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Exploring two-body strong decay properties for possible single charm molecular pentaquarks with strangeness |S| = 1,2

arXiv:2603.24998

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2026.3.30

第五届强子与重味物理理论与实验联合研讨会@石家庄

Outline

I. Background and motivation: exotic states; new Ω_c states and different explanations to them;

II. Framework: from mass spectrum to decay properties;

III. Numerical results: molecular candidates and decay widths;

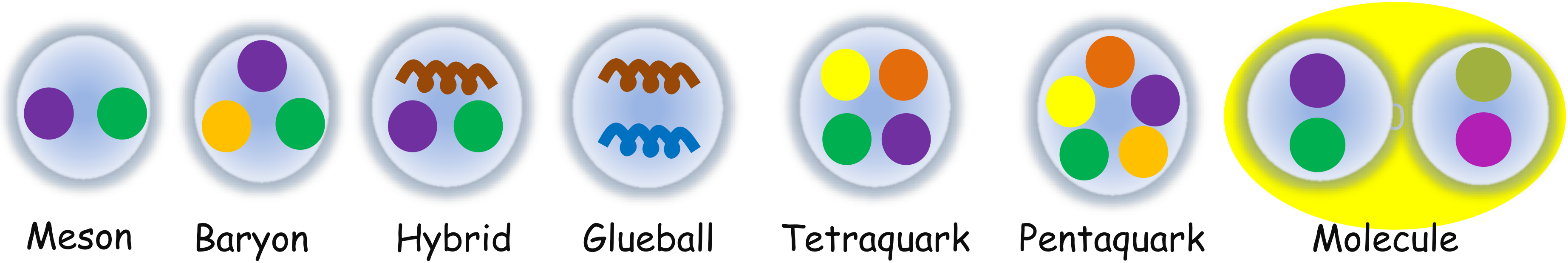
IV. Summary

I. Background: exotic states

- Different with traditional mesons and baryons but allowed by QCD.
- First proposed by Gell-man and Zweig in 1964; Phys. Lett. 8, 214-215 (1964).
- Since 2003, a lot of candidates were reported.

Phys. Rept. 639, 1-121(2016). Rev. Mod. Phys. 90, 015004(2018). Prog. Part. Nucl. Phys. 107, 237-320 (2019). Phys. Rept. 1019, 1-149 (2023). Rept. Prog. Phys. 86,026201 (2023). Rept. Prog. Phys.80, 076201 (2017).

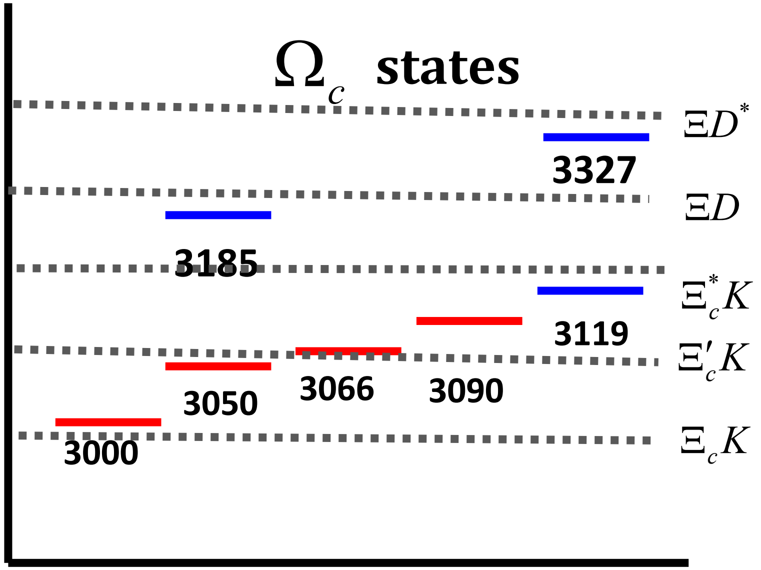
- Different theoretical explanations to them, like compact multiquarks, hybrids, glueballs, and hadronic molecules.



I. Background: new Ω_c states and different explanations

Observations

- LHCb@2017, reported five Ω_c states
  Phys. Rev. Lett. 118, no.18, 182001 (2017).
- Belle@2017, confirmed lower four states
  Phys. Rev. D 97, no.5, 051102 (2018).
- LHCb@2023, confirmed five states and observed another two $\Omega_c(3185)$ and $\Omega_c(3327)$
  Phys. Rev. Lett. 131, no.13, 131902 (2023).



I. Background: new Ω_c states and different explanations

- Baryons: excited Ω_c baryons.

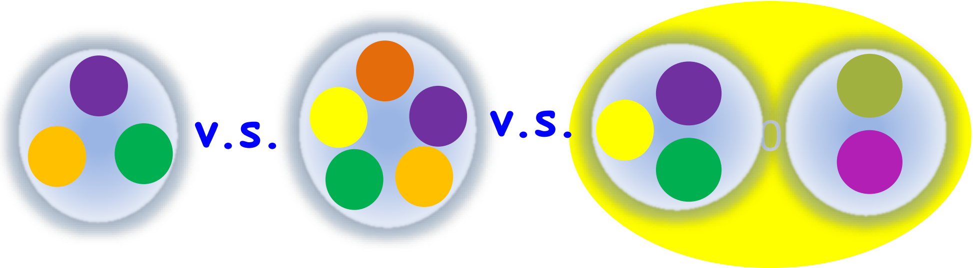
Phys. Rev. D110, 056052 (2024). Phys. Rev. D 109, no.3, 036032 (2024). Phys. Rev. D 95, 094008 (2017). Phys. Rev. D 95, 114012 (2017). Phys. Rev. D 95, 116010 (2017).Phys. Rev. D 96, 014024 (2017). Phys. Rev. Lett.119, 042001 (2017). Eur. Phys. J. C77, 325 (2017). Phys. Rev. D 95, 114024 (2017). Phys. Rev. D 107, 074041(2023)...

- Compact pentaquarks: $\Omega_c(3066)$, $\Omega_c(3090)$, and $\Omega_c(3119)$

Phys. Rev. D 96 no.3, 034012 (2017). Phys. Rev. D 97 no.3, 034023 (2018). Phys. Rev. D 108 no.9,094045 (2023). Eur. Phys. J. A54, 64 (2018)…

- Meson-baryon molecules: $\Omega_c(3050)$, $\Omega_c(3090)$, $\Omega_c(3119)$

Eur. Phys. J. A 54, 64 (2018). Phys. Rev. D 97, 094035 (2018). Eur. Phys. J. C 78, 407 (2018). Phys. Rev. D 97, 036016 (2018). Phys. Rev. D 97, 094013 (2018). Phys. Rev. D 105, 094036 (2022)…



I. Motivation: why decays?

Limitations of the mass spectrum

- The mass of the molecular state is consistent with that of the charmed baryon.
- **Difficult to distinguish** them based solely on the mass spectrum.

Advantages of decay properties

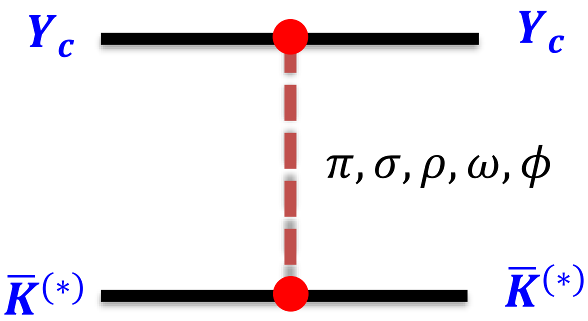
- Decay width and decay branching ratios are **highly sensitive to the wave functions**.
- Different internal structures exhibit **significant differences** in decay behaviors.

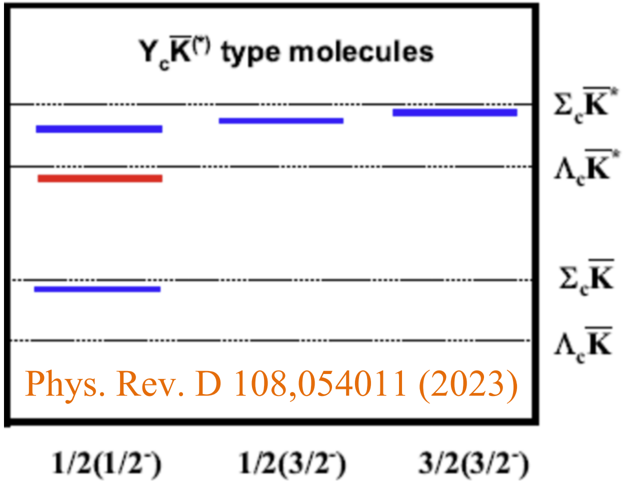
Phys. Rev. D 97, 094013 (2018). Phys. Rev. D 97, 036016 (2018). Phys. Rev. D 97, 034027 (2018). Phys. Rev. D 96, 094021 (2017). Phys. Rev. D 105, 094006 (2022)

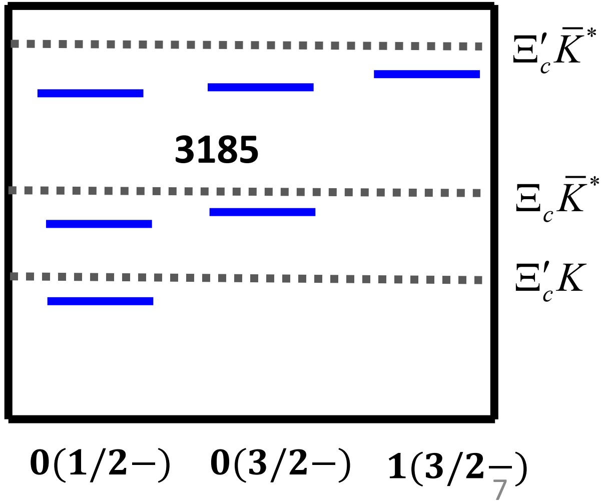
II. Framework: from mass spectrum to decay properties

Mass spectrum for possible $Y_c\bar{K}^{(*)}$ ($Y_c = \Lambda_c, \Sigma_c, \Xi_c^{(\prime)}$)

Study the interaction between charmed baryons and strange mesons using the one-boson-exchange model to search for possible candidates for hadronic molecular states.

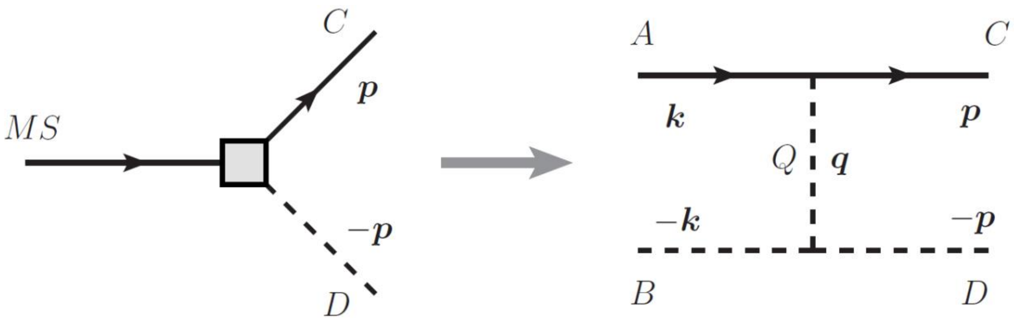






II. Framework: from mass spectrum to decay properties

Study their two-body strong decay properties using the effective Lagrangian method.



末态相对动量

$$|\vec{p}| = \frac{\lambda^{1/2}(m_{MS}^2, m_{f1}^2, m_{f2}^2)}{2m_{MS}}$$

其中 $\lambda(x,y,z) = [x-(y+z)^2][x-(y-z)^2]$ 为卡伦函数

高斯型形式因子

$$F(m,q,\Lambda) = \frac{\Lambda^4}{(m^2-q^2)^2+\Lambda^4}$$

用于正规化高动量行为，截止参数取 $\Lambda \approx 1.00 \text{ GeV}$

微分衰变宽度

$$d\Gamma = \frac{1}{2J+1}\frac{|\vec{p}|}{32\pi^2 m_{MS}^2}|\mathcal{M}|^2 d\Omega$$

J 为分子态自旋，m_{MS} 为其质量

Phys. Rev.D109 no.9, 094049(2024).

转换矩阵元 (Transition Matrix Element)

$$\langle f_1 f_2|V_{eff}|i\rangle = \sum_n \int \frac{d^3k}{(2\pi)^3}\psi_n(\vec{k})\frac{\mathcal{M}(A_n+B_n\to f_1+f_2)}{\sqrt{2E_{A_n}2E_{B_n}2E_{f_1}2E_{f_2}}}$$

有效拉格朗日量（顶点1）

为了计算散射振幅，我们采用符合SU(3)味对称性的有效拉格朗日量来描述强子间的相互作用。以下是涉及赝标介子(P)、矢量介子(V)和重子(B)的关键相互作用顶点：

Eur. Phys. J. C 82 no.5, 497 (2022).

赝标介子-赝标介子-矢量介子 (PPV)

$$\mathcal{L}_{PPV} = ig_{PPV}(P\partial_\mu P - \partial_\mu PP)V^\mu$$

矢量介子-矢量介子-赝标介子 (VVP)

$$\mathcal{L}_{VVP} = \frac{g_{VVP}}{m_V}\epsilon_{\mu\nu\alpha\beta}\partial^\mu V^\nu \partial^\alpha V^\beta P$$

三矢量介子耦合 (VVV)

$$\mathcal{L}_{VVV} = ig_{VVV}\langle V_\mu[V_\nu, \partial^\mu V^\nu]\rangle$$

重子-重子-赝标介子 (BBP)

$$\mathcal{L}_{BBP} = \frac{g_{BBP}}{m_P}\bar{B}\gamma^\mu\gamma_5\partial_\mu PB$$

参数说明

P, V, B: 赝标介子、矢量介子和重子场

g: 相应的强耦合常数

m_P, m_V: 参与顶点的具体介子质量

ε_μναβ: 列维-奇维塔张量

注意: 公式中的质量 m 使用物理质量而非 SU(3) 极限质量，以包含 SU(4) 味对称性破缺的唯象修正。

有效拉格朗日量（顶点2）与衰变宽度

继续展示涉及重子(B)、矢量介子(V)、赝标介子(P)和十重态重子(D)的相互作用顶点，以及二体强衰变的微分宽度计算公式：

重子-重子-矢量介子 (BBV)

$$\mathcal{L}_{BBV} = -g_{BBV}\bar{B}(\gamma^\mu - \frac{\kappa}{2m_B}\sigma^{\mu\nu}\partial_\nu)V_\mu B$$

重子-十重态重子-赝标介子 (BDP)

$$\mathcal{L}_{BDP} = \frac{g_{BDP}}{m_P}(\bar{B}\partial_\mu P D^\mu + \bar{D}_\mu \partial^\mu P B)$$

重子-十重态重子-矢量介子 (BDV)

$$\mathcal{L}_{BDV} = i\frac{g_{BDV}}{m_V}[\bar{B}\gamma_\mu\gamma_5 D_\nu F^{\mu\nu} + \bar{D}_\mu\gamma^\nu\gamma_5 B F^{\mu\nu}]$$

二体强衰变微分宽度

$$d\Gamma = \frac{1}{2J+1}\frac{|\vec{p}|}{32\pi^2 m_{MS}^2}|\mathcal{M}|^2 d\Omega$$

参数说明

D: 自旋3/2的十重态重子场

$F^{\mu\nu}$: 场强张量 $\partial^\mu V^\nu - \partial^\nu V^\mu$

κ: 磁矩型耦合常数

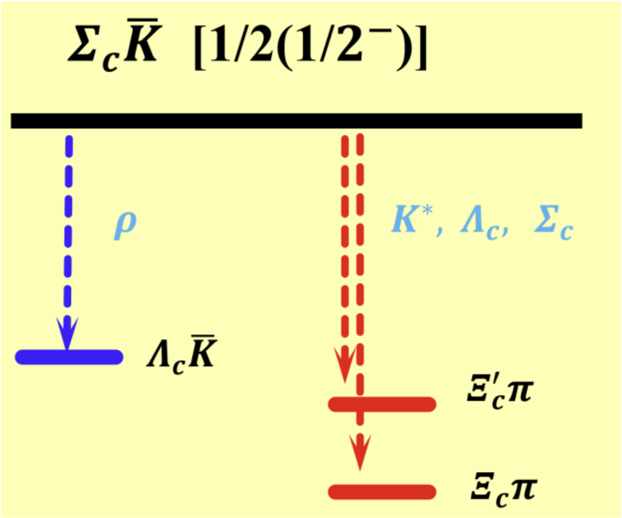
J, m_{MS}: 分子态的总自旋和质量

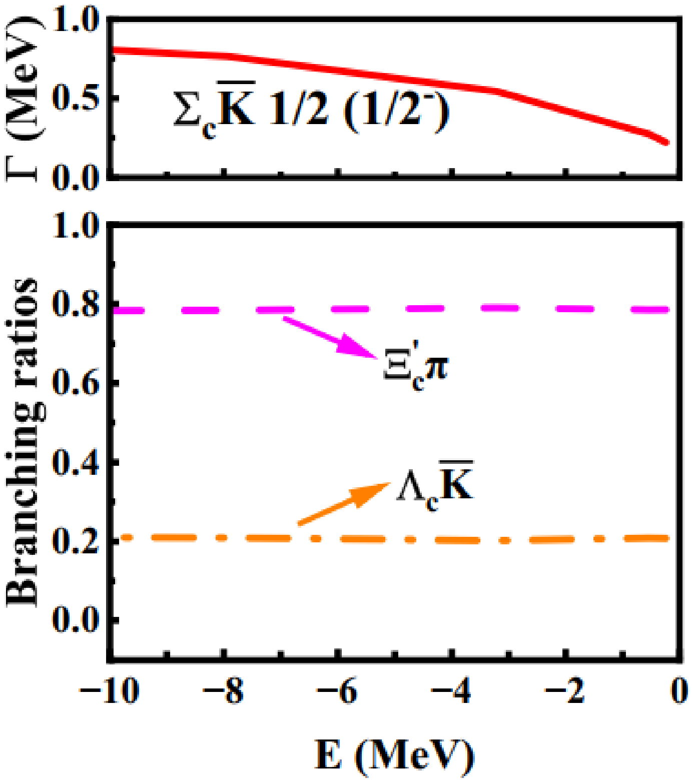
$|\vec{p}|$: 末态粒子在质心系的动量

$\mathcal{M}$: 散射振幅（包含形状因子）

说明: 有效拉格朗日量中的导数作用于相应的场，产生动量依赖的顶点因子。微分散射截面的积分给出了总衰变宽度。

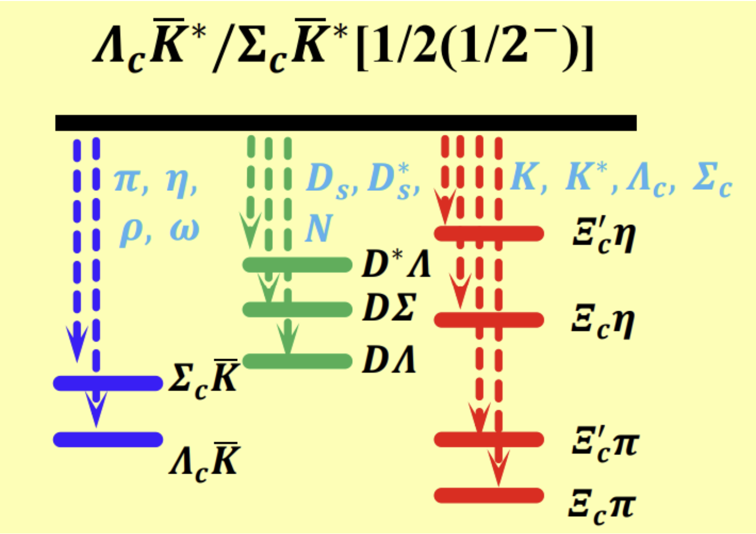
III. Numerical results

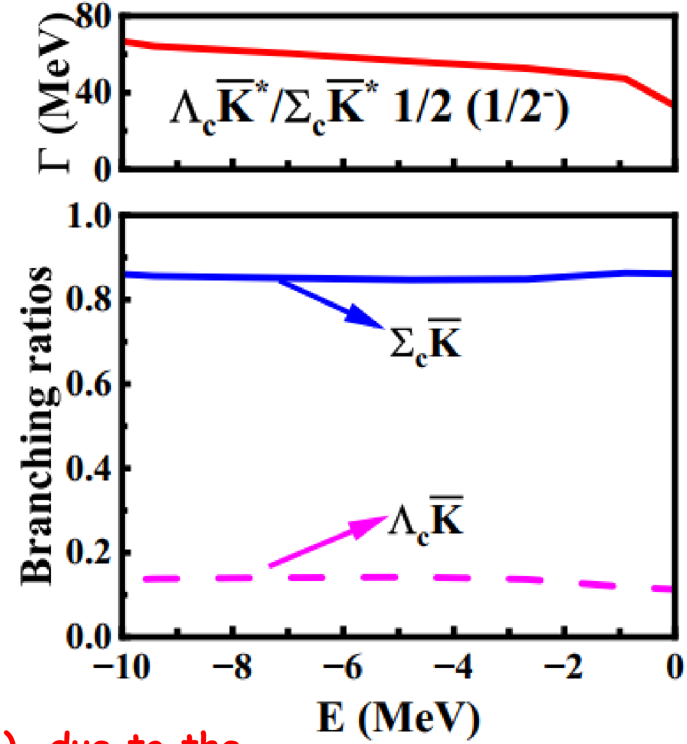




Total width Γ: less than 1 MeV.

Dominant decay channel: Ξ'c π (78%), larger phase space; Λc K̄ (20%).

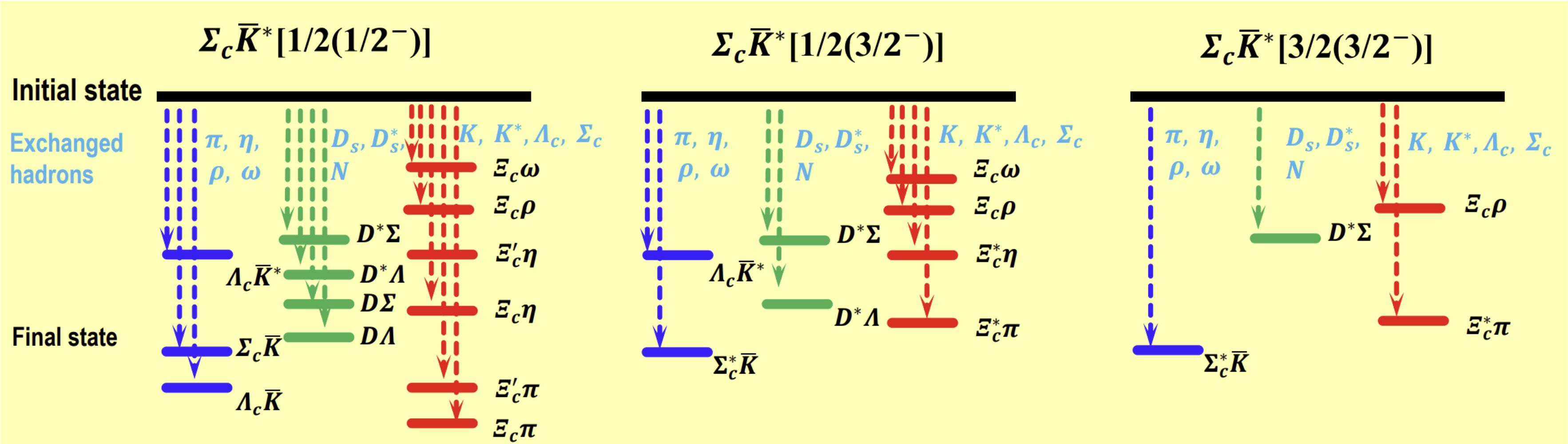


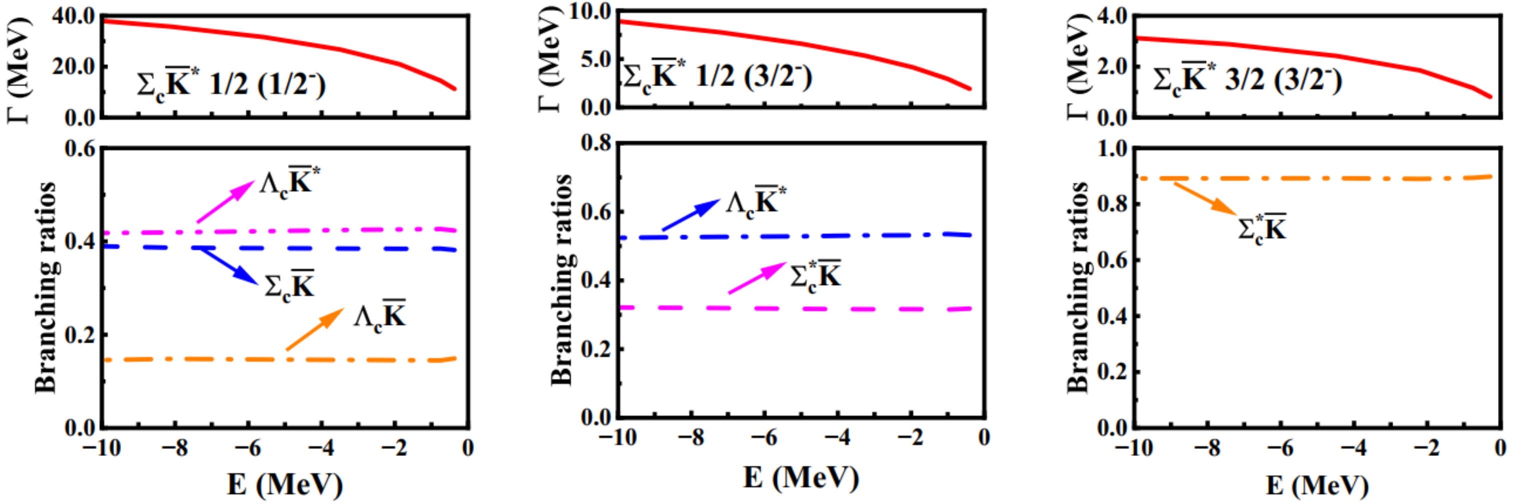


Total width Γ: from 30 to 76 MeV.

Dominant decay channel: $\Sigma_c\bar{K}$ component (about 85%), due to the strong pion-exchange mechanism; $\Lambda_c\bar{K}$ (14%), coupled channel effects and π exchange interactions.

ΣcK* molecules





I(JP) = 1/2(1/2-)

Total width Γ: 11 - 40 MeV.

Dominant decay channel: Λc K* (42%), ΣcK̄ (38%), ΛcK̄ (15%).

Characteristic: π exchange drives a significant width

I(JP) = 1/2(3/2-)

Total width Γ: 2 - 10 MeV.

Dominant decay channel: Λc K* (53%), Σc*K̄ (32%).

Characteristic: π exchange drives a significant width

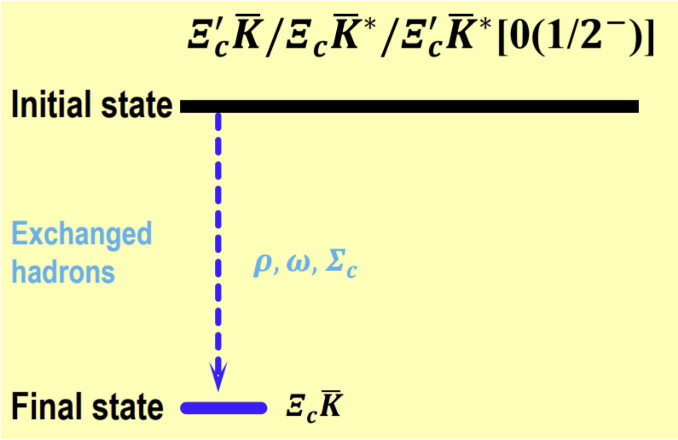
I(JP) = 3/2(3/2-)

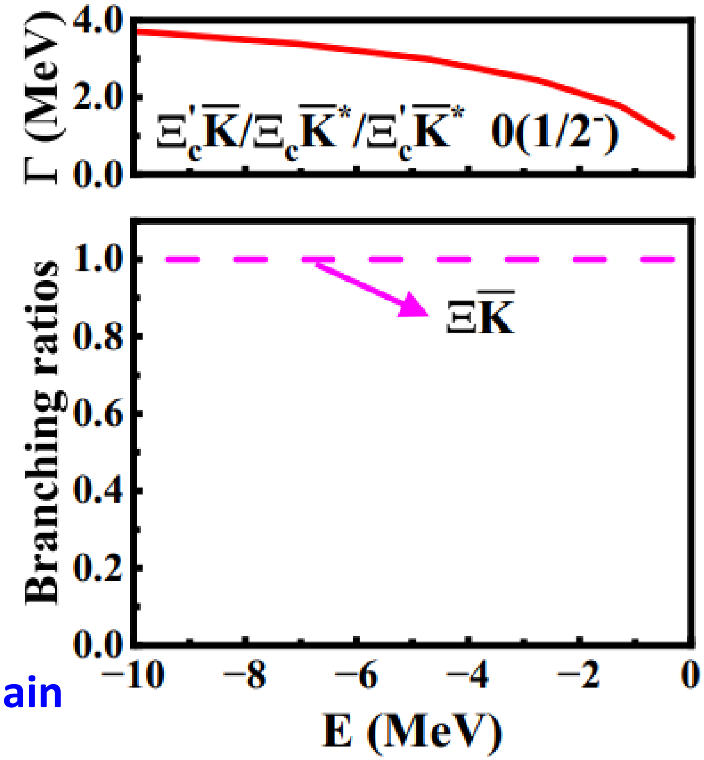
Total width Γ: 1 - 3.2 MeV.

Dominant decay channel: Σc*K̄ (90%).

Characteristic: π exchange drives a significant width.

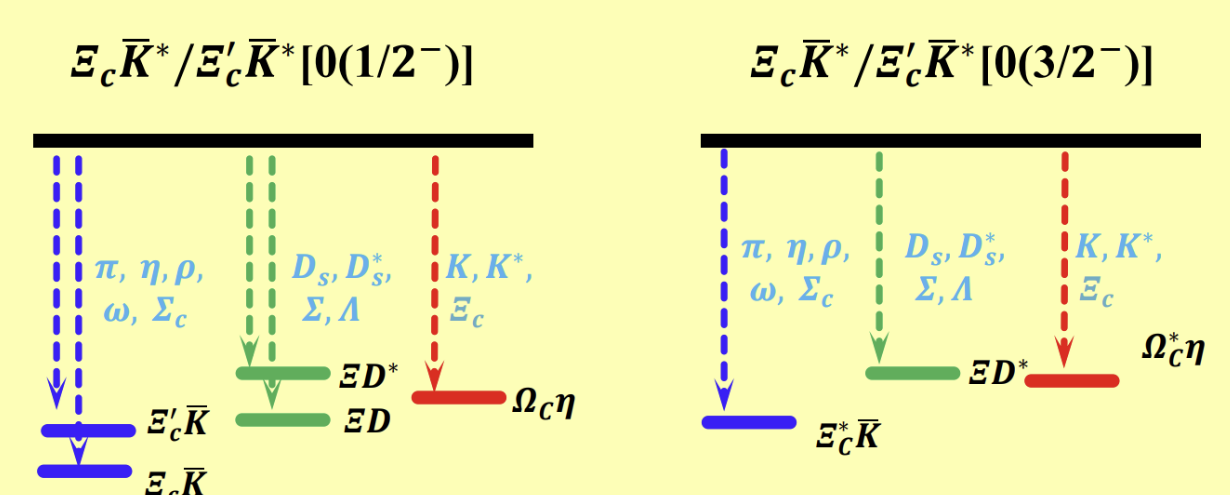
Ξ'c K/Ξc K*/Ξ'c K* I(JP) = 0(1/2-)





Total width Γ: 0.97 - 3.9 MeV .

The width is relatively narrow, and the main decay channel is single.



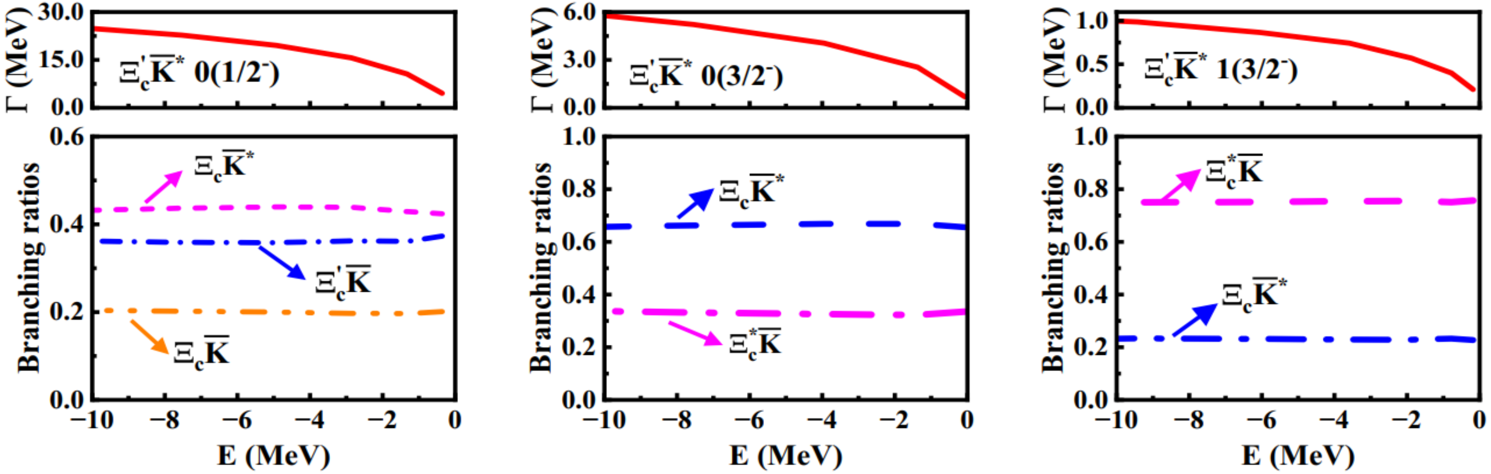
I(JP) = 0(1/2-)

Total width Γ: 0.6-2.5 MeV.
Dominant decay channel: Ξc K (90%), Ξ'c K (10%).
Characteristic: π exchange drives a significant width.

I(JP) = 0(1/2-)

Total width Γ: 15-5.4 MeV.
Dominant decay channel: Ξ*cK (98%).
Characteristic: π exchange drives a significant width.

$\Xi'_c \bar{K}^*$



I(JP) = 0(1/2-)

Total width Γ: 4.5-25 MeV.

Dominant decay channel:

Ξc K̄* (44%) > Ξ'cK̄ (35%) > ΞcK̄ (20%).

I(JP) = 1/2(3/2-)

Total width Γ: 0.7-6.2 MeV.

Dominant decay channel:

Ξc K̄* (66%) > Ξ*c K̄ (33%).

I(JP) = 3/2(3/2-)

Total width Γ: <1 MeV.

Dominant decay channel:

Ξ*c K̄ (75%) > Ξc K̄* (23%).

Γ(I = 1)< Γ (I = 0) with same binding energy

Interference effect: In the I = 1 system, significant destructive interference between the ρ and ω exchange amplitudes.

States	$I(J^P)$	Γ	Primary Decay		
$\Sigma_c\bar{K}$	$1/2(1/2^-)$	$(0.22, 0.90)$	$\Xi_c'\pi(78\%)$	$\Lambda_c\bar{K}(20\%)$	
$\Lambda_c\bar{K}^*/\Sigma_c\bar{K}^*$	$1/2(1/2^-)$	$(30, 76)$	$\Sigma_c\bar{K}(85\%)$	$\Lambda_c\bar{K}(14\%)$	
$\Sigma_c\bar{K}^*$	$1/2(1/2^-)$	$(11, 40)$	$\Lambda_c\bar{K}^*(42\%)$	$\Sigma_c\bar{K}(38\%)$	$\Lambda_c\bar{K}(15\%)$
	$1/2(3/2^-)$	$(2, 9.80)$	$\Lambda_c\bar{K}^*(53\%)$	$\Sigma_c^*\bar{K}(32\%)$	
	$3/2(3/2^-)$	$(0.8, 3.2)$	$\Sigma_c^*\bar{K}(90\%)$		
$\Xi_c'\bar{K}/\Xi_c\bar{K}^*/\Xi_c'\bar{K}^*$	$0(1/2^-)$	$(0.97, 3.9)$	$\Xi_c\bar{K}(100\%)$		
$\Xi_c\bar{K}^*/\Xi_c'\bar{K}^*$	$0(1/2^-)$	$(0.6, 2.5)$	$\Xi_c\bar{K}(90\%)$	$\Xi_c'\bar{K}(10\%)$	
	$0(3/2^-)$	$(1.47, 5.38)$	$\Xi_c^*\bar{K}(98\%)$		
$\Xi_c'\bar{K}^*$	$0(1/2^-)$	$(4.52, 25)$	$\Xi_c\bar{K}^*(44\%)$	$\Xi_c'\bar{K}(35\%)$	$\Xi_c\bar{K}(20\%)$
	$0(3/2^-)$	$(0.68, 6.24)$	$\Xi_c\bar{K}(66\%)$	$\Xi_c^*\bar{K}(33\%)$	
	$1(3/2^-)$	$(0.21, 1.00)$	$\Xi_c^*\bar{K}(75\%)$	$\Xi_c\bar{K}^*(23\%)$	

- **Large variation in width:** range from less than 1 MeV to several tens of MeV;
- **Main reason:** phase space and light meson exchange, especially pion;
- **Stable branching ratios:** predicted decay branching ratios are insensitive to variations in binding energy.

IV. Summary

Investigate the two-body strong decay properties of Yc K(*) molecules using the effective Lagrangian method combined with hadronic molecular wavefunctions derived from the one-boson-exchange (OBE) model.

- ✓ Predict the total decay widths and dominant branching ratios.
- ✓ The total decay widths vary significantly for different molecules.
- ✓ The branching ratios exhibit high stability.
- ✓ The decay dynamics are dominated by light meson (especially pion) exchange, leading to a strong preference for "charmed baryon + strange meson" final states.

Thank you!