Absence of the $Z_c(3900)$ in B decays

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In collaboration with

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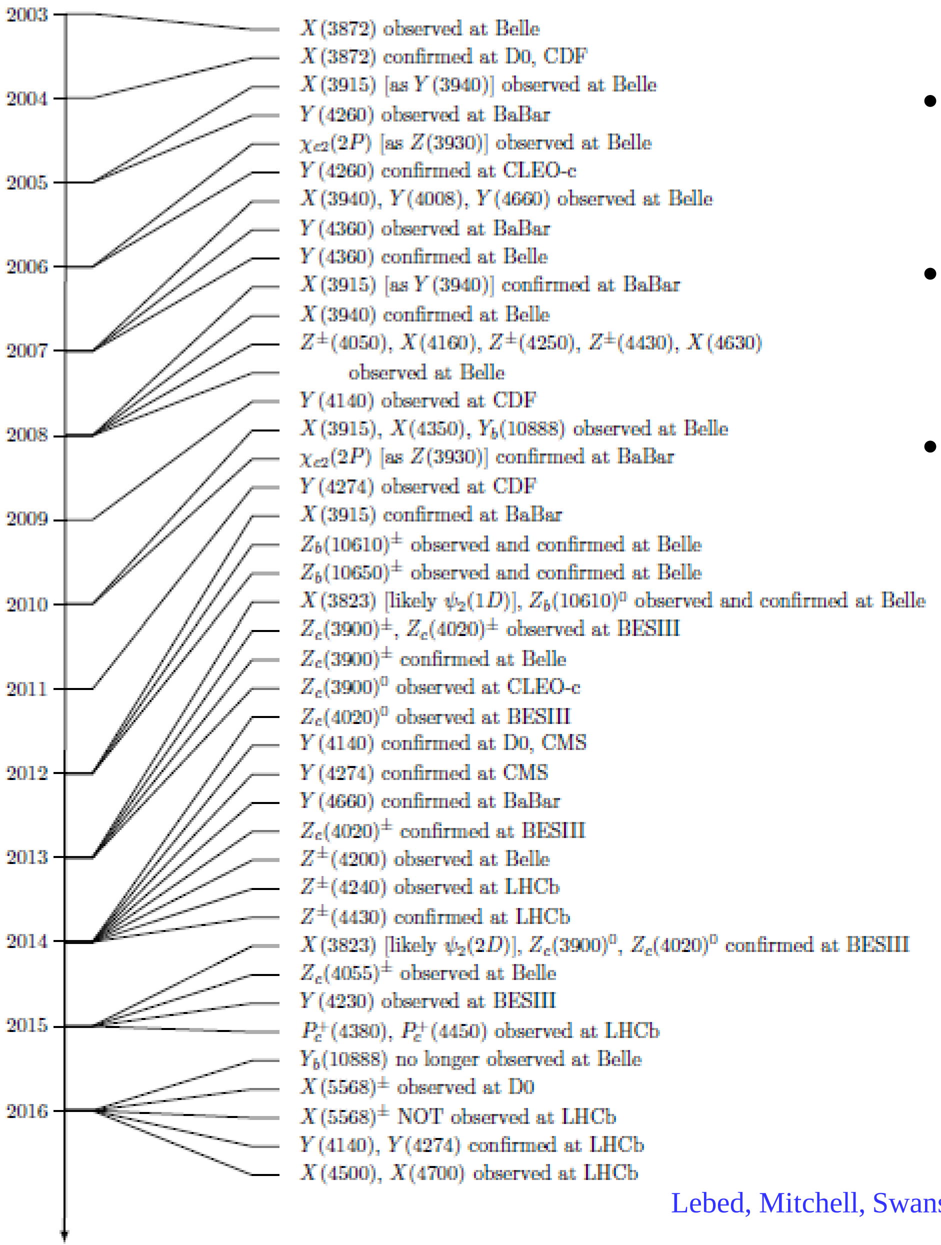
Based on the paper:
Isospin analysis of $B \to D^* \overline{D} K$ and the absence of the Zc(3900) in B decays,
arXiv: 1706:00960

Heavy-quark exotic hadrons



- Many new hadrons have been observed in the last decade.
- They can not fit into the conventional hadrons (mass and properties).
- Most of the exotic hadrons were found through b hadron decays, e^+e^- annihilation, or both.

Lebed, Mitchell, Swanson, PPNP93(2017)143

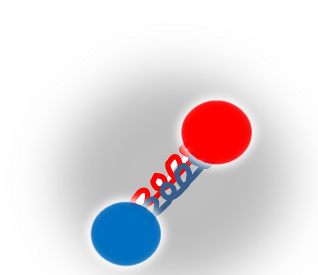
Hadron structures

- Conventional hadrons

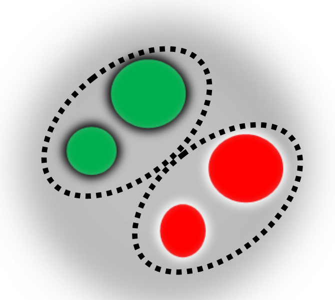
meson

baryon

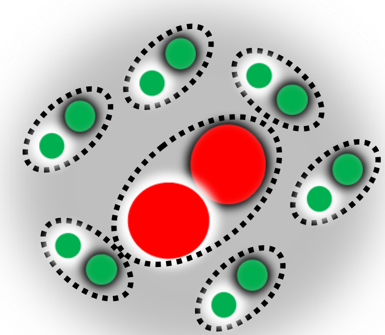
- Proposals for the heavy exotic hadrons



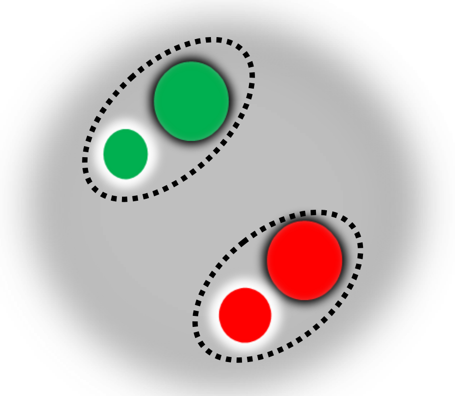
hybrid



Compact multiquark

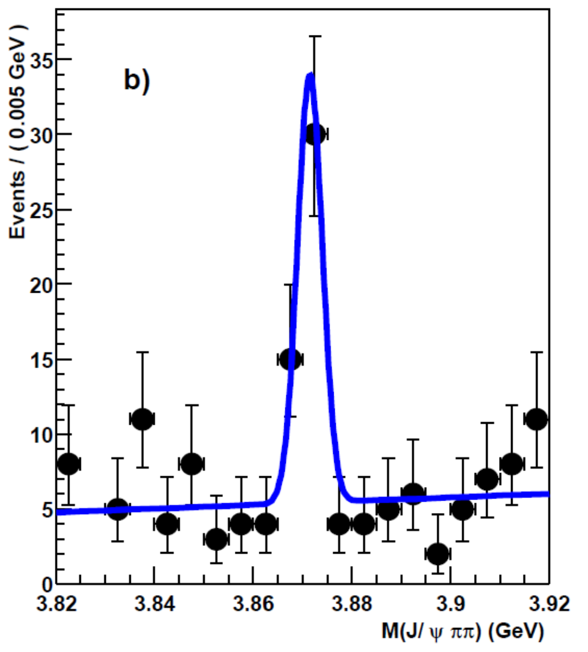


Hadro-Quarkonium



Hadronic molecule

X(3872)



- Discovered in $J/\psi\pi\pi$ mass distribution in B decay. Belle, PRL91(2003)262001
- Quantum number $J^{PC}=1^{++}$ LHCb, PRL110(2013)222001
- Tiny width $\Gamma<1.2$ MeV
- Extremely close to D^0D^{*0} threshold: $M_{D^0}+M_{D^{*0}}-M_X=(0.00\pm0.18)MeV$.
- Promising candidate for a $D^*\overline{D}$ hadronic molecule.

$Z_c(3900)$

- The charged one was observed in $J/\psi\pi^{\pm}$ mass distribution by BESIII and Belle.

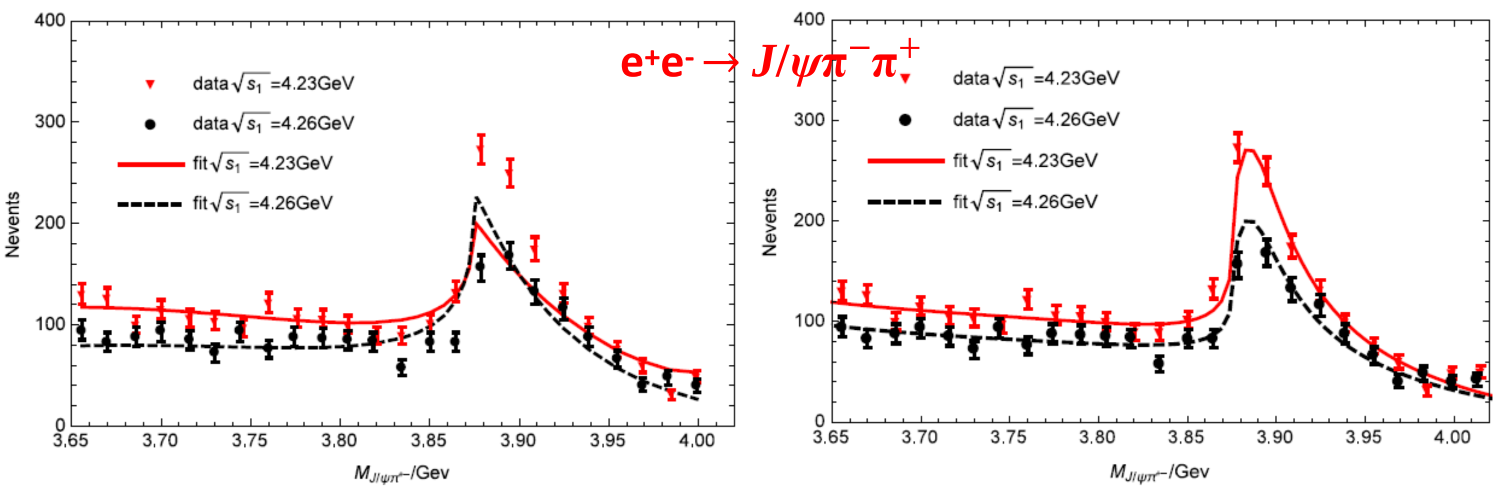
BESIII, PRL110(2013)252001; Belle, PRL110(2013)252002

- must contain at least 4 quarks, $c\bar{c}u\bar{d}$.
- slightly above the $D^*\bar{D}$ threshold.
  → Cusp effect. But in this scenario, it is not self consistent.

Guo, Hanhart. Wang and Zhao, PRD91(2015)051504

- hadronic molecule, not triangle singularity

Gong, Pang, Wang and Zheng, arXiv:1612.08159



(a) Triangle singularity

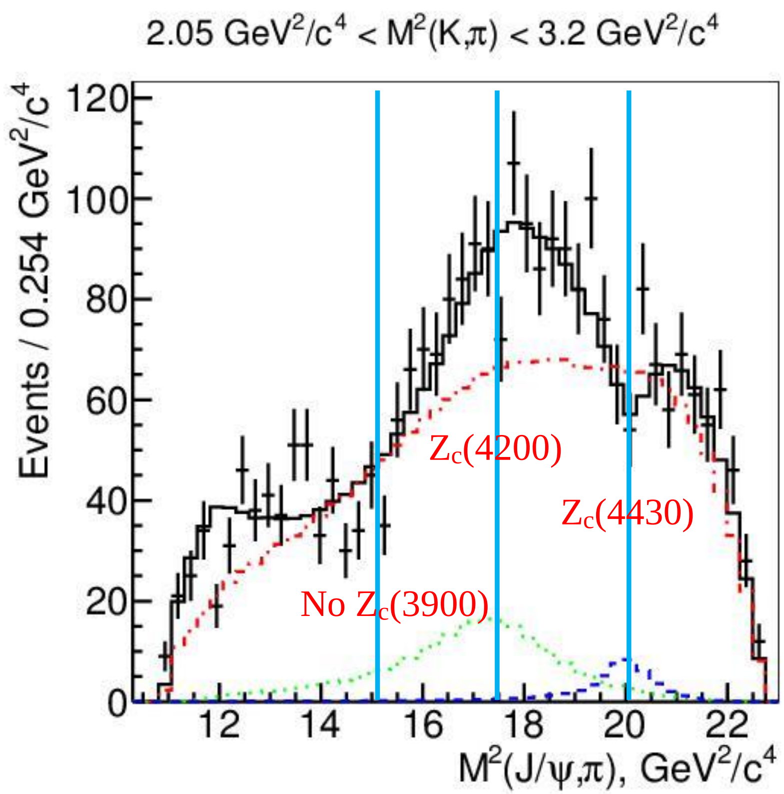
(b) Hadronic molecule

Absence of the $Z_c(3900)$

- The $Z_c(3900)$ is found through $e^+e^- \to J/\psi\pi\pi$ or $D^*\overline{D}\pi$.
- However, it was not found in the $B \to KZ_c$ with $Z_c \to J/\psi\pi$ decay. Instead, the $Z_c(4200)$ and $Z_c(4430)$ were found.

Belle performed a search for the $Z_c(3900)$. But no significant signal is found.

Belle, PRD90(2014)112009



Absence of the $Z_c(3900)$

What can we known from the absence ?

- The absence may have something to do with its internal structure.

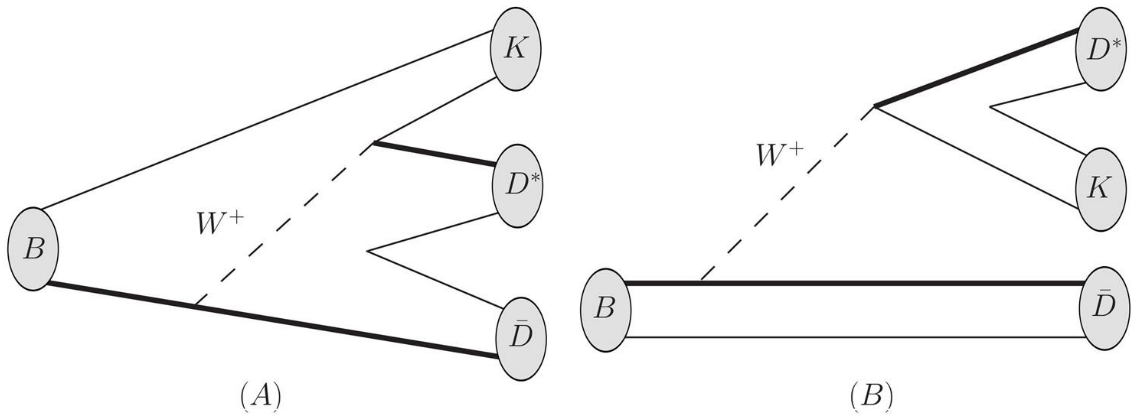
- Under the hadronic molecular picture, both X(3872) and $Z_c(3900)$ are $D^*\overline{D}$ bound state. The isospin of the $Z_c(3900)$ is 1, while for the X(3872) is 0.

- The production of the $D^*\overline{D}$ pair with isospin 1 is highly suppressed in B decays.

→ The Zc(3900) being a $D^*\overline{D}$ hadronic molecule naturally explains its absence in the B decays.

Isospin relation

- The decay $B \to D^*\overline{D}K$ occurs through isospin conserved weak transition $b \to c\overline{c}s$. The isospin violation diagram is CKM suppressed.



- Light quark pair created from the vacuum is a flavor and isospin singlet. The isospin relations:

$$\mathcal{M}[B^0 \to D^{*0} D^- K^+] = -\frac{1}{\sqrt{2}} B_1, \qquad \mathcal{M}[B^+ \to D^{*+} \bar{D}^0 K^0] = \frac{1}{\sqrt{2}} B_1,$$

$$\mathcal{M}[B^0 \to D^{*+} D^- K^0] = \frac{1}{\sqrt{2}} A_0 + \frac{1}{2}(B_0 + B_1) e^{i\theta}, \qquad \mathcal{M}[B^+ \to D^{*0} \bar{D}^0 K^+] = \frac{-1}{\sqrt{2}} A_0 + \frac{1}{2}(B_0 - B_1) e^{i\theta},$$

$$\mathcal{M}[B^0 \to D^{*0} \bar{D}^0 K^0] = -\frac{1}{\sqrt{2}} A_0, \qquad \mathcal{M}[B^+ \to D^{*+} D^- K^+] = \frac{1}{\sqrt{2}} A_0.$$

Production of $D^*\overline{D}$

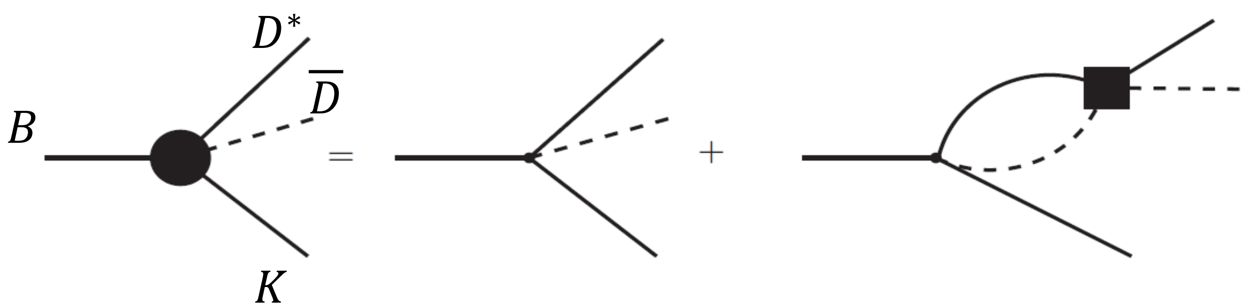
- The amplitudes A_0 and $B_{0(1)}$ have the simple form at the $D^*\overline{D}$ threshold,

$$A_0 = a_0 P \cdot \epsilon^*$$
$$B_{0(1)} = b_{0(1)} P \cdot \epsilon^*$$

which is required by Lorentz invariance.

Braaten, Kusunoki and Nussinov, PRL93(2004)162001

- Production of $D^*\overline{D}$ pair
  = Short-distance direct production + rescattering of the charmed mesons



- In addition, the relative momentum between kaon and charmed mesons is very large near $D^*\overline{D}$ threshold. The rescattering between kaon and one charmed meson can be neglected.

Rescattering of $D^*\overline{D}$

- The rescattering amplitude for the two channels $D^{*0}\overline{D}^0$ and $D^{*+}D^-$.

  Use the renormalizable effective field theory that describes two scattering channels with S-wave contact interactions.

Cohen, Gelman and Kolck, PLB588(2004)57

- The inverse of the two-body scattering amplitude:

$$\frac{1}{\mathcal{T}(E)} = \frac{1}{2\pi}\begin{pmatrix} \mu_1(-1/a_{11} - ip_0) & \sqrt{\mu_1\mu_2}/a_{12} \\ \sqrt{\mu_1\mu_2}/a_{12} & \mu_2(-1/a_{22} - ip_c) \end{pmatrix}$$

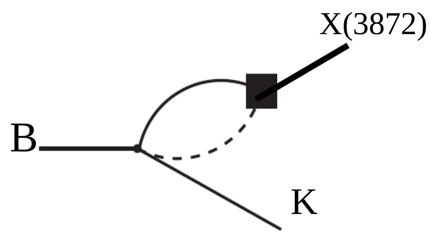
1 for channel $D^{*0}\overline{D}^0$;
2 for channel $D^{*+}D^-$.

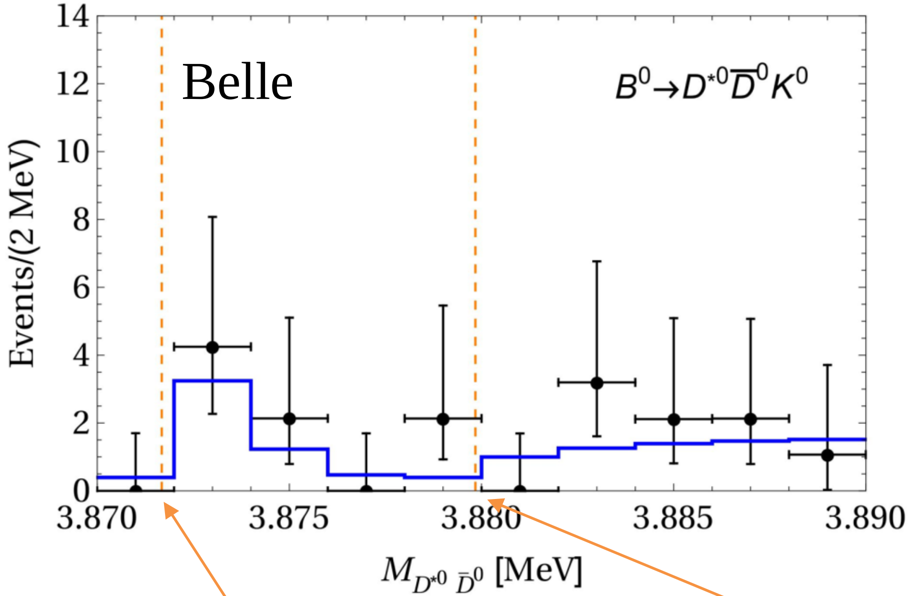
a_{11}, a_{12}, a_{22} are the unknown parameter.

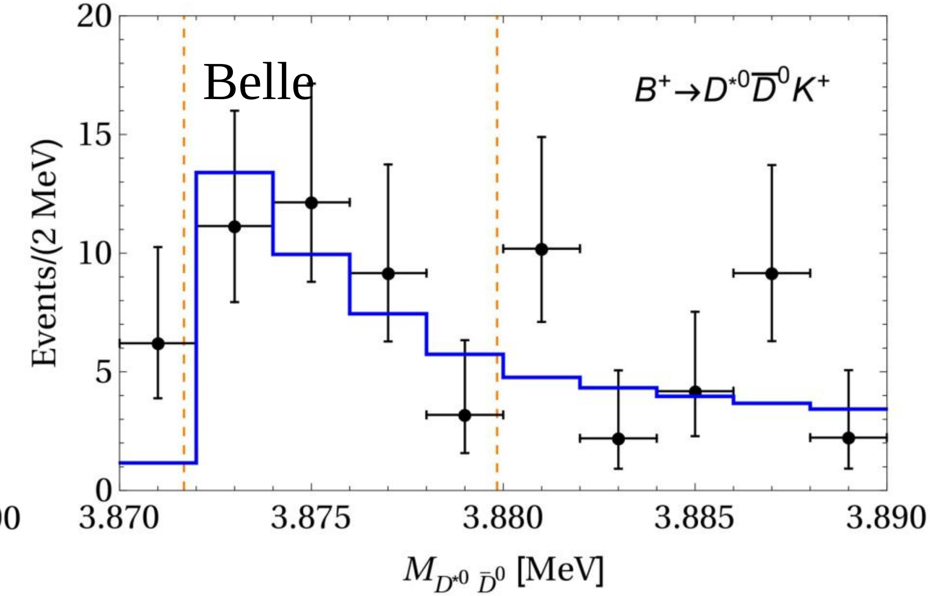
$D^*\overline{D}$ distributions

Fit the differential distributions of $D^{*0}\overline{D}^0$ and the ratio of X(3872) production:

$$\begin{cases} \dfrac{d\Gamma}{dM} = \dfrac{\mu\lambda^{3/2}(m_B, M, m_K)}{256\pi^3 m_B^3 M^2}\lambda^{1/2}(M, m_{D^{*0}}, m_{\bar{D}^0})|\mathcal{A}(E)|^2, \\[2ex] \dfrac{\mathcal{B}(B^0 \to XK^0)}{\mathcal{B}(B^+ \to XK^+)} = 0.50 \pm 0.14 \pm 0.04 \end{cases}$$







$D^{*0}\overline{D}^0$ threshold

$D^{*+}D^-$ threshold

Fit results

$$\mathcal{M}[B^0 \to D^{*0} D^- K^+] = -\frac{1}{\sqrt{2}} B_1, \qquad \mathcal{M}[B^+ \to D^{*+} \bar{D}^0 K^0] = \frac{1}{\sqrt{2}} B_1,$$

$$\boxed{\mathcal{M}[B^0 \to D^{*+} D^- K^0] = \frac{1}{\sqrt{2}} A_0 + \frac{1}{2}(B_0 + B_1) e^{i\theta}, \qquad \mathcal{M}[B^+ \to D^{*0} \bar{D}^0 K^+] = \frac{-1}{\sqrt{2}} A_0 + \frac{1}{2}(B_0 - B_1) e^{i\theta},}$$

$$\mathcal{M}[B^0 \to D^{*0} \bar{D}^0 K^0] = -\frac{1}{\sqrt{2}} A_0, \qquad \mathcal{M}[B^+ \to D^{*+} D^- K^+] = \frac{1}{\sqrt{2}} A_0.$$

$$A_0 = a_0 P \cdot \epsilon^* \qquad B_{0(1)} = b_{0(1)} P \cdot \epsilon^*$$

- a_0 and b_0 (b_1) are direct production strengths of diagram (A) and (B) with I=0 (I=1).
- The fit value for $|b_1|$ is quite small compared to $|a_0|$.
- For each individual channel, the ratios of the I = 1 and I = 0 components are:

Parameter	value
$\lvert a_0\rvert$	$(2.23 \pm 1.02)N \ \mathrm{GeV}^{-1}$
θ	0.46 ± 0.43 rad
$\lvert b_0\rvert$	$(5.00 \pm 1.10)N \ \mathrm{GeV}^{-1}$
$\lvert b_1\rvert$	$0.014^{+3.84}_{-0.014} N \ \mathrm{GeV}^{-1}$
a_{11}	$-1.56 \times 10^{11} \pm 0.28$ fm
a_{12}	3.37 ± 0.27 fm
a_{22}	0.94 ± 0.04 fm
$\chi^2/n_{d.o.f.}$	$7.44/14$

$$\boxed{B^0 \to D^{*+} D^- K^0 :}$$

$$\frac{|B_1/2|^2}{|A_0/\sqrt{2} + B_0 e^{i\theta}/2|^2} = (3.30 \times 10^{-6})^{+0.30}_{-3.30\times 10^{-6}},$$

$$\boxed{B^+ \to D^{*0} \bar{D}^0 K^+ :}$$

$$\frac{|B_1/2|^2}{|-A_0/\sqrt{2} + B_0 e^{i\theta}/2|^2} = (3.11 \times 10^{-5})^{+1235.56}_{-3.11\times 10^{-5}}.$$

Summary

- ✓ The internal structure of the $Z_c(3900)$ being a $D^*\overline{D}$ hadronic molecule naturally explains its absence in the B decays.

- ➢ Since the large uncertainty of the current experimental data, further high statistics data are necessary.

- ➢ Expect the explanation from other models, for example tetraquark. The explanation would be useful to understand the internal structure of the $Z_c(3900)$.

Thank you for your attention !