Charm physics measurement at BESIII

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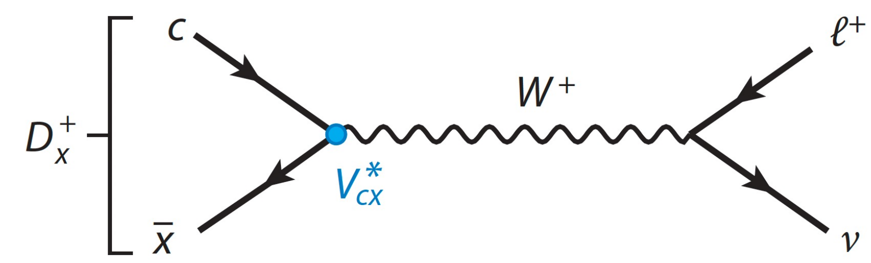
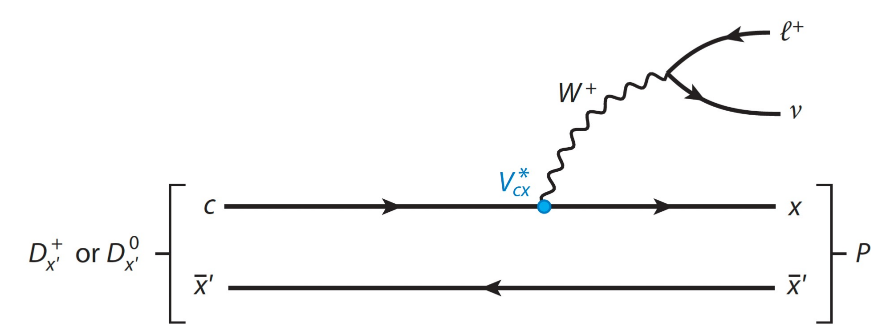
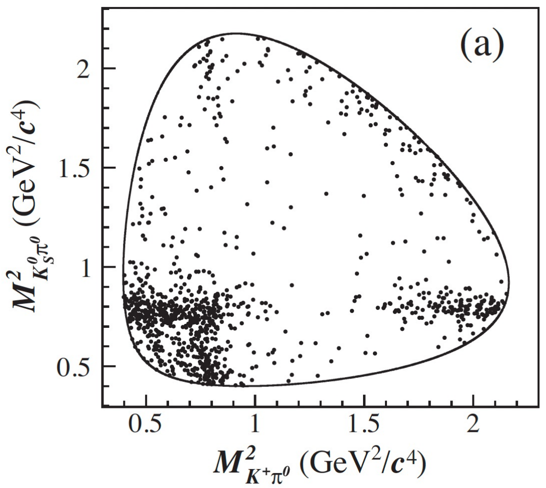
Outline

- BESIII dataset
- Charmed meson (D^0, D^+, D_s^+)
  - pure leptonic decays
  - semi-leptonic decays
  - hadronic decays
  - quantum correlation
- Charmed baryon (Λ_c^+)
  - semi-leptonic decays
  - hadronic decays
- Prospect







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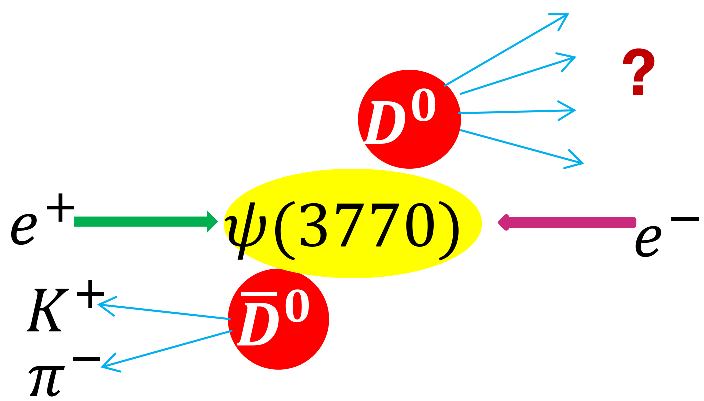
- Summary

BESIII Data Taken near Threshold

- 7.9 fb^{-1} at E$_{cm}$ 3.773 GeV: $e^+e^- \longrightarrow$ ψ(3770)$\longrightarrow D\bar{D}$
- 7.3fb^{-1} at E$_{cm}$ 4.128 - 4.226 GeV: $e^+e^- \longrightarrow D_s D_s^*$
- 4.5 fb^{-1} at Ecm = 4.600-4.699 GeV: $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$

Production of charm hadron pair



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.

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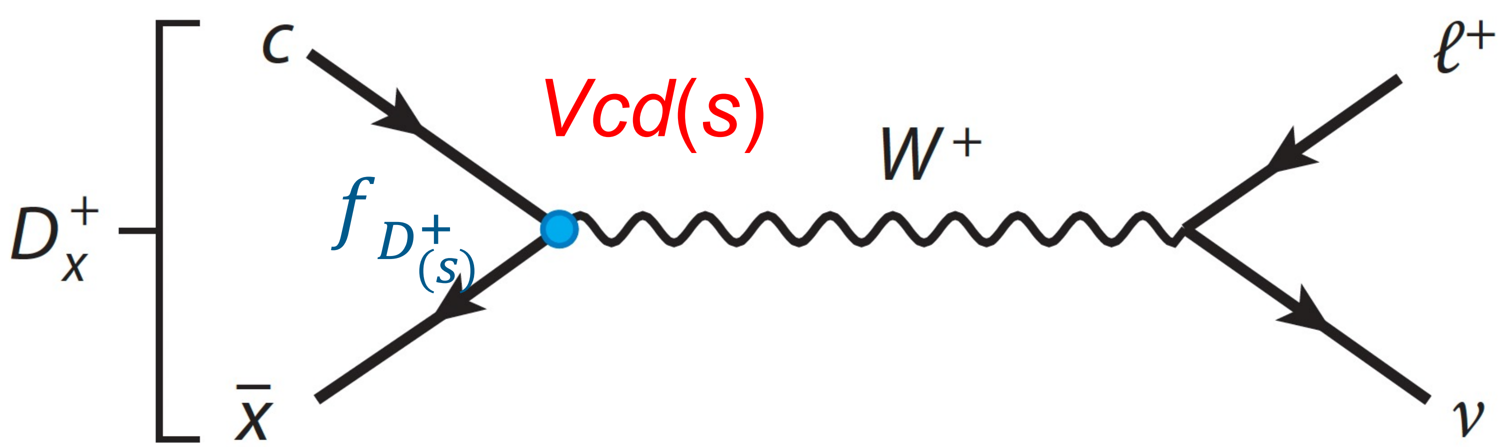
Pure leptonic D decay



$$\Gamma\left(D^+_{(s)} \to l^+\nu\right) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi}\left|V_{cd(s)}\right|^2 m_l^2 m_{D^+_{(s)}}\left(1 - \frac{m_l^2}{m^2_{D^+_{(s)}}}\right)^2$$

Decay constant $f_{D^+_{(s)}}$:

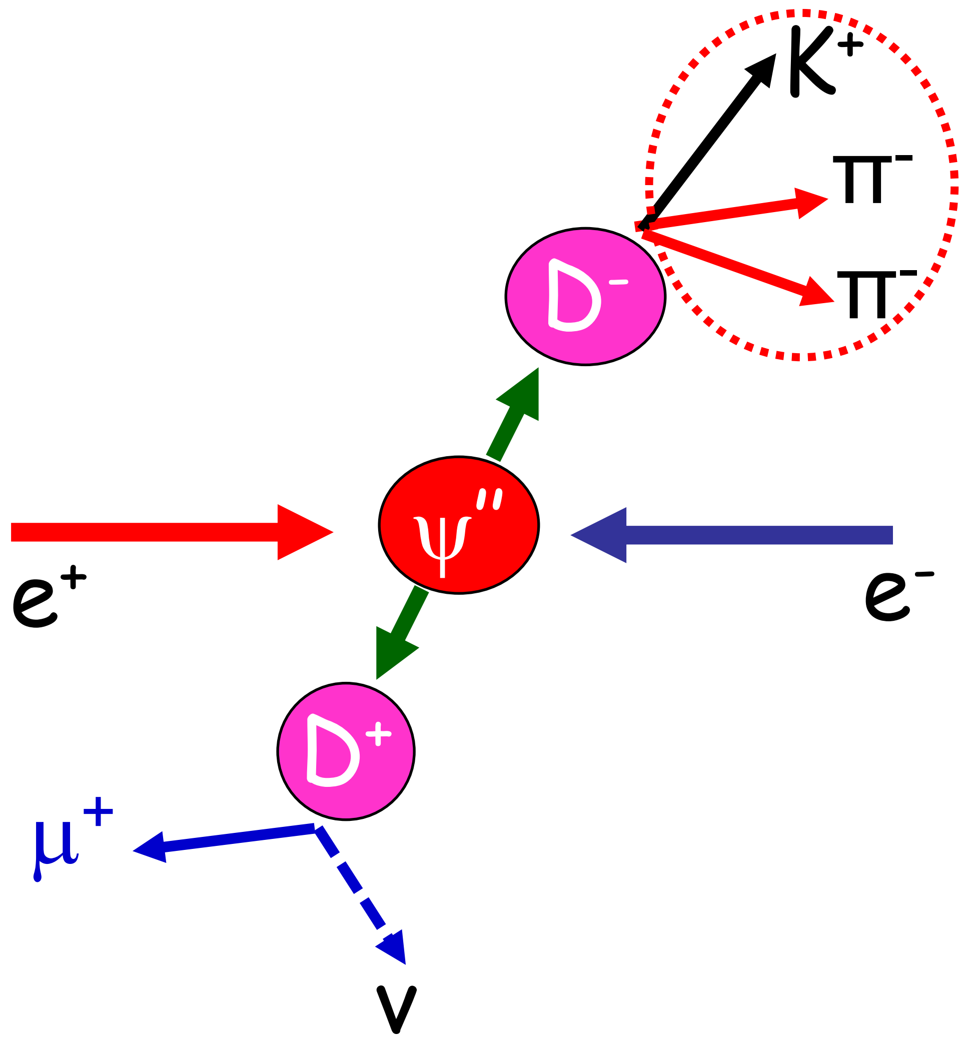
Calibrate Lattice QCD

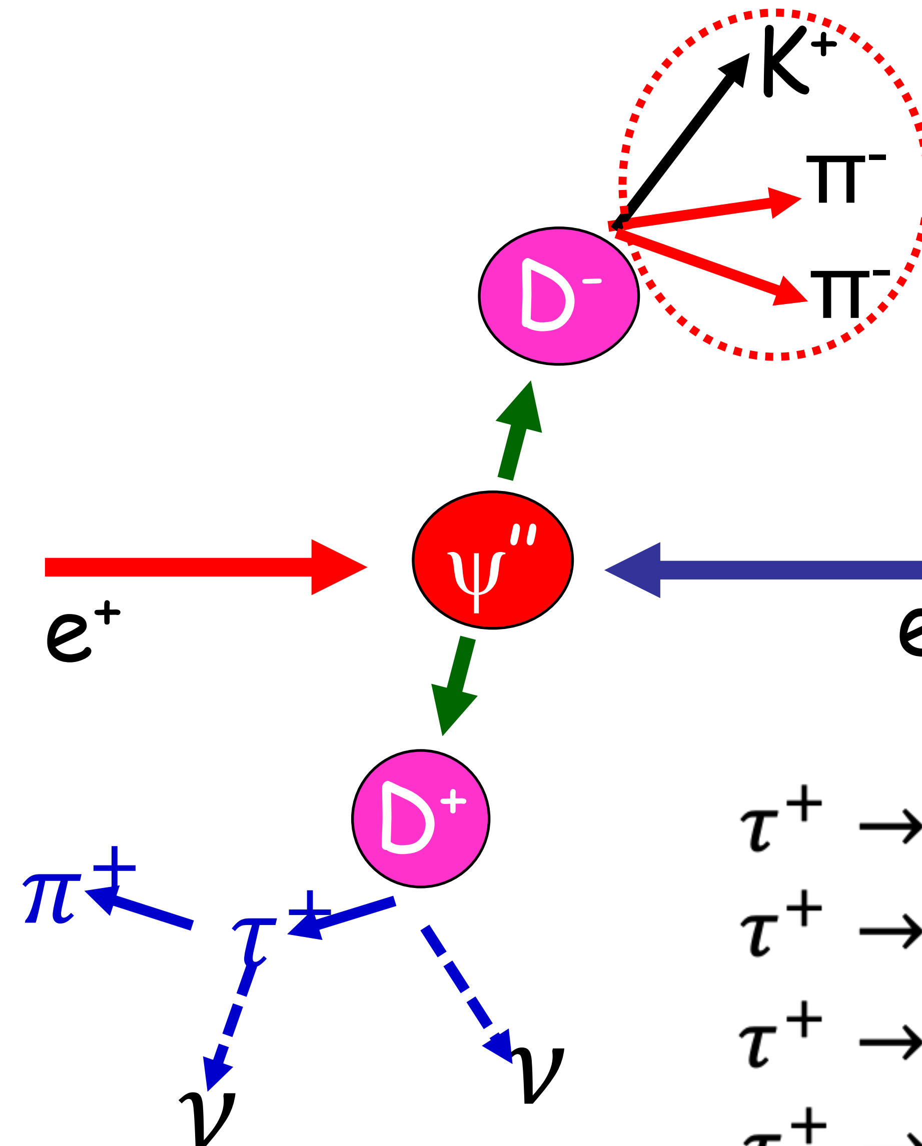
CKM matrix element $|V_{cd(s)}|$:

Test the unitarity of CKM matrix

Lepton flavor universality

	$e^+\nu_e$	$\mu^+\nu_\mu$	$\tau^+\nu_\tau$
D^+	10^{-5}	1	2.67
D_s^+	10^{-5}	1	9.75





$$\tau^+ \to e^+\nu_e\bar{\nu}_\tau$$
$$\tau^+ \to \pi^+\bar{\nu}_\tau$$
$$\tau^+ \to \rho^+\bar{\nu}_\tau$$
$$\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$$

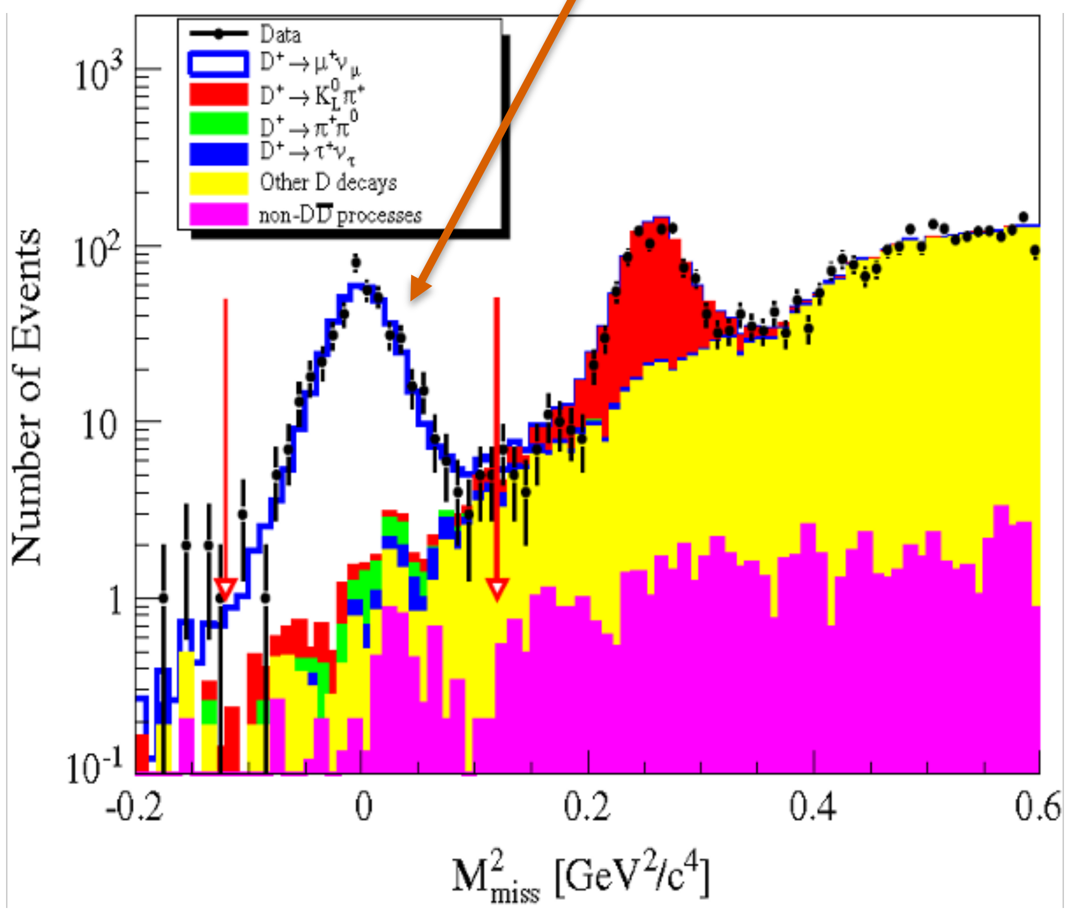
One neutrino missing in an muonic event

Two or three neutrinos missing in an tau event

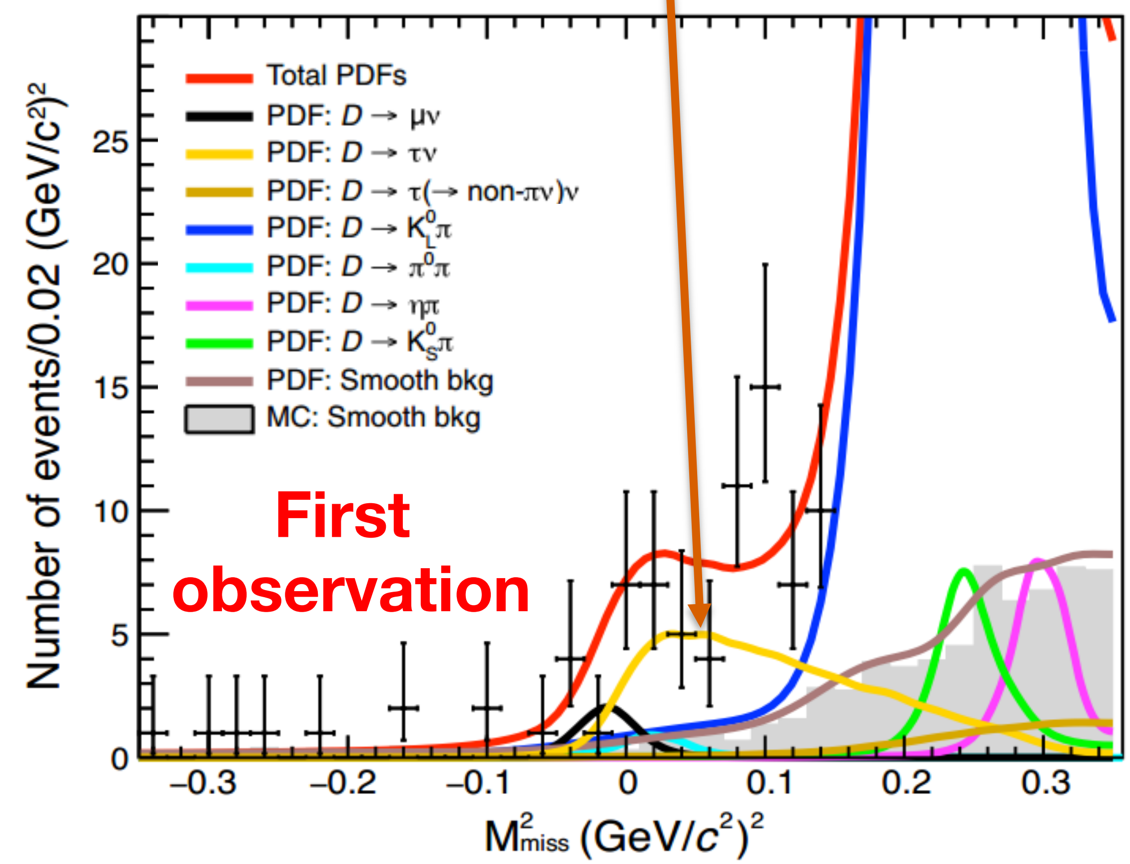
$$U_{\text{miss}} = E_{\text{miss}} - |\vec{p}_{\text{miss}}|$$
$$M^2_{\text{miss}} = E^2_{\text{miss}} - |\vec{p}^{\,2}_{\text{miss}}|$$

$D^+ \to l^+\nu_l$

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



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



τ^+ is reconstructed via $\tau^+ \to \pi^+\nu_\tau$

$\mathcal{B}(D^+ \to \mu^+\nu_\mu) = (3.71 \pm 0.19 \pm 0.06)\times 10^{-4}$

$f_{D^+}|V_{cd}| = 46.7 \pm 1.2 \pm 0.4$ MeV

Phys. Rev. D 89, 051104 (2014)

$\mathcal{B}(D^+ \to \tau^+\nu_\tau) = (1.20 \pm 0.24 \pm 0.12)\times 10^{-3}$

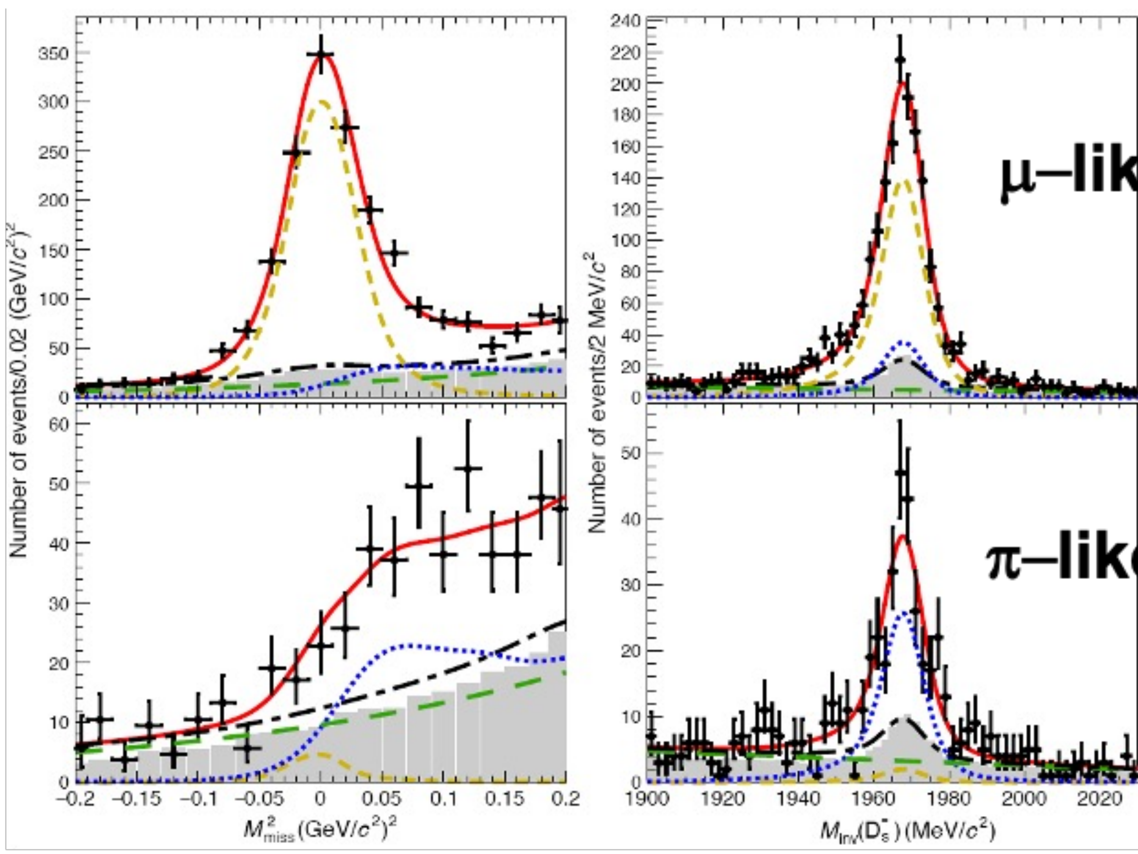
$f_{D^+}|V_{cd}| = 50.4 \pm 5.0 \pm 2.5$ MeV

Phys. Rev. Lett. 123, 211802 (2019)

Unfortunately $D^+ \to \tau^+\nu_\tau$ can't contribute to D^+ decay constant measurement

$D_s^+ \to l^+\nu$

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



$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (5.35 \pm 0.13 \pm 0.16)\times 10^{-3}$

$f_{D_s^+}|V_{cs}| = 243.1 \pm 3.0 \pm 3.7$ MeV[μ]

$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.21 \pm 0.25 \pm 0.17)\%$

$f_{D_s^+}|V_{cs}| = 243.0 \pm 5.8 \pm 4.0$ MeV[τ]

Phys. Rev. D 104, 052009 (2021)

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

$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.29 \pm 0.25 \pm 0.20)\%$

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

Phys. Rev. D 104, 032001 (2021)

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

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

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

Phys. Rev. Lett. 127, 171801 (2021)

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

$\mathcal{B}(D_s^+ \to \tau^+\nu) = (5.34 \pm 0.16 \pm 0.10)\%$

$f_{D_s^+}|V_{cs}| = (246.2 \pm 3.7_{\rm stat} \pm 2.5_{\rm syst})$ MeV.

arXiv: 2303.12468

$D^+ \to \tau^+\nu_\tau$ can contribute comparable statistics to $\mu^+\nu$

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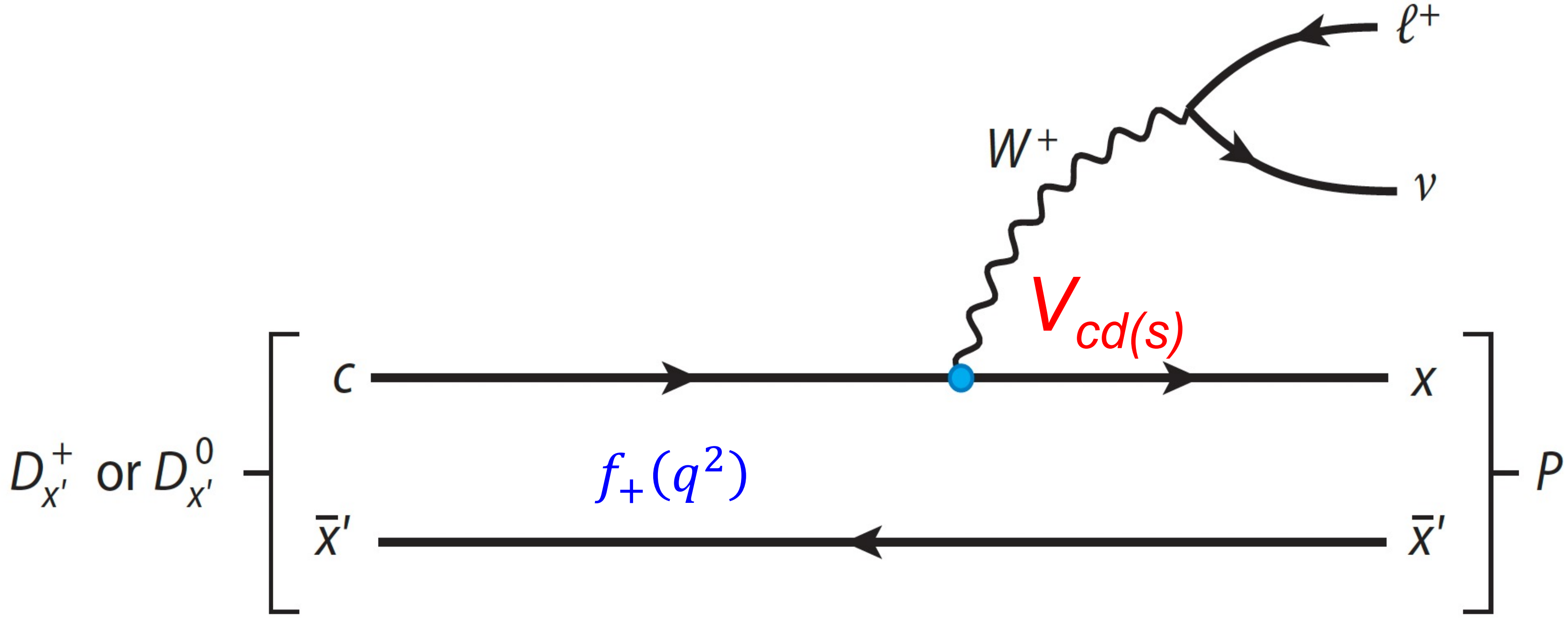
Semi-leptonic $D \to Pe^+\nu$



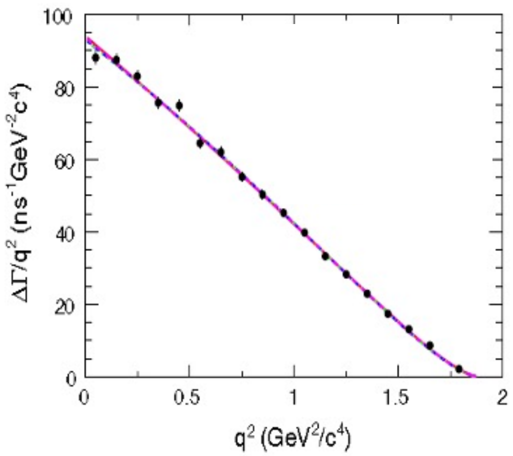
$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2 p^3}{24\pi^3}|f_+(q^2)|^2\left|V_{cd(s)}\right|^2$$

$$(X = 1 for K^-, \pi^-, \overline{K}^0, \eta^{(\prime)}; X = \frac{1}{2} for\ \pi^0)$$

Form factor $f_+(0)$: Calibrate Lattice QCD

CKM matrix element $|V_{cd(s)}|$: Test the unitarity of CKM matrix

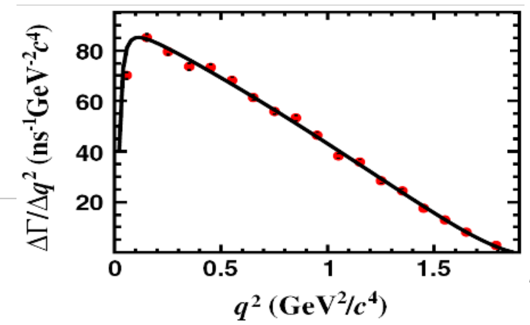
Test $\mathrm{e} - \mu$ Lepton flavor universality



$D^0 \to K^- e^+ \nu$

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

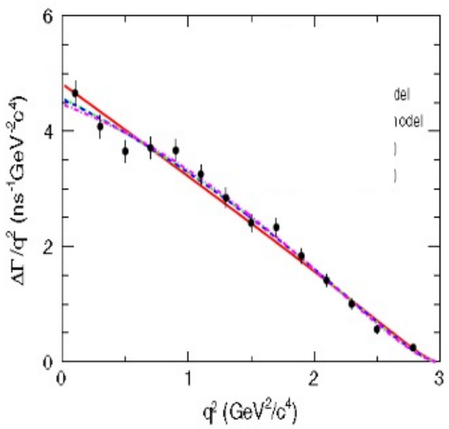
Phys. Rev. D 92, 072012 (2015)



$D^0 \to K^- \mu^+ \nu$

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

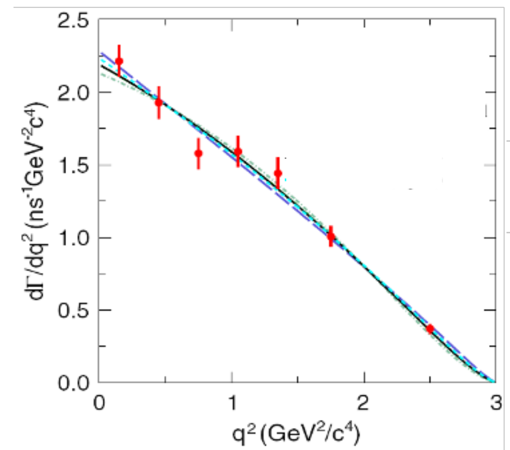
Phys. Rev. Lett. 122, 011804 (2019)



$D^0 \to \pi^- e^+ \nu$

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

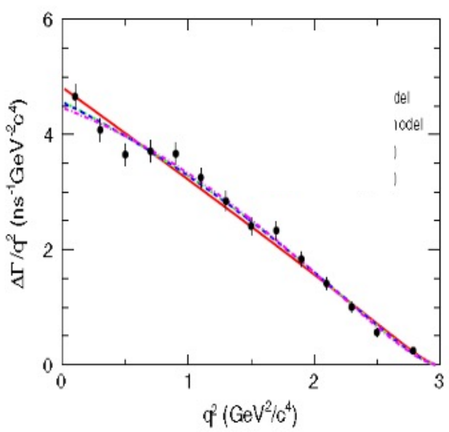
Phys. Rev. D 92, 072012 (2015)



$D^+ \to \pi^0 e^+ \nu$

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

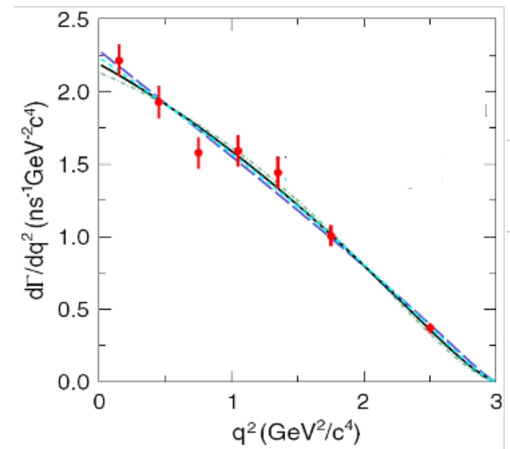
Phys. Rev. D 96, 012002 (2017)



$D^0 \to \pi^- e^+ \nu$

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

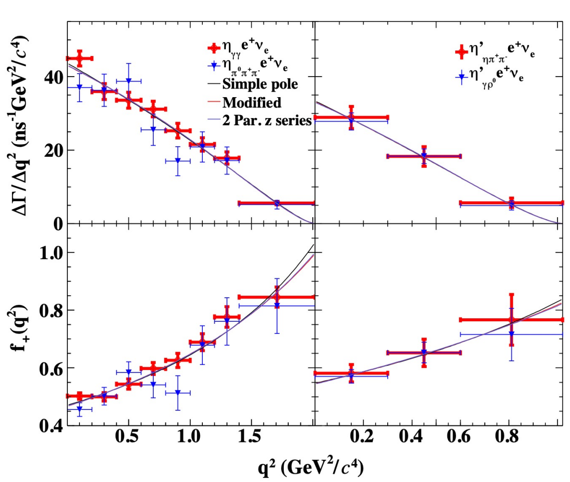
Phys. Rev. D 92, 072012 (2015)



$D^+ \to \pi^0 e^+ \nu$

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

Phys. Rev. D 96, 012002 (2017)



$D_s^+ \to \eta^{(\prime)} e^+ \nu$

$f_+^{\eta}(0)|V_{cs}| = 0.4553 \pm 0.0071_{\rm stat} \pm 0.0061_{\rm syst}$

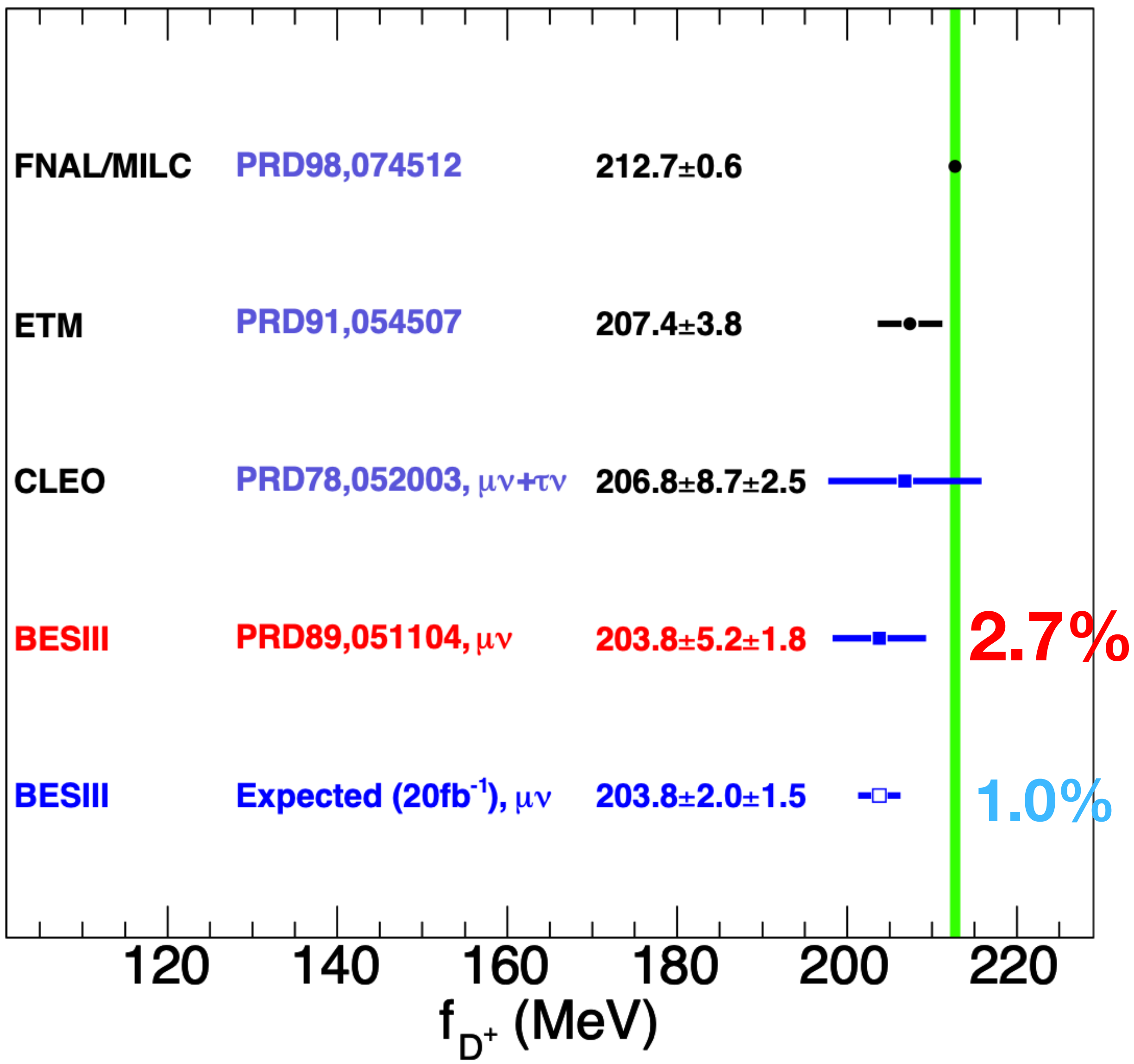
$f_+^{\eta'}(0)|V_{cs}| = 0.529 \pm 0.024_{\rm stat} \pm 0.008_{\rm syst}$

arXiv:2306.05194

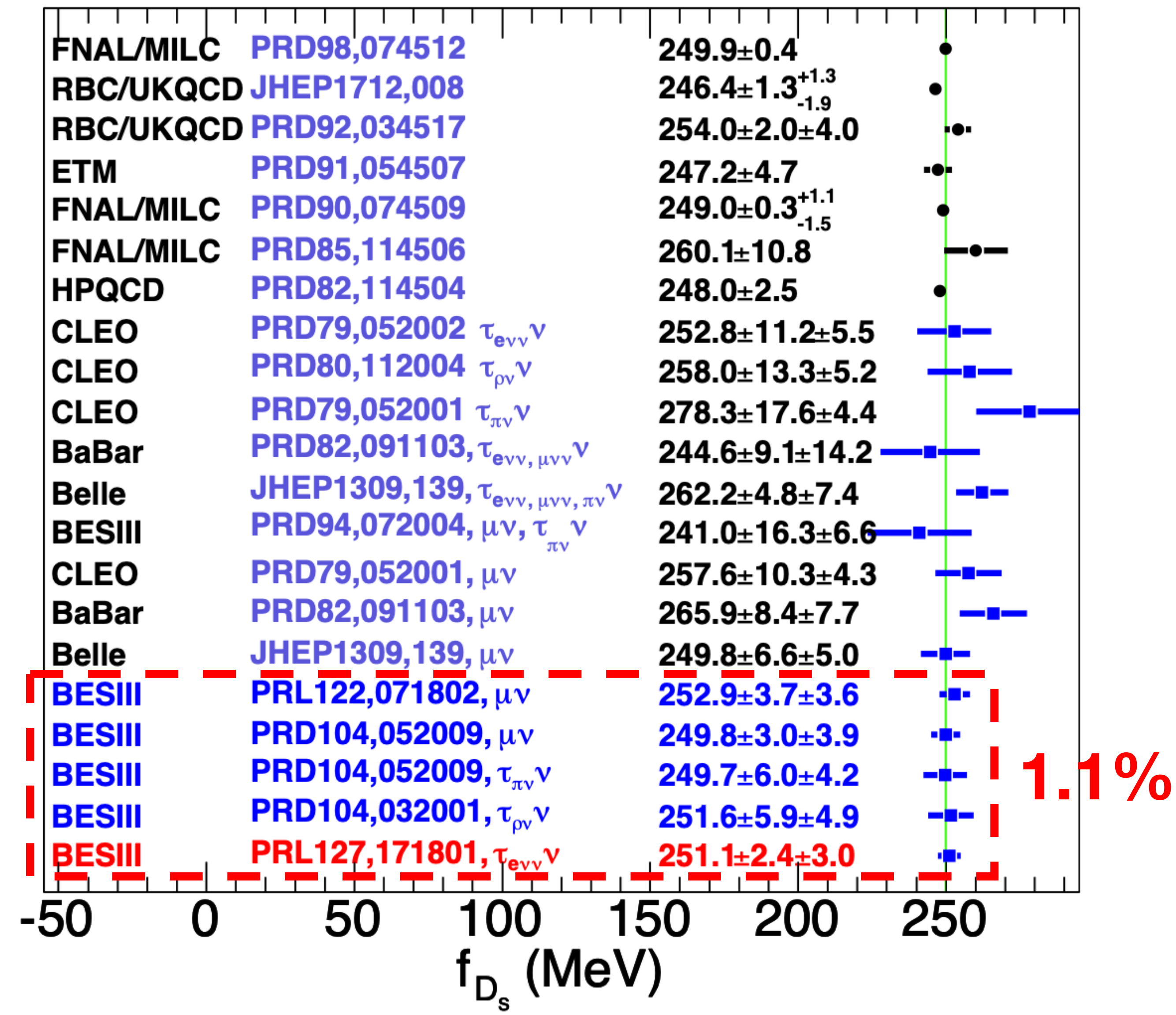
Phys. Rev. Lett. 123, 121801 (2019)

Comparison of decay constant

f_{D^+}



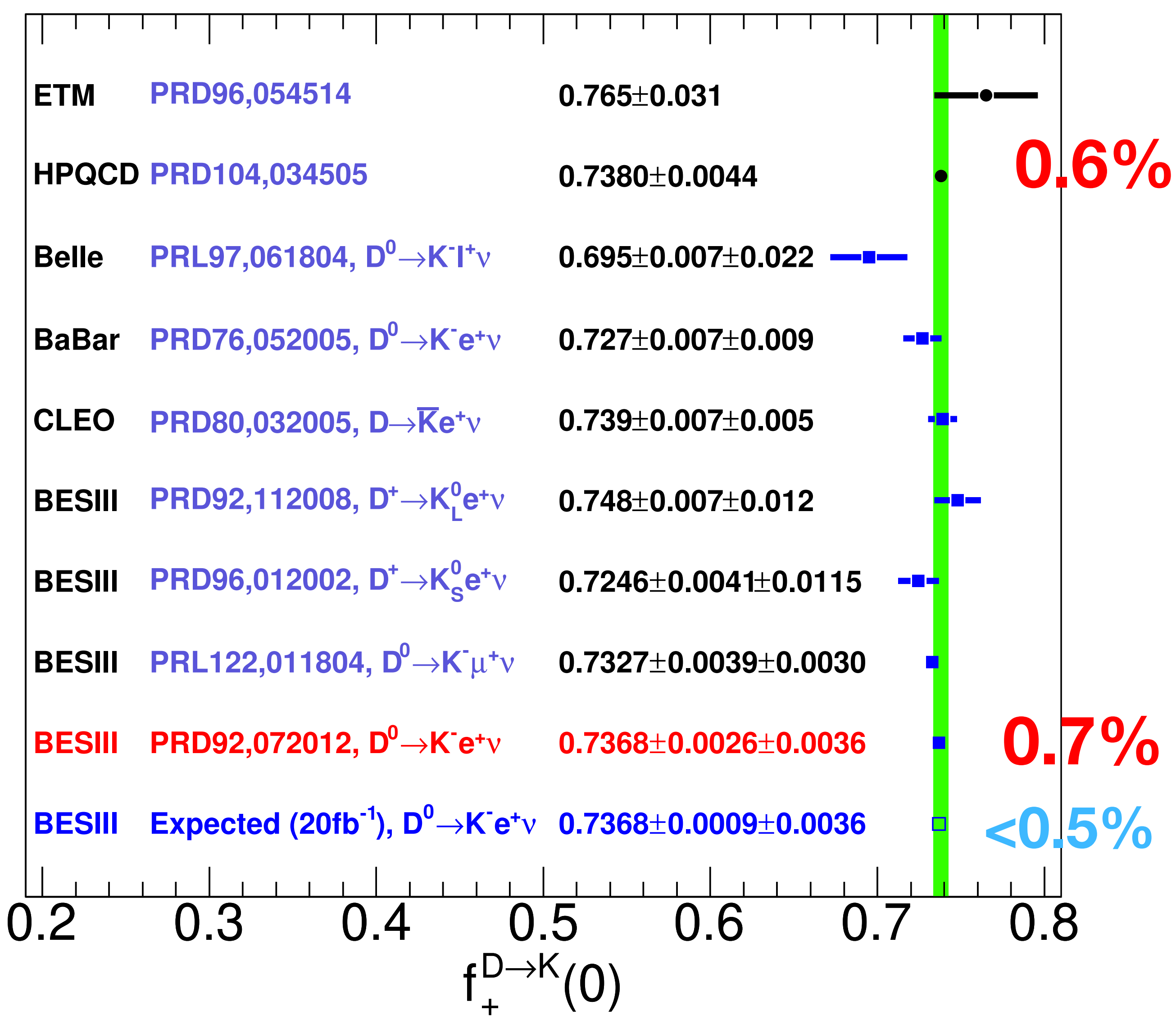
$f_{D_s^+}$



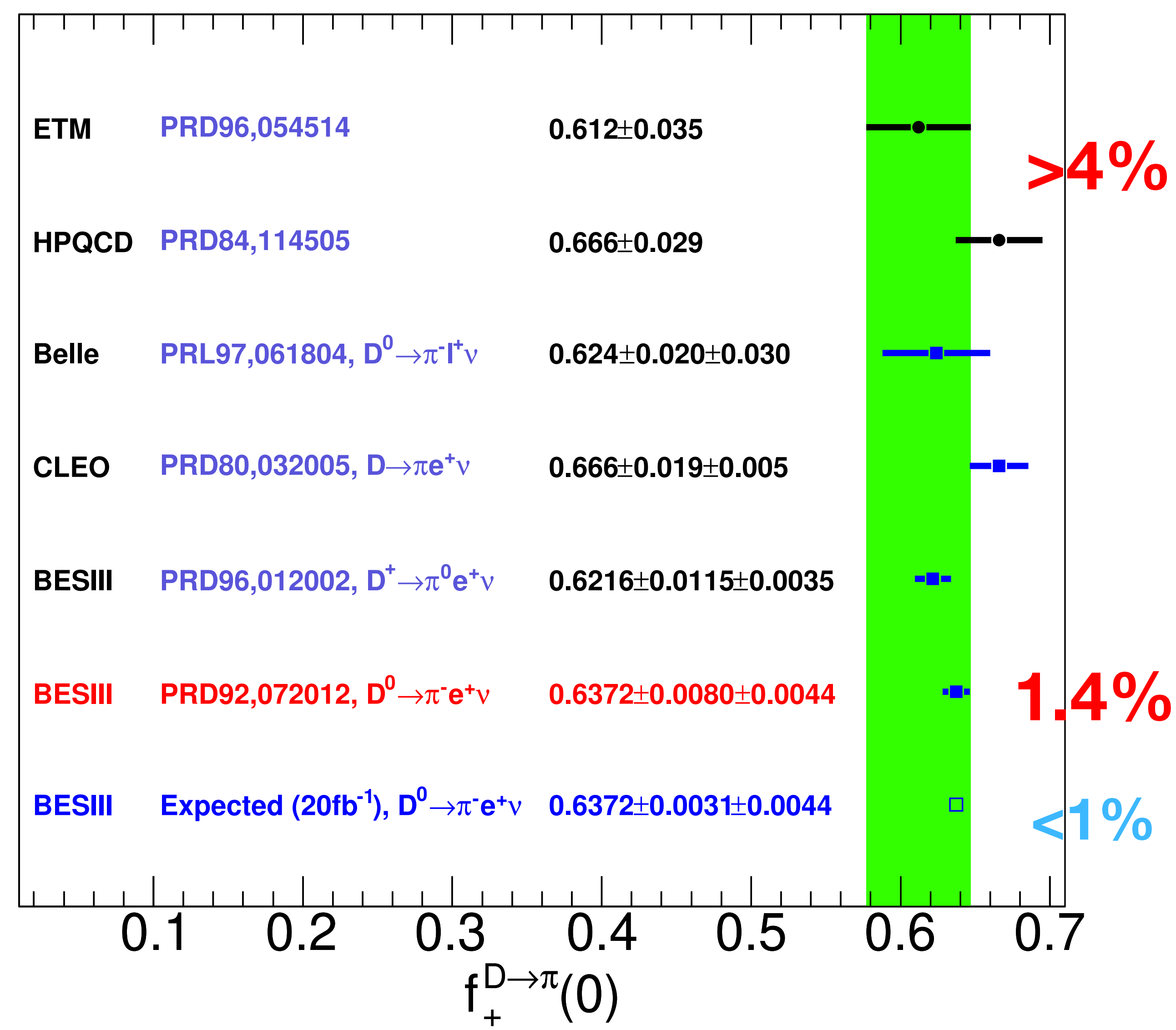
Dominated by statistical uncertainty

Comparison of form factor

$D \to K$



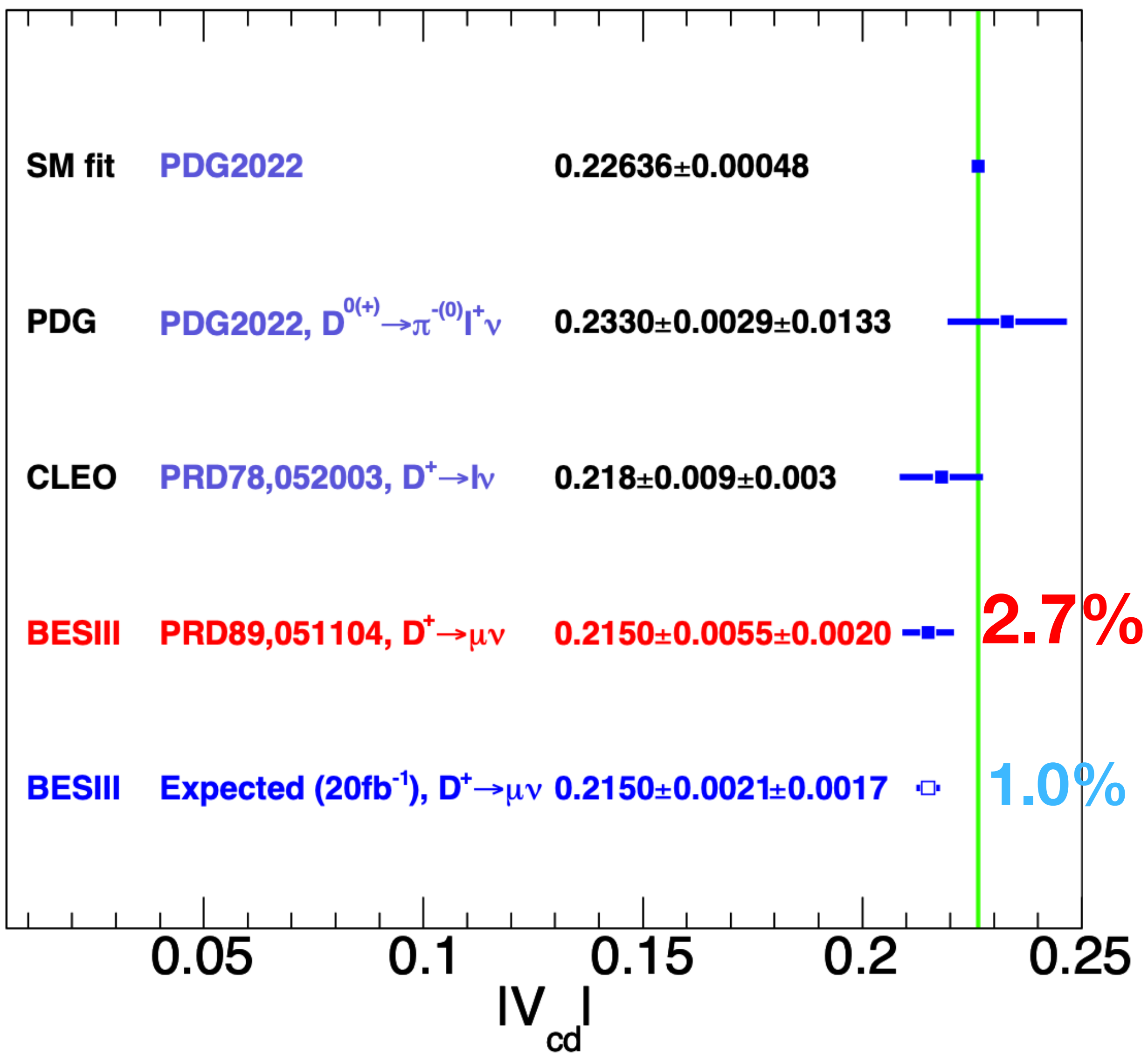
$D \to \pi$



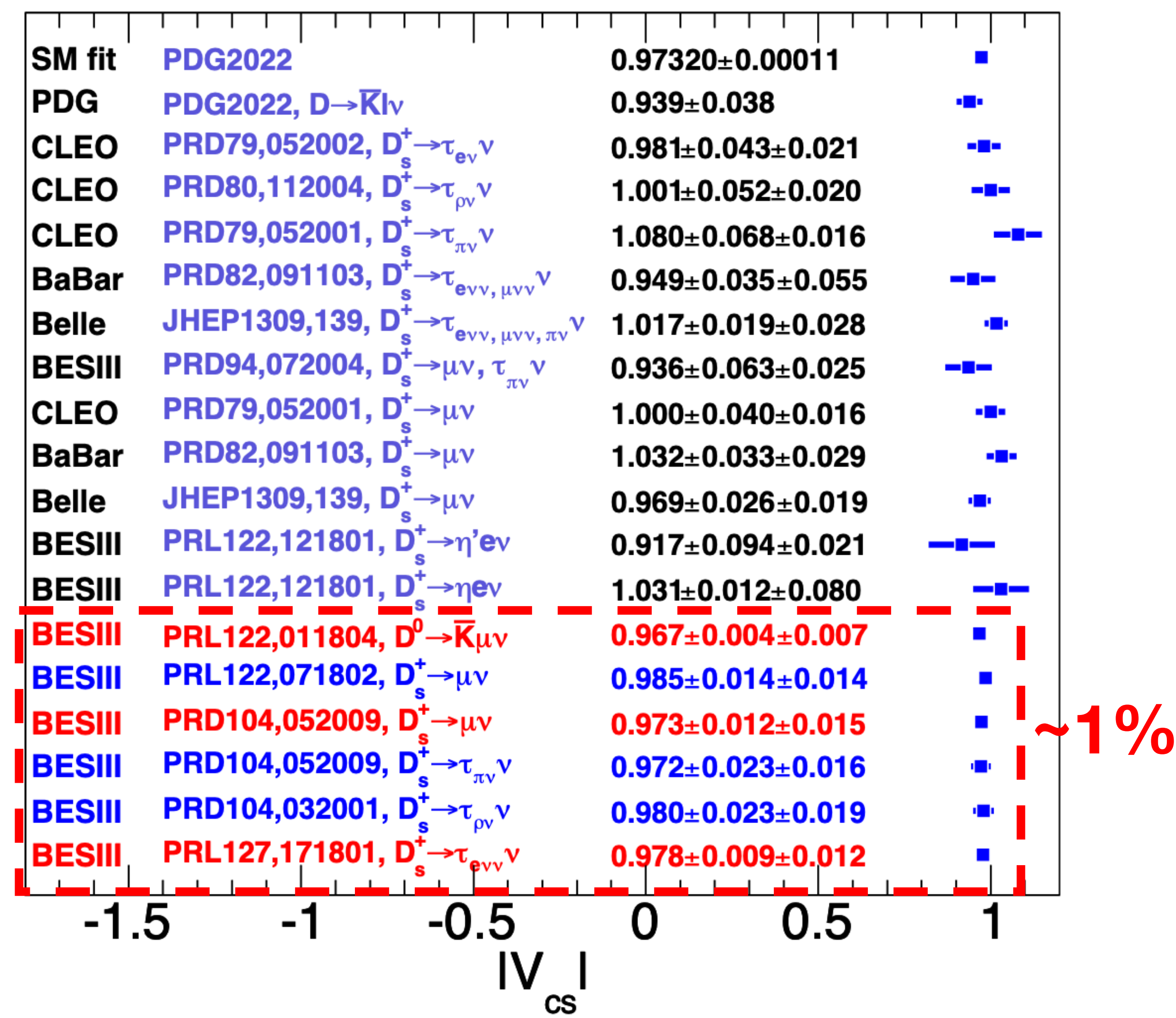
Experimental precision is comparable to the latest QCD result

Comparison of $|V_{cd(s)}|$

$|V_{cd}|$



$|V_{cs}|$



Both pure- and semi-leptonic decays contribute

We have also study…

$D \to Slv$

Observe $f_0(980)$ in $D_s^+ \to \pi^0\pi^0 e^+\nu$

$\mathcal{B} = (7.9 \pm 1.4 \pm 0.4)\times 10^{-4}$

Phys. Rev. D(L) 105, L031101 (2022)

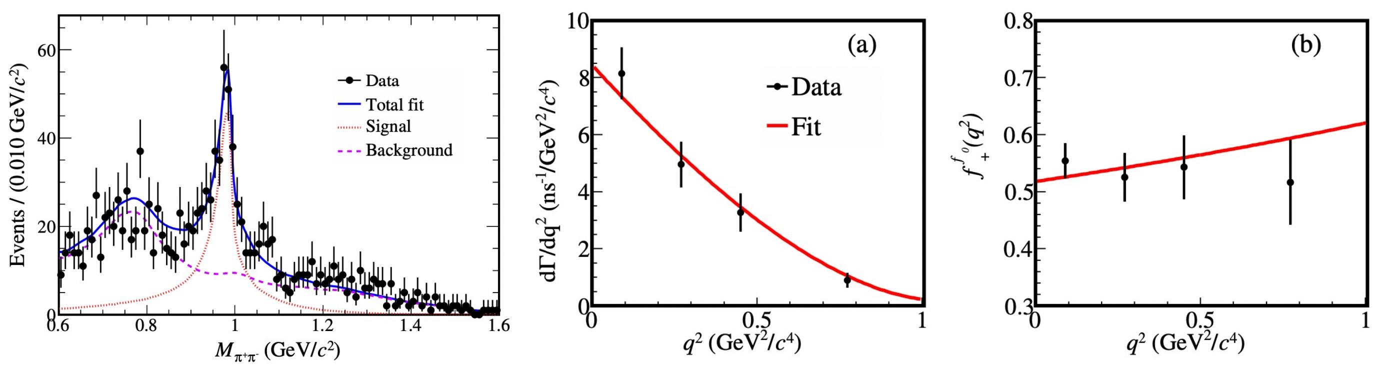
Study $f_0(980)$ in $D_s^+ \to \pi^+\pi^- e^+\nu_e$

$\mathcal{B} = (1.72 \pm 0.13 \pm 0.10)\times 10^{-3}$

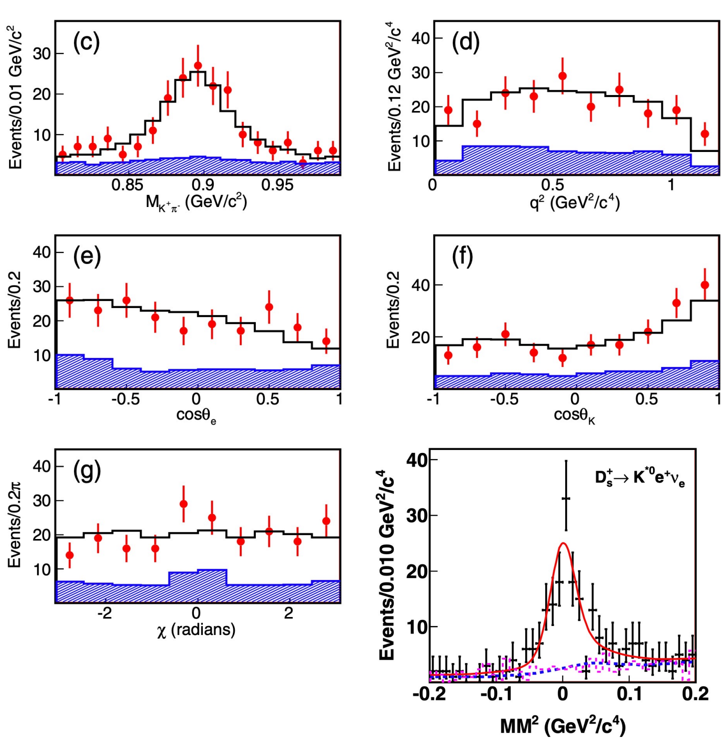
$f_+^{f_0}(0)|V_{cs}| = 0.504 \pm 0.017 \pm 0.035$

arXiv:2303.12927

First measurement



$D \to Vlv$



$D_s^+ \to K^{*0} e^+\nu_e$

$\mathcal{B} = (2.37 \pm 0.26 \pm 0.20)\times 10^{-3}$

$r_V = 1.67 \pm 0.34 \pm 0.16$

$r_2 = 0.77 \pm 0.28 \pm 0.07$

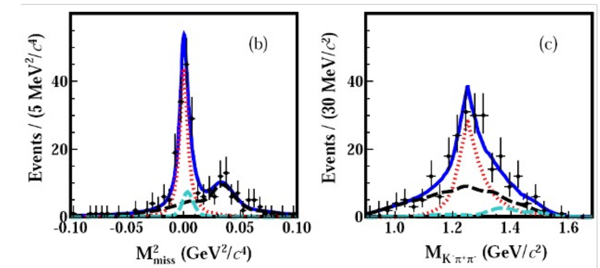
Phys. Rev. Lett. 122, 061801 (2019)

$D \to Alv$

$D^0 \to K_1(1270)^- e^+\nu$

$\mathcal{B} = (1.9 \pm 0.13 \pm 0.13 \pm 0.12)\times 10^{-4}$

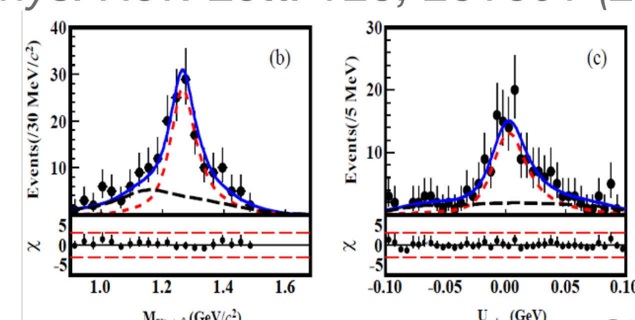
Phys. Rev. Lett. 127, 131801 (2021)



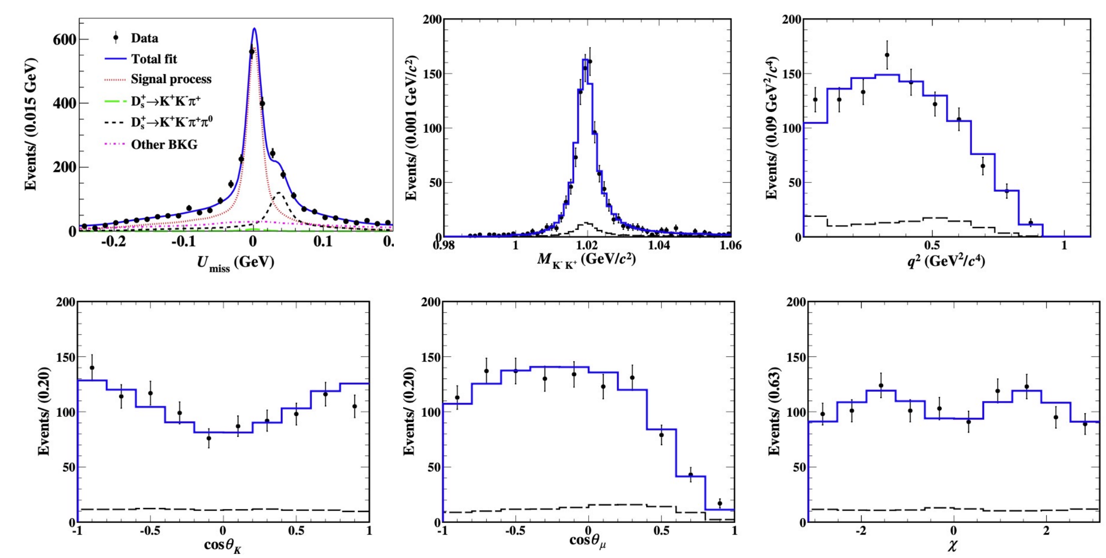
$D^+ \to K_1(1270)^0 e^+\nu$

$\mathcal{B} = (2.30 \pm 0.26 \pm 0.18 \pm 0.25)\times 10^{-4}$

Phys. Rev. Lett. 123, 231801 (2019)



arxiv: 2307.03024



$D_s^+ \to \phi\mu^+\nu_e$

$\mathcal{B} = (2.25 \pm 0.09 \pm 0.07)\times 10^{-2}$

$r_V = 1.58 \pm 0.17 \pm 0.02$

$r_2 = 0.77 \pm 0.28 \pm 0.07$

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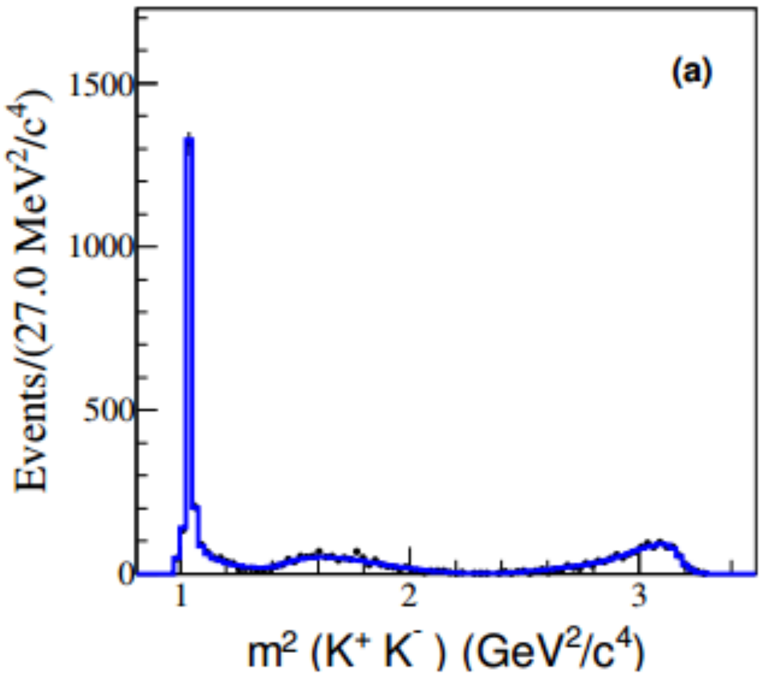
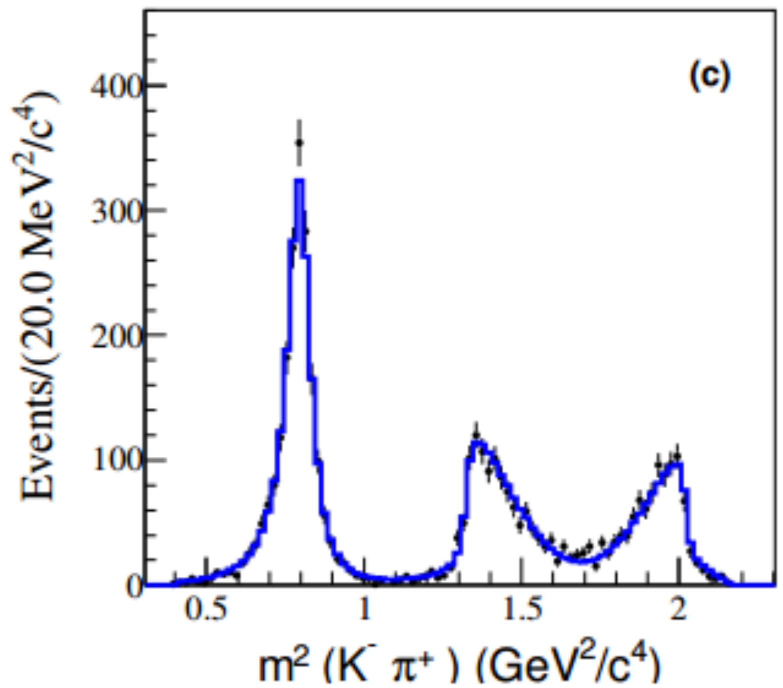
Amplitude analysis of $D_s^+ \to K^+K^-\pi^+$

Dalitz plot projections:





Considering interference of $D_s \to \phi\pi$ and other processes, such as $D_s \to K^*K$

The best precision at present

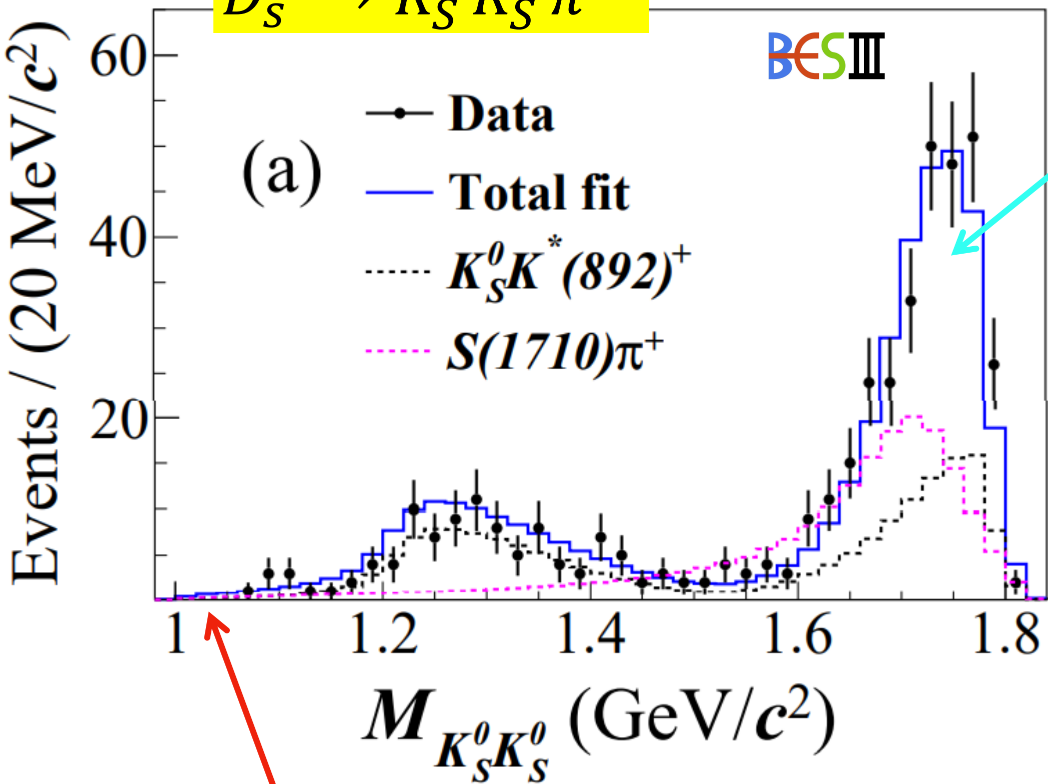
$$\mathcal{B}(D_s^+ \to K^+K^-\pi^+) = (5.47 \pm 0.08_{stat.} \pm 0.13_{syst.})\%$$

	BF (%)	
Process	BESIII (this analysis)	PDG
$D_s^+ \to \bar{K}^*(892)^0K^+$, $\bar{K}^*(892)^0 \to K^-\pi^+$	$2.64 \pm 0.06_{\text{stat}} \pm 0.07_{\text{sys}}$	2.58 ± 0.08
$D_s^+ \to \phi(1020)\pi^+$, $\phi(1020) \to K^+K^-$	$2.21 \pm 0.05_{\text{stat}} \pm 0.07_{\text{sys}}$	2.24 ± 0.08
$D_s^+ \to S(980)\pi^+$, $S(980) \to K^+K^-$	$1.05 \pm 0.04_{\text{stat}} \pm 0.06_{\text{sys}}$	1.14 ± 0.31
$D_s^+ \to \bar{K}_0^*(1430)^0K^+$, $\bar{K}_0^*(1430)^0 \to K^-\pi^+$	$0.16 \pm 0.03_{\text{stat}} \pm 0.03_{\text{sys}}$	0.18 ± 0.04
$D_s^+ \to f_0(1710)\pi^+$, $f_0(1710) \to K^+K^-$	$0.10 \pm 0.02_{\text{stat}} \pm 0.03_{\text{sys}}$	0.07 ± 0.03
$D_s^+ \to f_0(1370)\pi^+$, $f_0(1370) \to K^+K^-$	$0.07 \pm 0.02_{\text{stat}} \pm 0.01_{\text{sys}}$	0.07 ± 0.05
$D_s^+ \to K^+K^-\pi^+$ total BF	$5.47 \pm 0.08_{\text{stat}} \pm 0.13_{\text{sys}}$	5.39 ± 0.15

Observation of $a_0(1817)$ in D_s decays

PRD 105, L051103 (2022)

$D_s^+ \to K_S^0 K_S^0 \pi^+$



constructive interference: $a_0(1817)$ and $f_0(1710)$

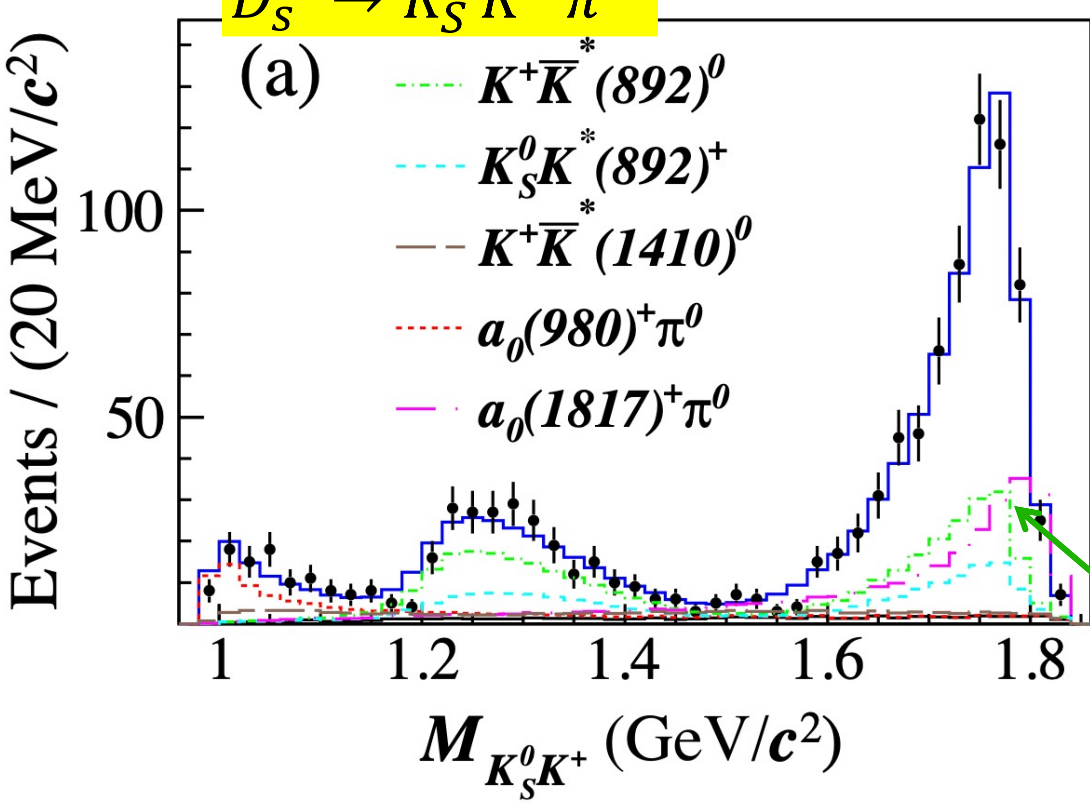
destructive interference: $a_0(980)$ and $f_0(980)$

- **The isovector partner of $f_0(1710)$ or $X(1812)$?**
- **Same resonance observed in η_c to $\pi\pi\eta$ by BaBar?**

PRD 104, 072002 (2021)

PRL 129, 182001

$D_s^+ \to K_S^0 K^+ \pi^0$



- M = $1.817 \pm 0.008 \pm 0.020$ GeV/c^2
- Γ = $0.097 \pm 0.022 \pm 0.015$ GeV/c^2
- $\mathcal{B}(D_s^+ \to a_0(1817)^+ \pi^0) = (3.44 \pm 0.52 \pm 0.32) \times 10^{-3}$
- **Significance > 10σ**

$a_0(1817)^+$ in $K_S^0 K^+$ mass spectrum

Amplitudes analyses of D_s decays

$D_s^+ \to \pi^+\pi^0\eta$	**Phys. Rev. Lett. 123, 112001 (2019)**
$D_s^+ \to K^+K^-\pi^+$	**Phys. Rev. D 104, 112016 (2019)**
$D_s^+ \to K^+K^-\pi^+\pi^0$	**Phys. Rev. D 104, 032011** (2021)
$D_s^+ \to K_s^0K^-\pi^+\pi^+$	**Phys. Rev. D 103 , 092006 (2021)**
$D_s^+ \to \pi^+\pi^-\pi^+\eta$	**Phys. Rev. D 104, L071101 (2021)**
$D_s^+ \to K_S^0\pi^+\pi^0$	**JHEP 06, 181 (2021)**
$D_s^+ \to K_S^0K^+\pi^0$	**Phys. Rev. Lett 129, 182001 (2022)**
$D_s^+ \to K_S^0K_S^0\pi^+$,	**Phys. Rev. D 105, L051103 (2022)**
$D_s^+ \to \pi^+\pi^0\eta'$	**JHEP 04, 058 (2022)**
$D_s^+ \to \pi^+\pi^-\pi^+$	**Phys. Rev. D 106, 112006 (2022)**
$D_s^+ \to \pi^+\pi^0\pi^0$	**JHEP 01, 052 (2022)**
$D_s^+ \to K^+\pi^+\pi^-$	**JHEP 08, 196 (2022)**
$D_S^+ \to K^+K^-\pi^+\pi^+\pi^-$	**JHEP 07, 051 (2022)**
$D_S^+ \to K^+\pi^+\pi^-\pi^0$	**JHEP 09(2022) 242**
$D_S^+ \to K^+\pi^+\pi^-$	**JHEP 08(2022) 196**

We have finished amplitude analyses of most three and four body decays of Ds

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Quantum Correlation

Quantum correlated data: $e^+e^- \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0$

Best laboratory to measure strong-phase parameters

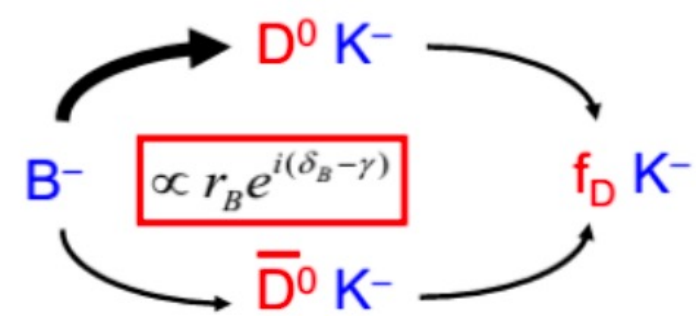
CP-odd: $\psi(3770) = \left(D^0\bar{D}^0 - D^0\bar{D}^0\right) = (D_+D_- - D_-D_+)$

$J^{PC} = 1^{--}$

CP-even eigenstate

CP-odd eigenstate

- **Inputs for CPV studies at B experiments**



- **The CKM angle γ/ϕ_3:**

  self-conjugated decay: CP fraction $F_+ \rightarrow$ GLW/GGSZ method;

  strong phase $ci(')$ and $si(')$ $\rightarrow$ GGSZ method

  non-self-conjugated decay: the coherence factor R and averaged strong phase difference $\delta \rightarrow$ ADS method

Determination of $\delta_D^{K\pi}$

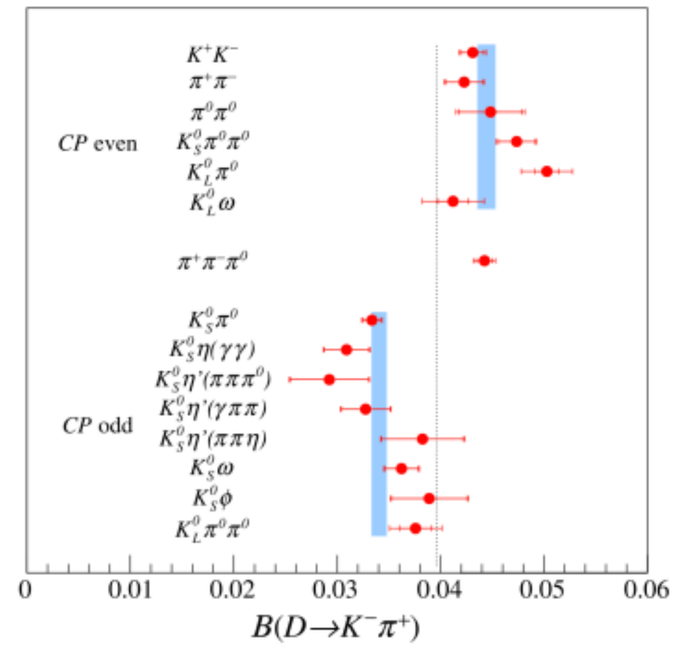
- **An update measurement of the asymmetry between CP-odd and CP-even eigenstate decays into $K^-\pi^+$**

30% more precise ！

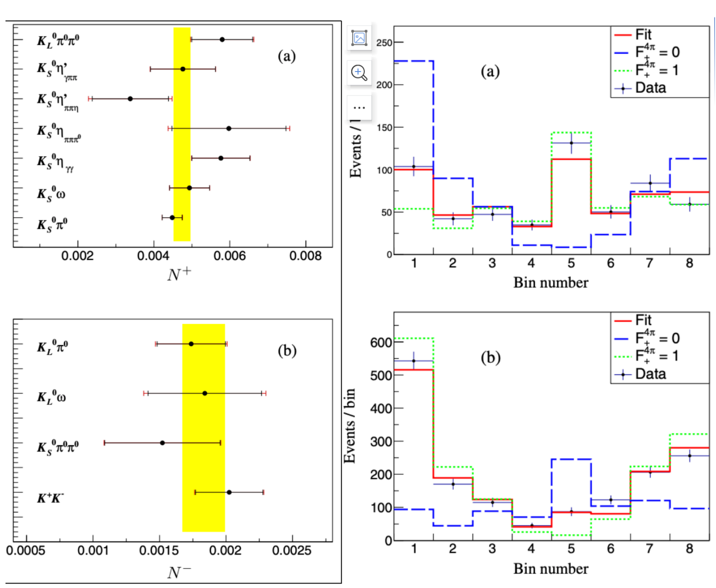
$$\mathcal{A}_{K\pi} \equiv \frac{\mathcal{B}(D_- \to K^-\pi^+) - \mathcal{B}(D_+ \to K^-\pi^+)}{\mathcal{B}(D_- \to K^-\pi^+) + \mathcal{B}(D_+ \to K^-\pi^+)} = \frac{-2r_D^{K\pi}\cos\delta_D^{K\pi} + y}{1 + \left(r_D^{K\pi}\right)^2} = 0.132 \pm 0.011 \pm 0.007$$

- $\delta_D^{K\pi}$=$(187.6^{+8.9+5.4}_{-9.7-6.4})$

EPJC 82, 1009 (2022)



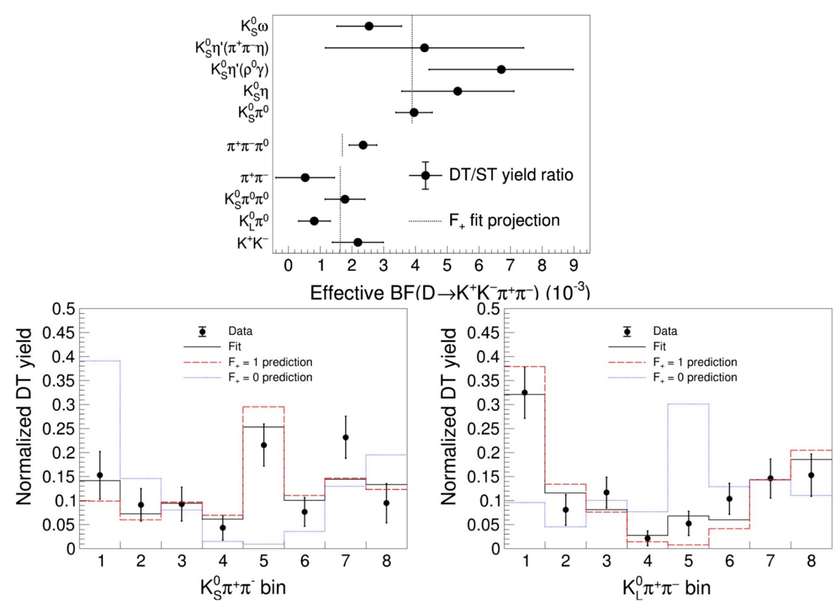
Determination of CP fraction



$D^0 \to \pi^+\pi^-\pi^+\pi^-$

$F_+ = 0.735 \pm 0.015 \pm 0.005$

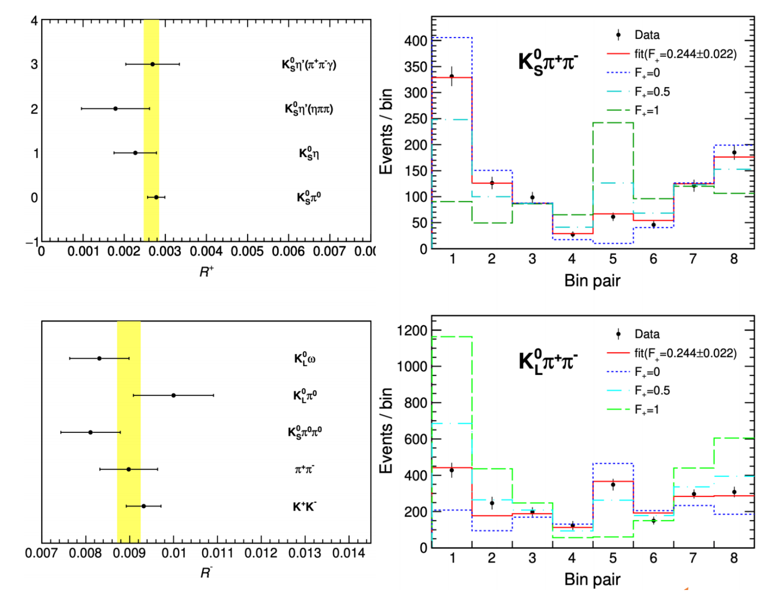
PRD 106, 092004(2022)



$D^0 \to K^+K^-\pi^+\pi^-$

$F_+ = 0.730 \pm 0.037 \pm 0.021$

PRD 107, 032009(2023)



$D^0 \to K_S^0\pi^-\pi^+\pi^0$

$F_+ = 0.235 \pm 0.010 \pm 0.002$

arxiv:2305.03975

- BESIII dataset
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  - hadronic decays
  - quantum correlation
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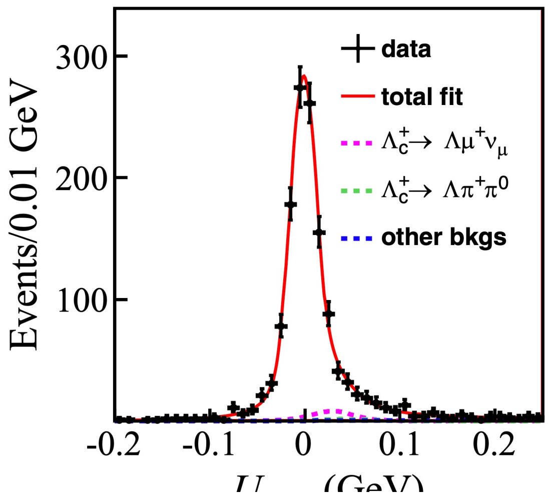
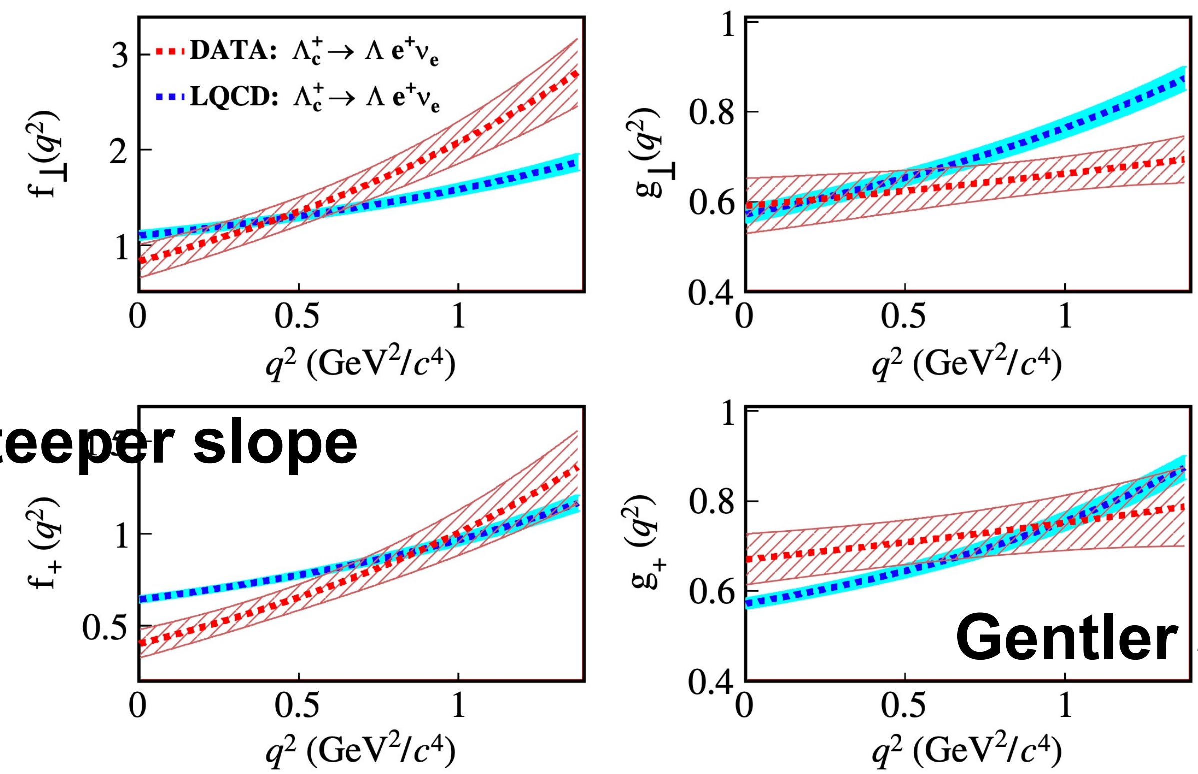
- Prospect

Study of $\Lambda_c^+ \to \Lambda e^+ \nu$



First direct comparisons to LQCD for $\Lambda_c^+ \to \Lambda$ decay form factor

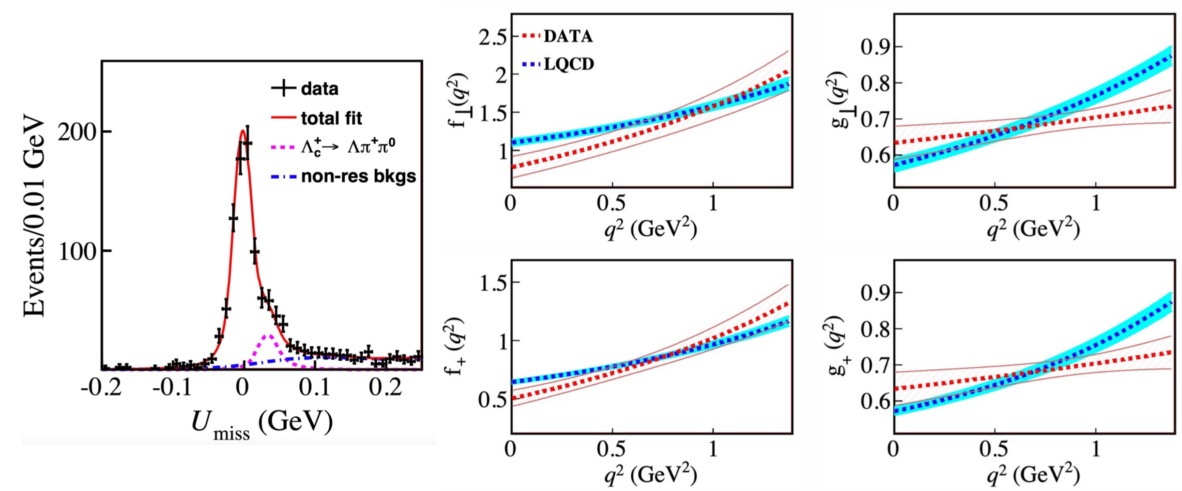
Different kinematic behavior compared to LQCD



Steeper slope

Gentler slope

Study of $\Lambda_c^+ \to \Lambda \mu^+ \nu$



Updated BF and first FF measurement:

~4% most precise

$$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu) = (3.56 \pm 0.11 \pm 0.07)\times 10^{-3}$$

$$|V_{cs}| = (0.936 \pm 0.017_{\mathcal{B}} \pm 0.024_{LQCD} \pm 0.0240.024_{\tau_{\Lambda_c^+}})\times 10^{-3}$$

PRL 129, 231803 (2022)

Agree with PDG 2022

$$\mathcal{B} = (3.48 \pm 0.14 \pm 0.10)\times 10^{-3}$$

$$R_{e/\mu} = 0.98 \pm 0.05 \pm 0.03$$

vs SM: 0.97 --> No LFUV

Arxiv:2306.02624 (2023)

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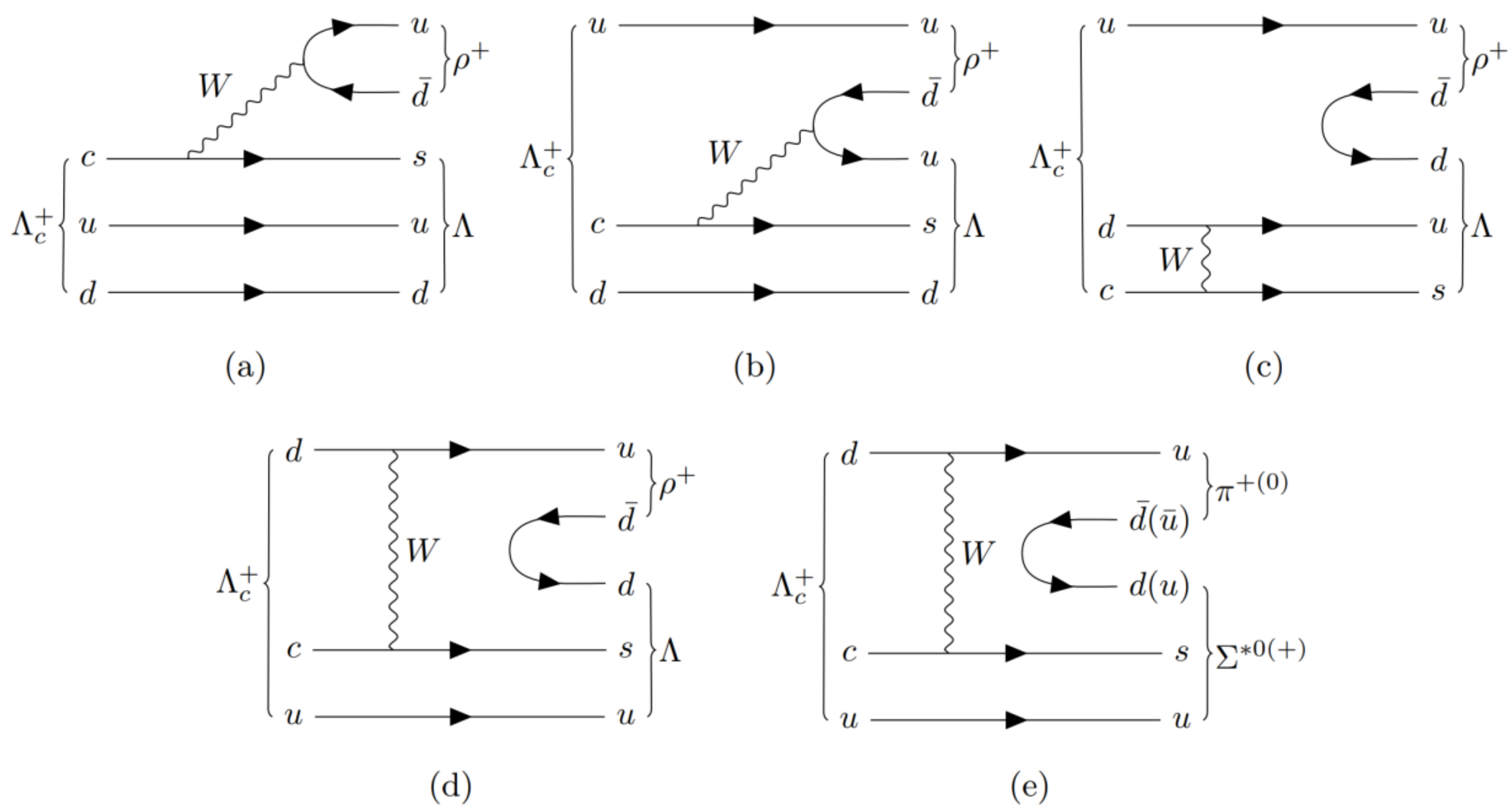
Partial wave analysis of the charmed baryon hadronic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$



$\Lambda_c^+ \to \Lambda\rho^+$: both factorizable(a) and non-factorizable(b-d)

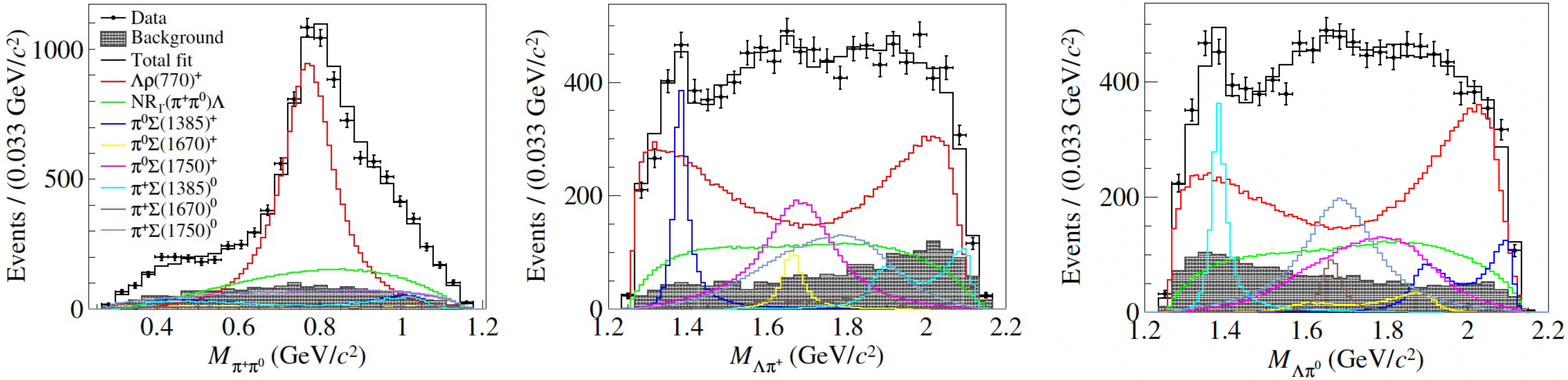
$\Lambda_c^+ \to \Sigma(1385)\pi$: pure non-factorizable(e)

Provide important inputs to the theoretical calculations for non-factorizable

Use new-developed Tensor Flow based package TF-PWA*.

(*BESIII Preliminary: https://github.com/jiangyi15/tf-pwa)

Partial wave analysis of the charmed baryon hadronic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$



The first PWA of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

	Theoretical calculation		This work	PDG
$10^2 \times \mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	4.81 ± 0.58 [13]	4.0 [14, 15]	4.06 ± 0.52	< 6
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	5.86 ± 0.80	—
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	6.47 ± 0.96	—
$\alpha_{\Lambda\rho(770)^+}$	-0.27 ± 0.04 [13]	-0.32 [14, 15]	-0.763 ± 0.070	—
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.917 ± 0.089	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.79 ± 0.11	—

The first measurement of the decay asymmetry parameters for the relevant resonance

Ref. [13]: PRD 101 (2020) 053002.
Ref. [14,15]: PRD 46 (1992) 1042; PRD 55 (1997) 1697.
Ref. [16]: EPJC 80 (2020) 1067.
Ref. [17]: PRD 99 (2019) 114022

Measurement of the absolute branching fraction of the singly Cabibbo suppressed decays of $\Lambda_c^+ \to n\pi^+$

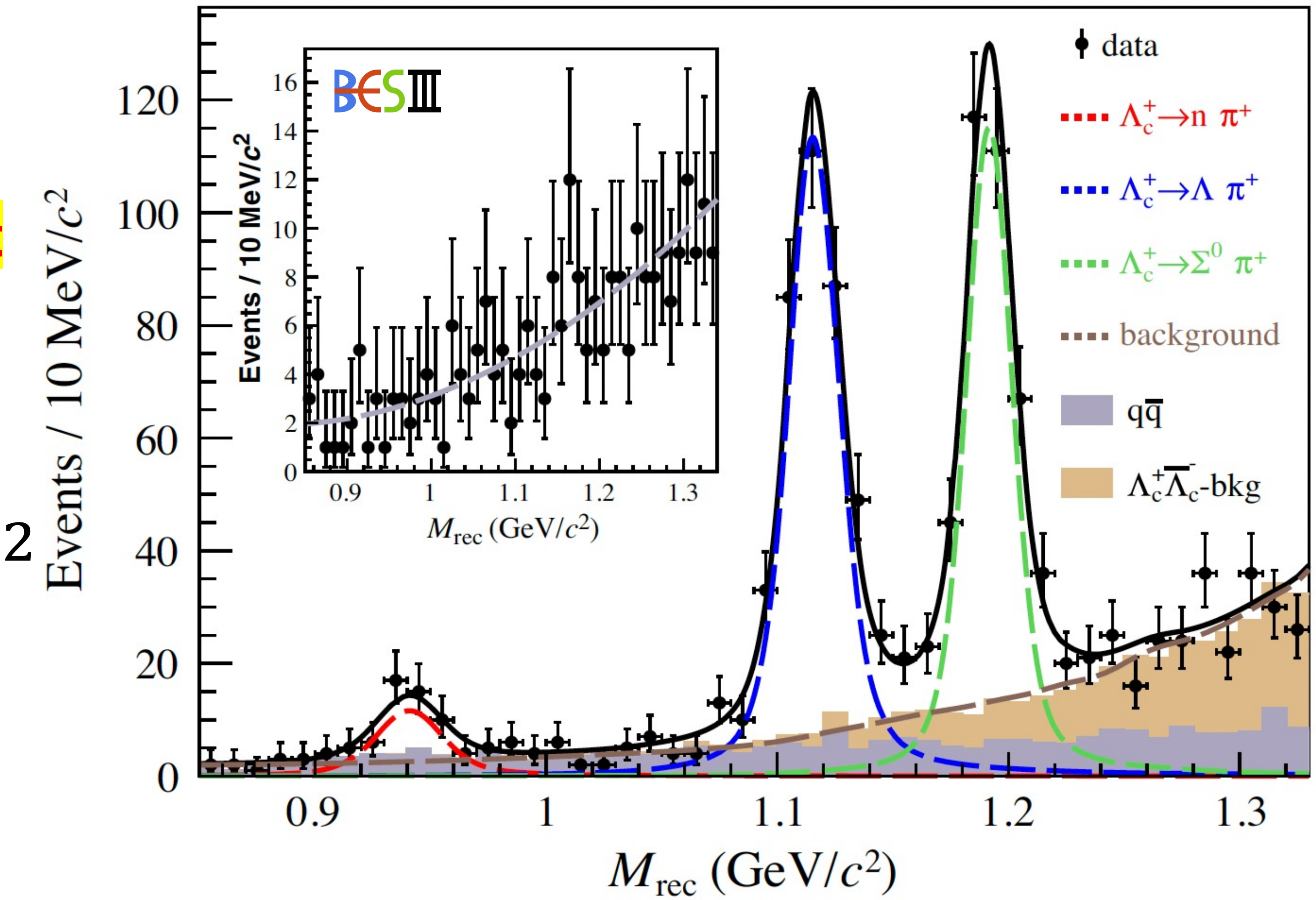
PRL 128, 142001 (2022)

$\mathcal{B}(\Lambda_c^+ \to n\pi^+)$ **First measurement**
$=(6.6 \pm 1.2 \pm 0.4)\times10^{-4}$

$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+)$
$=(1.31 \pm 0.08 \pm 0.05)\times10^{-2}$

$\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+)$
$=(1.22 \pm 0.08 \pm 0.07)\times10^{-2}$

$\mathcal{B}(n\pi^+)/\mathcal{B}(p\pi^0) > 7.2$ at 90% C.L.



Use recoil mass to access neutron

- **Disagrees with most predictions of phenomenological models**
- **Non-factorization contributions may be overestimated.**

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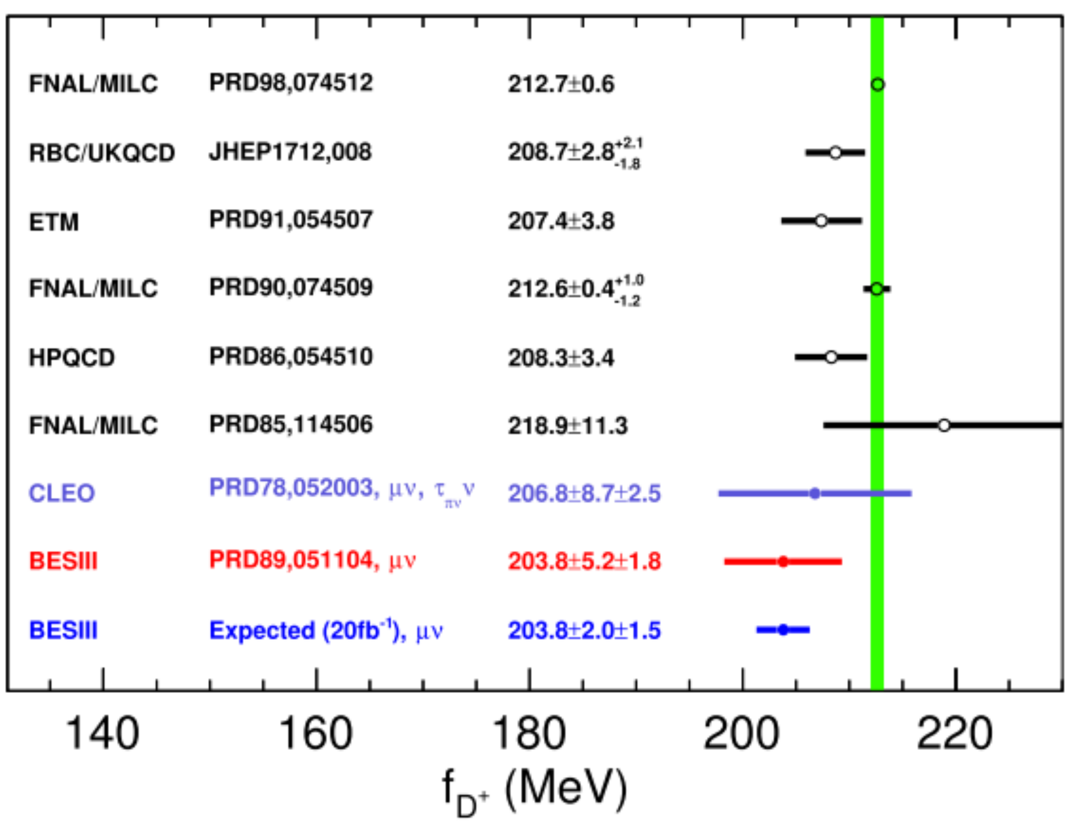
Prospect

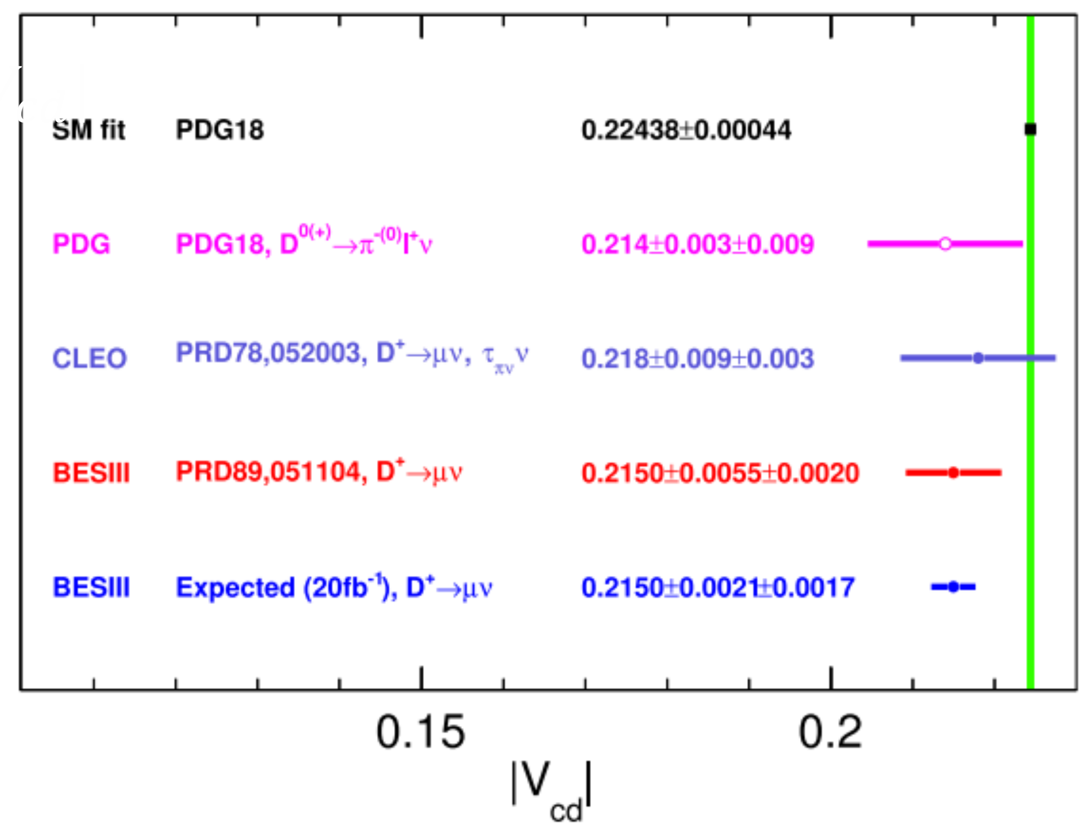
From White Paper (Chin. Phys. C 44, 040001 (2020))

20 fb^{-1} of data set at 3.773 GeV is on the way

Leptonic Decay

	2.93 fb^{-1}	20 fb^{-1}
f_{D^+}	2.6%	1.0%
$\lvert V_{cd}\rvert$	2.5%	1.0%
LFU	19%	8%





BESIII is expected to provide unique data to improve the knowledge of f_{D^+} and $|V_{cd}|$ and test LFU in $D^+ \to l^+\nu_l$ decays.

Prospect

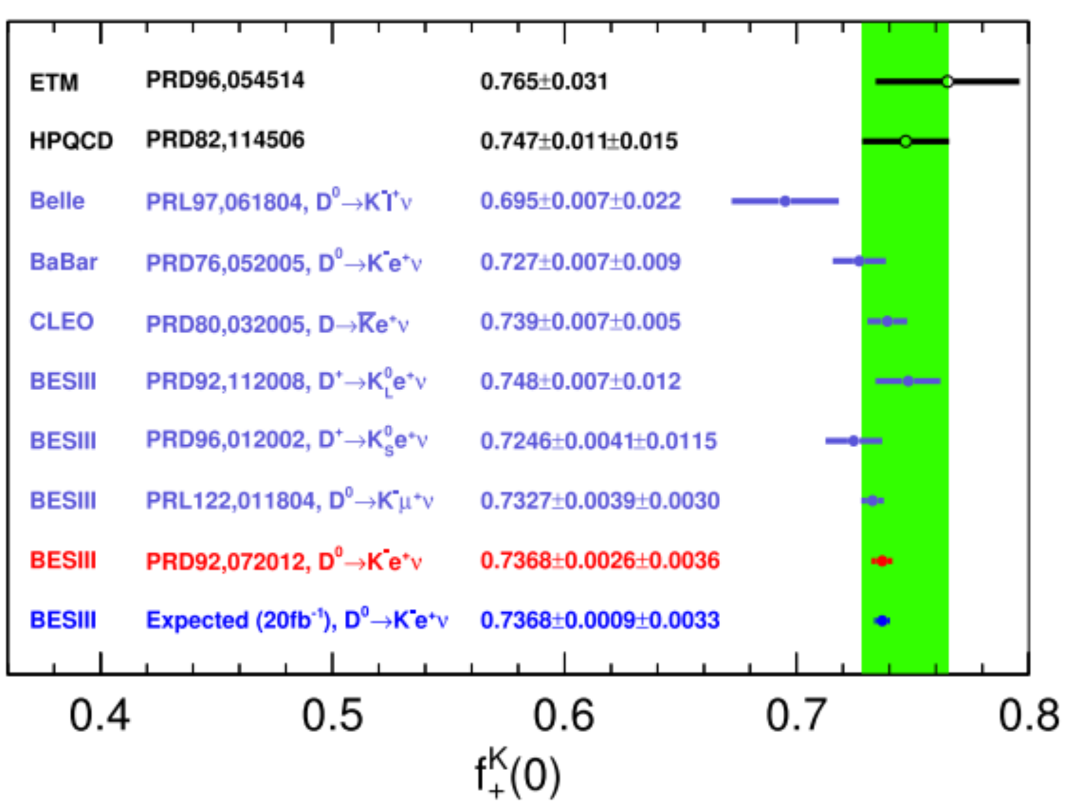
From White Paper (Chin. Phys. C 44, 040001 (2020))

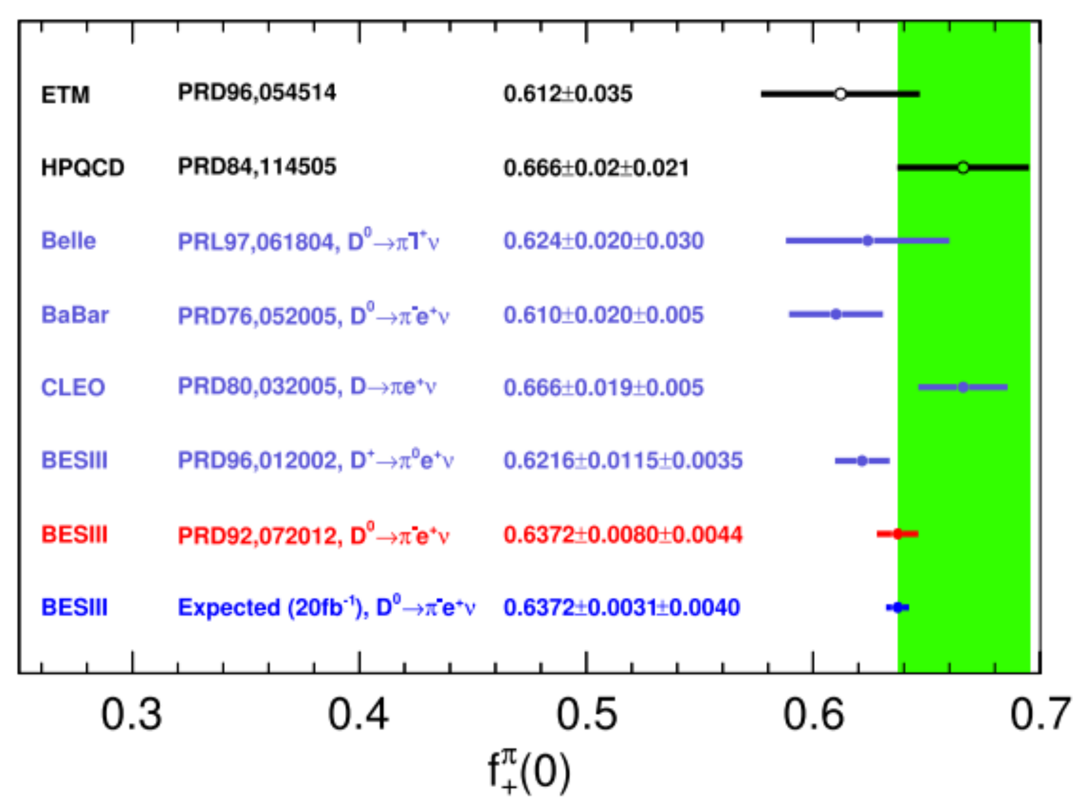
20 fb^{-1} of data set at 3.773 GeV is on the way

Semi-leptonic Decay

- ➢ All form-factor measurements which are currently statistically limited will be improved by a factor of up to 2.6.
- ➢ Determine FF for the first time: $D^0 \to K(1270)^- \nu_e$, $D^+ \to \overline{K}_1(1270)^0 e^+ \nu_e$, $D^+ \to \eta' \mu^+ \nu_\mu$, $D^0 \to a_0(980)^- e^+ \nu_e$, $D^+ \to a_0(980)^0 e^+ \nu_e$
- ➢ $|V_{cd(s)}|$ with SL $D^{0(+)}$ decays in electron channels are expected to reach to 0.5%.

	LQCD	Expected
$f_+^K(0)$	2.4%	1.0%
$f_+^\pi(0)$	4.4%	0.5%





Prospect

From White Paper (Chin. Phys. C 44, 040001 (2020))

Quantum correlation of neutral charmed meson pairs

Decay mode	Quantities	Status (2.93 fb^{-1})
$K_S^0\pi^+\pi^-$	c_i, s_i	Finished(2020)
$K_S^0K^+K^-$	c_i, s_i	Finished(2021)
$K^-\pi^+\pi^+\pi^-$	R, δ	Finished(2020)
$K^+K^-\pi^+\pi^-$	F_+ or c_i, s_i	F_+ Finished(2022), c_i, s_i on going
$\pi^+\pi^-\pi^+\pi^-$	F_+ or c_i, s_i	F_+ Finished(2022), c_i, s_i on going
$K^-\pi^+\pi^0$	R, δ	Finished(2021)
$K_S^0K^\pm\pi^\mp$	R, δ	On going
$\pi^+\pi^-\pi^0$	F_+	On going
$K_S^0\pi^+\pi^-\pi^0$	F_+ or c_i, s_i	F_+ Finished(2023), c_i, s_i on going
$K^+K^-\pi^0$	F_+	On going
$K^-\pi^+$	δ	Updated Finished (2022)

- Making progress in past few years.
- Many ongoing projects, eventually 20 fb^{-1} $\psi(3770)$ data samples.

Prospect

From White Paper (Chin. Phys. C 44, 040001 (2020))

Amplitude analyses and branching fraction measurement of charmed meson hadronic decays

Precisely measuring the structure of golden modes, for example $D^+ \to K^-\pi^+\pi^+$

First amplitude analysis of Cabbibo-suppressed decays.

Measuring the polarization of $\mathrm{D} \to \mathrm{VV}$ in $\mathrm{D} \to \mathrm{K3\pi}$ or $\mathrm{D} \to \mathrm{KK\pi\pi}$

Searching for new physics and rare decays

Flavor changing neutral currents (FCNC) $e^+e^-, \mu^+\mu^-$ etc.

Quantum number violation processes $e^+e^+, \mu^-\mu^-$ etc.

Radiative decays $\gamma\omega,\ \gamma K_1$ etc.

Thanks for your attention