用SU(3)味对称性/破缺方法研究 $D \to P/V/S/A\ell^+\nu_\ell$半轻衰变

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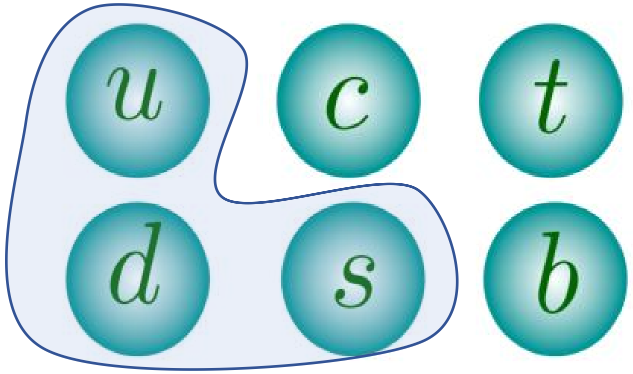
研究背景

- ➢一些 $B(D\to P/V\ell\nu)$ 已经很好的测量，而 $B(D\to S/A\ell\nu)$ 还没有很好的测量到;
- ➢在BESIII，LHCb和BelleII上产生很多粲强子的实验数据;
- ➢计算$D\to P/V\ell^+\nu_\ell$ 与$D\to S/A\ell^+\nu_\ell$的形状因子；
- ➢对称性方法可以为粒子物理提供一些非常重要的信息。

SU(3) 味对称方法

- 不可约表示方法 （哈密顿量，动力学细节）
- 拓扑图方法（夸克线，关联振幅）



优点

不依赖于动力学细节（不需要计算形状因子）

缺点

不能决定自身振幅的大小

用SU(3) 味对称方法研究介子衰变

decays \ baryons	Charmed mensons	Bottom mensons
$B/D \to M_1M_2$	① Hai -Yang Cheng et. al., PRD 86, 014014(2012); PRD 93, 114010(2016) ② Xiao-Gang He,Wei Wang et. al., EPJC 80, 359(2020) ; CPC 42, 103108(2018). ③ D. Pirtskhalava, PLB 742, 81 (2012). ④ ……	① Si -Hong Zhou et. al., PRD 92094016(2015); EPJC 77(2017) 2, 125;PRD 92, 094016(2015). ② Hai -Yang Cheng et. al., JHEP 09, 024(2011);PRD 91, 014011(2015). ③ Xiao-Gang He,Wei Wang et. al., EPJC 80, 359(2020) ; CPC 42, 103108(2018); PRD 93, 114002(2016); JHEP 08, 065(2013); PRD 69, 074002(2004); PRD 64, 034002(2001); EPJC 9, 443(1999); PRL 75, 1703(1995). ④ ……
$B/D \to Ml\nu$ $B/D \to M_1M_2l\nu$	$D \to P/V/Sl\nu$ NPB995,116349(2023) $D \to PPl\nu$ PRD107,056022(2023) $D \to A(A \to VP)l\nu$ arXiv: 2404. 03857	$B \to VPl\nu$ working

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介子多重态

介子 $q\bar{q}$ M^i_j $i,j=1,2,3$ *for u, d, s.*

$$D_i=\left(D^0(c\bar{u}),\ D^+(c\bar{d}),\ D^+_s(c\bar{s})\right)$$

$$P=\begin{pmatrix} \frac{\pi^0}{\sqrt{2}}+\frac{\eta_8}{\sqrt{6}}+\frac{\eta_1}{\sqrt{3}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}}+\frac{\eta_8}{\sqrt{6}}+\frac{\eta_1}{\sqrt{3}} & K^0 \\ K^- & \overline{K}^0 & -\frac{2\eta_8}{\sqrt{6}}+\frac{\eta_1}{\sqrt{3}} \end{pmatrix}$$

$$V=\begin{pmatrix} \frac{\rho^0}{\sqrt{2}}+\frac{\omega_8}{\sqrt{6}}+\frac{\omega_1}{\sqrt{3}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}}+\frac{\omega_8}{\sqrt{6}}+\frac{\omega_1}{\sqrt{3}} & K^{*0} \\ K^{*-} & \overline{K}^{*0} & -\frac{2\omega_8}{\sqrt{6}}+\frac{\omega_1}{\sqrt{3}} \end{pmatrix}$$

$$S=\begin{pmatrix} \frac{a_0^0}{\sqrt{2}}+\frac{\sigma}{\sqrt{2}} & a_0^+ & K_0^+ \\ a_0^- & -\frac{a_0^0}{\sqrt{2}}+\frac{\sigma}{\sqrt{2}} & K_0^0 \\ K_0^- & \overline{K}_0^0 & f_0 \end{pmatrix}$$

S^{im}_{jm}

$\sigma=u\bar{u}d\bar{d}$, $f_0=(u\bar{u}+d\bar{d})s\bar{s}/\sqrt{2}$,

$a_0^0=(u\bar{u}-d\bar{d})s\bar{s}/\sqrt{2}$, $a_0^+=u\bar{d}s\bar{s}$, $a_0^-=d\bar{u}s\bar{s}$,

$K_0^+=u\bar{s}d\bar{d}$, $K_0^0=d\bar{s}u\bar{u}$, $\bar{K}_0^0=s\bar{d}u\bar{u}$, $K_0^-=s\bar{u}d\bar{d}$,

$$\begin{pmatrix}\eta\\ \eta'\end{pmatrix}=\begin{pmatrix}\cos\theta_P & -\sin\theta_P\\ \sin\theta_P & \cos\theta_P\end{pmatrix}\begin{pmatrix}\eta_8\\ \eta_1\end{pmatrix}$$

$$\begin{pmatrix}f_0(980)\\ f_0(500)\end{pmatrix}=\begin{pmatrix}\cos\theta_S & \sin\theta_S\\ -\sin\theta_S & \cos\theta_S\end{pmatrix}\begin{pmatrix}f_0\\ \sigma\end{pmatrix}$$

$$A=\begin{pmatrix} \frac{a_1^0}{\sqrt{2}}+\frac{f_1}{\sqrt{3}}+\frac{f_8}{\sqrt{6}} & a_1^+ & K_{1A}^+ \\ a_1^- & -\frac{a_1^0}{\sqrt{2}}+\frac{f_1}{\sqrt{3}}+\frac{f_8}{\sqrt{6}} & K_{1A}^0 \\ K_{1A}^- & \overline{K}_{1A}^0 & \frac{f_1}{\sqrt{3}}-\frac{2f_8}{\sqrt{6}} \end{pmatrix}$$

$J^{PC}=1^{++}$

$$B=\begin{pmatrix} \frac{b_1^0}{\sqrt{2}}+\frac{h_1}{\sqrt{3}}+\frac{h_8}{\sqrt{6}} & b_1^+ & K_{1B}^+ \\ b_1^- & -\frac{b_1^0}{\sqrt{2}}+\frac{h_1}{\sqrt{3}}+\frac{h_8}{\sqrt{6}} & K_{1B}^0 \\ K_{1B}^- & \overline{K}_{1B}^0 & \frac{h_1}{\sqrt{3}}-\frac{2h_8}{\sqrt{6}} \end{pmatrix}$$

$J^{PC}=1^{+-}$

$$\begin{pmatrix}K_1(1270)\\ K_1(1400)\end{pmatrix}=\begin{pmatrix}\sin\theta_{K_1} & \cos\theta_{K_1}\\ \cos\theta_{K_1} & -\sin\theta_{K_1}\end{pmatrix}\begin{pmatrix}K_{1A}\\ K_{1B}\end{pmatrix}$$

$$\begin{pmatrix}f_1(1285)\\ f_1(1420)\end{pmatrix}=\begin{pmatrix}\cos\theta_{3P1} & \sin\theta_{3P1}\\ -\sin\theta_{3P1} & \cos\theta_{3P1}\end{pmatrix}\begin{pmatrix}f_1\\ f_8\end{pmatrix}$$

$$\begin{pmatrix}h_1(1170)\\ h_1(1415)\end{pmatrix}=\begin{pmatrix}\cos\theta_{1P1} & \sin\theta_{1P1}\\ -\sin\theta_{1P1} & \cos\theta_{1P1}\end{pmatrix}\begin{pmatrix}h_1\\ h_8\end{pmatrix}$$

衰变分支比

$$\mathcal{H}_{eff}(c \to q\ell^+\nu_\ell) = \frac{G_F}{\sqrt{2}} V_{cq} \bar{q}\gamma^\mu(1-\gamma_5)c\, \bar{\nu}_\ell\gamma_\mu(1-\gamma_5)\ell,$$

$$\mathcal{M}(D \to M\ell^+\nu_\ell) = \frac{G_F}{\sqrt{2}} \sum_{mm'} g_{mm'} L_m^{\lambda_\ell\lambda_\nu} H_{m'}^{\lambda_M},$$

$$L_m^{\lambda_\ell\lambda_\nu} = \epsilon_\alpha(m)\bar{\nu}_\ell\gamma^\alpha(1-\gamma_5)\ell,$$

$$H_{m'}^{\lambda_M} = \begin{cases} V_{cq}^*\epsilon_\beta^*(m')\langle P/S(p_{P/S})|\bar{q}\gamma^\beta(1-\gamma_5)c|D(p_D)\rangle \\ V_{cq}^*\epsilon_\beta^*(m')\langle V/A(p_{V/A},\epsilon^*)|\bar{q}\gamma^\beta(1-\gamma_5)c|D(p_D)\rangle \end{cases},$$

$$\frac{d\mathcal{B}(D_{(s)} \to M\ell^+\nu_\ell)}{dq^2} = \frac{\tau_D G_F^2 |V_{cq}|^2 \lambda^{1/2}(q^2 - m_\ell^2)^2}{24(2\pi)^3 M_{D_{(s)}}^3 q^2} \mathcal{H}_{\rm total},$$

$$\mathcal{H}_{\rm total} \equiv (\mathcal{H}_U + \mathcal{H}_L)\left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2}\mathcal{H}_S.$$

$D \to M\ell^+\nu_\ell$衰变强子螺旋度振幅

- $H(D \to M l^+ \nu_l) = c_0^M D_i M^i_j H^j$

- $\Delta H(D \to M l^+ \nu_l) = c_1^M D_a W^a_i M^i_j H^j + c_2^M D_i M^i_a W^a_j H^j$

其中，c_i^M 是非微扰系数，H^j 是CKM 矩阵元。

SU(3) 味破缺系数矩阵 $W = (W^i_j) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$

$D \to P/V\ell^+\nu_\ell$形状因子

C_1: 所有的形状因子都被视为常数，没有对强子动量转移q^2的依赖性

C_2: 具有SU (3)味对称，$F_i(q^2)$对的q^2依赖性的极点修正模型

$$F_i(q^2)=\frac{F_i(0)}{\left(1-\frac{q^2}{m_{pole}^2}\right)\left(1-\alpha_i\frac{q^4}{m_{pole}^4}\right)},$$

C_3: 具有SU(3)味对称 $F_i(q^2)=\frac{F_i(0)}{\left(1-\frac{q^2}{m_{pole}^2}\right)\left(1-\sigma_{1i}\frac{q^2}{m_{pole}^2}+\sigma_{2i}\frac{q^4}{m_{pole}^4}\right)}$ （$f_+^P(q^2)$ 和 $V(q^2)$），

$$F_i(q^2)=\frac{F_i(0)}{\left(1-\sigma_{1i}\frac{q^2}{m_{pole}^2}+\sigma_{2i}\frac{q^4}{m_{pole}^4}\right)}$$ （$f_0^P(q^2)$、$A_1(q^2)$ 和 $A_2(q^2)$），

C_4: 考虑SU(3)味破缺c^M_{12} 的形状因子

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$D \to P\ell^+\nu_\ell$衰变振幅

TABLE I: The hadronic helicity amplitudes for the $D \to P\ell^+\nu$ decays including both the SU(3) flavor symmetry and the SU(3) flavor breaking contributions. $A_1 \equiv c_0^P + c_1^P - 2c_2^P$, $A_2 \equiv c_0^P - 2c_1^P - 2c_2^P$, $A_3 \equiv c_0^P + c_1^P + c_2^P$, $A_4 \equiv c_0^P - 2c_1^P + c_2^P$. $A_1 = A_2 = A_3 = A_4 = c_0^P$ if neglecting the SU(3) flavor breaking c_1^P and c_2^P terms.

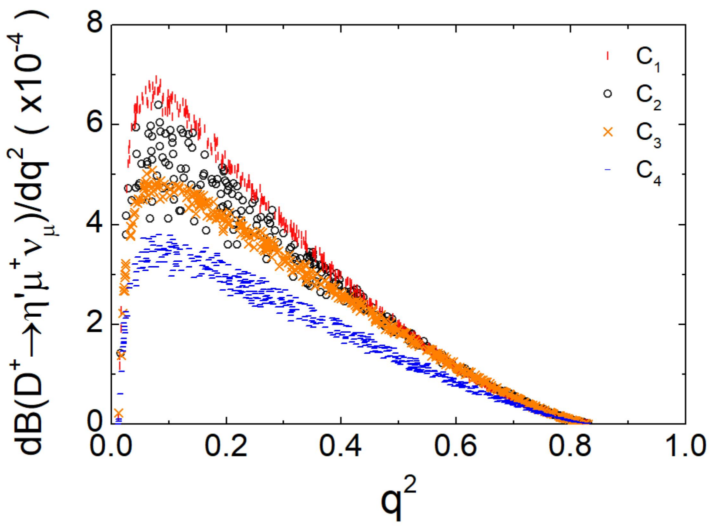
Hadronic helicity amplitudes	SU(3) flavor amplitudes
$H(D^0 \to K^-\ell^+\nu_\ell)$	$A_1 V_{cs}^*$
$H(D^+ \to \overline{K}^0\ell^+\nu_\ell)$	$A_1 V_{cs}^*$
$H(D_s^+ \to \eta\ell^+\nu_\ell)$	$\left(-cos\theta_P\sqrt{2/3} - sin\theta_P/\sqrt{3}\right)A_2 V_{cs}^*$
$H(D_s^+ \to \eta'\ell^+\nu_\ell)$	$\left(-sin\theta_P\sqrt{2/3} + cos\theta_P/\sqrt{3}\right)A_2 V_{cs}^*$
$H(D_s^+ \to \pi^0\ell^+\nu_\ell)$	$-\delta\left(-cos\theta_P\sqrt{2/3} - sin\theta_P/\sqrt{3}\right)A_2 V_{cs}^*$
$H(D^0 \to \pi^-\ell^+\nu_\ell)$	$A_3 V_{cd}^*$
$H(D^+ \to \pi^0\ell^+\nu_\ell)$	$-\frac{1}{\sqrt{2}}A_3 V_{cd}^*$
$H(D^+ \to \eta\ell^+\nu_\ell)$	$\left(cos\theta_P/\sqrt{6} - sin\theta_P/\sqrt{3}\right)A_3 V_{cd}^*$
$H(D^+ \to \eta'\ell^+\nu_\ell)$	$\left(sin\theta_P/\sqrt{6} + cos\theta_P/\sqrt{3}\right)A_3 V_{cd}^*$
$H(D_s^+ \to K^0\ell^+\nu_\ell)$	$A_4 V_{cd}^*$

$D \to P\ell^+\nu_\ell$衰变分支比

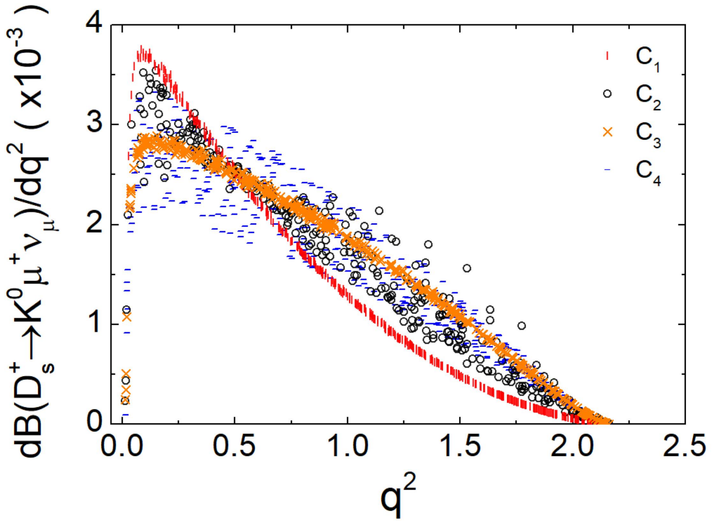
$10^{-3} \sim 10^{-5}$

Branching ratios	Exp. data	Ones in C_1	Ones in C_2	Ones in C_3	Ones in C_4	Previous ones
$\mathcal{B}(D^+ \to \overline{K}^0 e^+\nu_e)(\times 10^{-2})$	8.72 ± 0.18	8.84 ± 0.06	8.83 ± 0.07	8.84 ± 0.06	8.83 ± 0.07	
$\mathcal{B}(D^+ \to \pi^0 e^+\nu_e)(\times 10^{-3})$	3.72 ± 0.34	3.75 ± 0.05	$5.40 \pm 1.33^\dagger$	$5.04 \pm 0.12^\dagger$	3.70 ± 0.11	
$\mathcal{B}(D^+ \to \eta e^+\nu_e)(\times 10^{-3})$	1.11 ± 0.14	1.15 ± 0.05	1.20 ± 0.05	1.20 ± 0.05	0.92 ± 0.08	
$\mathcal{B}(D^+ \to \eta' e^+\nu_e)(\times 10^{-4})$	2.0 ± 0.8	2.59 ± 0.14	2.22 ± 0.34	2.09 ± 0.14	1.50 ± 0.20	
$\mathcal{B}(D^0 \to K^- e^+\nu_e)(\times 10^{-2})$	3.549 ± 0.052	3.52 ± 0.02	3.52 ± 0.03	3.52 ± 0.03	3.52 ± 0.02	
$\mathcal{B}(D^0 \to \pi^- e^+\nu_e)(\times 10^{-3})$	2.91 ± 0.08	2.95 ± 0.03	$4.23 \pm 1.03^\dagger$	$3.97 \pm 0.09^\dagger$	2.89 ± 0.06	
$\mathcal{B}(D_s^+ \to \eta e^+\nu_e)(\times 10^{-2})$	2.32 ± 0.16	2.37 ± 0.11	2.34 ± 0.14	2.36 ± 0.12	2.32 ± 0.16	
$\mathcal{B}(D_s^+ \to \eta' e^+\nu_e)(\times 10^{-3})$	8.0 ± 1.4	9.05 ± 0.04	8.25 ± 1.13	8.04 ± 0.43	8.02 ± 1.38	
$\mathcal{B}(D_s^+ \to K^0 e^+\nu_e)(\times 10^{-3})$	3.4 ± 0.8	3.10 ± 0.08	3.56 ± 0.39	3.54 ± 0.12	3.40 ± 0.80	
$\mathcal{B}(D_s^+ \to \pi^0 e^+\nu_e)(\times 10^{-5})$	...	1.51 ± 0.07	2.10 ± 0.56	1.96 ± 0.10	1.92 ± 0.13	2.65 ± 0.38 [76]
$\mathcal{B}(D^+ \to \overline{K}^0 \mu^+\nu_\mu)(\times 10^{-2})$	8.76 ± 0.38	8.56 ± 0.06	8.69 ± 0.15	8.61 ± 0.06	8.61 ± 0.06	
$\mathcal{B}(D^+ \to \pi^0 \mu^+\nu_\mu)(\times 10^{-3})$	3.50 ± 0.30	3.67 ± 0.05	$5.32 \pm 1.31^\dagger$	$4.96 \pm 0.12^\dagger$	3.64 ± 0.10	
$\mathcal{B}(D^+ \to \eta \mu^+\nu_\mu)(\times 10^{-3})$	1.04 ± 0.22	1.11 ± 0.05	1.18 ± 0.07	1.17 ± 0.05	0.90 ± 0.08	1.21 [7] 0.75 ± 0.15 [79]
$\mathcal{B}(D^+ \to \eta' \mu^+\nu_\mu)(\times 10^{-4})$	...	2.42 ± 0.13	2.10 ± 0.33	1.96 ± 0.13	1.41 ± 0.19	2.11 [7] 1.06 ± 0.20 [79]
$\mathcal{B}(D^0 \to K^- \mu^+\nu_\mu)(\times 10^{-2})$	3.41 ± 0.08	3.41 ± 0.02	3.44 ± 0.05	3.43 ± 0.02	3.43 ± 0.02	
$\mathcal{B}(D^0 \to \pi^- \mu^+\nu_\mu)(\times 10^{-3})$	2.67 ± 0.24	2.89 ± 0.02	$4.17 \pm 1.01^\dagger$	$3.90 \pm 0.09^\dagger$	2.85 ± 0.06	
$\mathcal{B}(D_s^+ \to \eta \mu^+\nu_\mu)(\times 10^{-2})$	2.4 ± 1.0	2.30 ± 0.10	2.30 ± 0.17	2.31 ± 0.12	2.26 ± 0.16	
$\mathcal{B}(D_s^+ \to \eta' \mu^+\nu_\mu)(\times 10^{-2})$	1.1 ± 1.0	0.86 ± 0.03	0.79 ± 0.11	0.77 ± 0.04	0.76 ± 0.13	
$\mathcal{B}(D_s^+ \to K^0 \mu^+\nu_\mu)(\times 10^{-3})$	...	3.01 ± 0.08	3.51 ± 0.38	3.46 ± 0.11	3.33 ± 0.78	3.9 [7] 3.85 ± 0.76 [79]
$\mathcal{B}(D_s^+ \to \pi^0 \mu^+\nu_\mu)(\times 10^{-5})$	...	1.48 ± 0.07	2.09 ± 0.53	1.93 ± 0.10	1.89 ± 0.13	
$\mathcal{B}(D_s^+ \to \pi^0 \tau^+\nu_\tau)(\times 10^{-10})$	...	3.45 ± 0.21	160.34 ± 149.53	4.20 ± 0.26	4.08 ± 0.34	$(27 \sim 36)$ [76]

D → $P\ell^+\nu_\ell$分支比对q2的依赖关系



(a)



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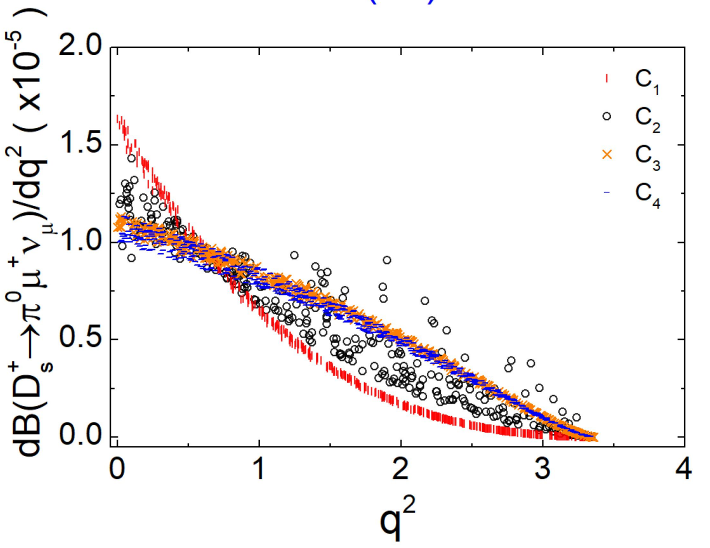
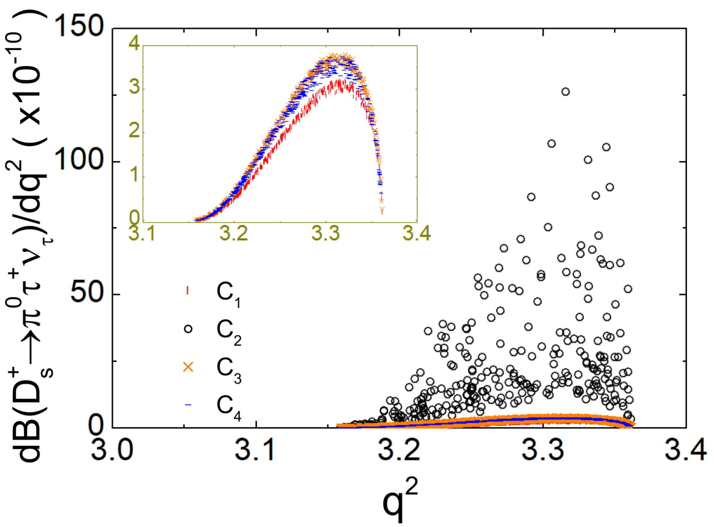


(c)



(d)

C_1 红色
C_2 黑色
C_3 黄色
C_4 蓝色

(a) $D^+ \to \eta'\mu^+\nu_\mu$

(b) $D^+_s \to K^0\mu^+\nu_\mu$

(c) $D^+_s \to \pi^0\mu^+\nu_\mu$

(d) $D^+_s \to \pi^0\tau^+\nu_\tau$

$D \to A\ell^+\nu_\ell$衰变振幅

$A = c_0^A,\ B = c_0^B$

TABLE II: The hadronic helicity amplitudes for the $D \to A\ell^+\nu$ decays including both the SU(3) flavor symmetry and the SU(3) flavor breaking contributions. $A_1 \equiv c_0^A + c_1^A - 2c_2^A$, $A_2 \equiv c_0^A - 2c_1^A - 2c_2^A$, $A_3 \equiv c_0^A + c_1^A + c_2^A$, $A_4 \equiv c_0^A - 2c_1^A + c_2^A$. $B_1 \equiv c_0^B + c_1^B - 2c_2^A$, $B_2 \equiv c_0^B - 2c_1^B - 2c_2^B$, $B_3 \equiv c_0^B + c_1^B + c_2^B$, $B_4 \equiv c_0^B - 2c_1^B + c_2^B$. $A_1 = A_2 = A_3 = A_4 = c_0^A$, $B_1 = B_2 = B_3 = B_4 = c_0^B$ if neglecting the SU(3) flavor breaking c_1^A, c_2^A and c_1^B, c_2^B terms.

Decay modes	SU(3) hadronic amplitudes	Decay modes	SU(3) hadronic amplitudes
$D^0 \to K_1(1270)^-\ell^+\nu_\ell$	$(sin\theta_{K_1}A_1 + cos\theta_{K_1}B_1)\ V_{cs}^*$	$D^0 \to K_1(1400)^-\ell^+\nu_\ell$	$(cos\theta_{K_1}A_1 - sin\theta_{K_1}B_1)\ V_{cs}^*$
$D^+ \to \overline{K}_1(1270)^0\ell^+\nu_\ell$	$(sin\theta_{K_1}A_1 + cos\theta_{K_1}B_1)\ V_{cs}^*$	$D^+ \to \overline{K}_1(1400)^0\ell^+\nu_\ell$	$(cos\theta_{K_1}A_1 - sin\theta_{K_1}B_1)\ V_{cs}^*$
$D_s^+ \to f_1(1285)\ell^+\nu_\ell$	$(\frac{1}{\sqrt{3}}cos\theta_{3P_1} - \sqrt{\frac{2}{3}}sin\theta_{3P_1})\ A_2\ V_{cs}^*$	$D_s^+ \to f_1(1420)\ell^+\nu_\ell$	$(-\frac{1}{\sqrt{3}}sin\theta_{3P_1} - \sqrt{\frac{2}{3}}cos\theta_{3P_1})\ A_2\ V_{cs}^*$
$D_s^+ \to h_1(1170)\ell^+\nu_\ell$	$(\frac{1}{\sqrt{3}}cos\theta_{1P_1} - \sqrt{\frac{2}{3}}sin\theta_{1P_1})\ B_2\ V_{cs}^*$	$D_s^+ \to h_1(1415)\ell^+\nu_\ell$	$(-\frac{1}{\sqrt{3}}sin\theta_{1P_1} - \sqrt{\frac{2}{3}}cos\theta_{1P_1})\ B_2\ V_{cs}^*$
$D^0 \to a_1(1260)^-\ell^+\nu_\ell$	$A_3\ V_{cd}^*$	$D^0 \to b_1(1235)^-\ell^+\nu_\ell$	$B_3\ V_{cd}^*$
$D^+ \to a_1(1260)^0\ell^+\nu_\ell$	$-\frac{1}{\sqrt{2}}\ A_3\ V_{cd}^*$	$D^+ \to b_1(1235)^0\ell^+\nu_\ell$	$-\frac{1}{\sqrt{2}}\ B_3\ V_{cd}^*$
$D^+ \to f_1(1285)\ell^+\nu_\ell$	$(\frac{1}{\sqrt{3}}cos\theta_{3P_1} + \frac{1}{\sqrt{6}}sin\theta_{3P_1})\ A_3\ V_{cd}^*$	$D^+ \to f_1(1420)\ell^+\nu_\ell$	$(-\frac{1}{\sqrt{3}}sin\theta_{3P_1} + \frac{1}{\sqrt{6}}cos\theta_{3P_1})\ A_3\ V_{cd}^*$
$D^+ \to h_1(1170)\ell^+\nu_\ell$	$(\frac{1}{\sqrt{3}}cos\theta_{1P_1} + \frac{1}{\sqrt{6}}sin\theta_{1P_1})\ B_3\ V_{cd}^*$	$D^+ \to h_1(1415)\ell^+\nu_\ell$	$(-\frac{1}{\sqrt{3}}sin\theta_{1P_1} + \frac{1}{\sqrt{6}}cos\theta_{1P_1})\ B_3\ V_{cd}^*$
$D_s^+ \to K_1(1270)^0\ell^+\nu_\ell)$	$(sin\theta_{K_1}A_4 + cos\theta_{K_1}B_4)\ V_{cd}^*$	$D_s^+ \to K_1(1400)^0\ell^+\nu_\ell)$	$(cos\theta_{K_1}A_4 - sin\theta_{K_1}B_4)\ V_{cd}^*$

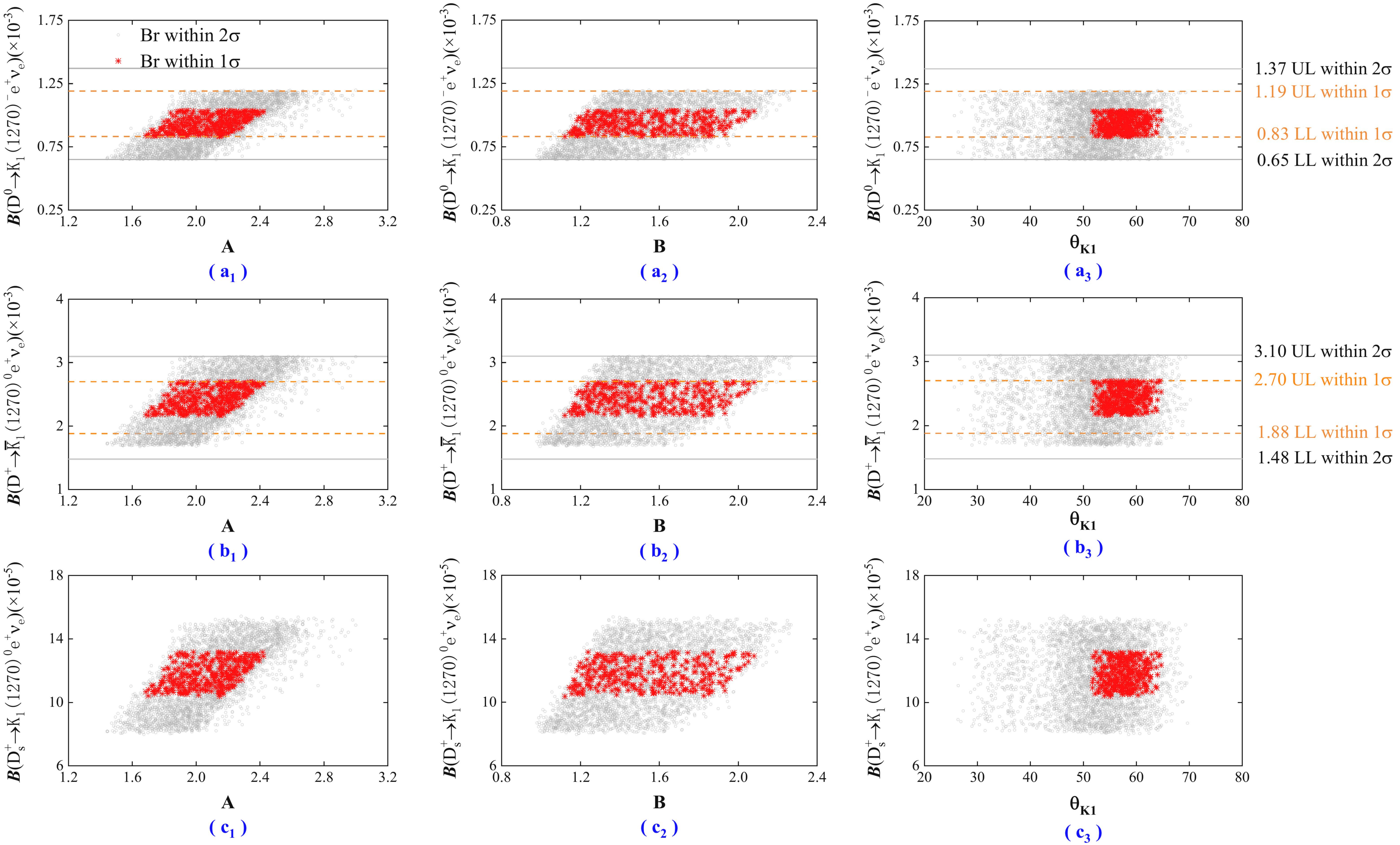
$D \to Ae^+\nu_e$衰变分支比

$$\mathcal{B}(D^+ \to b_1(1235)^0 e^+\nu_e,\ b_1(1235)^0 \to \omega\pi^0) \leq 1.75 \times 10^{-4},$$

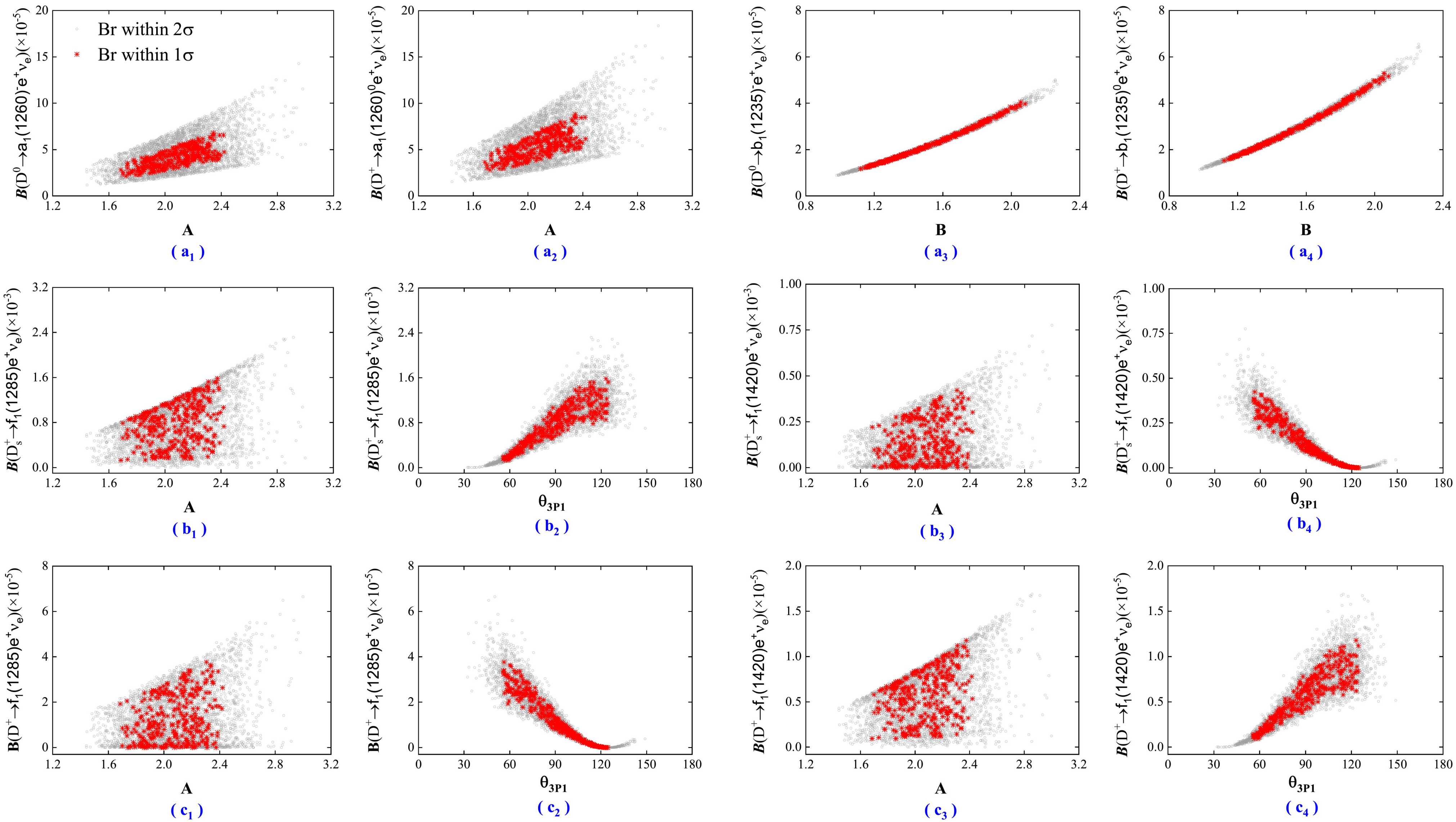
$$\mathcal{B}(D^0 \to b_1(1235)^- e^+\nu_e,\ b_1(1235)^- \to \omega\pi^-) \leq 1.12 \times 10^{-4}.$$

Branching ratios	Ones within 1σ error	Ones within 2σ error	Previous results
$\mathcal{B}(D^0 \to K_1(1270)^- e^+\nu_e)(\times 10^{-3})$	0.93 ± 0.10	0.92 ± 0.27	$\cdots$
$\mathcal{B}(D^0 \to K_1(1400)^- e^+\nu_e)(\times 10^{-3})$	0.02 ± 0.02	0.08 ± 0.08	$\cdots$
$\mathcal{B}(D^+ \to \overline{K}_1(1270)^0 e^+\nu_e)(\times 10^{-3})$	2.43 ± 0.27	2.39 ± 0.71	3.2 ± 0.40 [43]
$\mathcal{B}(D^+ \to \overline{K}_1(1400)^0 e^+\nu_e)(\times 10^{-3})$	0.05 ± 0.05	0.20 ± 0.20	$\{0.005, 0.02\}$ [43]
$\mathcal{B}(D_s^+ \to f_1(1285) e^+\nu_e)(\times 10^{-3})$	0.86 ± 0.73	1.16 ± 1.16	$\{0.06, 0.36\}$ [43]
$\mathcal{B}(D_s^+ \to f_1(1420) e^+\nu_e)(\times 10^{-3})$	0.21 ± 0.21	0.39 ± 0.39	0.25 ± 0.05 [43]
$\mathcal{B}(D_s^+ \to h_1(1170) e^+\nu_e)(\times 10^{-3})$	0.26 ± 0.26	0.43 ± 0.43	$\{0, 0.197\}$ [43]
$\mathcal{B}(D_s^+ \to h_1(1415) e^+\nu_e)(\times 10^{-3})$	0.28 ± 0.16	0.31 ± 0.24	0.64 ± 0.07 [43]
$\mathcal{B}(D^0 \to a_1(1260)^- e^+\nu_e)(\times 10^{-5})$	4.46 ± 2.32	7.72 ± 6.54	6.90 [40], $5.261^{+0.745}_{-0.639}$ [39]
$\mathcal{B}(D^0 \to b_1(1235)^- e^+\nu_e)(\times 10^{-5})$	2.61 ± 1.44	2.95 ± 2.06	4.85 [40]
$\mathcal{B}(D^+ \to a_1(1260)^0 e^+\nu_e)(\times 10^{-5})$	5.79 ± 3.00	9.95 ± 8.41	9.38 [40], $6.673^{+0.947}_{-0.811}$ [39]
$\mathcal{B}(D^+ \to b_1(1235)^0 e^+\nu_e)(\times 10^{-5})$	3.41 ± 1.88	3.84 ± 2.71	7.4 ± 0.70 [43], 6.58 [40]
$\mathcal{B}(D^+ \to f_1(1285) e^+\nu_e)(\times 10^{-5})$	1.88 ± 1.88	3.33 ± 3.33	3.7 ± 0.80 [43]
$\mathcal{B}(D^+ \to f_1(1420) e^+\nu_e)(\times 10^{-5})$	0.64 ± 0.54	0.84 ± 0.84	$\{0.02, 0.14\}$ [43]
$\mathcal{B}(D^+ \to h_1(1170) e^+\nu_e)(\times 10^{-5})$	5.28 ± 3.00	5.59 ± 4.50	14 ± 1.50 [43]
$\mathcal{B}(D^+ \to h_1(1415) e^+\nu_e)(\times 10^{-5})$	0.11 ± 0.11	0.18 ± 0.18	$\{0, 0.02\}$ [43]
$\mathcal{B}(D_s^+ \to K_1(1270)^0 e^+\nu_e)(\times 10^{-5})$	11.77 ± 1.39	11.70 ± 3.73	17 ± 2.00 [43]
$\mathcal{B}(D_s^+ \to K_1(1400)^0 e^+\nu_e)(\times 10^{-5})$	0.32 ± 0.32	1.17 ± 1.17	$\{0.05, 0.14\}$ [43]

D → Aℓ⁺ν_ℓ对参数变化的敏感度



$D\to Ae^+\nu_e$数值分析



预言 θ_{3P1}：

[55°,125°] 1σ

[30°,145°] 2σ

预言θ_{1P1}：

[8°,58°] 1σ

[-10°,75°] 2σ

目 录

总结与展望

- 用SU(3)味对称方法研究D介子半轻三体衰变；
- 预言了一些实验上尚未观测到的衰变过程，并且有一些衰变过程是首次预言的；
- 我们的预言结果未来有可能在BESIII, LHCb 和BelleII上观测到；

谢 谢！