Hidden-charm pentaquarks and their photo- and pion-induced productions

何军

南京师范大学

合作者：王晓云、黄虹霞、平加伦

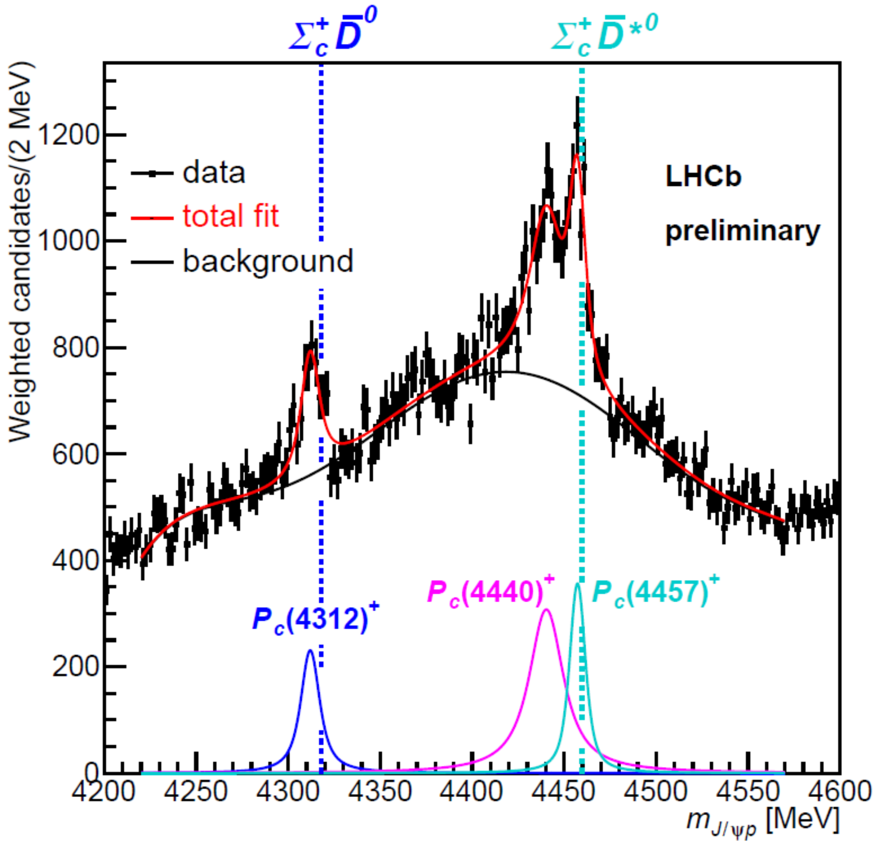
Eur.Phys.J. C79 (2019)393, arXiv:1903.11872; arXiv:1904.00221
Phys.Rev. D99 (2019)114007, arXiv:1904.11706; arXiv:1906.04044

第十八届全国中高能核物理大会，长沙，**2019**年**6**月**21-25**日

Outline

- LHCb pentaquarks
- Molecular state interpretation of P_c states
- Photo- and pion induced productions
- Summary

New results at LHCb



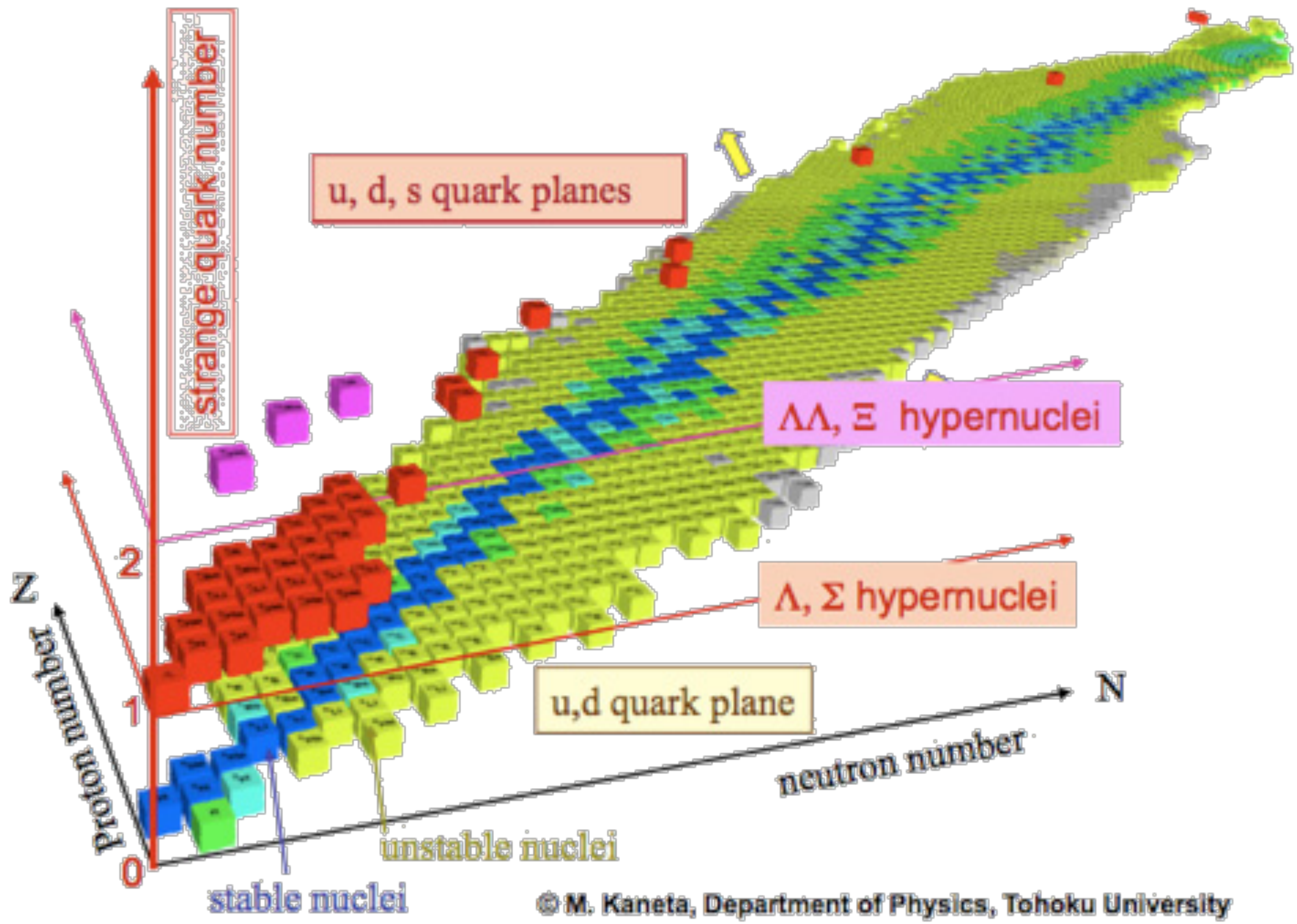
- $P_c(4450) \to P_c(4440) + P_c(4457)$
- New $P_c(4312)$
- Confirmation of $P_c(4380)$ awaits construction of new amplitude model

Moriond QCD, Tomasz Skwarnicki, Mar 26, 2019

Phys.Rev.Lett. 122 (2019) no.22, 222001

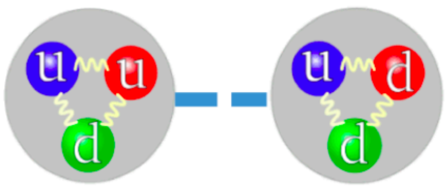
State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3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

Multi-Favored Nuclear Chart



Deuteron

Only well-established hadronic molecular state [1].

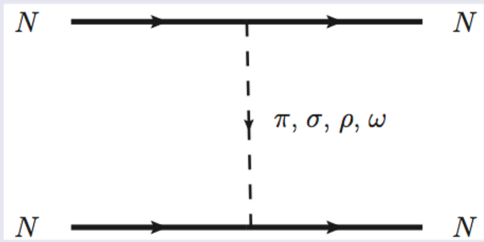


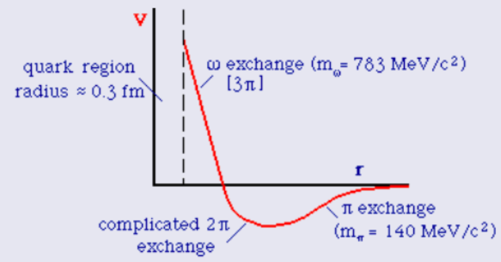
Phys. Rept., 639(2016)1

Main properties

- bound state of pn
- quantum number $J^P = 1^+$
- binding energy: about 2.2 MeV
  nucleon mass: about 1 GeV
- charge radius: about 2 fm
  nucleon radius: about 1 fm
- stable

Yukawa model





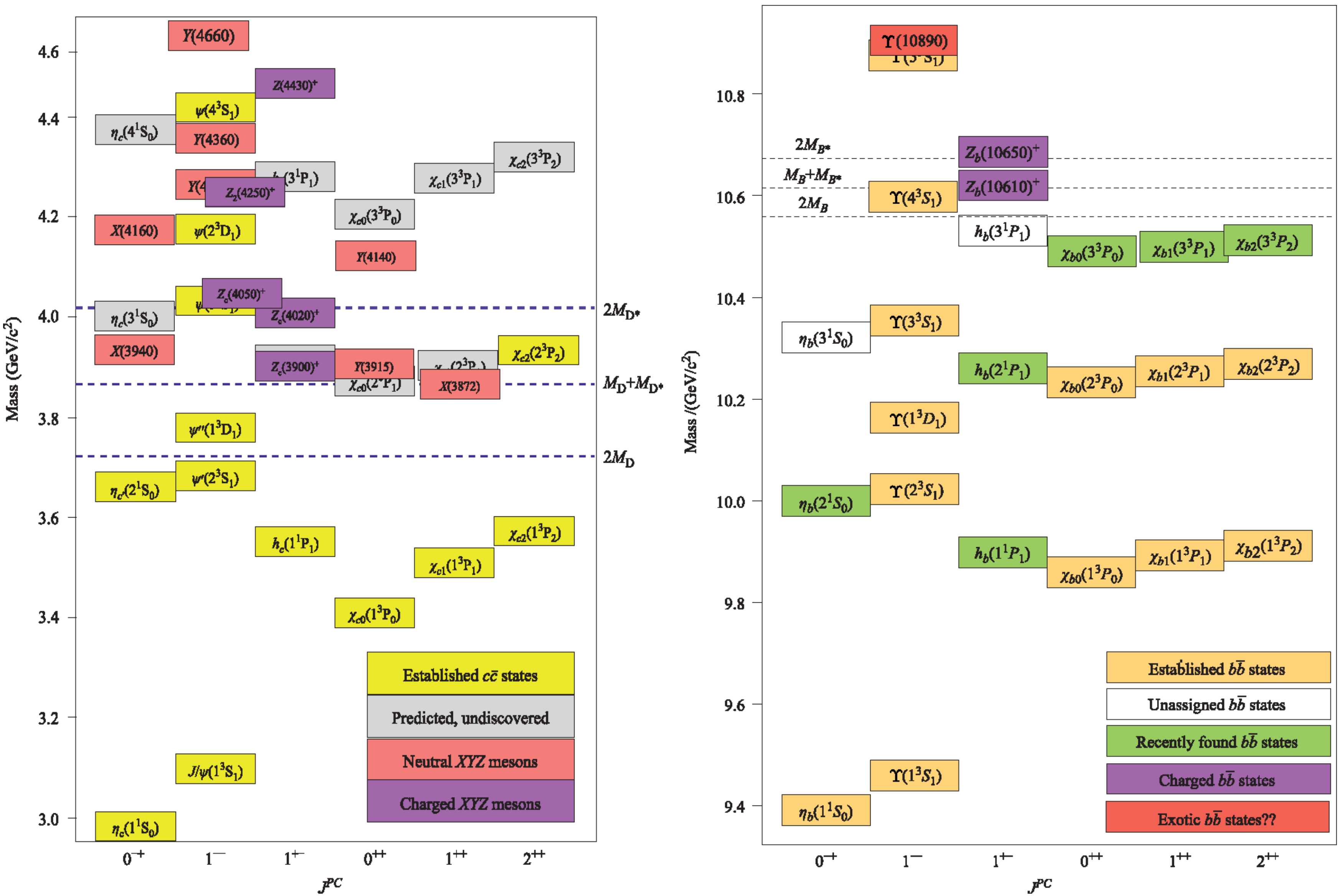
The effective πNN interaction Lagrangian

$$\mathcal{L} = g_{NN\pi}\bar{\psi} i\gamma_5 \boldsymbol{\tau}\psi \cdot \boldsymbol{\pi}.$$

The non-relativistic nucleon-nucleon potential [1]

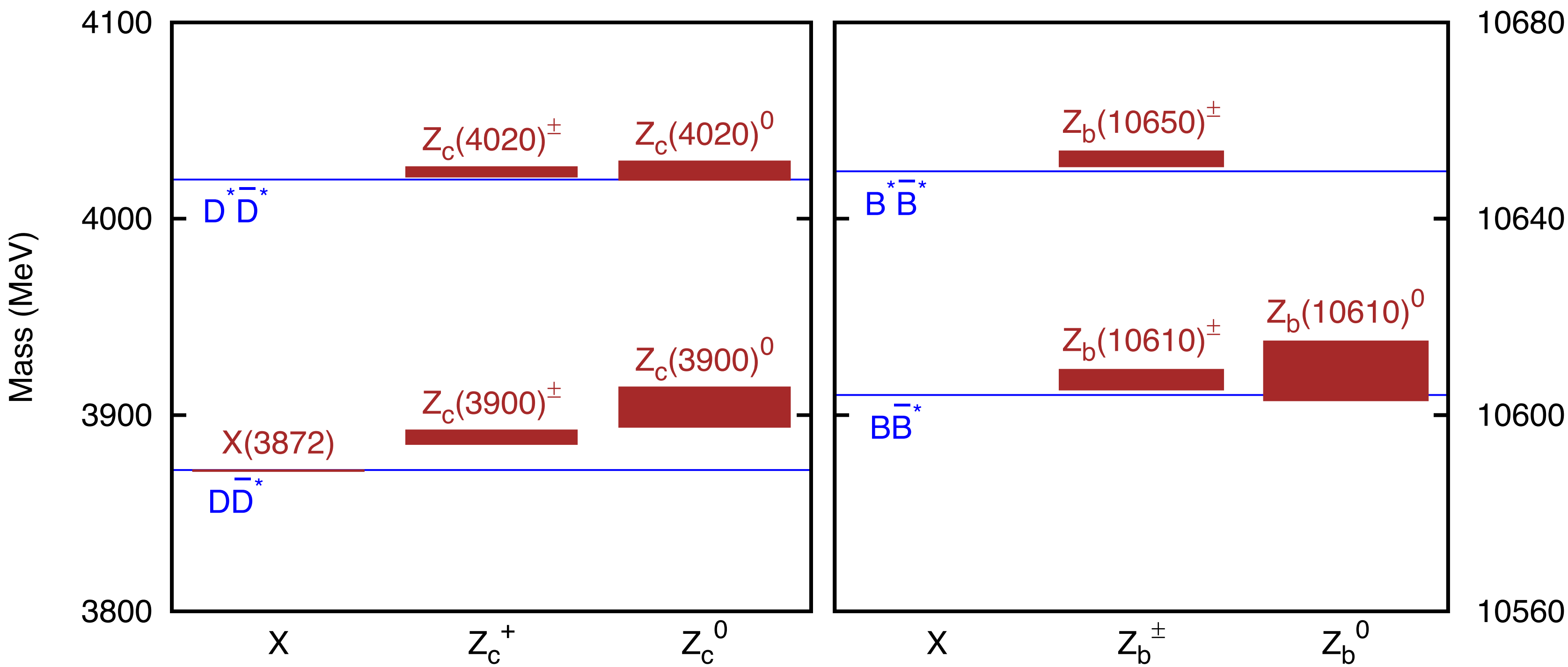
$$V_\pi = \frac{g_{NN\pi}^2}{4\pi}\frac{m_\pi^2}{12m_N^2}(\boldsymbol{\tau_1}\cdot\boldsymbol{\tau_2})\frac{e^{-m_\pi r}}{r}\left\{\boldsymbol{\sigma_1}\cdot\boldsymbol{\sigma_2} + \left[\frac{3(\boldsymbol{\sigma_1}\cdot\boldsymbol{r})(\boldsymbol{\sigma_2}\cdot\boldsymbol{r})}{r^2} - \boldsymbol{\sigma_1}\cdot\boldsymbol{\sigma_2}\right]\left[1 + \frac{3}{m_\pi r} + \frac{3}{m_\pi^2 r^2}\right]\right\}.$$

Exotic hadron and hadron-hadron threshold

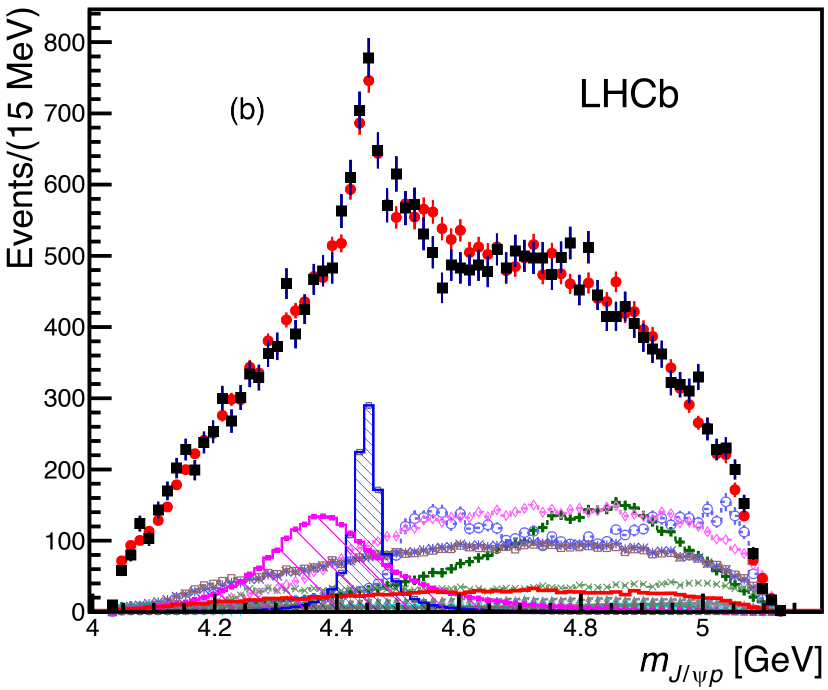


Olsen, Front. Phys. 10 (2015) 101401

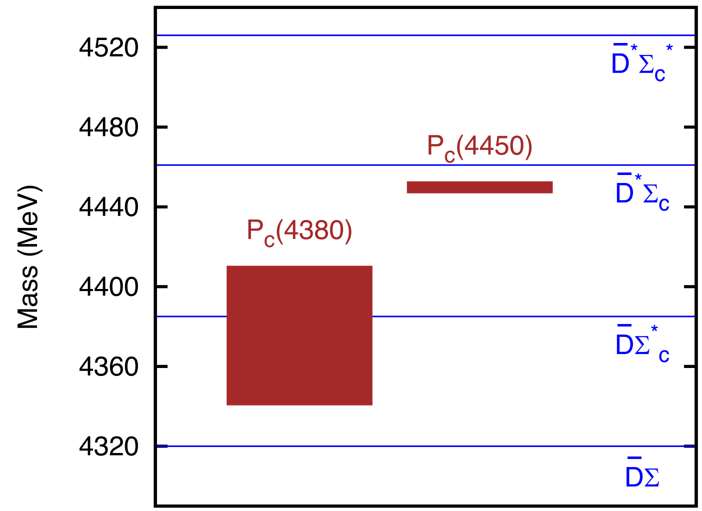
BB*/DD* thresholds



Old results at LHCb



J=3/2 or 5/2; opposite parities



无论是$5/2^-$ 还是$5/2^+$都很难在S波分子态图像下解释

特别是我们坚持分子态在阈值附近$P_c(4450)$: $\Sigma_c\bar{D}^*$, $P_c(4380)$: $\Sigma_c^*\bar{D}$.

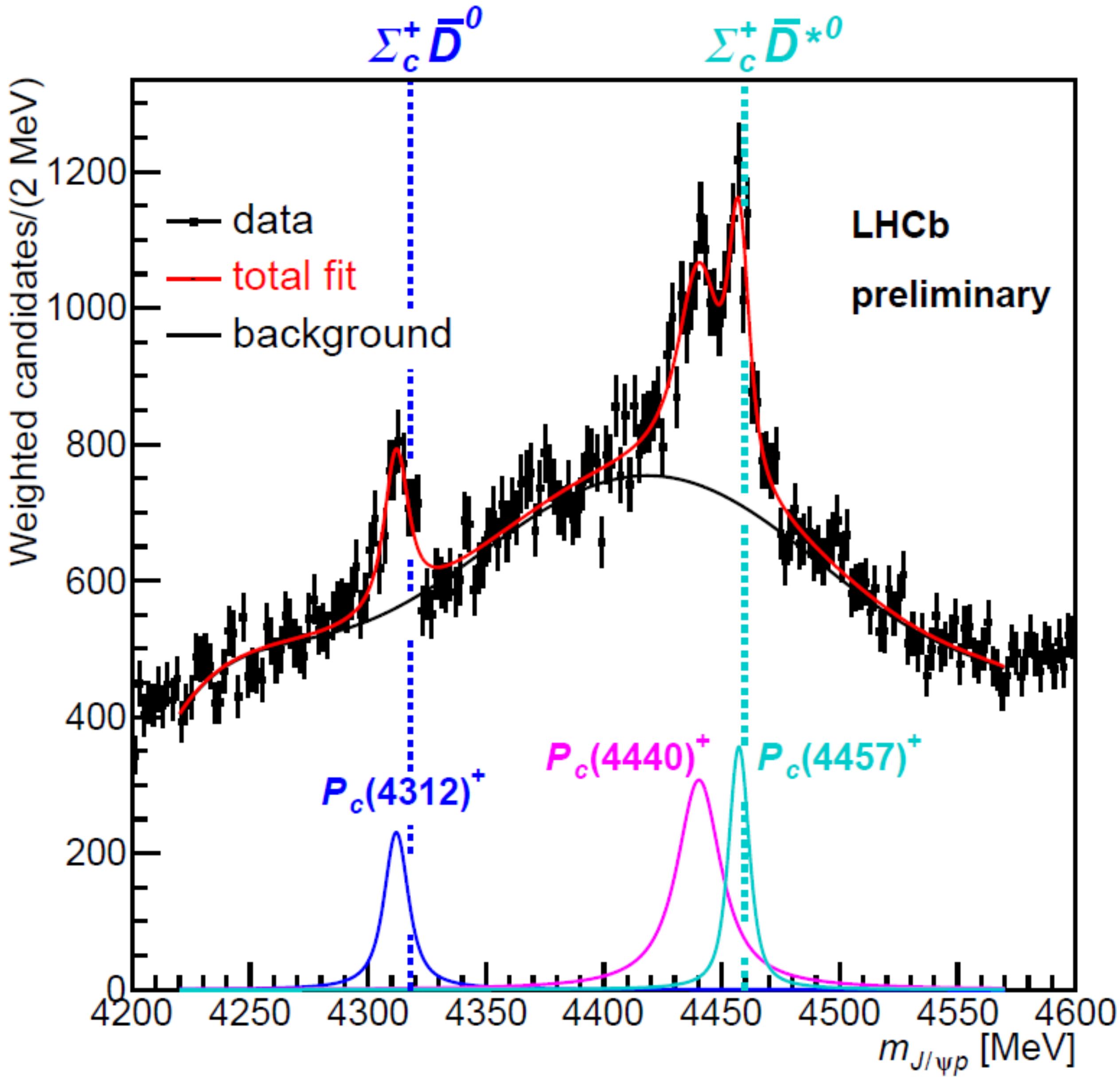
Difficulties of molecular state interpretation

$P_c(4380), \mathrm{P_c}(4450)$: $\Sigma_c\left(\frac{1}{2}^+\right)$, $\Sigma_c^*\left(\frac{3}{2}^+\right)$ *and* $\bar{D}(0^-), \bar{D}^*(1^-)$

No S-wave state with spin 5/2!

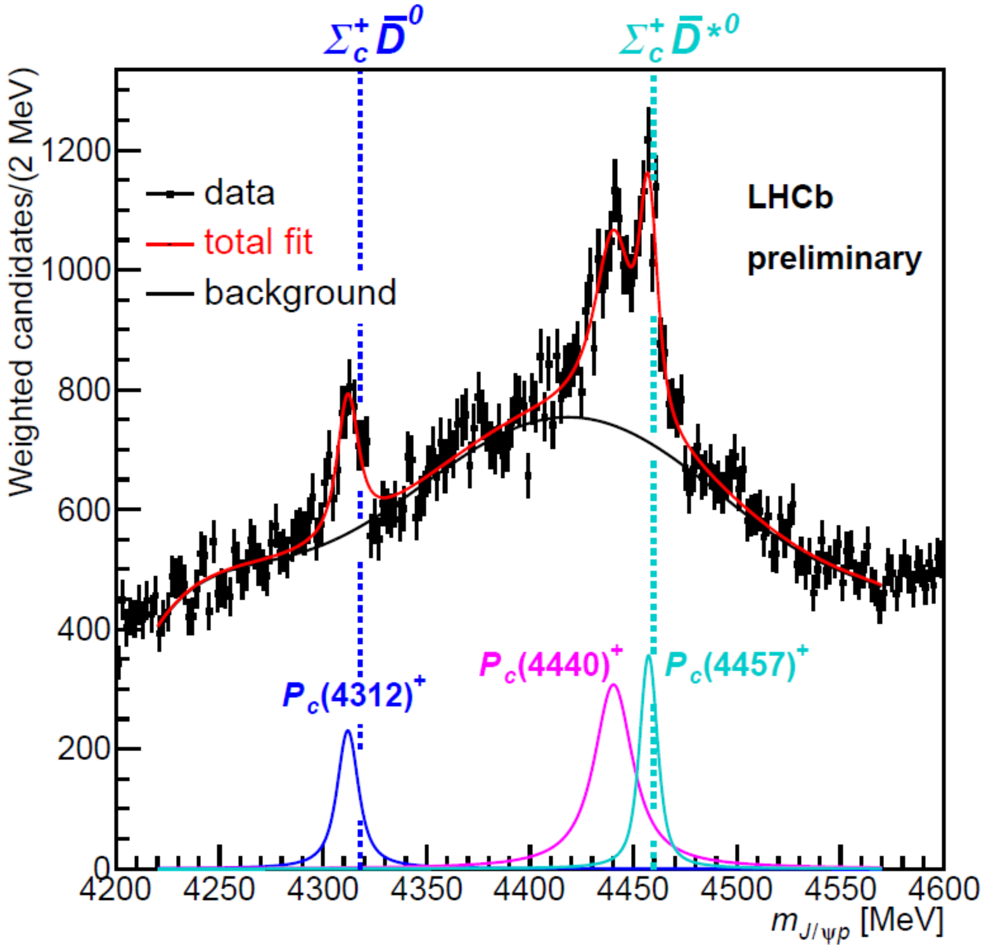
Exp: J=3/2 or 5/2; opposite parities.

- L.Roca, J.Nieves, E.Oset, PRD92 (2015) 094003;
  $P_c(4450): \Sigma_c\bar{D}^* - \Sigma_c^*\bar{D}^*\ (3/2^-)$; $P_c(4380): \Sigma_c^*\bar{D}$?
- R. Chen, X.Liu, X.Q.Li, S.L.Zhu, PRL115 (2015) 132002;
  $P_c(4450): \Sigma_c^*\bar{D}^*\ (5/2^-)$; $P_c(4380): \Sigma_c\bar{D}^*\ (3/2^-)$
- J.He, PLB 753 (2016)547 ;
  $P_c(4450): \Sigma_c\bar{D}^*\ (5/2^+)$; $P_c(4380): \Sigma_c^*\bar{D}(3/2^-)$
- ……



新的实验没有给出J^P, 5/2可能是来源于双峰

新结果更倾向于分子态解释



接近阈值

$\Sigma_c \bar{D}$: $P_c(4312)$

$\Sigma_c \bar{D}^*$: $P_c(4440), P_c(4457)$

$\Sigma_c^* \bar{D}$: $P_c(4380)$?

量子数　S波

$\Sigma_c \bar{D}$: $\frac{1}{2}^- \rightarrow P_c(4312)$

$\Sigma_c \bar{D}^*$: $\frac{1}{2}^-, \frac{3}{2}^- \rightarrow P_c(4440), P_c(4457)$

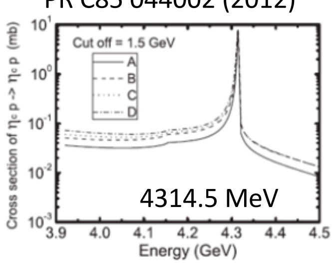
$\Sigma_c^* \bar{D}$: $\frac{3}{2}^- \rightarrow P_c(4380)$?

宽度

Comparison to numerical predictions

- Many theoretical predictions for $\Sigma_c^+ \overline{D}^{(*)0}$ published before 2015, **some in quantitative agreement with the LHCb data**
  - Wu,Molina,Oset,Zou, PRL105, 232001 (2010),
  - **Wang,Huang,Zhang,Zou, PR C84, 015203 (2011),**
  - **Yang,Sun,He,Liu,Zhu, Chin. Phys. C36, 6 (2012)**,
  - **Wu,Lee,Zou, PR C85 044002 (2012),**
  - Karliner,Rosner, PRL 115, 122001 (2015)

PR C85 044002 (2012)



ΔE – binding energy

Example:

Nucleon resonances with hidden charm in coupled-channels models

arXiv:1202.1036

Jia-Jun Wu, T.-S. H. Lee, and B. S. Zou
Phys. Rev. C **85**, 044002 – Published 17 April 2012

TABLE III: The pole position $(M - i\Gamma/2)$ and "binding energy" $(\Delta E = E_{thr} - M)$ for different cut-off parameter Λ and spin-parity J^P. The threshold E_{thr} is 4320.79 MeV of $\bar{D}\Sigma_c$ in PB system and 4462.18 MeV of $\bar{D}^*\Sigma_c$ in VB system. The unit for the listed numbers is MeV.

		PB System		VB System	
$J^p = \frac{1}{2}^-$	Λ	$M - i\Gamma/2$	ΔE	$M - i\Gamma/2$	ΔE
	650	-	-	-	-
	800	-	-	$4462.178 - 0.002i$	0.002
	1200	$4318.964 - 0.362i$	1.826	$4459.513 - 0.417i$	2.667
	1500	$4314.531 - 1.448i$	6.259	$4454.088 - 1.662i$	8.092
	2000	$4301.115 - 5.835i$	19.68	$4438.277 - 7.115i$	23.90
$J^p = \frac{3}{2}^-$					
	650	-	-	-	-
	800	-	-	$4462.178 - 0.002i$	0.002
	1200	-	-	$4459.507 - 0.420i$	2.673
	1500	-	-	$4454.057 - 1.681i$	8.123
	2000	-	-	$4438.039 - 7.268i$	23.14

$\Delta E(4312) = 5.8^{+1.0}_{-6.8}$ MeV

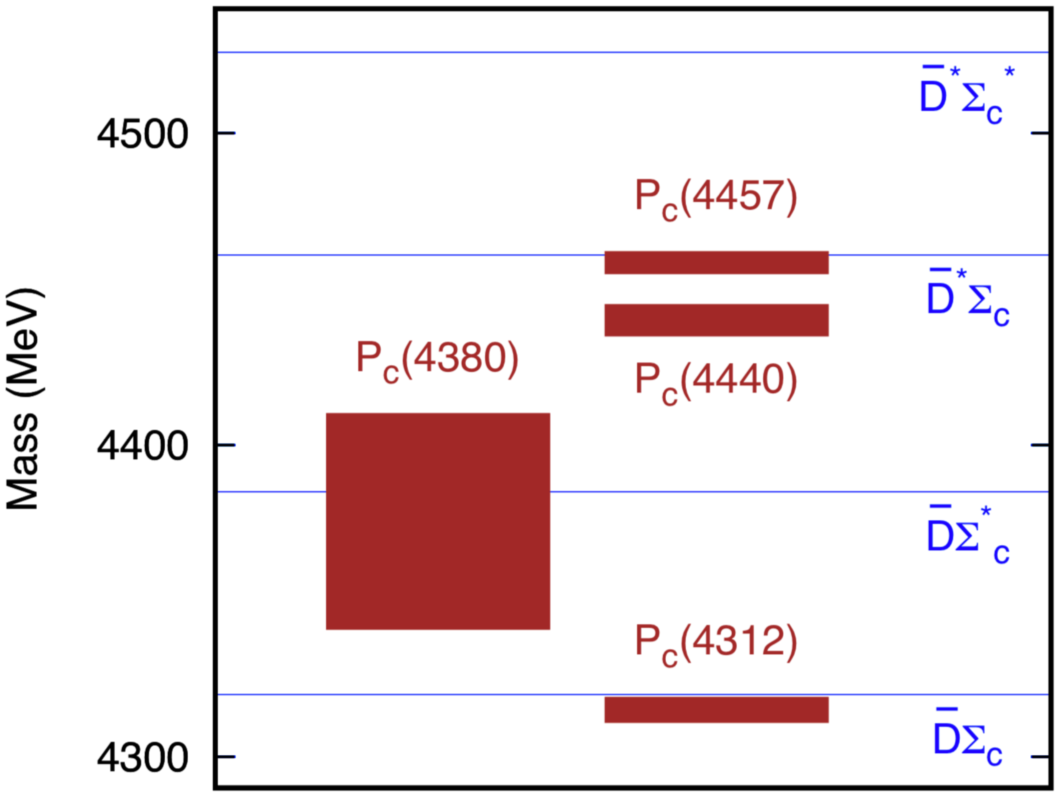
$\Delta E(4457) = 2.5^{+4.3}_{-4.1}$ MeV

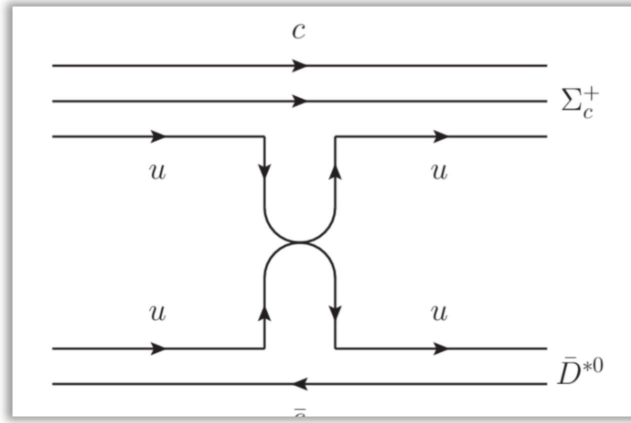
$\Delta E(4440) = 19.5^{+4.9}_{-4.3}$ MeV

Λ - cut off on exchanged meson mass.

Molecular state interpretation of $P_c(4312), P_c(4440), P_c(4457)$

LHCb五夸克态的分子态解释





$\bar{D}\Sigma_c - \bar{D}\Sigma_c^* - \bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$

Exchanged mesons :

$\pi, \eta, \rho, \omega, \sigma$

JH, Eur.Phys.J. C79 (2019) 393

Heavy quark limit and chiral symmetry

Chen et al. PRD47(1993)1030; Yan et al. PRD46(1992)1148;
Wise, PRD45(1992)2188; Casalbuoni et al. Phys. Rept. 281(1997)145

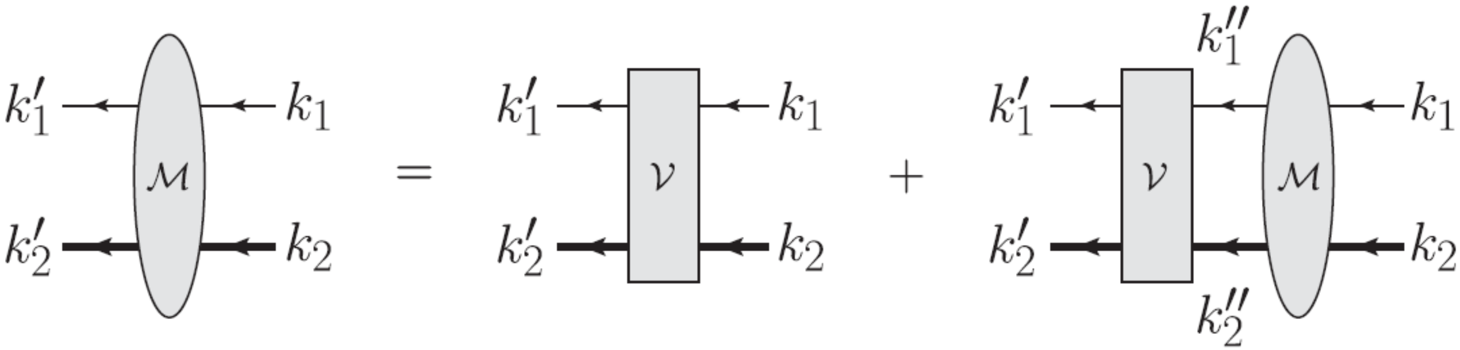
$$
\begin{aligned}
\mathcal{L}_{\tilde{\mathcal{P}}^*\tilde{\mathcal{P}}\mathbb{P}} &= i\frac{2g\sqrt{m_{\tilde{\mathcal{P}}}m_{\tilde{\mathcal{P}}^*}}}{f_\pi}(-\tilde{\mathcal{P}}^{*\dagger}_{a\lambda}\tilde{\mathcal{P}}_b + \tilde{\mathcal{P}}^\dagger_a\tilde{\mathcal{P}}^*_{b\lambda})\partial^\lambda\mathbb{P}_{ab},\\
\mathcal{L}_{\tilde{\mathcal{P}}^*\tilde{\mathcal{P}}^*\mathbb{P}} &= -\frac{g}{f_\pi}\epsilon_{\alpha\mu\nu\lambda}\tilde{\mathcal{P}}^{*\mu\dagger}_a\overleftrightarrow{\partial}^\alpha\tilde{\mathcal{P}}^{*\lambda}_b\partial^\nu\mathbb{P}_{ba},\\
\mathcal{L}_{\tilde{\mathcal{P}}^*\tilde{\mathcal{P}}\mathbb{V}} &= \sqrt{2}\lambda g_V\varepsilon_{\lambda\alpha\beta\mu}(-\tilde{\mathcal{P}}^{*\mu\dagger}_a\overleftrightarrow{\partial}^\lambda\tilde{\mathcal{P}}_b + \tilde{\mathcal{P}}^\dagger_a\overleftrightarrow{\partial}^\lambda\tilde{\mathcal{P}}^{*\mu}_b)(\partial^\alpha\mathbb{V}^\beta)_{ab},\\
\mathcal{L}_{\tilde{\mathcal{P}}\tilde{\mathcal{P}}\mathbb{V}} &= -i\frac{\beta g_V}{\sqrt{2}}\tilde{\mathcal{P}}^\dagger_a\overleftrightarrow{\partial}_\mu\tilde{\mathcal{P}}_b\mathbb{V}^\mu_{ab},\\
\mathcal{L}_{\tilde{\mathcal{P}}^*\tilde{\mathcal{P}}^*\mathbb{V}} &= -i\frac{\beta g_V}{\sqrt{2}}\tilde{\mathcal{P}}^{*\dagger}_a\overleftrightarrow{\partial}_\mu\tilde{\mathcal{P}}^*_b\mathbb{V}^\mu_{ab}\\
&\quad - i2\sqrt{2}\lambda g_V m_{\tilde{\mathcal{P}}^*}\tilde{\mathcal{P}}^{*\mu\dagger}_a\tilde{\mathcal{P}}^{*\nu}_b(\partial_\mu\mathbb{V}_\nu - \partial_\nu\mathbb{V}_\mu)_{ab},\\
\mathcal{L}_{\tilde{\mathcal{P}}\tilde{\mathcal{P}}\sigma} &= -2g_s m_{\tilde{\mathcal{P}}}\tilde{\mathcal{P}}^\dagger_a\tilde{\mathcal{P}}_a\sigma,\\
\mathcal{L}_{\tilde{\mathcal{P}}^*\tilde{\mathcal{P}}^*\sigma} &= 2g_s m_{\tilde{\mathcal{P}}^*}\tilde{\mathcal{P}}^{*\dagger}_a\tilde{\mathcal{P}}^*_a\sigma, \qquad (1)
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{L}_{\mathcal{B}\mathcal{B}\mathbb{P}} &= -\frac{g_1}{4f_\pi}\epsilon^{\alpha\beta\lambda\kappa}\langle\bar{\mathcal{B}}\overleftrightarrow{\partial}_\kappa\gamma_\alpha\gamma_\lambda\partial_\beta\mathbb{P}\,\mathcal{B}\rangle,\\
\mathcal{L}_{\mathcal{B}\mathcal{B}\mathbb{V}} &= -i\frac{\beta_S g_V}{2\sqrt{2}}\langle\bar{\mathcal{B}}\overleftrightarrow{\partial}\cdot\mathbb{V}\,\mathcal{B}\rangle\\
&\quad -\frac{im_{\mathcal{B}}\lambda_S g_V}{3\sqrt{2}}\langle\bar{\mathcal{B}}\gamma_\mu\gamma_\nu(\partial^\mu\mathbb{V}^\nu - \partial^\nu\mathbb{V}^\mu)\mathcal{B}\rangle,\\
\mathcal{L}_{\mathcal{B}\mathcal{B}\sigma} &= -\ell_S m_{\mathcal{B}}\langle\bar{\mathcal{B}}\,\sigma\,\mathcal{B}\rangle,\\
\mathcal{L}_{\mathcal{B}^*\mathcal{B}^*\mathbb{P}} &= \frac{-3g_1}{4f_\pi}\epsilon^{\alpha\beta\lambda\kappa}\langle\bar{\mathcal{B}}^*_\alpha\overleftrightarrow{\partial}_\kappa\partial_\beta\mathbb{P}\,\mathcal{B}^*_\lambda\rangle,\\
\mathcal{L}_{\mathcal{B}^*\mathcal{B}^*\mathbb{V}} &= i\frac{\beta_S g_V}{2\sqrt{2}}\langle\bar{\mathcal{B}}^{*\mu}\overleftrightarrow{\partial}\cdot\mathbb{V}\mathcal{B}^*_\mu\rangle\\
&\quad +\frac{im_{\mathcal{B}^*}\lambda_S g_V}{\sqrt{2}}\langle\bar{\mathcal{B}}^*_\mu(\partial^\mu\mathbb{V}^\nu - \partial^\nu\mathbb{V}^\mu)\mathcal{B}^*_\nu\rangle,\\
\mathcal{L}_{\mathcal{B}^*\mathcal{B}^*\sigma} &= \ell_S m_{\mathcal{B}^*}\langle\bar{\mathcal{B}}^*\,\sigma\,\mathcal{B}^*\rangle,\\
\mathcal{L}_{\mathcal{B}\mathcal{B}^*\mathbb{P}} &= \frac{\sqrt{3}g_S}{4f_\pi}\epsilon^{\mu\nu\lambda\kappa}\langle\bar{\mathcal{B}}\partial_\nu\mathbb{P}\overleftrightarrow{\partial}_\kappa\gamma^5\gamma_\mu\mathcal{B}^*_\lambda - \bar{\mathcal{B}}^*_\mu\partial_\nu\mathbb{P}\overleftrightarrow{\partial}_\kappa\gamma_\lambda\gamma^5\mathcal{B}\rangle,\\
\mathcal{L}_{\mathcal{B}\mathcal{B}^*\mathbb{V}} &= \frac{\beta_S g_V}{4\sqrt{6m_{\mathcal{B}}m_{\mathcal{B}^*}}}\langle\bar{\mathcal{B}}\overleftrightarrow{\partial}\cdot\mathbb{V}\overleftarrow{\partial}^\mu\gamma^5\mathcal{B}^*_\mu + \bar{\mathcal{B}}^*_\mu\gamma^5\overleftrightarrow{\partial}\cdot\mathbb{V}\overrightarrow{\partial}^\mu\mathcal{B}\rangle\\
&\quad + \frac{i\lambda_S g_V\sqrt{m_{\mathcal{B}}m_{\mathcal{B}^*}}}{\sqrt{6}}\langle\bar{\mathcal{B}}\gamma^5(\partial^\mu\mathbb{V}^\nu - \partial^\nu\mathbb{V}^\mu)(\gamma_\nu + \frac{i\overleftrightarrow{\partial}_\nu}{2\sqrt{m_{\mathcal{B}}m_{\mathcal{B}^*}}})\mathcal{B}^*_\mu\\
&\quad - \bar{\mathcal{B}}^*_\mu(\partial^\mu\mathbb{V}^\nu - \partial^\nu\mathbb{V}^\mu)(\gamma_\nu + \frac{i\overleftrightarrow{\partial}_\nu}{2\sqrt{m_{\mathcal{B}}m_{\mathcal{B}^*}}})\gamma^5\mathcal{B}\rangle \qquad (3)
\end{aligned}
$$

Table 1 The parameters and coupling constants adopted in our calculation. The λ and λ_S are in the unit of GeV^{-1}. Others are in the unit of 1.

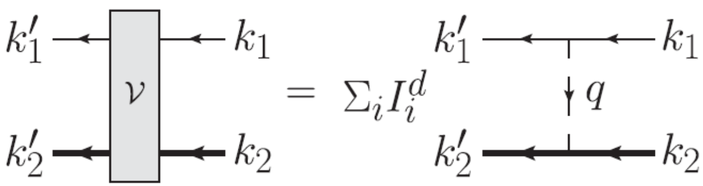
β	g	g_V	λ	g_s	β_S	ℓ_S	g_1	λ_S
0.9	0.59	5.8	0.56	0.76	-1.74	6.2	0.94	-3.31

Quasipotential Bethe-Salpeter equation



$$iM^{J^P}_{\lambda'\lambda}(p',p) = iV^{J^P}_{\lambda',\lambda}(p',p) + \sum_{\lambda''\geq 0}\int \frac{p''^2 dp''}{(2\pi)^3} \cdot iV^{J^P}_{\lambda'\lambda''}(p',p'')G_0(p'')iM^{J^P}_{\lambda''\lambda}(p'',p),$$

$$G_0 = 2\pi i \frac{\delta^+(k_1^2 - m_1^2)}{k_2^2 - m_2^2} = 2\pi i \frac{\delta^+(k_1^0 - E_1(\boldsymbol{k}))}{2E_1(\boldsymbol{k})[W - E_1(\boldsymbol{k})^2 - E_2^2(\boldsymbol{k})]},$$



$$iV^{J^P}_{\lambda'\lambda}(p',p) = 2\pi \int d\cos\theta\, [d^J_{\lambda\lambda'}(\theta) iV_{\lambda'\lambda}(\boldsymbol{p}',\boldsymbol{p}) + \eta d^J_{-\lambda\lambda'}(\theta) iV_{\lambda'-\lambda}(\boldsymbol{p}',\boldsymbol{p})],$$

- Form factors with cutoff **Λ** are introduced at the vertex for the offshell particles.

$$f(q^2) = (\Lambda_e^2 - m^2)/(\Lambda_e^2 - q^2),\ \Lambda_e = m + \alpha\, 0.22\ \mathrm{GeV} \qquad G_0(p) \to G_0(p)\left[e^{-(k^2-m^2)^2/\Lambda^4}\right]^2$$

$1/2^-$

Table 2 The position of the bound states with $J^P = 1/2^-$ in a unit of MeV. The Λ in the unit of GeV is the cutoff in the exponential regularization in Eq. (9). The CC means coupled-channel calculation and $\Sigma_c\bar{D}^*$ and $\Sigma_c\bar{D}$ mean the corresponding single-channel calculation.

Λ	$CC(1/2^-)_1$	$\Sigma_c\bar{D}^*(1/2^-)$	$CC(1/2^-)_2$	$\Sigma_c\bar{D}(1/2^-)$
0.8	4448.0	4450.8	4320.4	4320.3
1.0	4439.4	4444.8	4320.0	4319.5
1.2	4431.7	4439.0	4320.1	4318.7
1.4	4425.2	4433.9	4320.2	4318.0
1.6	4420.1	4429.8	4320.3	4317.5
1.8	4416.4	4426.7	4320.5	4317.1

$P_c(4440): \Sigma_c\bar{D}^* \left(\frac{1}{2}^-\right)$ $P_c(4312): \Sigma_c\bar{D} \left(\frac{1}{2}^-\right)$

耦合道的影响较小与ChPT的结果一致（见孟璐报告）

JH, Eur.Phys.J. C79 (2019) 393

$3/2^-$

Table 3 The position of the bound states with $J^P = 3/2^-$ in a unit of MeV. The Λ in the unit of GeV is the cutoff in the exponential regularization. The CC means coupled-channel calculation and $\Sigma_c\bar{D}^*$ means the single-channel calculation of $\Sigma_c\bar{D}^*$ interaction.

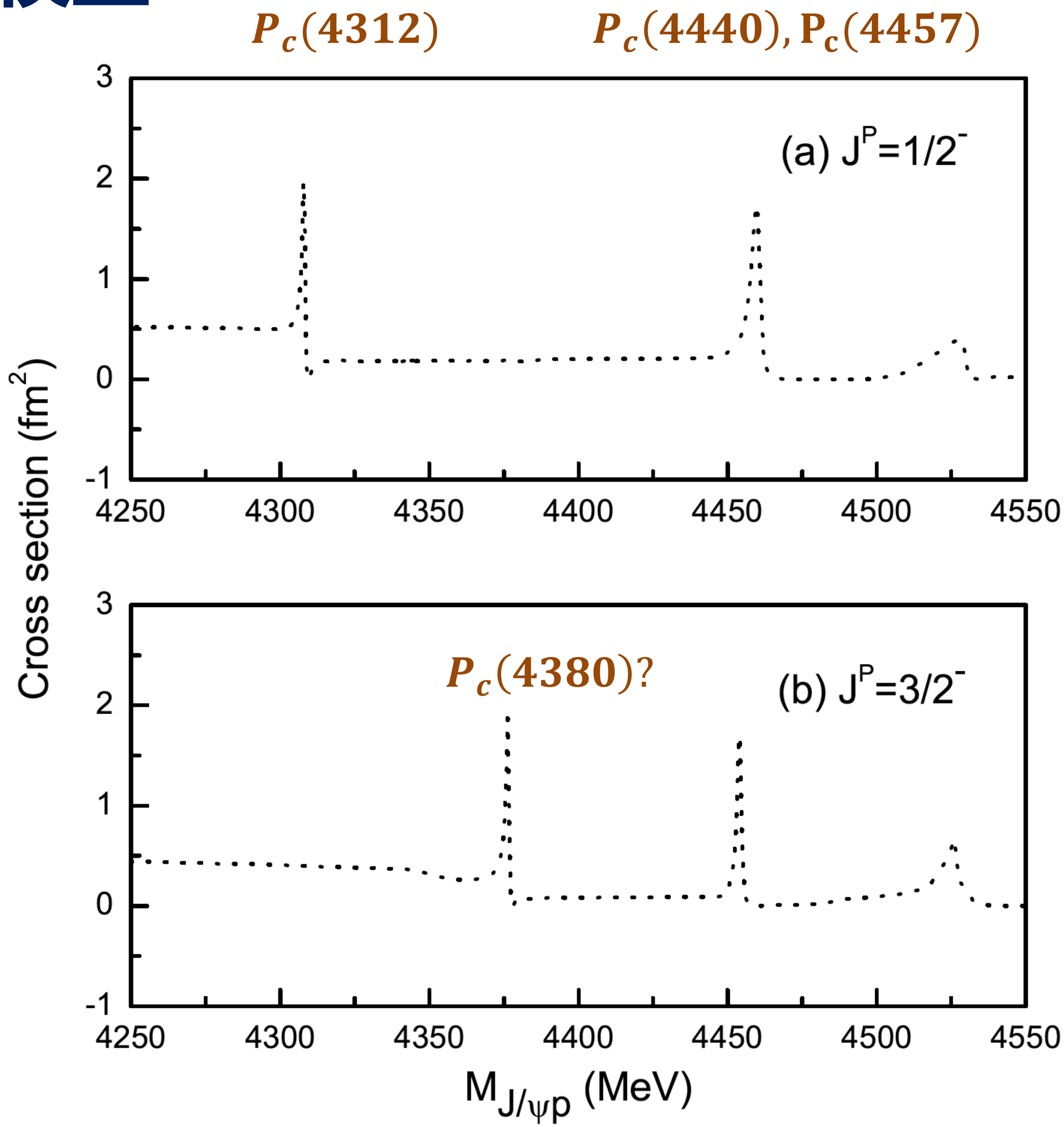
Λ	$CC(3/2^-)$	$\Sigma_c\bar{D}^*(3/2^-)$
0.8	$--$	4462.0
1.0	4461.7	4461.9
1.2	4461.5	4461.7
1.4	4461.3	4461.6
1.6	4461.1	4461.4
1.8	4460.9	4461.3

$\boldsymbol{P_c(4457): \Sigma_c\bar{D}^*\ (\frac{3}{2}^-)}$

$\boldsymbol{P_c(4380): \Sigma_c^*\bar{D}\ (\frac{3}{2}^-)}$： 有吸引，在散射中有增强。
如果cutoff变大，会有束缚态出现

JH, Eur.Phys.J. C79 (2019) 393

夸克模型



今天下午Parallel I
15:10 刘雪杰

HX,Huang, **JH**, JL Ping, arXiv:1904.00221

Our results support **the molecular state interpretation**:

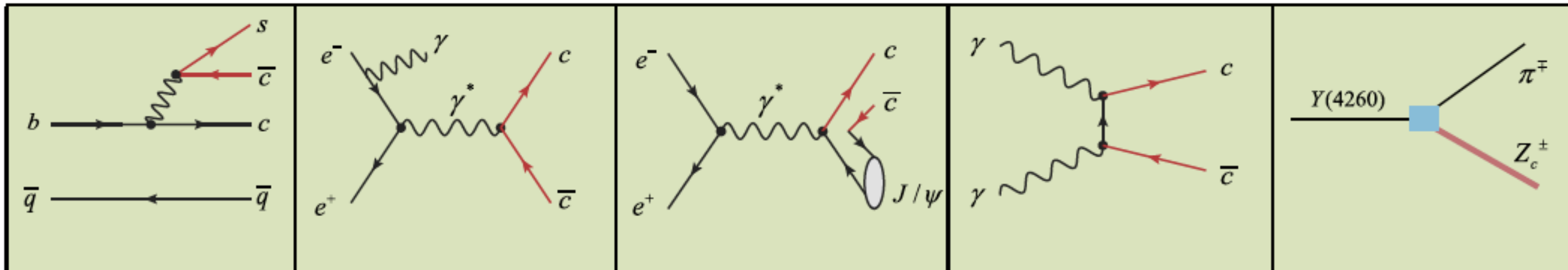
- $P_c(4450)$: $\Sigma_c \bar{D}^* \left(\frac{5}{2}^+\right) \rightarrow P_c(4440)$: $\Sigma_c \bar{D}^* \left(\frac{1}{2}^-\right)$, $P_c(4457)$: $\Sigma_c \bar{D}^* \left(\frac{3}{2}^-\right)$,
- $P_c(4380)$: $\Sigma_c^* \bar{D} \left(\frac{3}{2}^-\right) \rightarrow ?\, P_c(4380)$: $\Sigma_c^* \bar{D} \left(\frac{3}{2}^-\right)$, attractive, no bound state
- $P_c(4312)$: $\Sigma_c \bar{D} \left(\frac{1}{2}^-\right)$.

Other assignments are still not excluded.

Need determination of the spin parities of these P_c states.

Photo- and pion induced productions of $P_c(4312)$, $P_c(4440)$, $P_c(4457)$

Observations of the Pc's and XYZ particles



$X(3872)$	$Y(4260)$	$X(3940)$	$X(3915)$	$Z_c(3900)$
$Y(3940)$	$Y(4008)$	$X(4160)$	$X(4350)$	$Z_c(4025)$
$Z^+(4430)$	$Y(4360)$		$Z(3930)$	$Z_c(4020)$
$Z^+(4051)$	$Y(4630)$			$Z_c(3885)$
$Z^+(4248)$	$Y(4660)$			
$Y(4140)$				
$Y(4274)$				
$Z_c^+(4200)$				
$Z^+(4240)$				
$X(3823)$				

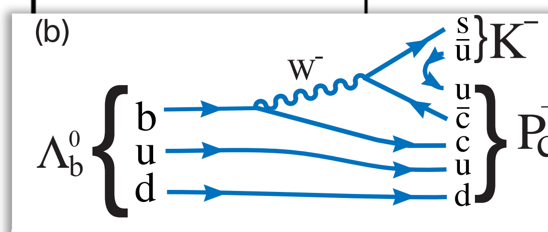
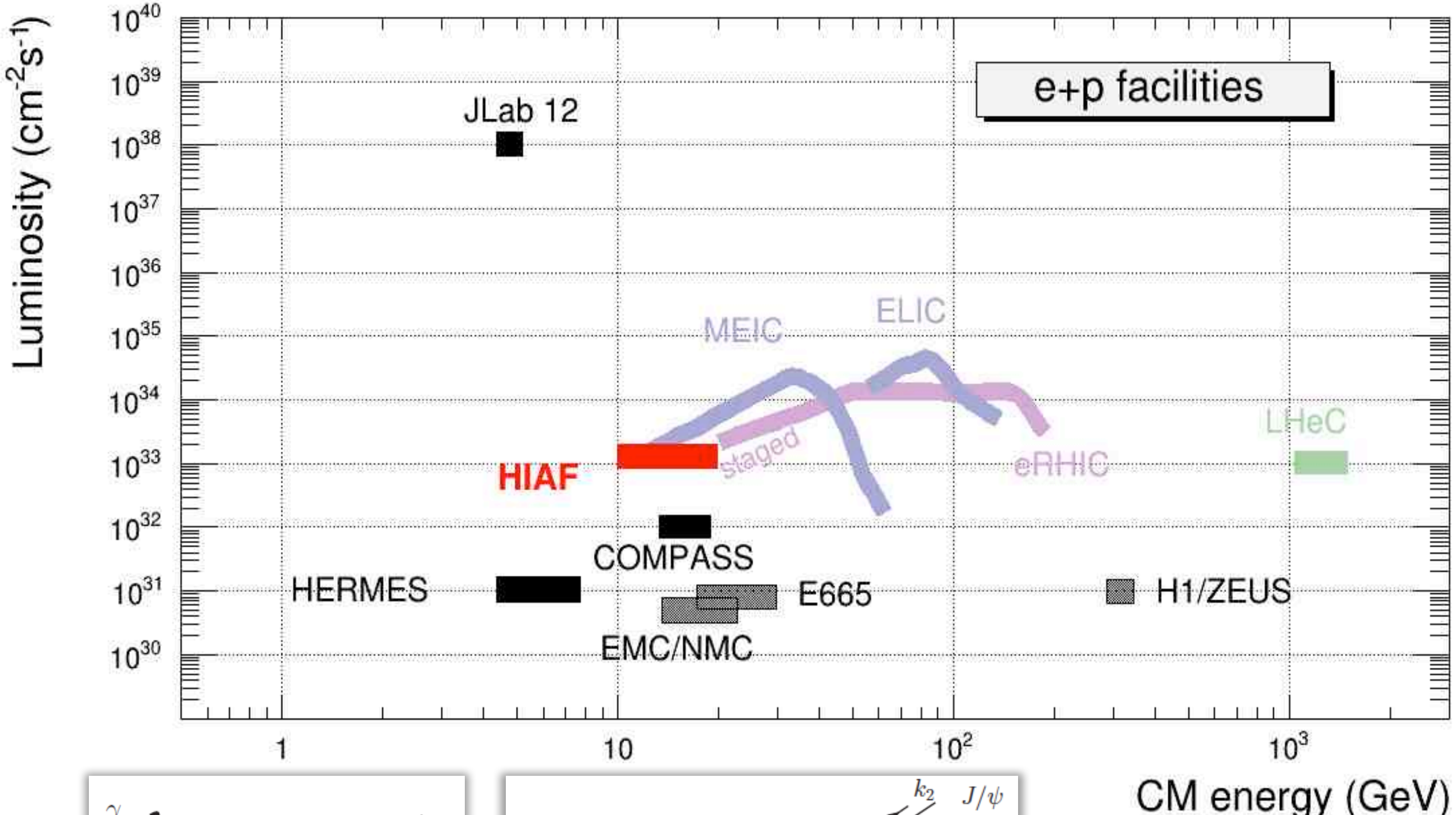
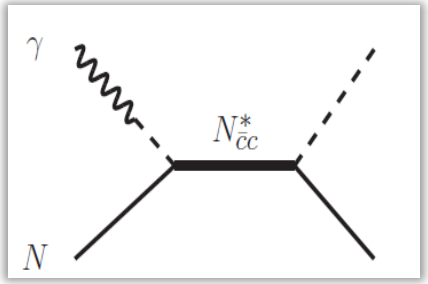


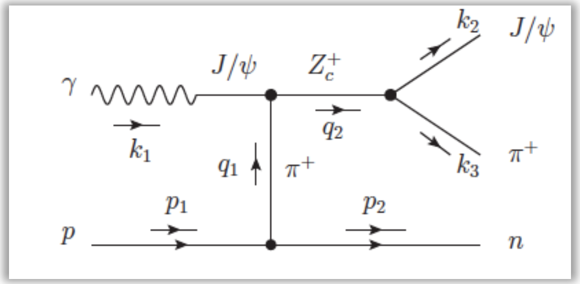
Fig. 2. (Color online) Five groups of the charmonium-like states corresponding to five production mechanisms.

Chen, Chen, Liu, Zhu, Phys. Rept.639(2016)1-121

Photoproduction

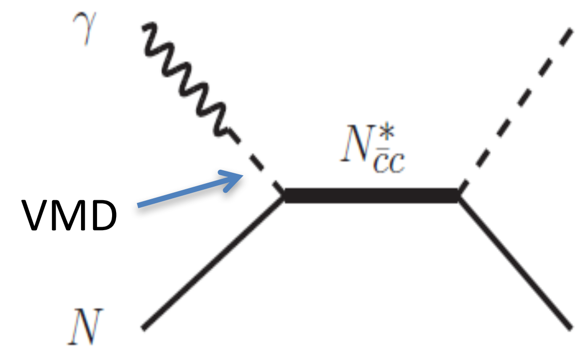


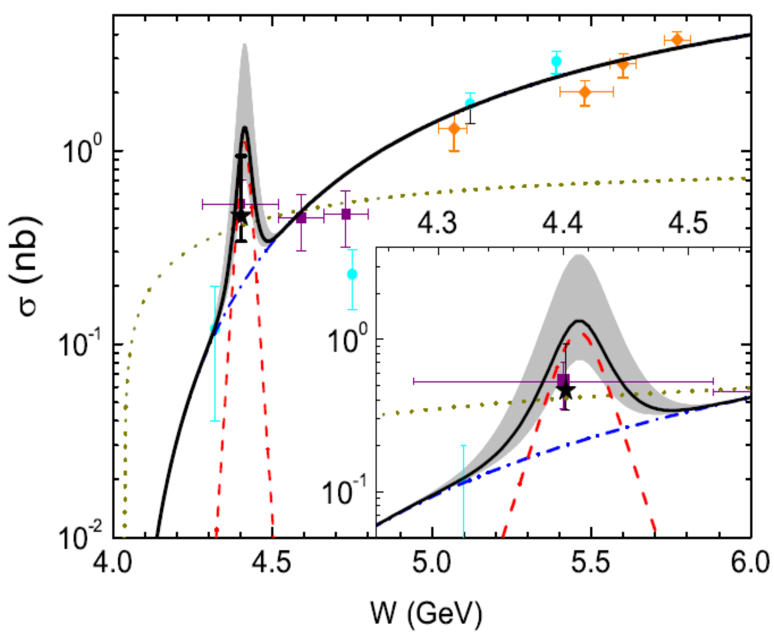




Prediction before LHCb observation of the hidden-charmed pentaquark

	$PB \to PB$						$VB \to VB$				
	$N^*_{c\bar{c}}$		$\Lambda^*_{c\bar{c}}$				$N^*_{c\bar{c}}$		$\Lambda^*_{c\bar{c}}$		
M		4261		4209	4394		4412			4368	4544
Γ		56.9		32.4	43.3		47.3			28.0	36.6
Γ_i	πN	3.8	KN	15.8	0.0	ρN	3.2		K^*N	13.9	0.0
	ηN	8.1	$\pi\Sigma$	2.9	10.6	ωN	10.4		$\rho\Sigma$	3.1	8.8
	$\eta' N$	3.9	$\eta\Lambda$	3.2	7.1	$K^*\Sigma$	13.7		$\omega\Lambda$	0.3	9.1
	$K\Sigma$	17.0	$\eta'\Lambda$	1.7	3.3				$\phi\Lambda$	4.0	0.0
			$K\Xi$	2.4	5.8				$K^*\Xi$	1.8	5.0
	$\eta_c N$	23.4	$\eta_c\Lambda$	5.8	16.3	$J/\psi N$	19.2		$J/\psi\Lambda$	5.4	13.8



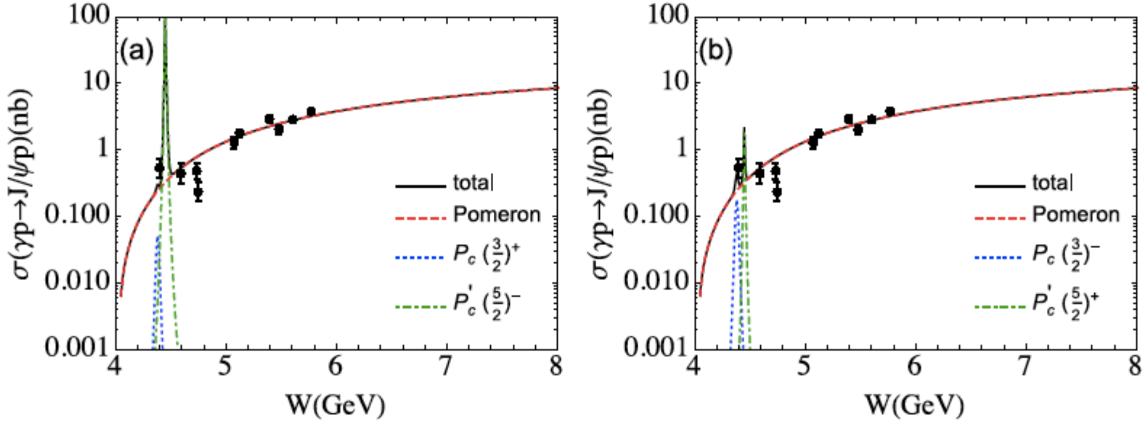


- The cross section of the hidden-charmed N* is at order of 0.1 nb
- The **off-shellness of the J/ψ** will suppress the cross sction heavily because of its large mass

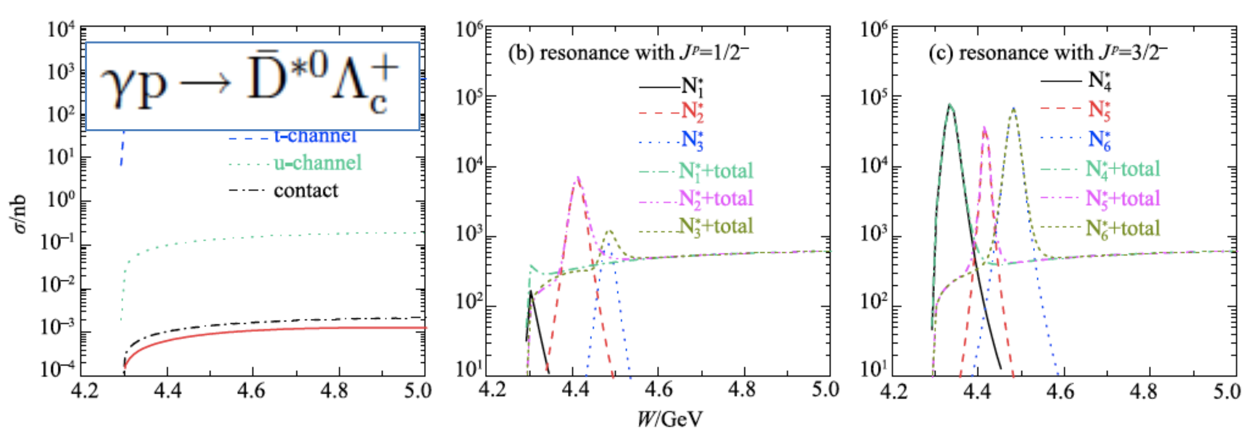
also adopted in [Wu,Lee,Zou, arXiv:1906.05375]

Huang, **JH**, Zhang, Chen, J.Phys. G41(2014) 11500

Predictions of Pc(4450) and Pc(4380) photoproduciton



Wang, Liu, Zhao. Phys. Rev. D92(2015)034022



Huang, Xie, JH, Chen, Zhang, Chinese Physics C, 2016, 40, 124104

Many other works…

New LHCb results → New predictions

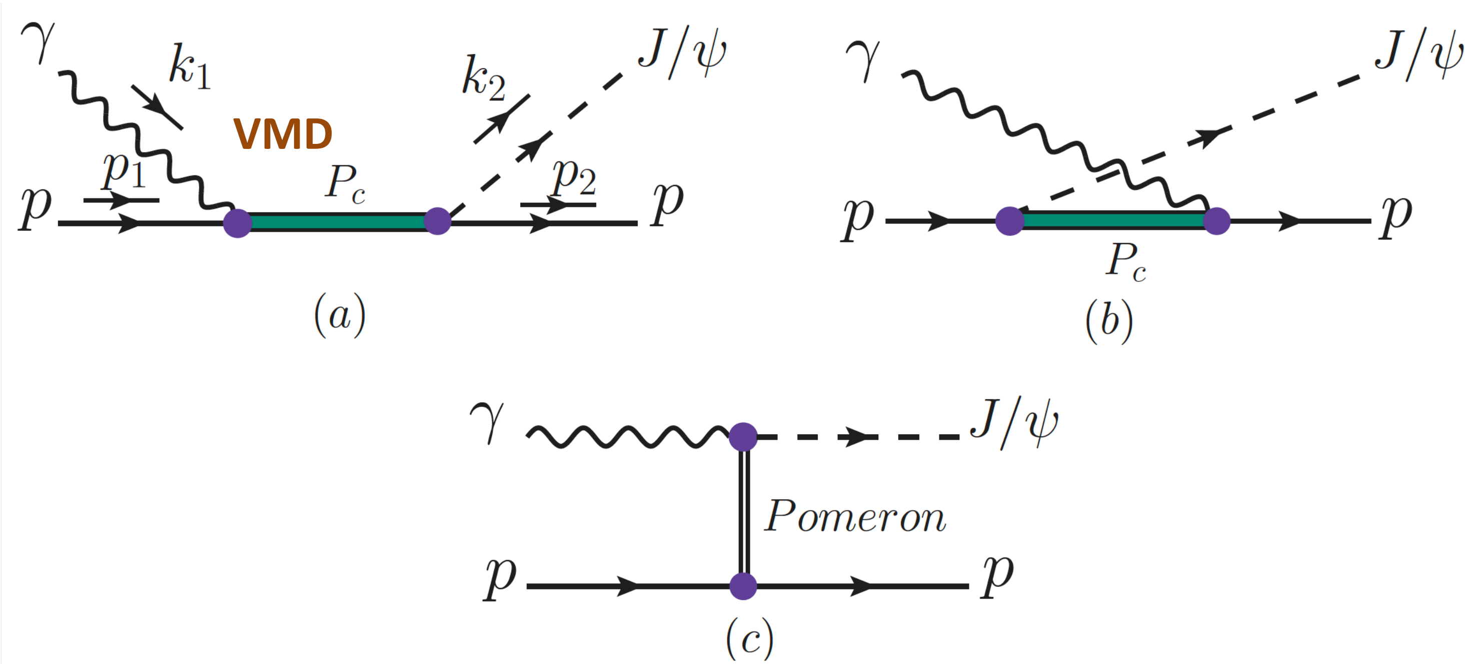
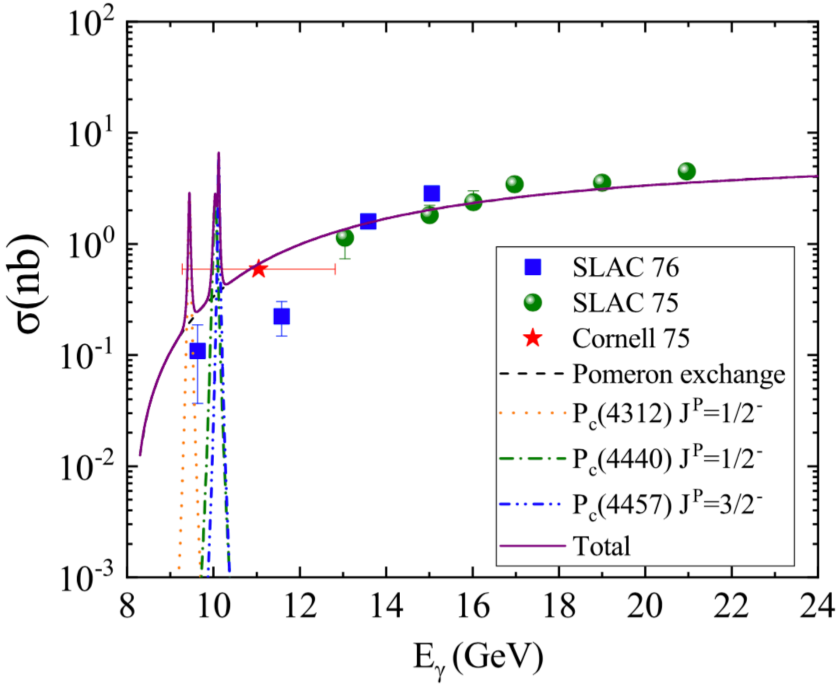
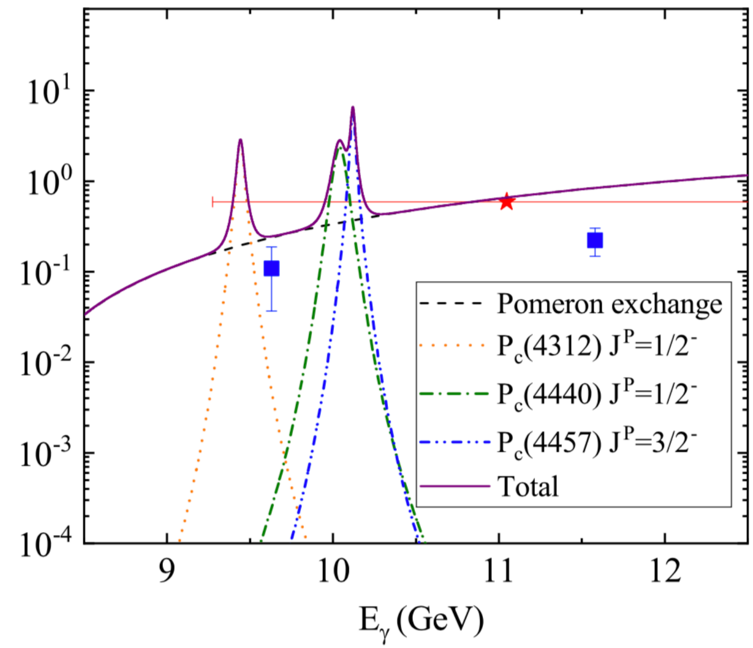


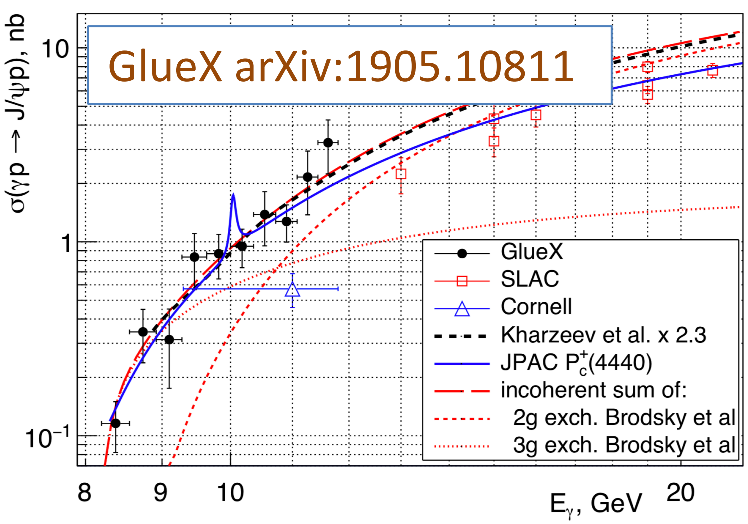
TABLE I. The values of coupling constants by assuming the $J/\psi p$ channel accounts for 3% of total widths of the P_c states.

States	$g_{P_c \psi N}$	eh or eh_1
$P_c(4312)$ ($J^P = \frac{1}{2}^-$)	0.06	0.0014
$P_c(4440)$ ($J^P = \frac{1}{2}^-$)	0.08	0.0018
$P_c(4457)$ ($J^P = \frac{3}{2}^-$)	0.036	0.0008

XY Wang, **JH**, XR chen, Phys.Rev. D99 (2019)114007







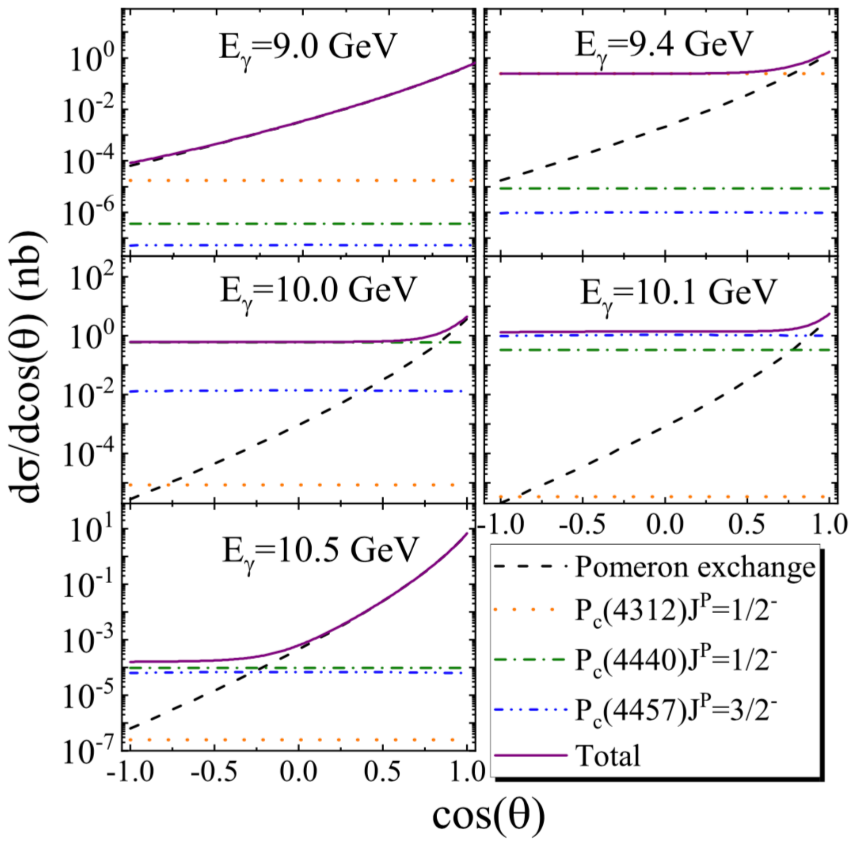
$Br[P_c \to J/\psi p] \cong 3\%.$

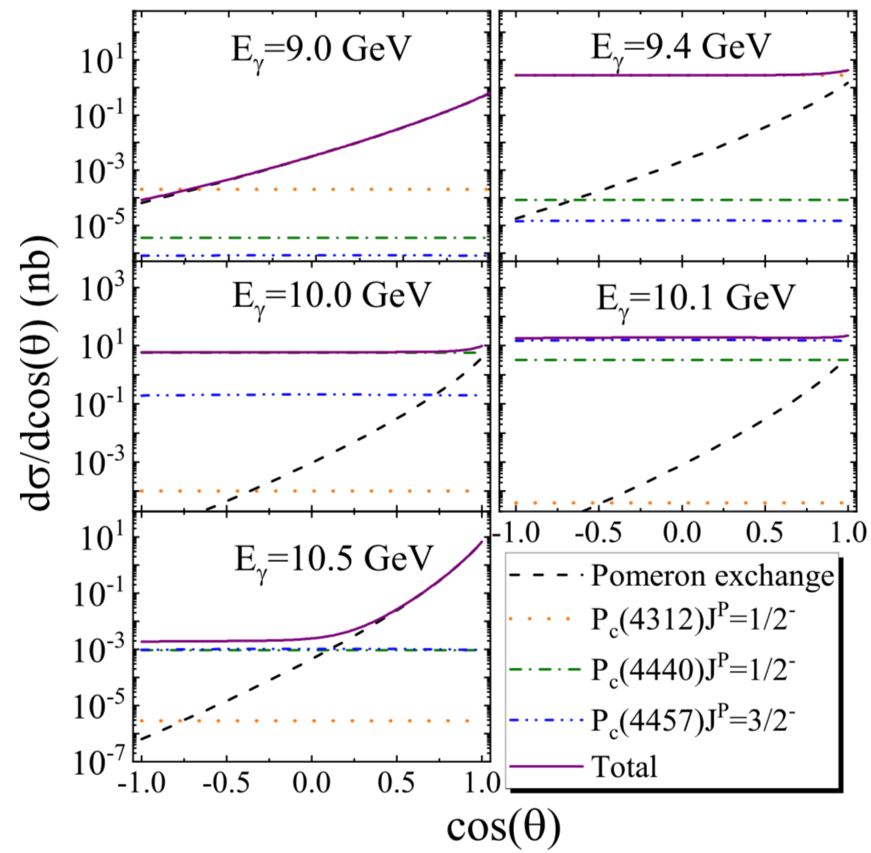
Two peaks: 0.1 nb within a bin of 100 MeV

Three peaks: 0.1nb/10 MeV

XY Wang, **JH**, XR chen, Phys.Rev. D99 (2019)114007

Differential cross section





The differential cross sections from the Pc states are flat due to the spin parities

XY Wang, **JH**, XR chen, Phys.Rev. D99 (2019)114007

Pion-induced production

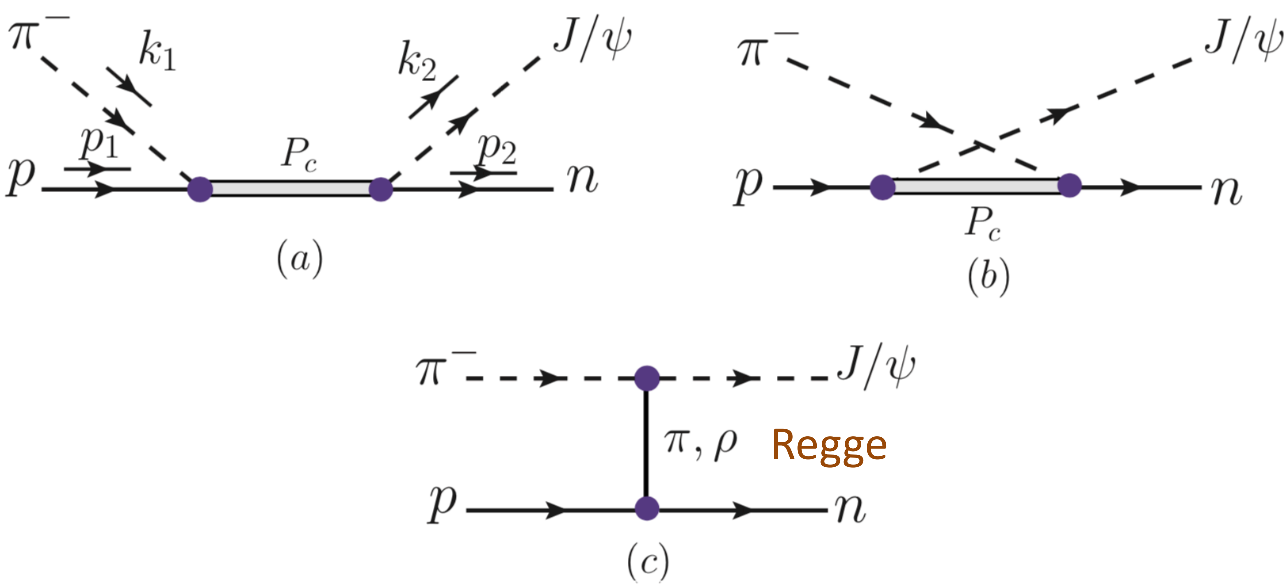
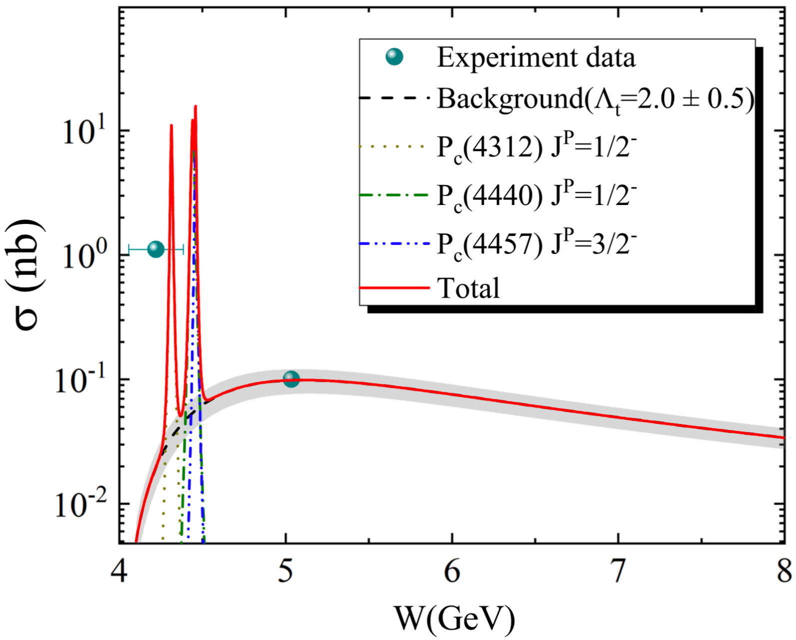
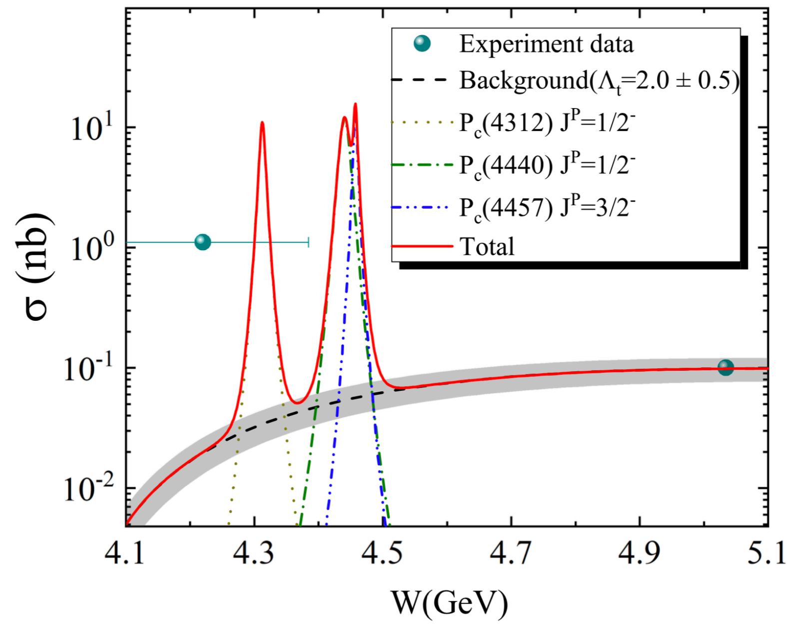


TABLE I. The values of coupling constants by assuming that the $J/\psi N$ and πN channels account for 3% and 0.05% of total widths of the P_c states, respectively.

	$P_c(4312)$	$P_c(4440)$	$P_c(4457)$
$g_{P_c\psi N}$	0.06	0.08	0.036
$g_{\pi N P_c}$	0.0036	0.0053	0.0005

XY Wang, **JH**, QJ Wang, XM Zhu, arXiv:1906.04044





$Br[P_c \to J/\psi p] \cong 3\%$ and $Br[P_c \to \pi p] \cong 0.05\%$.

Higher precision is required to distiguish $P_c(4440)$ and $P_c(4457)$

XY Wang, **JH**, QJ Wang, XM Zhu, arXiv:1906.04044

Summary

LHCb update their results about the hidden-charm pentaquarks.

Our results support **the molecular state interpretation**:

- $P_c(4450)$: $\Sigma_c \bar{D}^* \left(\frac{5}{2}^+\right) \rightarrow P_c(4440)$: $\Sigma_c\bar{D}^* \left(\frac{1}{2}^-\right)$, $P_c(4457)$: $\Sigma_c\bar{D}^* \left(\frac{3}{2}^-\right)$,
- $P_c(4380)$: $\Sigma_c^*\bar{D} \left(\frac{3}{2}^-\right) \rightarrow P_c(4380)?$: $\Sigma_c^*\bar{D} \left(\frac{3}{2}^-\right)$, attractive, no bound state
- $P_c(4312)$: $\Sigma_c\bar{D} \left(\frac{1}{2}^-\right)$.

Other assignments are still not excluded.
Need determination of the spin parities of these P_c states.

The photoproduction and pion-induced productions of the P_c :

- Two peaks: 0.1 nb within a bin of 100 MeV
- Three peaks: 0.1nb/10 MeV

谢谢！