Measurements of $|V_{cd(s)}|$, decay constants and form factors in (semi-)leptonic $D_{(s)}$ decays at BESIII

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Outline

- Introduction
- Leptonic charmed meson decays
  - $D^+ \to l^+\nu_l$
  - $D_s^+ \to l^+\nu_l$ $(l = \mu, \tau)$
- Semileptonic charmed meson decay
  - $D_{(s)} \to P\ l^+\nu_l$
  - $D_{(s)} \to V\ l^+\nu_l$ (P: psuedoscalar meson, V: vector meson)
  - $D_{(s)} \to S\ l^+\nu_l$
  - $D_{(s)} \to A\ l^+\nu_l$ (S: scalar meson, A: axial vector meson)
- Summary & Outlook

Introduction: Physics motivation

Charm Physics:

- Nonperturbative region ➔ QCD
- High precision frontier ➔ SM test

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9984 \pm 0.0007$$

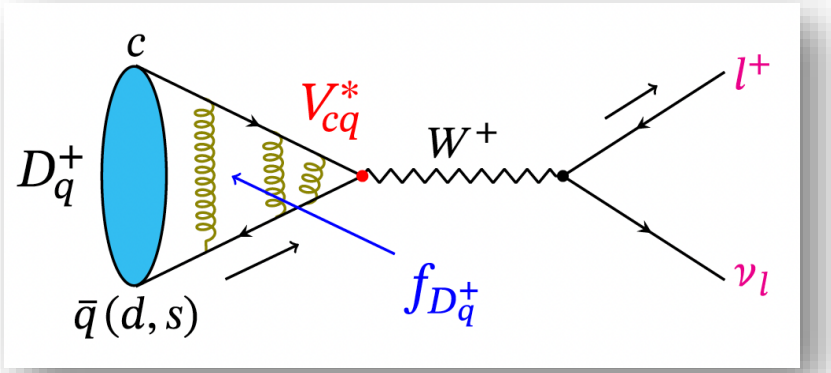
$$|V_{ud}|^2 + |V_{cd}|^2 + |V_{td}|^2 = 0.9986 \pm 0.0011$$

$$|V_{us}|^2 + |V_{cs}|^2 + |V_{ts}|^2 = 0.991 \pm 0.010$$

$$|V_{cd}|^2 + |V_{cs}|^2 + |V_{ub}|^2 = 0.991 \pm 0.010$$

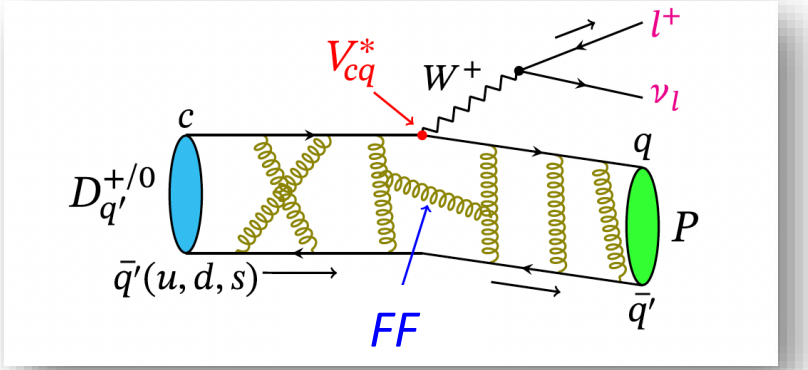
Introduction: Physics motivation

Leptonic decays: $D^+_{(s)} \to l^+\nu_l$



$\Gamma \propto f^2_{D_{(s)}} |V_{cd(s)}|^2$

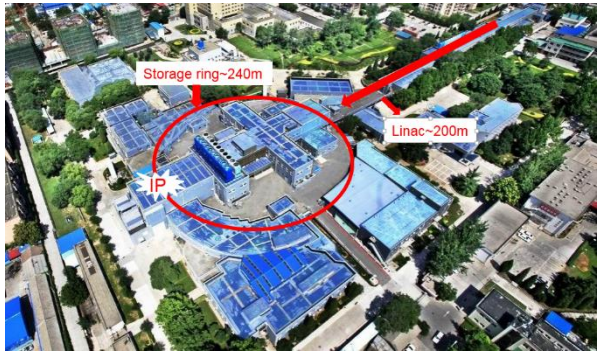
Semileptonic decays: $D^{+/0}_{(s)} \to Pl^+\nu_l$

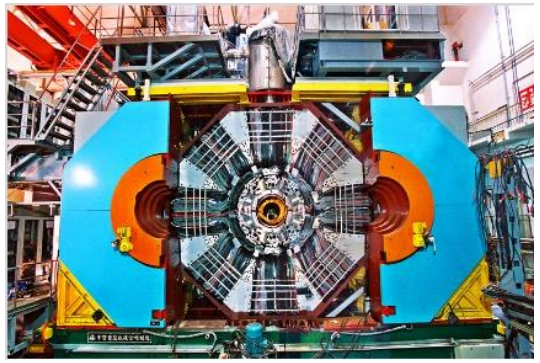


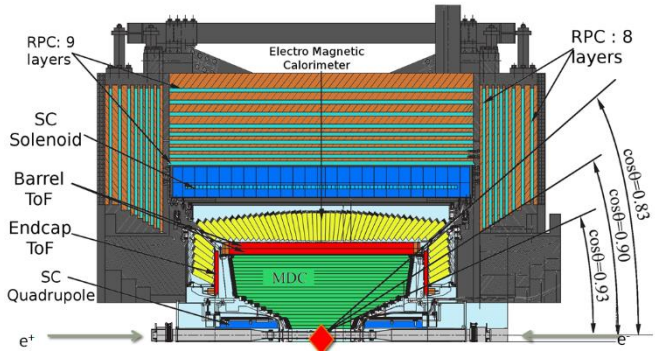
$\Gamma \propto |V_{cd(s)}|^2 \, |FF|^2$

- Decay constants and hadronic Form factor (*FF*) ➔ test and calibrate LQCD
- CKM matrix elements $|V_{cd(s)}|$ ➔ test CKM matrix unitarity
- Branching fraction (BF) ratios $\mathcal{R}^X_{\tau/\mu}, \mathcal{R}^X_{\mu/e}$ ➔ test Lepton flavor universality (LFU)
- BF and FF measurements in semileptonic decays ➔ study light hadrons

Introduction: BESIII experiment & data information





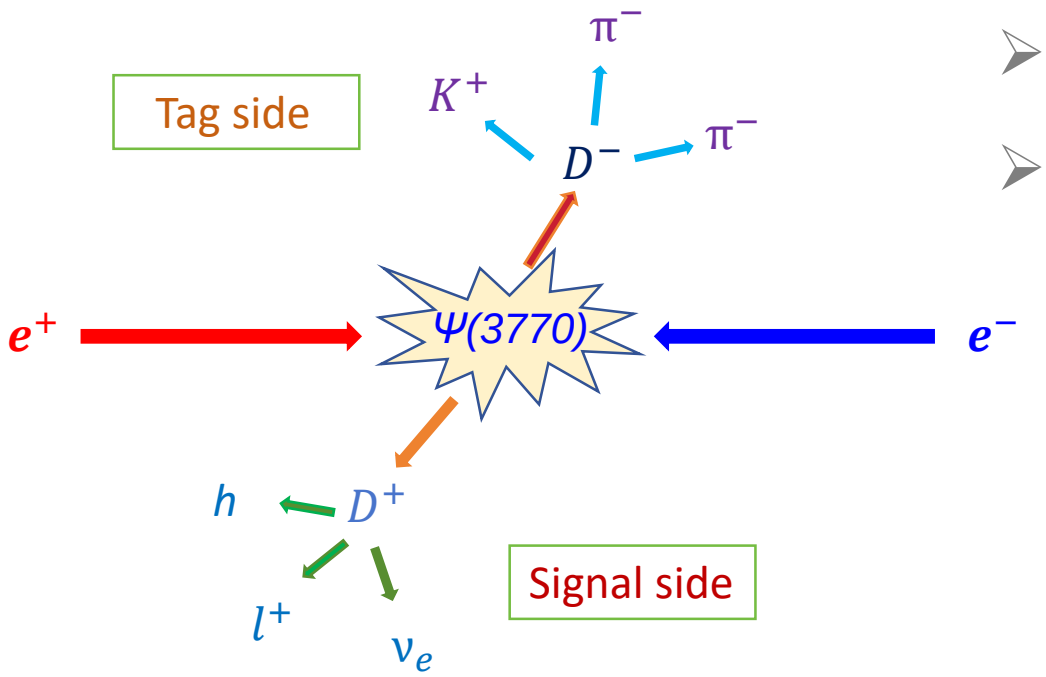


- Symmetric e^+ e^- collider
- $\sqrt{s} = 1.84 - 4.95$ GeV
- Charm mesons collected through pair production near threshold

- MDC: σ_p = 0.5% , $\sigma_{dE/dx}$ = 2.5% (6%) for barrel (endcap)
- TOF: σ_T = 68 (110) ps for barrel (endcap)
- EMC: σ_E = 2.5%(5%) for barrel (endcap)

Data sample	Data size (fb^{-1})	Energy region (GeV)	Single tag yields($\times 10^6$)
$e^+e^- \to \psi(3770) \to D\bar{D}$	20.3	3.773	$N_{ST}^{\bar{D}^0}$ ~16.9, $N_{ST}^{D^-}$ ~11.5
$e^+e^- \to D_s^{\pm}D_s^{*\mp}$	7.33	4.128 - 4.226	$N_{ST}^{D_s^-}$ ~0.8

Introduction: Double tag method



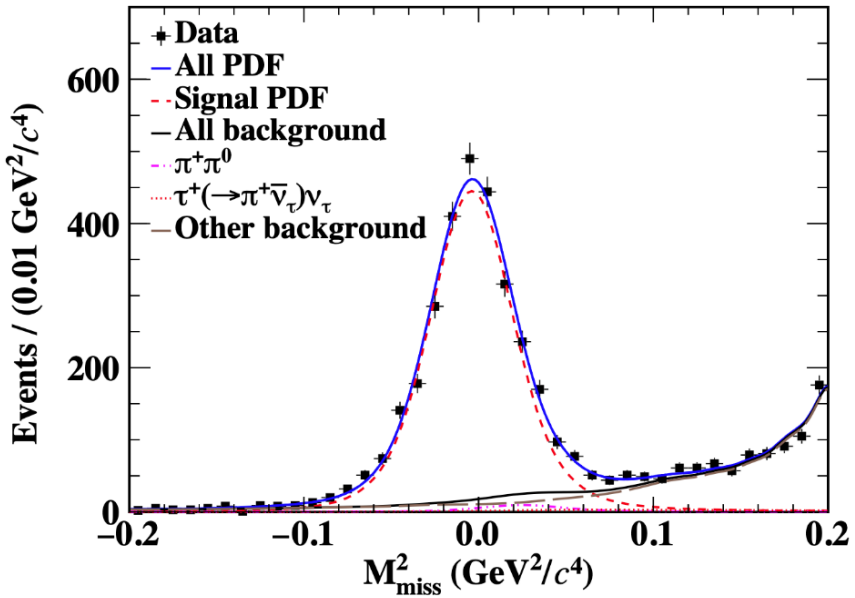
- Production near threshold: clean environment
- Systematic uncertainties from tag mostly canceled
- Almost full reconstruction

- $U_{\rm miss} = E_{\rm miss} - |\vec{p}_{\rm miss}|$
- $M^2_{\rm miss} = E^2_{\rm miss} - |\vec{p}_{\rm miss}|^2$

- $\mathcal{B} = \dfrac{N_{\rm sig}}{N_{\rm tag}\epsilon_{\rm sig}/\epsilon_{\rm tag}}$

$D\to l^+\nu_l$: $D^+ \to \mu^+\nu_\mu$ & $D^+ \to \tau^+\nu_\tau$

$D^+ \to \mu^+\nu_\mu$

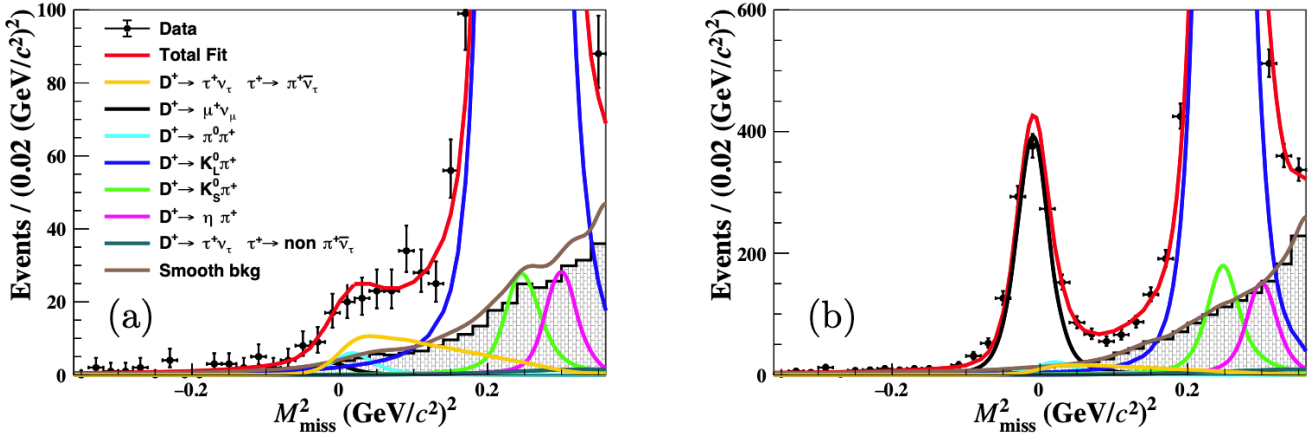


- 20.3 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 2832.7 \pm 56.8$
- $\mathcal{B}(D^+ \to \mu^+\nu_\mu) = (4.034 \pm 0.08 \pm 0.04) \times 10^{-4}$ (σ~2.2%)
- $f_{D^+}|V_{cd}| = (48.02 \pm 0.48 \pm 0.24 \pm 0.12_{\text{input}} \pm 0.15_{\text{EM}})$ MeV (σ~ 1.2%)
  - $f_{D^+} = (213.5 \pm 2.1_{stat} \pm 1.1_{syst} \pm 0.8_{input} \pm 0.7_{EM})$MeV
  - $|V_{cd}| = 0.2265 \pm 0.0023_{stat} \pm 0.0011 \pm 0.0009_{input} \pm 0.007_{EM}$

PRL 135, 061801 (2025)

$D^+ \to \tau^+\nu_\tau$, $\tau^+ \to \pi^+\bar{\nu}_\tau$

π-like: $E_{\text{EMC}} > 300$MeV μ-like: $E_{\text{EMC}} < 300$MeV



- 7.9 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 283 \pm 32$
- $\mathcal{B}(D^+ \to \tau^+\nu_\tau) = (9.9 \pm 1.1 \pm 0.5) \times 10^{-4}$ (σ~ 12.2%)
- $f_{D^+}|V_{cd}| = (45.9 \pm 2.5 \pm 1.2 \pm 0.1_{\text{input}})$ MeV (σ~6.0%)
  - $f_{D^+} = (204 \pm 11_{stat} \pm 5_{syst} \pm 1_{input})$MeV
  - $|V_{cd}| = 0.216 \pm 0.012_{stat} \pm 0.006_{syst} \pm 0.001_{input}$
- $\mathcal{R}_{\tau/\mu} = 2.49 \pm 0.31$ **vs** SM: 2.69 ➔ **No LFUV**

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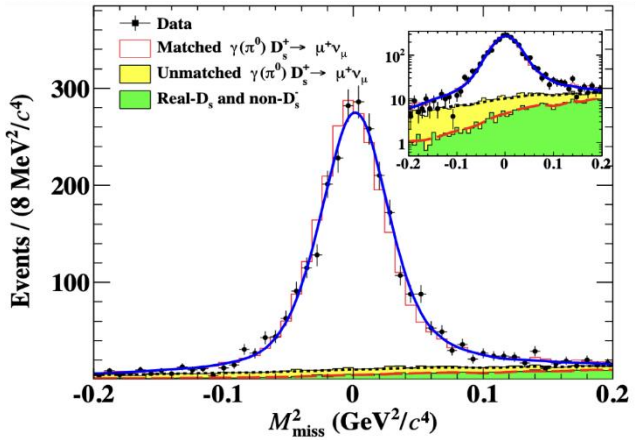
$D_s^+ \to l^+\nu_l$: $D_s^+ \to \mu^+\nu_\mu$ & $D_s^+ \to \tau^+\nu_\tau$

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

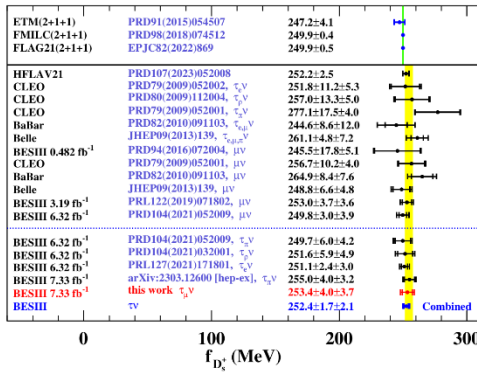
$D_s^+ \to \mu^+\nu_\mu$

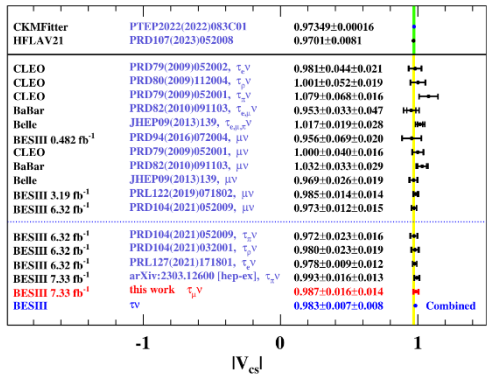


- $\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (0.5294 \pm 0.0108 \pm 0.0085)\%$ ($\sigma\sim$ 2.6%)
- $f_{D_s^+}|V_{cs}| = (241.8 \pm 2.5 \pm 2.2)$ MeV ($\sigma\sim$ 1.4%)
  - $f_{D_s^+} = (248.4 \pm 2.5_{\rm stat} \pm 2.1_{\rm syst})$MeV
  - $|V_{cs}| = 0.986 \pm 0.010_{\rm stat} \pm 0.009_{\rm syst}$

PRD 108, 112001 (2023)

$D_s^+ \to \tau^+\nu_\tau$, $\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$





- $\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.37 \pm 0.17 \pm 0.15)\%$ ($\sigma\sim$ 4.2%)
- $f_{D_s^+}|V_{cs}| = (246.7 \pm 3.9 \pm 3.6)$MeV ($\sigma\sim$ 2.2%)
  - $f_{D_s^+} = (253.4 \pm 4.0_{\rm stat} \pm 3.7_{\rm syst})$MeV
  - $|V_{cs}| = 0.987 \pm 0.016_{\rm stat} \pm 0.014_{\rm syst}$
- $\mathcal{R}_{\tau/\mu} = 9.89 \pm 0.50$ **vs** SM: 9.75 ± 0.01

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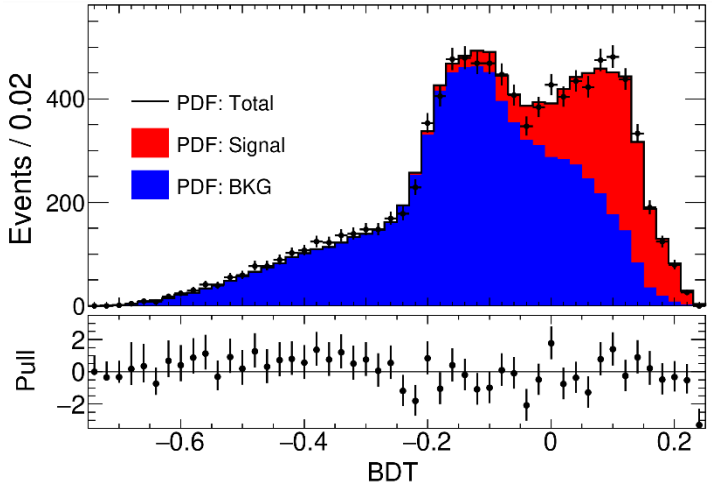
$D_s^+ \to \tau^+\nu_\tau$, $\tau^+ \to \pi^+\bar{\nu}_\tau$

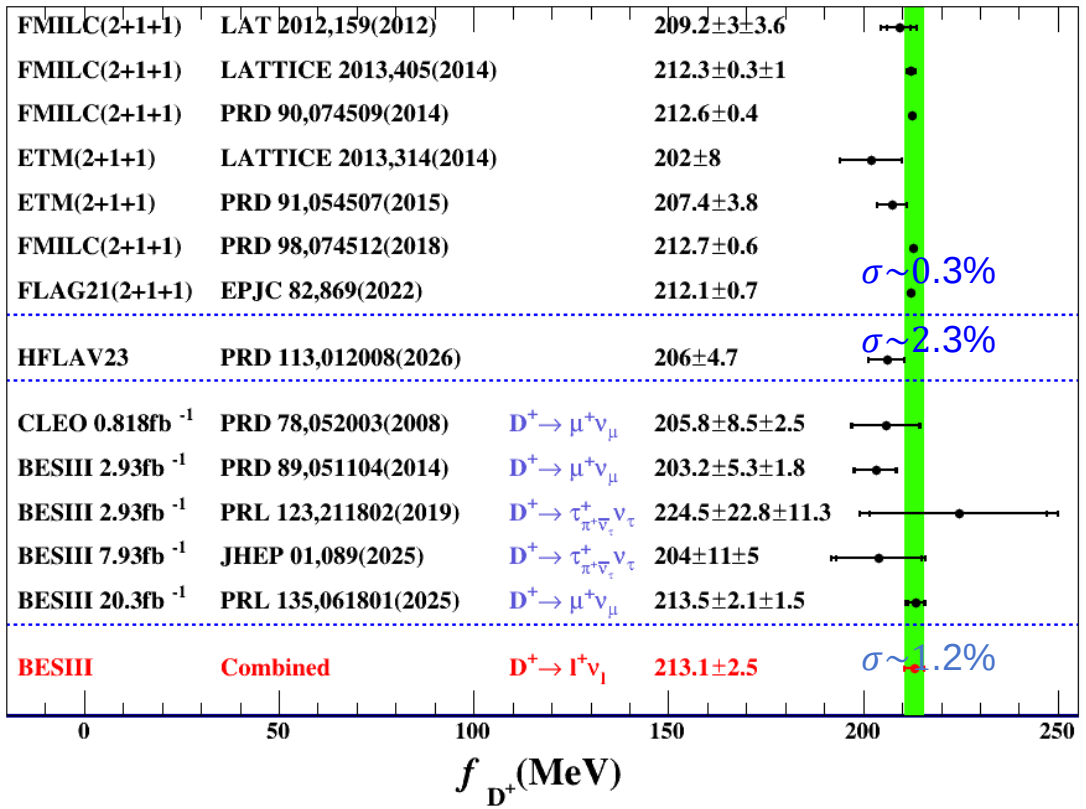


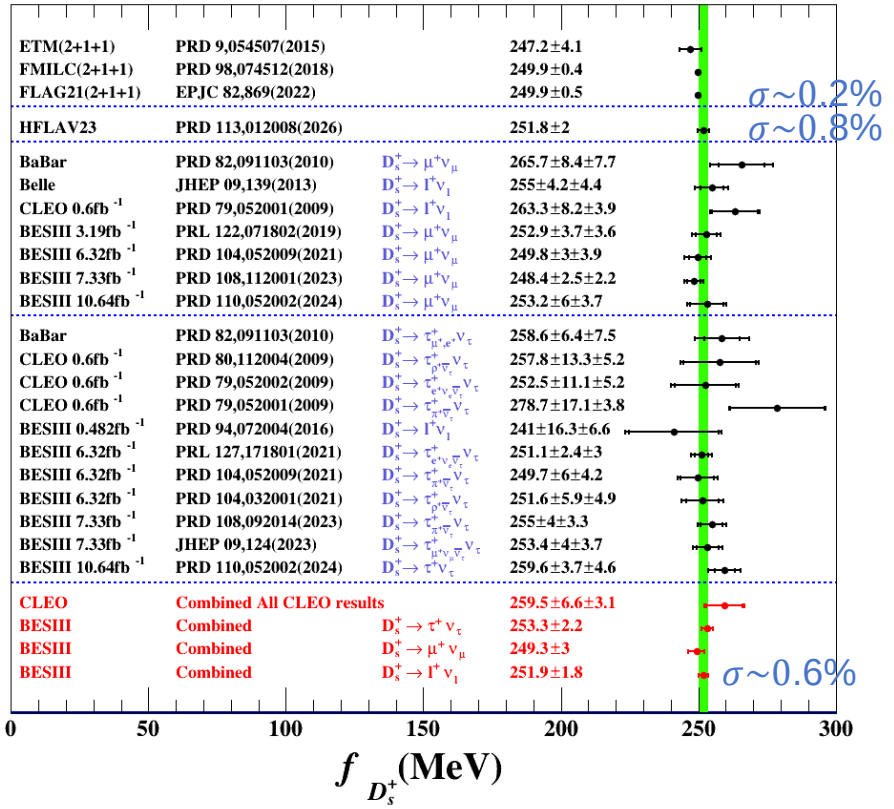
- $\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.44 \pm 0.17 \pm 0.13)\%$ ($\sigma\sim$ 3.9%)
- $f_{D_s^+}|V_{cs}| = (248.3 \pm 3.9 \pm 3.1)$MeV ($\sigma\sim$ 2.0%)
  - $f_{D_s^+} = (255.0 \pm 4.0_{\rm stat} \pm 3.2_{\rm syst} \pm 1.0_{\rm input})$MeV
  - $|V_{cs}| = 0.993 \pm 0.015_{\rm stat} \pm 0.012_{\rm syst} \pm 0.004_{\rm input}$
- $\mathcal{R}_{\tau/\mu} = 9.81 \pm 0.33$ **vs** SM: 9.75 ± 0.01

PRD 108, 092014 (2023)

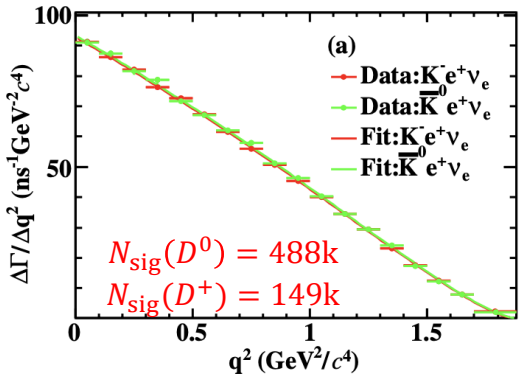
Decay constants

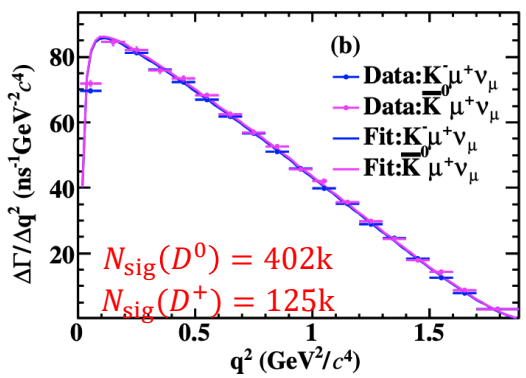
- The decays constants f_{D^+} and $f_{D_s^+}$ are measured with precision of 1.2% and 0.6%!
- These results are consisting with the Lattice QCD provided by FLAG in 2022.

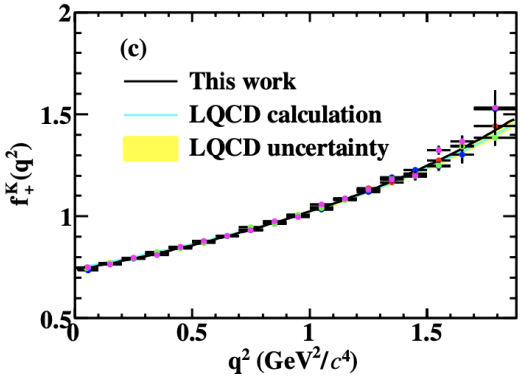


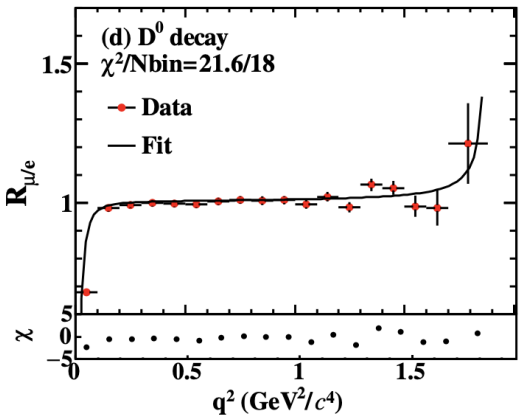


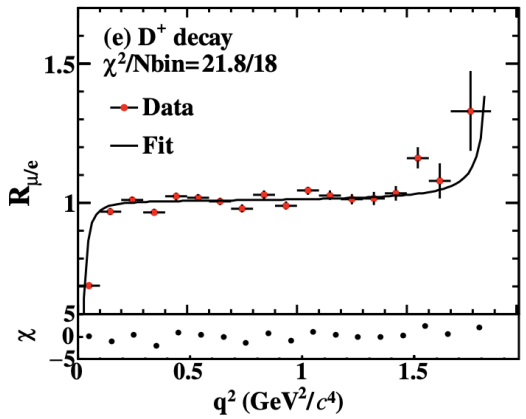
$D\to P\, l^+\nu_l$: $D^0 \to K^- l^+\nu_l$ & $D^+ \to \bar{K}^0 l^+\nu_l$











$\mathcal{R}_{\mu/e}^{D^0} = 0.972 \pm 0.003 \pm 0.004$ ($\sigma\sim 5.1\%$)

$\mathcal{R}_{\mu/e}^{D^+} = 0.982 \pm 0.004 \pm 0.002$ ($\sigma\sim 4.6\%$)

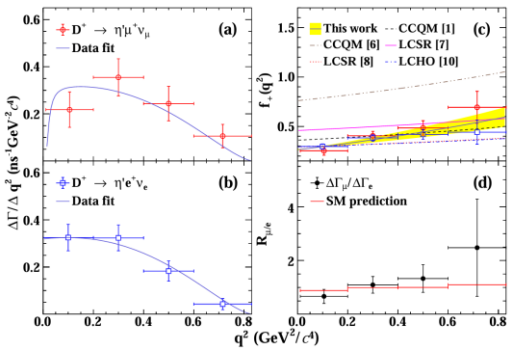
SM: 0.975 ± 0.001

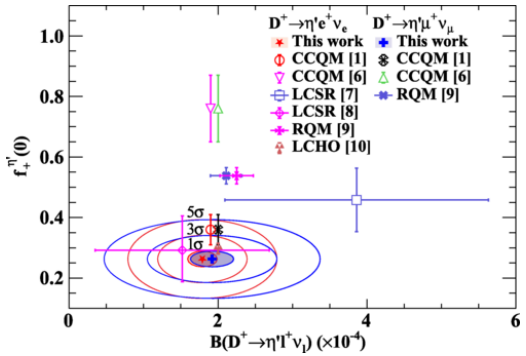
- 20.3 fb^{-1} data @ 3.773 GeV
- $\mathcal{B}(D^0 \to K^- e^+\nu_e) = (3.548 \pm 0.006 \pm 0.017)\%$ ($\sigma\sim 4.6\%$)
- $\mathcal{B}(D^0 \to K^- \mu^+\nu_\mu) = (3.445 \pm 0.007 \pm 0.017)\%$ ($\sigma\sim 5.4\%$)
- $\mathcal{B}(D^+ \to \bar{K}^0 e^+\nu_e) = (8.928 \pm 0.025 \pm 0.050)\%$ ($\sigma\sim 6.3\%$)
- $\mathcal{B}(D^+ \to \bar{K}^0 \mu^+\nu_\mu) = (8.770 \pm 0.029 \pm 0.053)\%$ ($\sigma\sim 6.8\%$)
- $f_+^K(0)|V_{cd}| = 0.7183 \pm 0.0007 \pm 0.0014$ ($\sigma\sim 2.2\%$)

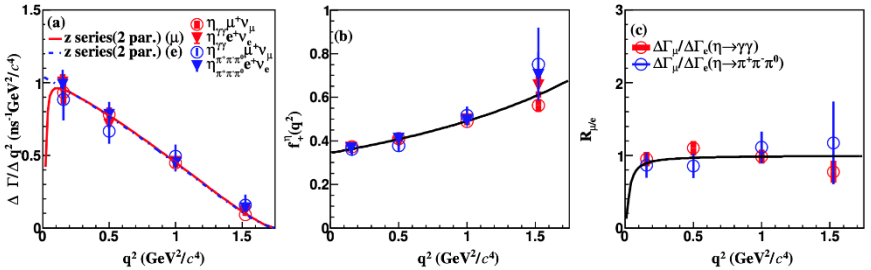
arXiv:2601.21185, 2601.21196 (Submitted to PRL and PRD)

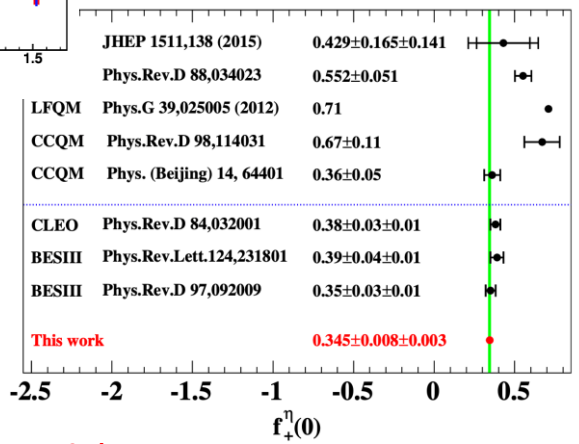
$D \to P\, l^+\nu_l$: $D^+ \to \eta'(\eta)\ell^+\nu_\ell$

20.3 fb^{-1} data @ 3.773 GeV









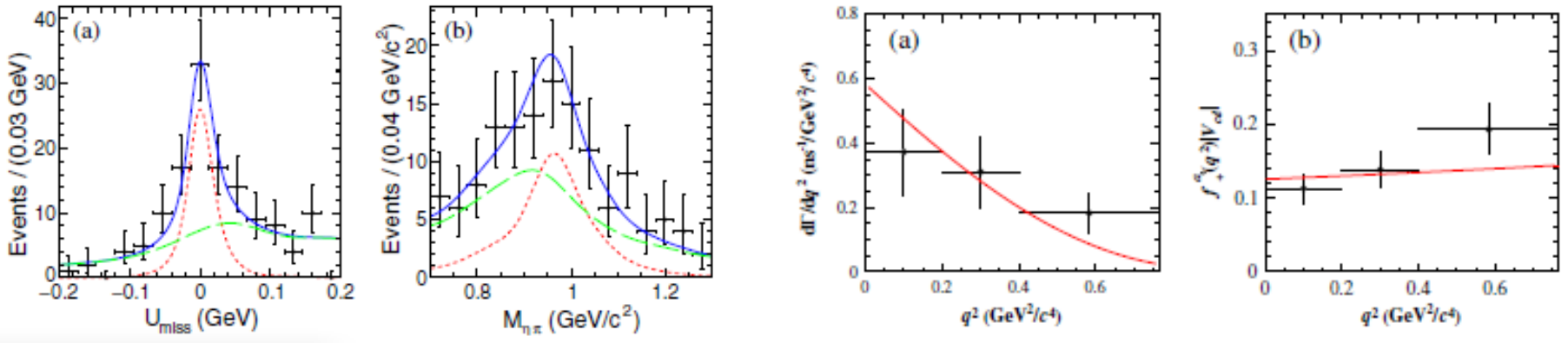
- $\mathcal{B}(D^+ \to \eta'\mu^+\nu_\mu) = (1.92 \pm 0.28 \pm 0.08) \times 10^{-4}$ 8.6σ
- $\mathcal{B}(D^+ \to \eta' e^+\nu_e) = (1.79 \pm 0.19 \pm 0.07) \times 10^{-4}$
- **LFU** test : $\mathcal{R}_{\mu/e} = 1.09 \pm 0.19 \pm 0.03$
- $f_+^{\eta'}(0)|V_{cd}| = (5.92 \pm 0.56 \pm 0.13) \times 10^{-2}$ (σ ~9.7%)
  - $f_+^{\eta'}(0) = 0.263 \pm 0.025 \pm 0.006$
- $\eta - \eta'$ mixing angle: $\phi_P = (39.8 \pm 0.8 \pm 0.3)^\circ$

PRL 134, 111801 (2025)

- $\mathcal{B}(D^+ \to \eta\, e^+\nu_e) = (9.75 \pm 0.29 \pm 0.28) \times 10^{-4}$ (σ~4.1%)
- $\mathcal{B}(D^+ \to \eta\, \mu^+\nu_\mu) = (9.08 \pm 0.35 \pm 0.23) \times 10^{-4}$ (σ ~4.6%)
- **LFU** test : $\mathcal{R}_{\mu/e} = 0.93 \pm 0.05 \pm 0.03$
- $f_+^{\eta}(0)|V_{cd}| = (0.078 \pm 0.002 \pm 0.001) \times 10^{-2}$ (σ ~2.9%)
  - $f_+^{\eta}(0) = 0.345 \pm 0.008 \pm 0.003$.

arXiv:2506.02521 (Submitted to JHEP)

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



- 7.93 fb^{-1} data @ 3.773 GeV

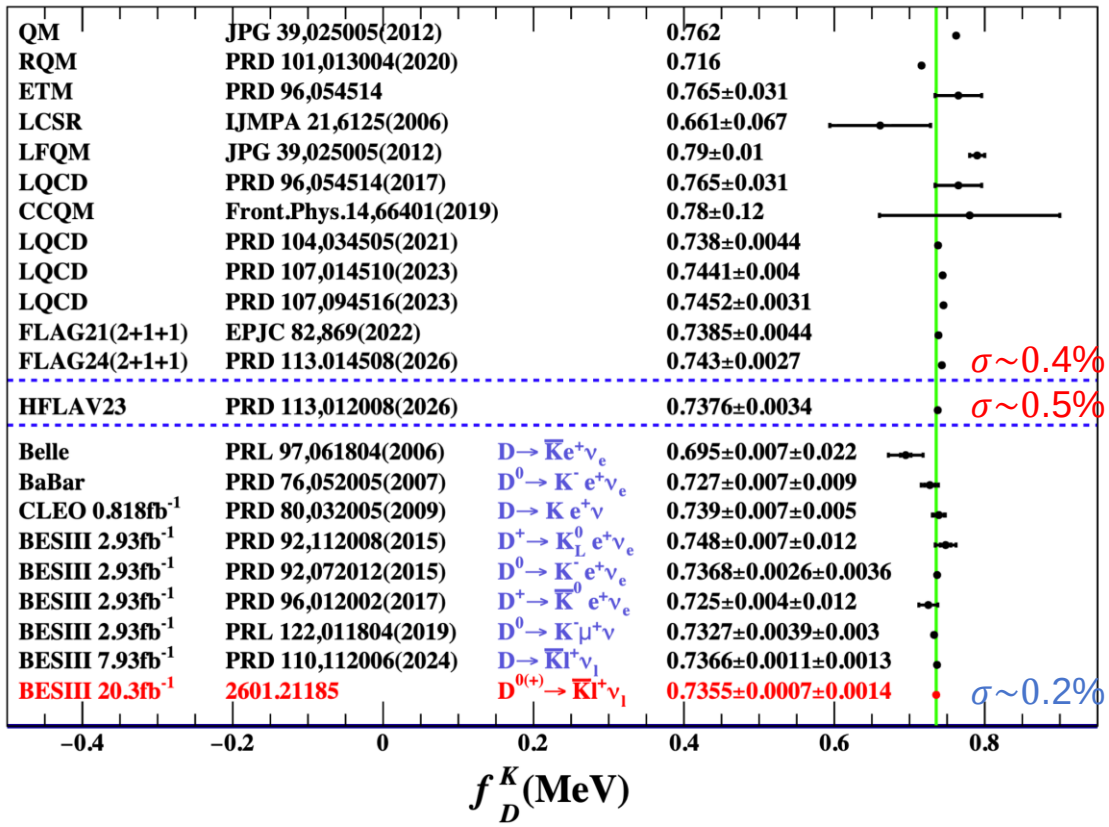
- Updated BF measurement:
  - $D^0 \to a_0(980)^- e^+\nu_e = (0.86 \pm 0.17 \pm 0.05) \times 10^{-4}$

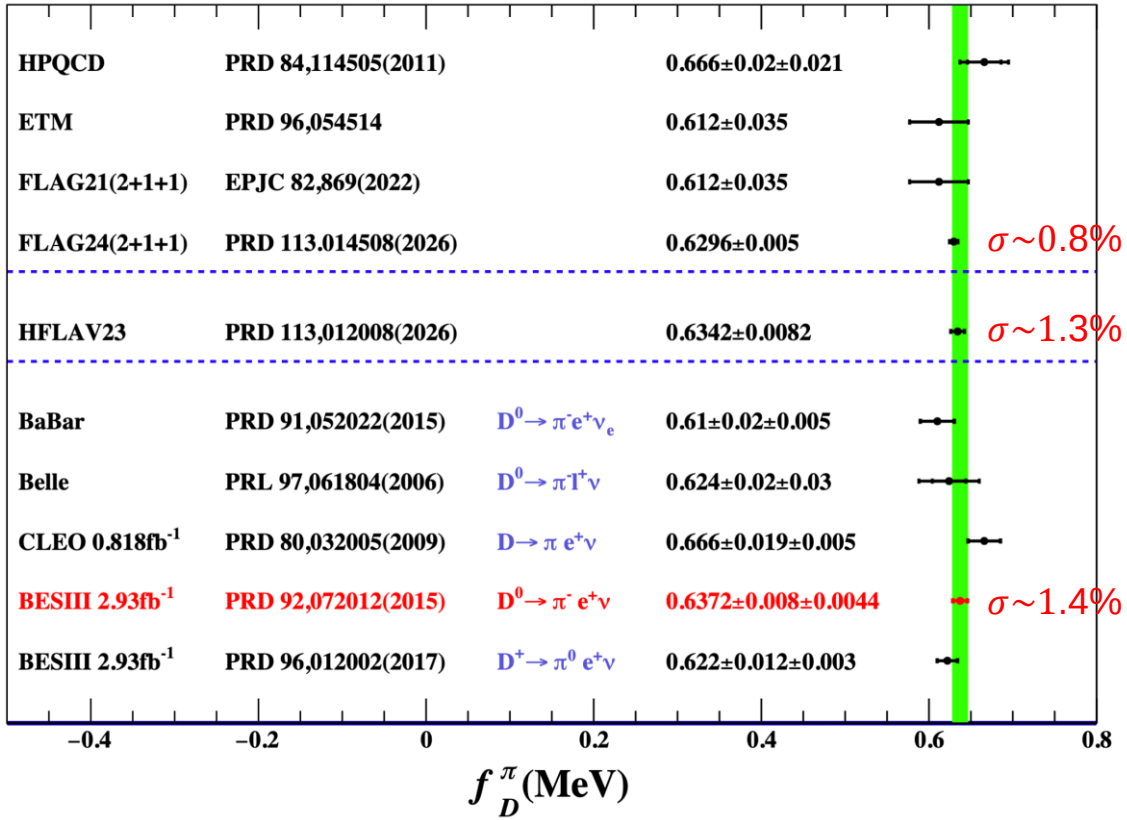
- First FF measurementwith single pole form:
  - $f_+^{a_0}(0)|V_{cd}| = 0.126 \pm 0.013 \pm 0.003$
  - $f_+^{a_0}(0) = 0.559 \pm 0.056 \pm 0.013$ with input $|V_{cd}| = 0.22487 \pm 0.00068$ from SM global fit (PDG2024)

PRD 111, L091501 (2025)

Form Factors $f_+^{D\to P}$

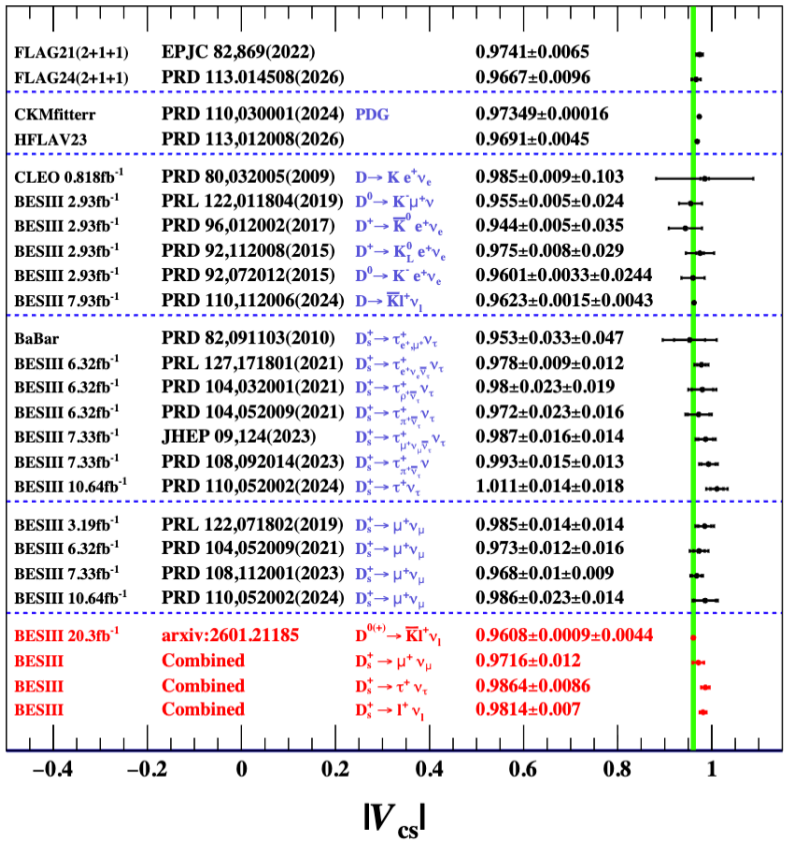
- $f_+^K(0)$ and $f_+^\pi(0)$ measurement reach precision 0.2% and 1.4%
- The results of $f_+^K(0)$ and $f_+^\pi(0)$ are consist with FLAG24(2+1+1) result.
- The $f_+^\pi(0)$ will be updated in future at BESIII using 20.3 fb^{-1}, and the predicted precision approaches to $\sigma\sim0.5\%$;

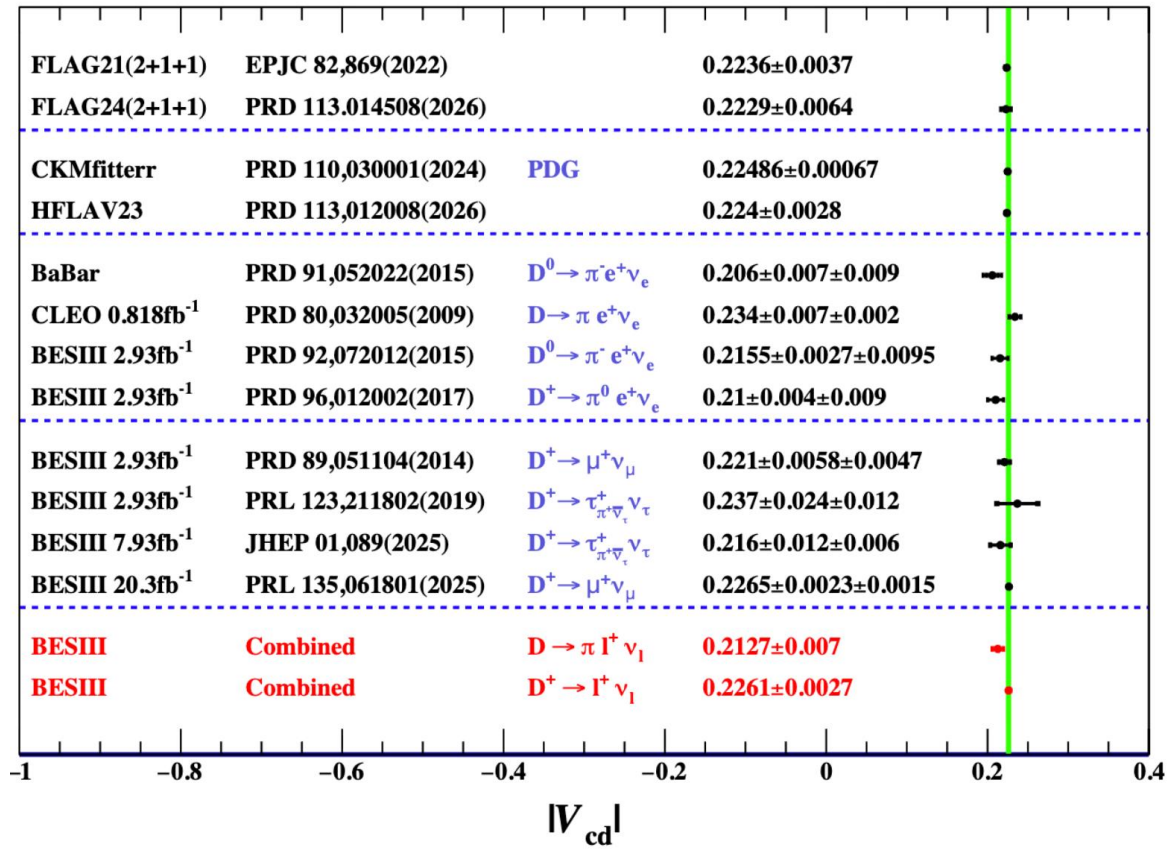




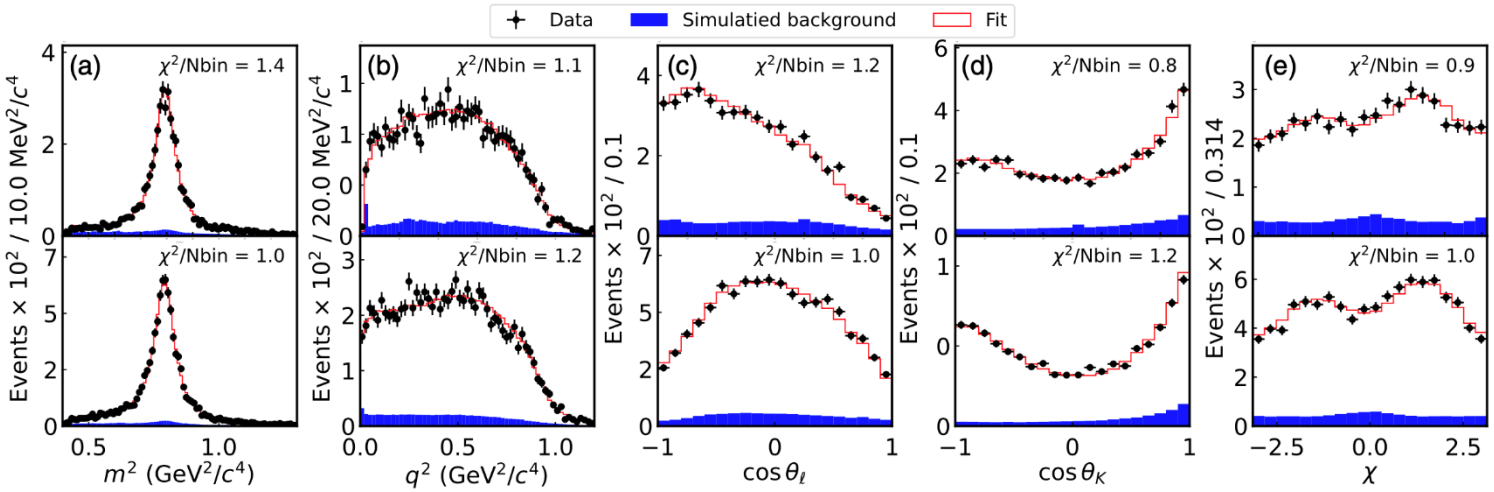
Measurements of $|V_{cs}|$ & $|V_{cd}|$

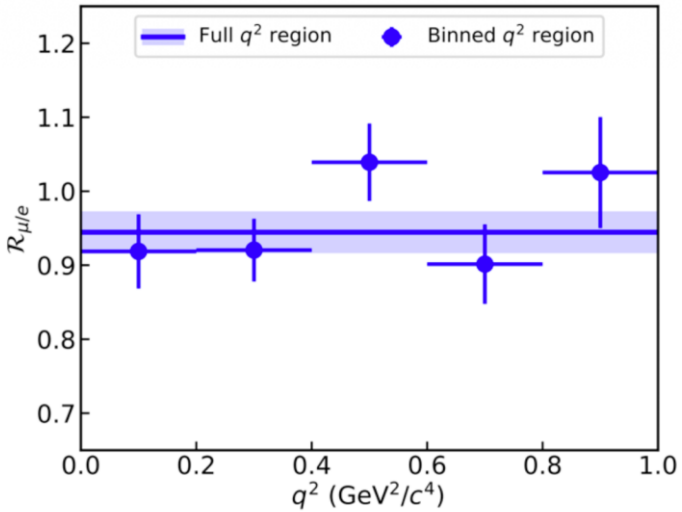
- The $D \to K \ell^+ \nu_\ell$ process provide the most precision for $|V_{cs}|$
- The value of $|V_{cs}|$ extract from $D \to K \ell^+ \nu_\ell$ and $D_s^+ \to \tau^+ \nu_\tau$ exhibit a tension
- The unitary test with BESIII results:





$D \to V(S)\, l^+\nu_l$: $D^+ \to K_S^0\pi^0 l^+\nu_l$





- 20.3 fb^{-1} data @ 3.773 GeV
- $\mathcal{B}(D^+ \to K_S^0\pi^0\mu^+\nu_\mu) = (0.896 \pm 0.017 \pm 0.008)\%$ ($\sigma\sim 2.1\%$)

  (First observation)
- $\mathcal{B}(D^+ \to K_S^0\pi^0 e^+\nu_e) = (0.943 \pm 0.012 \pm 0.010)\%$ ($\sigma\sim 1.7\%$)
- **LFU** test： $\mathcal{R}_{\mu/e} = 0.94 \pm 0.02 \pm 0.01$ vs SM: 0.92-0.95

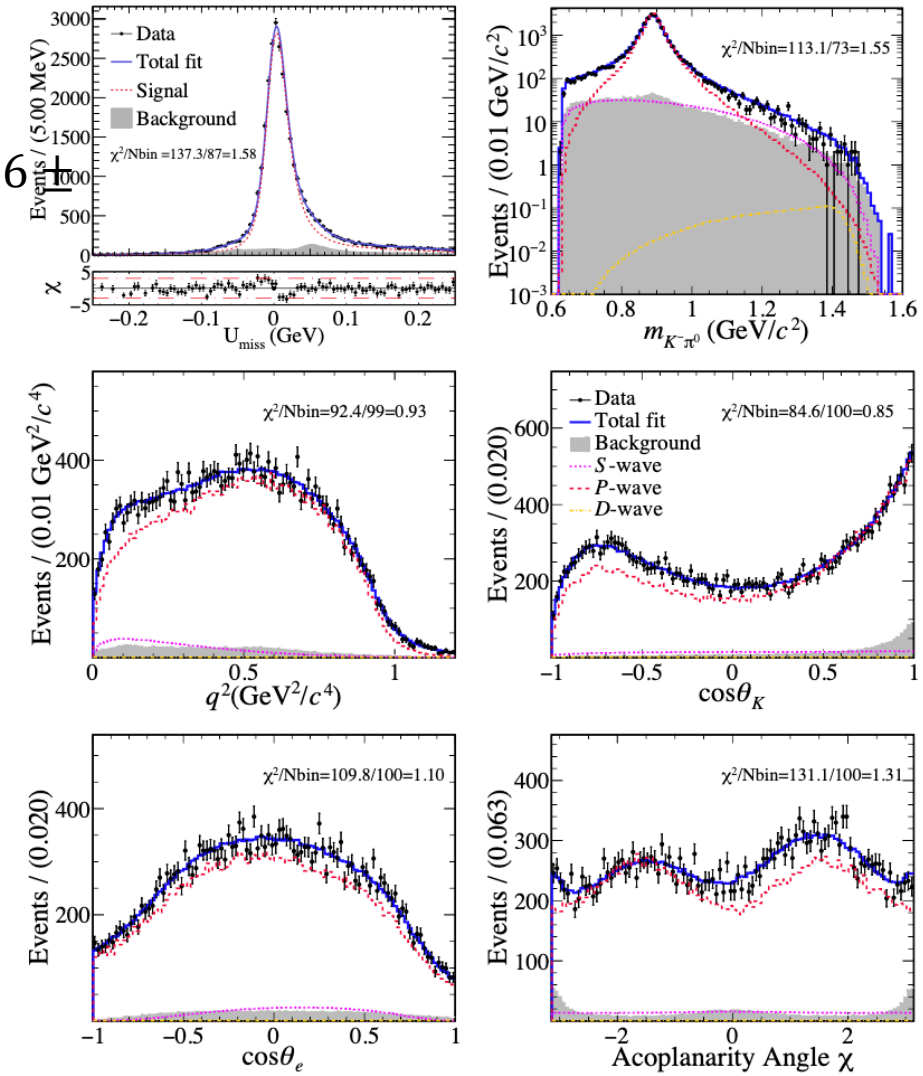
Variable	$D^+ \to K_S^0\pi^0 e^+\nu_e$	$D^+ \to K_S^0\pi^0\mu^+\nu_\mu$
$m_{\bar{K}^{*0}}$ (MeV/c^2)	$897.3 \pm 0.3 \pm 2.2$	
$\Gamma_{\bar{K}^{*0}}$ (MeV/c^2)	$45.2 \pm 0.6 \pm 0.5$	
r_V	$1.42 \pm 0.03 \pm 0.02$	
r_2	$0.75 \pm 0.03 \pm 0.01$	
$a_{S,BG}^{1/2}$ (GeV/c)$^{-1}$	$2.32 \pm 0.11 \pm 0.25$	$1.47 \pm 0.25 \pm 0.22$
r_S (GeV)$^{-1}$	$-8.44 \pm 0.13 \pm 0.37$	$-9.59 \pm 0.46 \pm 0.58$
$f_{S\text{-wave}}$	$6.39 \pm 0.17 \pm 0.14$	$7.10 \pm 0.68 \pm 0.41$
$f_{\bar{K}^{*0}}$	$93.50 \pm 0.18 \pm 0.28$	$92.81 \pm 0.67 \pm 0.47$

PRL 135, 171801 (2025)

$D \to V(S)\, l^+\nu_l$: $D^0 \to K^-\pi^0 e^+\nu_e$

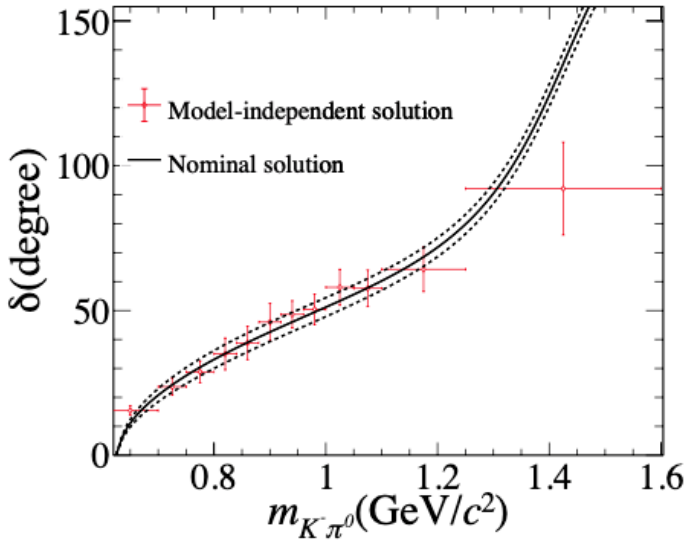
- 20.3 fb^{-1} data @ 3.773 GeV ➔ $N_{\rm sig} = 28900 \pm 224$
- **First amplitude analysis: the observation of $K_2^*(1430)$** $f_{\mathcal{D}}(\%) = 0.16 \pm 0.05 \pm 0.02$ **(7.9σ significance)**
  - $\mathcal{B}(D^0 \to K_2^*(1430)e^+\nu_e) = (7.603 \pm 2.457 \pm 0.194) \times 10^{-4}$
  - $\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e, K^*(892)^- \to K^-\pi^0)$
    = $(7.403 \pm 0.061 \pm 0.048) \times 10^{-3}$ (σ~1% level !)
  - $|V_{cd}|A_1(0) = 0.618 \pm 0.010 \pm 0.008$ (σ~2% level)
- LFU test： $\mathcal{R}^{\mu/e}_{K^*(892)^-} = 0.928 \pm 0.020 \pm 0.012$ (σ~2.5% level)
- **First test of isospin-breaking effect:**

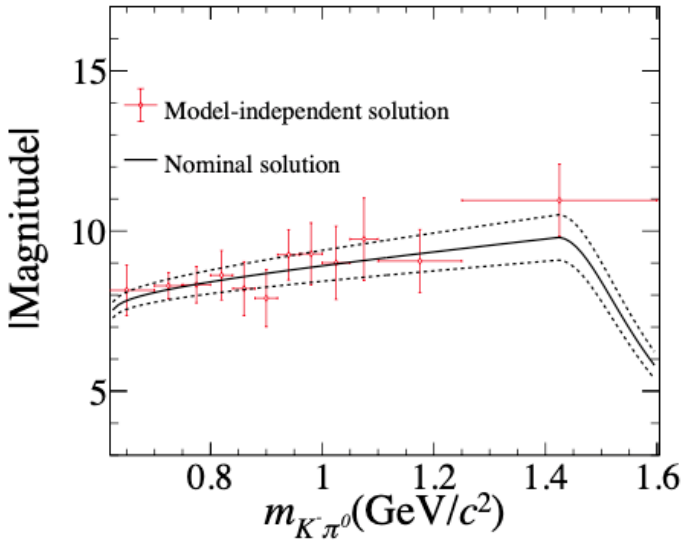
$$\mathcal{R}_{K^{*-}} = \frac{\mathcal{B}(K^*(892)^- \to K^-\pi^0)}{\mathcal{B}(K^*(892)^- \to K_S^0\pi^-)} = \begin{cases} 1.09 \pm 0.02 \pm 0.02\ (e \text{ channel}) \\ 1.07 \pm 0.02 \pm 0.03\ (\mu \text{ channel}) \end{cases}$$



arXiv: 2603.00743 (Submitted to PRL)

$D \to V(S)\, l^+ \nu_l$: $D^0 \to K^- \pi^0 e^+ \nu_e$



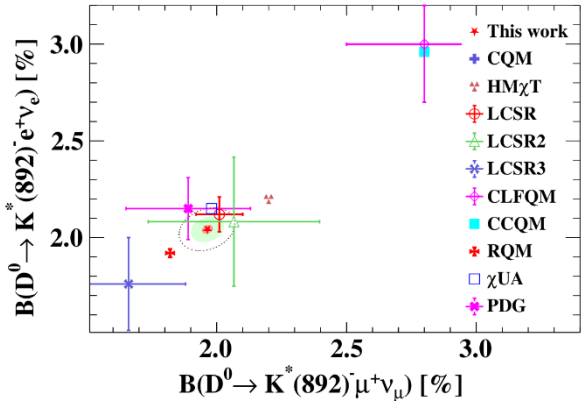


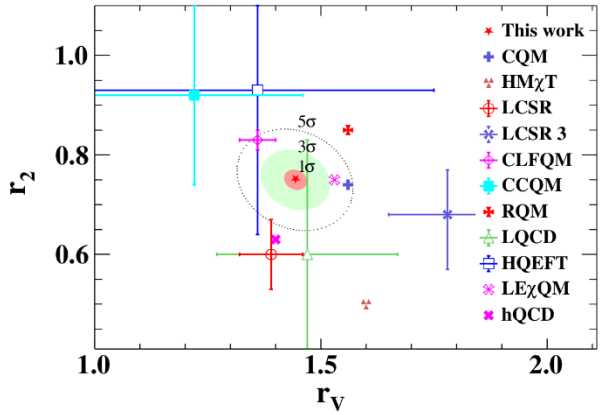
Variable	Value
$r_{\mathcal{S}}(\mathrm{GeV})^{-1}$	$-7.53 \pm 0.22 \pm 0.11$
$r_{\mathcal{S}}^{(1)}$	$0.14 \pm 0.04 \pm 0.01$
$a_{\mathcal{S},\mathrm{BG}}^{1/2}\ (\mathrm{GeV}/c)^{-1}$	$1.98 \pm 0.10 \pm 0.13$
$b_{\mathcal{S},\mathrm{BG}}^{1/2}\ (\mathrm{GeV}/c)^{-1}$	$0.57 \pm 0.53 \pm 0.27$
$m_A(\mathrm{GeV}/c^2)$	$2.72 \pm 0.18 \pm 0.11$
$m_V(\mathrm{GeV}/c^2)$	$1.70 \pm 0.11 \pm 0.02$
r_V	$1.41 \pm 0.05 \pm 0.01$
r_2	$0.77 \pm 0.04 \pm 0.02$
$m_{K^*(892)^-}(\mathrm{MeV}/c^2)$	892.9 ± 0.2
$\Gamma^0_{K^*(892)^-}(\mathrm{MeV})$	$47.9 \pm 0.5 \pm 0.4$
$r_{\mathrm{BW}}\ (\mathrm{GeV}/c)^{-1}$	$3.38 \pm 0.17 \pm 0.16$
$r_{\mathcal{D}}(\mathrm{GeV})^{-4}$	$11.0 \pm 1.6 \pm 1.7$
$\phi_{\mathcal{D}}$ (degree)	$-16.9 \pm 7.7 \pm 3.0$
$f_{\mathcal{S}}$ (%)	$5.86 \pm 0.18 \pm 0.21$
$f_{\mathcal{P}}$ (%)	$93.97 \pm 0.19 \pm 0.21$
$f_{\mathcal{D}}$ (%)	$0.16 \pm 0.05 \pm 0.02$

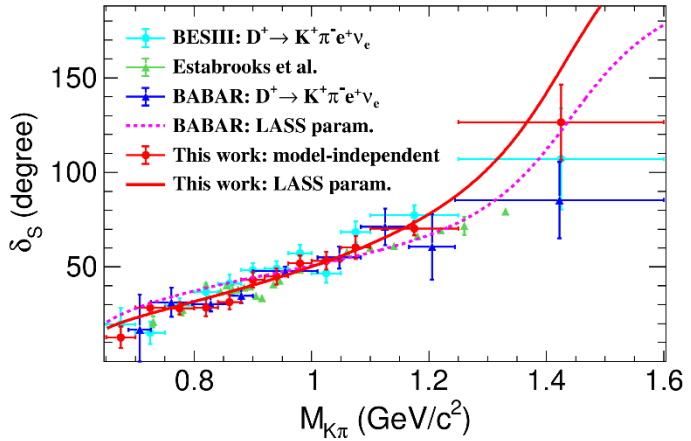
- the phase shift (magnitude) of the S-wave extracted in a model-independent way in this channel.

arXiv: 2603.00743 (Submitted to PRL)

$D \to V(S)\, l^+\nu_l$: $D^0 \to \bar{K}^0\pi^- l^+\nu_l$







- 20.3 fb^{-1} data @3.773GeV
- $\mathcal{B}(D^0 \to K^*(892)^-\mu^+\nu_\mu) = (1.964 \pm 0.018 \pm 0.012)\%$

  $\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e) = (2.043 \pm 0.018 \pm 0.012)\%$
- $\mathcal{B}(D^0 \to K_2^*(1430)^-\mu^+\nu_\mu) = (3.85 \pm 1.17 \pm 0.15) \times 10^{-5}$

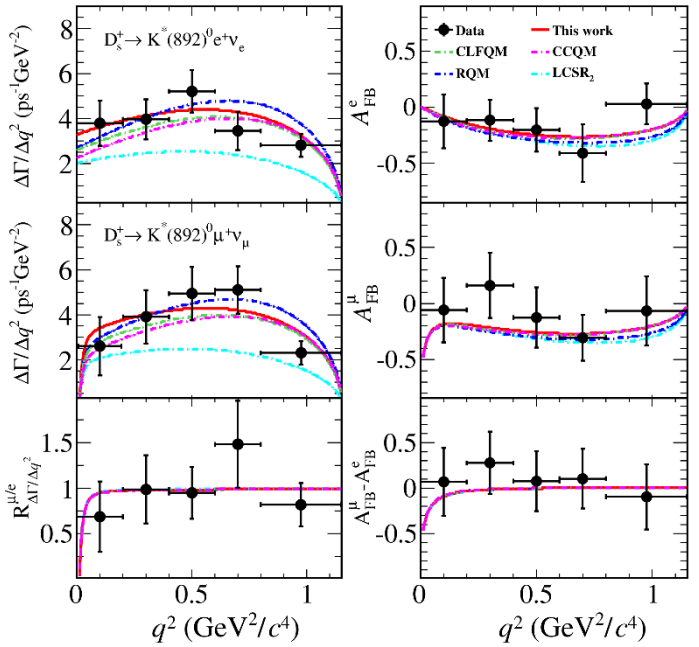
  $\mathcal{B}(D^0 \to K_2^*(1430))^-e^+\nu_e) = (4.00 \pm 1.22 \pm 0.78) \times 10^{-5}$
- $\mathcal{R}^{\mu/e}_{K^*(892)^-} = 0.961 \pm 0.012 \pm 0.005$
- $A_1(0) = 0.623 \pm 0.008 \pm 0.008$ (First measurement from this decay)

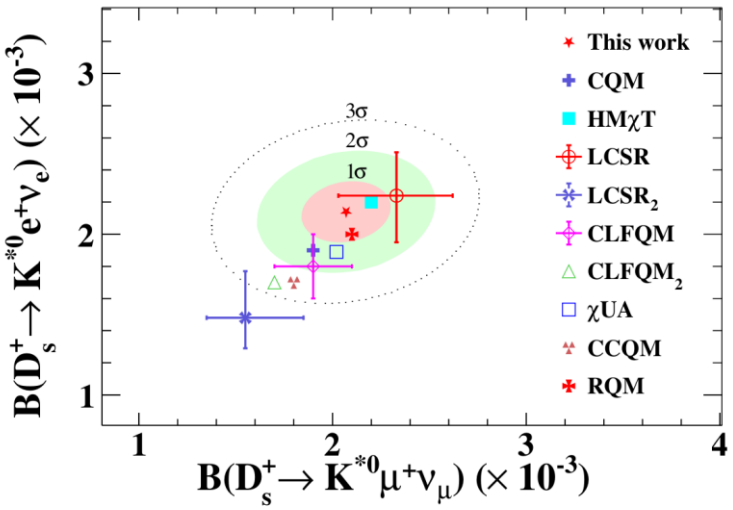
arXiv: 2603. 04136 (Submitted to PRL)

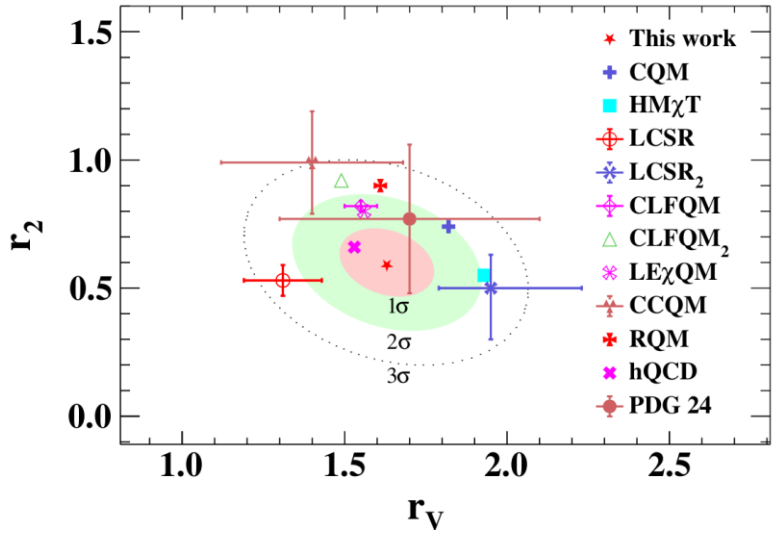
Variable	Value
r_V	$1.444 \pm 0.026 \pm 0.011$
r_2	$0.752 \pm 0.020 \pm 0.004$
r_S	$-13.21 \pm 0.49 \pm 0.36$
$a^{1/2}_{\mathrm{S,BG}}$ $(\mathrm{GeV}/c)^{-1}$	$1.24 \pm 0.11 \pm 0.08$
$b^{1/2}_{\mathrm{S,BG}}$ $(\mathrm{GeV}/c)^{-1}$	$-2.71 \pm 0.75 \pm 0.71$
$r_S^{(1)}$	$-0.05 \pm 0.04 \pm 0.03$
r_D	$11.52 \pm 2.00 \pm 1.16$
$f_{K^*(892)^-}$	$(94.12 \pm 0.19 \pm 0.09)\%$
$f_{S-\mathrm{wave}}$	$(5.81 \pm 0.19 \pm 0.09)\%$
$f_{D-\mathrm{wave}}$	$(0.092 \pm 0.028 \pm 0.018)\%$ 8σ

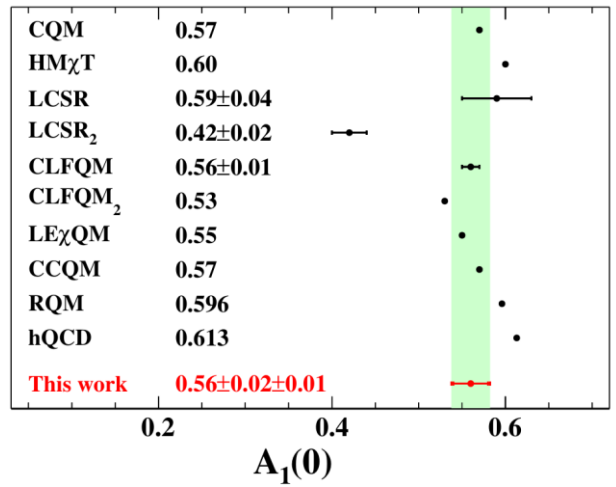
$D_s \to V(S)\, l^+\nu_l$: $D_s^+ \to K_S^0\pi^- l^+\nu_l$

- 7.33 fb^{-1} data @ 4.128-4.226 GeV
- $B\left(D_S^+ \to K^*(892)^0\mu^+\nu_\mu\right) = (2.07 \pm 0.22 \pm 0.10) \times 10^{-3}$ **first measurement**
- $B(D_S^+ \to K^*(892)^0 e^+\nu_e) = (2.14 \pm 0.18 \pm 0.10) \times 10^{-3}$ improved measurement
- $R^{\mu/e}_{K^*(892)} = 0.97 \pm 0.13 \pm 0.04$
- $r_V = 1.63 \pm 0.14 \pm 0.08, \quad r_2 = 0.60 \pm 0.13 \pm 0.06$
- $< A_{FB}^e > = -0.14 \pm 0.09 \pm 0.01$
- $< A_{FB}^\mu > = -0.12 \pm 0.10 \pm 0.01$





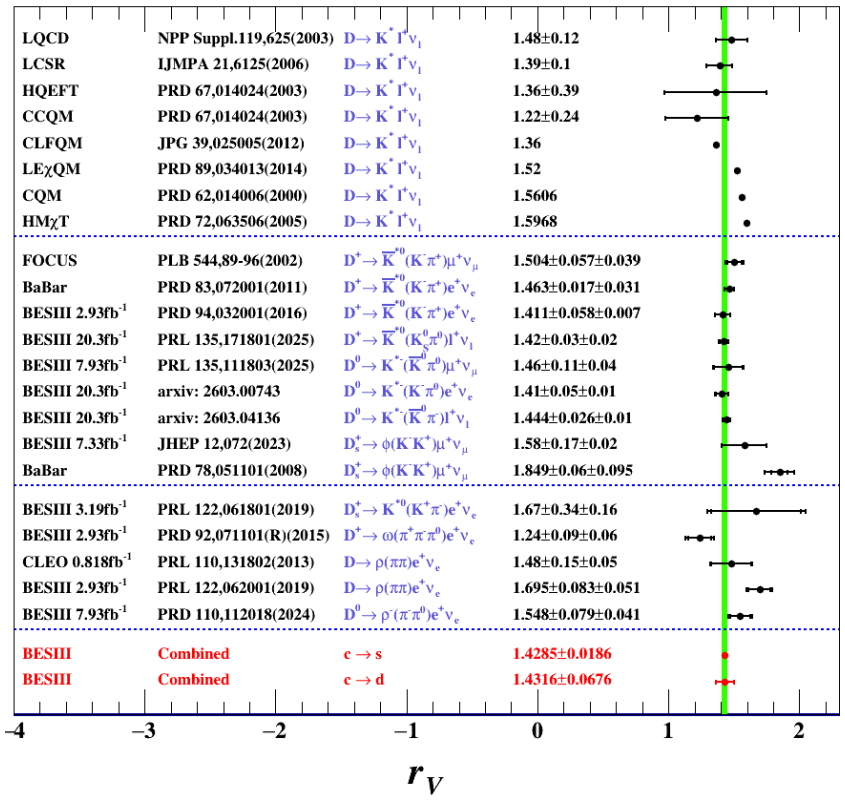




arXiv: 2605. 07176 (Submitted to PRL)

Comparisons of r_V and r_2

- The r_V and r_2 measurement reach precision 1.3%/1.9%;
- The spectator quark will not affect the result; → U-spin is not broken
- The theory needs to consider stricter constraints;



spectator quark

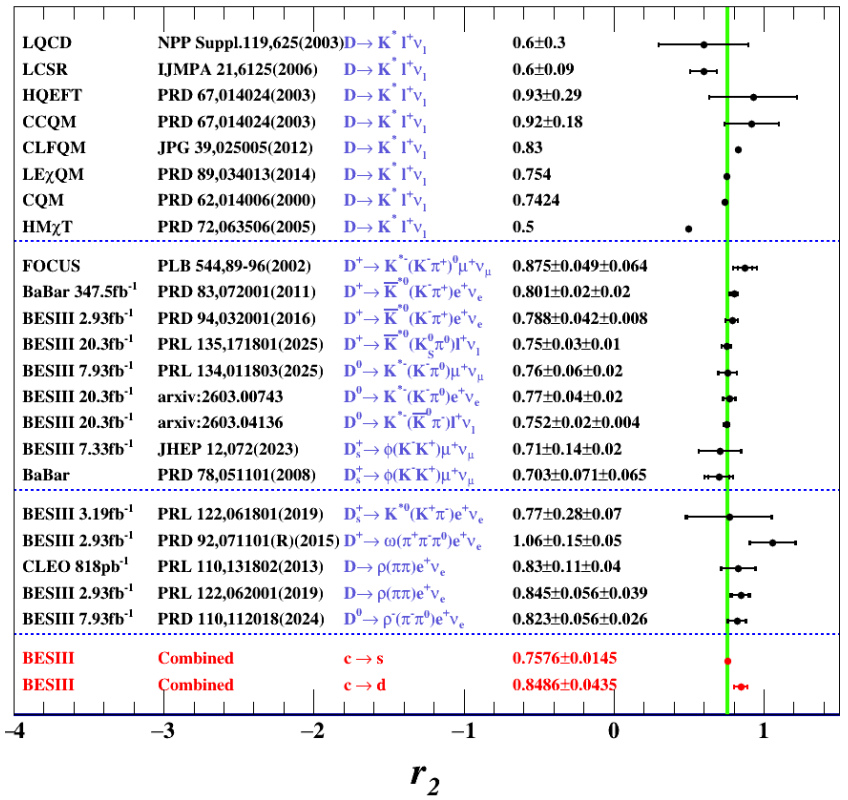
$\bar{u}$: 1.418 ± 0.031

$\bar{d}$: 1.432 ± 0.024

$\bar{s}$: 1.58 ± 0.17

σ~1.3%

σ~4.7%



spectator quark

$\bar{u}$: 0.763 ± 0.025

$\bar{d}$: 0.756 ± 0.018

$\bar{s}$: 0.71 ± 0.14

σ~1.9%

σ~5.2%

$D \to A\, l^+ \nu_l$: $D \to \bar{K}_1(1270) e^+ \nu_e$

- 20.3 fb^{-1} data @ 3.773 GeV ➔ $N_{\rm sig}^{D^+(D^0)} = 1270 \pm 56\ (731 \pm 35)$
- $\mathcal{B}(D^+ \to \bar{K}_1(1270)^0 e^+ \nu_e) = (2.27 \pm 0.11 \pm 0.07 \pm 0.07) \times 10^{-3}$
- $\mathcal{B}(D^0 \to K_1(1270)^- e^+ \nu_e) = (1.02 \pm 0.06 \pm 0.06 \pm 0.03) \times 10^{-3}$
- First **FF** measurement ($K_1(1400)$ is not observed)

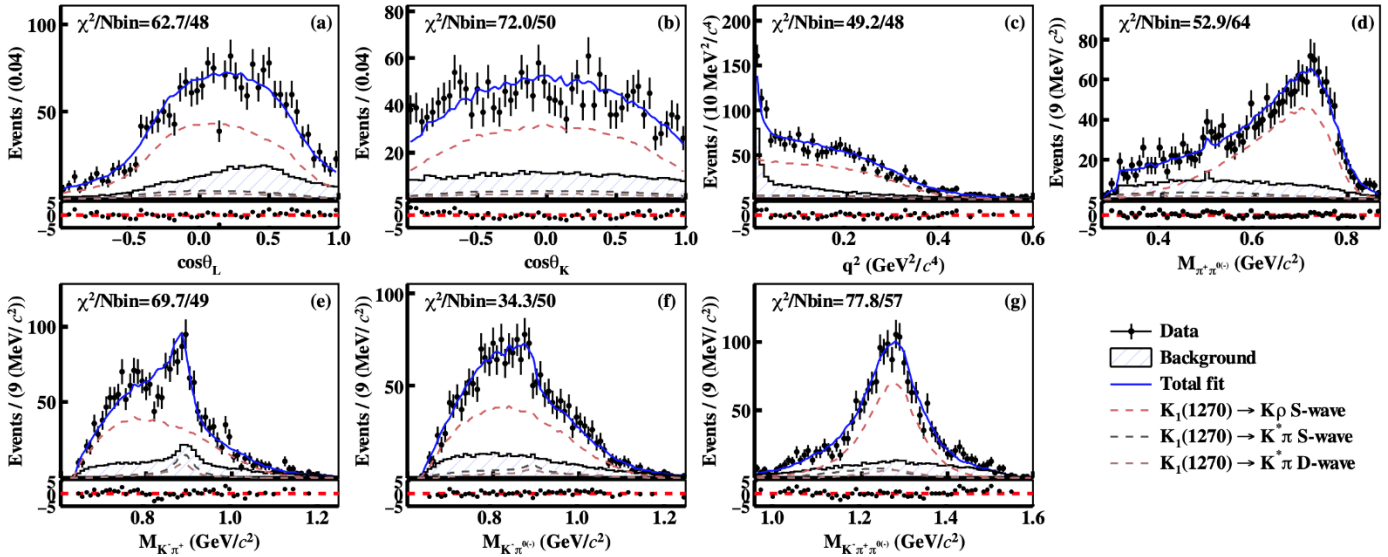


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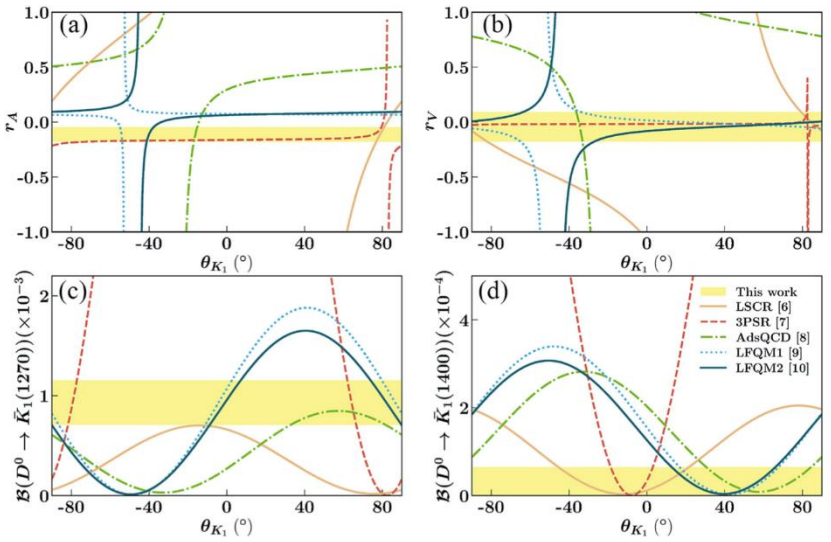
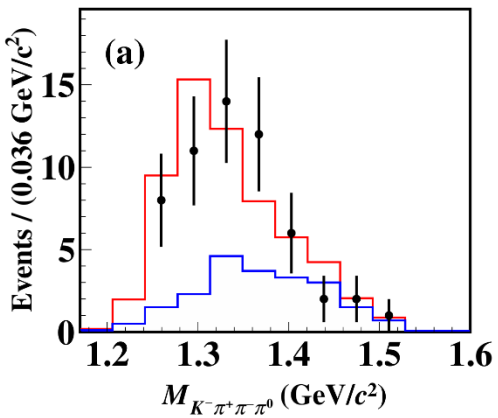
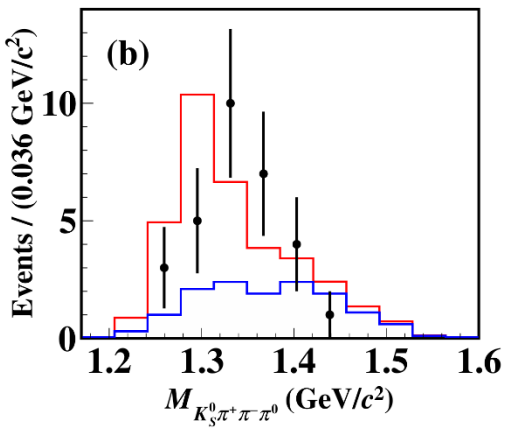
Table 2. Fitted parameters and fit fractions, where the first uncertainties are statistical and the second systematic.

Variable	Value
r_A $(\times 10^{-2})$	$-11.2 \pm 1.0 \pm 0.9$
r_V $(\times 10^{-2})$	$-4.3 \pm 1.0 \pm 2.4$
$f^{D^+}_{\rho K^-}$ (%)	$79.3 \pm 2.0 \pm 25.7$
$f^{D^+}_{\pi \bar{K}^*(892)}$ (%)	$10.9 \pm 1.2 \pm 3.0$
$f^{D^0}_{\rho K^-}$ (%)	$71.8 \pm 2.3 \pm 23.9$
$f^{D^0}_{\pi \bar{K}^*(892)}$ (%)	$19.5 \pm 1.9 \pm 5.2$
$m_{K_1(1270)}$ (MeV/c^2)	$1271 \pm 3 \pm 7$
$\Gamma_{K_1(1270)}$ (MeV)	$168 \pm 10 \pm 20$



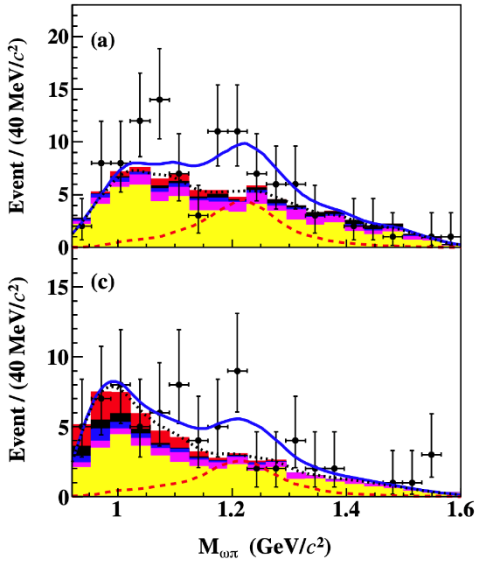
$D \to A\, l^+\nu_l$: $D^{0(+)} \to \bar{K}_1(1270)e^+\nu_e$ & $D^{0(+)} \to b_1(1235)^{+(0)}e^+\nu_e$

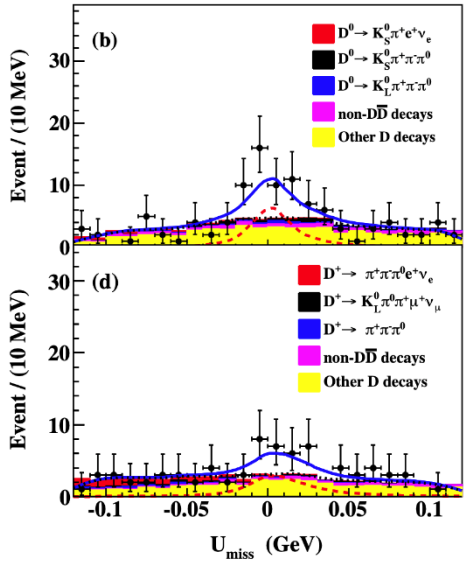




- 20.3 fb^{-1} data @ 3.773 GeV
- **First observation**
  - $B(D^0 \to K^-\omega e^+\nu_e) = (9.3^{+2.1}_{-1.9} \pm 0.7) \times 10^{-5} \to 8.0\sigma$
  - $B(D^+ \to K^0_S\omega e^+\nu_e) = (6.6^{+2.0}_{-1.8} \pm 0.6) \times 10^{-5} \to 5.8\sigma$
- **Assuming $\bar{K}_1(1270)$ to be the sole mediating resonance:**
  - $(\Gamma(K_1(1270)^- \to K^-\pi^+\pi^-)/(\Gamma(K_1(1270)^- \to K^-\omega) = 3.4^{+0.8}_{-0.7} \pm 0.3$
  - $(\Gamma(\bar{K}_1(1270) \to K^-\pi^+\pi^0)/(\Gamma(\bar{K}_1(1270) \to K^0_S\omega) = 9.6^{+3.0}_{-2.7} \pm 0.8$
- Determining the branching fraction:
  - $B(\bar{K}_1(1270) \to \bar{K}\omega) = (7.5 \pm 1.3 \pm 0.5)\%$

arxiv: 2601.01817 (Submitted to PRL)





- 7.9 fb^{-1} data @ 3.773 GeV
- **First observation ➔** $N_{\rm sig} = 35.6 \pm 8.9$ (**5.2σ**)

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

- **First evidence ➔** $N_{\rm sig} = 17.5 \pm 6.7$ (**3.1σ**)

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

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

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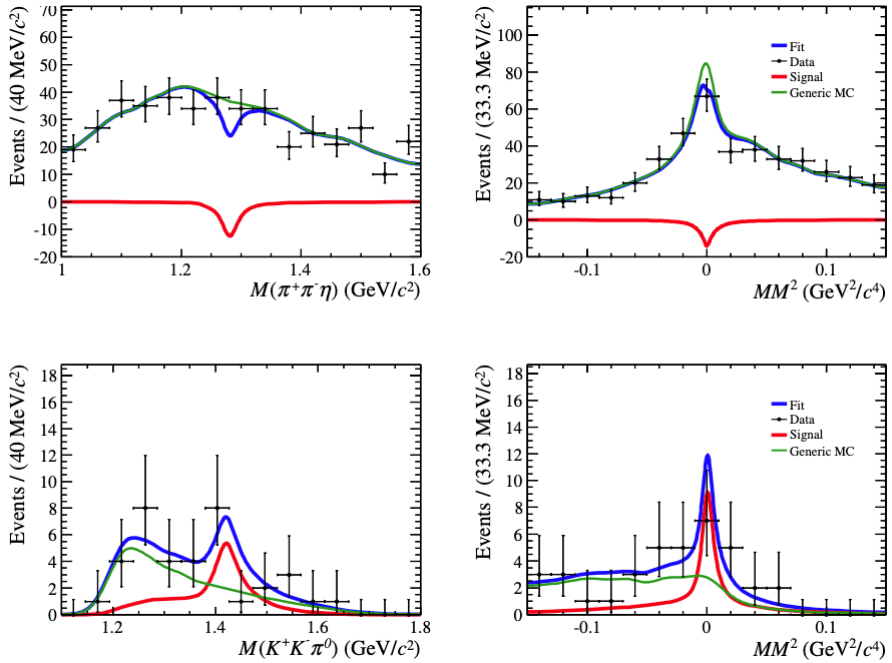
$D_s \to A\, l^+ \nu_l$: $D_s^+ \to f_1 e^+ \nu_e$

- 7.33 fb^{-1} data @ 4.128-4.226 GeV
- **First evidence of $D_s^+ \to f_1(1420) e^+ \nu_e$** ➔ $N_{\rm sig} = 13.2^{+5.8}_{-5.0}$, 3.4 σ
  - $\mathcal{B}(D_s^+ \to f_1(1420) e^+ \nu_e \to K^+K^-\pi^0) = (4.5^{+2.0}_{-1.7} \pm 0.4) \times 10^{-4}$
  - $\mathcal{B}(D_s^+ \to f_1(1420) e^+ \nu_e \to K^+K^-\pi^0) < 7.6 \times 10^{-4}$@90%C.L.
- **First search of $D_s^+ \to f_1(1285) e^+ \nu_e$ (<1σ)**

$\mathcal{B}(D_s^+ \to f_1(1285) e^+ \nu_e \to \pi^+\pi^-\eta) < 1.7 \times 10^{-4}$@90%C.L.



arXiv: 2601.16938 (Submitted to PRD)

Summary & Outlook

Summary:

- Precise measurement of $f_{D_{(s)}}/f_+^{D\to K}$ in charm decay ⇒ 1%/2% level
- Precise measurement of $|V_{cd}|/|V_{cs}|$ in charm decay ⇒ 1%/0.5% level
- No evidence of LFU violation found in charm sector ⇒ 5% precision level in $D \to K\ell^+\nu_\ell$
- Amplitude analysis in charm semi-leptonic decay ⇒ provide necessary information for dynamic study
- Charm semi-leptonic decay is helpful to study the nature of light hadrons (a_0, f_0, K_1 … …)

Outlook:

- More precision measurements and search of rare (semi-)leptonic charm decays will be presented.

Thank You!