Heavy Quarks and τ

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τ
- CVC test
- Michel parameters

Charm
- Mixing
- f_{D_s}

B
- f_B
- Two mysteries: N_c and η'K
- CKM: ππ, Kπ, V_{cb}, V_{ub}
- Lifetime and mixing
- CP search

Belle and Babar*

A very brief description of the Belle and Babar data sets:

Both run at: $L \sim 2 \times 10^{33}\ cm^{-1}s^{-2}$ (CLEO's peak: $\sim 8 \times 10^{32}$)

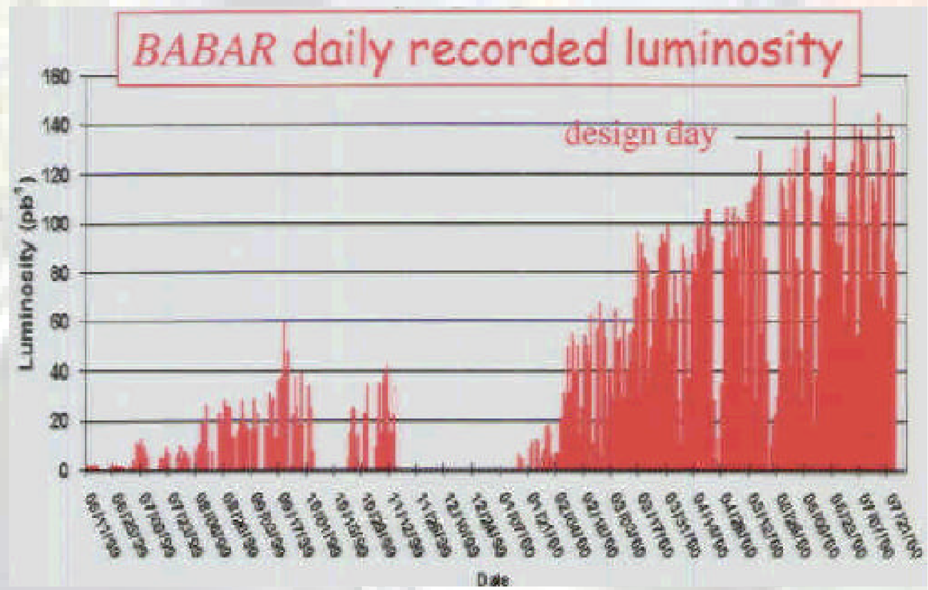
Integrated luminosities:

Babar: 9.9 fb^{-1} for Osaka, 7.7 fb^{-1} on 4S (>11 in the can, I think)

Belle: 6.8 fb^{-1} for Osaka, 6.2 fb^{-1} on 4S

CLEO: 14 fb^{-1}, 9 fb^{-1} on 4S

1 fb^{-1} is about 1 million $B\bar{B}$ pairs.



*"Beauty and the Beast"

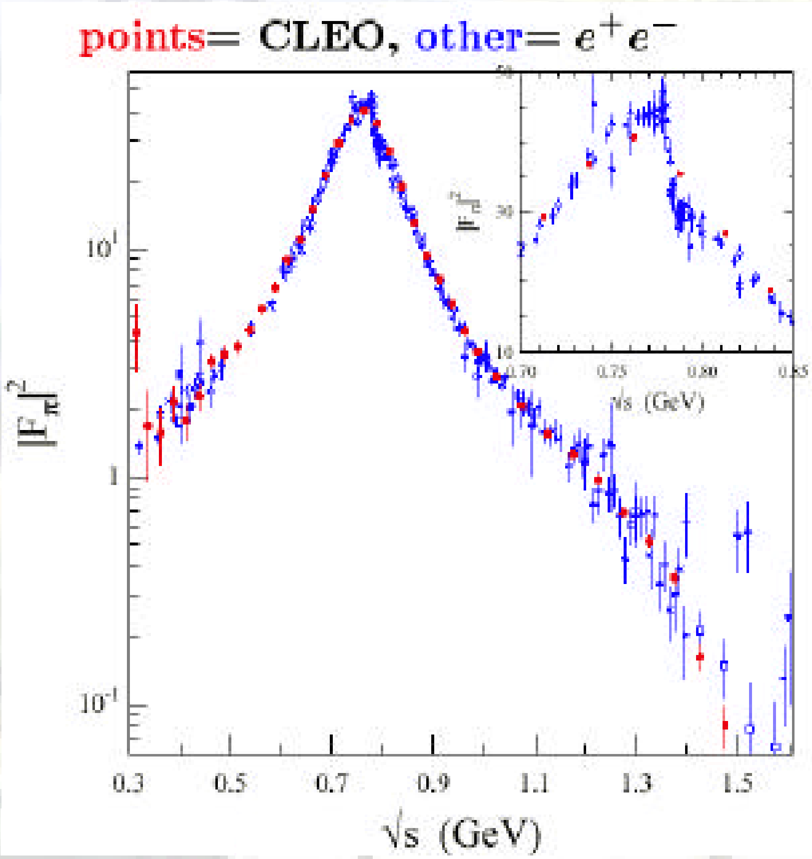
Two τ results, briefly

$\tau \to \pi\pi^0\nu$ goes via vector current.

CVC (e^+e^-) predicts: BR = (24.52±0.33)%

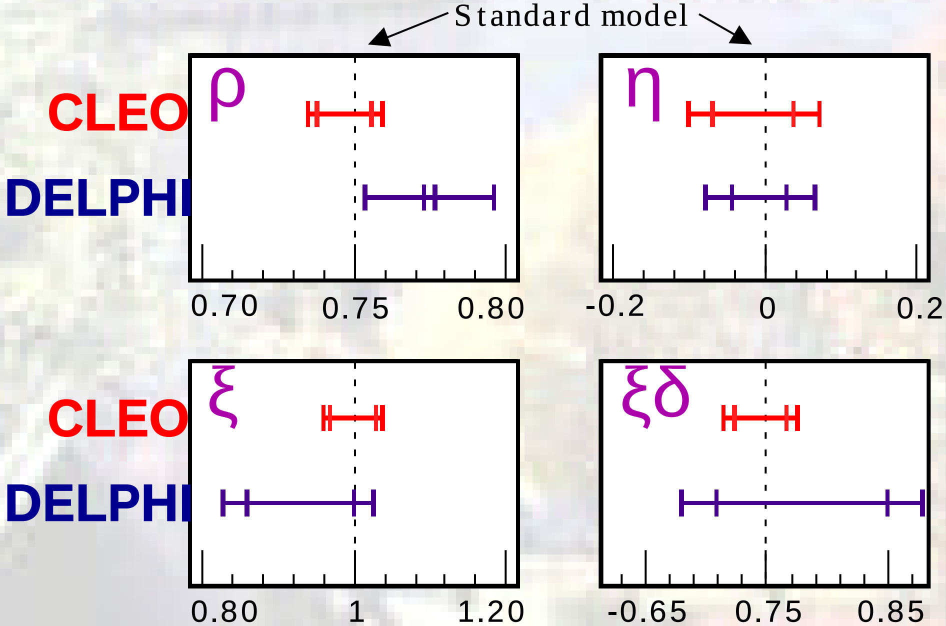
CLEO measures: (25.32±0.15)%

Fractional difference is (3.2±1.5)%.



Michel parameters:

DELPHI has new measurements. Still x5 worse than with muons, but B factories can improve this (not yet systematics limited).

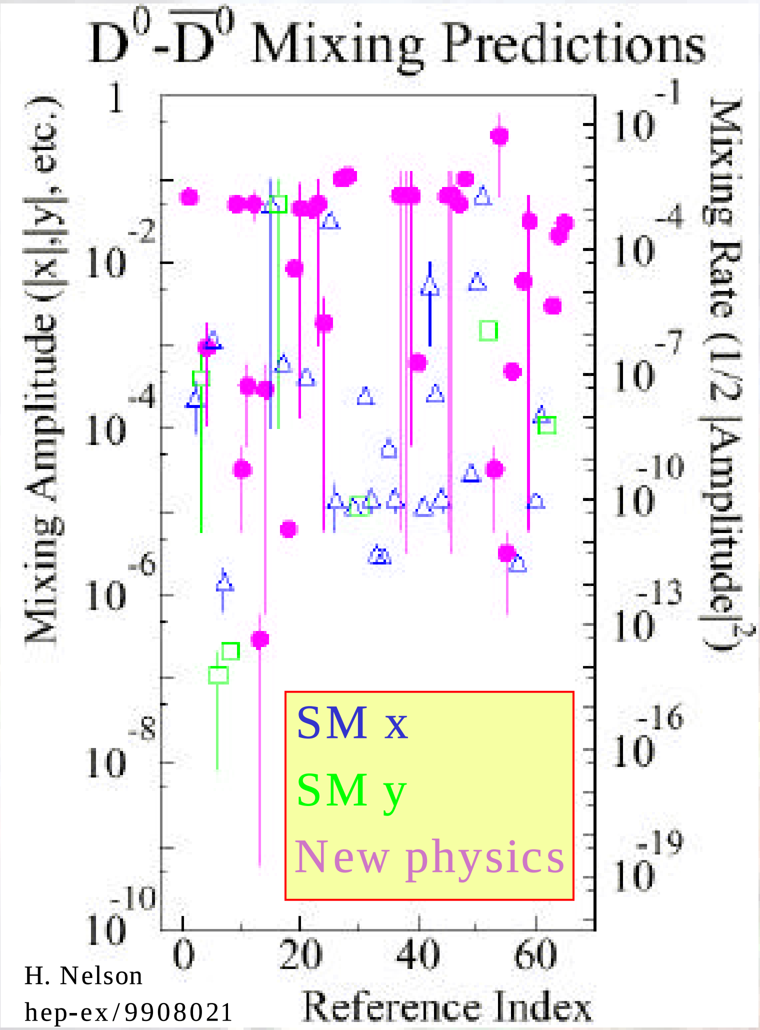


$D\bar{D}$ Mixing

The standard box diagram is GIM suppressed, because the top quark does not appear (only d,s,b).
However, theoretical predictions vary:

Parameters x and y are the imaginary and real parts of the mixing matrix.

Two methods:
- Compare the lifetime of decays to different CP states (eg, $D \rightarrow KK, K\pi$). Only sensitive to y.
- Look for interference between mixed and direct decays to the same state (eg, $D^o \rightarrow K^+\pi^-$).



Lifetime method:

Belle measures the lifetimes separately.
Focus performs a combined fit.

Belle:

$$\tau_{D^+} = (1040^{+23}_{-22} \pm 18)\ \text{fs}$$

$$\tau_{D^o} = (414 \pm 3.8 \pm 3.4)\ \text{fs}$$

$$\tau_{D_s} = (479^{+17}_{-16}{}^{+6}_{-8})\ \text{fs}$$

$$\tau_{D^o \to KK} = (408.9 \pm 14.3)\ \text{fs}$$

$$\tau_{D^o \to K\pi} = (412.9 \pm 3.8)\ \text{fs}$$

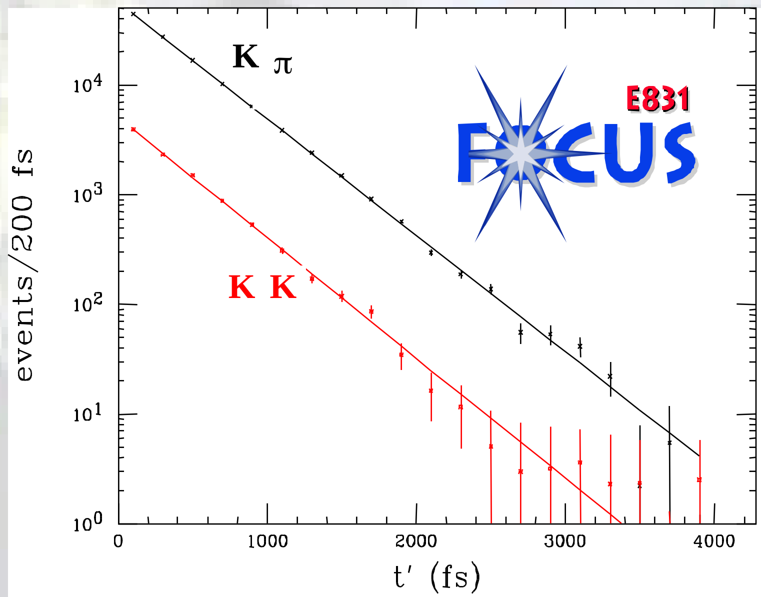
$$y_{CP} = \frac{\tau_{K\pi}}{\tau_{KK}} - 1 = (1.0^{+3.8}_{-3.5}{}^{+1.1}_{-2.1})\ \%$$

Belle's measurements verify their time calibration for $B \to J/\Psi K^o$

Focus:

$$\tau_{D^o \to K\pi} = (409.2 \pm 1.3 \pm ?)\ \text{fs}$$

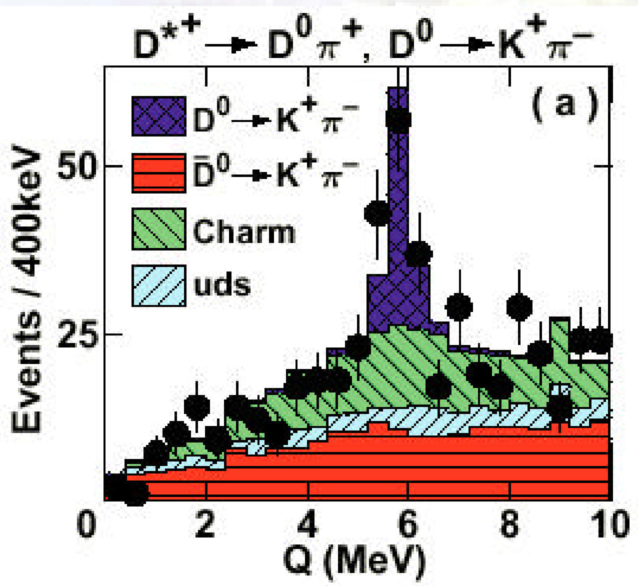
$$y_{CP} = (3.42 \pm 1.39 \pm 0.74)\ \%$$

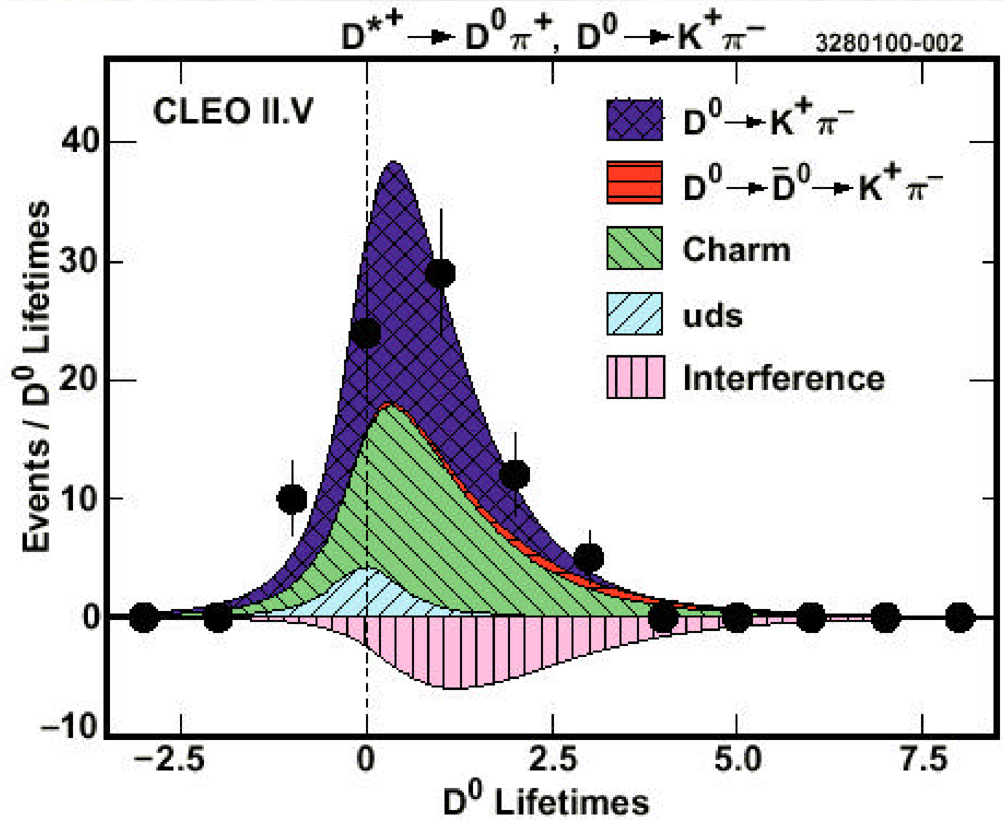


Interference method:

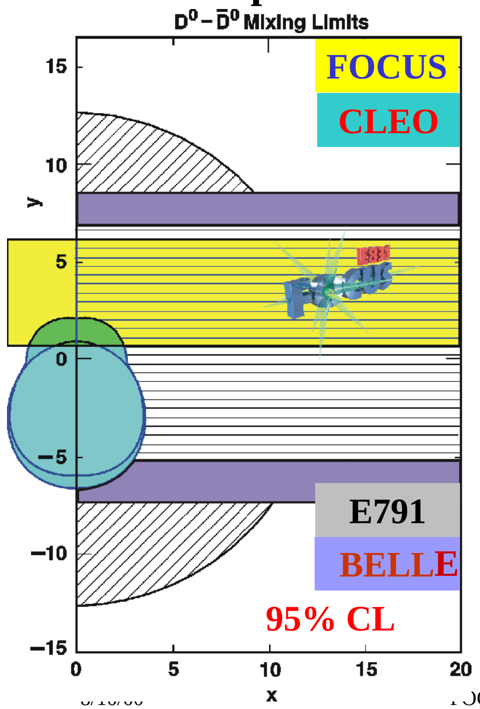
CLEO measures wrong sign Kπ only.
Look for interference between mixing and DCSD channels.
Measure both x' and y'. (Primes result from final state interactions.)

-5.8% < Y' < 1.0%
|x'| < 2.9%





Comparisons to CLEO, E791 and BELLE



The comparison to CLEO **is vaild only if** one assumes a small strong phase difference δ.

About the same sensitivity to the CLEO CP constrained fit, but the **opposite sign!**

FOCUS

$y_{CP} = 3.42 \pm 1.39 \pm 0.74$ %

Recent Measurements

E791: y_{CP} = 0.8 ± 2.9 ± 1 %

CLEO: -5.8 % < y' < 1% (95% CL)

BELLE prelim.: y_{CP} = $1.0^{+3.8+1.1}_{-3.5-2.1}$

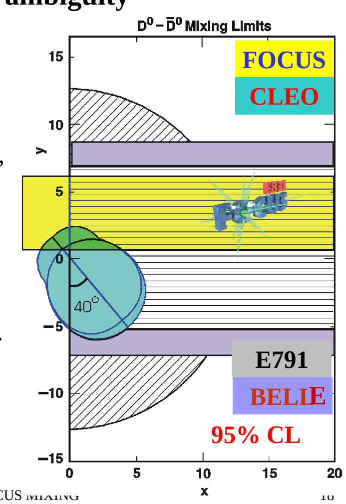
x splits masses,
y splits lifetimes.

Phase ambiguity

What if δ = 40°, the estimated maximum of the model of *Falk, Nir & Petrov (99)?* We see **some overlap...**

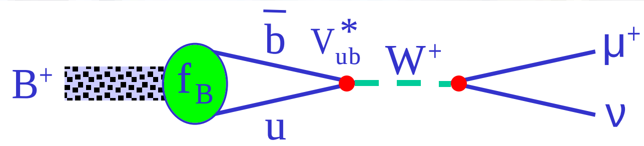
CLEO and FOCUS would be more consistent if δ > 90°...

Bergmann, Grossman et al(00).



Decay Constants (f_D, f_{D_s}, f_B)

Leptonic decay rates depend on the meson decay constants:



$$BR(B \to \ell\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Similarly for $D \to \mu\nu$, $D_s \to \mu\nu$, etc.

Many other processes depend on them also.
For example, in $B\bar{B}$ mixing:

$$\Delta M_d = 0.50\text{ps}^{-1}\left[\frac{\sqrt{B_{B_d}}\, f_{B_d}}{200\,MeV}\right]^2\left[\frac{\bar{m}_t(m_t)}{170\,GeV}\right]^{1.52}\left[\frac{|V_{td}|}{8.8\times 10^{-3}}\right]^2\left[\frac{\eta_B}{0.55}\right]$$

This is non-perturbative QCD - measure or calculate on lattice.
$B \to \tau\nu$ is difficult to measure; the approach for now is to use charm results to test the lattice calculations.

Recent Results

ALEPH

$D_s \to \tau\nu$: (5.86±1.18±2.09)% (e)

(5.78±0.85±1.76)% (μ)

$D_s \to \mu\nu$: (0.68±0.11±0.18)%

f_{Ds}

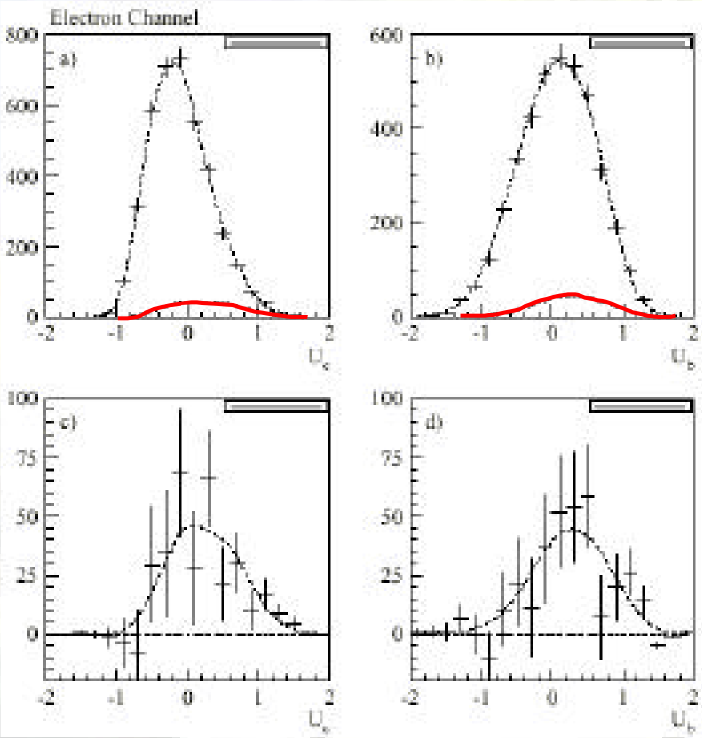
275±28±49 MeV

273±20±41

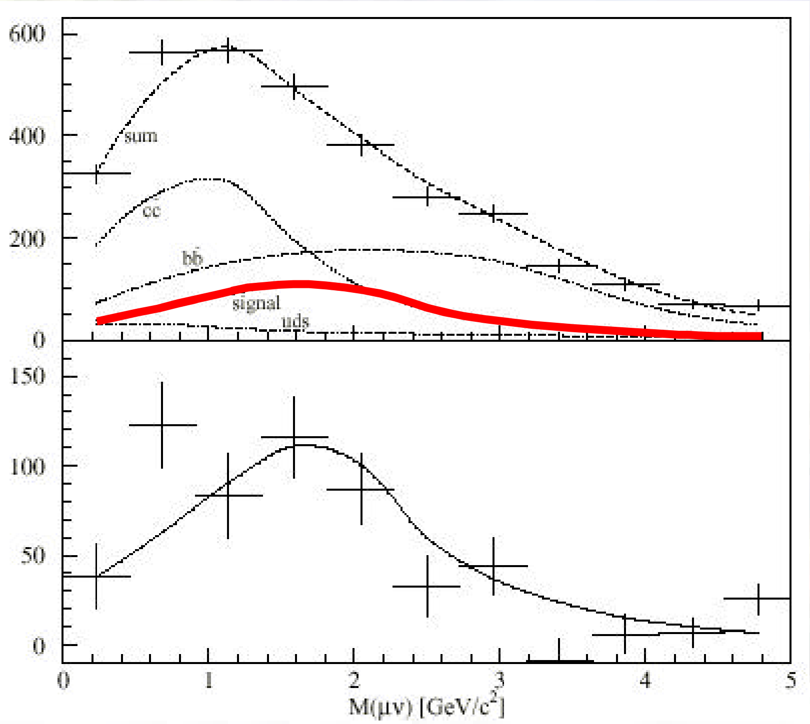
291±25±38

285±20±40 (combined)

$\tau \to e\nu\nu$



$\mu\nu$



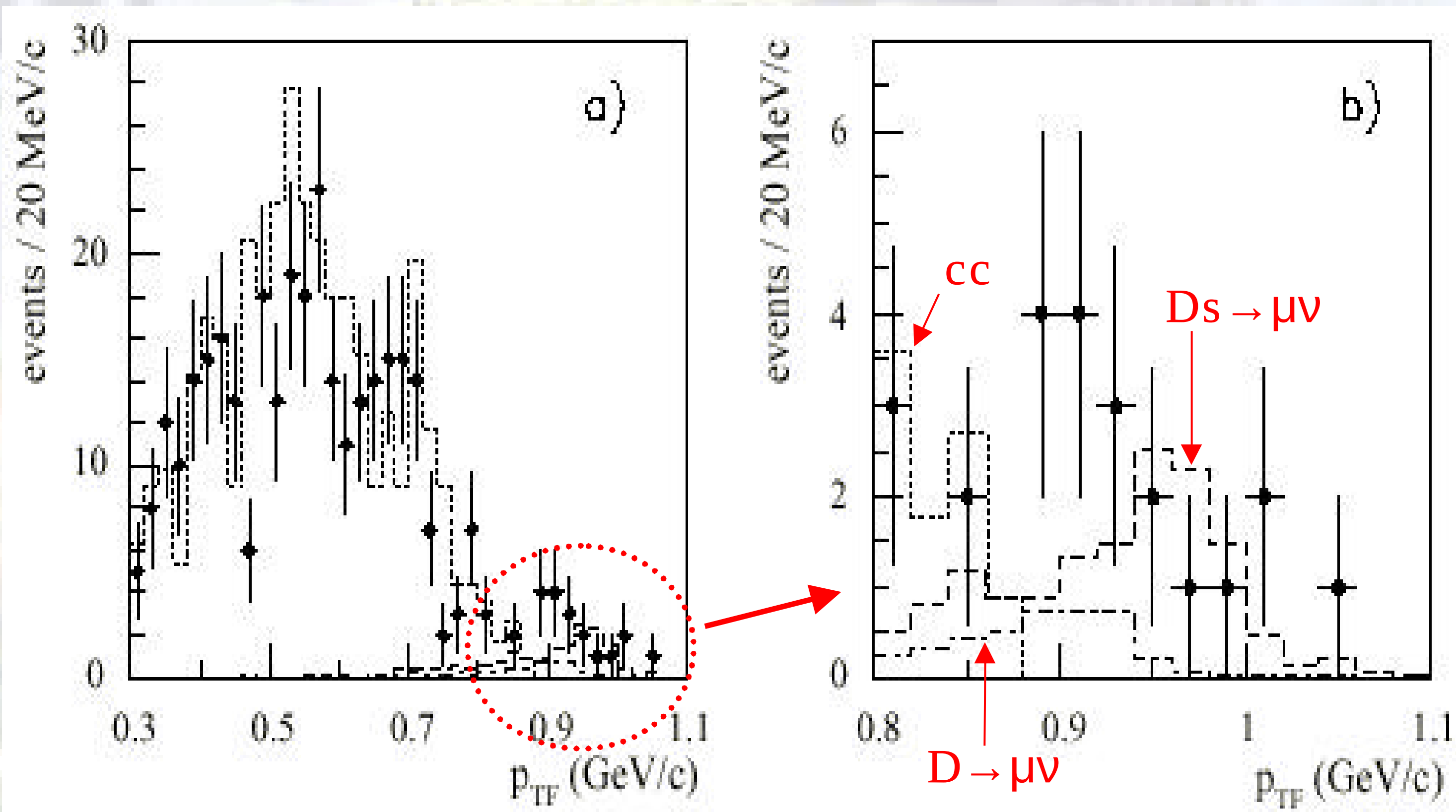
BEATRICE (WA92):
PL B478, 31(2000)

Fixed target: πW, πCu

Assume $\left(\frac{f_D}{f_{D_s}}\right)^2 = 0.82 \pm 0.09$

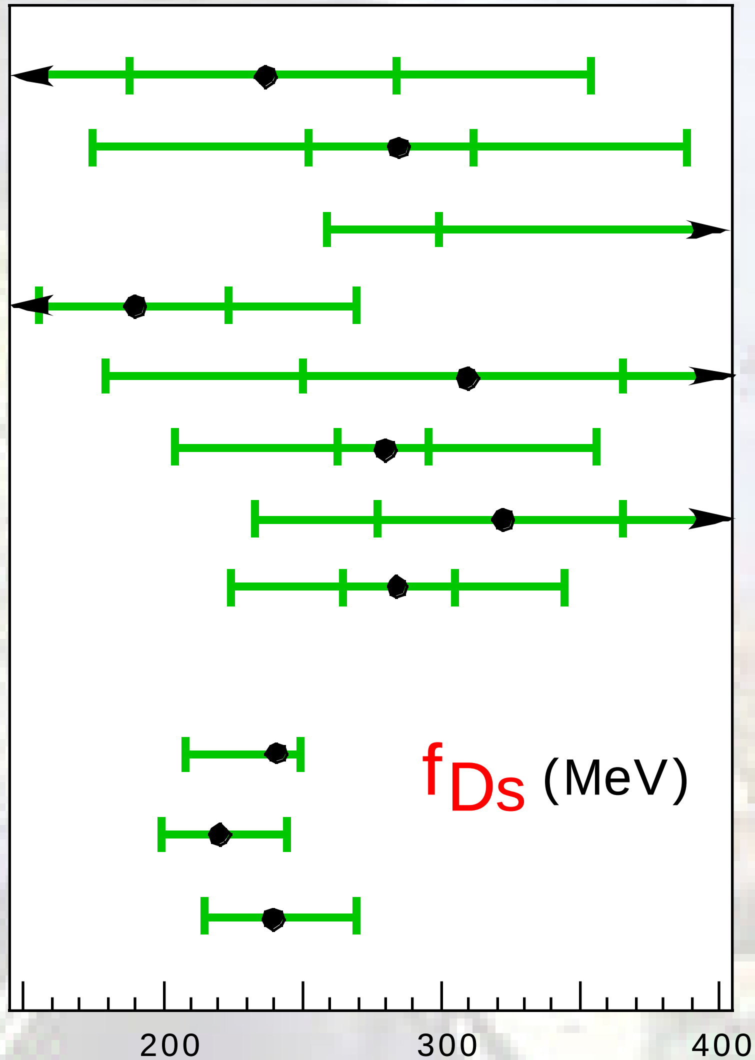
$D_s \to \mu\nu$ = (0.83 ± 0.23 ± 0.06 ± 0.18$(D_s \to \varphi\pi)$)%

f_{D_s} = 323±44±12±34 MeV



f_{D_s} summary

WA75 ('93)	$238 \pm 47 \pm 21 \pm 48$
CLEO ('94)	$282 \pm 30 \pm 43 \pm 34$
BES ('95)	$430^{+150}_{-130} \pm 40$
E653 ('96)	$190 \pm 34 \pm 20 \pm 26$
L3 ('97)	$309 \pm 58 \pm 33 \pm 38$
CLEO ('98)	$280 \pm 17 \pm 25 \pm 34$
Beatrice ('00)	$323 \pm 44 \pm 12 \pm 34$
ALEPH ('00)	$285 \pm 20 \pm 40$
Lattice	
UKQCD ('00)	241^{+9}_{-32}
Draper98(q)	220^{+25}_{-20}
(unq)	240^{+30}_{-25}



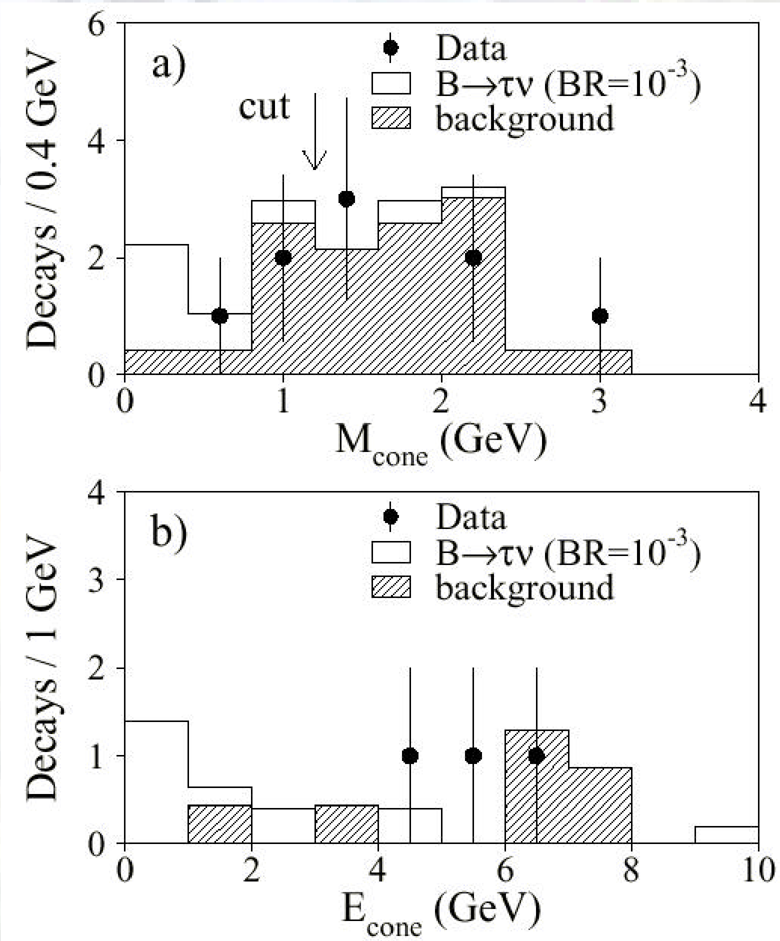
Systematic errors dominate

$B \rightarrow \tau\nu$

Predict: $(4.08 \pm 0.24) \times 10^{-4} \times |V_{ub}/V_{td}|^2 \sim$ few $\times 10^{-5}$ (Use Δm_B to eliminate f_B)

L3 (the best LEP result)

$B \rightarrow \tau\nu < 5.7 \times 10^{-4}$

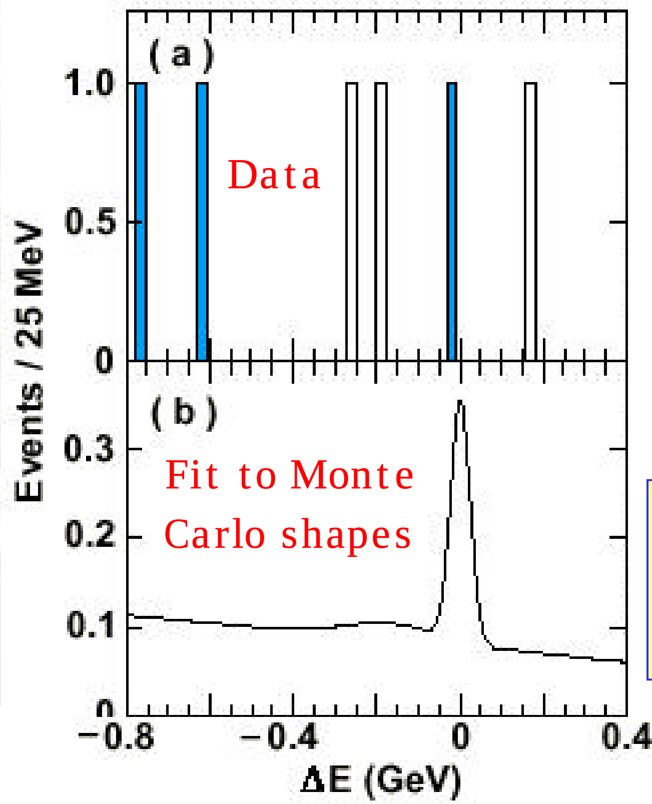


CLEO

At the Υ(4S) one can suppress background by reconstructing the other B.

$B \rightarrow \tau\nu < 8.4 \times 10^{-4}$

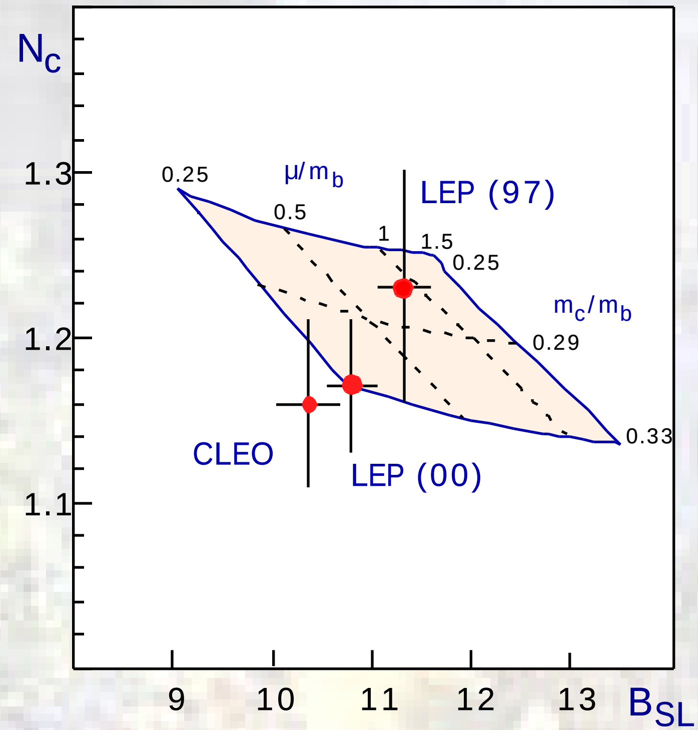
$B \rightarrow K^{\pm}\nu\nu < 2.4 \times 10^{-4}$



The Standard Model may be reachable.

Charm Counting

It is possible to calculate both the inclusive semileptonic BR and the number of charmed particles per decay in terms of fundamental quantities. In the past, the measurements have disagreed, making interpretation difficult. New ALEPH & DELPHI results change the picture. There is now experimental consistency.



$N_c = 1.171 \pm 0.040$
$B_{SL} = 10.79 \pm 0.25$

(Barker & Blyth @ ICHEP)

CLEO: $B_{SL} = (10.49 \pm 0.17 \pm 0.43)\%$
$Nc = 1.10 \pm 0.05$

Using new lifetimes

Note: LEP Vcb WG says: $B_{SL} = 10.56 \pm 0.11 \pm 0.18$

$B \rightarrow \eta' K$

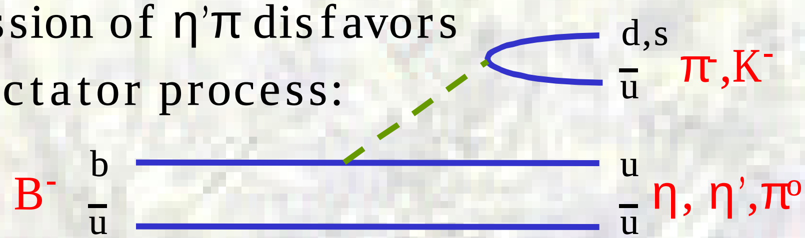
CLEO observed (1997) $B^{\pm} \rightarrow \eta' K^{\pm}$ to have a surprisingly large BR. This is now confirmed, and the K^o mode is also seen.

$BR(B^{\pm} \rightarrow \eta' K^{\pm}) = (8.0\,^{+1.0}_{-0.9} \pm 0.7) \times 10^{-5}$

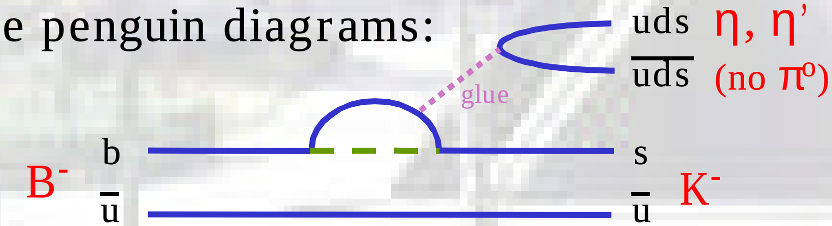
$BR(B^{o} \rightarrow \eta' K^{o}) = (8.9\,^{+1.8}_{-1.6} \pm 0.9) \times 10^{-5}$

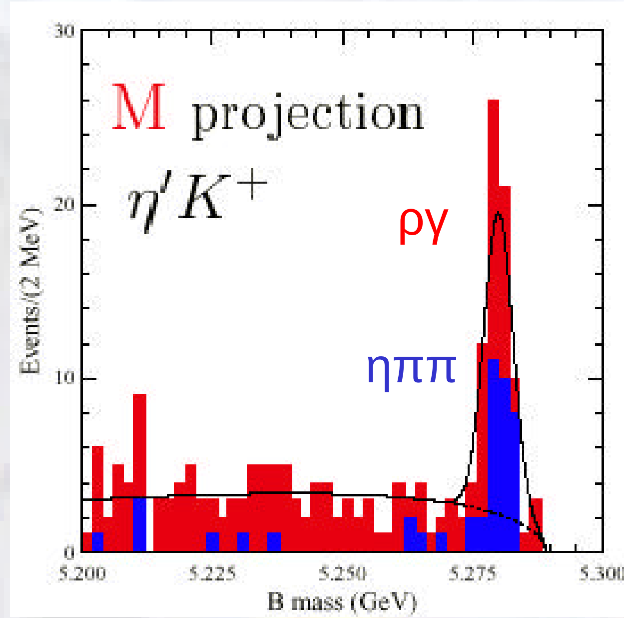
$BR(B^{\pm} \rightarrow \eta' \pi^{\pm}) < 1.2 \times 10^{-5}$

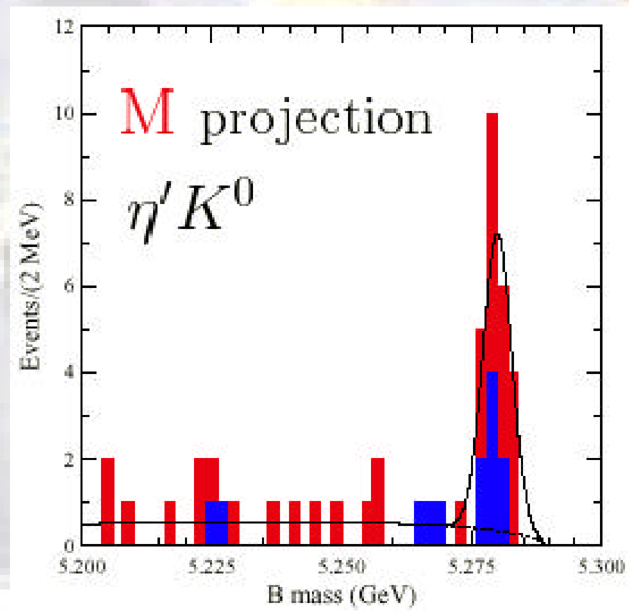
The equality of these BRs and the suppression of $\eta'\pi$ disfavors the spectator process:



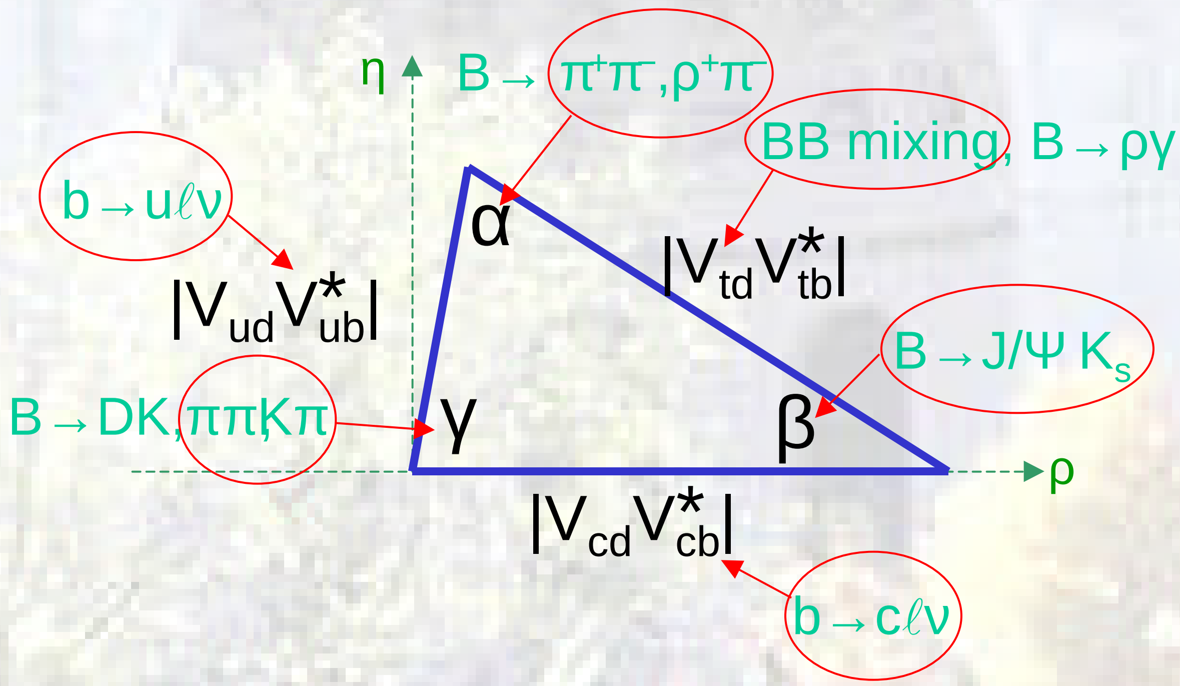
Intrinsic charm or glue content would enhance penguin diagrams:







How to measure the CKM Matrix

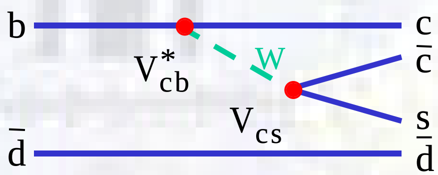


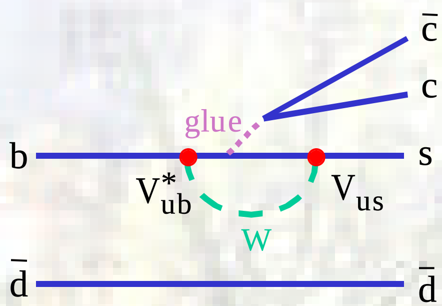
$B \rightarrow J/\psi K_s$ $\sin(2\beta)$

vs

$B \rightarrow \pi^+\pi^-$ $\sin(2\alpha)$

$B \rightarrow J/\psi K_s$

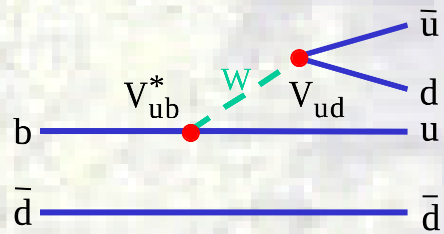


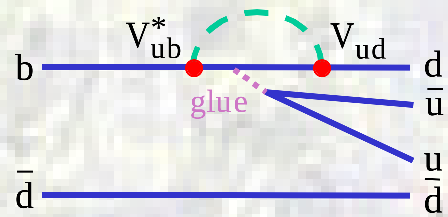


$$\frac{\text{Penguin}}{\text{Tree}} \sim \frac{A\lambda^4(\rho - i\eta)}{A\lambda^2(1-\lambda^2/2)}$$

$$\sim \lambda^2 \sim 0.05$$

$B \rightarrow \pi^+\pi^-$





$$\frac{\text{Penguin}}{\text{Tree}} \sim 1$$

Is this correct?

$B^o \rightarrow K^+\pi^-$ is dominated by penguins, so:

$$\frac{B^o \rightarrow \pi^+\pi^-}{B^o \rightarrow K^+\pi^-} \sim \frac{1}{4}$$

tells us that P/T ~ 0.5.

The presence of penguins requires an isospin analysis.
($\pi^0\pi^0$ BR < 6×10^{-6})

It may be easier to use $\rho\pi$, because the different charge states interfere.
(Snyder-Quinn)

$B \to K^+\pi^-, \pi^+\pi^-$ Data

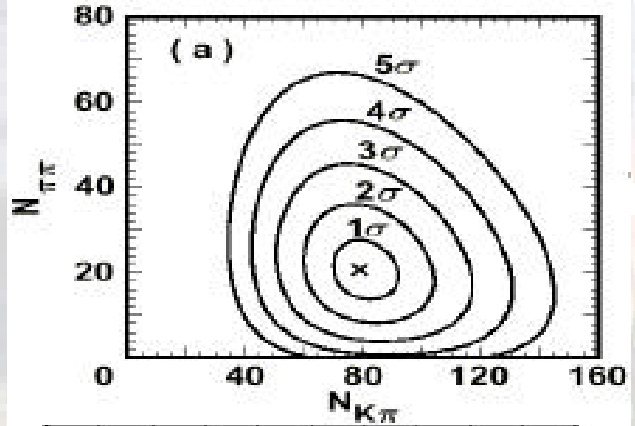
	CLEO	Babar	Belle
$K^\pm\pi^\mp$	$17.2^{+2.5}_{-2.4} \pm 1.2$	$12.5^{+3.0+1.3}_{-2.6-1.7}$	$17.4^{+5.1}_{-4.6} \pm 3.4$
$K^o\pi^\mp$	$18.2^{+4.6}_{-4.0} \pm 1.6$		< 34
$K^\pm\pi^o$	$11.6^{+3.0+1.4}_{-2.7-1.3}$		
$K^o\pi^o$	$14.6^{+5.9+2.4}_{-5.1-3.3}$		
$\pi^\pm\pi^\mp$	$4.3^{+1.6}_{-1.4} \pm 0.5$	$9.3^{+2.6+1.2}_{-2.3-1.4}$	< 16.5
$\pi^\pm\pi^o$	< 12.7		
$\pi^o\pi^o$	< 5.7		
$K^\pm K^\mp$	< 1.9	< 6.6	< 6
$K^\pm K^o$	< 5.1	$1.88^{+0.55}_{-0.49} \pm 0.23$	< 8
$K^o K^o$	< 17	$2.10^{+0.93+0.25}_{-0.78-0.23}$	

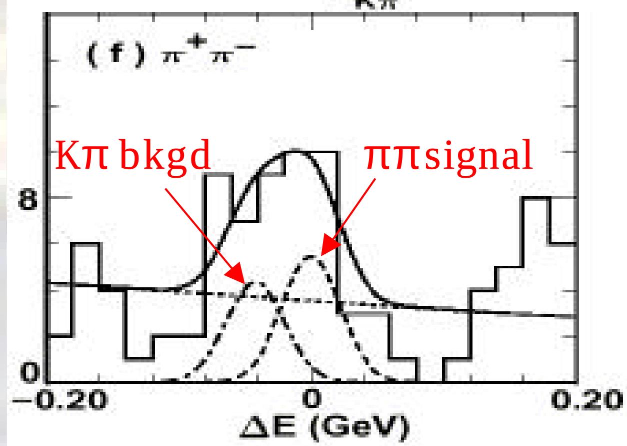
A complete set!

BRs are 10^{-6}

ULs are 90%

Particle ID is important:





V_{cb}

The differential decay rate, for $B \to D^* l \nu$ is:

$$\frac{d\Gamma}{dw} = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 |F(w)|^2 G(w)$$

w is the Lorentz γ factor of the recoiling D*.
It is a function of masses and q^2. ($1 \leq w \leq 1.5$)
w = 1 is the "zero recoil" point.

G(w) is a known kinematic function.

F(w) is the form factor. HQET constrains it.
As $m_{b,c} \to \infty$, $F(1) \to 1$.
For finite m, the corrections are $O(1/m^2)$.

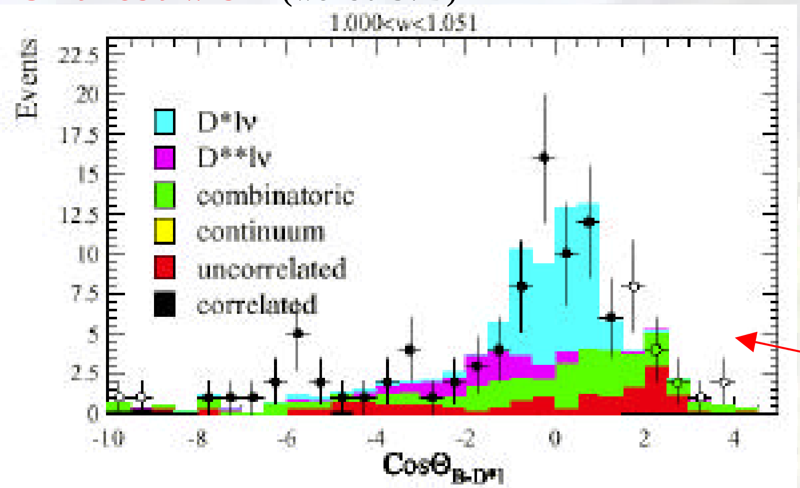
Two methods:

- Extrapolate differential rate to w = 1.
- Integrate the total $B(b \to X_c l \nu)$.

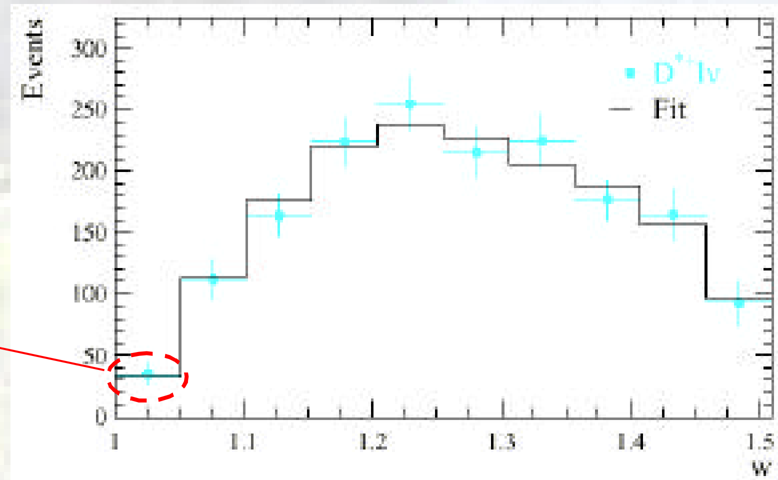
The first method is less sensitive to F(w) systematics, but has worse statistics.

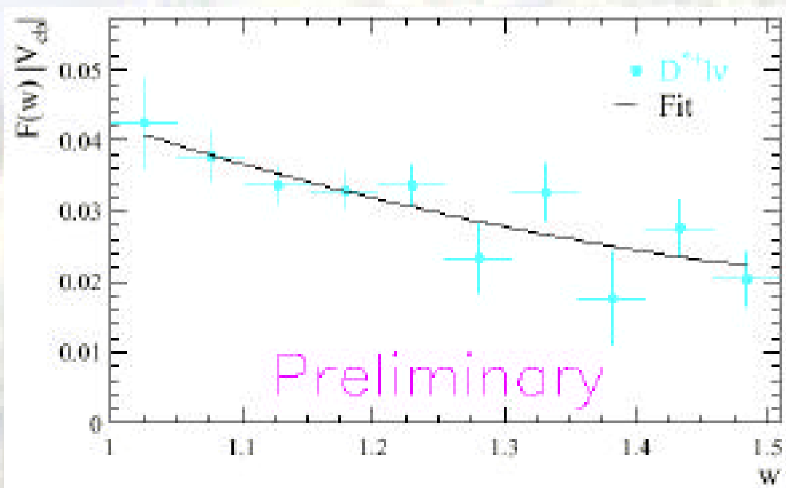
New CLEO result using w = 1 method.

Smallest w bin (worst S/B)

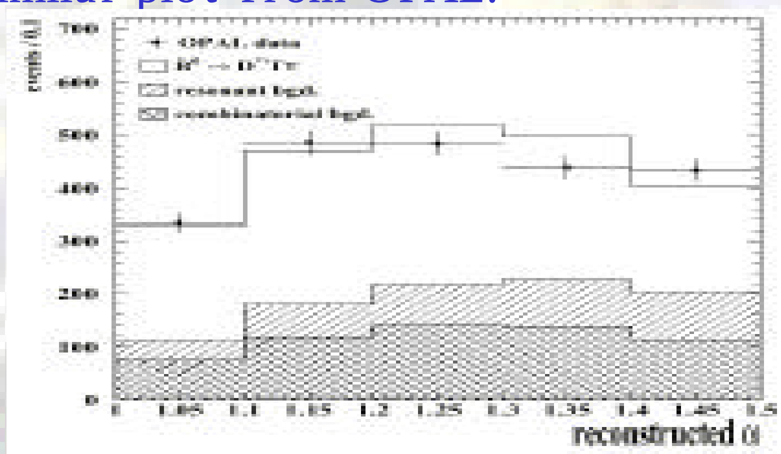


$d\Gamma/dw$





Similar plot from OPAL:



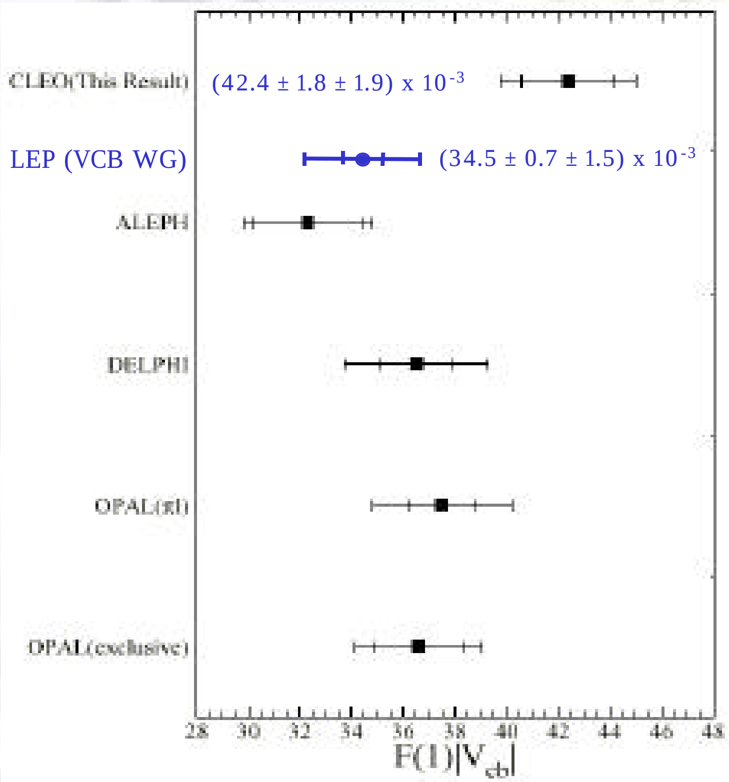
CLEO:

$F(1)|V_{cb}| = (42.4 \pm 1.8 \pm 1.9) \times 10^{-3}$ using: $F(1) = 0.913 \pm 0.042$

$BR(D^{*+} l \nu) = (5.66 \pm 0.29 \pm 0.33)\%$ yields: $|V_{cb}| = (46.4 \pm 2.0 \pm 2.1 \pm 2.1) \times 10^{-3}$

F(1) uncertainty

There appears to be a problem:



This result is strongly correlated with the measured slope, ρ^2, of F(w):

CLEO: $\rho^2 = 1.67 \pm 0.11 \pm 0.22$

LEP: $\rho^2 = 1.01 \pm 0.08 \pm 0.16$

As we saw, LEP and CLEO now agree about the total semileptonic BR.

Preliminary:

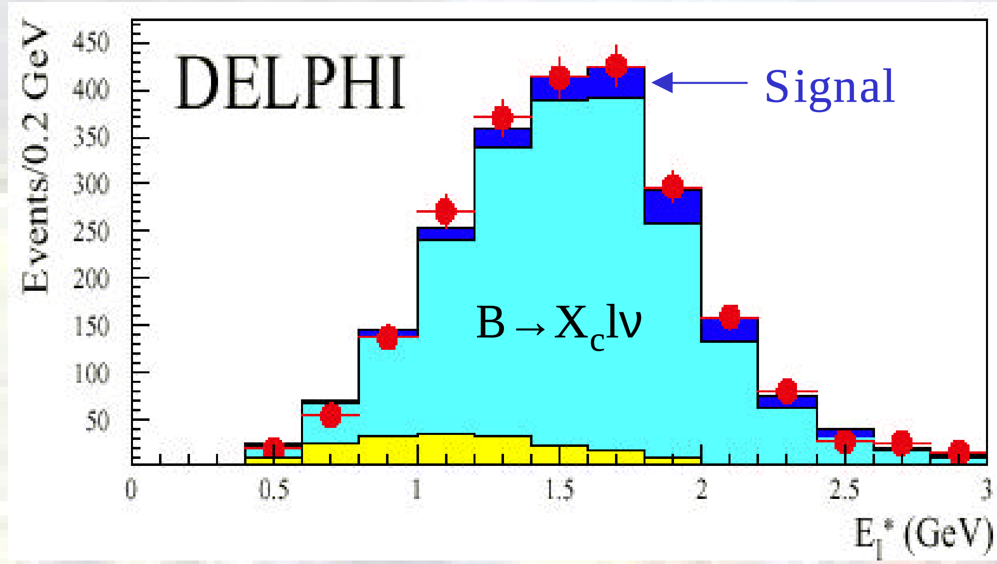
Belle: $BR(D^* l \nu) = (4.74 \pm 0.25 \pm 0.51)\%$

$BR(D l \nu) = (2.07 \pm 0.21 \pm 0.31)\%$

V_{ub}

$B \rightarrow X_u l \nu$ inclusive

$B \rightarrow \rho l \nu, \pi l \nu$ exclusive



New inclusive method:

Look at M_{had}

as well as E_{lep}

$BR(B \rightarrow X_u l \nu) = (1.57 \pm 0.35 \pm 0.48 \pm 0.27) \times 10^{-3}$

$|V_{ub}|/|V_{cb}| = 0.103\ ^{+0.011}_{-0.012} \pm 0.016 \pm 0.010$

LEP V_{ub}WG (ALEPH+DELPHI+L3):

$BR(B \rightarrow X_u l \nu) = (1.74 \pm 0.37 \pm 0.88 \pm 0.21) \times 10^{-3}$

$|V_{ub}| = (4.13\ ^{+0.42+0.43+0.24}_{-0.47-0.48-0.25} \pm 0.02 \pm 0.20) \times 10^{-3}$

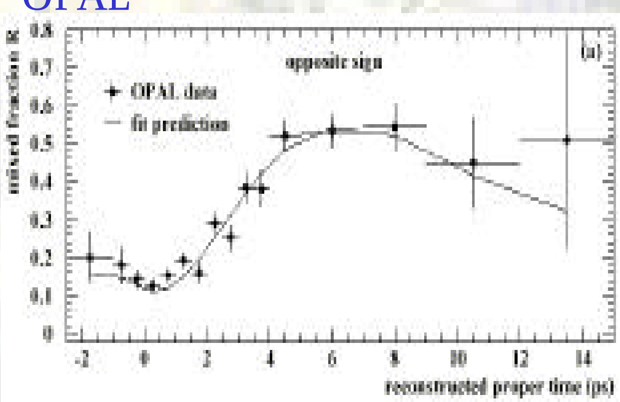
B Meson Lifetime & Δm_d

$$\frac{\text{unmixed - mixed}}{\text{unmixed + mixed}} = \cos(\Delta m\ t)$$

	$\tau(B^\pm)$ ps	$\tau(B0)$ ps	Ratio	$\Delta m_d\ \hbar\ ps^{-1}$
PDG2000	1.653±0.028	1.548±0.032	1.062±0.029	0.472±0.01
New:				
ALEPH	1.648±0.049±0.035	1.518±0.053±0.034	1.085±0.059±0.018	
OPAL		1.528±0.025±0.023		0.479±0.018±0.015
Babar	1.602±0.049±0.035	1.506±0.052±0.029	1.065±0.044±0.021	0.512±0.017±0.022(recon)
				0.507±0.015±0.022 (*ll*)
Belle	1.70 ±0.06 ± 0.1	1.50 ± 0.05 ± 0.07	1.14 ±0.06 ±0.06	0.456±0.008±0.030 (*ll*)
CLEO				0.522±0.029±0.031 *
CDF				0.495±0.026±0.025

* from χ_d = 0.198 ± 0.013 ± 0.014
assuming: $\Delta\Gamma = 0$
using τ_{Bo} = 1.55 ps

OPAL

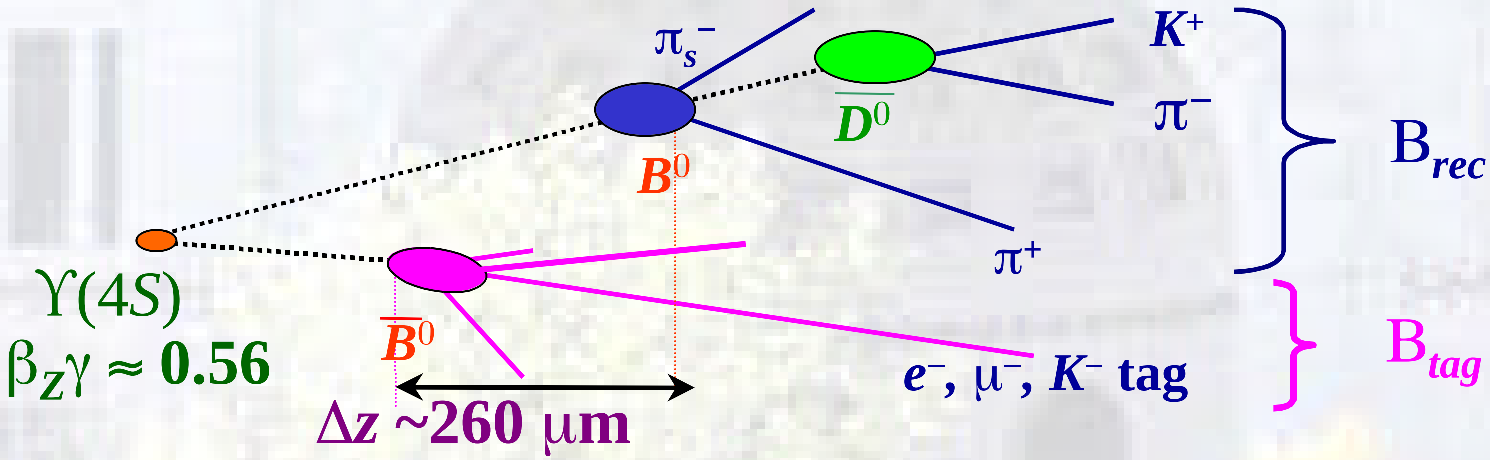


Comparison of systematic errors:

LEP τ: B momentum
Babar τ: z recon
Babar Δm: Misid (B^+ & cascade)
Belle Δm: B^+ contamination

These must be improved to make progress

Babar and Belle time measurement:

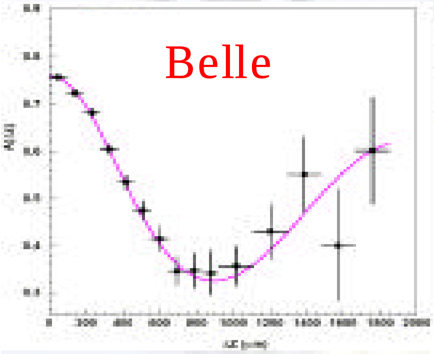


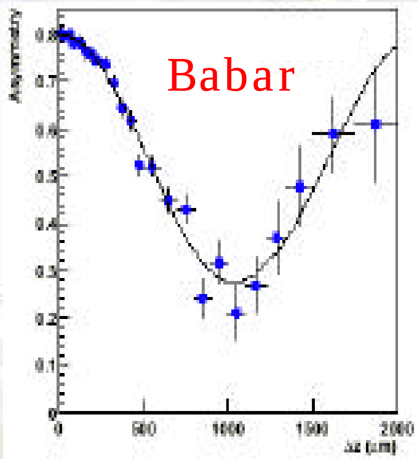
The time resolution is about $\tau_{B/2}$.

The primary vertex is not used (z_V is poorly known), except in dilepton analyses.

One B decay defines t = 0.

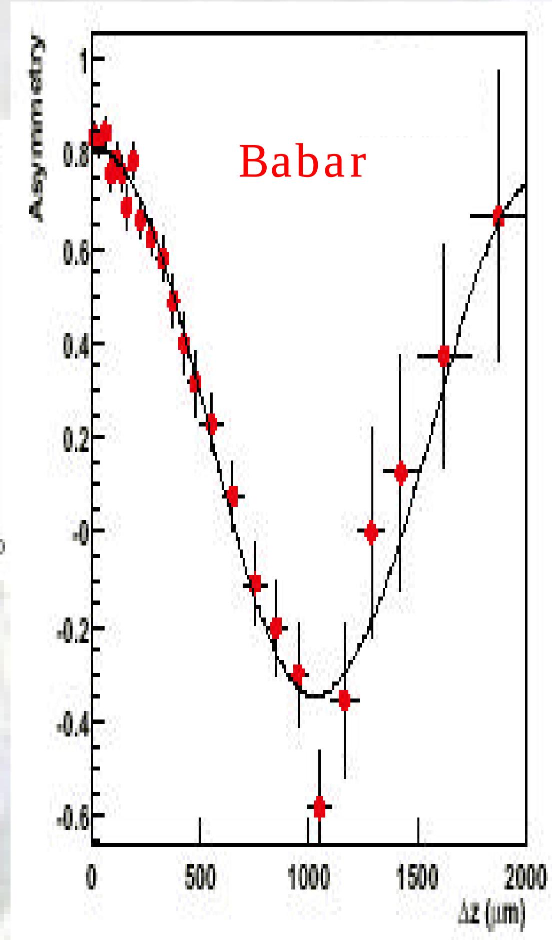
Dileptons



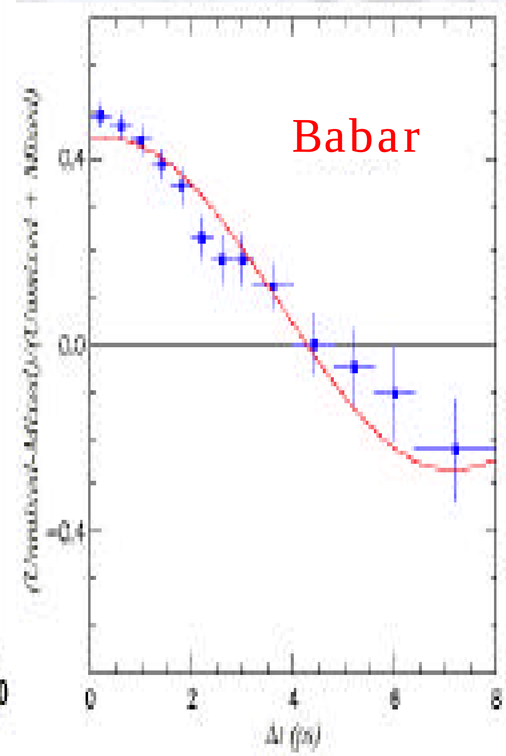


Enriched dileptons

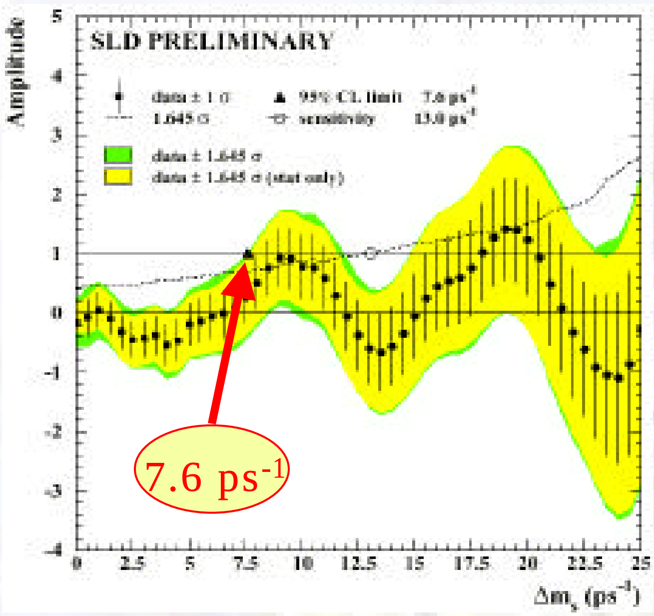
(soft $\pi^{\pm}$ selects B^{o})

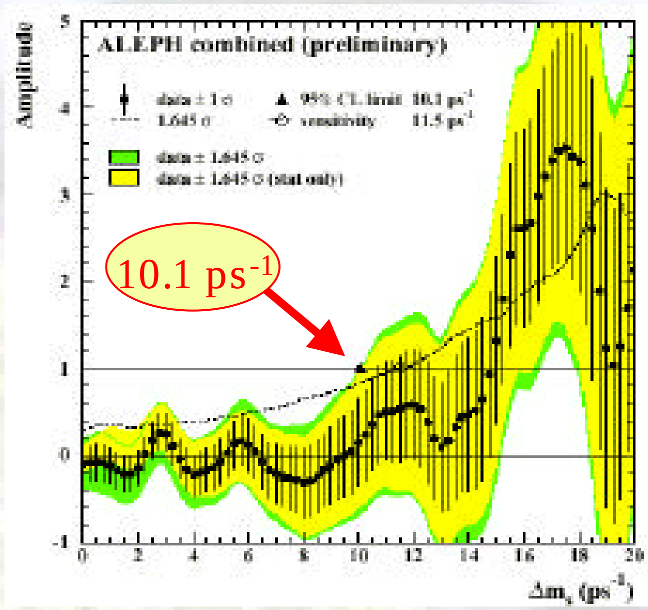


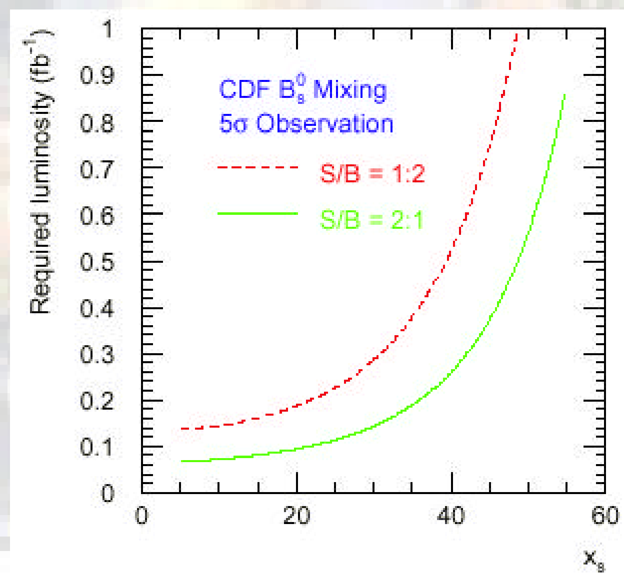
Recon + tag



Δm_s







Anticipated CDF sensitivity in Run-II:

Expect 2 fb^{-1}

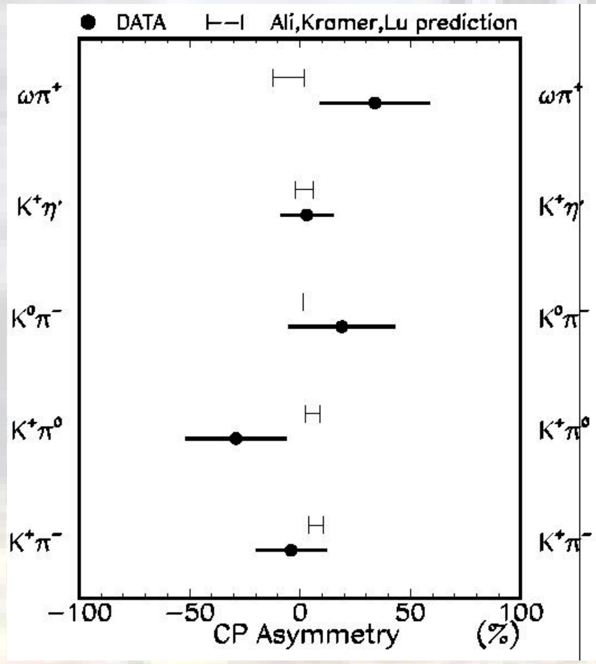
$x_s \sim 65$ ($\Delta m_s \sim 40\ ps^{-1}$).

CP violation in B system

Direct CP violation (without mixing): $\Gamma(B \to f) \neq \Gamma(\bar{B} \to \bar{f})$

CLEO:

pp,pv: Predictions require assumptions about strong phase shifts.



K*γ: Use self-tagging modes.

B^+: (38 ± 20)%

B^o: (-13 ± 17)%

both: (8 ± 13)%

SM predicts ~1%.

$$A_{CP} = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_b - \Gamma_{\bar{b}}}{\Gamma_b + \Gamma_{\bar{b}}}$$

$J/\psi K^\pm$:

A_{CP} = (-1.8±4.3)%

⇒ Direct CP violation does not complicate the $J/\psi K^o$ measurement.

CP in mixing (as in K^o system)

CLEO: Look for $\Upsilon(4S) \rightarrow BB \neq \Upsilon(4S) \rightarrow \bar{B}\bar{B}$

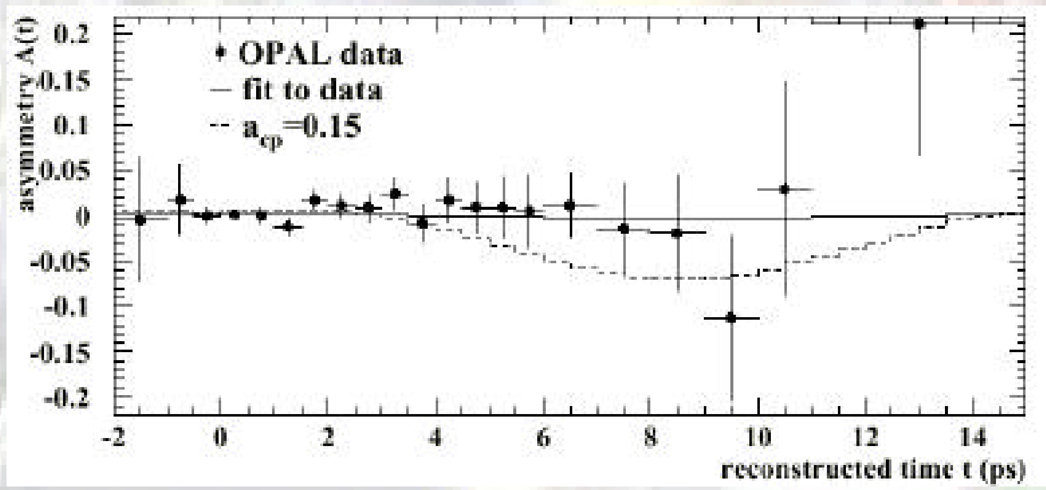
$A_{CP} = 4\mathrm{Re}(\varepsilon_B) = (\chi_+ - \chi_-)/(\chi_+ + \chi_-)$

$|\mathrm{Re}(\varepsilon_B)| = 0.004 \pm 0.018$

$< 3.4\%$ (95% c.l.) Expect about 10^{-3}

OPAL's time dependent measurement is similar:

$|\mathrm{Re}(\varepsilon_B)| = 0.001 \pm 0.014 \pm 0.003$



$B \rightarrow J/\psi K^o$

Interference between decay and mixing

Only one decay diagram contributes significantly.
Interference is provided via BB mixing.

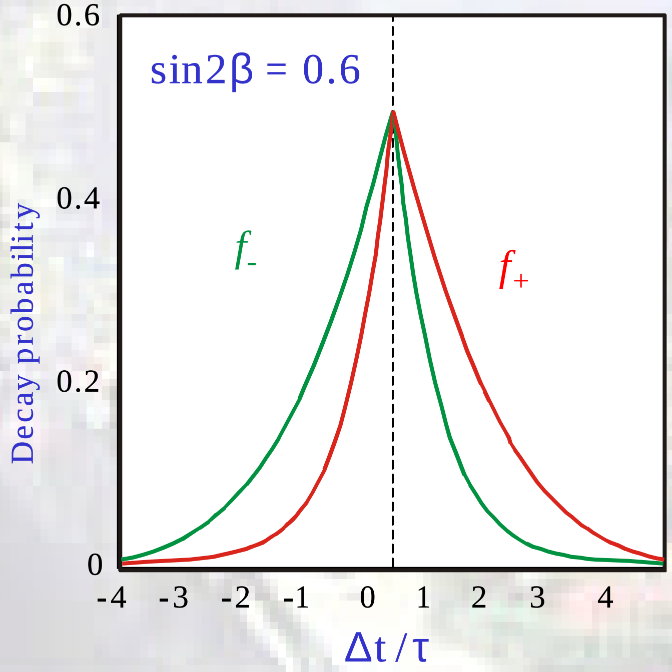
$$B^o \rightarrow \psi^{(')} K_{s,L} \neq \overline{B}^o \rightarrow \psi^{(')} K_{s,L}$$

$$A(t) \equiv \frac{B^o - \overline{B}^o}{B^o + \overline{B}^o} = \pm\sin(2\beta)\sin(\Delta m \Delta t)$$

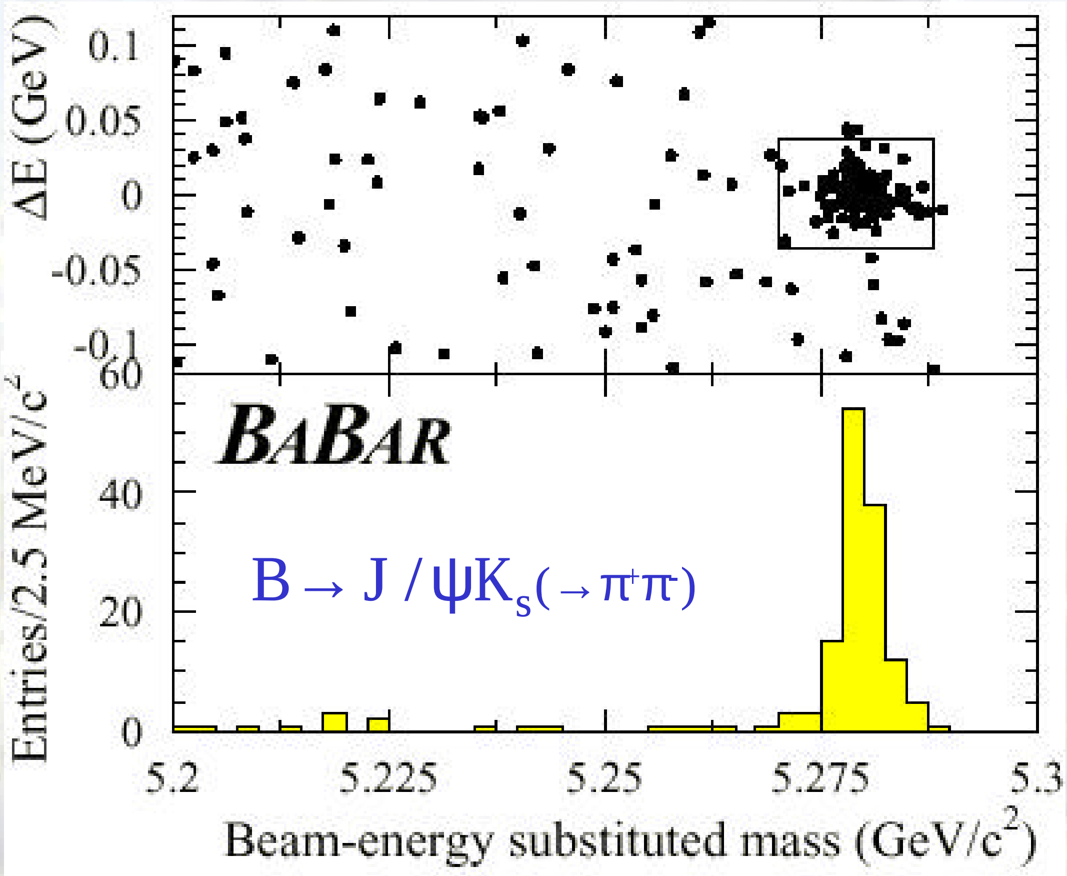
Decay rates for B tag (+) and $\overline{B}$ tag (-):

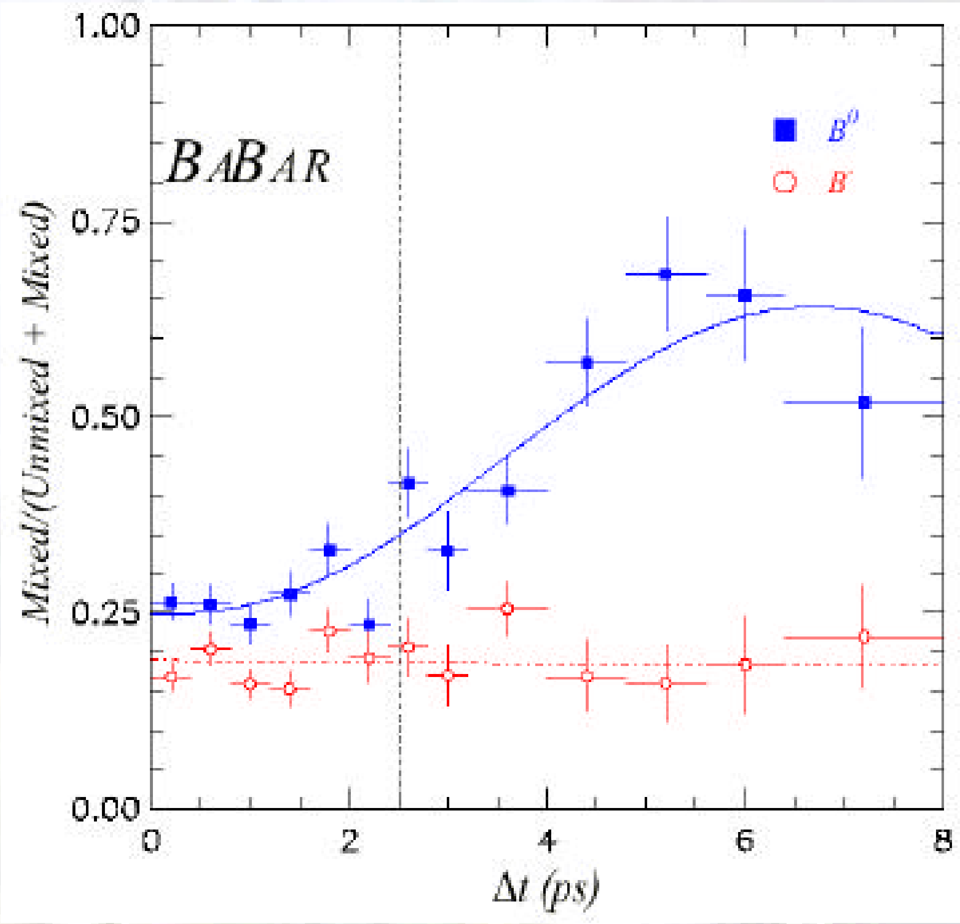
$$f_\pm = \frac{\Gamma e^{-\Gamma|\Delta t|}}{4}\left[1 \pm D\sin(2\beta)\sin(\Delta m \Delta t)\right]$$

Babar

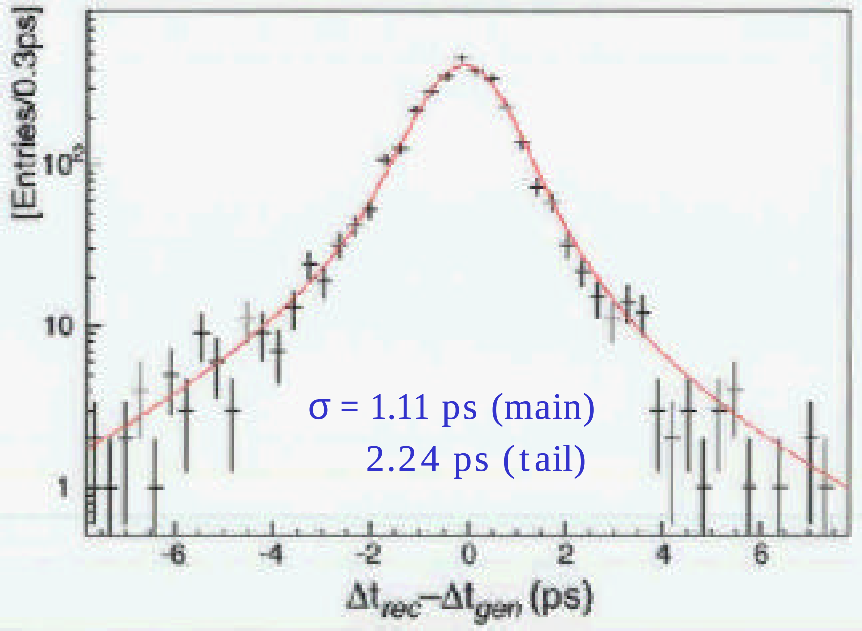


The signal is quite clean (94% for all $J/\psi K_s$), despite the small branching fraction.





Belle's time resolution:



Babar's is somewhat better:

0.6 ps (main)

1.8 ps (tail)

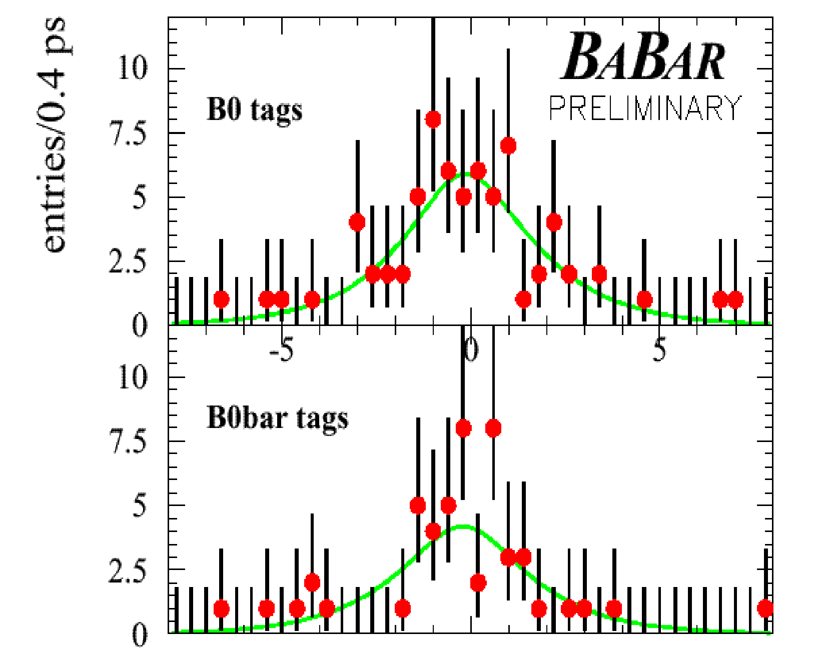
Babar

120 CP odd events:

85 $J/\psi K_s(\pi^+\pi^-)$

12 $J/\psi K_s(\pi^0\pi^0)$

23 $\psi' K_s(\pi^+\pi^-)$

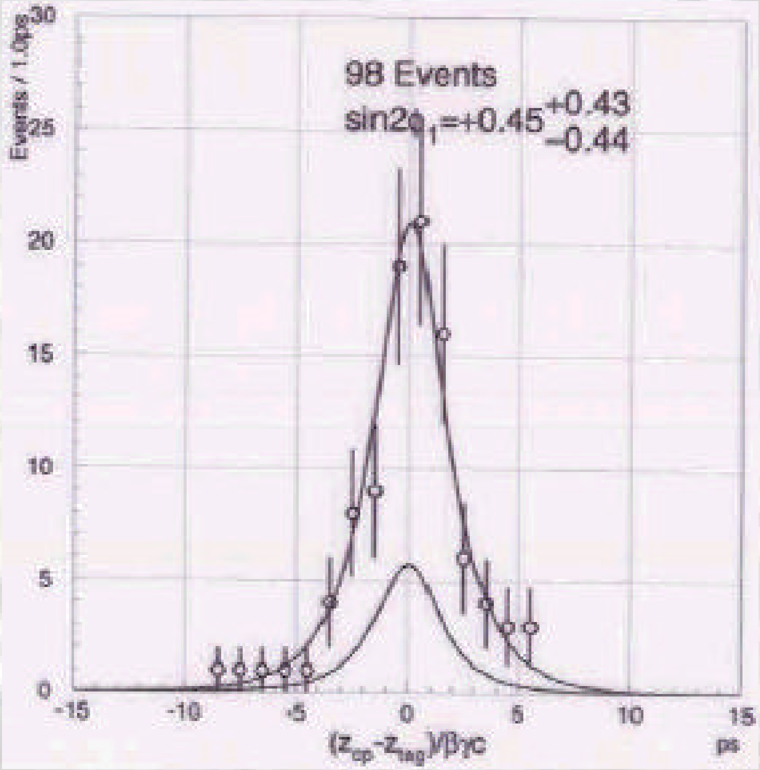


$\sin 2\beta = 0.12 \pm 0.37 \pm 0.09$

Belle

52 CP odd events (mostly $J/\psi K_s(\pi^+\pi^-)$)

46 CP even events (mostly $J/\psi K_L$)

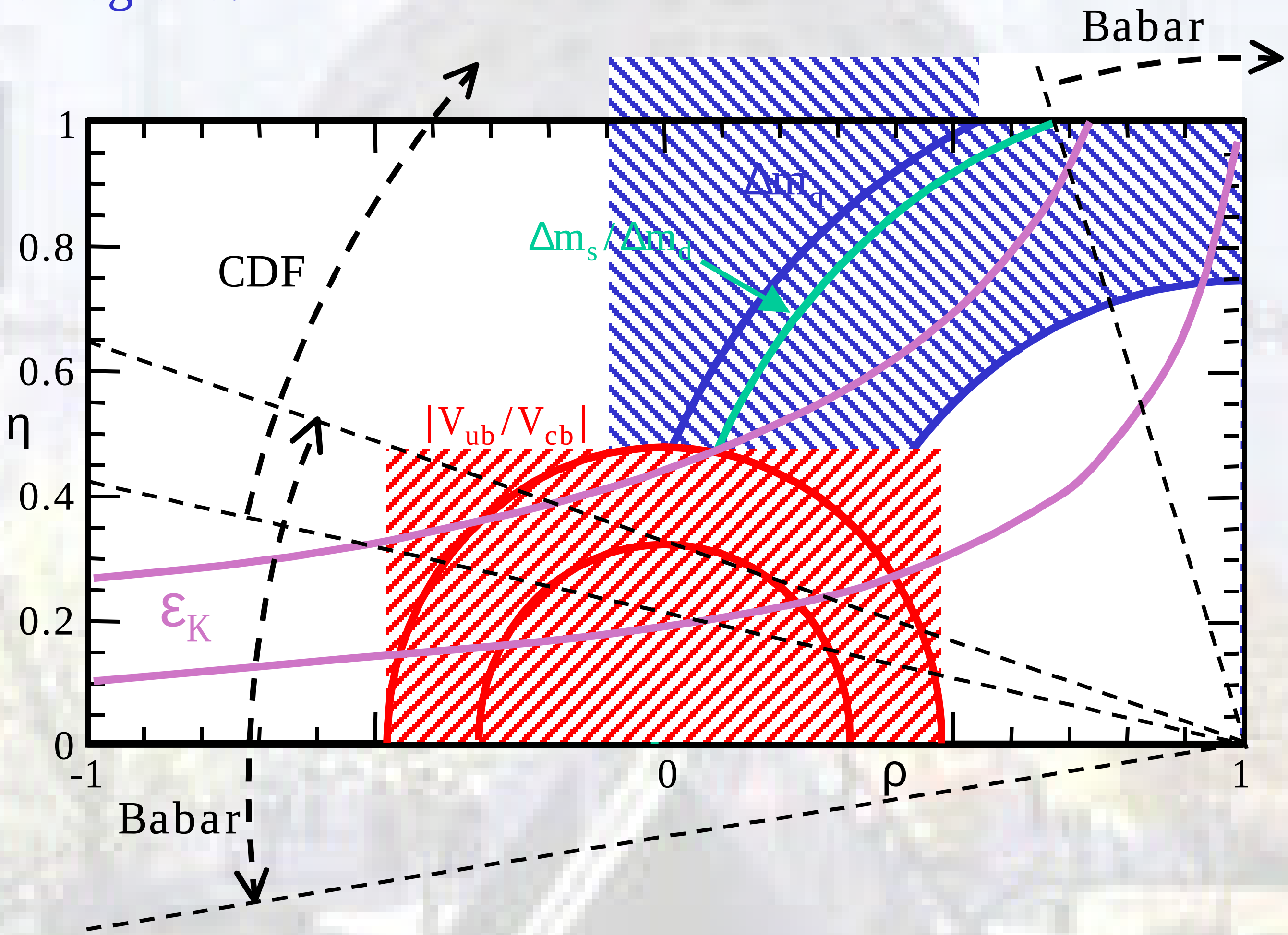


$\sin 2\beta = 0.45^{+0.43+0.07}_{-0.44-0.09}$

CDF:

$0.79^{+0.41}_{-0.44}$

±1 σ regions:



Babar
CDF
Babar
Δm_d
$\Delta m_s / \Delta m_d$
$|V_{ub}/V_{cb}|$
ε_K
η
ρ
1
0.8
0.6
0.4
0.2
0
-1
0
1

Nature **405**, 722 (6/15/2000):