ZHENGZHOU UNIVERSITY 郑州大学

第六届强子谱与强子结构会议

arXiv：2306.16101

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

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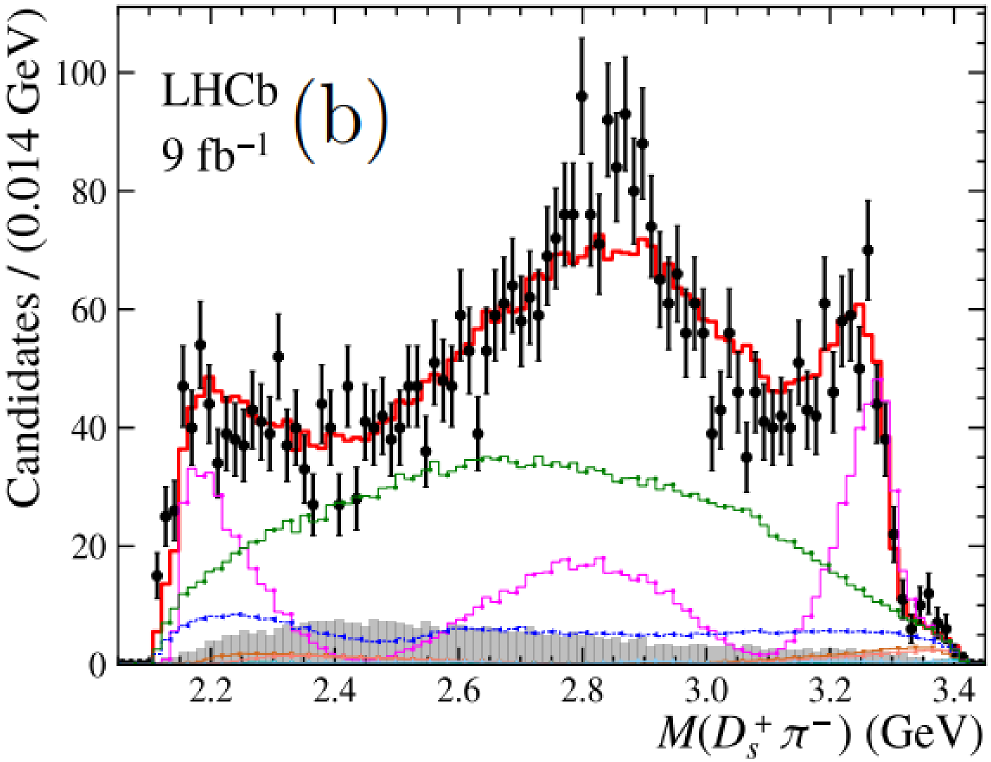
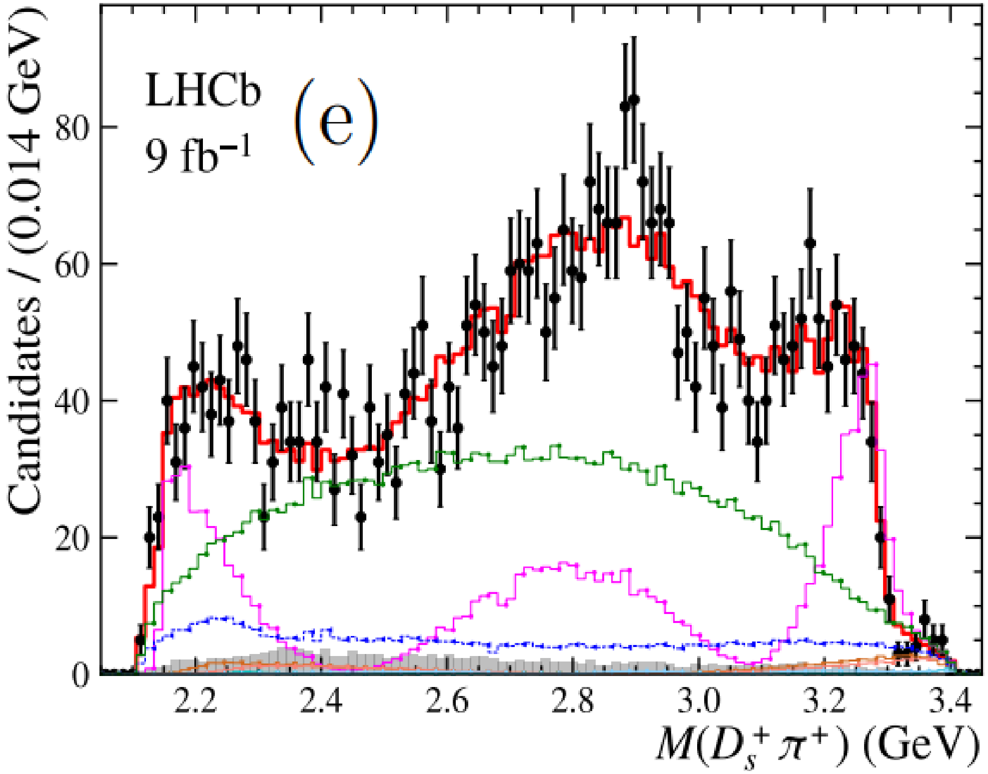
Motivation

- 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，$T_{c\bar{s}0}(2900)^0[c\bar{s}\bar{u}d]$和$T_{c\bar{s}0}(2900)^{++}[c\bar{s}u\bar{d}]$





[PhysRevLett. 131 (2023) 4, 041902]

Motivation

- $\mathbf{T_{c\bar{s}0}(2900)^{0}[c\bar{s}\bar{u}d]}$和$\mathbf{T_{c\bar{s}0}(2900)^{++}[c\bar{s}u\bar{d}]}$

$$\mathbf{J^P = 0^+}$$

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

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

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

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

[PhysRevLett. 131 (2023) 4, 041902]

Motivation

四夸克态	$[cq][\bar{s}\bar{q}]$	[PhysRevD 107 (2023) 096020]
强子分子态	D^*K^*	[PhysRevD 107 (2023) 9, 094019] [PhysRevD 107 (2023) 3, 034018] [2208.10196]
	$D_s^*\rho$	[J.Phys.G 50 (2023) 5, 055002]
类共振态结构	D^*K^* 阈值效应(三角奇异性)	[EPJC 82, 955]
	D^*K^*和 $D_s^*\rho$ 的耦合道效应	[PhysRevD 107 (2023) 5, 056015]

Motivation: Process selection

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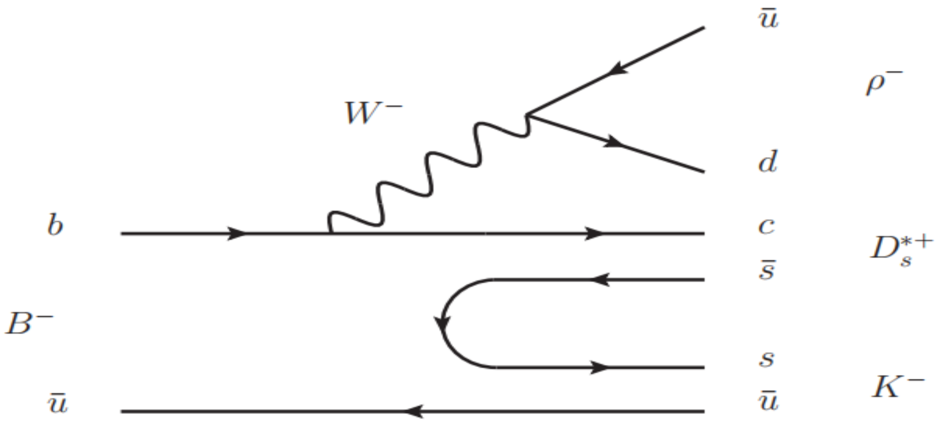
- $T_{c\bar{s}0}(2900)^0$的主要强衰变道为 [PhysRevD.107.034018(2023)]
  - $T_{c\bar{s}0}(2900)^0 \to D_s^+\pi^-$
  - $T_{c\bar{s}0}(2900)^0 \to D^0K^0$
  - $T_{c\bar{s}0}(2900)^0 \to D_s^{*+}\rho^-$
  - $T_{c\bar{s}0}(2900)^0 \to D_{s1}^+\pi^-$
  - $T_{c\bar{s}0}(2900)^0 \to D^{*0}(K\pi)^0$

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

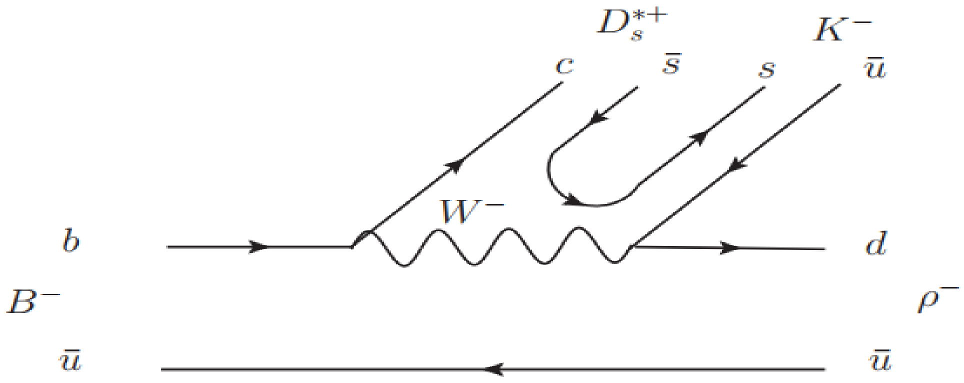
$$\mathcal{B}(B^+ \to D_s^- K^+\pi^+) = (1.71^{+0.07}_{-0.07}(\text{stat})^{+0.20}_{-0.20}(\text{syst}) \pm 0.15(\mathcal{B}_{int})) \times 10^{-4}$$

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

□ 强子化过程费曼图



(a)



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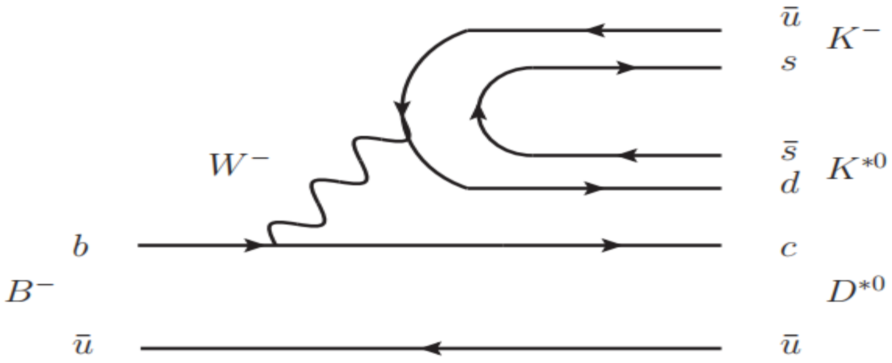

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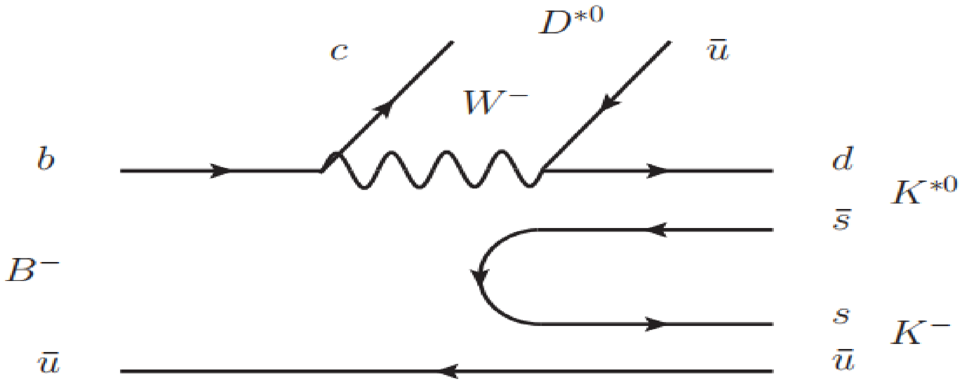
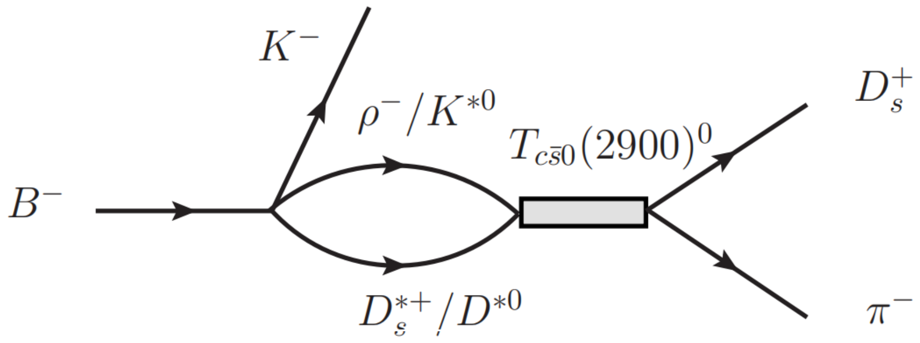


(b)

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

强子层次示意图



衰变振幅形式

$$\mathcal{T}^{T^0_{c\bar{s}0}} = \mathcal{Q}\epsilon(V_1)\cdot\epsilon(V_2)\times(C+1)\left[G_{\rho^-D_s^{*+}}t_{\rho^-D_s^{*+}\to D_s^+\pi^-}+G_{D^{*0}K^{*0}}t_{D^{*0}K^{*0}\to D_s^+\pi^-}\right]$$

$$t_{\rho^-D_s^{*+}\to D_s^+\pi^-}=\frac{g_{T^0_{c\bar{s}0},\rho^-D_s^{*+}}\,g_{T^0_{c\bar{s}0},D_s^+\pi^-}}{M^2_{T^0_{c\bar{s}0}}-m^2_{T^0_{c\bar{s}0}}+im_{T^0_{c\bar{s}0}}\Gamma_{T^0_{c\bar{s}0}}}$$

$$t_{D^{*0}K^{*0}\to D_s^+\pi^-}=\frac{g_{T^0_{c\bar{s}0},D^{*0}K^{*0}}\,g_{T^0_{c\bar{s}0},D_s^+\pi^-}}{M^2_{T^0_{c\bar{s}0}}-m^2_{T^0_{c\bar{s}0}}+im_{T^0_{c\bar{s}0}}\Gamma_{T^0_{c\bar{s}0}}}$$

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

□假设$T_{c\bar{s}}$作为D^*K^*分子态计算耦合常数

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

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

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

[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

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

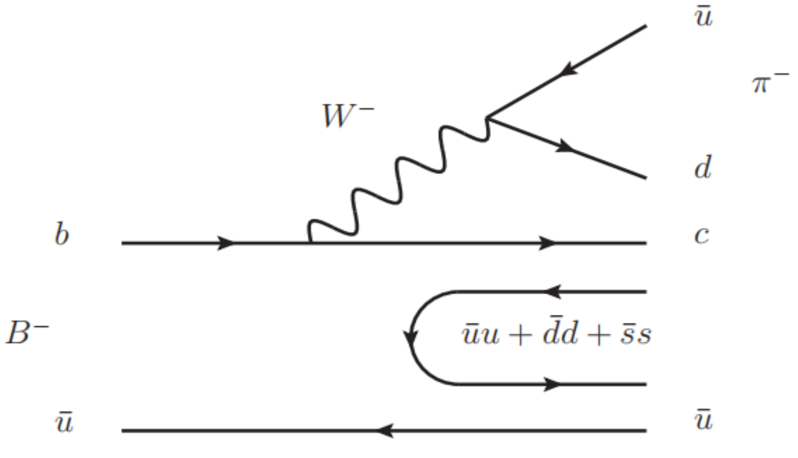
$$\Gamma_{T^0_{c\bar{s}0}\to D_s^+\pi^-} = \frac{1}{8\pi}\frac{1}{m^2_{T^0_{c\bar{s}0}}}\left|g_{T^0_{c\bar{s}0},D_s^+\pi^-}\right|^2|\vec{q}_\pi|$$

Channel	Width (MeV)
$T^0_{c\bar{s}0}\to D^0K^0$	52.6–101.7
$T^0_{c\bar{s}0}\to D_s^+\pi^-$	0.55–8.35
$T^0_{c\bar{s}0}\to D_s^{*+}\rho^-$	2.96–5.3
$T^0_{c\bar{s}0}\to D_{s1}^+\pi^-$	6.63–10.29
$T^0_{c\bar{s}0}\to D_{s1}'^+\pi^-$	6.63–10.3
$T^0_{c\bar{s}0}\to D^{*0}(K\pi)^0$	16.11–18.96

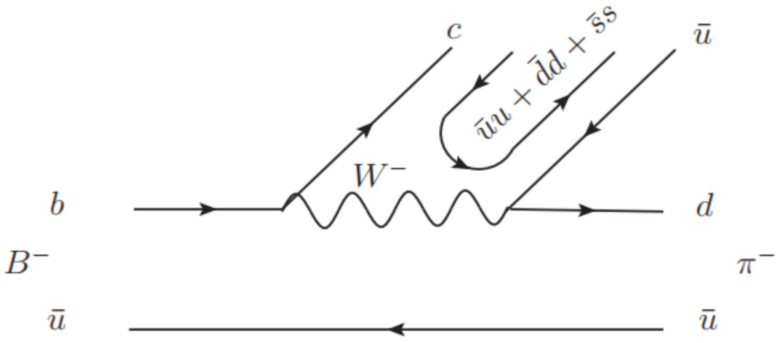
[PhysRevD.107.034018(2023)]

The role of $D_0^*(2300)$

强子化过程费曼图



(a)



(b)

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$(D^+, -D^0), (\bar{D}^0, D^-), (-\pi^+, \pi^0, \pi^-)$

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

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

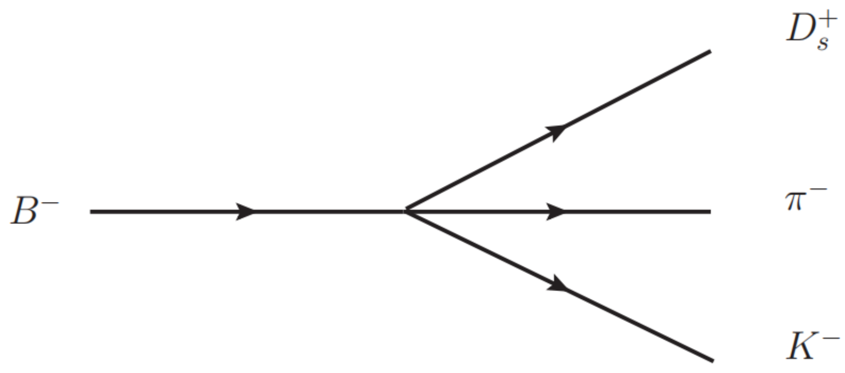
$$\frac{1}{\sqrt{2}}D^0\pi^0 + D^+\pi^-$$
$$= \left(-\sqrt{\frac{2}{3}}\cdot\sqrt{\frac{1}{2}} + \sqrt{\frac{1}{3}}\right)|D\pi\rangle^{I=\frac{3}{2}}$$
$$+ \left(\sqrt{\frac{1}{3}}\cdot\sqrt{\frac{1}{2}} + \sqrt{\frac{2}{3}}\right)|D\pi\rangle^{I=\frac{1}{2}}$$
$$= \sqrt{\frac{3}{2}}\,|D\pi\rangle^{I=\frac{1}{2}}$$

- 我们可以得到

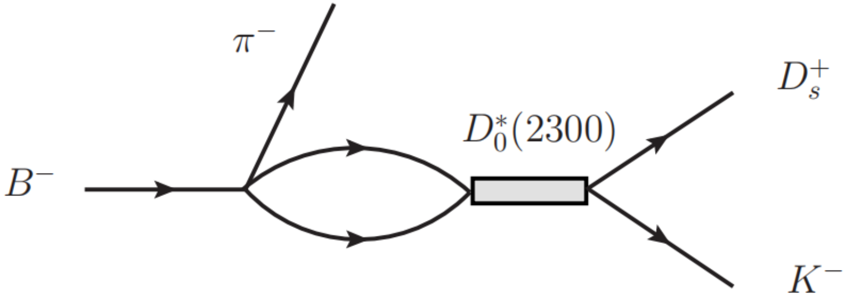
$$H = \pi^-\left(\sqrt{\frac{3}{2}}D\pi + \frac{1}{\sqrt{3}}D^0\eta + D_s^+K^-\right)$$

The role of $D_0^*(2300)$

□强子层次示意图



(a)



(b)

□衰变振幅形式

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

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

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

$$\Gamma_{B^-} \times \mathcal{B}(B^- \to D_s^+ K^- \pi^-)$$
$$= \mathcal{Q}'^2 \int \frac{1}{(2\pi)^3} \frac{(C+1)^2}{4M_{B^-}^2} P_\pi \tilde{P}_K$$
$$\times \left| (h_{D_s\bar{K}} + \sum_i h_i G_i t_{i\to D_s\bar{K}}) \right|^2 dM_{inv}(D_s^+ K^-)$$

Numerical results

□利用B-S方程计算散射振幅

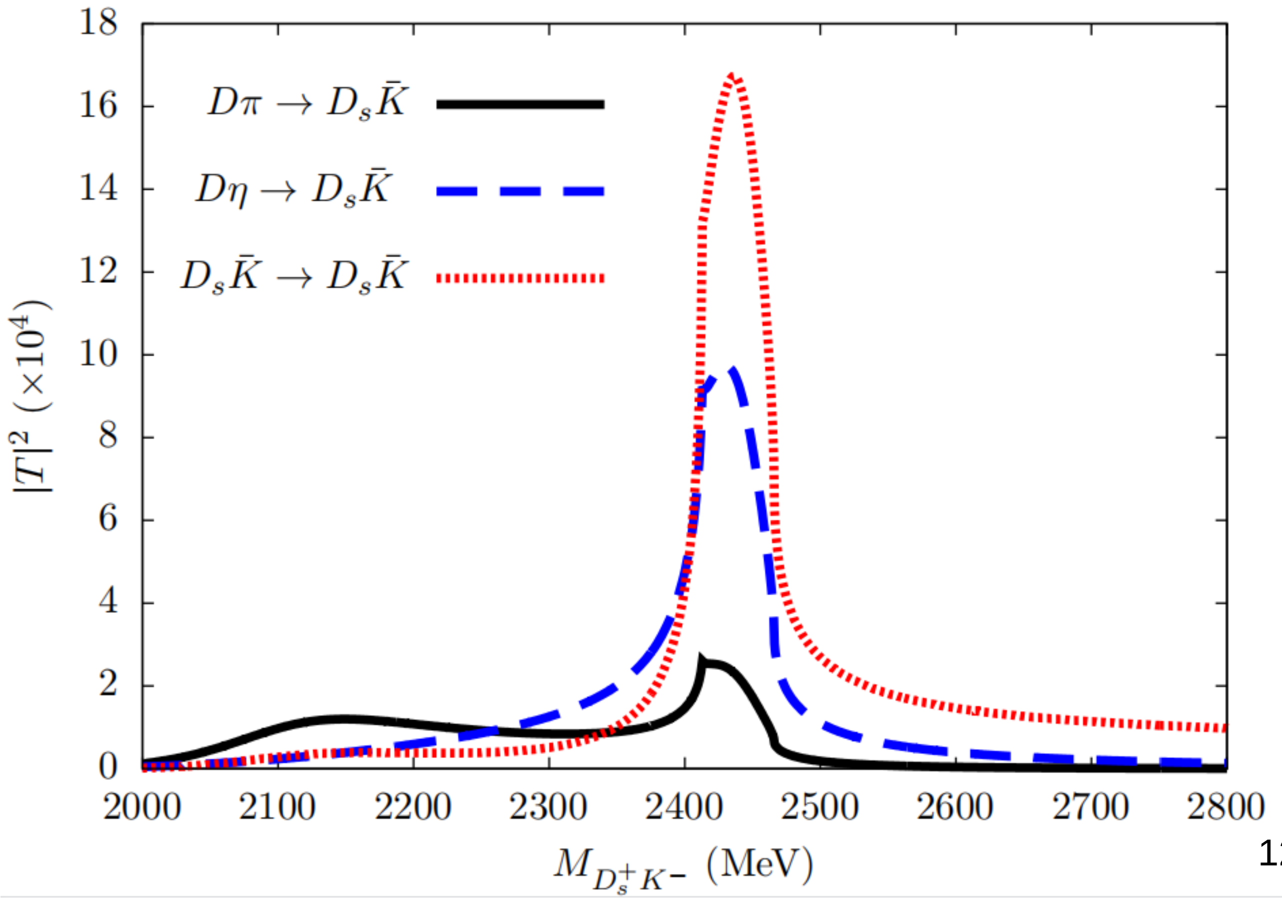
$$\mathbf{T} = [1 - \mathbf{VG}]^{-1}\mathbf{V}$$

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

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

[PhysRevD 87 (2013) 1, 014508]
[PhysRevD 102 (2020) 9, 096020]

□散射振幅的模方



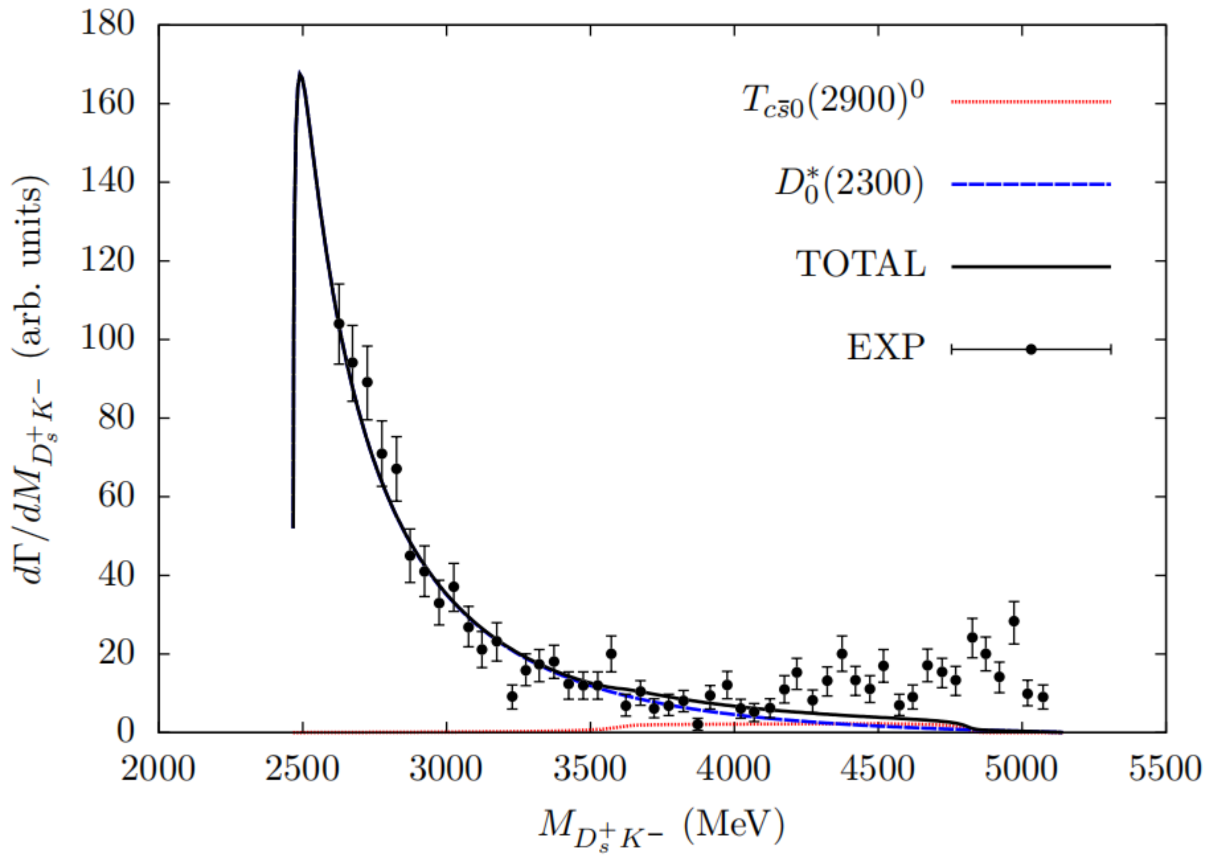
Numerical results

□衰变宽度不变质量分布公式

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

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

□$D_s^+K^-$不变质量分布



Numerical results

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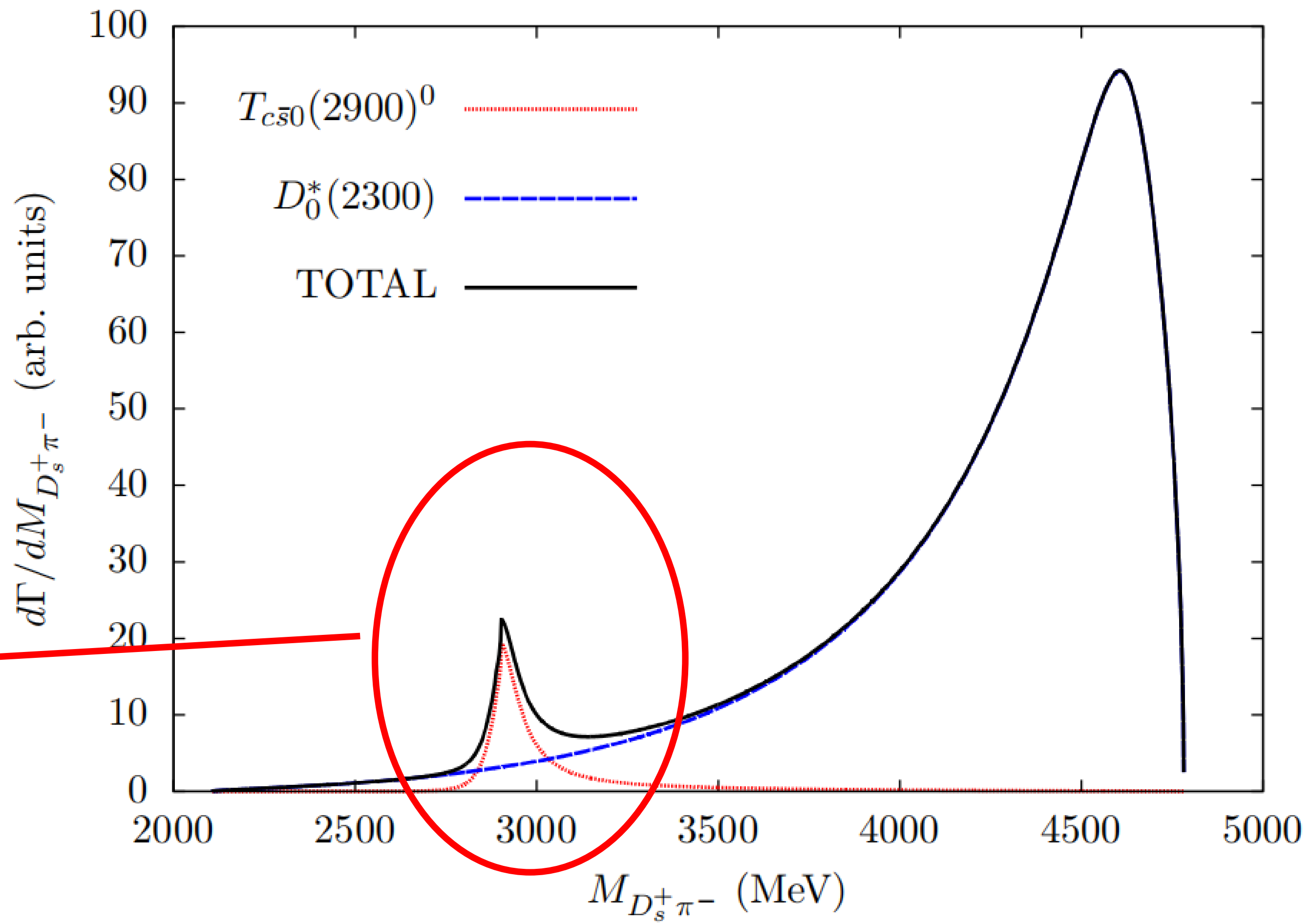
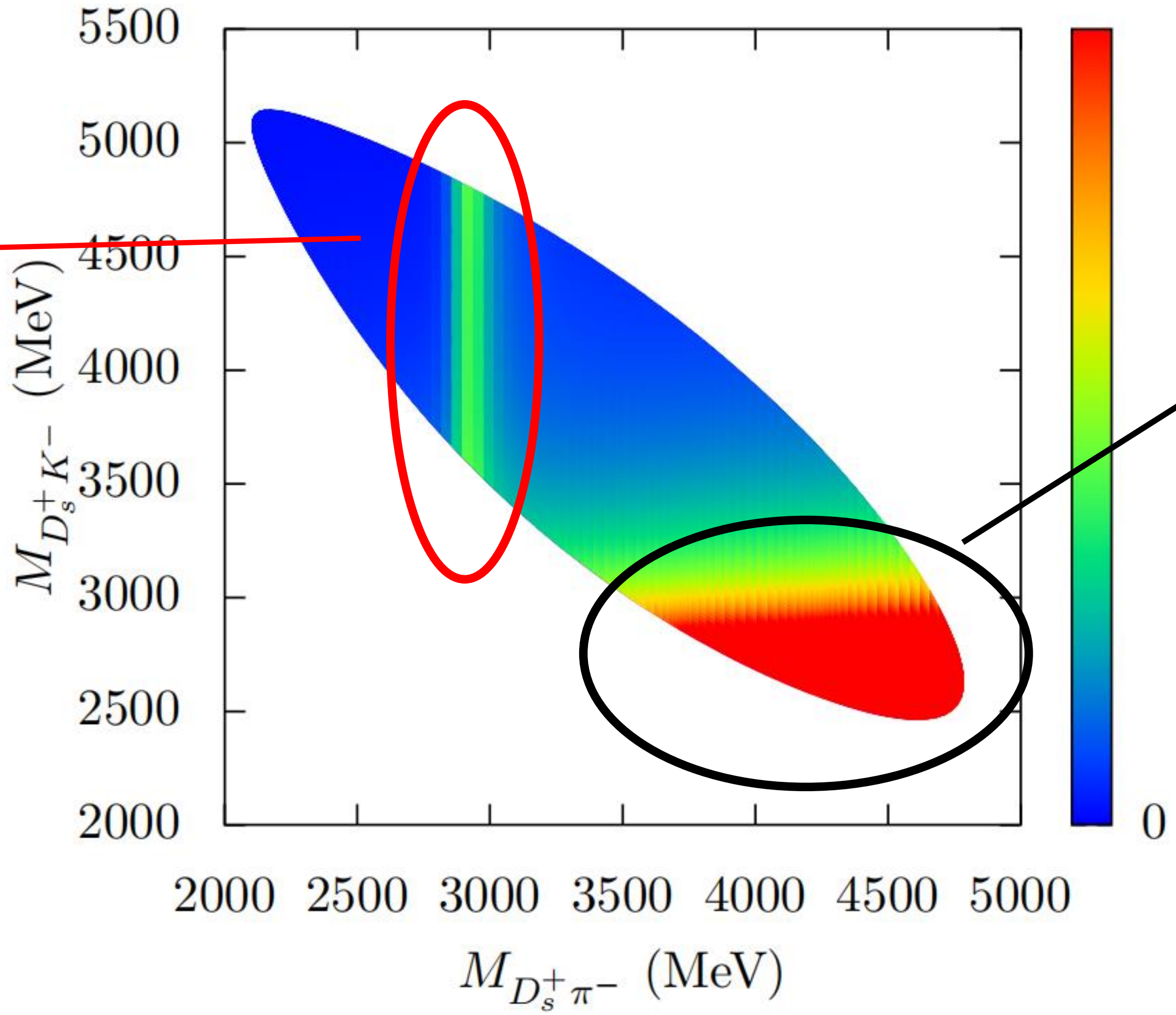
- $D_s^+\pi^-$不变质量分布



来自于$T_{c\bar{s}0}(2900)^0$的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

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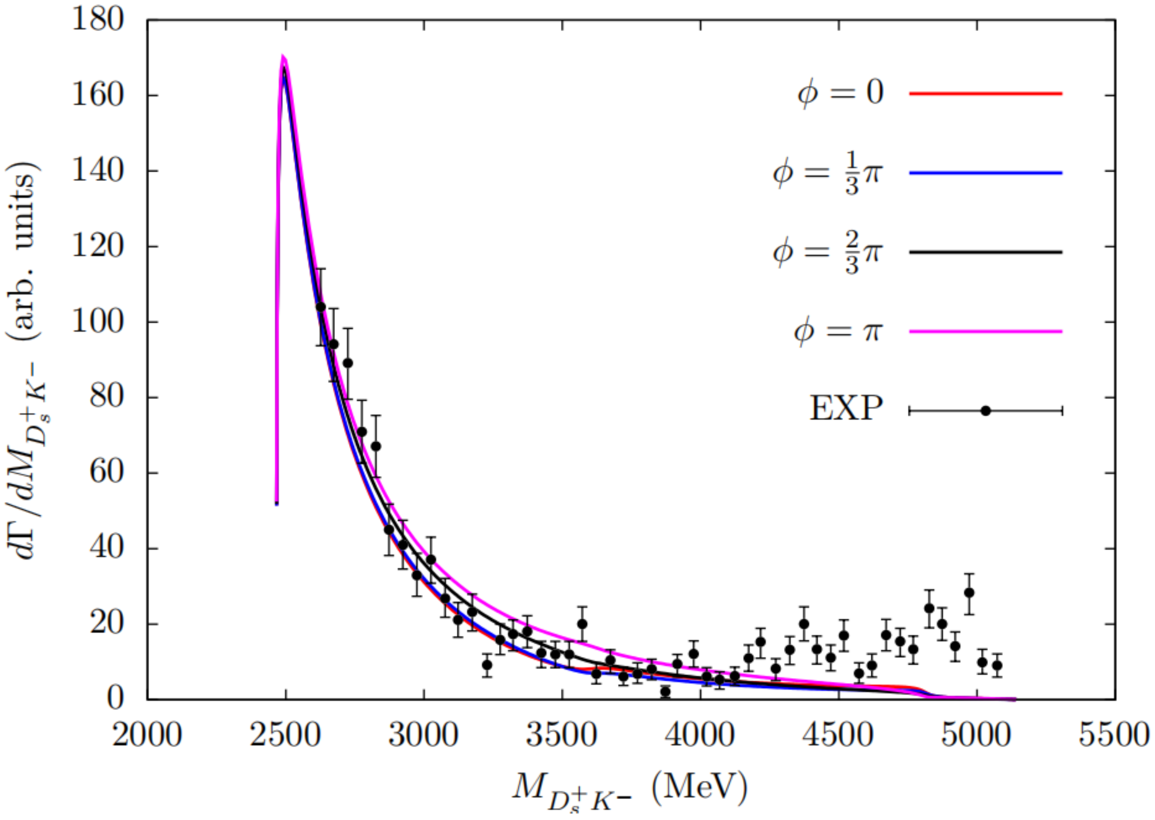
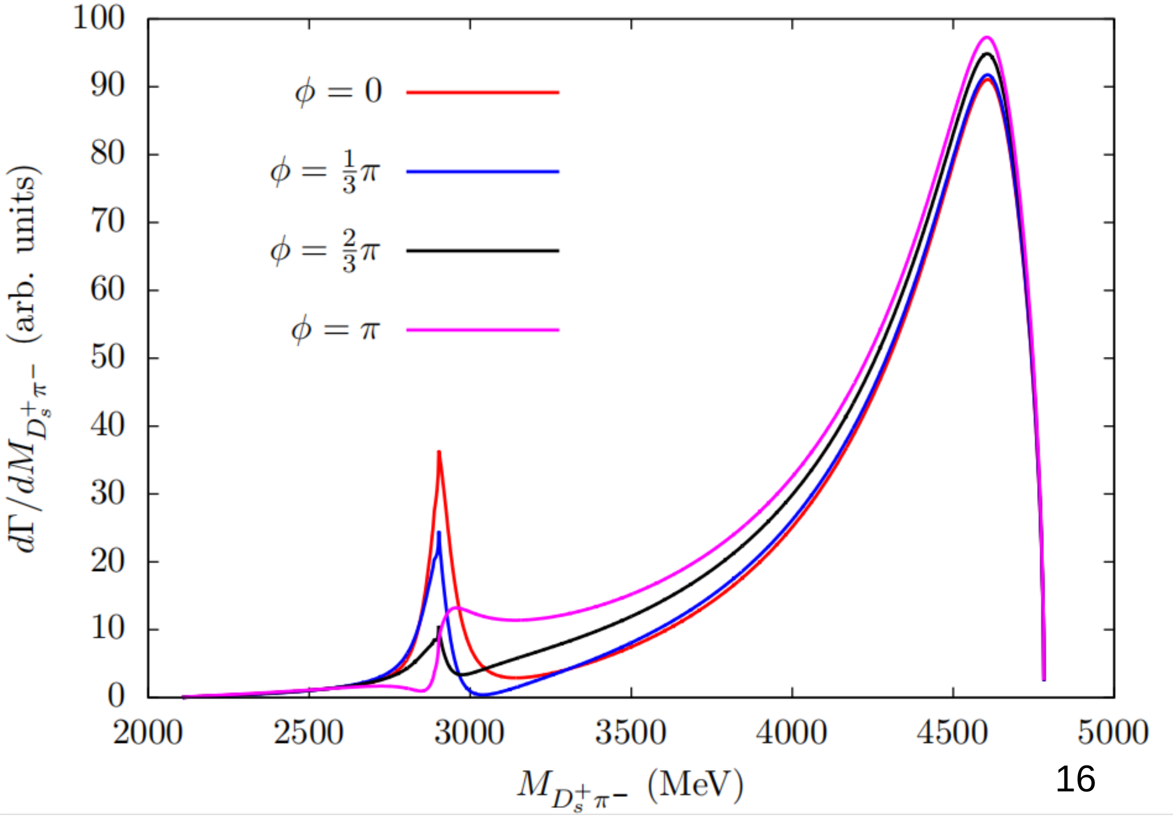
总振幅考虑两部分干涉

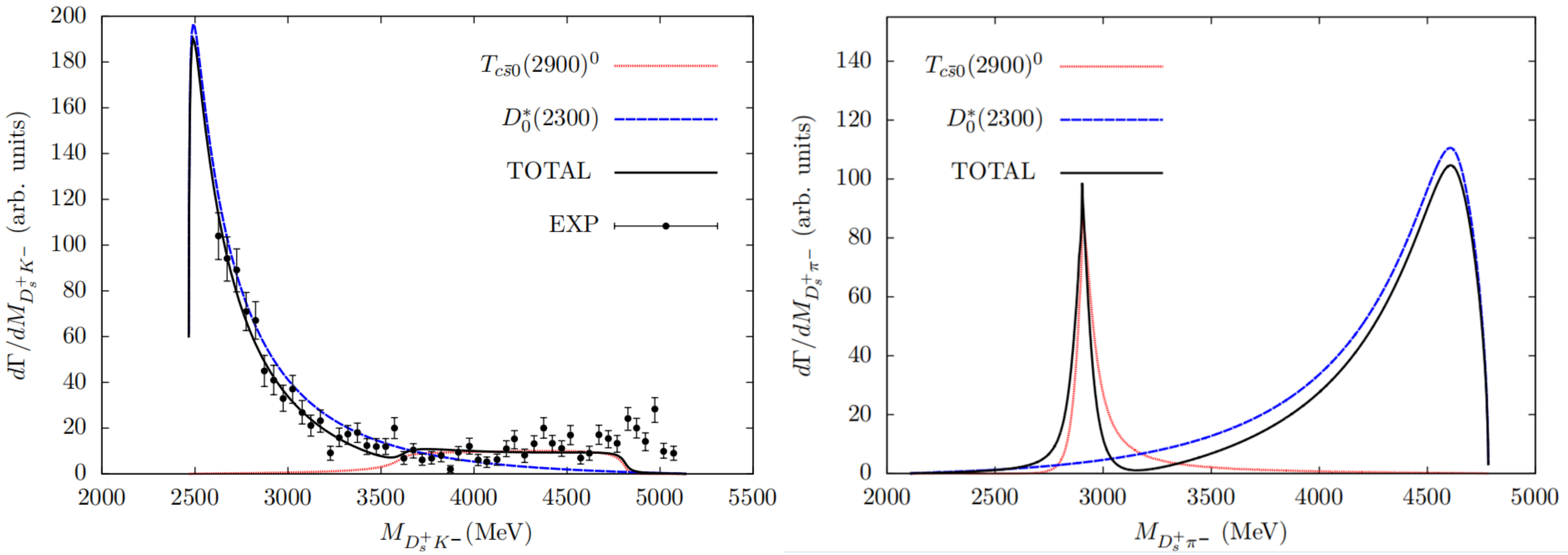
$$\left|\mathcal{T}^{\mathrm{total}}\right|^2 = \left|\mathcal{T}^{\mathrm{T}^0_{c\bar{s}0}} e^{i\phi} + \mathcal{T}^{\mathrm{D}_0^*(2300)}\right|^2$$





Numerical results

- $\Gamma_{T_{c\bar{s}0}(2900)^0 \to D_s^+\pi^-} = 17 \pm 2$ MeV, $\phi = 0.29\pi \pm 0.09\pi$
- $D_s^+K^-$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

- □ 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$T_{c\bar{s}0}(2900)^0$和$D_0^*(2300)$的结构
- □ 通过对$D_s^+K^-$实验数据的描述，对 $D_s^+\pi^-$的不变质量分布进行了预测。

谢谢大家！

请各位老师同学批评指正！