HEAVY QUARK LIFETIMES MIXING & CPV

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special thanks to
E. Blaylock, S. Willocq, H. Nelson, D. Asner

Please Please Please

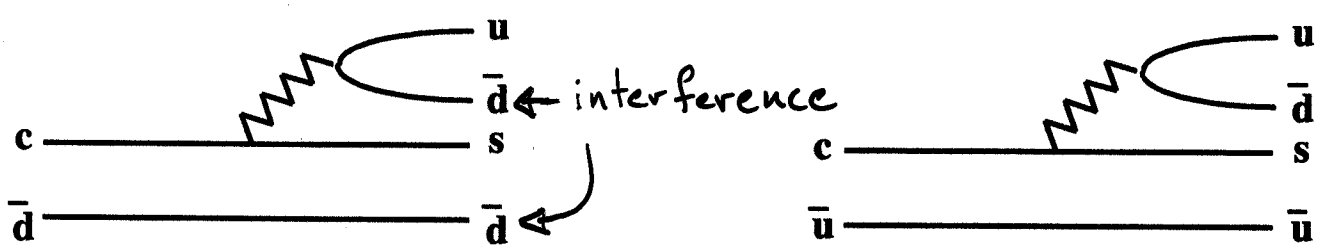
forgive me for omitting your favorites

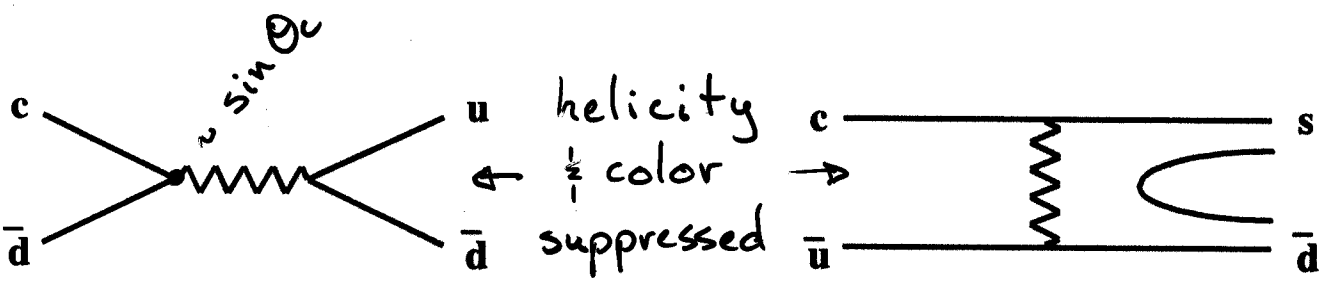
Highlights

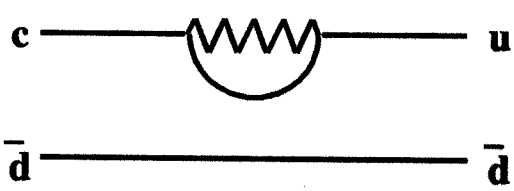
- New precision in charm lifetimes
- CLEO on charm mixing
- Updates on B_s mixing
- 2 items relevant to CPV in the B system

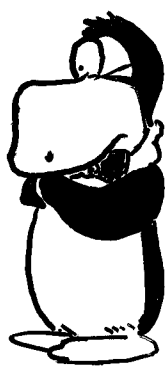
Why is $\tau(D^+) > \tau(D^0)$?

D^+ decays **D^0 decays**



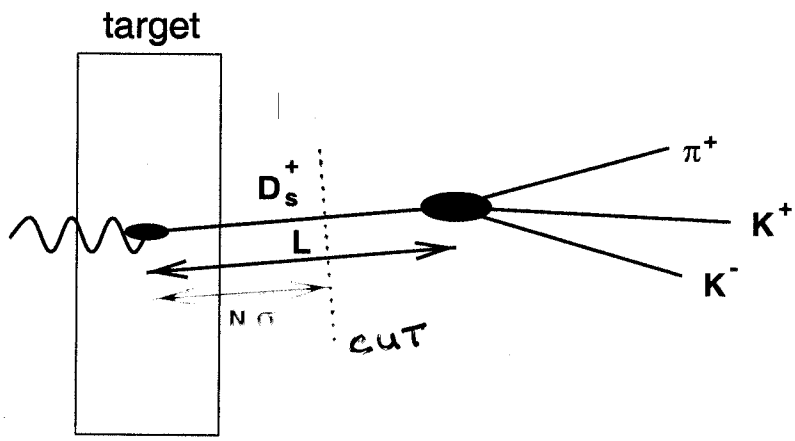






- Interference
  different patterns for baryons (e.g. $\Omega_c = css$)
- W exchange
  not helicity or color suppressed for baryons
- Annihilation
  not Cabibbo suppressed for D_s^+

Lifetime Measurements



Charm Decays

Fixed Target & CLEO

Use "reduced" time for separated vertex.

$\tau_{red} = \tau - \tau_{cut}$ (still exponential)

Bottom Decays (all collider expts.)

1) exclusive decays (e.g. $B^0 \to 4K_s$)
but BR's small!

2) B lepton & charm vtx (D or D^*)
but D^{**} confuses charge assignment

3) topological (separated vtx's & charge)
best so far for B^0 & B^+

Charm Lifetimes

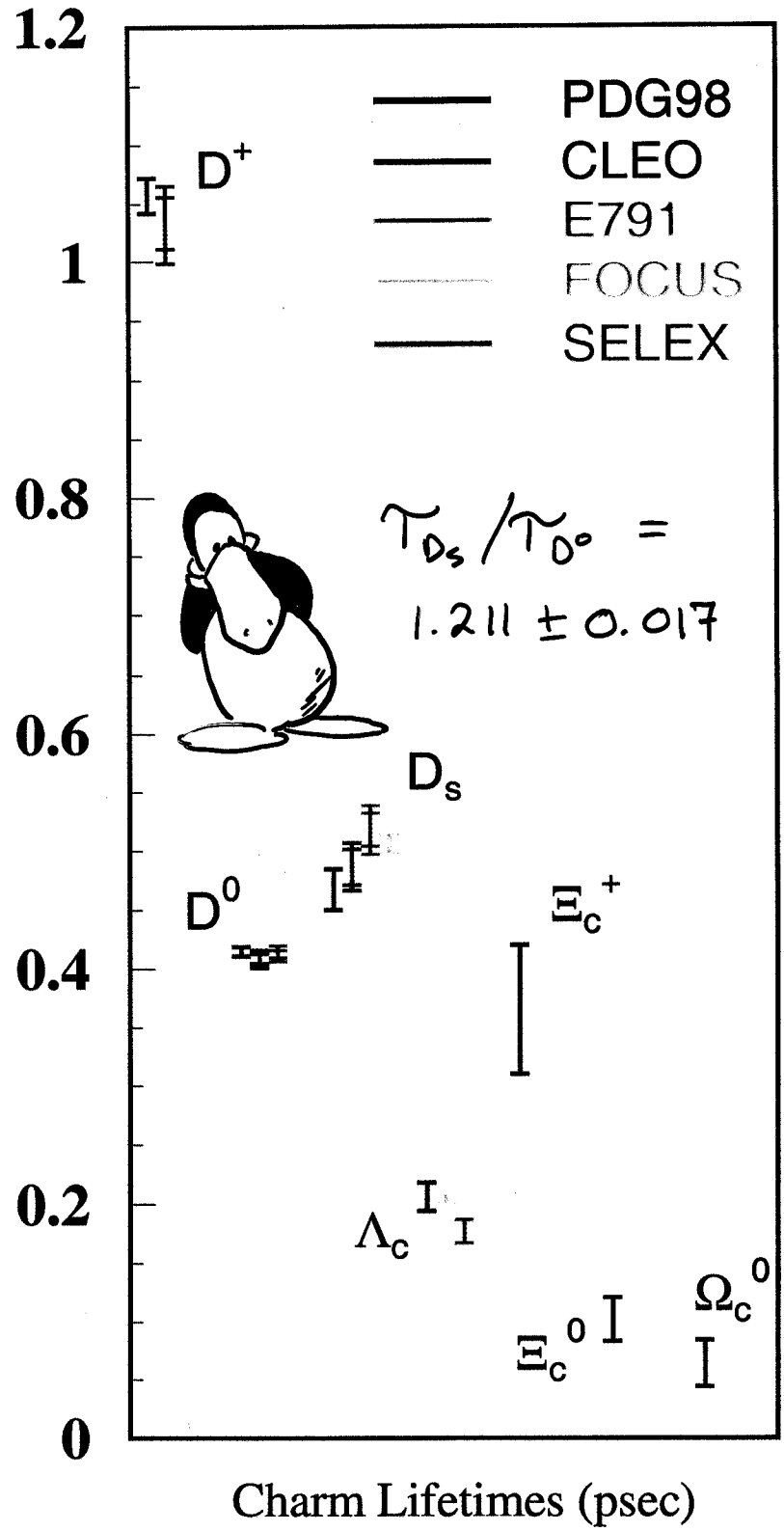
E791 D^0, D_s
hep-ex/9903012
PLB 445 (98) 294

CLEO D^0, D^+, D_s
PRL 82 (99) 4586

FOCUS
D_s & Λ_c

SELEX Λ_c

See talk by
H. Cheung
at HF8



Games for isolating PI, WX, WA

(see also H. Cheung HF8)

(1) $$\frac{BR(D^+ \to K^+\pi^+\pi^-)}{BR(D^+ \to K^-\pi^+\pi^+)} \approx \frac{\Gamma_{SP}}{\Gamma_{PI}} \times \tan^4\theta_c$$

$$= 0.68 \pm 0.09\% \quad \text{E791 \& FOCUS}$$

(2) $$\frac{\tau_{D^+}}{\tau_{D^0}} = \frac{\Gamma_{SP} + \Gamma_{WX} + \Gamma_{SL}}{\Gamma_{PI} + \Gamma_{SL}} = 2.55$$

$$\Longrightarrow \boxed{\Gamma_{WX}/\Gamma_{SP} = 0.26}$$

using $BR^0_{SL} = 13.4\%$

(3) $$\frac{\tau_{D_s}}{\tau_{D^0}} = \frac{(\Gamma_{SP} + \Gamma_{WX} + \Gamma_{SL})\,1.05}{(\Gamma_{SP} + \Gamma_{WA} + \Gamma_{SL})}$$

$$\Longrightarrow \boxed{\Gamma_{WA}/\Gamma_{SP} = 0.07}$$

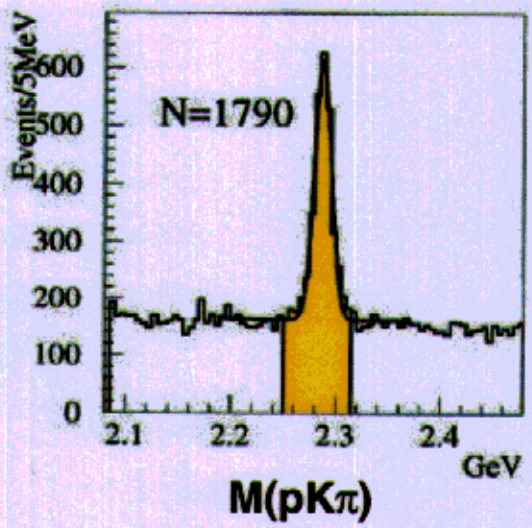
τ_{D_s} correction

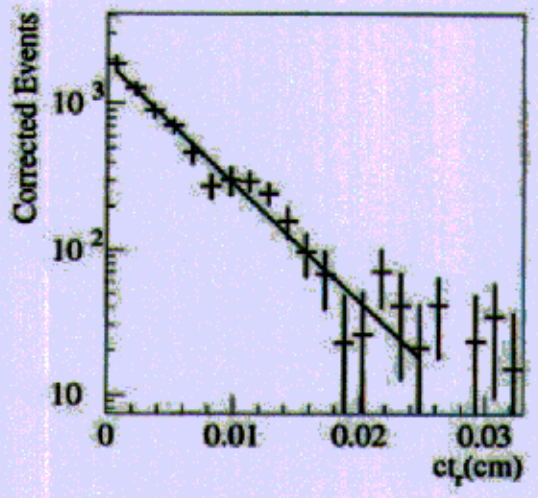
Bigi & Uraltsev

Z. Phys. C62 (94) 623

New FNAL Expts. on Λ_c Lifetime

SELEX (Σ,π,p beams)

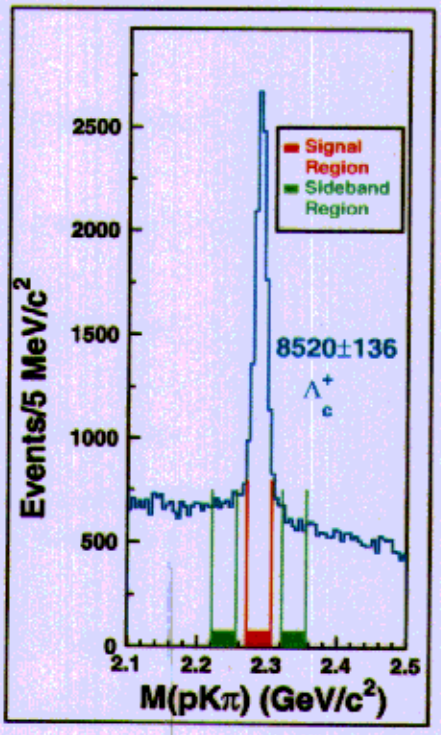


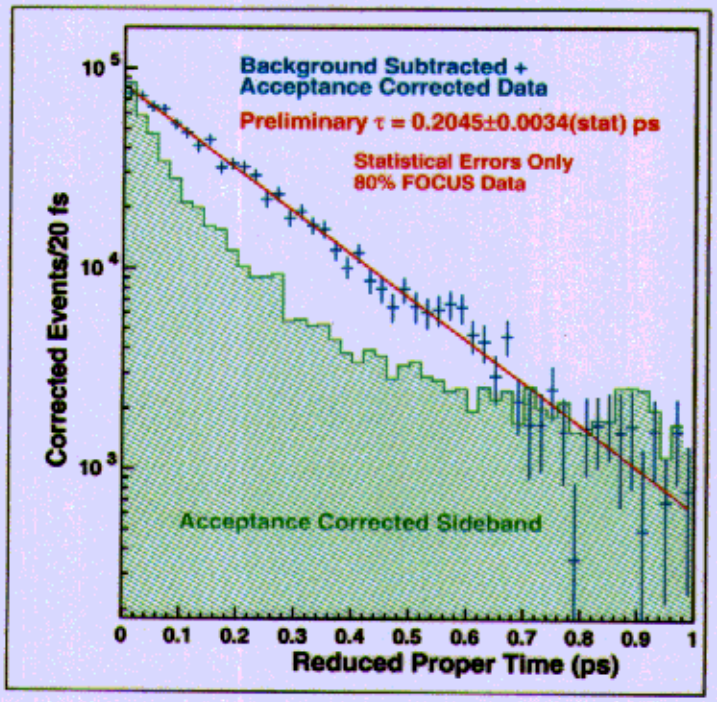


$\tau_{\Lambda_c} = 177 \pm 10$ fs

FOCUS (γ beam)

$\tau_{\Lambda_c} = 204.5 \pm 3.4$ fs





previous E687 had ~700 Λ_c's

UPDATES

Bottom Lifetimes

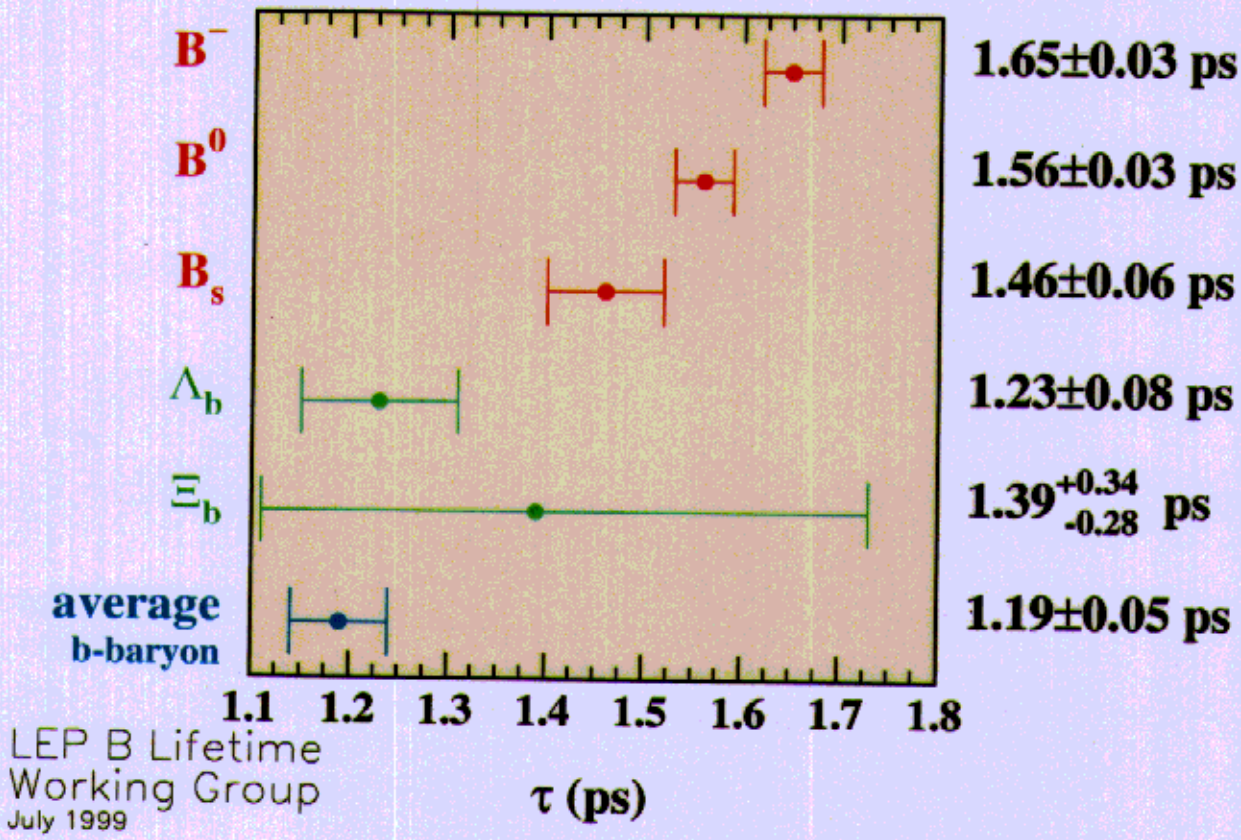
SLD (topological) $\tau_{B^+}/\tau_{B^0} = 1.037^{+0.025}_{-0.024} \pm 0.024$

SLAC-PUB-8206

Aleph $D^{(*)}\ell$ for B^0, B^+ Aleph 99-005

Opal (topological) for B^0, B^+ CERN-EP/98-195

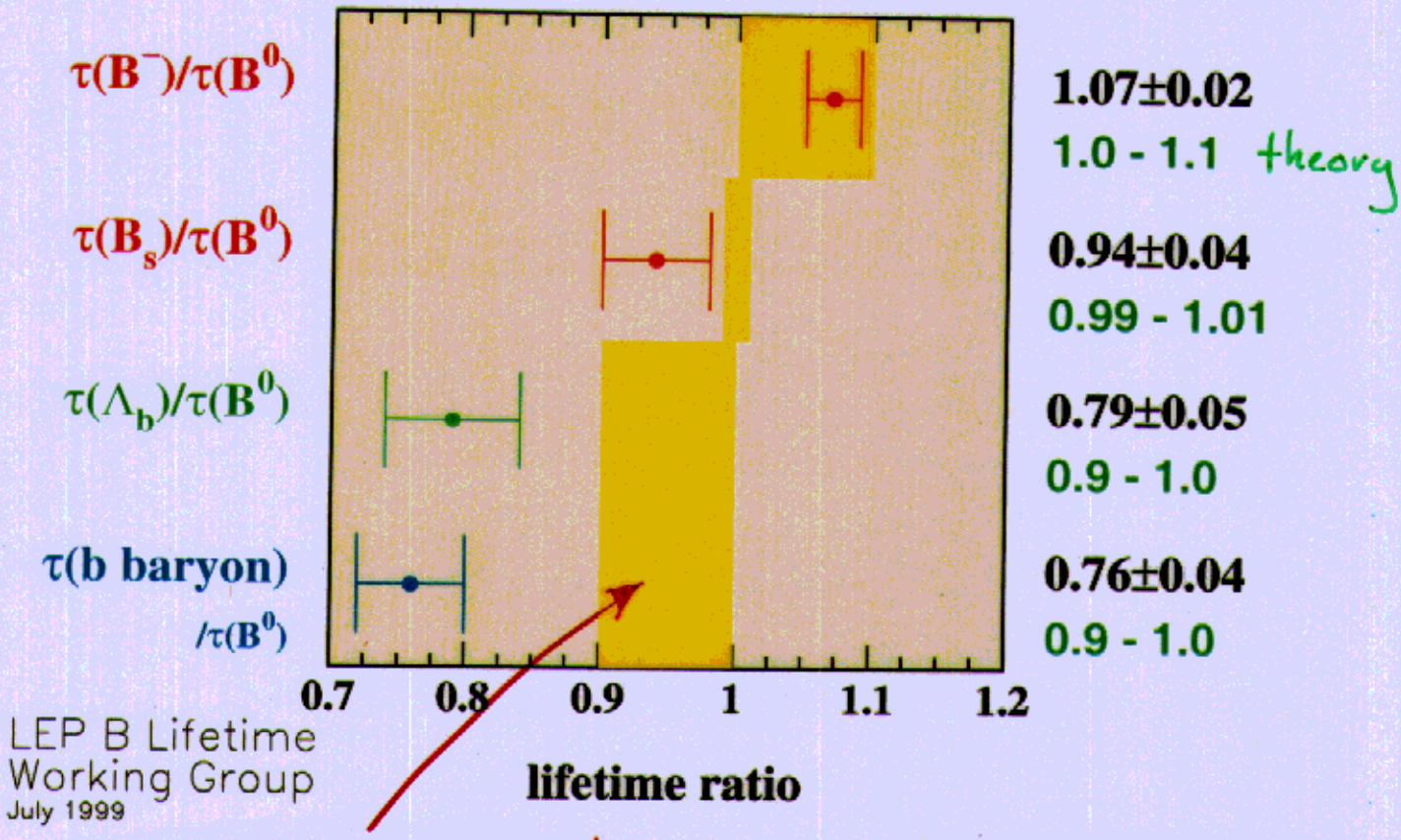
Delphi avg. b baryon CERN-EP/99-16



Not shown: CDF $\tau_{B_c} = 0.46^{+0.18}_{-0.16} \pm 0.03$ ps

PRL 81 (98) 2432 & PRD 58 (98) 112004

Lifetime Ratios



Bigi & Uraltsev
Z. Phys. C62 (94) 623

but see also ...

Neubert & Sachrajda
Nucl. Phys. B483 (97) 339

based on ...

Operator Product Expansion (Phys. Rept. 289)

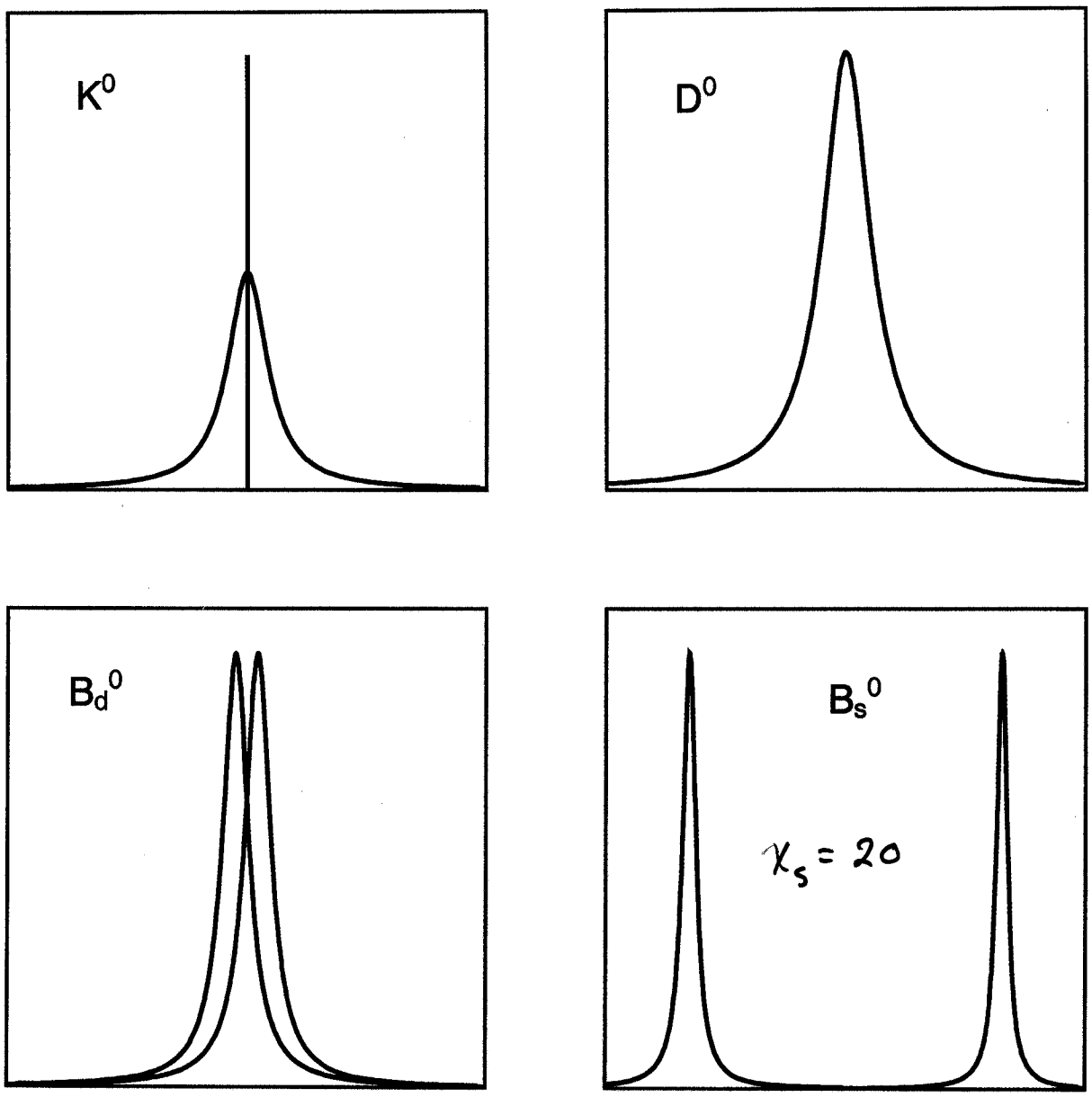
$$\Gamma \sim \frac{G_F^2 m_Q^5}{192\pi^3}\left(A_1 + \frac{A_2}{M_Q^2} + \frac{A_3}{M_Q^3} + \mathcal{O}\left(\frac{1}{M_Q^4}\right)\right)$$

A_1 is the spectator term

A_2 produces differences btwn baryons/mesons

A_3 includes WX, WA, PI effects

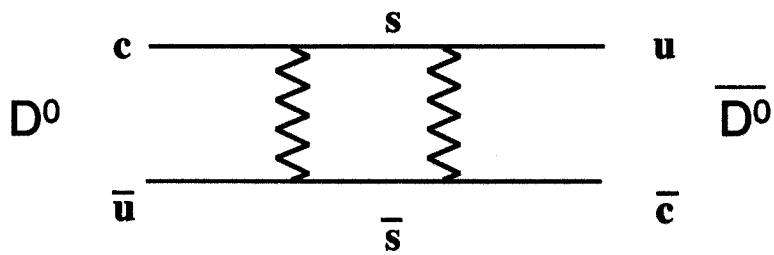
Neutral Meson Mixing



scales arbitrary
but aesthetically chosen

Thanks to G. Golowich

Mixing Formalism



$$r_{mix} \equiv \frac{\Gamma(M \to \bar{M} \to f)}{\Gamma(\bar{M} \to f)}$$

$$A^{B}_{box} \sim \frac{m_t^2}{m_W^2} \Longrightarrow r^{B}_{mix} \sim 1$$

$$A^{D}_{box} \sim \frac{m_s^2 - m_d^2}{m_W^2} \times \frac{m_s^2 - m_d^2}{m_c^2} \Longrightarrow r^{D}_{mix} \sim 10^{-10}$$

GIM

HQ suppression

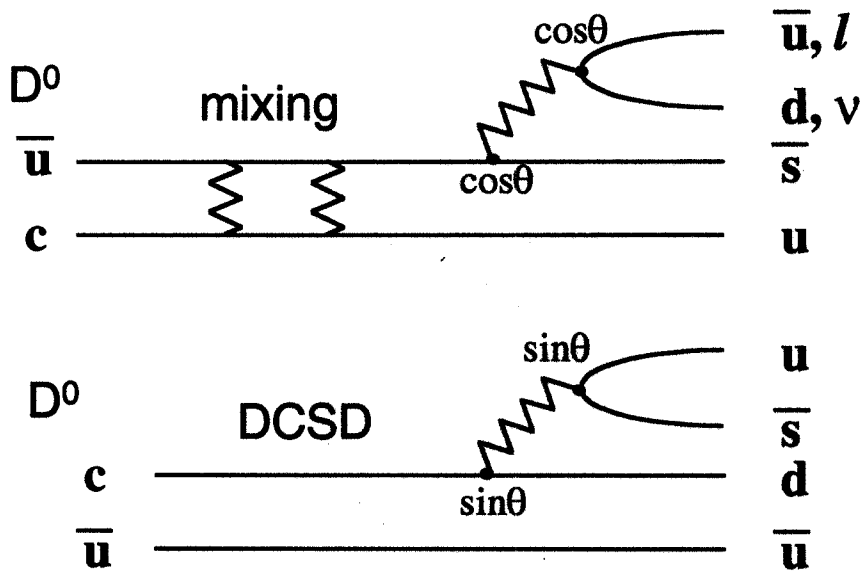
r^{D}_{mix} typically 10^{-10} to 10^{-6} from long range effects

Motivation:

B mixing $\Rightarrow$ study CKM

D mixing $\Rightarrow$ look for New Physics

Charm Mixing



Example:

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

with

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

(wrong sign)

DCSD

mixing

$$\Gamma(K^+\pi^-) \sim e^{-\Gamma t}\left[4|\lambda|^2 + \left(\Delta M^2 + \frac{\Delta\Gamma^2}{4}\right)t^2\right.$$

interference $\to$ $\left. + (2\,\mathrm{Re}\,\lambda\,\Delta\Gamma + 4\,\mathrm{Im}\,\lambda\,\Delta M)\,t\right]$

$$\Gamma(K^+\ell^-\nu) \sim e^{-\Gamma t}\left(\Delta M^2 + \frac{\Delta\Gamma^2}{4}\right)t^2 \leftarrow \text{mixing only}$$

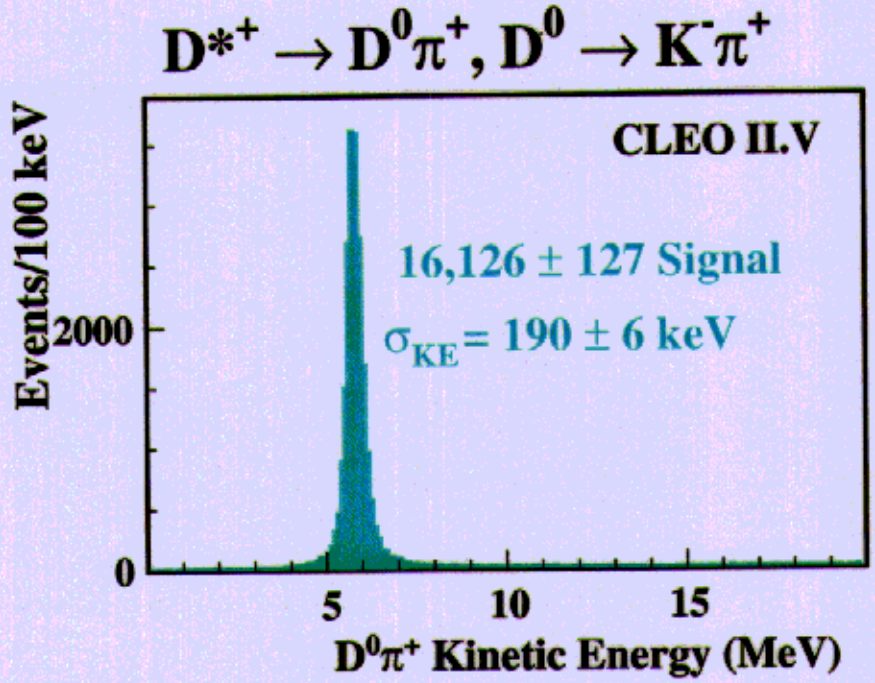
Best previous:

E791 $(K\ell\nu)$ $\quad r_{mix} < 0.50\%$

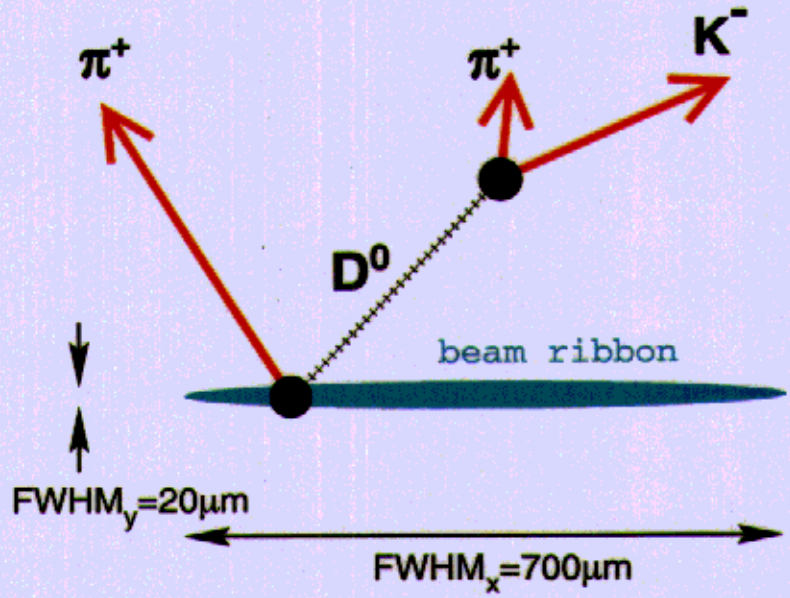
CLEO $(K\pi)$ $\quad r_{DCSD} = 0.77 \pm 0.25 \pm 0.25\%$

D Mixing at CLEO

Good σ_M and high eff. at low t is key.

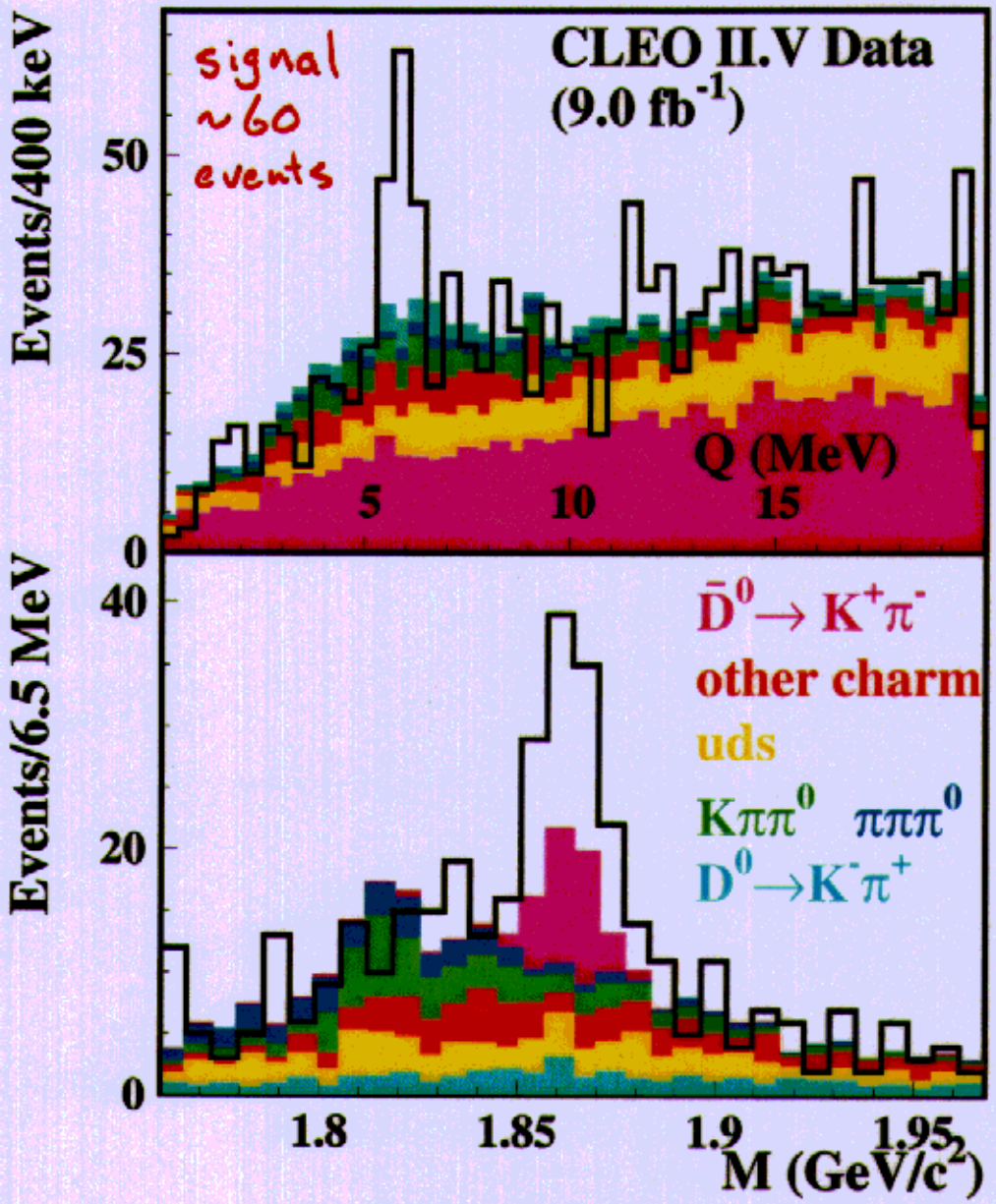


KE resolution due in part to beam constraint



Wrong sign Decays

$D^{*+} \rightarrow D^0\pi^+, D^0 \rightarrow K^+\pi^-$



$r_{ws} = 0.34 \pm 0.07 \pm 0.06\ \%$

PRELIMINARY (thursday)

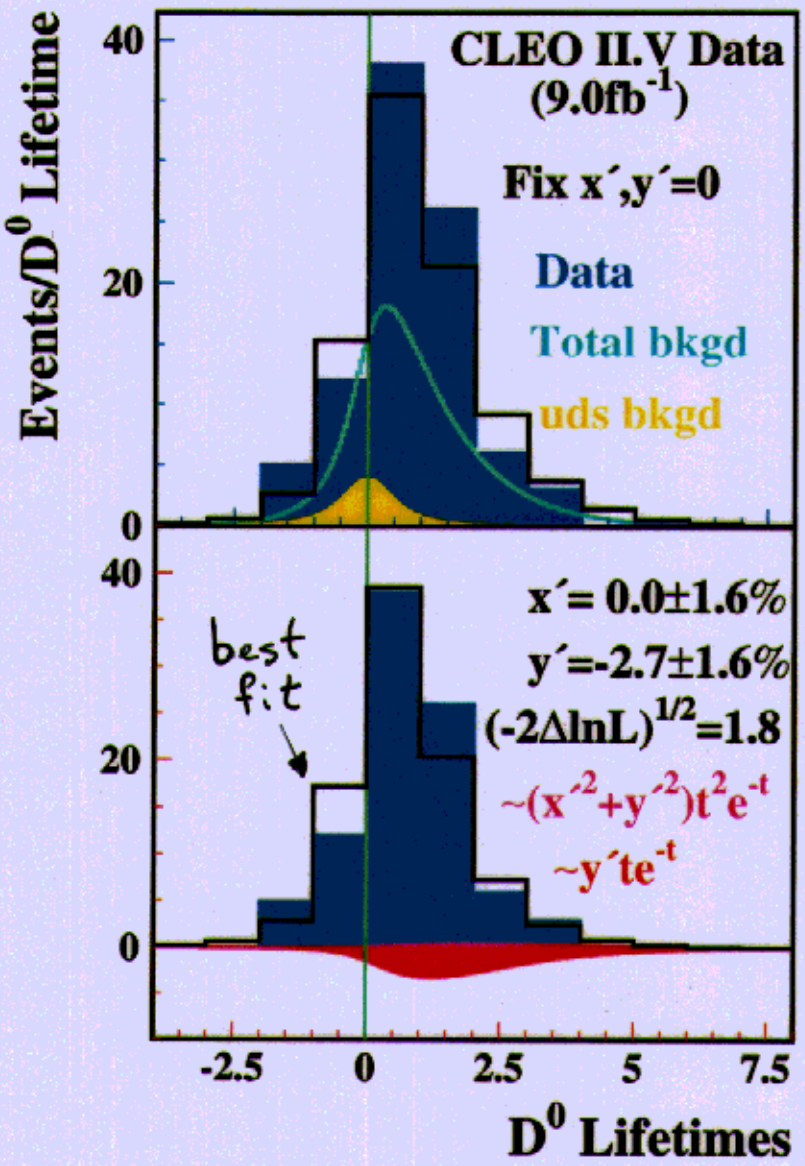
Using assumptions about strong phases

$\Downarrow$

$x' \longleftrightarrow \frac{\Delta M}{\Gamma}$

$y' \longleftrightarrow \frac{\Delta \Gamma}{2\Gamma}$

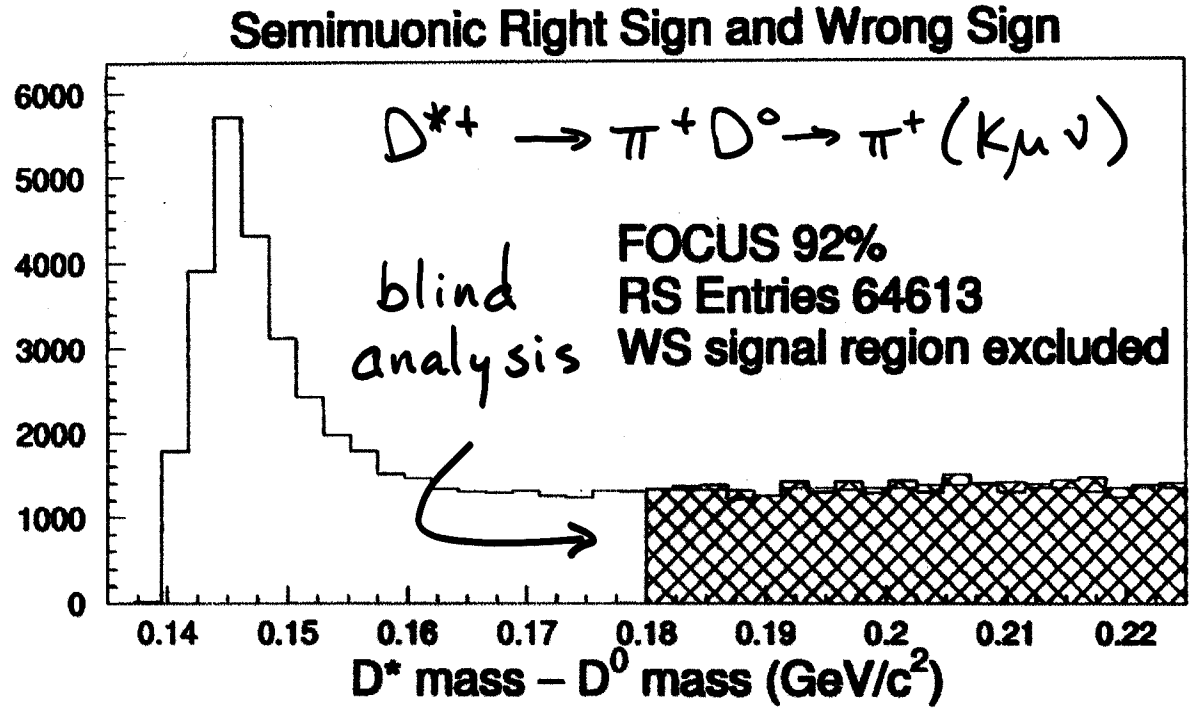
$\Downarrow$

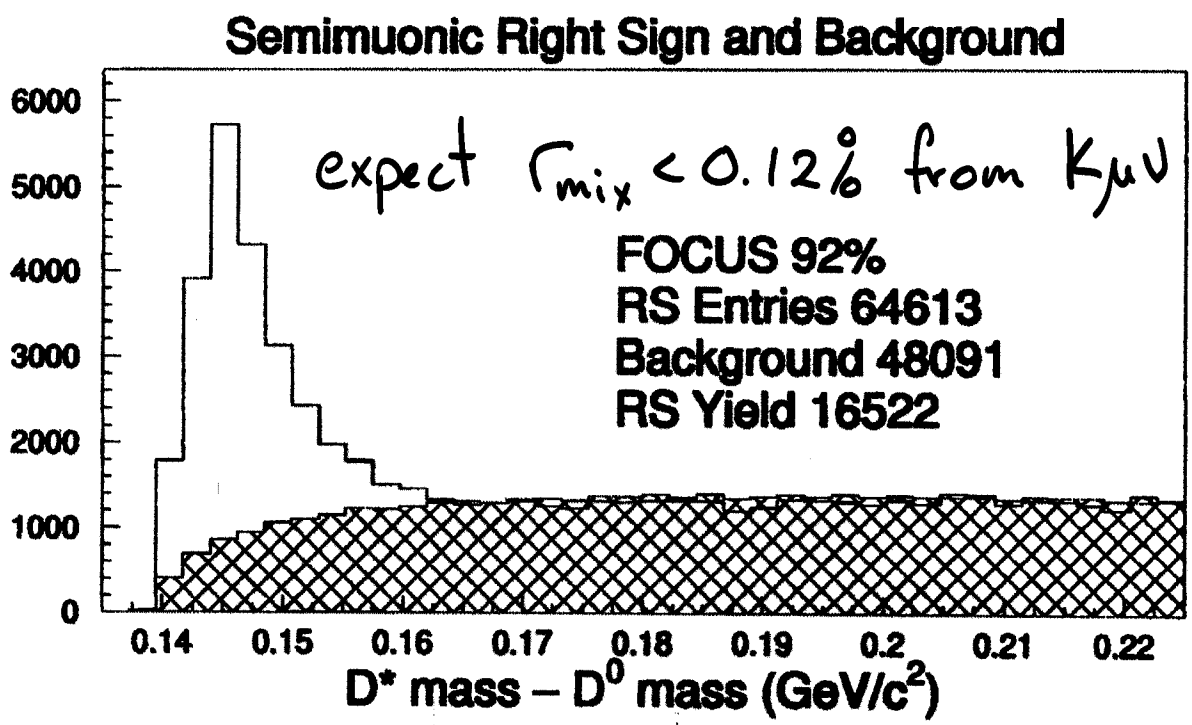


$r_{mix} < 2.3 \times 10^{-3}$ due to $\Delta\Gamma$

$r_{mix} < 4.2 \times 10^{-4}$ due to ΔM

Future Mixing Searches





n.b. BaBar makes $> 10^7$ $D^* \to \pi D^0$ year^{-1}

Measuring $\Delta\Gamma$

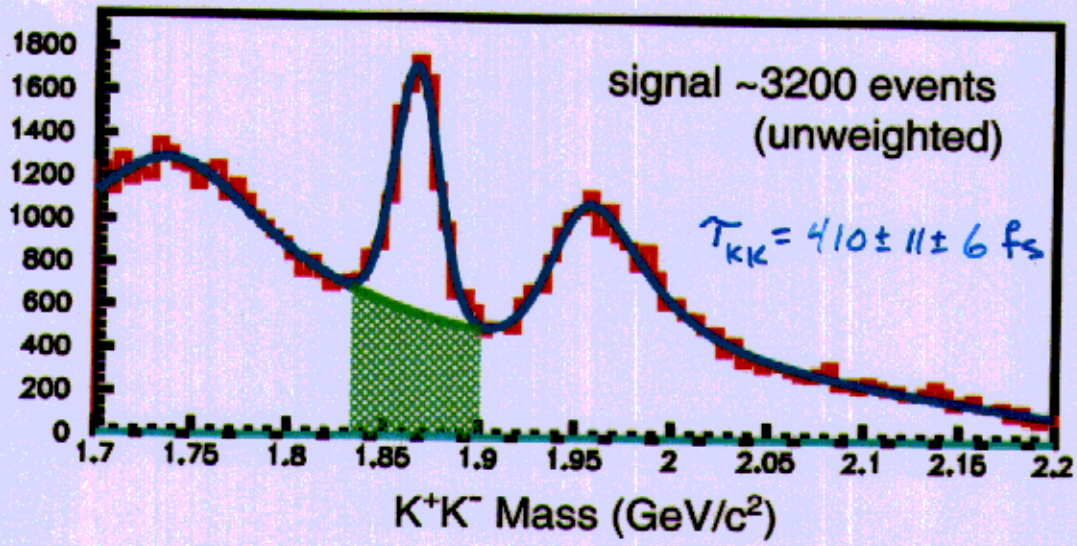
Hard to see Γ_1, Γ_2 in one distribution.

Easier to see $\Delta\Gamma$ btwn two final states.

e.g. $K_S \to \pi\pi$, $K_L \to \pi\pi\pi$

E791

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



$$\Delta\Gamma_{CP} = 2(\Gamma_{KK} - \Gamma_{K\pi}) = 0.04 \pm 0.14 \pm 0.05\ ps^{-1}$$

FOCUS & CLEO will look at

CP+ states K^+K^-, $\pi^+\pi^-$

CP- states $K_S\phi$, $K_S\rho$, $K_S\omega$

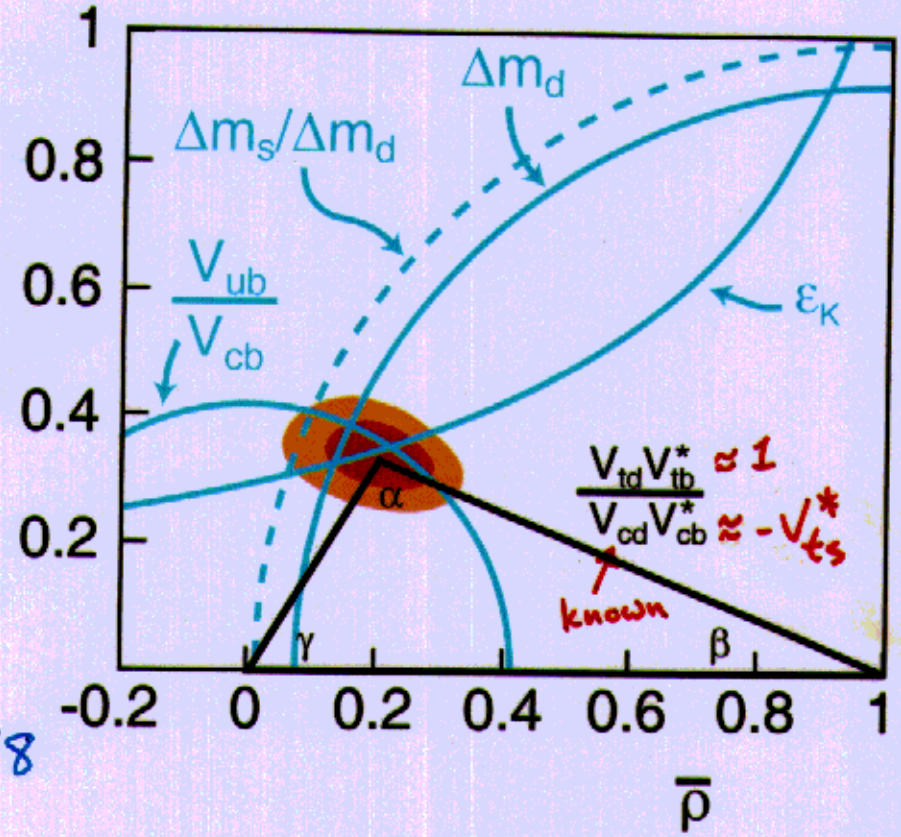
see P. Sheldon at HF8

B Mixing

Use B mixing to get V_{td}

contours by Parodi et al. hep-ex/9903063

see also Plaginski @ HF8



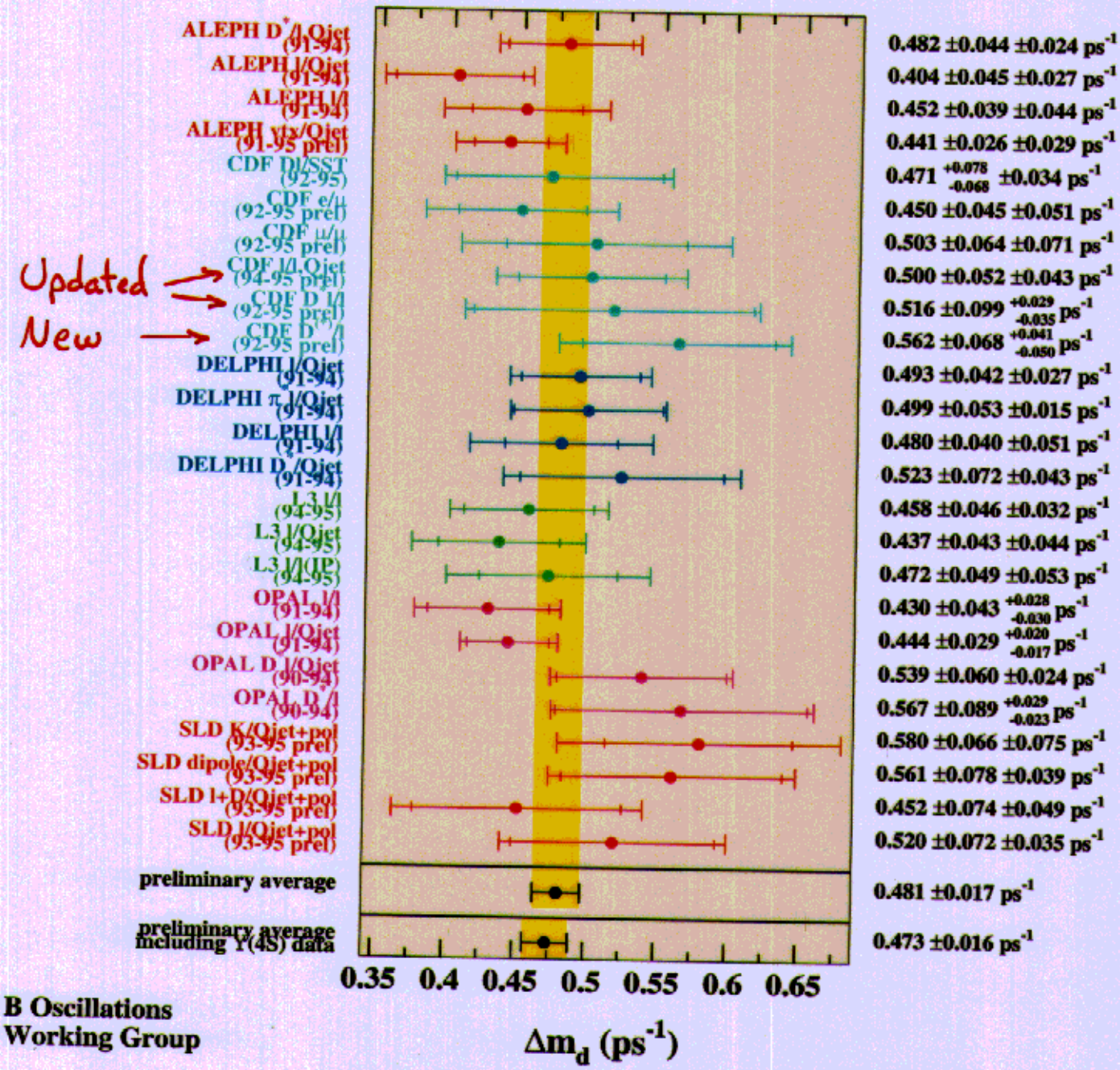
$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{B_d} f_{B_d}^2 B_{B_d} \eta_{QCD} F(m_t^2) \left| V_{td} V_{tb}^* \right|^2$$

(Altarelli & Franzini Z. Phys. C37 (88) 271)

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s} f_{B_s}^2 B_{B_s}}{m_{B_d} f_{B_d}^2 B_{B_d}} \left| \frac{V_{ts}}{V_{td}} \right|^2 = (1.15^{*} \pm 0.05)^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

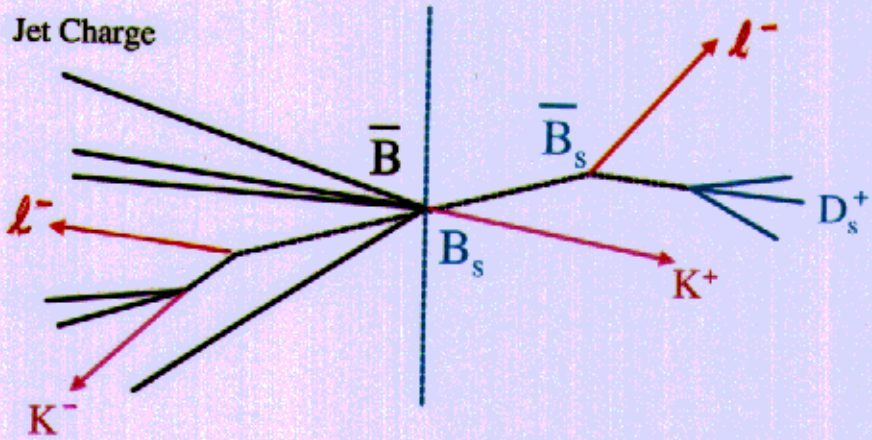
* Buras hep-ph/9711217

B_d Mixing



B Oscillations Working Group

B_s Mixing (just @ the corner)



Final State Tag

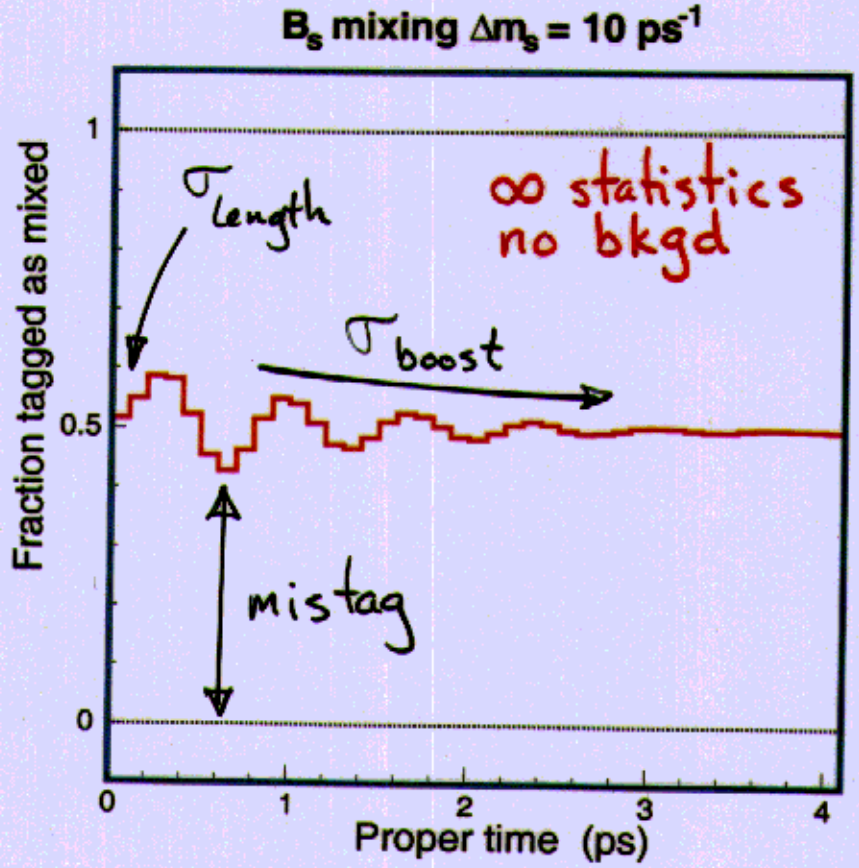
- leptons
- D decays
- charge dipole

Initial State Tag

- opposite B (ℓ, K)
- same side K
- jet charge
- polarization (SLD)

Requirements

- good σ_t
- high purity
- high statistics



$\text{Prob}^{mix} \sim 1 - A \cos \Delta m t$

$\hookrightarrow$ $A = 1$ if mixing present

Updates

Delphi

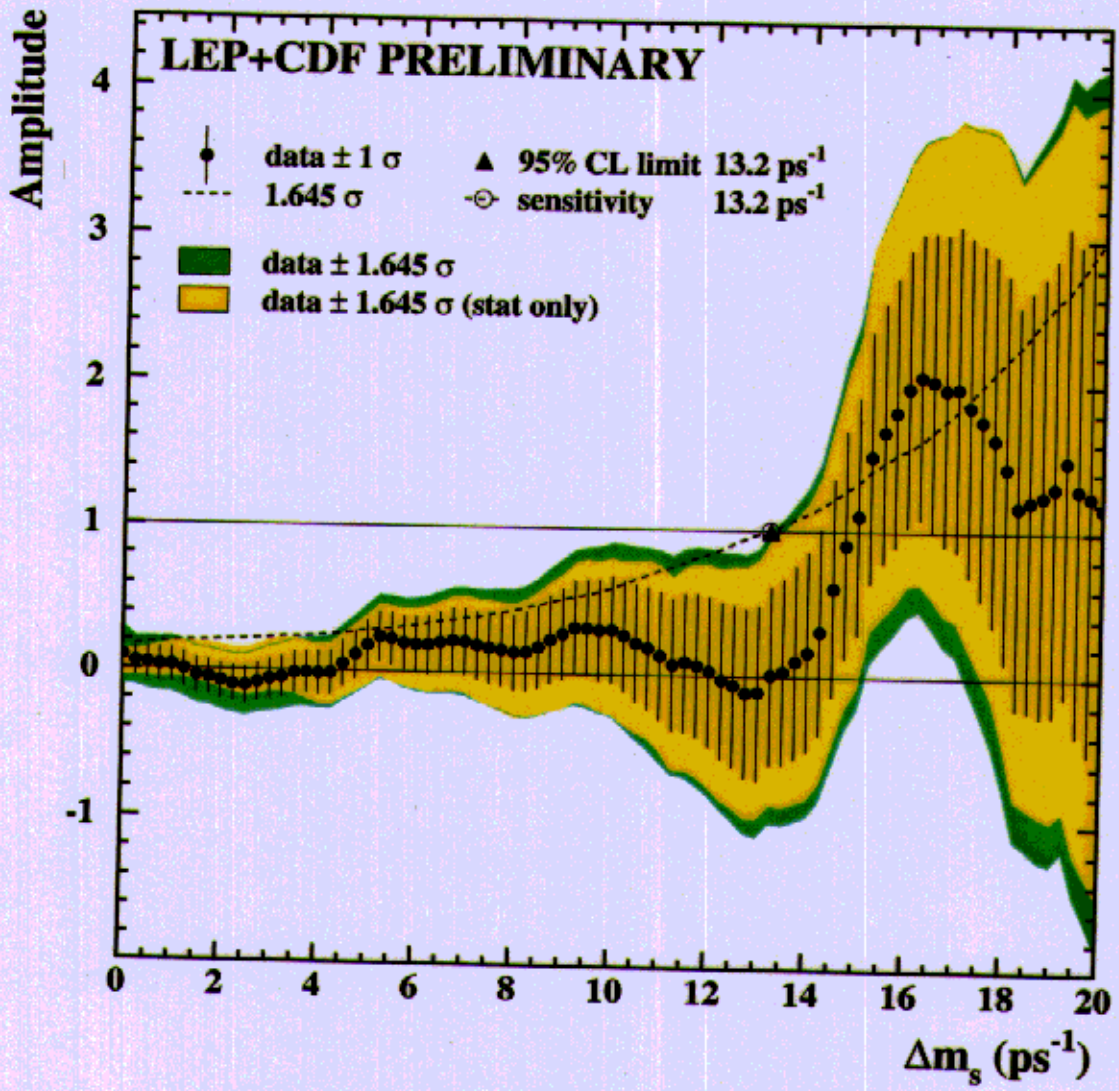
$D_s + \ell$

excl. B_s

$D_s + h$

Opal

incl. ℓ

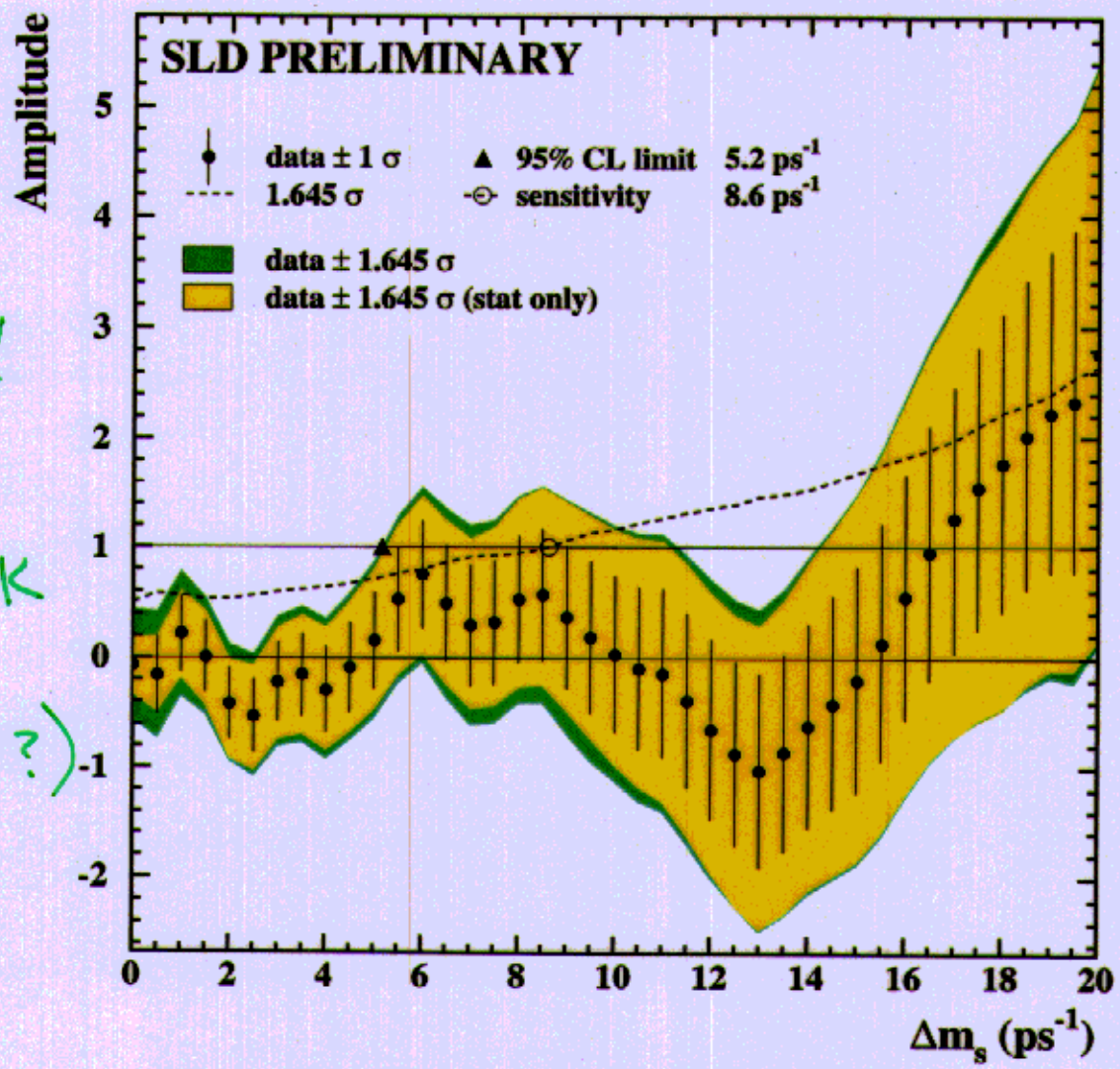


PRELIMINARY

- charm vtx + ℓ
- lepton + X
- dipole

updates

Driven by new tracking & improved resolution



NOT SHOWN

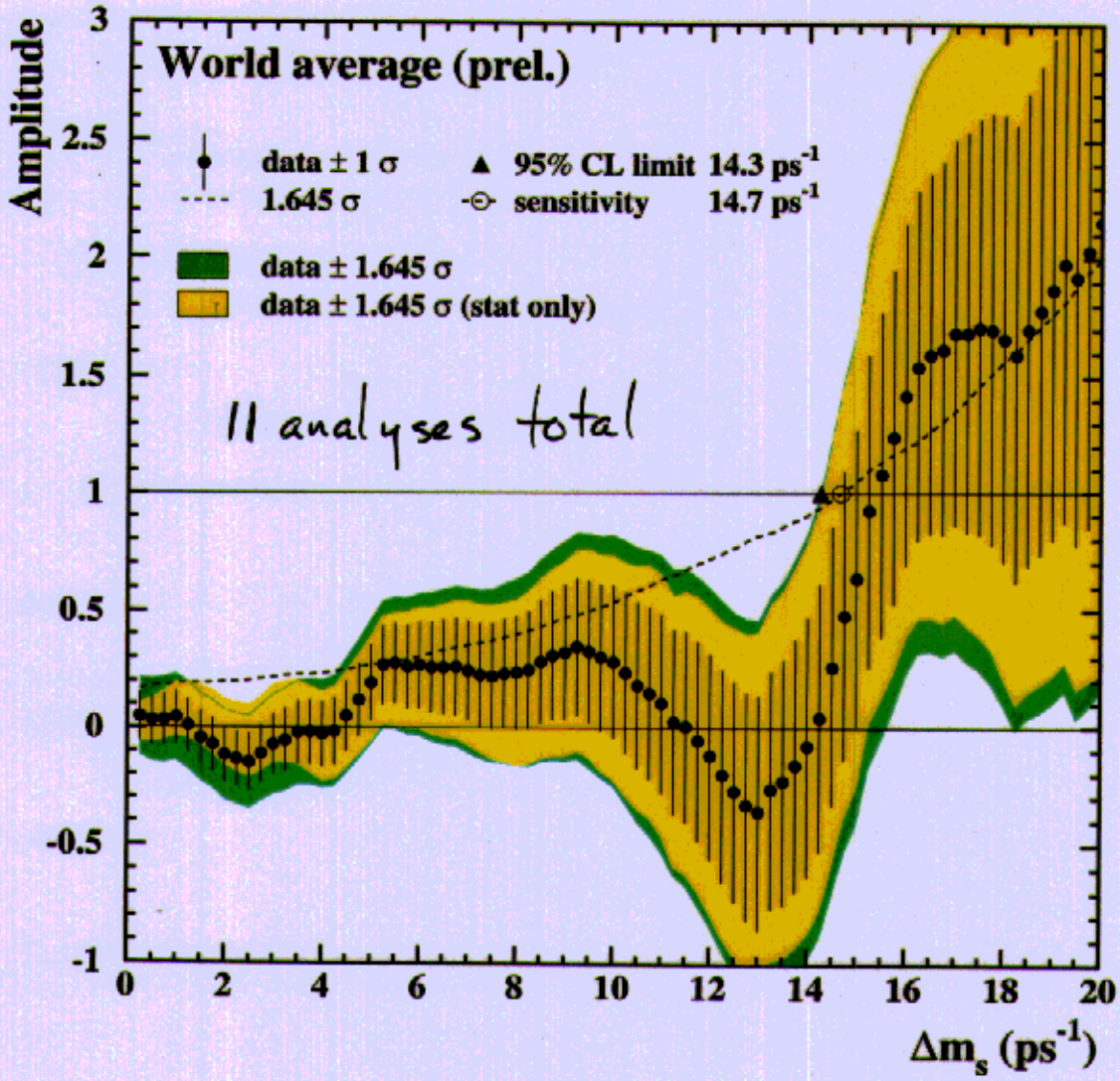
D_s + X

lepton + K

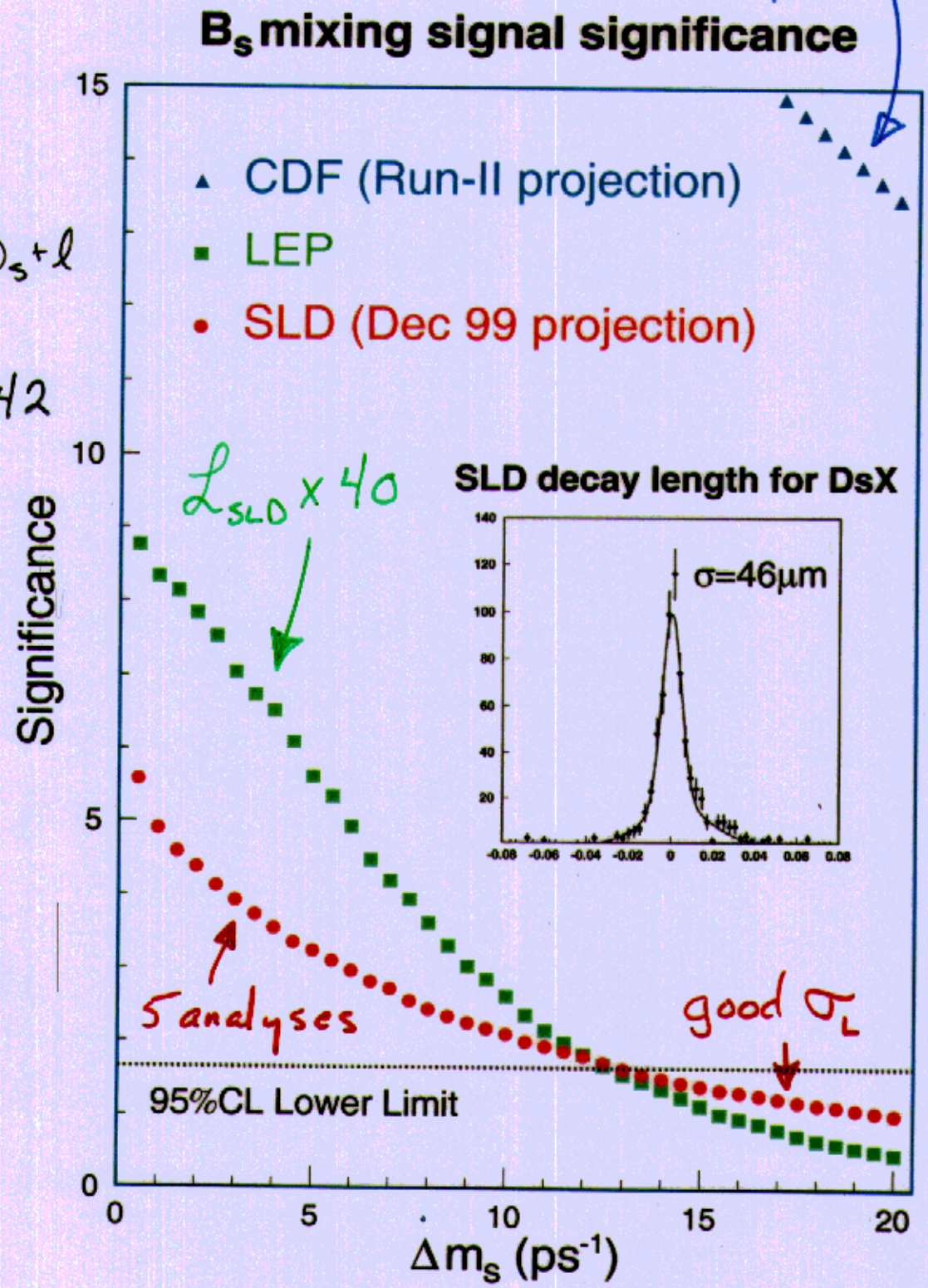
(Dec. 99?)

Private compilation (not blessed) using Bosc working group machinery

$\Delta M_s > 14.3\ ps^{-1}$ (12.4 ps^{-1} last week)



statistics are trumps



latest Delphi $D_s + \ell$

$\frac{\Delta\Gamma_s}{\Gamma_s} < 0.42$

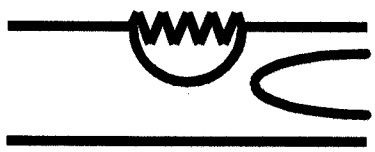
CDF $B_s \to \psi\phi$ for $\Delta\Gamma$ in the future

CP Violation Formalism

CPV needs ≥ 2 amplitudes with different phases

$c_1 A_1 e^{i\delta_1}$ ← strong phase

weak coupling



$c_2 A_2 e^{i\delta_2}$

$$M = c_1 A_1 e^{i\delta_1} + c_2 A_2 e^{i\delta_2} \; ; \; M_{CP} = c_1^* A_1 e^{i\delta_1} + c_2^* A_2 e^{i\delta_2}$$

$$\frac{\Gamma - \Gamma_{CP}}{\Gamma + \Gamma_{CP}} = \mathrm{Im}(c_1 c_2^*) \sin(\delta_1 - \delta_2)$$

CHARM

If only decay amplitudes ("direct"), CPV is constant. Measure w/ integrated rates.

BOTTOM

If one amplitude includes mixing ("indirect") CPV evolves in t. Measure time dependence.

Charm CP Violation

Search for NP and SM penguin CPV in time-integrated rates

$$A_{CP} = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})}$$

All FT results are normalized to $D^0 \to K\pi$ (or $D^+ \to KK\pi$) to account for production asymmetries due to beam and target.

	Old E791	New 59% FOCUS
$A_{K^+K^-}$	-0.010 ± 0.050	-0.004 ± 0.017
$A_{K^+K^-\pi^+}$	-0.014 ± 0.029	-0.003 ± 0.039

see D. Pedrini at Kaon 99

CPV in B Decays

Use indirect CPV in B decays to get at CKM

CP eigenstates are cleanest theoretically.

<u>Popular Examples</u>

$$A_{CP}(B^0 \to \psi K_S) = -\sin 2\beta \sin \Delta m t$$

$$A_{CP}(B^0 \to \pi^+\pi^-) = \sin 2\alpha \sin \Delta m t$$

but watch out for...

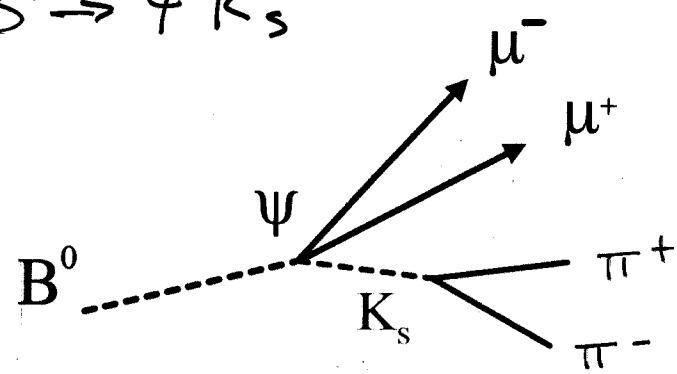
sin2β at CDF

constraints

m_{K_s}, m_ψ

3 vertices

$B^0 \to \psi K_s$

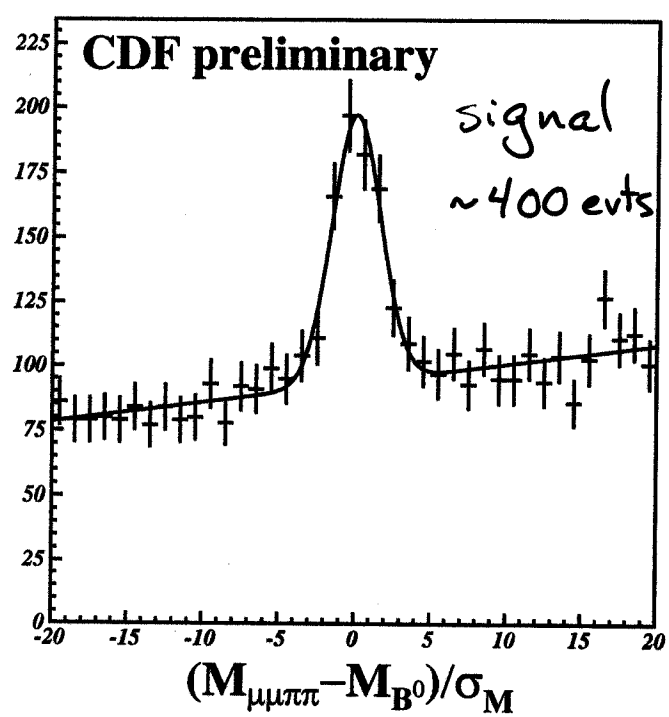


Initial State Tags

same side π, opposite lepton, opp. jet chg.

202 evts with good decay time

193 events w/o decay time

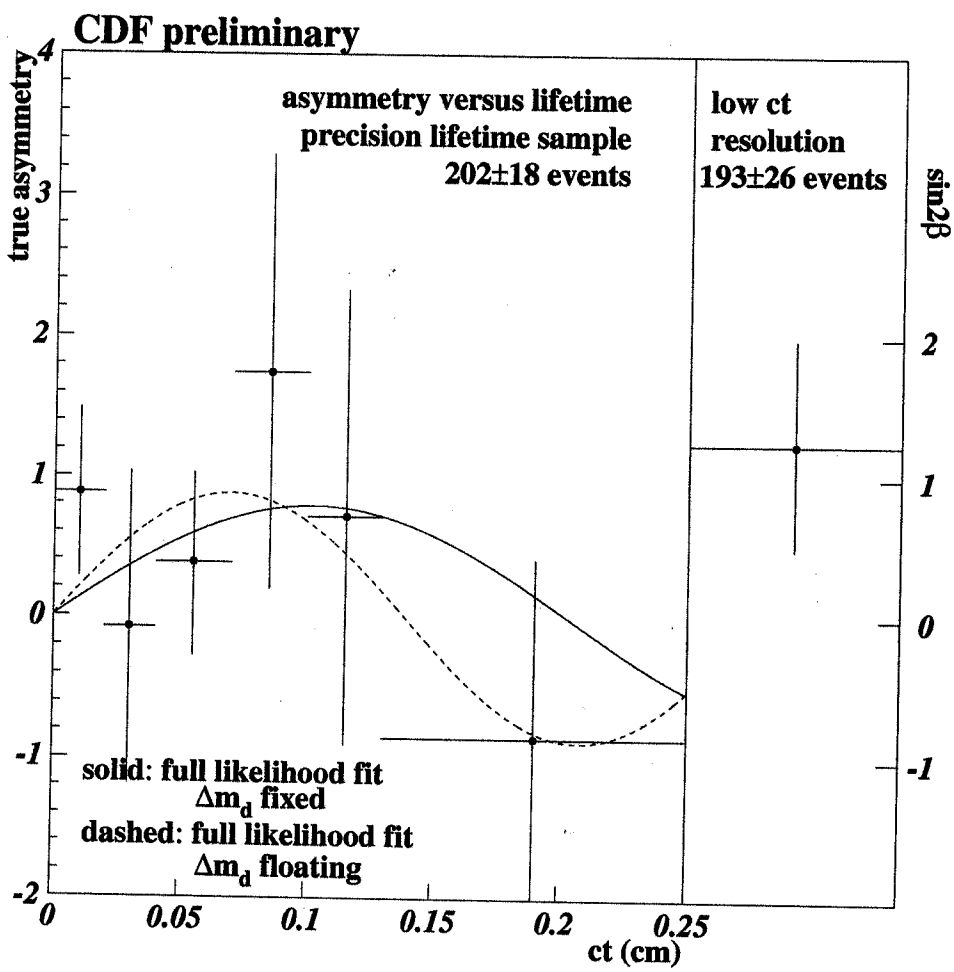


good t evts use $A_{CP}(t) = \sin 2\beta \sin \Delta m t$

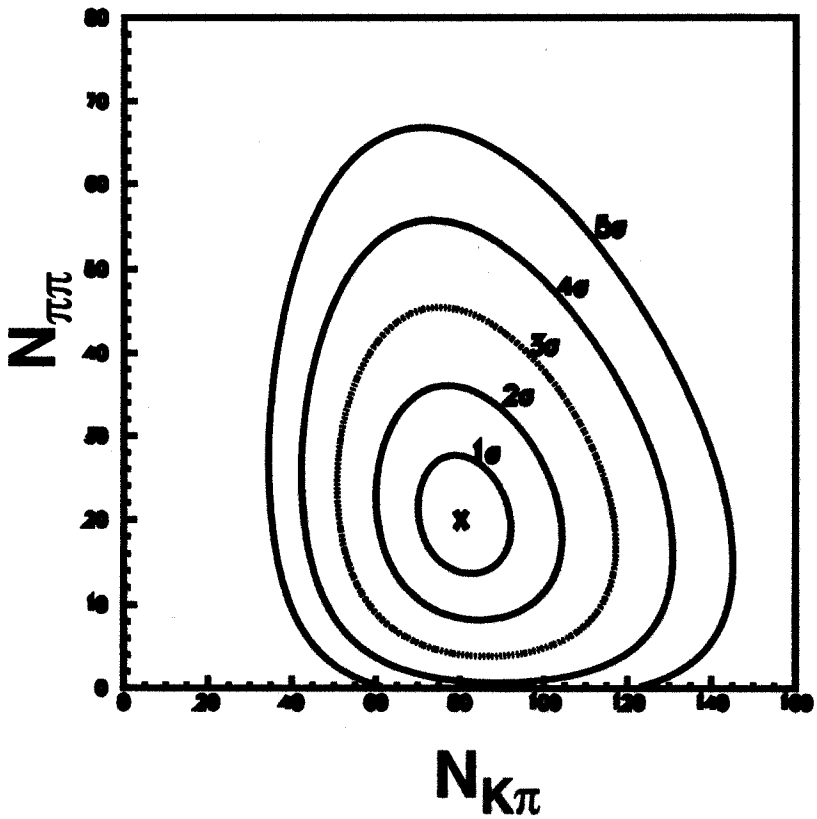
bad t evts use $A_{integ} = \sin 2\beta \dfrac{\Delta m/\Gamma}{1+(\Delta m/\Gamma)^2}$

Result: "indication of mixing"

$\sin 2\beta = 0.79^{+0.41}_{-0.44}$ $\left(\Delta 2 \ln \mathcal{L} = 3.0 \text{ from } \sin 2\beta = 0\right)$



B^0 Decays to $\pi^+\pi^-$ at CLEO



D. Jaffe at HF8

$BR(B^0 \to \pi^+\pi^-) =$

$(0.47 \,^{+0.18}_{-0.15} \pm 0.13) \times 10^{-5}$

$BR(B^0 \to K^+\pi^-) =$

$(1.88 \,^{+0.28}_{-0.26} \pm 0.06) \times 10^{-5}$

Large $B^0 \to K^+\pi^-$ (penguin) implies

$$0.25 \lesssim \frac{A^{\pi\pi}_{penguin}}{A^{\pi\pi}_{total}} \lesssim 0.57$$

BaBar Physics Book sect. 6.12

Can still get α from rates:

$B^\pm \to \pi^\pm \pi^0$

$\overset{(-)}{B}{}^0 \to \pi^0 \pi^0$

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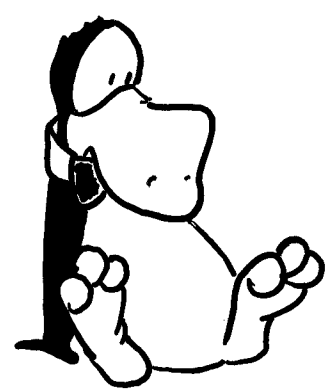
Summary

- $\tau_{D_s} \neq \tau_{D^0}$
- Charm baryon τ_s on the way
- ~×10 reduction in charm mixing limit
- Updates on B_s mixing $\Delta m_s > 14.3\ ps^{-1}$
- CDF $\sin 2\beta = 0.77^{+0.41}_{-0.44}$
- CLEO $BR(B^0 \to K\pi)/BR(B^0 \to \pi\pi)$ implies big penguins