Theoretical studies of doubly charmed pentaquark states

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Based on: PRD109, 094018 (2024); PRD110, 056022 (2024)

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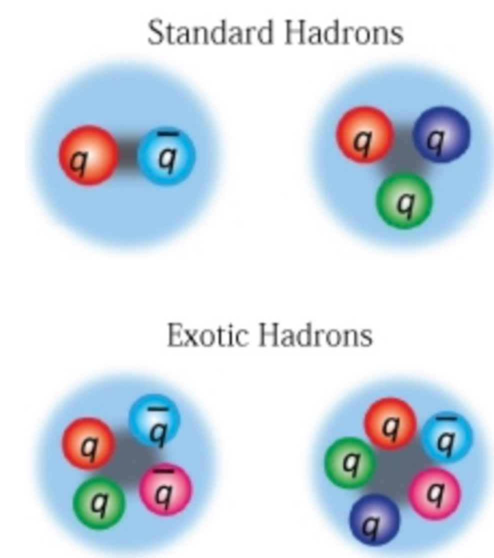
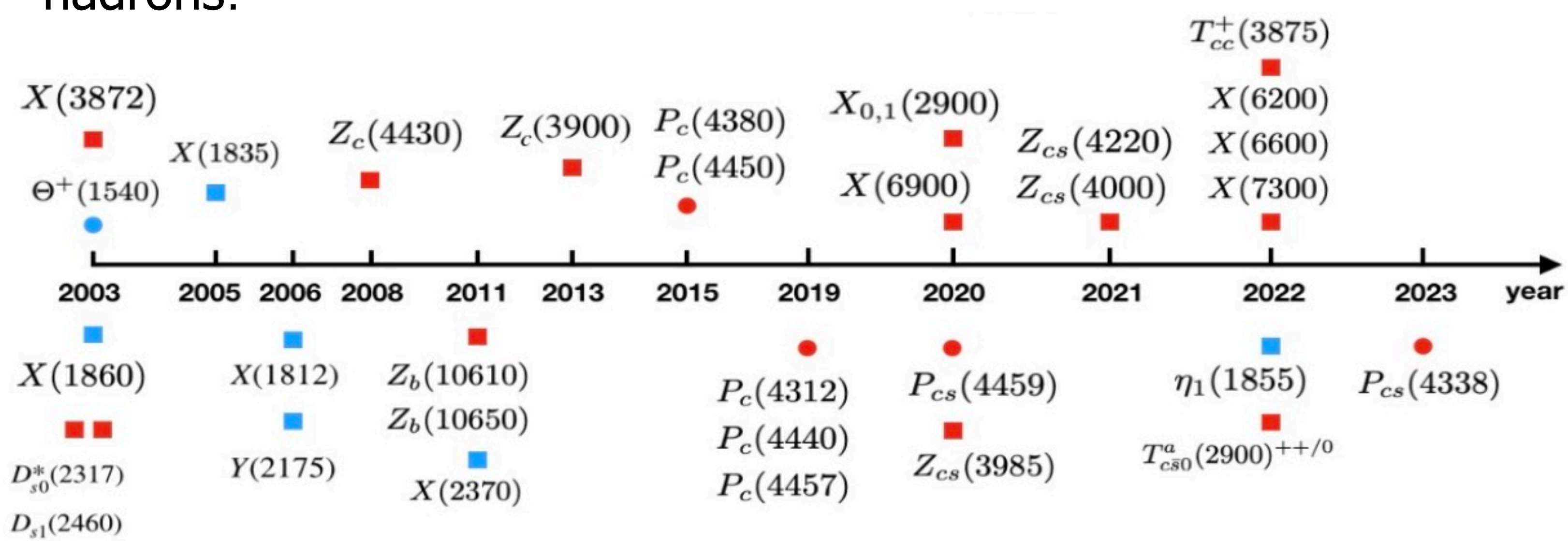
Outline

- **Exotic hadrons and pentaquark states**
- **Mass spectra of P_{cc} and P_{ccs}**
- **Decay behaviors**
- **Summary**

Quark model and Exotic hadrons

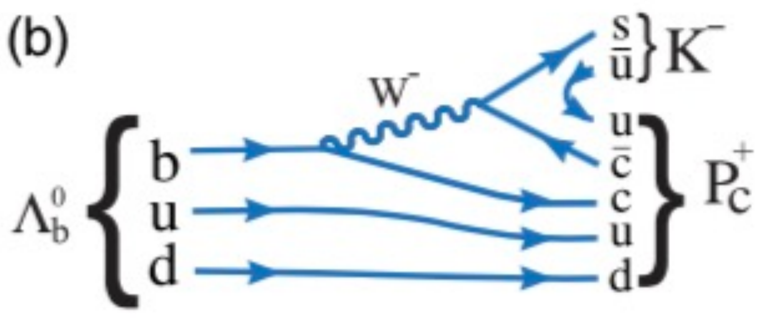


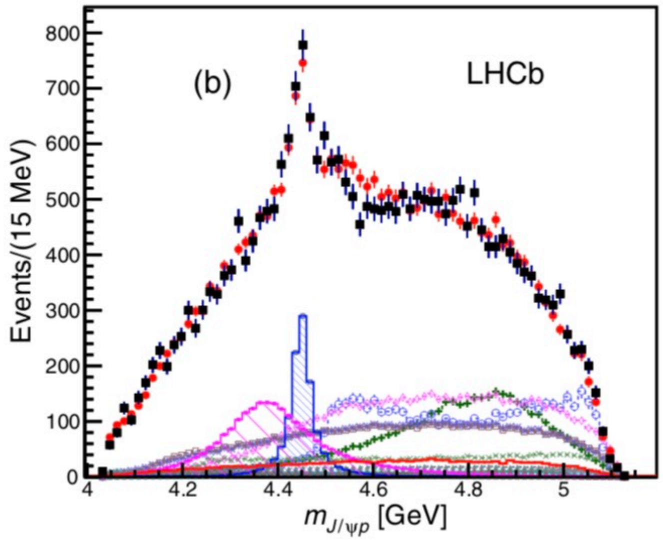
- **Quark Model:** $q\bar{q}$ mesons and qqq baryons
- **Exotic Hadrons:** hadrons beyond QM, such as multiquarks, hybrids, glueballs...
- Many of them contain charm quarks: hidden-charm pentaquarks and doubly charmed hadrons!

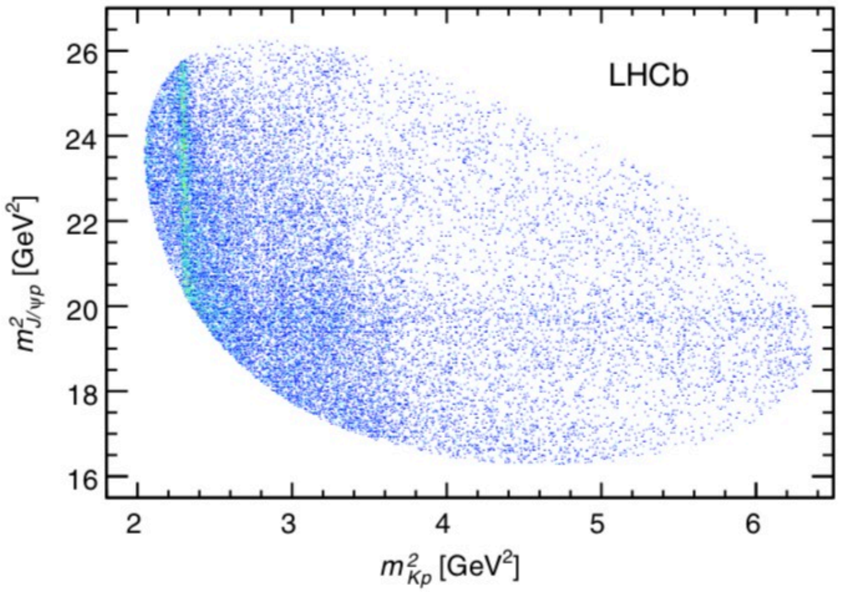


Pentaquarks: LHCb's observation in 2015

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





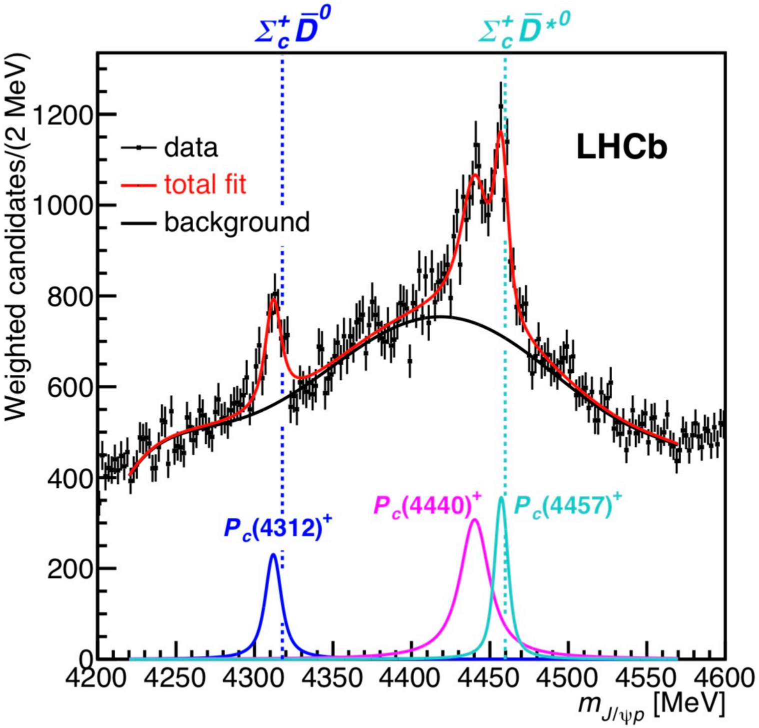


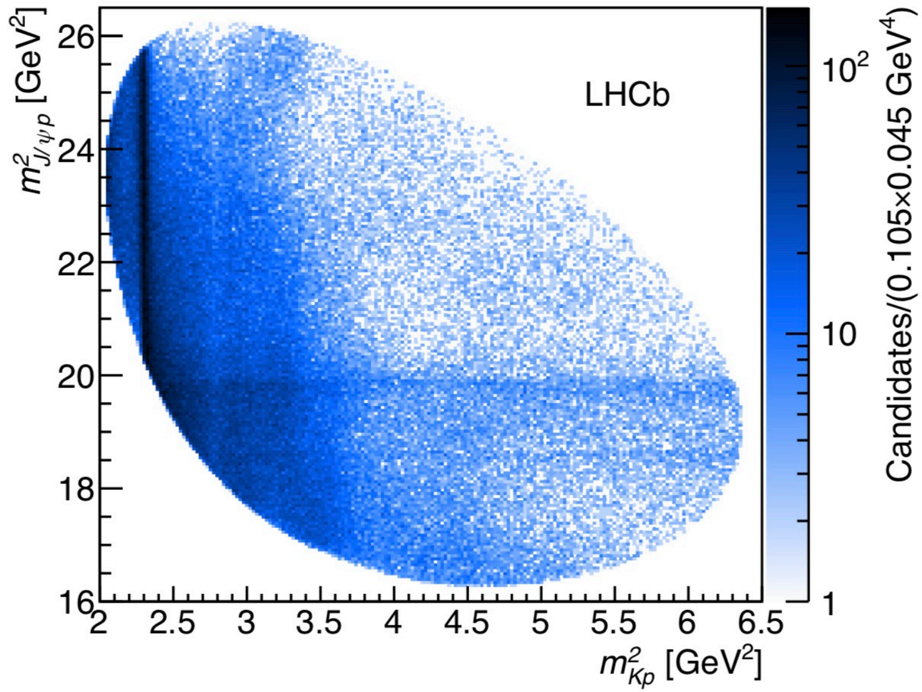
$P_c(4380)$ and $P_c(4450)$ in $J/\psi p$ structure (PRL115, 072001(2015))

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

Combined Run 2 data in 2019:

PRL 122 (2019) 222001

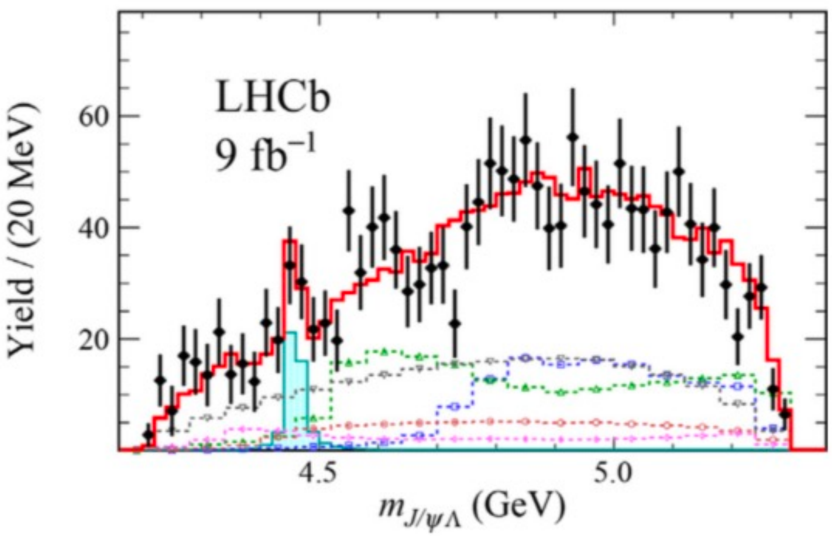




State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3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

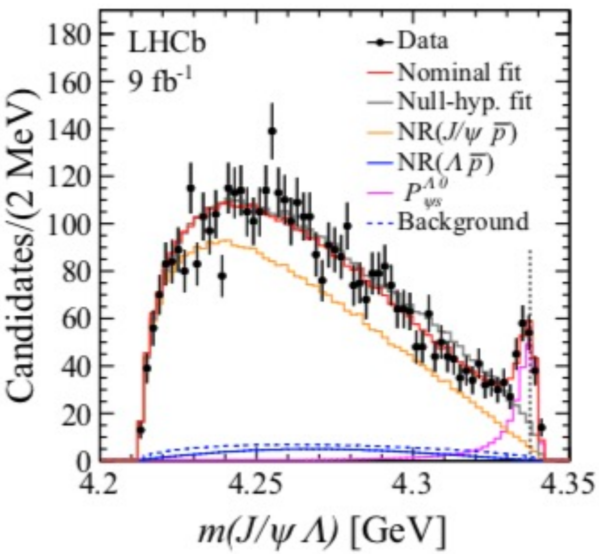


Sci. Bull. 66 (2021) 1278

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

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

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



PRL 122 (2023) 222001

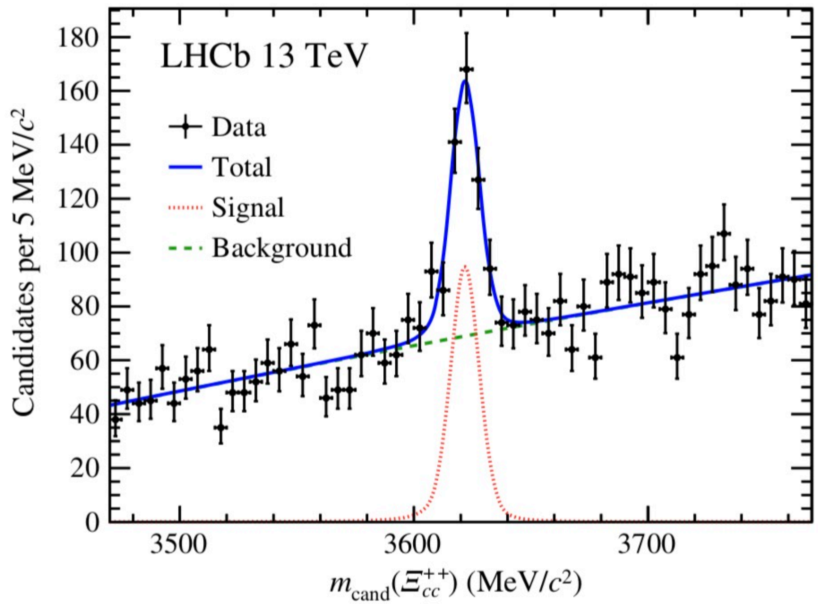
$P_{cs}(4338)^0$: $J^P = \frac{1}{2}^-$

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

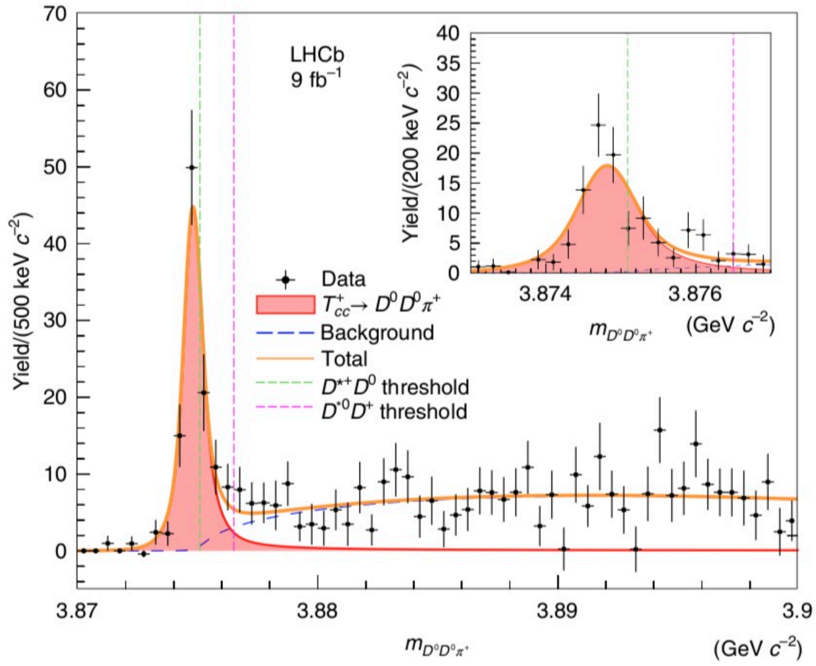
PRL119 (2017) 112001;

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 $cc\bar{u}\bar{d}$ 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.

Next, searching for doubly charmed P_{cc} pentaquarks?

Various theoretical investigations on the $\boldsymbol{P_{cc}}$ pentaquark states:

- 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 $\boldsymbol{P_{cc}}$ states without strangeness in the $\boldsymbol{\Lambda_c^{(*)}D^{(*)}, \Sigma_c^{(*)}D^{(*)}}$ **molecular picture** and with strangeness in both the $\boldsymbol{\Xi_c^{(*\prime)}D^{*}, \Xi_{cc}^{*}K^{*}, \Omega_{cc}^{*}\rho}$ **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:

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

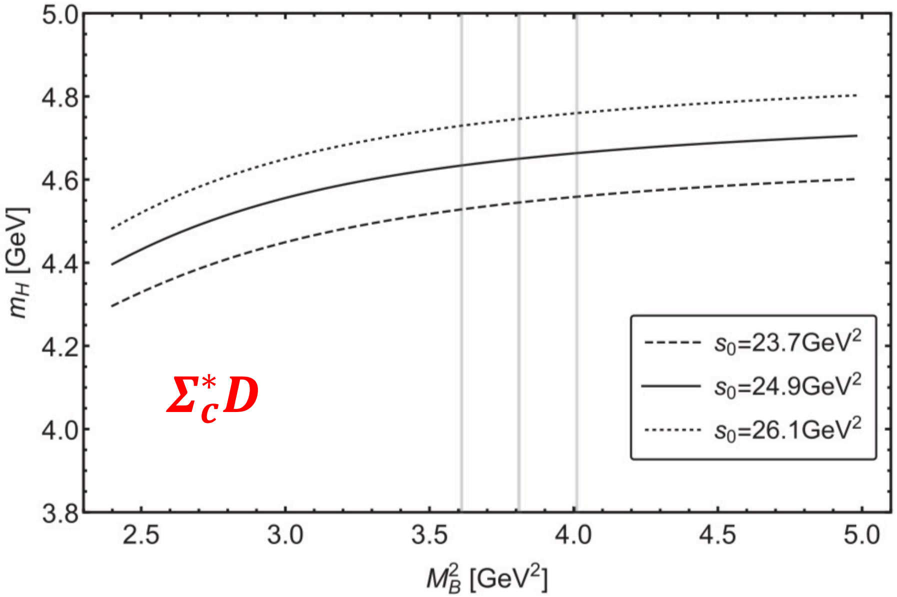
The invariant function contains both contributions

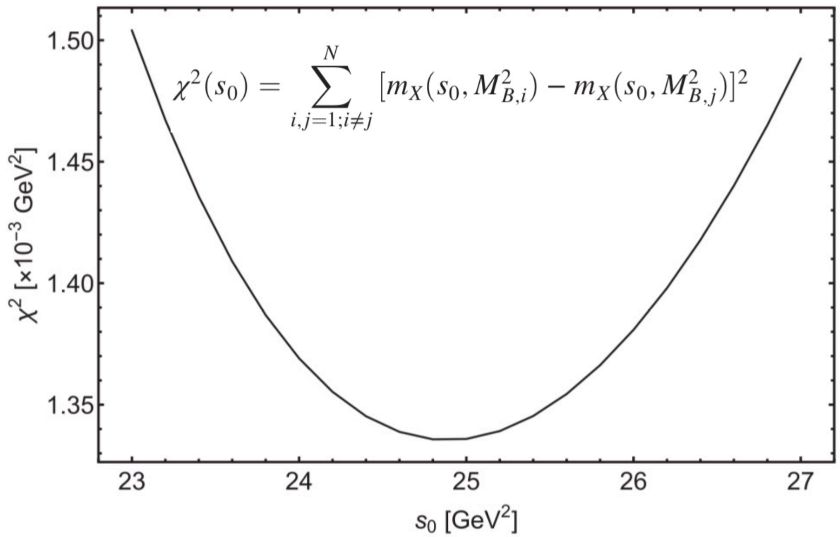
$$\Pi(p^2) = f_X^{-2}\frac{\hat{p}+M_X^-}{M_X^{-2}-p^2} + f_X^{+2}\frac{\hat{p}-M_X^+}{M_X^{+2}-p^2} + \cdots$$

The parity projected sum rules were adopted:

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

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

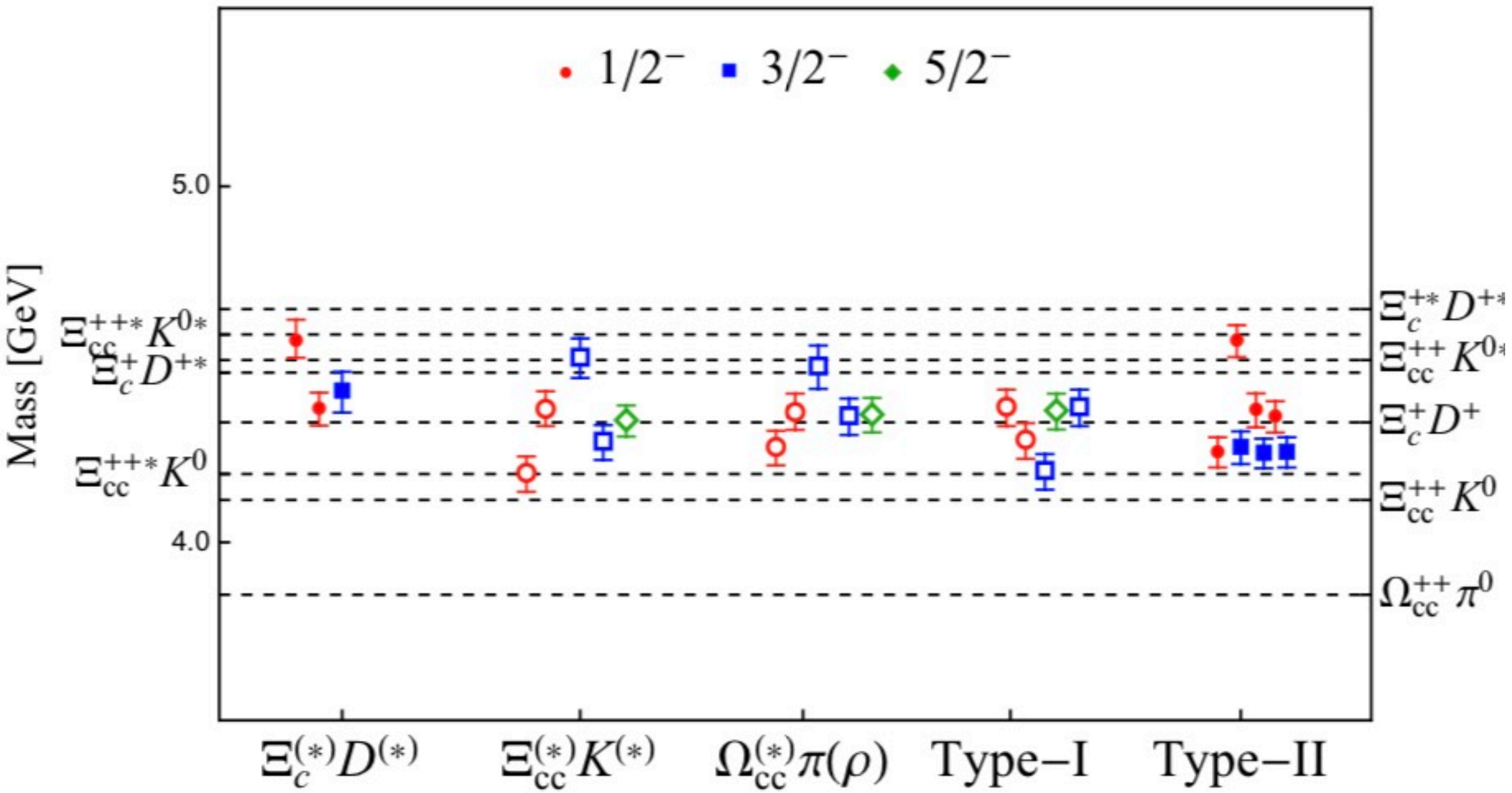
$\boldsymbol{P_{cc}^{+++} \to \Xi_{cc}^{(*)++}\pi^+/\rho^+, \Sigma_c^{(*)++}D^{(*)+}}$ and $\boldsymbol{P_{cc}^{0} \to \Xi_{cc}^{(*)+}\pi^-/\rho^-, \Sigma_c^{(*)0}D^{(*)0}}$

P_{ccs} pentaquarks with strangeness

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

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

P_{ccs} pentaquark mass predictions:



PRD110, 056022 (2024)

Two-body strong decays: $P_{ccs}^{++} \to \Xi_{cc}^{++}\bar{K}^0, \Omega_{cc}^{+}\pi^{+}$

- Three-point correlation function

$$\Pi(p, p', q) = \int d^4x d^4y\, e^{ip'\cdot x} e^{-iq\cdot y} \langle 0|T\{J_{P_{ccs}}(x) J_{\bar{K}}^{\dagger}(y) J_{\Xi_{cc}}^{\dagger}(0)\}|0\rangle$$

$$\Pi(p, p', q) = \int d^4x d^4y\, e^{ip'\cdot x} e^{-iq\cdot y} \langle 0|T\{J_{P_{ccs}}(x) J_{\pi}^{\dagger}(y) J_{\Omega_{cc}}^{\dagger}(0)\}|0\rangle$$

$$\boxed{\xi_1 = [\epsilon_{abc}(c_a^T C\gamma_\mu c_b)\gamma_\mu\gamma_5 u_c][\bar{d}_d\gamma_5 s_d],} \qquad J^P = 1/2^-$$

$$J_{\Xi_{cc}} = \epsilon_{abc}(c_a^T C\gamma_\mu c_b)\gamma_\mu\gamma_5 u_c,$$
$$J_{\Omega_{cc}} = \epsilon_{abc}(c_a^T C\gamma_\mu c_b)\gamma_\mu\gamma_5 s_c,$$

$$J_{\bar{K}} = i\,\bar{d}_a\gamma_5 s_a, \quad J_{\pi^+} = i\,\bar{d}_a\gamma_5 u_a,$$

Coupling to hadrons via:

$$\langle 0|\xi_1|P_{ccs}^{1/2^-}\rangle = \lambda_{P_{ccs}}^{-} u(p),$$

$$\langle 0|J_{\bar{K}}|\bar{K}\rangle = f_{\bar{K}}\frac{m_K^2}{m_s} \equiv \lambda_K,$$

$$\langle 0|J_{\pi^+}|\pi^+\rangle = f_\pi\frac{m_\pi^2}{m_u + m_d} \equiv \lambda_\pi.$$

$$\langle 0|J_{\Xi_{cc}}|\Xi_{cc}(p, s)\rangle = f_{\Xi_{cc}} u(p, s),$$

$$\langle 0|J_{\Omega_{cc}}|\Omega_{cc}(p, s)\rangle = f_{\Omega_{cc}} u(p, s).$$

Transition matrix elements are

$$\langle \Xi_{cc}(p', s')\bar{K}(q)|P_{ccs}(p)\rangle = g_{P_{ccs}\Xi_{cc}\bar{K}}\bar{u}_{\Xi_{cc}}(p', s')u_{P_{ccs}}(p, s),$$
$$\langle \Omega_{cc}(p', s')\pi(q)|P_{ccs}(p)\rangle = g_{P_{ccs}\Omega_{cc}\pi}\bar{u}_{\Omega_{cc}}(p', s')u_{P_{ccs}}(p, s).$$

$$\mathcal{L}_{P_{ccs}\Xi_{cc}\bar{K}} = g_{P_{ccs}\Xi_{cc}\bar{K}}P_{ccs}\bar{\Xi}_{cc}\bar{K},$$
$$\mathcal{L}_{P_{ccs}\Omega_{cc}\pi} = g_{P_{ccs}\Omega_{cc}\pi}P_{ccs}\bar{\Omega}_{cc}\bar{\pi},$$

$$\Downarrow$$

$$\Pi(p, p', q) = \int d^4x d^4y\, e^{ip'\cdot x}e^{-iq\cdot y}\langle 0|T\{J_{P_{ccs}}(x)J^\dagger_K(y)J^\dagger_{\Xi_{cc}}(0)\}|0\rangle$$
$$= \frac{\lambda^-_{P_{ccs}}\lambda_{\Xi_{cc}}\lambda_K g_{P_{ccs}\Xi_{cc}\bar{K}}}{(p^2 - m^2_{P_{ccs}})(p'^2 - m^2_{\Xi_{cc}})(q^2 - m^2_K)}(\not{p} + m_{P_{ccs}})(\not{p}' + m_{\Xi_{cc}}) + \cdots$$

$$\Pi(p, p', q) = \int d^4x d^4y\, e^{ip'\cdot x}e^{-iq\cdot y}\langle 0|T\{J_{P_{ccs}}(x)J^\dagger_\pi(y)J^\dagger_{\Omega_{cc}}(0)\}|0\rangle$$
$$= \frac{\lambda^-_{P_{ccs}}\lambda_{\Xi_{cc}}\lambda_K g_{P_{ccs}\Xi_{cc}\bar{K}}}{(p^2 - m^2_{P_{ccs}})(p'^2 - m^2_{\Omega_{cc}})(q^2 - m^2_\pi)}(\not{p} + m_{P_{ccs}})(\not{p}' + m_{\Omega_{cc}}) + \cdots,$$

In the chiral limit, we establish a sum rule for **the coupling constant** by picking out the **$1/q^2$ terms** in OPE

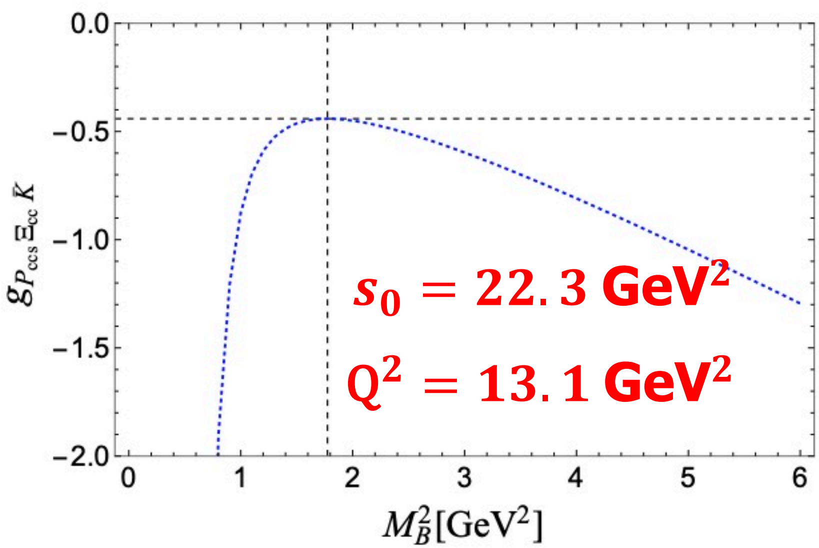
$$g_{P_{ccs}\Xi_{cc}\bar{K}}(s_0, M_B^2) = \frac{1}{\lambda_{P_{ccs}}^{-}\lambda_{\Xi_{cc}}\lambda_K(m_{P_{ccs}} + m_{\Xi_{cc}})} \frac{m_{P_{ccs}}^2 - m_{\Xi_{cc}}^2}{e^{-m_{\Xi_{cc}}^2/M_B^2} - e^{-m_{P_{ccs}}^2/M_B^2}} \left(\frac{Q^2 + m_K^2}{Q^2}\right)\left(\int_{s_<}^{s_0} ds\, \rho(s) e^{-s/M_B^2} + R(M_B^2)\right),$$

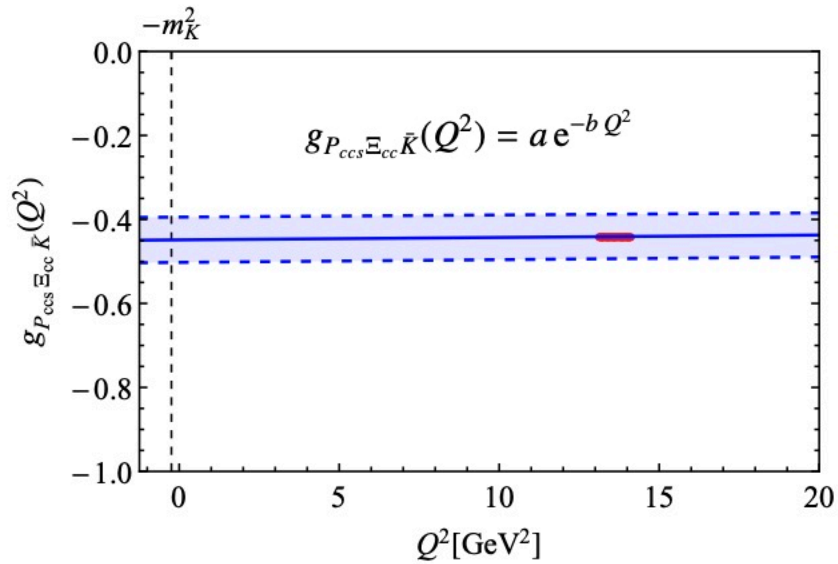
The spectral function: quark and gluon condensates contribute

$$\rho(s) = \int_{x_{\min}}^{x_{\max}} dx \int_{y_{\min}}^{y_{\max}} dy \frac{3}{512\pi^5} y\Big(\pi^2\langle GG\rangle m_s(2\langle\bar{q}q\rangle - \langle\bar{s}s\rangle)((x-2)y+1) - \frac{x}{y-1}\left(\langle GG\rangle + 16\pi^2 m_s(\langle\bar{s}s\rangle - 2\langle\bar{q}q\rangle)\right)$$
$$\Delta(x,y,s)\left(3(x-1)\Delta(x,y,s) + m_c^2 + 2s(x-1)(y-1)y\right)\Big),$$

Up to dim-4

Sum rules for the coupling constant: $\Xi_{cc}^{++}\overline{K}^{0}$ channel





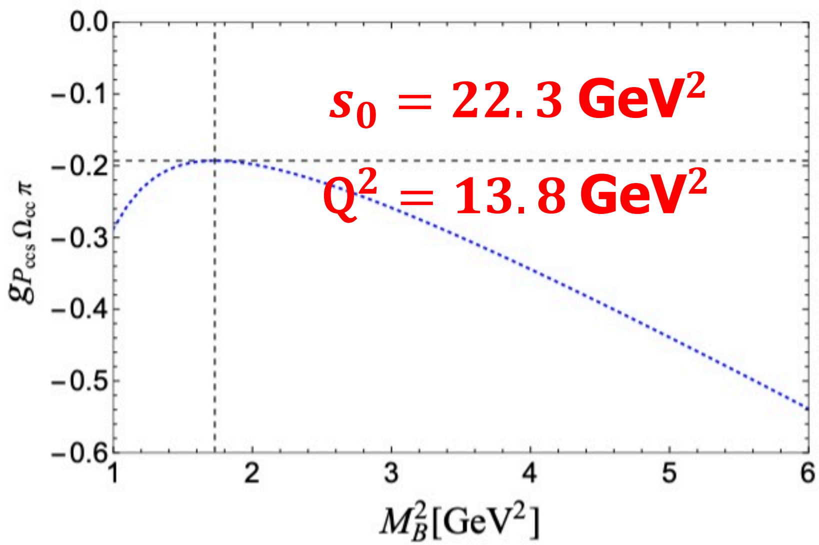
$$\boxed{\Gamma(P_{ccs}^{++} \to \Xi_{cc}^{++}\bar{K}^0) = \frac{\sqrt{\lambda(m_{P_{ccs}}^2, m_{\Xi_{cc}}^2, m_K^2)}}{8\pi m_{P_{ccs}}^2} g_{P_{ccs}\Xi_{cc}\bar{K}}(-m_K^2)\left((m_{P_{ccs}} + m_{\Xi_{cc}})^2 - m_K^2\right)}$$

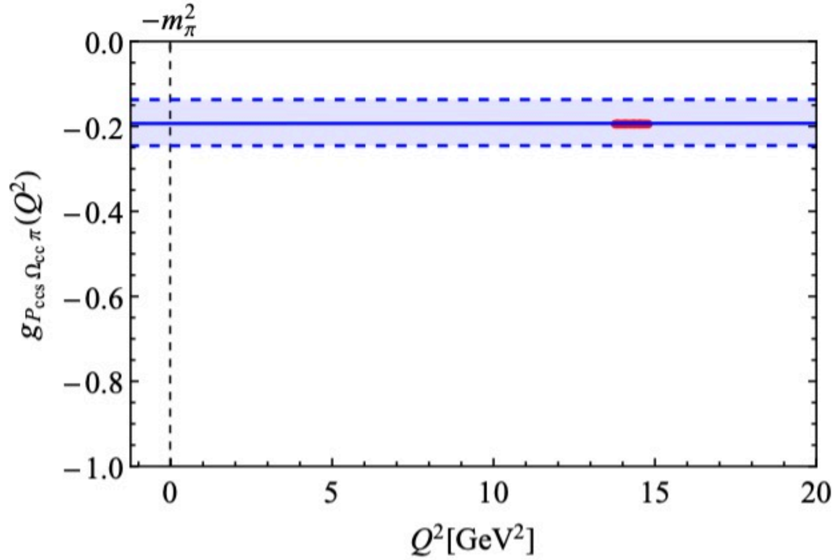
Coupling constant and decay width are:

$$g_{P_{ccs}^{++}\Xi_{cc}^{++}\overline{K}^{0}} = -(0.45 \pm 0.05)\ \mathbf{GeV^2}$$

$$\Gamma\left(P_{ccs}^{++} \to \Xi_{cc}^{++}\overline{K}^{0}\right) = 65.02 \pm 15.69\ \mathbf{MeV}$$

Sum rules for the $\Omega_{cc}^{+}\pi^{+}$ channel:





Coupling constant and decay width are:

$$g_{P_{ccs}^{++}\Omega_{cc}^{+}\pi^{+}} = -(0.193 \pm 0.03)\ \text{GeV}^2$$

$$\Gamma(P_{ccs}^{++} \to \Omega_{cc}^{+}\pi^{+}) = 19.56 \pm 10.36\ \text{MeV}$$

Total decay width: $\Gamma_{P_{ccs}^{++}} = 84.58 \pm 18.8\ \text{MeV}$

$$\Gamma\left(P_{ccs}^{++} \to \Xi_{cc}^{++}\overline{K}^{0}\right) : \Gamma(P_{ccs}^{++} \to \Omega_{cc}^{+}\pi^{+}) \approx 3.3:1$$

Summary

- **We systematically predicted the mass spectra of the doubly charmed pentaquark states P_{cc} and P_{ccs};**
- We suggest to search for the triply and neutral charged pentaquarks: $P_{cc}^{+++} \to \Xi_{cc}^{(*)++}\pi^{+}/\rho^{+}, \Sigma_{c}^{(*)++}D^{(*)+}$ and $P_{cc}^{0} \to \Xi_{cc}^{(*)+}\pi^{-}/\rho^{-}, \Sigma_{c}^{(*)0}D^{(*)0}$, belonging to the 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 $I = 3/2$.
- We calculate the decay width of P_{ccs}^{++} with $J^P = 1/2^-$ via the processes $P_{ccs}^{++} \to \Xi_{cc}^{++}\bar{K}^{0}, \Omega_{cc}^{+}\pi^{+}$.

Thank you