第四届中国格点量子色动力学研讨会

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Study Zc(3900) with three coupled channels based on T_{cc}

Jia-Jun Wu (University of Chinese Academy of Sciences)
Collaborator: Kang Yu (UCAS), G.-J. Wang(KEK), Zhi Yang(UESTC)

[hep-ph] 2409.10865

CLQCD2024 2024.10.14 Changsha, Hunan Nor

University of Chinese Academy of Sciences

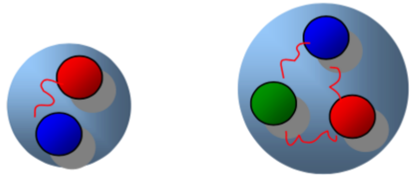
Outline

- Background
- Formalism
- Data Fit
- Pole and Finite volume spectra
- Summary and Outlook

Background

Tranditional Qurk model

convential hadron

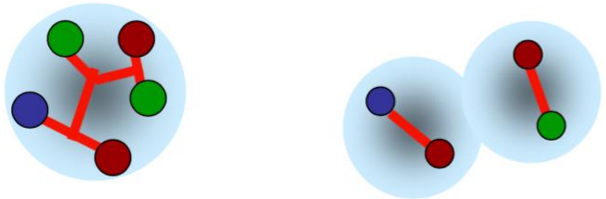


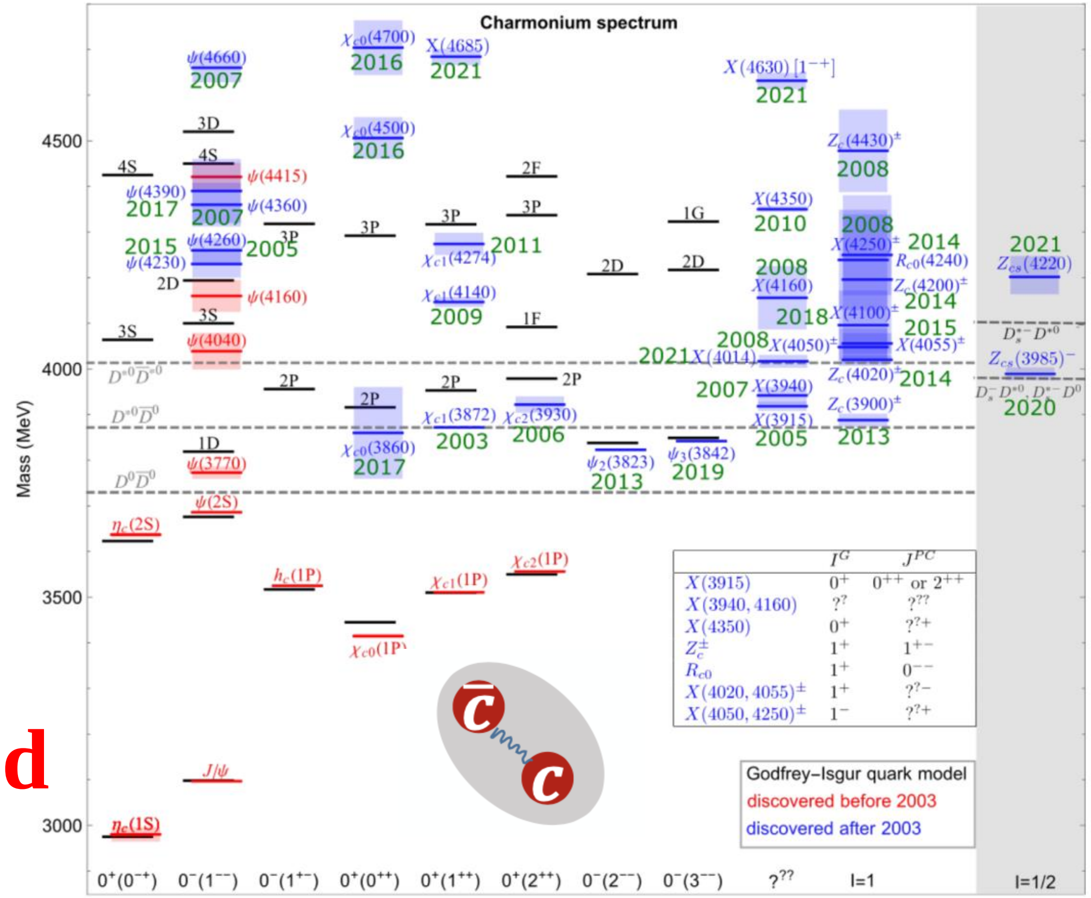
(q q̄)   (qqq)

Excotic

Hybrid   Glueball   Tetraquark

Pentaquark   Hadronic molecule





Question：How is a hadron composed of these possible components?

Background

Question： How is a hadron composed of these possible components?

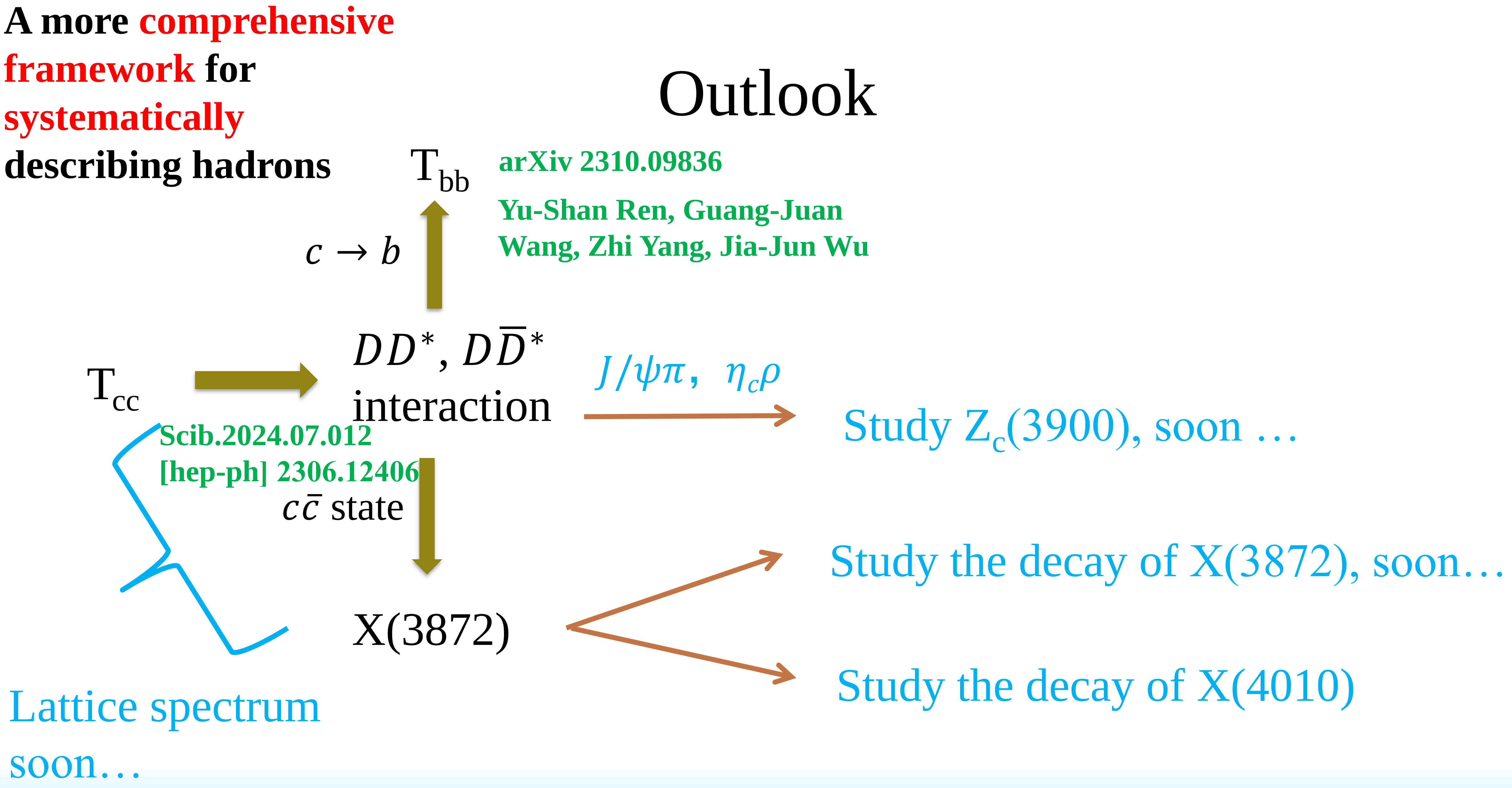
strong interaction
- Colorful → quark level
- Colorless → hadron level

A more comprehensive framework for systematically describing hadrons

quark level && hadron level.

Not only one, at least a set of hadron

Outlook


A more comprehensive framework for systematically describing hadrons
T_{bb}
arXiv 2310.09836
Yu-Shan Ren, Guang-Juan Wang, Zhi Yang, Jia-Jun Wu
$c \to b$
T_{cc}
$DD^*, D\bar{D}^*$ interaction
$J/\psi\pi$, $\eta_c\rho$
Study $Z_c(3900)$, soon …
Scib.2024.07.012
[hep-ph] 2306.12406
$c\bar{c}$ state
X(3872)
Study the decay of X(3872), soon…
Study the decay of X(4010)
Lattice spectrum soon…

A more **comprehensive framework** for **systematically** describing hadrons

Outlook

T_{bb}

arXiv 2310.09836

Yu-Shan Ren, Guang-Juan Wang, Zhi Yang, Jia-Jun Wu

$c \rightarrow b$

T_{cc}

DD^*, $D\bar{D}^*$ interaction

$J/\psi\pi$, $\eta_c\rho$

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Study $Z_c(3900)$,

Scib.2024.07.012

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$c\bar{c}$ state

X(3872)

Study the decay of X(3872), soon…

Study the decay of X(4010)

Lattice spectrum soon…

Zc(3900)

BESIII: $e^+e^- \to J/\psi\pi^+\pi^-$, PRL 110, 252001 (2013)
Belle-II: $e^+e^- \to J/\psi\pi^+\pi^-$, PRL 110, 252002 (2013)
CLEO-c: $e^+e^- \to J/\psi\pi^0\pi^0$, PLB 727, 366 (2013)
BESIII: $e^+e^- \to (D\bar{D}^*)^\mp\pi^\pm$, PRL 112, 022001 (2014)
PRD 92, 092006 (2015)
BESIII: $e^+e^- \to \eta_c\rho^\pm\pi^\mp$, IJMPA 33, 1830018 (2018)

Belle-II: $\bar{B}^0 \to J/\psi\pi^+K^-$, PRD 90, 112009 (2014)
LHCb: $B^0 \to J/\psi\pi^+\pi^-$, PRD 90, 012003 (2014)
LHCb: $B^0 \to \psi(nS)\pi^+K^-$, arXiv:2403.04051 [hep-ex].

Compact tetraquark states [12 - 16]
$\boldsymbol{D\bar{D}^*}$ resonances or virtual molecular states [17 - 27]
Cusp effects [28]
Non resonant mechanisms [29, 30]

[12] Braaten, PRLett. 111, 162003 (2013),
[13] Dias, Navarra, Nielsen, and Zanetti, PRD 88, 016004 (2013)
[14] Qiao, Tang, EPJC 74, 3122 (2014)
[15] Wang, CPC 45, 073107 (2021)
[16] Maiani, Polosa, Riquer, SB 66, 1616 (2021),
[17] Wang, Hanhart, Zhao, PRL 111, 132003 (2013),
[18] Aceti, Bayar, Oset, Torres, Khemchandani, Dias, Navarra, Nielsen, PRD 90, 016003 (2014)
[19] Albaladejo, Guo, Hidalgo-Duque, Nieves, PLB 755, 337 (2016)
[20] Gong, Guo, Meng, Tang, Wang, Zheng, PRD 94, 114019 (2016)
[21] He, Chen, EPJC 78, 94 (2018)
[22] Ortega, Segovia, Entem, Fernandez, EPJC 79, 78 (2019),
[23] Yang, Cao, Guo, Nieves, Valderrama, PRD 103, 074029 (2021)
[24] Yan, Peng, Sanchez, Valderrama, PRD 104, 114025 (2021)
[25] Du, Albaladejo, Guo, Nieves, PRD 105, 074018 (2022)
[26] Chen, Du, Guo, 2310.15965
[27] Lin, Wang, Cheng, Meng, Zhu, 2403.01727
[28] Swanson, PRD 91, 034009 (2015)
[29] Wang, Chen, Liu, Matsuki, EPJC 80, 1040 (2020)
[30] Detten, Baru, Hanhart, Wang, Winney, Zhao, 2402.03057

The lattice calculation of Zc(3900)

[1] Prelovsek, Leskovec, PLB 727, 172 (2013)
[2] Prelovsek, Lang, Leskovec, Mohler, PRD 91, 014504 (2015)
[3] Sadl,Collins,Guo,Padmanath,Prelovsek,Yan 2406.09842

[1] using $\pi J/\psi$ and $\bar{D}D^*$ meson-meson interpolators at $m_\pi \sim$ 266 MeV.
[2] included additional meson-meson and diquark-antidiquark interpolators in the simulation.
[3] combine with experimental data by $\pi J/\psi$ and $\bar{D}D^*$ two channel EFT they extract several poles around 3900 MeV.

[4] Hadron Spectrum, JHEP 12, 89 (2016)
[5] Y. Chen et al., PRD 89, 094506 (2014)
[6] Liu, Liu, Zhang, PRD 101, 054502 (2020)
[7] CLQCD Collaboration CPC 43 103103 (2019)

[4] found that compact tetraquark operators had minimal impact on finite volume spectra at $m_\pi \sim$ 391 MeV
[5, 6,7] using meson-meson interpolators at three different m_π values, none of these studies identified a clear candidate for the Zc state.

[8] HAL QCD, PRL. 117, 242001 (2016) [9] HAL QCD JPG 45, 024002 (2018)

[8, 9] extracted the $\pi J/\psi - \bar{D}\, D^* - \rho\eta_c$ coupled-channel potential and reproduced the experimental line shape. But they concluded that the Zc state is better understood as a threshold cusp rather than a conventional resonance. The off-diagonal channel-channel interactions play an important role.

Formalism-Three-body Coupled channel model

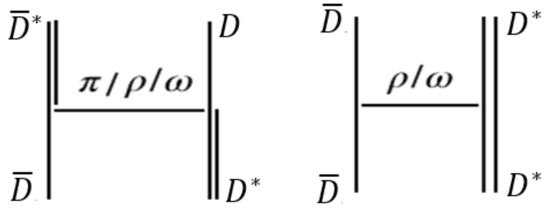
Three channels $\bar{D}D^*$, $J/\psi\pi$, $\eta_c\rho$

$$H = H_0 + H_I$$

$$v = \sum_{\alpha,\beta} |\alpha(k_\alpha)\rangle v_{\alpha,\beta} \langle \beta(k_\beta)|$$

$\bar{D}D^* \to \bar{D}D^*$

The interaction determined by Tcc



$$V_\pi = \frac{g^2}{f_\pi^2}\frac{(q\cdot\epsilon_\lambda)\left(q\cdot\epsilon_{\lambda'}^\dagger\right)}{q^2-m_\pi^2},$$

$$V_{\rho/\omega}^u = -2\lambda^2 g_V^2 \frac{(\epsilon_{\lambda'}^\dagger\cdot q)(\epsilon_\lambda\cdot q) - q^2\left(\epsilon_\lambda\cdot\epsilon_{\lambda'}^\dagger\right)}{q^2-m_{\rho/\omega}^2},$$

$$V_{\rho/\omega}^t = \frac{\beta^2 g_V^2}{2}\frac{\left(\epsilon_\lambda\cdot\epsilon_{\lambda'}^\dagger\right)}{q^2-m_{\rho/\omega}^2}.$$

	wave function	$I(J^{PC})$
DD^*	$\frac{1}{\sqrt{2}}(D^+D^{*0} - D^0D^{*+})$	$0(1^+)$ $[T_{cc}^+]$
	$\frac{1}{\sqrt{2}}(D^+D^{*0} + D^0D^{*+})$	$1(1^+)$
$D\bar{D}^*$	$\frac{1}{\sqrt{2}}([D^+D^{*-}] + [D^0\bar{D}^{*0}])$	$0(1^{++})[X(3872)]$
	$\frac{1}{\sqrt{2}}([D^+D^{*-}] - [D^0\bar{D}^{*0}])$	$1(1^{++})$
	$\frac{1}{\sqrt{2}}(\{D^+D^{*-}\} + \{D^0\bar{D}^{*0}\})$	$0(1^{+-})[h_c]$
	$\frac{1}{\sqrt{2}}(\{D^+D^{*-}\} - \{D^0\bar{D}^{*0}\})$	$1(1^{+-})$ $[Z_c(3900)]$

$D^{(*)}D^{(*)}$

$$H_a^{(Q)} = \frac{1+\not{v}}{2}\left[P_a^{*\mu}\gamma_\mu - P_a\gamma_5\right]$$

$$\bar{H}_a^{(Q)} \equiv \gamma_0 H^{(Q)\dagger}\gamma_0 = \left[P_a^{*\dagger\mu}\gamma_\mu + P_a^\dagger\gamma_5\right]\frac{1+\not{v}}{2}$$

$$P = (D^0, D^+, D_s^+)\ \&\ P^* = (D^{*0}, D^{*+}, D_s^{*+})$$

$$\mathcal{L}_{MH^{(Q)}H^{(Q)}} = ig\,\mathrm{Tr}\left[H_b^{(Q)}\gamma_\mu\gamma_5 A_{ba}^\mu \bar{H}_a^{(Q)}\right]$$

$$\mathcal{L}_{VH^{(Q)}H^{(Q)}} = i\beta\,\mathrm{Tr}\left[H_b^{(Q)} v_\mu\left(V_{ba}^\mu - \rho_{ba}^\mu\right)\bar{H}_a^{(Q)}\right] + i\lambda\,\mathrm{Tr}\left[H_b^{(Q)}\sigma_{\mu\nu}F^{\mu\nu}(\rho)_{ba}\bar{H}_a^{(Q)}\right]$$

Heavy Quark Symmetry

$$H_a^{(\bar{Q})} \equiv C\left(\mathcal{C}H_a^{(Q)}\mathcal{C}^{-1}\right)^T C^{-1} = \left[P_{a\mu}^{(\bar{Q})*}\gamma^\mu - P_a^{(\bar{Q})}\gamma_5\right]\frac{1-\not{v}}{2}$$

$$\bar{H}_a^{(\bar{Q})} \equiv \gamma_0 H_a^{(\bar{Q})\dagger}\gamma_0 = \frac{1-\not{v}}{2}\left[P_{a\mu}^{(\bar{Q})*\dagger}\gamma^\mu + P_a^{(\bar{Q})\dagger}\gamma_5\right]$$

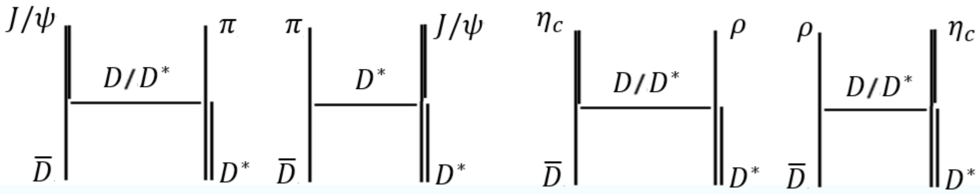
$$\tilde{P} = (\bar{D}^0, D^-, D_s^-)\ \&\ \tilde{P}^* = (\bar{D}^{*0}, D^{*-}, D_s^{*-})$$

$$\mathcal{L}_{MH^{(\bar{Q})}H^{(\bar{Q})}} = ig\,\mathrm{Tr}\left[\bar{H}_a^{(\bar{Q})}\gamma_\mu\gamma_5 A_{ab}^\mu H_b^{(\bar{Q})}\right]$$

$$\mathcal{L}_{VH^{(\bar{Q})}H^{(\bar{Q})}} = -i\beta\,\mathrm{Tr}\left[\bar{H}_a^{(\bar{Q})} v_\mu\left(V_{ab}^\mu - \rho_{ab}^\mu\right)H_b^{(\bar{Q})}\right] + i\lambda\,\mathrm{Tr}\left[\bar{H}_a^{(\bar{Q})}\sigma_{\mu\nu}F_{ab}'^{\mu\nu}(\rho)H_b^{(\bar{Q})}\right]$$

$D^{(*)}\overline{D^{(*)}}$

$\bar{D}D^* \to J/\psi\pi, \eta_c\rho$



$$\mathcal{L}_{\psi DD^*} = 2ig'\epsilon^{\mu\nu\alpha\beta}v_\alpha\psi_\beta\left(\tilde{P}_\nu^{*\dagger}\overleftrightarrow{\partial}_\mu P^\dagger + P_\nu^{*\dagger}\overleftrightarrow{\partial}_\mu\tilde{P}^\dagger\right),$$

$$\mathcal{L}_{\psi DD} = 2g'\psi^\mu P^\dagger\overleftrightarrow{\partial}_\mu\tilde{P}^\dagger,$$

$$\mathcal{L}_{\psi D^*D^*} = 2g'\left(\psi^\nu\tilde{P}_\nu^{*\dagger}\overleftrightarrow{\partial}^\mu P_\mu^{*\dagger} - \psi^\nu P_\nu^*\overleftrightarrow{\partial}^\mu\tilde{P}_\mu^{*\dagger} + \psi_\mu P^{*\nu\dagger}\overleftrightarrow{\partial}^\mu\tilde{P}_\nu^{*\dagger}\right),$$

$$\mathcal{L}_{\eta_c D^*D^*} = -2ig'\epsilon^{\mu\nu\alpha\beta}v_\alpha\eta_c\left(P_\beta^{*\dagger}\overleftrightarrow{\partial}_\mu\tilde{P}_\nu^{*\dagger}\right),$$

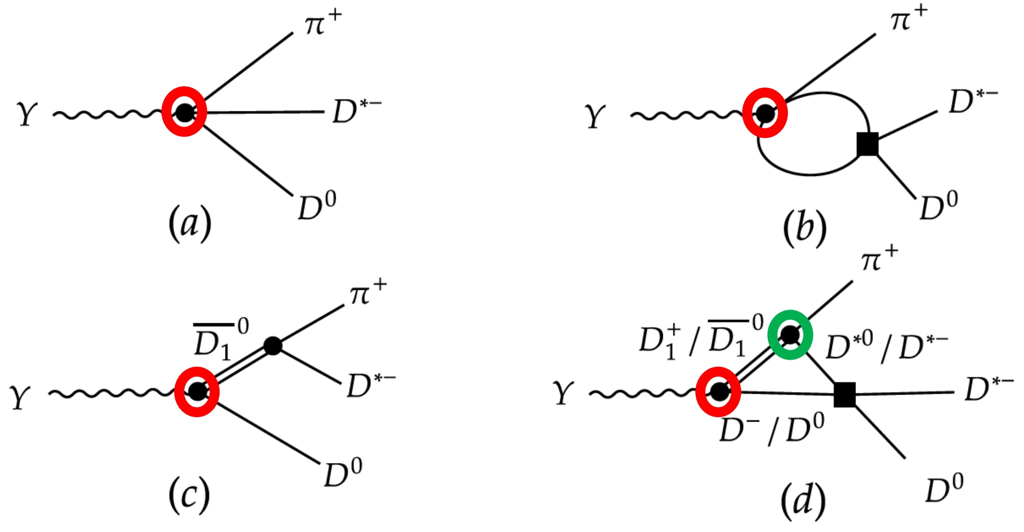
$$\mathcal{L}_{\eta_c DD^*} = 2g'\eta_c\left(P_\mu^{*\dagger}\overleftrightarrow{\partial}^\mu\tilde{P}^\dagger + P^\dagger\overleftrightarrow{\partial}^\mu\tilde{P}_\mu^{*\dagger}\right).$$

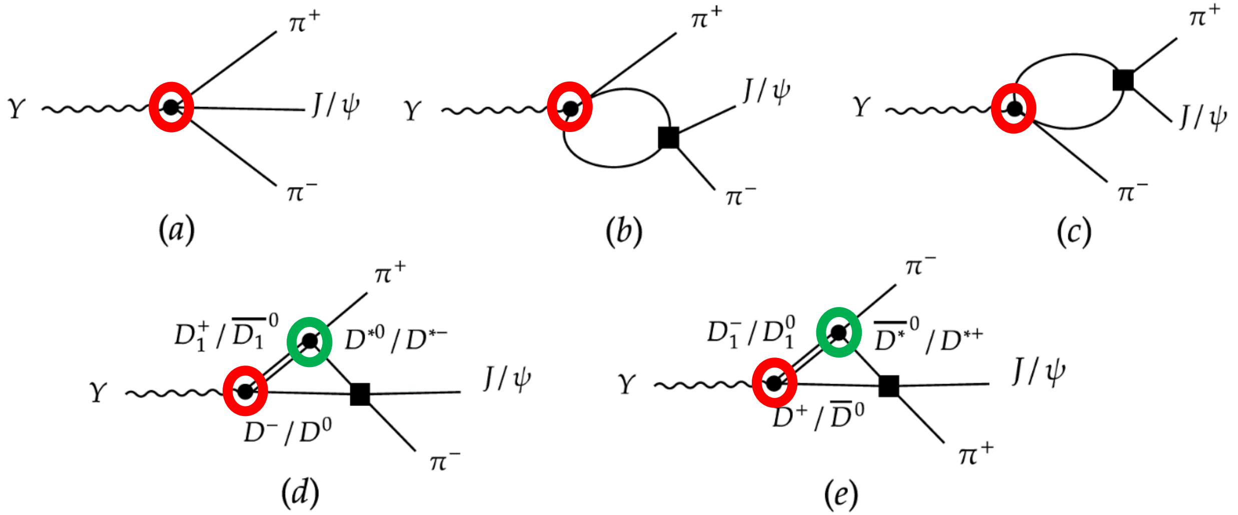
Only one free parameter g'

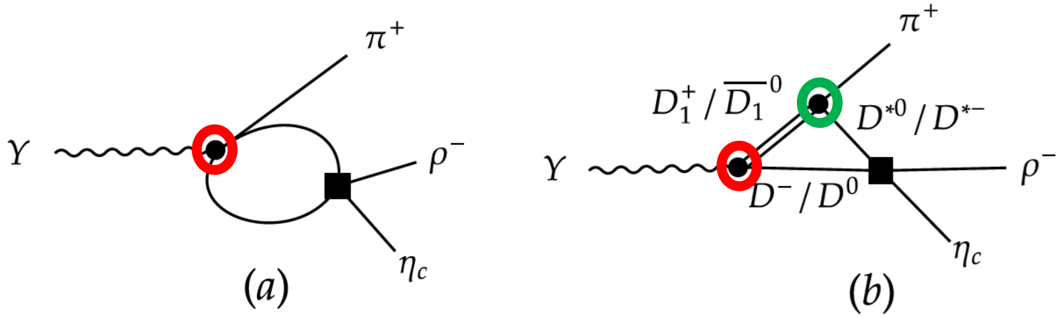
$$V_{\beta\alpha}(\boldsymbol{p},\boldsymbol{k}) \to V_{\beta\alpha}(\boldsymbol{p},\boldsymbol{k})\left(\frac{\Lambda_\alpha^2}{\Lambda_\alpha^2+\boldsymbol{k}^2}\right)^2\left(\frac{\Lambda_\beta^2}{\Lambda_\beta^2+\boldsymbol{p}^2}\right)^2$$

$$\Lambda_{[D\bar{D}^*]} = 1\ \text{GeV} \quad \Lambda_{\pi J/\psi} = \Lambda_{\rho\eta_c} = 1.5\ \text{GeV}$$

Formalism-Feynman digrams







$$\mathcal{L}_{YD_1D} = -g_{YD_1D}\, Y_i D_1^i \bar{D}, \quad \mathcal{L}^S_{Y\pi\pi J/\psi} = c^S_{\pi J/\psi}\pi^+\pi^- Y_i\psi^i,$$

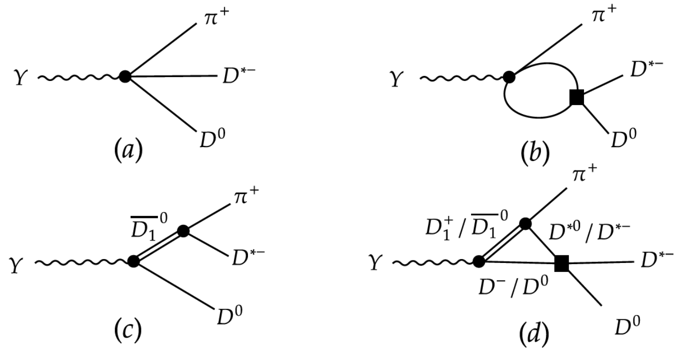
$$\mathcal{L}^D_{Y\pi\pi J/\psi} = c^D_{\pi J/\psi} Y_i\psi_j\left[\pi^+\left(\partial^i\partial^j - \frac{1}{3}\vec{\partial}^2\delta^{ij}\right)\pi^-\right] + (\pi^+ \leftrightarrow \pi^-)$$

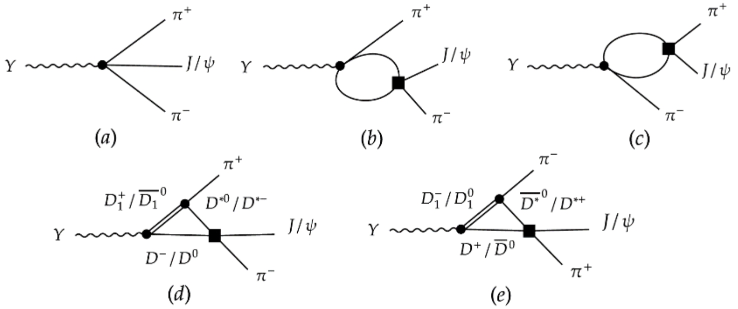
$$\mathcal{L}^S_{Y\pi D\bar{D}^*} = c^S_{D\bar{D}^*} Y^i\psi_i\left(D^0D^{*-} + D^-D^{*0}\right)\pi^+,$$

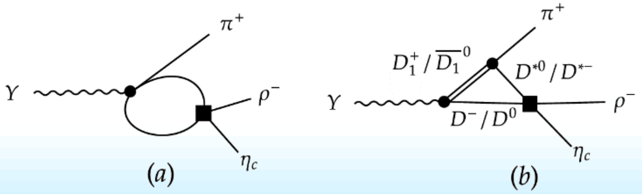
$$\mathcal{L}^S_{D_1D^*\pi} = i\frac{2h_S}{\sqrt{3}f_\pi}(D_1^{+i}D_0^{*i\dagger}\partial^0\pi^-),$$

$$\mathcal{L}^D_{D_1D^*\pi} = -\frac{2h_D}{\sqrt{3}f_\pi}\left(D_1^{+i}D_0^{*i\dagger}\vec{\partial}^2\pi^- - 3D_1^{+i}D_0^{*j\dagger}\partial^i\partial^j\pi^-\right)$$

Formalism-Feynman digrams







$$\left|\mathcal{M}^S_{D^0 D^{*-}}\right|^2 = \left| c^S_{D\bar{D}^*} + \sum_{\alpha=\pi J\psi,[D\bar{D}^*]} c^S_\alpha \mathcal{I}_{\alpha\to[D\bar{D}^*]} + g_{YD_1D} h'_S \omega_\pi \left(\frac{1}{s_{D^*\pi} - m^2_{D_1} + i m_{D_1}\Gamma_{D_1}} + \mathcal{Q}_{D\bar{D}^*} \right) \right|^2,$$

$$\left|\mathcal{M}^D_{D^0 D^{*-}}\right|^2 = \frac{2}{9} p^4_\pi \left| c^D_{\pi J/\psi} \mathcal{I}_{\pi J/\psi \to [D\bar{D}^*]} + g_{YD_1D} h'_D \left(\frac{1}{s_{D^*\pi} - m^2_{D_1} + i m_{D_1}\Gamma_{D_1}} + \mathcal{Q}_{D\bar{D}^*} \right) \right|^2,$$

$$\left|\mathcal{M}^S_{\pi^- J/\psi}\right|^2 = \left| c^S_{\pi J/\psi} + \sum_{\alpha=\pi J/\psi,[D\bar{D}^*]} x_\alpha c^S_\alpha \left(\mathcal{I}_{\alpha\to\pi^+ J/\psi} + \mathcal{I}_{\alpha\to\pi^- J/\psi} \right) + \mathcal{F}^+ + \mathcal{F}^- \right|^2,$$

$$\left|\mathcal{M}^D_{\pi^- J/\psi}\right|^2 = \frac{2}{9} p^4_{\pi^+} \left|\mathcal{A}^+\right|^2 + \frac{2}{9} p^4_{\pi^-} \left|\mathcal{A}^-\right|^2 + \frac{2}{9} p^2_{\pi^+} p^2_{\pi^-} \left(3\cos^2\theta_{\pi^+\pi^-} - 1\right) \mathrm{Re}\left(\mathcal{A}^{+*}\mathcal{A}^-\right),$$

$$\left|\mathcal{M}^S_{\rho\eta_c}\right|^2 = \left| \sum_{\alpha=\pi J/\psi,[D\bar{D}^*]} x_\alpha c^S_\alpha \mathcal{I}_{\alpha\to\rho\eta_c} + \sqrt{2} g_{YD_1D} h'_S \mathcal{Q}_{\rho\eta_c} \right|^2,$$

$$\mathcal{A}^\pm = c^D_{\pi J/\psi} + c^D_{\pi J/\psi} \mathcal{I}_{\pi^\mp J/\psi \to \pi^\mp J/\psi} + \sqrt{2} g_{YD_1D} h'_D \mathcal{Q}_{\pi^\mp J/\psi},$$

$$\mathcal{F}^\pm = \sqrt{2} g_{YD_1D} h'_S \omega_\pi(p_{\pi^\pm}) \mathcal{Q}_{\pi^\mp J/\psi},$$

$$\left|\mathcal{M}^D_{\rho\eta_c}\right|^2 = \frac{2}{9} p^4_\pi \left| c^D_{\pi J/\psi} \mathcal{I}_{\alpha\to\rho\eta_c} + \sqrt{2} g_{YD_1D} h'_D \mathcal{Q}_{\rho\eta_c} \right|^2,$$

$$\mathcal{I}_{\alpha\to\beta} = \int \frac{q^2 dq}{(2\pi)^3 4\omega_{\alpha_1}(q)\omega_{\alpha_2}(q)} \frac{T^{J=1}_{0,0;\alpha\to\beta}(\bar{p}_\beta, q; \sqrt{s_\beta})}{\sqrt{s_\beta} - \omega_{\alpha_1}(q) - \omega_{\alpha_2}(q) + i0^+},$$

$$\mathcal{Q}_\alpha = \int \frac{d^3\boldsymbol{q}}{(2\pi)^3 4\pi} \frac{T^{J=1}_{0,0;D\bar{D}^*\to\alpha}(q^*; \bar{p}_\alpha; \sqrt{s_\alpha})}{8\omega_{D_1}(|\boldsymbol{p_\pi}+\boldsymbol{q}|)\omega_{D^*}(q)\omega_D(|\boldsymbol{p_\pi}+\boldsymbol{q}|)} \times \frac{1}{\left(\sqrt{s} - \omega_{D_1}(|\boldsymbol{p_\pi}+\boldsymbol{q}|) - \omega_D(|\boldsymbol{p_\pi}+\boldsymbol{q}|) + i\frac{\Gamma_{D_1}}{2}\right)} \times \frac{1}{(\sqrt{s} - \omega_\pi(p_\pi) - \omega_{D^*}(q) - \omega_D(|\boldsymbol{p_\pi}+\boldsymbol{q}|) + i0^+)},$$

$$\frac{d\Gamma_{Y\to\pi^+\alpha}}{d\sqrt{s_\alpha}} = \mathcal{N}_\alpha \int_{t^-_\alpha(s_\alpha)}^{t^+_\alpha(s_\alpha)} \frac{|\mathcal{M}_\alpha|^2}{(2\pi)^3 16\sqrt{s^3}} \sqrt{s_\alpha}\, dt_\alpha + \mathcal{B}_\alpha,$$

$$\mathcal{B}_\alpha = b^\alpha_0 \left(\sqrt{s_\alpha} - m^-_\alpha\right)^{b^\alpha_1} \left(m^+ - \sqrt{s_\alpha}\right)^{b^\alpha_2},$$

$2 \times 11 + 1 = 23$ free parameters to fit over 250 experimental data points at $\sqrt{s} = 4.23$ and 4.26 GeV.

中国科学院大学
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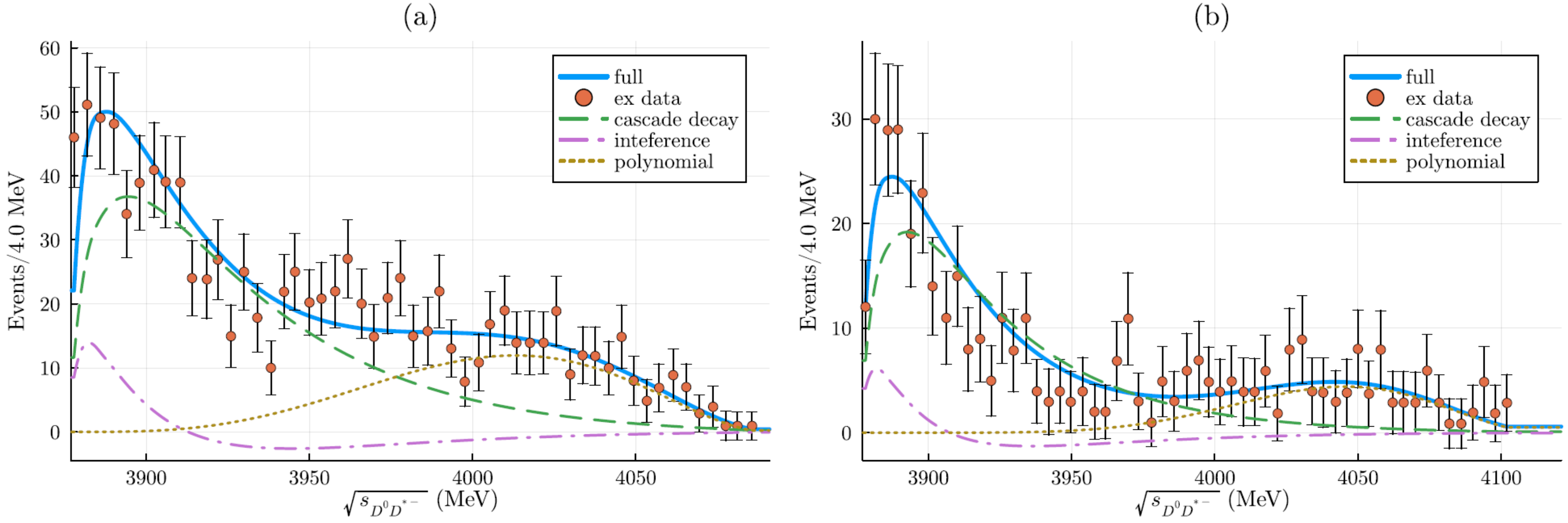
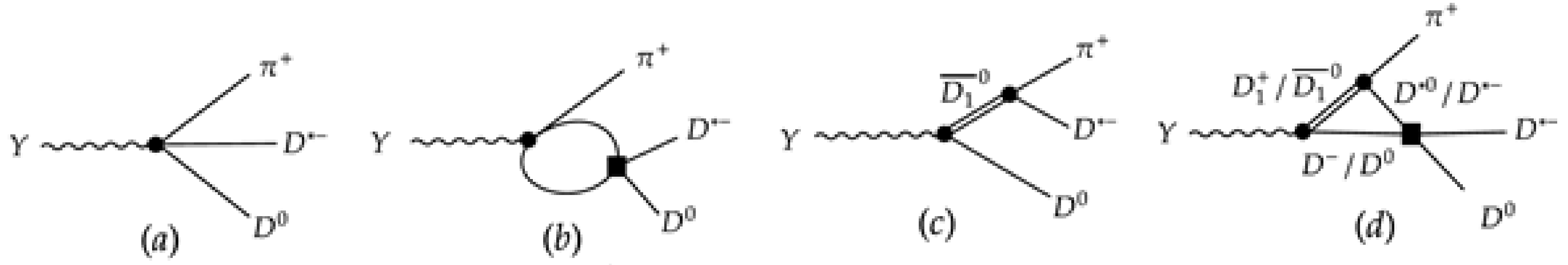
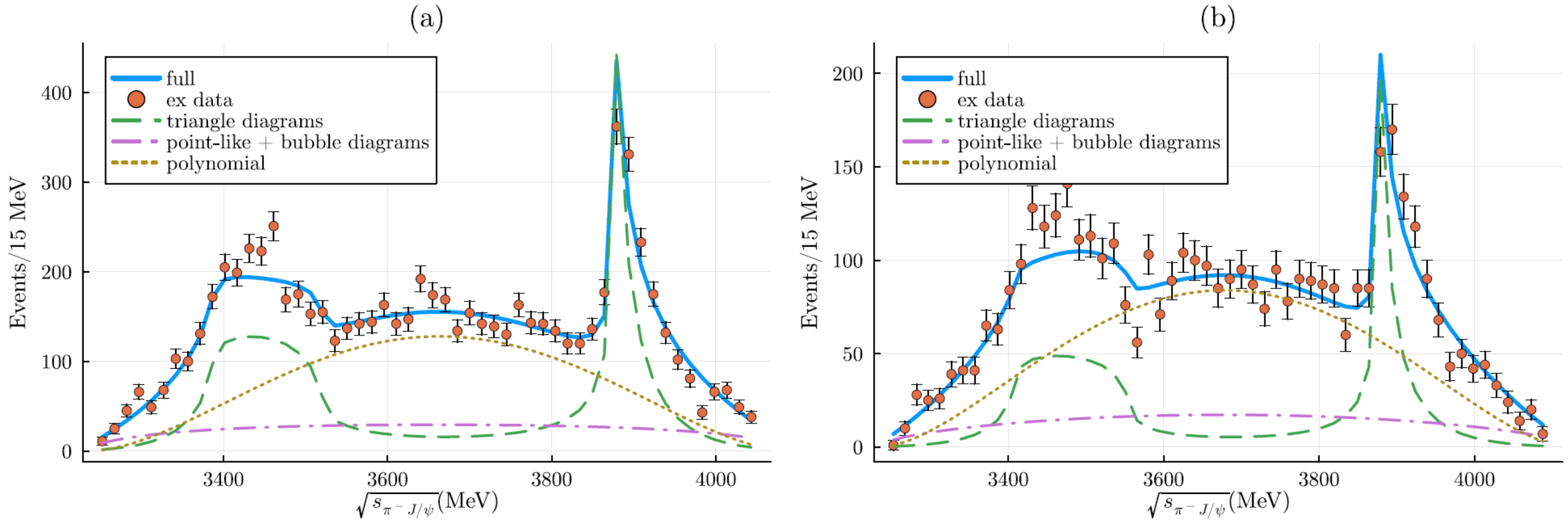
Data Fit-$D^{*-}D^0\pi^+$



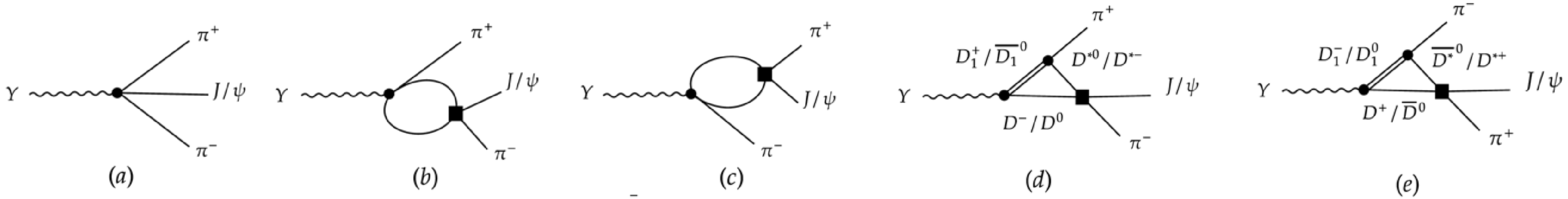


1. Cascade decay dominated Fig.(c)
2. The threshold peak from the interference between (c) and (a)
3. The background play important at higher invariant mass of $D^{*-}D^0$

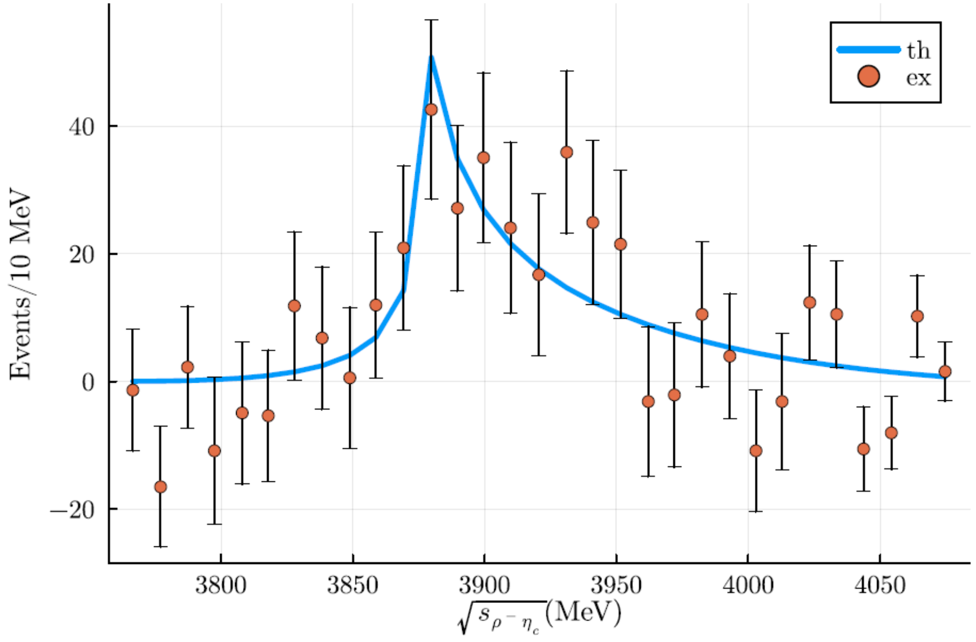
Data Fit-$J/\psi\pi^-\pi^+$

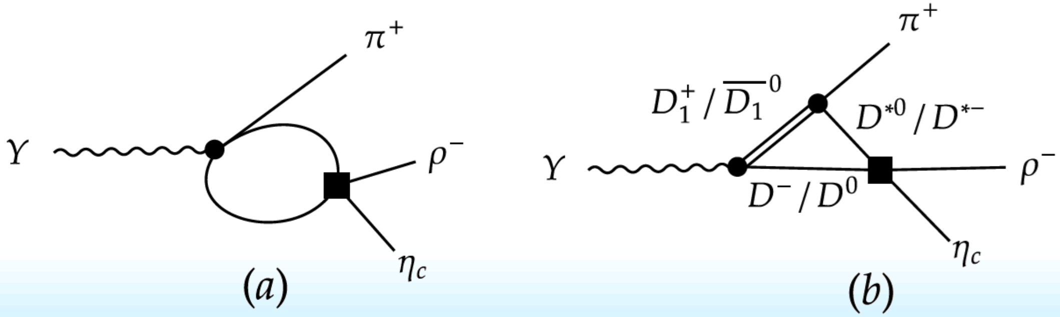


1. Peak from Triangle Loop
2. Fig(a-c) is not important
3. The background give the bump



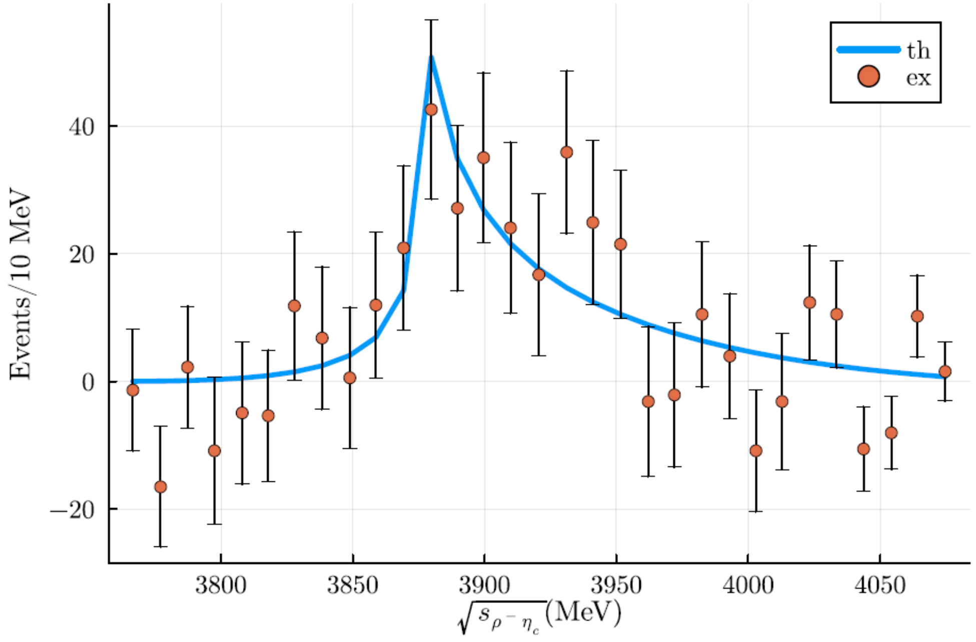
Data Fit-$\eta_c \rho^- \pi^+$

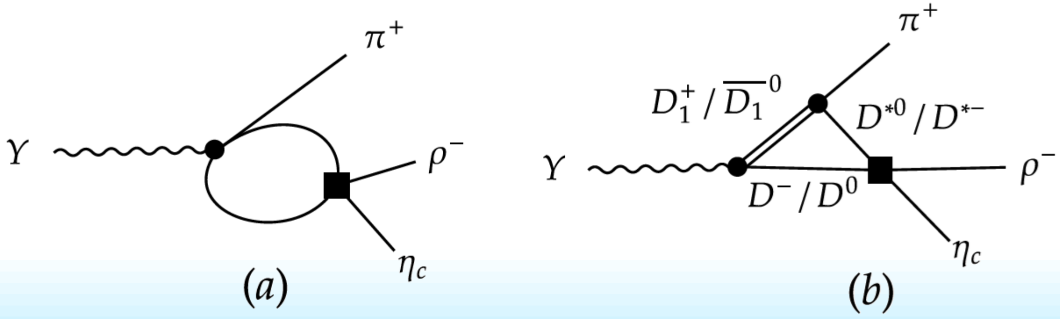




1. Data very limit
2. Peak is mainly from Fig.(b)
3. No background considered

Data Fit-$\eta_c \rho^- \pi^+$

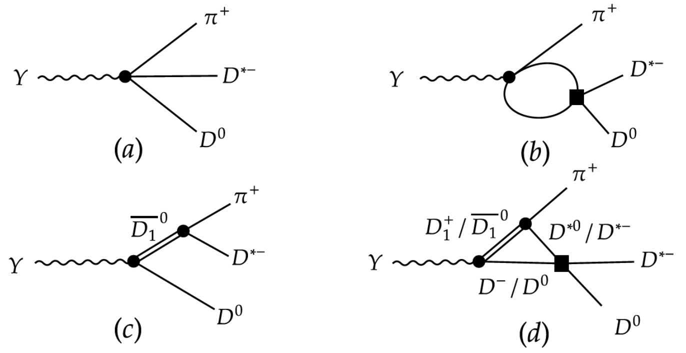


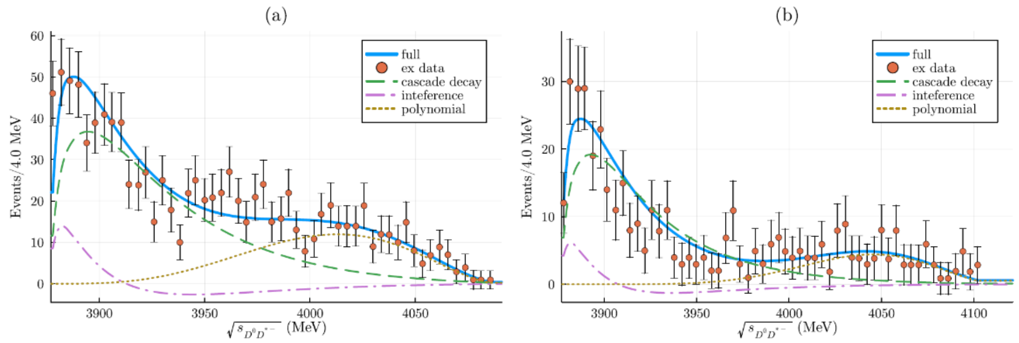


1. Data very limit
2. Peak is mainly from Fig.(b)
3. No background considered

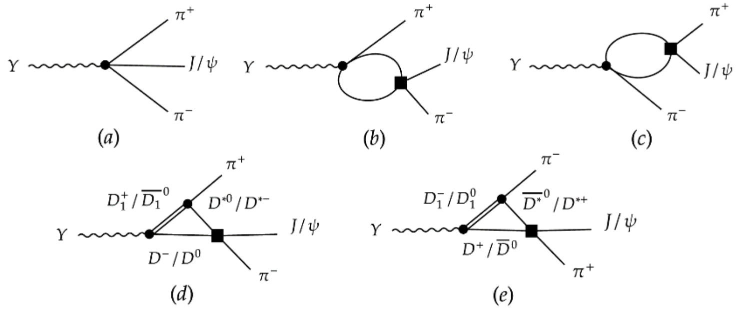
1. **Why are two-particle loops similar as Fig（a） not important ?**
2. **How is the contribution of Kinematical effect from Triangle loop ?**
3. **How is the contribution of the re-scattering T matrix ?**

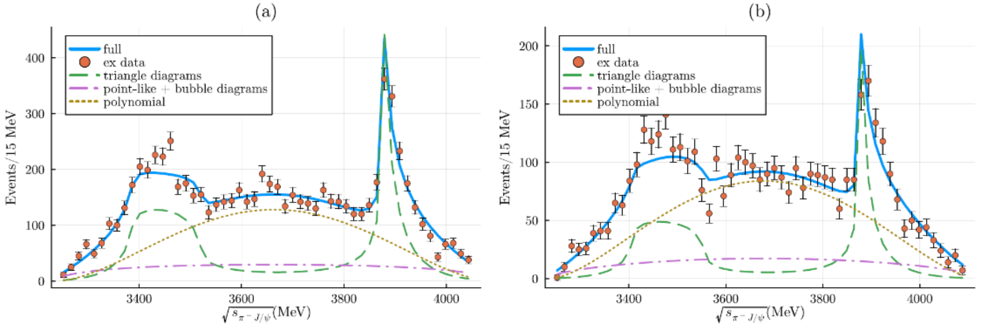
Data Fit-Two-body Loop





Since the scattering(Fig.b) is much weaker than direct decay (Fig.a). If we insist the contribution from Fig.b/c for $J\backslash\psi\pi\pi$ dominate, it will ask for Fig.a for $\bar{D}D^*\pi$ too large!

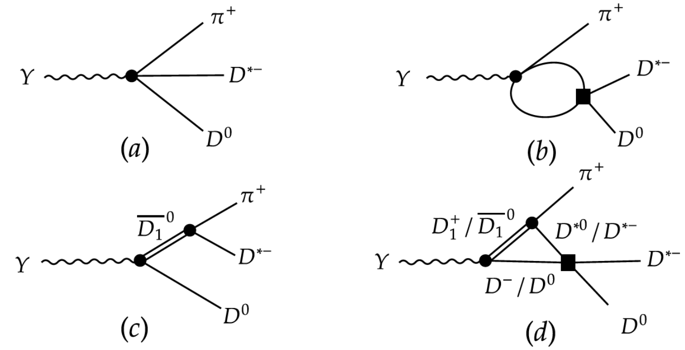


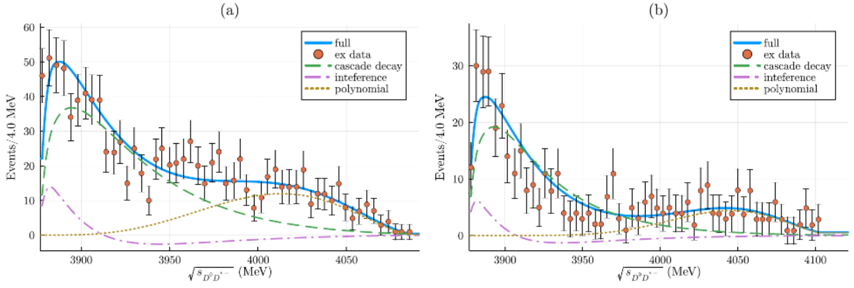


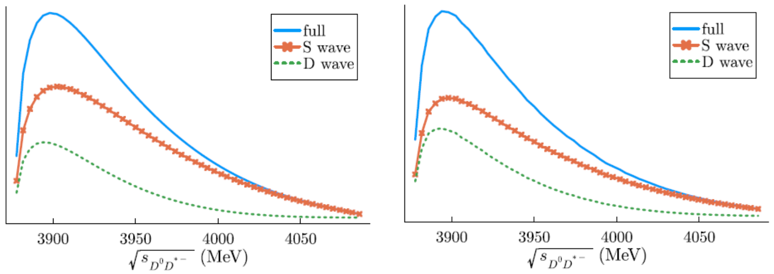
Coupled channel Constrain !

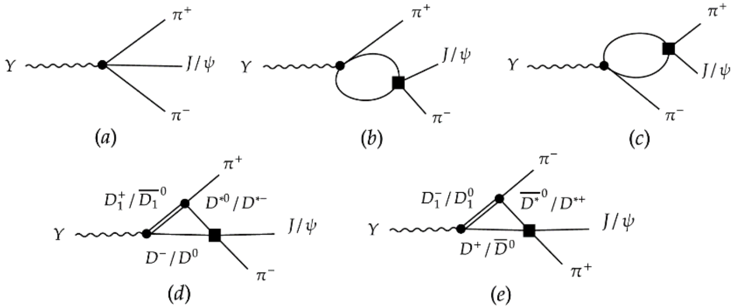
A more comprehensive framework for systematically describing hadrons

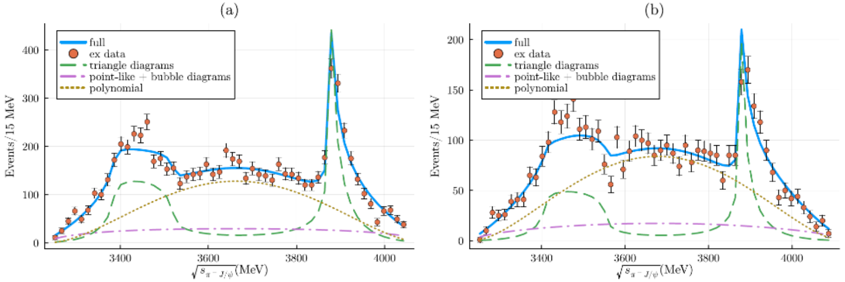
Data Fit- Kinematical effect from Triangle loop

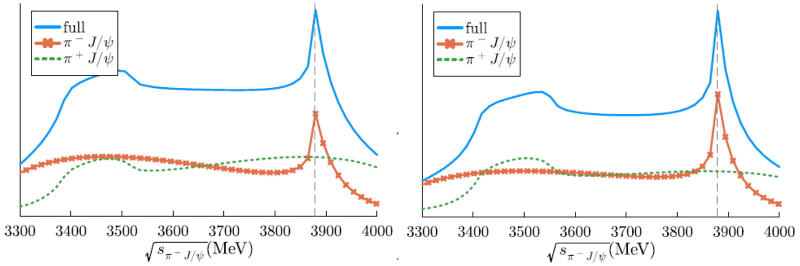






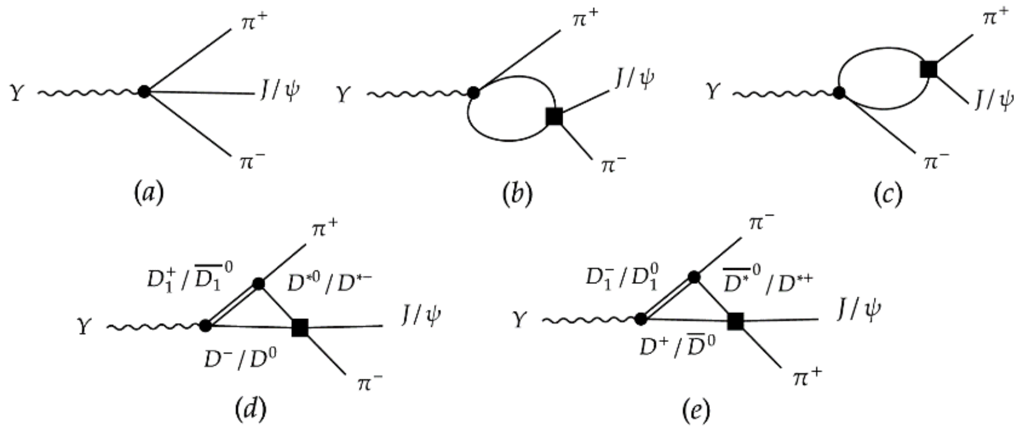


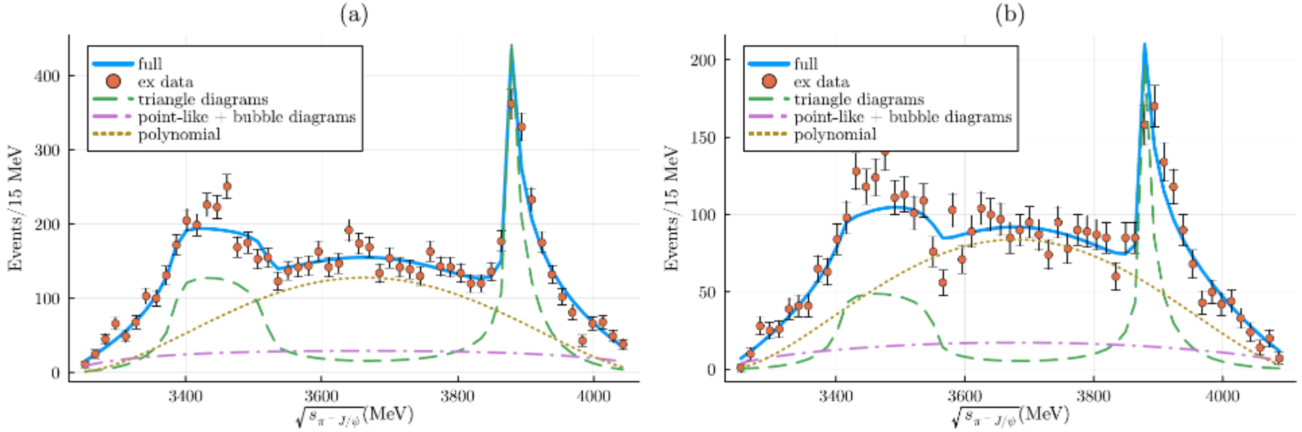


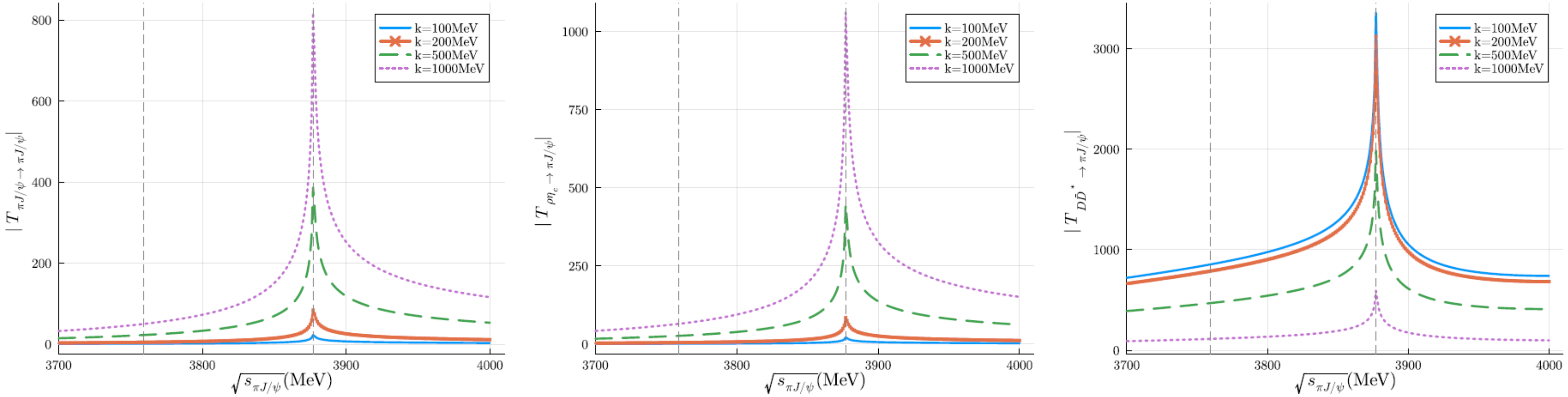


The Kinematical effect from Triangle loop plays the role, but not full reason !

Data Fit- re-scattering T matrix







The threshold cusp is clear, which should play important contribution for the peak!

Pole Position

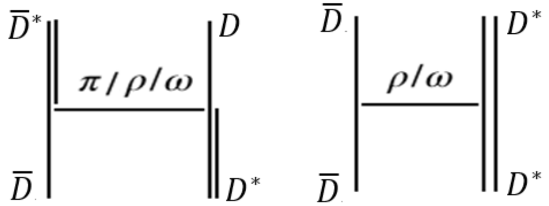
Three channels $\bar{D}D^*,\ J/\psi\pi,\ \eta_c\rho$

$$H = H_0 + H_I$$

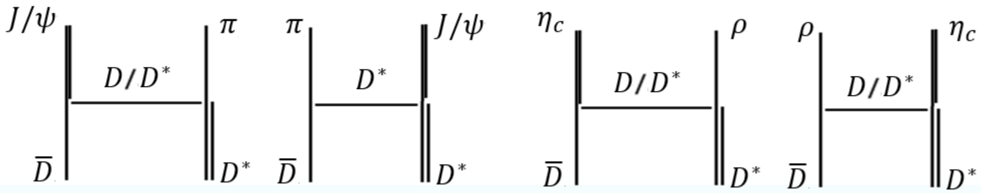
$$v = \sum_{\alpha,\beta} |\alpha(k_\alpha)\rangle v_{\alpha,\beta} \langle \beta(k_\beta)|$$

$\bar{D}D^* \to \bar{D}D^*$ Heavy Quark Symmetry

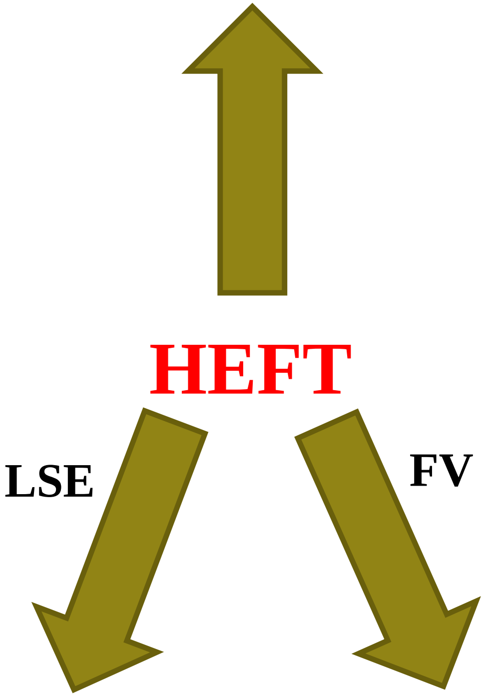
The interaction determined by Tcc



$\bar{D}D^* \to J/\psi\pi, \eta_c\rho$



Resonance
(Mass, width, pole position, coupling)



T matrix
(phase shift, Inelascity)

Lattice spectrum

	Pole Position	Type	Scheme($\Lambda_{\pi J/\psi}$)
This work	3798.72 - 1.10i	RS^{---} Virtual	1(1.3GeV)
	3798.46 - 1.71i		1(1.5GeV)
	3798.12 - 2.26i		1(1.7GeV)
	3798.27 - 2.02i		2(1.5GeV)
	3797.80 - 2.64i		2(1.7GeV)
Ref. [25]	3798^{+25}_{-31}	Virtual	-
	$3902(6) - 38(9)i$	Resonance	
Ref. [19]	3831^{+27}_{-38}	Virtual	
	$3894(6) - 30(13)i$	Resonance	
Ref. [21]	3870	Virtual	
Ref. [20]	3879	Virtual	
Ref. [22]	3872	Virtual	
Ref. [26]	3880(3) - 13(1)i	Resonance	
Ref. [30]	3884 - 22i	Resonance	
Ref. [27]	3840	Virtual	

A bit far away from the Zc(3900), thus, from this calculation, we interpolate the peak around 3900 is not from an physical state!

Finite volume spectra

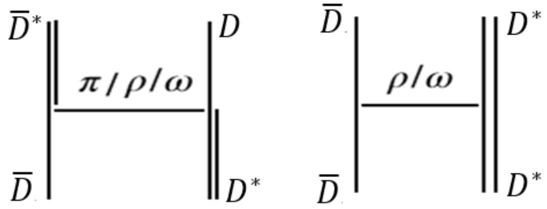
Three channels $\bar{D}D^*,\ J/\psi\pi,\ \eta_c\rho$

$$H = H_0 + H_I$$

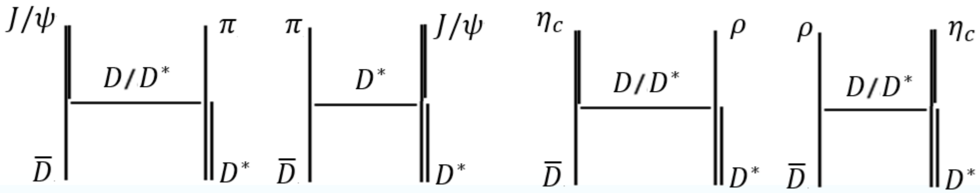
$$v = \sum_{\alpha,\beta} |\alpha(k_\alpha)\rangle v_{\alpha,\beta} \langle \beta(k_\beta)|$$

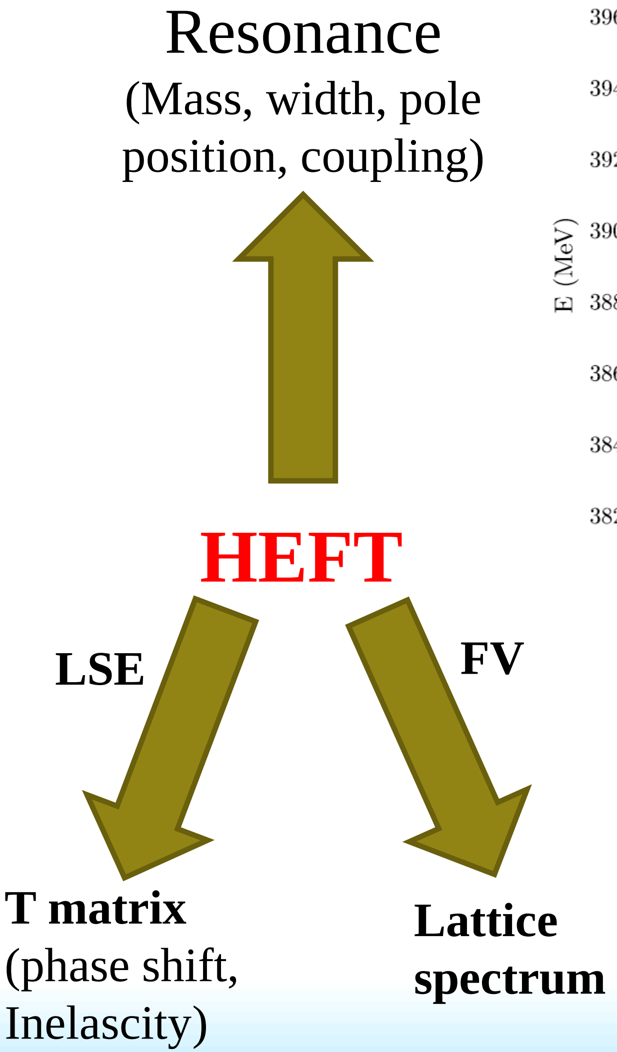
$\bar{D}D^* \to \bar{D}D^*$ Heavy Quark Symmetry

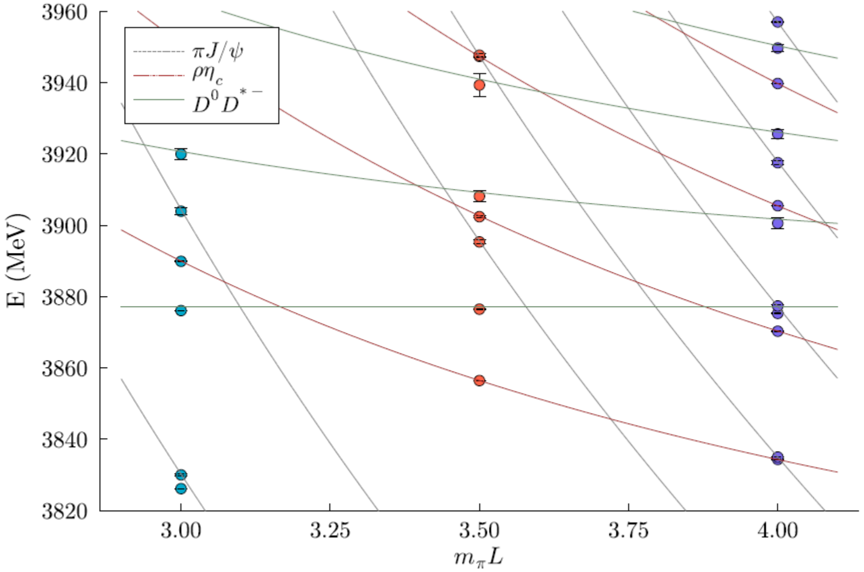
The interaction determined by Tcc



$\bar{D}D^* \to J/\psi\pi, \eta_c\rho$







The points are all close to the free energy, which is also consistent with existed lattice data, and also consistent with our interpolation of the peak structure.

The method please see Kang Yu's Post!

Summary

- We build a three channels model for Zc(3900).
- We symmetrically analysis three reactions, and nice describe the invariant mass spectra of $\bar{\mathrm{D}}\mathrm{D}^*$, $J/\psi\pi$, $\eta_c\rho$.
- We find that the peak around 3900 MeV could be explained as threshold cusps mainly because of triangle loop.
- The kinematical effect from triangle loop just enhance the cusp from the re-scattering T matrix from the three channels model.

Outlook

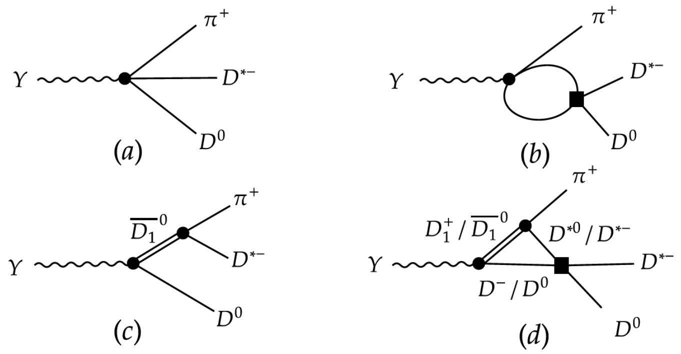
Weak Point

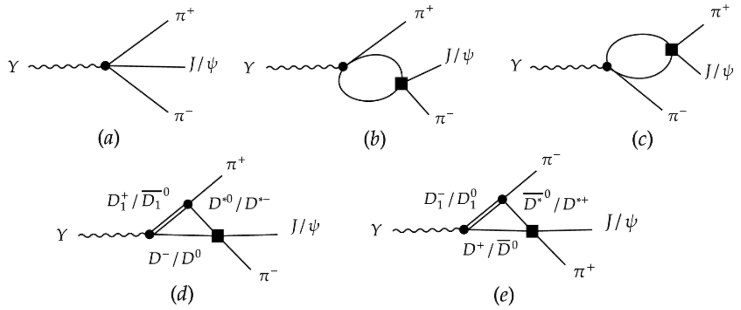
- Unknown Background !
- No $Y - \bar{D}D^*$ and $Y - J/\psi\ X$ contribution !

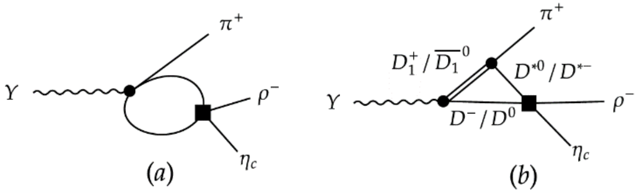
  --- Three body unitary model ?

  --- Too many parameters ?

  --- More experimental data and Lattice inputs !
- By using the current model, we want to analysis more data at different energies.







Thanks for attention