# Leptonic and semileptonic D decays

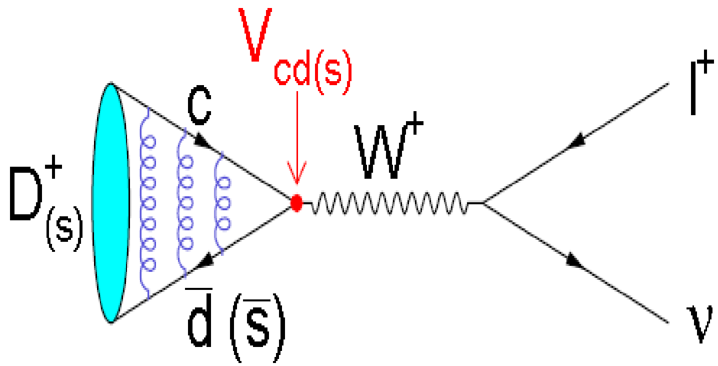
## Status and prospects at BESIII

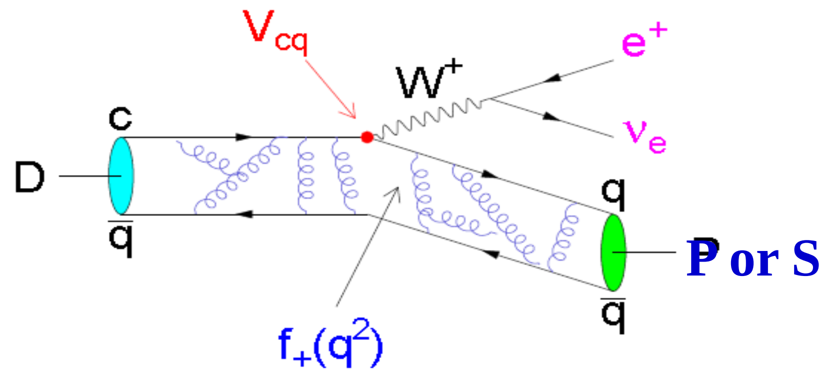
Hailong Ma (IHEP&BESIII)

**Joint BESIII-LHCb workshop in 2018**

**Feb. 8-9 2018, IHEP, Beijing**

# Main physics goals




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

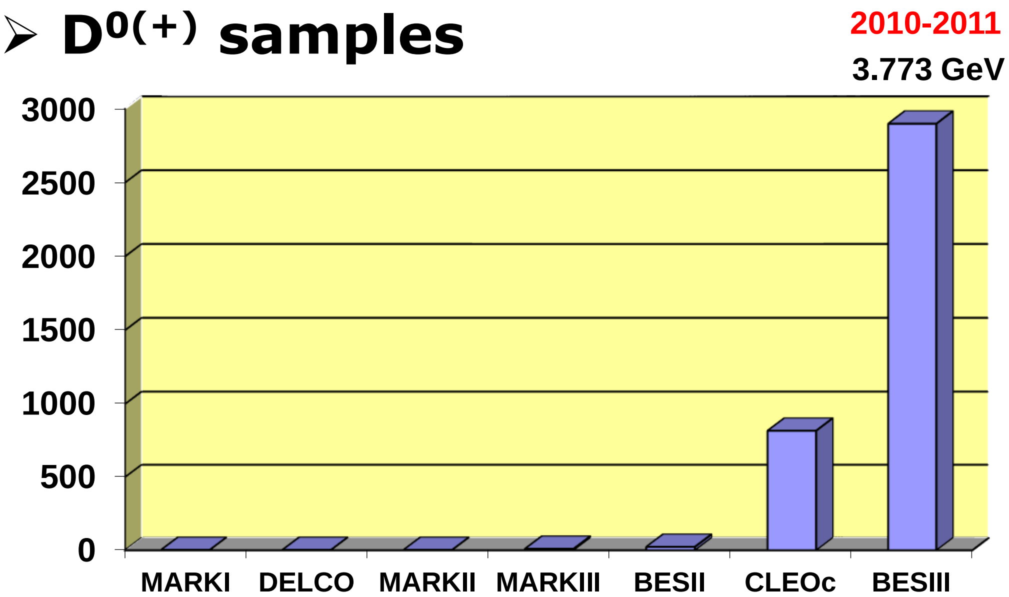
$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

1. $f_{D(s)+}$, $f^{K(\pi)}_+(0)$: better calibrate LQCD
2. $|V_{cs(d)}|$: better test on CKM matrix unitarity
3. Test on lepton flavor universality (LFU)
4. Search for new semileptonic decays

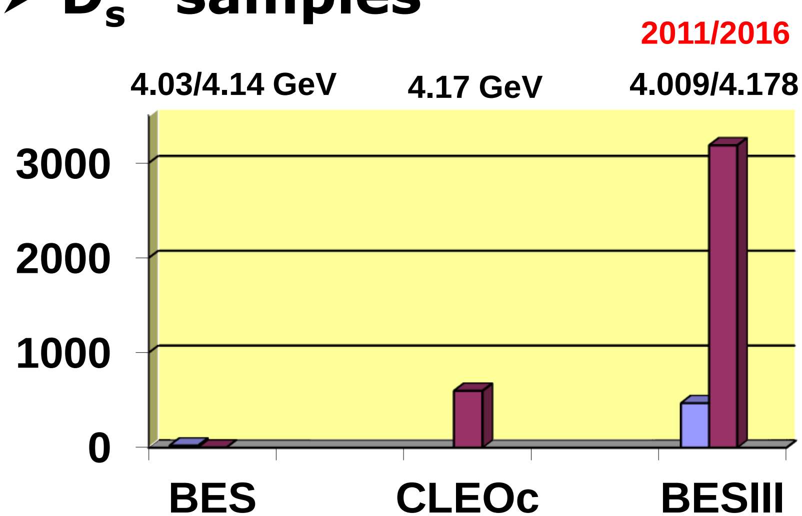
$$U = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \boldsymbol{V_{cb}} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

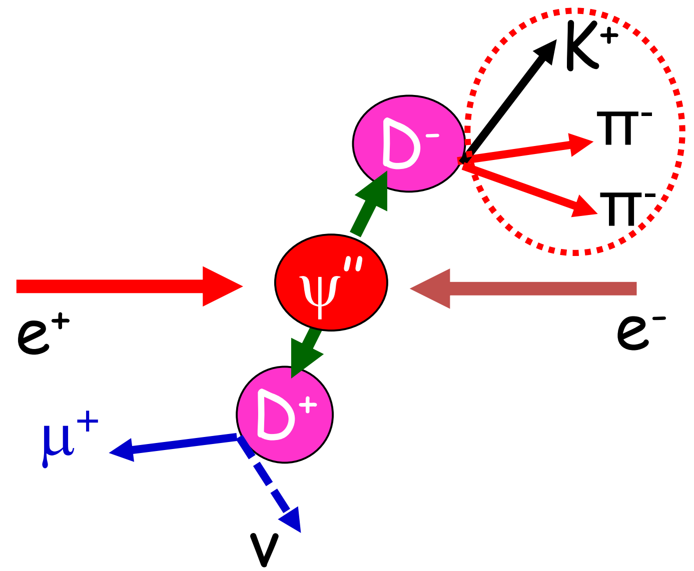
# Samples of $D^{0(+)}$ and $D_s^+$ at BESIII

- **$D^{0(+)}$ samples**




- **$D_s^+$ samples**




$$N^i_{\mathrm{ST}} = 2 \times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times \varepsilon^i_{\mathrm{ST}}$$

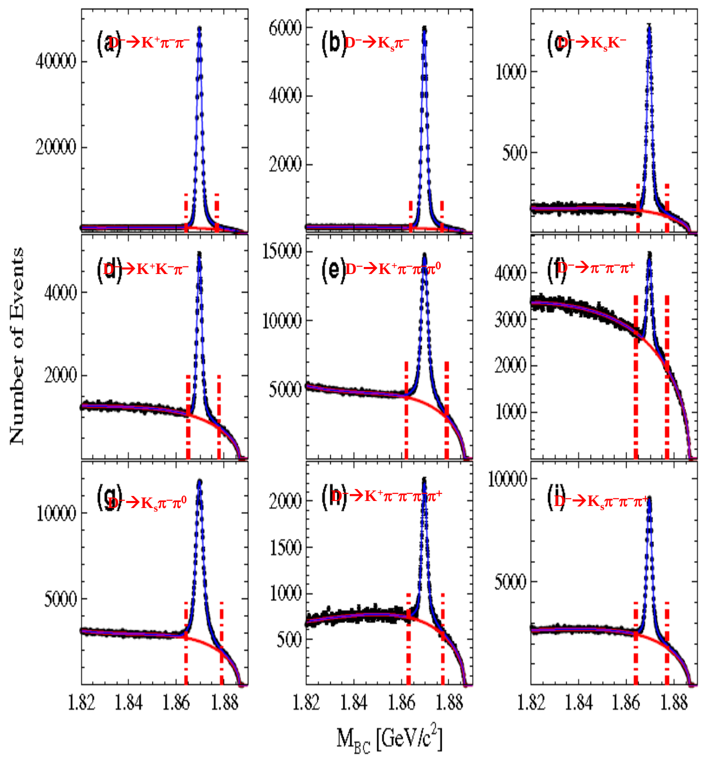
$$N^i_{\mathrm{DT}} = 2 \times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times B_{\mathrm{sig}} \times \varepsilon^i_{\mathrm{ST\ vs.sig}}$$

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

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

# Single tag $D^{0(+)}$ at BESIII

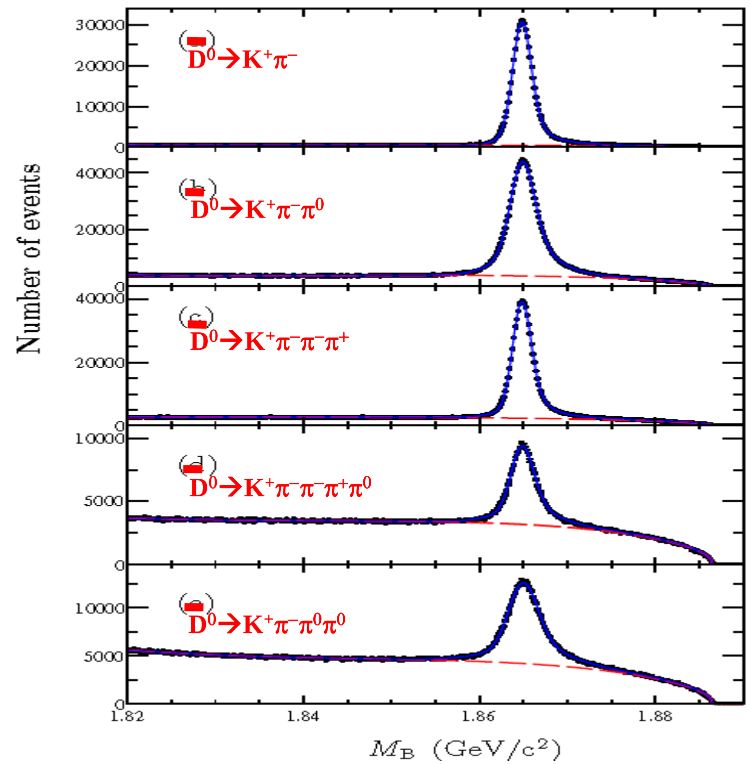
$e^+e^- \to \psi(3770) \to D^+D^-$




$$N_{D^-_{tag}} = (170.31 \pm 0.34) \times 10^4$$

**6 largest tag modes give 1.5 M $D^-$ tags**

$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$



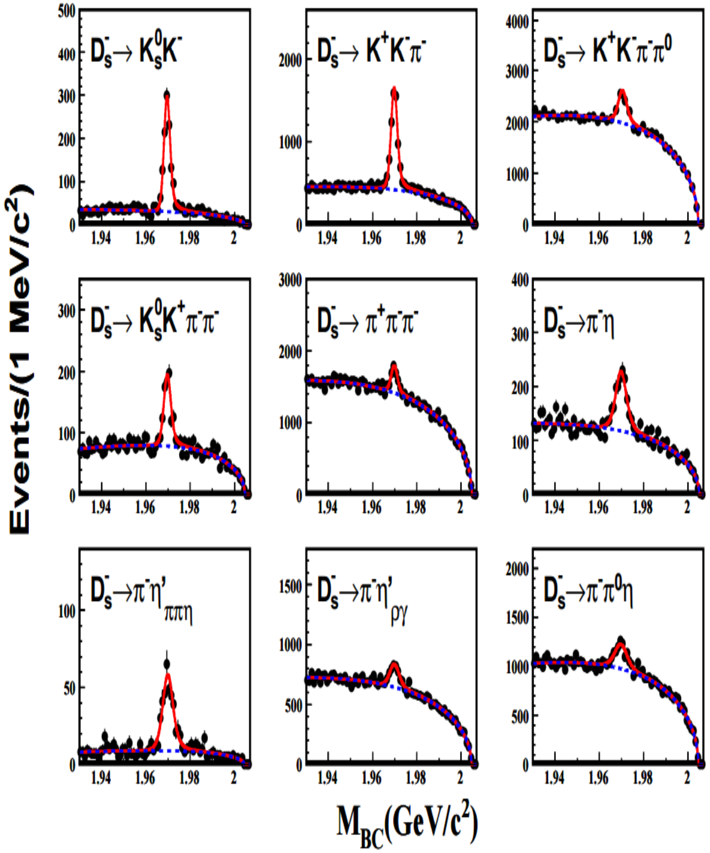

$$N_{\bar{D}^0_{tag}} = (279.33 \pm 0.37) \times 10^4$$

**3 largest tag modes give 2.3 M $D^0$ tags**

**Charge conjugations are included**

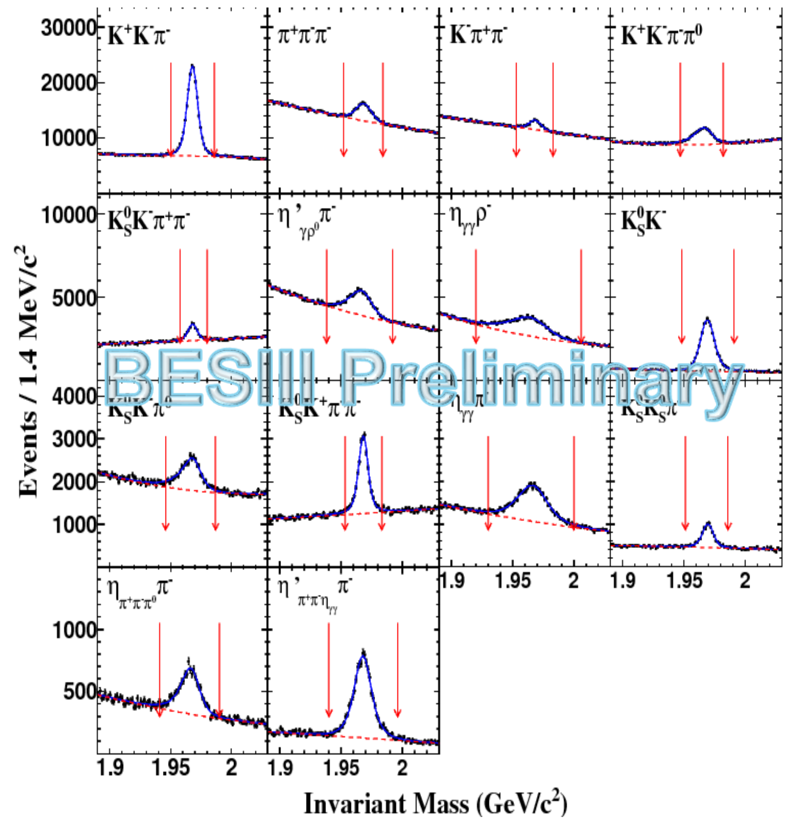
# Single tag $D_s^+$ at BESIII

## $e^+e^- \rightarrow D_s^+ D_s^- @ 4.009$ GeV




$N_{D_s^- tag} = 15127 \pm 312$

## $e^+e^- \rightarrow D_s^{*+} D_s^- + c.c. @ 4.178$ GeV

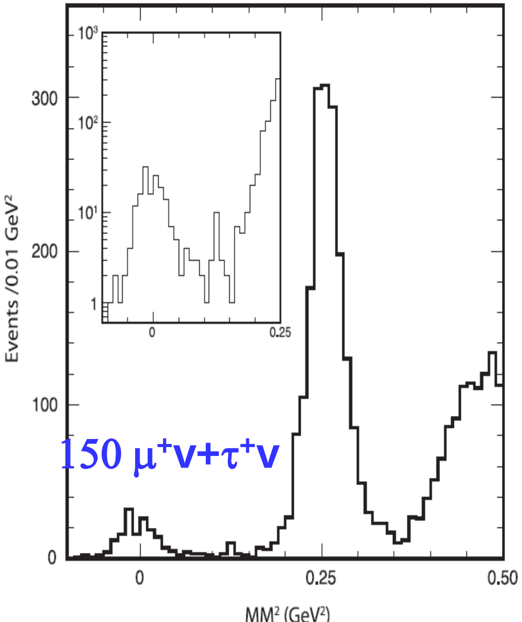



**0.39 M ST $D_s^-$ mesons**

# Measurement of $D^+ \to l^+ \nu$

**818 $pb^{-1}$ at $\psi(3770)$ (2004–2008)**

**PRD78(2008)052003**



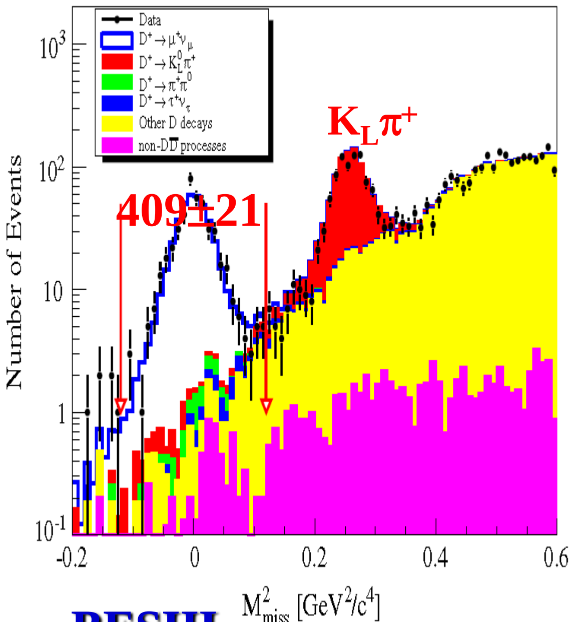

**CLEO**

$B_{D^+ \to \mu^+ \nu} = (3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$

$f_{D^+} = 205.8 \pm 7.5 \pm 2.5$ MeV

**2.93 $fb^{-1}$ data@3.773 GeV**

**PRD89(2014)051104R**



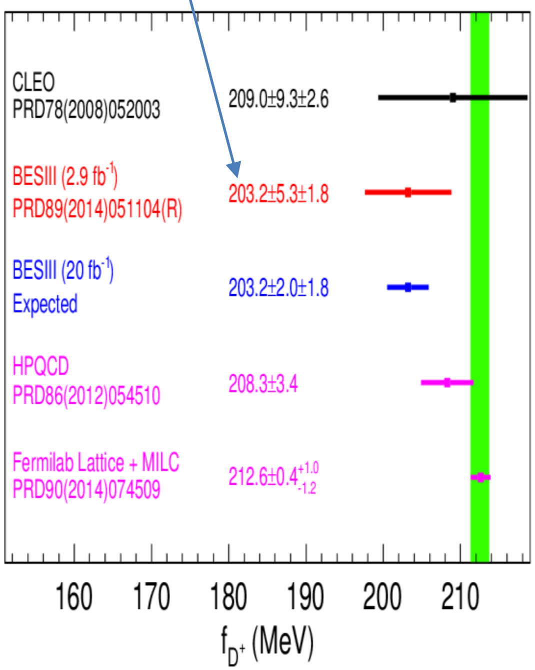

**BESIII**

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

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

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

**BESIII result has been re-calculated with the latest LQCD calculation**

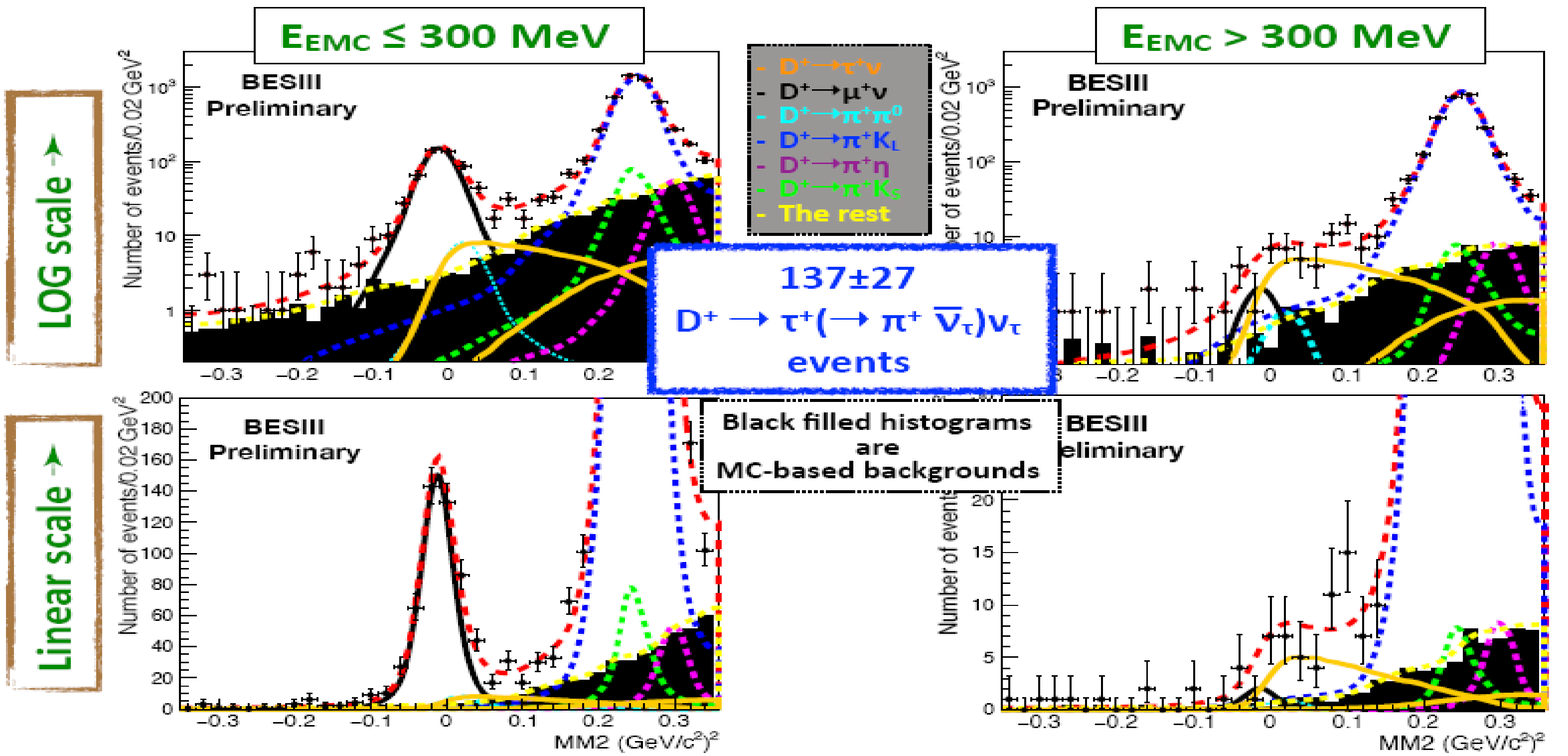



**20 $fb^{-1}$ data help to reduce the uncertainty of $f_{D^+}$ to 1%**

# Search for $D^+ \to \tau^+ \nu$

11

## Fitting to DATA




**4σ**

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

**20 $fb^{-1}$ data help to reduce the uncertainty to 8%**

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

**SM prediction: 2.66**

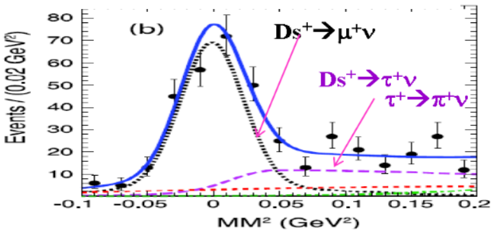
**BESIII: 3.21±0.64**

# Previous measurements of $D_s^+ \to l^+ \nu$

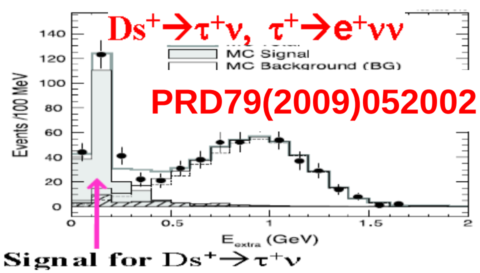
In the past 30 years, $D_s^+ \to l^+ \nu$ has been studied by WA75, CLEOII, E653, BESI, L3, OPAL, ALPHA, CLEO-c, BELLE, Babar

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

PRD79(2009)052001

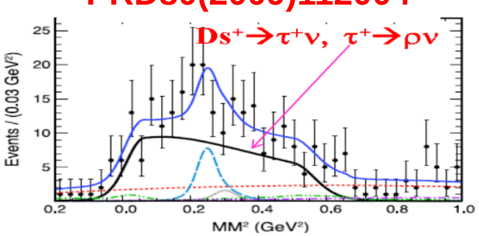



$f_{Ds+}$=263.3±8.2±1.9 MeV




$f_{Ds+}$=252.2±11.1±5.2 MeV

PRD80(2009)112004

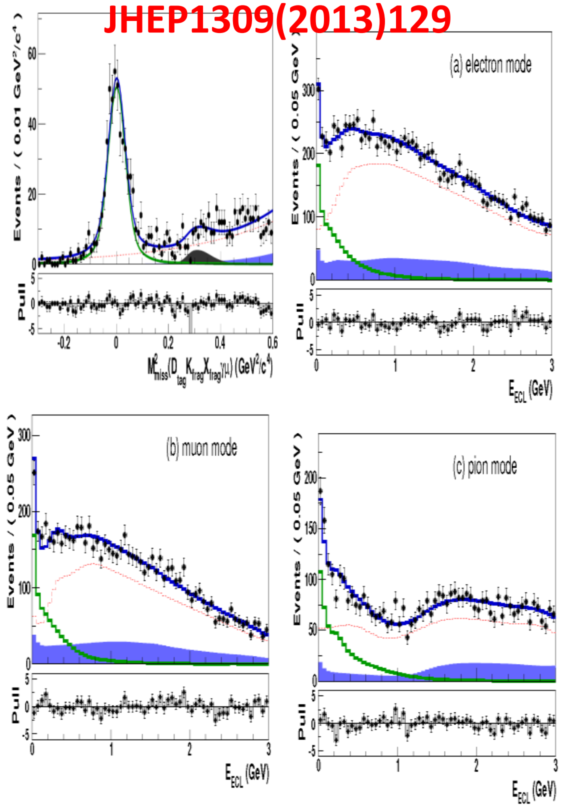



$f_{Ds+}$=257.8±13.3±5.2 MeV

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

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

JHEP1309(2013)129

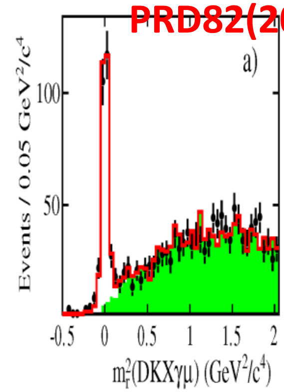


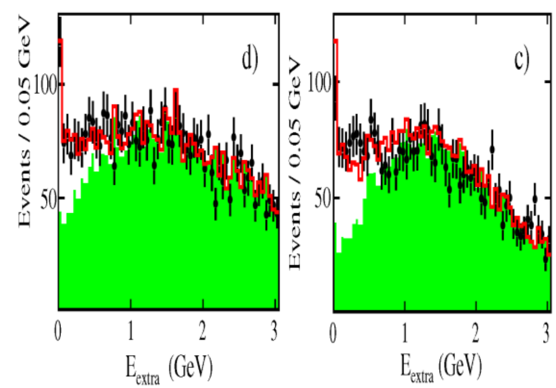

$f_{Ds+}$=255.5±4.2±5.1 MeV

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

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

PRD82(2010)091103



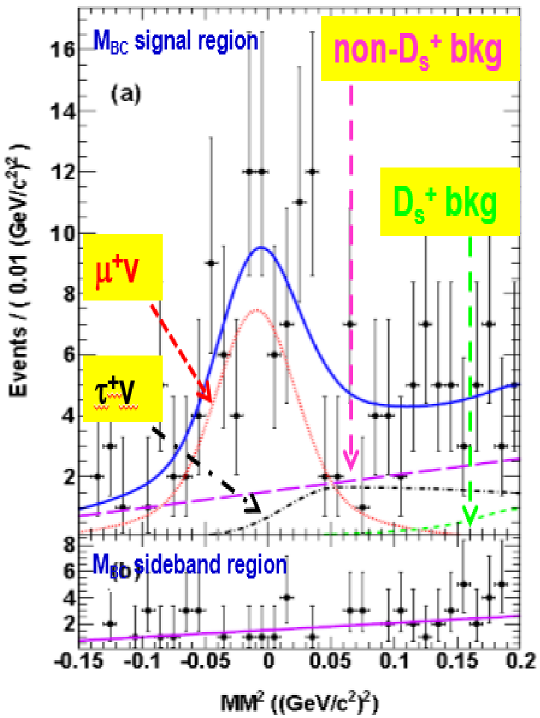




$f_{Ds+}$=258.6±6.4±7.5 MeV

# Measurement of $D_s^+ \to l^+\nu$

**0.482 $fb^{-1}$ data @4.009 GeV**

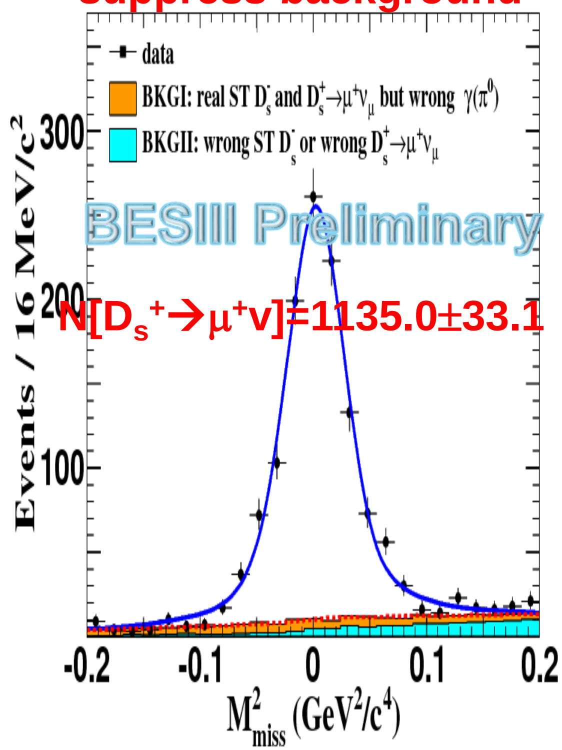
**PRD94(2016)072004**



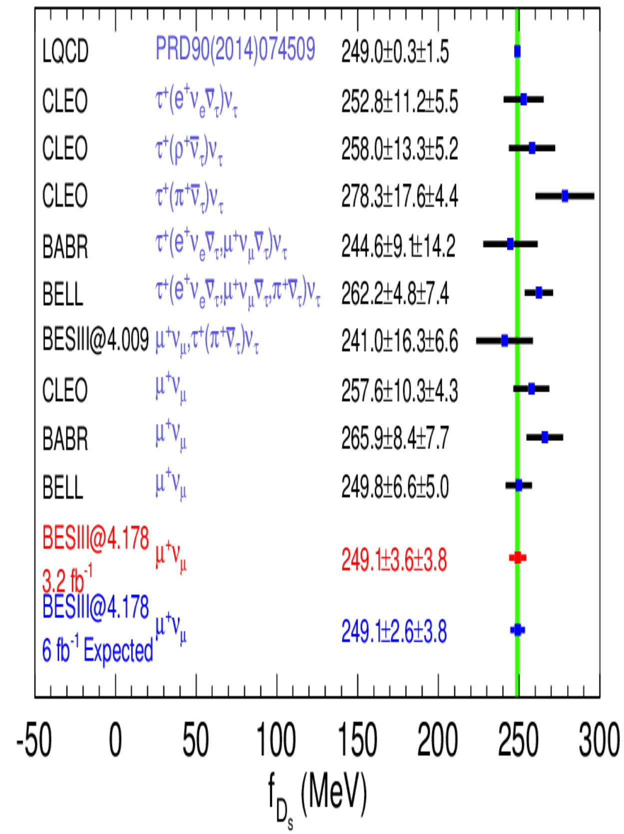

$f_{D_s^+}$=(241.0±16.3±6.6) MeV

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

**Use μ counter to suppress background**




$f_{D_s}|V_{cs}|$=242.5±3.5±3.7 MeV

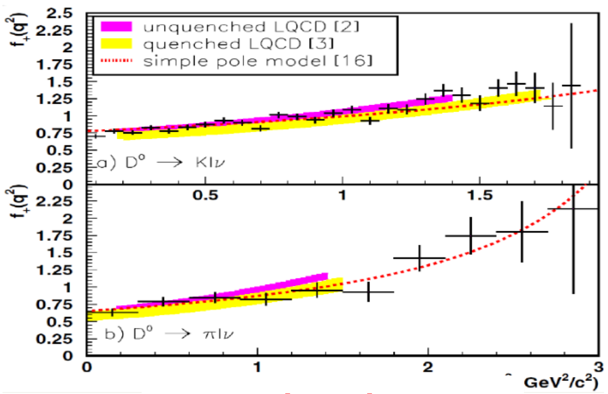



**Uncertainty of $f_{D_s^+}$ with μ/τv is expected to reach 1.5% with 3.19 $fb^{-1}$ data**

# Previous measurements of D→K(π)l⁺v

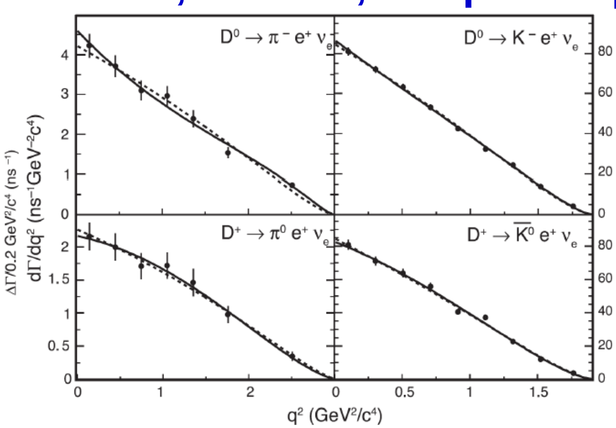
**In the past 30 years, studies of D→K(π)l⁺v were made by MARKIII, E691, CLEO, CLEOII, BESII, FOCUS, BELLE, Babar and CLEO-c**

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



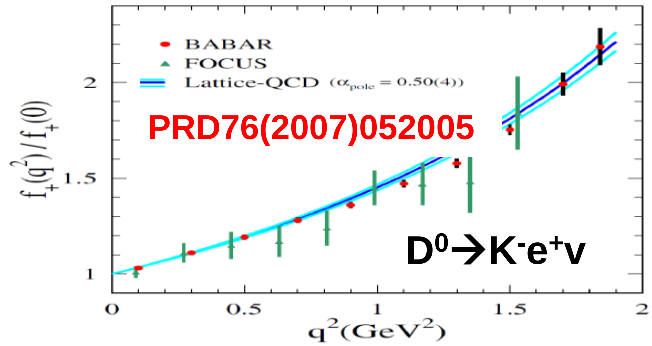

PRL97(2006)061804

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

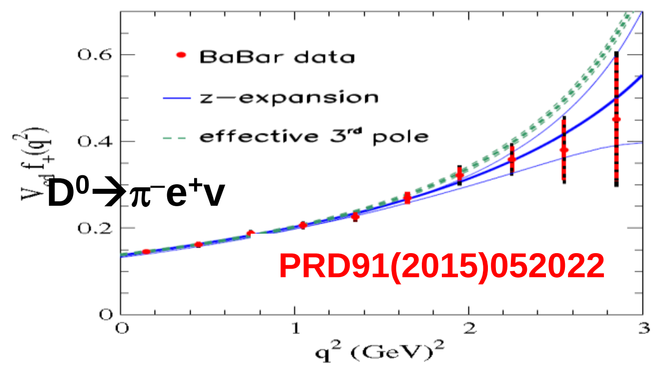



PRD80(2009)032005

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




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

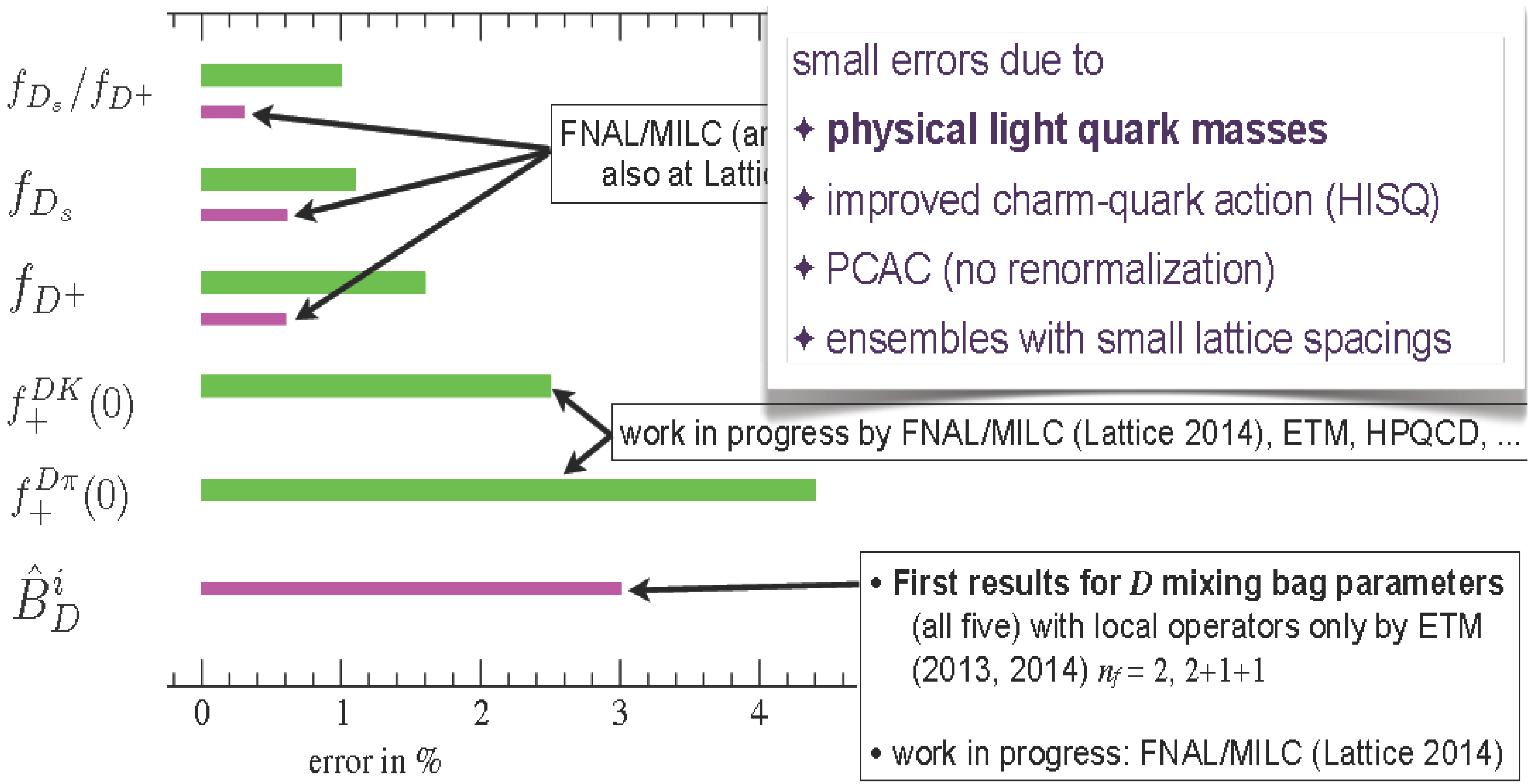



**Before 2010, the LQCD calculated $f_+^{D\to K(\pi)}(0)$ precision is at 10% level, thus limiting $|V_{cs(d)}|$ measurement**

# Progress in LQCD calculations

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

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

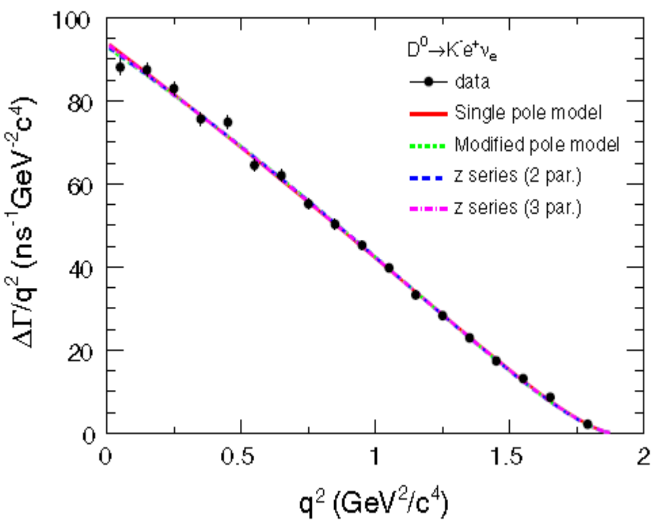



review by C. Bouchard @ Lattice 2014

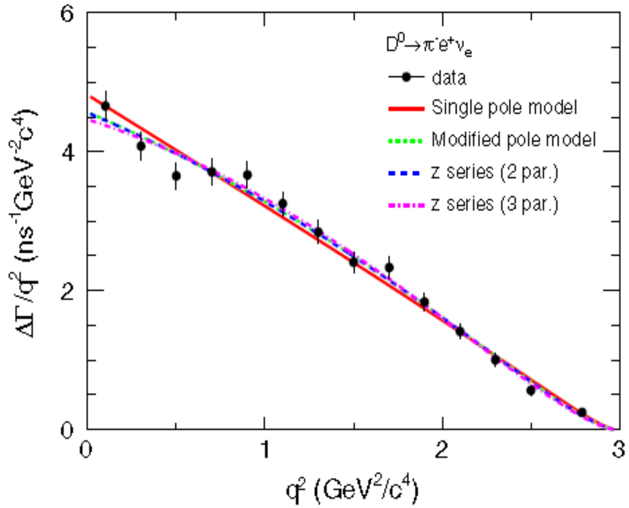
# Analysis of $D^0 \to K(\pi)^- e^+ \nu$

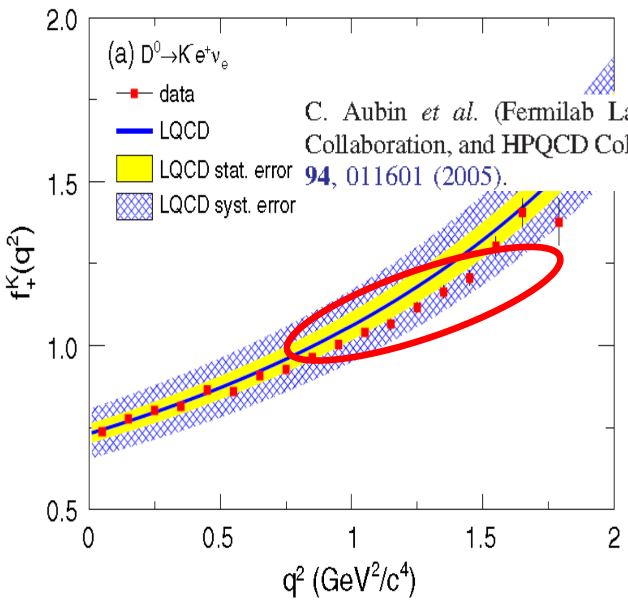
**PRD92(2015)072012**

$B_{D^0 \to K^- e^+ \nu} = (3.505 \pm 0.014 \pm 0.033)\%$

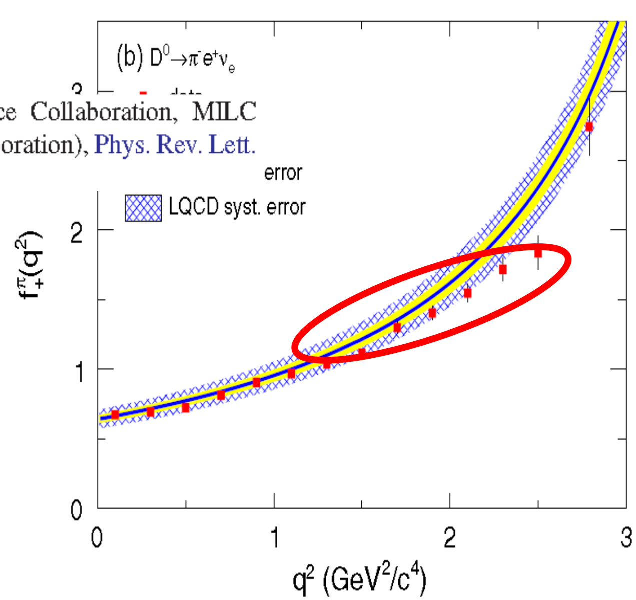



$B_{D^0 \to \pi^- e^+ \nu} = (0.2950 \pm 0.0041 \pm 0.0026)\%$




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




## Different parameterizations of form factor

- **Single pole**

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

- **Modified pole**

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

- **ISGW2**

$$f_+(q^2) = f_+(q^2_{max})\left(1 + \frac{r^2_{ISGW2}}{12}(q^2_{max} - q^2)\right)^{-2}$$

- **Series expansion**

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

# Analysis of $D^+ \to K_L e^+ v$

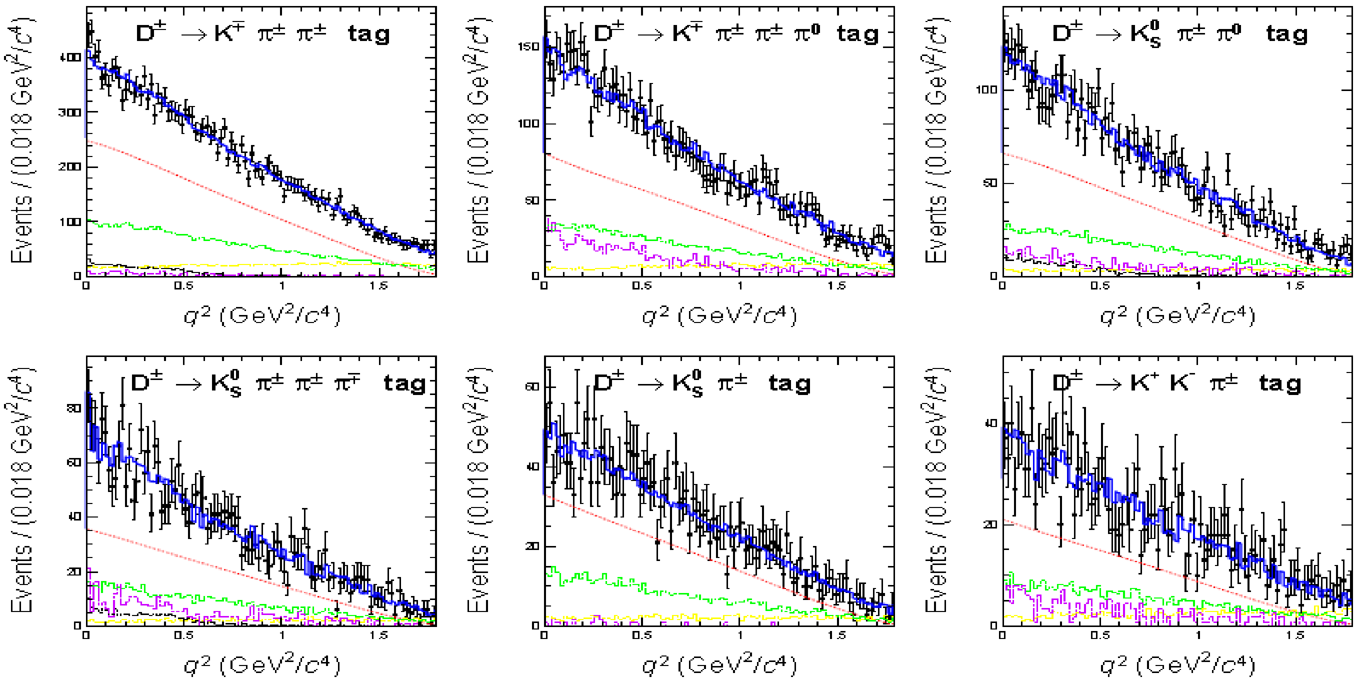
**PRD92(2015)112008**

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

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

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

$A_{CP}^{D+\to KLe+v} = (-0.59 \pm 0.60 \pm 1.50)\%$




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

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

# Analysis of $D^+ \to \bar{K}(\pi)^0 e^+ \nu$

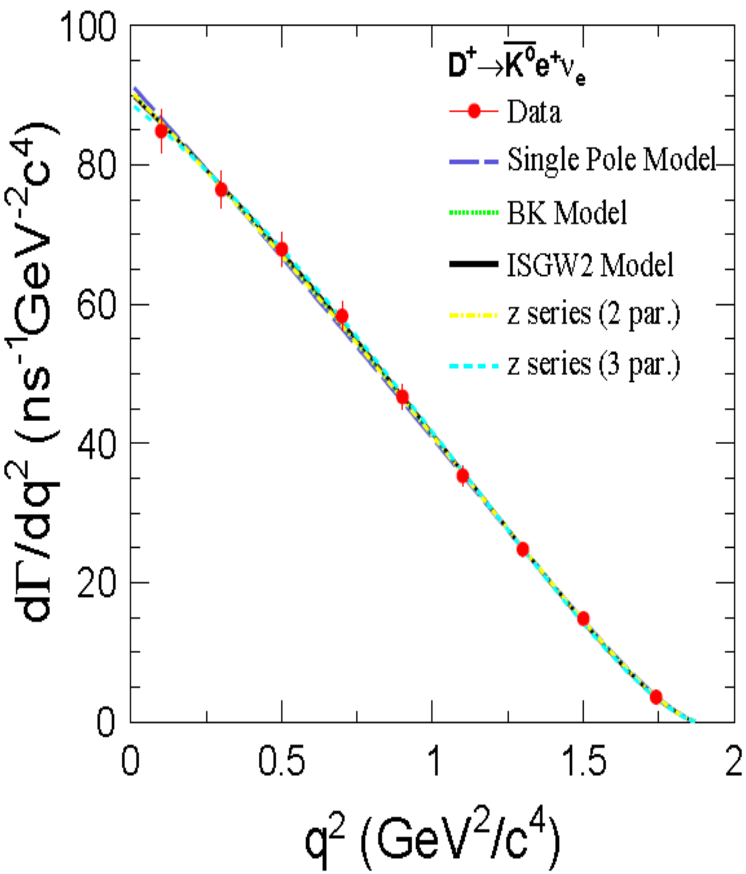
**PRD96(2017)012002**

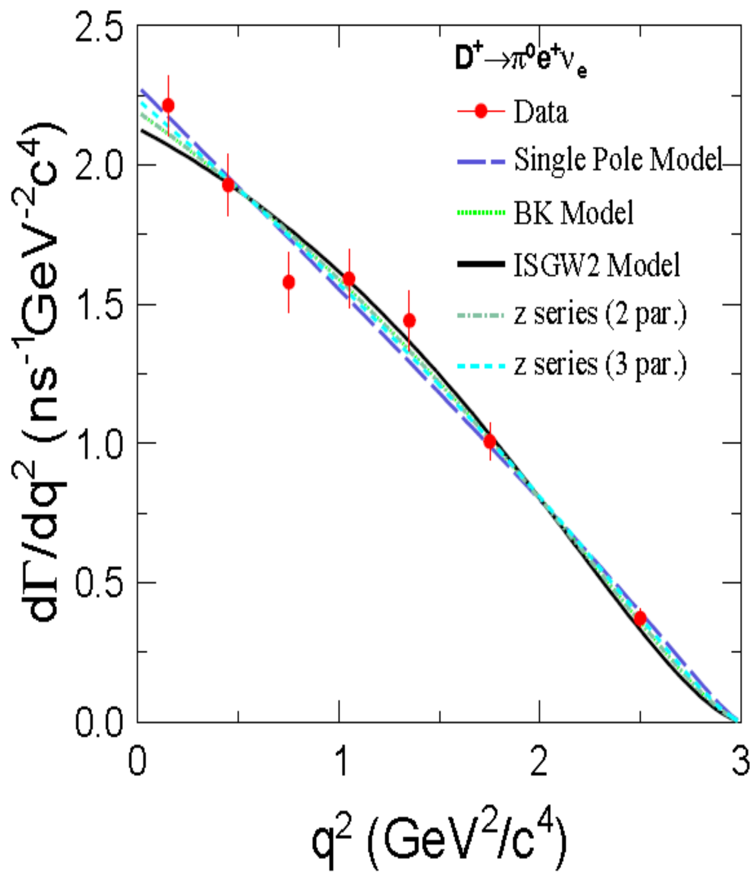
$B[D^+ \to \overline{K}^0 e^+ v] = (8.604 \pm 0.056 \pm 0.151)\%$

$B[D^+ \to \pi^0 e^+ v] = (3.631 \pm 0.075 \pm 0.051) \times 10^{-3}$

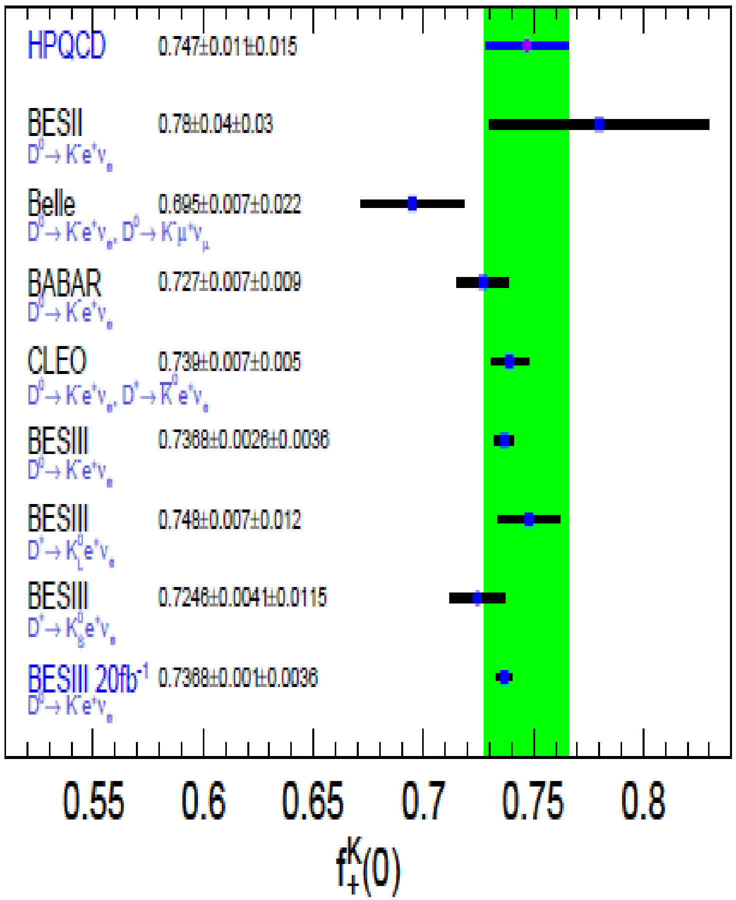
$$I_K \equiv \frac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\Gamma(D^+ \to \bar{K}^0 e^+ \nu_e)} = 1.03 \pm 0.01 \pm 0.02$$

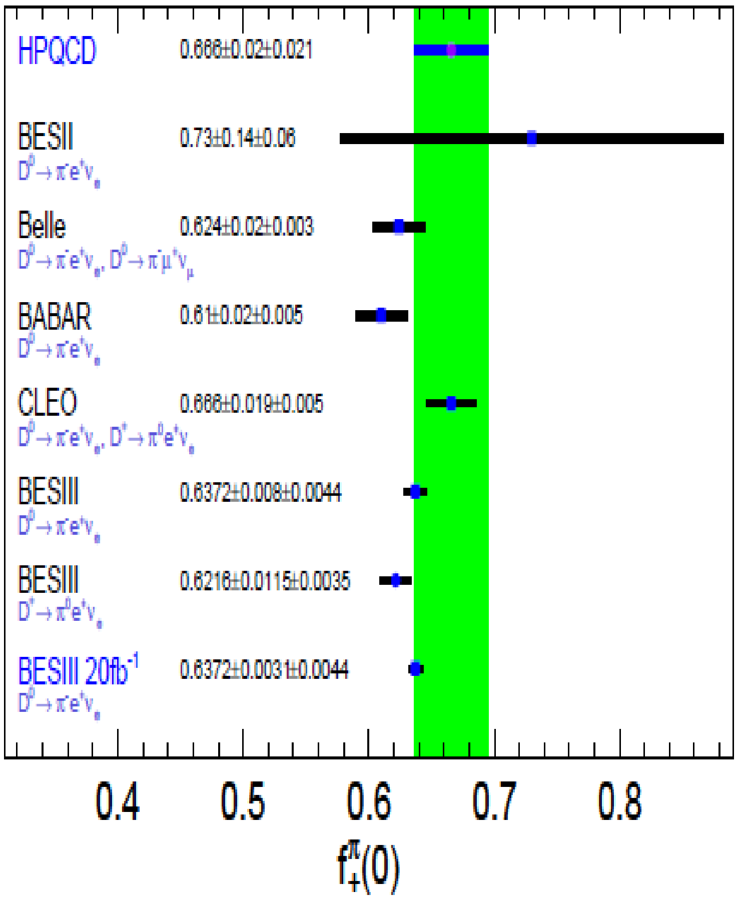
$$I_\pi \equiv \frac{\Gamma(D^0 \to \pi^- e^+ \nu_e)}{2\Gamma(D^+ \to \pi^0 e^+ \nu_e)} = 1.03 \pm 0.03 \pm 0.02$$



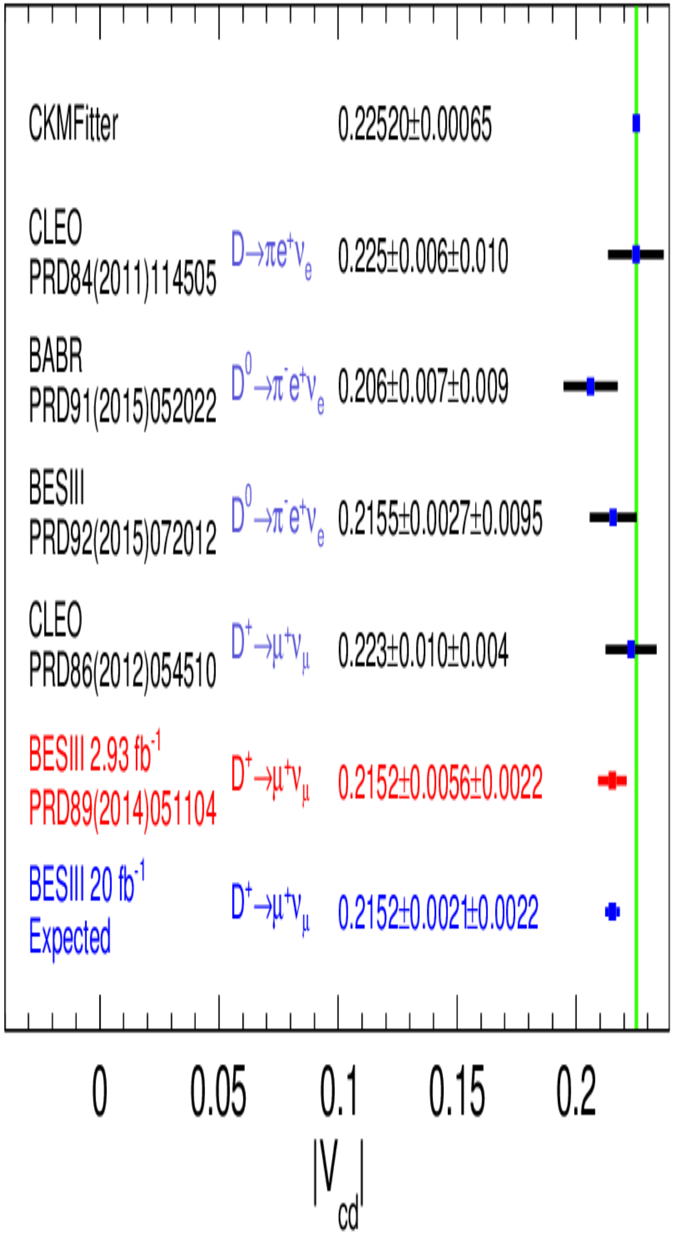



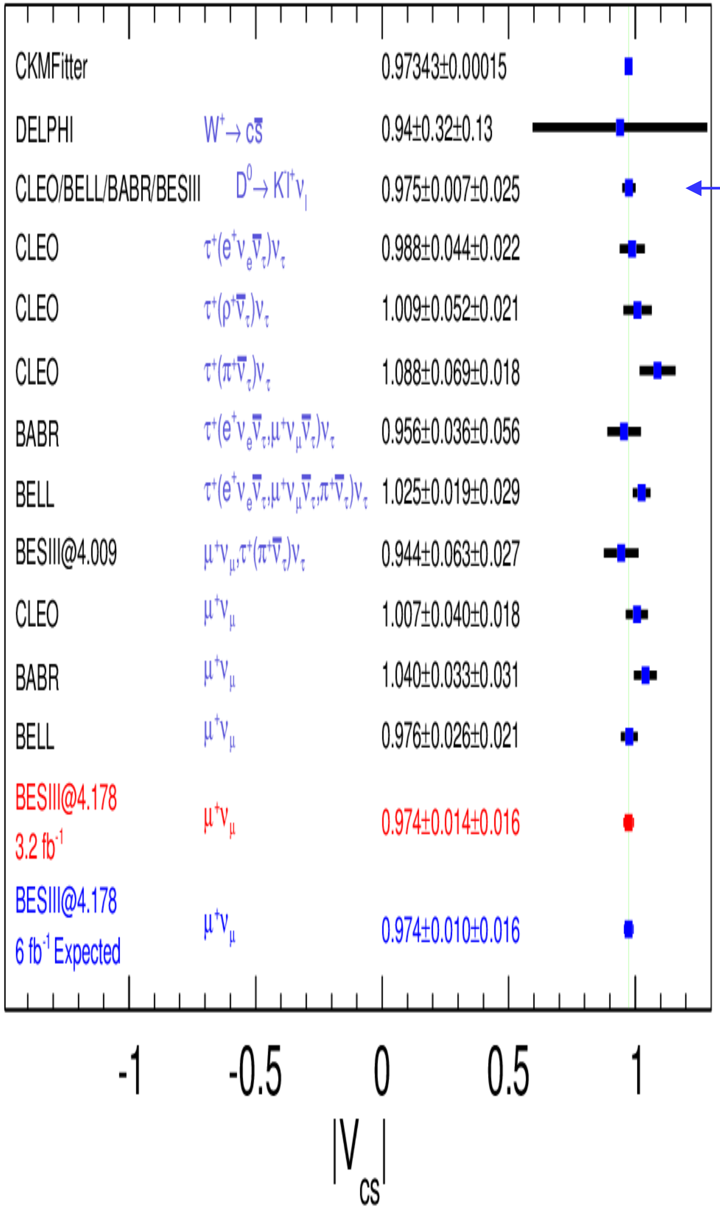
# Comparisons of $f^{D\to K(\pi)}_+(0)$



# Measurements of $|V_{cs(d)}|$



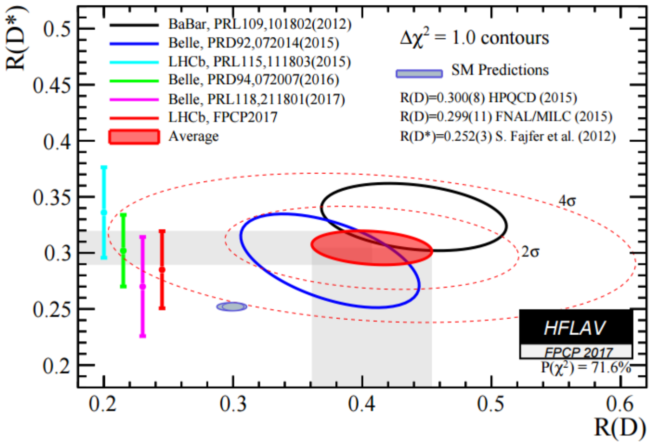




**Taken from PDG, and the SL method suffers about 2.4% error from LQCD**

# Test of LFU in $D^{0(+)} \rightarrow \pi l^+ \nu$ decays

**Evidence of LFV at 4σ in**

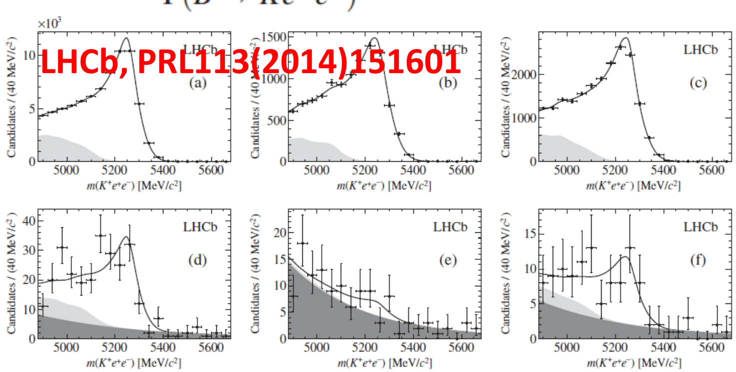
$$R(D^{(*)}) = \frac{B(B \rightarrow D^{(*)}\tau\nu)}{B(B \rightarrow D^{(*)} l \nu)}$$




**Evidence of LFV at 2.6σ in FCNC decays $B^+ \rightarrow K^+\mu^+\mu^-/K^+e^+e^-$**

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

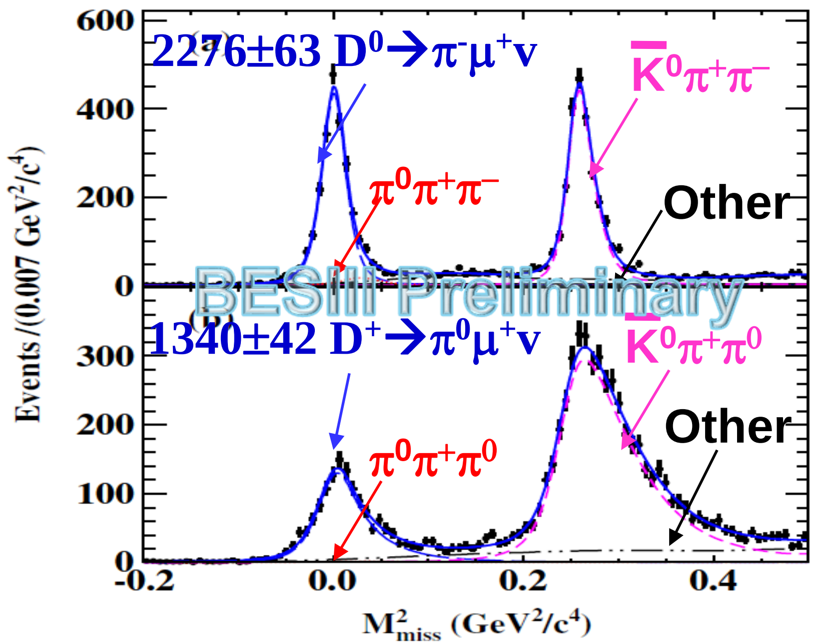
LHCb, PRL113(2014)151601




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

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

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




**$B[D^0 \rightarrow \pi^-\mu^+\nu] = (0.267 \pm 0.007 \pm 0.007)\%$**

**$B[D^+ \rightarrow \pi^0\mu^+\nu] = (0.342 \pm 0.011 \pm 0.010)\%$**

$R_{LU}^{0} = 0.918 \pm 0.036$ $\qquad$ $R_{LU}^{+} = 0.921 \pm 0.045$

# Observation of D→Se⁺ν

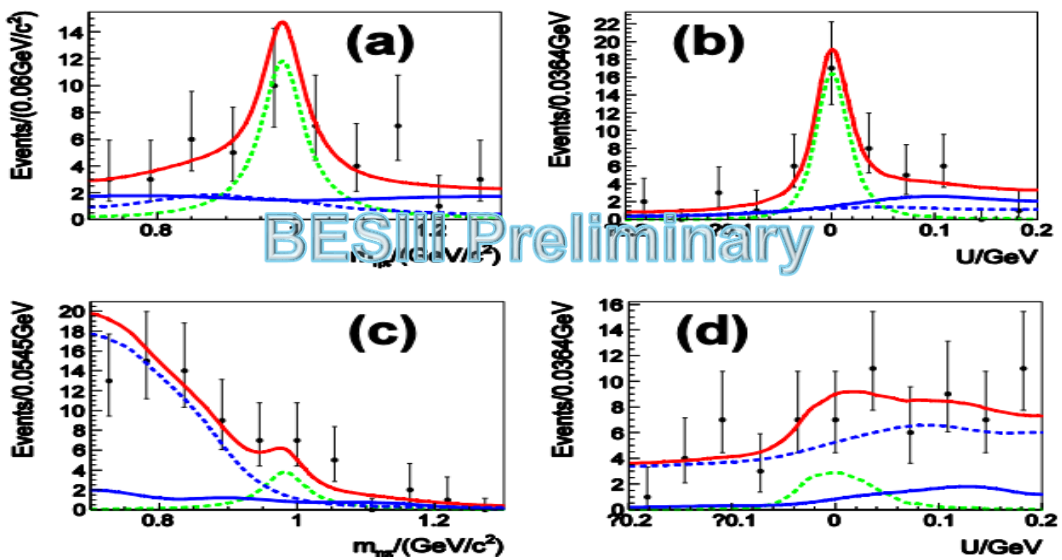
- Explore the nontrivial internal structure of light hadron mesons, traditional $q\bar{q}$ states, tetra quark system.

- With chiral unitarity approach in the coupled channels, BF is predicted to be order of 5(6)×$10^{-5}$ 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

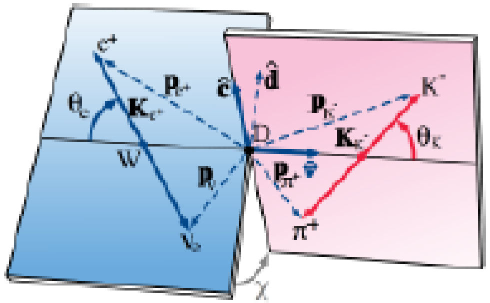



- $B(D^0 \to a_0(980)^- e^+ \nu_e) \times B(a_0(980)^- \to \eta\pi^-)$
  $= (1.12^{+0.31}_{-0.28}(stat) \pm 0.10(syst)) \times 10^{-4}$ — $5.9\sigma$

- $B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0)$
  $= (1.47^{+0.73}_{-0.59}(stat) \pm 0.14(syst)) \times 10^{-4}$ — $3.0\sigma$

- $B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0)$
  $< 2.7 \times 10^{-4}$ @ 90% C.L.

# Form factors of D→Ve⁺ν




- $m^2 = (p_{\pi^+} + p_{K^-})^2$
- $\cos(\theta_K) = \frac{\hat{\nu}\cdot \boldsymbol{K}_{K^-}}{|\boldsymbol{K}_{K^-}|}$
- $\cos(\chi) = \hat{\boldsymbol{c}} \cdot \hat{\boldsymbol{d}}$
- $q^2 = (p_{e^+} + p_{\nu_e})^2$
- $\cos(\theta_e) = -\frac{\hat{\nu}\cdot \boldsymbol{K}_{e^+}}{|\boldsymbol{K}_{e^+}|}$
- $\sin(\chi) = (\hat{\boldsymbol{c}} \times \hat{\boldsymbol{\nu}}) \cdot \hat{\boldsymbol{d}}$

## Decay rate depend on 5 variables and 3 form factors

$$d^5\Gamma = \frac{G_F^2|V_{cs}|^2}{(4\pi)^6 m_D^2} X \beta \mathcal{I}(m^2, q^2, \theta_K, \theta_e, \chi)\, dm^2\, dq^2\, d\cos(\theta_K)\, d\cos(\theta_e)\, d\chi$$

- $X = p_{K\pi} m_D$, $p_{K\pi}$ is the momentum of the $K\pi$ system in the $D$ rest frame
- $\beta = 2p^*/m$, $p^*$ is the breakup momentum of the $K\pi$ system in its rest frame
- $\mathcal{I}$ can be expressed in terms of helicity amplitudes $H_{0,\pm}$:

$$H_0(q^2) = \frac{1}{2m_q}\left[(m_D^2 - m^2 - q^2)(m_D + m)A_1(q^2) - 4\frac{m_D^2 p_{K\pi}^2}{m_D + m}A_2(q^2)\right]$$

$$H_\pm(q^2) = (m_D + m)A_1(q^2) \mp \frac{2m_D p_{K\pi}}{m_D + m}V(q^2)$$

- Vector form factor: $V(q^2) = \frac{V(0)}{1 - q^2/m_V^2}$; or: FF ratio $r_V = V(0)/A_1(0)$
- Axial-vector form factor: $A_1(q^2) = \frac{A_1(0)}{1 - q^2/m_A^2}$, $A_2(q^2) = \frac{A_2(0)}{1 - q^2/m_A^2}$; or: FF ratio $r_2 = A_2(0)/A_1(0)$

# PWA of $D^+ \to K^-\pi^+e^+\nu$

PRD94(2016)032001

- **Fractions with >5σ significance**

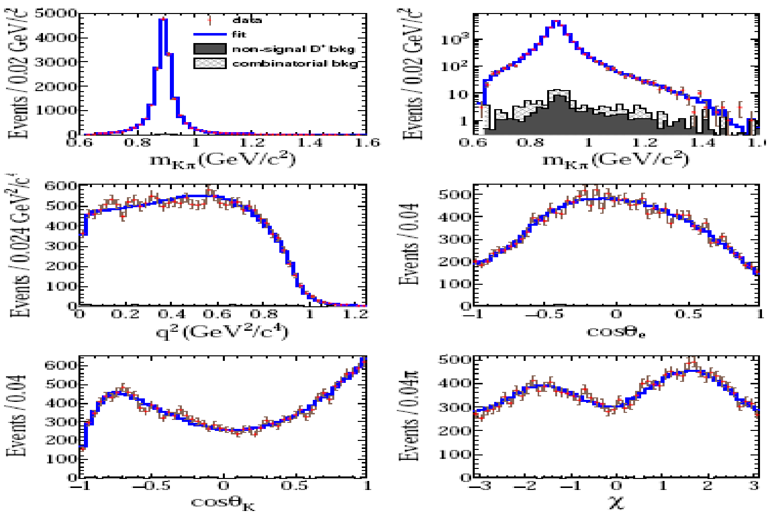
$$f(D^+ \to (K^-\pi^+)_{K^{*0}(892)} e^+\nu_e) = (93.93 \pm 0.22 \pm 0.18)\%$$

$$f(D^+ \to (K^-\pi^+)_{S-wave} e^+\nu_e) = (6.05 \pm 0.22 \pm 0.18)\%$$

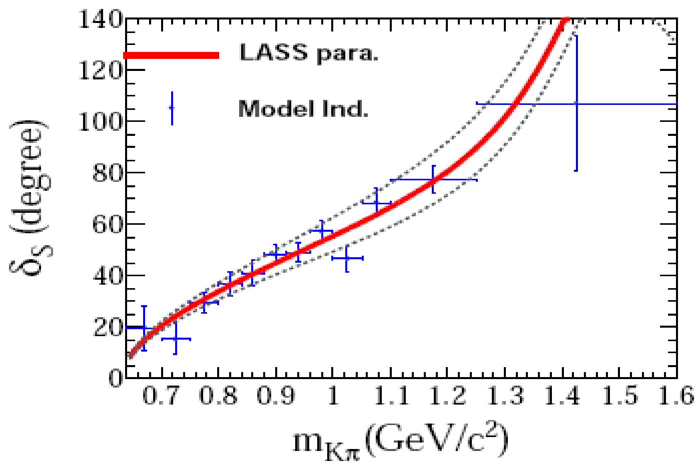
- **Properties of different Kπ (non-) resonant amplitudes**

$$m_{K^{*0}(892)} = (894.60 \pm 0.25 \pm 0.08)\ \mathrm{MeV}/c^2$$
$$\Gamma_{K^{*0}(892)} = (46.42 \pm 0.56 \pm 0.15)\ \mathrm{MeV}/c^2$$
$$r_{BW} = (3.07 \pm 0.26 \pm 0.11)\ (\mathrm{GeV}/c)^{-1}$$

- **$q^2$ dependent form factors in $D^+ \to \overline{K}^{*0}(892)e^+\nu$**



**Model independent S-wave phase measurement**




$$V(q^2) = \frac{V(0)}{1-q^2/m_V^2}, \quad A_{1,2}(q^2) = \frac{A_{1,2}(0)}{1-q^2/m_A^2}$$

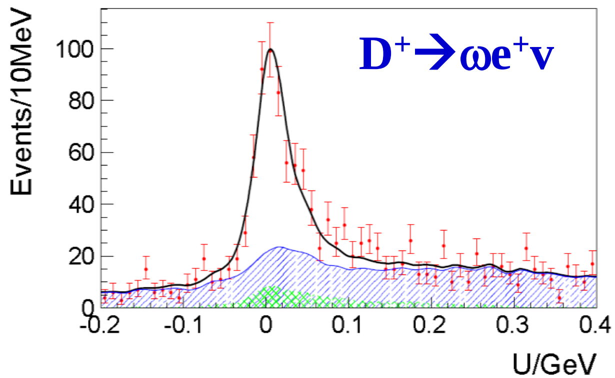
$M_{V/A}$ is expected to $M_{D^*(1^-/+)}$

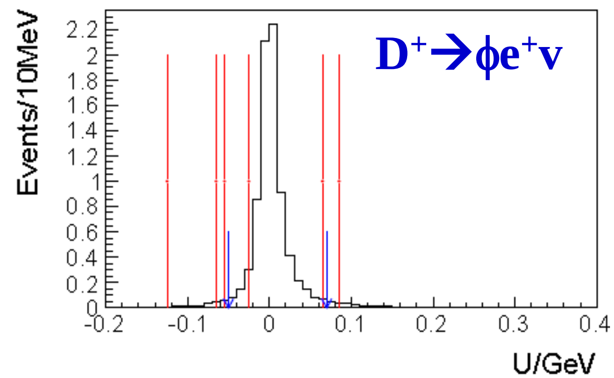
$$m_V = (1.81^{+0.25}_{-0.17} \pm 0.02)\ \mathrm{GeV}/c^2$$
$$m_A = (2.61^{+0.22}_{-0.17} \pm 0.03)\ \mathrm{GeV}/c^2$$
$$A_1(0) = 0.573 \pm 0.011 \pm 0.020$$
$$r_V = V(0)/A_1(0) = 1.411 \pm 0.058 \pm 0.007$$
$$r_2 = A_2(0)/A_1(0) = 0.788 \pm 0.042 \pm 0.008$$

**Model independent form factors**

# Study of $D^+ \to \omega e^+ v$ and search for $D^+ \to \phi e^+ v$

PRD92(2015)071101(RC)

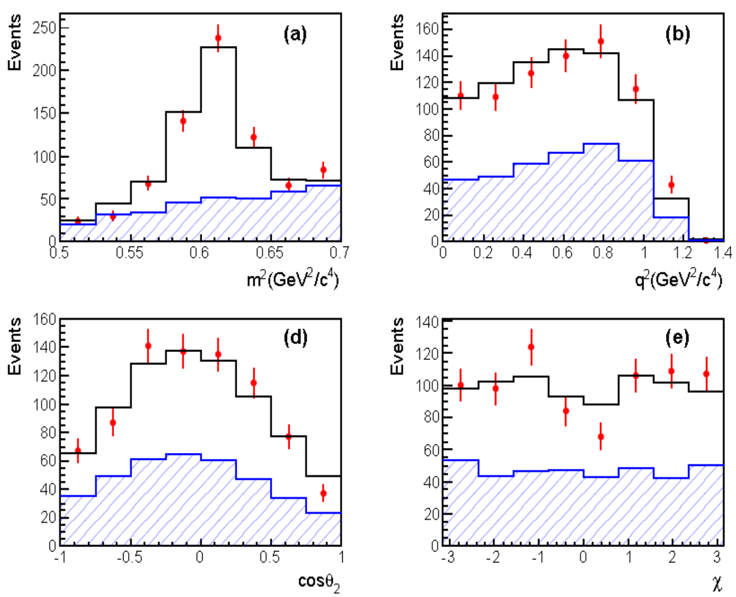



$B[D^+ \to \omega e^+ v] = (1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$

$B[D^+ \to \phi e^+ v] < 1.3 \times 10^{-5}$ at 90% C.L.

**Better precision or sensitivity**

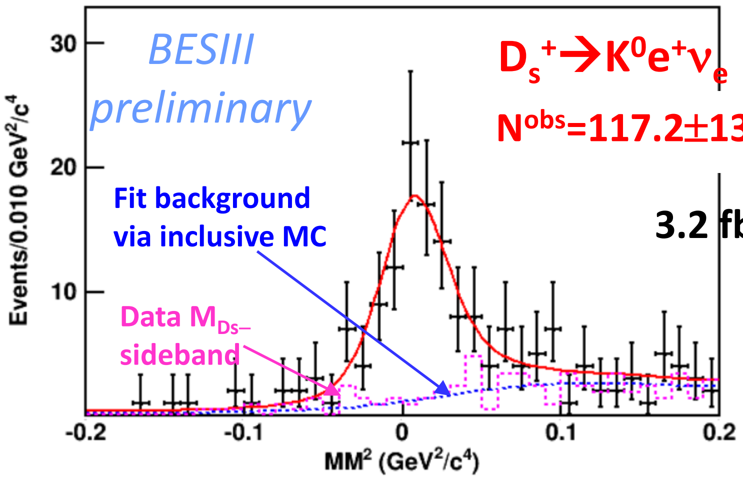



**Amplitude analysis of $D^+ \to \omega e^+ v$ is performed for the first time**

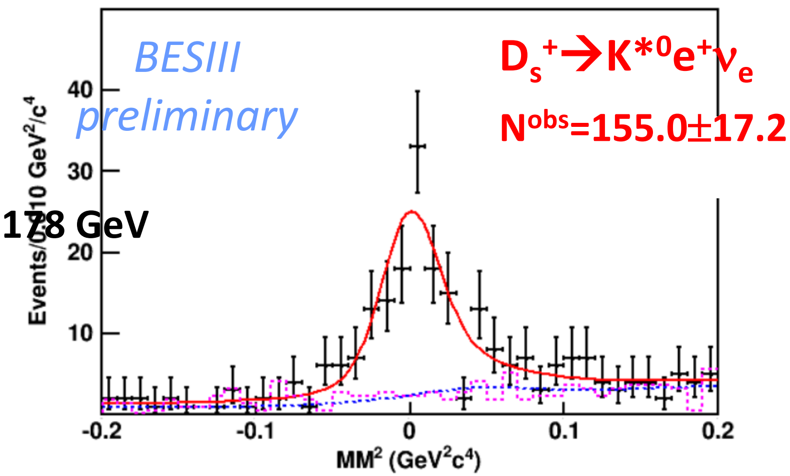
$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$

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

# Studies of $D_s^+ \to K^{(*)0} e^+ \nu$ at 4.178 GeV




3.2 fb$^{-1}$ data@4.178 GeV

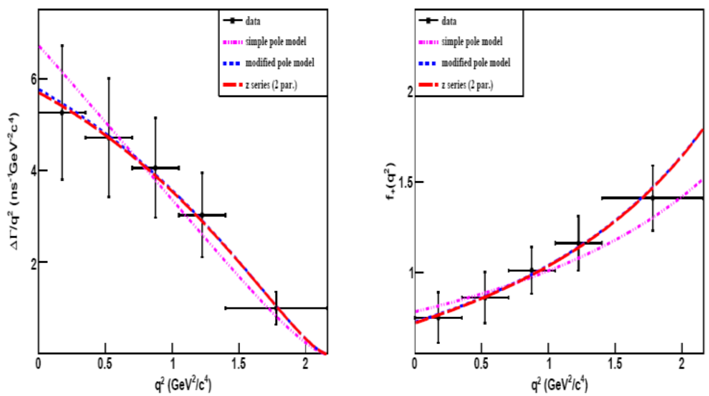



$B[D_s^+ \to K^0 e^+ \nu_e] = (3.25 \pm 0.38_{stat} \pm 0.14_{syst}) \times 10^{-3}$

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

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

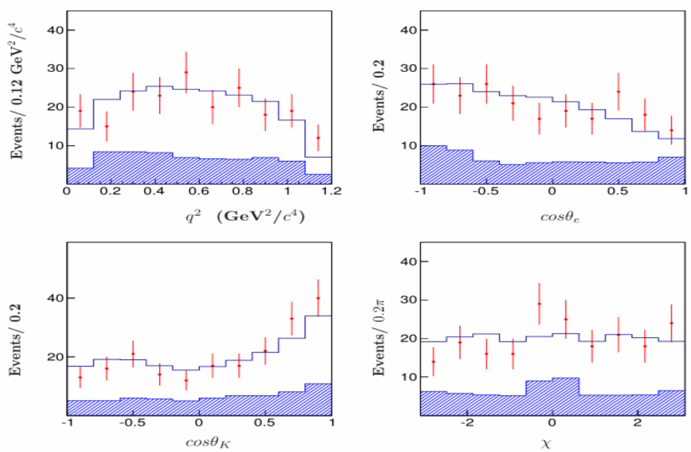
$(1.8 \pm 0.4) \times 10^{-3}$ [PDG17]




| 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 | $f_+(0)\|V_{cd}\|$ | $0.163 \pm 0.017 \pm 0.003$ | $0.725 \pm 0.076 \pm 0.013$ |
| | $\alpha$ | $0.45 \pm 0.44 \pm 0.02$ | |
| 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±0.34±0.16

$r_2$=0.77±0.28±0.07

# Summary

- With ~3/3 $fb^{-1}$ data taken at 3.773/4.178 GeV by BESIII, the leptonic decay of $D_{(s)}^+ \to l^+ v$ and some semi-leptonic D decays, and improved measurements of $|V_{cs(d)}|$, decay constants, form factors have been obtained

- More results are expected in the near future

$D_s^+ \to \tau^+ v$, $f_{Ds+}$ and $|V_{cs}|$

$D_s^+ \to \eta^{(')} e^+ v$, form factors and $|V_{cs}|$

$D_s^+ \to K^+K^-/\pi^+\pi^- e^+ v$, form factors ……

$D^0 \to K^- \mu^+ v$, $f^+_K(q^2)$ and $|V_{cs}|$

$D \to K_1(1270) e^+ v$

$D_{(s)}^{0(+)} \to X e^+ v$ ……

All Cabibbo-suppressed $D^{0(+)}$ decays and $D_s^+$ decays are restricted by the limited data

# Prospects at BESIII

- With 20/6 $fb^{-1}$ data taken at 3.773/4.178 GeV, some elementary constants can be further improved

| | Systematic error | Statistical error | |
|---|---|---|---|
| | | ~3 $fb^{-1}$ | Expected with 20/6 $fb^{-1}$ |
| $\Delta f_{D+}/f_{D+}$ | 0.9% | 2.6% | 0.5% |
| $\Delta f_{Ds+}/f_{Ds+}$ | 1.5% | 1.5% | ~1% |
| $\Delta f_{D\to K}/f_{D\to K}$ | 0.5% | 0.4% | 0.15% |
| $\Delta f_{D\to\pi}/f_{D\to\pi}$ | 0.7% | 1.3% | 0.5% |
| $\|V_{cs}\|^{Ds+\to l+v}$ | 1.5% | 1.5% | ~1% |
| $\|V_{cs}\|^{D0\to K\text{-}e+v}$ | 2.5%(2.4%$^{LQCD}$) | 0.4% | 0.15% |
| $\|V_{cd}\|^{D+\to\mu+v}$ | 0.9% | 2.6% | ~1% |
| $\|V_{cd}\|^{D0\to\pi\text{-}e+v}$ | 4.5%(4.4%$^{LQCD}$) | 1.3% | 0.5% |

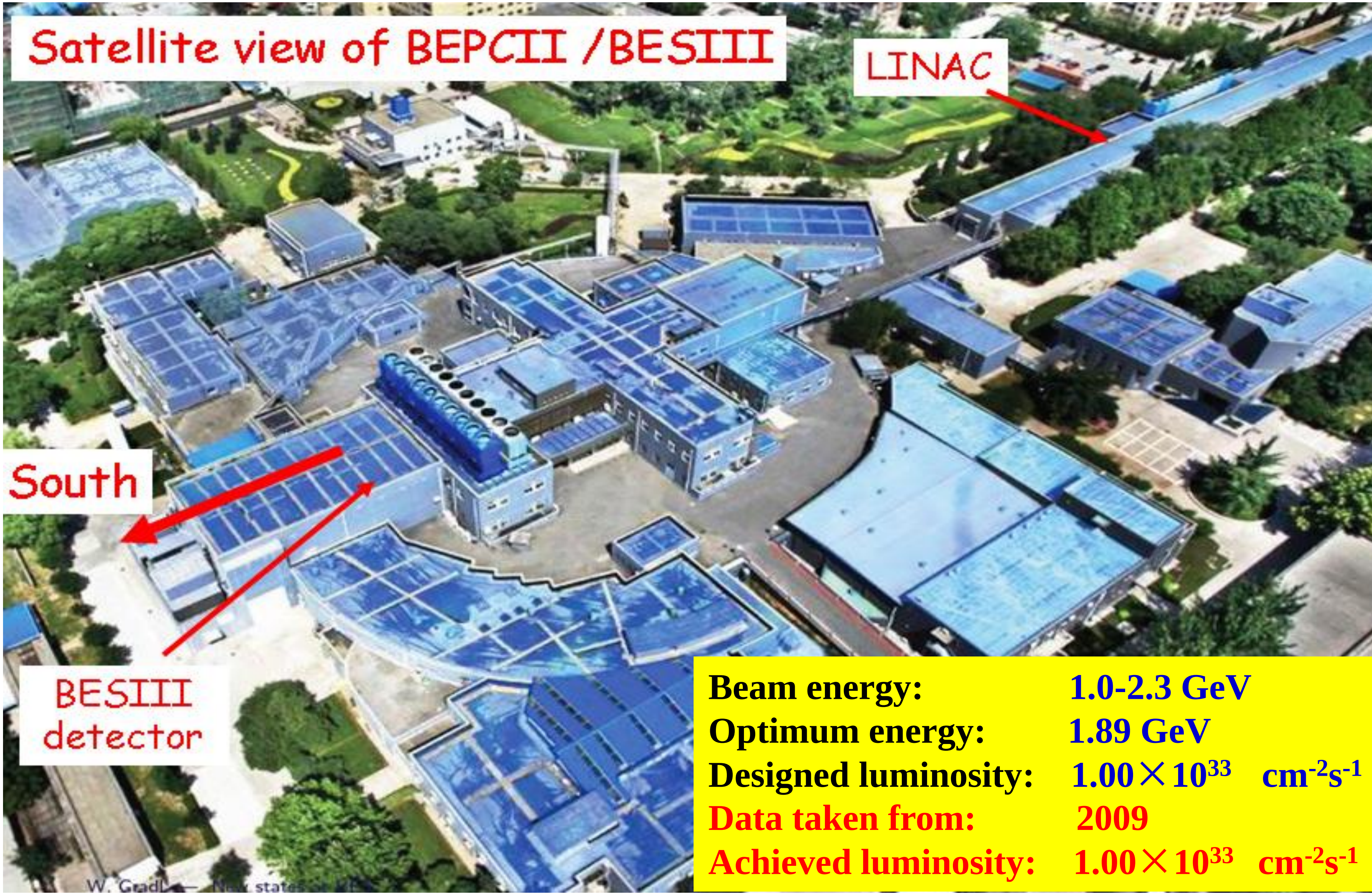
Only $D_s^+ \to \mu^+ v$ is considered. The contribution of $D_s^+ \to \tau^+ v$ will be comparable or slightly better than $D_s^+ \to \mu^+ v$

Once LQCD uncertainties reach <1% level, the $|V_{cs(d)}|$ will be much improved

- More or improved measurements of form factors of semileptonic decays, containing scalar or axial-vector meson, which are now statistically limited

# Thank you!

# BEPCII collider

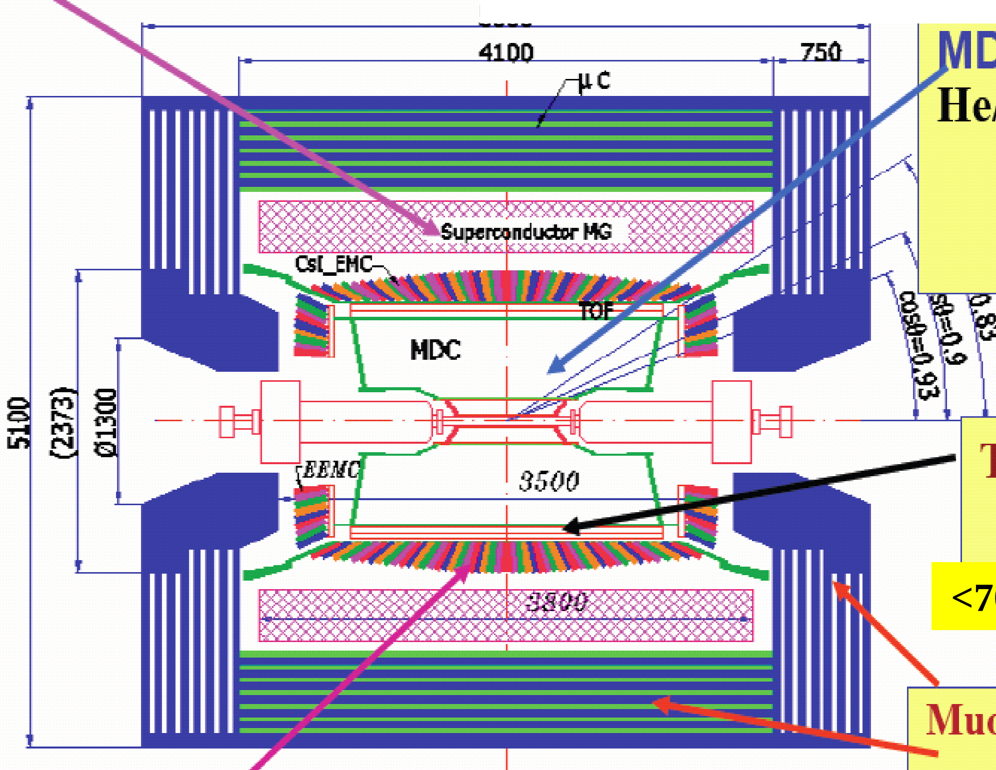



**Beam energy:** 1.0-2.3 GeV
**Optimum energy:** 1.89 GeV
**Designed luminosity:** $1.00 \times 10^{33}$ $cm^{-2}s^{-1}$
**Data taken from:** 2009
**Achieved luminosity:** $1.00 \times 10^{33}$ $cm^{-2}s^{-1}$

# BESIII detector

Nucl. Instr. Meth. A614, 345 (2010)

Magnet: 1 T Super conducting




MDC: small cell & Gas:
$He/C_3H_8$ (60/40), 43 layers
$\sigma_{xy}$=130 μm
$\sigma_p/p$ = 0.5% @1GeV
dE/dx=6%

TOF:
$\sigma_T$ = 100 ps Barrel

<70 ps endcap updated in 2015

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

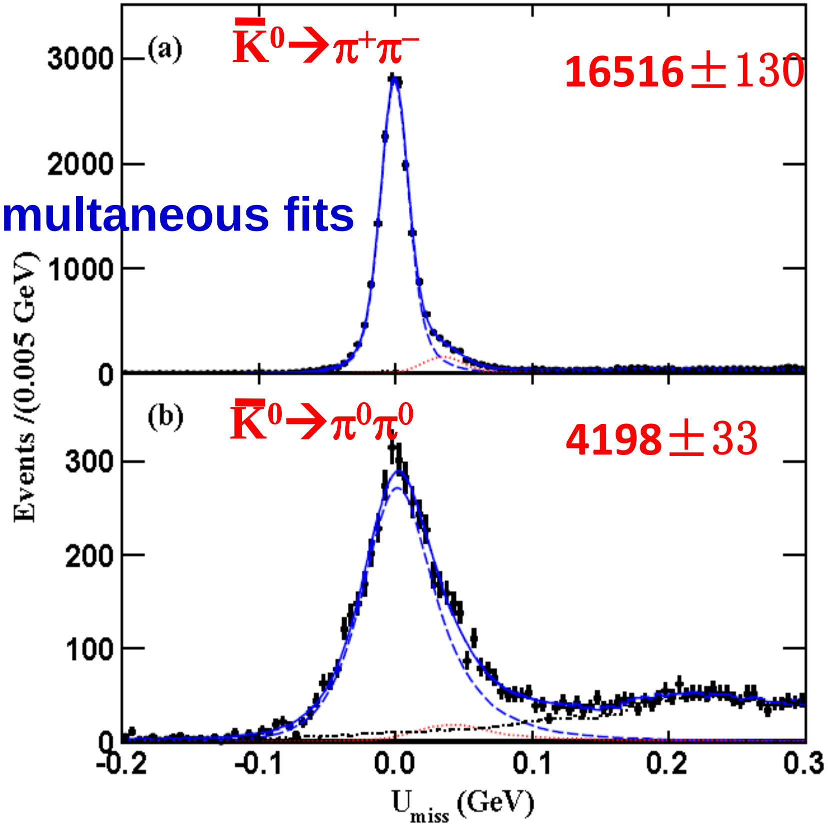
Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

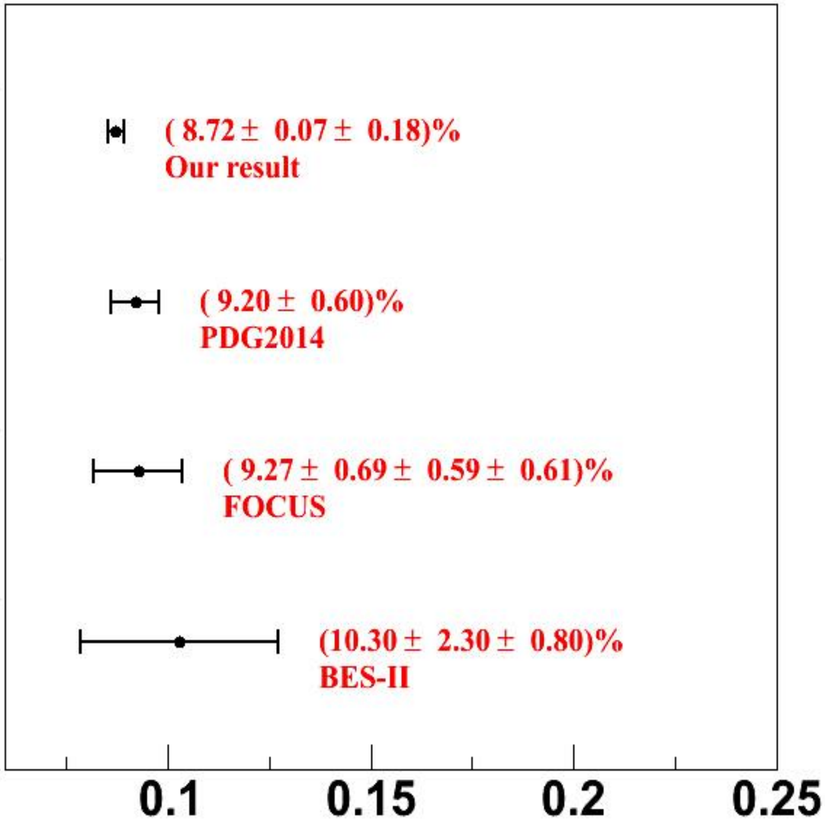
# Improved BF for $D^+ \to \bar{K}^0 \mu^+ \nu$

**With 6 dominant $D^-$ single tag**

**EPJC76(2016)369**

**Simultaneous fits**




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

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

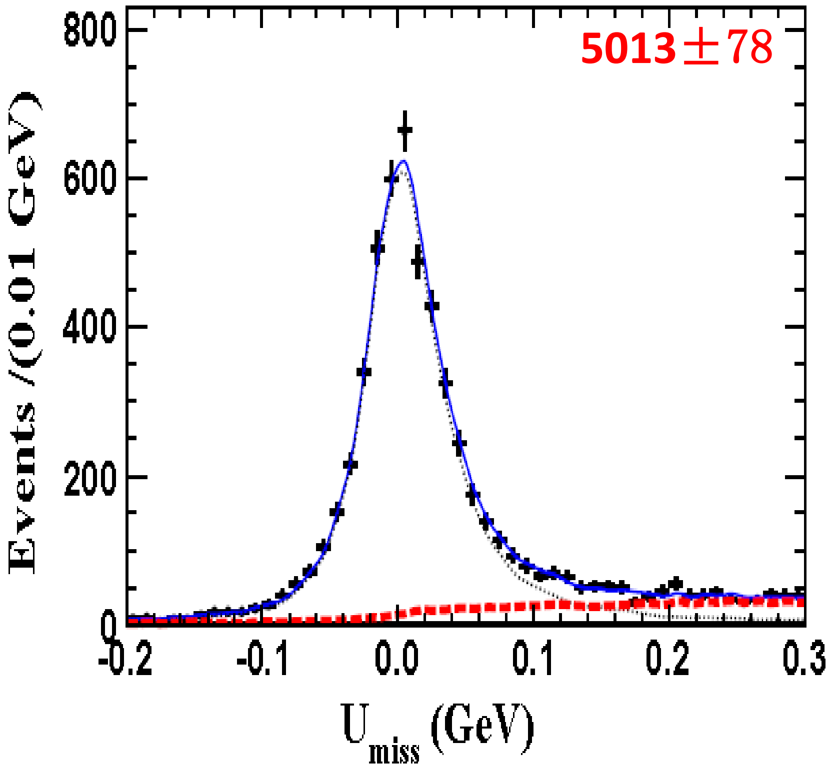
**Support isospin conservation in these two decays within errors**

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

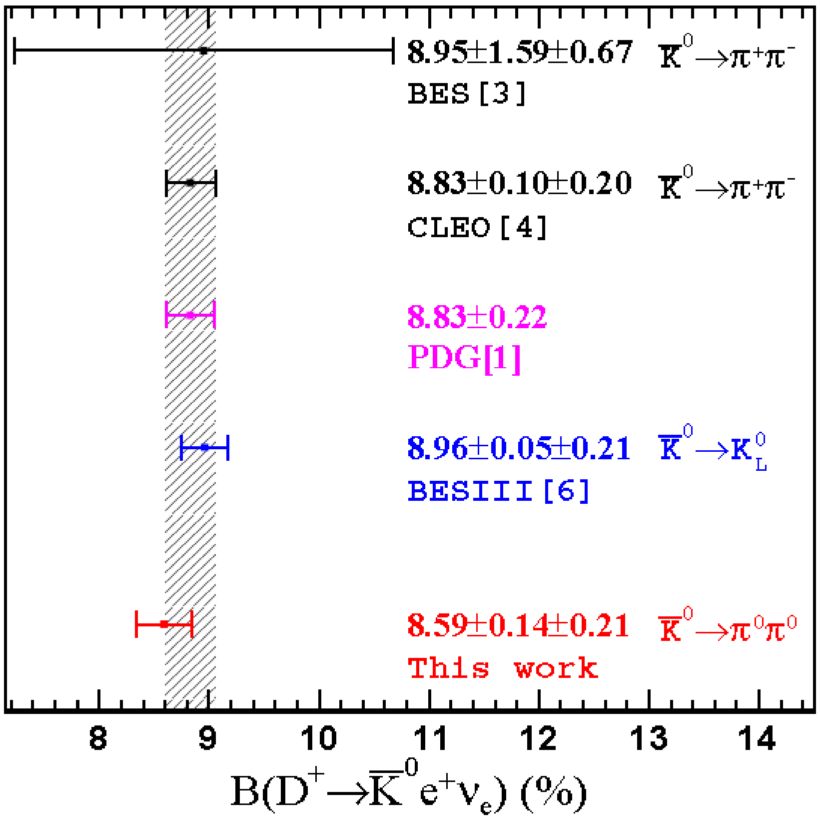
**Consistent with theory prediction 0.97 within error**

# 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**




CPC40(2016)113001




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

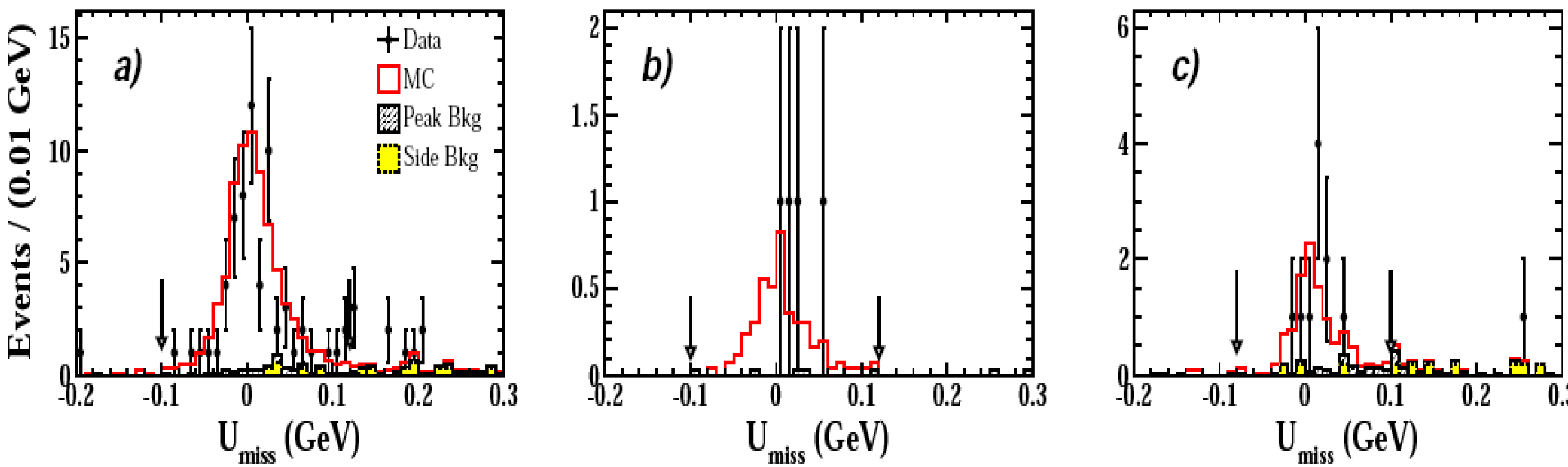
$$\frac{\Gamma[D^0 \to K^- e^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 e^+ \nu]} = 0.969 \pm 0.025$$

**Agrees with isospin conservation within 1.2σ**

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

- 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

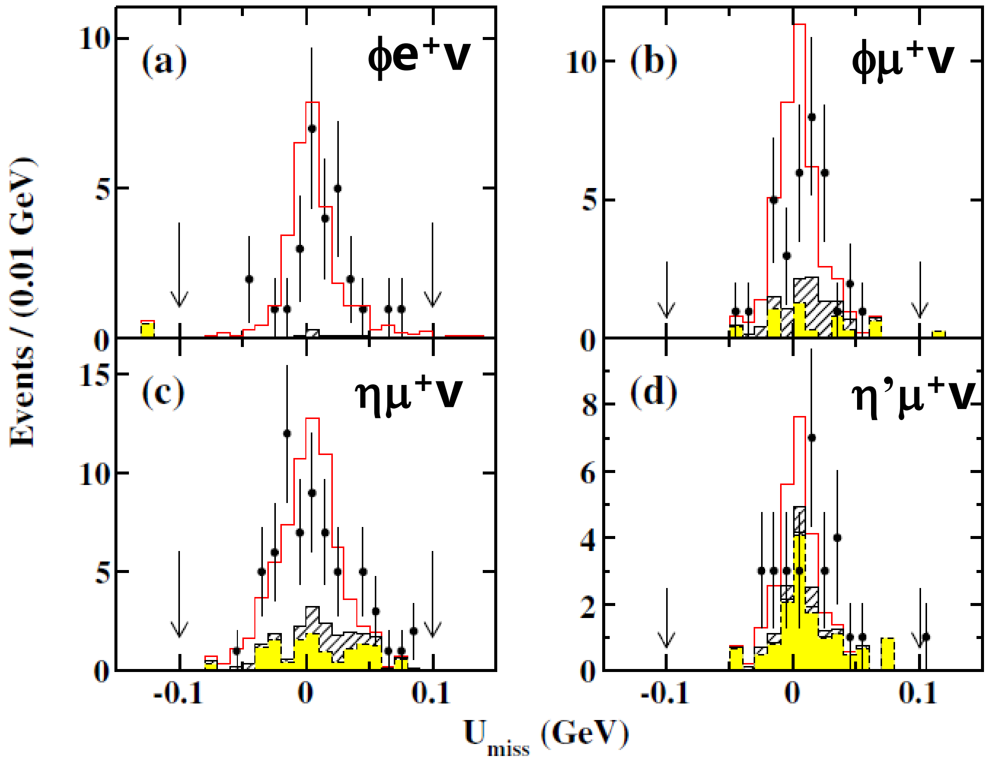
**482 $pb^{-1}$ data@4.009 GeV, PRD94(2016)112003**




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

# Measurements of BFs of $D_s^+ \to \phi/\eta^{(\prime)}\mu^+\nu$

**482 $pb^{-1}$ data@4.009 GeV, PRD97(2018)012006**




**The ratios of BFs**

$$\frac{\Gamma[D_s^+ \to \phi\mu^+\nu]}{\Gamma[D_s^+ \to \phi e^+\nu]} = 0.86 \pm 0.29$$

$$\frac{\Gamma[D_s^+ \to \eta\mu^+\nu]}{\Gamma[D_s^+ \to \eta e^+\nu]} = 1.05 \pm 0.24$$

$$\frac{\Gamma[D_s^+ \to \eta'\mu^+\nu]}{\Gamma[D_s^+ \to \eta' e^+\nu]} = 1.14 \pm 0.68$$

| $\mu^+$ mode | $\mathcal{B}_{\rm BESIII}$ (%) | $\mathcal{B}_{\rm PDG}$ (%) | $e^+$ mode | $\mathcal{B}_{\rm BESIII}$ (%) | $\mathcal{B}_{\rm PDG}$ (%) |
|---|---|---|---|---|---|
| $D_s^+ \to \phi\mu^+\nu_\mu$ | $1.94 \pm 0.53 \pm 0.09$ | ... | $D_s^+ \to \phi e^+\nu_e$ | $2.26 \pm 0.45 \pm 0.09$ | $2.39 \pm 0.23$ |
| $D_s^+ \to \eta\mu^+\nu_\mu$ | $2.42 \pm 0.46 \pm 0.11$ | ... | $D_s^+ \to \eta e^+\nu_e$ | $2.30 \pm 0.31 \pm 0.08$ [8] | $2.28 \pm 0.24$ |
| $D_s^+ \to \eta'\mu^+\nu_\mu$ | $1.06 \pm 0.54 \pm 0.07$ | ... | $D_s^+ \to \eta' e^+\nu_e$ | $0.93 \pm 0.30 \pm 0.05$ [8] | $0.68 \pm 0.16$ |

**BFs of semi-muonic decays are measured for the first time**