Leptonic and semi-leptonic D decays

-- at BESIII, BaBar and BELLE

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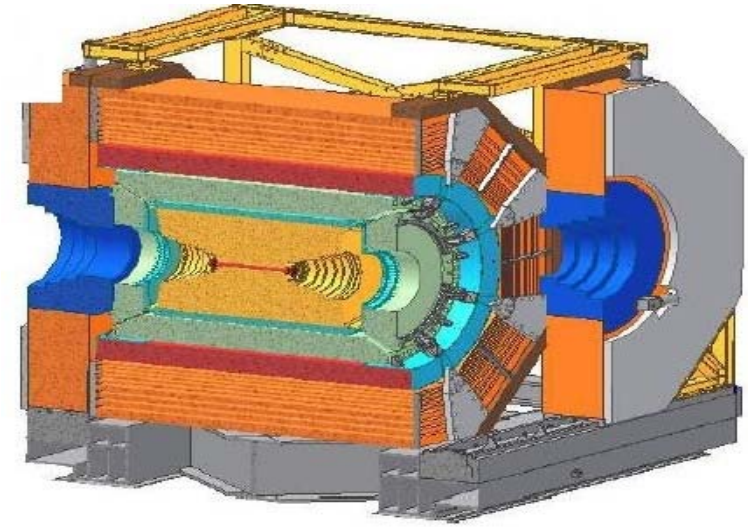
D^0 and D^+ samples used at BESIII

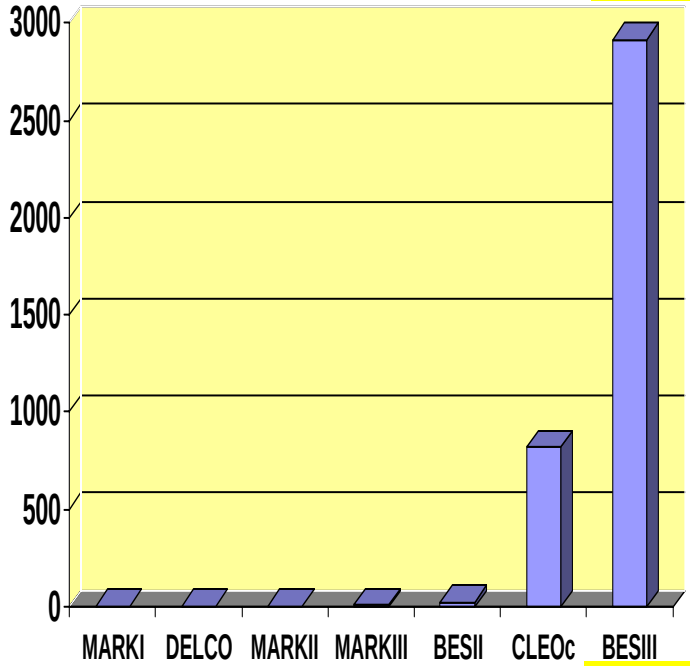
2.92 fb^{-1} data were taken around 3.773 GeV

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

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

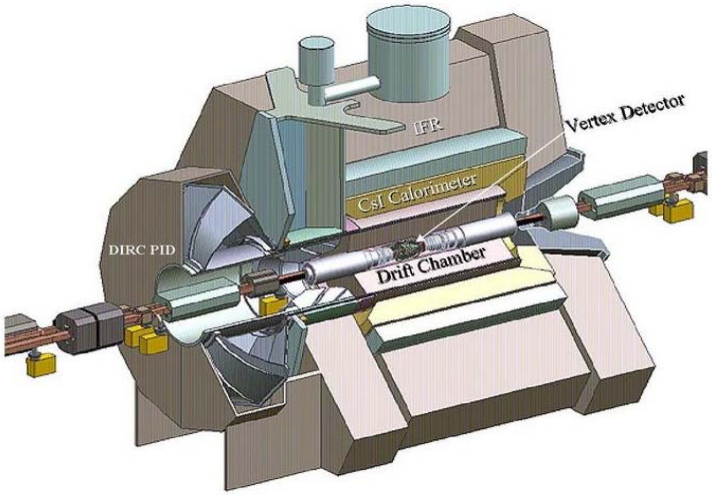


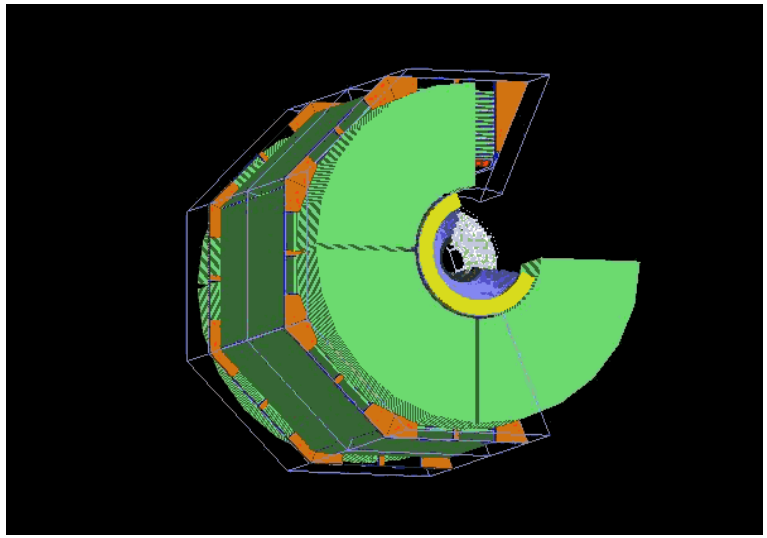
2010.1-2011.5



3.6×CLEOc

D^0 and D_s^+ samples used at B factories



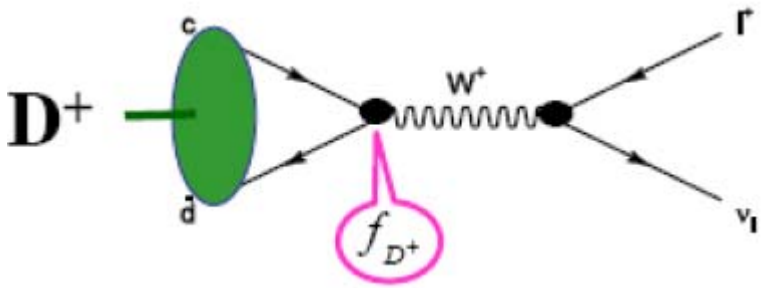


For each, several hundred fb^{-1} data were taken at Y(4S) or Y(5S)

D^0 or D_s^+ mesons are searched via decay chains

$$e^+e^- \to c\bar{c} \to D_{\rm tag} K_{\rm frag} X_{\rm frag} D_s^{*-}$$ **or** $$e^+e^- \to D^{(*)}_{\rm tag} D^{*-}_{\rm sig} X, D^{*-}_{\rm sig} \to \bar{D}^0_{\rm sig}\pi^-, X = \pi^+ {\rm or} \pi^+\pi^0 {\rm or} K^+$$

$D_{(s)}^{+} \rightarrow \mu(\tau)^{+}\nu$ and Decay Constant $f_{D(s)+}$



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

- **The strong interaction effects between the two quarks within $D_{(s)}^{+}$ meson is simply factorized into the decay constant $f_{D(s)+}$.**
- **Improved $f_{D(s)+}$ can accurately test LQCD calculation of $f_{D(s)+}$.**
- **In current LQCD calculations, the ratio f_{D+}:f_{Ds+}:f_{B+} has a significantly better precision than their individual values. Once the measured $f_{D(s)+}$ passes the test on LQCD, $f_{B(s)+}$ can be improved. As a result, $|V_{td(s)}|$ can also be improved in the of $B_{(s)}^{0}\overline{B}_{(s)}^{0}$ mixing experiment.**

$|V_{cd(s)}|$ measured via $D_{(s)}^{+} \rightarrow \mu(\tau)^{+}\nu$

- $|V_{cd(s)}|$ can be measured by $D_{(s)}^{+} \rightarrow \mu(\tau)^{+}\nu$ or $D \rightarrow \pi(K)e^{+}\nu$:
  - Recent HPQCD calculation of the $f_{K(\pi)}^{+}(0)$ for $D \rightarrow \pi(K)e^{+}\nu$ suffers uncertainty of 4.5(2.5)%.
  - $|V_{cd}|$ via $\nu\bar{\nu}$ interaction suffers 4.8% uncertainty (See PDG).
  - While, recent HPQCD calculation of the $f_{D(s)+}$ only suffers uncertainty of 1.7(1.0)%.

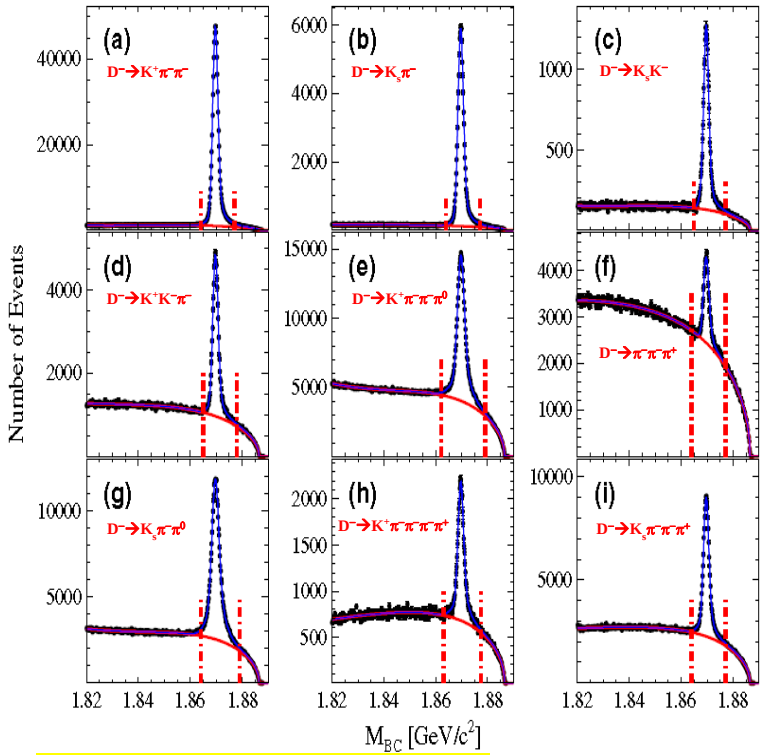
- Precision measurements of $|V_{cd(s)}|$ by $D_{(s)}^{+} \rightarrow l^{+}\nu$ can improve the stringency of unitarity constraints on the CKM matrix and test the SM.

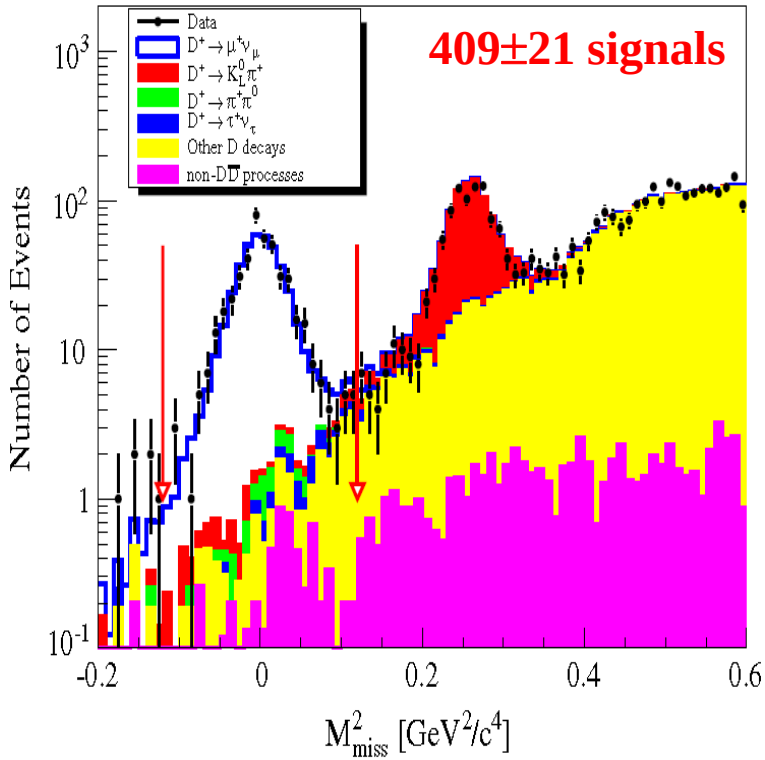
$D^+ \to \mu^+\nu$, f_{D+} and $|V_{cd}|$ at BESIII

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

2.92 fb^{-1} data@ 3.773 GeV

PRD89(2014)051104R





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

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

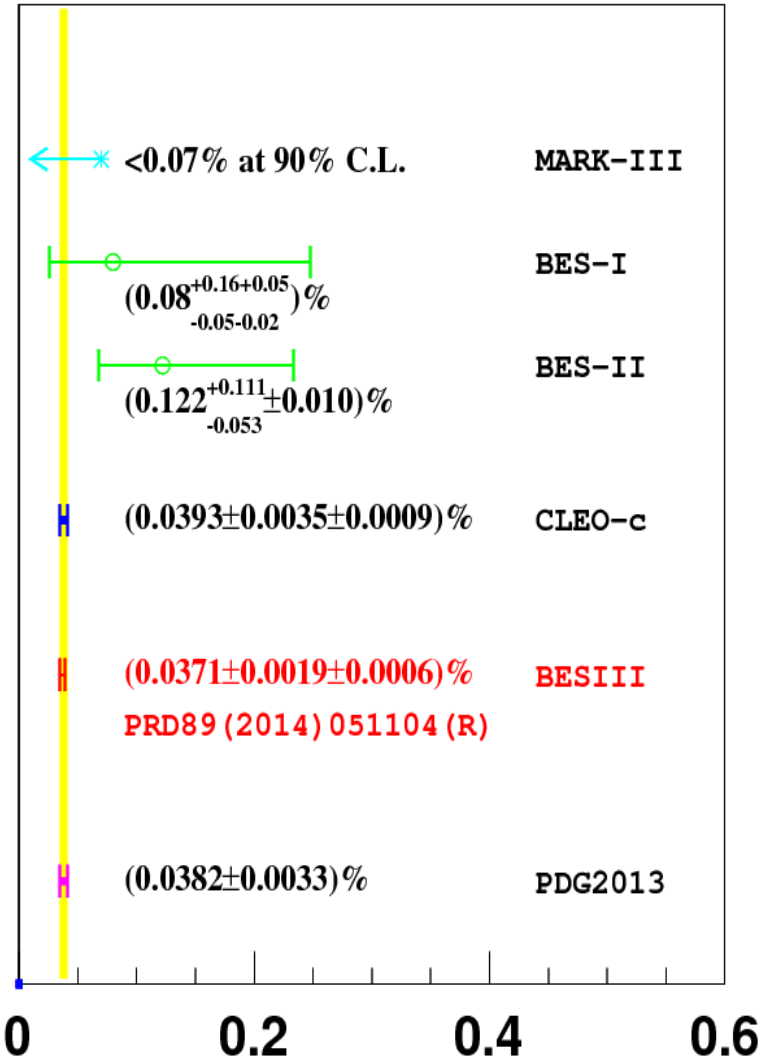
Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and $|V_{cd}|$ of CKM-Fitter

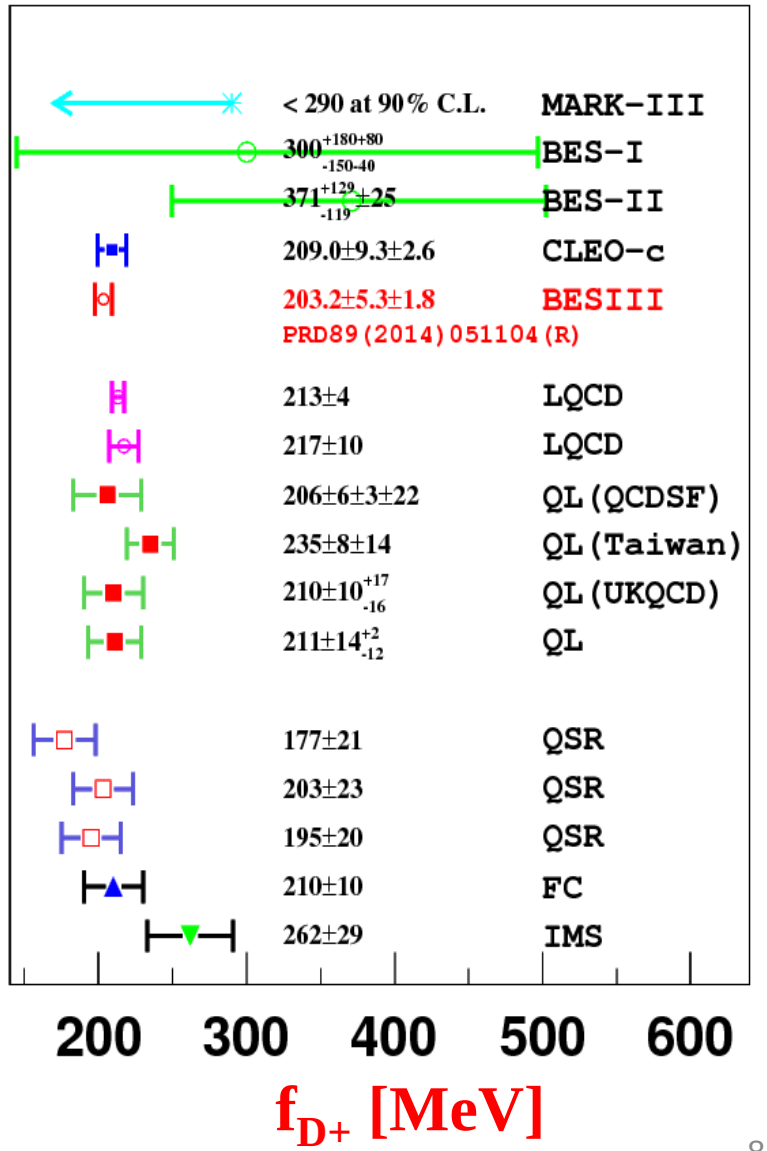
$f_{D+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and LQCD calculated $f_{D+} = 207 \pm 4$ MeV[PRL100(2008)062002]

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

Comparisons of $B[D^+ \to \mu^+ \nu_\mu]$ and f_{D+}

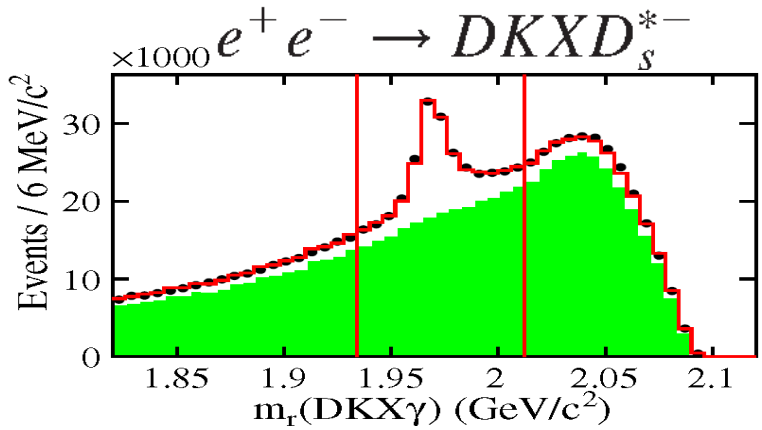


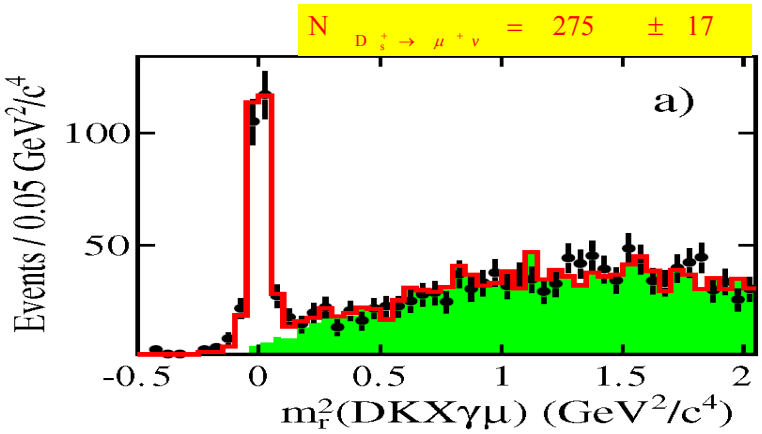


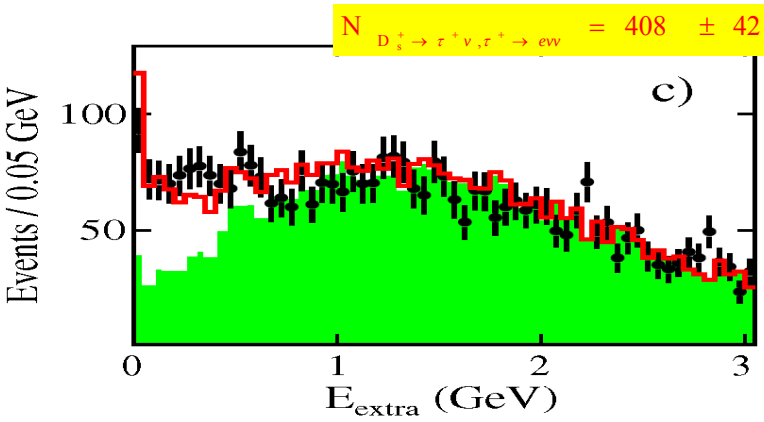
Studies of $D_s^+ \to \mu(\tau)^+\nu$ at BaBar

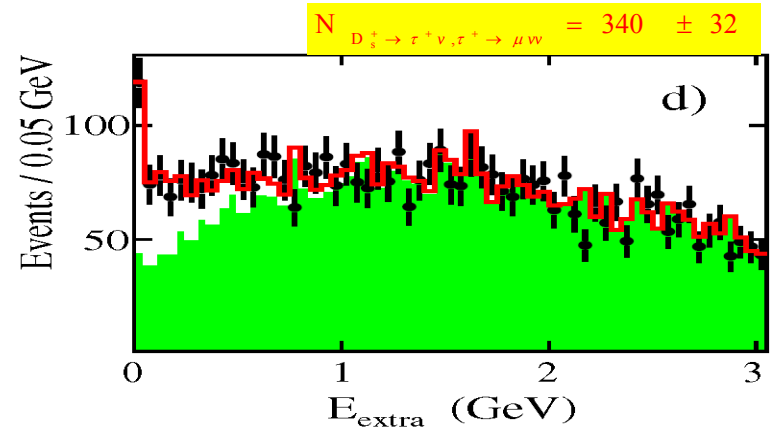
521 fb^{-1} data@ 10.58 GeV

PRD82(2010)091103R









$N_{D_s^+}^{inc} = (67.2 \pm 1.5) \times 10^3$

$B[D_s^+ \to \mu^+\nu] = (0.602 \pm 0.038 \pm 0.034)\%$

$B[D_s^+ \to \tau^+\nu] = (5.00 \pm 0.35 \pm 0.49)\%$

$f_{D_s^+} = (258.6 \pm 6.4 \pm 7.5)$ MeV

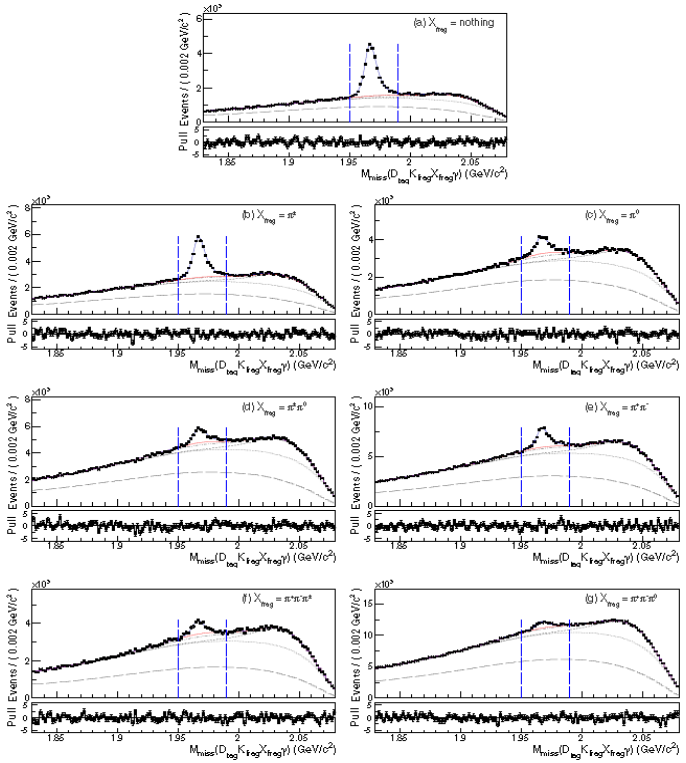
Studies of $D_s^+ \to \mu(\tau)^+\nu$ at BELLE

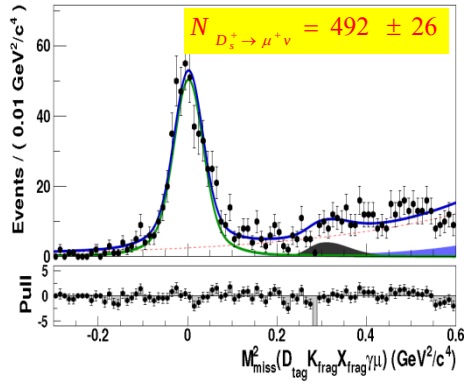
$D_s^+ \to \mu^+\nu$, 548 fb^{-1}: PRL100(2008)241801

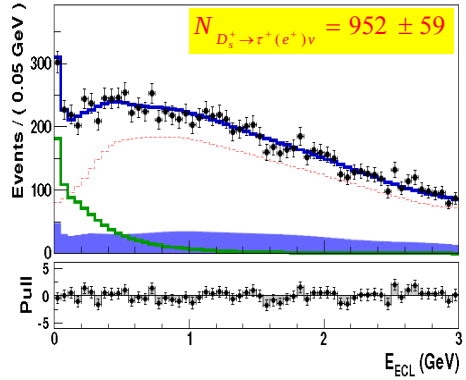
JHEP1309(2013)129

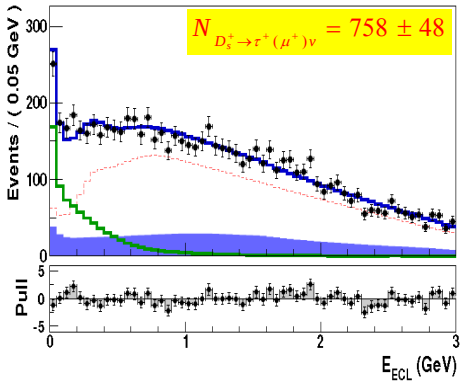
913 fb^{-1} data @ 10.6 GeV

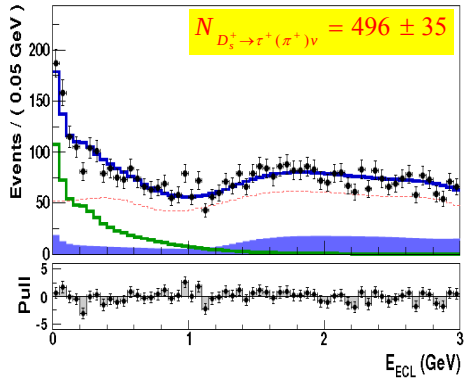
$$e^+e^- \to c\bar{c} \to D_{\rm tag} K_{\rm frag} X_{\rm frag} D_s^{*-}$$











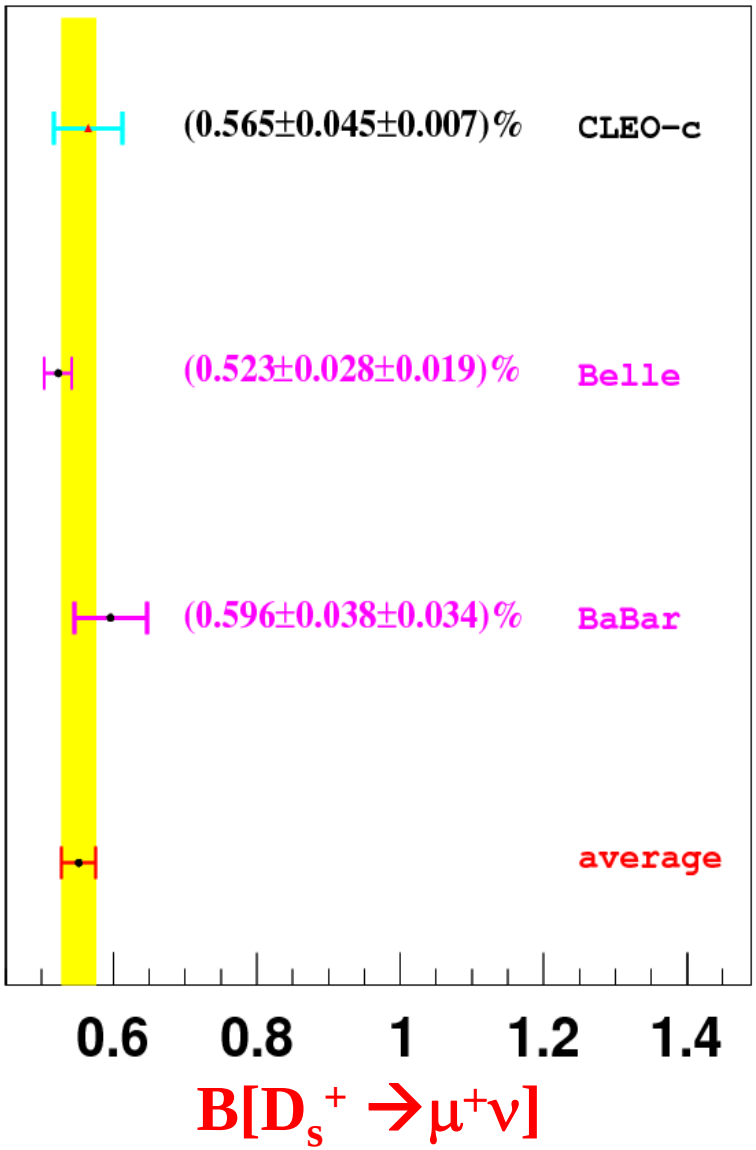
$$N^{\rm inc}_{D_s^+} = 94360 \pm 1310 \pm 1450$$

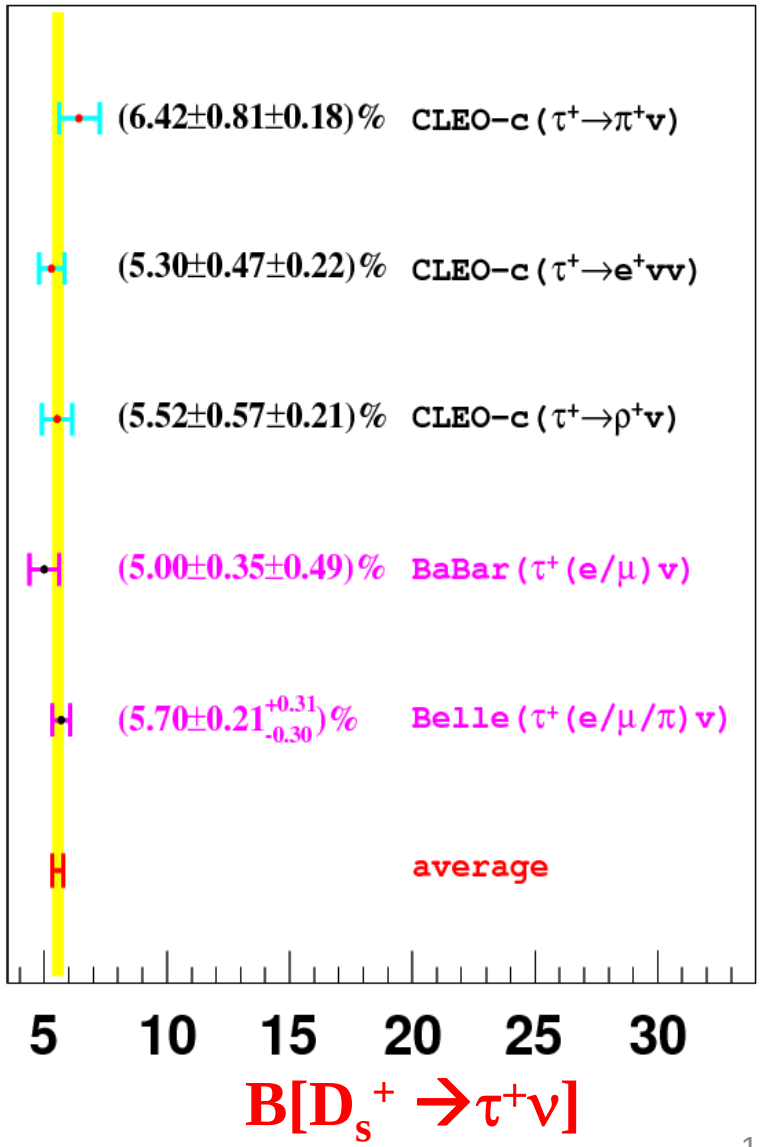
$$B[D_s^+ \to \mu^+\nu] = (0.531 \pm 0.028 \pm 0.020)\%$$

$$B[D_s^+ \to \tau^+\nu] = (5.70 \pm 0.21^{+0.31}_{-0.30})\%$$

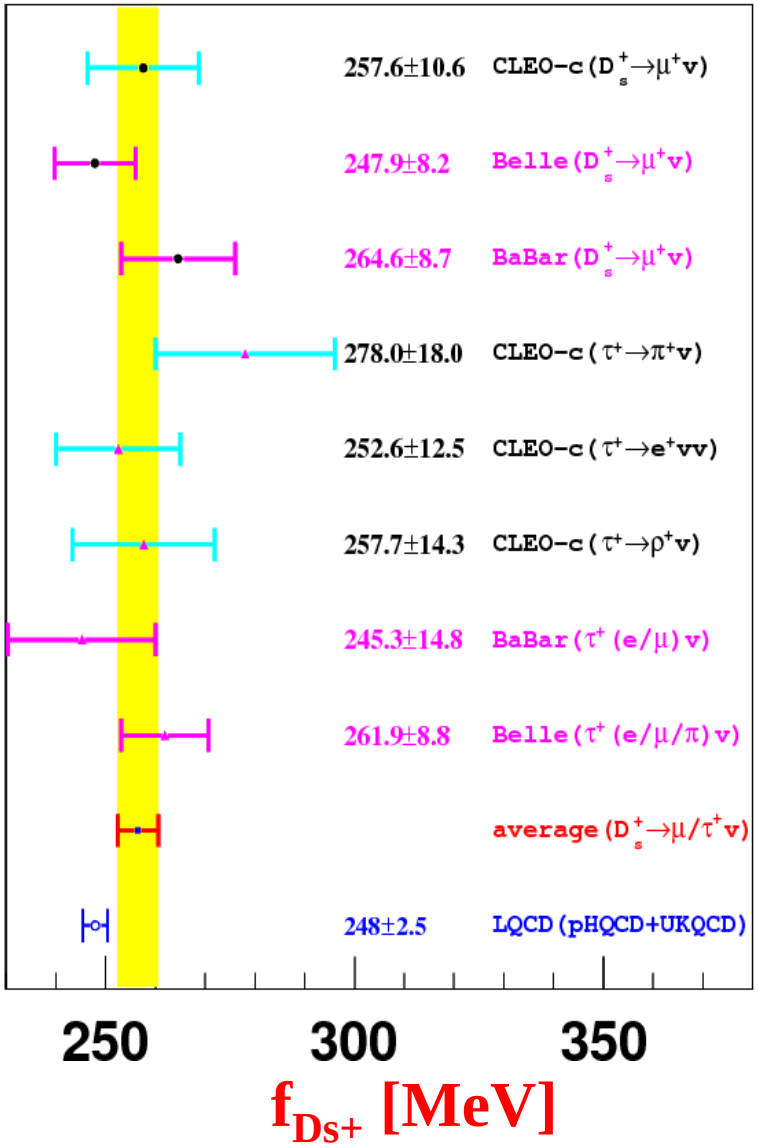
$$f_{D_s^+} = (255.5 \pm 4.2 \pm 5.1)\ {\rm MeV}$$

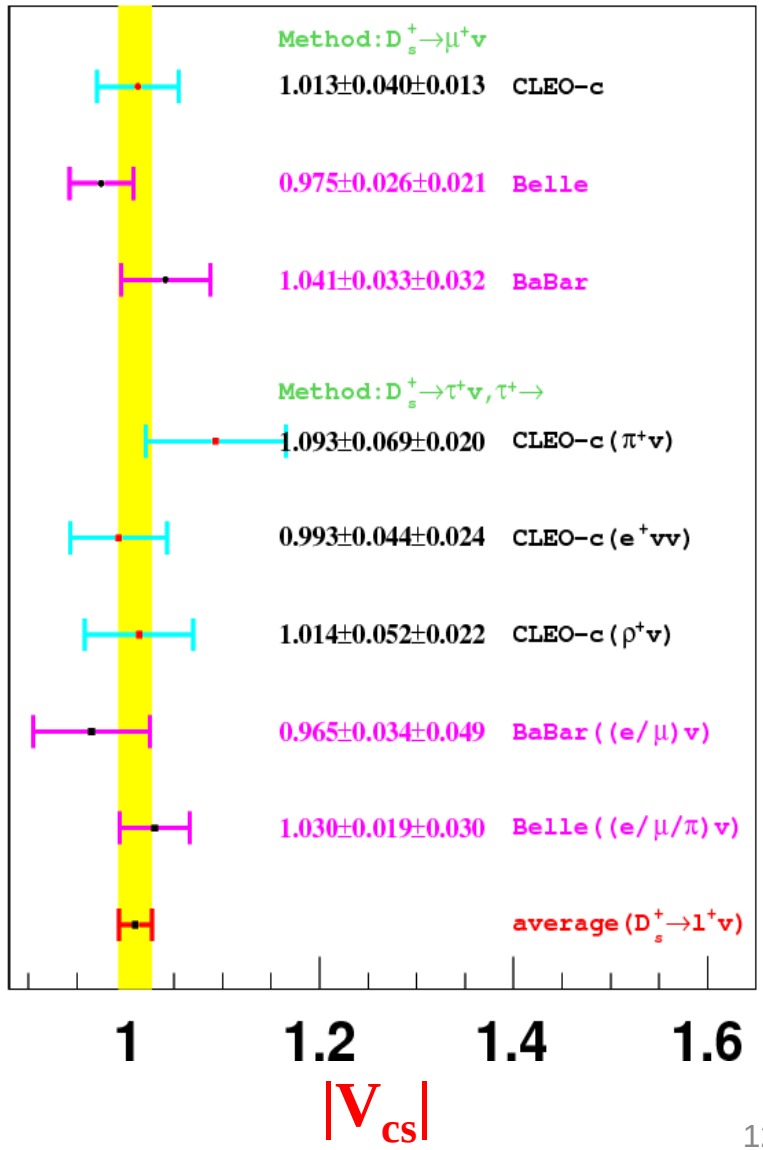
Comparisons of $B[D_s^+ \to \mu(\tau)^+\nu]$



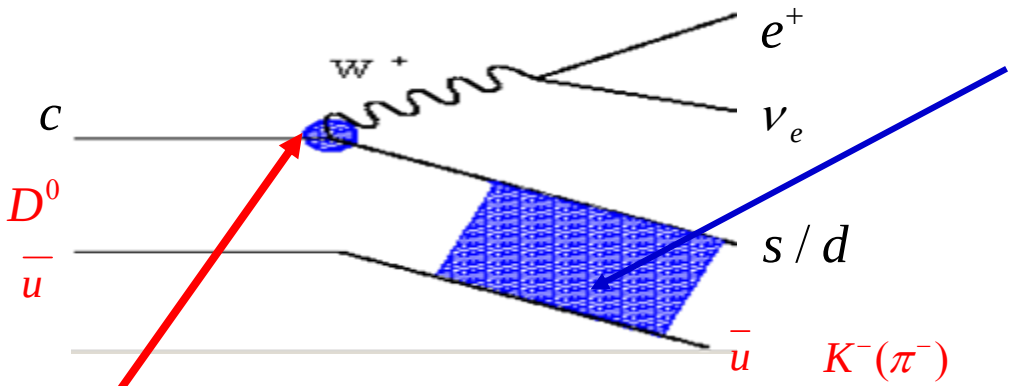


Comparisons of f_{Ds+} and $|V_{cs}|$





$f^{+}_{K(\pi)}(q^2)$ and $|V_{cs(d)}|$ from $D^0 \rightarrow K(\pi)^- e^+ \nu$



➢ **$|V_{cs(d)}|$ decirbes the mixing between the quark mass eigenstates and the the weak eigenstates.**

$$\frac{\Delta\Gamma(D^0 \rightarrow K(\pi)^- e^+ \upsilon_e)}{dq^2} = \frac{G_F^2 |V_{cs(d)}|^2}{24\pi^3} p^3 \left| f_+^2(q^2) \right|^2$$

$$q^2 = (p_{D^0} - p_{\pi^-})^2 = (p_{e^+} + p_{\nu})^2$$

➢ **The strong interaction effects between the two quarks within D^0 meson is simply factorized into the form factor $f^{+}_{K(\pi)}(q^2)$.**

– **Single pole form**

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

– **Modified pole model**

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

– **ISGW2 model**

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

– **Series expansion model**

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

$f^{+}_{K(\pi)}(q^2)$ and $|V_{cs(d)}|$ from $D^0 \rightarrow K(\pi)^- e^+ \nu$

- In experiment, studies of $D^0 \rightarrow K(\pi)^- e^+ \nu$ can provide
  - Hadronic form factors of hadronic current $f^{+}_{K(\pi)}(q^2)$
  - Recent HPQCD calculation of the $f_{K(\pi)}{}^{+}(0)$ for $D \rightarrow \pi(K) e^+ \nu$ achieve 4.5(2.5)% precision, thus provide chance to better measure quark mixing matrix element $|V_{cs(d)}|$.
- More precise measurements of $f^{+}_{K(\pi)}(q^2)$ can be used to validate the LQCD calculations on $f^{+}_{K(\pi)}(q^2)$, thus indirectly help to improve measurement precision in B meson studies.
- More accurate measurements of $|V_{cs(d)}|$ can precisely test the SM and search for the New Physics beyond the SM.

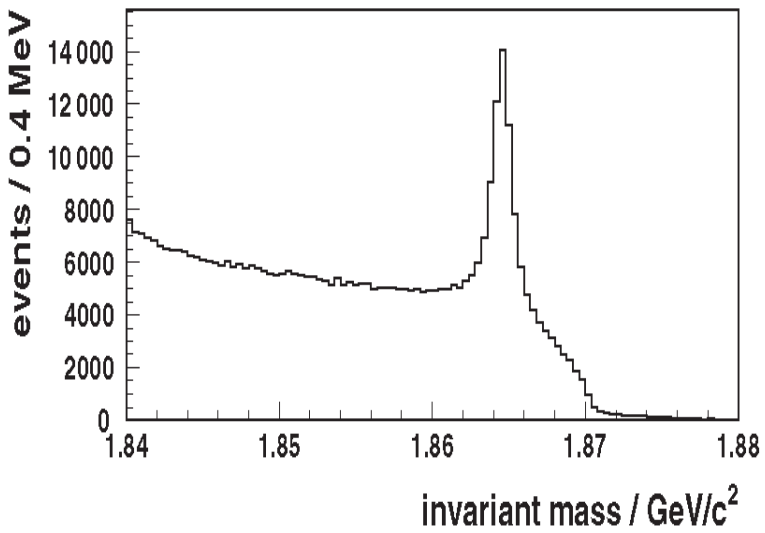
Previous studies of $D^0 \to K(\pi)^- e^+ \nu$ at BELLE

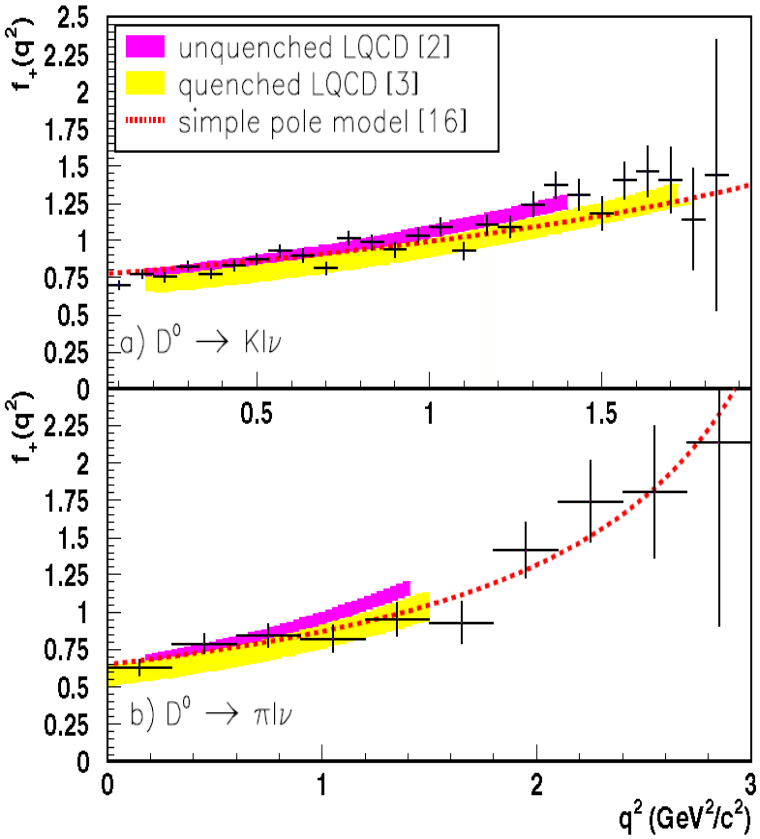
$$e^+e^- \to D^{(*)}_{\rm tag} D^{*-}_{\rm sig} X \,,\; D^{*-}_{\rm sig} \to \overline{D}{}^0_{\rm sig}\pi^- \,,\; X = \pi^\pm \text{ or } \pi^\pm \text{or} K^\pm$$

282 fb^{-1} data @ 10.58 GeV

PRL97(2006)061804

$$N_{\overline{D}{}^0_{\rm tag}} = 56461 \pm 309 \pm 830$$





$$B_{D^0 \to K^- e^+ \nu} = (3.45 \pm 0.10 \pm 0.19)\%$$

$$B_{D^0 \to \pi^- e^+ \nu} = (0.279 \pm 0.027 \pm 0.016)\%$$

$$B_{D^0 \to K^- \mu^+ \nu} = (3.45 \pm 0.10 \pm 0.21)\%$$

$$B_{D^0 \to \pi^- \mu^+ \nu} = (0.231 \pm 0.026 \pm 0.019)\%$$

$$f_+^K(0) = 0.695 \pm 0.007 \pm 0.022$$

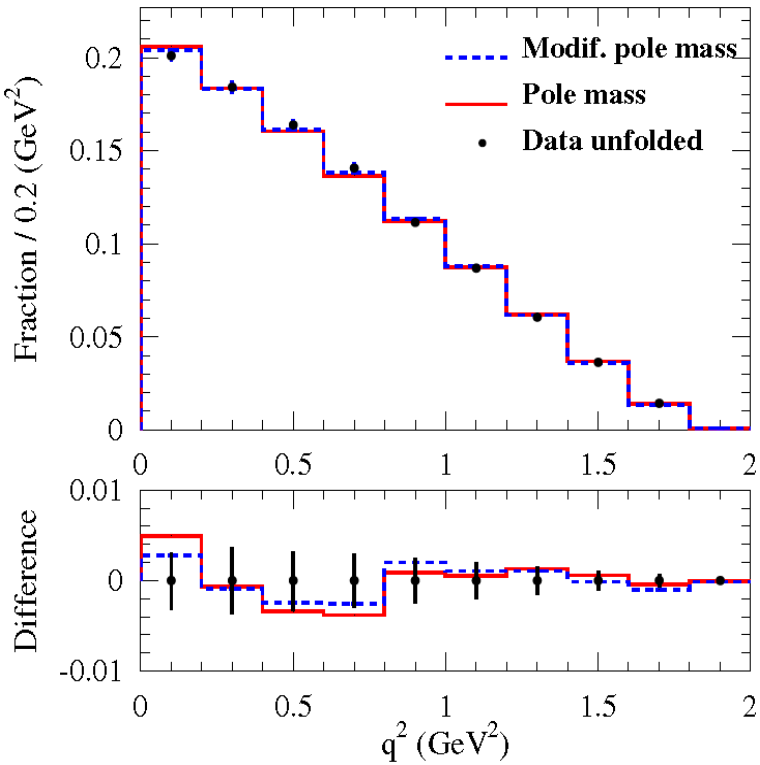
$$f_+^\pi(0) = 0.624 \pm 0.020 \pm 0.030$$

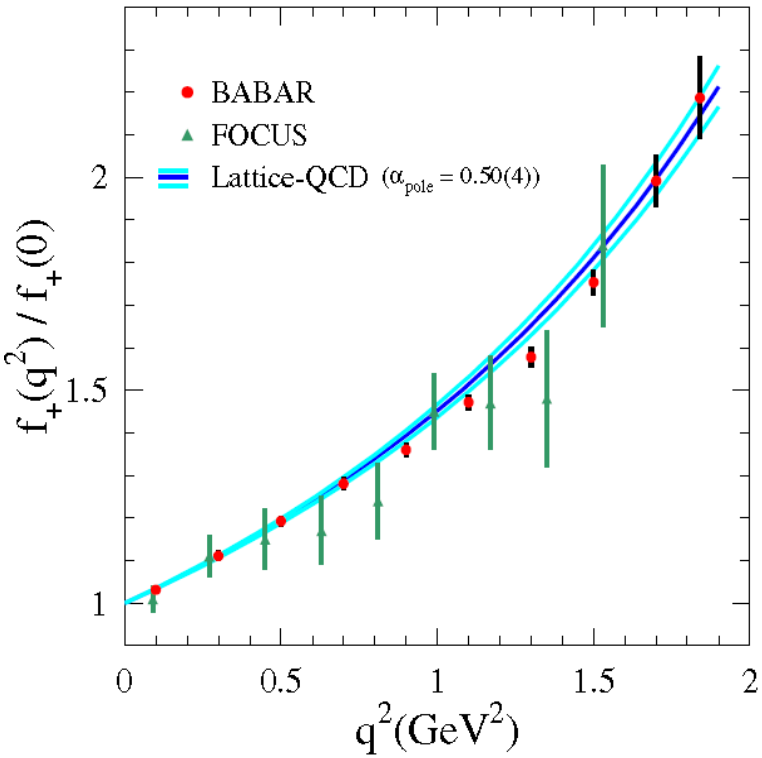
Previous studies of $D^0 \to K^- e^+ \nu$ at BaBar

$e^+e^- \to c\bar{c}, D^{*+} \to D^0\pi^+, D^0 \to K^- e^+ \nu(\gamma)$

75 fb^{-1} data @ 10.58 GeV

PRD76(2007)052005





$$R = \frac{B_{D^0 \to K^- e^+ \nu}}{B_{D^0 \to K^- \pi^+}} = 0.9269 \pm 0.0072 \pm 0.0119$$

Using $B^{PDG06}_{D^0 \to K^- \pi^+} = (3.80 \pm 0.07)\%$

$$B[D^0 \to K^- e^+ \nu] = (3.522 \pm 0.027 \pm 0.045 \pm 0.065)\%$$

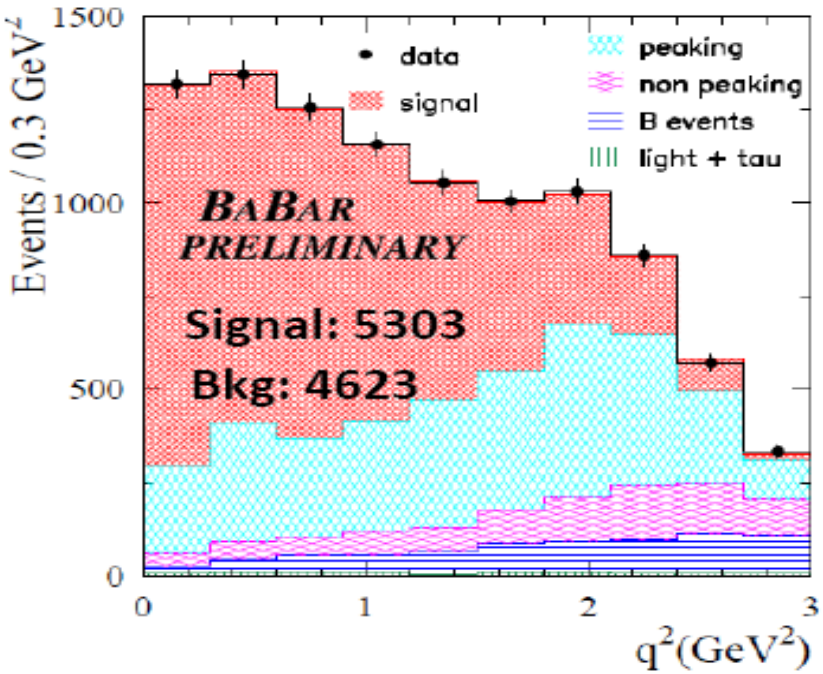
$$f_+^K(0) = 0.727 \pm 0.007 \pm 0.005 \pm 0.007$$

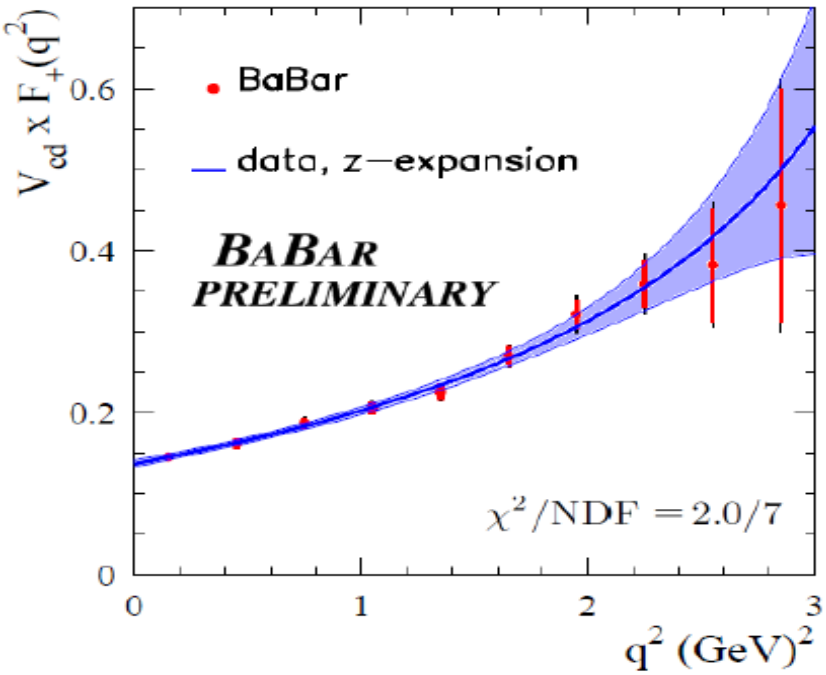
Preliminary results of $D^0 \to \pi^- e^+ \nu$ at BaBar

$e^+e^- \to c\bar{c}, D^{*+} \to D^0\pi^+, D^0 \to \pi^- e^+ \nu(\gamma)$

347.2 fb^{-1} data @ 10.58 GeV

Arantza Oyanguren talk presented at ICHEP2014





$$R = \frac{B_{D^0 \to \pi^- e^+ \nu}}{B_{D^0 \to K^- \pi^+}} = 0.0702 \pm 0.0017 \pm 0.0023$$

$$\xrightarrow{B^{\mathrm{PDG14}}_{D^0 \to K^- \pi^+}} \quad B[D^0 \to \pi^- e^+ \nu] = (2.770 \pm 0.068 \pm 0.092 \pm 0.037) \times 10^{-3}$$

$$f_+^K(0)\,|V_{cd}| = 0.1374 \pm 0.0038 \pm 0.0022 \pm 0.0009$$

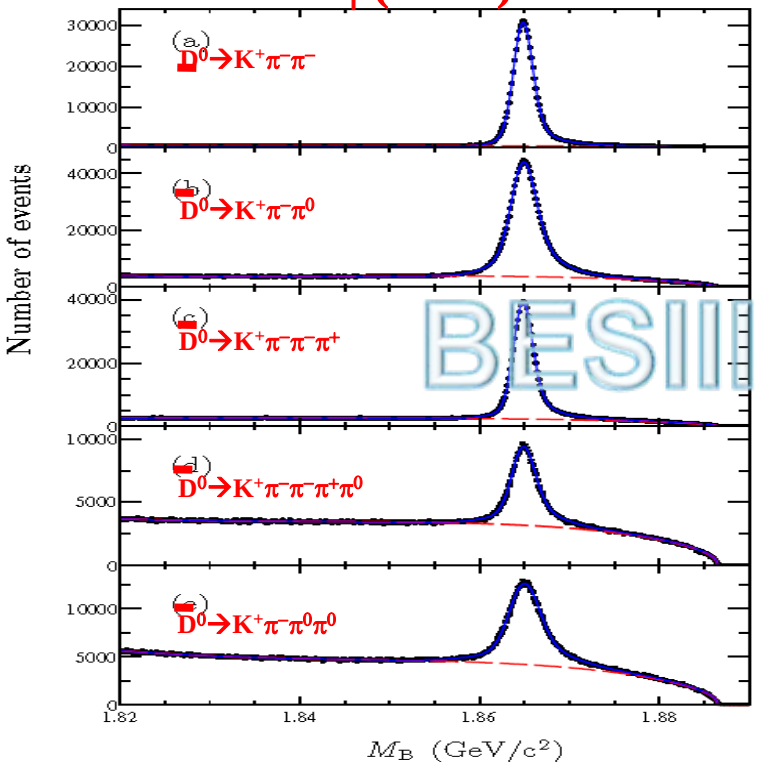
$$|V_{cd}| = 0.2252 \pm 0.0009 \quad \longrightarrow \quad f_+^\pi(0) = 0.610 \pm 0.017 \pm 0.010 \pm 0.005$$

$$f_+^\pi(0) = 0.666 \pm 0.020 \pm 0.021 \quad \longrightarrow \quad |V_{cd}| = 0.206 \pm 0.007 \pm 0.009_{\mathrm{LQCD}}$$

Studies of $D^0 \to K(\pi)^- e^+ \nu$ at BESIII

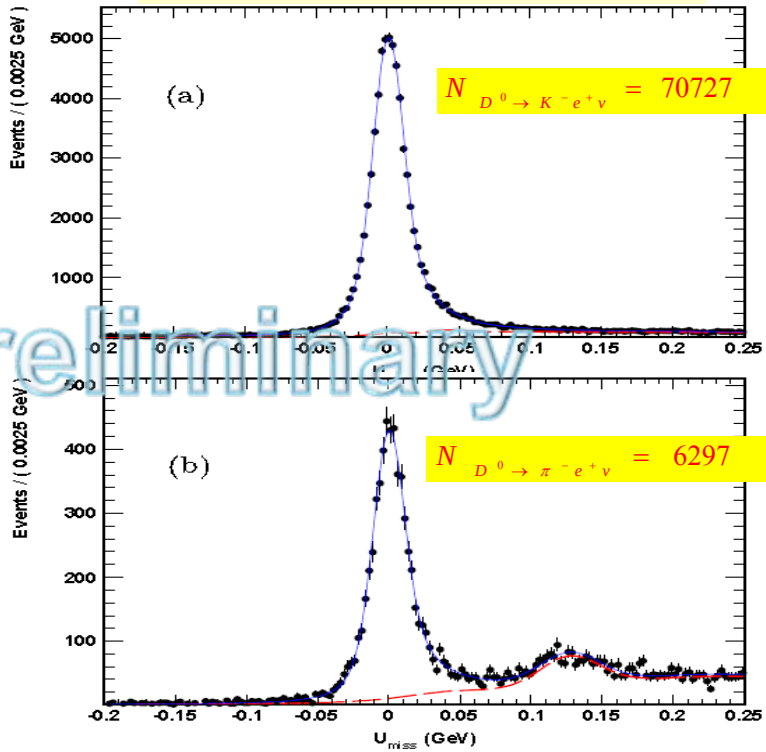
New results based on 2.92 fb^{-1} data supersede those preliminary results presented at CHARM2012 which was based on ~1/3 data.

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



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

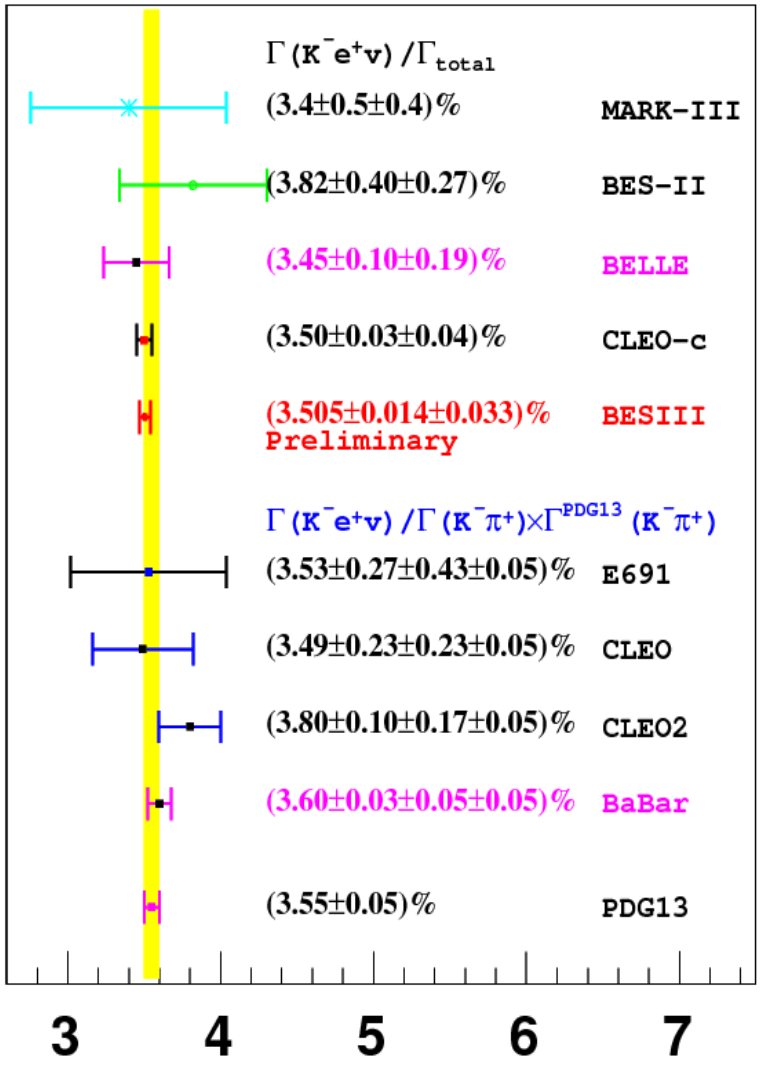
2.917fb^{-1} data@3.773 GeV



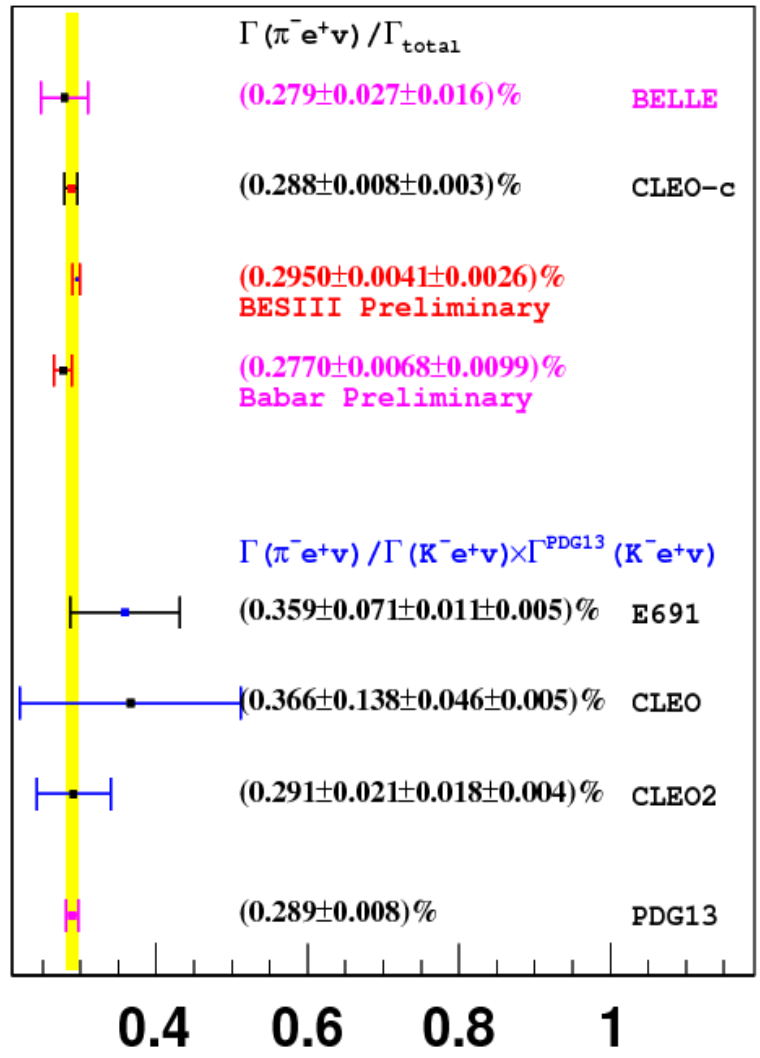
$B_{D^0 \to K^- e^+ \nu} = (3.505 \pm 0.014 \pm 0.033)\%$

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

Comparisons of $B[D^0 \to K(\pi)^- e^+ \nu]$

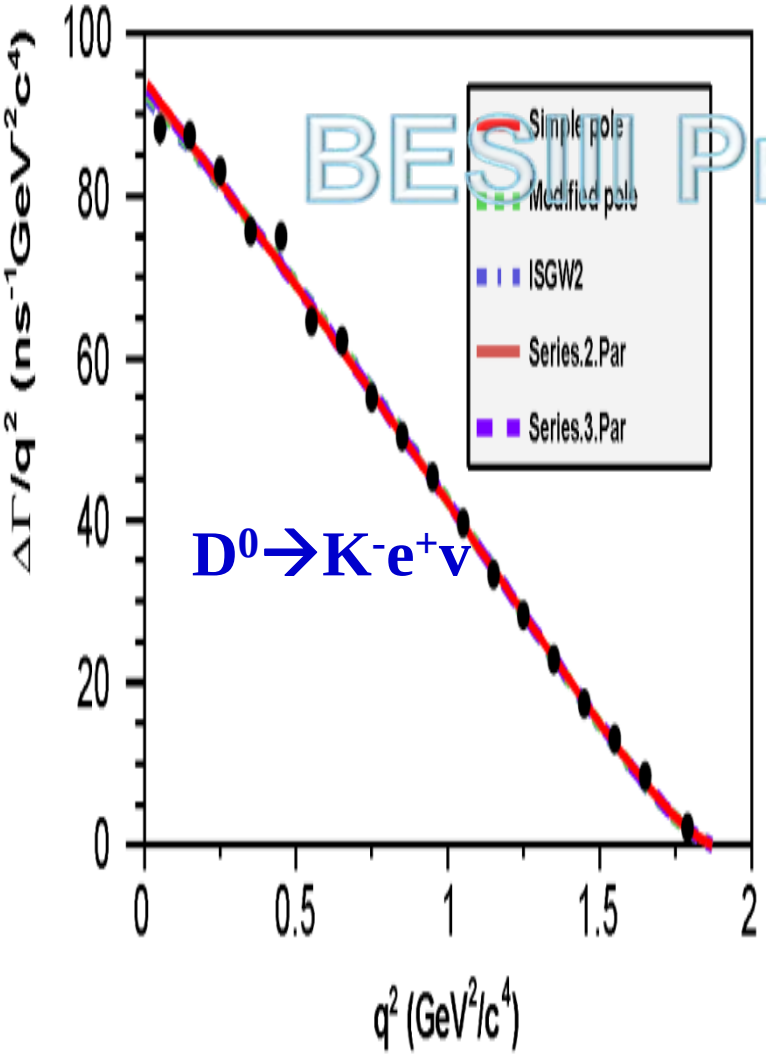


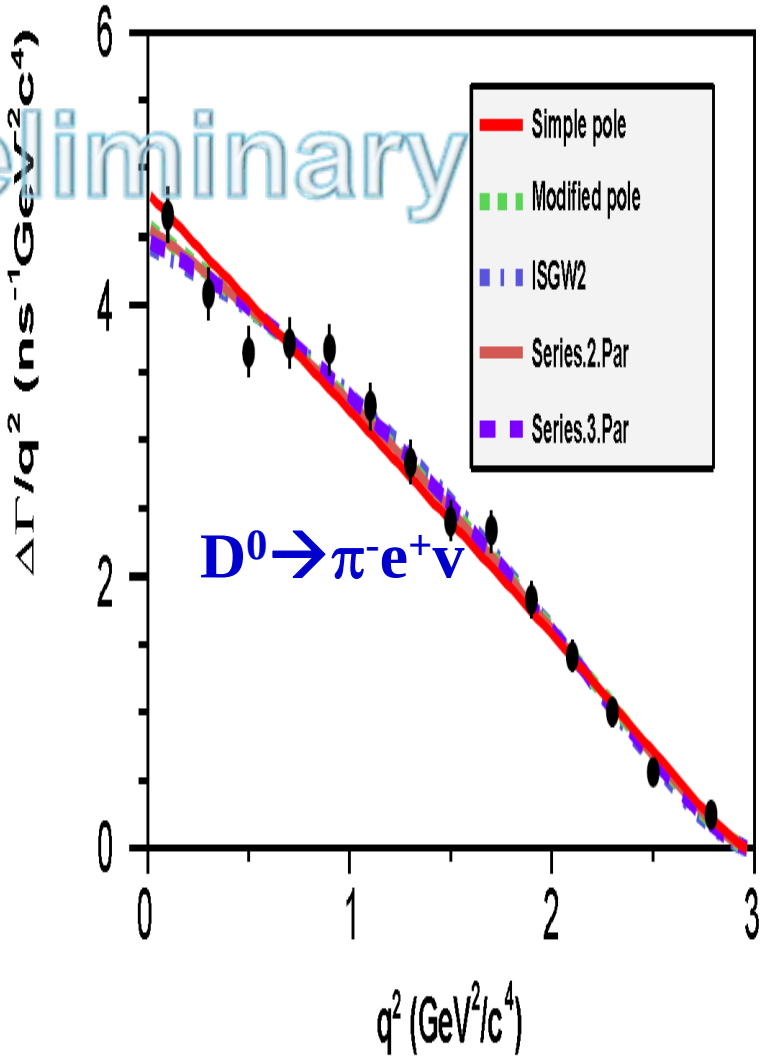
$B[D^0 \to K^- e^+ \nu]$



$B[D^0 \to \pi^- e^+ \nu]$

Fits to $\Delta\Gamma[D^0 \rightarrow K(\pi)^- e^+ \nu]$

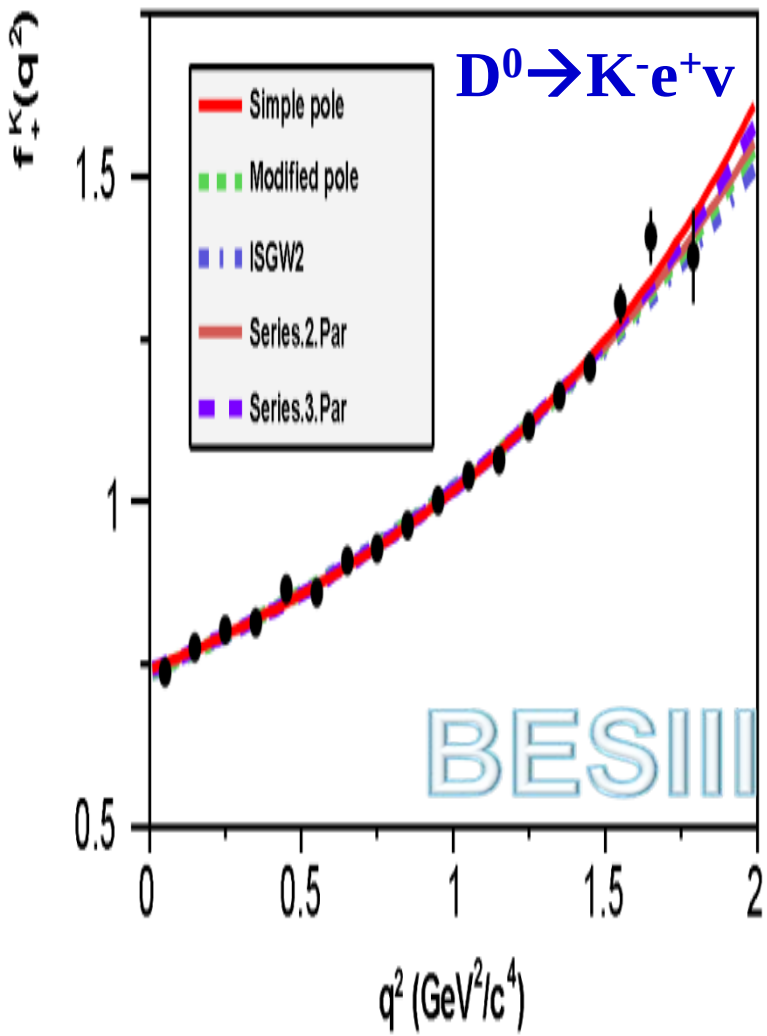


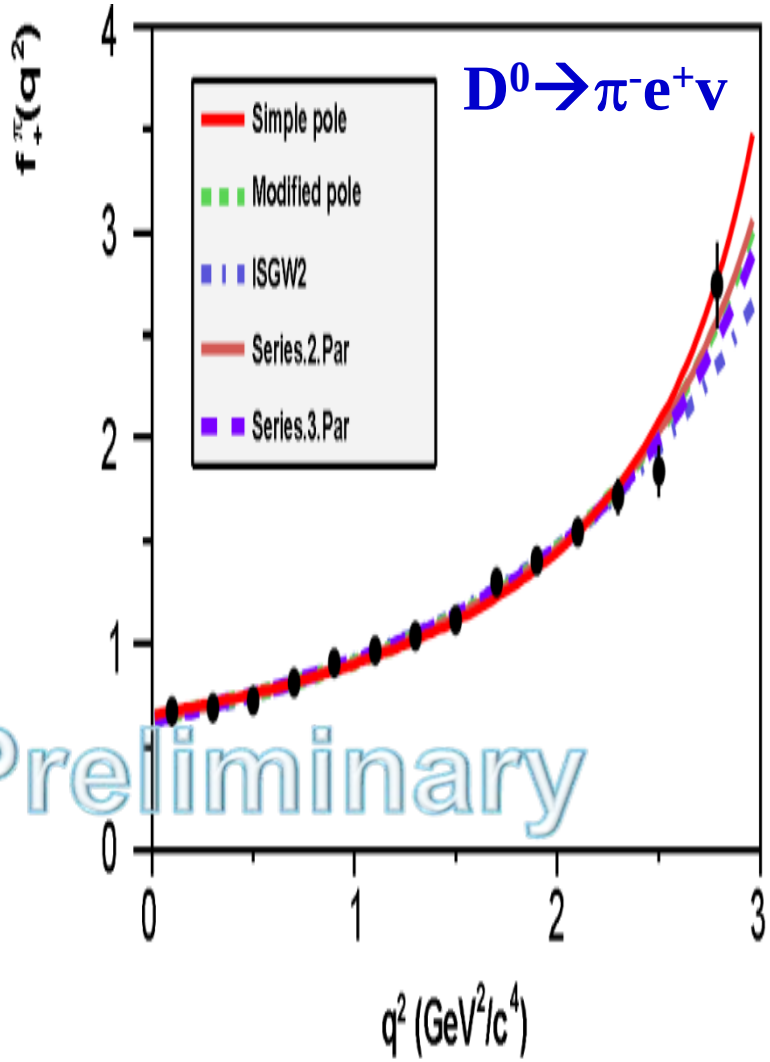


Extracted Parameters of Form Factors

		$D^0 \to K^- e^+ \nu$		$D^0 \to \pi^- e^+ \nu$
Simple Pole	$f_K^+(0)\|V_{cs}\|$	0.7209±0.0022±0.0033	$f_\pi^+(0)\|V_{cd}\|$	0.1475±0.0014±0.0005
	M_{pole}	1.9207±0.0103±0.0069	M_{pole}	1.9114±0.0118±0.0038
Mod. Pole	$f_K^+(0)\|V_{cs}\|$	0.7163±0.0024±0.0034	$f_\pi^+(0)\|V_{cd}\|$	0.1437±0.0017±0.0008
	α	0.3088±0.0195±0.0129	α	0.2794±0.0345±0.0113
ISGW2	$f_K^+(0)\|V_{cs}\|$	0.7139±0.0023±0.0034	$f_\pi^+(0)\|V_{cd}\|$	0.1415±0.0016±0.0006
	r_{ISGW2}	1.6000±0.0141±0.0091	r_{ISGW2}	2.0688±0.0394±0.0124
Series.2.Par	$f_K^+(0)\|V_{cs}\|$	0.7172±0.0025±0.0035	$f_\pi^+(0)\|V_{cd}\|$	0.1435±0.0018±0.0009
	r_1	-2.2278±0.0864±0.0575	r_1	-2.0365±0.0807±0.0260
Series.3.Par	$f_K^+(0)\|V_{cs}\|$	0.7196±0.0035±0.0041	$f_\pi^+(0)\|V_{cd}\|$	0.1420±0.0024±0.0010
	r_1	-2.3331±0.1587±0.0804	r_1	-1.8434±0.2212±0.0690
	r_2	3.4223±3.9090±2.4092	r_2	-1.3871±1.4615±0.4677

Projections on Form Factors $f^{K(\pi)}_{+}(q^2)$



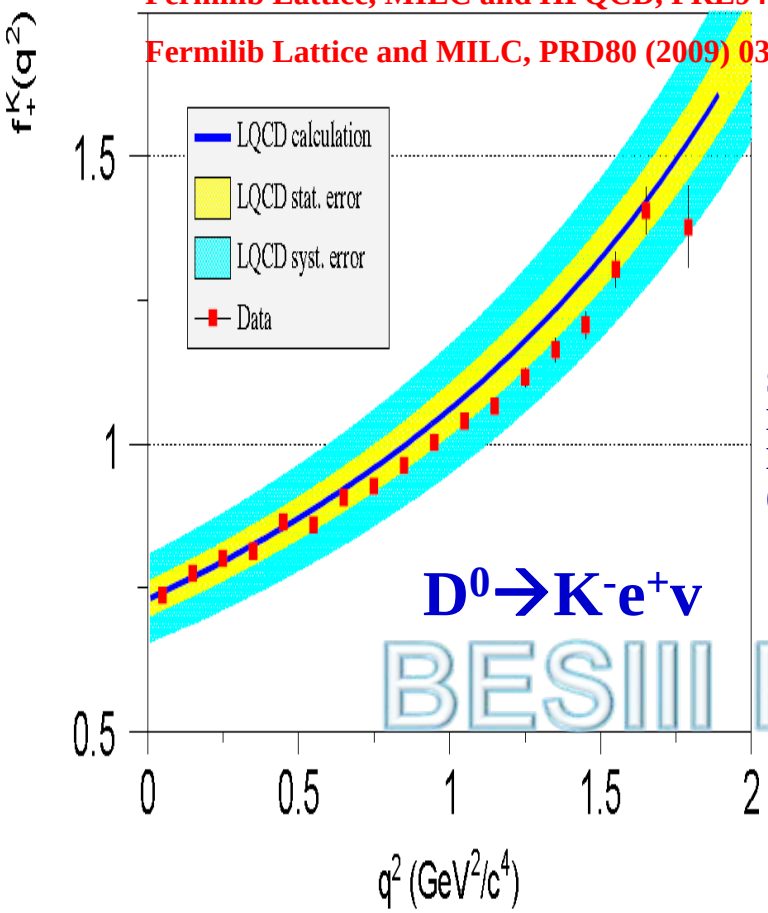


Comparisons of Form Factors

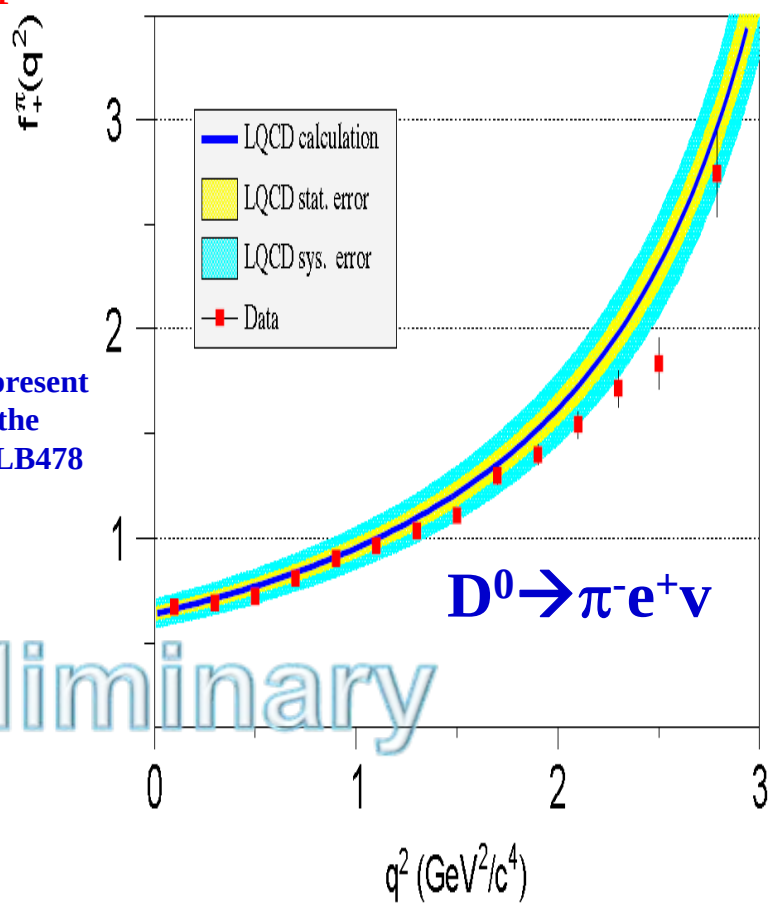
Experimental data calibrate LQCD calculation

Fermilib Lattice, MILC and HPQCD, PRL94 (2005) 011601

Fermilib Lattice and MILC, PRD80 (2009) 034026

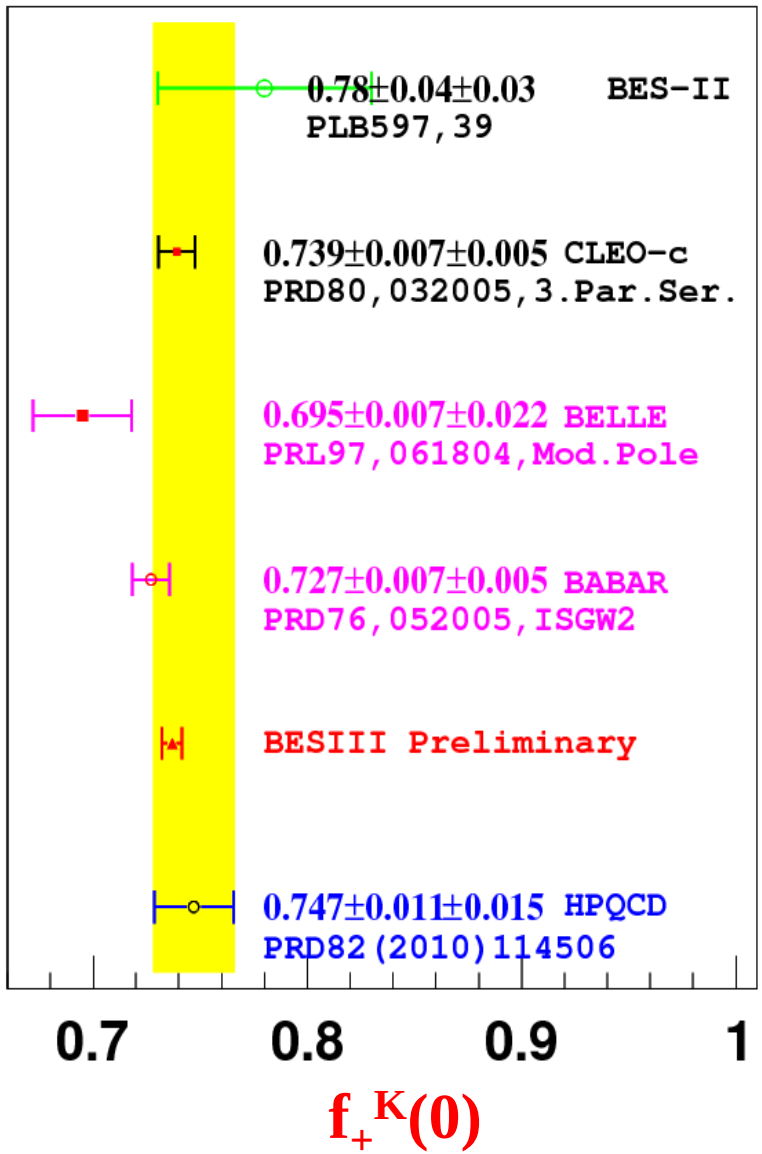


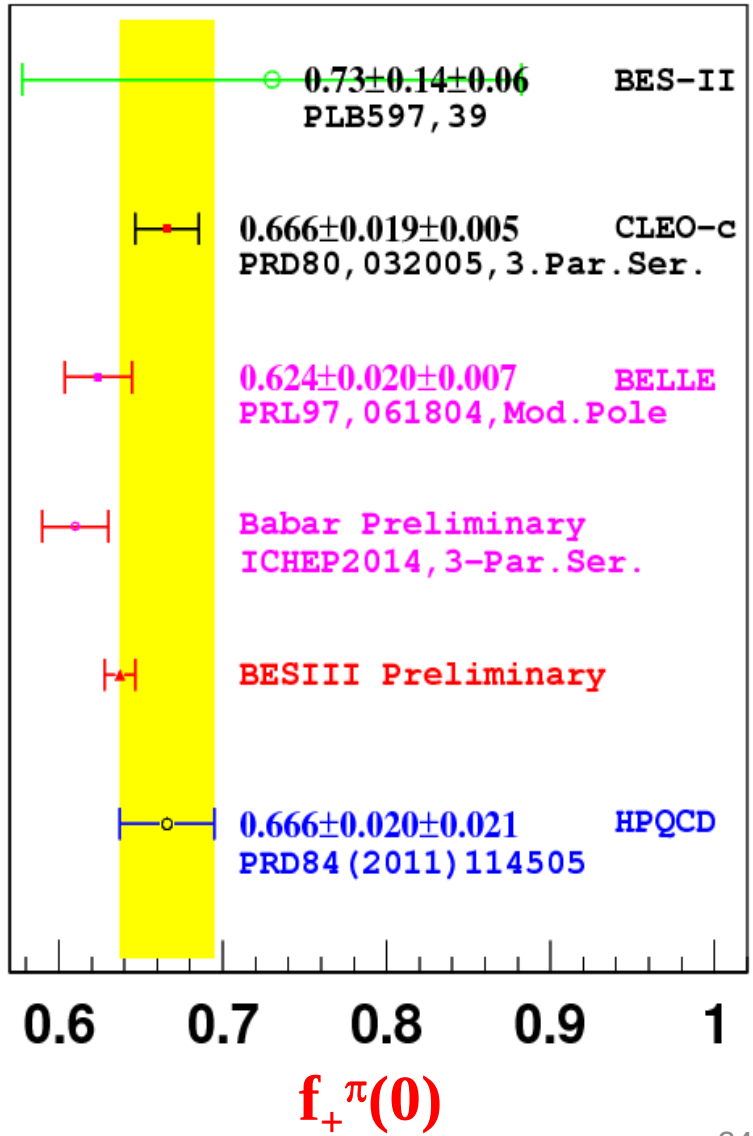
Solid lines represent LQCD fits to the BK model, PLB478 (2000)417



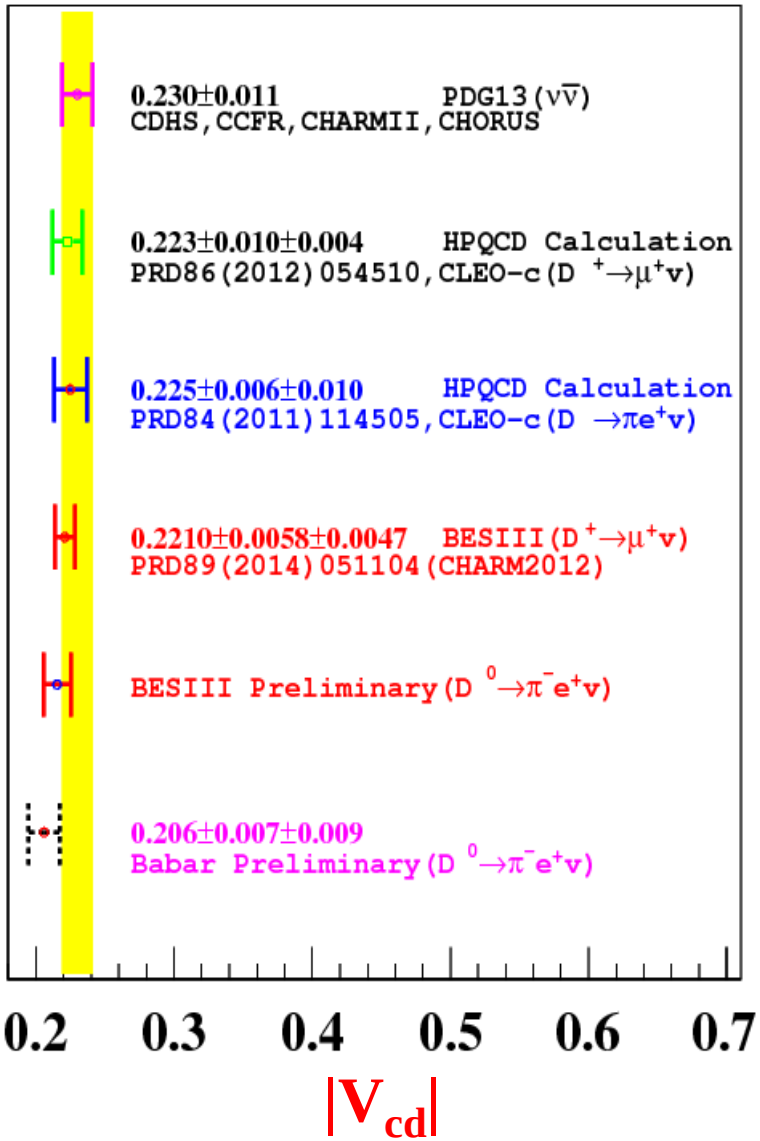
BESIII Preliminary

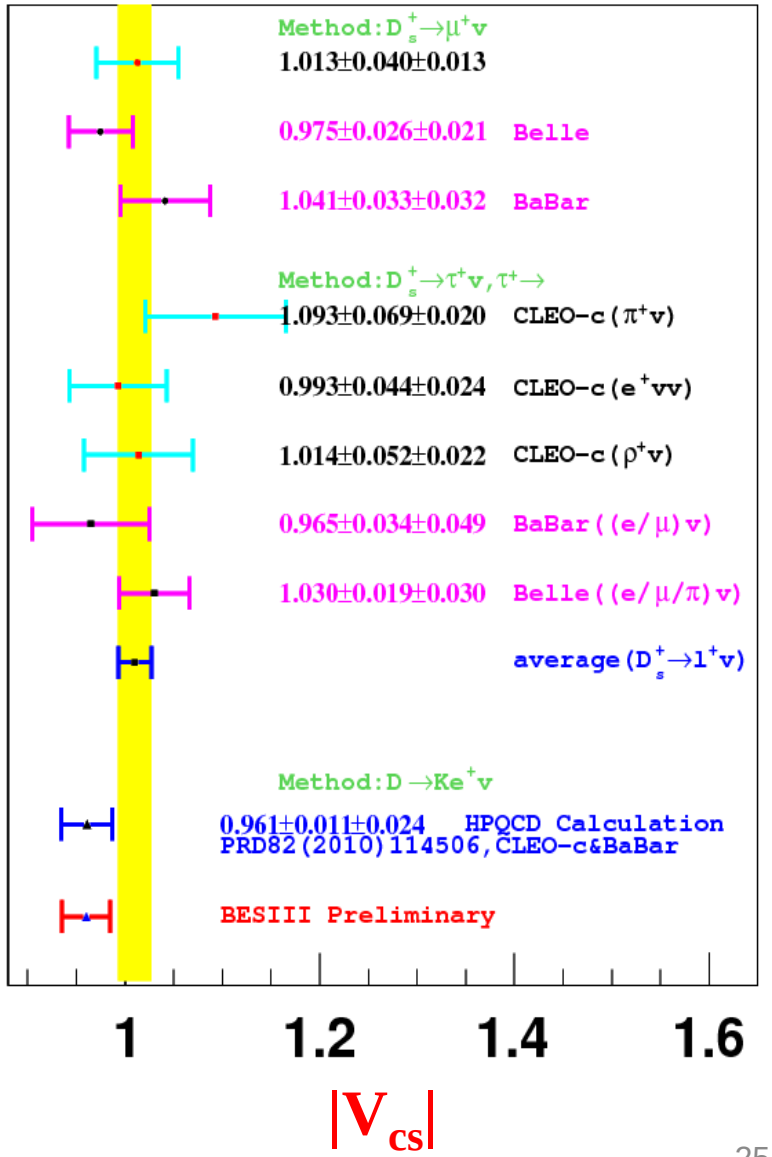
Calculations or measurements of $f_+^{K(\pi)}(0)$





Calculations or measurements of $|V_{cd(s)}|$





Summary

- **Precision studies of purely and semi-leptonic decays of $D_{(s)}$ mesons had been made by BaBar, BELLE and CLEO-c in the past several years.**

- **Recently, BESIII have studied the purely leptonic decay $D^+ \to \mu^+ \nu$ and the semi-leptonic decays of $D^0 \to K(\pi)^- e^+ \nu$ with better precisions.**

- **More new BESIII results in the near future:**
  - **2.92 fb^{-1} data@3.773 GeV in hand**

    $D^- \to K(\pi)^0 e^+ \nu$, $f^+_{K(\pi)}(q^2)$ and $|V_{cs(d)}|$

    $D^+ \to K^- \pi^+ e^+ \nu$ and form factors ……

- **3 fb^{-1} data@4.17 GeV to be taken in 2016**
  - **Uncertainty of LQCD calculation on f_{Ds+} reaches 1.0%.**

    Measurement of f_{Ds+} and $|V_{cs}|$ by $D_s^+ \to l^+\nu$ is limited by data.

    $D_s^+ \to \mu(\tau)^+\nu$, f_{Ds+} and $|V_{cs}|$
- **More 10 fb^{-1} data@3.773 GeV?**
  - **Uncertainty of LQCD calculation on $f_{K(\pi)}(0)$ reaches 2.5(4.5)%.**

    Measurement of $|V_{cs(d)}|$ by $D \to K(\pi)e^+\nu$ is still limited by theory.

    $D^0 \to \pi^- e^+\nu$, $D \to \pi$ form factor is limited by data
  - **Uncertainty of LQCD calculation on f_{D+} reaches 1.7%.**

    Measurement of f_{D+} and $|V_{cd}|$ by $D^+ \to \mu^+\nu$ is limited by data.

    $D^+ \to \mu^+\nu$, decay constant, $|V_{cd}|$
  - **……**

Thank you!