Experimental measurements of $D_{(s)}$ semileptonic branching fractions

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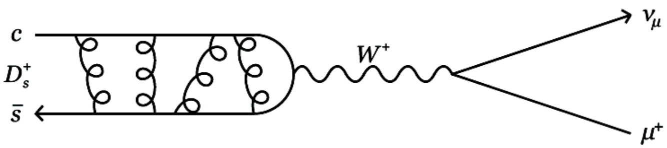
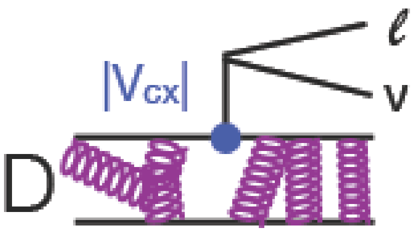
Nov. 29, 2016
9th International Workshop on the CKM Unitarity Triangle
TIFR, Mumbai

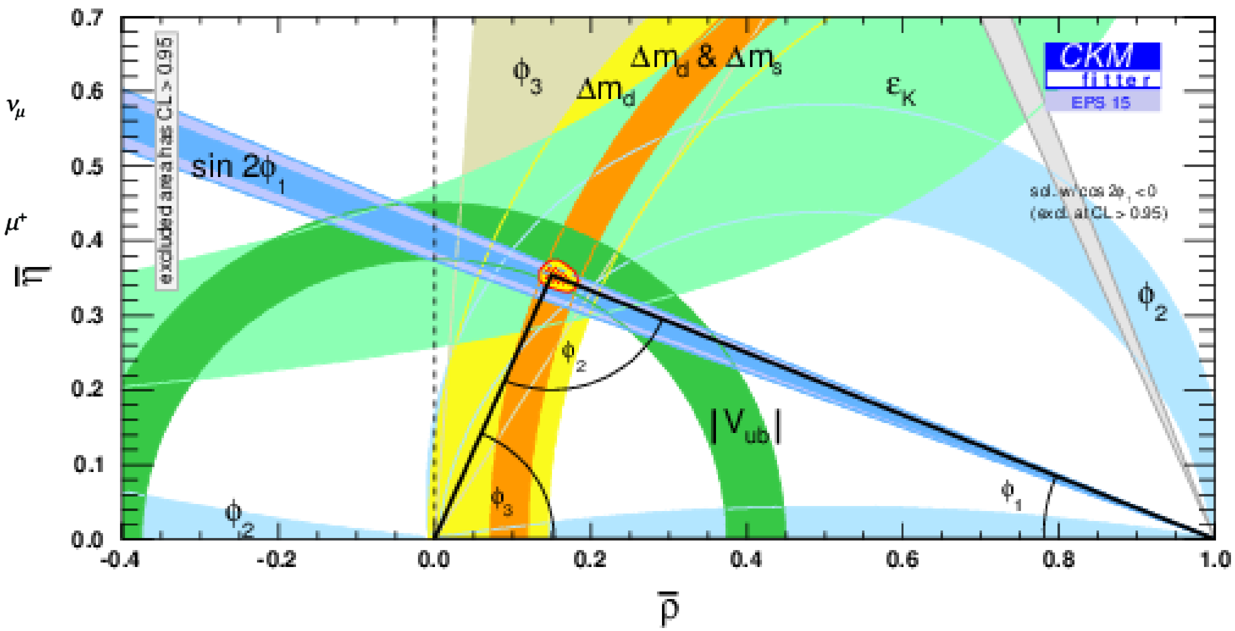
Outline

- Introduction
- Selected recent results in
  - $D \to P l \nu$ measurements: BF & Form factor fit $\Rightarrow f_+^{D\to\pi}(0), f_+^{D\to K}(0)$
  - $D \to V l \nu$ measurements
  - Rare/Forbidden decay search
    - $D \to \omega e\nu$ and $D \to \phi e\nu$ (new)
    - $D \to a_0(980) e\nu$ (new)
    - $D^+ \to D^0 e^+ \nu_e$ (new)
  - $D_s^+ \to \phi e^+\nu, \eta^{(\prime)} e^+\nu, f_0 e^+\nu$ (new)
- Summary

Introduction

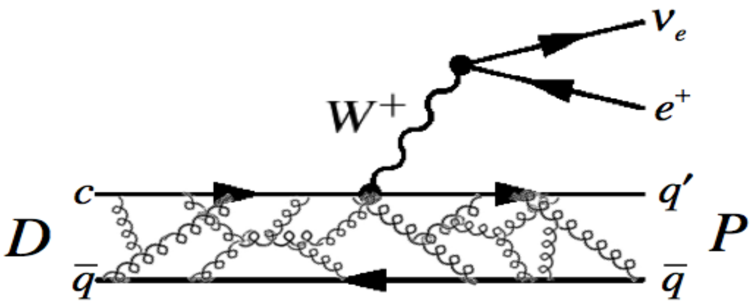






- ✦ **Windows on weak and strong physics**
- ✦ **Weak decay ⇒ theoretically clean**
- ✦ **Over-constrain CKM and search for New Physics**
- ✦ **Strong interaction ⇒ test Lattice QCD**

Semileptonic decays



$$\frac{d\Gamma(D \to K(p)e\nu)}{dq^2} = \frac{G_F^2 \left|V_{cs(d)}\right|^2 P_{K(p)}^3}{24\pi^3} \left|f_+(q^2)\right|^2$$

$q^2 = (p_l + p_\nu)^2 \Rightarrow$ **M^2_{inv} of lepton pair**

- $D_{(s)} \to P\, l\, \nu$
  - Measure $|V_{cx}|$ x FF
  - Charm physics: CKM-unitarity $\Rightarrow |V_{cx}|$, extract FF, test LQCD; Or input LQCD FF to test CKM-unitarity
  - B physics: FF in D semileptonic decays $\Rightarrow$ Validate and Calibrate LQCD calculation $\Rightarrow$ improve $|V_{ub}|$ measurement $\Rightarrow$ test CKM-unitarity
- $D_{(s)} \to V\, l\, \nu$
  - Extract more parameters, test pole dominance model
  - Study S-wave in $D \to K\pi\, l\, \nu$, $D \to KK\, l\, \nu$, $D \to \pi\pi\, l\, \nu$
- $D_{(s)} \to$ Rare/forbidden
  - Search for new physics
  - Study D_s structure and long-distant effect

Charm facilities

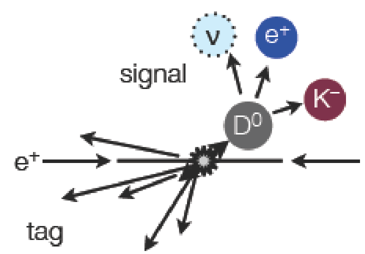
- **Hadron colliders (Huge cross-section, energy boost)**
  - **Tevetron (CDF, D0)**
  - **LHC (LHCb, CMS, ATLAS)**
- **e^+e^- Colliders (more kinematic constrains, clean environment, ~100% trigger efficiency)**
  - **B-factories (Belle, BaBar)**
    - **Prompt D* decays & B decays**
    - **High Luminosity ⇒ double tag technique possible**
  - **Threshold production (CLEOc, BESIII)**
    - **Can not compete in statistics with Hadron colliders & B-factories!**
    - **Only Charm hadron pairs, no extra CM Energy for pions**
    - **Quantum Correlations (QC) and CP-tagging are unique**
    - **Systematic uncertainties cancellations while applying double tag technique**

ν Recon. (Experimental challenges)

Commonly used techniques (Partial reconstruction)

- **Hadron Machines (FOCUS, LHCb)**
  - Applied for semileptonic decays
  - Secondary vertex ⇒ D direction
  - 4-momenta of charged decay product(s)
- **B-factories (BaBar, Belle)**
  - Get direction of the signal D from momentum conservation (sum of momentums of the rest decay products)

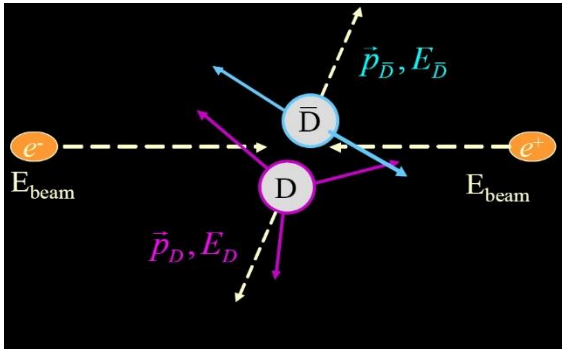
$$\vec{p}_D \propto - \sum \vec{p}_i$$



  - Fully reconstruct the tag side as D*X (better resolution but less statistics)
- **Charm @ threshold (see next slide)**

ν Recon. @charm threshold

- **CLEO-c, BESIII**
- **100% of beam energy converted to D pair (Clean environment, kinematic constrains ν Recon.)**
- ***D* generated in pair $\Rightarrow$ absolute Branching fractions**
- **At ψ(3770) charm production is $D^0\bar{D}^0$ and D^+D^-**
- **Fully reconstruct about 15% of *D* decays**



$$\Delta E = E_D - E_{\mathrm{Beam}}$$

$$M_{\mathrm{BC}} = \sqrt{E^2_{\mathrm{Beam}} - p^2_D}$$

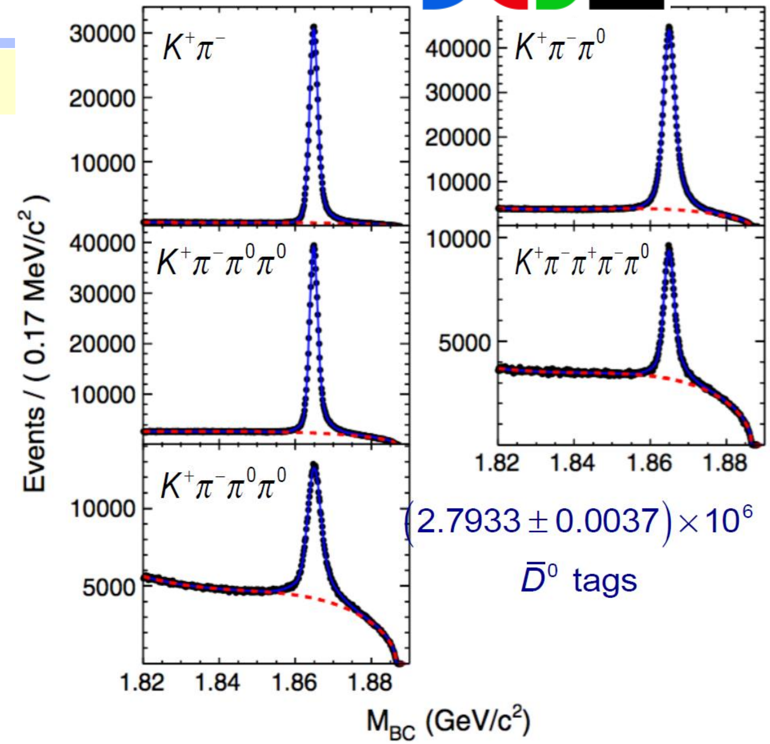
- **Double tag techniques: Hadronic tag on one side, on the other side for leptonic/semileptonic studies. Neutrino is reconstructed from missing energy and momentum (Double tag efficiency is high.)**

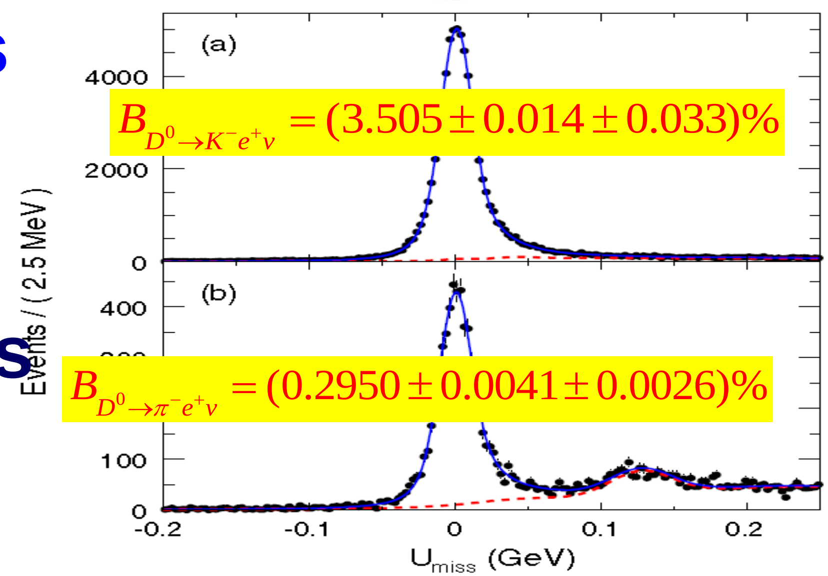
$D^0 \to Pe^+\nu$ ($P = K/\pi$)

PRD92(2015)072012

Data analysis

- **Full data samples: 2.93fb[-1] @3.773GeV**
- **5 tag modes**
- **Signal side: just positron and K/π, minimal extra energy**
- **Kinematic variable: U_{miss}**
- **Most precise measurements on FF and $|V_{cx}|$**
- **Branching fraction results are in excellent agreement with previous measurements and more precise**





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

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

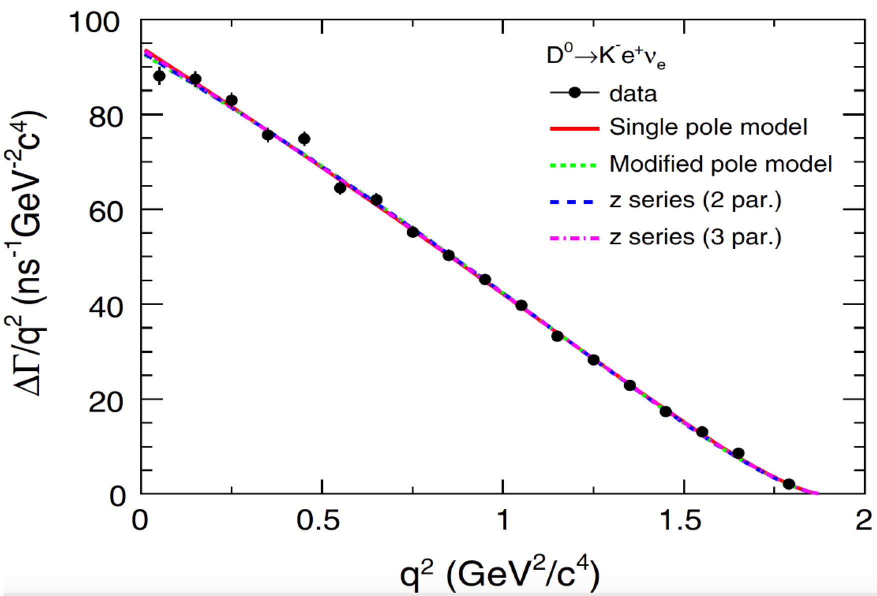
Differential partial width Fits

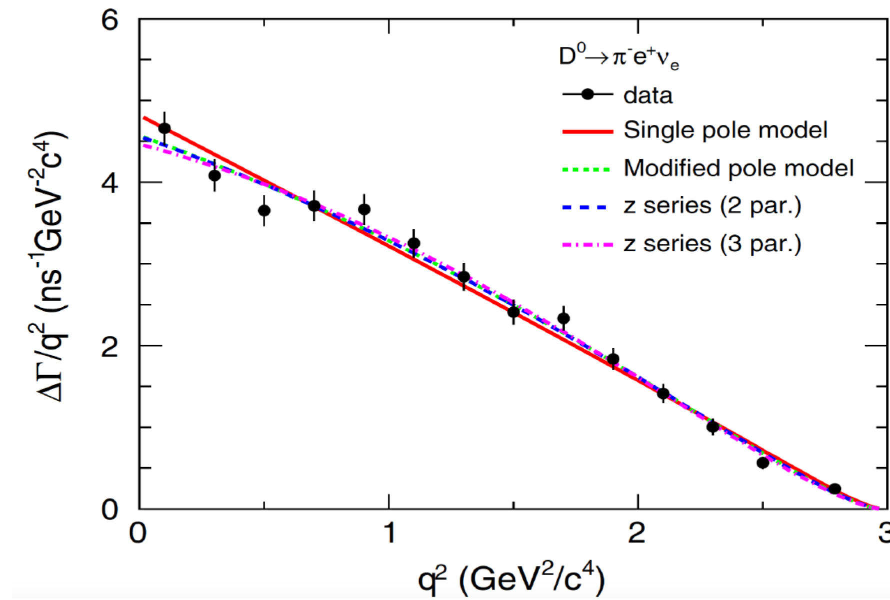
BESIII

- Fitted using different form factor models

PRD92(2015)072012

  - Simple pole model $f_+(q^2) = \frac{f_+(0)}{1 - q^2/m_{pole}^2}$
  - Modified pole model (Becirevic and Kaidalov, PLB 478, 417) $f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{pole}^2}\right)\left(1 - \alpha\frac{q^2}{m_{pole}^2}\right)}$
  - Series expansion (CLEO-c/BES III explored 2nd and 3rd order): $f_+(q^2) = \frac{1}{P(q^2)\,\phi(q^2,t_0)} \sum_{k=0}^{\infty} a_k(t_0)\,[z(q^2,t_0)]^k$





Using $f_+^{K(\pi)}(0)|V_{cs(d)}|$ from the 2-par. series fit and FFs from HPQCD:

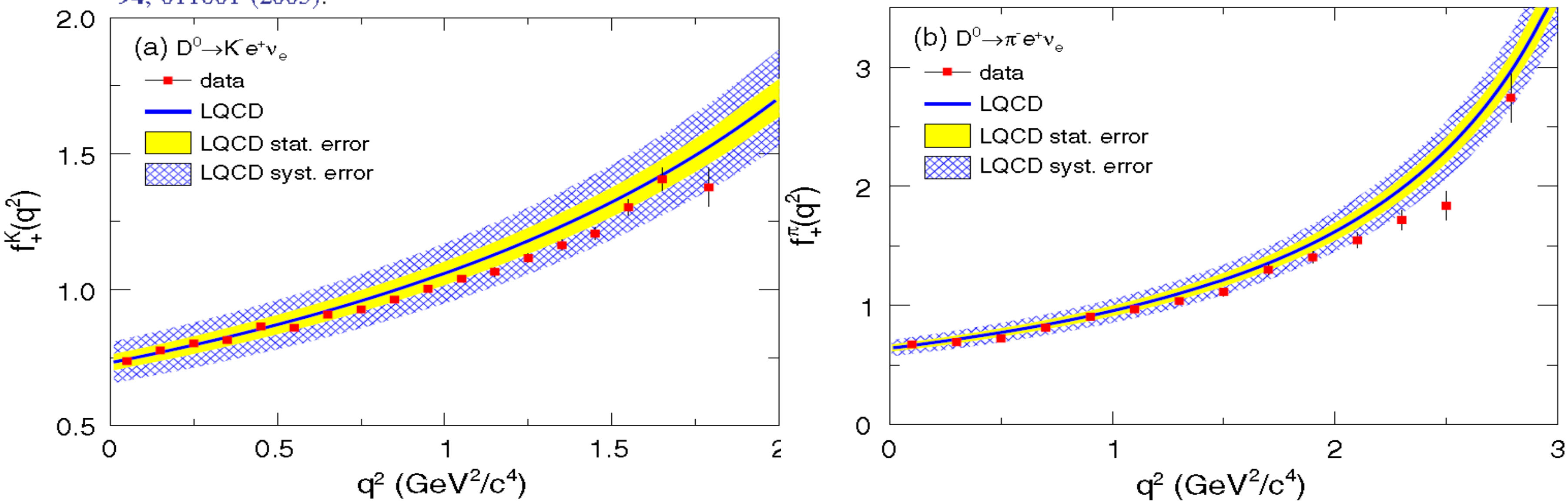
$$|V_{cs}| = 0.9601 \pm 0.0033 \pm 0.0047 \pm 0.0239$$

$$|V_{cd}| = 0.2155 \pm 0.0027 \pm 0.0014 \pm 0.0094$$

Measurement of Form Factors $f_+^{K(\pi)}(q^2)$

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

PRD92(2015)072012



- **The solid lines are the best fit to LQCD with modified pole model**
  - **Inner band is statistical uncertainty of the LQCD calculation**
  - **Outer band is stat.+syst. uncertainties of the LQCD calculation**
- **Slight tension between measurements and LQCD calculation at higher q^2 bins.**

The precision of these form factors is higher than that of the LQCD calculations by a factor of 3~4.

$f_+^{\pi}(0)/f_+^{K}(0)$ and $|V_{cd}|/|V_{cs}|$

PRD92(2015)072012

- **Experimentally**
  - $f_+^{\pi}(0)/f_+^{K}(0) = 0.8649 \pm 0.0112 \pm 0.0073$
- **Theoretically**
  - $f_+^{\pi}(0)/f_+^{K}(0) = 0.84 \pm 0.04$
  - LCSR: P. Ball, PLB 641, 50 (2006)

The ratio is in excellent agreement with the LCSR calculation.

- **BESIII**
  - $|V_{cd}|/|V_{cs}| = 0.238 \pm 0.004_{stat} \pm 0.002_{sys} \pm 0.011_{LCSR}$
- **Comparison of $|V_{cd}|/|V_{cs}|$ measurements**

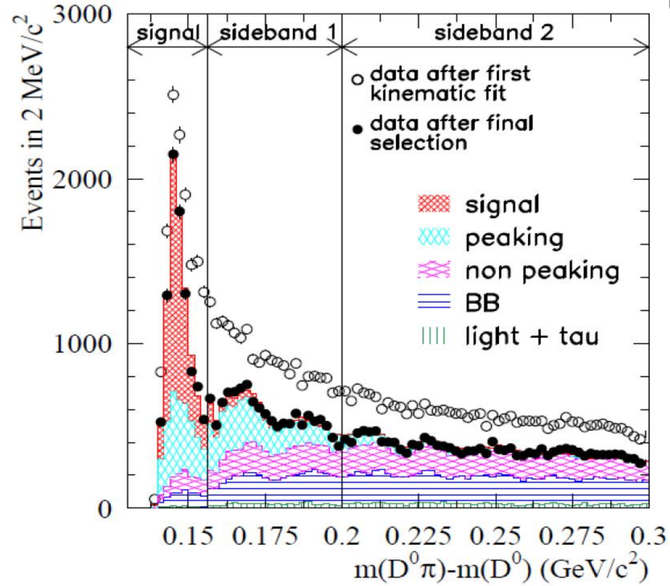
Experiment	$\lvert V_{cd}\rvert/\lvert V_{cs}\rvert$	Note
PDG2014 [6]	0.228 ± 0.009	Using $\lvert V_{cd}\rvert = 0.225 \pm 0.008$ and $\lvert V_{cs}\rvert = 0.986 \pm 0.016$
CLEO-c [23]	$0.242 \pm 0.011 \pm 0.004 \pm 0.012$	Using $D \to \pi e^+ \nu_e$ and $D \to K e^+ \nu_e$
BESIII (this work)	$0.238 \pm 0.004 \pm 0.002 \pm 0.011$	Using $D^0 \to \pi^- e^+ \nu_e$ and $D^0 \to K^- e^+ \nu_e$

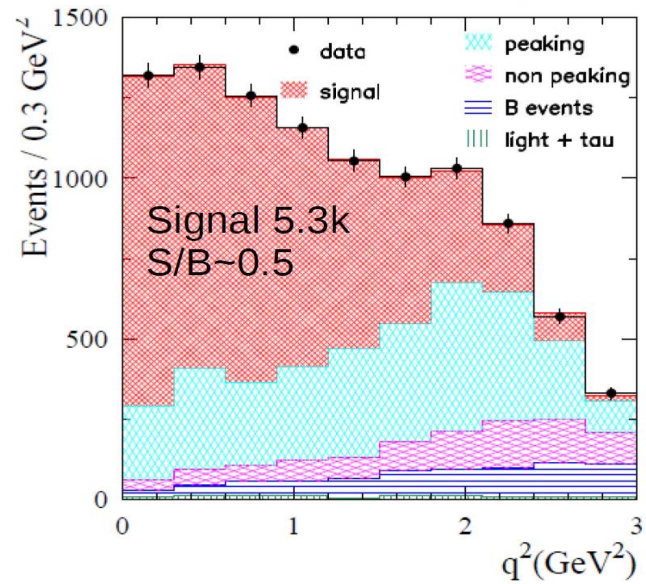
For the BES-III and CLEO-c results of $|V_{cd}|/|V_{cs}|$, the first error is statistical, second systematic, and the third is theoretical uncertainty

$D^0 \to \pi e^+ \nu$ signal (BaBar)

PRD91(2015)052022

- Data set: 347.2 fb^{-1} @Υ(4S)
  - Partial reconstruction: $D^{*+} \to D^0\pi$ with the $D^0 \to \pi e^+ \nu$
  - Normalization: $D^{*+} \to D^0\pi$ with the $D^0 \to K\pi$
- Imposing D^{*+} and D^0 mass constraint
- $q^2=(p_l+p_\nu)^2=(p_D-p_\pi)^2$
- Fisher discriminant $\Rightarrow$ suppress background from B events and other semileptonic decays from continuum





$D^0 \to \pi e^+ \nu$ Form Factor (BaBar)

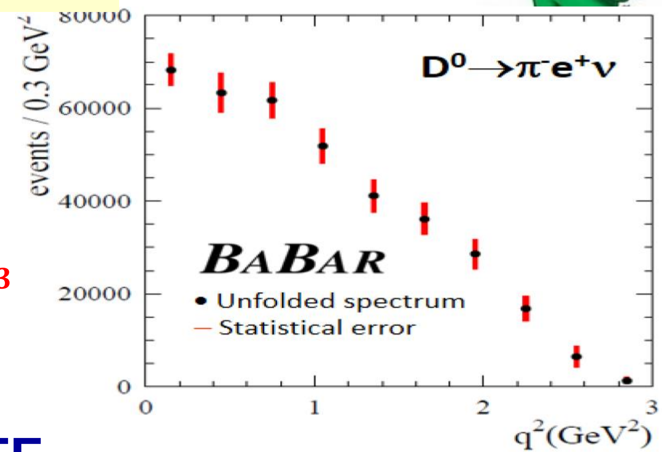
PRD91(2015)052022

- **Branching Fraction ratio**

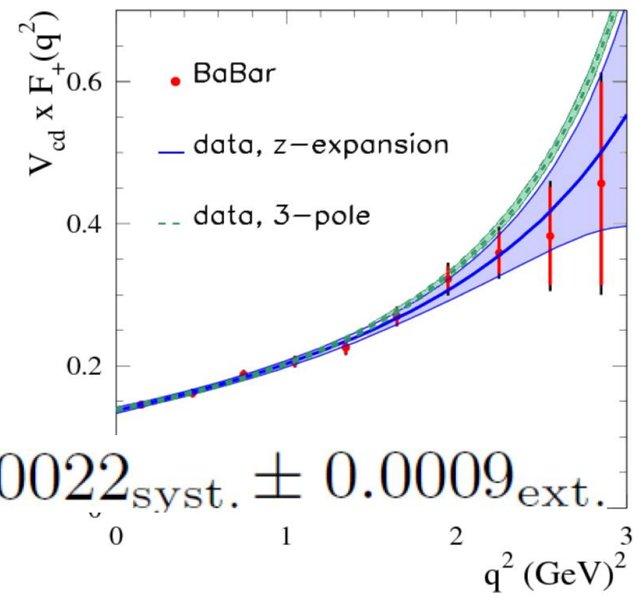
$$R_D = \frac{Br(D^0 \to \pi^- e^+ \nu_e)}{Br(D^0 \to K^- \pi^+)} = 0.0702 \pm 0.0017 \pm 0.0023$$

Using $D^0 \to K\pi$ BF from PDG:

$$Br(D^0 \to \pi^- e^+ \nu_e) = (2.770 \pm 0.068 \pm 0.092 \pm 0.037) \times 10^{-3}$$



- **Test FF parametrization**
  - 2 or 3 poles are used to parametrize the FF
  - Two pole parameterization cannot reproduce data
  - Three pole ansatz fits the data well up to 2 GeV²



- **For factor normalization**

$$|V_{cd}| f^{\pi}_{+,D}(0) = 0.1374 \pm 0.0038_{\rm stat.} \pm 0.0022_{\rm syst.} \pm 0.0009_{\rm ext.}$$

LQCD calculation

$f_+^{\pi}(0) = 0.610 \pm 0.029_{exp}$

$$|V_{cd}| = 0.206 \pm 0.007_{exp} \pm 0.009_{LQCD}$$

$|V_{cd}| = |V_{us}| = 0.2252 \pm 0.0009$

$$f_+^{\pi}(0) = 0.610 \pm 0.020_{exp} \pm 0.005_{ext}$$

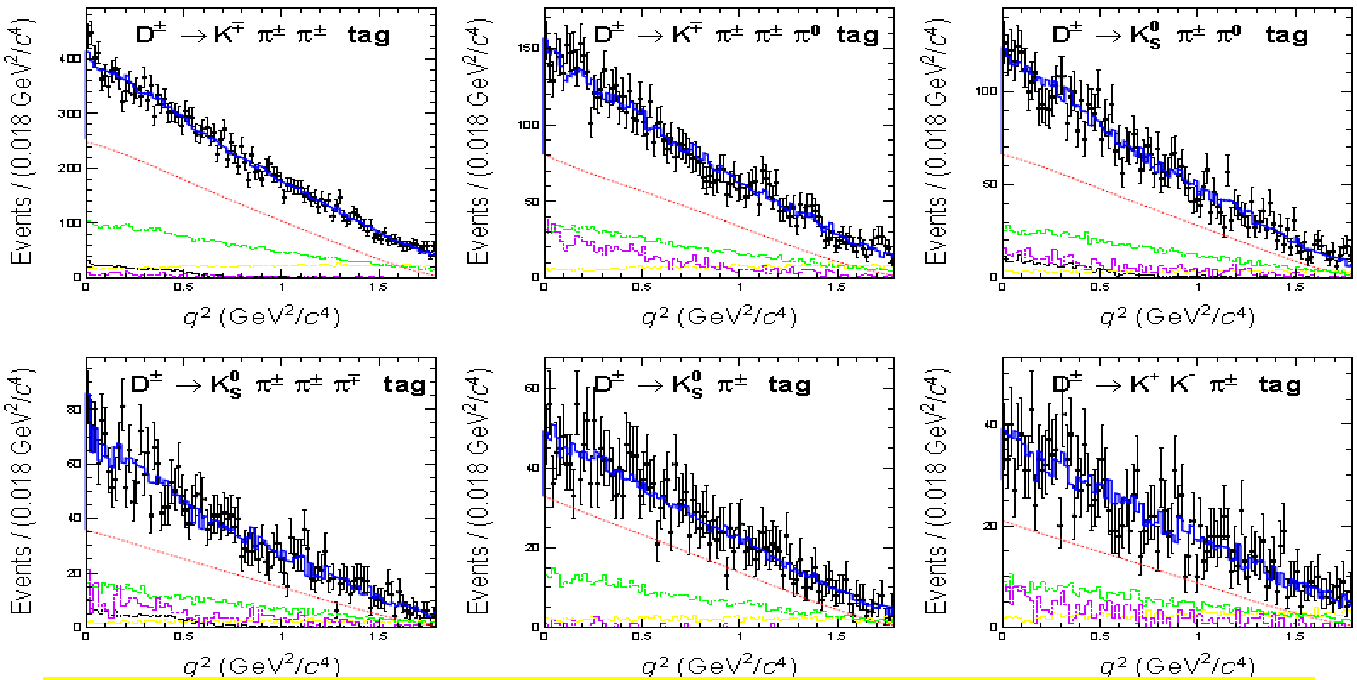
$D^+ \to K_L e^+ \nu$

PRD92(2015)112008

- K_L reconstruction (Partial recon.)
  - EMC neutral cluster $\Rightarrow K_L$ position
  - Fix $U_{miss}=0 \Rightarrow K_L$ momentum
- $D^+ \to K_L e^+ \nu$ is measured for the first time
- This result is consistent with theoretical prediction (-3.3×10^{-3}) [Z.Z. Xing, PLB353, 313(1995); PLB363, 266(1996)]

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

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



Simultaneous Fit to observed DT yields, red dash is signal

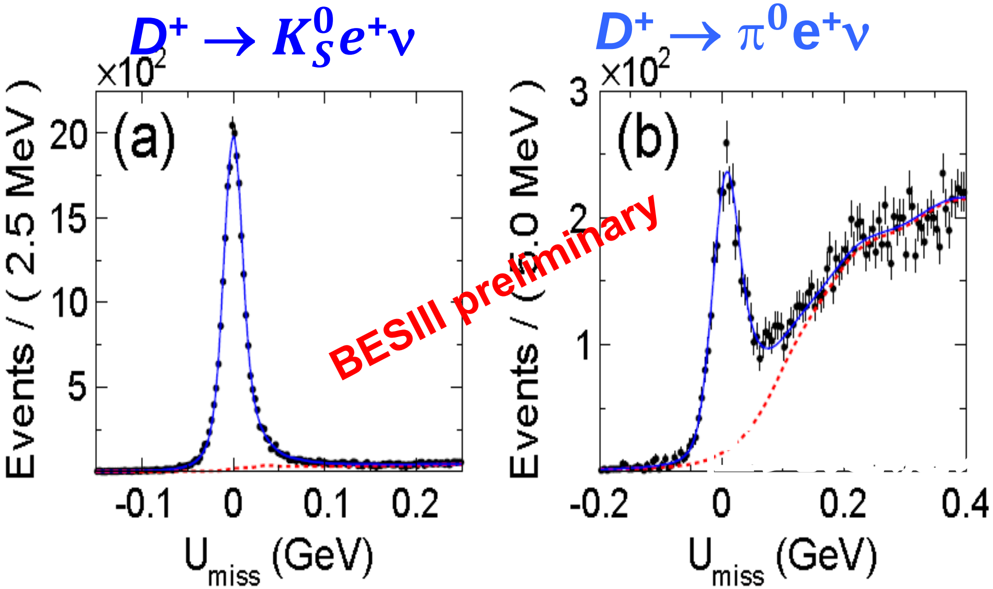
$f^K_+(0)|V_{cs}|$ $=0.728\pm0.006\pm0.011$

Direct measurement

$f^K_+(0) = 0.748 \pm 0.007 \pm 0.012 \Leftarrow$ [with $|V_{cs}|$ from SM constraint fit]

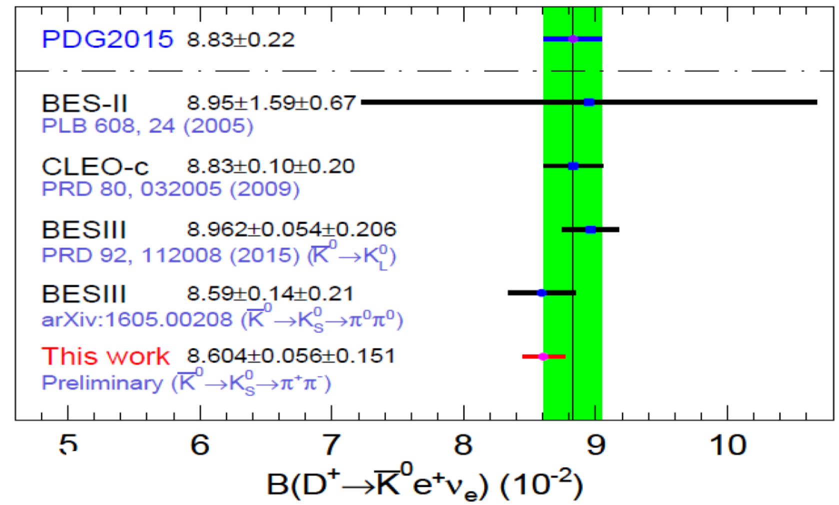
$|V_{cs}| = 0.975 \pm 0.008_{stat} \pm 0.015_{sys} \pm 0.025_{LQCD} \Leftarrow$ [with fK+(0)=0.747±0.019 (PRD82, 114506(2010)]

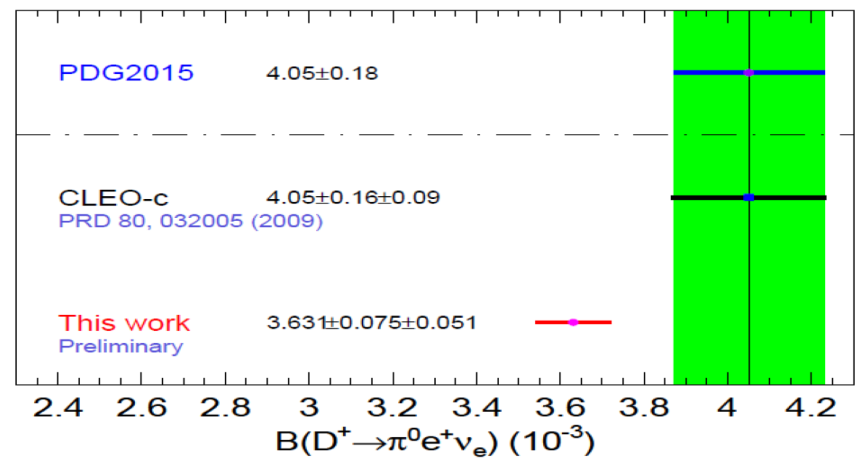
$D^+ \to K_S^0 e^+ \nu$ and $D^+ \to \pi^0 e^+ \nu$



$N_{D^- \to \overline{K}^0 e^+ \nu} = 26008 \pm 168$

$N_{D^+ \to \pi^- e^+ \nu} = 3402 \pm 70$





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

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

- **Full data set: 2.93 fb^{-1} data@ 3.773 GeV**
- **BESIII's BR for $D^+ \to \pi^0 e^+ \nu$ is lower than CLEOc's.**
- **Form Factors are also measured.**

$D^+ \to K_S^0 \mu^+ \nu$

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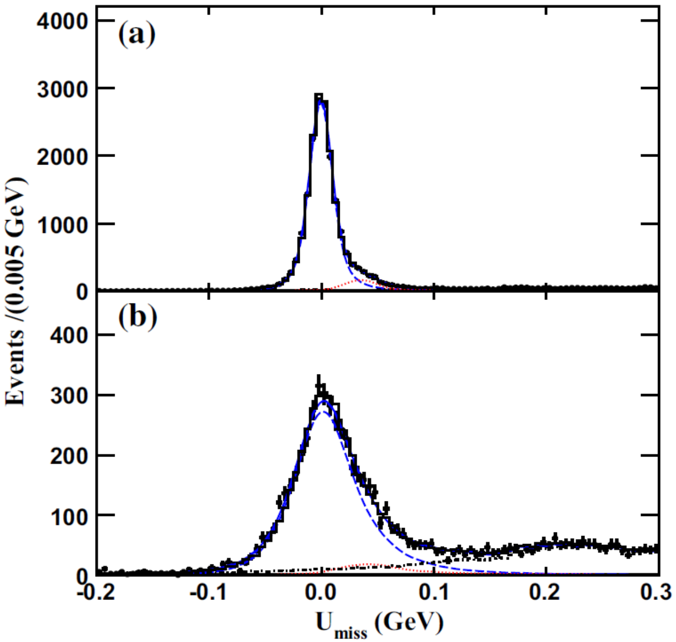
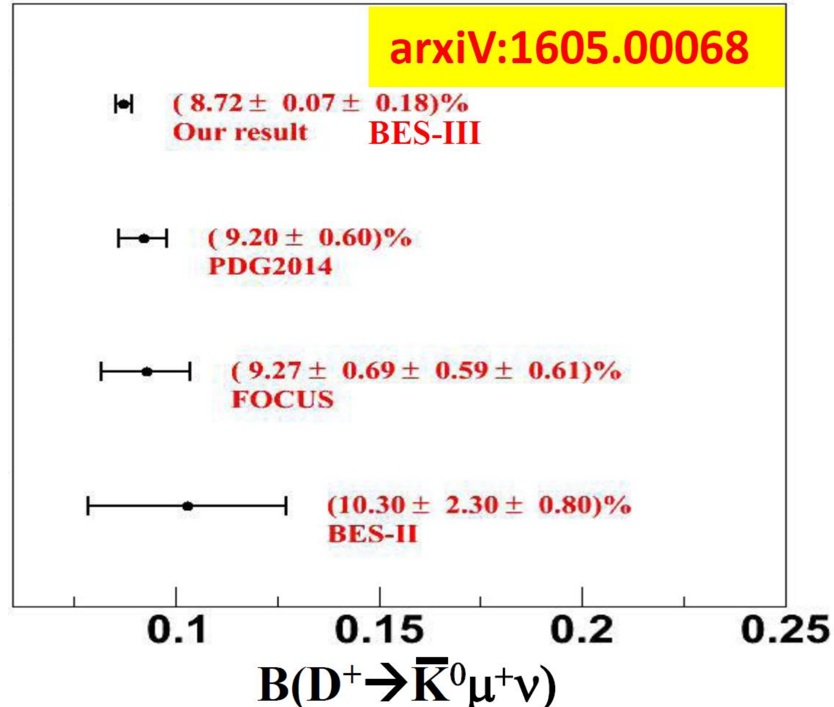
From Rong/Gang at CHARM2016



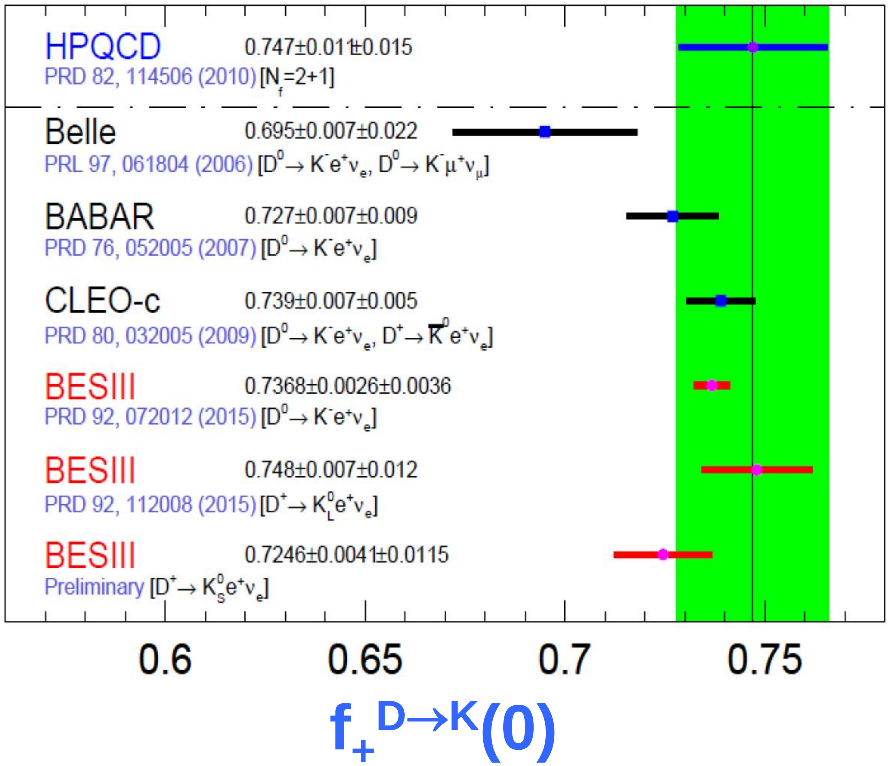


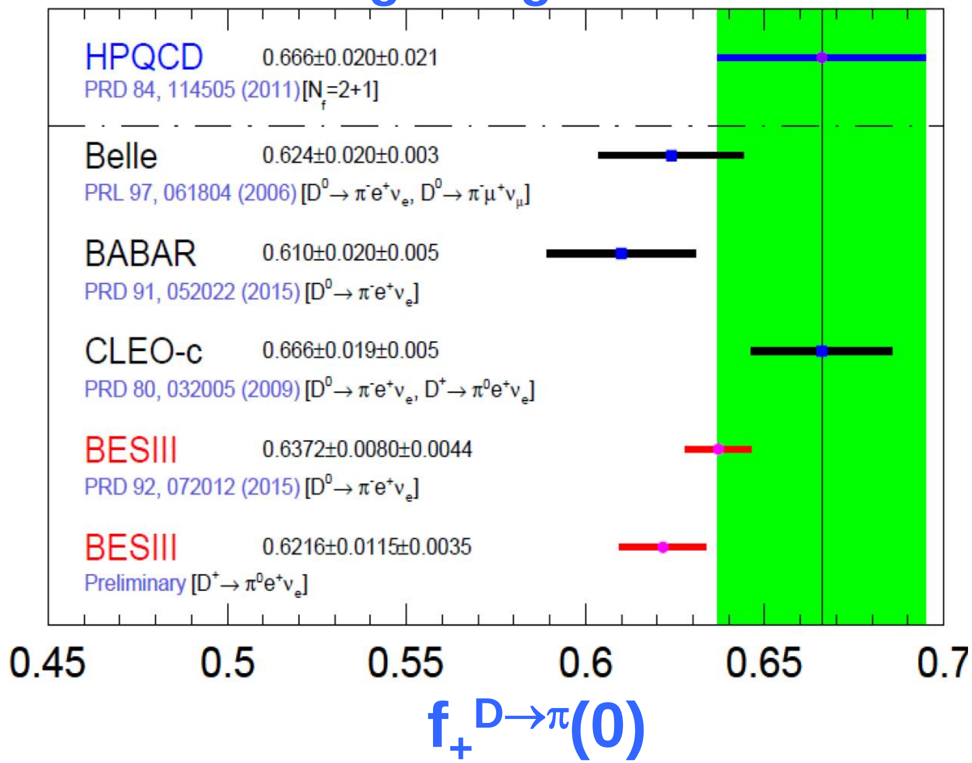
- **Full data set: 2.93 fb^{-1} data@ 3.773 GeV**
- **6 hadronic modes, 1.52×10^6 D^- tags**
- **Comparing this measured BF with PDG:**
  - $\frac{\Gamma[D^0\to K^-\mu^+\nu]}{\Gamma[D^+\to\bar{K}^0\mu^+\nu]}=0.963\pm0.044$ ⇒ **Supporting isospin conservation.**
  - $\frac{\Gamma[D^+\to\bar{K}^0\mu^+\nu]}{\Gamma[D^+\to\bar{K}^0e^+\nu]}=0.988\pm0.033$ ⇒ **consistent with theoretical prediction.**

Status of Form Factors $f_+^{D\to K(\pi)}(0)$

$f_+^{D\to K(\pi)}(0)$ determined from $f_+^{D\to K(\pi)}(0)\,|V_{cs(d)}|$ combining with $|V_{cs(d)}|$ from the SM global fit

From Rong/Gang at CHARM2016



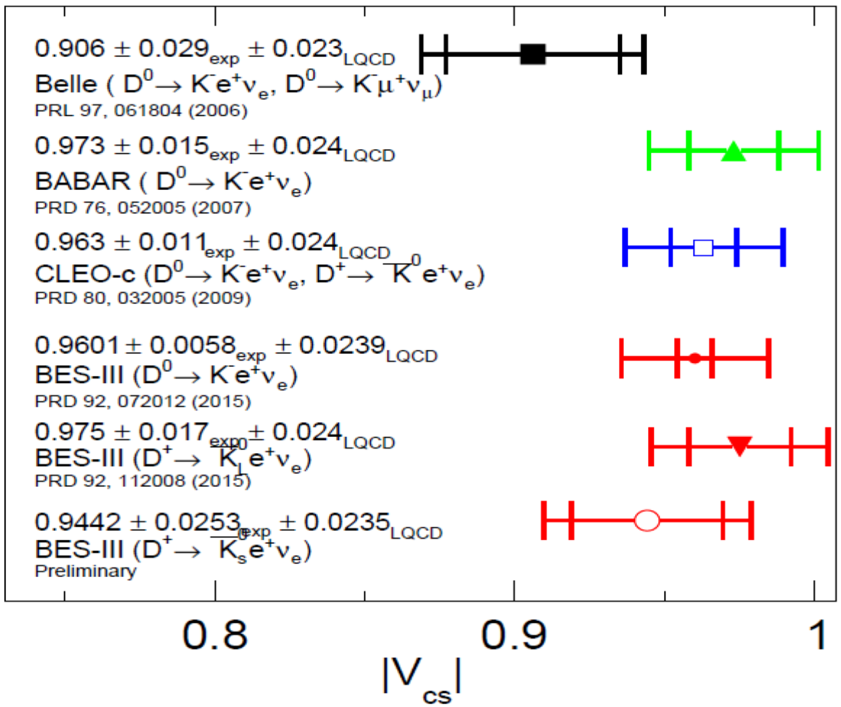


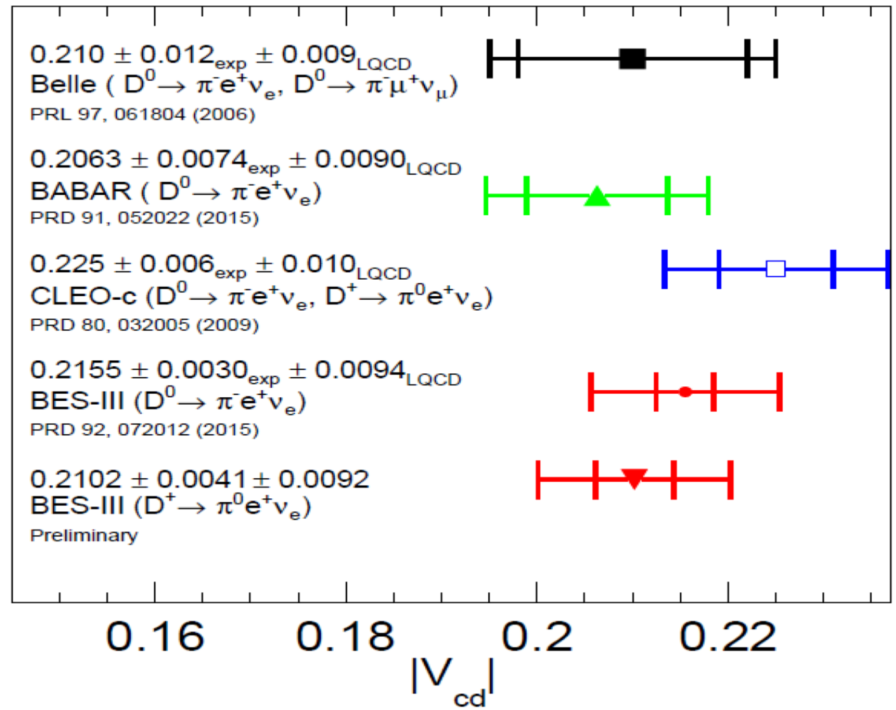
- **$D^0 \to \pi^- e^+\nu$ and $D^0 \to K^- e^+\nu$ from BESIII ⇒ most precise measurements**
- **Experimental accuracy is better than the LQCD calculation.**

Status of $|V_{cs}|$ and $|V_{cd}|$

$|V_{cs(d)}|$ extracted from $f_+^{D\to K(\pi)}(0)$ $|V_{cs(d)}|$ combining with $f_+^{D\to K(\pi)}(0)$ from LQCD calculation.

From Rong/Gang at CHARM2016

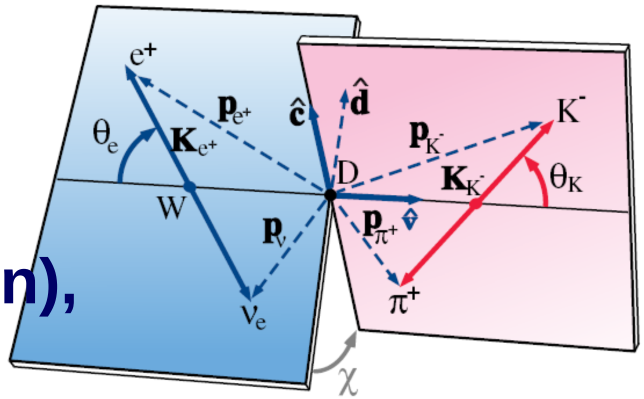




- The inner uncertainties are experimental; the outer uncertainties are due to uncertainties of LQCD calculations

$D \to V \, l \, \nu$

- **Kinematics ($K^* \to K\pi$ as Vector decay example): 5 degree of freedom (m^2 in K^* system, q^2 in $l\nu$ system, $\cos(\theta_K)$, $\cos(\theta_e)$ and χ**



- **For massless l (e: good approximation), need 3 form factors: 2 axial and a vector. Uaually parameterized with simple pole.**
- **Usually measure r_V and r_A**

Simple pole parameterization:

$$V(q^2) = \frac{V(0)}{1 - \frac{q^2}{m_V^2}}, \quad r_V \equiv \frac{V(0)}{A_1(0)}$$

$$A_1(q^2) = \frac{A_1(0)}{1 - \frac{q^2}{m_A^2}},$$

$$A_2(q^2) = \frac{A_2(0)}{1 - \frac{q^2}{m_A^2}}, \quad r_A \equiv \frac{A_2(0)}{A_1(0)}$$

- **Combined with $D \to \rho e \nu$, $D \to K^* e\nu$ and $B \to V\, l^+ l^-$, to extract $|V_{ub}|$ from $B \to \rho e \nu$ (PRD 70, 114005 (2004))**
- **Measure $D \to \{K\pi$ -S wave$\}e\nu$ component**
  - **fist observed: FOCUS, PLB535 (2002) 43-51**
  - **CLEOc confirmed evidence for S-wave with: 818 pb^{-1} PRD81 (2010) 112001**
  - **BaBar(348 fb^{-1}):PRD 83 (2011) 072001**

$D\to K^* e\nu$, $D^+\to K^-\pi^+e^+\nu$

PRD94(2016)032001

- **Fractions with >5σ significance**

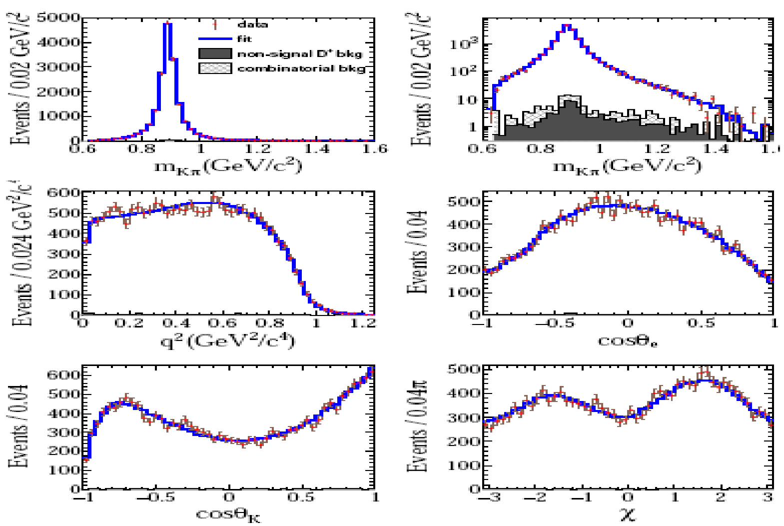
$$f(D^+\to (K^-\pi^+)_{K^{*0}(892)}\, e^+\nu_e) = (93.93 \pm 0.22 \pm 0.18)\%$$

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

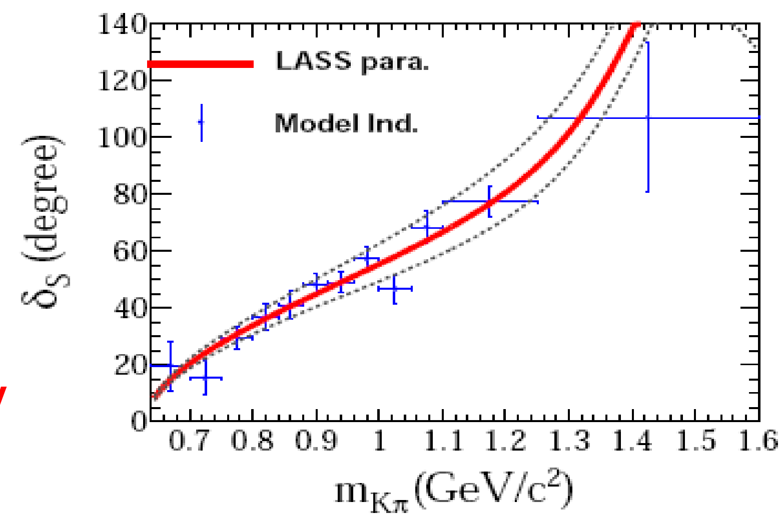
- **Properties of different Kπ (non-) resonant amplitudes**

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

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



Model independent S-wave phase measurement



$M_{V/A}$ 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

the dominate K*(892)0 component is accompanied by S-wave contribution（~6% of total）and that other component are negligible.

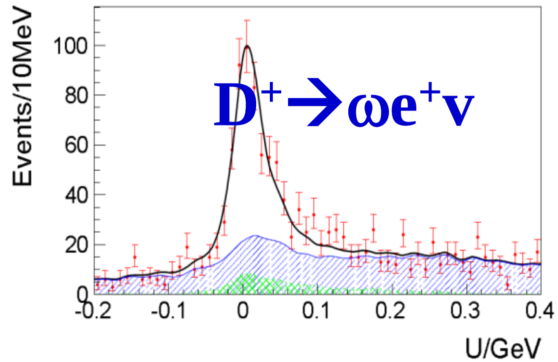
$D \to \omega e\nu$ and $D \to \phi e\nu$

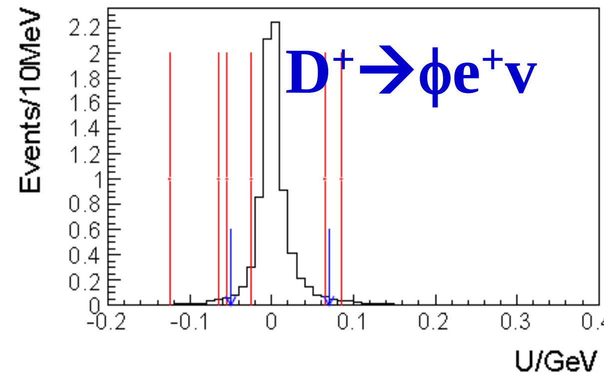
PRD92(2015)071101(R)

- CLEOc: $D \to \rho e\nu$ and $D \to \omega e\nu$
  - Measured FF for $D \to \rho e\nu$ for the first time.
  - PRL110, 131802 (2013)
- BESIII
  - Most precise BR for $D \to \omega e\nu$
  - Amplitude analysis of $D^+ \to \omega e^+ \nu$ is performed for the first time
  - Form Factor ratio

$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$
$r_2 = A_2(0)/A_1(0) = 1.06 \pm 0.15 \pm 0.05$

- BFs are consistent with FK predictions (Fajfer and Kamenik, Phys. Rev. D 72, 034029 (2005))

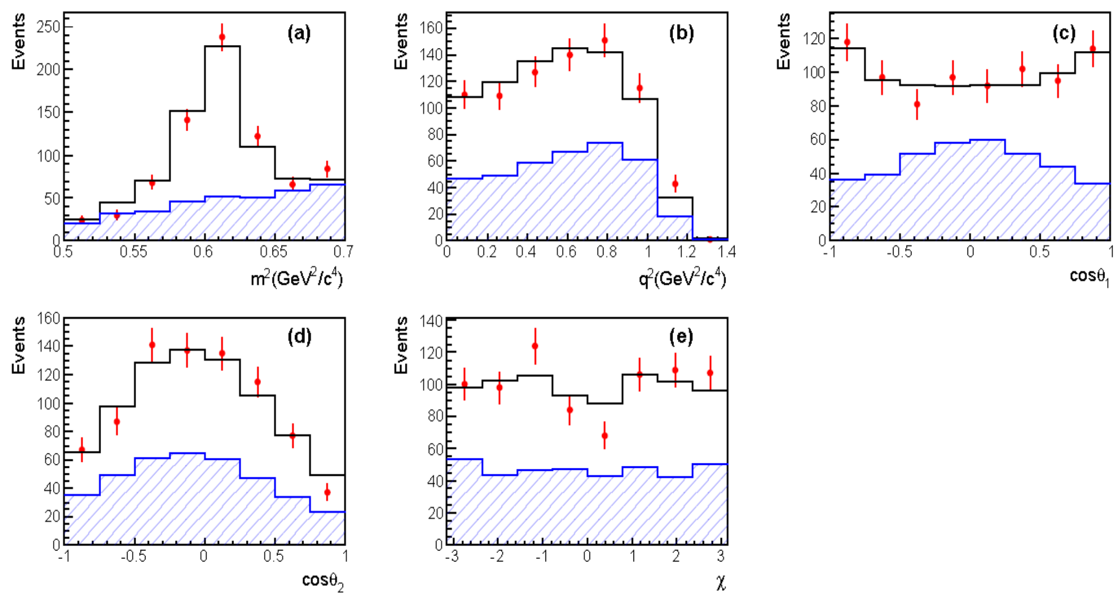




$B[D^+ \to \omega e^+ \nu] = (1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$

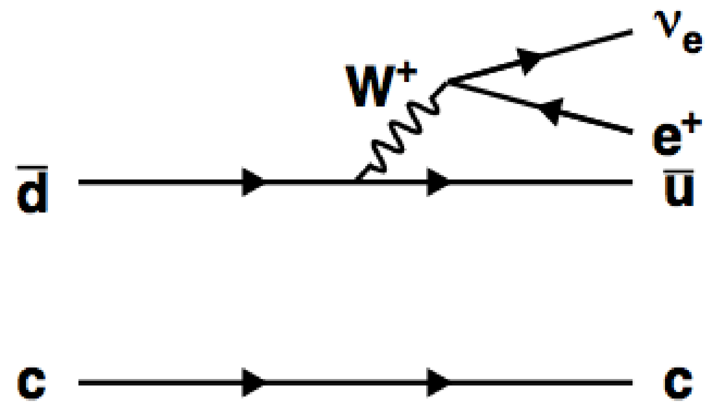
$B[D^+ \to \phi e^+ \nu] < 1.3 \times 10^{-5}$ at 90% C.L.

Better precision or sensitivity



$D^+ \to D^0 e^+ \nu_e$

- **Motivation**
  - **the weak decays ⇐ light-quark sectors (heavy-quark unchanged)**
  - **Theoretical prediction is 2.78×10^{-13} [EPJC, 59:841-845(2009) by Applying the SU(3) symmetry for the light quarks]**

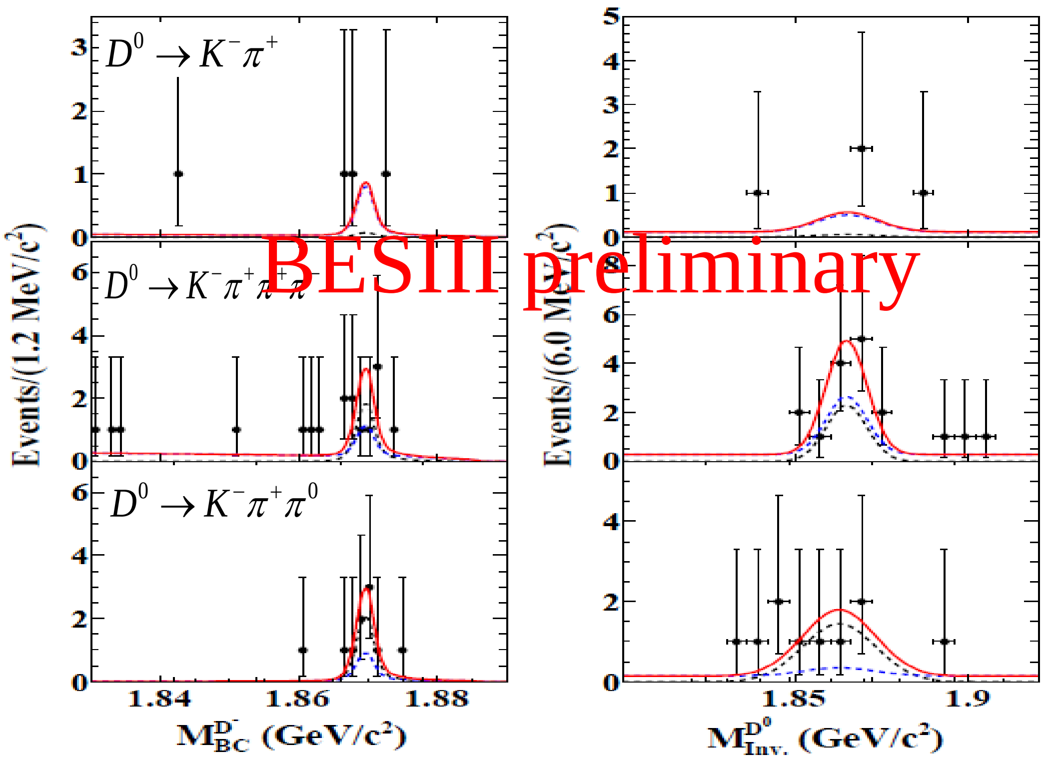


- **Data analysis (Double Tag technique applied)**
  - **D^- : reconstructed with six tag modes**
  - **D^0: reconstructed with three signal modes**
  - **D^0 momentum and D^-D^0 energy are used to suppress the background**

Tag Mode	Signal Mode
$K\pi\pi$	$K\pi$
$K\pi\pi\pi^0$	$K\pi\pi^0$
$K_S^0\pi\pi^0$	$K\pi\pi\pi$
$K_S^0\pi\pi\pi$	
$K_S^0\pi$	
$KK\pi$	

$D^+ \to D^0 e^+ \nu_e$

- **Two Dimension fit on candidates**
  - **Beam constrained mass for the D^- candidates**
  - **Invariant mass for the D^0 candidates**
- **Bayesian method : upper-limit of $B(D^+ \to D^0 e^+ \nu_e) < 7.8 \times 10^{-5}$ @ 90%C.L..**
- **Compatible with the theoretical prediction [EPJC, 59:841-845(2009)]**



$N_{data}^{obs.i}$ signal in data:

$D^0 \to K^- \pi^+ : 0.3 \pm 3.6$

$D^0 \to K^- \pi^+ \pi^+ \pi^- : 5.6 \pm 2.9$

$D^0 \to K^- \pi^+ \pi^0 : 6.4 \pm 3.5$

N_{bkg}^{i} estimated with Inc. MC:

$D^0 \to K^- \pi^+ : 3.0 \pm 0.6$

$D^0 \to K^- \pi^+ \pi^+ \pi^- : 8.5 \pm 1.0$

$D^0 \to K^- \pi^+ \pi^0 : 10.3 \pm 1.2$

$D \to a_0(980)e^+\nu_e$

BESIII

- **Motivation**
  - $R \equiv \frac{B(D^+\to f_0 l^+\nu)+B(D^+\to \sigma l^+\nu)}{B(D^+\to a_0 l^+\nu)}$ **: a model-independent way to study the structure of the light scalar mesons[Wang and Lu, PRD82, 034016 (2010), PDG review]**
  - **Chiral unitarity approach [PRD 92, 054038 (2015)] ⇒ BFs: ~5(6)x10^{-5} for $D^0(D^+)$**
- **Data analysis (Double Tag technique applied)**
  - **For Tag side:**

$\bar{D}^0 \to K^+\pi^-$

$\bar{D}^0 \to K^+\pi^-\pi^0$

$\bar{D}^0 \to K^+\pi^-\pi^+\pi^-$

$D^- \to K^+\pi^-\pi^-$

$D^- \to K^+\pi^-\pi^-\pi^0$

$D^- \to K_S^0\pi^-$

$D^- \to K_S^0\pi^-\pi^0$

$D^- \to K_S^0\pi^-\pi^+\pi^-$

$D^- \to K^+K^-\pi^-$

- **Signal side:**

$$D^0 \to a_0(980)^-e^+\nu_e,\ a_0(980)^- \to \eta\pi^-, \eta \to \gamma\gamma$$

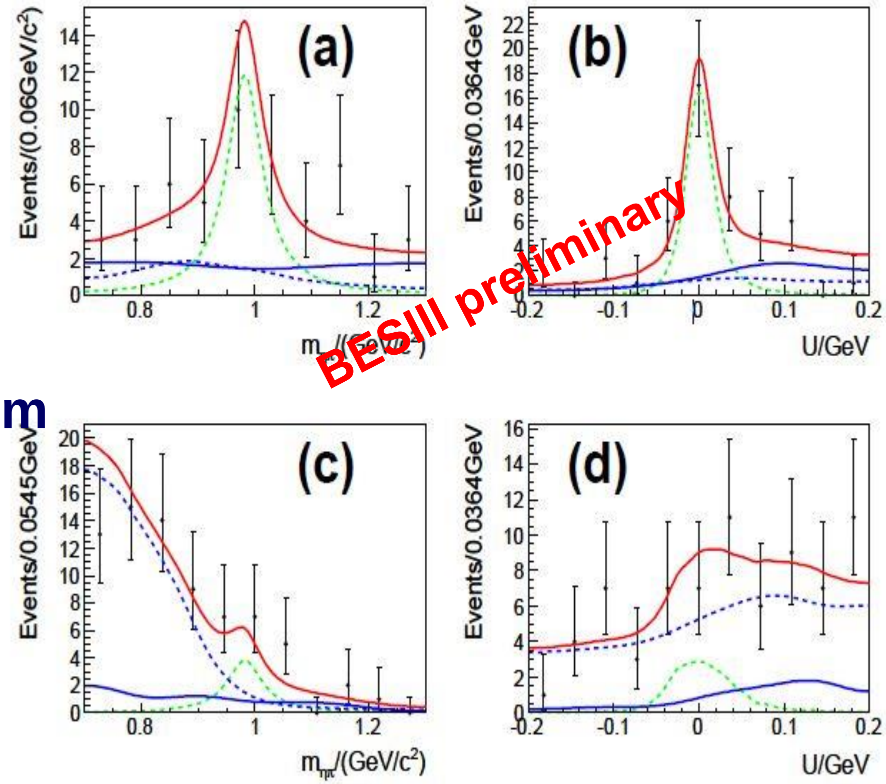
$$D^+ \to a_0(980)^0e^+\nu_e,\ a_0(980)^0 \to \eta\pi^0, \eta \to \gamma\gamma$$

$D \to a_0(980)e^+\nu_e$

- **Kinematic variables:**
  - Invariant mass of $\eta\,\pi$: $M_{\eta\pi}$
  - $U \equiv E_{miss} - c|\vec{p}_{miss}|$,

    $E_{miss} = E_{beam} - E_{\eta\pi} - E_e$,

    $\vec{p}_{miss} = -(\vec{p}_{tag} + \vec{p}_{\eta\pi} + \vec{p}_e)$
- **2-D unbinned extended maximum likelihood fits**
  - U shape ⇐ MC shape
  - $M_{\eta\pi}$ shape: fixed BW Function (Belle:PRD80, 032001 (2009))
  - BKG shapes ⇐ MC shape
- **Dominant sys errrors**
  - Model of decay dynamics
  - $a_0(980)$ lineshape



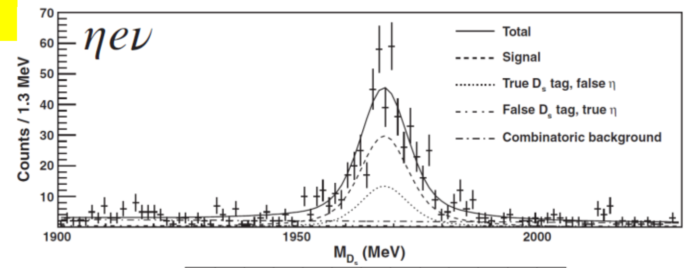
Projection of data set, the fit results and backgrounds on (left) $M_{\eta\pi}$ and (right) U for (top) $D^0 \to a_0(980)^- e^+\nu_e$ and (bottom) $D^+ \to a_0(980)^0 e^+\nu_e$.
[BESIII Preliminary]

First observation of $D^0 \to a_0(980)^- e^+\nu_e$ and **evidence** for $D^+ \to a_0(980)^0 e^+\nu_e$.

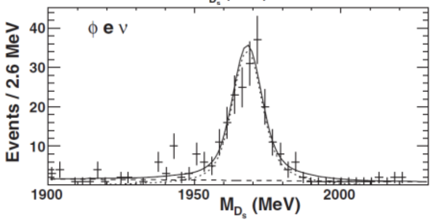
- $B(D^0 \to a_0(980)^- e^+\nu_e) \times B(a_0(980)^- \to \eta\pi^-) = (1.12^{+0.31}_{-0.28}(stat) \pm 0.10(syst)) \times 10^{-4}$ **5.9σ**
- $B(D^+ \to a_0(980)^0 e^+\nu_e) \times B(a_0(980)^0 \to \eta\pi^0) = (1.47^{+0.73}_{-0.59}(stat) \pm 0.14(syst)) \times 10^{-4} < 2.7 \times 10^{-4}$ @90% C. L.

$D_s^+ \to \phi\, e^+\nu\, , \eta^{(\prime)} e^+\nu, f_0 e^+\nu$(CLEOc data)

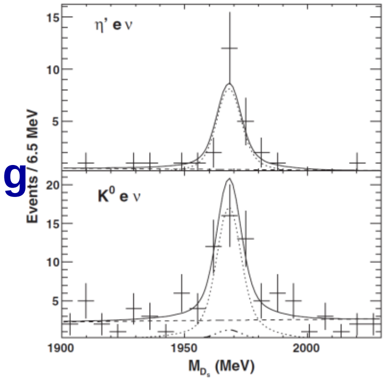
Hietala, Cronin-Hennessy, Pedlar, Shipsey, PRD 92, 012009 (2015)

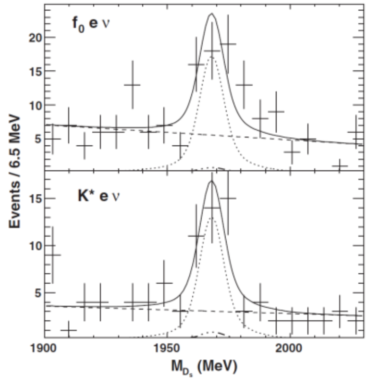


- **Motivation**
  - **Test Latice QCD & probe the quark contents of light mesons (η, η', f_0 …)**
  - **ISGW2 model (PRD 52, 2783 (1995)):Predict a difference between the *D* and D_s^+ inclusive semileptonic rates**
  - **Can be used to determine the η−η' & f_0-ss mixing angle.(PLB 404, 166 (1997))**



- **BRs measurements**
  - **Data sample: 586 pb^{-1} @4.17 GeV ($D_s D_s^*$)**
  - **Do not reconstruct the D_s^* daughter photon ⇒ higher efficiency & smaller Sys. Err. ⇒ ν missing mass can not be used**
  - **Significantly increasing the available statistics.**
  - **Agree to previous measurements.**
  - **η−η' mixing angle: 42º±2º±2º; f_0-ss mixing angle: $20^{o}{}^{+32^o}_{-20^o}$**





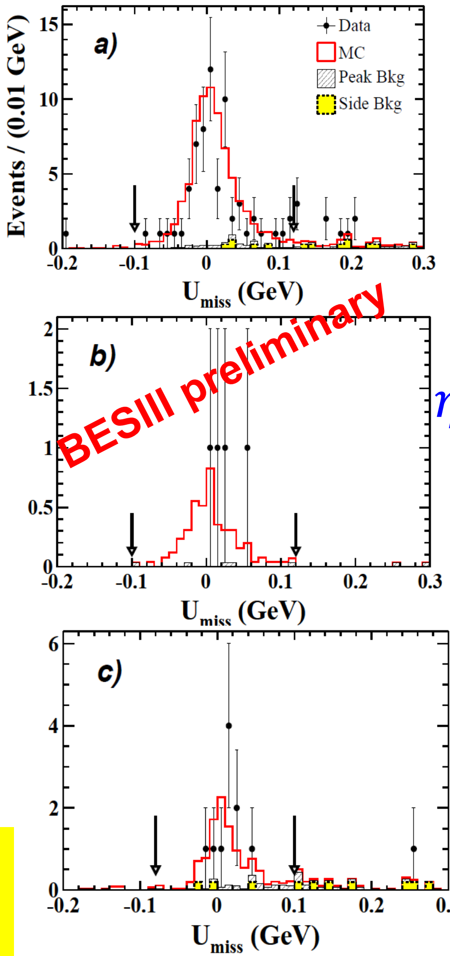
Signal mode	*BABAR* (%)	CLEO-c (%)	This analysis (%)
$D_s \to \phi e\nu$	$2.61 \pm 0.03 \pm 0.08 \pm 0.15$	$2.36 \pm 0.23 \pm 0.13$	$2.14 \pm 0.17 \pm 0.08$
$D_s \to \eta e\nu$	…	$2.48 \pm 0.29 \pm 0.13$	$2.28 \pm 0.14 \pm 0.19$
$D_s \to \eta' e\nu$	…	$0.91 \pm 0.33 \pm 0.05$	$0.68 \pm 0.15 \pm 0.06$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

$D_s^+ \to \eta^{(\prime)} e^+ \nu$

BESIII

Submitted to PRD arXiv 1608.06484

- **BRs measurements**
  - **Data sample: 482 pb^{-1} @4.009 GeV (D_sD_s threshold)**
  - **Double tag method used**
  - **Reconstruct a η or η' (to $\pi\pi\eta$ or $\gamma\rho$)**
  - **Agree to previous experimental measurements.**
  - **Improve upon the Ds+ semileptonic branching fraction precision.**
  - **Observed first time at D_sD_s threshold.**



$\eta e \nu$
58.5 ± 8.0

$\eta'(\eta\pi\pi) e \nu$
3.8 ± 2.0

$\eta'(\gamma\rho) e \nu$
8.2 ± 3.2

Ref. [7]: PRL 75, 3804 (1995) (CLEO II)
Ref. [8]: PRD 80, 052007 (2009) (CLEO-c)
Ref. [9]: PRD 92, 012009 (2015)

	BESIII	Ref. [7]	Ref. [8]	Ref. [9]	PDG [4]
$B(D_s^+ \to \eta e^+ \nu_e)[\%]$	$2.30 \pm 0.31 \pm 0.09$	—	$2.48 \pm 0.29 \pm 0.13$	$2.28 \pm 0.14 \pm 0.20$	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
$\frac{B(D_s^+ \to \eta' e^+ \nu_e)}{B(D_s^+ \to \eta e^+ \nu_e)}$	$0.40 \pm 0.14 \pm 0.02$	$0.35 \pm 0.09 \pm 0.07$	—	—	—

BESIII preliminary

Summary and future perspective

- BESIII has large and clean e+e- data samples near threshold. Many new and improved form factor measurements (Exist Lattice QCD calculations generally in good agreement with data)
- BESIII results on Ds decays at threshold have been released, statistics limited.
- In future
  - BESIII has collected 3 fb^{-1} 'D_S' data around Ecm ~ 4180 MeV, expect new results on D_S decays in the near future.
  - LHCb & Belle II (will turn on soon): Large inclusive samples of all charmed hadrons $\Rightarrow$ two challenges: control of systematics & better theoretical tools

Thank you

Backup slides