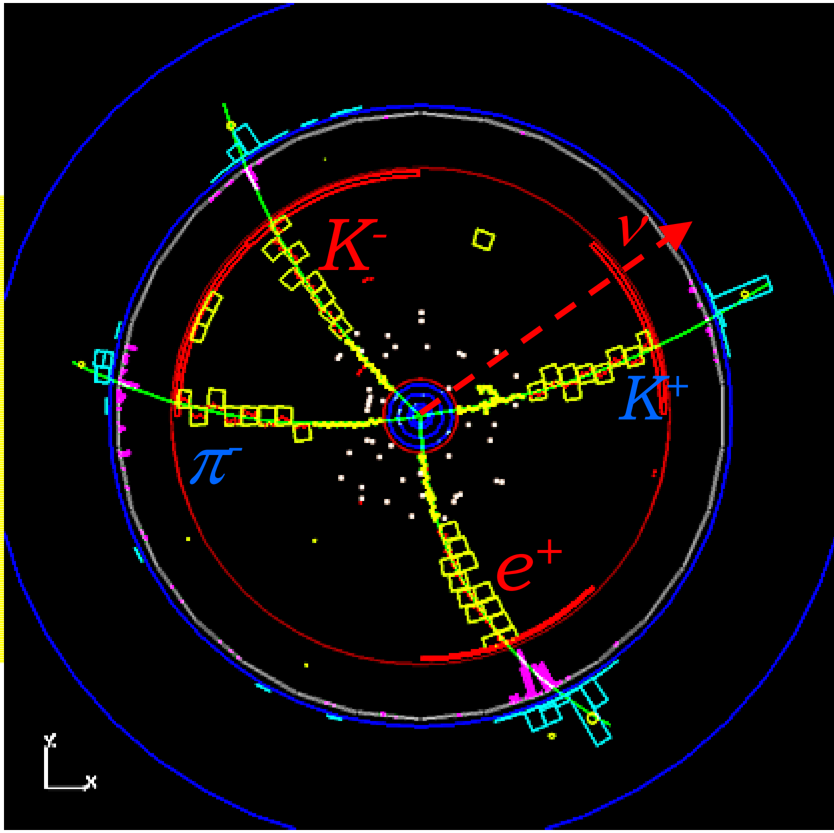
CKM Physics & Beyond the Standard Model
Physics with Charm

Outline:

1) *CKM Physics*:
Charm's role in testing the Standard Model description of Quark Mixing & CP Violation:
- Lifetimes
- Hadronic Decays
- Leptonic Decays
- Semileptonic Decays



$\psi(3770) \to D^0\ D^0$

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

2) *Physics Beyond the Standard Model*
- D mixing
- D CP Violation
- D Rare Decays

Outlook & conclusion

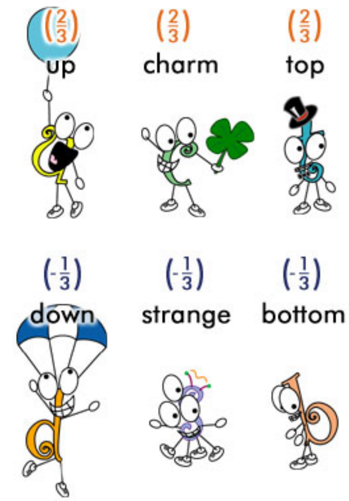
Not covered in this talk: D hadron spectroscopy & charmonium see talk of Jin Shan.

Ian Shipsey,
Purdue University

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

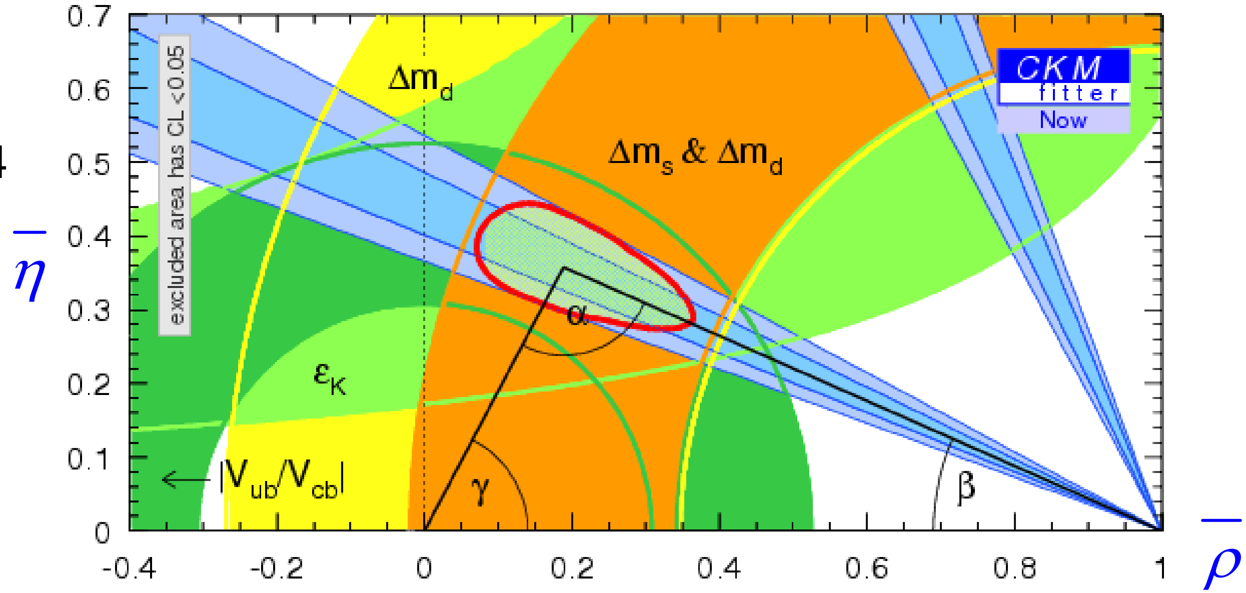
3 examples: Universe, kaons, beauty but Standard Model CP violation too small, need additional sources of CP violation.

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.

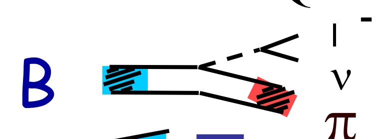
Precision Quark Flavor Physics: charm's role

2004

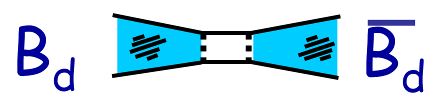


The B$_d$ system unitarity triangle is limited by systematic errors from QCD:

Form factors in semileptonic (β) decay $|V_{ub}|, |V_{cb}|$



Decay constants in B mixing $|V_{td}|, |V_{ts}|$



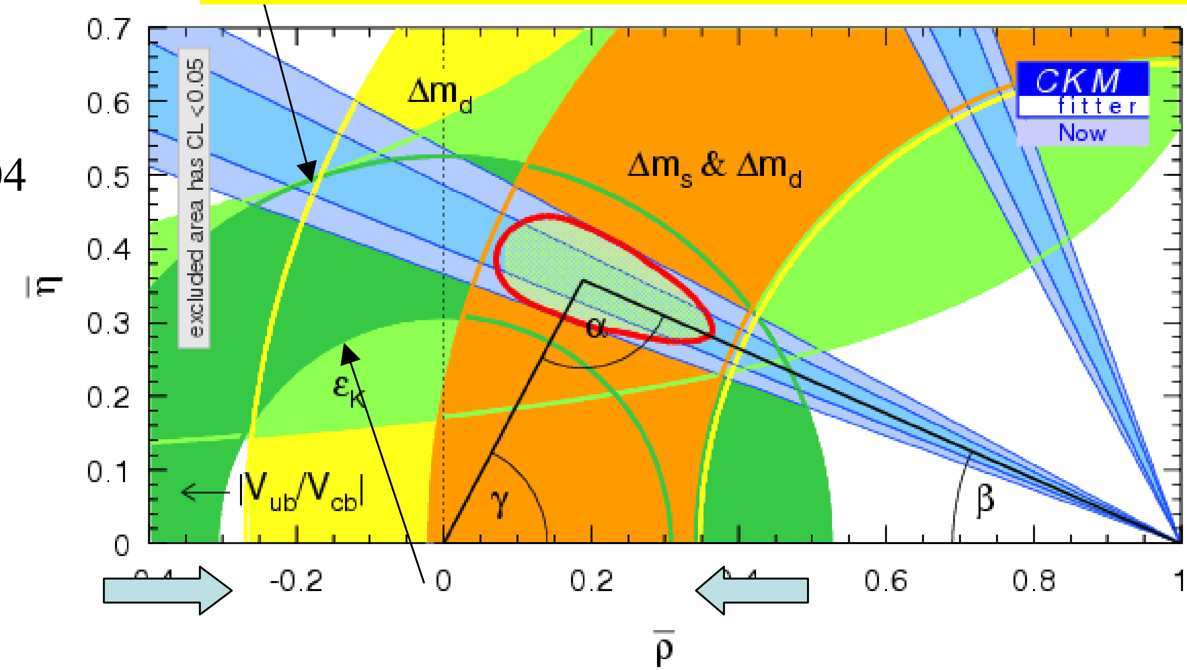
D system- the CKM matrix elements are known (tightly constrained to <1% by the unitarity of the matrix).

➔Work back from *measurements* of *absolute rates* for leptonic and semileptonic decays yielding decay constants and form factors to *test* QCD calculations.

In addition as Br(B➔ D)~100% *absolute* D branching ratios normalize B physics.

Precision theory + charm = large impact

2004



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

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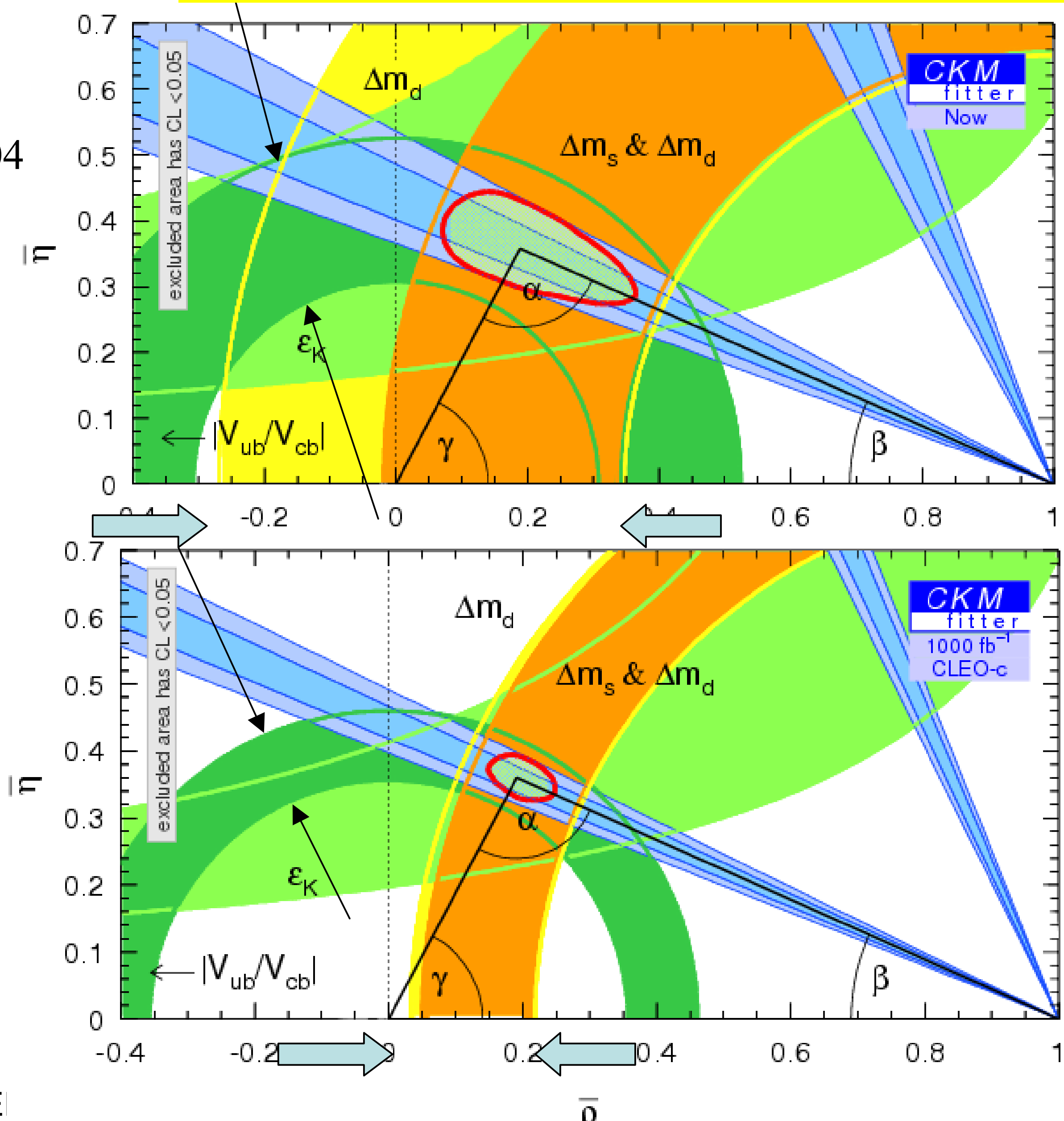
500 fb-1 @ BABAR/Belle

Precision theory + charm = large impact

2004



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

The Experiments

Results used in this talk have been obtained by the following Collaborations:

	Fixed Target		e^+e^-			$p\bar{p}$
	E791	FOCUS	LEP	CLEO	BaBar/Belle	CDF
Beam	Hadron	Photon	$e^+e^- \to Z^0$	e^+e^-		$p\bar{p}$
$K^-\pi^+$	$\sim 2 \times 10^4$	$\sim 2 \times 10^5$	$\sim 10^4$ /expt.	$\sim 2 \times 10^5$	$\sim 10^6$	$\sim 10^6$
σ_t	~ 40 fs	~ 40 fs	~ 100 fs	~ 140 fs	~ 160 fs	~ 50 fs

The B Factories and CDF now have the largest charm samples.

New this year:

(Pilot run) → CLEO-c

	BESII	CLEO-c
Beam	$e^+e^- \to \psi(3770)$	
$K^-\pi^+$	$\sim 2.7 \times 10^3$	$\sim 5.4 \times 10^3$
σ_t	Not applicable	Not applicable

Exceptionally low background charm samples were obtained at BESII & CLEO-c ideal for measuring absolute charm branching ratios.

Note: $K^-\pi^+$ is # reconstructed in published analyses, not total collected.

Charm Hadron Lifetimes

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

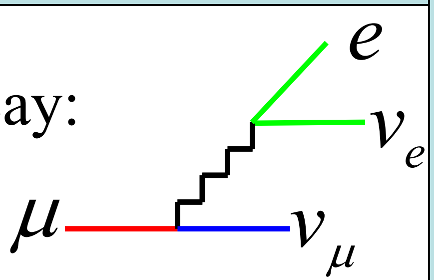
Lifetime needed to compare Br(expt) to Γ (theory)

Interpreted within O.P.E.

$$\Gamma(H_c) = \Gamma_{spect} + O(1/m_c^2) + \Gamma_{PI,WA,WS}(H_c) + O(1/m_c^4)$$

Spectator effects (PI.WA,WS) are $O(1/m_c^3)$ but phase space enhanced

Muon decay:



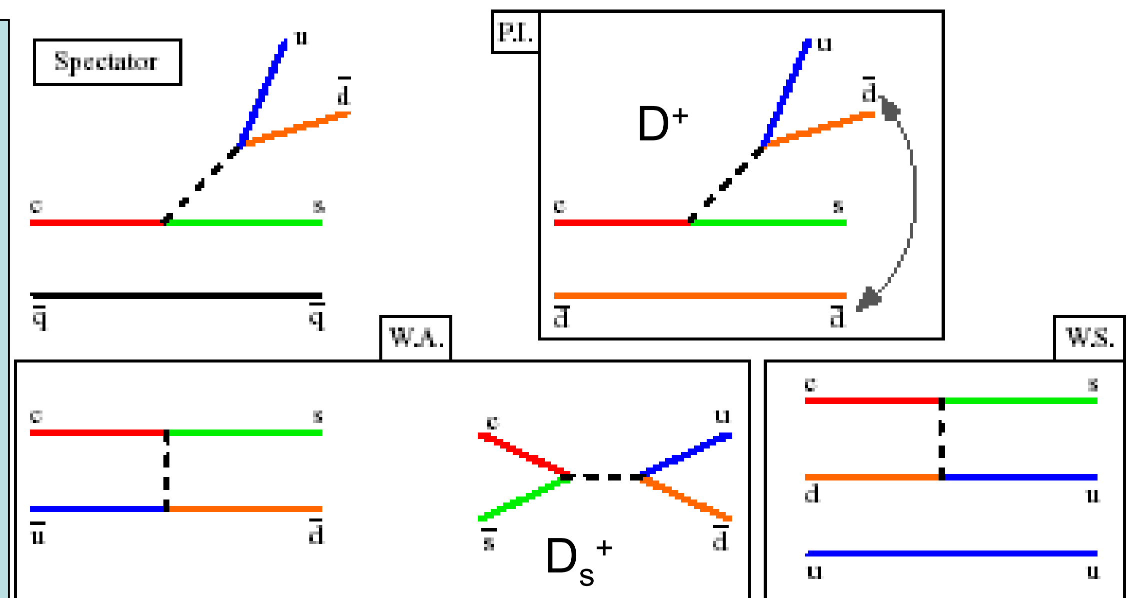
$$\Gamma_\mu = \frac{G_F^2 m_\mu^5}{192\pi^3}$$

Naïve spectator model:

$$\Gamma_{charm} = (2+3)\Gamma_\mu \quad e,\mu \quad ud$$

$$\Gamma_{charm} = \frac{G_F^2 m_c^5}{192\pi^3}|V_{cs}|^2 \Rightarrow \tau_{charm} = 700\,fs$$

$\tau(D^+) \sim 1{,}000$ fs $\tau(D^0) \sim 400$ fs.

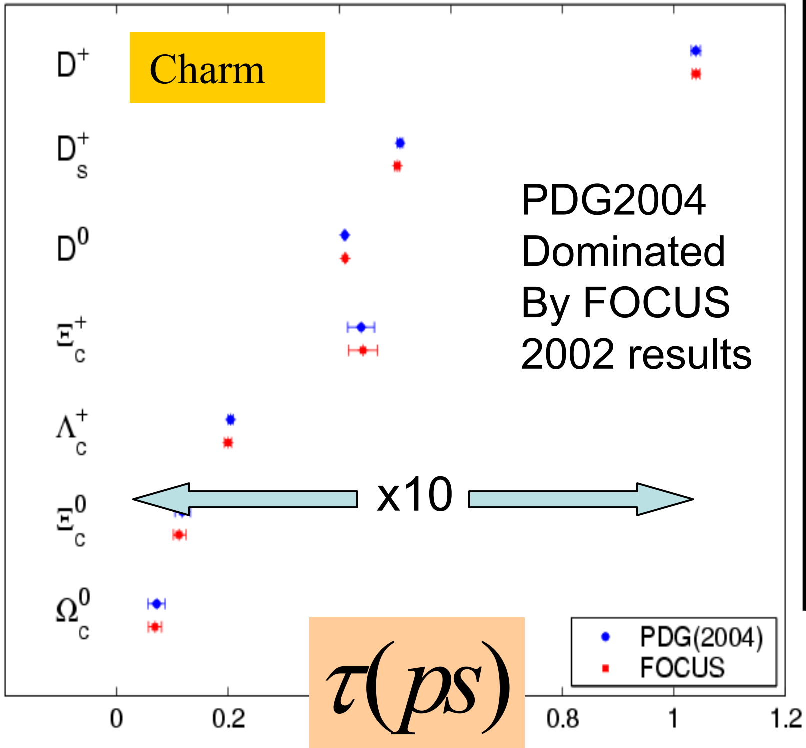


baryons

Gross features of lifetime hierarchy can be explained

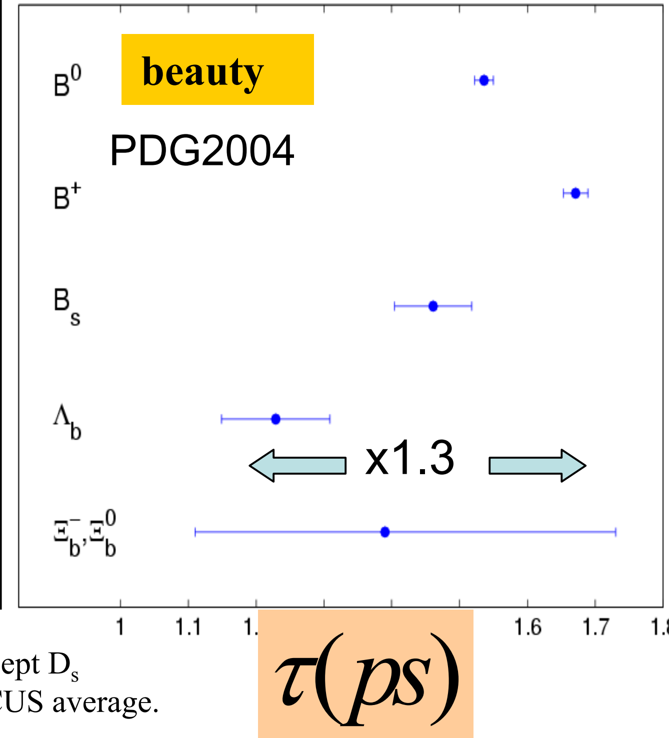
SELEX, FOCUS, CLEO
E791 E687

Charm Lifetimes



$\tau(D^+)$	$1040 \pm 7\ fs$
$\tau(D_s)$	$504 \pm 4\ fs$
$\tau(D^0)$	$410.3 \pm 1.5\ fs$
$\tau(\Xi^+{}_c)$	$442 \pm 26\ fs$
$\tau(\Lambda_c)$	$200 \pm 6\ fs$
$\tau(\Xi^0{}_c)$	$112^{+13}_{-10}\ fs$
$\tau(\Omega_c)$	$69 \pm 12\ fs$

Lifetimes are PDG2004 except D_s which is a PDG2004 + FOCUS average.



D^+ 7 ‰, D^0 4 ‰, D_s 8 ‰, Λ_c 3%, Ξ^0 10%, $\Xi^+{}_c$ 6 %, Ω_c 17%
some lifetimes known as precisely as kaon lifetimes.

$$\frac{\tau(D^+)}{\tau(D^0)} \approx 2.5 \qquad \frac{\tau(B^+)}{\tau(B^0)} \approx 1.1$$

PDG2004

Charm quarks more influenced by hadronic environment than beauty quarks.

Errors on lifetimes are *not* a limiting factor in the measurement of absolute rates.

Status of Absolute Charm Branching Ratios

Poorly known → Br

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

Measured very precisely → τ

decay constants

form factors

	Mode	PDG04 (%)	Error (%)
D^+		$0.08^{+0.17}_{-0.05}$	100
D_s^+	$\mu\nu$	0.60 ± 0.14	24
	$\pi^- e^+ \nu$	$0.39^{+0.23}_{-0.11} \pm .04$	45
D^o	$K^-\pi^+$	3.80 ± 0.09	2.4
D^+	$K^-\pi^+\pi^+$	9.2 ± 0.6	6.5
D_s^+	$\phi\pi^+$	3.6 ± 0.9	25
Λ_c	$pK^-\pi^+$	5.0 ± 1.3	26
J/ψ	$\mu^+\mu^-$	5.88 ± 0.10	1.7

Key hadronic charm decay modes used to normalize B physics (the last five rows of the table)

Charm produced at B Factories/Tevatron or at dedicated FT experiments allows relative rate measurements but absolute rate measurements are hard because backgrounds are sizeable & because # D's produced is not well known.

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

Backgrounds are large. (→ #X Observed)

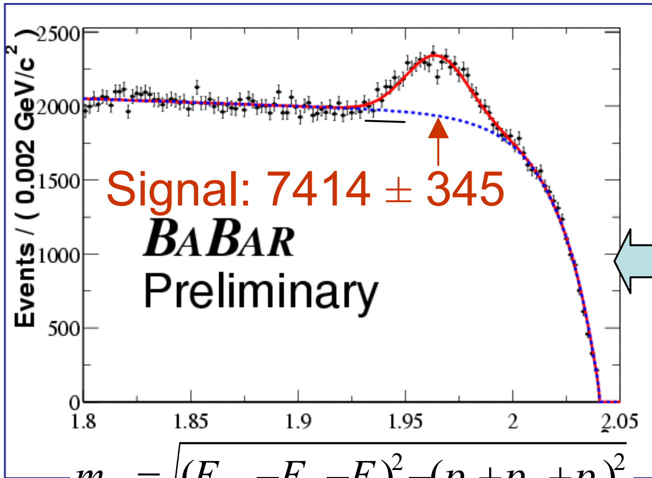
#D's produced is not well known. (→ #D's produced)

New Measurement of $\mathcal{B}(D_s^+ \to \phi\, \pi^+)$

ICHEP ABS11-0952

1: $B^0 \to D_s^{*+} D^{*-}$: *partial* reconstruction

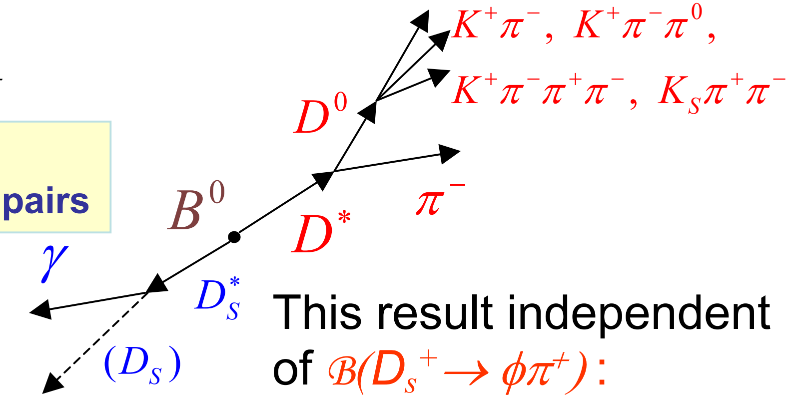
- D_s^+ from $D_s^{*+} \to D_s^+ \gamma$ is not reconstructed
- Pair D^{*-} ($\to D^0 \pi$) & γ, assume from $B^0 \to D_s^{*+} D^{*-}$



$$m_{miss} = \sqrt{(E_{beam} - E_{D^*} - E_\gamma)^2 - (p_B + p_{D^*} + p_\gamma)^2}$$

Recoil mass

Data sample: 124 million B pairs



This result independent of $\mathcal{B}(D_s^+ \to \phi\pi^+)$:

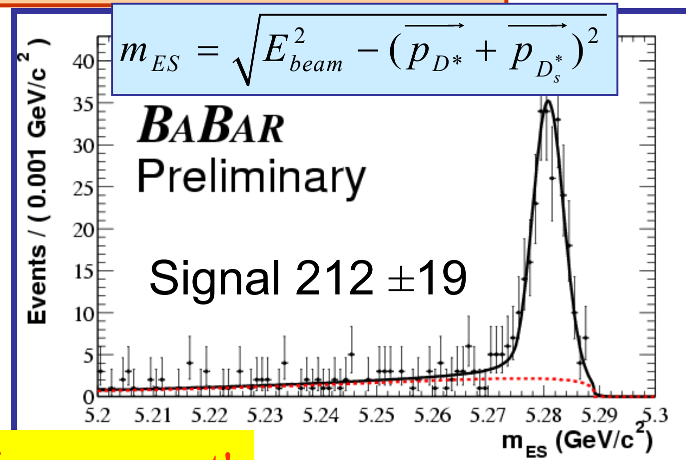
$\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.85 \pm 0.09_{(stat)} \pm 0.16_{(syst)})\%$ (A)

2: $B^0 \to D_s^{*+} D^{*-}$: *full* reconstruction

- $D_s^+ \to \phi\, (\to K^+K^-)\, \pi^+$ fully reconstructed

$\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) \times \mathcal{B}(D_s^+ \to \phi\, \pi^+) = (8.71 \pm 0.78_{(stat)}) \times 10^{-4}$

$$m_{ES} = \sqrt{E_{beam}^2 - (\vec{p}_{D^*} + \vec{p}_{D_s^*})^2}$$



Divide by (A) — 12.5% total error (7.5%) syst

$\mathcal{B}(D_s^+ \to \phi\, \pi^+) = (4.71 \pm 0.47_{(stat)} \pm 0.35_{(syst)})\%$

BIG improvement!

$\mathcal{B}(D_s^+ \to \phi\, \pi^+) = (3.6 \pm 0.9)\%$ (PDG) (25%)

CLEO Similar Partial recons. $B^0 \to D_s^{*+} D^{*-}$

$$\Gamma(D_s^+ \to \phi\pi) / \Gamma(D^0 \to K^-\pi^+)$$

Absolute Charm Branching Ratios at Threshold (CLEO-c)

CESR (10 GeV)
→ CESR-c (3-4GeV)

CLEO III Detector
→ CLEO-c Detector

CESR upgraded to CESR-c: 12 wigglers (for damping at low energy)

6 last summer 6 this summer

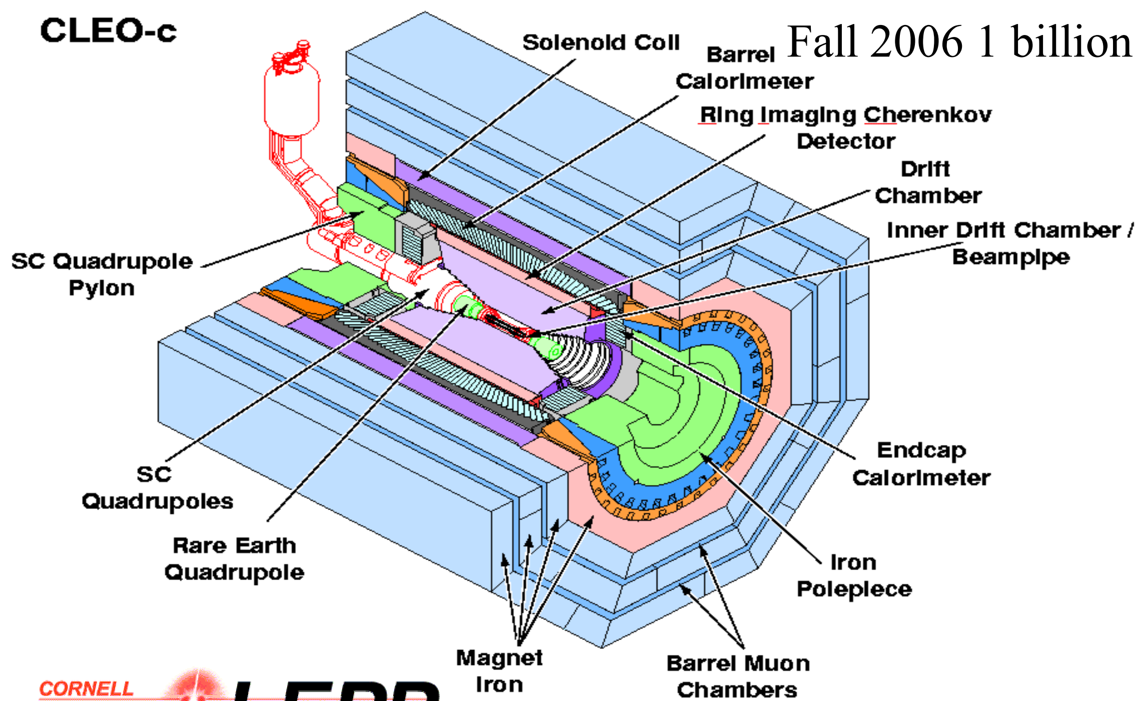
9/03-3/04 6 wiggler Pilot Run L=4.6 $\times 10^{31}$ (as expected)

57.1 pb^{-1} *at* $\psi(3770)$ ($\times 6$ MarkIII, $\times 3$ BESII)

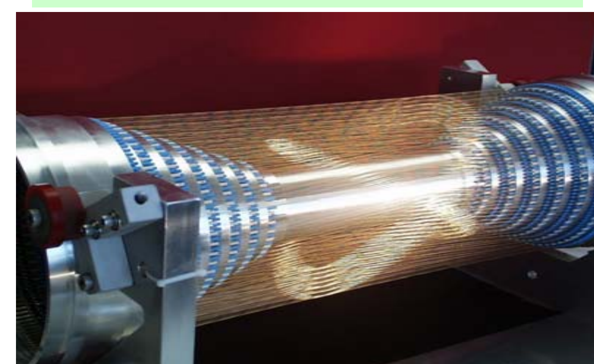
Fall 2004 goal: 3 fb^{-1} at $\psi(3770)$ ($D\overline{D}$) ($\times 60$ data in hand)

Fall 2005 goal: 3 fb^{-1} at ~ 4140 MeV $D_s\overline{D}_s$ threshold

Fall 2006 1 billion J/ψ



Minor modifications: replaced silicon with 6 layer low mass inner drift chamber summer '03. + B 1.5T→ 1.0T



CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

ICHEP ABS8-0775

Absolute Charm Branching Ratios at Threshold (CLEO-c)

- Operation at $\psi(3770) \rightarrow DD$

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57 pb^{-1} ~ 340,000 DD pairs

1st CLEO-c DATA

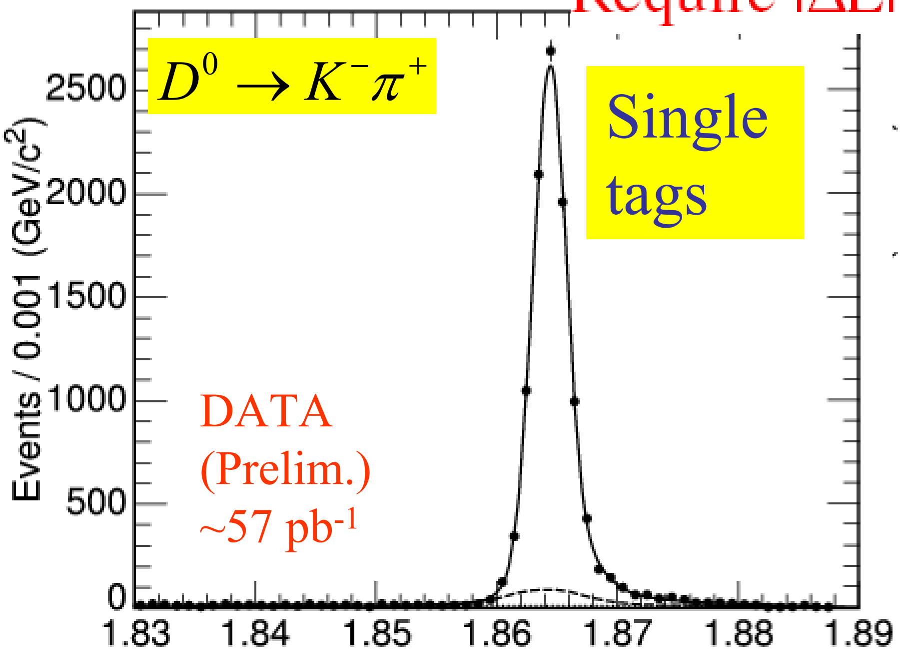
•Measurements use D tagging: exclusive reconstruction of 1 D
• D's: large, low multiplicity, branching ratios ~1-15%
• high reconstruction efficiency, favorable S/N

$$M_D = \sqrt{E_{beam}^2 - |p_D|^2}$$

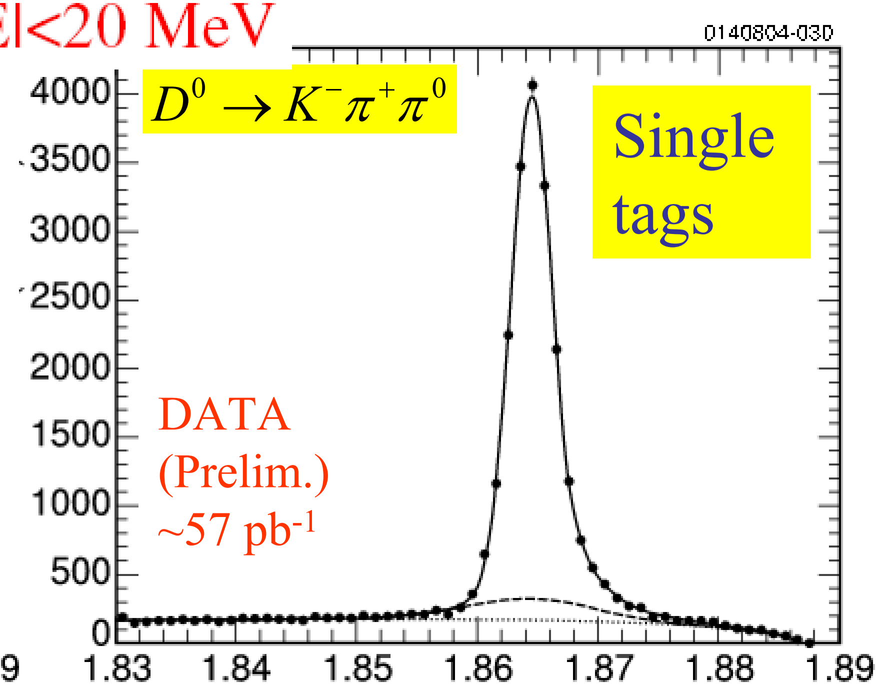
$$\Delta E = E \qquad - E$$

➔ High net tagging efficiency: ~25% of all D's produced are reconstructed (achieved).

Require |ΔE|<20 MeV



D^0 candidate Mass (GeV)



D^0 candidate Mass (GeV)

Absolute Charm Branching Ratios at Threshold

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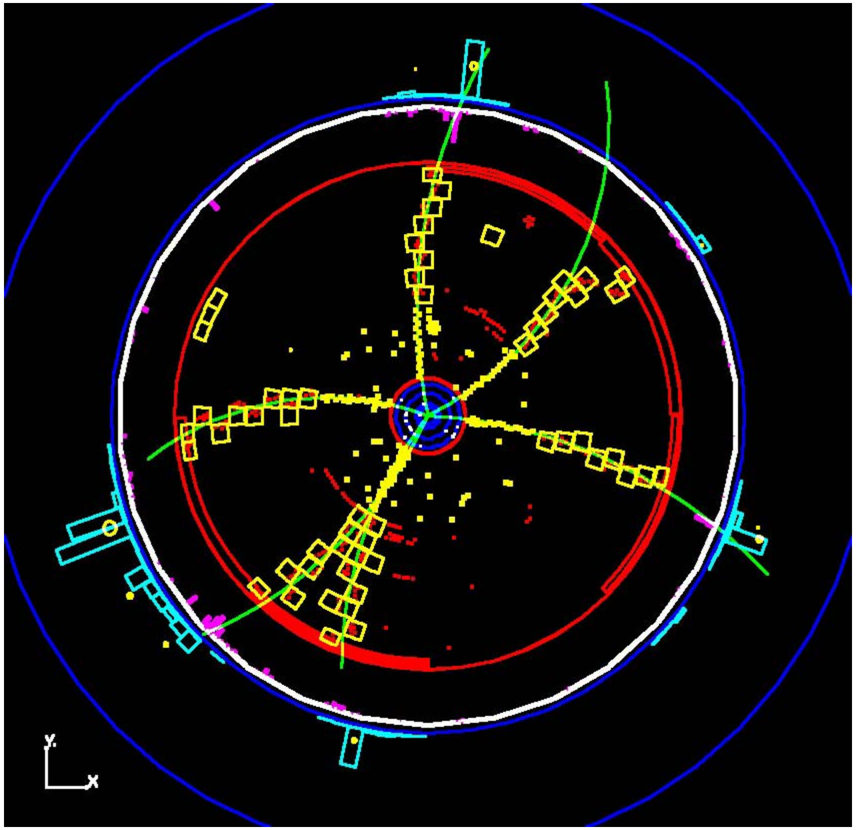
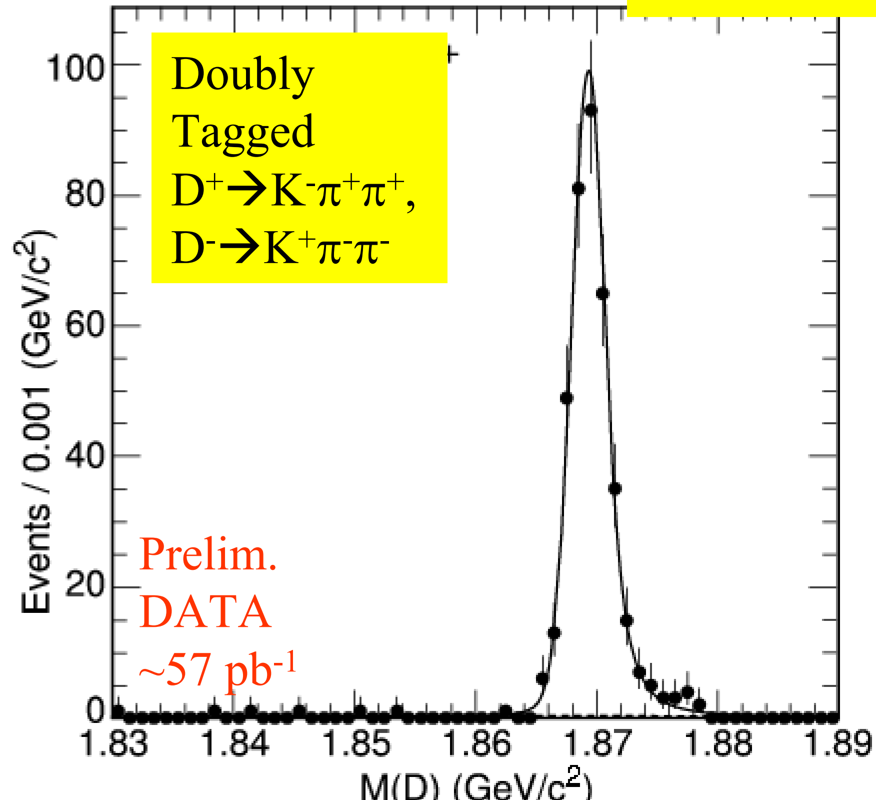


$$D^+ \to K^-\pi^+\pi^+,\ D^- \to K^+\pi^-\pi^-$$

Preliminary



D candidate mass (GeV)

Tagging effectively creates a single D beam

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

Where # of D's = # of tagged events

Absolute Charm Hadronic Branching Ratios and $\sigma\left(D\bar{D}\right)$

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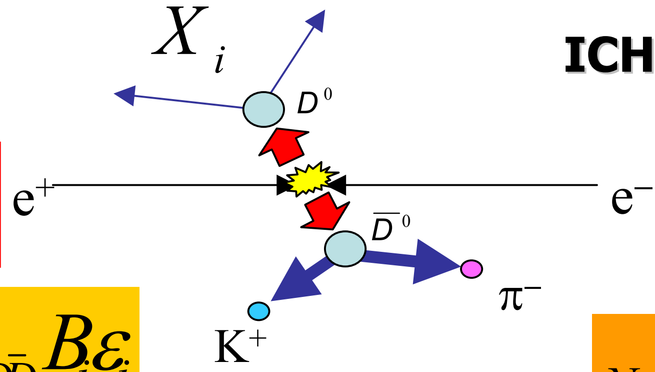
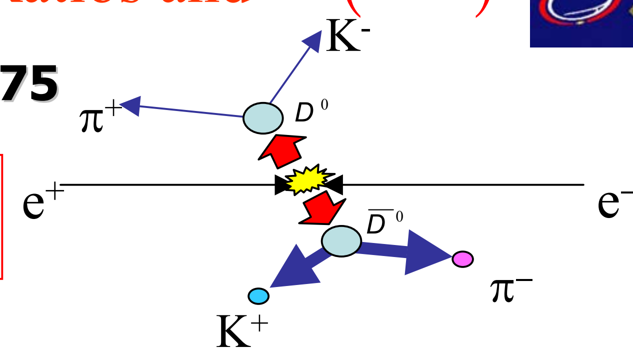
Single tagged D



$$N_i = 2N_{D\bar{D}}B_i\varepsilon_i$$

Technique pioneered by Mark III
5 modes, combined χ^2 fit extract 5 B_i & N(DD), convert to σ with Ldt.

Double tagged D



$$N_{D\bar{D}} = \frac{N_i^2}{4N_{ii}}\frac{\varepsilon_{ii}}{\varepsilon_i^2}$$

$$N_{ii} = N_{D\bar{D}}B_i^2\varepsilon_{ii}$$

$\sigma\left(D\bar{D}\right)$ required to estimate reach.

Parameter	Fitted Value
$N_{D^0\bar{D}^0}$	$(1.98 \pm 0.04 \pm 0.03) \times 10^5$
$\mathcal{B}\left(D^0 \to K^-\pi^+\right)$	$0.0392 \pm 0.0008 \pm 0.0023$
$\mathcal{B}\left(D^0 \to K^-\pi^+\pi^0\right)$	$0.143 \pm 0.003 \pm 0.010$
$\mathcal{B}\left(D^0 \to K^-\pi^+\pi^+\pi^-\right)$	$0.081 \pm 0.002 \pm 0.009$
$N_{D^+D^-}$	$(1.48 \pm 0.06 \pm 0.04) \times 10^5$
$\mathcal{B}\left(D^+ \to K^-\pi^+\pi^+\right)$	$0.098 \pm 0.004 \pm 0.008$
$\mathcal{B}\left(D^+ \to K_S^0\pi^+\right)$	$0.0161 \pm 0.0008 \pm 0.0015$
$\mathcal{B}\left(D^0 \to K^-\pi^+\pi^0\right)/\mathcal{B}\left(D^0 \to K^-\pi^+\right)$	$3.64 \pm 0.05 \pm 0.17$
$\mathcal{B}\left(D^0 \to K^-\pi^+\pi^+\pi^-\right)/\mathcal{B}\left(D^0 \to K^-\pi^+\right)$	$2.05 \pm 0.03 \pm 0.14$
$\mathcal{B}\left(D^+ \to K_S^0\pi^+\right)/\mathcal{B}\left(D^+ \to K^-\pi^+\pi^+\right)$	$0.164 \pm 0.004 \pm 0.006$

$\sigma(D^0\overline{D^0}) = (3.47 \pm 0.07 \pm 0.15)$nb
$\sigma(D^+D^-) = (2.59 \pm 0.11 \pm 0.11)$nb
$\sigma(DD) = (6.06 \pm 0.13 \pm 0.23)$nb
} CLEOc

$\sigma(DD) = (5.0 \pm 0.5)$nb (Mark III)

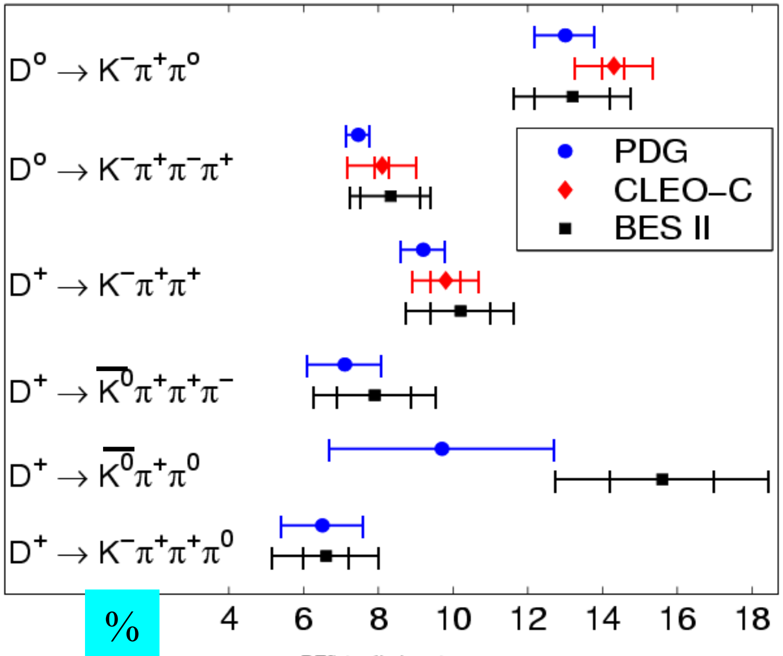
Cross section in agreement with Mark III

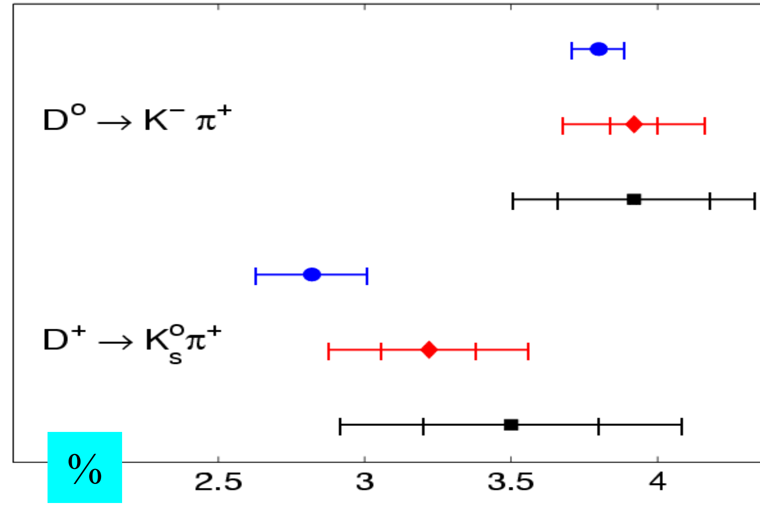
Meson factory figure of merit:

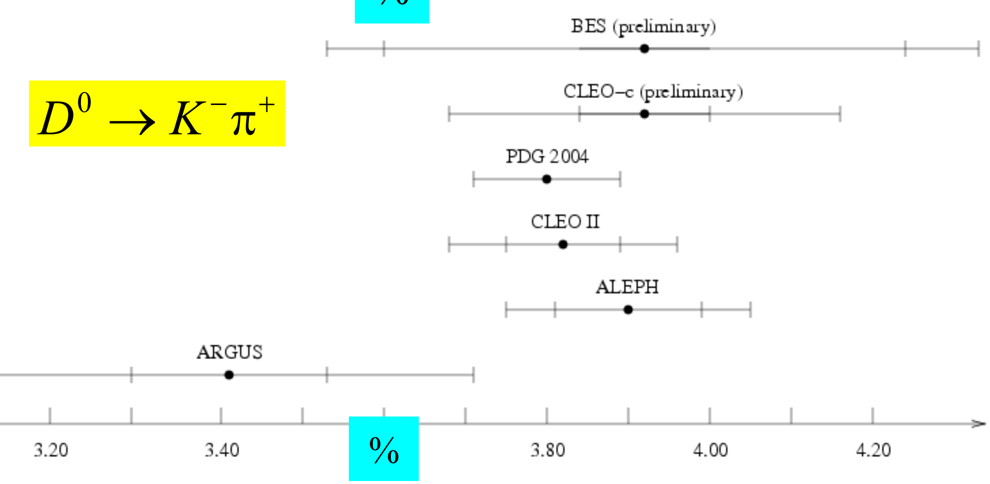
$$\frac{\text{\#B tags @B Factory}}{\text{\#D tags @Charm } Factory} = \frac{\sigma(BB)\ \varepsilon\text{tag} \int \text{Ldt}=500\text{fb}^{-1}}{\sigma(DD)\ \varepsilon\text{tag} \int \text{Ldt}=3\text{fb}^{-1}} \sim 1$$

BESII similar analysis using 8 modes.
but with less statistics comparison➔

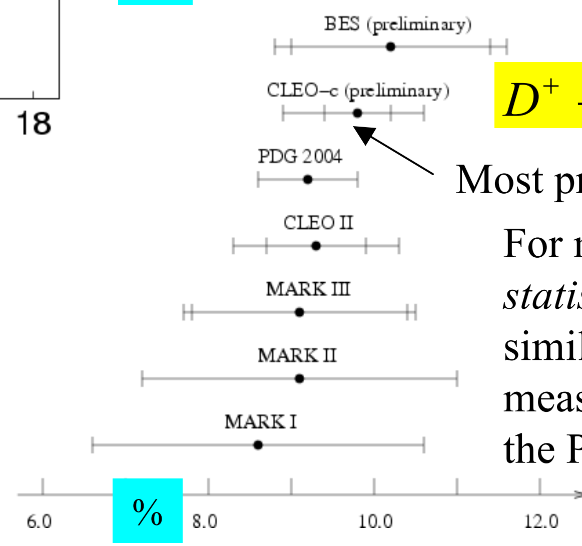
Absolute Hadronic Branching Ratio Summary BESII CLEO-c.







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



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

Most precise measurement.

For many other modes *statistical* precision is similar to other measurements entering the PDG average.

Agreement BES /CLEOc /PDG is good.

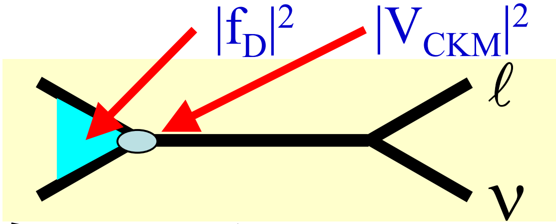
Outlook (my estimate) for 3 fb^{-1}
D^0 D^+ systematics limited.

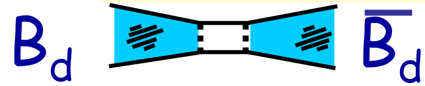
Decay	$\delta B / B(\%)$ PDG	CLEO – c
$D^0 \to K^-\pi^+$	2.4	0.6
$D^+ \to K^-\pi^+\pi^+$	6.1	0.7
$D_S^+ \to \phi\pi$	25% → 12.5% (*BABAR*)	1.9

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

$$B(D^+ \to \mu\nu)/\tau_{D^+} = (const.) f_{D^+}^2 |V_{cd}|^2$$

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





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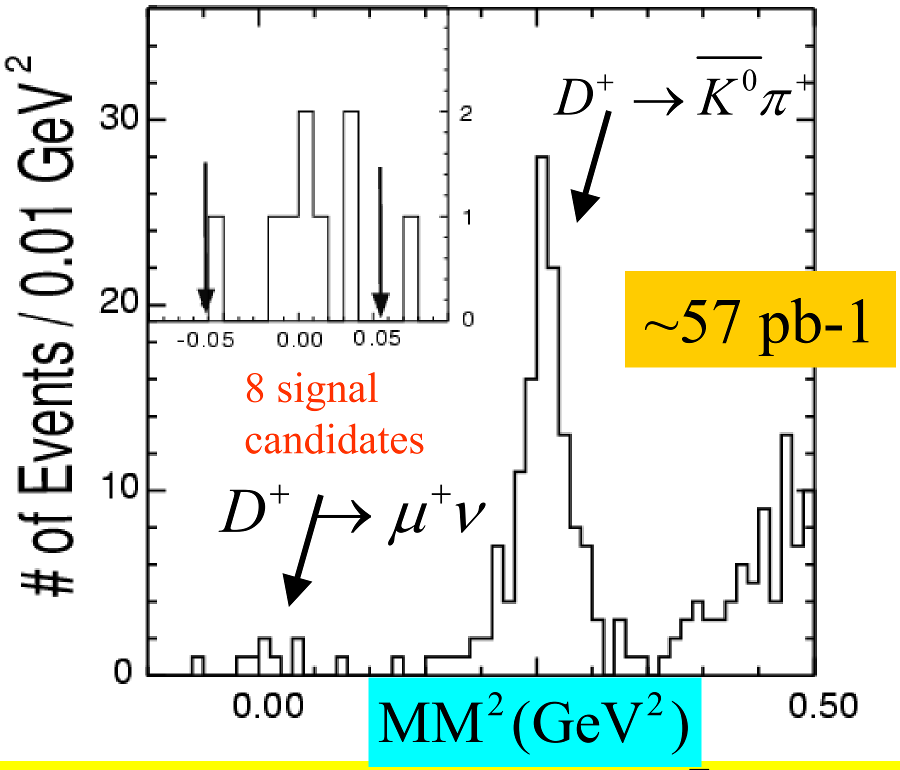
Mark III <290 MeV

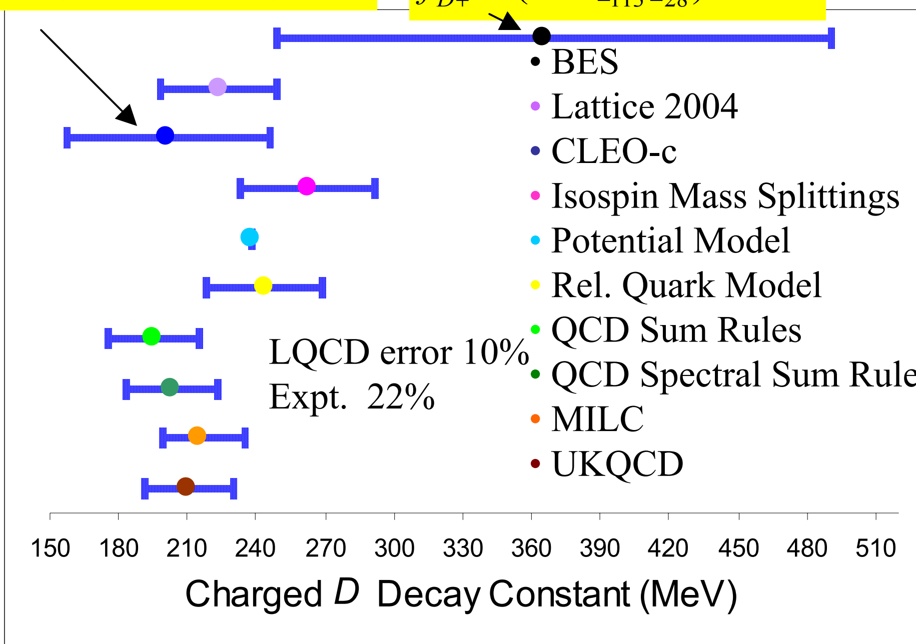
BES I: 1 event (1998)

Hadronic tag ← $D^- \; D^+ \to \mu^+\nu$ 1 track μ consistent no showers

$$MM^2 = (E_{beam} - E_\mu)^2 - (-\overrightarrow{P}_{Dtag^+} - \overrightarrow{P}_\mu)^2$$

CLEO-c preliminary	BESII (2004) preliminary
Tags 28575	5400
Signal 8	3
Bkgd 1.07 ± 1.07	0.25
$B = (3.5 \pm 1.4 \pm 0.6)\times 10^{-4}$	$B = (0.12\,^{+0.092}_{-0,063}\,^{+0.01}_{-0.009})\%$
$f_{D+} = (201 \pm 41 \pm 17) MeV$	$f_{D+} = (365\,^{+121}_{-113}\,^{+32}_{-28})$ MeV

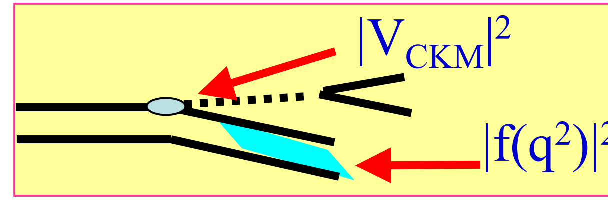




with $3fb^{-1}$: f_{D+} to 2.3% f_{Ds} to 1.9% @ $\sqrt{s} \sim 4140 MeV$

Absolute Charm Semileptonic Decay Rates

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



I. Absolute magnitude & shape of form factors are a stringent test of theory.

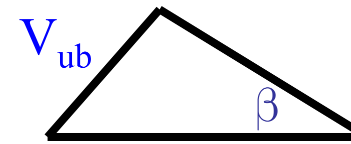
II. Absolute charm semileptonic rate gives direct measurements of V_{cd} and V_{cs}.

III Key input to precise Vub $(B \to \pi \ell \nu$ FNAL unquenched)

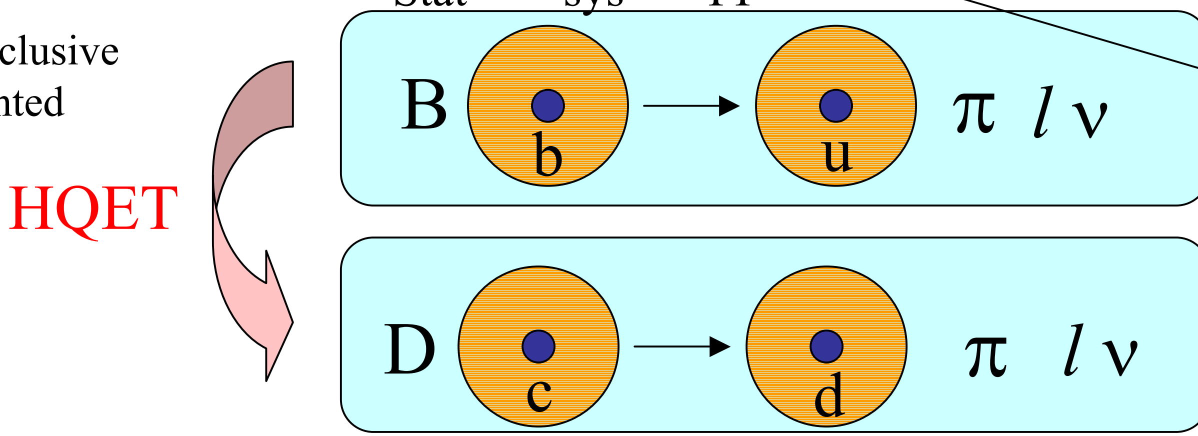
$$|V_{ub}| = (3.27 \pm 0.70 \pm 0.22^{+0.85}_{-0.51}) \times 10^{-3}$$

Stat sys FF

Typical exclusive Vub presented by A. Ali.



Theory error >20%.



1) Measure D→π form factor in D→πlν. *Tests* LQCD D→π form factor calculation.

2) BaBar/Belle can extract V_{ub} using *tested* LQCD calc. of B→π form factor.

3) But: need absolute Br(D →πlν) and high quality dΓ (D →πlν)/dEπ neither exist.

$D \to \pi l\nu / Kl\nu$ Rate & Form Factor

CLEO III at 10 GeV

Use $D^* \to D\pi$
Observable: $\Delta m = D^* - D$
ν reconstruction
1st measurement of a form factor in Cabibbo suppressed D semilpetonic decay.

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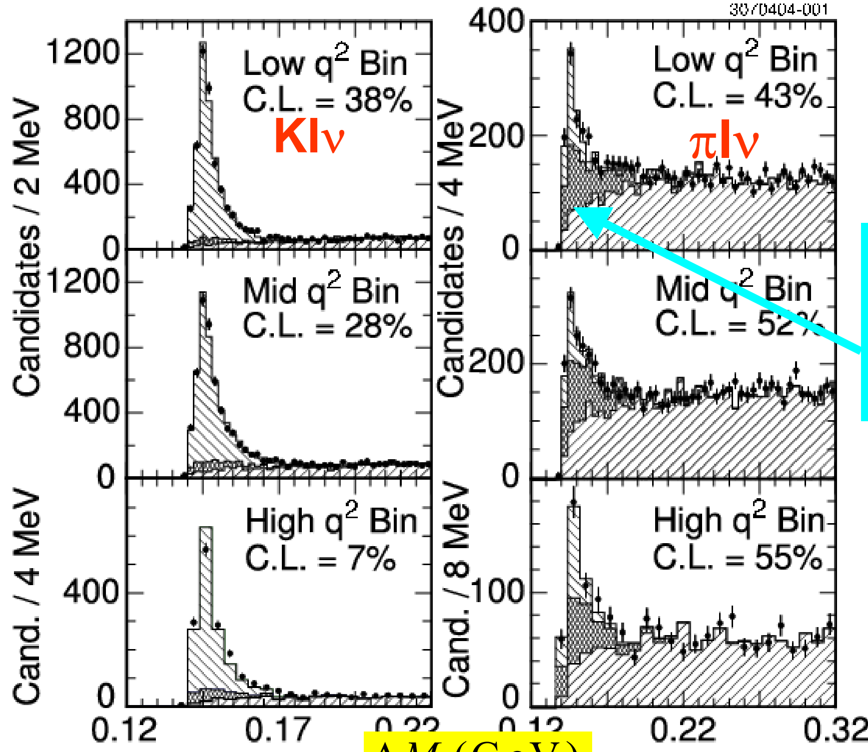
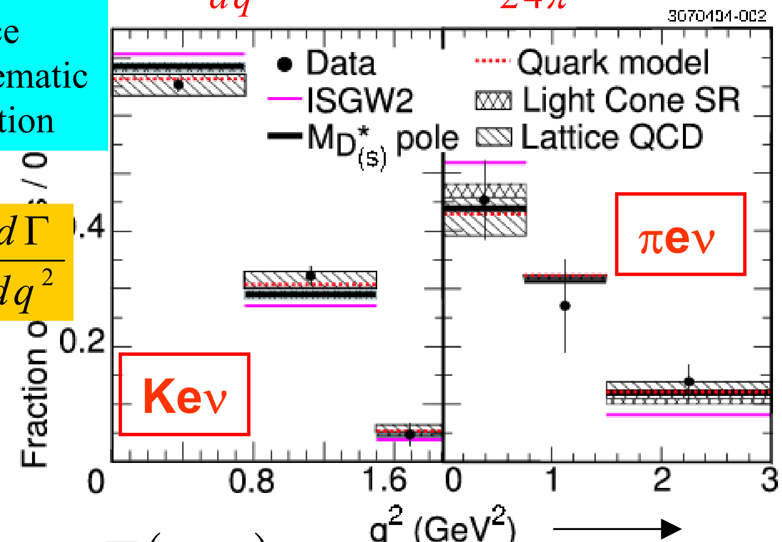


ΔM (GeV)

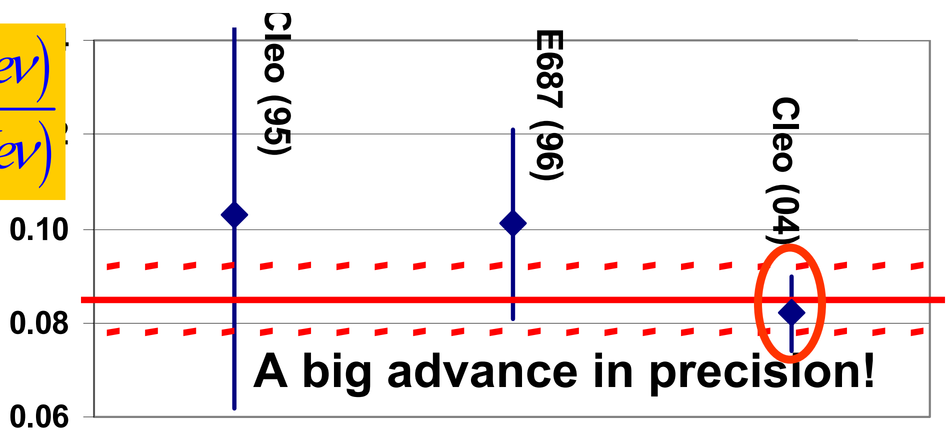
Note: absence of kinematic separation

$$\frac{d\Gamma(D \to P\ell\nu)}{dq^2} = \frac{G_F^2 |V_{cq}|^2 P_P^3}{24\pi^3} |f_+(q^2)|^2$$

$\frac{d\Gamma}{dq^2}$



$$\frac{\Gamma(\pi e\nu)}{\Gamma(Ke\nu)} = 0.082 \pm .006 \pm 0.005 \text{ CLEO}$$



$\frac{\Gamma(\pi e\nu)}{\Gamma(Ke\nu)}$

$$\frac{|f_+^\pi(0)|^2 |V_{cd}|^2}{|f_+^K(0)|^2 |V_{cs}|^2} = 0.038^{+0.006+0.005}_{-0.007-0.003}$$

(Measure of SU(3) breaking)

$$\frac{|f_+^\pi(0)|}{|f_+^K(0)|} = 0.86 \pm 0.07 \pm 0.05 \pm 0.01$$

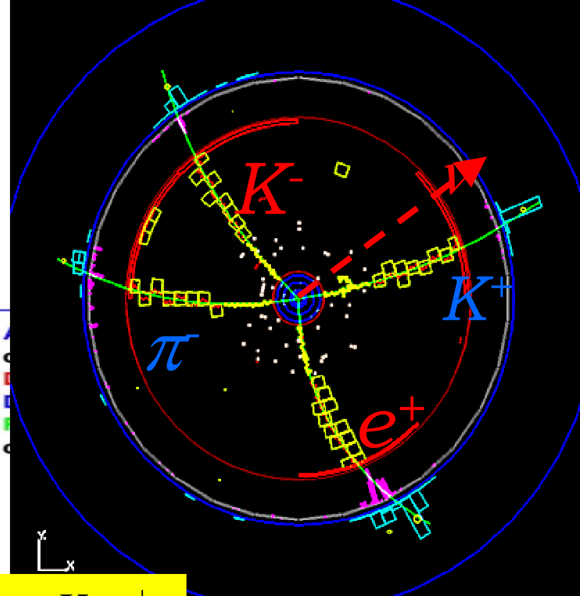
stat syst CKM

Absolute D^0 Semileptonic Branching Ratios at Threshold

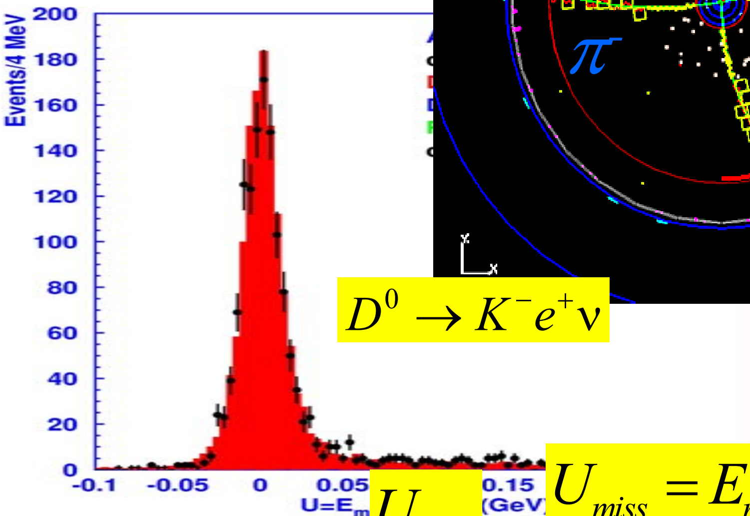
ICHEP ABS8-0781

$tag \leftarrow \overline{D}$

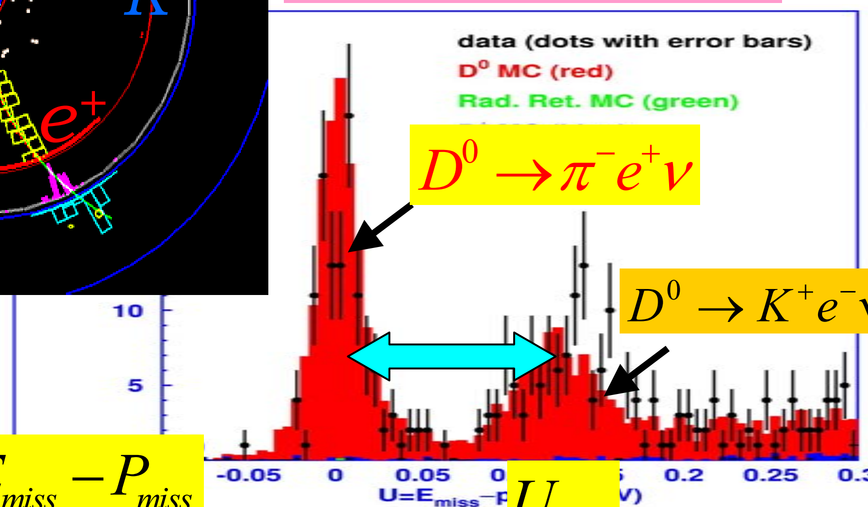
$D \rightarrow \left[K / K^* / \pi / \rho \right] e^+ \nu$



CABIBBO ALLOWED

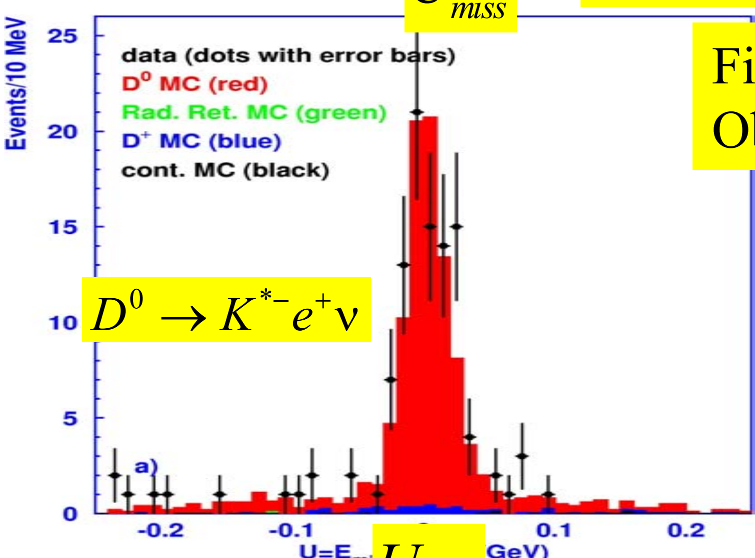


CABIBBO SUPPRESSED

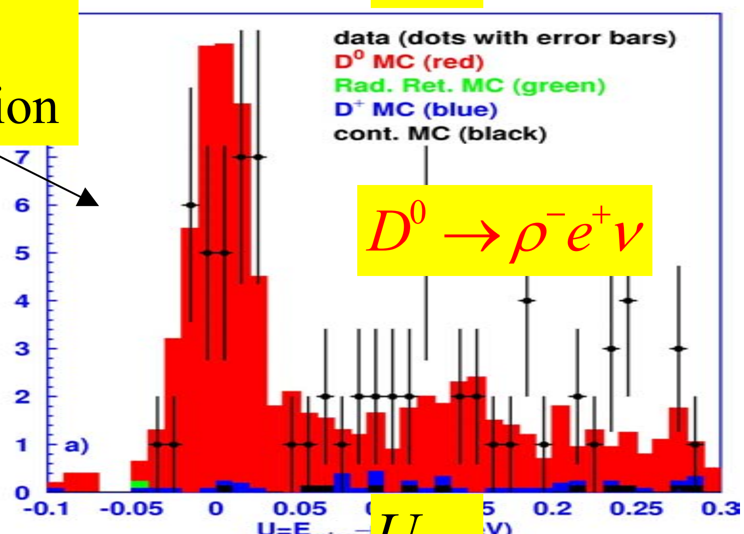


Note: kinematic separation.

$U_{miss} = E_{miss} - P_{miss}$



First Observation



Preliminary

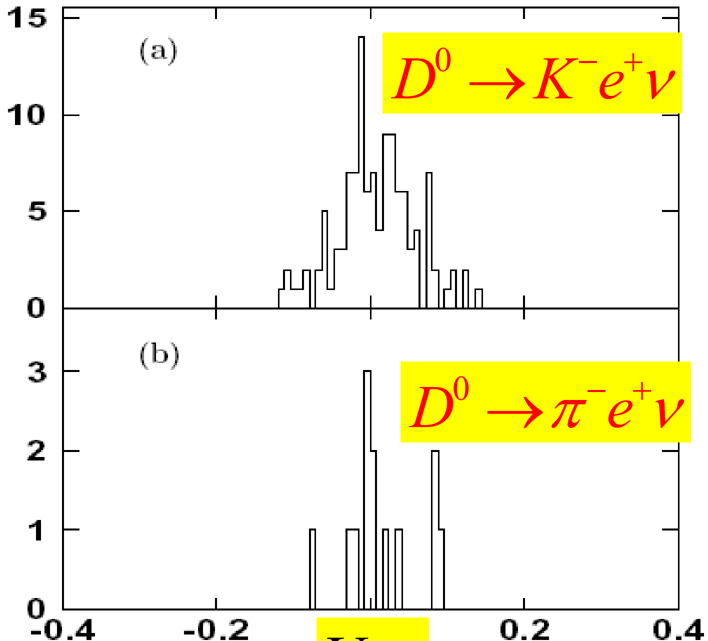
Absolute D^0 & D^+ Semileptonic Branching Ratios at BESII

$tag \leftarrow \overline{D}$

$D \rightarrow [K / K_S^0 / \pi] e^+ \nu$

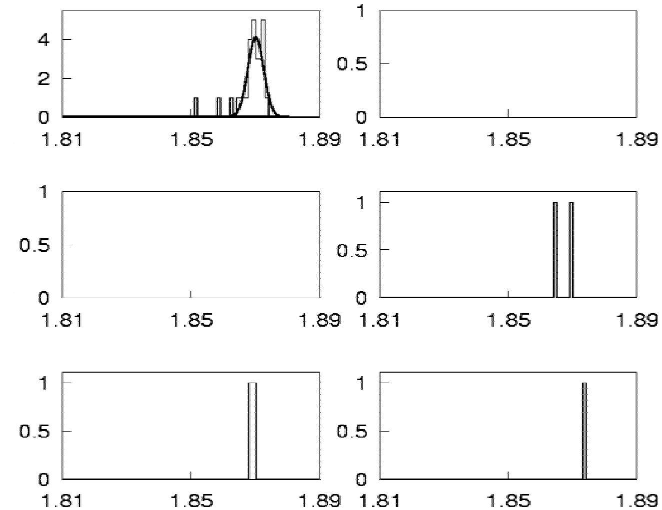
$D^0 \rightarrow K^- e^+ \nu$

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



U_{miss}

$D^+ \rightarrow K_S^0 e^+ \nu$



$K_S^0 e^+$ recoil mass (GeV)

preliminary

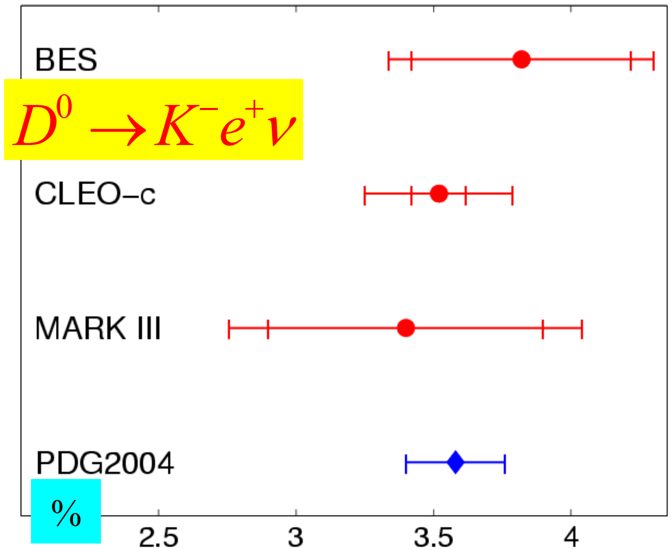
Experiment	BES II	MARK III	PDG2004
$\frac{\Gamma(D^0 \rightarrow K^- e^+ \nu)}{\Gamma(D^0 \rightarrow \overline{K^0}\ e^+ \nu)}$	$1.15 \pm 0.29 \pm 0.09$	1.44 ± 0.62	1.4 ± 0.2

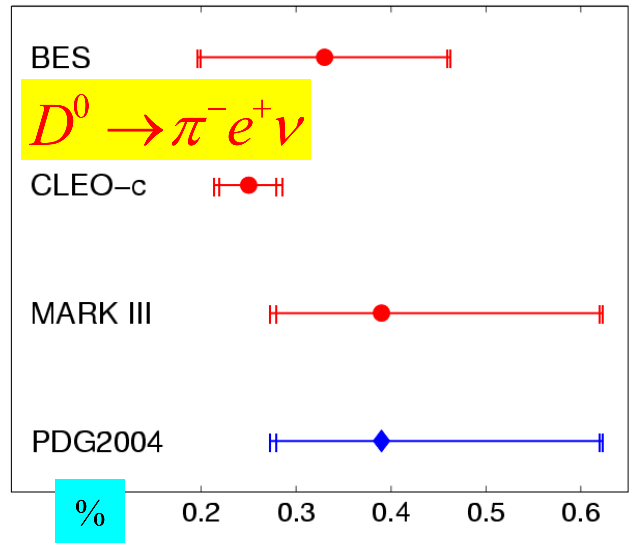
preliminary

Hep-ex/0406028
Phys. Lett. B597
(2004) 39-46

Longstanding puzzle in charm decay, ratio should be unity (Isospin),
New BES II result moves ratio in the right direction.

Absolute D^0 & D$^+$ Semileptonic Branching Ratios Summary BESII & CLEO-c



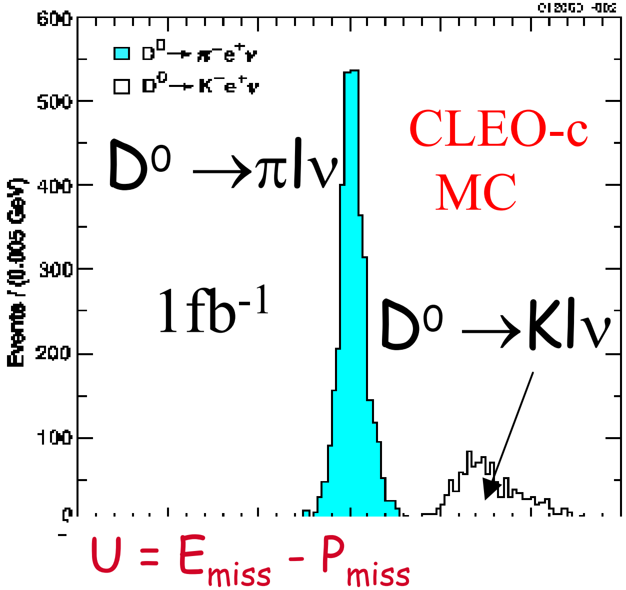


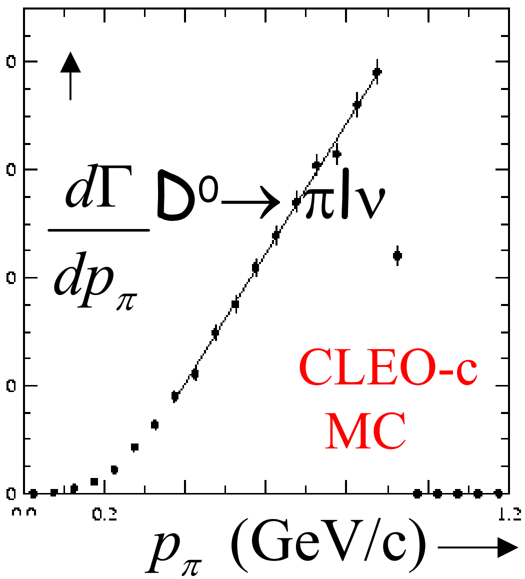
BES II/CLEO-c analyses in good agreement but statistics limited. For π e ν CLEO-c is already more precise than PDG. With 3fb^{-1} stat error on πeν will approach 1%. $D^0 \to \rho^0 e\nu$ has been observed for the first time: useful for Grinstein's Double Ratio.

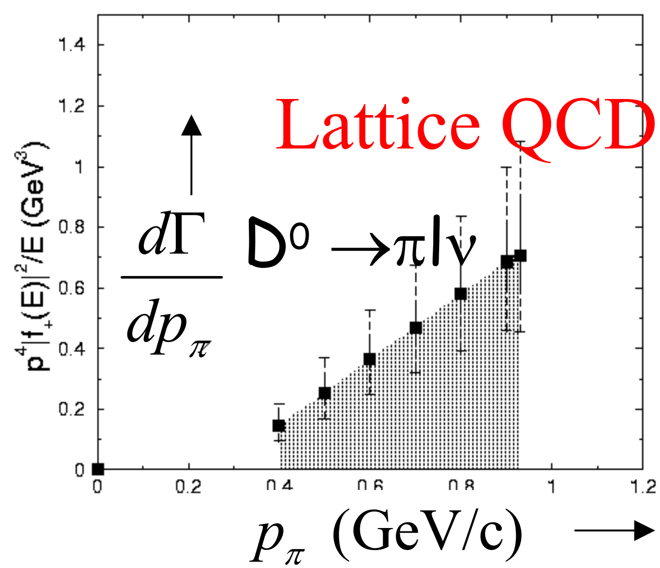
Experiment	$Br\left(D^0 \to K^- e^+ \nu_e\right)$ (%)	$Br\left(D^0 \to \pi^- e^+ \nu_e\right)$ (%)	$Br\left(D^+ \to \bar{K}^0 e^+ \nu_e\right)$ (%)
BES	$3.82 \pm 0.40 \pm 0.27$	$0.33 \pm 0.13 \pm 0.03$	$8.47 \pm 1.92 \pm 0.66$
CLEO-c	$3.52 \pm 0.10 \pm 0.25$	$0.25 \pm 0.03 \pm 0.02$	--
MARK III	$3.4 \pm 0.5 \pm 0.4$	$0.39^{+0.23}_{-0.11} \pm 0.04$	$6.0^{+2.2}_{-1.3} \pm 0.7$
PDG 04	3.58 ± 0.18	$0.39^{+0.23}_{-0.11} \pm 0.04$	6.7 ± 0.9

$B(D^0 \to \rho^- e^+ \nu) = (0.19 \pm 0.04 \pm 0.02)\%$ $\quad B(D^0 \to K^{*-} e^+ \nu) = (2.07 \pm 0.23 \pm 0.18)\%$

Testing the Lattice with (semi)leptonic Charm Decays







CLEO-c/BESIII PS $\to$ PS & PS $\to$ V *absolute* form factor magnitudes & slopes to a few%. Note: LQCD *most* precise where data is *least* but full q^2 range calculable.
➔Need LQCD FF with few % precision before these measurements are made.

$\Gamma(D^+ \to \pi l \nu) / \Gamma(D^+ \to l \nu)$ independent of Vcd tests amplitudes ~2%

$\Gamma(D_s \to \eta l \nu) / \Gamma(D_s \to l \nu)$ independent of Vcs tests amplitudes ~ 2%

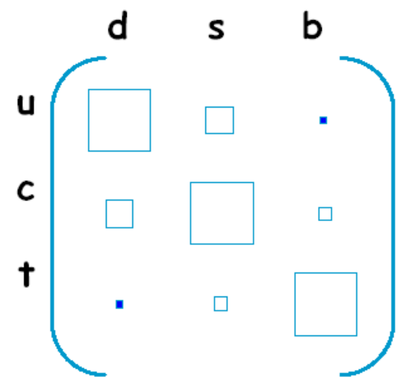
$3 fb^{-1}$

$D^0 \to K^- e^+ \upsilon$ $\delta Vcs / Vcs = 1.6\%$ (now ~10%) $D^0 \to \pi^- e^+ \upsilon$ $\delta Vcd / Vcd = 1.7\%$ (now: 7%)

Tested lattice to calc. B semileptonic form factor, B factories use $B \to \pi l \nu$ for precise Vub
$B \to \pi l \nu$ shape is an additional cross check.

Unitarity Tests Using Charm

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

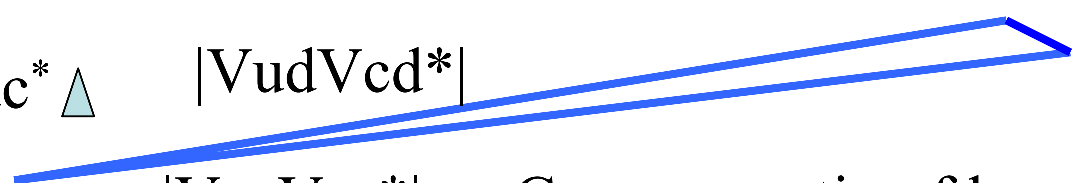


$uc^{*}=0$

- 2^{nd} row: $|Vcd|^2 + |Vcs|^2 + |Vcb|^2 = 1$??
  CLEO -c: test to ~3% (if theory $D \to K/\pi l\nu$ good to few %)
  & 1^{st} column: $|Vud|^2 + |Vcd|^2 + |Vtd|^2 = 1$?? with similar precision to 1^{st} row

($3fb^{-1}$)

- uc^{*} Δ

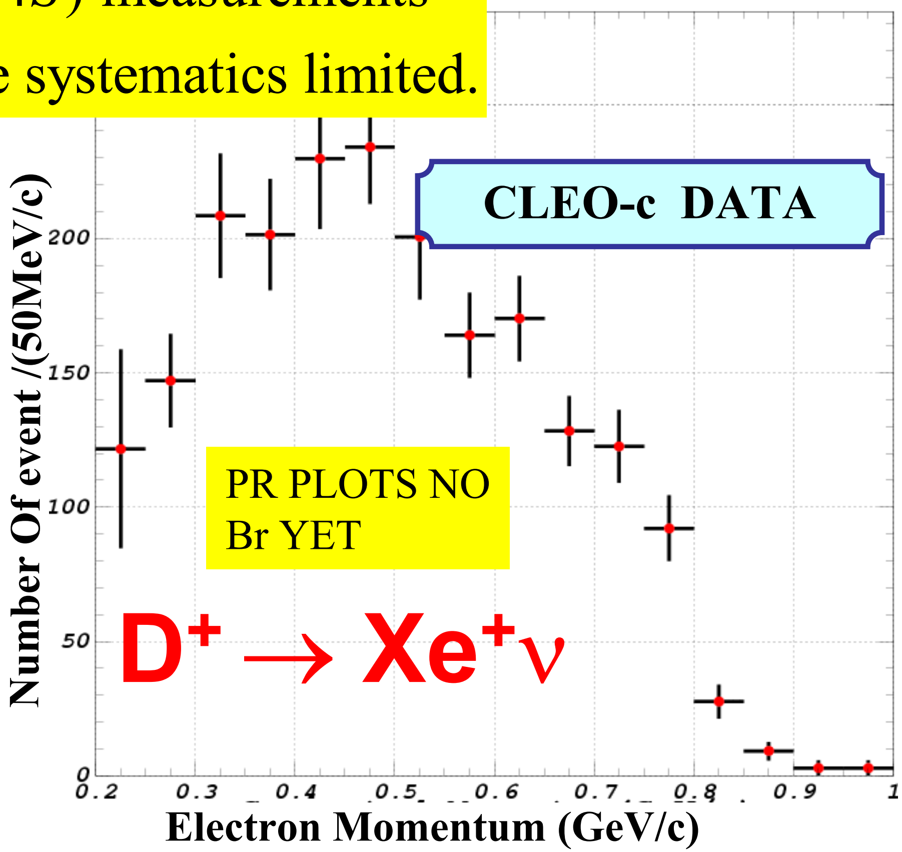


Compare ratio of long sides to 1.3%

Charm Inclusive Semileptonic Decay at Threshold

From 57 pb^{-1} of $\psi(3770)$ CLEO-c data: Preliminary

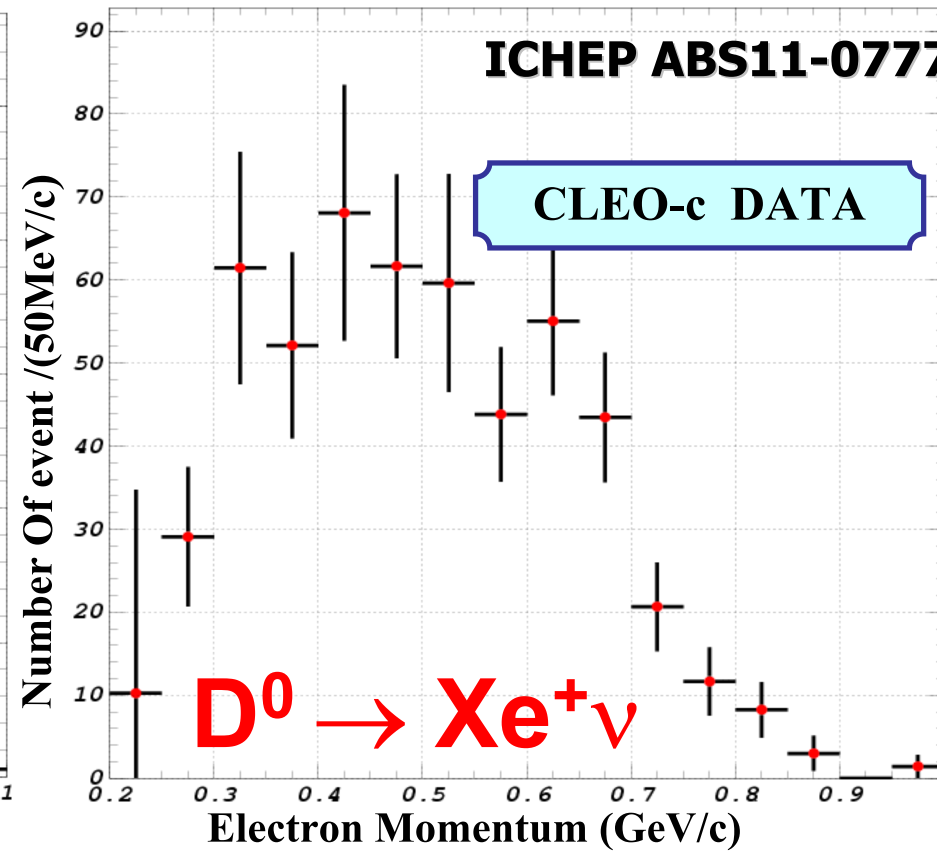
$\Upsilon(4S)$ measurements are systematics limited.



PR PLOTS NO Br YET

Stat. Uncertainty ~ 0.6%
PDG: BR = (17.2±1.9)%

ICHEP ABS11-0777



Stat. Uncertainty ~0.5%
PDG: BR = (6.75±0.29)%

Charm As a Probe of Physics Beyond the Standard Model

Can we find violations of the Standard Model at low energies?
Example β Decay ➔ missing energy
➔ W (100 GeV mass scale) from experiments at the MeV mass scale.

The existence of multiple fermion generations appears to originate at high mass scales ➔ can only be studied indirectly.

CP violation, mixing and rare decays ➔ may investigate the physics at these new scales through intermediate particles entering loops.

Why charm? in the charm sector the SM contributions to these effects are small ➔ large window to search for new physics

CP asymmetry $\leq 10^{-3}$

Rare decays $\leq 10^{-6}$

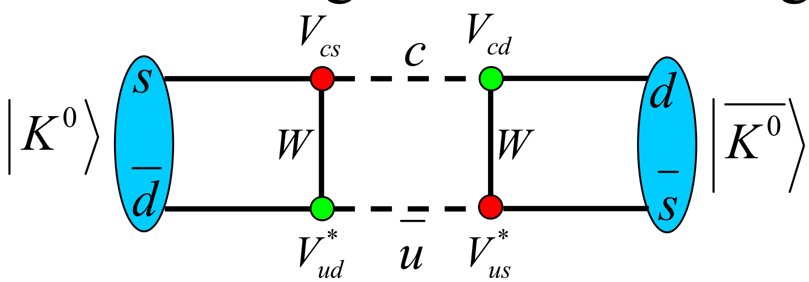
$D^0 - \bar{D}^0$ mixing $\leq 10^{-2}$

charm is the *unique* probe of the up-type quark sector (down quarks in the loop).

High statistics instead of High Energy

D Mixing

Mixing has been fertile ground for discoveries:

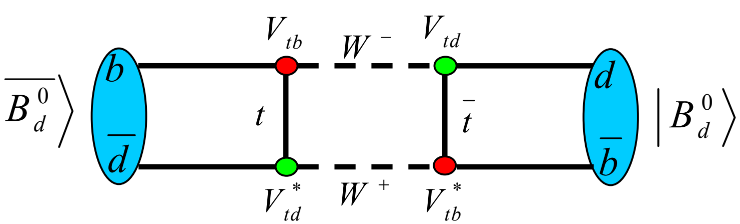


CKM factors $\propto \Theta_c^2$ same order as τ_{kaon} i.e.s → u

Mixing rate ≈1

Mixing rate (1958) used to bound c quark mass → discovery(1974).

CPV part of transition , ε_K (1964), was a crucial clue top quark existed → discovery (1994).



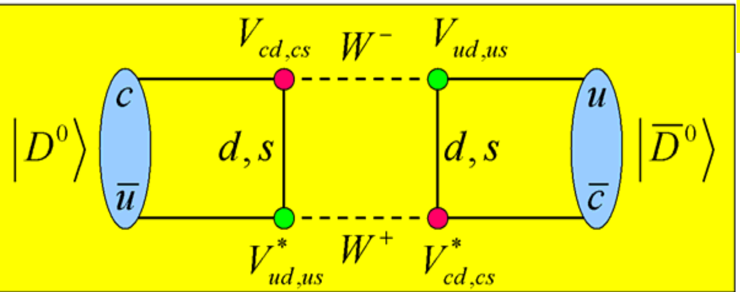
dominated by top $\propto (m_t^2 - m_{c,u}^2))/m_W^2$ → Large

B lifetime Cabibbo suppressed $\propto V_{cb}^2$

Mixing also Cabibbo suppressed (V_{td}^2)

Mixing rate → early indication m_{top} large

Mixing rate ≈1



CKM factors $\propto \Theta_c^2 \sim 0.05$

(b-quark $\propto V_{ub} V_{cb}$ negligible)

But τ_D not Cabbibo suppressed ($V_{cs} \sim 1$)

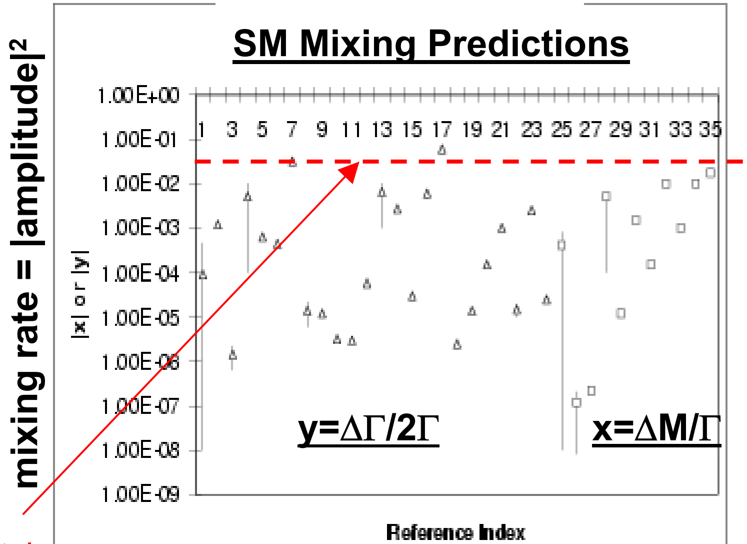
Mixing rate ≈0.05

Additional suppression: Mixing $\propto (m_s^2 - m_d^2)/ m_W^2 = 0$ SU(3) limit.

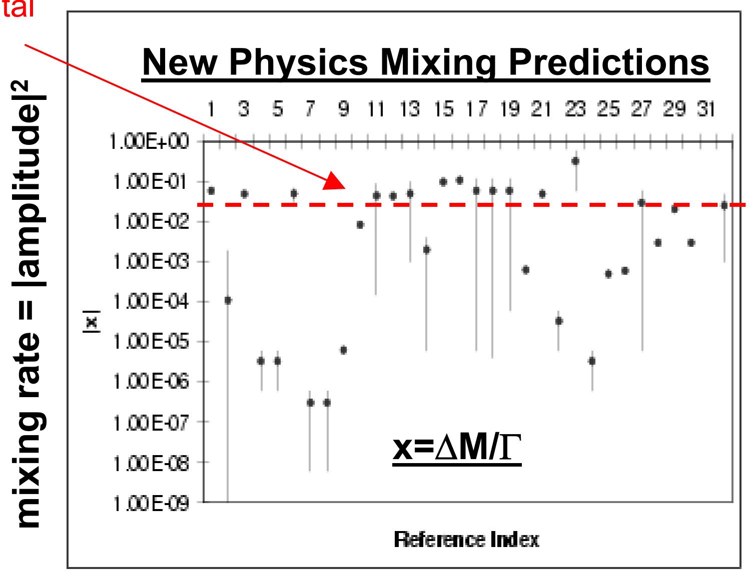
10^{-2} possible

SM mixing small $\propto \Theta_c^2$ x [SU(3) breaking]$^2 < O(10^{-3})$

Theoretical "Guidance"

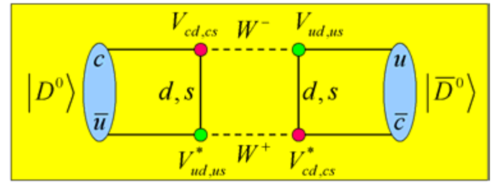


current experimental sensitivity



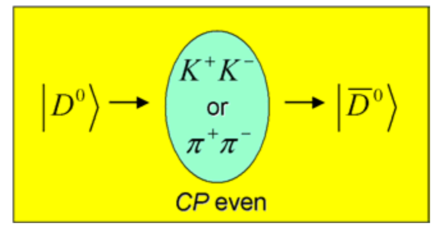
(A. Petrov, hep/ph 0311371)

x mixing: Channel for New Physics.



$$x = \frac{\Delta M}{\Gamma}$$

y (long-range) mixing: SM background.



$$y = \frac{\Delta\Gamma}{2\Gamma}$$

New physics will enhance *x* but not *y*.

$$R_{\text{mix}} \equiv \tfrac{1}{2}\left(x^2 + y^2\right)$$

SM mixing predictions ~ bounded by box diagram rate & expt. sensitivity. New Physics predictions span same large range ➔ mixing is not a clear indication of New Physics.

No CP-violating effects expected in SM. CP violation in mixing would therefore be an unambiguous signal of New Physics.

Status of y

$$y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_{CP^+} - \Gamma_{CP^-}}{\Gamma_{CP^+} + \Gamma_{CP^-}}$$

More recent analyses allow for CP violation comparing: ⇨ $\tau\left(D^0 \to K^-K^+\right)\tau\left(\overline{D^0} \to K^-K^+\right)$, $\tau\left(D^0 \to \pi^-\pi^+\right)\tau\left(\overline{D^0} \to \pi^-\pi^+\right)$

No evidence for CPV is found.

Easier, measure *CP*-even decay relative to $D^0 \to K^-\pi^+$: (1/2 CP even ½ CP odd)

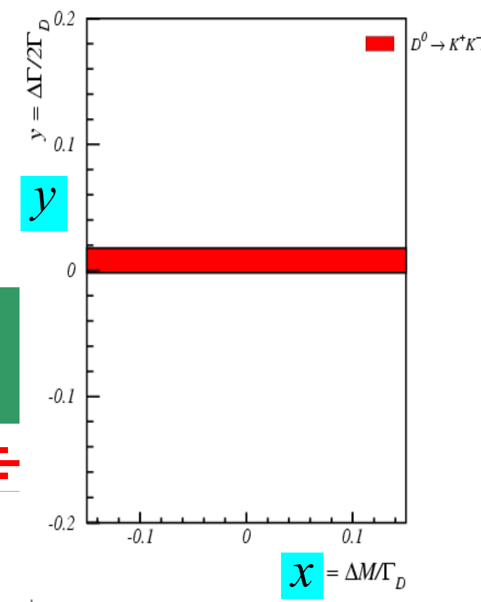
$$y_{CP} = \frac{\tau\left(D^0 \to K^-\pi^+\right)}{\tau\left(D^0 \to K^-K^+\right)} - 1$$

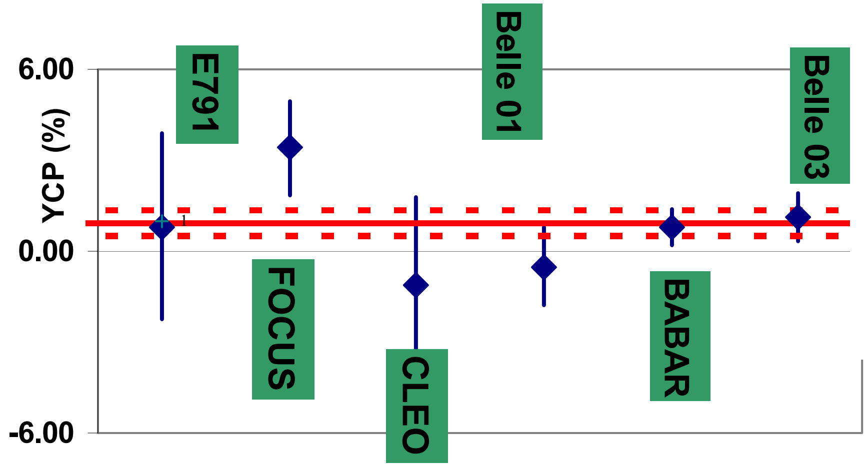
The observables become:

$$Y = y\cos\phi, \quad \Delta Y = x\sin\phi$$

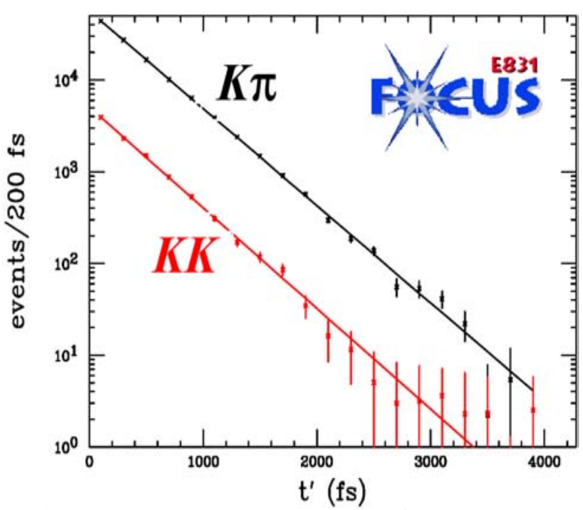
I take ϕ=0 in the average:

$$\langle y_{CP} \rangle = (0.9 \pm 0.4)\%$$





Early FOCUS measurement with non zero y_{CP}:



	y_{CP}
E791	$(0.8 \pm 2.9 \pm 1.0)\%$
FOCUS	$(3.4 \pm 1.4 \pm 0.7)\%$
CLEO	$(-1.1 \pm 2.5 \pm 1.4)\%$
Belle 01	$(-0.5 \pm 1.0 \pm 0.8)\%$
BABAR	$(0.8 \pm 0.4\ ^{+0.5}_{-0.4})\%$
Belle 03	$(1.15 \pm 0.69 \pm 0.38)\%$

Search for D Mixing in Semileptonic Decays

Two new measurements presented at this conference sensitive to $x^2 + y^2$

RS Right-Sign unmixed decays

$D^{*+} \to D^0 \pi^+_{tag}$, $D^0 \to K^- e^+ \nu$
$D^{*-} \to \overline{D}^0 \pi^-_{tag}$, $\overline{D}^0 \to K^+ e^- \overline{\nu}$

WS Wrong-sign mixed decays

$D^{*+} \to D^0 \pi^+_{tag}$, $D^0 \to \overline{D}^0 \to K^+ e^- \overline{\nu}$
$D^{*-} \to \overline{D}^0 \pi^-_{tag}$, $\overline{D}^0 \to D^0 \to K^- e^+ \nu$

- **D^{*+} decays: $D^{*+} \to D^0\pi^+$**
- Flavor at birth is tagged by pion from **D^*** decay
- Flavor at decay is tagged by lepton

The mixing rate is given by

$$\Gamma_{WS}(t) \approx \left[\exp\left(-t/\tau_{D^0} \right) \right] \left(\frac{t}{\tau_{D^0}} \right)^2 \left(\frac{x^2 + y^2}{4} \right)$$

$$\Gamma_{RS}(t) = \left[\exp\left(-t/\tau_{D^0} \right) \right]$$

Quadratic time dependence — **mixing rate**

Belle 140 fb^{-1}

$D^0 \to K(e/\mu)\nu$

ICHEP ABS11-0703

- Main observable: $\Delta m = m(\pi_s K \ell \nu_\ell) - m(K \ell \nu_\ell)$
- Counting Method : Fit WS and RS numbers.

Neutrino reconstruction

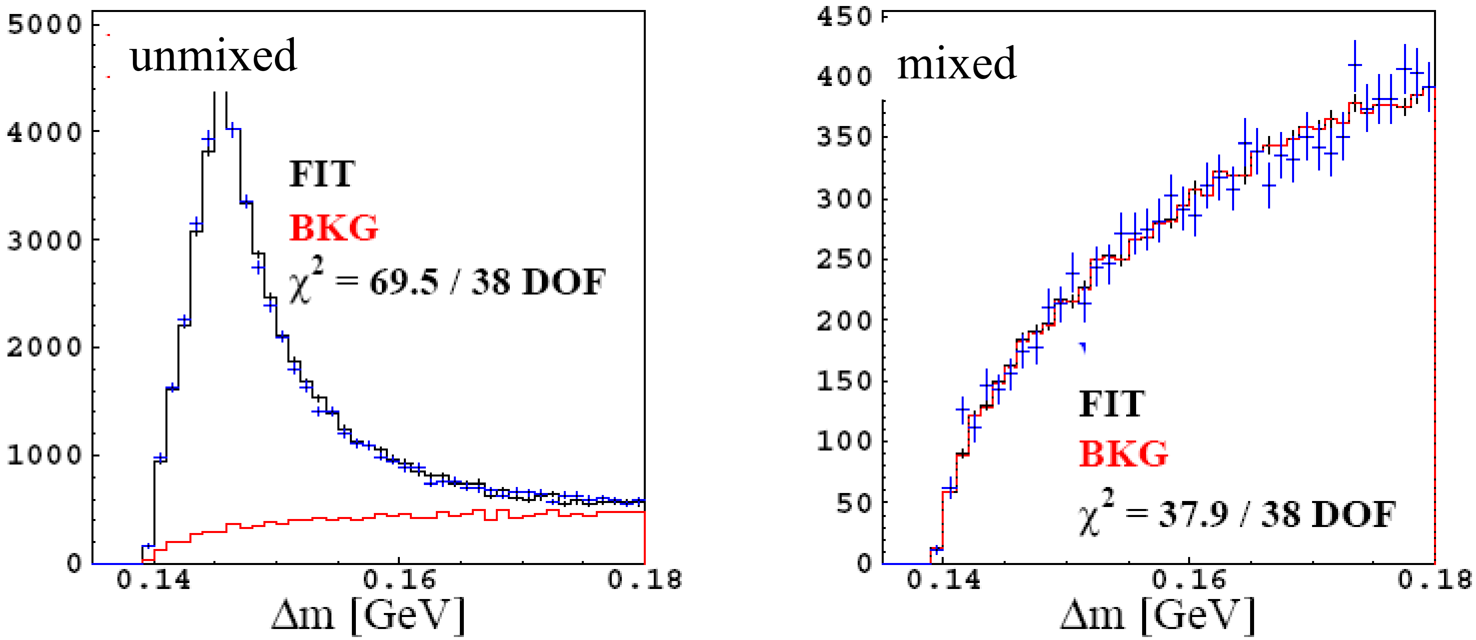
Proper Decay time:

WS background: $\delta(t) + e^{-t/\tau}$ v.s. WS signal: $t^2 \cdot e^{-t/\tau}$

Cut on proper decay time $\Rightarrow$ improve WS signal purity

CUT: $t > 1.5\ \tau_D$

Search for D Mixing in Semileptonic Decays



$$\Delta m = m(D^*) - (D^0)$$

$$N_{unmix} = 40198 \pm 329 \qquad N_{mix} = 19 \pm 67$$

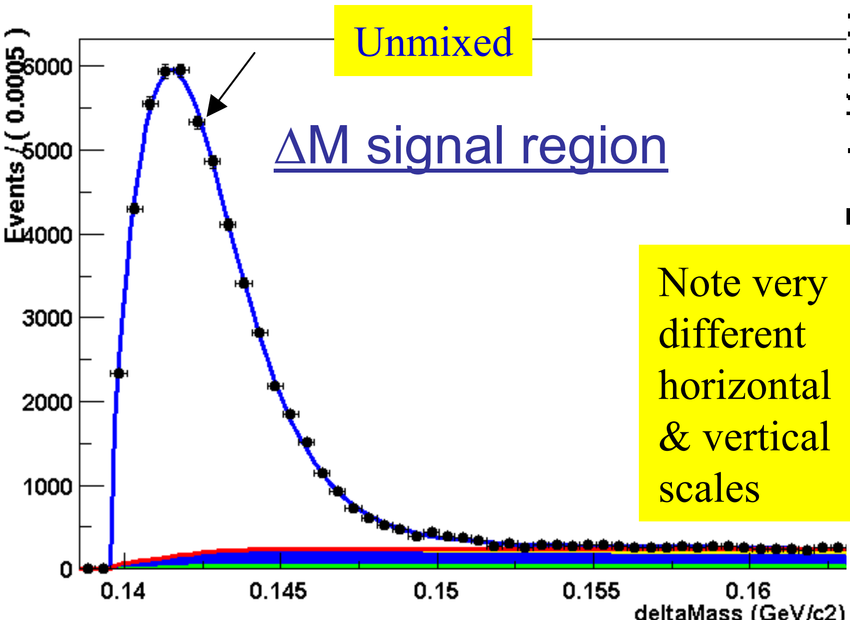
$$R_{mix} = \frac{N_{unmix}}{N_{mix}} \bullet \frac{\varepsilon_{unmix}}{\varepsilon_{mix}} = (0.20 \pm 0.70) \times 10^{-3} (\text{stat})$$

$$R_{mix} < 1.4 \times 10^{-3} \text{ at } 90\% \text{ CL (stat + sys)}$$

Search for D Mixing in Semileptonic Decays

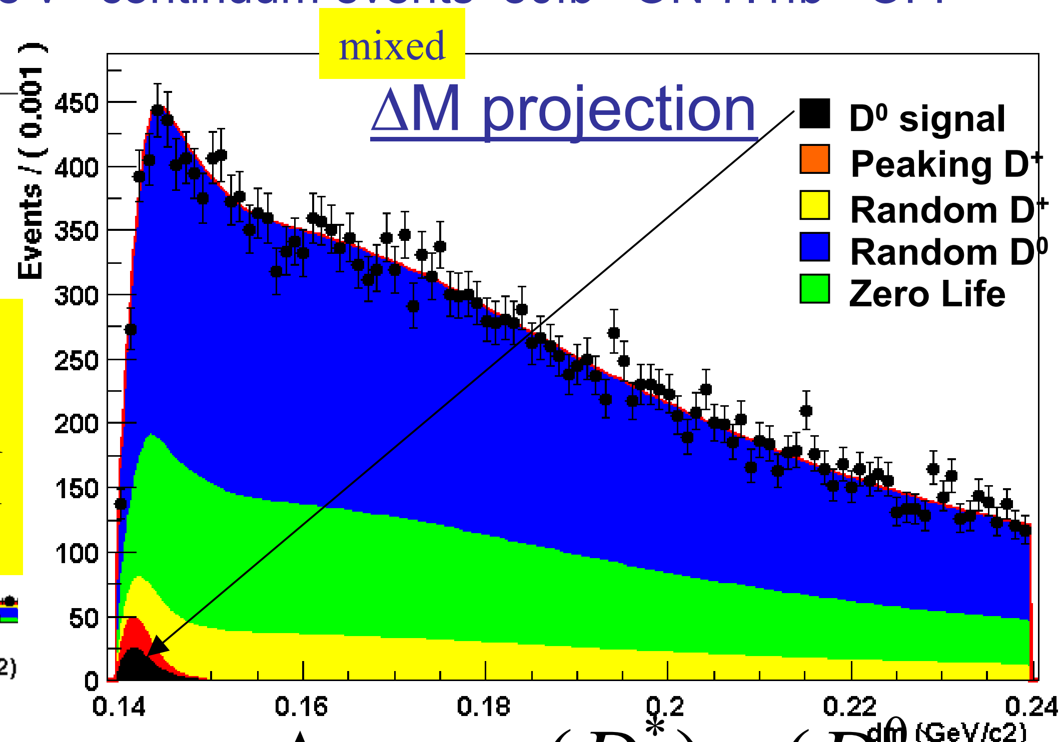
ICHEP ABS11-0629

- Unbinned extended maximum likelihood fit to transverse **lifetime** and **ΔM** = M(D*)-M(D^0) with 15 floated parameters D→K and K* e ν   continuum events 80fb^{-1} ON 7.1fb^{-1} OFF



$$\Delta m = m(D^*) - (D^0)$$

Unmixed D0 yield: **49620 ± 324 evts** (stat)



$$\Delta m = m(D^*) - (D^0)$$

- **N(mix): 114 ± 61**

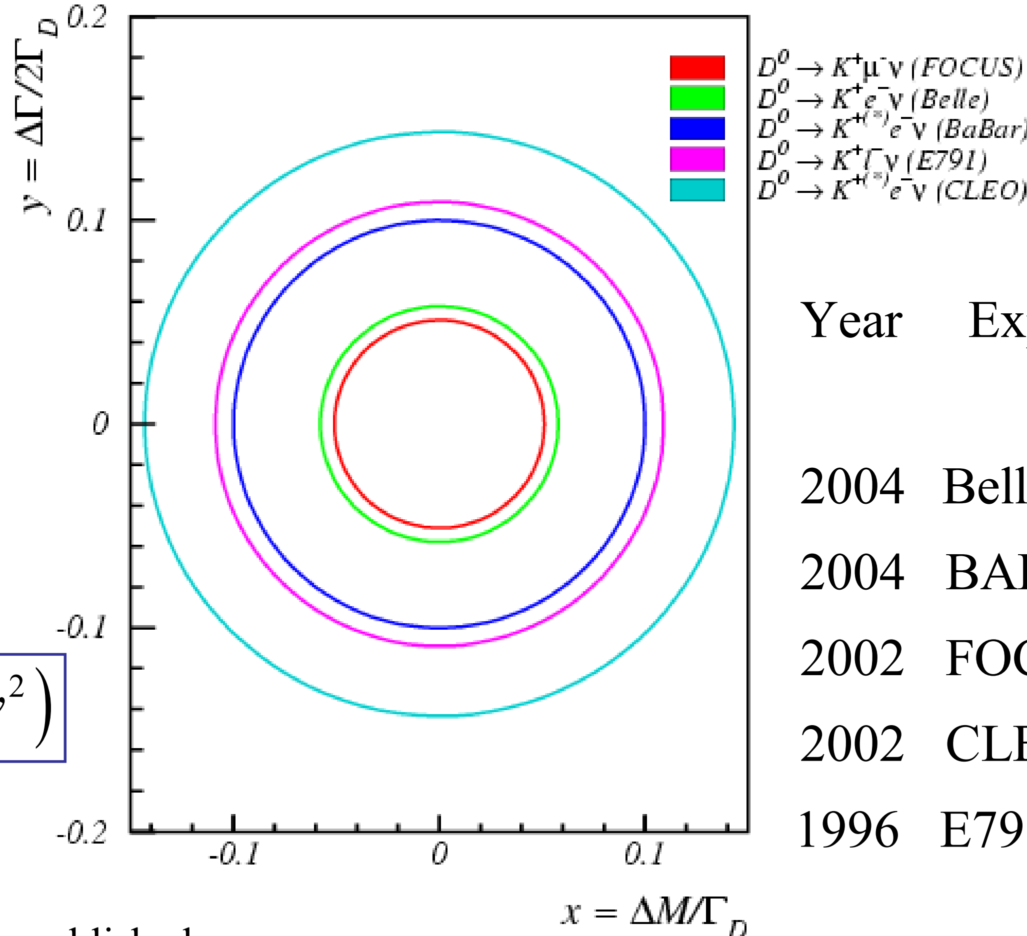
(~5% probability of getting a larger result for R_{mix}=0)

$$R_{mix} = N_{mix} / N_{unmix}$$

$$R_{mix} = 0.0023 \pm 0.0012(\mathrm{stat}) \pm 0.0004(\mathrm{syst})$$

$$R_{mix} < 0.0042(90\%\ \mathrm{C.L.})$$

D Mixing Semileptonic Summary



$$R_{\text{mix}} \equiv \tfrac{1}{2}\left(x^2 + y^2\right)$$

Year	Expt.	R_{mix} 90% C.L.
2004	Belle	$< 1.4\times10^{-3}$
2004	BABAR	$< 4.2\times10^{-3}$
2002	FOCUS	$< 1.31\times10^{-3}$
2002	CLEO	$< 8.6\times10^{-3}$
1996	E791	$< 5.0\times10^{-3}$

FOCUS result is unpublished
M. Hosack Fermilab Thesis 2002-25.

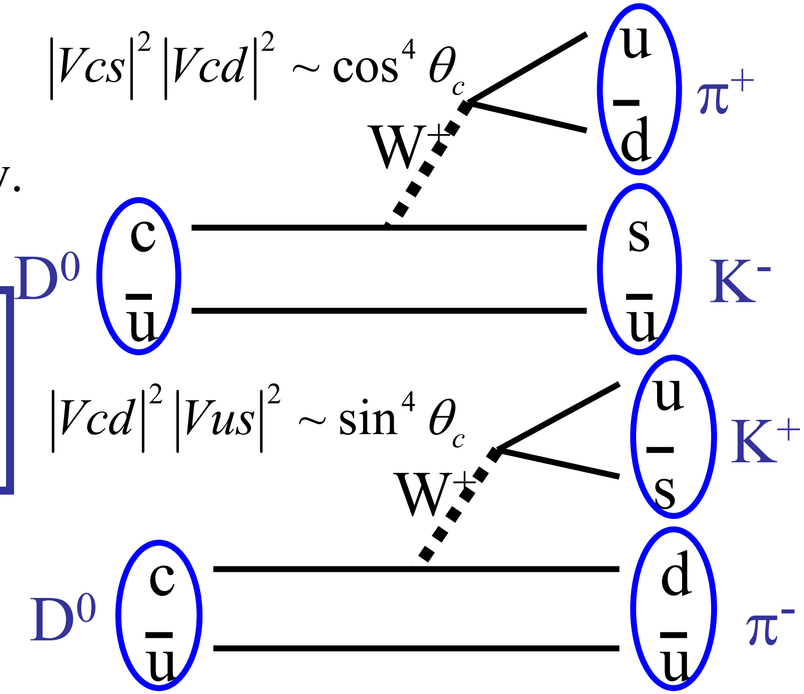
BABAR & Belle are adding more data and expect to publish improved upper limits soon.

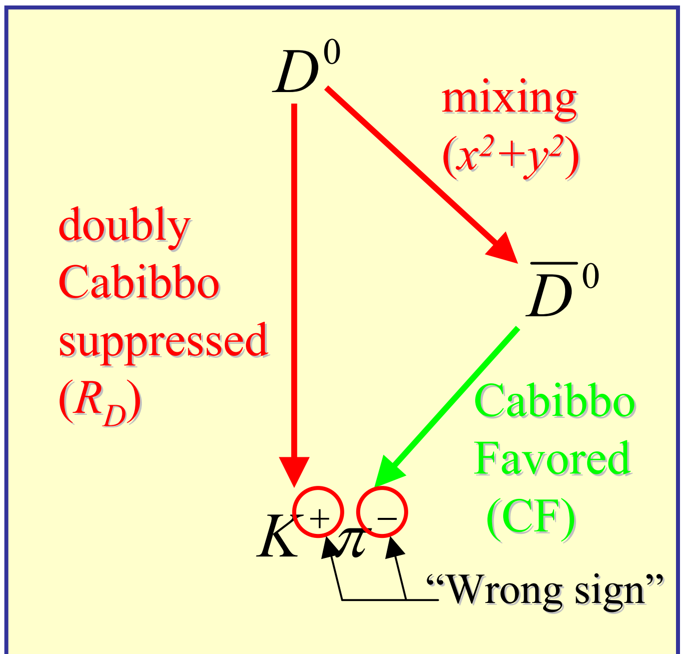
Search for D Mixing in D→Kπ

ICHEP ABS11-0704

Sensitive to both x and y, and linear in y.
Best constraints come from this mode.

"right-sign" (RS) => Cabibbo-favored decays
"wrong-sign" (WS) => Mixing or doubly Cabibbo-suppressed decays.





Need to fit proper decay time in order to distinguish mixing (both *x* and *y*) from doubly Cabibbo-suppressed (DCS) decays:

$$r(t) = \left(\underbrace{R_D}_{\text{DCS}} + \underbrace{\sqrt{R_D}\, y' t}_{\text{interference}} + \underbrace{\tfrac{1}{4}\left(x'^2 + y'^2\right) t^2}_{\text{mixing}} \right) e^{-t}$$

CP Violating effects are measured by fitting D^0 and $\overline{D}^0$ separately.

Complication: phase difference, $\delta_{K\pi}$, between CF and DCS amplitudes can lead to observable quantities *x'* and *y'*, related to *x* and *y* by a rotation.

The Wrong Sign Rate

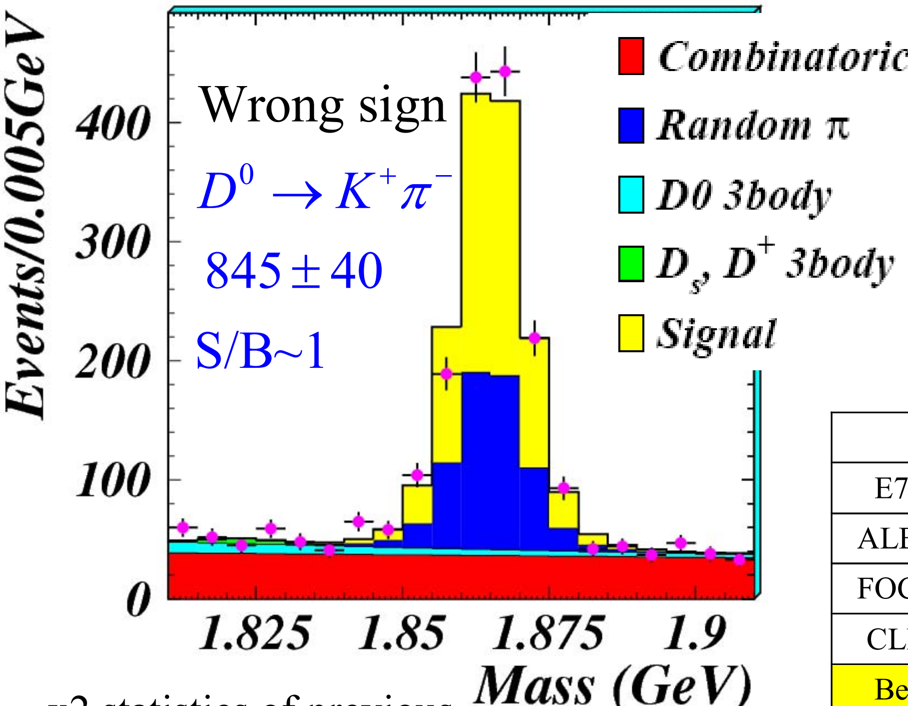
$90\, fb^{-1}$

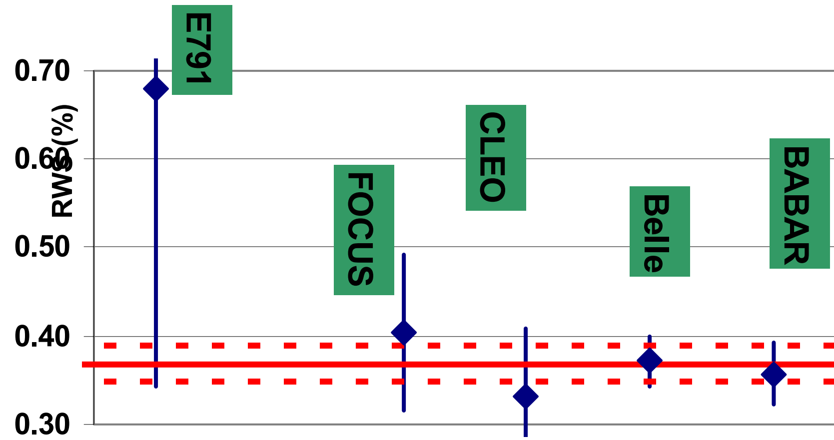
$D^{*+} \to D^0 \pi^+$

Right sign : $D^0 \to K^- \pi^+$ $228K$

Observables:
- $M = M(K, \pi)$
- $Q = M(K^+, \pi^-, \pi_{\text{slow}}) - M(K^+, \pi^-)$

3σ cut on Q





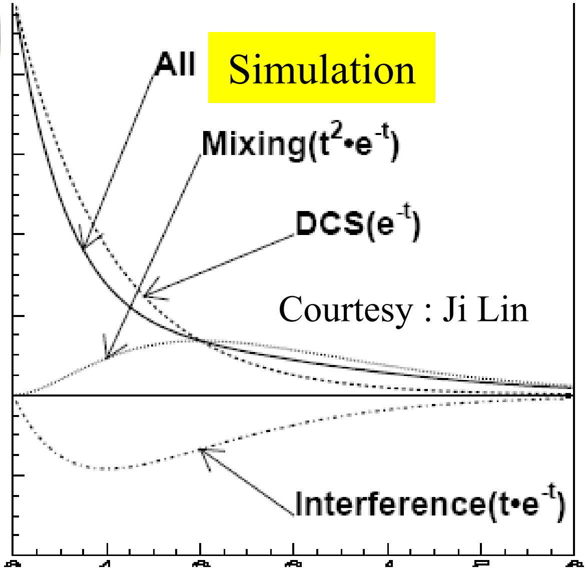
	$K^-\pi^+$	$K^+\pi^-$	R_{ws} [%]	A_D [%]
E791 (66)	5.6K	not quoted	$0.68^{+0.34}_{-0.33} \pm 0.07$	–
ALEPH (67)	1038	19	$1.84 \pm 0.59 \pm 0.07$	–
FOCUS (68)	37K	150	$0.404 \pm 0.085 \pm 0.025$	–
CLEO (61)	13.5K	45	$0.332^{+0.063}_{-0.065} \pm 0.040$	$-2^{+19}_{-20} \pm 1$
Belle (63)	83K	845	0.371 ± 0.018	-8.0 ± 7.7
BaBar (62)	120K	430	$0.357 \pm 0.022 \pm 0.027$	$9.5 \pm 6.1 \pm 8.3$
Average			0.368 ± 0.021	

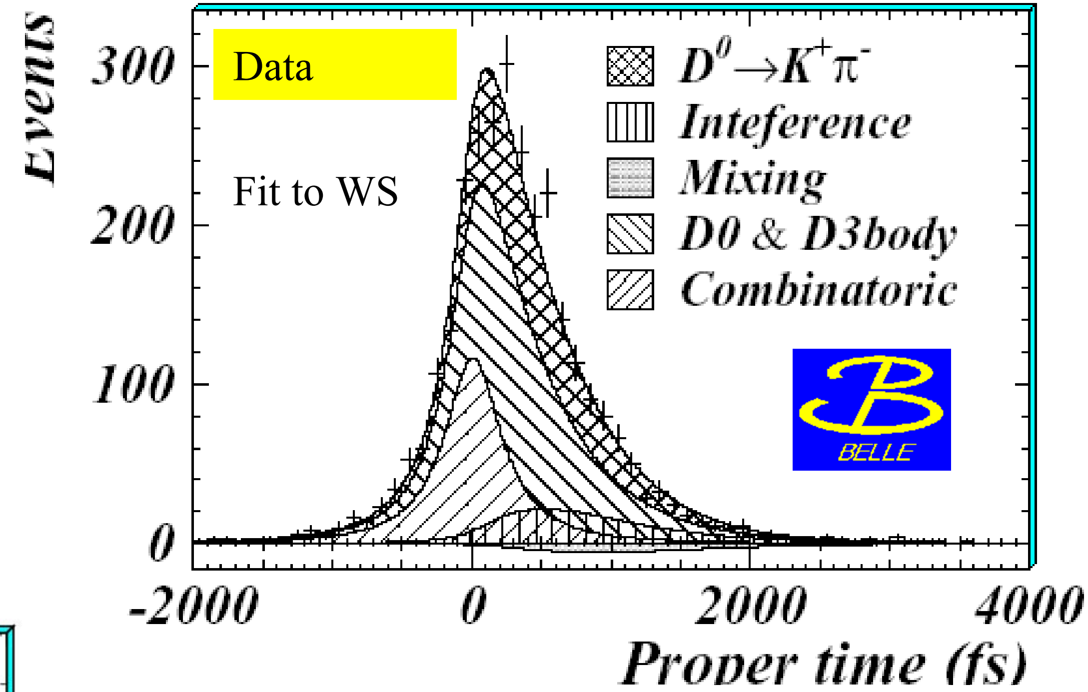
x2 statistics of previous measurements.

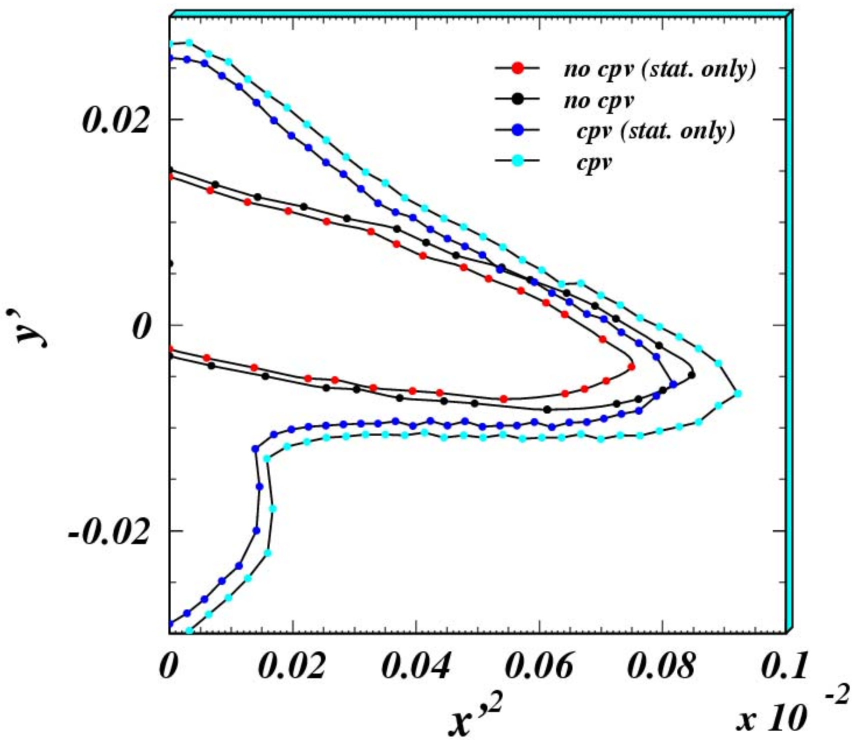
$$R_{WS} = \frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = (0.371 \pm 0.018)\% \sim \tan^4 \theta_c$$

$$B(D^0 \to K^+\pi^-) \sim 1.4 \times 10^{-4}$$

$$\langle R_{WS} \rangle = (0.368 \pm 0.021)\%$$







Fit case	Parameter	95% C.L. interval ($\times 10^{-3}$)
CPV	(decay) A_D	$-250 < A_D < 110$
	(Mixing) A_M	$-991 < A_M < 1000$
	x'^2	$x'^2 < 0.89$
	y'	$-30 < y' < 27$
no CPV	x'^2	$x'^2 < 0.81$
	y'	$-8.2 < y' < 16$
	R_D	$2.7 < R_D < 4.0$

This is a substantial improvement on previous results.

Mixing Summary

Combining all results:

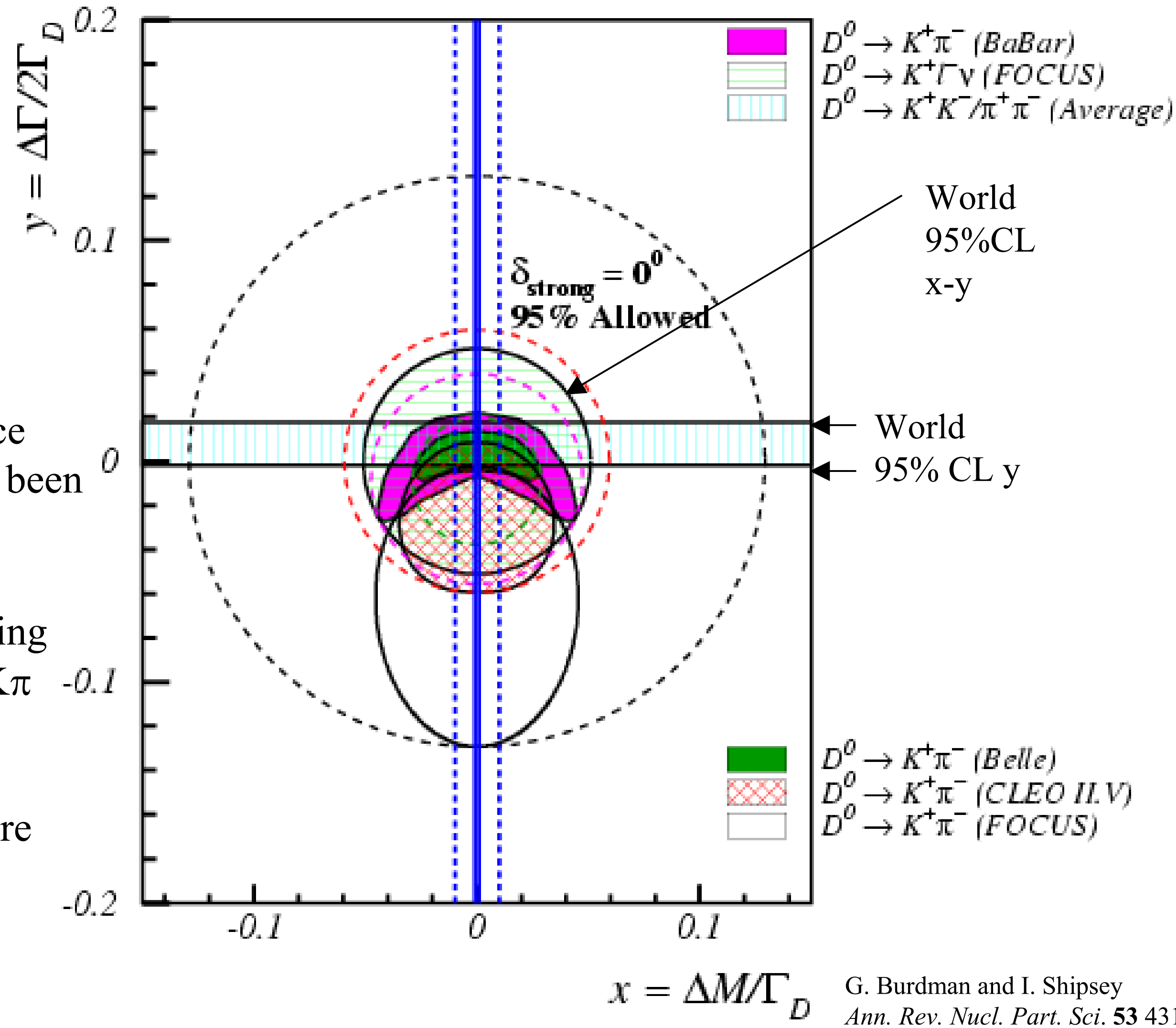
2004 update for ICHEP

CP conservation is assumed.

No statistically significant evidence for mixing has yet been found.

CDF expect a mixing result using D➔ Kπ soon.

Important to measure δ can be done at a charm factory.

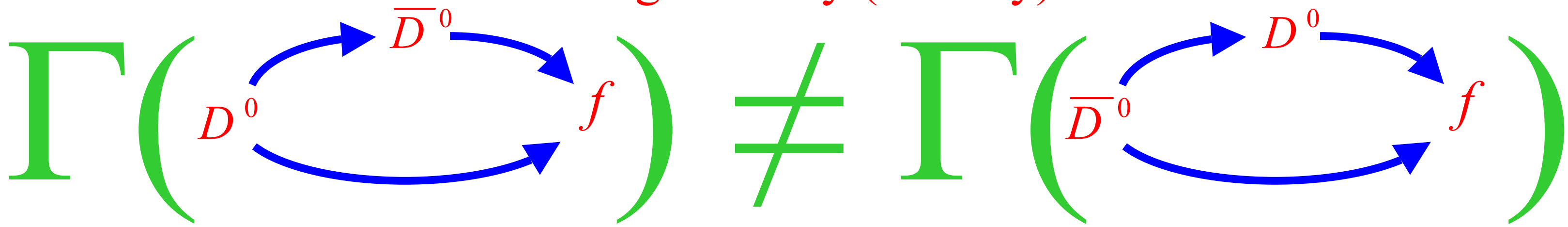


G. Burdman and I. Shipsey
Ann. Rev. Nucl. Part. Sci. **53** 431 (2003)
arXivhep-ph/0310076 (updated August 20 2004).

CPV in D Decays

I'll ignore CP violation in mixing (as it is negligible).

CPV via interference between mixing & decay (D^0 only)

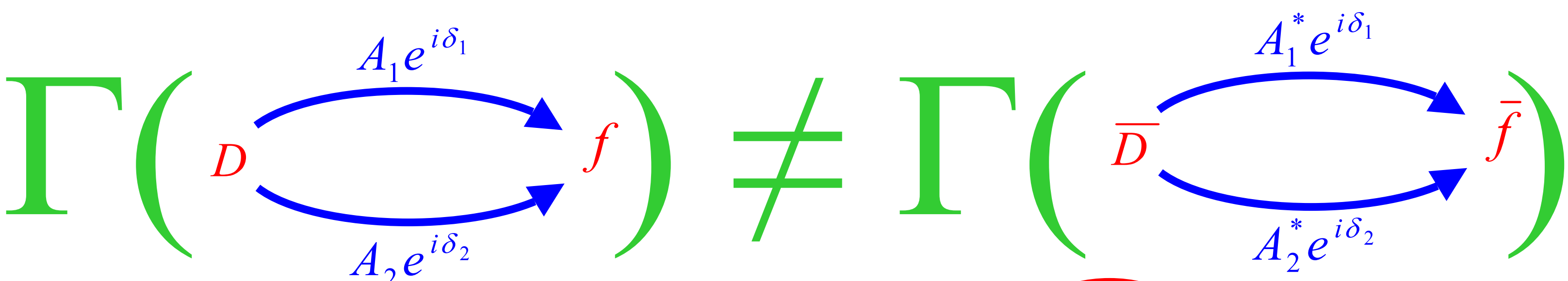


Very small in charm since mixing is suppressed (i.e. good hunting ground for New Physics).

Time dependent since mixing is involved

Direct CPV:

Experiment concentrates on this



$$A_{CP} = \frac{\Gamma(f)-\Gamma(\bar{f})}{\Gamma(f)+\Gamma(\bar{f})} = \frac{2 Im A_1 A_2^* \sin(\delta_1-\delta_2)}{|A_1|^2+|A_2|^2+2 Re A_1 A_2^* \cos(\delta_1-\delta_2)} < 10^{-3}$$

2 weak amplitudes with phase difference **strong phase-shift**

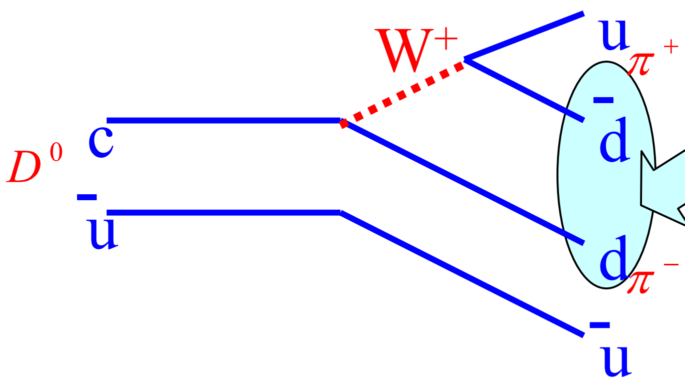
Direct CP Violation

$$Acp \approx \frac{\mathrm{Im}\left[V_{cd}V_{ud}^{*}V_{cs}V_{us}^{*}\right]}{\lambda^{2}}\sin\delta_{PT}\frac{P}{T} \simeq A^{2}\eta\lambda^{4}\sin\delta_{PT}\frac{P}{T} \leq 10^{-3}$$

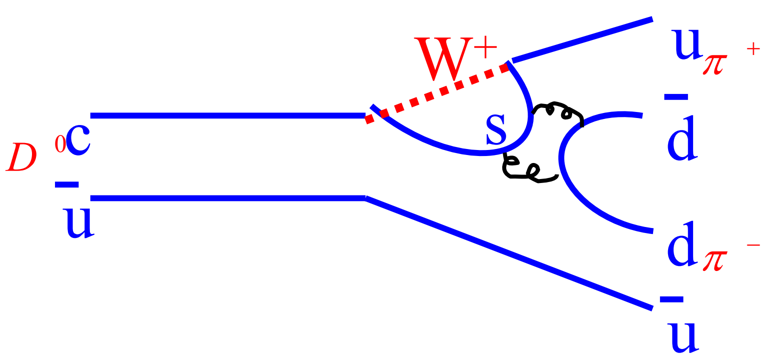
In Standard Model Direct CPV only for Singly Cabibbo suppressed decays.

1) Consider $D^0 \to \pi^+\pi^-$
(same for K^+K^- {$K^+K^-\pi^+$, $\phi\pi^+$, K^*K} $K^+K^-\pi^0$, $\pi^+\pi^-\pi^+$, $\pi^+\pi^-\pi^0$, etc...)

Standard Model Contribution $A_{CP} \sim 10^{-3}$
New Physics up to ~1%
If CP~1% observed: is it NP or hadronic enhancement of SM? Strategy: analyze many channels to elucidate source of CPV.



Since this decay is Singly Cabibbo Suppressed…



…we can modify it's topology in a simple way to get a penguin.

$V_{cd}^{*}V_{ud}$ ⇧ **different weak phases** ⇩ $V_{cs}^{*}V_{us}$

$\Delta I = \frac{1}{2}, \frac{3}{2}$ ⇧ **different strong phases are likely** ⇩ $\Delta I = \frac{1}{2}$

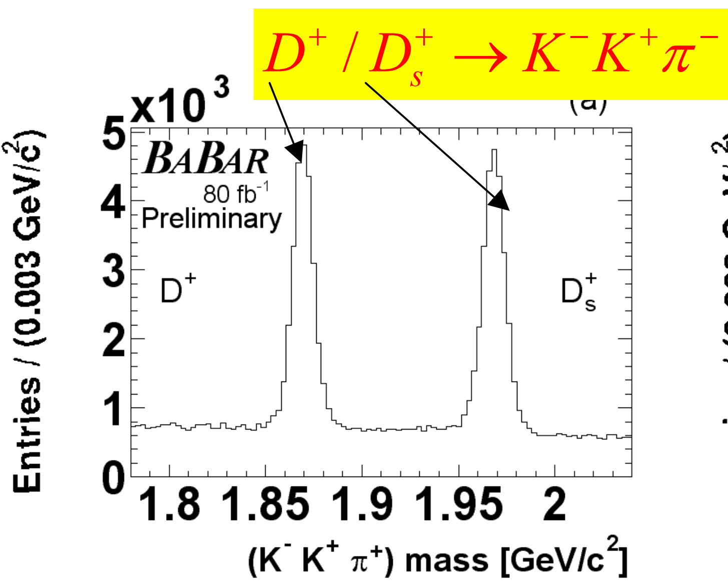
Search for Direct CP Violation in $D^+ \to K^- K^+ \pi^-$

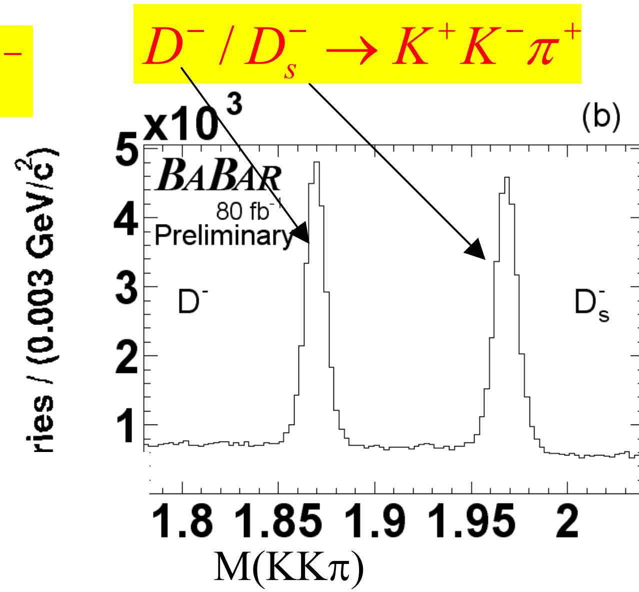
79.9 fb^{-1}

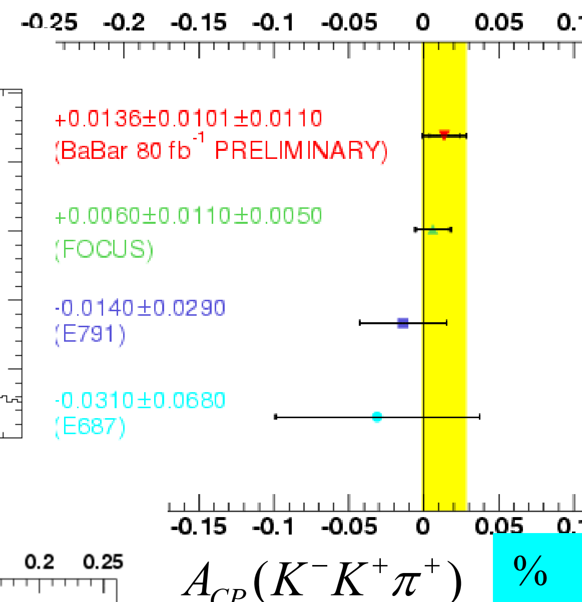
ICHEP ABS11-0629

Three A_{CP} measurements: (1) $KK\pi$ (2) $\phi\,\pi$, (3) K^*K ~43,000 events relative to $D_s^+ \to KK\pi$ as control [Cabibbo favored hence no CP].

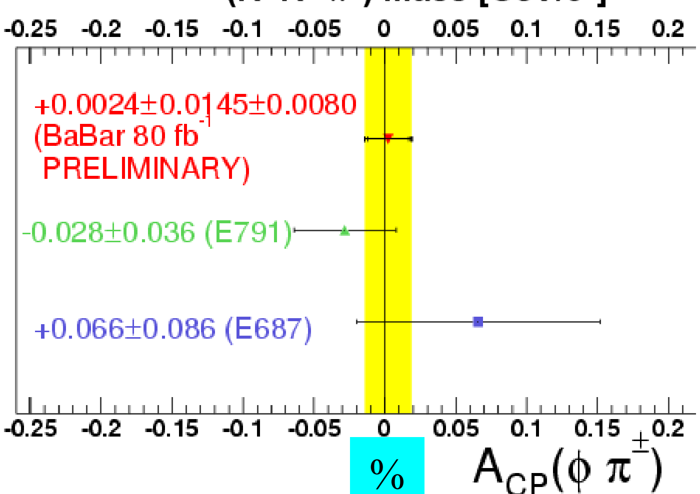
$$A_{CP} \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D^0} \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D^0} \to f)}$$

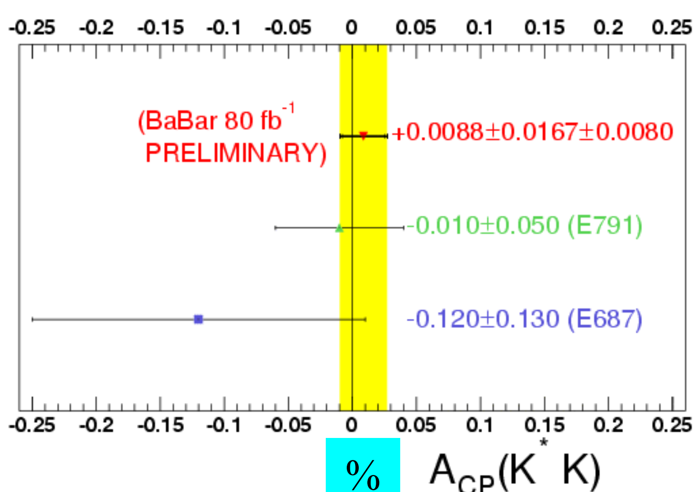






For $\phi\pi$ & K^*K significant improvement over previous measurements.





Search for Direct CP Violation in $D^0 \to \pi^+\pi^-, K^+K^-$

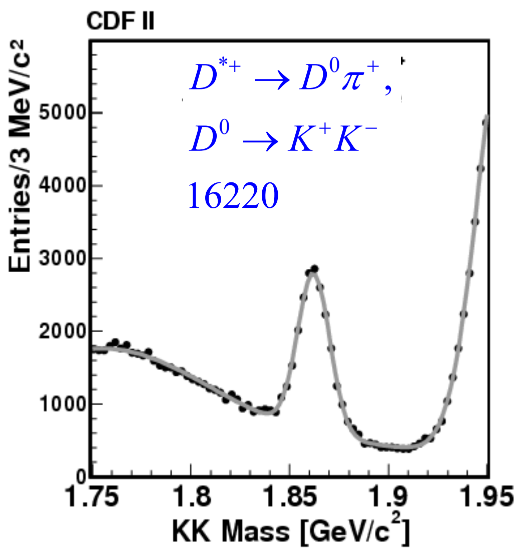
ICHEP ABS11-0535

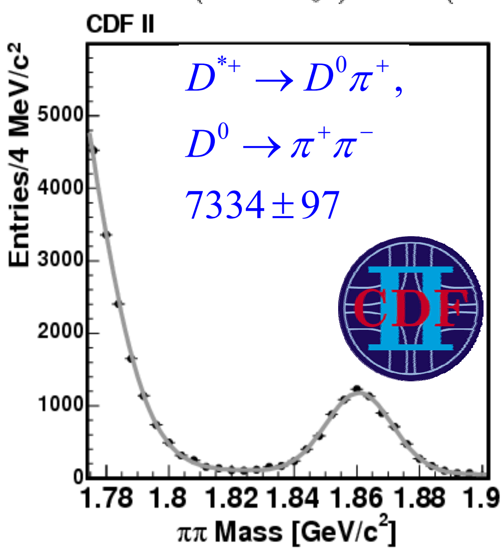
D^* to tag D^0 flavor. Measure relative to $D^0 \to K\pi$ Cabibbo allowed mode (Acp=0) as control). 123pb^{-1}

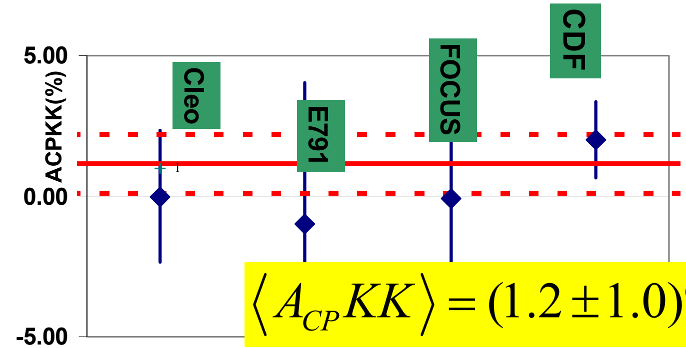
Mode	D^0	D^0	
KK	8190 ±140	8030 ±140	
ππ	3660±69	3674±68	

Time integrated
Most recent (& precise) result.

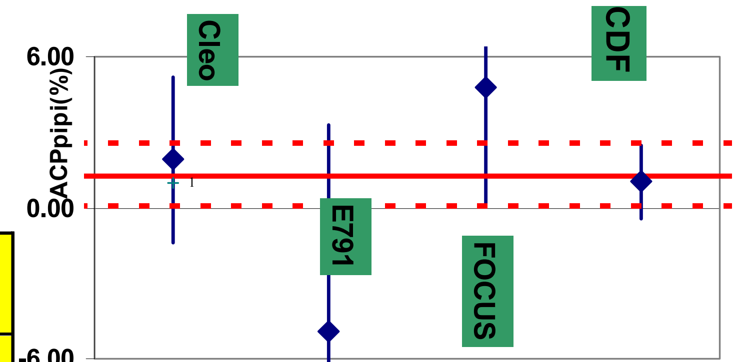
$$A_{CP} \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D^0} \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D^0} \to f)}$$







$\langle A_{CP} KK \rangle = (1.2 \pm 1.0)\%$



$\langle A_{CP} \pi\pi \rangle = (1.3 \pm 1.2)\%$

	$A_{CP}\, D^0 \to K^+K^-$	$A_{CP}\, D^0 \to \pi^+\pi^-$
CLEO	$(0.0 \pm 2.2 \pm 0.8)\%$	$(1.9 \pm 3.2 \pm 0.8)\%$
E791	$(-1.0 \pm 4.9 \pm 1.2)\%$	$(-4.9 \pm 7.8 \pm 2.5)\%$
FOCUS	$(-0.1 \pm 2.2 \pm 1.5)\%$	$(4.8 \pm 3.9 \pm 2.5)\%$
CDF	$(2.0 \pm 1.7 \pm 0.6)\%$	$(1.0 \pm 1.3 \pm 0.6)\%$

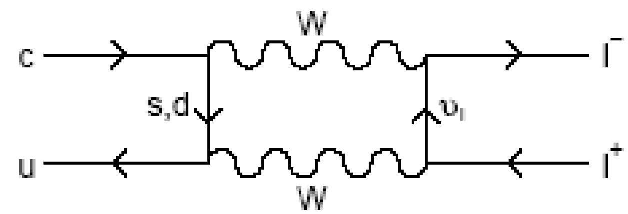
Time dependent measurements can distinguish direct & indirect CPV. CDF plan this. BABAR/Belle (2003) found no evidence for indirect CP at the 1% level (see y status slide).

Rare Decays

FCNC modes are suppressed by the GIM mechanism:

$D^0 \to e^+e^-$ $(\mathcal{B} \sim 10^{-23})$

$D^0 \to \mu^+\mu^-$ $(\mathcal{B} \sim 3\times 10^{-13})$



The lepton flavor violating mode $D^0 \to e^\pm\mu^\mp$ is strictly forbidden.

Beyond the Standard Model, New Physics may enhance these, e.g.,

R-parity violating SUSY:

$\mathcal{B}\left(D^0 \to e^+e^-\right)$ up to 10^{-10}

$\mathcal{B}\left(D^0 \to \mu^+\mu^-\right)$ up to 10^{-6}

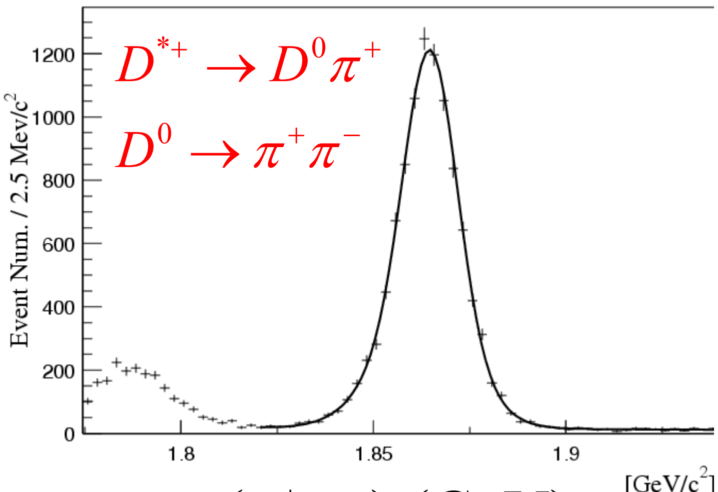
$\mathcal{B}\left(D^0 \to e^\pm\mu^\mp\right)$ up to 10^{-6}

(Burdman et al., Phys. Rev. D66, 014009).

Search for $D^0 \to e^+e^-, \mu^+\mu^-, e^\mp\mu^\pm$

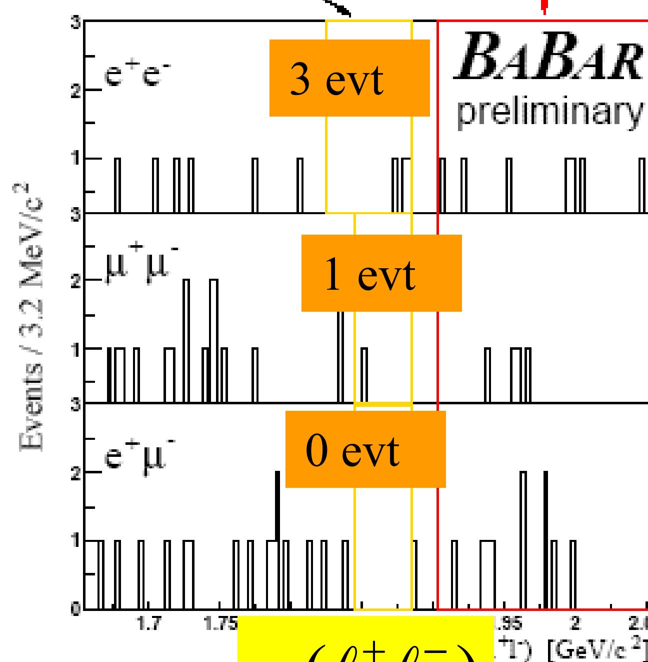
ICHEP ABS11-0964

Reference channel:~ 10,000 events in search window (depending on final state).



mass(π^+,π^-) (GeV)

Search channels

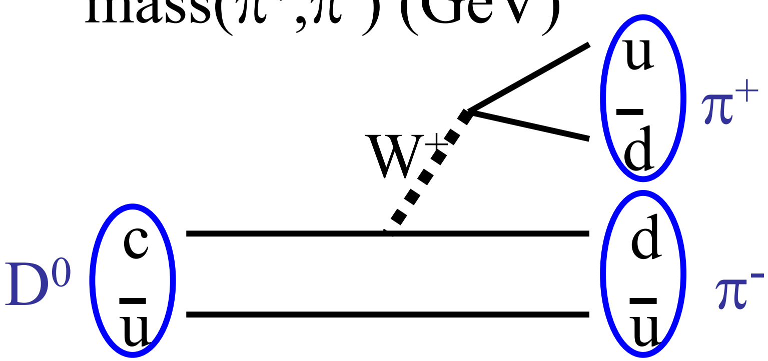


$m(\ell^+\ell^-)$

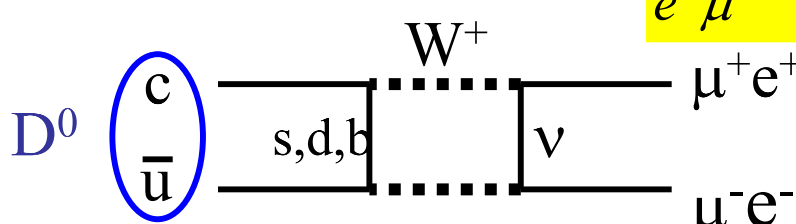
121.6 fb^{-1}

Large backgrounds, only D^0 final states are tractable in e+e- at 10 GeV so far.
Use $D^* \to D^0\pi$ tag.
Measure relative to $D \to \pi\,\pi$.

mode	UL$\times 10^{-6}$	prev
e^+e^-	1.2	6.2
$\mu^+\mu^-$	1.3	2.5
$e^\mp\mu^\pm$	0.81	8.1



standard model rate ~ 10^{-3}



standard model rate ~ 10^{-13} (10^{-23})

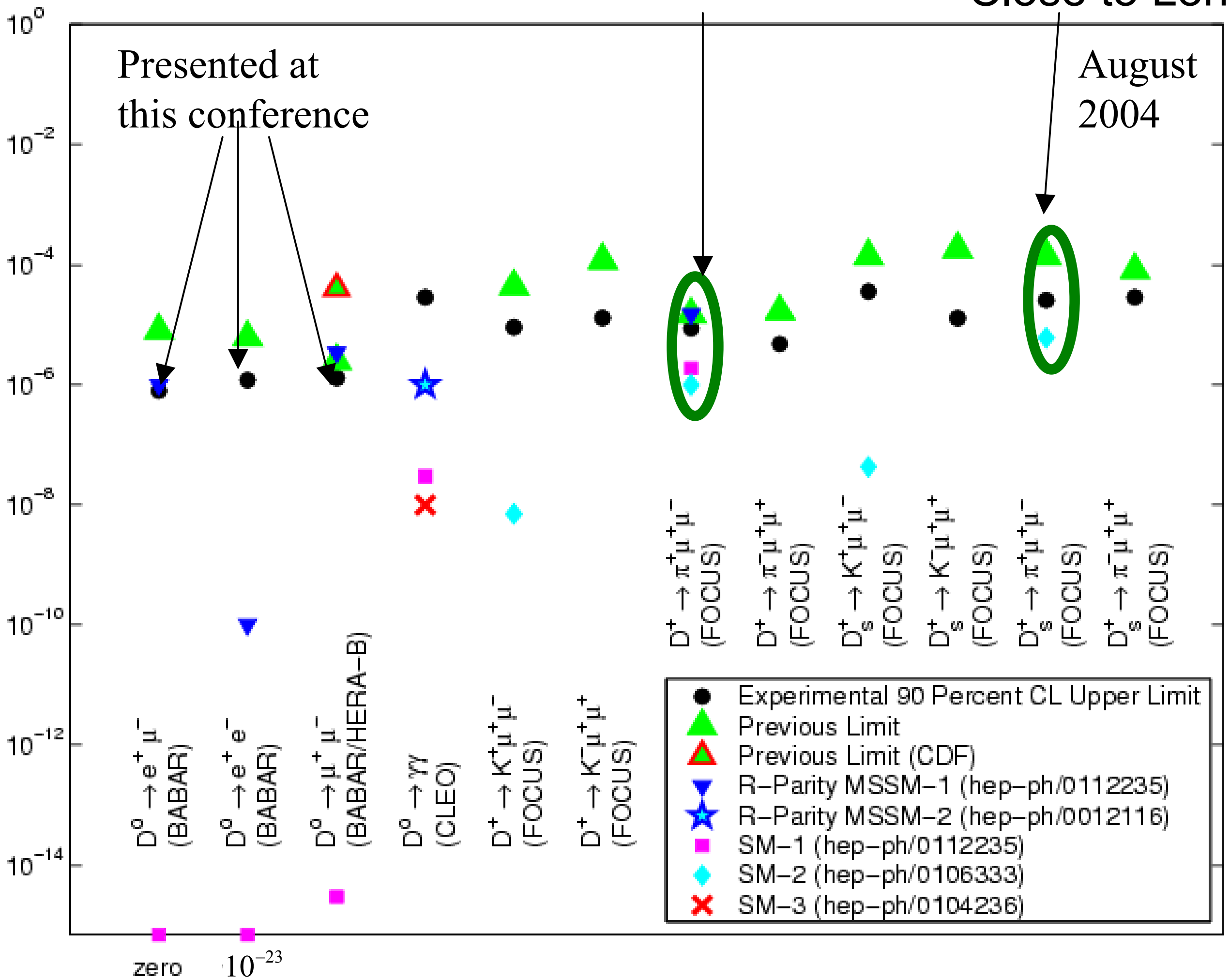
Big Improvement!

$D^0 \to e^\mp\mu^\pm$ forbidden.

Rare Decay Summary

Sets MSSM constraint

Close to Long Distance Predictions



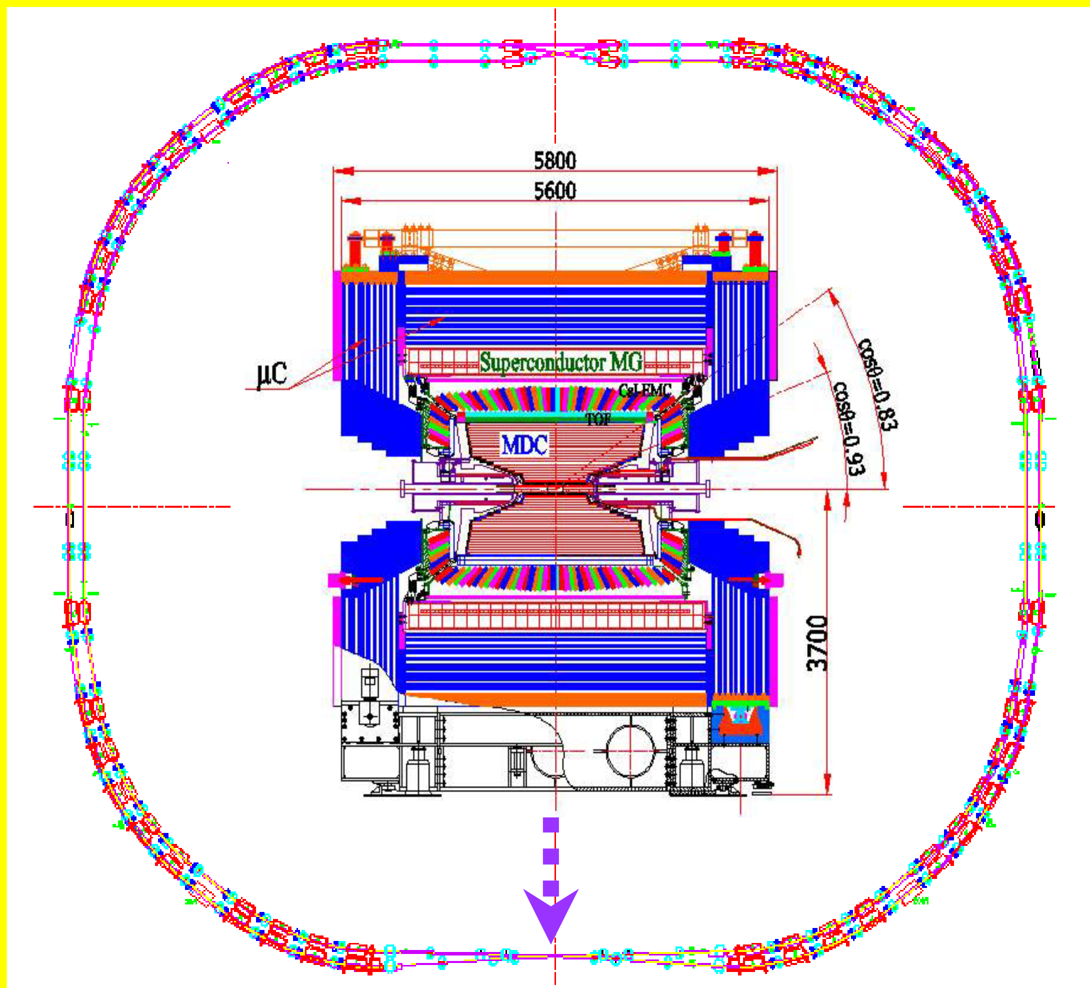
For D^+ all charged final states are well-suited to fixed target experiments FOCUS has best limits

Expt. sensitivity 10^{-5}-10^{-6} Just beginning to confront models of New Physics in an interesting way.

Still plenty of room for New Physics.

Outlook: bright CDF, B factories, charm factories, BTeV.

BEPCII/BESIII Project



Design

- Two ring machine
- 93 bunches each
- Luminosity

  10^{33} cm^{-2} s^{-1} @1.89GeV

  6×10^{32} cm^{-2} s^{-1} @1.55GeV

  6×10^{32} cm^{-2} s^{-1} @ 2.1GeV
- New BESIII

Status and Schedule

- Most contracts signed
- Linac installed 2004
- Ring installed 2005
- BESIII in place 2006
- Commissioning

  BEPCII/BESIII

  beginning of 2007

Summary

New Physics searches in D mixing, D CP violation and in rare decays by BABAR, Belle and CDF have become considerably more sensitive in the past year, however all results are null.

In charm's role as a natural testing ground for QCD techniques there has been solid progress. The start of data taking at the $\psi(3770)$ by BESII and CLEO-c (and later BESIII) promises an era of precision absolute charm branching ratios.

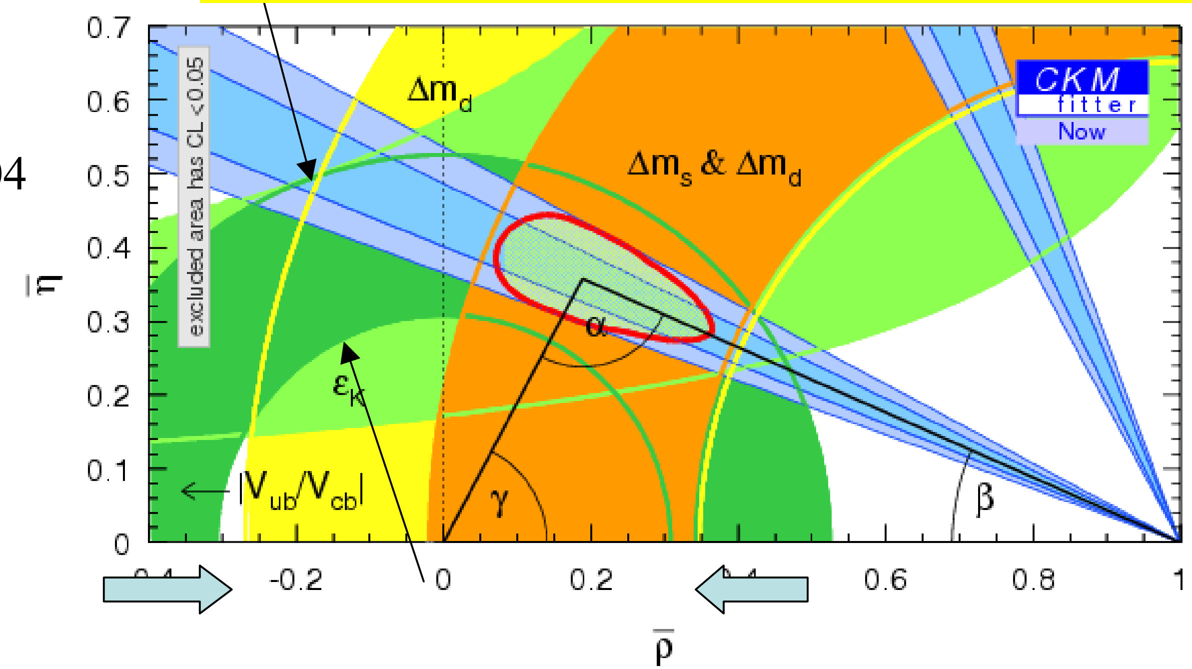
The precision with which the charm decay constant f_{D+} is known has already improved from 100% to ~20%. A reduction in errors for decay constants and form factors to the few % level is promised.

This comes at a fortuitous time, recent breakthroughs in precision lattice QCD need detailed data to test against. Charm can provide 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/BTeV to achieve precision 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

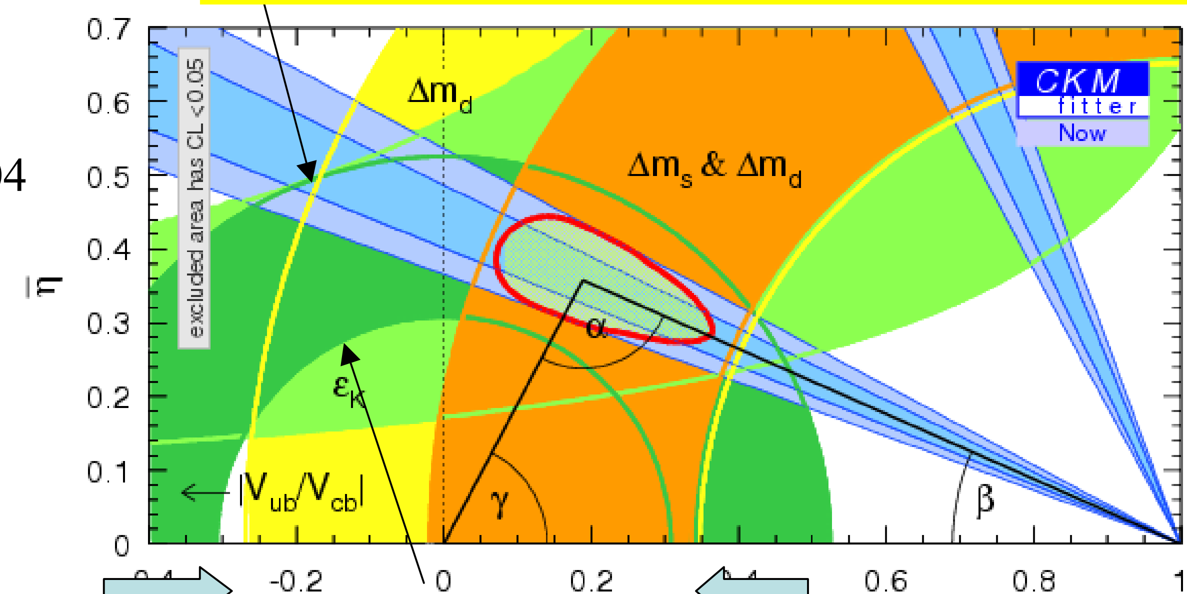
2004

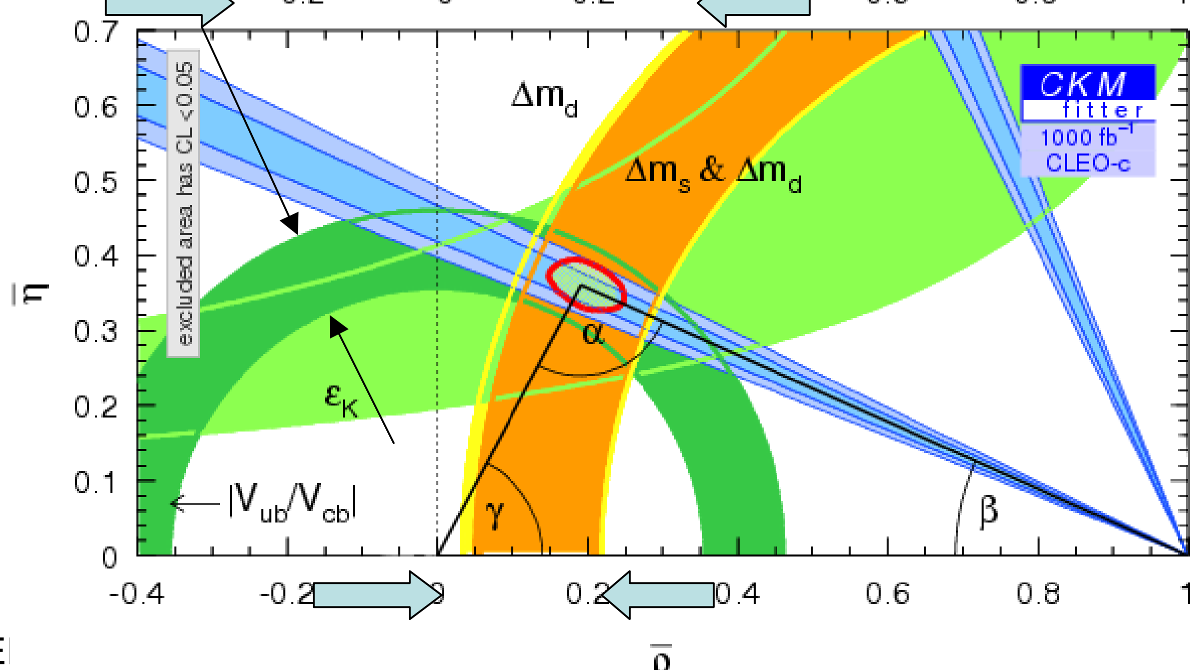


Theoretical errors dominate width of bands

Precision theory + charm = large impact

2004





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

- Results I did not have time to cover:
- Measurement of $\mathcal{B}\left(D_s^{*+} \to D_s^+\pi^0\right)/\mathcal{B}\left(D_s^{*+} \to D_s^+\gamma\right)$ [11-0953]
- Relative BF of Cabibbo-suppressed Λ_c^+ decay modes [11-0963]
- Study of $\Xi_c^0 \to \Omega^- K^+$ and $\Xi_c^0 \to \Xi^-\pi^+$ [11-0938]

(See excellent talk by Matt Charles in Parallel Session 11 HQ(5) for details.)

For more detail on results presented see talks in HQ(5) & HQ(6) by: Alex Cerri, Matt Charles, Jiangchuan Chen, Yongsheng Gao, Ji Lin, Milind Purohit, Gang Rong, and Anders Ryd.

Two recent reviews:
- S. Bianco, F. L. Fabbri, D. Benson & I. Bigi, hep-ex/0309021.
- G. Burdman & I. Shipsey, Ann. Rev. Nucl. Part. Sci., 2003, hep-ph/0310076.

Thanks to the BABAR, Belle, BES II, CDF, CLEO/CLEO-c, and FOCUS collaborations for producing such beautiful results. For their help providing plots and information for this talk thanks to:
BABAR: Matt Charles, Milind Purohit, Jeff Richman.
Belle: Tom Browder, Ji Lin, Bruce Yablsey.
BESII: Jiangchuan Chen, Fred Harris, Gang Rong, Li Weiguo.
CDF: Alex Cerri, Stefano Giagu.
CLEO-c Yongsheng Gao, Nabil Meena, Anders Ryd, Batbold Sanghi, Seunghee Son, Victor Pavlunin.
FOCUS: John Cumalat, Will Johns, Daniele Pedrini, Jim Wiss.
CKM Fitter: Andreas Hoecker, Lydia Roos.

Additional Slides

Precision Quark Flavor Physics

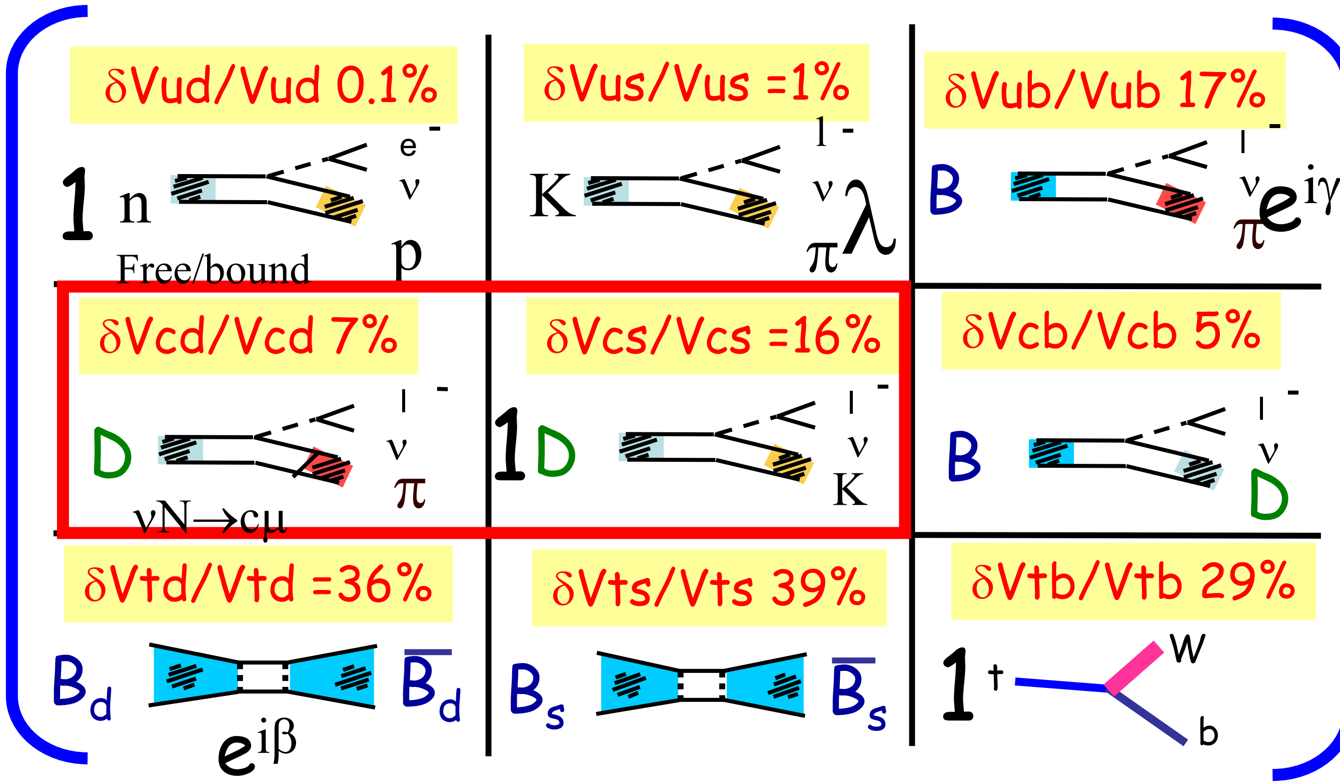
The goal

high precision determination V_{ub}, V_{cb}, V_{ts}, V_{td}, V_{cs}, V_{cd}, & associated phases.
Over-constrain the "Unitarity Triangles" - Inconsistencies → New physics !

status

V_{ud}, V_{us} & V_{cb} best determined due to flavor symmetries: I, SU(3), HQS.
Charm (V_{cd} & V_{cs}) beauty (Vub, Vtd, Vts) poorly determined. theoretical errors dominate.

CKM Matrix Current Status:



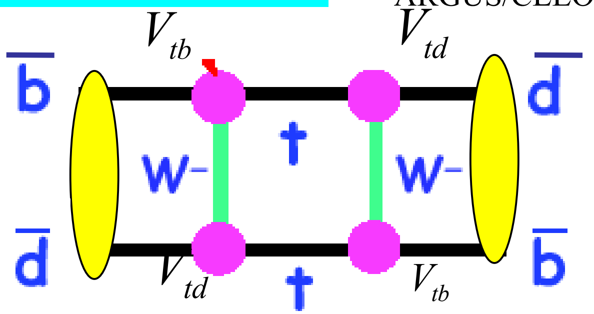
Solution

Precision measurements in *charm*, especially *absolute rates* can calibrate QCD techniques that will enable precise new measurements at Bfactories/Tevatron to be translated into greatly improved CKM precision.

B_d & B_s mixing & Charm Decay Constants

$B_d \rightarrow \overline{B_d}$ mixing

ALEPH,CDF,DELPHI, L3,OPAL.BABAR/BELLE, ARGUS/CLEO



$$\Delta m_d = (const.) f_{B_d}^2 B_{B_d} |V_{td}|^2 |V_{tb}|^2$$

$$\Delta M_d = 0.502 \pm 0.007 \;\; \text{ps}^{-1}$$

$$\frac{\delta \Delta M_d}{\Delta M_d} = 1.4\%$$

$f_B^2 B_B = (223 \pm 33 \pm 12)^2$ MeV^2 } Typical Lattice value

$|V_{td}| \cdot |V_{tb}| = (9.2 \pm 1.4 \pm 0.5)\ 10^{-3}$

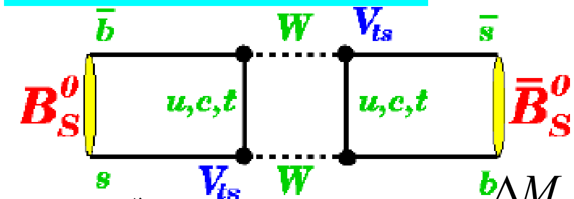
(15-20% error)

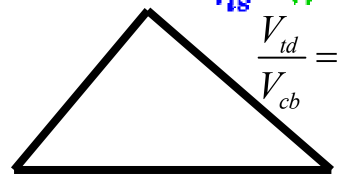
if $f_{Bd}\sqrt{B_d}$ was known to 3%

$|V_{td}||V_{tb}|$ would be known to ~5%

$B_s \rightarrow \overline{B_s}$ mixing

ALEPH,CDF, DELPHI,OPAL.SLD





$$\frac{V_{td}}{V_{cb}} = \frac{V_{td}}{V_{ts}}$$

ξ^2 (lattice)

$$\frac{\Delta M_d}{\Delta M_s} \propto \left[\frac{\sqrt{B_{B_d}} f_{B_d}}{\sqrt{B_{B_s}} f_{B_s}}\right]^2 \left[\frac{|V_{td}|}{|V_{ts}|}\right]^2$$

$\delta\xi/\xi \sim 6\text{–}8\%??$

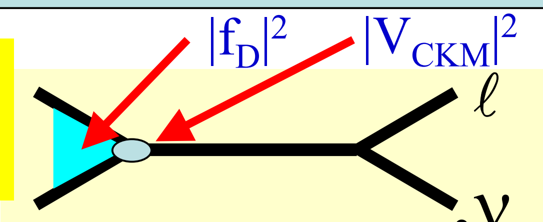
World Average

$\Delta ms < 14.5/ps$

Dominant error.

f_{Bd} f_{Bs} inaccessible

f_{D+} f_{Ds} accessible



$$B(D_{(s)}^+ \rightarrow \mu\nu)/\tau_{D_{(s)}^+} = (const.) f_{D_{(s)}^+}^2 |V_{cd(s)}|^2$$

Lattice → f_B/f_{Bs} & f_D/f_{Ds} with small errors

f_D/f_{Ds} (expt.) *tests* f_D/f_{Ds} (LQCD) & gives confidence to f_B/f_{Bs} (LQCD): precise $|V_{td}|/|V_{ts}|$

f_B/f_D (LQCD) & f_D (expt.) +ΔM_d → precise $|V_{td}|$

Same for $|V_{ts}|$

Role of precision *absolute* charm branching ratios

ALEPH, DELPHI, L3,OPAL.BABAR/BELLE, ARGUS/CLEO

Vcb Zero recoil in $B \to D^{*} l^{+} \nu$ & $B \to D l^{+} \nu$

$$\frac{d\Gamma}{dq^2}(B \to D^{*}\ell\nu) \propto F(q^2)^2 \left|V_{cb}\right|^2$$

$$F(q^2 = q^2_{\max}) = 0.91 \pm 0.04$$

$$\left|V_{cb}\right| = (41.6 \pm 0.9_{\exp} \pm 1.8_{theo}) \times 10^{-3}$$

(HFAG Summer 2004)

Lattice & sum rule

As B Factory data sets grow, & calculation of F improve a limiting systematic:

dB(D→Kπ)/dB(D→Kπ) → dV_{cb}/V_{cb}=1.2%

HQET spin symmetry test:

$$\frac{\Gamma\left(\bar{B}^{o} \to D^{*+} h^{-}\right)}{\Gamma\left(\bar{B}^{o} \to D^{+} h^{-}\right)} = 1$$

Test factorization with $B \to DD_s$

Understanding charm content of B decay (n_c)

Precision $Z \to bb$ and $Z \to cc$ (R_b & R_c)

At LHC/LC $H \to bb$ $H \to cc$

➤ CKM matrix elements Vcs Vcd at BESII

Vcs ~1

Vcd =sinθ_c

PDG

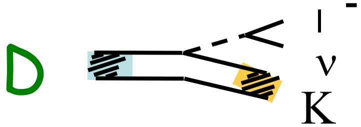
δVcs/Vcs =16%

13%

1.3%

but depends on Vud, Vus, Vub Vcd, Vcb

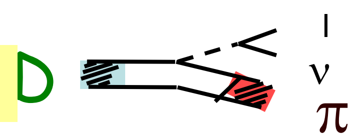
δVcd/Vcd 7%



$W \to cs$

$\frac{W \to \text{hadrons}}{W \to \ell \nu}$

$\nu_\mu d \to \mu^- c,\ c \to s \mu^+ \nu_\mu$ $+(cc)$



$\Gamma(D^0 \to K^- e^+ \nu) = 1.53 |V_{cs}|^2 |f_+^K(0)|^2 \times 10^{11}\ s$

$\Gamma(D^0 \to \pi^- e^+ \nu) = 3.01 |V_{cd}|^2 |f_+^\pi(0)|^2 \times 10^{11}\ s$

BES use current theoretical predictions with errors estimated at ~10%

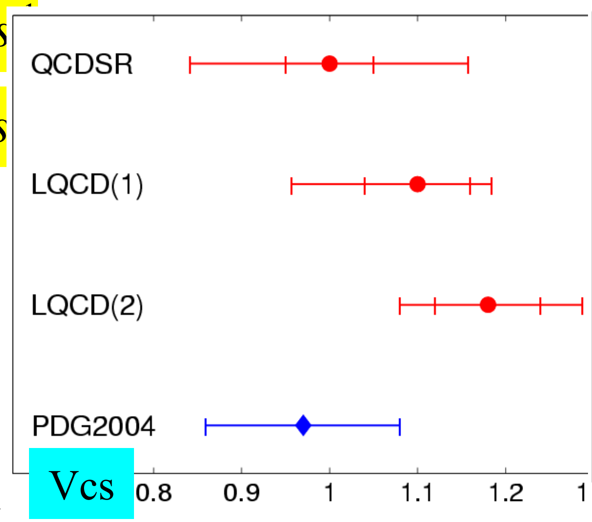
$f_+^K(0) \quad f_+^\pi(0)$

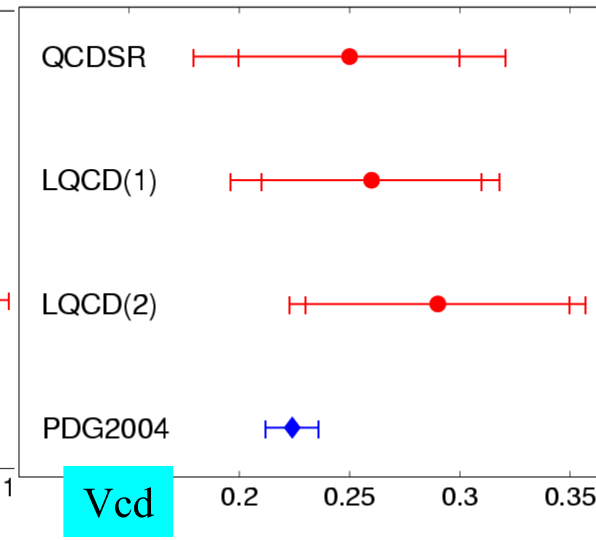
δVcs/Vcs ~10%

Best Determination with K$l\nu$

δVcd/Vcd =23%

Not yet competitive



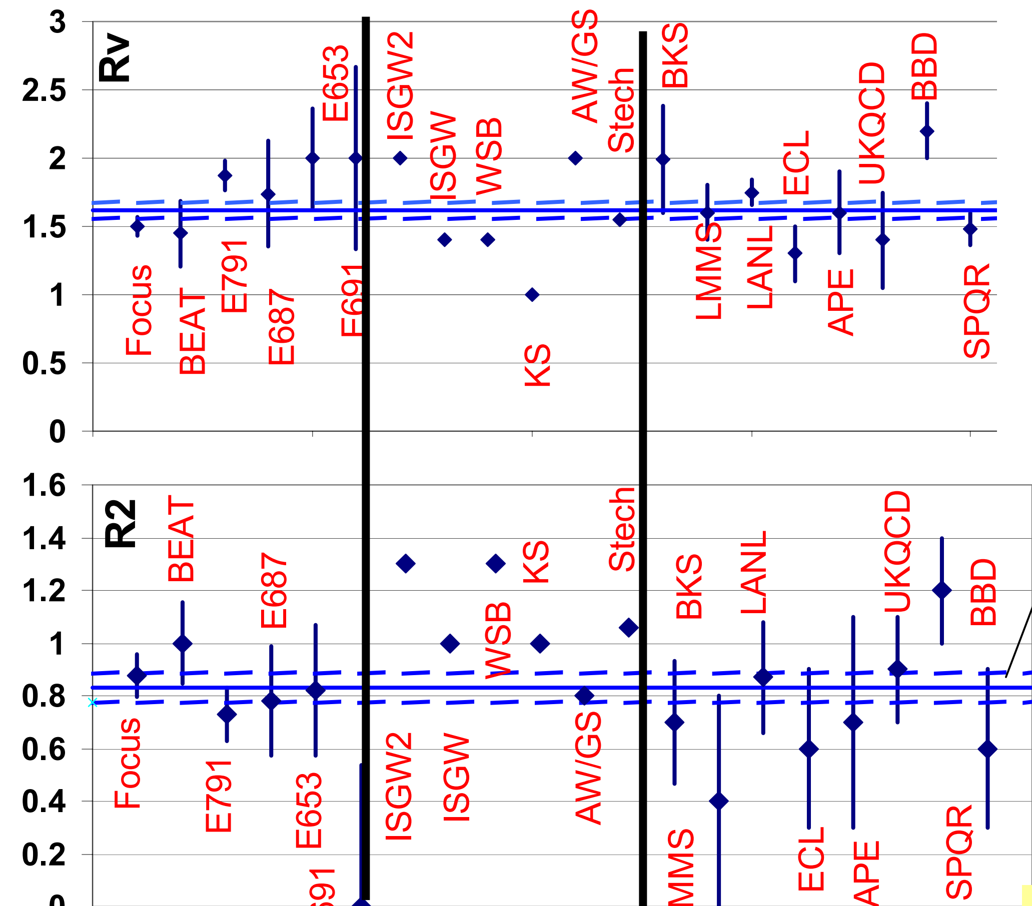


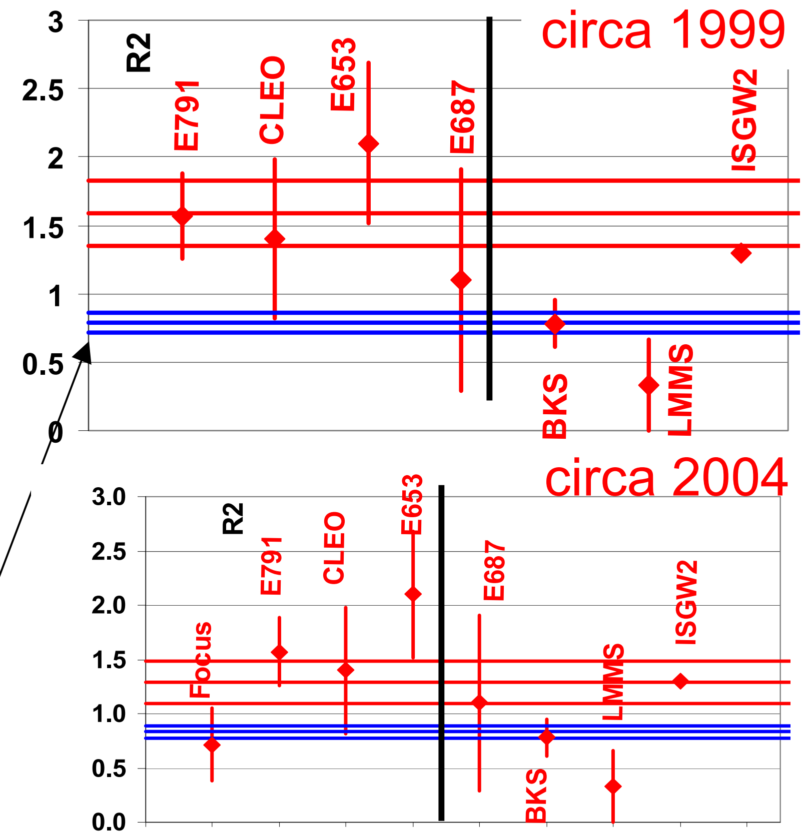
	$\lvert V_{cs}\rvert$(Expt) (theory)	$\lvert V_{cd}\rvert$(Expt) (theory)
BES(*QCD*SR)	$1.0 \pm 0.05 \pm 0.15$	$0.25 \pm 0.05 \pm 0.05$
BES(L*QCD(1)*)	$1.1 \pm 0.06^{+0.06}_{-0.13}$	$0.26 \pm 0.05^{+0.03}_{-0.04}$
BES(L*QCD(2)*)	$1.18 \pm 0.06^{+0.09}_{-0.08}$	$0.29 \pm 0.06 \pm 0.03$
PDG2004	0.97 ± 0.11(W→cs)	0.224 ± 0.012

Note: Goal of lattice QCD few % error on

$f_+^K(0) \quad f_+^\pi(0)$

$D^+ \to K^*\mu\nu$ & $D_s \to \phi\mu\nu$ form factor ratios



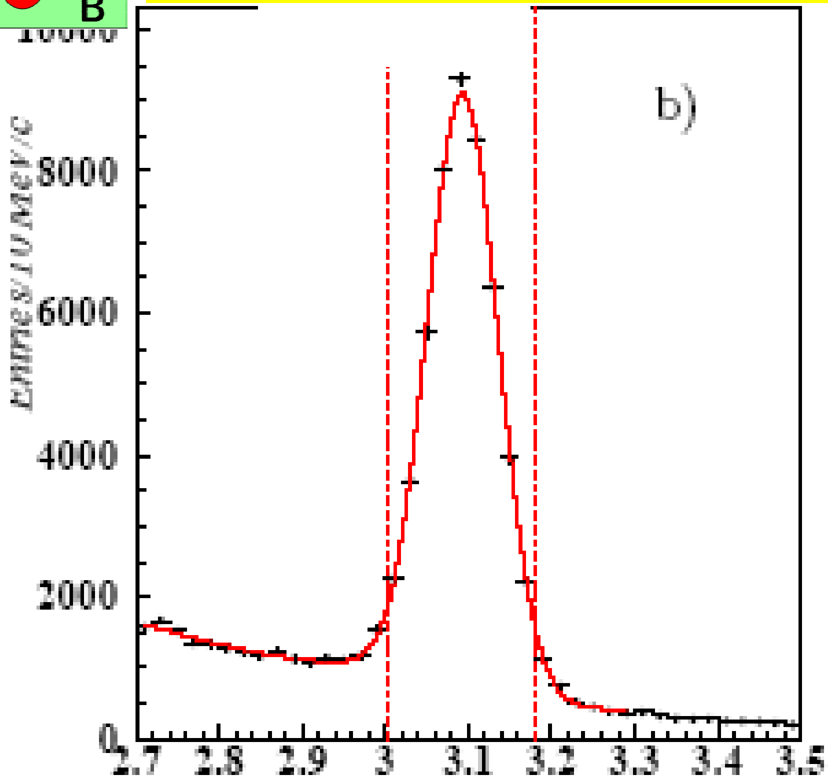


Results are getting very precise and more calculations are needed. *Absolute* values of indivudual form factiors soon with improved precision promised by CLEO-c.

$D_s \to \phi l \nu$ form factor should be within 10% of **$D \to K^* l \nu$** R2 for **$D_s \to \phi l \nu$** was ≈ 2⊗ higher than **$D \to K^* l \nu$** until FOCUS (2004) .

Search for $D^0 \to \mu^+\mu^-$

Reference channel:with similar kinematics.

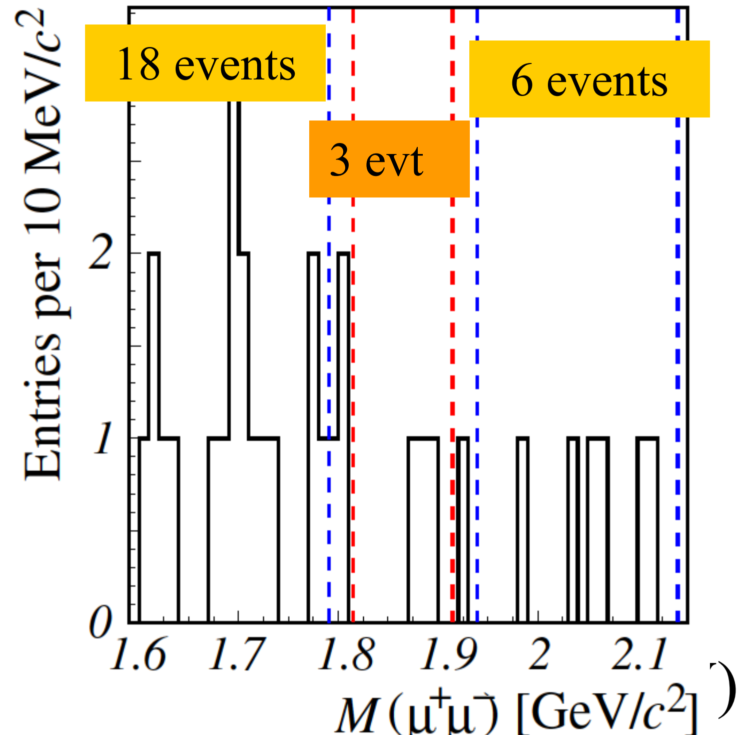


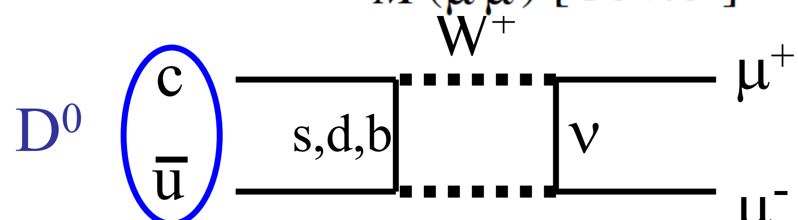
mass(μ^+,μ^-) (GeV)

$B(J/\psi \to \mu^+,\mu^-) = (5.88 \pm 0.10)\ \%$

+need to know relative production crosssection for J/ψ and D

Search channel: 3 events in search window





$BR(D^0 \to \mu^+\mu^-) < 2.0\times10^{-6}$ (90% CL)

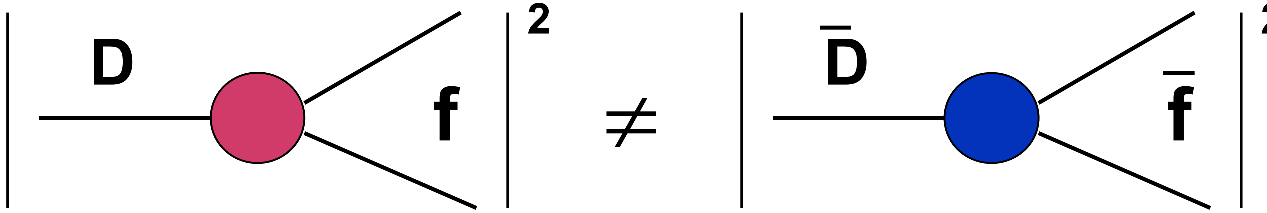
hep-ex/0405059

Three Types of CP Violation

Decay (A_D)

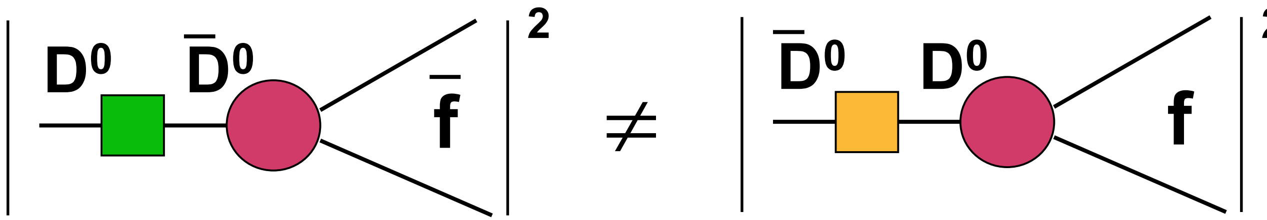
$|A_f| \neq |\bar{A}_{\bar{f}}|$

$SM \leq 10^{-3}$ SCS only



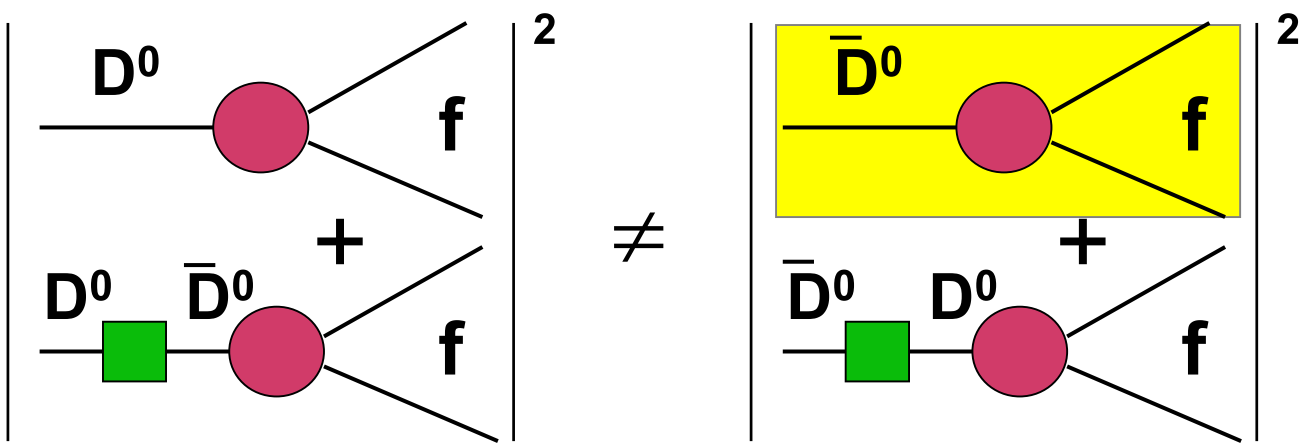
Mixing (A_M)

SM: Extremely small



Interference between mixing and decay (ϕ)

SM: Small because mixing is small



Experiments focus mostly on A_D