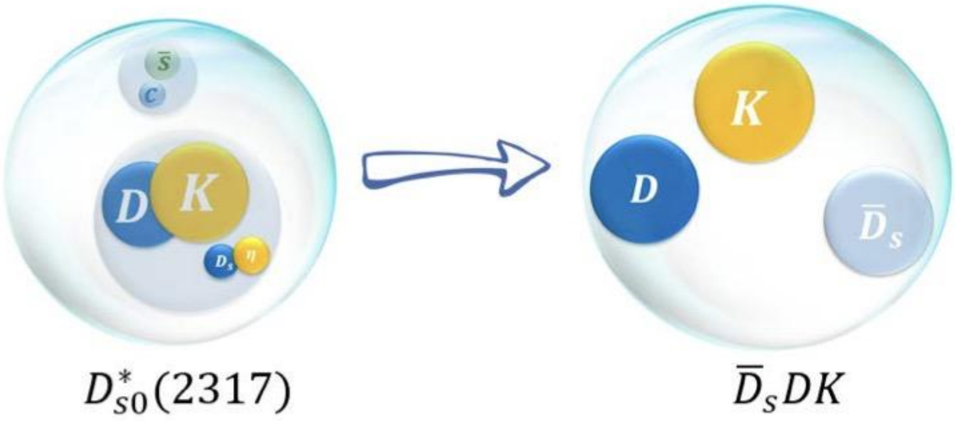


Existence of 0^{--} $\bar{D}_s DK$ on nature of $D^*_{s0}(2317)$

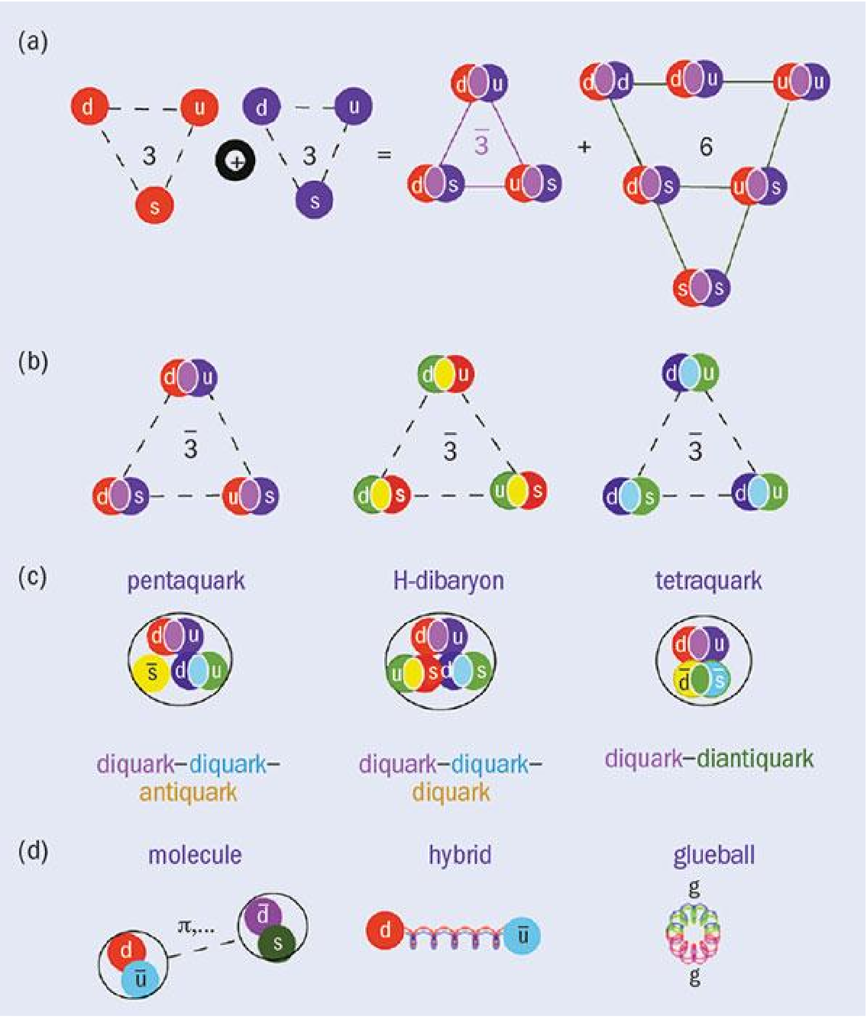
arxiv:2501.11358

吴天伟(中山大学)

Collaborators: Liu-Ming Zhu and Li-sheng Geng

2025.0414@长沙

Exotic hadronic states



Normal hadron:

meson: quark-antiquark pair

baryon: 3 quarks

Exotic hadron state:

1. Glueball

Composed of gluons

2. **Hybrid**

Composed of quarks and gluons

3. **Multiquark state**

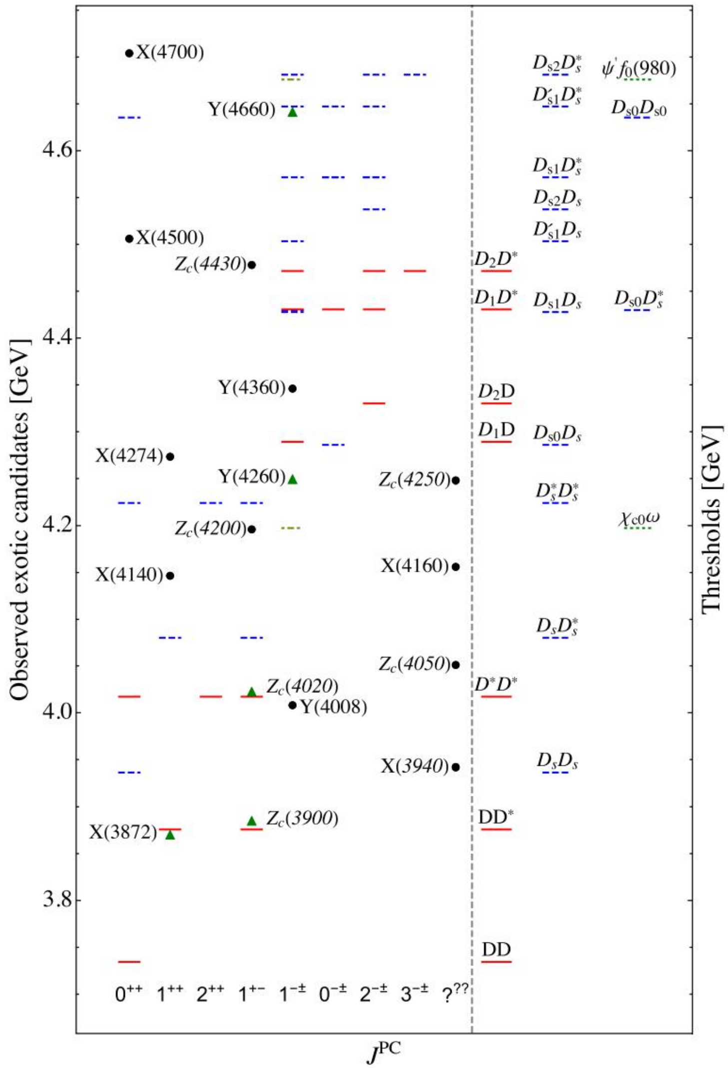
Composed of multi quarks(>3)

4. **Hadronic molecule**

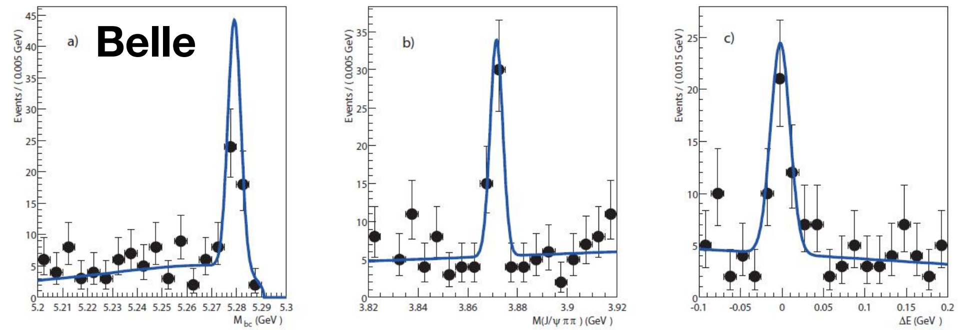
Composed of 2 or more hadrons

Hadronic molecules

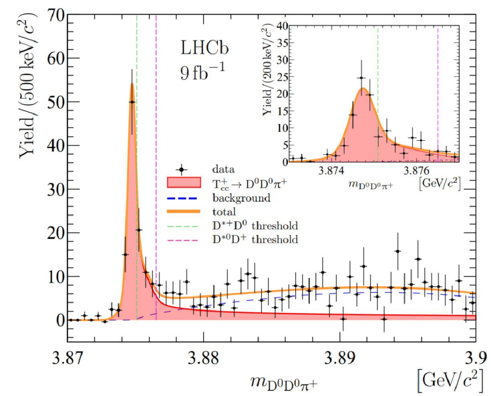
F.K. Guo, et al. Rev.Mod.Phys.90.015004



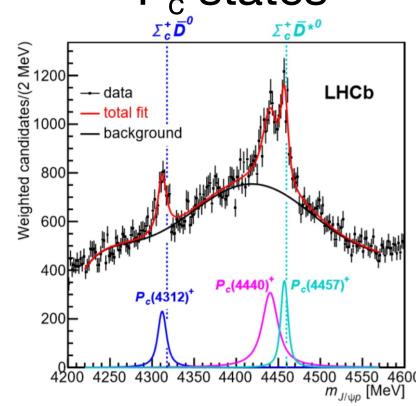
X(3872)



$T_{cc}(3875)$



P_c states

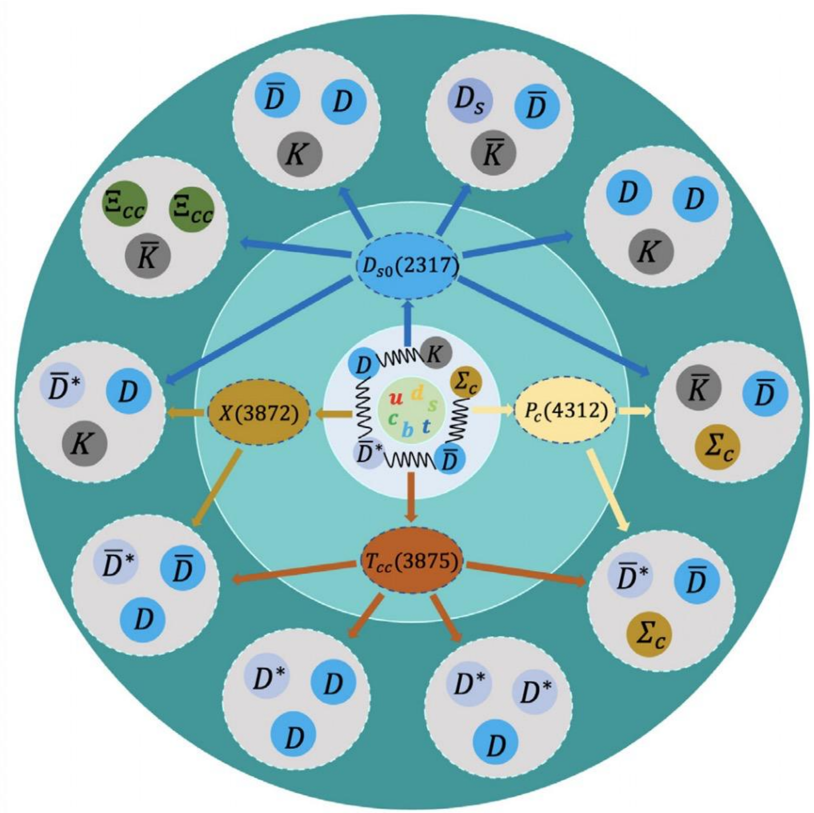


Many XYZ particles are close to two hadron mass thresholds.

X(3872)、T_{cc}(3875)、P_c pentaquarks、D_{s0}*(2317) are interpreted as hadronic molecules.

Three-body molecules

T.W. Wu, et al. Science Bulletin 67 (2022) 1735-1738



Study mainly focus on:

Existence (mass\structure)

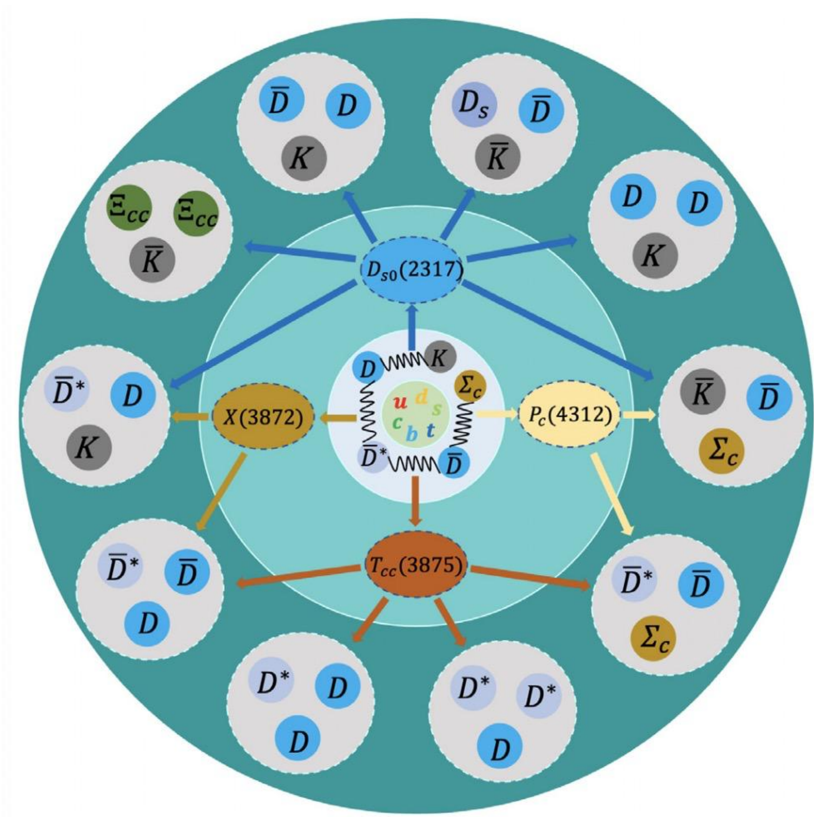
Decay (channel\partial width)

Production (B.F.\events)

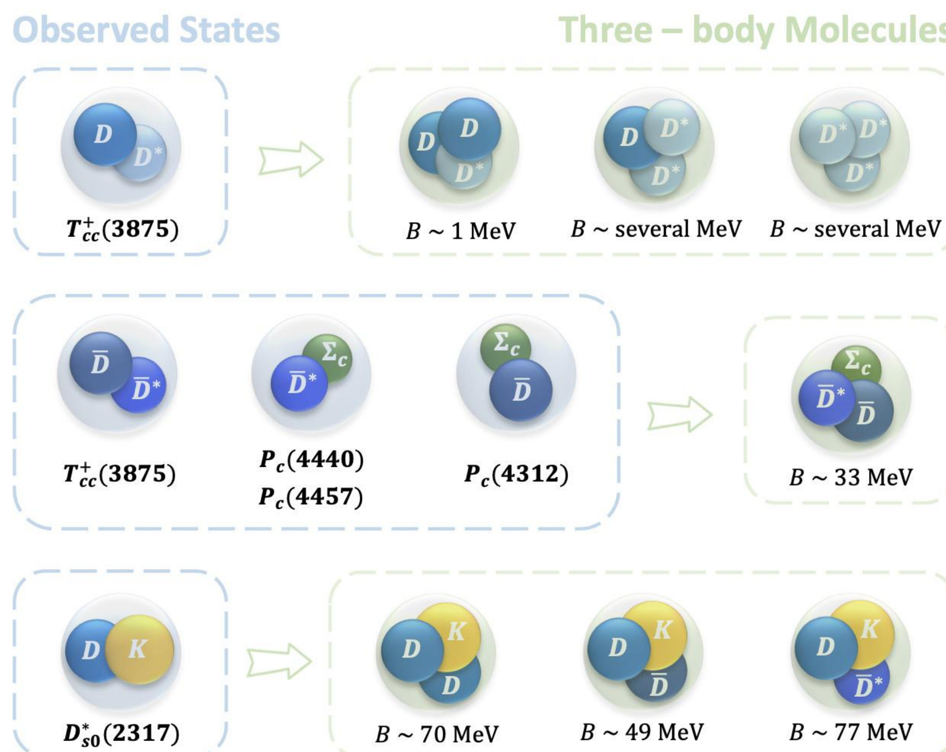
From two-body to three-body 3 > 2+1 > 1+1+1

Three-body molecules

T.W. Wu, et al. Science Bulletin 67 (2022) 1735-1738



M.Z. Liu, et al. Phys.Rept. 1108 (2025) 1-108

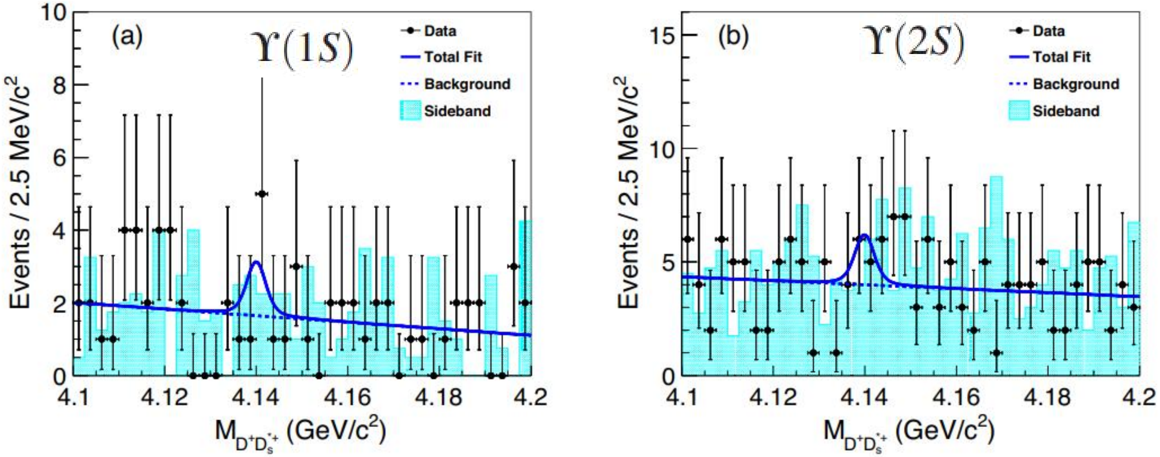


Three-body molecules based on two-body candidates

Seraching for DDK

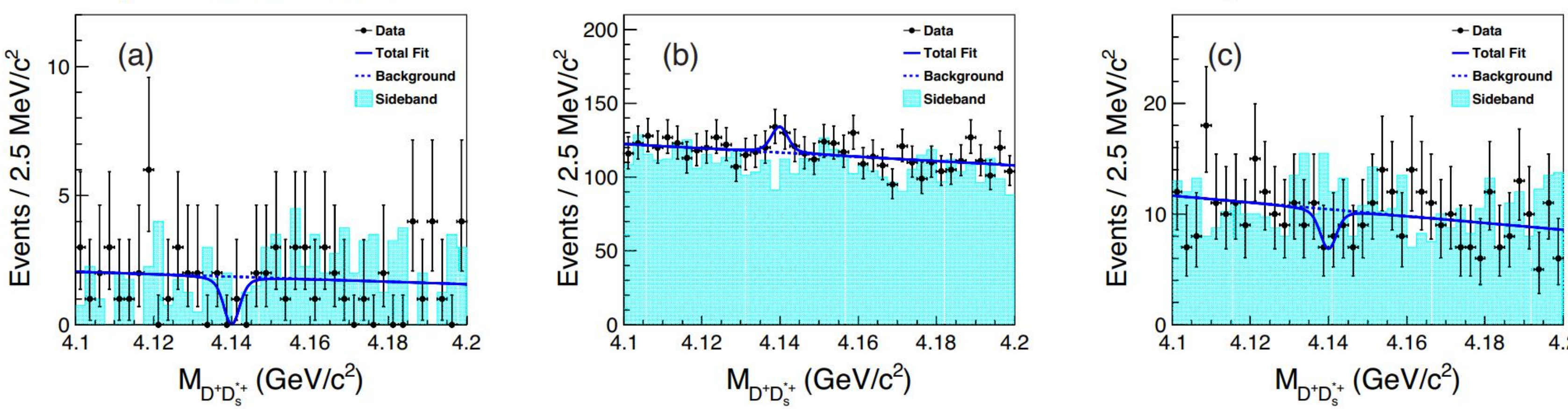
Phys.Rev. D102 (2020) 112001@Belle

$\Upsilon(1S)/\Upsilon(2S) \to R^{++} + \text{anything},\ R^{++} \to D^+ D_s^{*+}$



$e^+e^- \to R^{++} + \text{anything at } \sqrt{s} = 10.520/10.580/10.867\ \text{GeV},\ R^{++} \to D^+ D_s^{*+}$

$\sqrt{s} = 10.520$ GeV $\sqrt{s} = 10.580$ GeV $\sqrt{s} = 10.867$ GeV



Doubly charmed more difficult to produce.

Features of $\bar{D}_s D K$ system

How to find and verify three-body molecules?

✓ **No mixture of conventional hadrons**

0^{--} exotic quantum numbers

✓ **Two-body system can not bind**

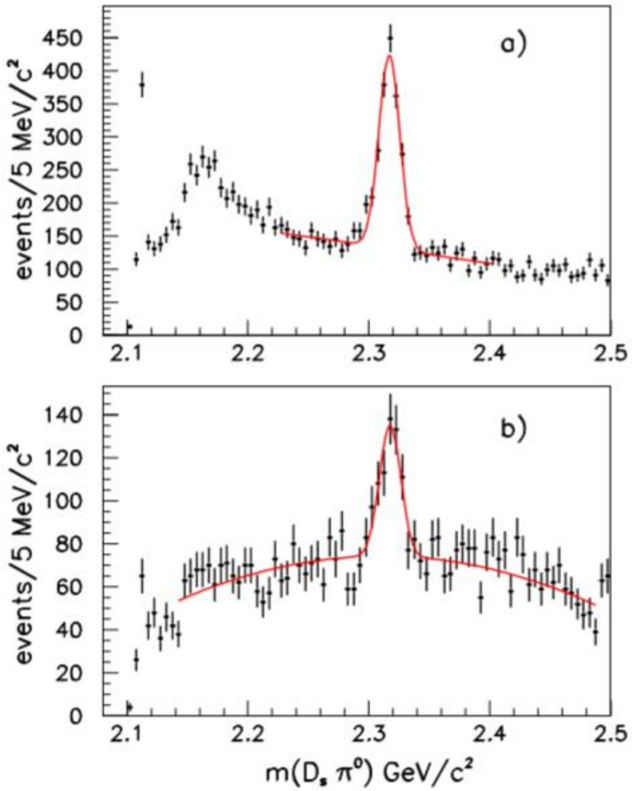
Suppressed by the OBE model or OZI rule

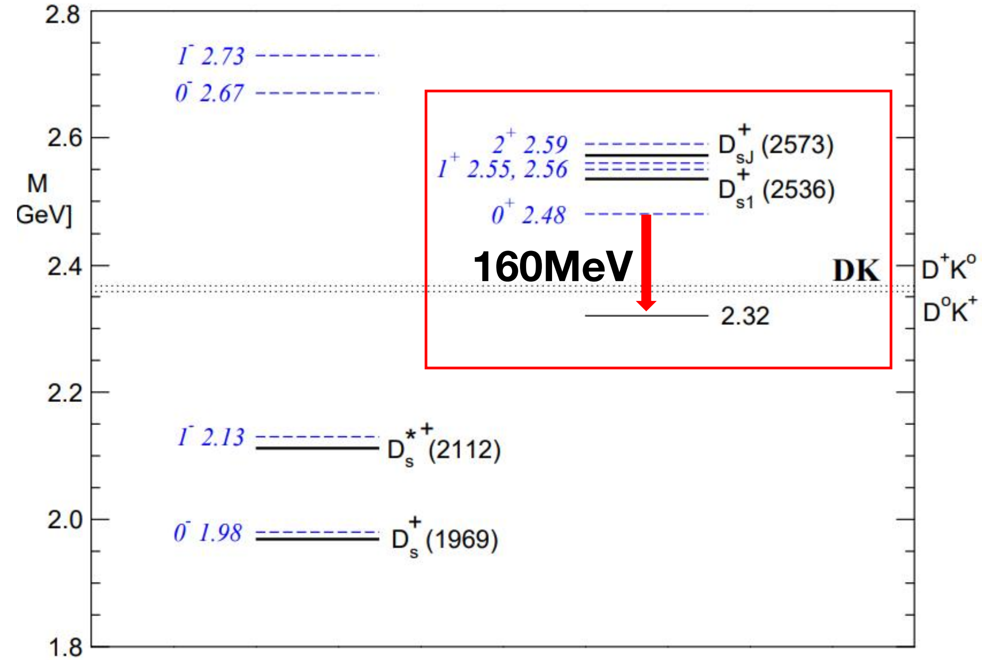
✓ **Produced in both e^+e^- and pp collisions**

Hidden charm/strange state easier to observe

$D_{s0}^*(2317)$

Ds0(2317), discovered by BABAR, CLEO and D0。





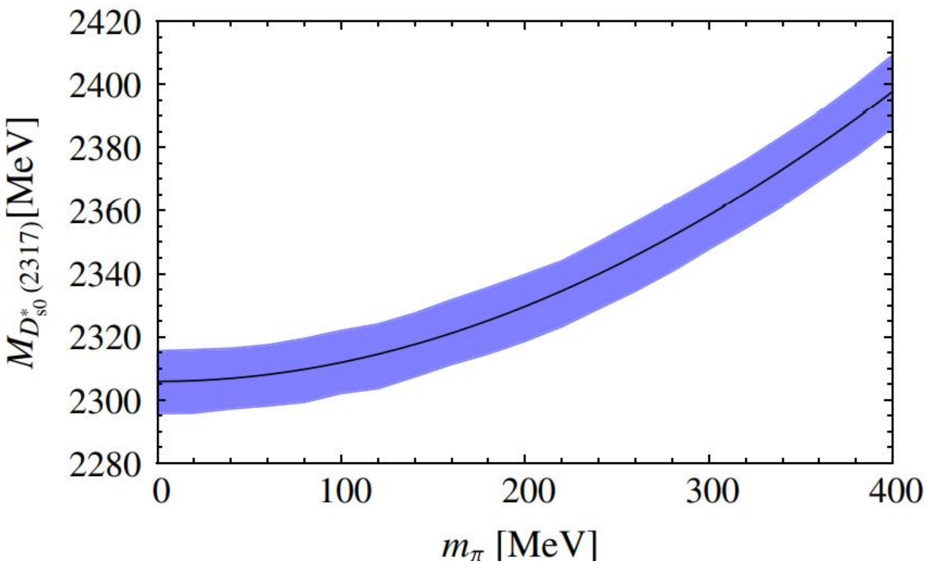
T. Barnes, et al. Phys. Rev. D 68, 054006

@PDG (Expe.)
Mass： 2317.7 MeV
Width： < 3.8MeV
Partner D_{s1}: 2460 MeV
$M(D_{s1})-M(D_{s0})$=140 MeV

@Quark model (Theo.)
Mass： 2480 MeV
Width： 270-990 MeV
Partner D_{s1}: 2560 MeV
$M(D_{s1})-M(D_{s0})$=80 MeV

Explanations of Ds0*(2317)

M. Altenbuchinger et al. Phys.Rev.D 89, 014026

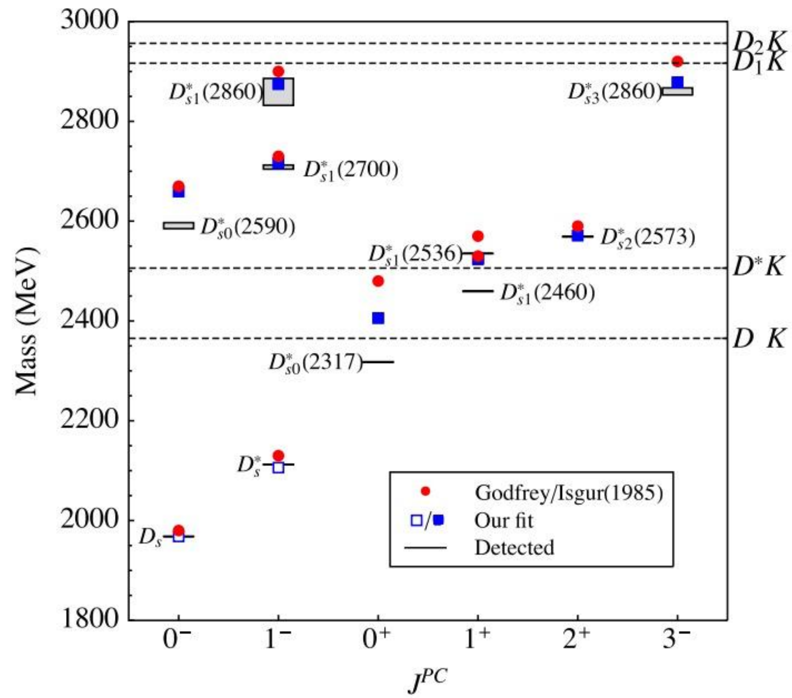


DK pole position@ChPT

TABLE V. Pole positions $\sqrt{s} = M - i\frac{\Gamma}{2}$ (in units of MeV) of charm mesons dynamically generated in the HQS UChPT.

(S, I)	$J^P = 0^+$	$J^P = 1^+$
(1, 0)	2317 ± 10	2457 ± 17
(0, 1/2)	$(2105 \pm 4) - i(103 \pm 7)$	$(2248 \pm 6) - i(106 \pm 13)$

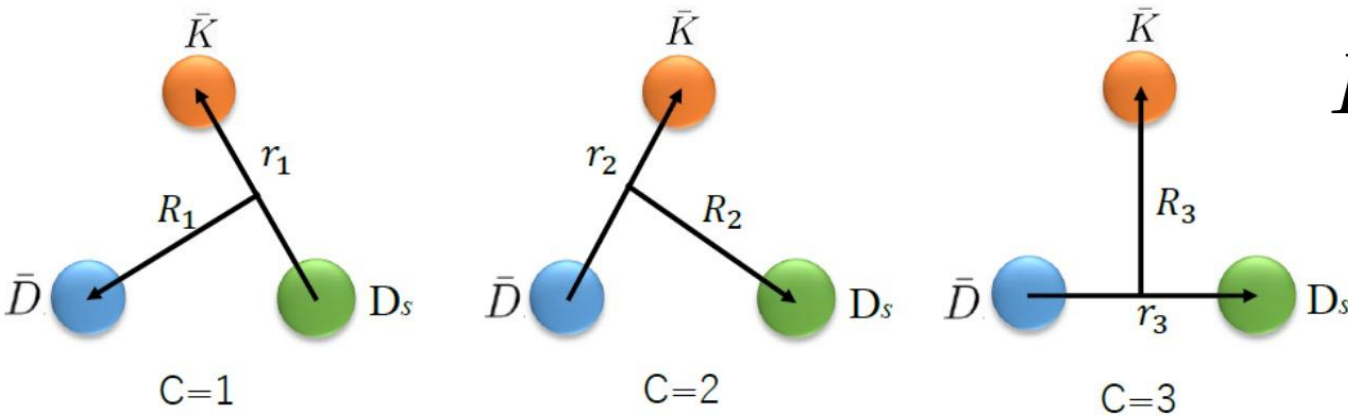
Z. Yang et al. PhysRevLett.128.112001



68 % DK+32 % $c\bar{s}$@LQCD

ChPT, Lattice and Exp. all surport that the D_{s0}(2317) is a DK molecule or at least has a large DK component.

Wave function of $\bar{D}_s D K$ with C parity



$\bar{D}_s D K$

$$\Psi^C = \frac{1}{\sqrt{2}}(\Psi_{\bar{D}_s D K} + C\Psi'_{D_s \bar{D}\bar{K}}), \quad \langle \Psi^C | (H - E) | \Psi^C \rangle = 0$$

$$C = \pm 1$$

$$\Psi'_{D_s \bar{D}\bar{K}} = \hat{C}\Psi_{\bar{D}_s D K} = \sum_{c=1,3} \Phi(r'_c, R'_c).$$

$$H = T + V + V_C$$

Two-body interaction (→ V)

C-parity interaction (→ V_C)

Solve three-body problem with GEM

Two-body interactions

DK interaction parameterized by a constant C_a

with **Contact-range EFT approach**

$DK - D_s\eta$ coupled channel interaction in matrix form

$$V^{J^P=0^+}_{DK-D_s\eta} = \begin{pmatrix} C_a & -\frac{\sqrt{3}}{2}C_a \\ -\frac{\sqrt{3}}{2}C_a & 0 \end{pmatrix}$$

V_{DK} in a Gaussian form in coordinate space

$$V(r) = C_a \frac{e^{(r/R_c)2}}{\pi^{3/2}R_c^3},$$

With SU(3) flavor symmtry

$$C_a^{DK} : C_a^{\bar{D}_s K} : C_a^{\bar{D}_s D} \approx 1 : 0.5 : 0.1$$

DK interaction fitting $D_{S0}(2317)$

Considering $D_{s0}(2317)$ as a $DK - D_s\eta$ molecule $+c\bar{s}$ state

TABLE IV. $D_{s0}^*(2317)$ coupling to its constituents (in units of GeV).

Momentum space

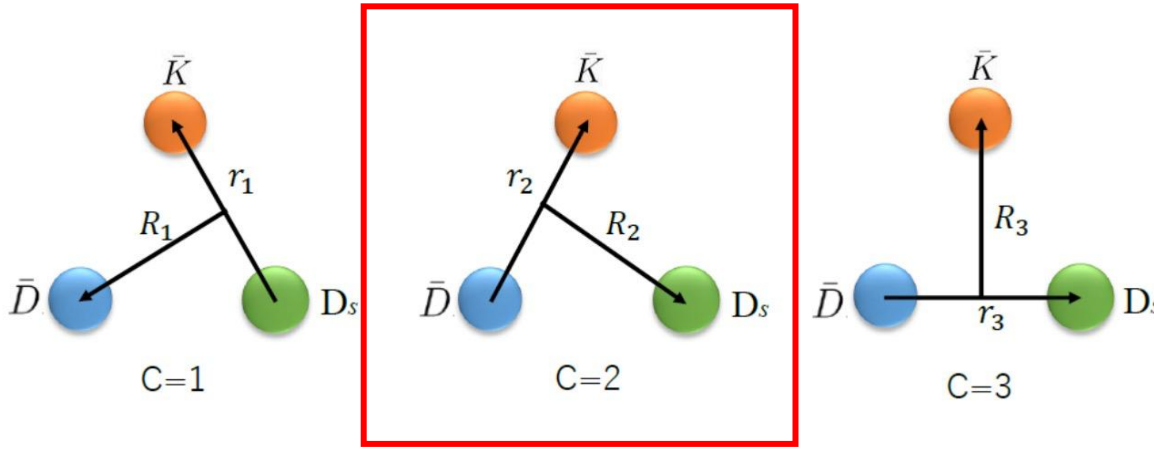
Couplings	$\Lambda = 0.50$	$\Lambda = 1.00$	$\Lambda = 1.50$	$\Lambda = 2.00$	$\Lambda = 0.50$	$\Lambda = 1.00$	$\Lambda = 1.50$	$\Lambda = 2.00$
$g_{D_{s0}^* DK}$	19.37	14.72	13.32	12.66	16.20	12.28	11.16	10.63
$g_{D_{s0}^* D_s\eta}$	13.23	9.54	8.40	7.86	10.42	7.70	6.89	6.50
$C_a(\mathrm{fm}^2)$	-5.78	-1.84	-1.03	-0.71	-6.96	-2.06	-1.12	-0.75
Compositeness	$\Lambda = 0.50$	$\Lambda = 1.00$	$\Lambda = 1.50$	$\Lambda = 1.00$	$\Lambda = 0.50$	$\Lambda = 1.00$	$\Lambda = 1.50$	$\Lambda = 2.00$
P_{DK}	0.92	0.90	0.89	0.88	0.65	0.63	0.62	0.62
$P_{D_s\eta}$	0.08	0.10	0.11	0.12	0.05	0.07	0.08	0.08

Coordinate space

Components of $D_{s0}^*(2317)$	$M(DK - D_s\eta)$	$M(DK)$	$M(c\bar{s})$ [4]	$P(c\bar{s})$	$P(DK)$	$P(D_s\eta)$
70% molecule+30% $c\bar{s}$	2280	2349	2406	30%	60%	10%
100% molecule	2318	2358	2406	0%	90%	10%
50% molecule+50% $c\bar{s}$	2230	2336	2406	50%	42%	8%

$DK - D_s\eta > c\bar{s}$ $\quad B_{DK} < 45$ MeV

C-parity interaction $\bar{D}_s D^*_{s0} - D_s \bar{D}^*_{s0}$



V_C **simplifies as**

η exchange potential

$$V^C_{\bar{D}_s D^*_{s0} - D_s \bar{D}^*_{s0}} = -\frac{2}{3} C \frac{k^2}{f_\pi^2} q_0^2 Y(r, m_{eff}, \Lambda)$$

$q_0 = m_{D^*_{s0}} - m_{D_s}, k = 0.56,$ $\Lambda = \alpha\Lambda_{QCD} + m_{eff}, m_{eff} = \sqrt{m_\eta^2 - (m_{D^*_{s0}} - m_{D_s})^2}.$

Binding and weights of Jacobi channels

0^{--} $\bar{D}_s D K$ molecule:

Sets	B.E.(0^{--})	$P_{\bar{D}_s K-D}$	$P_{DK-\bar{D}_s}$	$P_{\bar{D}_s D-K}$
$\alpha = 1$	22^{+23}_{-14}	11^{+1}_{-1} %	78^{-1}_{+2} %	11^{+0}_{-1} %
$\alpha = 2$	20^{+22}_{-13}	10^{+1}_{-1}%	80^{-1}_{+2} %	10^{+0}_{-1} %

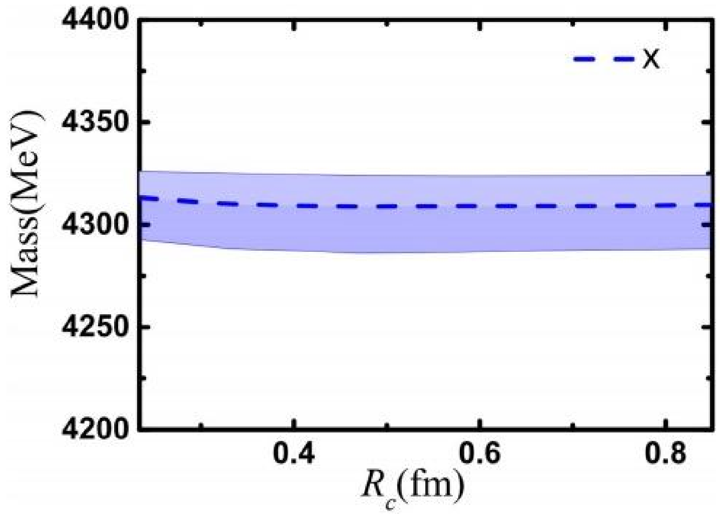
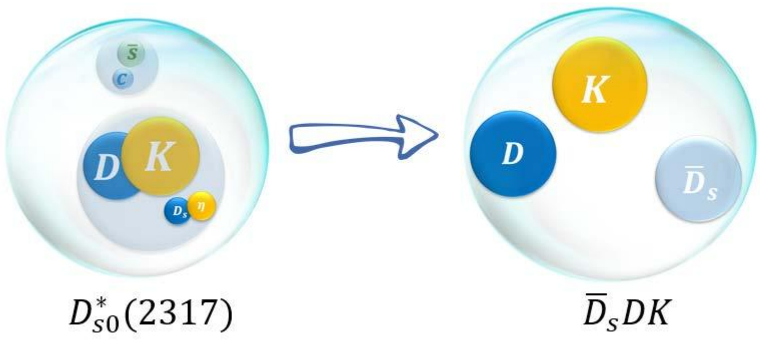


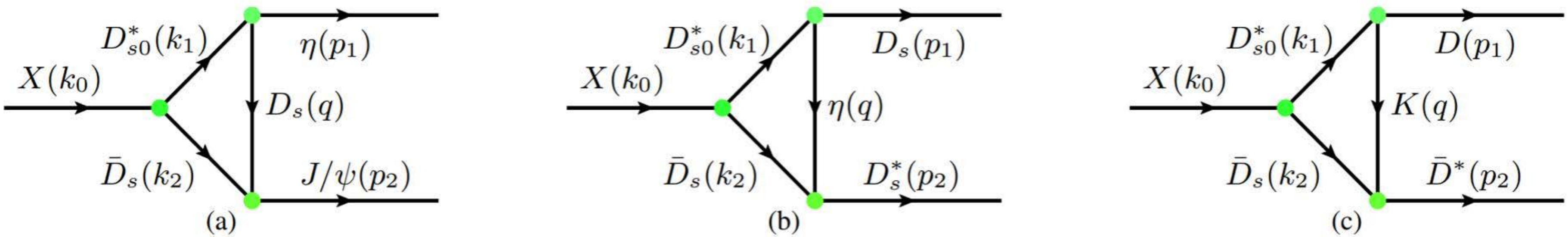
FIG. 5. Mass of X as a function of the cutoff R_c.



$$0^{--} \bar{D}_s DK : 4310^{+14}_{-24} MeV$$

Decays of 0^{--} $\bar{D}_s D K$ molecule

Triangle diagrams of the strong decays



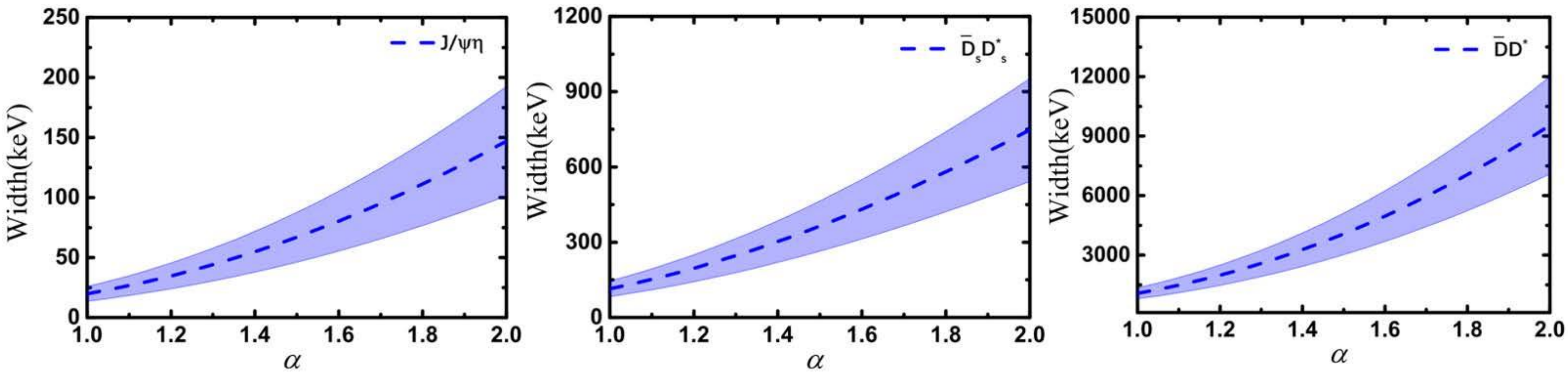
$$i\mathcal{M}_a = g_{XD^*_{s0}\bar{D}_s} g_{D^*_{s0}D_s\eta} g_{\psi\bar{D}_s D_s} \int \frac{d^4q}{(2\pi)^4}(k_2^\mu - q^\mu)\frac{1}{k_1^2 - m^2_{D^*_{s0}}}\frac{1}{k_2^2 - m^2_{\bar{D}_s}}\frac{1}{q^2 - m^2_{D_s}}\varepsilon_\mu(p_2)F(q^2),$$

$$i\mathcal{M}_b = g_{XD^*_{s0}\bar{D}_s} g_{D^*_{s0}D_s\eta} g_{\bar{D}_s D^*_s\eta} \int \frac{d^4q}{(2\pi)^4}q^\mu\frac{1}{k_1^2 - m^2_{D^*_{s0}}}\frac{1}{k_2^2 - m^2_{\bar{D}_s}}\frac{1}{q^2 - m^2_{\eta}}\varepsilon_\mu(p_2)F(q^2),$$

$$i\mathcal{M}_c = g_{XD^*_{s0}\bar{D}_s} g_{D^*_{s0}DK} g_{\bar{D}_s D^* K} \int \frac{d^4q}{(2\pi)^4}q^\mu\frac{1}{k_1^2 - m^2_{D^*_{s0}}}\frac{1}{k_2^2 - m^2_{\bar{D}_s}}\frac{1}{q^2 - m^2_{K}}\varepsilon_\mu(p_2)F(q^2),$$

$$\Gamma = \frac{1}{2J+1}\frac{1}{8\pi}\frac{|\vec{p}|}{M^2}|\bar{\mathcal{M}}|^2 \qquad F(q,\Lambda,m) = \left(\frac{\Lambda^2 - m_E^2}{\Lambda^2 - q^2}\right)^2$$

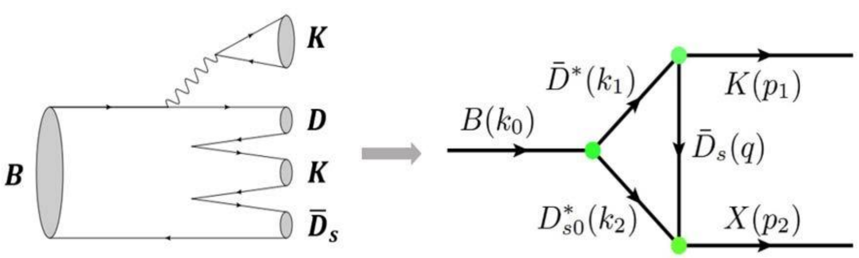
Partial decay widths

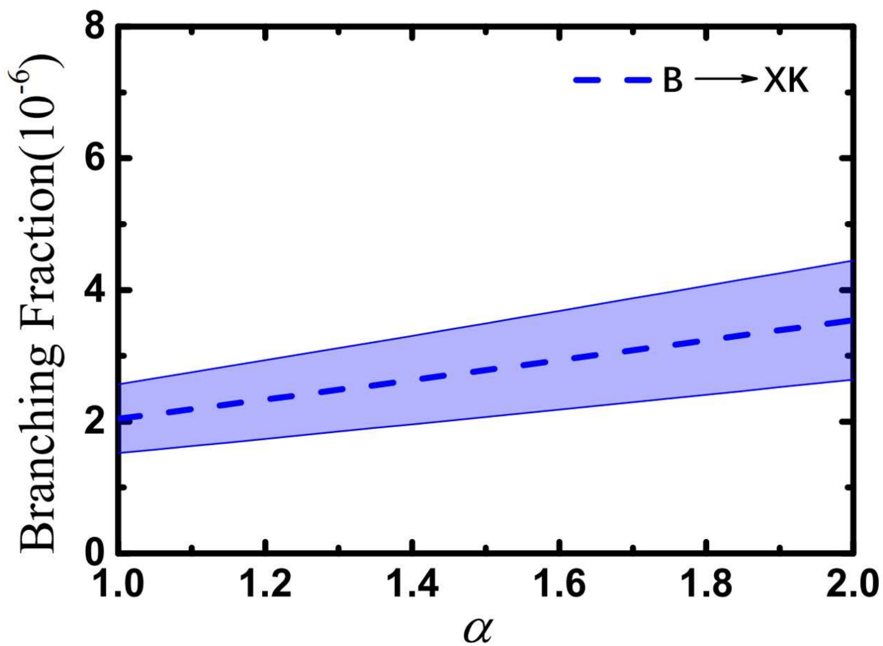


$X \to J/\psi\eta \sim 10^1$ $X \to \bar{D}_s D_s^* \sim 10^2$ $X \to \bar{D}^* D \sim 10^3$

Dominent decay: $X \to \bar{D}^* D$

Productions of 0^{--} $\bar{D}_s D K$ molecule





$$\mathcal{M} = g_{\bar{D}^*\bar{D}_s K} g_{D^*_{s0}\bar{D}_s X} \mathcal{A}(B \to D^*_{s0}\bar{D}^*)^\mu \frac{-g^{\mu\nu} + \frac{k_1^\mu k_1^\nu}{k_1^2}}{(k_1^2 - m^2_{\bar{D}^*})(k_2^2 - m^2_{D^*_{s0}})(q^2 - m^2_{\bar{D}_s})} p_1^\nu F(q^2),$$

$$\mathcal{A}(B \to D^*_{s0}\bar{D}^*) = \frac{G_F}{\sqrt{2}} V_{cb} V_{cs} a_1 f_{D^*_{s0}} \{-q_1 \cdot \varepsilon(q_2)(m_{D^*} + m_B) A_1(q_1^2) + (k_0 + q_2) \cdot \varepsilon(q_2) q_1 \cdot (k_0 + q_2) \frac{A_2(q_1^2)}{m_{D^*} + m_B} + (k_0 + q_2) \cdot \varepsilon(q_2)[(m_{D^*} + m_B) A_1(q_1^2) - (m_B - m_{D^*}) A_2(q_1^2) - 2 m_{D^*} A_0(q_1^2)]\},$$

Most promising process: $B^+ \to (X \to D^{*-} D^+) K^+ \sim 10^{-6}$

LHC integrated luminosity:		Events:
	50 fb^{-1}	10
	350 fb^{-1}	100

Summary:

arxiv:2501.11358

- 4310 MeV $\mathbf{0^{--}}$ $\bar{D}_s D K$ exotic molecule is predicted on the nature of $D_{s0}^*(2317)$ as a molecule and $c\bar{s}$ mixture
- Main decay $X \to \bar{D}^* D$ with several MeV width
- Production process $B \to (X \to \bar{D}^* D)K$ with 10^{-6} branching fraction

Experiment searches are strongly recommended!