A Review of Charm Physics

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CIPANP 2006

Westin Rio Mar Beach, Puerto Rico

31 May 2006

Outline

Charm in Parallel talks:

Bitenc: D mixing at B Factories
Blusk: CLEO Ds scan, Y(4260)
Cronin-Hennessy: CLEO Open Charm
Hinz: States around 4 GeV
Mallik: Y(4260) & other states
Marton: Future PANDA Experiment
Swanson: Charmonium Spectroscopy
Tomaradze: BES+CLEO Charmonium
Tsuboyama: Belle Charmed Baryons

Introductory Observations

Bread & Butter Physics:
- *Lifetimes & Masses*

Searches for New Physics:
- *D^0 - $\bar{D}^0$ Oscillations & Rare Decays*

QCD Effects & Heavy Flavor Physics:
- *Decay Constants, Form Factors, Absolute BFs*

Understanding the Charm Region:
- *Recent Work on $\psi(3770)$*

The Future

Conclusions

What's NOT included in this talk:

Spectroscopy: see Jon Rosner's plenary
Charm Production
Most of Charmonium is not covered
(and whatever else I couldn't fit …
apologies in advance !)

Favorite Reviews for Perspective

What we knew before Charm was discovered:

Search for Charm

M.K. Gaillard, B.W. Lee & J.L. Rosner
Rev. of Mod. Phys. 47, 277 (1975)
written before the November Revolution**

What we knew 30 years later:

A Cicerone for the Physics of Charm

S Bianco, F.L. Fabbri, D. Benson & I. Bigi
Nuovo Cimento 26, 1 (2003) ***200 pages !***

I'll try to emphasize new results & interconnections to other sub-fields

** **Nov. 1974 marked the discovery of the J/ψ $c\bar{c}$ state.**
This "November Revolution" helped to solidify the Standard Model.
(Japanese emulsion experiments had good evidence *before* this…)

Good Things Come in Pairs

B Factories

Charm Factories

Hadron Colliders

Fixed Target

Building on a fine tradition:

E791, LEP/SLD, E687, E691, WA89, MARKIII, H1, ZEUS, E835, R704, etc.

Experimental Issues

B Factories: ~120 x 10^6 ccbar pairs / 100 fb^{-1}

- Substantial continuum rate ($B \Rightarrow DX$ rate ~equal, but softer)
- Hard fragmentation: higher momentum, lower combinatorics
- Good with neutral daughters

Charm Factories: ~640 x 10^3 ccbar pairs / 100 pb^{-1}

- Modest Rates; low momentum: silicon not useful here
- Constrained Kinematics: very clean
- Good with neutral daughters & especially neutrinos

Hadron colliders:

- Very high rate
- Need detached vertex & lepton triggers
- Limited modes

Fixed Target:

- High rate
- Most modes accessible
- Large boosts good for lifetimes

Charm vs. Beauty

$\lambda = \sin\theta_C \sim 0.22$ Cabibbo quark-mixing angle

Decay rate: $\mathcal{O}(1)$ $\mathcal{O}(\lambda^4)$

"Cabibbo"-suppression of b decay compensates $\Gamma \sim m^5$ behavior
Long B life inspired Wolfenstein's famous CKM parameterization…
Advent of silicon vertex detectors revolutionizes b physics, as well as c

Mixing Ampl. : $\mathcal{O}(\lambda^2)$ $\mathcal{O}(\lambda^6)$ x $f(\, m_t\,)$

Charm decays too fast to mix
B mixing enhanced by top mass (actually, B_s enhanced too much!)

Fully Reconstruct: 13% ~ 0.1%

Factories produce **meson pairs**: A fully-reconstructed meson acts as a "***Tag***"
(more on tags later…)

Much larger B factory luminosity:
-- Compensates for smaller efficiency & cross-section for single tags
-- But high efficiency for charm allows for more "double tags"

Theory & Charm

Lattice QCD: *e.g., CLEO-c program & Lepage's talk*

Useful for charm & bottom
Charmonia more relativistic…
Good opportunities to test in charm sector

Spectator model, quark-hadron duality: *NOT like a free quark !*

Factor of ~15x spread in lifetimes
(Pauli interference, weak exchange/annihilation)
Compare: ~30% for bottom (only 4 states, vs. 7 for charm)
Large final-state interactions in charm

B vs. D decay & Penguin example: **Long-distance effects common**

B decay: integrate out top quark ⇒ local 4-quark operator
D decay: b ~decouples (CKM); dominant strange is light ⇒ not short-distance!

HQET:

Useful, but larger $(1/m)^N$ corrections,
& no heavy-to-heavy decays like $b \Rightarrow c\, l\, \nu$
Good for basic properties of P-wave mesons

SCET, OPEs, QCD Sum Rules, Dispersion Relations, Potential Models, Bag Models, …

Charm Lifetimes (~PDG 04)

	PDG ave	Best; error (fs)	#events
D^+	1040 ± 7 fs	FOCUS'02 ±8	110,000
D_s^+	501 ± 6 fs*	FOCUS'05 ±8	13,641
D^0	410.3 ± 1.5 fs	FOCUS'02 ±2	210,000
Λ_c	200 ± 6 fs*	FOCUS'02 ±4 CLEO'01 ±8	8034
Ξ_c^0	112^{+13}_{-10} fs	FOCUS'02 ±14* E687 '93 ±22*	110 42
Ξ_c^+	442 ± 26 fs	FOCUS'01 ±24	532
Ω_c	69 ± 12 fs	FOCUS'03 ±16 WA89 '95 ±24	64 86

*I've adeed FOCUS'05

*scale factor 1.6; CLEOII ~low

*asymmetric errors quoted

7 weakly-decaying ground states

Cutoff for my table: all ≤ 2x best error

FOCUS plays the dominant role !

Values very Useful : convert BF's to partial widths (extract CKM, …)

Low phase-space π & γ transitions:

CLEO '02 : $\Gamma(D^{*+}) = 96 \pm 4 \pm 22$ keV (syst. limited, no other attempts since…)

D^{*0}, D_s^*, $\Xi_c^{+\prime}$, $\Xi_c^{0\prime}$: too narrow to see width, too short-lived to see lifetime

Recent Mass & Lifetime Work

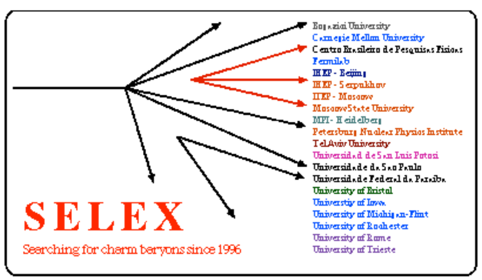
D_s lifetime: *507.4 ± 5.5 ± 5.1 fs*

PRL 95, 052003 (2005)

Λ_c^+ mass: *2286.46 ± 0.14 MeV*

4627+264 events of $\Lambda K_S K^+$ & $\Sigma^0 K_S K^+$

PRD 72, 052006 (2005)



Preliminary Ω_c lifetime:

69.3 ± 14.4 ± 8.6 fs

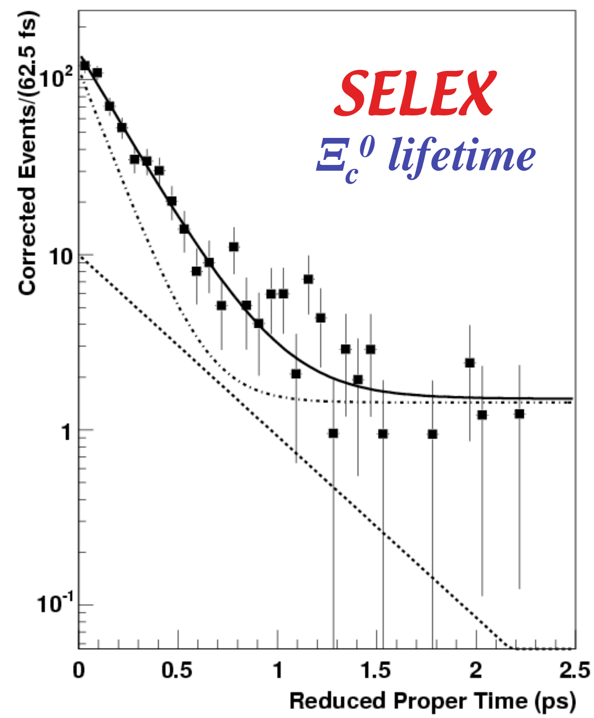
83 events in 2 channels

Preliminary Ξ_c^0 lifetime:

430 ± 22 ± 9 fs

301 events in 3 channels

Sidebands demonstrate good understanding of backgrounds



Charm Baryon Overview

Lifetimes less precise than for the mesons

Mesons: 0.4 - 1.3% *Baryons: 3% - 17%*

-- Limited statistics & shorter lifetimes

Need absolute branching fractions:

-- $B(\Lambda_c \Rightarrow pK\pi) = (5.0 \pm 0.5 \pm 1.2)$ % **CLEO, *with assumptions***

-- Nothing at all to set absolute scale for Ξ_c^0, Ξ_c^+, Ω_c !!!

BaBar, Belle, CLEO, FOCUS, SELEX all active:

-- New decay modes, semileptonic form-factors, masses, …

-- Many more results to extract from B-factory datasets

Spectroscopy also still quite active…

Mixing: Intro & Lifetime Differences

D^0 mixes very little in Standard Model: (and small CP violation)
-- An opportunity to see *new physics effects in loops*!
-- But… long-distance effects make SM prediction imprecise

Mixing parameters:
$x = \Delta m / \Gamma \quad y = \Delta\Gamma / 2\Gamma$

Δ's are between ~ CP-eigenstates:
$D_{CP\pm} = (D^0 \pm D^{0bar})/\sqrt{2}$

Measure lifetime difference y via :
-- CP-eigenstates: KK , ππ
-- "CP-average" state: Kπ

Best results on y are from 2003:

Belle:	$(1.15 \pm 0.69 \pm 0.38)$ %	158 fb^{-1}	hep-ex/0308034
BaBar:	$(0.8 \pm 0.4 \ {}^{+0.5}_{-0.4})$ %	91 fb^{-1}	PRL 91, 121801(2003)

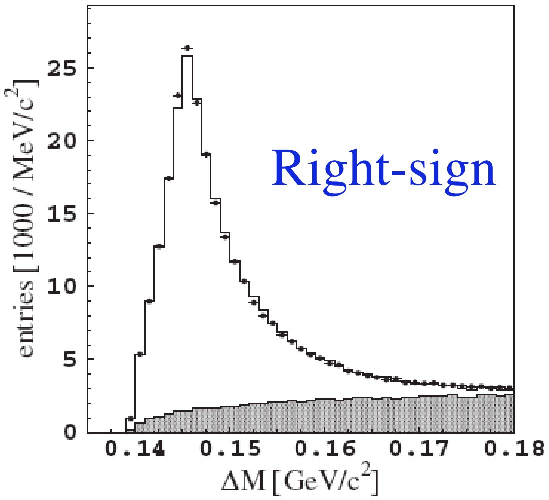
Pro: direct ***linear sensitivity*** to y; measuring a lifetime ***difference***
Con: systematic error improvement is ***still*** tough !

Semileptonic Mixing Limits

Tag initial flavor (*D^0 vs. D^{0bar}*) with *$D^{*+} \Rightarrow D^0 \pi^+$*

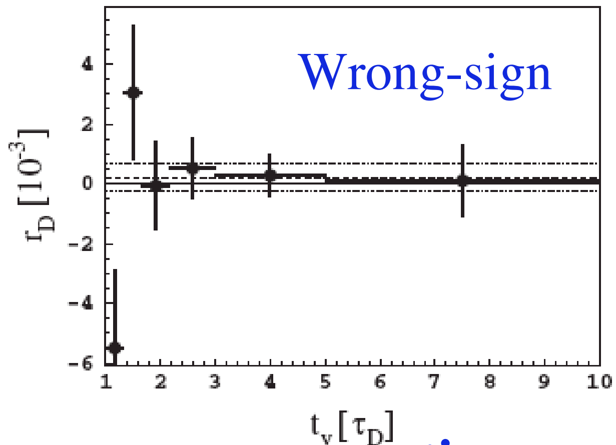
PRD 72, 071101
(2005) 253 fb^{-1}

$D^0 \Rightarrow K^{(*)-} e^+ \upsilon$



ΔM ($D^* - D$)

$D^0 \Rightarrow K^{(*)+} e^- \upsilon$



r_M vs. time

"Right" & "Wrong":
Lepton tags flavor
at decay time:
$c \Rightarrow s\, l^+ \upsilon$

Result: $R_M = (x^2 + y^2)/2 <$ 0.10% 90% CL
-- Pro: still statistics limited
-- Con: only quadratic in x, y

Unpublished FOCUS'02:
$r_M <$ 0.101% (90%CL)
(from Ph.D. Thesis + APS'03)

Mixing: Hadronic Final States

$D^0 \Rightarrow K^- \pi^+$: *Common decay* $D^0 \Rightarrow K^+ \pi^-$: *rarer, DCSD decay*

DCSD = Doubly-Cabibbo Suppressed Decay

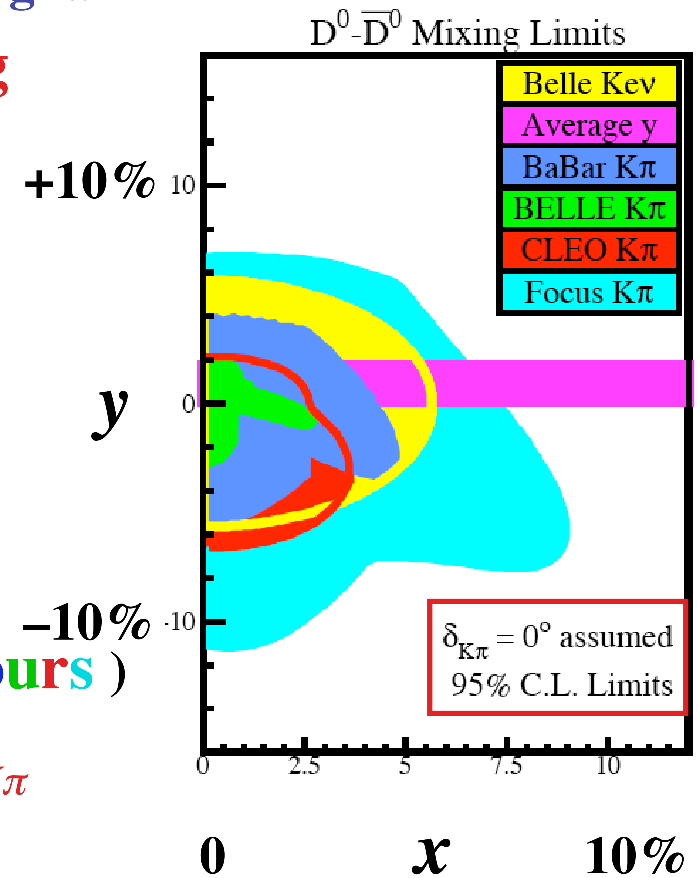
$c\,\bar{u} \;\Rightarrow\; s\,\bar{u}\,W^+ \;\Rightarrow\; s\,\bar{u}\,u\,\bar{d}$ $\quad \mathcal{A} \sim \mathcal{O}\,(1)$

$c\,\bar{u} \;\Rightarrow\; d\,\bar{u}\,W^+ \;\Rightarrow\; d\,\bar{u}\,u\,\bar{s}$ $\quad \mathcal{A} \sim \mathcal{O}(\lambda^2)$

So… DCSD final states look just like a mixing signal

Kaon charge is an imperfect flavor tag

D. Asner in '06 PDG Review:



Wrong-sign $K^+\pi^-$ *rate vs. time :*

$$r(t) = e^{-t}\,(\,R_D + \sqrt{R_D}\,y'\,t + R_M\,t^2/2\,)$$

Integrates to: $R_D + \sqrt{R_D}\,y' + R_M$

R_D : DCSD rate $\quad y', R_M$: Mixing

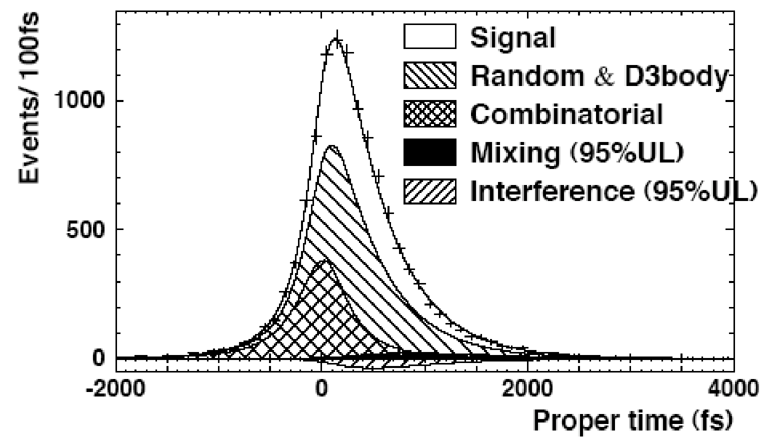
x', y' time-dependent analyses (**contours**)

Primes: x, y are rotated by strong phase $\delta_{K\pi}$

Mixing: Kπ time-dependence

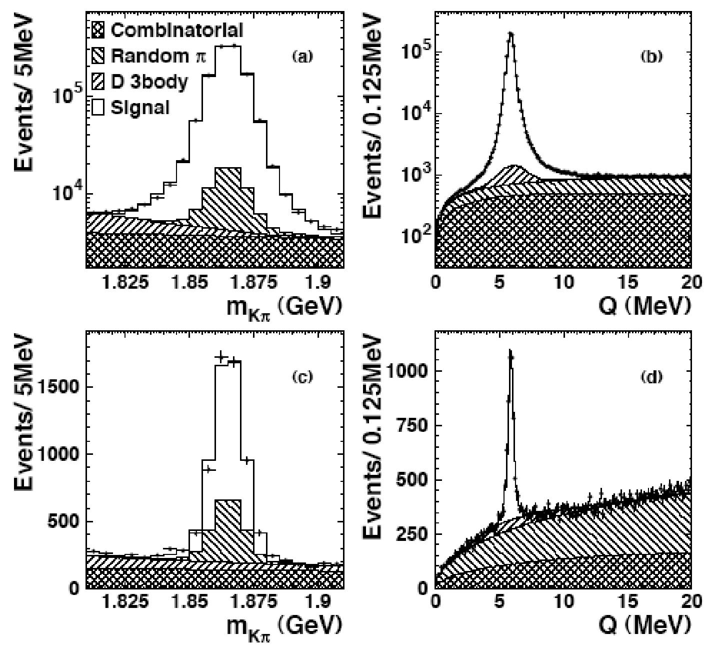
PRL 96, 151801
400 fb^{-1} (2006)

Tag flavor with *D :**
Use time-dependence
to separate DCSD
from possible mixing…



$K^-\pi^+$
Right-sign
(log y)

$K^+\pi^-$
Wrong-sign
DCSD
+ *?mixing?*
(linear y)



M(Kπ) *Q*

$Q = M(K\pi\,\pi) - M(K\pi) - M_\pi$
$D^* \quad - \quad D^0 \quad - \quad \pi$

Assuming no mixing:
$R_D = (0.377 \pm 0.008 \pm 0.005)$ %

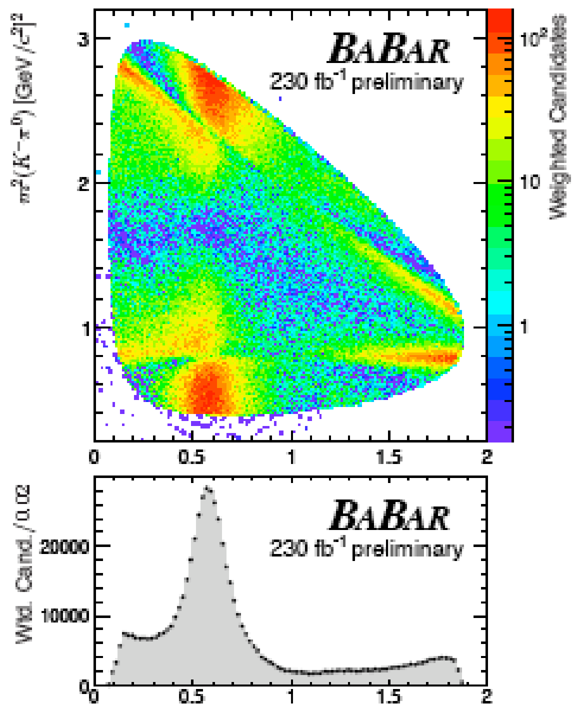
Mixing Limits:
green contour in x-y plot;
current best

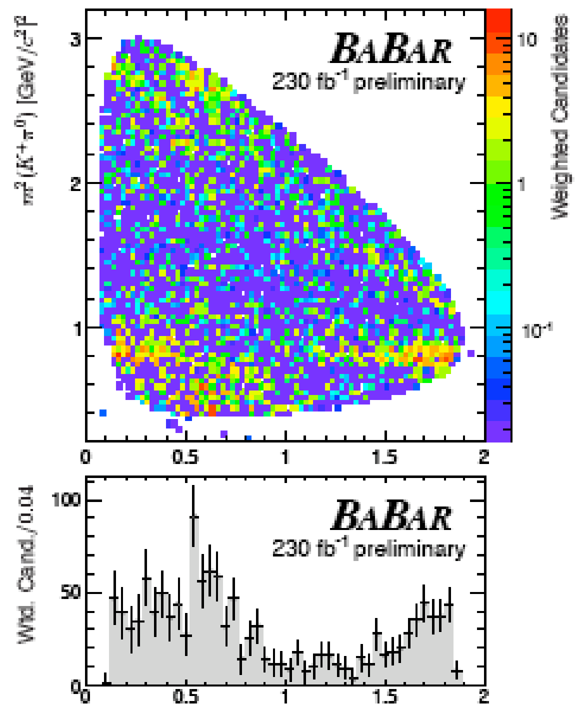
Consistency with no-mixing: 3.9%

Mixing: Kππ⁰ Dalitz Plot

Winter conf's (2006) 230 fb^{-1}

Use parts of Dalitz plot where Cabibbo-Favored is large relative to Doubly-Cabibbo Suppressed !



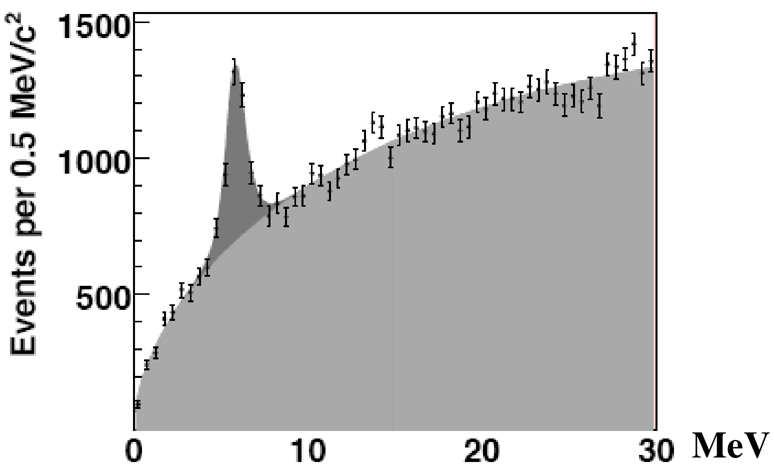


0 $M^2(\pi\pi^0)$ 2 GeV^2 0 $M^2(\pi\pi^0)$ 2 GeV^2

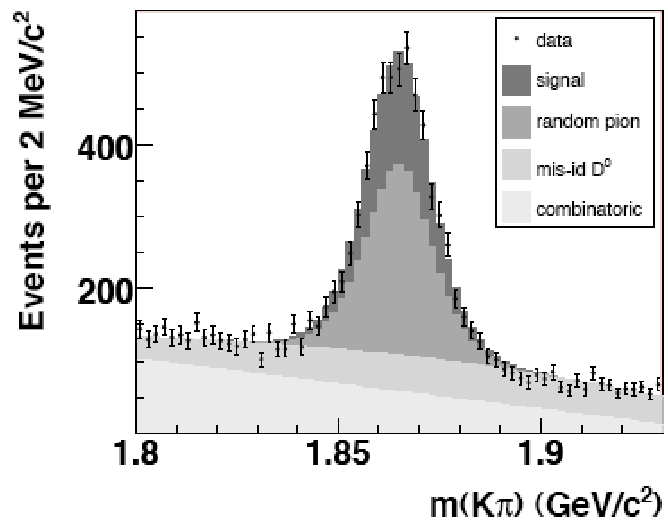
$R_M < 0.54 \times 10^{-3}$ (95% CL)   Consistency with no-mixing: 4.5%

New Dalitz technique is a very welcome addition !

Wrong-sign Kπ "Warm-up"



$Q = M(K\pi\pi) - M(K\pi) - M_\pi$



hep-ex/0605027
350 pb^{-1}

Exploits *detached vertex trigger*

Assuming no mixing:

$R_D = (0.405 \pm 0.021 \pm 0.011)\ \%$

Plan is to update to 1 fb $^{-1}$ for ICHEP 2006

& then move on to the full time-dependent analysis…

Rare Charm Decays

Rare decays can be important to constrain new physics

Superficially analogous to many familiar B decays
-- But… ***long-distance effects*** important in general
-- Limits are generally still far from SM rates

Lots of activity at many experiments
-- Good: More luminosity to come everywhere
-- Bad: All results have background, so sqrt(lumi) improvement
-- Envy: One CDF result has huge lumi gain to come soon…

$h^+ l^+ l^-$ modes are popular
Di-leptons, di-photon and radiative modes are also explored

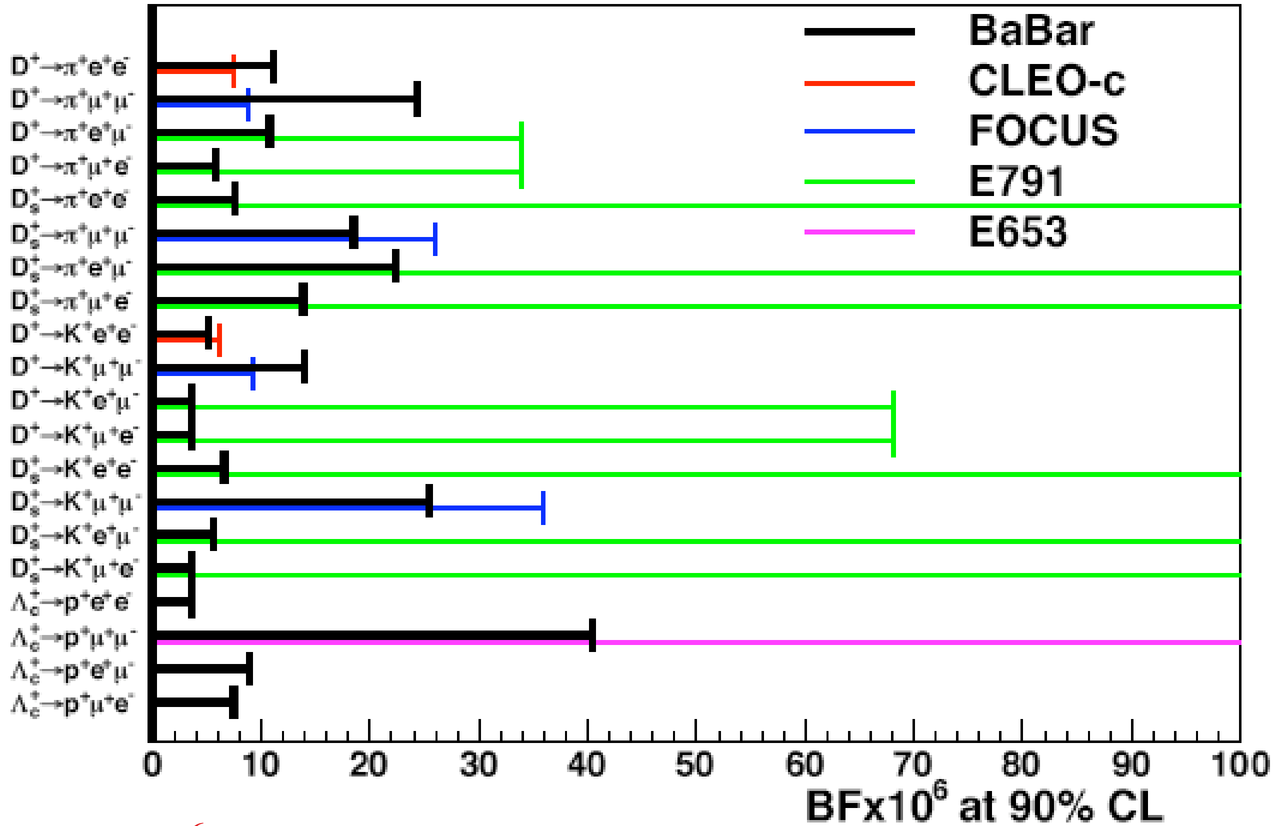
CP & T violation searches are also important for new physics

Rare Charm Decays

Recent BaBar analysis and compliation:

Winter Conf's

288 fb^{-1}



CLEO also reported:

$\mathcal{B}(D^+ \Rightarrow \pi^- e^+ e^+) < 3.6 \times 10^{-6}$

$\mathcal{B}(D^+ \Rightarrow K^- e^+ e^+) < 4.5 \times 10^{-6}$

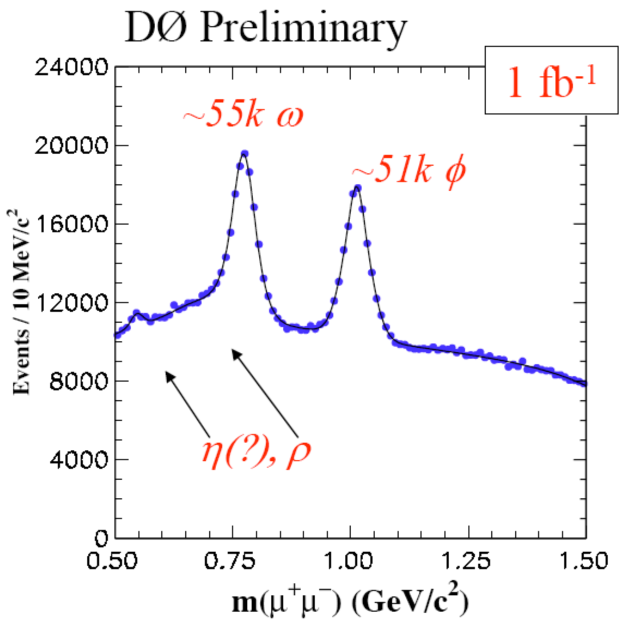
Tevatron Activity with Muon Triggers:

DØ (1 fb^{-1}): $\mathcal{B}(D^+ \rightarrow \pi^+ \mu^+ \mu^-) < 4.7 \times 10^{-6}$ Moriond EW

CDF (65 pb^{-1}): $\mathcal{B}(D^0 \Rightarrow \mu^+ \mu^-) < 2.5 \times 10^{-6}$ PRD 68, 091101 (2003)

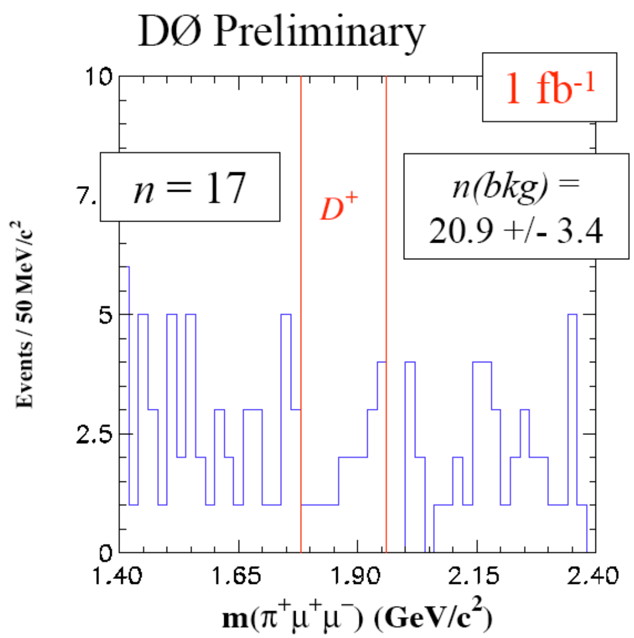
$D^+ \Rightarrow \pi^+\mu^+\mu^-$

DØ Prelim.
Moriond EW
B. Casey



Dimuon trigger
Global event topology + detached vertex

Short distance: Z penguin, W box
Long distance: phi, omega $\Rightarrow \mu^+\mu^-$



Results:

$\mathcal{B}(D^+ \Rightarrow \varphi\pi^+ \Rightarrow \pi^+\mu^+\mu^-)$
$= (1.75 \pm 0.70 \pm 0.50) \times 10^{-6}$

Consistent w/ previous...check.

Look away from φ mass region...

$\mathcal{B}(D^+ \Rightarrow \pi^+\mu^+\mu^-) < 4.7 \times 10^{-6}$

CP/T Violation: Survey of Results

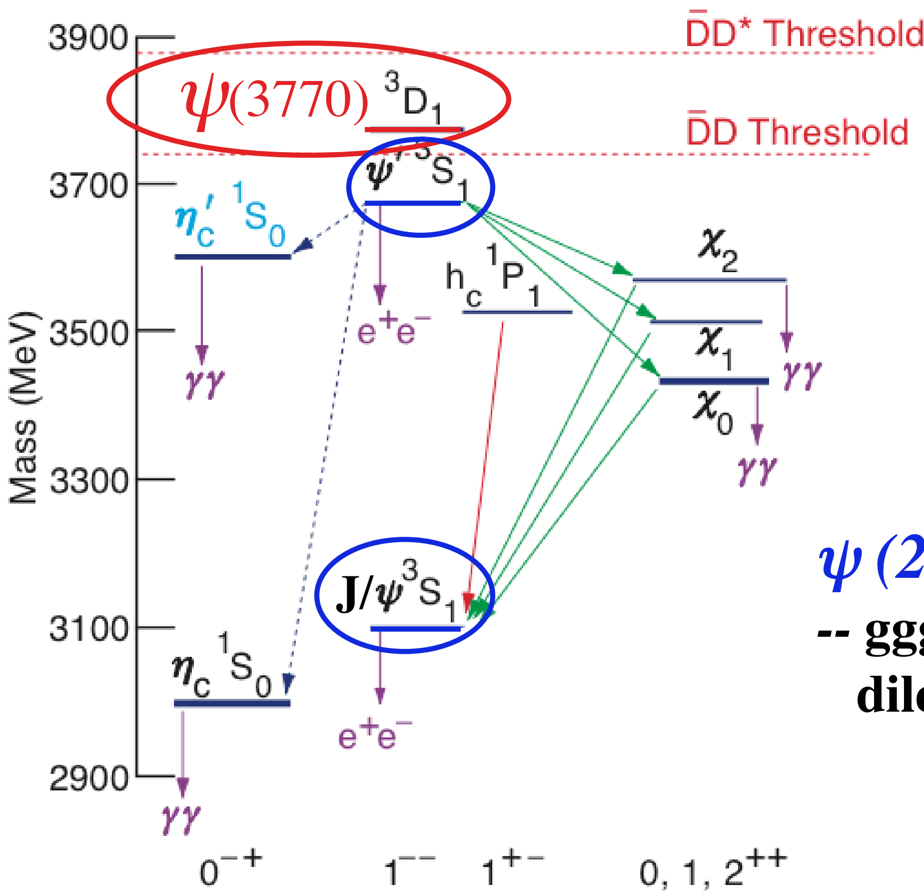
Experiment	Decay mode	A_{CP} (%)	Notes
BaBar	$D^+ \to K^- K^+ \pi^+$	$1.4 \pm 1.0 \pm 0.8$	
BaBar	$D^+ \to \phi\, \pi^+$	$0.2 \pm 1.5 \pm 0.6$	Resonant substructure of $D^+ \to K^- K^+ p^+$
BaBar	$D^+ \to K^{*0} K^+$	$0.9 \pm 1.7 \pm 0.7$	
CLEO II.V	$D^0 \to \pi^+ \pi^- \pi^0$	$1\,^{+9}_{-7} \pm 8$	Dalitz plot analysis
CDF	$D^0 \to K^+ K^-$	$2.0 \pm 1.2 \pm 0.6$	Direct CPV
CDF	$D^0 \to \pi^+ \pi^-$	$1.0 \pm 1.3 \pm 0.6$	Direct CPV
FOCUS	$D^0 \to K^+ K^- \pi^+ \pi^-$	$1.0 \pm 5.7 \pm 3.7$	T violation through triple product correlations
FOCUS	$D^+ \to K^o K^+ \pi^+ \pi^-$	$2.3 \pm 6.2 \pm 2.2$	
FOCUS	$D_S \to K^o K^+ \pi^+ \pi^-$	$-3.6 \pm 6.7 \pm 2.3$	

as compiled by Sheldon Stone for FPCP06

Charmonium Spectrum

Rich Spectroscopy, discussed elsewhere.

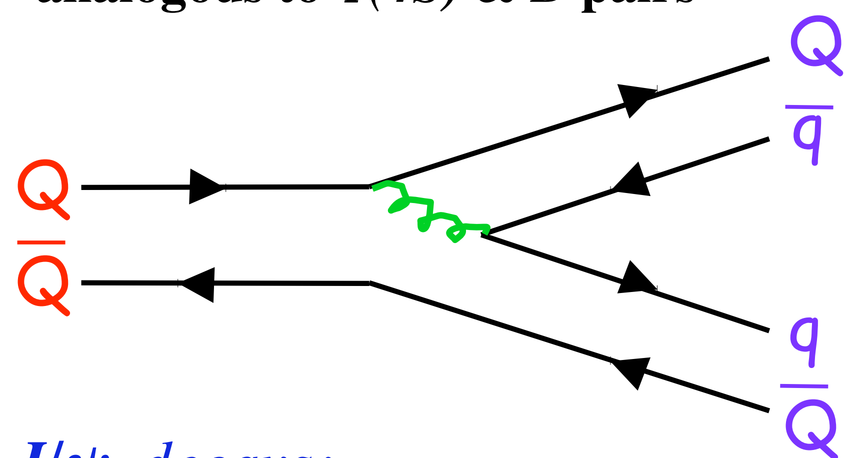
Main point for us: ψ(3770) is a good source of D mesons.



ψ (3770) decays:

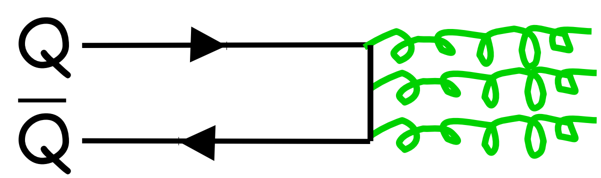
-- mostly to *D* pairs

-- analogous to *ϒ(4S)* & *B* pairs



ψ (2S), J/ψ decays:

-- ggg+ggγ ; other charmonia;
dileptons ; radiative



Charm Factory Datasets

BES

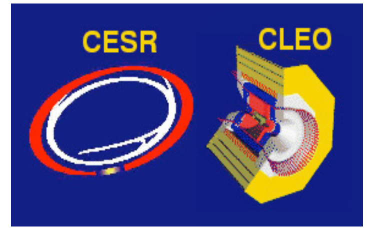
14×10^6 $\psi(2S)$

58×10^6 J/ψ

$6.4\ pb^{-1}$ cont'm @ 3.65 GeV

Dedicated R_{had} scans

$33\ pb^{-1}$ $\psi(3770)$



Only few days @ current lumi ! ~10x this summer

3.1×10^6 ψ (2S)

No J/ψ (access via $\psi(2S) \Rightarrow J/\psi\ X$)

$21\ pb^{-1}$ cont'm @ 3.67 GeV

$60\ pb^{-1}$ D_s scan; included Y(4260)

$281\ pb^{-1}$ $\psi(3770)$

$180\ pb^{-1}$ @ 4170 MeV for D_s

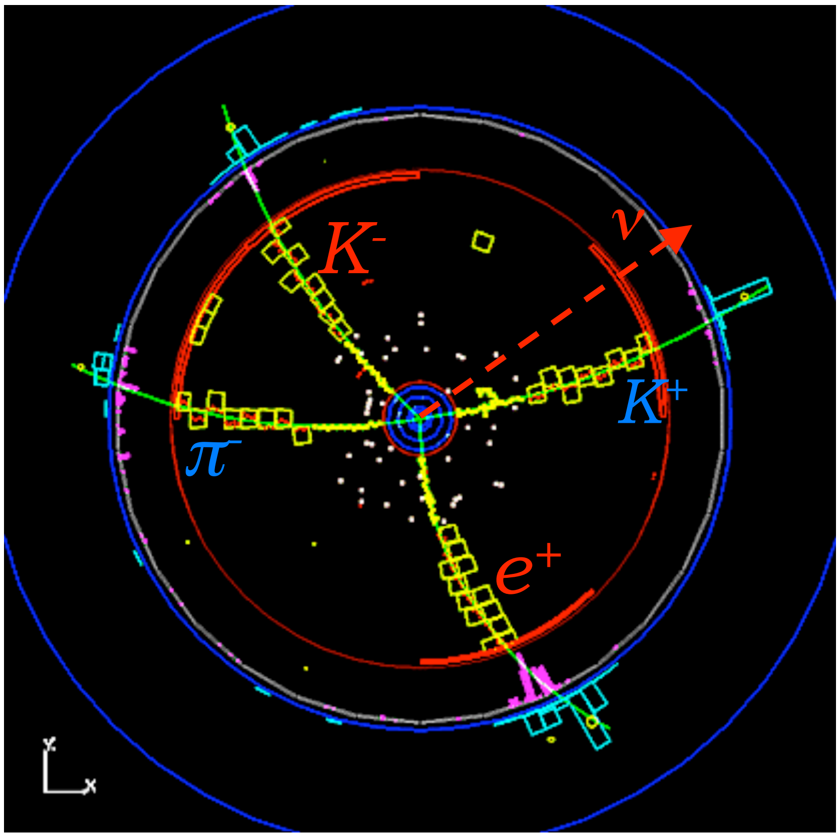
CLEO-c detector is superior to BESII…

But, BESIII upgrade is well underway!

More on this later…

CLEO-c Program: Precision Charm

Provides important tests of Lattice QCD
Necessary for overall Heavy Flavor program: helps B factories
Started with D^0, D^+, now extending to D_s mesons



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

$D^0 \rightarrow K^- e^+ \nu$ & $\bar{D}^0 \rightarrow K^+ \pi^-$

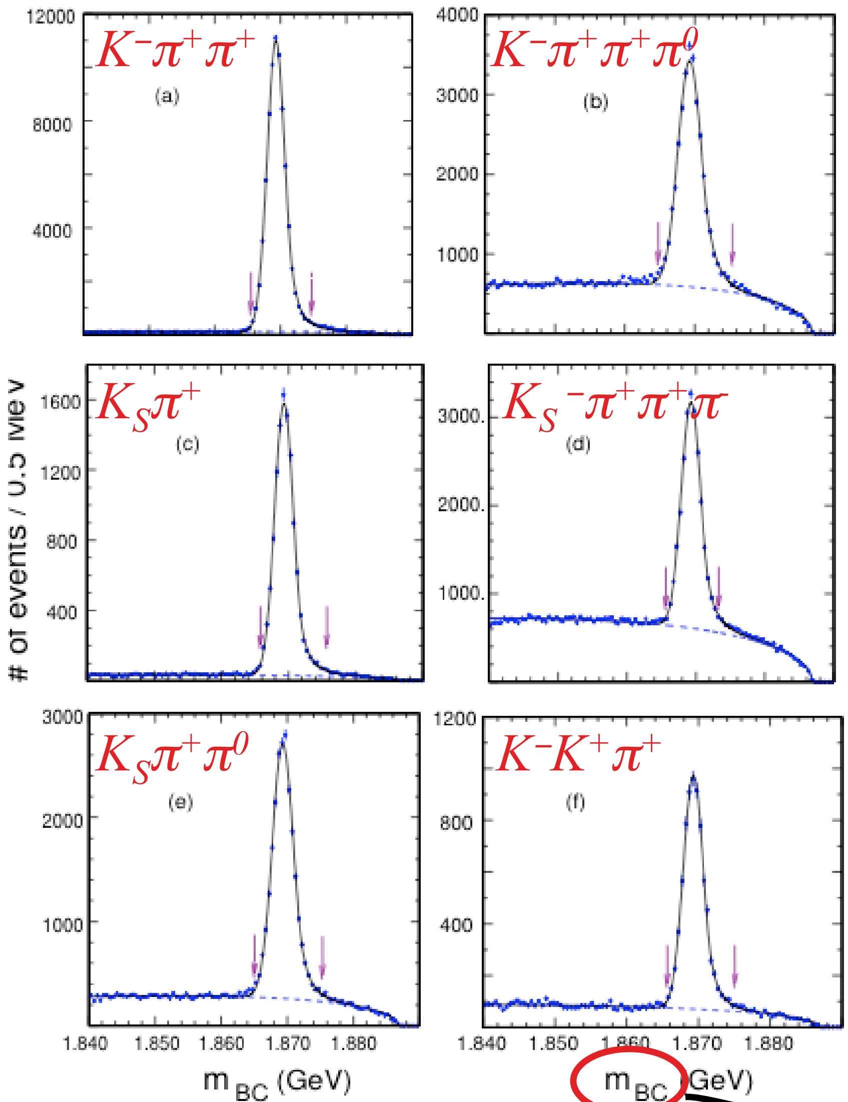
Semileptonic decay
opposite
a fully reconstructed
hadronic "Tag"

Cleanly *infer neutrinos!*

Almost all **first results** more precise than prior world averages

Reconstructing D Tag Samples

D^+ Tags Used for $D^+ \rightarrow \mu^+ \nu$
(similar for other analyses & D^0)



$\psi(3770)$:

-- $D\,\bar{D}$ pair + ~35 MeV extra energy

-- Not enough E for extra pions, etc.

All Tags Use:

Momentum Conservation:

$$M_{bc} = (E_{beam}^{\ 2} - p_D^{\ 2})^{1/2}$$

-- *"beam constrained mass"*

-- *Better resolution than 4-vector mass*
~1.5 MeV; mostly beam energy spread

Energy conservation:

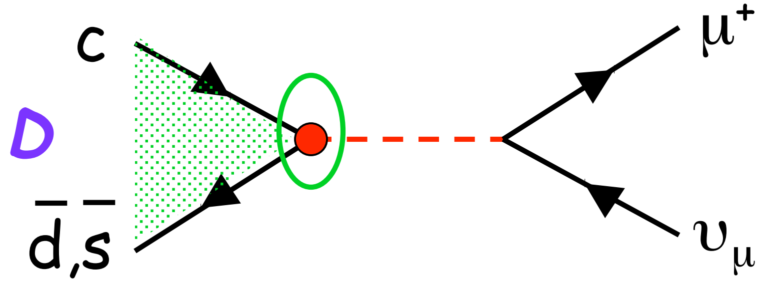
$$\Delta E = E_{cand} - E_{beam}$$

-- *Peaks at 0*

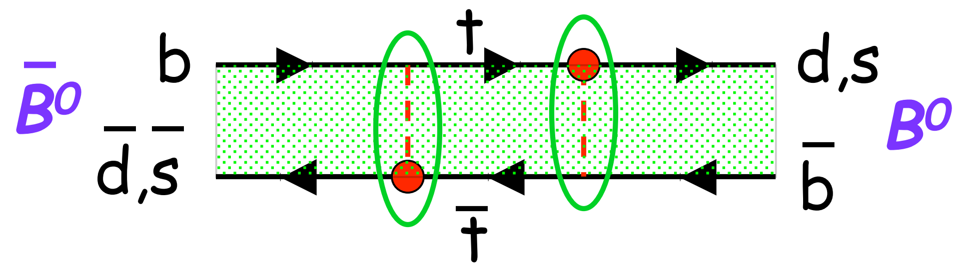
-- *sensitive to Particle ID, missing particles*

Charm as a QCD Lab I

Leptonic D Decays



f_D LQCD = exp't ?



use LQCD f_B here

for V_{td}, V_{ts}

f_D is a "decay constant":

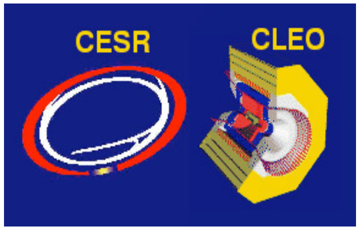
chance that quarks are at same place

~$|\psi(0)|^2$: square of wavefunction at origin

(weak interaction is short-range)

Lattice QCD: *Calculate strong force on computers*

$D^{+} \Rightarrow \mu^{+}\upsilon_{\mu}$: *Extracting* f_D



50 candidates; $2.81 \pm 0.30\ ^{+0.84}_{-0.27}$ background

Rely on ***data*** for systematic errors;

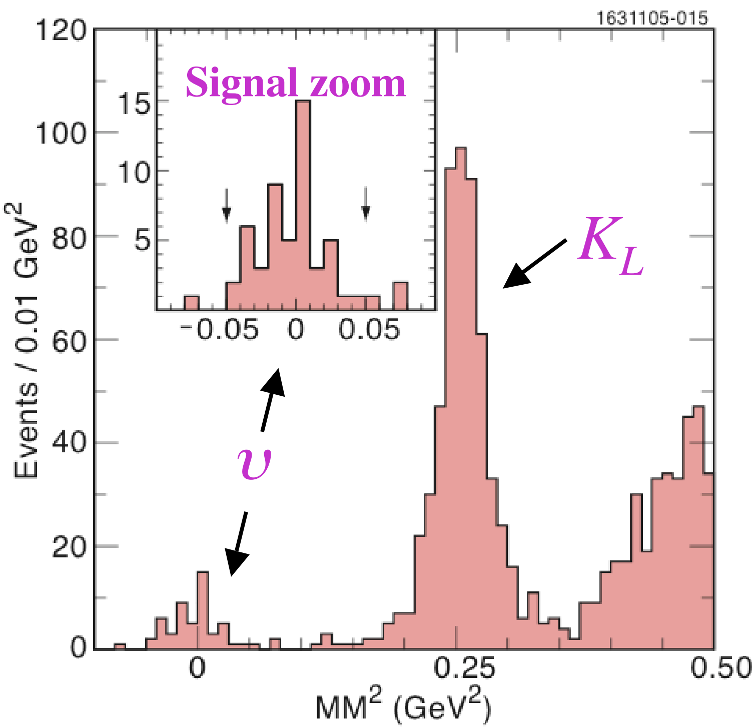
Background from data & MC

-- Key backgrounds: $D^{+} \Rightarrow \pi^{+}\pi^{0}$, $\tau\upsilon$, $K^{0}\pi^{+}$

$\mu\nu$ $e\nu$: PRL 95, 251801 (2005) 281 pb^{-1}

$\tau\nu$: hep-ex/0604043 to appear in PRD

Missing-mass^2: Data



Result:

$$f_D = (\,222.6 \pm 16.7\ ^{+2.8}_{-3.4}\,)\ \text{MeV}$$

Also limit:

$\mathcal{B}(D^{+} \rightarrow e^{+}\nu) < 2.4\text{x}10^{-5}$ **@ 90% c.l.**

and

$\mathcal{B}(D^{+} \rightarrow \tau^{+}\nu) < 1.8$ **x Std. Model @ 90% c.l.**

Theory Comparison for f_D

Will use f_D, f_{Ds}, & ratio to test lattice calculations

⇒ *confidence in* f_B, f_{Bs} *to interpret B mixing.*

Sample Lattice Calculations:

FNAL/MILC PRL 95, 122002 (2005)

Unquenched LQCD; $m_{u,d} << m_s$

(but "fourth root" trick)

$f_D = (201 \pm 3 \pm 17)$ MeV

$f_{Ds} = (249 \pm 3 \pm 16)$ MeV

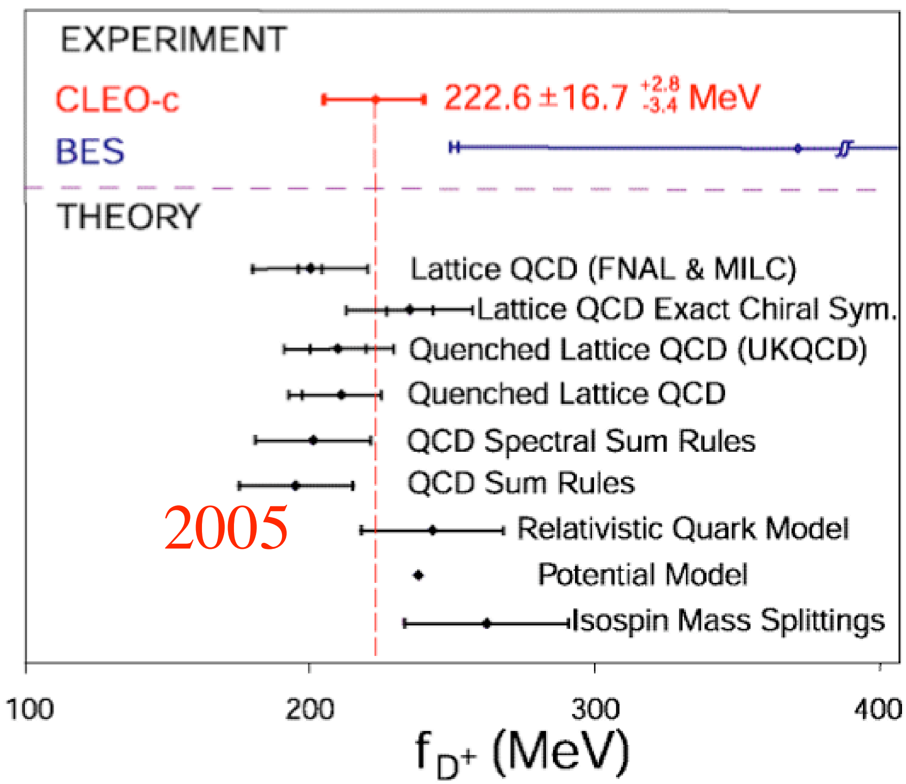
Chiu *et al.* PLB 624, 31 (2005)

Exact chiral symmetry,

***BUT* quenched** LQCD

$f_D = (235 \pm 8 \pm 14)$ MeV

$f_{Ds} = (266 \pm 10 \pm 18)$ MeV



Comparable experimental & theory errors; working to improve both

$D_s^+ \Rightarrow \mu^+ \upsilon_\mu$: Extracting f_{Ds}

High statistics B factory data: allows "continuum tagging" of opposite-side charm jet

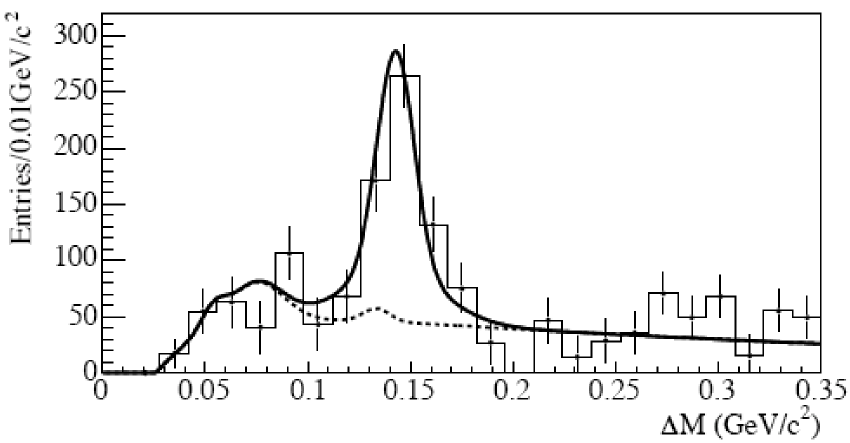
$\mu^- \upsilon_\mu$ *candidates opposite a* D^0, D^+, D^{*+}, *or* D_s^+ *tag*

BaBar $D_s^+ \Rightarrow \mu^+ \upsilon_\mu$

LaThuile 230 fb^{-1}

$f_{Ds} = 279 \pm 17 \pm 6 \pm 19$ MeV

Last error from $\phi\pi$ *BF*
(CLEO-c will improve)



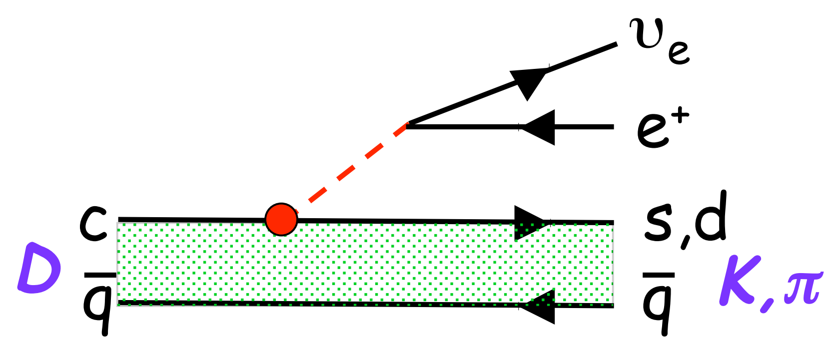
$\Delta M = M(D_s^*) - M(D_s)$

Bumps in dashed background are due to
lower: γ from π^0 in $D_s^* \Rightarrow Ds\ \pi^0$
higher: μ is mis-id π from τ decay in $D_s \Rightarrow \tau\upsilon$

Charm as a QCD Lab II

Semileptonic D Decays

Form factors, CKM
FF help w/ B decays



"Form Factor":

~ *Chance that quarks bind into a given final state*

Relate $B \Rightarrow \pi e \upsilon$ *to* $D \Rightarrow \pi e \upsilon$

for V_{ub}

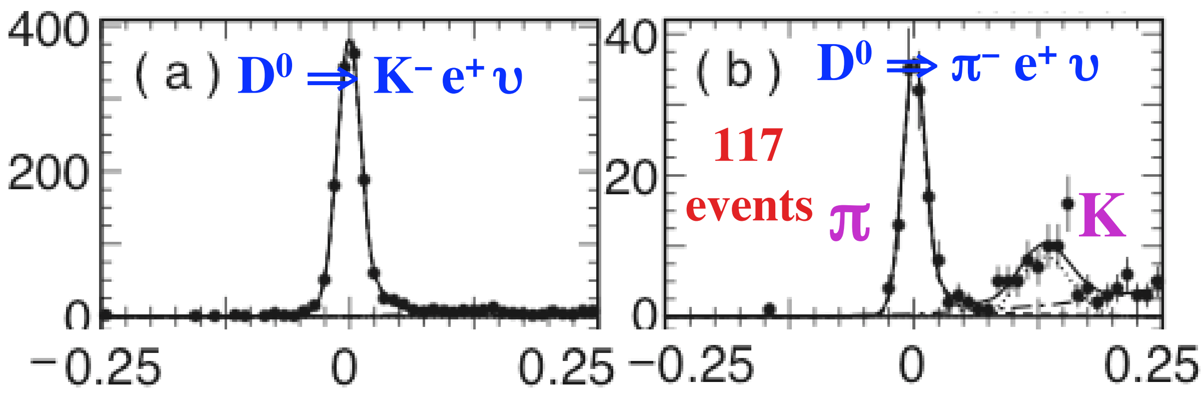
Also, ratios of $D \Rightarrow \pi e \upsilon$ *to* $D \Rightarrow \mu \upsilon$

and $D \Rightarrow K e \upsilon$ *to* $D_s \Rightarrow \mu \upsilon$

cancel CKM elements: Pure LQCD tests…

Exclusive Semileptonic

All with electrons: muons are too soft at ψ(3770)



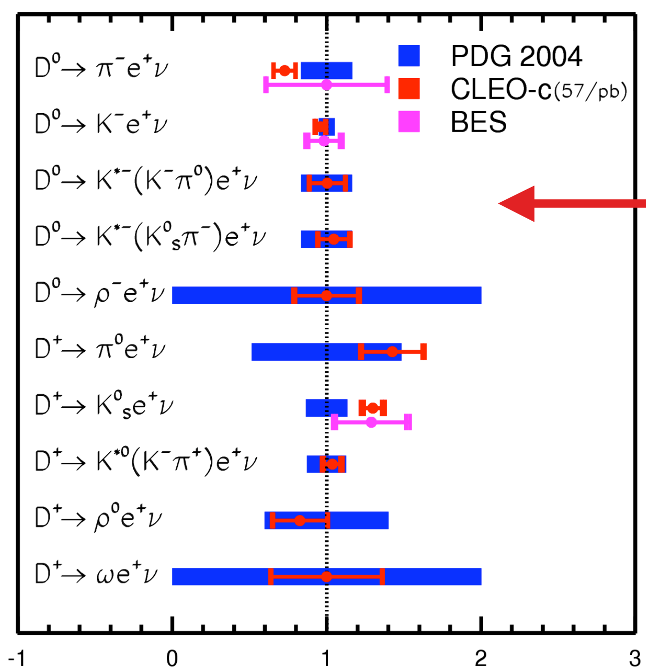
GeV

$U = E_{miss} - p_{miss}$ $U = E_{miss} - p_{miss}$

hep-ex/0506052
PRL 95, 181801/2 (2005) 56 pb^{-1}

Great kinematic K/π separation
(in addition to particle ID)

Very clean, especially given the neutrino…



Ratios of new CLEO-c to PDG World Ave
(two first observations!)

Also new BES results:
hep-ex/0606103

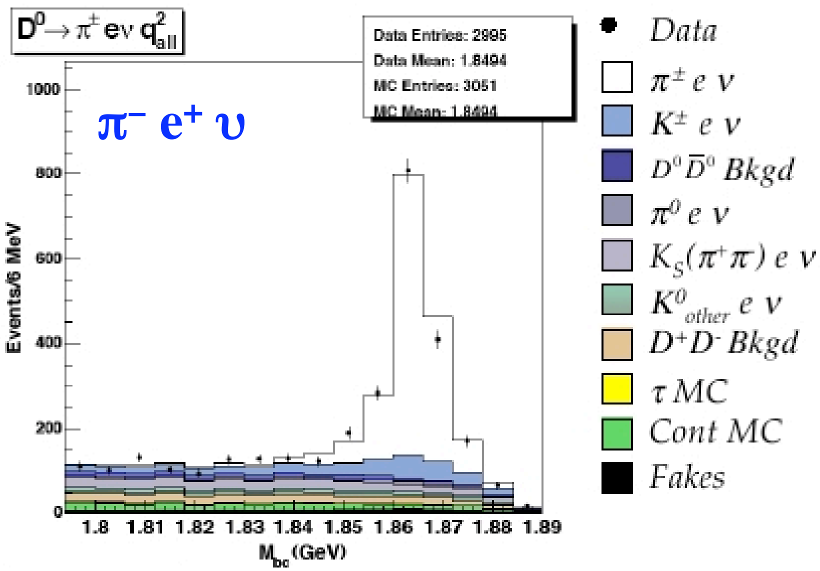
Form-factors with 5x data later this summer…
But CLEO-c also has ⇒

Semileptonics w/o Tags

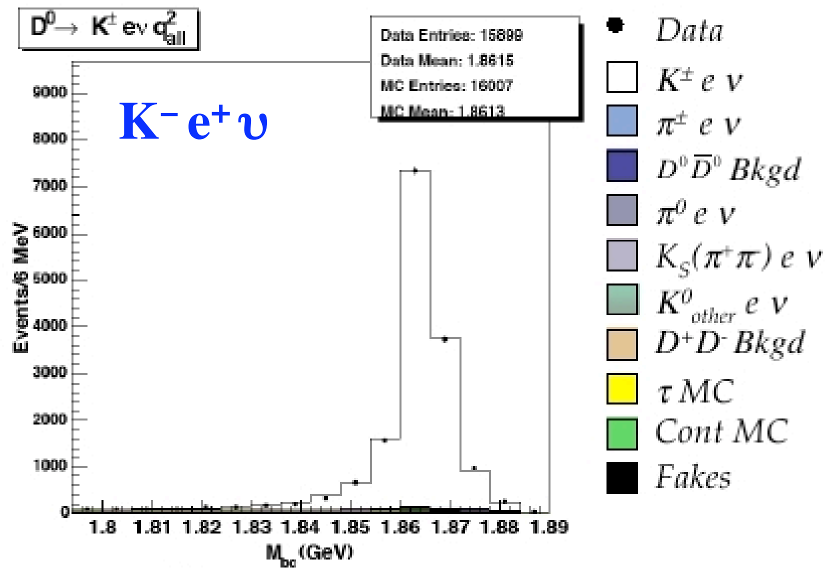
Uses neutrino reconstruction:
an alternative to tagging w/ higher efficiency

(q^2 resolution still more than sufficient)

Preliminary
281 pb^{-1}
FPCP06



M_{bc}



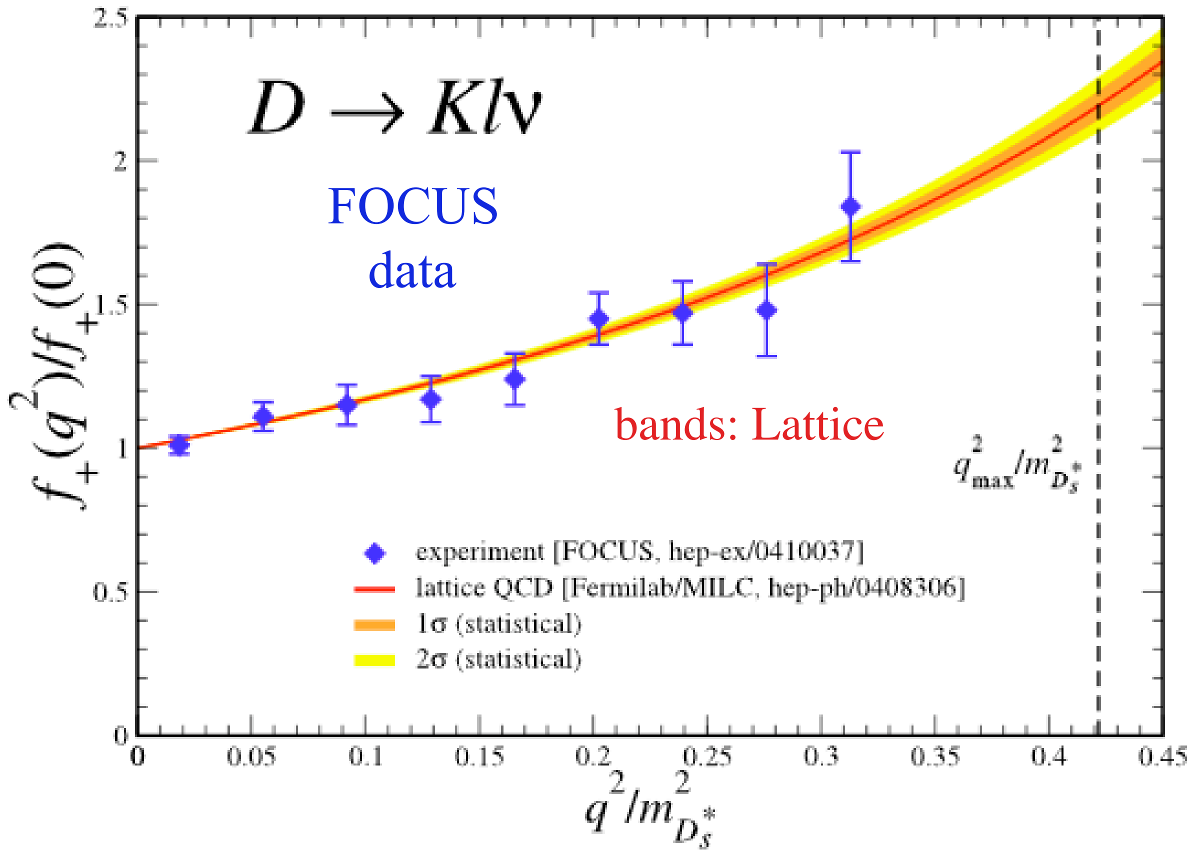
M_{bc}

Preliminary form-factor results from this analysis shown at FPCP.

-- Also analyze the $\pi^0 e^+ \upsilon$ and $K_S e^+ \upsilon$ modes as well.

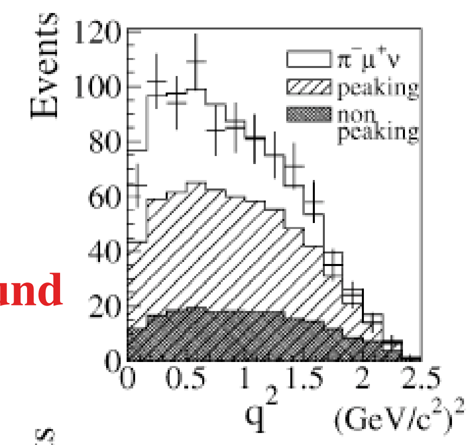
Current Form Factors

PLB 607, 233 (2005)

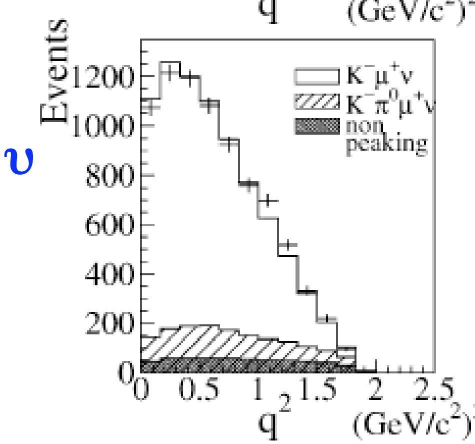


$\pi^- \mu^+ \upsilon$

larger background



$K^- \mu^+ \upsilon$



FOCUS: ~13,000 $Kl\nu$ events

CLEO-c: ~ 6,500 $Kl\nu$ events *(tagged)* in current 281 pb^{-1} sample

Big interest: use $D^0 \Rightarrow \pi^- l^+ \upsilon$ to understand $B^0 \Rightarrow \pi^- l^+ \upsilon$

CLEO-c sample is very clean!

Form Factors: B Factories

High statistics B factories:
"continuum tagging"

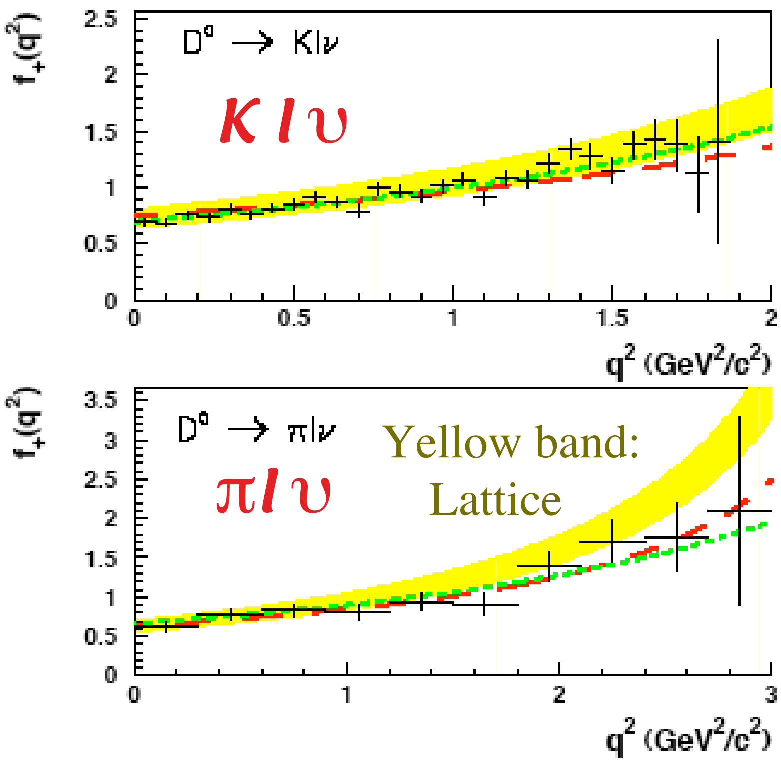
hep-ex/0604049
(to PRL) 282 fb^{-1}

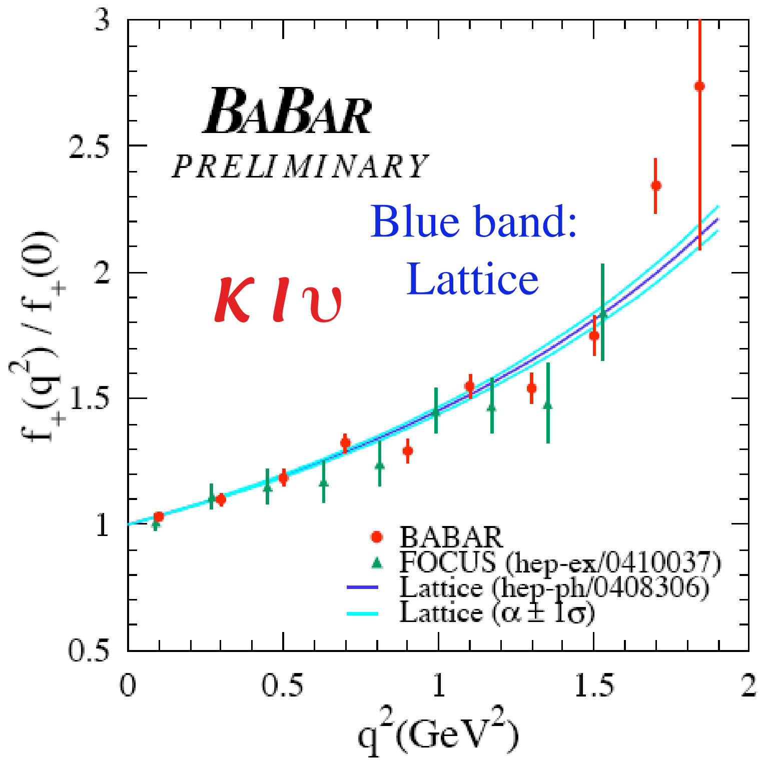
Belle $D^0 \Rightarrow K\,l\,\upsilon\ ,\ \pi\,l\,\upsilon$

$\pi l \upsilon$: 232 sig + 61 bkg

BaBar $D^0 \Rightarrow K\,l\,\upsilon$

Winter conf's
(2006) 75 fb^{-1}

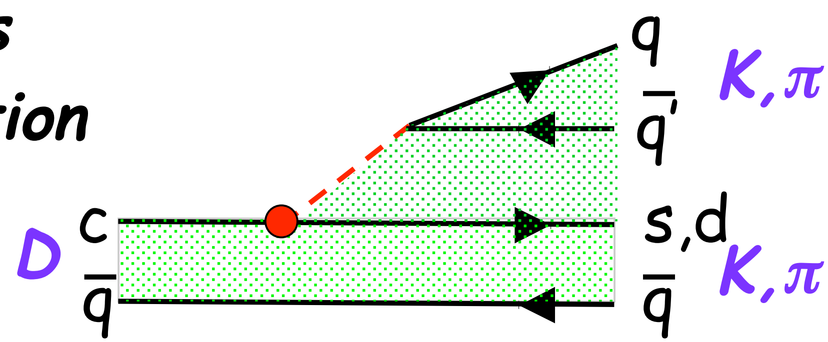




Charm as a QCD LAB III

Hadronic D Decays

Absolute Branching fractions (decay rates) for normalization
Cannot calculate



B decays most often to Charm:

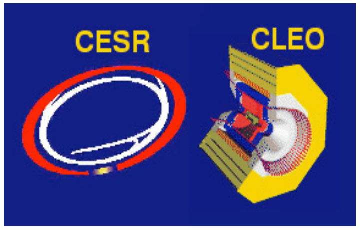
Form factors less of an issue for $B \Rightarrow D^* l \upsilon$

(use HQET methods…)

But B decay is normalized to charm

for V_{cb}

Absolute Branching Fractions



Method:

Double Tags: $D_{ij} = 2N_{DD}\mathcal{B}_i\mathcal{B}_j\,\varepsilon_{ij}$

Single Tags: $S_i = 2N_{DD}\mathcal{B}_i\,\varepsilon_i$

D/S Ratio independent of:

N_{DD}, $\int\mathcal{L}\,dt$, tag $\mathcal{B}_j$

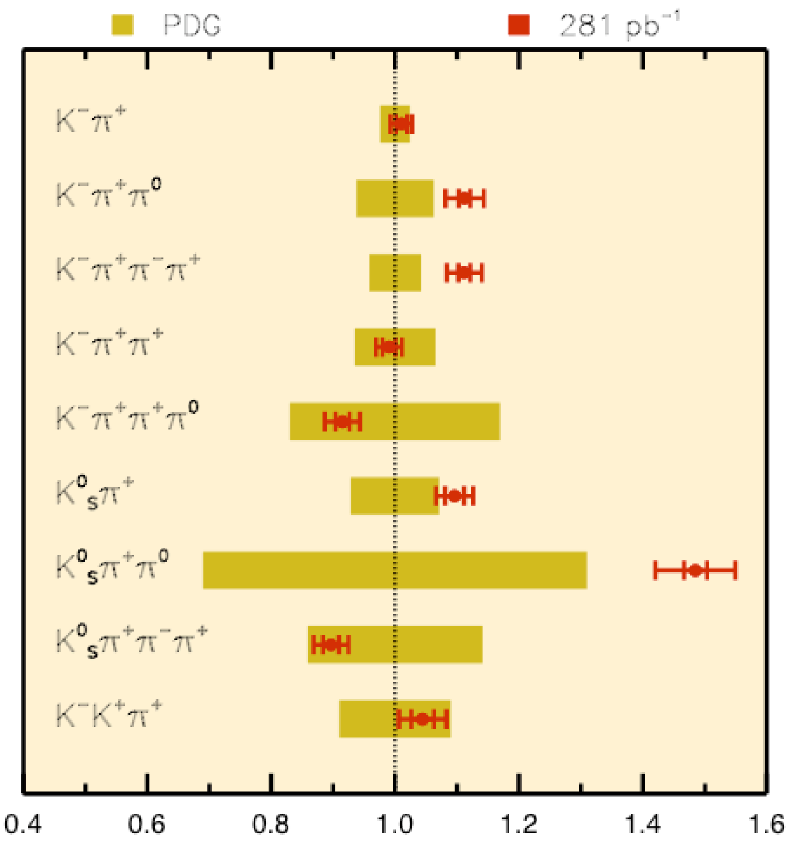
(& tag ε_j almost cancels)

Very Preliminary

from 281 pb^{-1}

See PRL95, 121801 (2005) for 56 pb^{-1}

Compare PDG to CLEO errors:



Ratios to **PDG World Ave**

(to keep modes on same scale…)

⇒ most precise already

(NOTE: includes final-state radiation; will make systematically higher…)

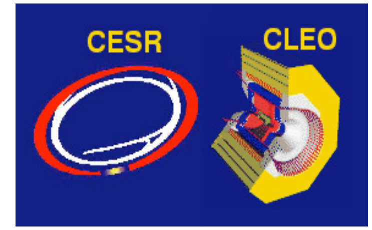
Systematics ~all from efficiency

(can study well with data; e.g. missing-mass for tracking efficiency, etc.)

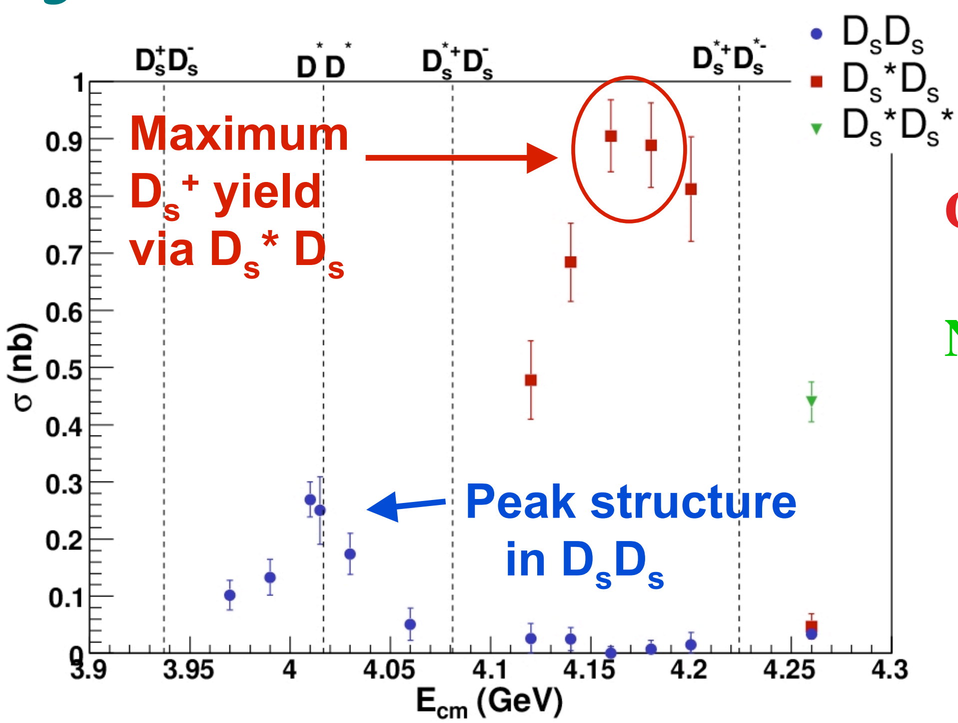
Also get precision cross-sections

(more on these later…)

D_s Absolute Branching Fractions



Scan: **Preliminary**
60 pb^{-1}
BFs: **Preliminary**
71 pb^{-1}



CLEO-c: 60 pb-1 energy scan

Now:
~ 200 pb^{-1} at or near 4170 MeV
+ more this summer

Mode	$\mathcal{B}$ (%) (CLEO-c)	$\mathcal{B}$ (%) PDG
K_SK^+	$1.28\ ^{+0.13}_{-0.12} \pm 0.07$	1.80±0.55
$K^+K^-\pi^+$	$4.54\ ^{+0.44}_{-0.42} \pm 0.25$	4.3±1.2
$K^+K^-\pi^+\pi^o$	$4.83\ ^{+0.49}_{-0.46} \pm 0.46$	-
$\pi^+\pi^+\pi^-$	$1.02\ ^{+0.11}_{-0.10} \pm 0.05$	1.00±0.28

Errors: 11% now; more data & more tag modes will improve

$\psi(3770)$: Mixing, non-DD decays, …

Naively, $\psi(2S)$: S-wave, $\psi(3770)$: D-wave

But ψ (3770) *must* have some S-wave to couple as much as it does to e^+e^-

BES has made many studies related to mixing of these states…

Older experiments: some indication that total resonant cross section exceeds the rate to make D pairs…

But not clear, and large errors.

BES

PLB 603, 130 (2004)

Newer results:

		CLEO-c	BES
$\sigma(D^+D^-)$	(nb)	$3.60 \pm 0.07\ ^{+0.07}_{-0.05}$	$3.58 \pm 0.09 \pm 0.31$
$\sigma(D^0\bar{D}^0)$	(nb)	$2.79 \pm 0.07\ ^{+0.10}_{-0.04}$	$2.56 \pm 0.08 \pm 0.26$

PRL 95, 121801 (2005) 56 pb^{-1}

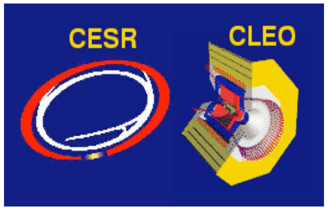
Tiny rates found for some particular non-DD modes…

But, need total cross-section to check for inclusive excess:

CLEO-c measures: σ_{tot} = $(6.38 \pm 0.08\ ^{+0.41}_{-0.30})$ nb

This gives non-DD as : $(-0.01 \pm 0.08\ ^{+0.41}_{-0.30})$ nb

No need for non-DD excess? Limit at ~10% level...



PRL 96, 092002 (2006) 281 pb^{-1}

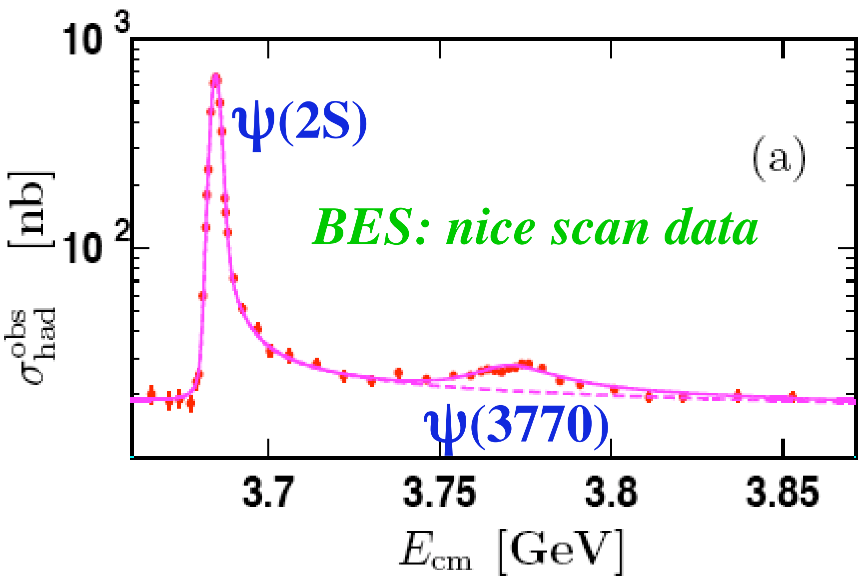
ψ(3770) ⇒ *non-DDbar decays*

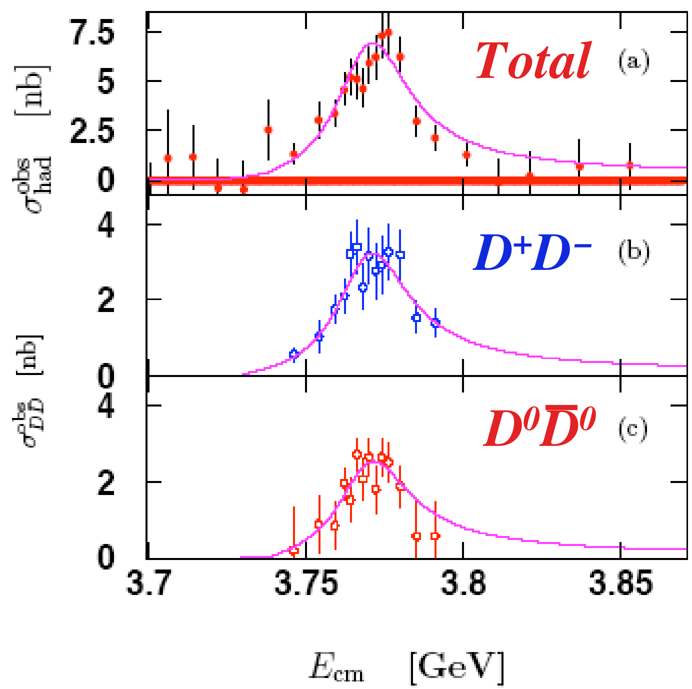
BES results: maybe there is significant non-DD after all ?!?
Two different analyses;

hep-ex/0606105
hep-ex/0606107

$\mathcal{B}(\psi(3770) \Rightarrow non\text{-}DD) = (16.1 \pm 1.6 \pm 5.7)\%$ (w/ R_{had})

$\mathcal{B}(\psi(3770) \Rightarrow non\text{-}DD) = (16.4 \pm 7.3 \pm 4.2)\%$ (w/ resonance fits)





Very detailed papers posted exactly one week ago to hep-ex.
Method of treatment of radiative corrections may be important ?
(Hard for me to digest papers with a beautiful beach so close by! My apologies…)

The Future: BESIII & BEPCII

B E S

Energy range	1 – 2.1 GeV
Optimum energy	1.89 GeV
Luminosity	1×10^{33} cm^{-2}s^{-1} @ 1.89 GeV
Injection	Full energy injection: 1.55 ??1.89 GeV Positron injection speed > 5 0 mA/min
Synchrotron mode	250 mA @ 2.5 GeV

BEPCII accelerator

Dec'07:
test run for luminosity
Dec'08:
achieve 3×10^{32} cm^{-2} s^{-1}

Yearly data possibilities:
(10^7 s at 1/2 peak lumi = 5 fb^{-1})

BESIIII detector: all new !

CsI calorimeter

Precision tracking

Time-of-flight + dE/dx PID

Data Sample	Central-of-Mass (MeV)	#Events per year
J/ψ	3097	10×10^9
$\tau^+\tau^-$	3670	12×10^6
$\psi(2S)$	3686	3.0×10^9
$D^0\overline{D}^0$	3770	18×10^6
D^+D^-	3770	14×10^6
$D_S^+D_S^-$	4030	1.0×10^6
$D_S^+D_S^-$	4170	2.0×10^6

For more information, see Weiguo Li at FPCP06

BESIII Physics Potential

BES

Many exciting ways to use higher luminosity !

Charmonium states: J/ψ, $\psi(2S)$, $\eta_c(1S)$, $\eta_c(2S)$, χ_{cJ}, and h_c

Exotics: hybrids, glueballs and other exotics in J/ψ and $\psi(2S)$ radiative decays;

Open charm physics: D, D^+, D_s (like CLEO-c)

- Improve statistics-hungry analyses
- Improved reach for mixing, rare decays, CP violation
- Quantum correlations, strong $K\pi$ phase, ...
- Spectroscopy via Dalitz plots

Energy scans: R_{had}, resonances, DD composition, ...

Tau Physics

No doubt many more innovations...

Also PANDA $p\bar{p}$ @ GSI !

Charm 2006 workshop next week in Beijing

Conclusion & Outlook

We are in a Charm Physics Renaissance

BESII showed us the richness of charm factory datasets
CLEO-c now in its prime: precise results aid flavor physics
$\Rightarrow$ both have re-written parts of the PDG re: charm…

CLEO-c will also do D_s: decay constants, semilept., abs. Hadr. BF's
& novel analyses at $\psi(3770)$ (quantum correl's, CP tags, etc.)
Great promise of BESIII upgrade beginning next year !
… plus p-pbar for charmonia will return with PANDA.

Much untapped potential at B factories
-- Precise mixing analyses
-- Hadronic BR's (esp. baryons), Dalitz plot analyses, Rare, …

What else will CDF & D0 learn to do with their large rates ???

Fixed target "done", but analysis machine goes on…
A *big* lesson here:
Let's hope Charm & B factories can do as well after their runs !

Selected Topics That Didn't Fit

Numerous J/ψ, $\psi(2S)$, χ decays	(BES & CLEO-c)
Dalitz analyses of D and J/ψ	(Many exp'ts)
Updates on $D_{sJ}(2317,2460)$ decays	(BaBar)
Inclusive D semileptonic	(CLEO-c)
$Ds \Rightarrow \varphi X$, ηX , $\eta' X$	(CLEO-c)

etc…

Acknowledgments

BaBar: Riccardo Faccini
BES: Chang-Zheng Yuan, Fred Harris
CDF: Matt Herndon
FOCUS: John Cumalat
Belle: Yoshi Sakai
CLEO: David Asner, Hanna Mahlke, Sheldon Stone
D0: Brendan Casey
SELEX: Jim Russ