$X_0(2900)$ in the molecular picture

Qian Wang
South China Normal University

In memory of Prof. Misha B. Voloshin

Experimental and theoretical status of and perspectives for XYZ states
April 12th-15th, 2021

Hu, Lao, Ling, QW, CPC45(2021)021003

Outline

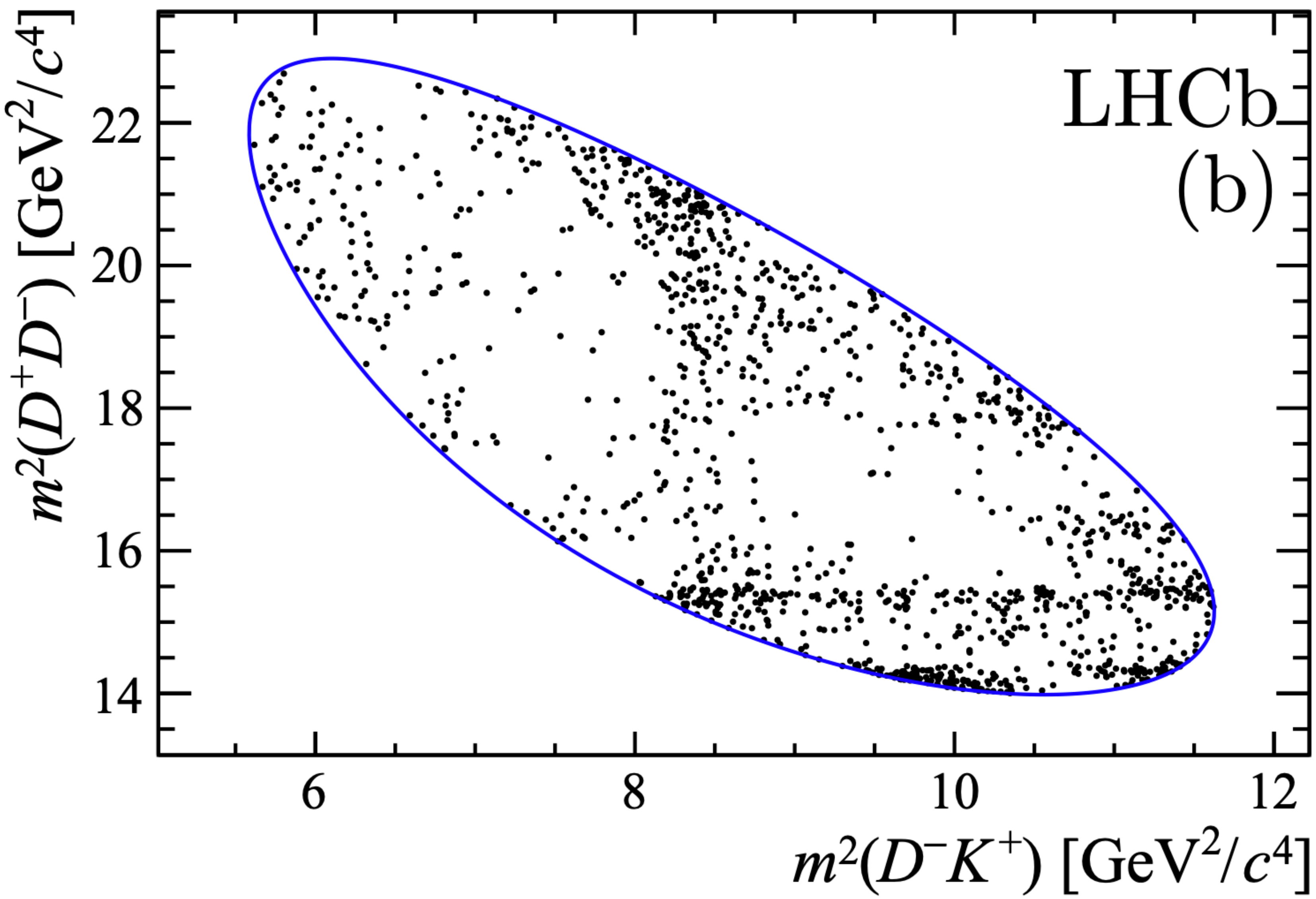
1. The observation of the $X_0(2900)$
2. Heavy quark spin structure
3. $X_0(2900)$ as a $\bar{D}^*K^*$ bound state
4. $X_0(2900)$ as a $\bar{D}^*K^*$ virtual state
5. Summary and Outlook

Outline

1. The observation of the $X_0(2900)$
2. Heavy quark spin structure
3. $X_0(2900)$ as a $\bar{D}^*K^*$ bound state
4. $X_0(2900)$ as a $\bar{D}^*K^*$ virtual state
5. Summary and Outlook

The observation of the $X_0(2900)$

$B^+ \to D^+D^-K^+$



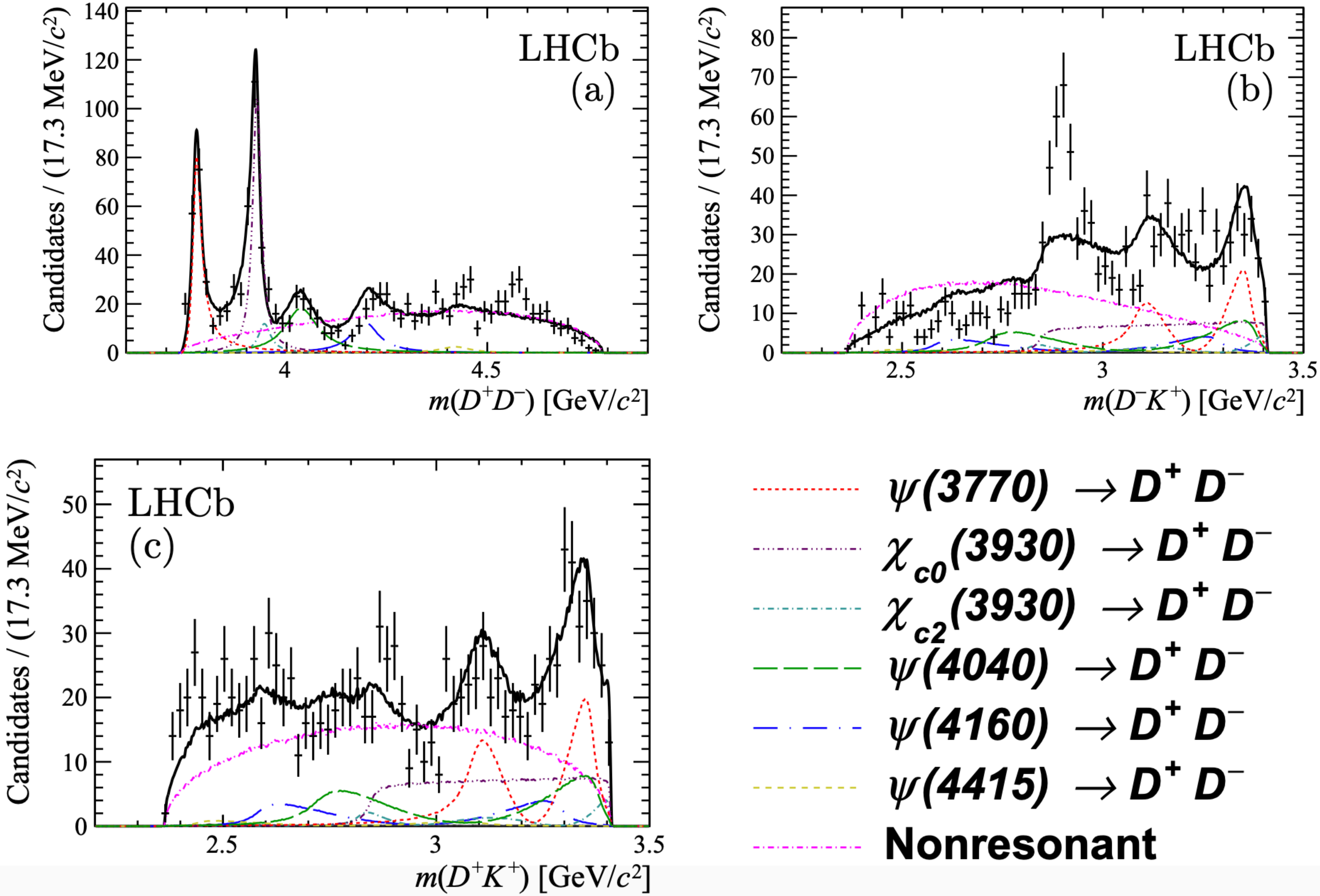
Model-independent analysis:

One or more new charm-strange resonances

LHCb, PRL125(2020)242001

The observation of the $X_0(2900)$

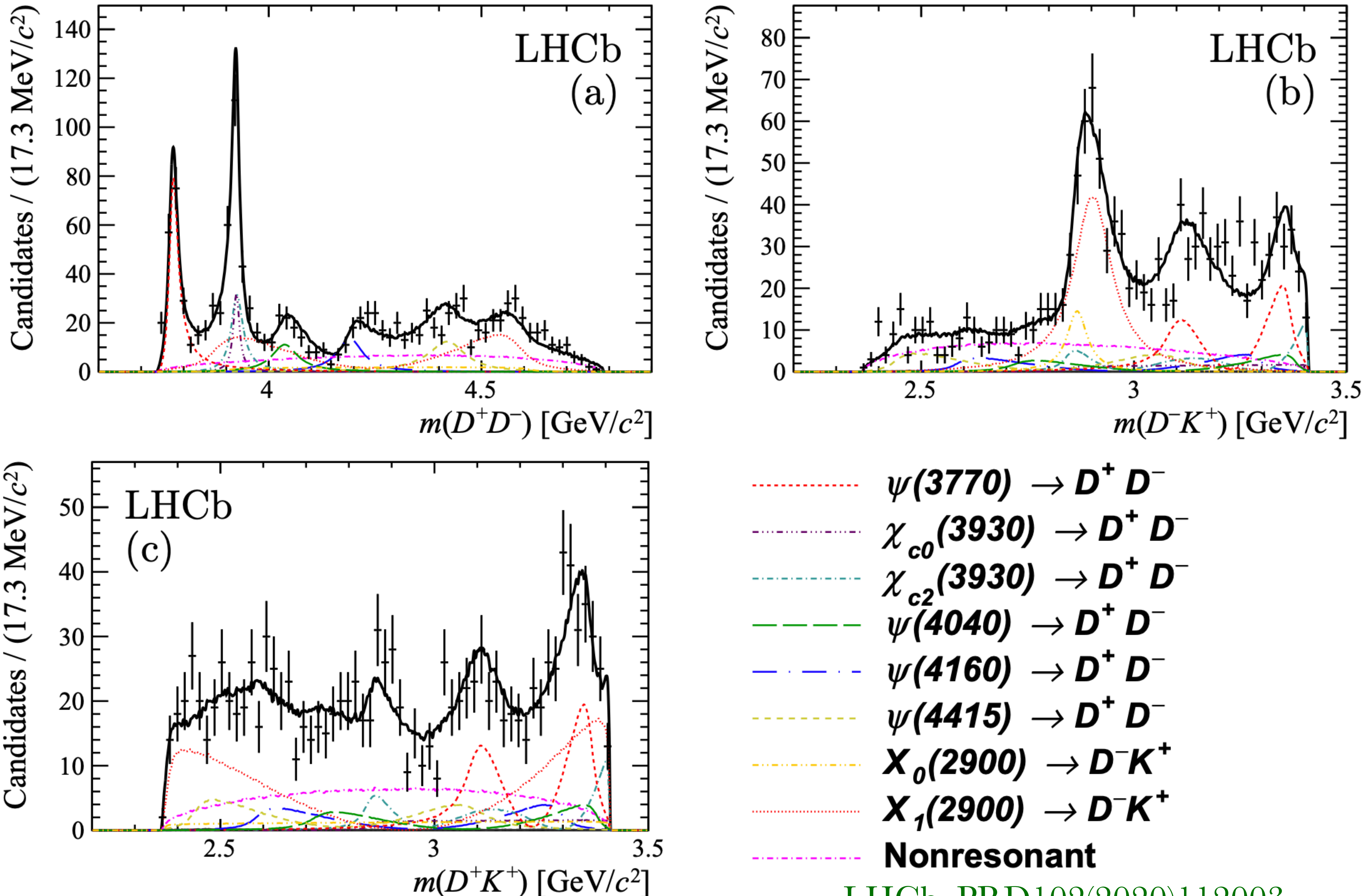
Amplitude analysis:



LHCb, PRD102(2020)112003

The observation of the $X_0(2900)$

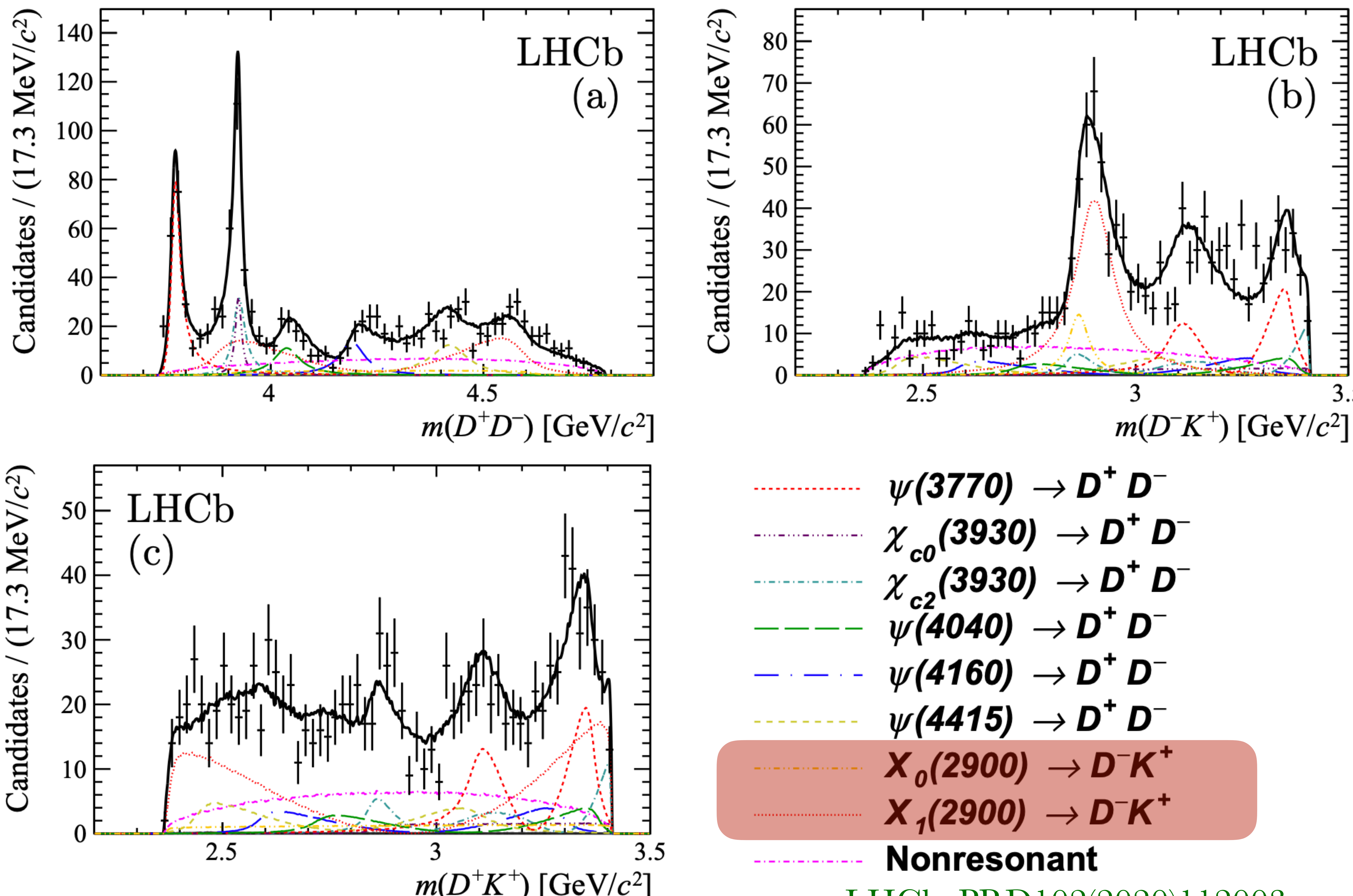
Amplitude analysis:



LHCb, PRD102(2020)112003

The observation of the $X_0(2900)$

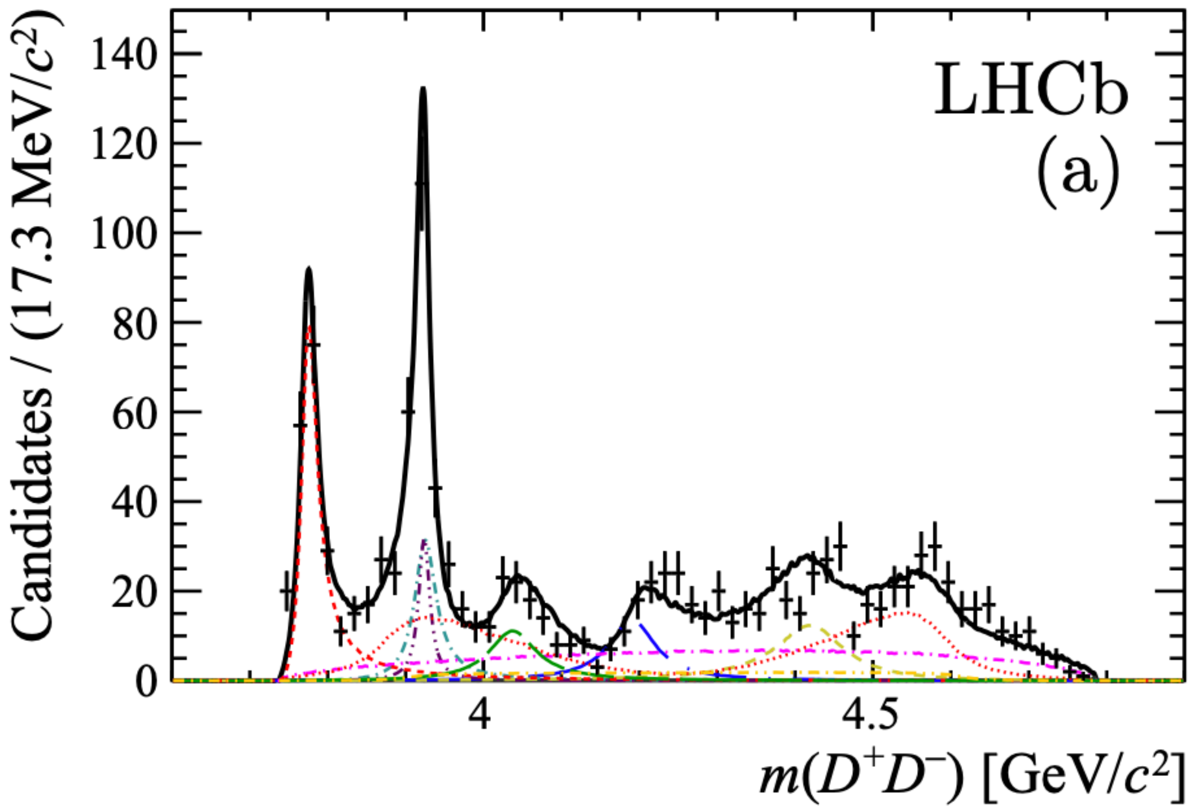
Amplitude analysis:

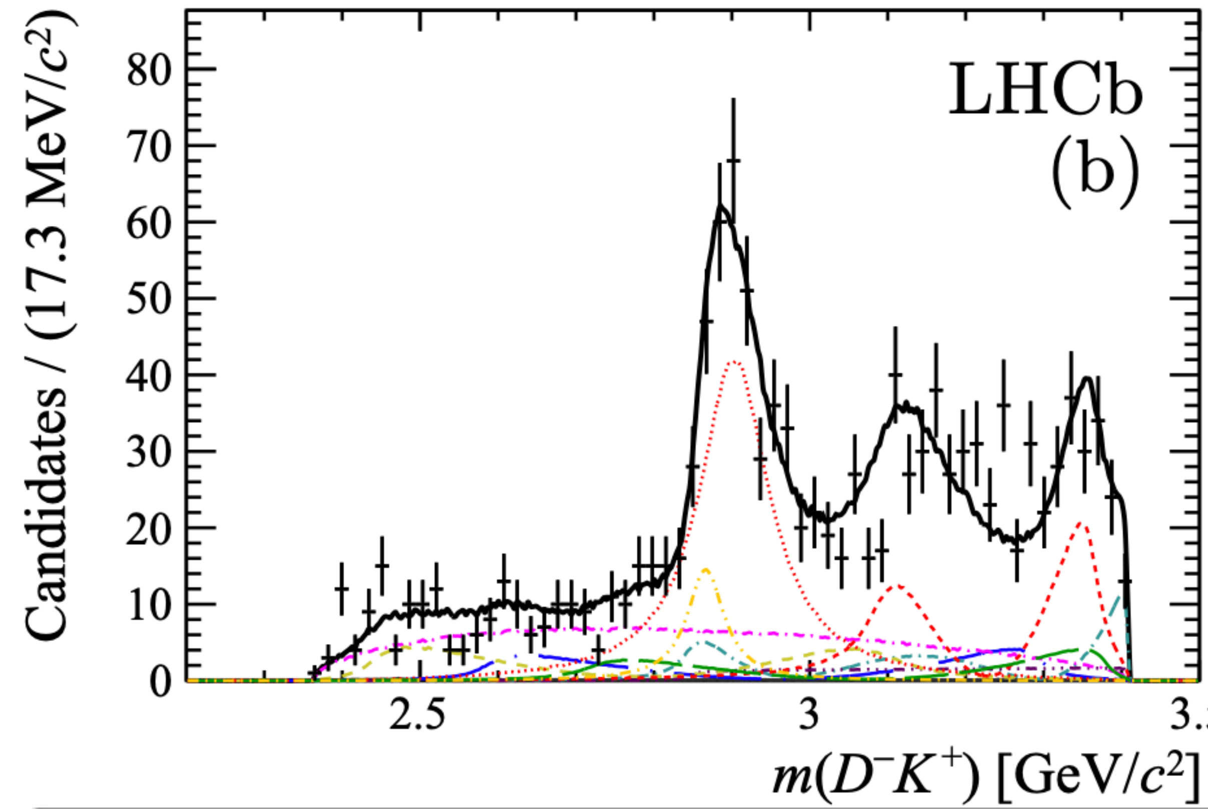


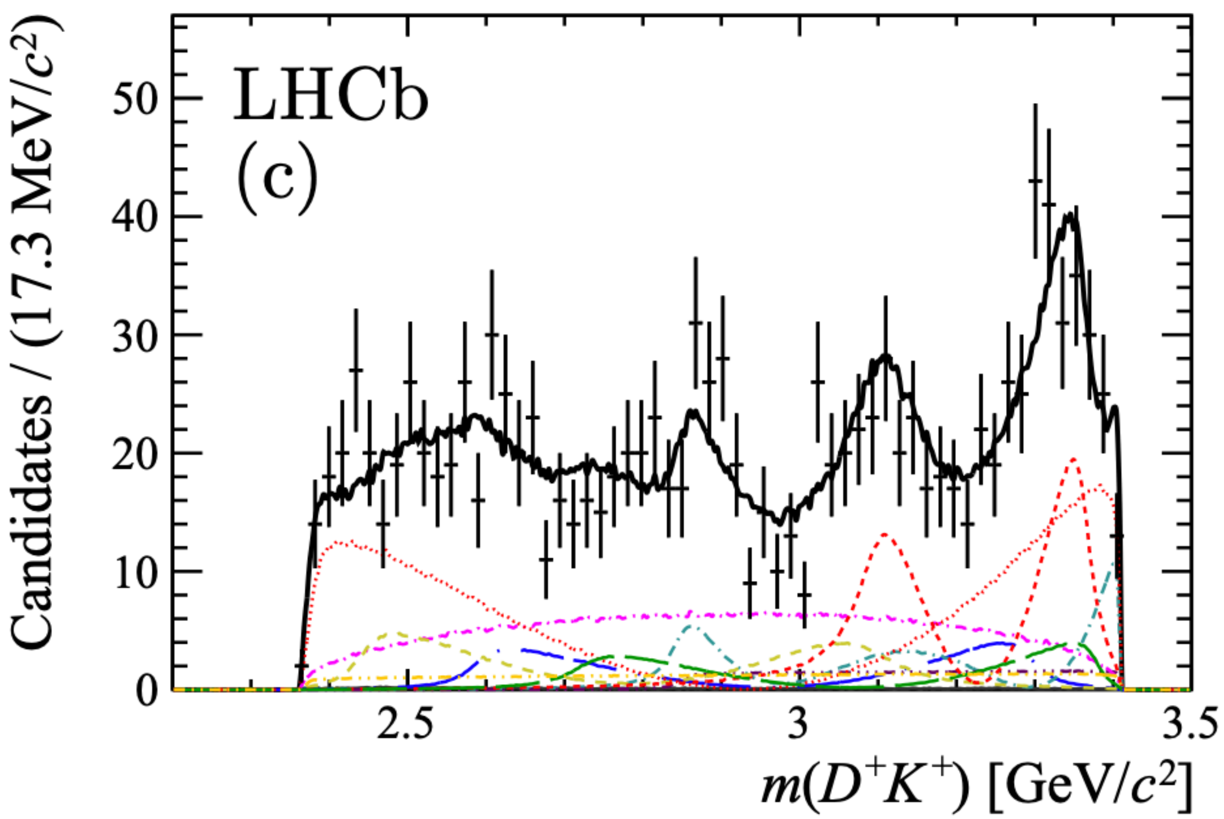
LHCb, PRD102(2020)112003

The observation of the $X_0(2900)$

Amplitude analysis:







$$M_{X_0(2900)} = 2866 \pm 7 \text{ MeV}$$

$$M_{X_1(2900)} = 2904 \pm 7 \text{ MeV}$$

LHCb, PRD102(2020)112003

The observation of the $X_0(2900)$

- The first four different flavor exotics $X_{0/1}(2900)[\bar{c}d\bar{s}u]$

- $X(3872)$ $[c\bar{c}q\bar{q}]$

$D^*\bar{D} + c.c.$ molecule or compact tetra quark

mix with the normal $c\bar{c}$ charmonium

Li, et al., PRD79(2009)094004, Coito, et al., EPJC71(2011)1762, Coito, et al., EPJC73(2013)2351

Meng et al., PRD75(2007)114002, Kalashnikova, PRD72(2005)034010, Zhang et al., PLB680(2009)453, Danilkin et al., PRL105(2020)102002,

- $D_{s0}(2317)$ $[c\bar{s}q\bar{q}]$

mix with the normal $c\bar{s}$ meson

Beveren et al., PRL91(2003)012003, EPJC32(2004)499, Coito et al., PRD84(2011)094020, Hwang et al., PLB601(2004)137, Simonov et al., PRD70(2004)114013, Lee et al, EPJC49(2007)737, Zhou et al., PRD84(2011)034023

$$M_{X_0(2900)} = 2866 \pm 7 \text{ MeV}$$

$$M_{X_1(2900)} = 2904 \pm 7 \text{ MeV}$$

LHCb, PRD102(2020)112003

The observation of the $X_0(2900)$

- Molecular picture

He et al., hep-ph: 2008.07782, Molina et al., PLB811(2020)135870, Agaev hep-ph:2008.13027, Dong et al., hep-ph:2009.11619, Xiao et al., PRD103(2021)034004, Chen hep-ph:2103.08586

- Tetraquark picture

Wang, Int.J.MPA35(2020)2050187, Qin et al., 2008.08026, Xue et al., PRD103(2021)054010, Yang et al., Sym. 12(2020)1869, Wang et al., EPJC81(2021)188, Yang et al., 2101.04933, Albuquerque et al., NPA1007(2021)122113, Chen et al., EPJC81(2021)71, Agaev et al., hep-ph: 2103.06151

- Kinematic effect

Burns et al., PLB813(2021)136057, Liu et al., EPJC80(2020)1178

- Other effects

Bondar et al., JHEP12(2020)015

Outline

1. The observation of the $X_0(2900)$
2. Heavy quark spin structure
3. $X_0(2900)$ as a $\bar{D}^*K^*$ bound state
4. $X_0(2900)$ as a $\bar{D}^*K^*$ virtual state
5. Summary and Outlook

Heavy quark spin structure

- Motivation: close to $\bar{D}^*K^*$ threshold
- Assumption: $X_0(2900)$ as a $I(J^P) = 0(0^+)$ $\bar{D}^*K^*$ molecule
- Goals: its physical impact
- Employ heavy quark spin structure
  - Proposed by M. B. Voloshin for the two Z_b case — Bondar et al.,PRD84(2011)054010
  - Successfully apply to double heavy exotics

Hanhart et al., PRL115(2015)202001, Guo et al., PRD93(2016)074031, Voloshin PRD84(2011)031502, Baru et al., JHEP06(2017)158, Wang et al., 98(2018) 074023, Baru et al., PRD99(2019)094013,…

  - Work better for single heavy system — Yasui et al., PLB727(2013)185

Heavy quark spin structure

- Heavy quark spin structure

$$|(\bar{c}_{j_1} q_{j_2})_{j_{12}} (\bar{s}q')_{j_3}\rangle_J = \sum_{s_l} (-1)^{j_2+j_3+j_{12}+s_l} \begin{Bmatrix} j_1 & j_2 & j_{12} \\ J & j_3 & s_l \end{Bmatrix} \hat{j_{12}} \hat{s_l} |\bar{c}_{j_1} (q_{j_2} (\bar{s}q')_{j_3})_{s_l}\rangle$$

j_1 spin of anticharm quark — j_3 spin of kaon — s_l light d.o.f.

j_2 spin of light quark — J angular momentum of the system

$\bar{D}^{(*)}K$ system $\quad |\bar{D}K\rangle_{0^+} = |\frac{1}{2}\rangle \qquad |\bar{D}^*K\rangle_{1^+} = |\frac{1}{2}\rangle$

$\bar{D}^{(*)}K^*$ system $\quad |\bar{D}^*K^*\rangle_{0^+} = -|\frac{1}{2}\rangle^* \qquad |\bar{D}^*K^*\rangle_{2^+} = |\frac{3}{2}\rangle^*$

$$|\bar{D}^*K^*\rangle_{1^+} = \sqrt{\frac{2}{3}}|\frac{1}{2}\rangle^* - \frac{1}{\sqrt{3}}|\frac{3}{2}\rangle^* \qquad |\bar{D}K^*\rangle_{1^+} = \frac{1}{\sqrt{3}}|\frac{1}{2}\rangle^* + \sqrt{\frac{2}{3}}|\frac{3}{2}\rangle^*$$

Hu, Lao, Ling, QW, CPC45(2021)021003

Heavy quark spin structure

Contact potentials

- Define leading order contact potential $C_{2l}^{(*)} \equiv^{(*)} \langle l \,|\, \hat{H}_{\rm HQS} \,|\, l \rangle^{(*)}$

$\bar{D}^{(*)}K$ system $\quad V_{0^+} = C_1 \qquad V_{1^+} = C_1$

$\bar{D}^{(*)}K^*$ system $\quad V^*_{0^+} = C^*_1 \qquad V^*_{2^+} = C^*_3$

$$V^*_{1^+} = \begin{pmatrix} \frac{1}{3}C^*_1 + \frac{2}{3}C^*_3 & \frac{\sqrt{2}}{3}\left(C^*_1 - C^*_3\right) \\ \frac{\sqrt{2}}{3}\left(C^*_1 - C^*_3\right) & \frac{2}{3}C^*_1 + \frac{1}{3}C^*_3 \end{pmatrix}$$

C^*_1 fixed by the mass position of the $X_0(2900)$

C^*_3 within a reasonable energy region

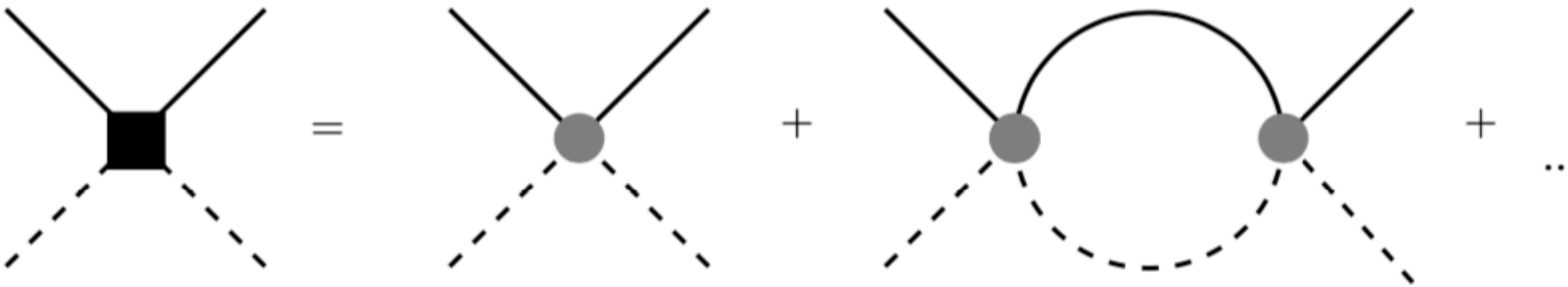
Hu, Lao, Ling, QW, CPC45(2021)021003

Outline

1. The observation of the $X_0(2900)$
2. Heavy quark spin structure
3. $X_0(2900)$ as a $\bar{D}^*K^*$ bound state
4. $X_0(2900)$ as a $\bar{D}^*K^*$ virtual state
5. Summary and Outlook

LSE

- Lippmann-Schwinger Equation



- Algebraic equation $T = V + VGT$ for contact potentials
- Hard cutoff for two-body propagator

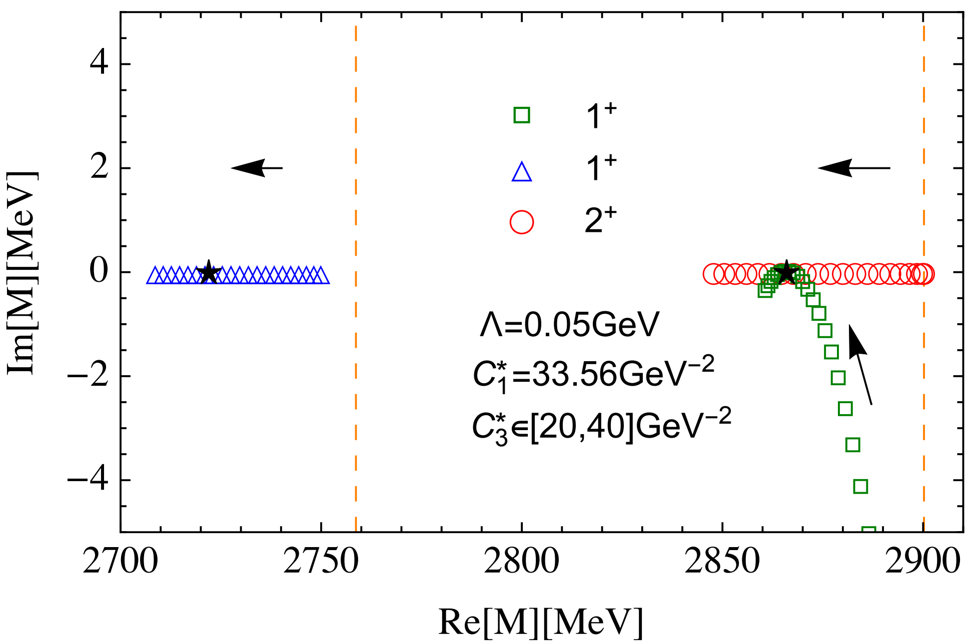
$$G_\Lambda(M, m_1, m_2) = \int \frac{d^3 q}{(2\pi)^3} \frac{1}{M - m_1 - m_2 - \vec{q}^{\,2}/(2\mu)} = \Lambda + i \frac{m_1 m_2}{2\pi(m_1 + m_2)} \sqrt{2\mu(M - m_1 - m_2)}$$

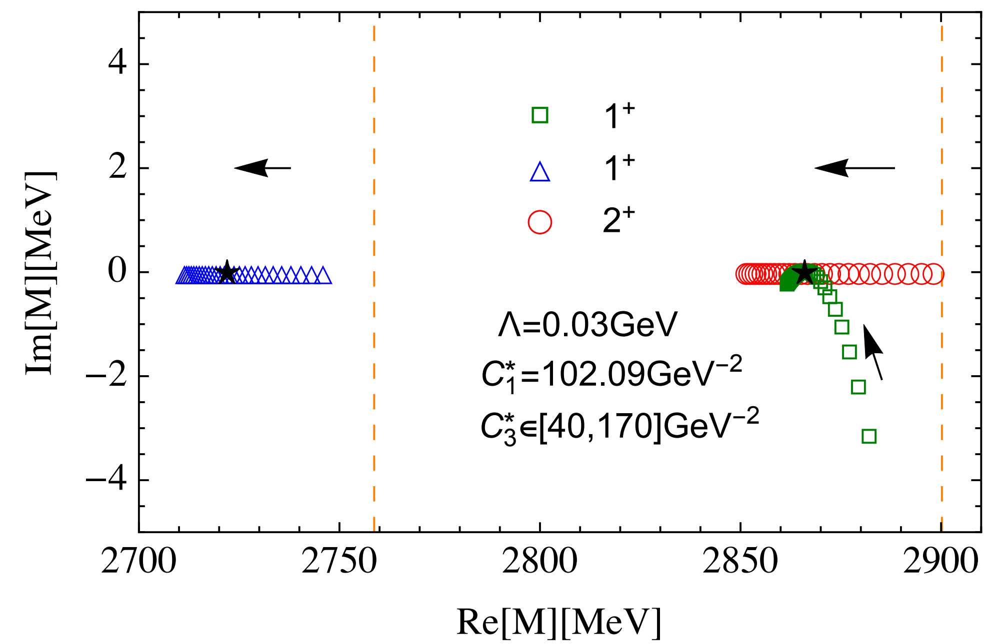
- G_Λ^{II} can be obtained by changing the sign of the second term
- Λ should be small to preserve HQSS

Guo et al., PRD88(2013)054007

Hu, Lao, Ling, QW, CPC45(2021)021003

$X_0(2900)$ as a $\bar{D}^*K^*$ bound state





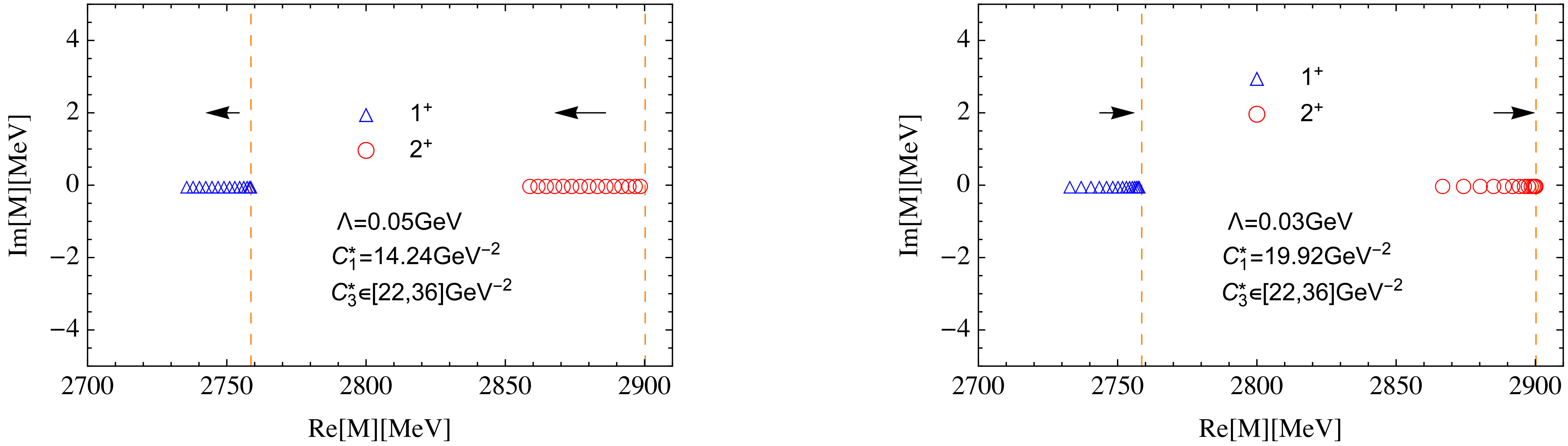
- Bound state: $1 - C_1^* G_\Lambda(m_{X_0(2900)}, m_{\bar{D}^*}, m_{K^*}) = 0$
- Two parameter sets: $\Lambda = 0.05$ GeV, $C_1^* = 33.56$ GeV^{-2} and $\Lambda = 0.03$ GeV, $C_1^* = 102.09$ GeV^{-2}
- One 1^+ bound state below $\bar{D}K^*$ threshold, one 1^+ resonance between $\bar{D}K^*$ and $\bar{D}^*K^*$ thresholds
- One 2^+ bound state below $\bar{D}^*K^*$ threshold
- $m_{2^+} = 2.866$ GeV, $m_{1^+} = 2.722$ GeV, $m_{1^+} = 2.866$ GeV in light quark limit

Voloshin, PRD93(2016)074011

Outline

1. The observation of the $X_0(2900)$
2. Heavy quark spin structure
3. $X_0(2900)$ as a $\bar{D}^*K^*$ bound state
4. $X_0(2900)$ as a $\bar{D}^*K^*$ virtual state
5. Summary and Outlook

$X_0(2900)$ as a $\bar{D}^*K^*$ virtual state



- Virtual state: $1 - C_1^* G_\Lambda^{\rm II}(m_{X_0(2900)}, m_{\bar{D}^*}, m_{K^*}) = 0$
- Two parameter sets: $\Lambda = 0.05$ GeV, $C_1^* = 14.24$ GeV^{-2} and $\Lambda = 0.03$ GeV, $C_1^* = 19.92$ GeV^{-2}
- One 1^+ bound state below $\bar{D}K^*$ threshold, one 2^+ resonance between $\bar{D}^*K^*$

Hu, Lao, Ling, QW, CPC45(2021)021003

Outline

1. The observation of the $X_0(2900)$
2. Heavy quark spin structure
3. $X_0(2900)$ as a $\bar{D}^*K^*$ bound state
4. $X_0(2900)$ as a $\bar{D}^*K^*$ virtual state
5. Summary and Outlook

Summary and Outlook

- The impact of the $X_0(2900)$ as a $I(J^P) = 0(0^+)$ $\bar{D}^*K^*$ hadronic molecule
- bound state: two 1^+ and one 2^+ states
- virtual state: one 1^+ and one 2^+ state

- Include the $(\bar{D}_1, \bar{D}_2)K$ threshold: $X_1(2900)$?
- Fit to all the existing relevant channels

$B^+ \to D^{(*)+}D^{(*)-}K^{(*)+}, \bar{D}^{(*)0}D^{(*)0}K^{(*)+}$

Thanks for your attention!