D meson semileptonic decay studies with CLEO-c

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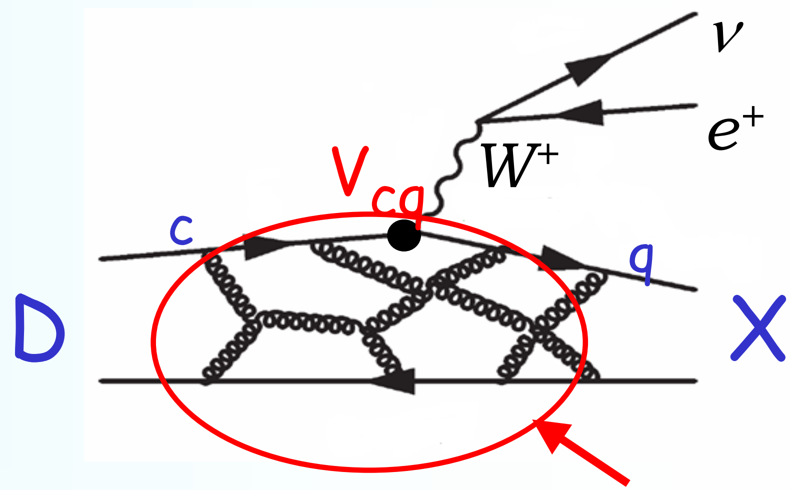
representing the CLEO collaboration

- Overview
  - Motivation
  - Absolute exclusive semileptonic branching fractions
  - Inclusive semileptonic decays
  - Conclusions

Semileptonic Decays: $D \to X\ell^+\nu$

- In principle, the best way to determine magnitudes of CKM elements, is to use semileptonic decays. Decay rate $\alpha|V_{cq}|^2$
- This is how V_{us} (λ) and V_{cb}(A) have been determined



Strong interaction effects

- Kinematics: $q^2 = \left(p_D^\mu - p_{hadron}^\mu\right)^2 = m_D^2 + m_P^2 - 2E_P m_D$
- Measure:

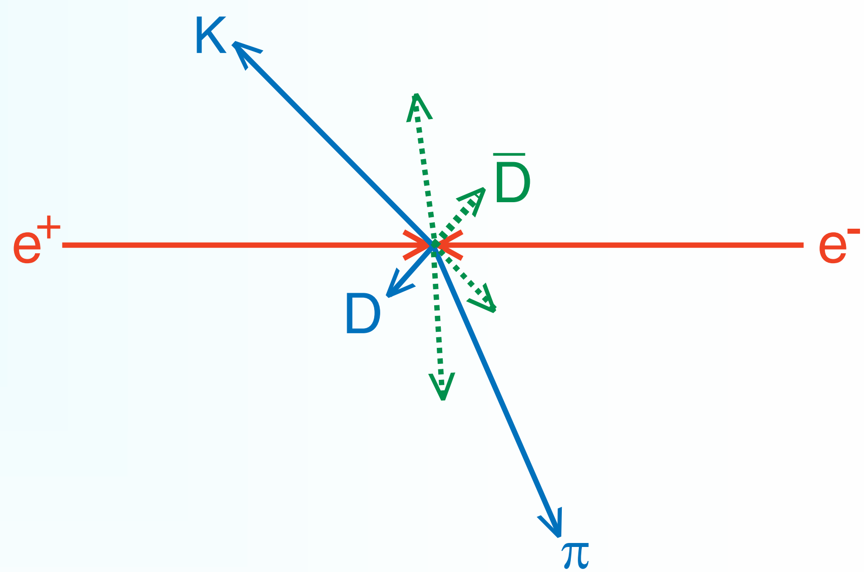
$$\frac{d\Gamma\left(D^+ \to Xe\nu\right)}{dq^2} \;\alpha\; P_\pi^3 \left|f_+(q^2)\right|^2$$

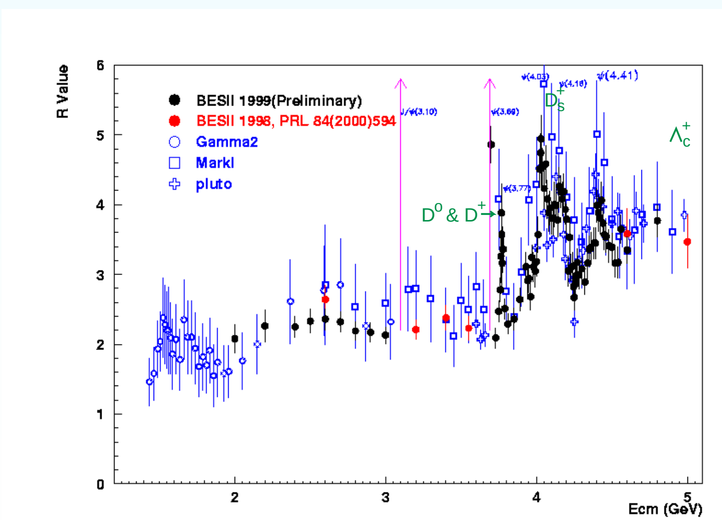
Goals in Semileptonic Decays

- Assuming V_{cs} and V_{cd} known:
  - $D \to K(K^*)\ell\nu$ determine form factor shapes & distinguish among models + test lattice QCD predictions
  - $D \to \pi \to \ell\nu$
  - Lattice checks comparing semileptonic ff & f_D
- measurements of V_{cd} & V_{cs} (+ V_{cb} would provide an important unitarity check)
- V_{ub} use $D \to \rho\ell\nu$ to get form-factor for $B \to \rho\ell\nu$, at same v•v point using HQET (& $\pi\ell\nu$)

Experimental method: CLEO-c

Results presented are based on first 55.8 pb^{-1} at $\psi(3770)$





•System is over-constrained
□$\Sigma p_i \Rightarrow 3$, $E_{tot} \Rightarrow 1$, $m_D = \bar{m}_D \Rightarrow$
5constraints –3(4) for p_ν

Exclusive semileptonic decays: analysis method

We start with tagged samples

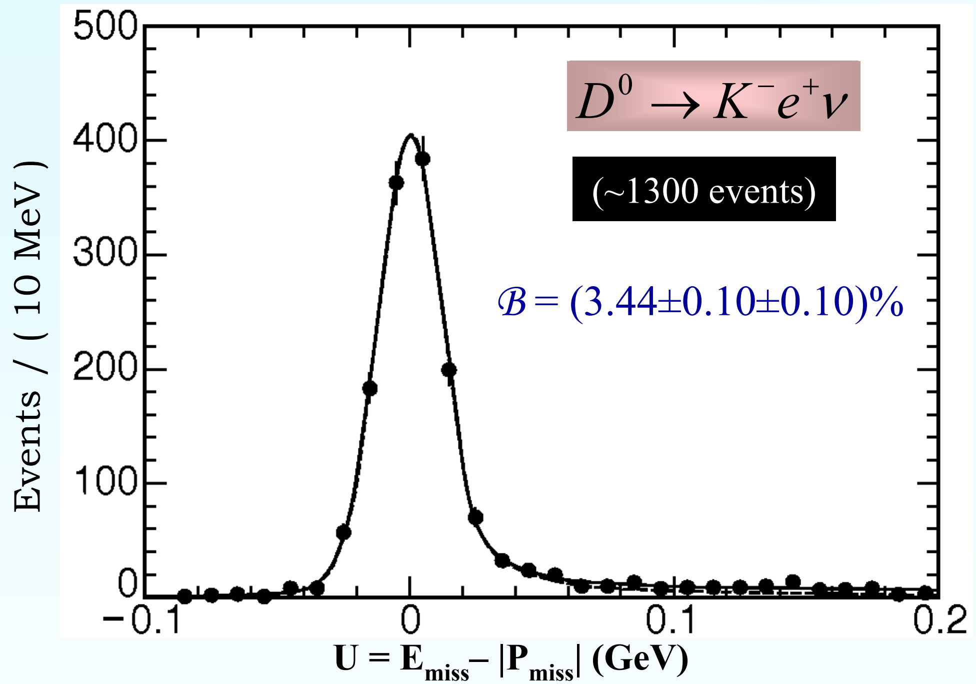
We use kinematic variable

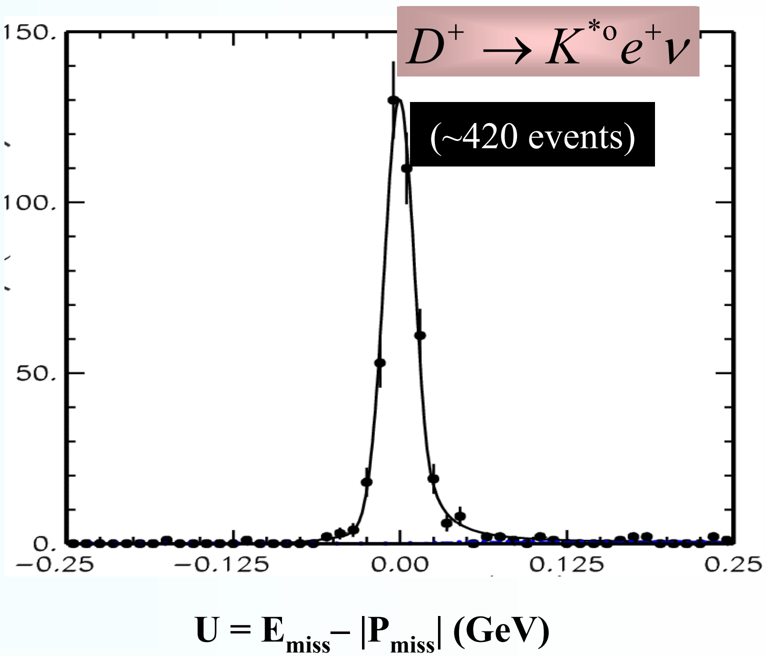
$$U \equiv E_{miss} - c\vec{p}_{miss}$$

to select a specific semileptonic channel

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

Cabibbo Favored Semileptonic Decays

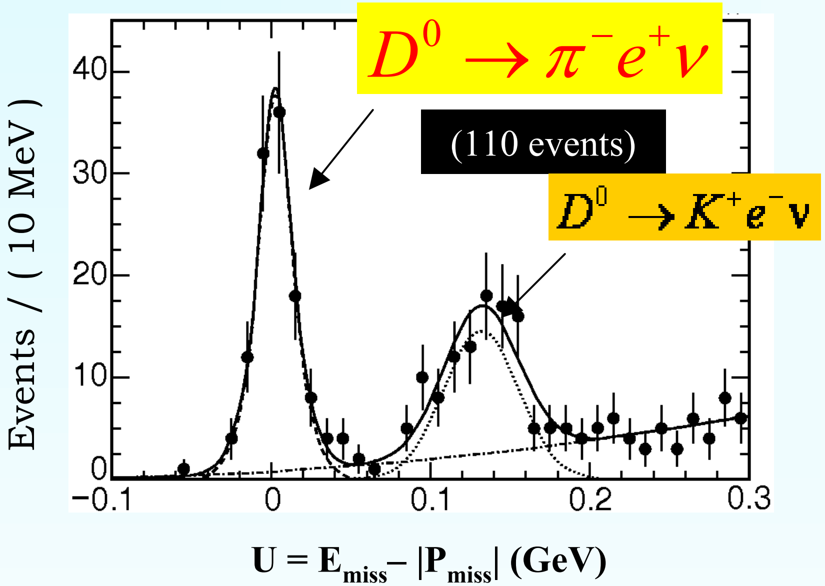


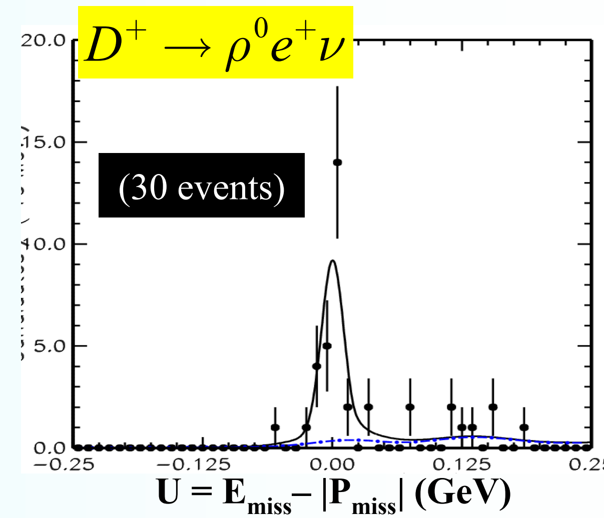


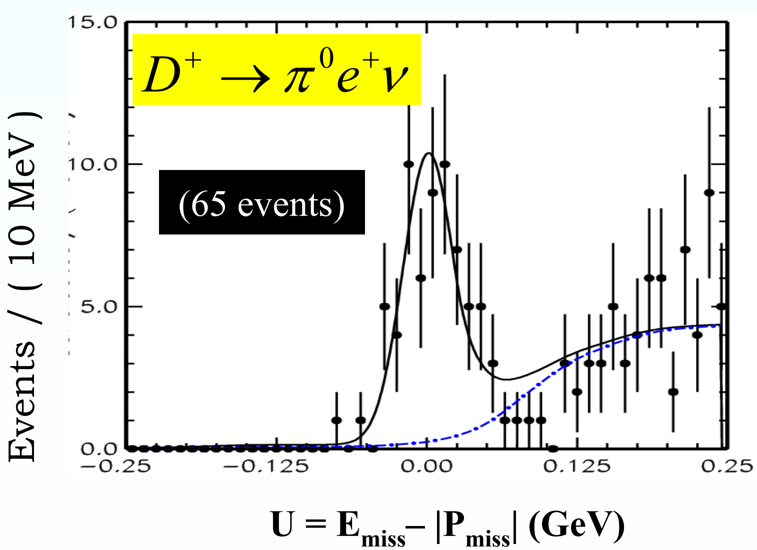
$\mathcal{B} = (5.70\pm0.28\pm0.25)\%$

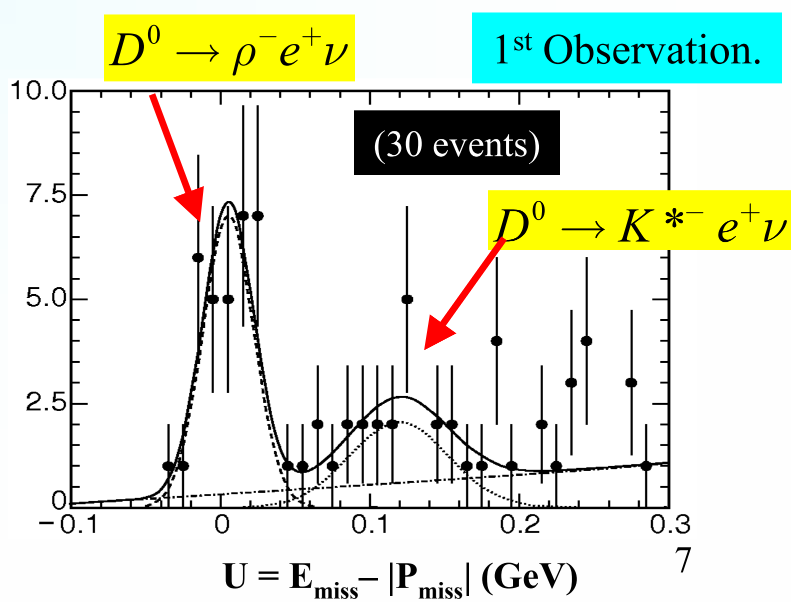
Uses tagged sample. These are the dominant modes, so backgrounds are almost non-existent

Cabibbo Suppressed Semileptonic Decays









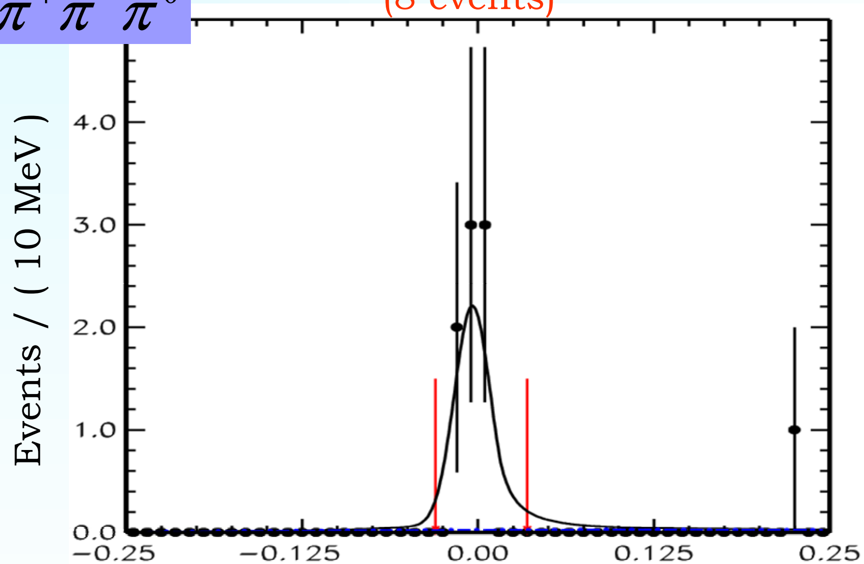
Cabibbo suppressed semileptonic decays-continued

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

$$\omega \to \pi^+ \pi^- \pi^0$$

World First Observation

(8 events)



U=(Emiss – |Pmiss|)

soon results from 281 pb^{-1} available, including study of the FF shape

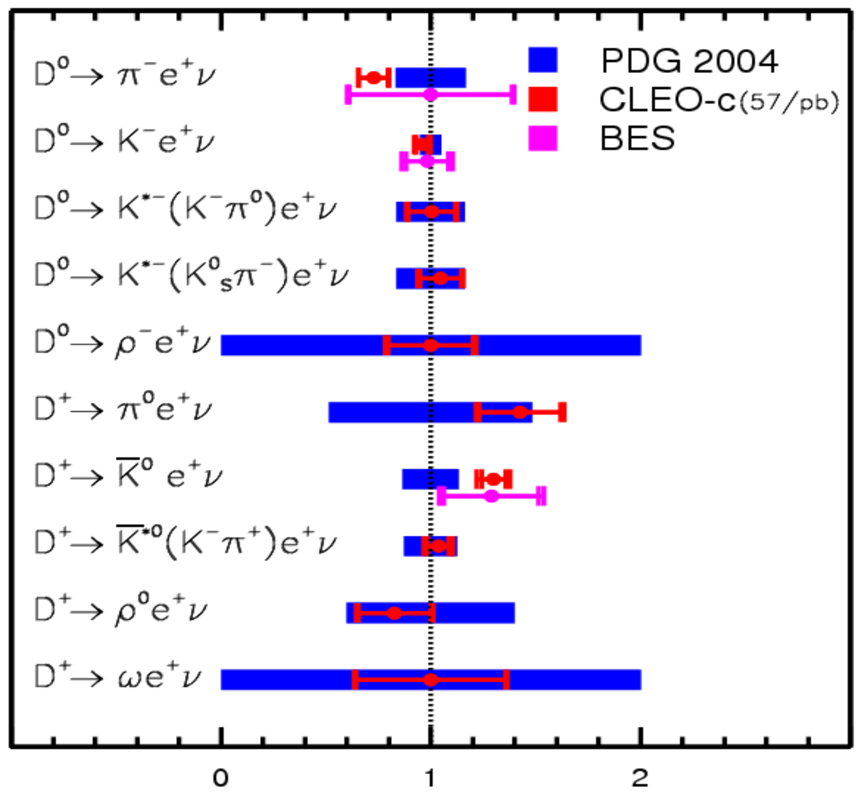
Summary of exclusive branching fractions measured

Decay Mode	$\mathcal{B}(\%)$	$\mathcal{B}(\%)$ BES	$\mathcal{B}(\%)$ (PDG)
$D^0 \to K^- e^+ \nu_e$	$3.44 \pm 0.10 \pm 0.10$	$3.82 \pm 0.40 \pm 0.27$	3.58 ± 0.18
$D^0 \to \pi^- e^+ \nu_e$	$0.262 \pm 0.025 \pm 0.008$	$0.33 \pm 0.13 \pm 0.03$	0.36 ± 0.06
$D^0 \to K^{*-} e^+ \nu_e$	$2.16 \pm 0.15 \pm 0.08$		2.15 ± 0.35
$D^0 \to \rho^- e^+ \nu_e$	$0.194 \pm 0.039 \pm 0.013$		
$D^+ \to \underline{K}^0 e^+ \nu_e$	$8.71 \pm 0.38 \pm 0.37$		6.7 ± 0.9
$D^+ \to \pi^0 e^+ \nu_e$	$0.44 \pm 0.06 \pm 0.03$		0.31 ± 0.15
$D^+ \to \underline{K}^{*0} e^+ \nu_e$	$5.56 \pm 0.27 \pm 0.23$		5.5 ± 0.7
$D^+ \to \rho^0 e^+ \nu_e$	$0.21 \pm 0.04 \pm 0.01$		0.25 ± 0.10
$D^+ \to \omega^0 e^+ \nu_e$	$0.16^{+0.07}_{-0.01} \pm 0.01$		

First measurements

CLEO Exclusive Semileptonic Branching Ratios: another view

- 5 D^0 and 6D^+ semileptonic modes measured in a consistent manner
- $D^0 \to \rho^- e^+ \nu$ and $D^+ \to \omega e^+ \nu$ are observed for the first time
- The widths of the isospin conjugate exclusive semileptonic decay modes are expected to be equal due to the isospin invariance of the hadronic current; we obtain:



$$\frac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\Gamma(D^+ \to \bar{K}^0 e^+ \nu_e)} = 1.00 \pm 0.05(stat) \pm 0.04(sys)$$

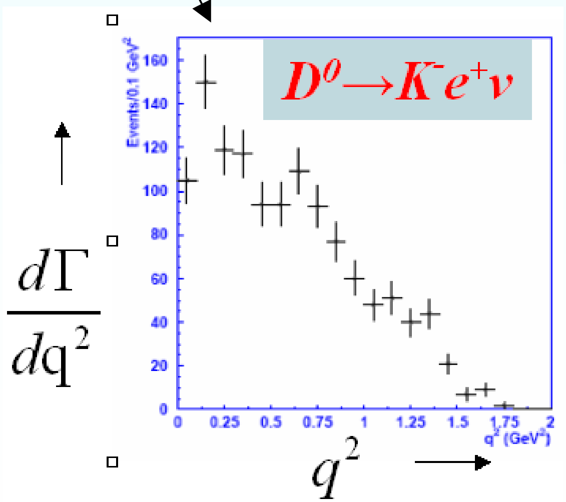
If we assume isospin invariance…

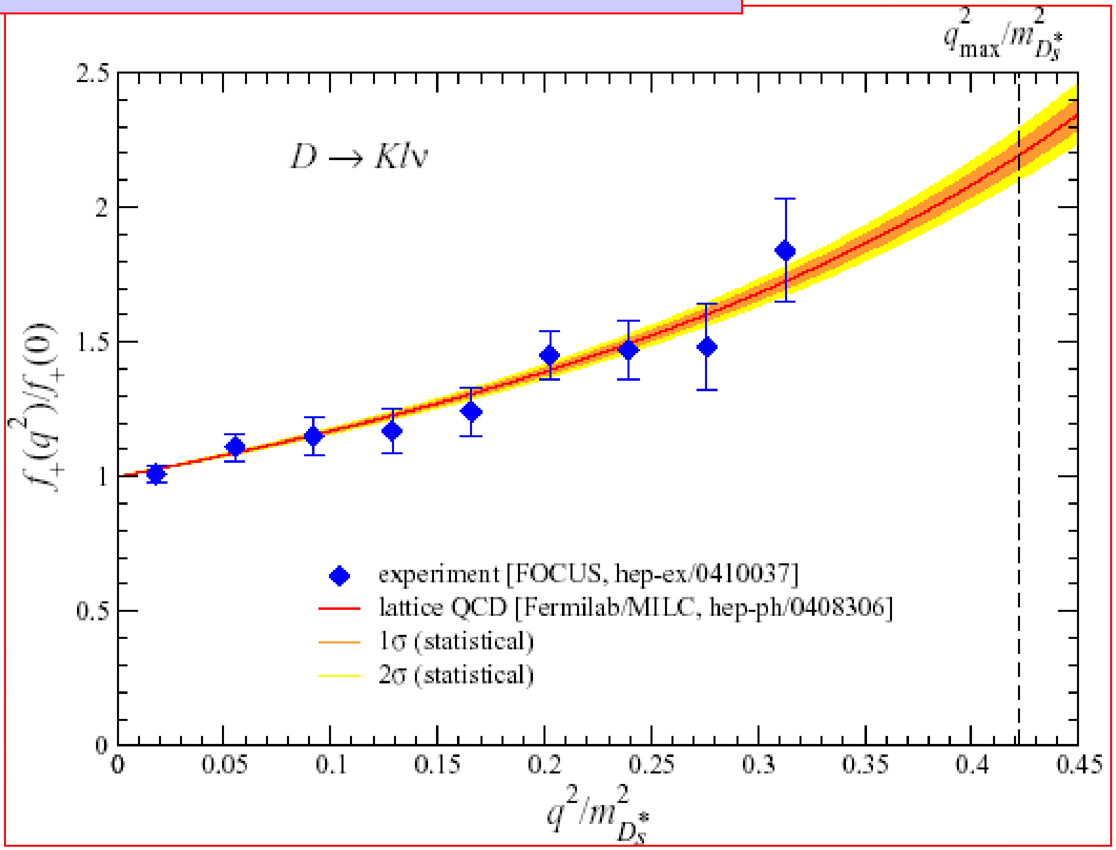
Decay mode	$\Gamma(ps^{-1})$
$D \to K e^+ \nu_e$	0.0838 ±0.0030 ±0.0023
$D \to \pi e^+ \nu_e$	0.0068 ±0.0005 ±0.0002
$D \to K^* e^+ \nu_e$	0.0532 ±0.0021 ±0.0020
$D \to \rho e^+ \nu_e$	0.0043 ±0.0006 ±0.0002

Lattice comparison - the shape

Comparison between non-parametric analysis by FOCUS and lattice prediction

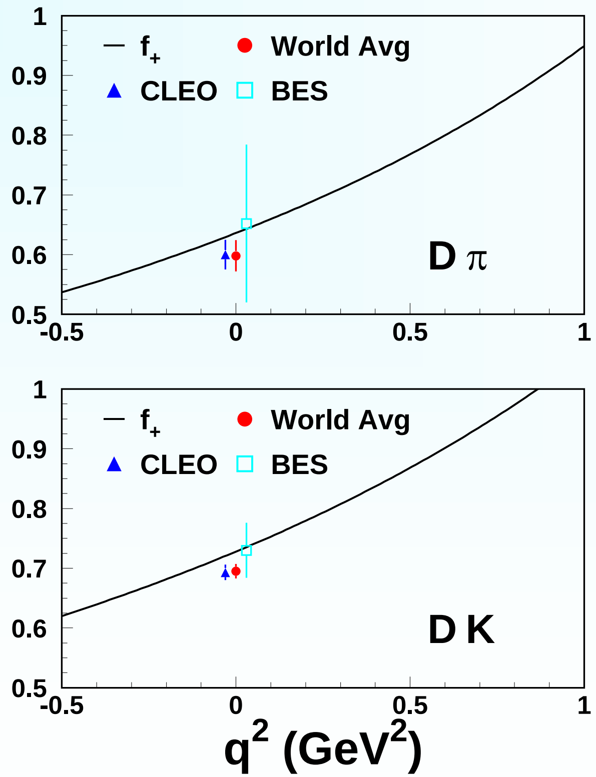
CLEO-c raw q^2 →No efficiency correction, results soon from 281 pb^{-1}





Lattice comparison – $f_+(0)$

If we assume that the lattice shape is OK ⇒we can use our branching fraction measurements to validate the normalization



V_{cs} and V_{cd}

- Assuming that shape and normalization of the form factors are OK:

$$V_{cs} = 0.958 \pm 0.017(exp) \pm 0.067(th)$$
$$V_{cd} = 0.214 \pm 0.009(exp) \pm 0.016(th)$$

Using isospin averaged widths

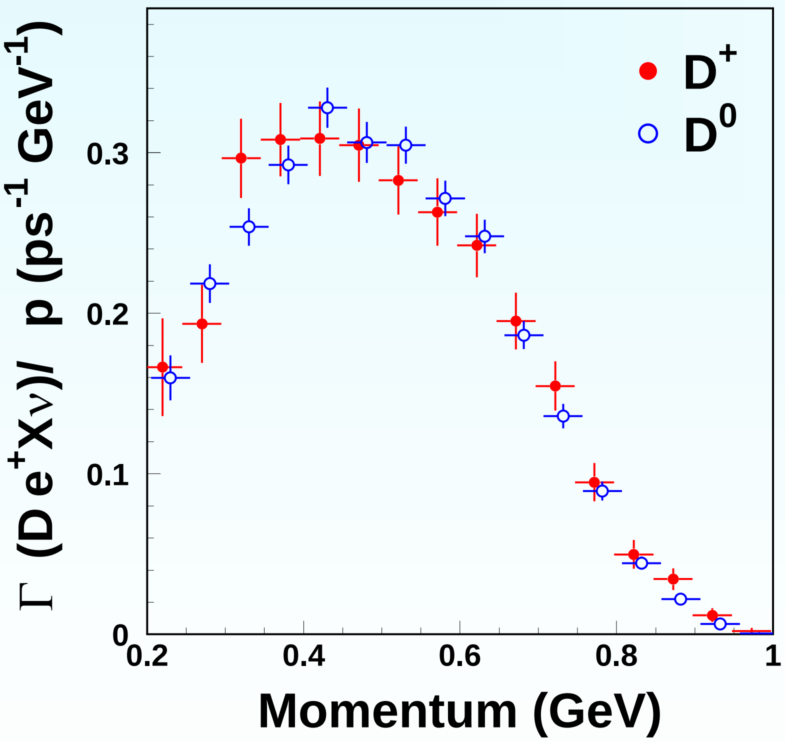
Inclusive semileptonic studies

- Motivation:
  - precision measurements of $\Gamma(D \rightarrow X \ell \nu)$ and $\Gamma(D_s \rightarrow X \ell \nu)$ constrains WA effects in B and D semileptonic decays
  - Comparison between $d\Gamma/dE_\ell(D^+ \rightarrow X \ell \nu)$ and $d\Gamma/dE_\ell(D^0 \rightarrow X \ell \nu)$

Analysis strategy

- Use a tagged D sample ($D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ + exploit knowledge of flavor of the tagging D (charge for D^+ and K charge for D^0)
- Evaluate raw e,π,K spectra (right and wrong sign)
- Unfold true e spectrum
- Subtract D background (sidebands)
- Extrapolate to the whole spectrum

Results



Lab momentum spectrum – no FSR correction

- Using MC simulation (including FSR) to extrapolate to the whole spectrum, we obtain:

$$B(D^+ \to Xe\nu) = (16.19 \pm 0.20 \pm 0.36)\%$$

$$B(D^0 \to Xe\nu) = (6.45 \pm 0.17 \pm 0.15)\%$$

Conclusions

- CLEO-c has achieved the most comprehensive and accurate study of exclusive and inclusive semileptonic branching fractions
- Results consistent with theory within error: true litmus test when theory and data will be at % level and shape of ff will be available from data
- Combination of studies of SL decays and f_D will allow lattice test independent of CKM input
- Form factors in Cabibbo suppressed semileptonic decays will lead to a better understanding of $B\to\pi\ell\nu$