Latest CLEO-c Results

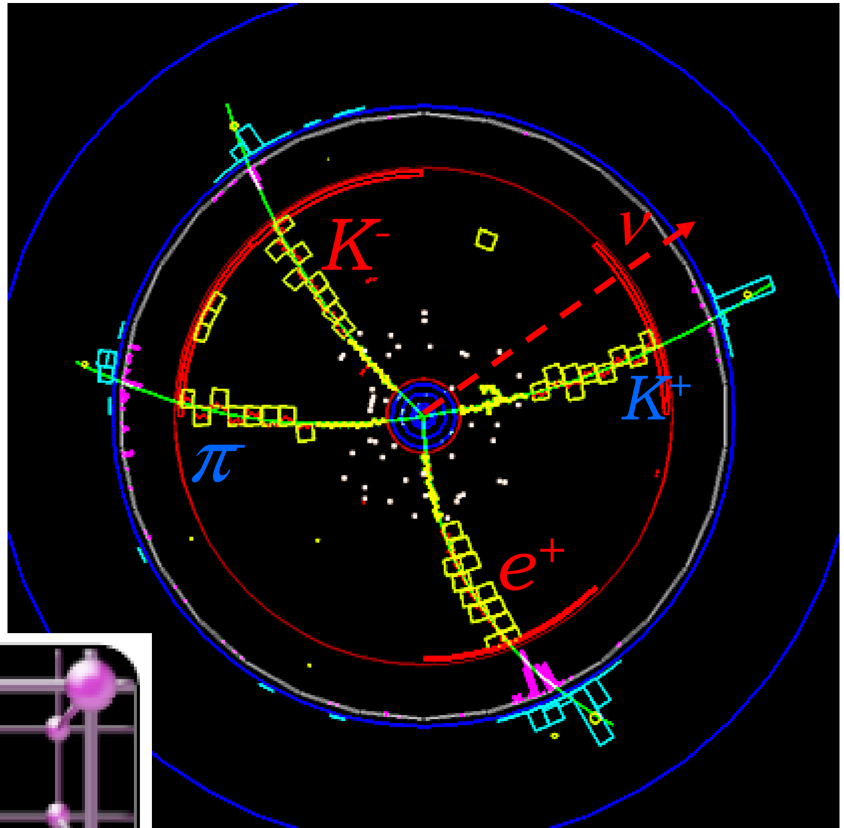
OUTLINE

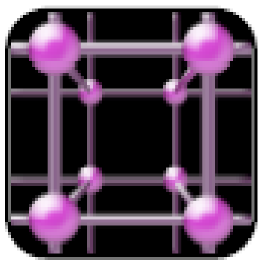
The role of charm in particle physics

Testing the Standard Model with precision quark flavor physics

Direct Searches for Physics Beyond the Standard Model

Ian Shipsey, Purdue University
CLEO-c Collaboration





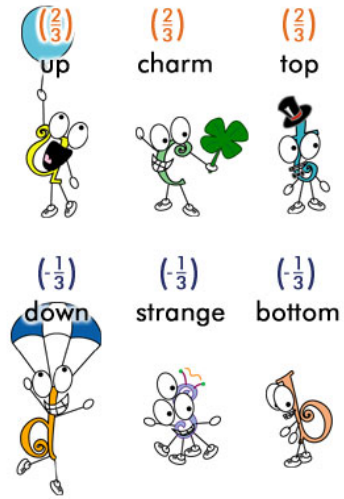
$$\psi(3770) \rightarrow D^0 \overline{D}^0$$

$$\overline{D}^0 \rightarrow K^+\pi^-, D^0 \rightarrow K^- e^+ \nu$$

Big Questions in Flavor Physics

Dynamics of flavor?

Why generations?
Why a hierarchy of masses & mixings?



Origin of Baryogenesis?

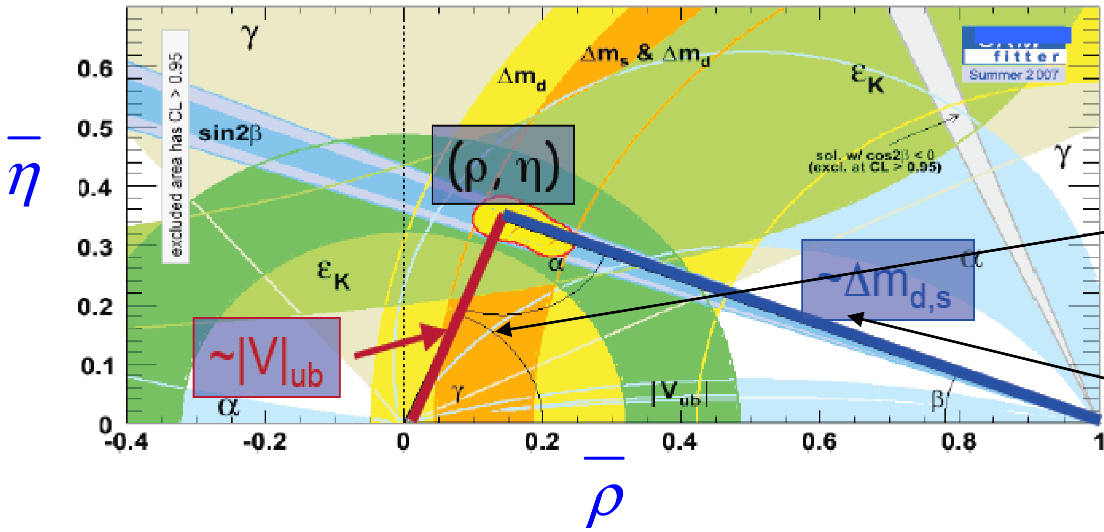
Sakharov's criteria: Baryon number violation
CP violation   Non-equilibrium

3 examples: Universe, kaons, beauty but Standard Model CP violation too small, need additional sources of CP violation

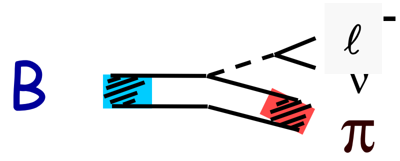
Connection between flavor physics & electroweak symmetry breaking?

Extensions of the Standard Model (ex: SUSY) contain flavor & CP violating couplings that should show up at some level in flavor physics, but *precision* measurements and *precision* theory are required to detect the new physics

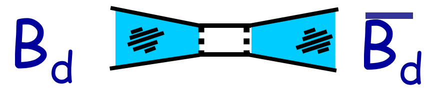
Precision Quark Flavor Physics



The discovery potential of B physics is limited by systematic errors from QCD:

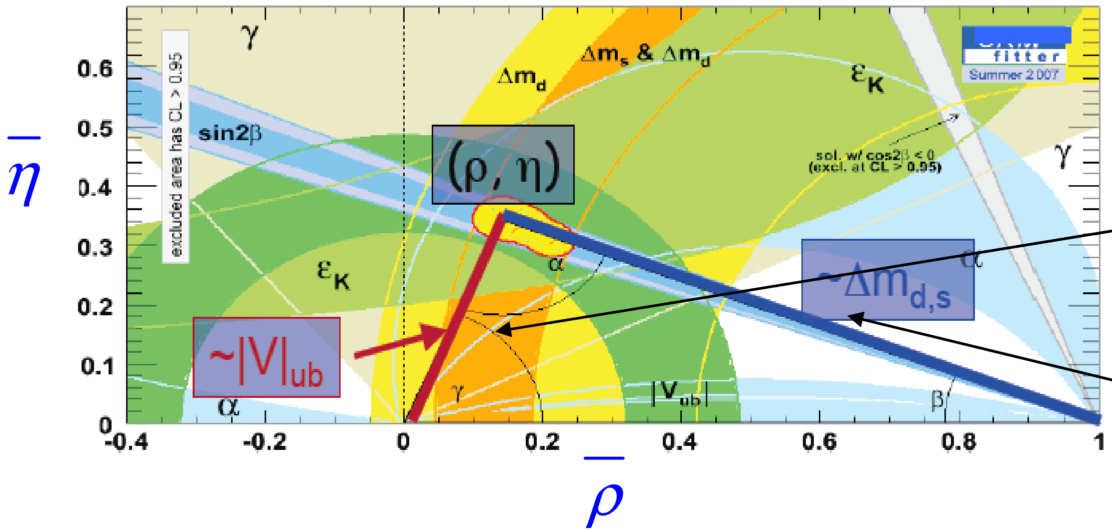


$$\propto \left[f^{B\to\pi}(q) \right]^2 \left| V_{ub} \right|^2$$



$$\propto \left[f_{Bd} \right]^2 \left| V_{td} \right|^2$$

Precision Quark Flavor Physics



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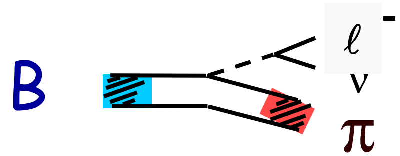
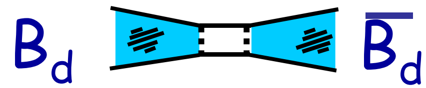
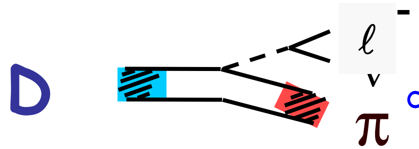


$$\propto \left[f^{B\to\pi}(q) \right]^2 |V_{ub}|^2$$

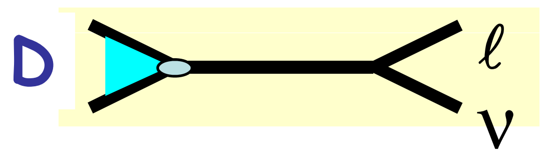


$$\propto \left[f_{Bd} \right]^2 |V_{td}|^2$$

D system- CKM elements known to <1% by unitarity



$$\propto \left[f^{D\to\pi}(q) \right]^2 |V_{cd}|^2$$



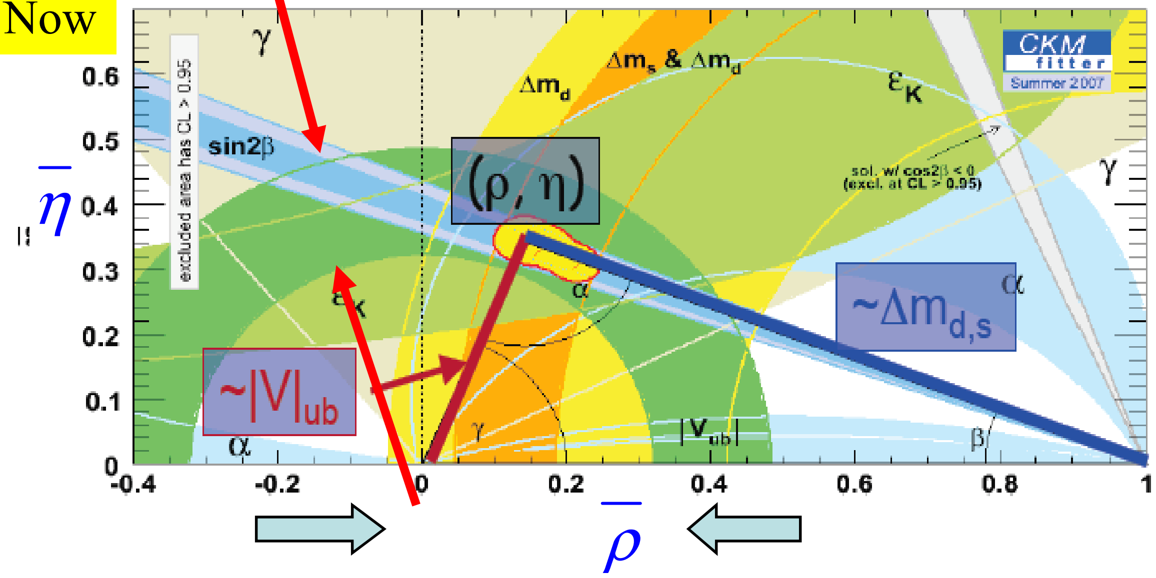
$$\propto \left[f_{D+} \right]^2 |V_{cd}|^2$$

→ *measurements of absolute rates* for D semileptonic & leptonic decays yield decay constants & form factors to *test* and hone QCD techniques into *precision theory* which can be applied to the B system enabling improved determination of the apex (ρ,η)

+ Br(B→ D)~100% *absolute* D hadronic rates normalize B physics important for Vcb (scale of triangle) - also normalize D physics

Precision theory + charm = large impact

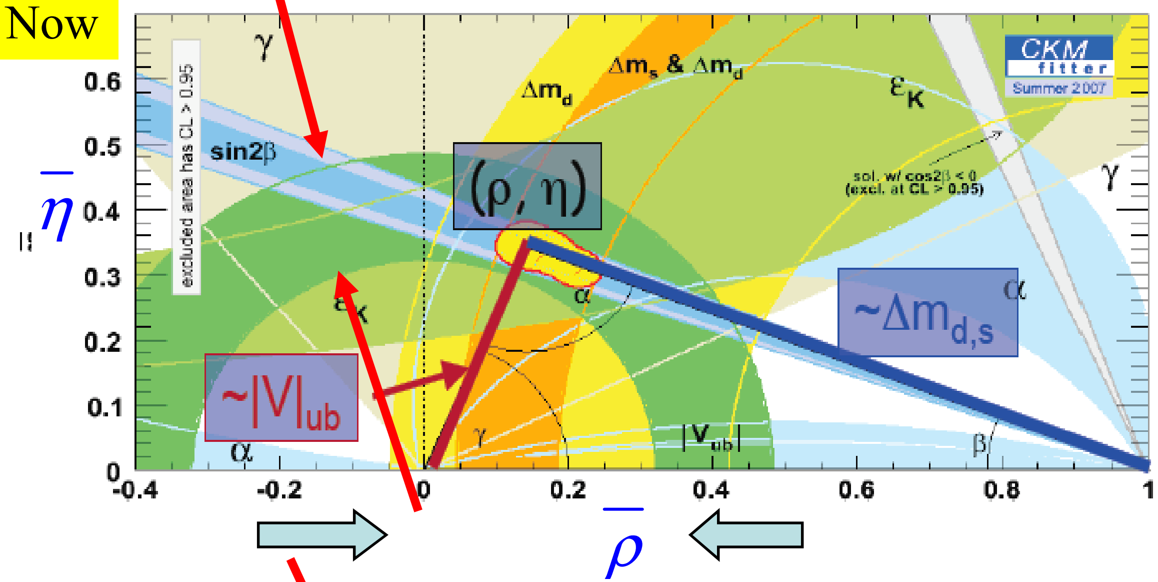
Now

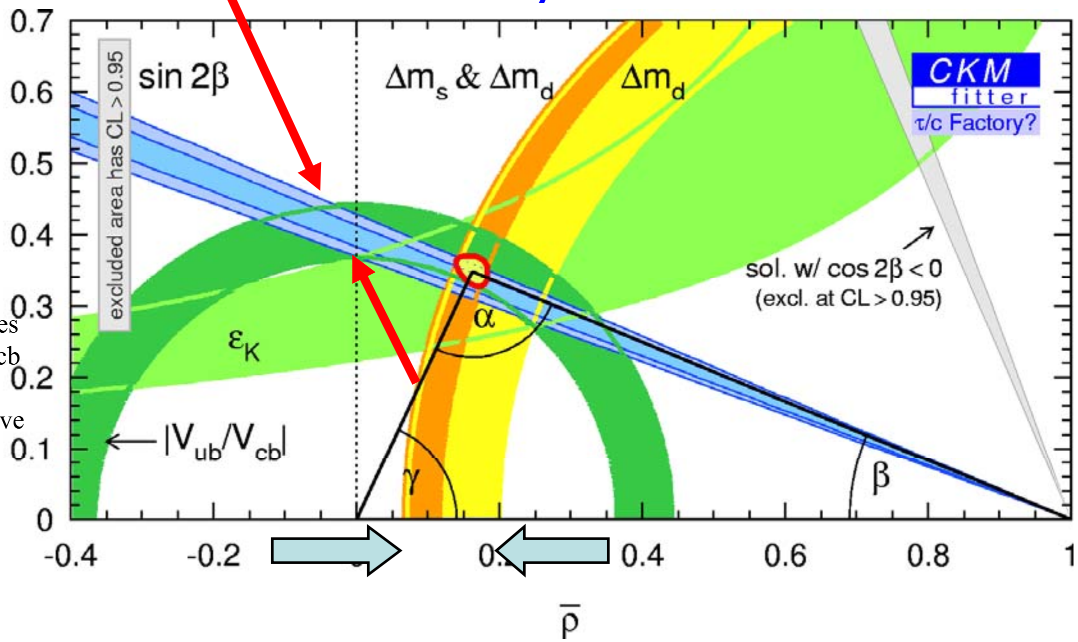


Theoretical errors dominate width of bands

Precision theory + charm = large impact

Now





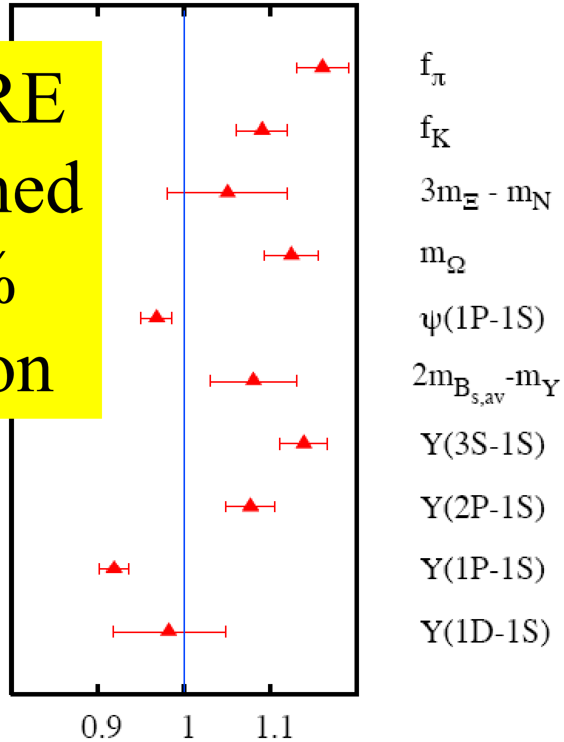
Plot uses Vub Vcb from exclusive decays only

Theoretical errors dominate width of bands

Few % precision QCD Calculations tested with few % *precision* charm data
➔theory errors of a few % on B system decay constants & semileptonic form factors

Precision theory? Lattice QCD

BEFORE
Quenched
10-15%
precision

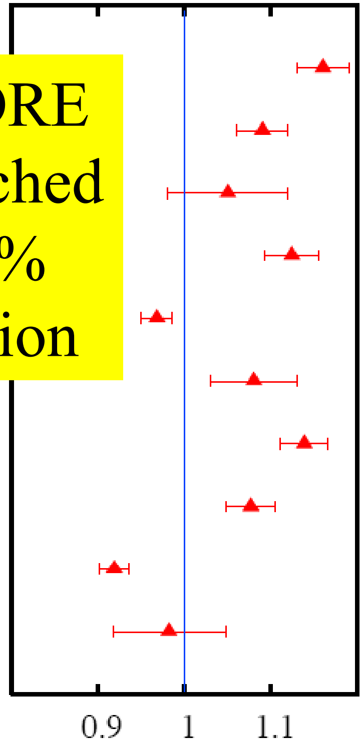


$$\frac{\text{theory-expt}}{\text{expt}}$$

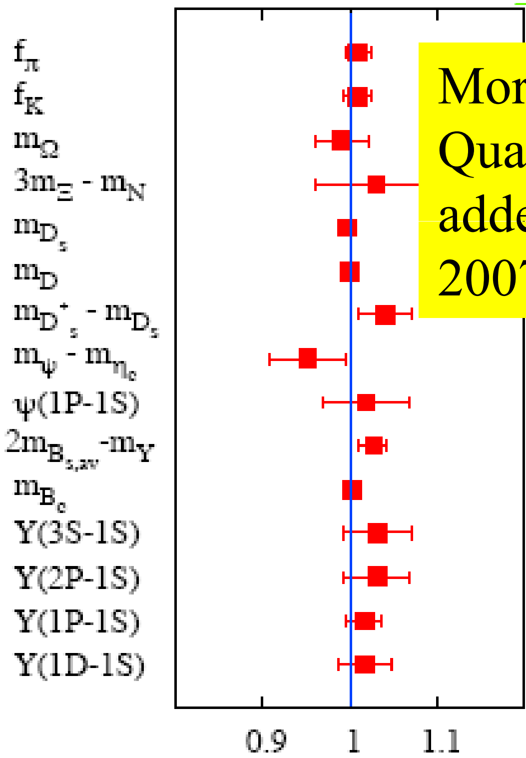
Precision theory? In 2003 a breakthrough in Lattice QCD

Recent revolutionary progress in algorithms allows inclusion of QCD vacuum polarization LQCD demonstrated it can reproduce a wide range of mass differences & decay constants. *These were postdictions*

BEFORE
Quenched
10-15%
precision



$\frac{\text{theory-expt}}{\text{expt}}$



$\frac{\text{theory-expt}}{\text{expt}}$

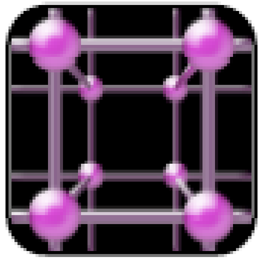
More Quantities added 2007

This dramatic improvement needs validation

Charm decay constants f_{D+} & f_{Ds}

Charm semileptonic Form factors

Understanding strongly coupled systems is important beyond flavor physics. LHC might discover new strongly interacting physics



Precision Experiment for charm?

Circa 2004 (pre-CLEO-c)

Experiment : Theory

Poorly known

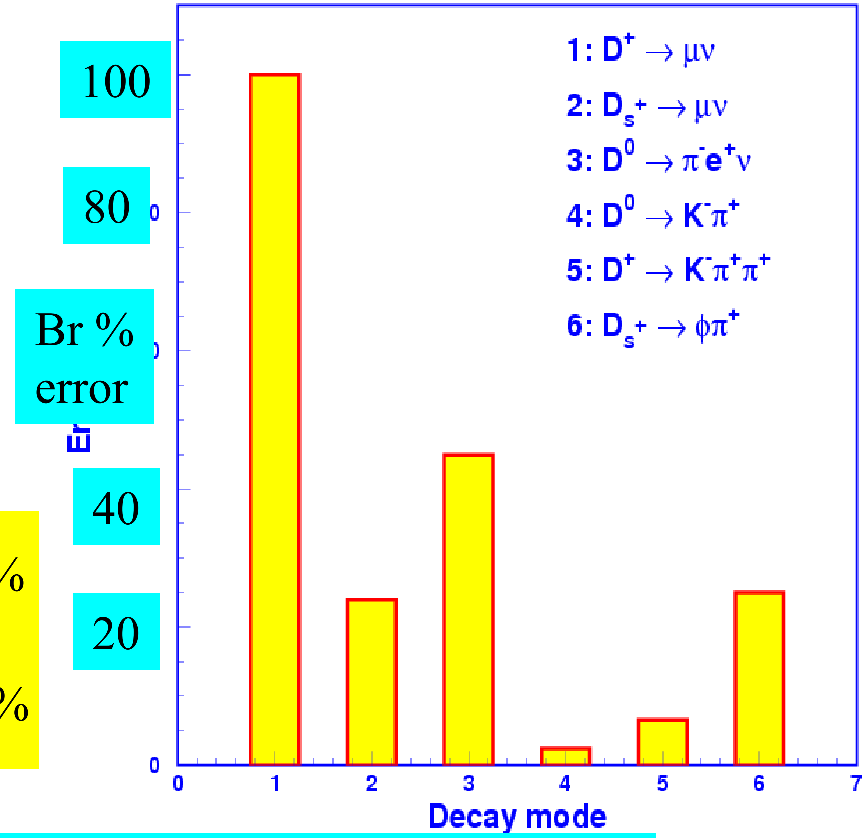
$$\frac{Br}{\tau} = \Gamma$$

Measured very precisely 0.4-0.8%

$$\frac{\delta B}{B}(D \to \pi e^+ \upsilon) = 45\%$$

$$\frac{\delta B}{B}(D^+ \to \mu^+ \upsilon) = 100\%$$

Key leptonic, semileptonic & hadronic modes:



Before CLEO-c precise measurements of charm decay constants and form factors did not exist, because at Tevatron/FT/ B factories:

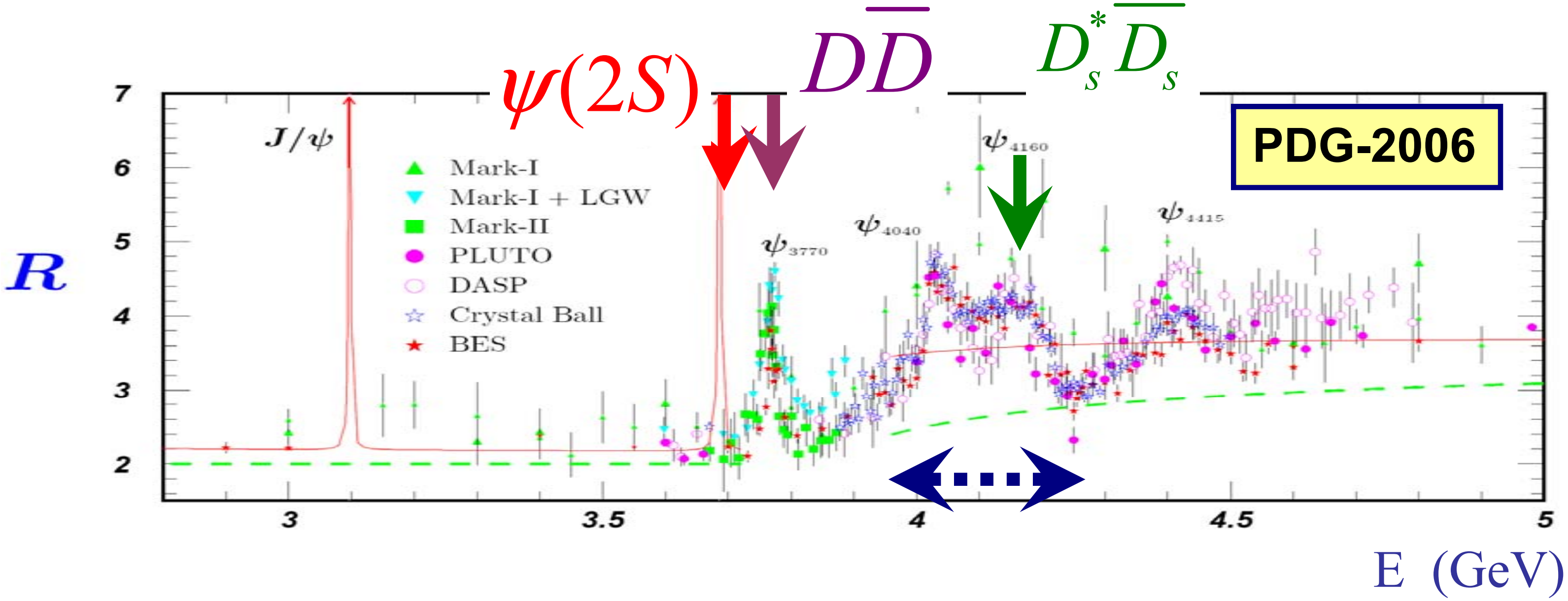
$$Br(D \to X) = \frac{\text{\#X Observed}}{\text{efficiency x \#D's produced}}$$

Backgrounds are large.

#D's produced is usually not well known.

CLEO-c: World's largest data sets at charm threshold

CLEO-c: Oct. 2003 – March 2008, **CESR (10GeV) → CESR-c at 4GeV**
CLEO III detector →CLEO-c



$\sqrt{s}$ (MeV)   Ldt (pb^{-1})

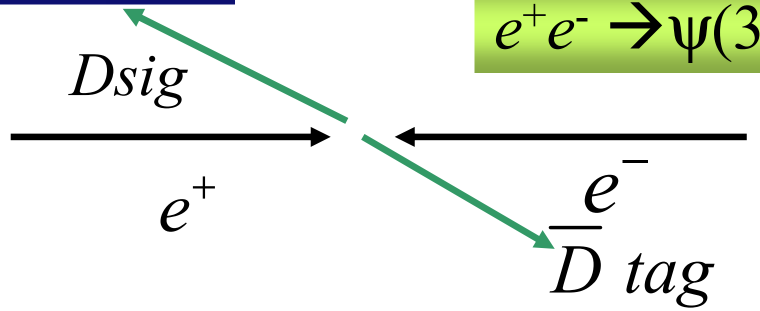
3686   54 $N(\psi(2S)) \approx 27M$

3773   800 $\psi(3770) \to D\overline{D} \approx 5.1\times10^6\, D\overline{D}$ ← X84 MARK III, X42 BES II

4170   314 $D_{(s)}^{(*)}\overline{D_{(s)}^{(*)}} \approx 3\times10^5\, D_s^*\overline{D}_s$ ← Expect to collect x2 by end of running

$\psi(3770)$ Analysis Strategy

$e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}$



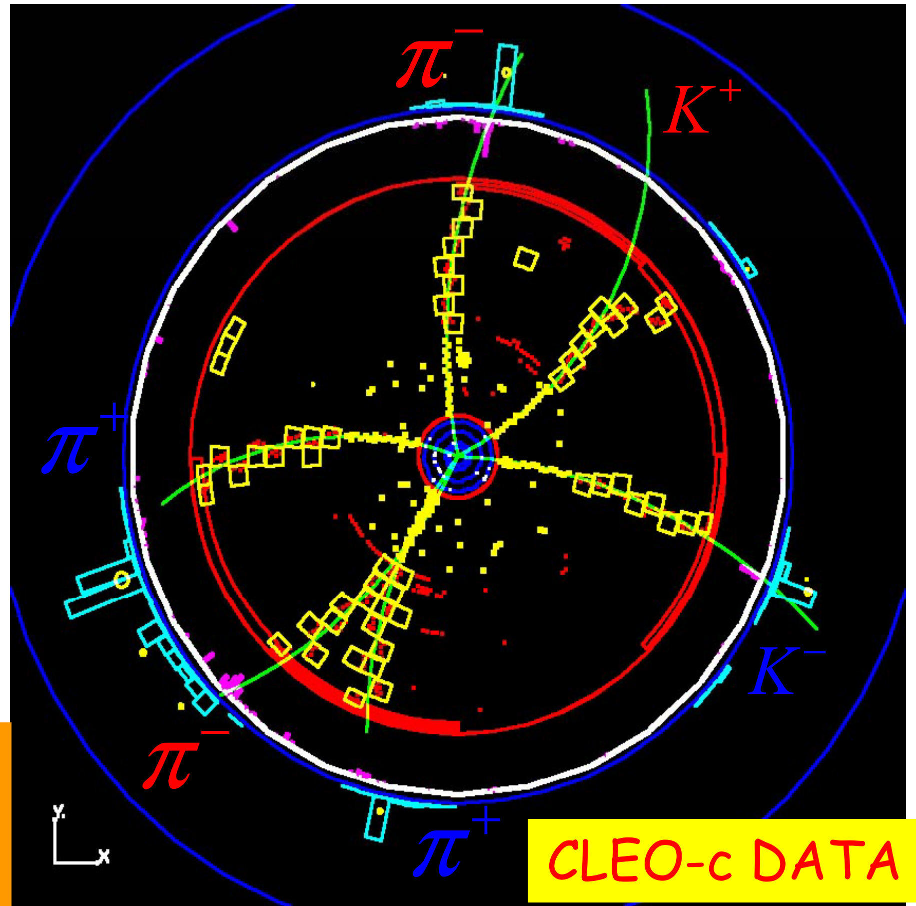
$\psi(3770)$ is to charm what Y(4S) is to beauty

- Pure DD, no additional particles ($E_D = E_{beam}$).
- σ (DD) = 6.4 nb (Y(4S)->BB ~ 1 nb)
- Low multiplicity ~ 5-6 charged particles/event

➔ high tag efficiency: ~25% of events

Compared to ~0.1% of B's at the Y(4S)

A little luminosity goes a long way:
Tagging ability:
D tags in 300 pb^{-1} @ charm factory
~ # B tags in 500 fb^{-1} @ Y(4S)



$\psi(3770) \rightarrow D^+ D^-$

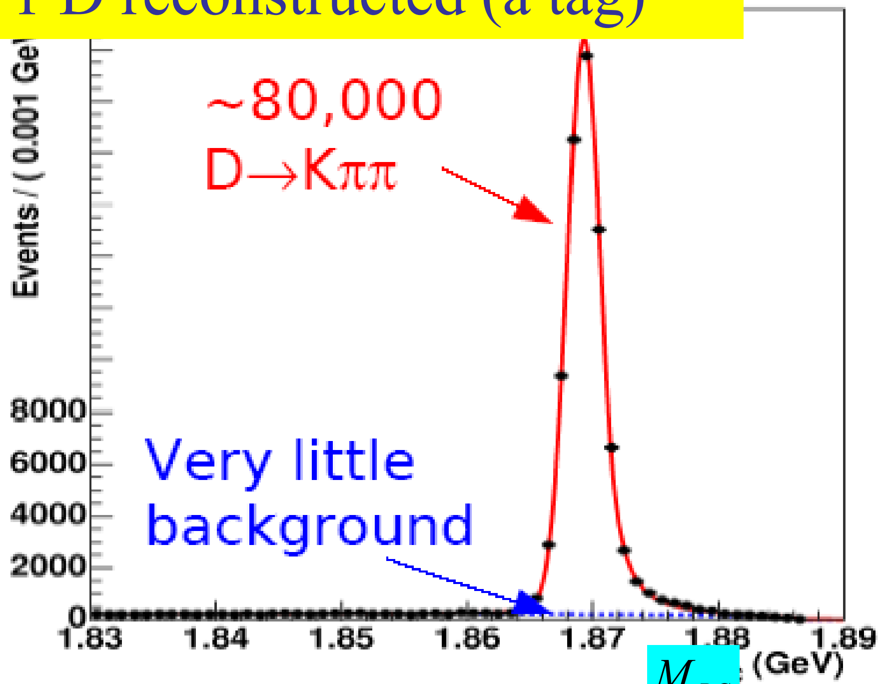
$D^+ \rightarrow K^-\pi^+\pi^+,\ D^- \rightarrow K^+\pi^-\pi^-$

Absolute Charm Branching Ratios at Threshold

281/pb

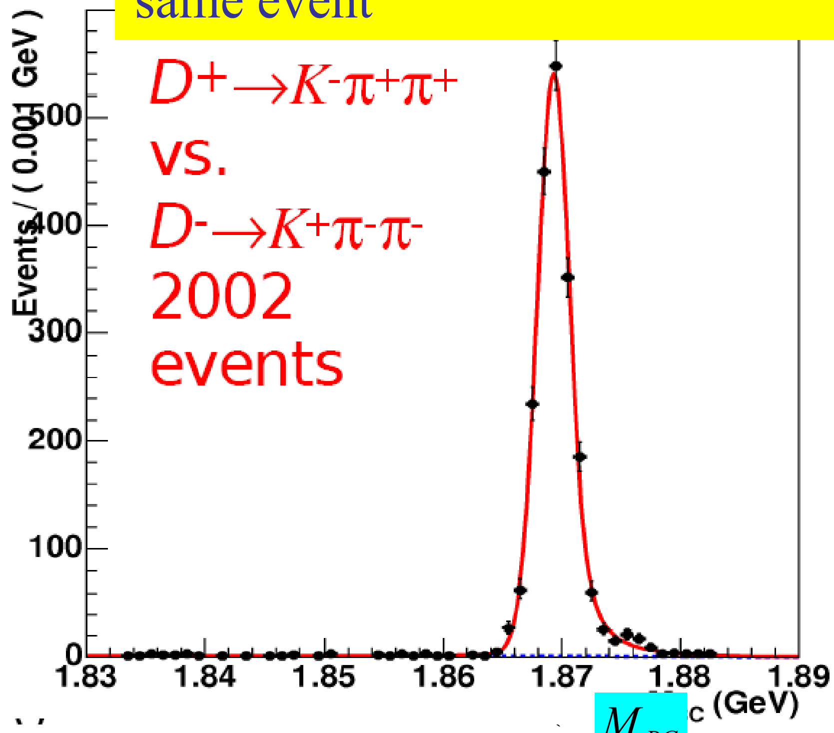
$$E_D \Rightarrow E_{beam}: \quad \Delta E = E_{beam} - E_D \qquad M_{BC} = \sqrt{E_{beam}^2 - |\,p_D\,|^2}$$

1 D reconstructed (a tag)



M_{BC}

1D+ & 1D- reconstructed in same event



M_{BC}

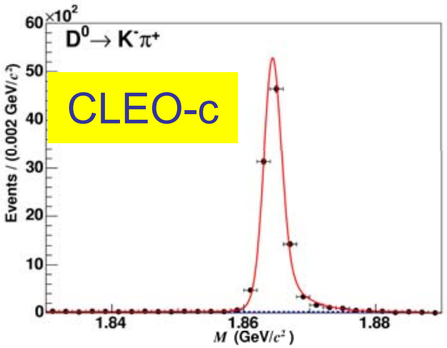
Independent of L and cross section

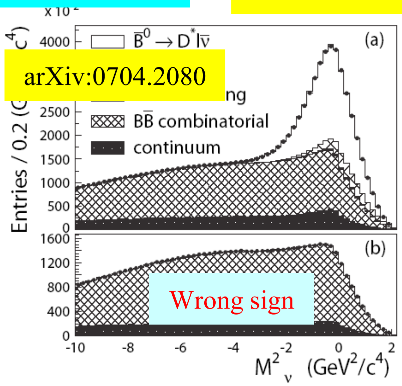
$$B(D^- \to K^+\pi^-\pi^-) = \frac{\#\,(K^+\pi^-\pi^-)\text{ Observed in tagged events}}{\text{detection efficiency for }(K^+\pi^-\pi^-)\ \bullet\ \#\text{D tags}}$$

$B(D^o \to K^- \pi^+)$

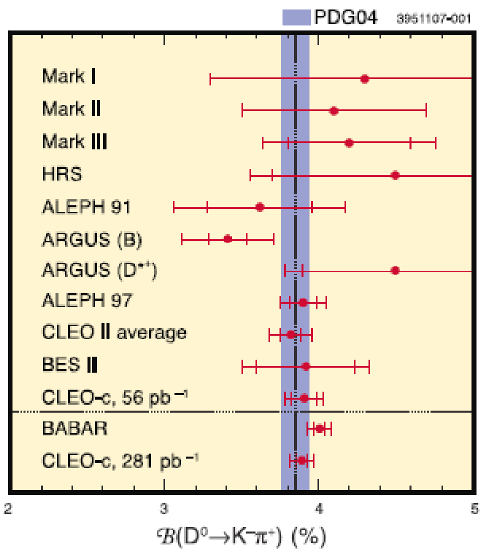
Sets scale of bd triangle

BABAR





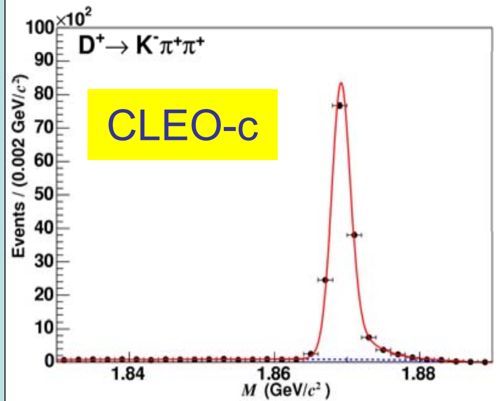
$\mathcal{B}$ (%)	Error(%)	Source
3.80 ±0.09	2.4	PDG04
3.891±0.035 ±0.069	2.0	CLEO-c
4.007 ±0.037 ±0.070	2.0	BABAR



Syst. limited: 2%

CLEO-c & BABAR agree vastly superior S/N at CLEO-c

$B(D^+ \to K^- \pi^+ \pi^+)$



Previous best:

measure:

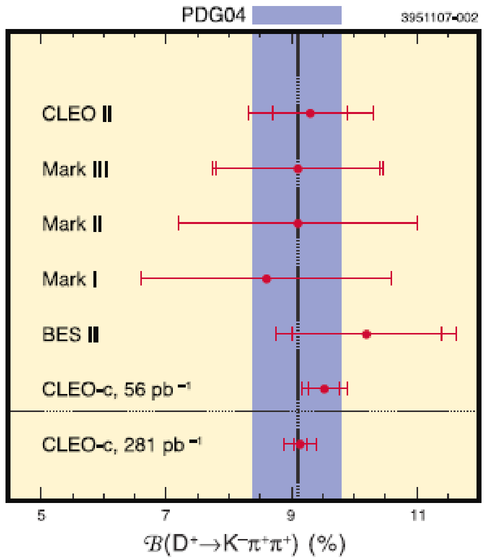
$$\frac{B(D^{*+} \to D^0 \pi^+)}{B(D^{*+} \to D^+ \pi^0)} \frac{B(D^0 \to K^- \pi^+)}{B(D^+ \to K^- \pi^+ \pi^+)}$$

$B(D^+ \to K^- \pi^+ \pi^+)$ *dependent on* $B(D^0 \to K^- \pi^+)$

$\mathcal{B}$ (%)	Error(%)	Source
9.3±0.6±0.8	10.8	CLEO
9.1±1.3±0.4	14.9	MKIII
9.1±0.7	7.7	PDG04
9.14 ±0.10±0.17	1.9	CLEO-c

now: $B(D^+ \to K^- \pi^+ \pi^+)$ *independently measure*

CLEO-c x 3.5 More precise than PDG



charm hadronic scale is finally on a SECURE FOUNDATION

Accepted by PRD arXiv:0709.3783

D_s Hadronic BRs

NEW

D_s hadronic BFs serve to nomalize many processes in D_s & B_s physics

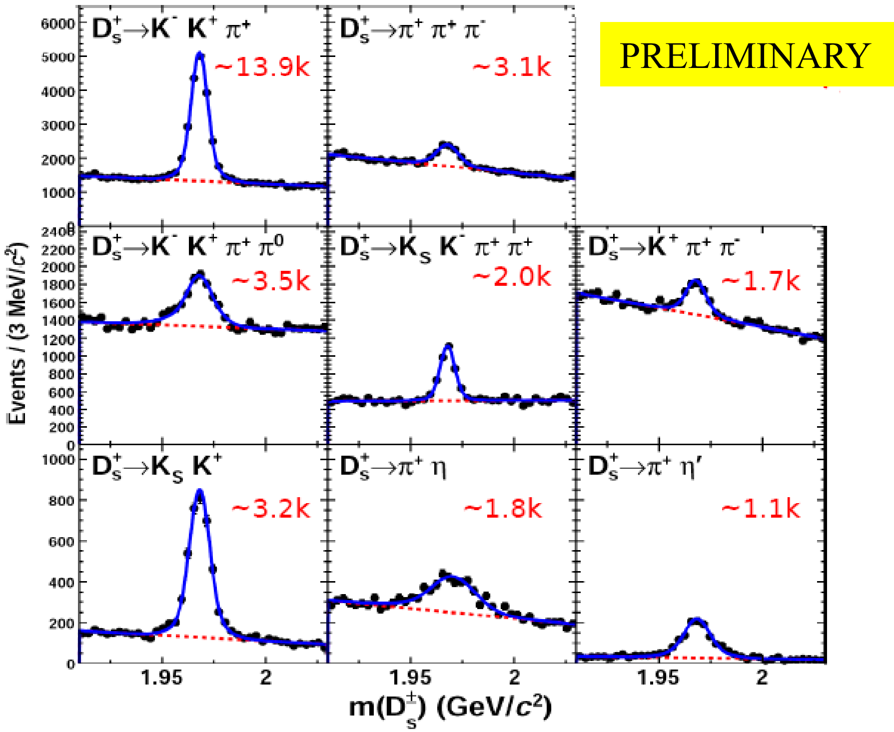
This is the 1st high statistics study @ threshold arXiv:0801.0680 (4 Jan 2008)

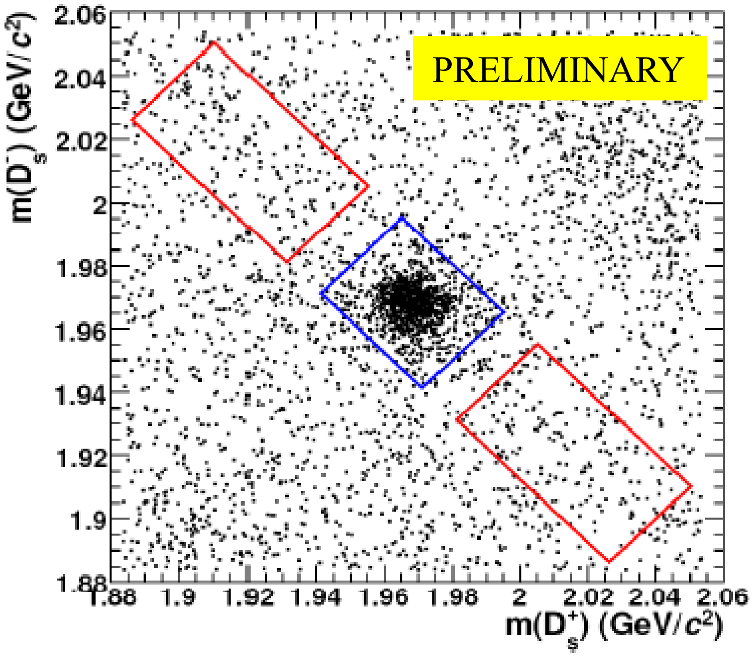
E_{cm}=4170 MeV. 298/pb Optimal energy for D_sD_s*production.

Analysis technique same as for DDbar at 3770

8 D_s single tag modes

~1000 double tags (all modes) (~3.5% stat.)





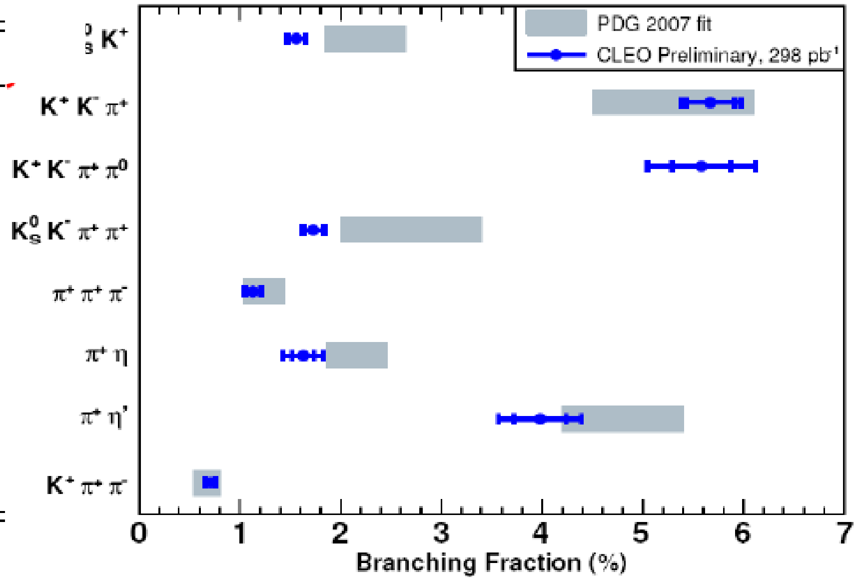
Absolute D_s hadronic $\mathcal{B}$'s

arXiv:0801.0680 (4 Jan 2008)

Errors already << PDG

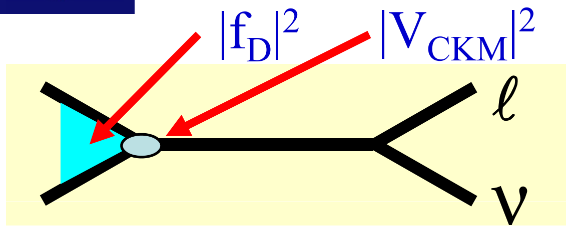
CLEO-c, 4170MeV, 298pb^{-1}

Mode	This Result $\mathcal{B}$ (%)	PDG 2007 fit $\mathcal{B}$ (%)
$K^0_S K^+$	$1.49 \pm 0.07 \pm 0.05$	2.2 ± 0.4
$K^- K^+ \pi^+$	$5.50 \pm 0.23 \pm 0.16$	5.3 ± 0.8
$K^- K^+ \pi^+ \pi^0$	$5.65 \pm 0.29 \pm 0.40$	—
$K^0_S K^- \pi^+ \pi^+$	$1.64 \pm 0.10 \pm 0.07$	2.7 ± 0.7
$\pi^+ \pi^+ \pi^-$	$1.11 \pm 0.07 \pm 0.04$	1.24 ± 0.20
$\pi^+ \eta$	$1.58 \pm 0.11 \pm 0.18$	2.16 ± 0.30
$\pi^+ \eta'$	$3.77 \pm 0.25 \pm 0.30$	4.8 ± 0.6
$K^+ \pi^+ \pi^-$	$0.69 \pm 0.05 \pm 0.03$	0.67 ± 0.13



$K^+K^+\pi^+$ in good agreement with PDG
We do not quote $B(D_s \to \phi\pi^+)$
Requires amplitude analysis
Results soon

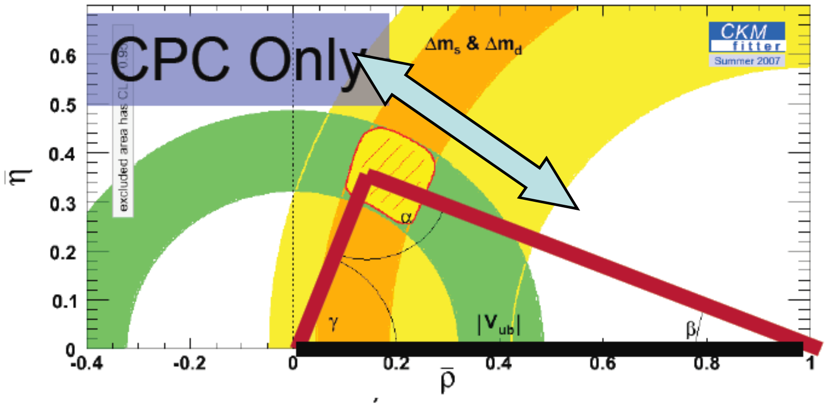
Importance of *absolute* charm leptonic branching ratios 1

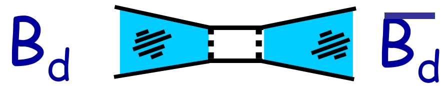


$$\Gamma(D_q^+ \to l\,\upsilon) = \frac{1}{8\pi} G_F^2 M_{D_q^+} m_l^2 \left(1-\frac{m_l^2}{M_{D+}^2}\right) f_{D+}^2 |V_{cq}|^2$$

1 Check lattice calculations of decay constants

2 Improve constraints from B mixing





$$rate = (const.)\left[f_{Bd}\right]^2 |V_{td}|^2 |V_{tb}|^2$$

0.8% (expt) HFAG

~10% (HPQCD) PRL95 212001 (2005)

~12%

if f_{Bd} to 3% → $|V_{td}||V_{tb}|$ to ~5%

$B \to \tau\nu \propto f_{B+} V_{ub}$ but rate low & V_{ub} not well known

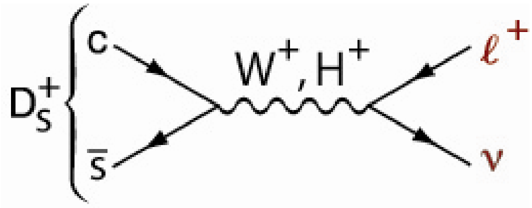
f_D CLEO-c and $(f_B/f_D)_{lattice}$ → f_B

(And f_D/f_{Ds} CLEO-c checks f_B/f_{Bs})lattice

precise $|V_{td}|$

important for $|V_{td}|/|V_{ts}|$

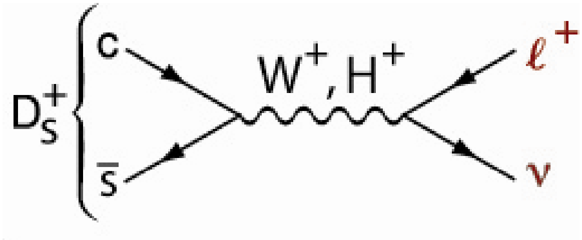
3 Sensitive to new physics



In 2HDM effect is largest for Ds

Importance of *absolute* charm leptonic branching ratios 2

A new charged Gauge Boson



SM Ratio of leptonic decays could be modified (e.g.)

$$\frac{\Gamma(P^+ \to \tau^+ \nu)}{\Gamma(P^+ \to \mu^+ \nu)} = m_\tau^2 \left(1 - \frac{m_\tau^2}{M_P^2}\right)^2 \Big/ m_\mu^2 \left(1 - \frac{m_\mu^2}{M_P^2}\right)^2$$

(If $H^\pm$ couples to M^2 no effect)

Hewett [hep-ph/9505246]
Hou, PRD 48, 2342 (1993).

In 2HDM predict
SM decay width is x by

$$r_q = \left[1 - M_D^2 \left(\frac{\tan\beta}{M_{H^\pm}}\right)^2 \left(\frac{m_q}{m_c + m_q}\right)\right]^2$$

Akeryod [hep-ph/0308260]

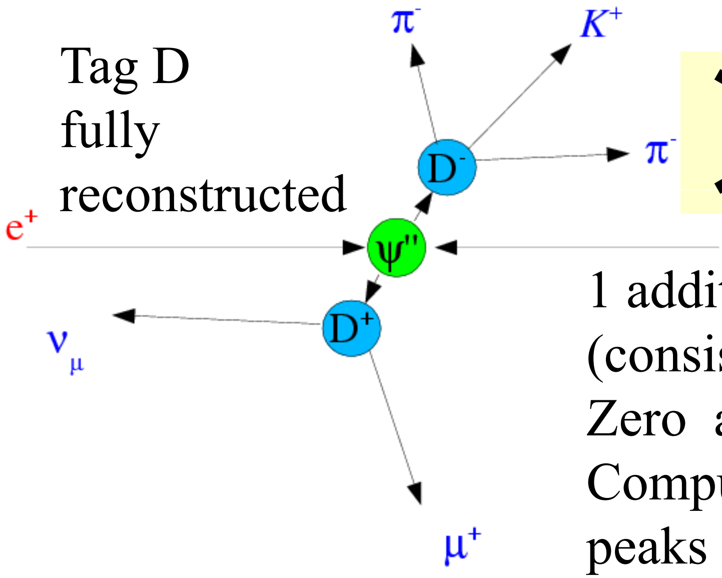
Since m_d is ~0, effect can be seen only in D_s

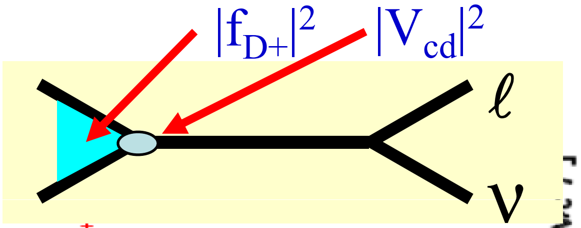
CLEO-c has made absolute measurements of

$$B(D^+ \to \mu\nu), B(D^+ \to \tau\nu), B(D_s^+ \to \mu\nu), B(D_s^+ \to \tau\nu)$$

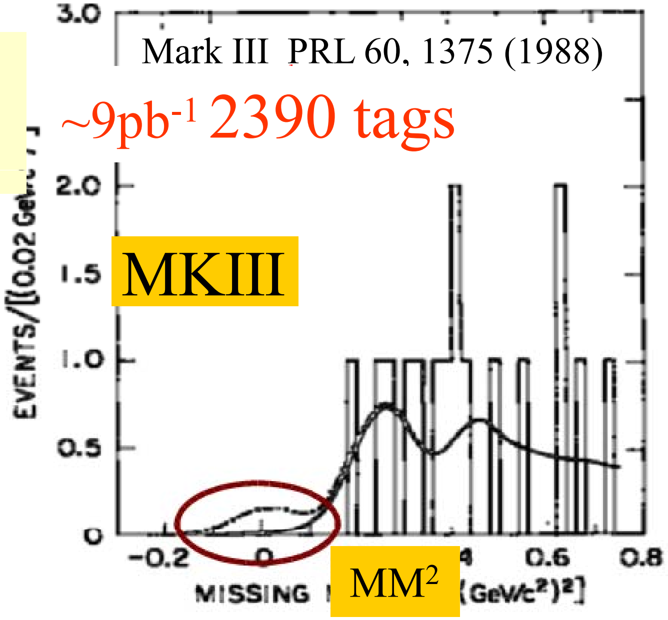
f_{D+} from Absolute Br($D^+ \to \mu^+\nu$) at $\psi(3770)$

Tag D fully reconstructed



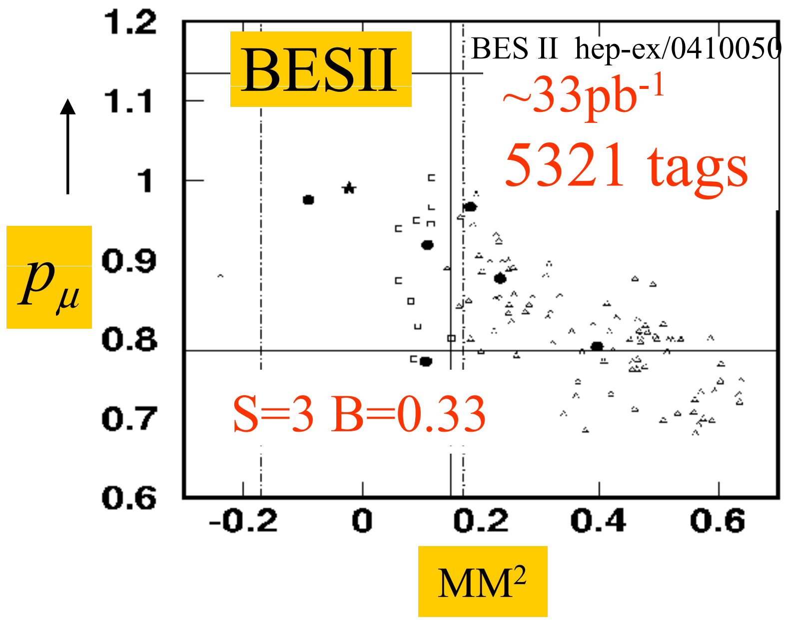


1 additional track
(consistent with a muon)
Zero additional photons
Compute missing mass^2:
peaks at 0 for signal



$$MM^2 = (E_D - E_\mu)^2 - (\overrightarrow{P_D} - \overrightarrow{P_\mu})^2$$

where $E_D = E_{beam}$, $\overrightarrow{P_D} = -\overrightarrow{P}_{D\,tag}$



	$B(D^+ \to \mu\nu)\times 10^{-4}$	f_D MeV
MkIII	< 7.2	< 290
BESII	$12.2^{11.1}_{-5.3} \pm 0.11$	$371^{+129}_{-119} \pm 25$

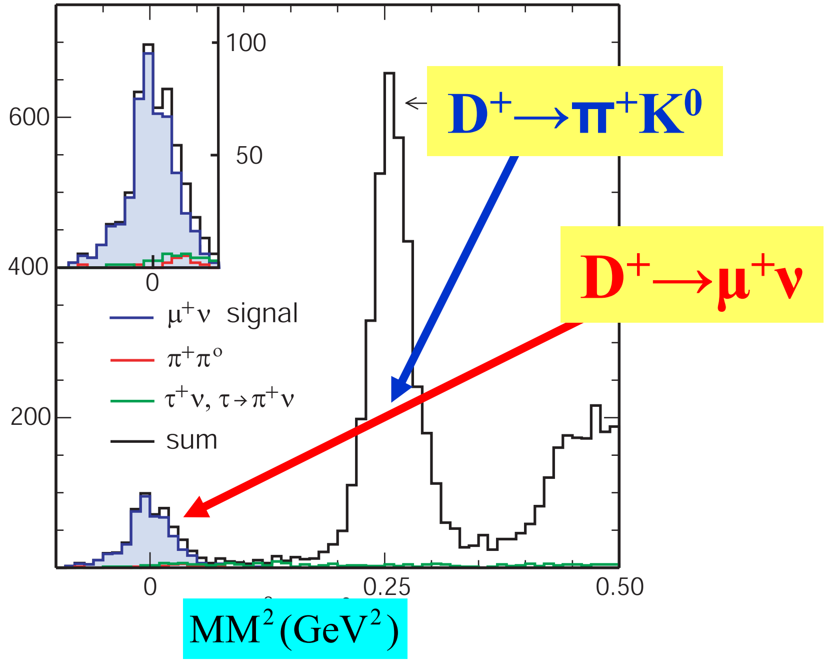
f_{D+} from Absolute Br($D^+ \to \mu^+\nu$)

$$MM^2 = (E_{beam} - E_{\mu})^2 - (-\vec{P}_{D\,tag} - \vec{P}_{\mu})^2$$

MC

6 x

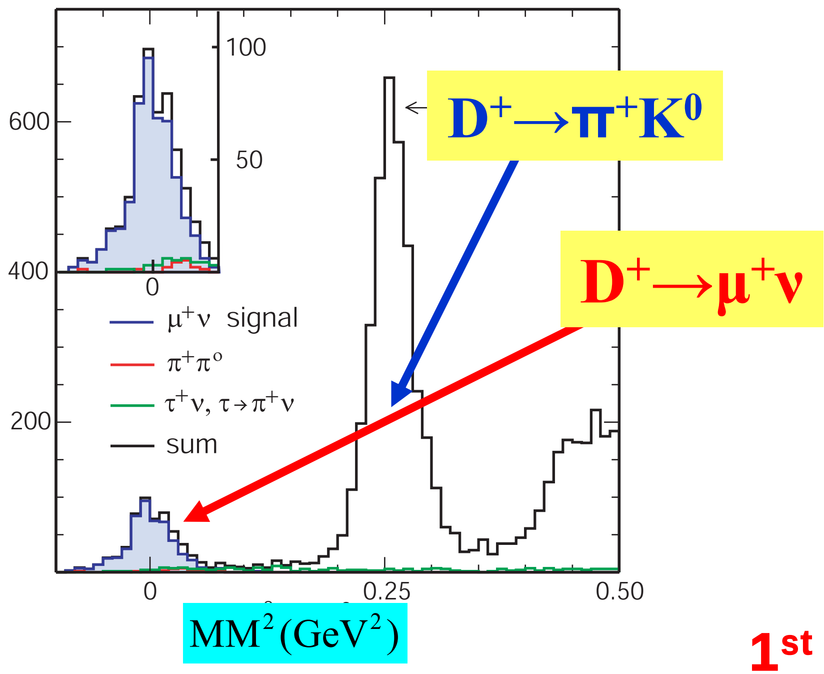
data



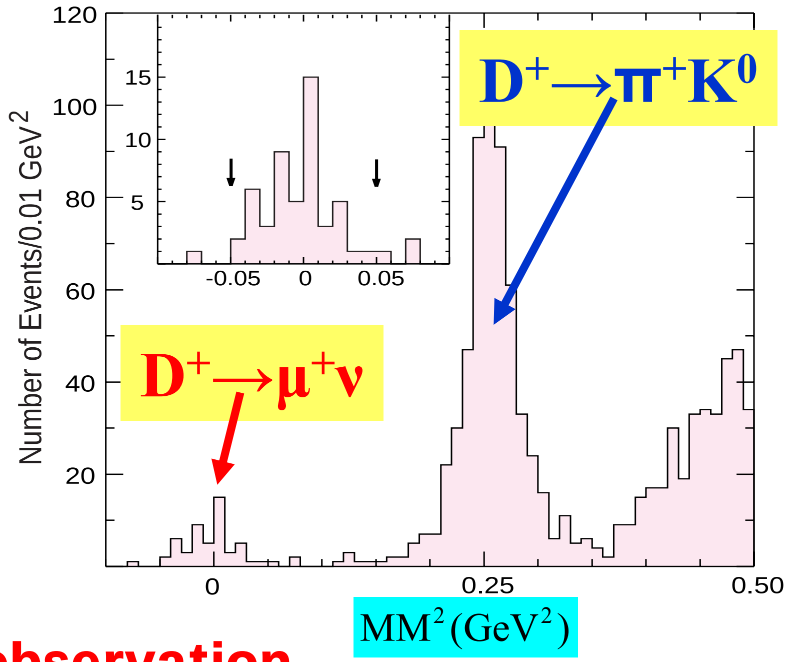
f_{D^+} from Absolute Br($D^+ \to \mu^+\nu$)

$$MM^2 = (E_{beam} - E_\mu)^2 - (-\overrightarrow{P}_{D\,tag} - \overrightarrow{P}_\mu)^2$$

MC
6 x
data



Data 281 pb^{-1} at ψ(3770)



1st observation of $D^+ \to \mu^+\nu$

$$B(D^+ \to \mu^+\upsilon) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$$

$$f_{D^+} = (222.6 \pm 16.7^{+2.8}_{-3.4})MeV$$

PRL 95, 251801 (2005)

Mode	Event
Data	50
$D^+ \to \pi^+ \pi^0$	1.4
$D^+ \to K_{long}\ \pi^+$	0.33
$D^+ \to \tau^+ \nu_\tau$	1.08
Total Bck:	2.81

$f_{D^+} = (201 \pm 3 \pm 17)$ MeV (LQCD) Expt/Theory agree ~ to 10%

$D^+ \to \tau^+\nu, \tau^+ \to \pi^+\nu$

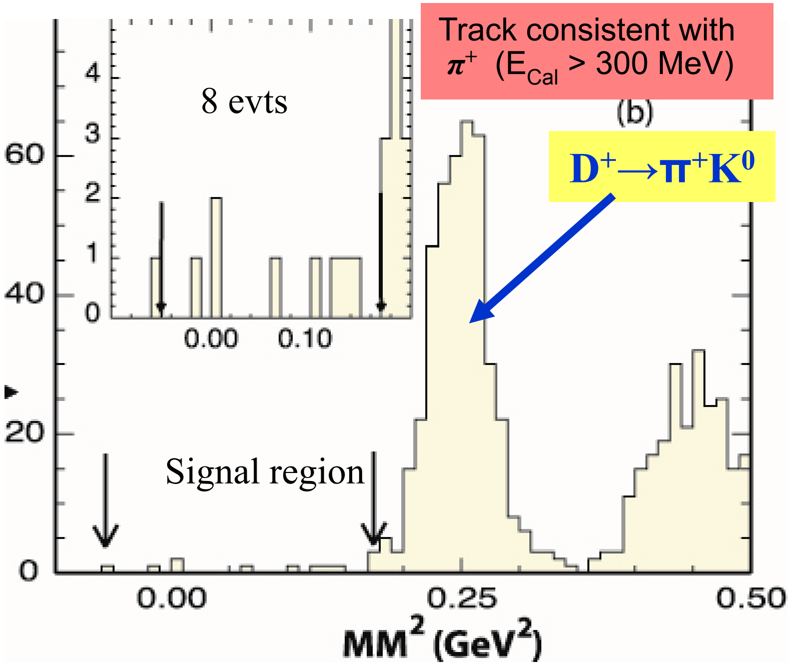
A test of lepton universality

D^- tag + single π track

two ν: larger MM^2 region

event yields consistent with bkgd estimates

$B(D^+ \to \tau^+ \nu_\tau) < 2.1 \times 10^{-3}$



In SM:

$$R = \frac{\Gamma(D^+ \to \tau^+\nu)}{\Gamma(D^+ \to \mu^+\nu)} = m_\tau^2 \left(1 - \frac{m_\tau^2}{M_{D^+}^2}\right)^2 \Big/ m_\mu^2 \left(1 - \frac{m_\mu^2}{M_{D^+}^2}\right)^2 = 2.65$$

combine with CLEO-c $B(D^+ \to \mu^+\nu)$:

$R_{CLEO} / R_{SM} < 1.8$ at 90% CL

First measurement of R

➔ lepton universality in purely leptonic *D+* decays is satisfied at the level of current experimental accuracy.

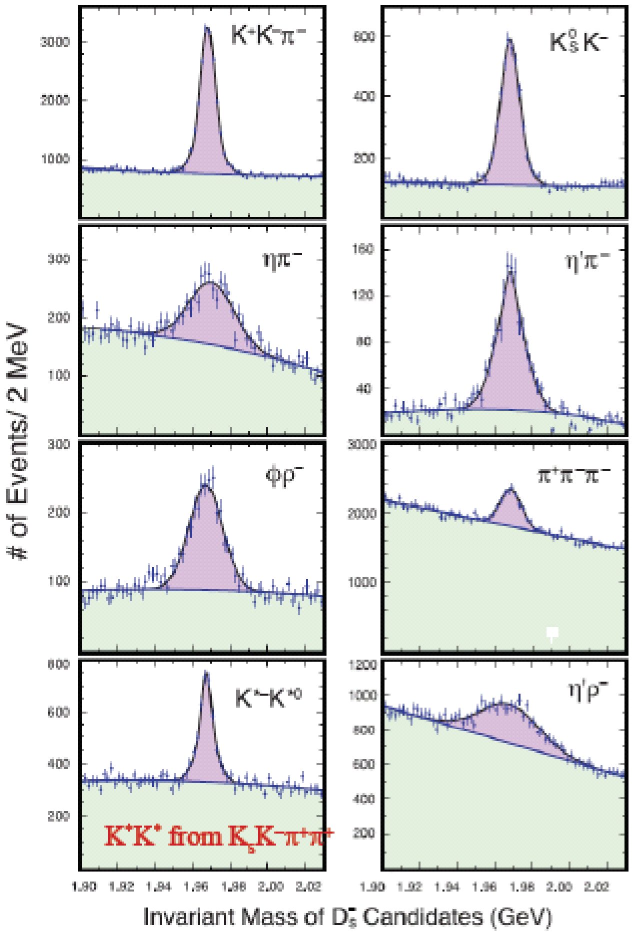
***PRD*73 112005 (2006)**

Method 1: $D_s \to \mu^+\nu, D_s \to \tau^+\nu, \tau^+ \to \pi^+\nu$ & f_{Ds}

D_s (tag) 8 modes

D_s tags 31302±472

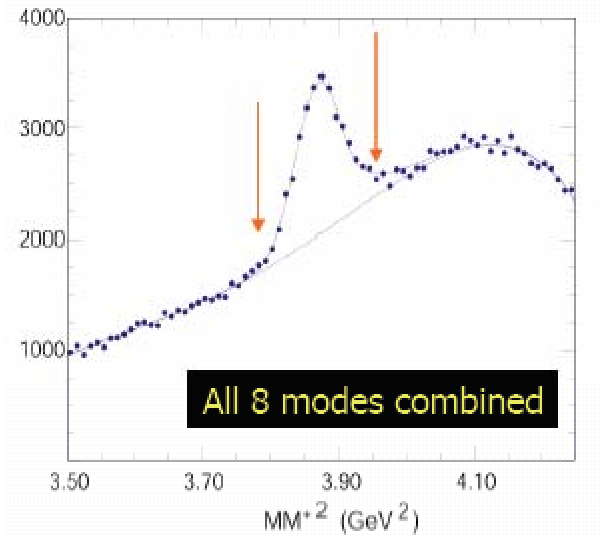
Cabibbo allowed decay compensates for smaller cross section @ 4170 MeV



@4170 $D_s D_s^*$, $D_s^* \to D_s\gamma$

Calculate MM^2 for D_s tag plus photon.

Peaks at D_s mass.
N(tag+γ)=18645±426



$$MM^{*2} = (E_{CM} - E_{D_S-tag} - E_\gamma)^2 - (-\vec{p}_{D_S-tag} - \vec{p}_\gamma)^2 \approx M_{D_S}^2$$

We search simultaneously for $D_s \to \mu\nu$ & $D_s \to \tau\nu$

- * For the signal: require one additional track and no unassociated extra energy
- * Calculate missing mass (next slide)

$D_s \to \mu^+\nu$ and $\tau^+(\pi^+\nu)\nu$

PRL 99 071802 (2007)
PRD 76 072002 (2007)

Three cases depending on particle type:

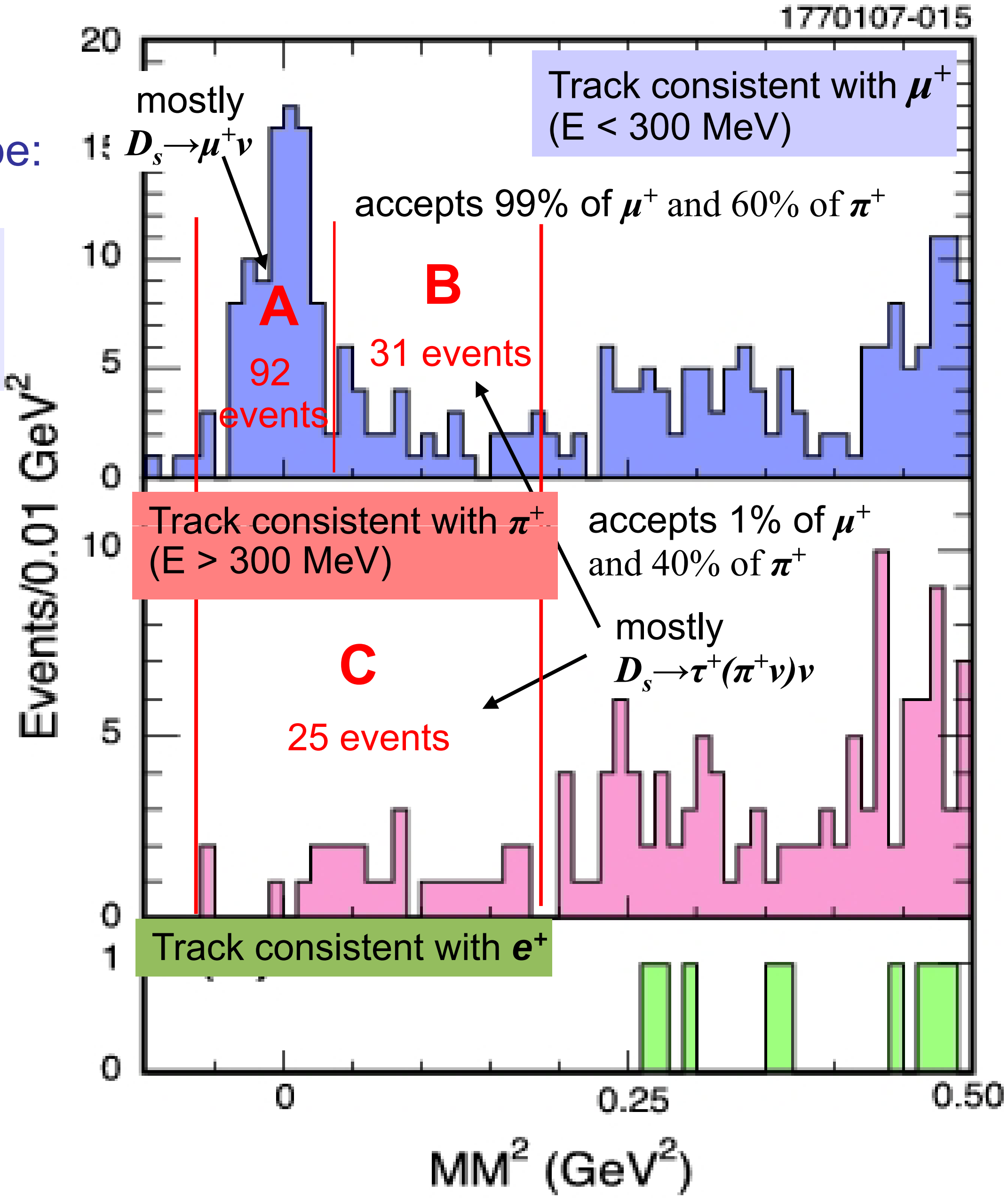
A $B(D_s \to \mu^+\nu)$
92 events (3.5 bkgd)
$B(D_s \to \mu^+\nu)$ = **(0.597 ± 0.067 ± 0.039)%**

B+C $B(D_s \to \tau^+\nu)$:
31+25 = 56 events (3.6+5= 8.6 bkgd)
$B(D_s \to \tau^+\nu)$ = **(8.0 ± 1.3 ± 0.4)%**

A+B+C: By summing both cases and using SM τ/μ ratio
$B^{eff}(D_s \to \mu^+\nu)$ = ***(0.638 ± 0.059 ± 0.033)%***

f_{D_s} = (274 ± 13 ± 7) MeV

$B(D_s \to e^+\nu)$ **< 1.3x10^{-4}**



Method 2: $D_s \to \tau^+\nu, \tau^+ \to e^+\nu\nu$ & f_{Ds}

NEW

300/pb @4170 MeV

Require D_s tag

Require 1 electron and no other tracks

Primary bkgd semileptonic ($D_s \to X e \nu$).

Suppress X by requiring low amount of extra energy in calorimeter. Shown on right.

Signal region E_{cc}(extra)< .4 GeV. Backgrounds from scaled MC.

Results:

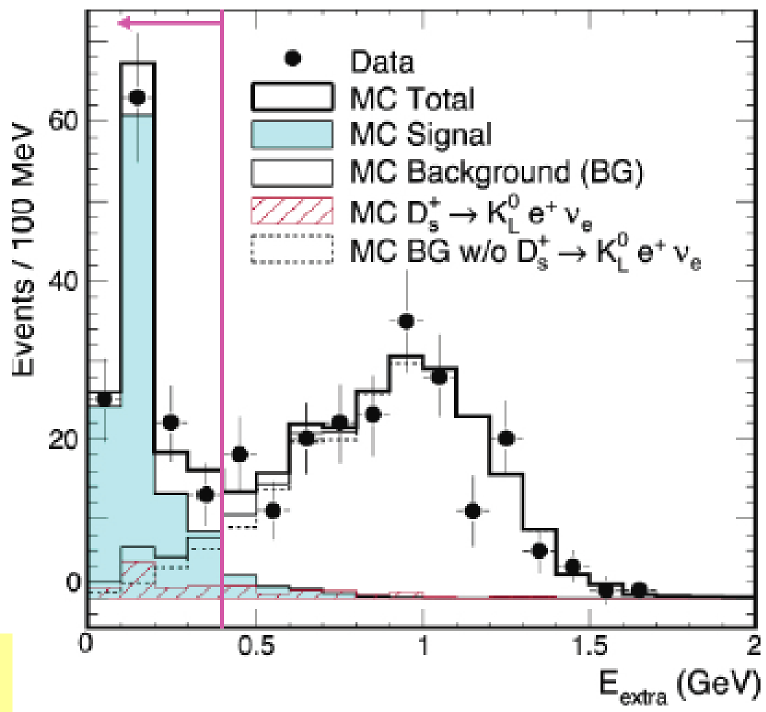
$B(D_s \to \tau^+ \nu)$ **= (6.17 ± 0.71 ± 0.36)%**

[PDG06: $B(D_s \to \tau^+ \nu)$ = (6.4 ± 1.5)%]

f_{Ds} **= (273 ± 16 ± 8) MeV**

This is the most precise determination of $B(D_s \to \tau^+ \nu)$

400 MeV



arXiv:0712.1175

(Submitted to PRL Dec 12 2007)

f_{Ds} & f_{Ds}/f_{D^+}

Combining method 1 $D_s \to \mu\nu$ & $D_s \to \tau\nu, \tau \to \pi\nu$

& method 2 $D_s \to \tau\nu, \tau \to e\nu$

weighted average: $f_{Ds} = (274 \pm 10 \pm 5)$ MeV

(syst. uncertainties are mostly uncorrelated between methods)

combine with $f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})$ MeV (CLEO)

$$f_{Ds}/f_{D^+} = 1.23 \pm 0.10 \pm 0.03$$

$$R = \frac{\Gamma(D_s^+ \to \tau^+\nu)}{\Gamma(D_s^+ \to \mu^+\nu)} = 11.0 \pm 1.4 \pm 0.6$$

compared to:

$$R = \frac{\Gamma(D_s^+ \to \tau^+\nu)}{\Gamma(D_s^+ \to \mu^+\nu)} = 9.72 \text{ (Standard Model)}$$

➔ lepton universality in purely leptonic *Ds* decays is satisfied at the level of current experimental accuracy.

Comparison with theory

CLEO fd consistent with calculations

CLEO fds higher than most calculations indicating an absence of the suppression expected for a H+

Our fds is ~3σ above the most recent & precise LQCD calculation (HPQCD).

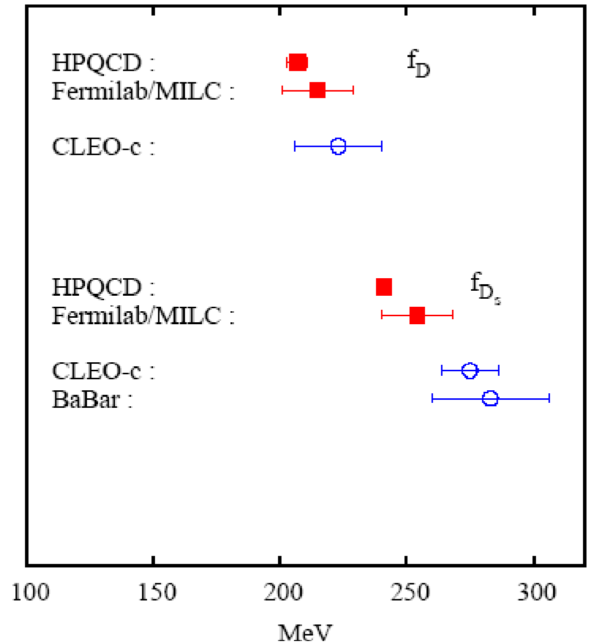
This discrepancy needs to be studied.

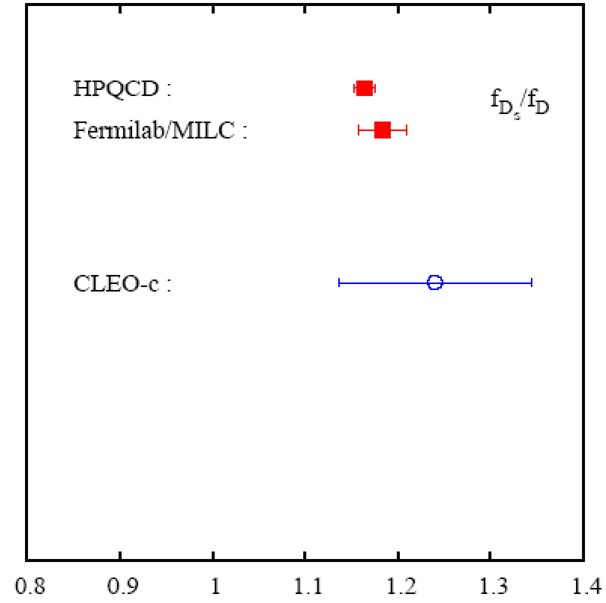
1) *HPQCD are checking against Γee for J/ψ & φ*
2) *Radiative corrections are not made to LQCD results. Expected magnitude a few % . Needs to be investigated with high priority.*

If all checks hold up, it is evidence for new physics that interferes constructively with the SM

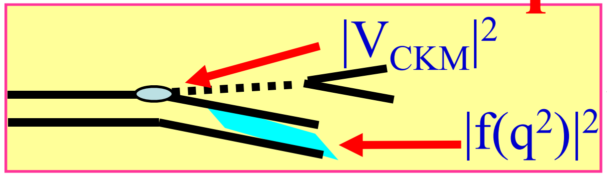
Comparing measured fDs/fD+ with HPQCD
mH>2.2 GeV tanβ @90% CL

Using HPQCD fDs/fD+ find:
|Vcd /Vcs|=0.217±0.019 (exp)±0.002(theory)





Importance of Charm Semileptonic Decays

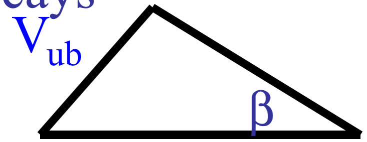


$$\frac{d\Gamma}{dq^2} \propto |V_{cs(d)}|^2 |f_+^{D\to(K)\pi}(q^2)|^2$$

1 Assuming th ff⇒V_{cs} and V_{cd}

2 Assuming V_{cs} and V_{cd} known, we can check theoretical calculations of the form factors

3 *Potentially* useful input to Vub from exclusive B semileptonic decays



$Br(B \to \pi l\nu)$ 6% precision

BABAR / Belle / CLEO

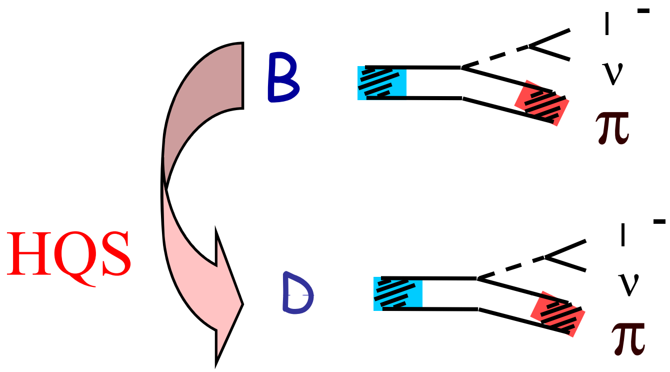
(HFAG (2007)

$$|V_{ub}| = (3.17 \pm 0.10 \pm^{+0.74}_{-0.44}) \times 10^{-3}$$

$$\pm \exp \pm \text{LQCD}$$

Expt. 3%

~16% HPQCD hep-lat/0601021



$$\propto \left[f^{B\to\pi}(q) \right]^2 |V_{ub}|^2$$

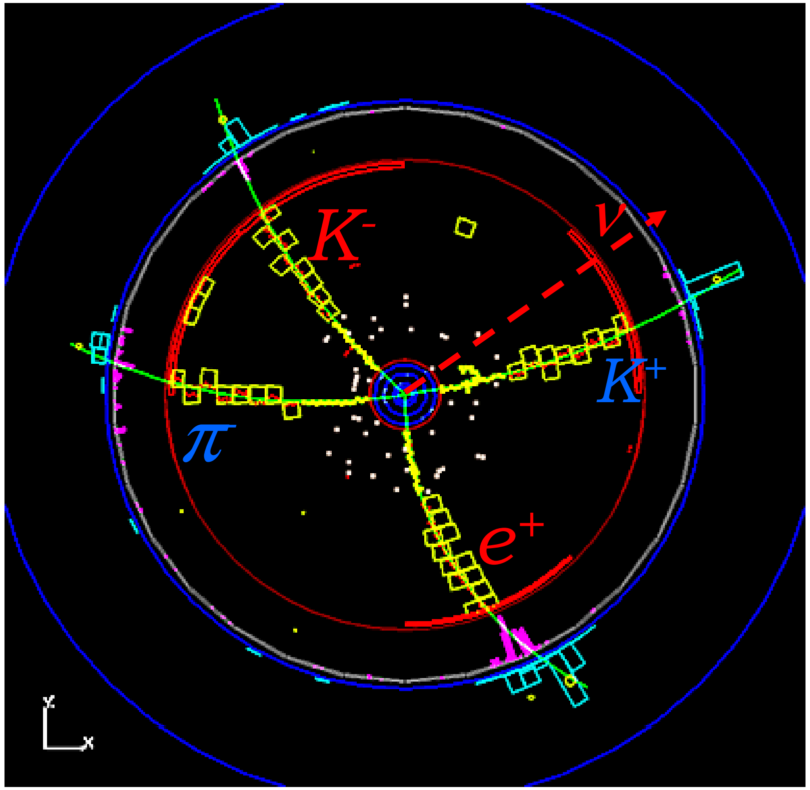
$$\propto \left[f^{D\to\pi}(q) \right]^2 |V_{cd}|^2$$

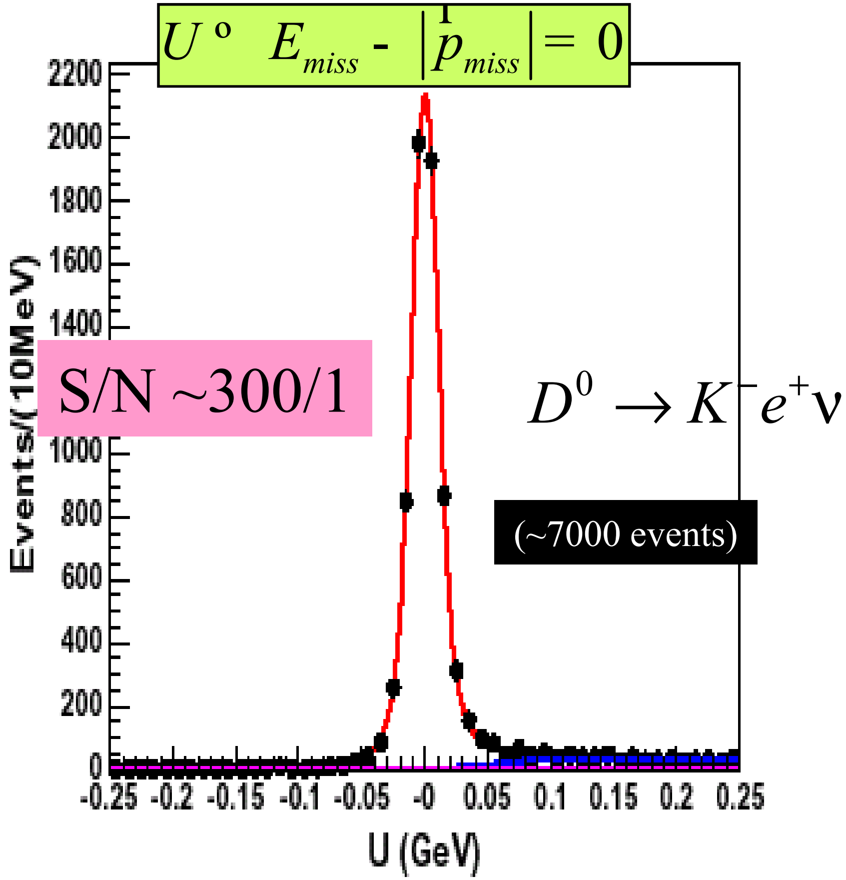
Related at same invariant 4 velocity

Absolute Semileptonic Branching Fractions

The neutrino direction is determined to 1^0

no kinematics ambiguity





$$\psi(3770) \rightarrow D^0 \overline{D^0}$$

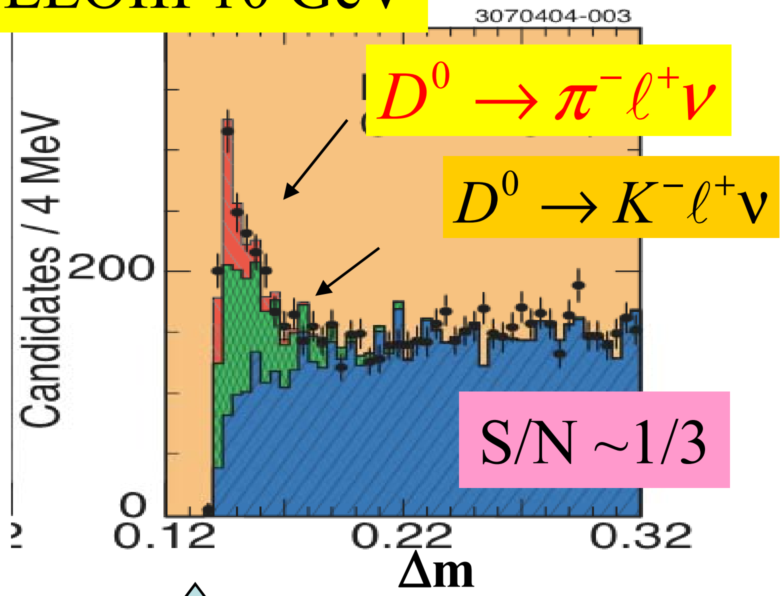
$$\overline{D^0} \rightarrow K^+\pi^-, D^0 \rightarrow K^- e^+ \nu$$

Tagging creates a single D beam of known 4-momentum

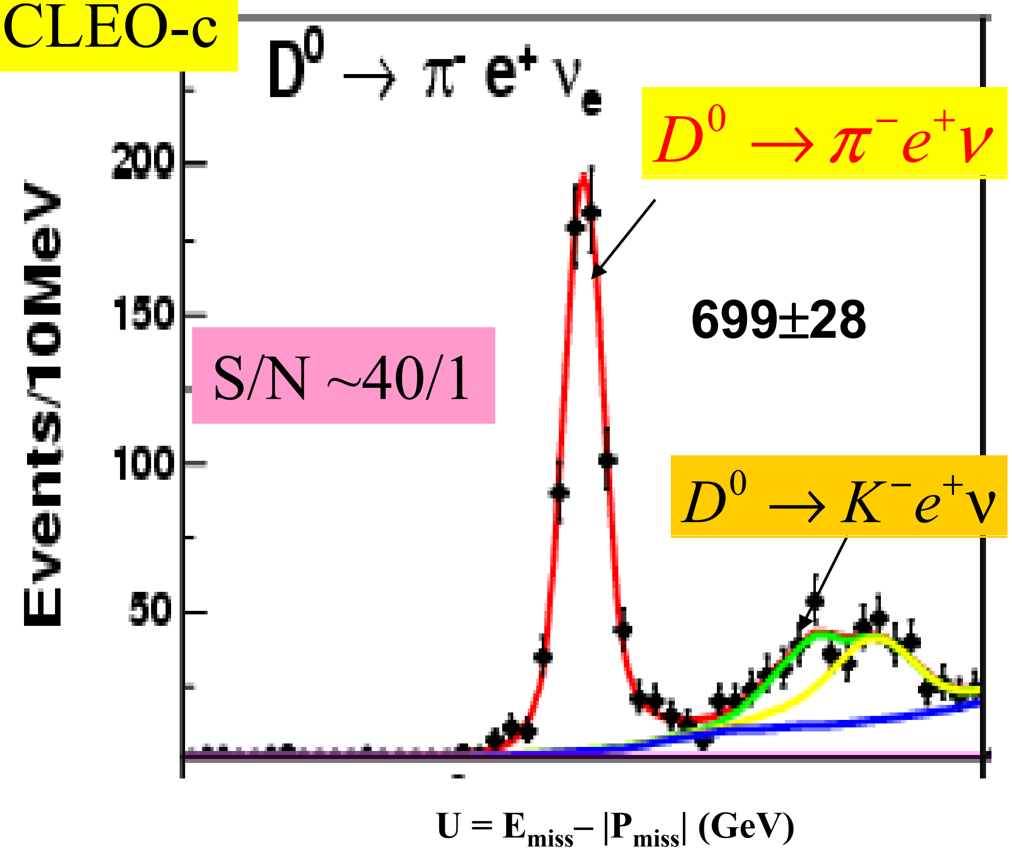
$$\mathcal{B}(D \rightarrow Ke\nu) = \frac{N(D \rightarrow Ke\nu)}{\text{Efficiency} \times N_{tags}}$$

$D^0 \to \pi^- e^+ \nu$

CLEOIII 10 GeV



CLEO-c



Tag with $D^{*+} \to D^0 \pi_s$

$D^0 \to \pi^- \ell^+ \nu$

observable:

$\Delta m = m(\pi_s \pi \ell \nu) - m(\pi \ell \nu)$

Compare to:
state of the
art measurement
at 10 GeV (CLEO III)
PRL 94, 11802 (2004)

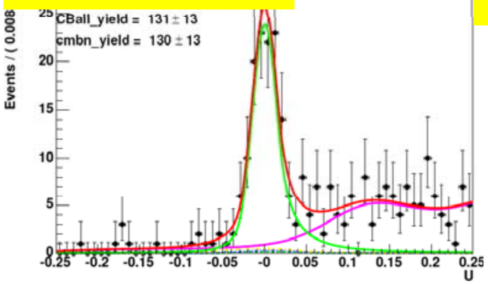
Note:
kinematic
separation.

Only other high statistics measurement is from Belle
282/fb (x1,000 CLEOc) 222± 17 events S/N 4/1

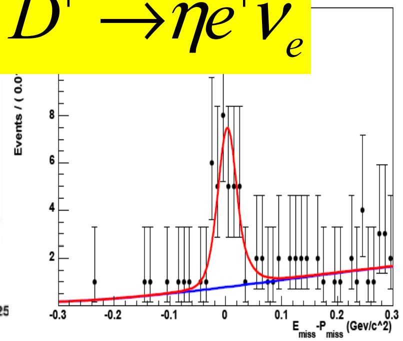
CLEO-c semileptonic tagging analysis technique: big impact

1^{st} Observations:

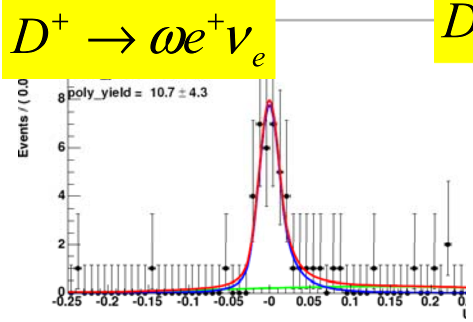
$D^0 \to \rho^- e^+ \nu_e$



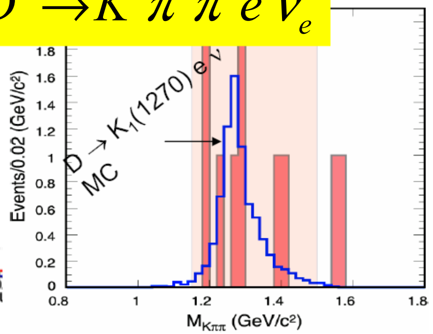
$D^+ \to \eta e^+ \nu_e$



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



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

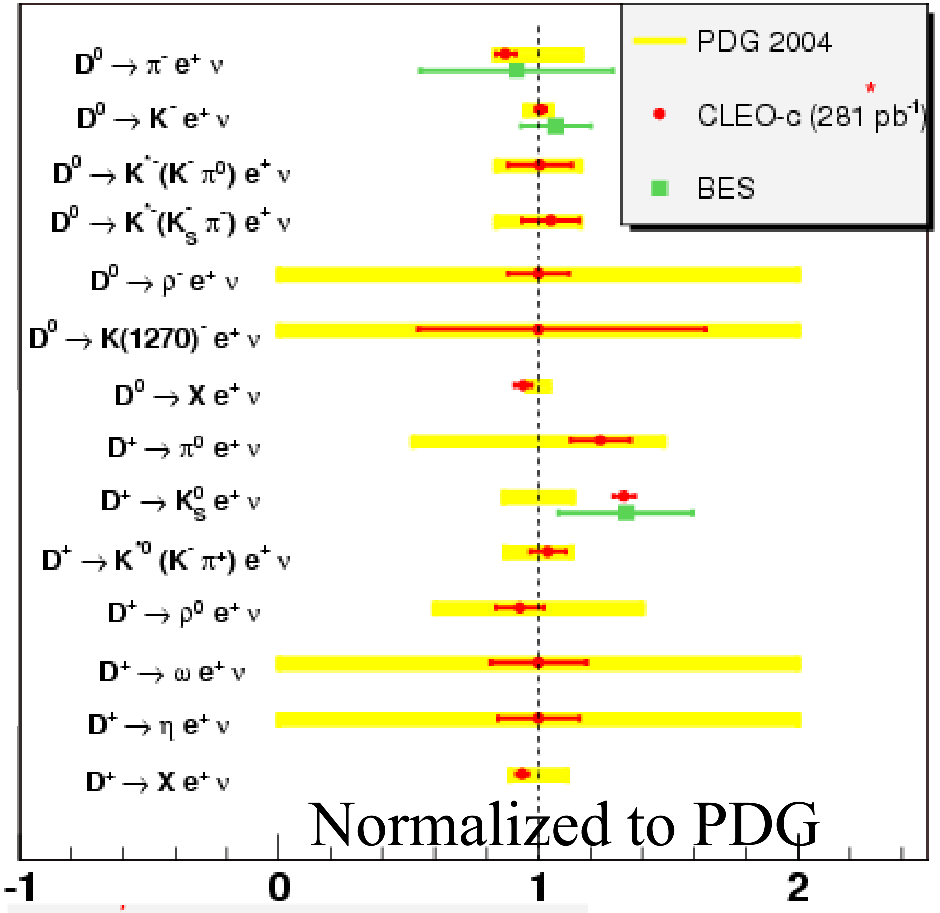


+ $D^+ / D^0 \to X e^+ \nu_e$

$D \to K^* e^+ \nu_e$ form factors

note: use PDG2004 as PDG2006 is dominated by CLEO-c measurements

Precision Measurements:



$D \to K / \pi e^+ \nu$ branching fractions are for 56/pb

CLEO's measurements most precise for ALL modes; *4 modes* observed for the first time

PRL 95, 181801 (2005); PRL 95, 181802 (2005)
PRL. 99, 191801 (2007)

$D \rightarrow K/\pi e^+\nu$ without tagging

Preliminary results FPCP 2006 now superseded

NEW

ArXiv 0712.1020 and 0712.1025

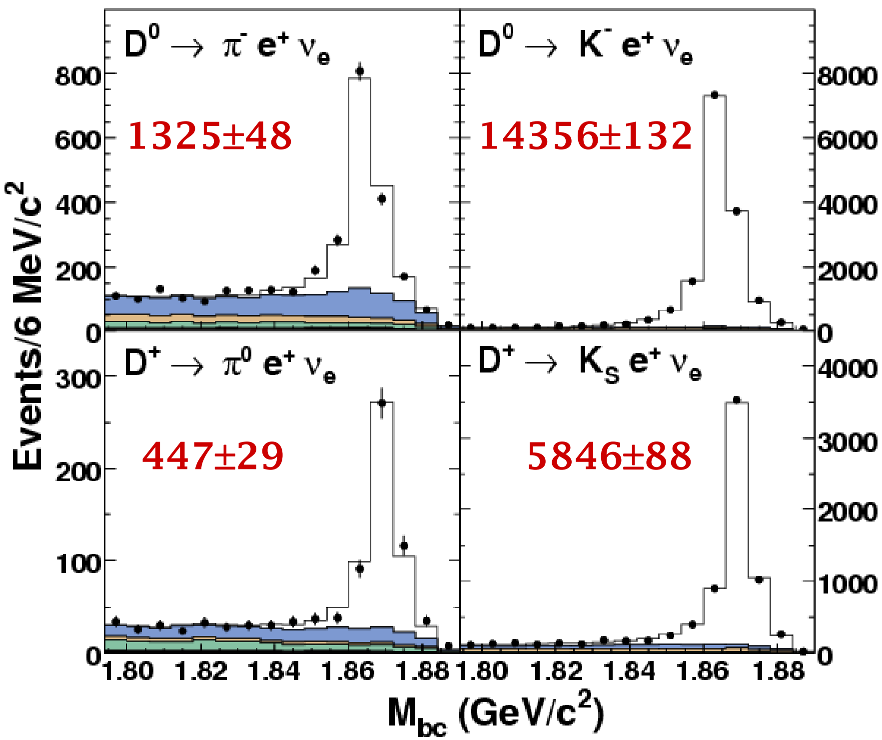
[analogous to neutrino reconstruction @ Υ(4S)]

Uses neutrino reconstruction:
Identify semileptonic decay.

Reconstruct neutrino 4-momentum from all measured energy in the event.

Use K(π), e, and missing 4-momentum and require consistency in energy and beam-energy constrained mass.

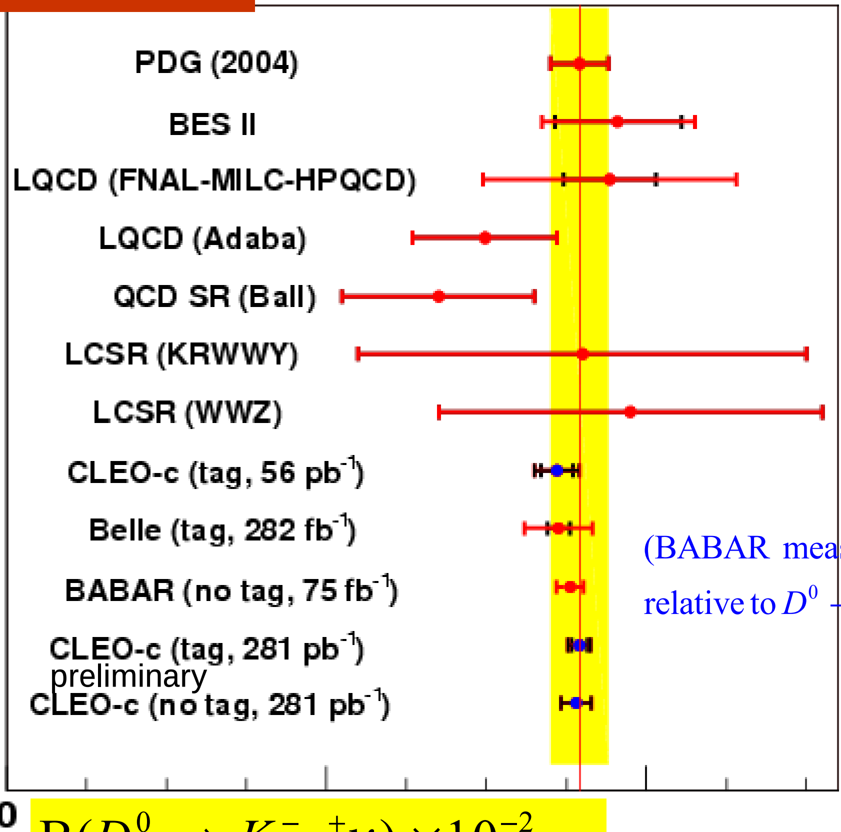
Higher efficiency than tagging but larger backgrounds



M_{bc} distributions fitted simultaneously in 5 q^2 bins to obtain d(BF)/dq^2. Integrate to get branching fractions and fit to get form factors

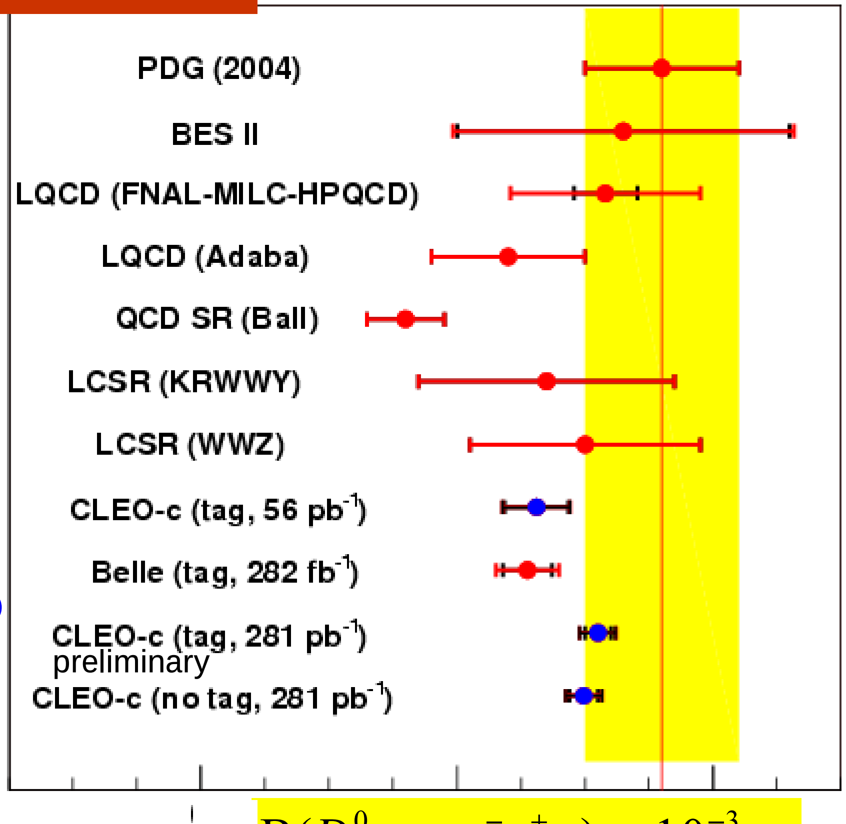
D →K, π eν Branching Fractions

$D \to K e^+$



(BABAR measures relative to $D^0 \to K^-\pi^+$)

$D \to \pi e^+$



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

3.58(5)(5) (tag) (prelim.)

3.56(3)(9) (notag)

$\sigma(B(Ke\nu))/B(Ke\nu) \sim 2\%$

$\sigma(B(\pi e\nu))/B(\pi e\nu) \sim 4.5\%$

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

0.31(1)(1) (tag) (prelim.)

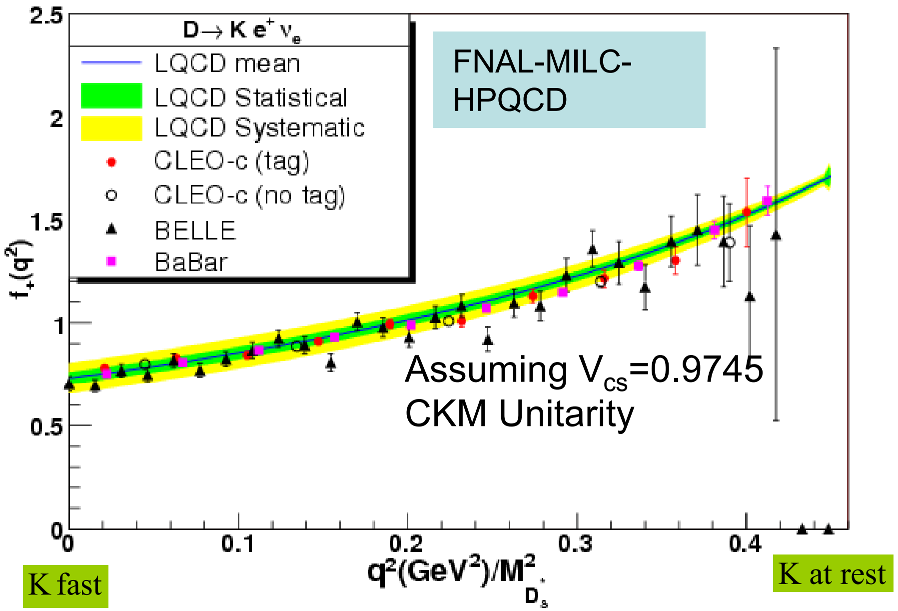
0.30(1)(1) (notag)

Precision measurements from BABAR/Belle/CLEO-c.
CLEO-c most precise. Theoretical precision lags experiment.

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

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

Form factor measures probability hadron will be formed

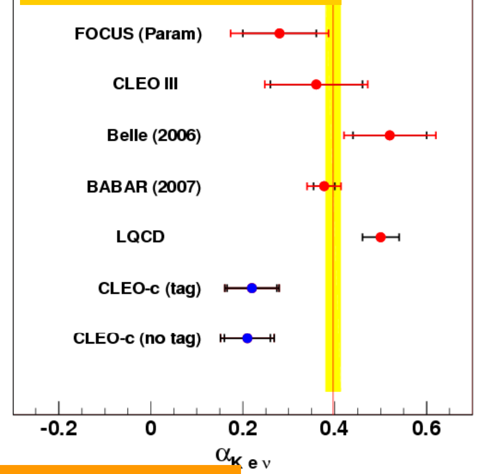


Modified pole model used as example

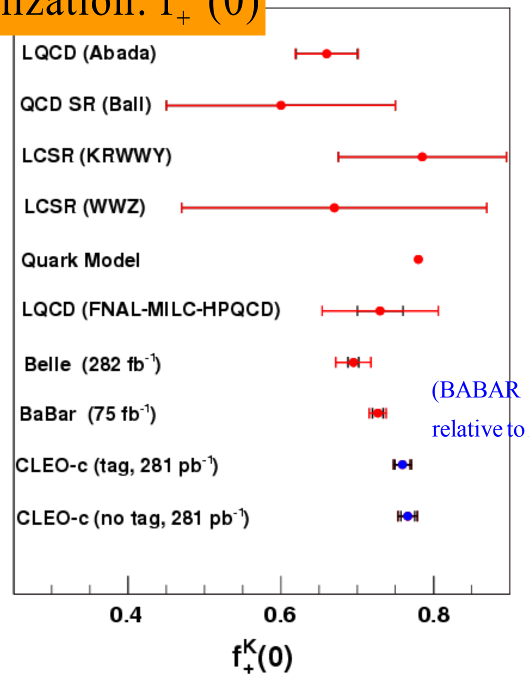
$$f_+(q^2) = \frac{f_+(0)}{\left(1 - q^2/m_{pole}^2\right)\left(1 - \alpha\, q^2/m_{pole}^2\right)}$$

Normalization: experiments (2%) consistent with LQCD (10%). *Theoretical precision lags.*
CLEO-c prefers smaller value for shape parameter, α

Shape: $\alpha(Ke\nu)$



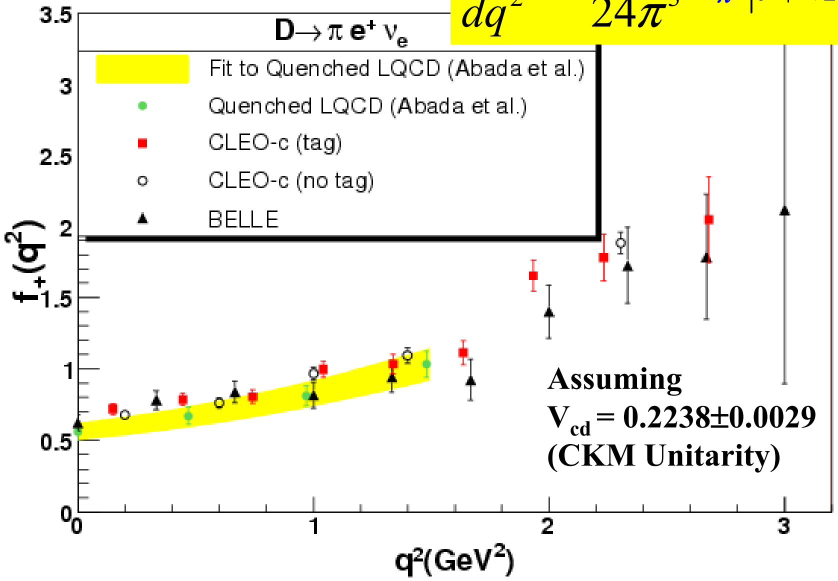
Normalization: $f_+^K(0)$



(BABAR measures relative to $D^0 \to K^- \pi^+$)

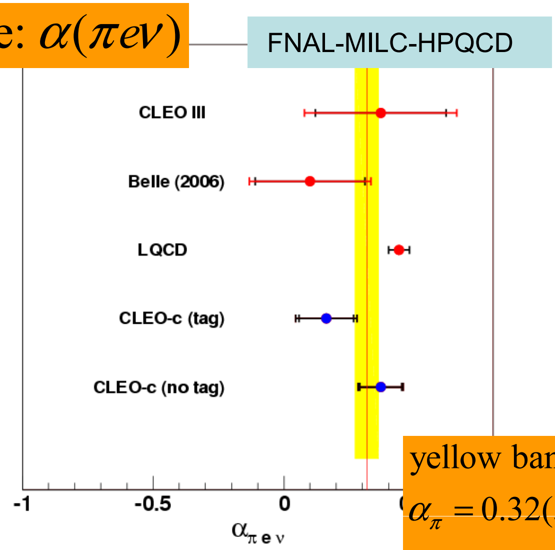
$D^0 \to \pi^- e^+ \nu$ Form Factor: test of LQCD

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



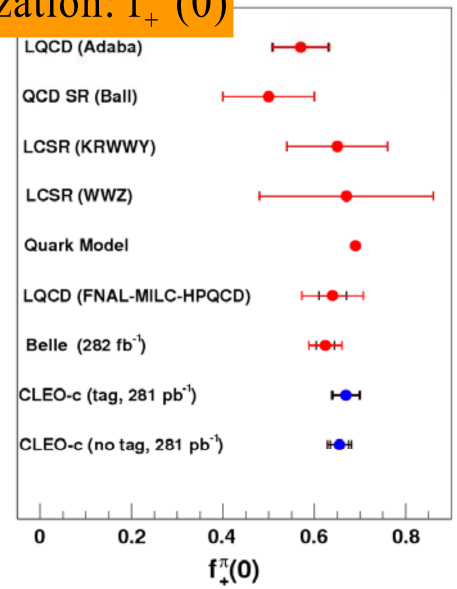
Assuming $V_{cd} = 0.2238 \pm 0.0029$ (CKM Unitarity)

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



yellow band $\alpha_\pi = 0.32(5)$ my avg.

Normalization: $f_+^K(0)$



Modified pole model used as example

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - q^2/m_{pole}^2\right)\left(1 - \alpha\, q^2/m_{pole}^2\right)}$$

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

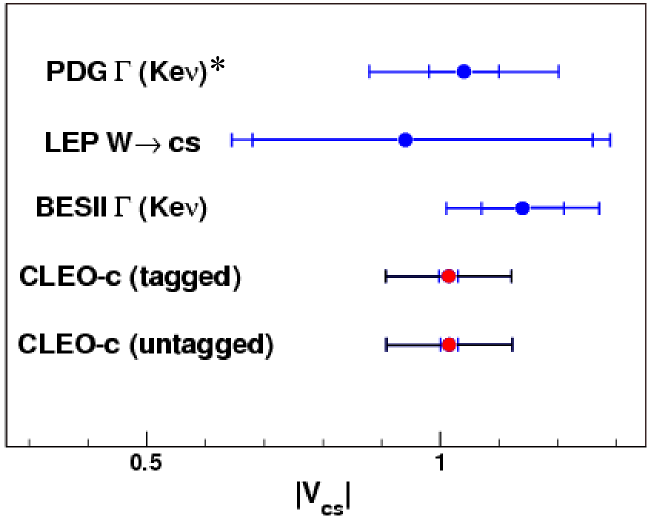
The data determines $|V_{cd}|f_+(q^2)$. To extract $|V_{cd}|$ we fit to $|V_{cd}|f_+(q^2)$, determine $|V_{cd}|f_+(0)$ & use $f_+(0)$ from theory (FNAL-MILC-HPQCD.) Same for $|V_{cs}|$

V_{cs} & V_{cd} Results

CLEO-c: the most precise *direct* determination of V_{cs}

$$\sigma(|V_{cs}|)/|V_{cs}| \sim 1.5\%(\text{expt}) \oplus 10\%(\text{theory})$$

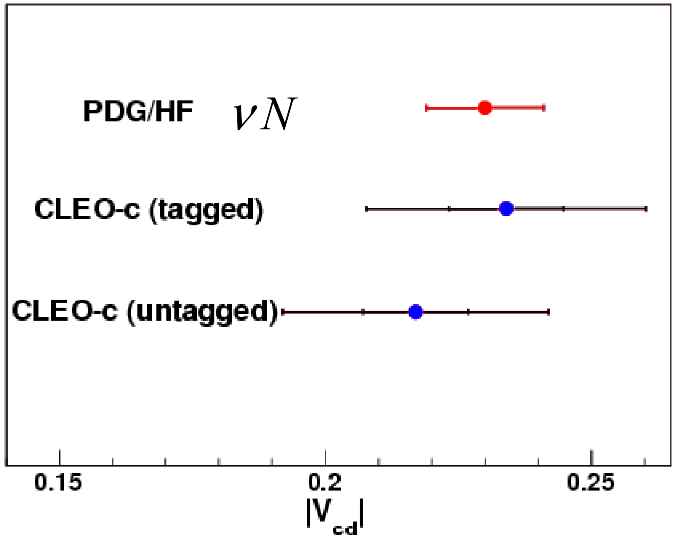
$CLEO-c$	V_{cs}
(tagged prelim)	$1.014 \pm 0.013 \pm 0.009 \pm 0.106$
(untagged final)	$1.015 \pm 0.010 \pm 0.011 \pm 0.106$
	stat syst theory



CLEO-c: $\sigma(|V_{cd}|)/|V_{cd}| \sim 4.5\%(\text{expt}) \oplus 10\%(\text{theory})$

νN remains most precise determination (*for now)*

$CLEO-c$	V_{cd}
(tagged prelim)	$0.234 \pm 0.010 \pm 0.004 \pm 0.024$
(untagged final)	$0.217 \pm 0.009 \pm 0.004 \pm 0.023$
	stat syst theory



Tagged/untagged consistent
40% overlap, DO NOT AVERAGE

We measure $|V_{cx}|f_+(0)$ using Becher-Hill parameterization & $f_+(0)$ from *FNAL-MILC-HPQCD.*

Unitarity Test: Compatibility of charm & beauty sectors of CKM matrix

$|V_{cd}|$ & $|V_{cs}|$ indirect

1) K & nucleon

$|V_{ud}| \approx |V_{cs}|$ & $|V_{cd}| \approx |V_{us}|$

2) B physics

Indirect= global CKM fit = 1+2

$|V_{cd}|$ & $|V_{cs}|$ direct

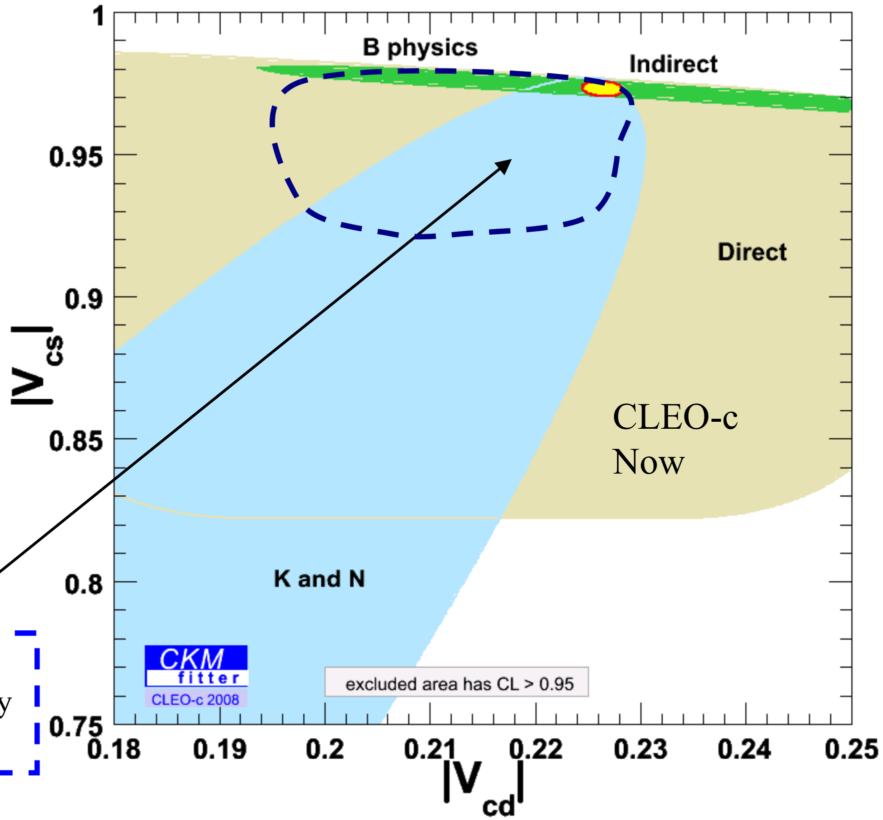
(D semileptonic decays CLEO)

Projections to full data set

$\sigma(|V_{cd}|)/|V_{cd}| \sim 2.5\% \oplus \text{theory}$

$\sigma(|V_{cs}|)/|V_{cs}| \sim 1.0\% \oplus \text{theory}$

CLEO-c full data set + Few % theory uncertainties



D semileptonic decay with theory uncertainties comparable to experimental uncertainty may lead to interesting competition between direct and indirect constraints

Plots by Sebastien Descortes-Genon & Ian Shipsey
See also talk by Descotres-Genon at joint BABAR-Belle-BESIII-CLEO-c Workshop 11/07, Beijing

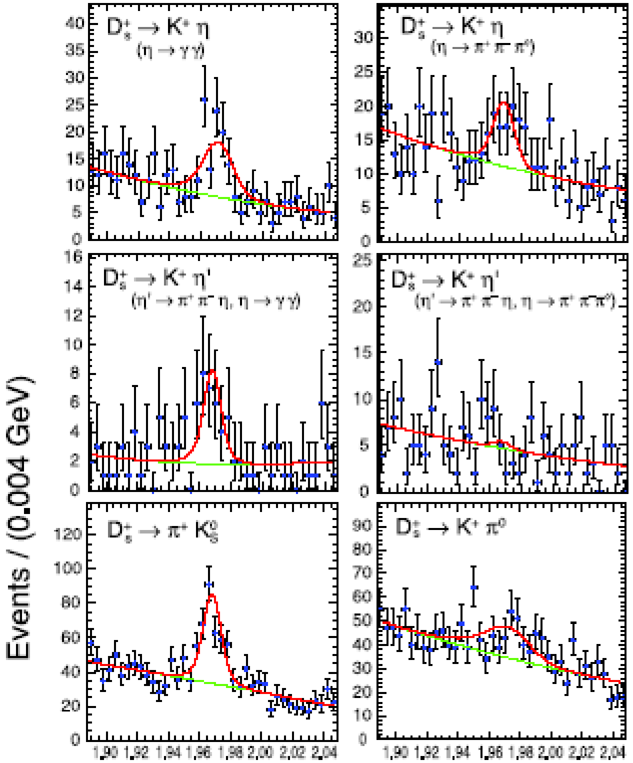
CLEO-c Searches for Direct CP violation in D decays

Many new modes: most promising in SM: Ds Cabibbo suppressed
If CPV seen in Cabibbo allowed or DCSD it would be new physics

Technique: tag & count separately $D \,\&\, \overline{D}$

$D_S \to PP$

PRL 99 191805 (2007)



arXiv 0801.0680

Mode	A_{CP} $(\mathcal{B}_+ - \mathcal{B}_-)(\%)$
$\mathcal{A}(D_s^+ \to K^+\eta)$	-20 ± 18
$\mathcal{A}(D_s^+ \to K^+\eta')$	-17 ± 37
$\mathcal{A}(D_s^+ \to \pi^+ K_S^0)$	27 ± 11
$\mathcal{A}(D_s^+ \to K^+\pi^0)$	2 ± 29

1st Observation of the Cabibbo suppressed decays

(Mostly) Cabibbo Allowed:

D_s

Mode	$\mathcal{A}_{CP}$ (%)
$K_S^0 K^+$	$-4.9 \pm 2.1 \pm 0.9$
$K^- K^+ \pi^+$	$+0.3 \pm 1.1 \pm 0.8$
$K^- K^+ \pi^+ \pi^0$	$-5.9 \pm 4.2 \pm 1.2$
$K_S^0 K^- \pi^+ \pi^+$	$-0.7 \pm 3.6 \pm 1.1$
$\pi^+\pi^+\pi^-$	$+2.0 \pm 4.6 \pm 0.7$
$\pi^+\eta$	$-8.2 \pm 5.2 \pm 0.8$
$\pi^+\eta'$	$-5.5 \pm 3.7 \pm 1.2$
$K^+\pi^+\pi^-$	$+11.2 \pm 7.0 \pm 0.9$

$D^0 \,/\, D^+$ arXiv:0709.3783

Mode	A_{CP} (%)
$D^0 \to K^-\pi^+$	$-0.4 \pm 0.5 \pm 0.9$
$D^0 \to K^-\pi^+\pi^0$	$0.2 \pm 0.4 \pm 0.8$
$D^0 \to K^-\pi^+\pi^+\pi^-$	$0.7 \pm 0.5 \pm 0.9$
$D^+ \to K^-\pi^+\pi^+$	$-0.5 \pm 0.4 \pm 0.9$
$D^+ \to K^-\pi^+\pi^+\pi^0$	$1.0 \pm 0.9 \pm 0.9$
$D^+ \to K_S^0\pi^+$	$-0.6 \pm 1.0 \pm 0.3$
$D^+ \to K_S^0\pi^+\pi^0$	$0.3 \pm 0.9 \pm 0.3$
$D^+ \to K_S^0\pi^+\pi^+\pi^-$	$0.1 \pm 1.1 \pm 0.6$
$D^+ \to K^+K^-\pi^+$	$-0.1 \pm 1.5 \pm 0.8$

.No statistically significant A_{CP} for any mode. CLEO-c best measurement all modes except D+→KKpi. δA_{CP} ~1% (best case) for Cabibbo allowed, larger for Cabibbo suppressed

$D \to X l^+ l^-$

D Rare decays

No FCNC in kaons → charm,
Bmixing → heavy top

How about charm?

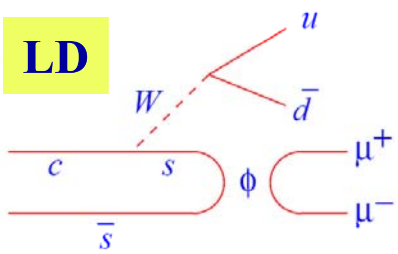
If new particles are to appear

on-shell at LHC

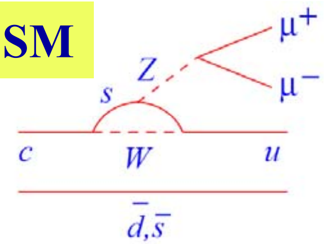
they must appear in virtual loops

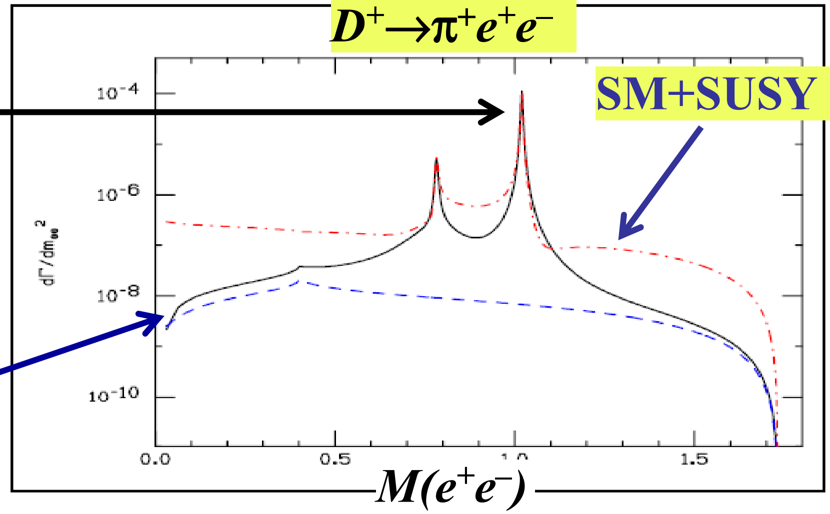
and affect amplitudes

LD



SM

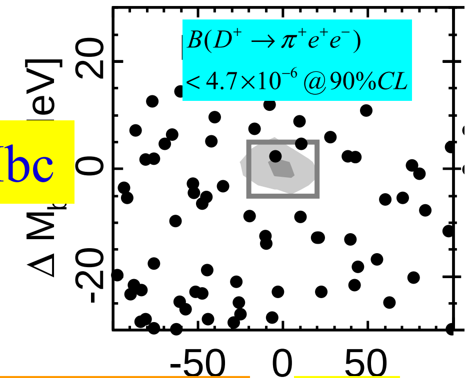




In the SM $\mathcal{B}(D^+ \Rightarrow \pi^+ e^+ e^-) \sim 2 \times 10^{-6}$

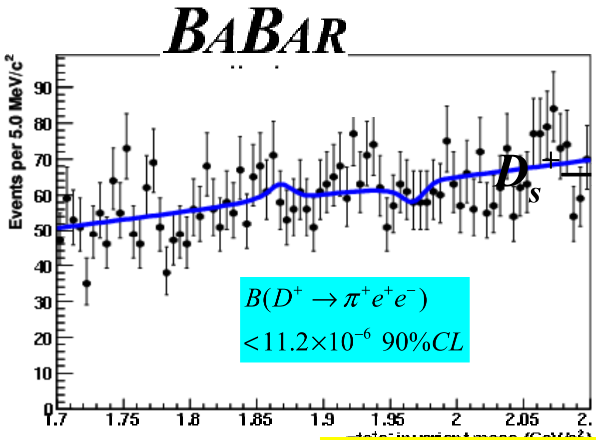
R-parity violating SUSY: $\sim 2.4 \times 10^{-6}$

CLEO-c

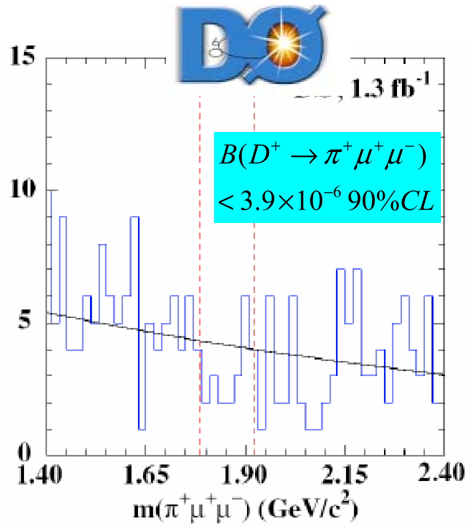


ΔMbc

ΔE



$M(\pi^+ e^+ e^-)$



Statistics limited

Bkgd limited

Tevatron may glimpse, study @ BES III, super B factories

Summary Slide

CLEO-c hadronic D^0, D^+ and D_s branching fractions more precise than PDG averages: (for D^0, D^+ 2% precision is syst.limited) CLEO establishes charm hadronic scale

most precise: $f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})$ MeV consistent with LQCD $\rightarrow$ 3.7% (8 MeV) full data

Most precise: $f_{Ds} = (274 \pm 10 \pm 5)$ MeV 3σ higher than LQCD. To interpret as "prosaic" or "exciting": calculation checks underway & radiative corrections need to be estimated

project: f_{Ds} 2.6% (7 MeV) full data set

lepton universality in D, D_s decays is satisfied

most precise $|V_{cs}| = 1.015 \pm 0.010 \pm 0.011 \pm 0.106_{theory}$

$|V_{cd}| = 0.217 \pm 0.009 \pm 0.004 \pm 0.023_{theory}$

most precise determination from semileptonic decay

Projections to full data set

$\sigma(|V_{cd}|)/|V_{cd}| \sim 2.5\% \oplus$ theory

$\sigma(|V_{cs}|)/|V_{cs}| \sim 1.0\% \oplus$ theory

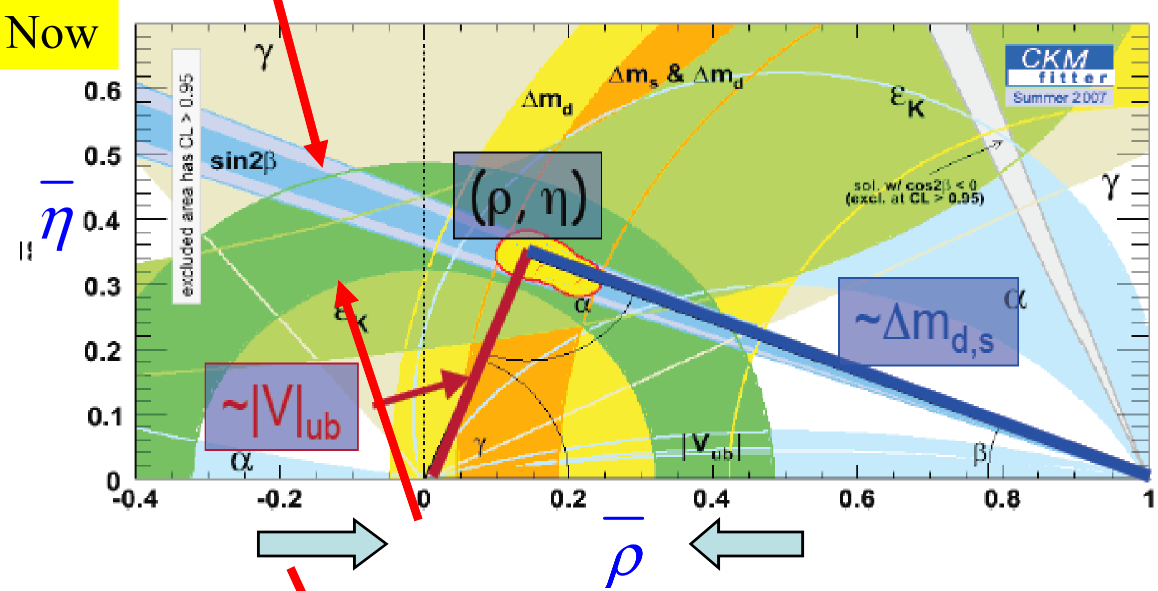
Best limits on direct CPV for many D modes

Best limit on $D \rightarrow \pi e^+ e^-$

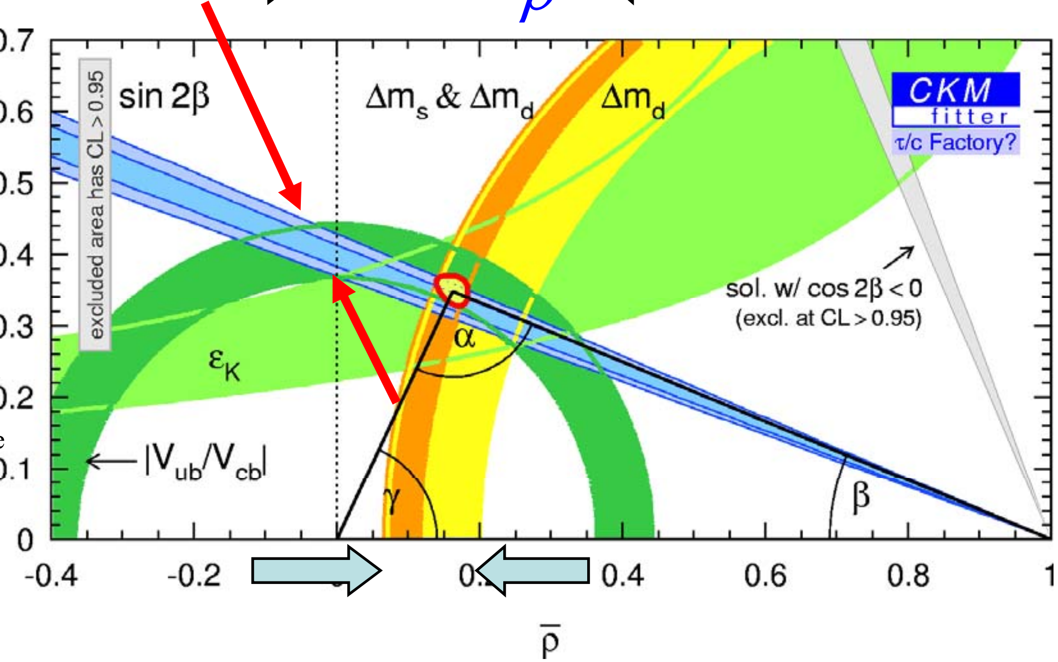
CLEO-c has 800/pb @ 3770 (x3) & 600/pb at 4170 (x2) by 3/31/08
➔more stringent tests of theory: fD+, fDs, D→ K/πev f+(0),shape, Vcs & Vcd by summer. Longer term the charm factory mantle passes to BES III.

Precision theory + charm = large impact

Now



Theoretical errors dominate width of bands



Plot uses Vub Vcb from exclusive decays only

Few % precision QCD Calculations tested with few % *precision* charm data
➔theory errors of a few % on B system decay constants & semileptonic form factors

A

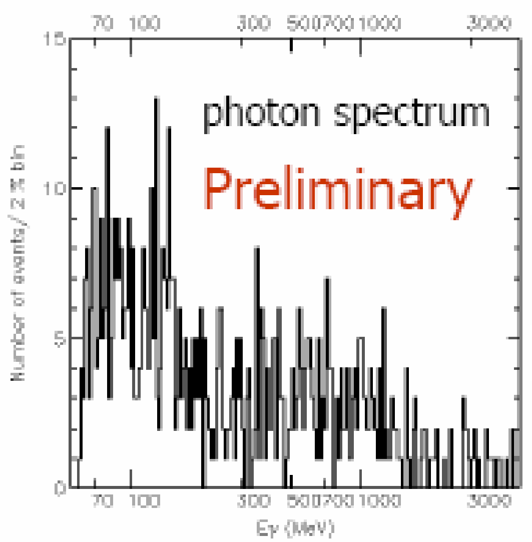
Search for a non-SM-like pseudoscalar Higgs

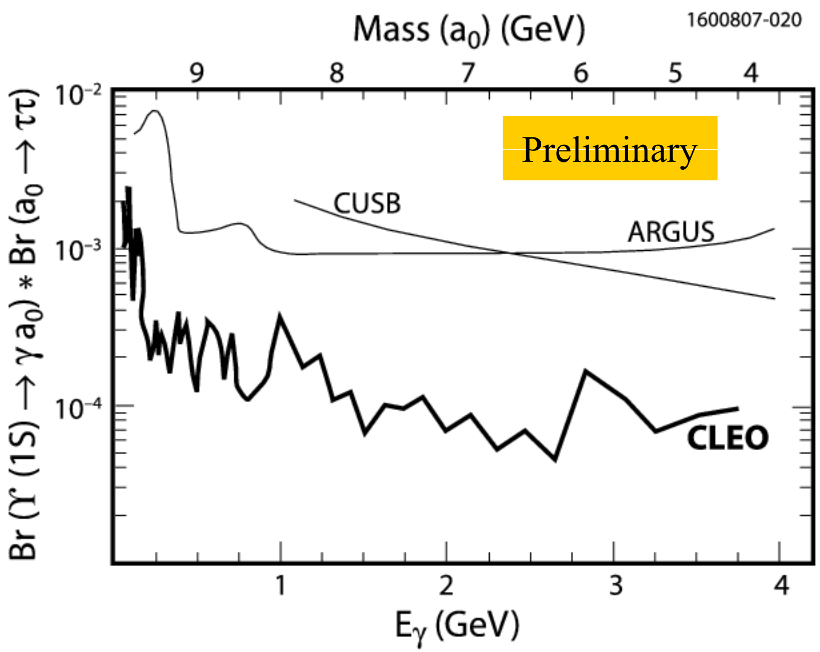
Dermisek, Gunion, McElrath propose adding to the MSSM a non-SM-like pseudoscalar higgs a_0 with $m_{a0} < 2m_b$ [hep-ph/0612031] "NMSSM"

- "natural," avoids fine tuning
- evades the LEP limit $M_h > 100$ GeV since $h \rightarrow a_0 a_0$, but $a_0 \not\rightarrow bb$ and LEP sought b jets
- $a_0 \rightarrow \tau^+\tau^-$ should predominate if $m_{a0} > 2m_\tau$
- Should be visible in $\Upsilon \rightarrow \gamma\, a_0$

Experimentally, CLEO seeks monochromatic γ

- Use $\Upsilon(2S) \rightarrow \pi\pi\Upsilon(1S)$ tag to eliminate $e^+e^- \rightarrow \tau\tau\gamma$ background
- Flag presence of τ pair with two 1-prong τ decays (one lepton), missing energy





ULs improved an order of magnitude or more

Rules out many, but not all NMSSM models

Improved $a_0 \rightarrow \tau^+\tau^-$ & $a_0 \rightarrow \mu^+\mu^-$ (c.f.Hyper-CP) by Spring '08

f_{Ds} & f_{Ds} / f_{D^+}

Combining method 1 $D_s \to \mu\nu$ & $D_s \to \tau\nu, \tau \to \pi\nu$

& method 2 $D_s \to \tau\nu, \tau \to e\nu$

weighted average: $f_{Ds} = (274 \pm 10 \pm 5)$ MeV

(syst. uncertainties are mostly uncorrelated between methods)

combine with $f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})$ MeV (CLEO)

$$f_{Ds}/f_{D^+} = 1.23 \pm 0.10 \pm 0.03$$

$$R = \frac{\Gamma(D_s^+ \to \tau^+\nu)}{\Gamma(D_s^+ \to \mu^+\nu)} = 11.0 \pm 1.4 \pm 0.6$$

compared to:

$$R = \frac{\Gamma(D_s^+ \to \tau^+\nu)}{\Gamma(D_s^+ \to \mu^+\nu)} = 9.72 \text{ (Standard Model)}$$

➔ lepton universality in purely leptonic *Ds* decays is satisfied at the level of current experimental accuracy.

Summary of CLEO-c Semileptonic Decay Results

1st observations of 4 modes

$$D^0 \to \rho^- e^+ \nu,\ D^+ \to \eta e^+ \nu,\ D^+ \to \omega e^+ \nu,\ D^0 \to K(1270) e^+ \nu$$

B(D→ Kev) pre-CLEO-c δB/B=6% now 2%,

$$|V_{cs}| = 1.014 \pm 0.013 \pm 0.009 \pm 0.106_{\text{theory}} \quad (\text{tag})$$

$$|V_{cs}| = 1.015 \pm 0.010 \pm 0.011 \pm 0.106_{\text{theory}} \quad (\text{notag})$$

Best *direct* determination of Vcs

B(D→ πev) pre-CLEO-c δB/B=45% now 4%, most precise f+(0) & shape

$$|V_{cd}| = 0.234 \pm 0.010 \pm 0.004 \pm 0.024_{\text{theory}} \quad (\text{tag})$$

$$|V_{cd}| = 0.217 \pm 0.009 \pm 0.004 \pm 0.023_{\text{theory}} \quad (\text{notag})$$

(most precise determination of Vcd from semileptonic decay)

CLEO-c has 800/pb @ 3770 to analyze & 600/pb at 4170 by 3/31/08

➔more stringent tests of theory for D→ K/πev f+(0) & shape

➔CKM Precision expected: Vcs (syst. limited) Vcd (stat limited)

$$D \to K e^+ \upsilon \quad \frac{\delta Vcs}{Vcs} = (0.9 - 1.2)\% \oplus \frac{\delta f_+^\pi(0)}{f_+^\pi(0)}$$

$$D \to \pi e^+ \upsilon \quad \frac{\delta Vcd}{Vcd} = (2.3 - 3.5)\% \oplus \frac{\delta f_+^\pi(0)}{f_+^\pi(0)}$$

Many other CLEO-c semileptonic analyses not discussed. Eagerly awaiting more precise LQCD calculations of semileptonic form factors at a variety of q^2 with associated correlation matrix to compare to experiment.

Summary

New Physics searches in D mix, D CPV & D rare are just beginning at CLEO-c Searches at BABAR,/Belle /CDF/D0/FOCUS have become considerably more sensitive. All results are null. As Ldt rises CLEO-c (& BES III) will become significant players.

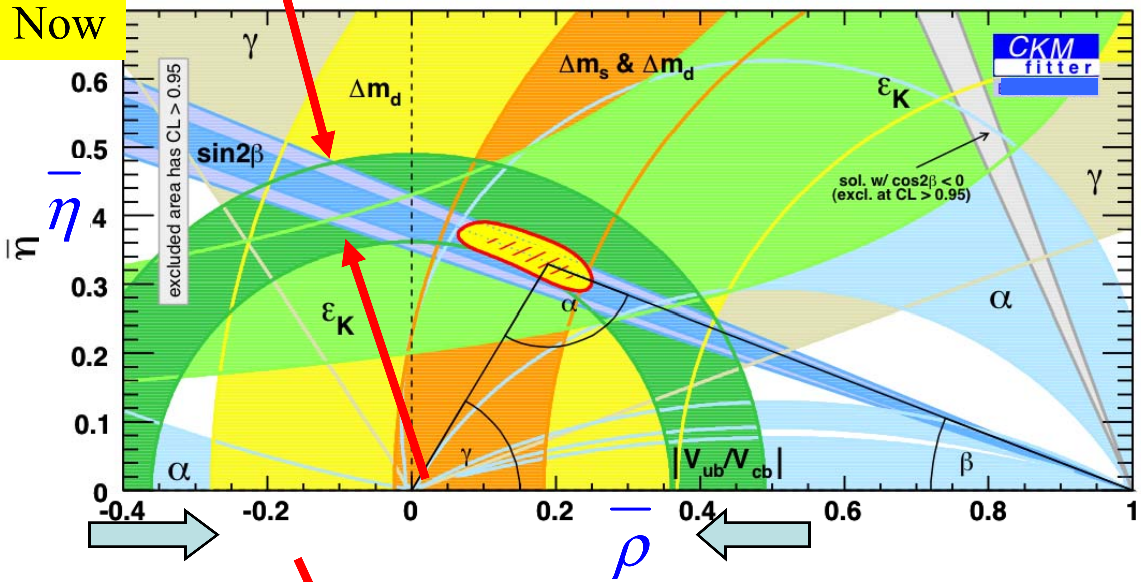
In charm's role as a natural testing ground for QCD techniques there has been solid progress. The precision with which the charm decay constant f_{D+} is known has already improved from 100% to ~8%. And the D→K semileptonic form factor has be checked to 10%. A reduction in errors for decay constants and form factors to at five - few % level is promised.

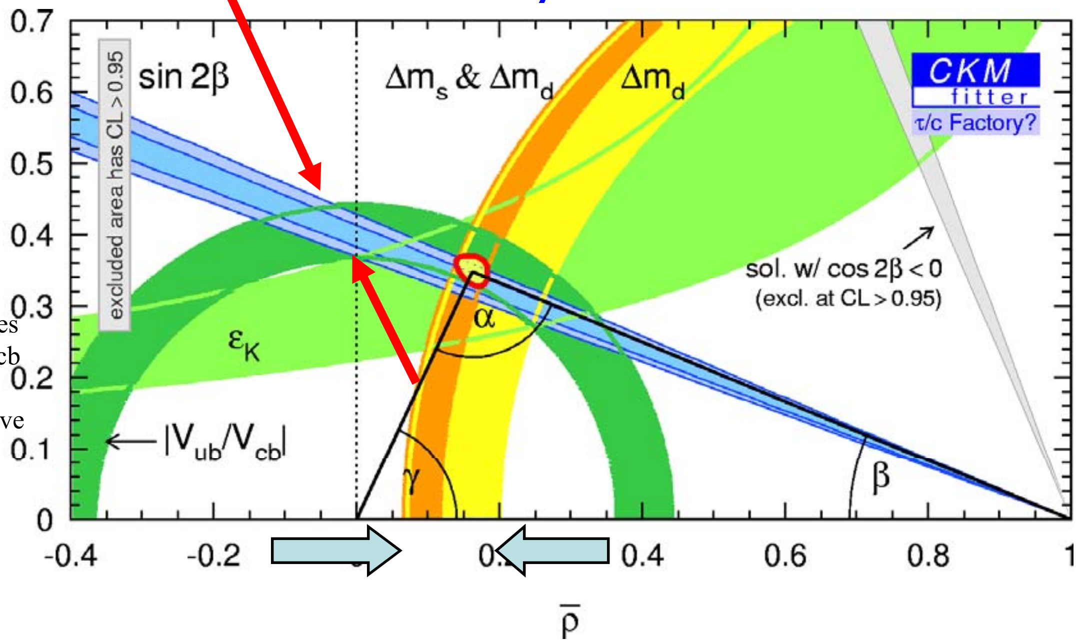
This comes at a fortuitous time, recent breakthroughs in precision lattice QCD need detailed data to test against. Charm is providing that data. If the lattice passes the charm test it can be used with increased confidence by: BABAR/Belle/CDF/D0//LHC-b/ATLAS/CMS to achieve improved precision in Determinations of the CKM matrix elements Vub, Vcb, Vts, and Vtd thereby maximizing the sensitivity of heavy quark flavor physics to physics beyond the Standard Model.

Charm is enabling quark flavor physics to reach its full potential. Or in pictures….

Precision theory + charm = large impact

Now





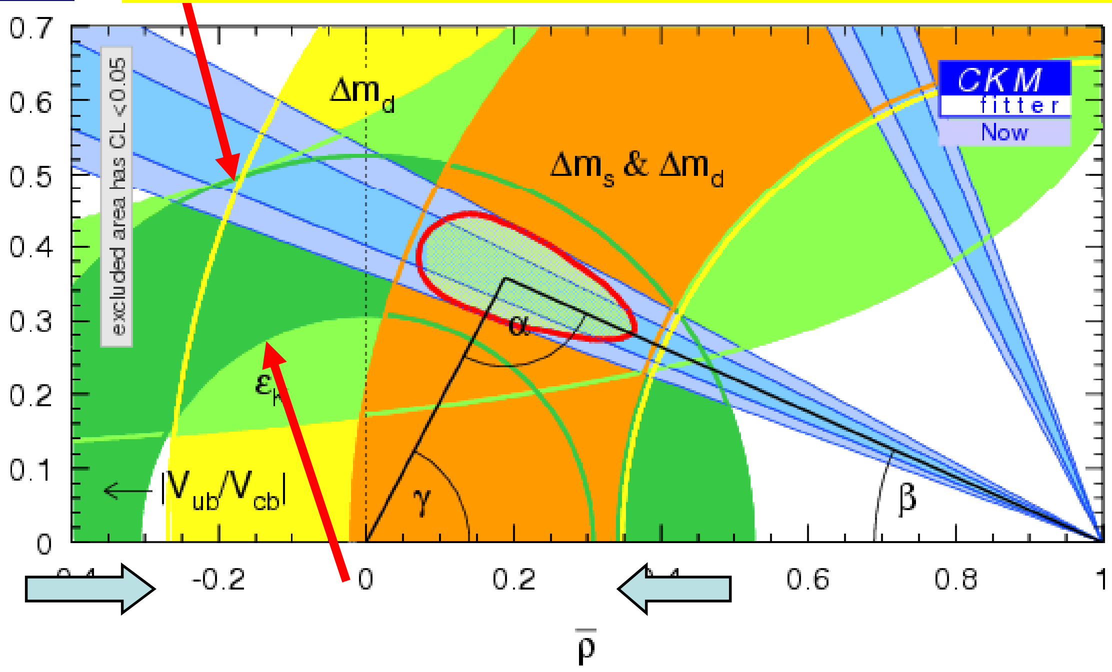
Plot uses Vub Vcb from exclusive decays only

Theoretical errors dominate width of bands

Few % precision QCD Calculations tested with few % *precision* charm data
➔theory errors of a few % on B system decay constants & semileptonic form factors

Precision theory + charm = large impact

Now



Theoretical errors dominate width of bands

precision QCD calculations tested with *precision* charm data

➔theory errors of a few % on B system decay constants & semileptonic form factors

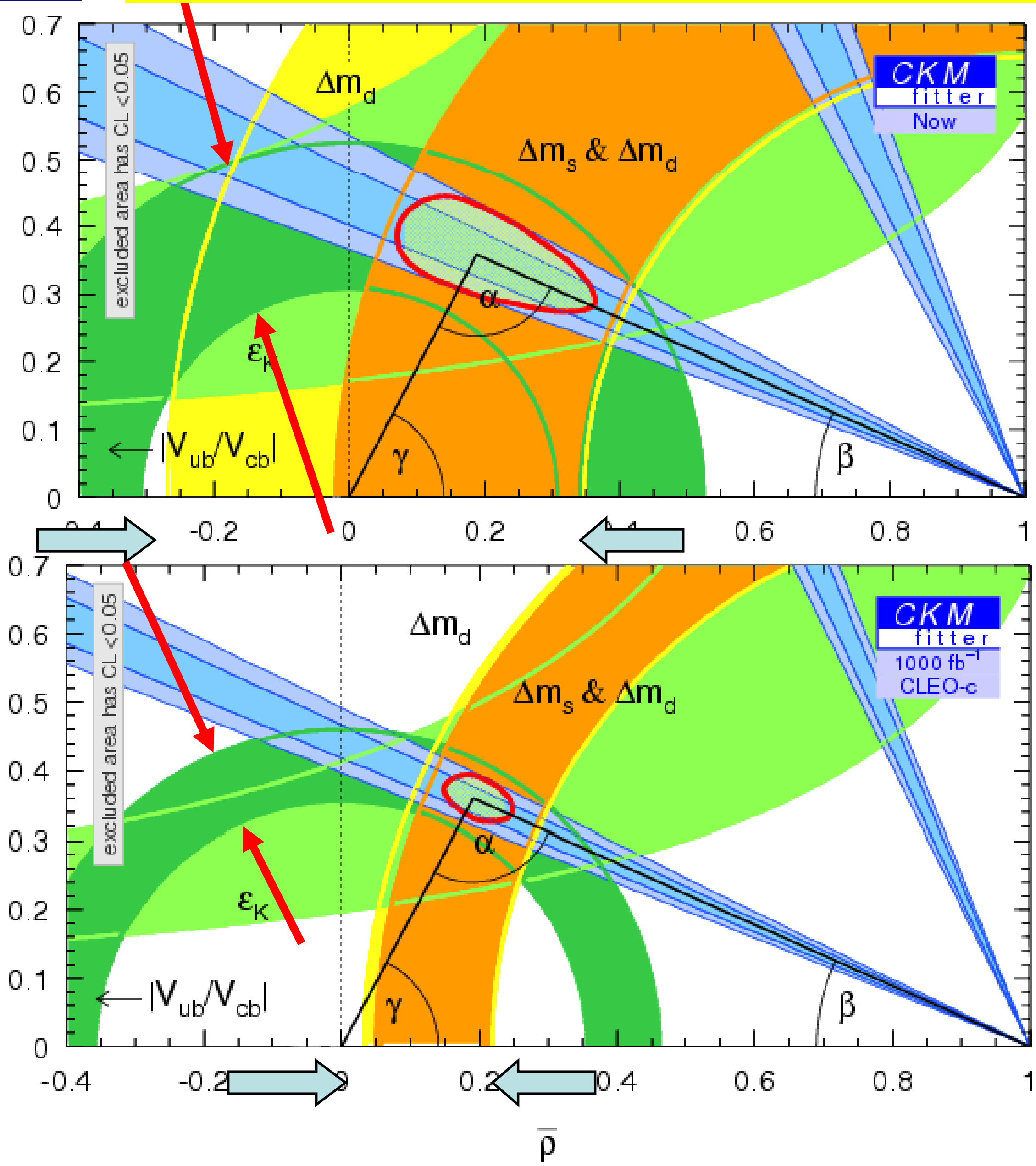
\+

500 fb-1 @ BABAR/Belle

Plot uses Vub Vcb from exclusive decays only

Precision theory + charm = large impact

Now



Plot uses Vub Vcb from exclusive decays only

Theoretical errors dominate width of bands

precision QCD calculations tested with *precision* charm data at threshold
➔theory errors of a few % on B system decay constants & semileptonic form factors

+

500 fb-1 @ BABAR/Belle

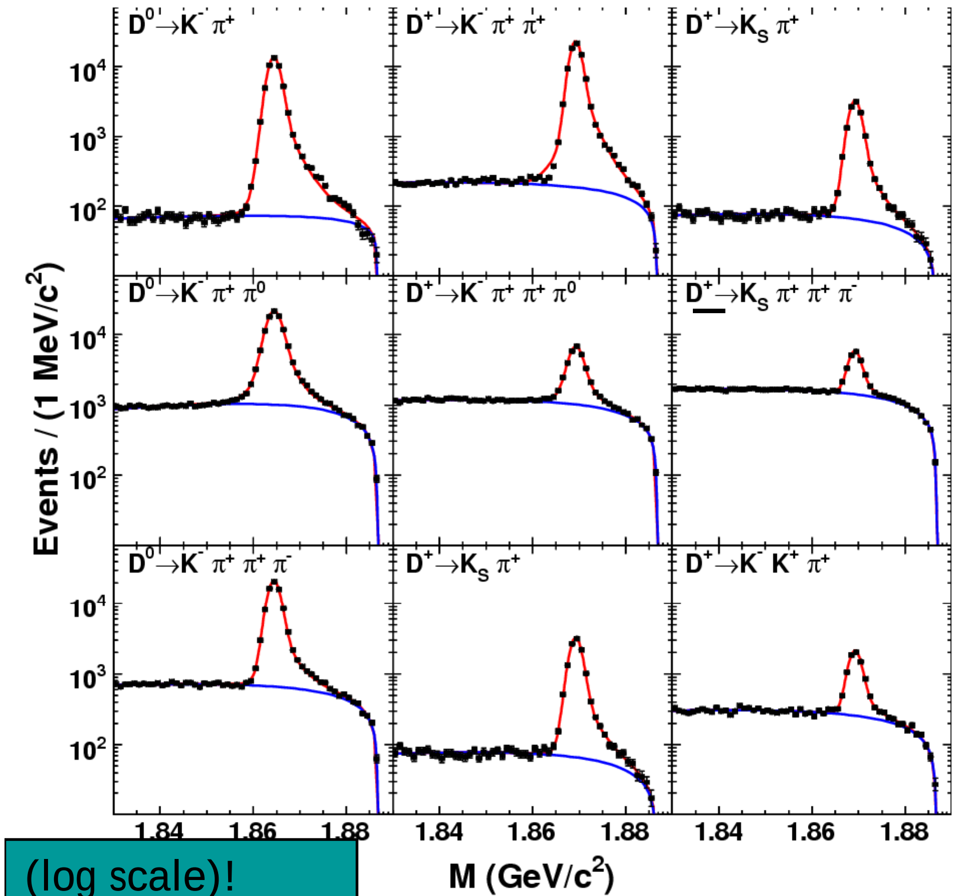
Additional Slides

1 D reconstructed

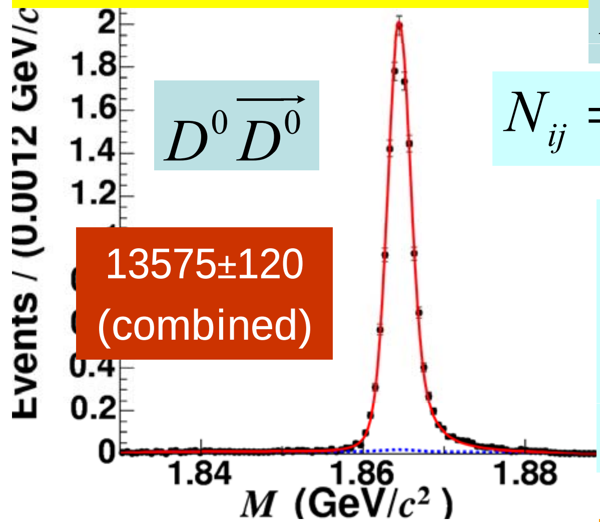
2 D's reconstructed

3 D^0 Modes

6 D^+ Modes



(log scale)!



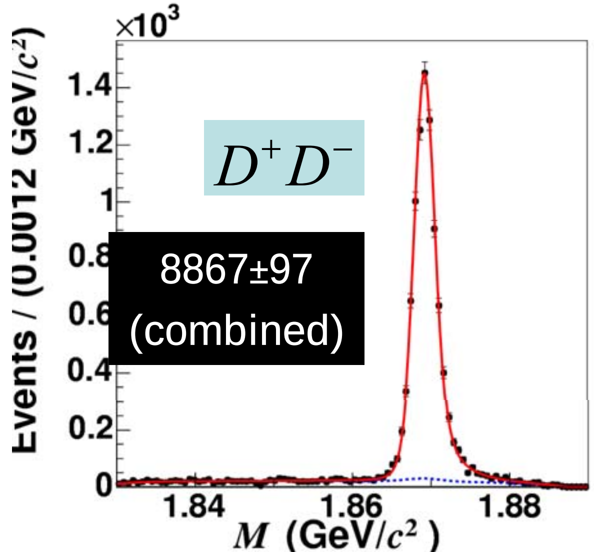
$$N_i = N_{D\bar{D}} B_i \varepsilon_i$$

$$N_{ij} = N_{D\bar{D}} B_i B_j \varepsilon_{ij}$$

$$B_i = \frac{N_{ij}}{N_j} \frac{\varepsilon_j}{\varepsilon_{ij}}$$

$$N_{D\bar{D}} = \frac{N_i N_j}{N_{ij}} \frac{\varepsilon_{ij}}{\varepsilon_i \varepsilon_j}$$

PRELIMINARY



Signal shape: ψ(3770) line shape, ISR, beam energy spread & momentum resolution, Bgkd: ARGUS

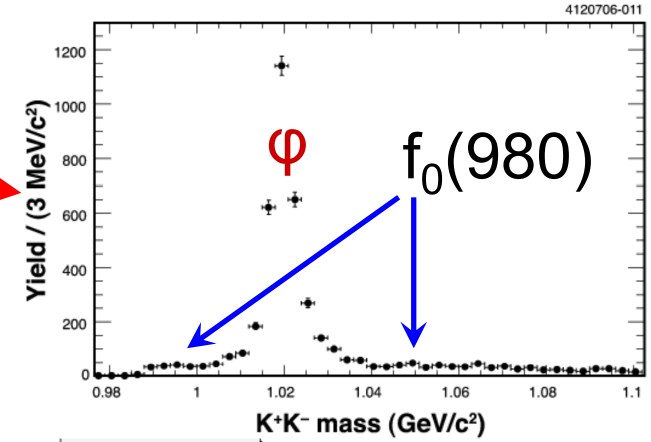
Global fit pioneered by MARK III 2x9 = 18 single & 45= ($3^2 + 6^2$) double tag yields (χ^2 minimization technique, syst, errors included) ➔ N_{DD} & 9 B_i's

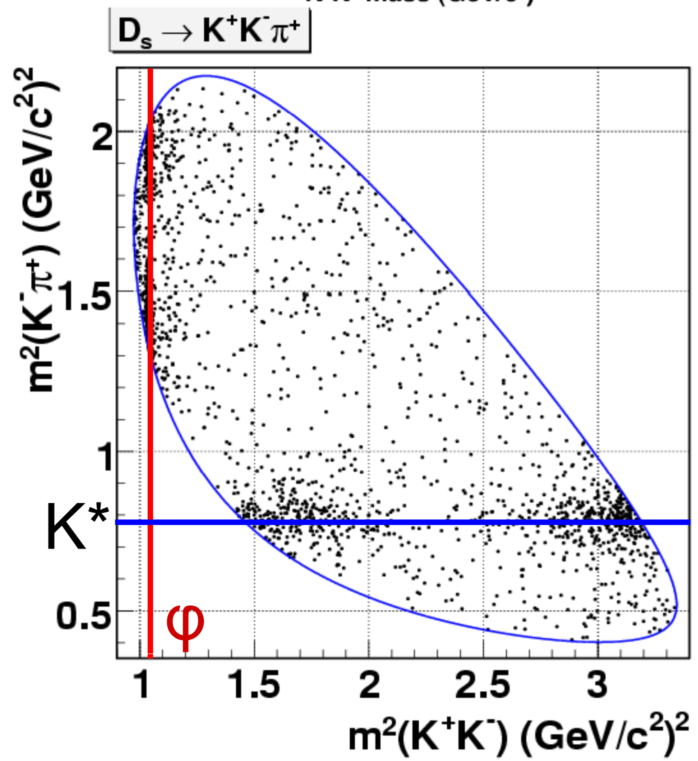
The $\varphi\pi^+$ problem in $D_s \to K^- K^+ \pi^+$

- Historically $D_s \to \varphi\pi^+$ used for normalization
- The process $f_0(980) \to K^- K^+$ contributes to any $\varphi \to K^- K^+$ mass region
- Correction depends on experiment's mass window, resolution, angular distribution requirements, contribution varies from <5% to >10% of observed yield (exceeds stat. uncertainty)=> do not quote $B(D_s \to \varphi\pi^+)$
- Instead produce partial $K^- K^+ \pi^+$ branching for 5,10, 15 and 20 MeV mass windows on each side of the φ mass:

Value	This Result $\mathcal{B}$ (%)
$\mathcal{B}_5$	$1.69 \pm 0.08 \pm 0.06$
$\mathcal{B}_{10}$	$1.99 \pm 0.10 \pm 0.05$
$\mathcal{B}_{15}$	$2.14 \pm 0.10 \pm 0.05$
$\mathcal{B}_{20}$	$2.24 \pm 0.11 \pm 0.06$

- Amplitude analysis is most appropriate to disentangle this problem…





Radiative Corrections

- Not just final state radiation which is already corrected for.
- Includes $D \rightarrow D^* \rightarrow \gamma D \rightarrow \gamma \mu^+ \nu$. Based on calculations of Burdman et al.
- $\Gamma(D_{(S)}^+ \rightarrow \gamma \mu^+ \nu) / \Gamma(D_{(S)}^+ \rightarrow \mu^+ \nu) \sim 1/40 - 1/100$
- Using narrow MM^2 region makes this much smaller
- Other authors in general agreement, see Hwang Eur. Phys. J. C46, 379 (2006), except Korchemsky, Pirjol & Yan PRD 61, 114510 (2000)
- Wang, Chang & Feng [hep-ph/0102251] find a -8% correction for $\Gamma(D_S \rightarrow \tau^+ \nu)$, negligible for $\Gamma(D_S \rightarrow \mu^+ \nu)$.

Comparison with Other Experiments

Exp.	Mode	$\mathcal{B}_{\phi\pi}$ (%)	$f_{D_s^+}$ (MeV)
CLEO-c	$\mu^+\nu$ [7]		$264 \pm 15 \pm 7$
CLEO-c	$\tau^+\nu$ [7]		$310 \pm 25 \pm 8$
CLEO-c	$\tau^+\nu$ [8]		$273 \pm 16 \pm 8$
CLEO-c	combined		$274 \pm 10 \pm 5$
Belle [9]	$\mu^+\nu$	preliminary Manchester EPS	$275 \pm 16 \pm 12$
Average			274 ± 10
CLEO [10]	$\mu^+\nu$	3.6±0.9	$273 \pm 19 \pm 27 \pm 33$
BEATRICE [11]	$\mu^+\nu$	3.6±0.9	$312 \pm 43 \pm 12 \pm 39$
ALEPH [12]	$\mu^+\nu$	3.6±0.9	$282 \pm 19 \pm 40$
ALEPH [12]	$\tau^+\nu$		
L3 [13]	$\tau^+\nu$		$299 \pm 57 \pm 32 \pm 37$
OPAL [14]	$\tau^+\nu$		$283 \pm 44 \pm 41$
BaBar [15]	$\mu^+\nu$	4.71±0.46	$283 \pm 17 \pm 7 \pm 14$

- CLEO-c is most precise result to date for f_{Ds} & f_{D+}
- & is an absolute measurement, specifically it *does not depend* on an external normalizing mode i.e B(Ds→Φπ)

Projection:

with 0.8fb^{-1} : f_{D+} to ~3.7% (8 MeV)

with 0.6fb^{-1} : f_{Ds} to ~2.6% (7 MeV)

(BESIII several % f_{D+} & f_{Ds})

f_B / f_D for V_{td} from Bmixing

f_{Ds} / f_D tests f_{Bs} / f_B for V_{td} / V_{ts} from **B**/Bs mixing

ArXiv 0712.1020
ArXiv 0712.1025

Table of dB/dq^2

TABLE VI: Summary of the efficiencies (ε) and efficiency-corrected yields for each q^2 interval and the corresponding partial branching fractions, the total branching fractions, the branching ratios and the isospin ratios. In all cases the first errors are statistical and the second are systematic.

	q^2 interval (GeV^2/c^4)					
	< 0.4	$0.4 - 0.8$	$0.8 - 1.2$	$1.2 - 1.6$	≥ 1.6	Total
			$D^0 \to \pi^- e^+ \nu_e$			
ε (%)	19.4	21.0	22.4	22.8	22.4	–
Yield	1452(113)(49)	1208(102)(35)	1242(99)(36)	906(85)(29)	1357(103)(46)	–
$\mathcal{B}(\pi^- e^+ \nu_e)$(%)	0.071(6)(3)	0.060(5)(2)	0.061(5)(2)	0.045(4)(2)	0.067(5)(3)	0.303(11)(9)
			$D^+ \to \pi^0 e^+ \nu_e$			
ε (%)	7.5	8.0	7.9	7.2	5.7	–
Yield	1379(168)(59)	1584(180)(61)	1012(154)(48)	1028(158)(35)	1101(174)(47)	–
$\mathcal{B}(\pi^0 e^+ \nu_e)$(%)	0.086(10)(4)	0.098(11)(4)	0.063(9)(3)	0.064(10)(2)	0.068(11)(3)	0.379(22)(14)
			$D^0 \to K^- e^+ \nu_e$			
ε (%)	19.2	20.5	20.0	18.3	13.9	–
Yield	29701(441)(569)	21600(377)(473)	14032(304)(301)	7001(225)(178)	991(112)(20)	–
$\mathcal{B}(K^- e^+ \nu_e)$(%)	1.46(2)(4)	1.06(2)(3)	0.691(15)(19)	0.345(11)(10)	0.049(6)(1)	3.61(3)(9)
			$D^+ \to \bar{K}^0 e^+ \nu_e$			
ε (%)	11.7	12.3	12.5	12.2	12.5	–
Yield	19480(466)(417)	14422(415)(306)	9009(327)(194)	4656(236)(107)	789(104)(26)	–
$\mathcal{B}(\bar{K}^0 e^+ \nu_e)$(%)	3.51(8)(10)	2.60(7)(7)	1.62(6)(5)	0.838(43)(24)	0.142(19)(5)	8.70(13)(24)
R_0(%)	4.89(39)(12)	5.59(48)(12)	8.85(74)(15)	12.9(13)(2)	137(19)(3)	8.41(32)(13)
R_+(%)	2.44(30)(9)	3.79(45)(13)	3.87(61)(17)	7.6(12)(2)	48(10)(2)	4.36(27)(12)
I_π	2.12(31)(10)	1.53(22)(7)	2.47(43)(14)	1.77(32)(7)	2.48(45)(13)	2.03(14)(9)
I_K	1.06(3)(4)	1.04(4)(4)	1.08(5)(4)	1.04(6)(4)	0.87(15)(4)	1.05(2)(4)

Don't read the table instead see plots on the next slides that interpret the table.

f+(0)Vcx & Shape Parameter(s) Fit Results

ArXiv 0712.1020
ArXiv 0712.1025

untagged analysis

Series Parameterization - Three Parameter Fits

Decay	a_0	a_1	a_2	ρ_{01}	ρ_{02}	ρ_{12}	$\|V_{cq}\|f_+(0)$	$1+1/\beta-\delta$	ρ	$\chi^2/d.o.f$
$\pi^- e^+ \nu_e$	0.045(2)(1)	-0.18(7)(2)	-0.03(35)(12)	0.81	0.71	0.96	0.141(7)(3)	1.30(37)(12)	-0.85	1.92/2
$\pi^0 e^+ \nu_e$	0.044(3)(1)	-0.23(11)(2)	-0.60(58)(15)	0.80	0.67	0.95	0.140(11)(4)	1.58(60)(13)	-0.85	2.84/2
$K^- e^+ \nu_e$	0.0235(3)(3)	-0.009(21)(7)	0.53(28)(6)	0.60	0.55	0.96	0.752(9)(10)	0.62(13)(4)	-0.61	0.23/2
$\bar{K}^0 e^+ \nu_e$	0.0226(4)(3)	0.010(32)(7)	0.77(42)(8)	0.72	0.63	0.96	0.741(14)(11)	0.51(20)(4)	-0.72	1.66/2

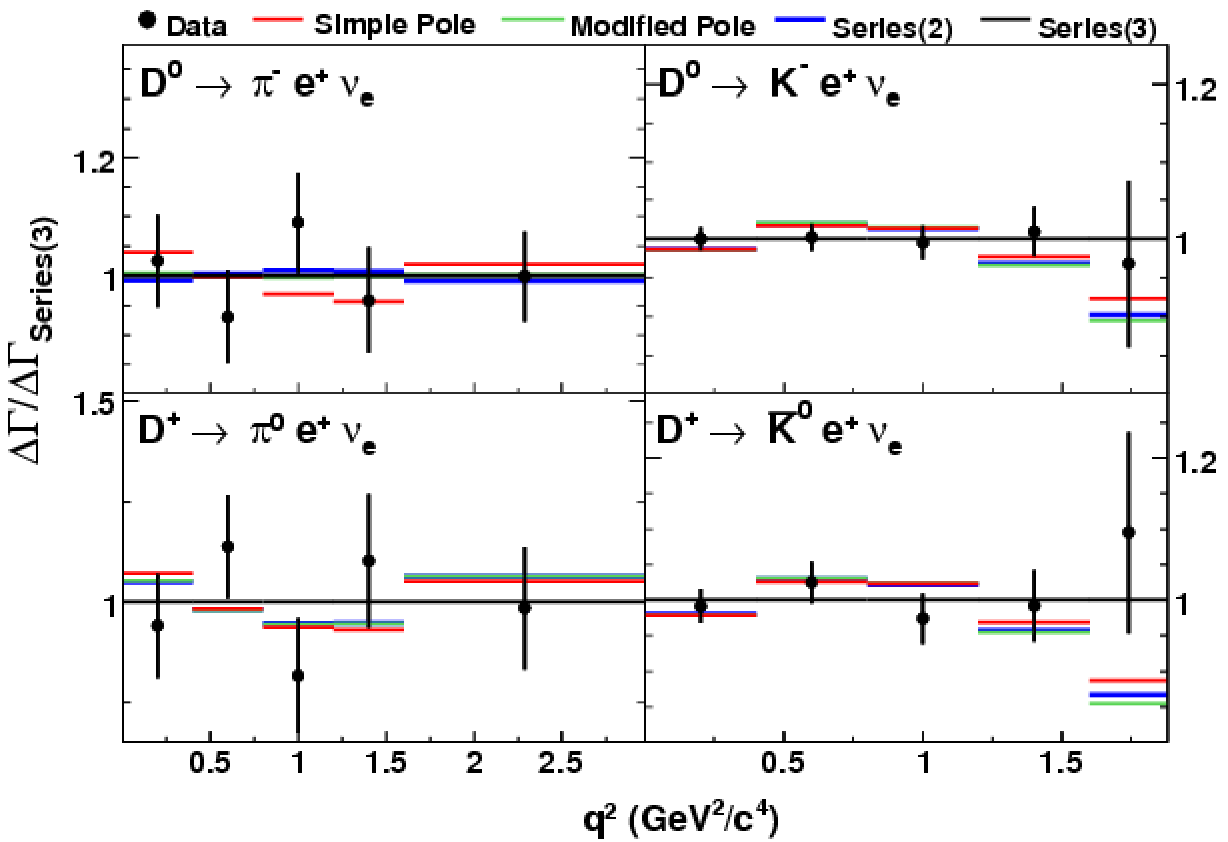
Series Parameterization - Two Parameter Fits

Decay	a_0	a_1	ρ	$\|V_{cq}\|f_+(0)$	$1+1/\beta-\delta$	ρ	$\chi^2/d.o.f$
$\pi^- e^+ \nu_e$	0.045(2)(1)	-0.175(19)(7)	0.65	0.141(5)(3)	1.27(12)(4)	-0.80	1.92/3
$\pi^0 e^+ \nu_e$	0.046(2)(1)	-0.125(30)(9)	0.68	0.148(7)(4)	1.01(16)(5)	-0.78	3.98/3
$K^- e^+ \nu_e$	0.0231(2)(3)	-0.047(6)(3)	0.33	0.739(6)(9)	0.86(4)(2)	-0.42	3.73/3
$\bar{K}^0 e^+ \nu_e$	0.0218(3)(3)	-0.046(9)(4)	0.53	0.721(10)(11)	0.87(6)(3)	-0.59	4.42/3

	Simple Pole Model Fits				Modified Pole Model Fits			
Decay	$\|V_{cq}\|f_+(0)$	m_{pole} (GeV/c^2)	ρ	$\chi^2/d.o.f$	$\|V_{cq}\|f_+(0)$	α	ρ	χ^2/ d.o.f
$\pi^- e^+ \nu_e$	0.147(4)(3)	1.87(3)(1)	0.70	3.11/3	0.142(4)(3)	0.37(8)(3)	-0.74	2.01/3
$\pi^0 e^+ \nu_e$	0.150(6)(4)	1.97(7)(2)	0.71	4.42/3	0.148(7)(4)	0.14(16)(5)	-0.76	4.07/3
$K^- e^+ \nu_e$	0.740(5)(9)	1.97(3)(2)	0.38	2.67/3	0.738(6)(9)	0.21(5)(3)	-0.41	4.32/3
$\bar{K}^0 e^+ \nu_e$	0.717(8)(11)	1.96(4)(2)	0.56	4.08/3	0.715(9)(11)	0.22(8)(4)	-0.59	5.26/3

$D \to \pi/Ke\nu$ Which Form Factor Parameterization?

Need to select 1 parameterization to measure intercept & determine $f_+(0)Vcx$, then use theory value of $f_+(0)$ to obtain Vcx



Form factor fits to partial branching fraction results in five q^2 ranges normalized to Hill series parameterization (Untagged shown)

- The confidence levels for all parameterizations are good, when shape parameters are *not* fixed to their model values
- As data does not support the physical basis for the pole & modified pole models ➔use the *model independent* Becher-Hill series parameterization for Vcx

DATA CROSS CHECK : ISOSPIN INVARIANCE

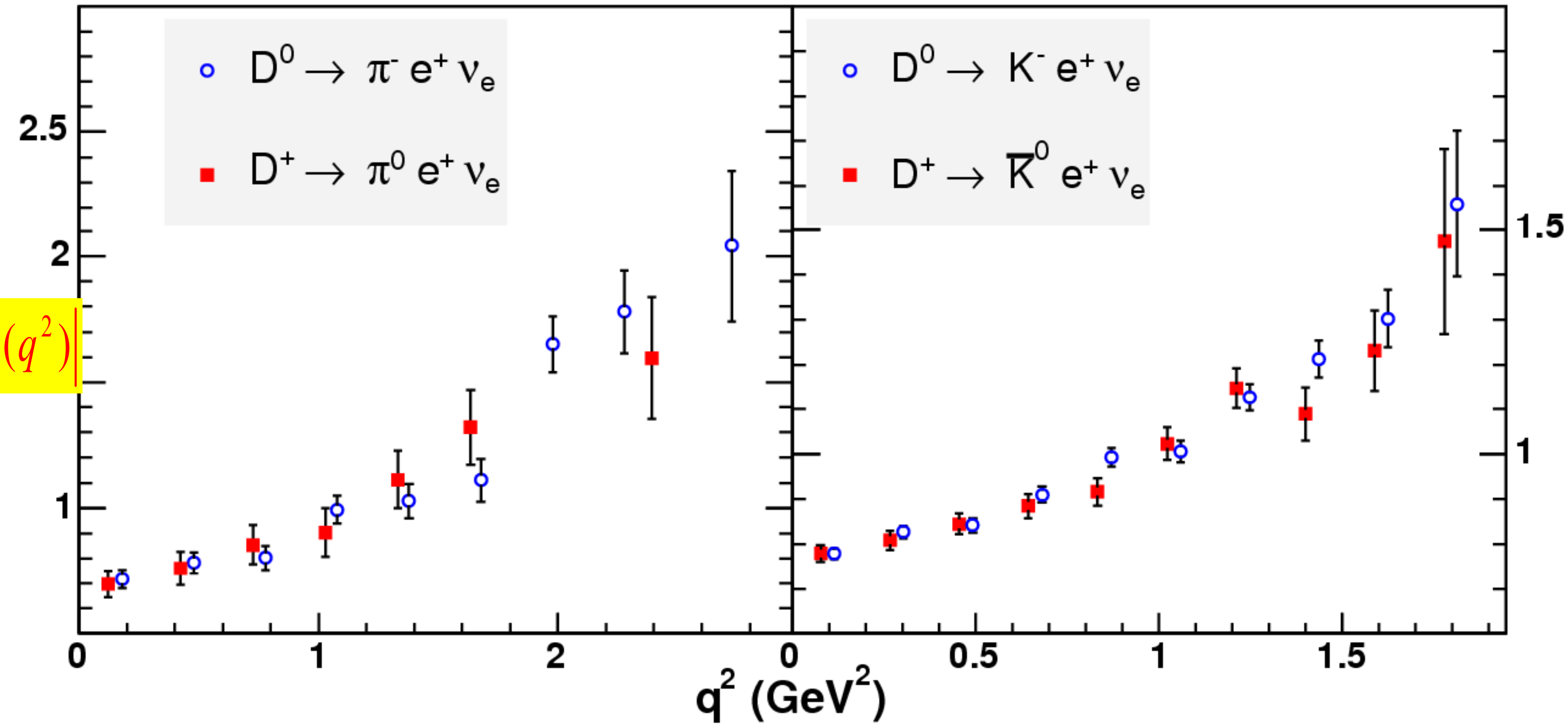
Removing the kinematic terms
reveals the form factor
(which varies by only a factor ~2 (~3))
across phase space for Keν ($\pi e\nu$))

$$|V_{cs(cd)}||f_+(q^2)| \sim \left[\frac{\Delta\Gamma_i(D \to K(\pi)e\nu)}{\Delta q_i^2} / P^3_{K(\pi)i}\right]^{1/2}$$

Isospin invariance

$$\Gamma(D^0 \to K^- e\nu) = \Gamma(D^+ \to \bar{K}^0 e\nu)$$
$$\Gamma(D^0 \to \pi^- e\nu) = 2\cdot\Gamma(D^+ \to \pi^0 e\nu)$$

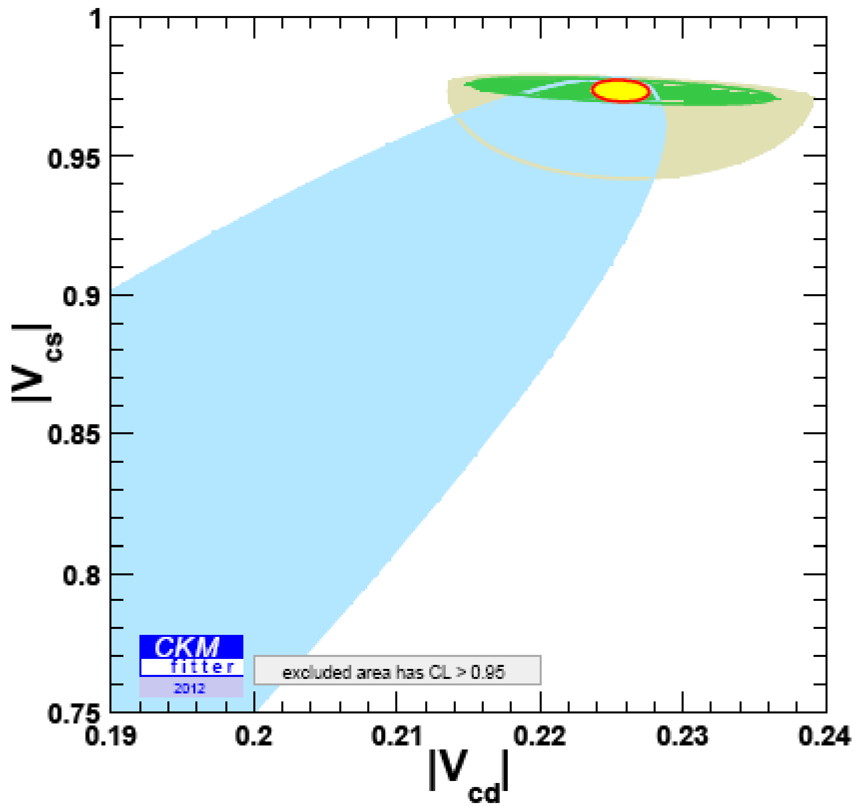
$|V_{cs(cd)}||f_+(q^2)|$



The q² spectra for isospin conjugate pairs are consistent a, *unique* to CLEO-c, powerful cross check of our understanding of the data

Compatibility between charm and beauty sectors of CKM matrix

Theory errors reduce to 1-2%
B factoroes
and full CLEO data set



Results: x 10^{-6} (90% CL) CLEO-c 0.28/fb BABAR 288/fb

		CLEO-c 0.28/fb	BABAR 288/fb
$\mathcal{B}(D^+ \Rightarrow \pi^+ e^+ e^-)$	(prev. 45)	7.4	11.2
		(stat, limited)	(background limited)

$B(D^+ \to \pi^+\mu^+\mu^-) < 4.7\times10^{-6}$ @90% CL Best Limit (1/fb)

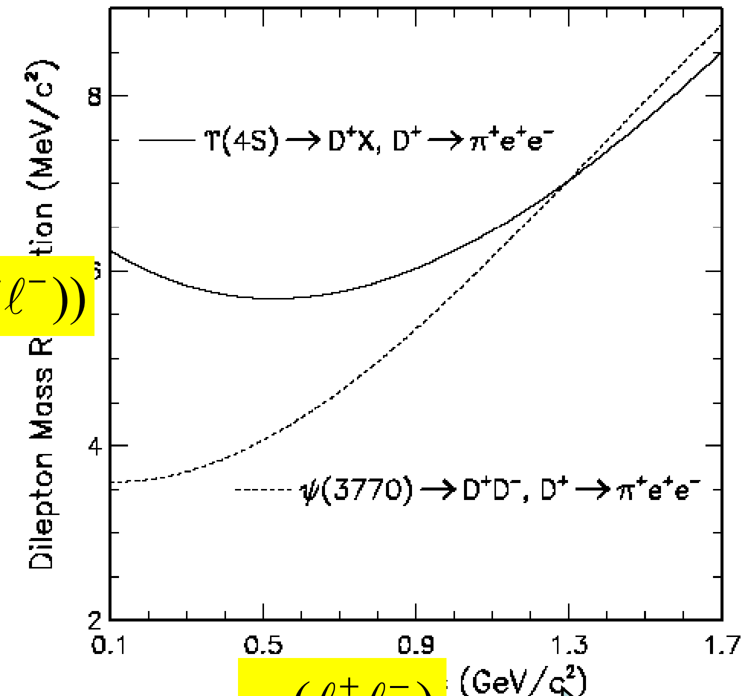
$B(D^+ \to \pi^+\phi \to \pi^+\mu^+\mu^-) < (1.75\pm0.7\pm0.5)\times10^{-6}$(long distance seen)

Limits are ~x4 above SM rates

BESIII: If $D^+ \Rightarrow \pi^+e^+e^-$ is @ SM level ➔~2 evt/fb
$D^+ \Rightarrow \pi^+e^+e^-$ /μμ ,$D^0 \Rightarrow \pi^0e^+e$ /μμ
⇒~50 events
If events cluster well away from φ/ρ/ω!
Smoking gun for new physics!

Superflavour facility @ 10GeV large backgrounds BUT @ψ(3770)
$D^+ \Rightarrow \pi^+e^+e^-$ ~3000 events (low bkgd)
also $D^0 \Rightarrow \pi^0e^+e^-$ accessible.
e+e- is unique probe of the rare decay frontier

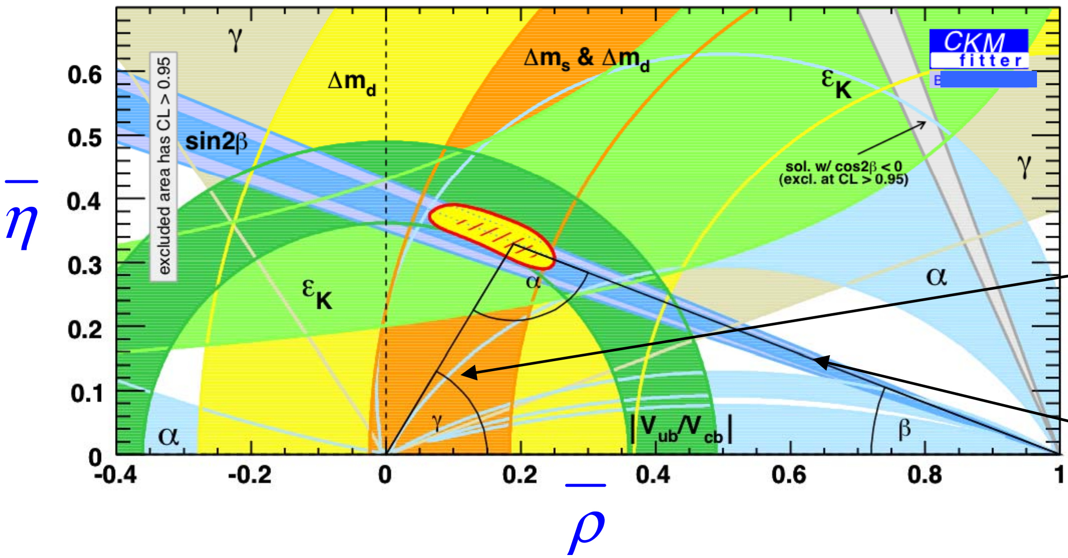
G. Burdman and I. Shipsey
Ann. Rev. Nucl. Part. Sci. **53** 431
(2003) arXivhep-ph/0310076



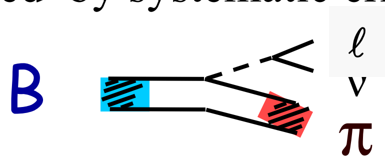
$\sigma(m(\ell^+\ell^-))$

$m(\ell^+\ell^-)$

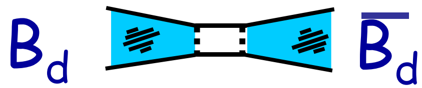
Precision Quark Flavor Physics



The discovery potential of B physics
At BABAR/Belle/CDF/D0/ LHC-b
is limited by systematic errors from
QCD:



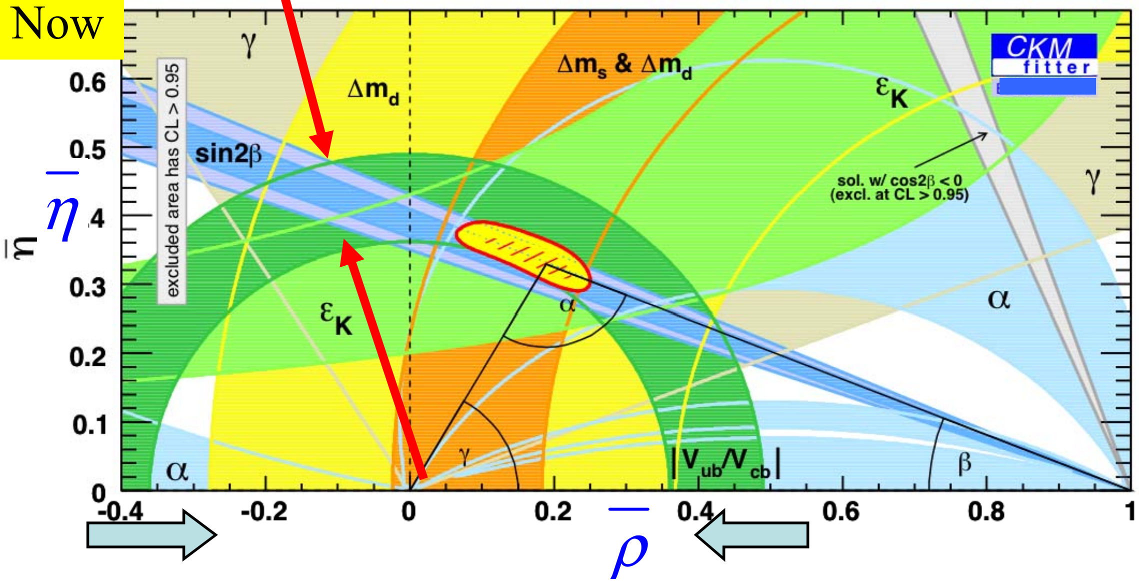
$$\propto \left[f^{B\rightarrow\pi}(q) \right]^2 |V_{ub}|^2$$



$$\propto \left[f_{Bd} \right]^2 |V_{td}|^2$$

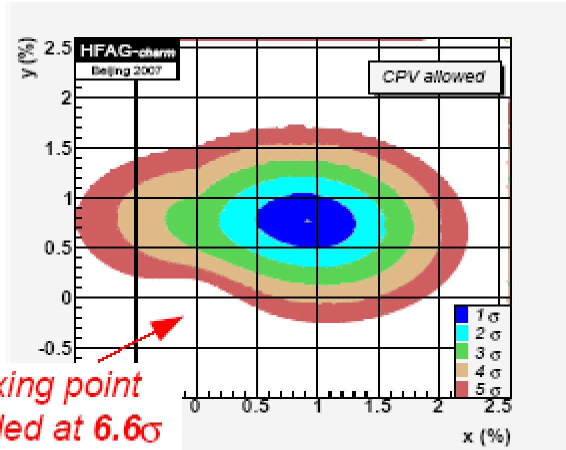
Precision theory + charm = large impact

Now



Theoretical errors dominate width of bands

precision QCD calculations tested with *precision* charm data
➔theory errors of a few % on B system decay constants & semileptonic form factors



no-mixing point excluded at 6.6σ

Comparison to other measurements $D^o \to K^-\pi^+$

THEN:

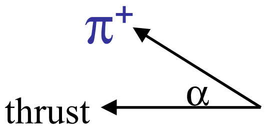
CLEO & ALEPH

$D^{*+} \to \pi^+ D^o$, $D^o \to K^-\pi^+$

compare to:

$D^{*+} \to \pi^+ D^o$, $D^o \to$ unobserved

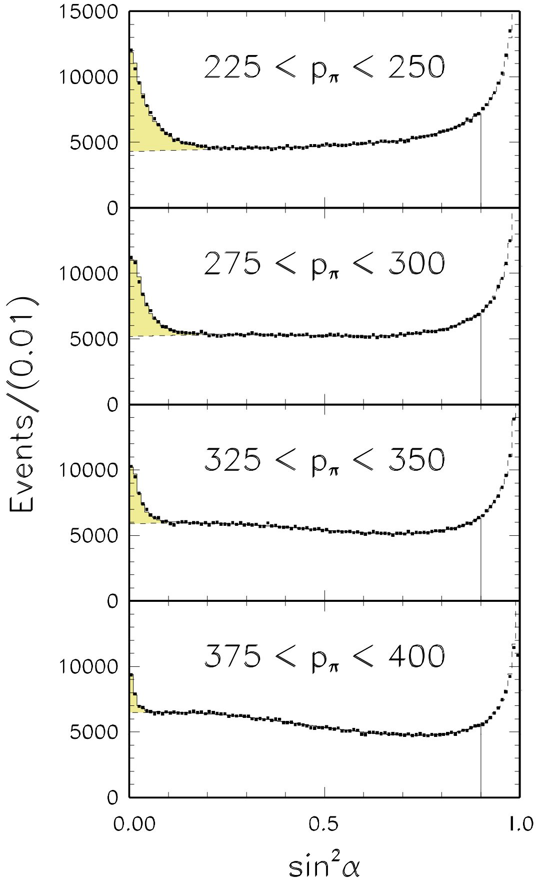
(Q~6MeV)



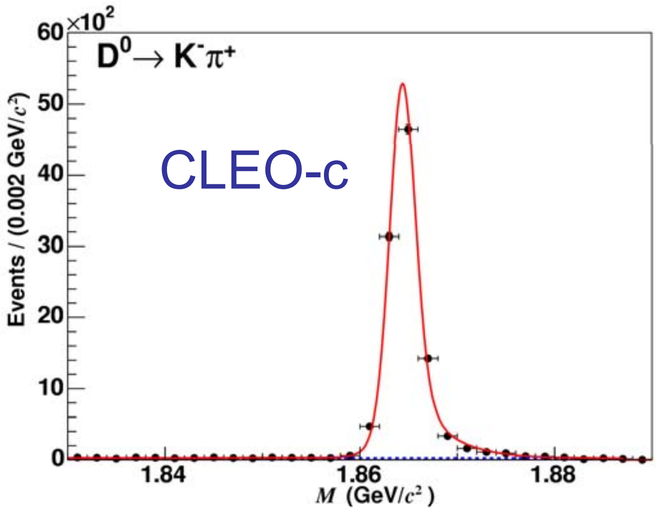
$\mathcal{B}$ (%)	Error(%)	Source
3.82±0.07±0.12	3.6	CLEO
3.90±0.09±0.12	3.8	ALEPH
3.80 ±0.09	2.4	PDG04
3.891±0.035 ±0.069	2.0	CLEO-c

arXiv:0709.3783 to appear in PRD

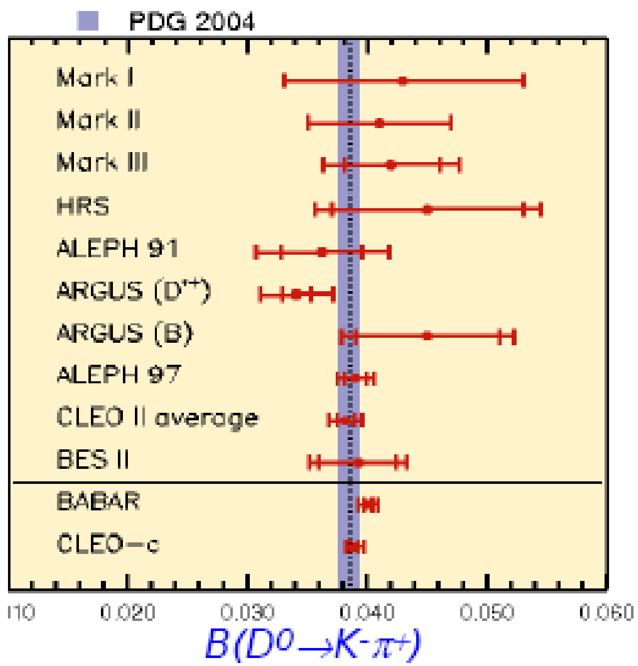
Systematics limited 2%



NOW:



CLEO-c (not in PDG04 average)



Measurement of fD_S^+ (at 4170 MeV)

Here expect in SM $$R = \frac{\Gamma(D_s^+ \to \tau^+\nu)}{\Gamma(D_s^+ \to \mu^+\nu)} = 9.72$$

1) $D_s^+ \to \mu^+\nu$ and $D_s^+ \to \tau^+\nu, \tau^+ \to \pi\nu$

in D_s tagged events

PRL 99 071802 (2007)
PRD 76 072002 (2007)

2) $D_s^+ \to \tau^+\nu, \tau^+ \to e^+\nu\nu$

in D_s tagged events

arXiv:0712.1175

(Submitted to PRL Dec 12 2007)

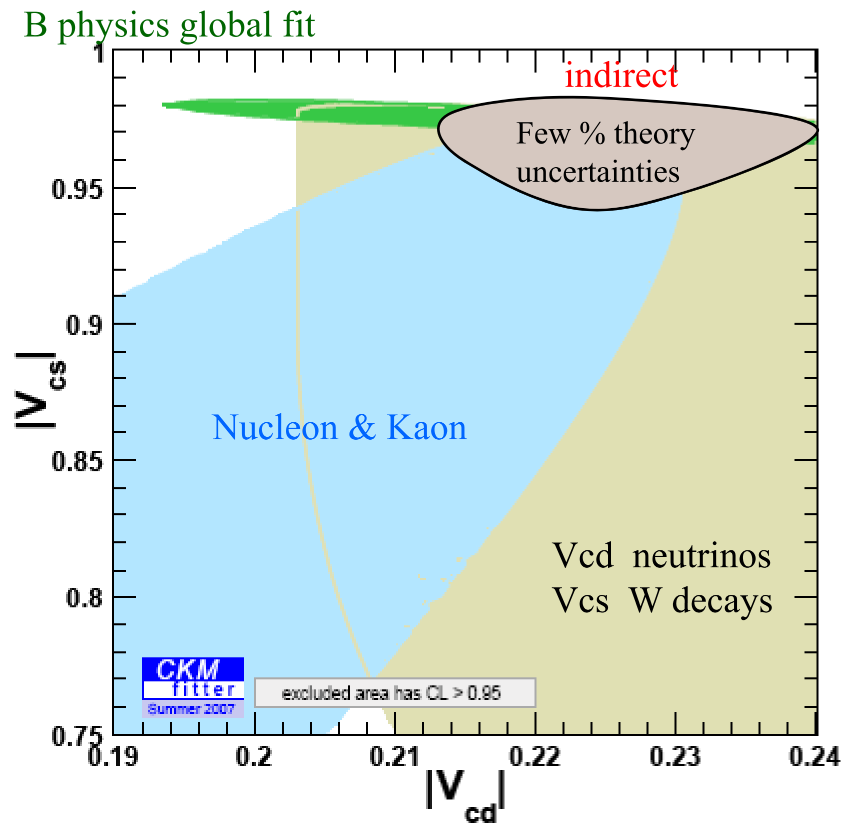
Unitarity Test: Compatibility of charm & beauty sectors of CKM matrix

Build a test for $|V_{cd}|$ & $|V_{cs}|$

Determine $|V_{cd}|$ & $|V_{cs}|$ indirectly
(K & B decays + SM)

Determine $|V_{cd}|$ & $|V_{cs}|$ directly
(D decays CLEO)

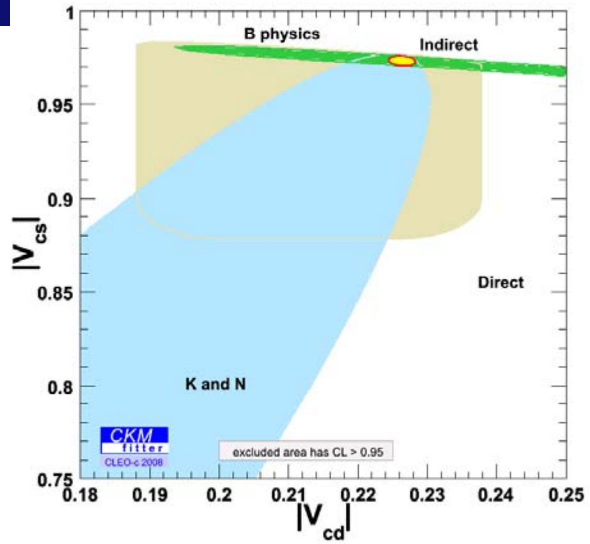
Determine compatibility between
the two determinations



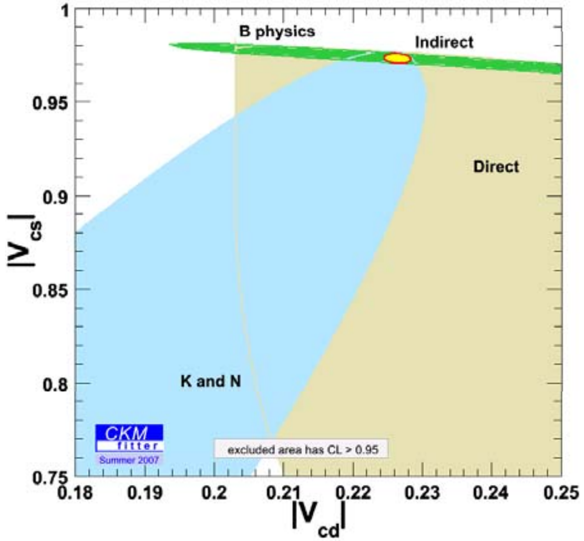
D semileptonic with theory uncertainties comparable to experimental uncertainty
May lead to interesting competition between direct and indirect constraints

Plots by Sebastien Descortes Genon & Ian Shipsey

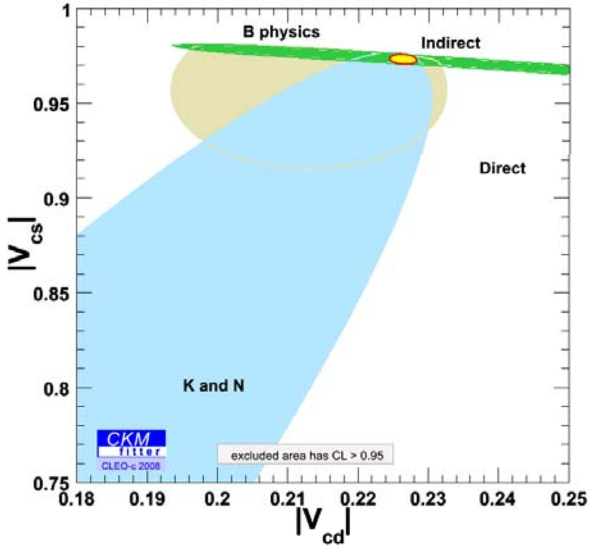
CLEO at 800/pb Vcs 0.9% Vcs 2.3% , lattice 6%



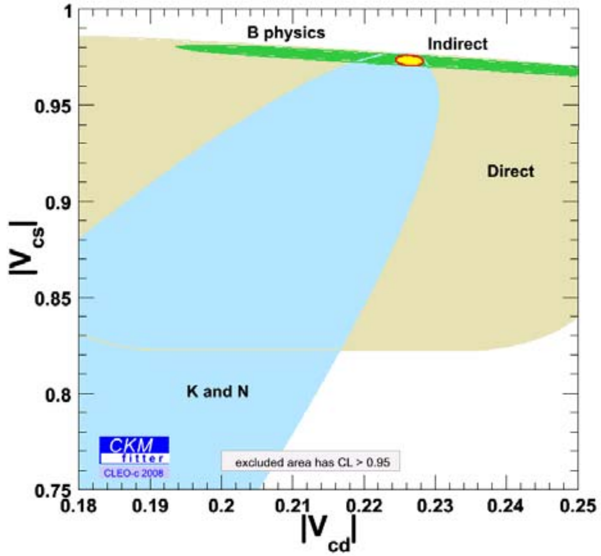
Summer 2007 Vcs Vcd neutrino



Vcs Vcd CLEO-c now + lattice 0%



Vcs Vcd CLEO-c now + lattice 11%



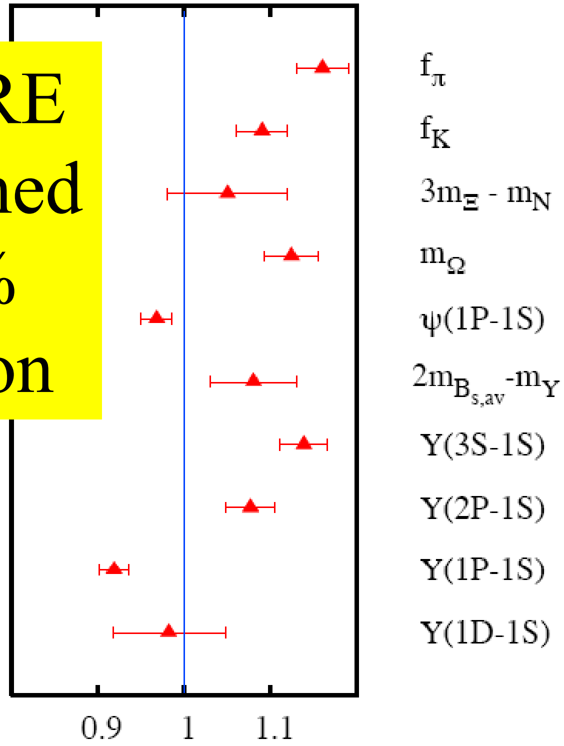
Charm: The Context

This Decade	Flavor physics is in the "sin 2β era' akin to precision Z. Over constrain CKM matrix with precision measurements Discovery potential is limited by systematic errors from non-perturbative QCD
2008 & beyond	LHC may uncover strongly coupled sectors in the physics Beyond the Standard Model. The ILC will study them. Strongly coupled field theories→ an outstanding challenge to theory. Critical need: reliable theoretical techniques & detailed data to calibrate them
The Lattice	Complete definition of pert. and non-pert. QCD Goal: Calculate B, D, Υ, ψ to 5% in a few years, and a few % longer term.

Charm can provide data to test & calibrate non-pert. QCD techniques such as the lattice (especially true at charm threshold)➔ CLEO-c

Precision theory? Lattice QCD

BEFORE
Quenched
10-15%
precision



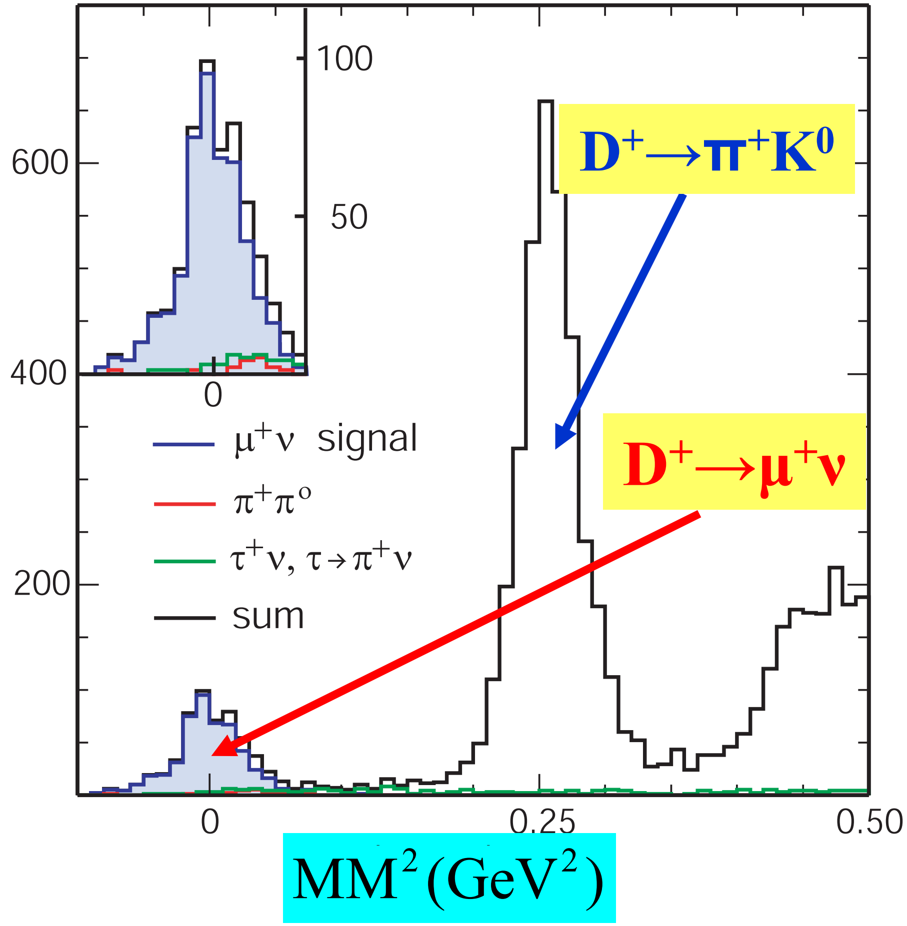
$$\frac{\text{theory-expt}}{\text{expt}}.$$

f_{D+} from Absolute Br($D^+ \to \mu^+\nu$)

$$MM^2 = (E_{beam} - E_\mu)^2 - (-\overrightarrow{P}_{D\,tag} - \overrightarrow{P}_\mu)^2$$

$$\delta MM^2 \sim M^2_{\pi 0}$$

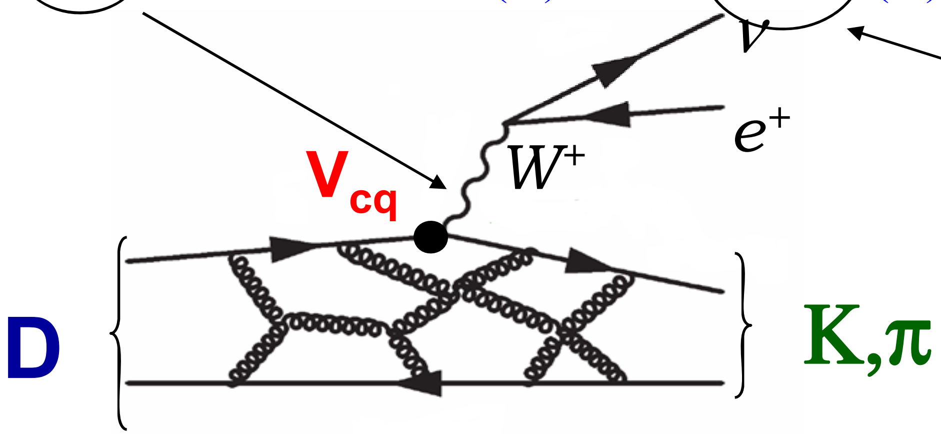
- **MC 1.7 fb^{-1}, 6 x data**



Semileptonic Decay Form Factors

$$M(D^0 \to \pi^- l^+ \nu) = -i\frac{G_{Fermi}}{\sqrt{2}} V_{cd}\ L_\mu\ H^\mu$$

$$q^2 = m_D^2 + m_{K(\pi)}^2 - 2m_D E_{K(\pi)}$$



In D rest frame

Squared 4-momentum transfer

Matrix element expressed as form-factors (for D→Pseudoscalar $\lambda^+\nu$)

simplest case for expt. and theory

$$H^\mu = \left\langle P(P_D)\middle| J_\mu \middle| D(P_{K,\pi})\right\rangle = f_+(q^2)(P_{K,\pi}+P_D)_\mu + f_-(q^2)(P_{K,\pi}-P_D)_\mu$$

For λ = e, $f_-(q^2) \to 0$: $$\frac{d\Gamma\left(D^+ \to K,\pi e\nu\right)}{dq^2} = \frac{G_F^2}{24\pi^3} P_{K,\pi}^3 \left|f_+(q^2)\right|^2 \left|V_{cs,d}\right|^2$$

form factor measures probability final state hadron will be formed

(ii) Form Factor Parameterizations

In general: $f_+(q^2) = \frac{f_+(0)}{1-\alpha}\frac{1}{\left(1-q^2/m^2_{pole}\right)} + \sum_{k=1}^{N}\frac{\rho_K}{1-\frac{1}{\gamma_K}\frac{q^2}{m^2_{pole}}}$

Models

- Single pole $f_+(q^2) = \frac{f_+(0)}{\left(1-q^2/m^2_{pole}\right)}$

$D \to Ke\nu$

$m_{pole} = m(D_S^*)$

- Modified Pole $f_+(q^2) = \frac{f_+(0)}{\left(1-q^2/m^2_{pole}\right)\left(1-\alpha q^2/m^2_{pole}\right)}$

(Allows for additional poles)

Model independent

- Series Expansion *Hill & Becher, Phys. Lett. B 633, 61 (2006)*

the function $z(q^2,t_0) = \frac{\sqrt{t_+-q^2}-\sqrt{t_+-t_0}}{\sqrt{t_+-q^2}+\sqrt{t_+-t_0}}$ $t \equiv q^2 = (P_D - P_K)^2$ $t_+ \equiv (M_D + m_K)^2$,

t_0: arbitrary q^2 value that maps to z=0

maps the physical q^2 region into -0.05<z<0.05 : $D \to Ke\nu$

form factors can be written as: $f_+(q^2) = \frac{1}{P(q^2)\phi(q^2)}\sum_{k=0}^{\infty} a_k(t_0)[z(q^2,t_0)]^k$

accounts for D_S^* pole

calculable function to make a_K's look simple

z small, converges rapidly → linear or quadratic sufficient

Experiment probes both the form factor magnitude & parameterization

Comparison with theory

For fds we are ~3σ above the most recent & precise LQCD calculation (Follana) HPQCD. Possibilities:

The calculation is not correct

This is evidence for new physics that interferes constructively with SM

Note: 2HDM is always destructive int. so no value of M_H is allowed in 2HDM @99.5% CL

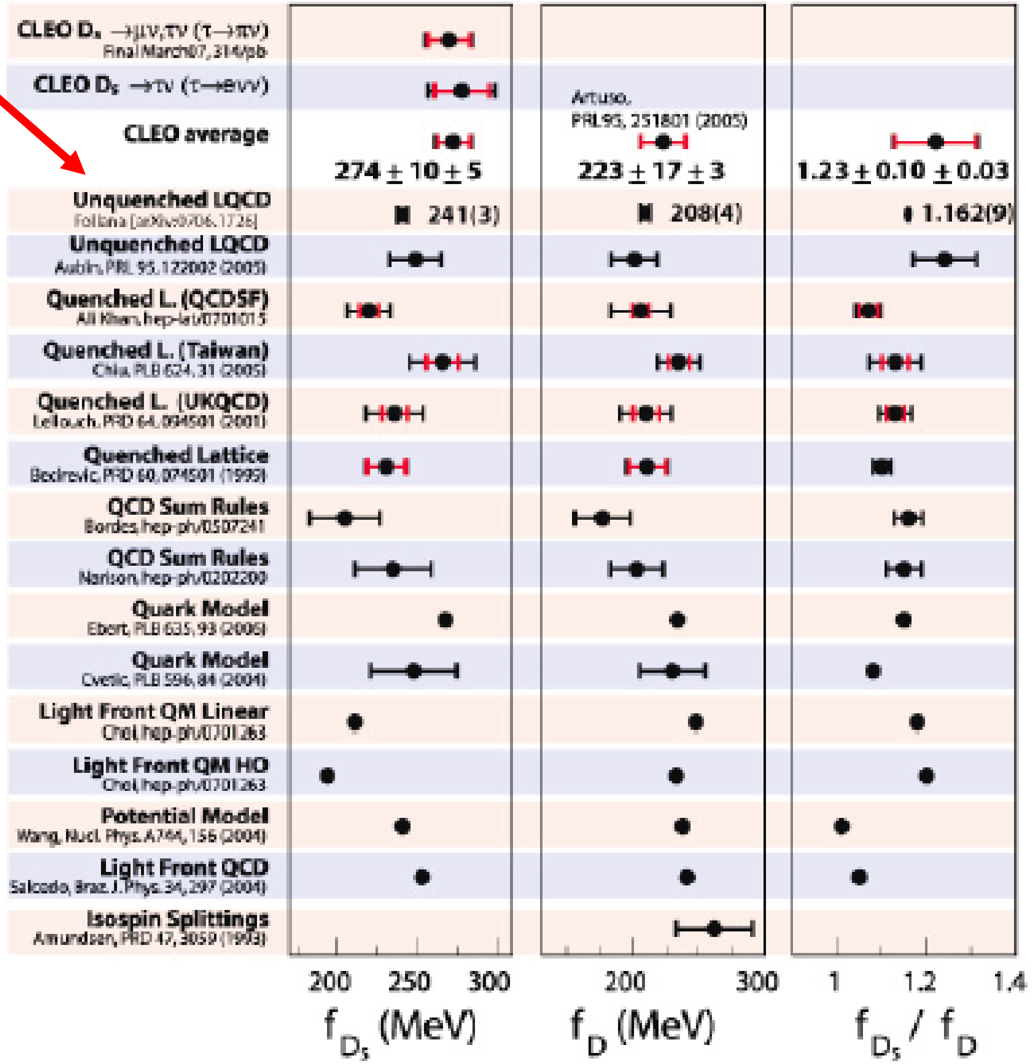
Comparing measured fDs/fD+

with Follana, and taking the 90% CL lower limit we find m_H>2.2 GeV tanβ

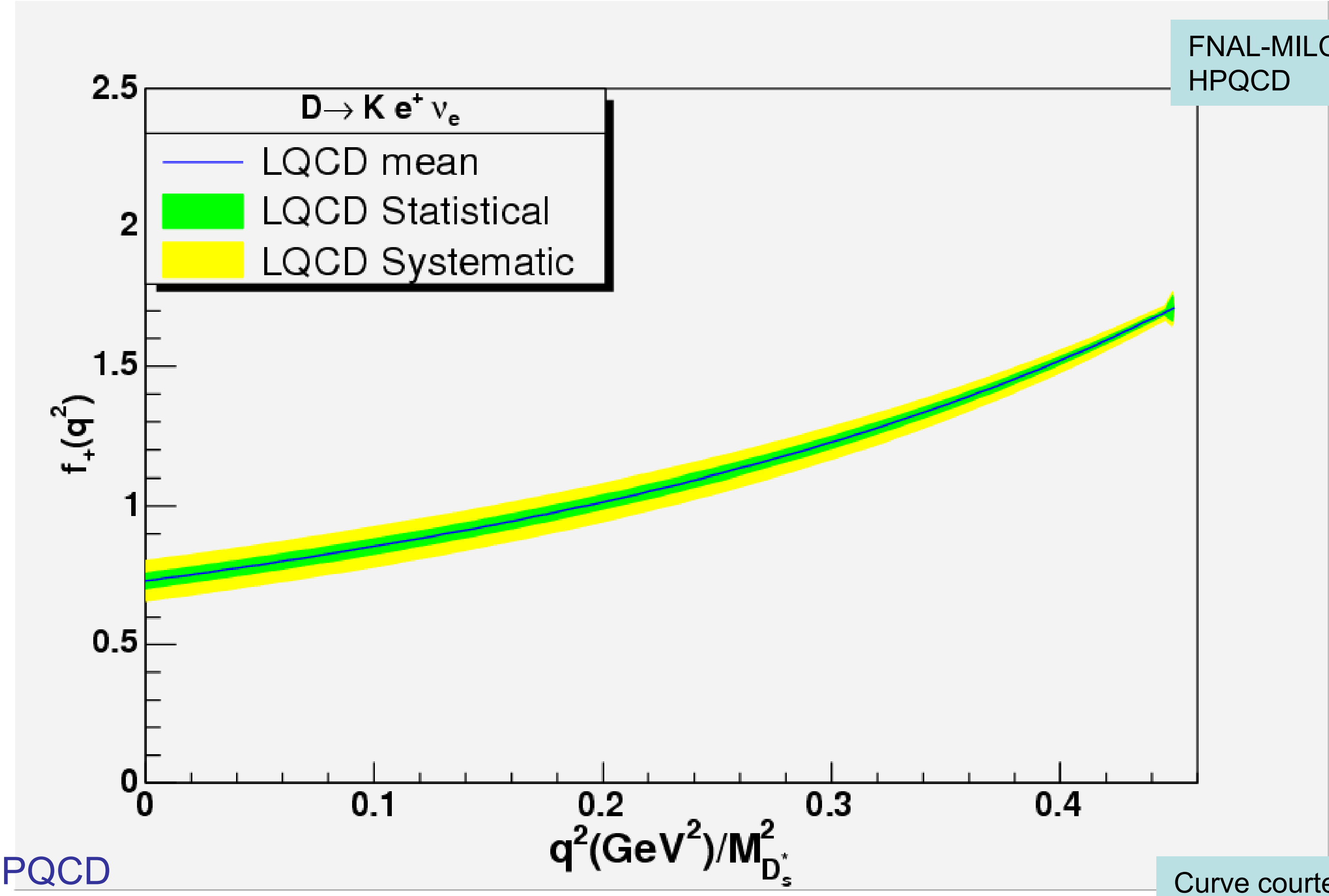
Using Follana ratio find

$|V_{cd}/V_{cs}|=0.217\pm0.019$ (exp)±0.002(theory)

CLEO statistically limited – more data is on the way!



Lattice Prediction shape *and* absolute normalization



FNAL-MILC-HPQCD

FNAL-MILC-HPQCD
uses mod. pole model
To fit for form factor from
"calculated"points
at fixed q^2

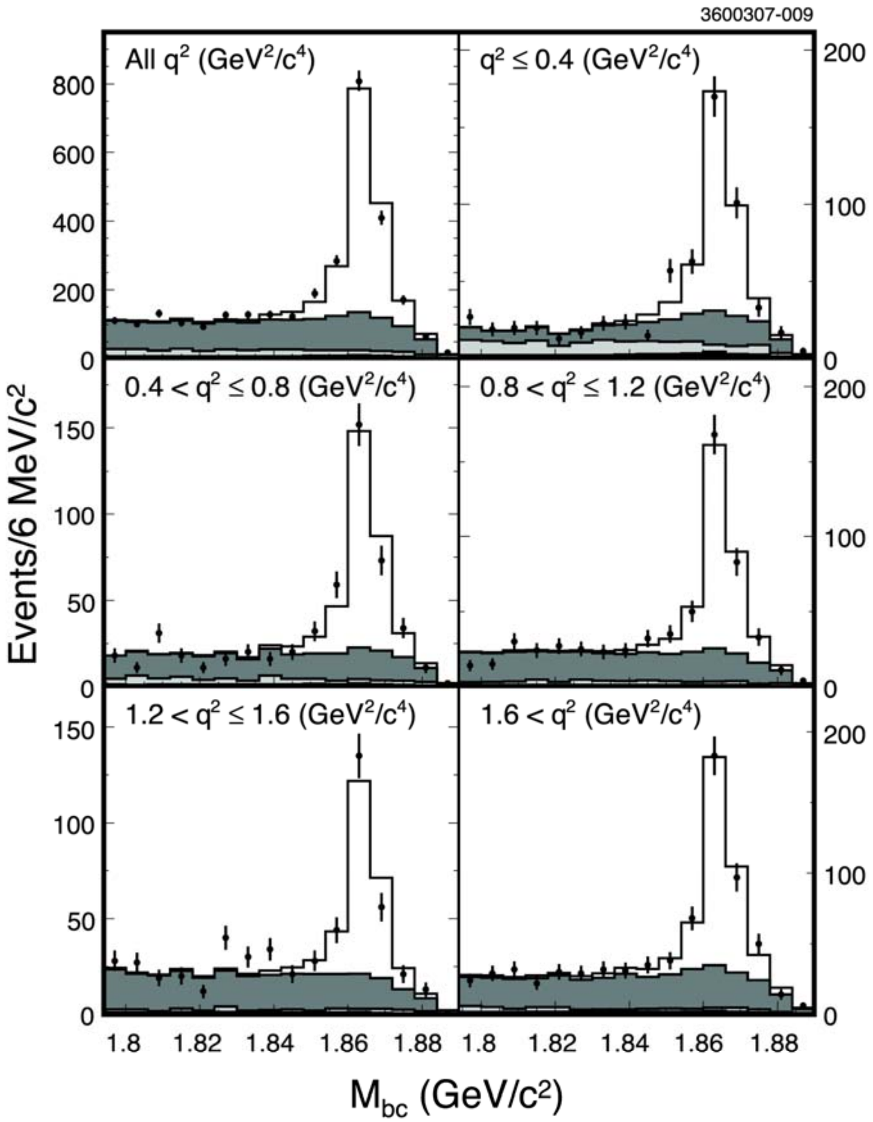
Curve courtesy Andreaas Kronfeld

ArXiv 0712.1020
ArXiv 0712.1025

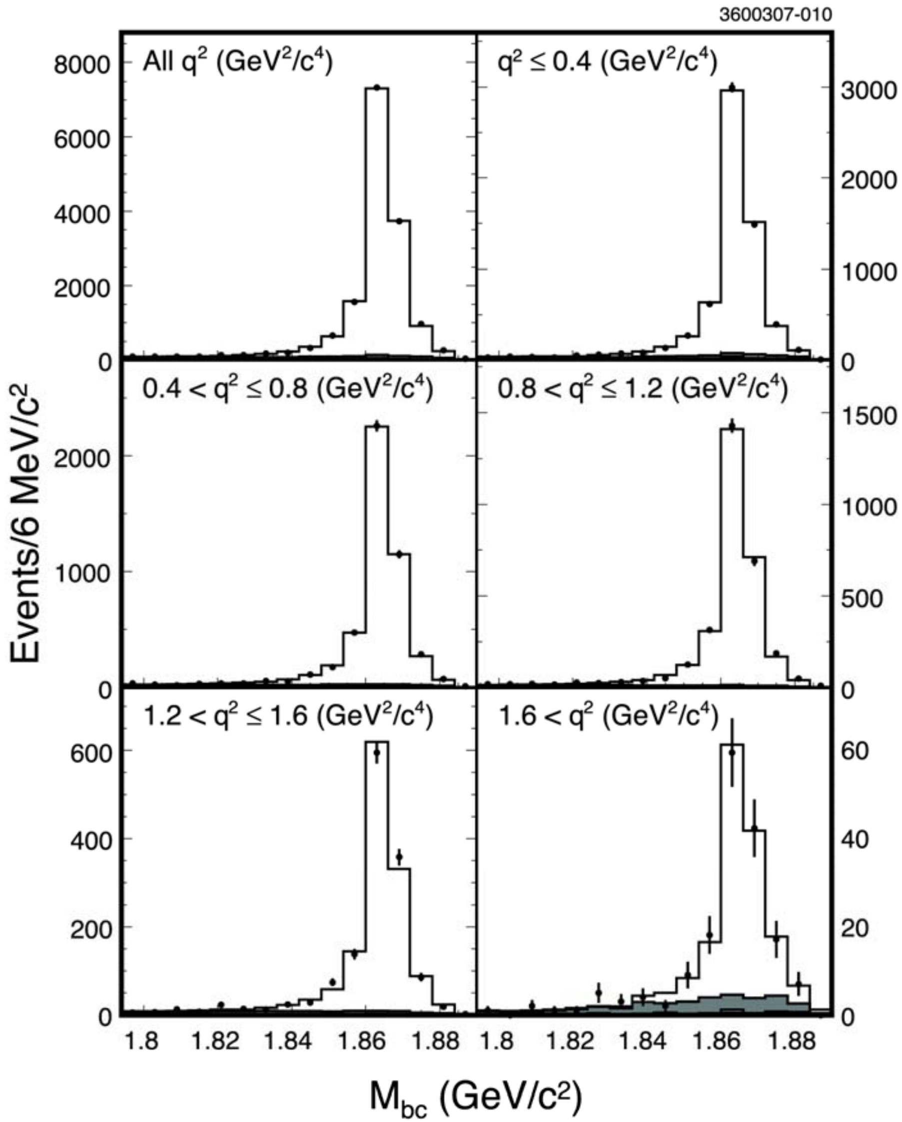
dB/dq^2

untagged analysis

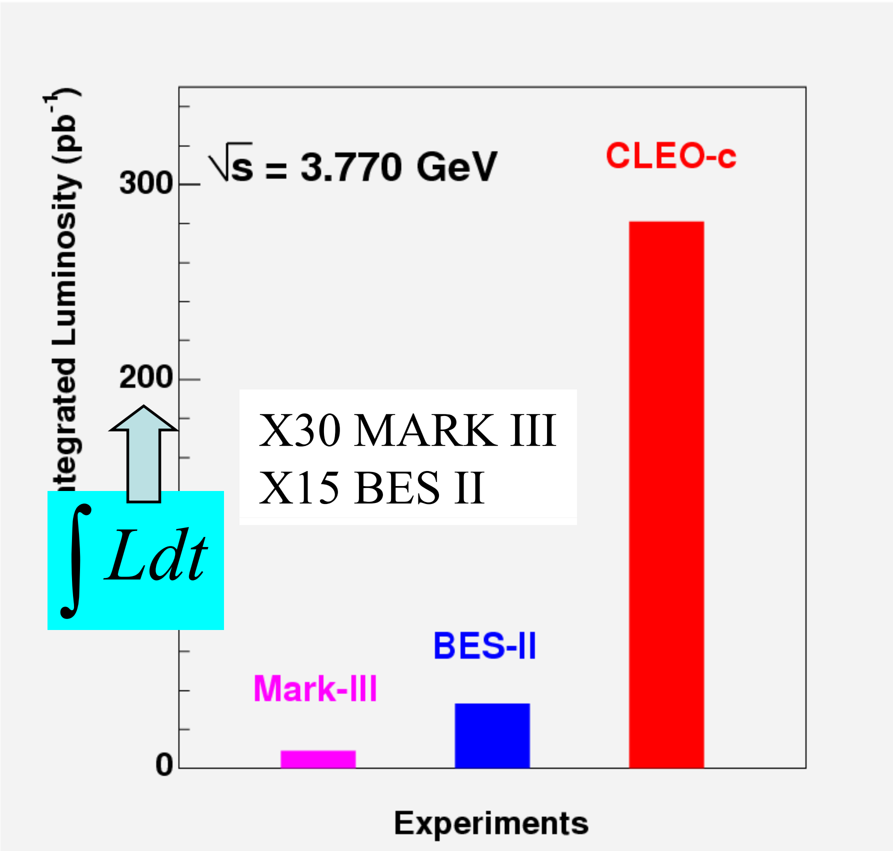
$D^0 \to \pi^- e^+ \nu$

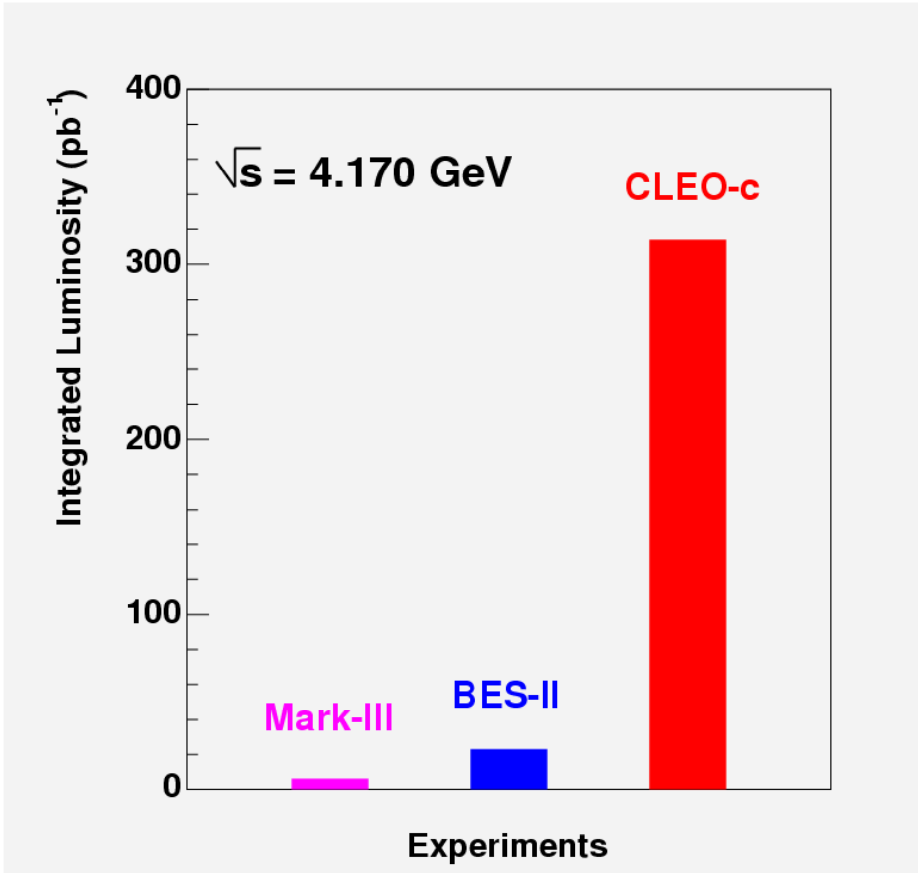


$D^0 \to K^- e^+ \nu$



World's largest data sets at charm threshold





$\psi(3770) \rightarrow D\overline{D}$

$281\ \text{pb}^{-1} = 1.8\times10^{6}\, D\overline{D}$

800 pb^{-1}collected

Results today

$4170 \rightarrow D_s^{*} D_S$

$314\ \text{pb}^{-1} \sim 3\times10^{5}\, D_s^{*} D_S$

expect to collect ~ 600pb^{-1}

Comparison to other measurements $D^0 \to K^- \pi^+$

BABAR use B partial reconstruction

$$B \to D^{*+} \ell \nu,\ D^{*+} \to D^0 \pi^+$$

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

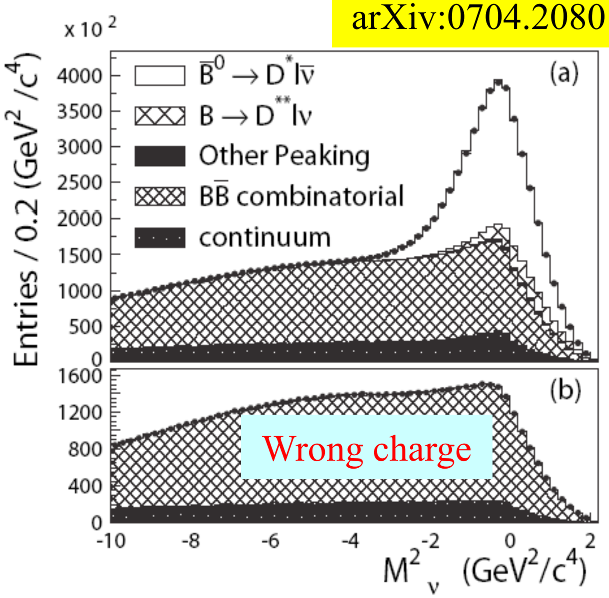
compare to

$$\ell \pi^+,\ D^0 \to unobserved$$

$\mathcal{B}$ (%)	Error(%)	Source
3.82±0.07±0.12	3.6	CLEO
3.90±0.09±0.12	3.8	ALEPH
3.80 ±0.09	2.4	PDG04
3.891±0.035 ±0.069	2.0	CLEO-c
4.007 ±0.037 ±0.070	2.0	BABAR

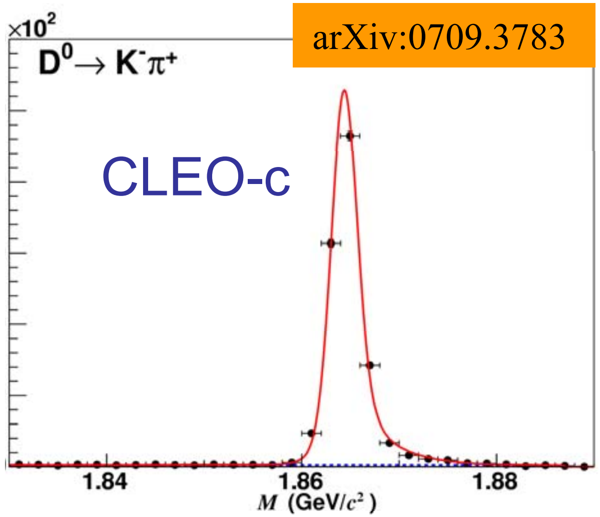
Systematics limited 2%

arXiv:0704.2080

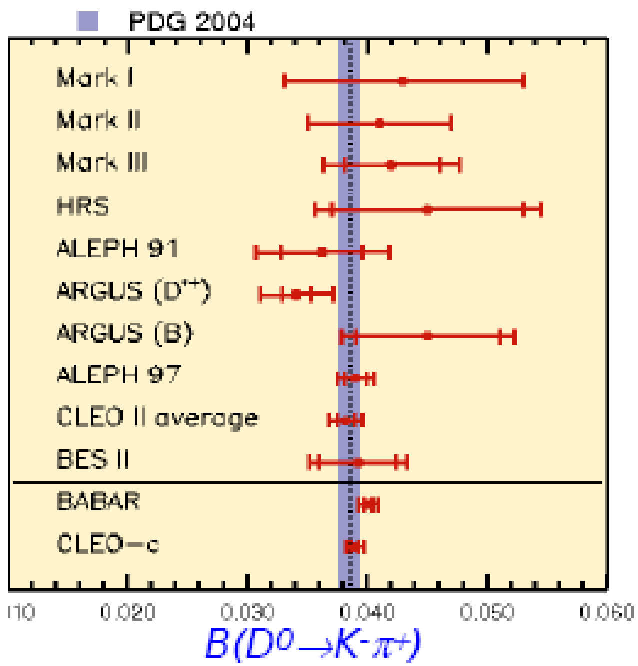


BABAR must know background shapes well

arXiv:0709.3783



CLEO-c (not in PDG04 average)



New Physics Possibilities II

- Leptonic decay rate is modified by $H^{\pm}$
- Can calculate in SUSY as function of m_q/m_c
- In 2HDM predicted decay width is x by

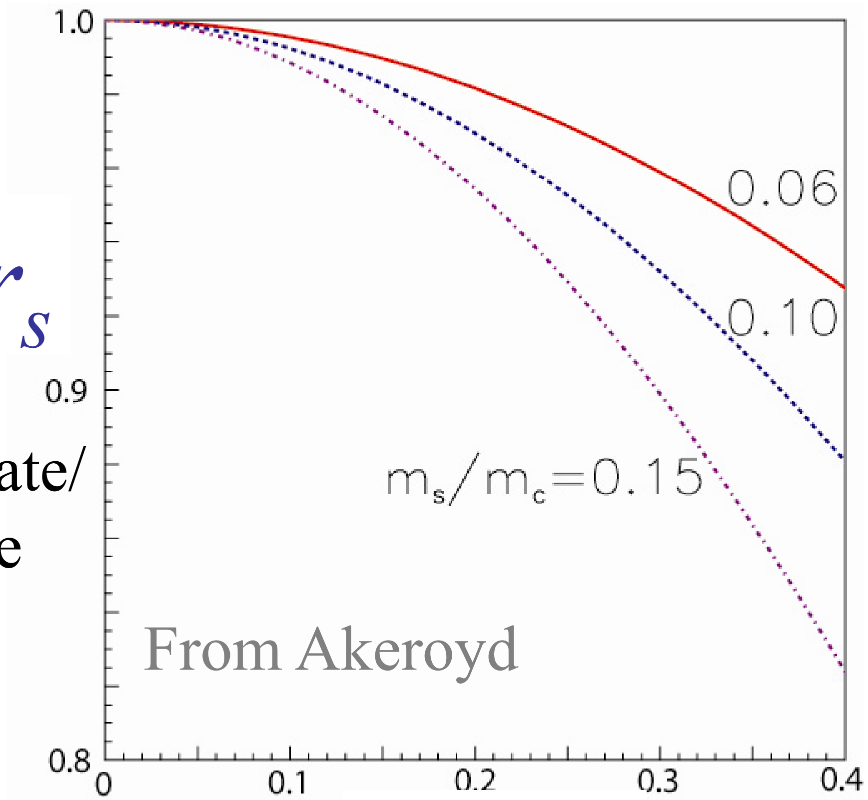
$$r_q = \left[1 - M_D^2 \left(\frac{\tan\beta}{M_{H^{\pm}}} \right)^2 \left(\frac{m_q}{m_c + m_q} \right) \right]^2$$

Since m_d is ~0, effect can be seen only in D_s

Akeryod [hep-ph/0308260]

r_s

Meas rate/ SM rate



$\tan\beta/m_H$

$D^+ \to \tau^+\nu, \tau^+ \to \pi^+\nu$

D^- tag + single π track

two ν : use intermediate MM^2 region

event yields consistent

BR(D⁺→ τ⁺ ν

In SM:

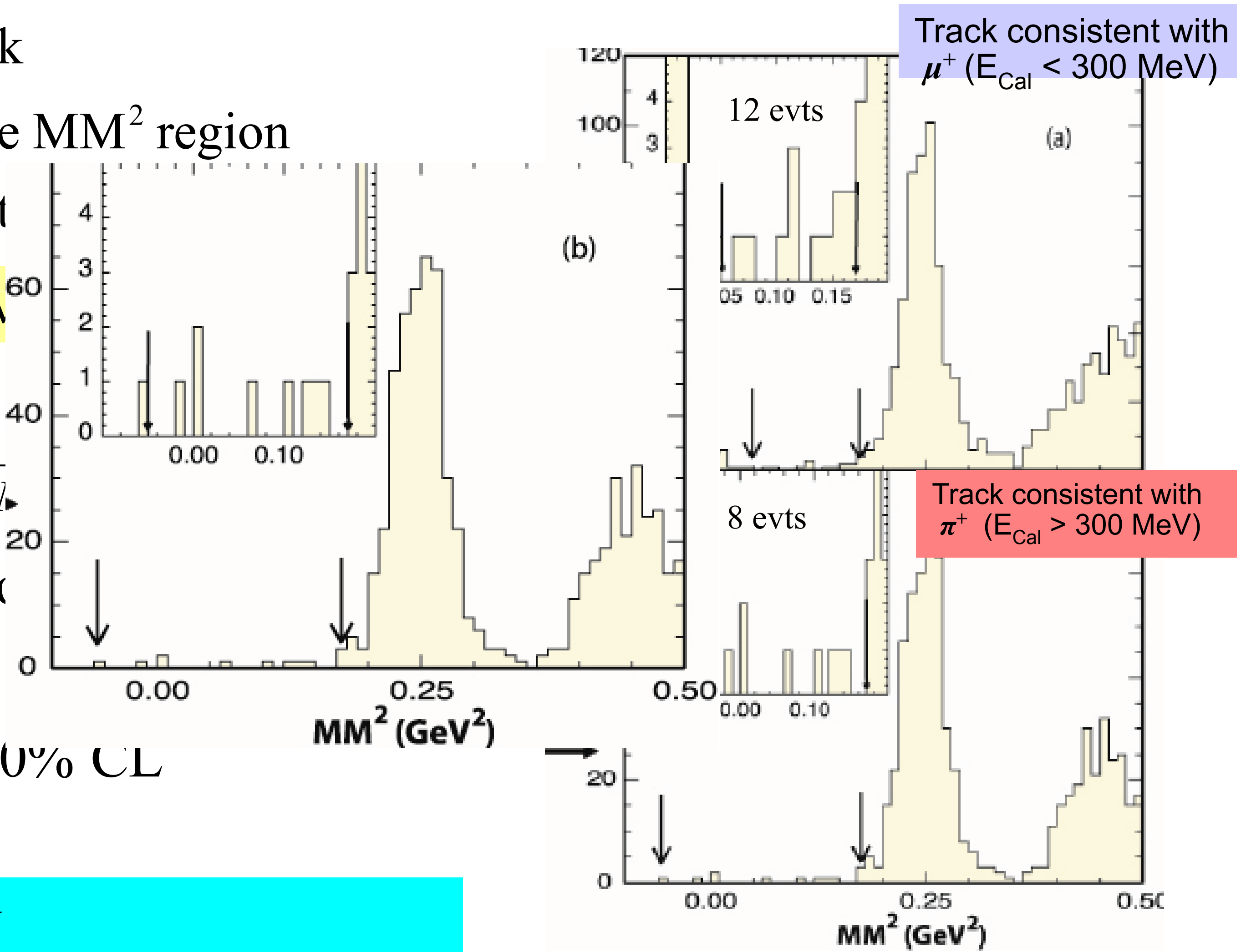
$$R = \frac{\Gamma(D^+ \to \tau^+\nu)}{\Gamma(D^+ \to \mu^+\nu)} = m_\tau^2 \left(1 - \right.$$

& our measurement o

we find

$R_{CLEO} / R_{SM} < 1.8$ at 90% CL

First measurement of R



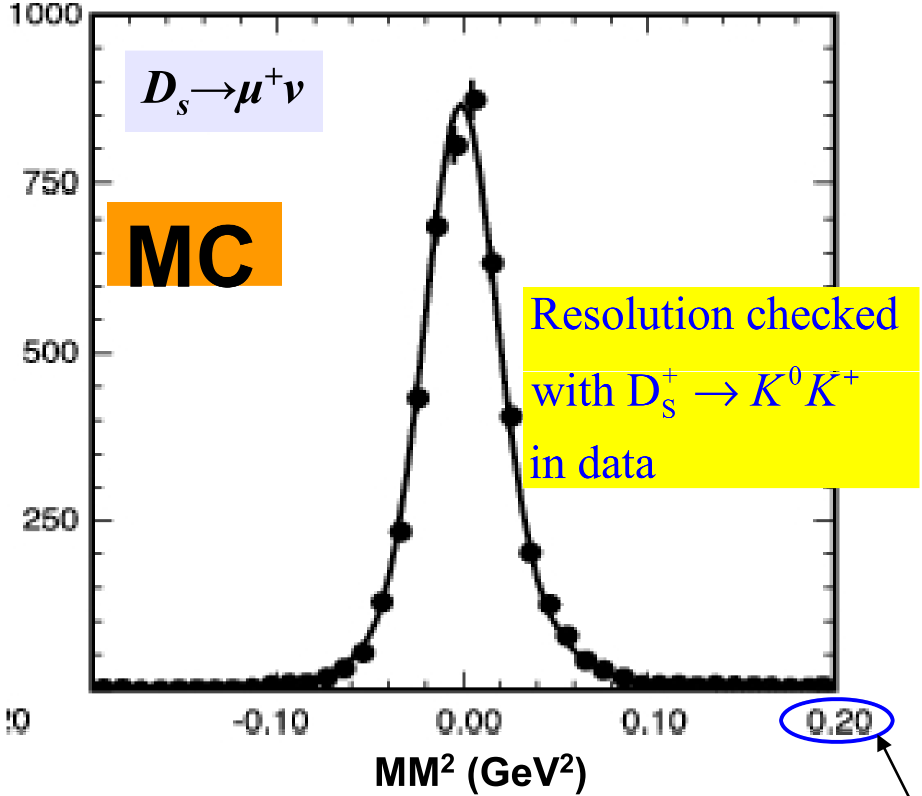
PRD73 112005 (2006)

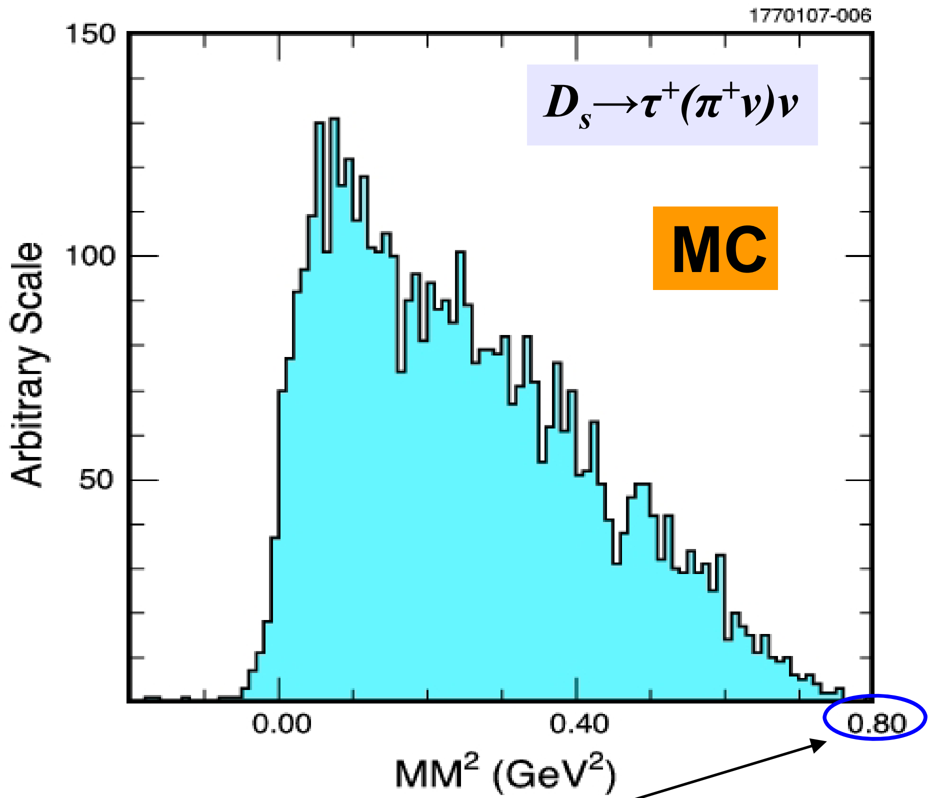
➔ lepton universality
in purely leptonic *D* decays is satisfied at the level of current experimental accuracy.

$D_s \rightarrow \mu^+ \nu$ and $\tau^+(\pi^+\nu)\nu$

- Require one additional track and no extra shower in CC with > 300 MeV
- Calculate missing mass in the event to infer the neutrino(s):

$$MM^2 = (E_{CM} - E_{D_S-tag} - E_\gamma - E_{\mu(\pi)})^2 - (-\vec{p}_{D_S-tag} - \vec{p}_\gamma - \vec{p}_\mu)^2$$





Note different scale

Comparison with theory

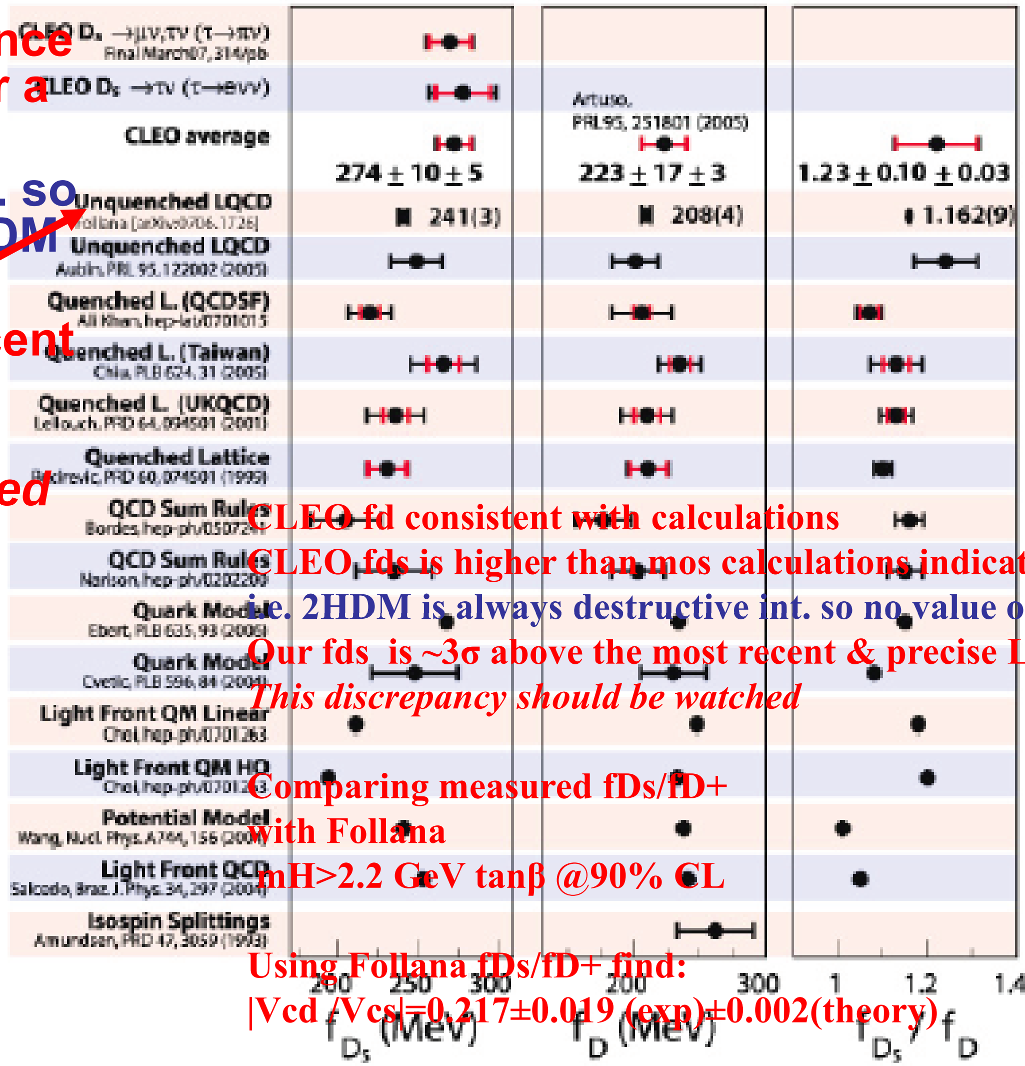
CLEO fd consistent with calculations

CLEO fds is higher than mos calculations indicating an absence of the suppression expected for a H+

i.e. 2HDM is always destructive int. so no value of M_H is allowed in 2HDM @99.5% CL

Our fds is ~3σ above the most recent & precise LQCD calculation (Follana) HPQCD.

This discrepancy should be watched



CLEO fd consistent with calculations
CLEO fds is higher than mos calculations indicating a
i.e. 2HDM is always destructive int. so no value of MH
Our fds is ~3σ above the most recent & precise LQCD
This discrepancy should be watched
Comparing measured fDs/fD+
with Follana
mH>2.2 GeV tanβ @90% CL
Using Follana fDs/fD+ find:
|Vcd /Vcs|=0.217±0.019 (exp)±0.002(theory)

Comparing measured fDs/fD+ with Follana

m_H>2.2 GeV tanβ @90% CL

Using Follana fDs/fD+ find:

$|V_{cd}/V_{cs}|=0.217\pm0.019$ (exp)±0.002(theory)

$D \to K/\pi e^+ \nu$ without tagging

Preliminary results FPCP 2006

- 1st presentation of final results this talk

ArXiv 0712.1020 and 0712.1025

$P_\nu \equiv P_{miss} = P_{event} - P_{visible}$

$q^2 = (P_e + P'_{miss})^2$

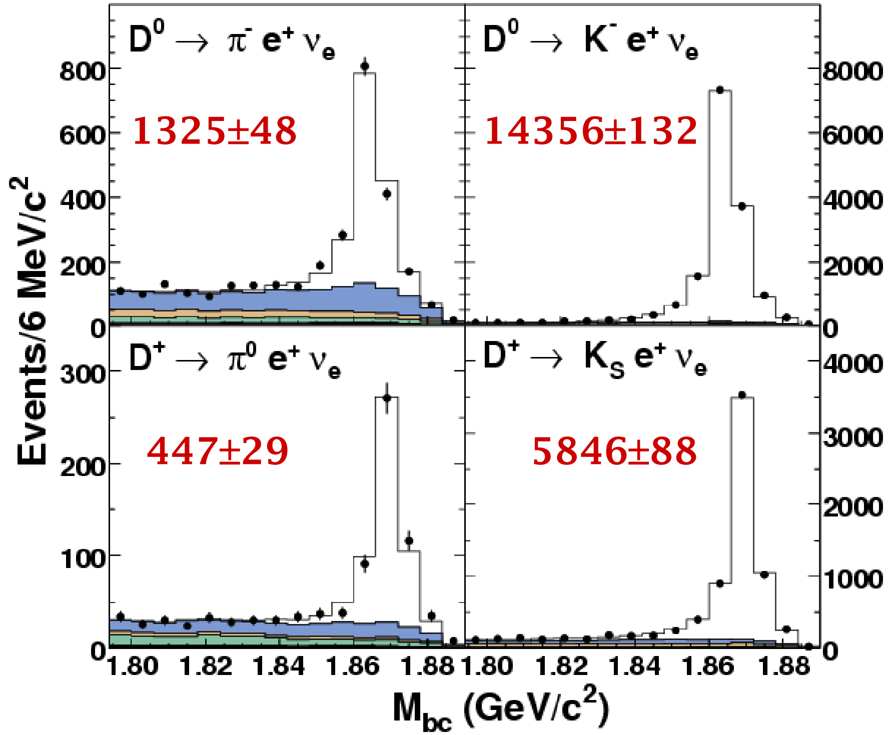
$P'_{miss} = \beta P_{miss}$ (β gives $\Delta E = 0$)

$\Delta E = E_K + E_e + |\mathbf{p}_{miss}| - E_{beam}$

$M_{bc} = \sqrt{E^2_{beam} - (\mathbf{p}_K + \mathbf{p}_e + \mathbf{p}'_{miss})^2}$

Untagged CLEO-c analysis:

[analogous to neutrino reconstruction @ Υ(4S)]



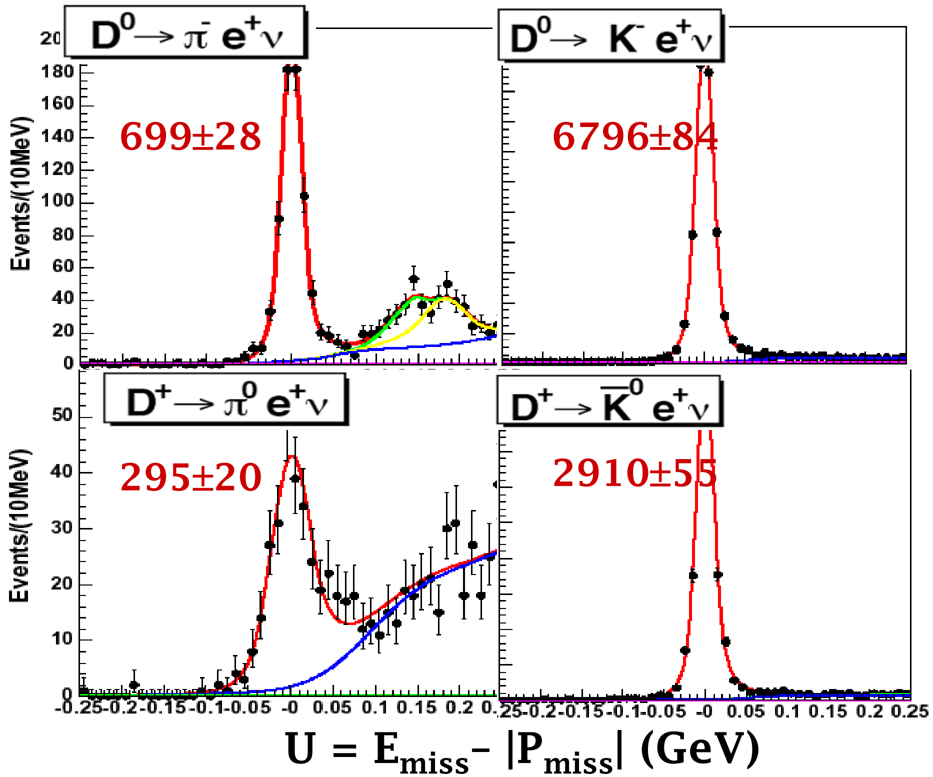
M_{bc} distributions fitted simultaneously in 5 q^2 bins to obtain $d(BF)/dq^2$. Integrate to get branching fractions

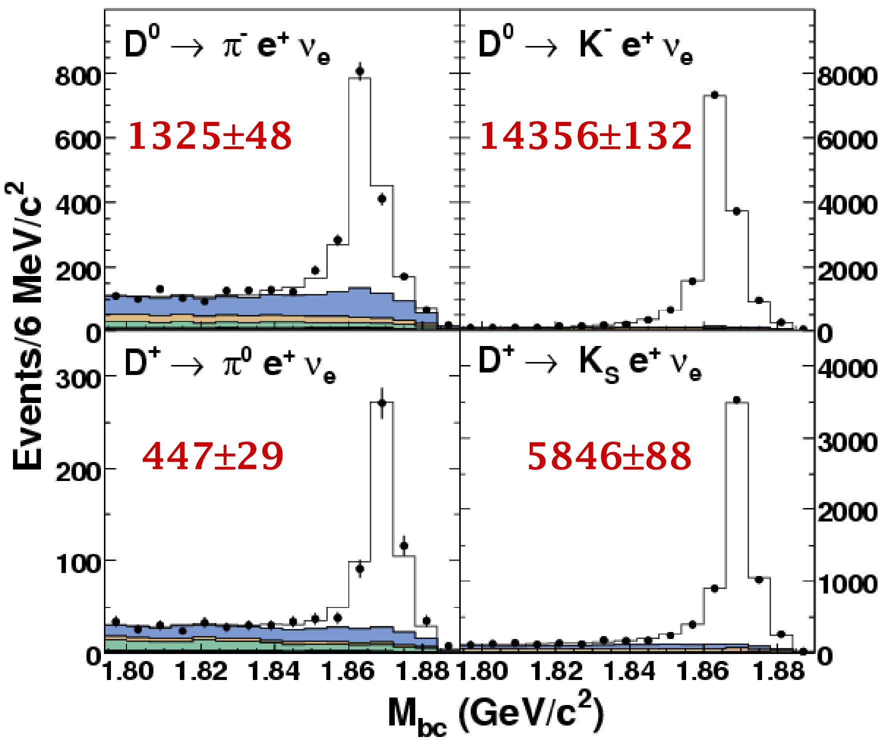
$D \to K / \pi e^+ \nu$ without tagging

1) Tagged CLEO-c analysis:
(preliminary ICHEP06 final results early '08)

2) Untagged CLEO-c analysis:
[analogous to neutrino reconstruction @ Υ(4S)]

ArXiv 0712.1020 and 0712.1025



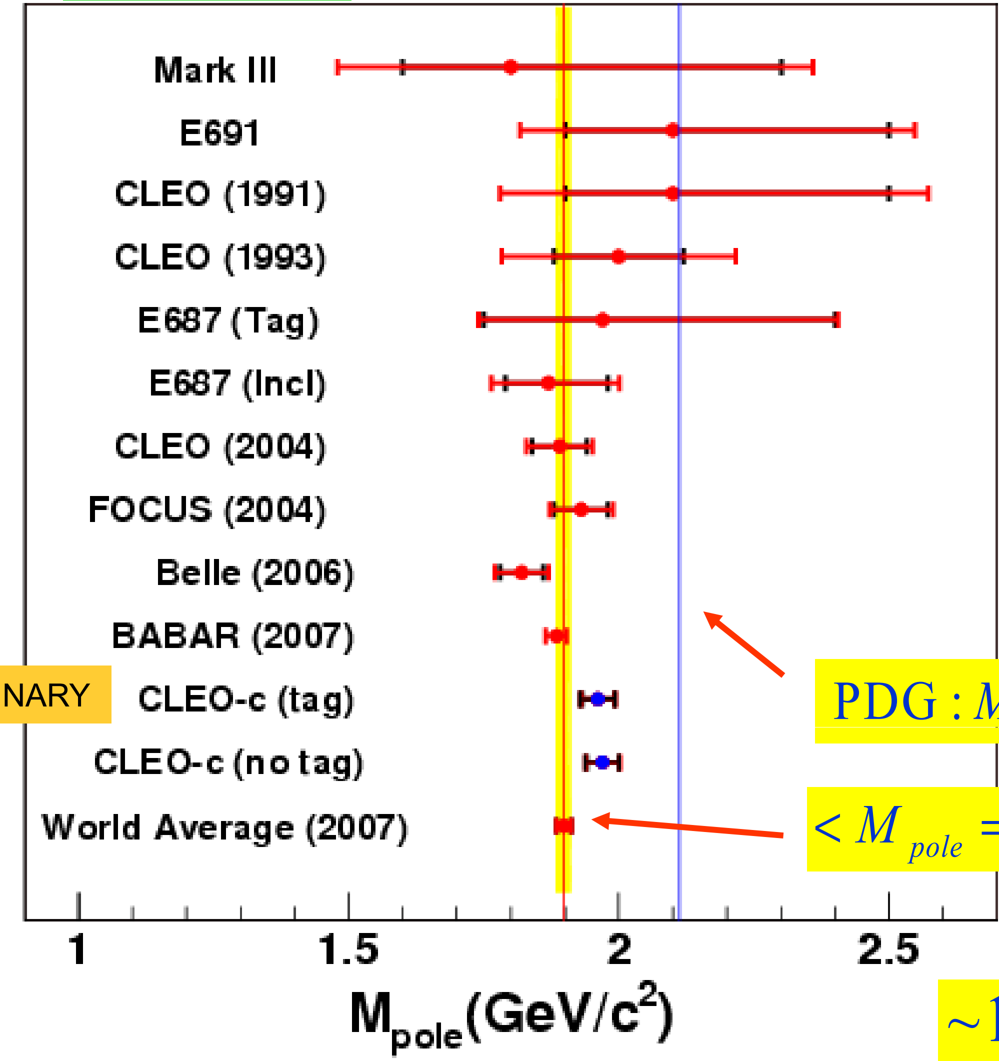


The untagged analysis has larger signal yields and larger backgrounds.

M_{pole}

$D \to K e^+$

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - q^2 / m^2_{pole}\right)}$$



pole model describes $D \to Ke\nu$
but not when the pole mass
is the spectrocopic pole $M(D_S^*)$

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

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

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

$\sim 14\sigma$ discrepancy

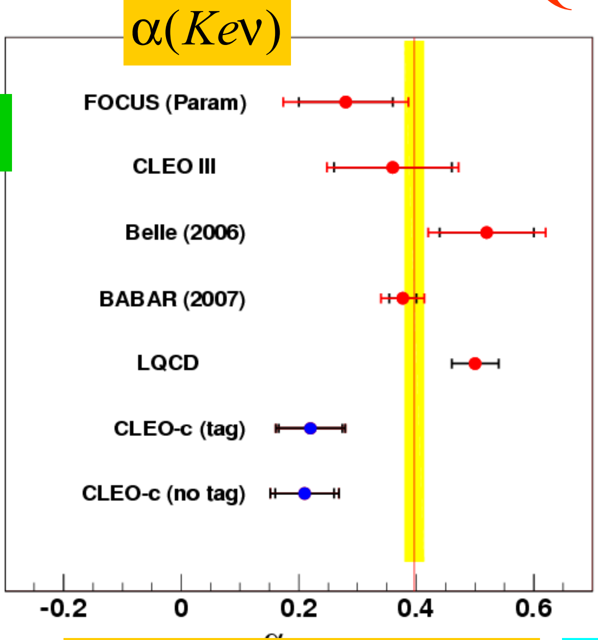
- CLEO-c 1st measurements of Mpole forr D^+ important consistency check
- BABAR most precise $D \to Ke^+\nu$

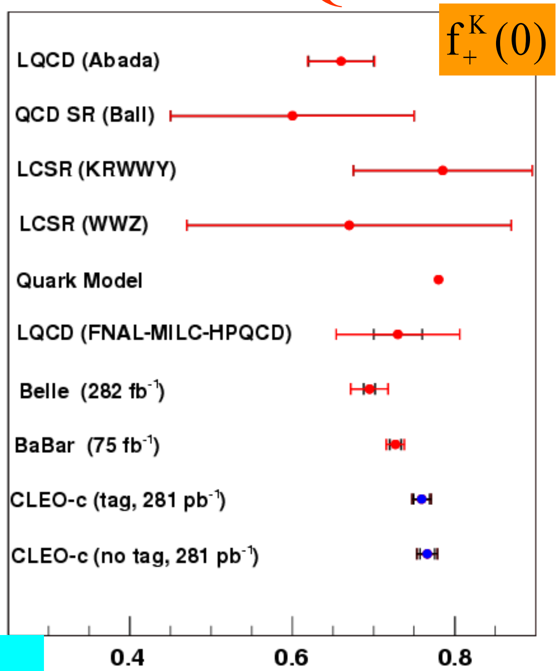
[CLEO-c no tag used in world average]

similar situation for $D \to \pi e \nu$
but limited statistics → more data

Test of LQCD FNAL-MILC-HPQCD

$D \to K e^+$





[CLEO-c no tag used in world average]

$\alpha(Ke\nu)$
0.22(5)(2) (tag)
0.21(5)(3) (no tag)
0.50(4) (syst.)(LQCD)
0.40(2) (my world avg)

BK paramterization
$\alpha \sim 1.75$
CLEO-c values
$\sim 27\sigma$ away

$f_+^K(0)$	
0.759(10)(7)	(tag)
0.766(9)(9)	(notag)
0.73(3)(7)	(LQCD)

Assuming V_{cs}=0.9745 (CKM Unitarity)

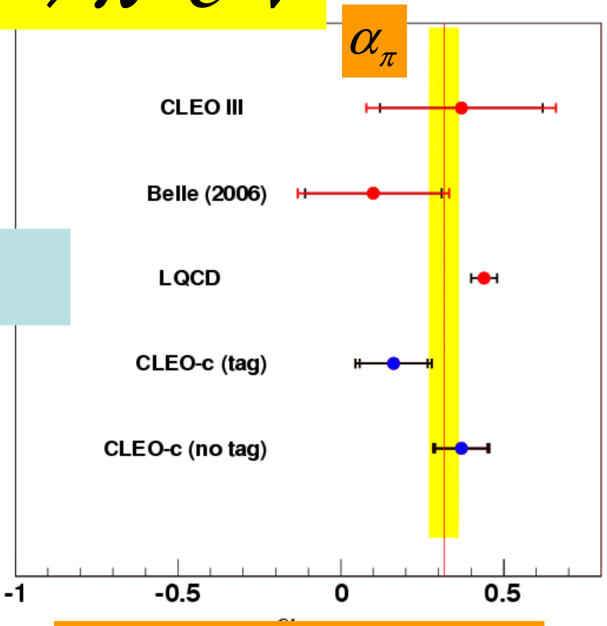
FNAL-MILC-HPQCD uses mod. pole model To fit for form factor from "calculated" points at fixed q^2

my world avg from combined fit to expt $f_+(q^2)$ distributions

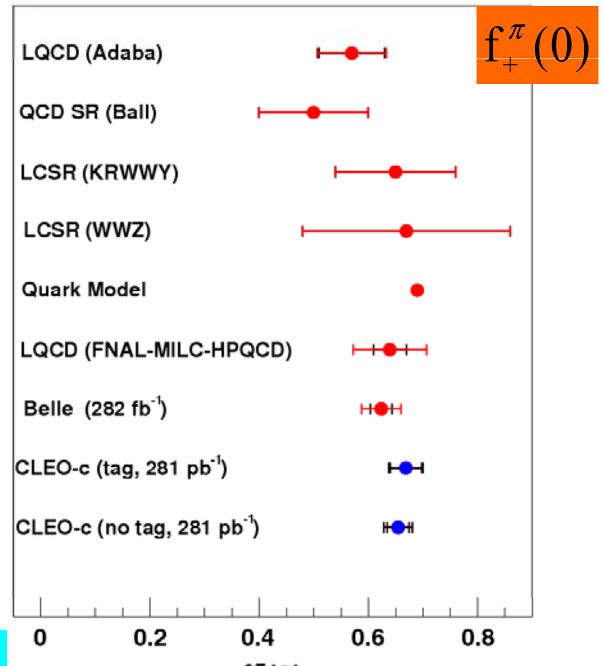
CLEO prefers smaller slope α
Normalization: experiments (2%) consistent with LQCD (10%)
Theoretical precision lags

$D^0 \to \pi^- e^+ \nu$

Test of shape *and* absolute normalization $f_+(q^2)$



FNAL-MILC-HPQCD



α_π

0.16(10)(5) CLEO tag

0.37(8)(3) CLEO no-tag

0.44(4)(syst.) LQCD

0.32(5) my avg.

BK paramterization

α ~ 1.75

CLEO-c values

~> 10σ away

$f_+^\pi(0)$

0.669(28)(11)(8) (tag)

0.625(31)(13)(8) (notag)

0.64(3)(6) (LQCD)

Shape: Experiments compatible with LQCD

Normalization: experiments (4%)

consistent with LQCD (10%) *Theoretical precision lags*

Assuming V_{cd} = 0.2238±0.0029 (CKM Unitarity)

Becher-Hill Parameterization

PRELIMINARY

Hill & Becher, Phys. Lett. B 633, 61 (2006)

*Physical basis of pole and modified pole models not supported by data

Becher-Hill adavantages: model independent,

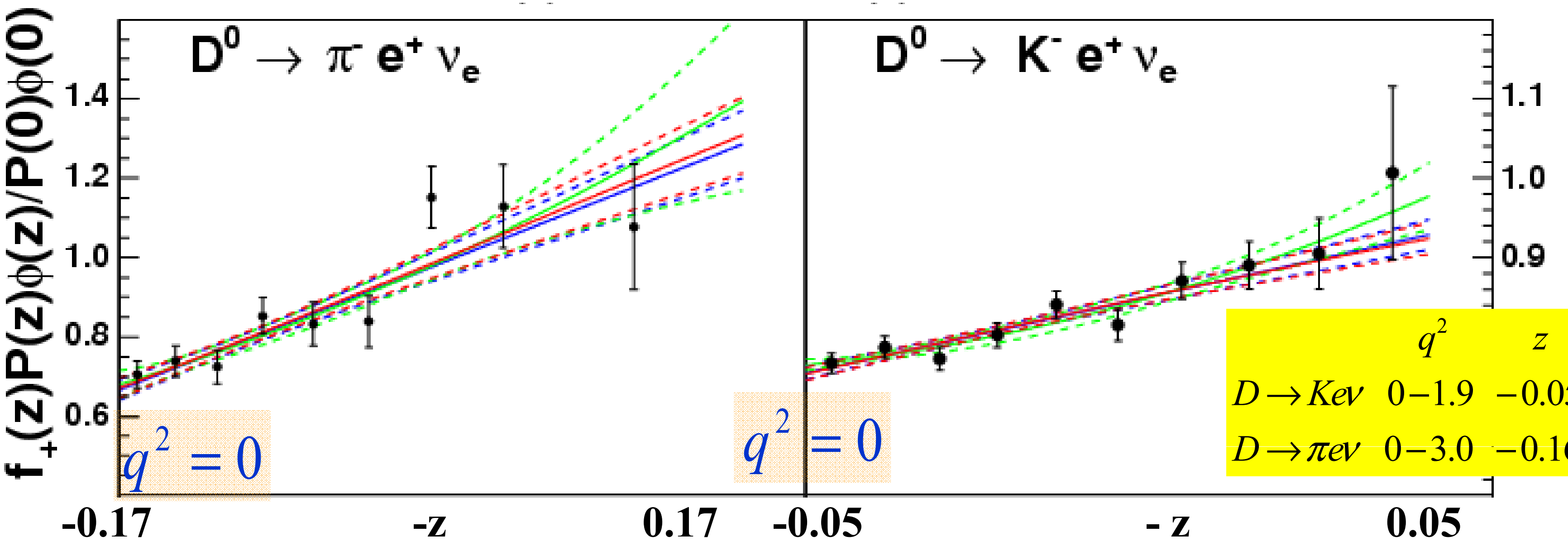
*shape variable "physically meaningful" slope at $q^2=0$

(1) Facilitates: future expt. test of LQCD (FNAL-MILC-HPCQD now using it) .

(2) D/B Measurements: the a_i in $D\rightarrow\pi$ constrain class of form factors needed to fit $B\rightarrow\pi$ hence improve determination of Vub

$$f_+(z) \propto f_+(0)[1+\frac{a_1}{a_0}z+\frac{a_2}{a_0}z^2]$$

(3) In HQET direct relations between a_i in D and B



	q^2	z
$D\rightarrow Kev$	0−1.9	−0.05−+0.05
$D\rightarrow \pi ev$	0−3.0	−0.165−+0.165

Parameterization describes data well Quadratic a_2 not well- determined with current statistics.

ArXiv 0712.1020
ArXiv 0712.1025

Form Factor Fit Plots

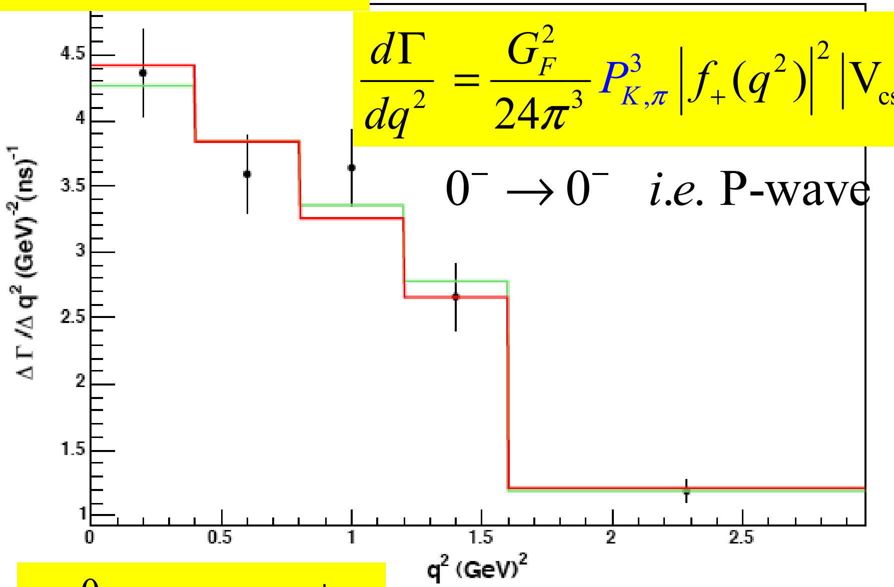
Simple pole $f_+(q^2) = \frac{f_+(0)}{(1 - q^2/m^2_{pole})}$

Modified pole $f_+(q^2) = \frac{f_+(0)}{(1 - q^2/m^2_{pole})(1 - \alpha q^2/m^2_{pole})}$

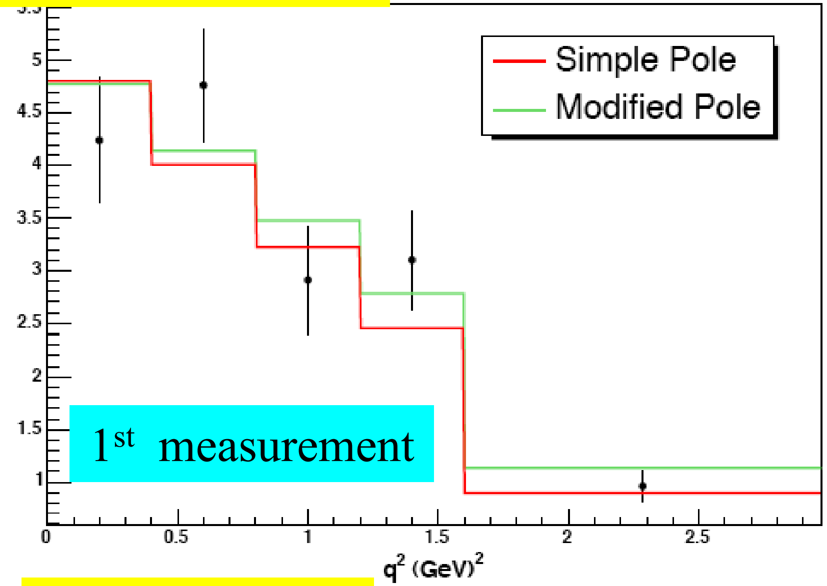
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} P^3_{K,\pi} \left|f_+(q^2)\right|^2 \left|V_{cs}\right|^2$$

$0^- \to 0^-$ *i.e.* P-wave

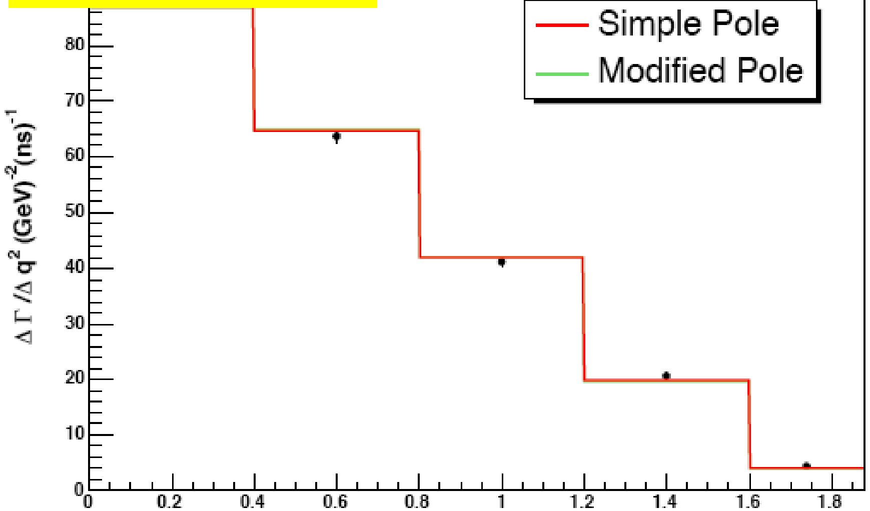
$D^0 \to \pi^- e^+ \nu$



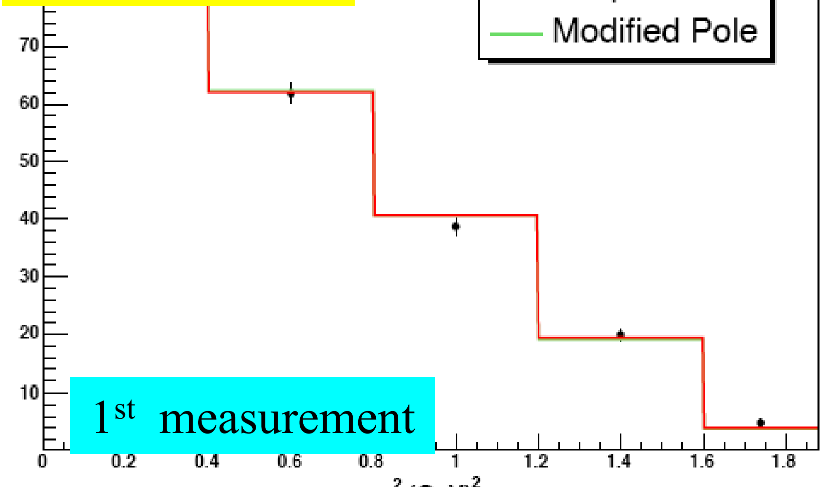
$(\times 2) D^+ \to \pi^0 e^+ \nu$



$D^0 \to K^- e^+ \nu$



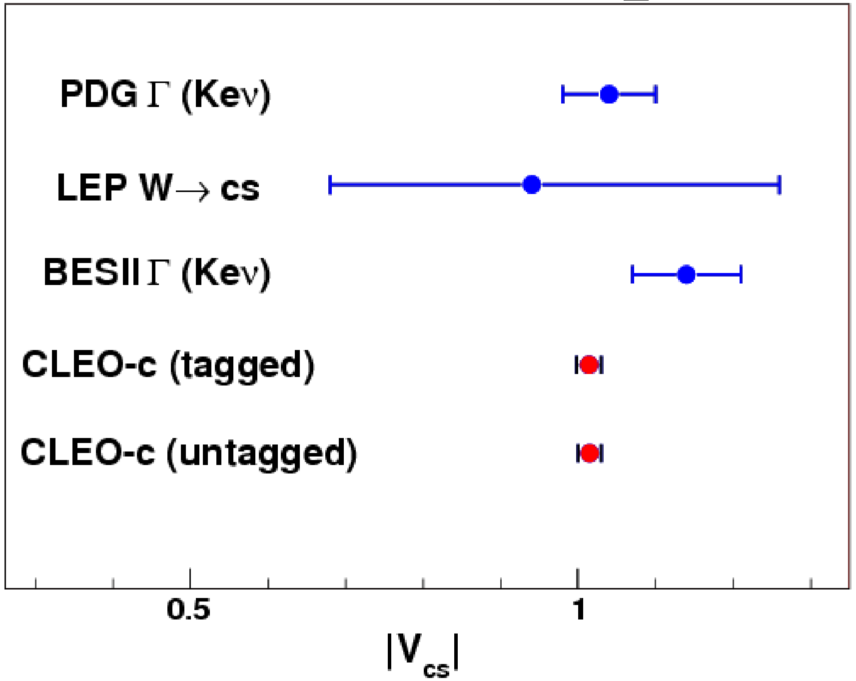
$D^+ \to \overline{K}^0 e^+ \nu$



Background subtracted efficiency corrected absolute $d\Gamma/dq^2$ distributions.

V_{cs} Result (if zero theory uncertainty)

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



Removing the dominant theoretical uncertainty stresses the experimental precision and underlines how eagerly we are awaiting new calculations from LQCD (expect LQCD df+(0)/f+(0) ~6% by Summer '08) and few % longer term

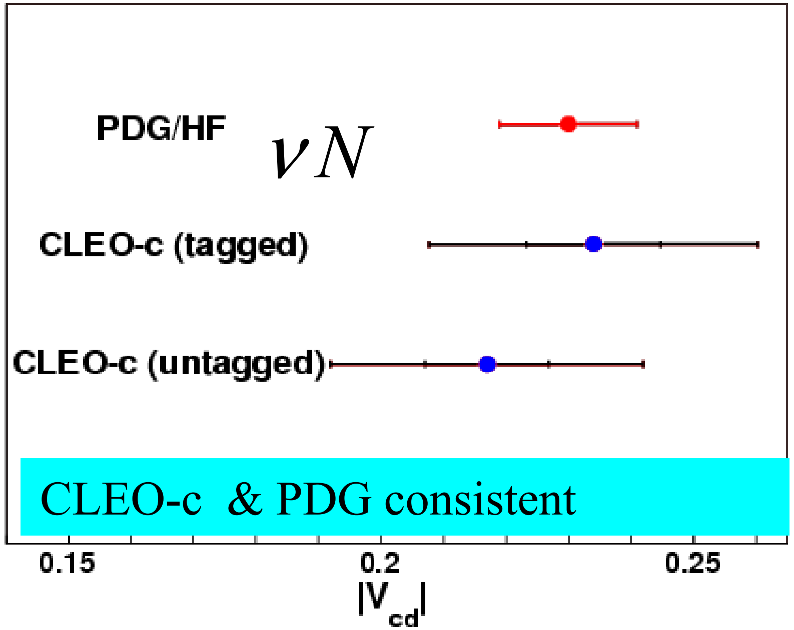
CLEO Full data set

$$D \to Ke^+\upsilon \quad \frac{\delta Vcs}{Vcs} = (0.9-1.2)\%\,(\exp) \oplus \frac{\delta f_+^{\pi}(0)}{f_+^{\pi}(0)}(\text{thy})$$

(Projection: Shipsey @ LQCD meet Expt Workshop 12/2007)

V_{cd} Result

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



CLEO − c	V_{cd}
(tagged)	$0.234 \pm 0.010 \pm 0.004 \pm 0.024$
(untagged)	$0.217 \pm 0.009 \pm 0.004 \pm 0.023$
	stat syst theory

Tagged/untagged consistent, 40% overlap
DO NOT AVERAGE

	V_{cd}	Uncertainty (%)
PDG $\nu d \rightarrow cu$	0.22 ± 0.011	5%
CLEO − c	$0.217 \pm 0.10 \pm 0.024$	$4.5\% \oplus 11.1\%$

(expect LQCD df+(0)/f+(0) ~6% by Summer '08) and few % longer term

CLEO-c: dominant uncertainty LQCD
νN remains most precise determination (*for now)*

CLEO Full data set

$$D \rightarrow \pi e^+ \upsilon \quad \frac{\delta Vcd}{Vcd} = (2.3-3.5)\%\ (\text{exp}) \oplus \frac{\delta f_+^{\pi}(0)}{f_+^{\pi}(0)}\ (\text{thy})$$

(Projection: Shipsey @ LQCD meet Expt Workshop 12/2007)

More Lattice checks: f_D & semileptonic form factors

A quantity independent of Vcd allows a CKM independent lattice check:

Experiment

$$R_{\ell sl} \equiv \sqrt{\frac{\Gamma(D^+ \to \mu\upsilon)}{\Gamma(D \to \pi\ell\upsilon)}} \propto \frac{f_D}{f_+^\pi(0)} \frac{V_{cd}}{V_{cd}}$$

Lattice

$$R_{\ell s\ell}^{th} = 0.212 \pm 0.028$$

(CLEO): $R_{\ell s\ell}^{\exp} = 0.237 \pm 0.019$ ← ~8% uncertainty

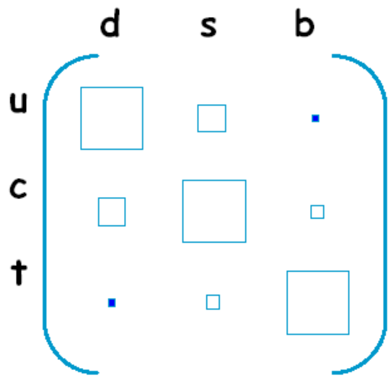
Theory & data consistent within large uncertainties

With $0.8 fb^{-1}$ @ $\psi(3770)$ R_{lsl}^{exp} ~5% uncertainty

Tested lattice for exclusive Vub determination at B factories

Unitarity Tests Using Charm

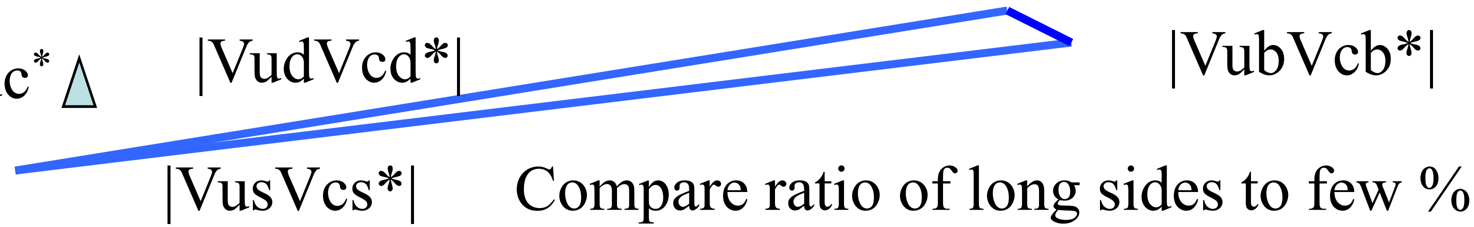
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



$uc^{*}=0$

- 2^{nd} row: $|Vcd|^2 + |Vcs|^2 + |Vcb|^2 = 1$?? (can only be tested with *direct* determination of each element)
  CLEO-c now: $1- \{|Vcd|^2 + |Vcs|^2 + |Vcb|^{2\}} = 0.012 \pm 0.181$
  Could be tested *now* to few% (if theory was good to few %)
  As Vcd precision improves 1^{st} column:
  $|Vud|^2 + |Vcd|^2 + |Vtd|^2 = 1$?? similar precision to 1^{st} row

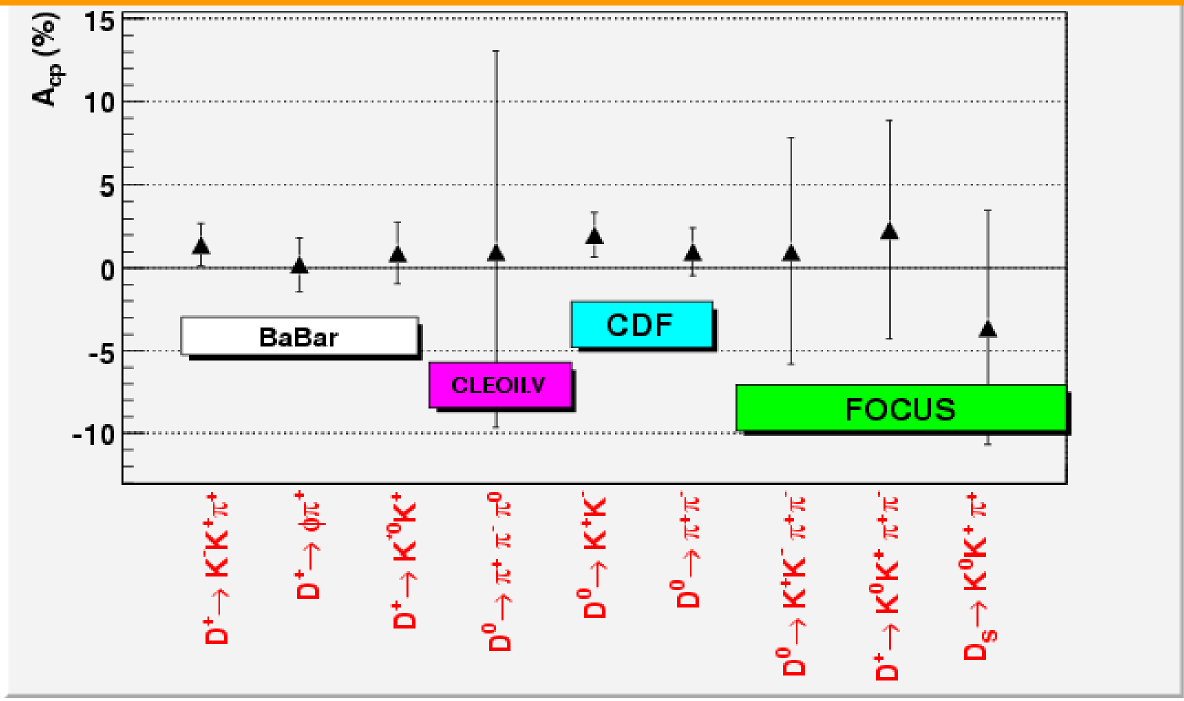
- uc^{*} Δ



Compare ratio of long sides to few %

Searches for CP violation in *D* decays

3 types (1) mixing, (2) decay amplitude (direct) or interference between (1) & (2) Small D mixing ➔ best bet direct CP violation
In SM only possible in singly Cabibbo suppressed decays.
(A_{CP} ~0.001 SM, larger NP). Direst CPV so time independent: event counting. Many limits from CDF/FOCUS/CLEOII/BABAR/BELLE some of the recent ones are shown here typical limits A_{CP} <~1%)



Note: if CP violation seen in Doubly Cabibbo suppressed or Cabibbo favored D decays it would be a clear indication of new physics