Leptonic and Semileptonic Decays in Charm

Yangheng Zheng

University of Chinese Academy of Sciences

(on behalf of BESIII collaboration)

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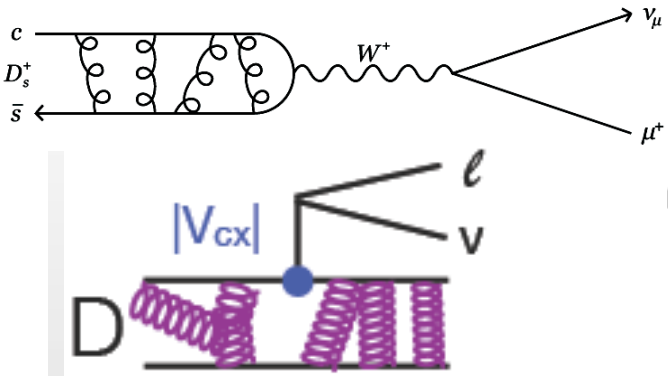
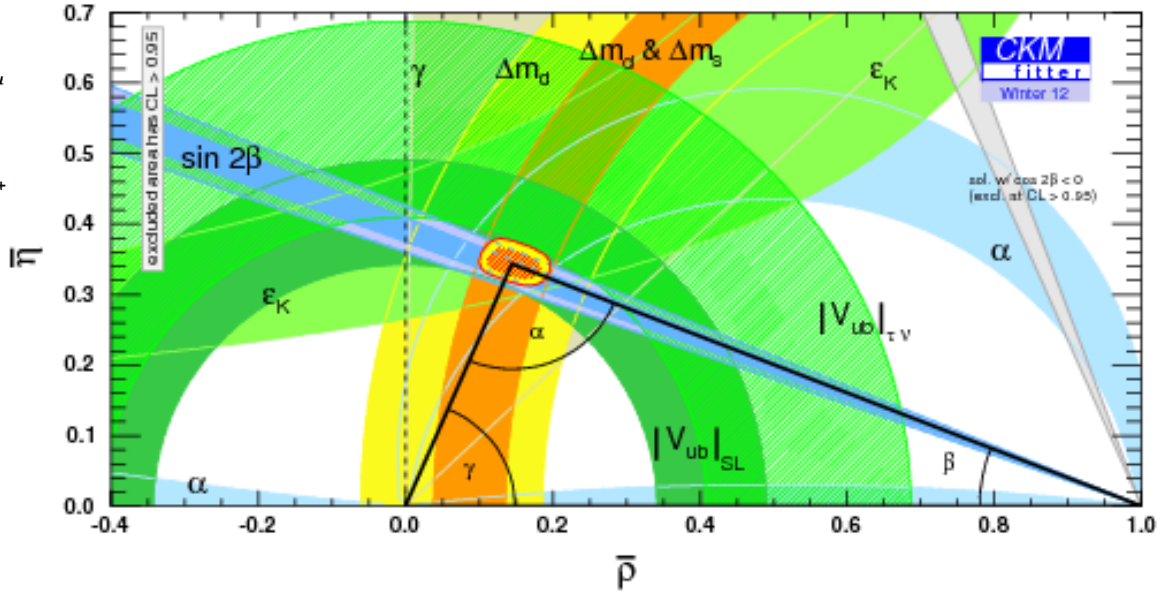
Outline

- Introduction
  - Leptonic decay
  - Semileptonic decay
- Experimental challenge
  - ν Reconstruction
- Recent experimental results
  - f_D/f_{Ds}
  - BF & Form factor fit: $f_+^{D\to\pi}(0)$, $f_+^{D\to K}(0)$
  - $D \to V\, l\, \nu$ measurements
  - Rare/Forbidden decay search
- Summary

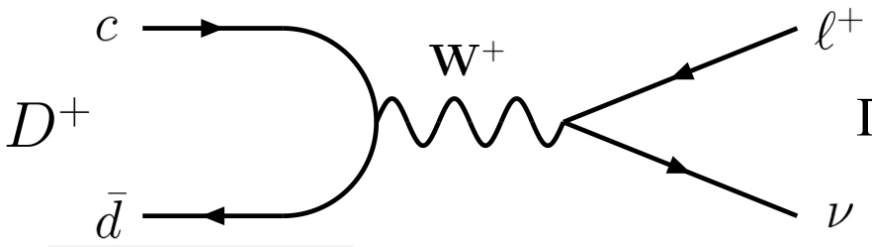
Overall picture





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

Leptonic decays



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

- Extract decay constant $f_{D(s)}$ incorporates the strong interaction effects (wave function at the origin)
  - Multiple tests with charm: f_D, f_{Ds} and f_D/f_{Ds}
- To validate Lattice QCD calculation of $f_{B(s)}$ and provide constrain of CKM-unitarity
- Sensitive to New Physics (Charged Higgs contribution, …)

Theoretical/Experimental status

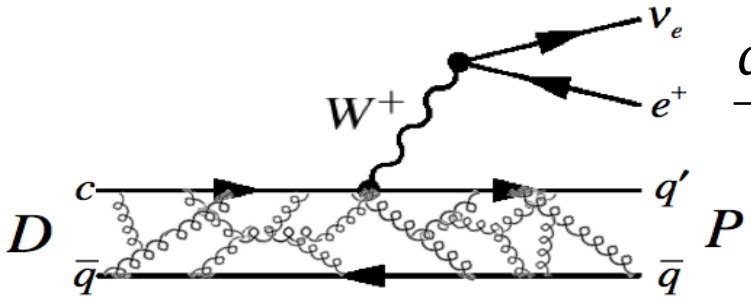
Table taken fromJ. L. Rosner and S. Stone, arXiv:1201.2401 [hep-ex].

Model	$f_{D_s^+}$ (MeV)	f_{D^+} (MeV)	$f_{D_s^+}/f_{D^+}$
Experiment (our averages)	260.0 ± 5.4	206.7 ± 8.9	1.26 ± 0.06
Lattice (HPQCD) [1]	248.0 ± 2.5	213 ± 4	1.164 ± 0.018
Lattice (FNAL+MILC) [2]	260.1 ± 10.8	218.9 ± 11.3	1.188 ± 0.025
PQL [3]	244 ± 8	197 ± 9	1.24 ± 0.03
QCD sum rules [4]	205 ± 22	177 ± 21	$1.16 \pm 0.01 \pm 0.03$
QCD sum rules [5]	$245.3 \pm 15.7 \pm 4.5$	$206.2 \pm 7.3 \pm 5.1$	$1.193 \pm 0.025 \pm 0.007$
Field correlators [6]	260 ± 10	210 ± 10	1.24 ± 0.03
Light front [7]	268.3 ± 19.1	206 (fixed)	1.30 ± 0.04

[1] PRD82,114504(2010); [2] arXiv:1112.3051; [3] JHEP0907,043(2009); [4] JHEP0511,014(2005); [5] PLB701,82(2011); [6] PRD75,116001(2007); [7] PRD81,054022(2010)

- **Experiment and HPQCD lattice calculation consist at 2 σ**
- **Experimental results**
  - **D $\rightarrow$ l ν : MARKIII, BESI, BESII, CLEOc, New BESIII preliminary results**
  - **Ds $\rightarrow$ l ν : WA75, E653, L3, ALEPH, OPAL, CLEOII, BESI, CLEOc, Belle, BaBar, New Belle preliminary results (919 fb^{-1}) for Ds $\rightarrow \mu(\tau)\ \nu$**

Semileptonic decays



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

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

- $D_{(s)} \to P\ l\ \nu$ (Theoretically clean)
  - 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: Validate LQCD for form factor, extract $|V_{ub}|$ to test CKM-unitarity
    - Example: $B \to \pi\ l\ \nu \Rightarrow |V_{ub}| = 3.92 \pm 0.09 \pm 0.45$(Theory) rely on LQCD Form Factor calculations (provide perfect calibration)
- $D_{(s)} \to V\ l\ \nu$
  - 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
  - Study D_s structure and long-distant effect
  - Search for new physics

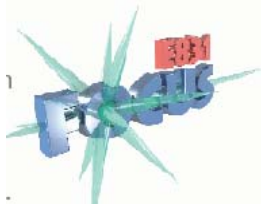
Charm meson productions

- 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)
  - Threshold production (CLEOc, BESIII)
    - Quantum correlations and CP-tagging are unique
    - Ratio of signal to background is optimum
    - Lots of systematic uncertainties cancellation while applying double tag method

ν Recon. (Experimental challenges)

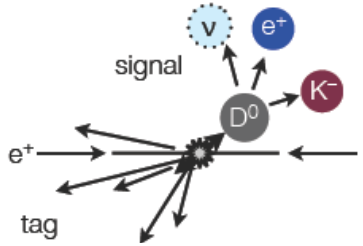
Commonly used techniques (Partial reconstruction)

- **Fix target experiment (FOCUS)**



  - **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)**

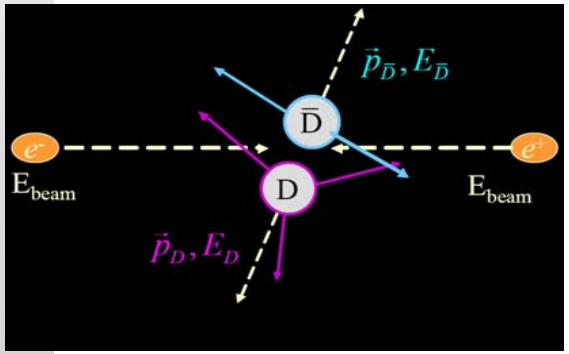
$$\vec{p}_D \propto -\sum \vec{p}_i$$



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

ν Recon. @charm threshold

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



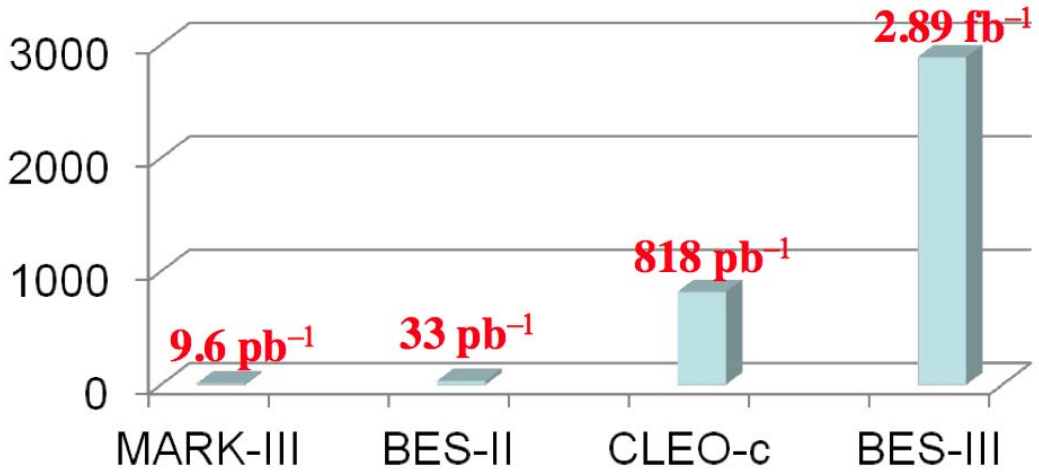
$$\Delta E = E_D - E_{\text{Beam}}$$

$$M_{\text{BC}} = \sqrt{E_{\text{Beam}}^2 - p_D^2}$$

- 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.)

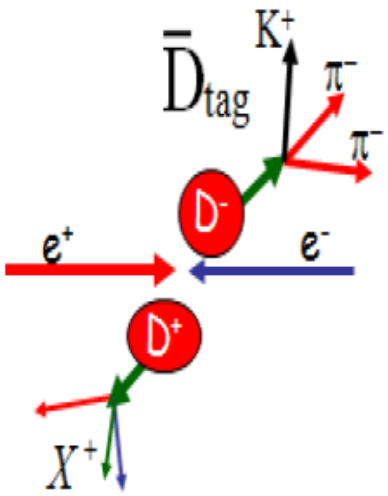
Data samples

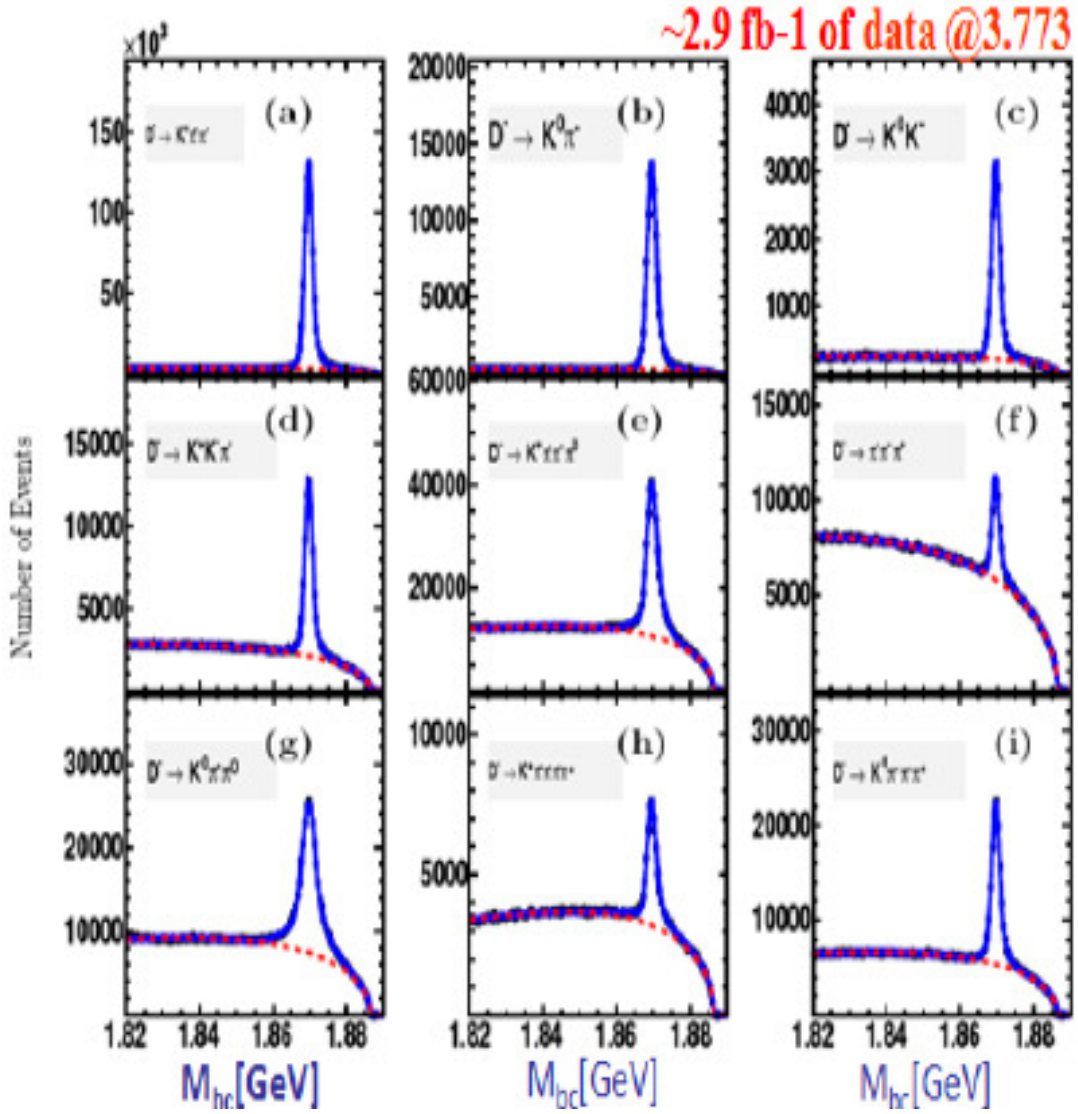
- Belle: 913 fb^{-1}
- BaBar: 521 fb^{-1}
- CLEO-c: 600 pb^{-1} @ 4170 MeV, 818 pb^{-1} @ 3770 MeV
- BESIII: 2.89 fb^{-1} (World largest $\psi(3770)$ sample; Semileptonic analysis is "partially blind" – 0.92 fb^{-1} analyzed so far. Full 2.9 fb^{-1} later for final results)



$D \to \mu\nu$ (BESIII: 2.9 fb^{-1})

- Tag side reconstruction:
  - 9 decay modes
  - Kinematic variables: Beam-constrained mass and ΔE
  - (1.57±0.2) M tags found

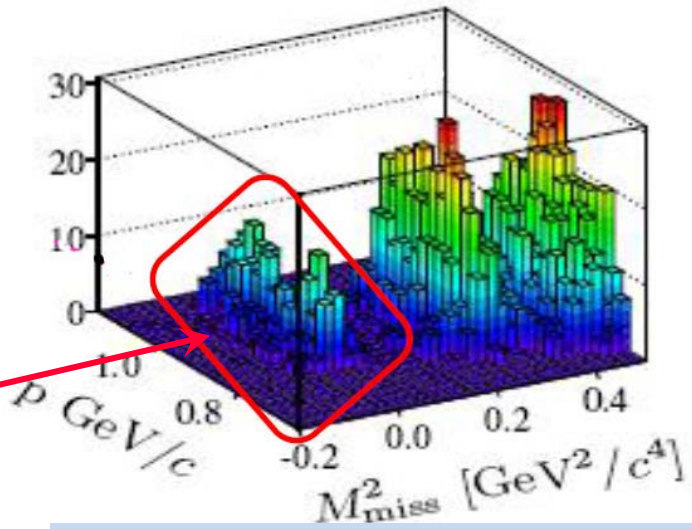




Beam-constrained mass of tag D

$D \to \mu\nu$ (BESIII: 2.9 fb^{-1})

- **Signal side reconstruction:**
  - **One charged track only**
  - **Identified as μ**
  - **No isolated photon**
  - **Kinematic variable: M^2_{miss}**
- **425 candidates**



$$M^2_{\text{miss}} = \left(E_{\text{Beam}} - E_\mu\right)^2 - \left(-\vec{p}_{\text{tag}} - \vec{p}_\mu\right)^2 \approx 0$$

BES III preliminary:

$N(D^+ \to \mu^+\nu) = 377.3 \pm 20.6$

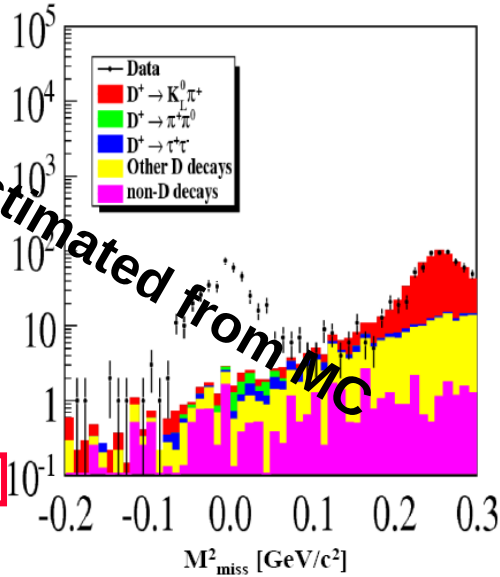
$B(D^+ \to \mu^+\nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$

$f_D = (203.91 \pm 5.72 \pm 1.97)$

Estimated with Monte Carlo events

Source mode	Number of events
$D^+ \to K^0_L\pi^+$	7.9 ± 0.8
$D^+ \to \pi^+\pi^0$	3.8 ± 0.5
$D^+ \to \tau^+\nu_\tau$	$6.9 \pm$
Other decays of D mesons	17.9 ± 1.1
$e^+e^- \to \gamma\psi(3686)$	0.2 ± 0.2
$e^+e^- \to \gamma J/\psi$	0.0 ± 0.0
$e^+e^- \to$ *light hadron* (continuum)	8.2 ± 1.4
$e^+e^- \to \tau^+\tau^-$	1.9 ± 0.5
$\psi(3770) \to non - D\bar{D}$	0.9 ± 0.4
Total	47.7 ± 2.3

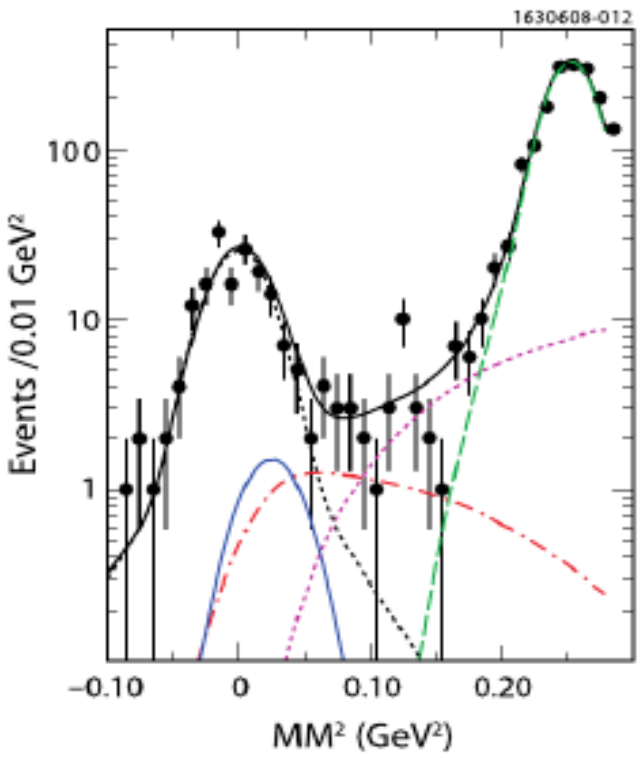
Background estimated from MC



$D \to \mu\nu$ (CLEO-c: 818 pb^{-1})

Similar method to BESIII

- **Tag side**
  - **6 decay modes**
  - **460K tags**
- **Signal side**
  - **Single extra track with Ecal<300 MeV (No muon detector)**
  - **Singal yields: 149.7±12.9 (with fix tau cross-feed)**
  - **Dominant Backgrouds: $\tau\nu$, $\pi\pi^0$,$K^0\pi$**



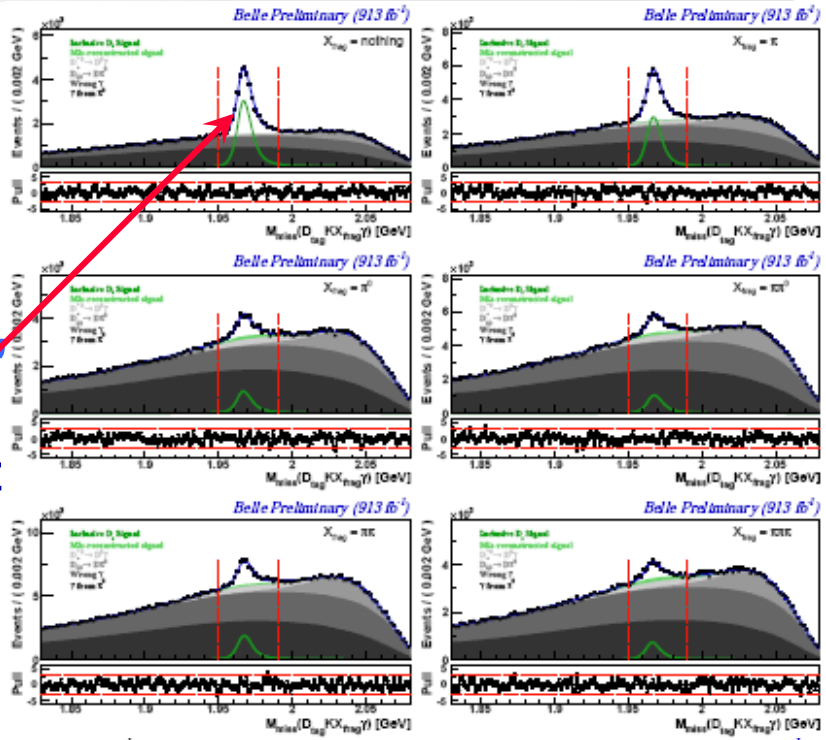
Experiment	$\mathcal{B}(D \to \mu\nu)$	f_d
BES III (preliminary)	$(3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$	$(203.91 \pm 5.72 \pm 1.97)$ MeV
CLEO-c	$(3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$	$(205.8 \pm 8.5 \pm 2.5)$ MeV
Average	$(3.76 \pm 0.18) \times 10^{-4}$	(204.5 ± 5.0) MeV

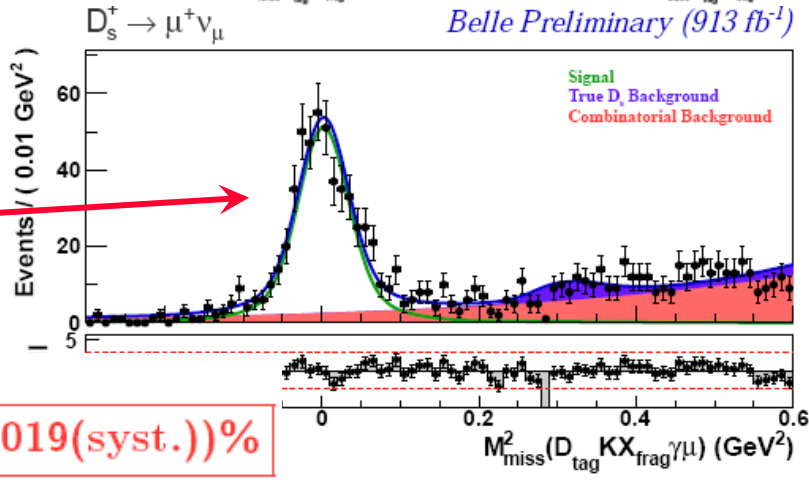
The error is still dominated by statistics, more data at threshold is needed.

$D_s \to \mu\nu$ (Belle: 913 fb^{-1} @10.6 GeV)

$$e^+e^- \to c\bar{c} \to \overline{D}_{tag} K X_{frag} D_s^{*+}$$

- $D_s^* \to D_s\gamma$, $X_{frag} \to n\pi$
- Updated with full data sample (Preliminary results, FPCP2012, A. Bozek)
  - $D_s \to \tau\nu$ channel analyzed (see next slide)
- Tag side ($D_{tag} K X_{frag} \gamma$)
  - Multivariate tool applied
  - Recoil mass of D_s
  - ~10000 D tags per 1 fb^{-1}
- Signal side($D_s \to \mu\nu$)
  - Kinematic variable: M^2_{miss}
  - Observed: 489 ±26 signals





Belle preliminary @ 913 fb^{-1}

$$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (0.528 \pm 0.028(\text{stat.}) \pm 0.019(\text{syst.}))\%$$

Most precise measurement

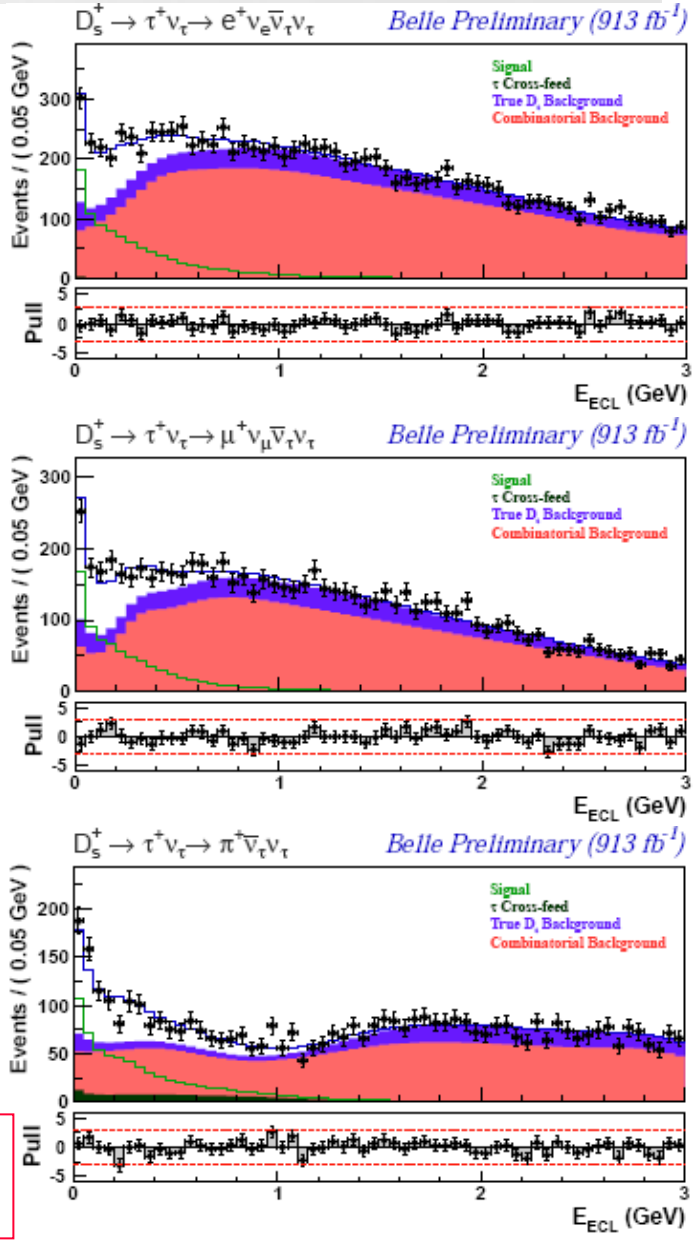
$D_s \to \tau\nu$ (Belle: 913 fb^{-1})

- **Tag side ($D_{tag}KX_{frag}\gamma$)**
  - **Same as $D_s \to \mu\nu$ mode**
- **Signal side ($D_s \to \tau\nu$)**
  - **3 τ decay modes: $\tau \to e\nu\nu$, $\mu\nu\nu$, $\pi\nu$**
  - **Kinematic variable: Extra energy in calorimeter (E_{ECL})**

τ decay mode	$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$ [$\times 10^{-2}$]
$e\nu\nu$	$5.37 \pm 0.33^{+0.35}_{-0.30}$
$\mu\nu\nu$	$5.88 \pm 0.37^{+0.34}_{-0.58}$
$\pi\nu$	$5.96 \pm 0.42^{+0.45}_{-0.39}$
Combination	$5.70 \pm 0.21^{+0.31}_{-0.30}$

Belle Preliminary (913 fb^{-1})

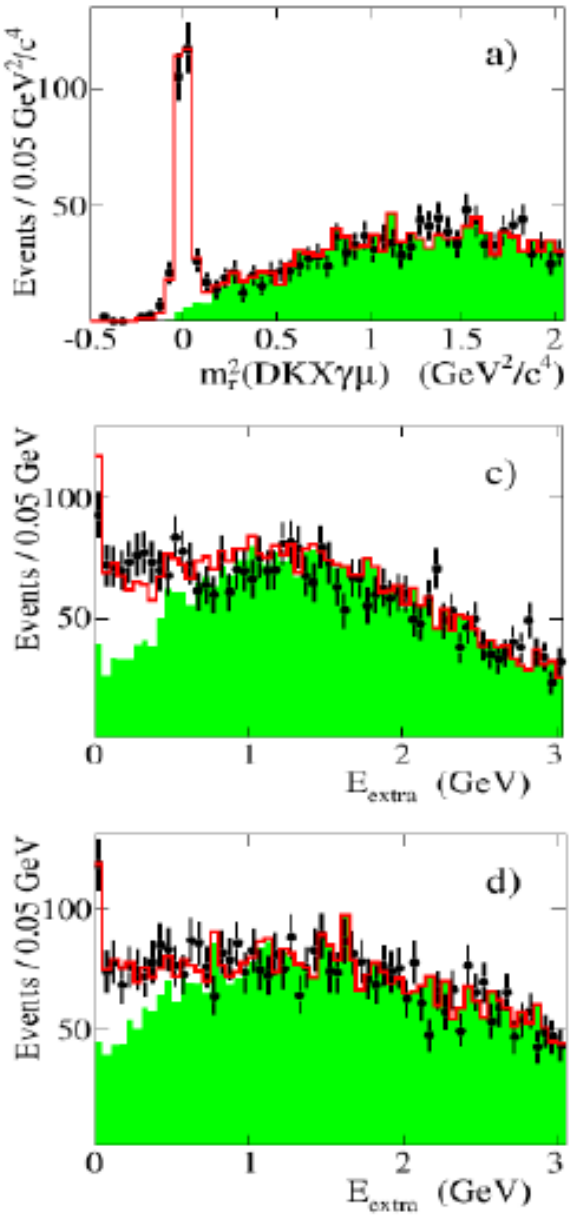
$D_s \to \ell\nu$	f_{D_s} [MeV]
$\mu\nu$	$249.0 \pm 6.6(\text{stat.}) \pm 4.6(\text{syst.}) \pm 1.7(\tau_{D_s})$
$\tau\nu$	$261.9 \pm 4.9(\text{stat.}) \pm 7.0(\text{syst.}) \pm 1.8(\tau_{D_s})$
Combination	$255.0 \pm 4.2(\text{stat.}) \pm 4.7(\text{syst.}) \pm 1.8(\tau_{D_s})$



Compare to previous Belle results 548 fb^{-1} PRL100, 241801(2008), total error reduce by factor of 3.

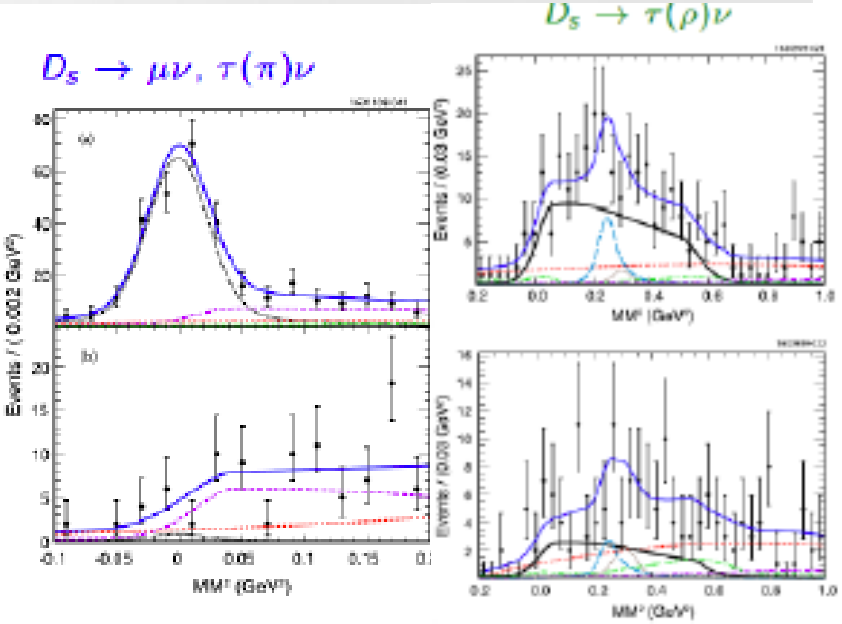
$D_s \to \mu\nu, \tau\nu$ (BaBar: 521 fb^{-1} @10.6 GeV)

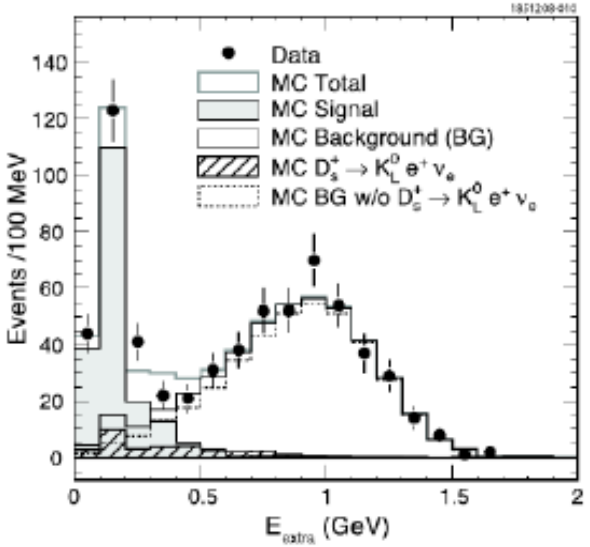
- PRD82, 091103(R)(2010)
- Recon. Method: Similar to Belle
- Tag side
  - 4 decay modes ($X \to n\pi$, n=0 - 3)
  - Background model: wrong flavor candidates (charge of not consistent with D_s)
  - # of tags: 67200±1500
- Signal side
  - $D_s \to \mu\nu$
    - Br($D_s \to \mu\nu$)=(0.602±0.038±0.034)%
  - $D_s \to \tau\nu$ ($\tau \to e\nu\nu$, $\mu\nu\nu$)
    - Br($D_s \to \tau\nu$)=(5.00±0.35±0.49)%
- Decay constant: f_{Ds} = (258.6 ± 6.4 ± 7.5)



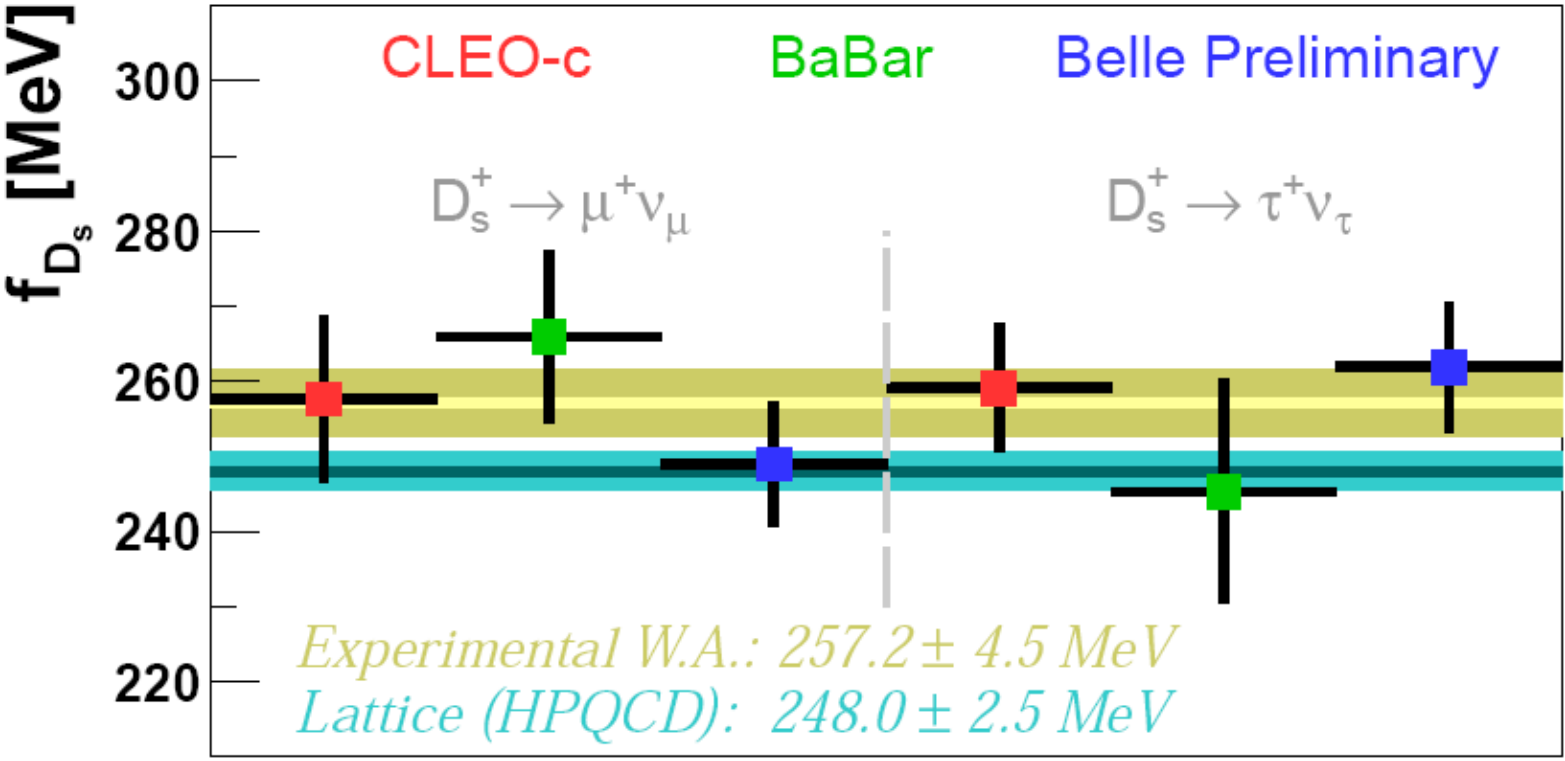
$D_s \to \mu\nu, \tau\nu$ (CLEO-c: 600 pb^{-1} @4.17GeV)

- PRD 79, 052001 (2009); PRD 80, 112004 (2009); PRD 79, 052002 (2009)
- $e^+e^- \to D_s D_s^*$ threshold ($D_s^* \to D_s\gamma$)
- Tag side
  - Fully reconstructed D_s^*
  - 9 decay modes
  - # of tags: 44000
- Signal side
  - $D_s \to \mu\nu$
    - Br($D_s \to \mu\nu$)=(0.565±0.045±0.017)%
  - $D_s \to \tau\nu$ ($\tau \to e\nu\nu$, $\mu\nu\nu$)
    - Br($D_s \to \tau\nu$)=(5.58±0.33±0.13)%
- Decay constant: f_{Ds} = (259.0 ± 6.2 ± 3.0)





f_{Ds} Comparison (from A. Zupanc)

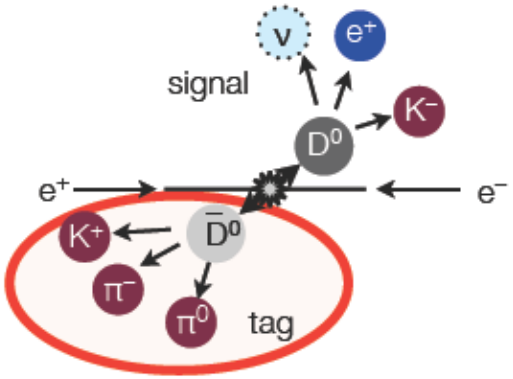


- Average of experimental determinations is consistent within 1.8σ with most precise lattice QCD calculation by HPQCD
- Need further lattice QCD results with comparable precision to confirm the calculation by HPQCD.
- BESIII currently have Ds data (0.4fb-1@4.01GeV), will acquire more data for f_{Ds} precise measurements.

Semileptonic decays

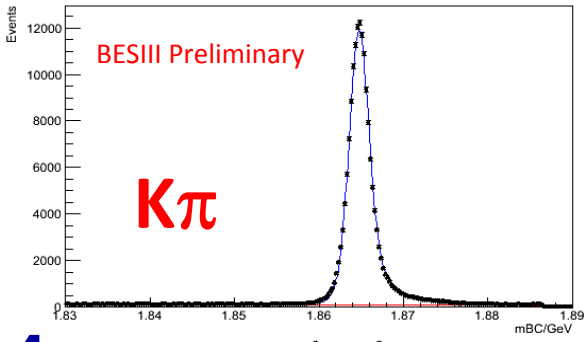
$D^0 \to K/\pi\, e^+\nu$ (BESIII: 0.9 fb^{-1})

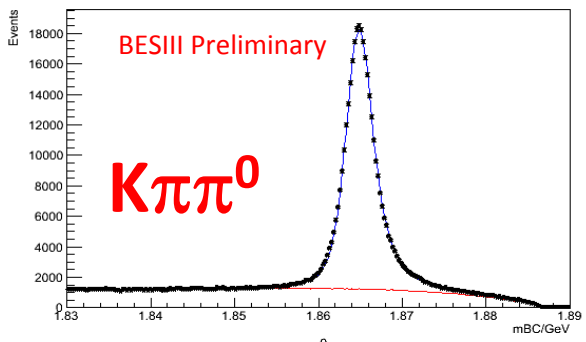
- **BESIII Preliminary results**
- **"Partially blind" analysis (0.9 fb^{-1} analyzed so far. Full 2.9 fb^{-1} later for final results)**

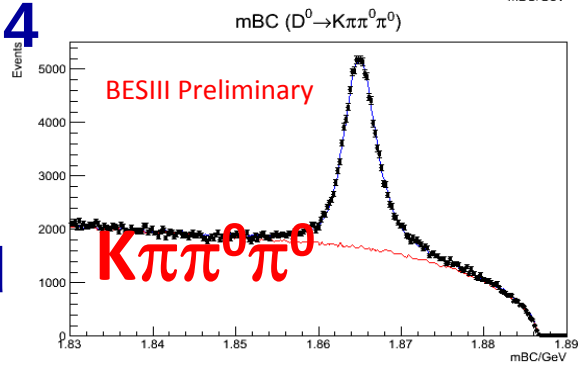


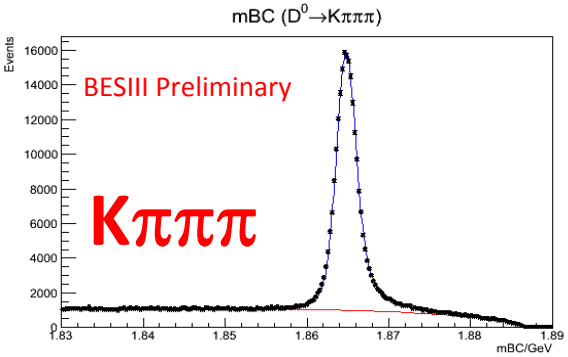
- **Tag side reconstruction:**
  - **Fully reconstruct 4 decay modes for one side D**
  - **0.77 M tags found**

Beam-constrained mass of tag D



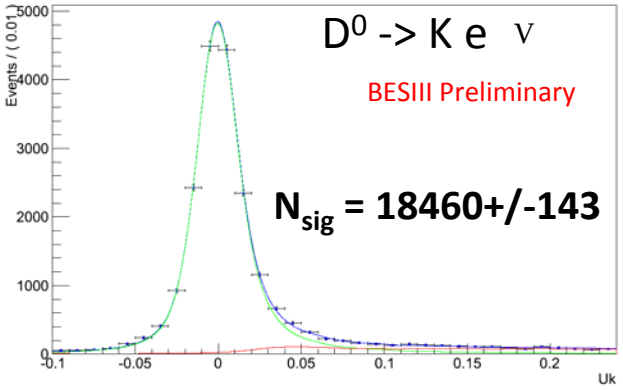


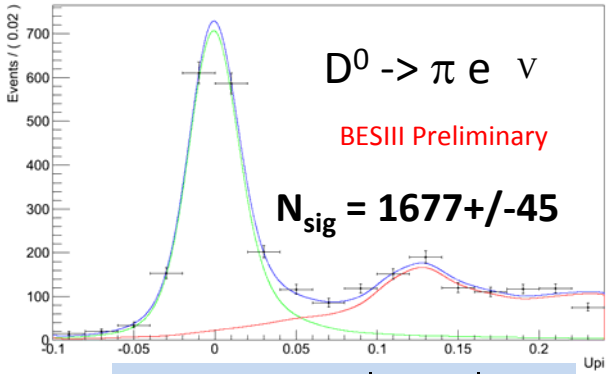




$D^0 \to K/\pi\, e^+\nu$ (BESIII: 0.9 fb^{-1})

- **Signal side reconstruction:**
  - Tag plus exactly two oppositely-charged tracks
  - Kaon/pion/electron ID
  - Electron has right charge
  - No extra neutral energy
  - Kinematic variable: U_{miss}
- **Systematic uncertainties are preliminary**
- **Good consistency with CLEO-c, statistical precision is comparable with only 1/3 data analyzed**





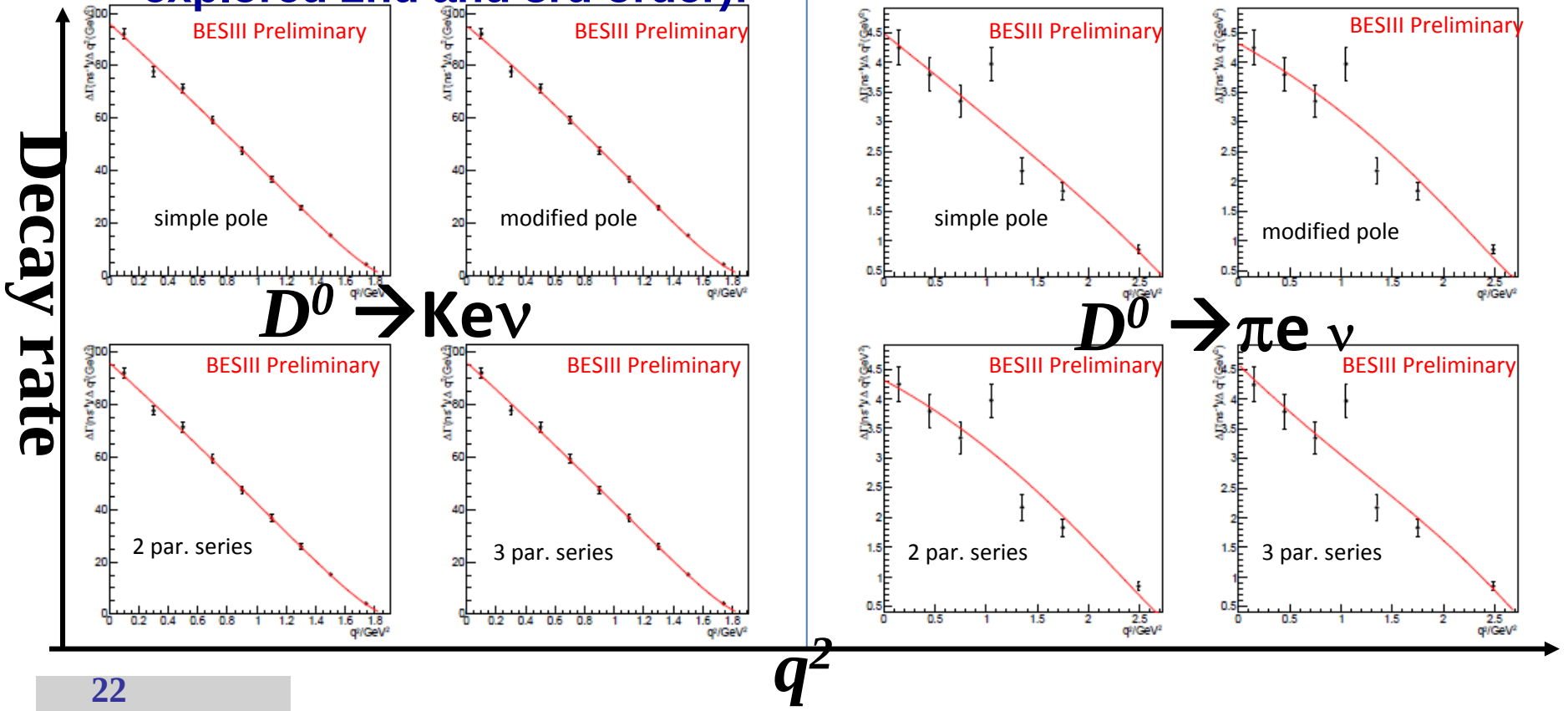
$$U = E_{\text{miss}} - \left|\vec{P}_{\text{miss}}\right| \approx 0$$

BESIII Preliminary

Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	3.542 $\pm$0.030$\pm$0.067	3.55 $\pm$0.04	3.50 $\pm$0.03 $\pm$0.04
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	0.288 $\pm$0.008$\pm$0.005	0.289 $\pm$0.008	0.288 $\pm$0.008$\pm$0.003

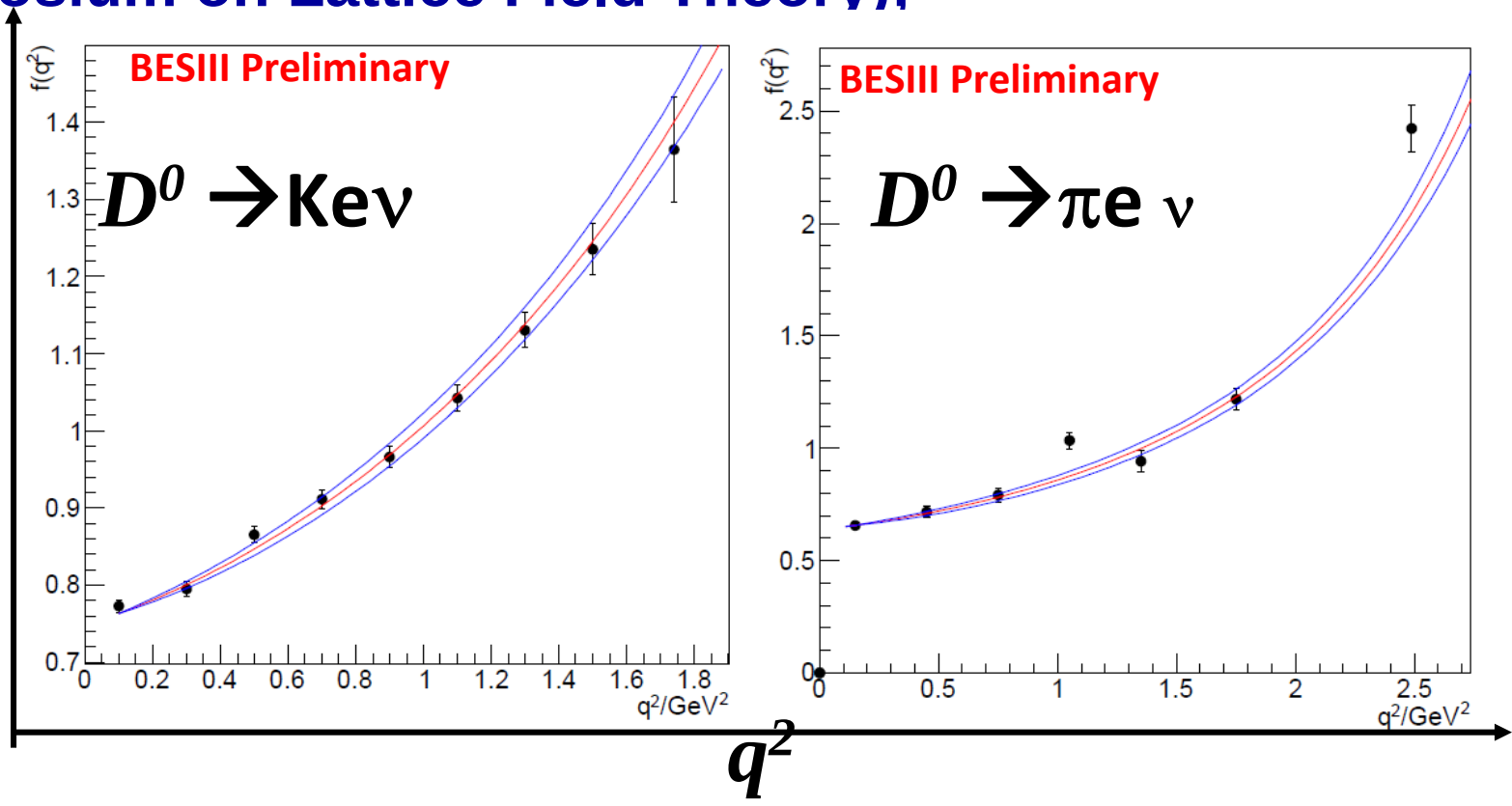
Form Factor Fits (BESIII: 0.9 fb^{-1})

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



$f(q^2)$ shapes (BESIII: 0.9 fb^{-1})

- Comparing shape only here
  - Points: BESIII preiminarydata with statistical error only
  - Curves: from Fermilab-MILC with 1σ stat. band, preliminary, arXiv:1111.5471 (XXIX International Symposium on Lattice Field Theory);

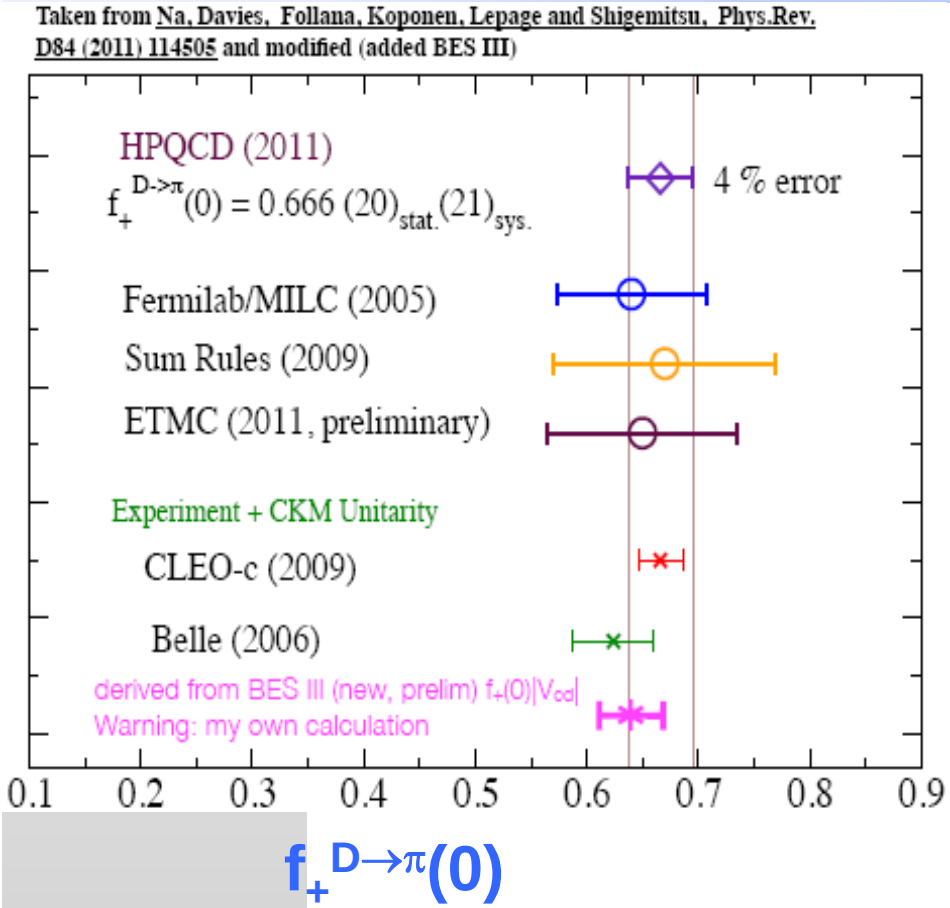


FF fit results (BESIII: 0.9 fb^{-1})

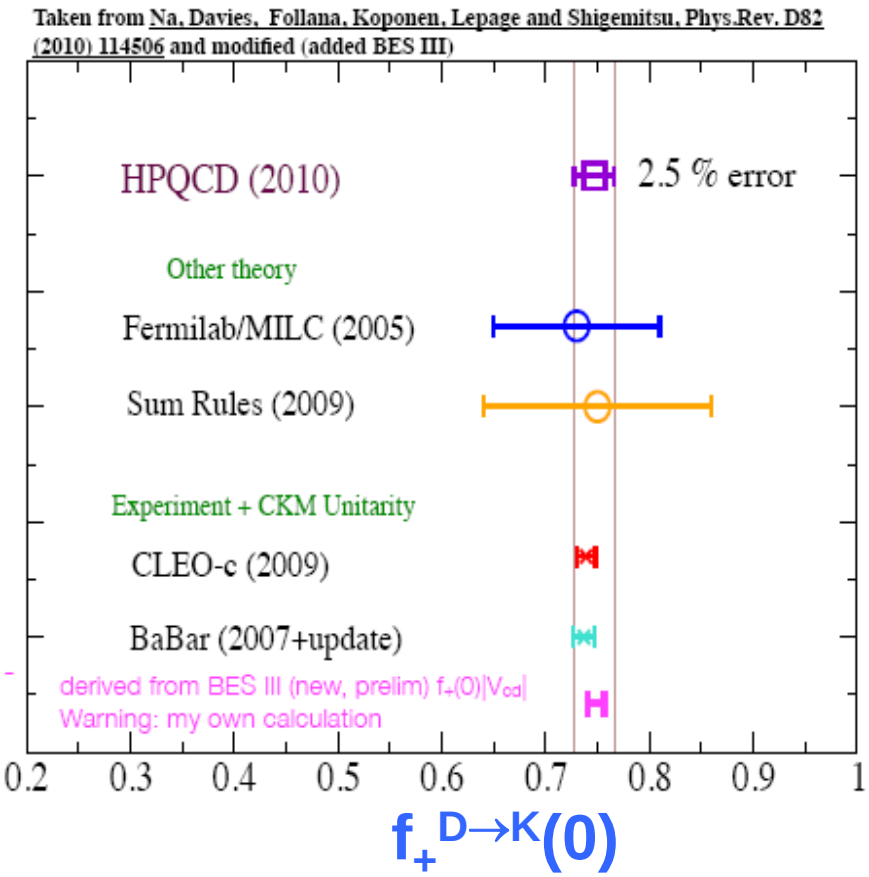
BESIII Preliminary

Simple Pole	$f_+(0)\|V_{cd(s)}\|$	m_{pole}	
$D^0 \to Ke\nu$	0.729±0.005±0.007	1.943±0.025±0.003	
$D^0 \to \pi e\nu$	0.142±0.003±0.001	1.876±0.023±0.004	
Modified Pole	$f_+(0)\|V_{cd(s)}\|$	α	
$D^0 \to Ke\nu$	0.725±0.006±0.007	0.265±0.045±0.006	
$D^0 \to \pi e\nu$	0.140±0.003±0.002	0.315±0.071±0.012	
2 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	
$D^0 \to Ke\nu$	0.726±0.006±0.007	−2.034±0.196±0.022	
$D^0 \to \pi e\nu$	0.140±0.004±0.002	−2.117±0.163±0.027	
3 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	r_2
$D^0 \to Ke\nu$	0.729±0.008±0.007	−2.179±0.355±0.053	4.539±8.927±1.103
$D^0 \to \pi e\nu$	0.144±0.005±0.002	−2.728±0.482±0.076	4.194±3.122±0.448

FF from experiment and theory



$f_+^{D\to\pi}(0)$



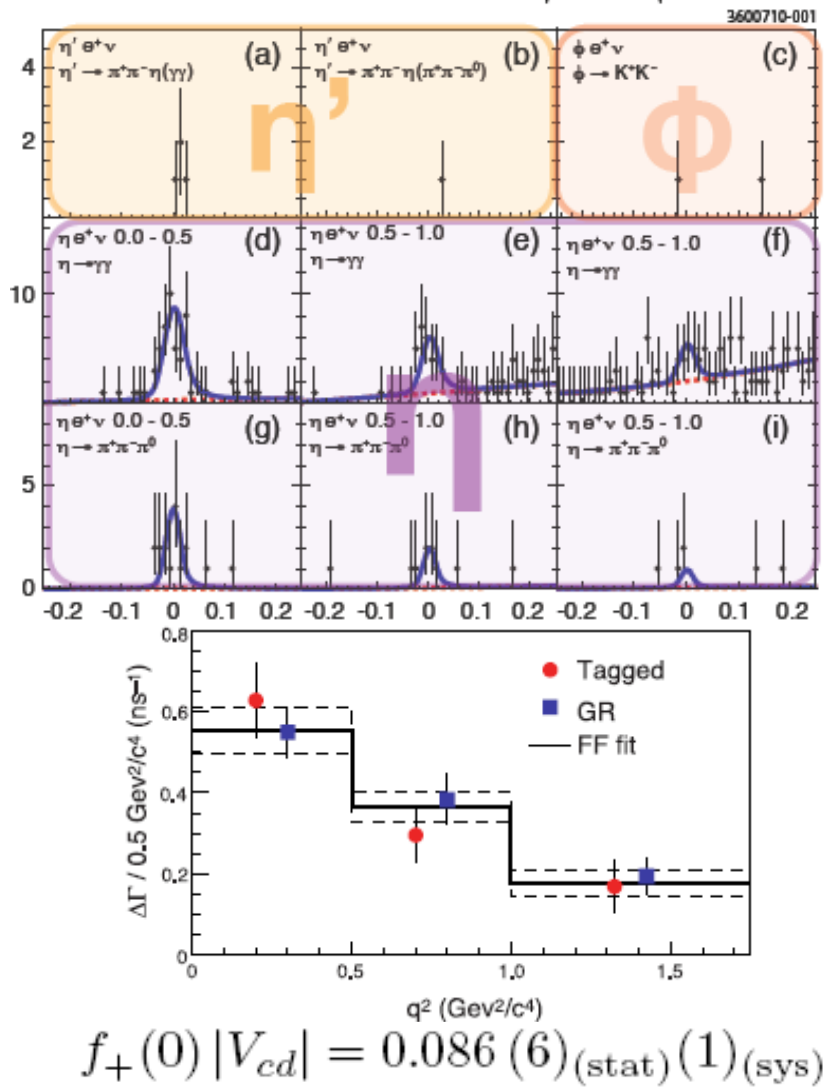
$f_+^{D\to K}(0)$

- From Jonas Rademacker at FPCP2012
- Note: BESIII result from D^0 only, CLEO-c use both D^0 and D^+

$D \to \{\eta,\eta' \text{ or } \phi\}\, e\nu$, (CLEO-c: 818 pb^{-1})

- CLEO: Phys.Rev. D84 (2011) 032001
  - form factor
  - η-η' mixing
  - QCD anomaly in heavy quak decay invl. η',
- Tag side
  - 6 decay modes
  - # of tags: 481K
- Signal side
  - Kinematic variable: U_{miss}
- Generic reconstruction method
  - No full reconstruction on Tag side
  - Adds up all momenta & energies in the event to identify ν
  - Fully reconstruct η, π^0 and Ks $\Rightarrow$ suppress background
- Combined results (Dorminated by "Generic recon method")
  - Br($D\to\eta' e\nu$)=(2.16±0.53±0.07) x10^{-4} (First observation, 5.8σ)
  - Br($D\to\eta e\nu$)=(11.4±0.9±0.4) x10^{-4}
  - Br($D\to\phi e\nu$)< 0.9x10^{-4} (@90% C.L.)

$$U \equiv E_{\rm miss} - |\vec{p}_{\rm miss}|$$

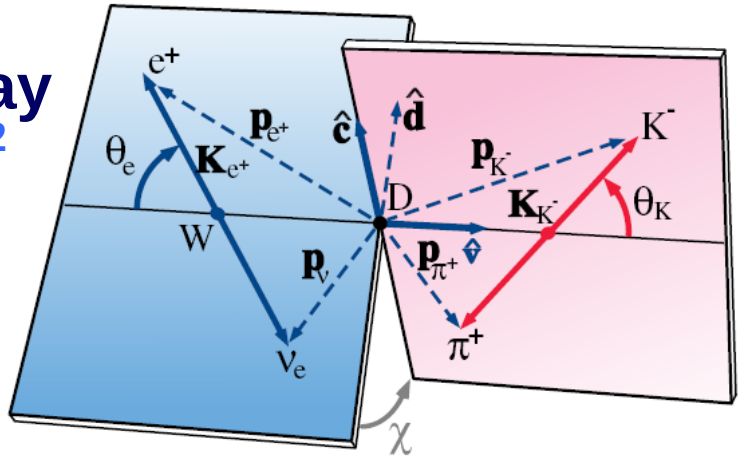


$$f_+(0)\,|V_{cd}| = 0.086\,(6)_{(\rm stat)}(1)_{(\rm sys)}$$

First D→ηeν Form Factor measurement

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

- **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**
- **Combined with $D \to \rho e \nu$, $D \to K^* e \nu$ a $B \to V\, l^+\, l^-$, 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 by FOCUS, PLB535 (2002) 43-51)**



Simple pole parameterization:

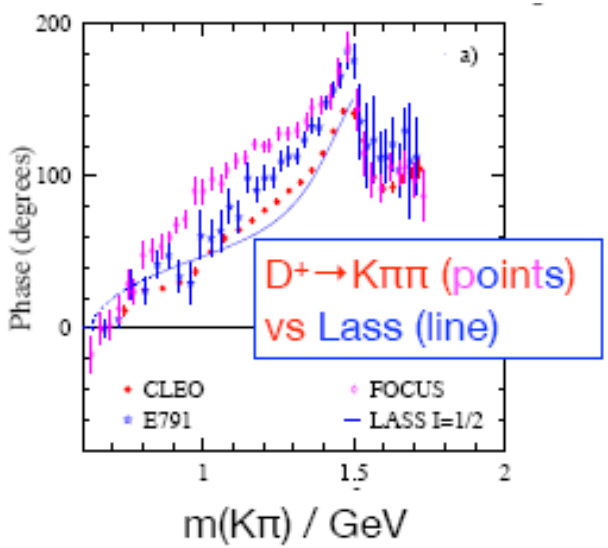
$$V(q^2) = \frac{V(0)}{1 - \frac{q^2}{m_V^2}}, \qquad r_V \equiv \frac{V(0)}{A_1(0)}$$

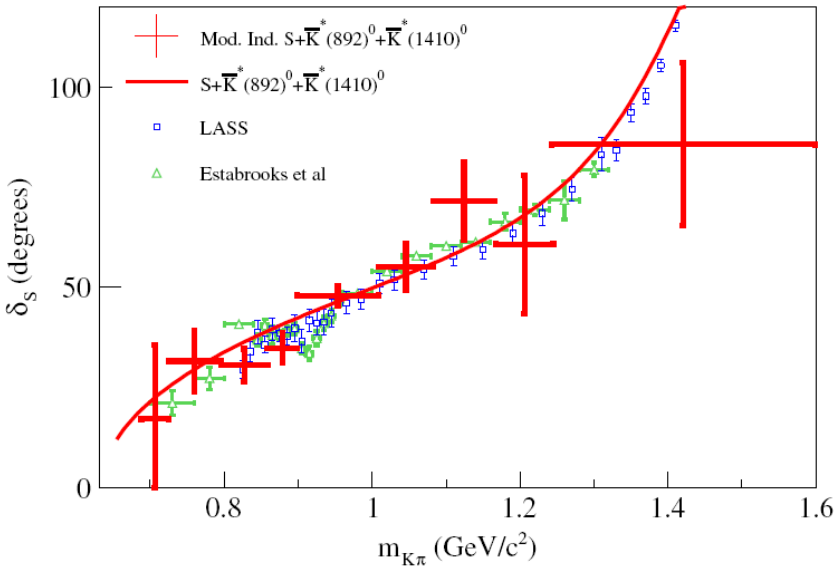
$$A_1(q^2) = \frac{A_1(0)}{1 - \frac{q^2}{m_A^2}}, \qquad r_A \equiv \frac{A_2(0)}{A_1(0)}$$

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

$D \to K^* e\nu$, $D \to K\pi e\nu$, (BaBar: 348 fb^{-1})

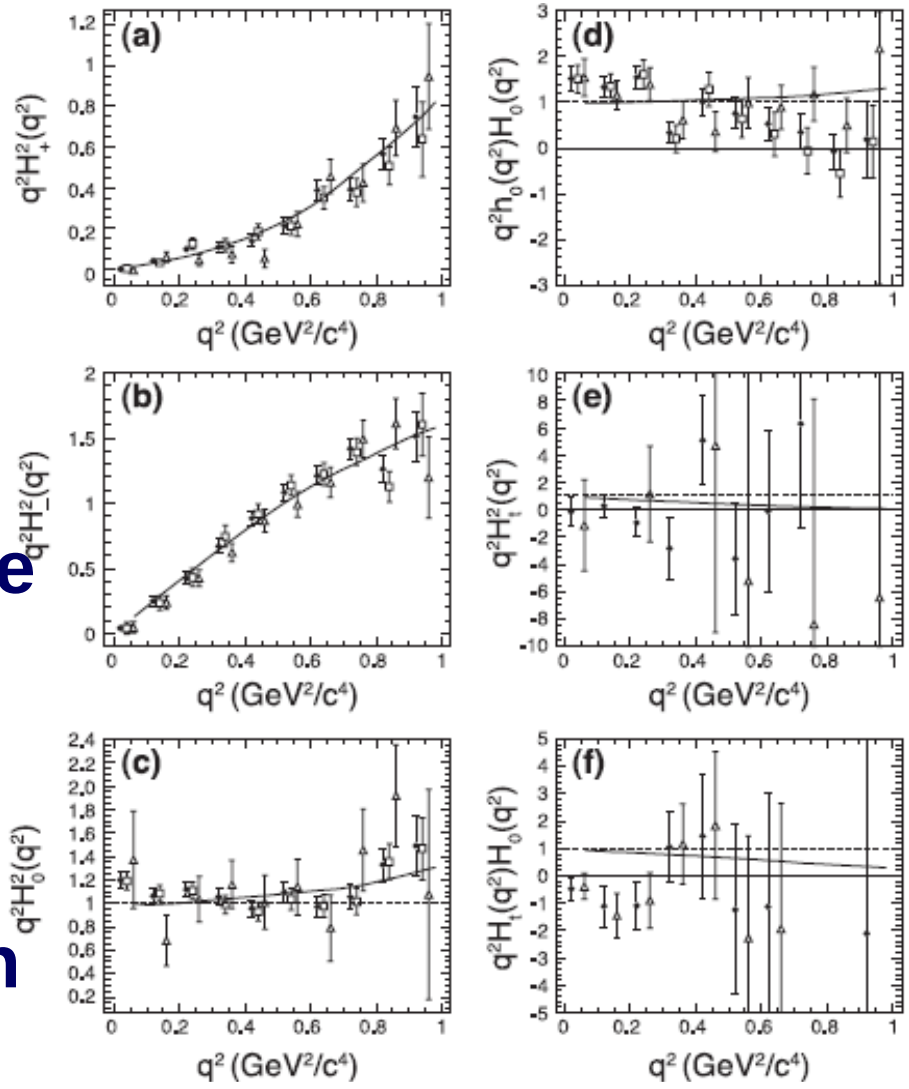
- Phys.Rev. D83 (2011) 072001
- Using 1/4 M tagged $D \to K\pi e\nu$ events, form factors of $D \to K^* e\nu$ were measured
  - m_A=2.63±0.10±0.13 GeV
    r_V=1.463±0.017±0.031
    r_A=0.801±0.020±0.020
- Performed detailed analysis of $K\pi$ S-wave ⇒ magnitude and phase δ_S
  - S-wave component was confirmed
- δ_S measurement (model-independent) agree with scattering data (D. Aston et al., Nucl. Phys. B 296, 493(1988)(LASS) and Estabrooks et al, Nucl. Phys. B 133, 490(1978)) better than the S-wave contributions measured in $D \to K\pi\pi$





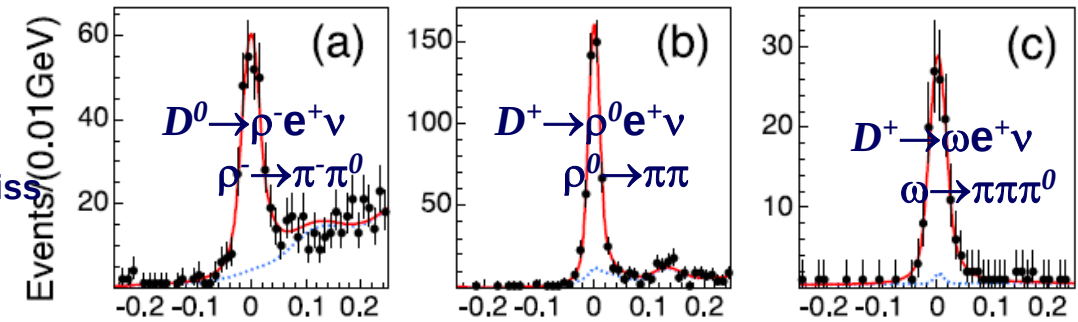
$D \to K\pi\ e/\mu\ \nu$ (CLEO-c: 818 pb^{-1})

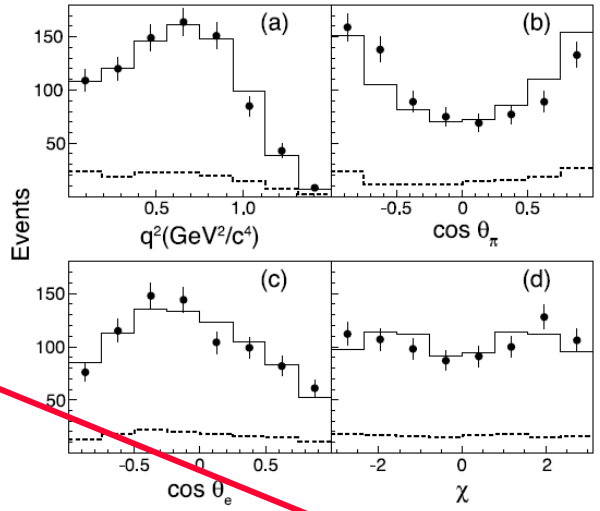
- Phys.Rev. D81 (2010) 112001
- Using a projective reweighting technique developed by FOCUS
- Compare model-independent measurements with simple pole model ⇒ good agreement
- Confirm evidence for S-wave
- $H_t H_0$ interference less than LQCD prediction



$D^0/D^+ \to \rho e \nu$, $D^+ \to \omega e \nu$ (CLEO-c: 818 pb^{-1})

- hep-ex: 1112.2884 (2011)
- Double tag technique, extract yields by fitting U = $E_{miss} - P_{miss}$
- Improved precision on BFs
- FF First measurement
  - $A_1(0) = 0.56 \pm 0.01 \pm 0.03$
    $A_2(0) = 0.47 \pm 0.06 \pm 0.04$
    $V(0) = 0.84 \pm 0.09 \pm 0.06$
- BFs (in unit 10^{-3}) are consistent with FK predictions (Fajfer and Kamenik, Phys. Rev. D 72, 034029 (2005))
- Results consistent with iso-spin invariance :(Iso-spin symmetry not expected to be exact due to ρ-ω interference)





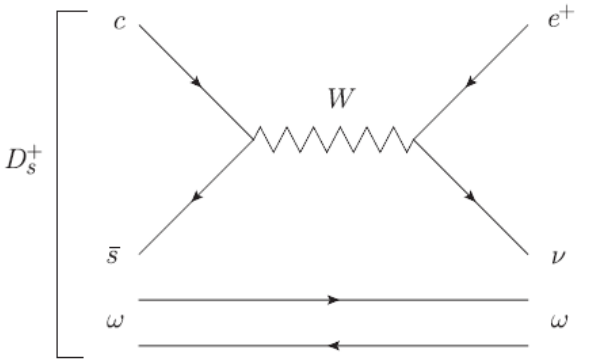
$$\frac{\Gamma(D^0 \to \rho^- e^+ \nu_e)}{2\Gamma(D^+ \to \rho^0 e^+ \nu_e)} = 1.03 \pm 0.09^{+0.08}_{-0.02}$$

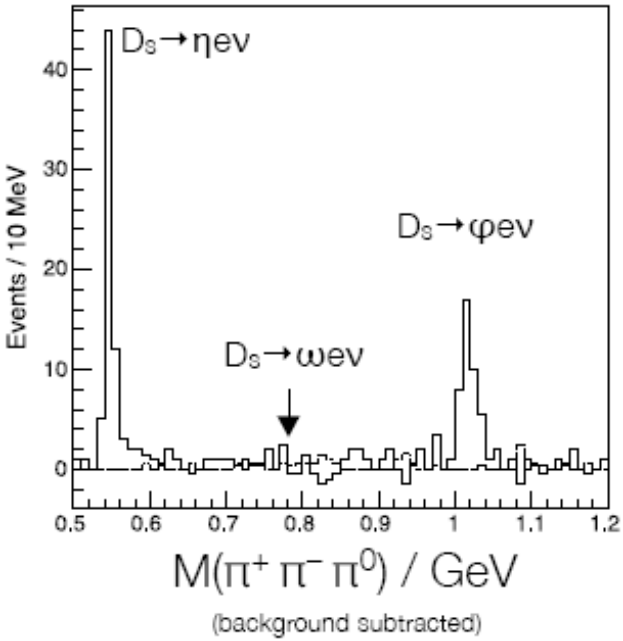
Decay Mode	ϵ (%)	$N_{\rm tag,\ SL}$	$\mathcal{B}_{\rm SL}$	$\mathcal{B}_{\rm SL}$(prev)	$\mathcal{B}_{\rm SL}$(ISGW2)	$\mathcal{B}_{\rm SL}$(FK)
$D^0 \to \rho^- e^+ \nu_e$	26.03 ± 0.02	304.6 ± 20.9	$1.77 \pm 0.12 \pm 0.10$	$1.94 \pm 0.39 \pm 0.13$	1.0	2.0
$D^+ \to \rho^0 e^+ \nu_e$	42.84 ± 0.03	447.4 ± 24.5	$2.17 \pm 0.12^{+0.12}_{-0.22}$	$2.1 \pm 0.4 \pm 0.1$	1.3	2.5
$D^+ \to \omega e^+ \nu_e$	14.67 ± 0.03	128.5 ± 12.6	$1.82 \pm 0.18 \pm 0.07$	$1.6^{+0.7}_{-0.6} \pm 0.1$	1.3	2.5

Search for $D_s \to \omega e\nu$ (CLEO-c: 586 pb^{-1})

- Gronau & Rosner (Phys.Rev. D79 (2009)074006)
  - Highly suppressed process
  - ω-ϕ mixing (ω has ssbar component): BR<2x10^{-4}
  - Weak annihilation (radiate an ω in a non-perturbative process before annihilating): BR~(0.13±0.05)%
  - Anything larger might be a hint to a 4-quark content of D_s
- Experimental search (PRD 84, 012005 (2011)) in $\omega \to \pi^+\pi^-\pi^0$ mode
  - Control samples: Ds $\to \{\eta,\phi\}e\nu$
  - No evidence of signals: Br($D_s \to \omega e\nu$) < 0.2%(@90% C.L.) $\Rightarrow$ No evidence of 4-quark content of D_s

A probe for a 4-quark contribution to the *Ds*





Summary and future perspective

- **Leptonic decays**
  - **BESIII released preliminary results on $D \to \mu\nu$**
  - **Experimental value of f_D is with precision of 2.5%**
  - **Belle released preliminary results: based on $D_s \to \mu\nu, \tau\nu$ final statistic**
  - **Experimental value of f_{Ds} is with precision of 1.75% (consistent within 1.8σ with most precise lattice QCD calculation)**
- **Semileptonic decays**
  - **Many new and improved form factor measurements (Exist Lattice QCD calculations generally in good agreement with data)**
  - **innovative ways of using semileptonic decays include rare decays to learn about the structure of D_s**
- **Most results are from experiments that have stopped data taking, and most are statistics limited**
- **In future**
  - **BES III have shown first results, much more are coming.**
  - **the super B factories: Large inclusive samples of all charmed hadrons**

Thank you

Backup slides