

Leptonic and semi-leptonic charm decays at BESIII

Bai-Cian Ke

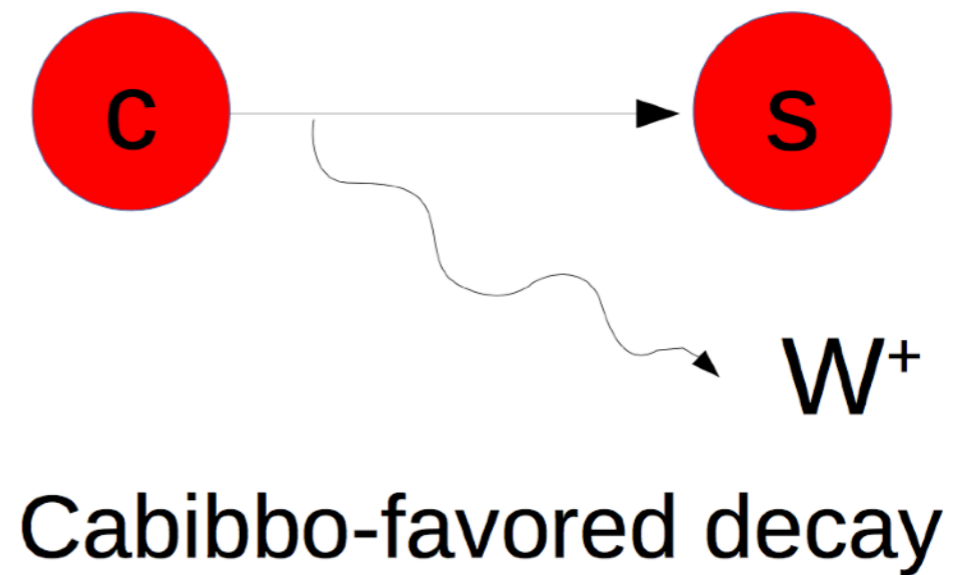
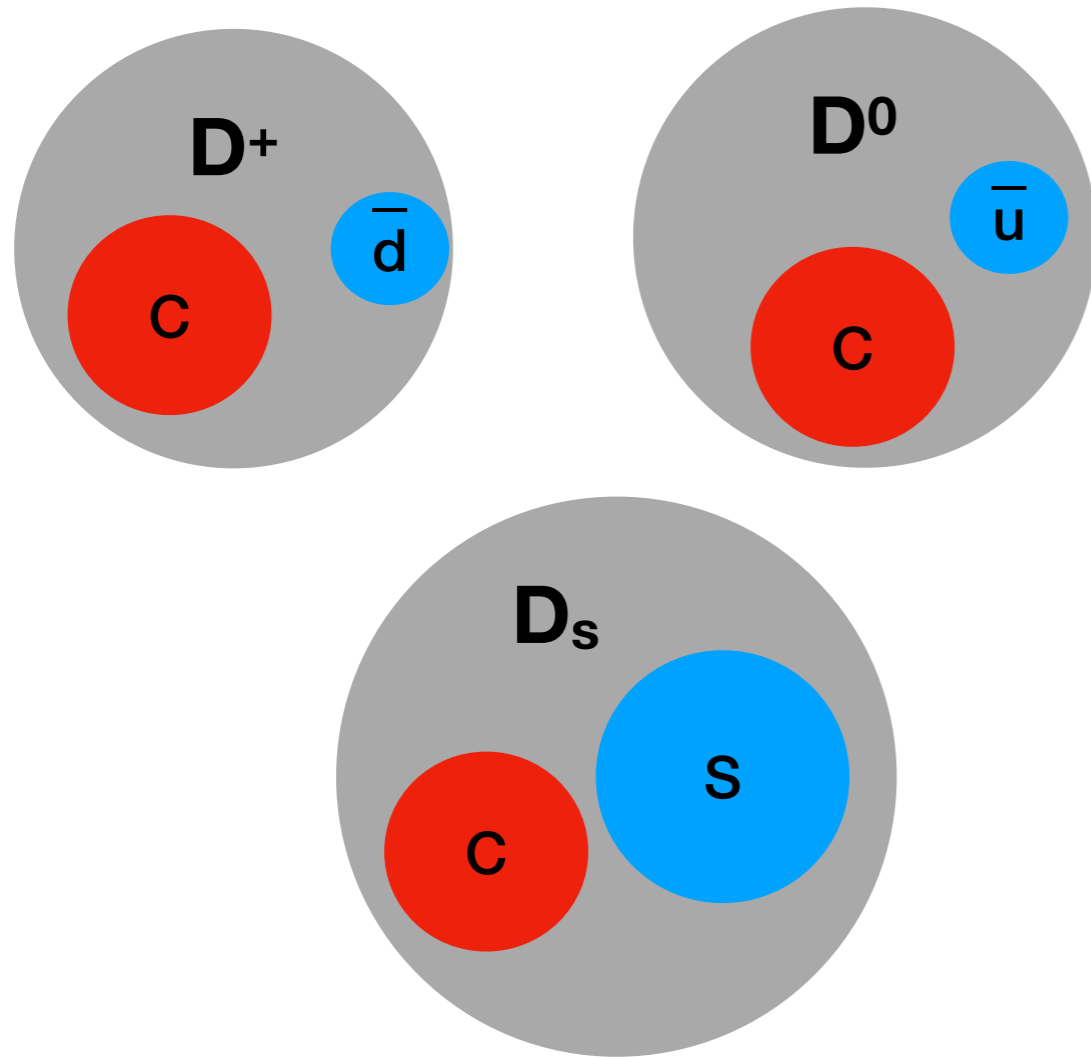
On behalf of the BESIII Collaboration



Outline

- Introduction
 - D^0 , D^+ , and D_s Dataset
 - DTag
- Pure leptonic decays of D^0
- Semi-leptonic decays of $D^{0(+)}$
- (Semi-) leptonic decays of D_s
- Summary

Physics of $D_{(s)}$ meson



- The lightest mesons containing a single charm quark
- Only decay through the weak interaction

BESIII Data Taken near DD^{bar} Threshold

- BEPCII e^+e^- collider
- 2.9 fb^{-1} dataset at $\psi(3770) \rightarrow DD^{\text{bar}}$ resonance
**Not even enough energy
for one additional pion**
- 3.19 fb^{-1} dataset at E_{cm} 4.178 GeV
 - D_s are produced mostly via $e^+e^- \rightarrow D_s D_s^*$
- XYZ dataset at E_{cm} 4.19 - 4.23 GeV (about .8x of 4180 data)
- Advantages:

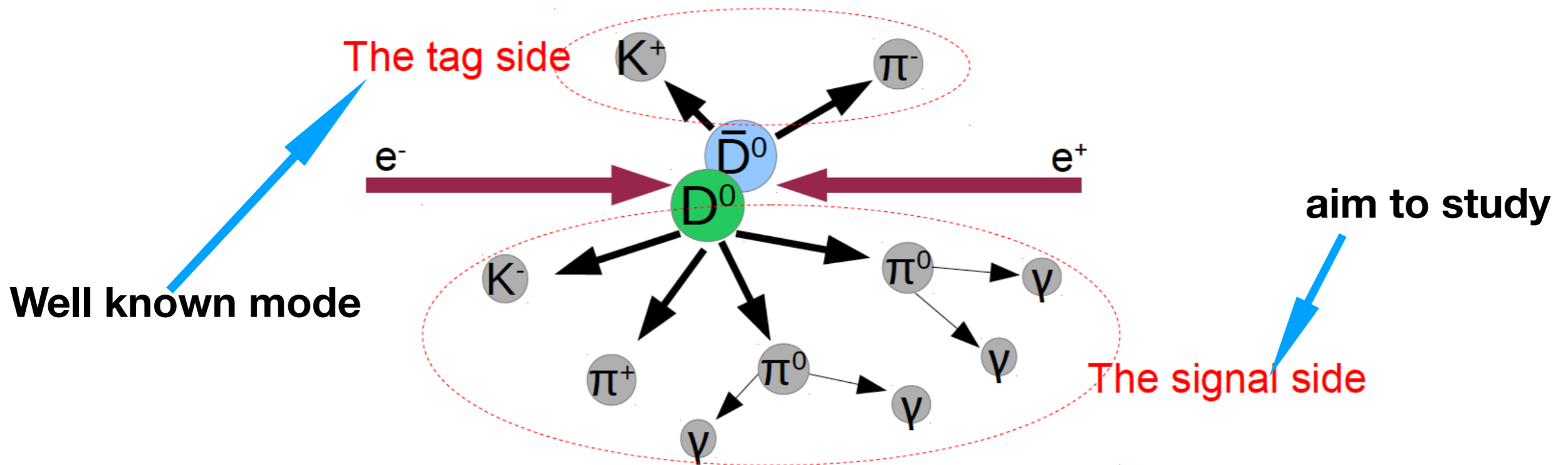
Clean Tagging

Access to absolute branching fraction

Many systematic uncertainties cancel

DTag Technique

- Two types of samples
- Single-tag (ST):
 - reconstruct only one D meson
- Double-tag (DT):
 - reconstruct both D mesons (fully reconstruct the event)



Branching Fraction and Tagging

- Single tag (ST)

$$N_{\text{tag}}^{\text{ST}} = 2N_{D^0\bar{D}^0}\mathcal{B}_{\text{tag}}\varepsilon_{\text{tag}}$$

- Double tag (DT)

$$N_{\text{tag,sig}}^{\text{DT}} = 2N_{D^0\bar{D}^0}\mathcal{B}_{\text{tag}}\mathcal{B}_{\text{sig}}\varepsilon_{\text{tag,sig}}$$

$$\varepsilon_{\text{tag,sig}} \approx \varepsilon_{\text{tag}}\varepsilon_{\text{sig}} \text{ (factorization)}$$

where $N_{D^0\bar{D}^0}$ is the total number of produced $D^0\bar{D}^0$ pairs, $\mathcal{B}_{\text{tag(sig)}}$ is the branching fraction of the tag (signal) side, and the ε are the corresponding efficiencies.

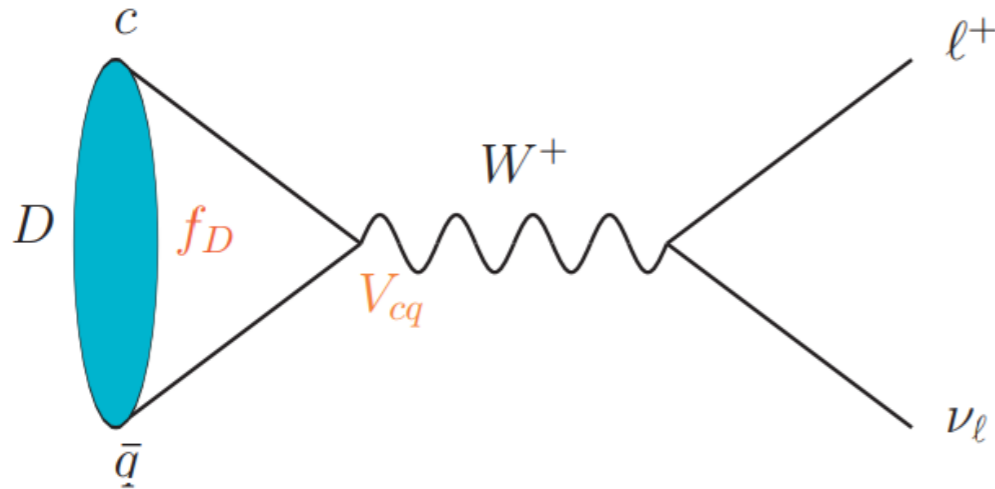
$$\mathcal{B}_{\text{sig}} = \frac{N_{\text{tag,sig}}^{\text{DT}}}{N_{\text{tag}}^{\text{ST}}} \frac{\varepsilon_{\text{tag}}}{\varepsilon_{\text{tag,sig}}}$$

$N_{D^0\bar{D}^0}$, \mathcal{B}_{tag} are canceled.
 ε_{tag} is approximately canceled due to factorization

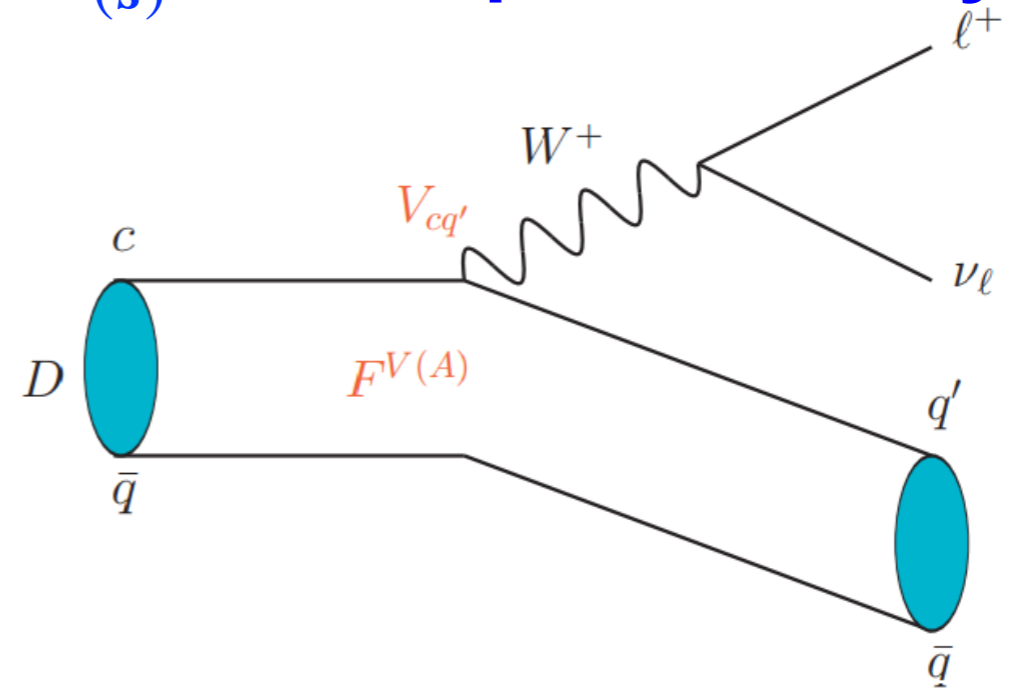
This is the basic idea for branching fraction.
Equations used in analysis vary case by case.

Introduction

$D_{(s)}$ pure leptonic decay



$D_{(s)}$ semi-leptonic decay



$$\mathcal{M} \propto |V_{cs(d)}| H^\mu L_\mu$$

$$\Gamma(D_{(s)}^+ \rightarrow l^+ \nu_l) \propto |f_{D_{(s)}^+}|^2 \cdot |V_{cd(s)}|^2$$

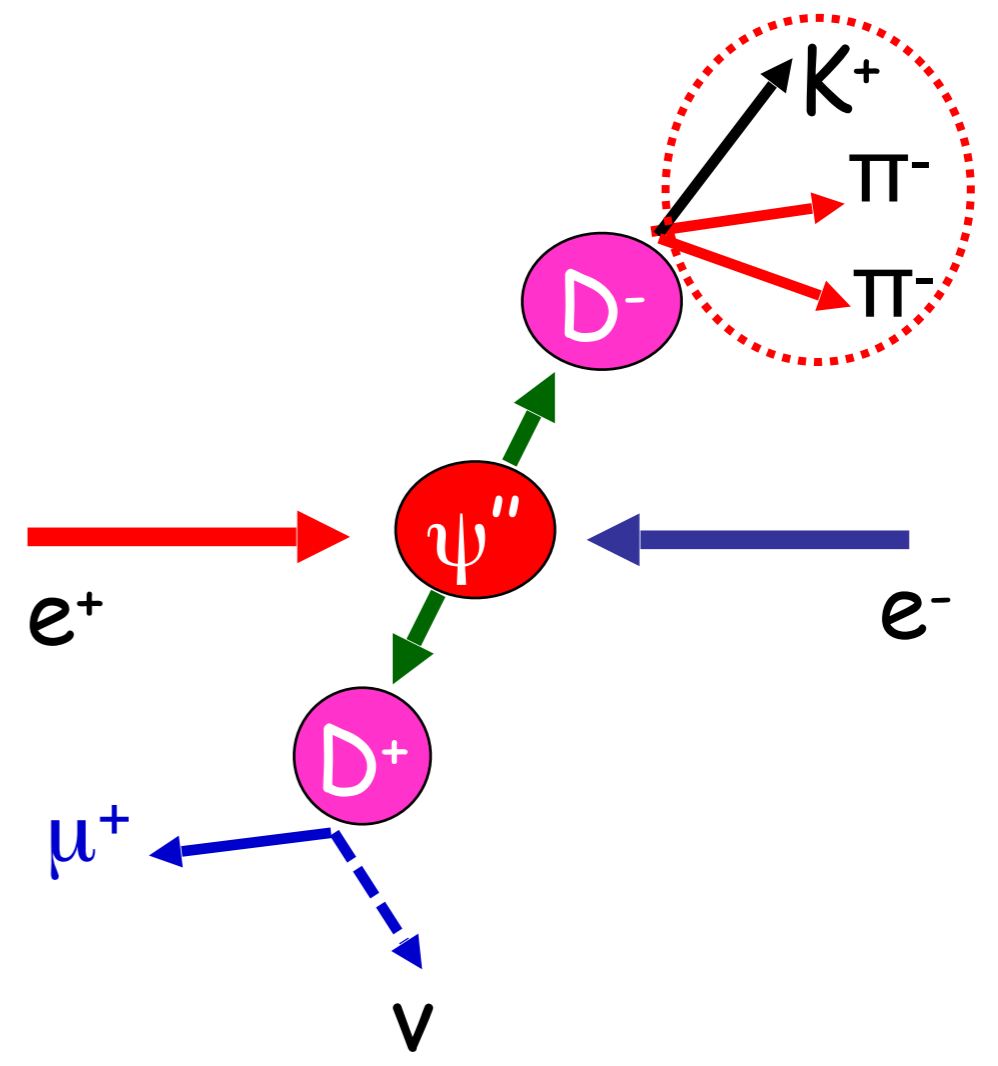
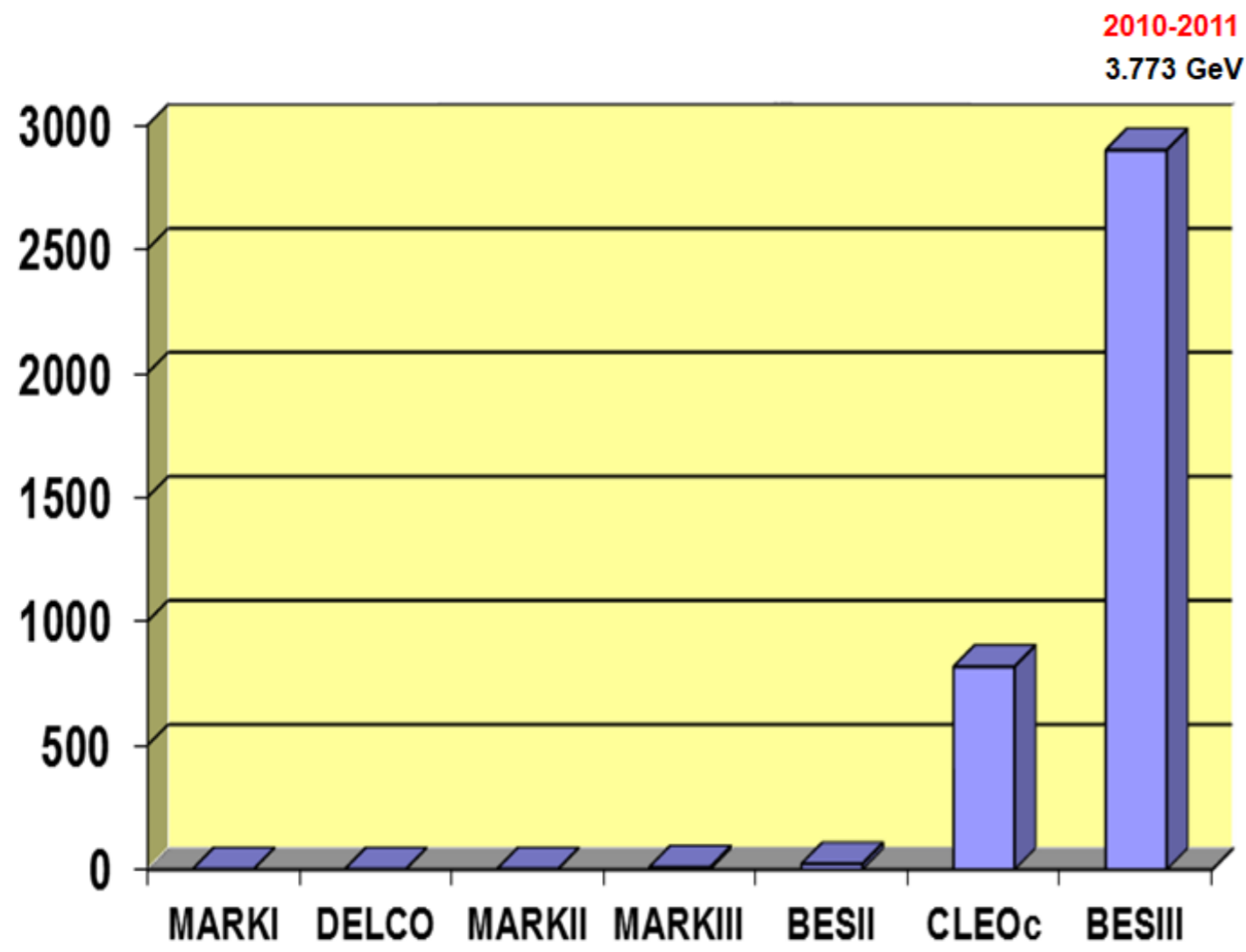
$$\Gamma(D_{(s)} \rightarrow P l^+ \nu_l) \propto |f_+(q^2)|^2 \cdot |V_{cd(s)}|^2$$

Decay constant $f_{D_{(s)}^+}$, form factor $f_+(q^2)$: Calibrate Lattice QCD

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

Lepton flavor universality test in charm sector

D⁰⁽⁺⁾ samples at ψ(3770)

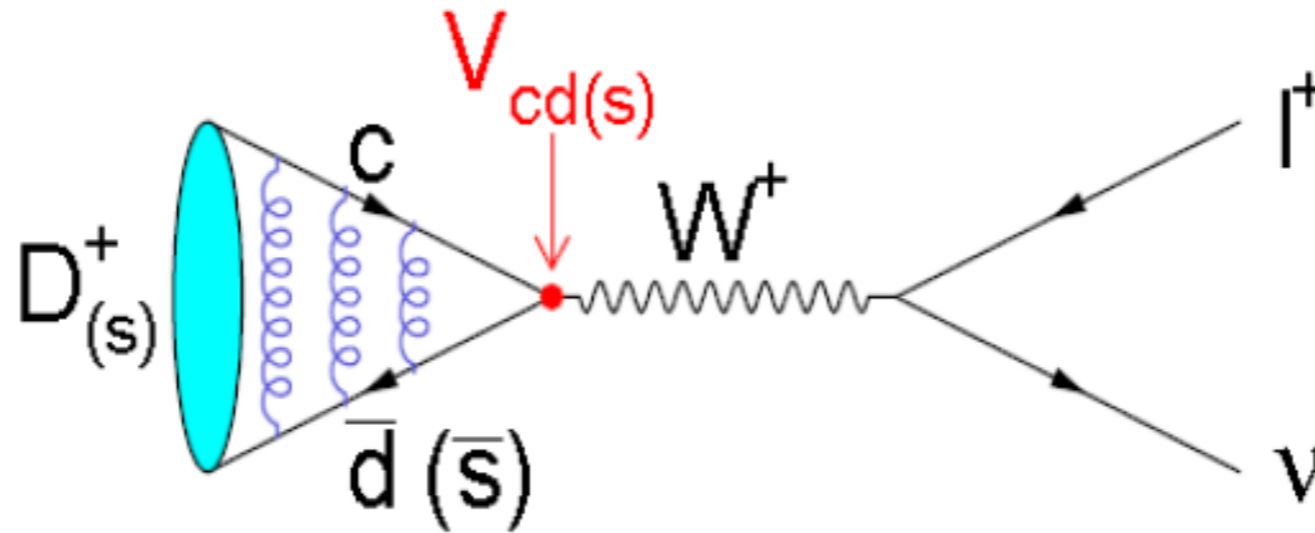


Neutrino is the only particle missing in an event

$$U_{\text{miss}} = E_{\text{miss}} - |\vec{p}_{\text{miss}}|$$

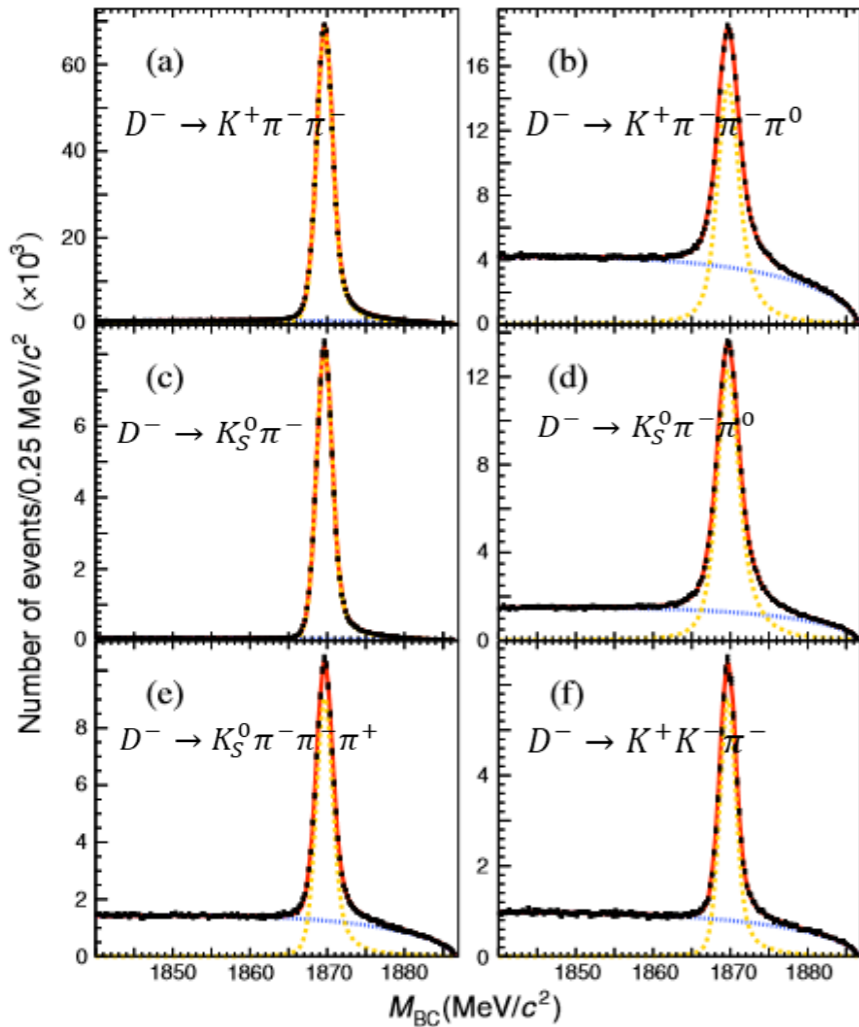
$$M_{\text{miss}}^2 = E_{\text{miss}}^2 - |\vec{p}_{\text{miss}}|^2$$

Pure leptonic D decay

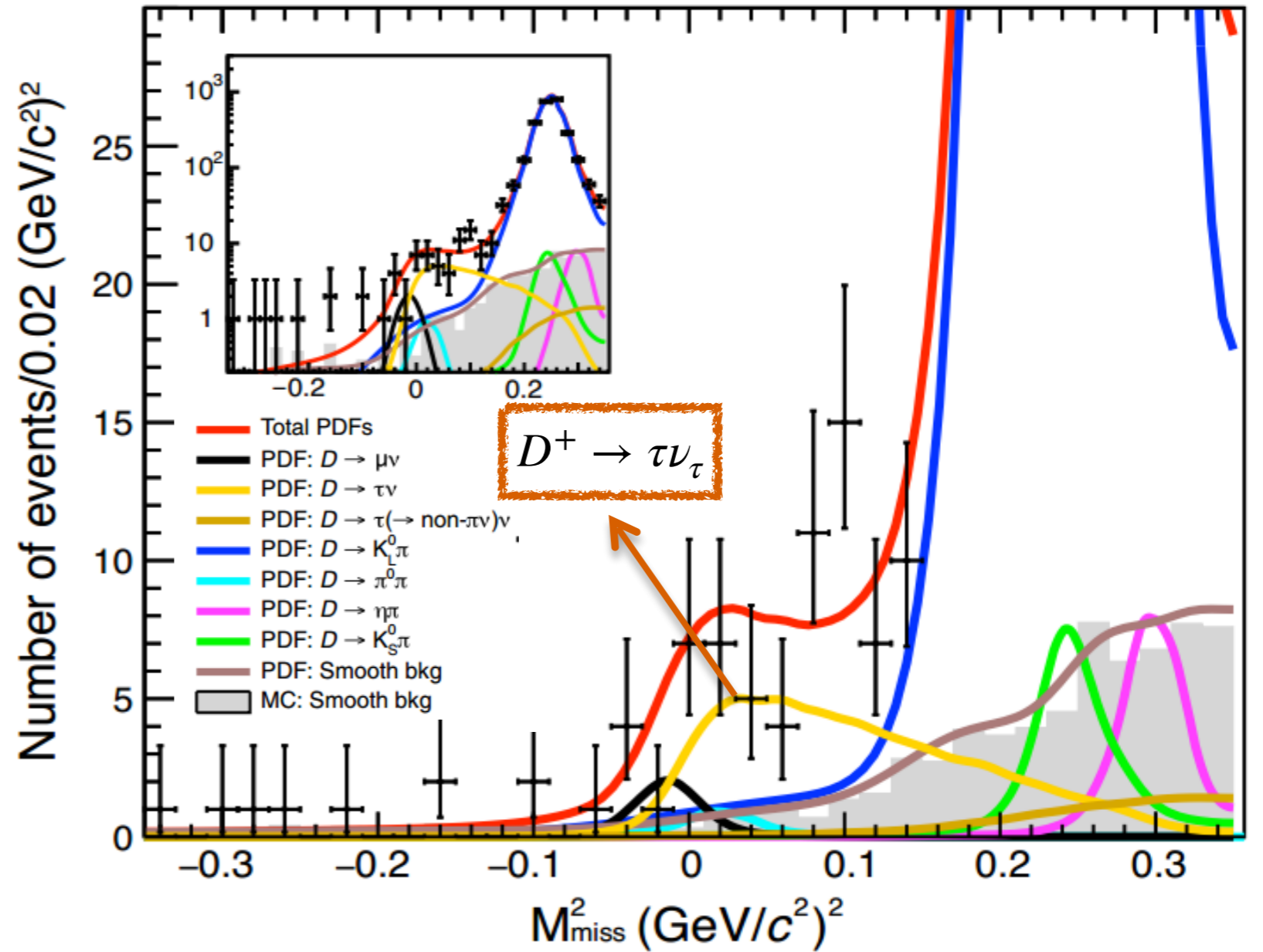


$$\Gamma\left(D_{(s)}^+ \rightarrow l^+ \nu\right) = \frac{G_F^2 f_{D_{(s)}^+}^2}{8\pi} \left| V_{cd(s)} \right|^2 m_l^2 m_{D_{(s)}^+} \left(1 - \frac{m_l^2}{m_{D_{(s)}^+}^2} \right)^2$$

$$D^+ \rightarrow \tau^+ \nu_\tau$$

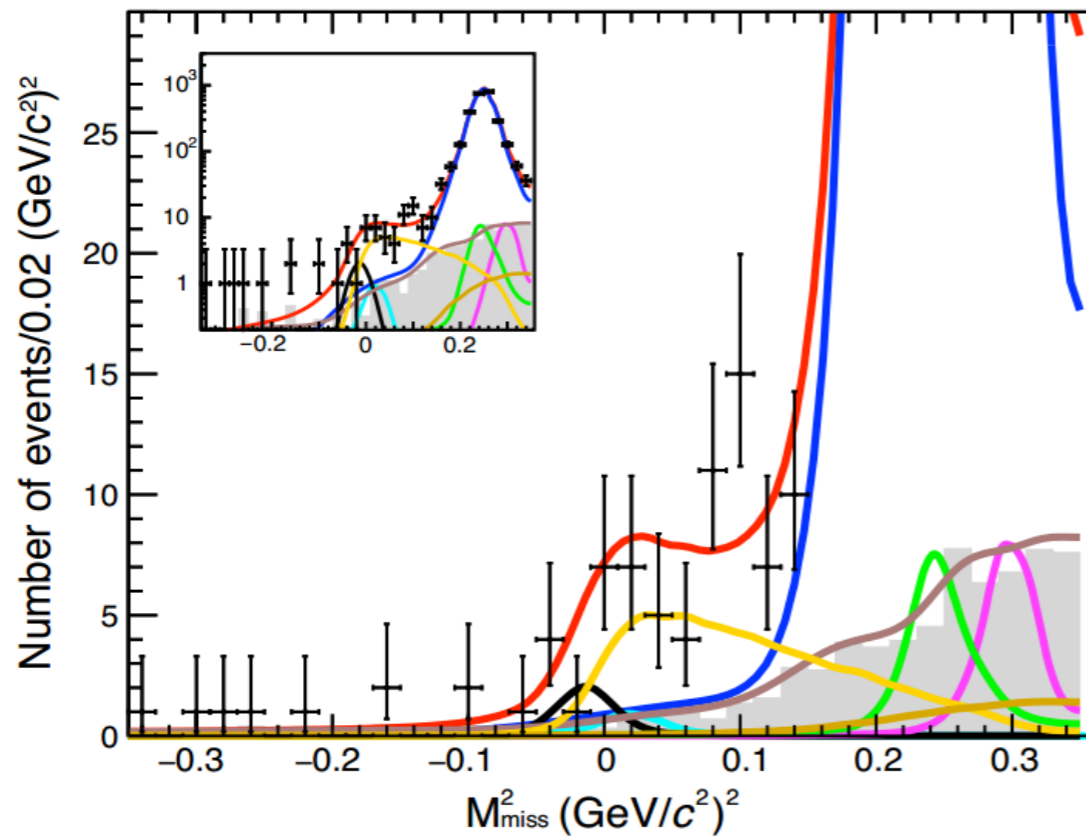


Tag modes, i	$N_{\text{tag}}^i (\times 10^3)$
$K^+ \pi^- \pi^-$	797.6 ± 1.0
$K^+ \pi^- \pi^- \pi^0$	245.1 ± 0.7
$K_S^0 \pi^-$	92.6 ± 0.3
$K_S^0 \pi^- \pi^0$	206.3 ± 0.6
$K_S^0 \pi^- \pi^- \pi^+$	110.2 ± 0.4
$K^+ K^- \pi^-$	68.1 ± 0.3



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

$$D^+ \rightarrow \tau^+ \nu_\tau$$



137±27 signal events

First observation with a significance of 5.1σ.

$$R_D \equiv \frac{\Gamma(D^+ \rightarrow \tau^+ \nu_\tau)}{\Gamma(D^+ \rightarrow \mu^+ \nu_\mu)} = 3.21 \pm 0.77$$

SM: \uparrow consistent

$$R_{\tau/\mu} = \frac{\Gamma(D^+ \rightarrow \tau^+ \nu_\tau)}{\Gamma(D^+ \rightarrow \mu^+ \nu_\mu)} = \frac{m_\tau^2 \left(1 - \frac{m_\tau^2}{M_{D^+}^2}\right)^2}{m_\mu^2 \left(1 - \frac{m_\mu^2}{M_{D^+}^2}\right)^2} = 2.7$$

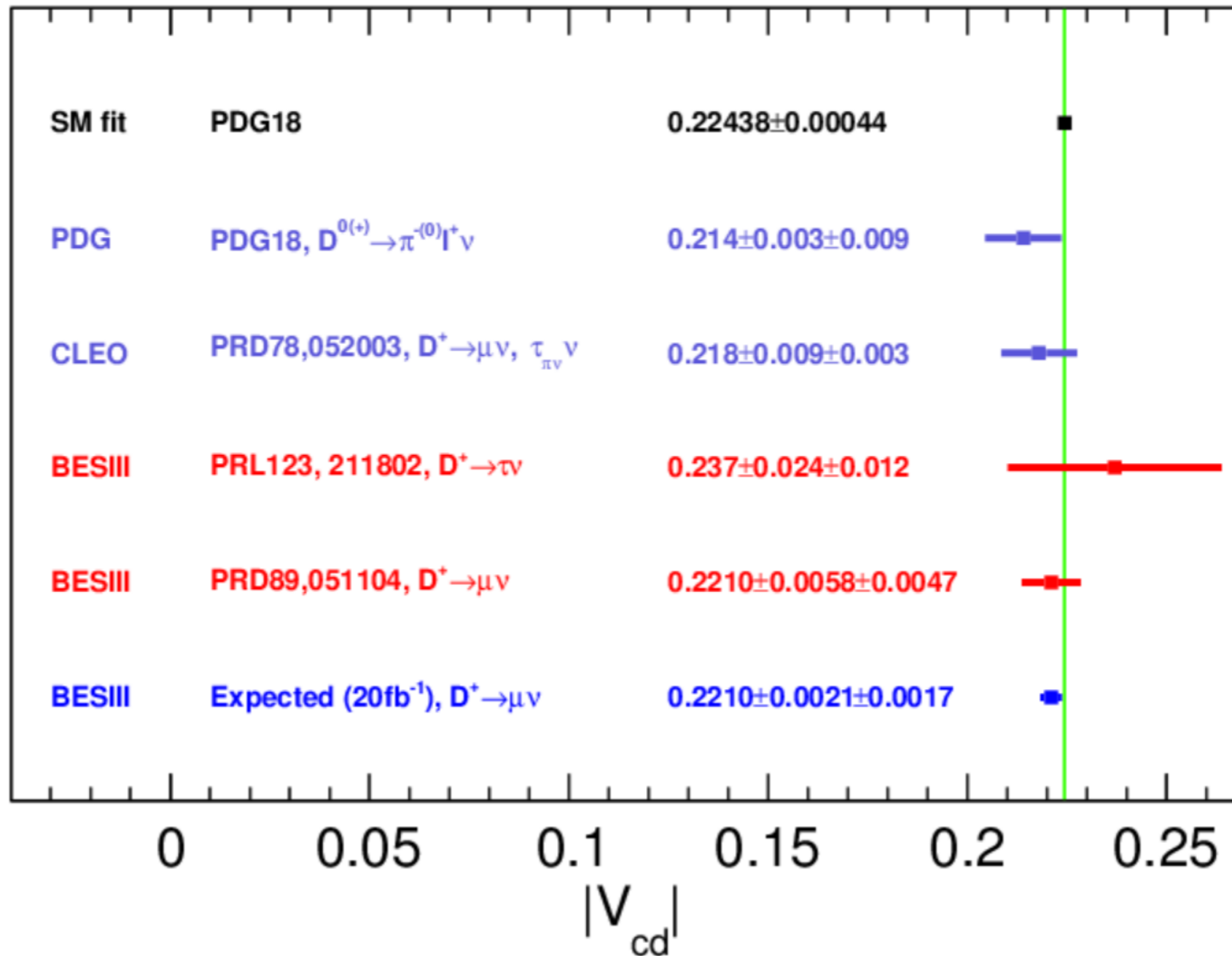
$$\mathcal{B}(D^+ \rightarrow \tau^+ \nu_\tau) = (1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$$

$$|V_{cd}| = 0.237 \pm 0.024_{\text{stat.}} \pm 0.012_{\text{system.}} \pm 0.001_{\text{ex-syst}}$$

$$f_{D^+} = 224.5 \pm 22.8_{\text{stat.}} \pm 11.3_{\text{system.}} \pm 0.9_{\text{ex-syst.}} \text{ MeV}$$

Comparison of $|V_{cd}|$

Input : $f_{D^+} = 212.3 \pm 0.6$ MeV LQCD average

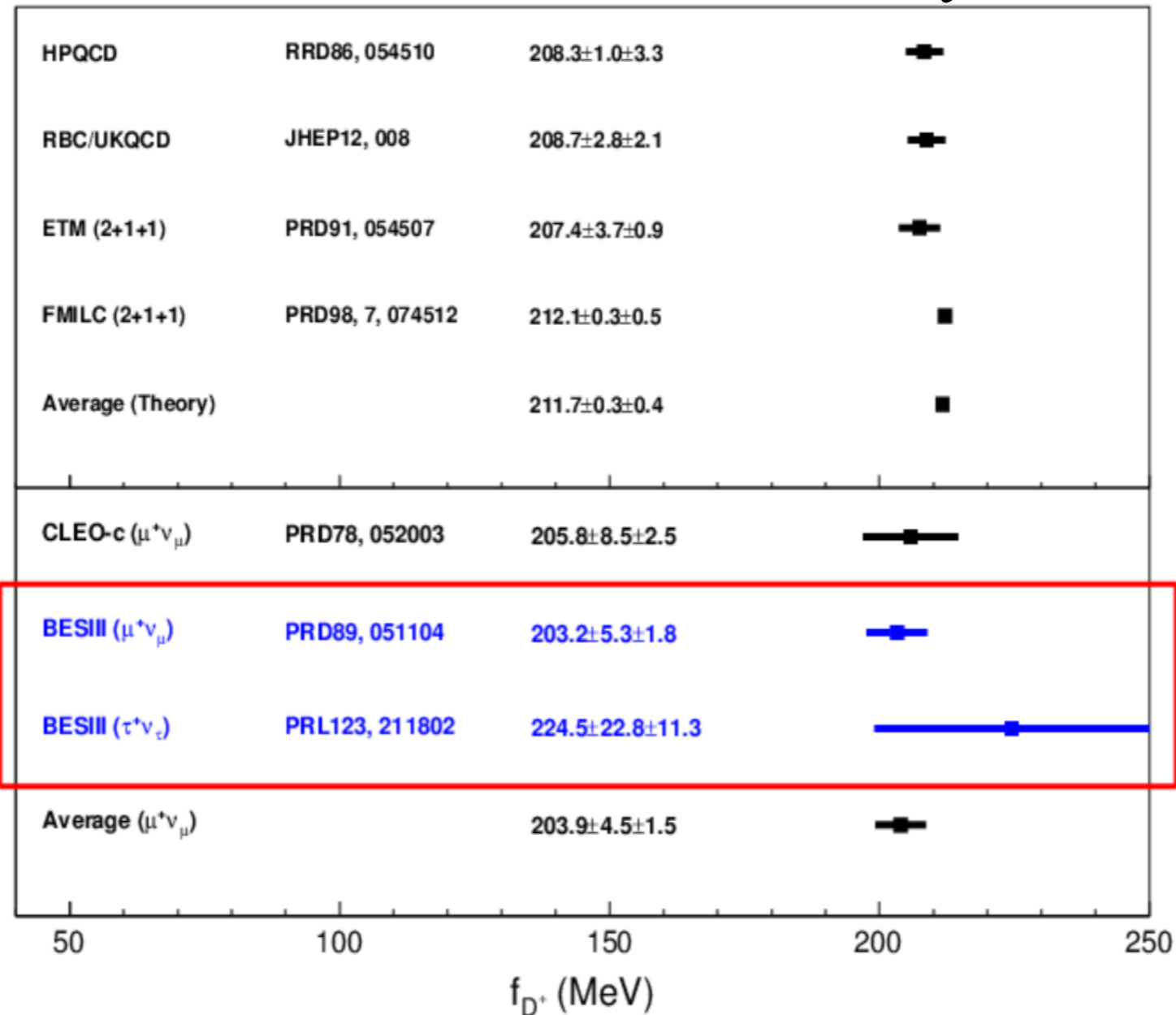


Comparison of f_{D^+}

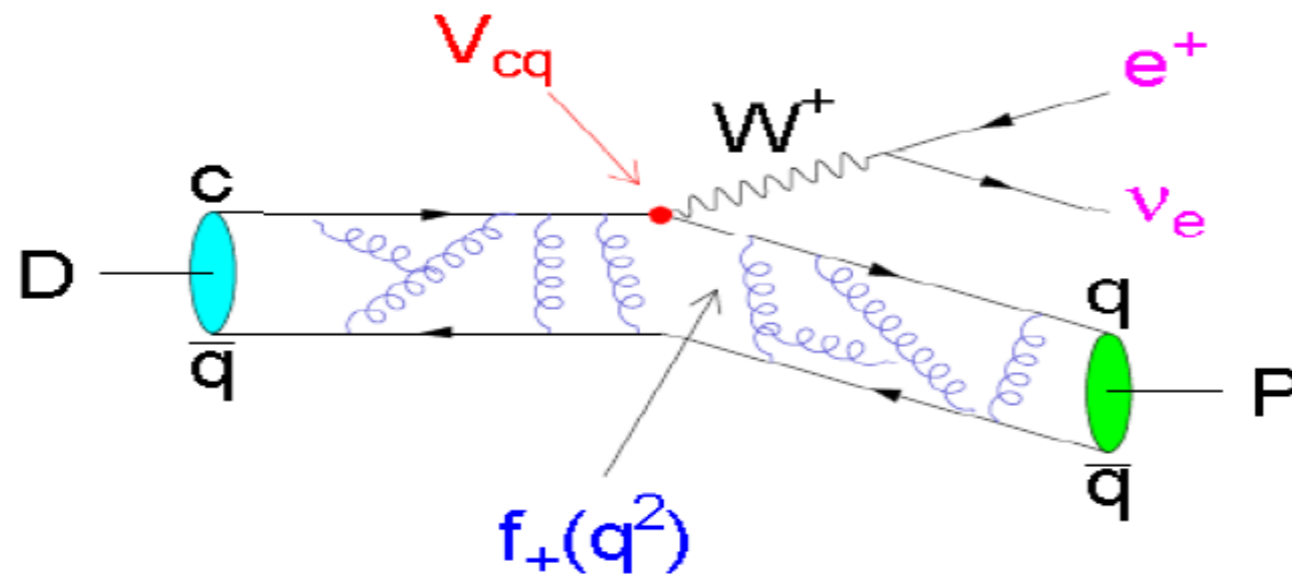
Input : $|V_{cd}|$

$=0.22438 \pm 0.00044$

PDG2018 from CKM unitarity



Semi-leptonic D decay



$$D \rightarrow P e^+ \nu (P = K, \pi, \eta^{(\prime)})$$

$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2 p^3}{24\pi^3} |f_+(q^2)|^2 |V_{cd(s)}|^2 \quad (X = 1 \text{ for } K^-, \pi^-, \bar{K}^0, \eta^{(\prime)}; X = \frac{1}{2} \text{ for } \pi^0)$$

– Single pole form

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

– ISGW2 model

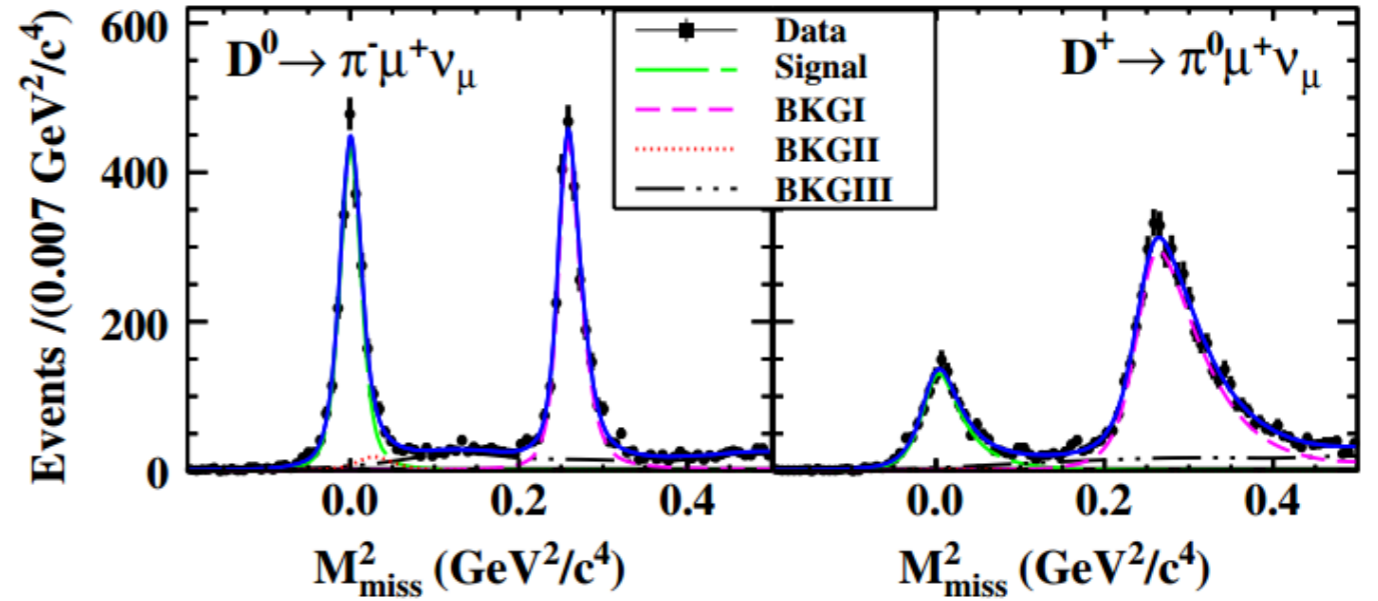
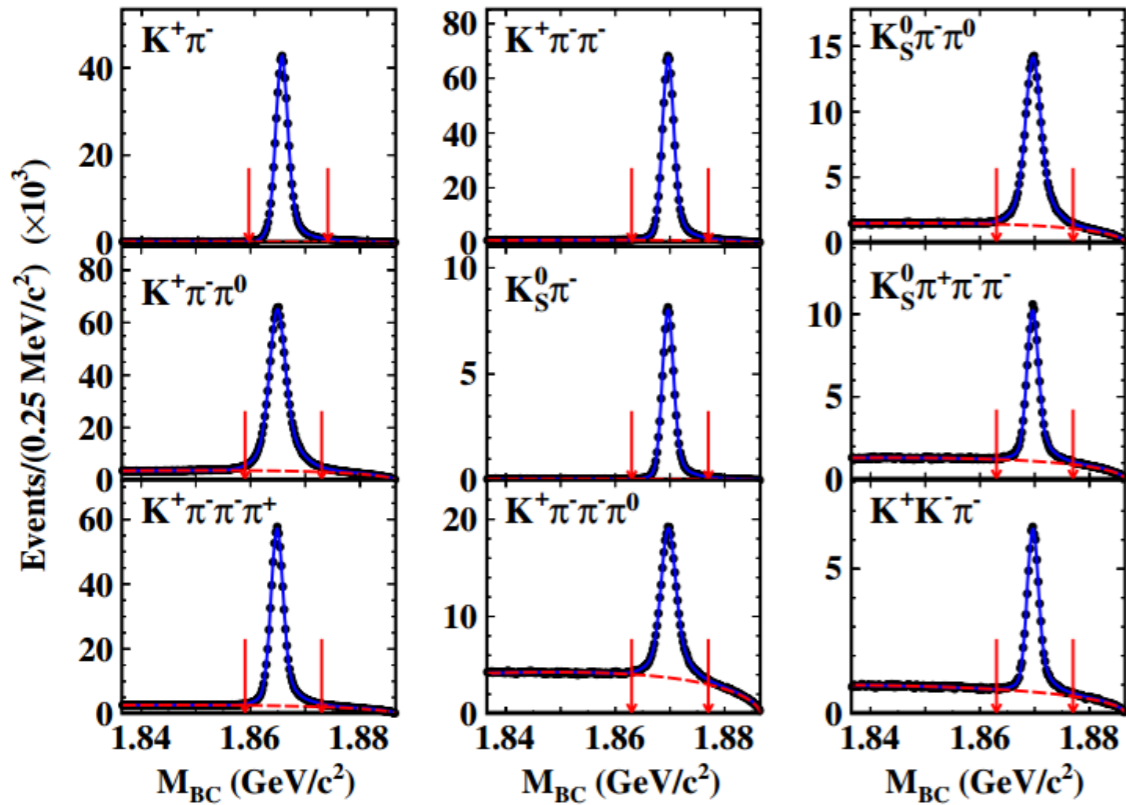
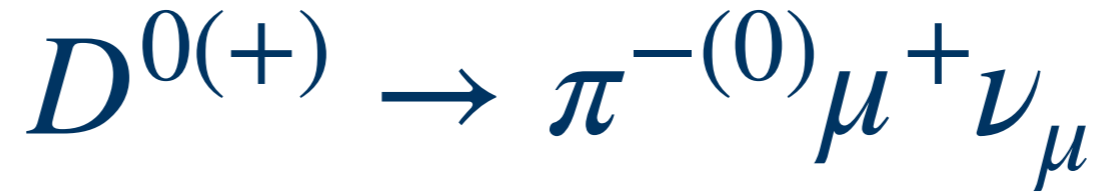
$$f_+(q^2) = f_+(q_{max}^2) \left(1 + \frac{r^2}{12} (q_{max}^2 - q^2) \right)^{-2}$$

– Modified pole model

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

– Series expansion model

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



BKGI: $D^{0(+)} \rightarrow \pi^{-(0)} \pi^+ \bar{K}^0$

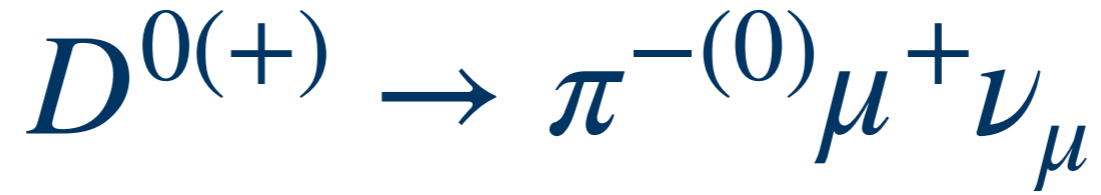
BKGI: $D^0 \rightarrow K^- \pi^+$, $D^{0(+)} \rightarrow \pi^{-(0)} \pi^+$,

$D^{0(+)} \rightarrow \pi^{-(0)} \pi^+ \pi^0$

BKGIII: other non-peaking backgrounds

$$\mathcal{B}(D^0 \rightarrow \pi^- \mu^+ \nu_\mu) = (0.272 \pm 0.008 \pm 0.006) \%$$

$$\mathcal{B}(D^+ \rightarrow \pi^0 \mu^+ \nu_\mu) = (0.350 \pm 0.011 \pm 0.010) \%$$

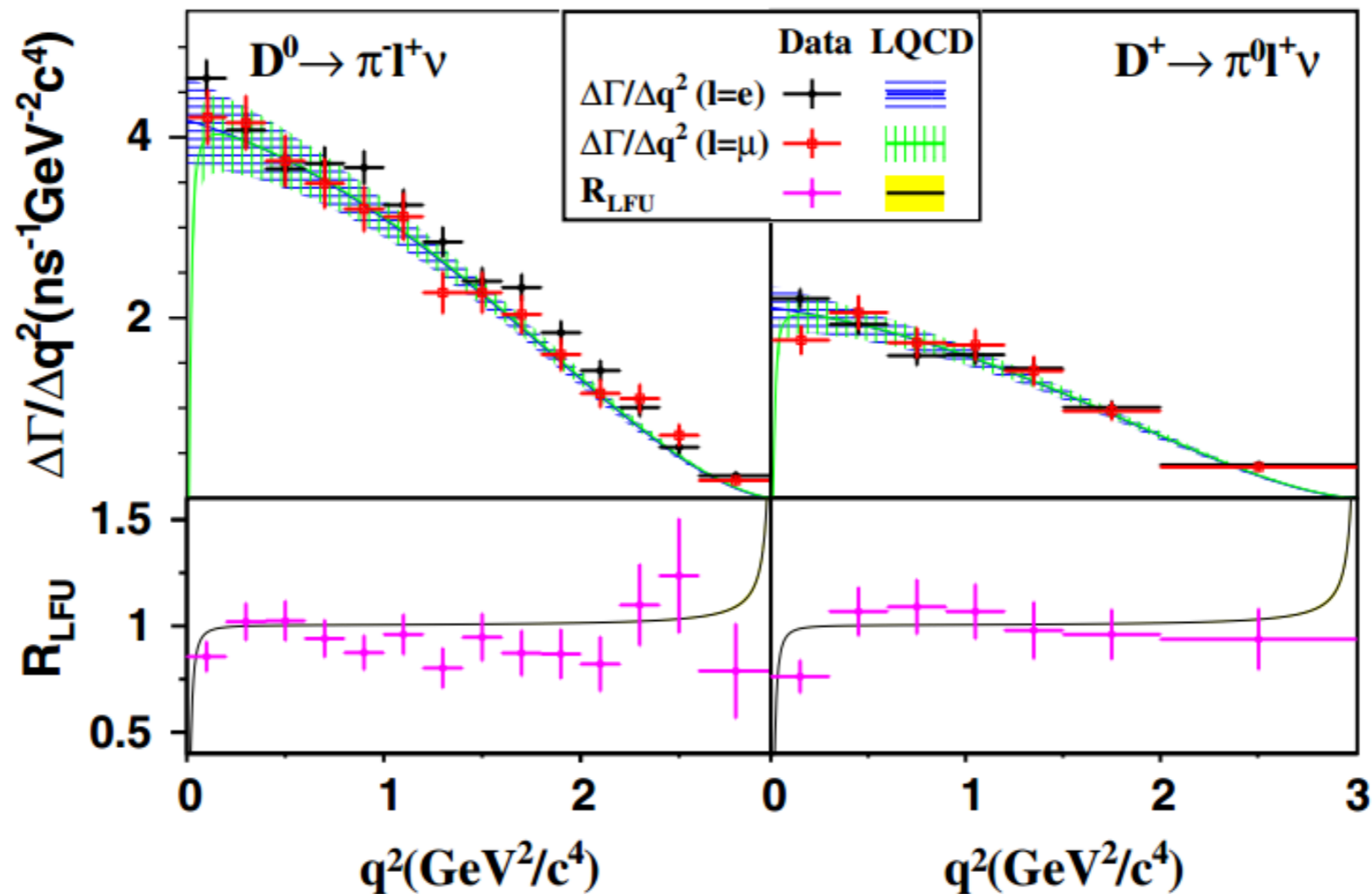


SM expectation: 0.985 ± 0.002 [*Eur. Phys. J. C*78, 501(2018)]

$$R_{LFU}^{\pi^-} = \frac{\Gamma(D^0 \rightarrow \pi^- \mu^+ \nu_\mu)}{\Gamma(D^0 \rightarrow \pi^- e^+ \nu_e)} = 0.922 \pm 0.030 \pm 0.022 \quad R_{LFU}^{\pi^0} = \frac{\Gamma(D^+ \rightarrow \pi^0 \mu^+ \nu_\mu)}{\Gamma(D^+ \rightarrow \pi^0 e^+ \nu_e)} = 0.964 \pm 0.037 \pm 0.026$$

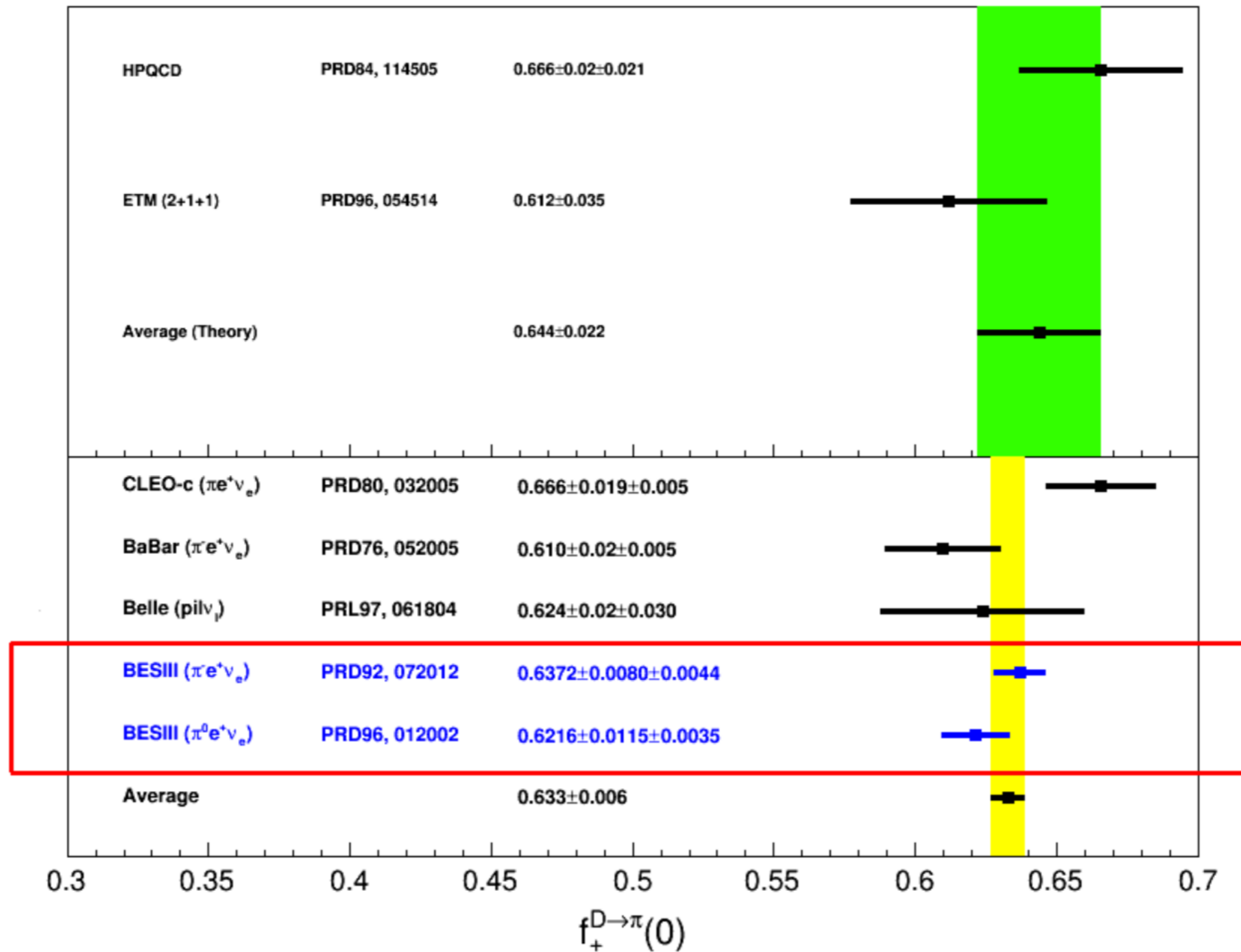
1.7 σ consistent

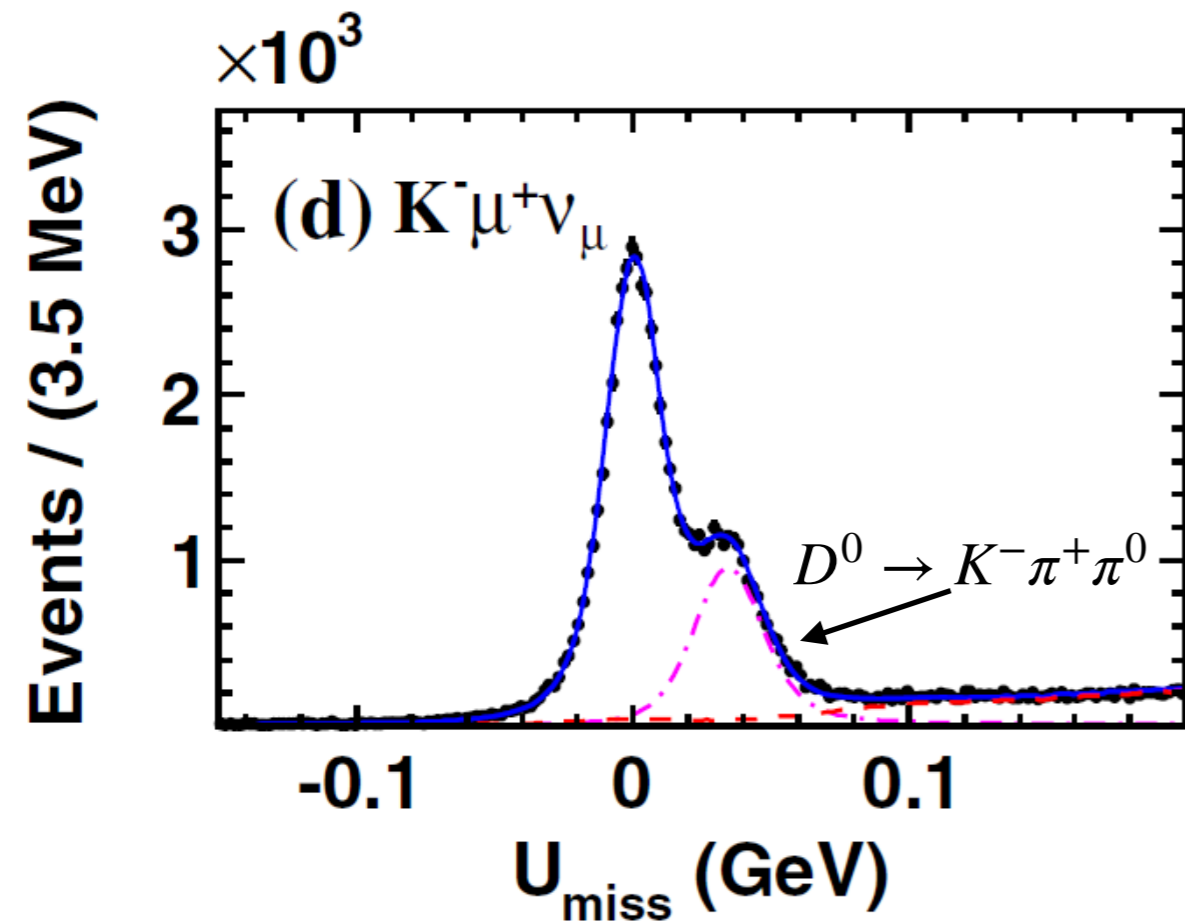
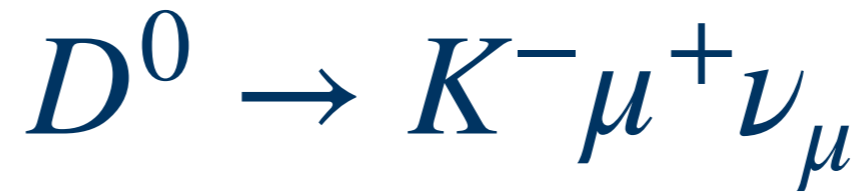
0.5 σ consistent



Comparison of $f_+^{D \rightarrow \pi}(0)$

Inputs from CKMFitter
 $|V_{cd}| = 0.22438 \pm 0.00044$





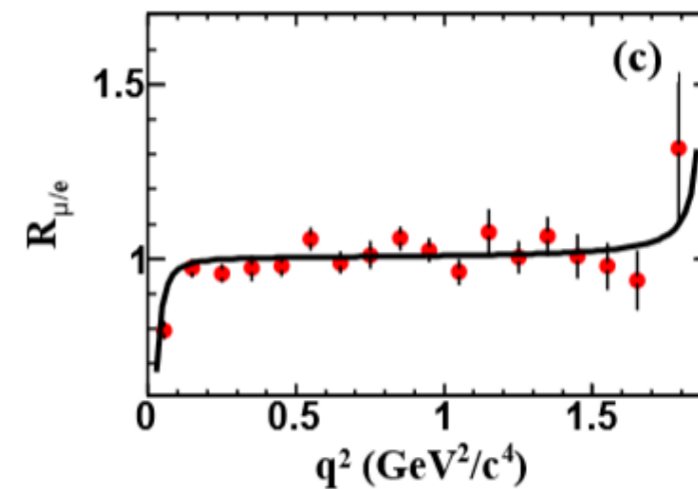
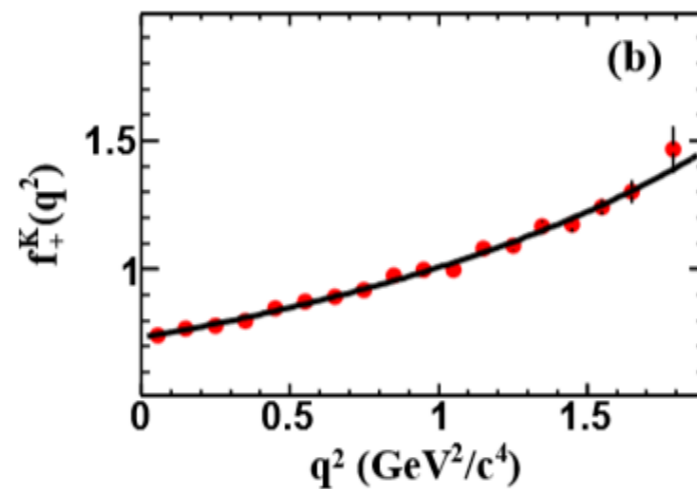
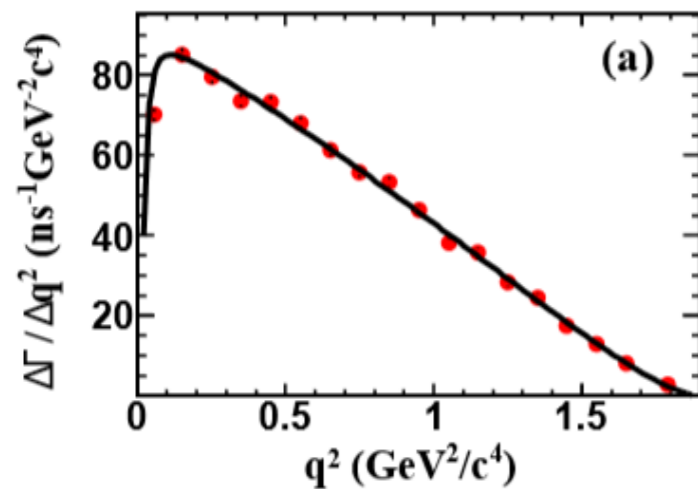
$$\mathcal{B}(D^0 \rightarrow K^- \mu^+ \nu_\mu) = (3.413 \pm 0.0019 \pm 0.035)\%$$

$$f_+^K(0)|V_{cs}| = (0.7133 \pm 0.0038 \pm 0.0030)$$

$$f_+^K(0) = (0.7327 \pm 0.0039 \pm 0.0030)$$

$$|V_{cs}| = (0.955 \pm 0.005 \pm 0.004 \pm 0.024)$$

$$\frac{\mathcal{B}(D^0 \rightarrow K^- \mu^+ \nu_\mu)}{\mathcal{B}(D^0 \rightarrow K^- e^+ \nu_e)} = (0.974 \pm 0.007 \pm 0.012) (0.975)$$

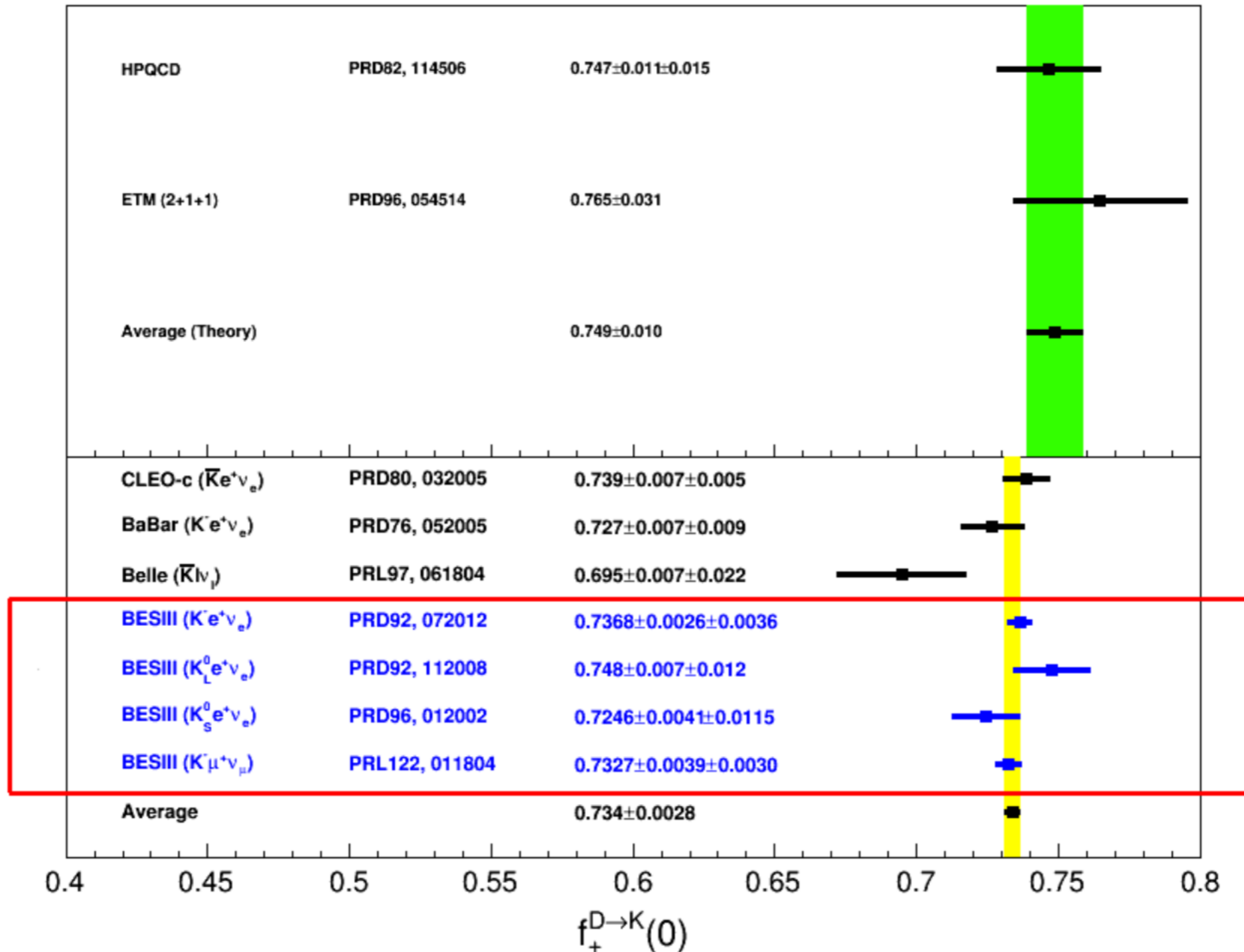


No significant evidence of LFU violation is found

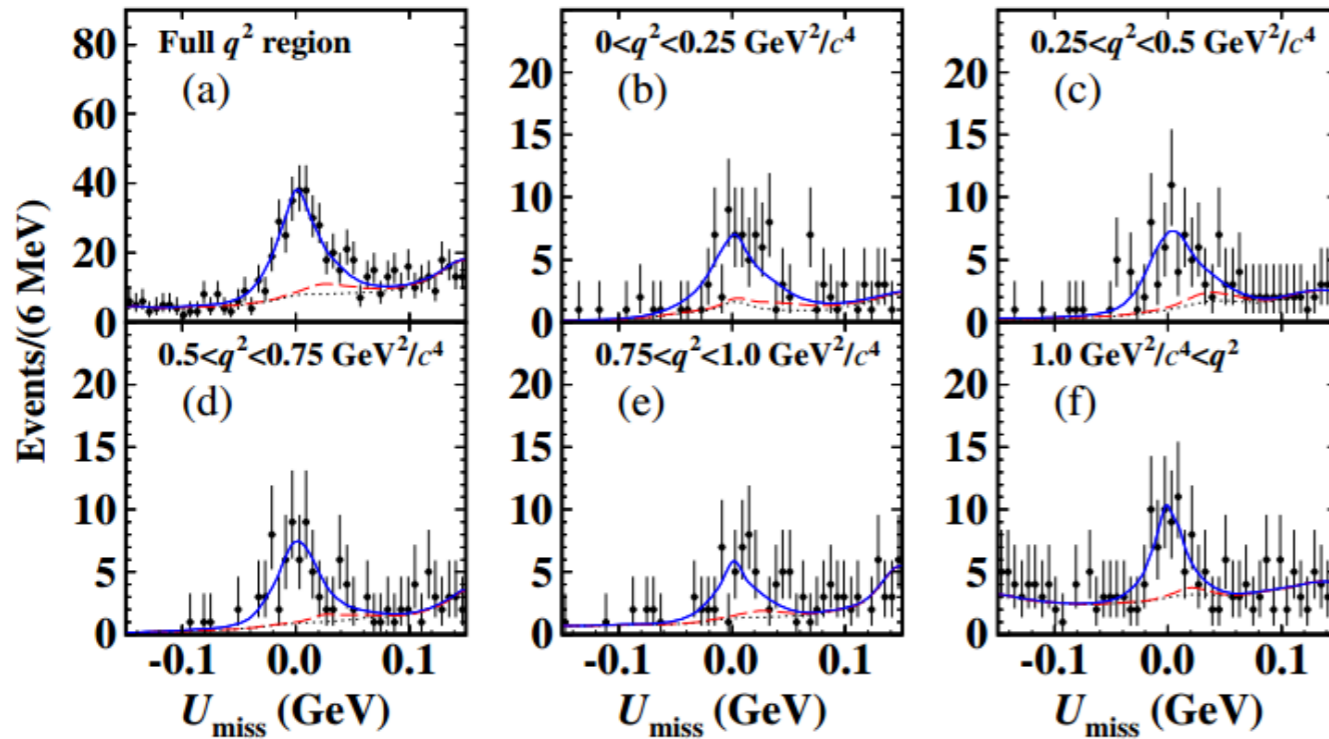
Comparison of $f_+^{D \rightarrow K}(0)$

Inputs from CKMFitter

$$|V_{cs}| = 0.97359^{+0.00010}_{-0.00011}$$



First observation of $D^+ \rightarrow \eta\mu^+\nu_\mu$



$$\mathcal{B}(D^+ \rightarrow \eta\mu^+\nu_\mu) = (10.4 \pm 1.0 \pm 0.5) \times 10^{-4}$$

$$f_+^\eta(0)|V_{cd}| = 0.087 \pm 0.008 \pm 0.002$$

$$f_+^\eta(0) = 0.39 \pm 0.04 \pm 0.01$$

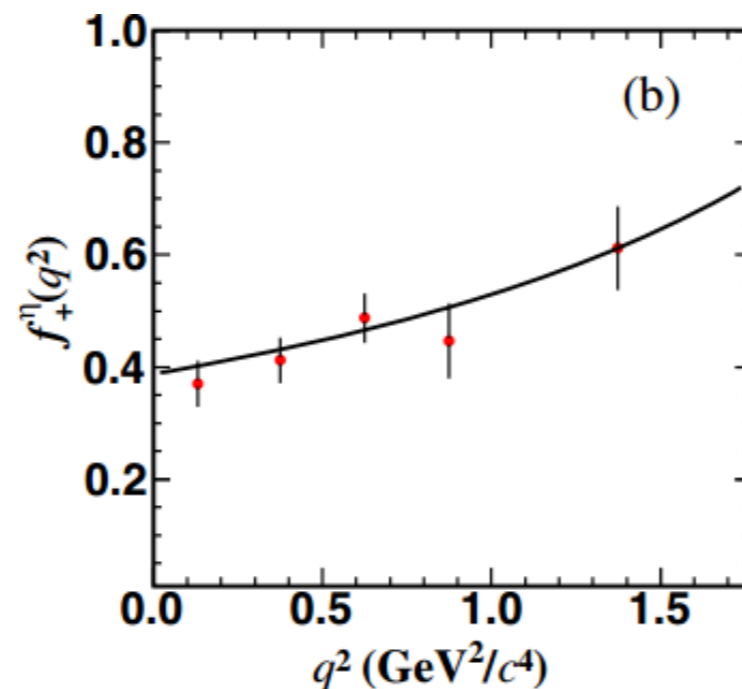
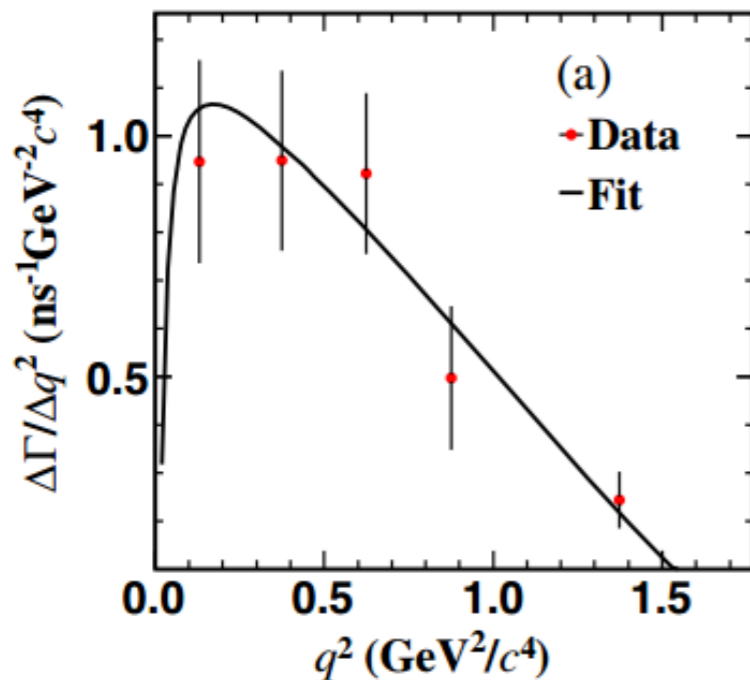
$$|V_{cd}| = 0.242 \pm 0.022 \pm 0.006 \pm 0.033$$

$$R = \frac{\mathcal{B}(D^+ \rightarrow \eta\mu^+\nu_\mu)}{\mathcal{B}(D^+ \rightarrow \eta e^+\nu_e)_{\text{PDG}}} = 0.91 \pm 0.13$$

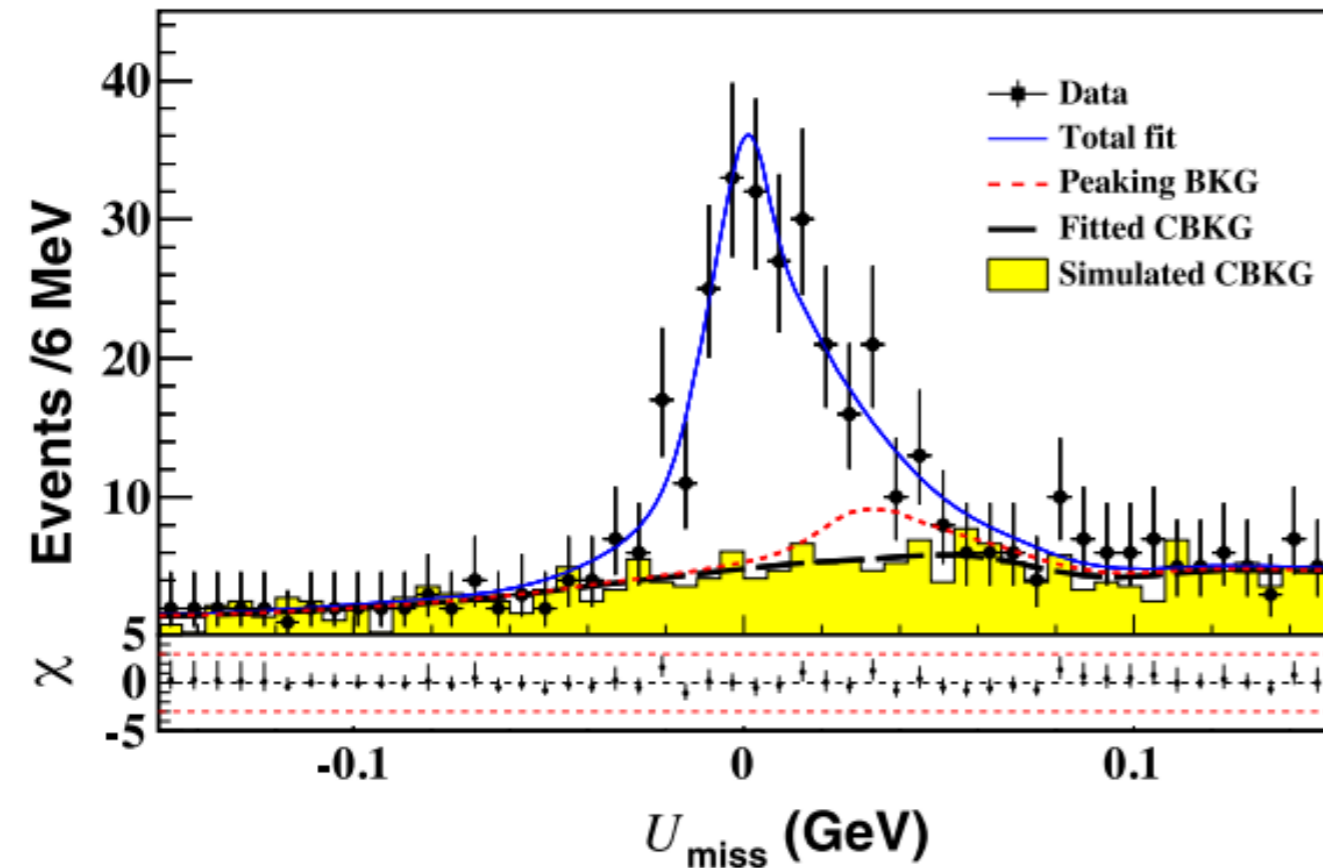
SM(0.97-1.00)

no LFU violation within current sensitivity

Experimental confirmation for the first time since it was predicted in 30 years ago.
 Phys. Rev. D 39, 799 (1989).



First observation of $D^+ \rightarrow \omega \mu^+ \nu_\mu$



$$\mathcal{B}(D^+ \rightarrow \omega \mu^+ \nu_\mu) = (17.7 \pm 1.8 \pm 1.1) \times 10^{-4}$$

Consistent with theoretical calculation (LFQM, CCQM, and LCSR methods).

$$R = \frac{\mathcal{B}(D^+ \rightarrow \omega \mu^+ \nu_\mu)}{\mathcal{B}(D^+ \rightarrow \omega e^+ \nu_e)_{\text{PDG}}} = 1.05 \pm 0.14$$

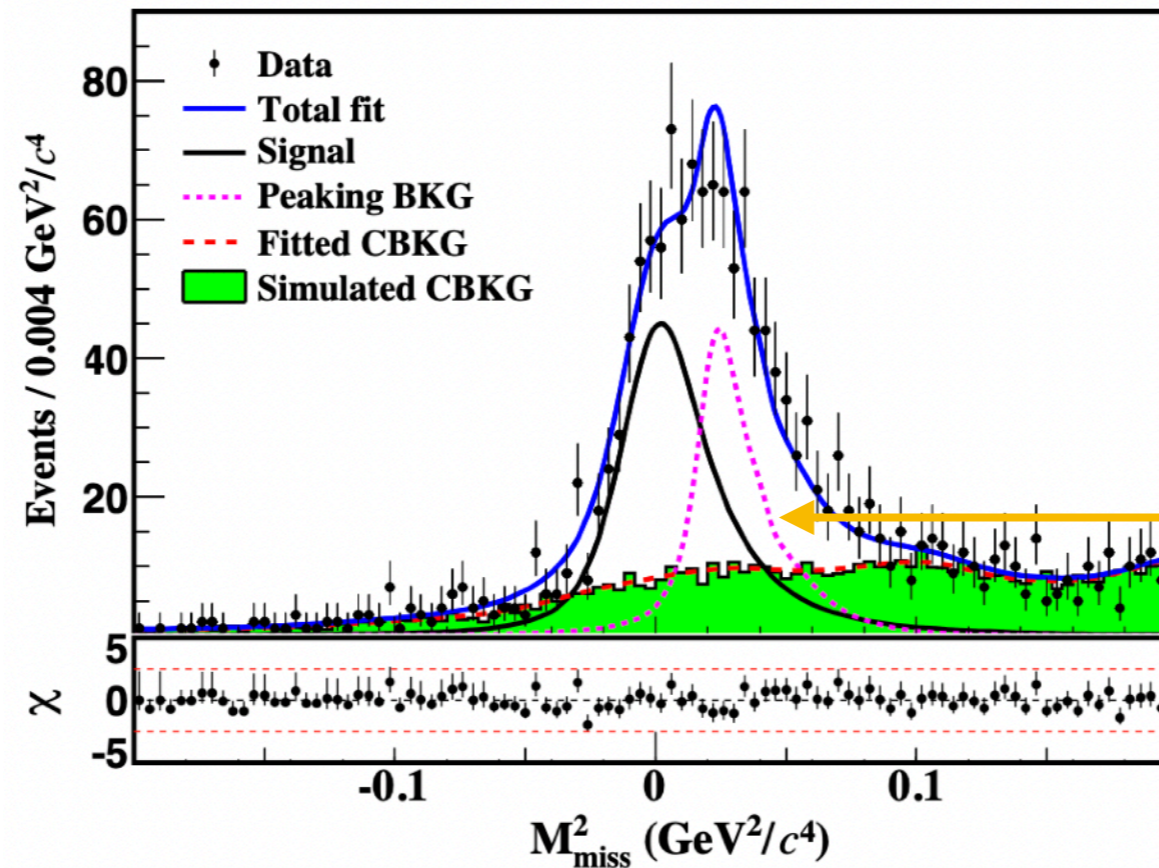
SM(0.93-0.99)

no LFU violation within current statistics

Experimental confirmation for the first time since it was predicted in 30 years ago.

Phys. Rev. D 39, 799 (1989).

First observation of $D^0 \rightarrow \rho^- \mu^+ \nu_\mu$



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

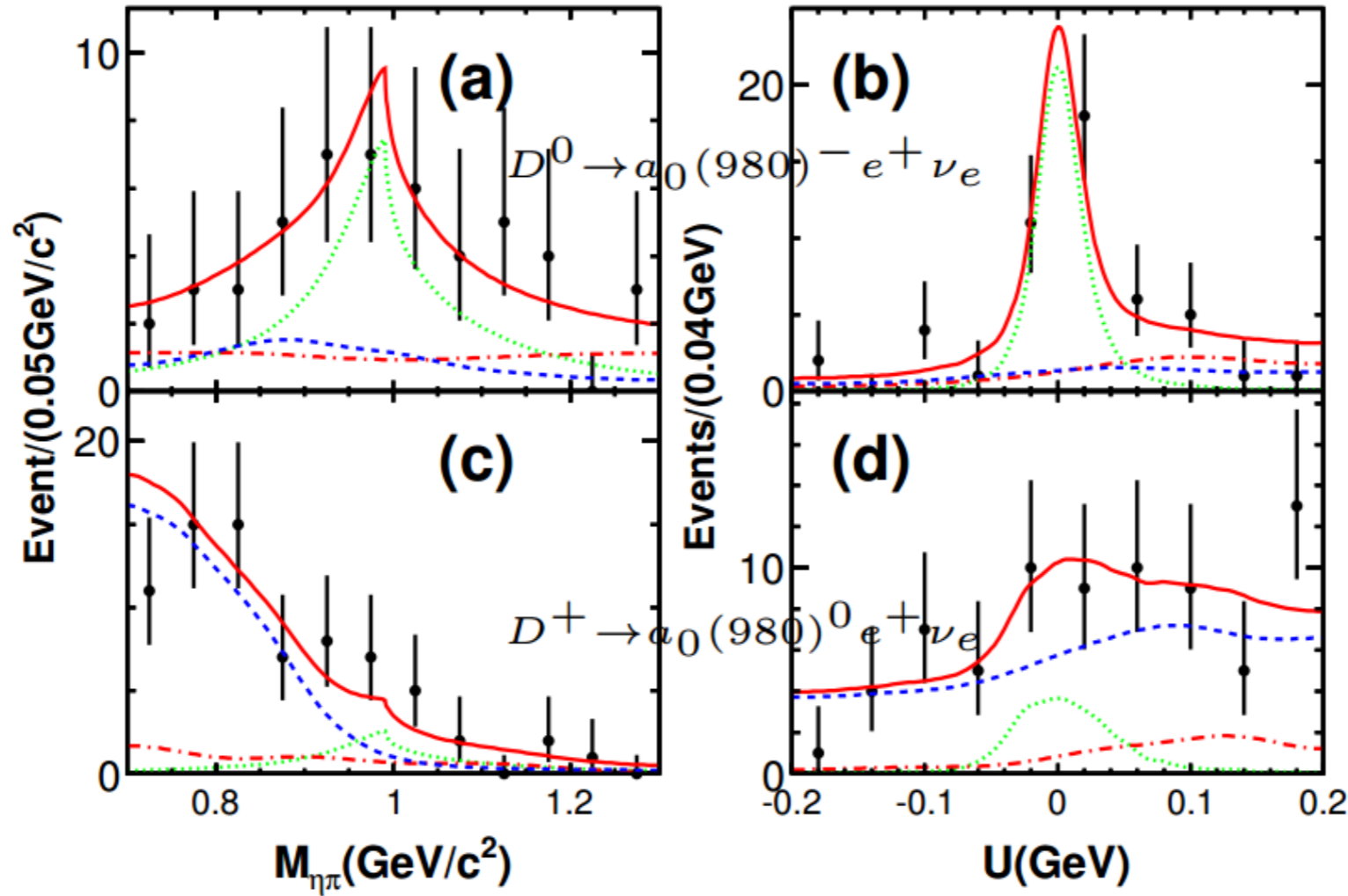
$$\mathcal{B}_{D^0 \rightarrow \rho^- \mu^+ \nu_\mu} = (1.35 \pm 0.09_{\text{stat}} \pm 0.09_{\text{syst}}) \times 10^{-3}$$

$$\mathcal{B}_{D^0 \rightarrow \rho^- \mu^+ \nu_e} / \mathcal{B}_{D^0 \rightarrow \rho^- e^+ \nu_e} = 0.90 \pm 0.11 \quad \text{SM}(0.93-0.96)$$

$$\Gamma_{D^0 \rightarrow \rho^- \mu^+ \nu_\mu} / (2\Gamma_{D^+ \rightarrow \rho^0 \mu^+ \nu_\mu}) = 0.71 \pm 0.14$$

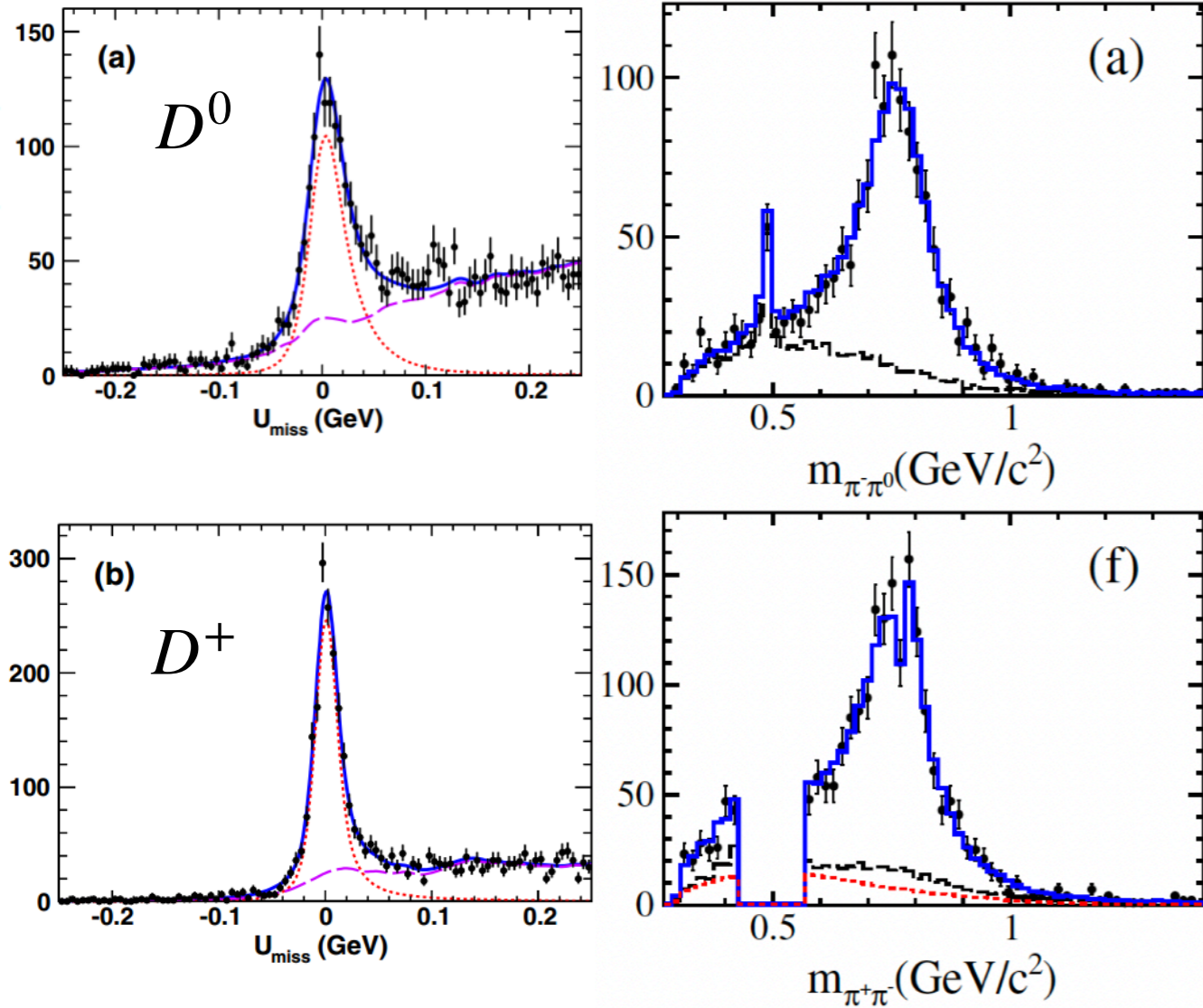
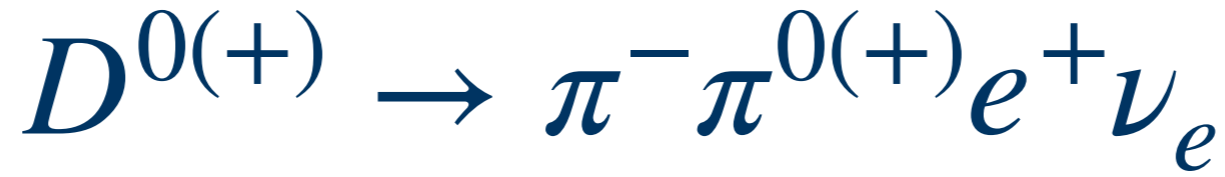
2.1 σ from unity based on isospin symmetry

$$D^{0(+)} \rightarrow a_0(980)^{-(0)} e^+ \nu_e$$



Semileptonic decay
to scalar meson

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



Signal mode	BF ($\times 10^{-3}$)
$D^0 \rightarrow \pi^- \pi^0 e^+ \nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^0 \rightarrow \rho^- e^+ \nu_e$	$1.445 \pm 0.048 \pm 0.039$
$D^+ \rightarrow \pi^- \pi^+ e^+ \nu_e$	$2.449 \pm 0.074 \pm 0.073$
$D^+ \rightarrow \rho^0 e^+ \nu_e$	$1.860 \pm 0.070 \pm 0.061$
$D^+ \rightarrow \omega e^+ \nu_e$	$2.05 \pm 0.66 \pm 0.30$
$D^+ \rightarrow f_0(500) e^+ \nu_e$	$0.630 \pm 0.043 \pm 0.032$
$f_0(500) \rightarrow \pi^+ \pi^-$	
$D^+ \rightarrow f_0(980) e^+ \nu_e$	< 0.028
$f_0(980) \rightarrow \pi^+ \pi^-$	

From Wang and Lu PRD82, 034016(2010)

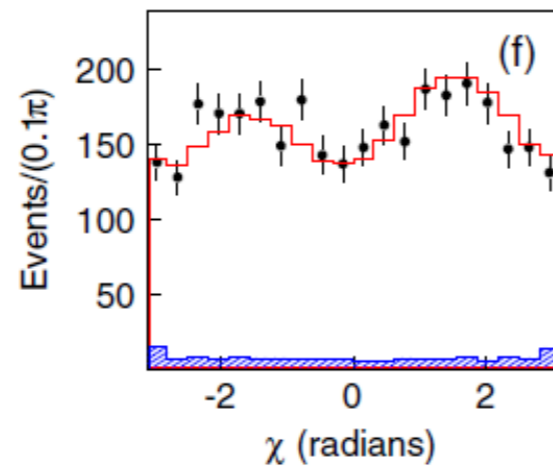
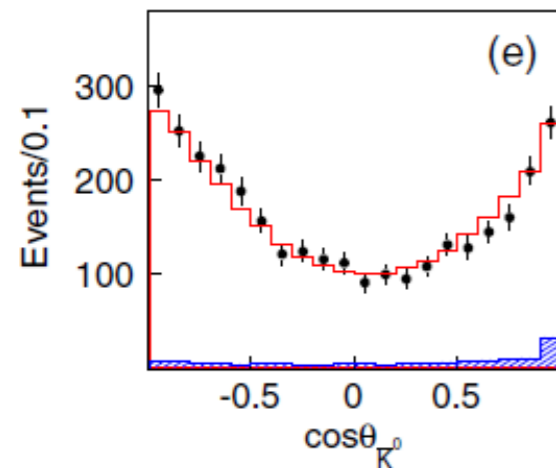
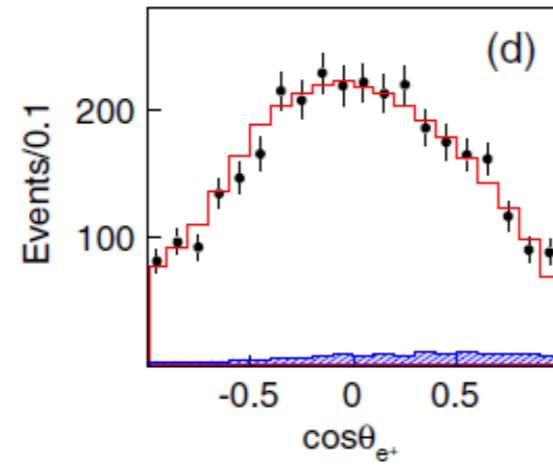
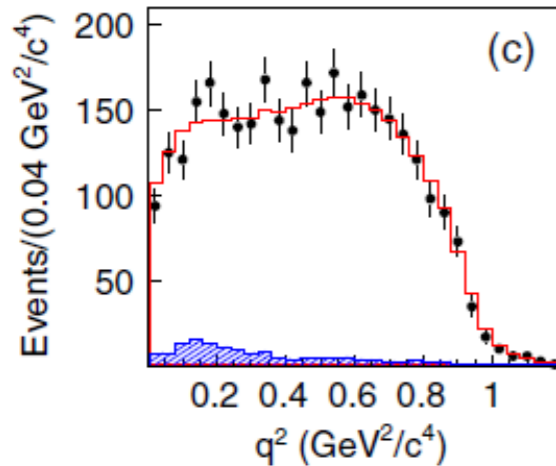
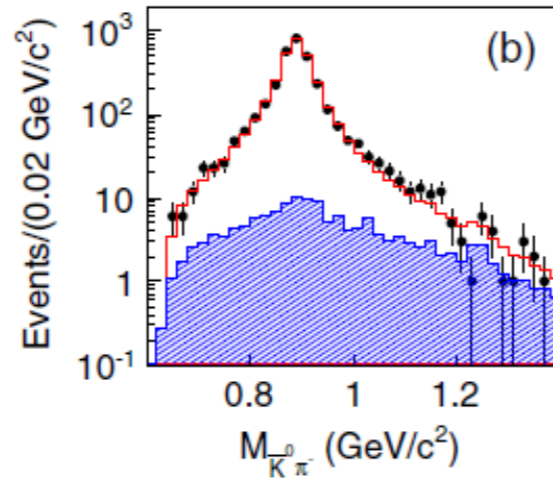
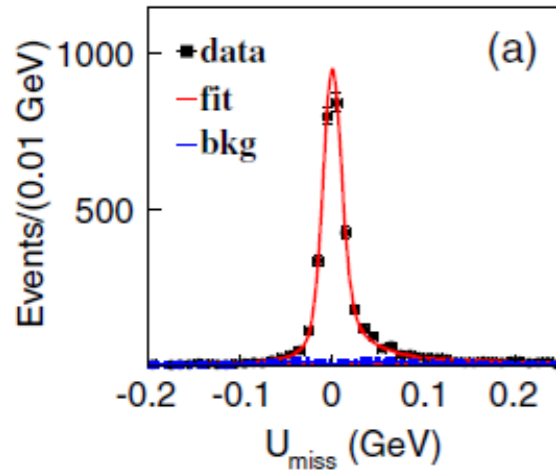
$$R = \frac{\mathcal{B}(D^+ \rightarrow f_0(500) e^+ \nu_e) + \mathcal{B}(D^+ \rightarrow f_0(980) e^+ \nu_e)}{\mathcal{B}(D^+ \rightarrow a_0(980)^0 e^+ \nu_e)}$$

$$= \begin{cases} 1.0 \pm 0.3 & \text{two quark description} \\ 3.0 \pm 0.9 & \text{tetraquark description} \end{cases}$$

Use $\mathcal{B}(D^+ \rightarrow a_0(980)^0 e^+ \nu_e) \times \mathcal{B}(a_0(980)^0 \rightarrow \eta \pi^0) < 3.0 \times 10^{-4}$ from BESIII PRL121,081802(2018) and other inputs from PDG.

$\Rightarrow R > 2.7 @ 90\% \text{CL} \Rightarrow$ Tetraquark favored for f_0 and a_0

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



$$B(D^0 \rightarrow \bar{K}^0 \pi^- e^+ \nu_e) = (1.434 \pm 0.029 \pm 0.032) \%$$

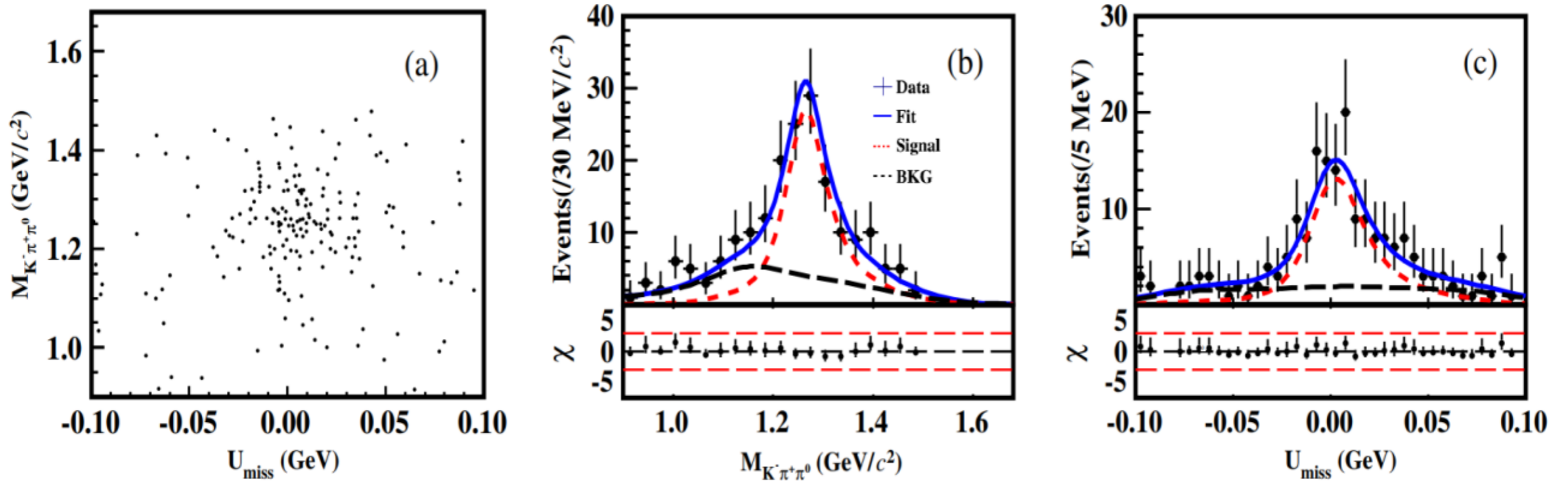
$$B(D^0 \rightarrow K^*(892)^- e^+ \nu_e) = (2.003 \pm 0.046 \pm 0.047) \%$$

observed

$$B\left(D^0 \rightarrow \left(\bar{K}^0 \pi^-\right)_{S\text{-wave}} e^+ \nu_e\right) = (7.90 \pm 1.40 \pm 0.91) \times 10^{-4}$$

$$D^0 \rightarrow \bar{K}_1(1270)^0 e^+ \nu_e$$

First observation of D meson semi-leptonic decay into axial-vector mesons.



$$\mathcal{B}_{D^0 \rightarrow K_1(1270)^- e^+ \nu_e} = (1.09 \pm 0.13_{-0.13}^{+0.09} \pm 0.12) \times 10^{-3}$$

Test the theoretical calculations (agree with the CLFQM and LCSR prediction.)

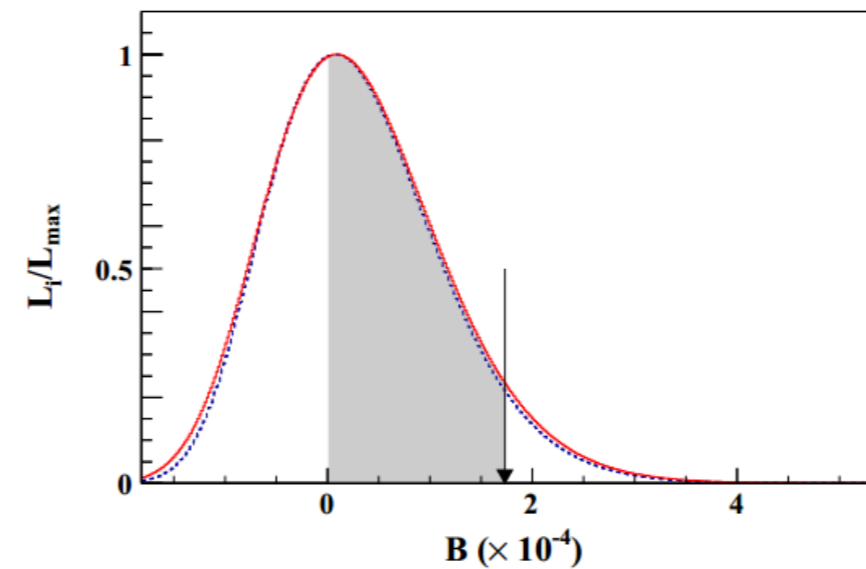
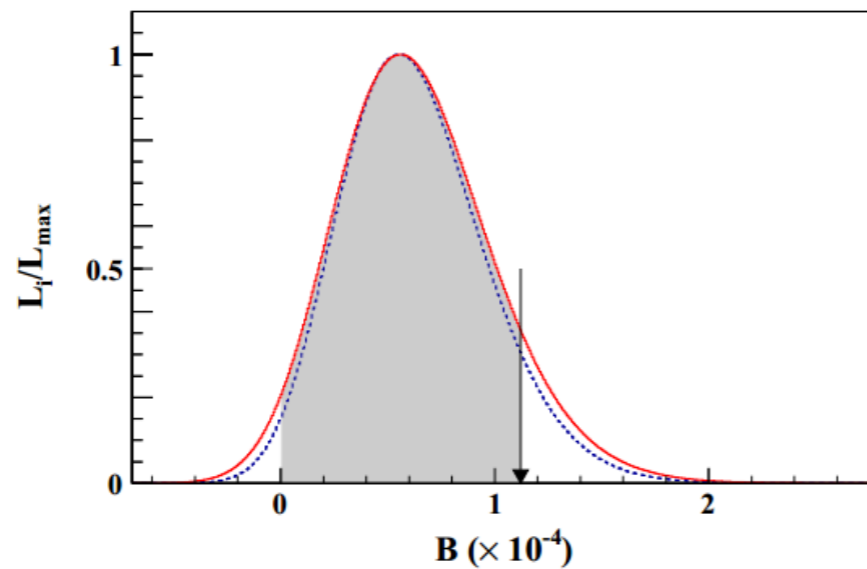
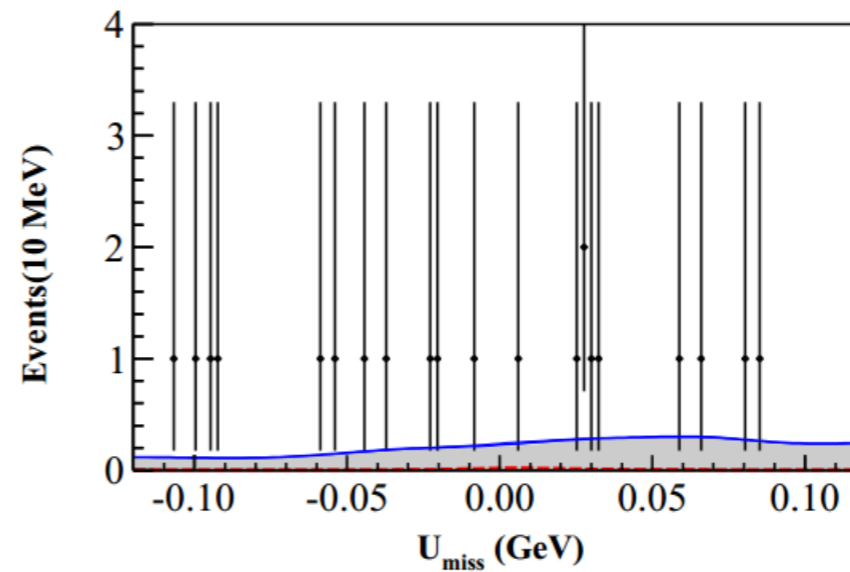
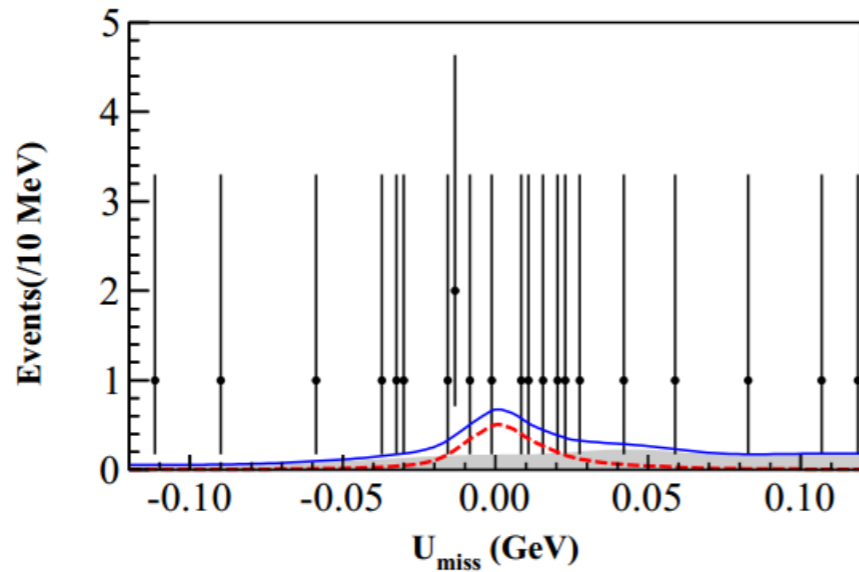
Provide important input to study the photon polarization in $B \rightarrow K_1 \gamma$ by measuring the ration of up-down asymmetries.

$$\frac{\Gamma(D^+ \rightarrow \bar{K}_1(1270)^0 e^+ \nu_e)}{\Gamma(D^0 \rightarrow K_1(1270)^- e^+ \nu_e)} = 1.2_{-0.5}^{+0.7} \quad (\text{Isospin conservation test})$$

$$D^{0(+)} \rightarrow b_1(1235)^{(-)0} e^+ \nu_e$$

$$D^0 \rightarrow b_1(1235)^- e^+ \nu_e$$

$$D^+ \rightarrow b_1(1235)^0 e^+ \nu_e$$



$$\mathcal{B}_{D^0 \rightarrow b_1(1235)^- e^+ \nu_e} \cdot \mathcal{B}_{b_1(1235)^- \rightarrow \omega \pi^-} < 1.12 \times 10^{-4}$$

$$\mathcal{B}_{D^+ \rightarrow b_1(1235)^0 e^+ \nu_e} \cdot \mathcal{B}_{b_1(1235)^0 \rightarrow \omega \pi^0} < 1.75 \times 10^{-4}$$

No significant signal is observed

Phys. Rev. D 102, 112005 (2020)

(Semi-)leptonic Ds decay

- **Pure leptonic decay**

- $D_s^+ \rightarrow \mu^+ \nu_\mu$ *Phys. Rev. Lett. 122, 071802 (2019)*

- **Semi-leptonic decay**

- $D_s^+ \rightarrow K^0 e^+ \nu_e, K^{*0} e^+ \nu_e$ *Phys. Rev. Lett. 122, 061801 (2019)*

- $D_s^+ \rightarrow \eta e^+ \nu_e, \eta' e^+ \nu_e$ *Phys. Rev. Lett. 122, 121801 (2019)*

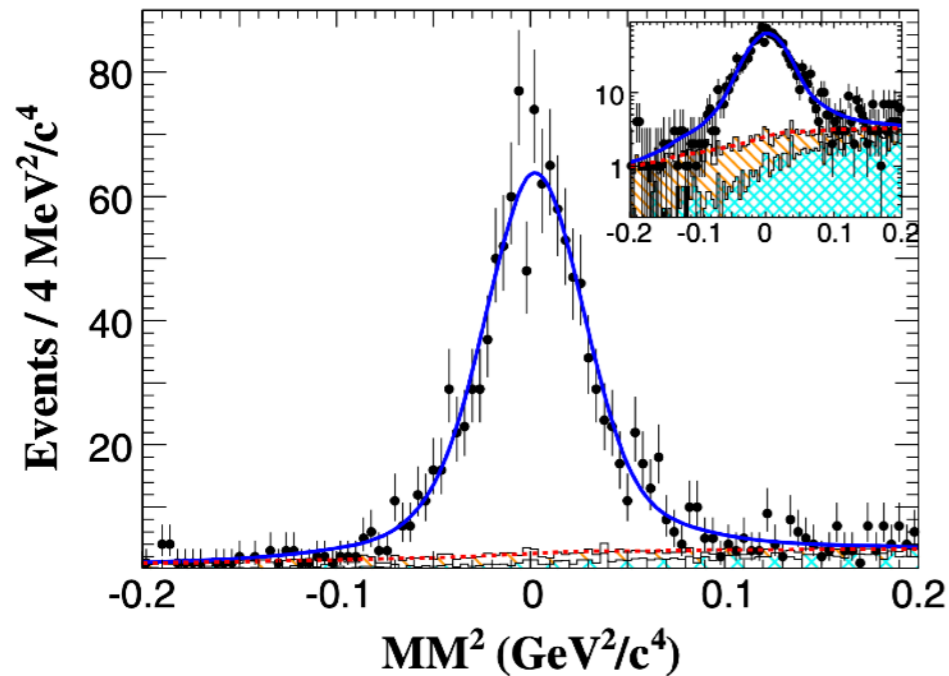
- $D_s^+ \rightarrow p \bar{p} e^+ \nu_e$ *Phys. Rev. D 100, 112008 (2019)*

- $D_s^+ \rightarrow \gamma e^+ \nu_e$ *Phys. Rev. D 99, 072002 (2019)*

- $D_s^+ \rightarrow X e^+ \nu_e$ *arXiv:2104.0731*

The talk “Leptonic Ds decay at BESIII” in Parallel session, 08 June 12:00

$$D_s^+ \rightarrow \mu^+ \nu_\mu$$



$$N_{DT}^{\text{tot}} = 1135.9 \pm 33.1$$

$$\mathcal{B}_{D_s^+ \rightarrow \mu^+ \nu_\mu} = (5.49 \pm 0.16_{\text{stat}} \pm 0.15_{\text{syst}}) \times 10^{-3}$$

$$A_{\text{CP}} = \frac{\mathcal{B}_{D_s^+ \rightarrow \mu^+ \nu_\mu} - \mathcal{B}_{D_s^- \rightarrow \mu^- \bar{\nu}_\mu}}{\mathcal{B}_{D_s^+ \rightarrow \mu^+ \nu_\mu} + \mathcal{B}_{D_s^- \rightarrow \mu^- \bar{\nu}_\mu}}$$

$$= (2.0 \pm 3.0_{\text{stat}} \pm 1.2_{\text{syst}}) \%$$

$$R_{\tau/\mu}^{D_s^+} \sim \frac{\mathcal{B}_{D_s^+ \rightarrow \tau^+ \nu_\tau}^{\text{PDG}}}{\mathcal{B}_{D_s^+ \rightarrow \mu^+ \nu_\mu}} = 9.98 \pm 0.52 \quad (\text{SM: } 9.74)$$

$$f_{D_s^+} |V_{cs}| = 246.2 \pm 3.6_{\text{stat}} \pm 3.5_{\text{syst}} \text{ MeV}$$

$$f_{D_s^+} |V_{cs}| = 246.2 \pm 3.6_{\text{stat}} \pm 3.5_{\text{syst}} \text{ MeV}$$

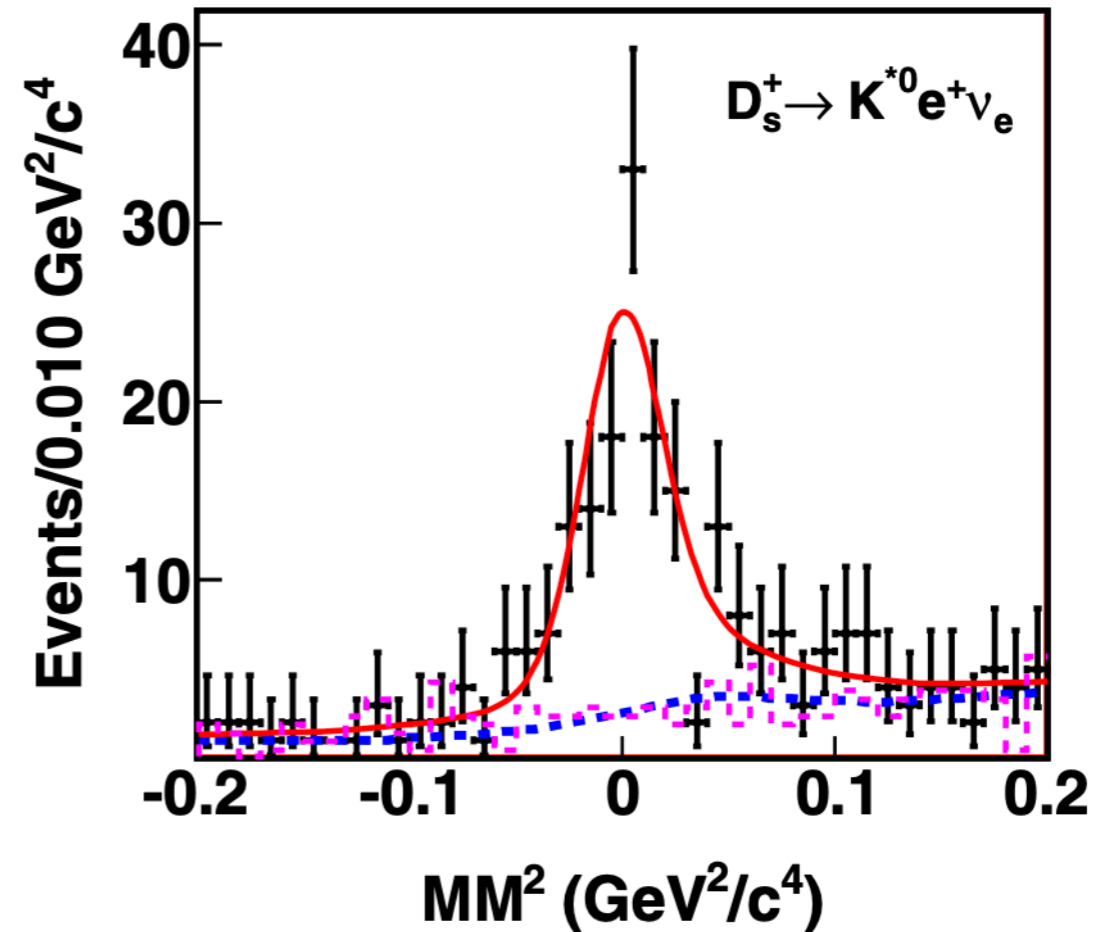
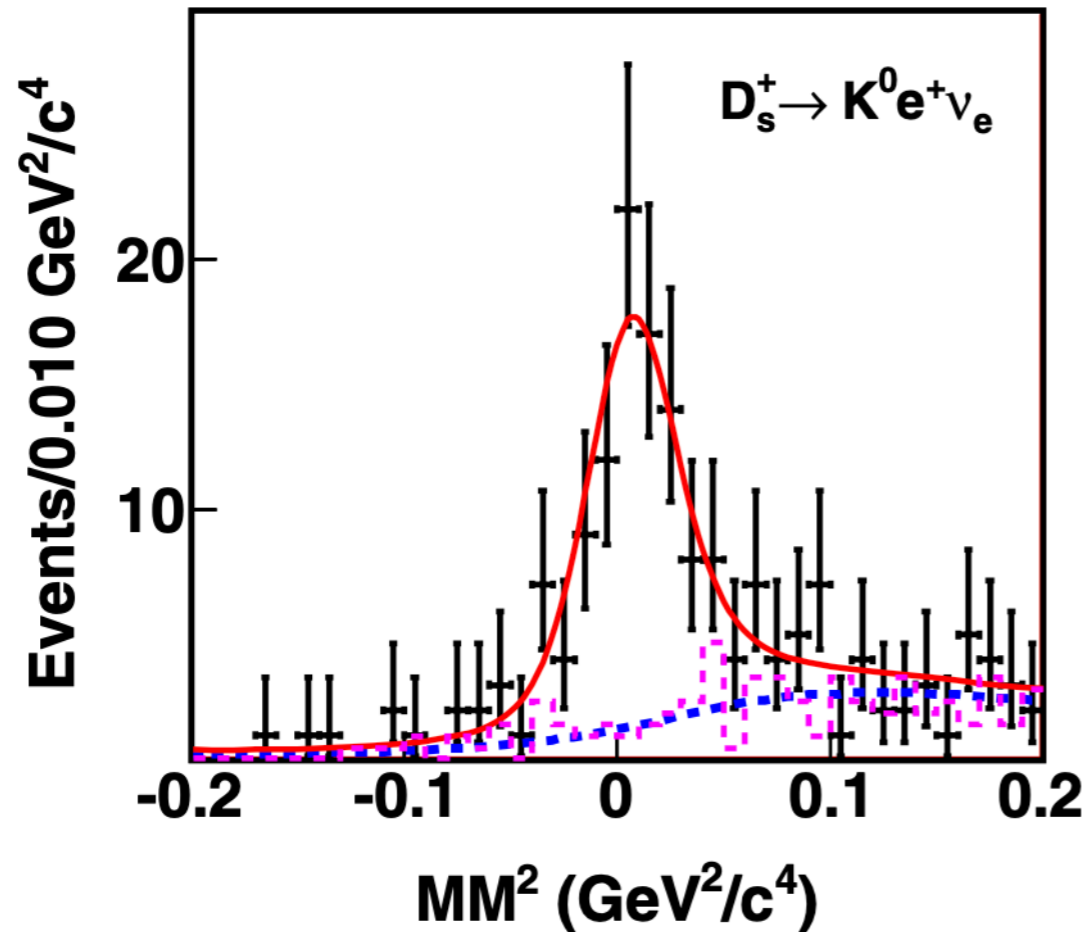
Phys. Rev. Lett. 122, 071802 (2019)



Cabibbo-suppressed channels

$$N_{DT}^{K^0} = 117.2 \pm 13.9$$

$$N_{DT}^{K^{*0}} = 155.0 \pm 17.2$$

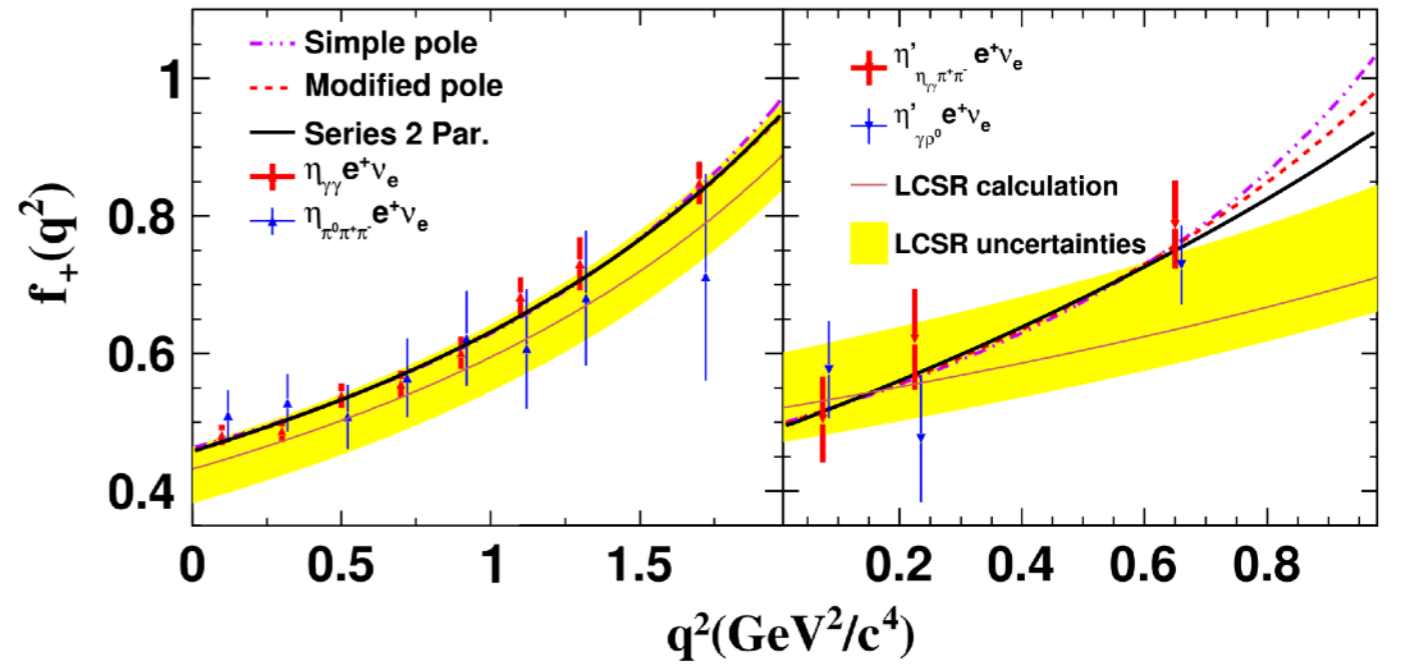
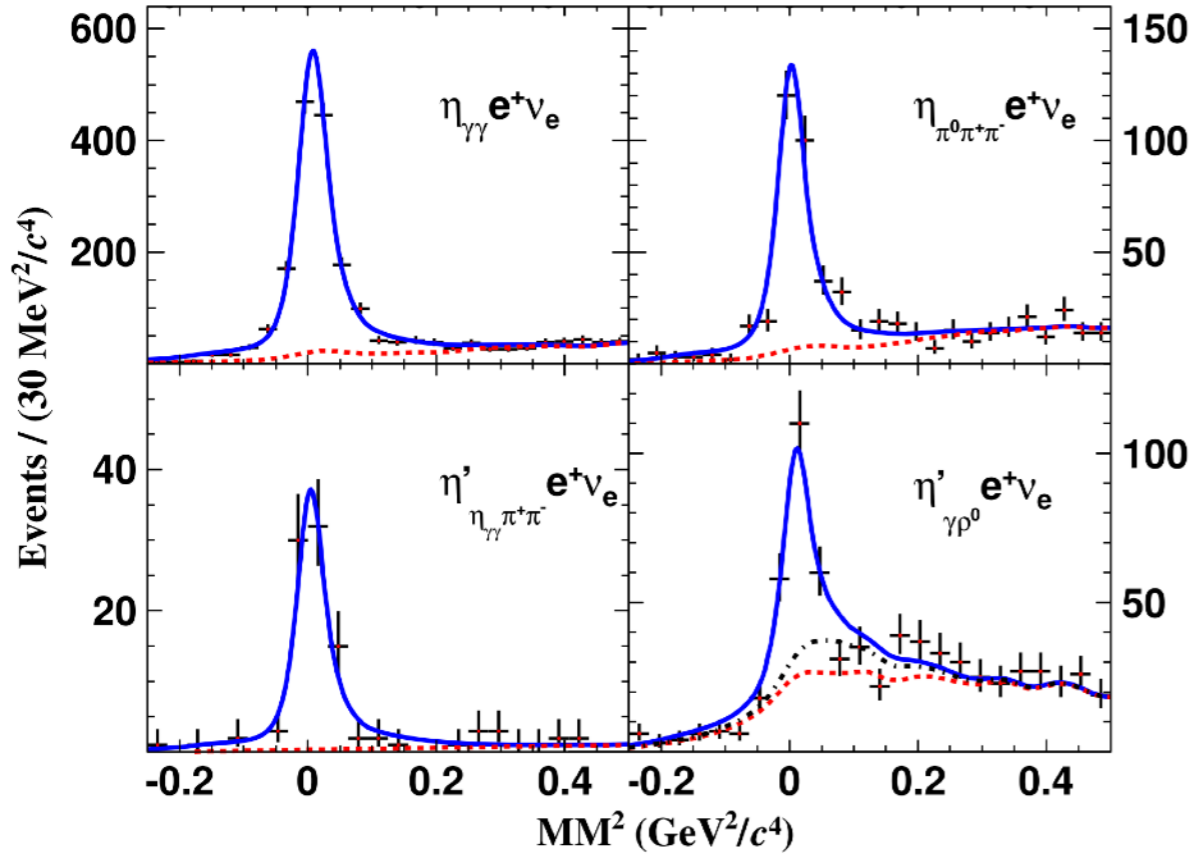


$$B(D_s^+ \rightarrow K^0 e^+ \nu_e) = (3.25 \pm 0.38 \pm 0.16) \times 10^{-3}$$

$$B(D_s^+ \rightarrow K^{*0} e^+ \nu_e) = (2.37 \pm 0.26 \pm 0.20) \times 10^{-3}$$

Precision improved 2 over PDG and First FF measurements

Phys. Rev. Lett. 122, 068801 (2019)



$$\mathcal{B}_{D_s^+ \rightarrow \eta e^+ \nu_e} = (2.323 \pm 0.063_{\text{stat}} \pm 0.063_{\text{syst}}) \%$$

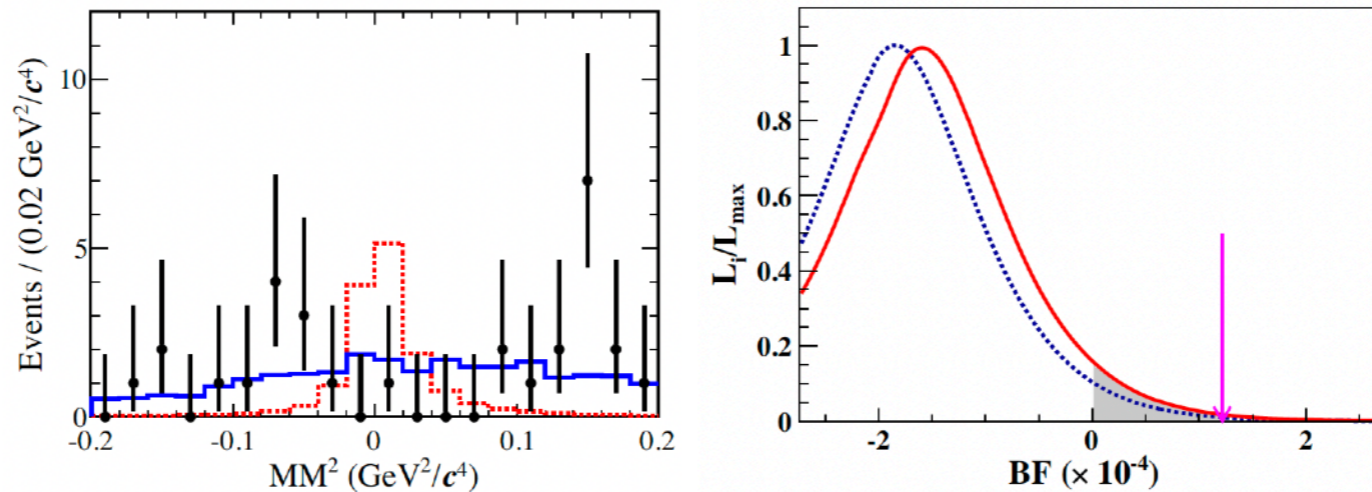
$$\mathcal{B}_{D_s^+ \rightarrow \eta' e^+ \nu_e} = (0.824 \pm 0.073_{\text{stat}} \pm 0.027_{\text{syst}}) \%$$

$$f_+^\eta(0) |V_{cs}| = 0.4455 \pm 0.0053_{\text{stat}} \pm 0.0044_{\text{syst}} \text{ MeV}$$

$$f_+^{\eta'}(0) |V_{cs}| = 0.477 \pm 0.049_{\text{stat}} \pm 0.011_{\text{syst}} \text{ MeV}$$

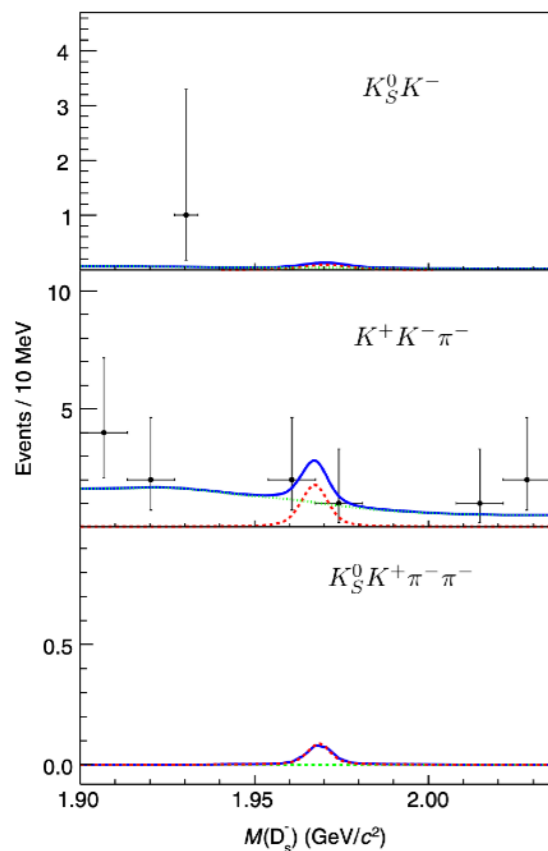
Phys. Rev. Lett. 122, 121801 (2019)

$$D_s^+ \rightarrow a_0(980)^0 e^+ \nu_e$$



$$\mathcal{B}(D_s^+ \rightarrow a_0(980)^0 e^+ \nu_e) \times \mathcal{B}(a_0(980)^0 \rightarrow \pi^0 \eta) < 1.2 \times 10^{-4}$$

Phys. Rev. D 103, 092004 (2021)



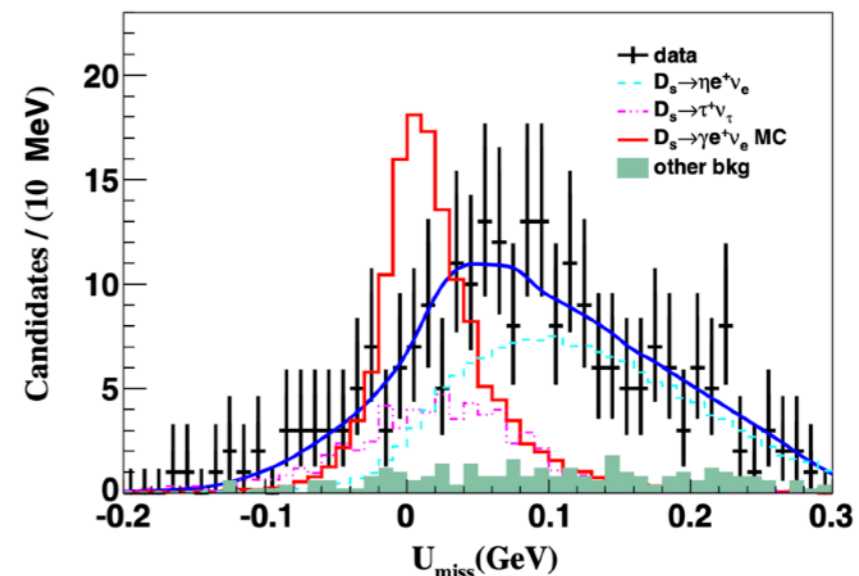
$$D_s^+ \rightarrow p \bar{p} e^+ \nu_e$$

Upper limit @ 90% CL.:

$$\mathcal{B}(D_s^+ \rightarrow p \bar{p} e^+ \nu_e) < 2.0 \times 10^{-4}$$

Phys. Rev. D 100, 112008 (2019)

$$D_s^+ \rightarrow \gamma e^+ \nu_e$$



$$\mathcal{B}_{D_s^+ \rightarrow \gamma e^+ \nu_e} < 1.3 \times 10^{-4}$$

Phys. Rev. D 99, 072002 (2019)

Summary

First evidence for:

$$D^+ \rightarrow a_0(980)^0 e^+ \nu_e$$

First observation for:

$$D^+ \rightarrow \tau^+ \nu_\tau$$

$$D^+ \rightarrow \pi^0 \mu^+ \nu_\mu$$

$$D^0 \rightarrow a_0(980)^- e^+ \nu_e$$

$$D^+ \rightarrow f_0(500) e^+ \nu_e$$

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

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

First measurements

the dynamics on:

$$D_s^+ \rightarrow \eta^{(\prime)} e^+ \nu_e$$

$$D_s^+ \rightarrow K^{0(*)} e^+ \nu_e$$

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

Precisely measured:

Decay constant f_{D_s}

Form factor $f_+^K(0), f_+^\pi(0), f_+^{\eta^{(\prime)}}(0)$

$|V_{cd(s)}|$

Test the lepton universality:

No evidence for LFUV in charm at 1.5% precision

Light hadron results:

$\eta - \eta'$ mixing angle

Test on θ_{K_1}

Tetraquark description favored for light scalar meson

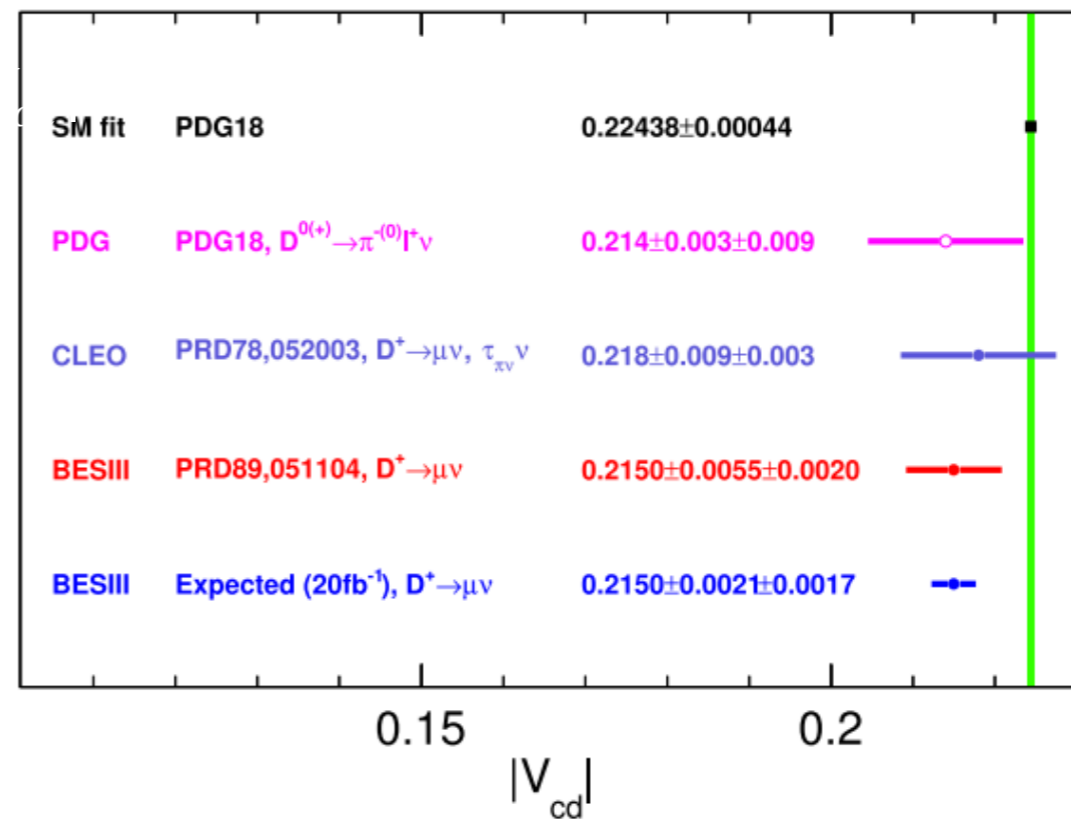
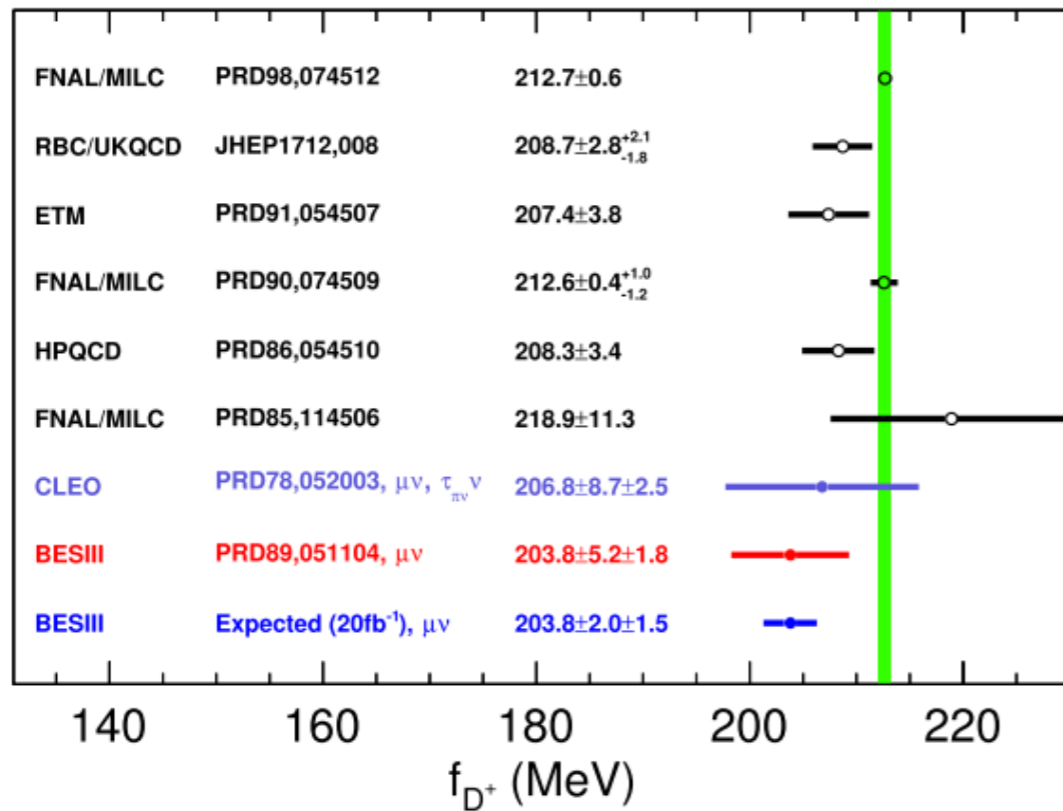
Prospect

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

With 20 fb⁻¹ of data set at 3.773 GeV in the coming two years

Leptonic Decay

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



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

Prospect

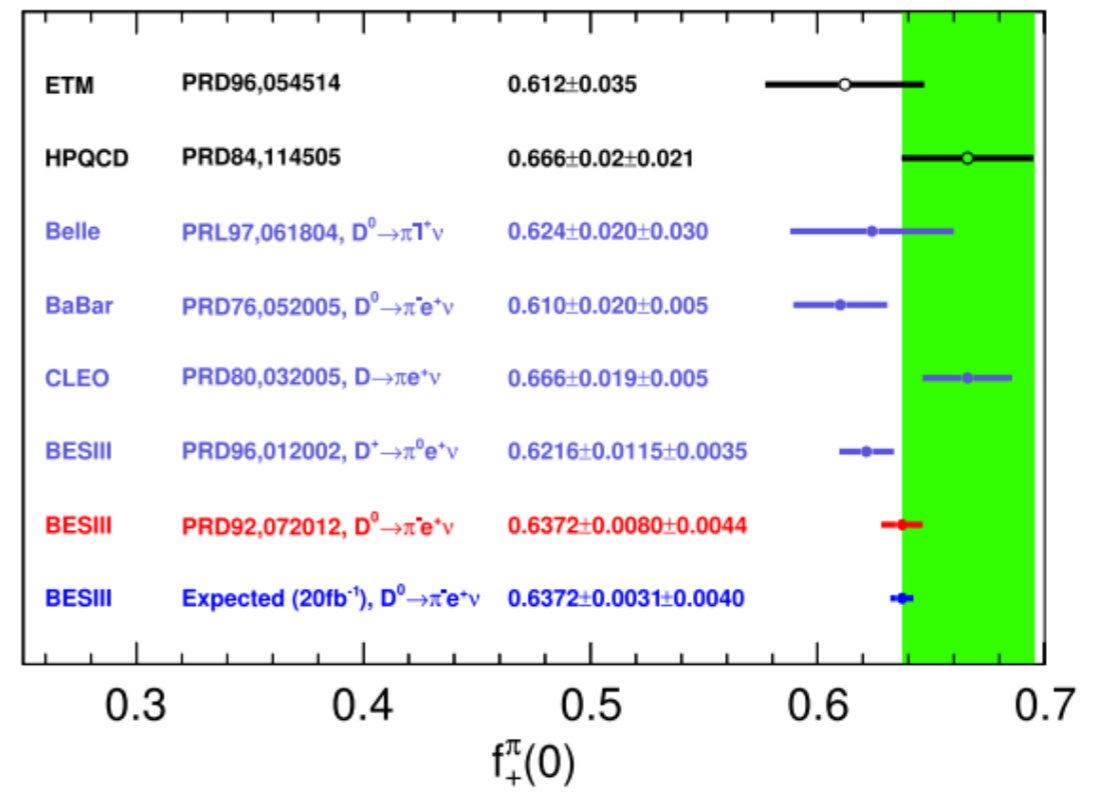
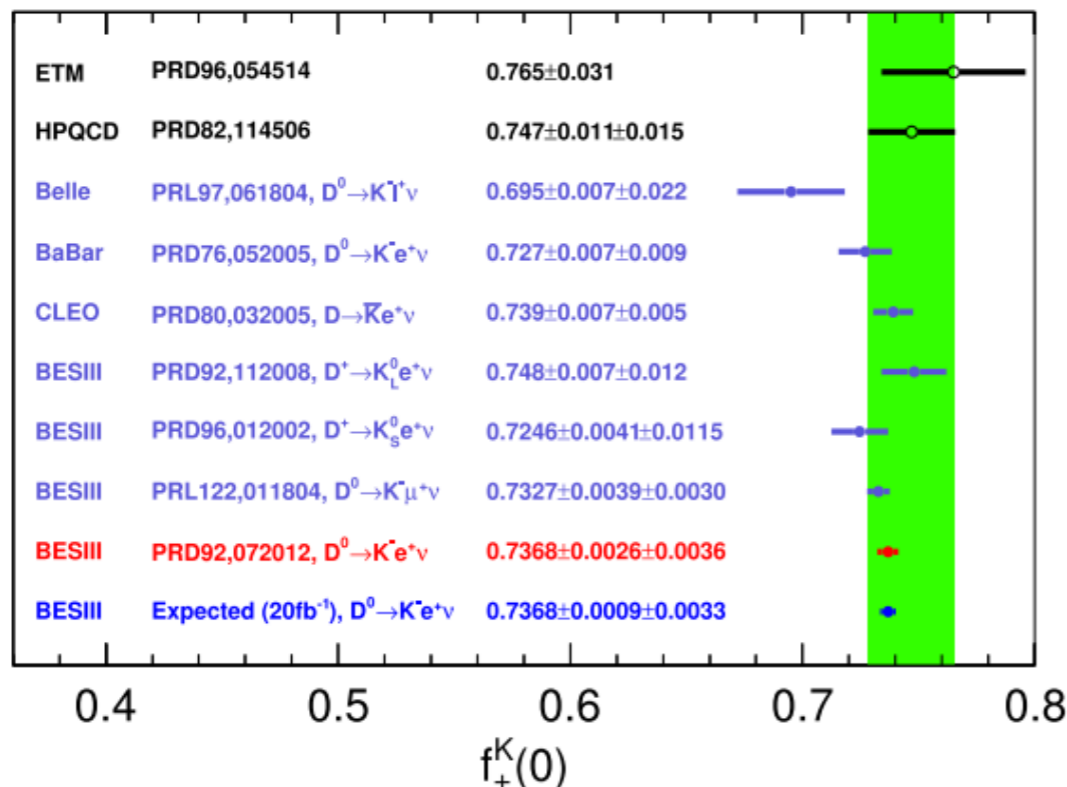
From White Paper (Chin. Phys. C 44, 040001 (2020))

With 20 fb⁻¹ of data set at 3.773 GeV in the coming two years

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: $D^0 \rightarrow K(1270)^- \nu_e$, $D^+ \rightarrow \bar{K}_1(1270)^0 e^+ \nu_e$, $D^+ \rightarrow \eta' \mu^+ \nu_\mu$, $D^0 \rightarrow a_0(980)^- e^+ \nu_e$, $D^+ \rightarrow a_0(980)^0 e^+ \nu_e$
- $|V_{cd(s)}|$ 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%



Thanks for your attention