1\bar{q}_2$ and $q_1q_2q_3$
  - Spectroscopy of conventional states is described reasonably well with potential models
- Hadrons with alternative content are referred to as *exotic states*
  - All knows exotic states decay via the strong interaction
  - Heavy tetraquarks (pentaquarks) are usually observed in a heavy quarkonium plus light meson (baryon) decay channels
- See review [Rev. Mod. Phys. 90 (2018) 15003]



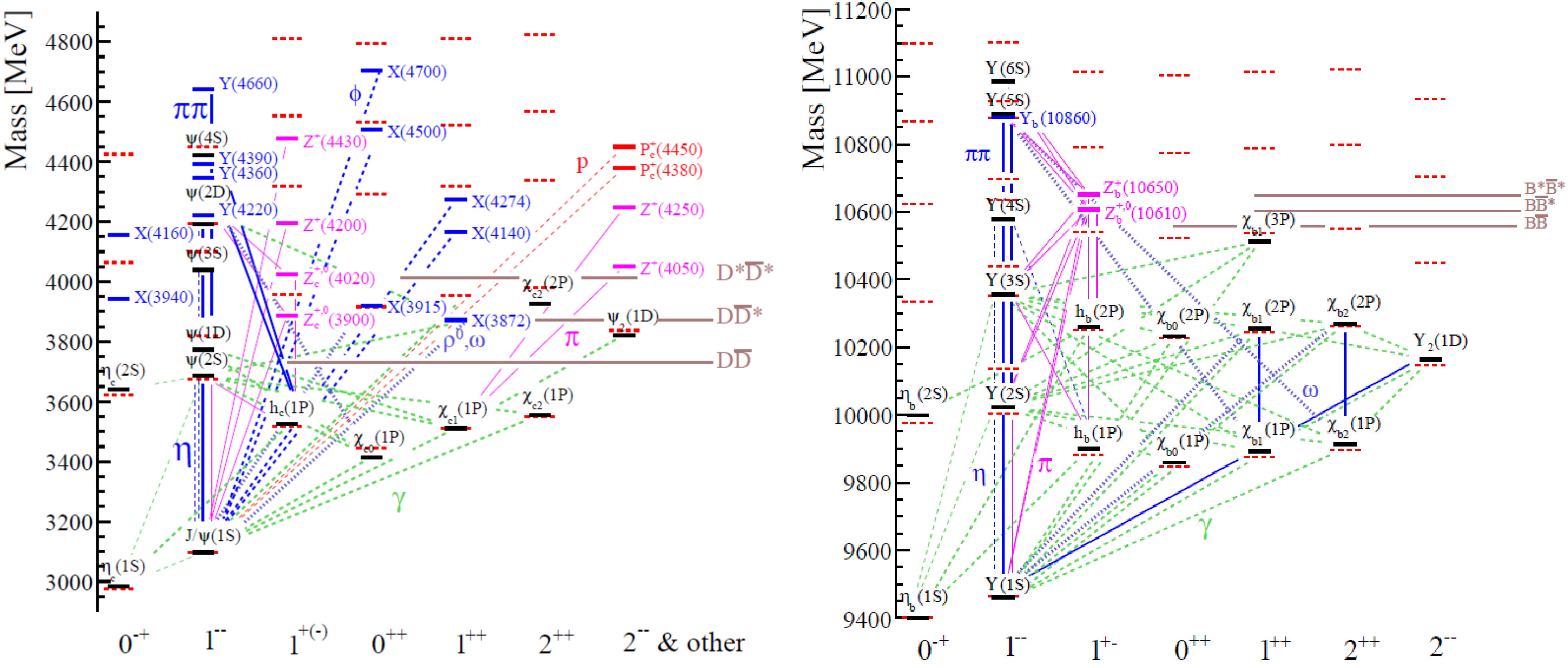
Heavy flavor quarkonium





[Rev. Mod. Phys. 90 (2018) 15003]

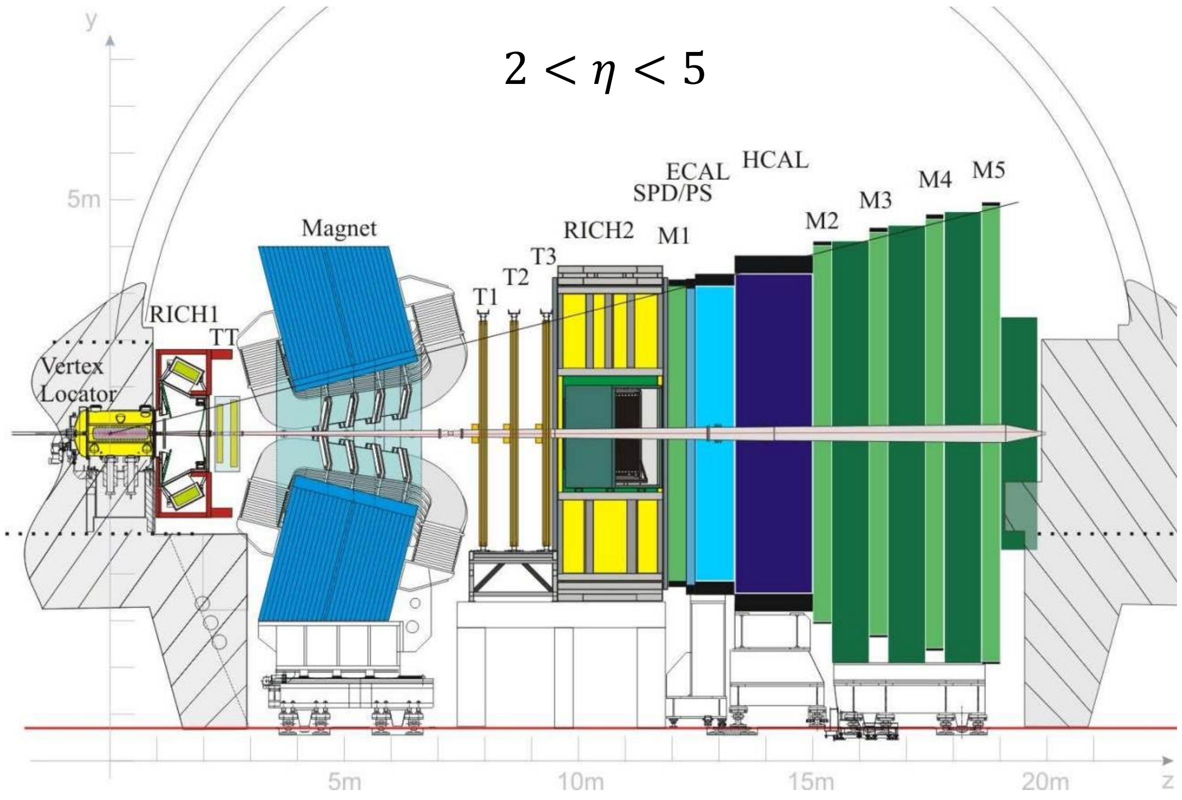
Heavy flavor quarkonium(like)



[Rev. Mod. Phys. 90 (2018) 15003]

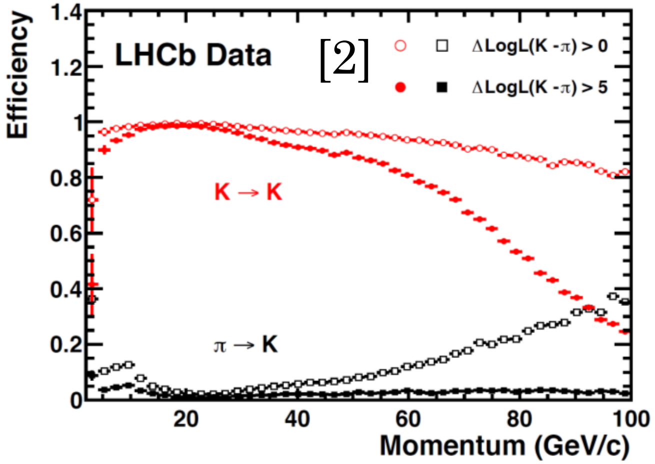
The LHCb detector

$2 < \eta < 5$



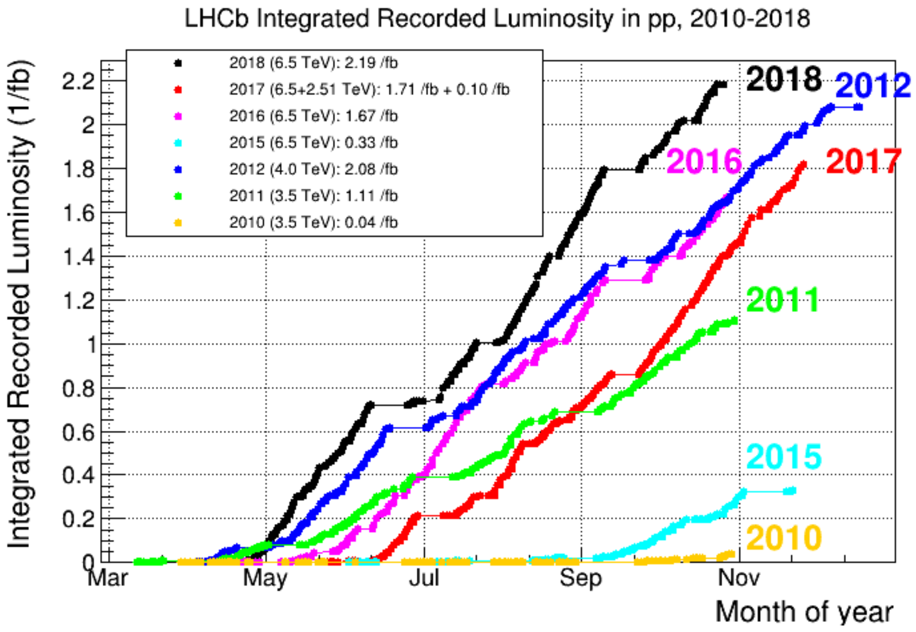
[1] JINST 3 (2008) S08005
[2] Int. J. Mod. Phys. A 30 (2015) 153022

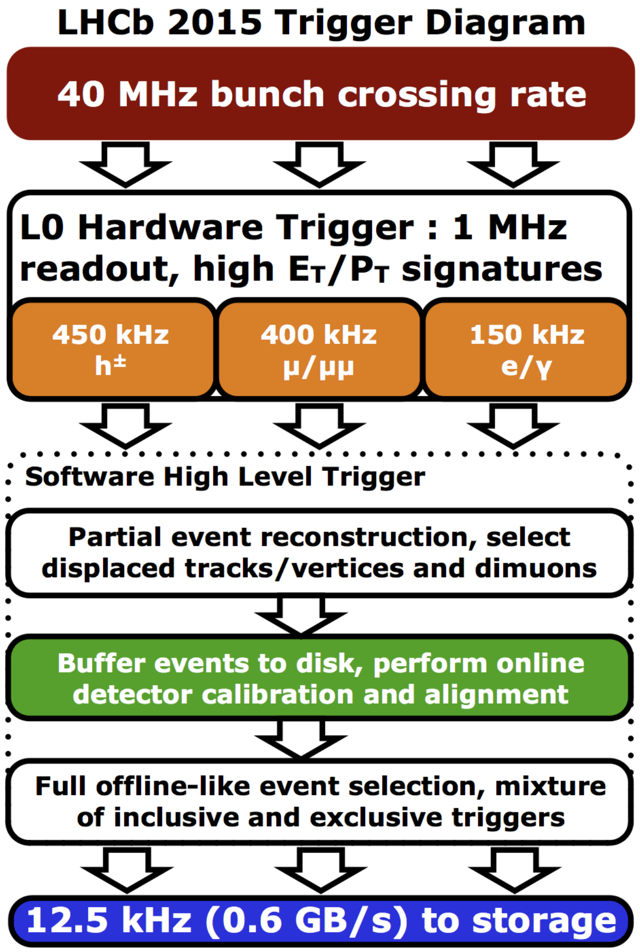
- Designed for precision b and c physics
- Excellent tracking and vertexing
  - $\sigma(p)/p < 1\%$ @ $\epsilon_{\text{track}} > 96\%$
  - $\sigma(\text{IP}) = (15 + 29/p_T)\ \mu m$
- Excellent PID
  - $\epsilon_{\text{PID}}(K) \approx 95\%$ @ $\text{MisID}(\pi \to K) \approx 5\%$
  - $\epsilon_{\text{PID}}(\mu) \approx 97\%$ @ $\text{MisID}(\pi \to \mu) \approx 3\%$



LHC*b* trigger and data set

- Instant luminosity corresponding to 1.1 visible interactions per bunch crossing
- Two stage trigger efficient for hadrons and muons
- Turbo stream for Run 2
  - Trigger level reconstruction
  - Smaller event size and increased acceptance rate





LHC			LH-LHC	
Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2022-24)	Run 4 (2027-30)	Run 5+ (2031+)
3 fb^{-1}	6 fb^{-1}	23 fb^{-1}	46 fb^{-1}	$> 300\ \mathrm{fb}^{-1}$ (?)

Upgrade I   Upgrade Ib   Upgrade II

[1] Comput. Phys. Commun. 208 35-42
[2] Int. J. Mod. Phys. A 30 (2015) 153022

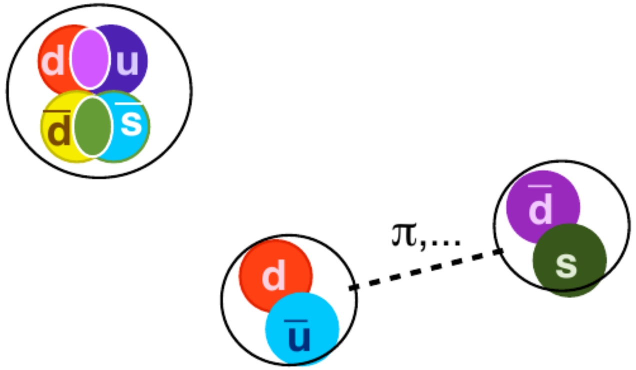
Outline

1. Tetraquarks with hidden charm
   - Updated amplitude analysis of $B^+ \to J/\psi \phi K^+$
   - Prompt production of the $X(6900) \to J/\psi\, J/\psi$
   - Updates on $X(3872)$:
     - ✓ $X(3872) \to J/\psi \pi^+\pi^-$ lineshape
     - ✓ $X(3872)$ in $B^+ \to (J/\psi \pi^+\pi^-)K^+$ decays
     - ✓ Multiplicity-dependent prompt production of $X(3872)$ and $\psi(2S)$ (2021)
2. Pentaquarks with hidden charm
   - Analysis of $\Lambda_b^0 \to J/\psi p K^-$
   - Amplitude analysis $B_s^0 \to J/\psi p \bar{p}$
   - Amplitude analysis of $\Xi_b^- \to J/\psi \Lambda K^-$
3. Doubly charmed tetraquark $T_{cc}^+(3875) \to D^0 D^0 \pi^+$
   - Discovery
   - Analysis

$(c\bar{c}s\bar{s})$
$(c\bar{c}c\bar{c})$
$(c\bar{c}\bar{s}u)$
$(c\bar{c}\bar{u}u)$
$(c\bar{c}uud)$
$(c\bar{c}sud)$
$(cc\bar{u}\bar{d})$

1. LHCb-PAPER-2019-014
2. LHCb-PAPER-2020-008
3. LHCb-PAPER-2020-009
4. LHCb-PAPER-2020-011
5. LHCb-PAPER-2020-023
6. LHCb-PAPER-2020-044
7. LHCb-PAPER-2020-039
8. LHCb-PAPER-2021-018
9. LHCb-PAPER-2021-031
10. LHCb-PAPER-2021-032

Tetraquarks

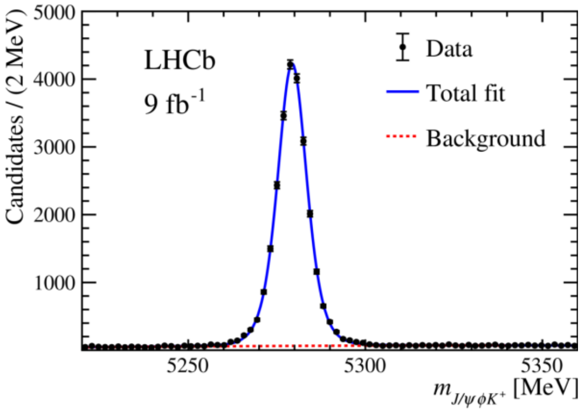


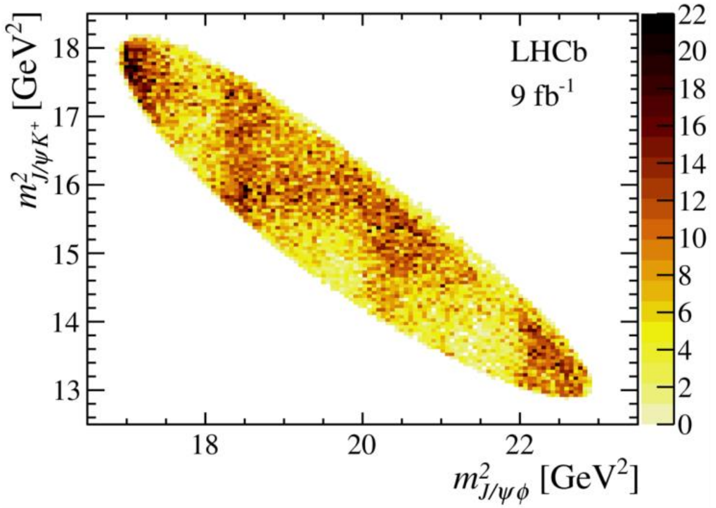
LHCb-PAPER-2020-044

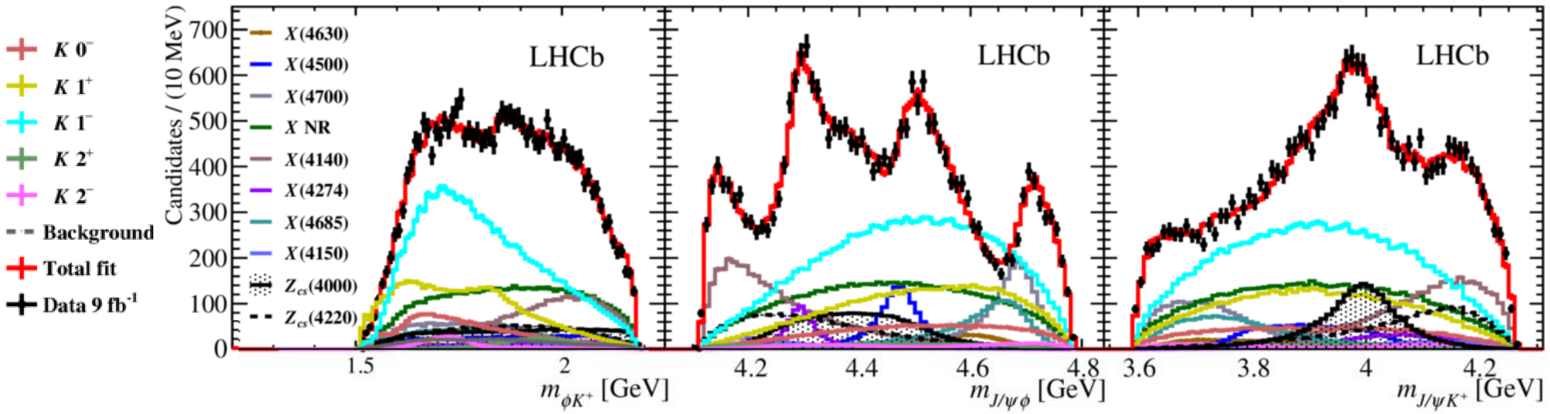
[Phys. Rev. Lett. 127 (2021) 082001]
supersedes PRL 118 (2017) 022003

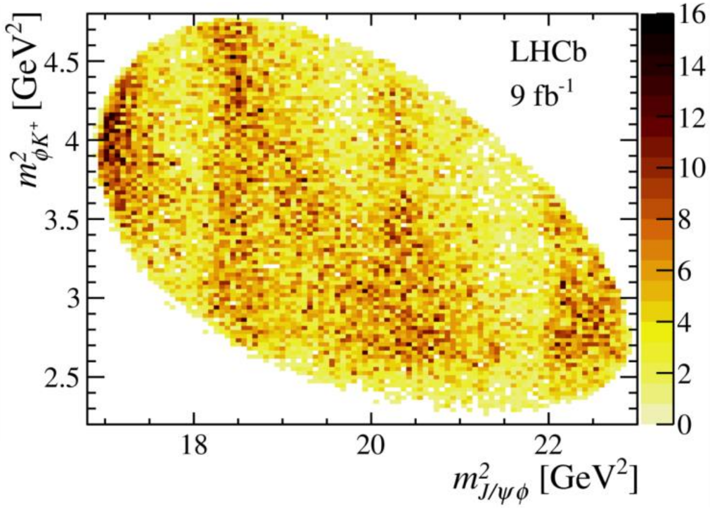
$Z_{cs}(4000)^+, Z_{cs}(4220)^+, X(4630), X(4685)$

- $9\ \mathrm{fb}^{-1}$ @ 7, 8 and 13 TeV
- $6D$ amplitude analysis of 24.2×10^3 $B^+ \to J/\psi\phi K^+$ decays:
  - 9 resonances in $[K^{*+} \to \phi K^+]J/\psi$
  - 7 resonances in $[X \to J/\psi\phi]K^+$
  - 2 resonances in $[Z_{cs} \to J/\psi K^+]\phi$ + 1 NR









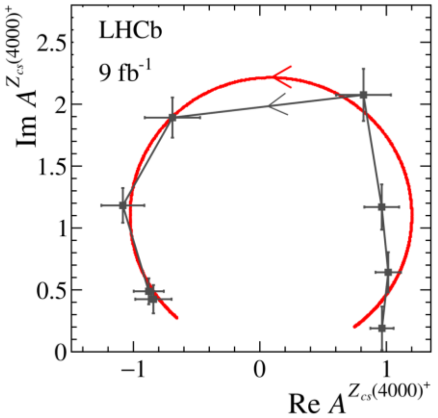
LHCb-PAPER-2020-044

[Phys. Rev. Lett. 127 (2021) 082001]
supersedes PRL 118 (2017) 022003

$Z_{cs}(4000)^+, Z_{cs}(4220)^+, X(4630), X(4685)$

- The 1st observation of strange exotic states with hidden charm!
- Systematic uncertainty is dominated by model uncertainty
- $X(4140)$ is near the $J/\psi\phi$ threshold

- The width of $Z_{cs}(4000)^-$ is much larger than the width of $Z_{cs}(3985)^-$ reported by BESIII
- The Argand diagram confirms resonant nature of the $Z_{cs}(4000)^-$ signal



To be confirmed

New!

Confirmed

New!

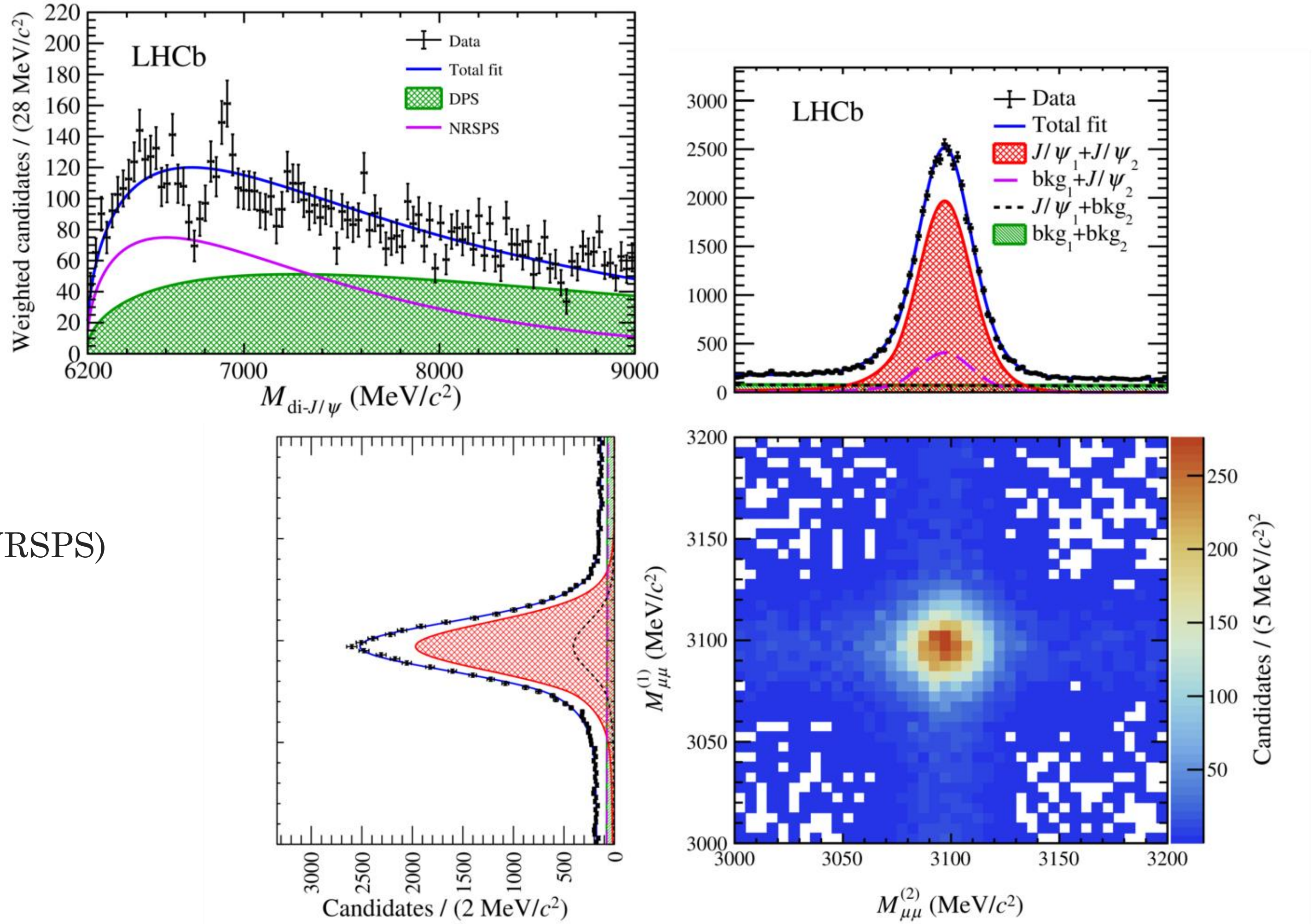
J^P	Contribution	Significance $[\times\sigma]$	M_0 [MeV]	Γ_0 [MeV]	FF [%]
2^-	$X(4150)$	4.8 (8.7)	$4146 \pm 18 \pm 33$	$135 \pm 28\,^{+59}_{-30}$	$2.0 \pm 0.5\,^{+0.8}_{-1.0}$
1^- or 2^-	$X(4630)$	5.5 (5.7)	$4626 \pm 16\,^{+18}_{-110}$	$174 \pm 27\,^{+134}_{-73}$	$2.6 \pm 0.5\,^{+2.9}_{-1.5}$
0^+	$X(4500)$	20 (20)	$4474 \pm 3 \pm 3$	$77 \pm 6\,^{+10}_{-8}$	$5.6 \pm 0.7\,^{+2.4}_{-0.6}$
	$X(4700)$	17 (18)	$4694 \pm 4\,^{+16}_{-3}$	$87 \pm 8\,^{+16}_{-6}$	$8.9 \pm 1.2\,^{+4.9}_{-1.4}$
	$\mathrm{NR}_{J/\psi\phi}$	4.8 (5.7)			$28 \pm 8\,^{+19}_{-11}$
1^+	$X(4140)$	13 (16)	$4118 \pm 11\,^{+19}_{-36}$	$162 \pm 21\,^{+24}_{-49}$	$17 \pm 3\,^{+19}_{-6}$
	$X(4274)$	18 (18)	$4294 \pm 4\,^{+3}_{-6}$	$53 \pm 5 \pm 5$	$2.8 \pm 0.5\,^{+0.8}_{-0.4}$
	$X(4685)$	15 (15)	$4684 \pm 7\,^{+13}_{-16}$	$126 \pm 15\,^{+37}_{-41}$	$7.2 \pm 1.0\,^{+4.0}_{-2.0}$
1^+ or 1^-	$Z_{cs}(4000)$	15 (16)	$4003 \pm 6\,^{+4}_{-14}$	$131 \pm 15 \pm 26$	$9.4 \pm 2.1 \pm 3.4$
	$Z_{cs}(4220)$	5.9 (8.4)	$4216 \pm 24\,^{+43}_{-30}$	$233 \pm 52\,^{+97}_{-73}$	$10 \pm 4\,^{+10}_{-7}$

LHCb-PAPER-2020-011

[Science Bulletin 65 (2020) 1983]

A structure in the J/ψ-pair spectrum

- 9 fb^{-1} @ 7, 8 and 13 TeV
- Selections and signal window:
  - $p_T(\mu) > 0.65\ GeV$, $p(\mu) > 6\ GeV$
  - Four muons are from the same PV
  - $p_T(J/\psi\, J/\psi) > 5.2\ GeV$
  - $3.065 < m(\mu\mu) < 3.135\ GeV$
- Total di-J/ψ signal yield is 33.6×10^3
- The di-J/ψ spectrum:
  - Non-resonant single-parton scattering (NRSPS)
  - Double-parton scattering (DPS)
  - Threshold charmonium rescattering:
    - $\chi_{c0}\chi_{c0}$ at 6829.4 MeV
    - $\chi_{c0}\chi_{c1}$ at 6925.4 MeV
  - $T_{c\bar{c}c\bar{c}} \to J/\psi\, J/\psi$
  - A feed-down like $T_{c\bar{c}c\bar{c}} \to [\chi_c \to J/\psi\gamma]J/\psi$?

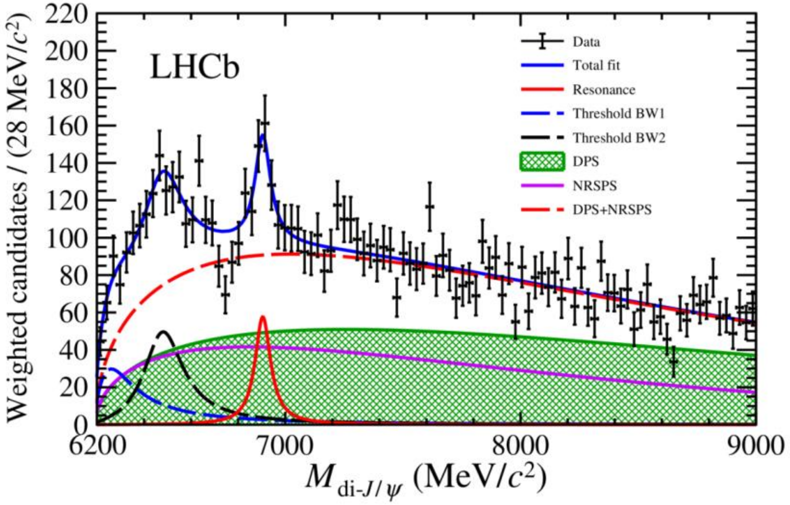


LHCb-PAPER-2020-011

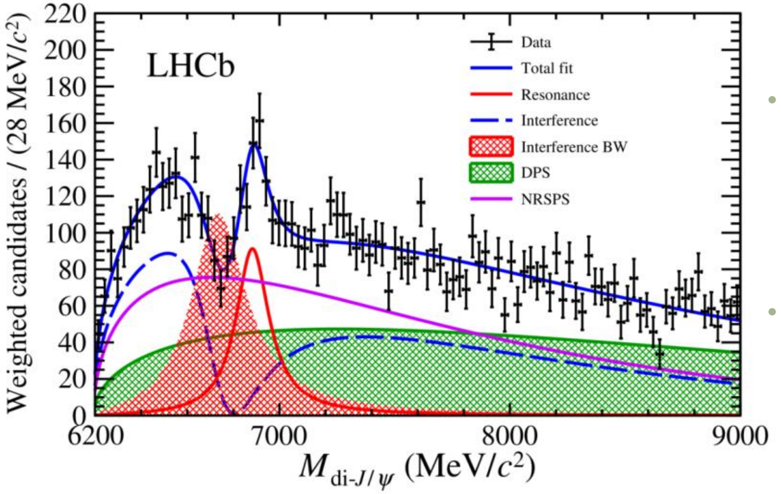
[Science Bulletin 65 (2020) 1983]

A structure in the J/ψ-pair spectrum

Model I, $\chi^2/\text{ndof} = 112.7/89$



Model II, $\chi^2/\text{ndof} = 104.7/91$



- Interference allowed between the NRSPS and threshold BW contributions
- The $T_{c\bar{c}c\bar{c}}$ signal is added incoherently

- The $X(6900)$ is described by a BW:

$$m(X(6900)) = 6905 \pm 11 \pm 7 \text{ MeV}$$
$$\Gamma(X(6900)) = 80 \pm 19 \pm 33 \text{ MeV}$$

- Signal yield: 252 ± 63 events
- Systematic uncertainty is dominated by the threshold structure shape and NRSPS + DPS modelling

✓ The signal significance exceeds 5σ in both models

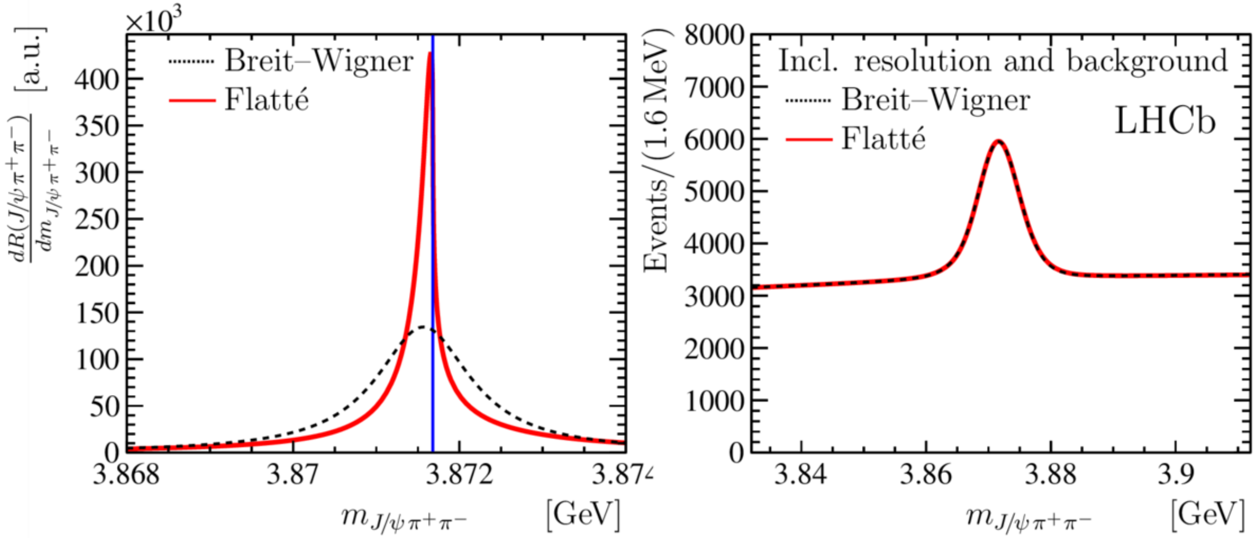
✓ The first (and the only one so far) state with doubly hidden heavy flavor

News on $X(3872)$ (aka $\chi_{c1}(3872)$)

LHCb-PAPER-2020-008
[PRD 102 (2020) 092005]

The $X(3872) \to J/\psi\pi^+\pi^-$ lineshape

- 3 fb^{-1} @ 7, and 8 TeV
  - Inclusive J/ψ produced by b hadrons are selected
  - Analysis in three bins of $p_{\pi^+\pi^-}$
- Systematics is dominated by momentum scale (mass) and background shape (width)



1. BW lineshape

$$m_{\mathrm{BW}} = 3871.695 \pm 0.067 \pm 0.068 \pm 0.010 \text{ MeV}$$

$$\Gamma_{\mathrm{BW}} = 1.39 \pm 0.24 \pm 0.24 \text{ MeV}$$

1st analysis resolving the X width

2. Flatte lineshape

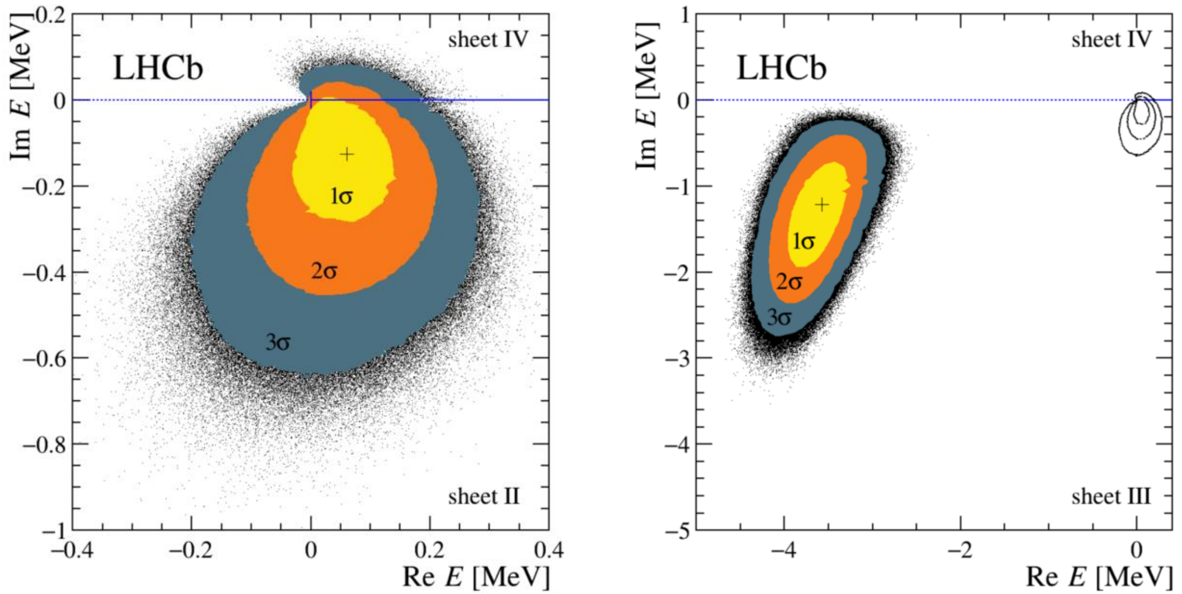
$$\text{mode} = 3871.69^{+0.00}_{-0.04}{}^{+0.05}_{-0.13} \text{ MeV}$$

$$\text{FWHM} = 0.22^{+0.07}_{-0.06}{}^{+0.11}_{-0.13} \text{ MeV}$$

LHCb-PAPER-2020-008
[PRD 102 (2020) 092005]

The $X(3872) \to J/\psi\pi^+\pi^-$ lineshape

- 3 fb^{-1} @ 7, and 8 TeV
  - Inclusive J/ψ produced by b hadrons are selected
  - Analysis in three bins of $p_{\pi^+\pi^-}$
- Systematics is dominated by momentum scale (mass) and background shape (width)
- Poles of the amplitude in the complex energy plane are identified with hadronic states
  - The pole location is a unique model-independent property of each state
- Lineshape analysis in the $D^0\bar{D}^{*0}$ channel is needed for more conclusive results!



- Analytical continuation of the Flatte amplitude yields pole position (for the selected Flatte mass parameter)

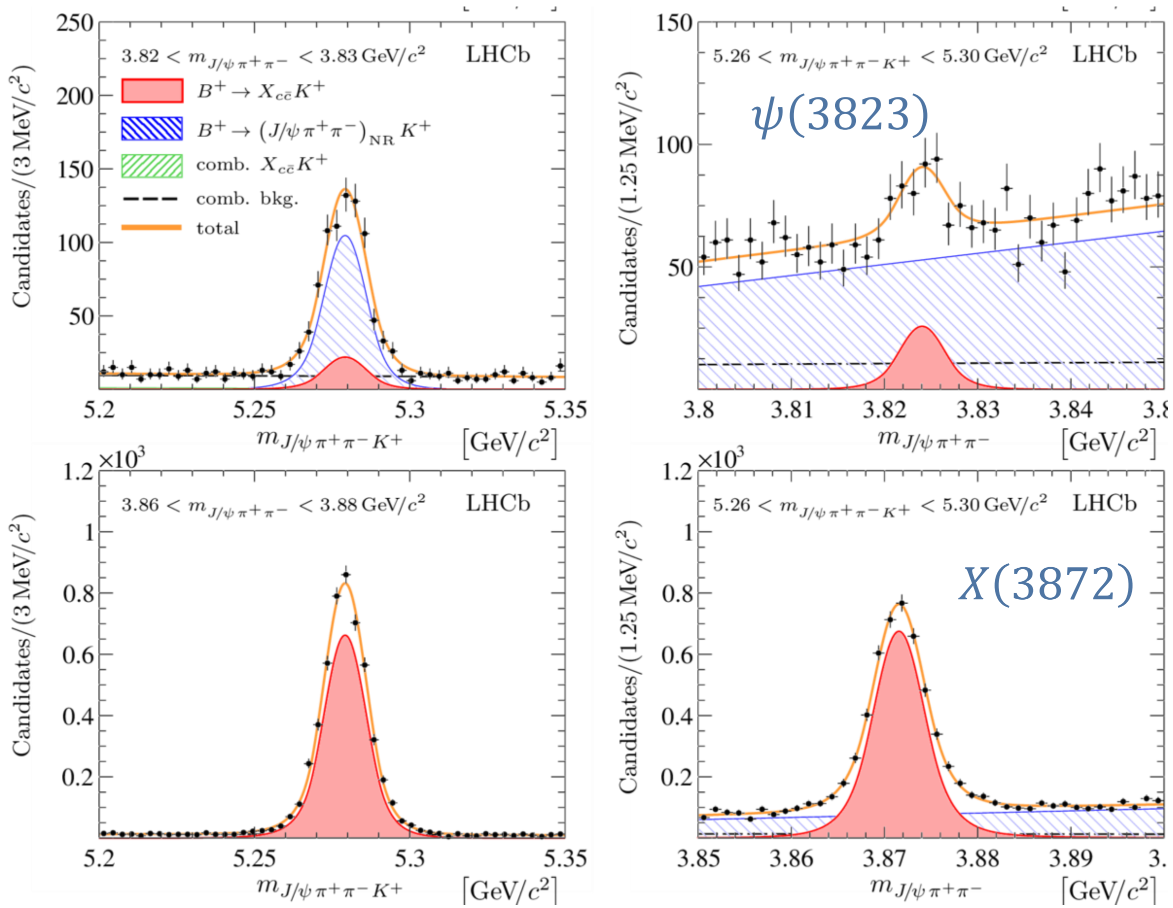
$$E'_{II} = (25 - 140i)\ \text{keV}$$

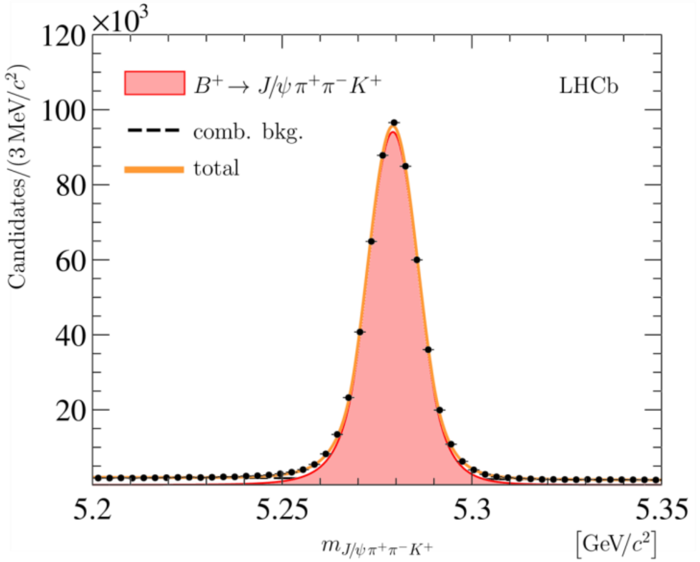
  - Location at sheet II (bound state) is preferred by data
  - Location at sheet IV (virtual state) is allowed with 2σ

LHCb-PAPER-2020-009
[JHEP 08 (2020) 123]

$X(3872)$ in $B^+ \to J/\psi \pi^+ \pi^- K^+$

- 0.548×10^6 B candidates with $9\ \mathrm{fb}^{-1}$ @ 7, 8 and 13 TeV





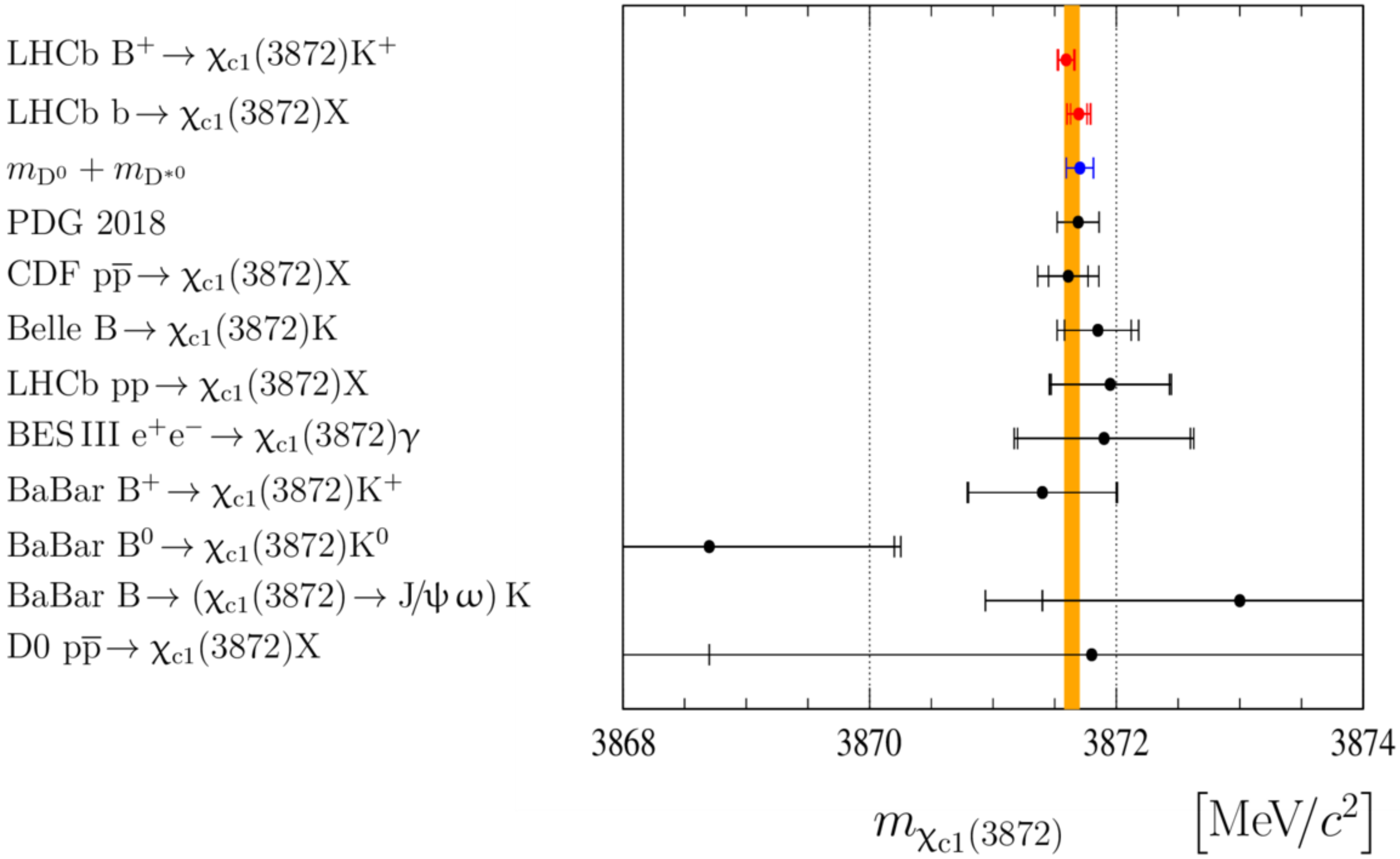
The LHCb-averaged mass:

$$m_{\mathrm{BW}} = 3871.64 \pm 0.06 \pm 0.01\ \mathrm{MeV}$$

$$\delta E = 0.07 \pm 0.12\ \mathrm{MeV}$$

$$\Gamma_{\mathrm{BW}} = 0.96^{+0.19}_{-0.18} \pm 0.21\ \mathrm{MeV}$$

5.5σ from zero



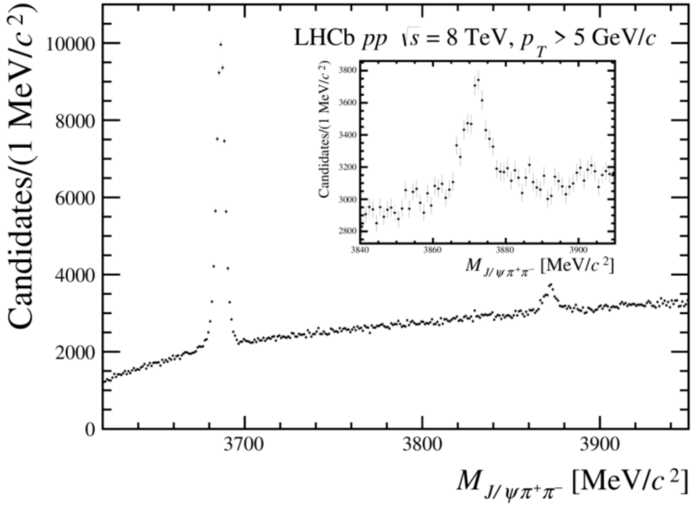
- The $X(3872)$ mass is still indistinguishable from the $D^0\bar{D}^{*0}$ threshold
  $\delta E = 0.07 \pm 0.12$ MeV
- The uncertainty is limited by the D^0 mass, too

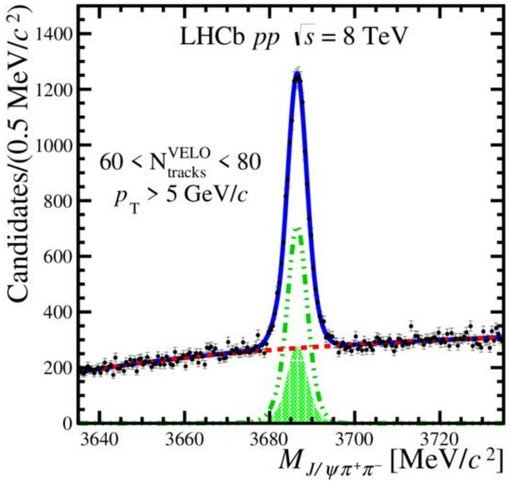
LHCb-PAPER-2020-023

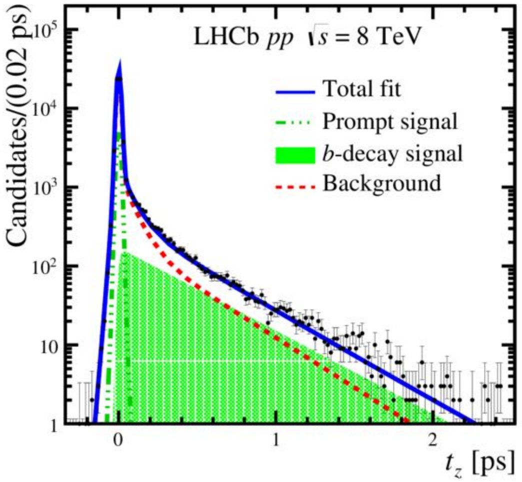
[PRL 126 (2021) 092001]

Production of $X(3872)$

- The $J/\psi\pi^+\pi^-$ final state with 2 fb^{-1} @ 8 TeV
- Selections:
  - Pions: $p > 3$ GeV, $p_T > 0.50$ GeV
  - Muons: $p > 10$ GeV, $p_T > 0.65$ GeV
  - J/ψ: $p_T > 3$ GeV
  - Common vertex, total $p_T > 5$ GeV
- Production of $X(3872)$ and $\psi(2S)$:
  - Prompt: direct or in strong decays of excited charmonia
  - In decays of b hadrons
  - Distinguished by fit of pseudo-decay-time t_z
- Fit in bins of $N_{\mathrm{tracks}}^{\mathrm{VELO}}$





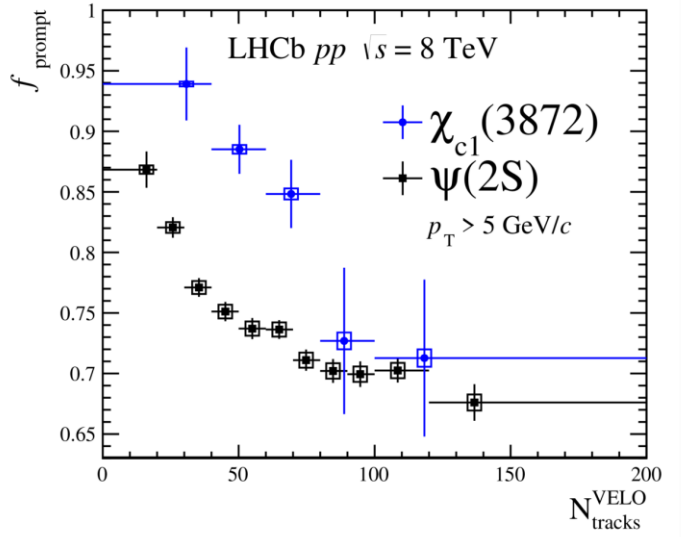


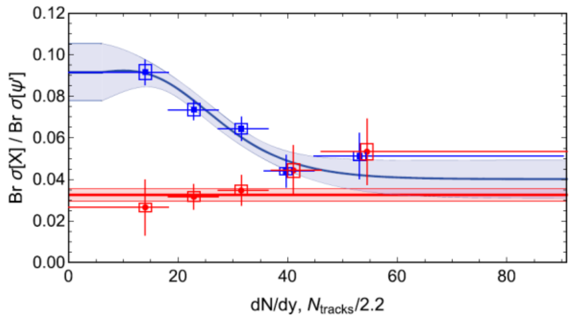
LHCb-PAPER-2020-023

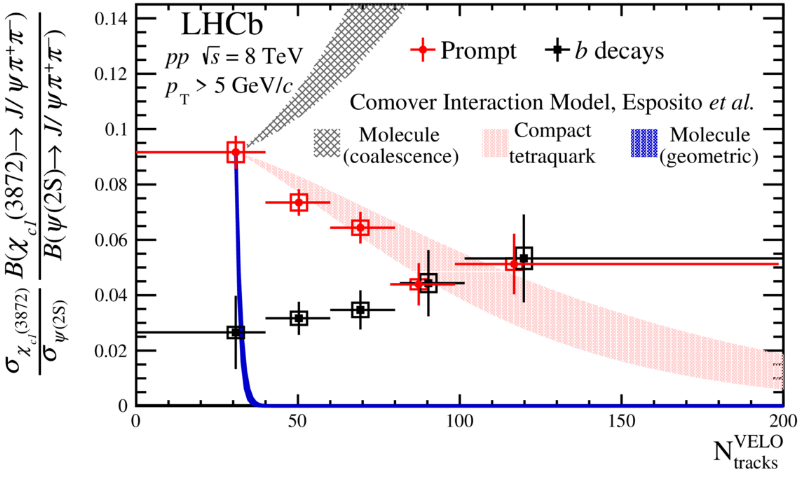
[PRL 126 (2021) 092001]

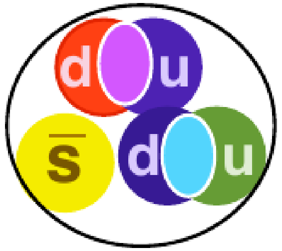
Production of $X(3872)$

- Fractions of promptly produced $X(3872)$ and $\psi(2S)$ as a function of charged particle multiplicity are measured
  - High-multiplicity *pp* collisions provide a testing ground for examining final-state effects in hadron production
  - Potential constraints on the $X(3872)$ structure and binding energy
- The ratio of prompt cross sections (times branching fractions) is consistent with a compact tetraquark model (see **EPJ C 81 (2021) 669** for details)
  - A purely molecular state has a large radius (~ 10 fm) and would quickly dissociate as multiplicity increases
  - The coalescence production mechanism suggests opposite trend
- E. Braaten et al. [**PRD 103 (2021) L071901**] describe the data in terms of a loosely bound molecular state







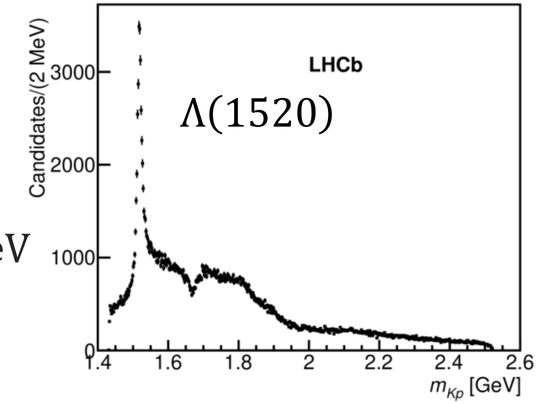


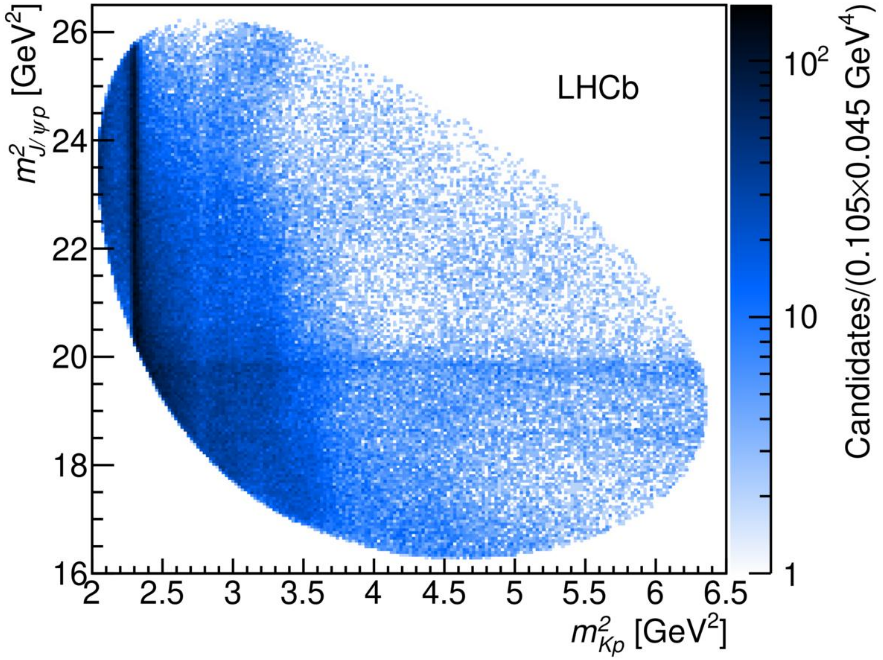
Pentaquarks

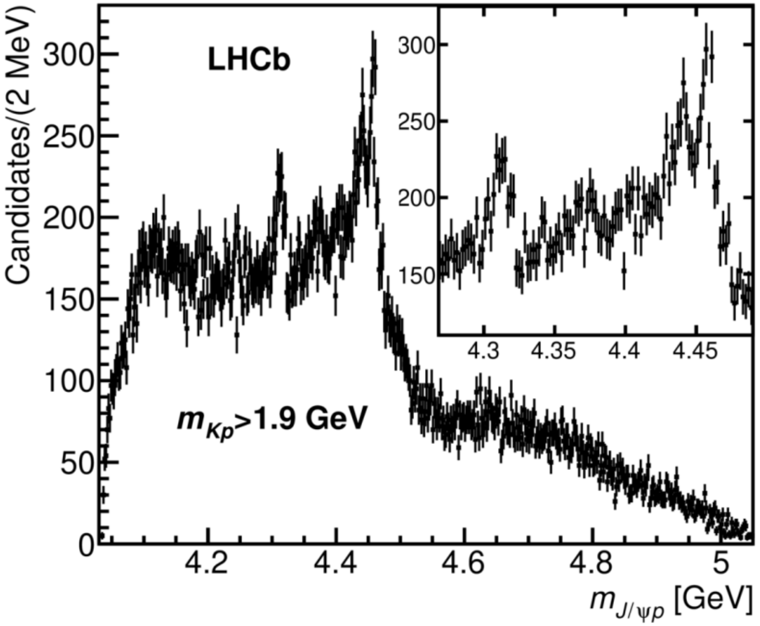
LHCb-PAPER-2019-014
[PRL 122 (2019) 222001]
supersedes PRL 115 (2015) 071001

$P_c(4312)^+$, $P_c(4440)^+$, $P_c(4457)^+$

- 9 fb^{-1} @ 7, 8 and 13 TeV
- Analysis of 0.25×10^6 $\Lambda_b^0 \to J/\psi p K^-$ decays
  - Binned χ^2 fit of the $m_{J/\psi p}$ distribution in the range $4.22 < m_{J/\psi p} < 4.57$ GeV
  - Signals are described with RBW amplitudes convoluted with resolution

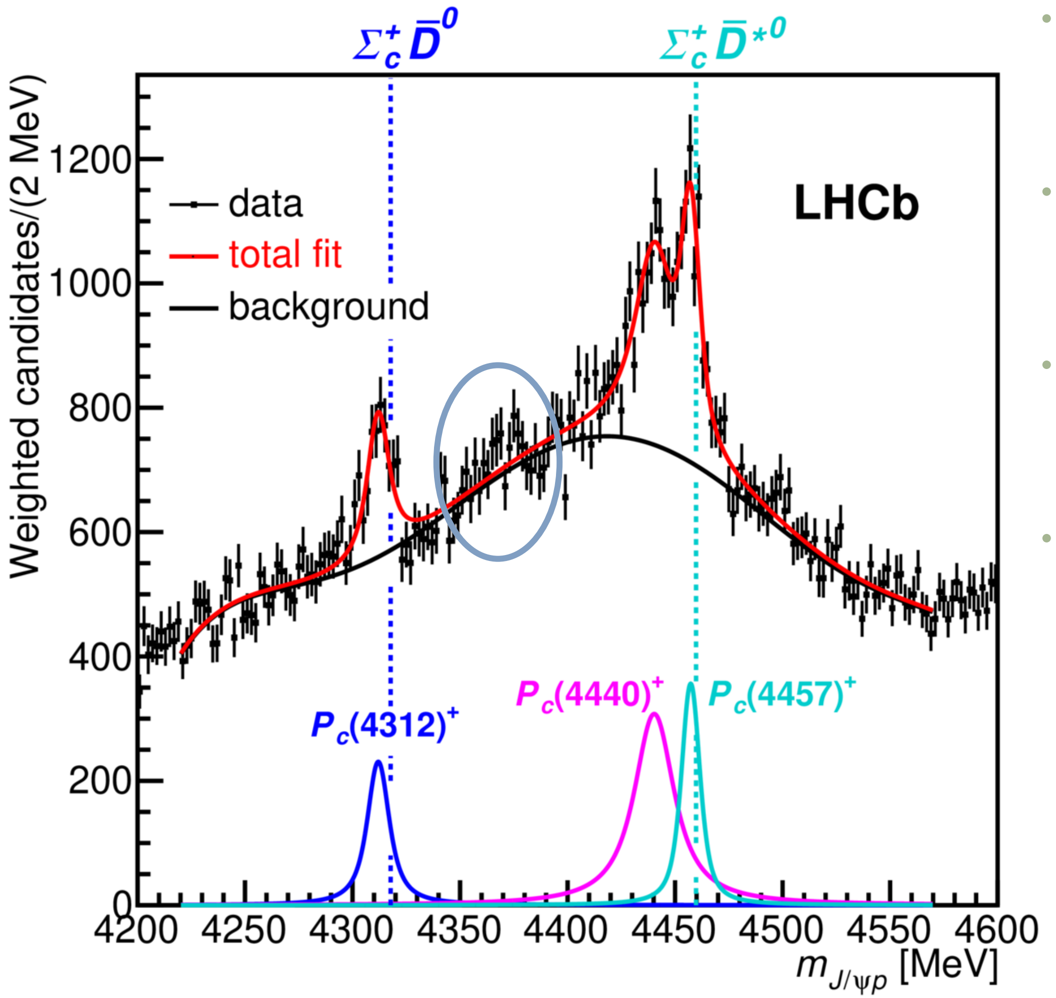




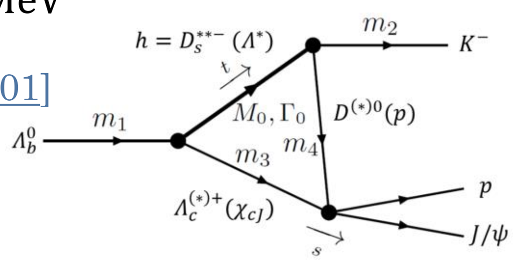


LHCb-PAPER-2019-014
[PRL 122 (2019) 222001]
supersedes PRL 115 (2015) 071001

$P_c(4312)^+$, $P_c(4440)^+$, $P_c(4457)^+$



- All narrow peaks are significant. The minimal quark content is $c\bar{c}uud$
- The wide structure near 4380 MeV cannot be addressed in a 1D analysis [see PRL 124 (2020) 072001]
- $P_c(4312)^+$ and $P_c(4457)^+$ are natural candidates for meson-baryon bound or virtual states
- $P_c(4457)^+$ could be a produced by a triangle diagram with $D_{s1}(2860)^-$ exchange, but this model does not describe well the signal shape

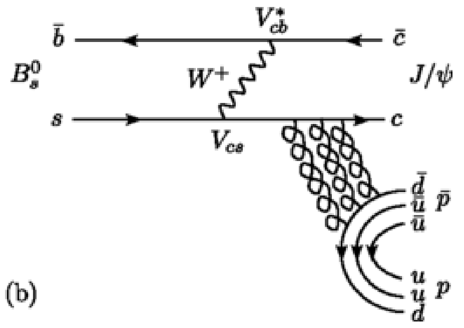


- The main systematic uncertainty comes from unaccounted interference effects

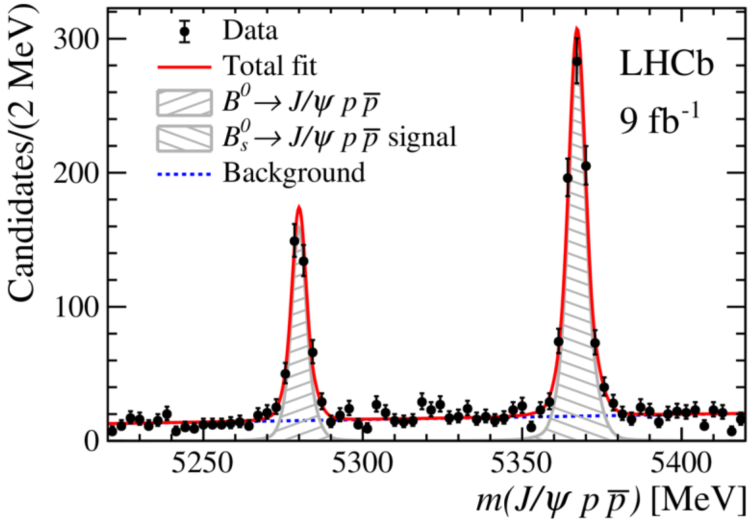
State	M [MeV]	Γ [MeV]	(95% CL)
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)

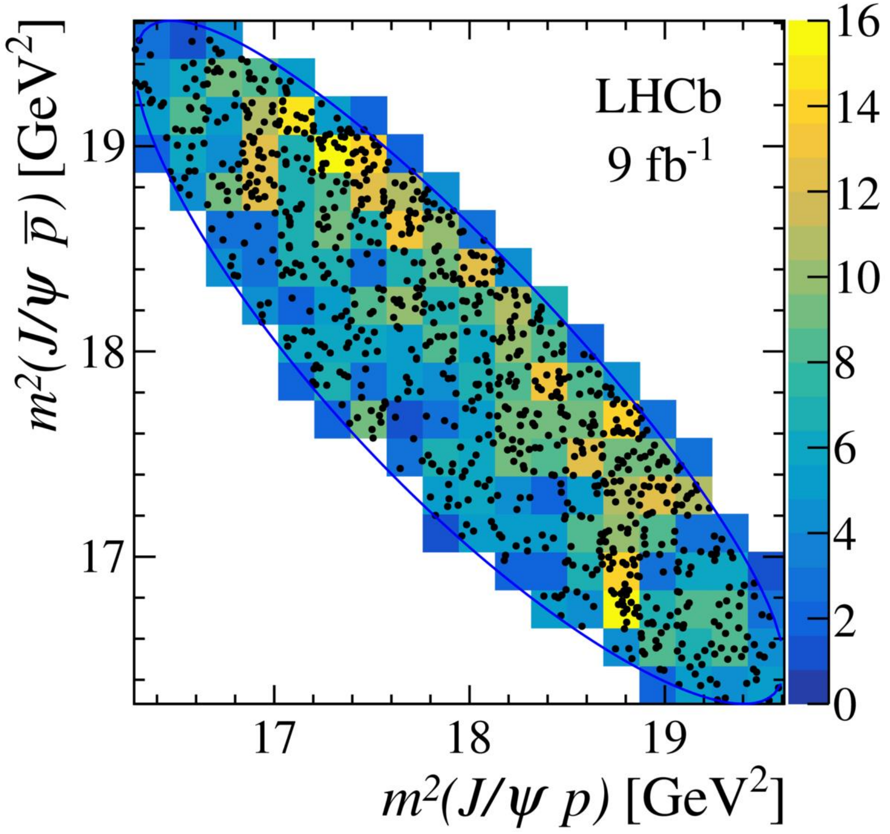
[LHCb-PAPER-2021-018](#)
[arXiv:2108.04720, submitted to PRL]
updates PRL 122 (2019) 191804

P_c^+ states in B_s^0 decays?



- 9 fb^{-1} @ 7, 8 and 13 TeV
- $4D$ amplitude analysis of 800 untagged $B_s^0 \to J/\psi p\bar{p}$ decays
  - No conventional resonances expected in this channel
  - Sensitive to the $J/\psi p$ resonances in the $[4034, 4429]$ MeV range
  - Sensitive to the glueball candidate $f_J(2220) \to p\bar{p}$



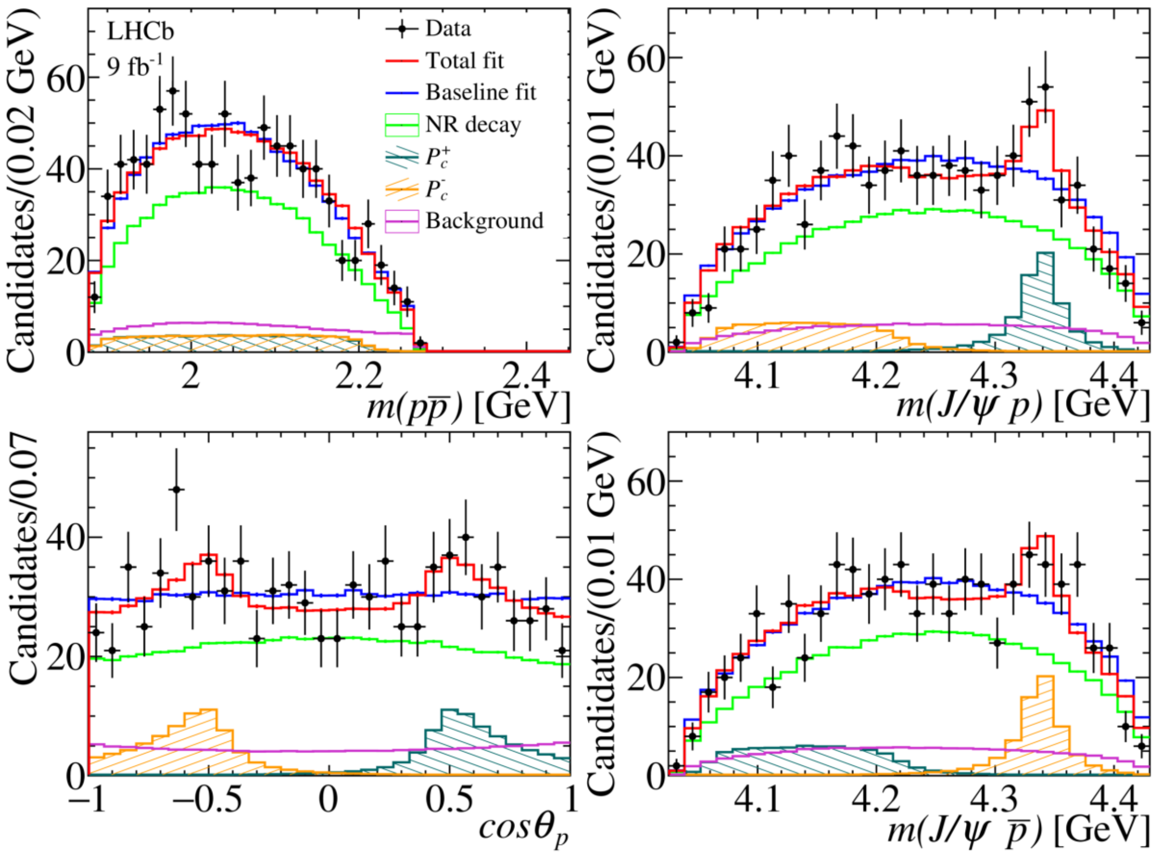


LHCb-PAPER-2021-018
[arXiv:2108.04720, submitted to PRL]
updates PRL 122 (2019) 191804

P_c^+ states in B_s^0 decays?

1. **The baseline model**: two independent NR $J^P = 1^-$ couplings for $B_s^0 \to J/\psi X$ and $X \to p\bar{p}$: $\chi^2/\text{ndf} = 64/38$
2. **The model with two identical resonances** in the $J/\psi p$ and $J/\psi\bar{p}$ systems:
   - No evidence for the $P_c(4312)^+$
   - $J^P = 1/2^+$ states with
     $$m(P_c) = 4337^{+7}_{-4} \pm 2 \text{ MeV}$$
     $$\Gamma(P_c) = 29^{+26}_{-12} \pm 14 \text{ MeV}$$
     give $\chi^2/\text{ndf} = 36.7/36.8$ and 3.7σ significance
   - Main systematics is due to alternative J^P hypotheses
3. No evidence of resonances in the $p\bar{p}$ system
4. No $p\bar{p}$ threshold enhancement is observed

✓ Evidence (3.1σ) for a new P_c state

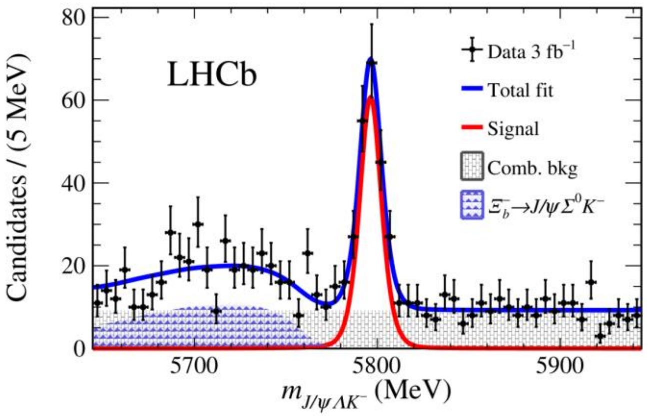


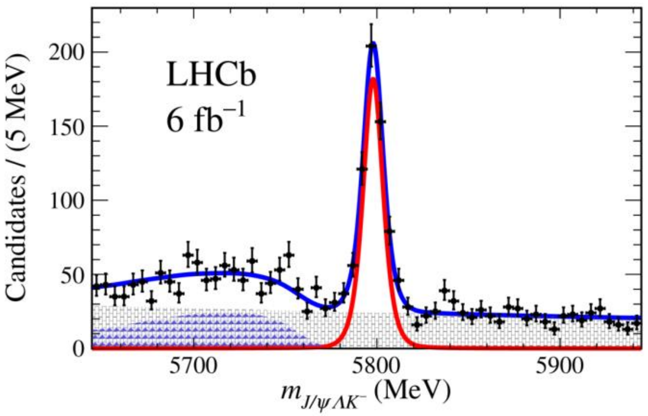
[LHCb-PAPER-2020-039](#)

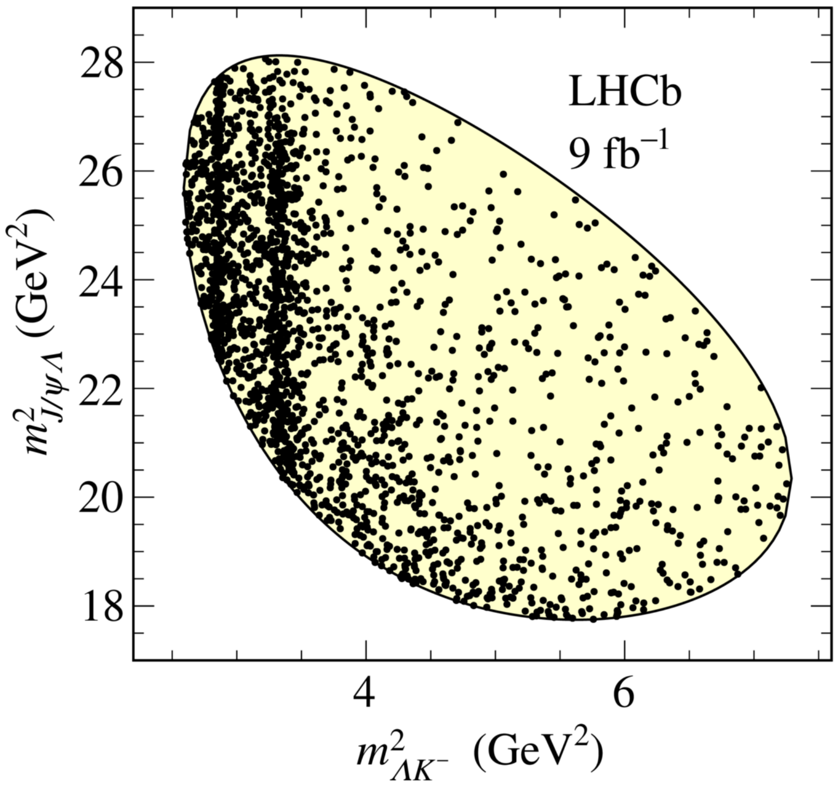
[Science Bulletin 66 (2021) 1278]

Evidence of $P_{cs}(4459)^0$

- 9 fb^{-1} @ 7, 8 and 13 TeV
- Amplitude analysis of 1750 $\Xi_b^- \to J/\psi \Lambda K^-$ decays
- Signal signature: $J/\psi \to \mu^+\mu^-$ and $\Lambda \to p\pi$ with displaced vertices
- Specific background from partially reconstructed $\Xi_b^- \to J/\psi[\Sigma^0 \to \Lambda\gamma]K^-$





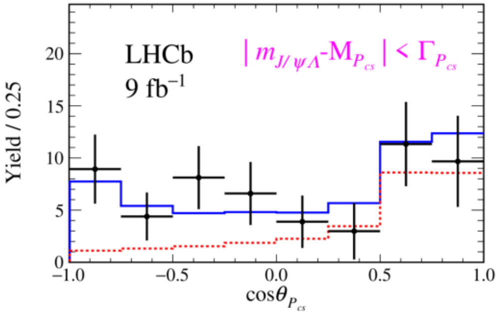


[LHCb-PAPER-2020-039](#)

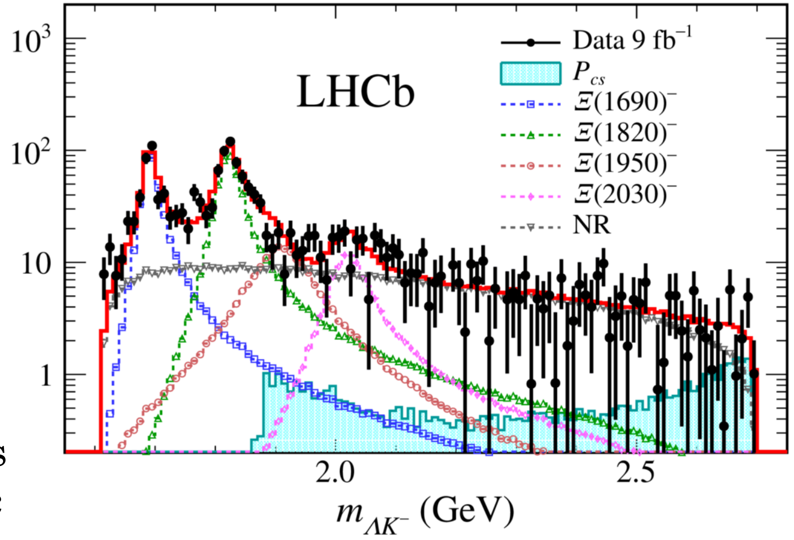
[[Science Bulletin 66 (2021) 1278]](#)

Evidence of $P_{cs}(4459)^0$

- $6D$ amplitude analysis with $m_{\Lambda K}$ and five angles
- 1st evidence for a charmonium pentaquark with strangeness (3.1σ)
- $P_{cs}(4459)^0$ is 19 MeV below the $\Xi_c^0\bar{D}^{*0}$ threshold and it may be a double system like $P_c(4440)^+$ and $P_c(4457)^+$

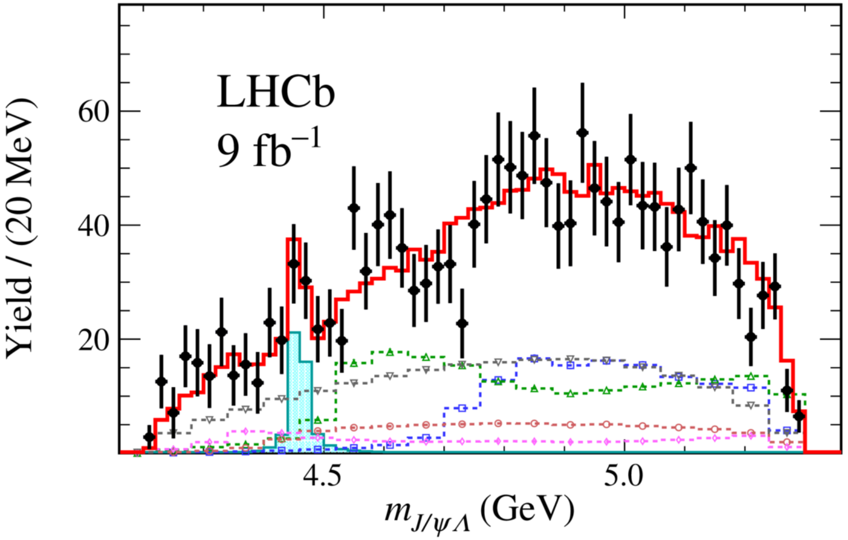


- Different J^P assignments are tested for systematic uncertainty assessment



Free parameters

State	M_0 (MeV)	Γ_0 (MeV)	FF (%)
$P_{cs}(4459)^0$	$4458.8 \pm 2.9^{+4.7}_{-1.1}$	$17.3 \pm 6.5^{+8.0}_{-5.7}$	$2.7^{+1.9}_{-0.6}{}^{+0.7}_{-1.3}$
$\Xi(1690)^-$	$1692.0 \pm 1.3^{+1.2}_{-0.4}$	$25.9 \pm 9.5^{+14.0}_{-13.5}$	$22.1^{+6.2}_{-2.6}{}^{+6.7}_{-8.9}$
$\Xi(1820)^-$	$1822.7 \pm 1.5^{+1.0}_{-0.6}$	$36.0 \pm 4.4^{+7.8}_{-8.2}$	$32.9^{+3.2}_{-6.2}{}^{+6.9}_{-4.1}$
$\Xi(1950)^-$	1910.6 ± 18.4	105.7 ± 23.2	$11.5^{+5.8}_{-3.5}{}^{+49.9}_{-9.4}$
$\Xi(2030)^-$	2022.8 ± 4.7	68.2 ± 8.5	$7.3^{+1.8}_{-1.8}{}^{+3.8}_{-4.1}$
NR	—	—	$35.8^{+4.6}_{-6.4}{}^{+10.3}_{-11.2}$



Doubly charmed T_{cc}^{+}

Doubly charmed tetraquark T_{cc}^{+}

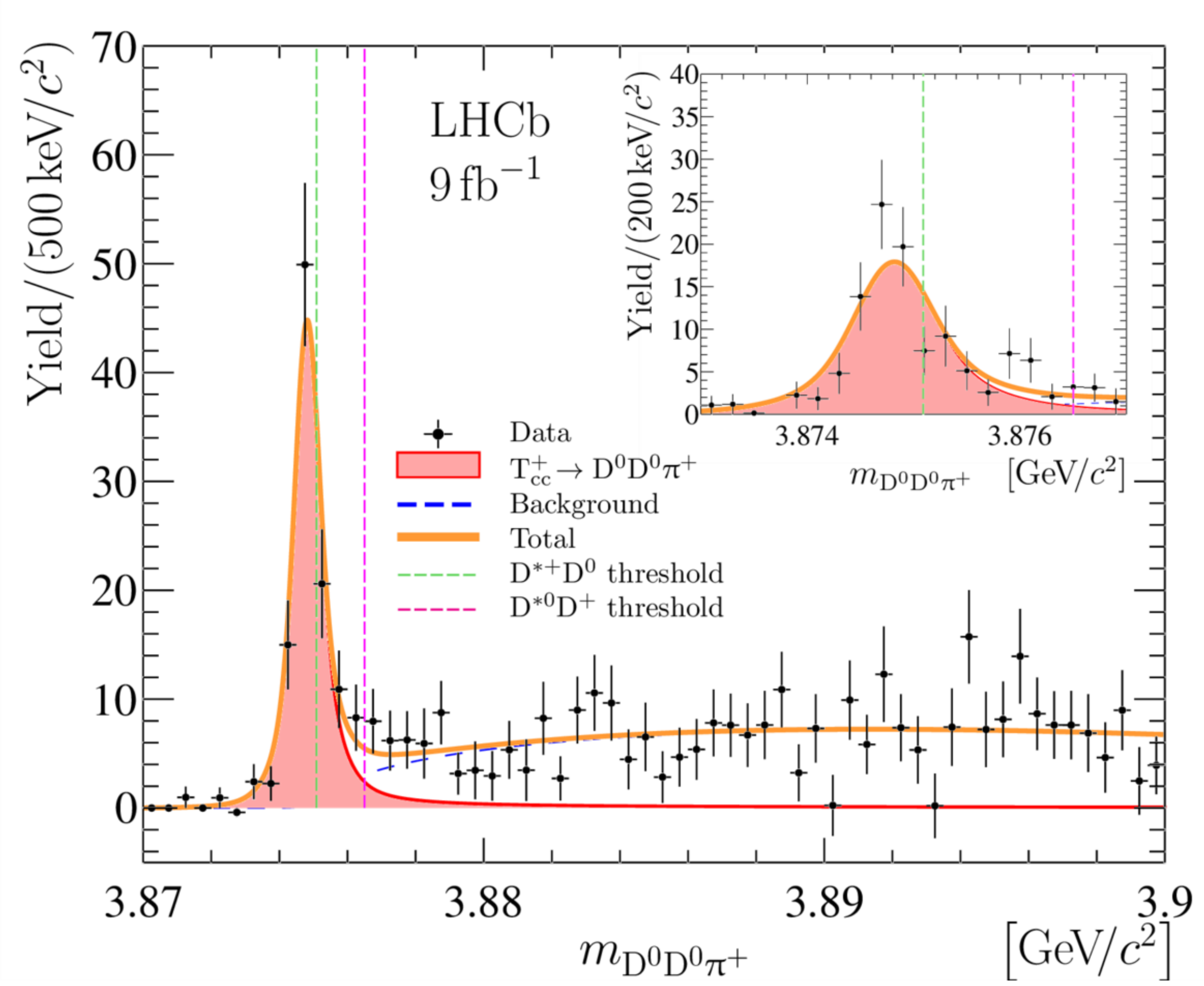
- 9 fb^{-1} @ 7, 8 and 13 TeV
- Inclusive analysis of the $D^0D^0\pi^+$ final state
- **A narrow T_{cc}^{+} state in the $D^0D^0\pi^+$ mass spectrum is observed near the $D^{*+}D^0$ threshold**
- Fit to the data with signal modelled as a $J^P = 1^+$ RBW yields

$$\delta m_{BW}(T_{cc}^{+}) = -273 \pm 63 \pm 5^{+11}_{-14}\ \text{keV}$$

$$\Gamma_{BW}(T_{cc}^{+}) = 410 \pm 165 \pm 43^{+18}_{-38}\ \text{keV}$$

$$\delta m \equiv m(T_{cc}^{+}) - (m(D^{*+}) - m(D^0))$$

- δm_{BW} is negative with 4.3σ. Signal yield is 117 ± 16 events
- This is the narrowest exotic state observed to date



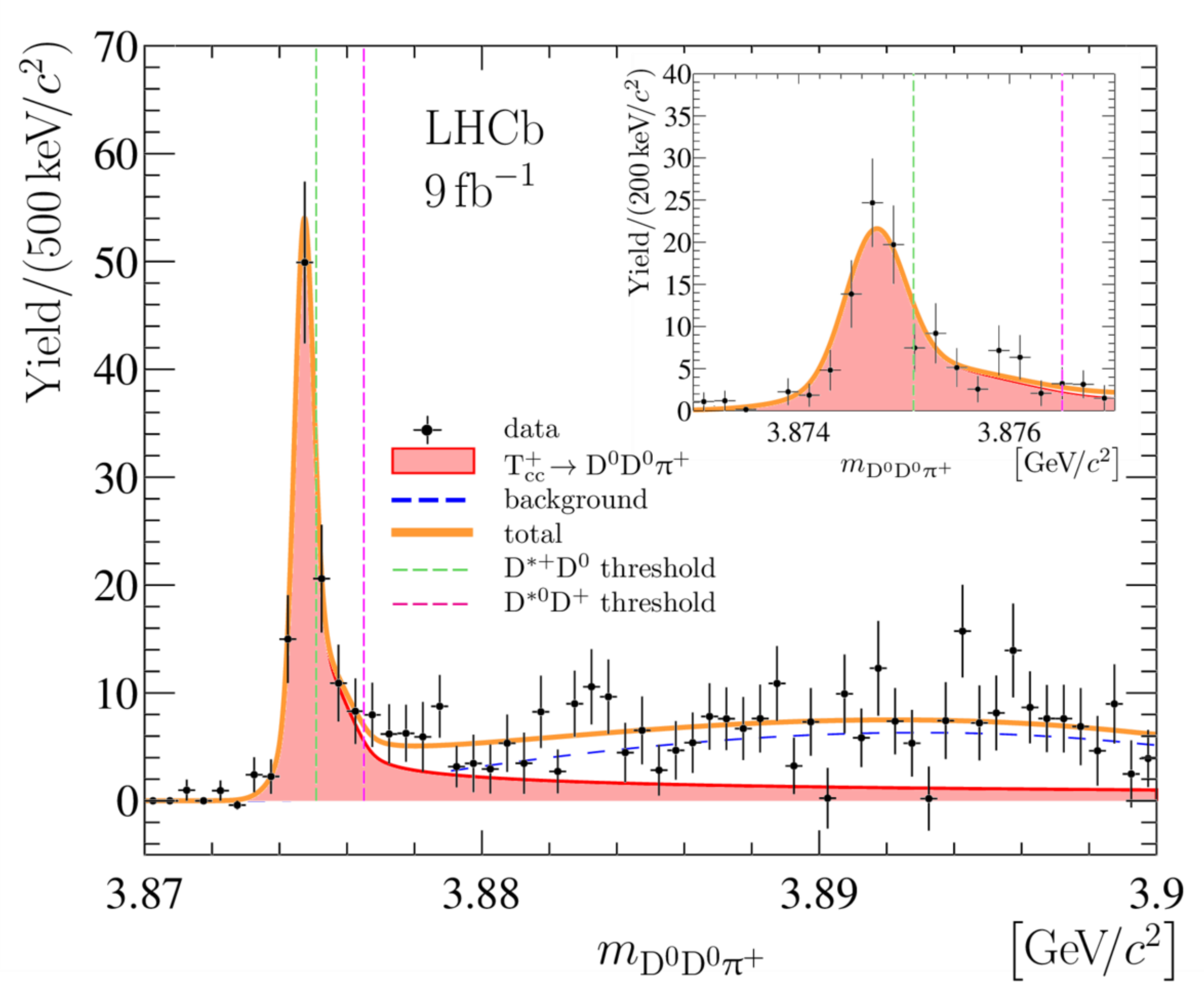
[arXiv:2109.01056]

Doubly charmed tetraquark T_{cc}^{+}

- Unitary model assuming strong coupling of T_{cc}^{+} to the DD^{*} channel:

$$\delta m_{\mathrm{U}}(T_{cc}^{+}) = -359 \pm 40\ \mathrm{keV}$$
$$\mathrm{FWHM}_{\mathrm{U}}(T_{cc}^{+}) = 47.8 \pm 1.9\ \mathrm{keV}$$

- The two heavy quarks Q_1Q_2 form a point-like color-antitriplet, an object analogous to an antiquark. An $Q_1Q_2\bar{q}_1\bar{q}_2$ state has like an antibaryon degrees of freedom (see Karliner, Rosner PRL 119 (2017) 202001)



Conclusions

1. Number of exotic states above the open flavor threshold exceeds the number of conventional states
2. Many states are in vicinity of meson-meson and meson-baryon thresholds
3. LHC*b* is a flagship experiment for discovery and measuring properties of the exotic states
4. A lot of efforts ahead from both theory and experiment
   - A RBW lineshape is unphysical for many heavy exotic states

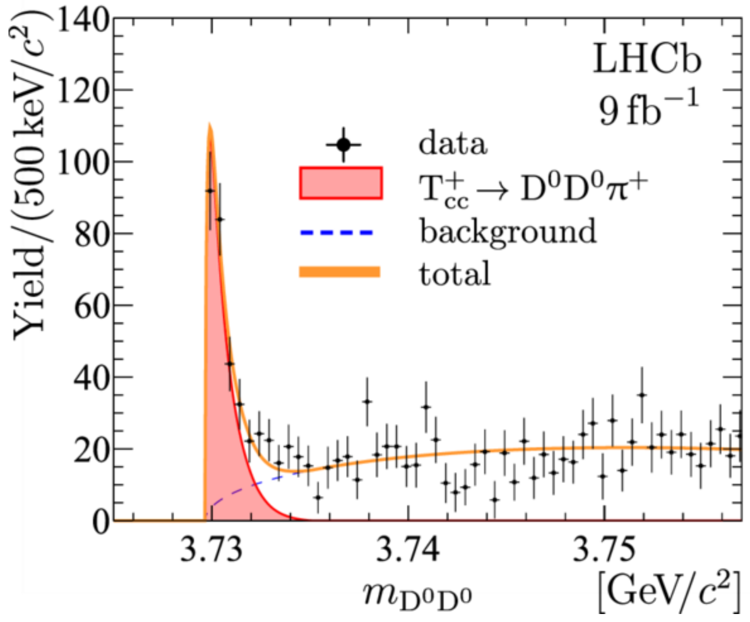
State	Nearby threshold	Minimal content
$X(3872)$	$D^0\bar{D}^{*0}$	$c\bar{c}u\bar{u}$
$T_{c\bar{c}c\bar{c}}(6900)$	No*	$c\bar{c}c\bar{c}$
$Z_{cs}(4000)^+$	No	$c\bar{c}u\bar{s}$
$Z_{cs}(4220)^+$	No	$c\bar{c}u\bar{s}$
$X(4630), X(4685)$	No	$c\bar{c}s\bar{s}$
$P_c(4312)^+$	$\Sigma_c^+\bar{D}^0$	$c\bar{c}uud$
$P_c(4440)^+$	No	$c\bar{c}uud$
$P_c(4457)^+$	$\Sigma_c^+\bar{D}^{*0}$	$c\bar{c}uud$
$P_{cs}(4459)^0$	$\Xi_c^0\bar{D}^{*0}$	$c\bar{c}sud$
T_{cc}^+	D^0D^{*+}	$cc\bar{u}\bar{d}$

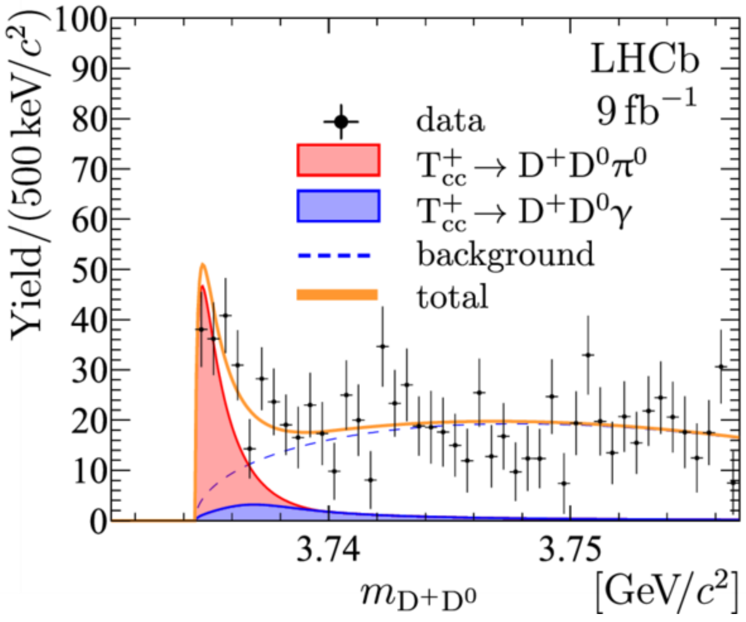
* See A. Nefediev's talk

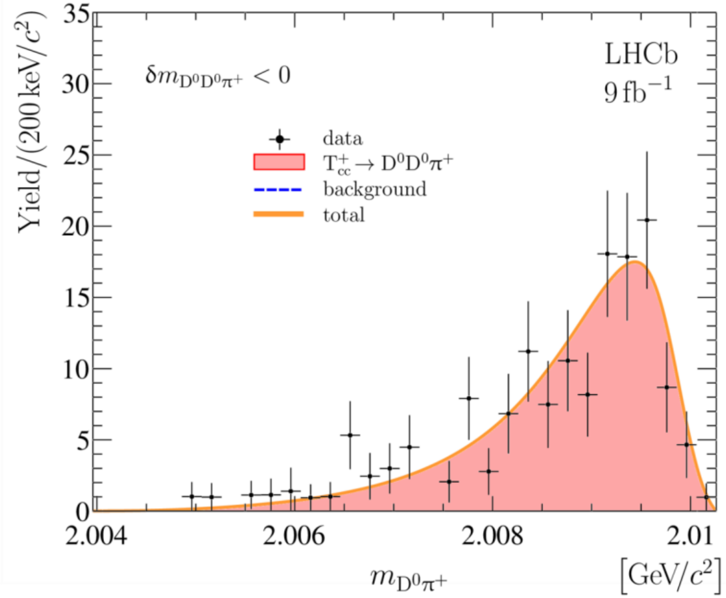
Backup

[arXiv:2109.01056]

Doubly charmed tetraquark T_{cc}^{+}







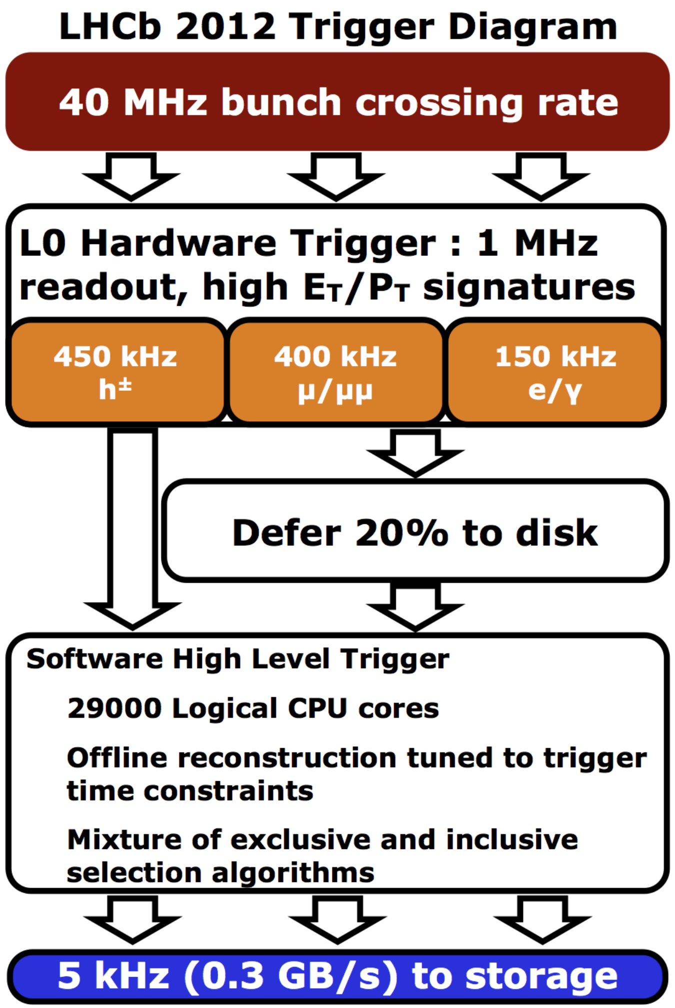
- Combined analysis of D^0D^0, D^+D^0 and $D^0\pi^+$ spectra
- Unitary model assuming strong coupling of T_{cc}^{+} to the DD^* channel:

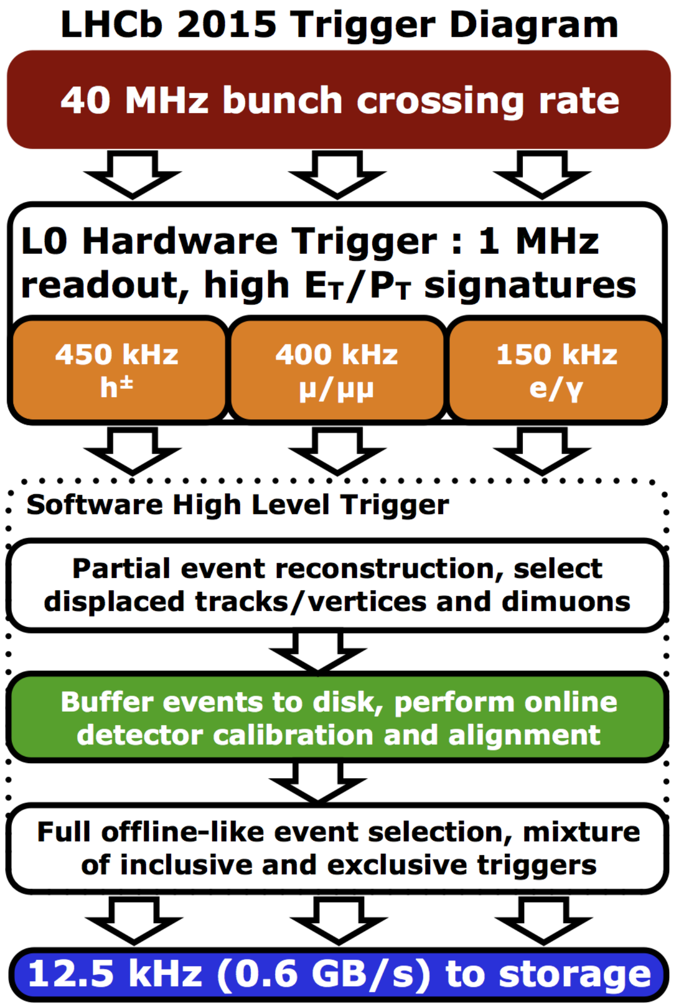
$$\delta m_{\text{pole}}(T_{cc}^{+}) = -360 \pm 40^{+4}_{-0}\text{ keV}$$
$$\Gamma_{\text{pole}}(T_{cc}^{+}) = 48 \pm 2^{+0}_{-14}\text{ keV}$$

- The signals are consistent with originating from off-shell $T_{cc}^{+} \to D^*D$ decays followed by the $D^* \to D\pi$ and $D^* \to D\gamma$ decays
- Signal yields: 263 ± 23 and 171 ± 26 for D^0D^0 and D^0D^+, respectively

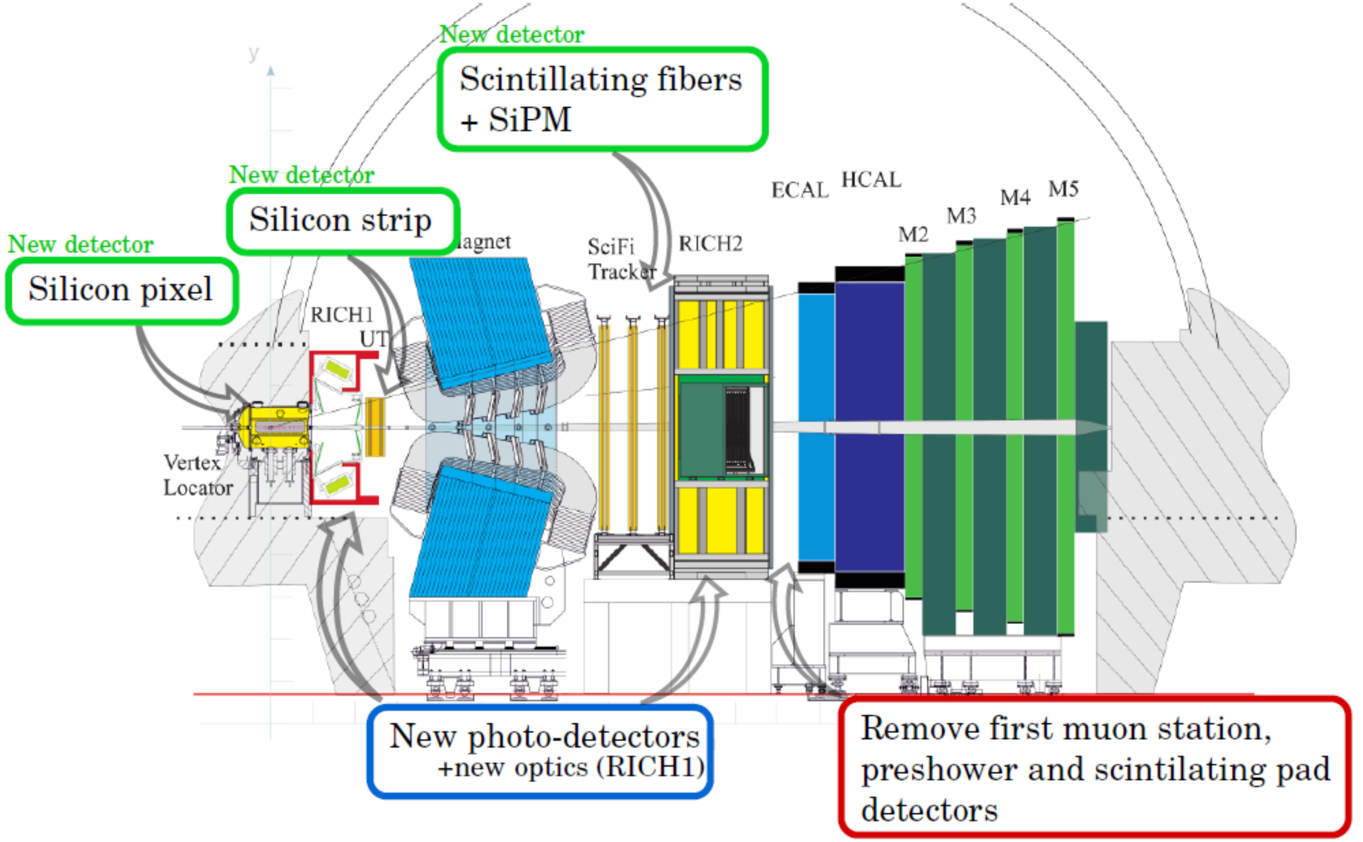
States	[arXiv:2109.01056v2 [hep-ex] 3 Sep 2021]	Quark content
$X_0(2900)$, $X_1(2900)$ [21, 22]		$\bar{c}du\bar{s}$
$\chi_{c1}(3872)$ [6]		$c\bar{c}q\bar{q}$
$Z_c(3900)$ [23], $Z_c(4020)$ [24, 25], $Z_c(4050)$ [26], $X(4100)$ [27], $Z_c(4200)$ [28], $Z_c(4430)$ [29–32], $R_{c0}(4240)$ [31]		$c\bar{c}u\bar{d}$
$Z_{cs}(3985)$ [33], $Z_{cs}(4000)$, $Z_{cs}(4220)$ [34]		$c\bar{c}u\bar{s}$
$\chi_{c1}(4140)$ [35–38], $\chi_{c1}(4274)$, $\chi_{c0}(4500)$, $\chi_{c0}(4700)$ [38], $X(4630)$, $X(4685)$ [34], $X(4740)$ [39]		$c\bar{c}s\bar{s}$
$X(6900)$ [14]		$c\bar{c}c\bar{c}$
$Z_b(10610)$, $Z_b(10650)$ [40]		$b\bar{b}u\bar{d}$
$P_c(4312)$ [41], $P_c(4380)$ [42], $P_c(4440)$, $P_c(4457)$ [41], $P_c(4357)$ [43]		$c\bar{c}uud$
$P_{cs}(4459)$ [44]		$c\bar{c}uds$

LHCb trigger data-flow





LHCb Upgrade I



+Upgraded electronics, trigger and data acquisition system