

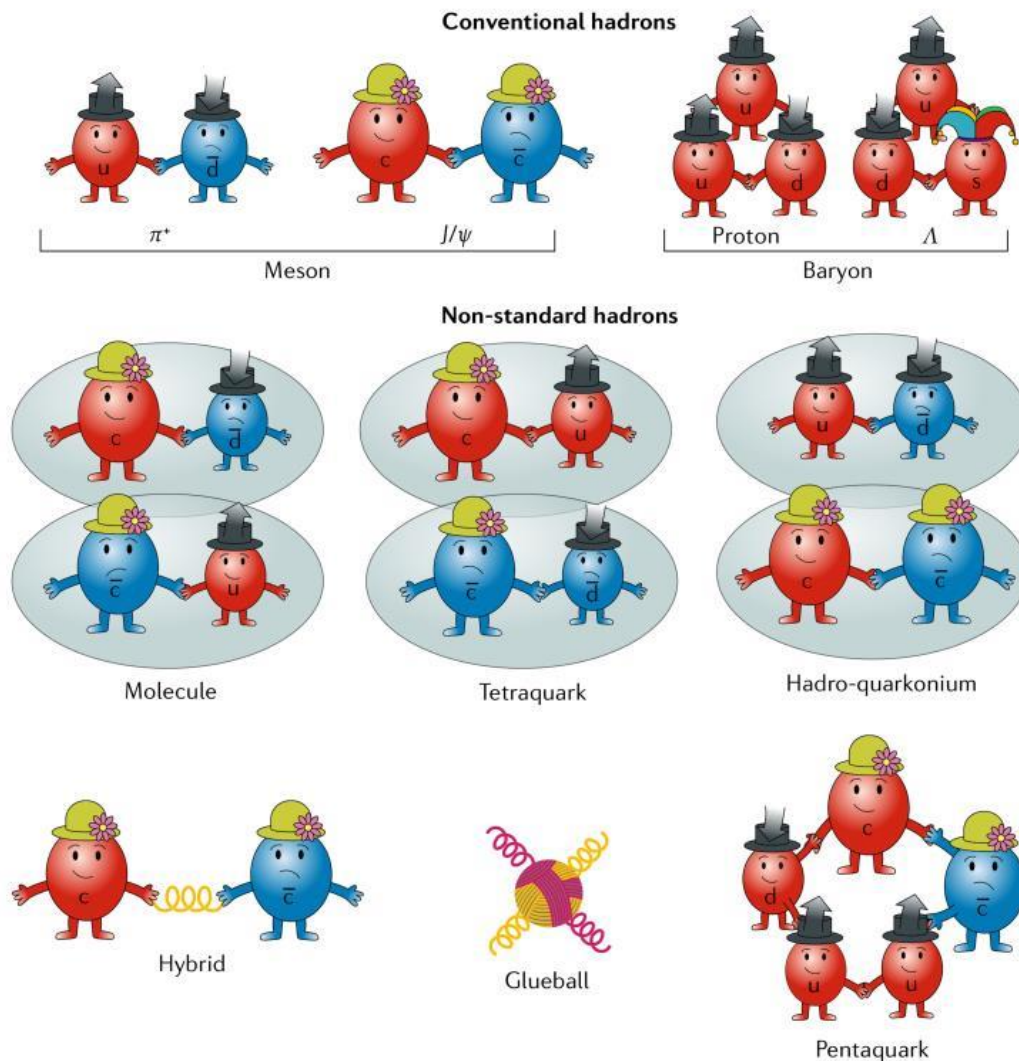
# 在 $B^- \rightarrow D_S^+ K^- \pi^-$ 衰变过程中研究 $T_{c\bar{s}0}(2900)^0$ 和 $D_0^*(2300)$

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# Hadrons



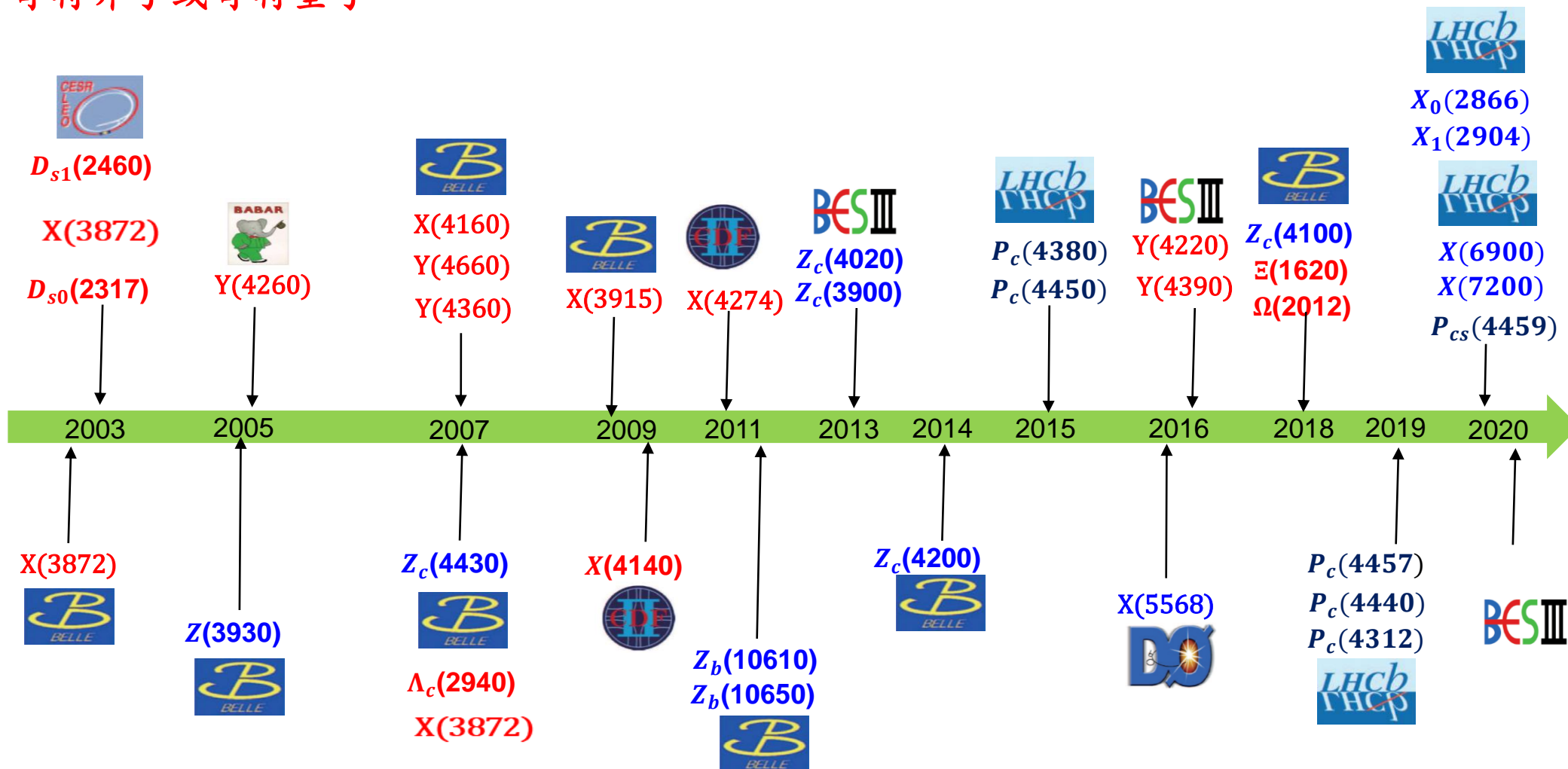
□在夸克模型下，强子分为介子和重子

□在量子色动力学(QCD)中，还允许一些奇特态的存在，如分子态，多夸克态，夸克胶子混杂态，胶球等

# Exotic states

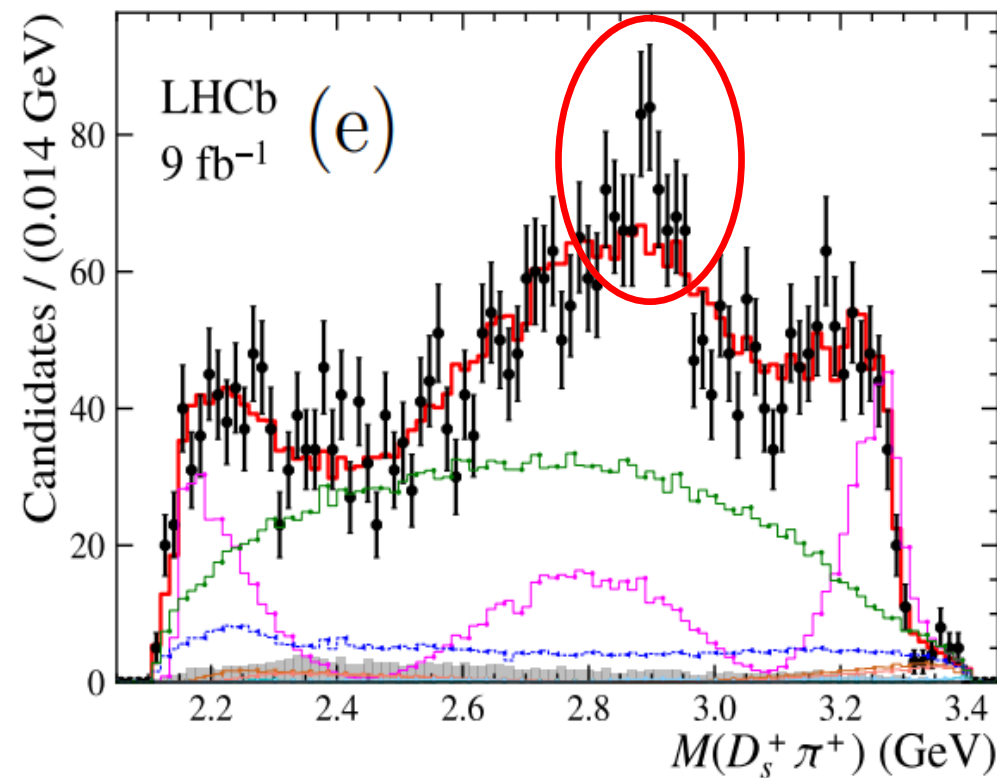
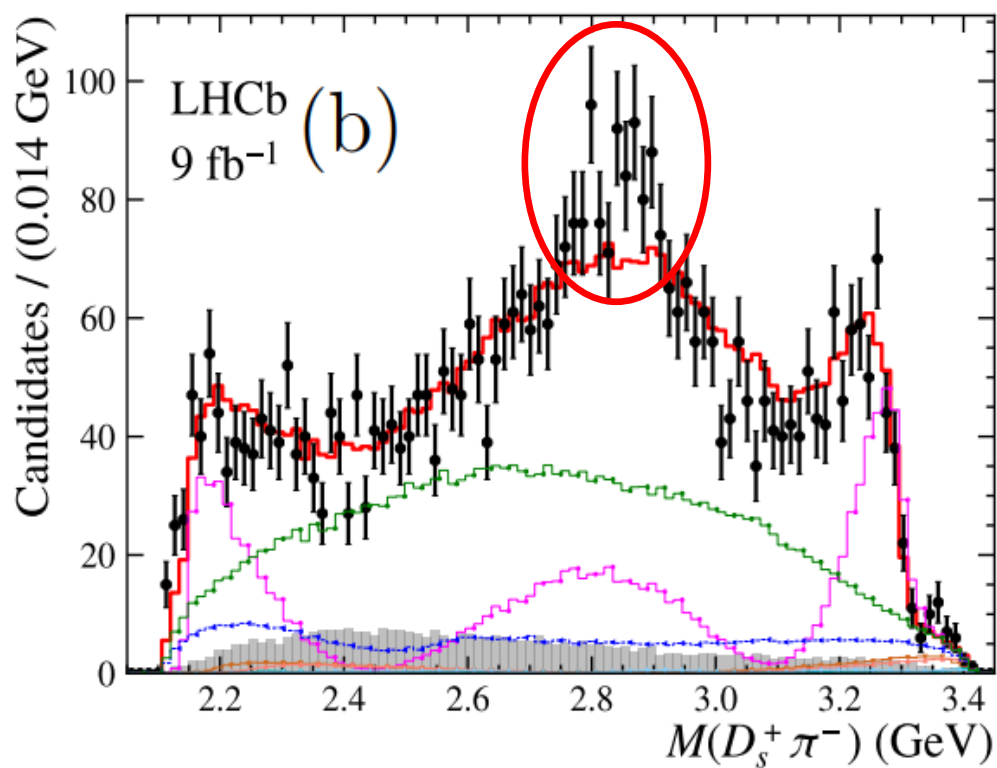


## 奇特介子或奇特重子



# Motivation

- 2022年7月，LHCb合作组在B介子衰变过程中，报告了两个新的开味四夸克态， $T_{c\bar{s}0}(2900)^0 [c\bar{s}ud]$ 和 $T_{c\bar{s}0}(2900)^{++} [c\bar{s}ud]$  [[arXiv:2212.02716](https://arxiv.org/abs/2212.02716)]



# Motivation



□  $T_{c\bar{s}0}(2900)^0 [c\bar{s}ud]$  和  $T_{c\bar{s}0}(2900)^{++} [c\bar{s}ud]$  [\[arXiv:2212.02716\]](#)

$$J^P = 0^+$$

$$T_{c\bar{s}0}(2900)^0: M = 2.892 \pm 0.014 \pm 0.015 \text{ GeV},$$

$$\Gamma = 0.119 \pm 0.026 \pm 0.013 \text{ GeV},$$

$$T_{c\bar{s}0}(2900)^{++}: M = 2.921 \pm 0.017 \pm 0.020 \text{ GeV},$$

$$\Gamma = 0.137 \pm 0.032 \pm 0.017 \text{ GeV}.$$

## □ 分子态

- $D^* K^*$  [2208.10196, 2212.03018, 2212.12001]
- $D_s^* \rho$  [2207.02648]

## □ 紧致态

- $[cu][\bar{s}d], [cs][\bar{u}d]$  [PhysRevD 107 (2023) 096023]

## □ 类共振态结构

- $D^* K^*$  阈值效应 [EPJC 82, 955]
- $D^* K^*$  和  $D_s^* \rho$  的耦合道效应 [2211.01302]

# Motivation: Process selection



□ 基于目前的理论研究， $T_{c\bar{s}0}(2900)^{0/++}$  的主要强衰变道为

- $T_{c\bar{s}0}(2900) \rightarrow D_s \pi$  (S波)
- $T_{c\bar{s}0}(2900) \rightarrow D K$  (S波)
- $T_{c\bar{s}0}(2900) \rightarrow D_s^* \rho$  (S波)
- $T_{c\bar{s}0}(2900) \rightarrow D_{s1} \pi$  (P波)

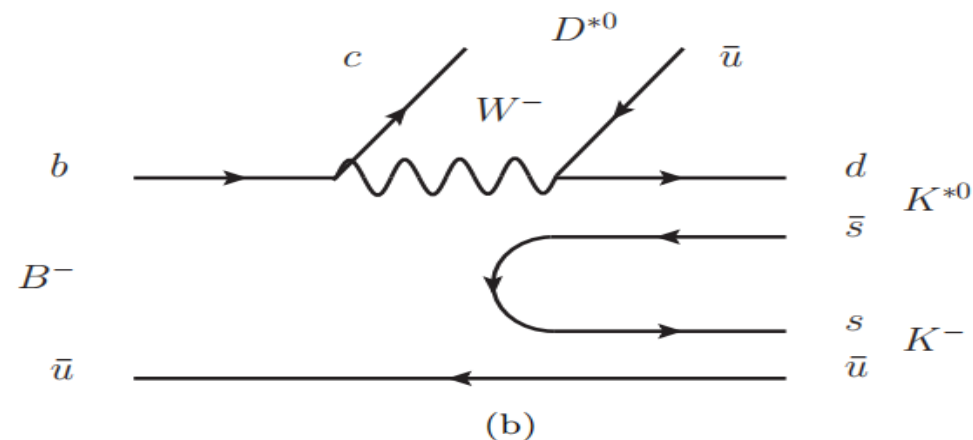
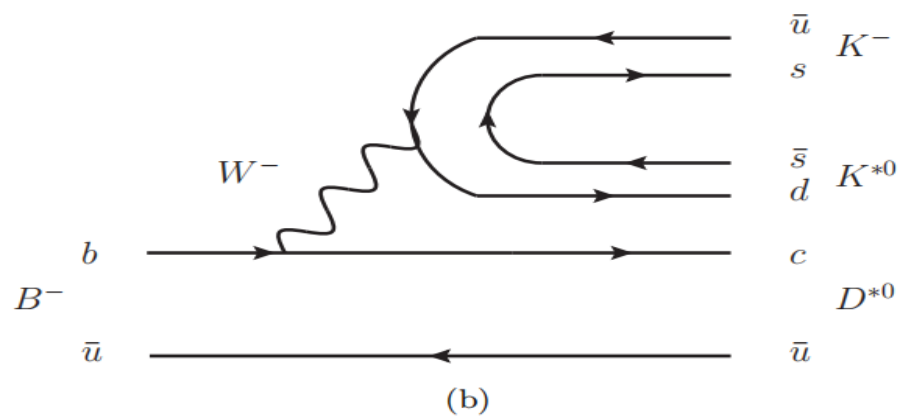
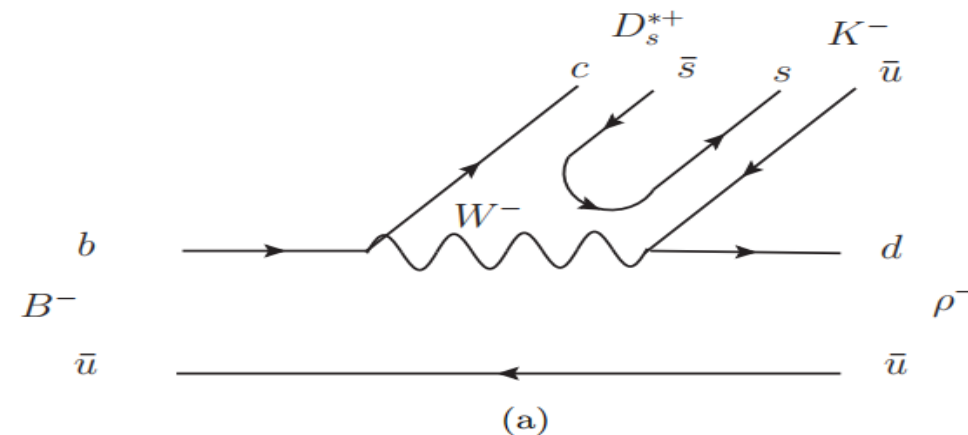
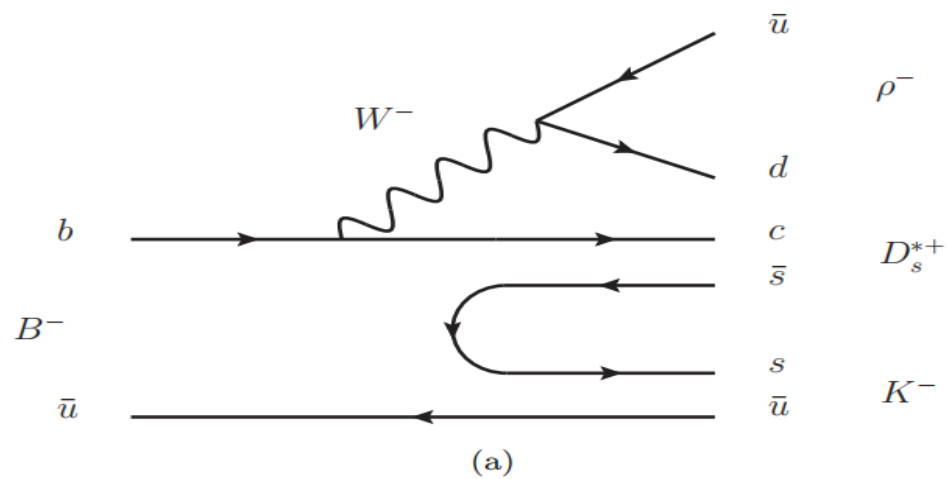
□ 2009年，Belle合作组对  $B^+ \rightarrow D_s^- K^+ \pi^+$  过程的分支比进行了测量 [[PhysRevD 80 \(2009\) 052005](#)]

$$\mathcal{B}(B^+ \rightarrow D_s^- K^+ \pi^+) = (1.71_{-0.07}^{+0.07}(\text{stat})_{-0.20}^{+0.20}(\text{syst}) \pm 0.15(\mathcal{B}_{int})) \times 10^{-4}$$

# The role of $T_{c\bar{s}0}(2900)^0$



## □ 强子化过程费曼图

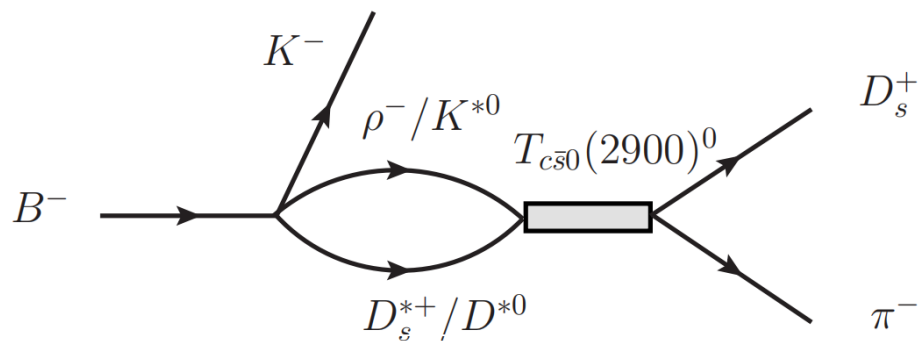




# The role of $T_{c\bar{s}0}(2900)^0$



## □ 强子层次示意图



## □ 衰变振幅形式

$$\begin{aligned} \mathcal{J}^{T_{c\bar{s}0}^0} &= Q\epsilon(V_1) \cdot \epsilon(V_2) \times (C \\ &+ 1)[G_{\rho^- D_s^{*+}} t_{\rho^- D_s^{*+} \rightarrow D_s^+ \pi^-} \\ &+ G_{D^{*0} K^{*0}} t_{D^{*0} K^{*0} \rightarrow D_s^+ \pi^-}] \end{aligned}$$

$$t_{\rho^- D_s^{*+} \rightarrow D_s^+ \pi^-} = \frac{g_{T_{c\bar{s}0}^0, \rho^- D_s^{*+}} g_{T_{c\bar{s}0}^0, D_s^+ \pi^-}}{M_{T_{c\bar{s}0}^0}^2 - m_{T_{c\bar{s}0}^0}^2 + im_{T_{c\bar{s}0}^0} \Gamma_{T_{c\bar{s}0}^0}}$$

$$t_{D^{*0} K^{*0} \rightarrow D_s^+ \pi^-} = \frac{g_{T_{c\bar{s}0}^0, D^{*0} K^{*0}} g_{T_{c\bar{s}0}^0, D_s^+ \pi^-}}{M_{T_{c\bar{s}0}^0}^2 - m_{T_{c\bar{s}0}^0}^2 + im_{T_{c\bar{s}0}^0} \Gamma_{T_{c\bar{s}0}^0}}$$

# The role of $T_{c\bar{s}0}(2900)^0$



□ 利用分子态图象计算耦合常数

$$g_{T_{c\bar{s}0}^0, D^* K^*}^2 = 16\pi(m_{D^*} + m_{K^*})^2 \tilde{\lambda}^2 \sqrt{\frac{2\Delta E}{\mu}}$$

$$\Delta E = m_{D^*} + m_{K^*} - m_{T_{c\bar{s}0}^0}$$

$$\mu = m_{D^*} m_{K^*} / (m_{D^*} + m_{K^*})$$

**PhysRev.137.B672(1965)**

**Phys. Lett. B 586, 53-61(2004)**

**PhysRevD.107.054044(2023)**

□ 利用有效拉氏量计算耦合常数

$$\Gamma_{T_{c\bar{s}0}^0 \rightarrow \rho^- D_s^{*+}} = \frac{3}{8\pi} \frac{1}{m_{T_{c\bar{s}0}^0}^2} \left| g_{T_{c\bar{s}0}^0, \rho^- D_s^{*+}} \right|^2 |\vec{q}_\rho|^2$$

$$\Gamma_{T_{c\bar{s}0}^0 \rightarrow D_s^+ \pi^-} = \frac{1}{8\pi} \frac{1}{m_{T_{c\bar{s}0}^0}^2} \left| g_{T_{c\bar{s}0}^0, D_s^+ \pi^-} \right|^2 |\vec{q}_\pi|^2$$

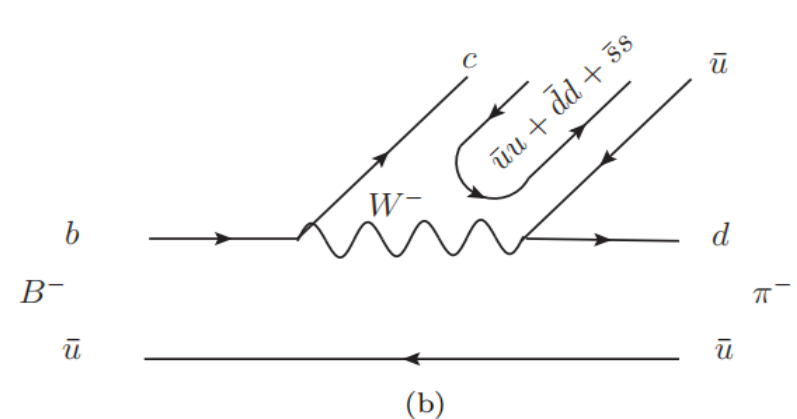
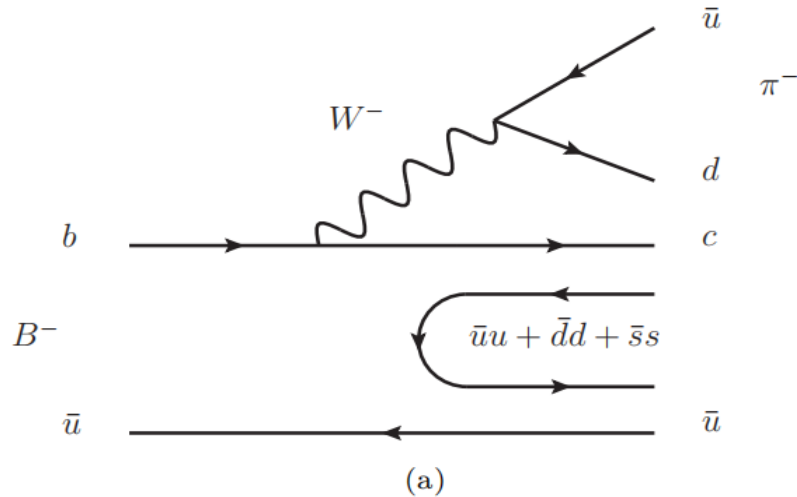
Channel	Width (MeV)
$T_{c\bar{s}0}^0 \rightarrow D^0 K^0$	52.6–101.7
$T_{c\bar{s}0}^0 \rightarrow D_s^+ \pi^-$	0.55–8.35
$T_{c\bar{s}0}^0 \rightarrow D_s^{*+} \rho^-$	2.96–5.3
$T_{c\bar{s}0}^0 \rightarrow D_{s1}^+ \pi^-$	6.63–10.29
$T_{c\bar{s}0}^0 \rightarrow D_{s1}^{\prime+} \pi^-$	6.63–10.3
$T_{c\bar{s}0}^0 \rightarrow D^{*0}(K\pi)^0$	16.11–18.96

**PhysRevD.107.034018(2023)**

# The role of $D_0^*(2300)$



## □ 强子化过程费曼图



## □ 强子化后可能的强子对

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

$$\sum_i c(\bar{u}u + \bar{d}d + \bar{s}s)\bar{u} = \sum_i P_{4i}P_{i1} = (P^2)_{41}$$

$$H = \pi^- \left( \frac{1}{\sqrt{2}} D^0 \pi^0 + \frac{1}{\sqrt{3}} D^0 \eta + D^+ \pi^- + D_s^+ K^- \right)$$

# The role of $D_0^*(2300)$



□ 基于同位旋多重态  $(D^+, -D^0), (\bar{D}^0, D^-), (-\pi^+, \pi^0, \pi^-)$

$$\begin{aligned} D^0 \pi^0 &= -\left|\frac{1}{2}, -\frac{1}{2}\right\rangle |1, 0\rangle \\ &= -\sqrt{\frac{2}{3}} \left|\frac{3}{2}, -\frac{1}{2}\right\rangle + \sqrt{\frac{1}{3}} \left|\frac{1}{2}, -\frac{1}{2}\right\rangle \end{aligned}$$

$$\begin{aligned} D^+ \pi^- &= \left|\frac{1}{2}, \frac{1}{2}\right\rangle |1, -1\rangle \\ &= \sqrt{\frac{1}{3}} \left|\frac{3}{2}, -\frac{1}{2}\right\rangle + \sqrt{\frac{2}{3}} \left|\frac{1}{2}, -\frac{1}{2}\right\rangle \end{aligned}$$

$$\begin{aligned} \frac{1}{\sqrt{2}} D^0 \pi^0 + D^+ \pi^- &= \left(-\sqrt{\frac{2}{3}} \cdot \sqrt{\frac{1}{2}} + \sqrt{\frac{1}{3}}\right) |D\pi\rangle^{I=\frac{3}{2}} \\ &+ \left(\sqrt{\frac{1}{3}} \cdot \sqrt{\frac{1}{2}} + \sqrt{\frac{2}{3}}\right) |D\pi\rangle^{I=\frac{1}{2}} \\ &= \sqrt{\frac{3}{2}} |D\pi\rangle^{I=\frac{1}{2}} \end{aligned}$$

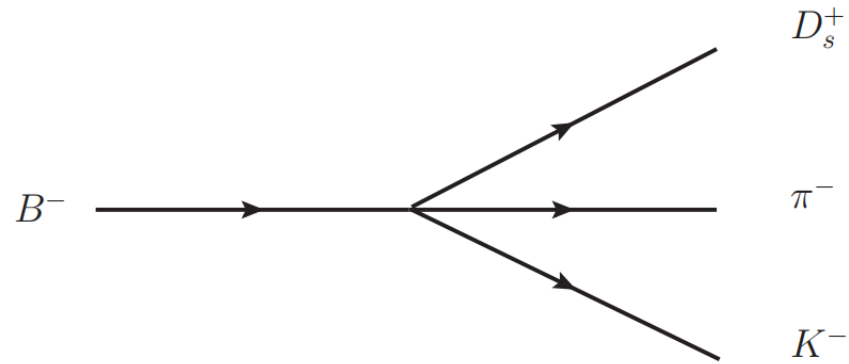
□ 我们可以得到

$$H = \pi^- \left( \sqrt{\frac{3}{2}} D\pi + \frac{1}{\sqrt{3}} D^0 \eta + D_s^+ K^- \right)$$

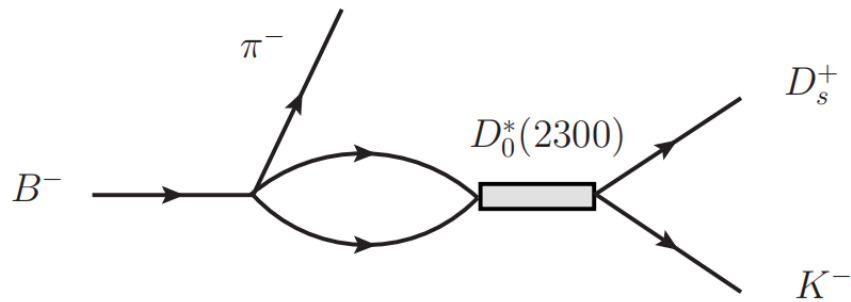
# The role of $D_0^*(2300)$



## □ 强子层次示意图



(a)



(b)

## □ 衰变振幅形式

$$\mathcal{T}^{D_0^*(2300)} = Q'(C+1)[h_{D_s\bar{K}} + \sum_i h_i G_i t_{i \rightarrow D_s\bar{K}}]$$

$$= \mathcal{T}^{tree} + \mathcal{T}^S$$

$$h_{D\pi} = \sqrt{\frac{3}{2}}, \quad h_{D\eta} = \sqrt{\frac{1}{3}}, \quad h_{D_s\bar{K}} = 1$$

$$\Gamma_{B-\mathcal{B}}(B^- \rightarrow D_s^+ K^- \pi^-)$$

$$= Q'^2 \int \frac{1}{(2\pi)^3} \frac{(C+1)^2}{4M_{B^-}^2} \mathbf{P}_\pi \tilde{\mathbf{P}}_K$$

$$\times \left| (h_{D_s\bar{K}} + \sum_i h_i G_i t_{i \rightarrow D_s\bar{K}}) \right|^2 dM_{inv}(D_s^+ K^-)$$

# Numerical results



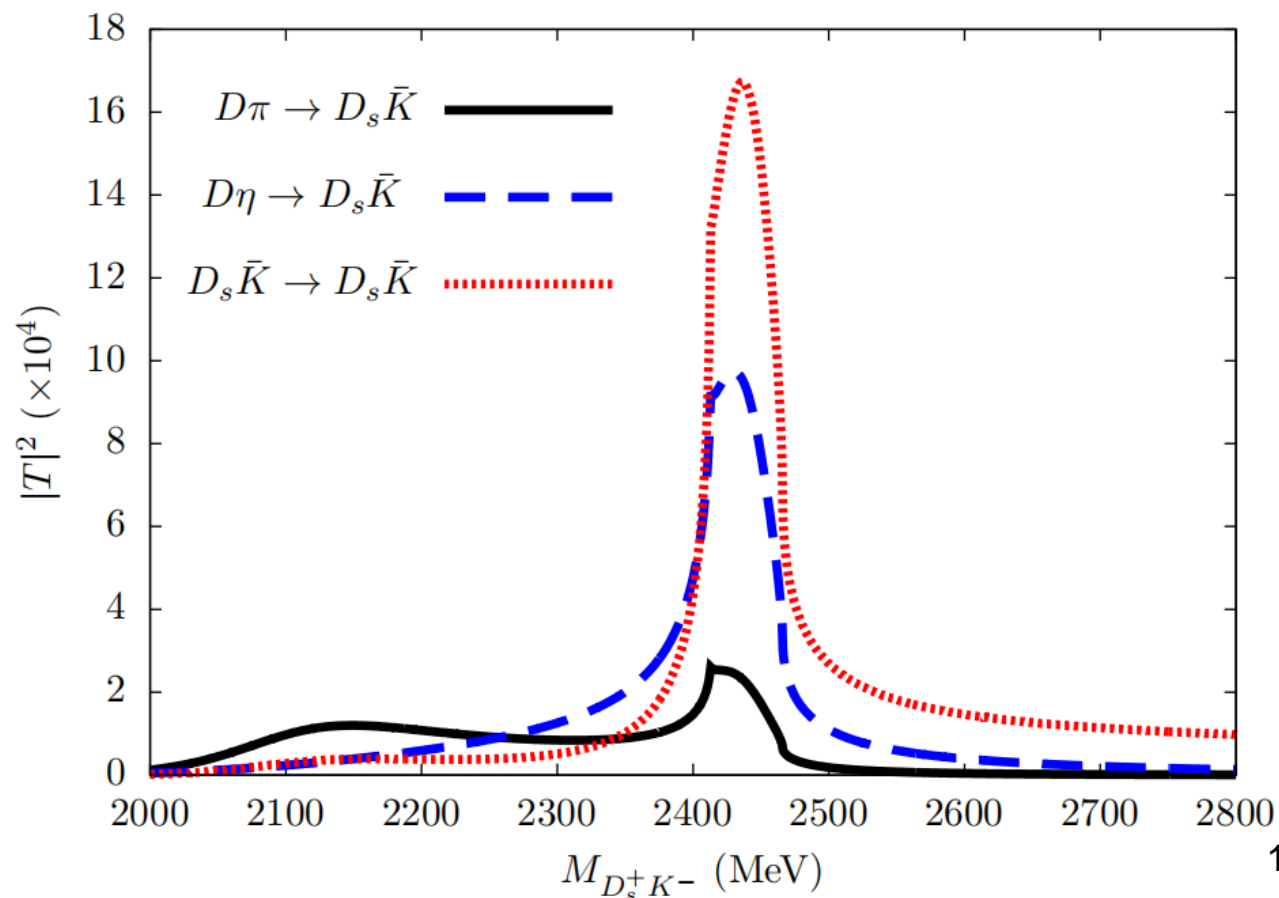
□ 利用B-S方程计算散射振幅

$$\mathbf{T} = [\mathbf{1} - \mathbf{V}\mathbf{G}]^{-1}\mathbf{V}$$

$$\begin{aligned} V_{ij} &= \frac{1}{4f_\pi^2} [C_{ij}(s - u)] \\ &= \frac{1}{4f_\pi^2} [C_{ij}(2s - m_2^2 - m_4^2 \\ &\quad - 2E_1E_3)] \end{aligned}$$

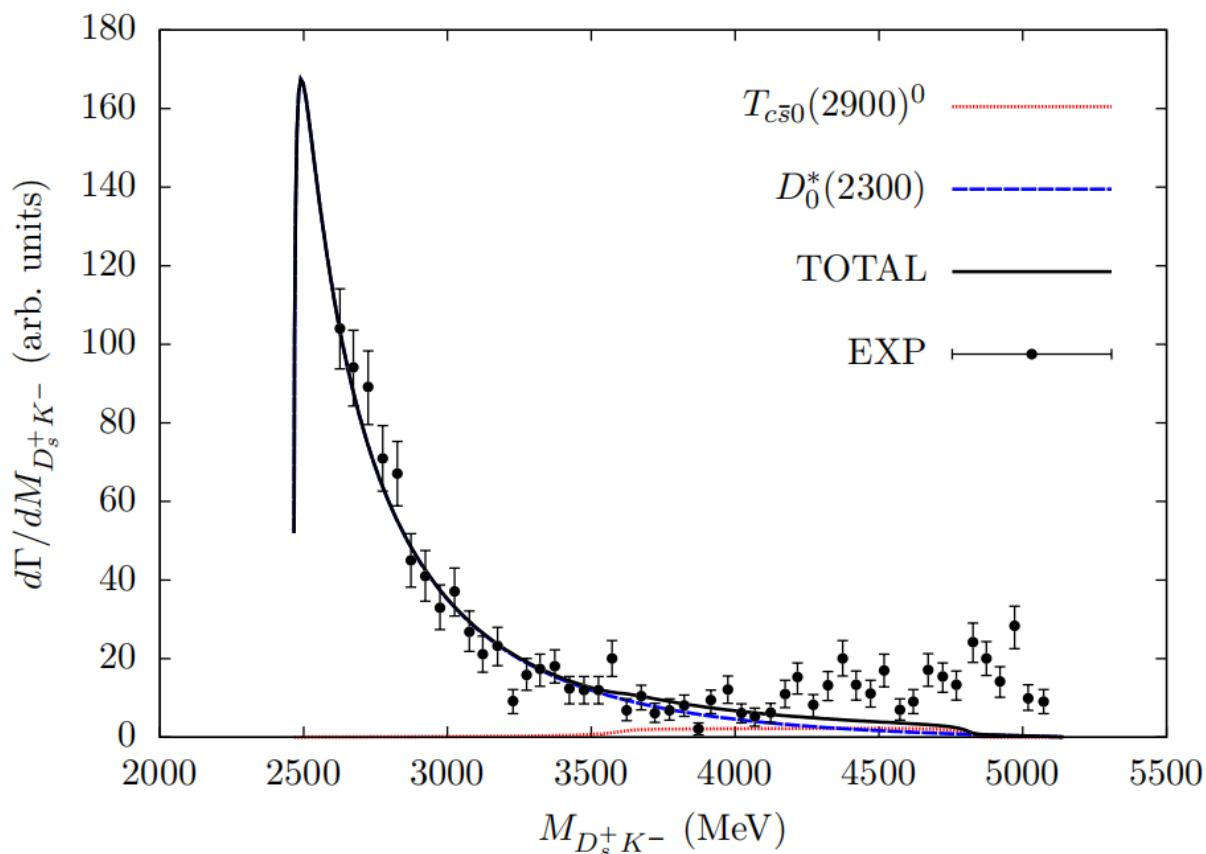
$$C_{ij} = \begin{pmatrix} -2 & 0 & -\sqrt{\frac{3}{2}} \\ 0 & 0 & -\sqrt{\frac{3}{2}} \\ -\sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} & -1 \end{pmatrix}$$

□ 散射振幅的模方



# Numerical results

## □ $D_s^+ K^-$ 不变质量分布



## □ 衰变宽度不变质量分布公式

$$\frac{d^2\Gamma}{dM_{D_s^+ K^-} dM_{D_s^+ \pi^-}} = \frac{1}{(2\pi)^3} \frac{2M_{D_s^+ K^-} 2M_{D_s^+ \pi^-}}{32M_{B^-}^3} |\mathcal{J}^{total}|^2$$

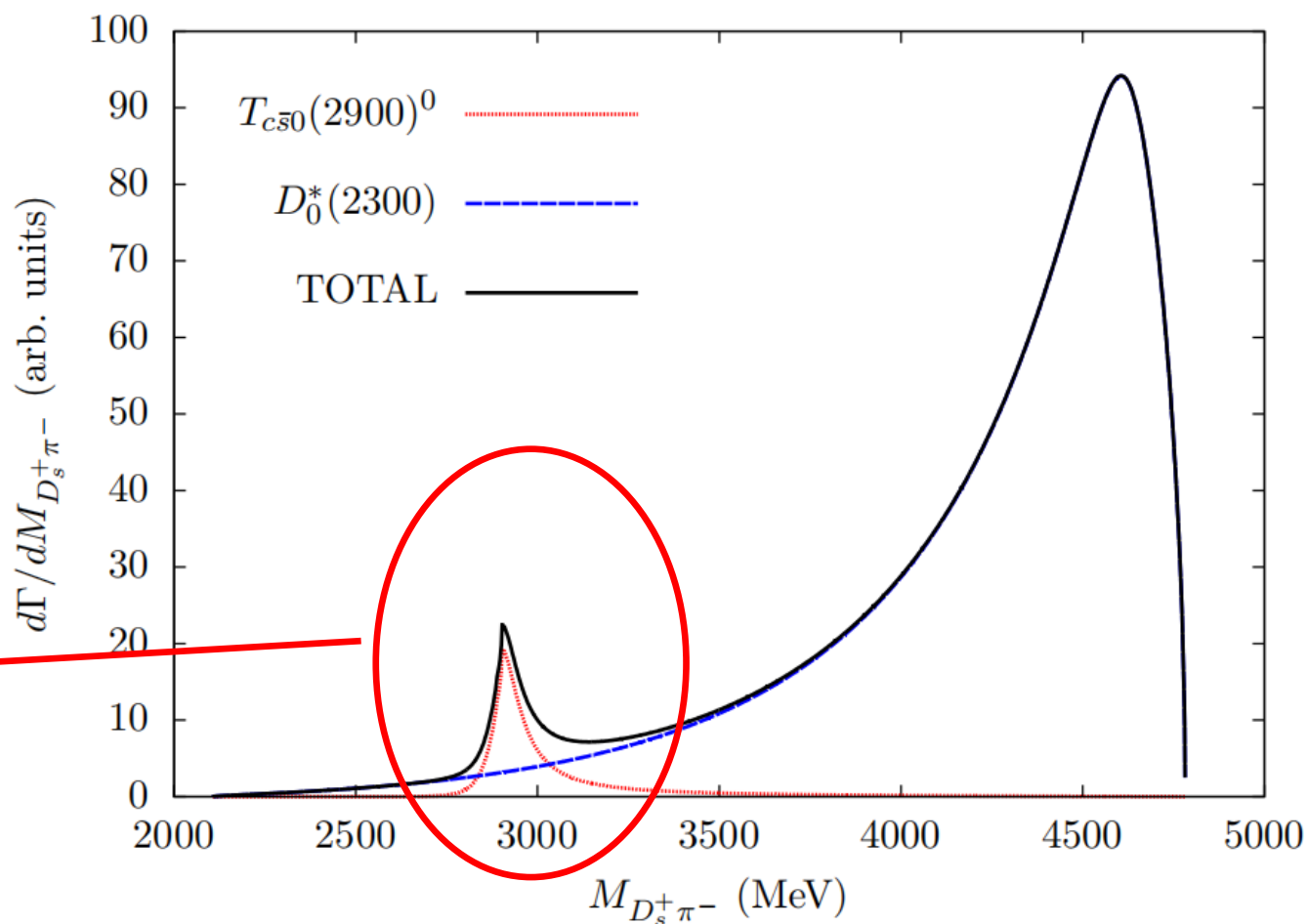
$$|\mathcal{J}^{total}|^2 = |\mathcal{J}^{T_{c\bar{s}0}^0}|^2 + |\mathcal{J}^{D_0^*(2300)}|^2$$

# Numerical results



## □ $D_s^+ \pi^-$ 不变质量分布

来自于  $T_{c\bar{s}0}(2900)^0$  的明显 peak 结构



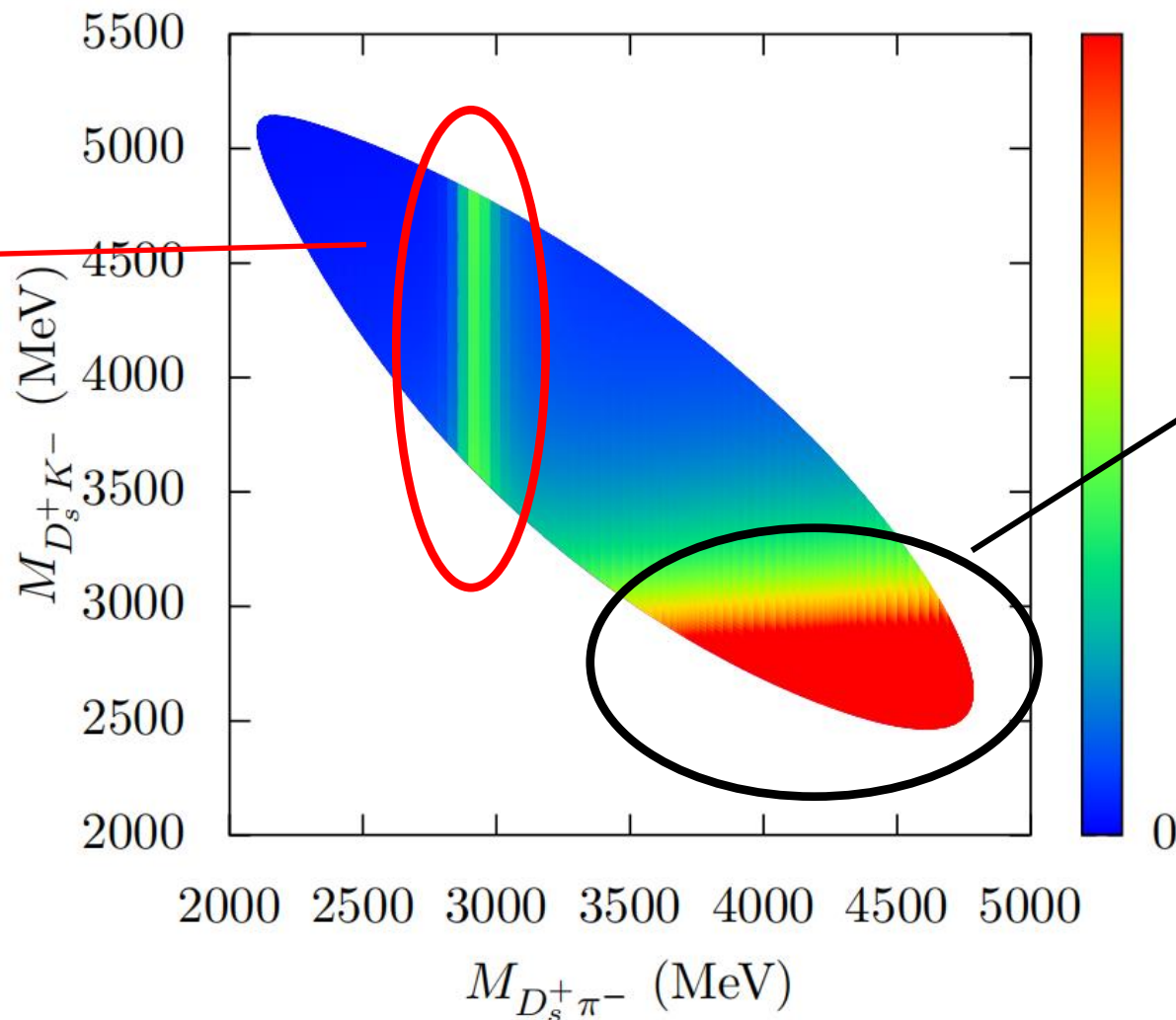


# Numerical results



## □ Dalitz 分布

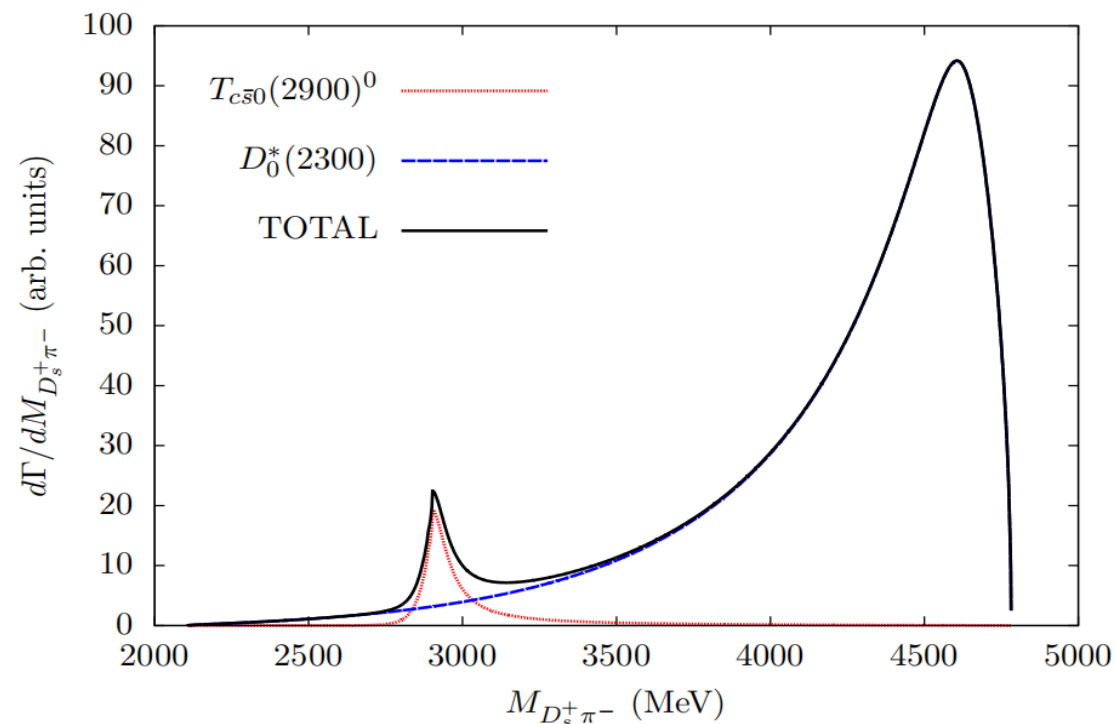
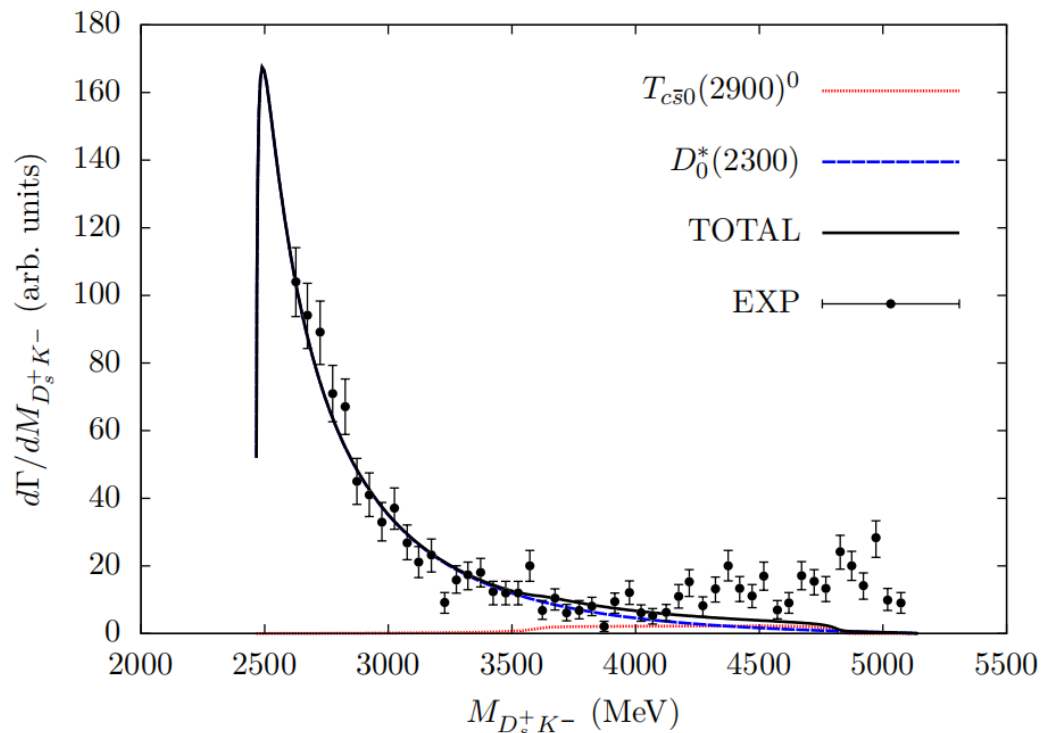
$T_{c\bar{s}0}(2900)^0$  的贡献



$D_0^*(2300)$  的贡献

# Numerical results

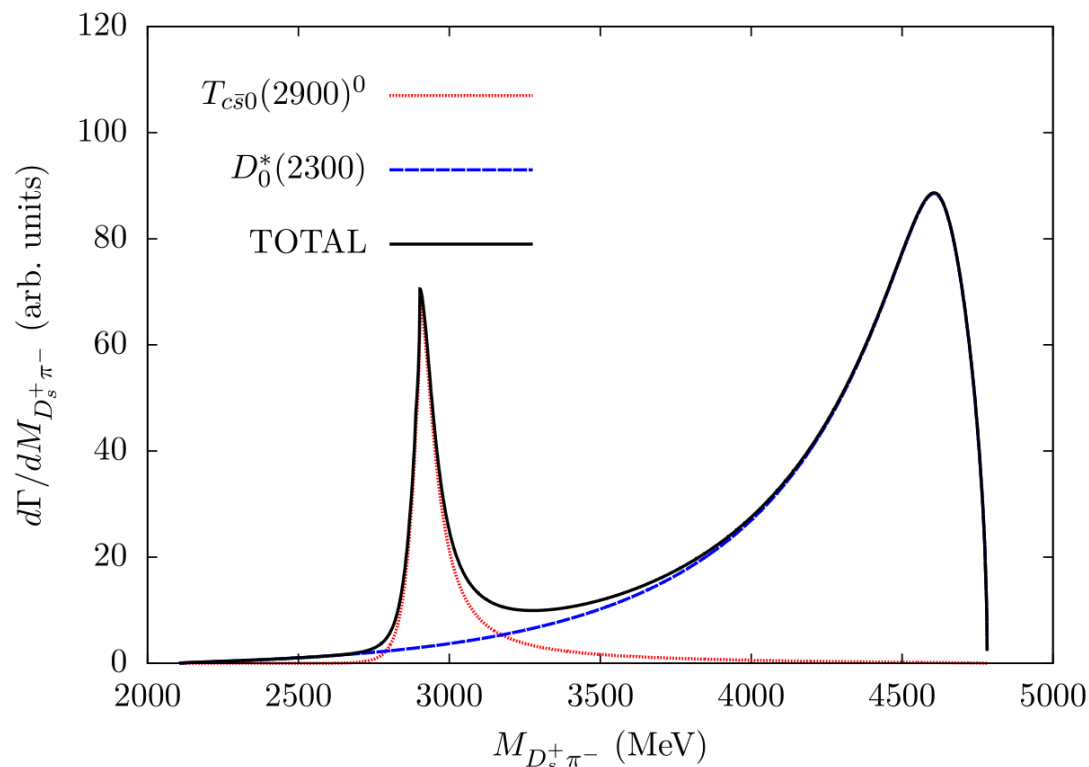
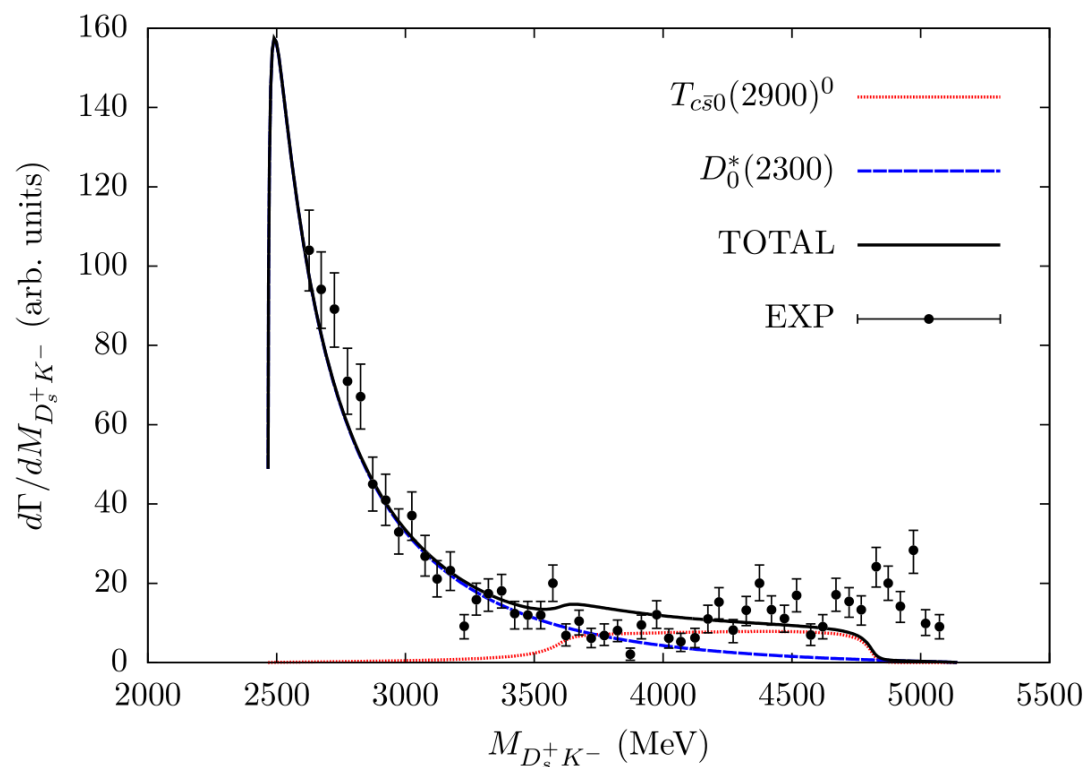
□ 我们将  $T_{c\bar{s}0}(2900)^0 \rightarrow D_s^+ \pi^-$  的衰变宽度作为自由参数进行拟合



# Numerical results



- $\Gamma_{T_{c\bar{s}0}(2900)^0 \rightarrow D_s^+ \pi^-} = 16.6 \text{ MeV}$
- $D_s^+ K^-$  质量谱的 2600 - 4700 MeV 描述与前面有所改善
- $D_s^+ \pi^-$  质量谱上  $T_{c\bar{s}0}(2900)^0$  的结构更加显著



# Summary



- 在分子态图象下对  $T_{c\bar{s}0}(2900)^0$  进行了分析
- 分析了通过S波赝标介子-赝标介子相互作用产生  $D_0^*(2300)$
- 给出了  $D_S^+ K^-$  和  $D_S^+ \pi^-$  的不变质量分布，显示了  $T_{c\bar{s}0}(2900)^0$  的结构
- 预言了  $T_{c\bar{s}0}(2900)^0 \rightarrow D_S^+ \pi^-$  的衰变宽度

谢谢大家！

请各位老师同学批评指正！