Recent measurements in the semi-leptonic D decays at BESIII

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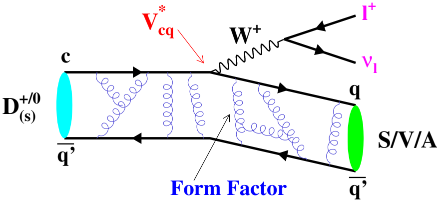
Outline

Main topic and formalization



- Form Factor and Branching ratios or decay rates measurements
  - ⇒Calibrate LQCD calculations
  - ⇒Test isospin symmetry
  - ⇒Test CP symmetry
  - ⇒Test lepton flavor universality (LFU)
- Sepearation of Strong and Weak interaction can test the SM and constriant the NP

Main topic and formalization

- Four body decay are listed as, $D_{(s)} \to K\pi\ell\nu_\ell$, $D_{(s)} \to \pi\pi\ell\nu_\ell$, $D \to \pi\eta\ell\nu_\ell$, $D_s^+ \to K^+K^-\ell^+\nu_\ell$

$$\mathcal{M}_{fi} = \frac{G_F}{\sqrt{2}} V_{cs} \langle \pi(p_\pi)K(p_K) | \bar{s}\gamma_\mu(1-\gamma_5)c | D(p_D)\rangle \times \bar{u}(p_\nu)\gamma^\mu(1-\gamma_5)v(p_{\bar{\ell}}),$$

Four body formalization [PRD46(1992)5040], expand the hadronic matrix element with form factors, the differenial decay rate with full independent five kinematic variables are

$$\frac{d^5\Gamma}{dm^2 dq^2 d\cos\theta_K d\cos\theta_\ell d\chi} = \frac{G_F^2|V_{cs}|^2}{(4\pi)^6 m_D^3}\lambda\beta_m\beta_\ell\Big(\mathcal{I}_1 + \mathcal{I}_2\cos 2\theta_\ell + \mathcal{I}_3\sin^2\theta_\ell\cos 2\chi + \mathcal{I}_4\sin 2\theta_\ell\cos\chi$$
$$+ \mathcal{I}_5\sin\theta_\ell\cos\chi + \mathcal{I}_6\cos\theta_\ell + \mathcal{I}_7\sin\theta_\ell\sin\chi + \mathcal{I}_8\sin 2\theta_\ell\sin\chi + \mathcal{I}_9\sin^2\theta_\ell\sin 2\chi\Big).$$

Main topic and formalization

The angular coefficients can be expanded in terms of four form factors $\mathcal{F}_{1,2,3,4}$ as

$$
\begin{aligned}
\mathcal{I}_1 =& \frac{\beta_\ell}{4}\left[(1+\frac{m_\ell^2}{q^2})|\mathcal{F}_1|^2 + \frac{3}{2}(1+\frac{m_\ell^2}{3q^2})\sin^2\theta_K(|\mathcal{F}_2|^2+|\mathcal{F}_3|^2) + \frac{2m_\ell^2}{q^2}|\mathcal{F}_4|^2\right],\\
\mathcal{I}_2 =& -\frac{\beta_\ell^2}{4}\left[|\mathcal{F}_1|^2 - \frac{1}{2}\sin^2\theta_K(|\mathcal{F}_2|^2+|\mathcal{F}_3|^2)\right],\\
\mathcal{I}_3 =& -\frac{\beta_\ell^2}{4}\left[(|\mathcal{F}_2|^2-|\mathcal{F}_3|^2)\right]\sin^2\theta_K,\\
\mathcal{I}_4 =& \frac{\beta_\ell^2}{2}\,\mathrm{Re}(\mathcal{F}_1\mathcal{F}_2^*)\sin\theta_K,\\
\mathcal{I}_5 =& \beta_\ell\,\mathrm{Re}\left[\mathcal{F}_1\mathcal{F}_3^* + \frac{m_\ell^2}{q^2}\mathcal{F}_4\mathcal{F}_2^*\right]\sin\theta_K,\\
\mathcal{I}_6 =& \beta_\ell\,\mathrm{Re}\left[\mathcal{F}_2\mathcal{F}_3^*\sin^2\theta_K - \frac{m_\ell^2}{q^2}\mathcal{F}_1\mathcal{F}_4^*\right],\\
\mathcal{I}_7 =& \beta_\ell\,\mathrm{Im}\left[(\mathcal{F}_1\mathcal{F}_2^*) + \frac{m_\ell^2}{q^2}\mathcal{F}_4\mathcal{F}_3^*\right]\sin\theta_K,\\
\mathcal{I}_8 =& \frac{\beta_\ell^2}{2}\,\mathrm{Im}(\mathcal{F}_1\mathcal{F}_3^*)\sin\theta_K,\\
\mathcal{I}_9 =& -\frac{\beta_\ell^2}{2}\,\mathrm{Im}(\mathcal{F}_2\mathcal{F}_3^*)\sin^2\theta_K.
\end{aligned}
$$

Main topic and formalization

The form factors $\mathcal{F}_{1,2,3,4}$ can be expanded into partial waves to show their explicit dependence on θ_K,

$$\mathcal{F}_1 = \sum_{l=0}^{\infty} \mathcal{F}_{1,l}\, P_l(\cos\theta_K),$$

$$\mathcal{F}_2 = \sum_{l=1}^{\infty} \frac{1}{\sqrt{l(l+1)}} \mathcal{F}_{2,l}\, \frac{d}{d\cos\theta_K} P_l(\cos\theta_K),$$

$$\mathcal{F}_3 = \sum_{l=1}^{\infty} \frac{1}{\sqrt{l(l+1)}} \mathcal{F}_{3,l}\, \frac{d}{d\cos\theta_K} P_l(\cos\theta_K),$$

$$\mathcal{F}_4 = \sum_{l=0}^{\infty} \mathcal{F}_{4,l}\, P_l(\cos\theta_K).$$

More transition can be tested in amplitude analysis

Main topic and formalization

- Five body decay are listed as, $D \to K\pi\pi\ell\nu_\ell$, $D \to \pi\pi\pi\ell\nu_\ell$ (only ω)
- For five body decay, more independent kinematic variables (5→8) make it hard to expand the partial waves
- The formalization is separate into two parts, $D \to \bar{K}_1 W^*$ and $\bar{K}_1 \to K^-\pi^+\pi^{0(-)}$

The amplitude for $D \to \bar{K}_1 e^+\nu_e$ is constructed as

$$\mathcal{M} = (V-A)^{\mu\eta} \cdot [\sum_{\lambda_W} \epsilon^*(\lambda_W)_\mu \epsilon(\lambda_W)_\rho] \cdot [\sum_{\lambda_{K_1}} \epsilon^*(\lambda_{K_1})_\eta \epsilon(\lambda_{K_1})_\sigma] \cdot \mathcal{R}_{\bar{K}_1} \cdot J^\sigma \cdot \bar{u}_\nu \gamma^\rho (1-\gamma_5) v_l .$$

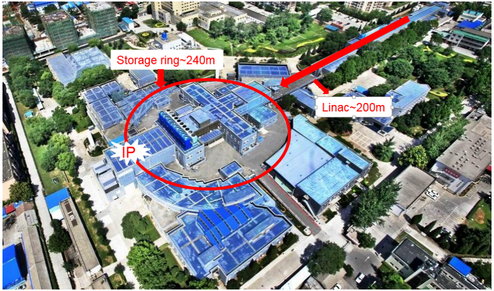
Here, $(V-A)^\mu$ is the current for $D \to \bar{K}_1 W^*$

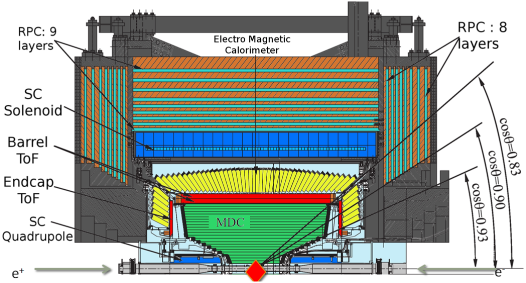
$$V^{\mu\eta}\epsilon^*(\lambda_{K_1})_\eta = -(m_D - M_{K_1}) V_1(q^2) \epsilon^{*\mu}(\lambda_{K_1}) + V_2(q^2)\left(\frac{q\cdot\epsilon^*(\lambda_{K_1})}{m_D - M_{K_1}}\right)(p_D + p_{K_1})^\mu ,$$

$$A^{\mu\eta}\epsilon^*(\lambda_{K_1})_\eta = -\frac{2iA(q^2)}{m_D - M_{K_1}} \epsilon^{\mu\eta p^D p^{K_1}} .$$

J^σ is the hadronic current of $\bar{K}_1 \to K^-\pi^+\pi^{0(-)}$; $W^* \to e^+\nu_e$ is described with $\bar{u}_\nu\gamma^\rho(1-\gamma_5)v_l$.

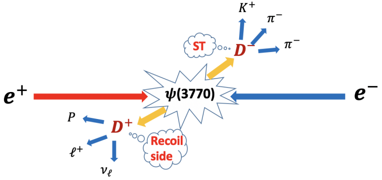
BESIII experiment





- $\sqrt{s} = (1.85 - 4.95)$ GeV
- Peak luminosity: $1.1{\times}10^{33}$ cm^{-2}s^{-1} @3.773 GeV
- MDC: $\sigma_P/P = 0.5\%$ @ 1 GeV; $\sigma_{dE/dx} = 6\%$
- TOF: $\sigma_T = 68(110)$ ps for barrel (endcap); endcap upgraded in 2015 $\sigma_T = 60$ ps
- EMC: σ_E/E =2.5%(5%) for barrel (endcap)

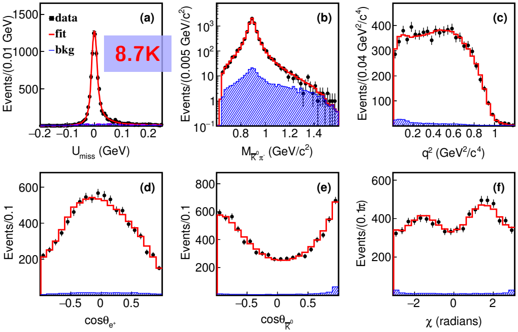
BESIII dataset and double-tag method



- e^+e^- annihilations data near threshold
  ⇒Double-tag method& Clean environment
- Undetectable neutrinos⇒extract the (semi-)leptonic signals
  $U_{\rm miss} = E_{\rm miss} - |\vec{p}_{\rm miss}|$, $M^2_{\rm miss} = E^2_{\rm miss} - |\vec{p}_{\rm miss}|^2$
- Branching fraction with double-tag method: $\mathcal{B} = \frac{N_{\rm DT}}{N_{\rm ST}\epsilon_{\rm DT}/\epsilon_{\rm ST}}$
  ⇒Systematic uncertainties on the ST mostly canceled

Data sample	$E_{\rm cm}$ (GeV)	$\mathcal{L}_{\rm int}$ (fb^{-1})	Single tag yields ($\times 10^6$)
$e^+e^- \to \psi(3770) \to D\bar{D}$	3.773	20.3	$\bar{D}^0$ ∼16.9; D^- ∼11.0
$e^+e^- \to D_s^{\pm}D_s^{*\mp}$	4.128-4.226	7.33	D_s^- ∼0.8
$e^+e^- \to D_s^{*+}D_s^{*-}$	4.237-4.669	10.64	D_s^- ∼0.12

Update measurement of $D^0 \to \bar{K}^0\pi^-\ell^+\nu_\ell$

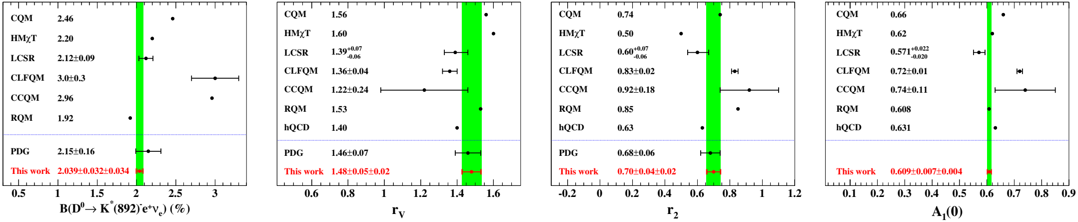


- JHEP03(2025)197
- 7.93 fb^{-1}data sample @3.773 GeV
- $\mathcal{B}(D^0 \to \bar{K}^0\pi^-e^+\nu_e) = (1.444 \pm 0.022_{\rm stat} \pm 0.024_{\rm syst})\%$

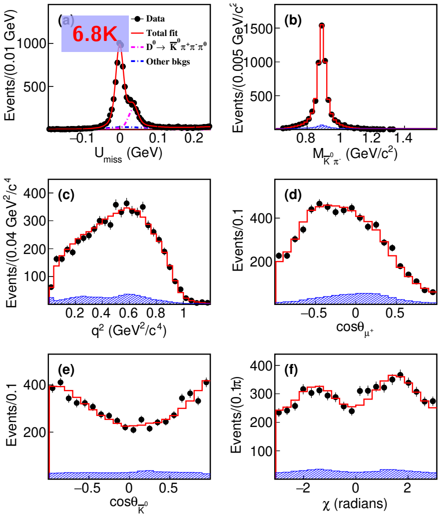
  $\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e) = (2.039 \pm 0.032_{\rm stat} \pm 0.034_{\rm syst})\%$ **Most precise**
- $r_V = V(0)/A_1(0) = 1.48 \pm 0.05_{\rm stat} \pm 0.02_{\rm syst}$

  $r_2 = A_2(0)/A_1(0) = 0.70 \pm 0.04_{\rm stat} \pm 0.02_{\rm syst}$ **First time**

  $A_1(0) = 0.610 \pm 0.007 \pm 0.004$

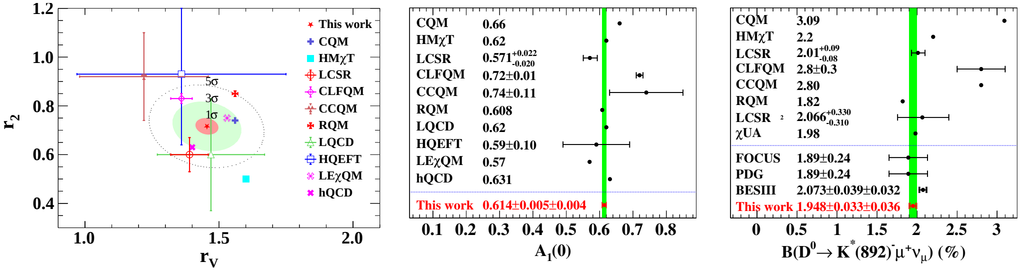


First study of $D^0 \to \bar{K}^0\pi^-\mu^+\nu_\mu$



- arXiv:2504.10867
- 7.93 fb^{-1}data sample @3.773 GeV
- $\mathcal{B}(D^0 \to \bar{K}^0\pi^-\mu^+\nu_\mu) = (1.373 \pm 0.020_{\text{stat}} \pm 0.023_{\text{syst}})\%$
  $\mathcal{B}(D^0 \to K^*(892)^-\mu^+\nu_\mu) = (1.948 \pm 0.033_{\text{stat}} \pm 0.036_{\text{syst}})\%$ **First time**
- $r_V = V(0)/A_1(0) = 1.46 \pm 0.11_{\text{stat}} \pm 0.04_{\text{syst}}$,
  $r_2 = A_2(0)/A_1(0) = 0.71 \pm 0.08_{\text{stat}} \pm 0.03_{\text{syst}}$
  $A_1(0) = 0.609 \pm 0.008_{\text{stat}} \pm 0.008_{\text{syst}}$
- Observation of the new muonic decay, study the decay dynamics

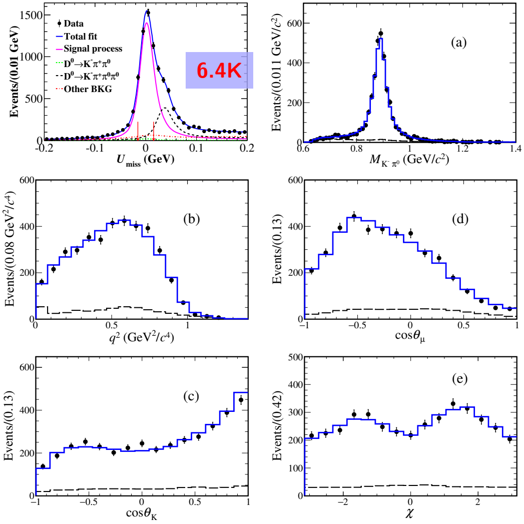
First study of $D^0 \to \bar{K}^0\pi^-\mu^+\nu_\mu$



- Positive and negative helicity partial widths ratio $R_{+/-} = \Gamma_+/\Gamma_- = 0.28 \pm 0.03_{\text{stat+syst}}$
- Longitudinal and transverse K^* polarizations $R_{L/T} = \Gamma_L/\Gamma_T = 1.21 \pm 0.05_{\text{stat+syst}}$
- LFU test: $\mathcal{R}^{\mu/e}_{K^*(892)} = 0.955 \pm 0.022_{\text{stat}} \pm 0.017_{\text{syst}}$

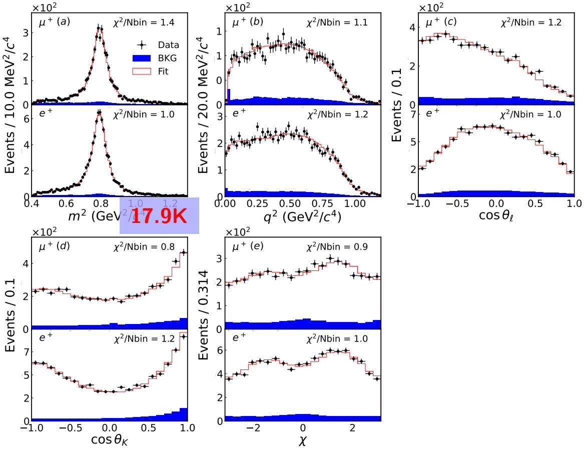
$$\mathcal{R}^{\mu/e}_{\bar{K}^0\pi} = \frac{\mathcal{B}(D^0 \to \bar{K}^0\pi^-\mu^+\nu_\mu)}{\mathcal{B}(D^0 \to \bar{K}^0\pi^- e^+\nu_e)} = 0.951 \pm 0.020_{\text{stat}} \pm 0.016_{\text{syst}}$$

First study of $D^0 \to K^-\pi^0\mu^+\nu_\mu$



- PRL 134(2025)011803
- 7.93 fb^{-1}data sample @3.773 GeV
- $\mathcal{B}(D^0 \to K^-\pi^0\mu^+\nu_\mu) = (0.773 \pm 0.014_{\rm stat} \pm 0.012_{\rm syst})\%$
  $\mathcal{B}(D^0 \to K^*(892)^-\mu^+\nu_\mu) = (2.073 \pm 0.039_{\rm stat} \pm 0.032_{\rm syst})\%$
- $r_V = V(0)/A_1(0) = 1.37 \pm 0.09_{\rm stat} \pm 0.03_{\rm syst}$
  $r_2 = A_2(0)/A_1(0) = 0.76 \pm 0.06_{\rm stat} \pm 0.02_{\rm syst}$
- LFU test: $\frac{\mathcal{B}(D^0 \to K^*(892)^-\mu^+\nu_\mu)}{\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e)} = 1.020 \pm 0.030_{\rm stat} \pm 0.028_{\rm syst}$
- First amplitude analysis for the $D^0 \to K^-\pi^0\mu^+\nu_\mu$ decay

Combined analysis of $D^+ \to \bar{K}^0\pi^0\ell^+\nu_\ell$



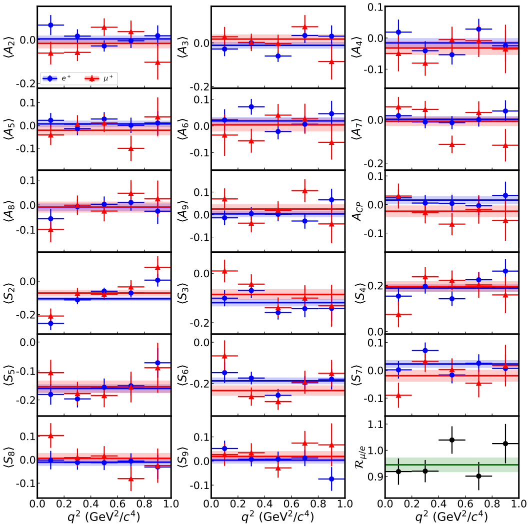
- arXiv:2506.05761
- 20.3 fb^{-1}data sample @3.773 GeV
- $\mathcal{B}(D^+ \to K_S^0\pi^0\mu^+\nu_\mu) = (0.896 \pm 0.017_{\rm stat} \pm 0.008_{\rm syst})\%$ **First time**

  $\mathcal{B}(D^+ \to \bar{K}^{*0}\mu^+\nu_\mu) = (4.99 \pm 0.10_{\rm stat} \pm 0.05_{\rm sys})\%$
- $\mathcal{B}(D^+ \to K_S^0\pi^0 e^+\nu_e) = (0.943 \pm 0.012_{\rm stat} \pm 0.010_{\rm syst})\%$

  $\mathcal{B}(D^+ \to \bar{K}^{*0} e^+\nu_e) = (5.29 \pm 0.07_{\rm stat} \pm 0.06_{\rm sys})\%$
- $r_V = V(0)/A_1(0) = 1.42 \pm 0.03_{\rm stat} \pm 0.02_{\rm syst}$

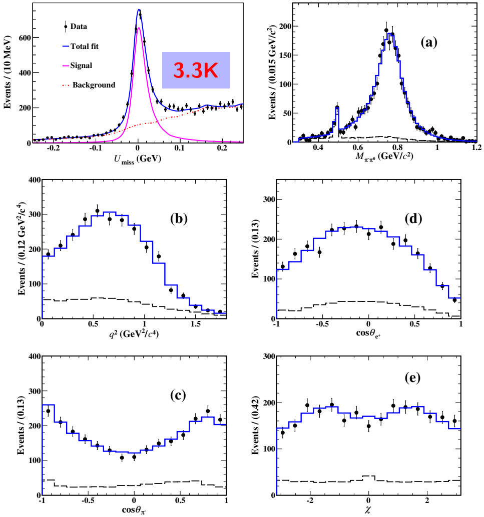
  $r_2 = A_2(0)/A_1(0) = 0.75 \pm 0.03_{\rm stat} \pm 0.01_{\rm syst}$
- Observation of the new muonic decay, study the decay dynamics

Combined analysis of $D^+ \to \bar{K}^0\pi^0\ell^+\nu_\ell$



- LFU test: $\mathcal{R}_{\mu/e} = 0.94 \pm 0.02_{\rm stat} \pm 0.01_{\rm syst}$
- Isospin test: $\mathcal{R}_{K^-\pi^+/K^0_S\pi^0} = 4.02 \pm 0.06_{\rm stat} \pm 0.10_{\rm syst}$
- First measurement of full set of CP asymmetries and averaged angular observables with A_{CP}
- All measured null-test observables A_{CP}, $\langle S_{7-9} \rangle$ and $\langle A_{2-9} \rangle$ are in agreement with the SM predictions, with the largest deviation being 1.7σ.

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

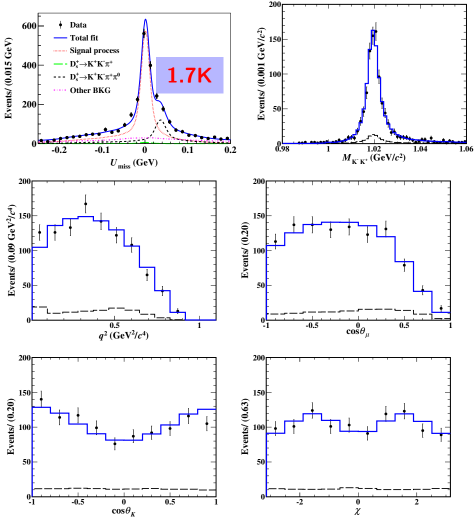


- PRD 110(2024)112018
- 7.93fb^{-1}data sample @3.773 GeV
- $\mathcal{B}(D_s^+ \to D^0 \to \rho(770)^- e^+ \nu_e) = (1.439 \pm 0.033(\text{stat.}) \pm 0.027(\text{syst.})) \times 10^{-3}$
- $r_V = V(0)/A_1(0) = 1.548 \pm 0.079(\text{stat.}) \pm 0.041(\text{syst.})$

  $r_2 = A_2(0)/A_1(0) = 0.823 \pm 0.056(\text{stat.}) \pm 0.026(\text{syst.})$

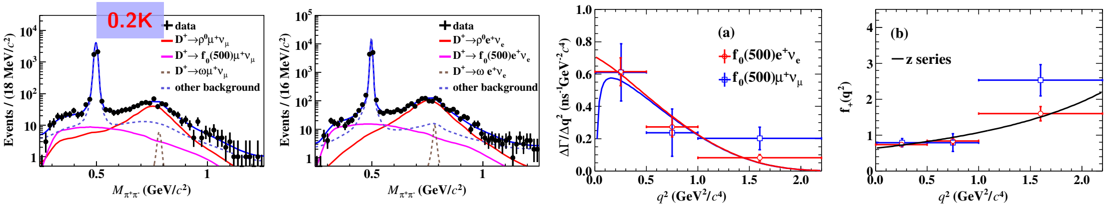
Improved by a factor of 1.6

Updated measurement of $D_s^+ \to K^+K^-\mu^+\nu_\mu$



- JHEP12(2023)072
- 7.33fb^{-1}data sample @4.128-4.226 GeV
- $\mathcal{B}(D_s^+ \to \phi\mu^+\nu_\mu) = (2.25 \pm 0.09 \pm 0.07) \times 10^{-2}$
  $\mathcal{B}(D_s^+ \to f_0(980)\mu^+\nu_\mu) \cdot \mathcal{B}(f_0(980) \to K^+K^-) < 5.45 \times 10^{-4}$ at 90% C.L.
- $r_V = \frac{V(0)}{A_1(0)} = 1.58 \pm 0.17 \pm 0.02$
  $r_2 = \frac{A_2(0)}{A_1(0)} = 0.71 \pm 0.14 \pm 0.02$ **Most precise**
- LFU test: $\frac{\mathcal{B}(D_s^+ \to \phi\mu^+\nu_\mu)}{\mathcal{B}(D_s^+ \to \phi e^+\nu_e)} = 0.94 \pm 0.08$

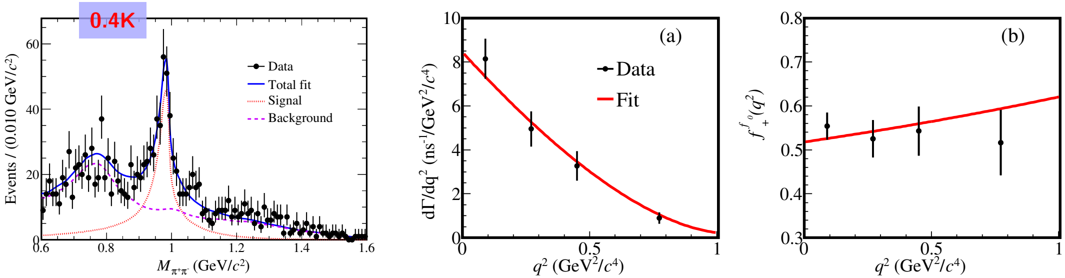
First study of $D^+ \to f_0(500)\mu^+\nu_\mu$



- Data: 2.93fb^{-1}@4.128-4.226 GeV PRD110(2024)092008
- $\mathcal{B}_{D^+\to f_0(500)\mu^+\nu_\mu}\mathcal{B}_{f_0(980)\to\pi^+\pi^-} = (0.72 \pm 0.13_{\rm stat} \pm 0.08_{\rm syst}) \times 10^{-3}$
- First extraction of the FF $f_+^{f_0}(0)|V_{cd}| = 0.143 \pm 0.014_{\rm stat} \pm 0.011_{\rm syst}$

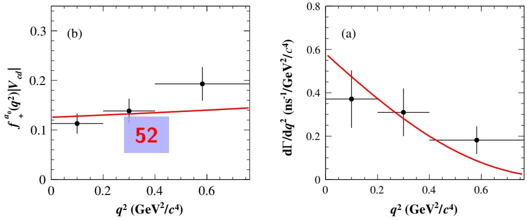
  Series expansion $r_1 = -5.8 \pm 2.4 \pm 0.5$
- LFU test: $\mathcal{B}_{D^+\to f_0(500)\mu^+\nu_\mu}/\mathcal{B}_{D^+\to f_0(500)e^+\nu_e} = 1.14 \pm 0.26$

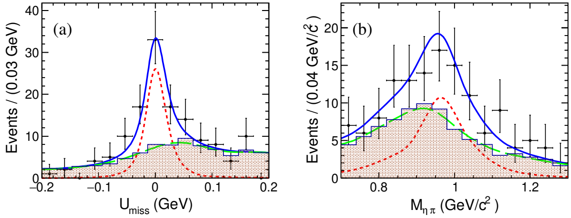
Study of $D_s^+ \to \pi^+\pi^- e^+\nu_e$



- Data: 7.33fb^{-1}@4.128-4.226 GeV PRD111(2025)l091501
- $\mathcal{B}_{D_s^+\to f_0(980)e^+\nu_e}\mathcal{B}_{f_0(980)\to\pi^+\pi^-} = (1.72 \pm 0.13_{\rm stat} \pm 0.10_{\rm syst}) \times 10^{-3}$
- First extraction of the FF $f_+^{f_0}(0)|V_{cs}| = 0.504 \pm 0.017_{\rm stat} \pm 0.035_{\rm syst}$.

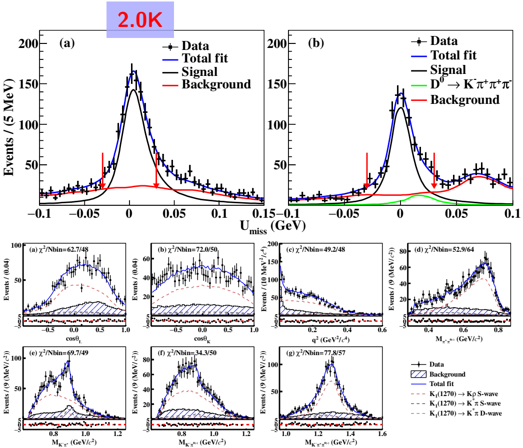
Updated measurement of $D^0 \to a_0(980)^- e^+ \nu_e$





- Data: 7.93fb^{-1}@3.773 GeV PRD111(2025)l091501
- $\mathcal{B}_{D^0\to a_0(980)^- e^+\nu_e}\mathcal{B}_{a_0(980)^-\to\eta\pi^-} = (0.86 \pm 0.17_{\text{stat}} \pm 0.05_{\text{syst}}) \times 10^{-4}$
- First extraction of the FF $f_+^{a_0}(0)|V_{cd}| = 0.126 \pm 0.013_{\text{stat}} \pm 0.003_{\text{syst}}$.

First study of $D^{0(+)} \to K^-\pi^+\pi^{0(-)}e^+\nu_e$



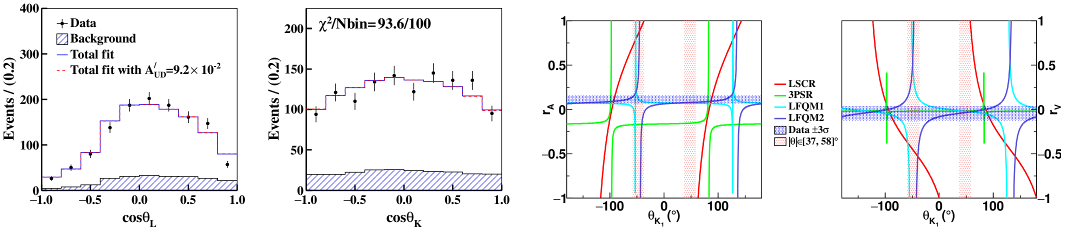
- arXiv:2503.02196
- 20.3fb^{-1}data sample @3.773 GeV
- $\mathcal{B}(D^+ \to K^-\pi^+\pi^0e^+\nu_e) = (1.27 \pm 0.06 \pm 0.04) \times 10^{-3}$

  $\mathcal{B}(D^0 \to K^-\pi^+\pi^-e^+\nu_e) = (0.32 \pm 0.02 \pm 0.02) \times 10^{-3}$
- $\mathcal{B}(D^+ \to \bar{K}_1^0(1270)e^+\nu_e) = (2.27 \pm 0.11 \pm 0.07 \pm 0.07) \times 10^{-3}$

  $\mathcal{B}(D^0 \to K_1^-(1270)e^+\nu_e) = (1.02 \pm 0.06 \pm 0.06 \pm 0.03) \times 10^{-3}$
- $r_A = (-11.2 \pm 1.0 \pm 0.9) \times 10^{-2}$

  $r_V = (-4.3 \pm 1.0 \pm 2.4) \times 10^{-2}$
- $\frac{\mathcal{B}(K_1(1270) \to K^*\pi)}{\mathcal{B}(K_1(1270) \to K\rho)} = (20.3 \pm 2.1 \pm 8.7)\%.$
- First amplitude and angular analyses of the decays $D^{+(0)} \to K^-\pi^+\pi^{0(-)}e^+\nu_e$

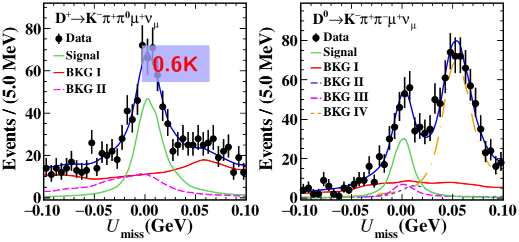
First study of $D^{0(+)} \to K^-\pi^+\pi^{0(-)}e^+\nu_e$



- From the angular analysis, the updown asymmetry is determined as $\mathcal{A}'_{ud} = 0.01 \pm 0.11$
- The $\bar{K}_1(1270)$ longitudinal polarization $F_L = 0.50 \pm 0.04$

Observation of $D \to \bar{K}_1(1270)\mu^+\nu_\mu$

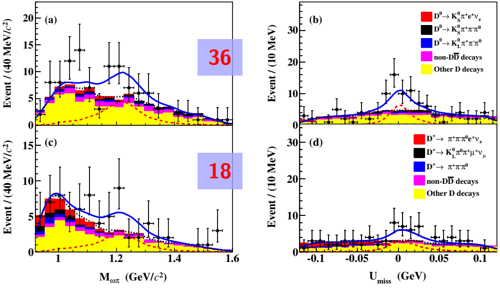
- PRD111(2025)L071101
- 7.93fb^{-1}data sample @3.773 GeV



- $\mathcal{B}(D^+ \to \bar{K}_1^0(1270)\mu^+\nu_\mu) = (2.36 \pm 0.20^{+0.18}_{-0.27} \pm 0.48) \times 10^{-3}$
  $\mathcal{B}(D^0 \to K_1^-(1270)\mu^+\nu_\mu) = (0.78 \pm 0.11^{+0.05}_{-0.09} \pm 0.15) \times 10^{-3}$
- LFU test:
  $$\frac{\mathcal{B}(D^0 \to K_1^-(1270)\mu^+\nu_\mu)}{\mathcal{B}(D^0 \to K_1^-(1270)e^+\nu_e)} = 0.74 \pm 0.13^{+0.08}_{-0.13}$$
  $$\frac{\mathcal{B}(D^+ \to \bar{K}_1^0(1270)\mu^+\nu_\mu)}{\mathcal{B}(D^+ \to \bar{K}_1^0(1270)e^+\nu_e)} = 1.03 \pm 0.14^{+0.11}_{-0.15}$$
- Isospin test:
  $$\frac{\Gamma(D^+ \to \bar{K}_1^0(1270)\mu^+\nu_\mu)}{\Gamma(D^0 \to K_1^-(1270)\mu^+\nu_\mu)} = 1.22 \pm 0.10^{+0.06}_{-0.09}$$

- Observable of the muonic decays $D \to \bar{K}_1(1270)\mu^+\nu_\mu$

Observation of $D^0 \to b_1(1235)^- e^+\nu_e$



- 2407.20551
- 7.93fb^{-1}data sample @3.773 GeV
- $\mathcal{B}(D^0 \to b_1^- e^+\nu_e) \times \mathcal{B}(b^- \to \omega\pi^-) = (0.72 \pm 0.18^{+0.06}_{-0.08}) \times 10^{-4}$

  $\mathcal{B}(D^+ \to b_1^0 e^+\nu_e) \times \mathcal{B}(b_1^0 \to \omega\pi^0) = (1.16 \pm 0.44 \pm 0.16) \times 10^{-4}$
- First observation of $D^0 \to b_1^- e^+\nu_e$ and evidence for $D^+ \to b_1^0 e^+\nu_e$

Other highlight works

- Search for $D \to K\bar{K}e^+\nu_e$ with data 7.93 fb^{-1}@3.773 GeV [PRD109(2024)072003]
  - $\mathcal{B}(D^0 \to K_S^0 K^- e^+\nu_e) < 2.13 \times 10^{-5}$ at 90% C.L.
  - $\mathcal{B}(D^+ \to K_S^0 K_S^0 e^+\nu_e) < 1.54 \times 10^{-5}$ at 90% C.L.
  - $\mathcal{B}(D^+ \to K^+ K^- e^+\nu_e) < 2.10 \times 10^{-5}$ at 90% C.L.
- Search for $D^0 \to P\eta e^+\nu_e, P = \eta, \bar{K}$ decays with data 7.93 fb^{-1}@3.773 GeV [PRD110(2024)112001]
  - $\mathcal{B}(D^0 \to K^-\eta e^+\nu_e) = 0.84^{+0.34}_{-0.29} \pm 0.22$ with 3.3σ
  - $\mathcal{B}(D^+ \to K_S^0\eta e^+\nu_e) < 2.0 \times 10^{-4}$ at 90% C.L.
  - $\mathcal{B}(D^+ \to \eta\eta e^+\nu_e) < 1.0 \times 10^{-4}$ at 90% C.L.
- Semi-leptonic D_s^+ decays using $D_s^{*+}D_s^{*-}$ sample with data 10.64 fb^{-1}@4.237-4.699 GeV [PRD110(2024)052002]
  - $\mathcal{B}(D_s^+ \to \phi_{K^+K^-} e^+\nu_e) = 2.21 \pm 0.16 \pm 0.11\%$
  - $\mathcal{B}(D_s^+ \to f_{0\ \pi^+\pi^-}(980) e^+\nu_e) = 0.15 \pm 0.02 \pm 0.01\%$
  - $\mathcal{B}(D_s^+ \to K^{0*} e^+\nu_e) = 0.19 \pm 0.03 \pm 0.01\%$

Channel	$\mathcal{L}_{\rm int}$ (fb^{-1}) / $E_{\rm cm}$ (GeV)	Reference
$D_s^+ \to hhe^+\nu_e, h = \pi, \bar{K}$	10.64 / 4.237-4.699	PRD110(2024)052002
$D \to P\eta e^+\nu_e, P = \eta, \bar{K}$	7.93 / 3.773	PRD110(2024)112001
$D \to K\bar{K}e^+\nu_e$	7.93 / 3.773	PRD109(2024)072003

Summary

- Purely and semileptonic decays of charm hadrons are important for determining CKM matrix elements, calibrating LQCD, testing LFU, *et al.*;
- Precisions of hadronic transition form factors have benn reduced to ∼4%, respectively;
- No evidence of LFU violation is found within precisions of ∼3% for $\mathcal{R}(\mu/e)$ via $D \to \bar{K}^{*}\ell^{+}\nu_{\ell}$;
- Isospin conservation is verified within strange meson of precision of 3% via $D^{+} \to \bar{K}^{*0}\ell^{+}\nu_{\ell}$;
- Machine learning has demonstrated the power in experimental particle physics, offering the possible in searching for the rare decays of charm hadrons in future.

Prospect

- 20.3 fb^{-1}data @3.773 GeV is ready at Jul. 2024, more precision measurements and searching for rare semileptonic decays will be presented;
- Additional 3 fb^{-1}data @4.178 GeV in future [CPC44(2020)040001] will further improve the precisions in D_s sector.

Thank you