物理与电子科学学院

第五届粒子物理天问论坛

Doubly charmed molecular pentaquarks with strangeness S=-1

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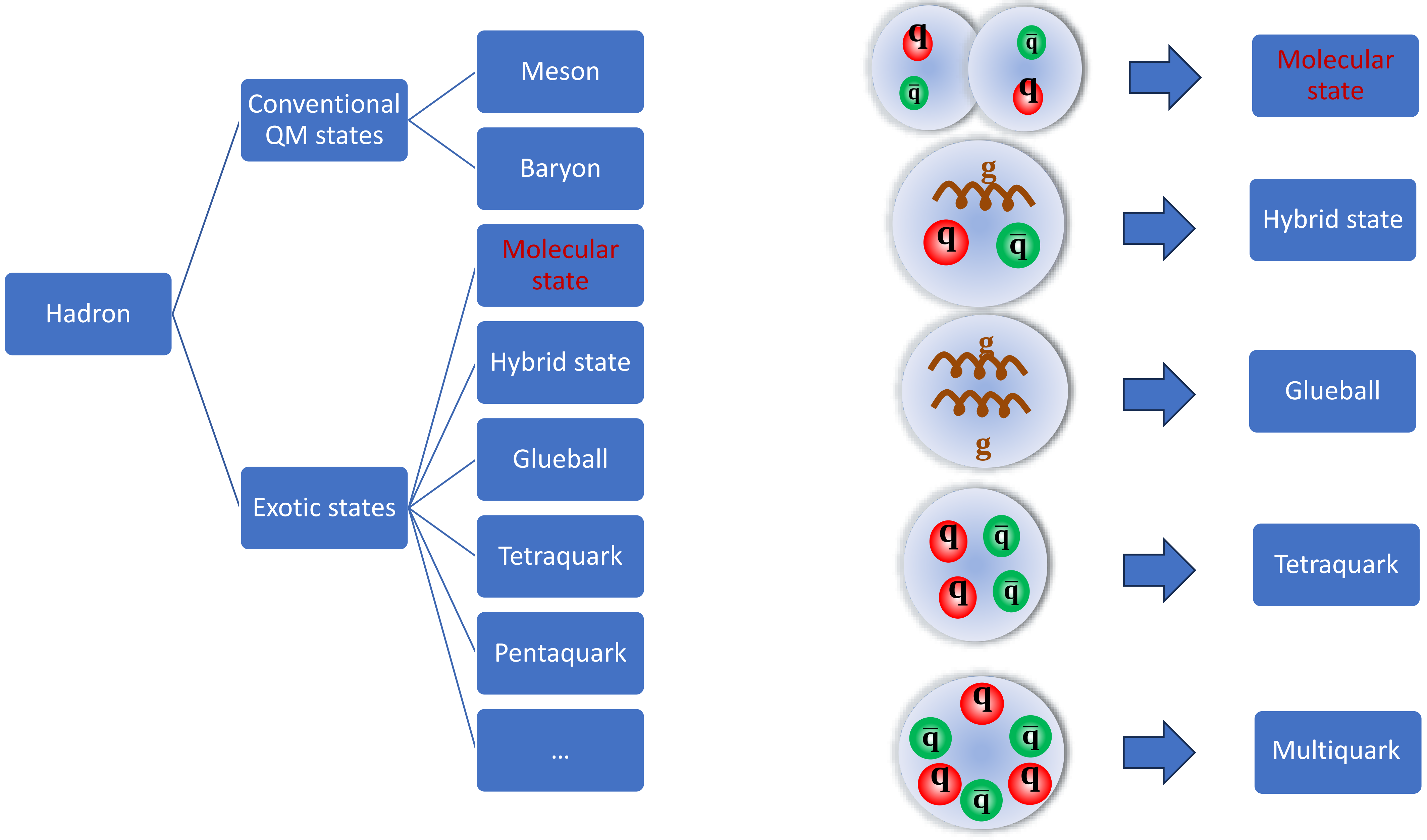
Outline

1. Background
2. Theoretical framework
3. Numerical results
4. Summary

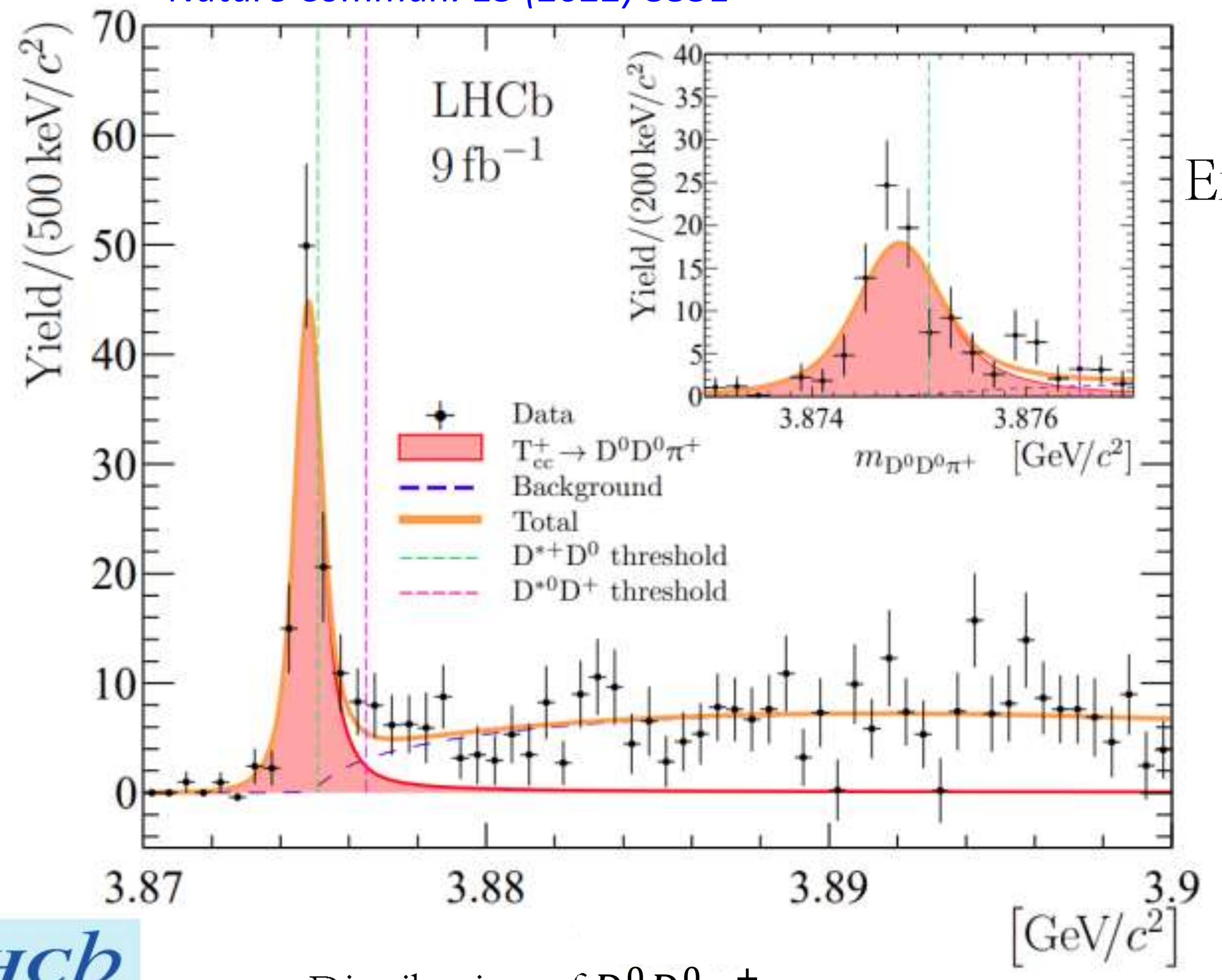
1.1: QCD color singlet



1.2: The doubly charmed molecular candidates

In 2021, LHCb obeserved the doubly charmed tetraquark state $T_{cc}^{+}(3875)$.

Nature Commun. 13 (2022) 3351



Distribution of $D^0 D^0 \pi^+$ mass

$T_{cc}^{+}(3875) \rightarrow cc\bar{q}\bar{q} \quad J^P = 1^+$

Explaination of the doubly heavy tetraquark states

- The compact tetraquark picture

  Phys. Rev. D 35 (1987) 969

  Phys. Lett. B 649 (2007) 166–172

  Phys. Rev. C 97 (3) (2018) 035211

  …

- The hadronic molecular picture

  Z. Phys. C 61 (1994) 525–537

  Few Body Syst. 35 (2004) 175-196

  …

$T_{cc}^{+}(3875) \rightarrow DD^{*}$ molecular state

1.3: The heavy-strange molecular candidates

Phys. Rev. D 101 (2020) 9, 094034

$f_0(980)$ → $K\bar{K}$ molecular state

$a_0(980)$ → $K\bar{K}$ molecular state

Phys. Rev. D 104 (2021) 9, 094012

$D_{s0}^*(2317)$ → DK molecular state

$D_{s1}(2460)$ → D^*K molecular state

Phys. Rev. D 82 (2010) 014010
Phys. Lett. B 811 (2020) 135870

$X(2900)$ → $\overline{D^*}K^*$ molecular state

ArXiv: 2208.10196 [hep-ph]

$T_{c\bar{s}}^{a0(++)}(2900)$ → D^*K^* molecular state

Phys. Rev. Lett. 117, 022002 (2016)
Chin. Phys. C 40 (2016) 9
Eur. Phys. J. C 76 (2016) 10, 558 …

$X(5568)$ → a $su\bar{b}\bar{d}$ tetraquark state

Eur. Phys. J. A 53 (2017) 6, 127
Eur. Phys. J. Plus 131 (2016) 10, 351

$X(5568)$ → $B\bar{K}$ molecular state

Eur. Phys. J. A 53 (2017) 6, 127

$X(5616)$ → $B^*\bar{K}$ molecular state

Phys. Rev. D 104 (9) (2021) 094012

$B_{s1}(6158)$ → $\bar{B}K^*$molecular state

1.4: $\Xi_{cc}K$ system

Because of the Schrödinger equations, the heavier the mass of quarks, the lower the kinetic energy of the system, the bound states can be generated easily.

$$-\frac{\hbar^2}{2m_\mu}\nabla^2$$

So, we can replace b quark or c quark by two c quarks, $\Xi_{cc}K(ccq-\bar{s}q)$.

Why we study $\Xi_{cc}K$ system?

① Understanding interaction between double-charm baryons and strange mesons.

② Enriching the family of the exotic states and helping us to understand the nature of the $\Xi_{cc}K$ system.

③ Giving indirect test of the molecular state picture for other structures, like D_{s0}^*, D_{s1}, X(2900), and so on.

2.1: Theoretical framework: the effective Lagrangians

The effective Lagrangians for the coupling of S-wave double-charm baryons with light mesons from nucleon-nucleon interaction.

$$\mathcal{L}_{\Xi_{cc}\Xi_{cc}\sigma} = g_\sigma \bar{\Xi}_{cc}\sigma\Xi_{cc},$$
$$\mathcal{L}_{\Xi_{cc}\Xi_{cc}\mathbb{P}} = g_\pi \bar{\Xi}_{cc} i\gamma_5 \mathbb{P}\Xi_{cc},$$
$$\mathcal{L}_{\Xi_{cc}\Xi_{cc}\mathbb{V}} = h_v \bar{\Xi}_{cc}\gamma_\mu \mathbb{V}^\mu \Xi_{cc} + \frac{f_v}{2M_{\Xi_{cc}}}\bar{\Xi}_{cc}\sigma_{\mu\nu}\partial^\mu \mathbb{V}^\nu \Xi_{cc}.$$

- *Phys. Rev. D 95, 114019 (2017)*
- *Eur. Phys. J. A 54 (2018) 9, 143*
- *Phys. Rev. D 96.114030 (2017)*

$$\mathbb{V} = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} \end{pmatrix}$$
$$\mathbb{P} = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & \pi^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} \end{pmatrix}$$

With the help of the quark model, coupling constants for the interactions of the double-charm baryons and light mesons are derived from nucleon-nucleon interaction.

$$g_\sigma = -2.82, g_{\rho NN} = 3.25, f_{\rho NN} = 19.82, g_{\pi NN} = 3.25$$

- *Phys. Rep. 149, 1 (1987)*
- *Phys. Rev. C 63, 024001 (2001)*
- *Phys. Rev. C 81, 065201 (2010)*

The effective Lagrangians for the strange mesons part.

$$\mathcal{L} = \mathcal{L}_{PPV} + \mathcal{L}_{VVP} + \mathcal{L}_{VVV}$$
$$= \frac{ig}{2\sqrt{2}}\langle\partial^\mu P(PV_\mu - V_\mu P)\rangle + \frac{g_{VVP}}{\sqrt{2}}\epsilon^{\mu\nu\alpha\beta}\langle\partial_\mu V_\nu \partial_\alpha V_\beta P\rangle$$
$$+ \frac{ig}{2\sqrt{2}}\langle\partial^\mu V^\nu (V_\mu V_\nu - V_\nu V_\mu)\rangle.$$

- *Phys. Rev. C 62, 034903 (2000)*
- *Eur. Phys. J. A 36, 73 (2008)*

The coupling constants for the strange meson part

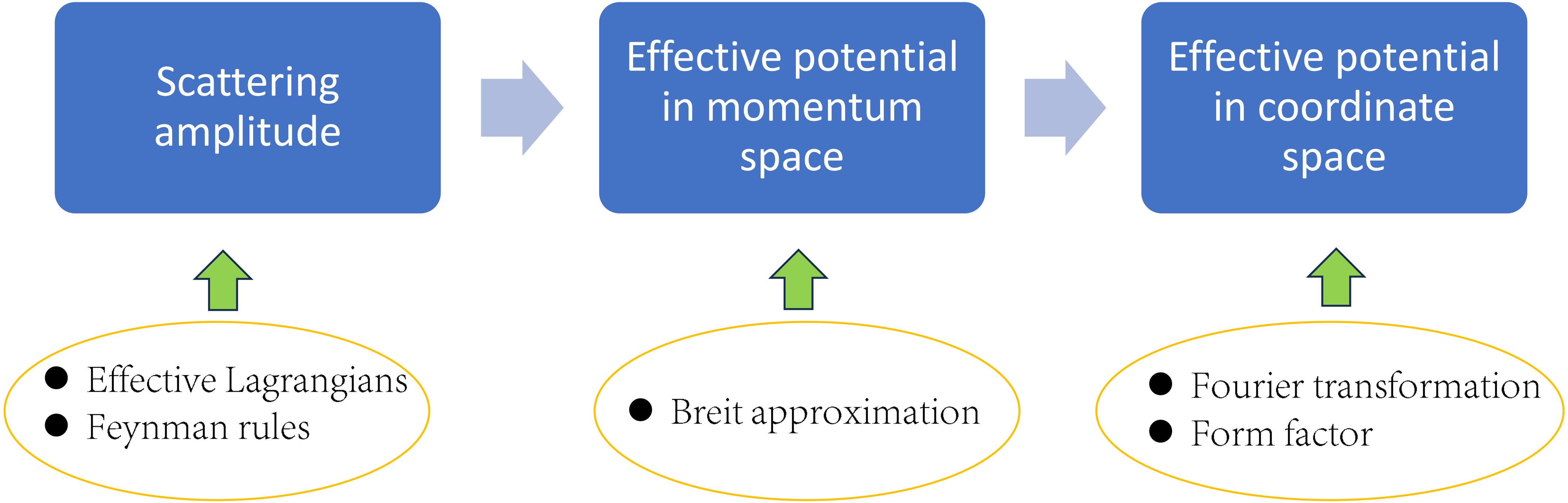
$$g'_\sigma = -3.65, g = 12.00, g_{VVP} = 7.33$$

- *Phys. Rev. D 30, 594 (1984)*
- *Phys. Rev. D 85, 014015 (2012)*
- *Phys. Rev. D 97, no. 3, 036016 (2018)*

2.2: One-boson-exchange(OBE) model

Yukawa, Proc. Phys. Math. Soc. Japan 17, 48 (1935)

- 1935, Yukawa: π-exchange and nucleon-nucleon interaction.
- Nijimegen potential and Bonn potential: scalar meson σ **exchange~two π** exchange; vector meson ρ/ω exchange~**multi-π** exchange.



$$\mathcal{M}_{fi}$$

$$V_{fi}(p) = -\frac{\mathcal{M}_{fi}}{\sqrt{\prod_f 2p_f^0 \prod_i 2p_i^0}} \approx -\frac{\mathcal{M}_{fi}}{\sqrt{\prod_f 2m_f^0 \prod_i 2m_i^0}}$$

$$V(r) = \int \frac{d^3\mathbf{q}}{(2\pi)^3} e^{i\mathbf{q}\cdot\mathbf{r}} \mathcal{V}_{fi}(\mathbf{q}) \mathcal{F}^2(q^2, m_E^2)$$

3.1: Numerical results

Form factor $\mathcal{F} = \frac{\Lambda^2 - m^2}{\Lambda^2 - q^2}$, Λ, m and q are the cut off, mass and four-momentum of the exchange meson respectively.

One free parameter

$\Lambda \sim 1$ GeV

- *N. A. Tornqvist, Z. Phys. C 61, 525 (1994)*
- *N. A. Tornqvist, Nuovo Cim. A 107, 2471 (1994)*

We search for the bound state solutions for all the discussed systems after solving the coupled channel Schrödinger equations.

Features of loosely bound molecular states

I. the binding energy falls within the range of several MeV to several tens of MeV.
II. the root-mean-square (RMS) radius measures approximately 1.00 fm or greater.

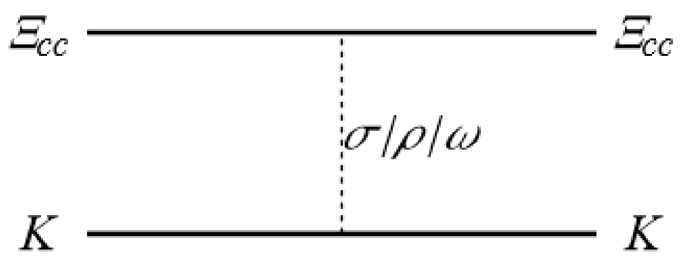
Research strategy,

1. Single channel with One-pion-exchange(OPE)
2. Single channel with OBE
3. Coupled channels with OPE
4. Coupled channels with OBE

3.2.1: $\Xi_{cc}K$ system

For $\Xi_{cc}K$ system in single channel. And the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	$\Lambda(\Xi_{cc}K(^2S_{1/2}))$	E	r_{RMS}
$0(1/2^-)$	3.60	−0.42	5.39
	4.30	−1.99	3.47
	5.00	−3.68	2.65
$1(1/2^-)$	…	…	…
	…	…	…
	…	…	…



The π/η exchange interactions are strongly suppressed as spin-parity conservation.

- For $\Xi_{cc}K$ system with $0(\frac{1}{2}^-)$, loosely solutions emerge only for Λ exceeding 3.60 GeV, which is far away from 1 GeV. The interaction provides a weak attraction.
- No bound solution for $\Xi_{cc}K$ system with $1(\frac{1}{2}^-)$.

3.2.2: $\Xi_{cc}K/\Xi_{cc}K^*$ coupled system in OPE case

In OPE case, considering the coupled channel effects,

$$V_{\Xi_{cc}K} = \begin{pmatrix} V_{\Xi_{cc}K\to\Xi_{cc}K} & V_{\Xi_{cc}K^*\to\Xi_{cc}K} \\ V_{\Xi_{cc}K\to\Xi_{cc}K^*} & V_{\Xi_{cc}K^*\to\Xi_{cc}K^*} \end{pmatrix}$$

The cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}K(^2S_{1/2})$	$\Xi_{cc}K^*(^2S_{1/2})$	$\Xi_{cc}K^*(^4D_{1/2})$
$0(1/2^-)$	2.49	−0.62	4.63	89.37	10.54	0.09
	2.51	−4.81	1.93	75.29	24.56	0.14
	2.53	−11.92	1.16	64.89	34.96	0.15
$1(1/2^-)$	…	…	…	…	…	…
	…	…	…	…	…	…
	…	…	…	…	…	…

- For $\Xi_{cc}K/\Xi_{cc}K^*$ system with $0\left(\frac{1}{2}^-\right)$, loosely solutions emerge only for Λ exceeding 2.49 GeV. The interaction provides a weak attraction.
- No bound solution for $\Xi_{cc}K/\Xi_{cc}K^*$ system with $1(\frac{1}{2}^-)$.

3.2.2: $\Xi_{cc}K/\Xi_{cc}K^*$ coupled system in OBE case

In OBE case, the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}K(^2S_{1/2})$	$\Xi_{cc}K^*(^2S_{1/2})$	$\Xi_{cc}K^*(^4D_{1/2})$
$0(1/2^-)$	1.43	−0.54	5.03	96.46	3.53	0.01
	1.45	−4.56	2.26	89.46	10.53	0.02
	1.47	−13.01	1.33	81.00	18.98	0.02
$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}K(^2S_{1/2})$	$\Xi_{cc}K^*(^2S_{1/2})$	$\Xi_{cc}K^*(^4D_{1/2})$
$1(1/2^-)$	2.58	−0.34	5.27	97.20	2.60	0.20
	2.60	−5.32	1.94	91.98	7.47	0.56
	2.62	−14.61	1.15	88.08	11.12	0.80

- $\Xi_{cc}K/\Xi_{cc}K^*$ system with $0(\frac{1}{2}^-)$ can be a prime molecular candidate, where the $\Xi_{cc}K(\,^2S_{1/2})$ channel dominates.
- For $\Xi_{cc}K/\Xi_{cc}K^*$ system with $1(\frac{1}{2}^-)$, weak solutions emerge only for Λ exceeding 2.58 GeV, which is far away from 1 GeV. Despite the interaction is attractive, we can exclude it as a suitable molecular candidate.
- $\sigma-\rho-\omega$ exchanges are more important than one π exchange in $\Xi_{cc}K/\Xi_{cc}K^*$ system.
- The coupled channel effects play an important role in $\Xi_{cc}K/\Xi_{cc}K^*$ system.

3.3.1: $\Xi_{cc}K^*$ system in OPE case

Considering S-D wave mixing effects, in OPE case, the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}K^*(^2S_{1/2})$	$\Xi_{cc}K^*(^4D_{1/2})$	$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}K^*(^4S_{3/2})$	$\Xi_{cc}K^*(^2D_{3/2})$	$\Xi_{cc}K^*(^4D_{3/2})$
$0(1/2^-)$	1.96	−0.29	5.11	99.72	0.28	$0(3/2^-)$	4.90	−0.81	4.03	97.92	0.28	1.79
	2.08	−4.50	1.80	99.34	0.66		5.09	−3.97	2.03	95.96	0.54	3.51
	2.20	−14.04	1.06	99.14	0.86		5.28	−10.09	1.32	94.21	0.75	5.05
$1(1/2^-)$	…	…	…	…	…	$1(3/2^-)$	…	…	…	…	…	…
	…	…	…	…	…		…	…	…	…	…	…
	…	…	…	…	…		…	…	…	…	…	…

- For $\Xi_{cc}K^*$ system with $0(\frac{1}{2}^-)$, loosely solutions emerge only for Λ exceeding 1.96 GeV. The interaction provides a weak attraction
- For $\Xi_{cc}K^*$ system with $0(\frac{3}{2}^-)$, loosely solutions emerge only for Λ exceeding 4.90 GeV. The interaction provides a weak attraction.
- No bound solution for $\Xi_{cc}K^*$ with $1(\frac{1}{2}^-)$.
- No bound solution for $\Xi_{cc}K^*$ with $1(\frac{3}{2}^-)$.

3.3.1: $\Xi_{cc}K^*$ system in OBE case

Considering S-D wave mixing effects, in OBE case, the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}K^*(^2S_{1/2})$	$\Xi_{cc}K^*(^4D_{1/2})$	$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}K^*(^4S_{3/2})$	$\Xi_{cc}K^*(^2D_{3/2})$	$\Xi_{cc}K^*(^4D_{3/2})$
$0(1/2^-)$	1.14	−0.30	5.19	99.89	0.11	$0(3/2^-)$	2.30	−0.17	5.81	99.66	0.06	0.28
	1.21	−4.83	1.86	99.79	0.21		3.30	−5.40	1.90	99.04	0.16	0.80
	1.28	−14.80	1.14	99.78	0.22		4.30	−14.13	1.27	98.80	0.19	1.00
$1(1/2^-)$	…	…	…	…	…	$1(3/2^-)$	3.25	−0.30	4.86	99.95	0.01	0.04
	…	…	…	…	…		3.27	−4.04	1.66	99.89	0.02	0.10
	…	…	…	…	…		3.29	−10.38	1.00	99.85	0.02	0.13

- $\Xi_{cc}K^*$ system with $0\left(\frac{1}{2}^-\right)$ can be a good molecular candidate, where the $\Xi_{cc}K^*(\,^2S_{1/2})$ channel dominates.
- For $\Xi_{cc}K^*$ with $0(\frac{3}{2}^-)$, loosely solutions emerge only for Λ exceeding 2.30 GeV. Despite the interaction is attractive, we can exclude it as a suitable molecular candidate.
- For $\Xi_{cc}K^*$ with $1(\frac{3}{2}^-)$, loosely solutions emerge only for Λ exceeding 3.25 GeV, which is far away from 1 GeV. Despite the interaction is attractive, we can exclude it as a suitable molecular candidate.
- No bound solution for $\Xi_{cc}K^*$ with $1(\frac{1}{2}^-)$.
- $\sigma-\rho-\omega$ exchanges are more important than one π exchange for $\Xi_{cc}K^*$ system with $0\left(\frac{1}{2}^-\right)$.

3.4: Brief summary

- Finding two possible hadronic molecular states: $\Xi_{cc}K/\,\Xi_{cc}K^*$ with $0\left(\frac{1}{2}^-\right)$, $\Xi_{cc}K^*$ with $0\left(\frac{1}{2}^-\right)$.
- The coupled channel effects play an important role in generation of hadronic molecular states.
- $\sigma-\rho-\omega$ exchanges are important to generate this two molecular states.

3.5.1: $\Xi_{cc}\bar{K}$ system

We calculate the effective potential of the $\Xi_{cc}\bar{K}$ system through the G-parity rule.

$$V_{B_1\bar{M}_2\to B_3\bar{M}_4} = (-1)^{G_E} V_{B_1 M_2\to B_3 M_4}$$

G_E stands for the G−parity for the exchanged meson in the B_1M_2 to B_3M_4 process.

The cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	$\Lambda(\Xi_{cc}\bar{K}(^2S_{1/2}))$	E	r_{RMS}
$0(1/2^-)$	1.69	−0.17	5.97
	1.88	−4.43	2.49
	2.07	−12.13	1.59
$1(1/2^-)$	...	...	...
	...	...	...
	...	...	...

- $\Xi_{cc}\bar{K}$ system with $0(\frac{1}{2}^-)$ loosely solutions emerge only for Λ exceeding 1.69 GeV, which is slightly far away from 1 GeV. Despite the interaction is attractive, we can exclude it as a suitable molecular candidate.
- No bound solution for $\Xi_{cc}\bar{K}$ system with $1\left(\frac{1}{2}^-\right)$.

3.6.1: $\Xi_{cc}\overline{K}/\Xi_{cc}\overline{K^*}$ coupled system in OPE

In OPE case, the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}\bar{K}(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^4D_{1/2})$
$0(1/2^-)$	3.27	−0.16	5.85	98.23	0.77	1.00
	3.35	−4.50	2.27	93.89	2.73	3.39
	3.43	−14.25	1.29	89.44	4.82	5.74
$1(1/2^-)$	...	...	...	...	...	...
	...	...	...	...	...	...
	...	...	...	...	...	...

- For $\Xi_{cc}\overline{K}\backslash\Xi_{cc}\overline{K^*}$ system with $0(\frac{1}{2}^-)$, loosely solutions emerge only for Λ exceeding 3.27 GeV. The interaction provides a weak attraction.
- No bound solution for $\Xi_{cc}\overline{K}\backslash\Xi_{cc}\overline{K^*}$ system with $1(\frac{1}{2}^-)$.

3.6.1: $\Xi_{cc}\overline{K}/\Xi_{cc}\overline{K^*}$ coupled system in OBE

In OBE case, the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}\bar{K}(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^4D_{1/2})$
$0(1/2^-)$	1.40	−0.26	5.76	99.63	0.05	0.32
	1.45	−3.76	2.68	98.74	0.25	1.01
	1.50	−12.05	1.59	97.31	0.77	1.92
$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}\bar{K}(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^4D_{1/2})$
$1(1/2^-)$	...	...	...	...	...	...
	...	...	...	...	...	...
	...	...	...	...	...	...

- $\Xi_{cc}\overline{K}\backslash\Xi_{cc}\overline{K^*}$ system with $0(\frac{1}{2}^-)$ can be a prime molecular state, where the $\Xi_{cc}\overline{K}$ ($^2S_{1/2}$) channel dominates.
- No bound solution for $\Xi_{cc}\overline{K}\backslash\Xi_{cc}\overline{K^*}$ system with $1(\frac{1}{2}^-)$.
- $\sigma-\rho-\omega$ exchanges are more important for $\Xi_{cc}\overline{K}\backslash\Xi_{cc}\overline{K^*}$ system with $0(\frac{1}{2}^-)$.

3.7.1: $\Xi_{cc}\overline{K^*}$ system in OPE case

In OPE case, the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}\bar{K}^*(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^4D_{1/2})$	$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}\bar{K}^*(^4S_{3/2})$	$\Xi_{cc}\bar{K}^*(^2D_{3/2})$	$\Xi_{cc}\bar{K}^*(^4D_{3/2})$
$0(1/2^-)$	…	…	…	…	…	$0(3/2^-)$	2.50	−0.56	4.44	98.39	0.37	1.24
	…	…	…	…	…		2.63	−4.25	1.91	96.56	0.80	2.64
	…	…	…	…	…		2.76	−11.86	1.20	95.20	1.11	3.69
$1(1/2^-)$	…	…	…	…	…	$1(3/2^-)$	…	…	…	…	…	…
	…	…	…	…	…		…	…	…	…	…	…
	…	…	…	…	…		…	…	…	…	…	…

- For $\Xi_{cc}\overline{K^*}$ with $0(\frac{3}{2}^-)$, loosely solutions emerge only for Λ exceeding 2.50 GeV. The interaction provides a weak attraction.
- No bound solution for $\Xi_{cc}\overline{K^*}$ with $0\left(\frac{1}{2}^-\right)$.
- No bound solution for $\Xi_{cc}\overline{K^*}$ with $1(\frac{1}{2}^-)$.
- No bound solution for $\Xi_{cc}\overline{K^*}$ with $1(\frac{3}{2}^-)$.

3.7.2: $\Xi_{cc}\overline{K^*}$ system in OBE case

In OBE case, the cutoff Λ, the binding energy E, and the root-mean-square r_{RMS} are in the units of GeV, MeV, and fm, respectively.

$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}\bar{K}^*(^2S_{1/2})$	$\Xi_{cc}\bar{K}^*(^4D_{1/2})$	$I(J^P)$	Λ	E	r_{RMS}	$\Xi_{cc}\bar{K}^*(^4S_{3/2})$	$\Xi_{cc}\bar{K}^*(^2D_{3/2})$	$\Xi_{cc}\bar{K}^*(^4D_{3/2})$
$0(1/2^-)$	1.36	−0.24	5.54	99.52	0.48	$0(3/2^-)$	1.15	−0.17	5.72	99.46	0.12	0.42
	1.43	−3.89	2.16	98.51	1.49		1.25	−5.18	1.92	98.18	0.40	1.42
	1.50	−12.52	1.30	97.57	2.43		1.35	−15.77	1.22	97.09	0.64	2.27
$1(1/2^-)$	…	…	…	…	…	$1(3/2^-)$	…	…	…	…	…	…
	…	…	…	…	…		…	…	…	…	…	…
	…	…	…	…	…		…	…	…	…	…	…

- $\Xi_{cc}\overline{K^*}$ system with $0\left(\frac{1}{2}^-\right)$ can be a prime molecular state, where the $\Xi_{cc}\bar{K}$ ($^2S_{1/2}$) channel dominates.
- $\Xi_{cc}\overline{K^*}$ system with $0\left(\frac{3}{2}^-\right)$ can be a good molecular state, where the $\Xi_{cc}\bar{K}$ ($^4S_{3/2}$) channel dominates.
- No bound solution for $\Xi_{cc}\overline{K^*}$ system with $1(\frac{1}{2}^-)$.
- No bound solution for $\Xi_{cc}\overline{K^*}$ system with $1(\frac{3}{2}^-)$.
- $\sigma-\rho-\omega$ exchanges are more important for $\Xi_{cc}\overline{K^*}$ system with $0\left(\frac{1}{2}^-\right)$ and $\Xi_{cc}\overline{K^*}$ system with $0\left(\frac{3}{2}^-\right)$.

4: Summary

- Finding five possible hadronic molecular states: $\Xi_{cc}K/\ \Xi_{cc}K^*$ with $0\left(\frac{1}{2}^-\right)$, $\Xi_{cc}\bar{K}/$ $\Xi_{cc}\overline{K^*}$ with $0\left(\frac{1}{2}^-\right)$, $\Xi_{cc}K^*$ with $0\left(\frac{1}{2}^-\right)$, $\Xi_{cc}\overline{K^*}$with $0\left(\frac{1}{2}^-\right)$, $\Xi_{cc}\overline{K^*}$with $0\left(\frac{3}{2}^-\right)$.
- The coupled channel effects play an important role in systems we studied.
- For $ccq - \bar{s}q$ system, $\sigma - \rho - \omega$ exchanges are important.

Thanks for your attention