Overview of leptonic and semi-leptonic decays of charmed hadrons

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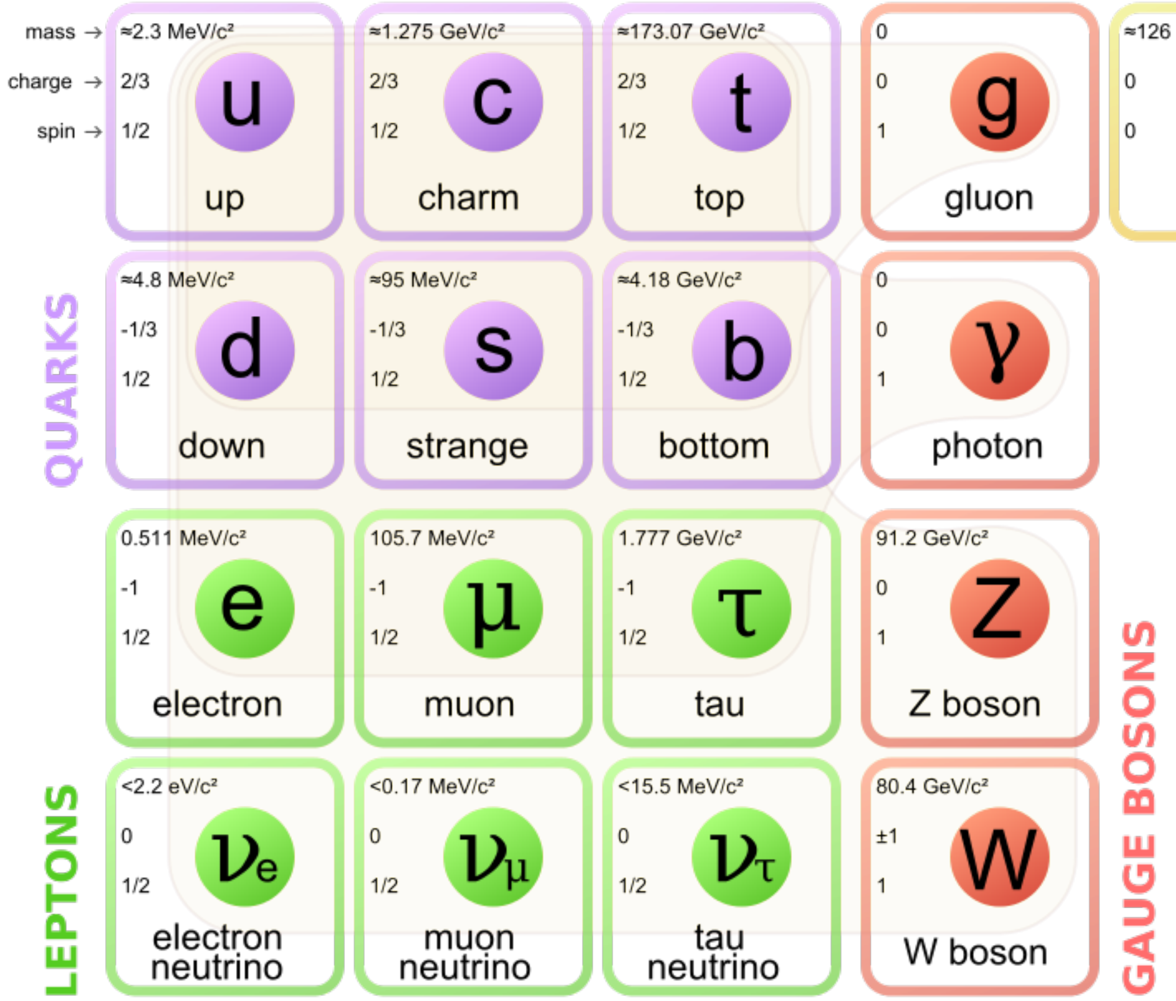
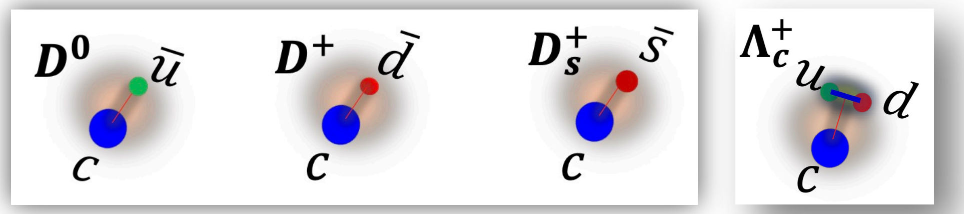
Content

Introduction: Physics motivation





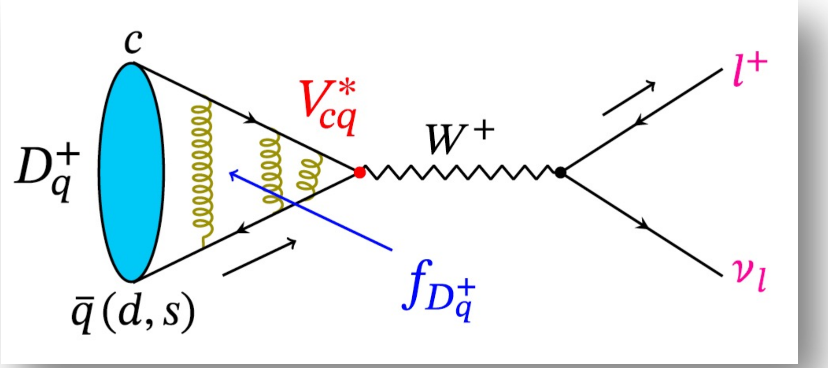
Charm physics

- High precision frontier -> **SM Test**
- Nonperturbative region -> **QCD**

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

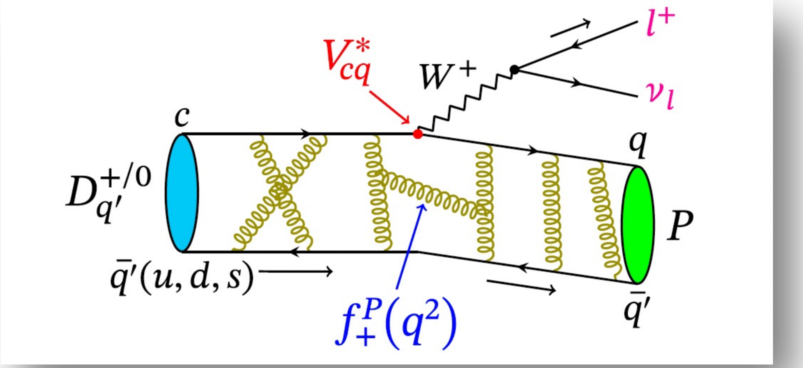
Introduction: Physics motivation

Pure leptonic decay



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

Semi-leptonic decay



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

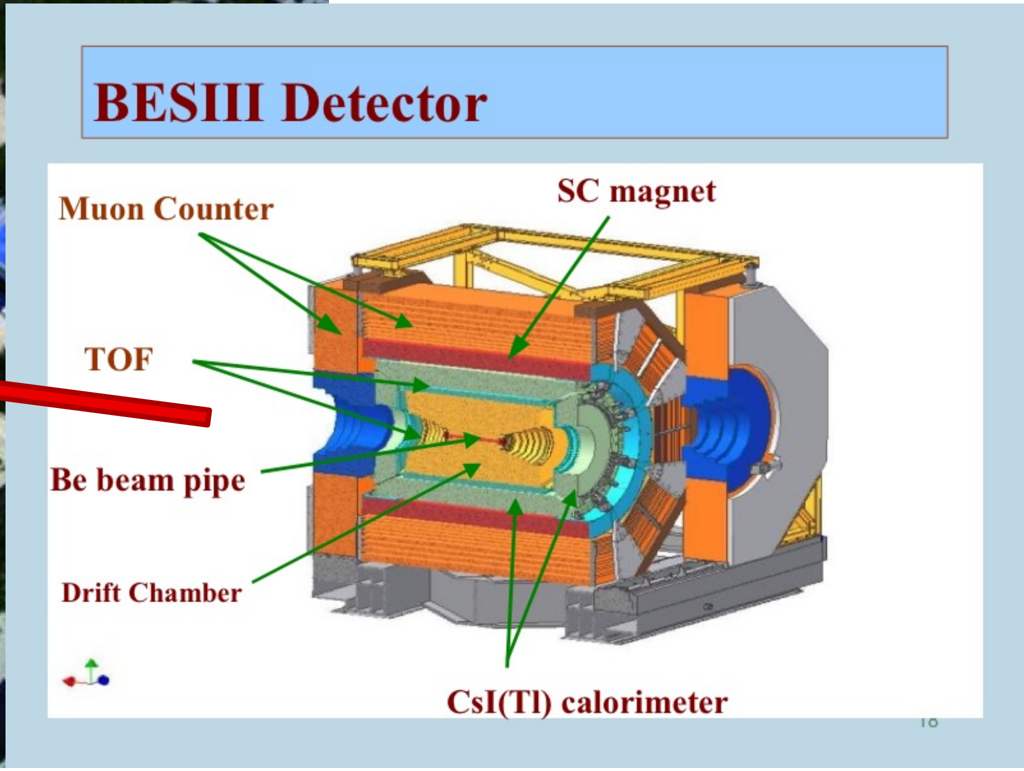
$(X = 1 \text{ for } K/\pi^-/\eta^{(\prime)};\ X = 1/2 \text{ for } \pi^0)$

- **Decay constants** and hadronic **Form factor(FF)** **--> Test and calibrate LQCD**
- CKM matrix elements $|V_{cd(s)}|$ **--> Test CKM matrix unitarity**
- **Branching fraction (BF)** ratios $\mathcal{R}^X_{\tau/\mu}, \mathcal{R}^X_{\mu/e}$ **--> Test Lepton flavor universality (LFU)**
- **BF** and **FF** measurement in semi-leptonic decays **--> Study light hadrons**
- ❖ Λ_c^+ **could do most things as above**

- $D_{(s)} \to \ell^+\nu_\ell$
- $D_{(s)} \to P\ell^+\nu_\ell$
- $D_{(s)} \to V\ell^+\nu_\ell$
- $D_{(s)} \to S\ell^+\nu_\ell$
- $D_{(s)} \to A\ell^+\nu_\ell$
- $\Lambda_c^+ \to B\ell^+\nu_\ell$

P = pseudoscalar,
V = vector, ***S*** = scalar
A = axial-vector, ***B*** = baryon

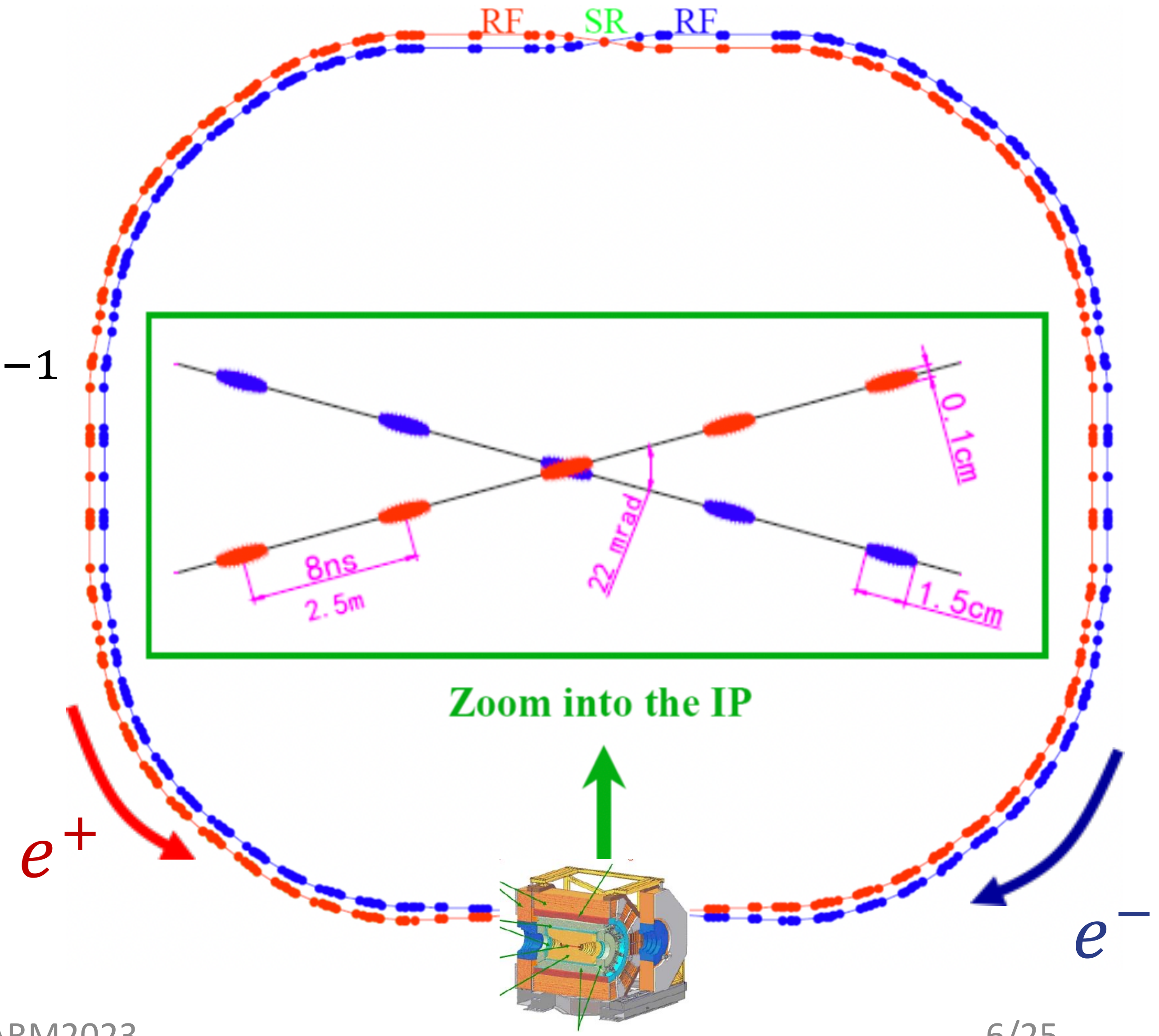
Introduction : BESIII experiment



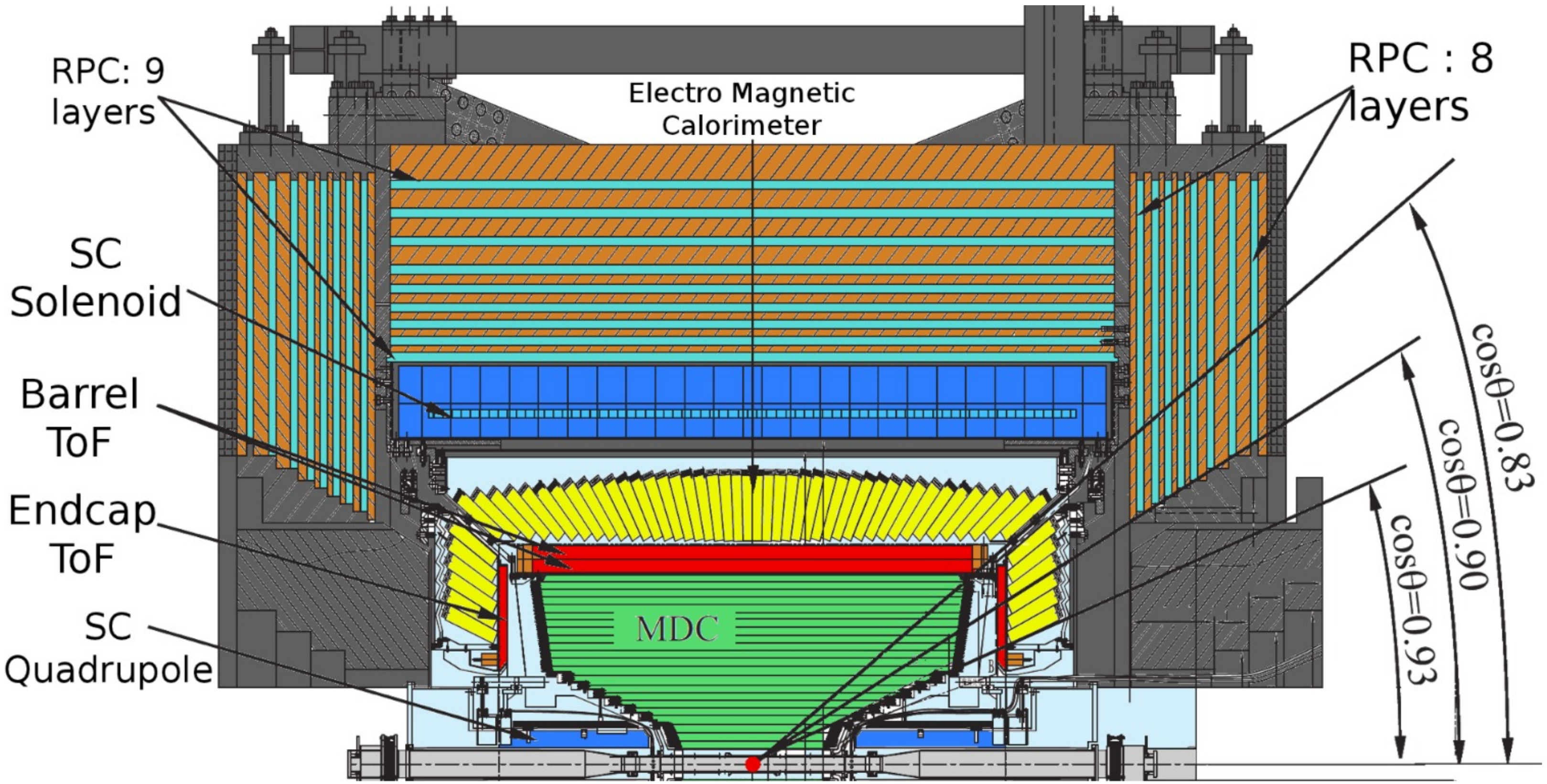
Introduction : BEPCII collider

- Two ring symmetric e^+e^- collider
- Circumference: 240 m
- Design luminosity: $1\times10^{33}cm^{-2}s^{-1}$

  Achieved time: 5 April, 2016
- E_{cm}: 2 – 5 GeV
- Beam crossing angle: 22 mrad



Introduction : BESIII detector



MDC
$\frac{\delta p}{p} < 0.5\%$ @1 GeV
$\frac{\delta(dE/dx)}{dE/dx} < 6\%$

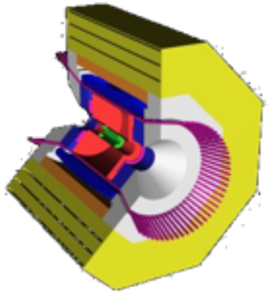
TOF
δt 80 ps Barrel
δt 110 ps Endcap

EMC
$\frac{\delta E}{E} < 2.5\%$ @1 GeV
$\delta z = 0.6/\sqrt{E}$

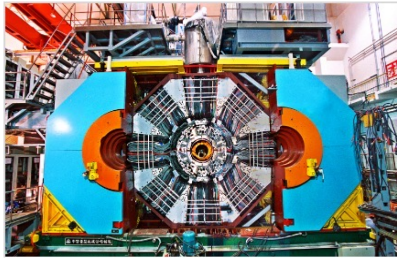
MUC
$\delta(xy) <2$ cm

Data sample

CLEO-c



BESIII



BABAR

Belle, Belle-II

- Symmetric e^+e^- collider
- E_{cm}: 2 – 5 GeV
- Charm collected through pair-production near threshold

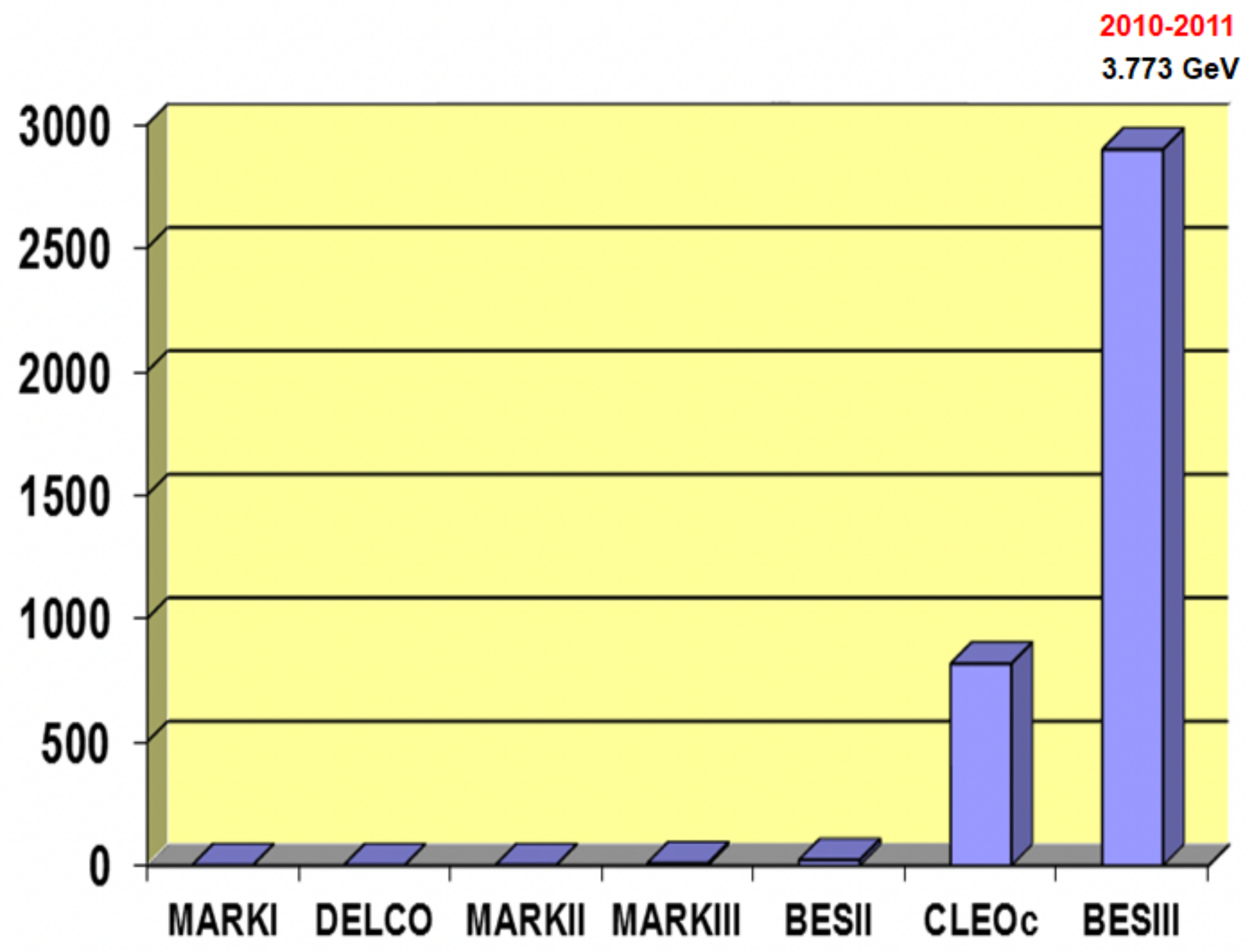
- Asymmetric e^+e^- collider
- E_{cm}: 10.58 GeV
- Charm collected through $b\bar{b}$ decays and $c\bar{c}$

Data sample

Experiment	Data size	Energy region	Time
BESIII	$D^{+(0)}$: 2.93 fb^{-1} D_s^+: 7.33 fb^{-1} Λ_c^+: 4.5 fb^{-1}	3.773 GeV 4.123-4.223GeV 4.600-4.699 GeV	2010-2011 2013-2017 2014/2020
CLEO-c	$D^{+(0)}$: 0.82 fb^{-1} D_s^+: 0.6 fb^{-1}	3.770 GeV 4.170 GeV	Till 2008
BABAR	468 fb^{-1}	Near $\Upsilon(4S)$	Till 2008
Belle	976 fb^{-1}	Near $\Upsilon(4S)$	Till 2010

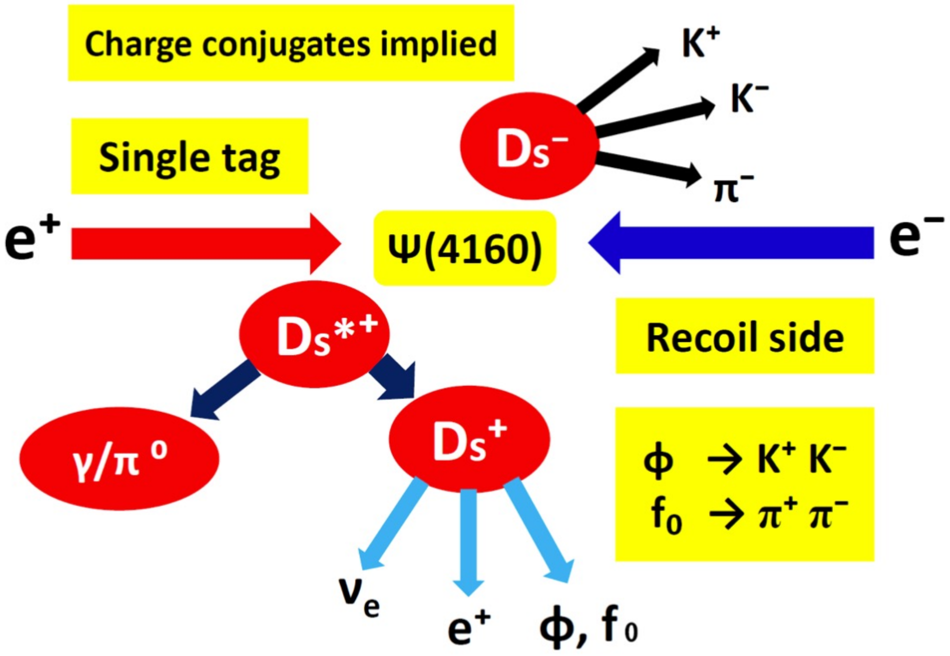
Data sample

$D^{0(+)}$ samples at $\psi(3770)$



Analysis method: Double Tag

Take Ds decay as an example (complicated case)



$\mathcal{B}_\gamma(D_S^* \to \gamma D_S)$

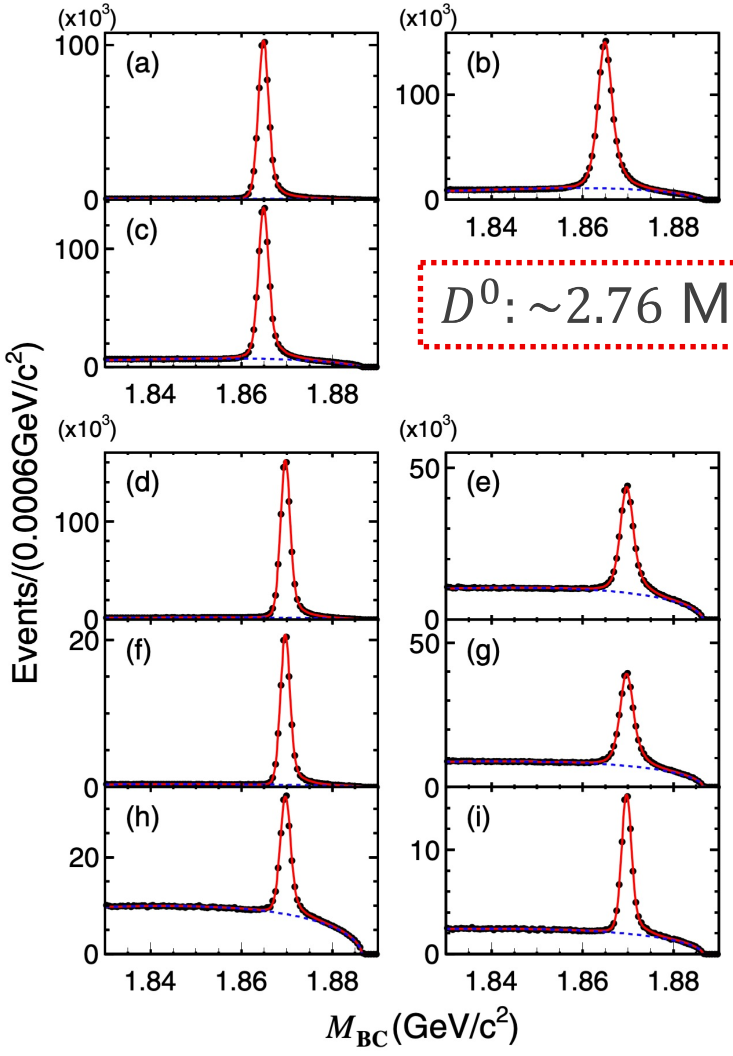
$$N_{tag} = 2N_{D_S^+ D_S^-} \mathcal{B}_{tag}\, \epsilon_{tag}$$
$$N_{sig} = 2N_{D_S^+ D_S^-} \mathcal{B}_{tag} \mathcal{B}_{sig} \mathcal{B}_\gamma \epsilon_{sig}$$

$$\mathcal{B}_{sig} = \frac{N_{sig}}{\mathcal{B}_\gamma N_{tag} \epsilon_{sig} / \epsilon_{tag}}$$

$$\mathcal{B}_{sig} = \frac{N_{sig}}{\mathcal{B}_\gamma \sum_\alpha N_{tag}^\alpha \epsilon_{sig}^\alpha / \epsilon_{tag}^\alpha}$$

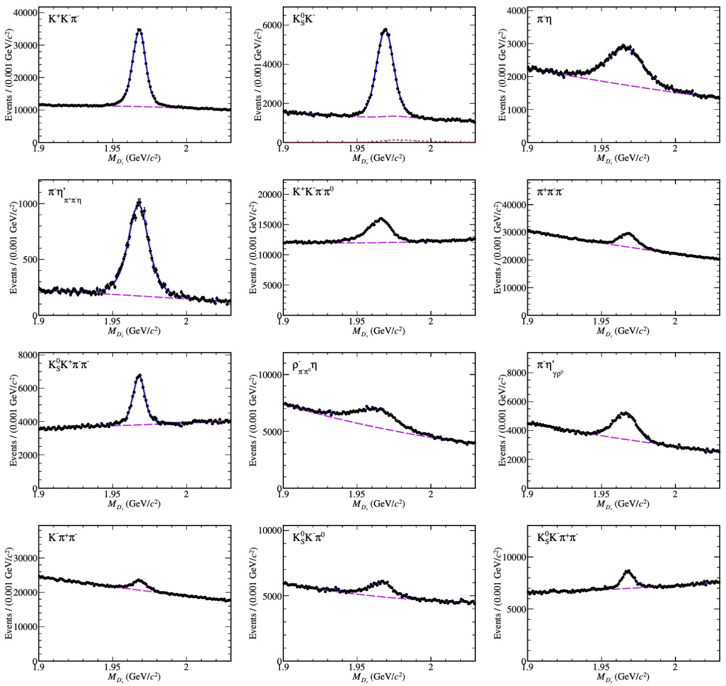
$$U_{miss} = E_{miss} - |\vec{p}_{miss}|$$
$$M_{miss}^2 = E_{miss}^2 - |\vec{p}_{miss}|^2$$

Analysis method: Single Tag sample

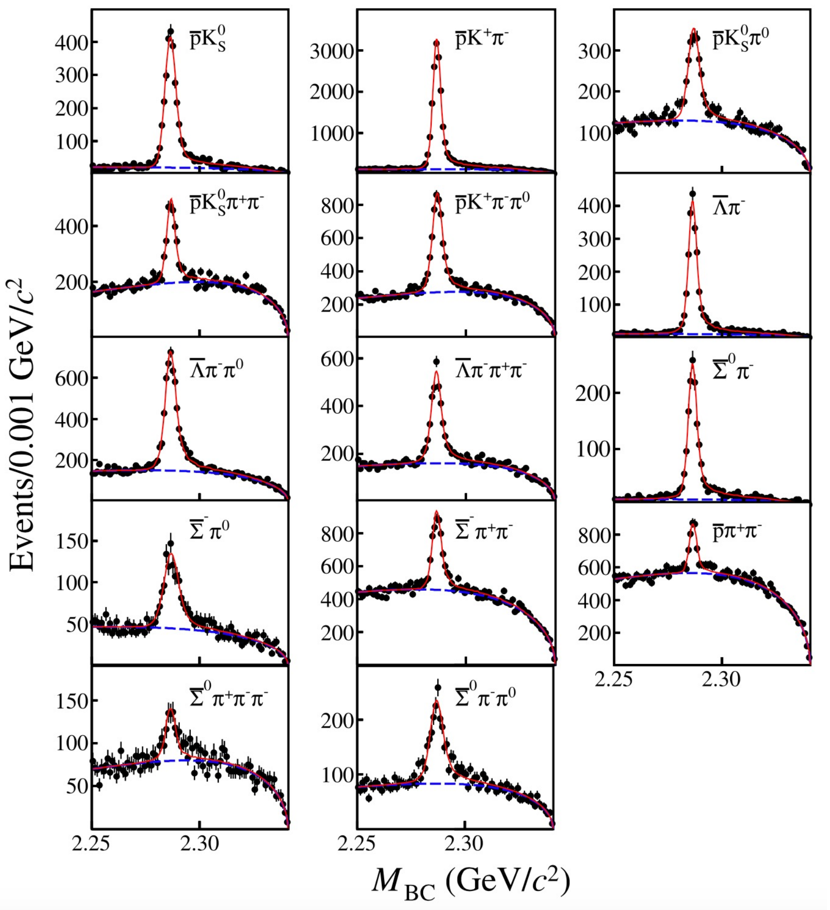


D^0: ~2.76 M

D^+: ~1.57 M



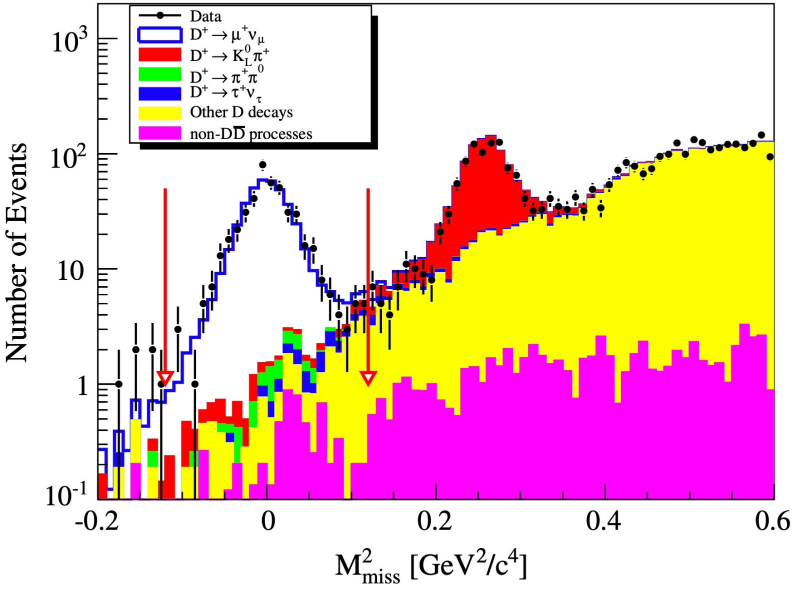
D_s: 0.77 M



Λ_c: 0.12 M

$D^+ \to \ell^+ \nu_\ell$

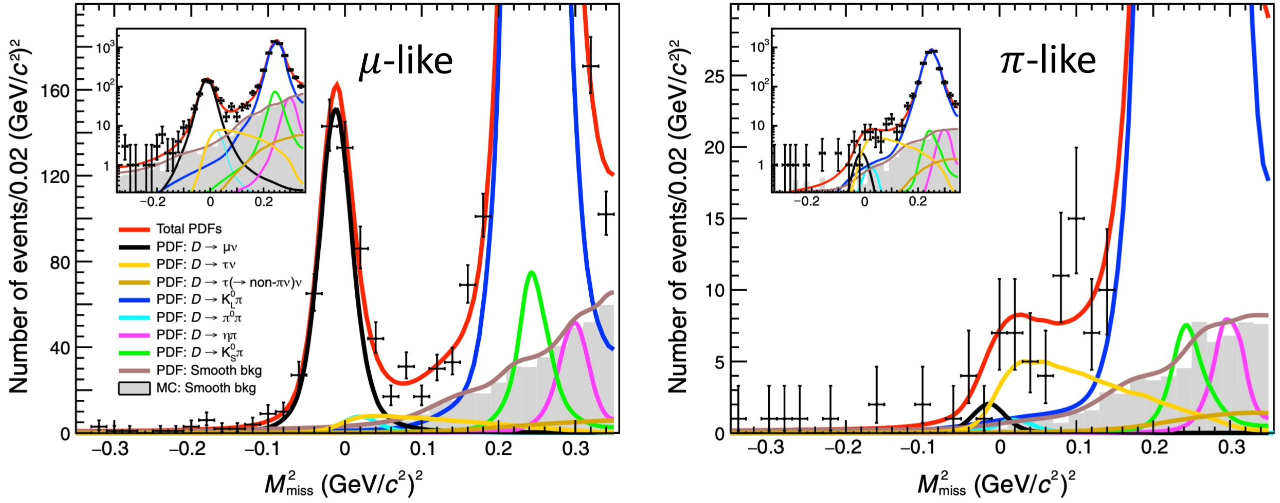
Phys. Rev. D 89, 051104(R) (2014)



- 2.93 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 409.0 \pm 21.2$
- $\mathcal{B}(D^+ \to \mu^+\nu_\mu) = (3.71 \pm 0.19 \pm 0.06)\times 10^{-4}$ (~5.4%)
- $f_{D^+}|V_{cd}| = (45.75 \pm 1.20 \pm 0.39)$ MeV (~2.8%)

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

$E_{EMC} \leq 300$MeV $\qquad$ $E_{EMC} > 300$MeV

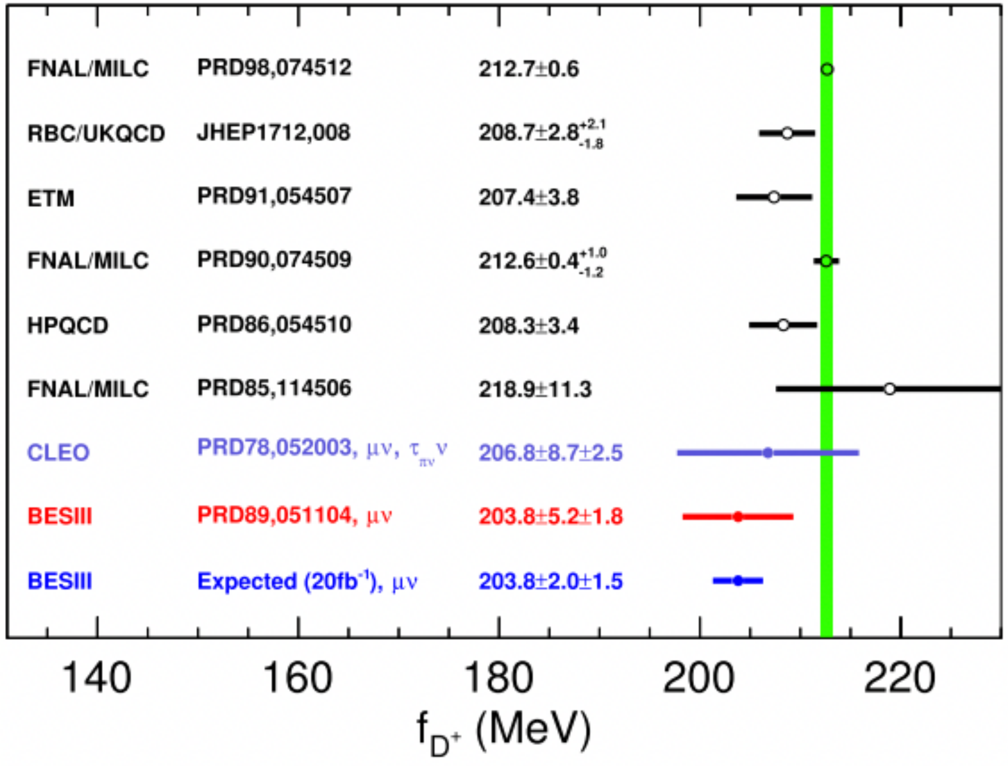


- 2.93 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 137 \pm 27$
- First observation (5.1 σ significance):

  $\mathcal{B}(D^+ \to \tau^+\nu_\tau) = (1.20 \pm 0.24 \pm 0.12)\times 10^{-3}$ (~22%)
- $\mathcal{R}_{\tau/\mu} = 3.21 \pm 0.64 \pm 0.43$ **vs** SM: 2.67 **--> No LFUV**
- $f_{D^+}|V_{cd}| = (50.4 \pm 5.1 \pm 2.5 \pm 0.2)$ MeV (~11.3%)

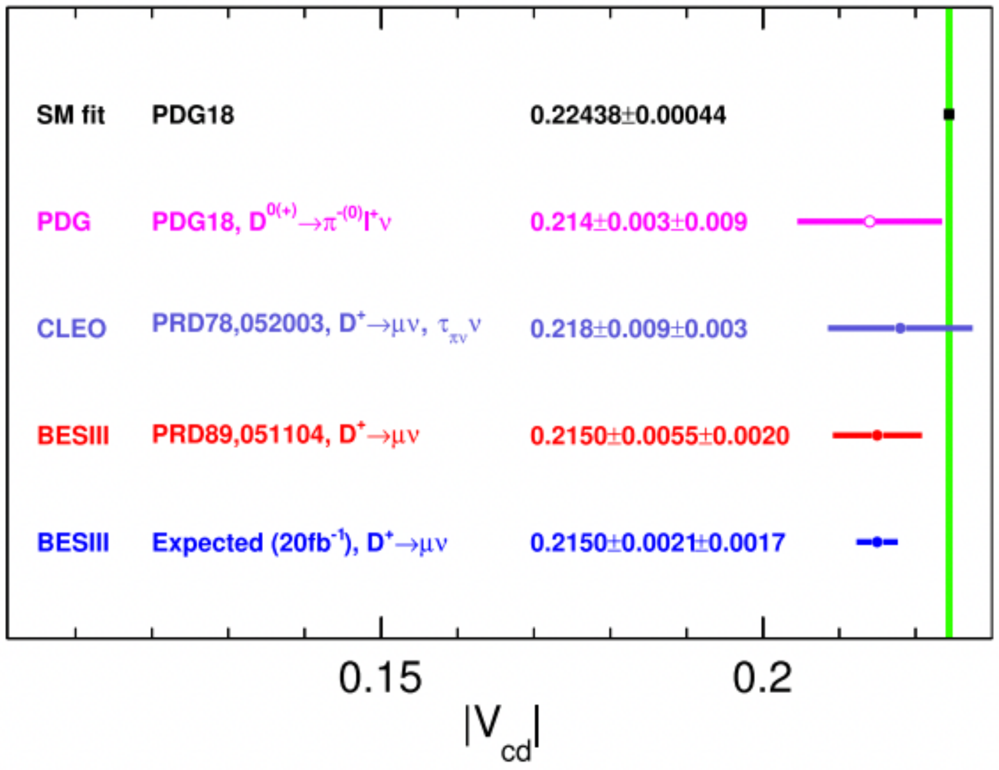
$D^+ \to \ell^+ \nu_\ell$

$$\Gamma(D^+ \to l^+\nu_l) = \frac{G_F^2 f_D^2}{8\pi}|V_{cd}|^2 m_l^2 m_D \left(1-\frac{m_l^2}{m_D^2}\right)^2$$



2.7%

1%

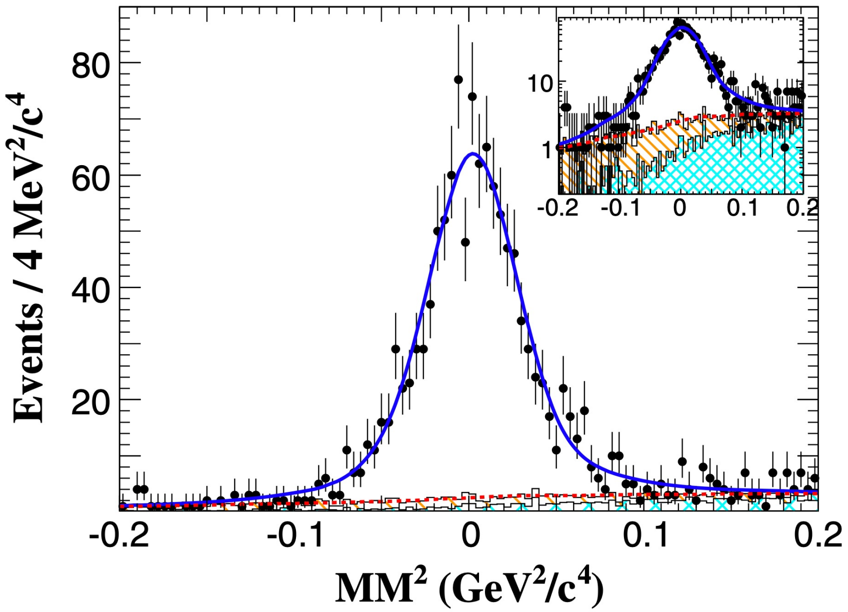


2.7%

1%

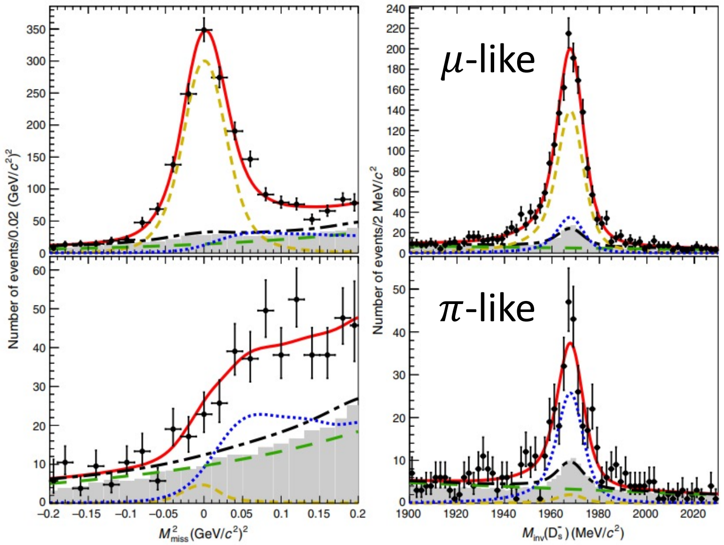
$D_s^+ \to \ell^+ \nu_\ell$

Phys. Rev. Lett. 122, 071802 (2019)



- 3.19 fb^{-1}data @ 4.178 GeV ➔ $N_{sig} = 1135.9 \pm 33.1$
- $\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (5.49 \pm 0.16 \pm 0.15)\times10^{-3}$ (~4%)
- $f_{D_s^+}|V_{cd}| = (246.2 \pm 3.6 \pm 3.5)$ MeV (~2%)

Phys. Rev. D 104, 052009 (2021)



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

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

- $N_{sig} = 2198 \pm 55$
- $N_{sig} = 946 \pm 46$

$\mathcal{B}(\tau^+ \to \pi^+\bar{\nu}_\tau) = 10.82\%$

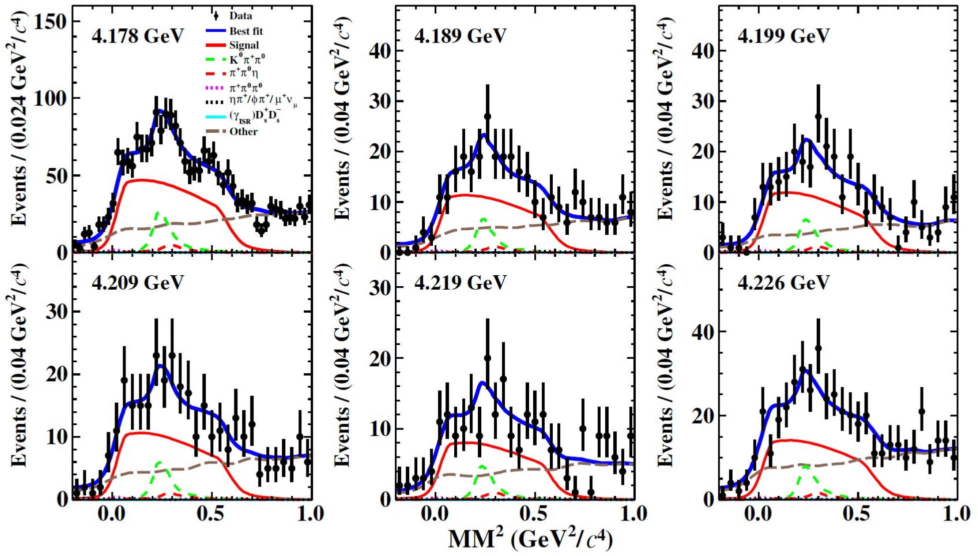
- 6.32 fb^{-1}data @4.18-4.23 GeV
- $\mathcal{B}(D_s^+ \to \mu^+ \nu_\mu) = (5.35 \pm 0.13 \pm 0.16)\times10^{-3}$ (~3.8%)
  $f_{D_s^+}|V_{cs}| = (243.1 \pm 3.0 \pm 3.7)$ MeV [μ] (~2.0%)
- $\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau) = (5.21 \pm 0.25 \pm 0.17)\%$ (~5.8%)
  $f_{D_s^+}|V_{cs}| = (243.0 \pm 5.8 \pm 4.0)$MeV [$\tau$] (~2.9%)
- $\mathcal{R}_{\tau/\mu} = 9.73^{+0.61}_{-0.58} \pm 0.37$ **vs** SM: 9.75 ± 0.01 **--> No LFUV**

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

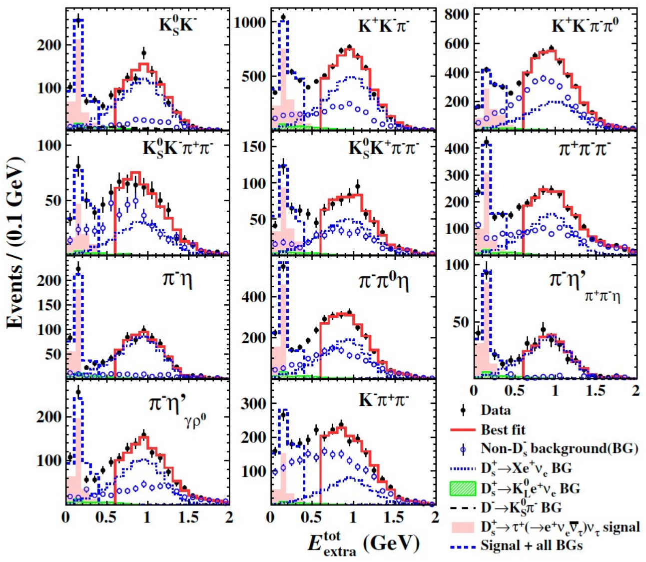
Phys. Rev. D 104, 032001 (2021)

Phys. Rev. Lett. 127, 171801 (2019)

$\mathcal{B}(\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau) = 25.49\%$



$\mathcal{B}(\tau^+ \to e^+\nu_e\bar{\nu}_\tau) = 17.82\%$



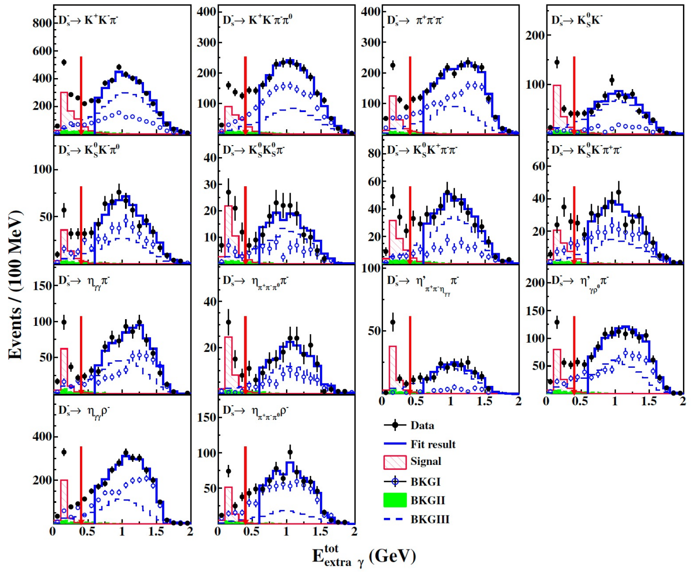
- 6.32 fb^{-1} data @4.18-4.23 GeV ➔ $N_{sig} = 1745 \pm 84$
- $\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau) = (5.29 \pm 0.25 \pm 0.20)\times 10^{-3}$ (~6%)
- $f_{D^+}|V_{cd}| = (244.8 \pm 5.8 \pm 4.8)$ MeV (~3%)
- $\mathcal{R}_{\tau/\mu} = 9.89 \pm 0.71$ **vs** SM: 9.75 ± 0.01

- 6.32 fb^{-1}data@4.18 −4.23 GeV ➔ $N_{sig} = 4940 \pm 97$
- $\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau) = (5.27 \pm 0.10 \pm 0.12)\%$ (~3%)
- $f_{D_s^+}|V_{cs}| = (244.1 \pm 2.3 \pm 2.9)$ MeV (~1.5%)
- $\mathcal{R}_{\tau/\mu} = 9.72 \pm 0.37$ **vs** SM: 9.75 ± 0.01

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

Arxiv:2303.12468 (submitted to JHEP)

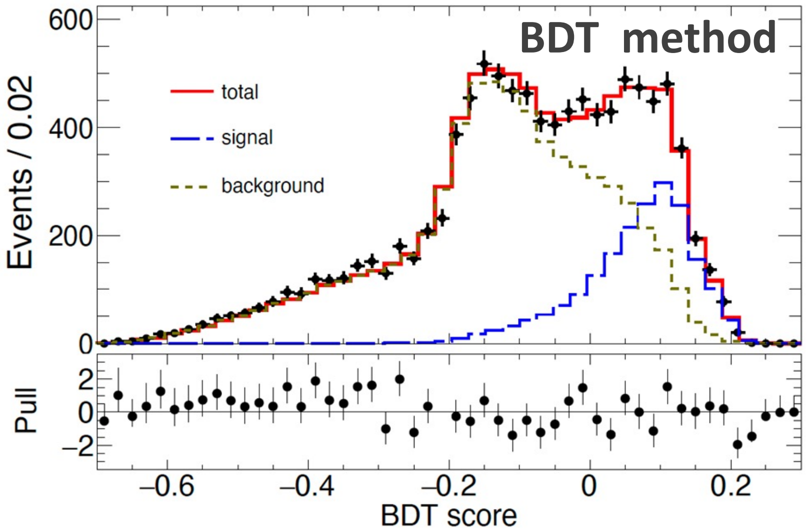
$\mathcal{B}(\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau) = 17.39\%$



- Data: 7.33 fb^{-1}@4.13-4.23 GeV ➔ $N_{sig} = 2172 \pm 64$
- $\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau) = (5.34 \pm 0.16 \pm 0.10)\%$ (~3.5%)
- $f_{D^+}|V_{cd}| = (246.2 \pm 3.7 \pm 2.5)$ MeV (~1.8%)
- $\mathcal{R}_{\tau/\mu} = 9.83 \pm 0.43$ **vs** SM: 9.75 ± 0.01

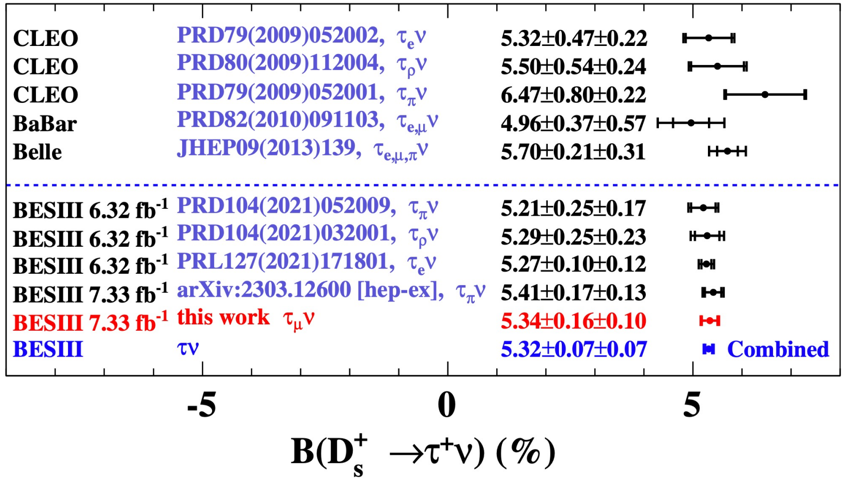
Arxiv:2303.12600 (submitted to PRD)

$\mathcal{B}(\tau^+ \to \pi^+ \bar{\nu}_\tau) = 10.82\%$



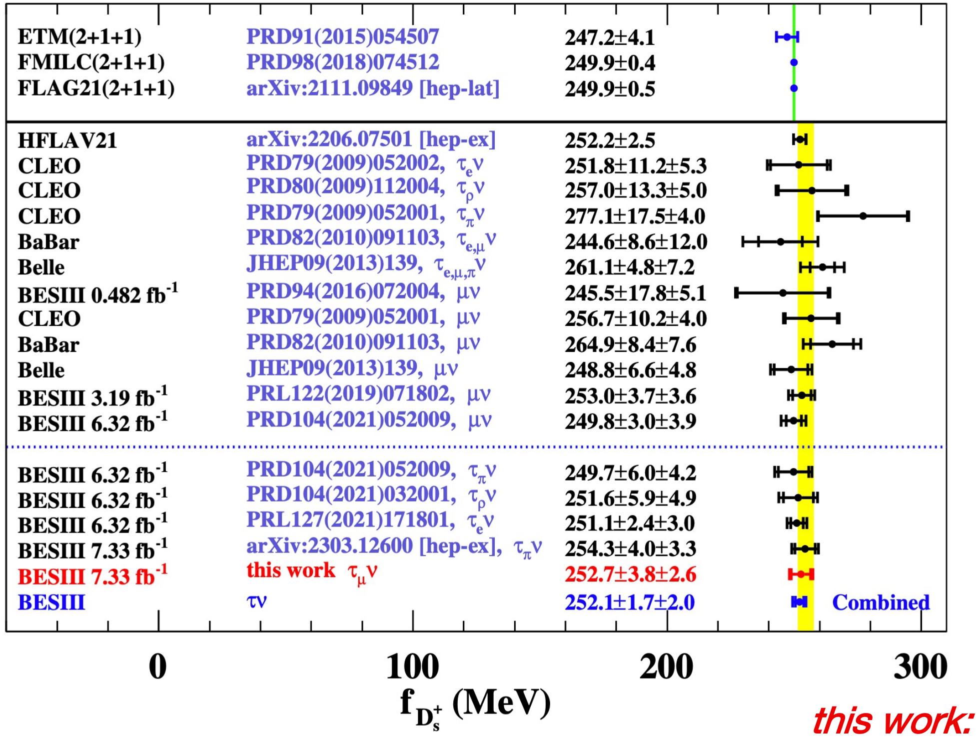
- Data: 7.33 fb^{-1} @4.18 − 4.23 GeV ➔ $N_{sig} = 2371 \pm 74$
- $\mathcal{B}(D_s^+ \to \tau^+ \nu_\tau) = (5.41 \pm 0.17 \pm 0.13)\%$ (~4%)
- $f_{D_s^+}|V_{cs}| = (247.6 \pm 3.9 \pm 3.2)$ MeV (~2%)
- $\mathcal{R}_{\tau/\mu} = 9.79 \pm 0.33$ **vs** SM: 9.75 ± 0.01

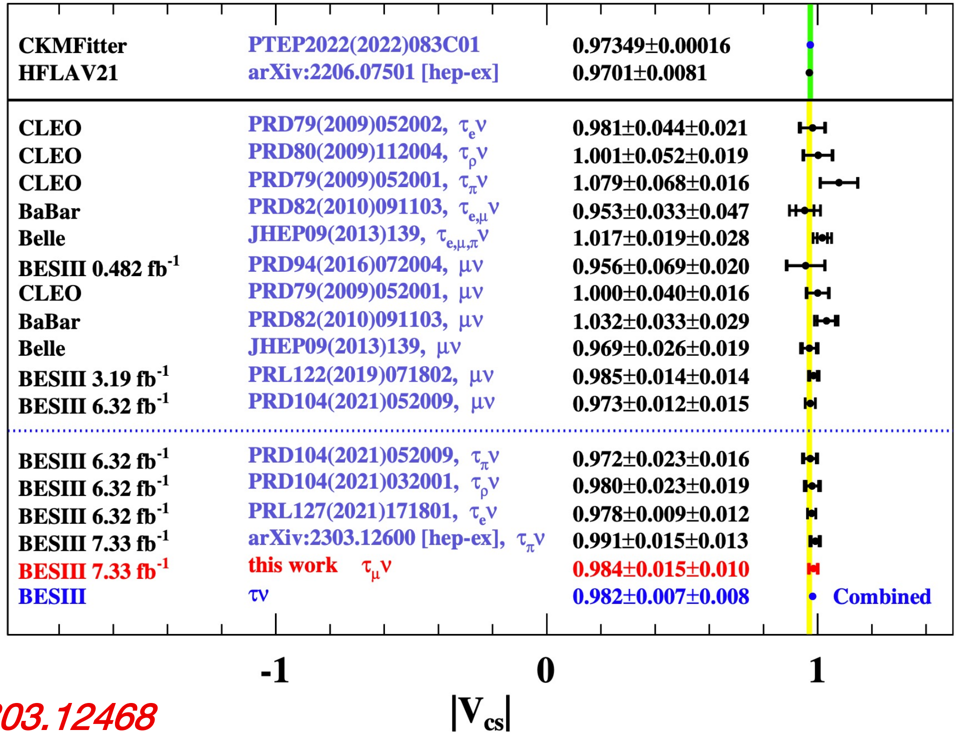
$D_s^+ \to \ell^+ \nu_\ell$



$$\Gamma(D_s^+ \to l^+\nu_l) = \frac{G_F^2 f_{D_s}^2}{8\pi} |V_{cs}|^2 m_l^2 m_{D_s} \left(1 - \frac{m_l^2}{m_{D_s}^2}\right)^2$$

$f_{D_s^+}$	249.9±0.5 MeV	LQCD
$\lvert V_{cs}\rvert$	0.97346±0.00016	CKM fitter
m_τ	1776.86±0.12 MeV	PDG2022
m_μ	105.6483755±0.0000023 MeV	PDG2022
m_{D_s}	1978.35 ±0.07 MeV	PDG2022





1%

this work: 2303.12468

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

arxiv: 2304.12159 (submitted to PRL)

Motivated by theoretical prediction:
EPJC 82, 1037 (2022); PRL 112, 212002 (2022)

- 7.33 fb^{-1} data @ 4.128-4.226 GeV
- First measurement of **BF** and $f_{D_s^{*+}}$

$$B(D_s^{*+} \to e^+\nu) = \left(2.1^{+1.2}_{-0.9}{}_{stat} \pm 0.2_{syst}\right)\times 10^{-5} \quad (2.9\sigma)$$

$$f_{D_s^{*+}} = (213.6^{+61.0}_{-45.8}{}_{\rm stat} \pm 43.9_{\rm syst})\ \mathrm{MeV}$$

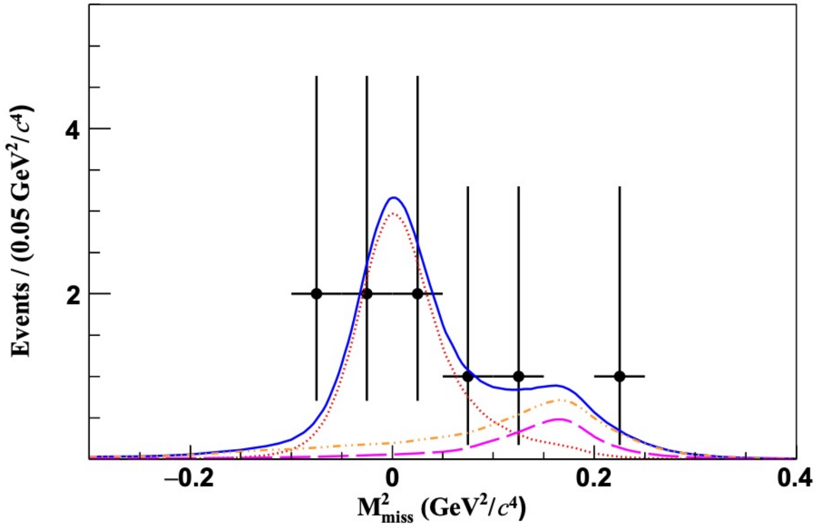
- Combine $\frac{f^+_{D_s^{*+}}}{f^+_{D_s^+}} = 1.12 \pm 0.01$ from LQCD calculation:

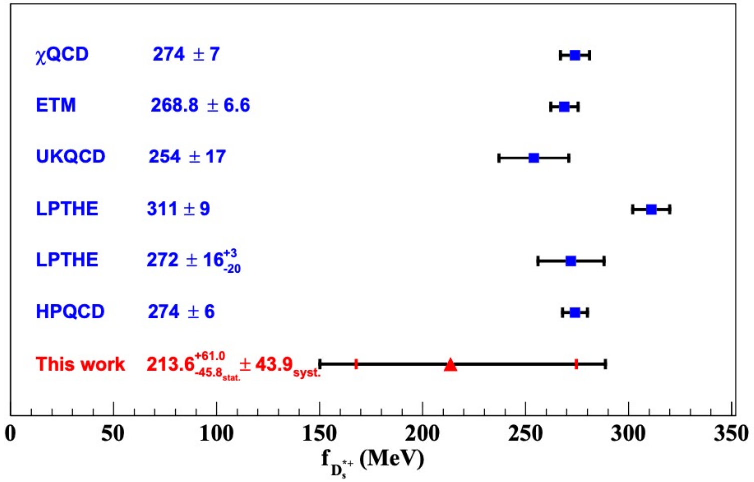
--> $\Gamma^{total}_{D_s^{*+}} = (121.9^{+69.6}_{-52.2} \pm 11.8)$ eV agree with LQCD prediction (70 ± 28) eV

--> Indirectly constrains the upper limit on $\Gamma^{total}_{D_s^{*+}}$ from MeV to KeV level.

$D_s^{*\pm}$ WIDTH   < 1.9 MeV CL=90.0%

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
< 1.9	90	GRONBERG	1995	CLE2	e^+e^-
< 4.5	90	ALBRECHT	1988	ARG	$E^{ee}_{\rm cm}$ = 10.2 GeV
• • We do not use the following data for averages, fits, limits, etc. • •					
< 4.9	90	BROWN	1994	CLE2	e^+e^-
< 22	90	BLAYLOCK	1987	MRK3	$e^+e^- \to D_s^\pm \gamma X$





$D_{(s)} \to P(S)\,\ell\nu_\ell$

$$\Gamma(D_{(s)} \to P(S)\ell^+\nu_\ell)/dq^2 \propto |V_{cd(s)}|^2|f_+(q^2)|^2$$

$P: K, \pi, \eta^{(\prime)}; S: a_0(980), f_0(500), f_0(980)$

- Use least χ^2 method to 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 form**

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

– **Modified pole model**

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

– **ISGW2 model**

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

– **Series expansion model**

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

The differential decay rate of $D_{(s)} \to P(S)\ell\nu_\ell$

- Point-like differential decay rate:

$$\frac{d\Gamma(D_{(s)}\to P\ell^+\nu_\ell)}{dq^2} = \frac{G_F^2|V_{cd(s)}|^2}{24\pi^3} p_{f_0}^3 |f_+(q^2)|^2$$

- Double differential decay rate (Resonance's width is considered):

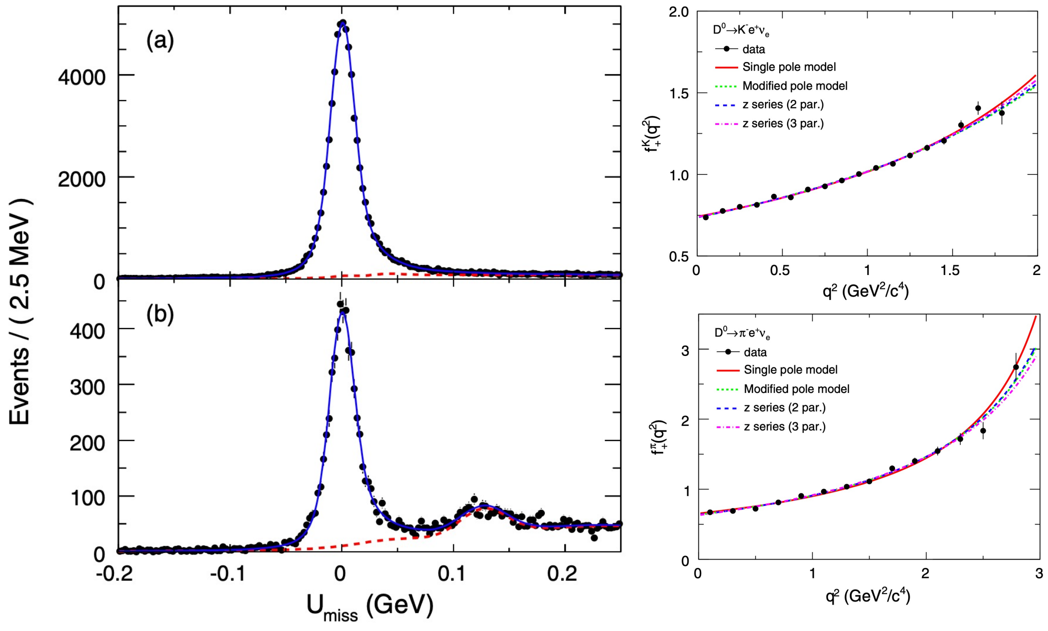
(N. N. Achasov *et al.*, PRD102,016022(2020); W. Wang, PLB759,501(2016))

$$\frac{d^2\Gamma(D_{(s)}\to S\ell^+\nu_\ell)}{ds\,dq^2} = \frac{G_F^2|V_{cd(s)}|^2}{192\pi^4 m_{D_{(s)}}^3} \lambda^{3/2}(m_{D_s}^2, s, q^2)|f_+(q^2)|^2 P(s)$$

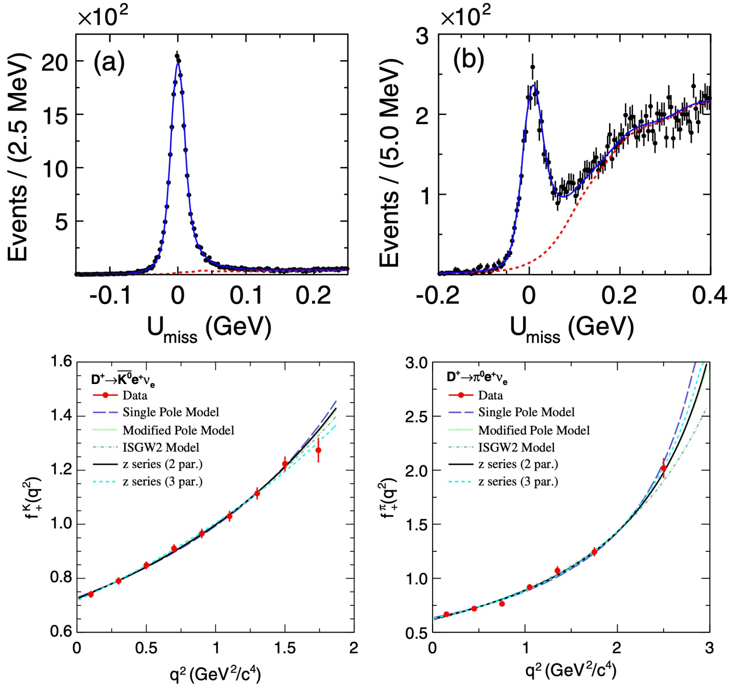
$$P(s) = \begin{cases} \dfrac{g_1\rho_{\pi\pi}}{|m_0^2 - s - i(g_1\rho_{\pi\pi} + g_1\rho_{KK})|^2}, & \text{Flatte for } a_0(980)/f_0(980) \\ \dfrac{m_{f_0}\Gamma(s)}{(s-m_{f_0}^2)^2 + m_{f_0}^2\Gamma^2(s)}, & \text{RBW for } f_0(500) \end{cases}$$

$D \to P\ell^+\nu_\ell$: $D \to K(\pi)e^+\nu_e$

Phys. Rev. D 92, 072012 (2015)



Phys. Rev. D 96, 012002 (2017)



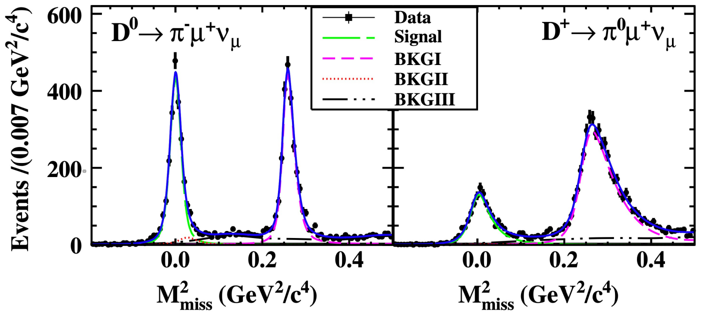
- $2.93\ \mathrm{fb}^{-1}$data@ 3.773 GeV ➔$N_{K(\pi)} = 70727(6297) \pm 278(87)$
- $\mathcal{B}(D^0 \to K^- e^+ \nu_e) = (3.505 \pm 0.014 \pm 0.033)\%$ (~1.0%)
- $\mathcal{B}(D^0 \to \pi^- e^+ \nu_e) = (0.295 \pm 0.004 \pm 0.003)\%$ (~1.7%)
- $f_+^K(0)|V_{cs}| = 0.7172 \pm 0.0025 \pm 0.0035$ (~0.6%)
- $f_+^\pi(0)|V_{cd}| = 0.1435 \pm 0.0018 \pm 0.0009$ (~1.2%)

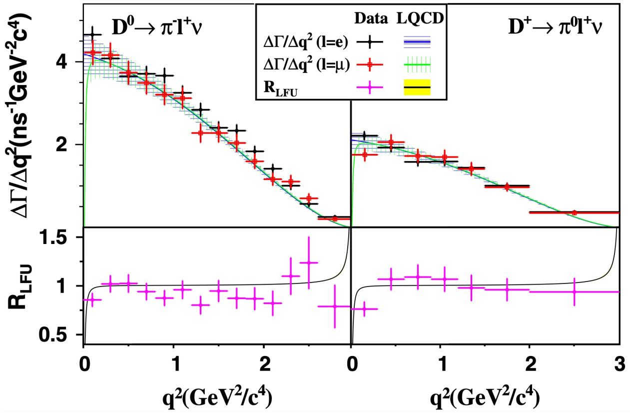
- $2.93\ \mathrm{fb}^{-1}$data@ 3.773 GeV➔ $N_{K(\pi)} = 26008(3402) \pm 168(70)$
- $\mathcal{B}(D^+ \to \bar{K}^0 e^+ \nu_e) = (8.60 \pm 0.06 \pm 0.15)\%$ (~1.9%)
- $\mathcal{B}(D^+ \to \pi^0 e^+ \nu_e) = (3.63 \pm 0.08 \pm 0.05)\times 10^{-3}$ (~2.6%)
- $f_+^K(0)|V_{cs}| = 0.7053 \pm 0.0040 \pm 0.0112$ (~1.7%)
- $f_+^\pi(0)|V_{cd}| = 0.1400 \pm 0.0026 \pm 0.0007$ (~1.7%)

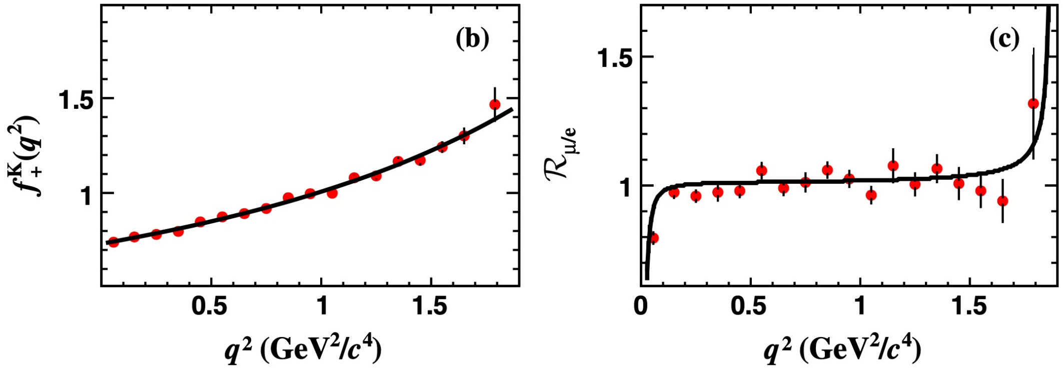
$D \to P\ell^+\nu_\ell$: $D \to K\,(\pi)\mu^+\nu_\mu$

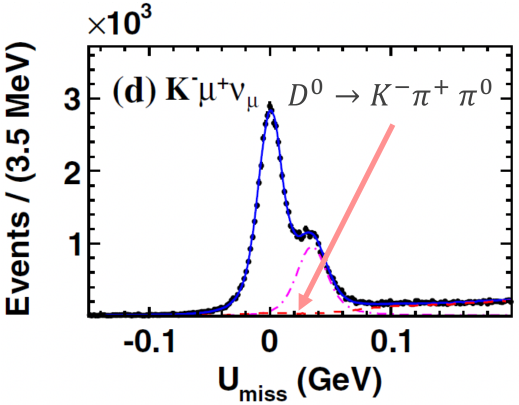
Phys. Rev. Lett. 121, 171803 (2018)

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





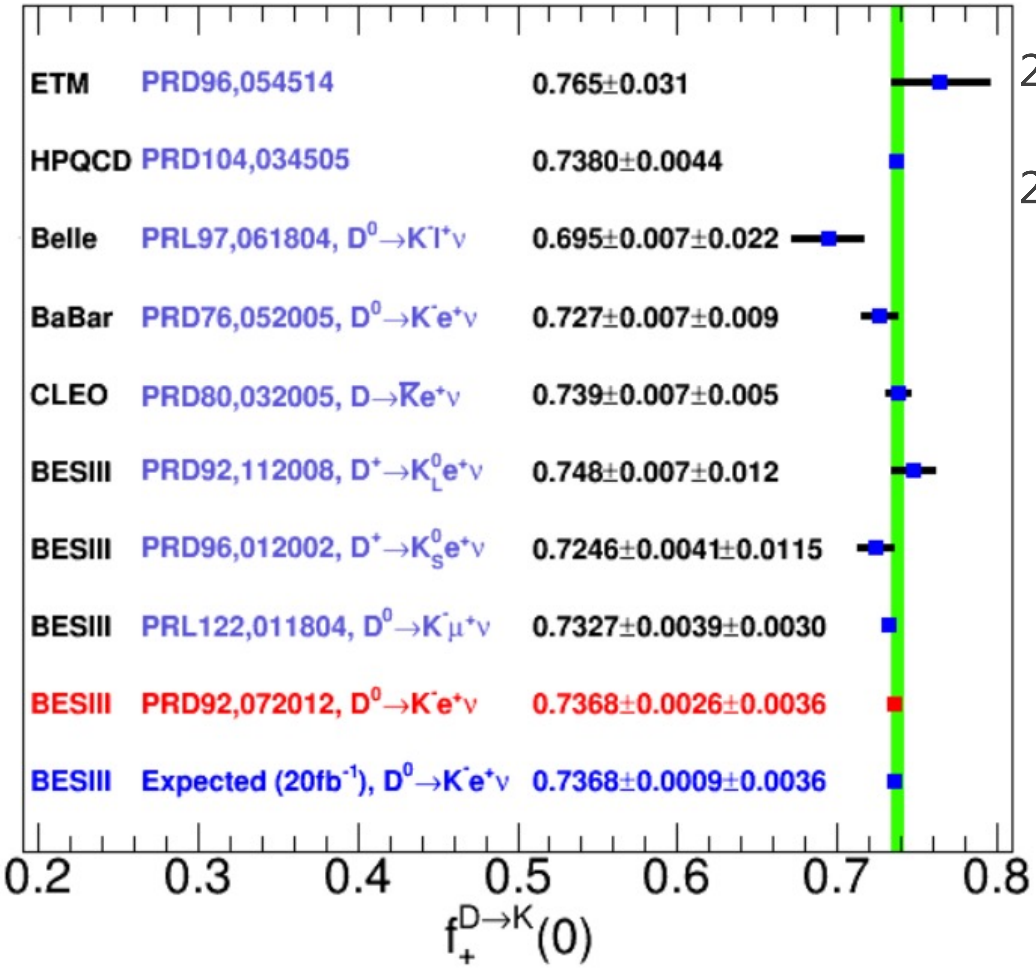




- $2.93\ \mathrm{fb}^{-1}$data@ 3.773 GeV
- $N_{\pi^-(\pi^0)} = 2265(1335) \pm 63(42)$
- $\mathcal{B}(D^0 \to \pi^-\mu^+\nu_\mu) = (0.272 \pm 0.008 \pm 0.006)\%$ (~2.9%)
- $\mathcal{B}(D^+ \to \pi^0\mu^+\nu_\mu) = (0.350 \pm 0.011 \pm 0.010)\%$ (~4.2%)
- $\mathcal{R}^0_{\mu/e} = 0.922 \pm 0.030 \pm 0.022$ **vs** SM: 0.985 ± 0.002
- $\mathcal{R}^+_{\mu/e} = 0.964 \pm 0.037 \pm 0.026$ **vs** SM: 0.985 ± 0.002

- $2.93\ \mathrm{fb}^{-1}$data@ 3.773 GeV
- $N_{sig} = 47100 \pm 259$
- $\mathcal{B}(D^0 \to K^-\mu^+\nu_\mu) = (3.413 \pm 0.019 \pm 0.035)\%$ (~1.2%)
- $f_+^K(0)|V_{cs}| = 0.7133 \pm 0.0038 \pm 0.0029$ (~0.6%)
- $\mathcal{R}_{\mu/e} = 0.974 \pm 0.007 \pm 0.012$ **vs** SM: 0.975 ± 0.001

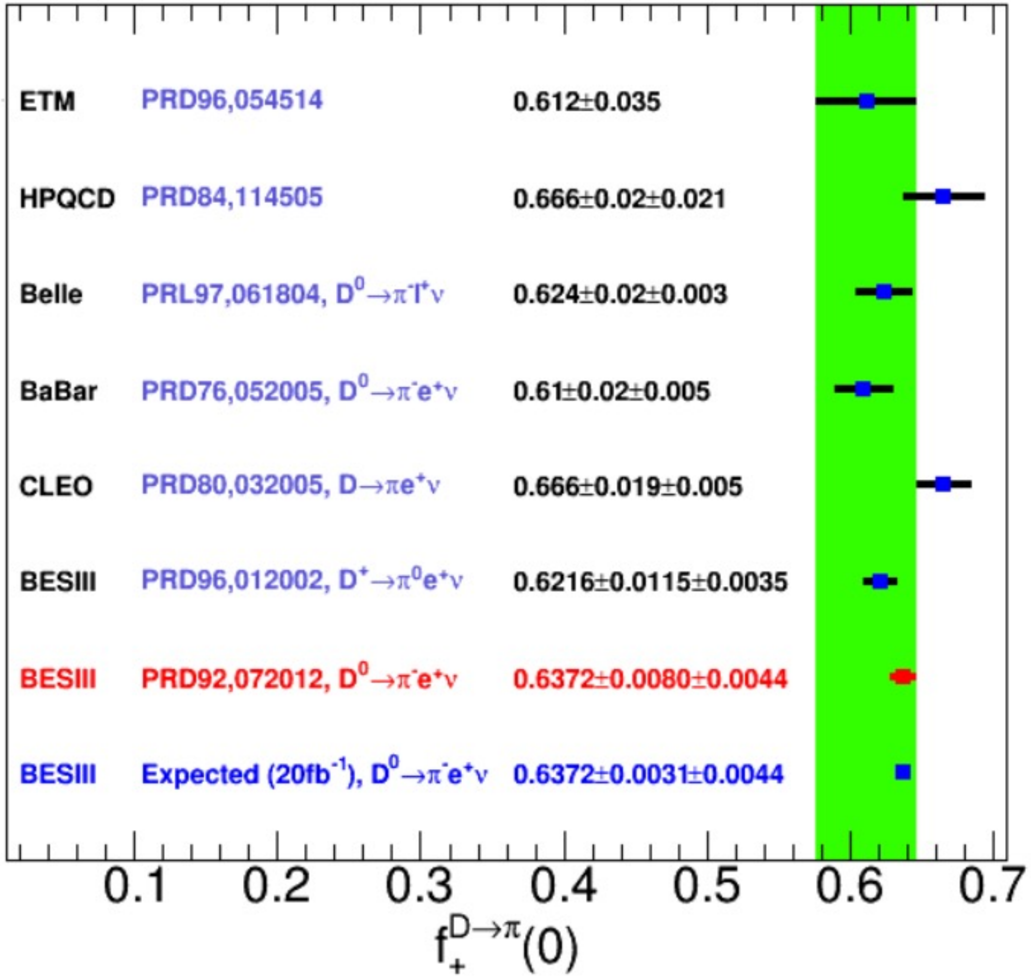
$D \to P\ell^+\nu_\ell$: $D \to K(\pi)\ell^+\nu_\ell$



2010 (2.4%)
⇩
2021 (0.6%)

0.7%

<0.5%



>4%

1.4%

<1%

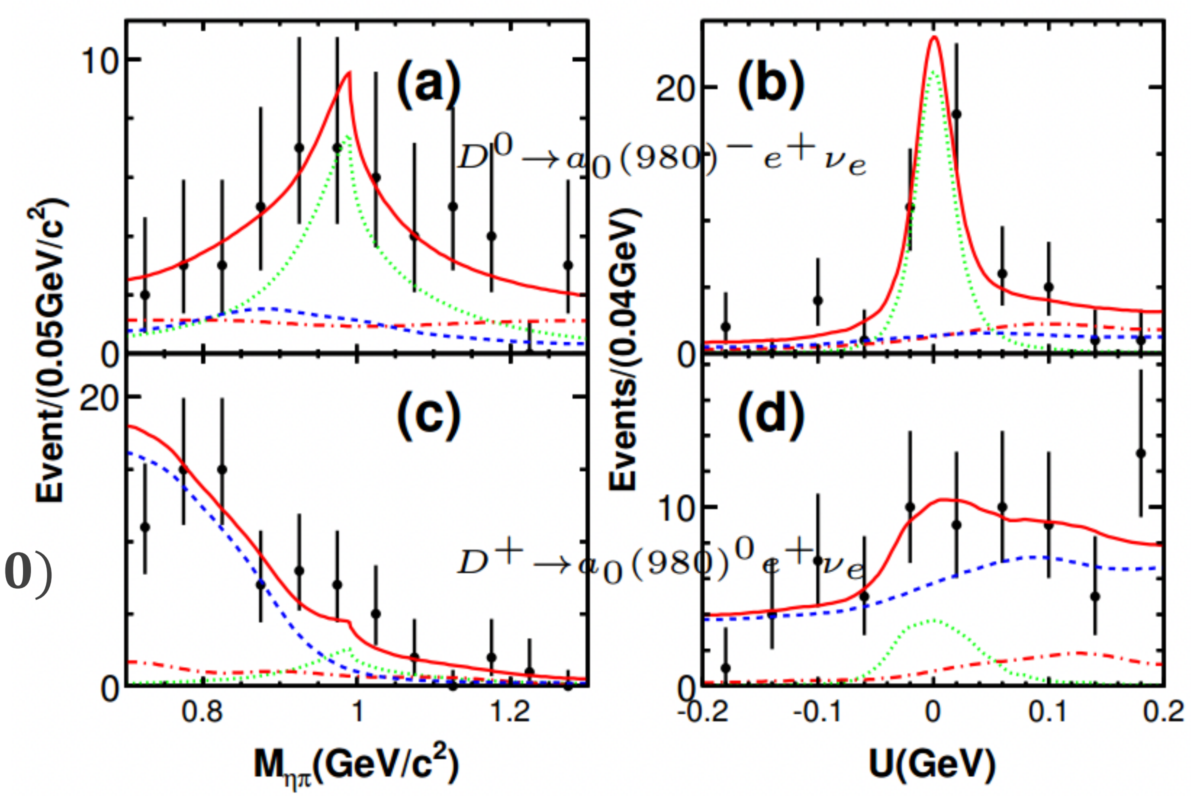
Experimental precision is comparable to the latest LQCD result

The measurements of the Cabibbo-suppressed decays are still dominated by statistical uncertainties

$D \to S\, e^{+}\nu_e$: $D \to a_0(980) e^{+}\, \nu_e$

Phys. Rev. Lett. 121, 081802 (2018)

- 2.93 fb^{-1} data @ 3.773 GeV
- $N_{sig}^{D^0} = 25.7^{+6.4}_{-5.7}$
- $N_{sig}^{D^+} = 10.2^{+5.0}_{-4.1}$
- BFs help to understand the nature of the $a_0(980)$



Decay	BF ($\times 10^{-4}$)	Significance
$D^0 \to a_0(980)^- e^+ \nu_e,\, a_0(980)^- \to \eta\pi^-$	$1.33^{+0.33}_{-0.29} \pm 0.09$	6.4σ
$D^+ \to a_0(980)^0 e^+ \nu_e,\, a_0(980)^0 \to \eta\pi^0$	$1.66^{+0.81}_{-0.66} \pm 0.11$ < 3.0 (90% C.L.)	2.9σ

$D_s^+ \to Se^+\nu_e : D_s^+ \to f_0\, e^+\nu_e, f_0 \to \pi^0\pi^0 / K_S^0 K_S^0$

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

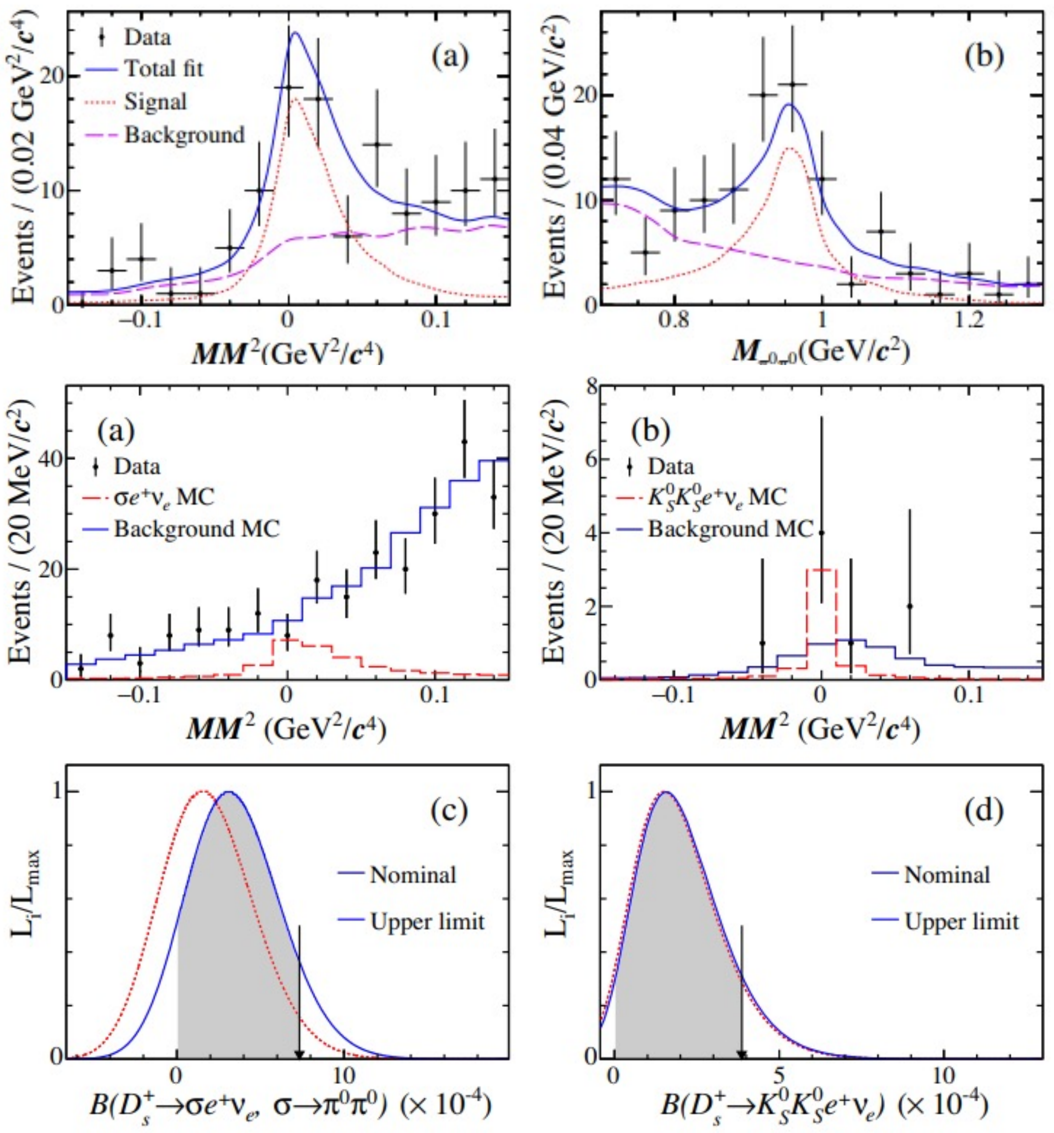
- $6.32\ \mathrm{fb}^{-1}$ data @ 4.178 - 4.226 GeV
- $N_{sig}^{f_0(980)} = 54.8 \pm 10.1$ (7.8 σ significance)
- First BFs Measurement:

$$\mathcal{B}(D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi^0\pi^0)$$
$$= (7.9 \pm 1.4 \pm 0.4)\times 10^{-4}$$

- No significant signal and upper limit on BF @90% C.L. :

$$\mathcal{B}(D_s^+ \to f_0(500)e^+\nu_e, f_0(500) \to \pi^0\pi^0) < 7.3\times 10^{-4}$$
$$\mathcal{B}(D_s^+ \to K_S^0 K_S^0 e^+\nu_e) < 3.8\times 10^{-4}$$

- BFs help to understand the nature of the $f_0(500)$ and $f_0(980)$, and test different theoretical calculations.



$D_s^+ \to Se^+\nu_e : D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi^+\pi^-$

arxiv: 2303.12927 (submitted to PRL)

- 7.33 fb^{-1} data @ 4.128-4.226 GeV ➔ $N_{sig} = 439 \pm 33$
- $\mathcal{B}(D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi^+\pi^-) = (1.72 \pm 0.13 \pm 0.10)\times 10^{-3}$

➔ $s\bar{s}$ **is dominant** based on $|f_0(980)\rangle = \sin\phi|\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\rangle + \cos\phi\,|s\bar{s}\rangle$

- **First form factor measurement** with simple pole form and Flatte formula:

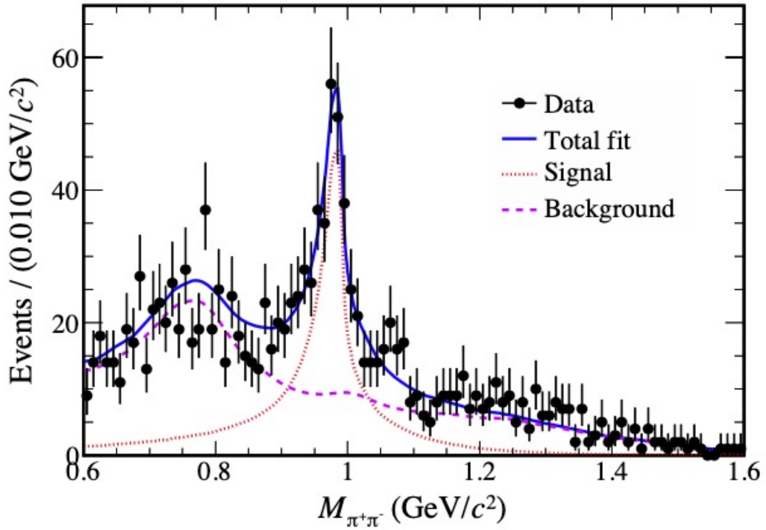
$$\frac{d^2\Gamma(D_s^+\to f_0(980)\ell^+\nu_\ell)}{dsdq^2} = \frac{G_F^2|V_{cs}|^2}{192\pi^4 m_{D_s^+}^3}\lambda^{3/2}\left(m_{D_s^+}^2, s, q^2\right)\left|f_+^{f_0}(0)\right|^2 P(s)$$

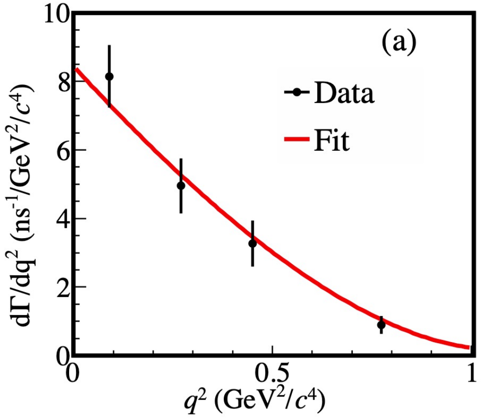
$$f_+^{f_0}(q^2) = \frac{f_+^{f_0}(0)}{1-q^2/M_{pole}^2},\quad P(s) = \frac{g_1\rho_{\pi\pi}}{|m_0^2 - s - i(g_1\rho_{\pi\pi} + g_1\rho_{KK})|^2}$$

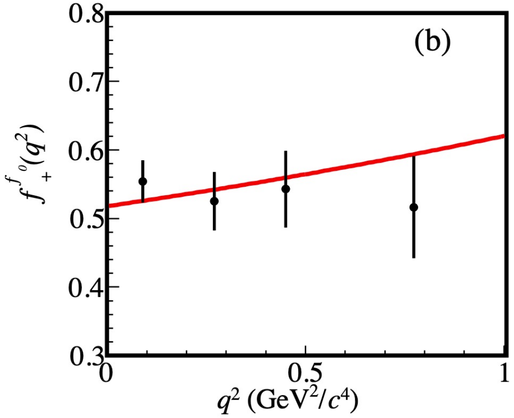
$f_+^{f_0}(0)|V_{cs}| = 0.504 \pm 0.017 \pm 0.035$

$|V_{cs}| = 0.97349 \pm 0.00016$ from SM global fit (PDG2022)

➔ $f_+^{f_0}(0) = 0.518 \pm 0.018 \pm 0.036$







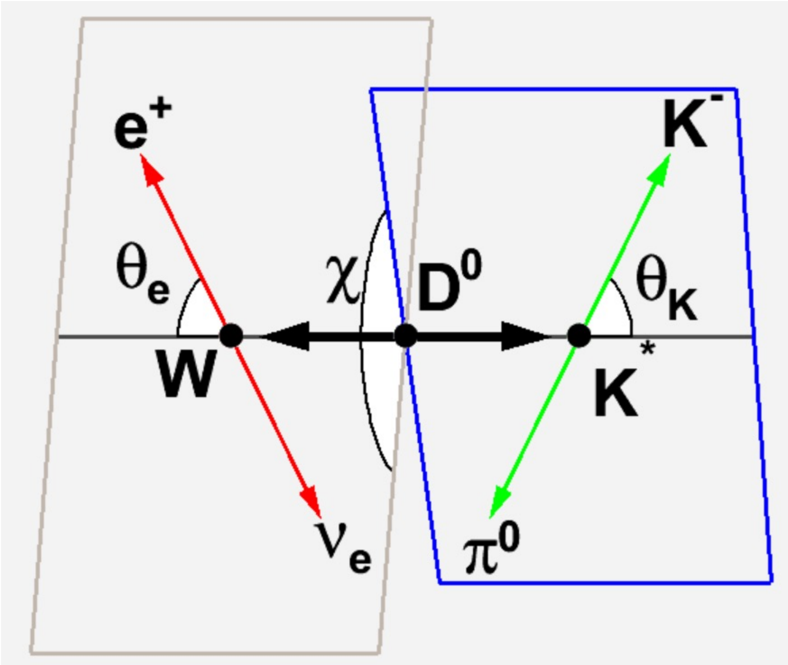
Partial wave analysis (PWA) — Helicity amplitude form

$$\Gamma(D_{(s)} \to V(S)\ell^+ \upsilon_\ell) \propto \left|V_{cd(s)}\right|^2 \mathfrak{I}(A_1(q^2), A_2(q^2), V(q^2), \dots) dm^2 dq^2 d\cos(\theta_h) d\cos(\theta_\ell) d\chi$$

V: ρ, ω, K^*, ϕ
S: $f_0(500), f_0(980)$

Formula: Phys. Rev. **137**, B438 (1965)
Phys. Rev. D **46**,5040 (1992)

- Decay intensity $\mathfrak{I}$ include *S, P, D* wave components
- Un-binned Maximum likelihood (Based on RooFit)
- FF parameterization (single pole)



$$A_i(q^2) = \frac{A_i(0)}{1 - q^2/M_A^2} \qquad V(q^2) = \frac{V(0)}{1 - q^2/M_V^2}$$

$$r_V = \frac{V(0)}{A_1(0)} \qquad r_2 = \frac{A_2(0)}{A_1(0)}$$

Partial wave analysis — Maximum likelihood fit

- Negative likelihood log (*NLL*) minimizing :

$$NLL = -\sum_{i=1}^{N} \ln \frac{\omega(\xi_i ,\eta)}{\sigma_s}$$

$\omega(\xi_i ,\eta)$: decay intensity, σ_s: integral normalized factor is realized by MC sample：

$$\sigma_s = \int d\xi\ \omega(\xi ,\eta)\ \epsilon(\xi) \ \propto \ \frac{1}{N_{selected}} \sum_{k=1}^{N_{selected}} \frac{\omega(\xi_k ,\eta)}{\omega(\xi_k ,\ \eta_0)}$$

- Low background: subtracted directly in *NLL*：

$$NLL = (-lnL_{data}) \ - \ (-lnL_{bkg})$$

- High background：

$$-\sum_{i=1}^{N}\ln\left((1-f_b)\frac{\omega(\xi_i,\eta)}{\int d\xi_i\omega(\xi_i,\eta)\epsilon(\xi_i)}+f_b\frac{B_\epsilon(\xi_i)}{\int d\xi_i B_\epsilon(\xi_i)\epsilon(\xi_i)}\right)$$

$D \to V e^+ \nu_e : D^+ \to \bar{K}^{*0} e^+ \nu_e$

Phys. Rev. D 94, 032001(2016)

- 2.93 fb^{-1} data @ 3.773 GeV
- $N_{\mathrm{sig}} = 18262$ (Bkg: 0.8%)
- $\mathcal{B}(D^+ \to K^- \pi^+ e^+ \nu_e) = (3.77 \pm 0.03 \pm 0.08)\%$

  $f_{S-\mathrm{wave}} = (6.05 \pm 0.22 \pm 0.18)\%$
- Form factor measurement by PWA：

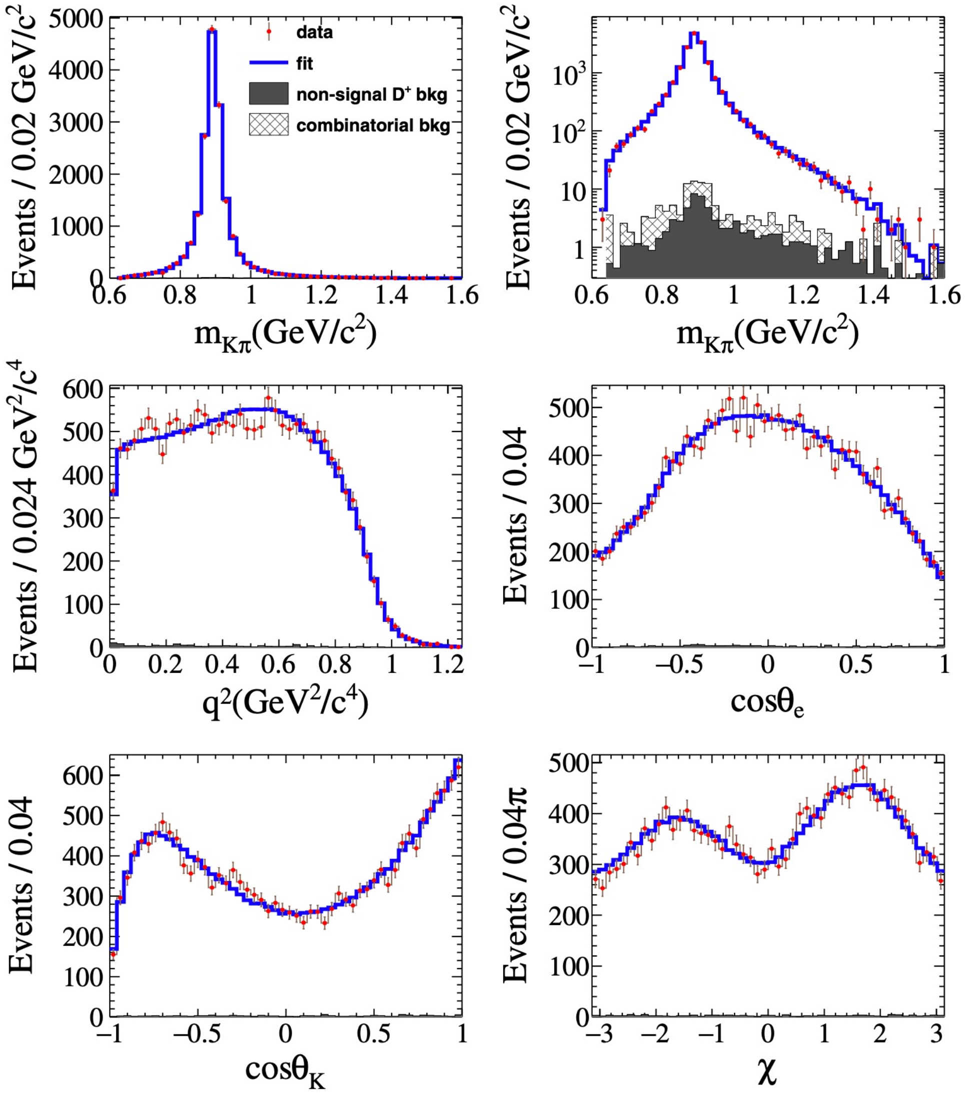
  $r_V = V(0)/A_1(0) = 1.411 \pm 0.058 \pm 0.007,$

  $r_2 = A_2(0)/A_1(0) = 0.788 \pm 0.042 \pm 0.008$

  Input $G_f, \tau_{D^+}, |V_{cs}|$ ➔

$A_1(0) = 0.589 \pm 0.010 \pm 0.012$ (zero width)

$A_1(0) = 0.619 \pm 0.011 \pm 0.013$ (consider width)



$D \to Ve^+\nu_e : D^0 \to K^{*-}e^+\nu_e$

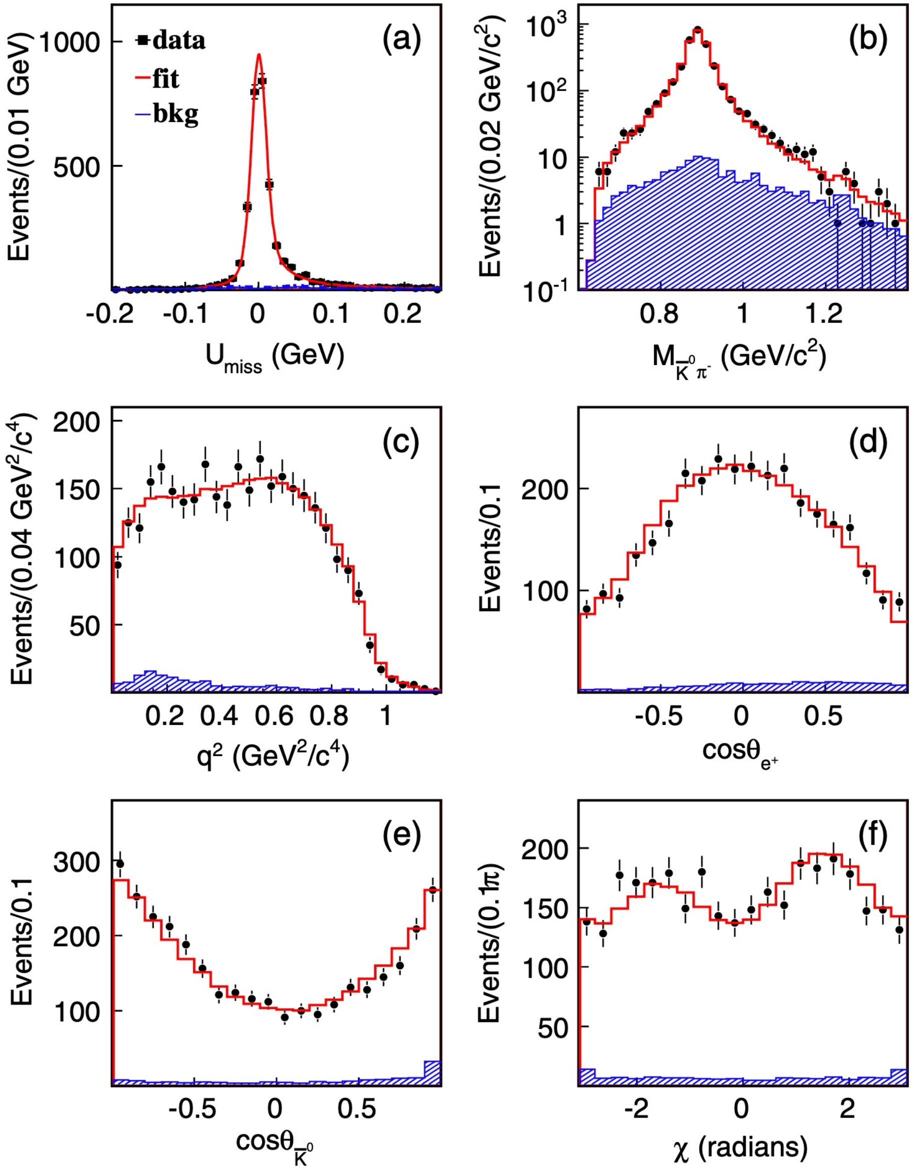
Phys. Rev. D 99, 0111003(R)(2019)

- $2.93\ \mathrm{fb}^{-1}$ data @ 3.773 GeV
- $N_{sig} = 3112 \pm 64$ (Bkg: 0.6%)
- $\mathcal{B}(D^0 \to \bar{K}^0\pi^+e^+\nu_e) = (1.434 \pm 0.029 \pm 0.032)\%$

  $f_{S\text{-wave}} = (5.51 \pm 0.97 \pm 0.62)\%$
- First FF measurement by PWA:

  $r_V = 1.46 \pm 0.07 \pm 0.02$

  $r_2 = 0.67 \pm 0.06 \pm 0.01$



$D_s^+ \to V(S)e^+\nu_e : D_s^+ \to K^+K^-\mu^+\nu_\mu$

arxiv: 2307.03024 (submitted to JHEP)

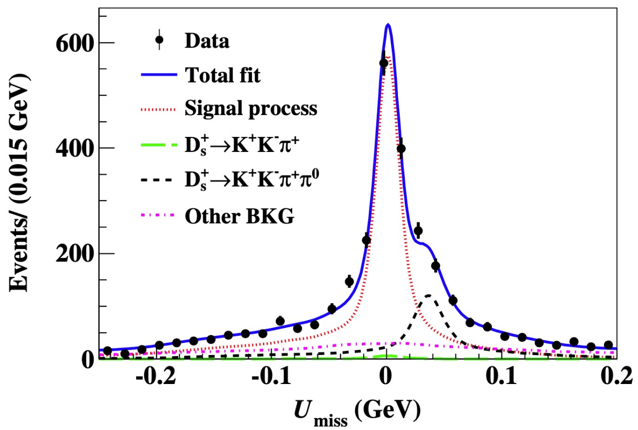
- 7.33 fb^{-1} data @ 4.128-4.226 GeV
- $N_{sig} = 1725 \pm 68$ for BF measurement

$\mathcal{B}(D_s^+ \to \phi\mu^+\nu_\mu) = (2.25 \pm 0.09 \pm 0.07)\times 10^{-2}$

$\mathcal{B}(D_s^+ \to \phi\mu^+\nu_\mu)/\mathcal{B}(D_s^+ \to \phi e^+\nu_e) = 0.94 \pm 0.08$ ➔ No **LFU** violation

$\mathcal{B}(D_s^+ \to f_0(980)\mu^+\nu_\mu)\cdot\mathcal{B}(f_0(980) \to K^+K^-) < 5.45\times 10^{-4}$@90% C.L. $\sim 2.2\sigma$

- **First FF measurement** based on single pole parameterization:
  - PWA is performed -> ϕ dominate
  - μ mass is considered in the formula



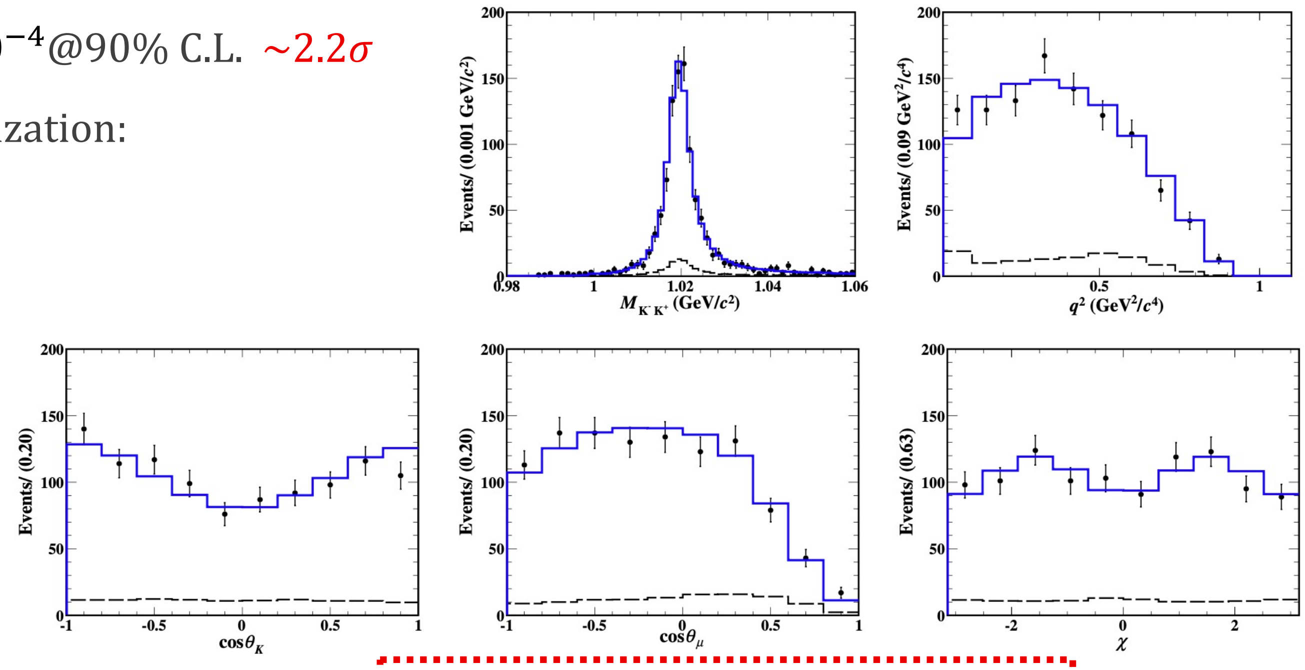


Table 5. Measured FF ratios and comparison with previous measurements.

Experiments	r_V	r_2
PDG [42]	1.80±0.08	0.84±0.11
This analysis	1.58±0.17±0.02	0.71±0.14±0.02
BABAR [25]	1.807±0.046±0.065	0.816±0.036±0.030
FOCUS [58]	1.549±0.250±0.148	0.713±0.202±0.284
Theory	r_V	r_2
CCQM [5]	1.34±0.27	0.99±0.20
CQM [6]	1.72	0.73
LFQM [7]	1.42	0.86
LQCD [3]	1.72±0.21	0.74±0.12
HMχT [8]	1.80	0.52

$|U_{miss}| < 0.02$ GeV
939 signal events with (9.8±0.7)% Bkg

$c \to s : D_{(s)} \to V e^+ \nu_e$

Decay Mode	Exp/Year/Yield	BF/FF/Polarization	BESIII Status
$D_s^+ \to \phi(K^+K^-)e^+\nu_e$	BESIII/2018/26 CLEO/2015/207 BABAR/2008/25k CLEO-II/1994/308	Y/N/N Y/N/N Y/Y/N N/Y/Y	Internal Review@4.13 ~ 4.23GeV
$D_s^+ \to \phi(K^+K^-)\mu^+\nu_\mu$	BESIII/2018/22 FOCUS/2004/793 E687/1994/90	Y/N/N N/Y/N N/Y/Y	Internal Review@4.13 ~ 4.23GeV
$D^+ \to \bar{K}^{*0}(K^-\pi^+)e^+\nu_e$	BESIII/2016/18k BABAR/2011/70k CLEO/2010/5k	Y/Y/N Y/Y/N Y/Y/N	✓
$D^+ \to \bar{K}^{*0}(K^-\pi^+)\mu^+\nu_\mu$	CLEO/2010/5k FOCUS/2002/15k	Y/Y/N N/Y/N	In process
$D^+ \to \bar{K}^{*0}(\bar{K}^0\pi^0)e^+\nu_e$	N	N/N/N	In process
$D^+ \to \bar{K}^{*0}(\bar{K}^0\pi^0)\mu^+\nu_\mu$	N	N/N/N	In process
$D^0 \to K^{*-}(K^-\pi^0)e^+\nu_e$	CLEO/2005/94	Y/N/N	In process
$D^0 \to K^{*-}(K^-\pi^0)\mu^+\nu_\mu$	N	N/N/N	In process
$D^0 \to K^{*-}(\bar{K}^0\pi^-)e^+\nu_e$	BESIII/2019/3k CLEO/2005/125	Y/Y/N Y/N/N	✓
$D^0 \to K^{*-}(\bar{K}^0\pi^-)\mu^+\nu_\mu$	FOCUS/2005/175	Y/Y/N	In process

$D \to V(S)e^+\nu_e$: $D^{+(0)} \to \pi^-\pi^{+(0)}e^+\nu_e$

Phys. Rev. Lett. 122, 062001 (2019)

D^0 mode: 1498 events (Bkg:~33.3%)
D^+ mode: 2017 events (Bkg:~23.8%)

$|U_{miss}| < 0.06$ GeV

- 2.93 fb^{-1} data @ 3.773 GeV
- For BFs: $N_{sig}^{D^0} = 1102 \pm 45$

  $N_{sig}^{D^+} = 1667 \pm 50$
- Simultaneous PWA fit:

$f_{\rho^0} = (76.0 \pm 1.7 \pm 1.1)\%$

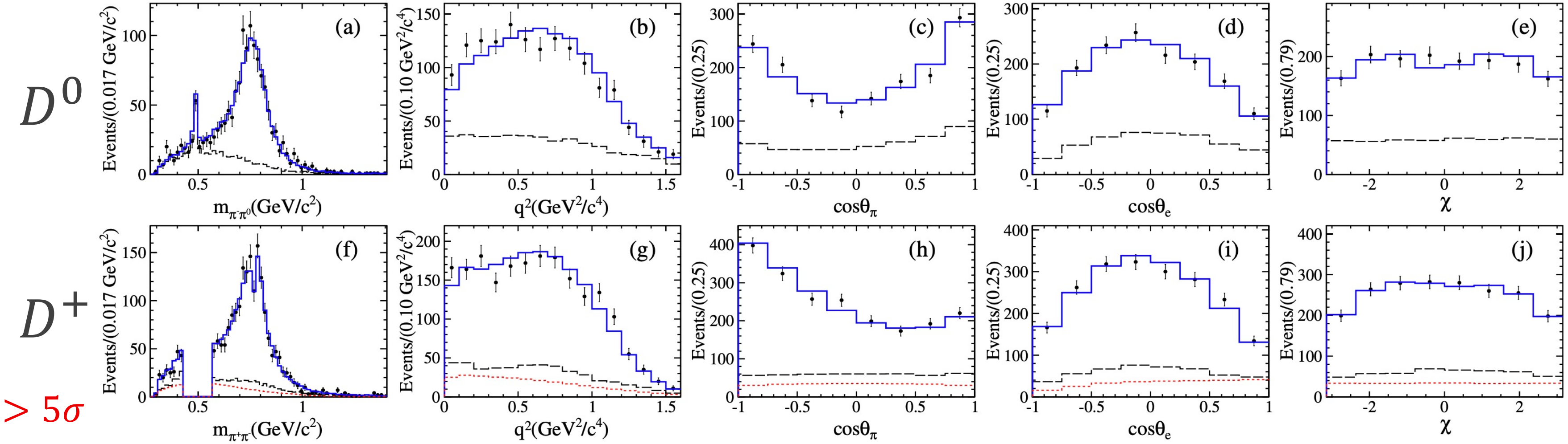
$f_\omega = (1.28 \pm 0.41 \pm 0.15)\% > 5\sigma$

$f_{f_0(500)} = (25.7 \pm 1.6 \pm 1.1)\% > 10\sigma$ (First observation)

$r_V = V(0)/A_1(0) = 1.695 \pm 0.083 \pm 0.051$

$r_2 = A_2(0)/A_1(0) = 0.845 \pm 0.056 \pm 0.039$

- $R = \frac{\mathcal{B}(D^+\to f_0(500)e^+\nu_e)+\mathcal{B}(D^+\to f_0(980)e^+\nu_e)}{\mathcal{B}(D^+\to a_0(980)e^+\nu_e)} > 2.7@90\%CL$
- Favor tetraquark ($R = 3$, PRD82, 034016(2010)) for f_0 and a_0



Signal mode	This analysis ($\times 10^{-3}$)
$D^0 \to \pi^-\pi^0 e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^0 \to \rho^- e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^+ \to \pi^-\pi^+ e^+\nu_e$	$2.449 \pm 0.074 \pm 0.073$
$D^+ \to \rho^0 e^+\nu_e$	$1.860 \pm 0.070 \pm 0.061$
$D^+ \to \omega e^+\nu_e$	$2.05 \pm 0.66 \pm 0.30$
$D^+ \to f_0(500)e^+\nu_e$, $f_0(500) \to \pi^+\pi^-$	$0.630 \pm 0.043 \pm 0.032$
$D^+ \to f_0(980)e^+\nu_e$, $f_0(980) \to \pi^+\pi^-$	<0.028

$D \to Ve^+\nu_e : D^0 \to \rho^-\mu^+\nu_\mu$

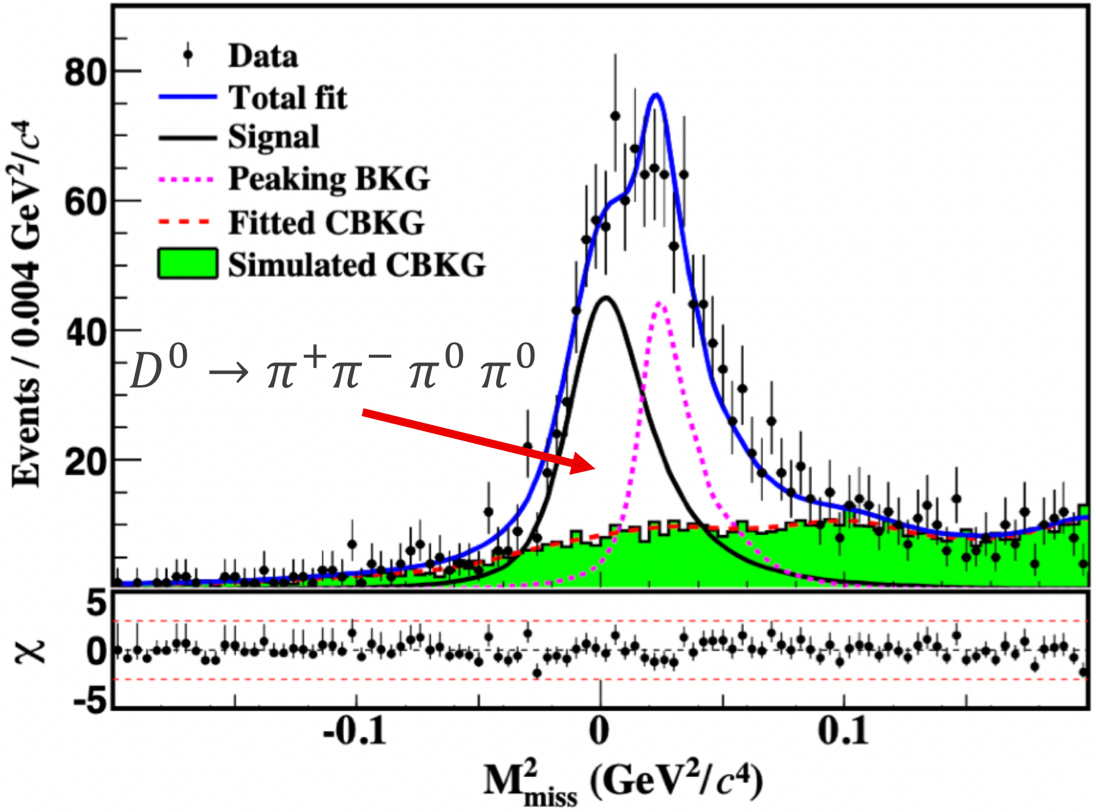
Phys. Rev. D 104, L091103 (2021)

- 2.93 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 570 \pm 40$
- $\mathcal{B}(D^0 \to \rho^-\mu^+\nu_\mu) = (1.35 \pm 0.09 \pm 0.09)\times 10^{-3}$

Agree with some theoretical calculations.

(LFQM, CCQM, and LCSR methods).

- $\mathcal{R}_{\mu/e} = 0.90 \pm 0.11$ **vs** SM: 0.93-0.96 --> **No LFUV**



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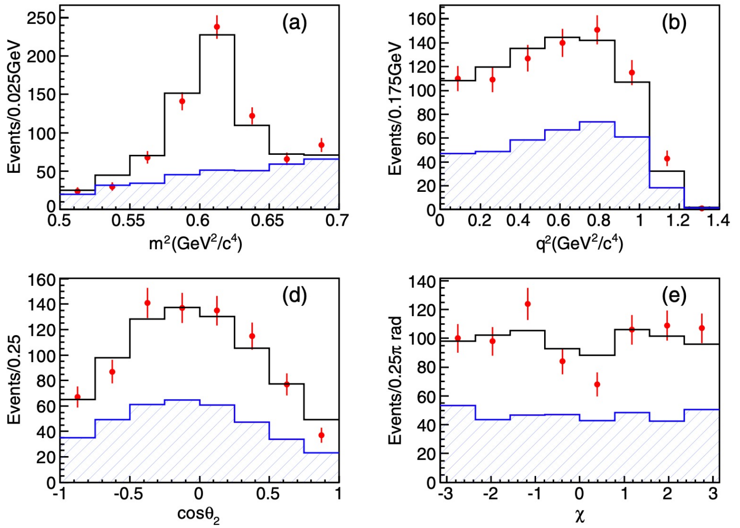
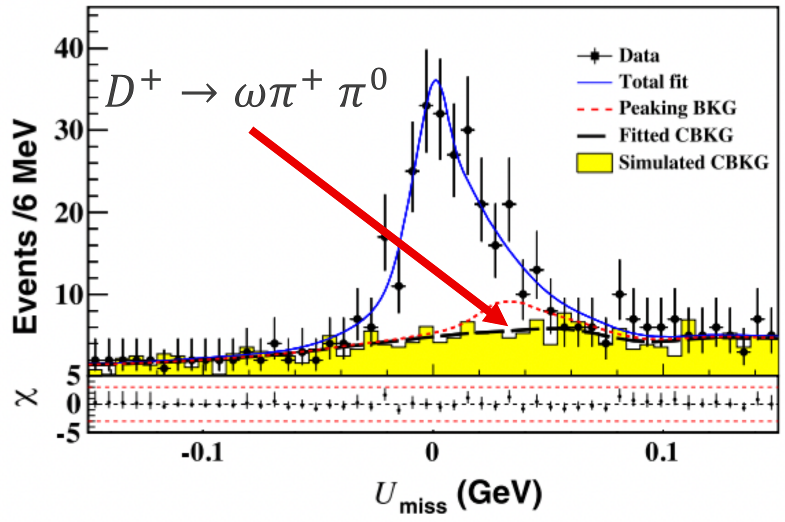
R. N. Faustov, V. O. Galkin, and X. W. Kang, Phys. Rev. D101, 013004 (2020)

$D \to V e^+ \nu_e$: $D^+ \to \omega\, e^+ \nu_e$

Phys. Rev. D 92, 071101(R) (2015)

Phys. Rev. D 101, 072005 (2020)





- 2.93 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 491 \pm 32$
- $\mathcal{B}(D^+ \to \omega\, e^+\nu_e) = (1.63 \pm 0.11 \pm 0.08)\%$
- First FF measurement：

  $r_V = 1.24 \pm 0.09 \pm 0.06$,

  $r_2 = 1.06 \pm 0.15 \pm 0.05$

- 2.93 fb^{-1} data @ 3.773 GeV
- $N_{sig} = 194 \pm 20$
- $\mathcal{B}(D^+ \to \omega\mu^+\nu_\mu) = (17.7 \pm 1.8 \pm 1.1)\times 10^{-4}$
- $\mathcal{R}_{\mu/e} = 1.05 \pm 0.14$ **vs** SM: 0.93-0.99 **--> No LFUV**

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

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

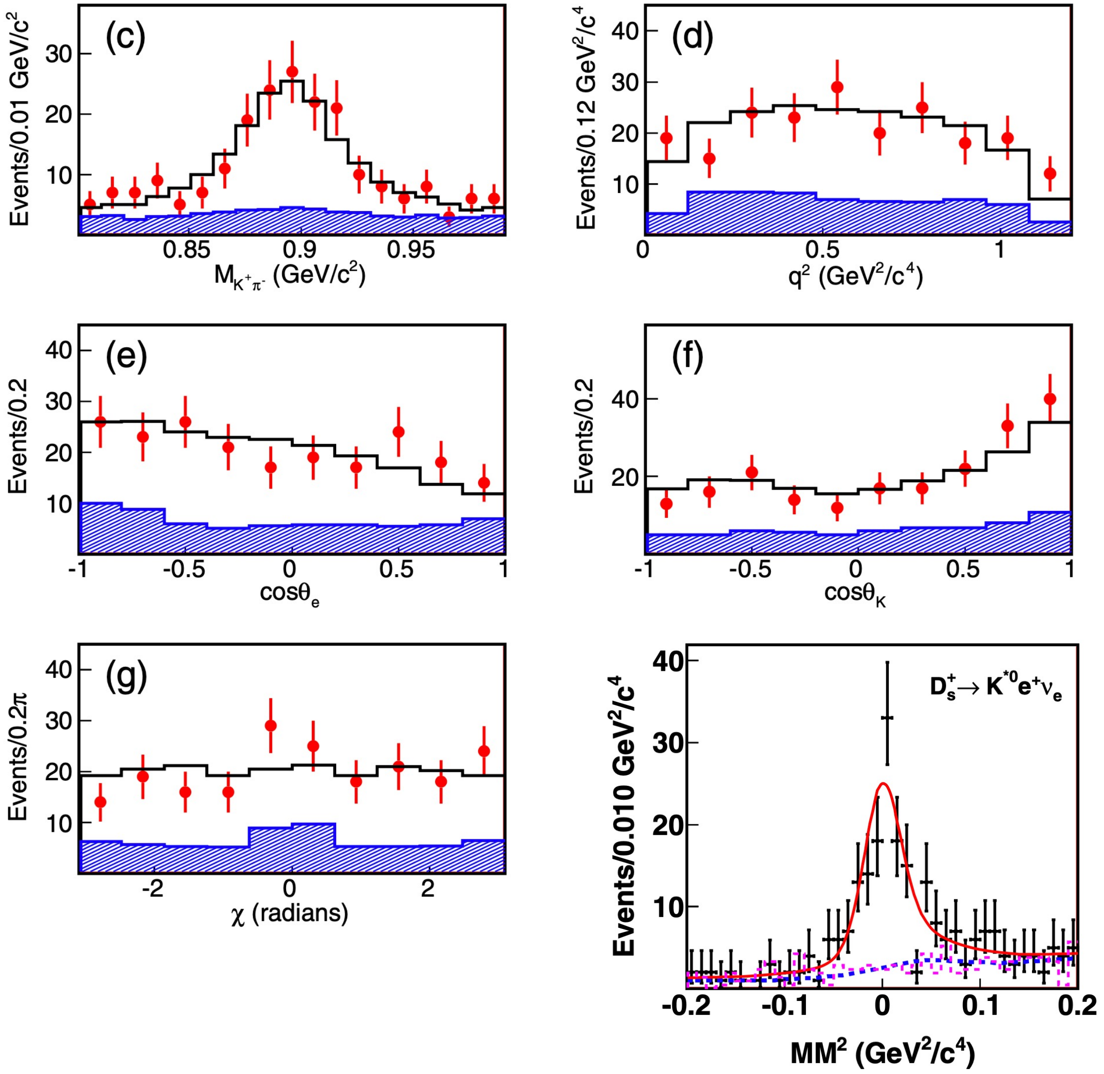
- 3.19 fb^{-1} data@4.18 GeV
- $N_{sig}(D_s^+ \to K^{*0} e^+ \nu_e) = 155.0 \pm 17.2$
- $\mathcal{B}(D_s^+ \to K^{*0} e^+ \nu_e) = (2.37 \pm 0.26 \pm 0.20) \times 10^{-3}$
- First FF measurement by PWA :

  $r_V = 1.67 \pm 0.34 \pm 0.16,\ r_2 = 0.77 \pm 0.28 \pm 0.07$
- Agree with LQCD and U-spin (d ↔ s) symmetry:

  FF is insensitive to spectator quark

Use BESIII and CLEO measurement

	Values
$f_+^{D_s^+ \to K^0}(0)/f_+^{D^+ \to \pi^0}(0)$	$1.16 \pm 0.14 \pm 0.02$
$r_V^{D_s^+ \to K^{*0}}/r_V^{D^+ \to \rho^0}$	$1.13 \pm 0.26 \pm 0.11$
$r_2^{D_s^+ \to K^{*0}}/r_2^{D^+ \to \rho^0}$	$0.93 \pm 0.36 \pm 0.10$



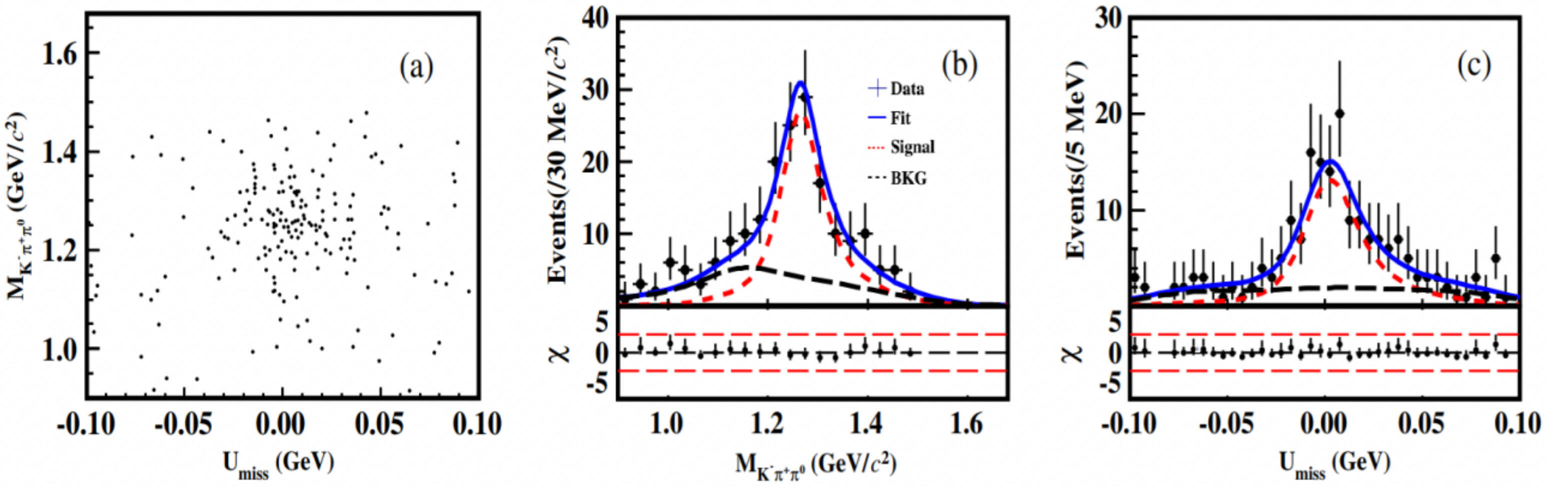
$c \to d : D_{(s)} \to V e^+ \nu_e$

Decay Mode	Exp/Year/Yield	BF/FF/Polarization	BESIII Status
$D_s^+ \to K^{*0}(K^+\pi^-)e^+\nu_e$	CLEO/2015/32 BESIII/2019/155	Y/N/N Y/Y/N	In process@4.13 ~ 4.23GeV
$D_s^+ \to K^{*0}(K^+\pi^-)\mu^+\nu_\mu$	**N**	**N**	In process@4.13 ~ 4.23GeV
$D^+ \to \rho^0(\pi^-\pi^+)e^+\nu_e$	CLEO/2013/447 BESIII/2019/1.7k	Y/Y/N Y/Y/N	✓
$D^+ \to \rho^0(\pi^-\pi^+)\mu^+\nu_\mu$	FOCUS/2006/320	Y/N/N	In process
$D^+ \to \omega(\pi^-\pi^+\pi^0)e^+\nu_e$	BESIII/2016/491	Y/Y/N	✓
$D^+ \to \omega(\pi^-\pi^+\pi^0)\mu^+\nu_\mu$	BESIII/2020/194	Y/N/N	✓
$D^0 \to \rho^-(\pi^-\pi^0)e^+\nu_e$	CLEO/2013/305 BESIII/2019/1.1k	Y/Y/N Y/Y/N	✓
$D^0 \to \rho^-(\pi^-\pi^0)\mu^+\nu_\mu$	BESIII/2021/570	Y/N/N	✓
$D^+ \to \phi(K^+K^-)e^+\nu_e$	BESIII/2016/-	Y/N/N	In process
$D^+ \to \phi(K^+K^-)\mu^+\nu_\mu$	N	N	In process

$D \to A\ell^+\nu_\ell : D^+ \to \bar{K}_1(1270)^0 e^+\nu_e$

Phys. Rev. Lett. 122, 062001 (2019)

- 2.93 fb^{-1} data @ 3.773 GeV
- $N_{sig} = 119.7 \pm 13.3$
- Benefit the study of the photon polarization in $B \to K_1\gamma$



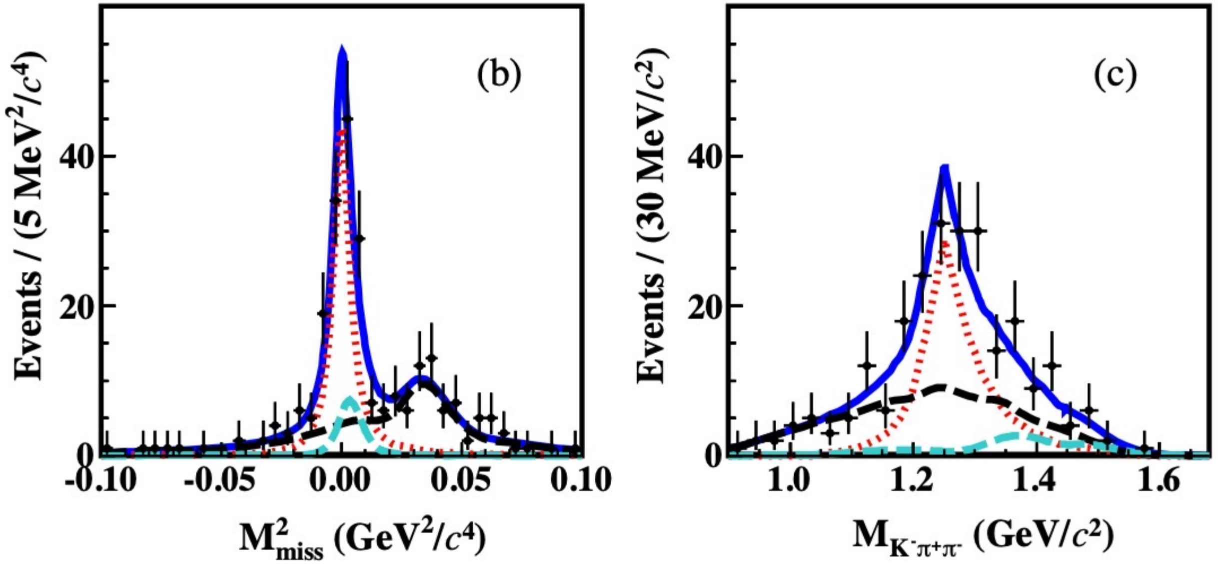
	$\mathcal{B}(D^+ \to \bar{K}_1(1270)^0 e^+\nu_e)$
This work	$(2.30 \pm 0.26 \pm 0.18 \pm 0.25) \times 10^{-3}$
CLFQM[EPJC77,863(2017)]($\theta_{K_1} = 33°$)	$(3.20 \pm 0.40) \times 10^{-3}$
LCSR[JPG46,105006(2019)]($\theta_{K_1} < 0$)	$(17 \sim 21) \times 10^{-3}$

θ_{K_1} is the mixing angle of two states $K_{1A}(^1P_1)$ and $K_{1B}(^3P_1)$

$D \to A\ell^+\nu_\ell : D^0 \to K_1(1270)^- e^+\nu_e$

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

- 2.93 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 109.0 \pm 12.5$
- $\mathcal{B}(D^0 \to K_1(1270)^- e^+\nu_e) = (1.09 \pm 0.13^{+0.09}_{-0.16} \pm 0.12)\times 10^{-3}$
- Benefit the study of the photon polarization in $B \to K_1\gamma$
- $F_L = 0.50 \pm 0.17 \pm 0.08$ agree with LCSR [J. Phys. G 46, 105006 (2019)]



$D \to A\ell^+\nu_\ell : D^{0(+)} \to b_1(1235)^{-(0)}e^+\nu_e$

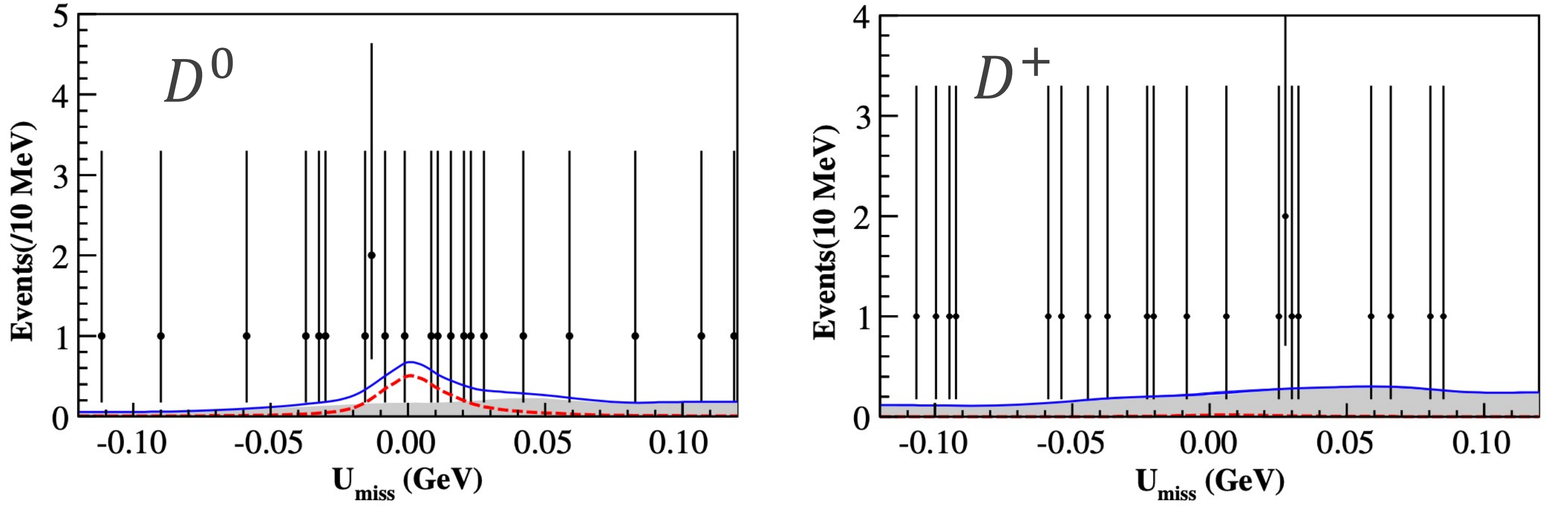
Phys. Rev. D 102, 112005 (2020)

- 2.93 fb^{-1} data @ 3.773 GeV
- First search and upper limit measurement on BF:

$\mathcal{B}(D^0 \to b_1(1235)^- e^+\nu_e, b_1(1235)^- \to \omega\pi^-) < 1.12\times10^{-4}$@90%C.L.

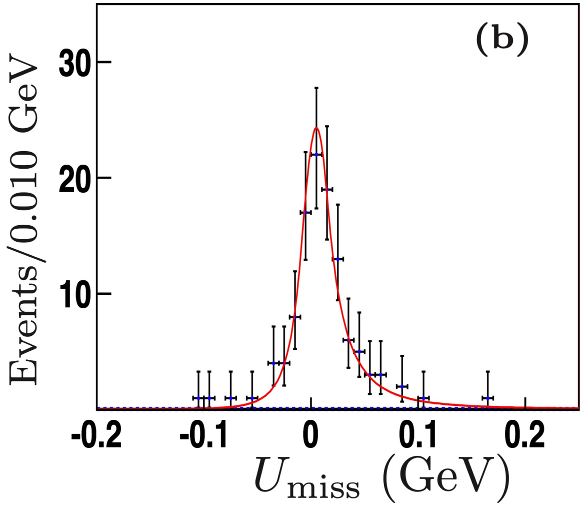
$\mathcal{B}(D^+ \to b_1(1235)^0 e^+\nu_e, b_1(1235)^0 \to \omega\pi^0) < 1.75\times10^{-4}$@90%C.L.

➔ Be comparable with the theoretical prediction [H. Y. Cheng and X. W. Kang, Eur. Phys. J. C 77, 587(2017)

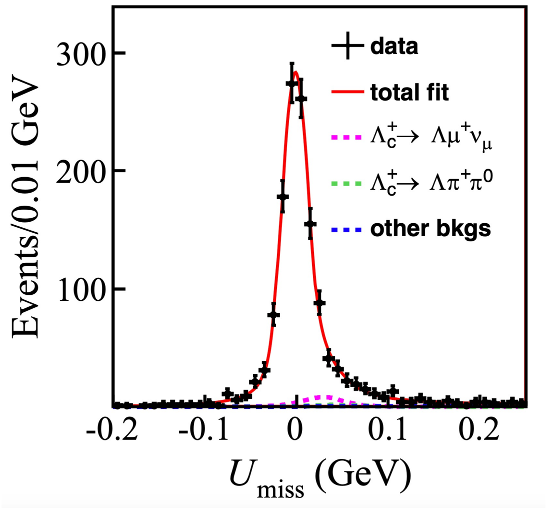


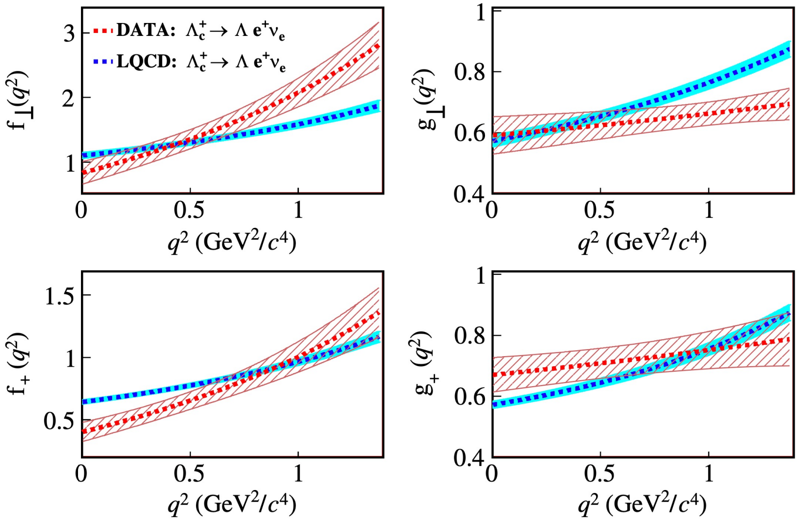
$\Lambda_c^+ \to B\ell^+\nu_\ell : \Lambda_c^+ \to \Lambda e^+\nu_e$

Phys. Rev. Lett. 115, 221805 (2015)



Phys. Rev. Lett. 129, 231803 (2022)





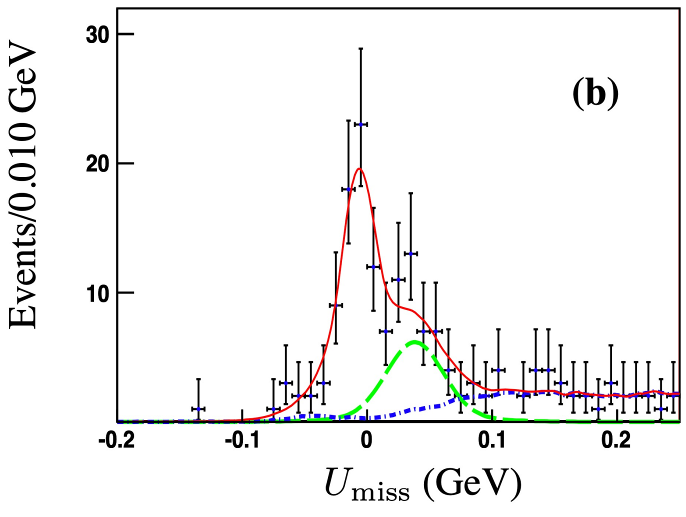
- 567 pb^{-1} data @ 4.600 GeV ➔ $N_{sig} = 103.5 \pm 10.9$
- First absolute BF measurement:
- $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$ (~12%)

- 4.5 fb^{-1} data @ 4.600-4.699 GeV ➔ $N_{sig} = 1253 \pm 39$
- Updated BF and first FF measurement:
- $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$ (~4%)
- $|V_{cs}| = 0.936 \pm 0.017_{\mathcal{B}} \pm 0.024_{\rm LQCD} \pm 0.024_{\tau_{\Lambda_c}}$

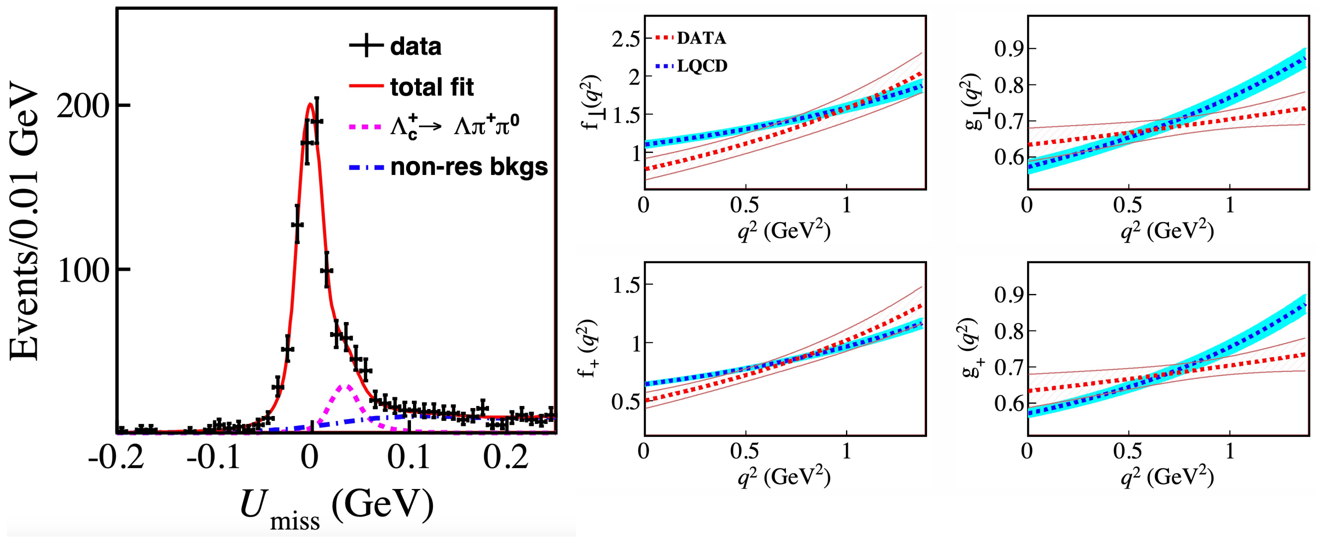
Agree with $|V_{cs}| = 0.939/0.972 \pm 0.038/0.007$ (PDG2020/2022)

$\Lambda_c^+ \to B\ell^+\nu_\ell : \Lambda_c^+ \to \Lambda\mu^+\nu_\mu$

Phys. Lett. B 767, 42-47 (2017)



Arxiv:2306.02624 (2023) (submitted to PRL)



- 567 $\rm pb^{-1}$ data @ 4.600 GeV ➔ $N_{sig} = 77.1 \pm 11.4$
- First absolute BF measurement:

$\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu) = (3.49 \pm 0.46 \pm 0.27)\%$ (~15%)

- $\mathcal{R}_{\mu/e} = 0.96 \pm 0.16 \pm 0.04$

- 4.5 $\rm fb^{-1}$ data @ 4.600-4.699 GeV ➔ $N_{sig} = 752 \pm 31$
- Updated BF and first FF measurement:

$\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu) = (3.48 \pm 0.14 \pm 0.10)\%$ (~5%)

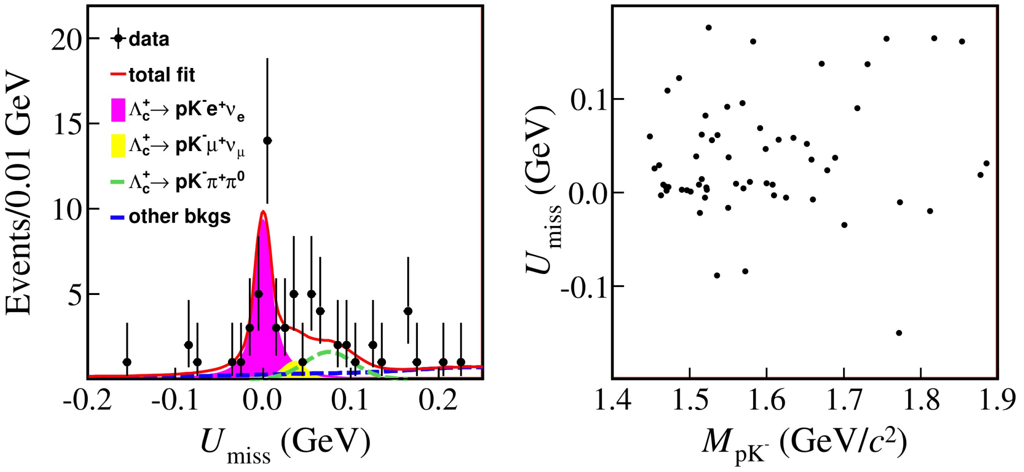
- $|V_{cs}| = 0.937 \pm 0.014_{\mathcal{B}} \pm 0.024_{\rm LQCD} \pm 0.007_{\tau_{\Lambda_c}}$
- $\mathcal{R}_{\mu/e} = 0.98 \pm 0.05 \pm 0.03$ **vs** SM: 0.97 **--> No LFUV**

$\Lambda_c^+ \to B\ell^+\nu_\ell : \Lambda_c^+ \to pK^-e^+\nu_e$

Phys. Rev. D. 106, 112010 (2022)

- 4.5 fb^{-1} data @ 4.600-4.699 GeV ➔ $N_{sig} = 33.5 \pm 6.3$
- New observed mode clearly confirms that SL $\boldsymbol{\Lambda_c^+}$ decays are not saturated by $\Lambda\ell^+\nu_\ell$

  $\mathcal{B}(\Lambda_c^+ \to pK^-e^+\nu_e) = (0.88 \pm 0.17 \pm 0.07) \times 10^{-3}$ (8.2 σ)



- To understand the nature of excited Λ^*

$\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)[\to pK^-]e^+\nu_e) = (0.23 \pm 0.12 \pm 0.02) \times 10^{-3}$ (3.3 σ)

$\mathcal{B}(\Lambda_c^+ \to \Lambda(1405)[\to pK^-]e^+\nu_e) = (0.42 \pm 0.19 \pm 0.04) \times 10^{-3}$ (3.2 σ)

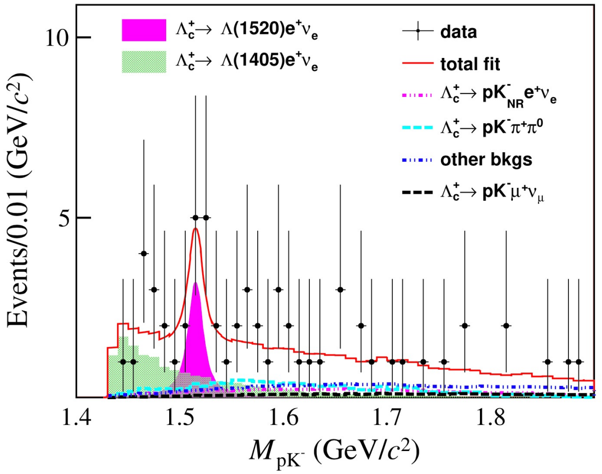
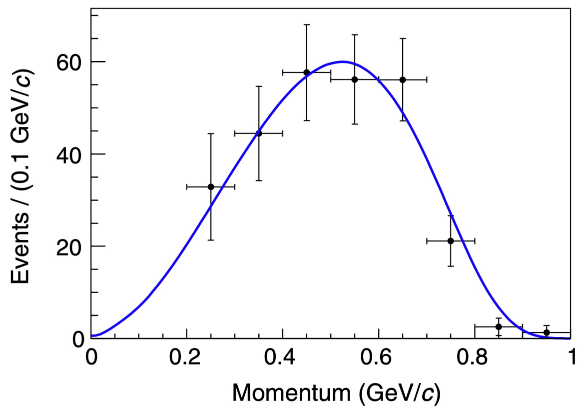


TABLE I. Comparison of $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)/\Lambda(1405)e^+\nu_e)$ [in $\times 10^{-3}$] between theoretical calculations and this measurement. The BF of $\Lambda(1405) \to pK^-$ is unknown [2].

	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e)$	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1405)e^+\nu_e)$
Constituent quark model [8]	1.01	3.04
Molecular state [9]	...	0.02
Nonrelativistic quark model [10]	0.60	2.43
Lattice QCD [12,13]	0.512 ± 0.082	...
Measurement	$1.02 \pm 0.52 \pm 0.11$	$\frac{0.42 \pm 0.19 \pm 0.04}{\mathcal{B}(\Lambda(1405) \to pK^-)}$

$\Lambda_c^+ \to B\ell^+\nu_\ell$: $\Lambda_c^+ \to Xe^+\nu_e$

Phys. Rev. Lett. 121, 251801 (2018)

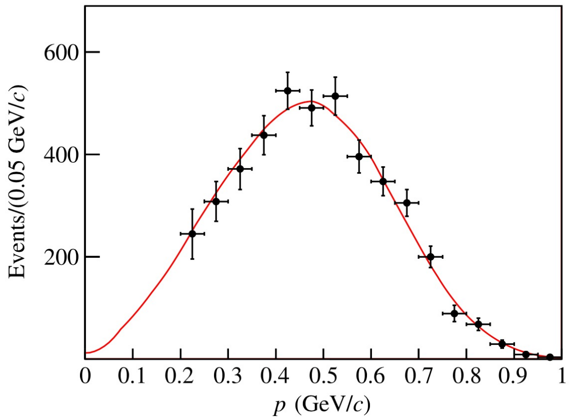


- $567\ \mathrm{pb}^{-1}$ data @ 4.600 GeV ➔ $N_{\mathrm{obs}} = 228.0 \pm 15.1$
- $\mathcal{B}(\Lambda_c^+ \to Xe^+\nu_e) = (3.95 \pm 0.34 \pm 0.09)\%$ (~ 9%)
- $\Gamma(\Lambda_c^+ \to Xe^+\nu_e)/\bar{\Gamma}(D \to Xe^+\nu_e) = 1.26 \pm 0.12$

TABLE V. Comparison of the branching fraction (in 10^{-2}) and ratio of the semileptonic decay width between experimental measurements and theoretical predictions.

Result	$\Lambda_c^+ \to Xe^+\nu_e$	$[\Gamma(\Lambda_c^+ \to Xe^+\nu_e)/\bar{\Gamma}(D \to Xe^+\nu_e)]$
BESIII	3.95 ± 0.35	1.26 ± 0.12
MARK II [11]	4.5 ± 1.7	1.44 ± 0.54
Effective-quark method [8,9]		1.67
Heavy-quark expansion [10]		1.2

Phys. Rev. D. 107, 052005 (2023)



- $4.5\ \mathrm{fb}^{-1}$ data @ 4.600-4.699 GeV ➔ $N_{\mathrm{obs}} = 3706 \pm 71$
- $\mathcal{B}(\Lambda_c^+ \to Xe^+\nu_e) = (4.06 \pm 0.10 \pm 0.09)\%$ (~ 3%)

  ➔ Unknown decays: ~0.5%

- $\Gamma(\Lambda_c^+ \to Xe^+\nu_e)/\bar{\Gamma}(D \to Xe^+\nu_e) = 1.28 \pm 0.05$

Phys. Lett. B 843, 137993 (2023)

- $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu_e) < 3.9\times10^{-4}$ @90%C.L.
- $\mathcal{B}(\Lambda_c^+ \to pK_S^0\pi^-e^+\nu_e) < 3.3\times10^{-4}$ @90%C.L.

Summary and prospect

Summary:

In this report, many (semi-)leptonic D decays are presented. Thanks to the largest data samples produced at at $D\bar{D}/D_sD_s^*/\Lambda_c^+\Lambda_c^-$ threshold, in a very clean environment, BESIII has a leading role as follow:

- Precise measurement of $f_{D_{(s)}}$ and FFs in SL D decay and CKM elements ⇒ 1% level
- No evidence of LFU violation found in charm sector ⇒ 1.5% precision level
- Many first observation channels, especially μ modes
- Amplitude analysis ⇒ provide necessary information for dynamic study
- Study the nature of light hadrons in semi-leptonic decay (a_0, f_0, K_1)

Summary and prospect

Prospect:

- BESIII has **8 fb^{-1}** @3.773 GeV now.
- BESIII will have **20 fb^{-1}** @3.773 GeV in total in the coming 2024!
- More results are on the way!

BESIII go after Best!

Thank you!

	BESIII	BESIII	Belle	Belle II
Luminosity	2.9 fb^{-1}@3.773 GeV	20 fb^{-1}@3.773 GeV	0.28 ab^{-1}	50 ab^{-1}
$D^0 \to K^- e^+ \nu_e$	$0.4\%_{\rm stat.}\ 0.5\%_{\rm syst.}$	$0.2\%_{\rm stat.} 0.4\%_{\rm syst.}$	$1.0\%_{\rm stat.}\ 3.2\%^*_{\rm syst.}$	$0.1\%_{\rm stat.} 1.6\%^*_{\rm syst.}$
$D^0 \to K^- \mu^+ \nu_\mu$	$0.5\%_{\rm stat.}\ 0.4\%_{\rm syst.}$	$0.2\%_{\rm stat.} 0.4\%_{\rm syst.}$		
$D^0 \to \pi^- e^+ \nu_e$	$1.3\%_{\rm stat.}\ 0.7\%_{\rm syst.}$	$0.5\%_{\rm stat.} 0.4\%_{\rm stat.}$	$3.2\%_{\rm stat.}\ 4.8\%^*_{\rm syst.}$	$0.2\%_{\rm stat.} 2.4\%^*_{\rm syst.}$
$D^0 \to \pi^- \mu^+ \nu_\mu$	NA	$0.8\%_{\rm stat.} 0.8\%_{\rm syst.}$		
$D^0 \to K^{*-} e^+ \nu_e$				
r_V	$5.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	$2.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	–	–
r_A	$10.\%_{\rm stat.} 2.0\%_{\rm syst.}$	$4.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	–	–
$D^0 \to a_0^-(980) e^+ \nu_e$	NA	$10.\%_{\rm stat.} 5.0\%_{\rm syst.}$	–	–
$D^0 \to K_1^-(1270) e^+ \nu_e$	NA	$10.\%_{\rm stat.} 5.0\%_{\rm syst.}$	–	–
$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.6\%_{\rm stat.}\ 1.7\%_{\rm syst.}$	$0.2\%_{\rm stat.} 1.0\%_{\rm syst.}$	–	–
$D^+ \to K^0_L e^+ \nu_e$	$0.9\%_{\rm stat.}\ 1.6\%_{\rm syst.}$	$0.4\%_{\rm stat.} 1.0\%_{\rm syst.}$	–	–
$D^+ \to \bar{K}^0 \mu^+ \nu_\mu$	NA	$0.3\%_{\rm stat.} 1.0\%_{\rm syst.}$	–	–
$D^+ \to \bar{K}^{*0} e^+ \nu_e$				
$A_1(0)$	$1.7\%_{\rm stat.}\ 2.0\%_{\rm syst.}$	$0.7\%_{\rm stat.} 1.0\%_{\rm syst.}$	–	–
r_V	$4.0\%_{\rm stat.}\ 0.5\%_{\rm syst.}$	$1.6\%_{\rm stat.} 0.5\%_{\rm syst.}$	–	–
r_A	$5.0\%_{\rm stat.}\ 1.0\%_{\rm syst.}$	$2.0\%_{\rm stat.} 1.0\%_{\rm syst.}$	–	–
$D^+ \to \pi^0 e^+ \nu_e$	$1.9\%_{\rm stat.}\ 0.5\%_{\rm syst.}$	$0.7\%_{\rm stat.} 0.5\%_{\rm syst.}$	–	–
$D^+ \to \pi^0 \mu^+ \nu_\mu$	NA	$1.0\%_{\rm stat.} 1.0\%_{\rm syst.}$	–	–
$D^+ \to \eta e^+ \nu_e$	$4.5\%_{\rm stat.} 2.0\%_{\rm syst.}$	$2.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	–	–
$D^+ \to \eta' e^+ \nu_e$	NA	$10.\%_{\rm stat.} 5.0\%_{\rm syst.}$	–	–
$D^+ \to \omega e^+ \nu_e$				
r_V	$7.2\%_{\rm stat.}\ 4.8\%_{\rm syst.}$	$3.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	–	–
r_A	$14\%_{\rm stat.}\ 5.0\%_{\rm syst.}$	$3.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	–	–
$D^+ \to a_0^0(980) e^+ \nu_e$	NA	$10.\%_{\rm stat.} 5.0\%_{\rm syst.}$	–	–
$D^+ \to \bar{K}_1^0(1270) e^+ \nu_e$	NA	$10.\%_{\rm stat.} 5.0\%_{\rm syst.}$	–	–
$D^{0(+)} \to \rho^{-(0)} e^+ \nu_e$				
r_V	$5.0\%_{\rm stat.} 4.0\%_{\rm syst.}$	$2.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	–	–
r_A	$8.0\%_{\rm stat.} 4.0\%_{\rm syst.}$	$3.0\%_{\rm stat.} 2.0\%_{\rm syst.}$	–	–