Exotic hadrons in heavy quark systems

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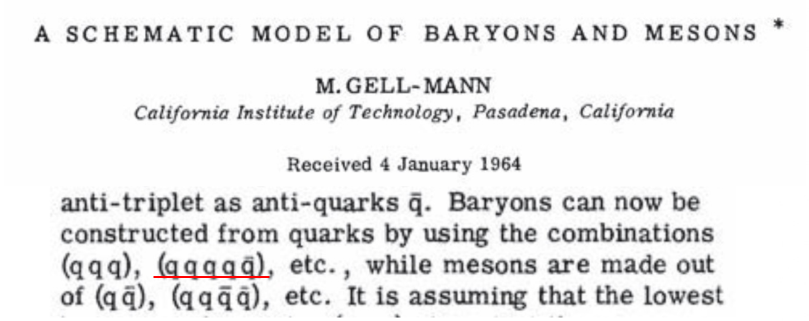
on behalf of the LHCb experiment

June 5th, 2023

HADRON 2023

20th International Conference on Hadron Spectroscopy and Structure
Genova, 5-9 Jun 23

Exotics and heavy quark sector

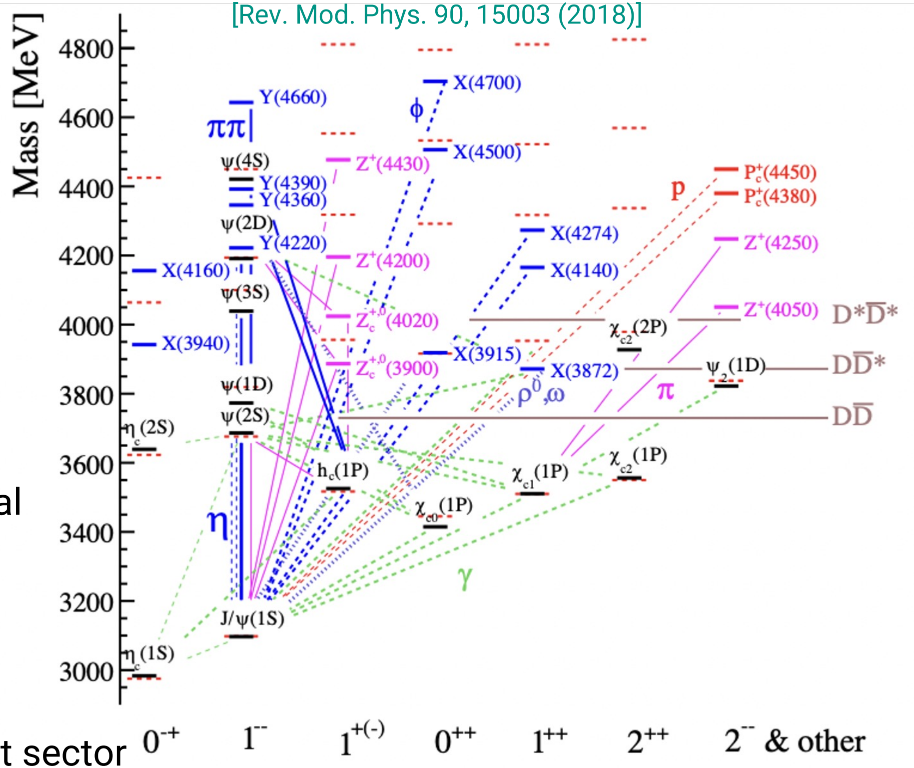

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest

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

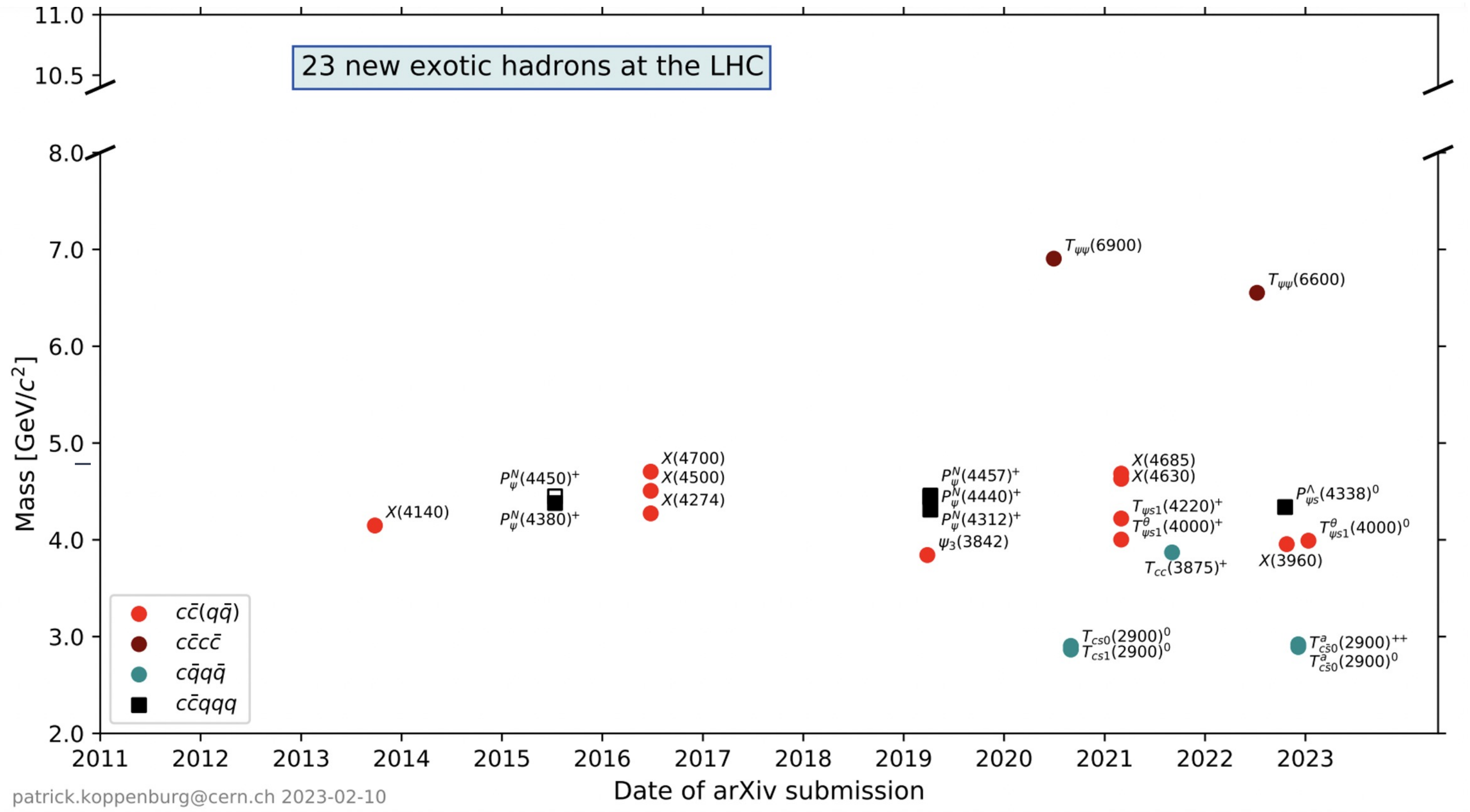


Hidden-charm sector is ideal for exotic searches

- **Theoretical models** well-established for conventional
- **Experimentally** easy to measure
  - Narrow and non-overlapping
  - Agreement below $D\bar{D}$ threshold

⇒ Exotics easier to identify respect to light and heavy-light sector

Spectroscopy at LHC



Link

The unresolved nature

Elementary particles

Quarks & gluons

⇔

strong interaction (long-distance effects)

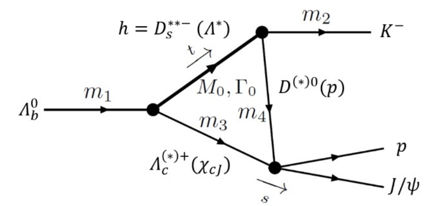
Nature

Color-singlet mesons and baryons

States could also be mimic by

Rescattering effects

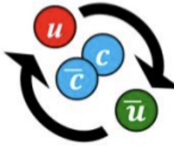
PRD 92 (2015) 071502
PLB 757 (2016) 231
PLB 757 (2016) 61
and others



Compact tetra/pentaquark

Color Forces

Diquark-antidiquark
PRD 71, 014028 (2005)
PLB 662 424 (2008)

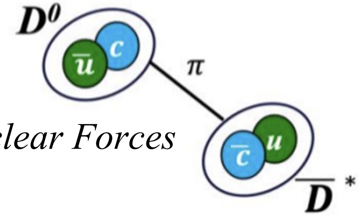


Hadrocharmonium/ adjoint charmonium
PLB 666 344 (2008)
PLB 671 82 (2009)

Hadronic molecules

PRL 105 (2010) 232001,
PRL 115 (2015) 122001
PRD 100 (2019) 011502 (R)
and others

Nuclear Forces



\+ qq̄g hybrid, glueball or mixture

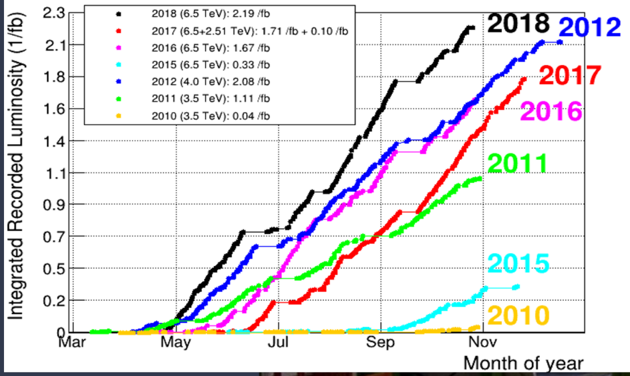
LHCb detector

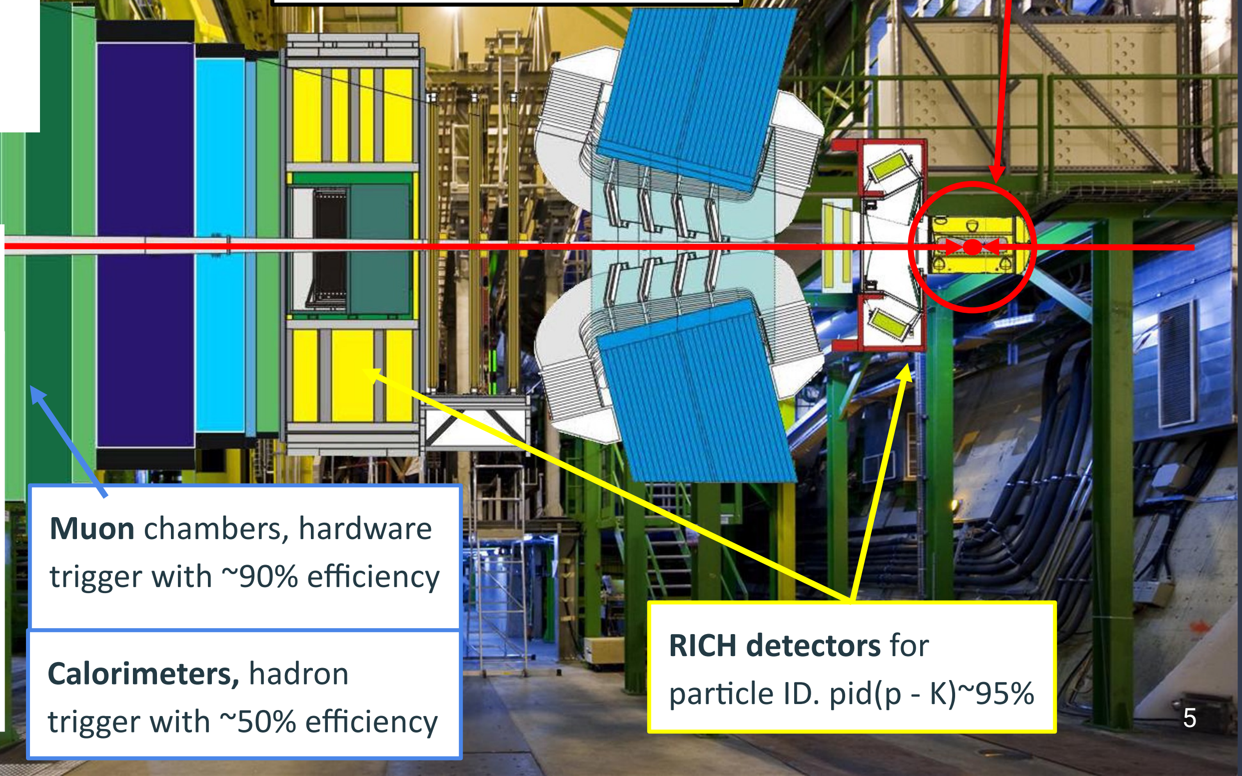
[JINST 3 (2008) S08005](#)
IJMP A 30, 1530022 (2015)

The major player in spectroscopy
thanks to its unique dedicated design

- high invariant mass resolution
- PID for separate *K, π, p*
- highly performant trigger

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





Tracking: momentum resolution of σ_p / p ~ 0,5 - 1%

VELO: vertex detector
IP resolution: ~25 μm

Muon chambers, hardware trigger with ~90% efficiency

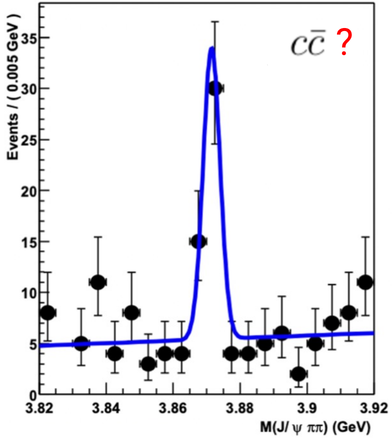
Calorimeters, hadron trigger with ~50% efficiency

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

First exotic candidates

$\chi_{c1}(3872)$

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



PRL **91**, 262001 (2003)

$\Rightarrow J^{PC}=1^{++}$ by LHCb

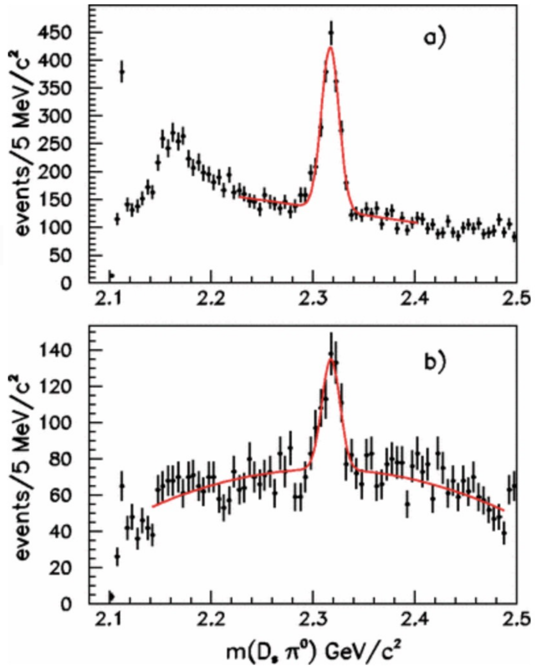
PRL. 110 (2013) 222001

***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

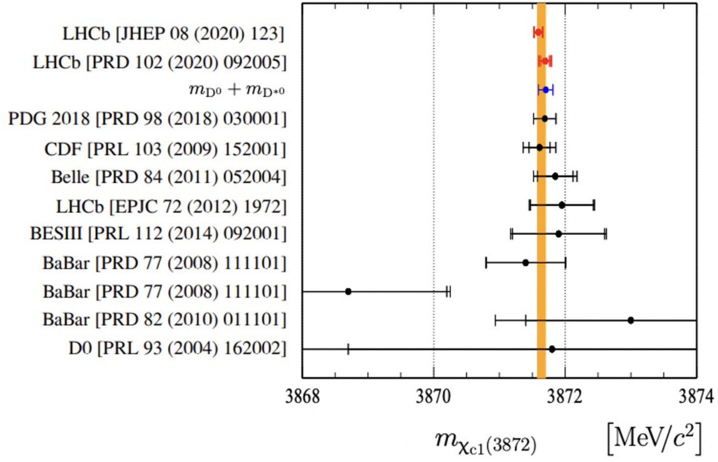
Many experiments contribute to it:

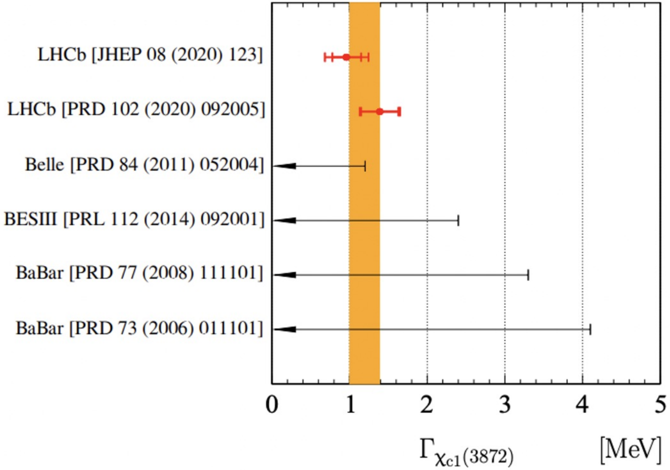
- Spin assignment: $J^{PC} = 1^{++}$ [1]
- Mass is consistent with **$m(D^0) + m(D^{*0})$**
- Width is surprisingly narrow

Its nature is still under debate!

→ conventional $\chi_{c1}(2^3P_1)$, DD^* molecular state, tetraquark, hybrid, vector glueball, or mixed?

JHEP 08 (2020) 123





[1] PRL. 110 (2013) 222001, PRD 92 (2015) 011102(R)

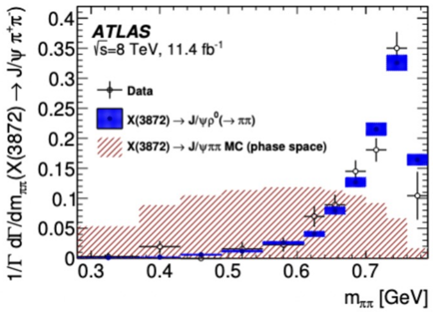
ω contribution in $\chi_{c1}(3872) \to J/\psi\pi\pi$

arXiv:2204.12597v1

Studying **decay processes** can help understand its nature:

- Measure the isospin violating $\chi_{c1}(3872) \to J/\psi\rho$

Previously only $\chi_{c1}(3872) \to J/\psi\rho$ dominates the phase space



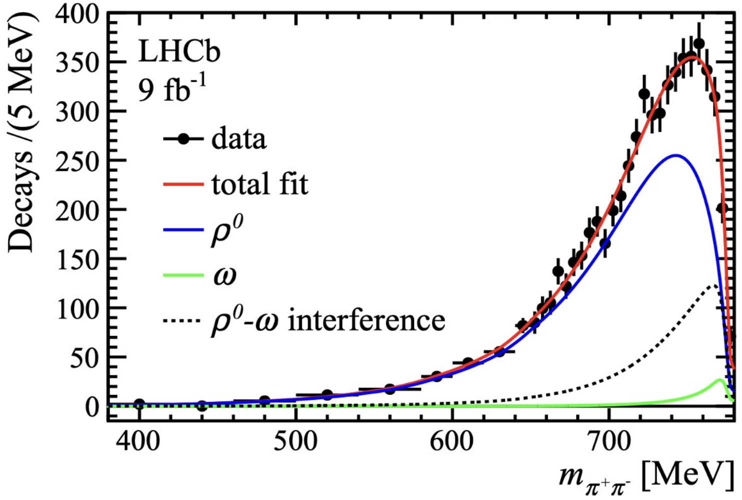
ATLAS: JHEP01(2017)117

Ratio of isospin violating to isospin conserving couplings is much larger than expected for a charmonium

$$\frac{g_{\chi_{c1}(3872)\to\rho^0 J/\psi}}{g_{\chi_{c1}(3872)\to\omega J/\psi}} = 0.29 \pm 0.04.$$

$$\frac{g_{\psi(2S)\to\pi^0 J/\psi}}{g_{\psi(2S)\to\eta J/\psi}} = 0.045 \pm 0.001$$

Latest LHCb analysis: ω contribution of 2%, enhanced by ω-ρ interference (~19%)



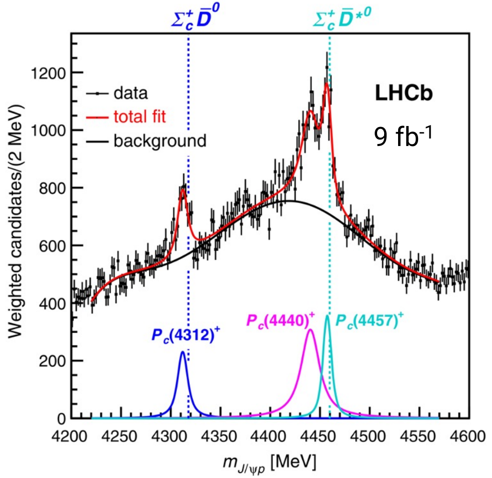
⇒ $\chi_{c1}(3872)$ cannot be a pure charmonium state

Manifestly exotic

Pentaquarks $c\bar{c}uud$

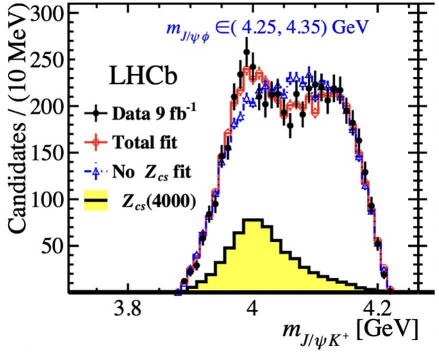
by LHCb in 2015 in $\Lambda_b \rightarrow J/\psi p K$ [1]

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

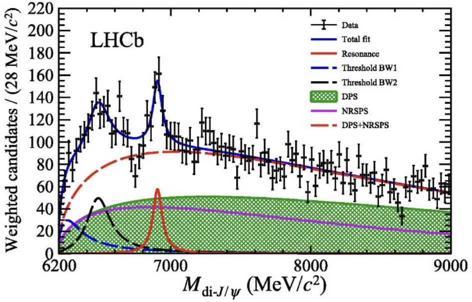


Tetraquarks

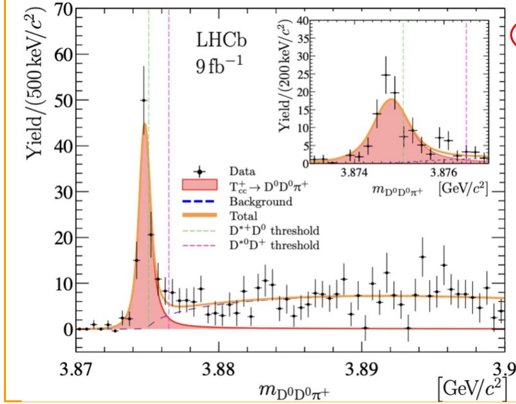
$Z_{cs}(4000)^+$ ($\rightarrow T^\theta_{\psi s1}$) [3] $c\bar{c}u\bar{s}$



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

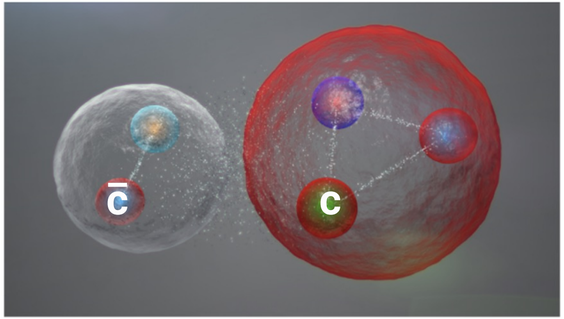


Doubly-charm tetraquark $T_{cc}(3875)^+$ [5,6] $cc\bar{u}\bar{d}$

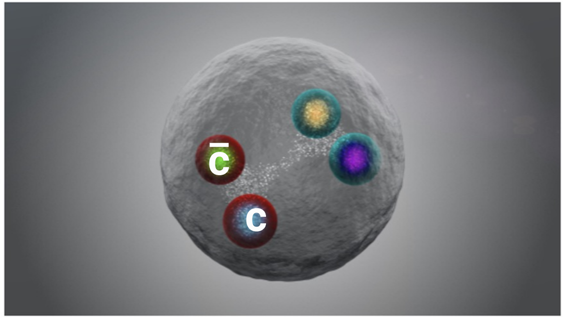


[1] PRL 115, 072001 (2015)
[2] PRL 122, 222001 (2019)
[3] PRL 127, 082001 (2021)
[4] Sc. Bull. 2020 65(23)1983-1993
[5] Nature Physics (2022),
[6] Nature Comm., 13, 3351 (2022)

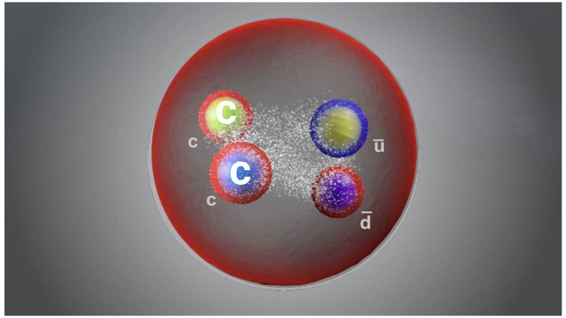
Exotics



Hidden-charm pentaquark

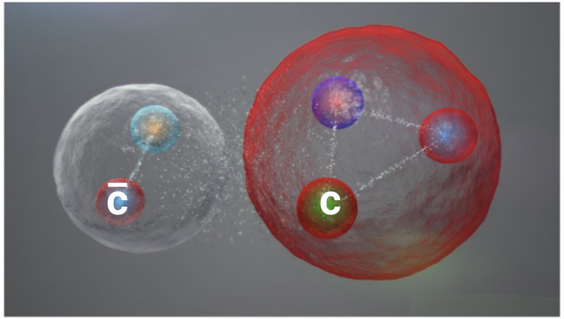


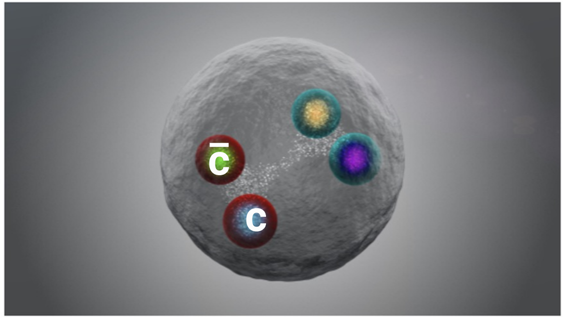
Hidden-charm tetraquarks

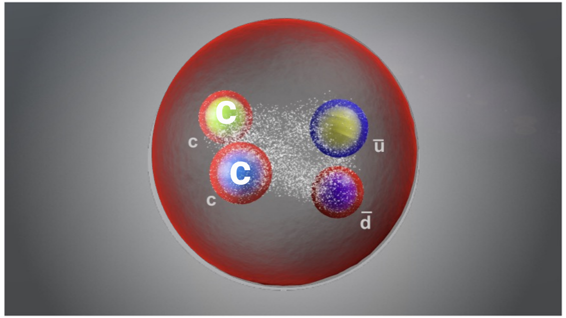


Beyond hidden-charm

Exotics







Hidden-charm pentaquark

Hidden-charm tetraquarks

Beyond hidden-charm

arxiv:2210.10346

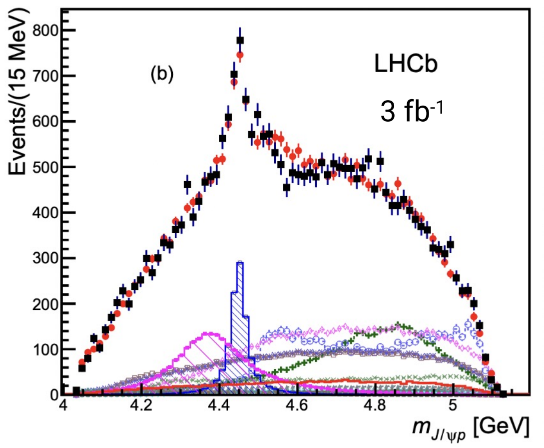
$P_{\psi}^{N}(4457)^{+}$
$P_{\psi}^{N}(4440)^{+}$
$P_{\psi}^{N}(4312)^{+}$

$P_{\psi s}^{\Lambda}(4338)^{0}$

PRL 115, 072001 (2015),
PRL 122, 222001 (2019)

The observation of P_c states

First observation by LHCb in $\Lambda_b \to J/\psi p K$ with Run1 data [PRL 115, 072001 (2015)]



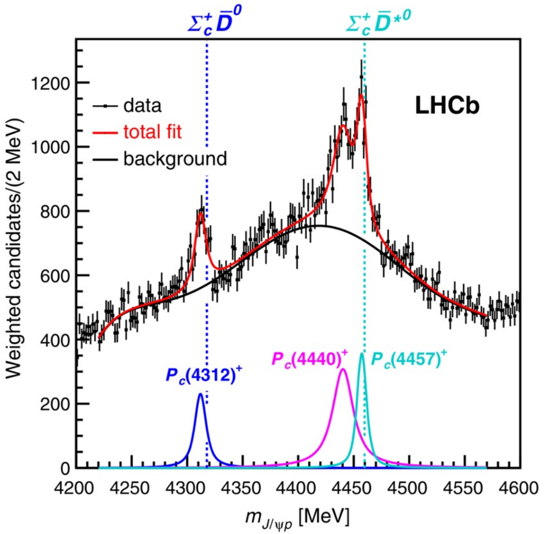
$P_c(4450)^+$ M = 4450 ± 2 ± 3 MeV
Γ = 39 ± 5 ± 19 MeV
Fit fraction = 4.1 ± 0.5 ± 1.1 %

$P_c(4380)^+$ M = 4380 ± 8 ± 29 MeV
Γ = 205 ± 18 ± 86 MeV
Fit fraction = 8.4 ± 0.7 ± 4.2 %

Run 1 + Run 2 dataset:

new state: $P_\psi^N(4312)^+$ + 2 peaks at 4450 MeV

[PRL 122, 222001 (2019)]



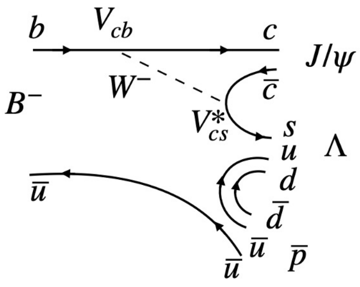
$B^- \to J/\psi \Lambda \bar{p}$ decays

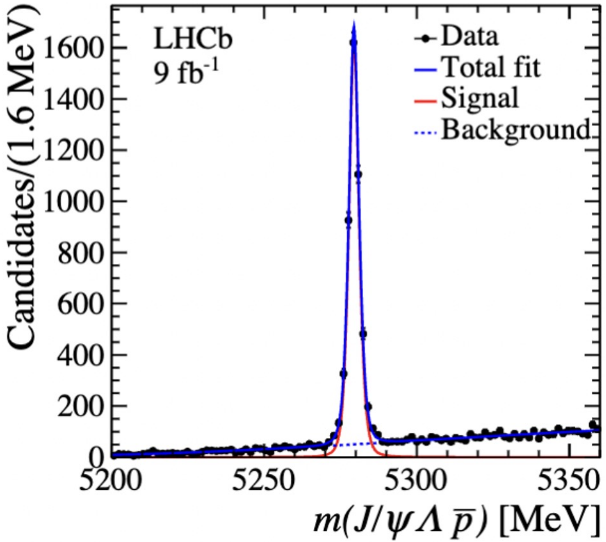
arxiv:2210.10346

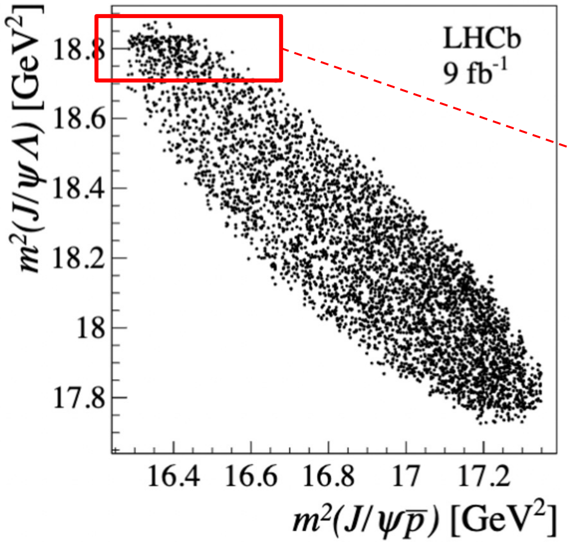
Search for pentaquark candidates in $J/\psi\Lambda$ and $J/\psi\bar{p}$

Full LHCb dataset: 9 fb^{-1}

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







Narrow structure in $J/\psi\Lambda$

Pentaquark with strangeness in J/ψΛ

arxiv:2210.10346

Mass and width (RBW) measured:

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

Significance larger than 10σ

⇒ **Spin-Parity:**

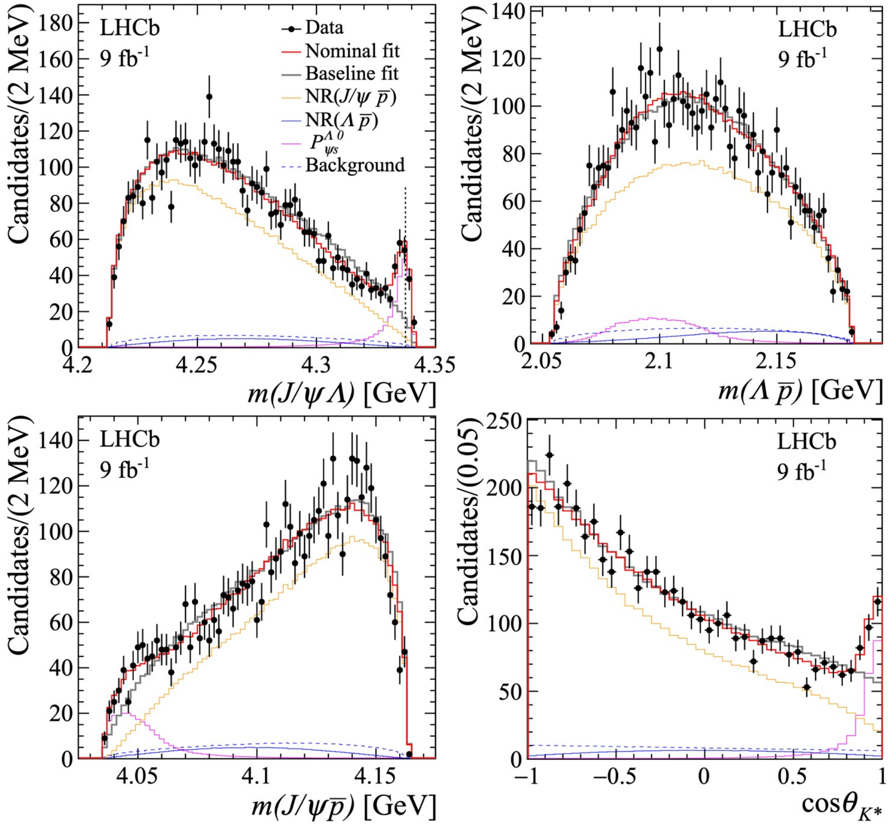
J = ½ determined

P = -1 favored, $½^+$ rejected @90% CL

✓ Narrow state

✓ Close to $\Xi_c^+ D^-$ threshold and in S-wave

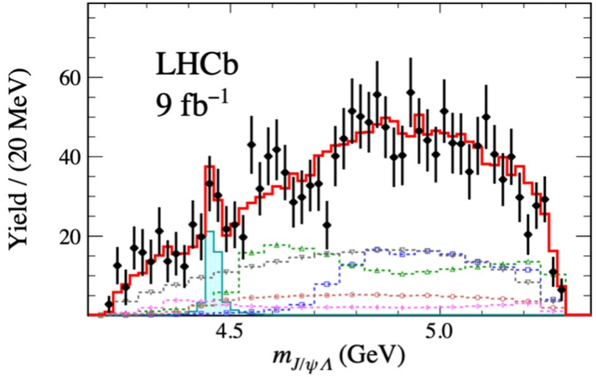
See Fang's talk



Other pentaquark evidences

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

$c\bar{c}uds$

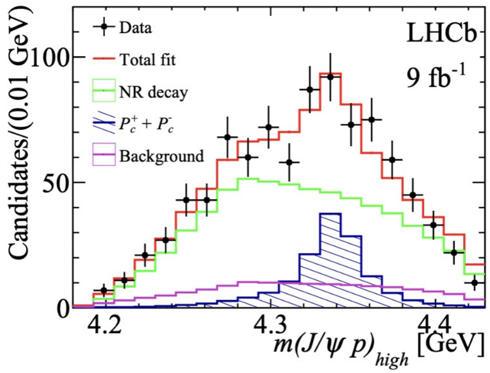


⇒ pentaquark with strangeness
✓ at $\Xi_c^0 D^{*0}$ threshold

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

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

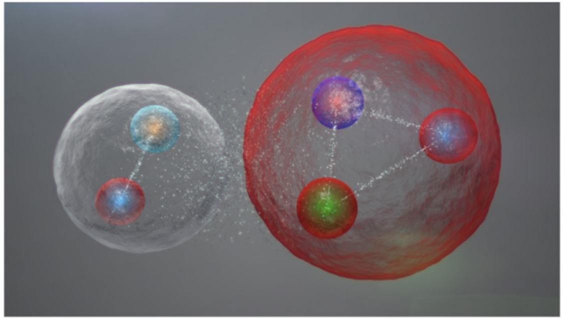
$c\bar{c}uud$



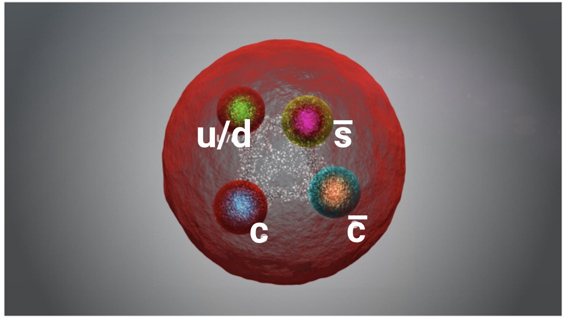
⇒ P_{ψ}^{N} in B meson decay
✓ $J^P = ½^+$ for P_{ψ}^{N+} preferred (?)

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

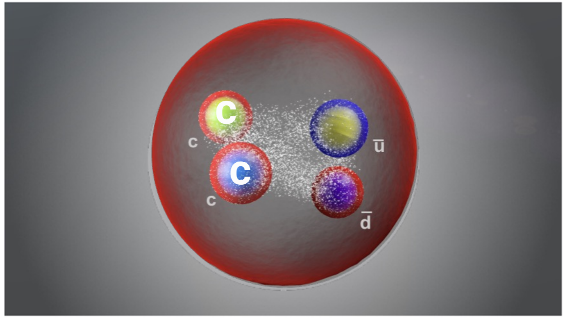
Exotics



Hidden-charm pentaquark



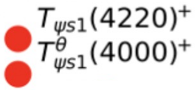
Hidden-charm tetraquarks



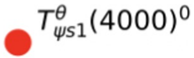
Beyond hidden-charm

with strange quark content:

$Z_{cs}{}^{+}$ ($\rightarrow T^{\theta}{}_{\psi s1}$)



PRL 127, 082001 (2021)

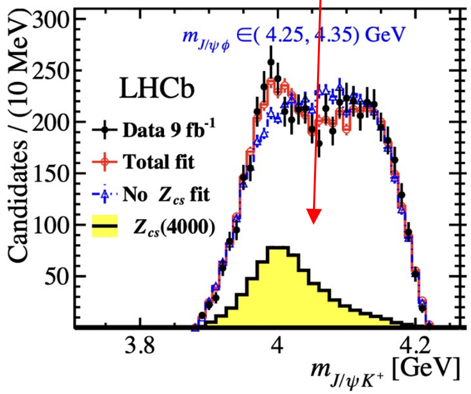


LHCb-PAPER-2022-040

Tetraquark with strangeness

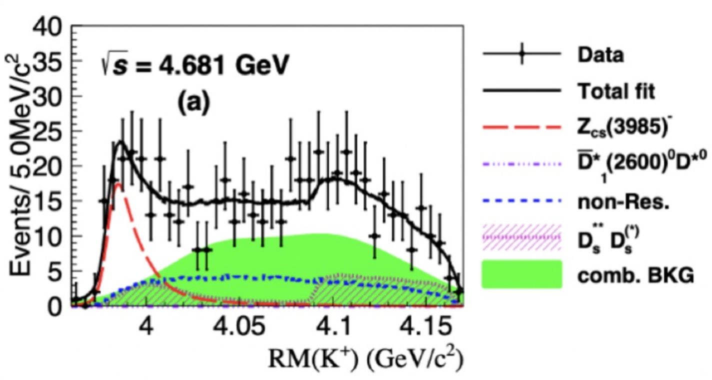
In $B^+ \to J/\psi \Phi K^+$ decays:

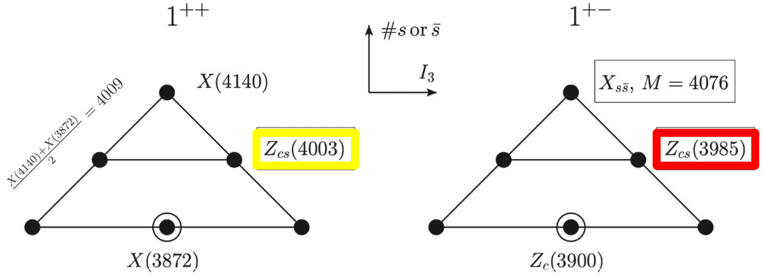
$T^\theta_{\psi s1}(4220)^+$ & $T^\theta_{\psi s1}(4000)^+$ state by LHCb PRL 127, 082001 (2021)



Degeneracy can be explained in compact tetraquark picture
[arXiv:2103.08331v2]

$T^\theta_{\psi s1}(3985)^+$ in $D_s^- D^{*0} + D^0 D_s^{*-}$ by BESIII
PRL 126 (2021) 102201



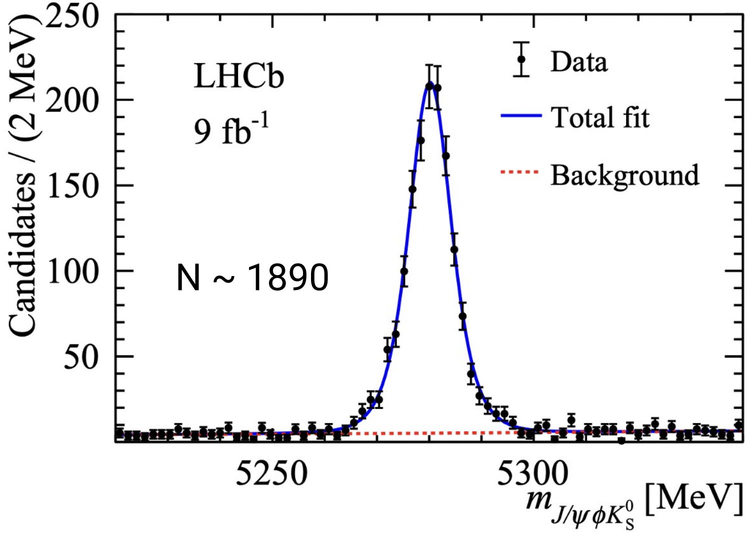


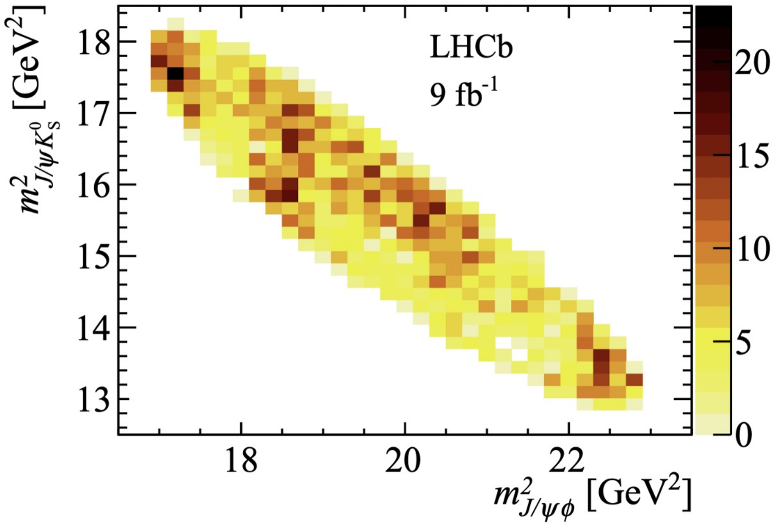
$B^0 \to J/\psi \Phi K_s$ decays

arxiv:2301.04899

Extension of $B^+ \to J/\psi \Phi K^+ \to$ isospin partner of ***$T^{\theta}_{\psi s1}$ states?***

$B^+ \to J/\psi \Phi K^+$ and $B^0 \to J/\psi \Phi K_s$ are related by isospin symmetry



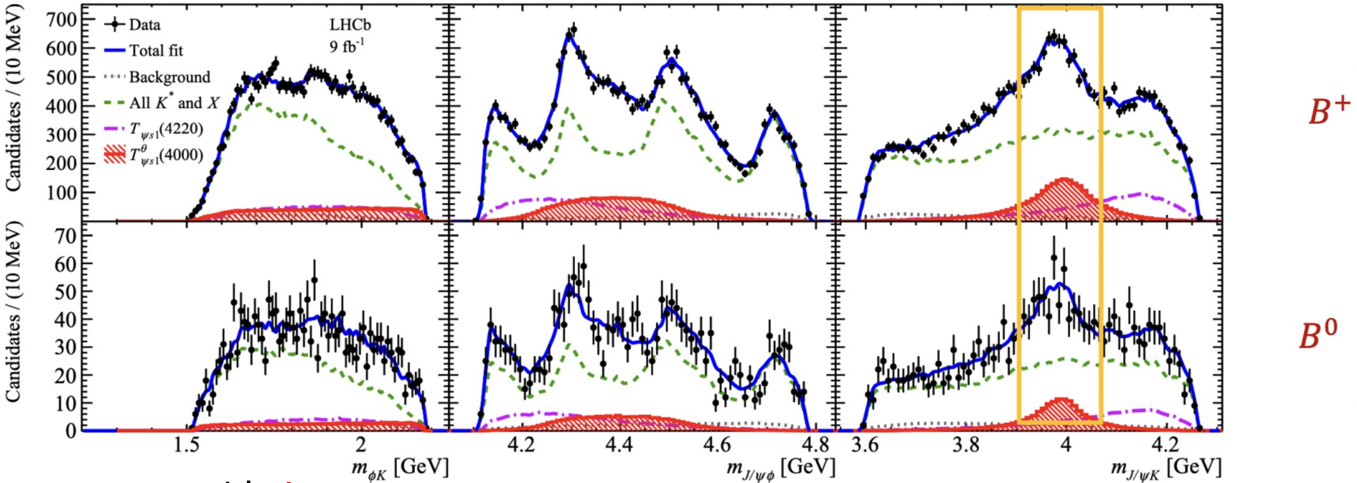


$B^0 \to J/\psi \Phi K_s$ decays

arxiv:2301.04899

Combined fit to B^+ and B^0 decays:

- All components except $\boldsymbol{T^{\theta}_{\psi s1}}$**(4000)** in B^0 decay are constrained by those in B^+ decay

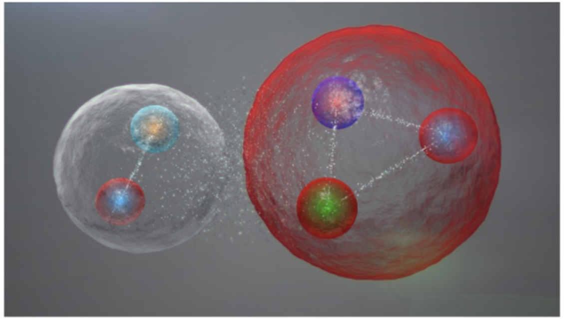


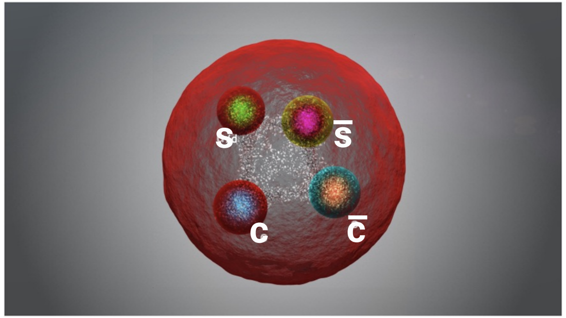
Evidence for a new state with 4σ

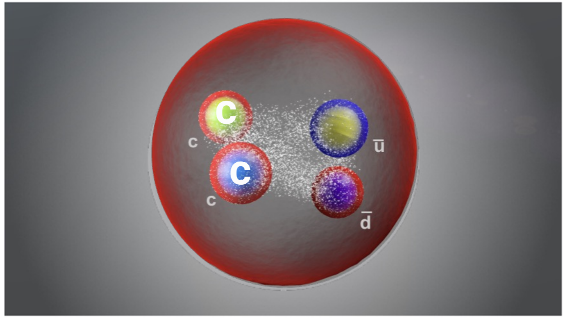
$$M(T^{\theta}_{\psi s1}(4000)^0) = 3991\,^{+12}_{-10}\,^{+\ 9}_{-17}\ \text{MeV},$$
$$\Gamma(T^{\theta}_{\psi s1}(4000)^0) = \ 105\,^{+29}_{-25}\,^{+17}_{-23}\ \text{MeV},$$

⇒ $\boldsymbol{T^{\theta}_{\psi s1}}$**(4000)^0** & $\boldsymbol{T^{\theta}_{\psi s1}}$**(4000)$^+$**: consistent with being isospin partners, $\Delta M = 12^{+11+6}_{-10-4}$ MeV

Exotics







Hidden-charm pentaquark

Hidden-charm tetraquarks

& hidden-strange

Beyond hidden-charm

$c\bar{c}s\bar{s}$?

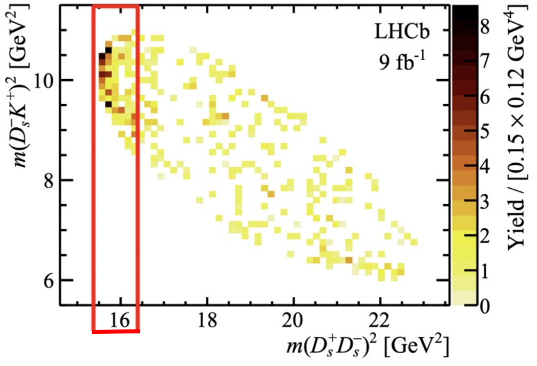
arXiv:2211.05034,
arXiv:2210.15153

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

arXiv:2211.05034, arXiv:2210.15153

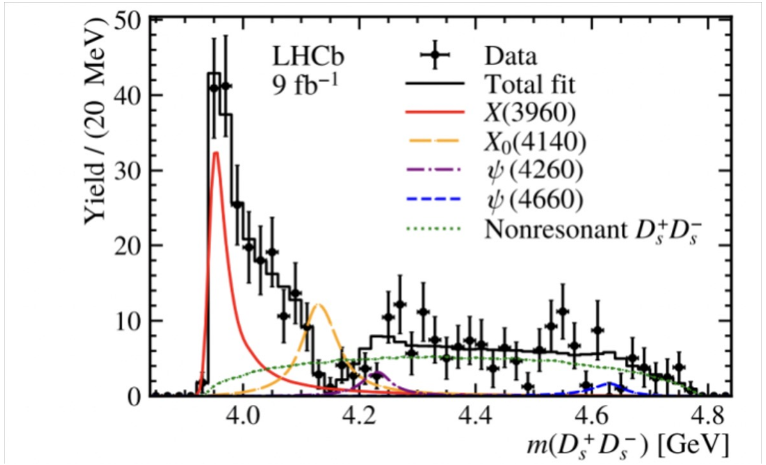
Signal yield: 360 events with 9 fb^{-1}

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



New states with $J^P=0^{++}$:

- X(3960) to describe the near-threshold enhancement
- X(4140) to describe the deep
  → but also described by $J/\psi\varphi \to D_s D_s$ rescattering



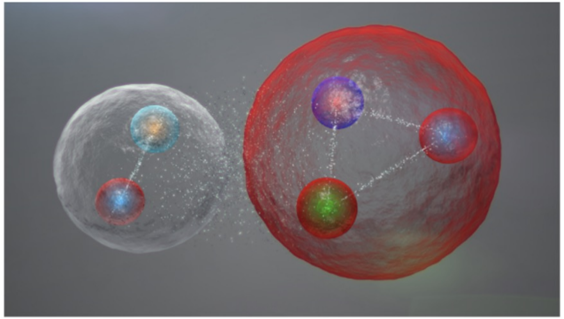
Same state as $\chi_{c0}(3930)$?

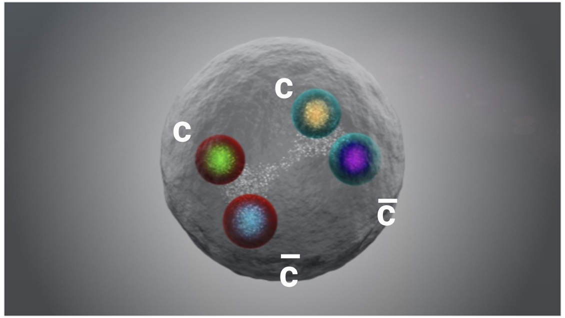
Exotic $c\bar{c}s\bar{s}$ or conventional state?

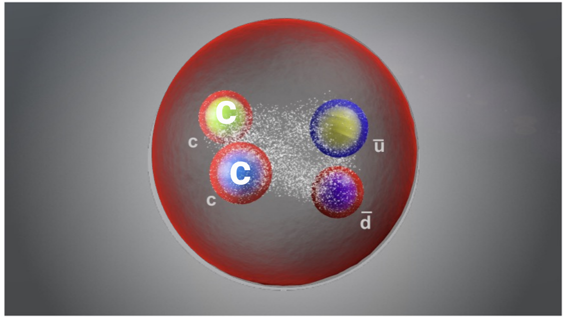
- conventional charmonium predominantly decay to $D^{(*)}D^{(*)}$, while:

$$\frac{\Gamma(X \to D^+ D^-)}{\Gamma(X \to D_s^+ D_s^-)} = 0.29 \pm 0.09 \pm 0.10 \pm 0.08$$

Exotics







Hidden-charm pentaquark

Hidden-charm tetraquarks

Beyond hidden-charm

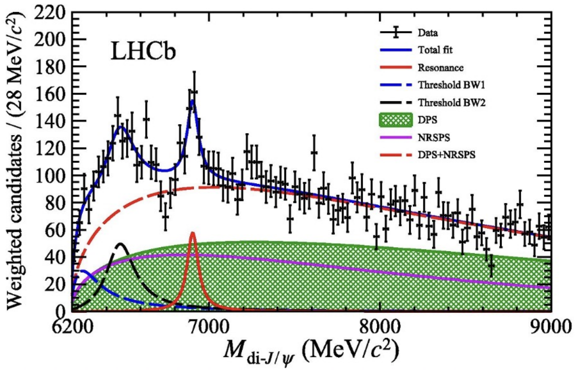
Di-ψ resonance

Sci.Bull. 65 (2020), 23

CMS-PAS-BPH-21-003

$T_{\psi\psi}$ resonances

Sci.Bull. 65 (2020), 23

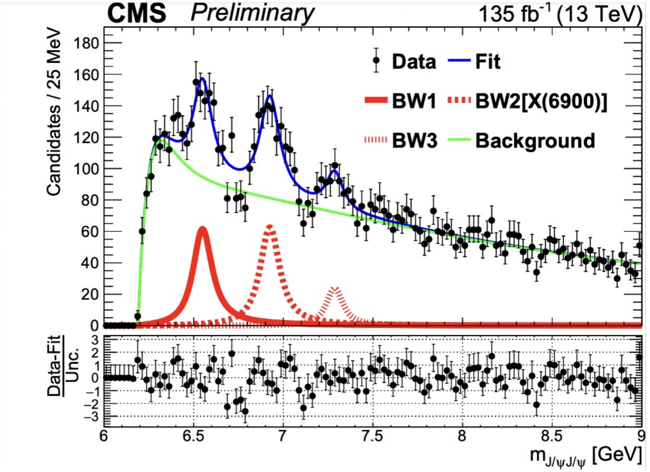


Narrow structure at 6.9 GeV
→ $T_{\psi\psi}$(6900)

Broad structure just above double-J/ψ threshold

→ **5σ deviation** from NR

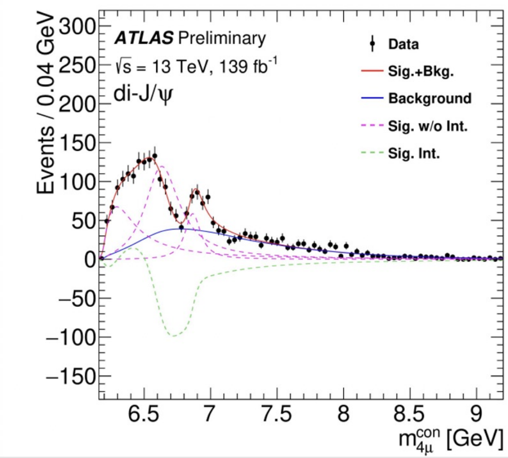
CMS-PAS-BPH-21-003



$T_{\psi\psi}$(6900) consistent with LHCb

\+ New peak at 6600 with ~10σ
3rd peak seen with 4σ

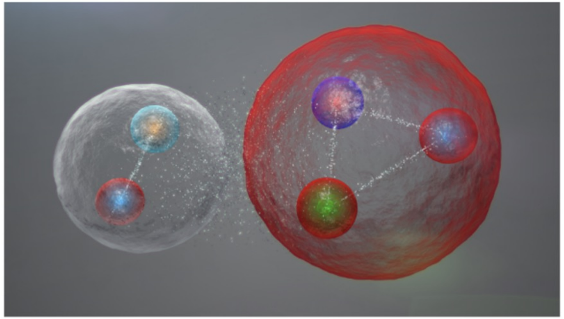
arXiv:2304.08962



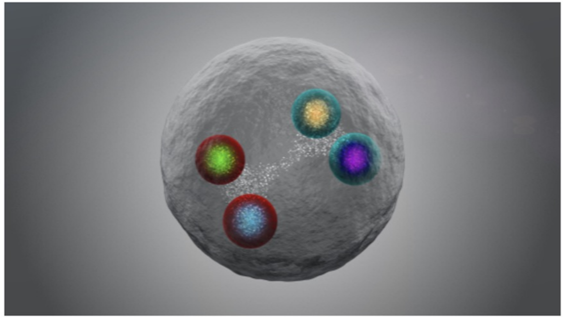
$T_{\psi\psi}$(6900) confirmed & consistent with LHCb

See Zhang's and Hu's talks

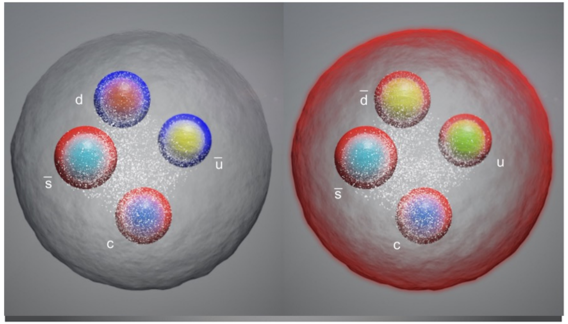
Exotics



Hidden-charm pentaquark



Hidden-charm tetraquarks



Beyond hidden-charm

Open-charm tetraquarks

- $T_{cs0}(2900)^0$
  $T_{cs1}(2900)^0$

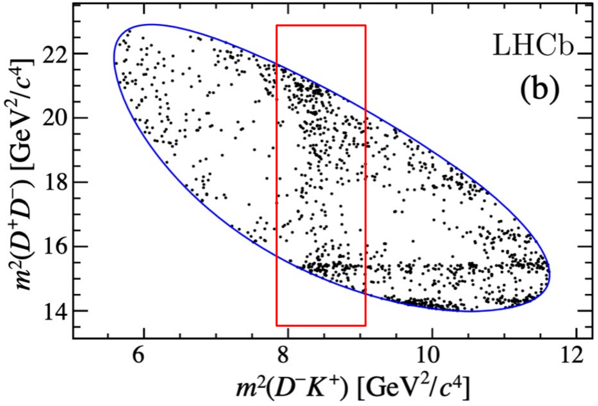
  PRD, 2005, 72: 054026

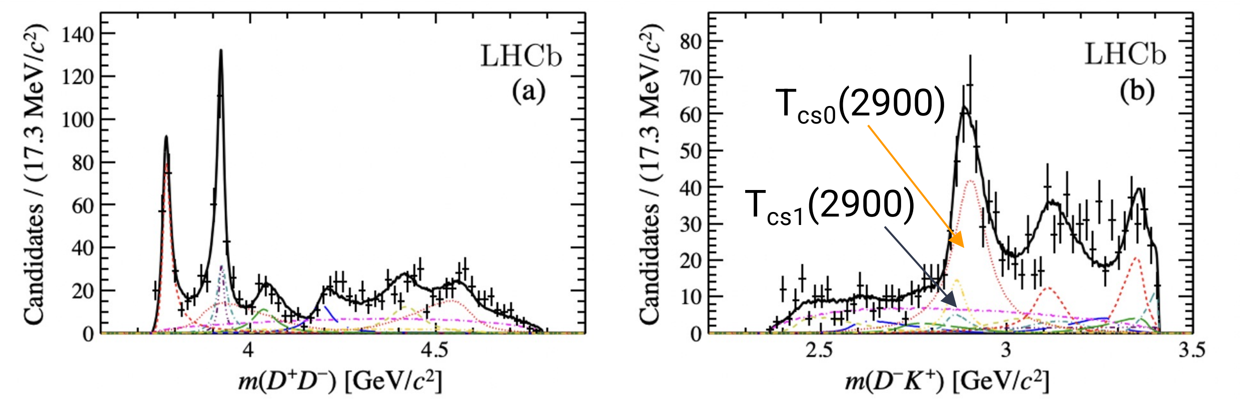
- $T^a_{c\bar{s}0}(2900)^{++}$
  $T^a_{c\bar{s}0}(2900)^0$

  arXiv:2212.02716

First T_{cs} in $B^+ \to D^+D^-K^+$ decays

[PRD 102 (2020) 112003, PRL 125 (2020) 242001]





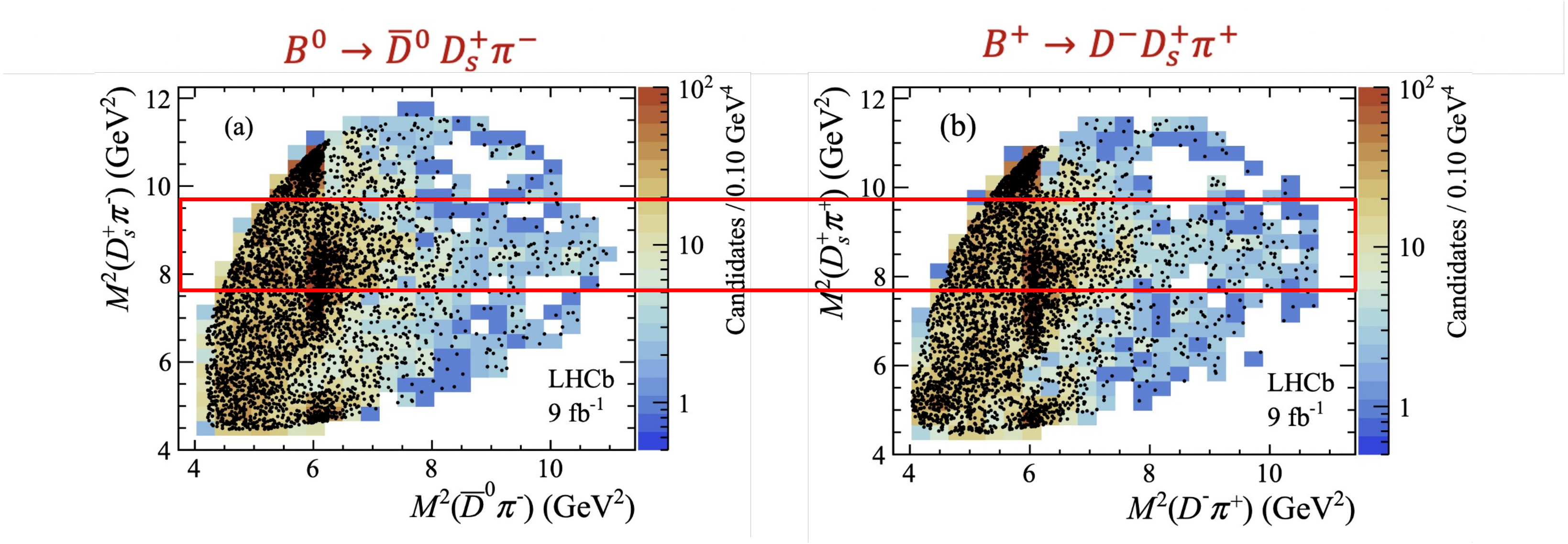
$T_{cs0,1}(2900) \to D^-K^+$: first $cs\bar{u}\bar{d}$ tetraquark

Models predict its SU(3) flavour partner: $T_{c\bar{s}} \to D_s\pi$ $\Rightarrow$ it motivates searches in ***B*→ *DD*$_s$*π*** decays

$B \to D D_s^+ \pi^{-/+}$ decays

arXiv:2212.02716, arxiv:2212.02717

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



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

⇒ tetraquark candidates?

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

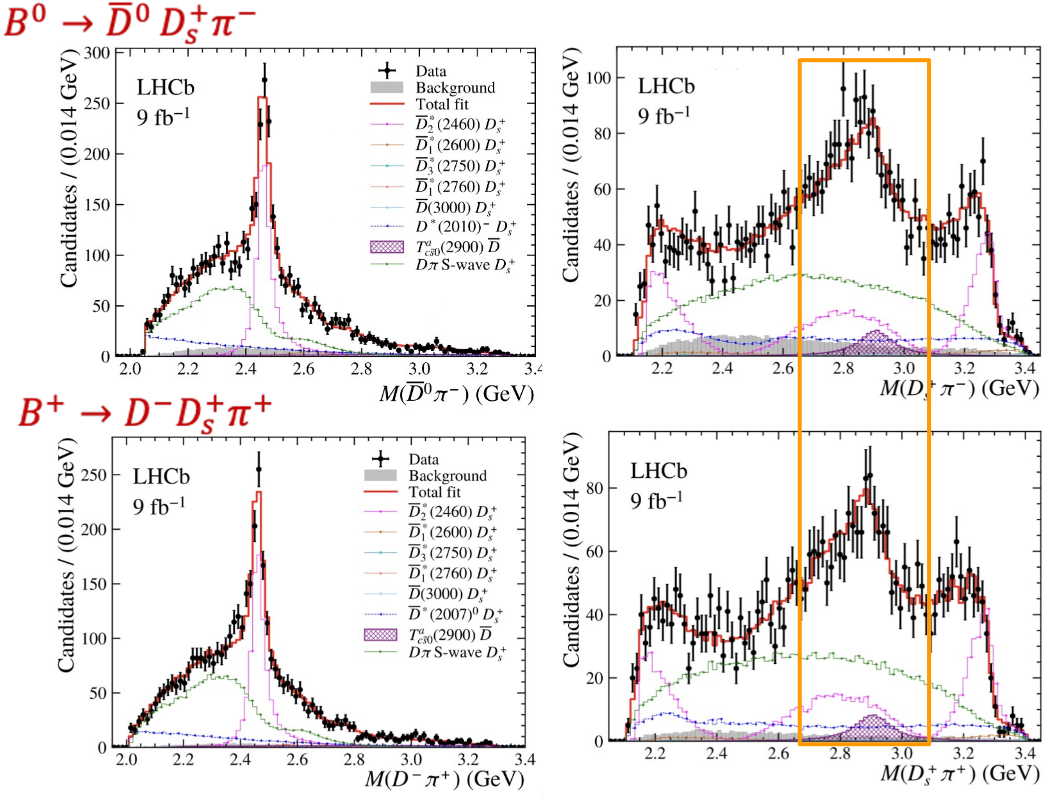
arXiv:2212.02716, arxiv:2212.02717

Isospin symmetry
→ combined amplitude
analysis of the 2 channels

$T^a_{c\bar{s}0}(2900)^{0/++}$ **> 9σ & J^P= 0^+**

$$M = 2.908 \pm 0.011 \pm 0.020\,\mathrm{GeV}$$
$$\Gamma = 0.136 \pm 0.023 \pm 0.011\,\mathrm{GeV}$$

(RBW)



$T^{a}_{c\bar{s}0}(2900)^{0/++}$ in $D_s^{+}\pi^{-/+}$

arXiv:2212.02716, arxiv:2212.02717

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

$T^{a}_{c\bar{s}0}(2900)^{++}$ = first doubly-charged tetraquark

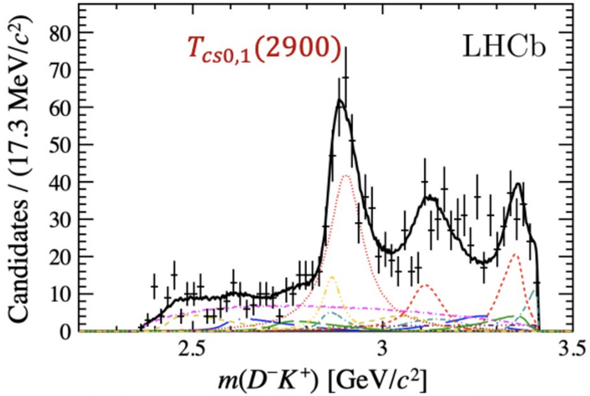
- Isospin triplet?

$T^{a}_{c\bar{s}0}(2900)^{0}$
$T^{a}_{c\bar{s}0}(2900)^{+}$? ⇒ to be searched for in $D_s^{+}\pi^{0}$
$T^{a}_{c\bar{s}0}(2900)^{++}$

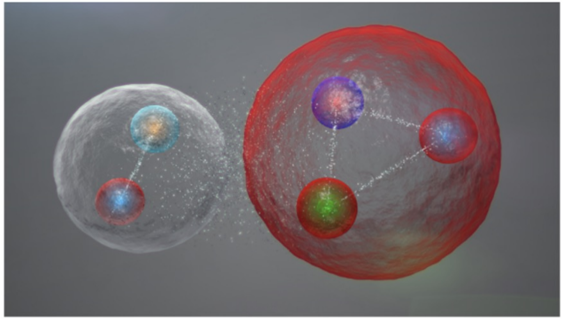
- Same mass as $T_{cs0}(2900)$ observed in $B^{+} \rightarrow D^{+}D^{-}K^{+}$ [1]

$T_{cs0}(2900)$ $cs\bar{u}\bar{d}$
$T_{c\bar{s}0}(2900)$ $c\bar{s}\bar{u}d$
⇒ SU(3) flavour partners?

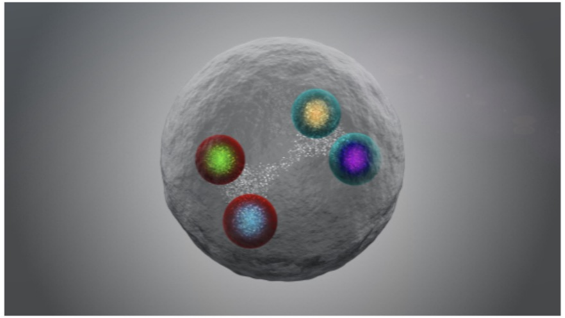
[1]PRD 2005, 72: 054026, PRD, 2009, 79: 094004



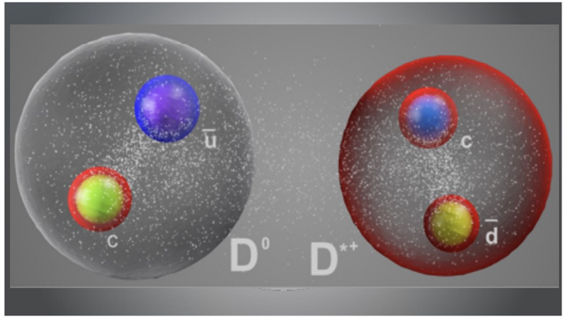
Exotics



Hidden-charm pentaquark



Hidden-charm tetraquarks



Beyond hidden charm

Doubly-charm tetraquark

$T_{cc}(3875)^+$

Nature Physics (2022);
Nat. Comm. 13, 3351 (2022)

Observation of doubly charm tetraquark

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

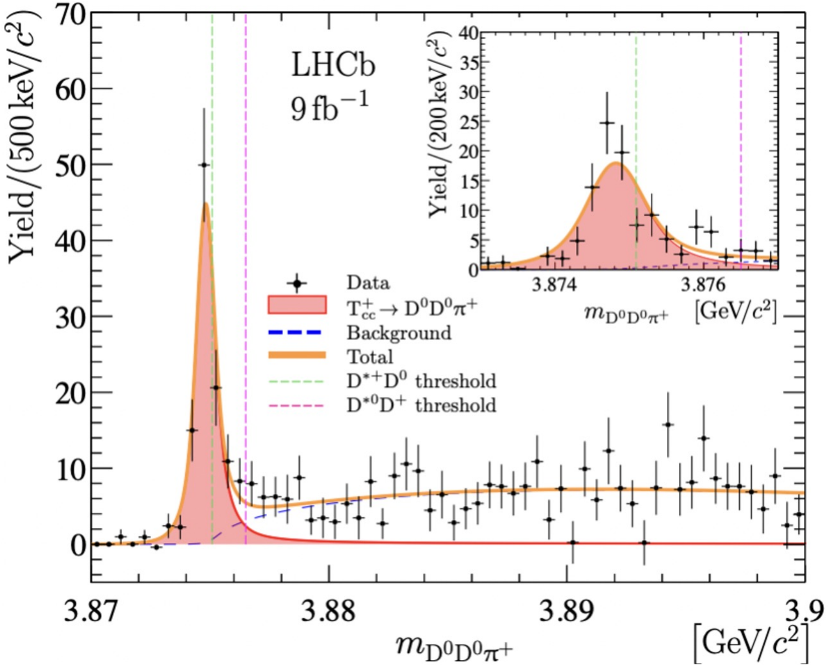
First observation of same-sign
double charmed tetraquark, $T_{cc}^{+}(3875) \rightarrow D^0D^0\pi^+$

$\Rightarrow$ 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** with **$J^P=1^+$**

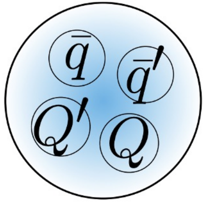


See Sarpis' talk

$QQ'\bar{q}\bar{q}'$ states

T_{cc}^{+} is the first representee of ($QQ'\bar{q}\bar{q}'$) hadrons

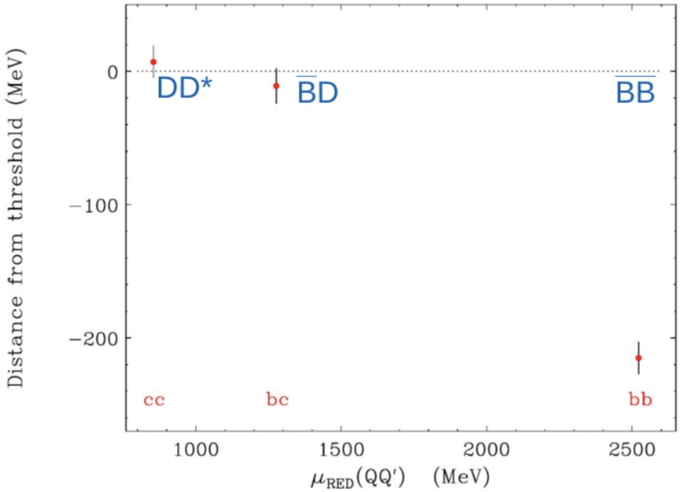
→ almost stable against strong interaction: $\tau \sim 10^{-20}$ s



⇒ It supports existence of:

T_{bb}^{-}(bbūd): stable against QCD with binding energy about 215 MeV with respect to *BB** threshold

T_{cb}^{0}(bcūd): either stable or almost, like T_{cc}^{+}



Phys. Rev. Lett. 119, 202001 (2017)

Conclusion & Prospects

Lots of exotic states discovered in recent years

Hidden-charm pentaquark, $P_{\psi s}$ (4338)

Hidden-charm tetraquark, $T^{\theta}_{\psi s1}(4000)^{0/+}$, $T_{\psi\psi}(6900)$

Open-charm $T_{c\bar{s}0}(2900)^{0,++}$ and **doubly-charm** tetraquarks T_{cc}^{+}

No coherent theoretical picture to describe all observed exotic hadron candidates

⇒ **call for more experimental studies**

Conclusion & Prospects

Run 3 data:

- higher integrated luminosity
- fully software-based trigger

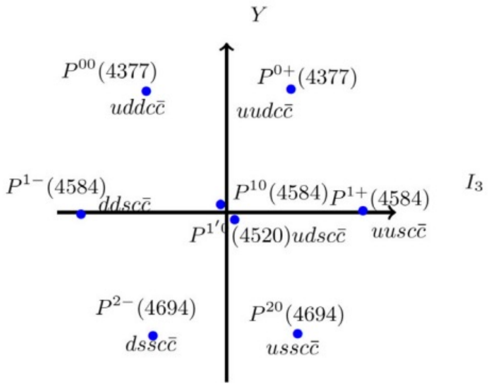
⇒ Boosting data to a new level!
x2 by Run3, x7 by Run4
(+ improvements of analysis skills)

More investigation of the observed states:

- Confirm states in different channels
- Measure J^P, study lineshape and resonance parameters

Many new states to explore:

- Access to *bc* tetraquarks and pentaquarks and *bb* sector
- Search for exotic flavour multiplets



PRD 96, 014014 (2017)

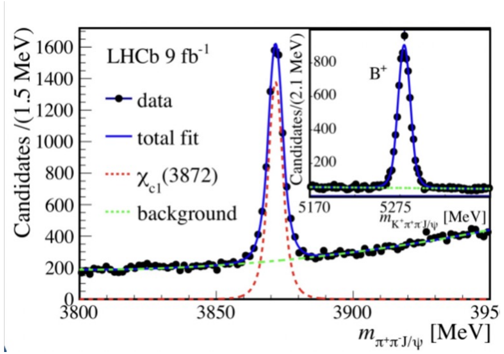
Thank you for listening!

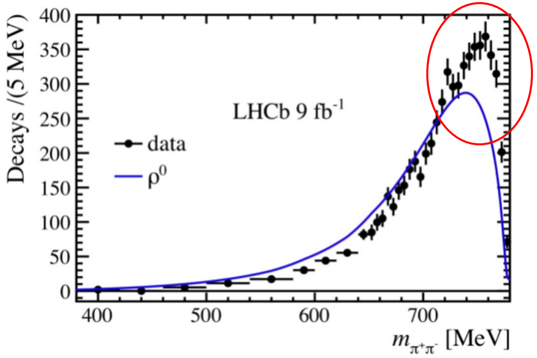
Backup

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

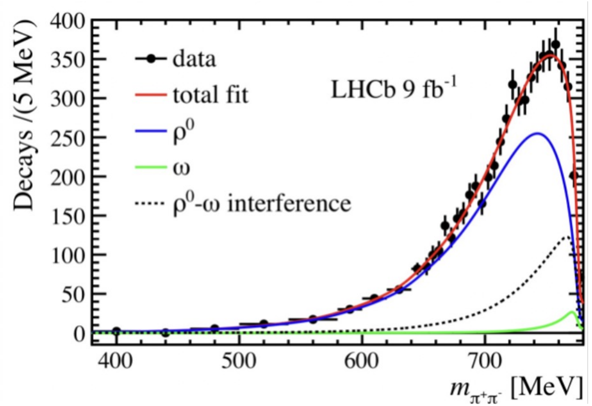
⇒ p(J/ψ) suppression factor missing in the simulations!

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!



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

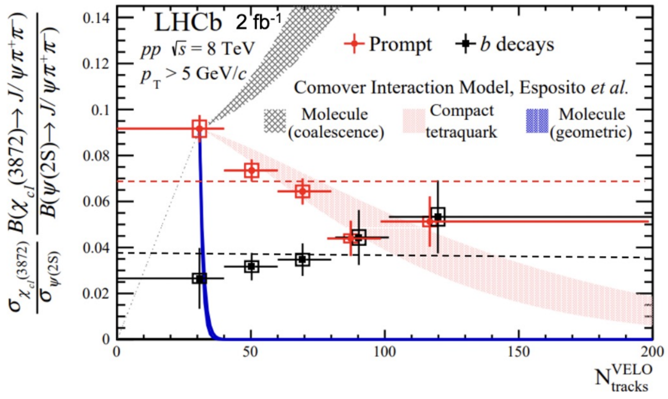
Its nature is still under debate!

→ conventional $\chi_{c1}(2^3P_1)$, DD^* molecular state, tetraquark, hybrid, vector glueball, or mixed?

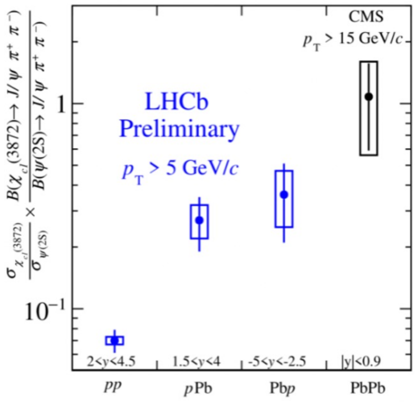
Study of production cross-section wrt $\psi(2S)$:

In pp: $\chi_{c1}(3872)$ suppression due to breakup by comoving particles → **compact tetraquark**

In pPb/PbPb: $\chi_{c1}(3872)$ enhancement due to coalescence mechanism → **molecule**



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



LHCb-CONF-2022-001

Controversial results in different systems
→ to be further investigated

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

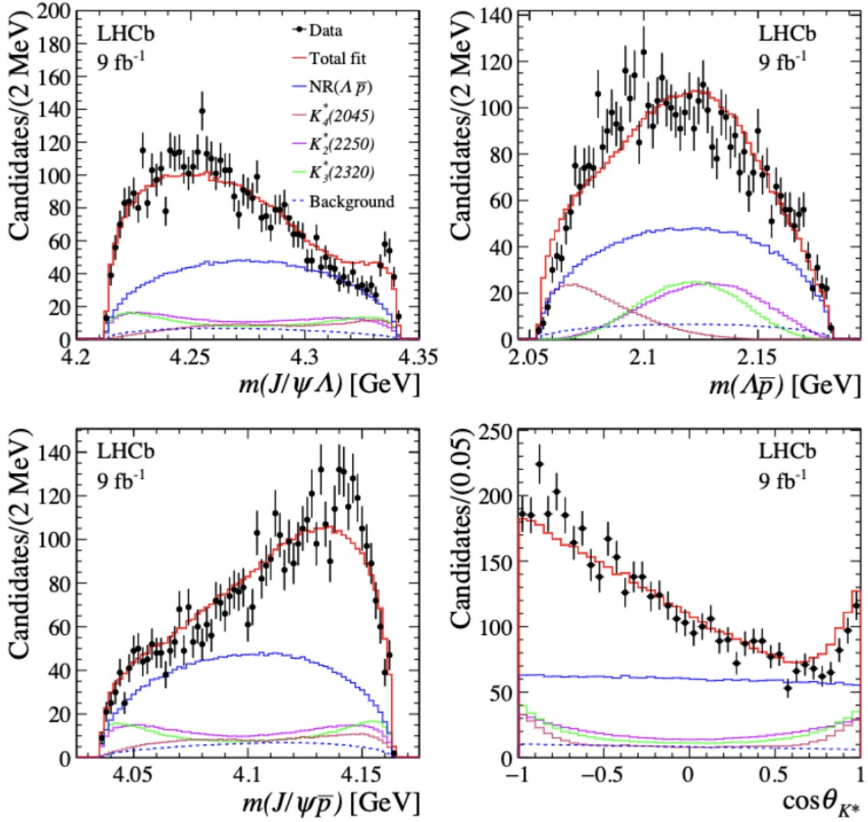
Resonance	Mass (MeV)	Natural width (MeV)	J^P
$K_4^*(2045)^+$	2045 ± 9	198 ± 30	4^+
$K_2^*(2250)^+$	2247 ± 17	180 ± 30	2^-
$K_3^*(2320)^+$	2324 ± 24	150 ± 30	3^+

PDG 2020

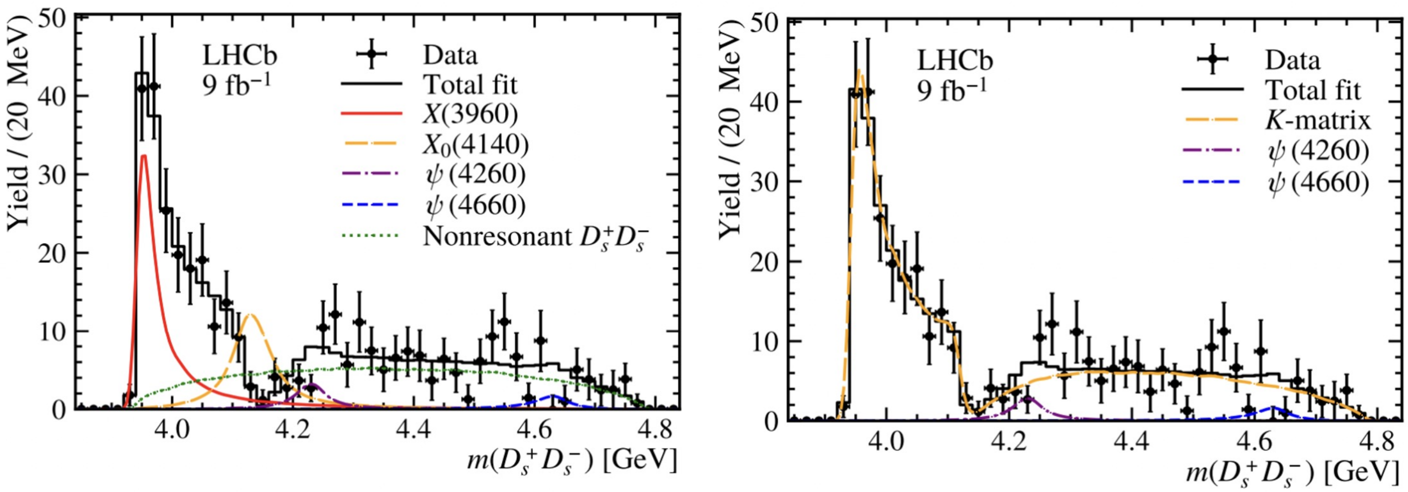
Model with K^* cannot describe data

Goodness-of-fit test

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



Looking again at X(4140)



The default model: dip@4.14GeV modelled by a new resonance, $X_0(4140)$

Can also be described by considering $J/\psi\phi \to D_s^+D_s^-$ rescattering in the K-matrix formula

No definitive conclusion on existence of $X_0(4140)$

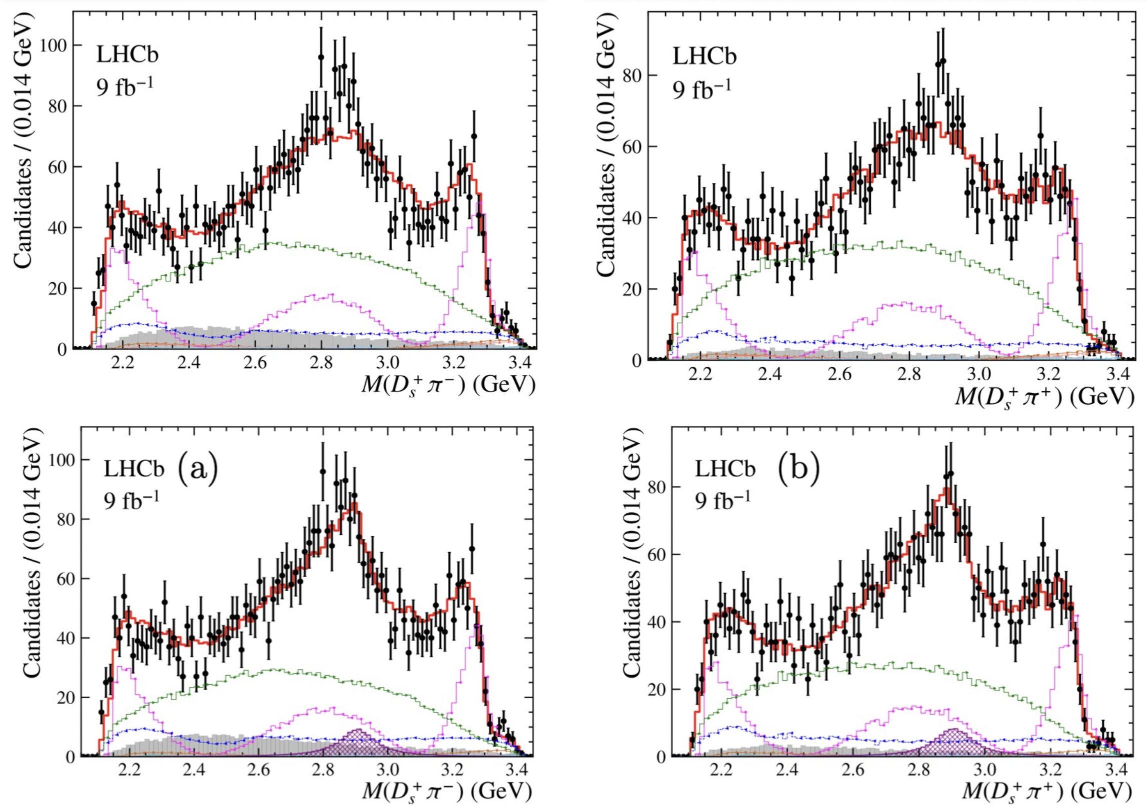
$T^{a}_{c\bar{s}0}(2900)^{0/++}$ in $D_s^+\pi^{-/+}$

arXiv:2212.02716, arxiv:2212.02717

$T^{a}_{c\bar{s}0}(2900)^{0/++}$ > 9σ & $J^P = 0^+$

$$M = 2.908 \pm 0.011 \pm 0.020\,\text{GeV}$$
$$\Gamma = 0.136 \pm 0.023 \pm 0.011\,\text{GeV}$$

(RBW)



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