New Physics in $B_s$ Mixing

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What can we learn from $\Delta M_s$?

Quite a few papers already...

- M. Endo and S. Mishima, hep-ph/0603251
What can we learn from $\Delta M_s$?

- 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 $\Delta M_d$ and $\Delta M_s$

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

\[ \Delta M_q = 2|M_{12}^q| \text{ with} \]

\[ M_{12}^q = M_{12}^{q, \text{SM}} (1 + \kappa_q e^{i\sigma_q}) \]

- \( \kappa_q > 0 \): NP amplitude
- \( \sigma_q \): new CP-violating phase

Deviation from SM measured by

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

Q: What is the SM prediction for \( \Delta M_q \)?
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Q: What is the SM prediction for \( \Delta M_q \)?
\( \Delta M_q \) in the SM

\[
M_{12}^{\text{SM}} = \frac{G_F^2 M_W^2}{12 \pi^2} M_{B_q} \hat{\eta}^B \hat{B}_{B_q} f_{B_q}^2 (V_{tq}^* V_{tb})^2 S_0(x_t)
\]

- \( S_0(x_t = m_t^2/M_W^2) = 2.35 \pm 0.06 \): Inami-Lim function
- \( \hat{\eta}^B = 0.552 \): NLO QCD correction (Buras/Jamin/Weiss '90)
- \( \hat{B}_{B_q} f_{B_q}^2 \propto \langle B_q^0 | (\bar{q}b)_{V\!-\!A} (\bar{q}b)_{V\!-\!A} | B_q^0 \rangle \): 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 $\lambda$, $|V_{ub}|$, $|V_{cb}|$ and $\gamma$:

$$|V_{td}V_{tb}|^2 = |V_{cb}|^2 \lambda^2 (1 - 2R_b \cos \gamma + R_b^2)$$

with $R_b \equiv \left(1 - \frac{\lambda^2}{2}\right) \frac{1}{\lambda} \frac{|V_{ub}|}{|V_{cb}|}$

$$|V_{ts}V_{tb}|^2 = |V_{cb}|^2 \left\{1 - (1 - 2R_b \cos \gamma) \lambda^2 + O(\lambda^4)\right\}$$

$\gamma = (65 \pm 20)^\circ$ from $B \rightarrow D^{(*)} K^{(*)}$

$R_b = 0.45 \pm 0.03$ 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 $\gamma$!

$|V_{ts}V_{tb}| = (41.3 \pm 0.7) \cdot 10^{-3}$
Hadronic Matrix Elements from Lattice

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

Kenway (ICHEP 2000)
Lellouch (ICHEP 2002)
JLQCD (2003)
Hashimoto (ICHEP 2004)
Kronfeld (CKM05)
Okamoto (Lattice 2005)
Hadronic Matrix Elements from Lattice

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

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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 $\Delta M_d^{SM}$

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

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

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

$$\rho_d|_{(\text{HP+JL})\text{QCD}} = 0.75 \pm 0.25(\gamma, R_b) \pm 0.16(f_{B_d} \hat{B}_d^{1/2})$$
Predictions for $\Delta M_s^{SM}$

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

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

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

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

JLQCD:

(HP+JL)QCD:


Predictions for $\Delta M_{s}^{\text{SM}}$

\[
\begin{align*}
\Delta M_{s}^{\text{SM}}|_{\text{JLQCD}} & = (16.1 \pm 2.8) \text{ ps}^{-1} \\
\rho_{s}|_{\text{JLQCD}} & = 1.08^{+0.03}_{-0.01}(\text{exp}) \pm 0.19(\text{th}) \\
\Delta M_{s}^{\text{SM}}|_{(\text{HP+JL})QCD} & = (23.4 \pm 3.8) \text{ ps}^{-1} \\
\rho_{s}|_{(\text{HP+JL})QCD} & = 0.74^{+0.02}_{-0.01}(\text{exp}) \pm 0.18(\text{th}) \quad 1.5\sigma!
\end{align*}
\]

Conclusion from this exercise:

$\Delta M_{q}^{\text{SM}}$ is not very well known!

Not even well enough to distinguish between $\rho_{s} < 1$ and $> 1$.

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

$\rho_q = \text{const.}$:

$\phi_{q}^{\text{NP}} = \text{const.}$:

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

In addition, $\phi_q^{\text{NP}} \neq 0$ implies a lower bound on $\kappa_q$:
**Status of \( \phi_d \)**

\[
b \rightarrow c\bar{c}s : \quad \sin \phi_d = \sin(2\beta + \phi_d^{NP}) = 0.687 \pm 0.032
\]

- central value down by 1\(\sigma\) in 2005 because of new Belle results

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

Depending on value of \(|V_{ub}|\), get

\[
\begin{align*}
\phi_d^{NP}|_{\text{incl}} &= -(10.1 \pm 4.6)^\circ, \\
\phi_d^{NP}|_{\text{excl}} &= -(2.5 \pm 8.0)^\circ
\end{align*}
\]

- error of \(\phi_d^{NP}\) dominated by \(|V_{ub}|\)
- dependence on \(\gamma\) small
- no non-perturbative parameters involved*
  
* in addition to \(|V_{ub}|\) extraction and up to tiny \(O(\lambda^2)\) effects
## A possible 2010 scenario

<table>
<thead>
<tr>
<th></th>
<th>2006 value</th>
<th>2010 value</th>
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</thead>
<tbody>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$</td>
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<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$(65 \pm 20)^\circ$</td>
<td>$(70 \pm 5)^\circ$</td>
</tr>
<tr>
<td>$R_b$</td>
<td>$[(0.45 \pm 0.03) \vee (0.39 \pm 0.06)]$</td>
<td>$0.45 \pm 0.02$</td>
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<tr>
<td>$R_t$</td>
<td>$0.91 \pm 0.16$</td>
<td>$0.95 \pm 0.04$</td>
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<td>V_{td}V_{tb}</td>
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<td>$</td>
<td>V_{ts}V_{tb}</td>
<td>$</td>
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<tr>
<td>$\beta$</td>
<td>$[(26.7 \pm 1.9)^\circ \vee (22.9 \pm 3.8)^\circ]$</td>
<td>$(26.6 \pm 1.2)^\circ$</td>
</tr>
<tr>
<td>$f_{B_d}\hat{B}_{B_d}^{1/2}$</td>
<td>JLQCD $\vee$ (HP+JL)QCD</td>
<td>(HP+JL)QCD</td>
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<td>(HP+JL)QCD</td>
</tr>
<tr>
<td>$\xi$</td>
<td>$[(1.14 \pm 0.06^{+0.13}<em>{-0}) \vee (1.210^{+0.047}</em>{-0.035})]$</td>
<td>$1.210^{+0.047}_{-0.035}$</td>
</tr>
</tbody>
</table>
$\Delta M_d$ and $\phi_d$ – 2006 and 2010

JLQCD:

(HP+JL)QCD:
$\Delta M_d$ and $\phi_d$ – 2006 and 2010

And in 2010:
Status of $\phi_s$

- no meaningful constraints yet*
- wait for $\Delta \Gamma_s$ and more precise $A_{SL}$ 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 $A_{SL}$

\[ \phi_s^{SM} \text{ and (HP+JL)QCD values} \quad \phi_s^{NP} = -(10 \pm 3)^\circ \text{ and (HP+JL)QCD values} \]
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 $\rho_L \exp(i\phi_L) \equiv (g'M_Z)/(gM_{Z'})B_{sb}^L$ with $B_{sb}^L$ being $\bar{s}Z'b$ coupling
- $\kappa_s < 2.5 \quad \iff \quad \rho_L < 2.6 \cdot 10^{-3}$
- can translate this into bound on $Z'$ mass:

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

- 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 $(\delta_{23}^d)_{LL}$ insertion using JLQCD lattice data. Open lines: constraints from a future measurement of $\phi_s$. 
NP contributions to $\Delta M_q$ not very strongly constrained because of large hadronic (lattice) uncertainties and, for $\Delta M_d$, the error on $\gamma$

more decisive constraints from NP mixing phases:
$\phi_d^{\text{NP}} = -(10.1 \pm 4.6) ^\circ$ for $|V_{ub}|$ from inclusive decays, which implies $\kappa_d > 0.09$

to reduce error, need more precise value of $|V_{ub}|$!

2010 scenario: $\phi_d^{\text{NP}} = -(9.8 \pm 2.0) ^\circ$, 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: $B_s \rightarrow J/\psi \phi$, $B_s \rightarrow \phi \phi$

more info also from $\Delta \Gamma_s$ and $A_{SL}$ (Tevatron & LHC)