Leptonic and Semileptonic Decays of D and D_s Mesons at CLEO-c

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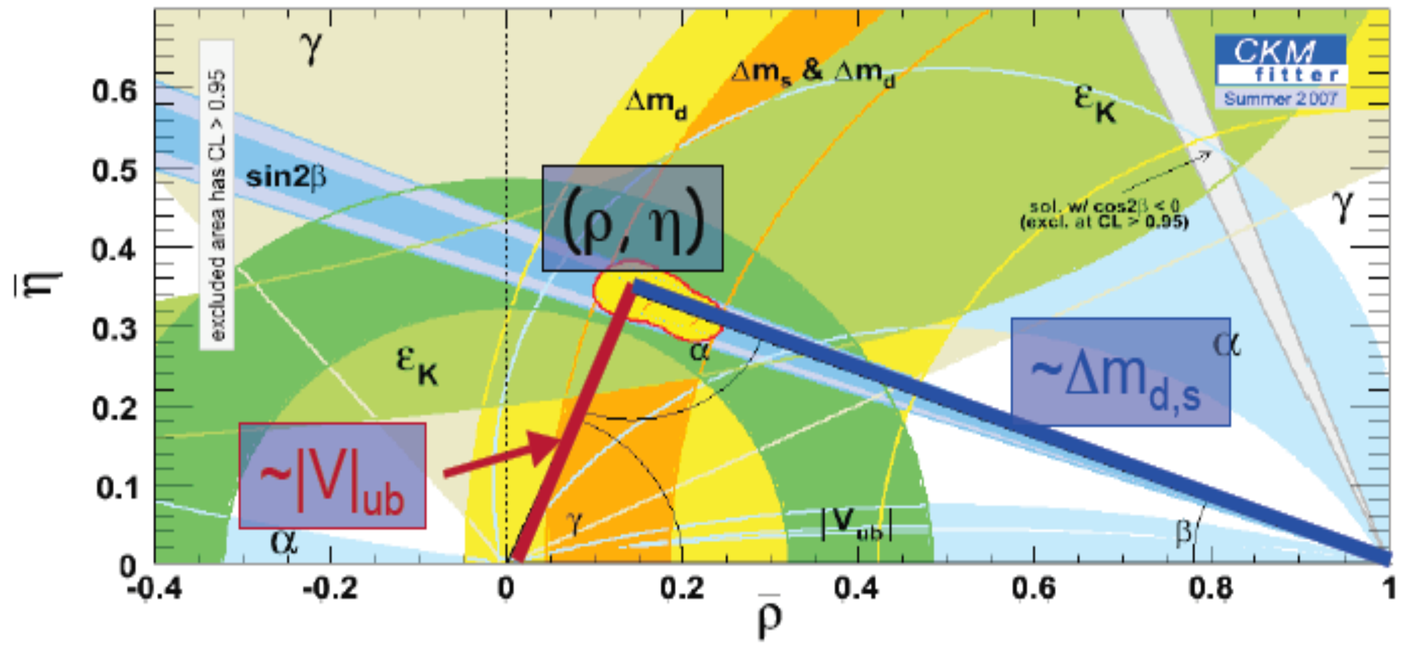
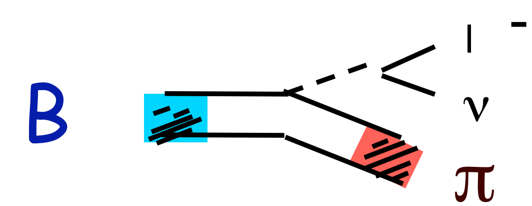
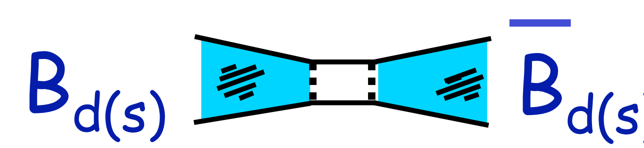
(on behalf of the CLEO Collaboration)

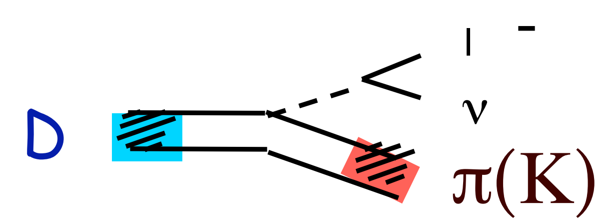
Motivation

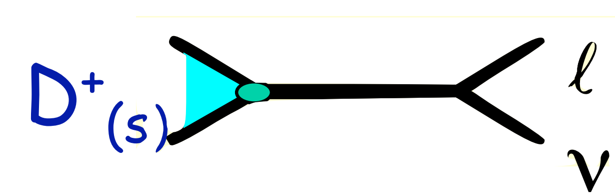
- Precision flavor physics is the central goal
- Tests of CKM unitarity depend on both theory and experiment input
- The role of CLEO-c: provide experimental measurements to validate needed theoretical inputs
- Focus on semileptonic form factors and leptonic decay constants









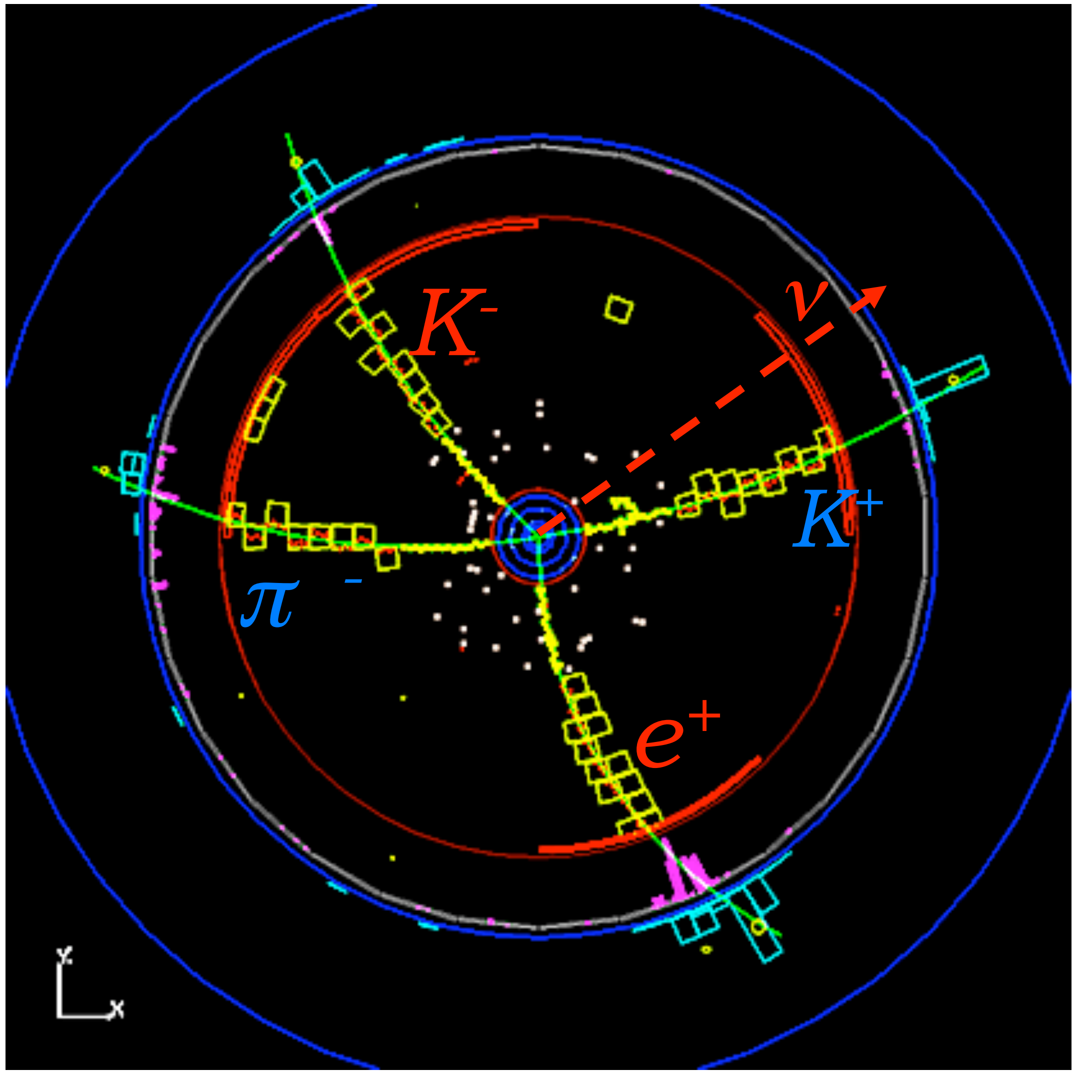


CLEO-c Data Sets/Outline

- Two data sets of primary interest for $D_{(s)}$ leptonic and semileptonic decays
  - 818 pb^{-1} taken at E_{cm} = 3770 MeV
    - $D\to(\mu,\tau)\nu$ results on entire data set
    - $D\to(\pi,K)e\nu$ results on 281 pb^{-1}
    - Omitted: $D\to(\eta,\eta',\Phi)e\nu$ (arXiv:0802.4222 [hep-ex])
  - 586 pb^{-1} taken at E_{cm} = 4170 MeV: peak D_s production cross section in the form of $D_sD_s^*$
    - Preliminary $D_s\to(\mu,\tau)\nu$ ($\tau\to\pi\nu$) using ~400 pb^{-1}
    - $D_s\to\tau\nu$ ($\tau\to e\nu\nu$) using ~300 pb^{-1}
    - Preliminary Exclusive D_s semileptonic BF's using ~300 pb^{-1}

D Tagging Technique

- At E_{cm} = 3770 MeV: pure two-body production of $D\overline{D}$
- Fully reconstruct one D as a "tag"
  - provides four-momentum of "signal D" -- enables clean reconstruction of final states with missing particles (neutrinos)
  - number of tags normalizes absolute branching fraction measurements
- At E_{cm} = 4170 MeV: production is $D_s\overline{D}_s^*$
  - similar strategy, but slight complication from extra γ



tag D's using:

$$M_{bc} = \sqrt{E_{beam}^2/c^4 - \left|\vec{p}_D\right|^2/c^2}$$

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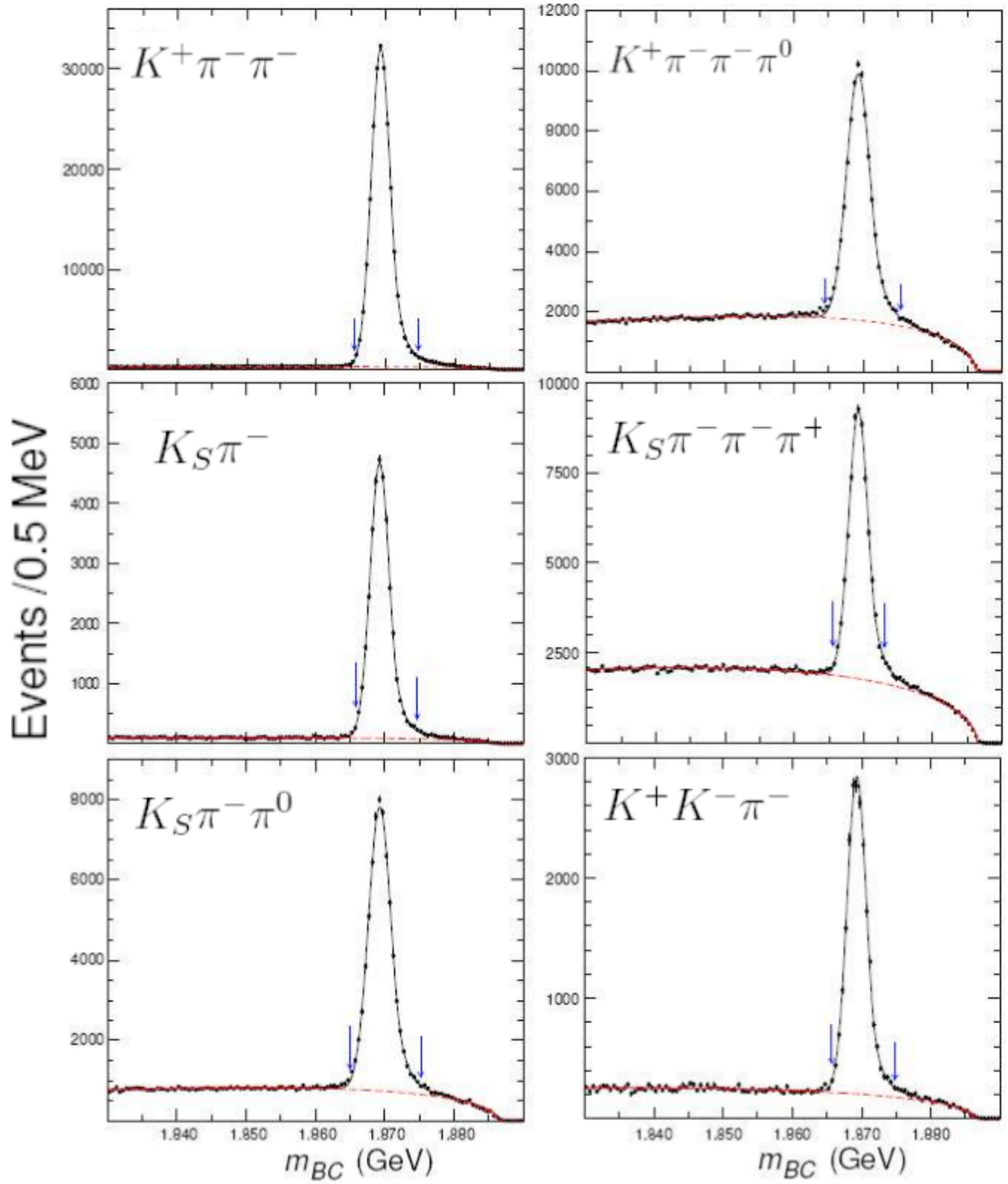
D→(μ,τ)ν Strategy

- Fully reconstruct one D
- Require only one additional track and no additional photons with E > 250 MeV
- Separate sample based on signal track energy in calorimeter (E_{cc})
  - E_{cc} < 300 MeV: efficiency 99% (muons) and 55% (pions)
  - E_{cc} > 300 MeV: efficiency 1% (muons) and 45% (pions)
- Plot missing-mass squared (MM^2) for each sample
  - D→μν (peak at zero)
  - D→ τν; τ→πν (broader structure near zero)

Tag Modes



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$D\to(\mu,\tau)\nu$ Results

- Fitting shapes:
  - $\mu\nu$, $\tau\nu$ (signal) : from MC
  - $K^0\pi^+$: from data using double tag DD events where both D decays to charged $K\pi$
  - $\pi^+\pi^0$ and Other bkg: from MC

When $\tau^+\nu/\mu^+\nu$ is fixed to SM ratio

149.7 ± 12.0 $\mu^+\nu$; 25.8 $\tau^+\nu$

$BF(D\to\mu\nu) = (3.82\pm0.32\pm0.09)\times10^{-4}$

$f_{D+} = (205.8\pm8.5\pm2.5)$ MeV

When $\tau^+\nu/\mu^+\nu$ is allowed to float

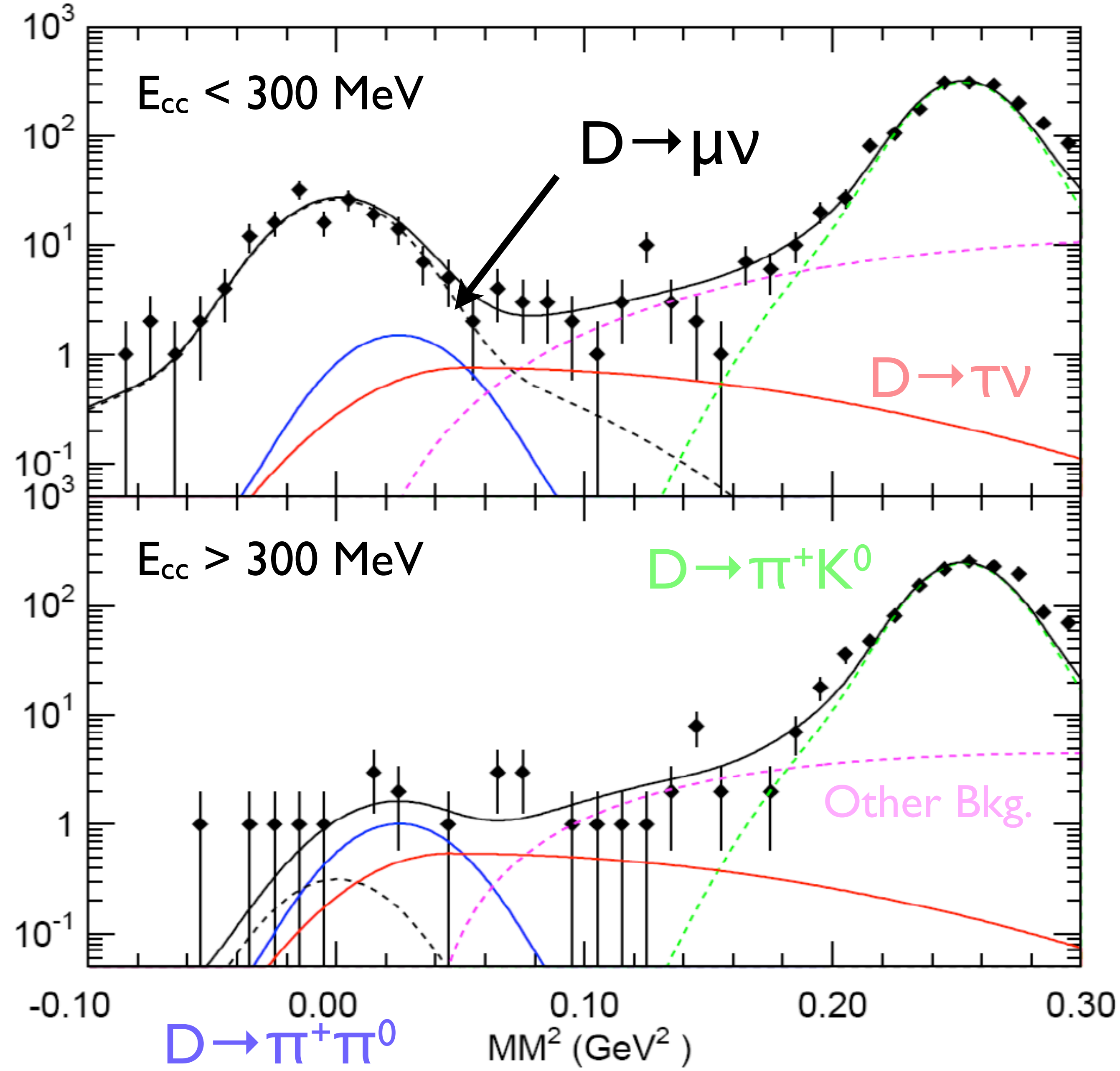
153.9 ± 13.5 $\mu^+\nu$; 13.5 ± 15.3 $\tau^+\nu$

$BF(D\to\mu\nu) = (3.93\pm0.35\pm0.10)\times10^{-4}$

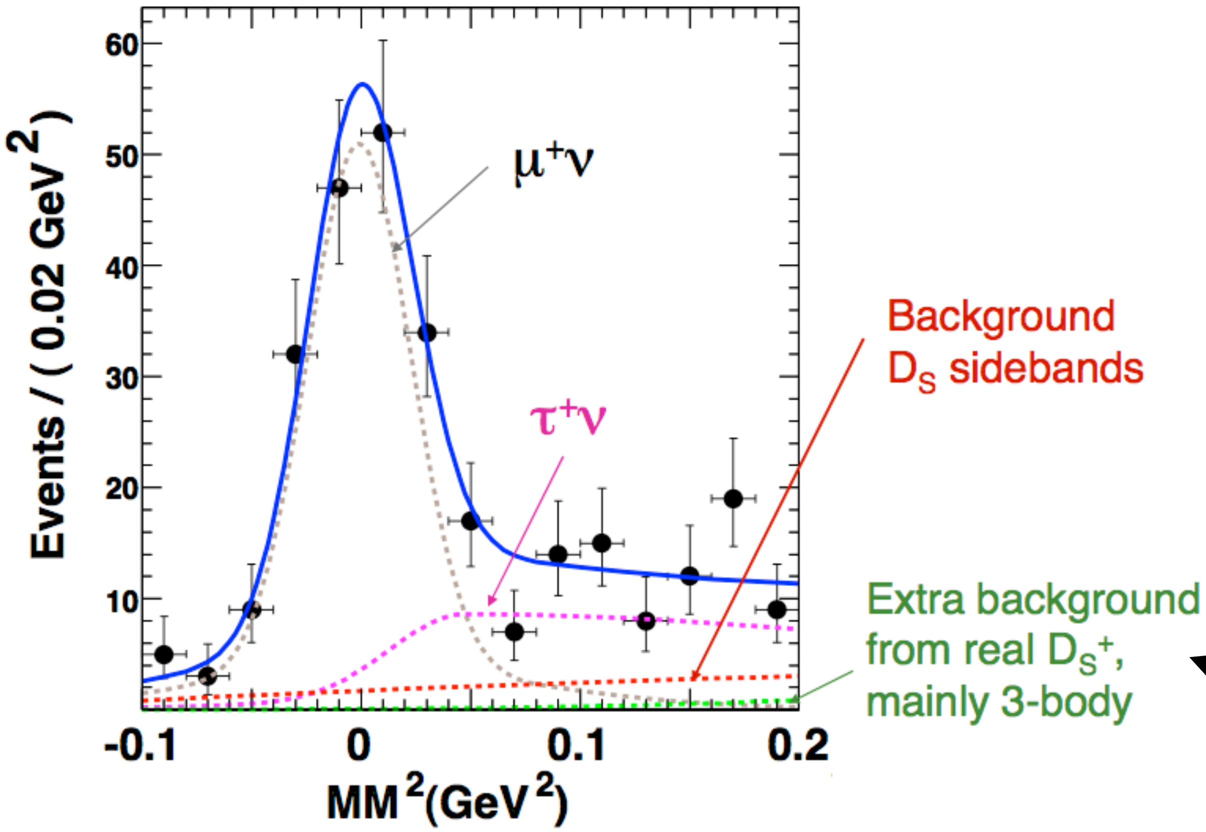
$f_{D+} = (207.6\pm9.3\pm2.5)$ MeV

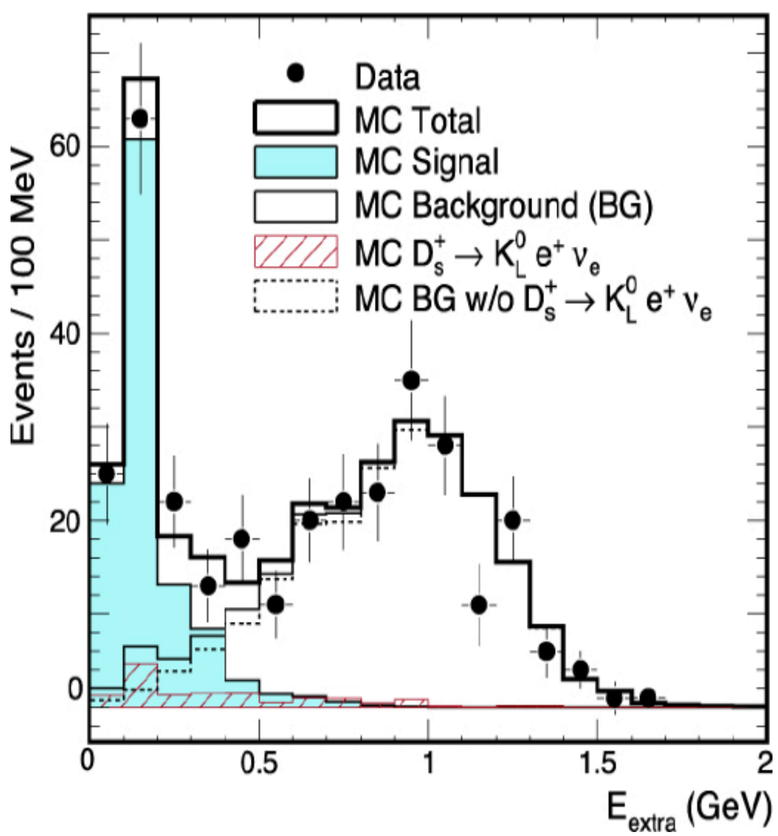
(includes 1% radiative correction)

PRD 78, 052003 (2008)



$D_s \to (\mu,\tau)\nu$ Strategy





PRL 100, 161801 (2008)

- Employ D_s tagging at E_{cm} = 4170 MeV
- Two complementary analyses provide sensitivity to $\tau \to \pi\nu$ and $\tau \to e\nu\nu$
  - single track against the tag ($\tau \to \pi\nu$)
    - separate based on E_{cc} and fit two simultaneously (similar to $D \to \mu\nu$)
    - E_{cc} separation provides discrimination between $\tau\nu$ and $\mu\nu$
  - identify electron ($\tau \to e\nu\nu$)
    - select signal based on extra energy in the calorimeter
    - backgrounds from D_s semileptonic decays
- *Consistent results*

$D_s \to (\mu,\tau)\nu$ and f_{D_s} Summary

Mode	BF (%)	f_{D_s} (MeV)	
(1) $\mu\nu+\tau\nu$ (fix SM ratio)	$BF^{eff}(D_s \to \mu\nu) = (0.613\pm0.044\pm0.020)$	$268.2\pm9.6\pm4.4$	(Preliminary)
(2) $\mu\nu$ only	$BF(D_s \to \mu\nu) = (0.600\pm0.054\pm0.020)$	$265.4\pm11.9\pm4.4$	
(3) $\tau\nu$, $\tau\to\pi\nu$	$BF(D_s \to \tau\nu) = (6.1\pm0.9\pm0.2)$	$271\pm20\pm4$	
(4) $\tau\nu$, $\tau\to e\nu\nu$	$BF(D_s \to \tau\nu) = (6.17\pm0.71\pm0.36)$	$273\pm16\pm8$	(PRL 100, 161801)
CLEO Average of (1) & (4)		$269.4\pm8.2\pm3.9$	
	Rad. corr.	$267.9\pm8.2\pm3.9$	(Preliminary)

The current CLEO measurement in the context of the standard model.

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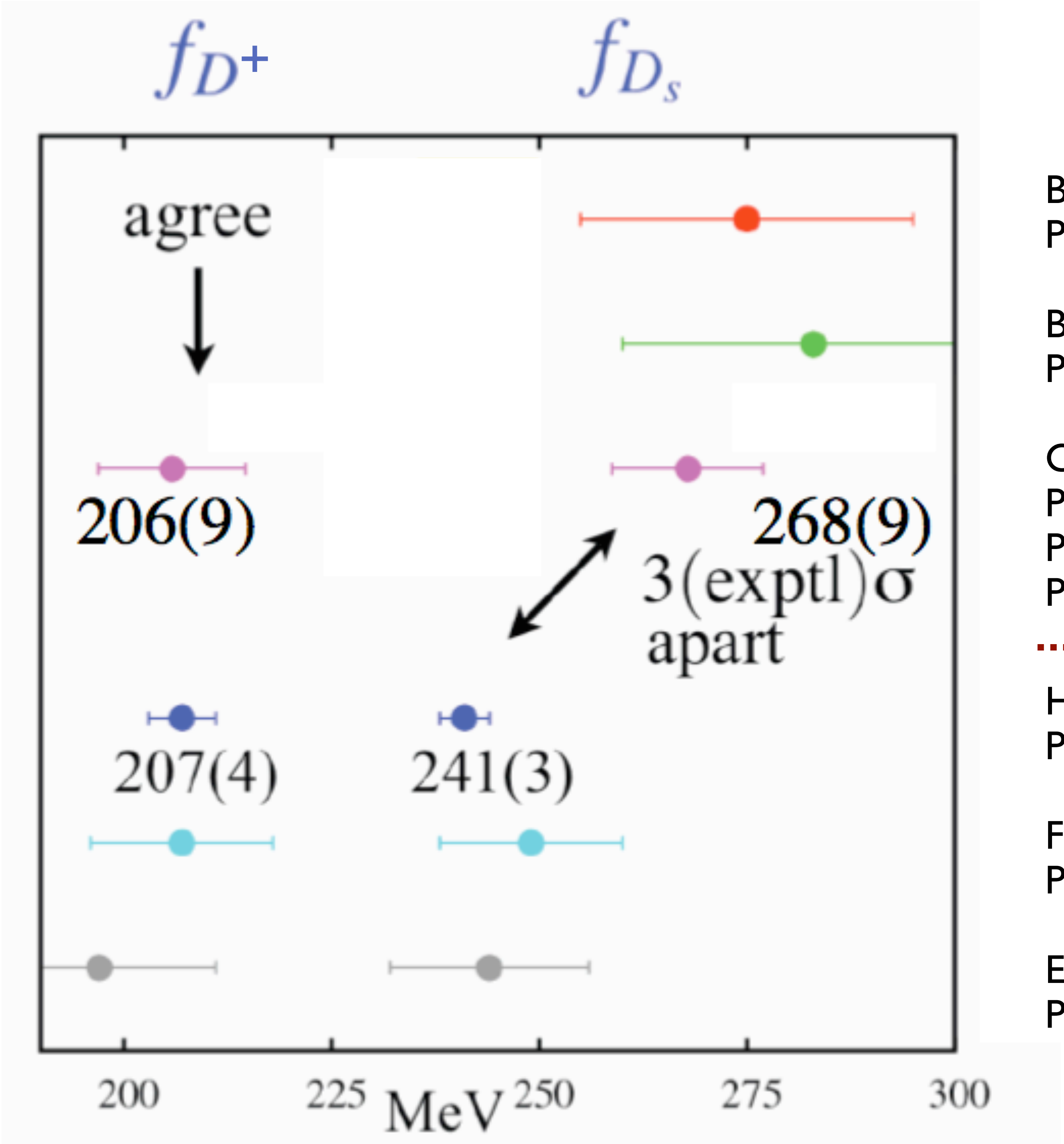
D(s) Decay Constant Summary



Belle (63% of current data)
PRL 100, 241801 (2008)

BaBar (47% of data)
PRL 98, 141801 (2007)

CLEO-c (~50% of data)
Preliminary f_{D_s}
PRD 78, 052003 (2008)
PRL 100, 161801 (2008)

experiment

theory

HPQCD HISQ
PRL 100, 062002 (2008)

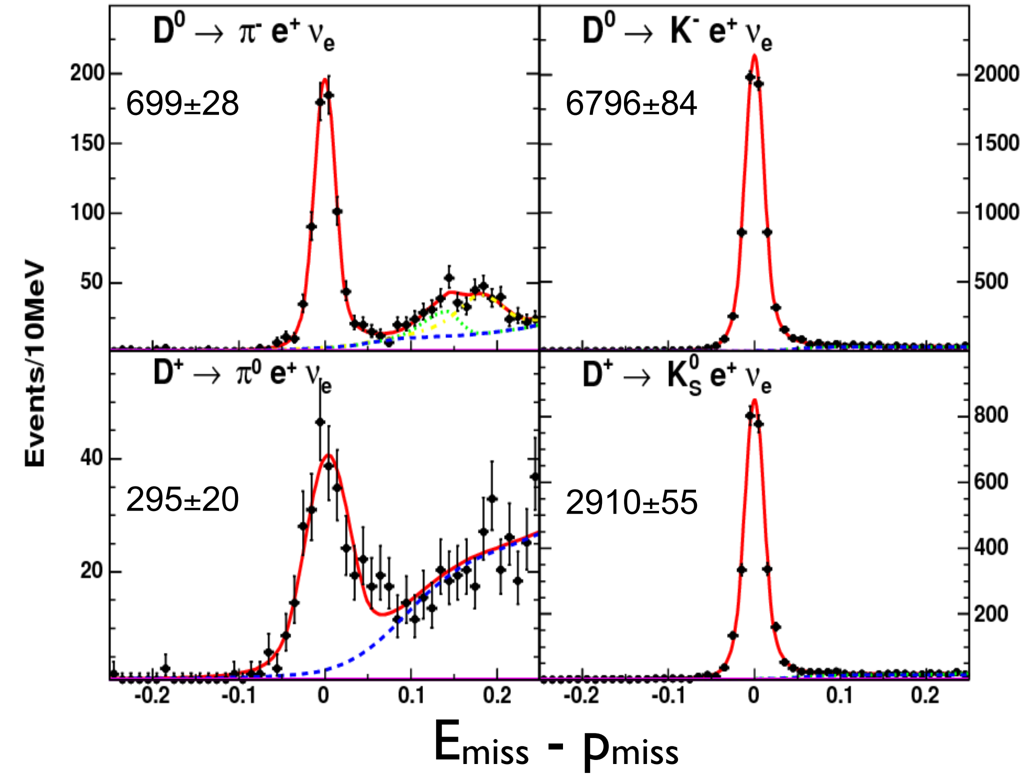
FNAL MILC (u,d,s)
Preliminary (LAT08)

ETMC (u,d)
Preliminary (LAT08)

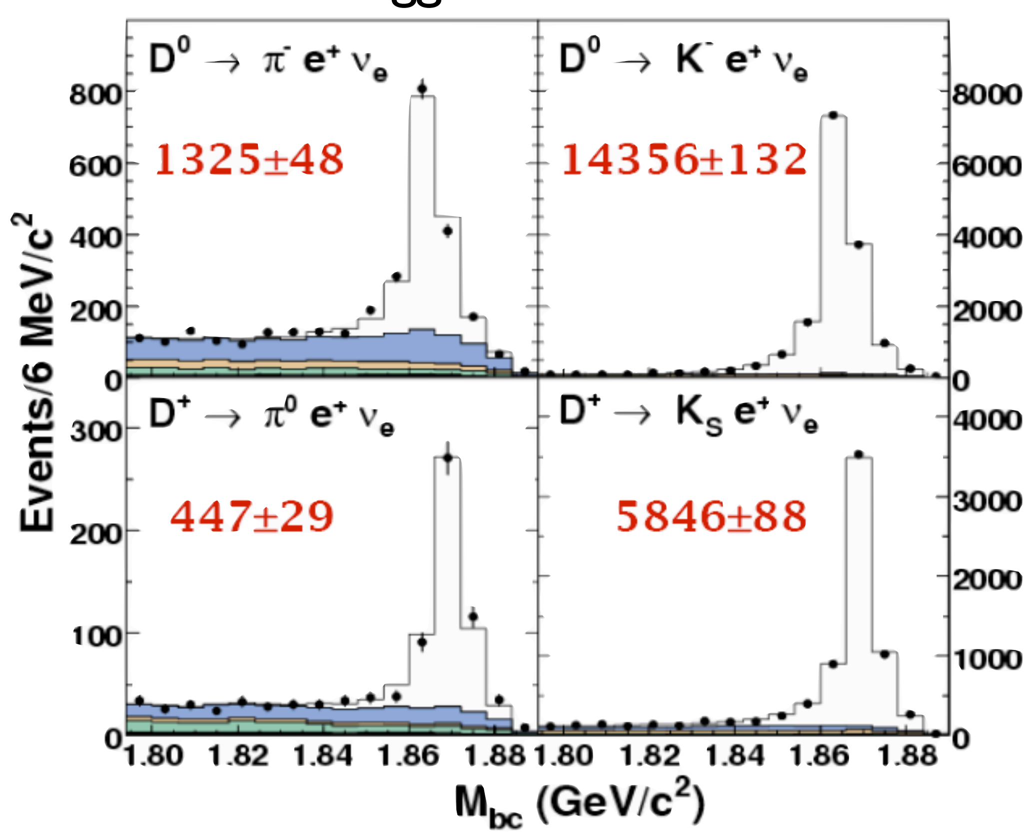
D Semileptonic

- Goal: precision measurement of rates and decay form factors
  - measure absolute branching fraction in bins of q^2
- For $D \rightarrow (\pi, K) e\nu$, two complementary CLEO analyses:
  - "tagged": tag one D, require that the other D be consistent with signal SL decay (arXiv:0810.3878 [hep-ex])
  - "untagged": reconstruct neutrino from missing 4-mom. and exclusively reconstruct D SL decay (PRL 100, 251802 (2008))
- Tagging fraction ~25%; results are correlated; average accounts for correlations

Tagged: higher purity



Untagged: more events



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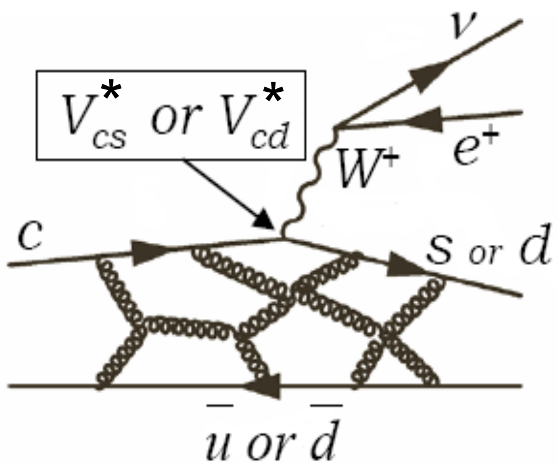
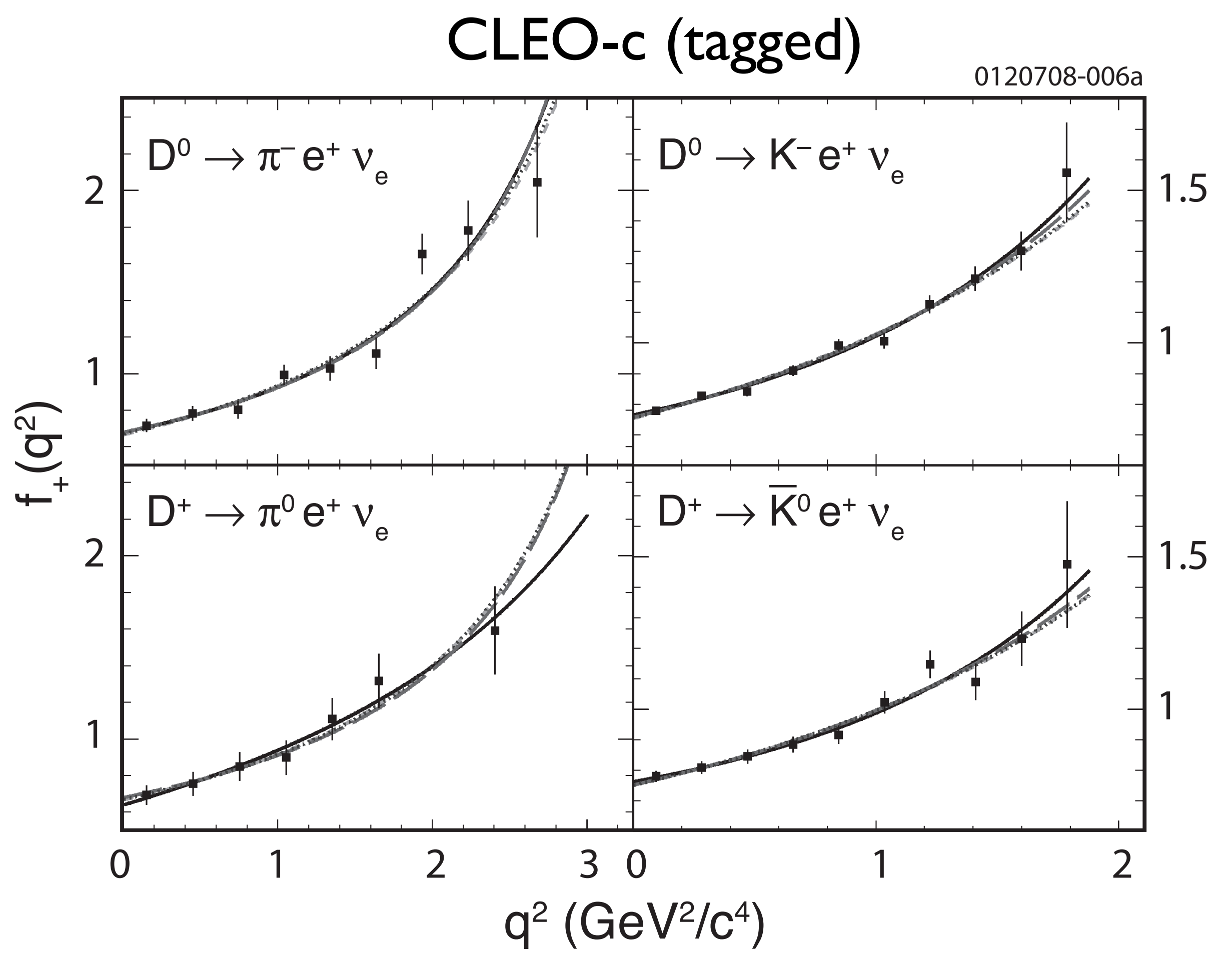
Form Factors

$$\frac{d\Gamma(D\rightarrow K(\pi)e\nu)}{dq^2} = \frac{G_F^2\left|V_{cs(cd)}\right|^2 P_{K(\pi)}^3}{24\pi^3}\left|f_+(q^2)\right|^2, where \quad q^2 \equiv M^2(e\nu)$$



- Strong physics is buried in the form factors
- Divide out phase space momentum dependence to expose the form-factor
- Expect a pole around $M(D_{(s)}^*)^2$
- Need a method of parametrizing the form factor for comparison to theory predictions



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Form Factor Parameterization

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

simple pole

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

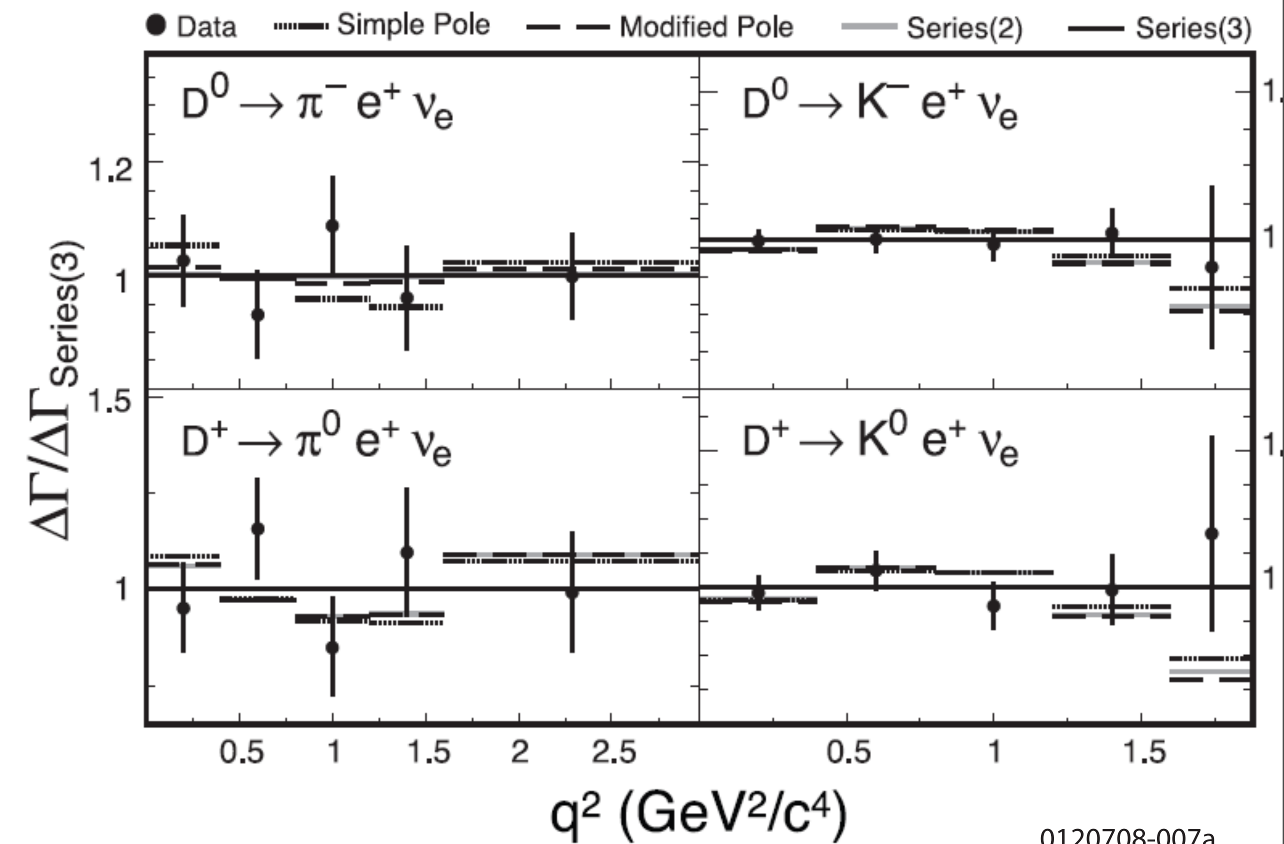
modified pole

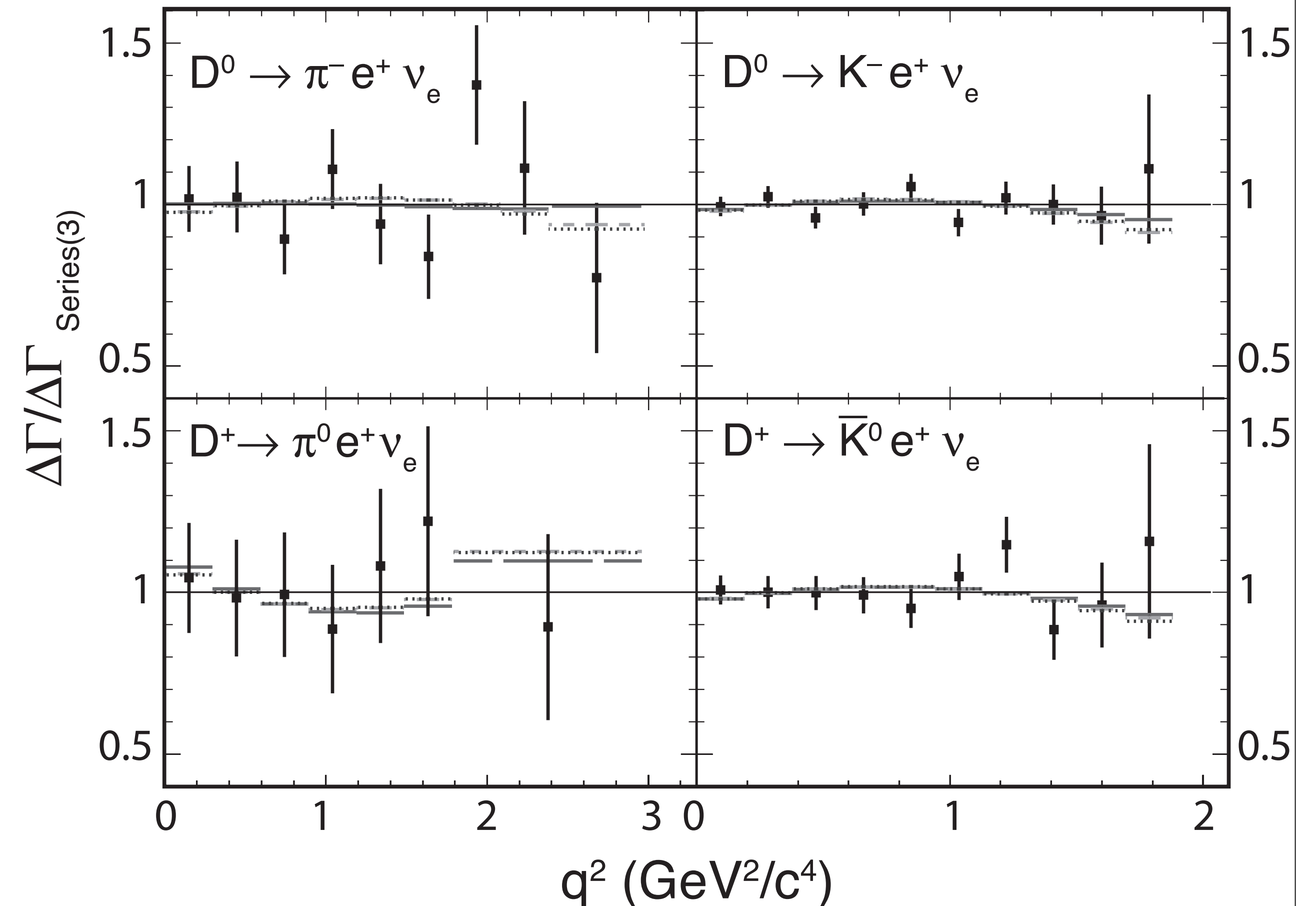
$$f_+(q^2) = \frac{a_0}{P(q^2)\phi(q^2, t_0)} \left(1 + \sum_{k=1}^{\infty} a_k(t_0) z(q^2, t^0)^k\right)$$

model indep. series expansion
(Beecher and Hill, PLB 63, 61)

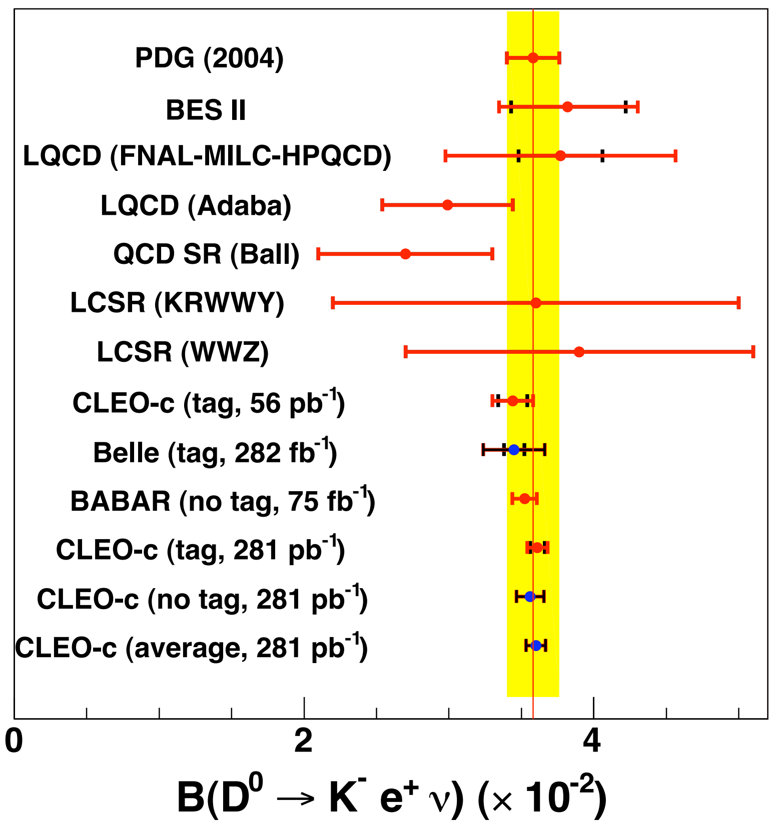
- With freely floating parameters, all parameterizations adequately describe data
- Pole models prefer a pole mass inconsistent with $M(D_{(s)}^*)$
- Tables of average values for form factor parameters in various parameterizations available: arXiv:0810.3878 [hep-ex]

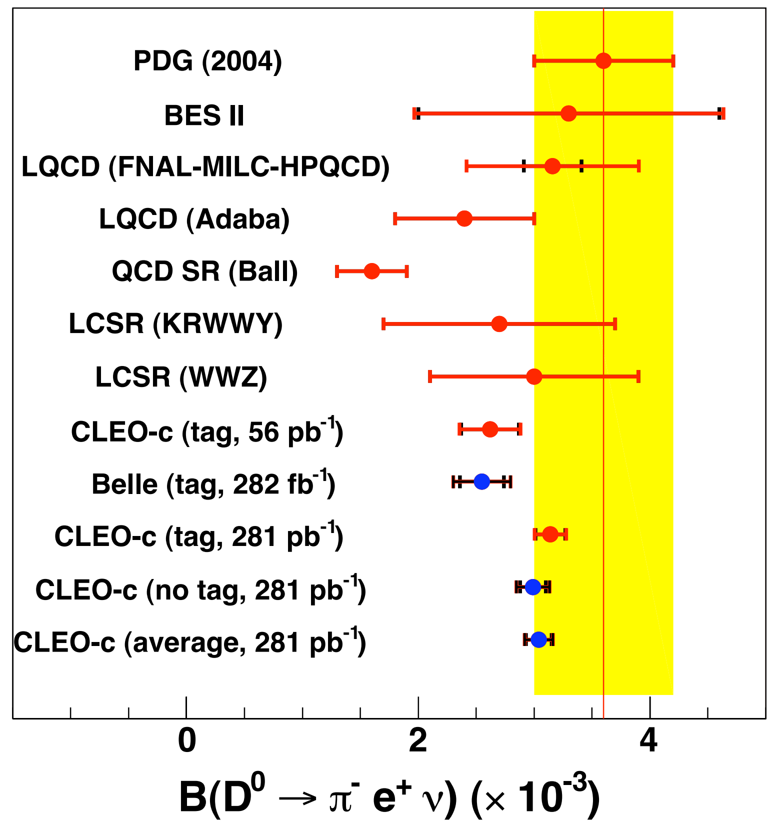
Parameterization Comparison
untagged (top); tagged (bottom)





$D \to (\pi, K) e \nu$ Summary

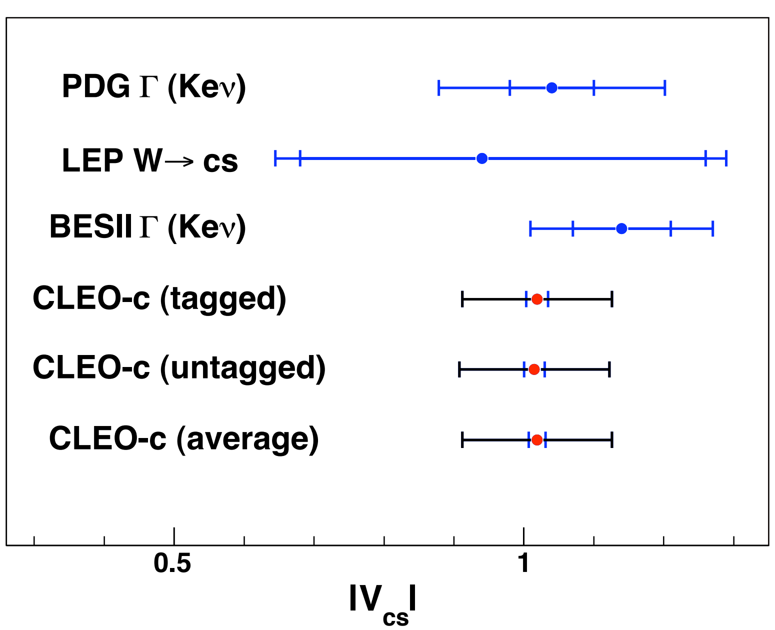


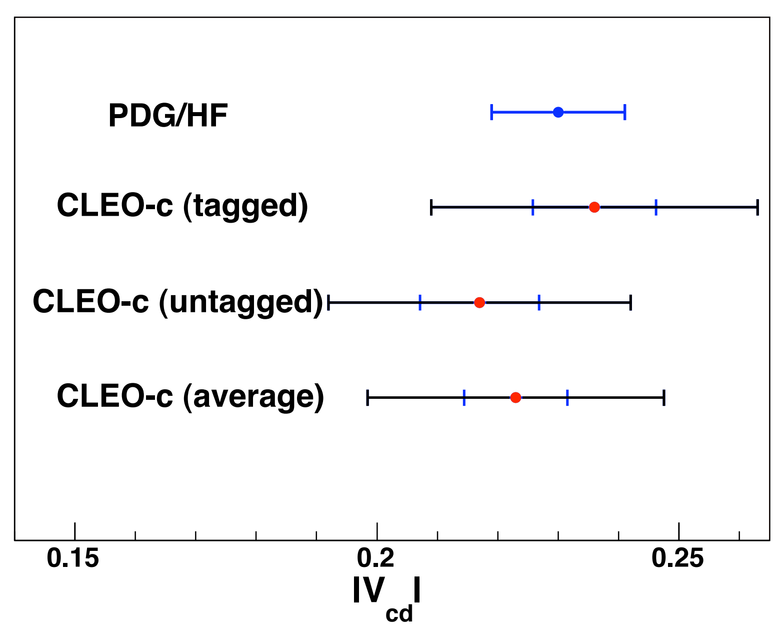


Branching Fractions [%]

	Tagged	Untagged	Average
$\pi^- e^+ \nu_e$	0.308(13)(4)	0.299(11)(8)	0.304(11)(5)
$\pi^0 e^+ \nu_e$	0.379(27)(23)	0.373(22)(13)	0.378(20)(12)
$K^- e^+ \nu_e$	3.60(5)(5)	3.56(3)(9)	3.60(3)(6)
$\bar{K}^0 e^+ \nu_e$	8.87(17)(21)	8.53(13)(23)	8.69(12)(19)

- Tagged and untagged results from CLEO-c are beautifully consistent
- Both represent most precise measurements
- Partial widths to charged and neutral states are consistent with what is expected from isospin symmetry





arXiv:0810.3878 [hep-ex] (PRD, submitted)

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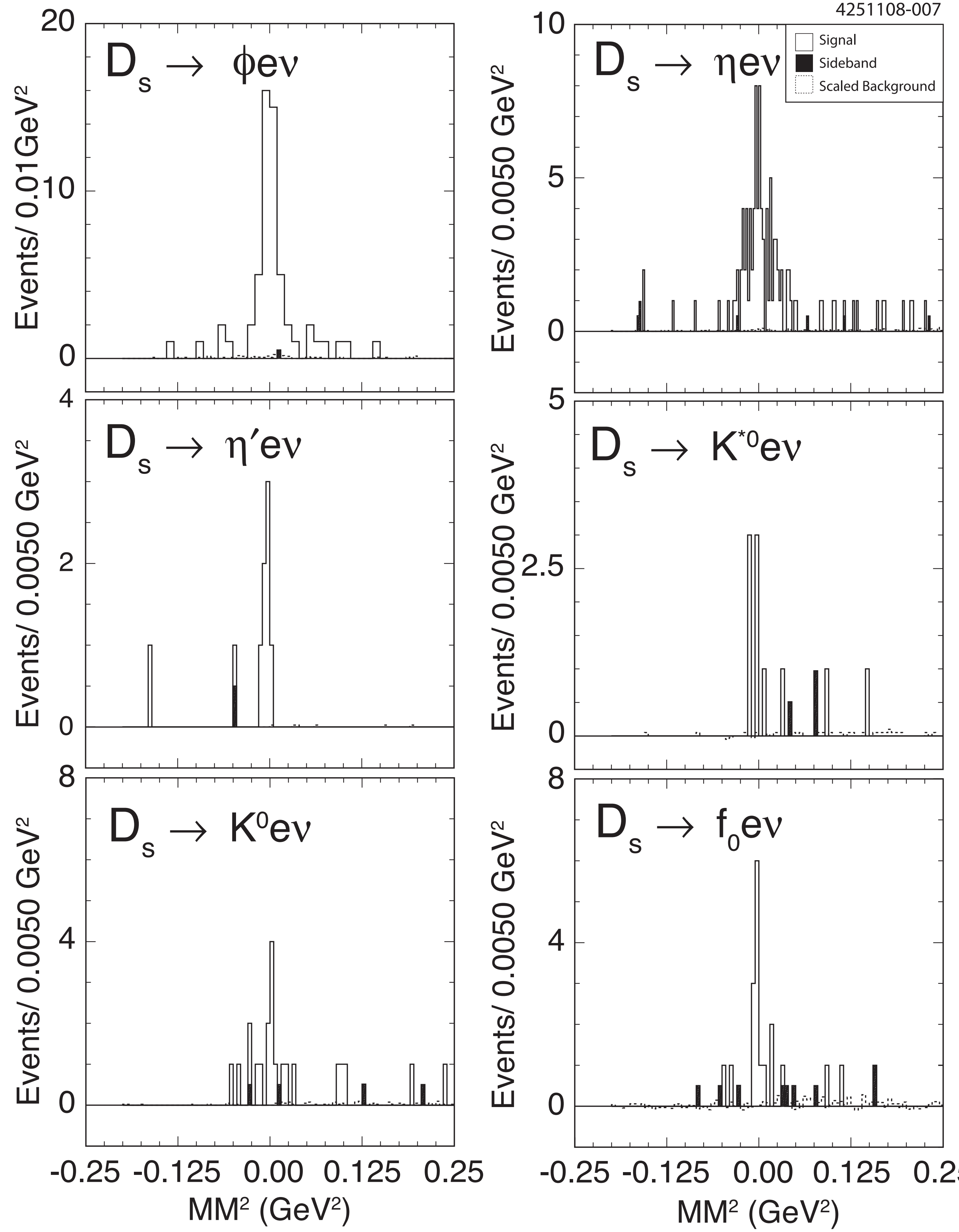
$D_s \to X_{excl} e\nu$

- Similar to $D_s \to \mu\nu$: tag; reconstruct visible parts of signal; plot MM^2
- First absolute branching fraction measurements for D_s decay

$$\mathcal{B}(D_S^+ \to \phi e^+ \nu_e) = (2.290 \pm 0.371 \pm 0.118)\%$$
$$\mathcal{B}(D_S^+ \to \eta e^+ \nu_e) = (2.314 \pm 0.268 \pm 0.119)\%$$
$$\mathcal{B}(D_S^+ \to \eta' e^+ \nu_e) = (0.843 \pm 0.310 \pm 0.043)\%$$
$$\mathcal{B}(D_S^+ \to K^0 e^+ \nu_e) = (0.370 \pm 0.101 \pm 0.019)\%$$
$$\mathcal{B}(D_S^+ \to K^{*0} e^+ \nu_e) = (0.179 \pm 0.066 \pm 0.008)\%$$
$$\mathcal{B}(D_S^+ \to f_0 e^+ \nu_e) = (0.241 \pm 0.067 \pm 0.011)\%$$

CLEO Preliminary

Interesting observation:
Sum of all BF's is about 20% less than inclusive SL rate obtained by assuming $\Gamma(D \to X_{incl} e\nu) = \Gamma(D_s \to X_{incl} e\nu)$



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Summary and Outlook

- D and D_s Leptonic
  - Final CLEO-c results for f_{D+}: excellent agreement with lattice predictions
  - Results for f_{Ds} using approximately 1/2 of final data set: 3σ discrepancy with HPQCD HISQ lattice calculations
    - Expect updated results from CLEO with full data set soon
- D Semileptonic
  - Most precise measurements of $D\to(\pi,K)e\nu$ using two techniques and approximately 1/3 of CLEO data
  - Working on updates with full data set
- D_s Semileptonic
  - First absolute branching fraction measurements using 1/2 total data set