BESIII实验上
CKM矩阵元测量

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海南三亞

味物理百期特别活动

Outline

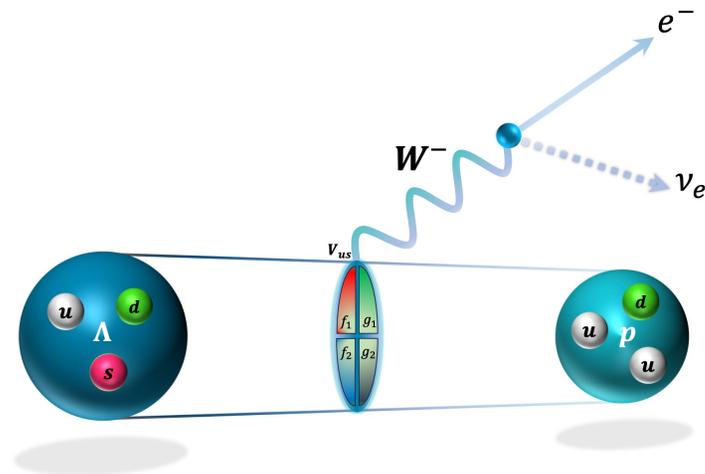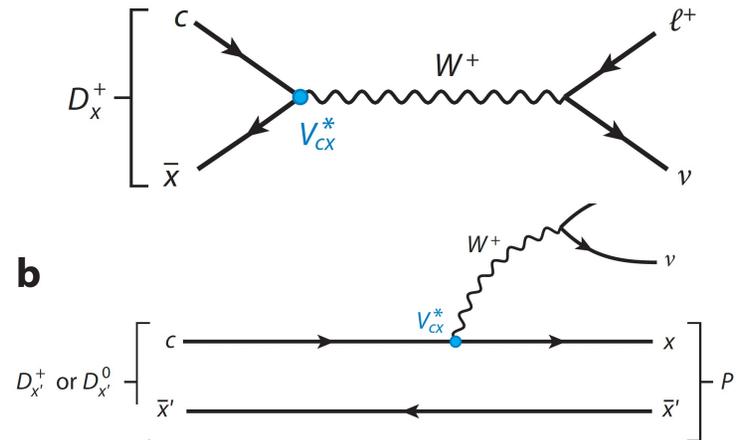- **BESIII dataset**

- **|Vcd| and |Vcs|**

  - pure leptonic charm decays
  - semi-leptonic charm decays
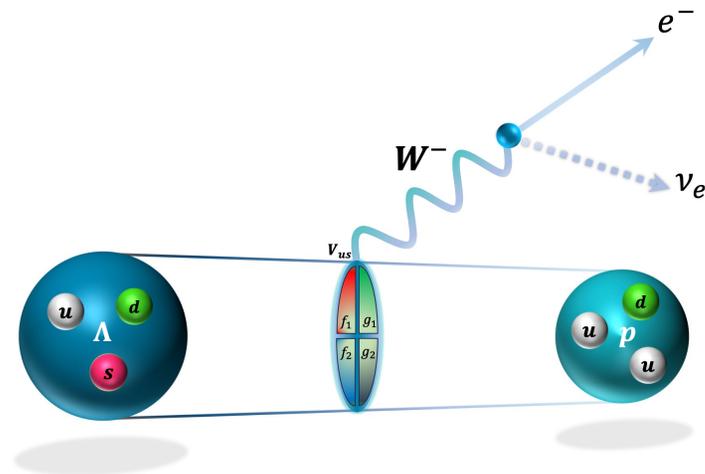
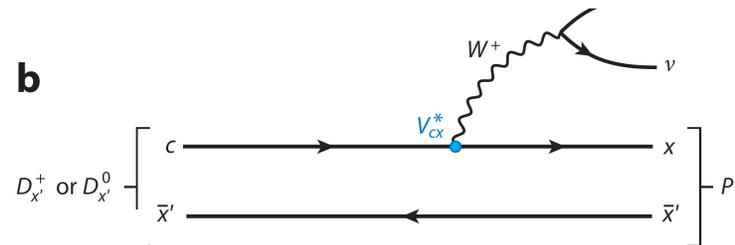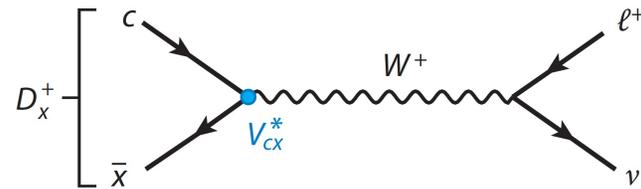- **|Vus|**

- **Summary**

Outline

- **BESIII dataset**

- |Vcd| and |Vcs|
  - pure leptonic charm decays
  - semi-leptonic charm decays

- |Vus|

- Summary

BESIII Data near Threshold

- 20.3 fb^{-1} at E$_{cm}$ 3.773 GeV: $e^+ e^- \to \psi(3770) \to D\bar{D}$

- 7.33 fb^{-1} at E$_{cm}$ 4.128 - 4.226 GeV: $e^+ e^- \to D_s D_s^*$

Production of charm hadron pair
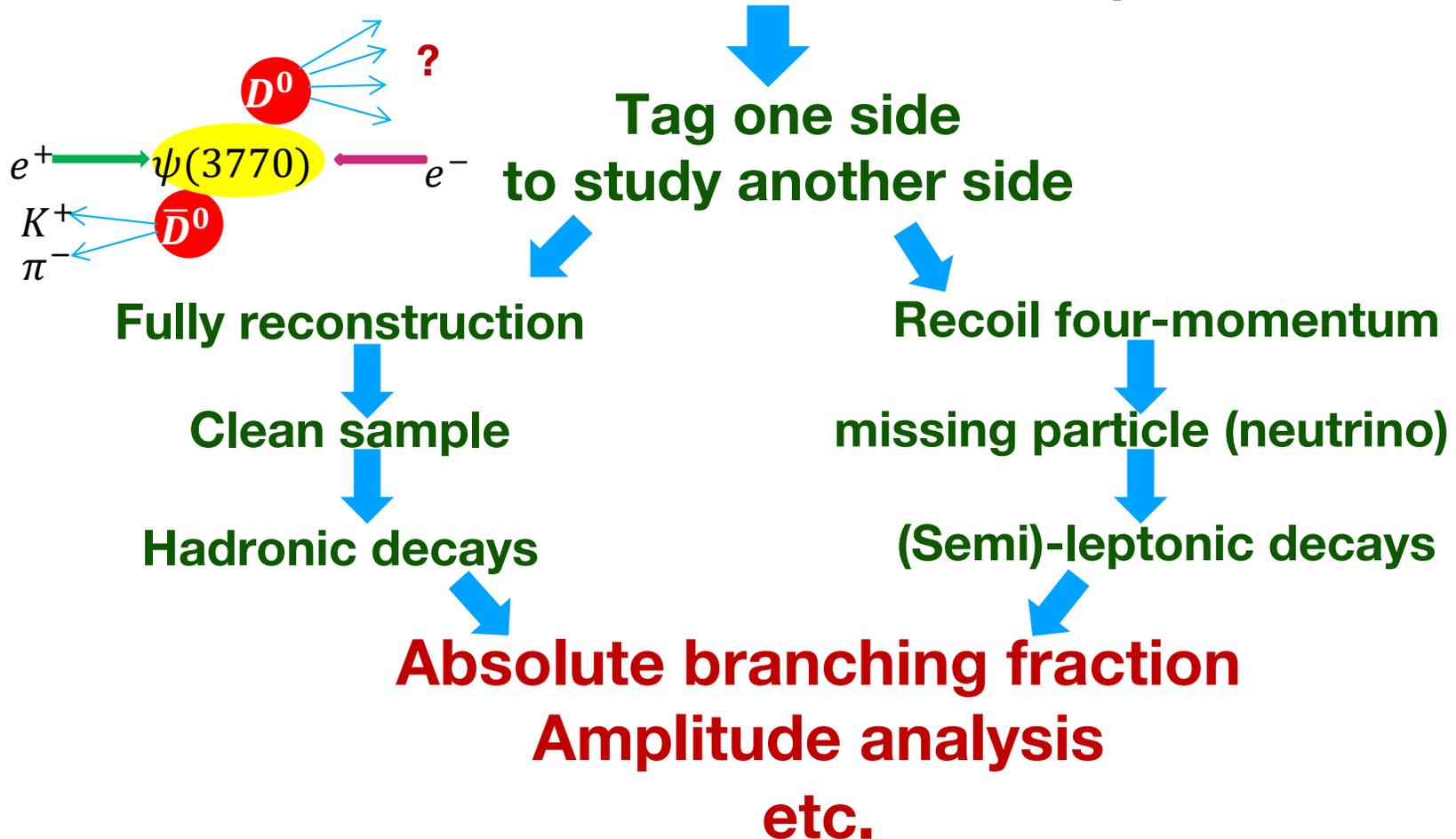
e^+ → $\psi(3770)$ ← e^-

D^0 **?**

$\bar{D}^0$ K^+ π^-

**Tag one side
to study another side**

Fully reconstruction

Clean sample

Hadronic decays

Recoil four-momentum

missing particle (neutrino)

(Semi)-leptonic decays

**Absolute branching fraction
Amplitude analysis
etc.**

Outline

- BESIII dataset

- **|Vcd| and |Vcs|**
  - **pure leptonic charm decays**
  - semi-leptonic charm decays

- |Vus|

- Summary
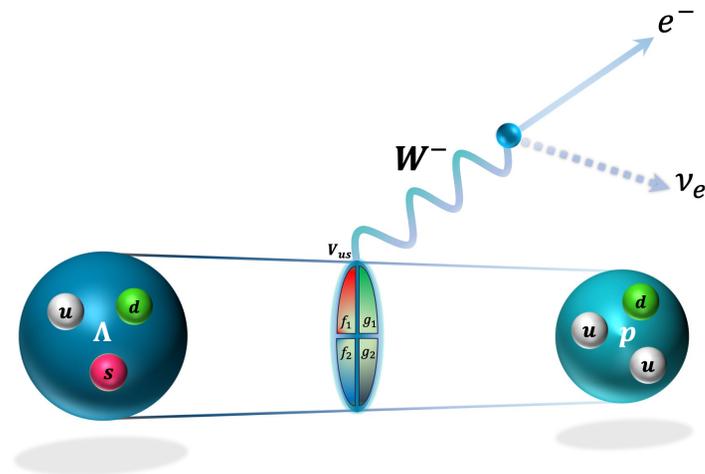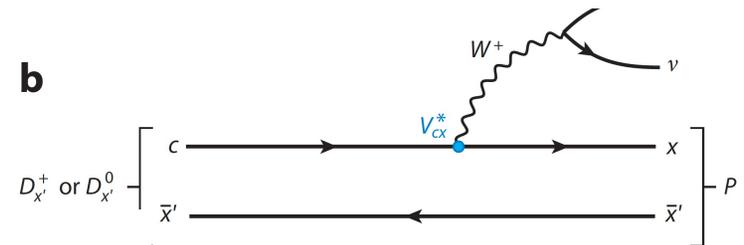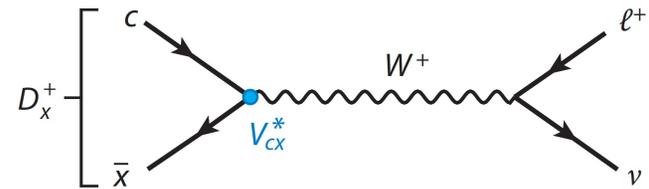
Motivation

- **Charm Decays: The Best Probe of $|V_{cd}|$ and $|V_{cs}|$**

  Pure & semi-leptonic channels provide the most precise measurement.

  $$V_{\text{CKM}}^{\text{PDG2024}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 0.97367 \pm 0.00032 & 0.22431 \pm 0.00085 & 0.00382 \pm 0.00020 \\ 0.221 \pm 0.004 & 0.975 \pm 0.006 & 0.0411 \pm 0.0012 \\ 0.0086 \pm 0.0002 & 0.0415 \pm 0.0009 & 1.010 \pm 0.027 \end{pmatrix}$$

- Verifying the unitarity of the CKM matrix to test the SM.

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9984 \pm 0.0007 \quad \sim 0.07\%$$

$$|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 1.001 \pm 0.012 \quad \sim 1\%$$

Precision of the second row is dominated by that of $|V_{cd}|$ and $|V_{cs}|$

Precise measurement of $|V_{cd}|$ and $|V_{cs}|$ is crucial

Motivation

Leptonic decays
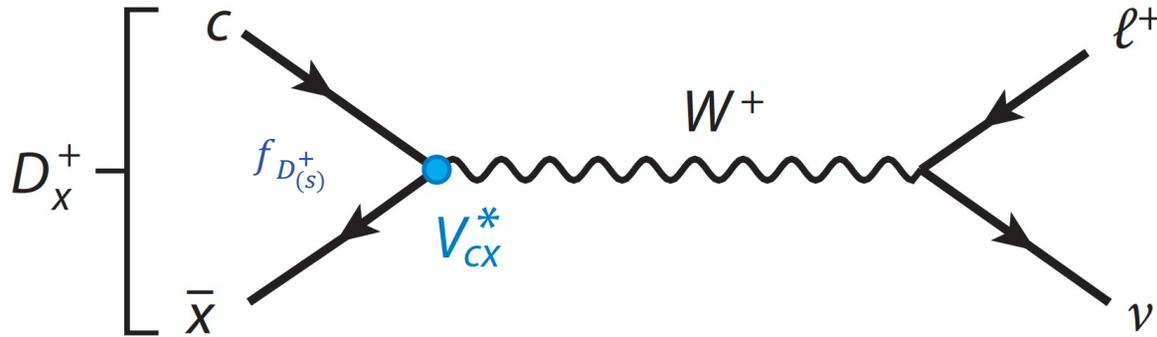
$$\Gamma\left(D_{(s)}^+ \to l^+\nu\right) = \frac{G_F^2 f_{D_{(s)}^+}^2}{8\pi} \left|V_{cd(s)}\right|^2 m_l^2 m_{D_{(s)}^+} \left(1 - \frac{m_l^2}{m_{D_{(s)}^+}^2}\right)^2$$

- $\left|V_{cd(s)}\right|$ measurement $\Longrightarrow$ Test CKM matrix unitarity

- Decay constant measurements $\Longrightarrow$ Calibrate LQCD calculations

- Branching Fractions $\mathcal{B}_{\mu/\tau}$ $\Longrightarrow$

  Test lepton flavor universality (LFU)

$e^+\nu_e \; : \; \mu^+\nu_\mu : \; \tau^+\nu_\tau$

$D^+ \; 10^{-5} : \quad 1 \quad : 2.67$

$D_s^+ \; 10^{-5} : \quad 1 \quad : 9.75$

$D^+ \rightarrow \mu^+ \nu_\mu$

20.3 fb^{-1}@E_{cm}=3.773 GeV

$N_{sig} = 2833 \pm 57$

Legend:
- • Data
- — All PDF
- --- Signal PDF
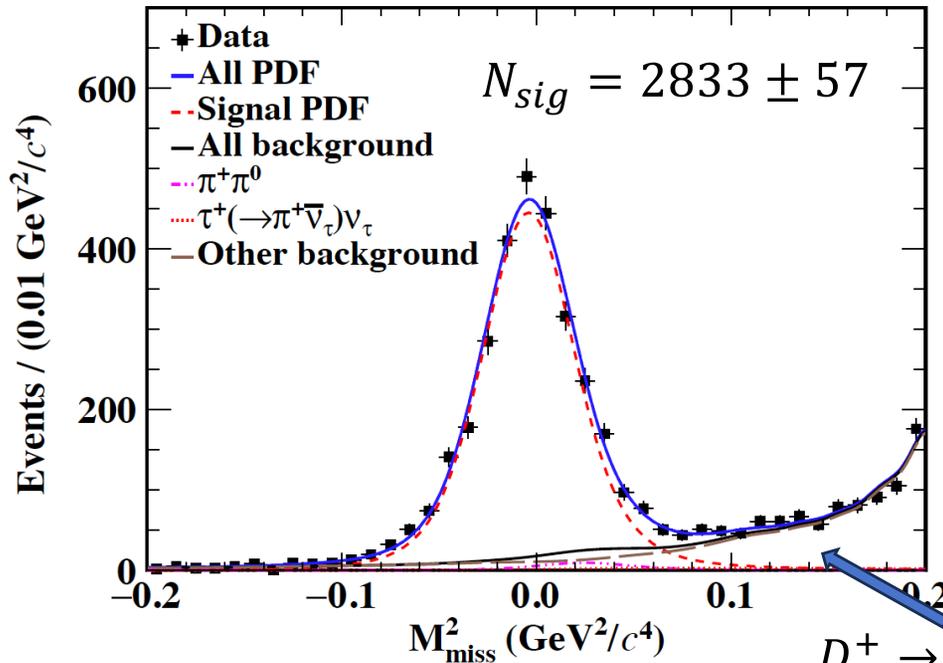- — All background
- --- $\pi^+\pi^0$
- ⋯ $\tau^+(\rightarrow\pi^+\overline{\nu}_\tau)\nu_\tau$
- — Other background

- • $\Gamma_{D^+\rightarrow\ell^+\nu_\ell} = \Gamma^0_{D^+\rightarrow\ell^+\nu_\ell}[1 + \frac{\alpha}{\pi}C_p] \Rightarrow$ Radiative correction term

1. Short-distance electroweak correction increases BF by 1.8% [PRD98,074512, NPB196,83]

2. Long-distance electroweak correction [inner bremsstrahlung and virtual photon] reduce BF by 2.5% with 0.6% uncertainty of unknown electromagnetic correction [PRD98,074512]

$D^+ \rightarrow \gamma\mu^+\nu_\mu$ background is simulated in the fit

$\mathcal{B}(D^+ \rightarrow \mu^+\nu_\mu) = (4.034 \pm 0.080 \pm 0.040)\times10^{-4}$

Precision is improved by 2.4x

$f_{D^+}|V_{cd}| = (48.02 \pm 0.48 \pm 0.24 \pm 0.12_{\text{input}} \pm 0.15_{\text{EM}})$ MeV

$f_{D^+} = (213.5 \pm 2.1 \pm 1.1 \pm 0.8 \pm 0.7)$ MeV (~1.2%) Most precise

$|V_{cd}| = (0.2265 \pm 0.0023 \pm 0.0011 \pm 0.0009 \pm 0.0007)$

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$D^+ \to \tau^+ \nu_\tau$ via $\tau^+ \to \pi^+ \nu_\tau$

$D^+ \to \tau^+ \nu_\tau$

7.93 fb^{-1}@E_{cm}=3.773 GeV $N_{sig} = 283 \pm 32$ JHEP01(2025)089
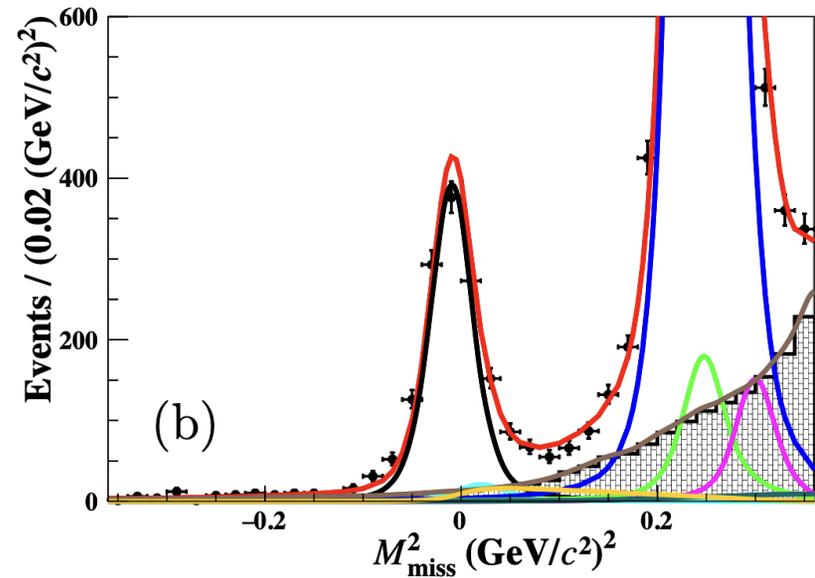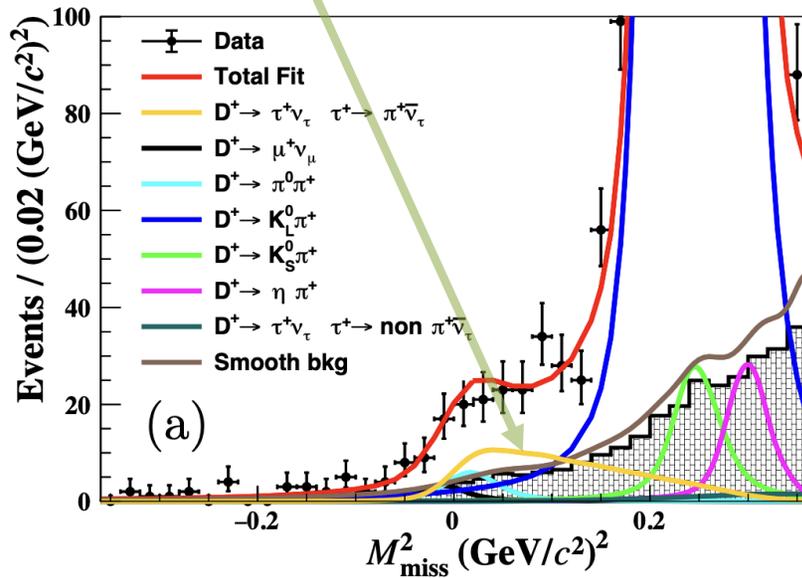
$$\mathcal{B}(D^+ \to \tau^+ \nu_\tau) = (9.9 \pm 1.1 \pm 0.5) \times 10^{-4}$$

$$f_{D^+}|V_{cd}| = (45.9 \pm 2.5 \pm 1.2 \pm 0.1_{\text{input}}) \text{ MeV}$$

$$f_{D^+} = (204 \pm 11 \pm 5 \pm 1) \text{ MeV} (\sim 5.9\%)$$

$$|V_{cd}| = 0.216 \pm 0.012 \pm 0.006 \pm 0.001$$

LFU: $\frac{\Gamma_\tau}{\Gamma_\mu} = 2.45 \pm 0.31$ consistent with SM 2.66 ± 0.01

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To be updated using the 20 fb^{-1} full dataset

$D^+ \to e^+\nu_e$ and $D^+ \to \gamma e^+\nu_e$
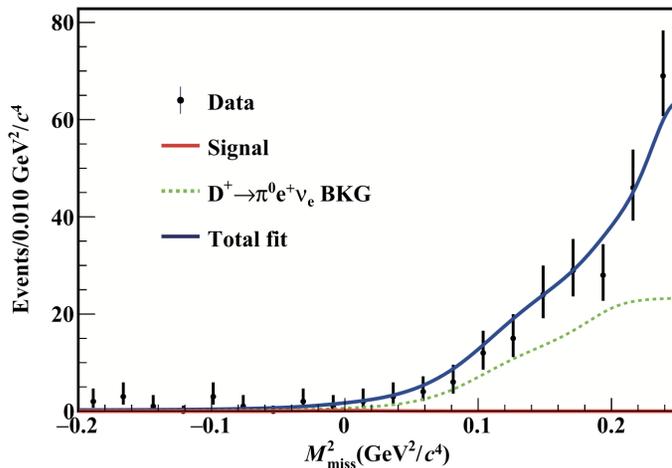
CPC 49, 063001 (2025) **CPC 49, 083001 (2025)**
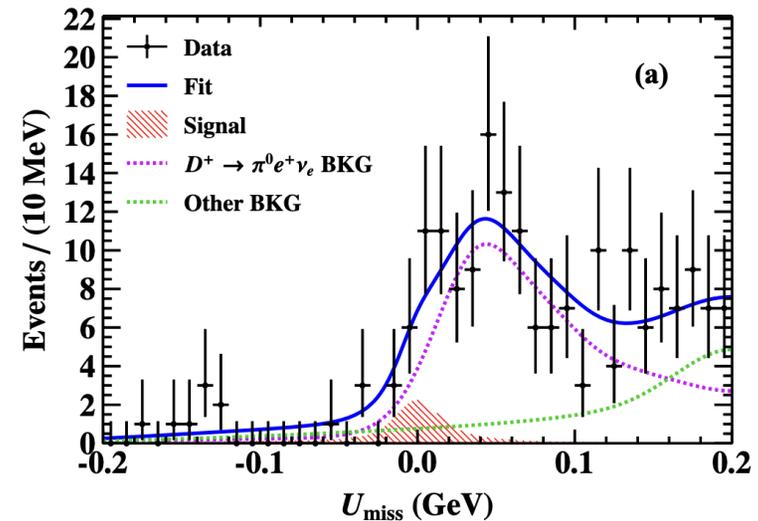
$D^+ \to e^+\nu_e$ is helicity suppressed. $D^+ \to \gamma e^+\nu_e$ can reduce this suppression.

Theo. Prediction: $\mathcal{B}(D^+ \to e^+\nu_e) < 10^{-8}$; $\mathcal{B}(D^+ \to \gamma e^+\nu_e) = 10^{-5} \sim 10^{-3}$

$\mathcal{B}(D^+ \to e^+\nu_e) < 9.7 \times 10^{-8}$ @90% C.L.

$\mathcal{B}(D^+ \to \gamma e^+\nu_e) = 1.2 \times 10^{-5}$ @90% C.L.

Help to estimate background in $D^+ \to \mu^+\nu_\mu$

$D_s^+ \rightarrow \mu^+ \nu_\mu$
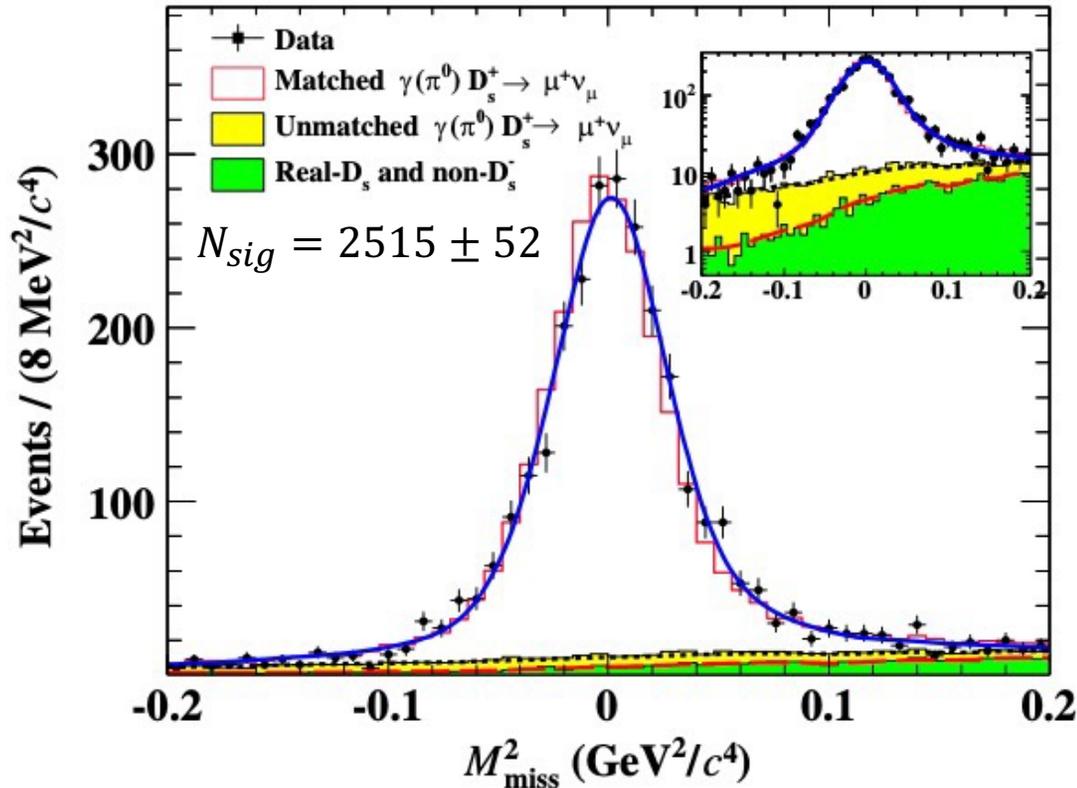
$$\mathcal{B}(D_s^+ \rightarrow \mu^+ \nu_\mu) = (5.294 \pm 0.108 \pm 0.085) \times 10^{-3}$$

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

$$f_{D_s^+} = (248.4 \pm 2.5 \pm 2.2) \text{ MeV } (\sim 1.4\%)$$

$$|V_{cs}| = 0.968 \pm 0.010 \pm 0.009 \ (\sim 1.4\%)$$

$D_s^+ \to \tau^+ \nu_\tau$

$\tau^+ \to e^+ \nu\nu$ **PRL 127, 171801 (2021)**

$\tau^+ \to \mu^+ \nu\nu$ **JHEP 09(2023)124**

$\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau) = (5.27 \pm 0.10 \pm 0.12)\%$

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

$f_{D_s^+} = (251.1 \pm 2.4 \pm 3.0)$ MeV (~1.5%)
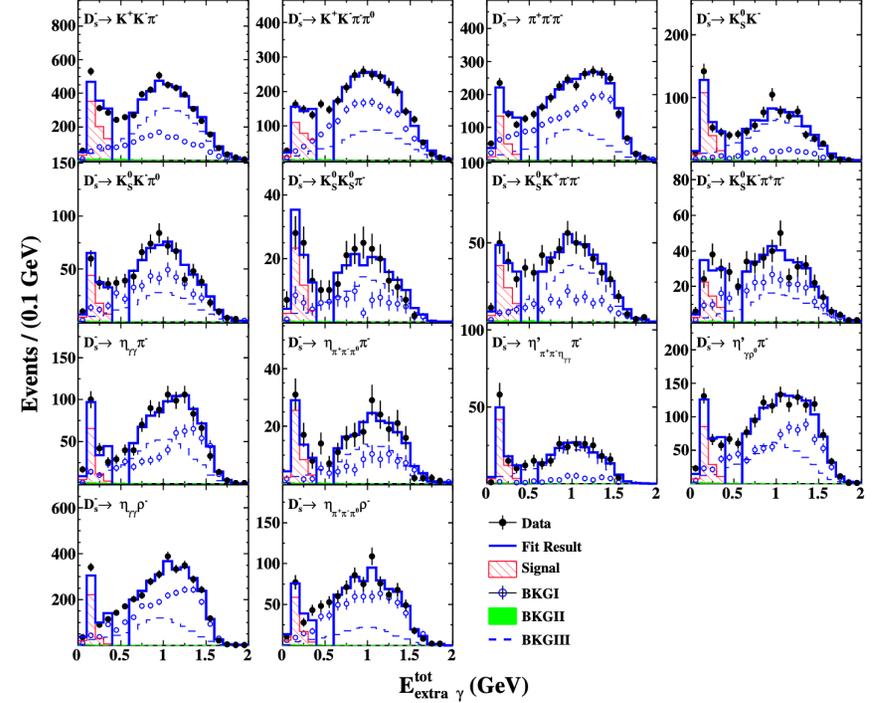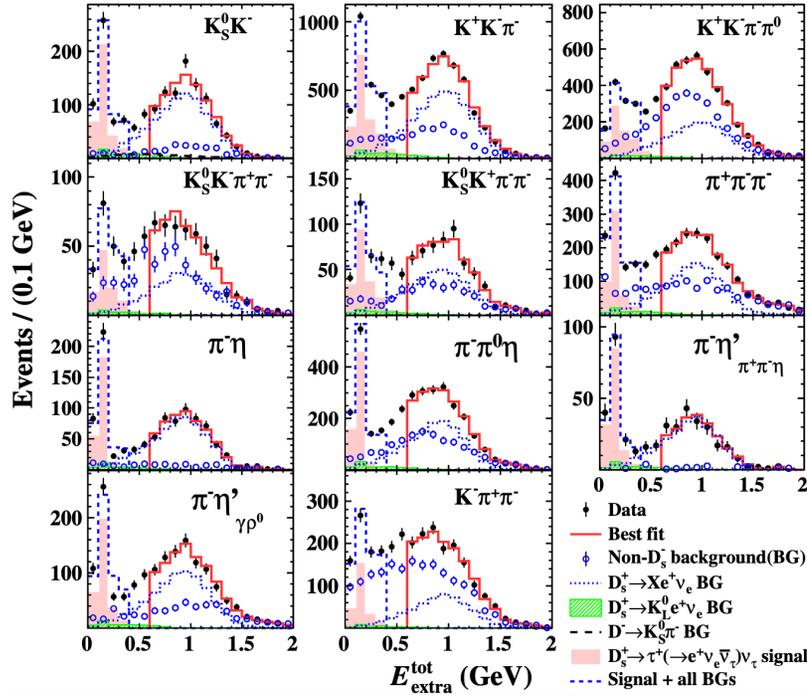
$|V_{cs}| = 0.978 \pm 0.009 \pm 0.012$ (~1.5%)

$\mathcal{B}(D_s^+ \to \tau^+ \nu) = (5.37 \pm 0.17 \pm 0.15)\%$

$f_{D_s^+}|V_{cs}| = (246.2 \pm 3.7 \pm 2.5)$ MeV

$f_{D_s^+} = (253.4 \pm 4.0 \pm 3.7)$ MeV (~2.2%)

$|V_{cs}| = 0.987 \pm 0.016 \pm 0.014$ (~2.2%)

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$D_s^+ \rightarrow \tau^+ \upsilon_\tau$

$\tau^+ \rightarrow \pi^+ \nu$ **PRD 108, 092014 (2023)**

$\tau^+ \rightarrow \pi^+ \pi^0 \nu$ **PRD 104, 032001 (2021)**
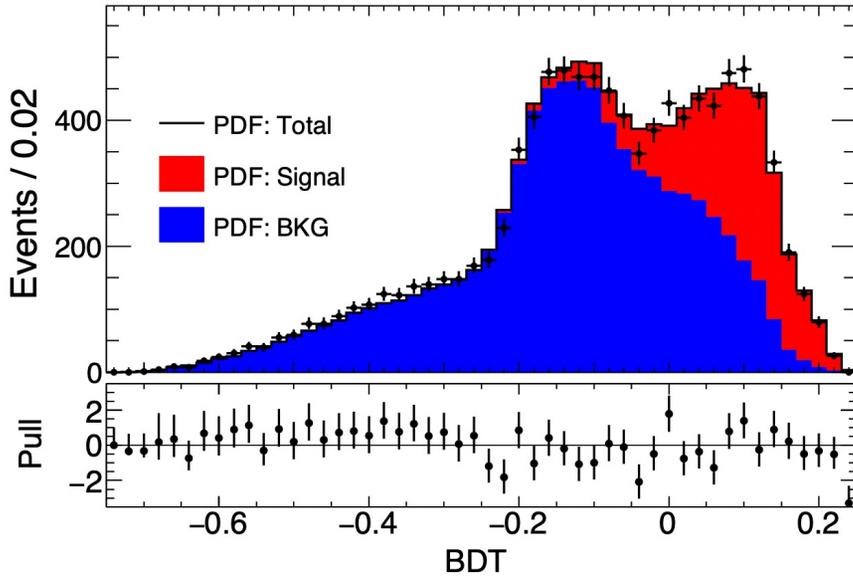
$\mathcal{B}(D_s^+ \rightarrow \tau^+ \nu_\tau) = (5.44 \pm 0.17 \pm 0.13)\%$

$f_{D_s^+}|V_{cs}| = (248.3 \pm 3.9 \pm 3.1 \pm 1.0)$ MeV

$f_{D_s^+} = (255.0 \pm 4.0 \pm 3.4)$ MeV (~2.1%)

$|V_{cs}| = 0.993 \pm 0.015 \pm 0.013$ (~2.0%)
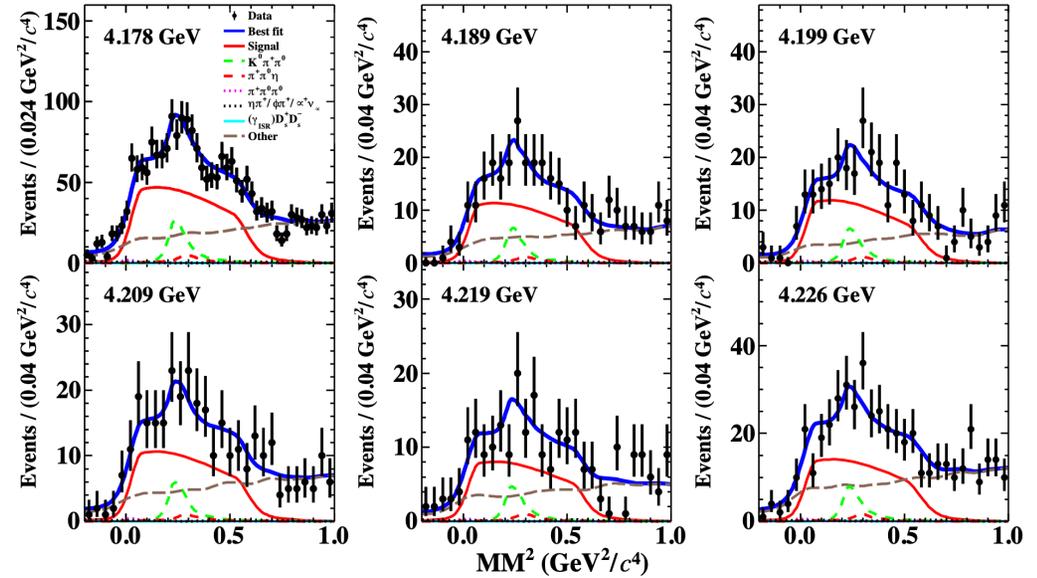
$\mathcal{B}(D_s^+ \rightarrow \tau^+ \nu_\tau) = (5.29 \pm 0.25 \pm 0.20)\%$

$f_{D_s^+}|V_{cs}| = (244.8 \pm 5.8 \pm 4.8)$ MeV

$f_{D_s^+} = (251.6 \pm 5.9 \pm 4.9)$ MeV (~3.0%)

$|V_{cs}| = 0.980 \pm 0.023 \pm 0.019$ (~3.0%)

$D_s^+ \to l^+ \nu_l$ via $e^+ e^- \to D_s^{*+} D_s^{*-}$

10.64 fb^{-1}@ 4.237-4.699 GeV

$\mathcal{B}(D_s^+ \to \mu^+ \nu_\mu) = (0.547 \pm 0.026 \pm 0.016)\%$

$f_{D_s^+}|V_{cs}| = (246.5 \pm 5.9 \pm 3.6 \pm 0.5)$ MeV

$f_{D_s^+} = (253.2 \pm 6.0 \pm 3.7 \pm 0.6)$ MeV
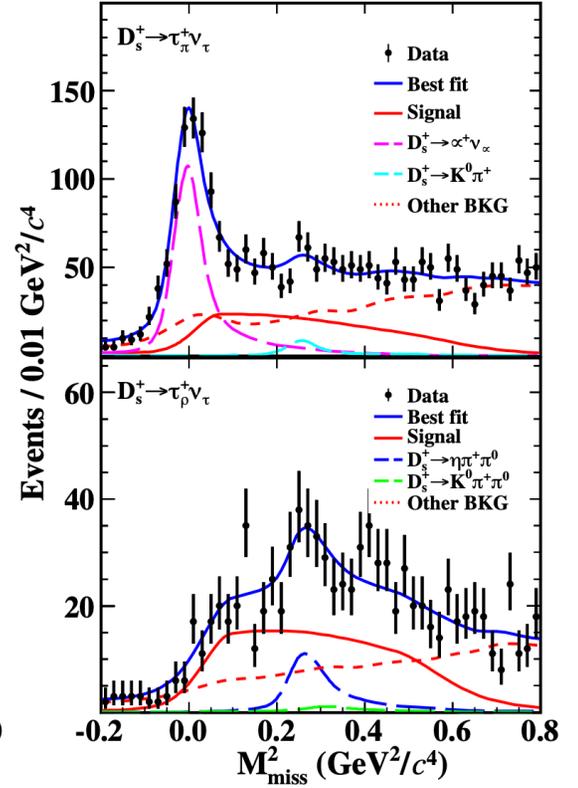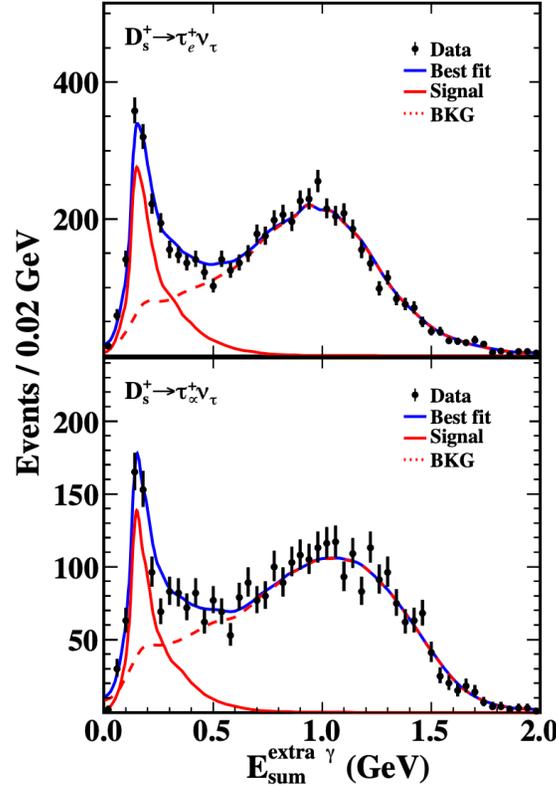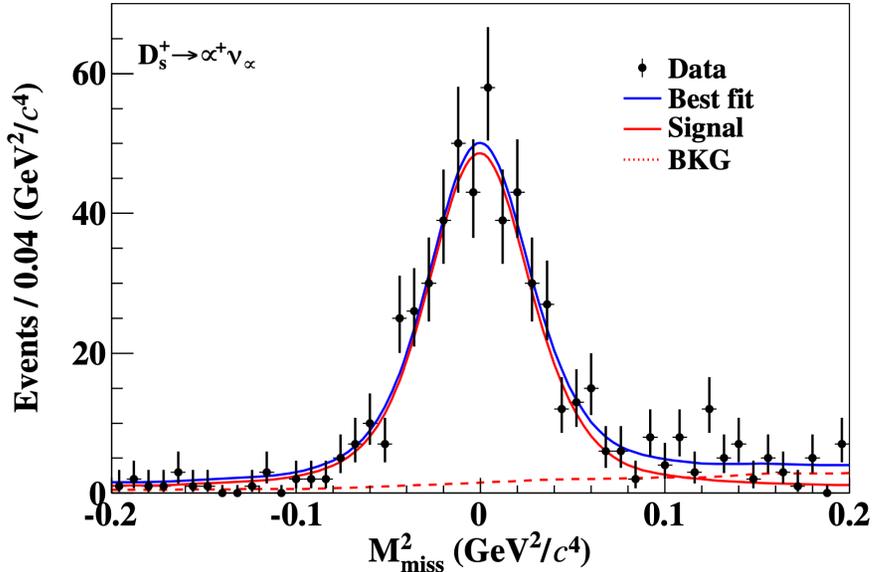
$|V_{cs}| = 0.986 \pm 0.023 \pm 0.014 \pm 0.003$

$\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau) = (5.60 \pm 0.16 \pm 0.20)\%$

$f_{D_s^+}|V_{cs}| = (252.7 \pm 3.6 \pm 4.5 \pm 0.6)$ MeV

$f_{D_s^+} = (259.6 \pm 3.7 \pm 4.6 \pm 0.6)$ MeV

$|V_{cs}| = 1.011 \pm 0.014 \pm 0.018 \pm 0.003$

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Comparison of f_{D^+}

FLAG21(2+1+1)	EPJC82(2022)869	212.1±0.7	
FMILC(2+1+1)	PRD98(2018)074512	212.7±0.6	
FMILC(2+1+1)	PRD90(2014)074509	212.6±0.4	
ETM(2+1+1)	PRD91(2015)054507	207.4±3.8	
ETM(2+1+1)	LATTICE2013(2014)314	202.0±8	
FMILC(2+1+1)	LATTICE2013(2014)405	212.3±0.3±1.0	
FMILC(2+1+1)	LAT2012(2012)159	209.2±3.0±3.6	
HFLAV21	PRD107(2023)052008	205.1±4.4	
CLEO,μν	PRD78(2008)052003	207.2±8.7±2.5	
BESIII,μν	2.9fb⁻¹,PRD89(2014)051104	204.2±5.3±1.7	
BESIII,τν	2.9fb⁻¹,PRL123(2019)211802	224.7±22.5±11.3	
BESIII,τν	7.9fb⁻¹,PRL123(2019)211802	204±11±5	
BESIII,μν	20.3fb⁻¹,PRL135,061801	213.5±2.1±1.5	1.2%

f_{D^+} (MeV)

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Comparison of $f_{D_s^+}$

ETM(2+1+1)	PRD91(2015)054507	247.2±4.1
FMILC(2+1+1)	PRD98(2018)074512	249.9±0.4
FLAG21(2+1+1)	EPJC82(2022)869	249.9±0.5
HFLAV21	PRD107(2023)052008	252.2±2.5
CLEO	PRD79(2009)052002, $\tau_e\nu$	251.8±11.2±5.3
CLEO	PRD80(2009)112004, $\tau_\rho\nu$	257.0±13.3±5.0
BaBar	PRD82(2010)091103, $\tau_{e,\mu}\nu$	244.6±8.6±12.0
Belle	JHEP09(2013)139, $\tau_{e,\mu,\pi}\nu$	261.1±4.8±7.2
BESIII 6.32 fb^{-1}	PRD104(2021)052009, $\tau_\pi\nu$	249.7±6.0±4.2
BESIII 6.32 fb^{-1}	PRD104(2021)032001, $\tau_\rho\nu$	251.6±5.9±4.9
BESIII 6.32 fb^{-1}	PRL127(2021)171801, $\tau_e\nu$	251.1±2.4±3.0
BESIII 7.33 fb^{-1}	PRD108(2023)092014, $\tau_\pi\nu$	255.0±4.0±3.1
BESIII 7.33 fb^{-1}	JHEP09(2023)124, $\tau_\mu\nu$	253.4±4.0±3.7
BESIII 10.6 fb^{-1}	PRD110,052002, $\tau\nu$, $D_s^{*+}D_s^{*-}$	259.6±3.7±4.6
BESIII 0.482 fb^{-1}	PRD94(2016)072004, $\mu\nu$	245.5±17.8±5.1
CLEO	PRD79(2009)052001, $\mu\nu$	256.7±10.2±4.0
BaBar	PRD82(2010)091103, $\mu\nu$	264.9±8.4±7.6
Belle	JHEP09(2013)139, $\mu\nu$	248.8±6.6±4.8
BESIII 3.19 fb^{-1}	PRL122(2019)071802, $\mu\nu$	253.0±3.7±3.6
BESIII 6.32 fb^{-1}	PRD104(2021)052009, $\mu\nu$	249.8±3.0±3.9
BESIII 7.33 fb^{-1}	PRD108(2023)112001, $\mu\nu$	248.4±2.5±2.2
BESIII 10.6 fb^{-1}	PRD110,052002, $\mu\nu$, $D_s^{*+}D_s^{*-}$	253.2±6.1±3.7
BESIII Combined	$\tau\nu$	253.93±1.54±1.82
BESIII Combined	$\tau\nu + \mu\nu$	252.08±1.34±1.82

0.9%

$f_{D_s^+}$ (MeV)

Outline

- **BESIII dataset**

- **|Vcd| and |Vcs|**
  - pure leptonic charm decays
  - **semi-leptonic charm decays**

- **|Vus|**

- **Summary**

Motivation

Semileptonic decays

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

Weak interaction:
CKM matrix

Strong interaction：
Form factor

P, S, V, A
P = pseudoscalar
S = scalar
V = vector
A = axial-vector
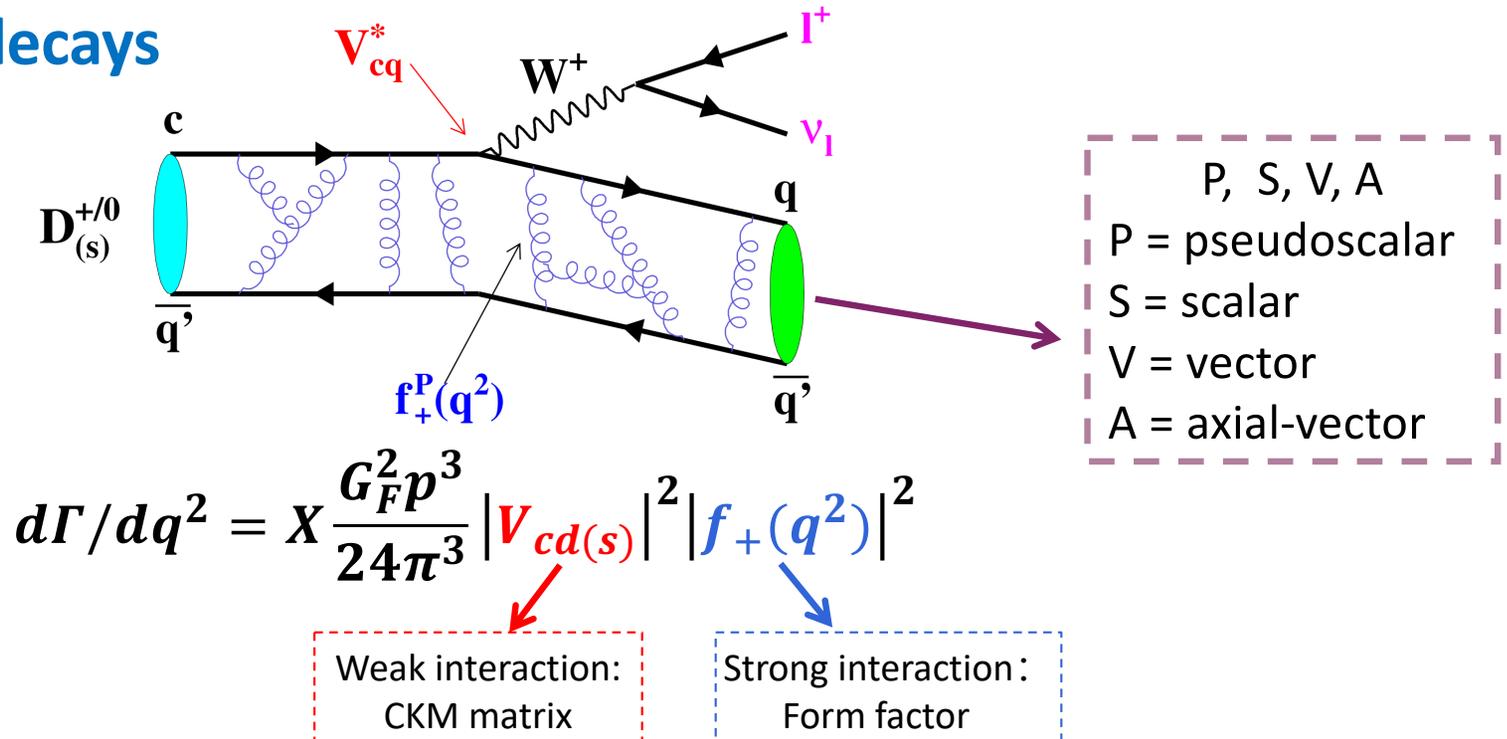
- $\left|V_{cd(s)}\right|$ measurement ⟹ Test CKM matrix unitarity

- Form factor $f_+(0)$ measurements ⟹ Calibrate LQCD calculations

- Branching Fractions $\mathcal{B}_{\mu/e}$ ⟹ Test lepton flavor universality (LFU)

- Rare decays ⟹ Search for new physics effects beyond the SM

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$$D \rightarrow P\, l^+ v_l$$

$$\Gamma(D \rightarrow Pl^+v_l)/dq^2 \propto \left|V_{cd(s)}\right|^2 \left|f_+(q^2)\right|^2$$

$$P:\ K, \pi, \eta, \eta'$$

$$q^2 = (E_{\ell^+} + E_{v_\ell})^2 - |\vec{p}_{\ell^+} + \vec{p}_{v_\ell}|^2$$

- **Fit the measured partial decay width in different q^2 bin**

- Taking the correlations among q^2 bins into account

- FF parameterized in different form

✓ Single pole model

$$f_+(q^2) = \frac{f_+(0)}{1 - \dfrac{q^2}{M_{pole}^2}}$$

✓ Modified pole model

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \dfrac{q^2}{M_{pole}^2}\right)\left(1 - \alpha\dfrac{q^2}{M_{pole}^2}\right)}$$

✓ ISGW2 model

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

✓ Series expansion mode

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

$D \to \bar{K}\ell^+\nu_\ell(\ell = e, \mu)$

7.9fb^{-1}@E_{cm}=3.773 GeV
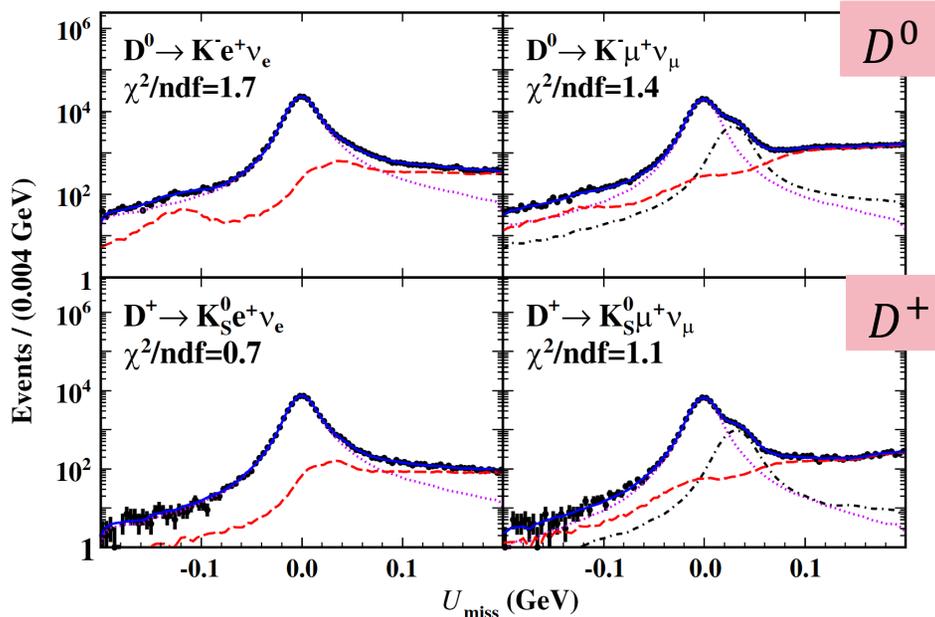
- BF measurement:

$\mathcal{B}(D^0 \to K^-e^+\nu_e) = (3.521 \pm 0.009 \pm 0.016)\%$

$\mathcal{B}(D^0 \to K^-\mu^+\nu_\mu) = (3.419 \pm 0.011 \pm 0.016)\%$

$\mathcal{B}(D^+ \to \bar{K}^0e^+\nu_e) = (8.864 \pm 0.039 \pm 0.082)\%$

$\mathcal{B}(D^+ \to \bar{K}^0\mu^+\nu_\mu) = (8.665 \pm 0.046 \pm 0.084)\%$

- LFU test (SM: 0.975±0.001):

$\mathcal{R}_{\mu/e}^{D^0 \to K^-} = 0.971 \pm 0.004 \pm 0.006(\sim 0.7\%)$

$\mathcal{R}_{\mu/e}^{D^+ \to \bar{K}^0} = 0.978 \pm 0.007 \pm 0.013(\sim 1.5\%)$

$D \to \bar{K} \ell^+ \nu_\ell (\ell = e, \mu)$

Simultaneous fit

e

μ

$f_+^K(q^2)$

$f_0^K(q^2)$

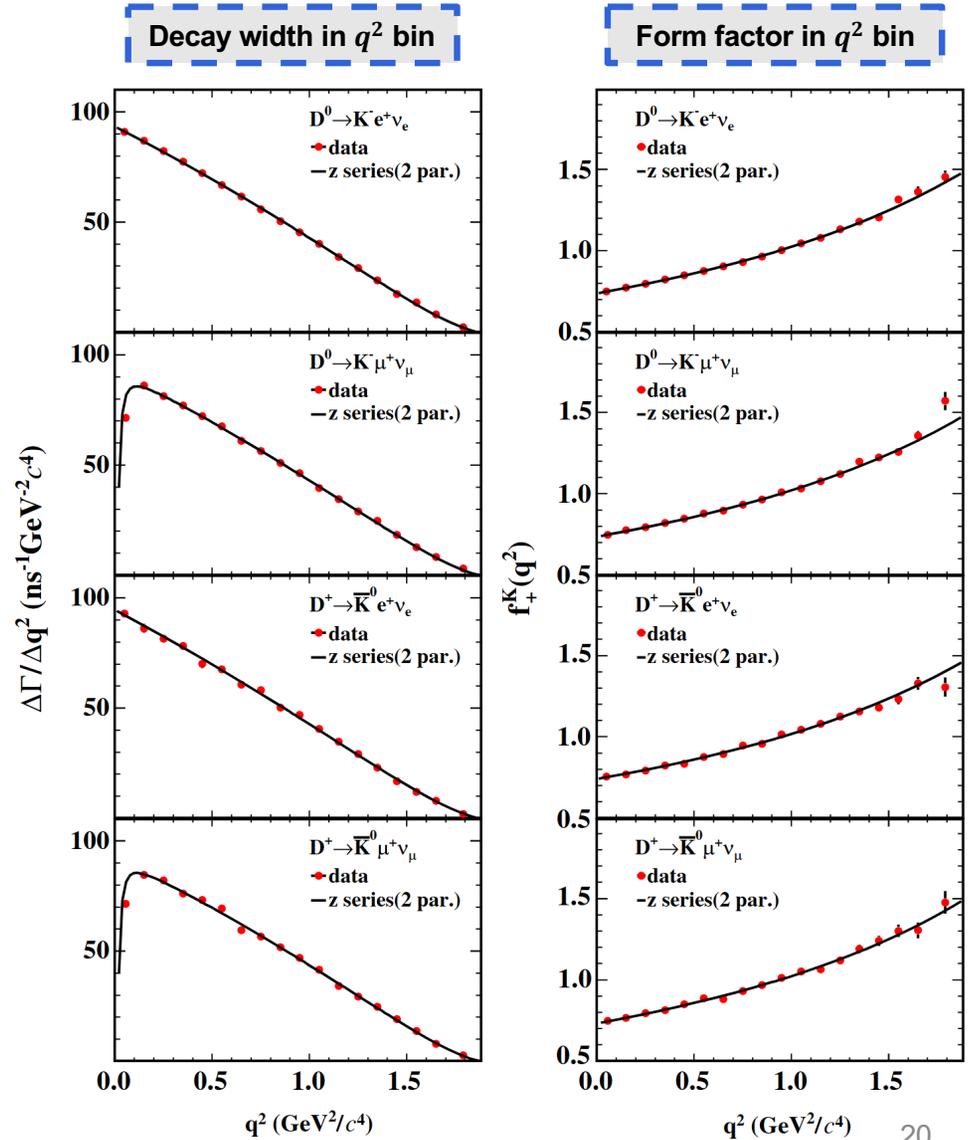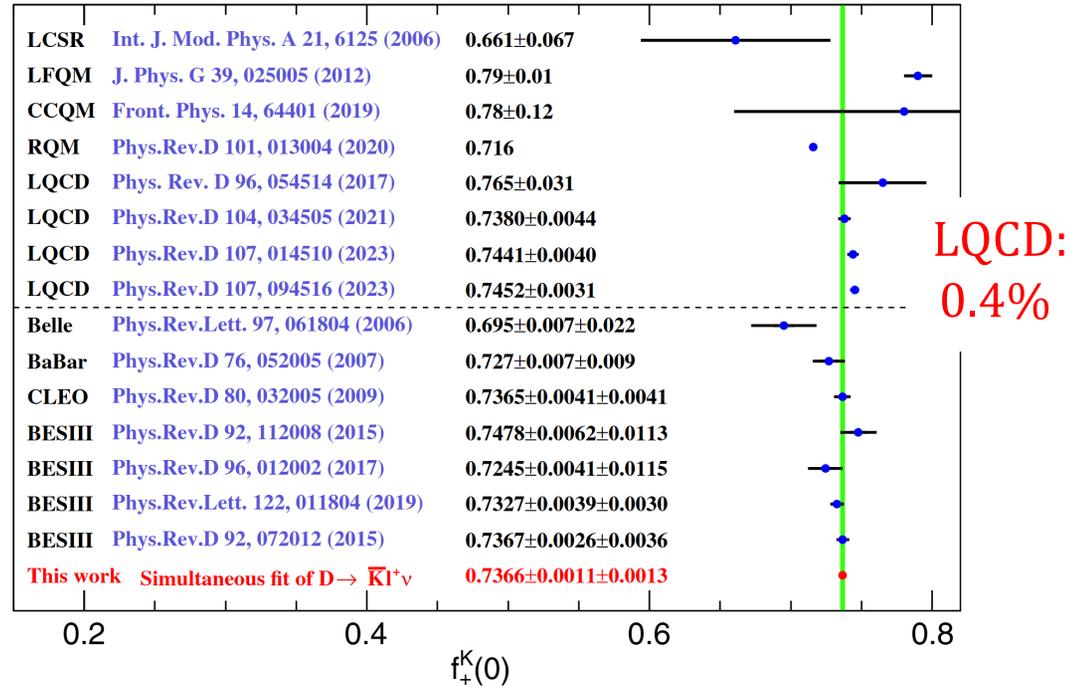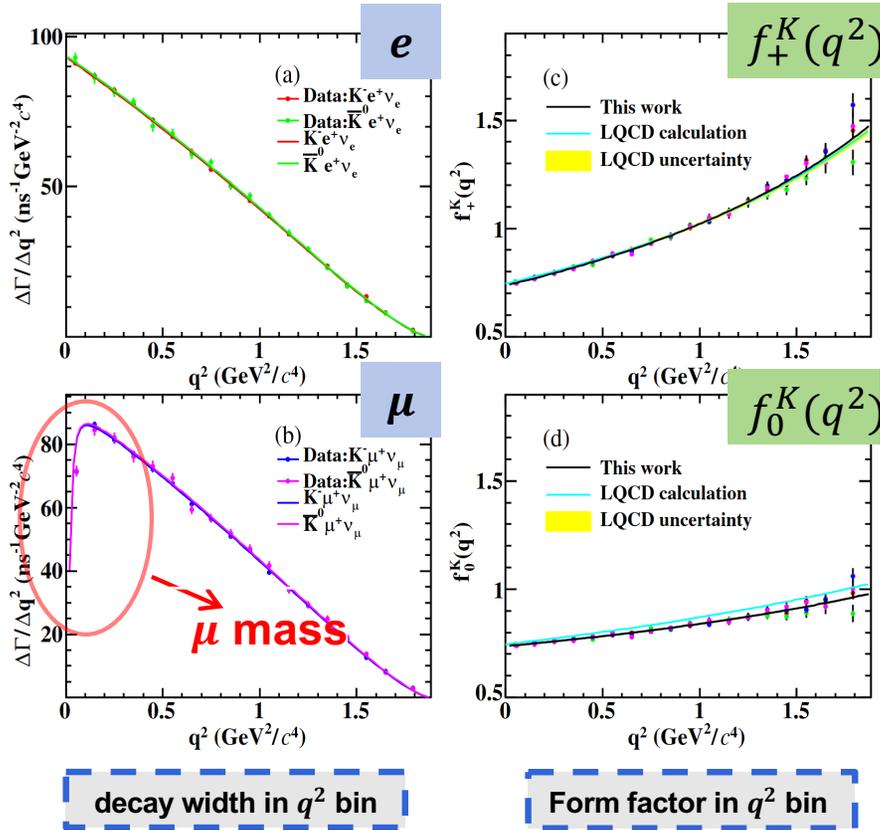PRD 110, 112006 (2024)

(a) Data: $K^- e^+ \nu_e$
Data: $\bar{K}^0 e^+ \nu_e$
$K^- e^+ \nu_e$
$\bar{K}^0 e^+ \nu_e$

(b) Data: $K^- \mu^+ \nu_\mu$
Data: $\bar{K}^0 \mu^+ \nu_\mu$
$K^- \mu^+ \nu_\mu$
$\bar{K}^0 \mu^+ \nu_\mu$

μ mass

(c) This work
LQCD calculation
LQCD uncertainty

(d) This work
LQCD calculation
LQCD uncertainty

decay width in q^2 bin   **Form factor in q^2 bin**

LQCD: 0.4%

|		$f_+^K(0)$
LCSR	Int. J. Mod. Phys. A 21, 6125 (2006)	0.661±0.067
LFQM	J. Phys. G 39, 025005 (2012)	0.79±0.01
CCQM	Front. Phys. 14, 64401 (2019)	0.78±0.12
RQM	Phys.Rev.D 101, 013004 (2020)	0.716
LQCD	Phys. Rev. D 96, 054514 (2017)	0.765±0.031
LQCD	Phys.Rev.D 104, 034505 (2021)	0.7380±0.0044
LQCD	Phys.Rev.D 107, 014510 (2023)	0.7441±0.0040
LQCD	Phys.Rev.D 107, 094516 (2023)	0.7452±0.0031
Belle	Phys.Rev.Lett. 97, 061804 (2006)	0.695±0.007±0.022
BaBar	Phys.Rev.D 76, 052005 (2007)	0.727±0.007±0.009
CLEO	Phys.Rev.D 80, 032005 (2009)	0.7365±0.0041±0.0041
BESIII	Phys.Rev.D 92, 112008 (2015)	0.7478±0.0062±0.0113
BESIII	Phys.Rev.D 96, 012002 (2017)	0.7245±0.0041±0.0115
BESIII	Phys.Rev.Lett. 122, 011804 (2019)	0.7327±0.0039±0.0030
BESIII	Phys.Rev.D 92, 072012 (2015)	0.7367±0.0026±0.0036
This work	Simultaneous fit of $D \to \bar{K}l^+\nu$	0.7366±0.0011±0.0013

➤ $f_+^K(0) = 0.7366 \pm 0.0011 \pm 0.0013$ (~0.24%) **improved by > a factor of 2**

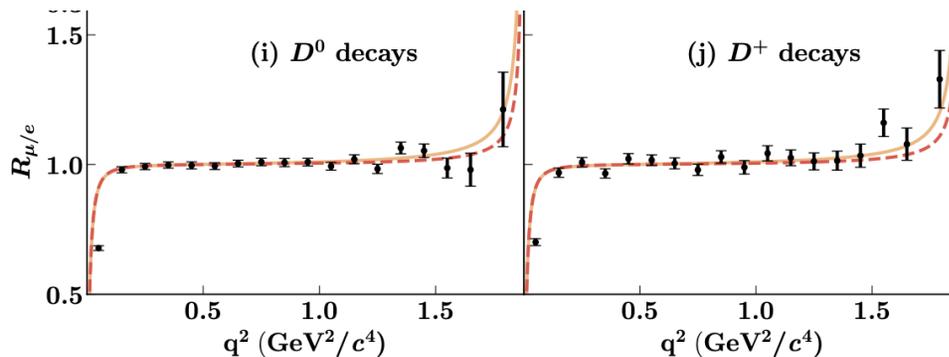➤ $|V_{cs}| = (0.9623 \pm 0.0015 \pm 0.0017 \pm 0.0040_{\text{LQCD}})(\sim 0.48\%)$

➤ Main uncertainty of $|V_{cs}|$ from the LQCD calculations in the input $f_+^K(0)(\sim 0.42\%)$

(~2% before)

$D \to \bar{K}\ell^+\nu_\ell(\ell = e, \mu)$

arXiv:2601.21185
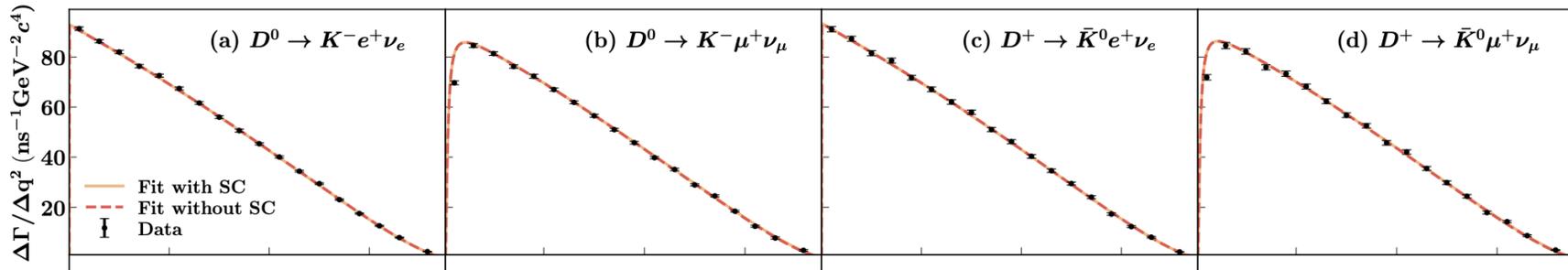
decay width in q^2 bin

LFU test in q^2 bin
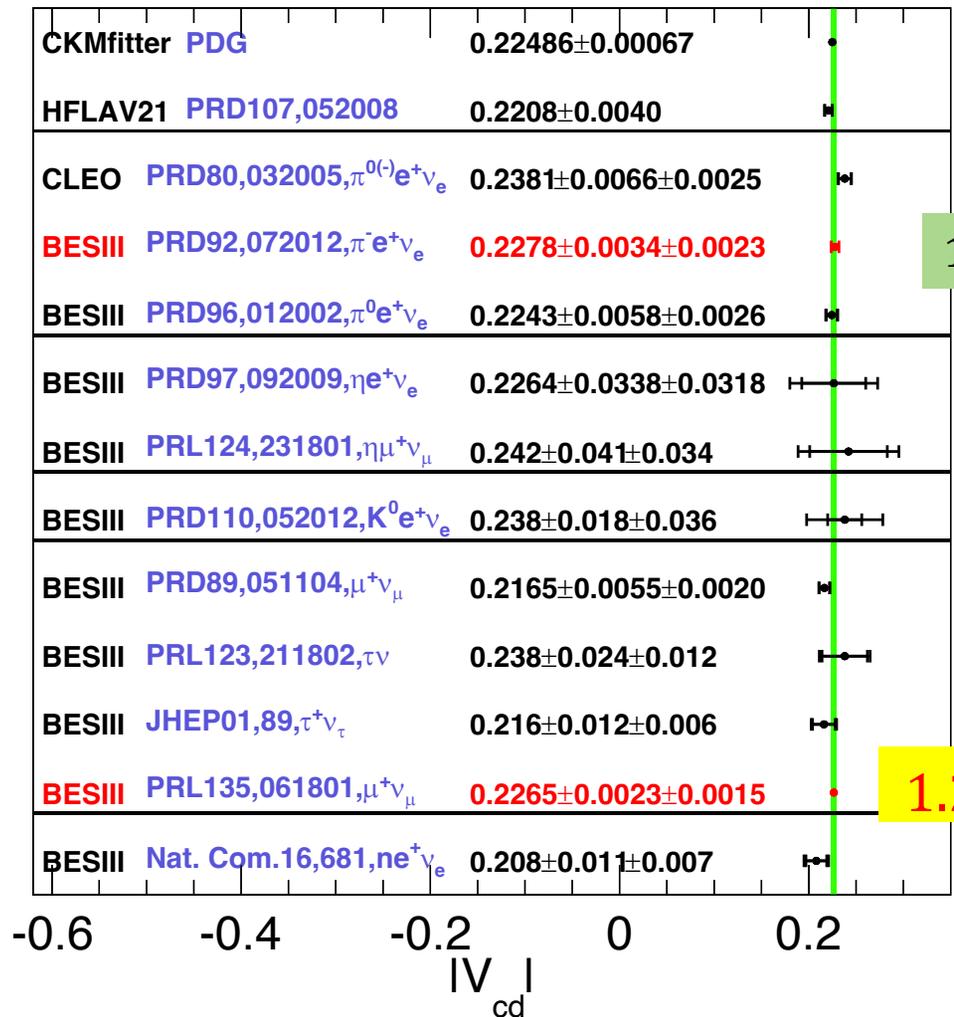
➤ Simultaneous fit to four $D \to \bar{K}\ell^+\nu_\ell$ channels with 20.3 fb^{-1} data.

➤ $f_+^K(0) = 0.7355 \pm 0.0007 \pm 0.0014 \ (\sim 0.21\%)$

most precise

➤ $|V_{cs}| = (0.9608 \pm 0.0009 \pm 0.0019 \pm 0.0040_{\text{LQCD}})(\sim 0.47\%)$

Comparison of $|V_{cd}|$

CKMfitter	PDG	0.22486±0.00067	
HFLAV21	PRD107,052008	0.2208±0.0040	
CLEO	PRD80,032005,$\pi^{0(-)}e^+\nu_e$	0.2381±0.0066±0.0025	
BESIII	PRD92,072012,$\pi^-e^+\nu_e$	0.2278±0.0034±0.0023	1.6%
BESIII	PRD96,012002,$\pi^0e^+\nu_e$	0.2243±0.0058±0.0026	
BESIII	PRD97,092009,$\eta e^+\nu_e$	0.2264±0.0338±0.0318	
BESIII	PRL124,231801,$\eta\mu^+\nu_\mu$	0.242±0.041±0.034	
BESIII	PRD110,052012,$K^0e^+\nu_e$	0.238±0.018±0.036	
BESIII	PRD89,051104,$\mu^+\nu_\mu$	0.2165±0.0055±0.0020	
BESIII	PRL123,211802,$\tau\nu$	0.238±0.024±0.012	
BESIII	JHEP01,89,$\tau^+\nu_\tau$	0.216±0.012±0.006	
BESIII	PRL135,061801,$\mu^+\nu_\mu$	0.2265±0.0023±0.0015	1.2%
BESIII	Nat. Com.16,681,$ne^+\nu_e$	0.208±0.011±0.007	

$|V_{cd}|$
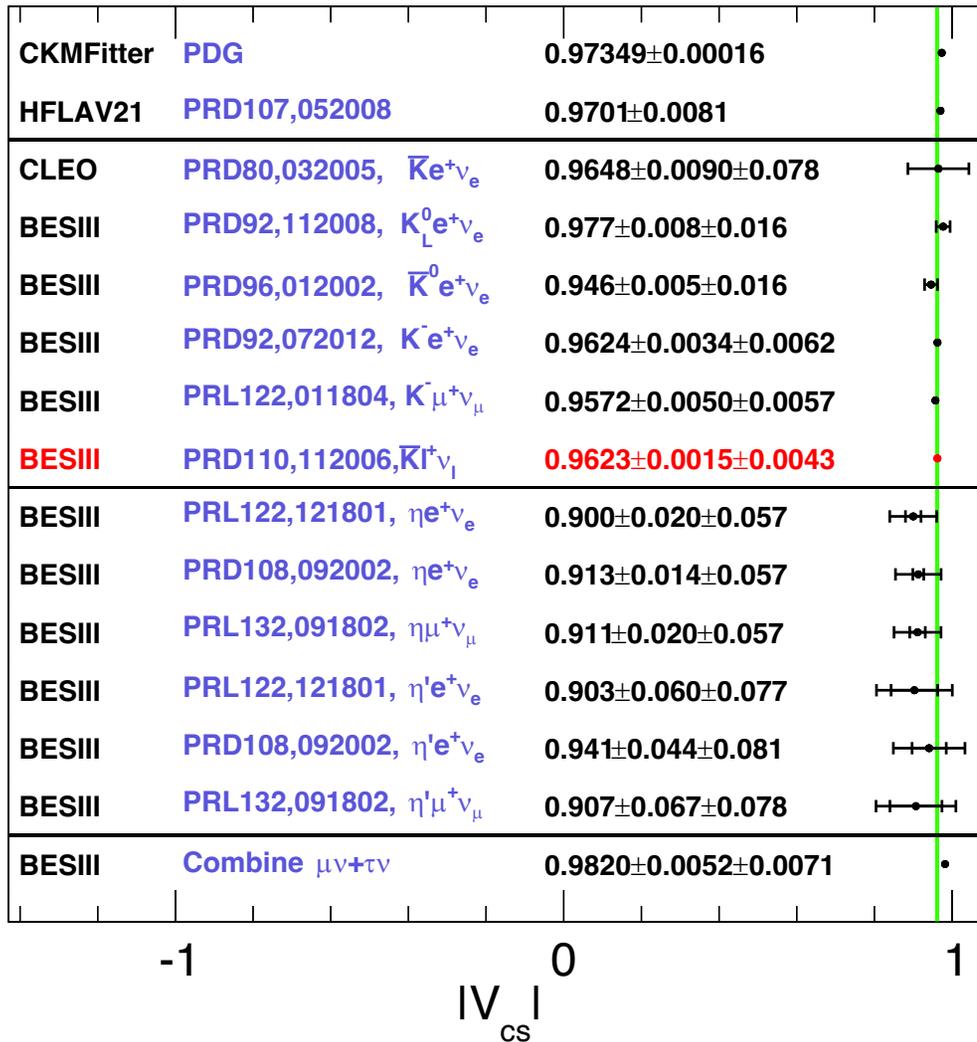
The semi-leptonic decays have potential to yield better precision (Stat. Uncertainty < 0.5%) depending on the uncertainty from LQCD.

The current best precision is from pure-leptonic decays

Comparison of $|V_{cs}|$

CKMFitter	PDG	0.97349 ± 0.00016	
HFLAV21	PRD107,052008	0.9701 ± 0.0081	
CLEO	PRD80,032005, $\overline{K}e^+\nu_e$	$0.9648\pm0.0090\pm0.078$	
BESIII	PRD92,112008, $K^0_L e^+\nu_e$	$0.977\pm0.008\pm0.016$	
BESIII	PRD96,012002, $\overline{K}^0 e^+\nu_e$	$0.946\pm0.005\pm0.016$	
BESIII	PRD92,072012, $K^- e^+\nu_e$	$0.9624\pm0.0034\pm0.0062$	
BESIII	PRL122,011804, $K^-\mu^+\nu_\mu$	$0.9572\pm0.0050\pm0.0057$	
BESIII	PRD110,112006, $\overline{K}l^+\nu_l$	$0.9623\pm0.0015\pm0.0043$	
BESIII	PRL122,121801, $\eta e^+\nu_e$	$0.900\pm0.020\pm0.057$	
BESIII	PRD108,092002, $\eta e^+\nu_e$	$0.913\pm0.014\pm0.057$	
BESIII	PRL132,091802, $\eta\mu^+\nu_\mu$	$0.911\pm0.020\pm0.057$	
BESIII	PRL122,121801, $\eta'e^+\nu_e$	$0.903\pm0.060\pm0.077$	
BESIII	PRD108,092002, $\eta'e^+\nu_e$	$0.941\pm0.044\pm0.081$	
BESIII	PRL132,091802, $\eta'\mu^+\nu_\mu$	$0.907\pm0.067\pm0.078$	
BESIII	Combine $\mu\nu+\tau\nu$	$0.9820\pm0.0052\pm0.0071$	

$|V_{cs}|$

$\overline{K}\ell^+\nu_\ell$ simultaneous fit (stat sys~0.2%)

Main systematic uncertainty from the

LQCD input $f^K_+(0)$)

0.5%

1.0% The best precision for pure-leptonic decays is 1%

$D \to K^*(892)l^+\nu_l(\ell = e, \mu)$

- BF measurement:

$\mathcal{B}(D^0 \to \bar{K}^0\pi^-\mu^+\nu_\mu) = (1.373 \pm 0.020 \pm 0.023)\%$

$\mathcal{B}(D^0 \to \bar{K}^0\pi^-e^+\nu_e) = (1.444 \pm 0.022 \pm 0.024)\%$

$\mathcal{B}(D^+ \to K_S^0\pi^0e^+\nu_e) = (0.943 \pm 0.012 \pm 0.010)\%$

$\mathcal{B}(D^+ \to K_S^0\pi^0\mu^+\nu_\mu) = (0.896 \pm 0.017 \pm 0.008)\%$

- **Using the Partial wave analysis method**

- **FF of $D \to K^*(892)$**

$\mathcal{B}(D^0 \to K^*(892)^-\mu^+\nu_\mu) = (2.062 \pm 0.039 \pm 0.032)\%$

$\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e) = (2.039 \pm 0.032 \pm 0.034)\%$

$\mathcal{B}(D^+ \to K^*(892)^0e^+\nu_e) = (5.29 \pm 0.07 \pm 0.06)\%$

$\mathcal{B}(D^+ \to K^*(892)^0\mu^+\nu_\mu) = (5.00 \pm 0.10 \pm 0.06)\%$

$r_V = \dfrac{V(0)}{A_1(0)} = 1.42 \pm 0.03 \pm 0.02 \ (3\% - 4\%)$

$r_2 = \dfrac{A_2(0)}{A_1(0)} = 0.75 \pm 0.03 \pm 0.01 \ (5\% - 6\%)$
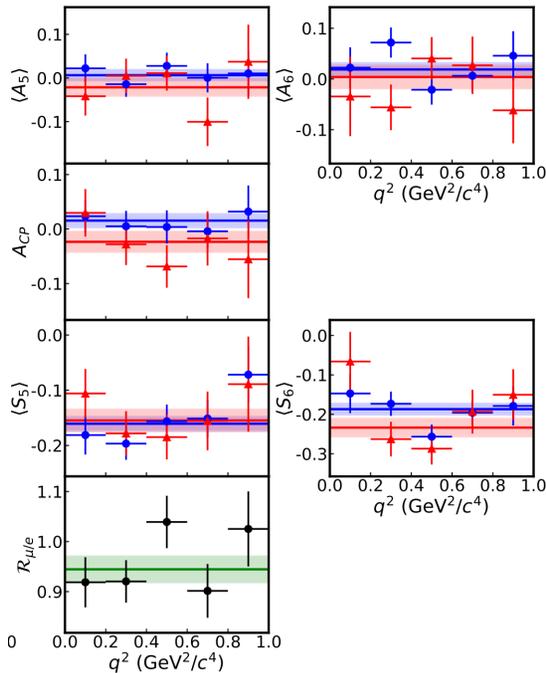

25
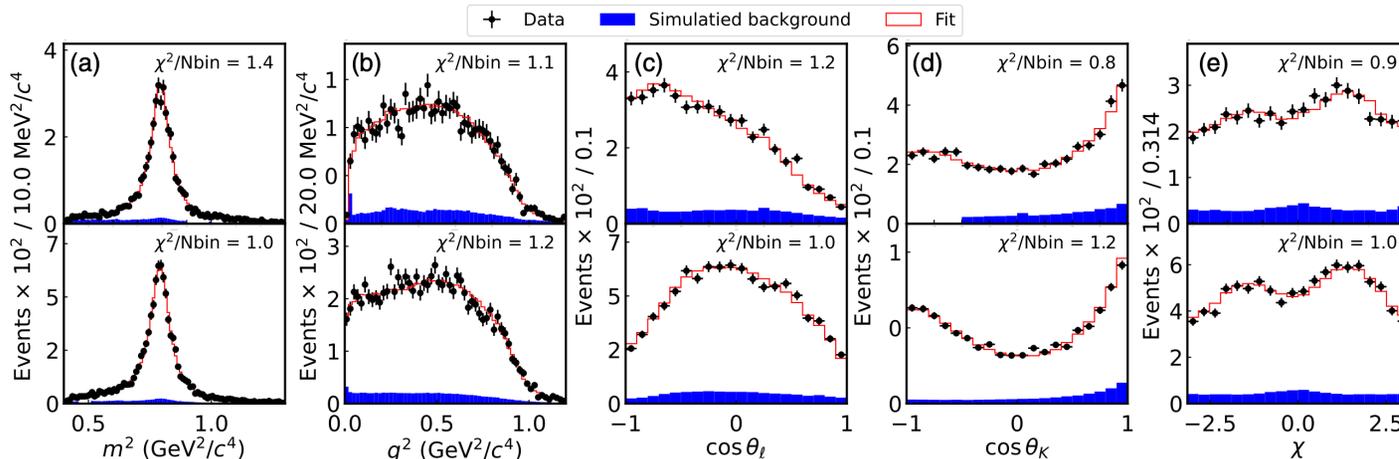
$D \rightarrow K^*(892)l^+\nu_l(\ell = e, \mu)$
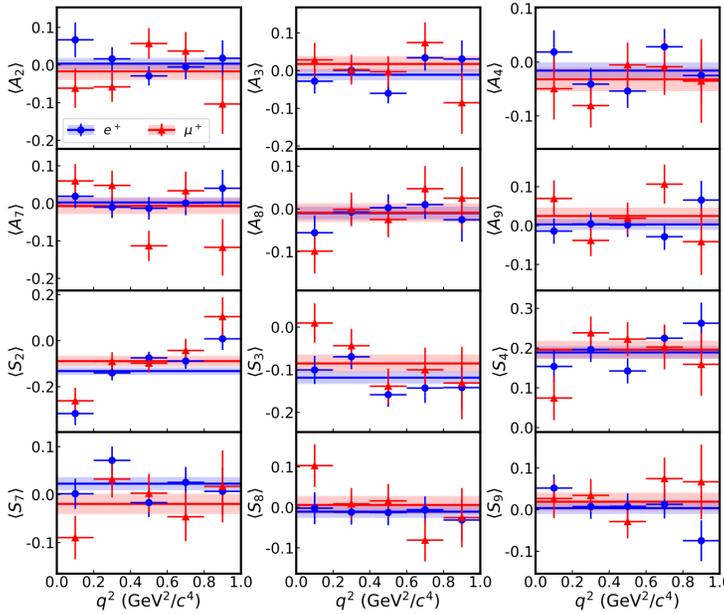
- LFU test:
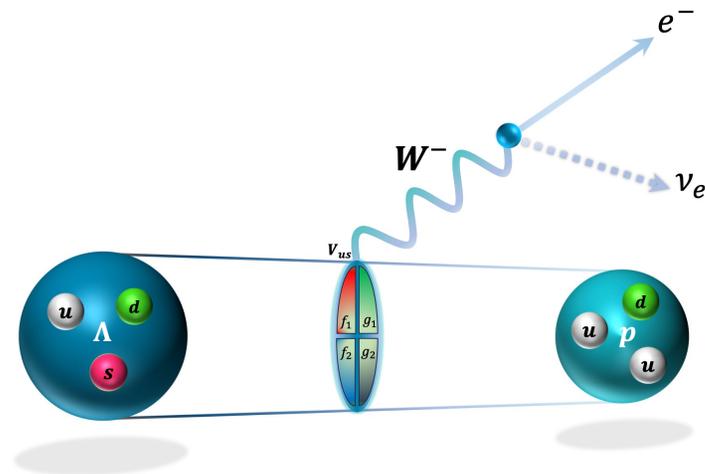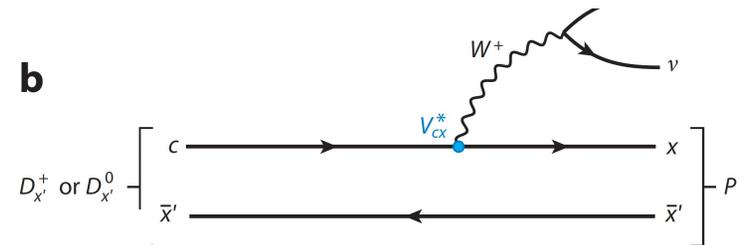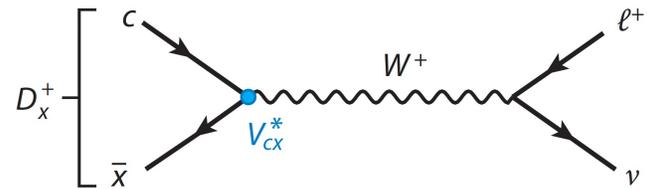
$$R_{\mu/e} = 0.94 \pm 0.02 \pm 0.01$$

- Isospin test:

$$R_{K^-\pi^+/K_S^0\pi^0} = 4.02 \pm 0.06 \pm 0.10$$

- First measurement of full set of CP asymmetries and averaged angular observables with A_{CP}

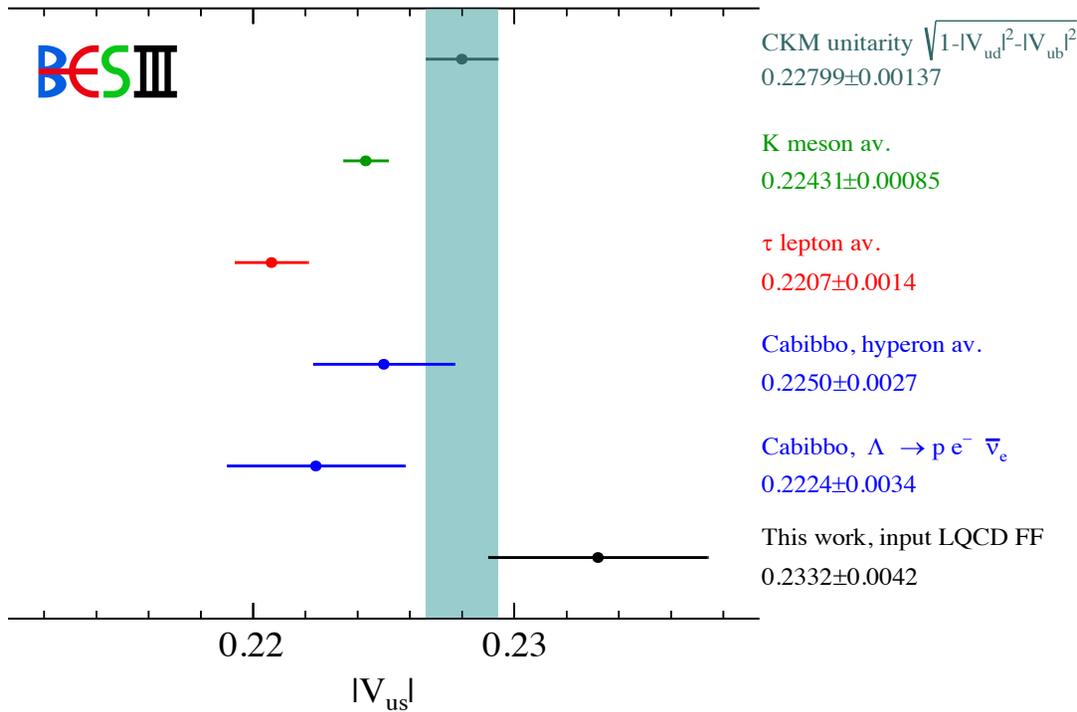- All measured null-test observables A_{CP}, $< S_{7-9} >$ and $< A_{2-9} >$ agree with the SM predictions.
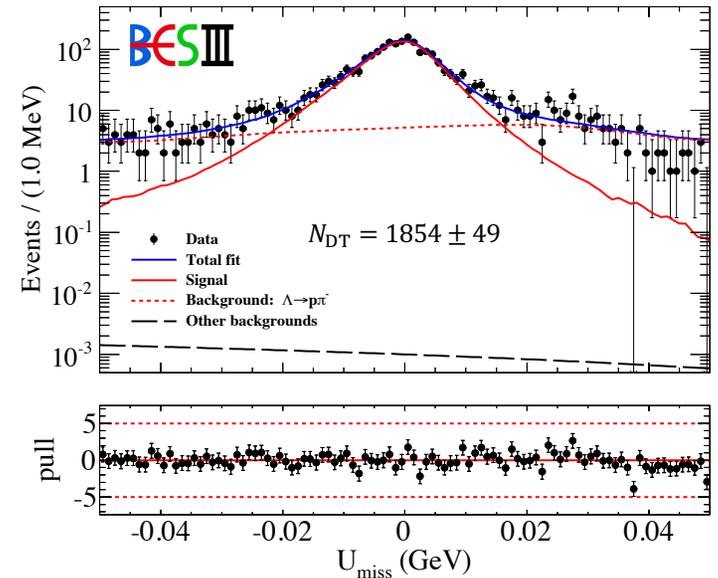
Outline

- BESIII dataset

- |Vcd| and |Vcs|
  - pure leptonic charm decays
  - semi-leptonic charm decays

- **|Vus|**

- Summary

$\Lambda \to p e^- \nu_e$

CKM unitarity $\sqrt{1-|V_{ud}|^2-|V_{ub}|^2}$
0.22799±0.00137

K meson av.
0.22431±0.00085

τ lepton av.
0.2207±0.0014

Cabibbo, hyperon av.
0.2250±0.0027

Cabibbo, $\Lambda \to p\, e^-\, \bar{\nu}_e$
0.2224±0.0034

This work, input LQCD FF
0.2332±0.0042

arXiv:2509.09266, submit to Nature

$N_{\mathrm{DT}} = 1854 \pm 49$

| | First absolute BF measurement |

$$\mathcal{B}(\Lambda \to p e^- \bar{\nu}_e) = (8.16 \pm 0.22 \pm 0.15)\times 10^{-4}$$

Determiantion of $|V_{us}|$

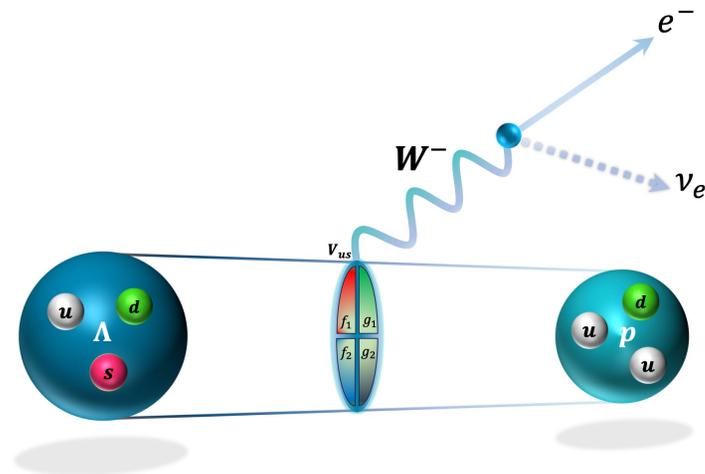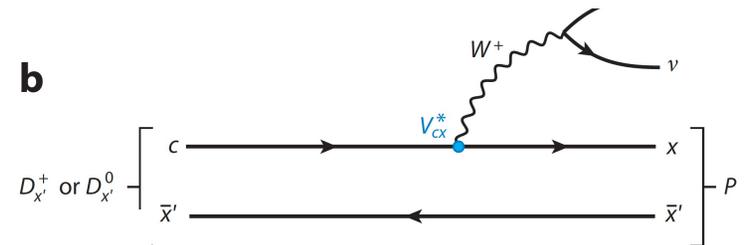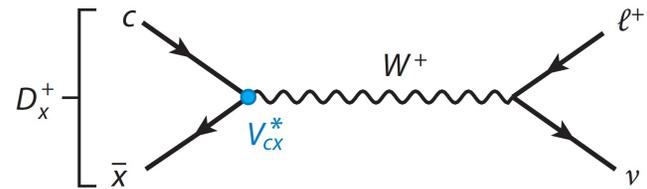➤ Assume SU(3) is conserved, $f_1 = \sqrt{3/2}$ [PRL92(2004)251803]

$|V_{us}|_{\mathrm{SU(3)}} = 0.2199 \pm 0.0036_{\mathrm{BESIII\ BF}} \pm 0.0087_{\mathrm{BESIII\ FF}} \pm 0.0004_{\tau_\Lambda} \pm 0.0005_{\mathrm{RC}}$

➤ Using LQCD FF prediction [arXiv:2507.09970]

$|V_{us}|_{\mathrm{LQCD}} = 0.2332 \pm 0.0039_{\mathrm{BESIII\ BF}} \pm 0.0004_{\tau_\Lambda} \pm 0.0006_{\mathrm{RC}} \pm 0.0014_{\mathrm{LQCD}}$

Outline

- **BESIII dataset**

- **|Vcd| and |Vcs|**
  - **pure leptonic charm decays**
  - **semi-leptonic charm decays**

- **|Vus|**

- **Summary**

Summary & Outlook

- Pure and semi-leptonic charm decays are idea for measuring $|V_{cd(s)}|$, decay constants and form factors of charmed mesons.

- Uncertainty from radiative correction becomes crucial for Pure leptonic decays.

- Current most precise measurement

$|V_{cs}| \Rightarrow$ **0.5%** from $D \to \overline{K}\ell^+\nu_\ell$ (dominate uncertainty: LQCD form factor)
$|V_{cd}| \Rightarrow$ **1.2%** from $D^+ \to \mu^+\nu_\mu$. ($D \to \pi e^+\nu_e$ will yield the most precise $|V_{cd}|$)

- $D \to V\ell^+\nu_\ell$ could also contribute to the measurement of $|V_{cs}|$.

- Systematic uncertainty dominates now. How to reduce systematic uncertainty will be the key to improve precision in the future experiments.

- First determiantion of $|V_{us}|$ using threshold data.

Thanks for the attention