P_c pentaquarks with pion exchange and quark core couplings

Yasuhiro Yamaguchi

Advanced Science Research Center, Japan Atomic Energy Agency, Japan

in collaboration with

Hugo García-Tecocoatzi (UNLP), Alessandro Giachino (INFN Genoa),

Atsushi Hosaka (RCNP, Osaka Univ.), Elena Santopinto (INFN Genoa),

Sachiko Takeuchi (Japan Coll. Social Work), Makoto Takizawa (Showa Pharmaceutical Univ.).

19th International Conference on Hadron Spectroscopy and Structure in memoriam Simon Eidelman

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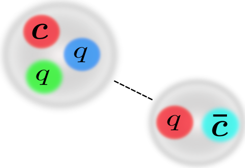
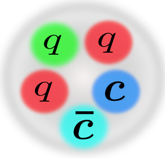
Outline

1. Introduction
   - Exotic hadrons
   - Hidden-charm pentaquarks P_c
2. Model setup
   - One pion exchange potential
   - Compact 5-quark potential
3. Numerical results for P_c
4. Numerical results for P_{cs} (Preliminary)
5. Summary



Hadronic molecule

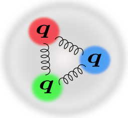
⇕ **Mixture?**



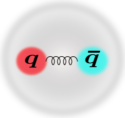
Pentaquark (Compact)

Hadron structure: Constituent quark model

- Hadron = Quark composite system
- Ordinary Hadrons: Baryon (qqq) and Meson ($q\bar{q}$)



Baryon(proton,nucleon,...)



Meson (ρ,$K^{(*)}$,...)

Hadron structure: Constituent quark model

- Hadron = Quark composite system
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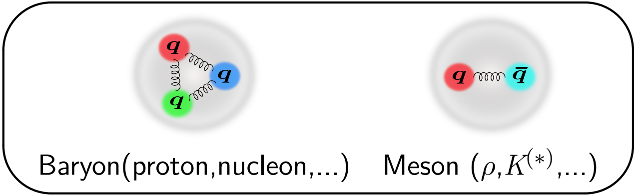
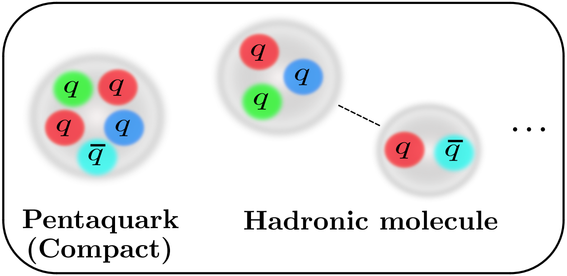
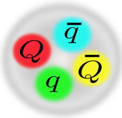


- Exotic Hadrons ($\neq qqq$, $q\bar{q}$): **Multiquark? Multihadron?**

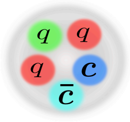


Candidates of Exotic structures ?

Compact multiquarks

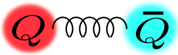


Tetraquark

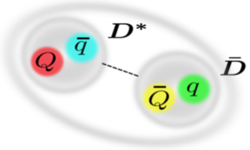


Pentaquark

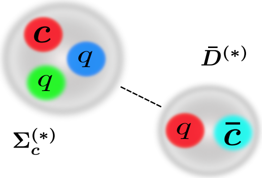
$Q\bar{Q}g$ Hybrid



Hadronic molecules

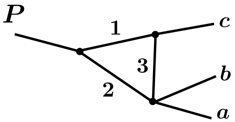


Meson-Meson



Meson-Baryon

Triangle Singularity

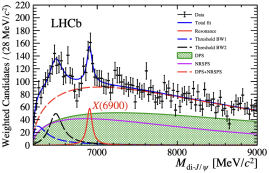


(w/o Resonance)

Recent reports of Exotic hadrons!

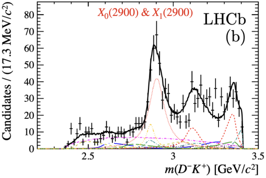
▷ $X(6900)$ $(cc\bar{c}\bar{c}?)$

LHCb, Science Bulletin 65 (2020) 1983



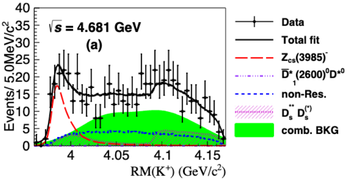
▷ $X_{0,1}(2900)$ $(\bar{c}\bar{s}ud?)$

LHCb, PRL125, 242001 (2020), PRD102, 112003 (2020)



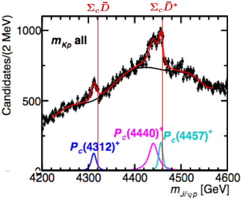
▷ Z_{cs} $(c\bar{c}s\bar{u}?)$

BESIII, PRL126,102001 (2021)



▷ P_c $(uudc\bar{c}?)$,

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



Recent reports of Exotic hadrons!

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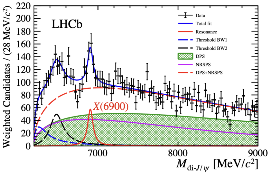

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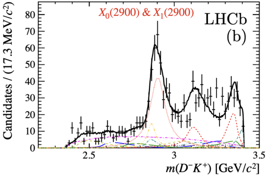
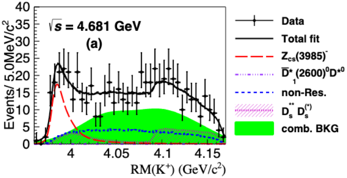


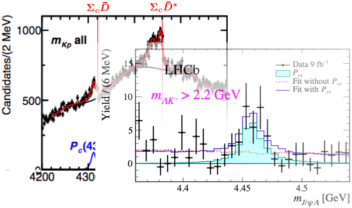
▷ Z_{cs} $(c\bar{c}s\bar{u}?)$

BESIII, PRL126,102001 (2021)



▷ P_c $(uudc\bar{c}?)$, P_{cs} $(udsc\bar{c}?)$

LHCb PRL**115**(2015)072001, **122**(2019)222001 , Sci.Bull.**66**(2021)1278-1287



Observation of two P_c pentaquarks in LHCb (2015)

- Observation of the Hidden-charm Pentaquark ($c\bar{c}uud$) in $\Lambda_b^0 \to J/\psi K^- p$ Decay? R.Aaij, *et al.* (LHCb collaboration) PRL**115**(2015)072001

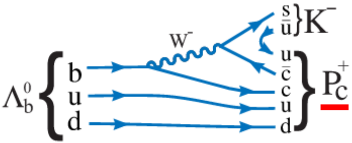
PRL **115,** 072001 (2015) PHYSICAL REVIEW LETTERS week ending 14 AUGUST 2015

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays

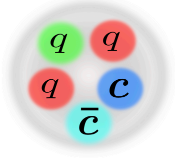
R. Aaij *et al.**
(LHCb Collaboration)
(Received 13 July 2015; published 12 August 2015)

P_c in $\Lambda_b^0 \to J/\psi p K^-$ decay

$c\bar{c}uud$ state ?



$\Rightarrow$

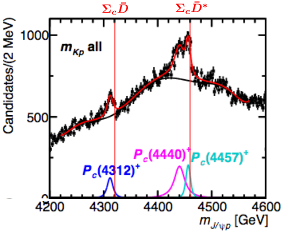


$P_c(4380)$: M =4380 MeV, Γ= 205 MeV

$P_c(4450)$: M =4449.8 MeV, Γ = 39 MeV

New LHCb analysis in 2019!

- R. Aaij, *et al.* Phys.Rev.Lett. 122 (2019) 222001



- $P_c(4450)$ in 2015 $\longrightarrow$ $P_c(4440)$ and $P_c(4457)$

  $P_c(4440)$: $(M,\Gamma)=(4440.3, 20.6)$ MeV
  $P_c(4457)$: $(M,\Gamma)=(4457.3, 6.4)$ MeV

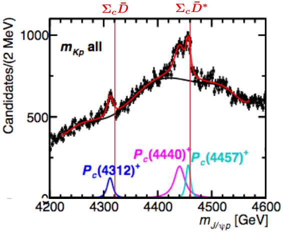
- Observation of **New state!**

  $P_c(4312)$: $(M,\Gamma)=(4311.9, 9.8)$ MeV

- $P_c(4380)$ in 2015? "these fits can neither confirm nor contradict the existence of the $P_c(4380)^+$"

New LHCb analysis in 2019!

- R. Aaij, *et al.* Phys.Rev.Lett. 122 (2019) 222001



- $P_c(4450)$ in 2015 $\longrightarrow$ $P_c(4440)$ and $P_c(4457)$

  $P_c(4440)$: $(M, \Gamma) = (4440.3, 20.6)$ MeV
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- Observation of **New state!**

  $P_c(4312)$: $(M, \Gamma) = (4311.9, 9.8)$ MeV

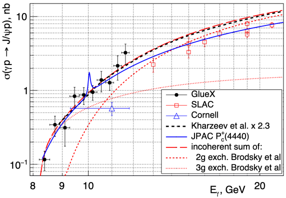
- $P_c(4380)$ in 2015? "these fits can neither confirm nor contradict the existence of the $P_c(4380)^+$"

- Complementary experiments: $\gamma p \to J/\psi p$ in GlueX@J-Lab

  GlueX Collaboration, PRL**123**(2019)072001.

  $\to$ No triangle singularity

  No evidence of $\gamma p \to P_c \to J/\psi p$



What is the structure of the pentaquarks?

Proposals of various structures!

H.X.Chen, *et al.*, Phys.Rept.**639**(2016)1, A.Esposito, *et al.*,Phys.Rept.**668**(2016)1, A.Ali,*et al.*,PPNP**97**(2017)123

- Compact pentaquark $(c\bar{c}qqq)$?

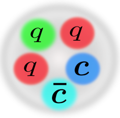
  S.G.Yuan, *et al.* (2012), L.Maiani, *et al,* (2015), S.Takeuchi, *et al,* (2017), J. Wu, *et al.* (2017), E. Hiyama, *et al.* (2018), ...

- Hadronic molecule $(\bar{D}\Sigma_c^*,\ \bar{D}^*\Sigma_c, \ldots)$?

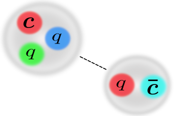
  J.-J.Wu *et al.,* (2010) (2011), C. Garcia-Recio, *et al.* (2013), R. Chen, *et al.* (2015), Y.Shimizu, *et al.* (2016-2019), C. W. Xiao, *et al.* (2019), M.-Z. Liu, *et al.* (2019), M. L. Du, *et al.* (2019), ...

- Triangle singularity?
  (Non-resonant explanation)

  F.K.Guo, *et al.* (2015), X.H.Liu, *et al.* (2016), S.X.Nakamura PRD103, L111503 (2021), ...



Pentaquark (Compact)

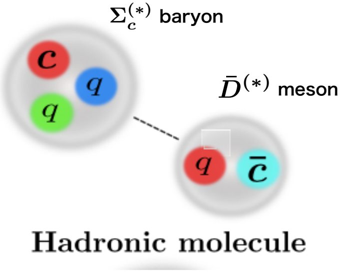


Hadronic molecule

Hadronic molecules?

- Exotics as Hadronic molecule ⇒ Hadron (quasi) bound state

→ expected **near the thresholds**



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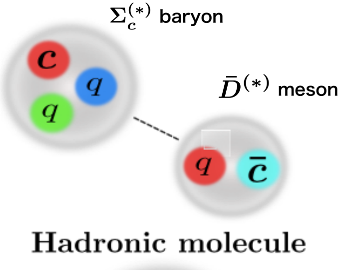
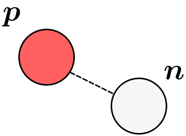


Analogous to Deuteron

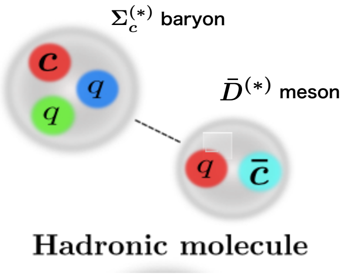


$B = 2.2$ MeV

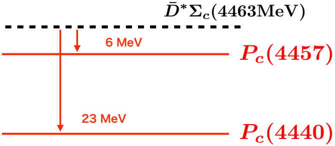
Hadronic molecules?

- Exotics as Hadronic molecule $\Rightarrow$ Hadron (quasi) bound state

$\rightarrow$ expected **near the thresholds**



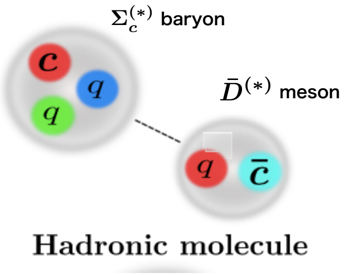
$$P_c = \bar{D}^{(*)}\Sigma_c^{(*)} \text{ molecules?}$$



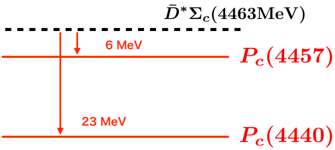
Hadronic molecules?

- Exotics as Hadronic molecule ⇒ Hadron (quasi) bound state

→ expected **near the thresholds**



$P_c = \bar{D}^{(*)}\Sigma_c^{(*)}$ molecules?

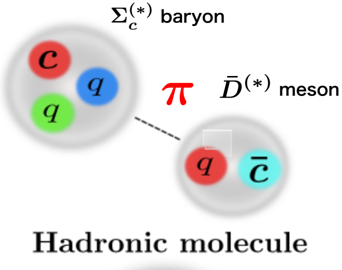


▷ Q. Interactions?: **Heavy hadron interactions** are not established yet...

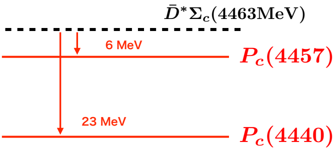
Hadronic molecules?

- Exotics as Hadronic molecule ⇒ Hadron (quasi) bound state

→ expected **near the thresholds**



$P_c = \bar{D}^{(*)}\Sigma_c^{(*)}$ molecules?



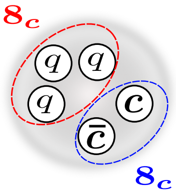
▷ Q. Interactions?: **Heavy hadron interactions** are not established yet...

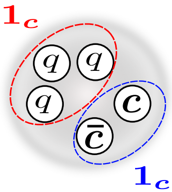
⇒ Importance of π **exchange** is expected due to the heavy quark symmetry! S. Yasui and K. Sudoh, Phys. Rev. D **80** (2009), 034008

⇒ Hadronic molecular structure is favored?

Compact $5q$ state?

- S. Takeuchi and M. Takizawa, PLB**764** (2017) 254-259.
  P_c states by the quark cluster model
- 5-quark configurations





$S_{q^3} = 1/2, 3/2,\ S_{c\bar{c}} = 0, 1 \quad S_{q^3} = 1/2,\ S_{c\bar{c}} = 0, 1$

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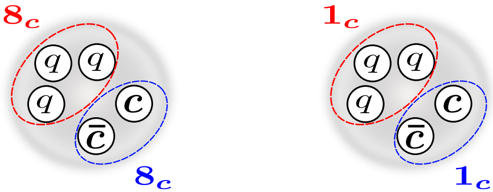

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- $[q^3\,8_c\,3/2]$: Color magnetic int. is attractive!

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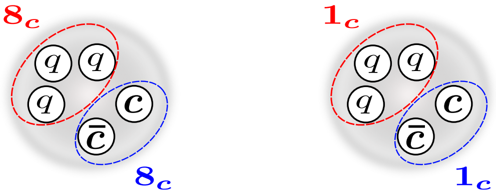


$S_{q^3} = 1/2, 3/2,\ S_{c\bar{c}} = 0, 1 \qquad S_{q^3} = 1/2,\ S_{c\bar{c}} = 0, 1$

- $[q^3\, 8_c\, 3/2]$: Color magnetic int. is attractive!

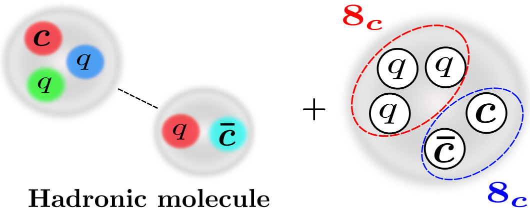
  $\Rightarrow$ Couplings to (qqc) baryon-$(q\bar{c})$ meson, e.g. $\bar{D}\Sigma_c$,
  are allowed!

$\boxed{\textbf{Mixing of Compact state and Hadronic Molecule!}}$

Model setup in this study

- **Hadronic molecule + Compact state ($5q$)**

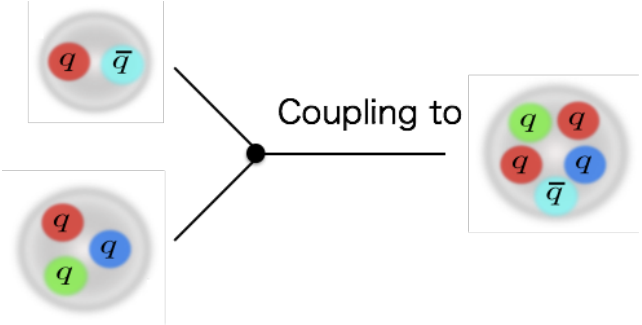
$MB + 5q$



Model setup in this study

- **Hadronic molecule + Compact state ($5q$)**
  $\Rightarrow$ Meson-Baryon couples to $5q$ (Feshbach projection)

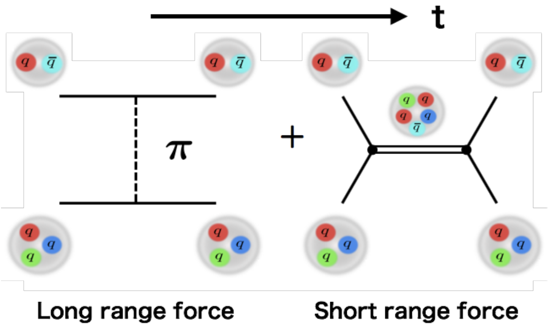
$MB + 5q$



Model setup in this study

- **Hadronic molecule + Compact state ($5q$)**
  $\Rightarrow$ Meson-Baryon couples to $5q$ (Feshbach projection)

Meson-Baryon interactions

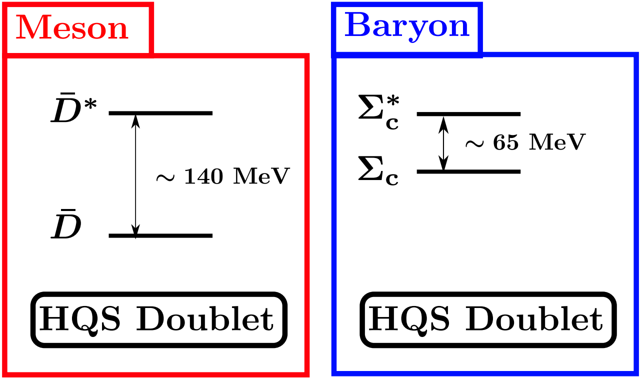


- **Long range** interaction: One pion exchange potential (OPEP)
- **Short range** interaction: $5q$ potential

Mass degeneracy $\to$ $\bar{D} - \bar{D}^*$, $\Sigma_c - \Sigma_c^*$ mixing!

- Mass Degeneracy of $(0^-, 1^-)$ Mesons, $(1/2^+, 3/2^+)$ Baryons

$\Rightarrow$ $(\bar{D}, \bar{D}^*)$ and (Σ_c, Σ_c^*) mixing

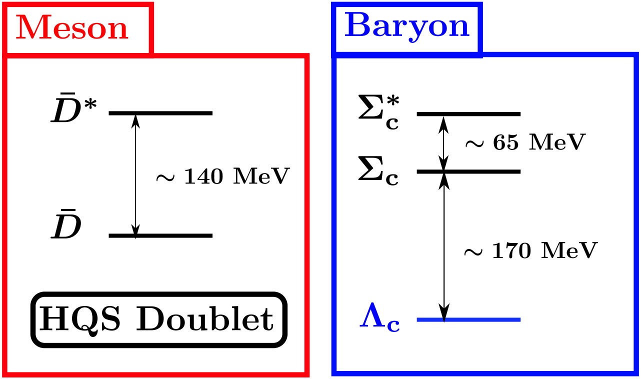


- Coupled channels of $\bar{D}\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$ and $\bar{D}^*\Sigma_c^*$!
  $\Rightarrow$ These thresholds are close to each other

Mass degeneracy → $\bar{D}-\bar{D}^*$, $\Sigma_c-\Sigma_c^*$ mixing!

- Mass Degeneracy of $(0^-,1^-)$ Mesons, $(1/2^+,3/2^+)$ Baryons

⇒ $(\bar{D},\bar{D}^*)$ and (Σ_c,Σ_c^*) mixing

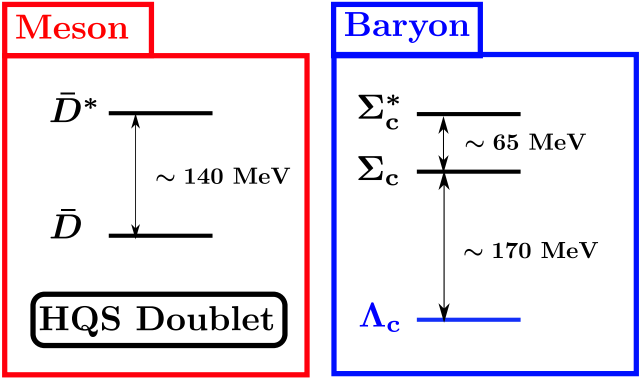


- Coupled channels of $\bar{D}\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$ and $\bar{D}^*\Sigma_c^*$!
  ⇒ These thresholds are close to each other
- In addition, Λ_c (cqq): $\bar{D}^{(*)}\Lambda_c$ channel!?

Mass degeneracy $\to$ $\bar{D}-\bar{D}^*$, $\Sigma_c-\Sigma_c^*$ mixing!

- Mass Degeneracy of $(0^-,1^-)$ Mesons, $(1/2^+,3/2^+)$ Baryons

$\Rightarrow$ $(\bar{D},\bar{D}^*)$ and (Σ_c,Σ_c^*) mixing

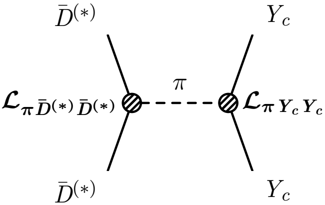


- 6 meson-baryon components

$$(1)\ \bar{D}\Lambda_c,\ (2)\ \bar{D}^*\Lambda_c,\ (3)\ \bar{D}\Sigma_c,\ (4)\ \bar{D}\Sigma_c^*,$$
$$(5)\ \bar{D}^*\Sigma_c,\ (6)\ \bar{D}^*\Sigma_c^*$$

$\bar{D}^{(*)} Y_c$ Interaction: Long range force

- One pion exchange potential



$\bar{D}^{(*)}$: $\bar{D}$ or $\bar{D}^*$

Y_c: Λ_c, Σ_c or Σ_c^*

$$V^{\pi}_{\bar{D}^{(*)} Y_c - \bar{D}^{(*)} Y_c} = -\frac{g_\pi g_1}{3 f_\pi^2} \left[\vec{S}_1 \cdot \vec{S}_2 C(r) + S_{S_1 S_2} T(r) \right]$$

(Contact term is removed)

$$g_\pi = 0.59, g_1 = 1.00$$

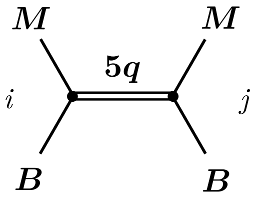
- Form factor with Cutoff Λ (determined by the hadron size)

$$F(\vec{q}^2) = \frac{\Lambda^2 - m_\pi^2}{\Lambda^2 + \vec{q}^2}, \quad \Lambda_{\bar{D}} \sim 1130 \text{ MeV}, \Lambda_{Y_c} \sim 840 \text{ MeV}$$

Y.Y, A. Giachino, A. Hosaka, E. Santopinto, S. Takeuchi, M. Takizawa, PRD**96**(2017)114031

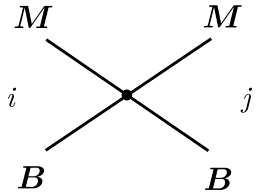
Model: 5-quark potential

- 5-quark potential $\Rightarrow$ s-channel diagram...But



Model: 5-quark potential

- 5-quark potential $\Rightarrow$ **Local Gaussian potential** is employed.
  Massive M_{5q} (few hundred MeV above $\bar{D}^*\Sigma_c^*$) $\rightarrow$ **Attractive**



$\Rightarrow -fS_iS_je^{-\alpha r^2}$

Channel $i,j = \bar{D}^{(*)}\Lambda_c,\ \bar{D}^{(*)}\Sigma_c^{(*)}$ with $S-$wave

J	$[q^3 8 \frac{1}{2}]0$	$[q^3 8 \frac{1}{2}]1$	$[q^3 8 \frac{3}{2}]0$	$[q^3 8 \frac{3}{2}]1$
$\frac{1}{2}$	4816.2	4759.1	-	4772.2
$\frac{3}{2}$	-	4822.3	4892.5	4835.4
$\frac{5}{2}$	-	-	-	4940.7

Masses of compact $5q$ states
with the color octet (8) q^3

S. Takeuchi and M. Takizawa, PLB**764** (2017) 254-259.

$> \bar{D}^*\Sigma_c^*(4527.1\,\text{MeV})$

$^*[q^3 8 S_{q^3}]S_{c\bar{c}}$

Model: 5-quark potential

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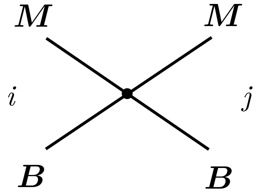

$$\Rightarrow -f S_i S_j e^{-\alpha r^2}$$

Channel $i, j = \bar{D}^{(*)}\Lambda_{\rm c},\ \bar{D}^{(*)}\Sigma_{\rm c}^{(*)}$ with $S-$wave

Free Parameters

Strength $\boldsymbol{f}$ and Gaussian para. $\boldsymbol{\alpha}$ ($\rightarrow$ may be fixed in the future)
(f vs E will be shown latter. $\alpha = 1$ fm^{-2} is fixed.)

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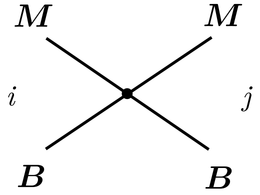

$$\Rightarrow -f S_i S_j e^{-\alpha r^2}$$

Channel $i, j = \bar{D}^{(*)}\Lambda_c,\ \bar{D}^{(*)}\Sigma_c^{(*)}$ with $S-$wave

Free Parameters

Strength $\boldsymbol{f}$ and Gaussian para. $\boldsymbol{\alpha}$ (→ may be fixed in the future)
(f vs E will be shown latter. $\alpha = 1$ fm^{-2} is fixed.)

Relative strength S_i

Spectroscopic factors ⇒ determined by **the spin structure** of $5q$

Spectroscopic factor S_i

- **Overlap** of the color-flavor-spin wavefunctions of 5-quark state and $\bar{D}Y_c$

$$S_i = \left\langle (\bar{D}Y_{\rm c})_i \,\middle|\, 5q \right\rangle$$

Table: Spectroscopic factors S_i for each meson-baryon channel.

J		$S_{c\bar{c}}$	S_{3q}	$\bar{D}\Lambda_c$	$\bar{D}^*\Lambda_c$	$\bar{D}\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Sigma_c^*$
1/2	(i)	0	1/2	0.4	0.6	−0.4	—	0.2	−0.6
	(ii)	1	1/2	0.6	−0.4	0.2	—	−0.6	−0.3
	(iii)	1	3/2	0.0	0.0	−0.8	—	−0.5	0.3
3/2	(i)	0	3/2	—	0.0	—	−0.5	0.6	−0.7
	(ii)	1	1/2	—	0.7	—	0.4	−0.2	−0.5
	(iii)	1	3/2	—	0.0	—	−0.7	−0.8	−0.2
5/2	(i)	1	3/2	—	—	—	—	—	−1.0

Spectroscopic factor S_i

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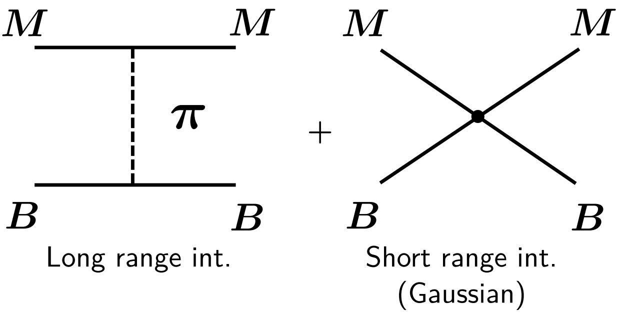
J		$S_{c\bar{c}}$	S_{3q}	$\bar{D}\Lambda_\mathrm{c}$	$\bar{D}^*\Lambda_\mathrm{c}$	$\bar{D}\Sigma_\mathrm{c}$	$\bar{D}\Sigma_\mathrm{c}^*$	$\bar{D}^*\Sigma_\mathrm{c}$	$\bar{D}^*\Sigma_\mathrm{c}^*$
$1/2$	(i)	0	$1/2$	0.4	**0.6**	-0.4	—	0.2	**-0.6**
	(ii)	1	$1/2$	**0.6**	-0.4	0.2	—	**-0.6**	-0.3
	(iii)	1	$3/2$	0.0	0.0	**-0.8**	—	-0.5	0.3
$3/2$	(i)	0	$3/2$	—	0.0	—	**-0.5**	**0.6**	**-0.7**
	(ii)	1	$1/2$	—	**0.7**	—	0.4	-0.2	-0.5
	(iii)	1	$3/2$	—	0.0	—	**-0.7**	**-0.8**	-0.2
$5/2$	(i)	1	$3/2$	—	—	—	—	—	**-1.0**

- **Large S_i** will play an important role.

Numerical Results for Hidden-charm sector



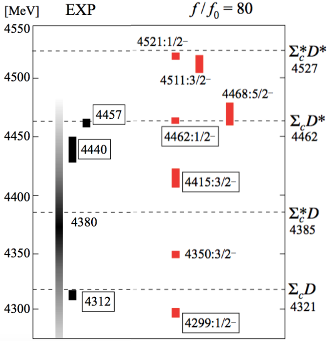
Bound state and Resonance

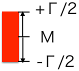
- Coupled-channel Schrödinger equation for $\bar{D}\Lambda_c$, $\bar{D}^*\Lambda_c$, $\bar{D}\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ (6 MB components).
- For $J^P = 1/2^-$, $3/2^-$, $5/2^-$ (Negative parity)

For New P_c states by LHCb in 2019

Y.Y., H.Garcia-Tecocoatzi, A.Giachino, A.Hosaka, E.Santopinto, S.Takeuchi, M.Takizawa, PRD **101** (2020) 091502(R)

$(f_0 = 6$ MeV$)$





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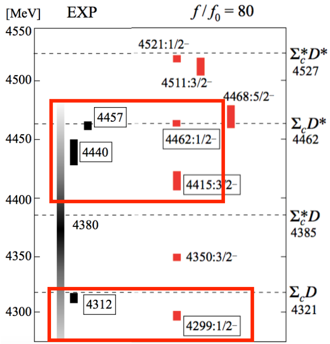

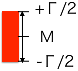

- **Agreement with $P_c(4312)$, $P_c(4440)$, and $P_c(4457)$**

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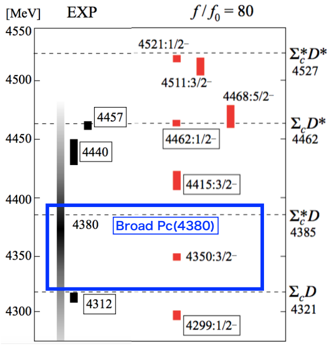
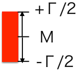
Y.Y., H.Garcia-Tecocoatzi, A.Giachino, A.Hosaka, E.Santopinto, S.Takeuchi, M.Takizawa, PRD **101** (2020) 091502(R)



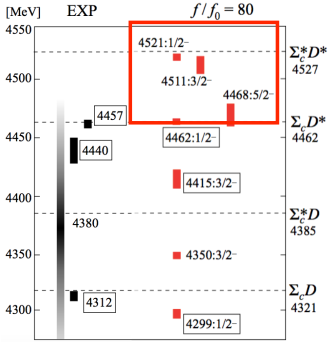
($f_0 = 6$ MeV)



- **Agreement with $P_c(4312)$, $P_c(4440)$, and $P_c(4457)$**
- For Broad $P_c(4380)$, we obtain the similar mass. But width...?

For New P_c states by LHCb in 2019

Y.Y., H.Garcia-Tecocoatzi, A.Giachino, A.Hosaka, E.Santopinto, S.Takeuchi, M.Takizawa, PRD **101** (2020) 091502(R)



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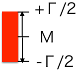
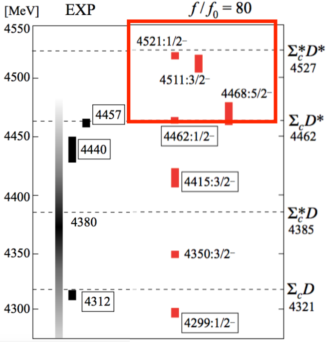


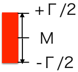
- **Agreement with $P_c(4312)$, $P_c(4440)$, and $P_c(4457)$**
- For Broad $P_c(4380)$, we obtain the similar mass. But width...?
- Predictions: $(1/2^-, 3/2^-, 5/2^-)$ states below $\bar{D}^* \Sigma_c^*$

For New P_c states by LHCb in 2019

Y.Y., H.Garcia-Tecocoatzi, .**01** (2020) 091502(R)

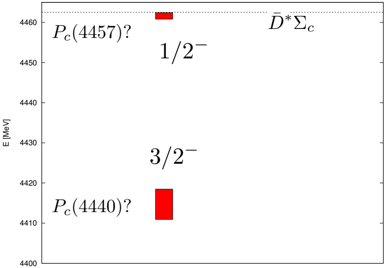
$(f_0 = 6\ \text{MeV})$





P_c	LHCb (M,Γ)	J^P	Ours $5q$+OPEP	C. W. Xiao, *et al.*, PRD**100**(2019)014021 Local hidden gauge	M. Z. Liu, *et al.*, PRL**122**(2019)242002 Cont (B)	M. L. Du, *et al.*, 2102.07159 Cont+OPEP (IIB)
$P_c(4312)$	(4312,9.8)	$1/2^-$	(4299,9.4)	(4306,15)	4306	(4313,6)
$P_c(4380)$	(4380,205)	$3/2^-$	(4350,5)	(4374,14)	4371	(4376,12)
$P_c(4440)$	(4440,21)	$3/2^-$	(4415,15)	(4452,3.0)	4440 (input)	(4441,8)
$P_c(4457)$	(4457,6.4)	$1/2^-$	(4462,3.2)	(4453,23)	4457 (input)	(4461,10)
P_c	—	$1/2^-$	(4521,2.8)	(4520,22)	4523	(4525,18)
P_c	—	$3/2^-$	(4511,14)	(4519,14)	4517	(4520,24)
P_c	—	$5/2^-$	(4468,18)	(4519,0)	4500	(4500,16)

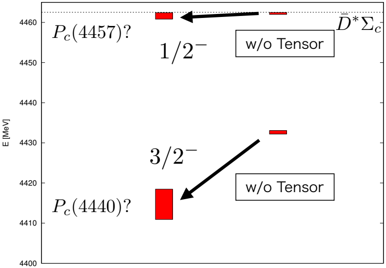
Role of Interactions in P_c



- ▷ Our J^P assignment
  $P_c(4440)$: $3/2^-$
  $P_c(4457)$: $1/2^-$

$\boldsymbol{E(1/2^-) > E(3/2^-)}$

Role of Interactions in P_c



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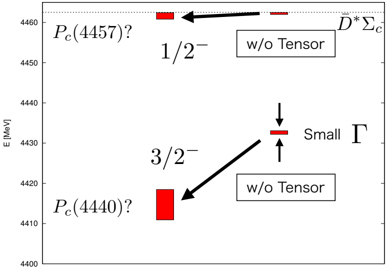
- with Tensor (original) vs without Tensor for V^π

$\Rightarrow$ Mass and Width are **reduced!**

$1/2^-$: $(E, \Gamma) = (4462, 1.6)$ [MeV] $\Rightarrow (4462, \mathbf{0.48})$ [MeV]

$3/2^-$: $(E, \Gamma) = (4415, 7.5)$ [MeV] $\Rightarrow \mathbf{(4433, 0.88)}$ [MeV]

Role of Interactions in P_c



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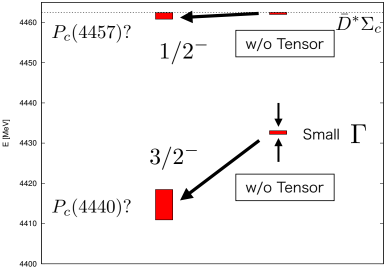
▷ V^{5q}: Major role to determine **Energy Levels**

Role of Interactions in P_c



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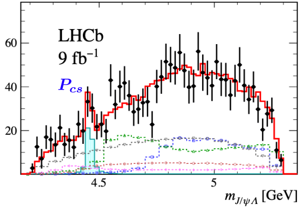
▷ V^{5q}: Major role to determine **Energy Levels**

▷ V^π: Major role to enhance **Decay Width** (Channel-coupling effect)

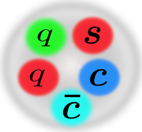
Strange partner $P_{cs}(ud\mathbf{s}c\bar{c})$ in 2020!

R.Aaij, *et al.* (LHCb collaboration), Sci. Bull. 66 (2021) 1278-1287

$\boxed{P^0_{cs} \text{ in } \Xi_b^- \to J/\psi\Lambda K^- \text{ decay}}$



$\boxed{ud\mathbf{s}c\bar{c} \text{ state ?}}$



- Mass (M) and Width (Γ),

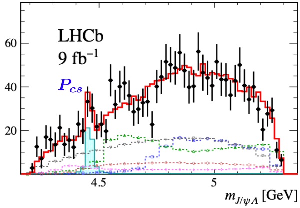
$$M = 4458.8 \pm 2.9^{+4.7}_{-1.1}\,\text{MeV}, \quad \Gamma = 17.3 \pm 6.5^{+8.0}_{-5.7}\,\text{MeV}$$

$\Rightarrow$ 19 MeV below **the $\Xi_c^0 \bar{D}^{*0}$ threshold**

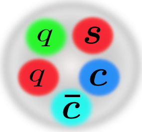
Strange partner $P_{cs}(ud\mathbf{s}c\bar{c})$ in 2020!

R.Aaij, *et al.* (LHCb collaboration), Sci. Bull. 66 (2021) 1278-1287

P^0_{cs} in $\Xi_b^- \to J/\psi \Lambda K^-$ decay



$ud\mathbf{s}c\bar{c}$ state ?



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$\Rightarrow$ 19 MeV below **the $\Xi_c^0 \bar{D}^{*0}$ threshold**

- Two-peak structure hypothesis with predicted $J^P = 1/2^-, 3/2^-$

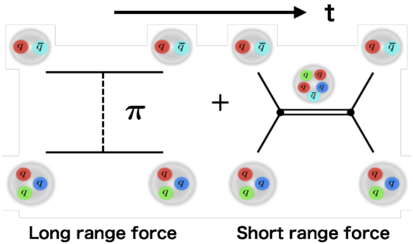
(B.Wang, *et al.*, PRD**101**(2020)034018)

$M_1 = 4454.9 \pm 2.7$ MeV, $\Gamma_1 = 7.5 \pm 9.7$ MeV

$M_2 = 4467.8 \pm 3.7$ MeV, $\Gamma_2 = 5.2 \pm 5.3$ MeV

Summary

- Hidden-charm pentaquarks P_c and P_{cs} reported by LHCb
- Hadronic molecule + Compact multiquark Model was applied
  - Long range force: π and K exchanges
  - Short range force: Coupling to Compact $5q$ states ($5q$ potential)
- By solving the Schrödinger equations, $Y_c\bar{D}$ resonances are obtained close to thresholds
  - Short-range force determining $\boldsymbol{E_{re}}$
  - Long-range force doing $\boldsymbol{\Gamma}$



Y. Yamaguchi, A. Giachino, A. Hosaka, E. Santopinto, S. Takeuchi, M. Takizawa, Phys. Rev. D **101** (2020) 091502(R)

Thank you for your kind attention.