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粲-奇异奇特强子及其伙伴态的衰变性质

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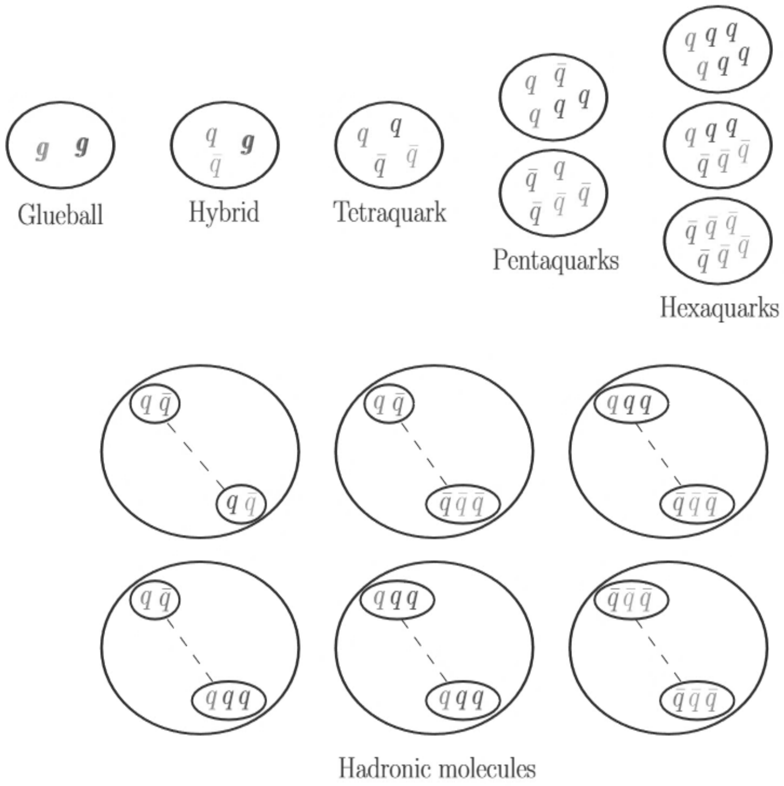
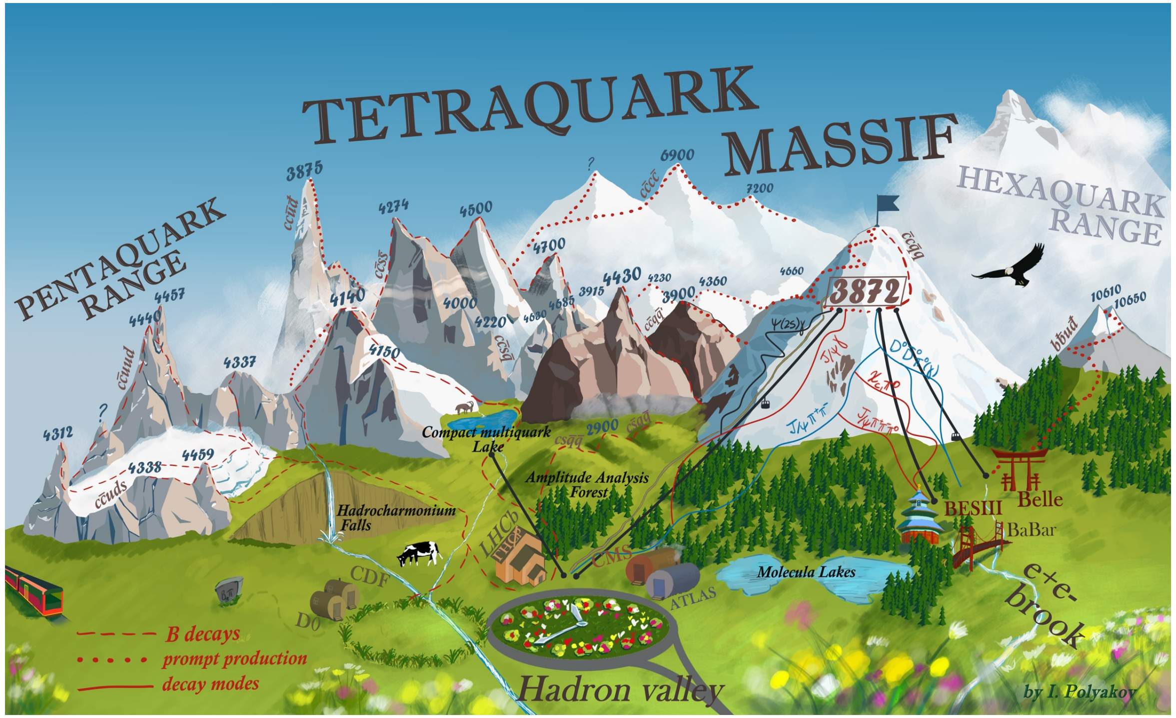
中国科学院理论物理研究所

第八届强子谱和强子结构研讨会

目 录

背景介绍：奇特强子态



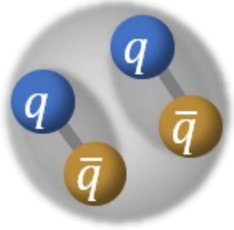


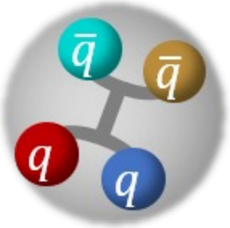
- 奇特强子态：超出传统的夸克模型
- 近二十年来大量新强子态的实验发现
- 随着实验技术的提高，对于强子性质的描述越来越精确

强子分子态的概念

- 强子分子态：

  类似于原子核，由无色的强子之间的相互作用束缚起来
- 区别于紧致多夸克态，空间尺度较大，位于强子对的阈值附近
- 低能系统：具备良好的有效场论描述



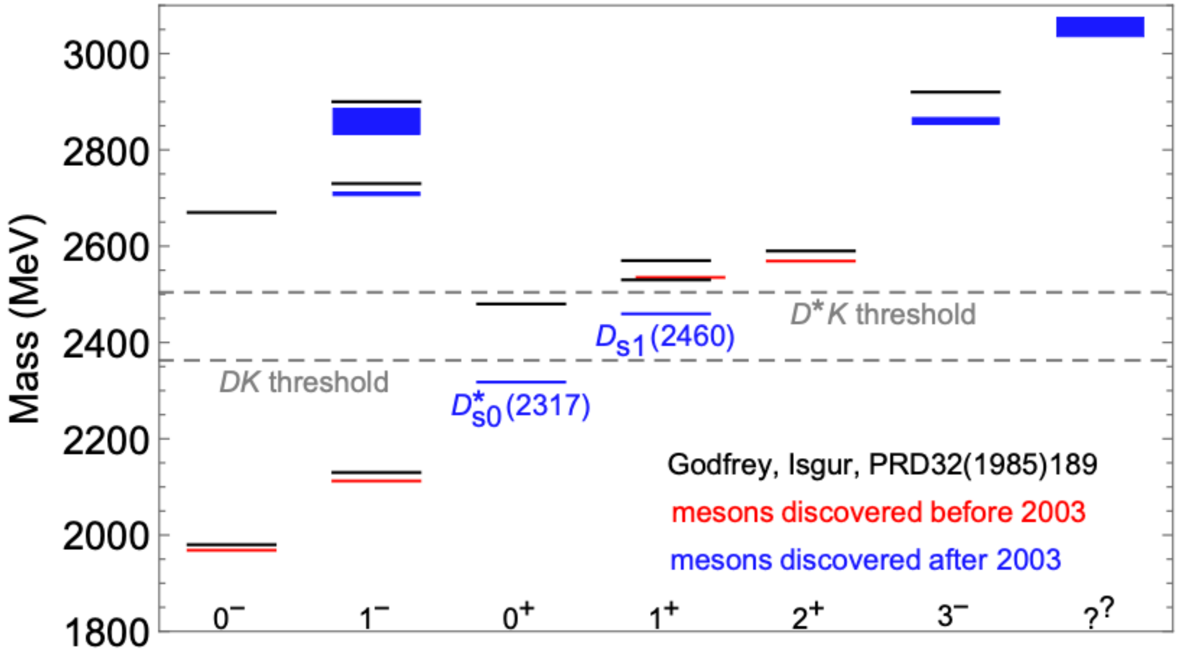


$X(3872)$　$Z_c(3900)^{\pm}$		$D\bar{D}^*$
$T_{cc}(3875)$		DD^*
$Z_c(4020)^{\pm}$		$D^*\bar{D}^*$
$Z_b(10610)^{\pm}$　$Z_b(10650)^{\pm}$	$\simeq$	$B\bar{B}^*$　$B^*\bar{B}^*$
$Z_{cs}(3985)$		$\bar{D}_s D^*$　$\bar{D}_s^* D$
P_c		$\bar{D}^{(*)}\Sigma_c$
P_{cs}		$\bar{D}^{(*)}\Xi_c$

温伯格复合度关系：

$$a \approx -\frac{2(1-Z)}{(2-Z)\sqrt{2\mu E_B}}, \quad r_e \approx \frac{Z}{(1-Z)\sqrt{2\mu E_B}}$$

粲–轻奇特强子



$D^*_{s0}(2317)$: BaBar (2003)

$J^P = 0^+$, $\Gamma < 3.8$ MeV

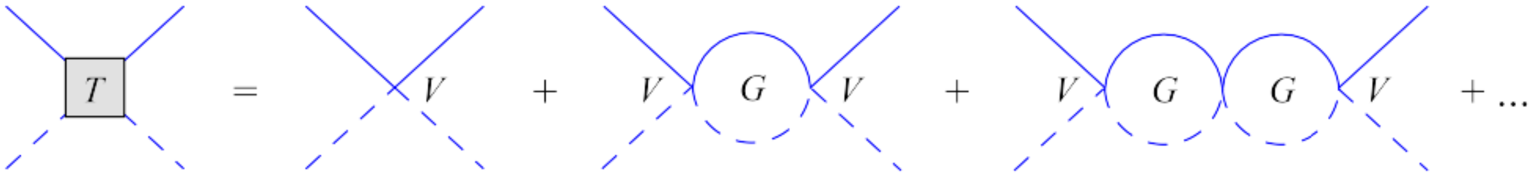
$D_{s1}(2460)$: CLEO (2003)

$J^P = 1^+$, $\Gamma < 3.5$ MeV

- 质量低于夸克模型的预言
- 精细调节的质量：$\underbrace{M_{D_{s1}(2460)} - M_{D^*_{s0}(2317)}}_{(141.8\pm0.8)\text{ MeV}} \simeq \underbrace{M_{D^{*\pm}} - M_{D^\pm}}_{(140.67\pm0.08)\text{ MeV}}$?

粲–轻系统的手征幺正方法

- 手征幺正方法



- 手征拉氏量

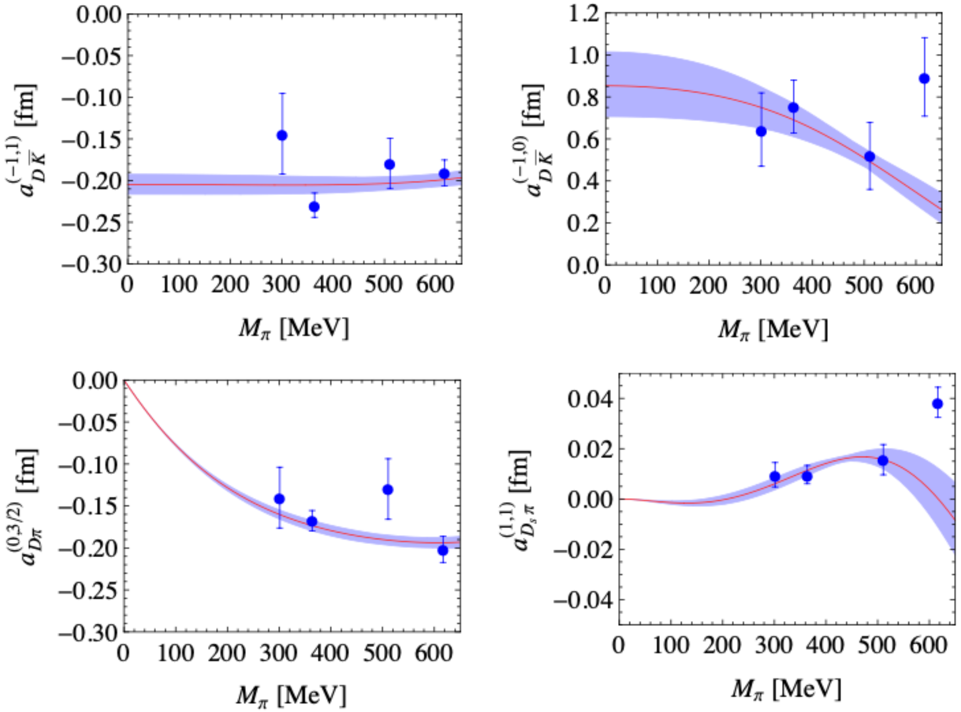
$$\mathcal{L}_{\phi P}^{(1)} = D_\mu P D^\mu P^\dagger - m^2 P P^\dagger \;\propto E_\phi + \mathcal{O}(1/M_D)\ (S\text{-wave})$$ Weinberg–Tomozawa项

$$P = (D^0, D^+, D_s^+)$$

$$\mathcal{L}_{\phi P}^{(2)} = P\left[-h_0\langle\chi_+\rangle - h_1\chi_+ + h_2\langle u_\mu u^\mu\rangle - h_3 u_\mu u^\mu\right]P^\dagger$$
$$+D_\mu P\left[h_4\langle u_\mu u^\nu\rangle - h_5\{u^\mu, u^\nu\}\right]D_\nu P^\dagger$$

Feng-Kun Guo et al., Phys.Lett.B 666 (2008)

- 通过格点QCD的结果拟合低能常数



Liuming Liu et al., Phys.Rev.D 87 (2013)

a_D	h_{24}	h'_4	h_{35}	h'_5
−1.88	−0.10	−0.32	0.25	−1.88

- 势能项：

$$V(s,t,u) = \frac{1}{F_\pi^2}\left[\frac{C_{LO}}{4}(s-u) - 4C_0h_0 + 2C_1h_1 - 2C_{24}H_{24} + 2C_{35}H_{35}\right]$$

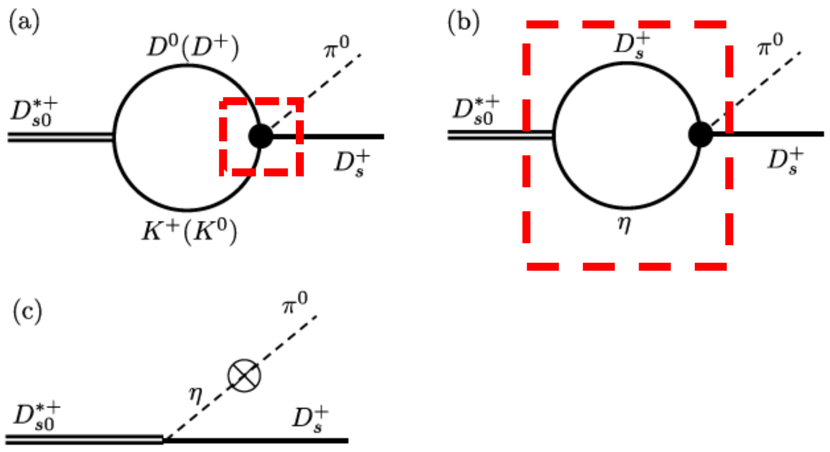
$$H_{35} = h_{35}p_2\cdot p_4 + h_5(p_1\cdot p_2 p_3\cdot p_4 + p_1\cdot p_4 p_2\cdot p_3 - 2\bar{M}_D^2 p_2\cdot p_4)$$

$$H_{24} = 2h_{24}p_2\cdot p_4 + h_4(p_1\cdot p_2 p_3\cdot p_4 + p_1\cdot p_4 p_2\cdot p_3 - 2\bar{M}_D^2 p_2\cdot p_4)$$

- 低能常数的关系

$$\{h_i'^B\} \sim \{h_i'^D\}\frac{m_B}{m_D}$$

粲–轻奇特强子：衰变宽度



- 强子分子态图像下可以给出较大的同位旋破坏衰变宽度，与紧致态有显著差别

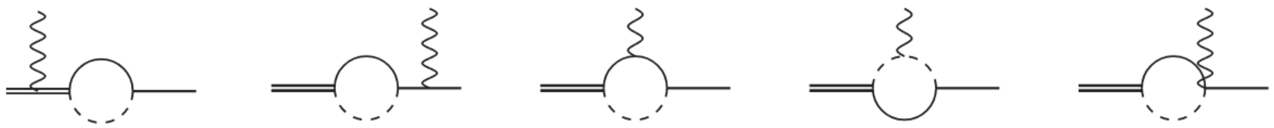
衰变道	圈图	π^0-η 混合	完整结果 keV
$D_{s0}^* \to D_s\pi^0$	50 ± 3	20 ± 2	132 ± 7
$D_{s1} \to D_s^*\pi^0$	37 ± 7	20 ± 3	111 ± 15
$B_{s0}^* \to B_s\pi^0$	15 ± 2	22 ± 3	75 ± 6
$B_{s1} \to B_s^*\pi^0$	16 ± 2	23 ± 3	76 ± 7

- 完整的同位旋破坏机制:
  顶角处和含有介子对的圈图都存在同位旋破坏

辐射衰变

Electric Charge (EC):

(a) (b) (c) (d) (e)

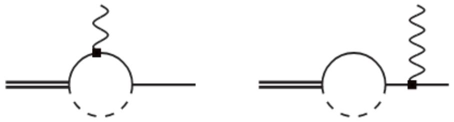


$$\mathcal{L}_{MM} = \frac{i}{2} e F^{\mu\nu} \sqrt{m_D m_{D^*}} [\varepsilon^{\mu\nu\alpha\beta} v_\alpha (\beta Q + \frac{Q'}{m_Q})_{ab} (P_a V_b^{\dagger\beta} - V_a^\beta P_b^\dagger) + V_a^\mu V_b^{\dagger\nu} (\beta Q - \frac{Q'}{m_Q})_{ab}]$$

Jie Hu & T. Mehen, Phys.Rev.D 73 (2006)

Magnetic Moment (MM):

(a) (b)



$$\mathcal{L}_{contact} = \kappa F_{\mu\nu} (v^\mu D_{s0}^* D_s^{*\dagger\nu} + D_{s1}^\mu v^\nu D_s^\dagger + \varepsilon^{\mu\nu\alpha\beta} D_{s1\alpha} D_{s\beta}^{*\dagger}) + \tilde{\kappa} \varepsilon^{\mu\nu\alpha\beta} F_{\mu\nu} v_\beta D_{s1\alpha} D_{s0}^{*\dagger} + h.c.$$

衰变道	EC	MM	CT	完整结果 keV
$D_{s0}^* \to D_s^* \gamma$	3.5 ± 0.3	0.06 ± 0.02	0.04	3.7 ± 0.3
$D_{s1} \to D_s \gamma$	13 ± 1	6.5 ± 0.6	0.1	42 ± 4
$D_{s1} \to D_s^* \gamma$	12 ± 2	0.8 ± 0.1	0.1	13 ± 2
$D_{s1} \to D_{s0}^* \gamma$	–	3.0 ± 0.6	?	?
$B_{s0}^* \to B_s^* \gamma$	58 ± 8	2.1 ± 0.3	0.02	59 ± 8
$B_{s1} \to B_s \gamma$	70 ± 10	41 ± 6	0.02	220 ± 31
$B_{s1} \to B_s^* \gamma$	110 ± 15	0.19 ± 0.02	0.03	100 ± 15
$B_{s1} \to B_{s0}^* \gamma$	–	0.03 ± 0.01	?	?

- 实验输入： $R_2 = \frac{\Gamma(D_{s1} \to D_s \gamma)}{\Gamma(D_{s1} \to D_s^* \pi^0)}$ $\Gamma(D^{*0} \to D^0 \gamma)$ $\Gamma(D^{*+} \to D^+ \gamma)$

衰变分支比

$$R_1=\frac{\Gamma(D_{s0}^*\to D_s^*\gamma)}{\Gamma(D_{s0}^*\to D_s\pi^0)},\quad R_2=\frac{\Gamma(D_{s1}\to D_s\gamma)}{\Gamma(D_{s1}\to D_s^*\pi^0)},$$

$$R_3=\frac{\Gamma(D_{s1}\to D_s^*\gamma)}{\Gamma(D_{s1}\to D_s^*\pi^0)},\quad R_4=\frac{\Gamma(D_{s1}\to D_{s0}^*\gamma)}{\Gamma(D_{s1}\to D_s^*\pi^0)},$$

$$R_5=\frac{\Gamma(D_{s1}\to D_s^*\pi^0)}{\Gamma(D_{s1}\to D_s^*\pi^0)+\Gamma(D_{s1}\to D_{s0}^*\gamma)},$$

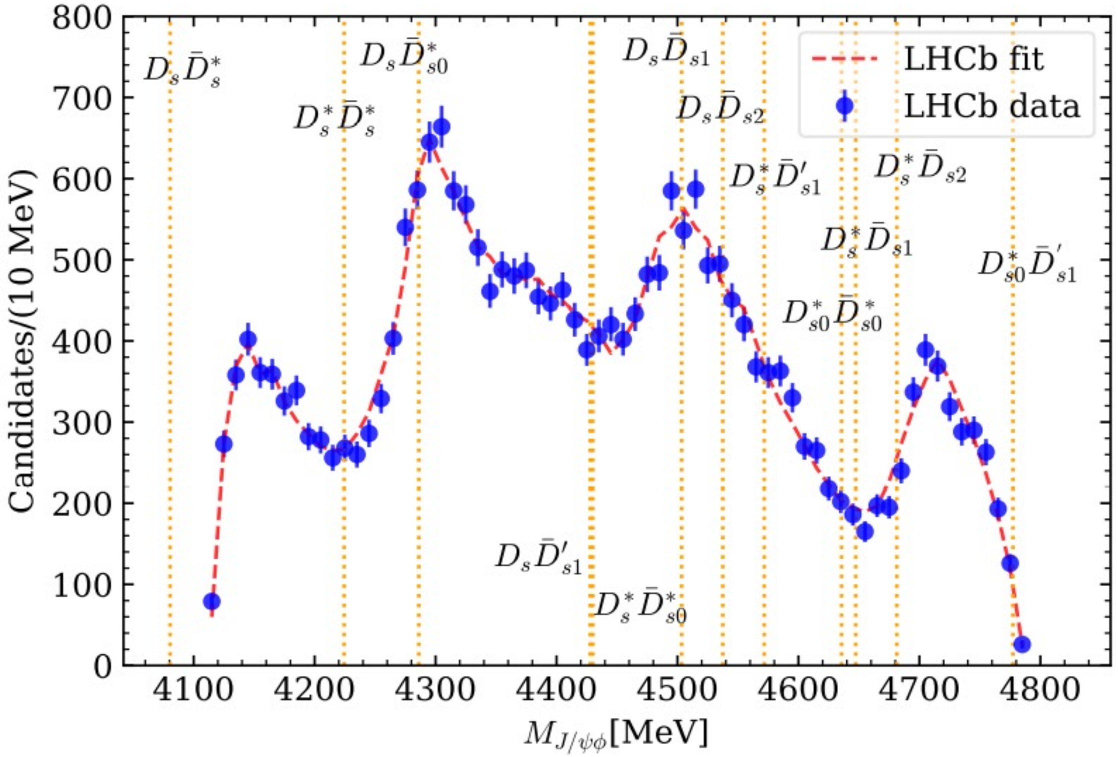
$$R_6=\frac{\Gamma(D_{s1}\to D_s\gamma)}{\Gamma(D_{s1}\to D_s^*\pi^0)+\Gamma(D_{s1}\to D_{s0}^*\gamma)},$$

$$R_7=\frac{\Gamma(D_{s1}\to D_s^*\gamma)}{\Gamma(D_{s1}\to D_s^*\pi^0)+\Gamma(D_{s1}\to D_{s0}^*\gamma)},$$

$$R_8=\frac{\Gamma(D_{s1}\to D_{s0}^*\gamma)}{\Gamma(D_{s1}\to D_s^*\pi^0)+\Gamma(D_{s1}\to D_{s0}^*\gamma)}.$$

分支比	理论结果 粲介子	测量值 粲介子	理论结果 底介子
R_1	0.028 ± 0.009	<0.059	0.79 ± 0.13
R_2	0.38(固定)±0.08	0.38 ± 0.05	2.9 ± 0.5
R_3	0.12 ± 0.02	<0.16	1.4 ± 0.2
R_4	0.028 ± 0.006	<0.22	$(4\pm1)\times10^{-4}$
R_5	0.97 ± 0.01	0.93 ± 0.09	1.0 ± 0.1
R_6	0.37 ± 0.08	0.35 ± 0.04	2.9 ± 0.5
R_7	0.12 ± 0.02	<0.24	1.4 ± 0.2
R_8	0.027 ± 0.004	<0.25	$(4\pm1)\times10^{-4}$

利用阈效应测量强子分子态质量



- B_{s0}^*和B_{s1}的主要衰变道：

$$B_{s0}^* \to B_s^0\pi^0, B_s^{*0}\gamma$$

$$B_{s1} \to B_s^{*0}\pi^0, B_s\gamma, B_s^*\gamma, B_{s0}^*\gamma$$

末态光子难以精确测量对发现这些奇特态提出挑战

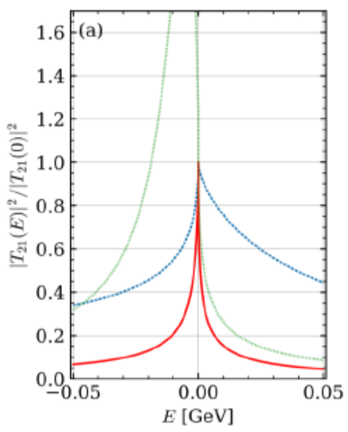
- 利用阈效应间接测量辐射衰变为主的强子态质量

近阈结构

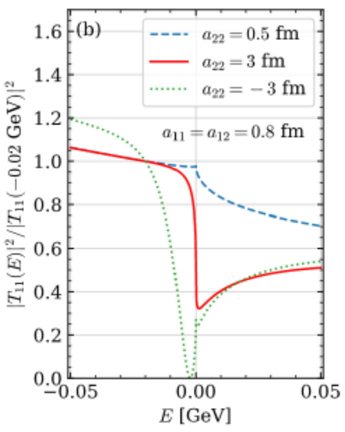
Xiang-Kun Dong et al., Phys.Rev.Lett. 126 (2021)

$$T(E)=8\pi\Sigma_2\begin{pmatrix}-\frac{1}{a_{11}}+ik_1 & \frac{1}{a_{12}}\\ \frac{1}{a_{12}} & -\frac{1}{a_{22}}-\sqrt{-2\mu_2E-i\epsilon}\end{pmatrix}^{-1}$$

$$\frac{1}{a_{22,\mathrm{eff}}}=\frac{1}{a_{22}}-\frac{a_{11}}{a_{12}^2(1+a_{11}^2k_1^2)}-i\frac{a_{11}^2k_1}{a_{12}^2(1+a_{11}^2k_1^2)}$$

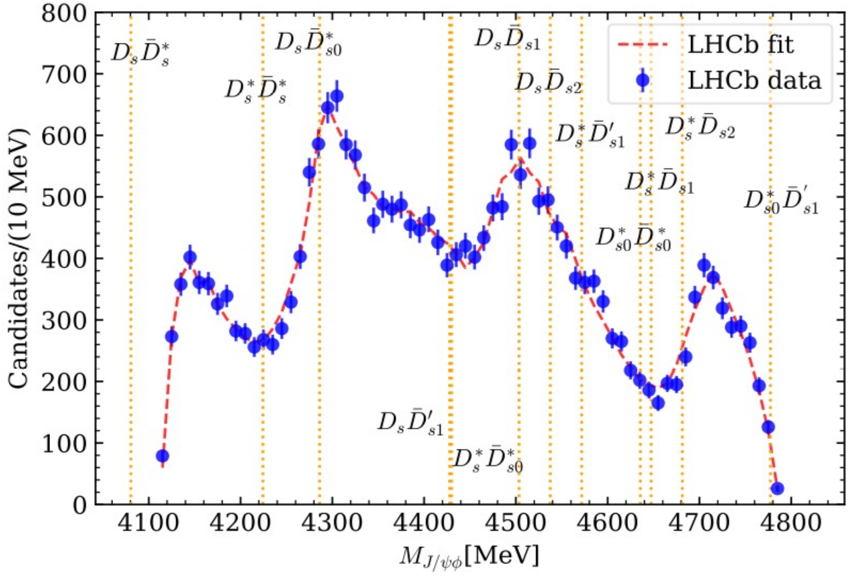


$$T_{21}\propto\frac{1}{a_{22,\mathrm{eff}}^{-1}-i\sqrt{2\mu_2E}}$$



$$T_{11}\propto\frac{a_{22}^{-1}-i\sqrt{2\mu_2E}}{a_{22,\mathrm{eff}}^{-1}-i\sqrt{2\mu_2E}}$$

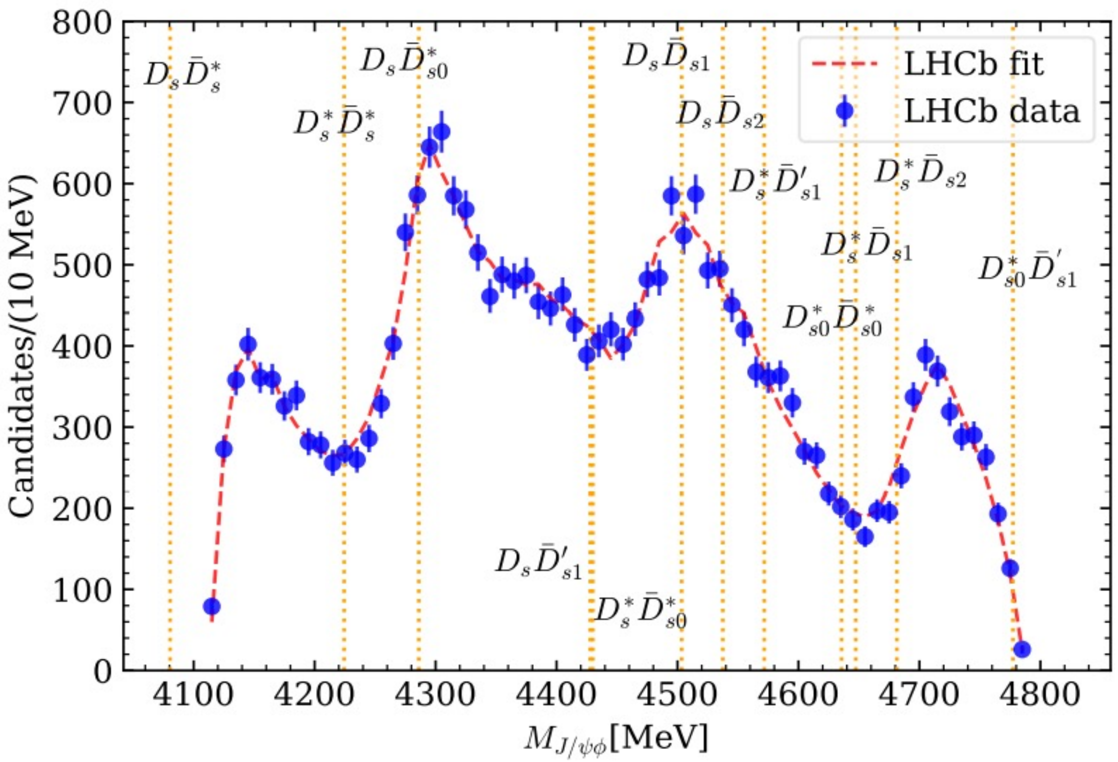
?



Xiang-Kun Dong et al., Prog.Phys. 41 (2021)

- 对于吸引的相互作用，在一对强子的阈值附近必定出现峰-谷的结构
- 对于虚态，阈值处出现尖峰(cusp),对于束缚态，极点处出现共振峰

利用阈效应测量强子分子态质量



- 利用阈效应精确测量辐射衰变为主的强子态质量
- 对于重味系统$\Upsilon\phi$：耦合到$B_{s0}^*\bar{B}_s$

虚态： $M_{virtual} = M_1 + M_2$

束缚态： $M_{res} = M_1 + M_2 - \Delta M$

- 例子：

$J/\psi\phi$末态：$X(4274)$ PDG., Phys.Rev.D 110 (2024)

$4286\ \mathrm{MeV} - m_{D_s} = 2318\ \mathrm{MeV}$

量子数为0^{-+}而非1^{++}

三体系统的低能有效场论

有效场论描述 辅助场方法

$$\mathcal{L}_d = \psi^\dagger \left(i\partial_t + \frac{\nabla^2}{2m} \right) \psi + g_2\, d^\dagger d - g_2 \left(d^\dagger \psi^2 + \left(\psi^\dagger\right)^2 d \right) - g_3\, d^\dagger d \psi^\dagger \psi$$

dimer传播子:

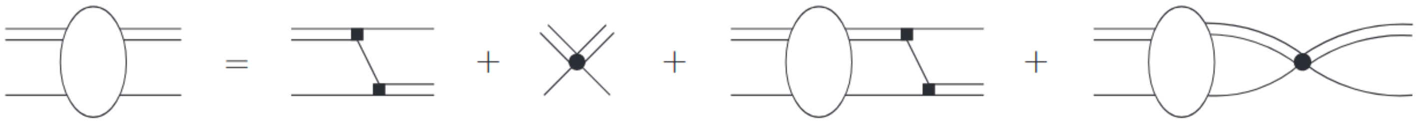
$$iD(p_0,\mathbf{p}) = iD^0 + iD^0 i\Sigma D^0 + \ldots$$

$$= iD^0 \sum_{n=0}^{\infty} (-\Sigma D^0)^n = \frac{i}{(D^0)^{-1} + \Sigma}.$$

$$iD(p_0,\mathbf{p}) = -\frac{2\pi}{m g_2^2} \frac{i}{-\gamma + \sqrt{-m p_0 + \frac{\mathbf{p}^2}{4} - i\varepsilon}}.$$

S-波散射方程

E. Braaten & H.W. Hammer, Phys.Rept. 428 (2006)



$$T(E,k,p) = \frac{16\pi\,\gamma}{m} \left[\frac{1}{2kp} \ln\left(\frac{p^2 + pk + k^2 - E - i\varepsilon}{p^2 - pk + k^2 - E - i\varepsilon} \right) - \frac{1}{4m} \frac{g_3}{g_2^2} \right]$$
$$+ \frac{4}{\pi} \int_0^\Lambda dq \frac{q^2\, T(E,k,q)}{-\gamma + \sqrt{-mE + \frac{3}{4}q^2 - i\varepsilon}} \left[\frac{1}{2qp} \ln\left(\frac{p^2 + pq + q^2 - E - i\varepsilon}{p^2 - pq + q^2 - E - i\varepsilon} \right) - \frac{1}{4m} \frac{g_3}{g_2^2} \right]$$

- 不加入三体项，在$\Lambda \to \infty$时无法收敛到唯一解。

三体力的准周期性行为

三体项作为重整化要求的截断依赖项

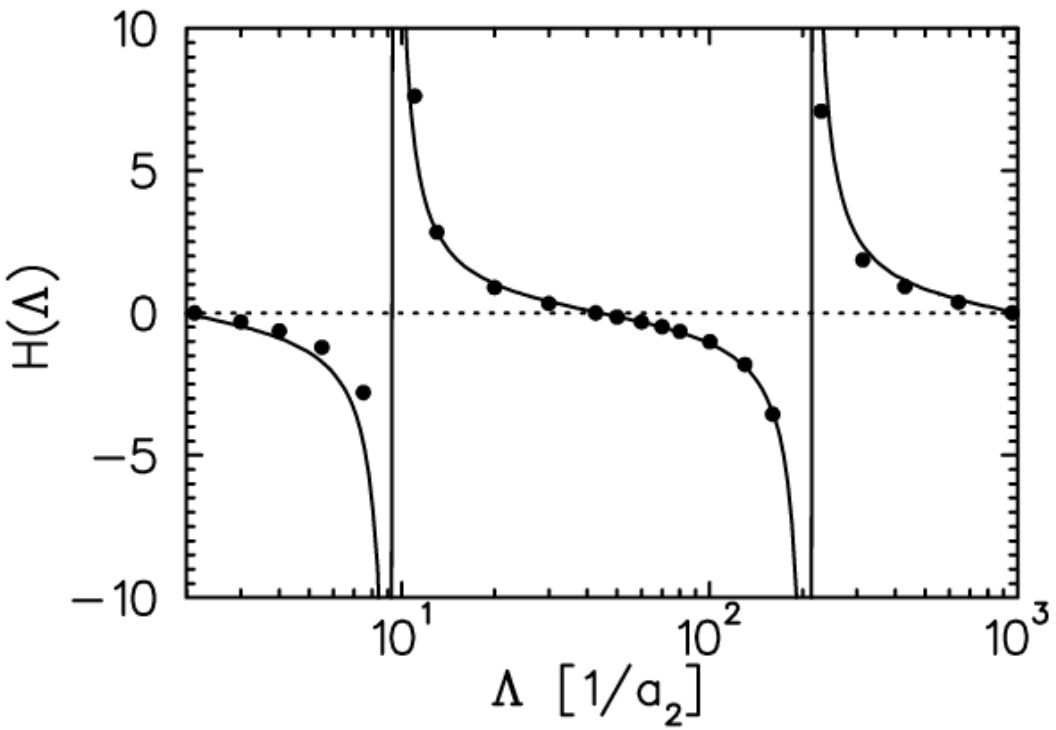
$$g_3 = -\frac{4mg_2^2}{\Lambda^2}H(\Lambda)$$

P. Bedaque et al., Phys.Rev.Lett. 82 (1999)

$$H(\Lambda) = \frac{\cos\left[s_0 \ln\left(\frac{\Lambda}{\Lambda_*}\right) + \arctan(s_0)\right]}{\cos\left[s_0 \ln\left(\frac{\Lambda}{\Lambda_*}\right) - \arctan(s_0)\right]}$$

- 新的参数 Λ_*，物理意义是三体力为0的点，需要额外的输入来固定
- 所有截断依赖性被三体项吸收
- 周期性行为是重整化群极限环的体现 $\frac{g}{r^2}$类型的势能

D.Kaplan et al., Phys.Rev.D 80 (2009)



三体$\bar{D}_s DK$系统的散射方程

$$\psi_a = (\psi_K, \psi_{\bar{D}_s}, \psi_D)$$

$$\mathcal{L}_1 = \psi_a^\dagger \left(i\partial_0 + \frac{\nabla^2}{2m_i} \right) \psi_a$$

$$\mathcal{L}_2 = \sigma_i^\dagger \left(-i\partial_0 + \Delta_i \right) \sigma_i - g_i \left(\sigma_i^\dagger \psi_a \psi_b + \text{h.c.} \right)$$

dimer场

能量：$E(p) = \frac{p^2}{2\mu} - B_{DK}$

$$iG_i(E, \vec{p}) = \frac{-i\, 2\pi / \left(\mu_i g_i^2\right)}{-1/a_i + \left[2\mu_i \left(\frac{\vec{p}^2}{2M_i} - E - i\epsilon \right) \right]^{1/2}} \qquad Z_i^{-1} = \frac{\mu_i^2 g_i^2 |a_i|}{2\pi}$$

$$|D_{s0}^* \bar{D}_s\rangle = \frac{1}{\sqrt{2}} \left(|D^0 K^+\rangle |\bar{D}_s\rangle + |D^+ K^0\rangle |\bar{D}_s\rangle \right)$$

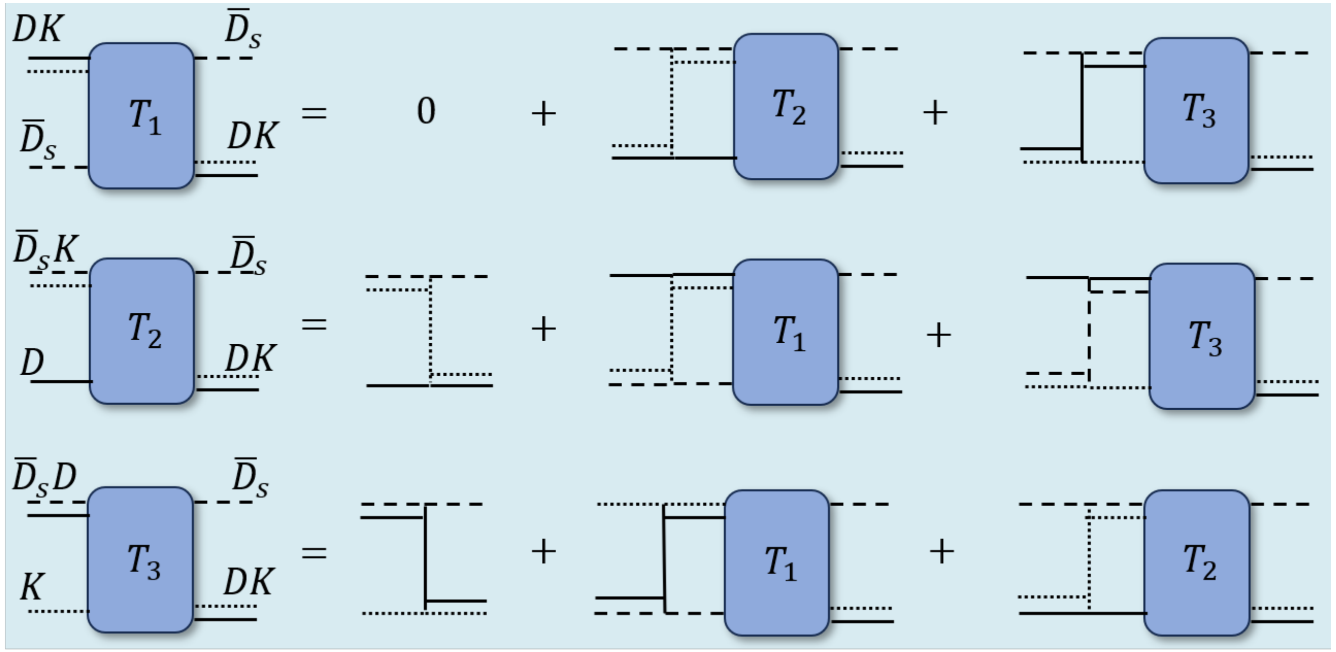
1道： $J = 0, I = 0$

$$|\sigma_{\bar{D}_s K} D\rangle = \frac{1}{\sqrt{2}} \left(|\bar{D}_s K^+\rangle |D^0\rangle + |\bar{D}_s K^0\rangle |D^+\rangle \right)$$

2道： $J = 0, I = 0$

$$|\sigma_{\bar{D}_s D} K\rangle = \frac{1}{\sqrt{2}} \left(|\bar{D}_s D^0\rangle |K^+\rangle + |\bar{D}_s D^+\rangle |K^0\rangle \right)$$

3道： $J = 0, I = 0$



- 单粒子交换（OPE）型势能

$$V_{21}(\vec{p},\vec{q},E)=\frac{-\sqrt{Z_2}\sqrt{Z_1}g_2g_1}{E-\frac{p^2}{2m_D}-\frac{q^2}{2m_{\bar{D}_s}}-\frac{(\vec{q}+\vec{p})^2}{2m_K}+i\epsilon}$$

$$V_{31}(\vec{p},\vec{q},E)=\frac{-\sqrt{Z_3}\sqrt{Z_1}g_3g_1}{E-\frac{p^2}{2m_K}-\frac{q^2}{2m_{\bar{D}_s}}-\frac{(\vec{q}+\vec{p})^2}{2m_D}+i\epsilon}$$

$$V_{23}(\vec{p},\vec{q},E)=\frac{-\sqrt{Z_2}\sqrt{Z_3}g_2g_3}{E-\frac{p^2}{2m_D}-\frac{q^2}{2m_K}-\frac{(\vec{q}+\vec{p})^2}{2m_{\bar{D}_s}}+i\epsilon}$$

- S波投影：

$$V_{ij}(p,q,E)=\sqrt{Z_i}\sqrt{Z_j}g_ig_j\frac{m_3}{2pq}\log\frac{-E+\frac{p^2}{2m_1}+\frac{q^2}{2m_2}+\frac{(p+q)^2}{2m_3}-i\epsilon}{-E+\frac{p^2}{2m_1}+\frac{q^2}{2m_2}+\frac{(p-q)^2}{2m_3}-i\epsilon}$$

- 散射方程（不含三体项）

$$\begin{pmatrix} iT_1(p,q)\\ iT_2(p,q)\\ iT_3(p,q)\end{pmatrix}=\begin{pmatrix}0\\ iV_{21}(p,q)\\ iV_{31}(p,q)\end{pmatrix}+\int_0^\Lambda\frac{k^2dk}{2\pi^2}\begin{pmatrix}0 & iV_{12}(p,k) & iV_{13}(p,k)\\ iV_{21}(p,k) & 0 & iV_{23}(p,k)\\ iV_{31}(p,k) & iV_{32}(p,k) & 0\end{pmatrix}\begin{pmatrix}Z_1^{-1}iG_1(E-\frac{k^2}{2m_{D_s}},k)iT_1(k,q)\\ Z_2^{-1}iG_2(E-\frac{k^2}{2m_D},k)iT_2(k,q)\\ Z_3^{-1}iG_3(E-\frac{k^2}{2m_K},k)iT_3(k,q)\end{pmatrix}$$

数值结果

DK $\quad a_{DK} = 1.04$ fm

由$D_{s0}^*(2317)$的质量固定 $\quad B_i = 1/(2\mu_i a_i^2)$

$\bar{D}_s K$ $\quad a_{\bar{D}_s K} = -2.57$ fm

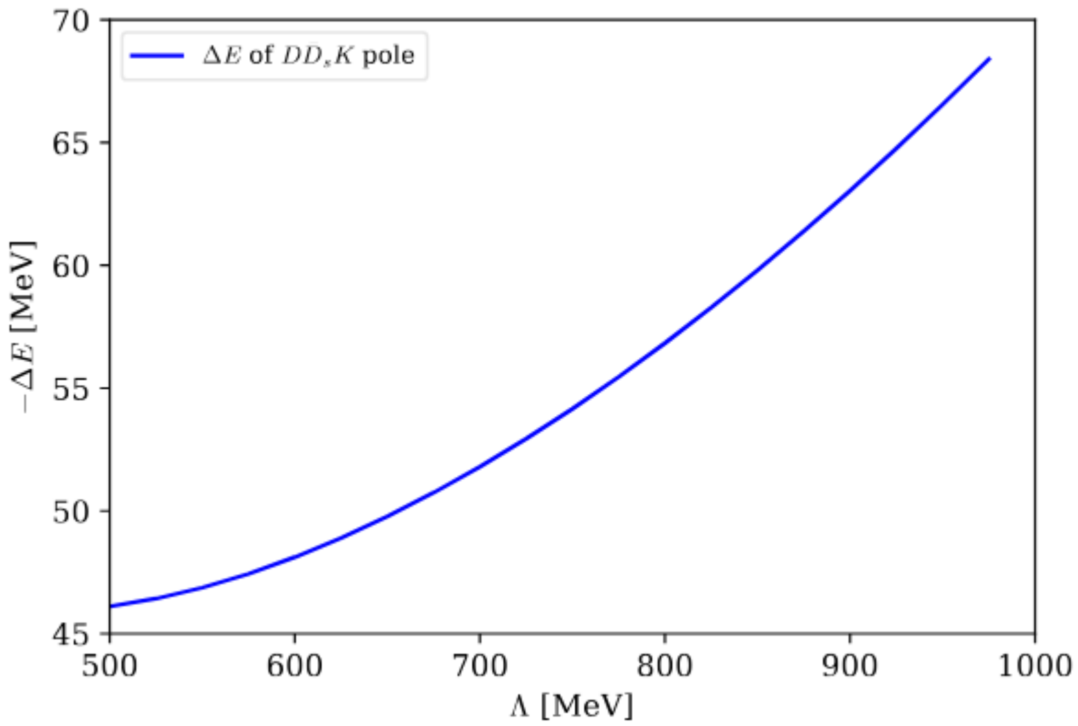
由手征幺正方法计算：

$\bar{D}_s K$-$\bar{D}\pi$-$\bar{D}\eta$

$\bar{D}_s D$ $\quad \bar{H}H$ 系统的SU(3)多重态分析： Teng Ji et al., Phys.Rev.D 106 (2022)

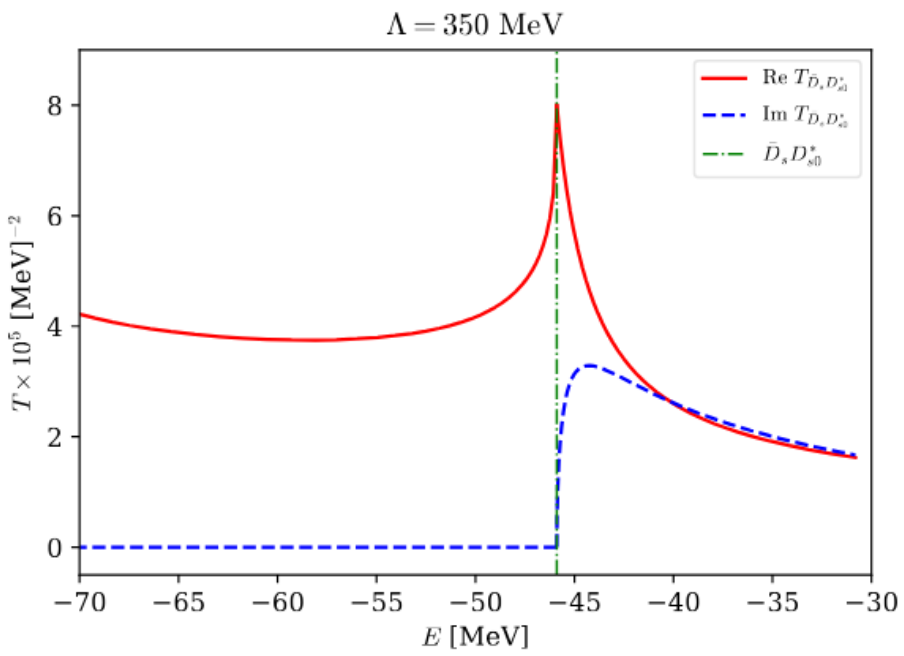
$a_{\bar{D}_s D} = 0.22$ fm ($\Lambda_2 = 0.5$ GeV)

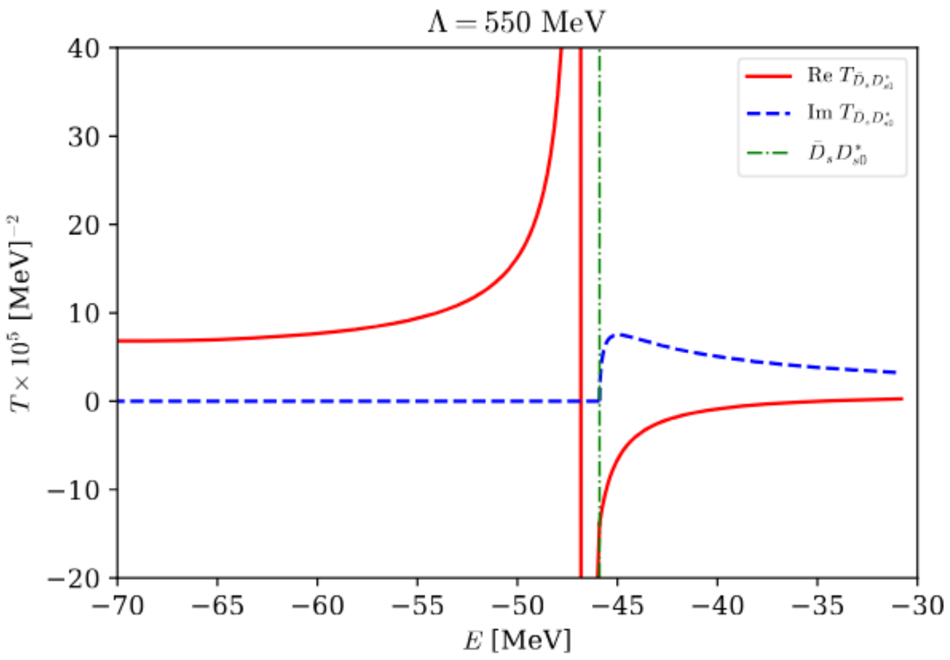
-0.45 fm ($\Lambda_2 = 1.0$ GeV)



- 极点位置表现出明显的截断依赖性

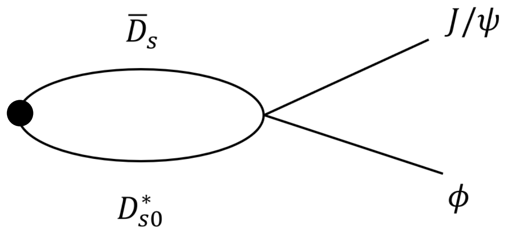
P. Bedaque et al., Phys.Rev.Lett. 82 (1999)



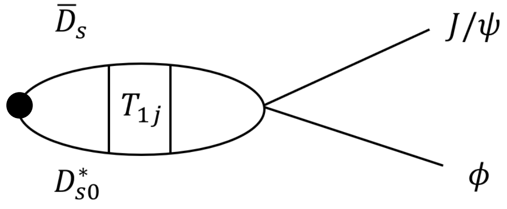


需引入三体项：$iV_{ij}^{S} = i\mu_i g_i c g_j \mu_j$

拟合LHCb实验数据



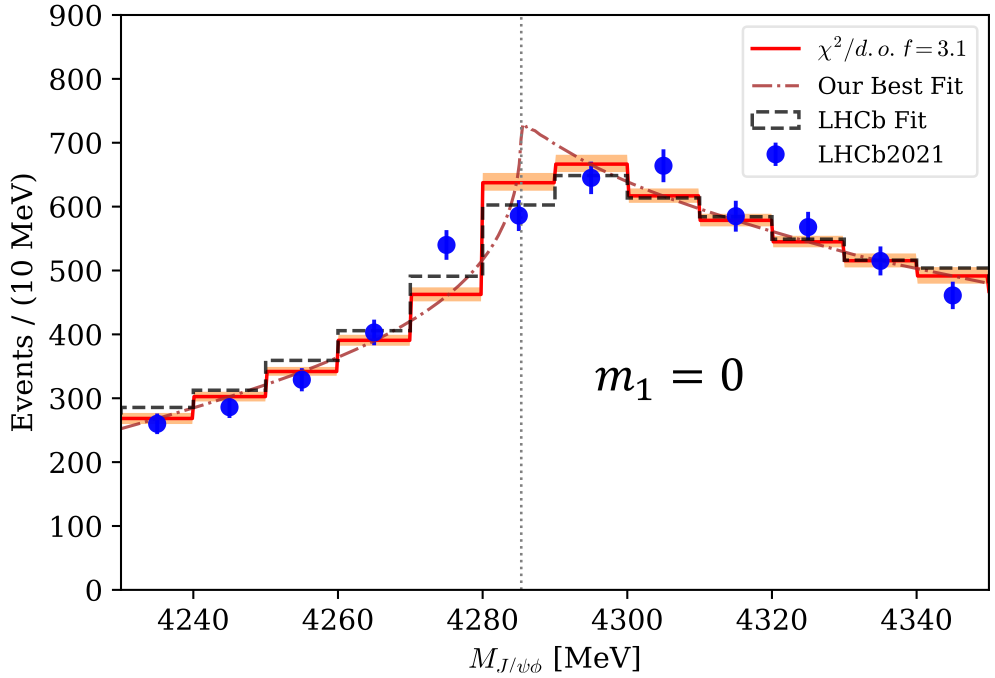
$\tilde{\Lambda} = 1$ GeV



$\Lambda = 1$ GeV

$$iF = iF_1 + iF_2$$

$$F_2 = U_1 iG_1 iV_{10} + U_1 iG_1 iT_{1j} iG_j iV_{j0}$$



- 拟合参数：$c = c_1 + ic_2 \quad \mathcal{N}, m_0 = m_1 + im_2$
- 与LHCb最佳拟合之间的 $\chi^2/d.o.f. = 0.9$
- $D_{s0}^* \bar{D}_s$极点位置：$4264.85^{+0.02}_{-0.02} + (-1.70^{+0.08}_{-0.09})i$ MeV

$$\frac{dN}{dM_{J/\psi\phi}} = \mathcal{N}^2 \left|f_1 + f_2 + m_0\right|^2 \text{p.s.}$$

重夸克味道伙伴态系统

$BK \quad a_{BK} = 0.88$ fm

$\bar{B}_s K \quad a_{\bar{B}_s K} = -5.73$ fm

- 与BK和$\bar{B}_s K$计算方法相同

$\bar{B}_s B$

- 只存在势能水平的重夸克味道对称性，近似估计:

V.Baru et al., Eur.Phys.J.C 79 (2019)

$$a_{\bar{D}_s D} \to \Lambda_2 \to a_{\bar{B}_s B}$$

$$\Lambda_2 \downarrow 0.5\sim1.0 \text{ GeV}$$

$$a_{\bar{B}_s B} = 0.44 \text{ fm } (\Lambda_2 = 0.5 \text{ GeV})$$

$$2.43 \text{ fm } (\Lambda_2 = 1.0 \text{ GeV})$$

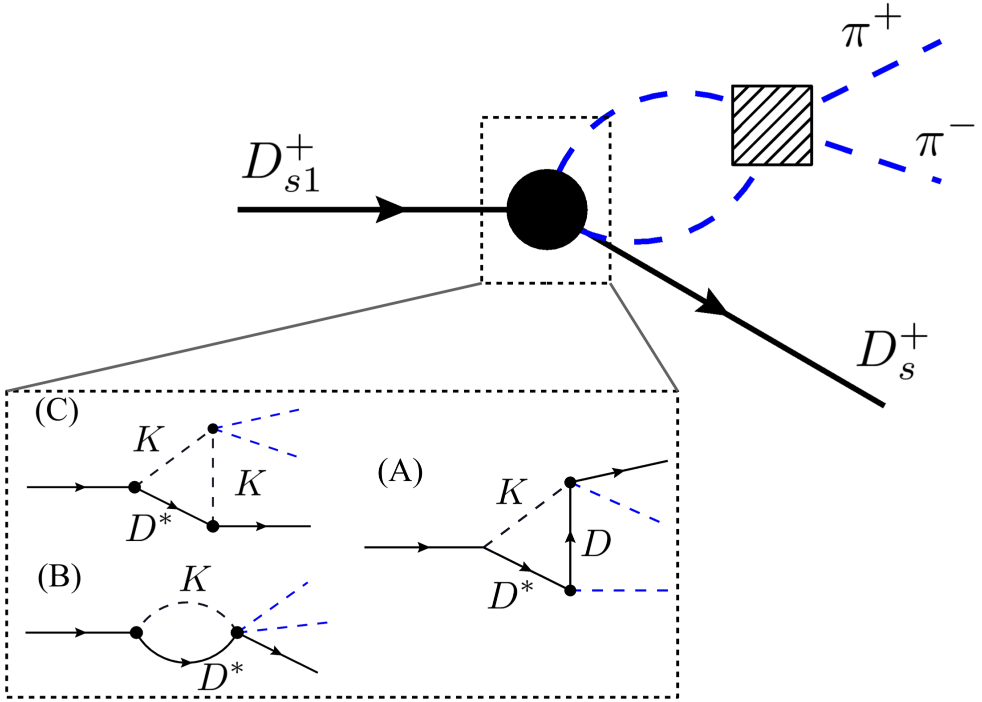
$c_* = 17.6 - 11.0i$ GeV^{-3}	pole position	ΔE_B(MeV)
$\Lambda = 0.50$ GeV	-/-	–
$\Lambda = 0.75$ GeV	v/v	$-6.07/-6.68$
$\Lambda = 1.00$ GeV	v/v	$-1.18/-1.66$
$\Lambda = 1.25$ GeV	b/v	$-0.08/-0.0004$
$\Lambda = 1.50$ GeV	b/b	$-2.22/-1.24$

- 对底介子系统：三体项仅使用粲介子系统中三体项的实部
- 当减小截断值时，底介子三体系统的极点由束缚态向虚态转变

$D_{s1}(2460) \to D_s \pi \pi$

- 不变质量分布中的双峰结构

Meng-Na Tang et al., CTP 75 (2023)



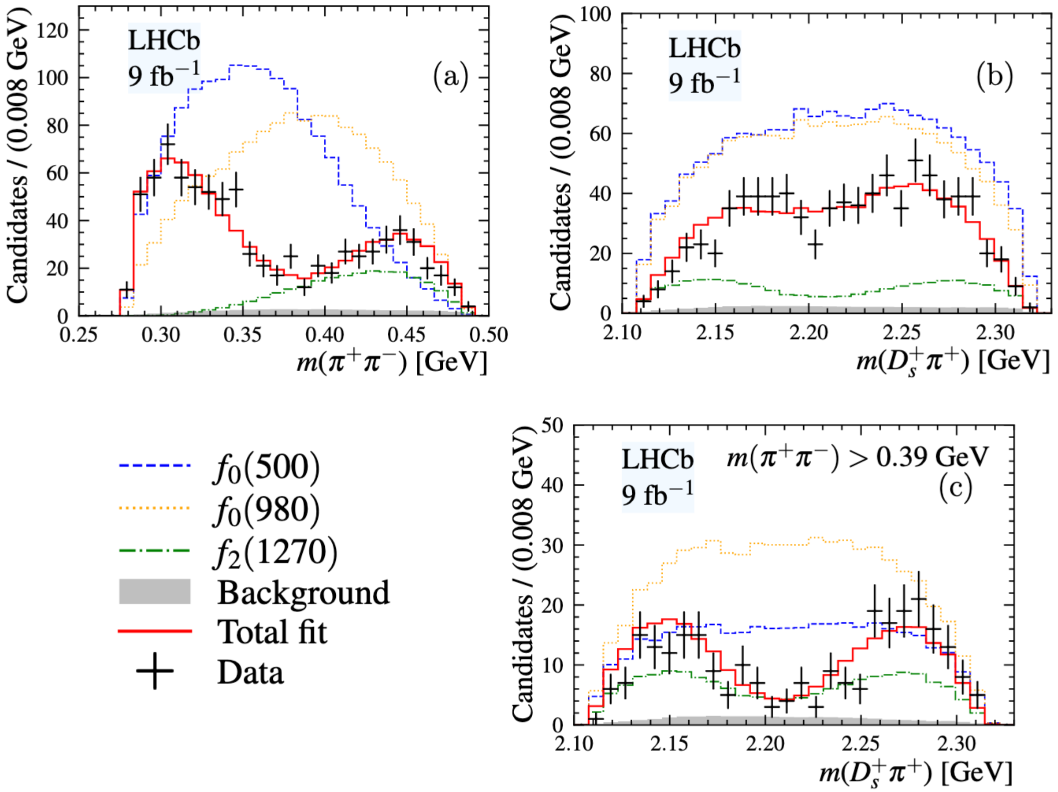
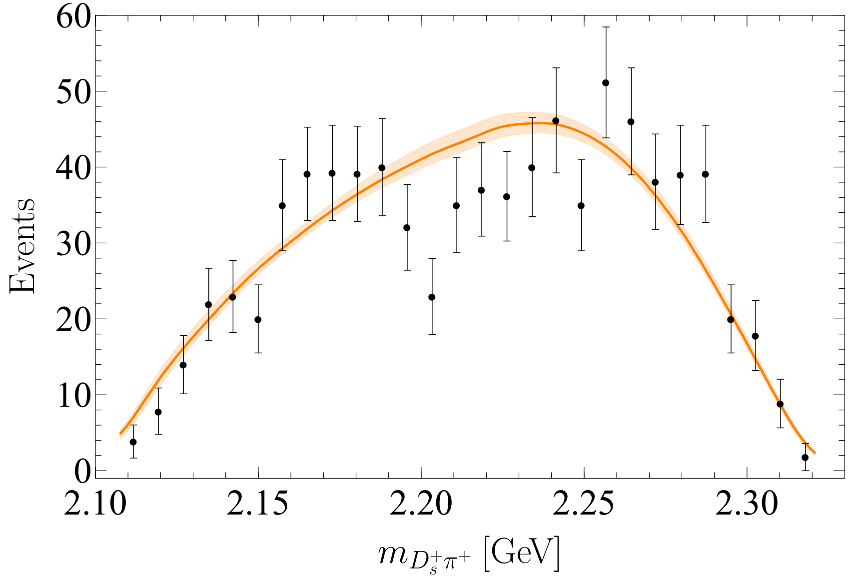
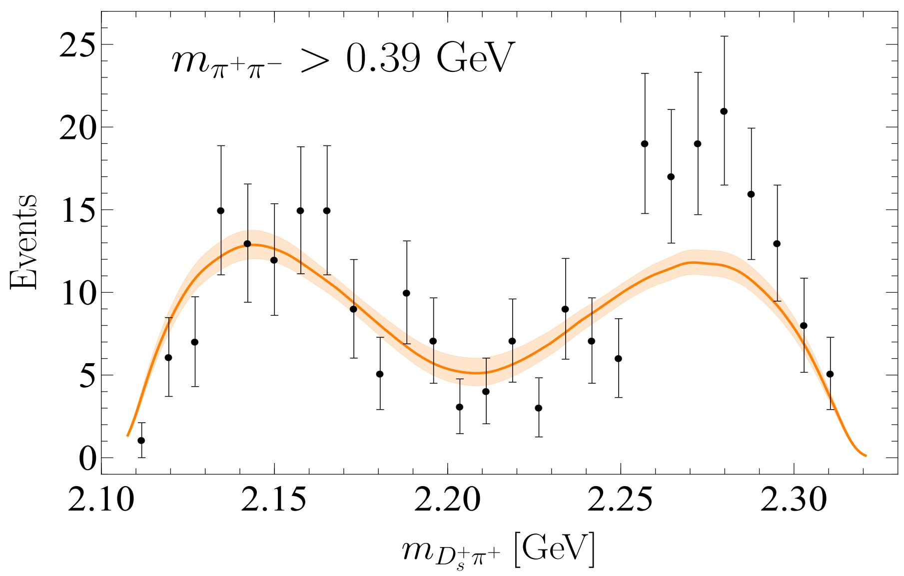


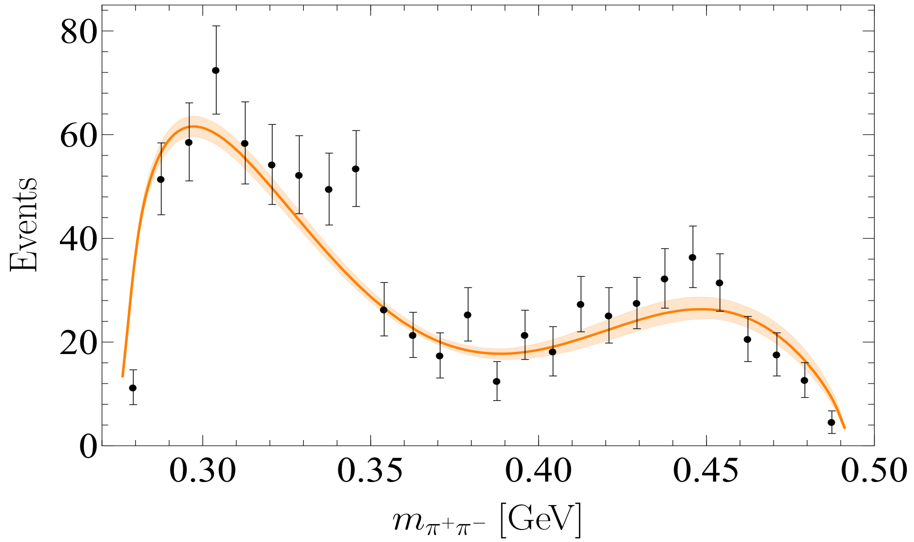
Figure 3: Comparison between data (black error bars) and results of the fit with the $f_0(500) + f_0(980) + f_2(1270)$ model (red solid line). The distributions are for the three channels combined in (a) $m(\pi^+\pi^-)$, (b) $m(D_s^+\pi^+)$, and (c) $m(D_s^+\pi^+)$ requiring $m(\pi^+\pi^-) > 0.39$ GeV. Individual components, corresponding to the background contribution estimated from $m(D_s^+\pi^+\pi^-)$ sideband regions (gray-filled) and the different resonant contributions (coloured dashed lines), are also shown as indicated in the legend.

- 被LHCb的观测所证实

LHCb Sci.Bull. 70 (2025)



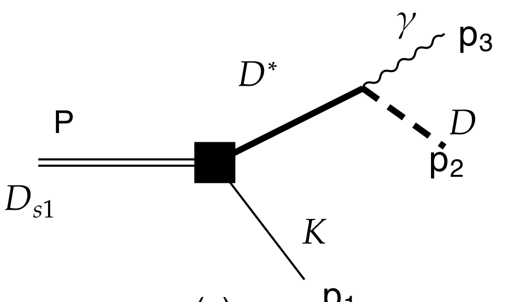




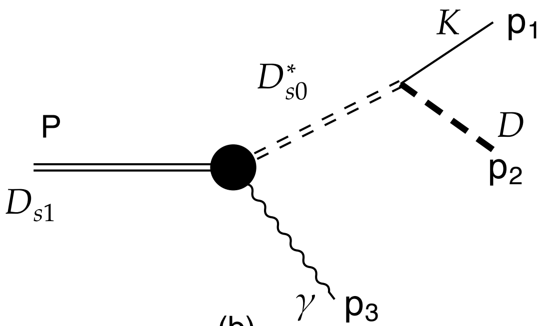
- 完整的计算显示LHCb的数据可以在分子态图像下得到较好的解释，无需引入新的奇特态

Hai-Long Fu et. al., in preparation

$D_{s1}(2460) \to D\,K\,\gamma$

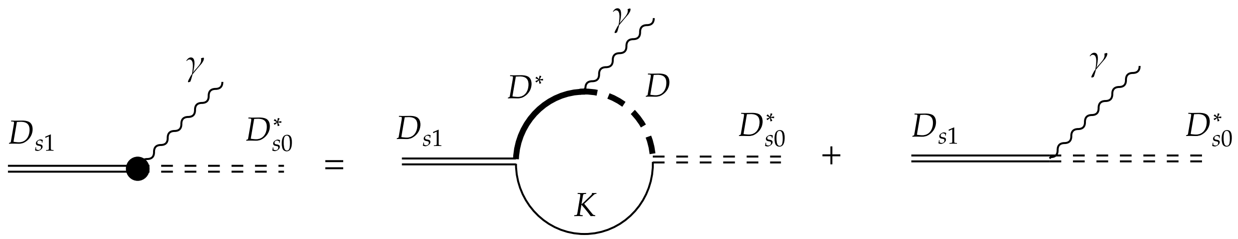


(a)

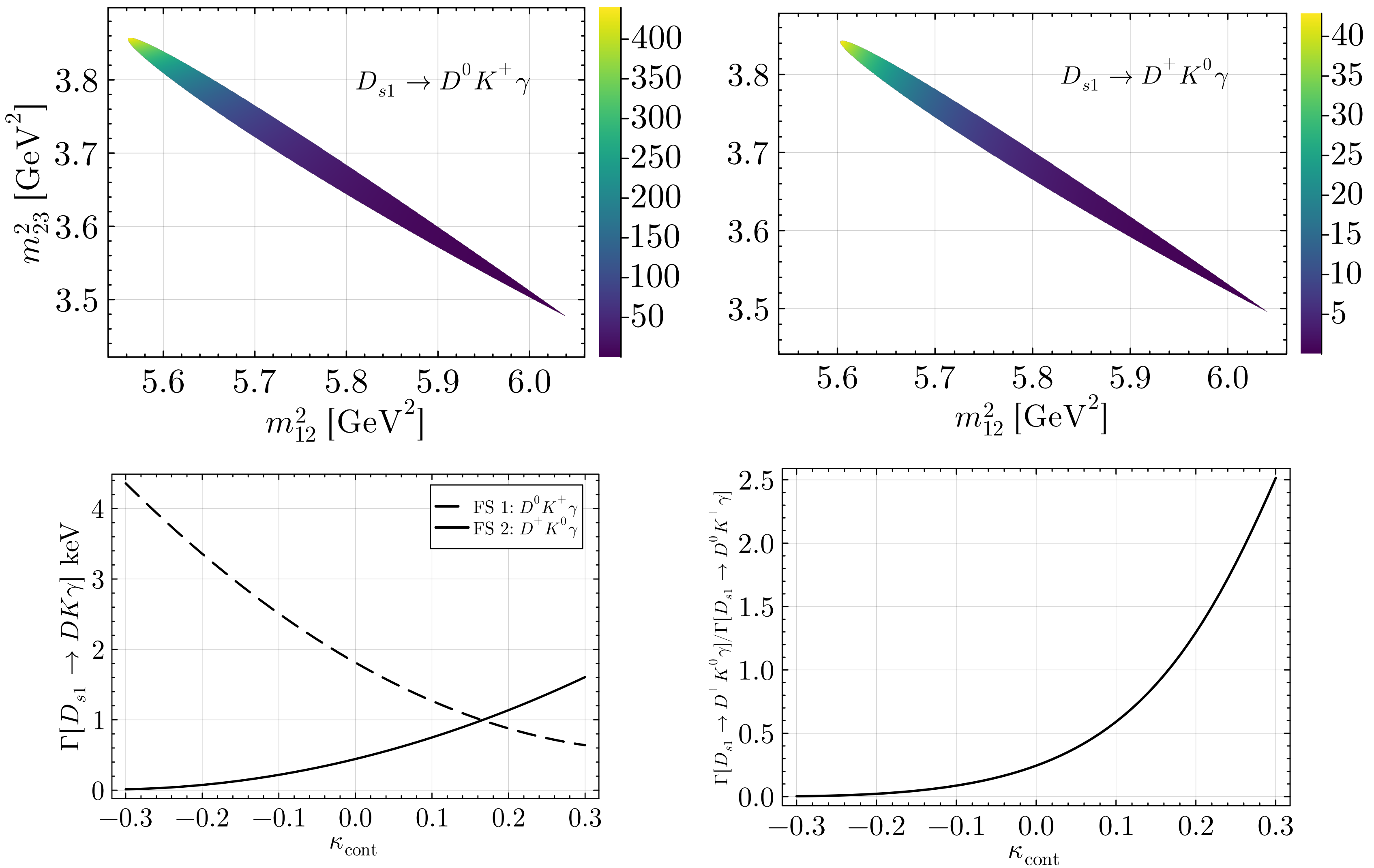


(b)

- $D_{s1} \to D_{s0}\gamma$的参数未能完全确定
- 接触项强度$\Lambda_{\mathrm{QCD}}/m_c \sim 0.3$



$\kappa_{\mathrm{loop}} \sim 0.19$



- $D_{s1} \to D_{s0}\gamma$的短程相互作用对于三体末态的辐射衰变较为敏感。
- 相对于总宽度的分支比在百分之一的水平

Mode	$D_s^*\pi^0$	$D_s\gamma$	$D_s^*\gamma$	$D_s\pi^+\pi^-$	$D_s\pi^0\pi^0$	γDK
Width, keV	111	42	13	16	8	$\simeq 1..10$

Hai-Long Fu et. al., in preparation