Charm Physics at CLEO

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(CLEO collaboration)

Second Workshop on Theory, Phenomenology and Experiments in Heavy Flavour Physics

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CLEO-c

- The goal of the CLEO-c program is to provide precision measurements of charm decays
- 818pb^{-1} at the $\Psi(3770)$ taken just above DD threshold
- ~600pb^{-1} taken at 4170 MeV to maximize D_s production
- ~27 million $\psi(2S)$ decays

This Talk

- Leptonic decays of the D^+ and D_s
- Semileptonic D-decays

In my posted lecture

- Discovery of $D_S^+ \to p\bar{n}$
- Absolute D_S Branching Ratios

Recent CLEO Talks

Aspen	Shipsey
FPCP(Taiwan)	Stone, Skwarnicki
HQL(Melbourne)	Briere, Rademacker
Meson08(Cracow)	Skwarnicki

Leptonic decays of the D^+ and D_s

Test lepton Universality and new physics

The Standard Model predicts the $e\nu:\mu\nu:\tau\nu$ ratios for D (2.3×10^{-5}: 1: 2.65) and D_s (2.4×10^{-5}: 1: 9.7).

Test LQCD predictions

Measuring both f_D and f_{Ds} and their ratio f_D/f_{Ds} and CKM independent quantities such as $\mathcal{B}(D^+\rightarrow l^+\nu)/\ \mathcal{B}(D^+\rightarrow\pi l^+\nu)$ provide ever more stringent tests of LQCD.

Improve precision on CKM matrix elements and B physics

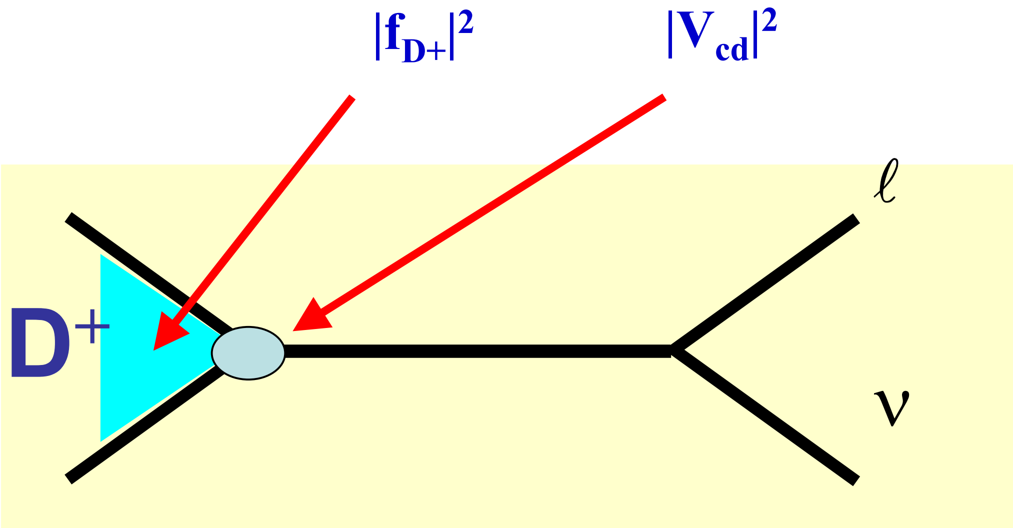
LQCD predicts f_B/f_D with a small error so a precision measurement of f_D → Precision Lattice estimate of f_B → precision determination of V_{td}

Similarly f_D/f_{Ds} checks f_B/f_{Bs} and lattice calculations → V_{cs} and V_{cd}.

In the extraction of the decay constants we use

$V_{cd} = V_{us} = 0.2256$, $V_{cs} = V_{ud} = 0.9742$

$D^+ \to l^+ \nu$



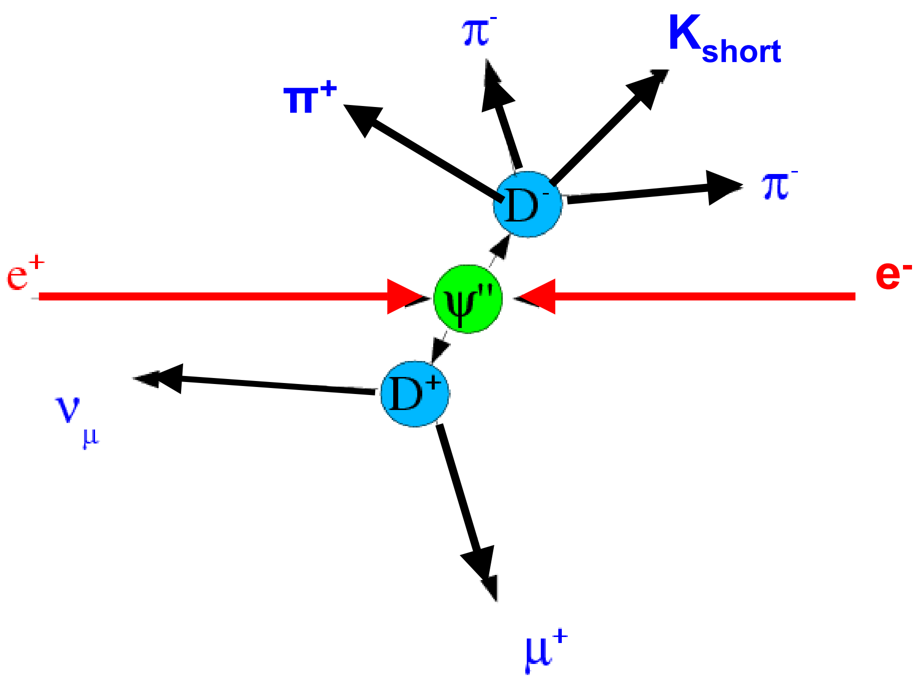
V_{ud}	V_{us}	V_{ub}
$\pi \to l\nu$	$K \to \pi l\nu$	$B \to \pi l\nu$
V_{cd}	V_{cs}	V_{cb}
$D \to \pi l\nu$	$D \to K l\nu$	$B \to D^{(*)} l\nu$
$D \to l\nu$	$D_s \to l\nu$	
V_{td}	V_{ts}	V_{tb}
$\langle B_d \vert \overline{B}_d \rangle$	$\langle B_s \vert \overline{B}_s \rangle$	

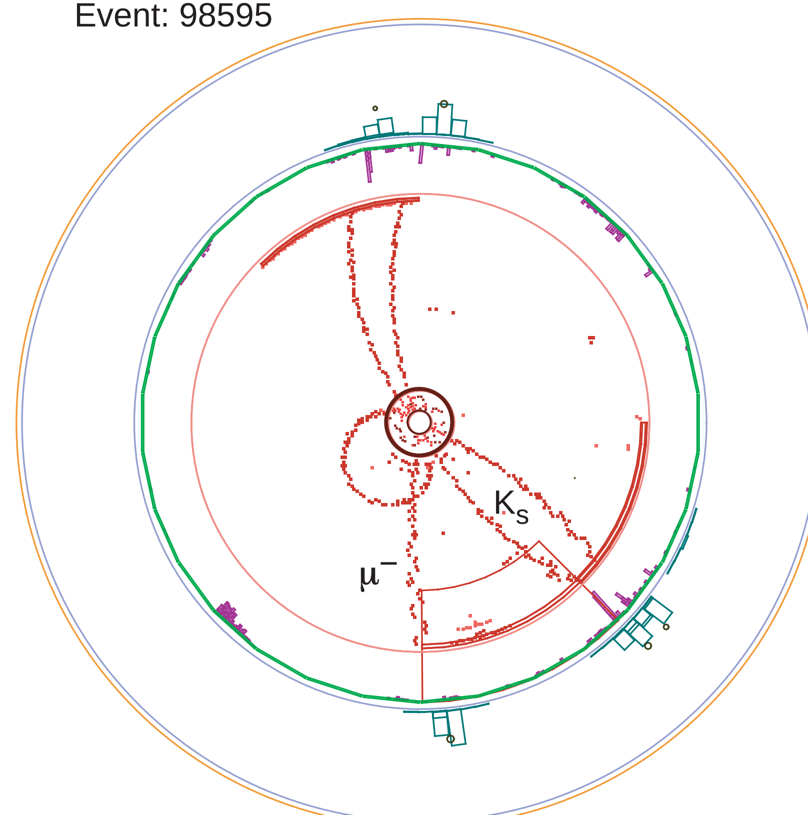
$$\Gamma\left(D^+ \to l^+ \nu\right) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_l^2 M_{D^+} \left(1 - \frac{m_l^2}{M_{D^+}^2}\right)^2$$

We use V_{cd} = 0.2256

Hadronic Tagging

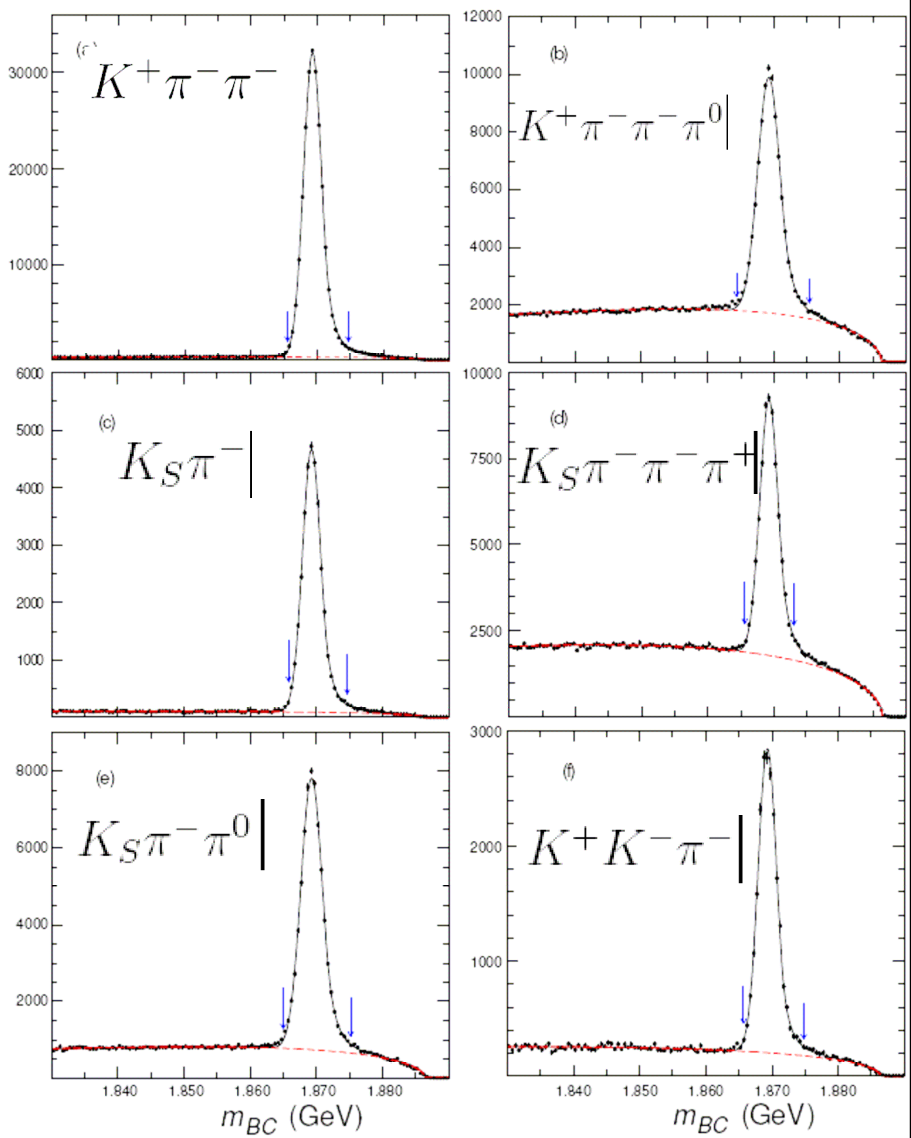
Since we are just above threshold for $e^+ e^- \rightarrow D\bar{D}$ we fully reconstruct a hadronic decay (the tag) and then analyze the recoil decay to isolate the leptonic decay. Events with one missing neutrino can then be identified with very low backgrounds





$K_S\pi^-\pi^+\pi^+$ Tag

Hadronic tags used for $D^+ \to \mu^+ \nu$



$$M_{BC} = \sqrt{E_{\text{beam}}^2 - |p(D)|^2}$$

$$\Delta E = E(D) - E_{\text{beam}}$$

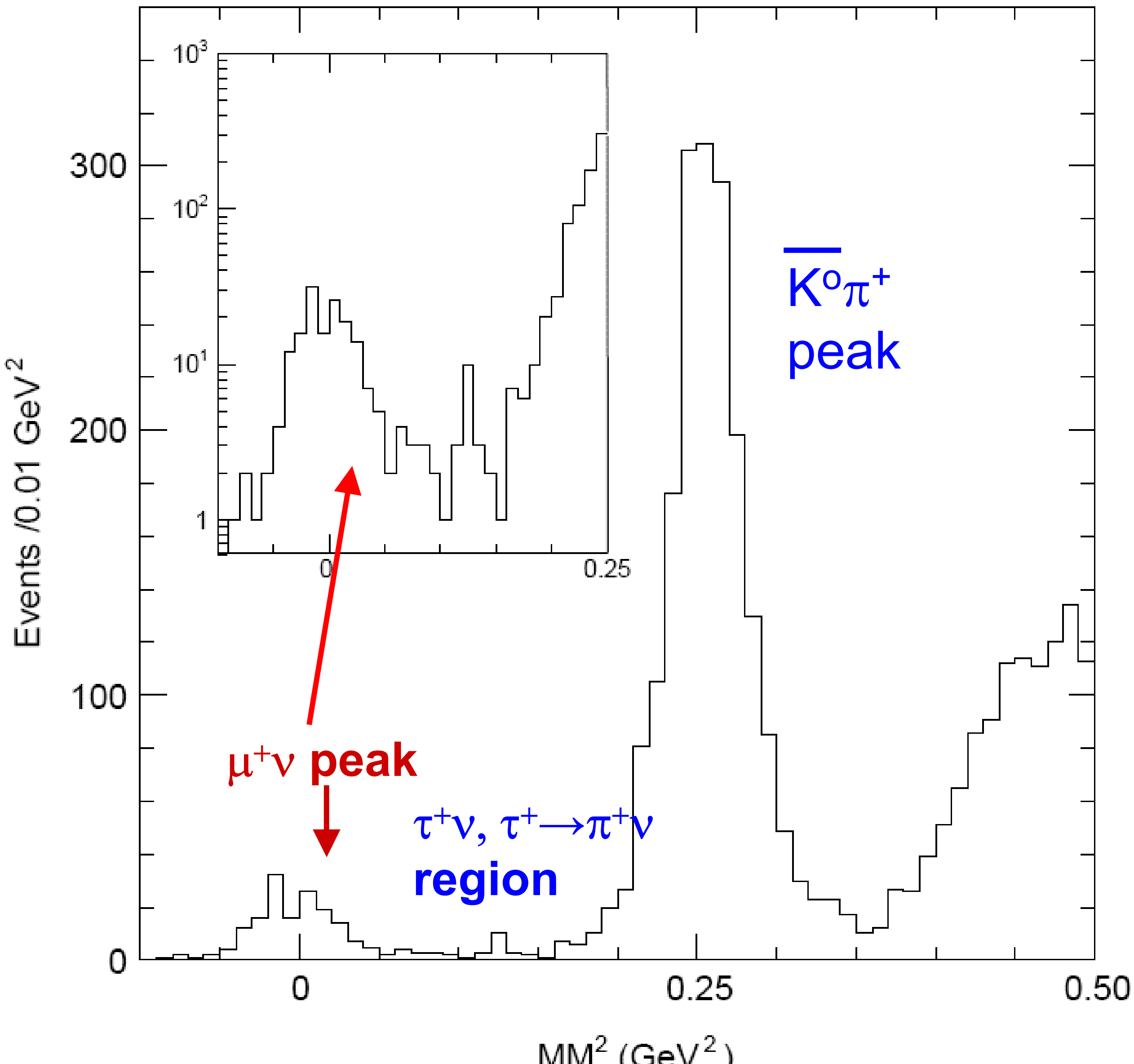
- **Total of 460,055 ± 787 tags**
- **Background 89,472**

Analysis uses the full data set of 818 pb^{-1}

The MM^2 Distribution

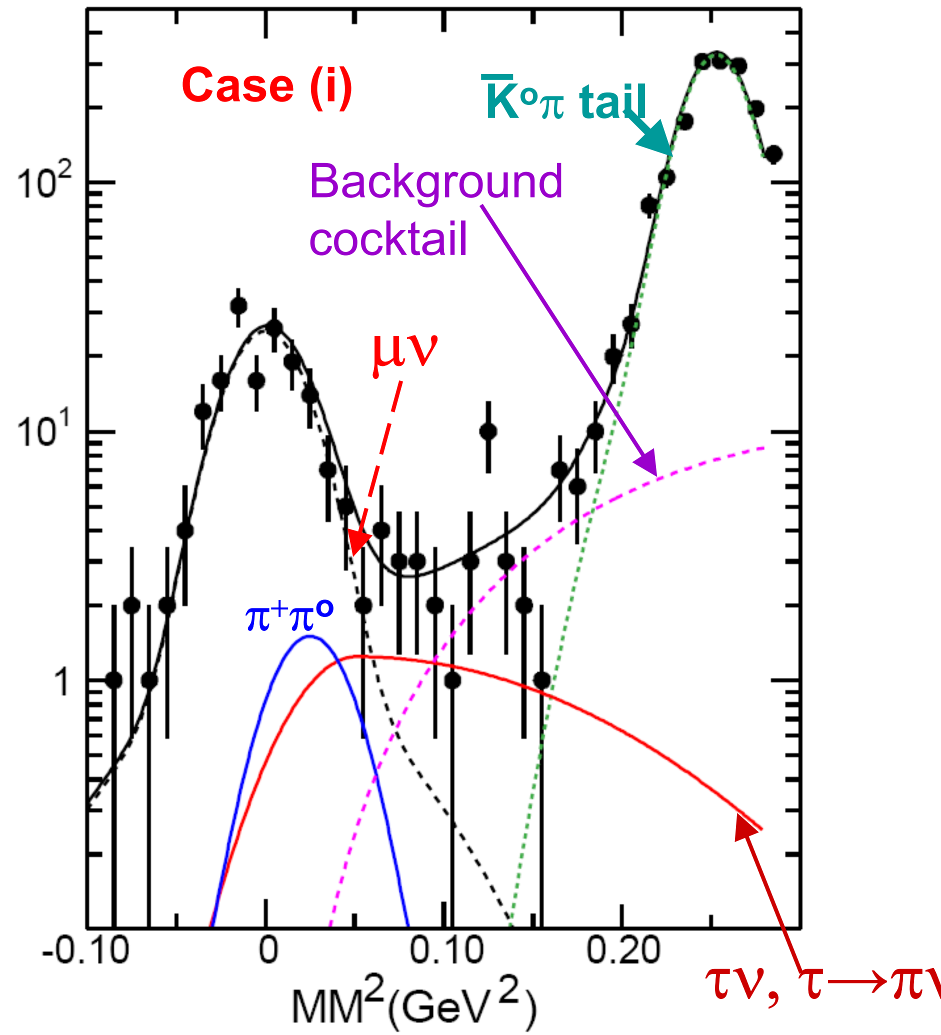
Events are selected with a hadronic tag and a single recoiling particle consistent with being a muon.

E < 300 MeV in the CsI calorimeter (99% of muons)



Fit MM^2 to sum of signal & bkgrd

- Case(i) E< 300 MeV where $\tau^+\nu/\mu^+\nu$ is fixed to SM ratio
  - 149.7±12.0 $\mu\nu$
  - 25.8 $\tau\nu$
- Case(ii) E< 300 MeV where $\tau^+\nu/\mu^+\nu$ is allowed to float
  - 153.9±13.5 $\mu\nu$
  - 13.5±15.3 $\tau\nu$



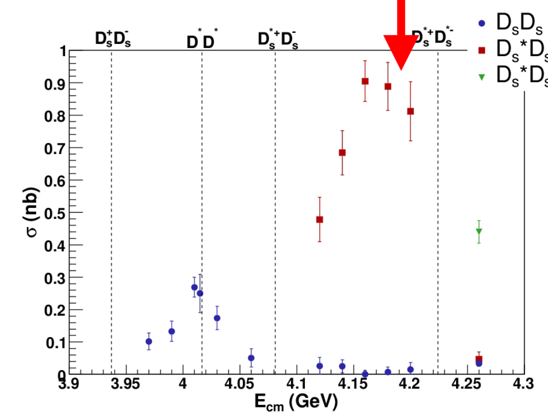
Branching Fractions & f_{D^+}

- Fix $\tau\nu/\mu\upsilon$ arxiv.org/abs/0806.2112
  - $\mathcal{B}(D^+\rightarrow\mu^+\nu)= (3.82\pm0.32\pm0.09)\times10^{-4}$
  - $f_{D^+}=(205.8\pm8.5\pm2.5)$ MeV
  - This is best number in context of SM
- Float $\tau\nu/\mu\upsilon$
  - $\mathcal{B}(D^+\rightarrow\mu^+\nu)= (3.93\pm0.35\pm0.09)\times10^{-4}$
  - $f_{D^+}=(207.6\pm9.3\pm2.5)$ MeV
  - This is best number for use with Non-SM models
  - $\mathcal{B}(D^+\rightarrow \tau^+\nu) < 1.2 \times 10^{-3}$ (fitting both case (i) and (ii))
  - $\mathcal{B}(D^+\rightarrow e^+\nu) < 8.8 \times 10^{-6}$
  - $A_{cp} = (\Gamma(D^+\rightarrow\mu^+\nu) - \Gamma(D^-\rightarrow\mu^-\nu))/ \text{sum} = 0.08\pm0.08$

Improved Measurement of f_{D_s}

- Use $e^+e^- \rightarrow \overline{D_S} D_S^*$ at 4170 MeV
  $D_S^* \longrightarrow \gamma D_S$
- CLEO has two methods of measuring f_{D_s}
  1. Measure $\mu^+\nu$ & $\tau^+\nu$, $\tau^+ \rightarrow \pi^+\nu$ using similar MM² technique used for D⁺.
  2. Measure $\tau^+ \rightarrow e^+\nu\nu$ using missing energy.

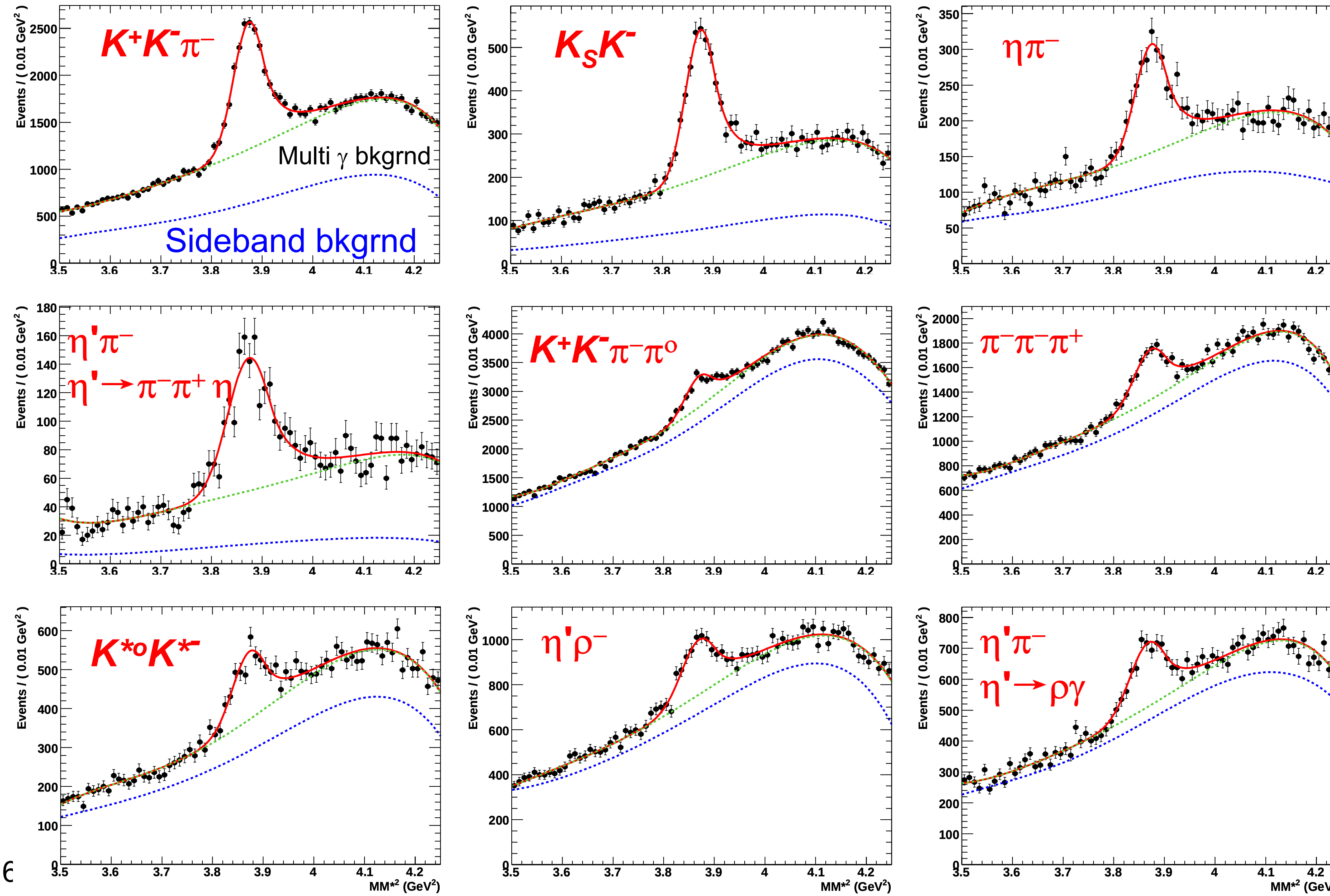
Maximum D_s^+ yield via $D_s^* D_s$



- Reconstruct D_S^-
- Find the γ from the D_S^* & compute MM^{*2} from D_S^- & γ
- Select combinations consistent with a missing D_S^+ & count the number
- Find MM² from candidate muon for (i) < 300 MeV in Ecal, (ii) E>300 MeV (iii) e- candidate

We use V_{cs} = 0.9742

MM*2 Distributions From $D_s^- + \gamma$

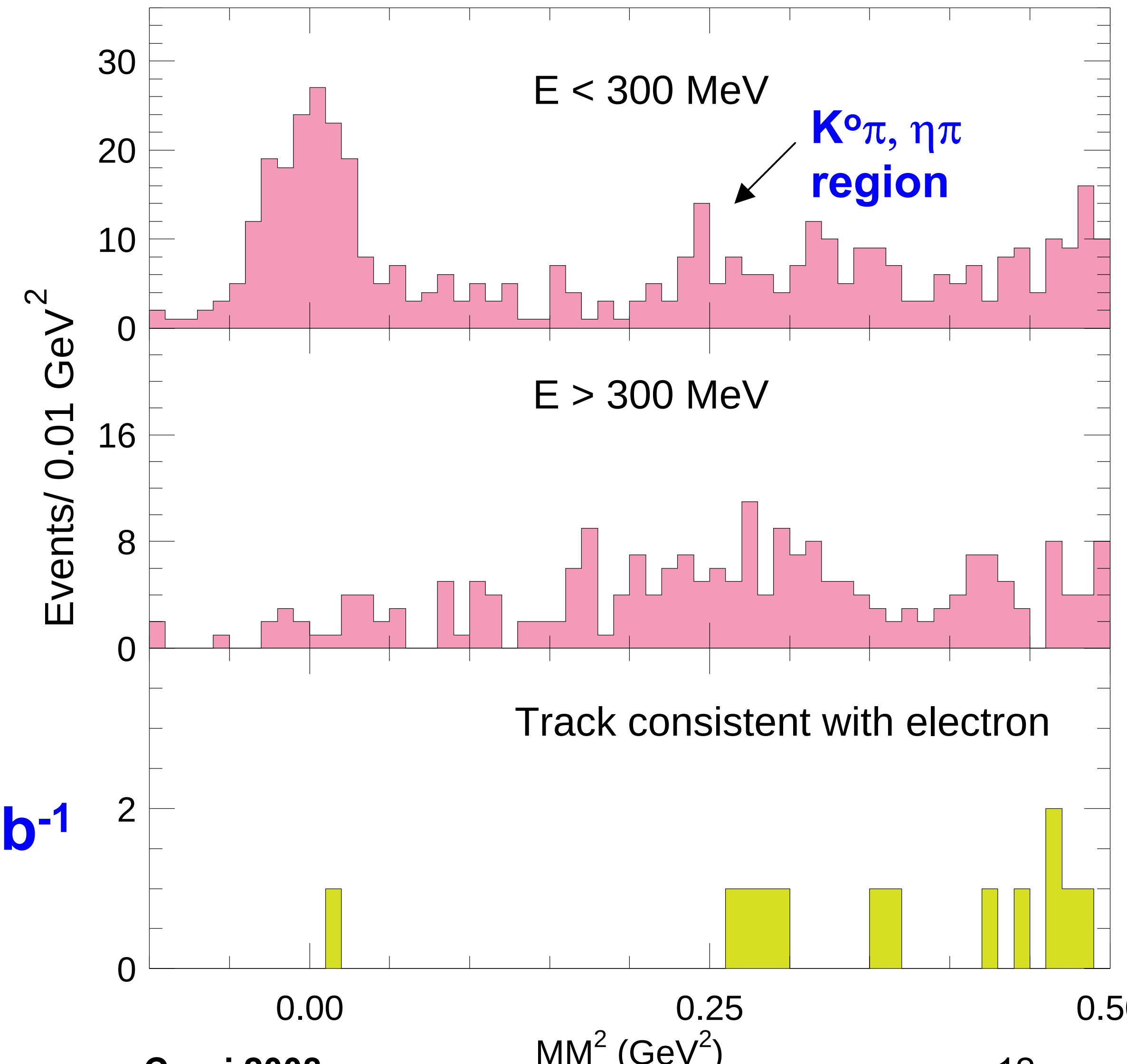


June 16th – 18th

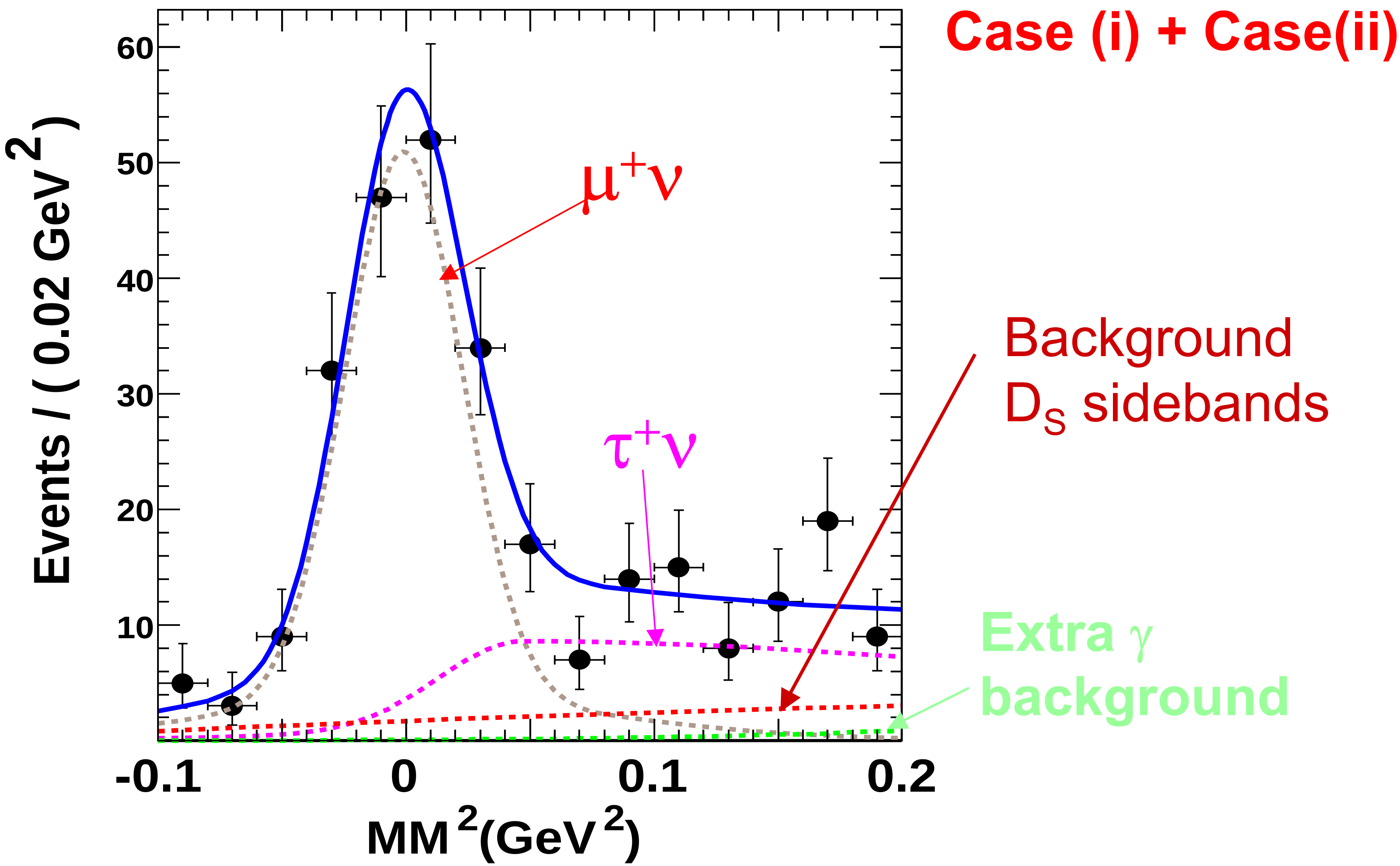
MM^2 data for D_s

- **Total of 30848±695 tags**
- **99% of $\mu^+\nu$ in E < 300 MeV**
- **55%/45% split of $\tau^+\nu$, $\tau^+\to\pi^+\nu$ in two cases**

Analysis uses ~ 400 pb^{-1}



Fit to signal & background



Branching Ratio & f_{Ds} *(preliminary)*

Mode	*$\mathcal{B}$ (%)*	f_{DS}(MeV)
(1) $\mu\nu+\tau\nu$ (fix SM ratio) (400 pb^{-1})	$\mathcal{B}^{eff}(D_s \to \mu\nu)$ = (0.613±0.044±0.020)	268.2±9.6±4.4
(2) $\mu\nu$ only	$\mathcal{B}(D_s \to \mu\nu)$ = (0.600±0.054±0.020)	265.4±11.9±4.4
(3) $\tau\nu$, $\tau\to\pi\nu$	$\mathcal{B}(D_s \to \tau\nu)$ = (6.1±0.9±0.2)	271±20±4
(4) $\tau\nu$, $\tau\to e\nu\nu$ (298 pb^{-1}) (PRL100.161801 (2008)	$\mathcal{B}(D_s \to \tau\nu)$ = (6.17±0.71±0.34)	273±16±8
CLEO	Average (1) & (4)	269.4±8.2±3.9

Unquenched Lattice Calculation

- Follana et al HPQCD & UKQCD collaborations (PRL 100, 062002 (2008)) New predictions

  f_D+= 207±4 MeV

  f_{Ds} = 241±3 MeV

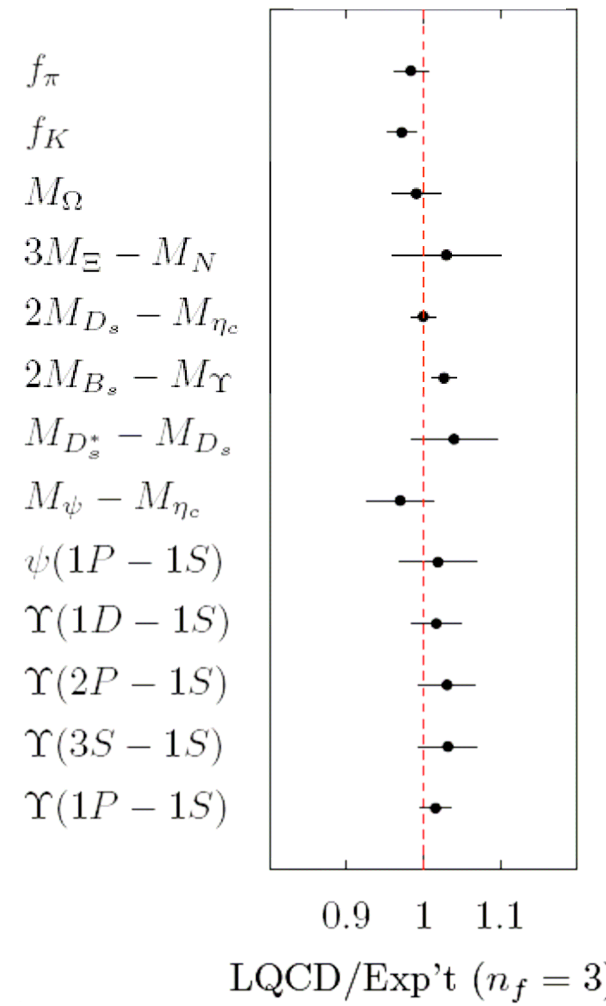
- Older unquenched from FNAL+MILC +HPQCD are:

  f_D+= 201±3 ±17 MeV

  f_{Ds} = 249±3 ±16 MeV

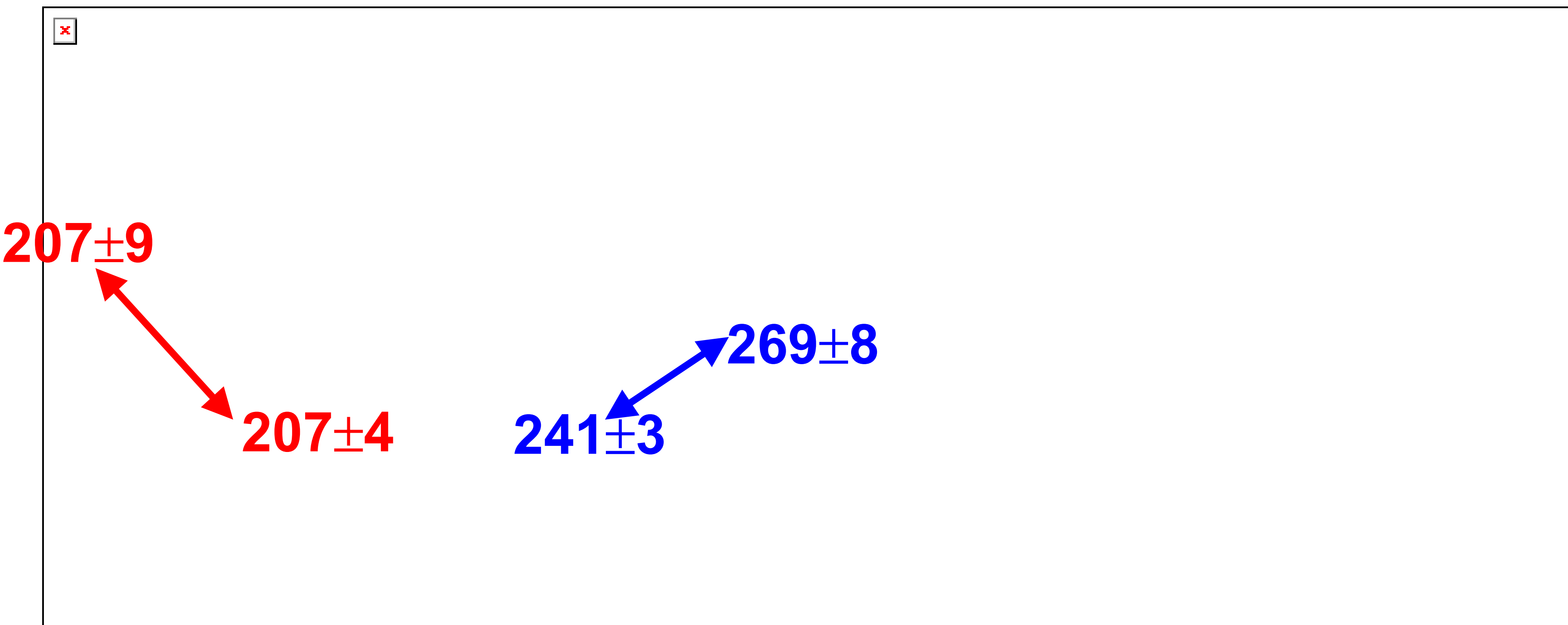
  (Aubin et al.,

  PRL 95, 122002 (2005))

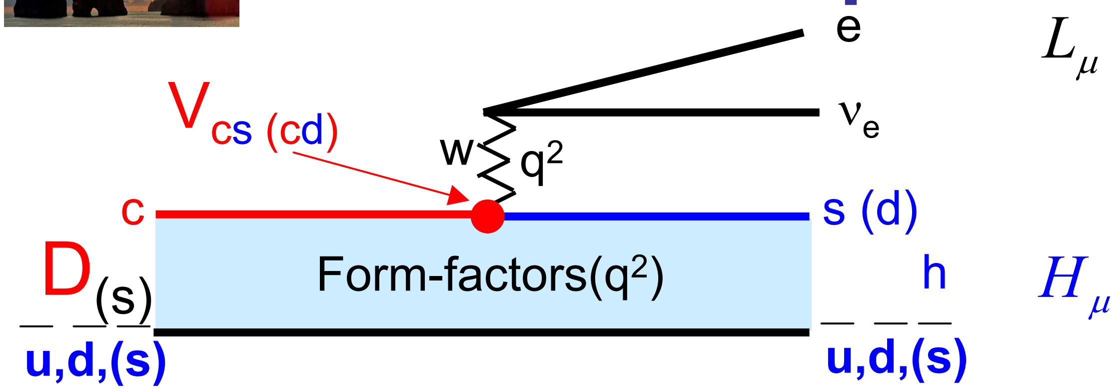


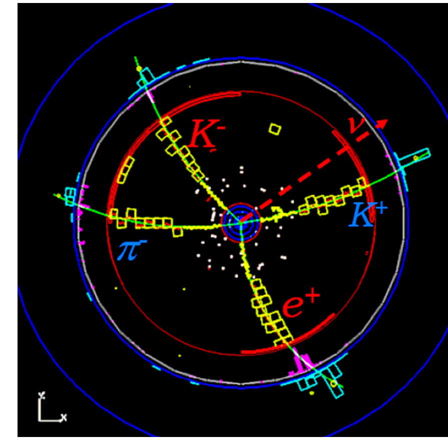
Conclusions on Decay Constants

- We are in agreement with the Follana et al calculation for f_D+. This gives credence to their methods
- The disagreement with f_{Ds} is enhanced
- Decay constants of charged pseudoscalar Mesons arXiv:0802.1043v3 (for PDG 2008 Rosner, Stone)



D semileptonic decays





Weak Physics

QCD Physics

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

Use theory to extract $|V_{cs}|$ *and* $|V_{cd}|$ *or* since $|V_{cs}|$ *and* $|V_{cd}|$ are tightly constrained by unitarity, we can check theoretical calculations of the form factors

Tested theory can then be applied to B semileptonic decays to extract $|V_{ub}|$.

Cabbibo favored $D^0\rightarrow K^-e^+\nu,\quad D^+\rightarrow \overline{K}^0e^+\nu$

Cabbibo suppressed $D^0\rightarrow \pi^-e^+\nu,\quad D^+\rightarrow \pi^0e^+\nu$

Experimental challenges

- Neutrino escapes detection so we need hermeticity, lepton and hadron identification and detection of photons to find the missing four vector for the neutrino

TAGGED

Full reconstruction of the other D in the event and two recoiling particles consistent with an electron and the required hadron. CLEO-c reconstructs a tag in about ~25% of all $D\bar{D}$ events compared to ~0.1% tagging B efficiency at Υ(4S).

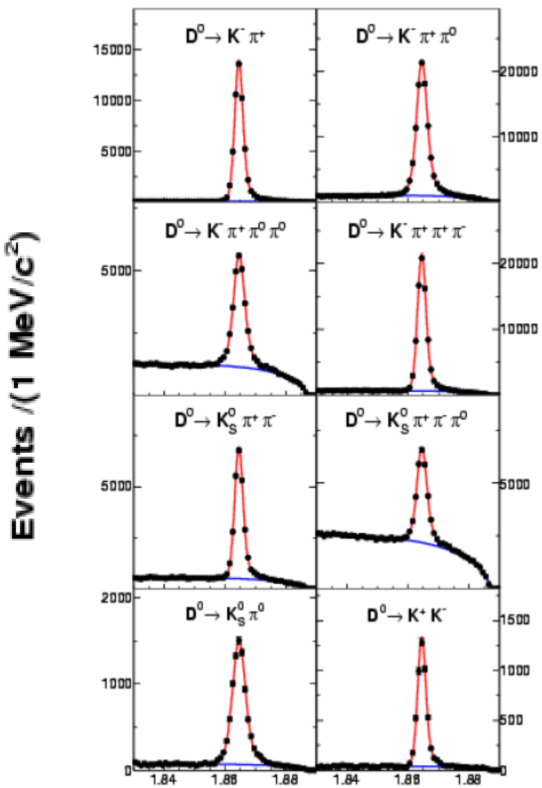
UNTAGGED

Inclusive reconstruction of all detectable particles ($\Sigma Q=0$) and photons in the event. The missing energy and momentum give neutrino four-vector ("neutrino reconstruction"). This leads to higher efficiency than tagging but also higher backgrounds and larger systematic uncertainty.

Tagging method

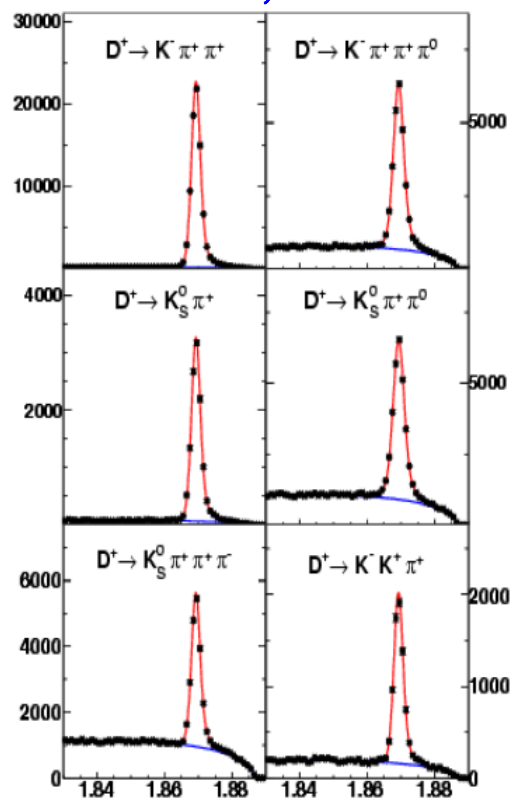
CLEO-c 281 pb^{-1}

~310,000 D^0



M_{bc} (GeV)

~160,000 D^+



M_{bc} (GeV)

For the missing neutrino we compute

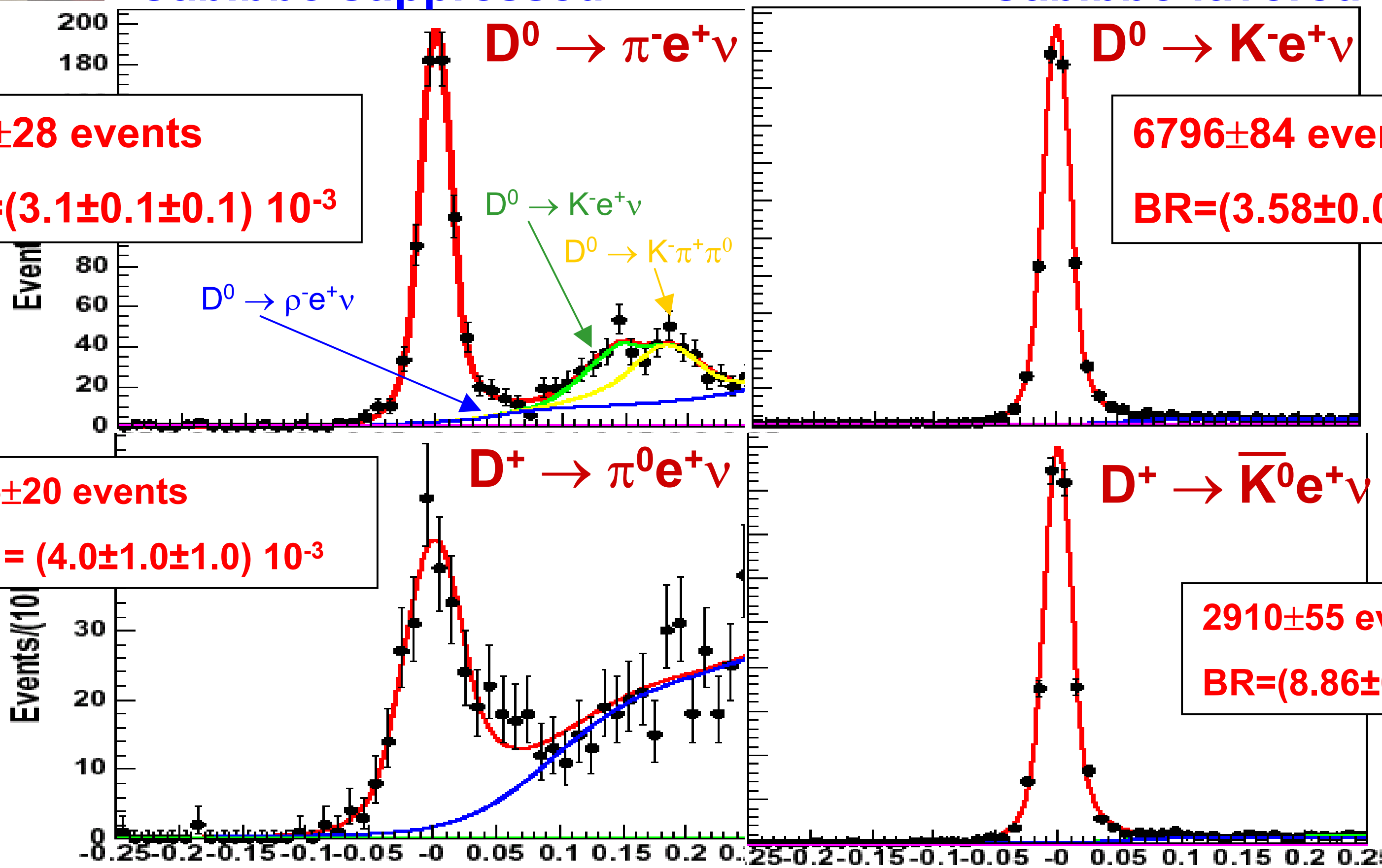
$U_{miss} = E_{miss} - |p_{miss}| = 0$

$\mathcal{B} = (N_{signal} / \varepsilon_{signal}) / (N_{tag} / \varepsilon_{tag})$

$q^2 = (E_{beam} - E_h)^2 - (- p_{D\,tag} - p_h)^2$

Signal – π, K (tagged)

Cabibbo suppressed | Cabibbo favored



CLEO-c
281 pb^{-1}
Preliminary

$U_{miss} = E_{mis} - |p_{mis}|$ (GeV)

$$\frac{\Gamma\left(D^0 \to \pi^- e^+ \nu\right)}{2\cdot\Gamma\left(D^+ \to \pi^0 e^+ \nu\right)} = 0.975 \pm 0.075$$

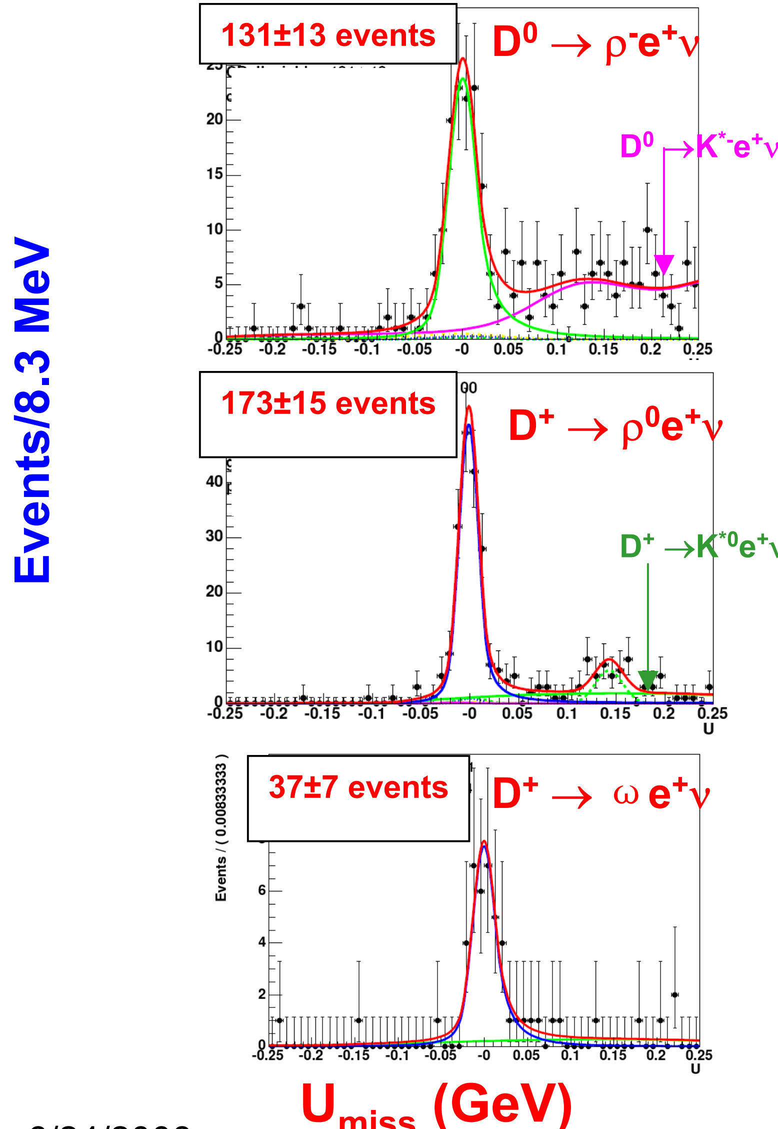
(isospin symmetry)

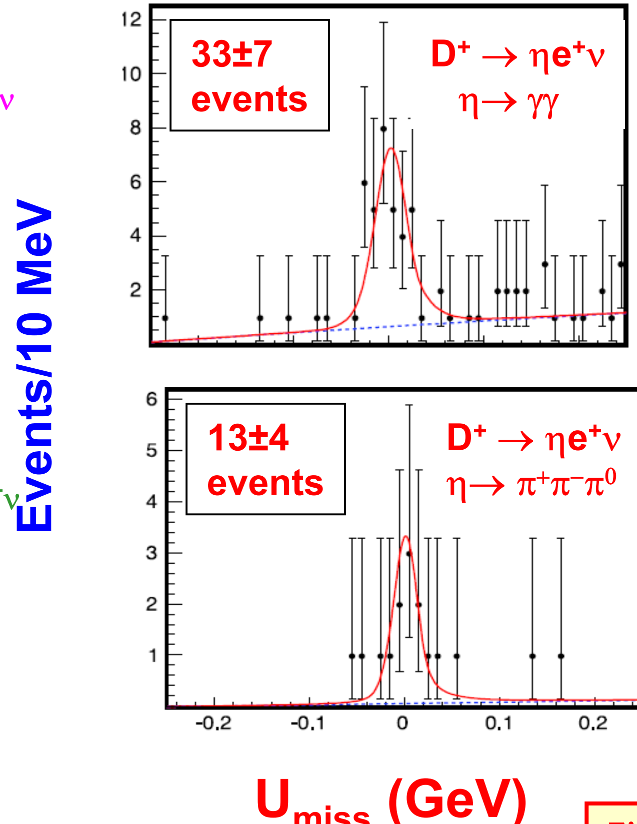
$$\frac{\Gamma\left(D^0 \to K^- e^+ \nu\right)}{\Gamma\left(D^+ \to \bar{K}^0 e^+ \nu\right)} = 1.024 \pm 0.024$$

$\rho e^+\nu$, $\eta\, e^+\nu$ (tagged)

Cabibbo suppressed

arXiv:0802.4222





CLEO-c
281 pb^{-1}

First observation of four new decay modes
PRL 95, 181801 (2005);
PRL 95, 181802 (2005)
PRL. 99, 191801 (2007
PRL 99, 191801 (2007) for first observation of $D^0 \to K^-\pi^+\pi^- e^+\nu$

Results for $\rho e^+\nu$, $\eta e^+\nu$ (tagged)

Preliminary!

$\mathcal{B}(D^0 \to \rho^- e^+ \nu) = (15.8 \pm 1.6 \pm 0.9)\ 10^{-4}$

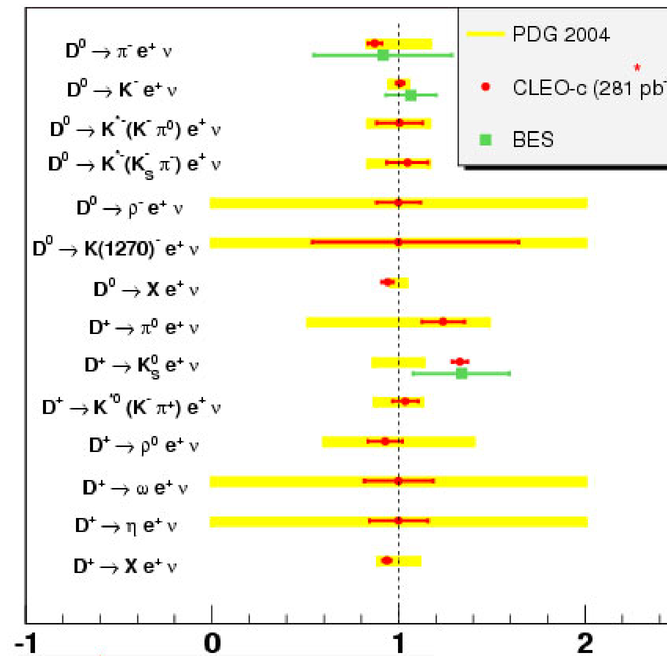
$\mathcal{B}(D^+ \to \rho^0 e^+ \nu) = (23.6 \pm 2.0 \pm 1.2)\ 10^{-4}$

$\mathcal{B}(D^+ \to \eta e^+ \nu) = (13.3 \pm 2.0 \pm 0.6)\ 10^{-4}$

$\mathcal{B}(D^+ \to \omega e^+ \nu) = (14.9 \pm 2.7 \pm 0.5)\ 10^{-4}$

$$\frac{\Gamma\left(D^0 \to \rho^- e^+ \nu\right)}{2 \cdot \Gamma\left(D^+ \to \rho^0 e^+ \nu\right)} = 0.85 \pm 0.11$$

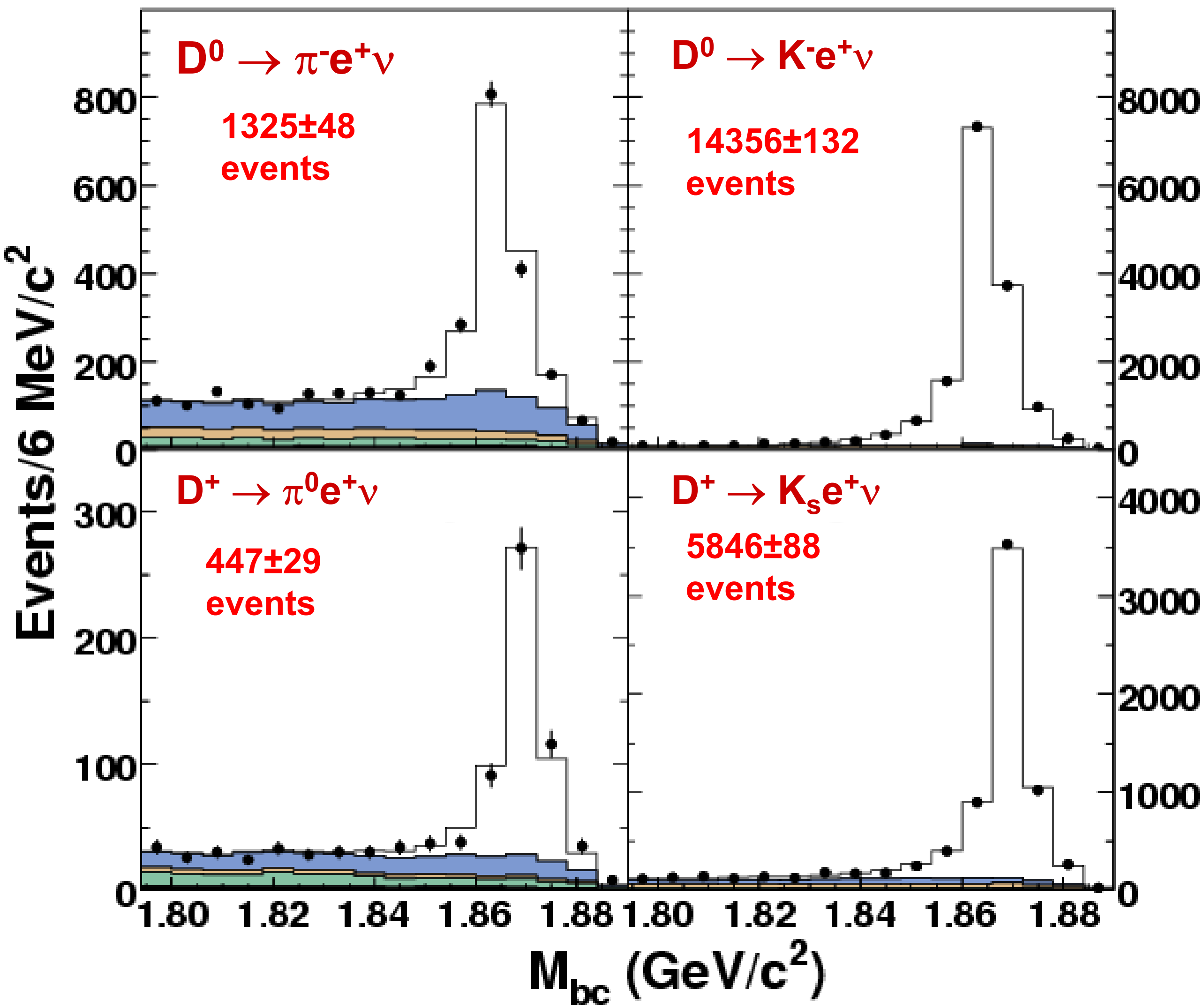
(isospin symmetry)



Untagged $\pi^- e^+ \nu$, $K^- e^+ \nu$

Cabibbo suppressed — **Cabibbo favored**

CLEO-c 281 pb^{-1}

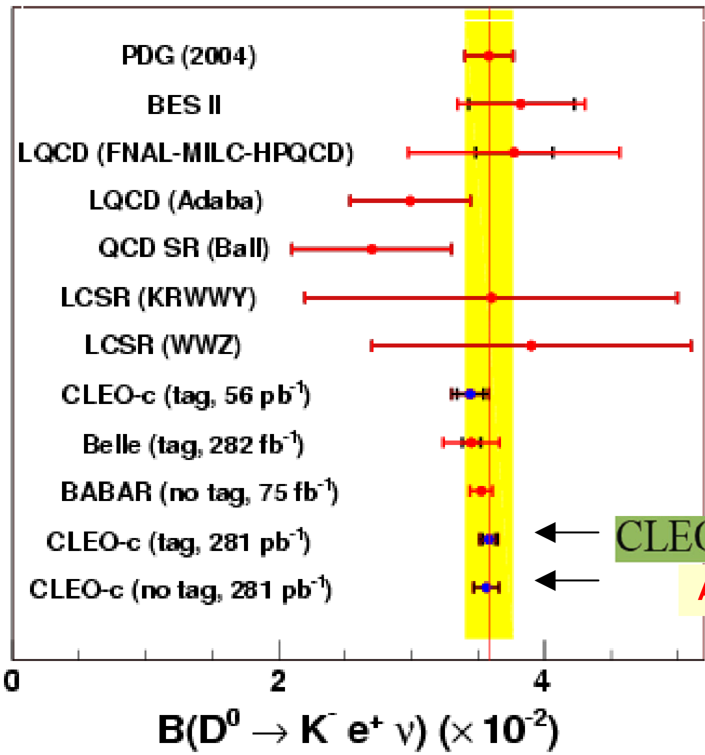


Factor ~2 increase compared to tagged analysis

Histogram – MC
Points – data
Backgrounds
Cross feed
Non signal $D\bar{D}$
Continuum MC
e^+ fakes

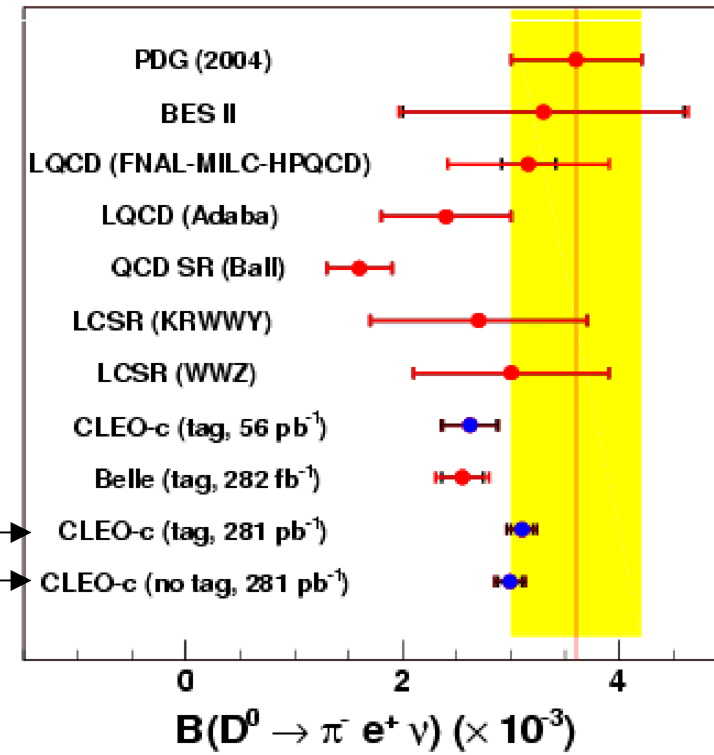
arXiv:0712.1012
arXiv:0712.0998
(accepted by PRL)

$D \to K/\pi e^+ \nu$ Branching Fractions



CLEO preliminary

ArXiv 0712.1020



$B(D^0 \to K^- e^+ \nu) \times 10^{-2}$

$3.58 \pm 0.05 \pm 0.05$ (tag)

$3.56 \pm 0.03 \pm 0.09$ (notag)

$B(D^0 \to \pi^- e^+ \nu) \times 10^{-3}$

$0.31 \pm 0.01 \pm 0.01$ (tag)

$0.30 \pm 0.01 \pm 0.01$ (notag)

Form factors

- Form factors relate to the probability of forming final state at given q^2.
- Theoretical predictions for form factors are needed to turn the measured rates into $V_{cs\,(cd)}$ determinations.
- Theory often calculates this probability at fixed q^2 and uses parameterizations to extrapolate to full q^2 range.
- Theoretical approaches include phenomenological models, QCD sum rules, LQCD.

pseudoscalar:

$$H^{\mu} = \bigcirc\,(P_D + P_h)^{\mu}$$

vector:

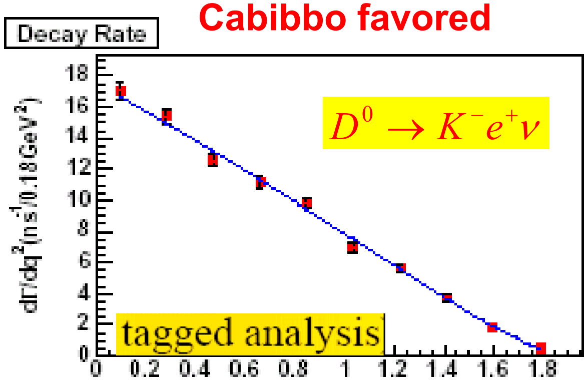
$$H^{\mu} = \frac{2i\varepsilon^{\mu\nu\alpha\beta}}{m_D + m_h} e_{\nu}^{*} P_{h\alpha} P_{D\beta}\,\bigcirc - (m_D + m_h) e^{\mu *}\,\bigcirc + \frac{e^{*\alpha} q_{\alpha}}{m_D + m_h} (P_D + P_h)^{\mu}\,\bigcirc$$

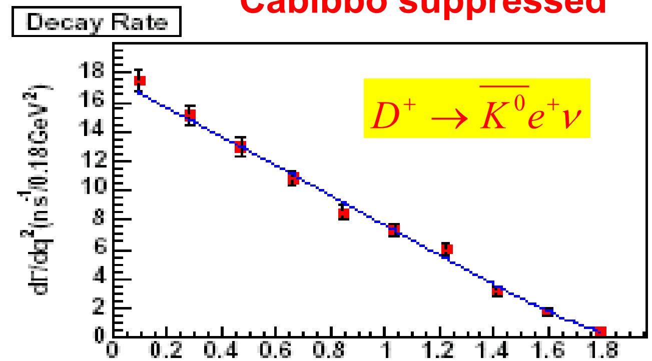
Simplicity favors pseudoscalar decay modes.

Absolute d Γ /dq² Distributions

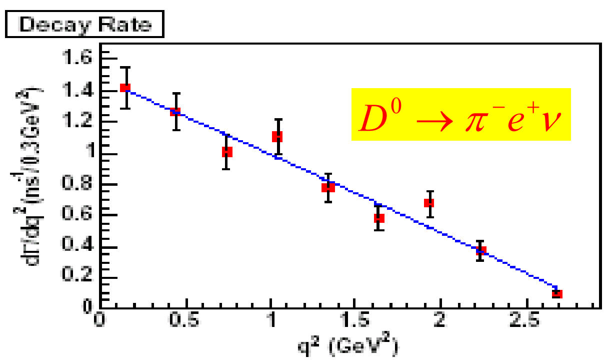
$$\frac{d\Gamma(D\to K(\pi)e\nu)}{dq^2} = \frac{G_F^2 |V_{cs(cd)}|^2 P_{K(\pi)}^3}{24\pi^3} |f_+(q^2)|^2$$

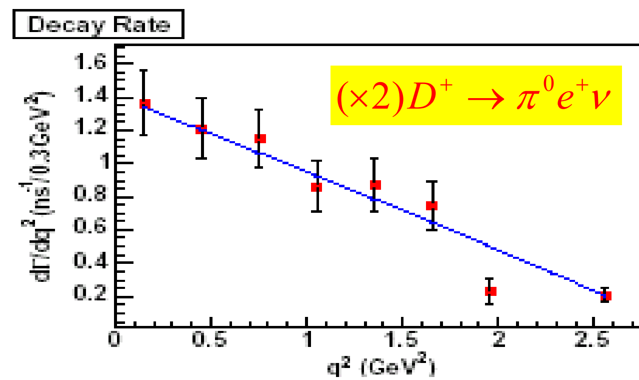
Cabibbo favored | **Cabibbo suppressed**





Fit to Simple Pole Model Shown





PRELIMINARY

Simple Pole Model

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

Modified Pole (BK) Model

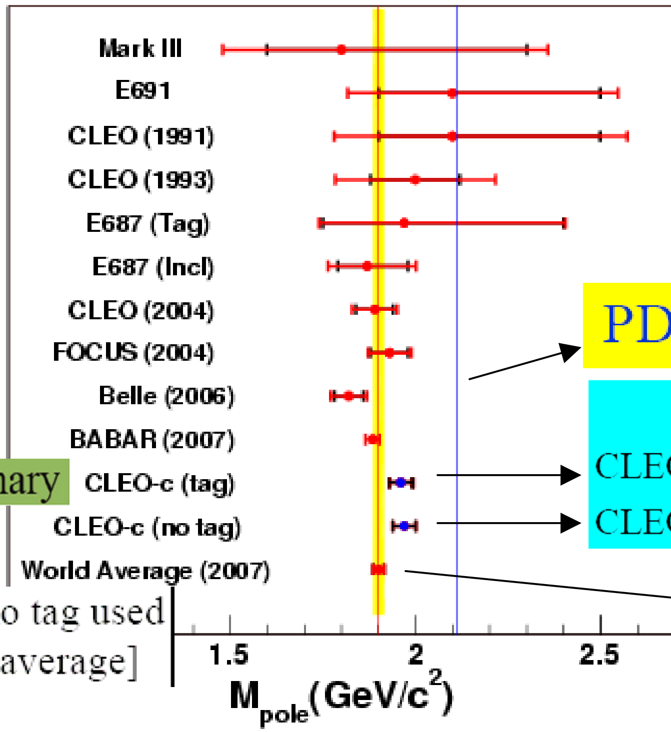
$$f^+(q^2) = \frac{f^+(0)}{(1 - q^2/m_{pole}^2)(1 - \alpha q^2/m_{pole}^2)}$$

Becher Hill Series parameterization

$$f_+(q^2) = \frac{1}{P(q^2)\phi(q^2,0)} \left[\sum_k a_k z^k (q^2, 0) \right]$$

$D \rightarrow K e^+ \nu$

Simple Pole Model



preliminary

[CLEO-c no tag used in world average]

$$f(q^2) = \frac{f(0)}{\left(1 - q^2 / M_{pole}^2\right)}$$

$$\text{PDG}: M(D_S^*) = (2112.0 \pm 0.6)\text{MeV}$$

	m_{pole} (GeV)
CLEOc tag	1.96(3)(1)
CLEOc notag	1.97(3)(1)

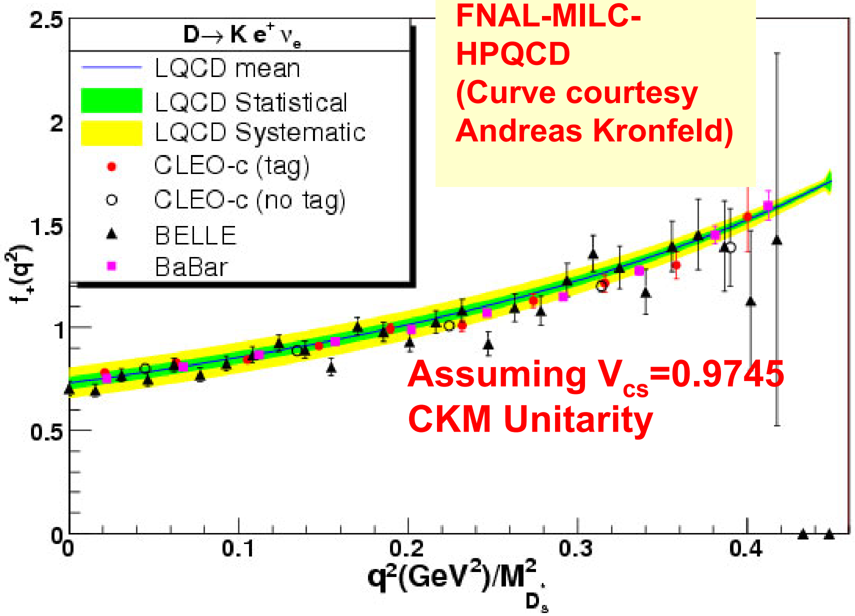
$$< M_{pole} = (1901 \pm 14)\text{MeV} >$$

$\sim 14\sigma$ discrepancy

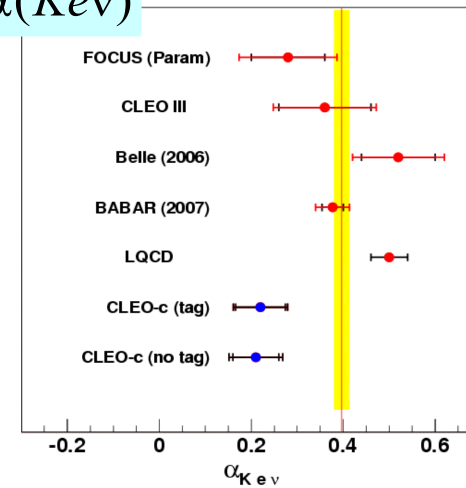
Pole model fits but not when the pole mass is the spectroscopic pole M(D*)

$D^0 \to K^- e^+ \nu$ Form factors: test of LQCD

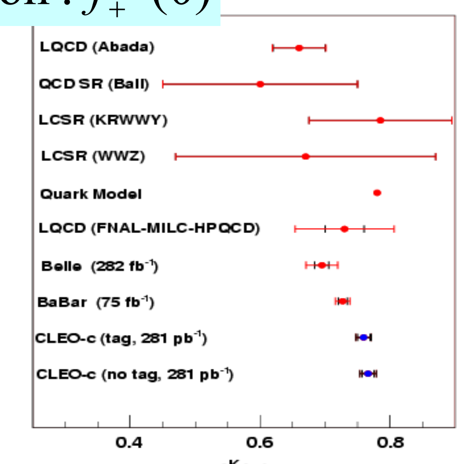
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} P_K^3 \left|f_+(q^2)\right|^2 \left|V_{cs}\right|^2$$



Shape: $\alpha(Ke\nu)$



Normalization : $f_+^K(0)$



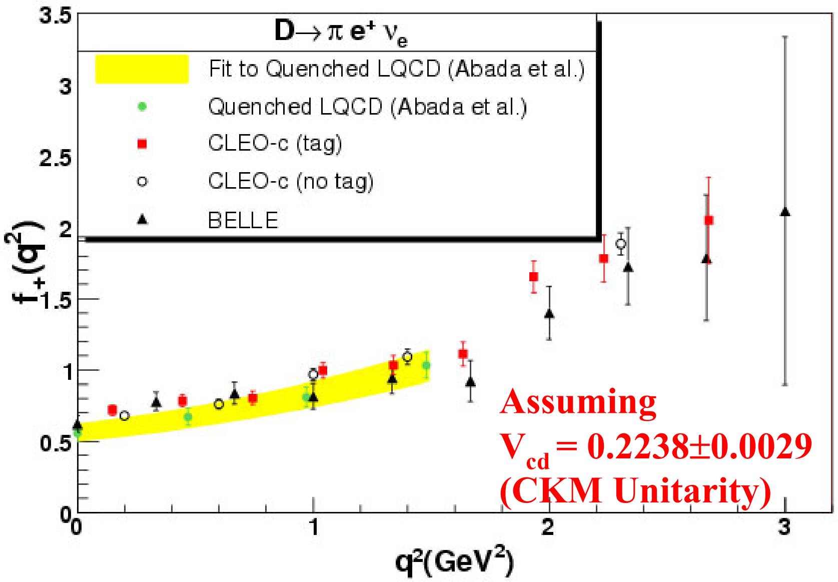
Modified pole model used as example

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - q^2/m_{pole}^2\right)\left(1 - \alpha\, q^2/m_{pole}^2\right)}, \text{with } M_{pole} = M(D_s^*)$$

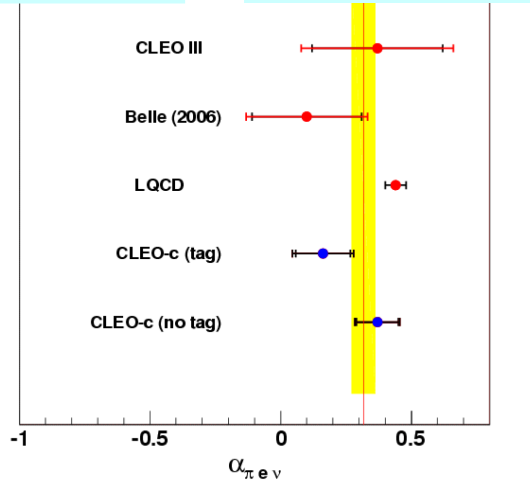
Experiments (2%) consistent with LQCD (10%). ***Theoretical precision lags.***

$D^0 \to \pi^- e^+ \nu$ Form factors: test of LQCD

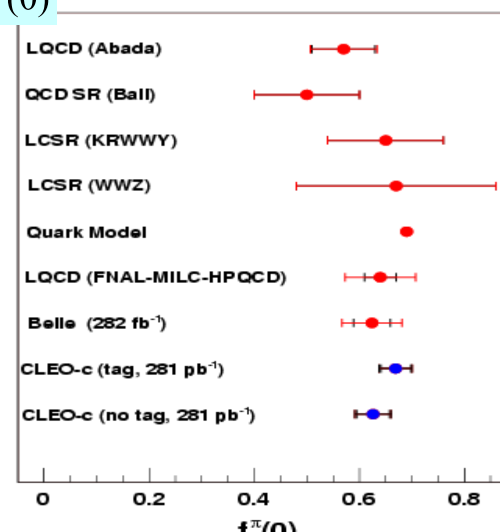
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} P_\pi^3 \left| f_+(q^2) \right|^2 \left| V_{cd} \right|^2$$



shape: $\alpha(\pi e \nu)$



Normalization: $f_+^\pi(0)$



Modified pole model used as example

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - q^2/m_{pole}^2\right)\left(1 - \alpha\, q^2/m_{pole}^2\right)}, \; with\ M_{pole} = M(D^*)$$

Shape: experiments compatible with LQCD
Normalization: experiments (4%) consistent with LQCD (10%).
CLEO-c is most precise. *Theoretical precision lags.*

V_{cs} and V_{cd} Results

Combine measured $|V_{cx}|f_+(0)$ **values using Becher-Hill parameterization** ***with (FNAL_MILC-HPQCD) for*** $f_+(0)$

Expt. uncertainties Vcs <2% Vcd~4% Theory 10%

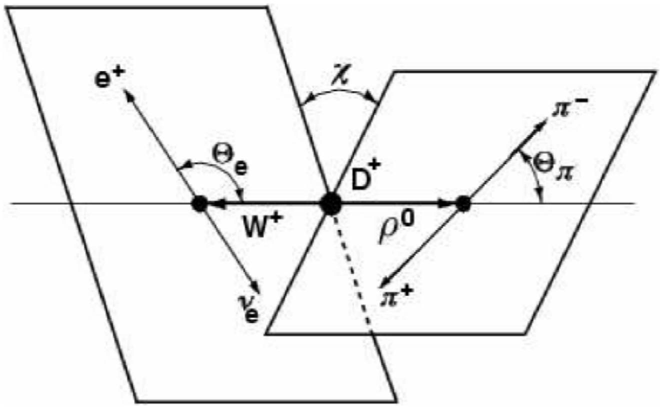
Decay Mode	$\|V_{cx}\| \pm (stat) \pm (syst) \pm (theory)$	
PRELIMINARY $D \to \pi e \nu$ (tagged)	0.234 ± 0.010 ± 0.004 ± 0.024	
$D \to \pi e \nu$ (untagged)	0.217 ± 0.009 ± 0.004 ± 0.023	
PRELIMINARY $D \to K e \nu$ (tagged)	1.014 ± 0.013 ± 0.009 ± 0.106	
$D \to K e \nu$ (untagged)	1.015 ± 0.010 ± 0.011 ± 0.106	

Tagged/ untagged consistent, 40% overlap DO NOT AVERAGE

CLEO-c: Determination of |Vcs|, and |Vcd| in good agreement with PDG

$D \to \rho e \nu$ Form Factors

$$\frac{d\Gamma}{dq^2 d\cos\theta_\pi d\cos\theta_e d\chi} = BR(\rho^0 \to \pi\pi)\frac{3G_F^2}{8(4\pi)^4}|V_{cs}|^2 \frac{P_\rho q^2}{M_D^2} \times$$



$$\{ \; (1+\cos\theta_e)^2 \sin^2\theta_\pi \left|H_+(q^2, m_{\pi\pi})\right|^2$$
$$+ \; (1-\cos\theta_e)^2 \sin^2\theta_\pi \left|H_-(q^2, m_{\pi\pi})\right|^2$$
$$+ \; 4\sin^2\theta_e \cos^2\theta_\pi \left|H_0(q^2, m_{\pi\pi})\right|^2$$
$$+ \; 4\sin\theta_e(1+\cos\theta_e)\sin\theta_\pi \cos\theta_\pi \cos\chi H_+(q^2, m_{\pi\pi})H_0(q^2, m_{\pi\pi})$$
$$- \; 4\sin\theta_e(1-\cos\theta_e)\sin\theta_\pi \cos\theta_\pi \cos\chi H_-(q^2, m_{\pi\pi})H_0(q^2, m_{\pi\pi})$$
$$- \; 2\sin^2\theta_e \sin^2\theta_\pi \cos 2\chi H_+(q^2, m_{\pi\pi})H_-(q^2, m_{\pi\pi}) \quad \}$$

$$H_\pm(q^2, m_{\pi\pi}) = (M_D + m_{\pi\pi})A_1(q^2) \mp 2\frac{M_D P_{\pi\pi}}{M_D + m_{\pi\pi}} V(q^2)$$

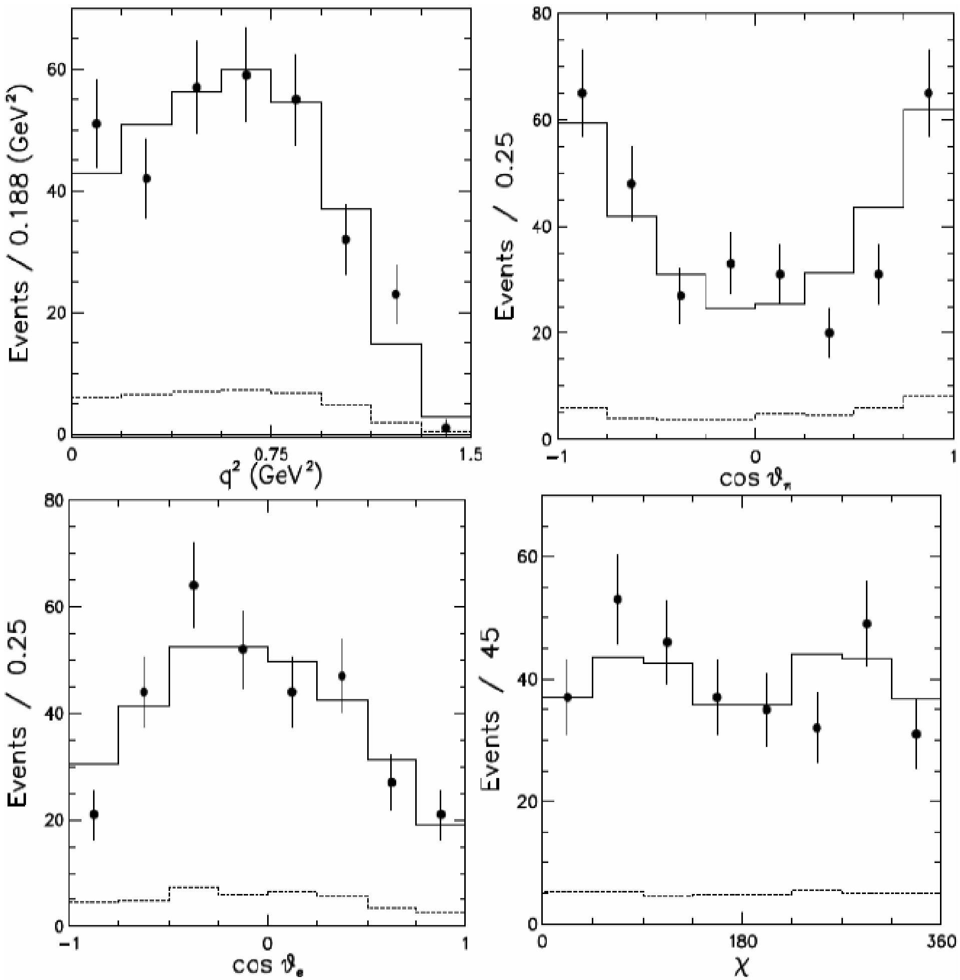
$$H_0(q^2, m_{\pi\pi}) = \frac{1}{2m_{\pi\pi}\sqrt{q^2}}\left[(M_D^2 - m_{\pi\pi}^2 - q^2)(M_D + m_{\pi\pi})A_1(q^2) - 4\frac{M_D^2 P_{\pi\pi}^2}{M_D + m_{\pi\pi}} A_2(q^2)\right]$$

- **Use Simple Pole Model for** $V(q^2)$,$A_1(q^2)$ **and** $A_2(q^2)$
- **Fit data (in 4D) for ratios of form factor normalizations:**
  - $R_V = V(0)/A_1(0)$
  - $R_2 = A_2(0)/A_1(0)$

$D \to \rho e \nu$ Form Factors

- Two isospin conjugate modes

$D^+ \to \rho^0 e \nu$ and $D^0 \to \rho^- e \nu$ were fit *simultaneously*.



CLEO-c 281 pb^{-1}
Preliminary
~300 events

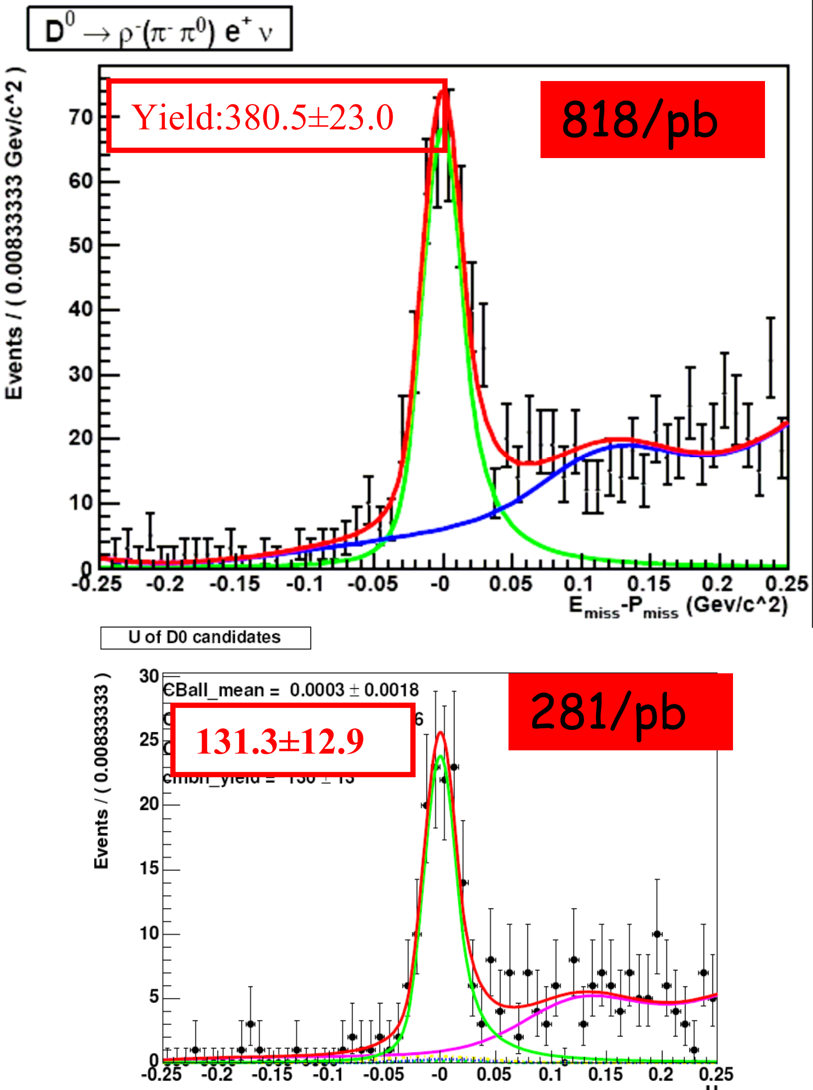
$$R_V = 1.40 \pm 0.25$$
$$R_2 = 0.57 \pm 0.19$$

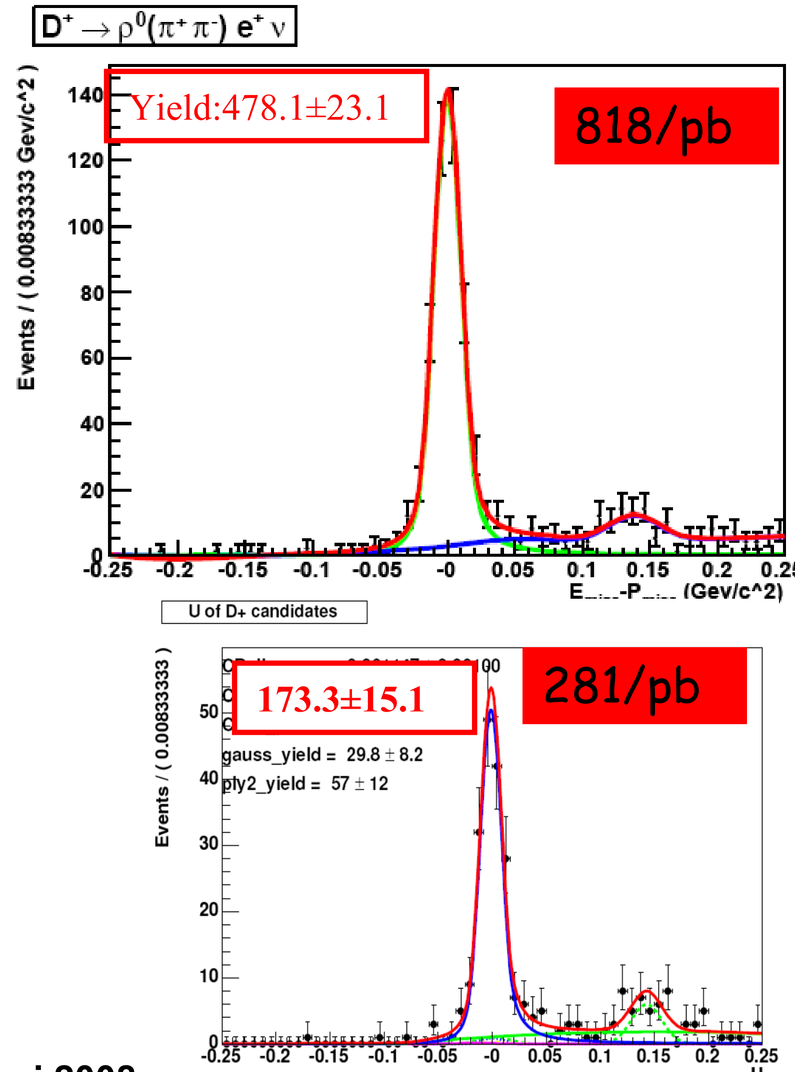
(first measurement in Cabibbo suppressed mode)

Not much different from Cabibbo favored $D \to K^* \mu \nu$ form factor ratios (FOCUS):

$$R_V = 1.50 \pm 0.07$$
$$R_2 = 0.88 \pm 0.08$$

First look at 818/pb





Semileptonic Summary

$\mathcal{B}(D \to Ke\nu)$ 6% error (PDG2004) $\to$ 2% combined with LQCD calculations (10% errors) leads to best direct determination of Vcs

$\mathcal{B}(D \to \rho e\nu)$ 45% error(PDG2004) $\to$ 4%

Potential for best direct determination of Vcd if LQCD errors are improved

First measurements of many decays with small BRs

Many new and improved form factor measurements.

CLEO-c (3770) statistics have been recently increased by a factor of 3.

Expectations from analysis of the full data sample (in progress):

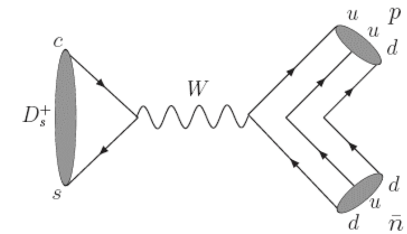
- More stringent tests of theory on form factor normalizations and slopes.
- Improved determinations of CKM elements:
  - Vcs ~ 0.9-1.2% (systematics limited) + theory error
  - Vcd ~ 2.3-3.5% (statistics limited) + theory error

Expect CLEO-c results for tagged semileptonic decays of D_s this summer

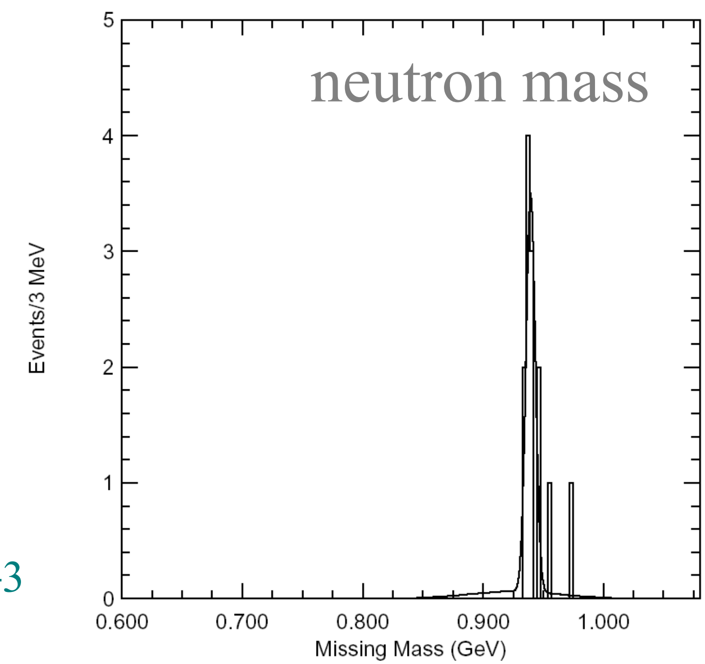
Summary

The CLEO-c program has been highly successful in making precision measurements of charm meson decays. Data taking is finished and the detector is being decommissioned. Some preliminary results from the full data set are available and there will be more at ICHEP2008 in August. We expect that within a year final results will be published from the full data sets

Discovery of $D_s^+ \to p\bar{n}$



- Use same technique as for $\mu^+\nu$, but plot MM from a detected proton
- No background
- First example of a charm meson decaying into baryons
- Consequences for understanding W annihilation dynamics
- see Chen, Cheng & Hsiao arXiv:0803.2910v3 [hep-ph]

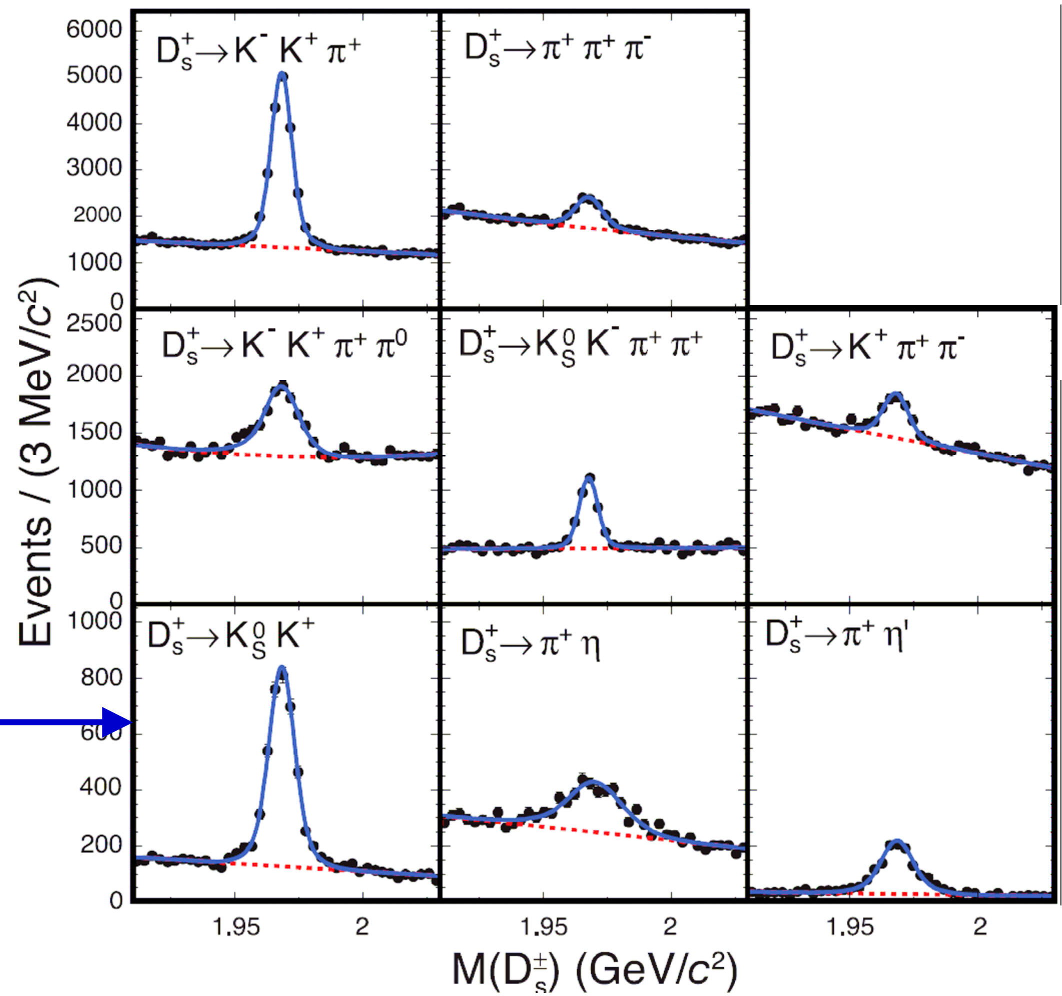


arXiv:0803.1118v2 [hep-ex]

$$B(D_s^+ \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16})\ x10^{-3}$$

Absolute D_s Branching Ratios

- Use ratio of Double tags/Single tags
  - $\#T_1 = 2N_{DD}\varepsilon_1\mathcal{B}_1$
  - To first order $\#T_{11} = N_{DD}\varepsilon_1^2\mathcal{B}_1^2$
  - $\therefore \#T_{11}/\#T_1 = (1/2)\,\varepsilon_1\mathcal{B}_1$
  - $\mathcal{B}_1 = (2/\varepsilon_1)\,(\#T_{11}/\#T_1)$
  - We use all combinations of these modes

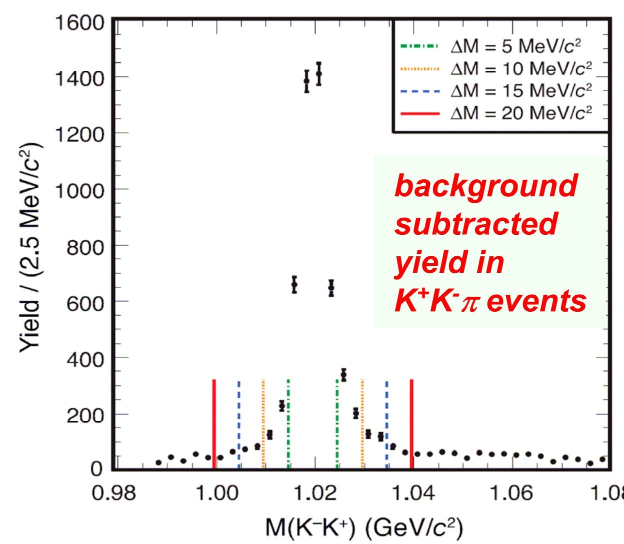


D_S Absolute $\mathcal{B}$ Results (300 pb^{-1})

Mode	This Result $\mathcal{B}$ (%)	PDG 2007 fit $\mathcal{B}$ (%)	$\mathcal{B}/\mathcal{B}(K^-K^+\pi^+)$	$\mathcal{A}_{CP}$ (%)
$K^0_S K^+$	$1.49 \pm 0.07 \pm 0.05$	2.2 ± 0.4	$0.270 \pm 0.009 \pm 0.008$	$+4.9 \pm 2.1 \pm 0.9$
$K^-K^+\pi^+$	$5.50 \pm 0.23 \pm 0.16$	5.3 ± 0.8	1	$+0.3 \pm 1.1 \pm 0.8$
$K^-K^+\pi^+\pi^0$	$5.65 \pm 0.29 \pm 0.40$	—	$1.03 \pm 0.05 \pm 0.08$	$-5.9 \pm 4.2 \pm 1.2$
$K^0_S K^-\pi^+\pi^+$	$1.64 \pm 0.10 \pm 0.07$	2.7 ± 0.7	$0.298 \pm 0.014 \pm 0.011$	$-0.7 \pm 3.6 \pm 1.1$
$\pi^+\pi^+\pi^-$	$1.11 \pm 0.07 \pm 0.04$	1.24 ± 0.20	$0.202 \pm 0.011 \pm 0.009$	$+2.0 \pm 4.6 \pm 0.7$
$\pi^+\eta$	$1.58 \pm 0.11 \pm 0.18$	2.16 ± 0.30	$0.288 \pm 0.018 \pm 0.033$	$-8.2 \pm 5.2 \pm 0.8$
$\pi^+\eta'$	$3.77 \pm 0.25 \pm 0.30$	4.8 ± 0.6	$0.69 \pm 0.04 \pm 0.06$	$-5.5 \pm 3.7 \pm 1.2$
$K^+\pi^+\pi^-$	$0.69 \pm 0.05 \pm 0.03$	0.67 ± 0.13	$0.125 \pm 0.009 \pm 0.005$	$+11.2 \pm 7.0 \pm 0.9$

$\mathcal{B}(D_S^+ \to \phi\pi^+)$ – Not well defined due to interferences and structures in Dalitz plot. Depends on both mass resolution & cut in K^+K^- mass

K^+K^- mass cut	$\mathcal{B}(D_S^+ \to \phi\pi^+)$ (%)
± 5 MeV	3.43±0.16±0.12
±10 MeV	4.04±0.20±0.10
±15 MeV	4.35±0.20±0.10
±20 MeV	4.55±0.22±0.12



D_s Hadronic Branching fractions

Mode	This Result $\mathcal{B}$ (%)	PDG 2007 fit $\mathcal{B}$ (%)	$\mathcal{B}/\mathcal{B}(K^-K^+\pi^+)$	$\mathcal{A}_{CP}$ (%)
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