Recent (semi-)leptonic decays of charmed hadrons at BESIII

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(on behalf of the BESIII collaboration)

第三届BESIII-Belle II-LHCb粲强子物理联合研讨会
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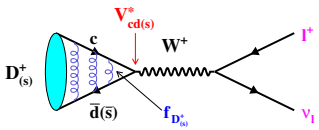
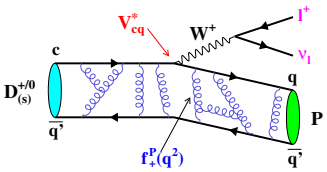
Outline

Introduction





$$\Gamma = \frac{G_F^2}{8\pi}|V_{cq}|^2|f_{D^+_{(s)}}|^2 m_\ell^2 m_{D^+_{(s)}}(1 - m_\ell^2/m^2_{D^+_{(s)}})^2$$

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

X is a multiplicative factor due to isospin

- Decay constant $f_{D^+_{(s)}}$ and FF $f_+(0)$ measurements⇒Calibrate LQCD calculations
- $|V_{cq}|$ measurement ⇒Test CKM matrix unitarity
- Branching Fractions $\mathcal{B}_{\mu/e}$,$\mathcal{B}_{\tau/\mu}$⇒Test lepton flavor universality (LFU)
- Rare decays ⇒ Search for new physics effects beyond the Standard Model
- Λ_c ⇒As the ground-state charmed baryon, despite over 40 years of study, remains incompletely understood, yet its semileptonic decays provide crucial insights into both strong and weak interactions.

BESIII dataset

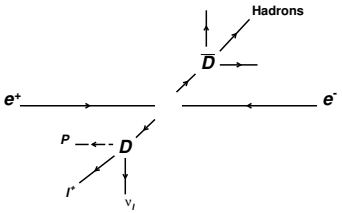
Data for charmed meson(D^0, D^+, D_s^+) studies:

Data sample	$E_{\rm cm}$ (GeV)	Year and $\mathcal{L}_{\rm int}$ ($\rm fb^{-1}$)	Total $\mathcal{L}_{\rm int}$ ($\rm fb^{-1}$)	Single tag yields ($\times 10^6$)
$e^+e^- \to \psi(3770) \to D\bar{D}$	3.773	2010-2011: 2.93 2021-2022: 4.995 2022-2023: 8.157 2023-2024: 4.191	20.3	D^+ ~1.61; $\bar{D}^0$ ~2.47 D^+ ~2.66; $\bar{D}^0$ ~4.12 D^+ ~3.84; $\bar{D}^0$ ~6.76 D^+ ~2.29; $\bar{D}^0$ ~3.51
$e^+e^- \to D_s^{\pm}D_s^{*\mp}$	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

Data for charmed baryon(Λ_c^+) studies:

- 0.567 $\rm fb^{-1}$@ 4.6 GeV in 2014;
- 3.9 $\rm fb^{-1}$@ 4.61 - 4.70 GeV scan data in 2020-2021;
- 1.9 $\rm fb^{-1}$@ 4.74 - 4.95 GeV in 2021-2022;
- Totally 6.4$\rm fb^{-1}$ data from 13 energy point, 1 million pairs

Analysis 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
- Deep learning method⇒Powerful Pattern Recognition; Rigorous Validation; Event-Level Topology Analysis.

Publications

Charmed D meson decay:

Topic	Channel	$\mathcal{L}_{\rm int}$ (fb^{-1}) / $E_{\rm cm}$ (GeV)	Reference
$D^+ \to \ell^+\nu_\ell$	$D^+ \to \mu^+\nu_\mu$	20.3 / 3.773	arXiv:2410.07626
	$D^+ \to \tau^+\nu_\tau$	7.9 / 3.773	JHEP01(2025)89
$D_s^+ \to \ell^+\nu_\ell$	$D_s^+ \to \mu^+\nu_\mu$	7.33 / 4.128-4.226	PRD108(2023)112001
	$D_s^+ \to \tau^+\nu_\tau$ ($\tau \to \mu^+\nu_\mu\bar{\nu}_\tau$)	7.33 / 4.128-4.226	JHEP(2023)124
	$D_s^+ \to \tau^+\nu_\tau$ ($\tau^+ \to \pi^+\bar{\nu}_\tau$)	7.33 / 4.128-4.226	PRD108(2023)092014
	$D_s^+ \to \ell^+\nu_\ell, \ell = \mu$ or τ	10.64 / 4.237-4.699	PRD110(2024)052002
$D^{+(0)} \to P\ell^+\nu_\ell$	$D \to K\ell^+\nu_\ell, \ell = e$ or μ	7.93 / 3.773	PRD110 (2024)112006
	$D^+ \to \eta'\ell^+\nu_\ell, \ell = e$ or μ	20.3 / 3.773	PRL134(2025)111801
$D^{+(0)} \to V\ell^+\nu_\ell$	$D^+ \to K^0\pi^0 e^+\nu_e$	7.93 / 3.773	JHEP10(2024)199
	$D^+ \to K^-\pi^0\mu^+\nu_\mu$	7.93 / 3.773	PRL134(2025)011803
	$D^0 \to \bar{K}^0\pi^- e^+\nu_e$	7.93 / 3.773	JHEP03(2025)197
	$D^0 \to \pi^0\pi^- e^+\nu_e$	7.93 / 3.773	PRD110(2024)112018
$D^{+(0)} \to S\ell^+\nu_\ell$	$D^+ \to f_0(500)\ell^+\nu_\ell, \ell = e$ or μ	2.93 / 3.773	PRD110(2024)092008
	$D^0 \to a_0(980)e^+\nu_e$	7.93 / 3.773	PRD111(2025)L091501
$D \to A\ell^+\nu_\ell$	$D \to b_1(1235)e^+\nu_e$	7.93 / 3.773	arXiv:2407.20551
	$D \to K_1(1270)\mu^+\nu_\mu$	7.93 / 3.773	PRD111(2025)L071101
	$D \to K_1(1270)e^+\nu_e$	20.3 / 3.773	arXiv:2503.02196
$D_s^+ \to P\ell^+\nu_\ell$	$D_s^+ \to \eta^{(\prime)}\mu^+\nu_\mu$	7.33 / 4.128-4.226	PRL132(2024)091802

- P, S, V, A represent pseudoscalar, scalar, vector, and axion mesons, respectively.

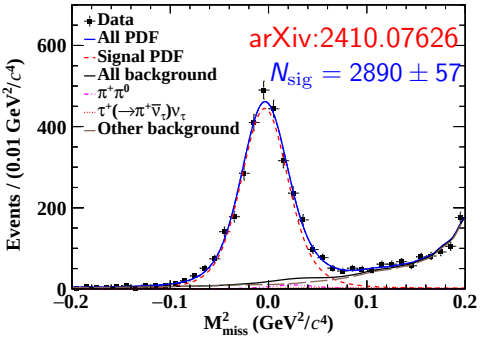
Charmed Λ_c^+ baryon decay:

$\Lambda_c^+ \to ne^+\nu_e$ Nat. Comm. 16, 681(2025)

Leptonic decays

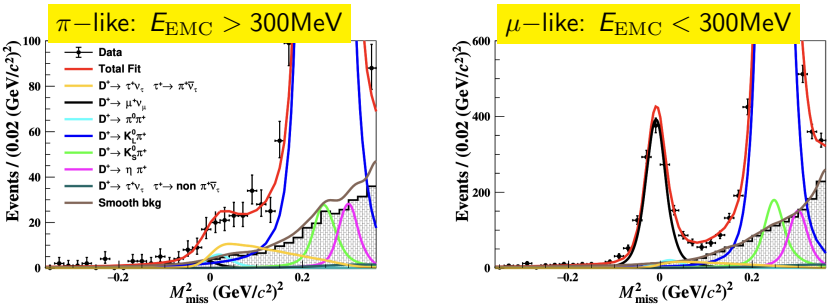
Precision measurement of the branching fraction of $D^+ \to \mu^+\nu_\mu$

Reference	$\mathcal{L}$ (fb^{-1})	BF($\times 10^{-4}$)	f_{D^+} (MeV)	$\lvert V_{cd}\rvert$	Precision (%)
CLEO, PRD78,052003	0.818	3.82(32)(09)	207.1(87)(24)(08)	0.2195(92)(26)(09)	4.4
BESIII, PRD89,051104	2.93	3.71(19)(06)	204.1(52)(17)(08)	0.2164(55)(17)(09)	2.7
BESIII, arXiv:2410.07626	20.3	3.981(79)(40)	211.5(21)(11)(08)	0.2242(23)(11)(09)	1.2 ★



Measurement of the branching fraction of $D^+ \to \tau^+\nu_\tau$ via $\tau^+ \to \pi^+\bar{\nu}_\tau$

Reference	$\mathcal{L}$ (fb^{-1})	BF($\times 10^{-3}$)	f_{D^+} (MeV)	$\lvert V_{cd}\rvert$	Precision (%)
PRL123,211802	2.93	1.20(24)(12)	225(23)(11)(01)	0.238(24)(12)(01)	11
JHEP01(2025)089	7.9	0.99(11)(05)	204(11)(05)(01)	0.216(12)(06)(01)	6.1 ★



- LFU test:

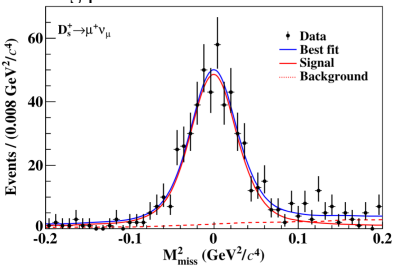
$\mathcal{R}_{\tau/\mu} = \Gamma_{D^+\to\tau^+\nu_\tau}/\Gamma_{D^+\to\mu^+\nu_\mu} = 2.49 \pm 0.31$, consistent with $\mathcal{R}^{\rm SM}_{\tau/\mu} = \frac{m_\tau^2(1-m_\tau^2/m_{D^+}^2)^2}{m_\mu^2(1-m_\mu^2/m_{D^+}^2)^2} = 2.69$

$D_s^+ \to \ell\nu_\ell$ ($\ell = \mu^+, \tau^+$) via $e^+e^- \to D_s^{*+}D_s^{*-}$

Data: 10.64 fb^{-1} 4.237-4.669 GeV

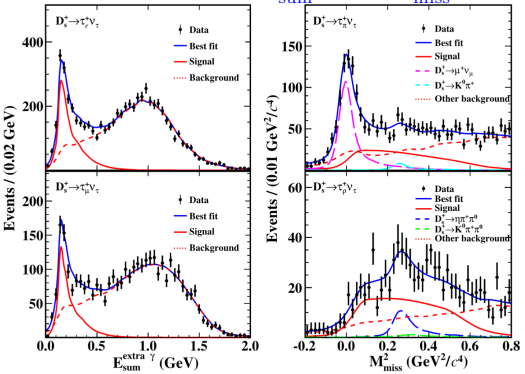
PRD110(2024)052002

$N_{\rm ST} = 124027 \pm 1121$



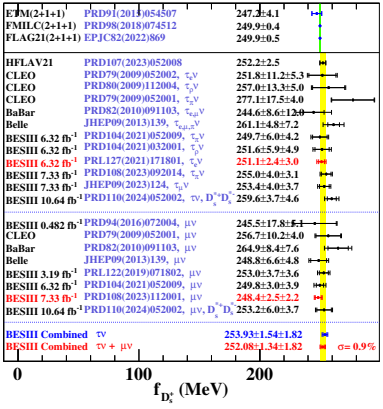
- $N_{\rm DT} = 507 \pm 26$
- $\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (0.547 \pm 0.026 \pm 0.016)\%$
- $f_{D_s^+}|V_{cs}| = (246.5 \pm 5.9 \pm 3.6 \pm 0.5_{\rm input})$ MeV

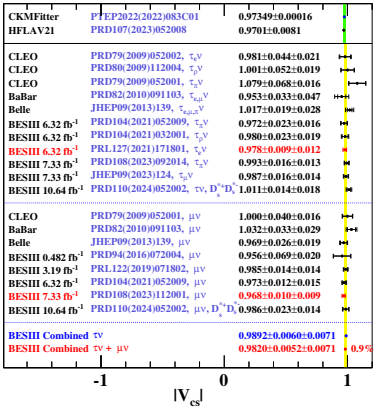
Simultaneous fit to the $E_{\rm sum}^{\rm extra\gamma}$ and $M^2_{\rm miss}$



- $N_{\rm DT} = 2845 \pm 83$
- $\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.60 \pm 0.16 \pm 0.20)\%$
- $f_{D_s^+}|V_{cs}| = (252.7 \pm 3.6 \pm 4.5 \pm 0.6_{\rm input})$ MeV
- $\mathcal{R}(\tau/\mu) = 10.24 \pm 0.57$, consistent with the SM (9.75±0.01) within 0.9σ

Summary of leptonic D_s decays



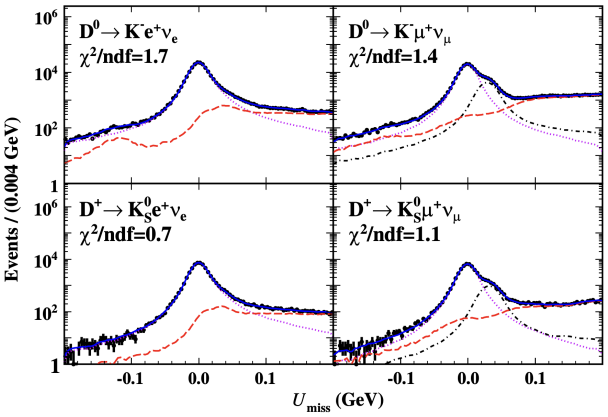


- Averaged BESIII results, precisions of f_{D_s} and $|V_{cs}|$: 0.9%
- $\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (0.5310 \pm 0.0099 \pm 0.0053)\%$ and $\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.359 \pm 0.067 \pm 0.074)\%$
  $\mathcal{R}(\tau/\mu) = 10.09 \pm 0.28$ ($\sigma \sim 2.8\%$), consistent within SM (9.75±0.01) 1.2σ

Semileptonic decays

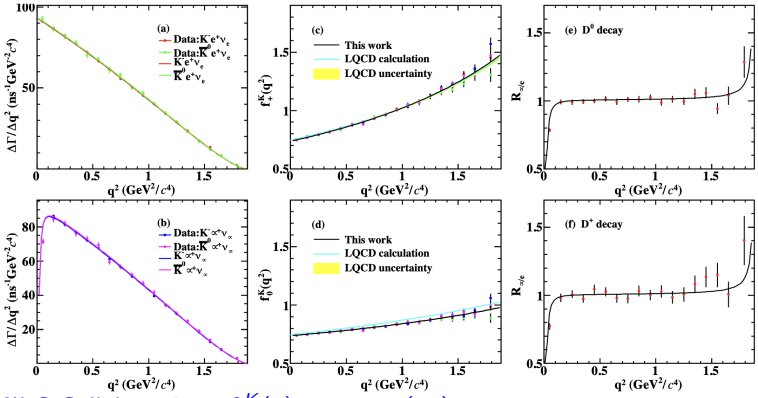
Improved measurements of $D^0 \to K^-\ell^+\nu_\ell$ and $D^+ \to \bar{K}^0\ell^+\nu_\ell$

- Phys. Rev. D **110**, 112006 (2024)
- 7.93 fb^{-1}data sample @3.773 GeV



- $\mathcal{B}(D^0 \to K^- e^+ \nu_e) = (3.521 \pm 0.009 \pm 0.016)\%$
  $\mathcal{B}(D^0 \to K^- \mu^+ \nu_\mu) =$
  $(3.419 \pm 0.011 \pm 0.016)\%$
  $\mathcal{B}(D^+ \to \bar{K}^0 e^+ \nu_e) = (8.864 \pm 0.039 \pm 0.082)\%$
  $\mathcal{B}(D^+ \to \bar{K}^0 \mu^+ \nu_\mu) =$
  $(8.665 \pm 0.046 \pm 0.084)\%$
- LFU test (SM: 0.975±0.001) ∼consistent
  $\frac{\mathcal{B}(D^0 \to K^- \mu^+ \nu_\mu)}{\mathcal{B}(D^0 \to K^- e^+ \nu_e)} = 0.971 \pm 0.004 \pm 0.006$
  $\frac{\mathcal{B}(D^+ \to \bar{K}^0 \mu^+ \nu_\mu)}{\mathcal{B}(D^+ \to \bar{K}^0 e^+ \nu_e)} = 0.978 \pm 0.007 \pm 0.013$
- Isospin test ∼consistent
  $\frac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\Gamma(D^+ \to \bar{K}^0 e^+ \nu_e)} = 1.000 \pm 0.007 \pm 0.012$
  $\frac{\Gamma(D^0 \to K^- \mu^+ \nu_\mu)}{\Gamma(D^+ \to \bar{K}^0 \mu^+ \nu_\mu)} = 0.993 \pm 0.008 \pm 0.012$

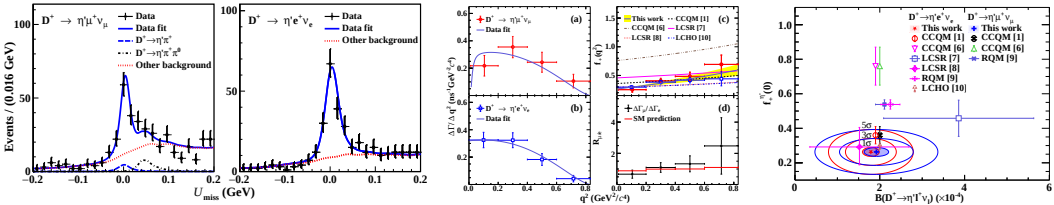
Improved measurements of $D^0 \to K^-\ell^+\nu_\ell$ and $D^+ \to \bar{K}^0\ell^+\nu_\ell$



- FNAL/MILC Collaboration: $f_+^K(0) = 0.7452(31)$; $|V_{cs}| = 0.9589(23)^{Expt}(40)^{QCD}(15)^{EW}(05)^{SIB}[95]^{QED}$ Phys.Rev.D 107.094516
- BESIII Collaboration: $f_+^K(0) = 0.7366 \pm 0.0011_{\rm stat} \pm 0.0013_{\rm syst}$; $|V_{cs}| = 0.9623 \pm 0.0015_{\rm stat} \pm 0.0017_{\rm syst} \pm 0.0040_{\rm LQCD}$
- Experimental uncertainties of $f_+^K(0)$ and $|V_{cs}|$: 0.23%
- Additional uncertainty of the input $f_+^K(0)$ calculated by LQCD: 0.42%

First study of $D^+ \to \eta' \ell^+ \nu_\ell$ decay dynamics

Data: 20.3 fb^{-1}@3.773 GeV PRL134(2025)111801



- First observation of $D^+ \to \eta' \mu^+ \nu_\mu$ with significance of 8.6σ

  $\mathcal{B}(D^+ \to \eta' \mu^+ \nu_\mu) = (1.92 \pm 0.28 \pm 0.08) \times 10^{-4}$;
  $\mathcal{B}(D^+ \to \eta' e^+ \nu_e) = (1.79 \pm 0.19 \pm 0.07) \times 10^{-4}$

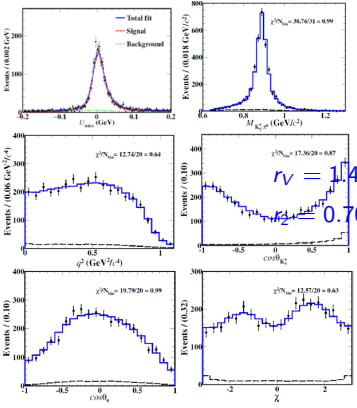
- First extraction of the FF of $D^+ \to \eta' \ell^+ \nu_\ell$: $f_+^{\eta'}(0) = 0.263 \pm 0.025 \pm 0.006$

- LFU test: $\mathcal{R}_{\mu/e}^{\eta'} = 1.07 \pm 0.19 \pm 0.03$

- $\eta - \eta'$ mixing angle: $\phi_P = (39.8 \pm 0.8 \pm 0.3)^\circ$ ($\cot^4 \phi_P = \frac{\Gamma_{D_s^+ \to \eta' \ell^+ \nu_\ell} / \Gamma_{D_s^+ \to \eta \ell^+ \nu_\ell}}{\Gamma_{D^+ \to \eta' \ell^+ \nu_\ell} / \Gamma_{D^+ \to \eta \ell^+ \nu_\ell}}$)

$D^+ \to \bar{K}^0\pi^0 e^+\nu_e$ and $D^0 \to K^-\pi^0\mu^+\nu_\mu$

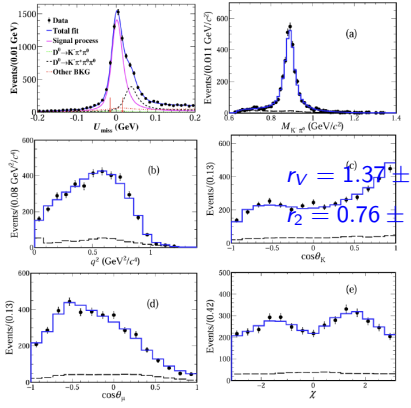
$D^+ \to \bar{K}^0\pi^0 e^+\nu_e$ JHEP10(2024)199



$r_V = 1.48 \pm 0.05 \pm 0.02$

$r_2 = 0.70 \pm 0.04 \pm 0.02$

$D^0 \to K^-\pi^0\mu^+\nu_\mu$ PRL134(2025)011803



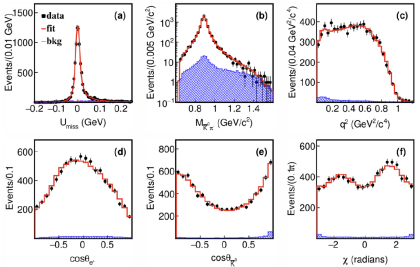
$r_V = 1.37 \pm 0.09 \pm 0.03$

$r_2 = 0.76 \pm 0.06 \pm 0.02$

- Based on the 7.93 fb^{-1} dataset, the first measurements of branching ratios and form factors.

$D^0 \to \bar{K}^0\pi^-e^+\nu_e$ and $D^0 \to \pi^0\pi^-e^+\nu_e$

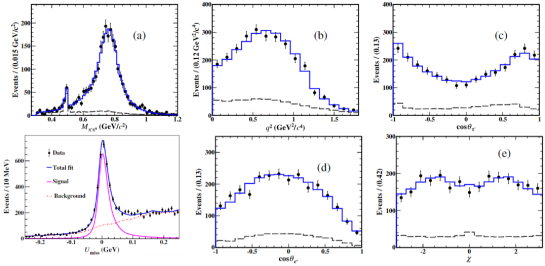
$D^0 \to \bar{K}^0\pi^-e^+\nu_e$ JHEP03(2025)197



$r_V = 1.48 \pm 0.05 \pm 0.02$

$r_2 = 0.70 \pm 0.04 \pm 0.02$

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



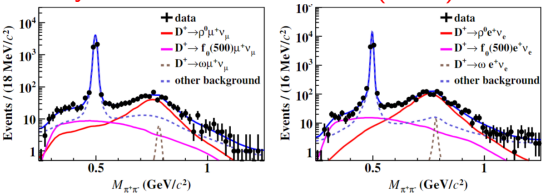
$r_V = 1.548 \pm 0.079 \pm 0.041$

$r_2 = 0.823 \pm 0.056 \pm 0.026$

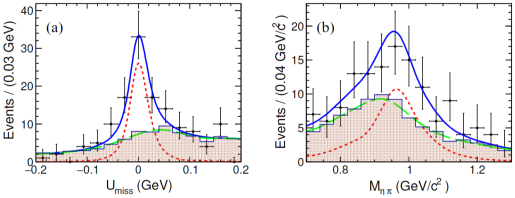
- Data: 7.9 fb^{-1}@3.773 GeV
- $\mathcal{B}(D^0 \to \bar{K}^0\pi^-e^+\nu_e) = (1.444 \pm 0.022 \pm 0.024)\%$,$\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e) = (2.039 \pm 0.032 \pm 0.034)\%$ ~statistical precision within 2%!
- $\mathcal{B}(D^0 \to \rho(770)^-e^+\nu_e = (1.439 \pm 0.033 \pm 0.027) \times 10^{-3}$ ~precision improved 1.6 times.

$D^+ \to f_0(500)(\pi^+\pi^-)\ell^+\nu_\ell$ and $D^0 \to a_0(980)^-(\eta\pi^-)e^+\nu_e$

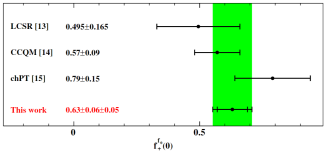
Phys. Rev. D 110, 092008 (2024)



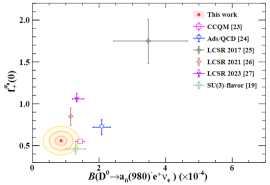
arXiv: 2411.07730



$D^+ \to f_0(500)(\pi^+\pi^-)\ell^+\nu_\ell$



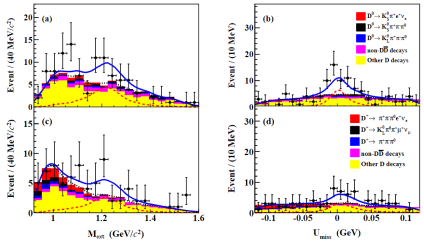
$D^0 \to a_0(980)^-(\eta\pi^-)e^+\nu_e$



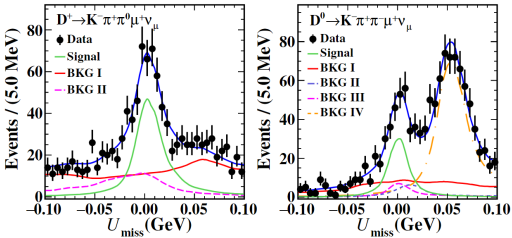
- First form factor measurements based on 2.93/7.93 fb^{-1} data: Understanding light scalar mesons $f_0(500)$ and $a_0(980)$.

$D \to b_1(1235)e^+\nu_e$ and $D \to K_1(1270)\mu^+\nu_\mu$

arXiv: 2407.20551



Phys. Rev. D 111, L071101 (2025)



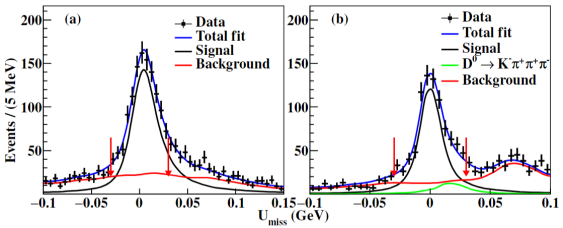
$D \to b_1(1235)e^+\nu_e$

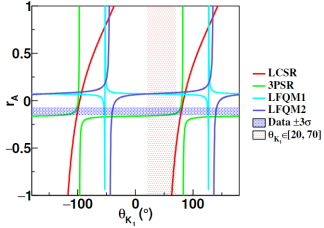
- First observation of $D^0 \to b_1(1235)^- e^+\nu_e$ and evidence for $D^+ \to b_1(1235)^0 e^+\nu_e$(7.93 fb^{-1})
- $\mathcal{B}(D^0 \to b_1(1235)^- e^+\nu_e) \times \mathcal{B}(b_1(1235)^- \to \omega\pi^-) = (0.72 \pm 0.18^{+0.06}_{-0.08}) \times 10^{-4}$
- $\mathcal{B}(D^+ \to b_1(1235)^0 e^+\nu_e) \times \mathcal{B}(b_1(1235)^0 \to \omega\pi^0) = (1.16 \pm 0.44 \pm 0.16) \times 10^{-4}$

$D \to K_1(1270)\mu^+\nu_\mu$

- First observation of $D \to K_1(1270)\mu^+\nu_\mu$(7.93 fb^{-1})
- $\mathcal{B}(D^0 \to K_1(1270)^- \mu^+\nu_\mu) = (0.78 \pm 0.11^{+0.05}_{-0.09} \pm 0.15) \times 10^{-3}$
- $\mathcal{B}(D^+ \to \bar{K}_1(1270)\mu^+\nu_\mu) = (2.36 \pm 0.20^{+0.18}_{-0.27} \pm 0.48) \times 10^{-3}$

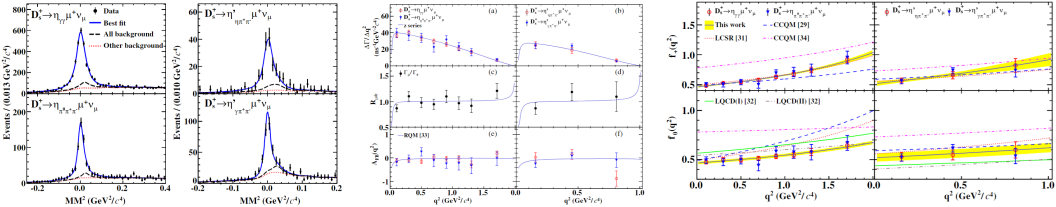
First amplitude and angular analyses of $D \to K_1(1270)e^+\nu_e$





- Data: 20.3 fb^{-1}@3.773 GeV [arXiv:2503.02196]
- First determination of the FF of $D \to K_1(1270)e^+\nu_e \to$ extract the θ_K
  - $r_A = (-11.2 \pm 1.0 \pm 0.9) \times 10^{-2}$ $r_V = (-4.3 \pm 1.0 \pm 2.4) \times 10^{-2}$
  - $f_{D_q \to K_1(1270)} = f_{D_q \to K_{1A}} \sin\theta_K + f_{D_q \to K_{1B}} \cos\theta_K$
- The BF ratio of the two dominant components in the $K_1(1270)$ decay to be $\frac{\mathcal{B}(K_1(1270) \to K^*\pi)}{\mathcal{B}(K_1(1270) \to K^*\rho)} = (20.3 \pm 2.1 \pm 8.7)\%$
- The angular analysis yields an up-down asymmetry $\mathcal{A}_{ud}^{'} = 0.01 \pm 0.11$

First study of $D_s^+ \to \eta^{(\prime)}\mu^+\nu_\mu$ decay dynamics



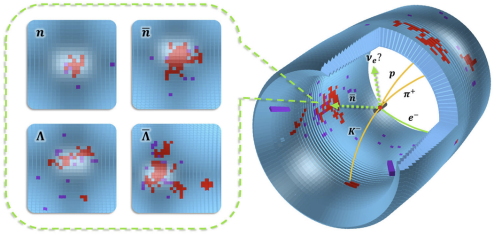
- Data: 7.33 fb^{-1}@4.128-4.226 GeV [PRL132(2024)091802]
- The precision of branching fractions improved by factors of 6.0 and 6.6 compared to the previous best measurements.
- FFs of $D_s^+ \to \eta(')\mu^+\nu_\mu$: $f_+^{\eta}(0) = 0.465 \pm 0.010 \pm 0.007, f_+^{\eta'}(0) = 0.518 \pm 0.038 \pm 0.012$
- LFU test: $\mathcal{R}^{\eta}_{\mu/e} = 0.991 \pm 0.029 \pm 0.016$, $\mathcal{R}^{\eta'}_{\mu/e} = 0.988 \pm 0.082 \pm 0.031$
- The forward-backward asymmetries are determined for the first time: $\langle A_{\rm FB}^{\eta} \rangle = -0.0059 \pm 0.031 \pm 0.005$, $\langle A_{\rm FB}^{\eta'} \rangle = -0.0064 \pm 0.079 \pm 0.006$.

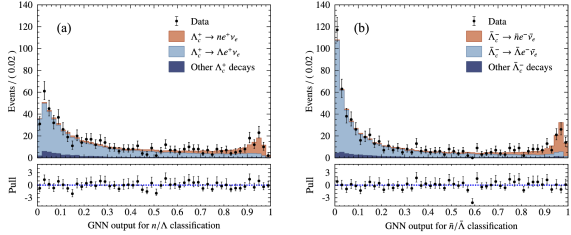
Other works

Channel	$\mathcal{L}_{\rm int}$ (fb^{-1}) / $E_{\rm cm}$ (GeV)	Reference
$D^+ \to e^+\nu_e$	20.3 / 3.773	CPC49(2025)063001
$D^{*+} \to \ell^+\nu_\ell, \ell = e$ or μ	6.32 / 4.178-4.226	PRD110(2024)012003
$D \to P\eta e^+\nu_e, P = \eta, \bar{K}$	7.93 / 3.773	PRD110(2024)112001
$D_s^+ \to \eta^{(\prime)} e^+\nu_e$	7.33 / 4.128-4.226	PRD108(2023)092003
$D_s^+ \to K^0 e^+\nu_e$	7.33 / 4.128-4.226	PRD110(2024)052012
$D_s^+ \to P e^+\nu_e, P = \eta^{(\prime)}, K^0$	10.64 / 4.237-4.699	PRD110(2024)072017

Observation of $\Lambda_c^+ \to ne^+\nu_e$ with Deep Learning

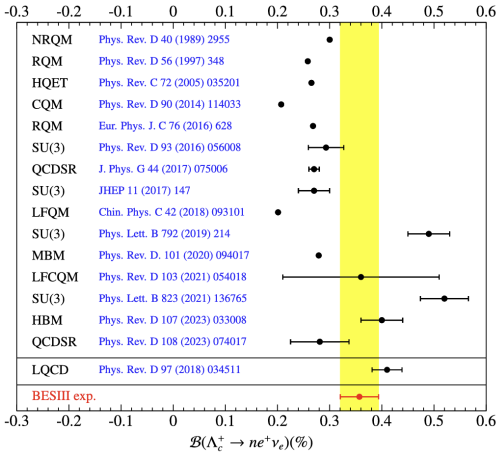
- **Unobserved Λ_c^+ CS transition:** The $c \to d\ell^+\nu_\ell$ decay mode has never been experimentally observed; Nat. Comm. 16, 681(2025)
- **Experimental Challenges:** The process is complicated by two missing particles (the neutron n and neutrino ν), as well as extensive background from $\Lambda_c^+ \to \Lambda(n\pi^0)\ell^+\nu$;
- **Novel Deep Learning Approach:** Deep Learning method is employed to effectively separate the signal from the dominant background;
- **Cross-Check on $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu)$**





Observation of $\Lambda_c^+ \to ne^+\nu_e$ with Deep Learning

Nat. Comm. 16, 681(2025)

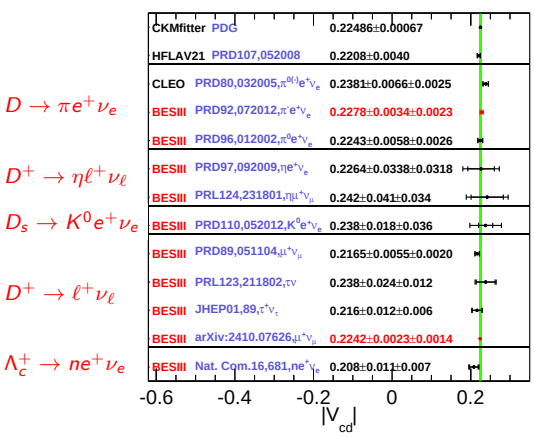


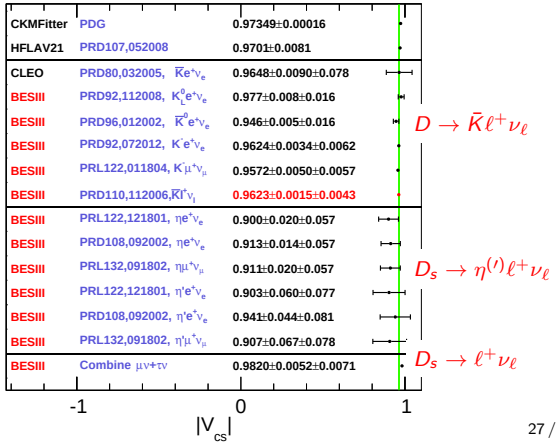
- $\mathcal{B}(\Lambda_c^+ \to ne^+\nu_e) = (0.357 \pm 0.034 \pm 0.014)\%$ ($>10\sigma$)
- $|V_{cd}| = 0.208 \pm 0.011_{\rm exp.} \pm 0.007_{\rm LQCD} \pm 0.001_{\tau_{\Lambda_c^+}}$
- This measurement demonstrates a level of precision comparable to the LQCD prediction;
- The first determination of the CKM matrix element $|\mathrm{V_{cd}}|$ from charmed baryon decays.

Comparison of $|V_{cd}|$, $|V_{cs}|$, f_{D^+}, and $f_+(0)$

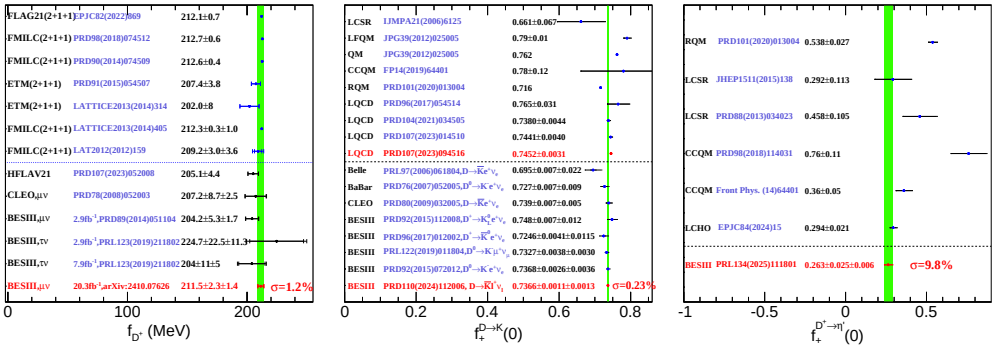
Comparison of $|V_{cd}|$ and $|V_{cs}|$

- Based on analyzing the dynamics of SL decays, one can obtain the product of f_+^M and $|V_{\mathrm{cd(s)}}|$. The form factor $f_+^M|V_{\mathrm{cd(s)}}|$ (M denote a meson) can be extracted from a fit to the measured partial decay rates in separated q^2 intervals. Taking the value of $|V_{\mathrm{cs(d)}}|$ from the global SM fit, or that of $f_+^M(f_D)$ from the lattice quantum chromodynamics calculation as input, the $f_+^M(f_D)$ and $|V_{\mathrm{cs(d)}}|$ can be determined.





Comparison of decay constant f_{D^+} and FFs $f_+(0)$



- Precisions of the measured f_{D^+}, $f_+^{D\to\bar{K}}(0)$, and $f_+^{D^+\to\eta'}(0)$ are 1.2%, 0.23%, and 9.8%, respectively, using $|V_{cd}| = 0.22486 \pm 0.00067$ (PDG 2022), $|V_{cs}| = 0.97349 \pm 0.00016$, and $|V_{cd}| = 0.22487 \pm 0.00068$ (PDG 2024) as inputs.
- Measured FF $f_+^{D\to\bar{K}}(0)$ is consistent with the LQCD calculations within 2.5σ

Summary

- **Improved precision**:
  - $|V_{cs}|$: precision improved to **0.5%**
  - $|V_{cd}|$: precision improved to **1.2%**
  - f_{D^+}: precision improved to **1.2%**
  - $f_+^{D\to\bar{K}}(0)$: precision improved to **0.3%**
- **LFU test**(No LFU violation observed):
  - $\mathcal{R}(\mu/e)$ precision: **0.8%** (via $D \to \bar{K}\ell^+\nu_\ell$)
  - $\mathcal{R}(\tau/\mu)$ precision: **12%** (via $D^+ \to \ell^+\nu_\ell$)
- **Those results** play a vital role in determining CKM matrix elements, validating Lattice QCD (LQCD) calculations, and testing lepton flavor universality (LFU).
- $\Lambda_c^+ \to ne^+\nu$ were **firstly observed and studied with deep learning method**, which provide opportunity to many analyses of BESIII.

Prospect

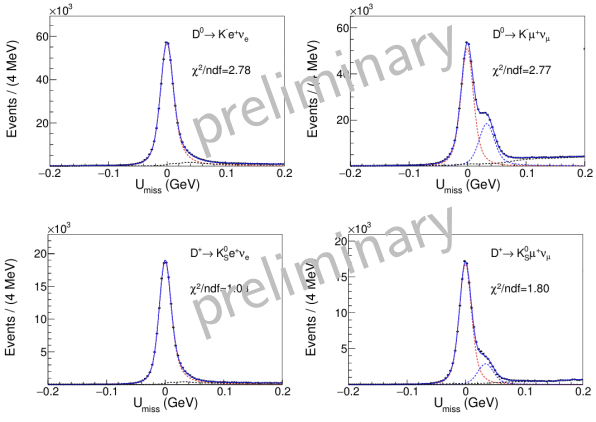
- 20.3 fb^{-1}data @3.773 GeV is ready at Jul. 2024, more precision measurements and searching for rare semileptonic decays will be presented;
- The interior upgrade of the CGEM detector has been successfully completed. Furthermore, the acquisition of an additional 3 fb^{-1}data @4.178 GeV in the future [CPC44(2020)040001] will further improve the precisions in D_s sector;
- 2025/26 BEPCII-U will be more efficient and 9 fb^{-1}more will be obtained @ 4.68 GeV.

Thank you!

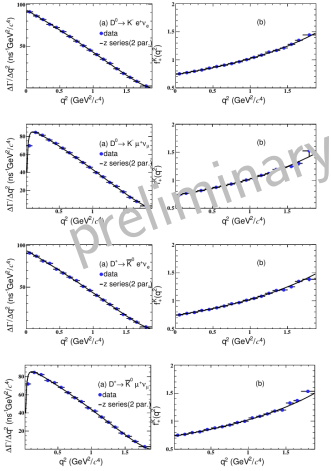
Backup

$D^0 \to K^-\ell^+\nu_\ell$ and $D^+ \to \bar{K}^0\ell^+\nu_\ell$

- 20.3 fb^{-1}data sample @3.773 GeV

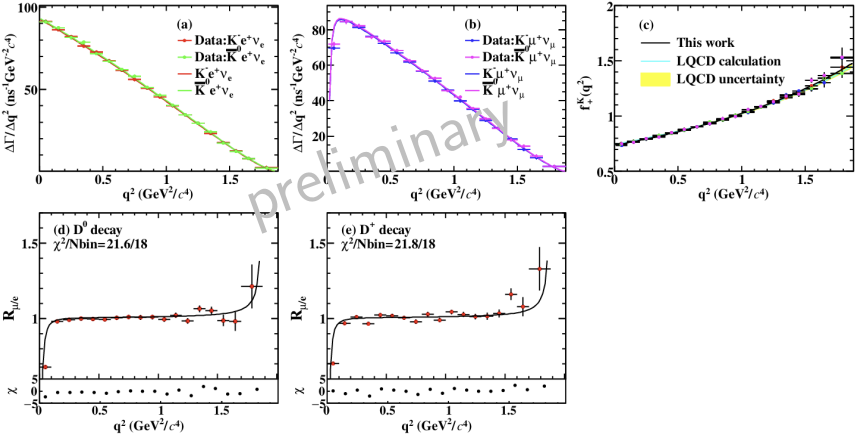


- (a) Fits to the differential decay rates of $D^{0(+)} \to K\bar{\ell}^+\nu_\ell$ and (b) projections to the form factor as function of q^2.



$D^0 \to K^-\ell^+\nu_\ell$ and $D^+ \to \bar{K}^0\ell^+\nu_\ell$

- (a)(b) Simultaneous fit to $D^{0(+)} \to K\bar{\ell}^+\nu_\ell$. (c) Projection of $f_+^K(q^2)$ as function of q^2 of $D^{0(+)} \to K\bar{\ell}^+\nu_\ell$. (d)(e) The ratio of differential decay rates of $D \to \bar{K}\mu^+\nu_\mu$ over $D \to \bar{K}e^+\nu_e$ in each q^2 bin.



Tension in $|V_{cs}|$ Determinations: Leptonic vs. Semileptonic

Data samples	Reference	Channel	$\lvert V_{cs}\rvert$	Input f_{D_s} (MeV)
6.32 fb^{-1}	PRD104(2021)052009	$\tau_\pi\nu$	$0.972 \pm 0.023 \pm 0.016$	249.9±0.5
6.32 fb^{-1}	PRD104(2021)032001	$\tau_\rho\nu$	$0.980 \pm 0.023 \pm 0.019$	
6.32 fb^{-1}	PRL127(2021)171801	$\tau_e\nu$	$0.978 \pm 0.009 \pm 0.012$	
7.33 fb^{-1}	PRD108(2023)092014	$\tau_\pi\nu$	$0.993 \pm 0.016 \pm 0.014$	
7.33 fb^{-1}	JHEP09(2023)124	$\tau_\mu\nu$	$0.987 \pm 0.016 \pm 0.014$	
10.64 fb^{-1}	PRD110(2024)052002	$\tau\nu$, $D_s^{*+}D_s^{*-}$	$1.011 \pm 0.014 \pm 0.018$	
0.492 fb^{-1}	PRD94(2016)072004	$\mu\nu$	$0.956 \pm 0.069 \pm 0.020$	249.9±0.5
3.19 fb^{-1}	PRL122(2019)071802	$\mu\nu$	$0.985 \pm 0.014 \pm 0.014$	249.9±0.4
6.32 fb^{-1}	PRD104(2021)052009	$\mu\nu$	$0.973 \pm 0.012 \pm 0.015$	249.9±0.5
6.32 fb^{-1}	PRD108(2023)112001	$\mu\nu$	$0.968 \pm 0.010 \pm 0.009$	
10.64 fb^{-1}	PRD110(2024)052002	$\mu\nu$, $D_s^{*+}D_s^{*-}$	$0.986 \pm 0.023 \pm 0.014$	
Combined	$\tau\nu+\mu\nu$		$0.9820 \pm 0.0052 \pm 0.0071$	

Data samples	Reference	Channel	$\lvert V_{cs}\rvert$	Input $f_+^K(0)$
8.0 fb^{-1}	PRD110(2021)112006	$\bar{K}l^+\nu$	$0.9623 \pm 0.0015 \pm 0.0043$	0.7452±0.0031

Determinations of $f_+^{D\to K}(0)$ Using Global-Fit $|V_{cs}|$ in the SM

Data samples	Reference	Channel	$f_+^{D\to K}(0)$	Input $\lvert V_{cs}\rvert$
2.92 fb^{-1}	PRD92(2015)112008	$D^+ \to K_L^0 e^+ \nu_e$	$0.748 \pm 0.007 \pm 0.012$	0.97343±0.00015
2.93 fb^{-1}	PRD96(2017)012002	$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.7246 \pm 0.0041 \pm 0.0115$	0.97351±0.00013
2.93 fb^{-1}	PRL122(2019)011804	$D^0 \to K^- \mu^+ \nu_\mu$	$0.7327 \pm 0.0038 \pm 0.0030$	$0.97359^{+0.00010}_{-0.00011}$
2.92 fb^{-1}	PRD92(2015)072012	$D^0 \to K^- e^+ \nu_e$	$0.7368 \pm 0.0026 \pm 0.0036$	0.97343±0.00015
8.0 fb^{-1}	PRD110(2024)112006	$D \to \bar{K} l^+ \nu_l$	$0.7366 \pm 0.0011 \pm 0.0013$	0.97349±0.00016