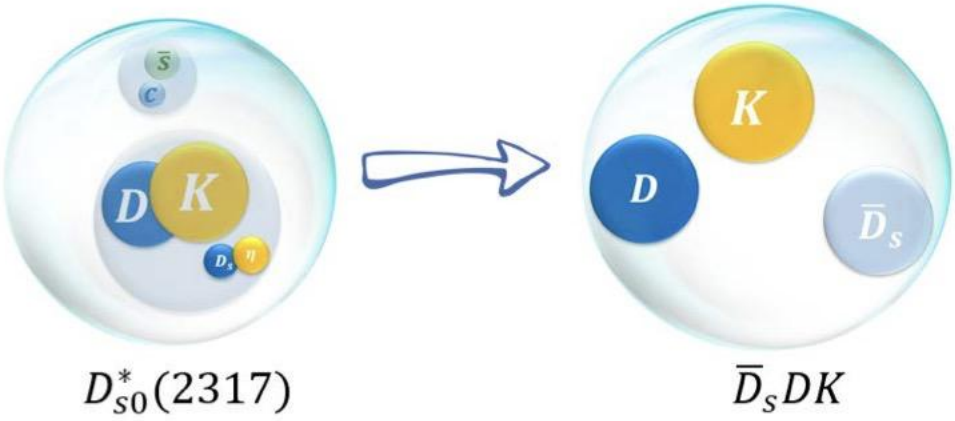

Existence of $\mathbf{0^{--}}$ $\bar{D}_s D K$ on nature of $D_{s0}^*(2317)$

arxiv:2501.11358

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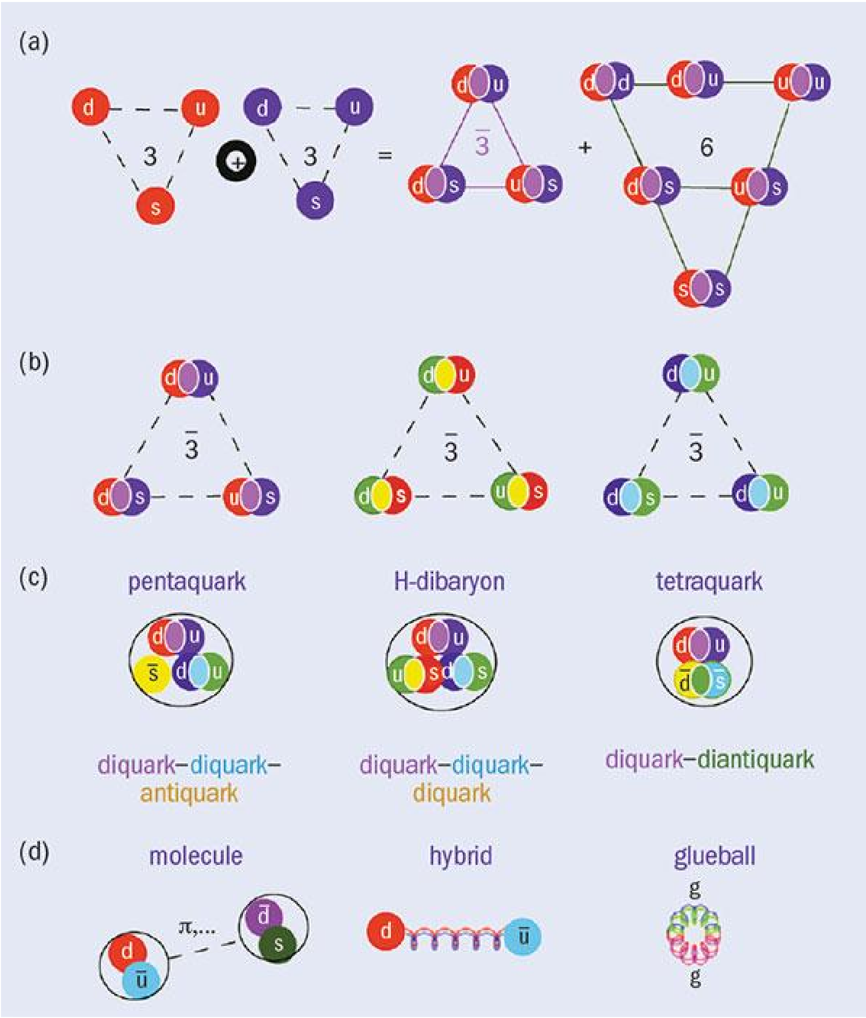
Collaborators: Liu-Ming Zhu and Li-sheng Geng

2025.0323@兰州

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**

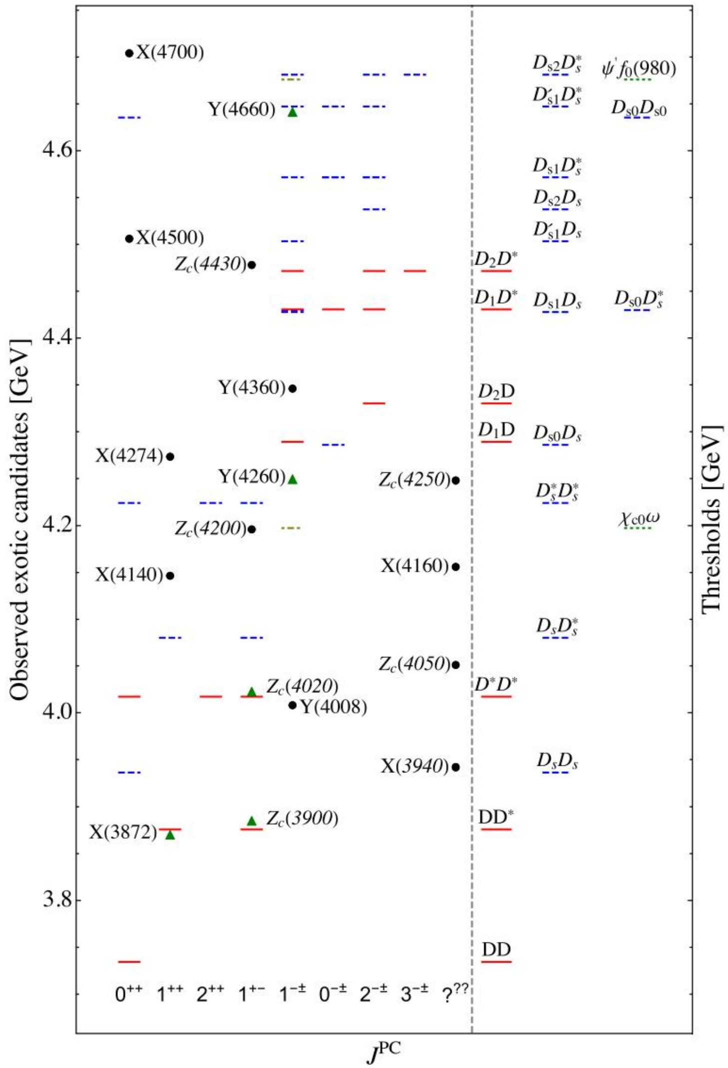
Composed of multi quarks(>3)

4. **Hadronic molecule**

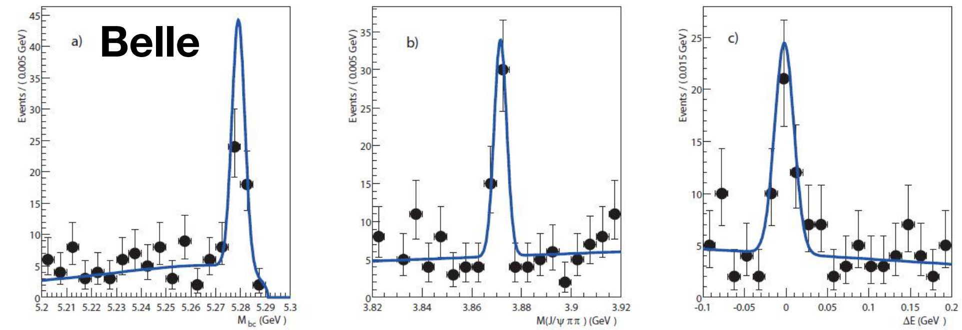
Composed of 2 or more hadrons

Hadronic molecules

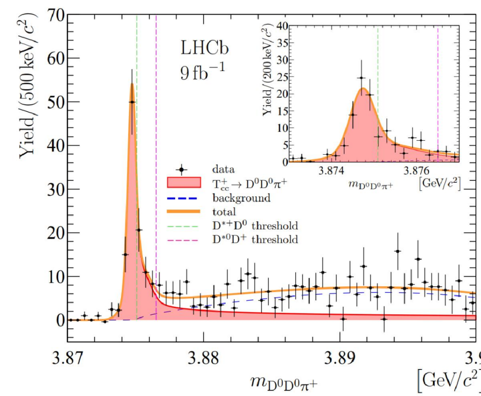
F.K. Guo, et al. Rev.Mod.Phys.90.015004



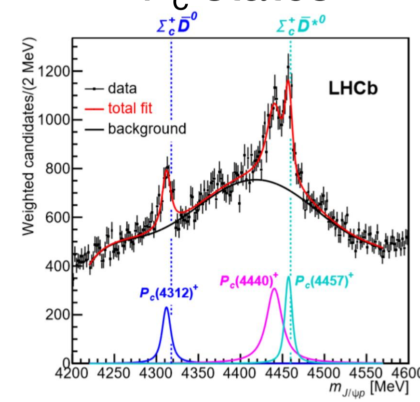
X(3872)



$T_{cc}(3875)$



P_c states

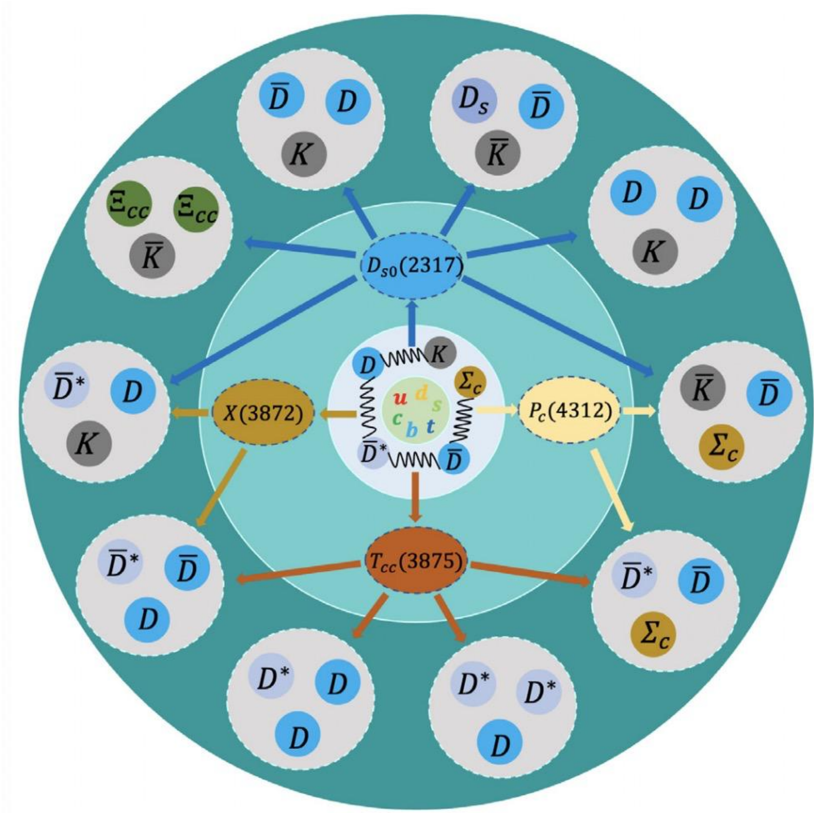


X(3872)、T_{cc}(3875)、P_c pentaquarks、D_{s0}*(2317) are interpreted as hadronic molecules.

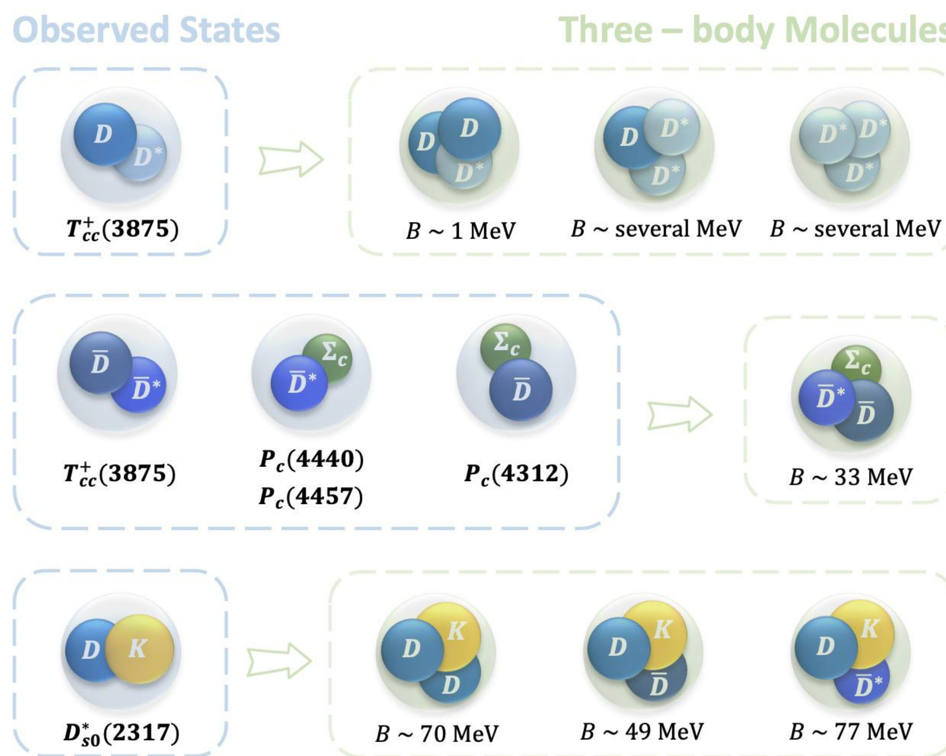
Many XYZ particles are close to two hadron mass thresholds.

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

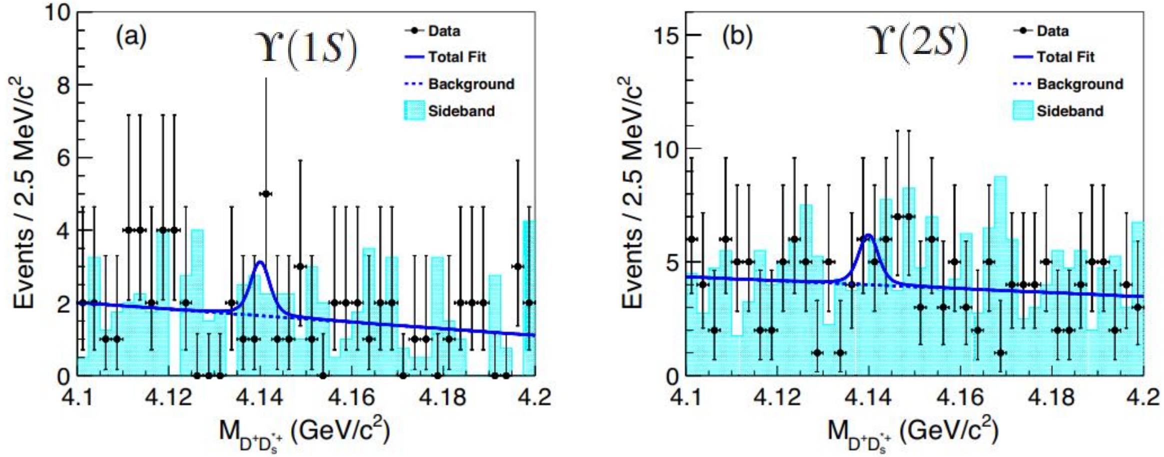


Three-body molecules based on two-body candidates

Seraching for DDK

Phys.Rev. D102 (2020) 112001@Belle

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

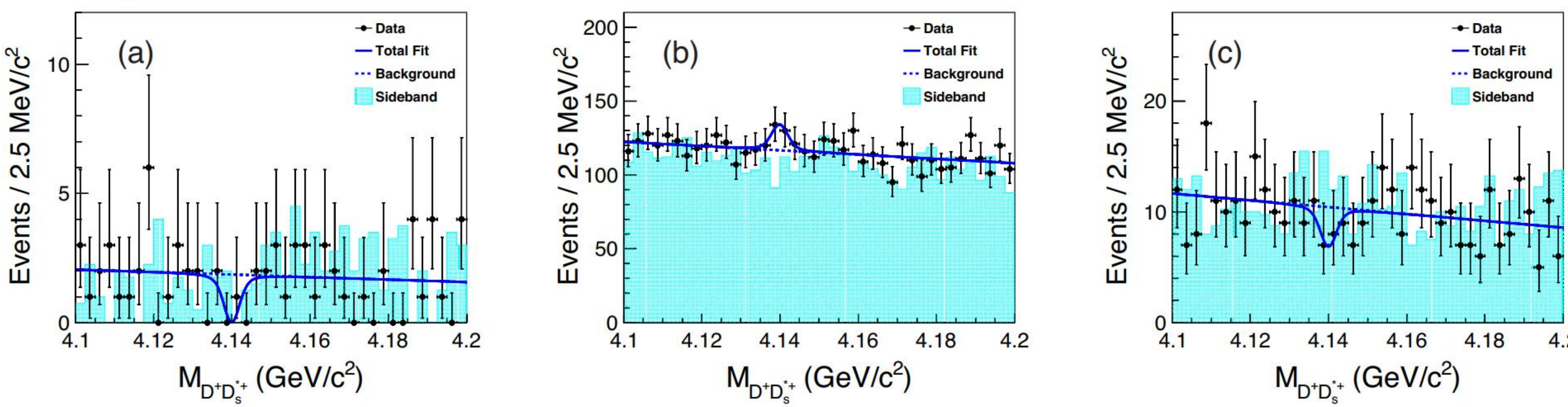


$e^+e^- \to R^{++} + \text{anything at } \sqrt{s} = 10.520/10.580/10.867 \text{ GeV},\ R^{++} \to D^+ D_s^{*+}$

$\sqrt{s} = 10.520$ GeV

$\sqrt{s} = 10.580$ GeV

$\sqrt{s} = 10.867$ GeV



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

How to find and verify three-body molecules?

- ✓ **No mixture of conventional hadrons**

  $\mathbf{0}^{--}$ exotic quantum numbers

- ✓ **Two-body system can not bind**

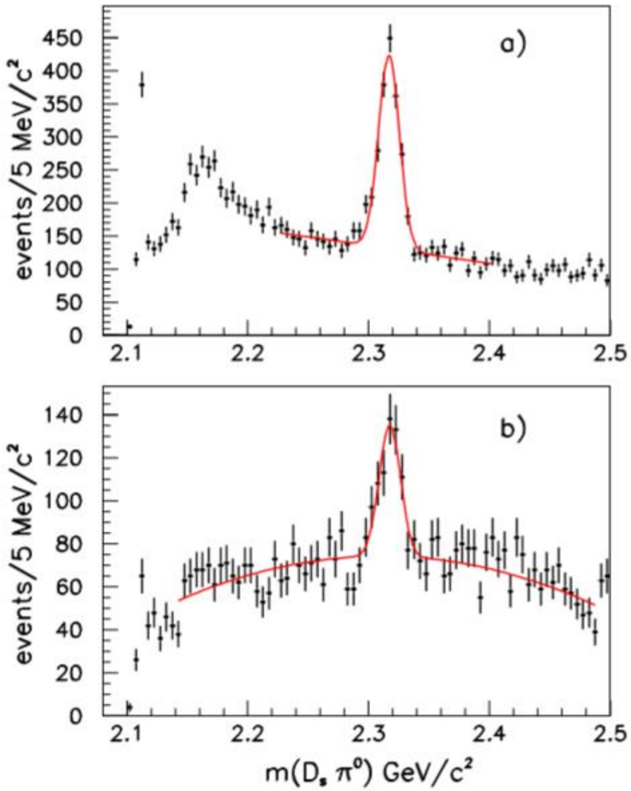
  Suppressed by the OBE model or OZI rule

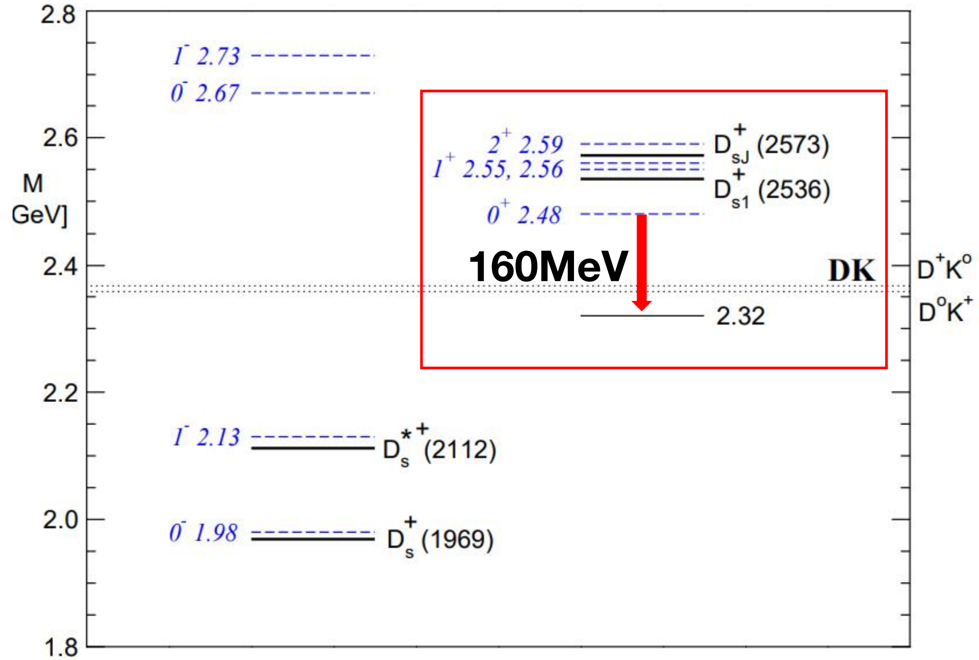
- ✓ **Produced in both e^+e^- and pp collisions**

  Hidden charm/strange state easier to observe

$D_{s0}^{*}(2317)$

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





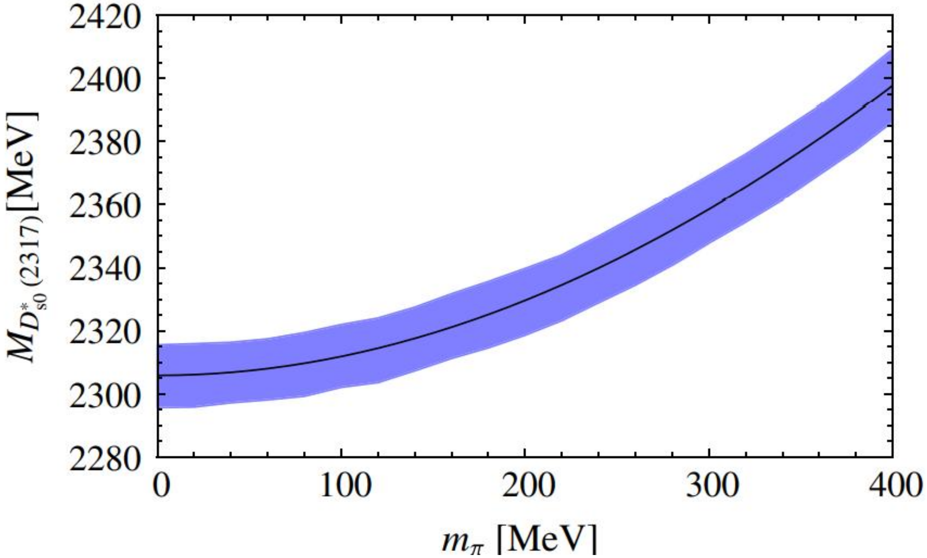
T. Barnes, et al. Phys. Rev. D 68, 054006

@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

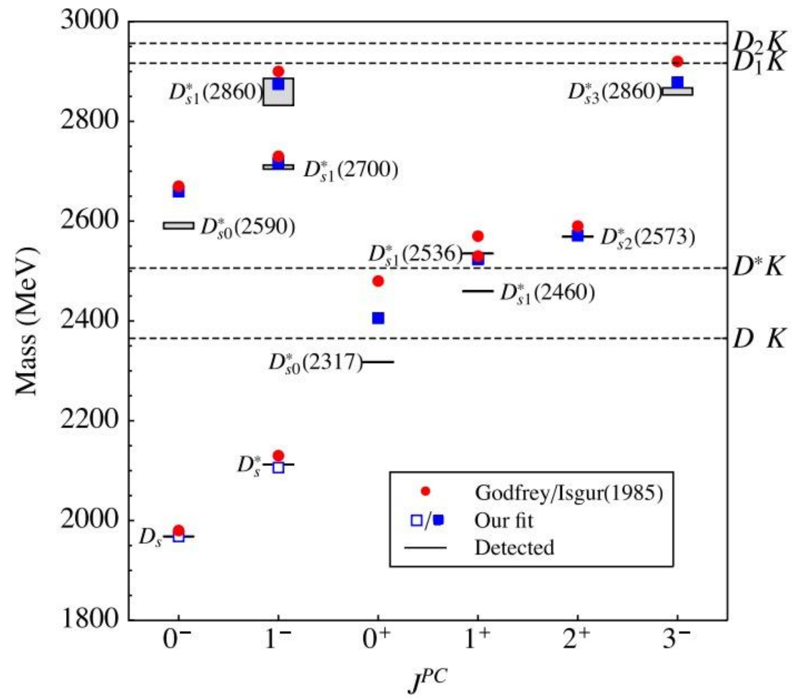
Molecular explanation of Ds0*(2317)

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



DK pole position@ChPT

Z. Yang et al. PhysRevLett.128.112001



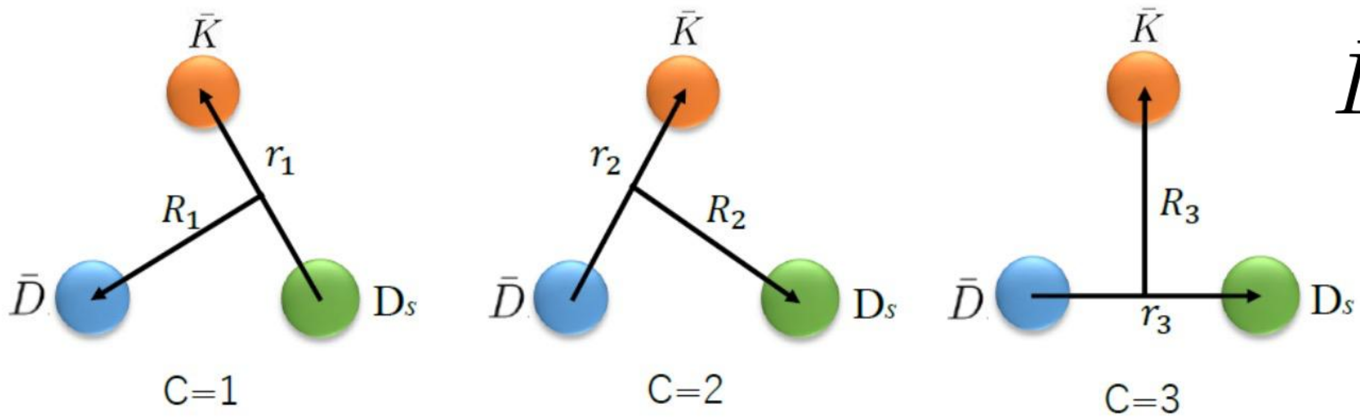
68 % DK+32 % $c\bar{s}$@LQCD

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)	$(2105 \pm 4) - i(103 \pm 7)$	$(2248 \pm 6) - i(106 \pm 13)$

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

C-parity interaction

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

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

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**

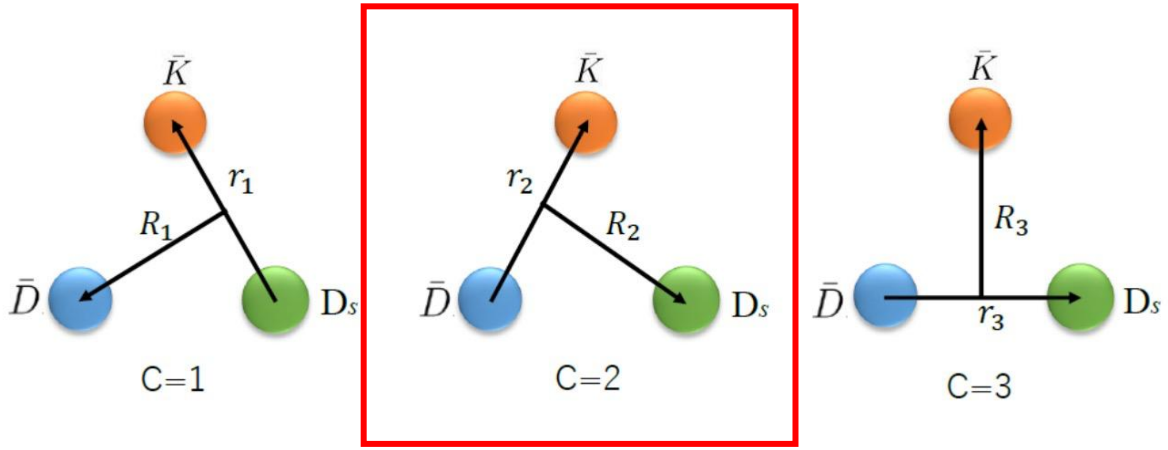
Couplings	$\Lambda = 0.50$	$\Lambda = 1.00$	$\Lambda = 1.50$	$\Lambda = 2.00$	$\Lambda = 0.50$	$\Lambda = 1.00$	$\Lambda = 1.50$	$\Lambda = 2.00$
$g_{D_{s0}^* DK}$	19.37	14.72	13.32	12.66	16.20	12.28	11.16	10.63
$g_{D_{s0}^* D_s\eta}$	13.23	9.54	8.40	7.86	10.42	7.70	6.89	6.50
$C_a(\mathrm{fm}^2)$	-5.78	-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%

[4] Z. Yang et al. PhysRevLett.128.112001

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



V_C **simplifies as**

η exchange potential

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

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

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} %

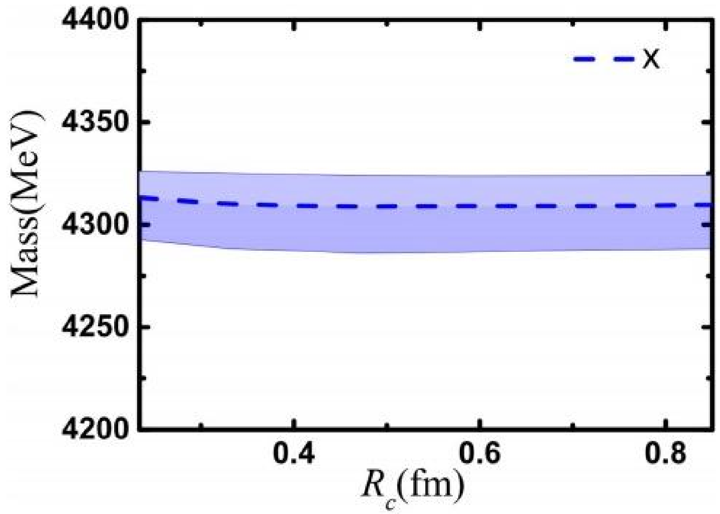
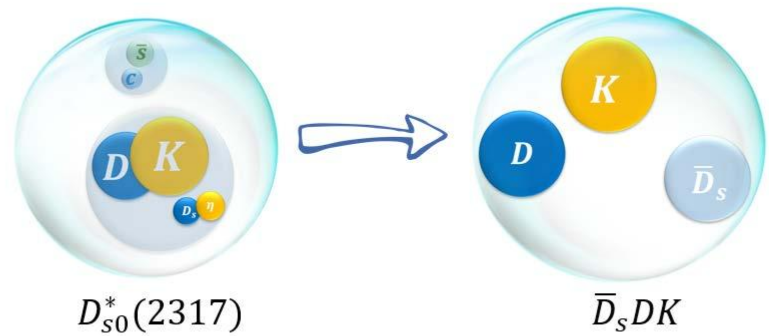


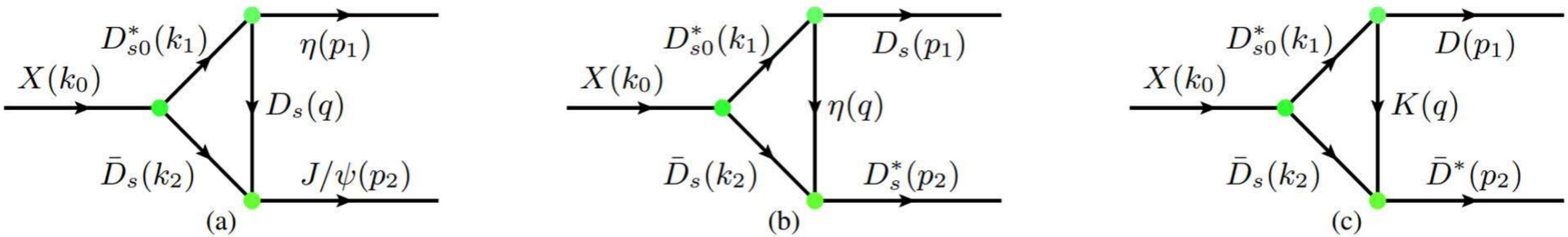
FIG. 5. Mass of X as a function of the cutoff R_c.



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

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

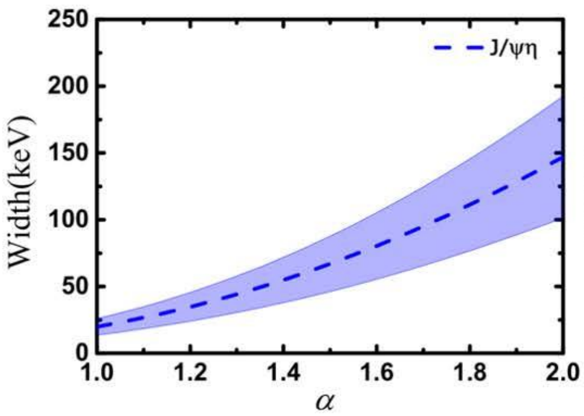
Triangle diagrams of the strong decays

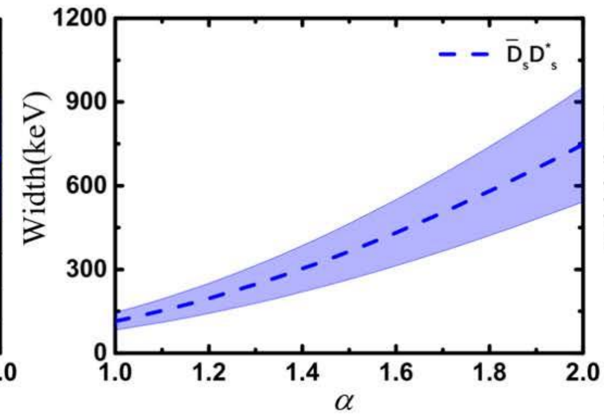


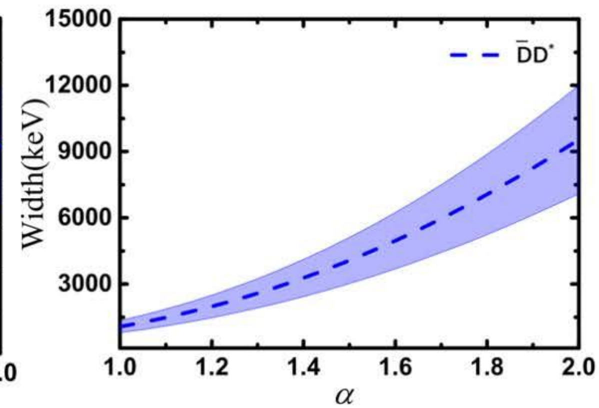
$$
\begin{aligned}
i\mathcal{M}_a &= g_{XD^*_{s0}\bar{D}_s} g_{D^*_{s0}D_s\eta} g_{\psi\bar{D}_s D_s} \int \frac{d^4q}{(2\pi)^4}(k_2^\mu - q^\mu)\frac{1}{k_1^2 - m^2_{D^*_{s0}}}\frac{1}{k_2^2 - m^2_{\bar{D}_s}}\frac{1}{q^2 - m^2_{D_s}}\varepsilon_\mu(p_2)F(q^2),\\
i\mathcal{M}_b &= g_{XD^*_{s0}\bar{D}_s}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

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

Partial decay widths



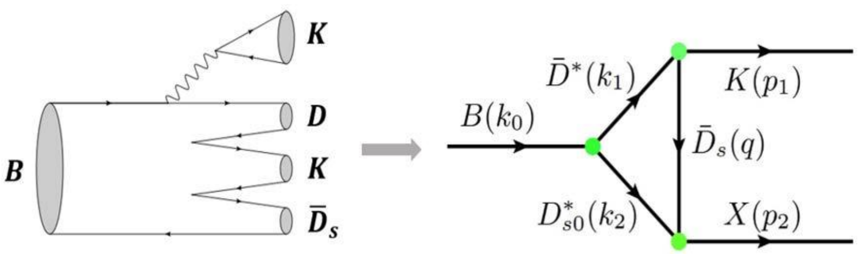


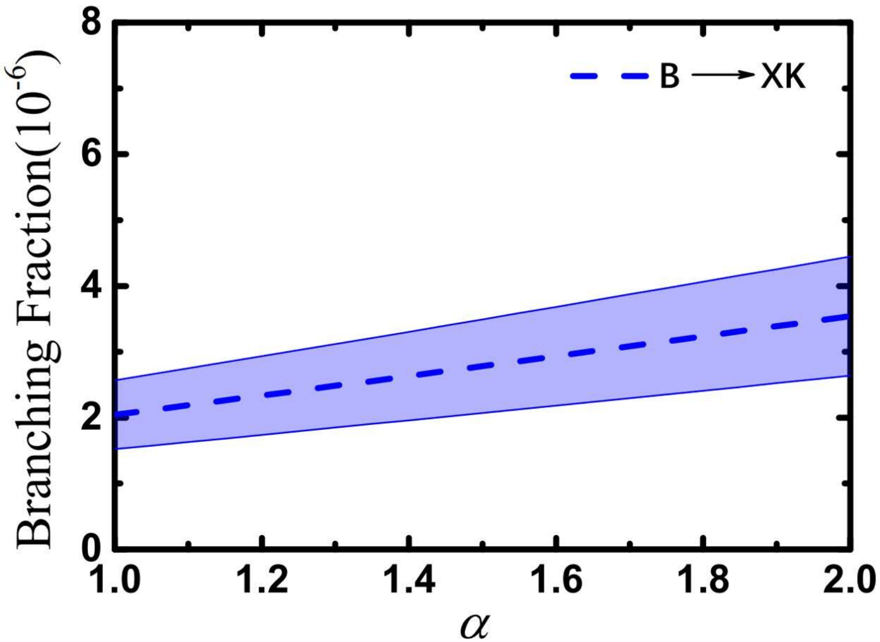


$X \to J/\psi\eta \sim 10^1$ $\quad X \to \bar{D}_s D_s^* \sim 10^2$ $\quad X \to \bar{D}^* D \sim 10^3$

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

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





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

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

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

LHC integrated luminosity:	50 fb^{-1}	Events:	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 recommanded!