Doubly charmed pentaquark states with and without strangeness

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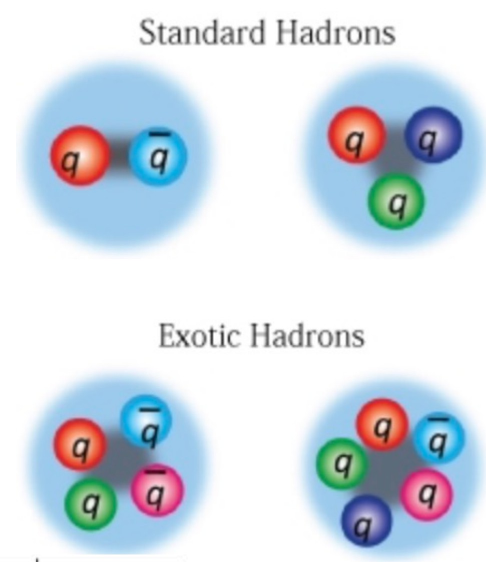
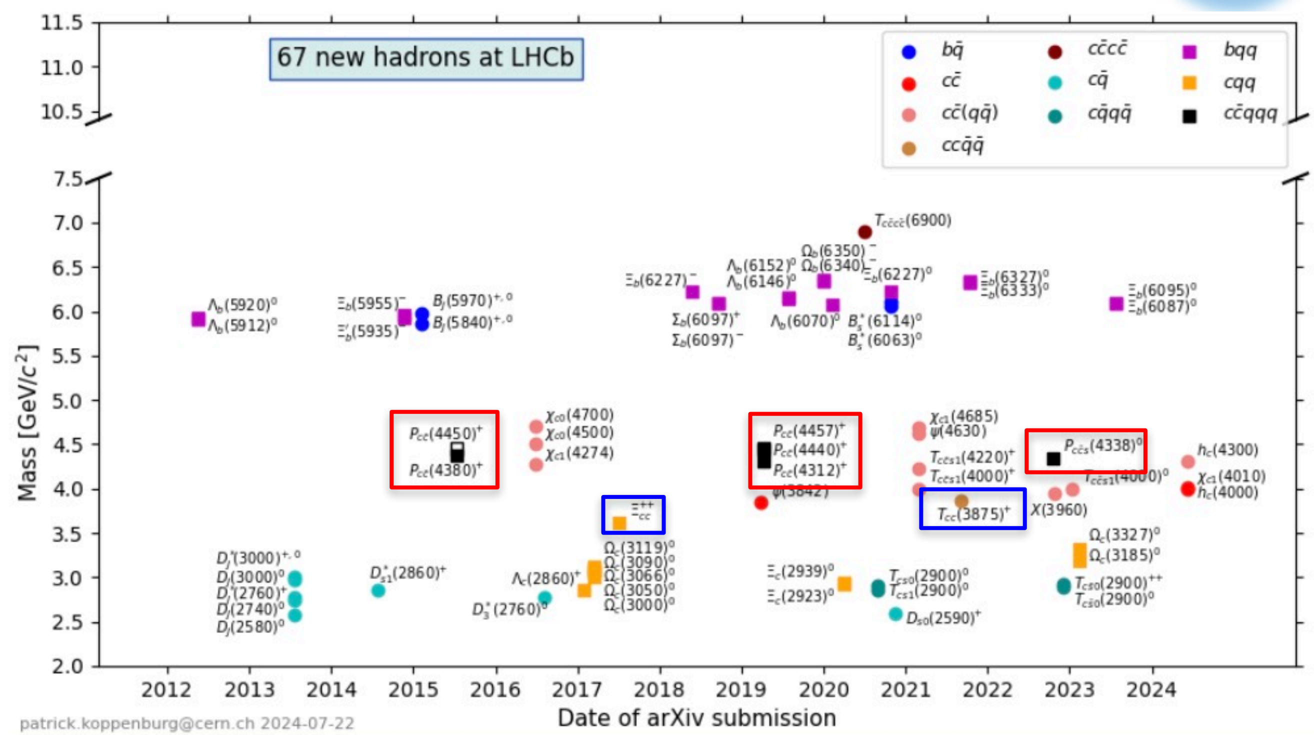
Outline

- **Exotic hadrons and pentaquark states**
- **Doubly charmed pentaquarks without strangeness**
- **Doubly charmed pentaquarks with strangeness**
- **Summary**

Quark model and Exotic hadrons

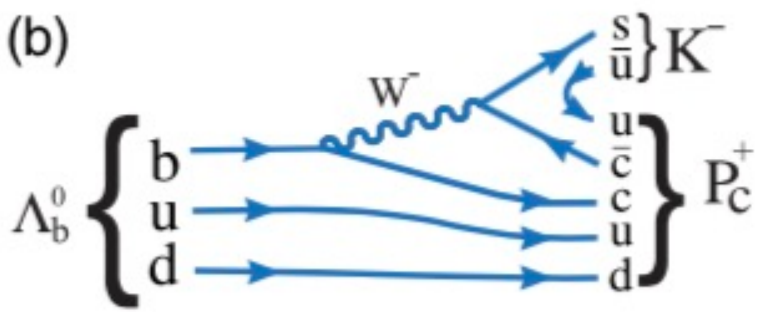


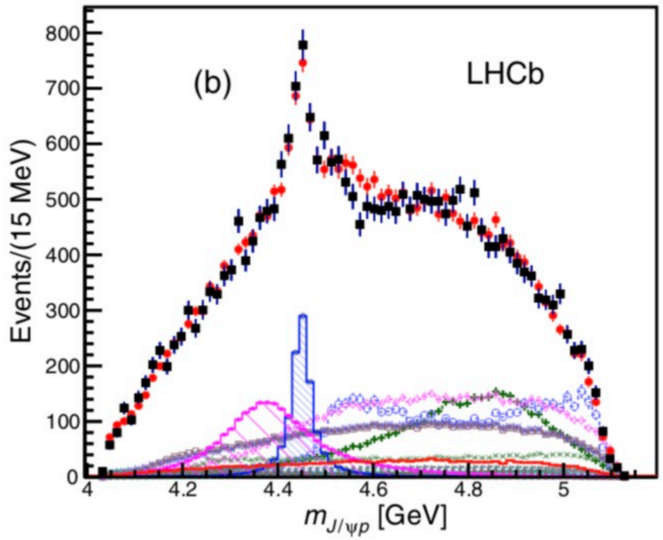
- **Quark Model:** $q\bar{q}$ mesons and qqq baryons
- **Exotic Hadrons:** hadrons beyond QM, such as multiquarks, hybrids, glueballs...
- Many contributions from LHCb!

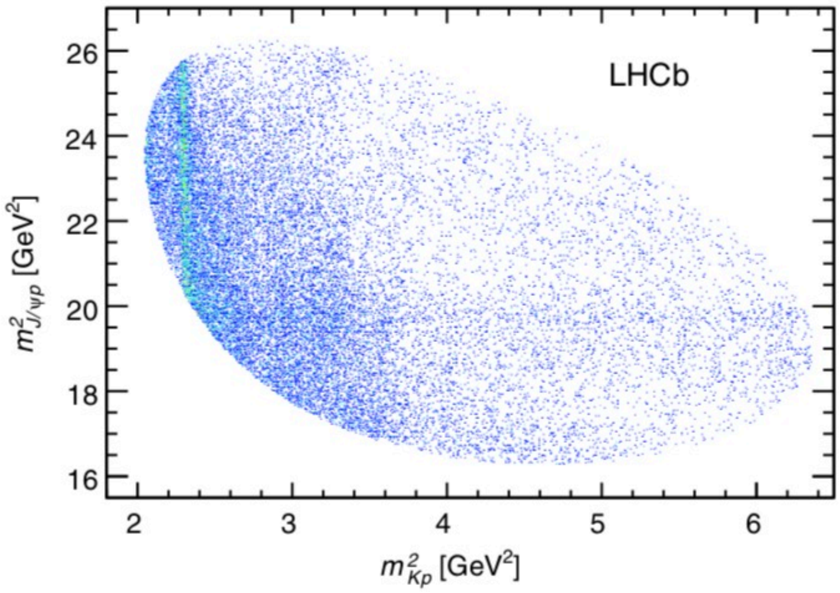


Pentaquarks: LHCb's observation in 2015

Two hidden-charm Pc states were observed in $\Lambda_b^0 \to J/\psi K^- p$ process





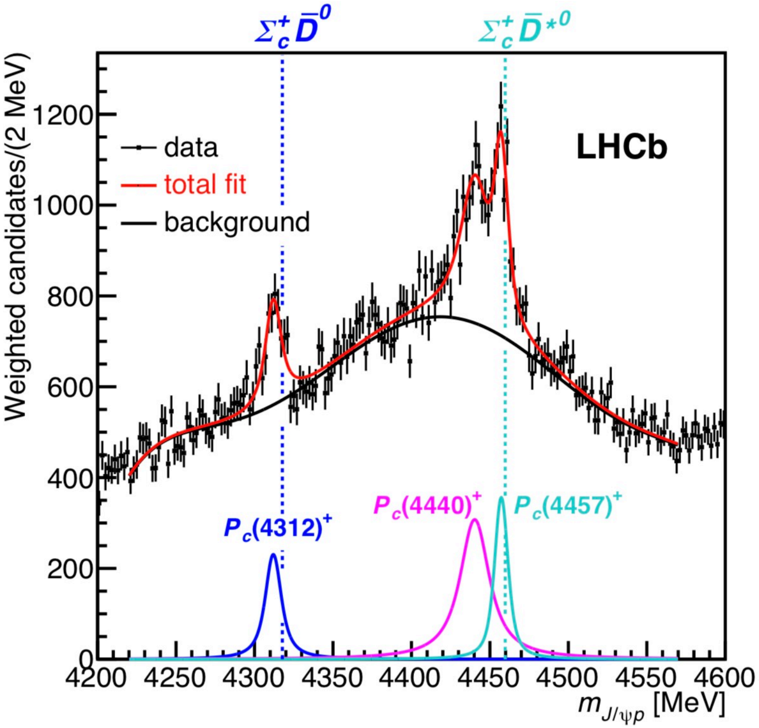


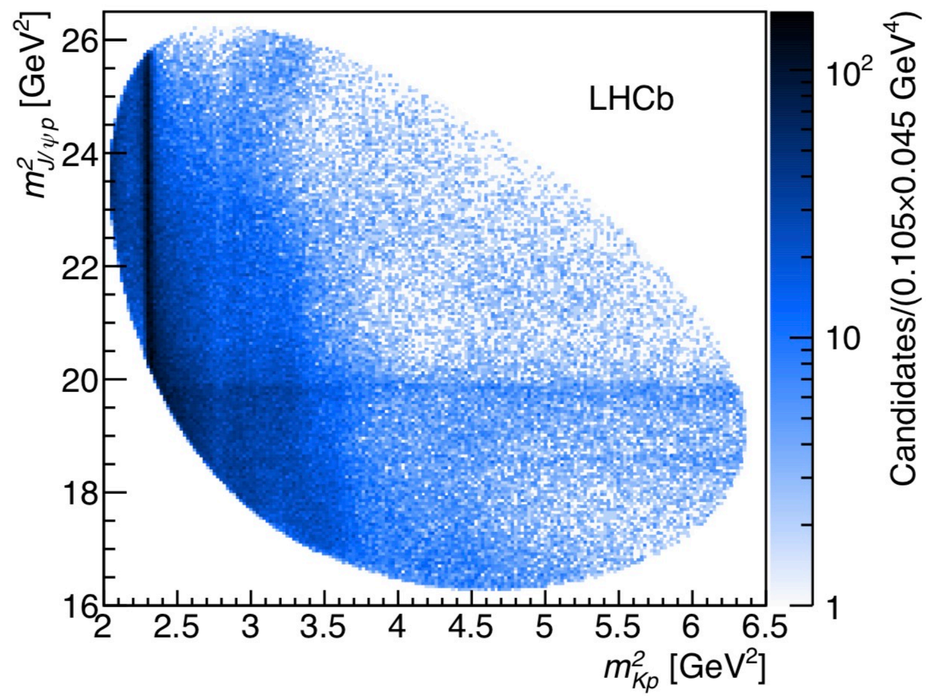
$P_c(4380)$ and $P_c(4450)$ in $J/\psi p$ structure (PRL115, 072001(2015))

$$M_1 = (4380 \pm 8 \pm 29)\,\mathrm{MeV}\,,$$
$$\Gamma_1 = (205 \pm 18 \pm 86)\,\mathrm{MeV}\,,$$
$$M_2 = (4449.8 \pm 1.7 \pm 2.5)\,\mathrm{MeV}\,,$$
$$\Gamma_2 = (39 \pm 5 \pm 19)\,\mathrm{MeV}\,.$$

Combined Run 2 data in 2019:

PRL 122 (2019) 222001

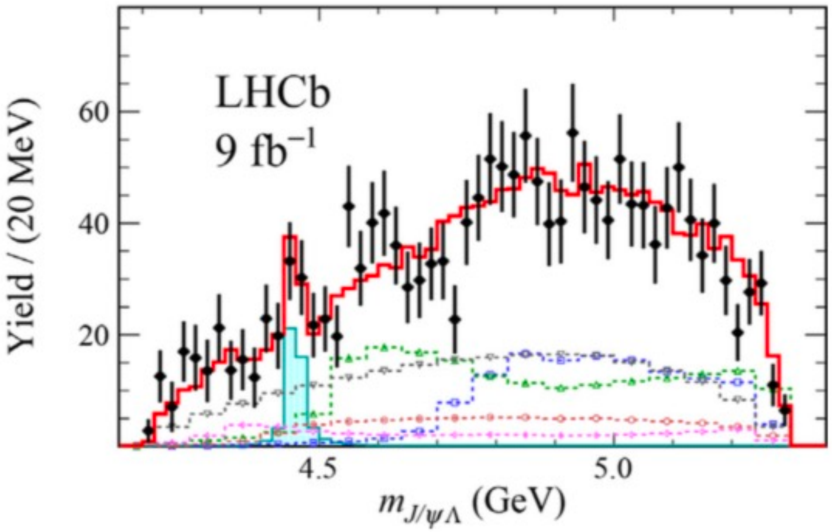




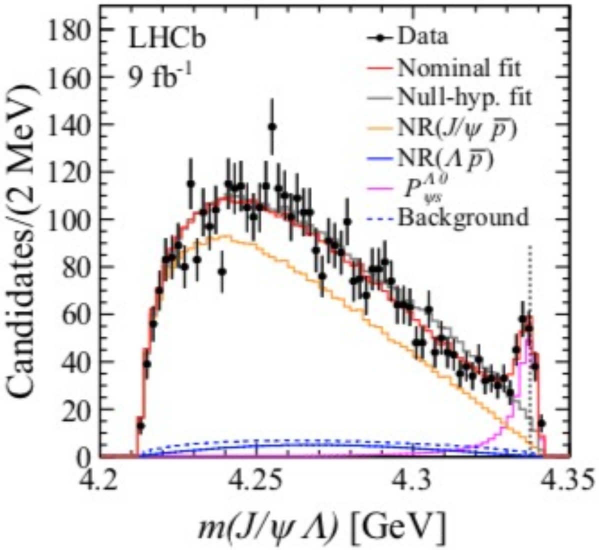
State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

Pcs pentaquarks with strangeness

Two hidden-charm pentaquark states with strangeness were observed in the $J/\psi\Lambda$ **invariant mass spectrum**!



Sci. Bull. 66 (2021) 1278



PRL 122 (2023) 222001

$P_{cs}(4459)^0$:

$M = 4458.8 \pm 2.9^{+4.7}_{-1.1}$ MeV

$\Gamma = 17.3 \pm 6.5^{+8.0}_{-5.7}$ MeV

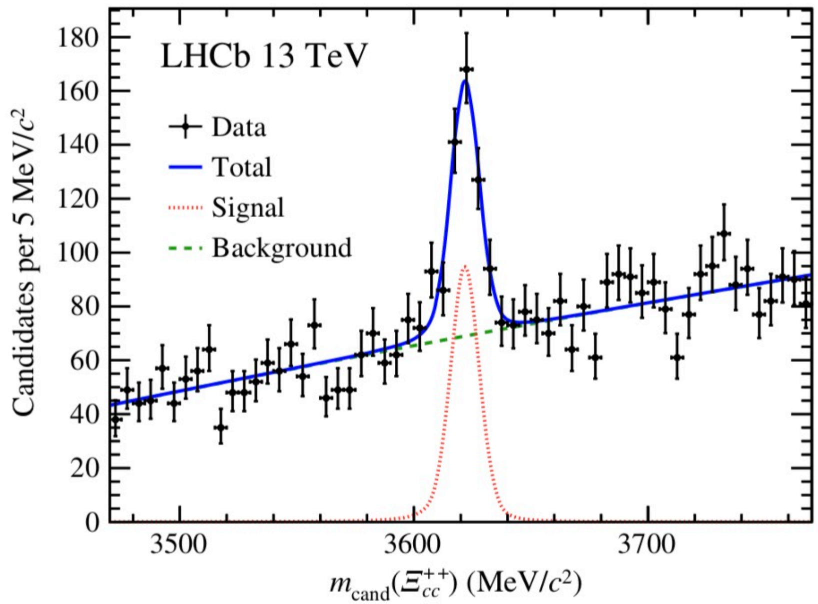
$P_{cs}(4338)^0$: $J^P = \frac{1}{2}^-$

$M = 4338.2 \pm 0.7 \pm 0.4$ MeV

$\Gamma = 7.0 \pm 1.2 \pm 1.3$ MeV

Doubly charmed baryon Ξ_{cc}^{++}

LHCb discovered Ξ_{cc}^{++} in $\Lambda_c^+ K^- \pi^+ \pi^+$ final states:



A long-lived, weakly decaying doubly charmed baryon:

$M = 3621.40 \pm 0.72 \pm 0.27 \pm 0.14$ **MeV**

$\tau = 0.256^{+0.024}_{-0.022} \pm 0.014$ **ps**

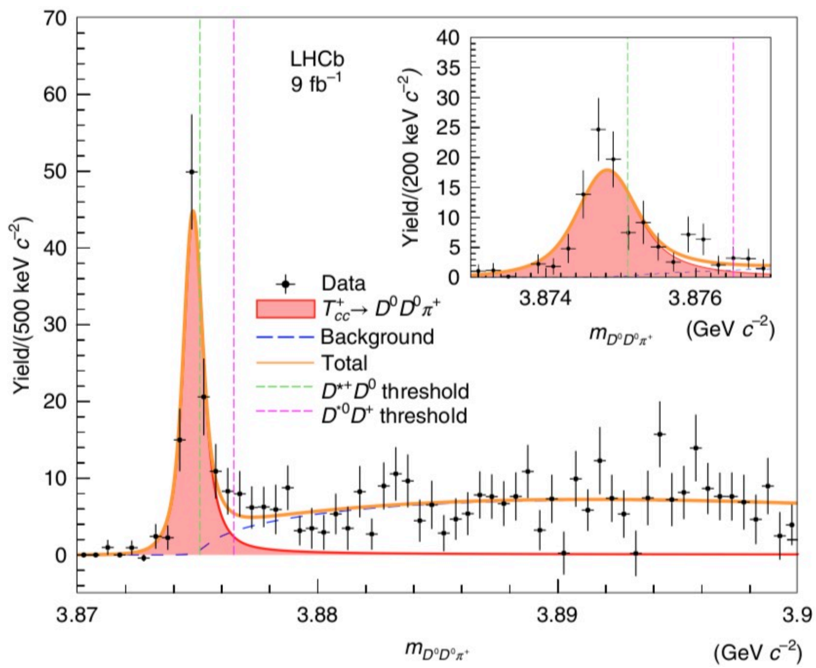
PRL119 (2017) 112001;

PRL121 (2018) 052002.

Doubly charmed tetraquark $T_{cc}(3875)^+$

In 2022, LHCb reported T_{cc}^+ in the mass spectrum of $D^0D^0\pi^+$:

an exotic narrow tetraquark state with $c c \bar{u} \bar{d}$ and $I = 0,\ J^P = 1^+$



$$\delta m_{\mathrm{BW}} = -273 \pm 61 \pm 5\ ^{+11}_{-14}\ \mathrm{keV}\ c^{-2},$$

$$\Gamma_{\mathrm{BW}} = 410 \pm 165 \pm 43\ ^{+18}_{-38}\ \mathrm{keV},$$

Nature Phys. 18 (2022) 751;

Nature Comm. 13 (2022) 3351.

Searching for doubly charmed pentaquarks?

Various theoretical investigations on both hadronic molecule and compact pentaquark configurations:

- One-boson-exchange (OBE) models, Chiral effective field theory, Bethe-Sapeter approach, QCD sum rules, Resonating group method, Chiral quark model……
- In QCD sum rules, we study the doubly charmed pentaquarks without strangeness in the $\Lambda_c^{(*)}D^{(*)}, \Sigma_c^{(*)}D^{(*)}$ **molecular picture** and with strangeness in both the $\Xi_c^{(*\prime)}D^*, \Xi_{cc}^*K^*, \Omega_{cc}^*\rho$ **molecular picture** and **diquark-diquark-antiquark compact picture.**

P_{cc} pentaquarks without strangeness

We construct the $\Lambda_c^{(*)}D^{(*)}, \Sigma_c^{(*)}D^{(*)}$ molecular currents:

$$J^{\Lambda_c D} = \varepsilon^{abc}[(u_a^T C\gamma_\mu c_b)\gamma_5\gamma^\mu d_c - (d_a^T C\gamma_\mu c_b)\gamma_5\gamma^\mu u_c][\bar{d}_d i\gamma_5 c_d],$$

$$J_\mu^{\Lambda_c D^*} = \varepsilon^{abc}[(u_a^T C\gamma_\nu c_b)\gamma_5\gamma^\nu d_c - (d_a^T C\gamma_\nu c_b)\gamma_5\gamma^\nu u_c][\bar{d}_d \gamma_\mu c_d],$$

$$J_\mu^{\Lambda_c^* D} = \varepsilon^{abc}[(u_a^T C\gamma_\mu c_b)d_c - (u_a^T C\gamma_\mu d_b)c_c][\bar{d}_d i\gamma_5 c_d],$$

$$J_{\mu\nu}^{\Lambda_c^* D^*} = \varepsilon^{abc}[(u_a^T C\gamma_\nu c_b)d_c - (u_a^T C\gamma_\nu d_b)c_c][\bar{d}_d \gamma_\mu c_d] + (\mu \leftrightarrow \nu),$$

$$J^{\Sigma_c D} = \varepsilon^{abc}[(u_a^T C\gamma_\mu c_b)\gamma_5\gamma^\mu d_c + (d_a^T C\gamma_\mu c_b)\gamma_5\gamma^\mu u_c][\bar{d}_d i\gamma_5 c_d],$$

$$J_\mu^{\Sigma_c D^*} = \varepsilon^{abc}[(u_a^T C\gamma_\nu c_b)\gamma_5\gamma^\nu d_c + (d_a^T C\gamma_\nu c_b)\gamma_5\gamma^\nu u_c][\bar{d}_d \gamma_\mu c_d],$$

$$J_\mu^{\Sigma_c^* D} = \varepsilon^{abc}[2(u_a^T C\gamma_\mu c_b)u_c + (u_a^T C\gamma_\mu u_b)c_c][\bar{d}_d i\gamma_5 c_d],$$

$$J_{\mu\nu}^{\Sigma_c^* D^*} = \varepsilon^{abc}[2(u_a^T C\gamma_\nu c_b)u_c + (u_a^T C\gamma_\nu u_b)c_c][\bar{d}_d \gamma_\mu c_d] + (\mu \leftrightarrow \nu).$$

Both negative and positive parities are considered!

Parity projected sum rules:

The non-γ_5 and γ_5 couplings to opposite parities:

$$\langle 0|J_-|X_{1/2^-}\rangle = f_X^- u(p),$$
$$\langle 0|J_-|X_{1/2^+}\rangle = f_X^+ \gamma_5 u(p),$$

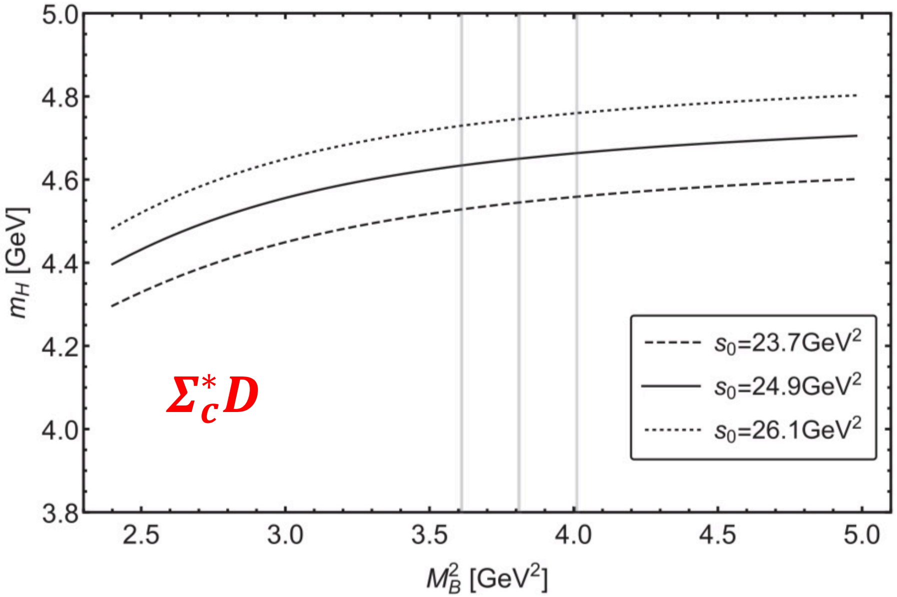
The invariant function contains both contributions

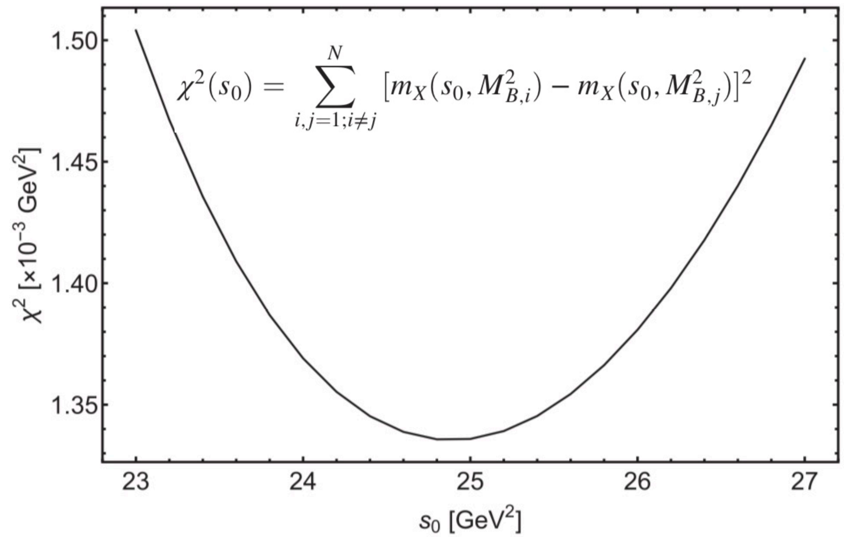
$$\Pi(p^2) = f_X^{-2}\frac{\hat{p} + M_X^-}{M_X^{-2} - p^2} + f_X^{+2}\frac{\hat{p} - M_X^+}{M_X^{+2} - p^2} + \cdots$$

The parity projected sum rules were adopted:

$$M_{j,\pm}^2 = \frac{\int_{4m_c^2}^{s_0}[\sqrt{s}\rho_{j,\mathrm{QCD}}^1(s) \mp \rho_{j,\mathrm{QCD}}^0(s)]\exp\left(-\frac{s}{M_B^2}\right)s\,ds}{\int_{4m_c^2}^{s_0}[\sqrt{s}\rho_{j,\mathrm{QCD}}^1(s) \mp \rho_{j,\mathrm{QCD}}^0(s)]\exp\left(-\frac{s}{M_B^2}\right)ds},$$

P_{cc} pentaquark mass predictions:





$$\mathrm{CVG}_{\pm} \equiv \left| \frac{\int_{4m_c^2}^{\infty} [\sqrt{s}\rho^1_{\langle\bar{q}q\rangle^3}(s) \mp \rho^0_{\langle\bar{q}q\rangle^3}(s)] \exp\left(-\frac{s}{M_B^2}\right) ds}{\int_{4m_c^2}^{\infty} [\sqrt{s}\rho^1(s) \mp \rho^0(s)] \exp\left(-\frac{s}{M_B^2}\right) ds} \right|,$$

$$\mathrm{PC}_{\pm} \equiv \frac{\int_{4m_c^2}^{s_0} [\sqrt{s}\rho^1(s) \mp \rho^0(s)] \exp\left(-\frac{s}{M_B^2}\right) ds}{\int_{4m_c^2}^{\infty} [\sqrt{s}\rho^1(s) \mp \rho^0(s)] \exp\left(-\frac{s}{M_B^2}\right) ds}.$$

P_{cc} pentaquark mass predictions:

PRD109 (2024) 094018

Current	J^P	$s_0[\text{GeV}^2]$	$M_B^2[\text{GeV}^2]$	Mass [GeV]	Two-hadron threshold [GeV]
$J^{\Lambda_c D}$	$\frac{1}{2}^-$	$19.5(\pm 5\%)$	2.83–3.43	$4.13^{+0.10}_{-0.09}$	4.15
$J^{\Sigma_c D}$	$\frac{1}{2}^-$	$18.3(\pm 5\%)$	3.40–3.70	$4.08^{+0.18}_{-0.13}$	4.32
$J^{\Sigma_c D^*}$	$\frac{3}{2}^-$	$20.3(\pm 5\%)$	3.17–3.47	$4.14^{+0.18}_{-0.15}$	4.46
$J^{\Sigma_c^* D}$	$\frac{3}{2}^-$	$22.8(\pm 5\%)$	3.82–4.22	$4.47^{+0.11}_{-0.10}$	4.39
$J^{\Lambda_c D^*}$	$\frac{3}{2}^-$	$21.0(\pm 5\%)$	3.55–3.95	$4.31^{+0.11}_{-0.10}$	4.29
$J^{\Lambda_c^* D}$	$\frac{3}{2}^-$	$22.8(\pm 5\%)$	2.91–3.51	$4.42^{+0.13}_{-0.12}$	4.73
$J^{\Lambda_c^* D^*}$	$\frac{5}{2}^-$	$22.1(\pm 5\%)$	3.09–3.69	$4.41^{+0.17}_{-0.14}$	4.86
$J^{\Sigma_c^* D^*}$	$\frac{5}{2}^-$	$25.0(\pm 5\%)$	4.0–4.6	$4.69^{+0.12}_{-0.11}$	4.53

- **Some P_{cc} states were predicted to be lower than their thresholds!**
- Pentaquarks in the isospin quartet with $I = 3/2$ are absolute exotic:

  $[P_{cc}^{+++}(ccuu\bar{d}), P_{cc}^{++}(ccuu\bar{u}), P_{cc}^{+}(ccdd\bar{d}), P_{cc}^{0}(ccdd\bar{u})]$

Strong decays

PRD109 (2024) 094018

J^P	Current	Partial wave	$I=\frac{1}{2}$	$I=\frac{3}{2}$
$\frac{1}{2}^-$	$J^{\Lambda_c D}$	S	$\Xi_{cc}\pi$	$\varnothing$
		P	$\Xi_{cc}\sigma$	$\varnothing$
	$J^{\Sigma_c D}$	S	$\Xi_{cc}\pi$	$\Xi_{cc}\pi$
		P	$\cdots$	$\cdots$
$\frac{3}{2}^-$	$J^{\Sigma_c D^*}$	S	$\Xi^*_{cc}\pi$	$\Xi^*_{cc}\pi$
		P	$\Xi_{cc}\sigma$	$\cdots$
	$J^{\Sigma^*_c D}$	S	$\Lambda_c D^*, \Sigma_c D^*, \Sigma^*_c D, \Xi_{cc}\rho/\omega, \Xi^*_{cc}\pi/\eta$	$\Sigma_c D^*, \Sigma^*_c D, \Xi_{cc}\rho, \Xi^*_{cc}\pi$
		P	$\Lambda_c(2595)D, \Xi^{(*)}_{cc}\sigma$	$\cdots$
	$J^{\Lambda_c D^*}$	S	$\Lambda_c D^*, \Xi^*_{cc}\pi/\eta$	$\varnothing$
		P	$\Xi^{(*)}_{cc}\sigma$	$\varnothing$
	$J^{\Lambda^*_c D}$	S	$\Lambda_c D^*, \Sigma^*_c D, \Sigma^{(*)}_c D^*, \Xi_{cc}\omega/\rho, \Xi^*_{cc}\pi/\omega/\rho/\eta/\eta'$	$\varnothing$
		P	$\Lambda_c(2595)D^{(*)}, \Lambda_c D_0/D_1, \Xi^{(*)}_{cc}\sigma/a_0/f_0(980)$	$\varnothing$
$\frac{5}{2}^-$	$J^{\Lambda^*_c D^*}$	S	$\cdots$	$\varnothing$
		P	$\Xi^*_{cc}\sigma$	$\varnothing$
	$J^{\Sigma^*_c D^*}$	S	$\Sigma^*_c D^*, \Xi^*_{cc}\rho/\omega$	$\Sigma^*_c D^*, \Xi^*_{cc}\rho$
		P	$\Lambda_c(2595)D^*, \Xi^*_{cc}\sigma/f_0(980)/a_0$	$\Xi^*_{cc}a_0$

- Especially interesting for the triply and neutral charged pentaquarks:

$P_{cc}^{+++} \to \Xi_{cc}^{(*)++}\pi^+/\rho^+, \Sigma_c^{(*)++}D^{(*)+}$ and $P_{cc}^{0} \to \Xi_{cc}^{(*)+}\pi^-/\rho^-, \Sigma_c^{(*)0}D^{(*)0}$

P_{ccs} pentaquarks with strangeness

- In heavy antiquark-diquark symmetry (HADS), a heavy diquark field with $\bar{3}_c$ behaves like a heavy antiquark in the color space:
  $QQ \leftrightarrow \bar{Q},\ \ \bar{Q}\bar{Q} \leftrightarrow Q$
- $T_{cc}^{+}(cc\bar{u}\bar{d}) \leftrightarrow \bar{\Lambda}_c(\bar{c}\bar{u}\bar{d})$
- $T_{c\bar{s}0}^{a}(cd\bar{u}\bar{s})^{0} \leftrightarrow \bar{P}_{\bar{c}\bar{c}\bar{s}}(\bar{c}\bar{c}\bar{u}\bar{s}d)^{--}$
- **From the HADS point of view, one expects the mass relation**

$$m(QQq\bar{q}) - m(QQ\bar{q}\bar{q}) = m(qq\bar{q}\bar{Q}) - m(\bar{Q}\bar{q}\bar{q})$$

- **The observation of strange charmed tetraquark $T_{c\bar{s}0}^{a}(2900)^{0}$ sugguests the existence of strange doubly charmed pentaquarks!**

P_{ccs} pentaquarks with strangeness

Interpolating currents in the $\Xi_c^{(*\prime)} D^{(*)}$ molecular picture:

$$
\begin{aligned}
\eta_1 &= \frac{1}{\sqrt{2}}\epsilon_{abc}\left[\left(u_a^T C\gamma_5 s_b - s_a^T C\gamma_5 u_b\right) Q_c\right]\left[\bar{d}_d\gamma_5 Q_d\right],\\
\eta_2 &= \frac{1}{\sqrt{2}}\epsilon_{abc}\left[\left(u_a^T C\gamma_\mu\gamma_5 s_b - s_a^T C\gamma_\mu\gamma_5 u_b\right)\gamma_\mu Q_c\right]\left[\bar{d}_d\gamma_5 Q_d\right],\\
\eta_3 &= \frac{1}{\sqrt{2}}\epsilon_{abc}\left[\left(u_a^T C\gamma_5 s_b - s_a^T C\gamma_5 u_b\right)\gamma_\mu Q_c\right]\left[\bar{d}_d\gamma_\mu Q_d\right],\\
\eta_{4\mu} &= \frac{1}{\sqrt{2}}\epsilon_{abc}\left[\left(u_a^T C\gamma_\nu\gamma_5 s_b - s_a^T C\gamma_\nu\gamma_5 u_b\right)\gamma_\nu Q_c\right]\left[\bar{d}_d\gamma_\mu Q_d\right],\\
\eta_{5\mu} &= \sqrt{\frac{2}{3}}\epsilon_{abc}\left[(s_a^T C\gamma_\mu u_b)\gamma_5 Q_c + (u_a^T C\gamma_\mu Q_b)\gamma_5 s_c + (Q_a^T C\gamma_\mu s_b)\gamma_5 u_c\right]\left[\bar{d}_d\gamma_5 Q_d\right],\\
\eta_6 &= \sqrt{\frac{2}{3}}\epsilon_{abc}\left[(s_a^T C\gamma_\mu u_b)\gamma_5 Q_c + (u_a^T C\gamma_\mu Q_b)\gamma_5 s_c + (Q_a^T C\gamma_\mu s_b)\gamma_5 u_c\right]\left[\bar{d}_d\gamma_\mu Q_d\right],\\
\eta_{7,\mu\nu} &= \sqrt{\frac{2}{3}}\epsilon_{abc}\left[(s_a^T C\gamma_\mu u_b)\gamma_5 Q_c + (u_a^T C\gamma_\mu Q_b)\gamma_5 s_c + (Q_a^T C\gamma_\mu s_b)\gamma_5 u_c\right]\left[\bar{d}_d\gamma_\nu Q_d\right] + (\mu \leftrightarrow \nu),
\end{aligned}
$$

Interpolating currents in the $\boldsymbol{\Xi_{cc}^{*}K^{*}, \Omega_{cc}^{*}\pi/\rho}$ molecular picture:

$$\xi_1 = \left[\epsilon_{abc}(Q_a^T C\gamma_\mu Q_b)\gamma_\mu\gamma_5 u_c\right]\left[\bar{d}_d\gamma_5 s_d\right],$$

$$\xi_{2\mu} = \left[\epsilon_{abc}(Q_a^T C\gamma_\nu Q_b)\gamma_\nu\gamma_5 u_c\right]\left[\bar{d}_d\gamma_\mu s_d\right],$$

$$\xi_{3\mu} = \frac{1}{\sqrt{3}}\epsilon_{abc}\left[2\left(u_a^T C\gamma_\mu Q_b\right)\gamma_5 Q_c + \left(Q_a^T C\gamma_\mu Q_b\right)\gamma_5 u_c\right]\left[\bar{d}_d\gamma_5 s_d\right],$$

$$\xi_4 = \frac{1}{\sqrt{3}}\epsilon_{abc}\left[2\left(u_a^T C\gamma_\mu Q_b\right)\gamma_5 Q_c + \left(Q_a^T C\gamma_\mu Q_b\right)\gamma_5 u_c\right]\left[\bar{d}_d\gamma_\mu s_d\right],$$

$$\xi_{5,\mu\nu} = \frac{1}{\sqrt{3}}\epsilon_{abc}\left[2\left(u_a^T C\gamma_\mu Q_b\right)\gamma_5 Q_c + \left(Q_a^T C\gamma_\mu Q_b\right)\gamma_5 u_c\right]\left[\bar{d}_d\gamma_\nu s_d\right] + (\mu \leftrightarrow \nu),$$

$$\psi_i = \xi_i\ (u \leftrightarrow s),$$

Only spin-1 $[cc]$ diquark field exists due to Pauli principle!

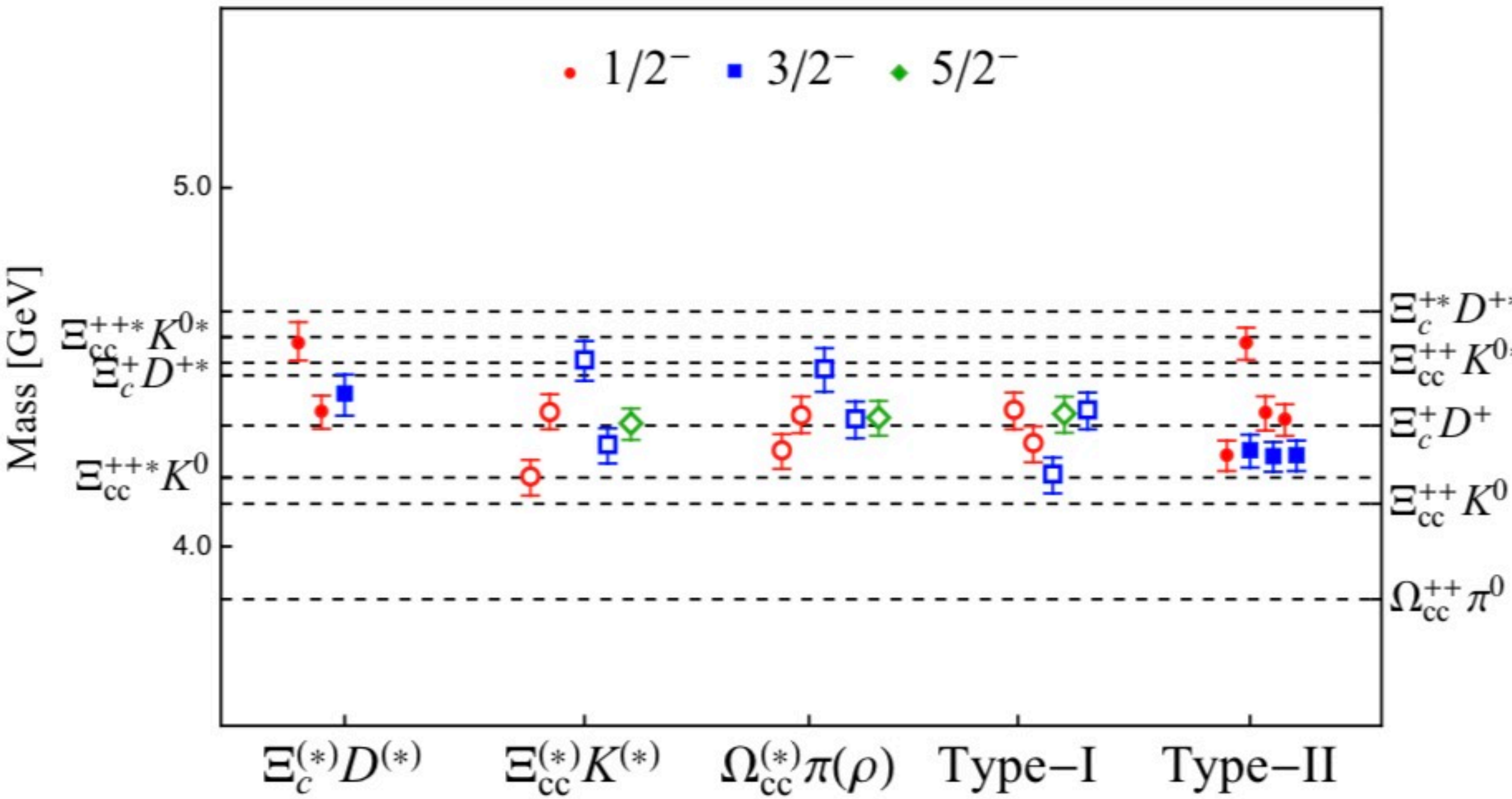
Interpolating currents in **two compact pentaquark pictures:**

$$
\begin{aligned}
J_{1,2} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu Q_j\right)\left(u_k^T C\gamma_\mu s_l\right)\gamma_5 C\bar{d}_c^T\,,\\
J_{1,3} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu Q_j\right)\left(u_k^T C\gamma_5 s_l\right)\gamma_\mu C\bar{d}_c^T\,,\\
J_{1,5\mu} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu Q_j\right)\left(u_k^T C\gamma_5 s_l\right)\gamma_5 C\bar{d}_c^T\,,\\
J_{1,8\mu} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\nu Q_j\right)\left(u_k^T C\gamma_\nu s_l\right)\gamma_\mu C\bar{d}_c^T\,,\\
J_{1,9\mu\nu} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu Q_j\right)\left(u_k^T C\gamma_\nu s_l\right)\gamma_5 C\bar{d}_c^T + (\mu \leftrightarrow \nu),
\end{aligned}
$$

and

$$
\begin{aligned}
J_{2,1} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_5 u_j\right)\left(Q_k^T C\gamma_5 s_l\right)\gamma_5 C\bar{d}_c^T\,,\\
J_{2,2} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu u_j\right)\left(Q_k^T C\gamma_\mu s_l\right)\gamma_5 C\bar{d}_c^T\,,\\
J_{2,3} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu u_j\right)\left(Q_k^T C\gamma_5 s_l\right)\gamma_\mu C\bar{d}_c^T\,,\\
J_{2,4} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_5 u_j\right)\left(Q_k^T C\gamma_\mu s_l\right)\gamma_\mu C\bar{d}_c^T\,,\\
J_{2,5\mu} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu u_j\right)\left(Q_k^T C\gamma_5 s_l\right)\gamma_5 C\bar{d}_c^T\,,\\
J_{2,6\mu} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_5 u_j\right)\left(Q_k^T C\gamma_\mu s_l\right)\gamma_5 C\bar{d}_c^T\,,\\
J_{2,7\mu} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_5 u_j\right)\left(Q_k^T C\gamma_5 s_l\right)\gamma_\mu C\bar{d}_c^T\,,\\
J_{2,8\mu\nu} &= \epsilon_{aij}\epsilon_{bkl}\epsilon_{abc}\left(Q_i^T C\gamma_\mu u_j\right)\left(Q_k^T C\gamma_\nu s_l\right)\gamma_5 C\bar{d}_c^T + (\mu \leftrightarrow \nu),
\end{aligned}
$$

P_{ccs} pentaquark mass predictions:



arXiv:2405.09067

Predictions for the HADS tetraquark partners:

Current	J^P	Structure	b[GeV]	c[GeV^2]	$m_{P_{bbs}}$[GeV]	$m_{T_{c\bar{s}}}$[GeV]	$J^P(T_{c\bar{s}})$
η_3	$\frac{1}{2}^-$	$\Xi_c^+ D^{*+}$	1.53	0.40	$10.04^{+0.06}_{-0.05}$	–	–
$\eta_{4\mu}$	$\frac{3}{2}^-$	$\Xi_c'^+ D^{*+}$	1.67	0.25	$10.19^{+0.06}_{-0.05}$	–	–
η_6	$\frac{1}{2}^-$	$\Xi_c^{*+} D^{*+}$	2.26	-0.35	$10.61^{+0.06}_{-0.05}$	–	–
ξ_1	$\frac{1}{2}^-$	$\Xi_{cc}^{++} \bar{K}^0$	1.48	0.24	$9.93^{0.06}_{0.05}$	2.94	0^+
$\xi_{2\mu}$	$\frac{3}{2}^-$	$\Xi_{cc}^{++} \bar{K}^{*0}$	1.64	0.44	$10.17^{0.06}_{0.06}$	3.26	1^+
$\xi_{3\mu}$	$\frac{3}{2}^-$	$\Xi_{cc}^{*++} \bar{K}^0$	1.46	0.38	$9.96^{+0.06}_{-0.05}$	3.03	1^+
ξ_4	$\frac{1}{2}^-$	$\Xi_{cc}^{*++} \bar{K}^{*0}$	1.04	1.07	$9.59^{+0.07}_{-0.07}$	3.16	0^+
$\xi_{5\mu\nu}$	$\frac{5}{2}^-$	$\Xi_{cc}^{*++} \bar{K}^{*0}$	1.50	0.38	$9.99^{+0.06}_{-0.05}$	3.07	$0^+, 1^+, 2^+$
ψ_1	$\frac{1}{2}^-$	$\Omega_{cc}^{*+} \pi^+$	1.48	0.30	$9.96^{+0.06}_{-0.05}$	2.99	0^+
$\psi_{2\mu}$	$\frac{3}{2}^-$	$\Omega_{cc}^{+} \rho^+$	1.57	0.51	$10.04^{+0.06}_{-0.06}$	3.25	1^+
$\psi_{3\mu}$	$\frac{3}{2}^-$	$\Omega_{cc}^{*+} \pi^+$	1.45	0.47	$9.96^{+0.06}_{-0.05}$	3.09	1^+
ψ_4	$\frac{1}{2}^-$	$\Omega_{cc}^{*+} \rho^+$	1.16	0.88	$9.71^{+0.06}_{-0.06}$	3.12	0^+
$\psi_{5\mu\nu}$	$\frac{5}{2}^-$	$\Omega_{cc}^{*+} \rho^+$	1.61	0.25	$10.14^{+0.07}_{-0.06}$	3.08	$0^+, 1^+, 2^+$

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Summary

- The observations of hidden-charm pentaquarks and doubly charmed tetraquarks directly inspired the investigations on doubly charmed pentaquark states;
- **We systematically predicted the mass spectra of the doubly charmed pentaquark states with and without strangeness;**
- We suggest to search for the triply and neutral charged pentaquarks: $\boldsymbol{P_{cc}^{+++} \to \Xi_{cc}^{(*)++}\pi^+/\rho^+, \Sigma_c^{(*)++}D^{(*)+}}$ and $\boldsymbol{P_{cc}^{0} \to \Xi_{cc}^{(*)+}\pi^-/\rho^-, \Sigma_c^{(*)0}D^{(*)0}}$, which belong to the absolute exotic isospin quartet $[P_{cc}^{+++}(ccuu\bar{d}), P_{cc}^{++}(ccuu\bar{u}), P_{cc}^{+}(ccdd\bar{d}), P_{cc}^{0}(ccdd\bar{u})]$ with $I = 3/2$.

Thank you