Results of Hadron Spectroscopy at LHCb

NSTAR2022

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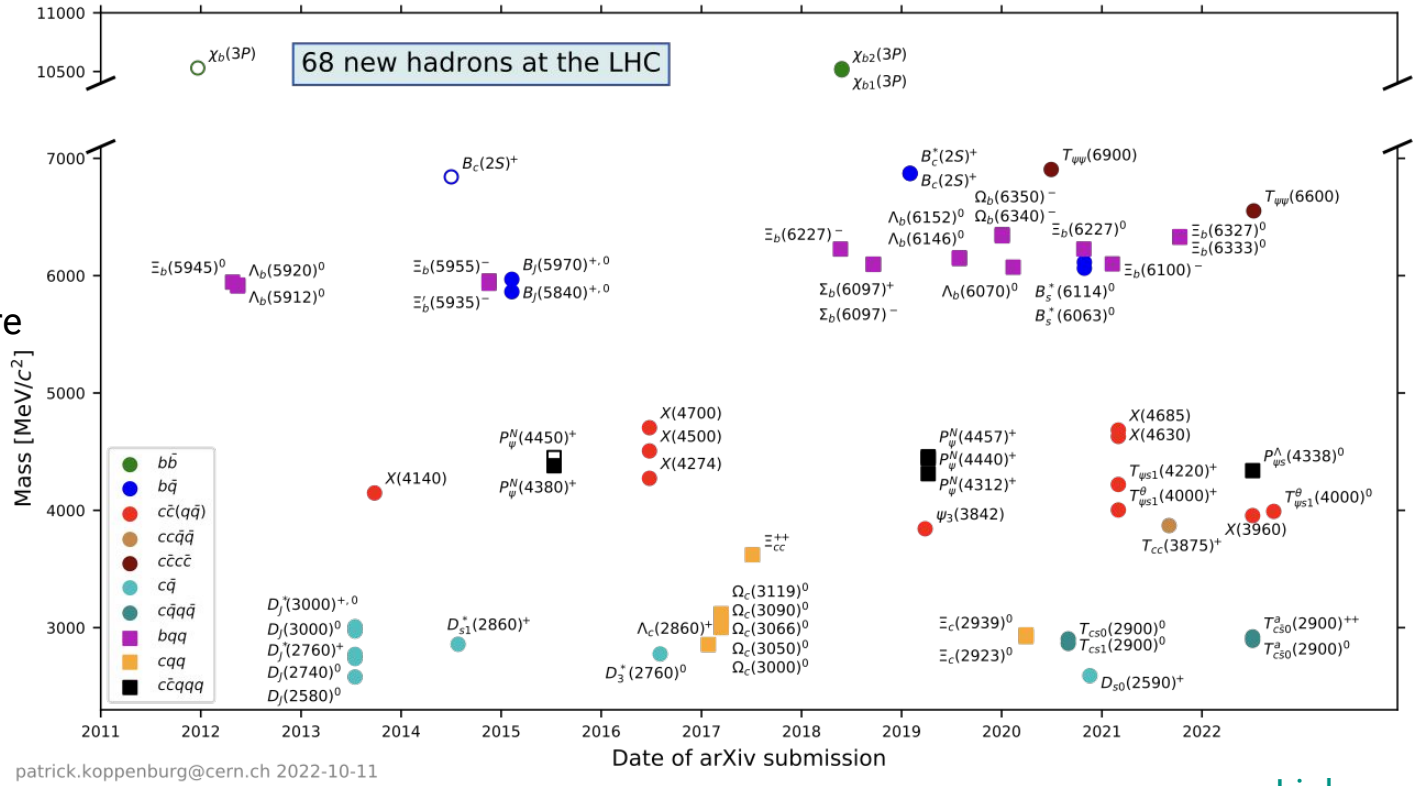
on behalf of the LHCb experiment

Oct 20th, 2022

Spectroscopy at LHC

Over the past 10 years more than 60 new hadrons

More than 15 states are exotics:
⇒ New naming scheme used here
arxiv2206.15233



Link

QCD and spectroscopy

Standard Model

Quarks & gluons

Nature

Color-singlet mesons and baryons

strong interaction
(long-distance effects)

Conventional spectroscopy

HQET predicts the masses of the heavy hadrons:

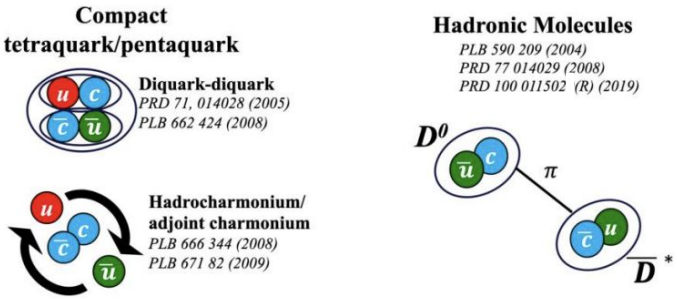
- expansion in $\Lambda_{QCD}/m_Q \sim 0$

Need for precise measurements of the excited hadron properties to test the validity of HQET

Exotic spectroscopy

Many states predicted with minimal quark content different from $q\bar{q}$ and qqq

Lots of theoretical models



Study of exotics in production and decays to discriminate among models

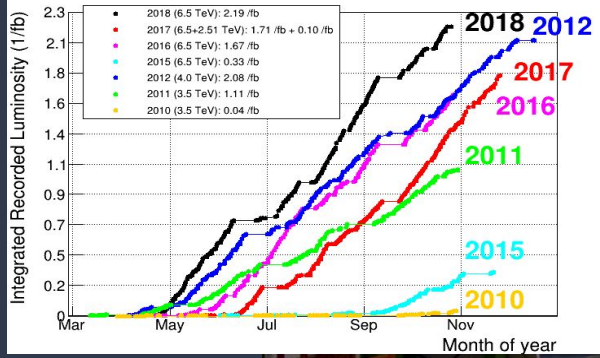
Both can be used to test **Lattice QCD** calculations at low energies

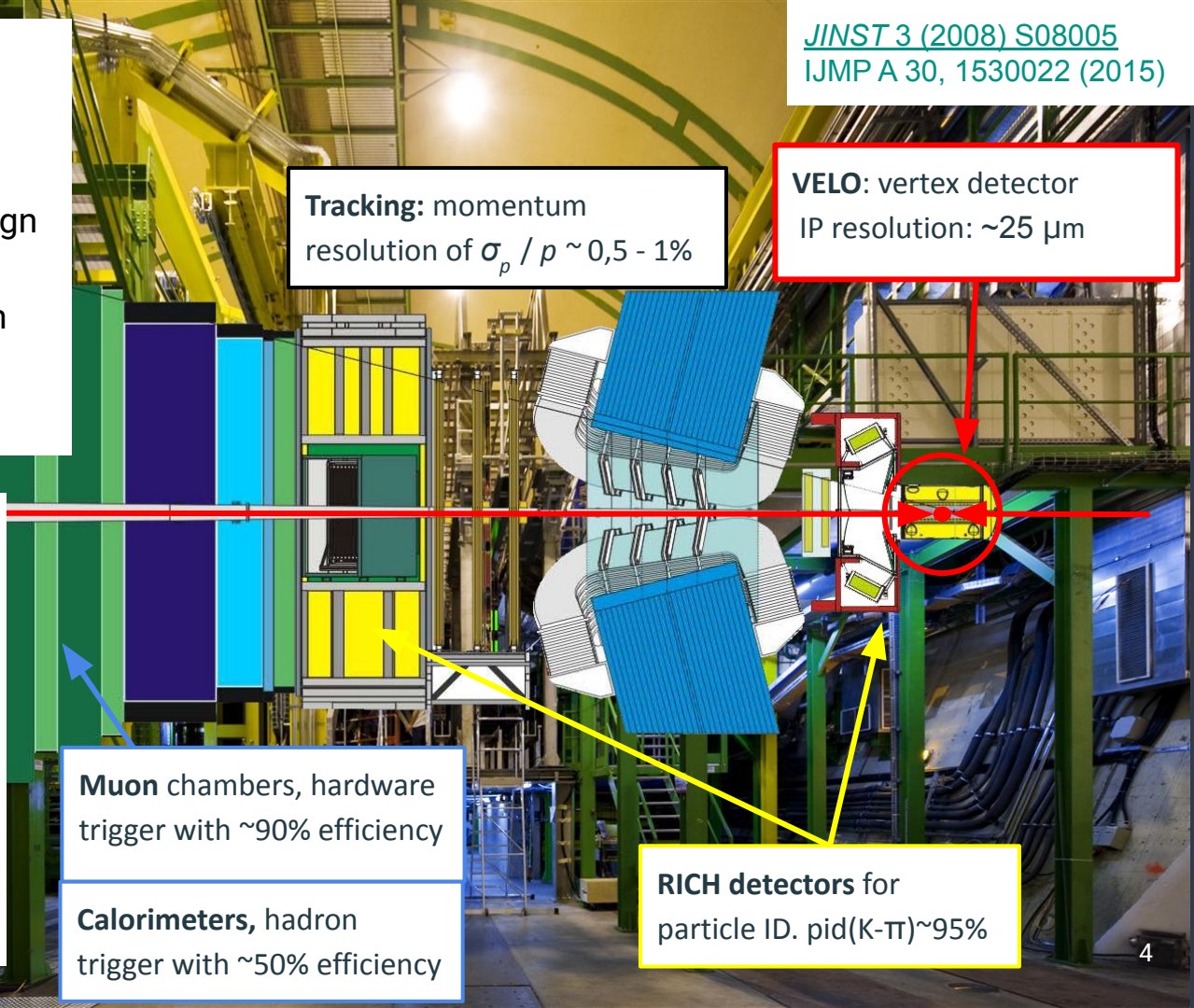
LHCb detector

The major player in spectroscopy thanks to its unique dedicated design

- high vertex resolution
- high invariant mass resolution
- RICH detectors for PID
- highly performant trigger

Luminosity:
Run 1 and Run 2: 9 fb^{-1}





JINST 3 (2008) S08005
IJMP A 30, 1530022 (2015)

Tracking: momentum resolution of $\sigma_p / p \sim 0{,}5 - 1\%$

VELO: vertex detector
IP resolution: ~25 μm

Muon chambers, hardware trigger with ~90% efficiency

Calorimeters, hadron trigger with ~50% efficiency

RICH detectors for particle ID. pid(K-π)~95%

Outline

Conventional spectroscopy

Observation of excited Ξ_b^0, Ξ_c^0 and Ξ_{cc}^{++} baryons

Search for Ξ_{cc}^{+}, Ξ_{bc}^{0}, Ξ_{bc}^{+} , Ω_{bc}^{0}

see also talk by Roberta Cardinale

Exotic spectroscopy

$\chi_{c1}(3872)$ state: dipion mass spectrum

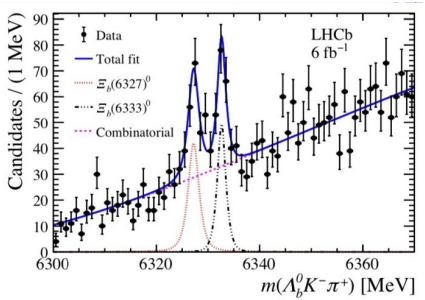
Tetraquarks:

- doubly charmed tetraquark T_{cc}
- charm-strange tetraquarks $T_{cs0}(2600)^{0/++}$

Pentaquark with strangeness

Spectroscopy study techniques

Invariant-mass fit



PRL 126 (2021) 252003

To extract mass peaks parameters, M and Γ

⇒ used for conventional resonances

Amplitude analysis

Phase space: masses and angles

DATA **MODEL**

Helicity/ Tensor formalism + lineshape

FIT

Maximum $\mathcal{L}$ fit to extract parameters

To measure J^P, mass and width & account for reflections

⇒ more important for exotic hadron studies

Moment analysis

Legendre poly expansion

⇒ Model independent check

Conventional spectroscopy

Excited Ξ_c states

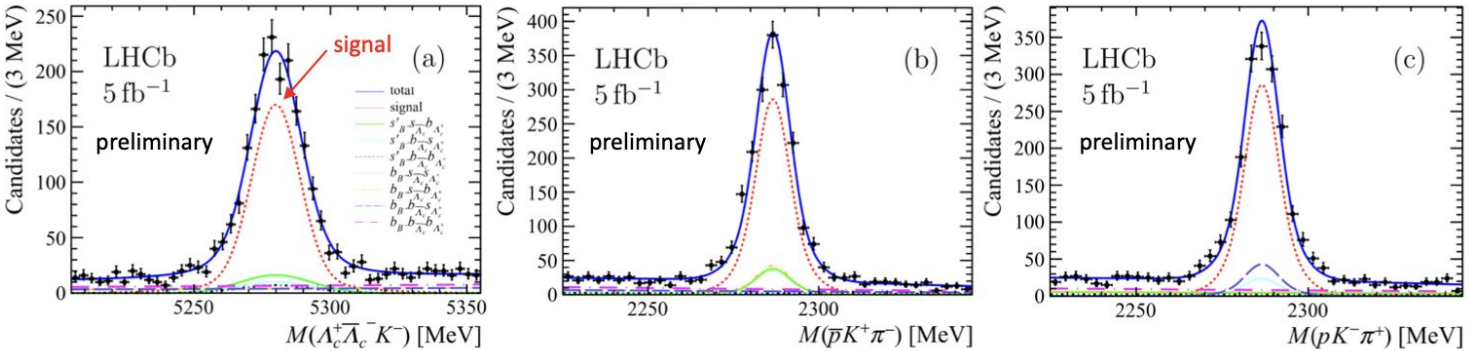
NEW

LHCb-PAPER-2022-028, in preparation

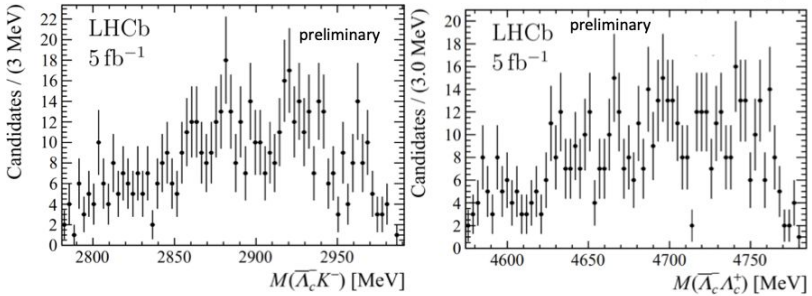
$B^- \to \Lambda_c^+ \overline{\Lambda}_c^- K^-$ interesting for conventional & exotics

↳ $\Lambda_c^+ K^-$ ↳ $\Lambda_c^+ \overline{\Lambda}_c^-, \Lambda_c^+ K^-$

High-purity sample with N=1365 ± 42



No significant hint of exotics in $\Lambda_c^+ \overline{\Lambda}_c^-, \Lambda_c^+ K^-$
on the contrary of Belle result in $\Lambda_c^+ \overline{\Lambda}_c^-$



[1] Phys.Rev.Lett.101:172001,2008

Excited Ξ_c states (1)

NEW

LHCb-PAPER-2022-028, in preparation

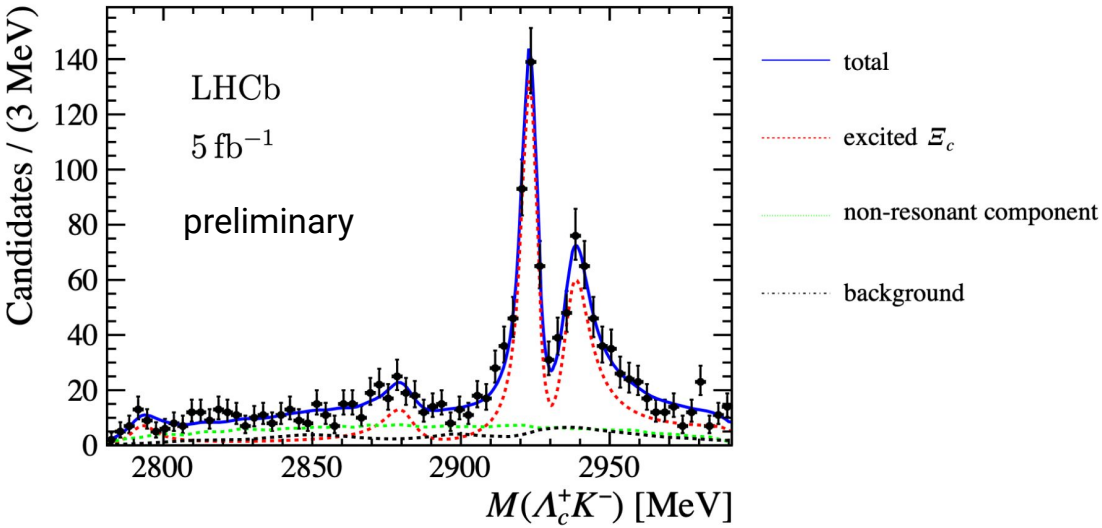
Search for excited Ξ_c states in $B^- \to \Lambda_c^+ \bar{\Lambda}_c^- K^-$ decays, decaying to $\Lambda_c^+ K^-$

$\Xi_c(2930)^0$ state observed by Belle[1] is resolved into 2 peaks:

- $\Xi_c(2923)^0$ with Γ~5 MeV
- $\Xi_c(2939)^0$ with Γ~11 MeV

Evidence at ~ 3.7σ of:

- new **state** $\Xi_c(2880)^0$
- new **decay mode** of $\Xi_c(2790)^0$



Observation of new excited Ξ_b

PRL 128, 162001 (2022)

Few excited Ξ_b states observed so far:

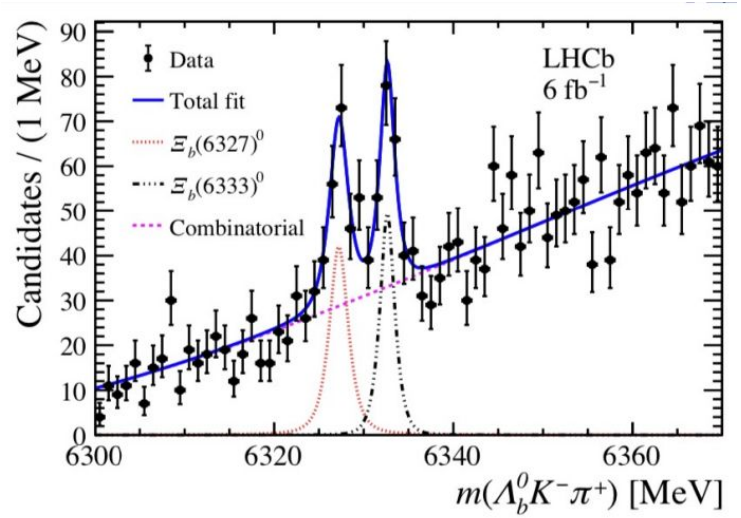
- $\Xi_b(6227)^0/\Xi_b(6227)^-$ by LHCb [1,2]
- $\Xi_b(6100)^-$ by CMS [3]

New searches in $\Lambda^0_b K^- \pi^+$ final state

⇒ 2 states observed: $\Xi_b(6327)^0$, $\Xi_b(6333)^0$

$$m[\Xi_b(6327)^0] = 6327.28^{+0.23}_{-0.21}\ \text{MeV},$$
$$m[\Xi_b(6333)^0] = 6332.69^{+0.17}_{-0.18}\ \text{MeV},$$
$$\Gamma[\Xi_b(6327)^0] = 0.93^{+0.74}_{-0.60}\ \text{MeV},$$
$$\Gamma[\Xi_b(6333)^0] = 0.25^{+0.58}_{-0.25}\ \text{MeV},$$

(RBW)



- Widths consistent with mass reso
- 1D doublet, $J^P = 3/2^+$ and $J^P = 5/2^+$

[1] Phys. Rev. Lett. 121, 072002 (2018).
[2] Phys. Rev. D 103, 012004 (2021).
[3] Phys. Rev. Lett. 126, 252003 (2021).

Observation of $\Xi_{cc}^{++} \to \Xi_c^{'+}\pi^+$

JHEP 2205 (2022) 038

Partially reconstructed decay of $\Xi_c^{'+} \to \Xi_c\gamma$
& exploiting decay of $\Xi_c \to pK\pi$

With different trigger requirements

$\Xi_c^{++} \to \Xi_c^{'+}\pi^+$:
shifted and distorted

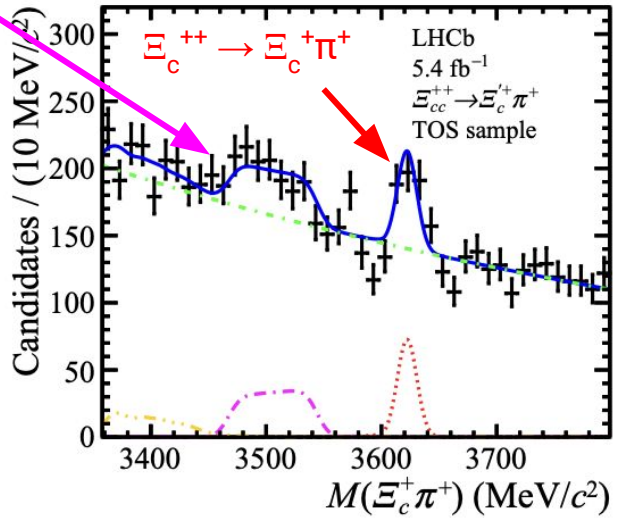
triggered by at least one of the Ξ_c^+ decay products

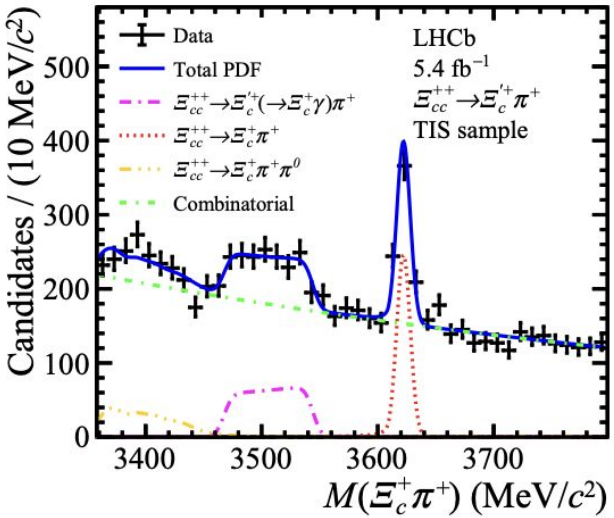
exclusively triggered

⇒ Observed at 9.6σ

Ratio of BRs

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{'+}\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+\pi^+)} = 1.41 \pm 0.17 \pm 0.10$$





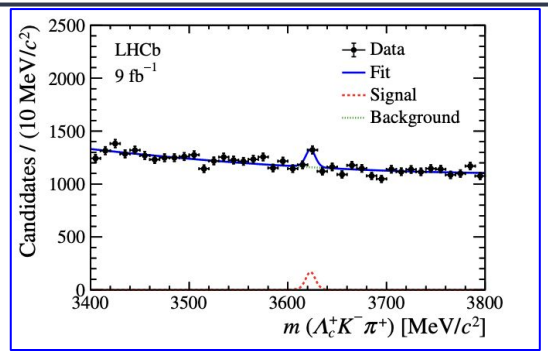
Search for Ξ_{cc}^{+} states

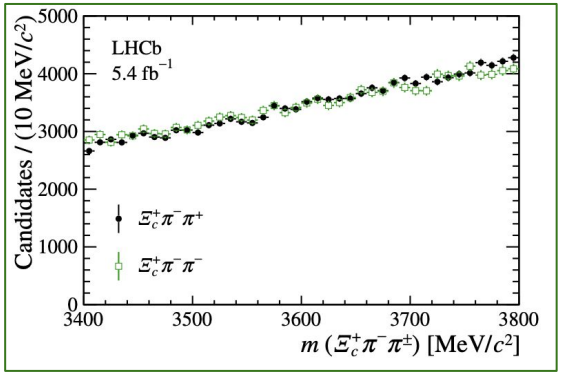
JHEP 2112 (2021) 107

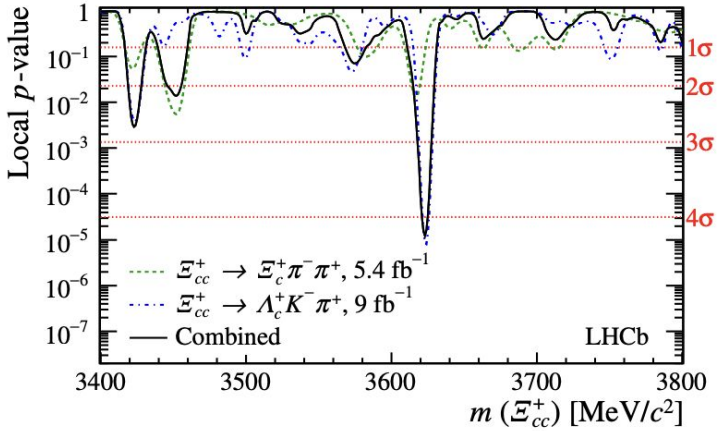
Search in $\Xi_c^{+}\pi^{-}\pi^{+}$ final state
→ No peaks are seen and UL are set on R

R: production cross-section multiplied by BR and normalised to $\Xi_c^{++} \to \Xi_c^{+}\pi^{+}$

Results combined with $\Lambda_c^{+}K^{-}\pi^{+}$ results [1]







Local significance of ~4σ at 3620 MeV

[1] Sci. China Phys. Mech. Astron. 63 (2020) 221062

Search for Ξ_{bc}^{0}, Ω_{bc}^{0}, Ξ_{bc}^{+}

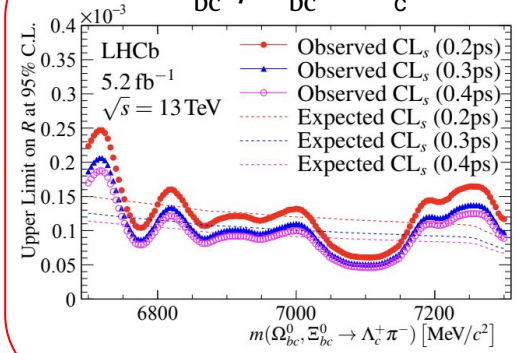
Chin. Phys. C 45 093002, arXiv:2204.09541v1

Search for peaks in the $\Lambda_c^+\pi^-$ / $\Xi_c^+\pi^-$ and $J/\psi\ \Xi_c^+$ final states

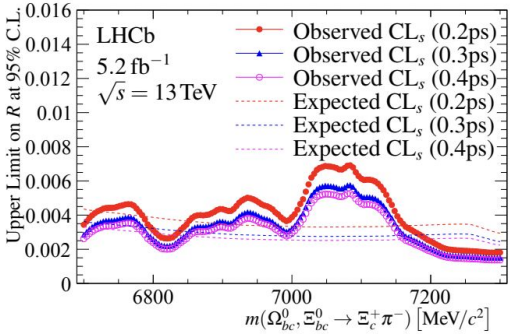
- No obvious peaks
- UL are set at 95% CL

R: production cross-section multiplied by BR and normalised with Λ_b^0/Ξ^0_b (decays to $\Lambda_c^+\pi^-/\Xi^+_c\pi^-$) and $B_c^+\to J/\psi\ D_s^+$

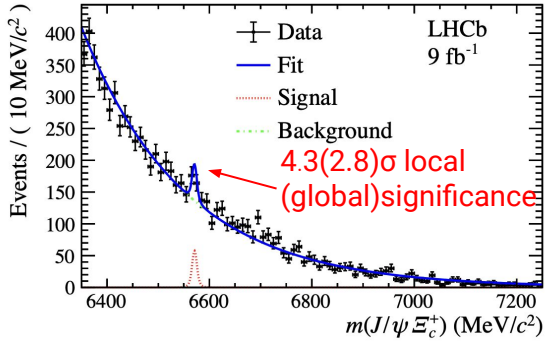
$\Xi_{bc}^{0}/\Omega_{bc}^{0} \to \Lambda_c^+\pi^-$

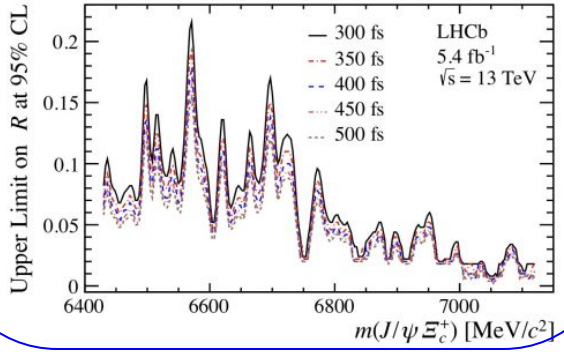


$\Xi_{bc}^{0}/\Omega_{bc}^{0} \to \Xi_c^+\pi^-$



$\Xi_{bc}^{+} \to J/\psi\ \Xi_c^+$



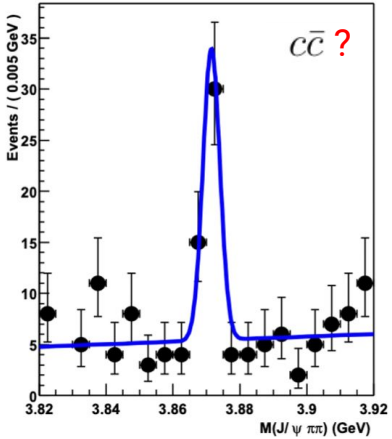


Exotic spectroscopy

First exotic candidates

$\chi_{c1}(3872)$

by Belle in 2003 in
$B^{\pm}\to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays



PRL **91**, 262001 (2003)

⇒ $J^{PC}=1^{++}$ by LHCb

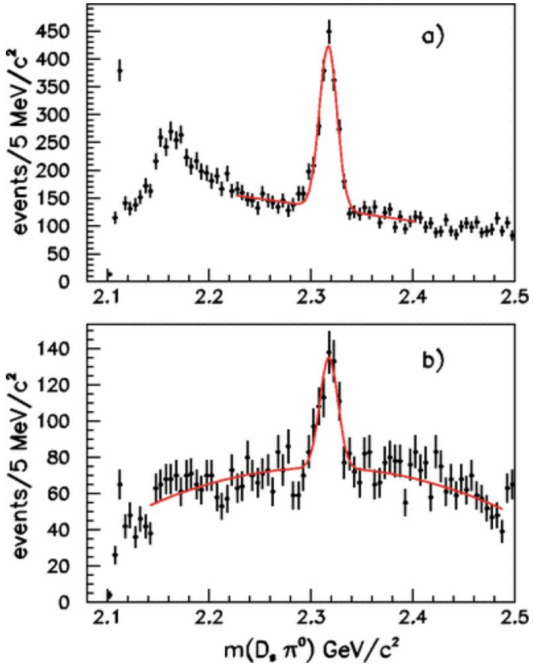
PRL. 110 (2013) 222001

$D^*_{s0}(2317)$

by BABAR in 2003
in the isospin violating
$D^{+}_{s}\pi^{0}$ decay

PRL 90, 242001 (2003)

$c\bar{s}$?



Nature of $\chi_{c1}(3872)$ state

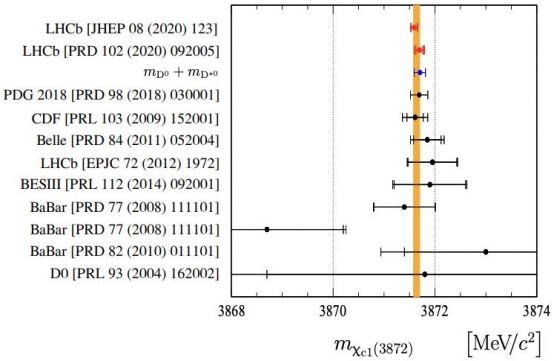
Many experiments contribute to it:

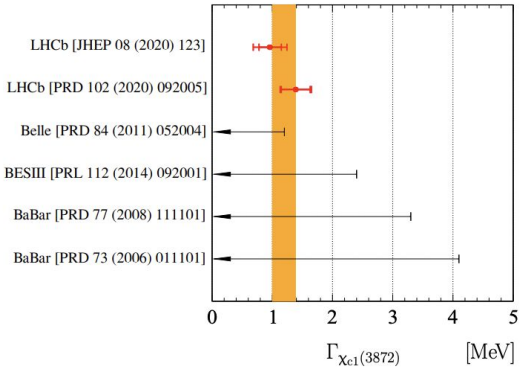
- Spin assignment: $J^{PC} = 1^{++}$ [1]
- Mass is consistent with $m(D^0) + m(D^{*0})$
- Width is surprisingly narrow

Its nature is still under debate!

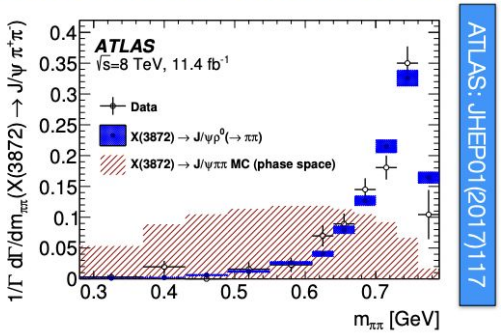
Study of decay processes can help understand its nature, ie. decay to $\pi^+\pi^- J/\psi$

⇒ $\rho^0(770)$ contamination seemed to describe the phsp [2]





JHEP 08 (2020) 123

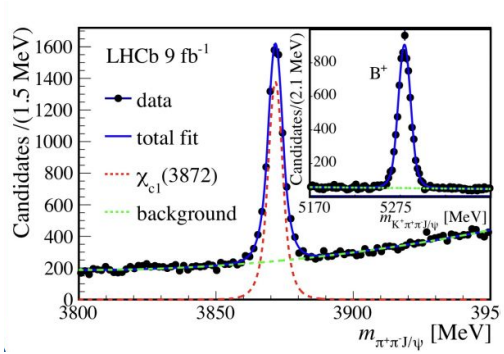


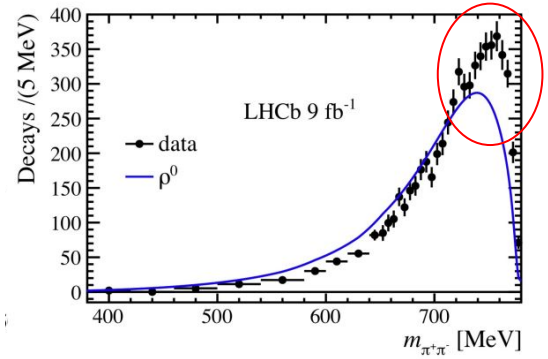
[1] PRL. 110 (2013) 222001,
PRD 92 (2015) 011102(R)
[2] JHEP 01(2017)117

Is it all $\chi_{c1} \to \rho^0 J/\psi$?

LHCb-PAPER-2021-045, arXiv:2204.12597v1

2D fits in $m(\pi^+\pi^- J/\psi)$ and $m(\pi^+\pi^-)$ intervals





Previous $\chi_{c1}(3872) \to \varrho J/\psi$ simulations do not simulate the effects of phase space on resonance masses in a decay sequence

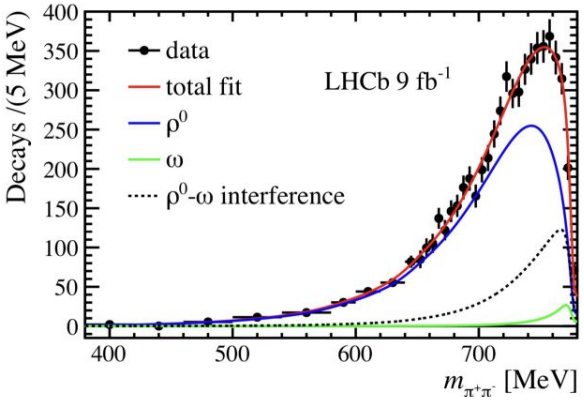
⇒ $p(J/\psi)$ suppression factor missing in the simulations!

ω contribution is small (~2%) but is enhanced by ω-ρ interference (~19%)

Ratio of isospin violating to isospin conserving $\chi_{c1}(3872)$ couplings: much larger than expected for a charmonium state

$$\frac{g_{\chi_{c1}(3872)\to\rho^0 J/\psi}}{g_{\chi_{c1}(3872)\to\omega J/\psi}} = 0.29 \pm 0.04. \qquad \frac{g_{\psi(2S)\to\pi^0 J/\psi}}{g_{\psi(2S)\to\eta J/\psi}} = 0.045 \pm 0.001$$

⇒ hint of exotic nature!

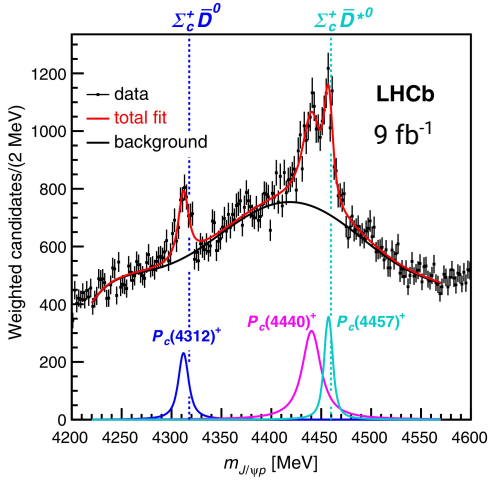


Manifestly exotic

Pentaquarks $c\bar{c}uud$

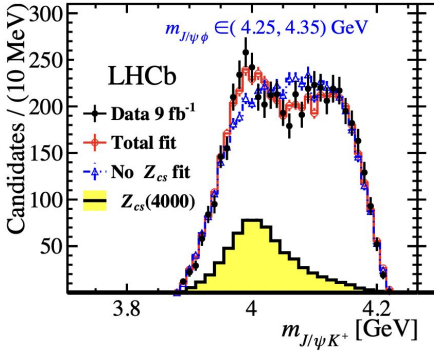
by LHCb in 2015 in $\Lambda_b \rightarrow J/\psi p K$ [1]

$P^N_\psi(4312)^+$ + 2 peaks at 4450 MeV [2]

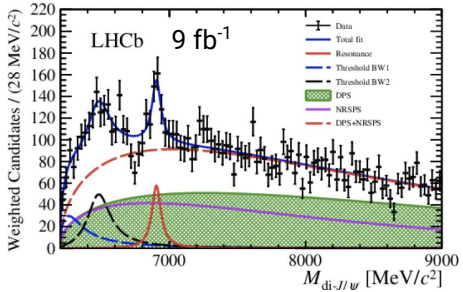


Tetraquarks

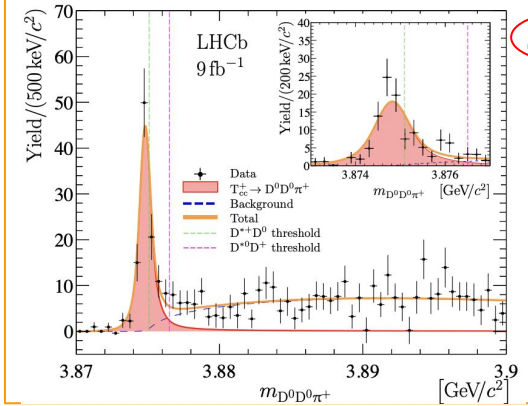
$Z_{cs}(4000)^+ (\rightarrow T^\theta_{\psi s1})$ [3] $c\bar{c}u\bar{s}$



$T_{\psi\psi}(6900)$: di-ψ resonance [4] $c\bar{c}c\bar{c}$



Doubly-charm tetraquark $T_{cc}(3875)^+$ [5,6] $c\bar{c}\bar{u}\bar{d}$

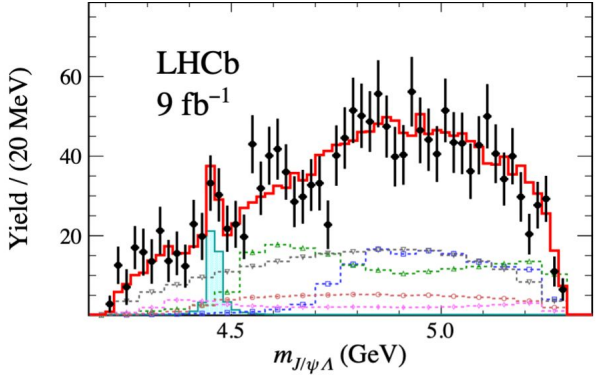


[1] PRL 115, 072001 (2015)
[2] PRL 122, 222001 (2019)
[3] PRL 127, 082001 (2021)
[4] Sc. Bull. 2020 65(23)1983-1993
[5] Nature Physics (2022),
[6] Nature Comm., 13, 3351 (2022)

Other pentaquark evidences

Evidence for $P^{\Lambda}_{\psi s}(4459)$
in $\Xi_b^- \to J/\psi \Lambda K^-$ at 3.1σ

$c\bar{c}uds$

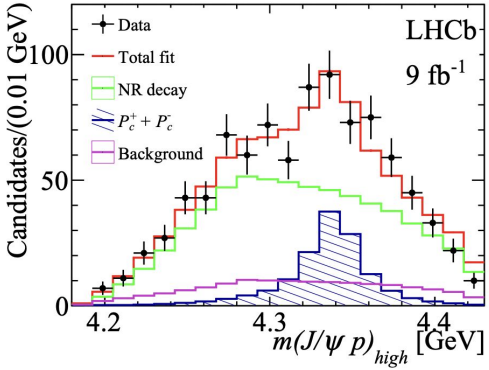


⇒ pentaquark with strangeness
✓ at $\Xi_c^0 D^{*0}$ threshold

Sci.Bull. 66 (2021) 1278-1287
PLB 772 (2017) 265-273

Evidence for $P^{N}_{\psi}(4337)$
in $B_s \to J/\psi p\bar{p}$ at 3.1σ

$c\bar{c}uud$



⇒ P^{N}_{ψ} in B meson decay
✓ $J^P = ½^+$ for P^{N+}_{ψ} preferred (?)

PRL 122, 191804 (2019)
PRL 128, 062001 (2022)

New Tetraquarks

Observation of doubly charm tetraquark

Nature Physics (2022); *Nature Communications* 13, 3351 (2022)

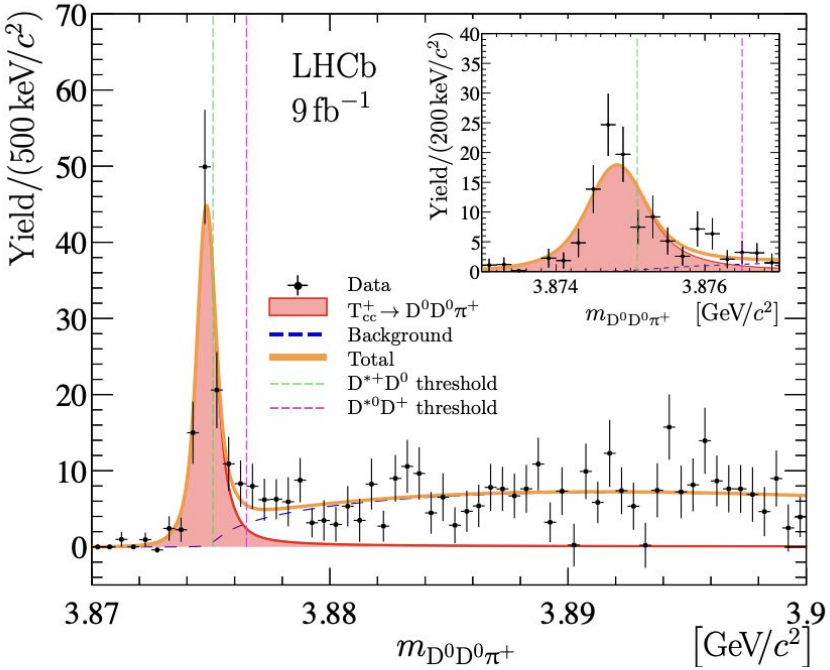
First observation of same-sign
double charmed tetraquark, $T_{cc}^{+}(3875)$

⇒ exotic quark content $cc\bar{u}\bar{d}$

Mass close to $D^{*+}D^{0}$ threshold and very narrow

$$\delta m_{\mathrm{BW}} = -273 \pm 61(\mathrm{stat}) \pm 5(\mathrm{syst})^{+11}_{-14}(\mathrm{model})\ \mathrm{keV}$$
$$\Gamma = 410 \pm 65(\mathrm{stat}) \pm 43(\mathrm{syst})^{+18}_{-38}(\mathrm{model})\ \mathrm{keV}$$

Consistent with isoscalar $J^{P}=1^{+}$



Tetraquark candidates in $B \to DDh$

$T^a_{c\bar{s}0}(2900)^{++} \to D_s^+\pi^+$ in $B^+ \to \bar{D}^- D_s^+ \pi^+$

$T^a_{c\bar{s}0}(2900)^{0} \to D_s^+\pi^-$ in $B^0 \to \bar{D}^0 D_s^+ \pi^-$

- Quark contents: $[c\bar{s}u\bar{d}]$, $[c\bar{s}\bar{u}d]$

LHCb-PAPER-2022-026

$X(3960) \to D_s^+ D_s^-$ in $B^+ \to D_s^+ D_s^- K^+$

- Quark content: $[c\bar{c}s\bar{s}]$?

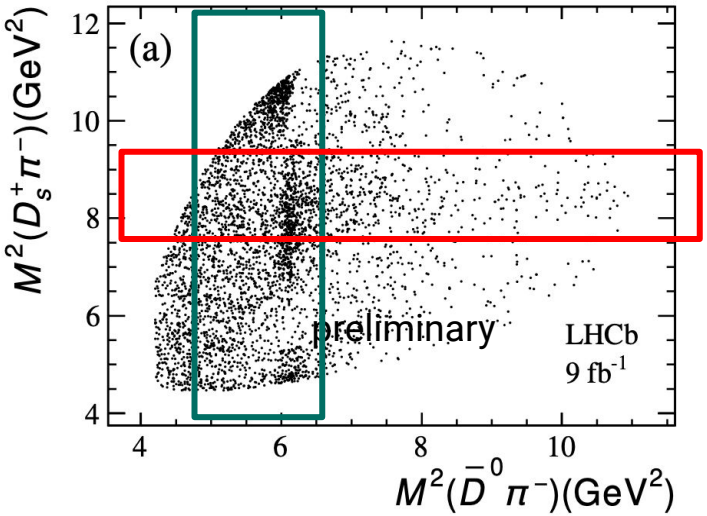
LHCb-PAPER-2022-018

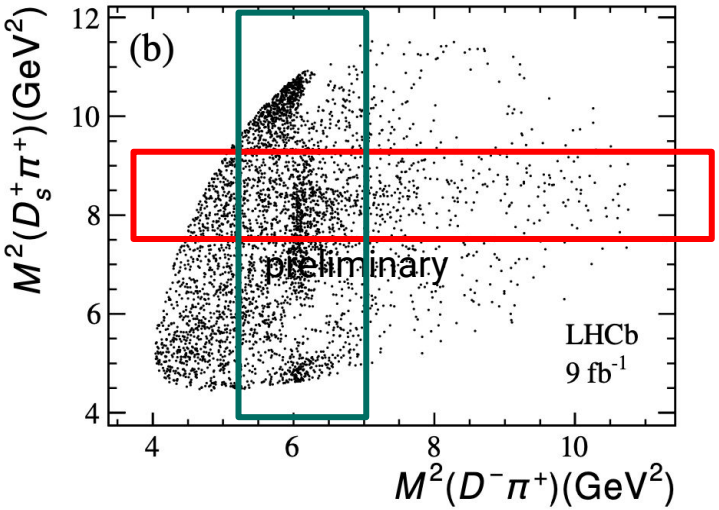
Dalitz plot of $B^{0/+} \to D^{0/-} D_s^{+} \pi^{-/+}$ decays

LHCb-PAPER-2022-026

$B^0 \to \bar{D}^0 D_s^+ \pi^-$ $B^+ \to D^- D_s^+ \pi^+$

Signal yields: ~4000 with 90% signal purity 3750 with 95% signal purity





Clear vertical band at $M^2(D\pi)$~6 GeV^2: $D_2^*(2460)$

Horizontal band at $M^2(D_s\pi)$~8.5 GeV^2

⇒ tetraquark candidates?

$T^a_{c\bar{s}0}(2900)^{0/++} \to D_s^+\pi^{-/+}$ states

LHCb-PAPER-2022-026

$B^0 \to \bar{D}^0 D_s^+\pi^-$ $\quad$ $B^+ \to D^- D_s^+\pi^+$

Not well described, even adding new D**

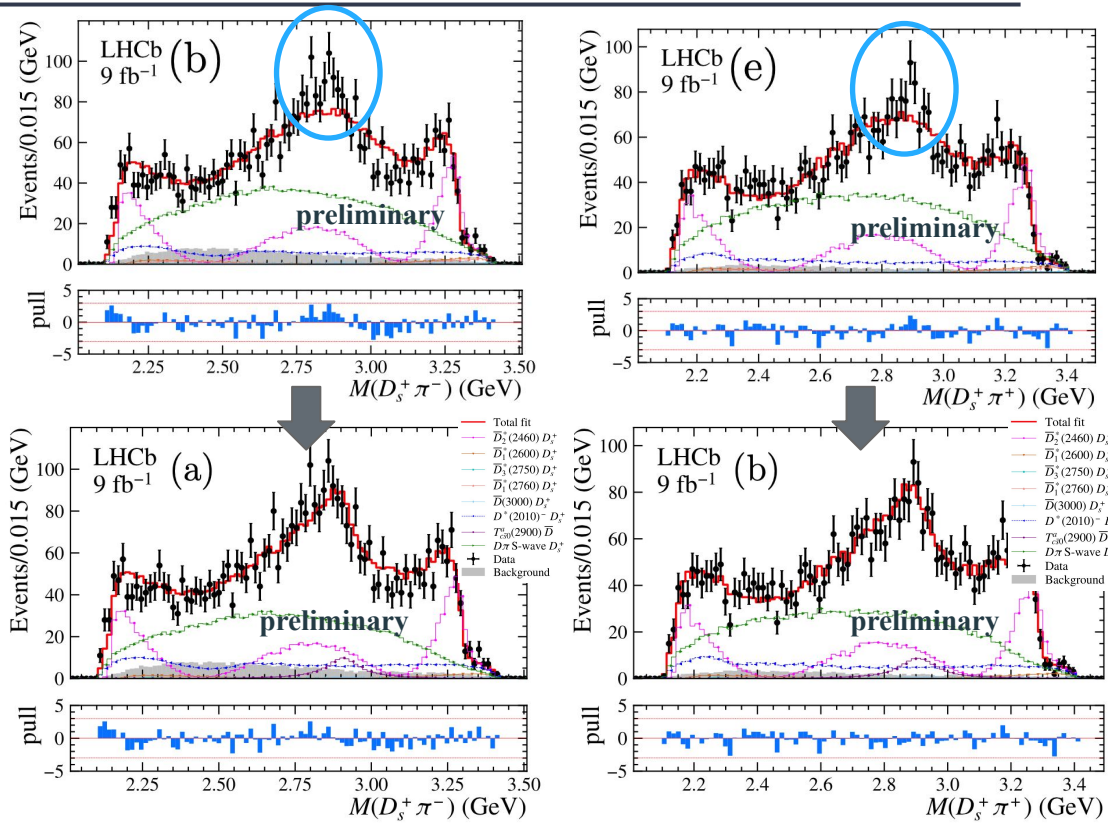
Inclusion of a single resonance in $D_s\pi$

- with significance **> 9σ**
- $J^P = 0^+$ preferred at 7.5 σ

$$T^a_{c\bar{s}0}(2900)^0 : M = 2.892 \pm 0.014 \pm 0.015\,\text{GeV}$$
$$\Gamma = 0.119 \pm 0.026 \pm 0.012\,\text{GeV}$$
$$T^a_{c\bar{s}0}(2900)^{++} : M = 2.921 \pm 0.017 \pm 0.019\,\text{GeV}$$
$$\Gamma = 0.137 \pm 0.032 \pm 0.014\,\text{GeV}$$

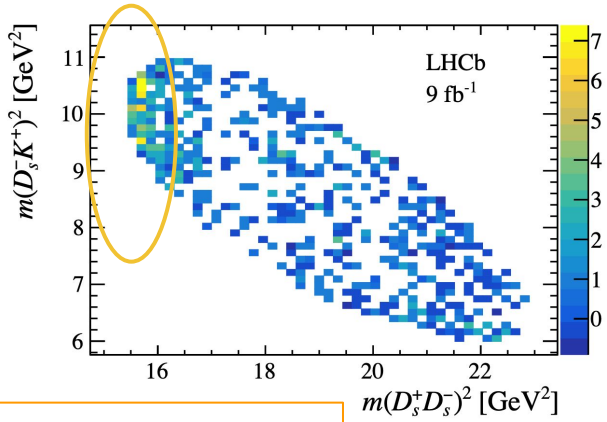
(RBW)

Consistent masses → Isospin partners



New $X(3960) \rightarrow D_s^+ D_s^-$

LHCb-PAPER-2022-018



Signal yield: 360 events with 9 fb^{-1}

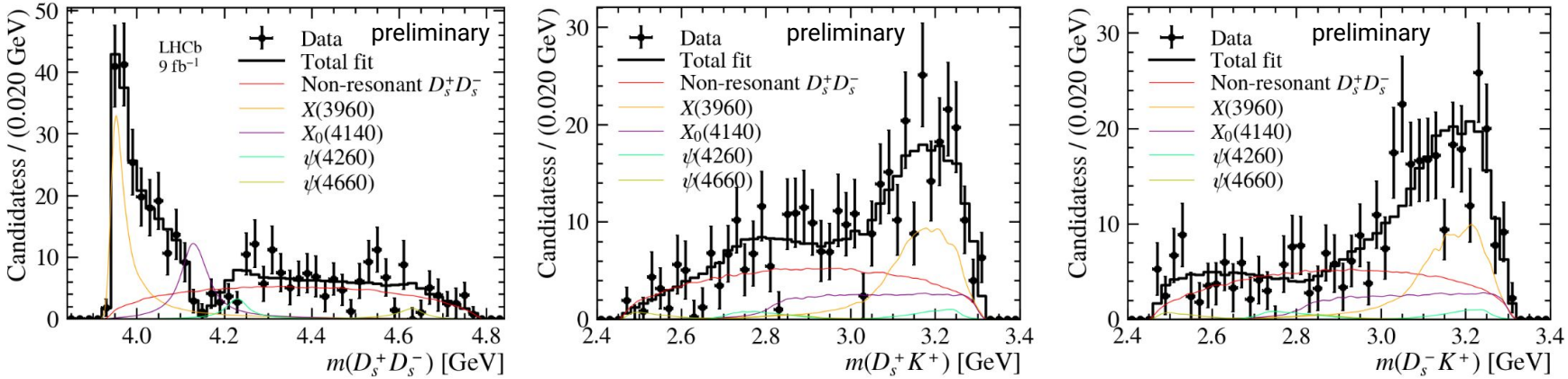
Near threshold enhancement in $D_s^+ D_s^-$

Baseline model:

0^{++}: $X_0(4140)$, NR, + new X(3960)

1^{--}: $\psi(4260)$, $\psi(4660)$

- X(3960) describes the near-threshold enhancement
- $X_0(4140)$ to describe the dip at ~4.14 GeV via interference

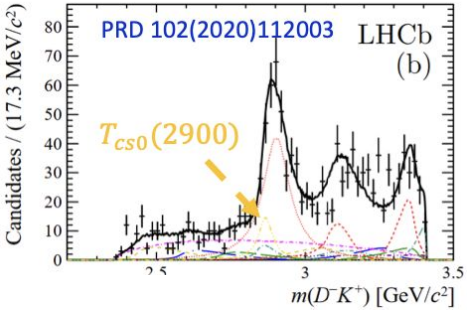


Summary of new tetraquark states

$T^a_{c\bar{s}0}(2900)^{0/++}$

First tetraquark candidates composed of $c\bar{s}u\bar{d}$ and $c\bar{s}\bar{u}d$

- first doubly charged tetraquark
- isospin triplets
- flavour partners of $T_{cs0}(2900)$ observed in $B^+ \to D^+ D^- K^+$ [1]?



$T_{cs0}(2900)$:
$\bar{c}\bar{s}ud$
$T^a_{c\bar{s}0}(2900)^0$:
$c\bar{s}\bar{u}d$
$T^a_{c\bar{s}0}(2900)^{++}$:
$c\bar{s}u\bar{d}$

$X(3960)$

Same state as $\chi_{c0}(3930)$?

Exotic $c\bar{c}s\bar{s}$ or conventional state?

- not compatible with predicted mass
- conventional charmonium predominantly decay to $D^{(*)}D^{(*)}$, while:
  $\Gamma(X \to D^+D^-) < \Gamma(X \to D_s^+ D_s^-)$

⇒ more precise measurements are needed

[1] Phys. Rev. D, 2005, 72: 054026, PRD, 2009, 79: 094004
[2] JHEP 06 (2021) 035, Sci. Bull., 2021, 66: 1413

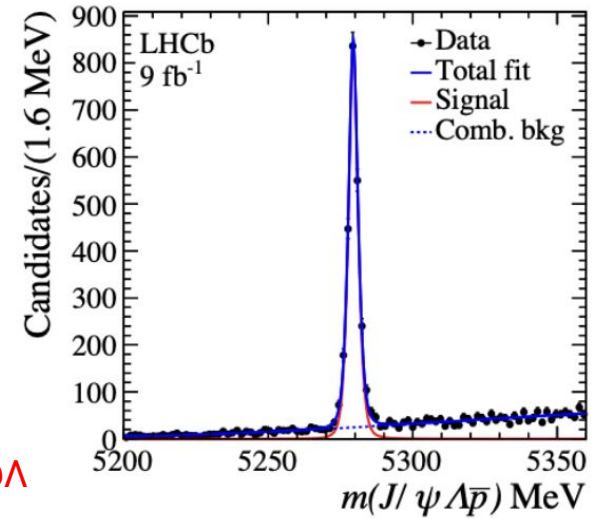
Pentaquarks

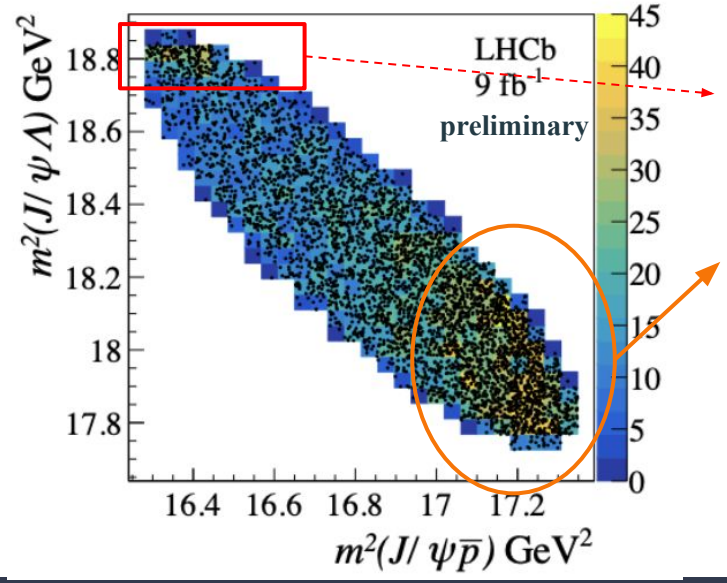
$B^- \to J/\psi \Lambda \bar{p}$ decays

Search for pentaquark candidates in $J/\psi\Lambda$ and $J/\psi\bar{p}$

Full LHCb dataset: 9 fb^{-1}

⇒ 4600 candidates in 2.5σ around peak with 93% of purity





Narrow structure in $J/\psi\Lambda$

Activity in $J/\psi\bar{p}$

Possible reflections from $K^*_{2,3,4}$?
⇒ need for a full amplitude analysis

Model with only K*

LHCb-PAPER-2022-031, arxiv:2210.10346

Amplitude contributions:

- NR($\bar{p}\Lambda$)
- $K^{*+}_{2,3,4}$ → peaks out of phsp, no obvious contribution in $\bar{p}\Lambda$ distribution

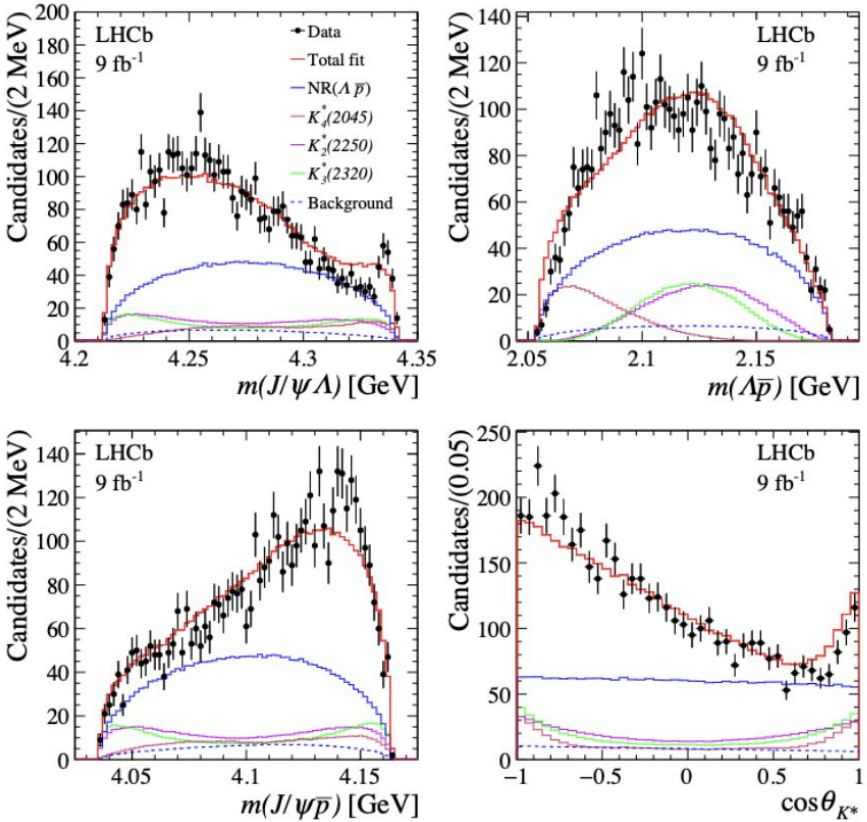
Resonance	Mass (MeV)	Natural width (MeV)	J^P
$K_4^*(2045)^+$	2045 ± 9	198 ± 30	4^+
$K_2^*(2250)^+$	2247 ± 17	180 ± 30	2^-
$K_3^*(2320)^+$	2324 ± 24	150 ± 30	3^+

PDG 2020

Model with K^* cannot describe data

Goodness-of-fit test

$$\chi^2/ndf = 123/33$$



Pentaquark with strangeness in J/ψΛ

LHCb-PAPER-2022-031, arxiv:2210.10346

Amplitude contributions:

- NR($\bar{p}\Lambda$), NR($\bar{p}J/\psi$), $P^{\Lambda}_{\psi s}(J/\psi\Lambda)$

Mass and width (RBW) measured:

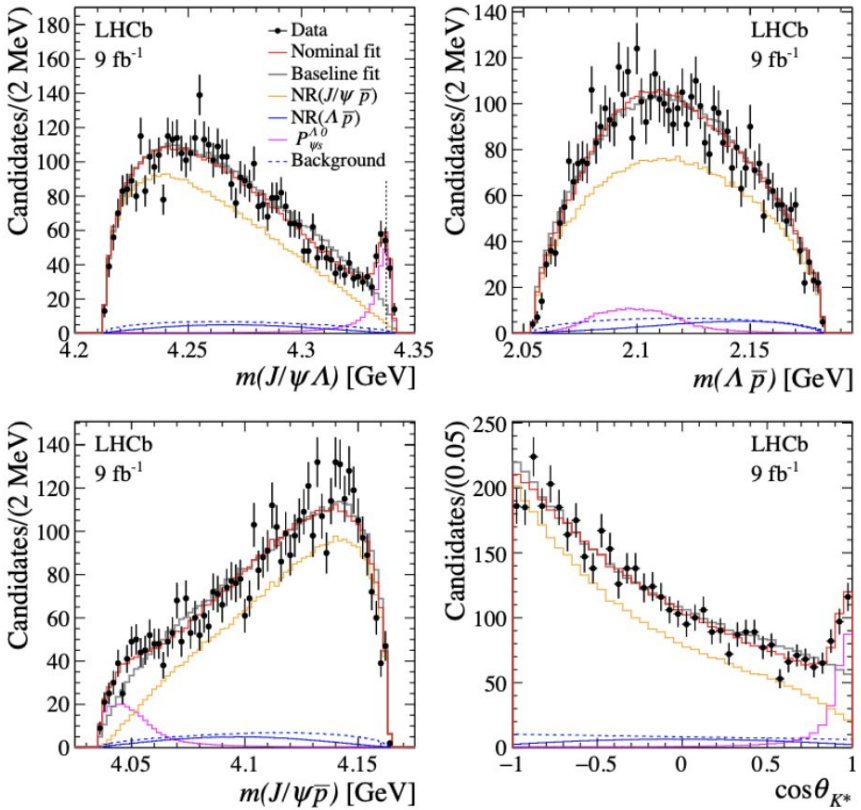
$m(P^{\Lambda}_{\psi s})$	$4338.2 \pm 0.7\ MeV$
$\Gamma(P^{\Lambda}_{\psi s})$	$7.0 \pm 1.2\ MeV$

with significance >10σ

⇒ Spin-parity:

J = ½ determined

P = -1 favored, ½⁺ rejected @90% CL



Discussion on the new J/ψΛ state

LHCb-PAPER-2022-031, arxiv:2210.10346

First pentaquark candidate $P_{\psi s}^{\Lambda}(4338)$ with strange quark content $c\bar{c}uds$,

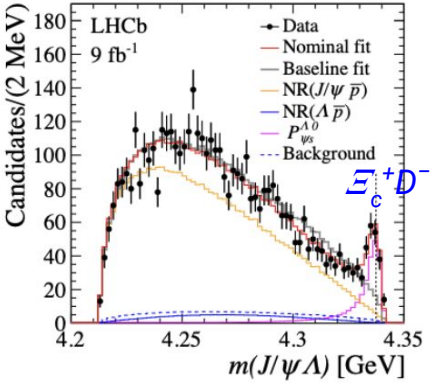
$$M_{P_{cs}} = 4338.2 \pm 0.7 \pm 0.4\,\text{MeV}$$

$$\Gamma_{P_{cs}} = 7.0 \pm 1.2 \pm 1.3\,\text{MeV}$$

⇒ first pentaquark with spin-parity determined at 90%CL → $J^P = 1/2^-$

For theoretical interpretation

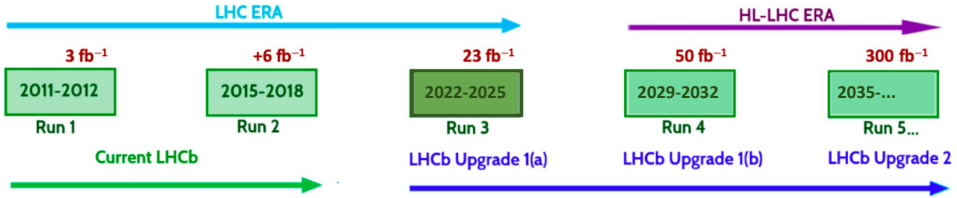
- ✓ narrow and close to $\Xi_c^+ D^-$ threshold
- ✓ not compatible with state outside the phsp
- ✓ pentaquark with strangeness due to SU(3) symmetry



Conclusion & Prospects

Spectroscopy of heavy hadrons
- excited *b* and *c* hadrons
- *bc* searches already started

Exotic contributions
- New tetraquark: T_{cc}^{+}, $T_{cs0}(2900)^{0,++}$
- First pentaquark with strangeness



We are looking for collaborators for LHCb Upgrade 2
→ pleased to have you onboard!

Upcoming Run 3 data:
- higher integrated luminosity
- new detector with fully software-based trigger

⇒ Boosting data to a new level!
x2 by Run3, x7 by Run4
(+ improvements of analysis skills)

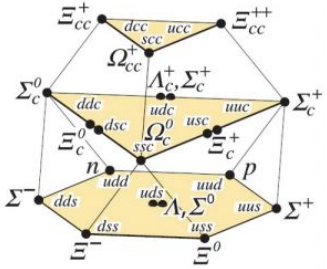
Conclusion & Prospects

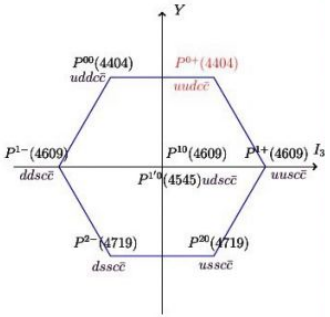
More investigation of the observed states:

- Confirm P_c and P_{cs} states
- Measure quantum numbers

Many new states to explore:

- Observation of Ξ_{cc}^{+}, Ω_{cc}^{+}?
- Access to *bc* tetraquarks and pentaquarks and *bb* spectroscopy
- Search for exotic flavour multiplets





Thank you for listening!

Backup slides

New naming scheme

LHCb-PUB-2022-013, arxiv2206.15233

No PDG rule for

- exotic mesons with s, c, b quantum numbers
- no extension for pentaquark states

Idea of the proposal

- *T* for tetra, *P* for penta
- **Superscript**: based on existing symbols, to indicate isospin, parity and G-parity
- **Subscript**: heavy quark content

Impact on existing states

Minimal quark content	Current name	$I^{(G)}$, $J^{P(C)}$	Proposed name
$c\bar{c}$	$\chi_{c1}(3872)$	$I^G = 0^+$, $J^{PC} = 1^{++}$	$\chi_{c1}(3872)$
$c\bar{c}u\bar{d}$	$Z_c(3900)^+$	$I^G = 1^+$, $J^P = 1^+$	$T^b_{\psi 1}(3900)^+$
$c\bar{c}u\bar{d}$	$Z_c(4100)^+$	$I^G = 1^-$	$T_\psi(4100)^+$
$c\bar{c}u\bar{d}$	$Z_c(4430)^+$	$I^G = 1^+$, $J^P = 1^+$	$T^b_{\psi 1}(4430)^+$
$c\bar{c}u\bar{s}$	$Z_{cs}(4000)^+$	$I = \frac{1}{2}$, $J^P = 1^+$	$T^\theta_{\psi s1}(4000)^+$
$c\bar{c}u\bar{s}$	$Z_{cs}(4220)^+$	$I = \frac{1}{2}$, $J^P = 1^?$	$T_{\psi s1}(4220)^+$
$c\bar{c}c\bar{c}$	$X(6900)$	$I^G = 0^+$, $J^{PC} = ?^{?+}$	$T_{\psi\psi}(6900)$
$cs\bar{u}\bar{d}$	$X_0(2900)$	$J^P = 0^+$	$T_{cs0}(2900)^0$
$cs\bar{u}\bar{d}$	$X_1(2900)$	$J^P = 1^-$	$T_{cs1}(2900)^0$
$cc\bar{u}\bar{d}$	$T_{cc}(3875)^+$		$T_{cc}(3875)^+$
$b\bar{b}u\bar{d}$	$Z_b(10610)^+$	$I^G = 1^+$, $J^P = 1^+$	$T^b_{\Upsilon 1}(10610)^+$
$c\bar{c}uud$	$P_c(4312)^+$	$I = \frac{1}{2}$	$P^N_\psi(4312)^+$
$c\bar{c}uds$	$P_{cs}(4459)^0$	$I = 0$	$P^\Lambda_{\psi s}(4459)^0$

P_ψ^N contributions in $\bar{p}J/\psi$?

Amplitude contributions:

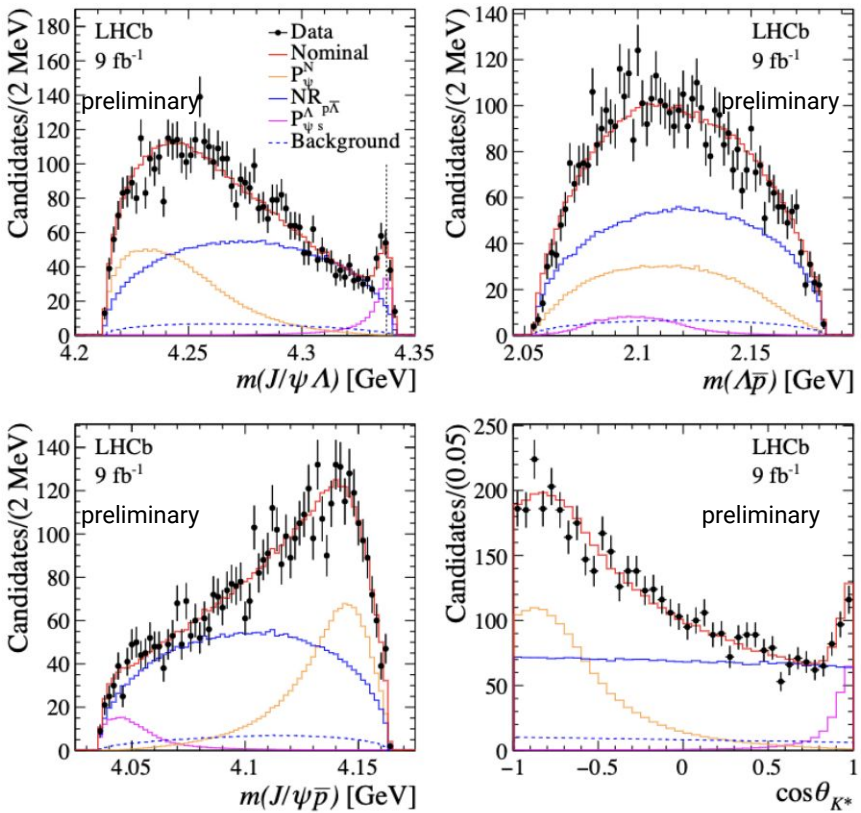
- NR($\bar{p}\Lambda$)
- ~~NR($\bar{p}J/\psi$)~~ → BW(P_ψ) $J^P=½^-$
- $P_{\psi s}^{\Lambda}$($J/\psi\Lambda$)

Compatible $P_{\psi s}^{\Lambda}$ results

$m(P_{\psi s}^{\Lambda})$	$4338.8 \pm 1.1\ MeV$
$\Gamma(P_{\psi s}^{\Lambda})$	$8.4 \pm 1.6\ MeV$
$m(P_{\psi}^{N})$	$4152.3 \pm 2.0\ MeV$
$\Gamma(P_{\psi}^{N})$	$41.8 \pm 6.0\ MeV$

-*logL* decreases by 80 wrt nominal model

⇨ Model with NR polynomial is preferred, not very sensitive to $\bar{p}J/\psi$ structures with current statistics

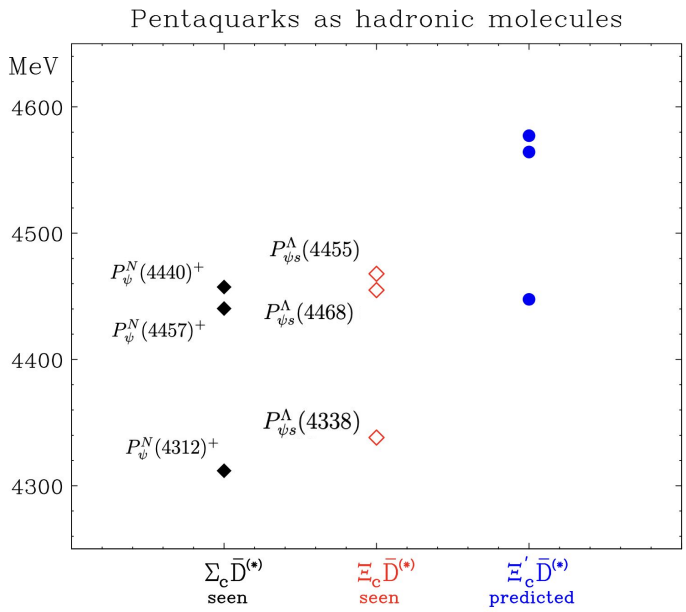


Molecular interpretations for P_{cs}

Phys. Rev. D **106**, 036024

- Vicinity to the relevant baryon-meson threshold: 0.8 MeV above $\Xi_c^+ D^-$ threshold
- Spin-parity: states in S-wave as the hadronic molecules
- Narrow width: 7 MeV is unnaturally small given the Q-value of the decay (~126 MeV).
  - Decay requires the charm and anti-charm quarks getting close, but the distance between is Ξ_c^+ and D^- >> 1fm ⇒ suppression mechanism

Prediction of states at $\Xi_c' D$ thresholds



New pentaquark: $P_c(4337)$

PRL 128, 062001 (2022)

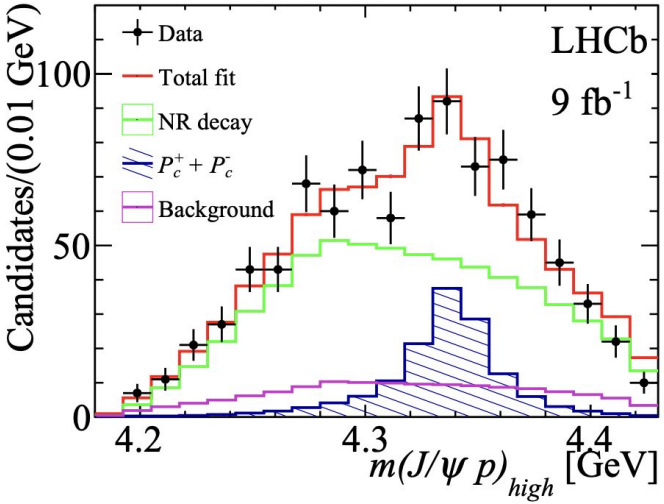
In $B^0_{(s)} \to J/\psi p\bar{p}$ decays: ~800 events

4D amplitude analysis
in $\Phi=(m_{pp}, \cos\theta_l, \cos\theta_v, \varphi)$

Evidence for a structure in $J/\psi p$ and $J/\psi \bar{p}$

$$M_{P_c} = 4337^{+7}_{-4}(\text{stat}) \pm 2(\text{sys})\text{MeV},$$
$$\Gamma_{P_c} = 29^{+26}_{-12}(\text{stat}) \pm 14(\text{sys})\ \text{MeV}$$

No evidence
for ***$P_c(4312)$***
nor for ***$f_J(2220)$*** glueball[1]



Peculiar that:
- $P_c(4312)$ only in Λ_b decays
- $P_c(4337)$ only in B_s decays

[1]Eur. Phys. J. C75 (2015), no. 3 101

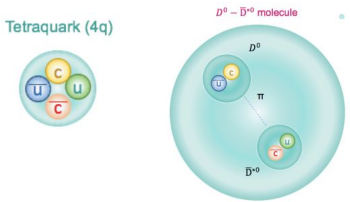
χ_{c1} production in pp @ LHCb

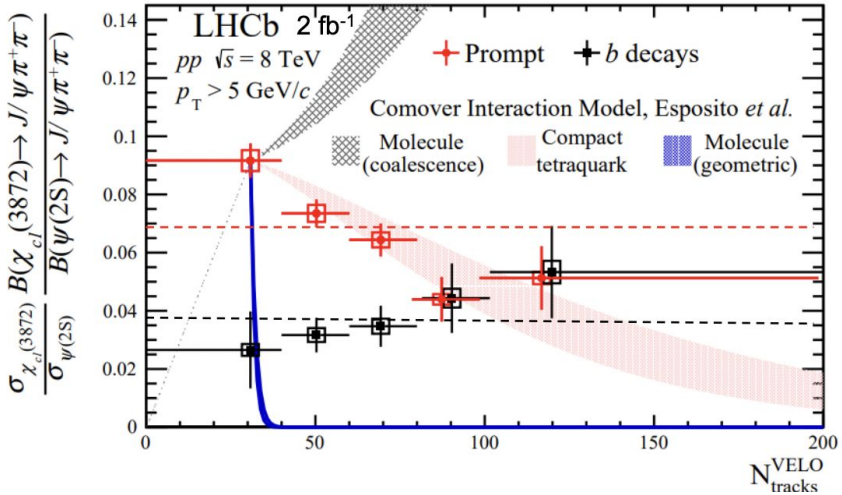
PRL 126 (2021) 092001, JHEP 01 (2022) 131

Differential cross section ratio of $\chi_{c1}(3872)$ relative to $\psi(2S)$

- Both in prompt pp collisions and from b-hadron decays
- Measured as a function of track multiplicity, p_T and y

Separate a compact tetraquark (r<1 fm) from a large-sized molecular state (r~10 fm)





Prompt ratio is suppressed as multiplicity increases (5σ)
→ compact tetraquark model favored
→ Dominated by **comover breakup**[1]**:**
small radius = decrease of xsection ratio

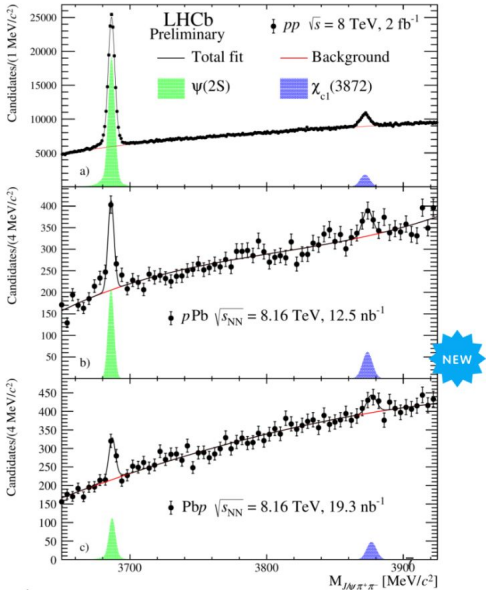
[1]PRD 103 (2021) 7, EPJC 81 (2021) 669

What happens in HI collisions?

LHCb-CONF-2022-001

Production of $\chi_{c1}(3872)$ in pPb collisions to help understand the dynamics

- Formation of QGP could enhance the $\chi_{c1}(3872)$ production through the **quark coalescence mechanism**

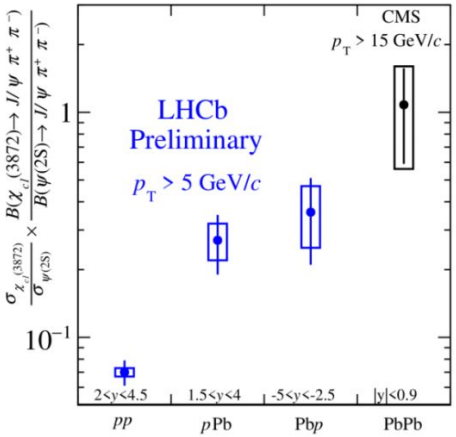


- ψ(2S) is suppressed in pPb and Pbp
- $\chi_{c1}(3872)$ production may also be enhanced as in PbPb collisions

⇨ Increasing trend:

at high density quark coalescence can become the dominant mechanism affecting χ_{c1} production

But still large uncertainties



$\propto N_{tracks}$

Molecule, tetraquark or a mixture?