Experimental review of (semi-)leptonic charm decays

Hailong Ma (IHEP&BESIII)

2nd International Workshop on Physics at Future High Intensity Collider @ 2-7GeV in China, March 19-21 2018

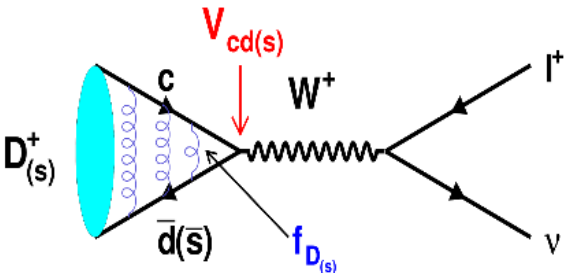
UCAS, Beijing, China

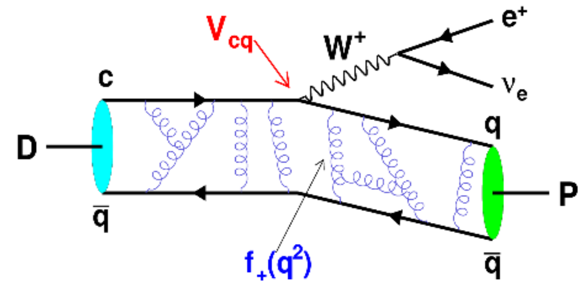
Contents

- Introduction
- Data sample
- $D_{(s)} \rightarrow l^+ v$
- $D \rightarrow K(\pi) e^+ v$
- Other topics (D, D_s, Λ_c) at threshold
- Summary

Introduction

Studies of (semi-)leptonic charm decays are important to explore weak and strong effects in charm decays





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

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

- **Precise measurements of decay constants f_{D^+}, $f_{D_s^+}$, form factors $f_+^{D(s)\to P}(q^2)$ of semi-leptonic (SL) $D_{(s)}$ decays will calibrate LQCD calculations at higher accuracy. Once they pass experimental tests, the precisely LQCD calculated f_D/f_B, f_{D_s}/f_{B_s} and $f_+^{D\to P}(0)/f_+^{B\to P}(0)$ will be helpful for measurements in B decays**

- **Improved LQCD calculations on $f_{D(s)+}$[0.5(0.5)%], $f_+^{D\to K(\pi)}(0)$ [2.4(4.4)%] help to precisely measure the CKM matrix element $|V_{cs(d)}|$, which are important for the CKM matrix unitarity test and search for NP beyond SM**

- **Test on lepton flavor universality in charm sector**

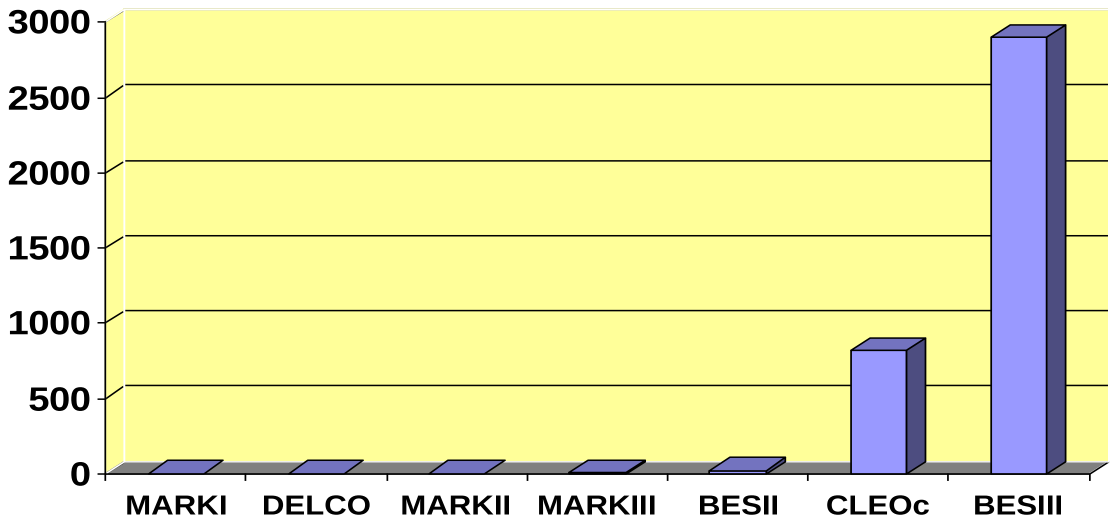
Recent $D^{0(+)}$, D_s^+ and Λ_c^+ samples

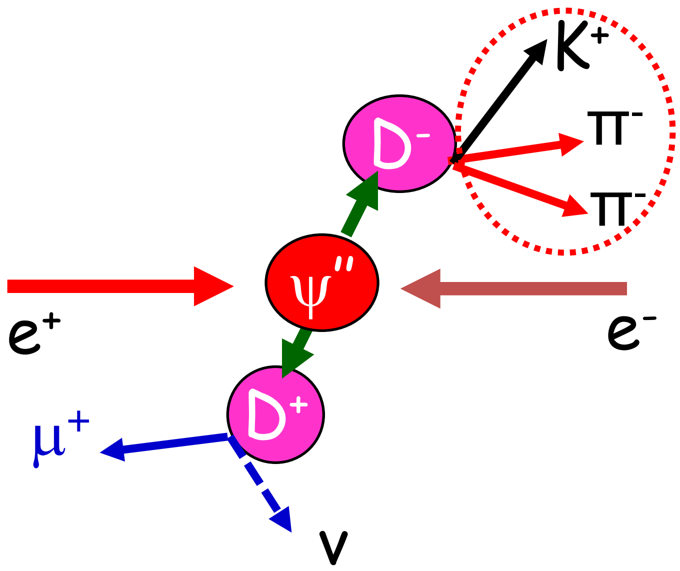
Taking from Longke Li's talk at joint workshop of BESIII/Belle/LHCb at Nankai

Experiment	Machine	C.M	Lumin.	N(D)	efficiency	advantage/disadvantage
CLEO	CESR (e^+e^-)	3.77 GeV	0.8 fb^{-1}	2.9×10^6 $2.3 \times 10^6 (D^\pm)$	~10-30%	☺ extremely clean enviroment ☺ pure D-beam, almost no bkg ☺ quantum coherence ☹ no CM boost, no T-dep analyses
		4.17 GeV	0.6 fb^{-1}	0.6×10^6		
BESIII	BEPC-II (e^+e^-)	3.77 GeV	2.92 fb^{-1}	10.5×10^6 8.4×10^6 $D^{0(+)}$		
		4.18 GeV	3 fb^{-1}	D_s^+ $3 \times 10^{[illegible]}$		
		4.6 GeV	**0.567 fb^{-1}**	Λ_c^+ ★	★★★	
Belle	KEKB (e^+e^-)	10.58 GeV	1 ab^{-1}	1.3×10^9	~5-10%	☺ clear event environment ☺ high trigger efficiency ☺ high-efficiency detection of neutrals ☺ many high-statistics control samples ☺ time-dependent analysis ☹ smaller cross-section than pp colliders
BaBar	PEP-II (e^+e^-)	10.58 GeV	0.5 ab^{-1}	6.5×10^8 ★★	★★	
CDF	Tevatron ($p\bar{p}$)	1.96 TeV	9.6 fb^{-1}	1.3×10^{11}	<0.5%	☺ large production cross-section ☺ large boost: excellent time resolution ☹ dedicated trigger required ☹ hard to do neutrals and neutrinos
LHCb	LHC (pp)	7 TeV 8 TeV	1.0 fb^{-1} 2.0 fb^{-1}	5.0×10^{12} ★★★	★	

Charm samples (pb^{-1}) at threshold

➢ $D^{0(+)}$ samples





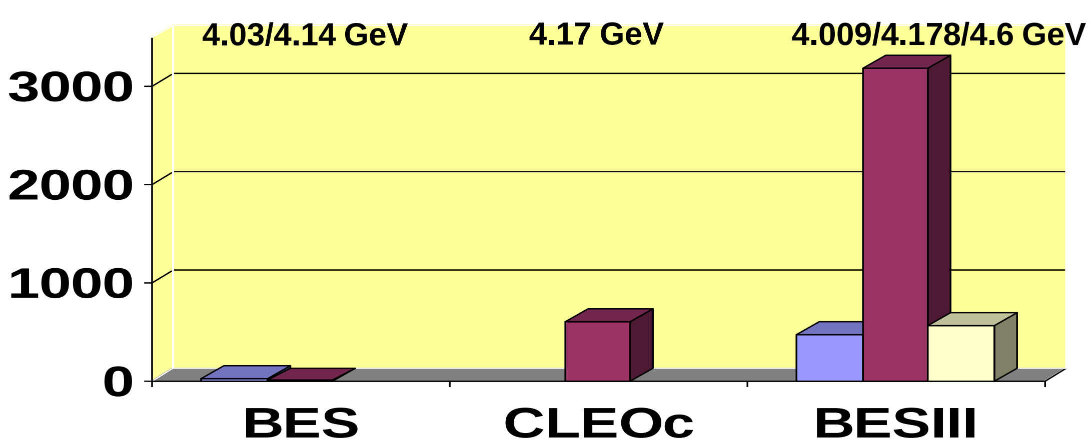
$$N_{ST}^{i} = 2 \times N_{D\bar{D}} \times B_{ST}^{i} \times \varepsilon_{ST}^{i}$$

$$N_{DT}^{i} = 2 \times N_{D\bar{D}} \times B_{ST}^{i} \times B_{sig} \times \varepsilon_{ST\ vs.sig}^{i}$$

$$B_{sig} = \frac{N_{DT}^{tot}}{N_{ST}^{tot} \times \bar{\varepsilon}_{sig}}$$

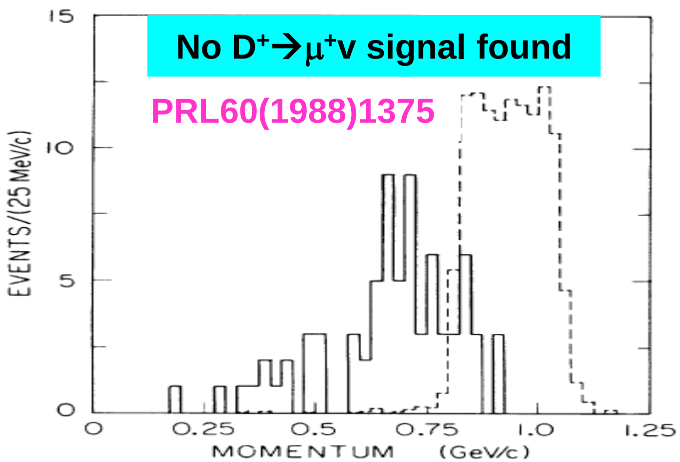
$$\bar{\varepsilon}_{sig} = \sum_{i=1}^{N} (N_{ST}^{i} \times \varepsilon_{ST\ vs.sig}^{i} / \varepsilon_{ST}^{i}) / \sum_{i=1}^{N} N_{ST}^{i}$$

➢ $D_s^+/D_s^+/\Lambda_c^+$ samples



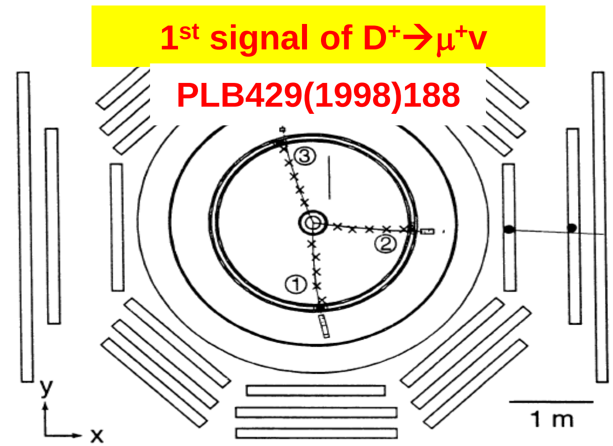
Earlier searches or measurements of f_{D+}

- **MARKIII, 9.6 pb^{-1} at ψ''**



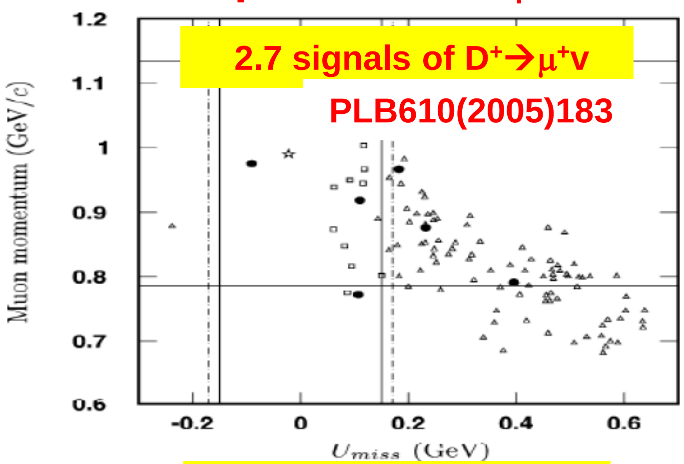
f_{D+}<290 MeV @ 90% C.L.

- **BESI, 22.3 pb^{-1} at 4.03 GeV**



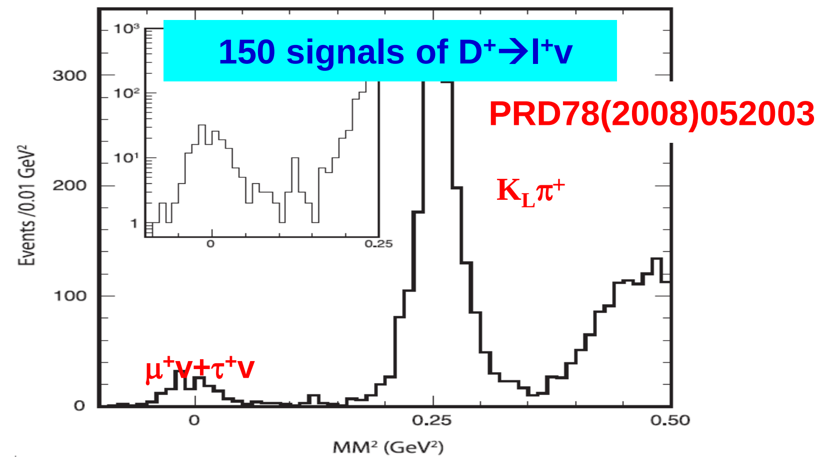
$$f_{D^+} = (300^{+180+80}_{-150-40})\ \text{MeV}$$

- **BESII, 33 pb^{-1} data at ψ''**



$$f_{D^+} = (371^{+129}_{-119} \pm 25)\ \text{MeV}$$

- **2004-2008, CLEO-c, 818 pb^{-1} at ψ''**

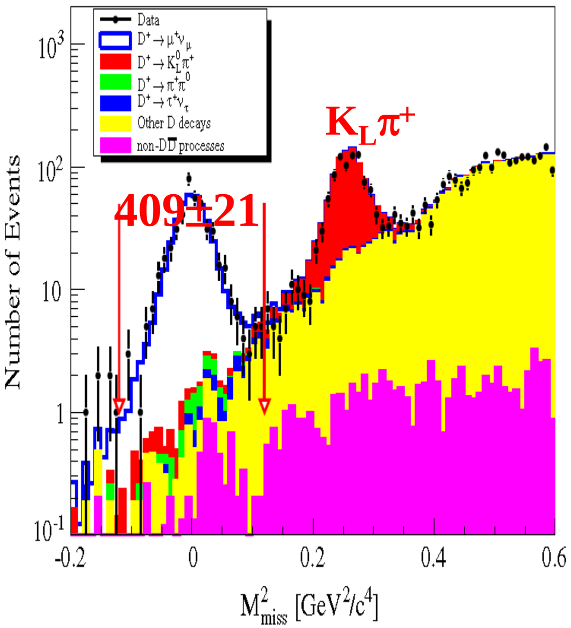


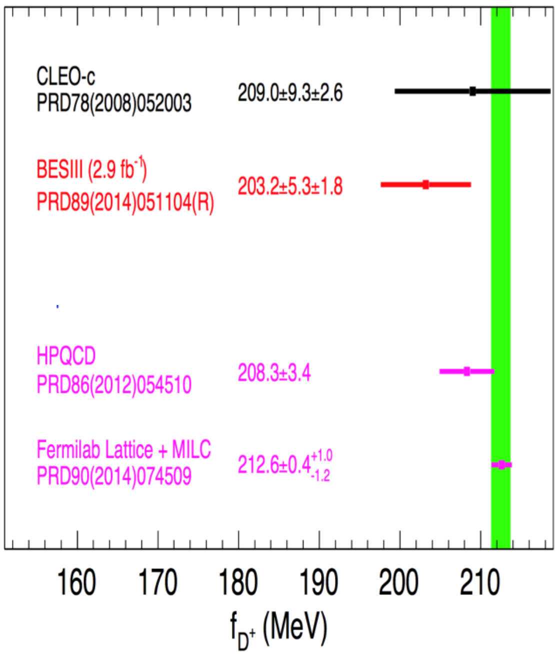
f_{D+}=205.8±7.5±2.5 MeV

Results on $B[D^+ \to l^+ \nu]$, $f_{D+}|V_{cd}|$

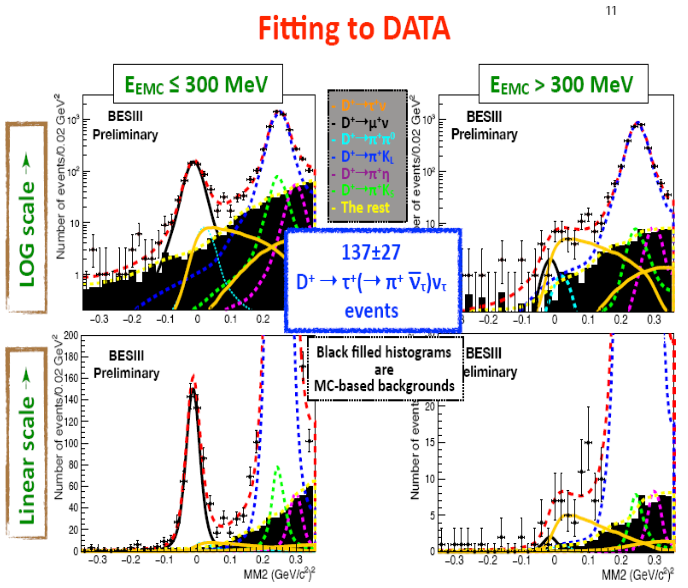
2.93 fb^{-1} data@ 3.773 GeV

BESIII, PRD89(2014)051104R





Evidence of $D^+ \to \tau^+ \nu$



$B[D^+ \to \tau^+ \nu] = (1.20 \pm 0.24_{stat.}) \times 10^{-3}$

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

$f_{D+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$

20 fb^{-1} data can reduce the statistical error of f_{D+} to 1%

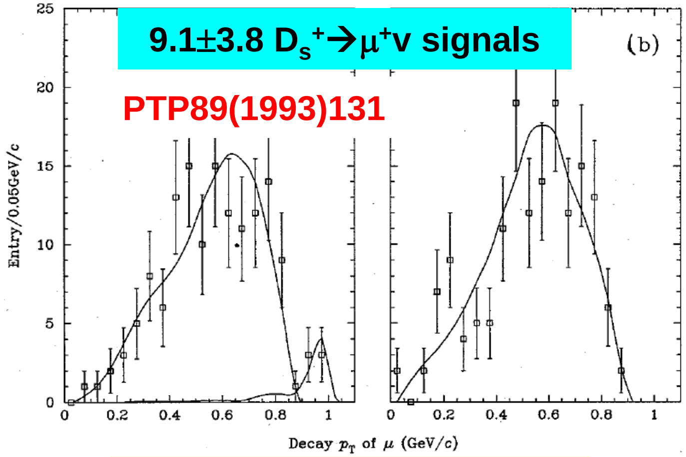
$$R \equiv \frac{\Gamma(D^+ \to \tau^+ \nu)}{\Gamma(D^+ \to \mu^+ \nu)} = \frac{m_{\tau^+}^2 \left(1 - \frac{m_{\tau^+}^2}{M_{D^+}^2}\right)^2}{m_{\mu^+}^2 \left(1 - \frac{m_{\mu^+}^2}{M_{D^+}^2}\right)^2}$$

SM prediction: 2.66

BESIII: 3.21±0.64

Earlier measurements of f_{D_s+}

- **WA75, Fixed target experiment**

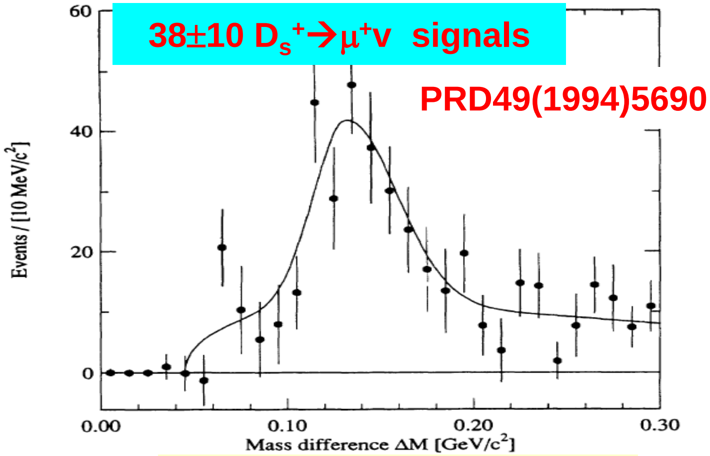


9.1±3.8 $D_s^+ \to \mu^+ \nu$ signals

PTP89(1993)131

f_{Ds+}=232±45±20±48 MeV

- **CLEOII, 2.13 fb^{-1} at 10.6 GeV**

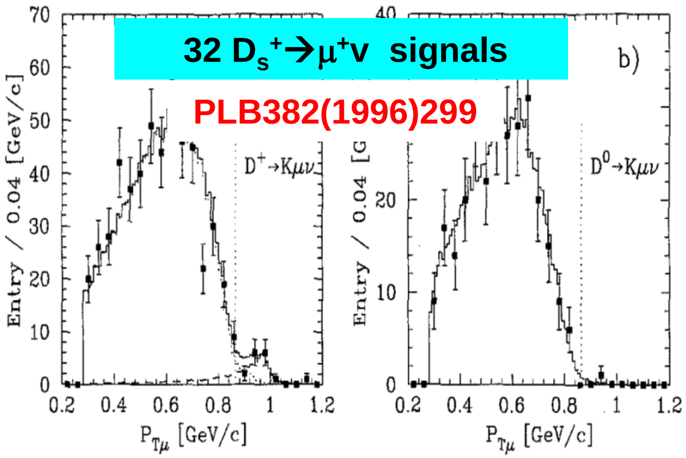


38±10 $D_s^+ \to \mu^+ \nu$ signals

PRD49(1994)5690

f_{Ds+}=344±37±52±42 MeV

- **E653, Fermilab fixed target experiment**

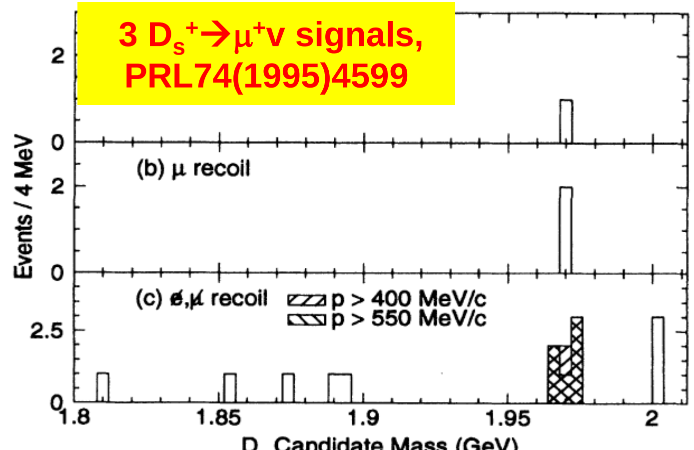


32 $D_s^+ \to \mu^+ \nu$ signals

PLB382(1996)299

f_{Ds+}=194±35±20±14 MeV

- **BESI, 22.3 pb^{-1} at 4.03 GeV**



3 $D_s^+ \to \mu^+ \nu$ signals, PRL74(1995)4599

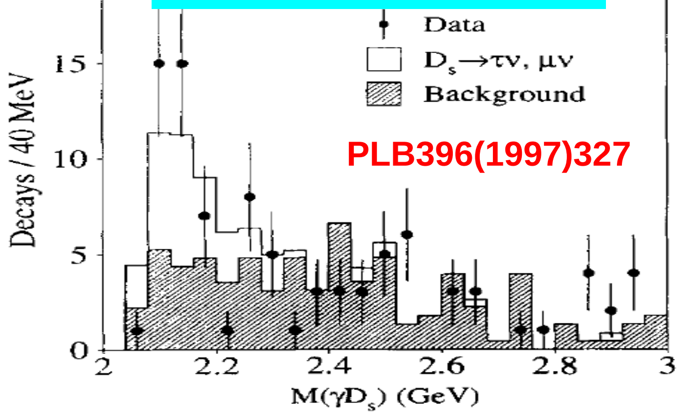
$f_{D_s^+} = (430^{+150+40}_{-130-40})$ MeV

First absolute measurement

Earlier measurements of f_{D_s+}

- L3, $Z \rightarrow q\bar{q}$, 49.6 pb^{-1} at 91.2 GeV

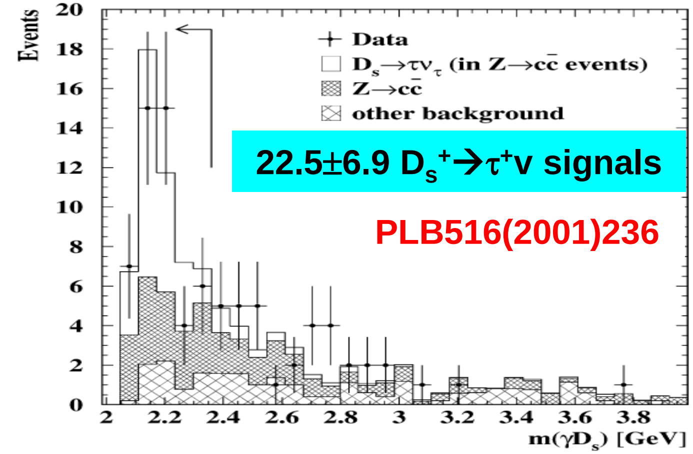
15.6±6.0 $D_s^+ \rightarrow \mu^+ \nu$ signals



PLB396(1997)327

f_{Ds+}=309±58±33±38 MeV

- OPAL, 3.9×10⁶ $e^+e^- \rightarrow q\bar{q}$



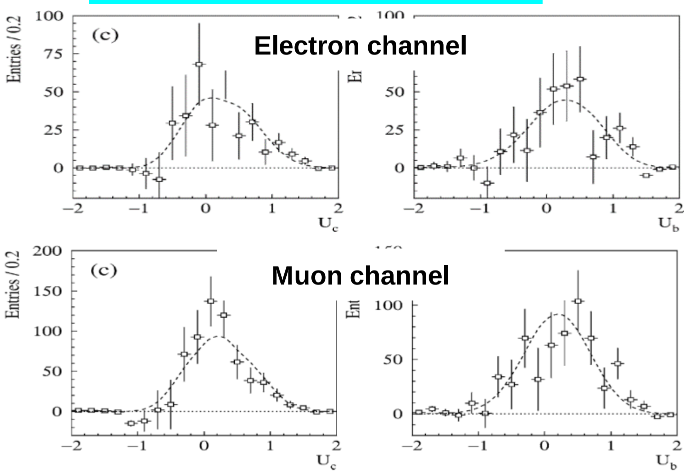
22.5±6.9 $D_s^+ \rightarrow \tau^+ \nu$ signals

PLB516(2001)236

f_{Ds+}=286±44±41 MeV

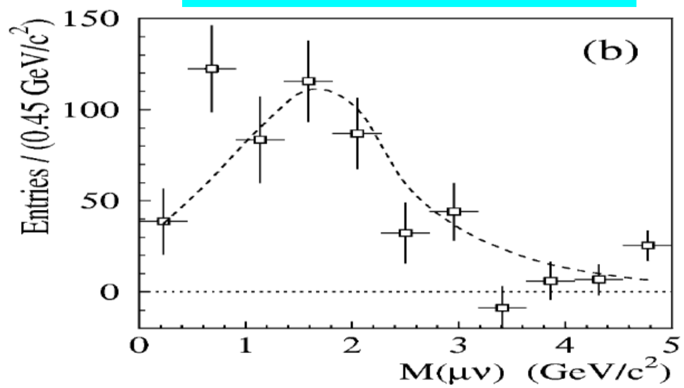
- ALPHA, 3.97×10⁶ Z hadronic decay

306±62 $D_s^+ \rightarrow \tau^+ \nu$ signals



PLB528(2002)1

575±84 $D_s^+ \rightarrow \mu^+ \nu$ signals

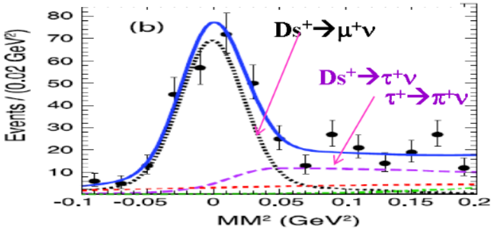


f_{Ds+}=285±19±40 MeV

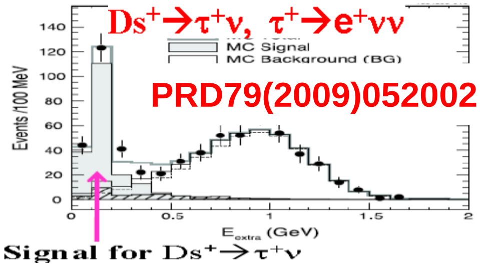
Results of f_{Ds+} at CLEO/Belle/BaBar

- $D_s^{*+}D_s^-$, 600 pb^{-1} @ 4.17 GeV [697 $l^+\nu$]

PRD79(2009)052001



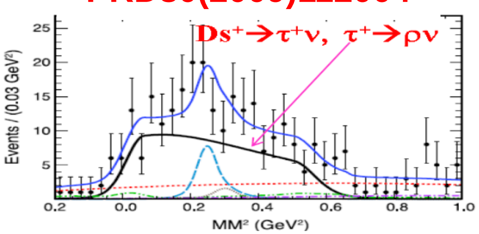
f_{Ds+}=263.3±8.2±1.9 MeV



PRD79(2009)052002

f_{Ds+}=252.2±11.1±5.2 MeV

PRD80(2009)112004

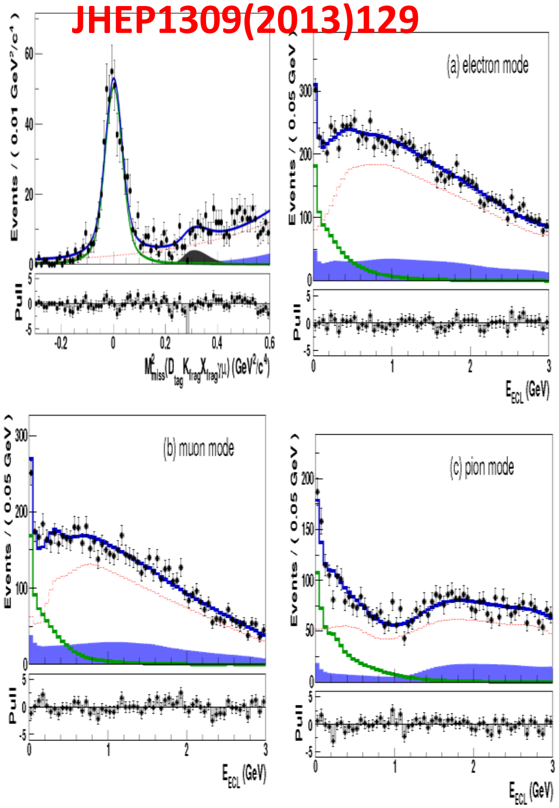


f_{Ds+}=257.8±13.3±5.2 MeV

- Belle, 913 fb^{-1} at 10.58 GeV [2698 $l^+\nu$]

$$e^+e^- \to DKXD_s^{*-}$$

JHEP1309(2013)129

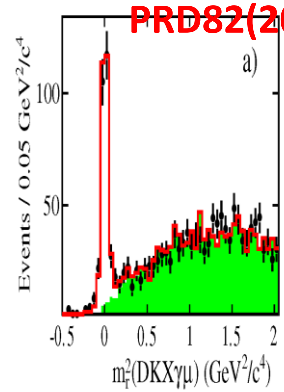


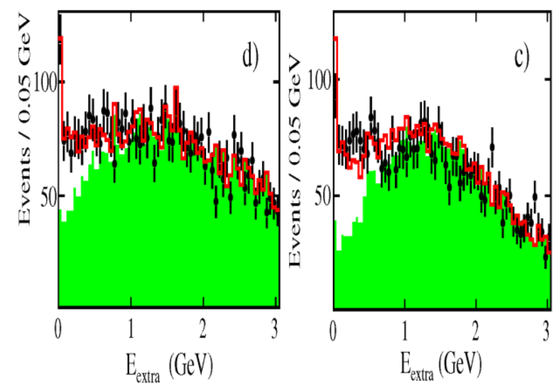
f_{Ds+}=255.5±4.2±5.1 MeV

- Babar, 521 fb^{-1} at 10.58 GeV [1023 $l^+\nu$]

$$e^+e^- \to DKXD_s^{*-}$$

PRD82(2010)091103





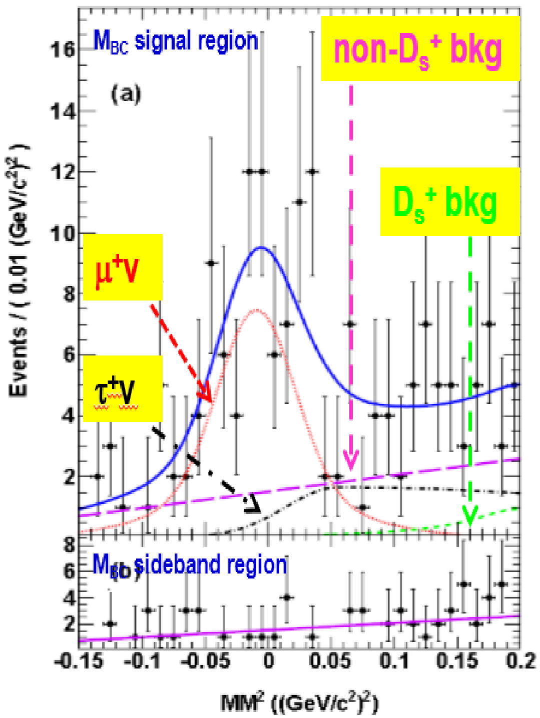
f_{Ds+}=258.6±6.4±7.5 MeV

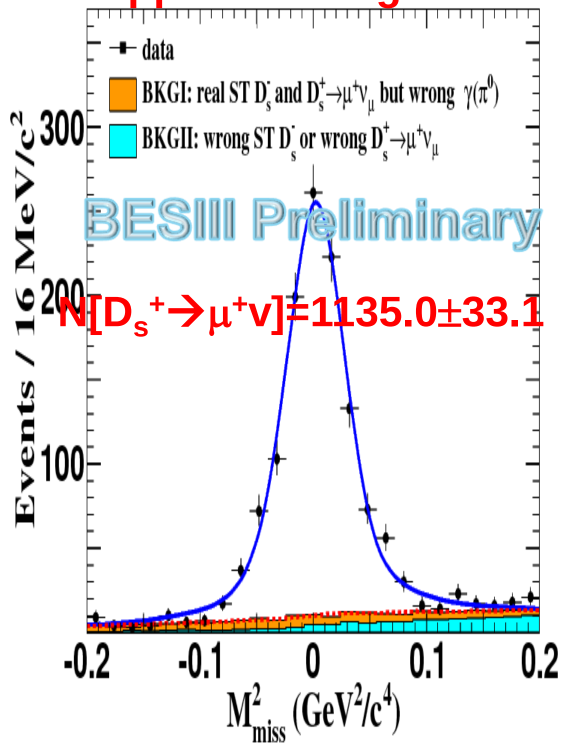
Results on $B[D_s^+ \to \mu^+\nu]$, $f_{D_s^+}|V_{cs}|$ at BESIII

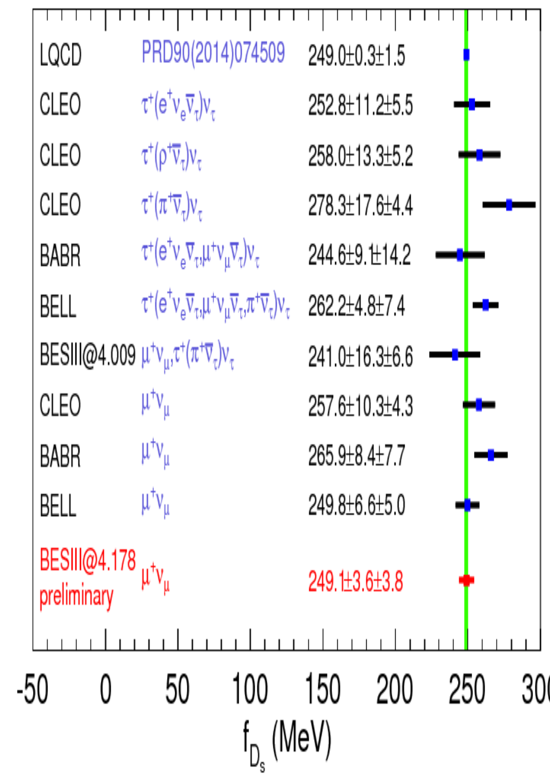
$0.48\ fb^{-1}$ data@4.01 GeV **$3.19\ fb^{-1}$ data@4.178 GeV**

PRD94(2016)072004

Use μ counter to suppress background







$f_{D_s^+}=(241.0\pm16.3\pm6.6)$ MeV

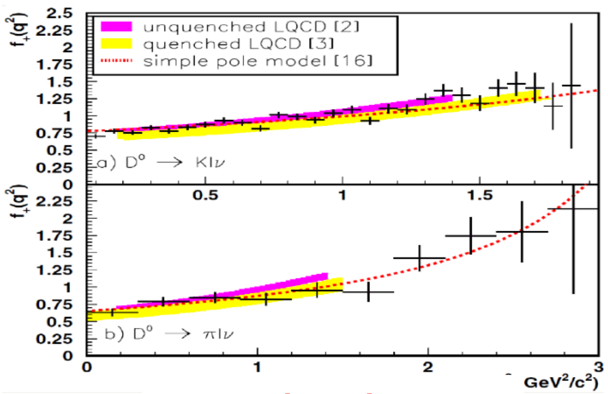
$f_{D_s}|V_{cs}|=242.5\pm3.5\pm3.7$ MeV

Precision on $f_{D_s^+}$ reach 2%. Combining $\tau^+\nu$ can reduce it to 1.5%

Previous measurements of $f^{D\to K(\pi)}(0)|V_{cs(d)}|$

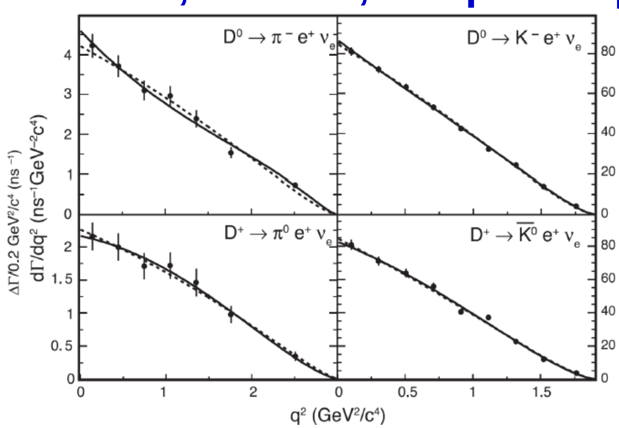
In the past 30 years, studies of $D\to K(\pi)l^+v$ were made by MARKIII, E691, CLEO, CLEOII, BESII, FOCUS, BELLE, Babar and CLEO-c

- **BELLE, 282 fb^{-1} at 10.58 GeV**



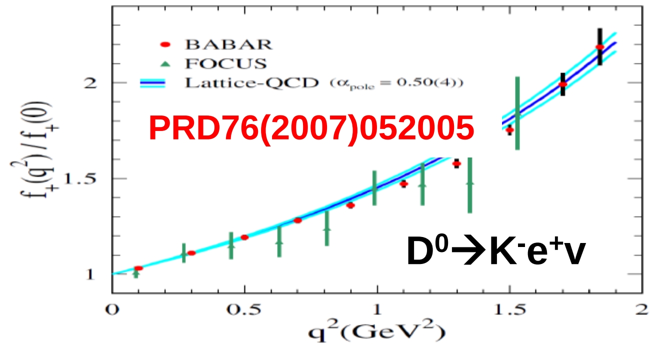
PRL97(2006)061804

- **2004-2009, CLEO-c, 818 pb^{-1} at ψ''**



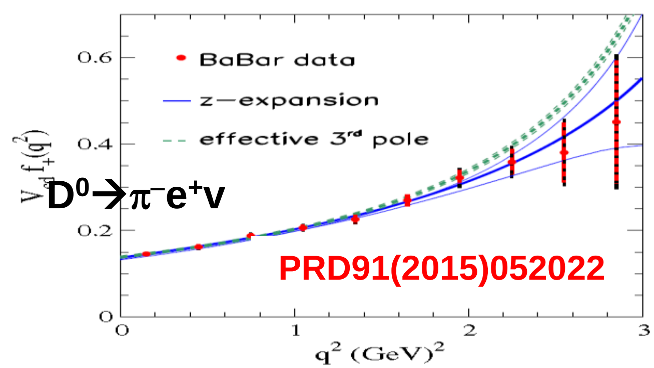
PRD80(2009)032005

- **Babar, 75 fb^{-1} at 10.58 GeV**



PRD76(2007)052005

- **Babar, 347.2 fb^{-1} at 10.58 GeV**

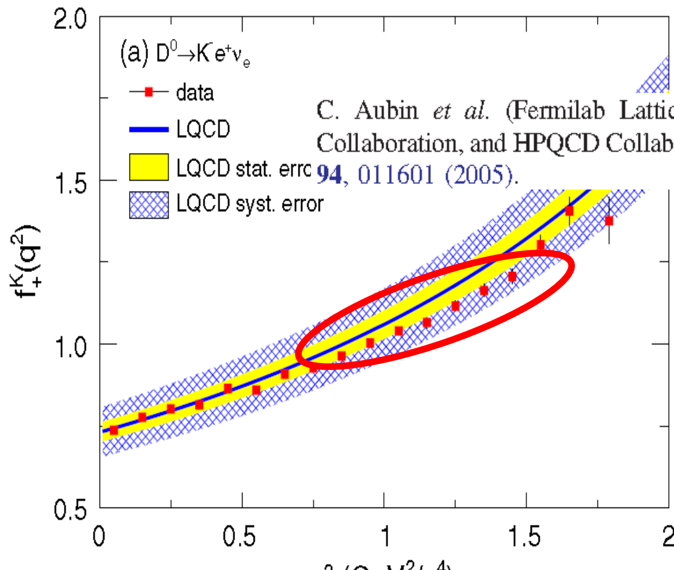


PRD91(2015)052022

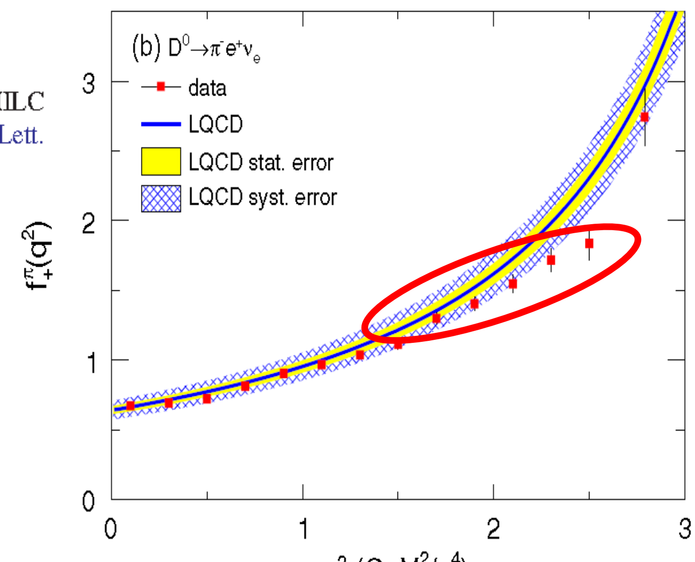
Before 2010, the LQCD calculated $f_+^{D\to K(\pi)}(0)$ precision is at 10% level, thus limiting $|V_{cs(d)}|$ measurement

Impact of $f^{D\to K(\pi)}(q^2)$ on LQCD

BESIII, PRD92(2015)072012

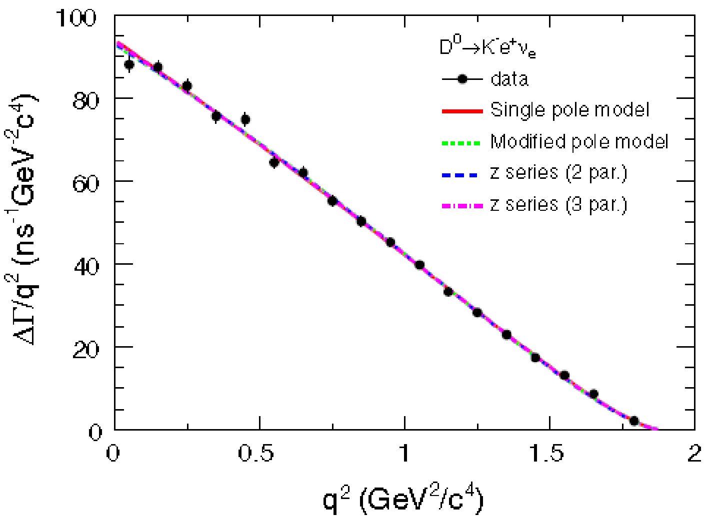


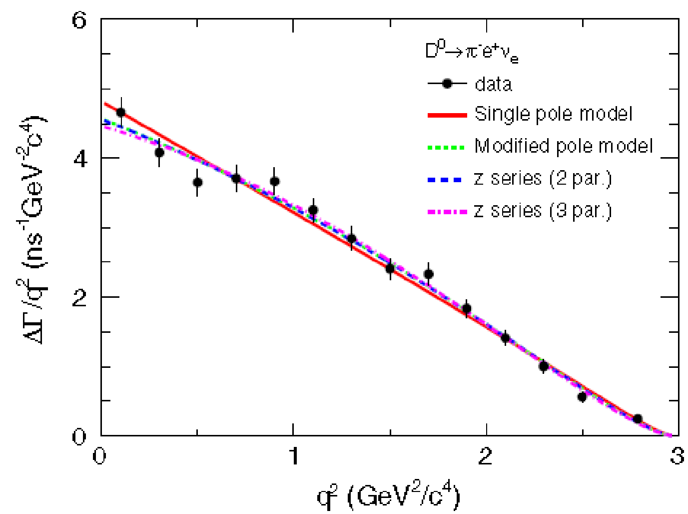
C. Aubin *et al.* (Fermilab Lattice Collaboration, MILC Collaboration, and HPQCD Collaboration), Phys. Rev. Lett. **94**, 011601 (2005).



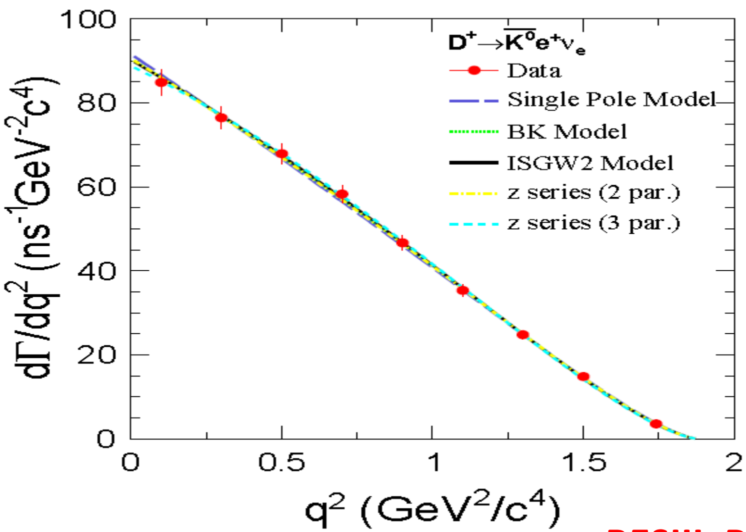
$D^0 \to K^- e^+ \nu$

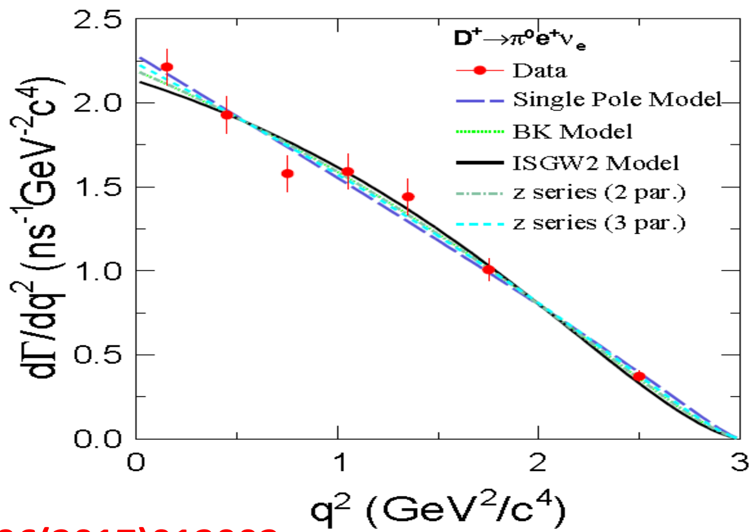
$D^0 \to \pi^- e^+ \nu$



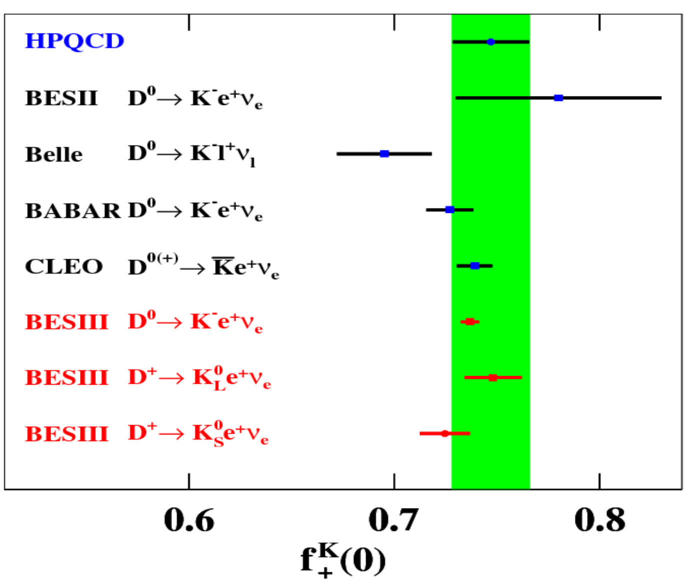


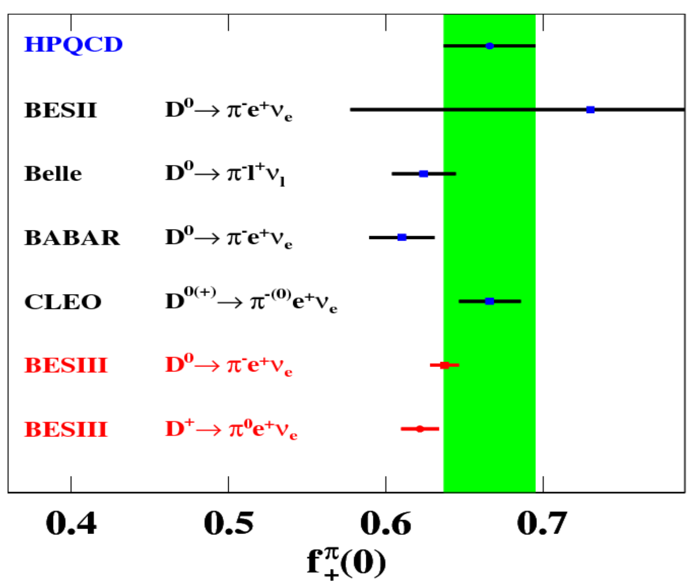
Comparisons of $f^{D\to K(\pi)}(0)$ with LQCD





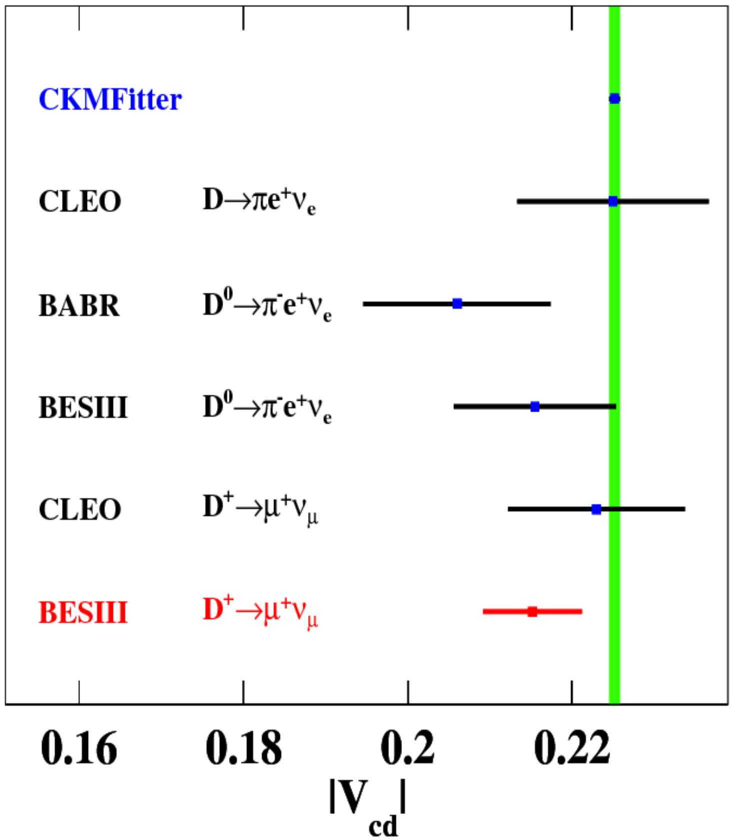
BESIII, PRD96(2017)012002

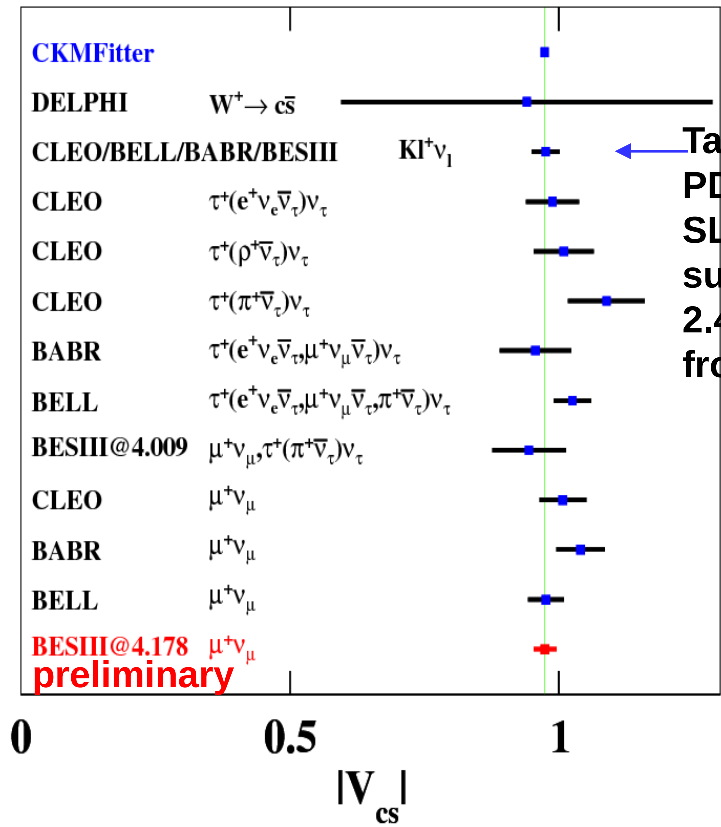




Comparisons of the measured $|V_{cs(d)}|$

- **Method 1** $f_{D(s)}|V_{cd(s)}|$ $|V_{cd(s)}|$
- **Method 2** $f^{D\to K(\pi)}_{+}(0)|V_{cs(d)}|$ $|V_{cs(d)}|$
- **Method 3** $f^{D(s)\to\eta}_{+}(0)|V_{cd(s)}|$ $|V_{cd(s)}|$ ← Limited by both statistics and LQCD input





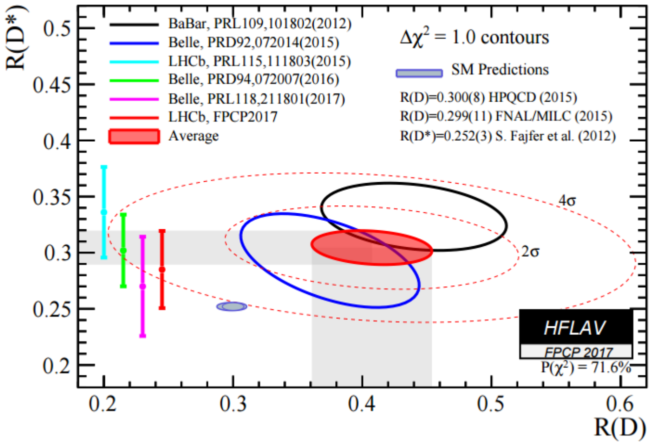
← Taken from PDG, and the SL method suffers about 2.4% error from LQCD

Further improved LQCD calculations on $f_{+}^{D(s)\to P}(0)$ will improve the measurement of $|V_{cs(d)}|$ with much improved precision

LFU test in CS decay $D^{0(+)} \to \pi l^+ v$ at BESIII

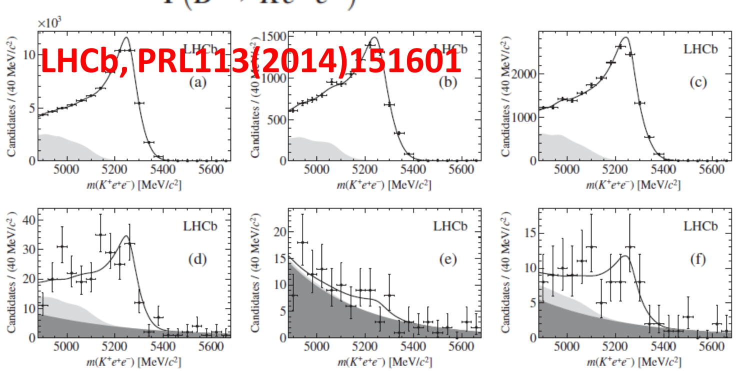
Evidence of violation of LFU at 4σ in

$$R(D^{(*)}) = \frac{B(B \to D^{(*)}\tau\nu)}{B(B \to D^{(*)}l\nu)}$$



Evidence at 2.6σ in FCNC decays $B^+ \to K^+\mu^+\mu^-/K^+e^+e^-$

$$R_K = \frac{\Gamma(\bar{B} \to \bar{K}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}e^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

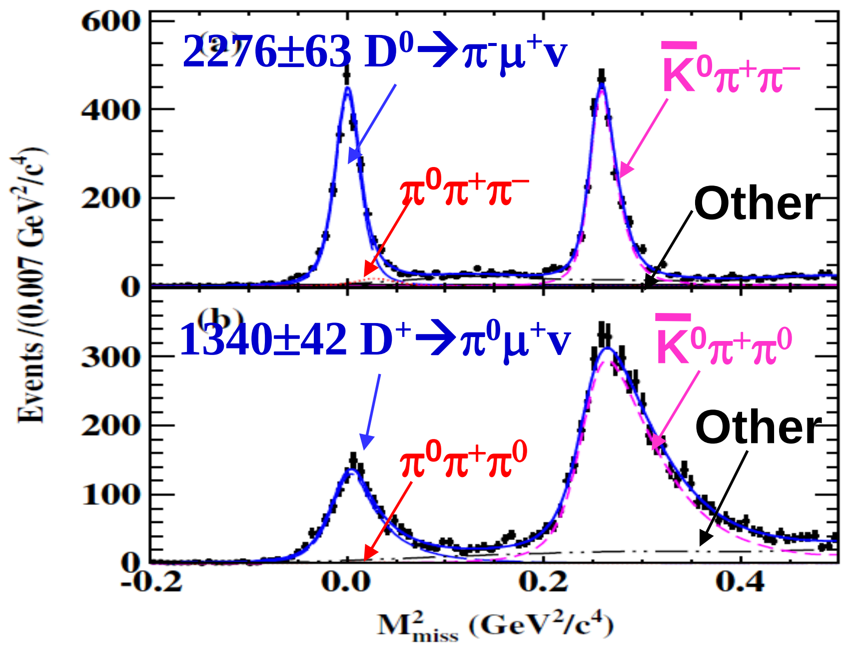


$$R_{LU}^{0(+)} = \frac{B(D^{0(+)} \to \pi^{-(0)}\mu^+\nu)}{B(D^{0(+)} \to \pi^{-(0)}e^+\nu)} \sim 0.97$$

B^PDG16: $R_{LU}^{0} = 0.82 \pm 0.08 \quad (\sim 2.0\sigma)$

$B(D^0 \to \pi^-\mu^+\nu) = (0.237 \pm 0.024)\%$

BESIII, arXiv:1802.05492



$B[D^0 \to \pi^-\mu^+v] = (0.267 \pm 0.007 \pm 0.007)\%$

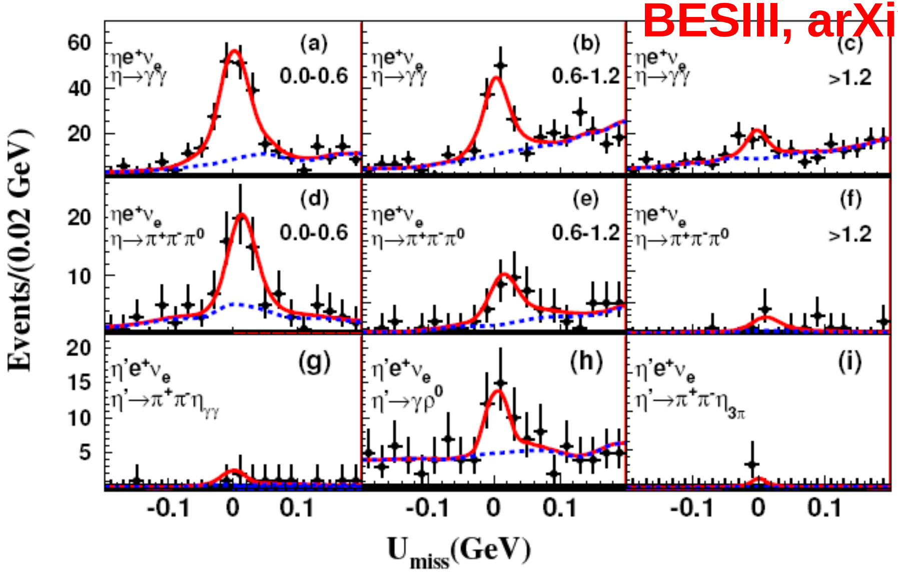
$B[D^+ \to \pi^0\mu^+v] = (0.342 \pm 0.011 \pm 0.010)\%$

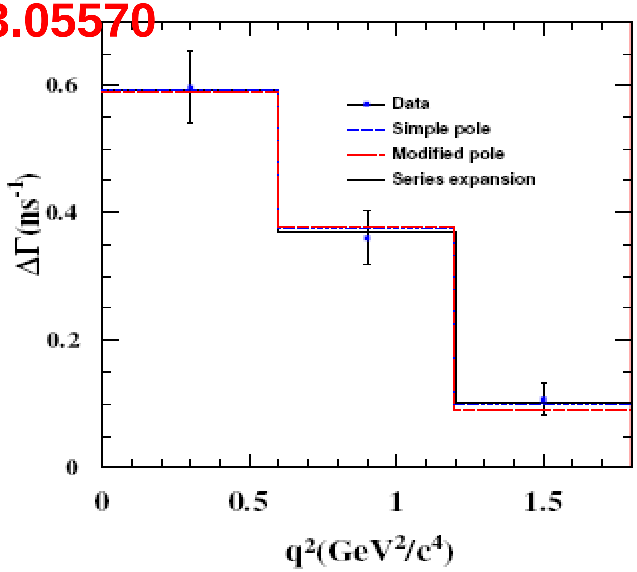
$$\mathcal{R}_{LU}^{0} = 0.905 \pm 0.027_{stat.} \pm 0.023_{syst.}$$

$$\mathcal{R}_{LU}^{+} = 0.942 \pm 0.037_{stat.} \pm 0.027_{syst.}$$

Study of $D^+ \rightarrow \eta^{(\prime)} e^+ \nu$ at BESIII

BESIII, arXiv:1803.05570





$$\mathcal{B}_{\eta e^+\nu_e} = (10.74 \pm 0.81 \pm 0.51) \times 10^{-4}$$

$$\mathcal{B}_{\eta' e^+\nu_e} = (1.91 \pm 0.51 \pm 0.13) \times 10^{-4}$$

$$\frac{d\Gamma(D^+ \to \eta e^+ \nu_e)}{dq^2} = \frac{G_F^2 |V_{cd}|^2}{24\pi^3} |\vec{p}_\eta|^3 |f_+(q^2)|^2$$

Fit parameters	Simple pole	Modified pole	Series expansion
$f_+(0)\|V_{cd}\|$ ($\times 10^{-2}$)	$8.15 \pm 0.45 \pm 0.18$	$8.24 \pm 0.51 \pm 0.22$	$7.86 \pm 0.64 \pm 0.21$
Shape parameter	$1.73 \pm 0.17 \pm 0.03$	$0.50 \pm 0.54 \pm 0.08$	$-7.33 \pm 1.69 \pm 0.40$
ρ	0.80	−0.85	0.90
χ^2/ndf	$0.1/(3-2)$	$0.3/(3-2)$	$0.5/(3-2)$

BFs help to constrain gluon component

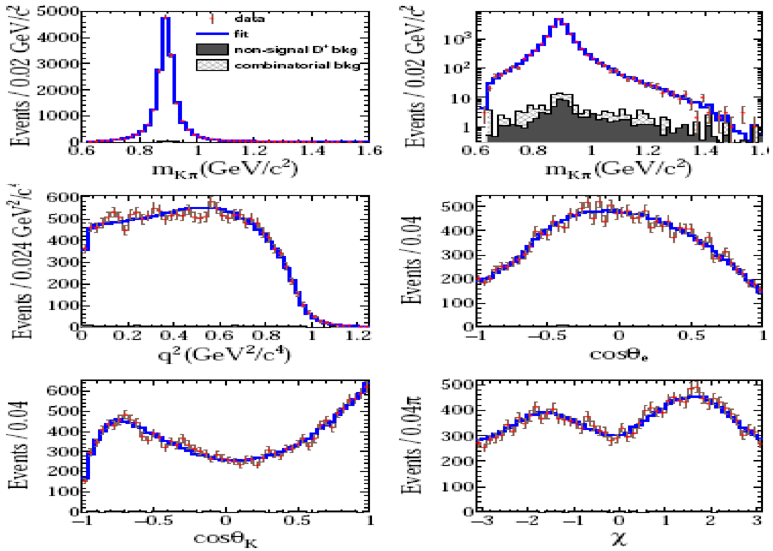
$$\begin{pmatrix} \eta \\ \eta' \\ G \end{pmatrix} = \begin{pmatrix} \cos\phi' & -\sin\phi' & 0 \\ \sin\phi'\cos\phi_G & \cos\phi'\cos\phi_G & \sin\phi_G \\ -\sin\phi'\sin\phi_G & -\cos\phi'\sin\phi_G & \cos\phi_G \end{pmatrix} \begin{pmatrix} \eta_q \\ \eta_s \\ g \end{pmatrix}$$

Combing CLEO's BFs and taking input value by EPJC69,133 and NPPS162, 312, the $\eta-\eta'$ mixing angle is determined to be $\phi_P=(40\pm3_{experiment}\pm3_{theory})^0$

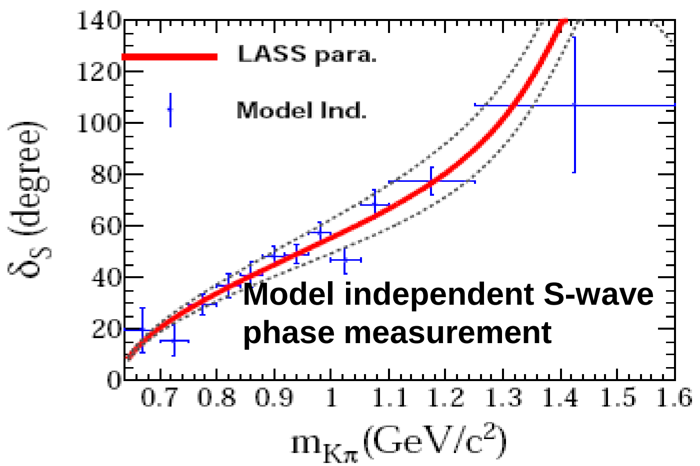
Other topics: $D \rightarrow V e^+ \nu$ at BESIII

BESIII,PRD94(2016)032001

$D^+ \rightarrow K^- \pi^+ e^+ \nu$

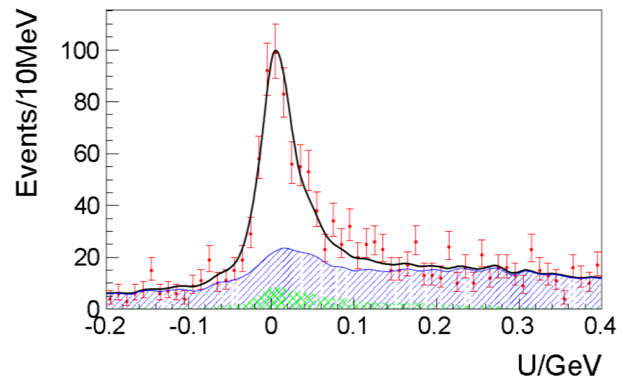


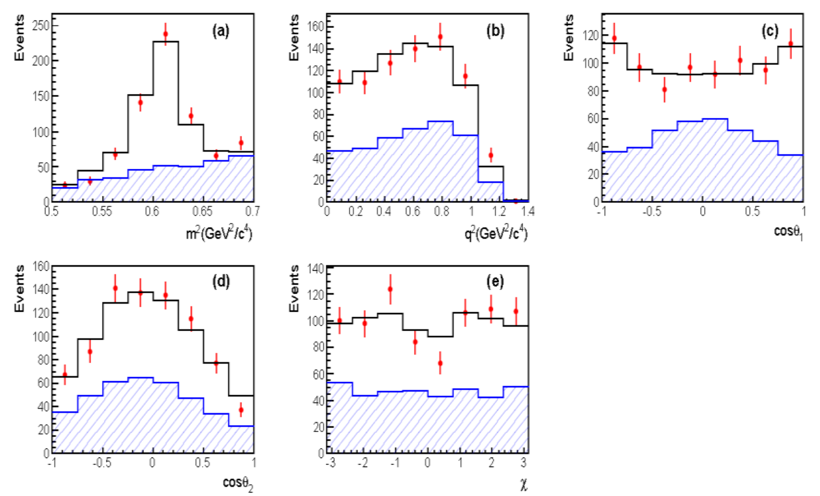
Model independent form factors



BESIII,PRD92(2015)071101(RC)

$D^+ \rightarrow \omega e^+ \nu$





$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$

$r_2 = A_2(0)/A_1(0) = 1.06 \pm 0.15 \pm 0.05$

Observation of D→Se⁺v at BESIII

- Explore the nontrivial internal structure of light hadron mesons, traditional $q\bar{q}$ states, tetra quark system.

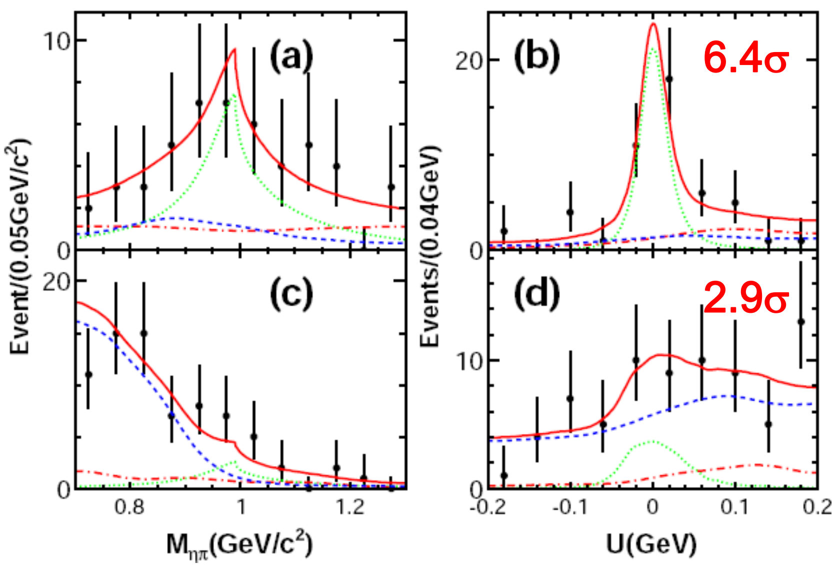
- With chiral unitarity approach in the coupled channels, BF is predicted to be order of $5(6)\times10^{-5}$ for $D^{0(+)}$ decays

- Improve understanding of classification of light scalar mesons

$$R \equiv \frac{B(D^+\to f_0 l^+ \nu)+B(D^+\to \sigma l^+ \nu)}{B(D^+\to a_0 l^+ \nu)}$$

R=1(3) if traditional $q\bar{q}$ (tetra quark) system

BESIII, arXiv:1803.02166

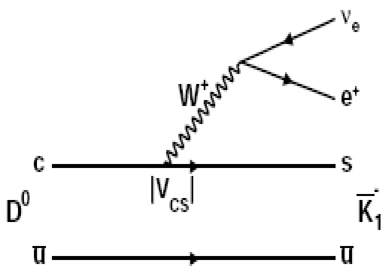


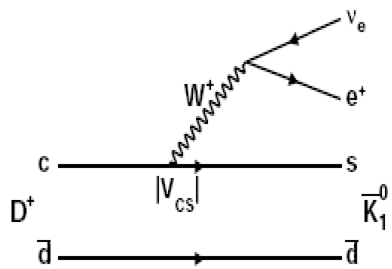
$$\mathcal{B}(D^+ \to a_0(980)^0 e^+\nu_e) \times \mathcal{B}(a_0(980)^0 \to \eta\pi^0)$$
$$= (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}, \qquad < 3.0 \times 10^{-4} \text{ at the } 90\% \text{ C.L.}$$

$$\mathcal{B}(D^0 \to a_0(980)^- e^+\nu_e) \times \mathcal{B}(a_0(980)^- \to \eta\pi^-)$$
$$= (1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$$

$$\frac{\Gamma(D^0 \to a_0(980)^- e^+\nu_e)}{\Gamma(D^+ \to a_0(980)^0 e^+\nu_e)} = 2.03 \pm 0.95 \pm 0.06$$

Evidence of D→Ae⁺ν at CLEO





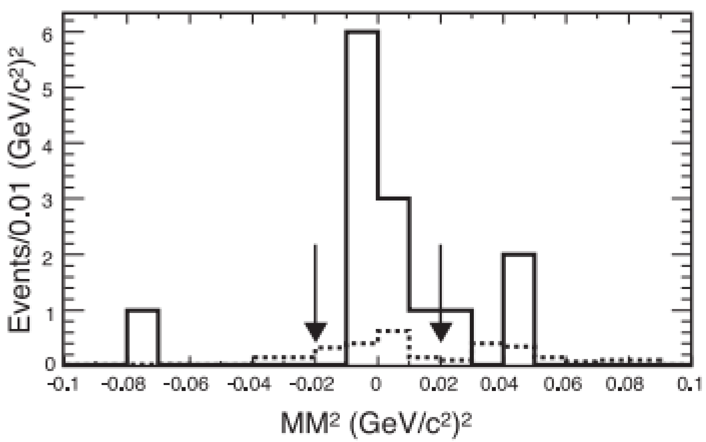
EPJC77(2017)587/863

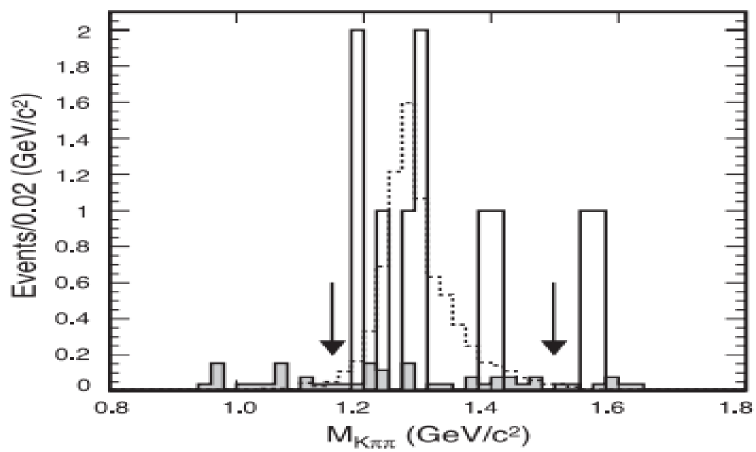
D^+ decay

	$D \to K_1(1270)$	$D \to K_1(1400)$
Theory (10^{-5})	320 ± 40	$\{0.5, 2.0\}$

CLEO, PRL(2007)191801

with 281 pb^{-1} data@3.773 GeV





$$\mathcal{B}(D^0 \to K^-\pi^+\pi^- e^+\nu_e) = [2.8^{+1.4}_{-1.1}(\text{stat}) \pm 0.3(\text{syst})] \times 10^{-4}$$

$$\mathcal{B}(D^0 \to K_1^-(1270)e^+\nu_e) \times \mathcal{B}(K_1^-(1270) \to K^-\pi^+\pi^-) = [2.5^{+1.3}_{-1.0}(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-4}$$

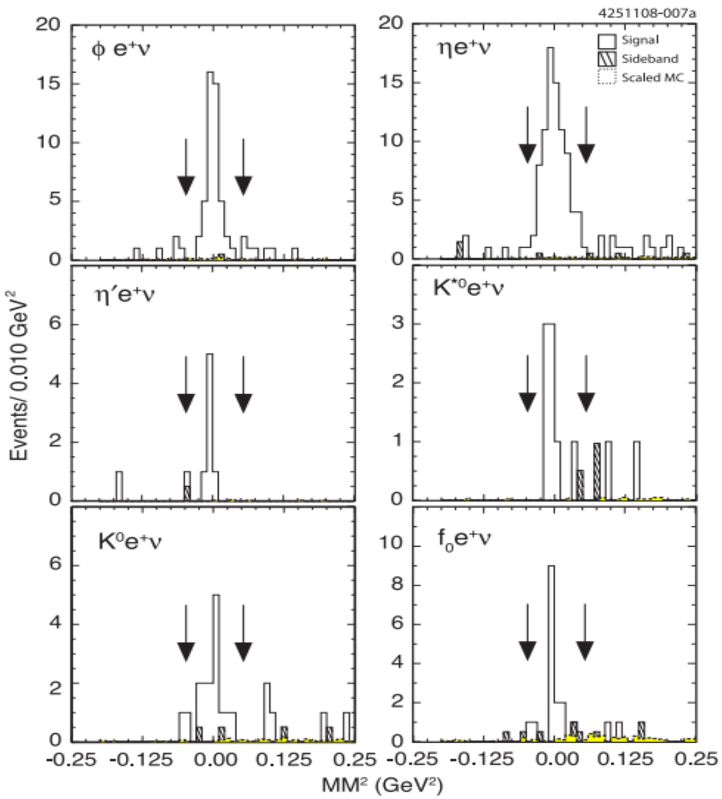
Using $\mathcal{B}(K_1^-(1270) \to K^-\pi^+\pi^-) = (33 \pm 3)\%$

$$\mathcal{B}(D^0 \to K_1^-(1270)e^+\nu_e) = [7.6^{+4.1}_{-3.0}(\text{stat}) \pm 0.6(\text{syst}) \pm 0.7] \times 10^{-4}$$

BFs of SL D_s^+ decays at CLEO

CLEO, PRD80(2009)052007

with 310 pb^{-1} data@4.17 GeV

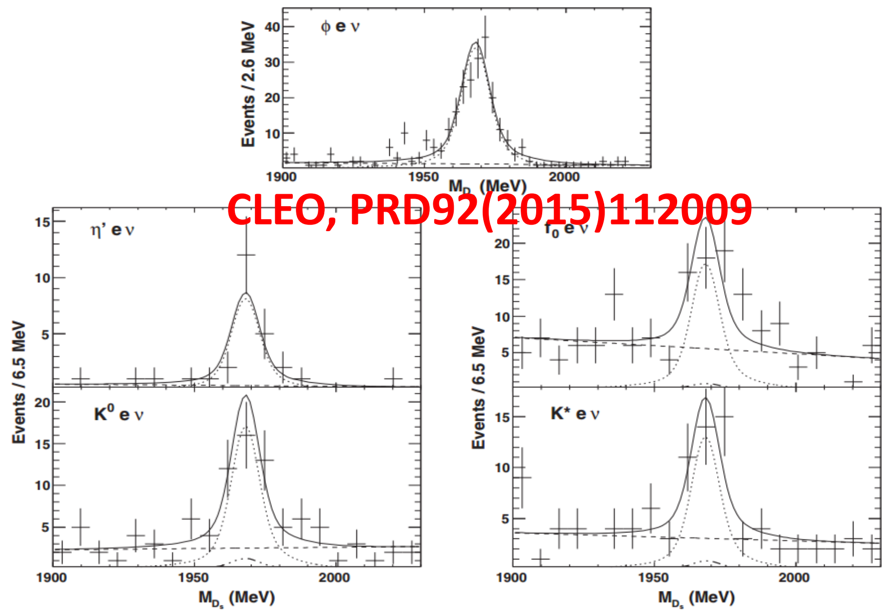


$$\frac{\Gamma(D_s \to \eta' e\nu)}{\Gamma(D_s \to \eta e\nu)} = R_D \cot^2\phi$$

$$\frac{\Gamma(D_s \to \eta' e\nu)/\Gamma(D_s \to \eta e\nu)}{\Gamma(D^+ \to \eta' e\nu)/\Gamma(D^+ \to \eta e\nu)} = \cot^4\phi$$

J. Hietala,[1,*] D. Cronin-Hennessy,[1,†] T. Pedlar,[2] and I. Shipsey[3]

with 600 pb^{-1} data@4.17 GeV



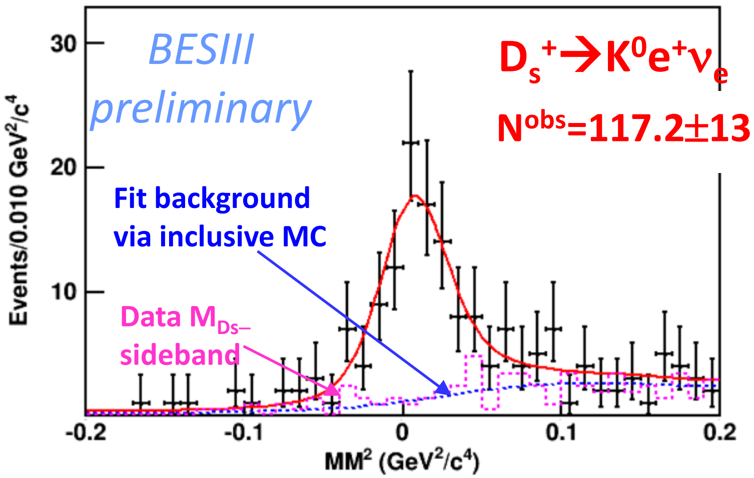
CLEO, PRD92(2015)112009

Signal mode	BABAR (%)	CLEO-c (%)	This analysis (%)
$D_s \to \phi e\nu$	$2.61 \pm 0.03 \pm 0.08 \pm 0.15$	$2.36 \pm 0.23 \pm 0.13$	$2.14 \pm 0.17 \pm 0.08$
$D_s \to \eta e\nu$	...	$2.48 \pm 0.29 \pm 0.13$	$2.28 \pm 0.14 \pm 0.19$
$D_s \to \eta' e\nu$	...	$0.91 \pm 0.33 \pm 0.05$	$0.68 \pm 0.15 \pm 0.06$
$D_s \to f_0 e\nu, f_0 \to \pi\pi$	Seen	$0.20 \pm 0.03 \pm 0.01$	$0.13 \pm 0.03 \pm 0.01$
$D_s \to K_S e\nu$	...	$0.19 \pm 0.05 \pm 0.01$	$0.20 \pm 0.04 \pm 0.01$
$D_s \to K^* e\nu$	...	$0.18 \pm 0.07 \pm 0.01$	$0.18 \pm 0.04 \pm 0.01$

θ(η–η′ mixing angle)=$(42\pm2\pm2)^0$

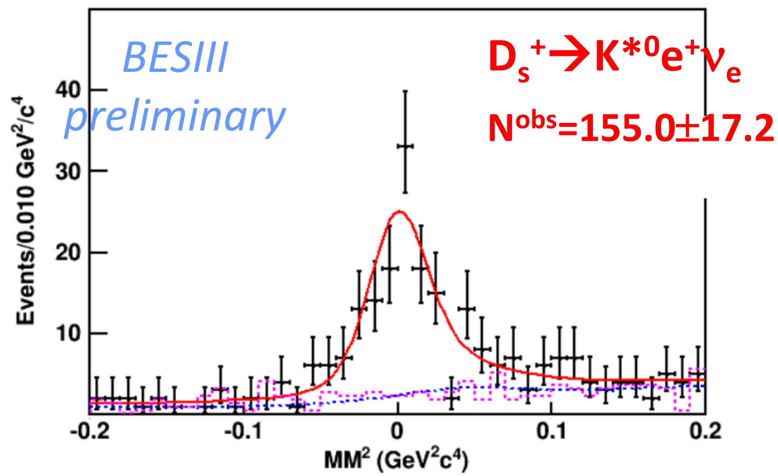
θ(f_0–ss mixing angle)=$(20^{+32}_{-20})^0$

First study of $D_s^+ \to K^{(*)0} e^+ \nu$ dynamics at BESIII



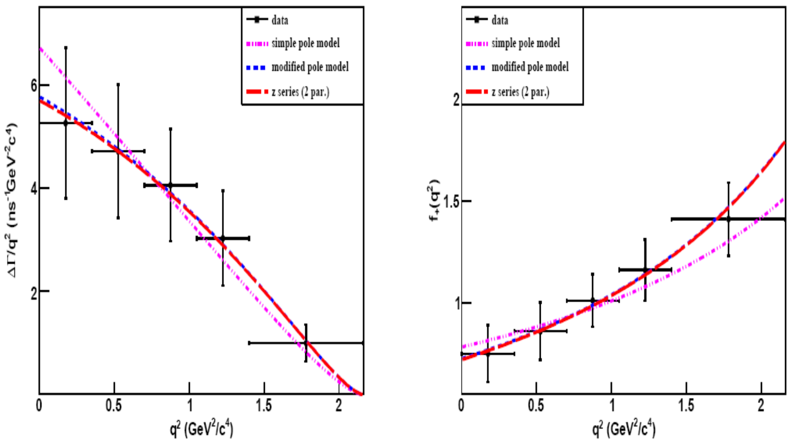
$B[D_s^+ \to K^0 e^+ \nu_e] = (3.25 \pm 0.38_{stat} \pm 0.14_{syst}) \times 10^{-3}$

$(3.9 \pm 0.9) \times 10^{-3}$ [PDG17]



$B[D_s^+ \to K^{*0} e^+ \nu_e] = (2.38 \pm 0.26_{stat} \pm 0.12_{syst}) \times 10^{-3}$

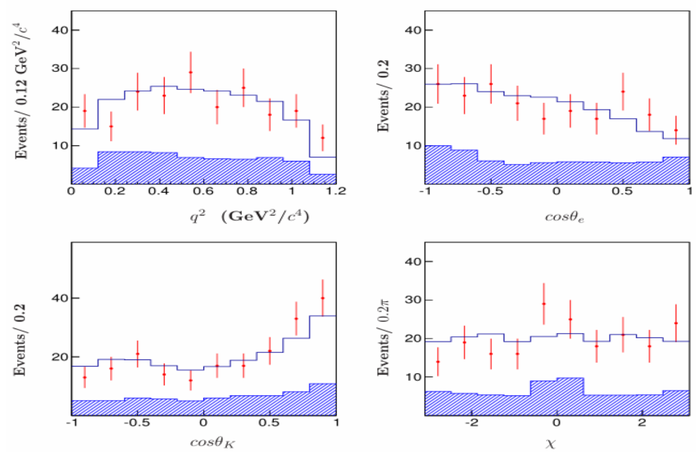
$(1.8 \pm 0.4) \times 10^{-3}$ [PDG17]



Model	Parameter	Value	$f_+(0)$
Simple pole	$f_+(0)\|V_{cd}\|$	$0.175 \pm 0.010 \pm 0.001$	$0.778 \pm 0.044 \pm 0.004$
Modified pole model	$f_+(0)\|V_{cd}\|$	$0.163 \pm 0.017 \pm 0.003$	$0.725 \pm 0.076 \pm 0.013$
	α	$0.45 \pm 0.44 \pm 0.02$	
Series two parameters	$f_+(0)\|V_{cd}\|$	$0.162 \pm 0.019 \pm 0.003$	$0.720 \pm 0.084 \pm 0.013$
	r_1	$-2.94 \pm 2.32 \pm 0.14$	

Taking $|V^{CKMfitter}_{cd}|$ as input

Four dimensional un-binned likelihood fit is performed. K* paramters are fixed



$r_V = 1.67 \pm 0.34 \pm 0.16$

$r_2 = 0.77 \pm 0.28 \pm 0.07$

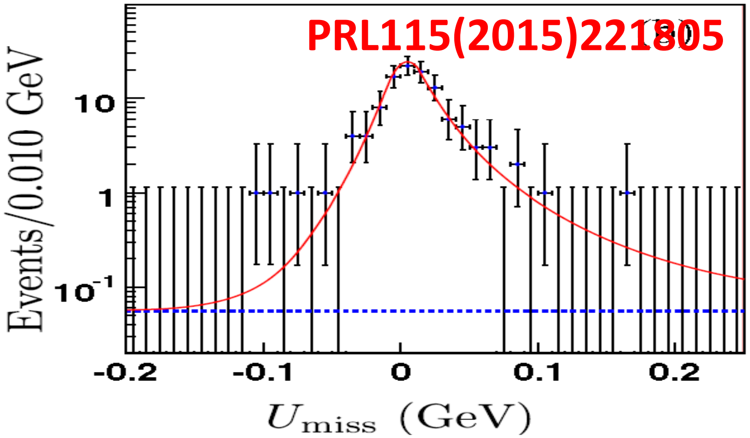
First absolute BF of $\Lambda_c^+ \to \Lambda l^+ \nu$ at BESIII

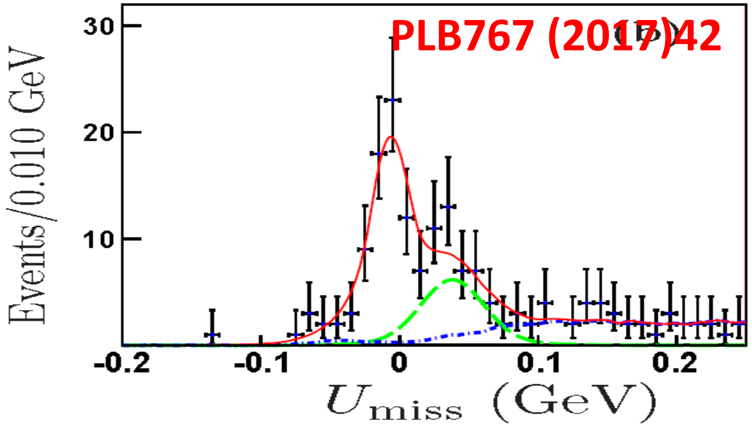
- Λ_c^+ was observed in 1979
- All decays of Λ_c^+ were measured with high energy data and relative to $pK^-\pi^+$, which suffers an error of 25%. No absolute measurement using threshold Λ_c^+ data before BESIII
- Only about 60% decays are known

Theory: (1.4-9.2)%

Theoretical Models	predicated branching fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$
MBM [1]	1.9%
NRQM [1]	2.6%
SU(4)-symmetry limit [2]	9.2%
RSQM [3]	4.4%
QCM [4]	5.62%
SQM [5]	1.96%
NRQM2 [6]	2.15%
NRQM3 [7]	1.42%
QCD SR1 [8]	$(3.0 \pm 0.9)\%$
QCD SR2 [9]	$(2.6 \pm 0.4)\%$
QCD SR3 [9]	$(5.8 \pm 1.5)\%$
STSR [10]	2.22% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
STNR [10]	1.58% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HOSR [10]	4.72% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HONR [10]	4.2% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
LCSRs [11]	$(3.0 \pm 0.3)\%$ for $\Lambda_c^+ \to \Lambda l^+ \nu_l$ (CZ-type)
PDG 2014 [14]	$(2.1 \pm 0.6)\%$
BESIII	$(3.63 \pm 0.38 \pm 0.20)\%$

3 fb^{-1} help to explore FF studies





$B[\Lambda_c^+ \to \Lambda e^+ \nu] = (3.63 \pm 0.38 \pm 0.20)\%$

$B[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$

$\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu] / \Gamma[\Lambda_c^+ \to \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

Summary

- With 2.9/3.2 fb^{-1} data taken at 3.773/4.178 GeV, BESIII has obtained the most precise measurements of $D_{(s)}^+ \to l^+ v$, $D \to P l^+ v$ and other SL decays

  Improved measurements of $f_{D(s)+}$ and $f_+^{D\to K(\pi)}(q^2)$, which are important to calibrate LQCD calculations

  Improved measurements of $|V_{cs(d)}|$, which is important for unitarity test of the CKM matrix

  Other studies of D SL decays (form factor measurements, new decay modes) are ongoing and will be ready soon

- With 0.567 fb^{-1} data taken at 4.6 GeV, BESIII reported the first absolute BFs of $\Lambda_c^+ \to \Lambda l^+ v$

  In the near future, more 10 fb^{-1} data at 3.773 GeV and 3 fb^{-1} data at ~4.65 GeV at BESIII will further benefit all measurements

Prospects at HIEPA

If 300 fb^{-1} data can be collected at 3.773, 4.18 and 4.65 GeV, respectively

	Systematic error	Statistical error		
		~3 fb^{-1}	12 fb^{-1}	300 fb^{-1}
$\Delta f_{D+}/f_{D+}$	~0.9%	2.6%	1.3%	0.26%
$\Delta f_{Ds+}/f_{Ds+}$	~1.5%	1.1%	0.6%	0.11%
$\Delta f_{D\to K}/f_{D\to K}$	~0.5%	0.35%	0.18%	0.04%
$\Delta f_{D\to\pi}/f_{D\to\pi}$	~0.7%	1.26%	0.63%	0.13%
$\|V_{cs}\|^{Ds+\to l+v}$	~1.5%	1.8%	0.9%	0.18%
$\|V_{cs}\|^{D0\to K-e+v}$	2.5%(2.4%^{LQCD})	0.35%	0.18%	0.04%
$\|V_{cd}\|^{D+\to\mu+v}$	2.1%(1.9→0.5%^{LQCD})	2.6%	1.3%	0.26%
$\|V_{cd}\|^{D0\to\pi-e+v}$	4.5% (4.4%^{LQCD})	1.26%	0.63%	0.13%

- **LQCD calculation uncertainties in the FFs of D→Pl^+v are expected to reduce to (0.5-1.0)% to better measure $|V_{cs(d)}|$ using D SL decays**

- **Precise FF studies, especially for D→S/Ae^+v and Λ_c^+ SL decays, as well as other suppressed SL decays**

Thank you!

Study of $D^+ \to K_L e^+ \nu$ at BESIII

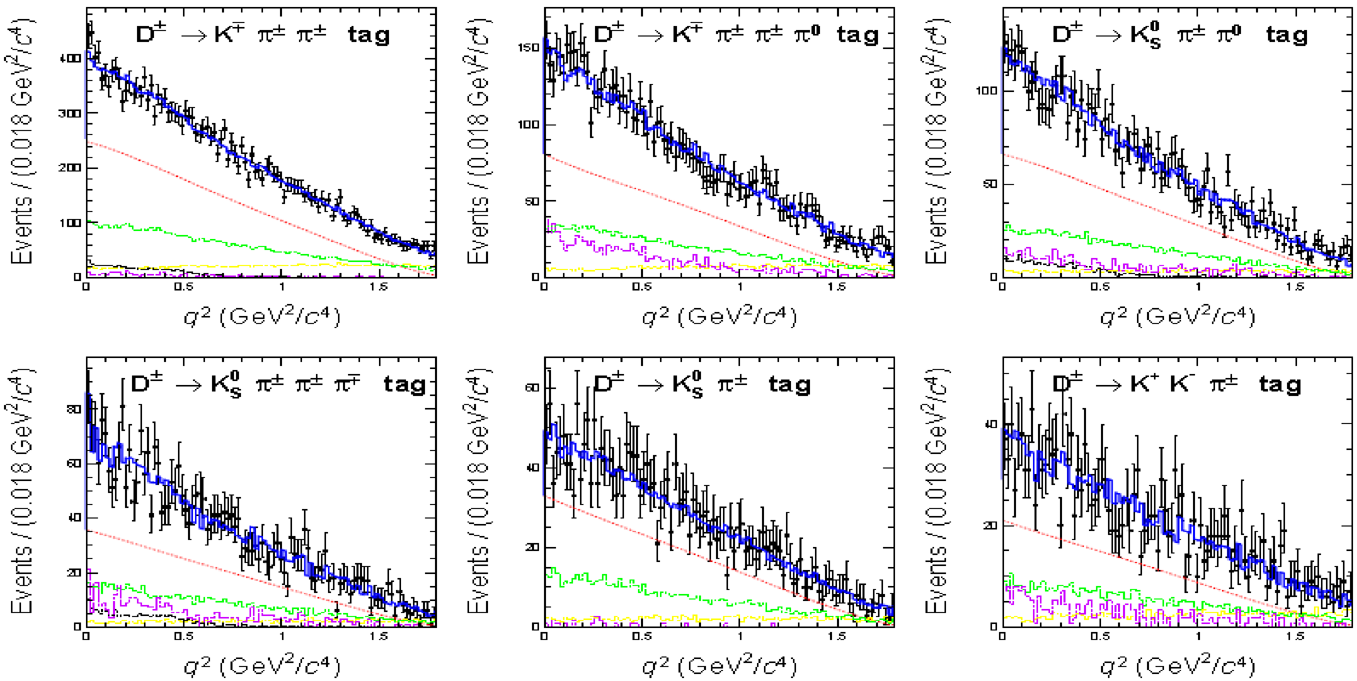
- **Regardless of long flight distance, K_L interact with EMC and deposit part of energy, thus giving position information**
- **After reconstructing all other particles, K_L can be inferred with position information and constraint $U_{miss} \to 0$**

$\bar{\mathcal{B}}(D^+ \to K_L e^+ \nu) = (4.482 \pm 0.027 \pm 0.103)\%$

$$A_{CP} \equiv \frac{\mathcal{B}(D^+ \to K^0_L e^+ \nu_e) - \mathcal{B}(D^- \to K^0_L e^- \bar{\nu}_e)}{\mathcal{B}(D^+ \to K^0_L e^+ \nu_e) + \mathcal{B}(D^- \to K^0_L e^- \bar{\nu}_e)}$$

$A_{CP}^{D^+ \to K_L e^+ \nu} = (-0.59 \pm 0.60 \pm 1.50)\%$

Simultaneous fit to event density $I(q^2)$ with 2-par. series Form Factor



$D^+ \to K_L e+v$ is measured for the first time

PRD92(2015)112008

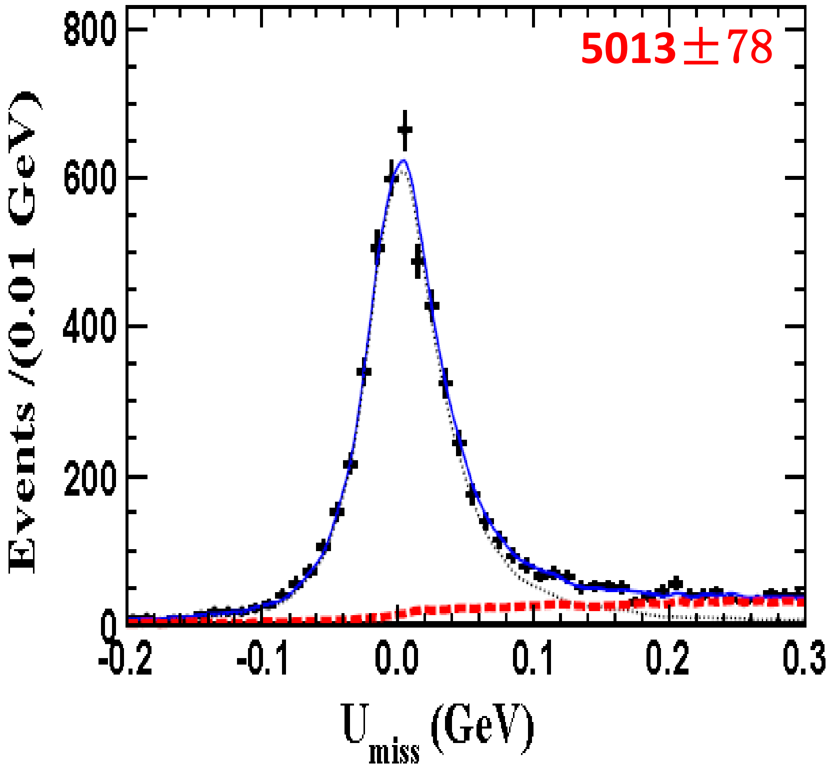
With 6 dominant D^- single tag

$f^K_+(0)|V_{cs}| = 0.728 \pm 0.006 \pm 0.011$

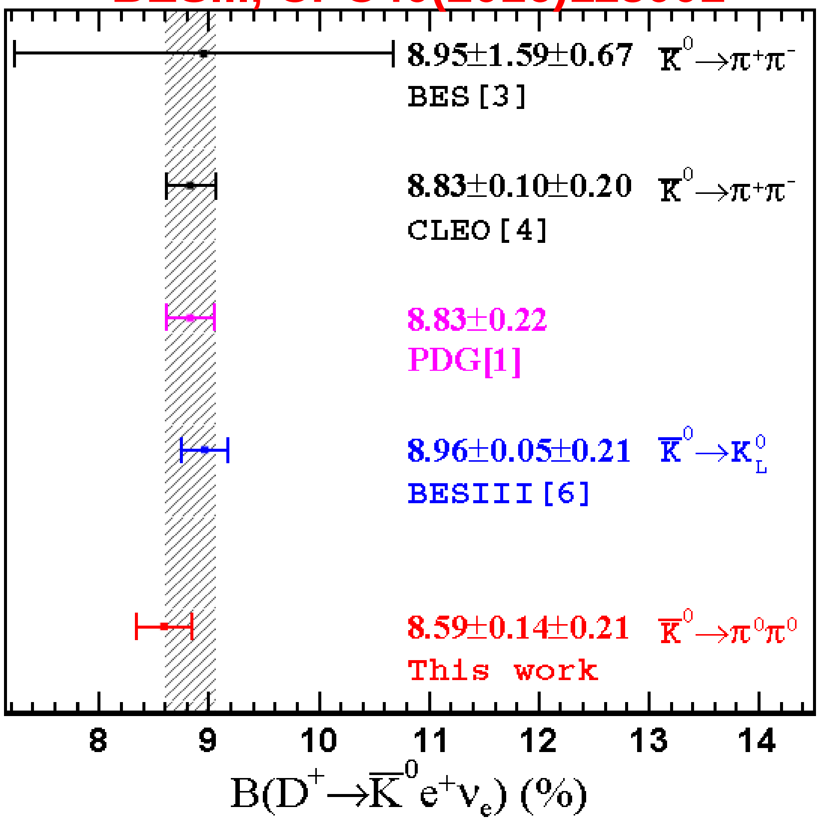
$r_1 = a_1/a_0 = -1.91 \pm 0.33 \pm 0.24$

Absolute BF for $D^+ \to \bar{K}^0 e^+ \nu$ via $\bar{K}^0 \to \pi^0\pi^0$

With 6 dominant D^- single tag



BESIII, CPC40(2016)113001



Taking τ_{D+}, τ_{D0}, $B[D^0 \to K^- e^+ \nu]$ and $B[D^+ \to \bar{K}^0 e^+ \nu]$ from the PDG as input

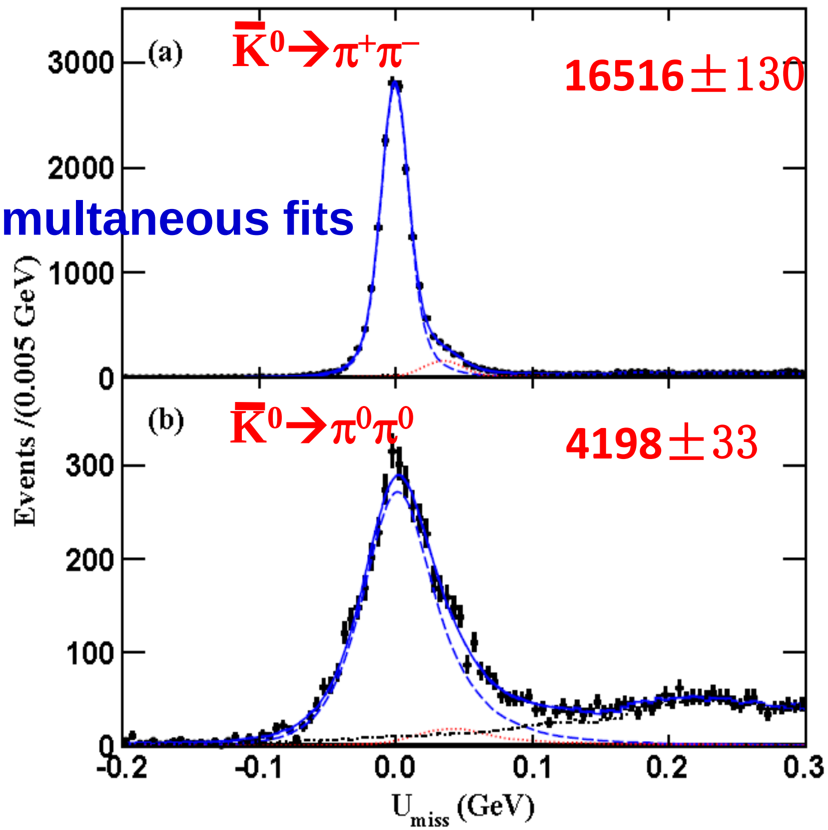
$$\frac{\Gamma[D^0 \to K^- e^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 e^+ \nu]} = 0.969 \pm 0.025$$

Agrees with isospin conservation within 1.2σ

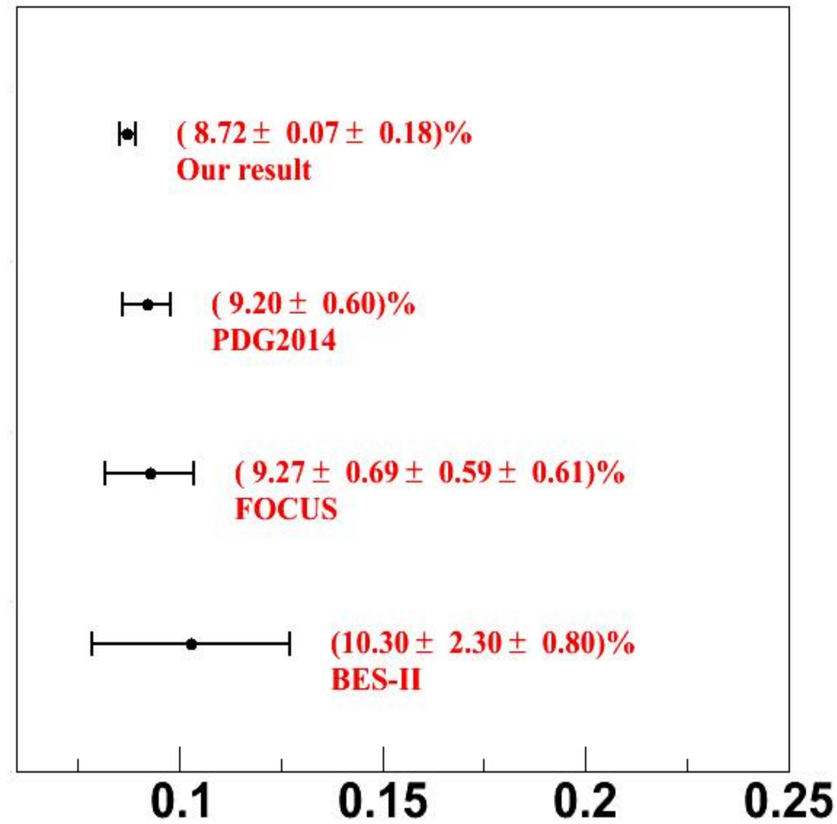
Improved BF for $D^+ \to \bar{K}^0 \mu^+ \nu$ at BESIII

With 6 dominant D^- single tag

Simultaneous fits



BESIII, EPJC76(2016)369



Taking $B[D^0 \to K^- \mu^+ \nu]$ and $B[D^+ \to \bar{K}^0 e^+ \nu]$ from the PDG as input

$$\frac{\Gamma[D^0 \to K^- \mu^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 \mu^+ \nu]} = 0.963 \pm 0.044$$

Support isospin conservation in these two decays within errors

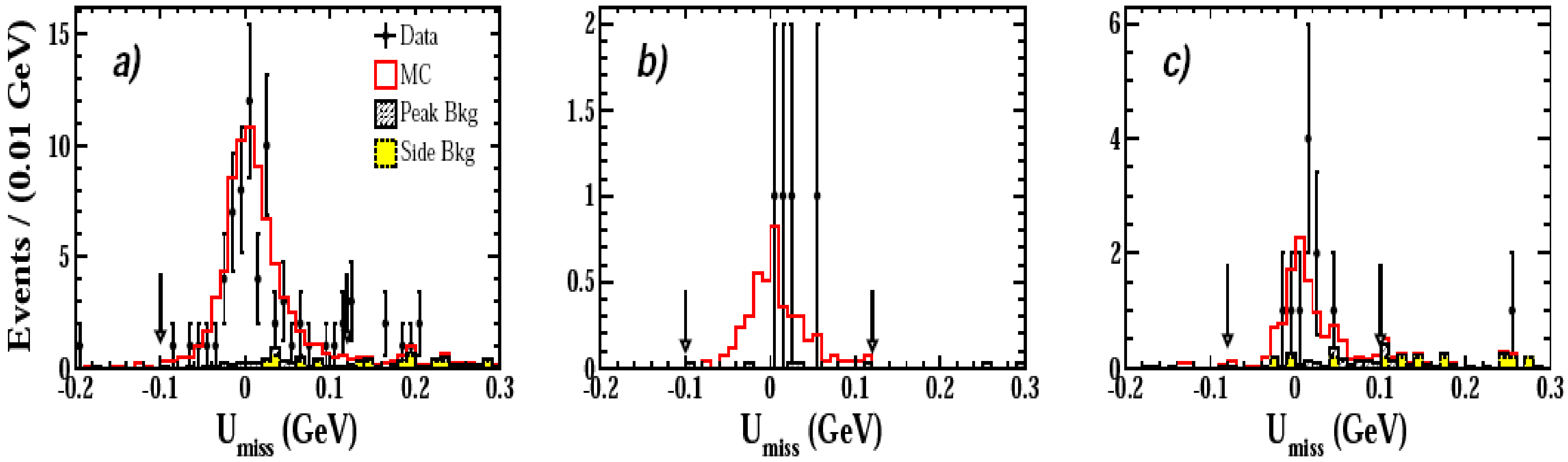
$$\frac{\Gamma[D^+ \to \bar{K}^0 \mu^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 e^+ \nu]} = 0.988 \pm 0.033$$

Consistent with theory prediction 0.97 within error

BFs of $D_s^+ \to \eta^{(\prime)} e^+ \nu$ at BESIII

- Benefit the understanding of the source of difference of inclusive decay rates of $D^{0(+)}$ and D_s^+
- Complementary information to understand η–η' mixing

482 pb^{-1} data@4.009 GeV, PRD94(2016)112003

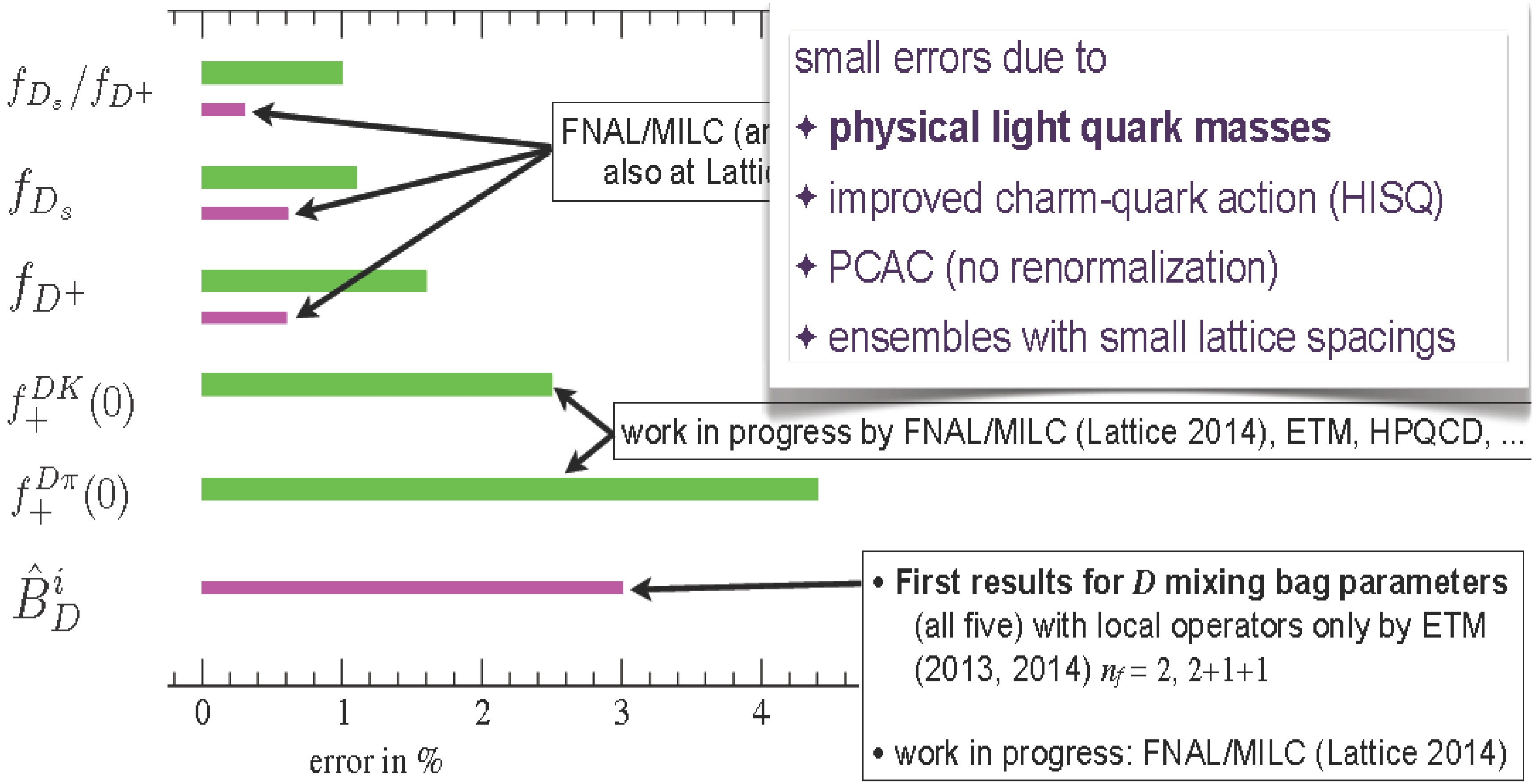


	BESIII	CLEOII 95	CLEOc09	CLEOc15	PDG [4]
$B(D_s^+ \to \eta e^+ \nu_e)[\%]$	$2.30 \pm 0.31 \pm 0.08$	—	$2.48 \pm 0.29 \pm 0.13$	$2.28 \pm 0.14 \pm 0.20$	2.67 ± 0.29
$B(D_s^+ \to \eta' e^+ \nu_e)[\%]$	$0.93 \pm 0.30 \pm 0.05$	—	$0.91 \pm 0.33 \pm 0.05$	$0.68 \pm 0.15 \pm 0.06$	0.99 ± 0.23
$\frac{B(D_s^+ \to \eta' e^+ \nu_e)}{B(D_s^+ \to \eta e^+ \nu_e)}$	$0.40 \pm 0.14 \pm 0.02$	$0.35 \pm 0.09 \pm 0.07$	—	—	—

Much improved LQCD calculations

Taking from Aida X. El-Khadra's talk at Beauty2014

errors (in %) comparison: **FLAG-2 averages** vs. **new results**



review by C. Bouchard @ Lattice 2014