Exotic baryons as a hadronic molecule in the heavy quark region

Yasuhiro Yamaguchi[1]

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Yasuhiro Yamaguchi and Elena Santopinto , arXiv:1606.08330 [hep-ph].

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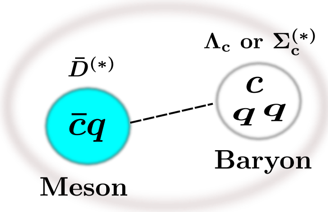
on Meson-Nucleon Physics and the Structure of the Nucleon
25-30 July 2016, Kyoto, Japan

Outline

Hidden-charm pentaquarks as a molecules

1. Introduction
   - Exotic hadron in the heavy quark region
   - Observed Pentaquarks
   - Heavy Quark Spin Symmetry and Coupled channels
2. Meson-Baryon molecules: $\bar{D}^{(*)}\Lambda_c^{(*)} - \bar{D}^{(*)}\Sigma_c^{(*)}$
3. Summary



2-body system

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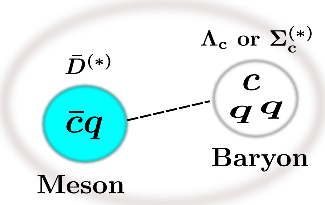
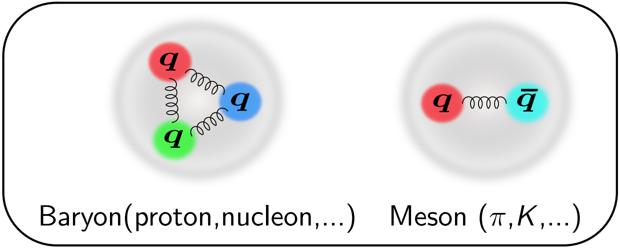


2-body system

Hadrons in the heavy quark region

- Hadron: Composite particle of **Quarks** and **Gluons**
- Constituent quark model (Baryon(qqq) and Meson $q\bar{q}$) has been successfully applied to the hadron spectra!



▷ Quark-quark potential S. Godfrey and N. Isgur, PRD**32**(1985)189

$$V(r) = -\frac{a}{r} + br + \ldots$$

Exotic hadrons in the heavy quark region

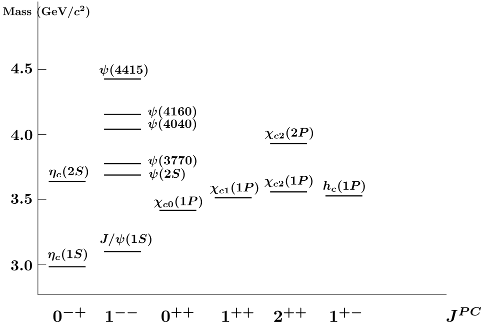
Introduction

- Observation of **the Exotic Hadron** in **the heavy quark $(\mathbf{c}, \mathbf{b})$** sectors!

Exotic hadrons in the heavy quark region
Introduction

- ▷ Observation of **the Exotic Hadron** in **the heavy quark (c, b)** sectors!

e.g. Spectra of Charmonia



Charmonium **$c\bar{c}$**

N. Brambilla, *et al.* Eur.Phys.J.C **71**(2011)1534
S. Godfrey and N. Isgur, PRD**32**(1985)189

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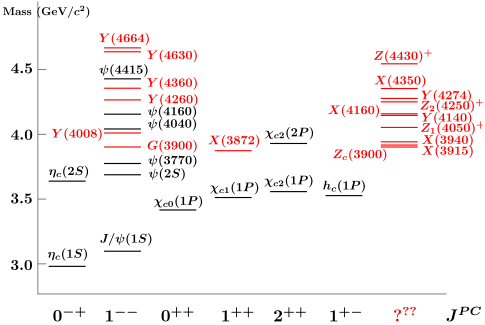
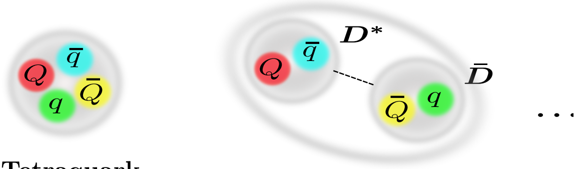


Charmonium **$c\bar{c}$**
and
Exotic hadrons ($\neq c\bar{c}$)
X, Y, Z

N. Brambilla, *et al.* Eur.Phys.J.C **71**(2011)1534
S. Godfrey and N. Isgur, PRD**32**(1985)189

- ▷ What is **the structure of exotic hadrons** ?
- ▷ Why are many exotic hadrons found in **the heavy quark region**?

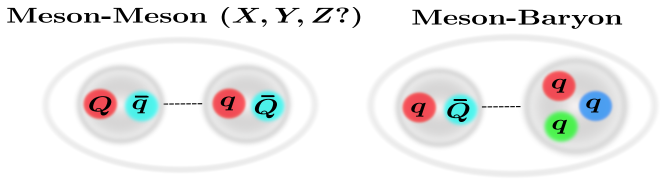
Exotic hadrons ⇒ Multiquark states?



Tetraquark (Compact)

Hadronic molecule

Hadronic molecules



X(3872), Z_b   **Λ_c^*, Pentaquark???**

- Loosely bound states (resonances) of hadrons

  → Appearing **near the thresholds** (M-M, M-B,...)

  ⇒ Analogous to **Atomic Nuclei**

- Molecules are formed by **the Hadron-Hadron interaction** dynamically.

Hadronic molecules

Meson-Meson ($X, Y, Z?$) — **Meson-Baryon**

X(3872), Z_b — **Λ_c^*, Pentaquark???**

▷ Theoretical researches

- $X(3872)$ as $D\bar{D}^*$,

  M. T. AlFiky, *et al.*,PLB**640**(2006)238,M. B. Voloshin, Prog.Part.Nucl.Phys.**61**(2008)455
- Z_b as $B\bar{B}^*$, J. R. Zhang, *et al.*, PLB**704**(2011)312,S.Ohkoda,*et al.*, PRD**86**(2012)014004
- $\Lambda(1405)$ as $\bar{K}N$, T. Hyodo and D. Jido, Prog. Part. Nucl. Phys. **67** (2012) 55
- Λ_c^* as DN, T.Mizutani, A.Ramos,PRC**74**(2006)065201,C. Garcia-Recio, *et al.*, PRD**79**(2009)054004

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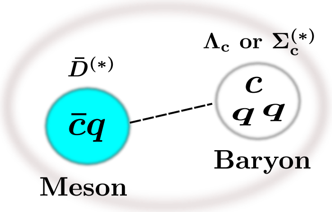


2-body system

Observation of two hidden-charm pentaquarks !!
Introduction

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

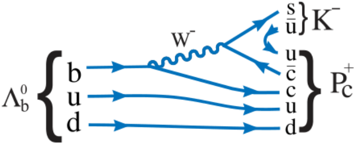
Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays

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

Observations of exotic structures in the $J/\psi p$ channel, which we refer to as charmonium-pentaquark states, in $\Lambda_b^0 \to J/\psi K^- p$ decays are presented. The data sample corresponds to an integrated luminosity of 3 fb^{-1} acquired with the LHCb detector from 7 and 8 TeV pp collisions. An amplitude analysis of the three-body final state reproduces the two-body mass and angular distributions. To obtain a satisfactory fit of the structures seen in the $J/\psi p$ mass spectrum, it is necessary to include two Breit-Wigner amplitudes that each describe a resonant state. The significance of each of these resonances is more than 9 standard deviations. One has a mass of ① $4380 \pm 8 \pm 29$ MeV and a width of $205 \pm 18 \pm 86$ MeV, while the second is narrower, with a mass of ② $4449.8 \pm 1.7 \pm 2.5$ MeV and a width of $39 \pm 5 \pm 19$ MeV. The preferred J^P assignments are of opposite parity, with one state having spin 3/2 and the other 5/2.

DOI: 10.1103/PhysRevLett.115.072001 PACS numbers: 14.40.Pq, 13.25.Gv

$\Lambda_b^0 \to K^- P_c^+$ decay



$c\bar{c}uud$
Pentaquark!

$J = 3/2, 5/2$

Observation of two hidden-charm pentaquarks !!

Introduction

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1. $M = 4380 \pm 8 \pm 29$ MeV, $\Gamma = 205 \pm 18 \pm 86$ MeV (Broad)
2. $M = 4449.8 \pm 1.7 \pm 2.5$ MeV, $\Gamma = 39 \pm 5 \pm 19$ MeV (Narrow)

- J^P Assignment: $3/2^-, 5/2^+$; $3/2^+, 5/2^-$; $5/2^+, 3/2^-$

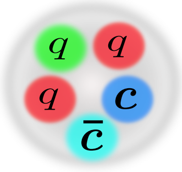
Theoretical discussions

- Compact pentaquark?
  - ▷ Quark model

    W.L.Wang *et al.*, PRC**84**(2011)015203

    G. Yang and J. Ping, (2015), arXiv:1511.09053.

    ...



Pentaquark (Compact)

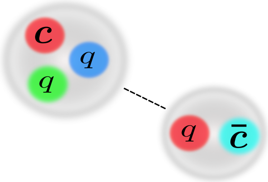
- Hadronic molecule?
  - ▷ SU(4) flavor symmetry

    J.-J.Wu *et al.*, PRL**105**(2010)232001

    C.W.Xiao *et al.*, PRD**88**(2013)056012

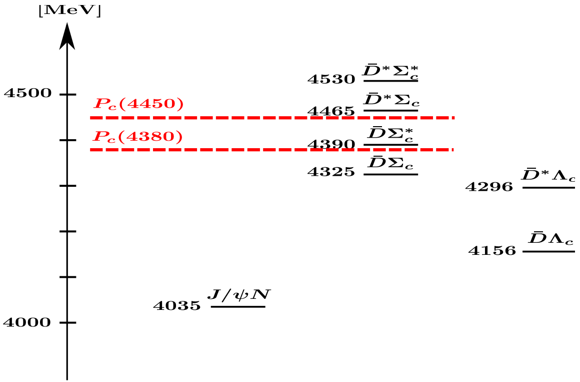
    T. Uchino,*et al.*, Eur.Phys.J.A**52**(2016)43

    ...



Hadronic molecule

1. Pentaquarks are close to **the meson-baryon thresholds**
   ⇒ **Hadronic molecules** appears near the thresholds!



2. **Heavy Quark Spin Symmetry**
   ⇒ SU(4) symmetry is broken in the charm quark sector.

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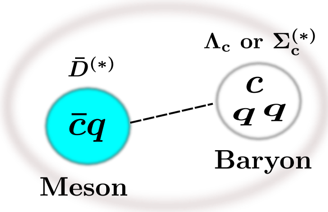


2-body system

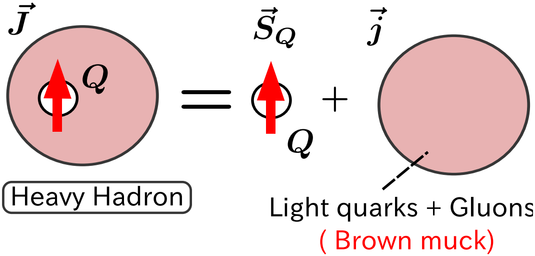
Heavy Quark Spin Symmetry (HQS)

N.Isgur,M.B.Wise,PLB**232**(1989)113

- **Suppression of Spin-spin force** in $m_Q \to \infty$.

$\Rightarrow$ Decomposition of **Heavy quark spin** and **Light components**

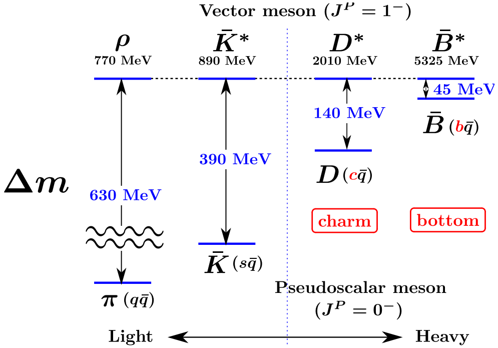
$$\vec{\mathbf{J}} = \vec{\mathbf{L}} + \vec{\mathbf{S}} = \vec{\mathbf{S}}_{\mathbf{Q}} + \vec{\mathbf{j}}$$



$\Rightarrow$ **Mass degeneracy** of hadrons with the different J

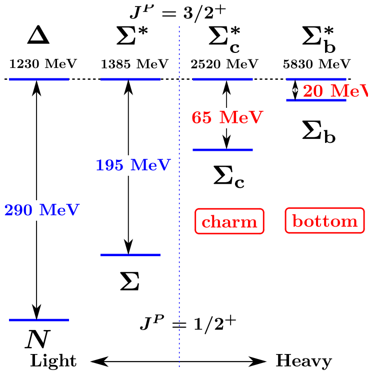
- Mass degeneracy of $\{D, D^*\}(Q\bar{q})$, $\{\eta_c, J/\psi\}(Q\bar{Q})$, $\{\Sigma_c, \Sigma_c^*\}(Qqq)$ (baryons)...

- Mass difference between vector and pseudoscalar mesons. ($Q\bar{q}$, $q = u, d$)



- ▷ Δm decreases when the quark mass increases.
- ▷ Mass degeneracy of heavy hadrons appears!

- Mass difference between $1/2^+$ and $3/2^+$ baryons. (Qqq, $q = u, d$)



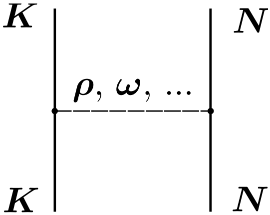
▷ Δm decreases when the quark mass increases.

▷ Mass degeneracy of heavy hadrons appears!

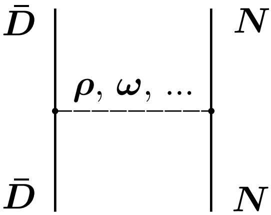
⇒ Small mass splitting leads to **Channel couplings!**

- Interaction between K (light meson) and N
  $\Rightarrow$ Short range force (ρ, ω exchanges...) dominates.

Strange (Light)



Charm (Heavy)



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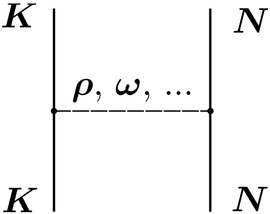
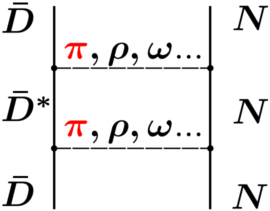
Strange (Light) (**KKπ** $\times$)



Charm (Heavy)

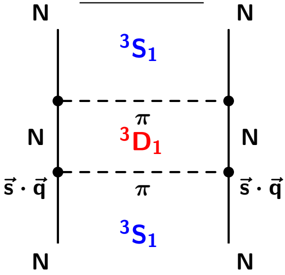


- In the heavy (c, b) sector, the Heavy Quark Spin Symmetry induces **the $\bar{D} - \bar{D}^*$ mixing**.
  $m_{K^*} - m_K \sim 400$ MeV $\Leftrightarrow$ $m_{D^*} - m_D \sim 140$ MeV
- Appearance of the **the one π exchange potential** .

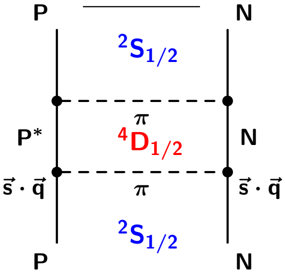
T.D.Cohen,P.M.Hohler,R.F.Lebed PRD**72**(2005)074010,S.Yasui,K.Sudoh, PRD**80**(2009)034008,
Y.Yamaguchi,S.Ohkoda,S.Yasui,A.Hosaka PRD**84**(2011)014032,...

- ▷ OPEP is important to bind atomic nuclei.
- ▷ **Tensor force** of the OPEP generates a strong attraction.

Deuteron



$P^{(*)} - N$



Tensor force $\Rightarrow$ $^3S_1 - {}^3D_1$

$PN(^2S_{1/2}) - P^*N(^4D_{1/2})$

π exchange potential (OPEP) and Coupled channel

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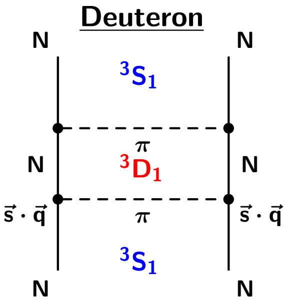
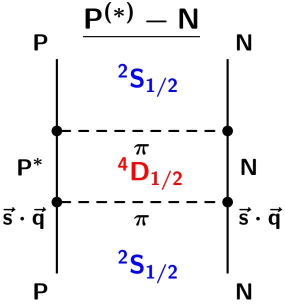
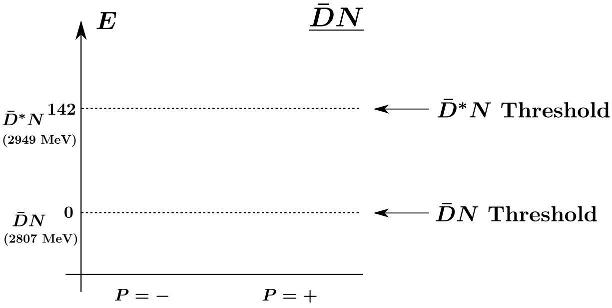




Tensor force $\Rightarrow$ $^3S_1 - {}^3D_1$ $\quad$ $PN(^2S_{1/2}) - P^*N(^4D_{1/2})$

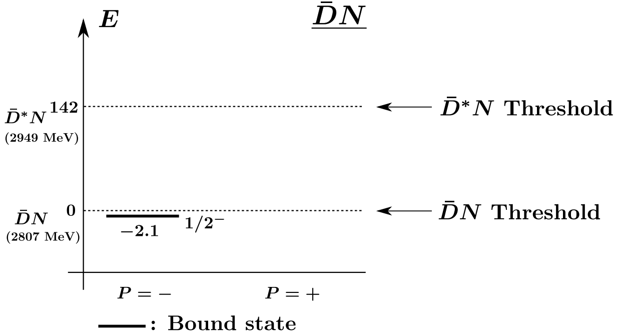
- HQS: mixing of $D - D^*$
- Tensor force: mixing of $S - D$ $(P - F)$



Unit: MeV

Y.Y., S.Ohkoda, S.Yasui and A.Hosaka, PRD**84** 014032 (2011) and PRD**85** 054003 (2012)

- One bound state



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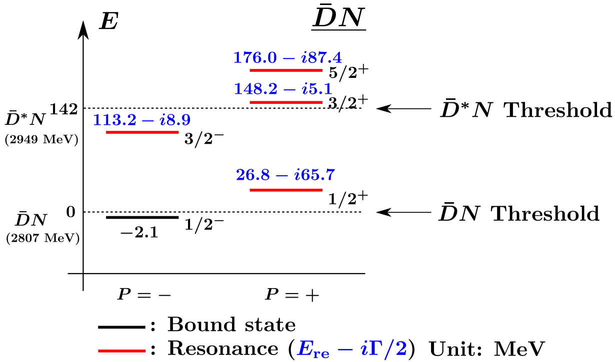
- One bound state, and resonances in charm



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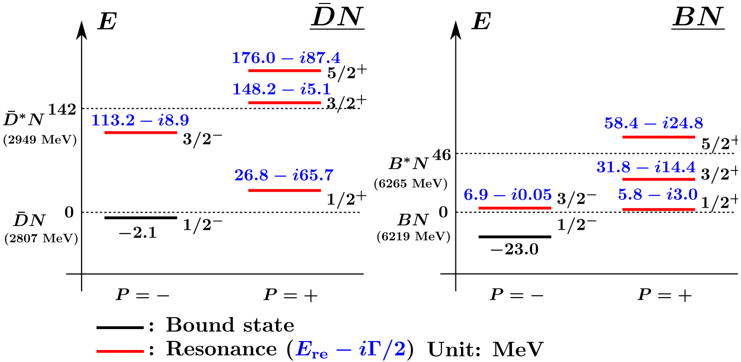
- One bound state, and resonances in charm and bottom sectors!



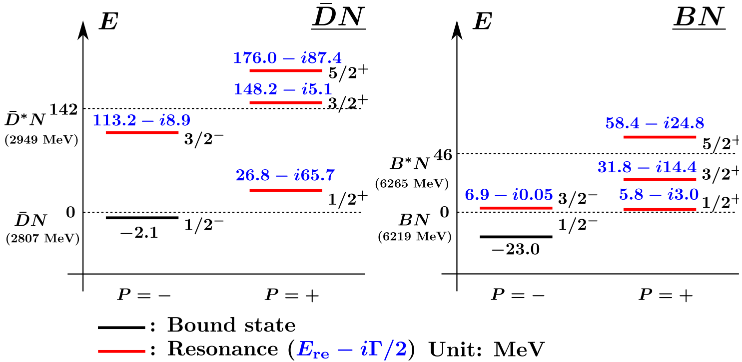
Y.Y., S.Ohkoda, S.Yasui and A.Hosaka, PRD**84** 014032 (2011) and PRD**85** 054003 (2012)

- Many states near the thresholds. ⇔ **No KN bound state**

Energy spectra of D̄ meson-Nucleon (D̄N) states

Introduction

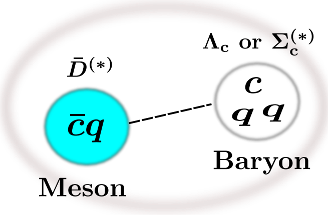
- One bound state, and resonances in charm and bottom sectors!



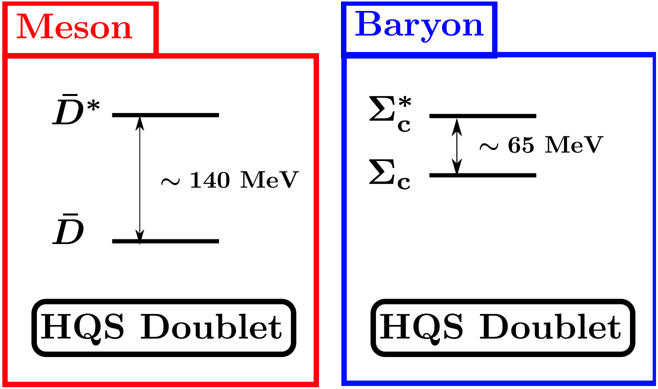
Y.Y., S.Ohkoda, S.Yasui and A.Hosaka, PRD**84** 014032 (2011) and PRD**85** 054003 (2012)

- Many states near the thresholds. ⇔ **No KN bound state**
- **The tensor force from the $\bar{\text{D}} - \bar{\text{D}}^*$ mixing** is important to produce a strong attraction!

Channel coupling of Hidden-charm meson-baryon state

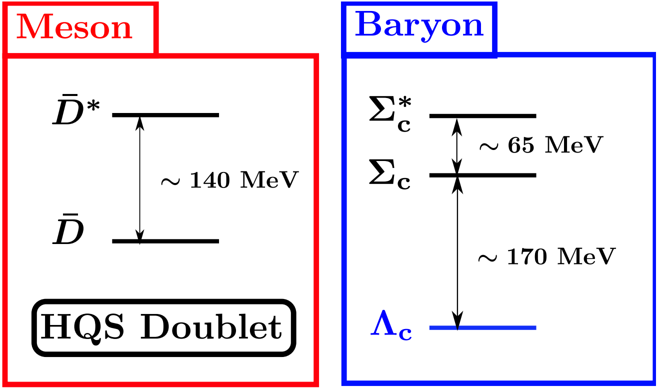


- $\bar{D} - \bar{D}^*$ and $\Sigma_c - \Sigma_c^*$ mixings



- Mass degeneracy of $\bar{D}\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$ and $\bar{D}^*\Sigma_c^*$

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

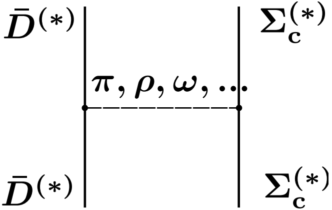


- Mass degeneracy of $\bar{D}\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$ and $\bar{D}^*\Sigma_c^*$
- **Λ_c (cqq)**: $\bar{D}^{(*)}\Lambda_c$ channel?

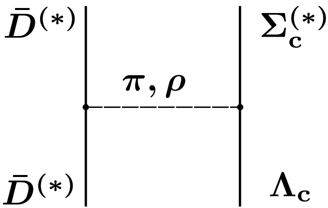
Coupled channels of the hidden-charm pentaquark
Introduction

- $\bar{D}^{(*)}\Lambda_c - \bar{D}^{(*)}\Sigma_c^{(*)}$ mixing (analogous to $\Lambda N - \Sigma N$)
  $m_{\Sigma_c} - m_{\Lambda_c} \sim 170$ MeV

$\bar{D}^{(*)}\Sigma_c^{(*)}$ coupling



$\bar{D}^{(*)}\Lambda_c^{(*)} - \bar{D}^{(*)}\Sigma_c^{(*)}$ coupling



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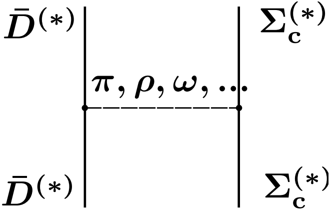
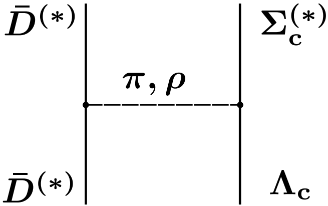


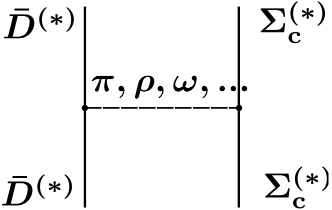
$\bar{\text{D}}^{(*)}\Lambda_c^{(*)} - \bar{\text{D}}^{(*)}\Sigma_c^{(*)}$ coupling



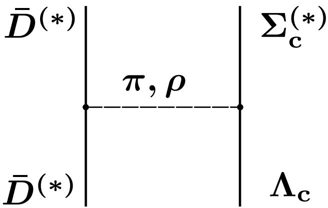
$\Rightarrow$ $\bar{D}\Lambda_c, \bar{D}^*\Lambda_c, \bar{D}\Sigma_c, \bar{D}\Sigma_c^*, \bar{D}^*\Sigma_c, \bar{D}^*\Sigma_c^*$ (**6 thresholds!**)

- $\bar{D}^{(*)}\Lambda_c - \bar{D}^{(*)}\Sigma_c^{(*)}$ mixing (analogous to $\Lambda N - \Sigma N$)
  $m_{\Sigma_c} - m_{\Lambda_c} \sim 170$ MeV

$\bar{D}^{(*)}\Sigma_c^{(*)}$ coupling



$\bar{D}^{(*)}\Lambda_c^{(*)} - \bar{D}^{(*)}\Sigma_c^{(*)}$ coupling



$\Rightarrow$ $\bar{D}\Lambda_c, \bar{D}^*\Lambda_c, \bar{D}\Sigma_c, \bar{D}\Sigma_c^*, \bar{D}^*\Sigma_c, \bar{D}^*\Sigma_c^*$ (**6 thresholds!**)

- Coupling to a state with $\ell \neq 0$ ($D-$wave,...)
  $\Rightarrow$ **Tensor force producing a strong attraction!**

Coupled-Channels

- Allowed channels (^{2S+1}L) for $J^P = 3/2^{\pm}, 5/2^{\pm}$

J^P	Channels
$3/2^-$	
$3/2^+$	
$5/2^-$	
$5/2^+$	

- $J^P = 3/2^{\pm}$:
- $J^P = 5/2^{\pm}$:

Coupled-Channels

- Allowed channels (^{2S+1}L) for $J^P = 3/2^\pm, 5/2^\pm$

J^P	Channels
$3/2^-$	$\bar{D}\Lambda_c(^2D)$, $\bar{D}^*\Lambda_c(^4S,^2D,^4D)$, $\bar{D}\Sigma_c(^2D)$, $\bar{D}\Sigma_c^*(^4S,^4D)$, $\bar{D}^*\Sigma_c(^4S,^2D,^4D)$, $\bar{D}^*\Sigma_c^*(^4S,^2D,^4D,^6D,^6G)$
$3/2^+$	
$5/2^-$	
$5/2^+$	

- $J^P = 3/2^\pm$: **15 channels!**
- $J^P = 5/2^\pm$:

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$3/2^+$	$\bar{D}\Lambda_c(^2P)$, $\bar{D}^*\Lambda_c(^2P,^4P,^4F)$, $\bar{D}\Sigma_c(^2P)$, $\bar{D}\Sigma_c^*(^4P,^4F)$, $\bar{D}^*\Sigma_c(^2P,^4P,^4F)$, $\bar{D}^*\Sigma_c^*(^2P,^4P,^6P,^4F,^6F)$
$5/2^-$	
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$5/2^+$	

- $J^P = 3/2^\pm$: **15 channels!**
- $J^P = 5/2^\pm$: **16 channels!**

Coupled-Channels

- Allowed channels (^{2S+1}L) for $J^P = 3/2^{\pm}, 5/2^{\pm}$

J^P	Channels
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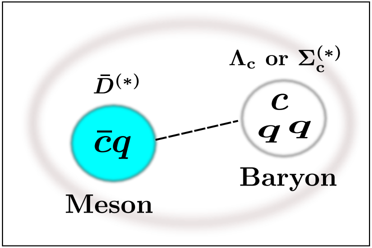
Main Subject: Pentaquarks

- Hadronic molecules formed by **hidden-charm meson-baryon**.



- Bound and resonant states of $\bar{D}^{(*)}\Lambda_c - \bar{D}^{(*)}\Sigma_c^{(*)}$

▷ Coupling to $\mathbf{\bar{D}^{(*)}\Lambda_c}$ and $\mathbf{\bar{D}^{(*)}\Sigma_c^{(*)}}$
▷ Coupling to the state with $\ell \neq \mathbf{0}$
▷ Negative and Positive parity states $\mathbf{(P = \pm)}$

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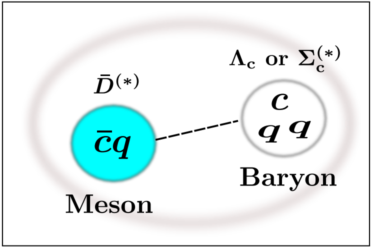

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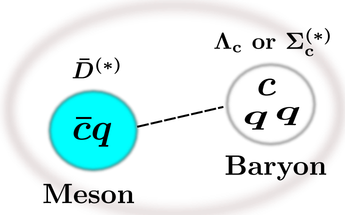
The full-coupled channel analysis of $\bar{D}^{(*)}\Lambda_c - \bar{D}^{(*)}\Sigma_c^{(*)}$ has never performed so far !

Results of $\bar{\mathrm{D}}^{(*)}\mathrm{B}$ states (2-body)



$\bar{D}^{(*)}\Lambda_c - \bar{D}^{(*)}\Sigma_c^{(*)}$

Exotic states ($c\bar{c}qqq$)

<u>Bound state and Resonance</u>

- We solve the coupled-channel Schrödinger equations with $J^P = 3/2^{\pm}, 5/2^{\pm}$ and isospin $I = 1/2$.
- Interaction: $\pi\rho\omega\sigma$ exchange potentials

$\bar{\mathrm{D}}^{(*)}$B Interaction: Meson exchange potential

- Effective Lagrangian with heavy quark symmetry

  R.Casalbuoni *et al.*, Phys.Rept.**281** (1997)145, T.M.Yan *et al.*, PRD**46**(1992)1148, Y.-R.Liu and M.Oka, PRD**85**(2012)014015

Meson: $\mathcal{L}_{\pi HH} = g_\pi \mathrm{Tr}\left[H_b \gamma_\mu \gamma_5 A^\mu_{ba} \bar{H}_a\right]$

Baryon:

$$\mathcal{L}_{\pi BB} = \frac{3}{2} g_1 i v_\kappa \varepsilon^{\mu\nu\lambda\kappa} \mathrm{tr}\left[\bar{S}_\mu A_\nu S_\lambda\right] + g_4 \mathrm{tr}\left[\bar{S}^\mu A_\mu \Lambda_\mathrm{c}\right]$$

Heavy meson and baryon fields

$$H_a = \frac{1+\not{v}}{2}\left[\mathbf{P}^*_{\mathbf{a}\,\boldsymbol{\mu}} \gamma^\mu - \mathbf{P}_\mathbf{a} \gamma^5\right] \quad (1^- \text{ and } 0^-)$$

$$S_\mu = \boldsymbol{\Sigma}^*_{\boldsymbol{\mu}} + \frac{\delta}{\sqrt{3}} (\gamma_\mu + v_\mu) \gamma_5 \boldsymbol{\Sigma} \quad (3/2^+ \text{ and } 1/2^+)$$

- $\bar{D} - \bar{D}^*$ and $\Sigma_\mathrm{c} - \Sigma^*_\mathrm{c}$ mixings

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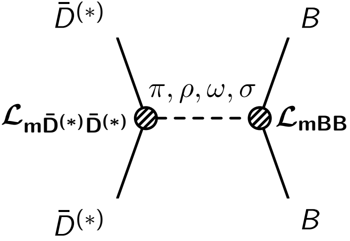

Fig: Meson exchange diagram

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

B: Λ_c, Σ_c or Σ_c^*

m: π, ρ, ω or σ

$$V^{\pi}_{\bar{D}^{(*)}B-\bar{D}^{(*)}B} = G\left[\vec{\mathcal{O}}_1 \cdot \vec{\mathcal{O}}_2 C(r) + S_{\mathcal{O}_1\mathcal{O}_2} T(r)\right]$$

$C(r)$: Central force, $T(r)$: Tensor force

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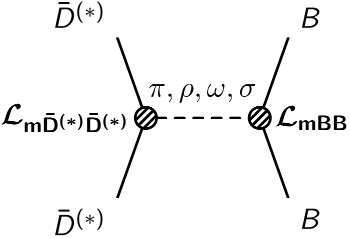

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- Form factor with common cutoff $\Lambda \leftarrow$ Free parameter

$$F(\Lambda, \vec{q}\,) = \frac{\Lambda^2 - m_\alpha^2}{\Lambda^2 + |\vec{q}\,|^2}$$ (fixed by the observed mass of P_c)

Determination of cutoff Λ by observed $\mathbf{P_c^+}$

- Narrow resonance $P_c^+(4450)$ (12σ)

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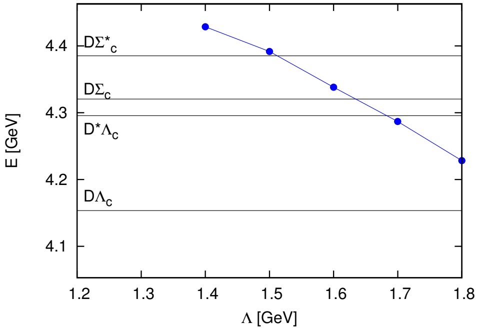
$\rightarrow$ In our results, only **the $J^P = 5/2^-$ state** appears above the $\bar{D}\Sigma_c^*$ threshold!



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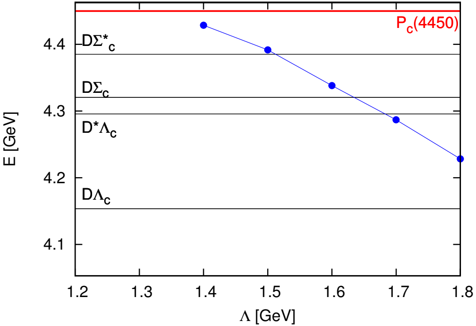

$P_c^+(4450)$: $M = 4449.8 \pm 1.7 \pm 2.5$ MeV
$J^P = 5/2^-$ state: $M = 4428.6$ MeV in **$\Lambda = 1400$ MeV**

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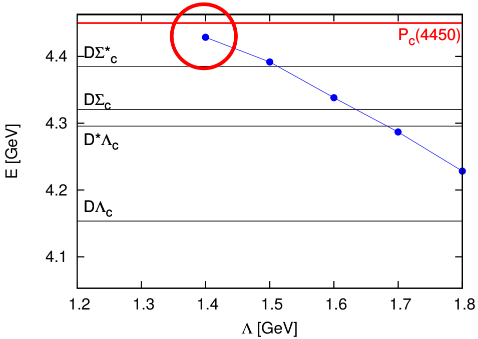

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Cutoff $\Lambda = 1400$ MeV, J^P of $P_c^+(4450) = 5/2^-$

What is J^P of $P_c^+(4380)$?

- $P_c^+(4450)$: $J^P = 5/2^- \Rightarrow J^P$ of $P_c^+(4380)$ is **$3/2^+$!**

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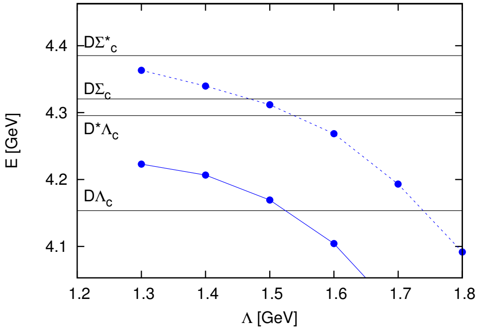

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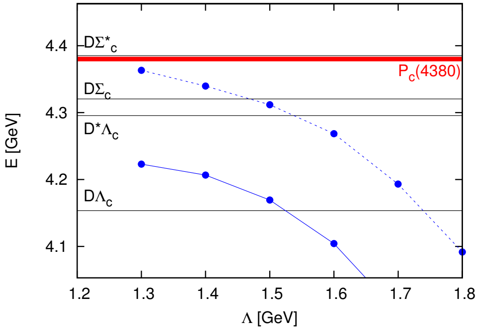

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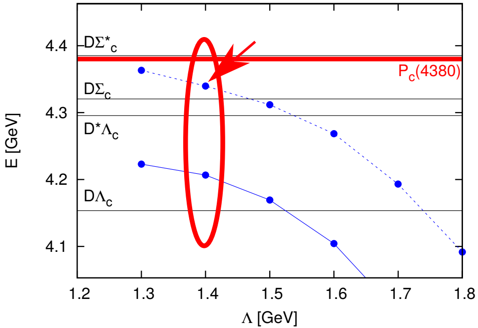

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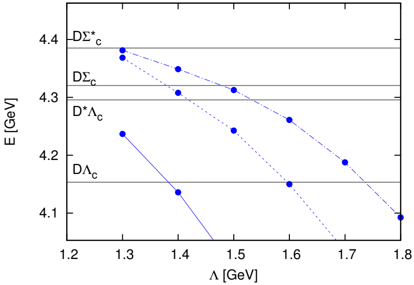
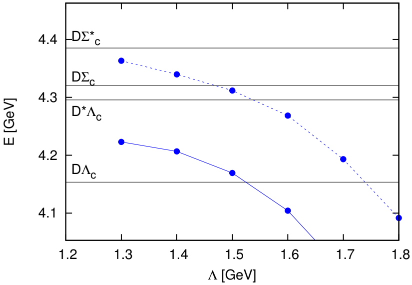
Cutoff $\Lambda = 1400$ MeV

Other predicted states

(i) $J^P = 3/2^-$



(ii) $J^P = 3/2^+$



- In $\Lambda = 1400$ MeV,

  $J^P = 3/2^-$: 4136.0 MeV, 4307.9 MeV and 4348.7 MeV

  $J^P = 3/2^+$: 4206.7 MeV

New states are predicted!

(can be decayed to $J/\psi p$, $\bar{D}^{(*)}\Lambda_c$,...)

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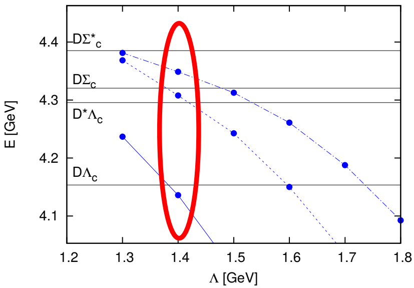

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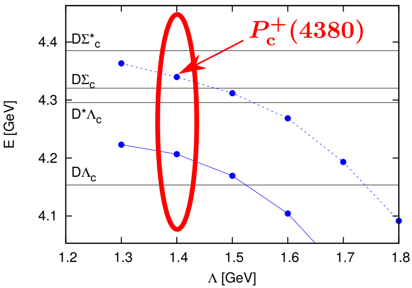

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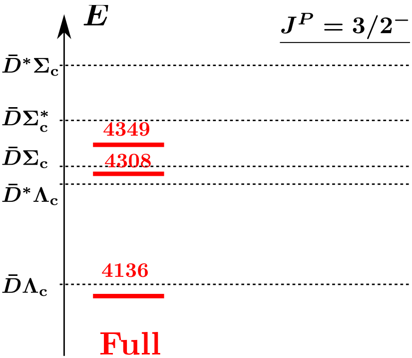
Channel-coupling effects

- Obtained mass with **Full channel coupling**, **without $\bar{D}^{(*)}\Lambda_c$** and **without $\ell > 0$ ($\ell > 1$)**



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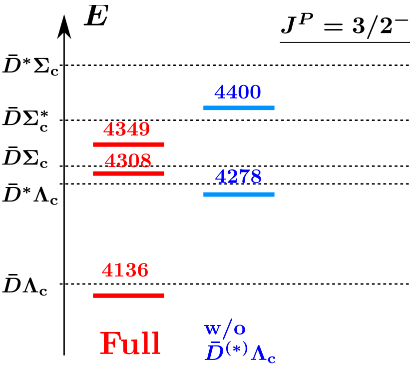

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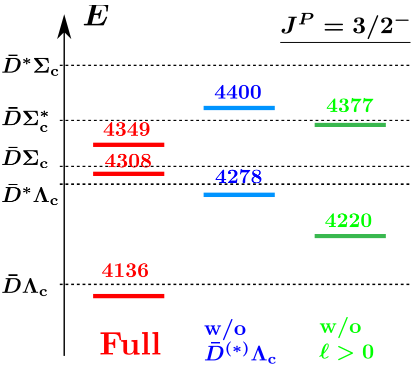

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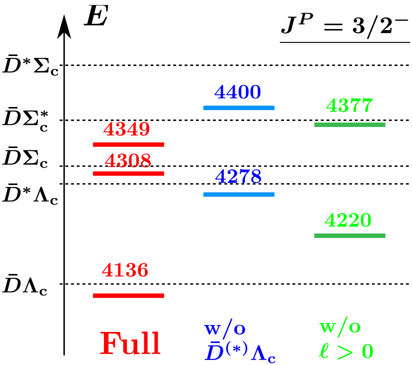

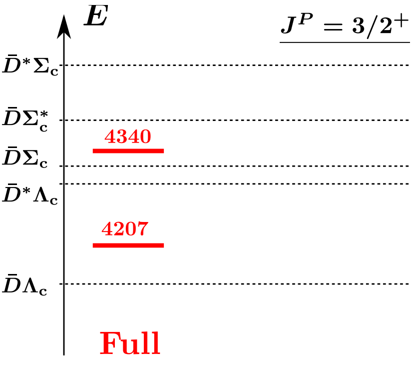

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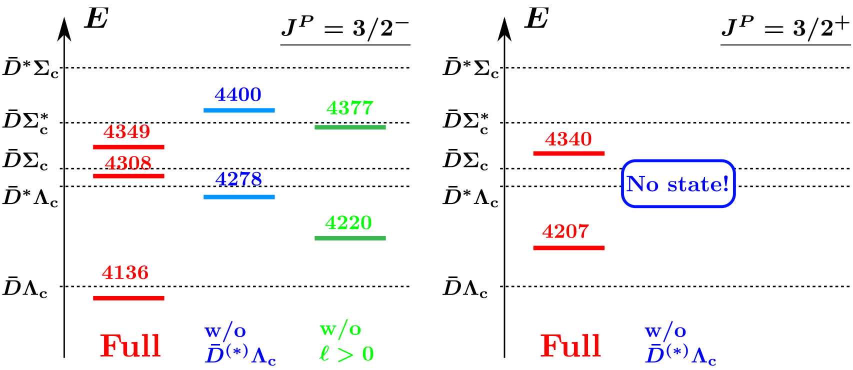

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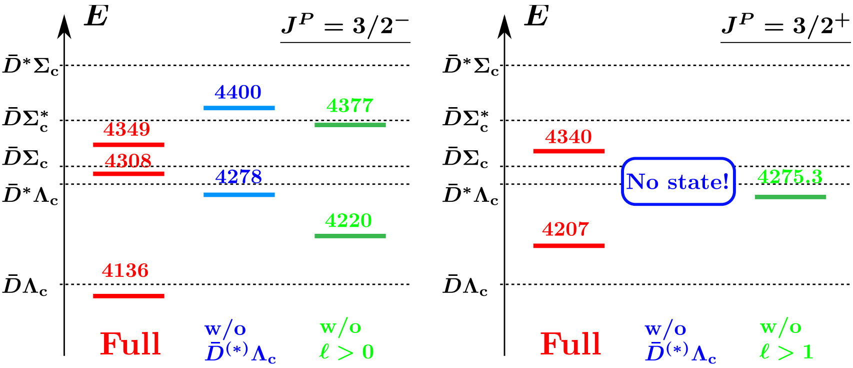

- **$\bar{D}^{(*)}\Lambda_c$ and $\ell > 0$ ($\ell > 1$)** components are not negligible.

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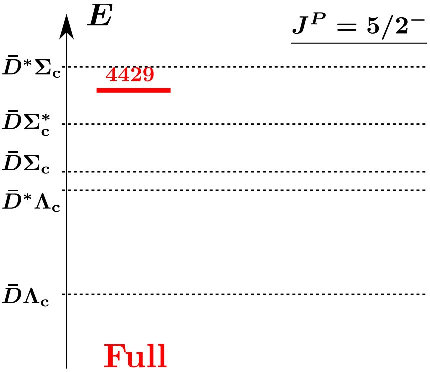

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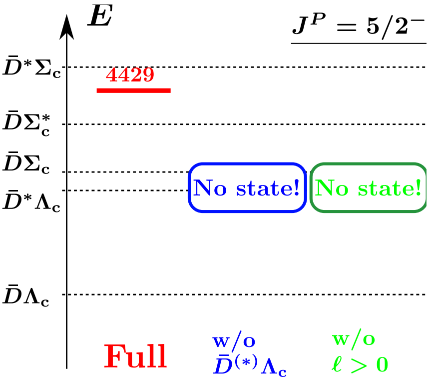

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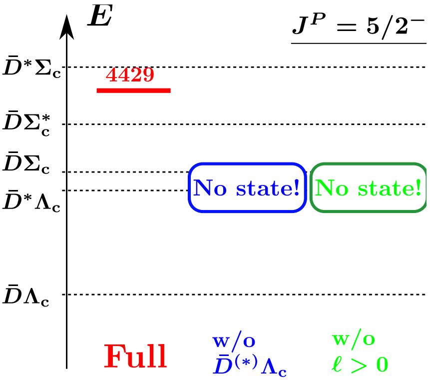


- **$\bar{D}^{(*)}\Lambda_c$ and $\ell > 0$** components are important!

Summary

Subject: Hidden-charm pentaquarks as a meson-baryon molecule

⇓

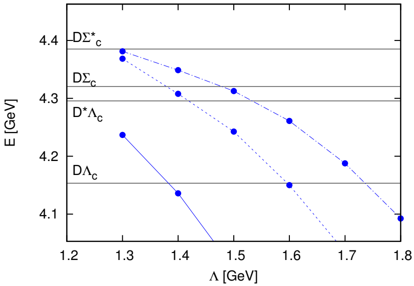
- Coupled-channel analysis is peformed, taking into acoount...
  - ▷ Meson-baryon components $\bar{\mathbf{D}}^{(*)}\mathbf{\Lambda_c} - \bar{\mathbf{D}}^{(*)}\mathbf{\Sigma_c^{(*)}}$
  - ▷ Couplings to states with $\ell > 0$ ($S - D - G$, $P - F - H$)
    $\Rightarrow$ **Tensor force**
  - ▷ Negative and positive parity states with $J^P = 3/2^{\pm}, 5/2^{\pm}$
- The meson exchange potential respecting to **the heavy quark spin symmetry** is employed.
- The J^P assignment of $P_c^+(4380)$ and $P_c^+(4450)$ is **$3/2^+$** and **$5/2^-$**, respectively.
- New states are predicted in $J^P = 3/2^{\pm}$.

Outlook

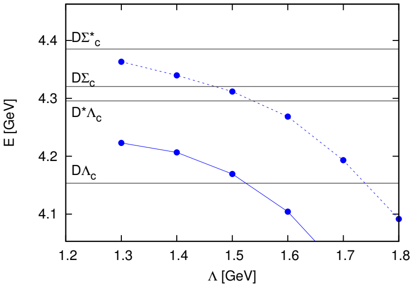
- Coupling to $J/\psi p$, cutoff Λ, $1/m_Q$ correction,...

Back up

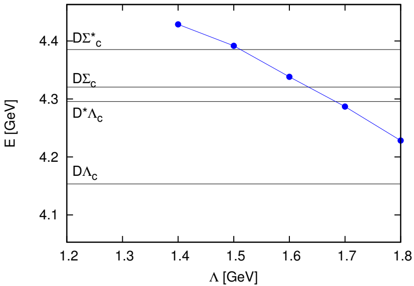
(i) $J^P = 3/2^-$



(ii) $J^P = 3/2^+$



(iii) $J^P = 5/2^-$



(iv) $J^P = 5/2^+$

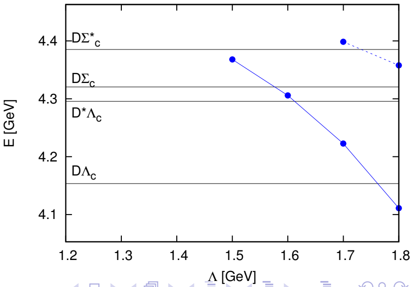


Table : Obtained masses in $\Lambda = 1400$ MeV.

J^P	$E = E_{\rm re} - i\Gamma/2$ [MeV]
$3/2^-$	4136.0, $4307.9 - i18.8$, $4348.7 - i21.1$
$3/2^+$	$4206.7 - i41.2$, $4339.7 - i26.8$
$5/2^-$	$4428.6 - i89.1$

Table : Obtained masses with full channel coupling (Full), without $\bar{D}^{(*)}\Lambda_c$ (w/o $\bar{D}^{(*)}\Lambda_c$) and without large orbital angular momentum ℓ (w/o $\ell > 0$ or w/o $\ell > 1$) in $\Lambda = 1400$ MeV.

J^P	Channels	Mass [MeV]
$3/2^-$	Full	4136.0, 4307.9, 4348.7
	w/o $\bar{D}^{(*)}\Lambda_c$	4278.4, 4400.4
	w/o $\ell > 0$	4220.4, 4376.6
$3/2^+$	Full	4206.7, 4339.7
	w/o $\bar{D}^{(*)}\Lambda_c$	—
	w/o $\ell > 1$	4275.3
$5/2^-$	Full	4428.6
	w/o $\bar{D}^{(*)}\Lambda_c$	—
	w/o $\ell > 0$	—

Table : Comparison of the lowest mass of hidden-charm meson-baryon molecules with $I(J^P) = 1/2(3/2^-)$ by this work with the early works. The obtained masses are shown in the second column in the unit of MeV. The value of this work is in $\Lambda = 1400$ MeV. The third column gives the channels which are considered in those works.

Ref.	Mass [MeV]	Channels
This work	4136.0	$\bar{D}\Lambda_c$, $\bar{D}^*\Lambda_c$, $\bar{D}\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$
PRL**105**(2010)232001	4415	$\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ with only S-wave
PRC**84**(2010)015202	4454	$\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ with only S-wave
PRD88(2013)056012	4334.5	$J/\psi N$, $\bar{D}^*\Lambda_c$, $\bar{D}^*\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c^*$ with only S-wave