



第三届BESIII-BelleII-LHCb粲强子物理 联合研讨会

Study of the $D_{s0}^*(2317)$ in $\Lambda_b \rightarrow \Lambda_c (\bar{D}\bar{K})^-$ decays

- ➡ Chu-Wen Xiao (肖赭文)
- ➡ Guangxi Normal University (广西师范大学)
- ➡ Collaborators: Eulogio Oset , Wei-Hong Liang
Ju-Jun Xie, Hai-Peng Li

arXiv: [2411.17098](https://arxiv.org/abs/2411.17098) --> EPJC85(2025)616

2025.6. 长沙



Outline

1. Introduction
2. Formalism
3. Results
4. Summary

§ 1. Introduction

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



Mainly decay mode

$$D_s^+ \pi^0$$

$$I(J^P) = 0(0^+)$$

Also found on 2003

Isospin $I = 1$

Fraction (Γ_i/Γ)

$$(100^{+0}_{-20}) \%$$

VALUE (MeV)

$$< 3.8$$

theoretical predicted widths from 10 keV to 100 keV

PDG review on “Heavy Non- $q\bar{q}$ Mesons”

79. Heavy Non- $q\bar{q}$ Mesons

Revised March 2024 by T. Gutsche (Tübingen U.), C. Hanhart (FZ Jülich) and R.E. Mitchell (Indiana U.).



DK molecular picture--most favored :

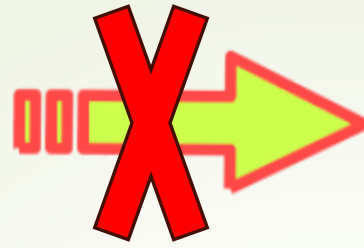
E. van Beveren and G. Rupp, Phys. Rev. Lett. 91, 012003 (2003)
T. Barnes, F. E. Close, and H. J. Lipkin, Phys. Rev. D 68, 054006 (2003)
Y.-Q. Chen and X.-Q. Li, Phys. Rev. Lett. 93, 232001 (2004)
E. E. Kolomeitsev and M. F. M. Lutz, Phys. Lett. B 582, 39 (2004)
D. Gamermann, E. Oset, D. Strottman, and M. J. Vicente Vacas, Phys. Rev. D 76, 074016 (2007)
F.-K. Guo, P.-N. Shen, H.-C. Chiang, R.-G. Ping, and B.-S. Zou, Phys. Lett. B 641, 278 (2006)
F.-K. Guo, P.-N. Shen, and H.-C. Chiang, Phys. Lett. B 647, 133 (2007)
M.-Z. Liu, X.-Z. Ling, L.-S. Geng, E. Wang, and J.-J. Xie, Phys. Rev. D 106, 114011 (2022)

DK molecular picture—Lattice QCD support:

L. Liu, K. Orginos, F.-K. Guo, C. Hanhart, and U.-G. Meißner, Phys. Rev. D 87, 014508 (2013)
D. Mohler, C. B. Lang, L. Leskovec, S. Prelovsek, and R. M. Woloshyn, Phys. Rev. Lett. 111, 222001 (2013)
C. B. Lang, L. Leskovec, D. Mohler, S. Prelovsek, and R. M. Woloshyn, Phys. Rev. D 90, 034510 (2014)
A. Martínez Torres, E. Oset, S. Prelovsek, and A. Ramos, JHEP 05, 153 (2015)
G. S. Bali, S. Collins, A. Cox, and A. Schäfer, Phys. Rev. D 96, 074501 (2017)
G. K. C. Cheung, C. E. Thomas, D. J. Wilson, G. Moir, M. Peardon, and S. M. Ryan (Hadron Spectrum), JHEP 02, 100 (2021)
Z. Yang, G.-J. Wang, J.-J. Wu, M. Oka, and S.-L. Zhu, Phys. Rev. Lett. 128, 112001 (2022)

$D_{s0}^*(2317)$

DK molecule



DK channel

Enhancement close to threshold
(how strong)

the LHCb collaboration had observed the reaction

$$\Lambda_b \rightarrow \Lambda_c \bar{D}^0 K^-$$

R. Aaij et al. (LHCb), Eur. Phys. J. C 84, 575 (2024)

What can we learn from the *DK* invariant mass distribution in the future measurement?

$D_{s0}^*(2317)$

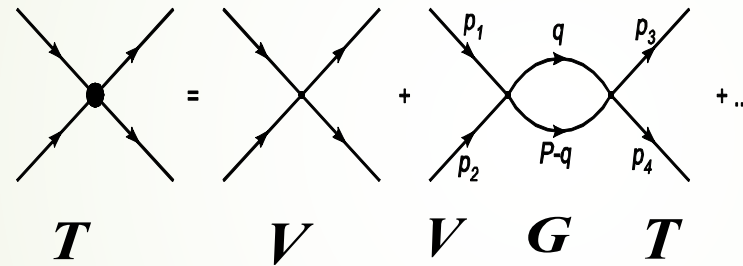


§2. Formalism

(1) Coupled channel interaction from the chiral unitary approach

- **Chiral Unitary Approach**: solving Bethe-Salpeter equations, which take on-shell approximation for the loops.

$$T = V + V G T, \quad T = [1 - V G]^{-1} V$$



D. L. Yao, L. Y. Dai, H. Q. Zheng
and Z. Y. Zhou, Rept. Prog. Phys.
84, 076201 (2021)

where **V** matrix (potentials) can be evaluated from the interaction Lagrangians.

$$V_{ij} = C_{ij} g^2 (p_1 + p_3) \cdot (p_2 + p_4)$$

$$C_{ij} = \begin{pmatrix} -\frac{1}{2} \left(\frac{1}{M_\rho^2} + \frac{1}{M_\omega^2} \right) & -\frac{1}{M_\rho^2} & \frac{2}{\sqrt{3}} \frac{1}{M_{K^*}^2} \\ -\frac{1}{2} \left(\frac{1}{M_\rho^2} + \frac{1}{M_\omega^2} \right) & \frac{2}{\sqrt{3}} \frac{1}{M_{K^*}^2} & 0 \end{pmatrix}$$

$\bar{D}^0 K^-$

$D^- \bar{K}^0$

$D_s^- \eta$

J. A. Oller and E. Oset, Nucl. Phys. A
620 (1997) 438

E. Oset and A. Ramos, Nucl. Phys. A
635 (1998) 99

J. A. Oller and U. G. Meißner, Phys.
Lett. B 500 (2001) 263

G is a diagonal matrix with the loop functions of each channels:

$$G_{ll}(s) = i \int \frac{d^4 q}{(2\pi)^4} \frac{1}{(P-q)^2 - m_{l1}^2 + i\varepsilon} \frac{1}{q^2 - m_{l2}^2 + i\varepsilon}$$

The coupled channel scattering amplitudes **T matrix satisfy the unitary** :

$$\text{Im } T_{ij} = T_{in} \sigma_{nn} T_{nj}^*$$

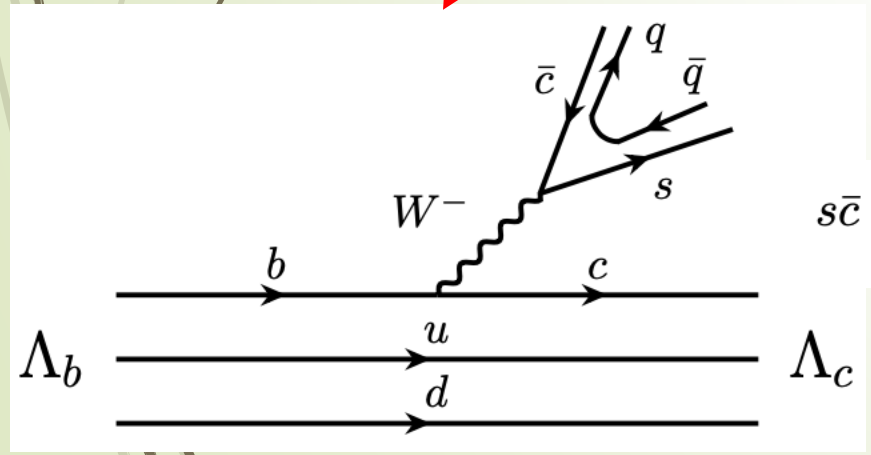
$$\sigma_{nn} \equiv \text{Im } G_{nn} = - \frac{q_{cm}}{8\pi\sqrt{s}} \theta(s - (m_1 + m_2)^2)$$

To search the poles of the resonances, we should extrapolate the scattering amplitudes to the second Riemann sheets:

$$G_{ll}^{II}(s) = G_{ll}^I(s) + i \frac{q_{cm}}{4\pi\sqrt{s}}$$

(2) Final state interaction

The weak decay process at the quark level



$$s\bar{c} \rightarrow \sum_i s\bar{q}_i q_i \bar{c}, \quad q_i = u, d, s, c.$$

$$T = [1 - VG]^{-1} V$$

S-wave

The final state interaction at the hadron level

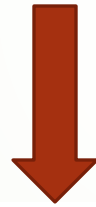
$$\mathcal{P} = \begin{pmatrix} \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} + \frac{\pi^0}{\sqrt{2}} & \pi^+ & K^+ & \bar{D}^0 \\ \pi^- & \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} - \frac{\pi^0}{\sqrt{2}} & K^0 & D^- \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} + \sqrt{\frac{2}{3}}\eta' & D_s^- \\ D^0 & D^+ & D_s^+ & \eta_c \end{pmatrix}$$

$$s\bar{c} \rightarrow \sum_i \mathcal{P}_{3i} \mathcal{P}_{i4} = (\mathcal{P}^2)_{34}$$

$$= \underline{K^- \bar{D}^0 + \bar{K}^0 D^-} - \frac{\eta}{\sqrt{3}} D_s^-$$

$$t_{K^- \bar{D}^0} = A \left\{ 1 + G_{K^- \bar{D}^0} t_{K^- \bar{D}^0, K^- \bar{D}^0} + G_{\bar{K}^0 D^-} t_{\bar{K}^0 D^-, K^- \bar{D}^0} - \frac{1}{\sqrt{3}} G_{\eta D_s^-} t_{\eta D_s^-, K^- \bar{D}^0} \right\}$$

$$t_{\bar{K}^0 D^-} = A \left\{ 1 + G_{K^- \bar{D}^0} t_{K^- \bar{D}^0, \bar{K}^0 D^-} + G_{\bar{K}^0 D^-} t_{\bar{K}^0 D^-, \bar{K}^0 D^-} - \frac{1}{\sqrt{3}} G_{\eta D_s^-} t_{\eta D_s^-, \bar{K}^0 D^-} \right\}$$



$$\frac{d\Gamma}{dM_{\text{inv}}} = \frac{1}{(2\pi)^3} \frac{1}{4M_{\Lambda_b}^2} p_{\Lambda_c} \tilde{p}_{\bar{K}} \overline{\sum} \sum |t|^2$$

$$p_{\Lambda_c} = \frac{\lambda^{1/2} (M_{\Lambda_b}^2, M_{\Lambda_c}^2, M_{\text{inv}}^2(\bar{K} \bar{D}))}{2M_{\Lambda_b}}$$

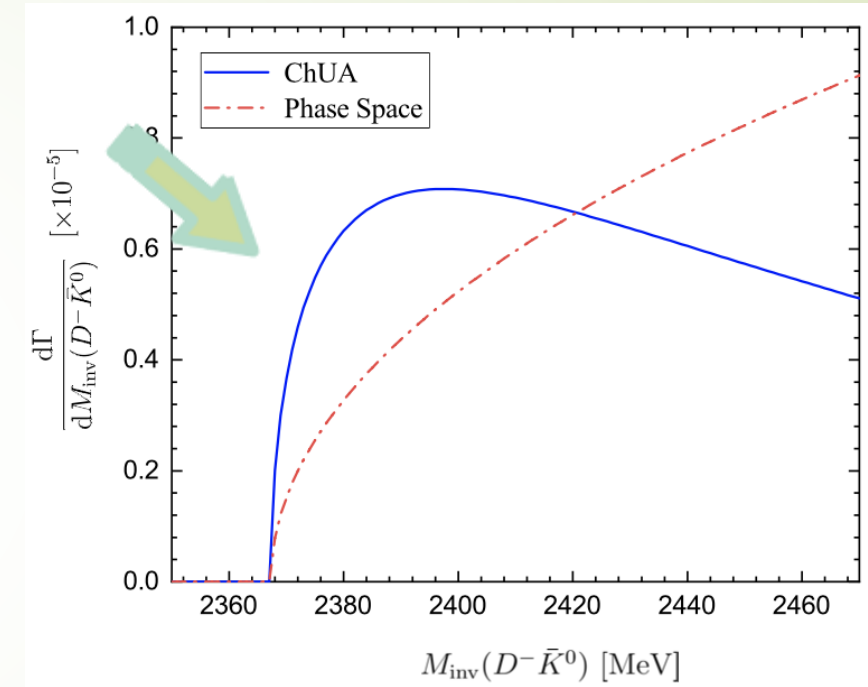
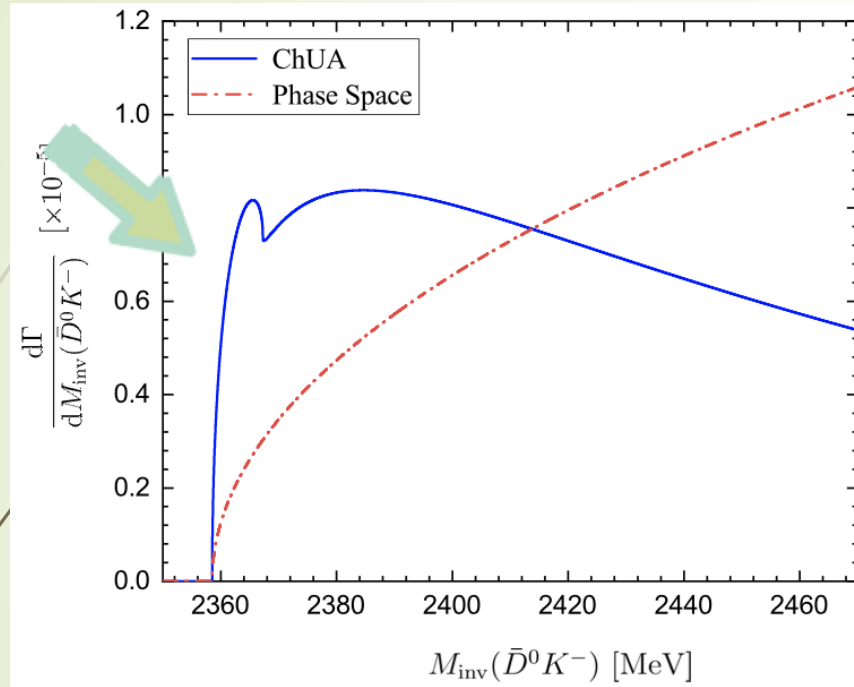
$$\tilde{p}_{\bar{K}} = \frac{\lambda^{1/2} (M_{\text{inv}}^2(\bar{K} \bar{D}), M_{\bar{K}}^2, M_{\bar{D}}^2)}{2M_{\text{inv}}(\bar{K} \bar{D})}$$

§3. Results

(1) Theoretical results

$$q_{\max} = 706 \text{ MeV}$$

$$A = 1$$



$$g_1^2 = \lim_{s \rightarrow s_0} (s - s_0) T_{11}; \quad g_j = g_1 \lim_{s \rightarrow s_0} \frac{T_{1j}}{T_{11}},$$

$$P_i = -g_i^2 \left. \frac{\partial G_i}{\partial s} \right|_{s=s_0}$$

pole [MeV]	g_1	g_2	g_3
2317.85	8182.29	8144.59	-5571.38
πD_s	P_1	P_2	P_3
	0.34	0.29	0.04

$$T = -8\pi \sqrt{s} f^{QM} \approx -8\pi \sqrt{s} \frac{1}{-\frac{1}{a} + \frac{1}{2} r_0 k^2 - ik}$$

$$\text{Im } G = -\frac{1}{8\pi \sqrt{s}} k$$



$$-\frac{1}{a} = -8\pi \sqrt{s} T^{-1} \Big|_{s=s_{\text{th}}}$$

$$\begin{aligned} r_0 &= \frac{\partial}{\partial k^2} 2(-8\pi \sqrt{s} T^{-1} + ik) \\ &= \frac{\sqrt{s}}{\mu} \frac{\partial}{\partial s} 2(-8\pi \sqrt{s} T^{-1} + ik) \Big|_{s=s_{\text{th}}} \end{aligned}$$

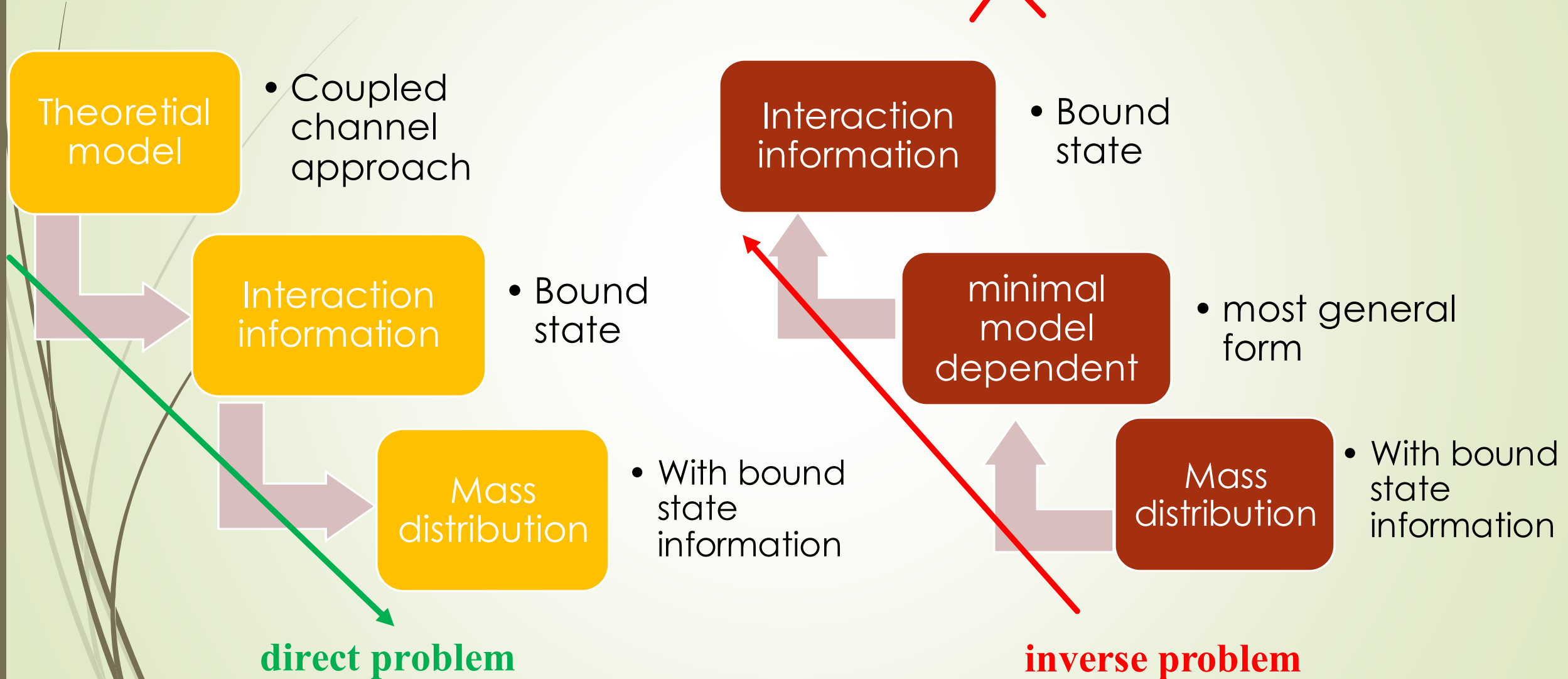
a_1	a_2	a_3
0.70	$0.51 - i0.12$	$0.21 - i0.06$
$r_{0,1}$	$r_{0,2}$	$r_{0,3}$
-2.25	$0.14 - i2.41$	$0.12 + i0.11$

(2) What is the inverse problem?

Without experimental data of mass distribution



Fits with theoretical model





(3) How to do the inverse problem?

Assume an energy dependence interaction potential

$$V = \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ & V_{11} & V_{13} \\ & & 0 \end{pmatrix} \quad \text{Isospin symmetric}$$

$$V_{11} = V'_{11} + \frac{\alpha}{M_V^2}(s - s_0)$$

$$V_{12} = V'_{12} + \frac{\beta}{M_V^2}(s - s_0)$$

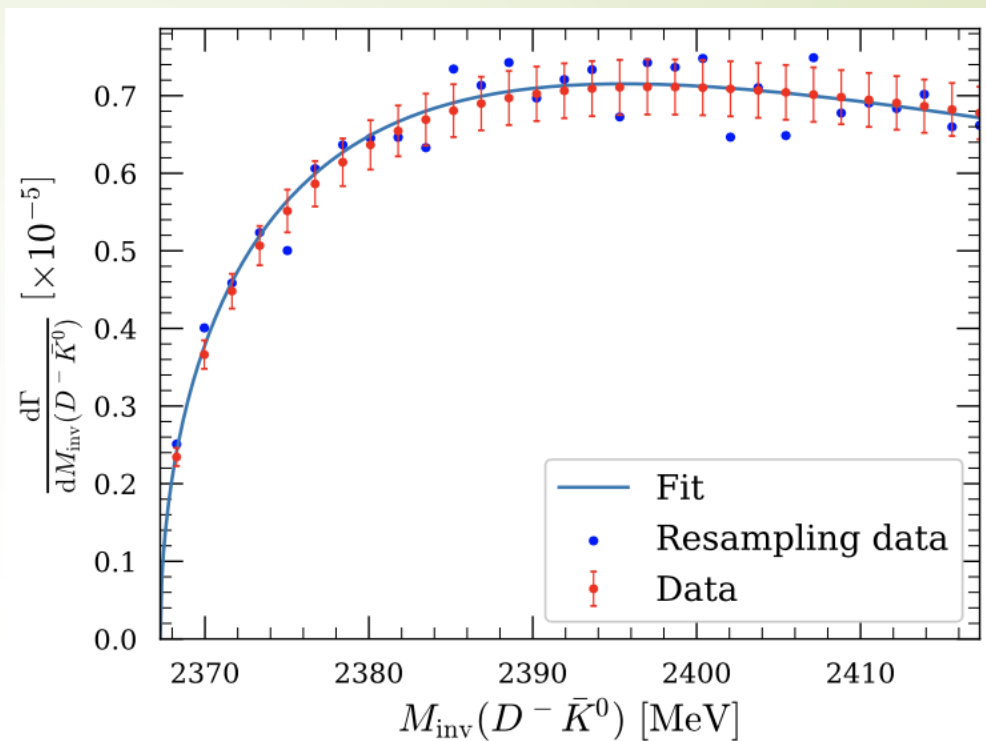
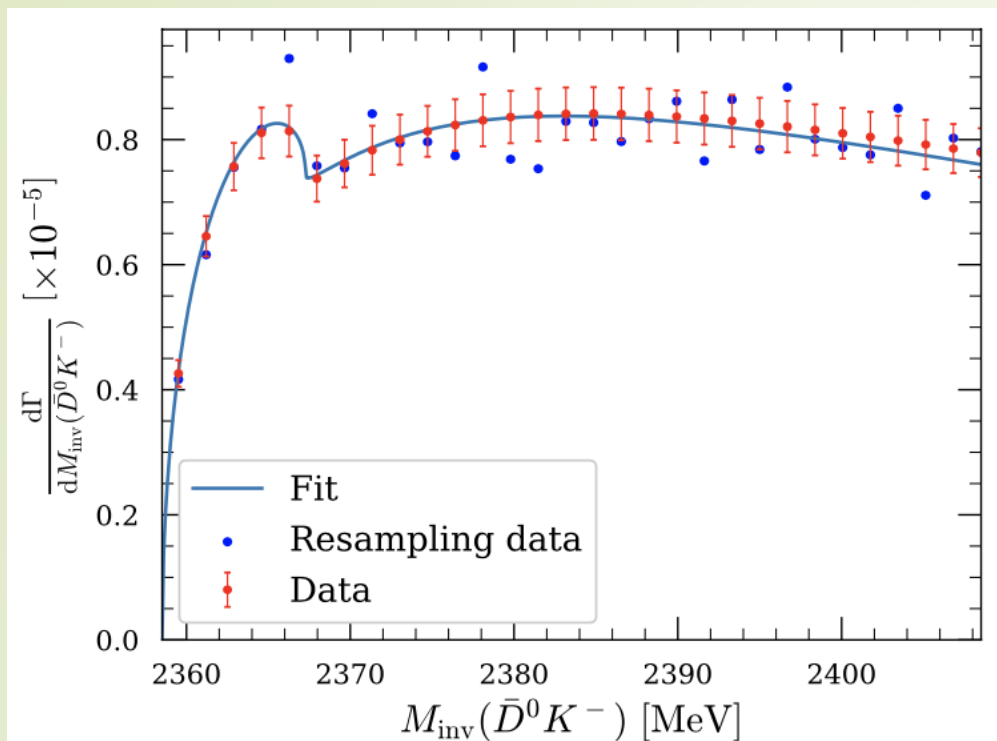
$$V_{13} = V'_{13} + \frac{\gamma}{M_V^2}(s - s_0)$$

8 free parameters totally:

$$V'_{11}, V'_{12}, V'_{13}, \alpha, \beta, \gamma, q_{\max} \text{ and } A$$

Generating random centroids of the data from the theoretical results

Using the bootstrap or resampling method $\longrightarrow$ Doing 50 fits



V'_{11}	V'_{12}	V'_{13}	α
-89.71 ± 31.50	-130.48 ± 27.73	98.15 ± 10.03	38.41 ± 128.72
β	γ	$q_{\max}$ [MeV]	A
-103.88 ± 120.34	7.28 ± 33.75	688.38 ± 32.87	0.95 ± 0.09

$$|\bar{K}\bar{D}, I=0\rangle = \frac{1}{\sqrt{2}} |\bar{K}^0 D^- + K^- \bar{D}^0\rangle$$

$$|\bar{K}\bar{D}, I=1\rangle = \frac{1}{\sqrt{2}} |\bar{K}^0 D^- - K^- \bar{D}^0\rangle$$



$$V^{I=0} = \frac{1}{2}(V_{11} + V_{22} + 2V_{12}) = V_{11} + V_{12}$$

$$V^{I=1} = \frac{1}{2}(V_{11} + V_{22} - 2V_{12}) = V_{11} - V_{12}$$



attractive

repulsive

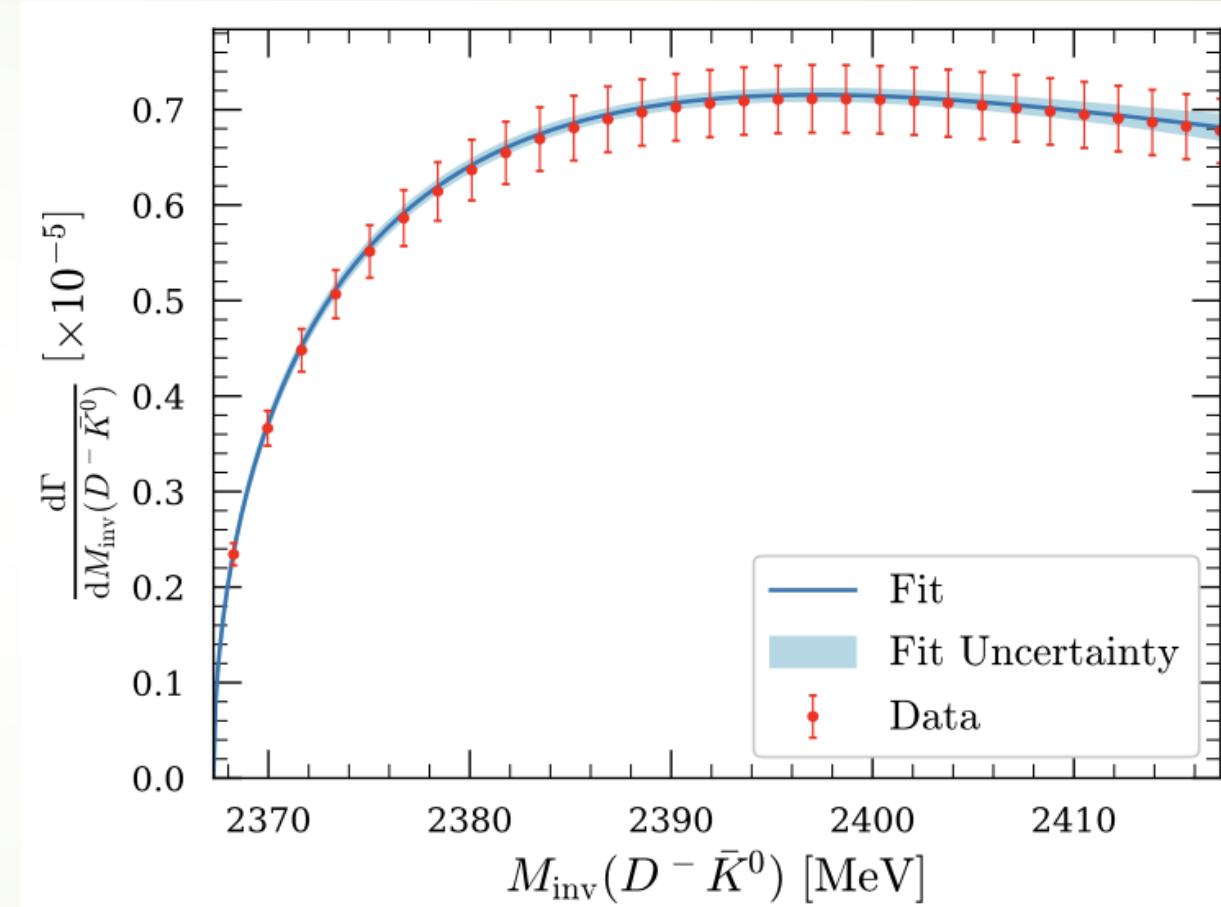
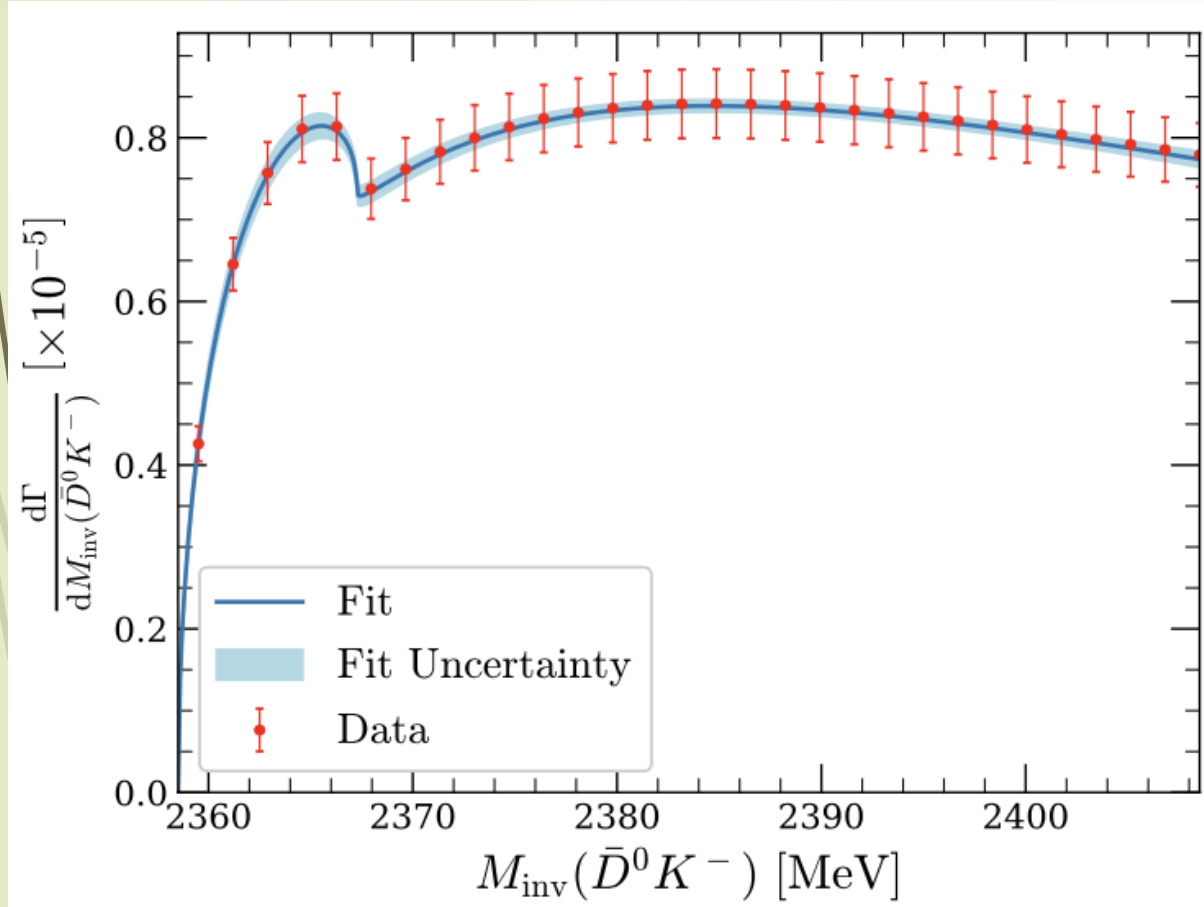
pole	g_1	g_2	g_3
2319.32 ± 3.92	8480.92 ± 612.18	8436.40 ± 578.85	-6594.20 ± 927.89

a_1	a_2	a_3
0.77 ± 0.11	$(0.59 \pm 0.10) - i(0.11 \pm 0.03)$	$(0.18 \pm 0.09) - i(0.05 \pm 0.02)$
$r_{0,1}$	$r_{0,2}$	$r_{0,3}$
-1.80 ± 0.64	$(0.42 \pm 1.09) - i(1.49 \pm 0.77)$	$-(2.75 \pm 4.33) - i(1.00 \pm 1.72)$

P_1	P_2	P_3
0.38 ± 0.06	0.32 ± 0.05	0.05 ± 0.01

Consistent with the theoretical results before

Results of the resampling with a narrow band for the uncertainty





§4. Summary

- We use the chiral unitary approach to dynamically generate the state $D_{s0}^*(2317)$
- Taking the pseudo data from theory, we use the resampling method for the inverse problem in the fitting of mass distribution, with a minimum model dependent method.
- The enhancement of this resonance at the DK threshold of the spectra can be tested by the information from the correlation functions.

Hope future experiments bring more clarifications on these issues.....



Thanks for your attention!

感谢大家的聆听！