粲介子含轻衰变

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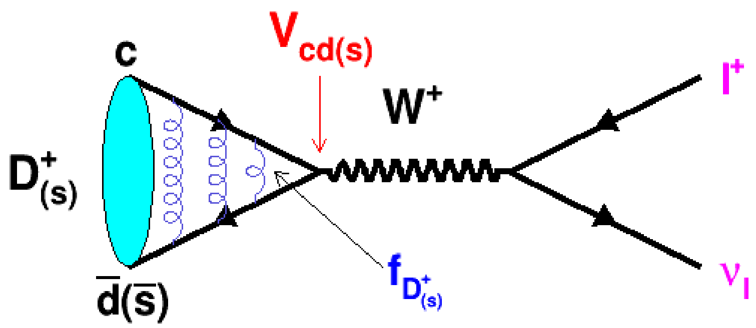
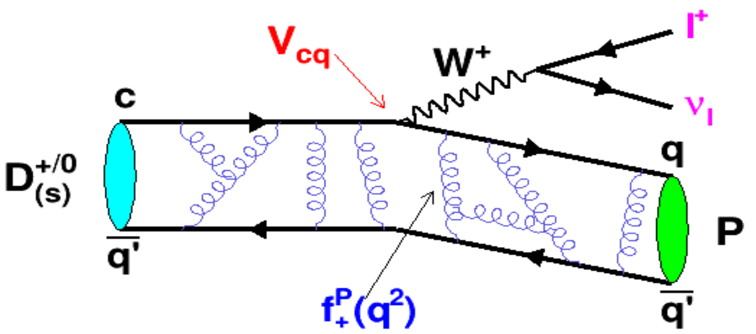
Main contents

- Introduction
- Data samples
- Leptonic D decays
- Semileptonic D decays
- Summary

(Semi)leptonic *D* decays

探讨夸克和轻子相互作用的理想桥梁，检验标准模型的理想探针之一





$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+_{(s)}}^2}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m_{D^+_{(s)}}^2}\right)^2$$

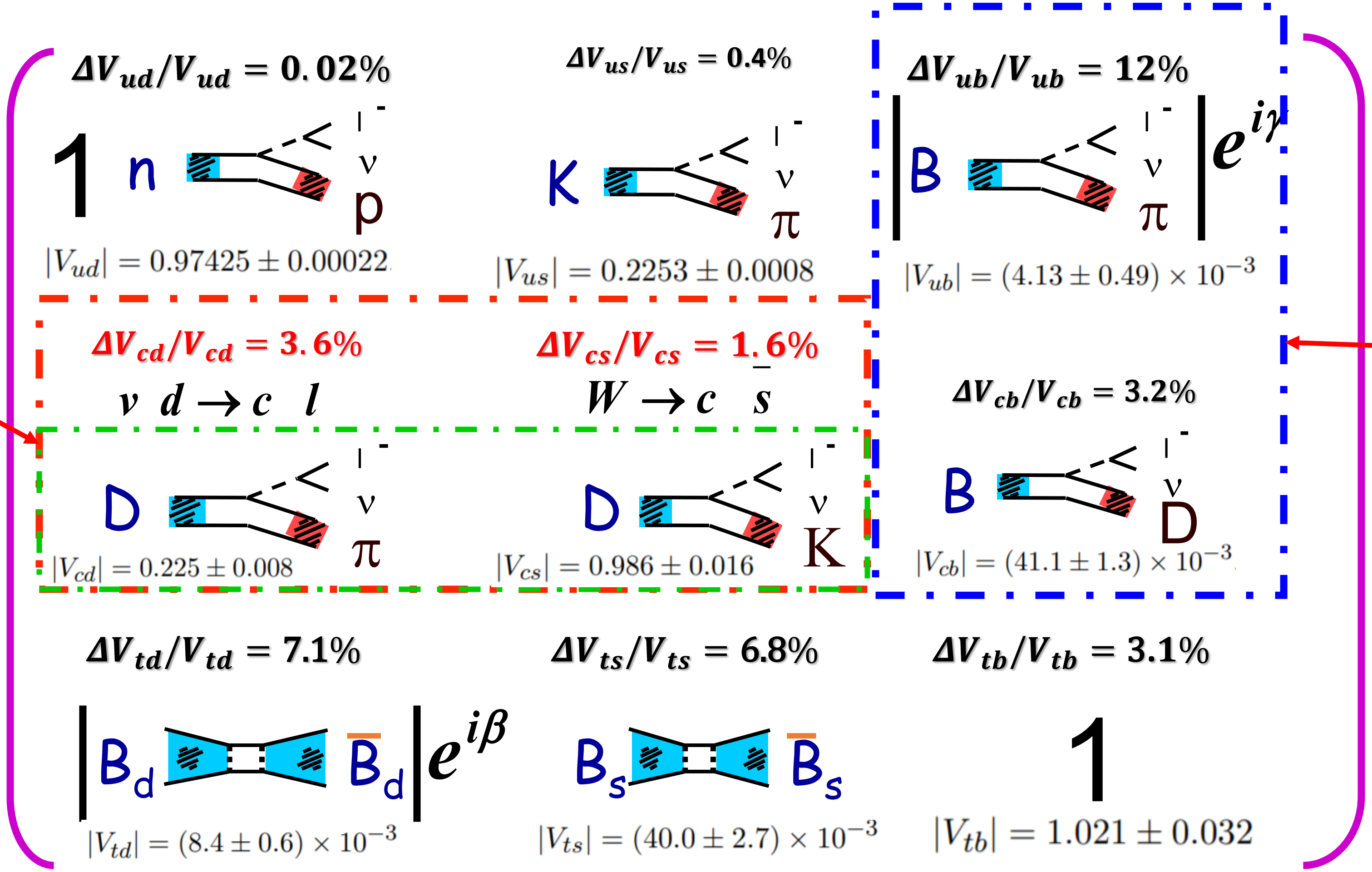
$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

- 衰变常数、半轻衰变形状因子 →精密刻度格点QCD等计算
- CKM矩阵元$|V_{cs}|$、$|V_{cd}|$ →在更高精度下检验CKM矩阵的幺正性
- 分支比之比$B_{\mu/e}$、$B_{\tau/\mu}$ →精确检验轻子普适性

$|V_{cs(d)}|$ measurements before BESIII

PDG2014

Direct measurement: (semi)leptonic D decays



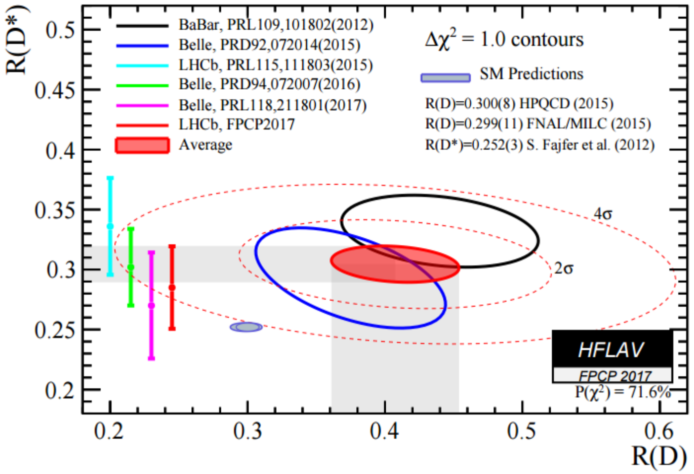
Indirect constraint: Hadronic D decays

V_{ud}, V_{us} and V_{cb} are the best determined due to flavor symmetries: I, SU(3), HQS. Charm (V_{cd} & V_{cs}) and rest of the beauty sector (V_{ub}, V_{td}, V_{ts}) are poorly determined. Theoretical errors on hadronic matrix element dominate.

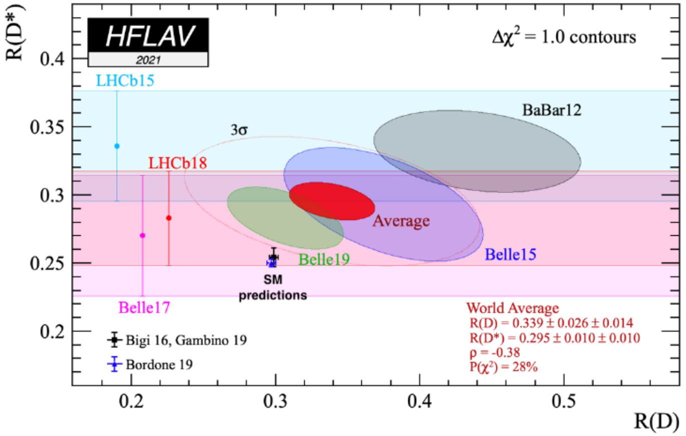
LFU tests in semileptonic D decays before BESIII

Tension in B physics

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\,\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\,l\,\nu_l)}$$



3.9σ



3.3σ

Tension in D physics

$$\mathrm{B}^{\mathrm{PDG18}}[D^0 \to \pi^-\mu^+\nu] = (0.237 \pm 0.024)\%$$

$$\frac{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^-\mu^+\nu]}{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^- e^+\nu]} = 0.82 \pm 0.08$$

(2.1σ)

SM prediction: 0.985

The knowledge of semimuonic charm meson decays is very poor

	D^0		D^+		D_s^+	
$c \to sl^+\nu$	K^-	4%[Belle]	$\bar{K}^0$	7%[FOCUS]	η	NA
	K^{*-}	13%[FOCUS]	$\bar{K}^{*0}$	3%[CLEOc]	η'	NA
	K_1^-	NA	$\bar{K}_1^0$	NA	ϕ	NA
	b_1^-	NA	b_1^0	NA	f_0	NA
$c \to dl^+\nu$	π^-	10%[Belle]	π^0	NA	K^0	NA
	ρ^-	NA	ρ^0	17%[FOCUS]	K^{*0}	NA
			f_0	NA		
			ω	NA		
			η	NA		
			η'	NA		

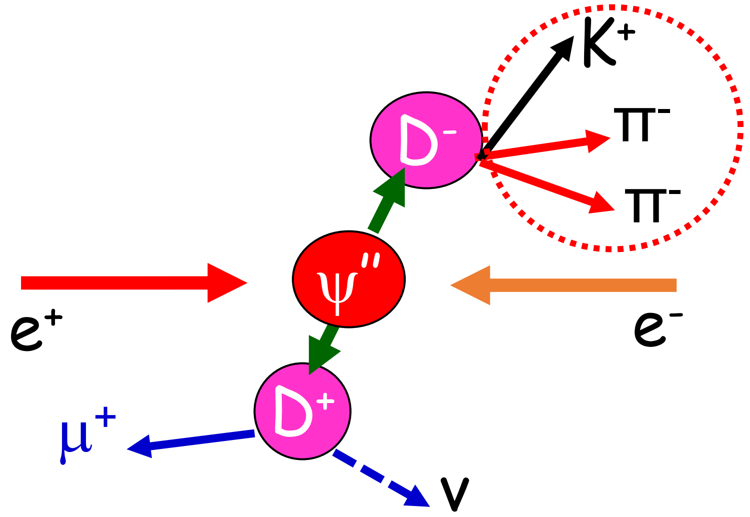
Data samples at BESIII

2009: 106M $\psi(3686)$
225M J/ψ
2010: 0.98 fb^{-1} $\psi(3770)$
2011: 2.93 fb^{-1} $\psi(3770)$ ($D^{0(+)}$, total)
0.48 fb^{-1} @4.01 GeV
2012: 0.45B $\psi(3686)$ (total)
1.30B J/ψ (total)
2013: 1.09 fb^{-1} @4.23 GeV (XYZ&D_s^+)
0.83 fb^{-1} @4.26 GeV
0.54 fb^{-1} @4.36 GeV
10×0.05 fb^{-1} XYZ scan@3.81-4.42 GeV
2014: 1.03 fb^{-1} @4.42 GeV
0.11 fb^{-1} @4.47 GeV
0.11 fb^{-1} @4.53 GeV
0.05 fb^{-1} @4.575 GeV
0.57 fb^{-1} @4.60 GeV (XYZ&Λ_c^+)
0.80 fb^{-1} R scan @3.85-4.59 GeV
2009: 106M $\psi(3686)$
2015: R-scan 2-3 GeV+2.175 GeV

2016: 3.20 fb^{-1} @4.178 GeV (XYZ&D_s^+)
2017: 7×0.50 fb^{-1} @4.19-4.22 GeV (XYZ&D_s^+),
@4.24-4.27 (XYZ)
2018: More J/ψ+tuning new RF cavity
2019: 10B J/ψ (total)
8×0.50 fb^{-1} XYZ scan@4.13, 4.16 (XYZ&D_s^+),
4.29-4.44 GeV
2020: 3.8 fb^{-1} @ 4.61-4.7 GeV (XYZ&Λ_c^+)
2021: 2.0 fb^{-1} @ 4.74-4.946 GeV
2.7B $\psi(3686)$ (total)
2022: 0.4 fb^{-1} @3.650 GeV
0.4 fb^{-1} @3.682 GeV
2.9→7.9 fb^{-1} $\psi(3770)$ ($D^{0(+)}$, total)
2023-2024: 7.9→20.3 fb^{-1} $\psi(3770)$ ($D^{0(+)}$, total)
2×0.42 fb^{-1} $\psi(3770)$ scan
0.14 fb^{-1} @3.800-3.885 GeV
0.13 fb^{-1} @3.554 GeV
0.025 fb^{-1} @1.84-2.00 GeV

>50 fb^{-1} at E_{cm} between 1.84 and 4.95 GeV in 15 year running

The world largest threshold charmed mesons at BESIII



Produced in pair → Double tag method
Low background → low systematic uncertainties
Quantum correlation for $\psi(3770) \to D^0\bar{D}^0$ pairs

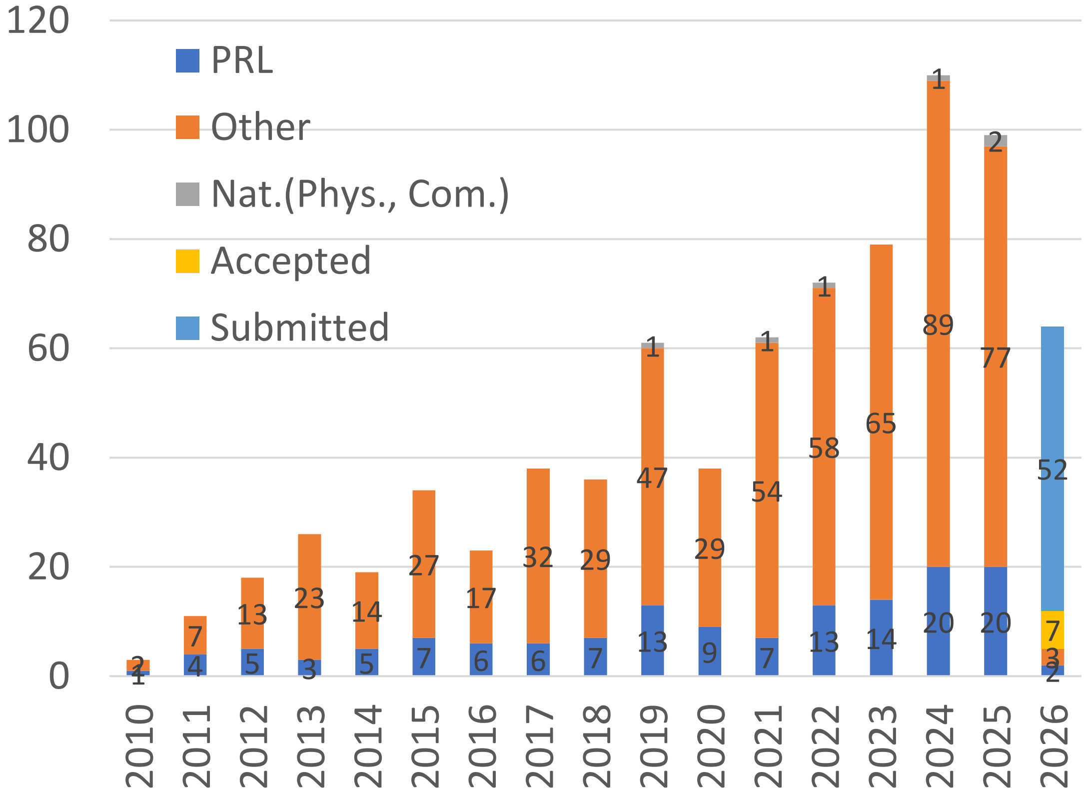
Yields of Singly Tagged (ST) charmed hadrons

E_{cm} (GeV)	Data taking year	L (fb^{-1})	ST D^0 yield	ST D^+ Yield	ST D_s^+ yield
3.773	2010-11 (+2022, 23, 24)	2.9 (→7.9→20.3)	2.7M (~7×)	1.7M (~7×)	
4.13-4.23	2016 (+2017, 2012, 2019)	3.2 (→6.3, 7.3)			0.8M

Total yields of various charmed hadrons at BESIII are lower than Belle and LHCb by 2-3 orders.
However, BESIII, Belle and LHCb have complimentary advantages in various charm physics

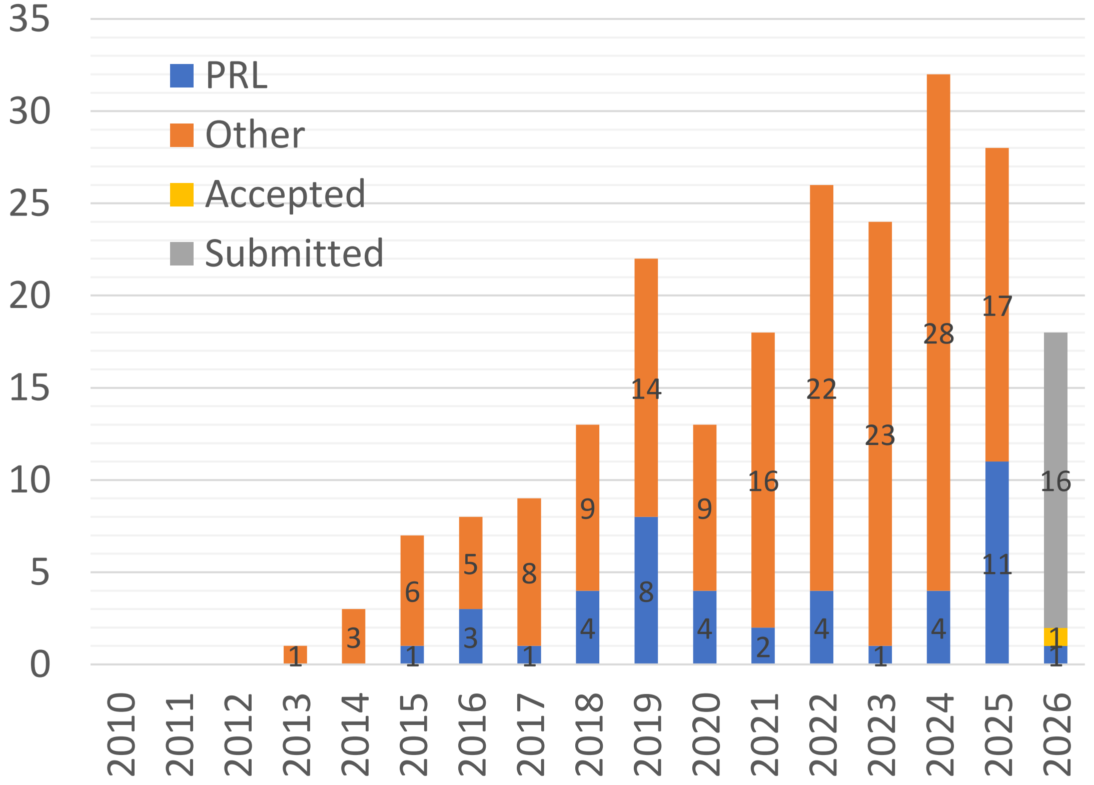
Publications of BESIII (as of Feb. 06 2026)

BESIII physics



793 papers and 141 in PRL

Charm hadron physics at BESIII



222 papers and 44 in PRL

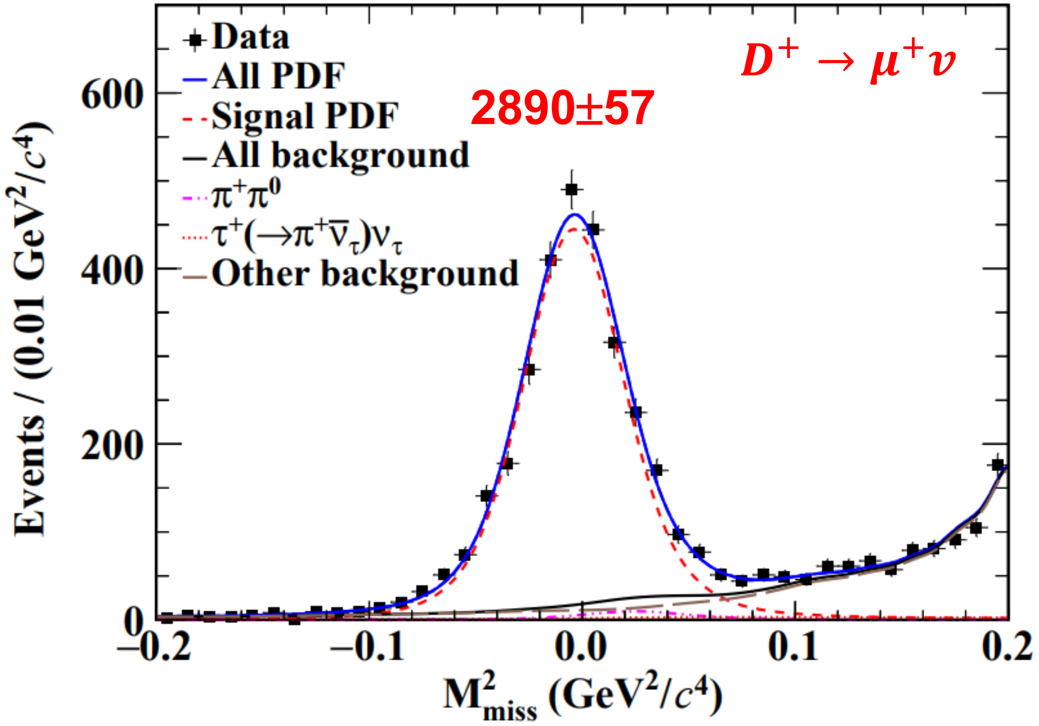
粲介子含轻: 72 papers and 21 in PRL

Leptonic D decays

Precision measurements of $D^+ \to l^+\nu_l$ and LFU test

PRD89(2014)051104, 2.93 fb^{-1}@3.773 GeV

PRL135(2025)061801, 20.3 fb^{-1}@3.773 GeV



The most precise to date

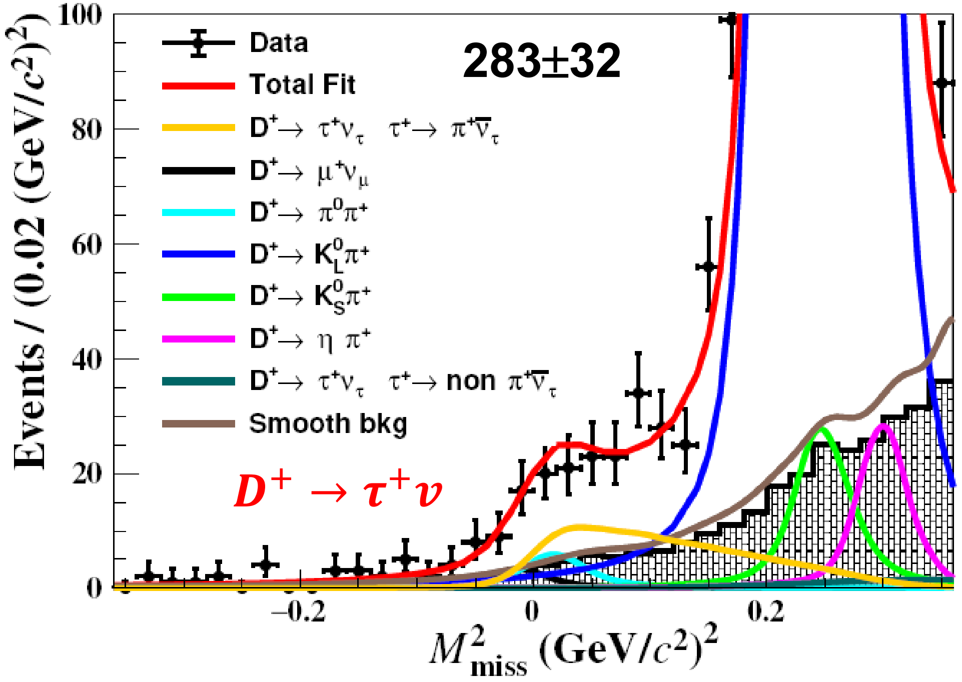
$B[D^+ \to \mu^+ v] = (4.03 \pm 0.08 \pm 0.04) \times 10^{-4}$

$f_{D^+}|V_{cd}| = 48.52 \pm 0.48 \pm 0.19$ MeV

Precision~1.2%

PRL123(2019)211802, 2.93 fb^{-1}@3.773 GeV

JHEP01(2025)089, 7.9 fb^{-1}@3.773 GeV



$B[D^+ \to \tau^+ v] = (9.1 \pm 1.1 \pm 0.5) \times 10^{-4}$

$f_{D^+}|V_{cd}| = 45.9 \pm 2.5 \pm 1.2$ MeV

Precision~5.5%

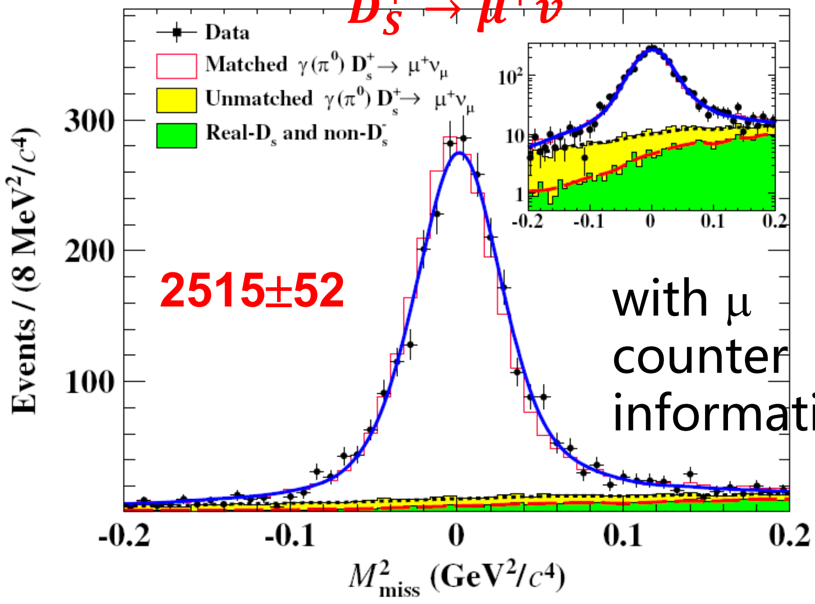
$$R_D = \frac{B[D^+ \to \tau^+ v]}{B[D^+ \to \mu^+ v]} = 2.49 \pm 0.31$$

SM prediction: 2.67

Precision measurements of $D_s^+ \to l^+ \nu_l$ and LFU test

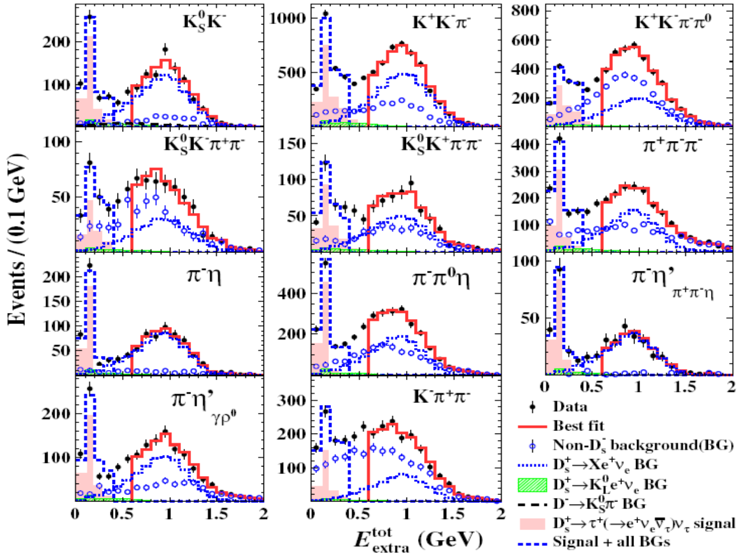
PRL122(2019)071802, 3.19 fb^{-1}@4.18 GeV
PRD104(2021)052009, 6.3 fb^{-1}@4.18-4.23GeV
PRD108(2023)112001, 7.33 fb^{-1}@4.18-4.23GeV

$D_s^+ \to \mu^+ \nu$



$D_s^+ \to \tau^+(e^+\nu\nu)\nu$

PRL127(2021)171801, 6.3 fb^{-1}@4.18-4.23GeV



4940±97

PRD108(2023)092014, PRD104(2021)032001, JHEP09(2023)124

$D_s^+ \to \tau^+(\pi^+\nu)\nu$,
$D_s^+ \to \tau^+(\rho^+\nu)\nu$,
$D_s^+ \to \tau^+(\mu^+\nu\nu)\nu$

The most precise to date

$$B[D_s^+ \to \mu^+ \nu] = (5.29 \pm 0.11 \pm 0.09) \times 10^{-3}$$

$$f_{D_s^+}|V_{cs}| = (241.8 \pm 2.5 \pm 2.2)\ \text{MeV}$$

Precision~1.4%

The most precise to date

$$B[D_s^+ \to \tau^+ \nu] = (5.27 \pm 0.10 \pm 0.12)\%$$

$$f_{D_s^+}|V_{cs}| = (244.4 \pm 2.3 \pm 2.9)\ \text{MeV}$$

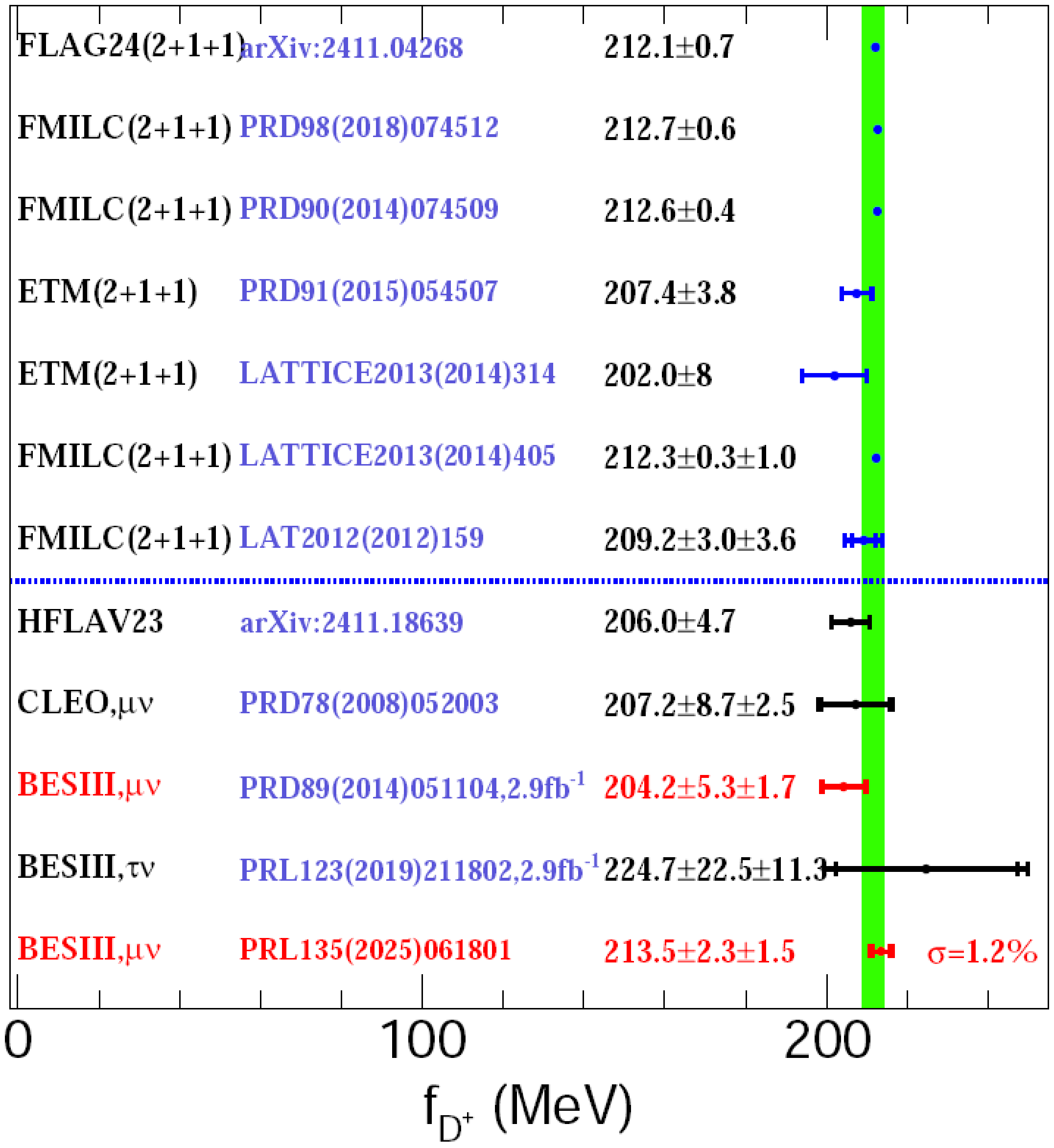
Precision~1.5%

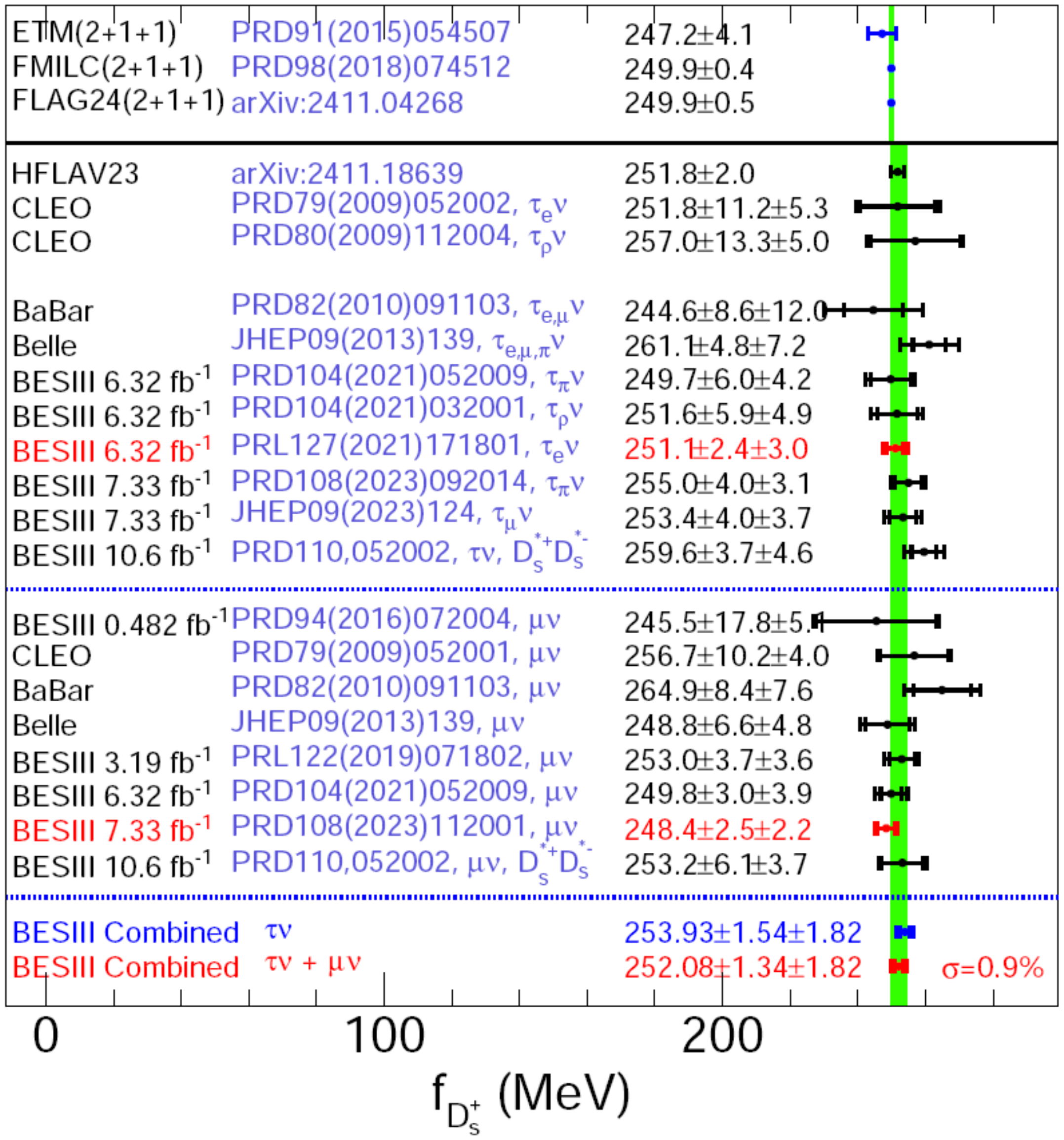
$$B^{\rm BESIII}[D_s^+ \to \tau^+ \nu] = (5.32 \pm 0.07 \pm 0.07)\%$$

$$R_{Ds} = \frac{B[D_s^+ \to \tau^+ \nu]}{B[D_s^+ \to \mu^+ \nu]} = 10.05 \pm 0.35$$

SM prediction: 9.75

Comparisons of f_{D^+} and $f_{D_s^+}$

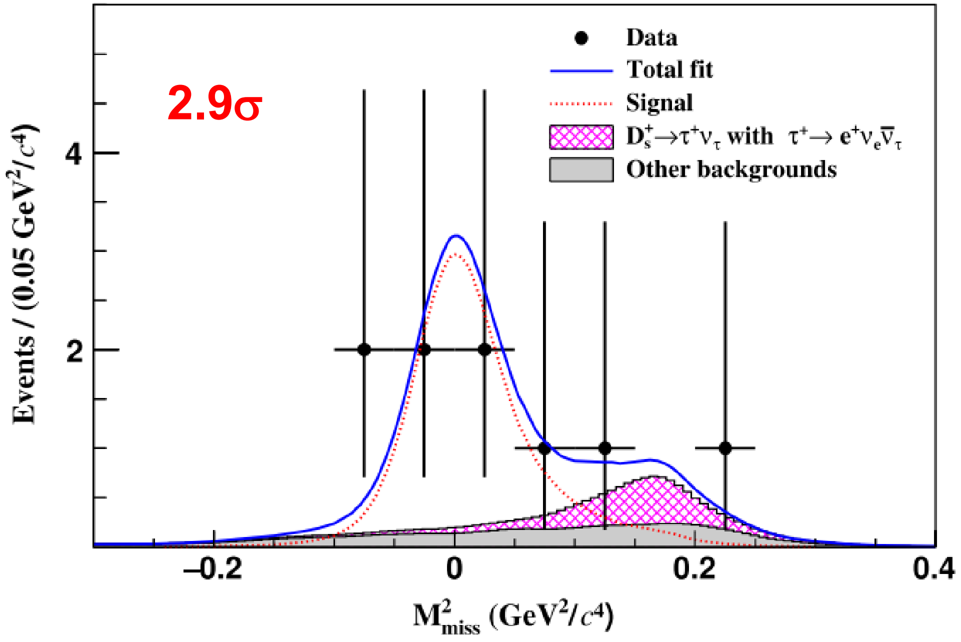




First experimental study of $D_s^{*+} \to e^+\nu_e$

PRL131 (2023) 141802

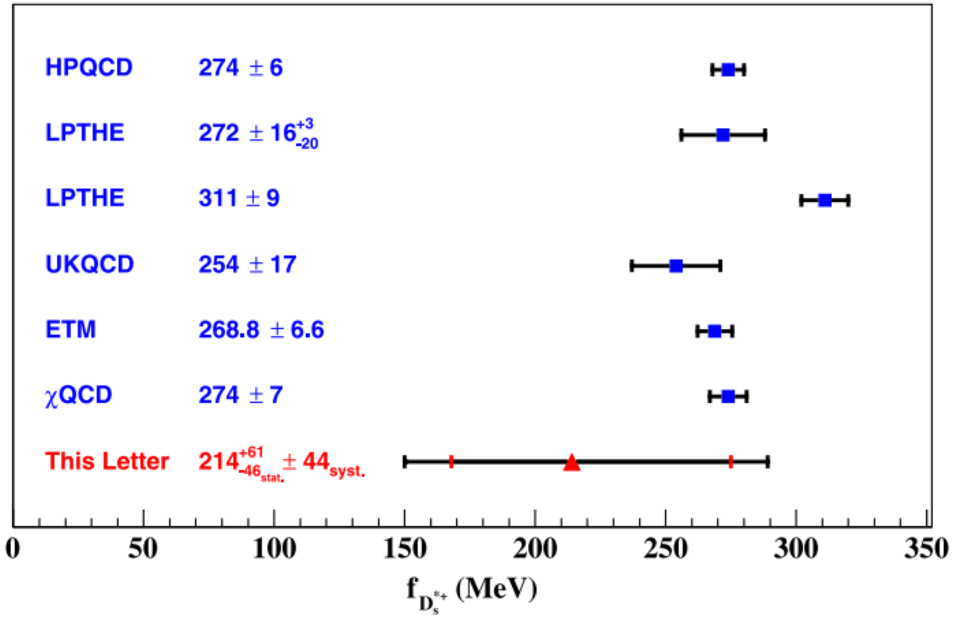
7.33 fb^{-1}@4.13-4.23 GeV



$$\mathcal{B}(D_s^{*+} \to e^+\nu_e) = (2.1^{+1.2}_{-0.9\,\text{stat}} \pm 0.2_{\text{syst}}) \times 10^{-5}$$

$$\Gamma(D_s^{*+} \to \ell^+\nu_\ell) = \frac{G_F^2}{12\pi}|V_{cs}|^2 f^2_{D_s^{*+}} m^3_{D_s^{*+}} \left(1 - \frac{m^2_{\ell^+}}{m^2_{D_s^{*+}}}\right)^2 \times \left(1 + \frac{m^2_{\ell^+}}{2m^2_{D_s^{*+}}}\right),$$

联合格点QCD计算的D_s^{*+}总宽度，首次抽取D_s^{*+}衰变常数



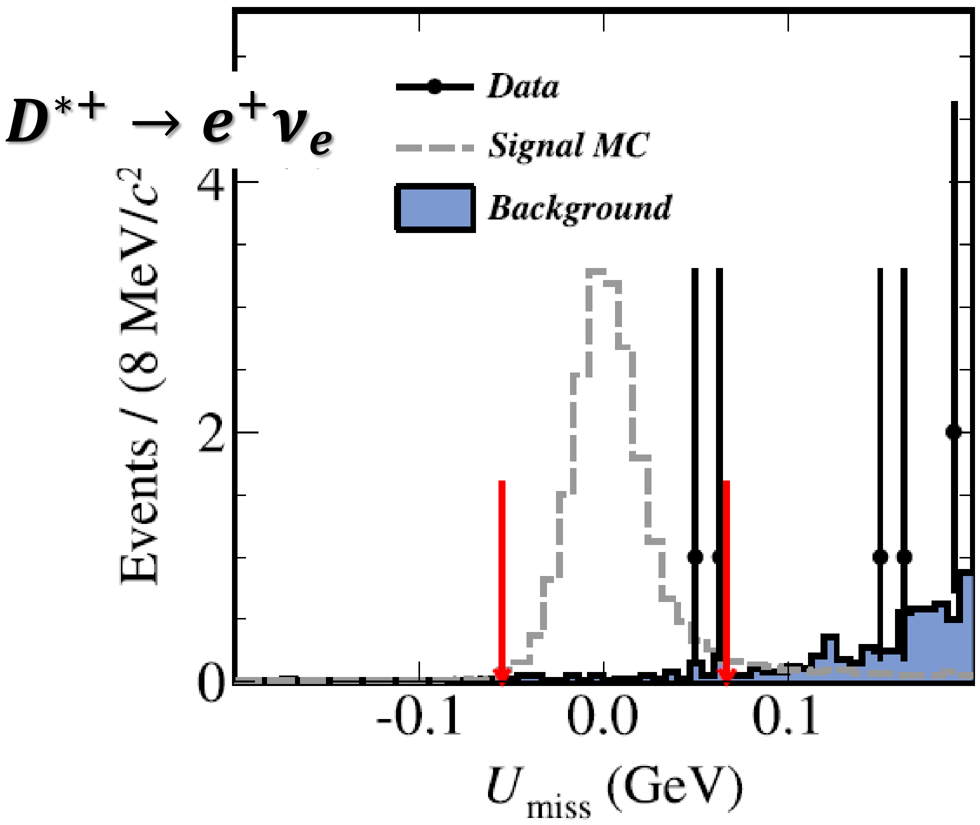
→ 为约束格点QCD计算的D_s^{*+}衰变常数首次提供实验依据

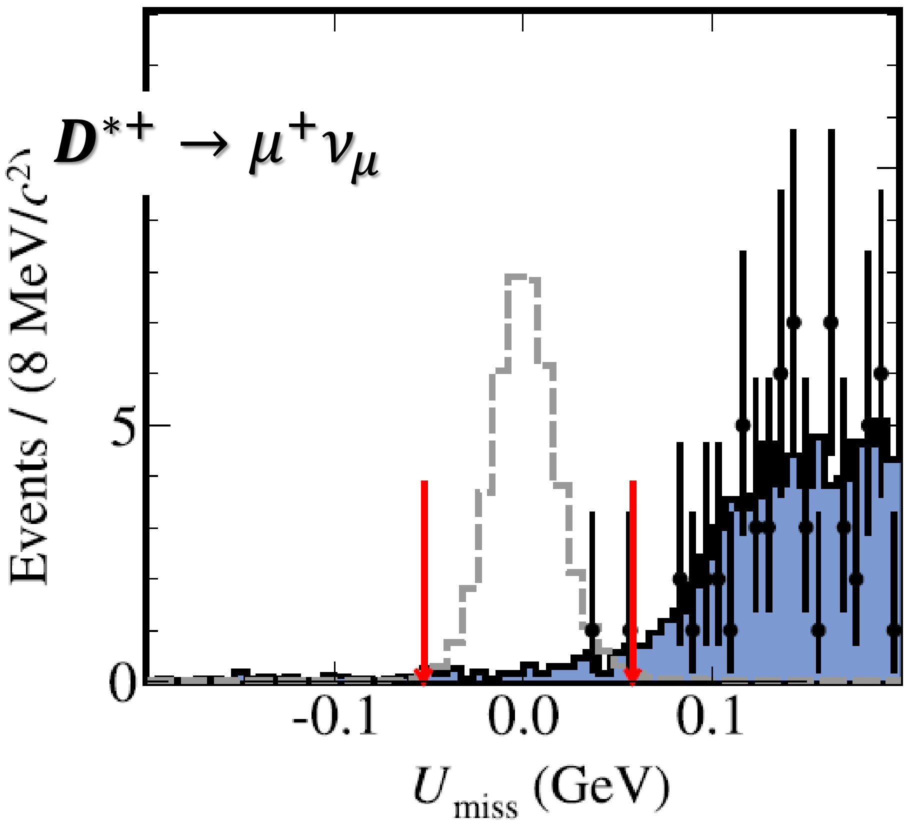
→ 对D_s^{*+}宽度上限的约束改进3个量级

Search for $D^{*+} \to l^+ \nu_l$

6.3 fb^{-1}@4.18-4.23 GeV

PRD110 (2024) 012003





$B[D^{*+} \to e^+ v] < 1.1 \times 10^{-5}$

$B[D^{*+} \to \mu^+ v] < 4.3 \times 10^{-6}$

@90% CL

(Semi)leptonic D decays

- Semileptonic decays of $D \to P/S/V/Ae^+\nu_e$

$D \to P/Sl^+\nu_l$半轻衰变的研究

Dynamic study

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2 \longrightarrow f_+^{D\to P/S}(0)|V_{cs(d)}|$$

Form factor parameterizations:

– Single pole form $$f_+(q^2) = \frac{f_+(0)}{1-\frac{q^2}{M^2_{\rm pole}}}$$

– Modified pole $$f_+(q^2) = \frac{f_+(0)}{(1-\frac{q^2}{M^2_{\rm pole}})(1-\alpha\frac{q^2}{M^2_{\rm pole}})}$$

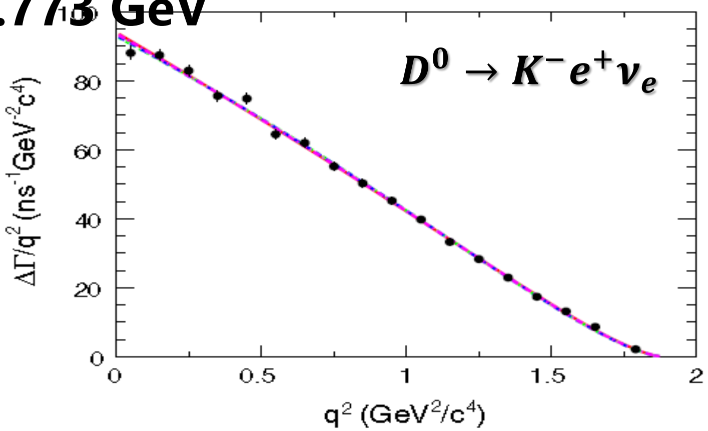
– ISGW2 $$f_+(q^2) = f_+(q^2_{\rm max})\left(1+\frac{r^2_{\rm ISGW2}}{12}(q^2_{\rm max}-q^2)\right)^{-2}$$

– Series expansion $$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)}a_0(t_0)\left(1+\sum_{k=1}^{\infty}r_k(t_0)[z(t,t_0)]^k\right)$$

Studies of $c \to s l^+ \nu_l$ semileptonic decays

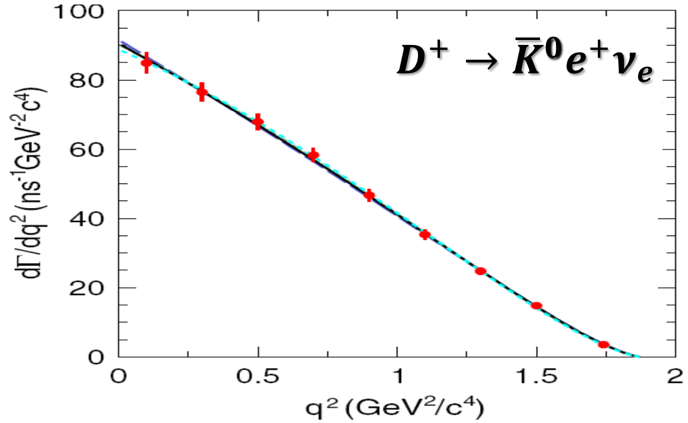
2.93 fb^{-1} @3.773 GeV

PRD92(2015)072012



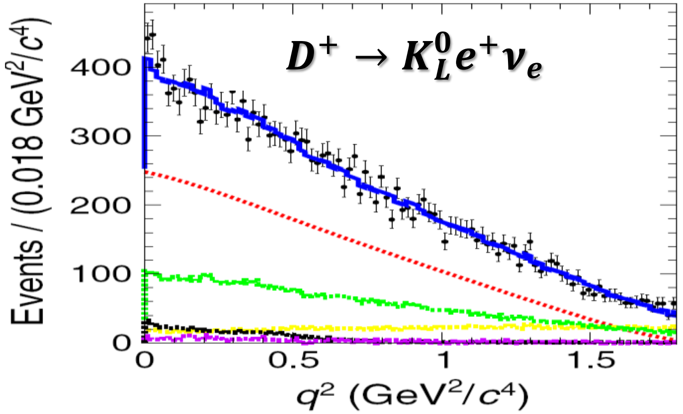
$f_+^{D\to K}(0)|V_{cs}| = 0.717(03)(04)$

PRD96(2017)012002



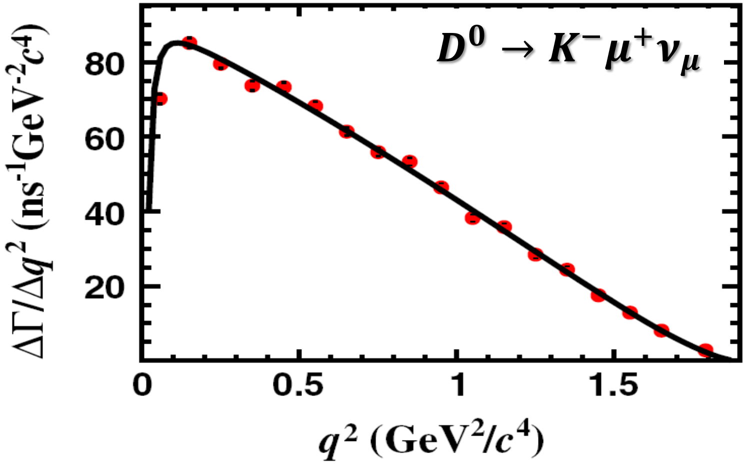
$f_+^{D\to K}(0)|V_{cs}| = 0.705(04)(11)$

PRD92(2015)112008



$f_+^{D\to K}(0)|V_{cs}| = 0.728(06)(11)$

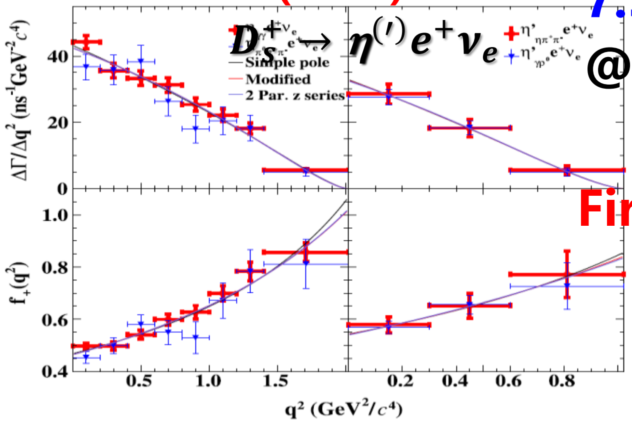
PRL122(2019)011804



$f_+^{D\to K}(0)|V_{cs}| = 0.7148(38)(29)$

PRL123(2019)121801→

PRD108(2023)092003

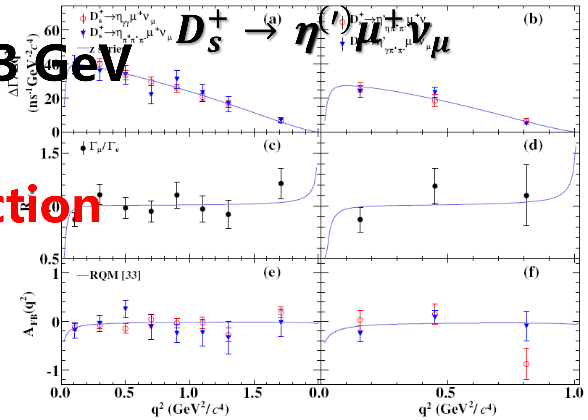


$f_+^{D_s\to\eta}(0)|V_{cs}| = 0.452(07)(07)$

$f_+^{D_s\to\eta'}(0)|V_{cs}| = 0.525(24)(09)$

7.33 fb^{-1} @4.13-4.23 GeV

PRL132(2024)091802



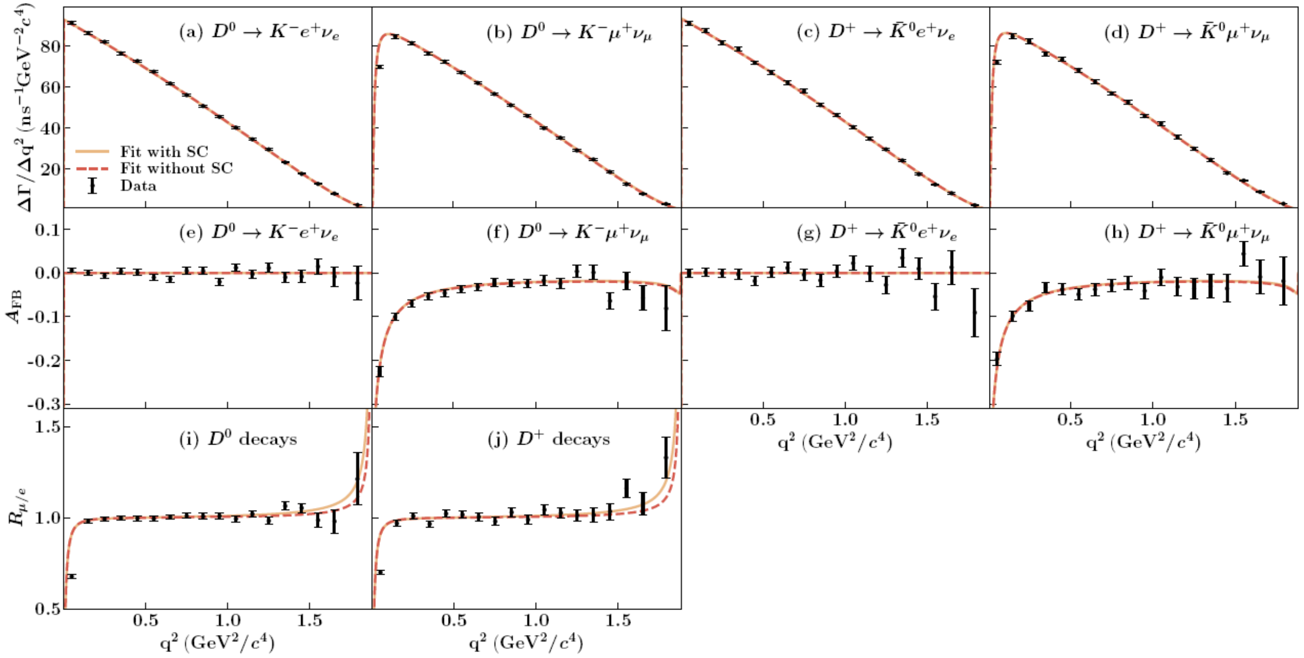
First extraction

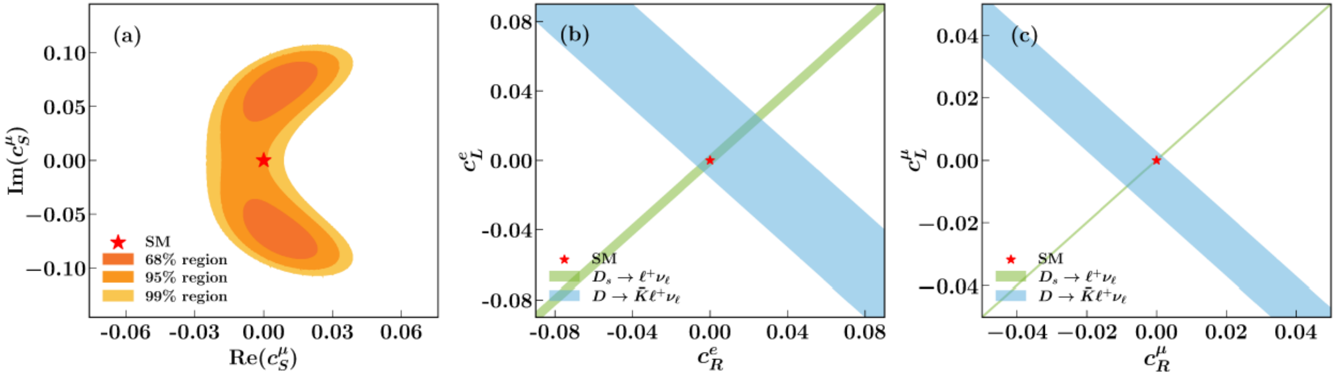
$f_+^{D_s\to\eta}(0)|V_{cs}| = 0.451(10)(08)$

$f_+^{D_s\to\eta'}(0)|V_{cs}| = 0.506(37)(11)$

Very recent results of $D^{0(+)} \to \bar{K}\ell^+\nu_\ell$ ($\ell = e$ or μ)

7.9 → 20.3 fb^{-1} @3.773 GeV　　PRD110(2024)112006 → arXiv:2601.21185, 2601.21196





精确测量：分支比、$D \to K$形状因子、|V$_{cs}$|、检验轻子普适性

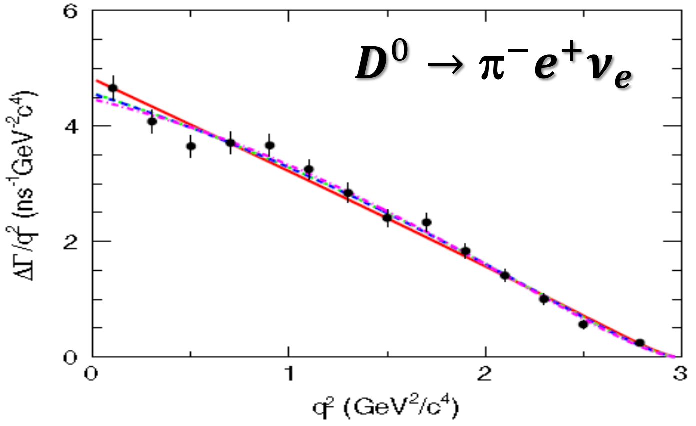
首次：测量前后冲不对称参数，约束标量流贡献(1.9σ)

Channel	$N_{\rm DT}$ $(\times 10^3)$	$\bar{\epsilon}_{\rm sig}$ (%)	$\mathcal{B}_{\rm sig}$ (%)
$D^0 \to K^- e^+ \nu_e$	488.0 ± 0.8	68.39 ± 0.02	$3.527 \pm 0.005 \pm 0.016$
$D^0 \to K^- \mu^+ \nu_\mu$	402.1 ± 0.8	57.98 ± 0.02	$3.429 \pm 0.007 \pm 0.017$
$D^+ \to \bar{K}^0 e^+ \nu_e$	149.4 ± 0.4	45.46 ± 0.02	$8.918 \pm 0.025 \pm 0.050$
$D^+ \to \bar{K}^0 \mu^+ \nu_\mu$	125.1 ± 0.4	38.77 ± 0.02	$8.763 \pm 0.029 \pm 0.052$

Variable	With SC	Without SC
$f_+(0)\lvert V_{cs}\rvert$	$0.7167 \pm 0.008 \pm 0.014$	$0.7160 \pm 0.007 \pm 0.014$
r_1	$-2.28 \pm 0.04 \pm 0.02$	$-2.32 \pm 0.02 \pm 0.02$
$\lvert c_S^e\rvert$	$0.02 \pm 0.02 \pm 0.02$	—
Re(c_S^μ)	$0.007 \pm 0.008 \pm 0.006$	—
Im(c_S^μ)	$\pm 0.070 \pm 0.013 \pm 0.010$	—
χ^2/ndf	132.9/139	138.5/142

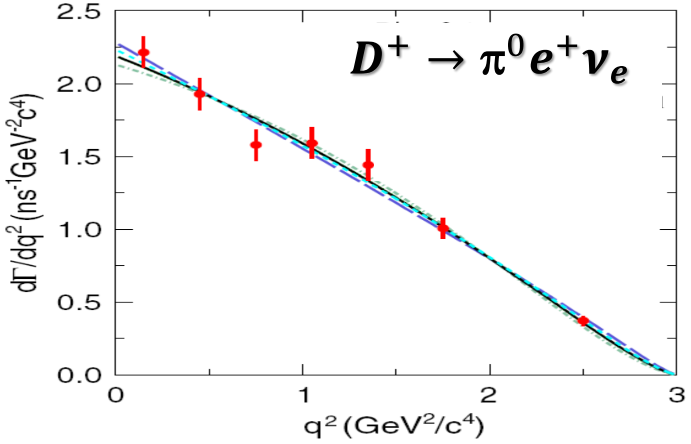
Earlier studies of $c \to d l^+ \nu_l$ semileptonic decays

PRD92(2015)072012



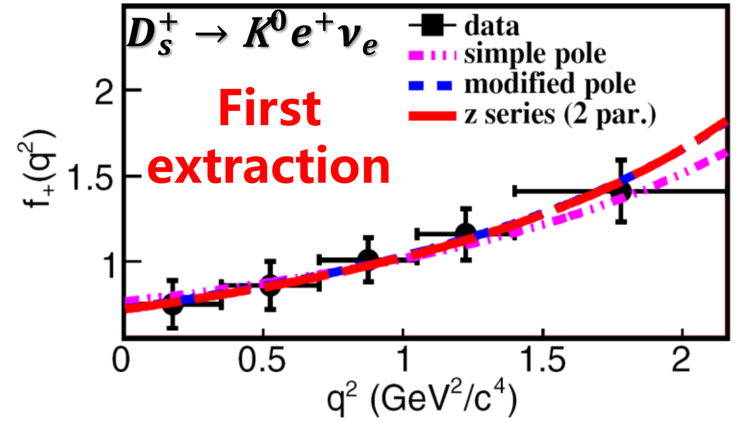
$f_+^{D\to\pi}(0)|V_{cd}| = 0.144(02)(01)$

PRD96(2017)012002



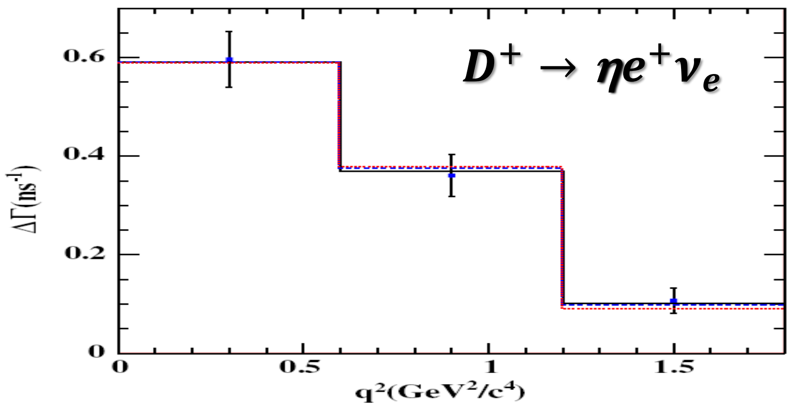
$f_+^{D\to\pi}(0)|V_{cd}| = 0.140(03)(01)$

PRL122(2019)061801



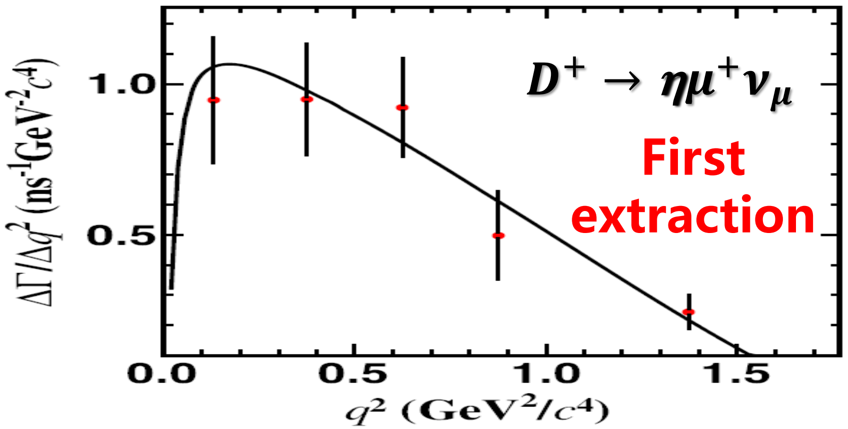
$f_+^{D_s\to K}(0)|V_{cd}| = 0.162(19)(03)$

PRD97(2018)092009



$f_+^{D\to\eta}(0)|V_{cd}| = 0.079(06)(02)$

PRL124(2020)231801



$f_+^{D\to\eta}(0)|V_{cd}| = 0.087(08)(02)$

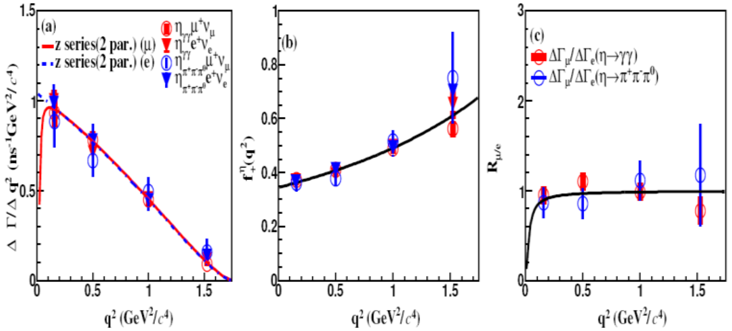
Recent studies of $D^+_{(s)} \to P\ell^+\nu_\ell$ ($\ell = e$ or μ)

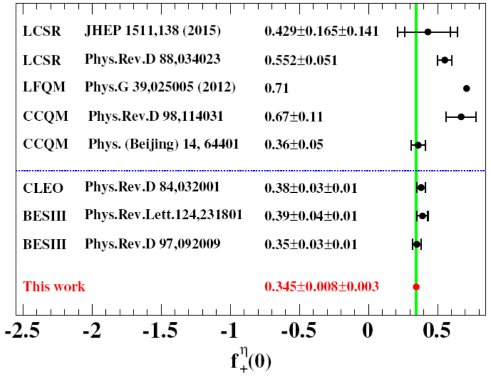
20.3 fb^{-1} @3.773 GeV

7.33 fb^{-1} @4.128-4.226 GeV

$D^+ \to \eta\ell^+\nu_\ell$

arXiv:2506.02521





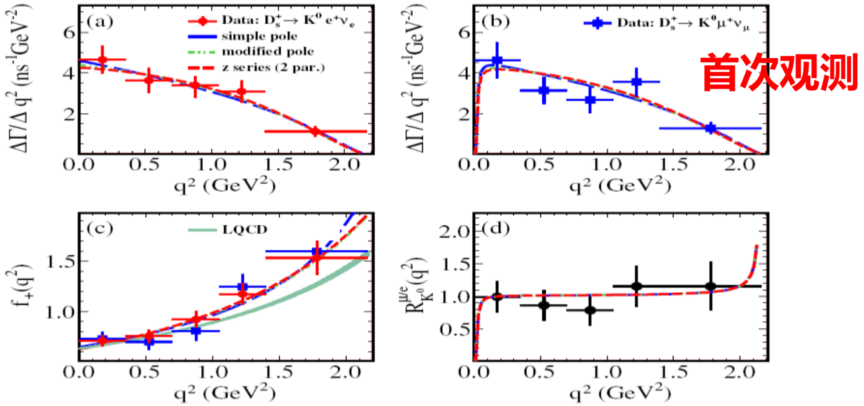
$f_+^{D\to\eta}(0)|V_{cd}| = (7.8 \pm 0.2 \pm 0.1)\%$

$D^+ \to \eta$形状因子精度改进3.4倍

$D_s^+ \to K^0\ell^+\nu_\ell$

PRD110,052012

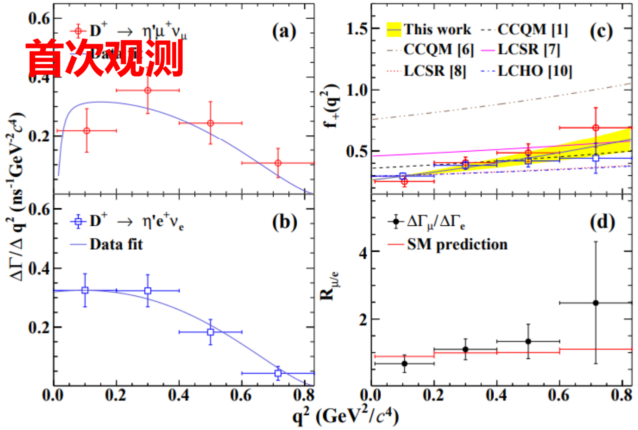
arXiv:2510.05904

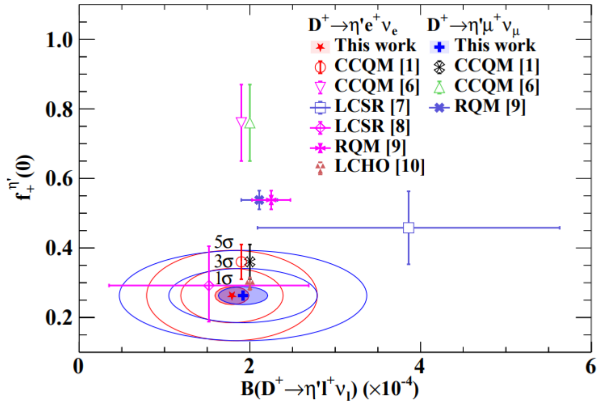


$f_+^{D_s\to K^0}(0)|V_{cd}| = (14.0 \pm 0.8 \pm 0.2)\%$

$D^+ \to \eta'\ell^+\nu_\ell$

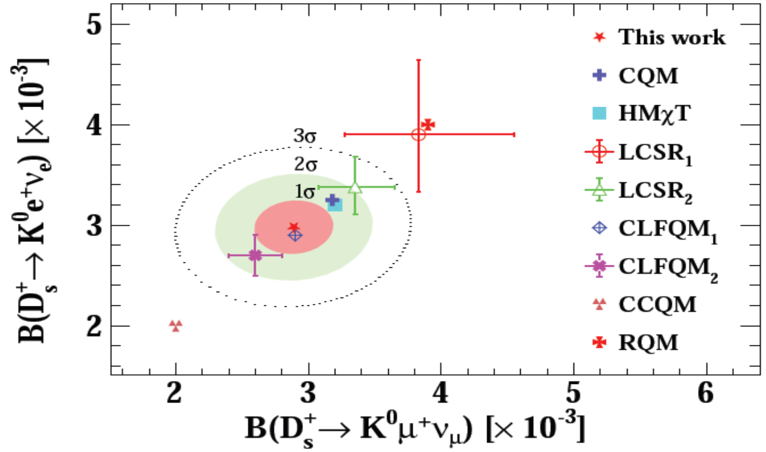
PRL134(2025)111801





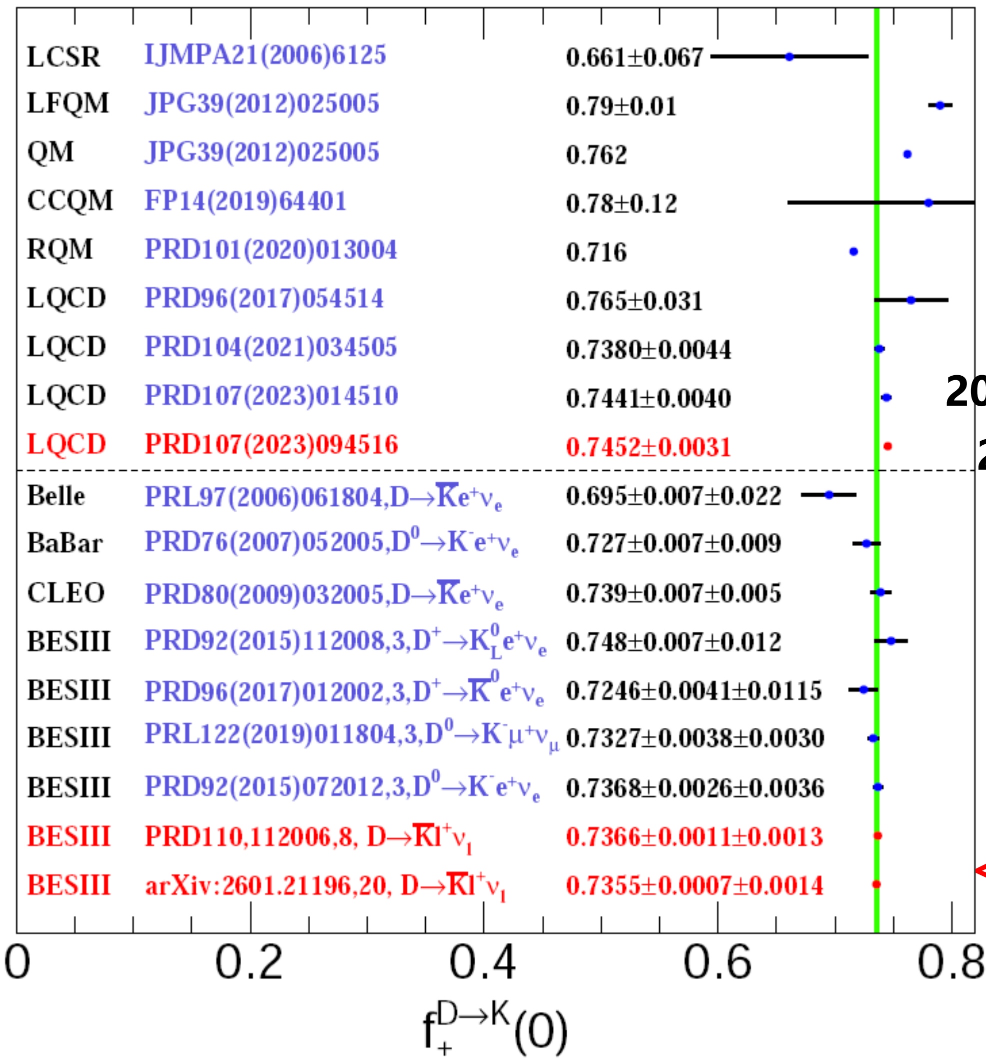
$f_+^{D\to\eta'}(0)|V_{cd}| = (5.92 \pm 0.56 \pm 0.13)\%$

首次抽取$D^+ \to \eta'$形状因子



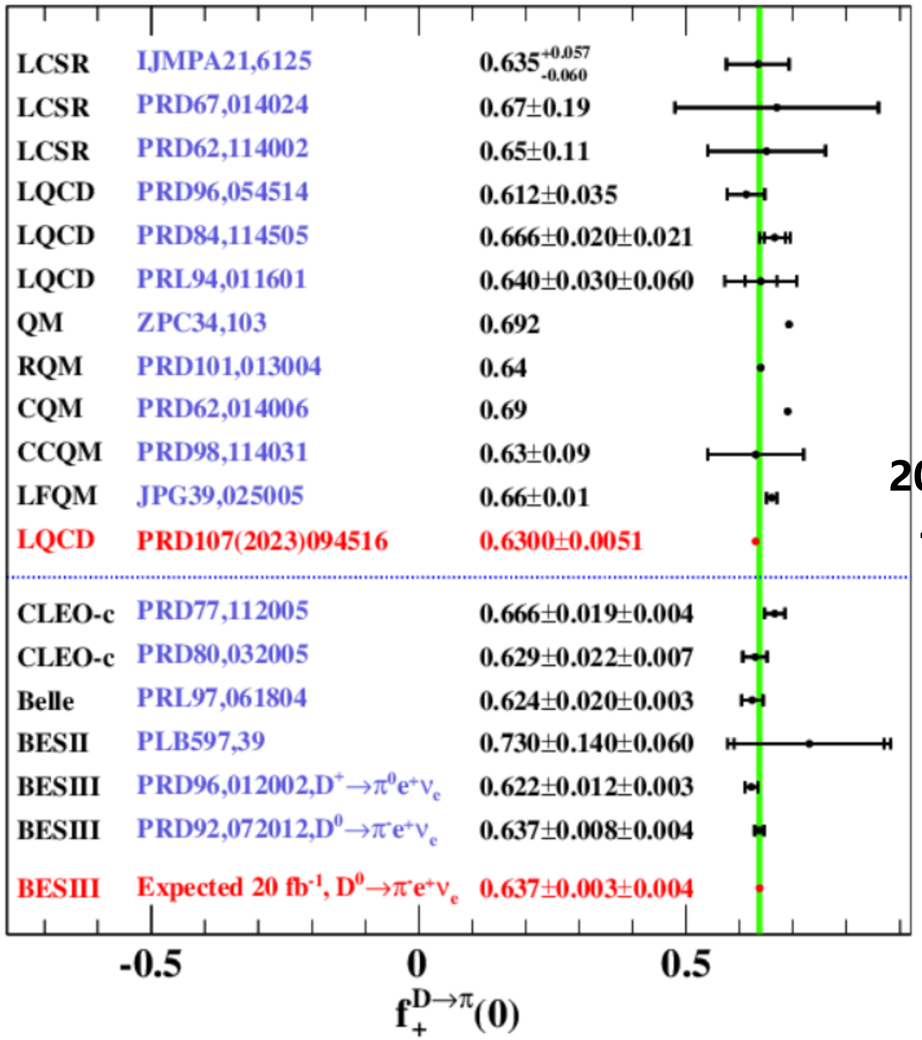
精确测量$D_s^+ \to K^0$形状因子

Comparisons of $f_+^{D\to K}(0)$ and $f_+^{D\to\pi}(0)$



2010→2023
2.4→0.4%

<0.3%



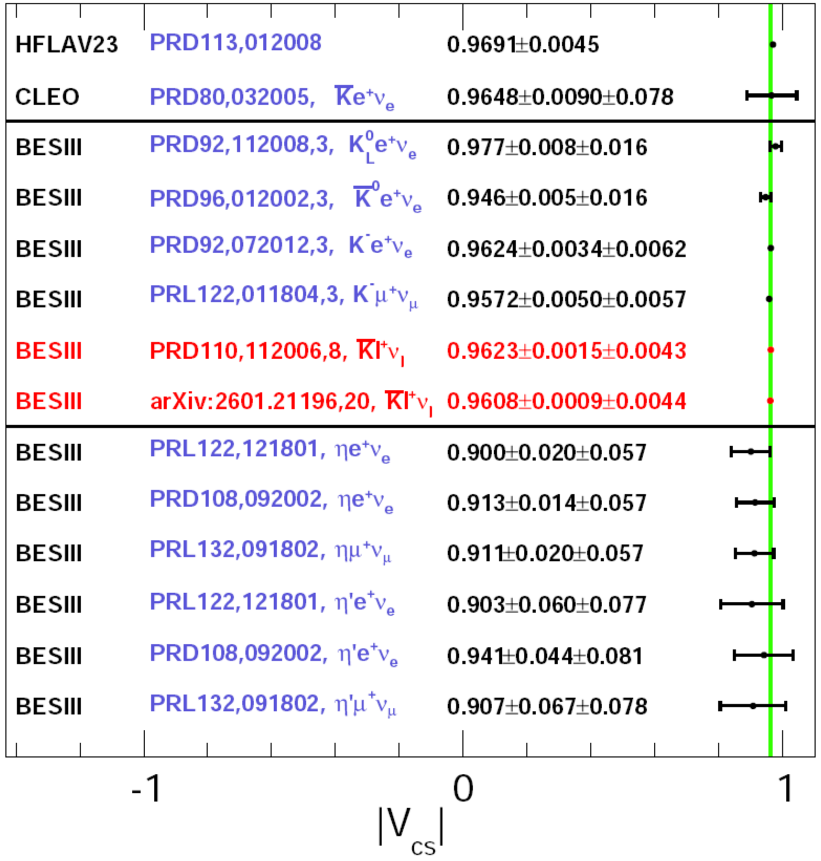
2011→2023
4.4→0.8%

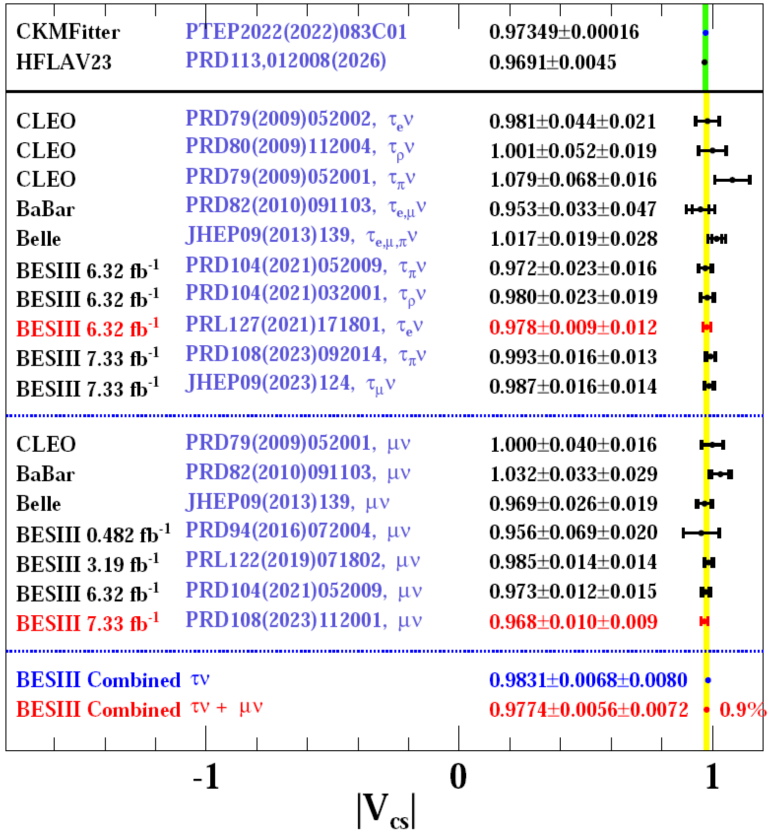
1.6%

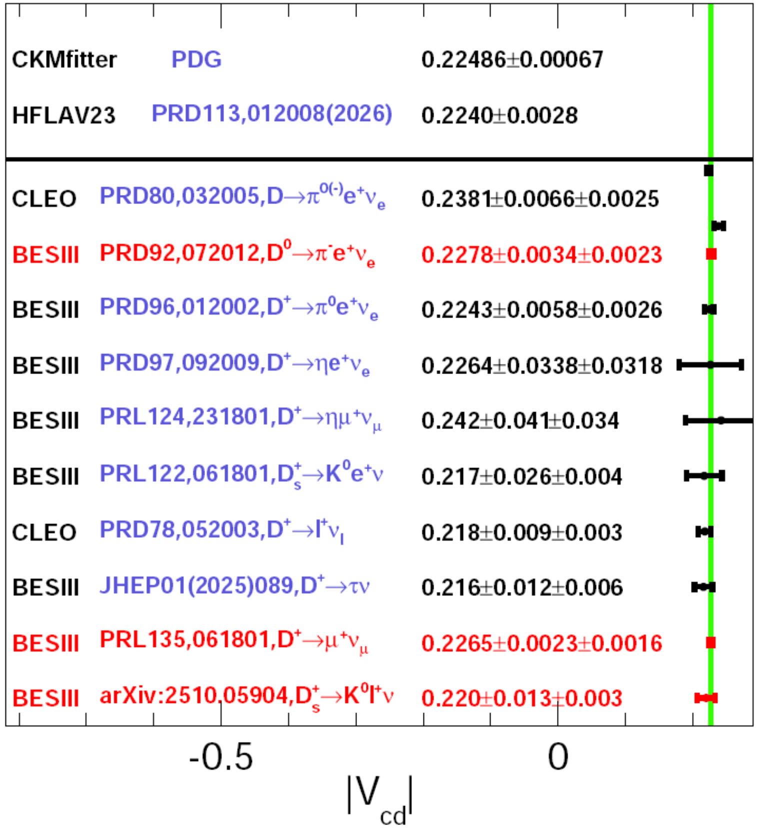
Experimental precision of $f_+^{D\to K}(0)$ is comparable to the latest LQCD precision

Experimental precision of $f_+^{D\to\pi}(0)$ is still dominated by statistical uncertainties

Comparisons of $|V_{cs}|$ and $|V_{cd}|$



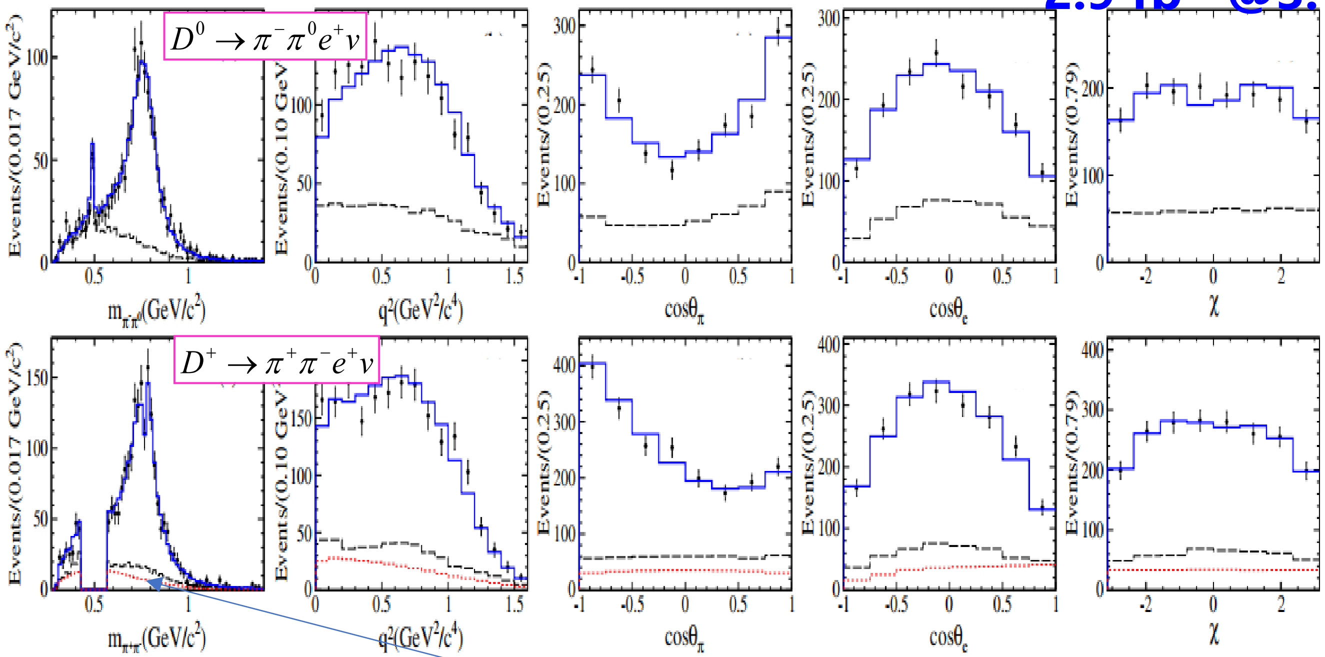




Observation of $D \to S e^+ \nu_e$

PRL122(2019)062001

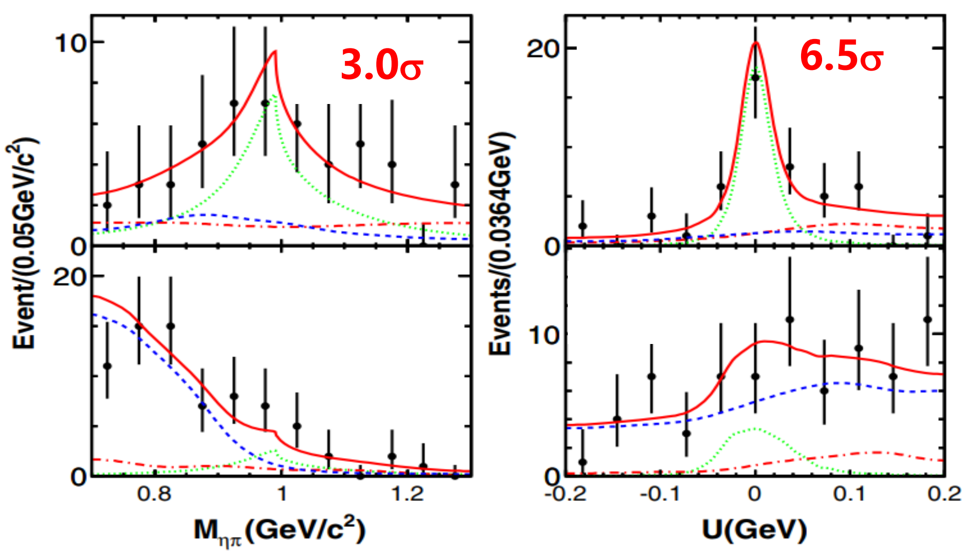
2.9 fb^{-1} @3.773 GeV



$r_V = 1.695 \pm 0.083 \pm 0.051$ $\quad r_2 = 0.845 \pm 0.056 \pm 0.039$

PRL121(2018)081802

$D^+ \to a_0(980)^0 e^+ \nu_e$ $\quad D^0 \to a_0(980)^- e^+ \nu_e$



$B_{D^0 \to a_0(980)^- e^+ \nu} B_{a_0(980)^- \to \eta\pi^-} = (1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$

$B_{D^+ \to a_0(980)^0 e^+ \nu} B_{a_0(980)^0 \to \eta\pi^0} = (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}$

Observation of $D^+ \to f_0(500)\, e^+ \nu_e$

Signal mode	This analysis ($\times 10^{-3}$)
$D^0 \to \pi^- \pi^0 e^+ \nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^0 \to \rho^- e^+ \nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^+ \to \pi^- \pi^+ e^+ \nu_e$	$2.449 \pm 0.074 \pm 0.073$
$D^+ \to \rho^0 e^+ \nu_e$	$1.860 \pm 0.070 \pm 0.061$
$D^+ \to \omega e^+ \nu_e$	$2.05 \pm 0.66 \pm 0.30$
$D^+ \to f_0(500) e^+ \nu_e$, $f_0(500) \to \pi^+ \pi^-$	$0.630 \pm 0.043 \pm 0.032$
$D^+ \to f_0(980) e^+ \nu_e$, $f_0(980) \to \pi^+ \pi^-$	<0.028

$[B_{D^+ \to f_0(500) e^+ \nu} + B_{D^+ \to f_0(980) e^+ \nu}] / B_{D^+ \to a_0(980)^0 e^+ \nu} > 2.7$

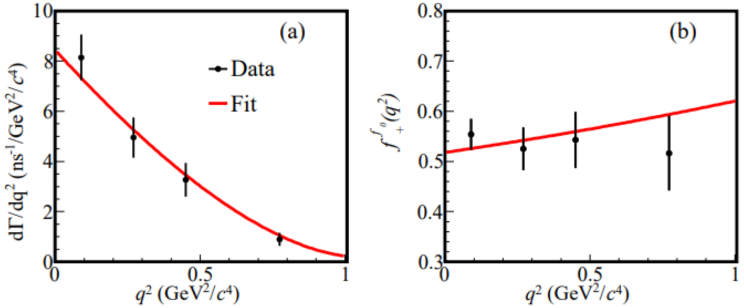
Supports tetraquark assumption for light mesons of a_0 and f_0

Recent studies of $D \to S l^+ \nu_l$

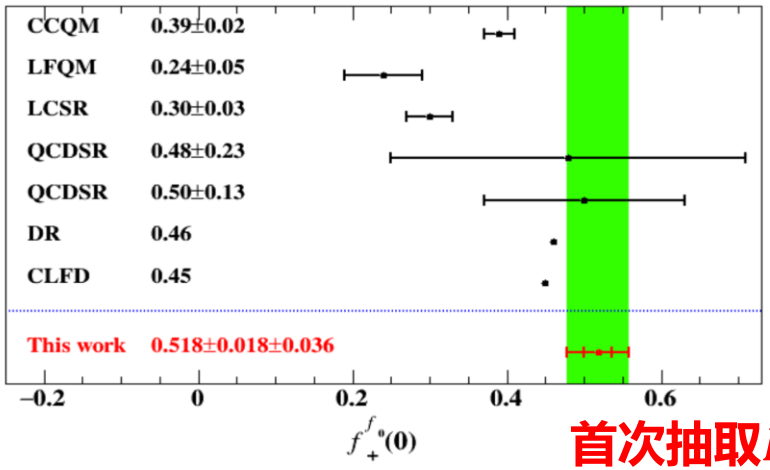
7.33 fb^{-1}@4.13-4.23 GeV

$D_s^+ \to f_0(980)^0 e^+ \nu_e$

PRL132(2024)141901



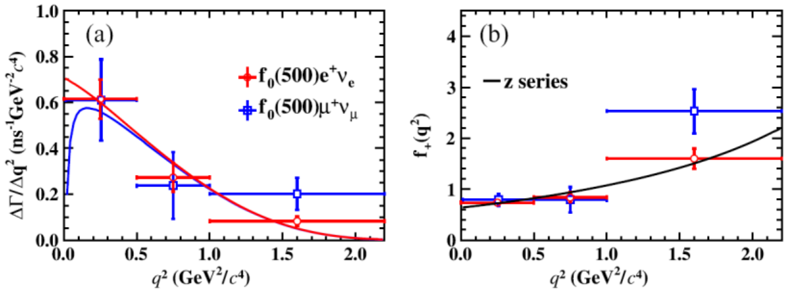
$f_+^{D_s \to f_0(980)}(0)|V_{cs}| = 0.504(17)(35)$



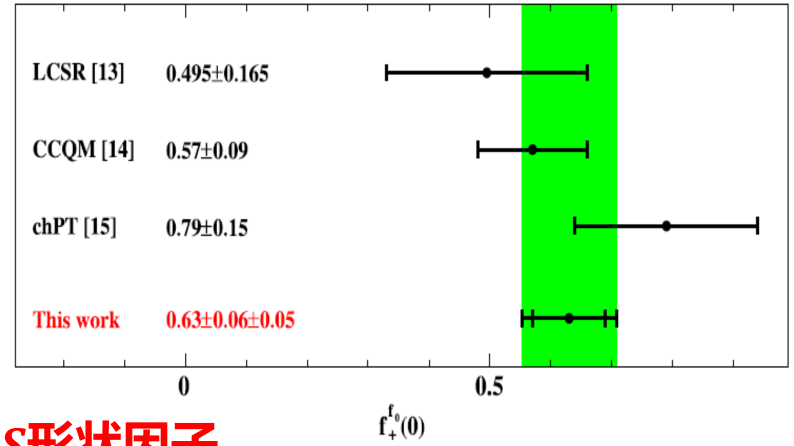
2.9 fb^{-1} @3.773 GeV

$D^+ \to f_0(500)^0 e^+ \nu_e$

PRD110(2024)092008



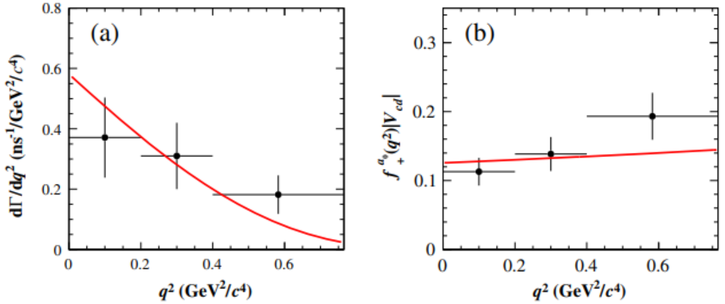
$f_+^{D^+ \to f_0(500)}(0)|V_{cd}| = 0.143(14)(11)$



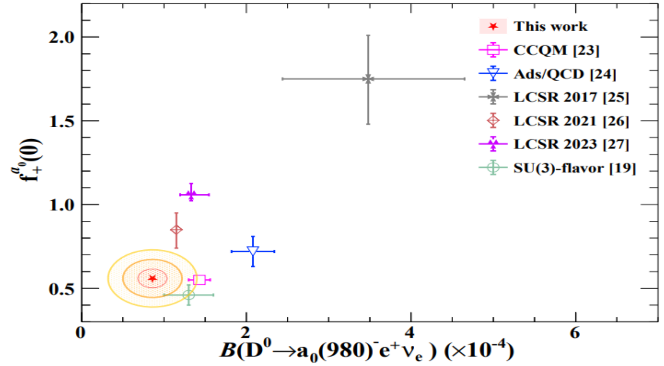
7.9 fb^{-1} @3.773 GeV

$D^0 \to a_0(980)^- e^+ \nu_e$

PRD111(2025)L091501

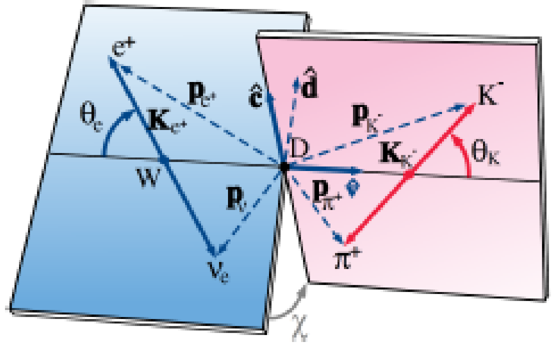


$f_+^{D^0 \to a_0(980)}(0)|V_{cd}| = 0.126(13)(03)$



首次抽取$D \to S$形状因子

$D \to V e^+ \nu_e$半轻衰变的研究



- $m^2 = (p_{\pi^+} + p_{K^-})^2$
- $\cos(\theta_K) = \frac{\vec{p} \cdot \mathbf{K}_{K^-}}{|\mathbf{K}_{K^-}|}$
- $\cos(\chi) = \hat{c} \cdot \hat{d}$
- $q^2 = (p_{e^+} + p_{\nu_e})^2$
- $\cos(\theta_e) = -\frac{\vec{p} \cdot \mathbf{K}_{e^+}}{|\mathbf{K}_{e^+}|}$
- $\sin(\chi) = (\hat{c} \times \vec{p}) \cdot \hat{d}$

Decay rate depend on 5 variables and 3 form factors

$$d^5\Gamma = \frac{G_F^2 |V_{cs}|^2}{(4\pi)^6 m_D^2} X \beta \mathcal{I}(m^2, q^2, \theta_K, \theta_e, \chi) dm^2 dq^2 d\cos(\theta_K) d\cos(\theta_e) d\chi$$

- $X = p_{K\pi} m_D$, $p_{K\pi}$ is the momentum of the $K\pi$ system in the D rest frame
- $\beta = 2p^*/m$, p^* is the breakup momentum of the $K\pi$ system in its rest frame
- $\mathcal{I}$ can be expressed in terms of helicity amplitudes $H_{0,\pm}$:

  $H_0(q^2) = \frac{1}{2mq}\left[(m_D^2 - m^2 - q^2)(m_D + m)A_1(q^2) - 4\frac{m_D^2 p_{K\pi}^2}{m_D + m} A_2(q^2)\right]$

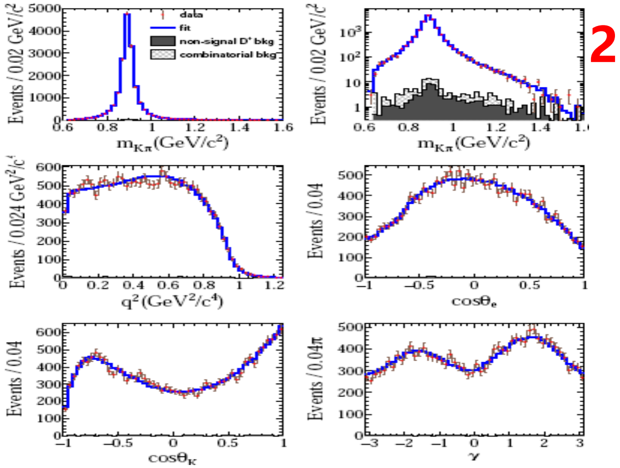
  $H_\pm(q^2) = (m_D + m)A_1(q^2) \mp \frac{2m_D p_{K\pi}}{m_D + m} V(q^2)$

- Vector form factor: $V(q^2) = \frac{V(0)}{1 - q^2/m_V^2}$; or: FF ratio $r_V = V(0)/A_1(0)$
- Axial-vector form factor: $A_1(q^2) = \frac{A_1(0)}{1 - q^2/m_A^2}$, $A_2(q^2) = \frac{A_2(0)}{1 - q^2/m_A^2}$; or: FF ratio $r_2 = A_2(0)/A_1(0)$

Earlier studies of $D \to V e^+ \nu_e$

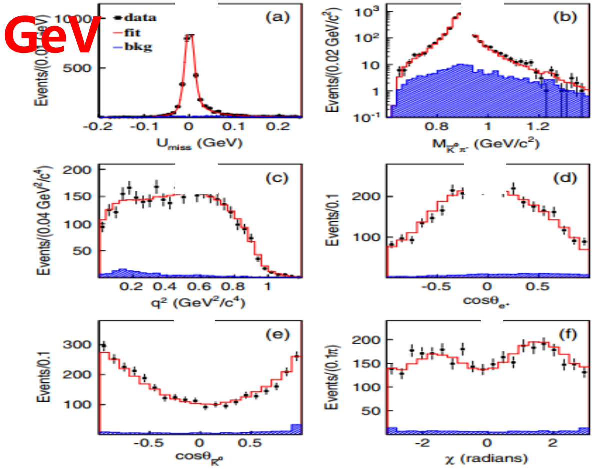
$D^+ \to \bar{K}^{*0} e^+ \nu_e$ PRD94(2016)032001

2.9 fb^{-1} @3.773 GeV



$r_V = 1.411 \pm 0.058 \pm 0.007$ $r_2 = 0.788 \pm 0.042 \pm 0.008$

$D^0 \to K^{*-} e^+ \nu_e$ PRD99(2018)011103

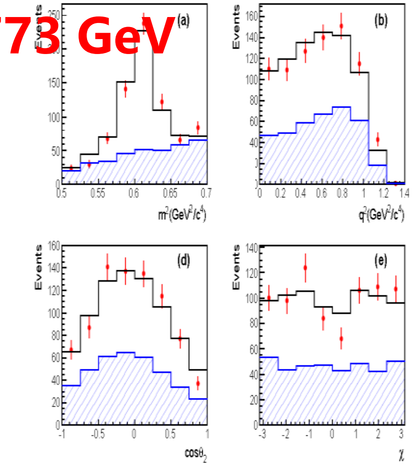


First extraction

$r_V = 1.46 \pm 0.07 \pm 0.02$ $r_2 = 0.67 \pm 0.06 \pm 0.01$

$D^+ \to \omega e^+ \nu_e$ PRD92(2015)071101

2.9 fb^{-1} @3.773 GeV

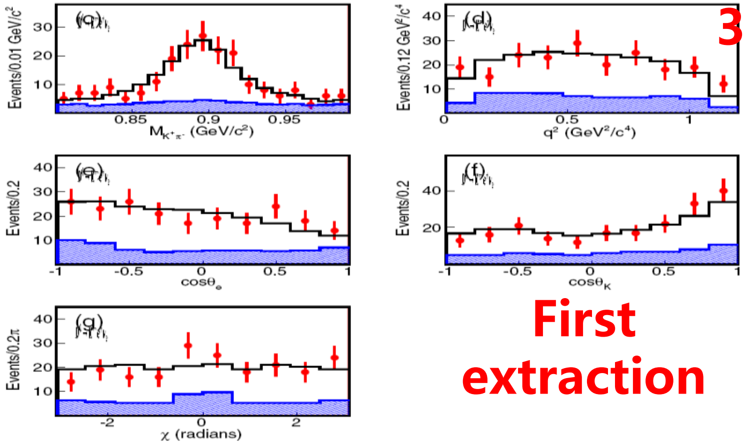


First extraction

$r_V = 1.24 \pm 0.09 \pm 0.06$ $r_2 = 1.06 \pm 0.15 \pm 0.05$

$D_s^+ \to K^{*0} e^+ \nu_e$ PRL122(2019)061801

3.19 fb^{-1}@4.178 GeV



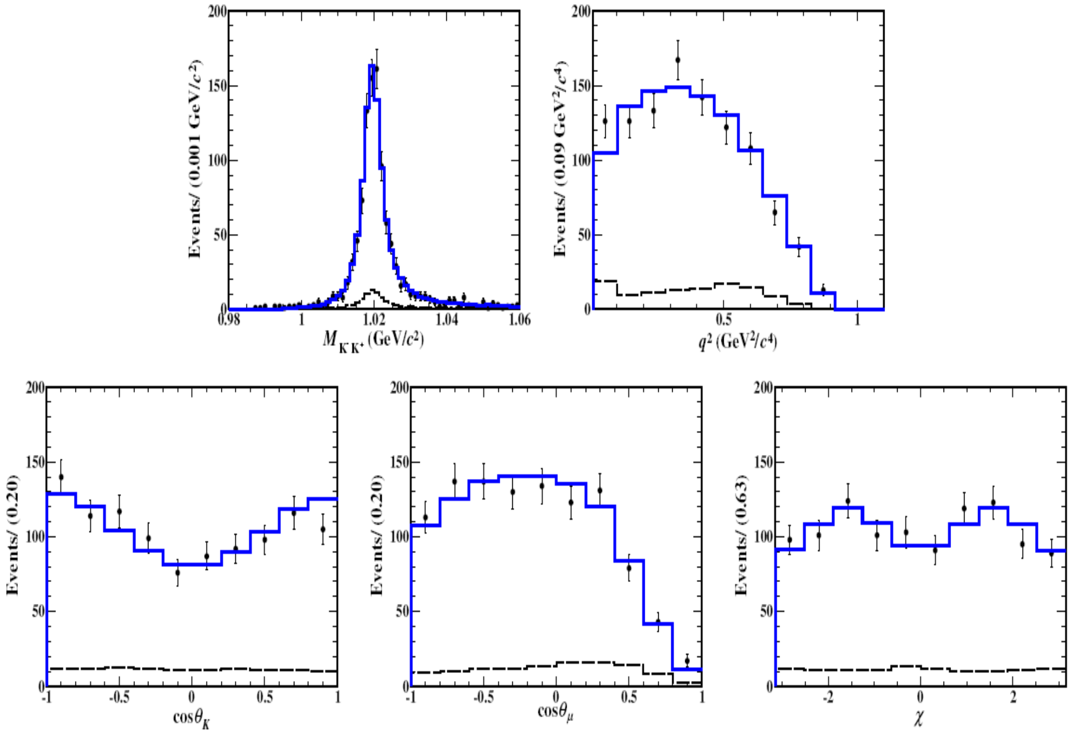
First extraction

$r_V = 1.67 \pm 0.34 \pm 0.16$ $r_2 = 0.77 \pm 0.28 \pm 0.07$

Study of $D_s^+ \to \phi\mu^+\nu_\mu$

7.33 fb^{-1}@4.13-4.23 GeV

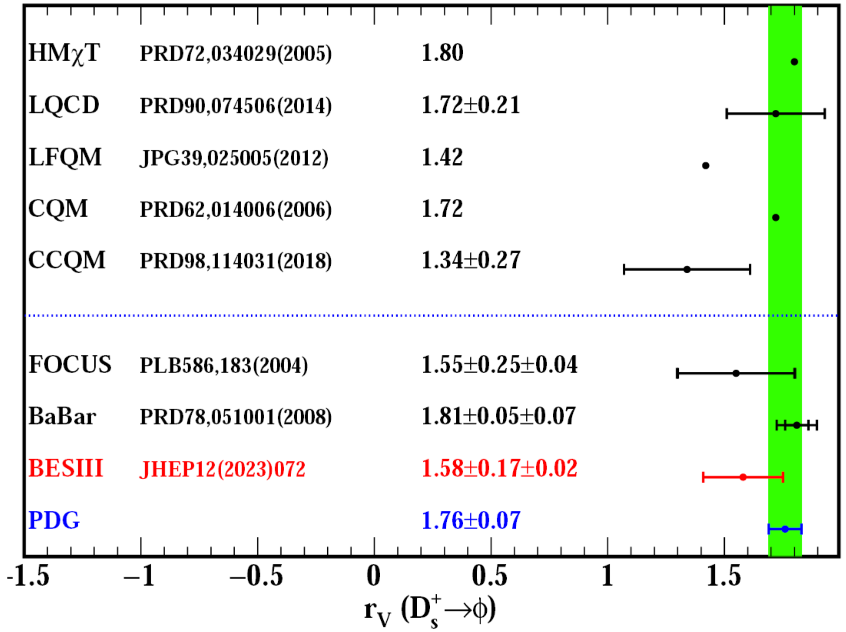
$D_s^+ \to \phi\mu^+\nu_\mu$ JHEP12(2023)072

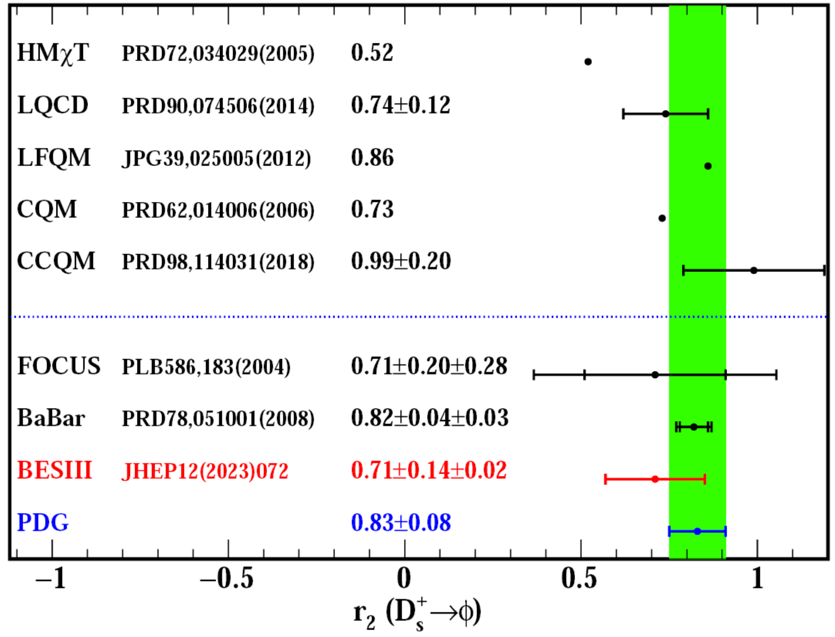


$$r_V = 1.58 \pm 0.17 \pm 0.02$$

$$r_2 = 0.71 \pm 0.14 \pm 0.02$$

测量$D_s \to \phi$形状因子

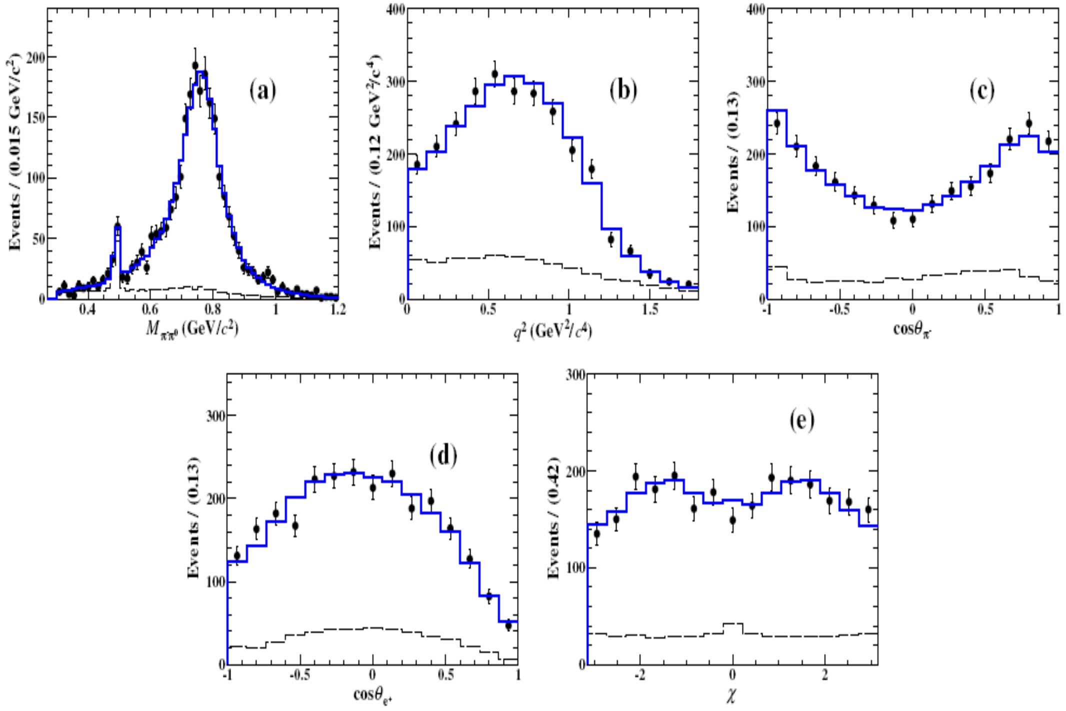




Study of $D^0 \to \rho^- e^+ \nu_e$

7.9 fb^{-1}@3.773 GeV

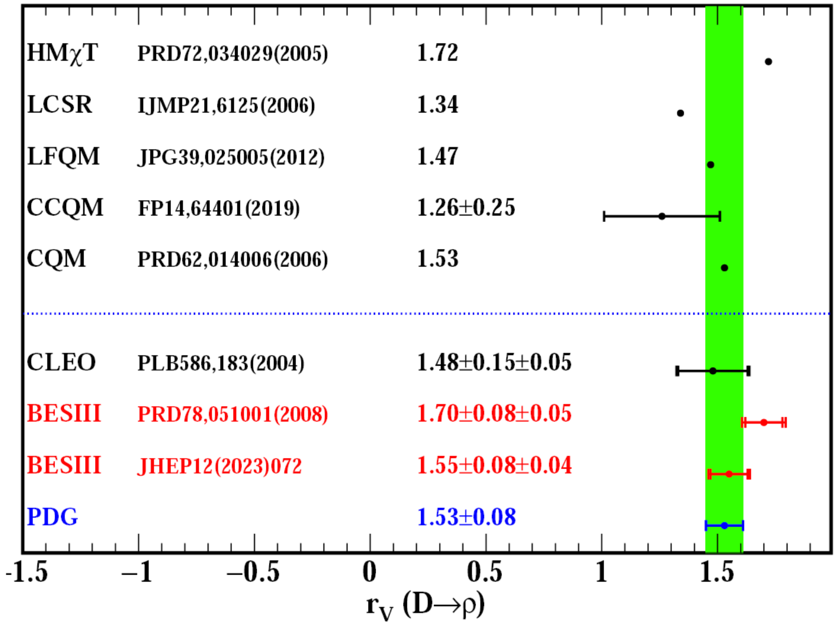
$D^0 \to \rho^- e^+ \nu_e$ PRD110(2024)112018

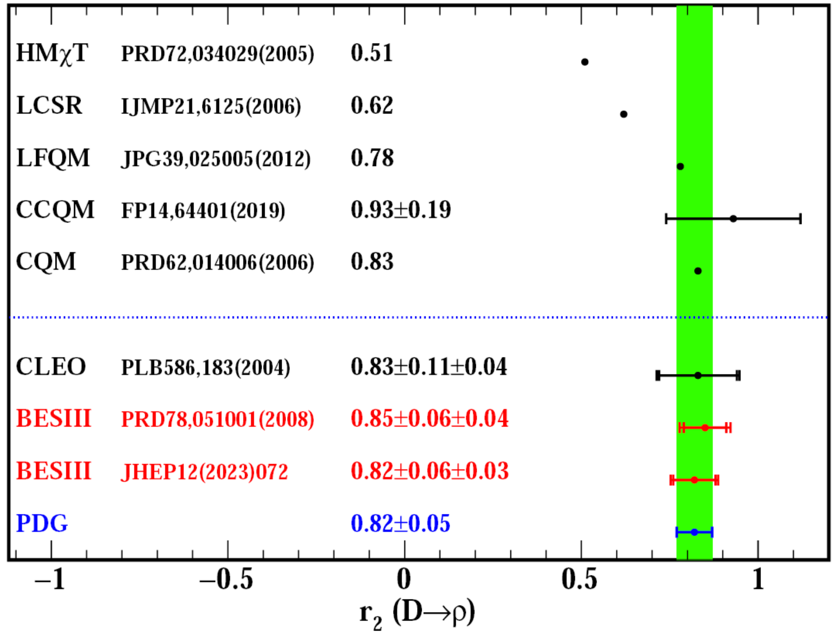


$$r_V = 1.55 \pm 0.08 \pm 0.04$$

$$r_2 = 0.82 \pm 0.06 \pm 0.03$$

精确测量$D \to \rho$形状因子

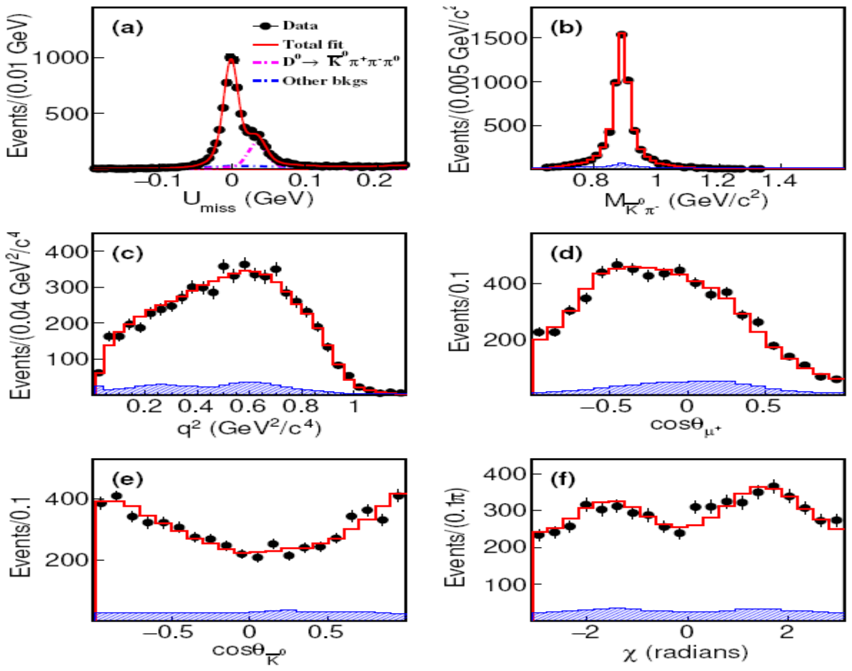


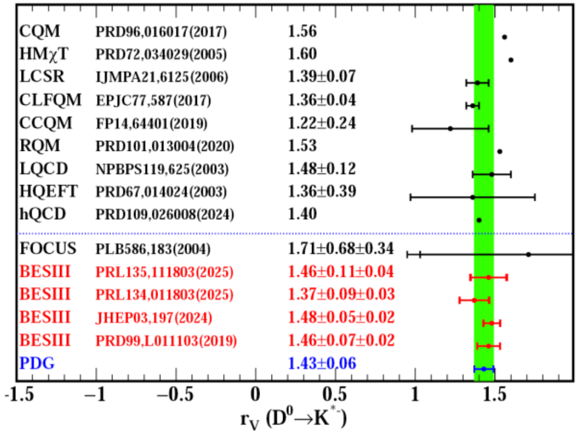


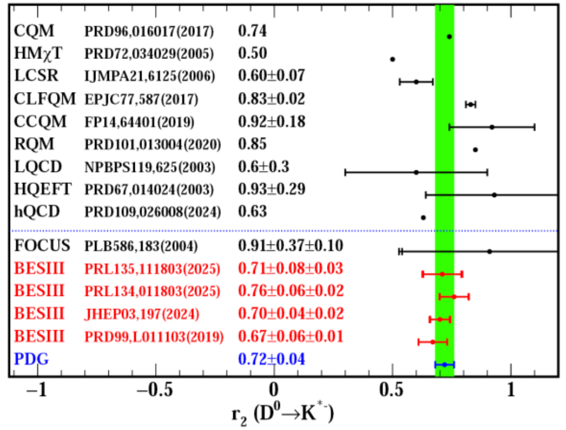
Recent results of $D^0 \to K^{*-} l^+ \nu_l$

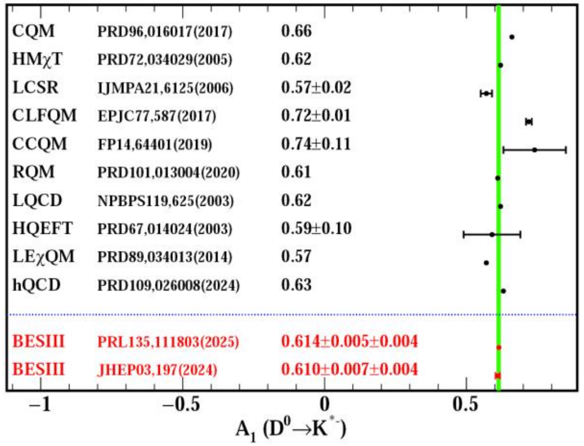
7.9 fb^{-1}@3.773 GeV

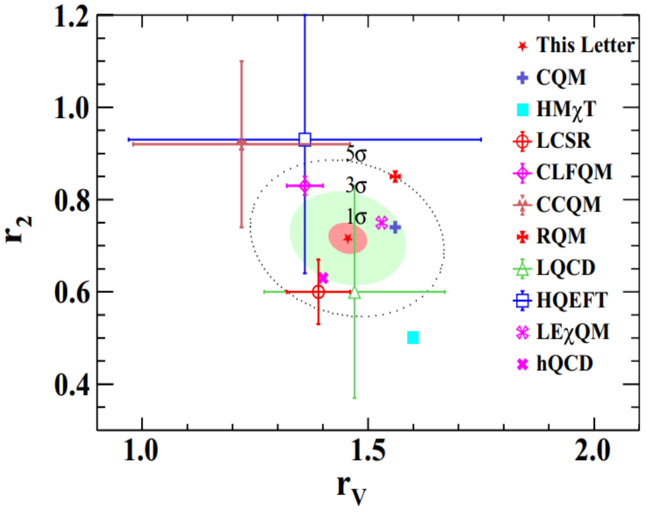
$D^0 \to K^{*-}(K_S^0\pi^-)e^+\nu_e$	JHEP03(2024)197
$D^0 \to K^{*-}(K^-\pi^0)\mu^+\nu_\mu$	PRL134(2025)011803
$D^0 \to K^{*-}(K_S^0\pi^-)\mu^+\nu_\mu$	PRL135(2025)111803











$r_V = 1.46 \pm 0.11 \pm 0.03$

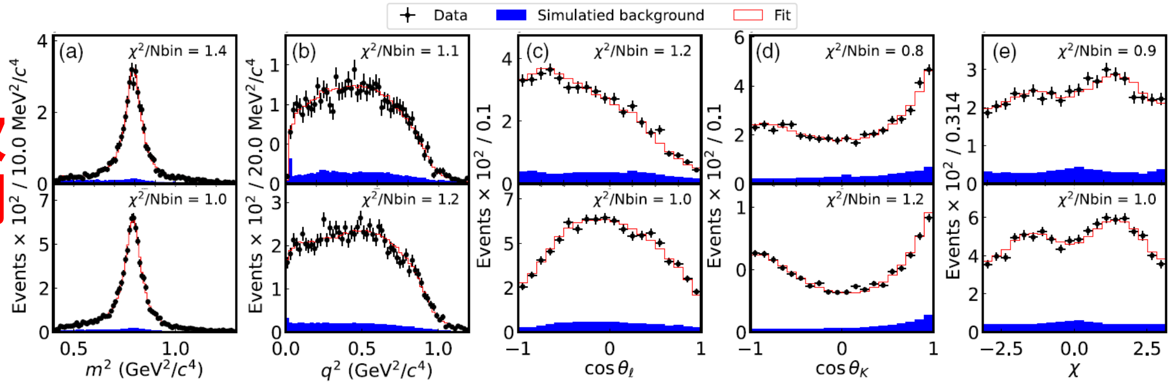
$r_2 = 0.71 \pm 0.08 \pm 0.03$

精确测量$D^0 \to K^{*-}$ 形状因子

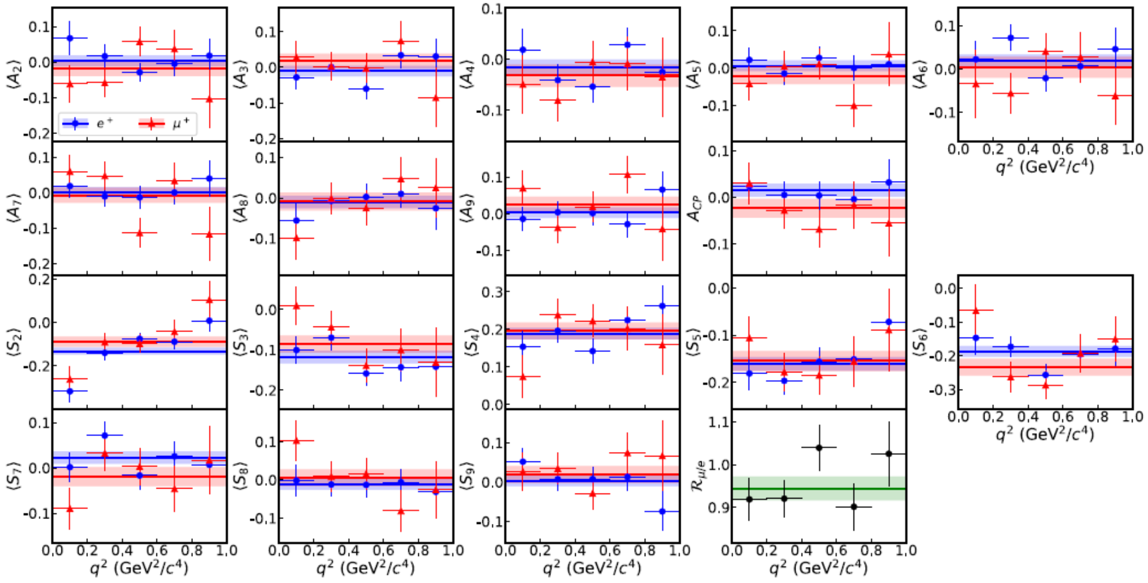
Recent results of $D^+ \to \bar{K}^{*0} e^+ \nu_e$

$D^+ \to \bar{K}^{*0}(K_S^0\pi^0)l^+\nu_l$ PRL135 (2025)171801 **20.3 fb^{-1}@3.773 GeV**

首次观测

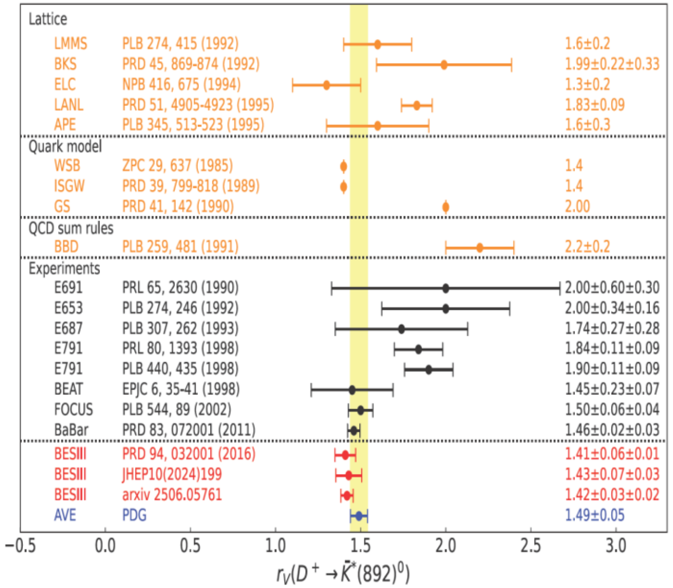


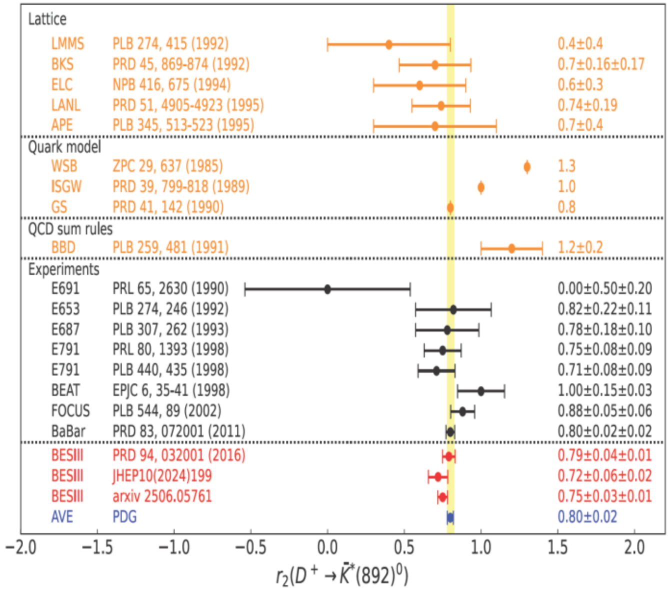
$$r_V = 1.42 \pm 0.03 \pm 0.02 \quad r_2 = 0.75 \pm 0.03 \pm 0.01$$



角分布+振幅分析 → 首次在粲衰变中抽取到多个角分布变量和CP破坏参数

精确测量 $D^+ \to \bar{K}^{*0}$ 形状因子

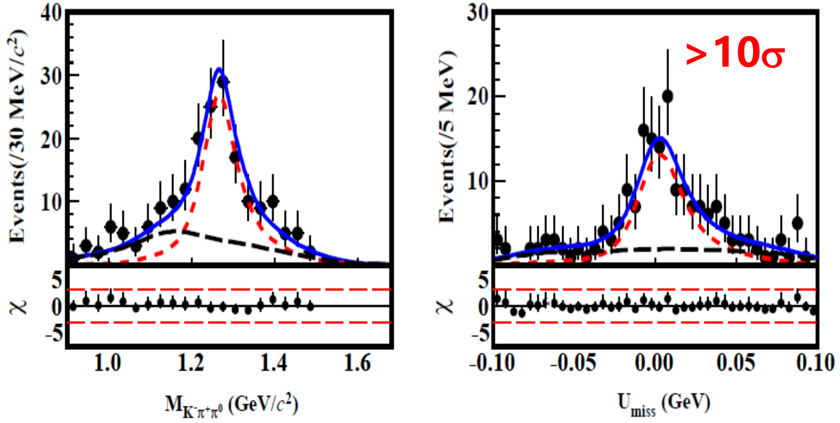




Observation of $D \to A e^+ \nu_e$

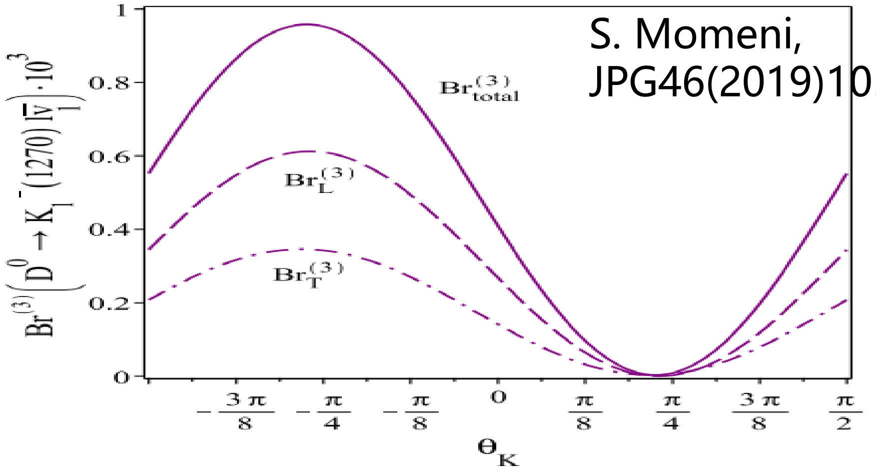
2.93 fb^{-1}@3.773 GeV

$D^+ \to \bar{K}_1^0(1270) e^+ \nu_e$ PRL123(2019)231801



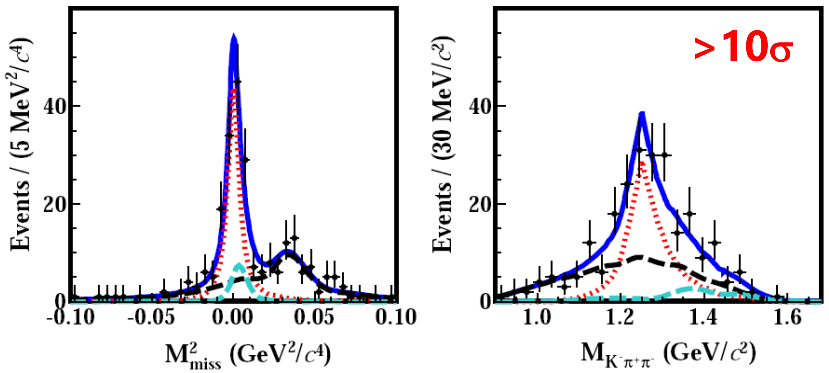
$$B_{D^+ \to \bar{K}_1^0(1270) e^+ \nu_e} = (2.30 \pm 0.26 \pm 0.18 \pm 0.25) \times 10^{-3}$$

Helps to test various theoretical calculations which are sensitive to K_1 mixing angle



S. Momeni, JPG46(2019)105006

$D^0 \to K_1(1270)^- e^+ \nu_e$ PRL127(2021)131801



$$B_{D^0 \to K_1(1270)^- e^+ \nu_e} = (1.09 \pm 0.13 \pm 0.13 \pm 0.12) \times 10^{-3}$$

New window to explore the property and nature of K_1 and K_1 mixing angle

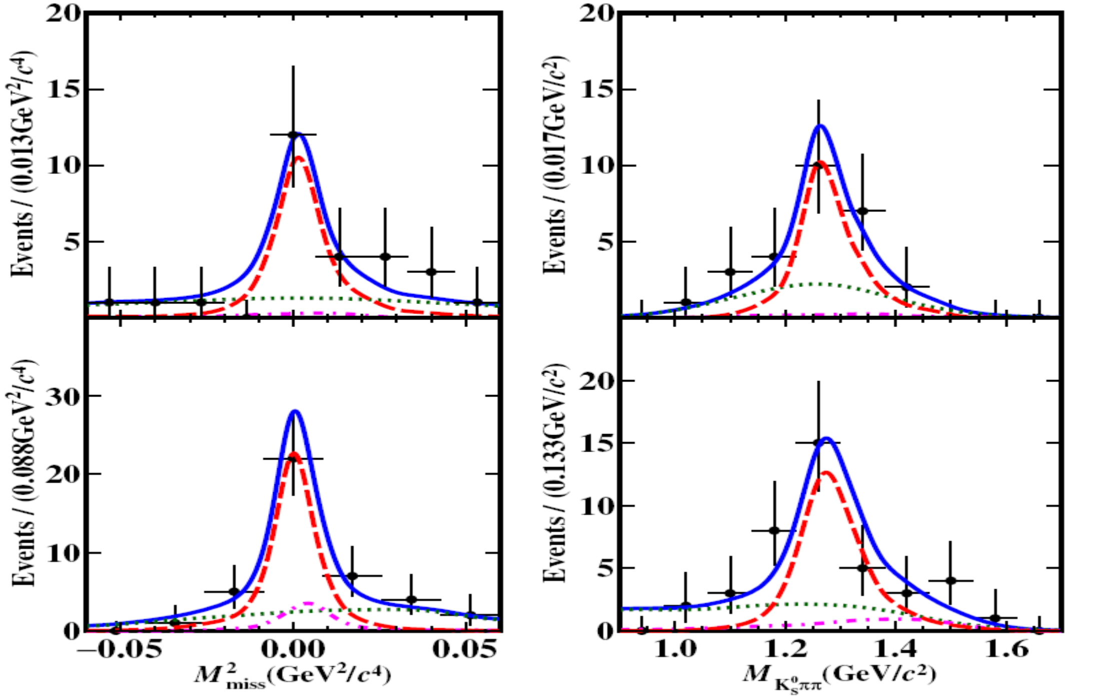
Combined analysis of $D \to \bar{K}_1 e^+ \nu$ and $B \to \gamma \bar{K}_1$ helps to constrain new physics effect in the studies of photon polarization in $b \to s\gamma$ process

Wei Wang et al. PRL125(2020)051802

More studies of $D \to K_1(1270)e^+\nu_e$

2.93 fb^{-1}@3.773 GeV

$D \to K_S\pi\pi e^+\nu_e$ **JHEP09(2024)089**

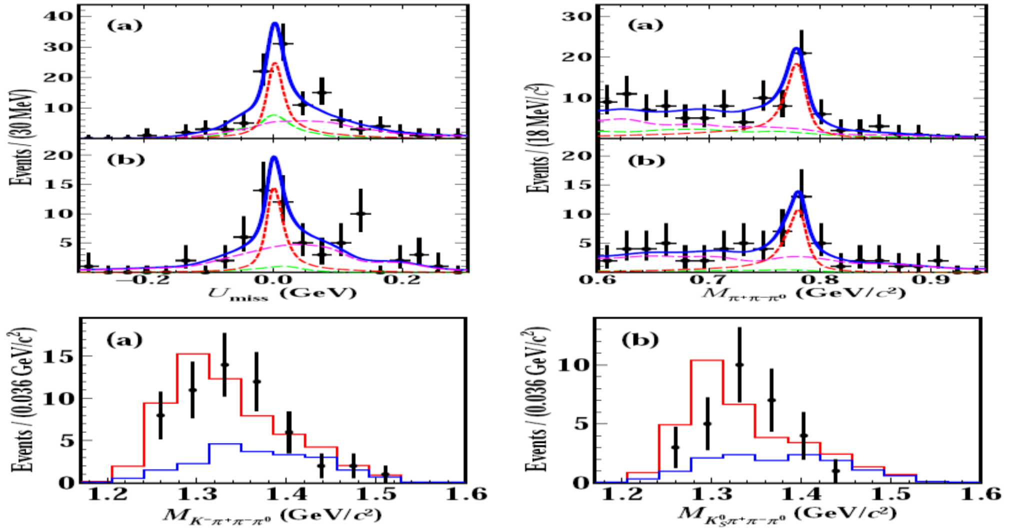


$$\mathcal{B}(D^0 \to K_1(1270)^-(\to K^0_S\pi^-\pi^0)e^+\nu_e) = (1.69^{+0.53}_{-0.46}\pm 0.15)\times 10^{-4}$$

$$\mathcal{B}(D^+ \to \bar{K}_1(1270)^0(\to K^0_S\pi^+\pi^-)e^+\nu_e) = (1.47^{+0.45}_{-0.40}\pm 0.14)\times 10^{-4}$$

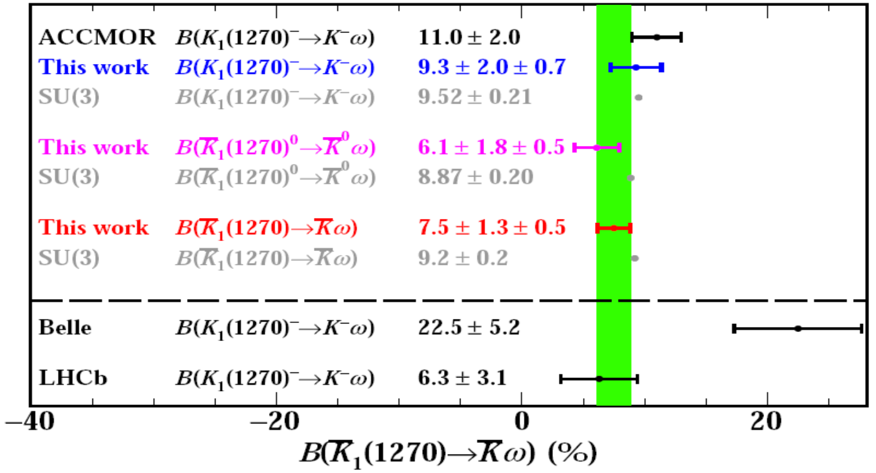
20.3 fb^{-1} @3.773 GeV

$D \to K\omega e^+\nu_e$ **arXiv.2601.01817**



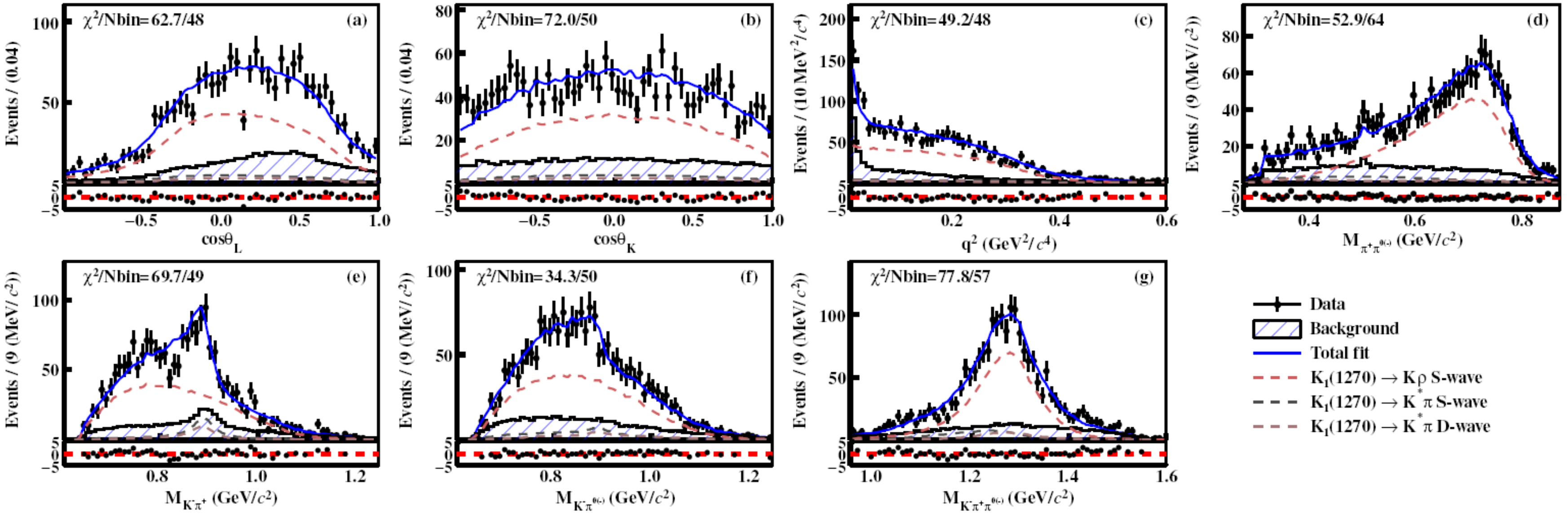
$$\mathcal{B}(D^0 \to K^-\omega e^+\nu_e) = (9.3^{+2.1}_{-1.9}\pm 0.7)\times 10^{-5}$$

$$\mathcal{B}(D^+ \to K^0_S\omega e^+\nu_e) = (6.6^{+2.0}_{-1.8}\pm 0.6)\times 10^{-5}$$

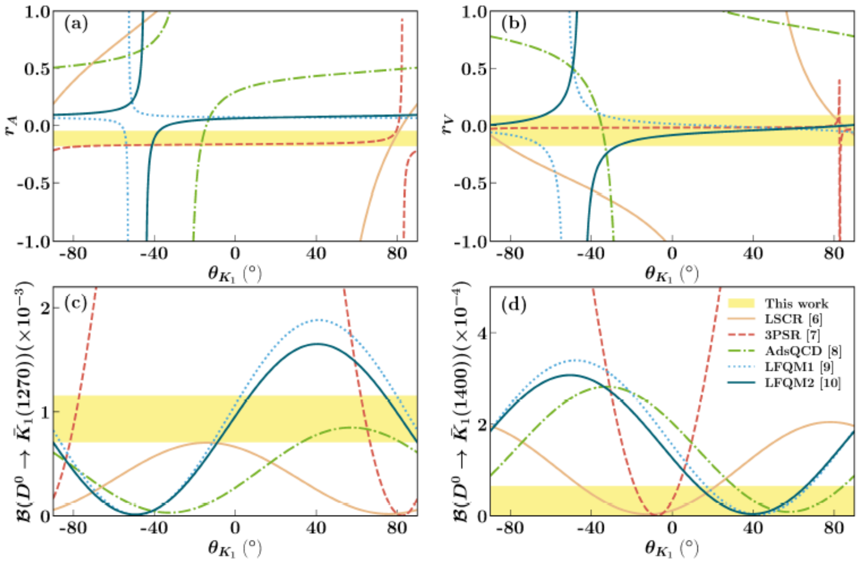


Recent study of $D^{0(+)} \to \bar{K}_1(1270)/\bar{K}_1(1400)e^+\nu_e$

20.3 fb^{-1} @3.773 GeV　　PRL135(2025)091801



Variable	Value
r_A $(\times 10^{-2})$	$-11.2 \pm 1.0 \pm 0.9$
r_V $(\times 10^{-2})$	$-4.3 \pm 1.0 \pm 2.5$
$f^{D^+}_{\rho K^-}$ (%)	$79.3 \pm 2.0 \pm 25.7$
$f^{D^+}_{\pi \bar{K}^*(892)}$ (%)	$10.9 \pm 1.2 \pm 3.0$
$f^{D^+}_{\bar{K}_1(1400)}$ (%)	< 5
$f^{D^0}_{\rho K^-}$ (%)	$71.8 \pm 2.3 \pm 23.9$
$f^{D^0}_{\pi \bar{K}^*(892)}$ (%)	$19.5 \pm 1.9 \pm 5.2$
$f^{D^0}_{\bar{K}_1(1400)}$ (%)	< 9
$m_{K_1(1270)}$ (MeV/c^2)	$1271 \pm 3 \pm 7$
$\Gamma_{K_1(1270)}$ (MeV)	$168 \pm 10 \pm 20$

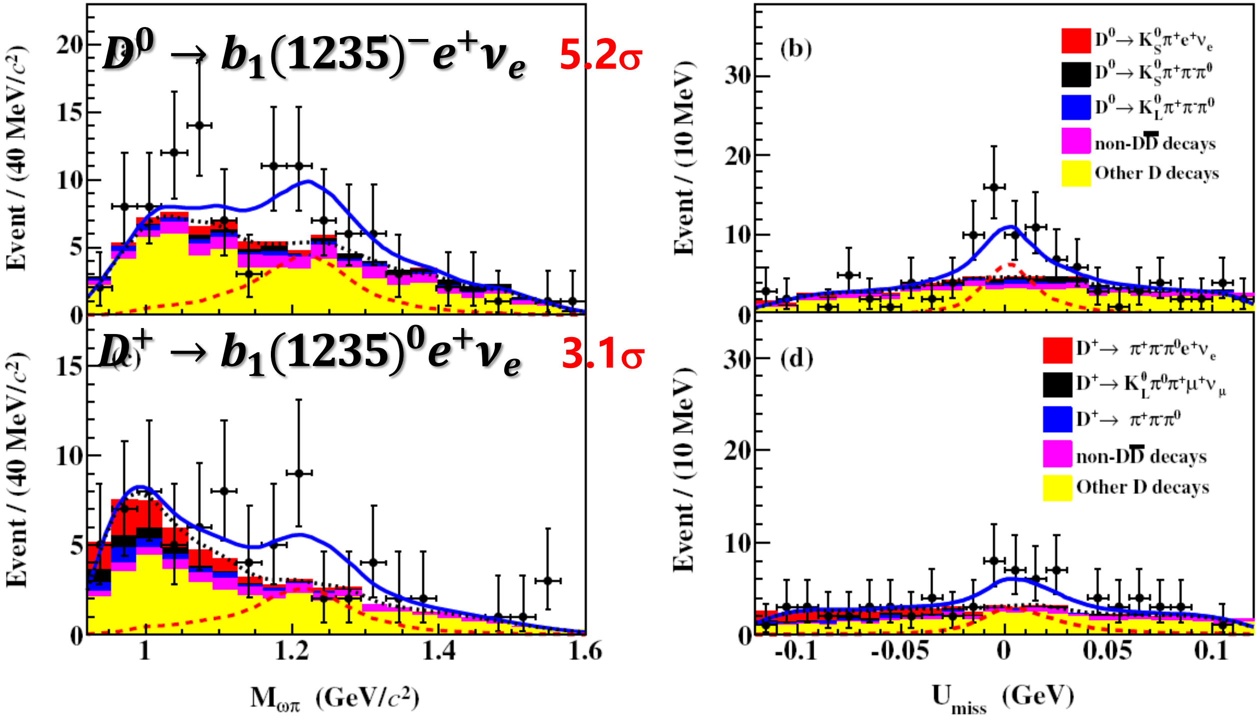


- 首次抽取到$D \to A$跃迁形状因子；
- 精确测量$D \to \bar{K}_1(1270)e^+\nu_e$分支比，首次寻找$D \to \bar{K}_1(1400)e^+\nu_e$；
- 有助于深入探讨轴矢量介子的性质、约束K_1混合角

→有效约束末态包含K_1的τ、D、B等相关的理论计算

Observation/Evidence of $D \to A e^+ \nu_e$

20.3 fb^{-1} @3.773 GeV PRL136(2026)021801



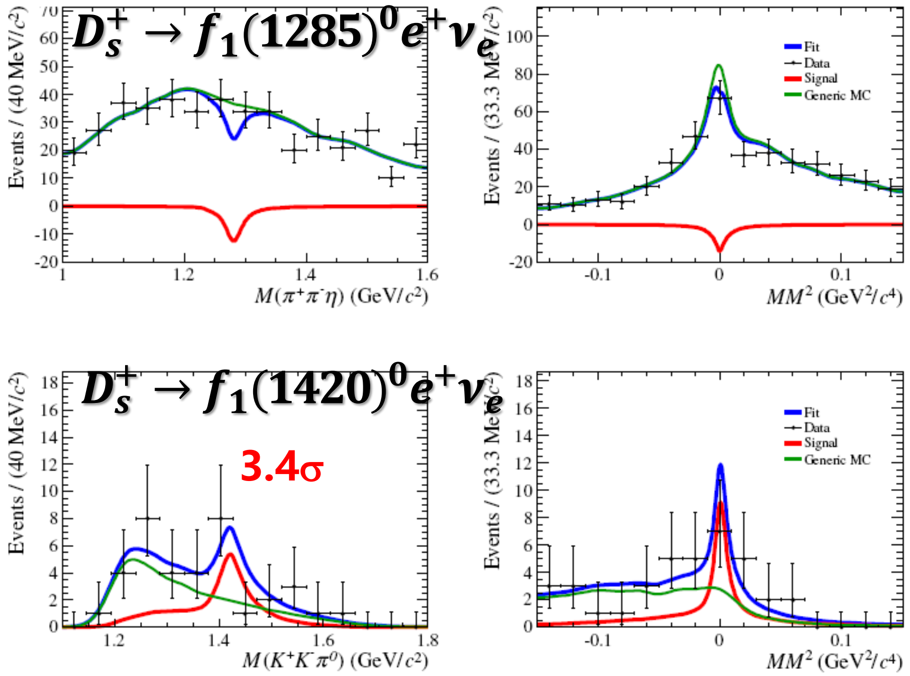
$$\mathcal{B}(D^0 \to b_1(1235)^- e^+ \nu_e) \times \mathcal{B}(b_1(1235)^- \to \omega\pi^-) = (0.72 \pm 0.18^{+0.06}_{-0.08}) \times 10^{-4}$$

$$\mathcal{B}(D^+ \to b_1(1235)^0 e^+ \nu_e) \times \mathcal{B}(b_1(1235)^0 \to \omega\pi^0) = (1.16 \pm 0.44 \pm 0.16) \times 10^{-4}$$

$$\frac{\Gamma(D^0 \to b_1^- e^+ \nu_e)}{2\Gamma(D^+ \to b_1^0 e^+ \nu_e)} = 0.78 \pm 0.19^{+0.04}_{-0.05}$$

Reveal that the ωπ is the dominant decay of b_1

7.33 fb^{-1} @4.13-4.23 GeV arxiv:2601.16938



$$\mathcal{B}(D_s^+ \to f_1(1420) e^+ \nu_e) \cdot \mathcal{B}(f_1(1420) \to K^+ K^- \pi^0)$$
$$(4.5^{+2.0}_{-1.7}(\text{stat}) \pm 0.4(\text{syst})) \times 10^{-4}$$

$$\mathcal{B}(D_s^+ \to f_1(1285) e^+ \nu_e) \cdot \mathcal{B}(f_1(1285) \to \pi^+ \pi^- \eta) < 1.7 \times 10^{-4}$$

Status of semielectronic D decays at BESIII

	D^0		D^+		D_s^+	
$c \to sl^+\nu$	K^-	1.4%→0.48%	$\bar{K}^0$	2.5%→0.63%	η	11%→2.8%
	$K^{*-}(K^-\pi^0)$	7.4%→ongoing	$\bar{K}^{*0}(K^-\pi^+)$	2.7%→1.7%...	η'	23%→5.5%
	$K^{*-}(K_S^0\pi^-)$	7.4%→2.3%...	$\bar{K}^{*0}(K_S^0\pi^0)$	NA→1.7%	ϕ	5.6%→ongoing
	K_1^-	53%→9.8%	$\bar{K}_1^0$	NA→8.8%	$f_0(980)$	16%→9.5%
	b_1^-	NA→27%...	b_1^0	NA→40%...	K^0	27%→8.7%
$c \to dl^+\nu$	π^-	2.8%→1.7%...	π^0	4.4%→2.6%...	K^{*0}	38%→14%...
	ρ^-	9%→3.0%...	ρ^0	11.5%→10%...		
			$f_0(500)$	NA→6.5%...		
			ω	10.4%→8.3%...		
			η	8.8%→4.1%		
			η'	23%→11%		

黄底色：全部数据发表或投稿　　蓝底色：全部数据年内可投稿　　…：已有部分数据测量

Status of semimuonic D decays at BESIII

	D^0		D^+		D_s^+	
$c \to s l^+ \nu$	K^-	4%→0.54%	$\bar{K}^0$	7%→0.68%	η	NA→3.3%
	$K^{*-}(K^-\pi^0)$	13%→2.4%...	$\bar{K}^{*0}(K^-\pi^+)$	3%→ongoing	η'	NA→7.7%
	$K^{*-}(K_S^0\pi^-)$	13%→2.5%...	$\bar{K}^{*0}(K_S^0\pi^0)$	NA→2.1%	ϕ	NA→5.0%
	K_1^-	NA→25%...	$\bar{K}_1^0$	NA→25%...	$f_0(980)$	NA→ongoing
	b_1^-	NA...	b_1^0	NA...	K^0	NA→10%
$c \to d l^+ \nu$	π^-	10%→3.7%...	π^0	NA→4.2%...	K^{*0}	NA→ongoing
	ρ^-	NA→9.4%...	ρ^0	17%→10%...		
			$f_0(500)$	NA→21%...		
			ω	NA→12%...		
			η	NA→4.6%		
			η'	NA→15%		

首次观测到10多个含轻衰变新模式；以世界最高精度测量了其它含轻衰变

Summary of LFU tests at BESIII

	Branching fraction ratio		Reference
μ/e	$D^0 \to K^-$	$0.972 \pm 0.003 \pm 0.004$	arXiv:2601.21185
	$D^0 \to \pi^-$	$0.922 \pm 0.030 \pm 0.022$	PRL121(2018)171803
	$D^0 \to \rho^-$	0.90 ± 0.11	PRD104(2021)L091003
	$D^+ \to \bar{K}^0$	$0.982 \pm 0.004 \pm 0.002$	arXiv:2601.21185
	$D^+ \to \pi^0$	$0.964 \pm 0.037 \pm 0.026$	PRL121(2018)171803
	$D^+ \to \eta$	$0.93 \pm 0.05 \pm 0.02$	arXiv:2506.02521
	$D^+ \to \eta'$	$1.07 \pm 0.19 \pm 0.03$	PRL134(2025)111801
	$D^0 \to K^-\pi^0$	$1.020 \pm 0.030 \pm 0.028$	PRL134(2025)011803
	$D^0 \to K_S^0\pi^-$	$0.955 \pm 0.022 \pm 0.017$	PRL135(2025)111803
	$D^+ \to K_S^0\pi^0$	$0.94 \pm 0.02 \pm 0.01$	PRL135(2025)171801
	$D^0 \to K_1^-$	$0.74 \pm 0.13 \pm 0.13$	PRD111(2025)L071101
	$D^+ \to \bar{K}_1^0$	$1.03 \pm 0.14 \pm 0.015$	

SM predictions for semileptonic decays: 0.90-0.99

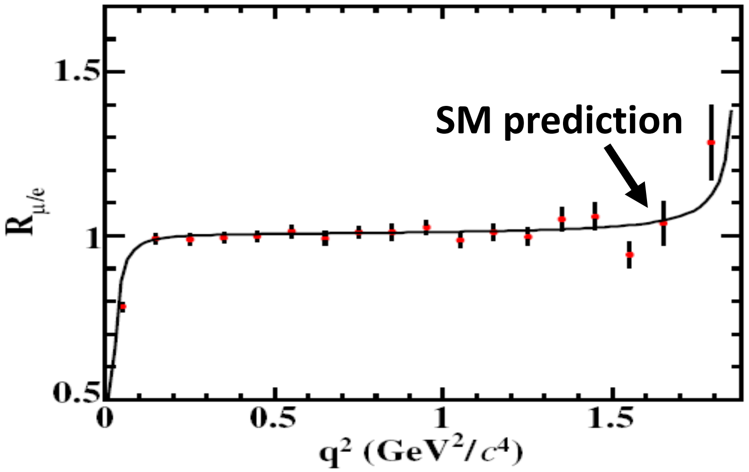
14 new decay modes are observed

No deviation greater than 1.7σ is found!

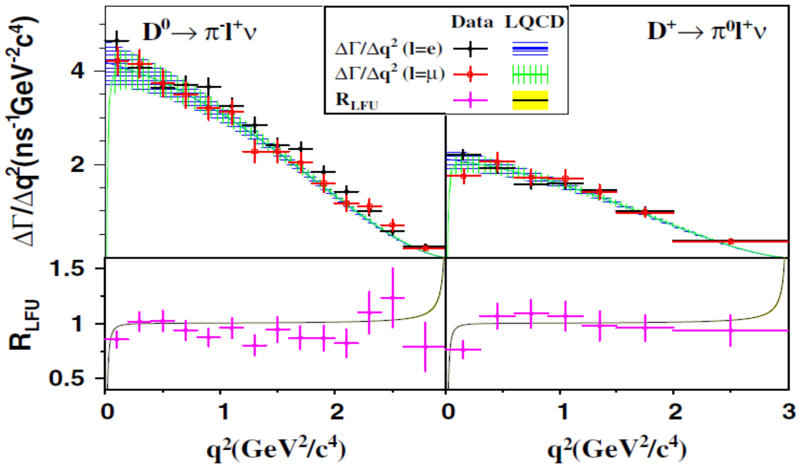
	Branching fraction ratio		Reference
μ/e	$D^+ \to \omega$	1.05 ± 0.14	PRD101(2020)072005
	$D^+ \to f_0$	1.14 ± 0.28	PRD110(2024)092008
	$D^+ \to \rho^0$	0.88 ± 0.10	PRD110(2024)092008
	$D_s^+ \to \eta$	$0.984 \pm 0.028 \pm 0.016$	PRL132(2024)091802
	$D_s^+ \to \eta'$	$0.989 \pm 0.082 \pm 0.034$	
	$D_s^+ \to K^0$	$0.97 \pm 0.12 \pm 0.04$	arXiv:2510.05904
	$D_s^+ \to \phi$	0.94 ± 0.08	JHEP12(2023)072
τ/μ	$D^+ \to \tau^+$	2.49 ± 0.31	JHEP01(2025)089
	$D_s^+ \to \tau^+$	10.05 ± 0.35	PRL127(2021)171801

μ-e LFU tests with semileptonic decays in different q^2 bins

$D^0 \to K^- \mu^+ \nu_\mu$ PRL122(2019)011804 → PRD110(2024)012006

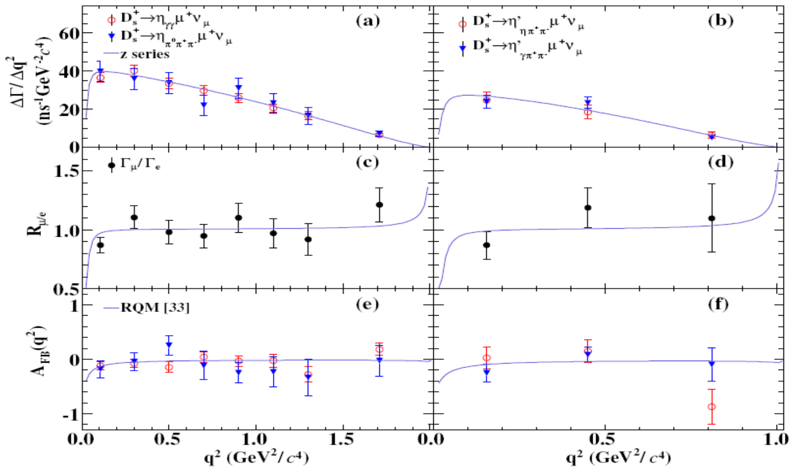


$D^{0,+} \to \pi^{-,0} \mu^+ \nu_\mu$ PRL121(2018)171803

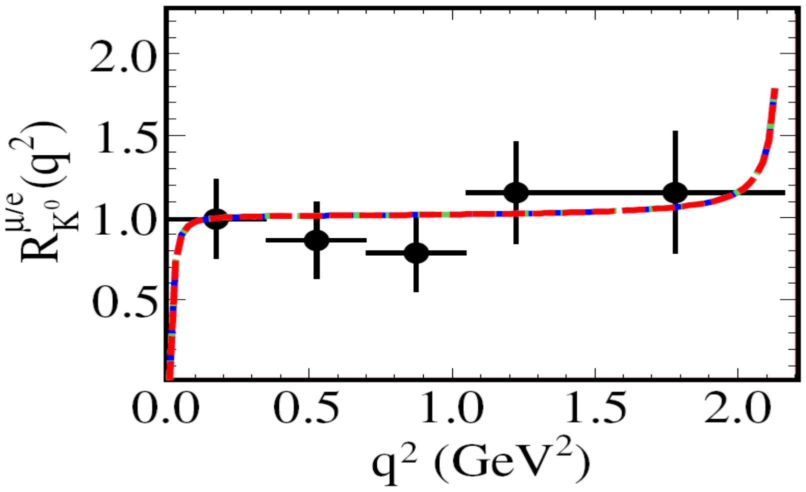


SM predictions: 0.93-0.99

$D_s^+ \to \eta^{(\prime)} \mu^+ \nu_\mu$ PRD97(2018)012006 → PRL132(2024)091802



$D_s^+ \to K^0 \mu^+ \nu_\mu$ arXiv:2510.05904



Summary

- **With current 20.3 fb^{-1}@3.773 GeV and 7.33 fb^{-1}@(4.13-4.23) GeV, many results of (semi)leptonic D decays have been obtained**

$|V_{cs}|$: 1.6% → <0.5%

$|V_{cd}|$: 3.6% → ~1%...

$f_+^{D\to K}(0)$: 0.3%

$f_+^{D\to\pi}(0)$: 1.6%...

$LFU_{\mu/e}$: ~0.5%

$LFU_{\tau/\mu}$: ~3.5%

……

- **Studies of Cabibbo-suppressed decays are relatively slow**

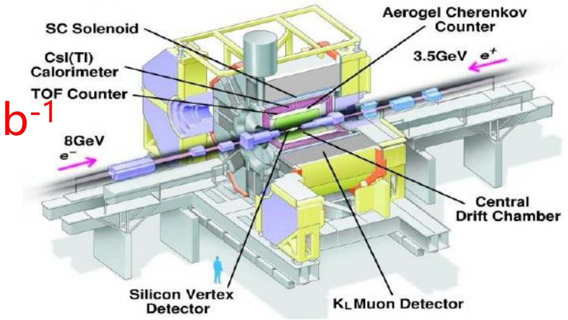
- **More data around 4.2 GeV?**

谢谢!

Experiments and data samples

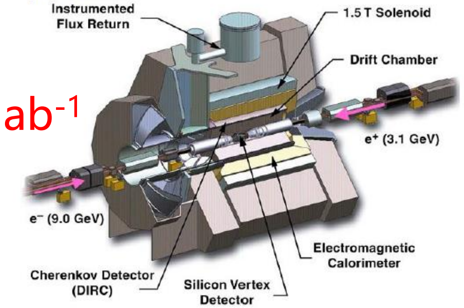
Belle @ KEKB
e^+e^- : ~10.6 GeV ($\Upsilon(4S)$)
$\sigma(e^+e^- \to cc)$ = 1.3 nb
$L_{peak} = 2 \times 10^{34}\ cm^{-2}\ s^{-1}$

0.98 ab^{-1}

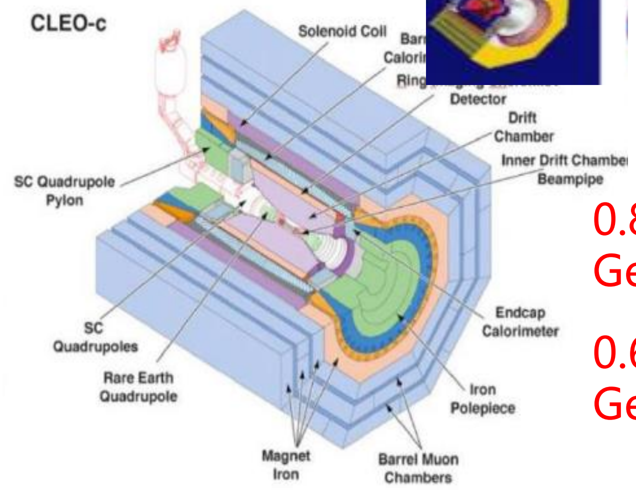


BaBar @ PEP-II
e^+e^- : ~10.6 GeV ($\Upsilon(4S)$)
$\sigma(e^+e^- \to cc)$ = 1.3 nb
$L_{peak} = 1 \times 10^{34}\ cm^{-2}\ s^{-1}$

0.54 ab^{-1}



CLEO-c



0.8 fb^{-1}@3.774 GeV

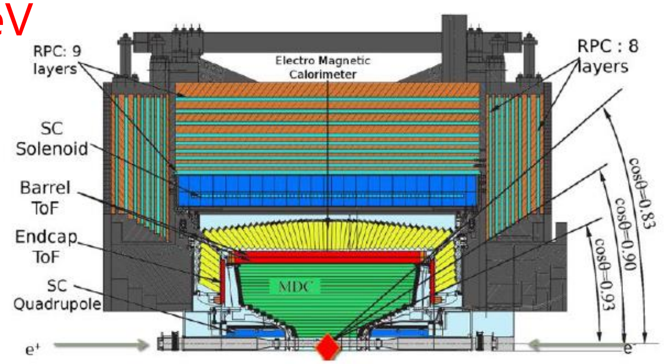
0.6 fb^{-1}@4.170 GeV

BESIII @ BEPC II
e^+e^- : 2-4.6 GeV
$\sigma(e^+e^- \to cc)$ = 3 nb
$L_{peak} = 1 \times 10^{33}\ cm^{-2}\ s^{-1}$

2.93 fb^{-1}@3.773 GeV

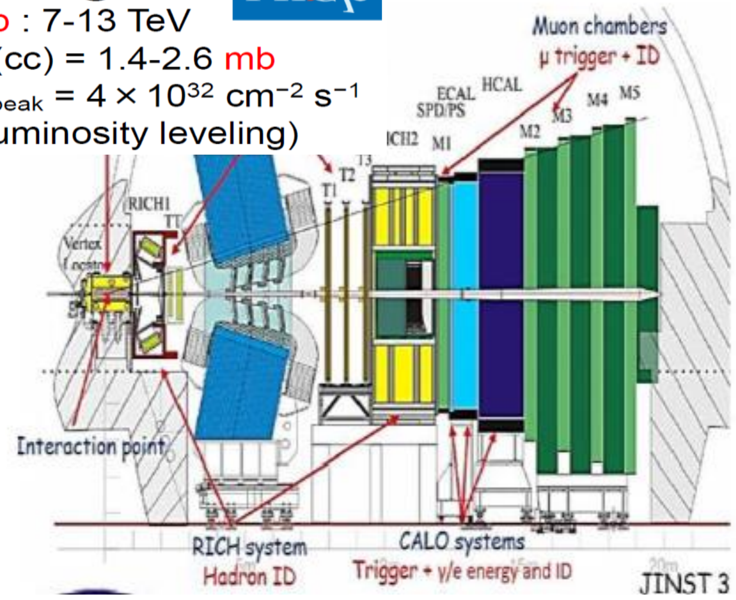
7.33 fb^{-1}@4.13-4.23 GeV

4.50 fb^{-1}@4.6-4.7 GeV



LHCb @ LHC
pp : 7-13 TeV
$\sigma(cc)$ = 1.4-2.6 mb
$L_{peak} = 4 \times 10^{32}\ cm^{-2}\ s^{-1}$
(luminosity leveling)

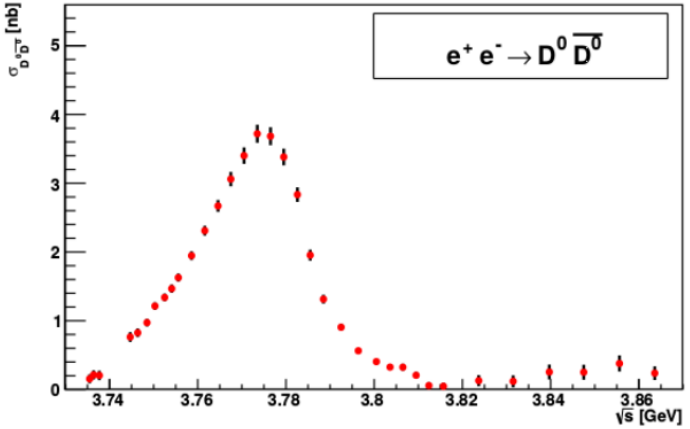
9 fb^{-1}

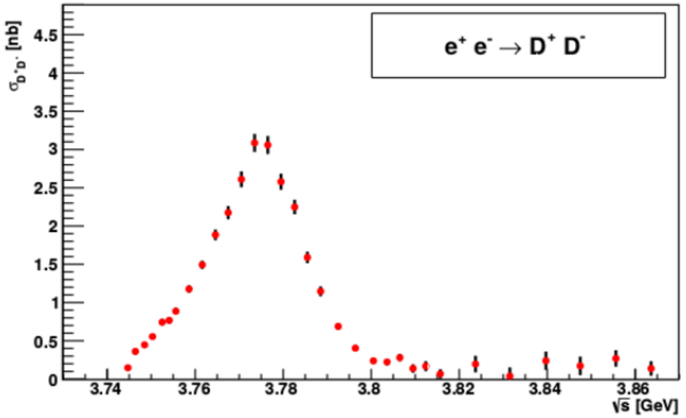


Production of charmed mesons at BESIII

$e^+e^- \to \psi(3770) \to D\bar{D}$

2.93→20.3 fb^{-1}@3.773 GeV

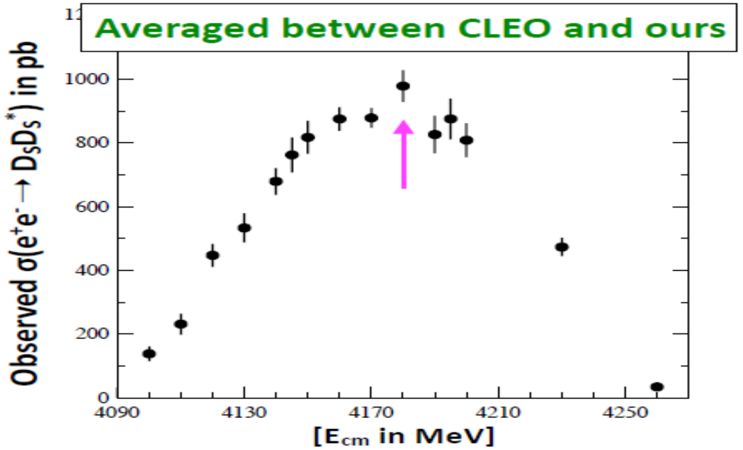




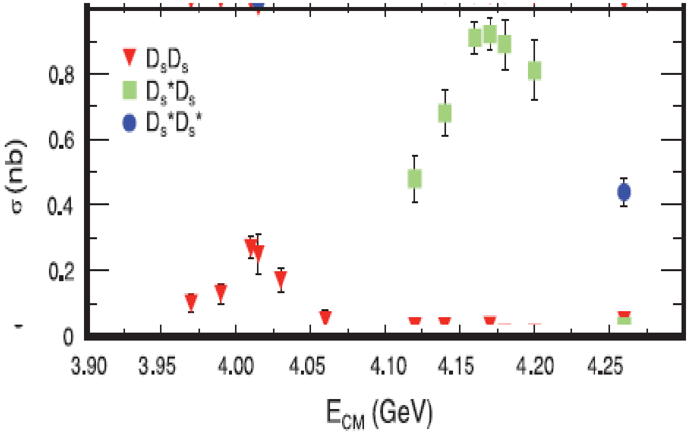
ψ(3770)质量刚刚高于$D^0\bar{D}^0$和D^+D^-对产生阈能量, 是研究D介子衰变的最理想的源

$e^+e^- \to \psi(4160) \to D_s^+D_s^{*-} + c.c.$

3.19→7.33 fb^{-1}@4.13-4.23 GeV

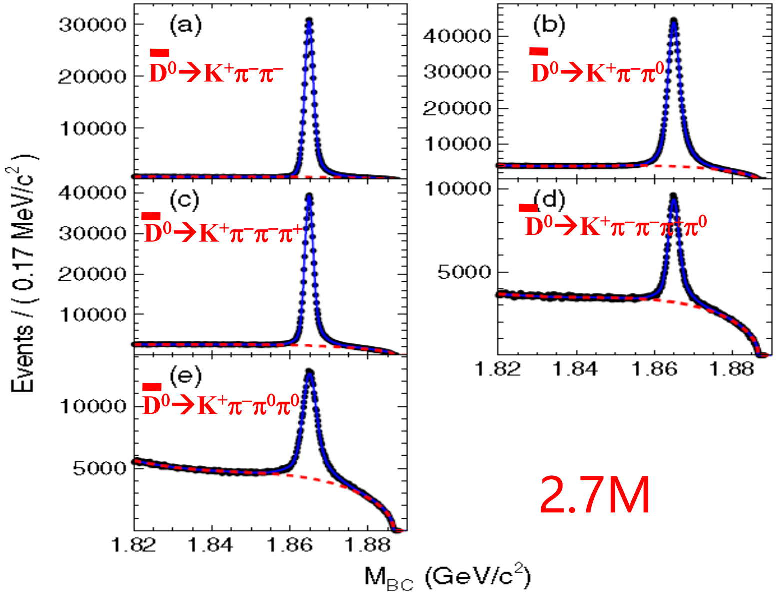


CLEO, PRD80, 072001 (2009)



Single-tag charmed mesons at BESIII

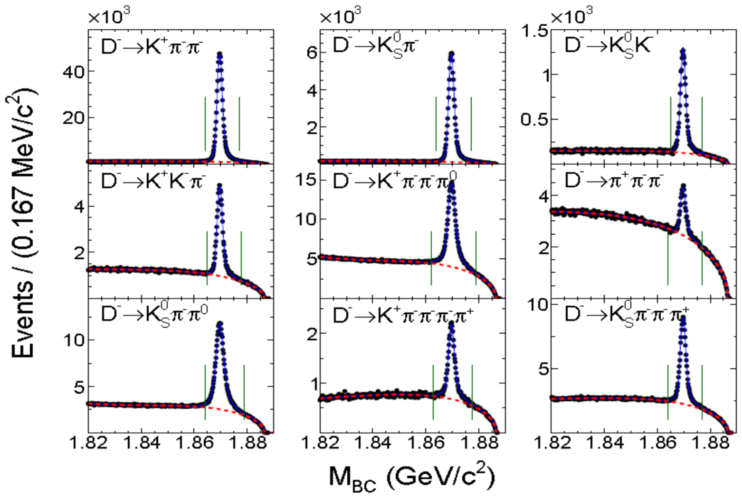
$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$



2.93→20.3 fb^{-1}
@3.773 GeV

2.7M

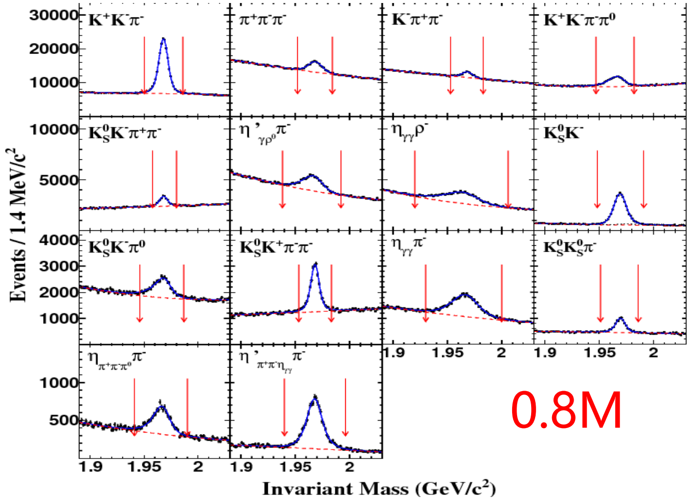
$e^+e^- \to \psi(3770) \to D^+D^-$



2.93→20.3 fb^{-1}
@3.773 GeV

1.7M

$e^+e^- \to \psi(4160) \to D_s^+ D_s^{*-} + c.c.$



3.19→7.33 fb^{-1}
@4.13-4.23 GeV

0.8M

The total single-tag yields of $\bar{D}^0$, D^-, and D_s^- are >20, >20, and 9 times CLEO-c, respectively

Comparisons of other $D \to P$ form factors