Leptonic decays of Charm mesons

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(CLEO collaboration)

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Hyperons, Charm And Beauty Hadrons
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University of Lancaster, England.

Physics goals

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}.

Leptonic decays are just one part of extensive analysis including semi leptonic decays (See talk of Doris Kim this conference)

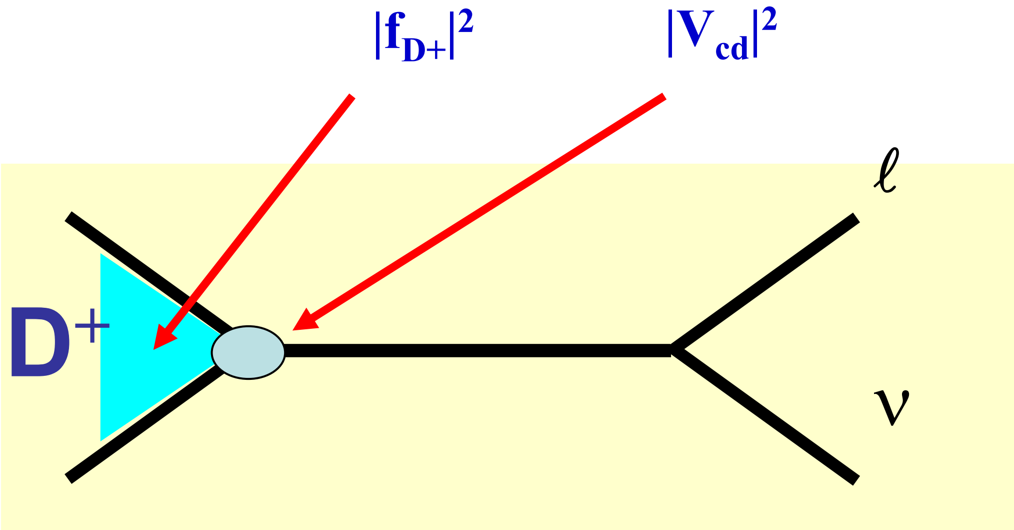
This talk

Leptonic decays of the D^+ and D_s

- $D^+ \rightarrow \mu^+ \nu$ Mark III and BES II
- $D^+ \rightarrow \mu^+ \nu$ CLEO-c
- $D^+ \rightarrow e^+ \nu$ CLEO-c
- $D^+ \rightarrow \tau^+ \nu$ CLEO-c
- $D_s^+ \rightarrow \mu^+ \nu$ BaBar
- $D_s^+ \rightarrow \varphi \pi$ (importance for f_{Ds})
- $B^+ \rightarrow \tau^+ \nu$ Belle

Recent talks on D and D_s decays CHARM 2006, FPCP 2006

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

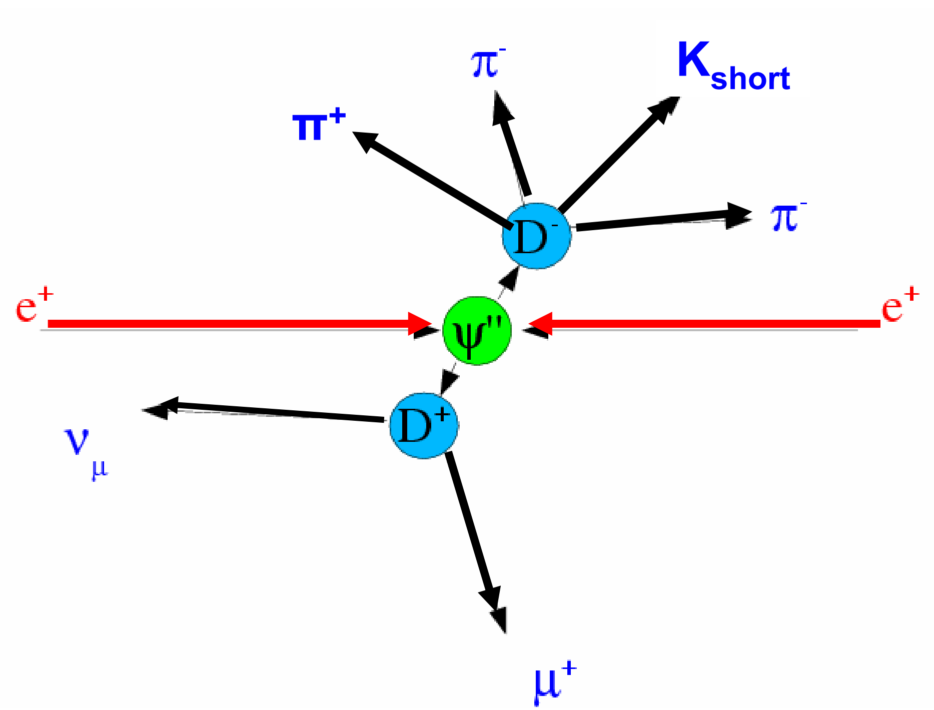


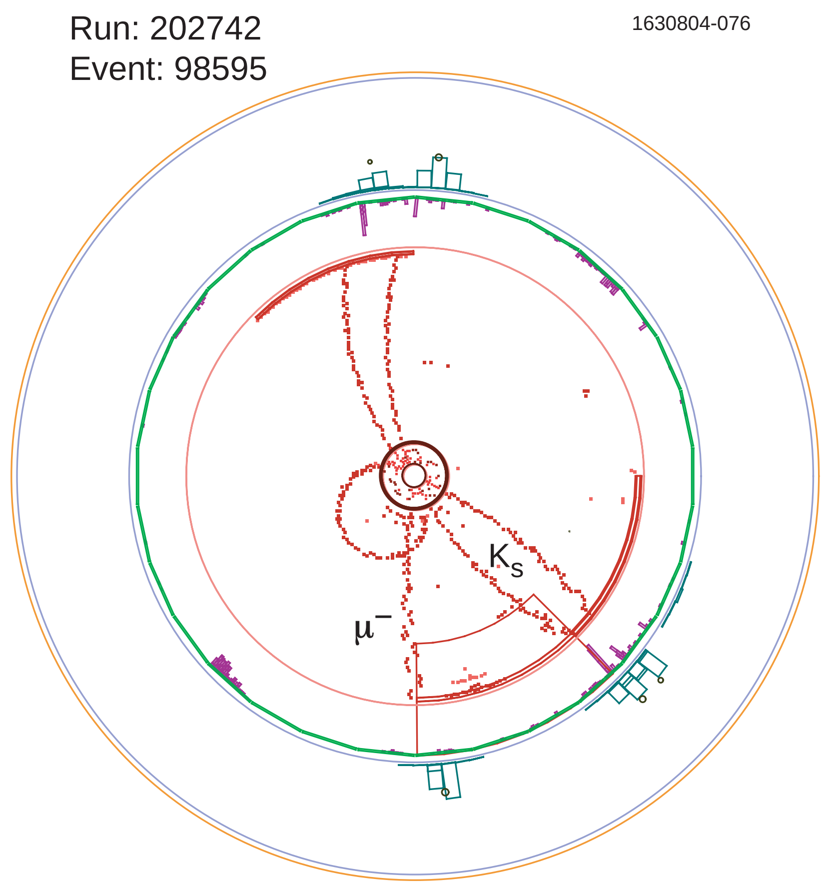
V_{ud}	V_{us}	V_{ub}
$\pi \to l\nu$	$K \to \pi l\nu$	$B \to \pi l\nu$
V_{cd}	V_{cs}	V_{cb}
$D \to \pi l\nu$	$D \to K l\nu$	$B \to D^{(*)} l\nu$
$D \to l\nu$	$D_s \to l\nu$	
V_{td}	V_{ts}	V_{tb}
$\langle B_d \vert \overline{B}_d \rangle$	$\langle B_s \vert \overline{B}_s \rangle$	

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

Hadronic Tagging

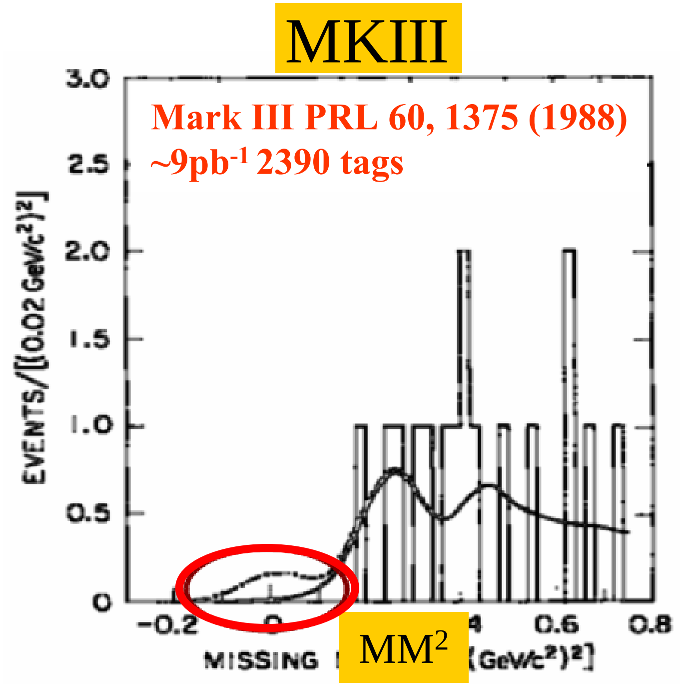
All the analyses use $e^+ e^- \rightarrow c\bar{c}$ **and fully reconstruct a hadronic decay (the tag) and then analyze the recoil decay to isolate the leptonic decay**

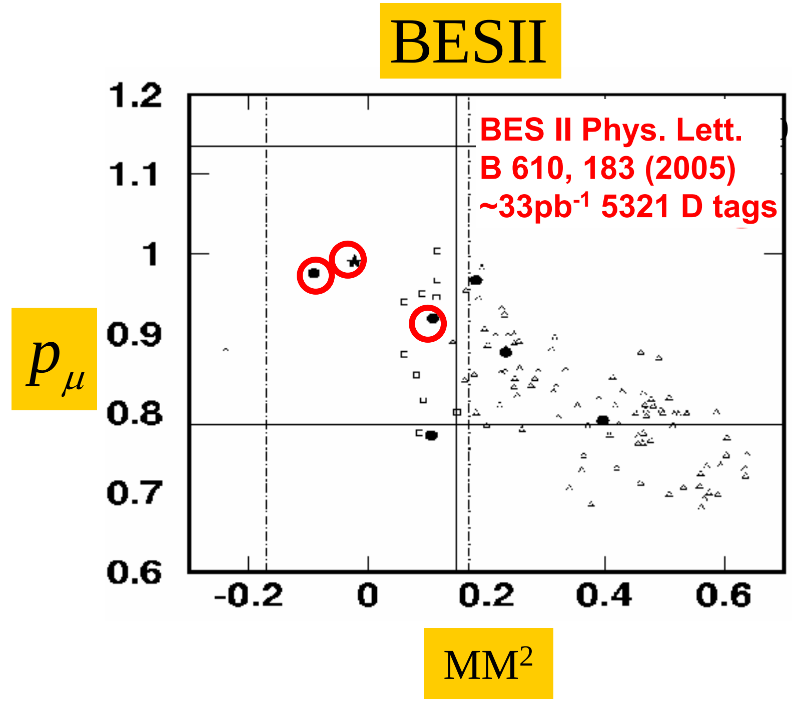




$K_S\pi^-\pi^+\pi^+$ Tag

Mark III and BES II $D^+ \to \mu^+ \nu$



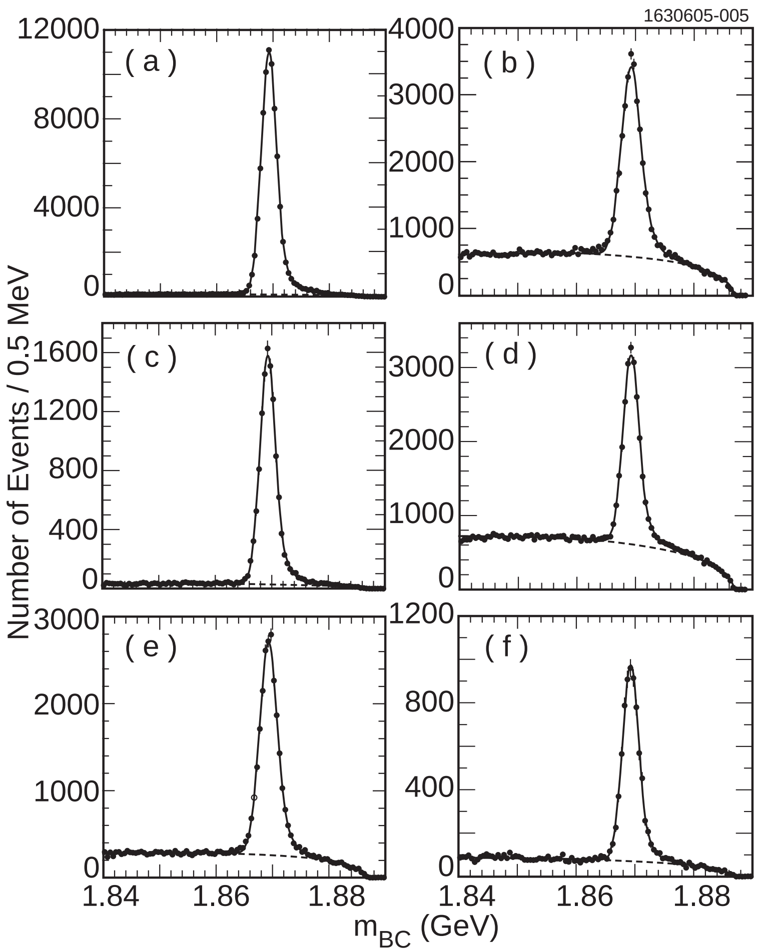


	$B(D^+ \to \mu\nu)\times 10^{-4}$	f_D MeV
MkIII	< 7.2	< 290
BESII	$12.2^{11.1}_{-53} \pm 0.11$	$371^{+129}_{-119} \pm 25$

CLEO-c $D^+ \to \mu^+ \nu$, $D^+ \to e^+ \nu$, $D^+ \to \tau^+ \nu$

- The goal of the CLEO-c program is to provide precision measurements of charm decays
- 281pb^{-1} at the Ψ(3770) taken just above $D\bar{D}$ threshold
- 200pb^{-1} taken at 4170 MeV to maximize D_s production
- 100pb^{-1} scheduled at 4170 MeV July/August, 2006
- 30 million ψ(2S) decays scheduled August/Sept
- November 2006 – March 2008 increase the 3770 and 4170 data samples to > 0.75fb^{-1}

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



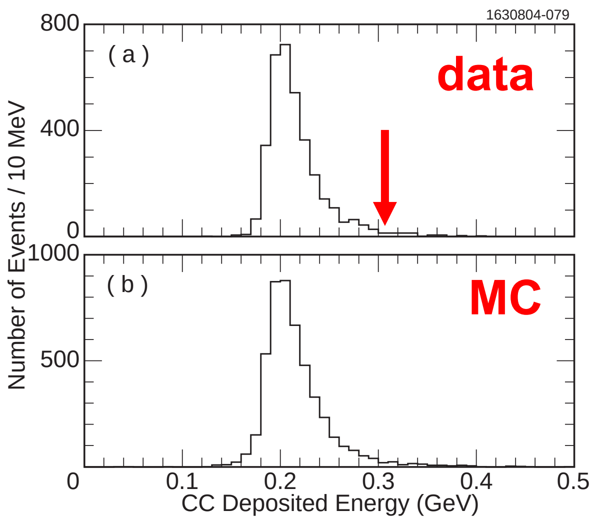
$$M_{BC} = \sqrt{E_{\mathbf{beam}}^2 - |p(D)|^2}$$

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

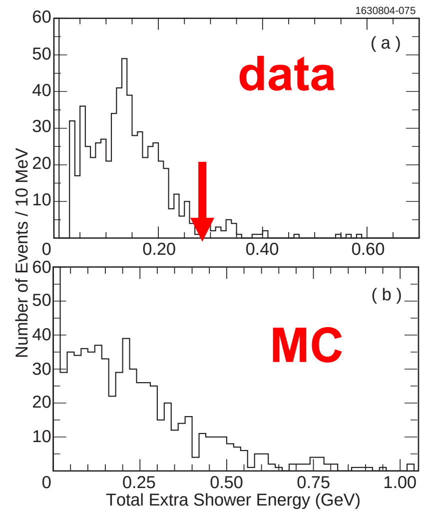
Mode	Signal	Background
$K^+\pi^-\pi^-$	77387 ± 281	1868
$K^+\pi^-\pi^-\pi^0$	24850 ± 214	12825
$K_S\pi^-$	11162 ± 136	514
$K_S\pi^-\pi^-\pi^+$	18176 ± 255	8976
$K_S\pi^-\pi^0$	20244 ± 170	5223
$K^+K^-\pi^-$	6535 ± 95	1271
Sum	158354 ± 496	30677

Event selection for $D^+\to\mu^+\nu$

Muon deposited energy in calorimeter



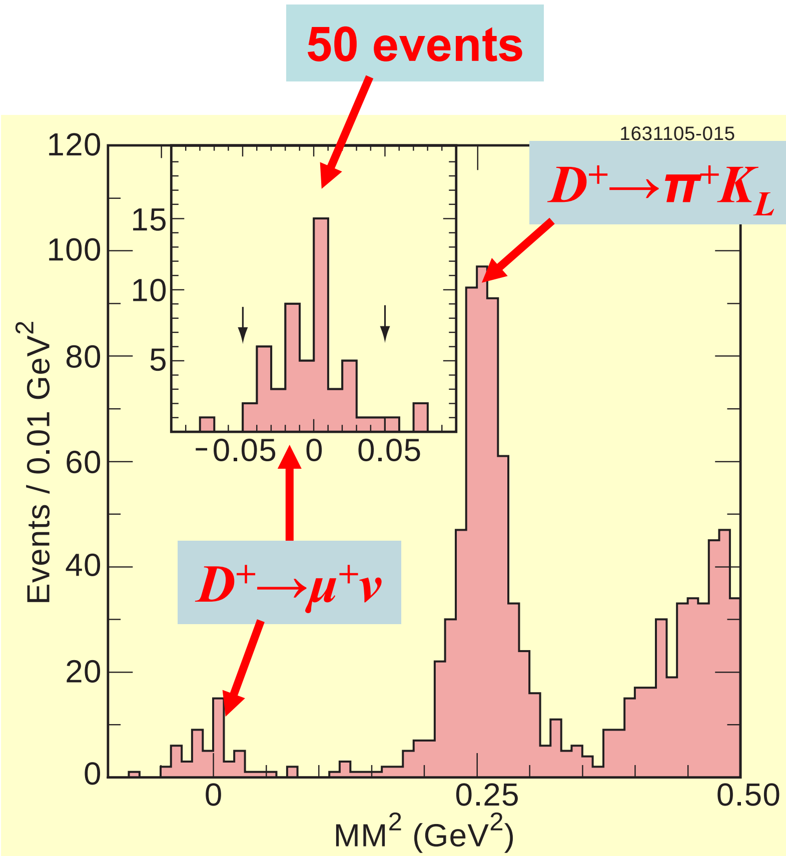
Extra shower energy Sample of $D\bar{D}$ events



Select events with a single track in addition to the tag

- $\theta > 39^0$ with respect to the beam
- E < 300 MeV deposited by the "μ" in the calorimeter
- Veto kaons
- Veto events with a neutral energy cluster > 250 MeV
- μ efficiency is 69.4%

Signal for $D^+ \to \mu^+ \nu$



$$MM^2 = \left(E_{\text{beam}} - E_\mu\right)^2 - \left(-p_{D^-} - p_\mu\right)^2$$

Mode	Events
Data	50
$D^+ \to \pi^+ \pi^0$	1.4
$D^+ \to K_L \pi^+$	0.33
$D^+ \to \tau^+ \nu_\tau$	1.08
Total Bck:	2.81

The same analysis is also done selecting an electron and no candidates were found

Results for $D^+ \to \mu^+ \nu$, $D^+ \to e^+ \nu$

$\mathcal{B}(D^+ \to \mu^+ \nu) = (4.4 \pm 0.7 \pm 0.1) \times 10^{-4}$

D lifetime = 1.040± 0.007ps
V_{cd} = 0.2238±0.0029

f_{D+} = (223±17±3) MeV

$f_{D+}^{FNAL/MILC}$ = (201±3±17) MeV

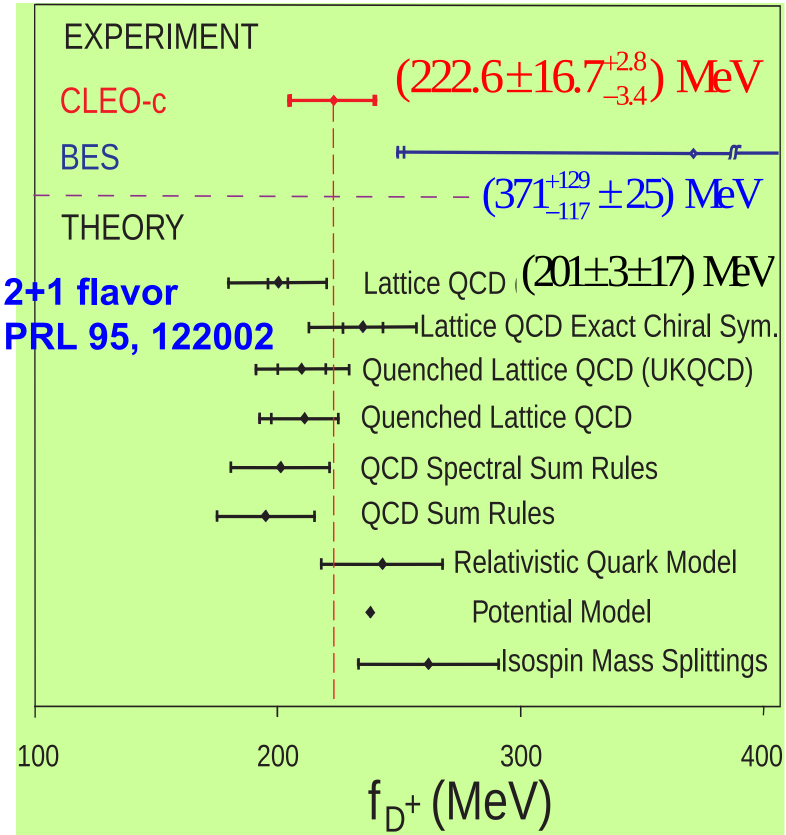
$\mathcal{B}(D^+ \to e^+ \nu) < 2.3 \times 10^{-5}$ (90% CL)

CLEO-c result is statistics limited

Plan is to take ~ 750 pb^{-1} at Ψ(3770)

and measure f_{D+} to ~ 4.5%

Circa 2005



2+1 flavor
PRL 95, 122002

CLEO-c results
Artuso et al PRL. 95, 251801 (2005)

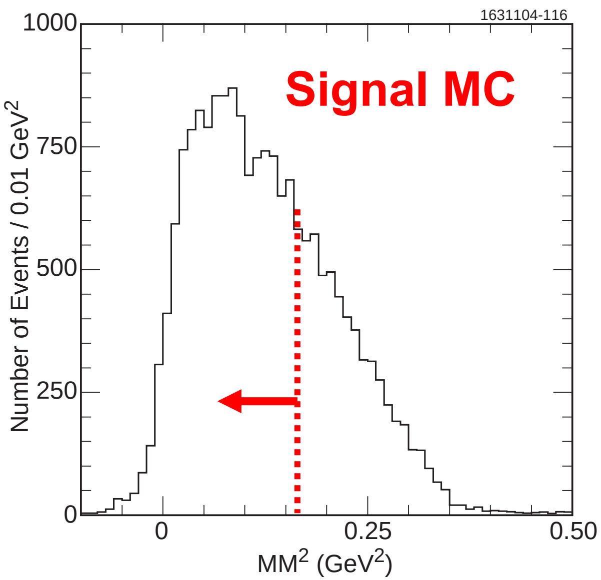
$D^+ \to \tau^+ \nu$

Complementary analysis: selection of $D^+ \to \tau^+ \nu$ ($\tau^+ \to \pi^+ \nu$) in events with the same hadronic tags used for $D^+ \to \mu^+ \nu$.

Sample subdivided based on energy deposit of candidate track:

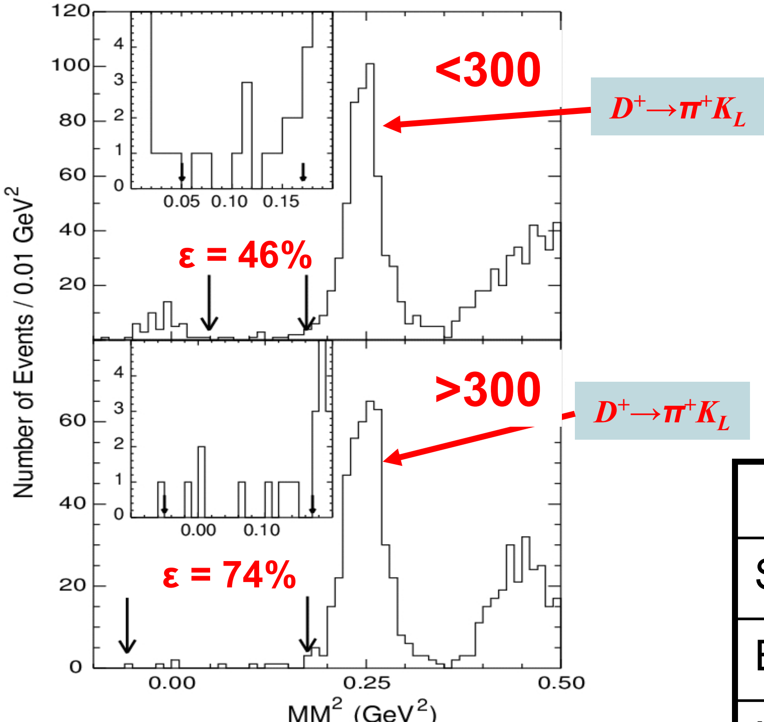
(a) <300 MeV (includes muons and K_L as a background)

(b) >300 MeV. (mainly hadronic backgrounds)



This analysis is more complicated because there are two neutrinos in the final state so the MM^2 distribution is much broader.

Results for $D^+ \to \tau^+ \nu$



Mode	$\mathcal{B}$ (%)	# of events case(i)	# of events case(ii)
$\pi^+\pi^0$	0.12±0.01	0.13±0.02±0.01	1.40±0.07±0.11
$\overline{K}^0\pi^+$	2.77±0.18	2.44±0.51±0.17	1.59±0.41±0.11
$\mu^+\nu$	0.04±0.01	1.25±0.03±0.19	0.46±0.07±0.07
$\rho^+\pi^0$	0.38±0.03	0.18±0.05±0.01	0.23±0.05±0.02
$\pi^0\mu^+\nu$	0.44±0.07	0.98±0.14±0.15	0.002±0.001±0.001
$\tau^+\nu$, $\tau^+ \to \rho^+\nu$	0.030±0.005	0.14±0.01±0.02	0.15±0.01±0.02
$\tau^+\nu$, $\tau^+ \to \mu^+\nu\overline{\nu}$	0.020±0.003	0.27±0.01±0.04	0.03(32% C.L.)
Other D^+ modes	-	0.08(32% C.L.)	0.08(32% C.L.)
D^0 modes	-	0.23±0.12±0.01	0.42±0.16±0.01
Continuum	-	0.45±0.26±0.03	0.74±0.33±0.05
Sum	-	6.07±0.60±0.31	4.99±0.56±0.19

	<300	>300
Signal Region	12	8
Estimated BG	6.1±0.6±0.3	5.0±0.6±0.2
Net	5.9	3.0

$\mathcal{B}(D^+ \to \tau^+ \nu) < 2.1 \times 10^{-3}$ (90% CL)

$$\frac{(D^+ \to \tau^+ \nu / D^+ \to \mu^+ \nu)_{measured}}{(D^+ \to \tau^+ \nu / D^+ \to \mu^+ \nu)_{SM}} < 1.8$$

SM : $\mathcal{B}(D^+ \to \tau^+ \nu) = (1.1 \pm 0.2) \times 10^{-3}$

PRD 73, 112005 (2006)

Babar $D_s^+ \to \mu^+\nu$

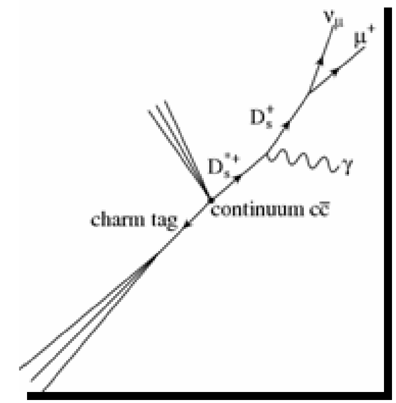
230 fb^{-1} preliminary results

Reconstruct charm mesons D^0, D^+, D_s

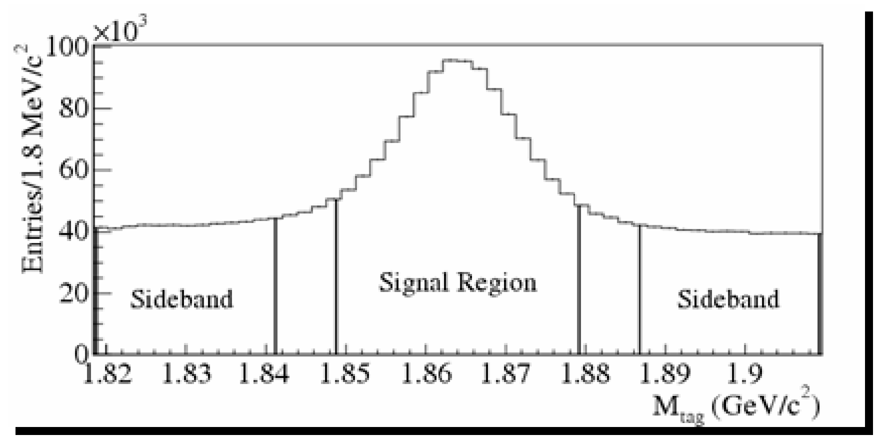
13 tag modes with tag momentum >2.35 GeV

- Search for $D_s^{*+} \to \gamma D_s^+ \to \gamma\mu^+\nu$ in recoil

(Check using $D^{0*} \to \gamma D^0 \to \gamma K^-\pi^+$ Remove π^+ and treat K^- as μ^-)



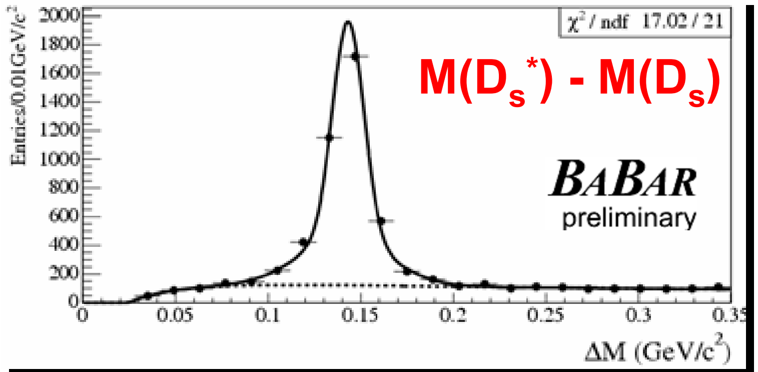
- $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$
- $D^+ \to K^-\pi^+\pi^+(\pi^0), K_S^0\pi^+(\pi^0), K_S^0\pi^+\pi^+\pi^-, K^+K^-\pi^+, K_S^0K^+$
- $D_S^+ \to K_S^0K^+, \varphi\rho^+$
- $D^{*+} \to D^0\pi^+, D^0 \to K_S^0\pi^+\pi^-(\pi^0), K_S^0K^+K^-, K_S^0\pi^0$

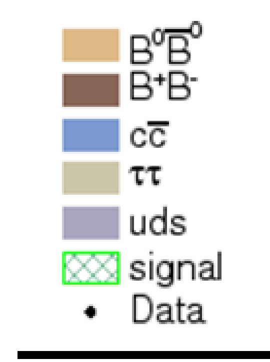


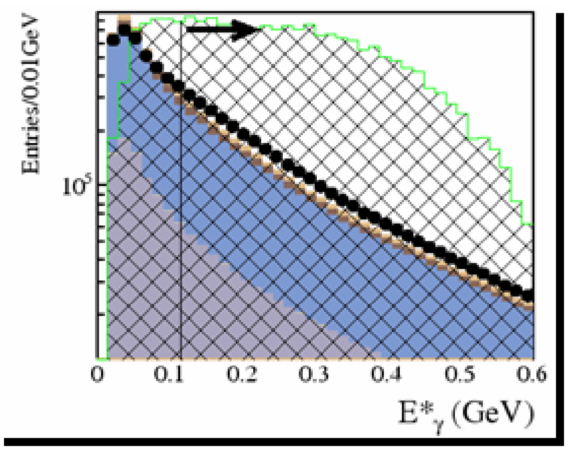
Paul D Jackson Charm 2006

Event selection

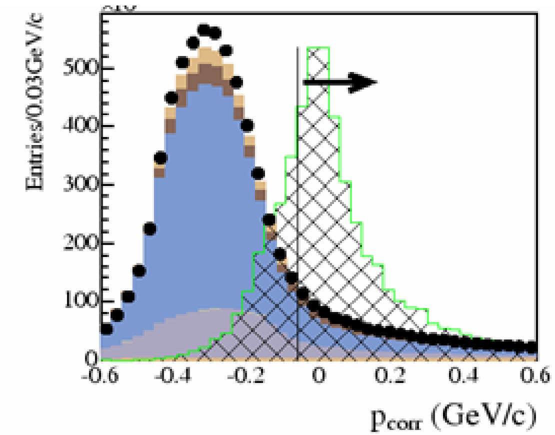
$D_s^{*+} \rightarrow \gamma D_s^+ \rightarrow \gamma \mu^+ \nu$



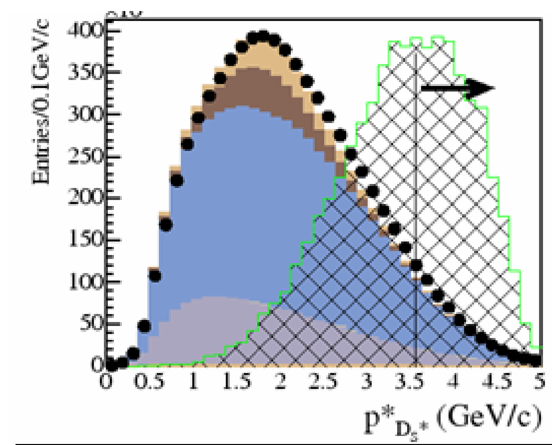




Photon energy



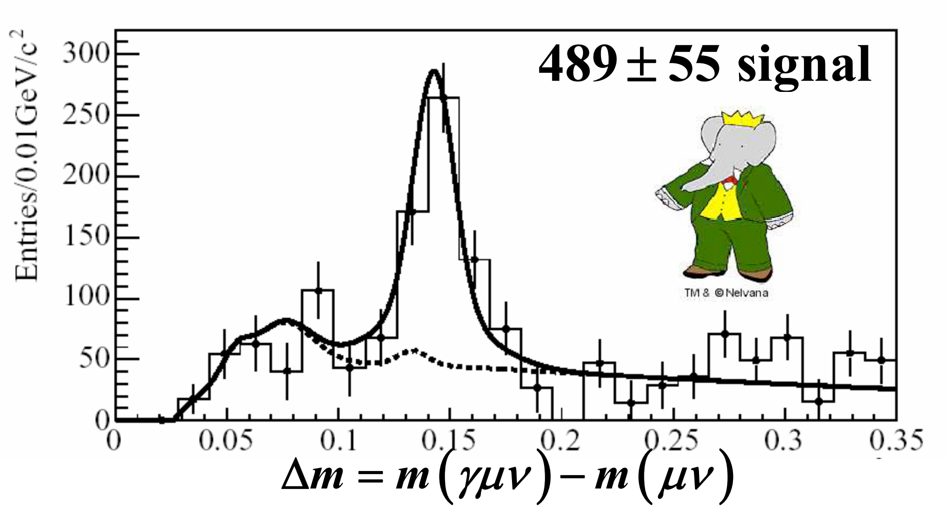
$p_{corr} = |p_{miss}| - |p_\nu|$



D_s^{*+} momentum

Results

- Fit to Signal, leptonic background $D \rightarrow \mu\nu$, and fake muon combinatoric background (shapes from simulation)



- Binned χ^2-fit
- Vary: signal and background yield
- Fix: relative background size

$N_{\mu\nu}$=489 ± 55

- χ^2/d.o.f. = 31/22

Normalized to $D_s \rightarrow \varphi\pi$ = (4.81±0.52±0.38)%

PRD-RC 71, 091104 (2005)

$$f_{D_s} = (279 \pm 17_{\text{stat}} \pm 6_{\text{syst}} \pm 19_{D_s \to \phi\pi})\,\text{MeV}$$

$$\text{B}(D_s^+ \to \mu^+ \nu_\mu) = (6.5 \pm 0.8 \pm 0.3 \pm 0.9) \times 10^{-3}$$

Importance of $\mathcal{B}(D_s \to \varphi\pi)$

The PDG value of Ds→φπ is 3.6 ± 0.9% which has a 25% error. Fits use a mass cut and line shape (BW + Gaussian) however the presence of $f_0\pi^+$ & other interferences complicates precise measurements.

- CLEO $\mathcal{B}^{eff}(D_S \to \phi\pi^+)$ = (3.59 ± 0.77 ± 0.48)% Phys. Lett.B378:364-372,1996
- BaBar $\mathcal{B}^{eff}(D_S \to \phi\pi^+)$ = (4.81 ± 0.52 ± 0.38)% PRD-RC 71, 091104 (2005)

CLEO-c does not yet have a new measurement but we are accumulating data

From the FPCP talk of Sheldon Stone using 71pb^{-1} of CLEO-c data.

±10 MeV cut in K^+K^- mass finds $\mathcal{B}^{eff}(D_S \to \phi\pi^+)$ = (3.49 ± 0.39)%.
±20 MeV cut in K^+K^- mass finds $\mathcal{B}^{eff}(D_S \to \phi\pi^+)$ = (3.73 ± 0.42)%.
$\mathcal{B}^{eff}(D_S \to \phi\pi^+)$=(3.5 ± 0.4)%. (using inclusive production)
$\mathcal{B}^{eff}(K^+K^-\pi^+)$ 4.54 ± 0.43 ± 0.25 (PDG = 4.3±1.2)

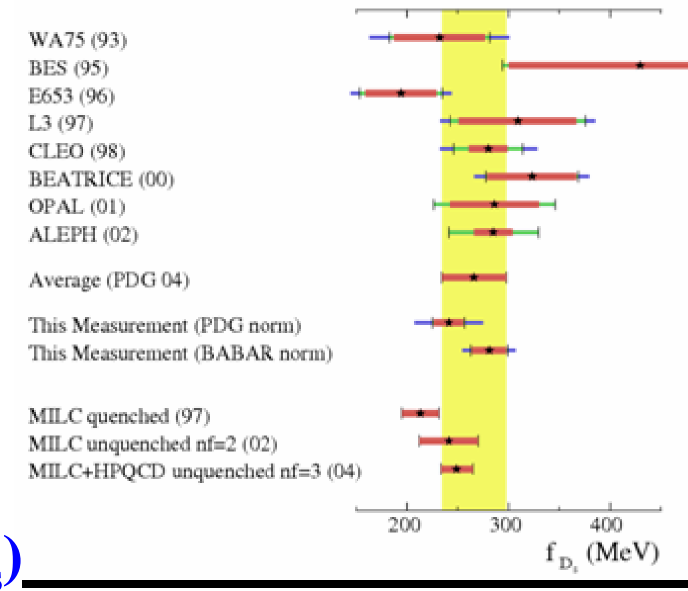
Summary of $D_s^+ \to \mu^+ \nu$ measurements

- normalized to
  - $\mathcal{B}(D_s^+ \to \varphi\pi^+) = (3.6 \pm 0.9)\%$ (PDG)
    - BaBar $f_{Ds} = 248 \pm 35$ MeV

New average:

$f_{Ds} = (261 \pm 31)$ MeV

- Dominated by $\mathcal{B}(D_s^+ \to \varphi\pi^+)$ (12.5% on f_{Ds})



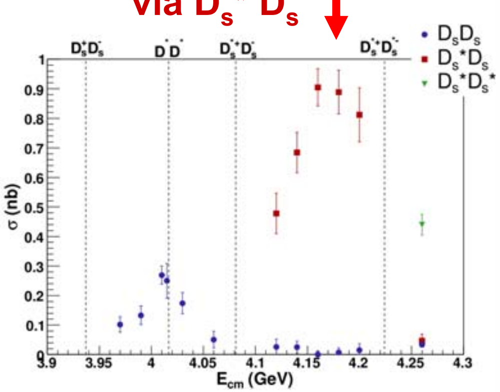
Lattice QCD: $f_{D_s} = (249 \pm 17)\text{MeV}$

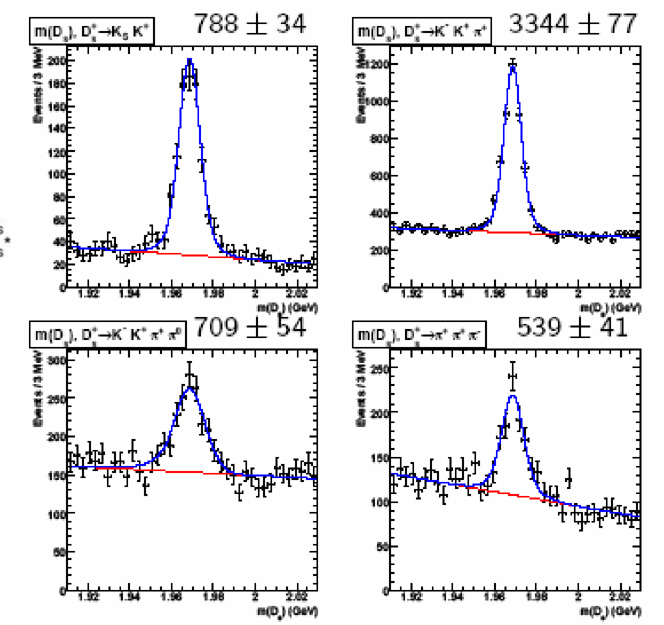
$f_{D_s}^{average} / f_{D+}^{CLEO} = 1.17$

Lattice ~ 1.24

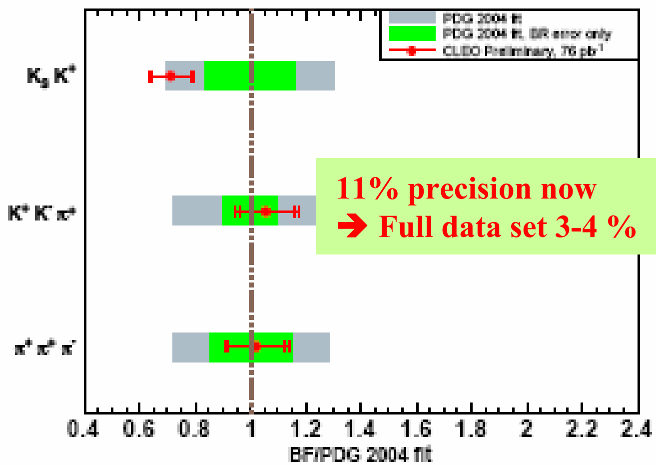
Future for CLEO-c D_s

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





71/pb^{-1}



The extra photon in $D_s{}^*D_s$ is not a real complication.
The cross-section for D_s is smaller than for D^+D^- at the 3770 as is the tag efficiency but since the D_s decay is not Cabibbo suppressed the signal yield (per pb^{-1}) will be at least as good as for D^+ so comparable data samples will yield the same precision

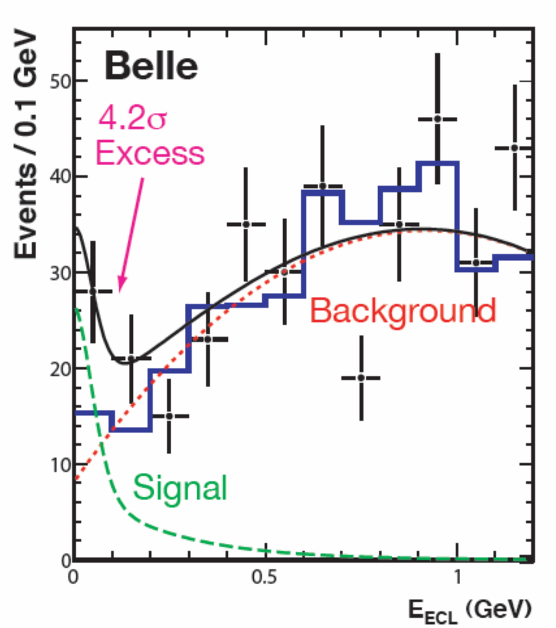
CLEO-c ~200 pb^{-1} at E_{cm} ≈4170 MeV this summer

Plan to take ~750 pb^{-1} at E_{cm} ≈ 4170 MeV by March 2008

First observation of $B^+ \to \tau^+ \nu$

K Ikado [Belle Collaboration],
FPCP 2006 hep-ex/0605068.

Observe 21.2 $^{+6.7}_{-5.7}$ events with a significance of 4.2σ



Data sample is 414fb^{-1}
5 tau decay modes are used
Variable is total neutral energy in calorimeter not associated with the tag

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.06^{+0.34}_{-0.28}(\text{stat})^{+0.18}_{-0.16}(\text{syst})) \times 10^{-4}$$

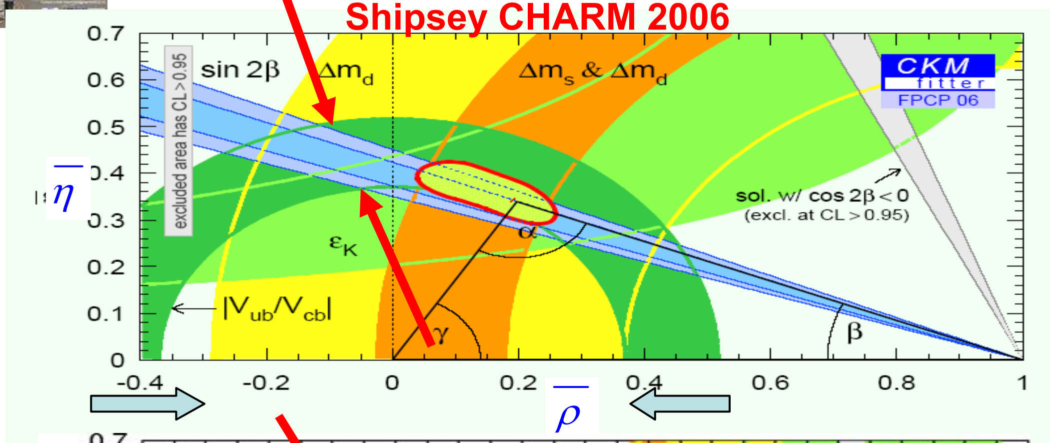
SM : $B(B \to \tau\nu) = (1.59 \pm 0.40) \times 10^{-4}$

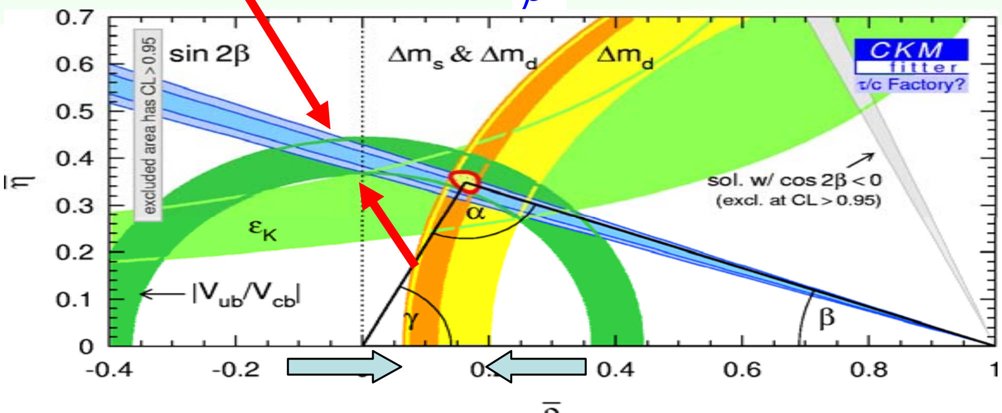
$$f_B \cdot |V_{ub}| = (7.73^{+1.24}_{-1.02}(\text{stat})^{+0.66}_{-0.58}(\text{syst})) \times 10^{-4}\ \text{GeV}$$

$$f_B = 0.176^{+0.028}_{-0.023}(\text{stat})^{+0.020}_{-0.018}(\text{syst})\ \text{GeV}$$

$f_B = 0.216 \pm 0.022$ GeV (HPQCD)

Summary/Future





Theory errors dominate the width of the bands.
***Precision* QCD and *precision* charm data → theory errors of a few % on B system decay constants & Semileptonic form factors**

f_D and f_{Ds}

Experiment and LQCD consistent CLEO-c error 8% LQCD error 8%
with 0.75fb^{-1} errors ~ 4.5% BES III errors ~2%
CLEO-c, BaBar, Belle, BES III and advances in LQCD are all required