New Physics in B_s Mixing

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What can we learn from ΔM_s?

Quite a few papers already. . .

- M. Ciuchini and L. Silvestrini, hep-ph/0603114
- M. Endo and S. Mishima, hep-ph/0603251
- M. Blanke, A.J. Buras, D. Guadagnoli and C. Tarantino, hep-ph/0604057
- Z. Ligeti, M. Papucci and G. Perez, arXiv:hep-ph/0604112
- J. Foster, K.I. Okumura and L. Roszkowski, hep-ph/0604121
- P. Ball and R. Fleischer, arXiv:hep-ph/0604249
- S. Khalil, arXiv:hep-ph/0605021
- Y. Grossman, Y. Nir and G. Raz, arXiv:hep-ph/0605028
- A. Datta, arXiv:hep-ph/0605039

What can we learn from ΔM_s?

- standard approach: determine $|V_{td}/V_{ts}|$ from $\Delta M_d/\Delta M_s$ with "small" theoretical uncertainty, test CKM picture by comparing with UT
- our approach: take V_{tq} from UT and constrain new physics (NP) from ΔM_d and ΔM_s

Focus of this talk:

model-independent analysis of NP contributions

including

- a critical discussion of (hadronic and CKM) input parameters
- a possible 2010 scenario

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Note: this product is free of MFV!

Generic Parametrisation of New Physics

$\Delta M_q = 2|M_{12}^q|$ with

- $M_{12}^q = M_{12}^{q,\mathrm{SM}}(1 + \kappa_q e^{i\sigma_q})$
- $\kappa_q > 0$: NP amplitude
- σ_q: new CP-violating phase

Deviation from SM measured by

$$\rho_q \equiv \left|\frac{\Delta M_q}{\Delta M_q^{\mathrm{SM}}}\right| = (1 + 2\kappa_q \cos\sigma_q + \kappa_q^2)^{1/2}$$

Q: What is the SM prediction for ΔM_q?

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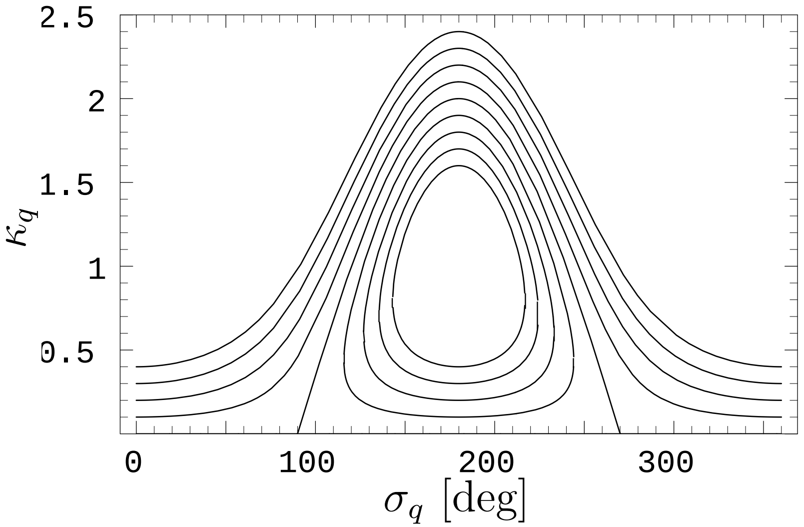
Lines of ρ_q =const.:



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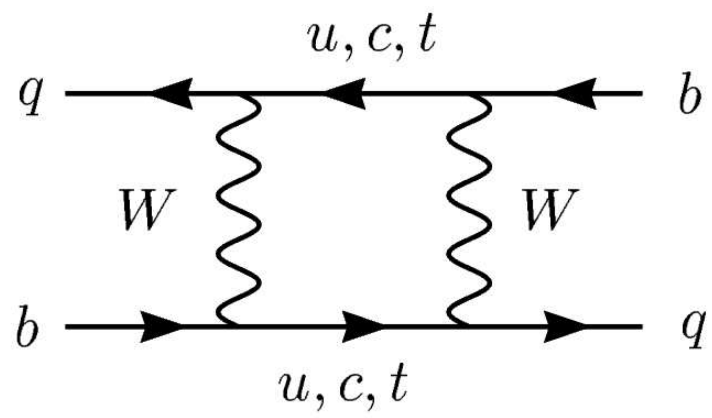
Q: What is the SM prediction for ΔM_q?

ΔM_q in the SM

$$M_{12}^{\rm SM} =$$



$$= \frac{G_{\rm F}^2 M_W^2}{12\pi^2} M_{B_q} \hat{\eta}^B \hat{B}_{B_q} f_{B_q}^2 (V_{tq}^* V_{tb})^2 S_0(x_t)$$

- $S_0(x_t = m_t^2/M_W^2) = 2.35 \pm 0.06$: Inami-Lim function
- $\hat{\eta}^B = 0.552$: NLO QCD correction (Buras/Jamin/Weiss '90)
- $\hat{B}_{B_q} f_{B_q}^2 \propto \langle B_q^0 | (\bar{q}b)_{V-A} (\bar{q}b)_{V-A} | \bar{B}_q^0 \rangle$: hadronic matrix element, from lattice
- $V_{tq}^* V_{tb}$: from tree-level processes

CKM Input: tree-level quantities

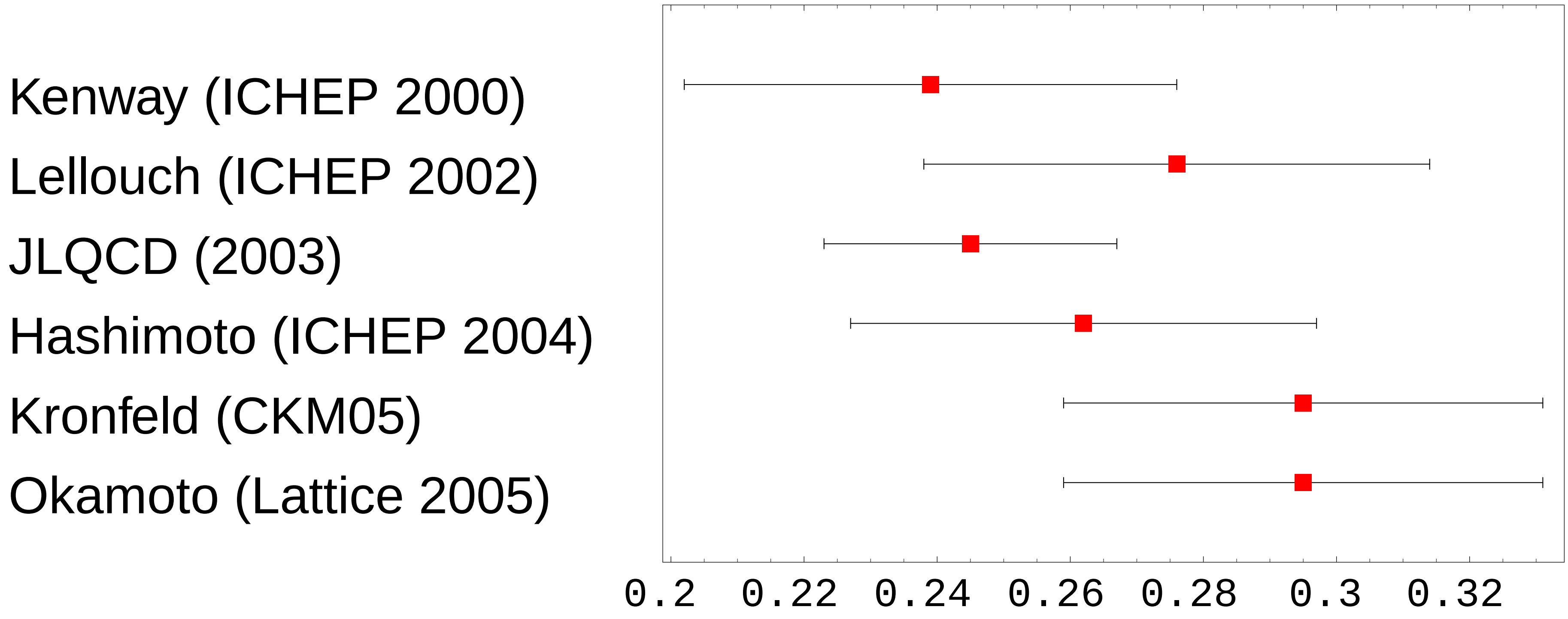
Express all CKM factors in terms of λ, $|V_{ub}|$, $|V_{cb}|$ and γ:

$$
\begin{aligned}
|V_{td}^* V_{tb}|^2 &= |V_{cb}|^2 \lambda^2 (1 - 2R_b \cos\gamma + R_b^2) \\
\text{with} \quad R_b &\equiv \left(1 - \frac{\lambda^2}{2}\right) \frac{1}{\lambda} \left|\frac{V_{ub}}{V_{cb}}\right| \\
|V_{ts}^* V_{tb}|^2 &= |V_{cb}|^2 \left\{1 - (1 - 2R_b \cos\gamma)\lambda^2 + O(\lambda^4)\right\}
\end{aligned}
$$

- $\gamma = (65 \pm 20)^\circ$ from $B \to D^{(*)} K^{(*)}$
- $R_b = 0.45 \pm 0.03$ with $|V_{ub}|$ from inclusive decays
- $R_b = 0.39 \pm 0.06$ with $|V_{ub}|$ from exclusive decays
- $|V_{td}^* V_{tb}| = \ (8.6 \pm 1.5) \cdot 10^{-3}$: very sensitive to γ!
- $|V_{ts}^* V_{tb}| = (41.3 \pm 0.7) \cdot 10^{-3}$

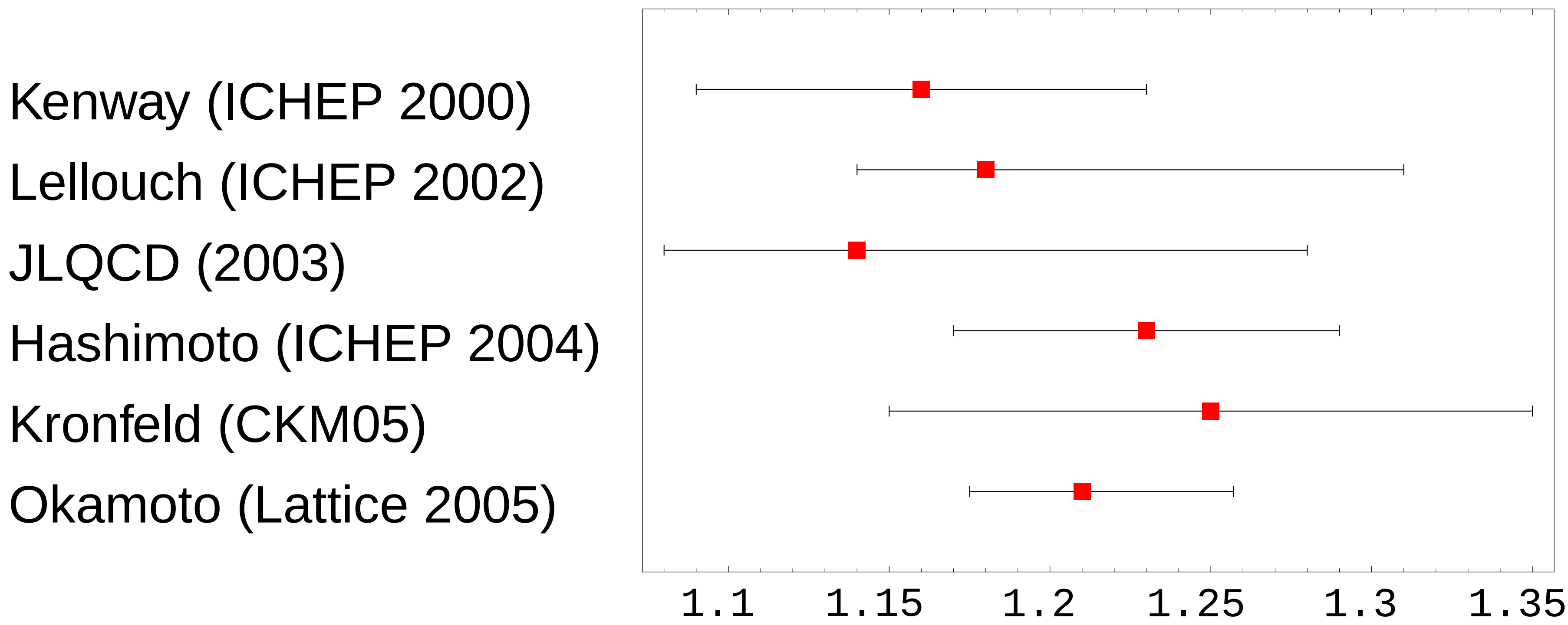
Hadronic Matrix Elements from Lattice

$$f_{B_s}\hat{B}_{B_s}^{1/2}$$



Hadronic Matrix Elements from Lattice

$$\xi = \frac{f_{B_s} \hat{B}_{B_s}^{1/2}}{f_{B_d} \hat{B}_{B_d}^{1/2}}$$



Hadronic Matrix Elements from Lattice

Take (unquenched) JLQCD and (JL+HP)QCD results as 2006 benchmarks, (JL+HP)QCD as 2010 benchmark.

Open questions:

- validity of staggered fermion action (2005 HPQCD results for f_{B_q})
- error on combining HPQCD results for f_B and JLQCD results for $\hat{B}_B$? (Okamoto 2005)
- Wilson fermions at smaller m_q/m_s? (to reduce log effects of chiral extrapolation)
- non-perturbative renormalisation of staggered fermion results?
- ...

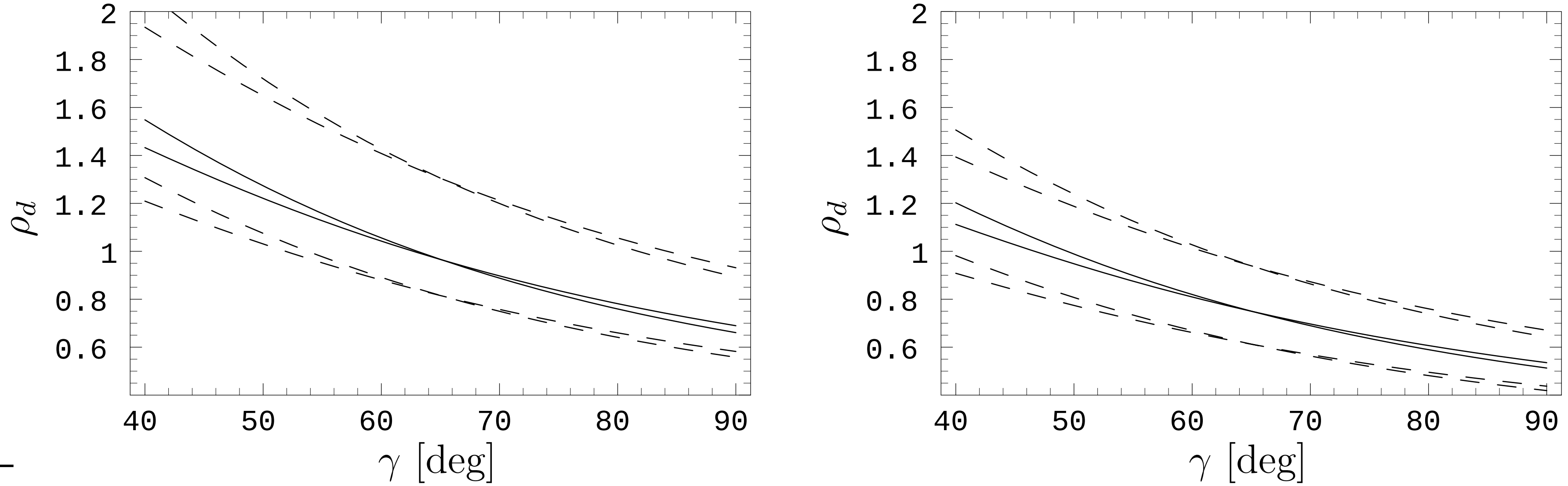
Predictions for ΔM_d^{SM}

$$\Delta M_d^{\mathrm{SM}}\big|_{\mathrm{JLQCD}} = \left[0.52 \pm 0.17(\gamma, R_b)^{-0.09}_{+0.13}(f_{B_d}\hat{B}_{B_d}^{1/2})\right]\ \mathrm{ps}^{-1}$$

$$\rho_d\big|_{\mathrm{JLQCD}} = 0.97 \pm 0.33(\gamma, R_b)^{-0.17}_{+0.26}(f_{B_d}\hat{B}_{B_d}^{1/2})$$

$$\Delta M_d^{\mathrm{SM}}\big|_{\mathrm{(HP+JL)QCD}} = \left[0.69 \pm 0.13(\gamma, R_b) \pm 0.08(f_{B_d}\hat{B}_{B_d}^{1/2})\right]\ \mathrm{ps}^{-1}$$

$$\rho_d\big|_{\mathrm{(HP+JL)QCD}} = 0.75 \pm 0.25(\gamma, R_b) \pm 0.16(f_{B_d}\hat{B}_{B_d}^{1/2})$$



Predictions for $\Delta M_s^{\rm SM}$

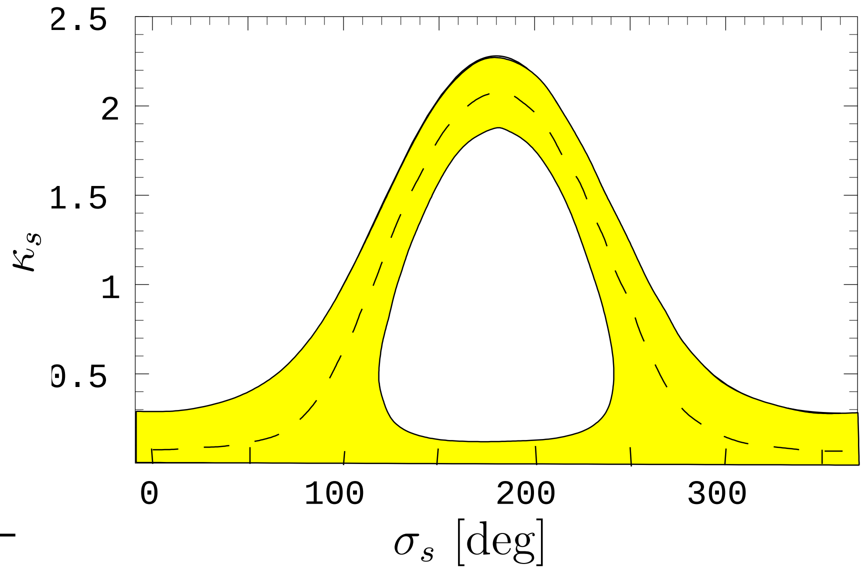
$$\Delta M_s^{\rm SM}\Big|_{\rm JLQCD} = (16.1 \pm 2.8)\,{\rm ps}^{-1}$$

$$\rho_s\Big|_{\rm JLQCD} = 1.08^{+0.03}_{-0.01}\text{(exp)} \pm 0.19\text{(th)}$$

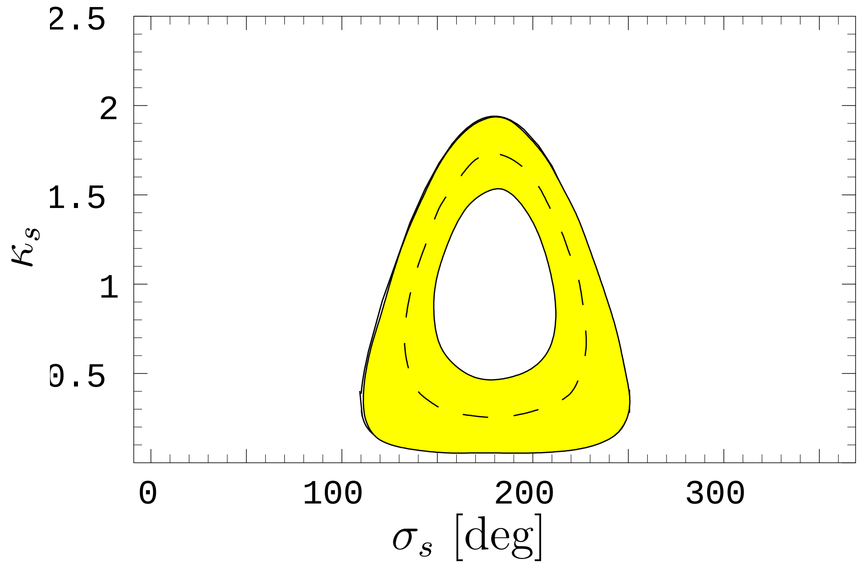
$$\Delta M_s^{\rm SM}\Big|_{\rm (HP+JL)QCD} = (23.4 \pm 3.8)\,{\rm ps}^{-1}$$

$$\rho_s\Big|_{\rm (HP+JL)QCD} = 0.74^{+0.02}_{-0.01}\text{(exp)} \pm 0.18\text{(th)} \quad 1.5\sigma!$$

JLQCD:



(HP+JL)QCD:



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Conclusion from this exercise:

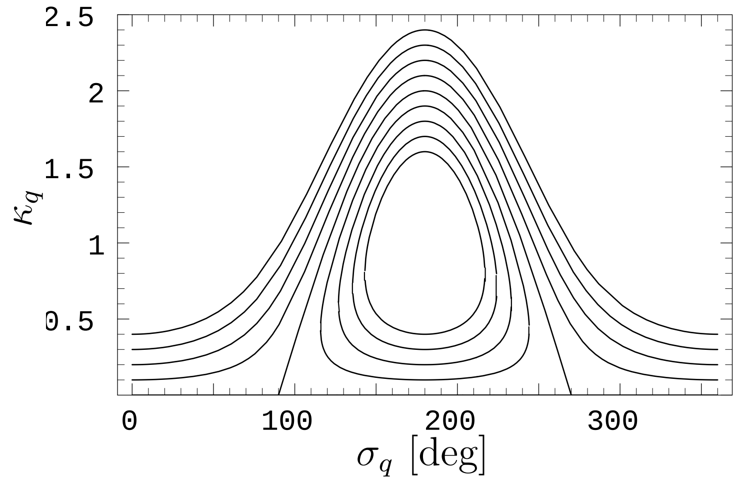
$\Delta M_q^{\rm SM}$ is *not* very well known!

Not even well enough to distinguish between $\rho_s < 1$ and > 1.

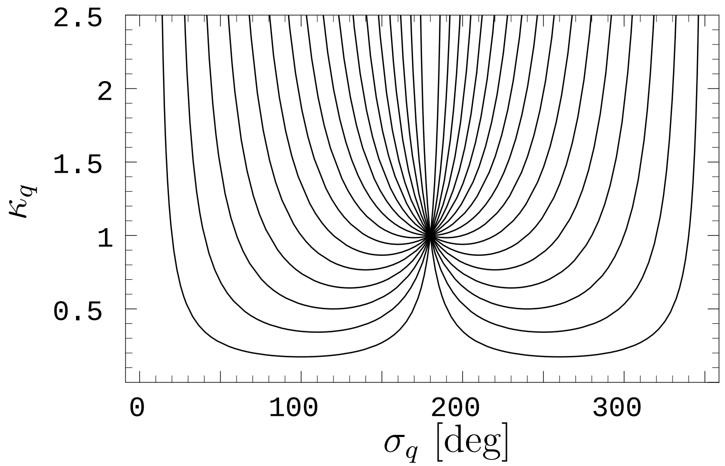
For better constraints, need mixing phase $\phi_q = \arg M_{12}^q$!

Constraints from ϕ_q

ρ_q =const.:

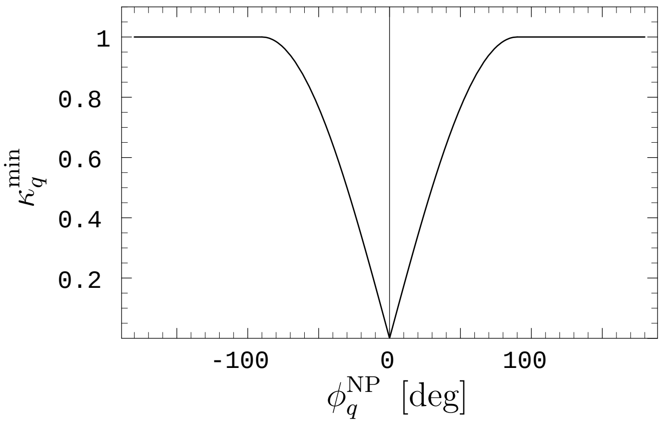


$\phi_q^{\rm NP}$ =const.:



$$\phi_q = \arg M_{12}^q = \phi_q^{\rm SM} + \phi_q^{\rm NP} \text{ with } \phi_d^{\rm SM} = 2\beta,\ \phi_s^{\rm SM} = -2\lambda^2 R_b \sin\gamma \approx 2^\circ$$

In addition, $\phi_q^{\rm NP} \neq 0$ implies a lower bound on κ_q:



Status of ϕ_d

$$b \to c\bar{c}s : \quad \sin\phi_d = \sin(2\beta + \phi_d^{\rm NP}) = 0.687 \pm 0.032$$

- central value down by 1σ in 2005 because of new Belle results

Relation to tree-level CKM parameters: $\sin\beta = \dfrac{R_b \sin\gamma}{\sqrt{1 - 2R_b\cos\gamma + R_b^2}}$

Depending on value of $|V_{ub}|$, get

$$\phi_d^{\rm NP}\Big|_{\rm incl} = -(10.1 \pm 4.6)^\circ\,, \qquad \phi_d^{\rm NP}\Big|_{\rm excl} = -(2.5 \pm 8.0)^\circ$$

- error of $\phi_d^{\rm NP}$ dominated by $|V_{ub}|$
- dependence on γ small
- no non-perturbative parameters involved*

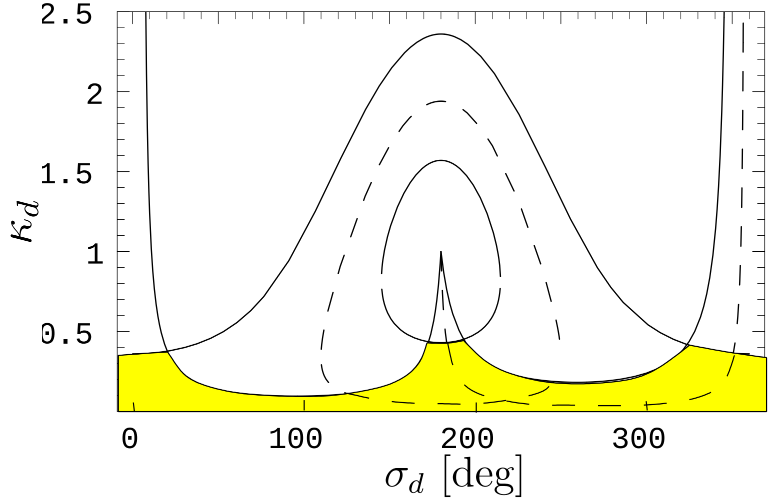
* in addition to $|V_{ub}|$ extraction and up to tiny $O(\lambda^2)$ effects

A possible 2010 scenario

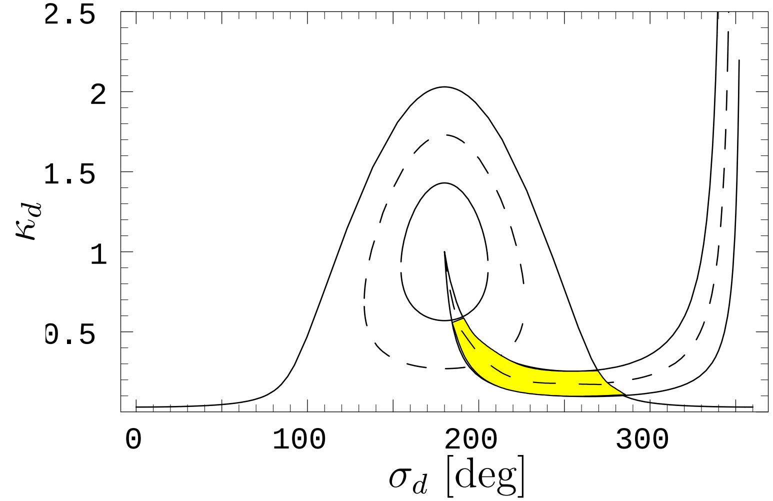
	2006 value	2010 value
$\lvert V_{cb}\rvert$	$(42.0 \pm 0.7) \cdot 10^{-3}$	$(42.0 \pm 0.7) \cdot 10^{-3}$
$\lvert V_{ub}\rvert$	$[(4.4 \pm 0.3) \vee (3.8 \pm 0.6)] \cdot 10^{-3}$	$(4.4 \pm 0.2) \cdot 10^{-3}$
γ	$(65 \pm 20)^\circ$	$(70 \pm 5)^\circ$
R_b	$[(0.45 \pm 0.03) \vee (0.39 \pm 0.06)]$	0.45 ± 0.02
R_t	0.91 ± 0.16	0.95 ± 0.04
$\lvert V_{td}^* V_{tb}\rvert$	$(8.6 \pm 1.5) \cdot 10^{-3}$	$(8.9 \pm 0.4) \cdot 10^{-3}$
$\lvert V_{ts}^* V_{tb}\rvert$	$(41.3 \pm 0.7) \cdot 10^{-3}$	$(41.3 \pm 0.7) \cdot 10^{-3}$
β	$[(26.7 \pm 1.9)^\circ \vee (22.9 \pm 3.8)^\circ]$	$(26.6 \pm 1.2)^\circ$
$f_{B_d} \hat{B}_{B_d}^{1/2}$	JLQCD $\vee$ (HP+JL)QCD	(HP+JL)QCD
$f_{B_s} \hat{B}_{B_s}^{1/2}$	JLQCD $\vee$ (HP+JL)QCD	(HP+JL)QCD
ξ	$\left[\left(1.14 \pm 0.06^{+0.13}_{-0}\right) \vee \left(1.210^{+0.047}_{-0.035}\right)\right]$	$1.210^{+0.047}_{-0.035}$

ΔM_d and ϕ_d – 2006 and 2010

JLQCD:



(HP+JL)QCD:



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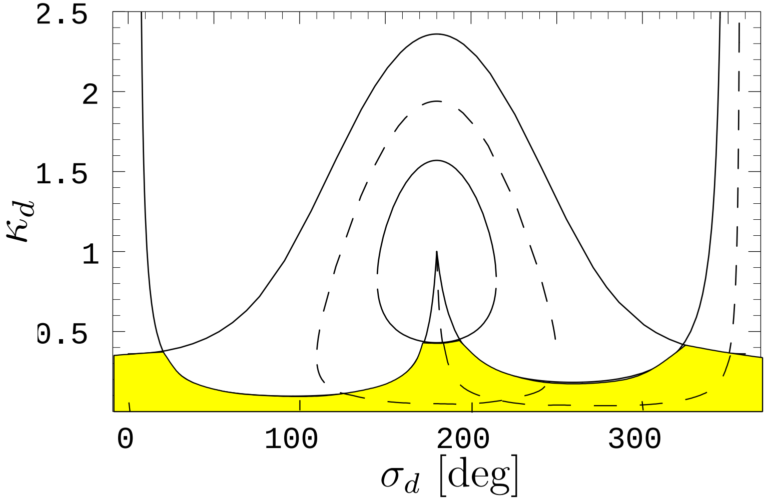
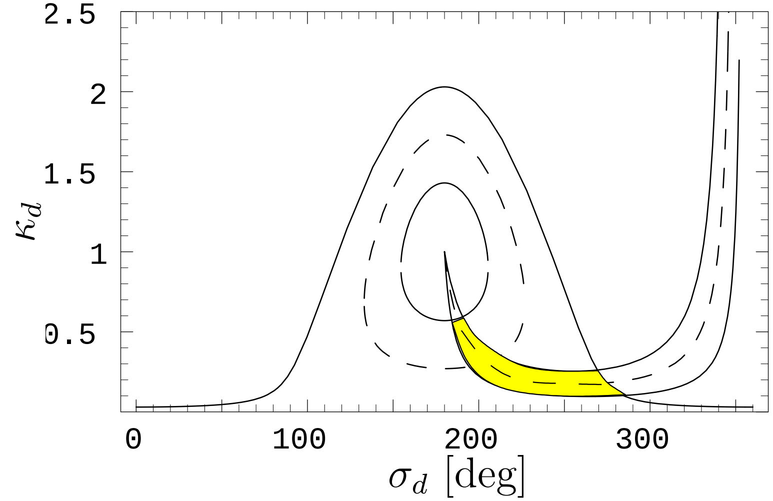
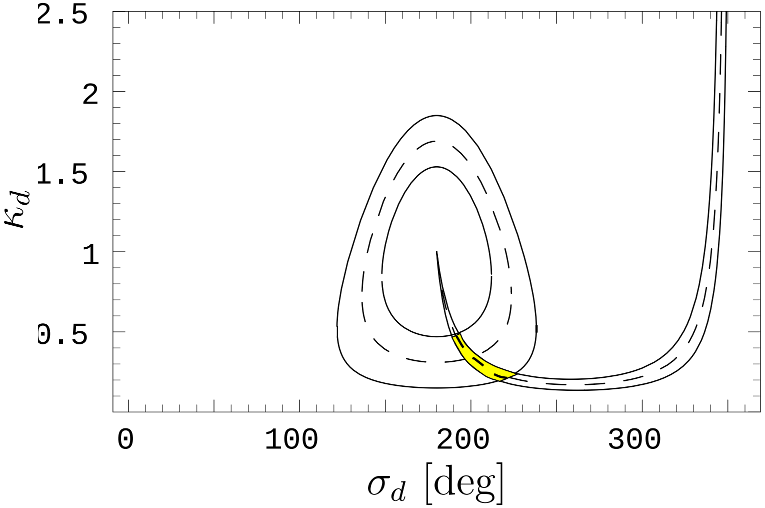


(HP+JL)QCD:



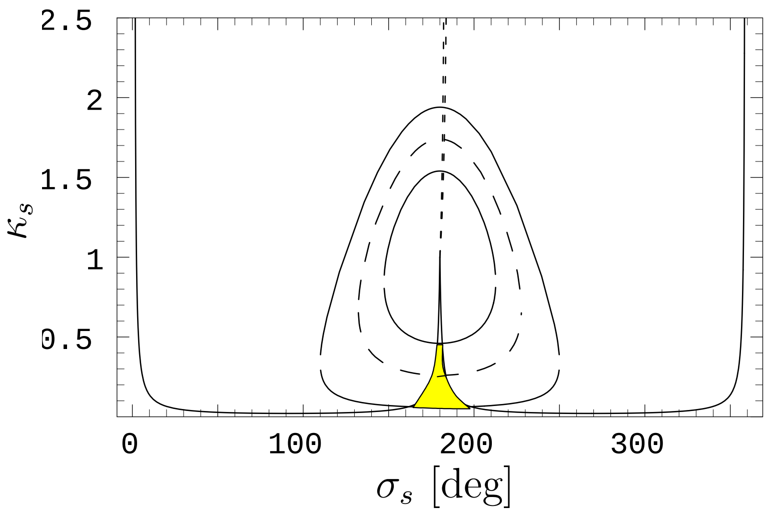
And in 2010:



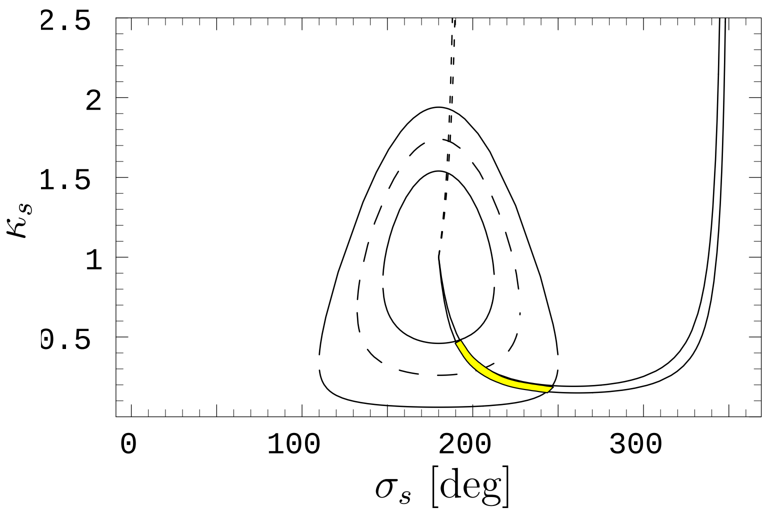
Status of ϕ_s

- no meaninful constraints yet*
- wait for $\Delta\Gamma_s$ and more precise $A_{\rm SL}$ from Tevatron and $B_s \to J/\psi, \phi\phi$ at LHC

* except for Grossman/Nir/Raz, hep-ph/0604028, who exclude large positive $\sin\phi_s$ from the D0 measurement of $A_{\rm SL}$



$\phi_s^{\rm SM}$ and (HP+JL)QCD values



$\phi_s^{\rm NP} = -(10 \pm 3)^\circ$ and (HP+JL)QCD values

Constraints on Specific NP Models: Z'

- assume absence of Z–Z' mixing, i.e. flavour-diagonal Z couplings
- assume flavour non-diagonal Z' couplings only to q_L
- constrain $\rho_L \exp(i\phi_L) \equiv (g' M_Z)/(g M_{Z'}) B^L_{sb}$ with B^L_{sb} being $\bar{s} Z' b$ coupling
- $\kappa_s < 2.5 \quad \longleftrightarrow \quad \rho_L < 2.6 \cdot 10^{-3}$
- can translate this into bound on Z' mass:

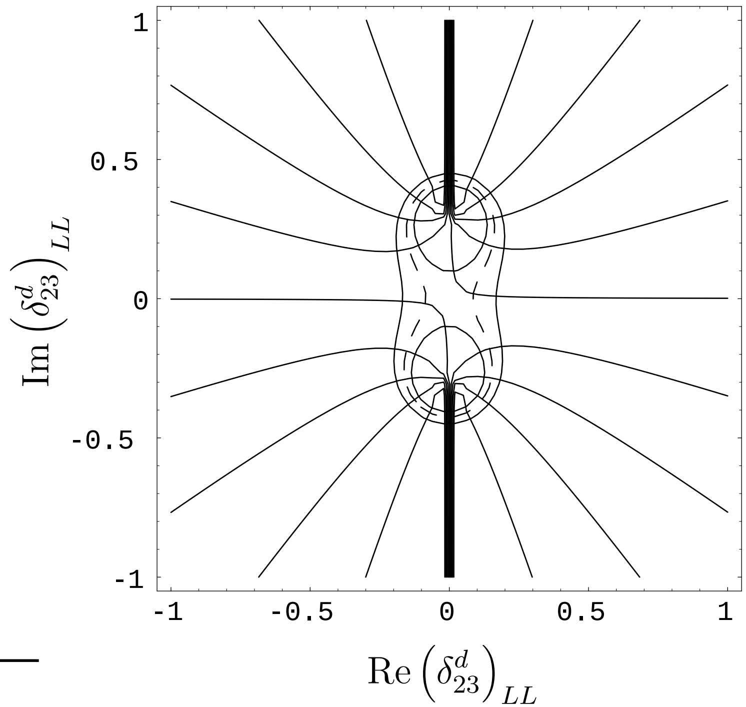
$$1.5\,\text{TeV} \left(\frac{g'}{g}\right) \left|\frac{B^L_{sb}}{V_{ts}}\right| < M_{Z'}$$

- should be interesting for direct searches!

MSSM (in MIA)

- MSSM (box diagram) contributions from charged Higgs, neutralinos, photinos, gluinos and charginos*
- for B_s mixing, only gluino contributions relevant
- full NLO analysis in preparation $\rightarrow$ Guadagnoli's talk

* also from double Higgs penguins, which are however only relevant for large $\tan\beta$



Constraints on $(\delta^d_{23})_{LL}$ insertion using JLQCD lattice data.
Open lines: constraints from a future measurement of ϕ_s.

Summary

- NP contributions to ΔM_q not very strongly constrained because of large hadronic (lattice) uncertainties and, for ΔM_d, the error on γ
- more decisive constraints from NP mixing phases: $\phi_d^{\rm NP} = -(10.1 \pm 4.6)^\circ$ for $|V_{ub}|$ from inclusive decays, which implies $\kappa_d > 0.09$
- to reduce error, need more precise value of $|V_{ub}|$!
- 2010 scenario: $\phi_d^{\rm NP} = -(9.8 \pm 2.0)^\circ$, i.e. $\kappa_d > 0.14$
- need to measure NP phase in B_s mixing!

  (and there's plenty of scope for it, don't believe Gino!)
- good channels at the LHC: $B_s \to J/\psi\phi$, $B_s \to \phi\phi$
- more info also from $\Delta\Gamma_s$ and $A_{\rm SL}$ (Tevatron & LHC)