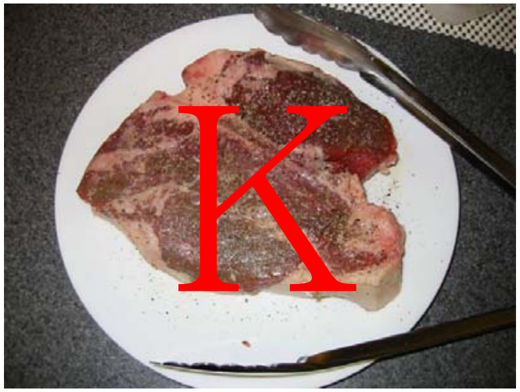


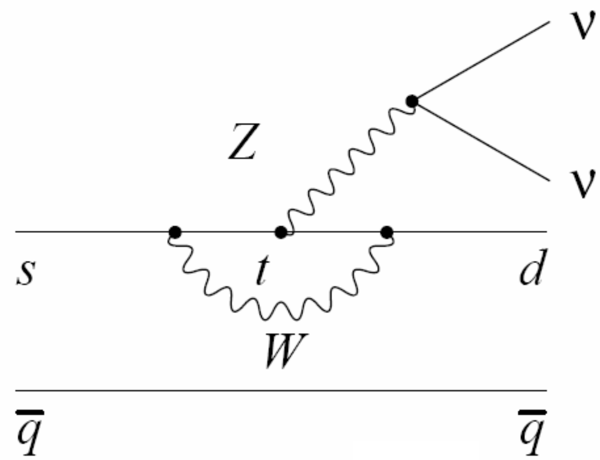
Working Group 3 Summary: V_{td}, V_{ts}, and Friends

Jeffrey Berryhill
Laurent Lellouch
Mikolaj Misiak
Christoph Paus

CKM Workshop, UCSD
March 18, 2005

$V_{td}V_{ts}^*$ from Rare K Decays: $K^+ \rightarrow \pi^+\nu\nu$, $K_L \rightarrow \pi^0\nu\nu$

Buchalla



et al.

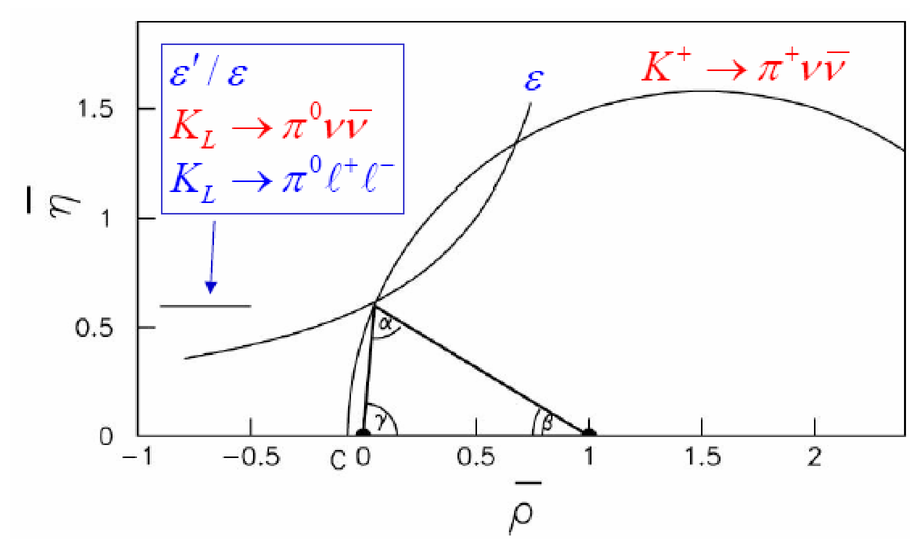
Theoretically "Gold-Plated" relations of BFs to $\lambda_t = V_{td}\, V_{ts}^*$

$K^+ \rightarrow \pi^+\nu\nu$ rate ~ $|V_{td}V_{ts}^*|^2$

Theory error in $|V_{td}|$ extraction from BF ~10%
mostly parametric errors from m_c, V_{cb}
Only 5% error from scale dependence

$K_L \rightarrow \pi^0\nu\nu$ rate ~ $(\mathrm{Im}\ \lambda_t)^2 \sim \bar{\eta}^2$

Theory error in η extraction from BF ~3%



K+→ $\pi^+\nu\nu$: Measurement Status

Jaffe

BNL E787/E949:
Stop kaon, measure outgoing pion
Aggressively and redundantly
veto huge backgrounds

$$\mathcal{B}(K^+ \rightarrow \pi^+\nu\bar{\nu}) = (1.47^{+1.30}_{-0.89}) \times 10^{-10}$$

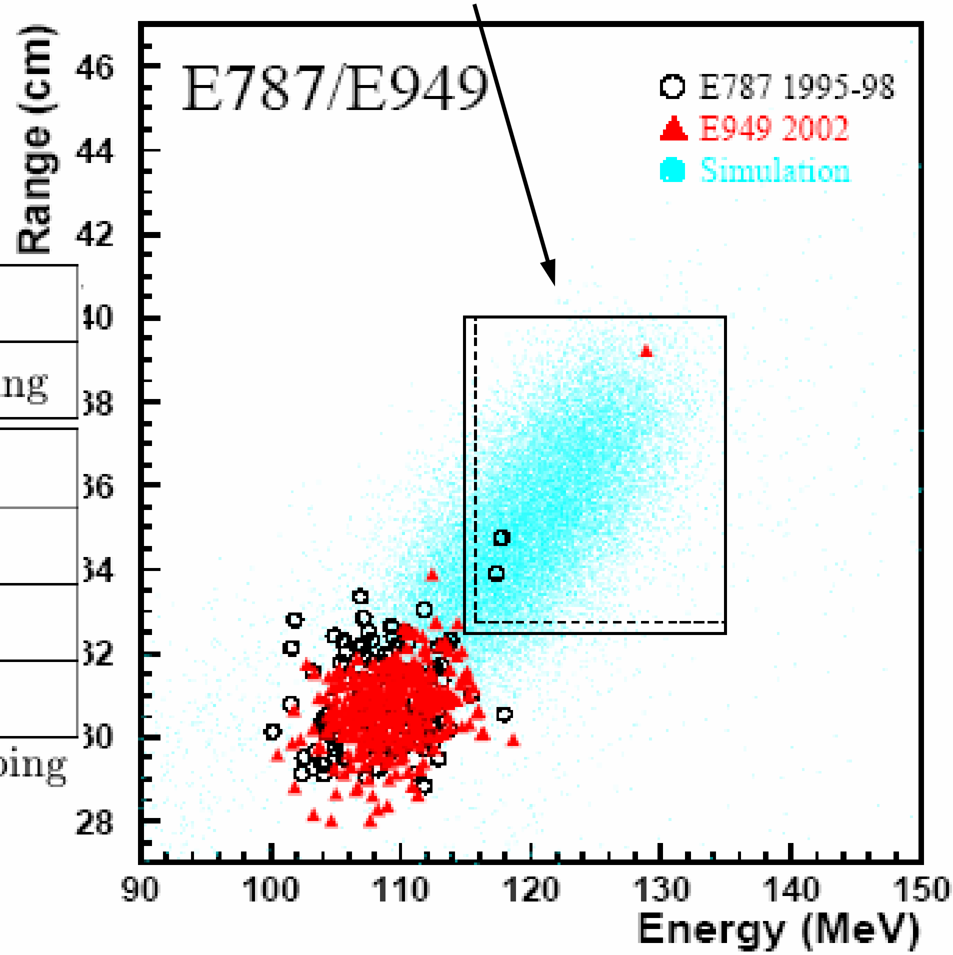
SM $= (0.77 \pm 0.11) \times 10^{-10}$

	Suppression method			
Source	Kine	PID	Veto	Timing
$K^+ \rightarrow \mu^+\nu(\gamma)$	$\surd$	$\surd$	$(\surd)$	
$K^+ \rightarrow \pi^+\pi^0$	$\surd$		$\surd$	
Scattered beam		$\surd$		$\surd$
CEX			$\surd$	$\surd$

Veto includes both γ and charged particle vetoing

No new data expected
15% precision improvement
from final analysis

Blind analysis
3 candidate events in the signal box
Background probability = 0.001 (>3σ)



Rare K Decays: Summary

K+ signal in the right range

David E. Jaffe (CKM Workshop 2005) 2 March 2005

What do we know about $K^0_L \to \pi^0 \ell^+ \ell^-$, $K^+ \to \pi^+ \nu \bar{\nu}$ and $K^0_L \to \pi^0 \nu \bar{\nu}$

$K^+ \to \pi^+ \nu \bar{\nu}$	$K^0_L \to \pi^0 \nu \bar{\nu}$	$K^0_L \to \pi^0 e^+ e^-$	$K^0_L \to \pi^0 \mu^+ \mu^-$	Process
7×10^{-11}	3×10^{-11}	$4 \times 10^{-11*}$	$1 \times 10^{-11*}$	$\mathcal{B}$(SM)
$(1.47^{+1.30}_{-0.89}) \times 10^{-10}$	$< 5.9 \times 10^{-7}$	$< 2.8 \times 10^{-10}$	$< 3.8 \times 10^{-10}$	$\mathcal{B}$(expt)
10%	< 2%	10%	10%	$\sigma_{\mathcal{B}}/\mathcal{B}$
$\lvert\lambda_t\rvert$	$Im(\lambda_t)$	$Im(\lambda_t)$	$Im(\lambda_t)$	UT
E787/E949	E391a	NA48/5	NA48/5	Expts
1989-2002(+?)	2002-			When
CKM2,NA48/3	KOPIO			Expts
2009?	2010-			When

Interesting SM-like precision is years away

$\lambda_t \equiv V^*_{ts} V_{td}$, All limits at 90% CL. * Assumes positive interference (next pages)

K^0 Mixing: Theory Precision

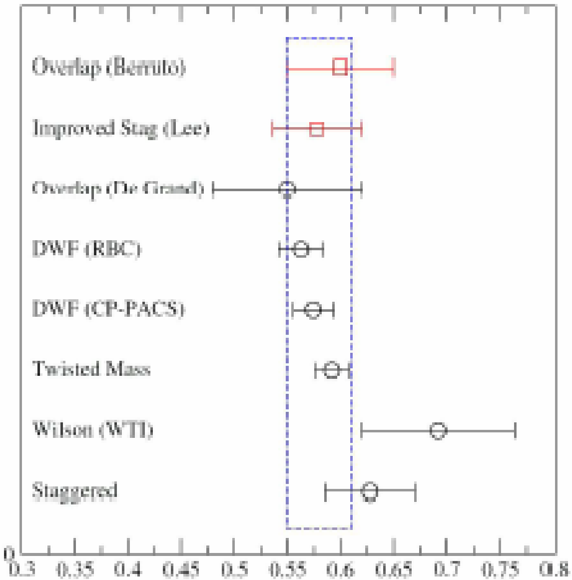
$K^0\!-\!\bar{K}^0$ mixing induces indirect CP violation in $K \to \pi\pi$ which is governed by

$$|\epsilon_K| \simeq C_\epsilon A^2 \lambda^6 \bar{\eta} \left[A^2 \lambda^4 (1-\bar{\rho}) \eta_2 S(x_t) + P(x_t, x_c, \cdots) \right] c_K(\mu) B_K(\mu)$$

$$c_K(\mu) \langle \bar{K}^0 | (\bar{s}d)_{V-A} (\bar{s}d)_{V-A}(\mu) | K^0 \rangle = \frac{8}{3} M_K^2 f_K^2 \hat{B}_K^{RGI}$$

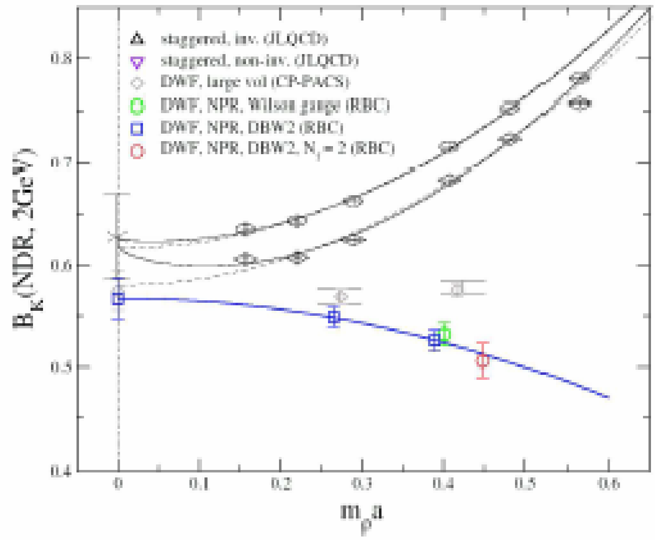
- For CKMology, assume no NP in this FCNC process and CKM unitarity
- many quenched calculations of B_K with different fermion discretizations agree in continuum limit
- newer calculations performed with “chirally-improved” fermions give value of B_K slightly lower than reference JLQCD ’97 result
- $\star$ 2 new $N_f = 2$ calculations (C^-) (UKQCD ’04, RBC ’05) suggest mild decrease of B_K with m_{sea}

Recent quenched $B_K^{NDR}(2\,\mathrm{GeV})$



(Dawson, WG 3)

$N_f = 2$ and quenched vs lattice spacing



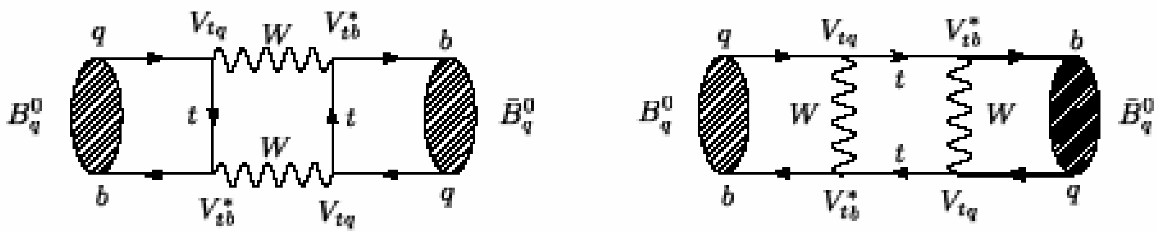
(Dawson, WG 3)

⋆ Summary (Dawson, WG3)

$$\hat{B}_K^{RGI} = 0.79(4)(9) \qquad [0.86(6)(14)\text{–ICHEP '02}]$$

- central value is average of recent quenched results
- $N_f = 2$ used to estimate quenching uncertainty
- $\delta B_K = 12\%$ of which 10% is (educated) guess of quenching uncertainty
- ⋆ situation will be clarified by $N_f = 2+1$ calculations underway
- Non lattice estimates in certain limits of QCD: Peris et al '00, Bijnens et al '95 & '05, . . .

$B^0_{(d,s)} - \bar{B}^0_{(d,s)}$ *oscillations in SM*



$$\Delta M_q \simeq \frac{G_F^2}{8\pi^2} M_W^2 \, |V_{tq} V_{tb}^*|^2 \, \eta_B S_0(x_t) c_B(\mu) \, \frac{|\langle \bar{B}_q | (\bar{b}q)_{V-A} (\bar{b}q)_{V-A}(\mu) | B_q \rangle|}{2 M_{B_d}}$$

$$c_B(\mu) \langle \bar{B}^0_q | (\bar{b}q)_{V-A} (\bar{b}q)_{V-A}(\mu) | B^0_q \rangle = \frac{8}{3} M^2_{B_q} f^2_{B_q} \hat{B}_{B_q}$$

- CKMology assumes no NP in these FCNC processes and CKM unitarity
- In $\Delta M_d / \Delta M_s$, short distance coefficients and many lattice uncertainties cancel
- f_{B_q} and B_{B_q} on lattice separately, because systematics very different
- methods similar as those for $f_{D_{d,s}}$ $\rightarrow$ important rôle of CLEO-c

Extrapolation in light u valence and u, d sea quark necessary for f_B and B_B

2002: inclusion large chiral log term could lower value of f_B obtained from extrapolating lattice results obtained w/ $m_u = m_d \gtrsim m_s^{phys}/2$ (Kronfeld et al)

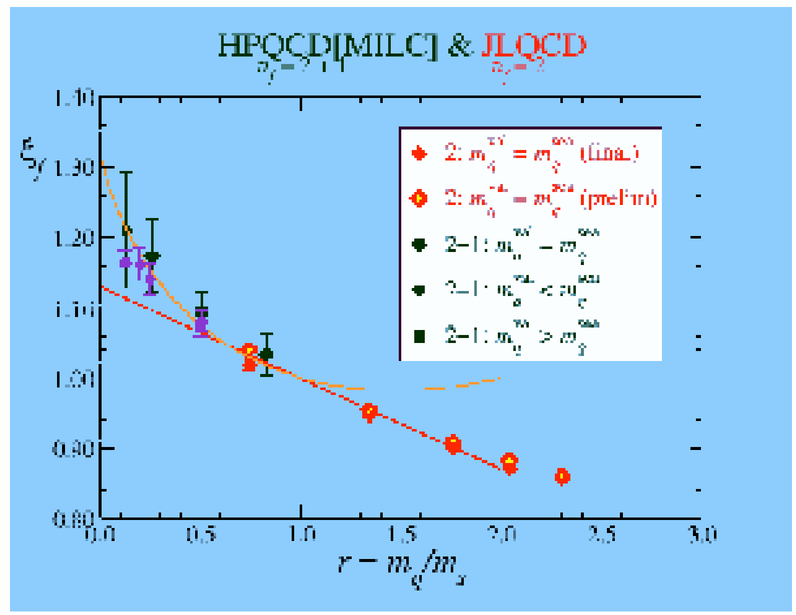
- by $O(20\%)$ (Yamada; Kronfeld et al)
- by $O(10\%)$ (Lellouch; Becirevic)

⋆ New results on subset of $N_f = 2+1$, MILC gauge configurations (C$^-$ on Bernard scale): Wingate et al '04 and Gray et al '04 (preliminary)

$\longrightarrow$ some evidence for log

$\longrightarrow$ $O(10\%)$ effect

$\longrightarrow$ will be checked with full χPT fit



$f_{B_s}\sqrt{M_{B_s}}/f_B\sqrt{M_B}$ from Kronfeld WG3

Not an issue for B_B, B_{B_s} and f_{B_s}

Lattice summary:

Qty	Lellouch ICHEP 2002	Hashimoto ICHEP 2004
$f_B \hat{B}_B^{1/2}$	$235(33)(^{+\ 0}_{-24})$	214(38)
$f_{B_s} \hat{B}_{B_s}^{1/2}$	276(38)	262(35)
ξ	$1.18(4)(^{+12}_{-\ 0})$	1.23(6)

(Decay constants in MeV)

QCD sum-rules results:

$f_B = 210(19)\,\mathrm{MeV}$,

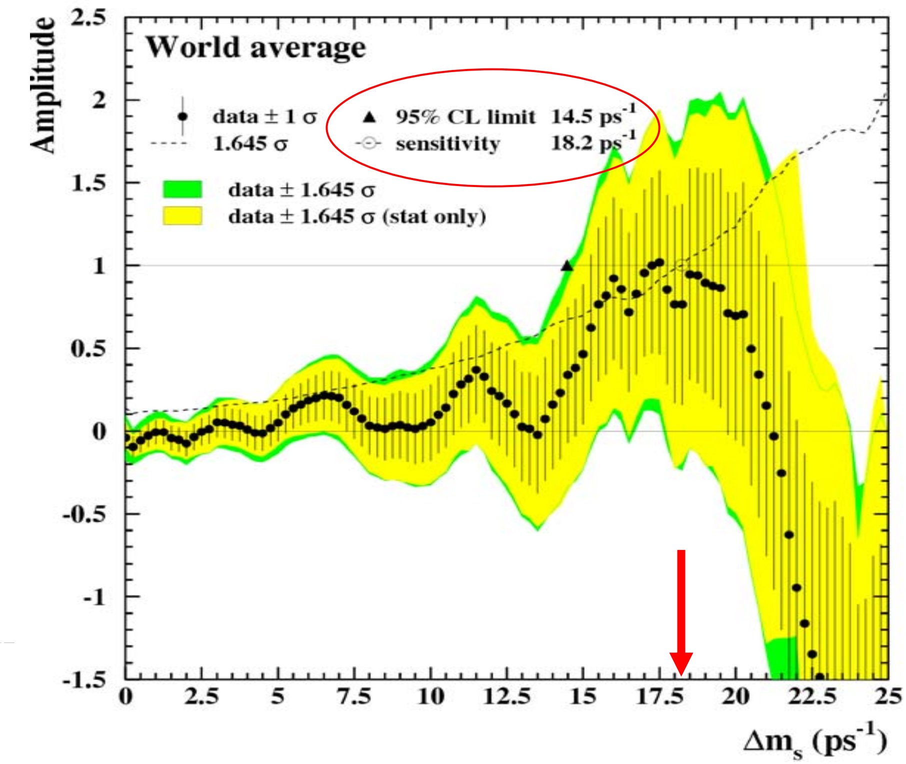
$f_{B_s} = 244(21)\,\mathrm{MeV}$ (Jamin et al '02)

$\hat{B}_B = 1.60(3)$ (Körner et al '03)

- Evidence for chiral logs in $f_{B_s} \rightarrow$ central value shifts to middle of asymmetric error range
- Summary numbers are C$^-$ results
- $\star$ Expect C$^+$–B$^-$ results in coming year or so ($N_f = 2+1$ staggered at more than 1 lattice spacing)
  $\longrightarrow$ most of chiral extrapolation error will be statistical
- Also need non-staggered $N_f = 2+1$ results to check assumptions and methods used
- $\delta_{th}|V_{td}| \simeq 20\%$ from ΔM_d
- $\delta_{th}|V_{td}/V_{ts}| \simeq 5\%$ from $\Delta M_d/\Delta M_s$

B_s Mixing Measurements

CKM fits expect $\Delta m_s \approx$ 14-24 ps^{-1}



World average
"Amplitude scan"
Δm_s > 14.5 ps^{-1}

- naïve picture:

  fit time-dependant asymmetry:

$$A_{mix}(t) = \frac{N_{unmix}(t) - N_{mix}(t)}{N_{unmix}(t) + N_{mix}(t)} = D \cdot \cos(\Delta m t)$$

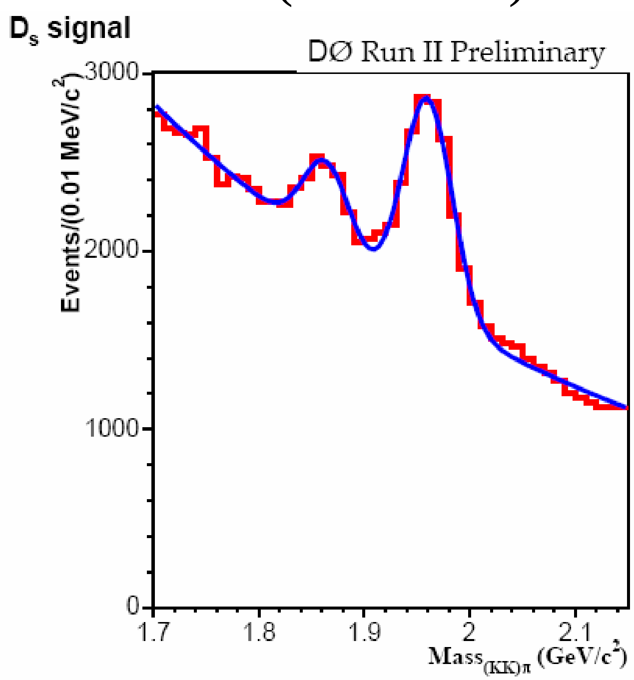
- in reality, perform amplitude scan using likelihood fit (discussed in more detail later)

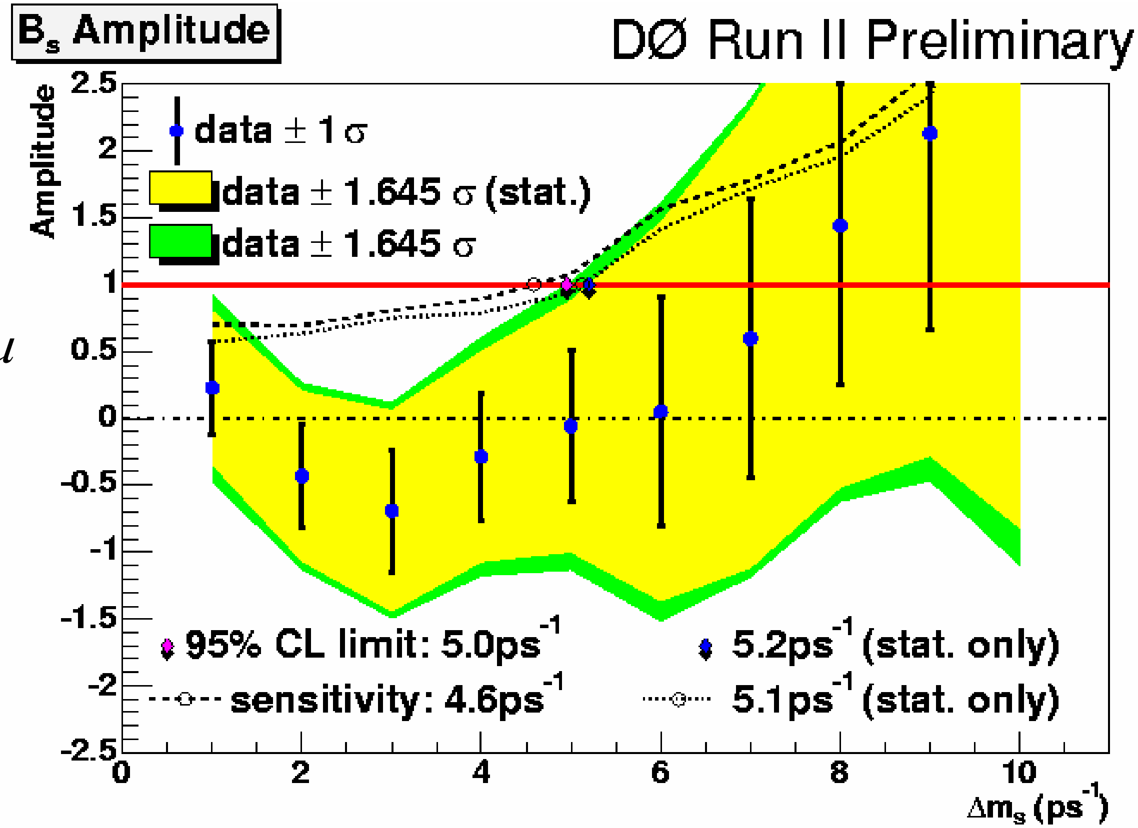
$$\text{Signif} = \sqrt{\frac{N\epsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

DØ B_s Mixing in Semileptonics

Abbott

- $B_s \to D_s\, \mu\, X$ **(460 pb^{-1})**
  - $D_s \to \phi\pi$
  - Enhanced opposite side μ tag
  - 7037 events (376 tags)
  - εD^2=(1.17±0.04)%





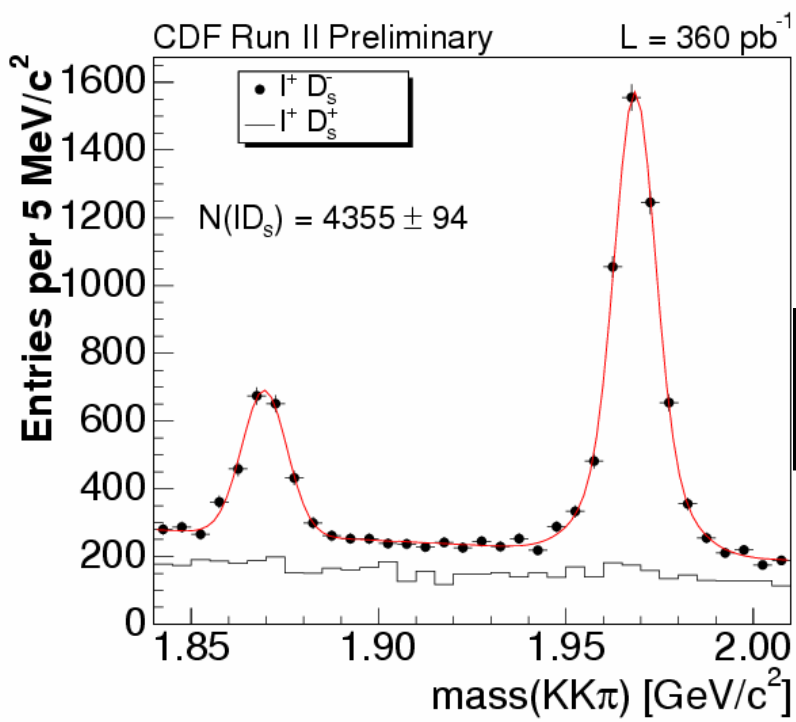
Limit: Δm_s > 5.0ps^{-1} @95% CL
Sensitivity: 4.6 ps^{-1}

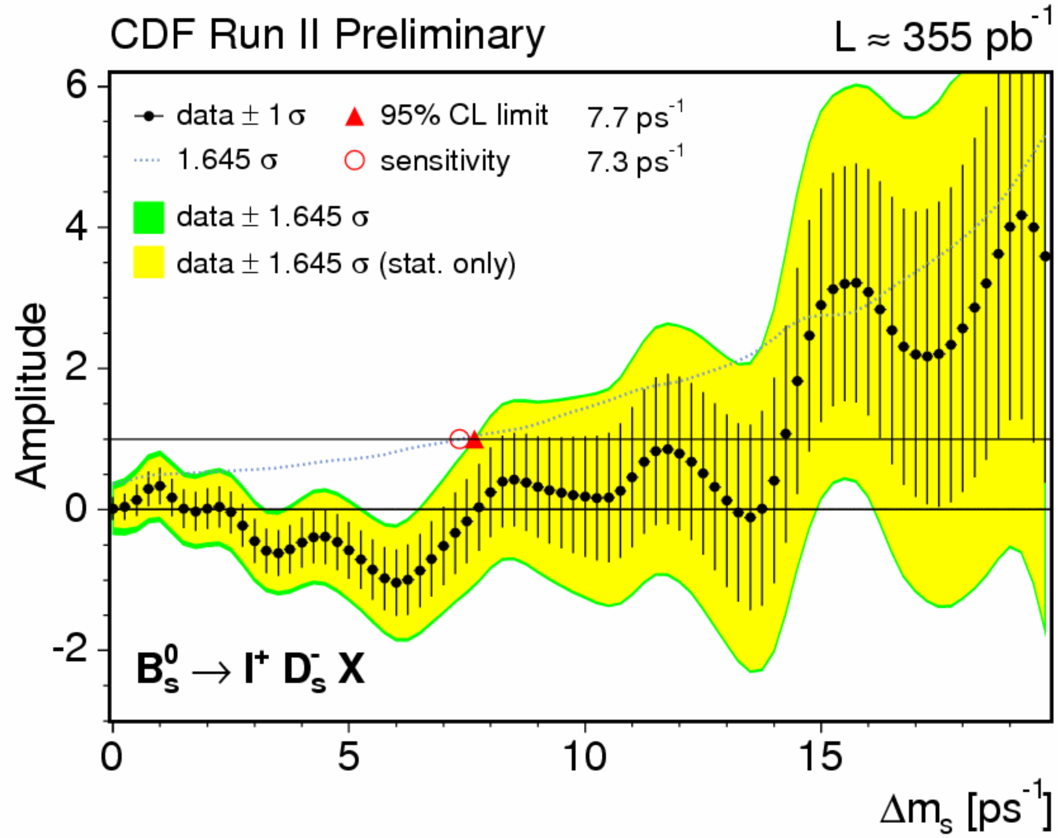
CDF B_s Mixing in Semileptonics

Furic

- $B_s \rightarrow D_s$ + lepton (e/μ)
  - $D_s \rightarrow \phi\pi$, K^*K, $\pi\pi\pi$
  - 4355 events
  - Trigger: 4GeV e/μ + track
  - Opposite side flavor tags

  e,μ,jetcharge εD^2**=(1.43±0.09)%**





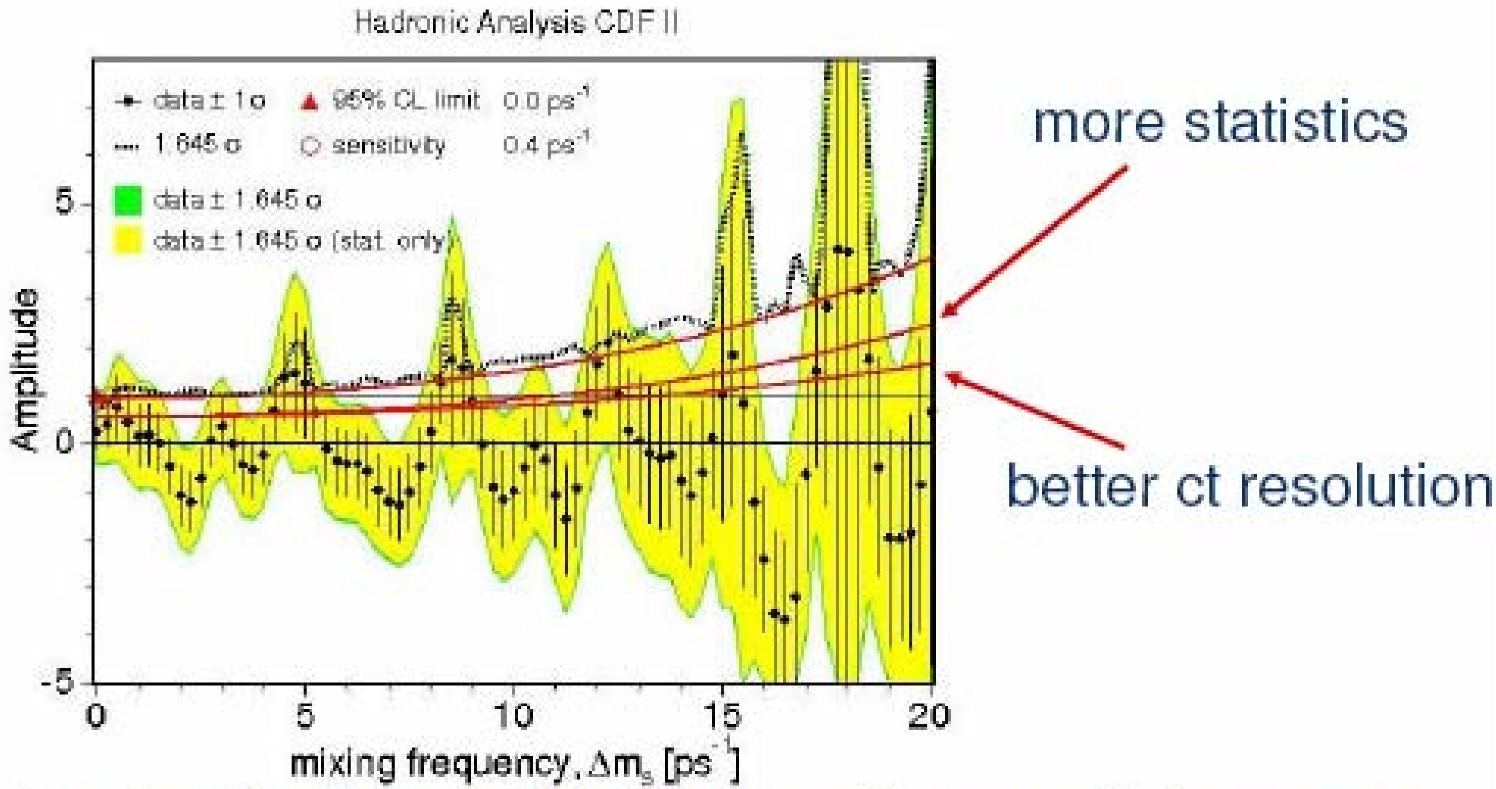
Limit: $\Delta m_s > 7.7\,ps^{-1}$ @95% CL
Sensitivity: $7.3\ ps^{-1}$

For both CDF+D0, semileptonic decays rapidly lose ct resolution at realistic Δm_s

CDF Hadronic B decays

Furic

Improvements: Hadronic

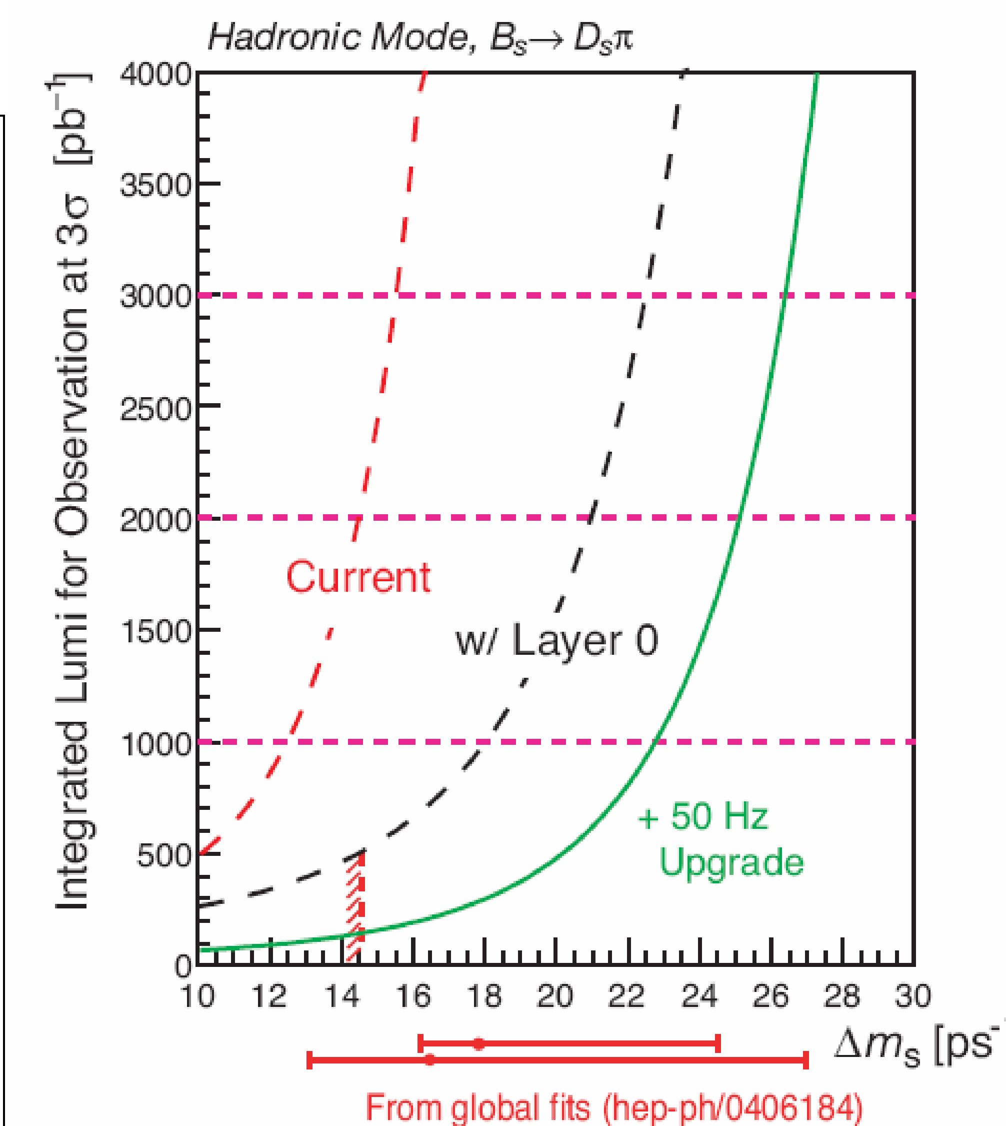


- assuming 4x effective statistics lowers the sensitivity curve
- 20% improvement in ct resolution further flattens sensitivity curve in the region of interest

B_s Mixing, Roadmap to Improvement

Abbott

- More integrated luminosity
- Better flavor tagging
  (same-side K tag)
- Improve proper time resolution
  (event-by-event vertexing)
- Hadronic decays matter more for larger Δm_s
- D0 tracking upgrade (add small radius silicon this summer)
- DAQ/trigger/offline upgrades
- **Peril: can present trigger efficiency be maintained at high instantaneous luminosity?**



D0 projections

Friends of B_s mixing: leptonic D decays

Ryd

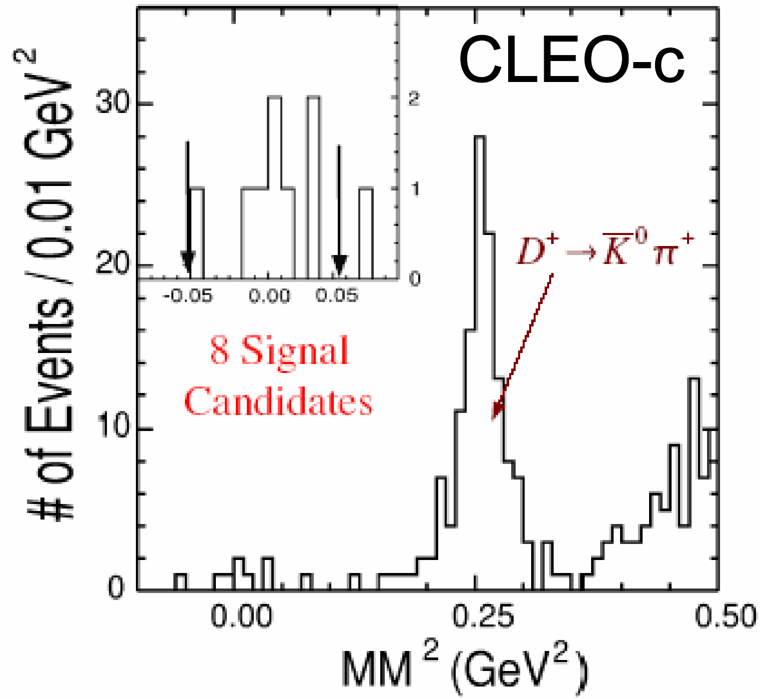
$$\Gamma(D^+ \to l^+ \nu) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_l^2 M_{D^+} \left(1 - \frac{m_l^2}{M_{D^+}^2}\right)^2 |V_{cd}|^2$$

Extract f(D^+) from $D^+ \to \mu\nu$ decay rate

30k fully reconstructed $\psi'' \to D^+ D^-$ events
8 signal events with missing mass = 0

Can improve to 3% precision for f(D^+)

f(D_s^+) 2% precision expected from $\psi(3770) \to D_s^+ D_s^-$ running ($\tau\nu$ and $\mu\nu$)



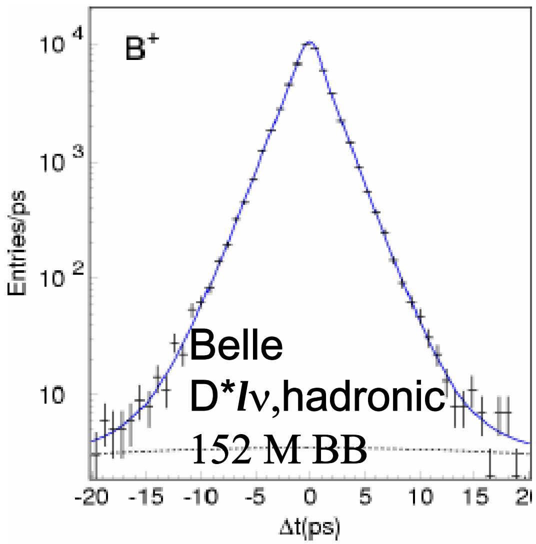
BF($D^+ \to \mu\nu$) = 3.5 ± 1.4 ± 0.6 10^{-4}
f(D^+) = 202 ± 41 ± 17 MeV
LAT = 225 ± 13 ± 21 MeV

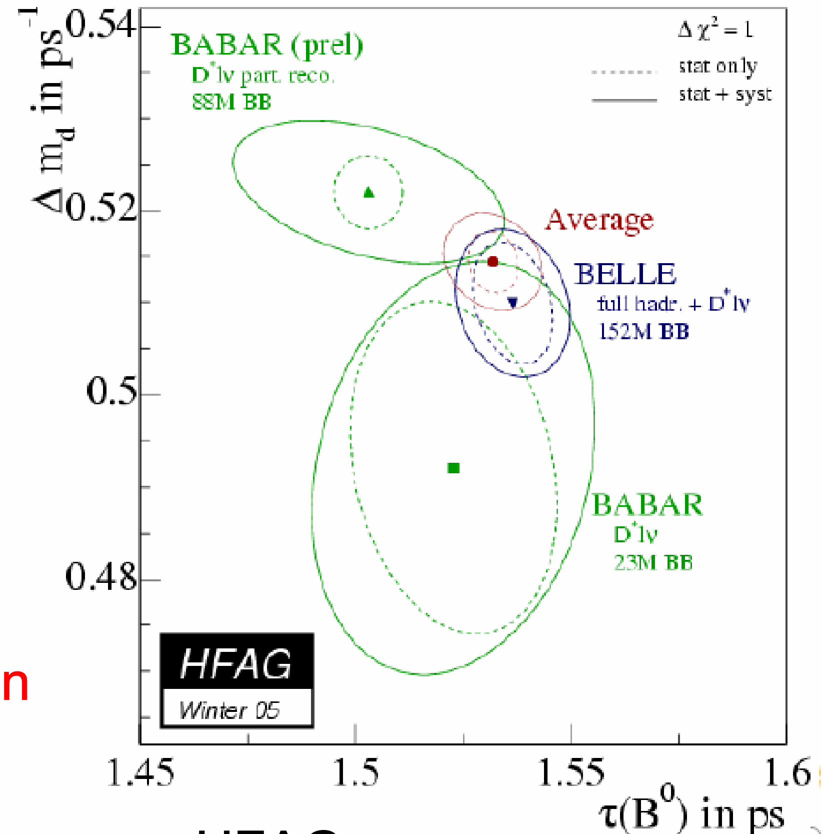
D decay constants and their ratios check or bound errors of lattice estimates of B decay constants

Friends of B_s Mixing: B mixing and lifetime

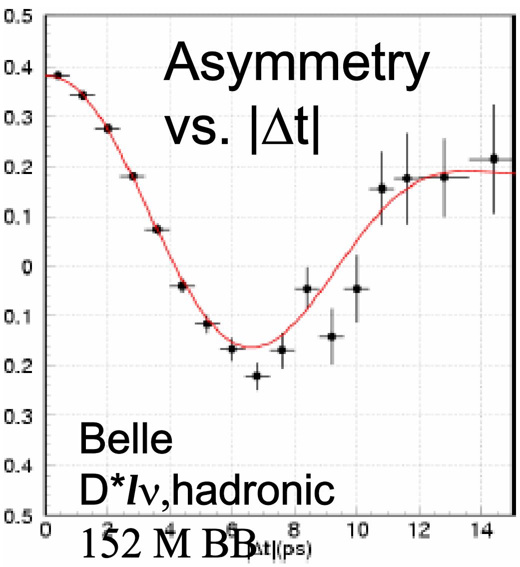
Hastings

Further improvement in B^0, B^+ lifetime and B^0 mixing from B factories





HFAG average



< 1% B factory precision on lifetime and mixing

Results

$$\Delta m_d = (0.514 \pm 0.005)\ \mathrm{ps}^{-1}$$
$$\tau_{B^0} = (1.532 \pm 0.011)\ \mathrm{ps}$$

Mixing and lifetimes from B factories could ultimately improve by another 2x

b-hadron lifetime ratios and width differences: theory

Review by Tarantino in WG 3

$$\Gamma_{H_q} \sim \mathrm{Im}\langle H_q|\mathcal{T}|H_q\rangle \qquad \Delta\Gamma_q \sim \mathrm{Im}\langle \bar{B}_q|\mathcal{T}|B_q\rangle$$

$$\mathcal{T} = i\int d^4x\, T\left\{H_{eff}^{\Delta B=1}(x)H_{eff}^{\Delta B=1}(0)\right\}$$

$m_b \gg \lambda_{QCD}$ allows short distance expansion in $\alpha_s(m_b)$ and $1/m_b$

Lifetime ratios and width differences differ from 1 and 0 at order $1/m_b^3$, when spectator effects appear

Lifetime ratios

- $O(\alpha_s)$ (Beneke et al, Franco et al '02)
- $\star\, O(1/m_b^4)$ estimated (Gabbiani et al '04)
- $O(\alpha_s)$ penguins neglected

Width differences

- $O(\alpha_s)$ (Beneke et al, Ciuchini et al '03)
- $O(1/m_b^4)$ estimated (Beneke et al '96)
- $\star\, O(1/m_b^5)$ in progress (Lenz et al)

Lifetime ratios

- $O(1/m_b^3)$, $\Delta B{=}0$ matrix elements computed in quenched approximation for mesons (Di Pierro et al '98, APE '01) and baryons (Di Pierro et al '99)
- for mesons also with sum rules (Baek et al '98)
- agreement less good for color suppressed matrix elements
- NLO corrections can be large, as are $O(1/m_b^4)$ for $\tau(\Lambda_b)/\tau(B_d)$

$\rightarrow$ $O(30{-}40\%)$ uncertainties in deviation from 1

- effect of neglected penguins on $\tau(\Lambda_b)/\tau(B_d)$?

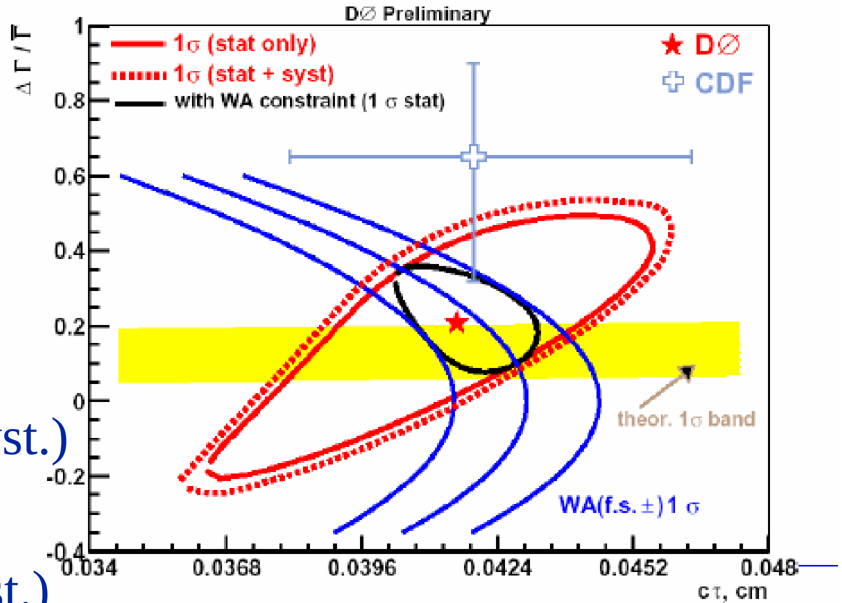
Width differences

- $O(1/m_b^3)$, $\Delta B{=}2$ matrix elements computed in quenched approximation (Gimenez et al '00, Hi-KEK '00, APE '01-'02) and with $N_f = 2$ (JLQCD '01-'03)
- results are consistent
- NLO corrections of order -35%
- estimated $1/m_b^4$ corrections further reduce LO result

$\rightarrow$ $O(30{-}40\%)$ uncertainties in deviation from 0

Friends of B_s Mixing: recent lifetimes progress

Abbott



$\Delta\Gamma_s/\Gamma_s$: new D0 measurement consistent with predictions

- New DØ result

  $\Delta\Gamma_s/\Gamma_s=0.21\ {+0.33}{-0.45}$(stat.+syst.)

- Constrain τ_{Bs}=1.39 ps

  $\Delta\Gamma_s/\Gamma_s=0.23{+0.16}{-0.17}$(stat.+syst.)

Tarantino

HFAG measurements

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.081 \pm 0.015, \quad \frac{\tau(B_s)}{\tau(B_d)} = 0.939 \pm 0.044, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.803 \pm 0.047$$

NLO+ $O(1/m_b^4)$	1.06(2)	1.00(1)	0.88(5)

Predictions

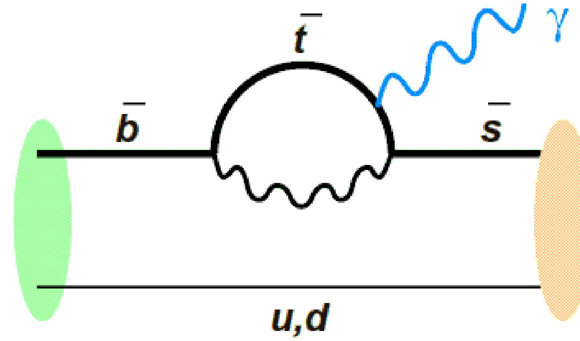
Recent predictions and measurements exhibit no serious “lifetime puzzle”

Radiative Penguin

Nishida

Radiative B decays : penguin diagram

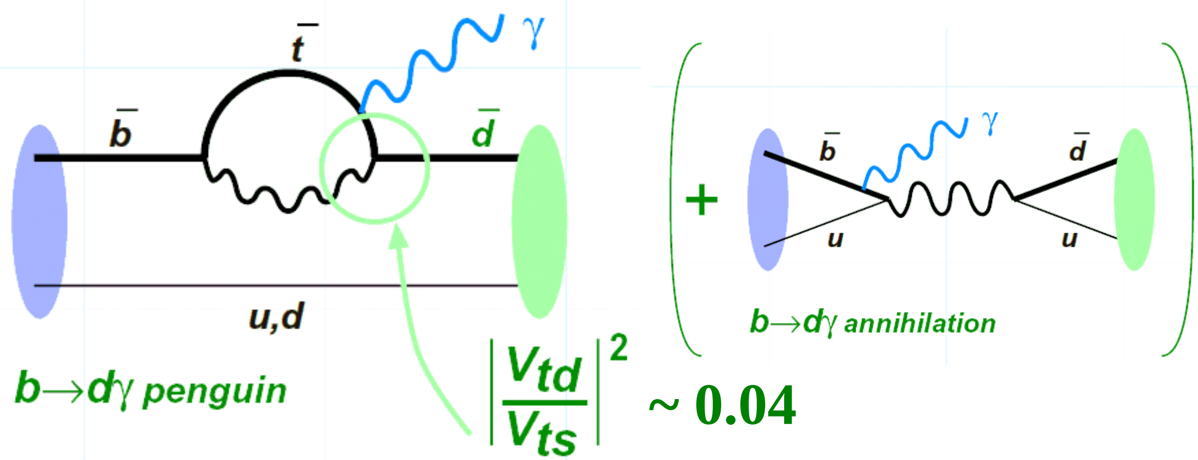
→ **Sensitive to New Physics**



b→sγ penguin

b → sγ process has been studied.
- **Branching fraction.**
- **Charge and isospin asymmetry.**
- **Mixing induced CP asymmtery.**

But, **b → dγ is not observed yet.**
- **suppressed by $|V_{td} / V_{ts}|^2$ in SM.**
- **Search for B→ργ, ω γ has been done.**



Search for $B \to \rho\gamma$, $B \to \omega\gamma$

Nishida

Search for $B^+ \to \rho^+ \gamma$,
$B^0 \to \rho^0 \gamma$, $B^0 \to \omega \gamma$

Isospin relation

$\mathcal{B}(B \to (\rho,\omega)\gamma)$

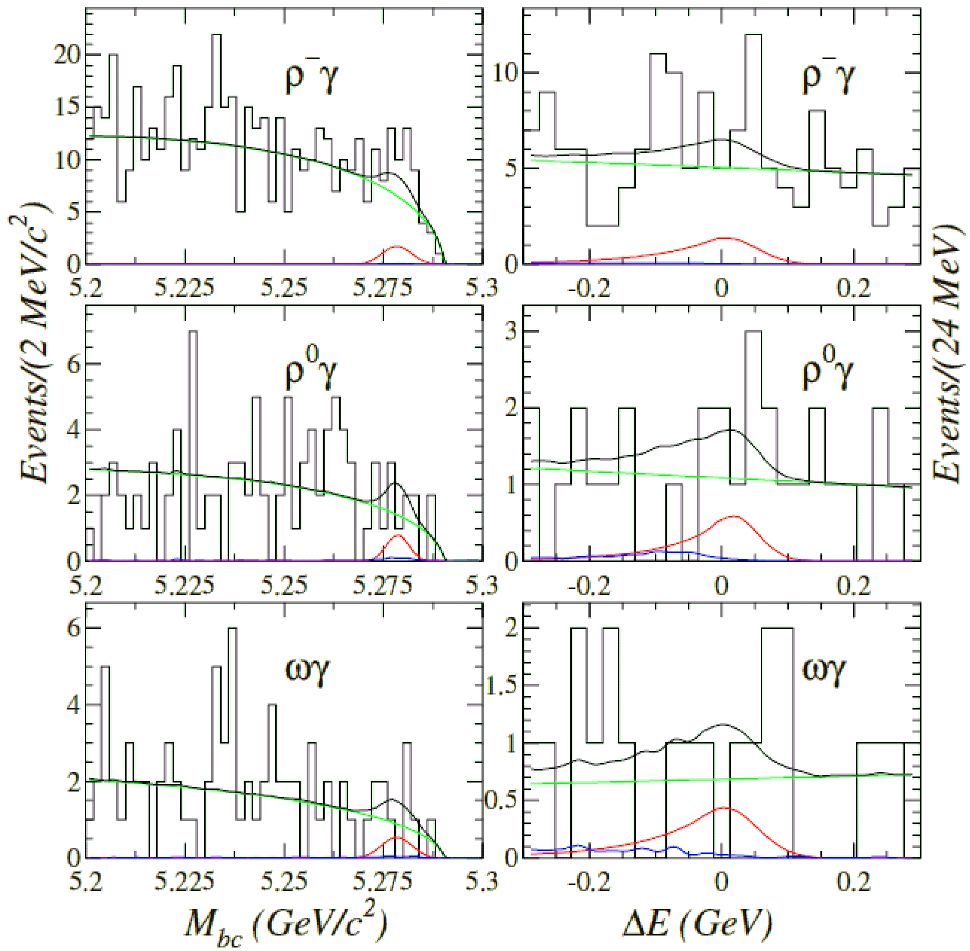
$\equiv \mathcal{B}(B^+ \to \rho^+ \gamma)$

$= 2(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to \rho^0 \gamma)$

$= 2(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to \omega\gamma)$

Analysis

- **Severe continuum background.**
- **$b \to s\gamma$ (esp. $B \to K^*\gamma$) background.**
- **Non-negligible BB background.**



Simultaneous fit to 3 modes (+$B \to K^*\gamma$)

SM prediction: $\mathcal{B}(B \to (\rho,\omega)\gamma) = (0.9\text{-}1.8) \times 10^{-6}$

$b \rightarrow d\,\gamma$ Branching Fractions: Exclusive

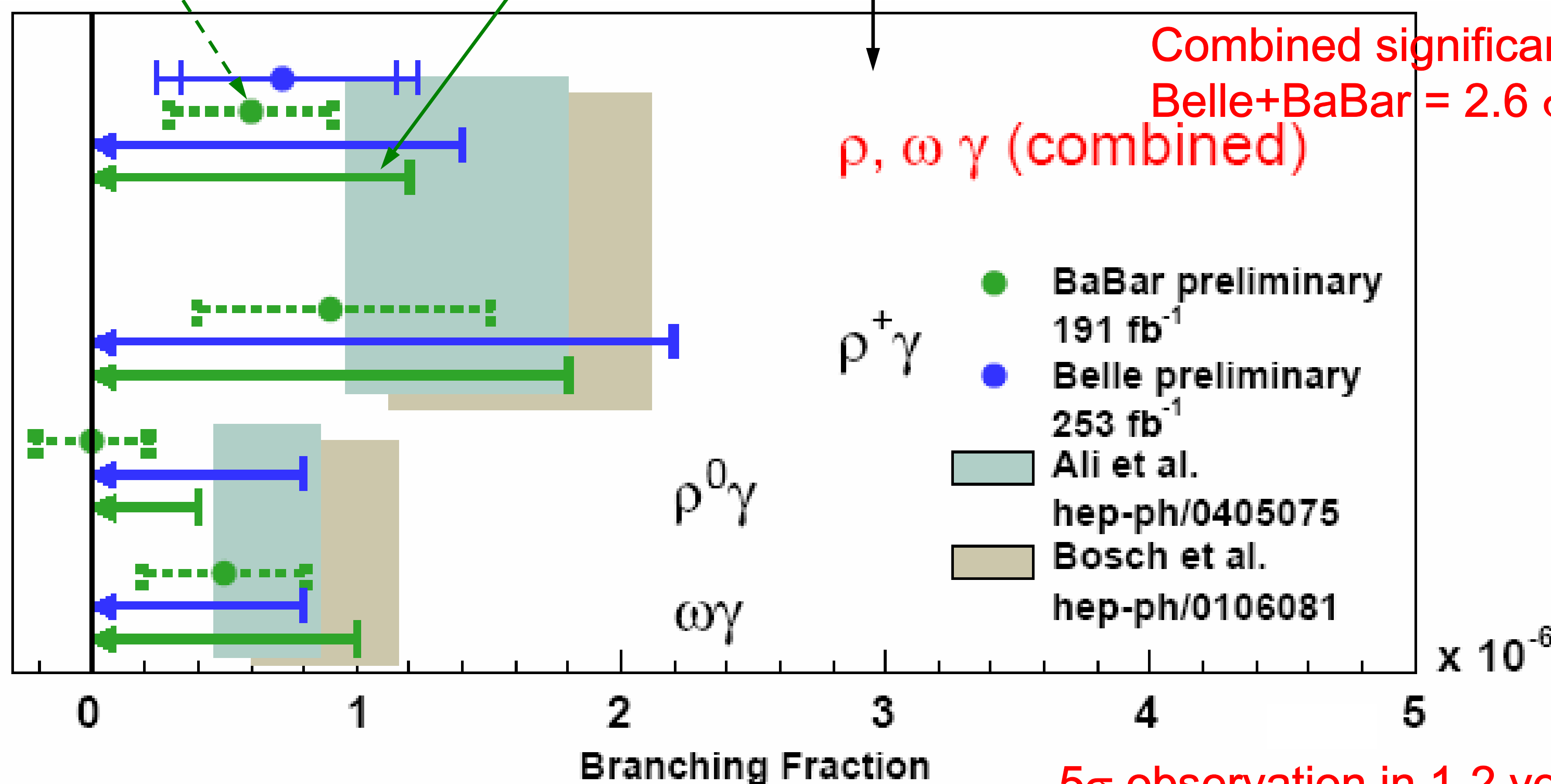
Nishida

$$\bar{\mathcal{B}}[B \to (\rho,\omega)\,\gamma] \equiv \frac{1}{2}\left\{\mathcal{B}(B^+ \to \rho^+\gamma) + \frac{\tau_{B^+}}{\tau_{B^0}}\left[\mathcal{B}(B_d^0 \to \rho^0\gamma) + \mathcal{B}(B_d^0 \to \omega\gamma)\right]\right\}$$

central value

90% C.L. upper limit

Combined significance
Belle+BaBar = 2.6 σ



5σ observation in 1-2 years

$|V_{td}/V_{ts}|$ from $\mathcal{B}(B \to \rho\gamma)/\mathcal{B}(B \to K^*\gamma)$

(talk by S. Bosch)

Bosch

The ρ^0/K^{*0} modes are theoretically the cleanest.
The ratio of their CP-averaged branching fractions reads

$$R_0 \equiv \frac{\mathcal{B}(B^0 \to \rho^0\gamma) + \mathcal{B}(\bar{B}^0 \to \rho^0\gamma)}{\mathcal{B}(B^0 \to K^{*0}\gamma) + \mathcal{B}(\bar{B} \to \bar{K}^{*0}\gamma)} = \frac{K}{2\xi^2}\left|\frac{V_{td}}{V_{ts}}\right|^2 (1+\Delta),$$

where

$K = 1.023$ — kinematic factor.
ξ — ratio of heavy-to-light formfactors ($\xi \to 1$ when $m_d \to m_s$).

"SU(3) limit"

Δ — subleading contributions:

(i) weak annihilation (suppression by $C_1 + \frac{1}{3}C_2 \simeq -0.2$ and Λ/m_b)

(ii) $(\text{penguin})_c - (\text{penguin})_u$ (suppression by $m_c^2/m_b^2 \simeq 0.1$)

Δ depends on the CKM parameters. In the domain of interest for the SM ($0.3 < \sqrt{\bar{\rho}^2 + \bar{\eta}^2} < 0.5$, $\frac{\pi}{4} < \gamma < \frac{\pi}{2}$), the CKM factor in Δ becomes a suppression factor ~ 0.2. Consequently, $|\Delta| < 0.04$ $\Rightarrow$ Uncertainties in Δ have little effect on the determination of $|V_{td}/V_{ts}|$.

What is the value of ξ ?

$B(B \to \rho\gamma)/B(B \to K^*\gamma)$

Bosch

- Ratio R_0 of neutral branching fractions $\sim \xi = F_{K^*}/F_\rho$
- R_0 theoretically clean
- $R_t = 0.82 \frac{\xi}{1.3}\sqrt{\frac{R_0}{0.01}}$ within $\pm 3\%$

$\xi_{\mathrm{LCSR}} = 1.25 \pm 0.20$

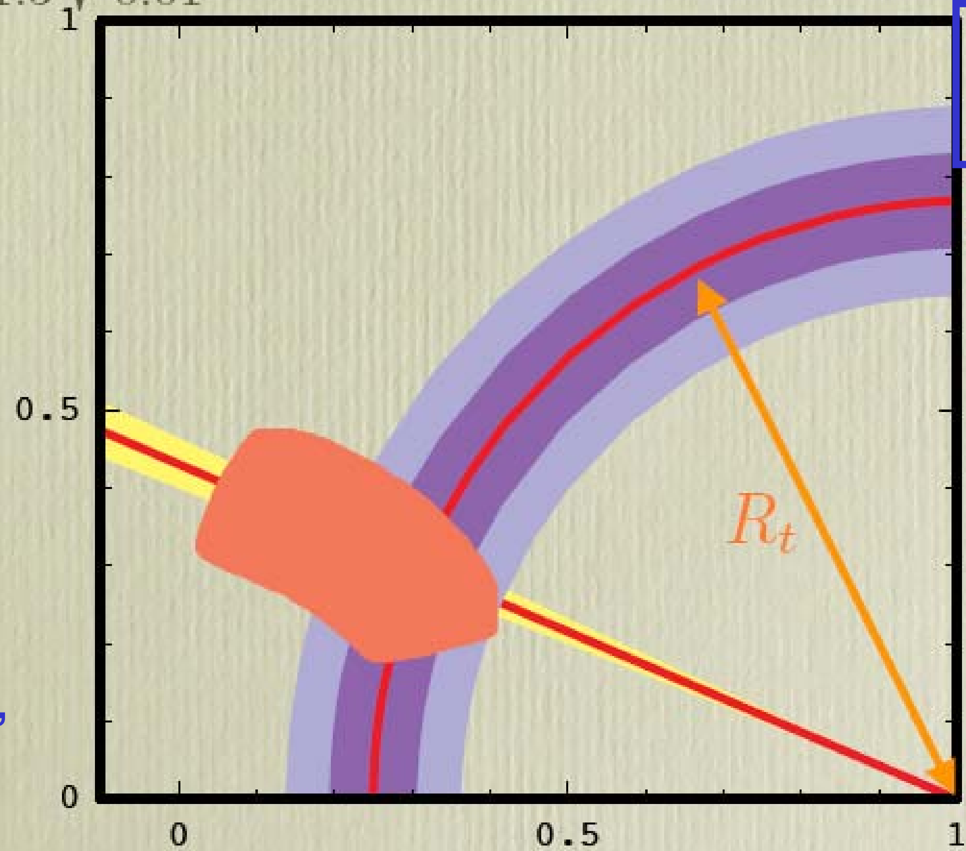
Ball, Zwicky

$\xi_{\mathrm{LQCD}} = 1.1 \pm 0.1$

Becirevic, Mescia

$\xi = 1.2 \pm 0.1$

CKM2005 round table



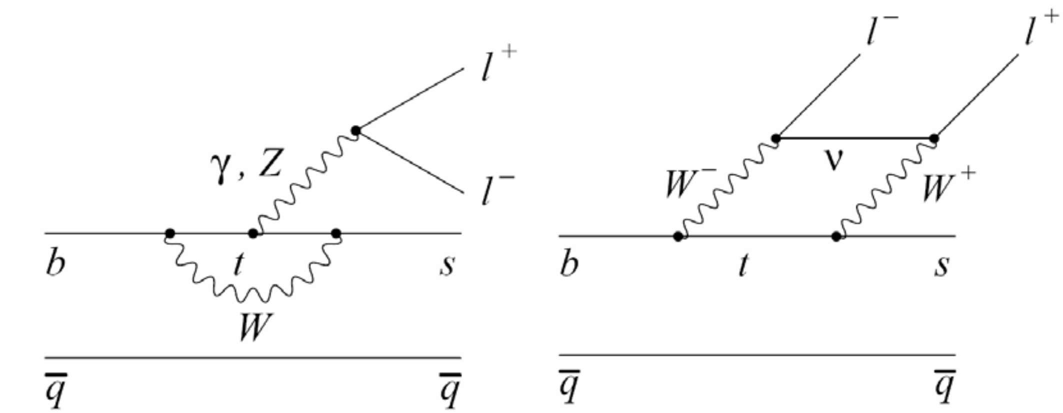
vary ξ

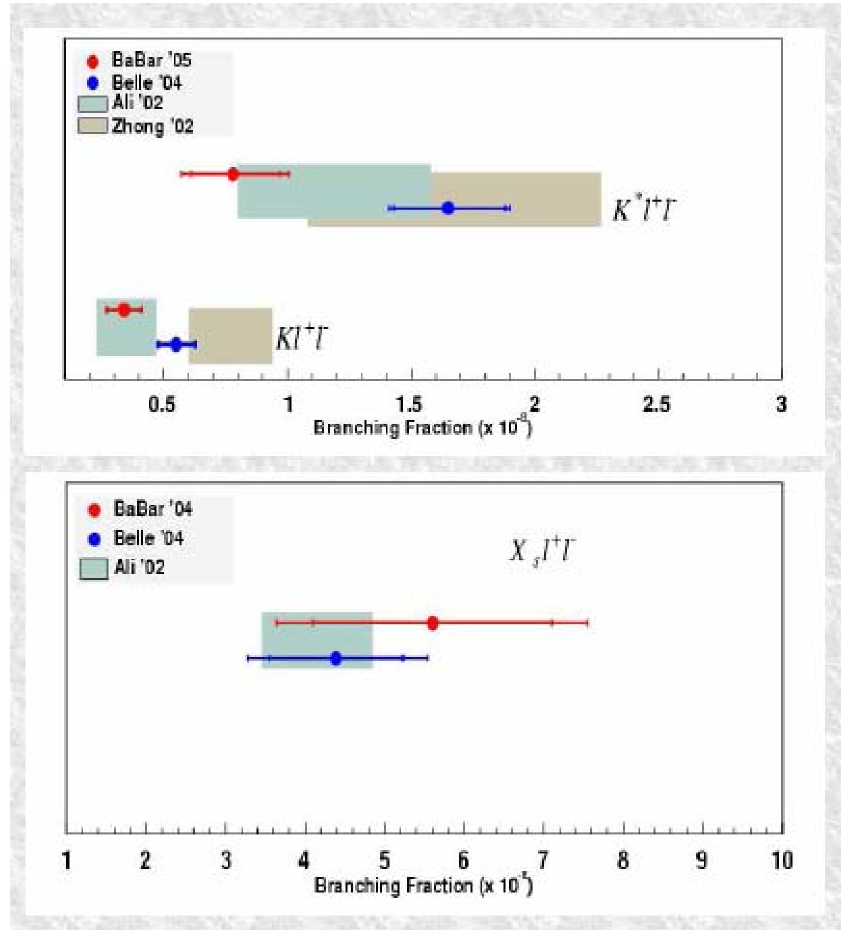
Beneke, Feldmann, Seidel
Ali, Parkhomenko, Lunghi
SWB, Buchalla

Inclusive ratio $b \to d\gamma / b \to s\gamma$ better theory errors for V_{td}/V_{ts}, but might need SuperB factory

Other Penguin Decays

Hollar, Feldmann





B →K(*)ll, s ll branching fractions measured by B factories and theory error already dominant

More will be learned from distributions and asymmetries

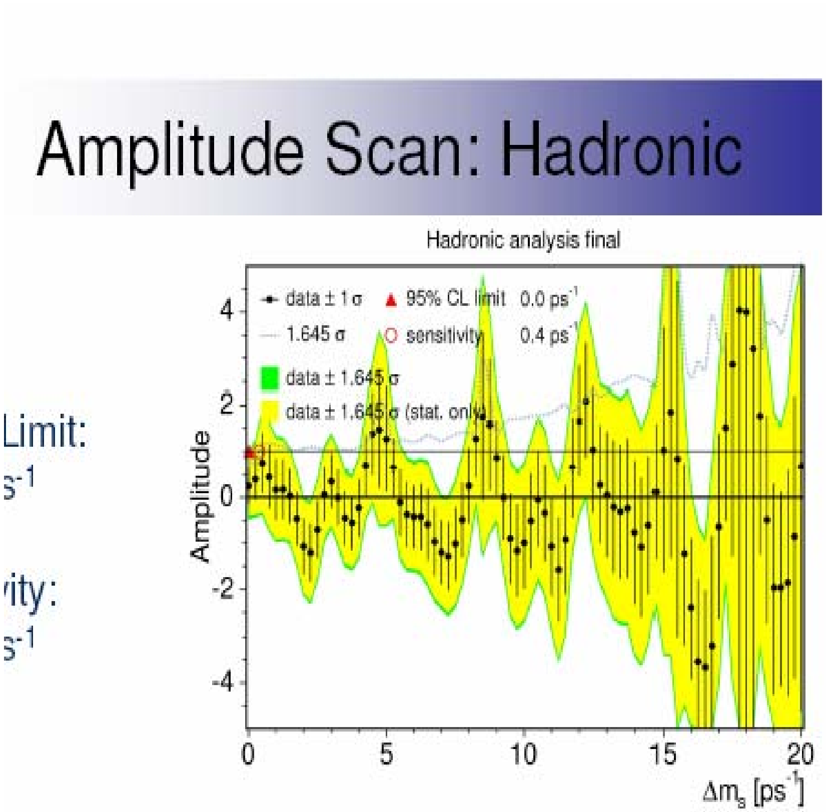
B→ π ***ll*** has possibility for observation at B factories (not background limited) ρ***ll*** much harder

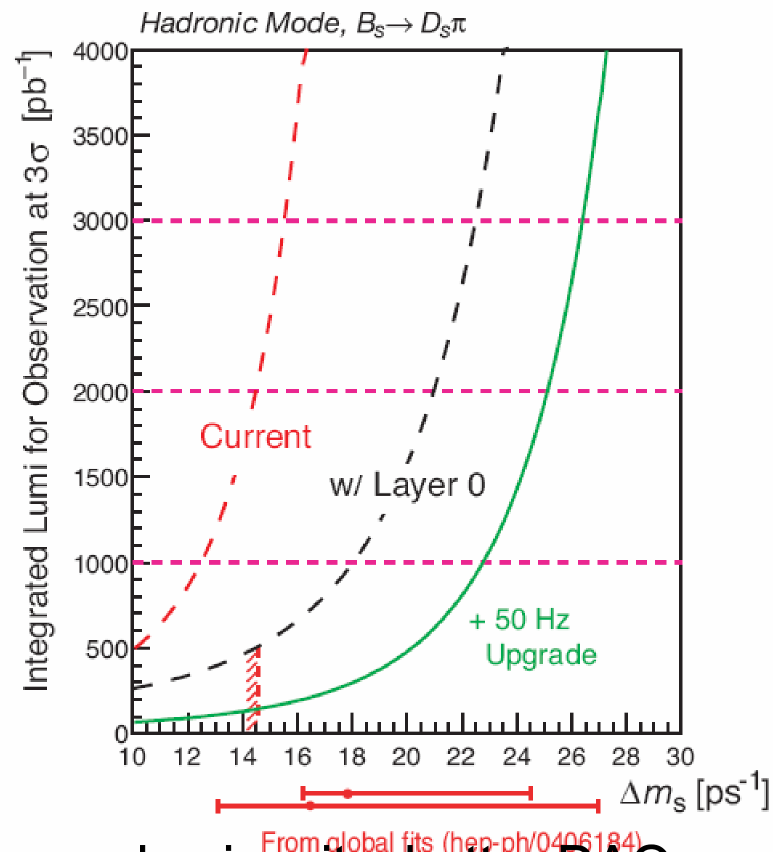
Challenges

A list of future challenges to the Workshop participants.

Challenges

To the Tevatron: Now that you have a good shovel, break substantial new ground with it for Δm_s constraints.





Upgrades, better tagging, better vertexing, more luminosity, better DAQ, Whatever it takes! The flavor physics community is cheering you on!

Challenges

To the Lattice community: Raise the “letter grade” above “C” level for f_B, B_B et al., so that the impact of future Tevatron results is maximized.

$f_{B_s} = 260 \pm 7 \pm 28 \text{ MeV [HPQCD]}$	C
$\hat{B}_{B_s} = 1.31 \pm 0.10 \text{ [JLQCD; Lattice2003]}$	D^+/C^-
$\xi_B = 1.022 \pm 0.018 \text{ [JLQCD; Lattice2003]}$	D^+
$\xi = 1.25 \pm 0.10 \text{ [Lattice2003]}$	D

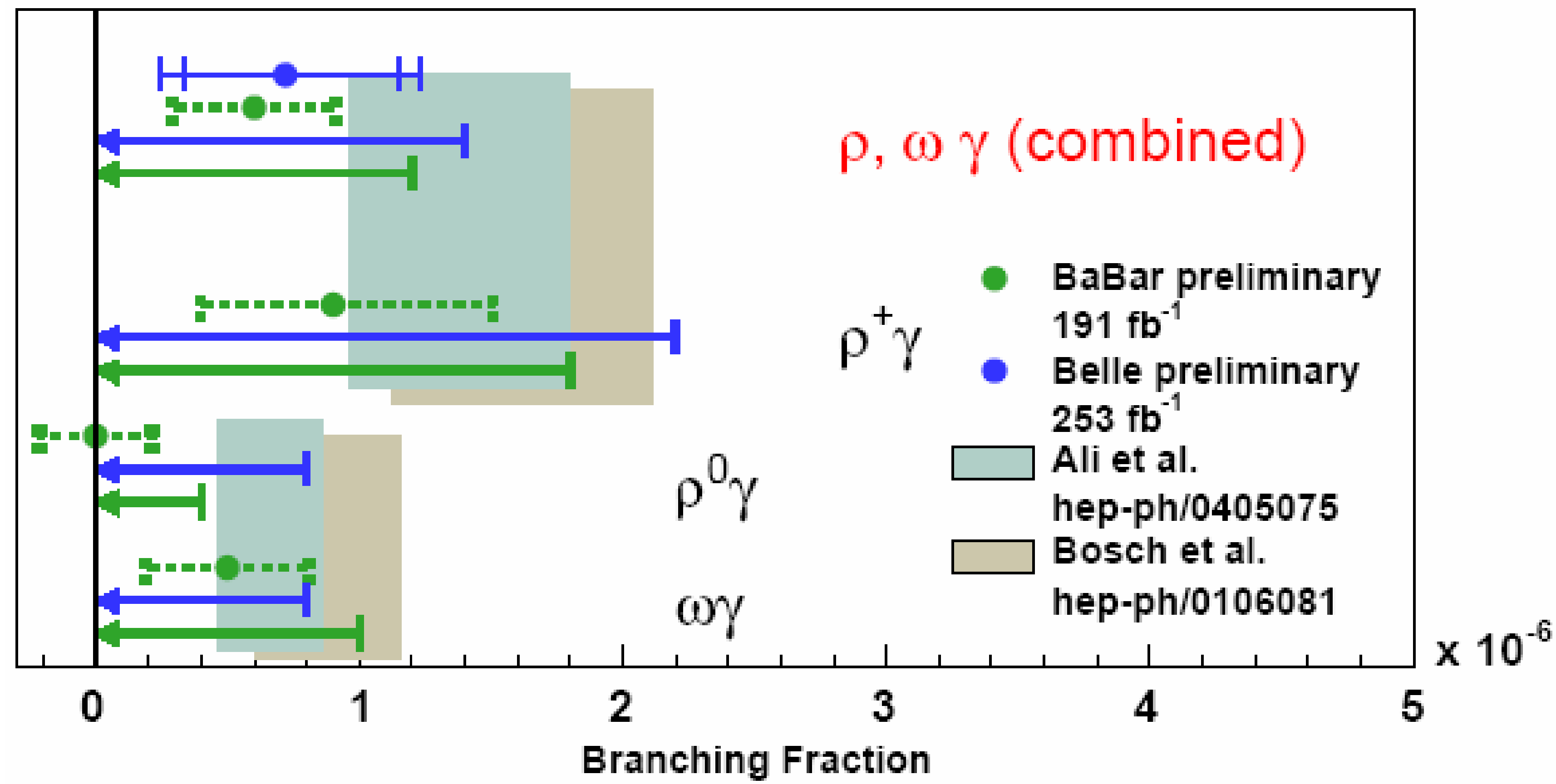
Andreas Kronfeld

↑ My grade in Claude’s scheme

To CLEO-c et al.: Continue to keep the lattice community honest!

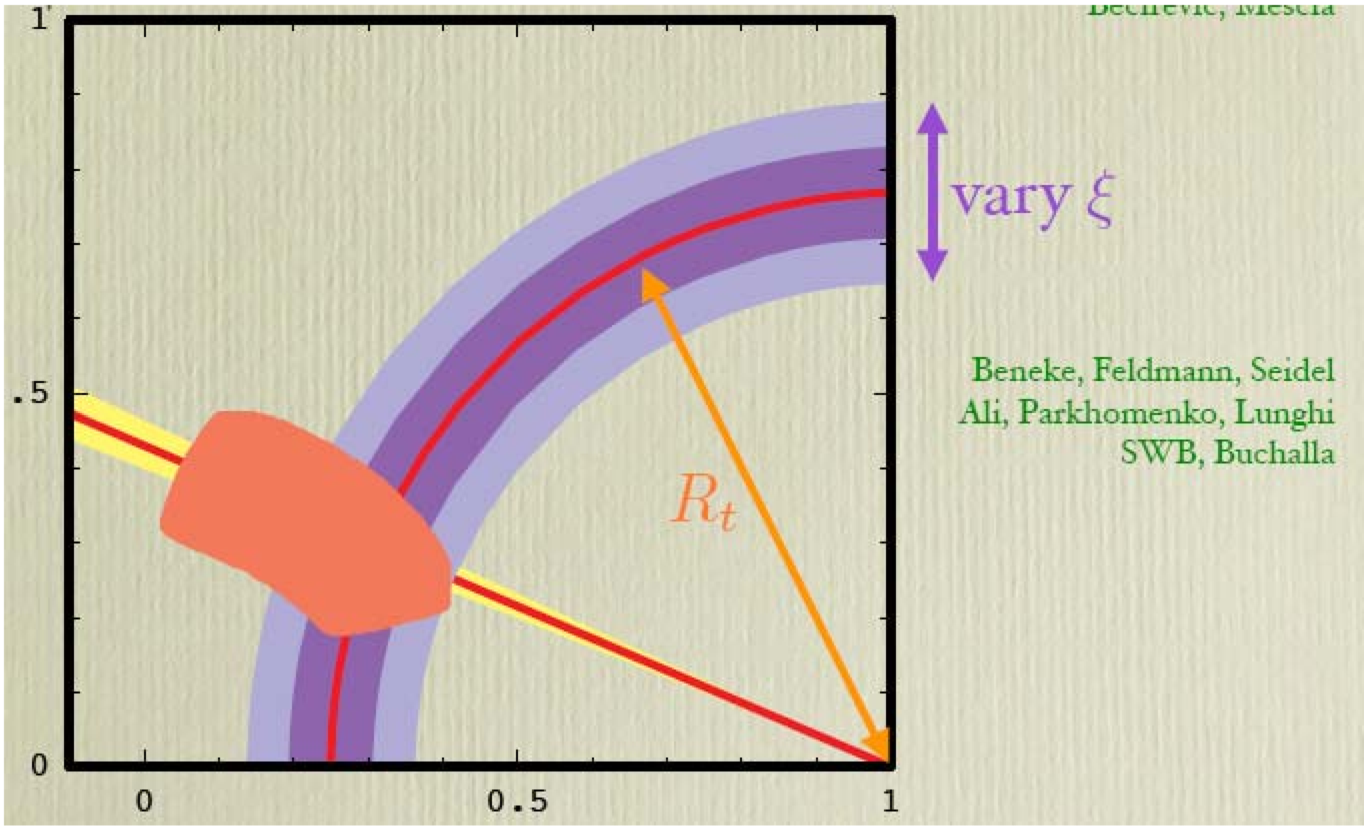
Challenges

To the B factories: Measure a clear signal for $B \to \rho\gamma$ or drive lower limit off the (CKM) map!



Challenges

To the heavy quark theory community: Improve and/or realistically bound the impact of penguins on V_{td}/V_{ts} et al. The measurements are there and ready to be exploited now!



Challenges

To the Kaon physics community: Keep your future projects alive (and Andrzej out of retirement). The small theory errors mean these may ultimately be the best attainable CKM constraints on V_{td} and η.