Supersymmetric Flavour physics

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in memory of Nicola Cabibbo
(10 Apr 1935 – 16 Aug 2010)

May 14, 2010

Fermilab Wine&Cheese seminar, talk by Guennadi Borrisov:

Evidence for an anomalous like-sign dimuon charge asymmetry

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>
> *Joe Lykken, a theorist at Fermilab, said, "So I would not say that this announcement is the equivalent of seeing the face of God, but it might turn out to be the toe of God."*

Contents

Basics

Flavour physics

studies transitions between fermions of different generations.

Standard Model: misalignment of 3×3 Yukawa matrices in flavour space

parametrised by the

Cabibbo-Kobayashi-Maskawa (CKM) matrix V

in the quark sector

Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix U

in the lepton sector

CKM matrix V and PMNS matrix U occur only in the couplings of W bosons.

Expand the CKM matrix V in $V_{us} \simeq \lambda = 0.2246$:

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3\left(1+\frac{\lambda^2}{2}\right)(\overline{\rho}-i\overline{\eta}) \\ -\lambda - iA^2\lambda^5\overline{\eta} & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\overline{\rho}-i\overline{\eta}) & -A\lambda^2 - iA\lambda^4\overline{\eta} & 1 \end{pmatrix}$$

with the Wolfenstein parameters λ, A, $\overline{\rho}$, $\overline{\eta}$

CP violation $\Leftrightarrow \overline{\eta} \neq 0$

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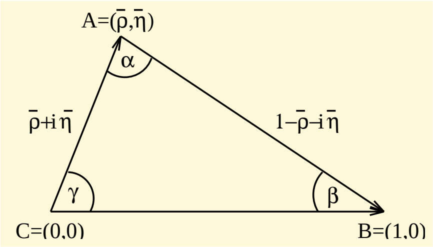
Unitarity triangle:

Exact definition:

$$\overline{\rho} + i\overline{\eta} = -\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}} = \left|\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right| e^{i\gamma}$$



Suppression factors in Flavour-changing neutral current (FCNC) processes:

weak loop, small CKM elements,
often also GIM factor $(m_c^2 - m_u^2)/M_W^2$ or
helicity suppression m_b/M_W.

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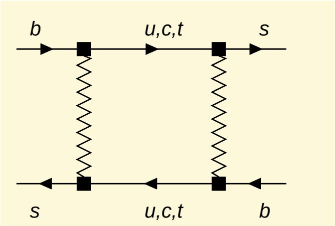
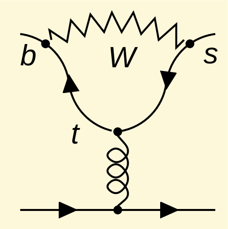
Examples of FCNC processes:



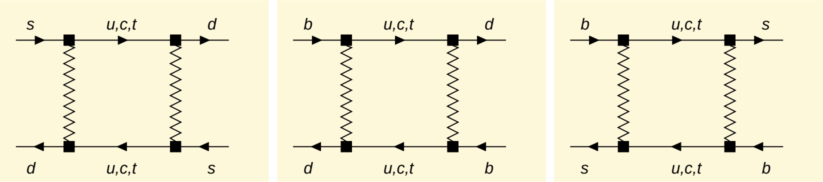
$B_s - \overline{B}_s$ mixing



penguin diagram

New-physics analysers:

- Global fit to UT: overconstrain $(\overline{\rho}, \overline{\eta})$,
probes FCNC processes $K-\overline{K}$, $B_d-\overline{B}_d$ and $B_s-\overline{B}_s$ mixing.



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- Global fit to $\mathrm{B_s}-\overline{\mathrm{B}}_\mathrm{s}$ mixing: mass difference Δm_s, width difference $\Delta\Gamma_s$, CP asymmetries in $B_s \to J/\psi\phi$ and $\overset{(-)}{B}_s \to X\ell\nu_\ell$.

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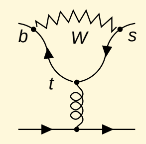
- Penguin decays: $B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$, $B \to K\pi$, $B_d \to \phi K_S$, $B_s \to \mu^+\mu^-$, $K \to \pi\nu\overline{\nu}$.



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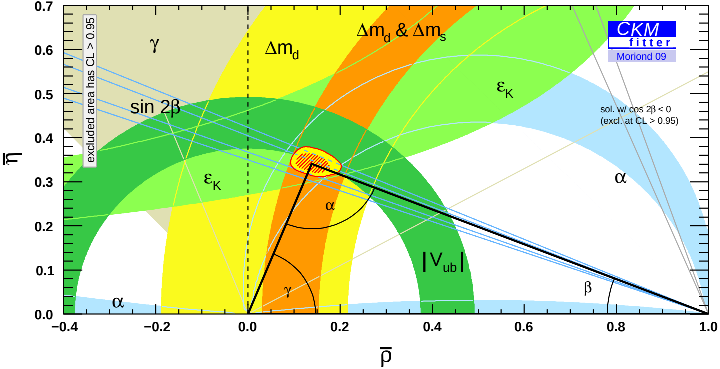
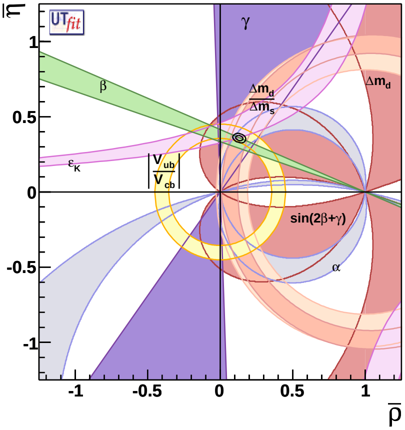
- CKM-suppressed or helicity-suppressed tree-level decays: $B^+ \to \tau^+\nu$, $B \to \pi\ell\nu$, $B \to D\tau\nu$, probe charged Higgses and right-handed W-couplings.

Global fit in the SM from CKMfitter:



Statistical method: Rfit, a Frequentist approach.

Global fit in the SM from UTfit:



Statistical method: Bayesian.

$B_s - \overline{B}_s$ mixing and new physics

Schrödinger equation for $B_s \sim \overline{b}s$ and $\overline{B}_s \sim b\overline{s}$:

$$i\frac{d}{dt}\begin{pmatrix} |B_s(t)\rangle \\ |\overline{B}_s(t)\rangle \end{pmatrix} = \left(M - i\frac{\Gamma}{2}\right)\begin{pmatrix} |B_s(t)\rangle \\ |\overline{B}_s(t)\rangle \end{pmatrix}$$

Here $|B_s(t)\rangle$ is a linear superposition of $|B_s\rangle$ and $|\overline{B}_s\rangle$ with $|B_s(0)\rangle = |B_s\rangle$.

Mass and decay matrices $M = M^\dagger$ and $\Gamma = \Gamma^\dagger$.

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3 physical quantities in $B_s-\overline{B}_s$ mixing:

$$\left|M_{12}^s\right|, \quad \left|\Gamma_{12}^s\right|, \quad \phi_s \equiv \arg\left(-\frac{M_{12}^s}{\Gamma_{12}^s}\right)$$

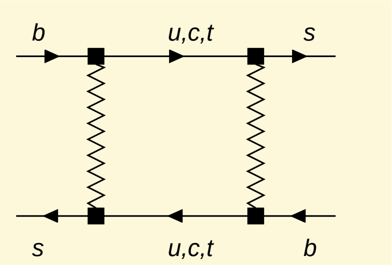
Two mass eigenstates with masses M_H, M_L and widths Γ_H, Γ_L.

Mass and width differences:

$$\begin{aligned}\Delta m_s &= M_H - M_L \simeq 2|M_{12}^s|,\\ \Delta\Gamma_s &= \Gamma_L - \Gamma_H \simeq 2|\Gamma_{12}^s|\cos\phi_s\end{aligned}$$

Standard Model:

M_{12}^s from dispersive part of box,
only internal t relevant;



New physics can barely affect Γ_{12}^s, which stems from tree-level decays.

M_{12}^s is very sensitive to virtual effects of new heavy particles.

Generic new physics

The phase $\phi_s = \arg(-M_{12}/\Gamma_{12})$ is negligibly small in the Standard Model:

$$\phi_s^{\rm SM} = 0.2^\circ.$$

Define the complex parameter Δ_s through

$$M_{12}^s \equiv M_{12}^{\rm SM,s} \cdot \Delta_s \, , \qquad \Delta_s \equiv |\Delta_s| e^{i\phi_s^\Delta} .$$

In the Standard Model $\Delta_s = 1$. Use $\phi_s = \phi_s^{\rm SM} + \phi_s^\Delta \simeq \phi_s^\Delta$.

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The CDF measurement

$$\Delta m_s = (17.77 \pm 0.10 \pm 0.07) \text{ ps}^{-1}$$

implies

$$|\Delta_s| = 0.92 \pm 0.14_{\text{(th)}} \pm 0.01_{\text{(exp)}}$$

Flavour-specific decay: $B_s \to f$ is allowed, while
$\bar{B}_s \to f$ is forbidden

CP asymmetry in flavour-specific decays (semileptonic CP asymmetry):

$$a^s_{\rm fs} = \frac{\Gamma(\bar{B}_s(t) \to f) - \Gamma(B_s(t) \to \bar{f})}{\Gamma(\bar{B}_s(t) \to f) + \Gamma(B_s(t) \to \bar{f})}$$

with e.g. $f = X\ell^+\nu_\ell$ and $\bar{f} = \overline{X}\ell^-\overline{\nu}_\ell$. Untagged rate:

$$a^s_{\rm fs,unt} \equiv \frac{\int_0^\infty dt \left[\Gamma(\overset{(-)}{B}_s \to \mu^+ X) - \Gamma(\overset{(-)}{B}_s \to \mu^- X)\right]}{\int_0^\infty dt \left[\Gamma(\overset{(-)}{B}_s \to \mu^+ X) + \Gamma(\overset{(-)}{B}_s \to \mu^- X)\right]} \simeq \frac{a^s_{\rm fs}}{2}$$

Relation to M_{12}^s:

$$a_{\rm fs}^s = \frac{|\Gamma_{12}^s|}{|M_{12}^s|} \sin\phi_s = \frac{|\Gamma_{12}^s|}{|M_{12}^{\rm SM,s}|} \cdot \frac{\sin\phi_s}{|\Delta_s|} = (4.97 \pm 0.94) \cdot 10^{-3} \cdot \frac{\sin\phi_s}{|\Delta_s|}$$

A. Lenz, UN, 2006

Dilepton events:

Compare the number N_{++} of decays $(B_s(t), \bar{B}_s(t)) \to (f, f)$ with the number N_{--} of decays to $(\bar{f}, \bar{f})$.

Then $a_{\rm fs}^s = \dfrac{N_{++} - N_{--}}{N_{++} + N_{--}}$.

At the Tevatron all b-flavoured hadrons are produced. Still only those events contribute to $(N_{++} - N_{--})/(N_{++} + N_{--})$, in which one of the b hadronises as a B_d or B_s and undergoes mixing.

May 15, 2010: DØ presents

$$a_{\rm fs} \;=\; (-9.57 \pm 2.51 \pm 1.46) \cdot 10^{-3}$$

for a mixture of B_d and B_s mesons with

$$a_{\rm fs} \;=\; (0.506 \pm 0.043) a_{\rm fs}^d + (0.494 \pm 0.043) a_{\rm fs}^s$$

The result is 3.2σ away from $a_{\rm fs}^{\rm SM} = \left(-0.23^{+0.05}_{-0.06}\right) \cdot 10^{-3}$.

A. Lenz, UN, 2006

Averaging with an older CDF measurement yields

$$a_{\rm fs} = (-8.5 \pm 2.8) \cdot 10^{-3},$$

which is 3.0σ away from $a_{\rm fs}^{\rm SM}$.

$$a_{\mathrm{fs}}^{s} = (4.97 \pm 0.94) \cdot 10^{-3} \cdot \frac{\sin \phi_s}{|\Delta_s|}$$

If there is no new physics in a_{fs}^{d}, the Tevatron measurement of $a_{\mathrm{fs}} = (-8.5 \pm 2.8) \cdot 10^{-3}$ roughly implies $a_{\mathrm{fs}}^{s} = (-17 \pm 6) \cdot 10^{-3}$. With $|\Delta_s| \geq 0.78$ find

$$\sin \phi_s \leq -2.2 \pm 0.7.$$

Closer look: Allow for new physics in $\mathrm{B_d} - \overline{\mathrm{B}}_\mathrm{d}$ mixing as well:

$$\frac{M_{12}^d}{M_{12}^{\mathrm{SM,d}}} \equiv \Delta_d = |\Delta_d| e^{i\phi_d^\Delta}$$

Measurement by B factories: $a_{\mathrm{fs}}^d = (-4.7 \pm 4.6) \cdot 10^{-3}$

However: a_{fs}^d can be better determined indirectly through

$$a_{\mathrm{fs}}^d = \frac{|\Gamma_{12}^d|}{M_{12}^{\mathrm{SM,d}}} \frac{\sin(\phi_d^{\mathrm{SM}} + \phi_d^\Delta)}{|\Delta_d|} \qquad \text{with} \quad \phi_d^{\mathrm{SM}} = (-5 \pm 2)^\circ$$

using the measurements of $\Delta m_d = 2|M_{12}^d|$ and of $2\beta + \phi_d^\Delta = (21 \pm 1)^\circ$ from $A_{CP}^{\mathrm{mix}}(B_d \to J/\psi K_S)$.

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$\Rightarrow$ requires fit to unitarity triangle to find β

Other connection between B_d and B_s mixing:
The global fit to the unitarity triangle involves $\frac{\Delta m_d}{\Delta m_s}$ from which hadronic uncertainties cancel to a large extent.

Global analysis of $B_s - \overline{B}_s$ mixing and $B_d - \overline{B}_d$ mixing

Based on work with A. Lenz and the CKMfitter Group (J. Charles, S. Descotes-Genon, A. Jantsch, C. Kaufhold, H. Lacker, S. Monteil, V. Niess) arXiv:1008.1593

Rfit method: No statistical meaning is assigned to systematic errors and theoretical uncertainties.

We have performed a simultaneous fit to the Wolfenstein parameters and to the new physics parameters Δ_s and Δ_d in three scenarios.

Scenario I: arbitrary complex parameters Δ_s and Δ_d

Scenario II: new physics is minimally flavour violating (MFV) (meaning that all flavour violation stems from the Yukawa sector) and y_b is small: one real parameter $\Delta = \Delta_s = \Delta_d$

Scenario III: MFV with a large y_b: one complex parameter $\Delta = \Delta_s = \Delta_d$

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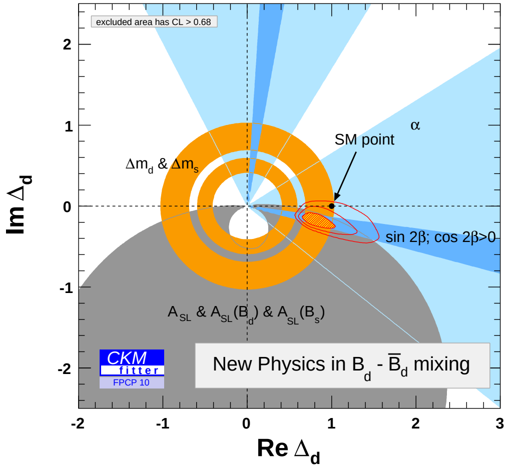
Examples: Scenario I covers the MSSM with generic flavour structure of the soft terms and small $\tan\beta$.
Scenario II covers the MSSM with MFV and small $\tan\beta$.
Scenario III covers certain two-Higgs models (but not the MFV-MSSM).

Results in scenario I:



SM point $\Delta_d = 1$ disfavoured by $\geq 2.5\sigma$.

$\phi_d^\Delta < 0$ helps to explain DØ dimuon asymmetry.

Reason for the tension with the SM: $B(B^+ \to \tau^+ \nu_\tau)$

SM prediction (CL$=2\sigma$):

$$B(B^+ \to \tau^+ \nu_\tau) = \left(0.763^{+0.214}_{-0.097}\right) \cdot 10^{-4}$$

Average of several measurements by BaBar and Belle:

$$B^{\rm exp}(B^+ \to \tau^+ \nu_\tau) = (1.68 \pm 0.31) \cdot 10^{-4}$$

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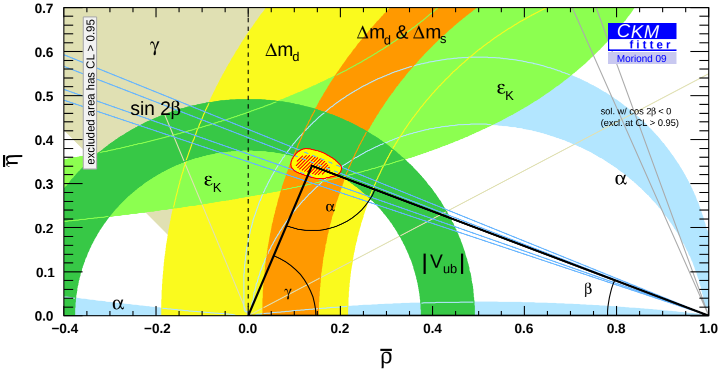
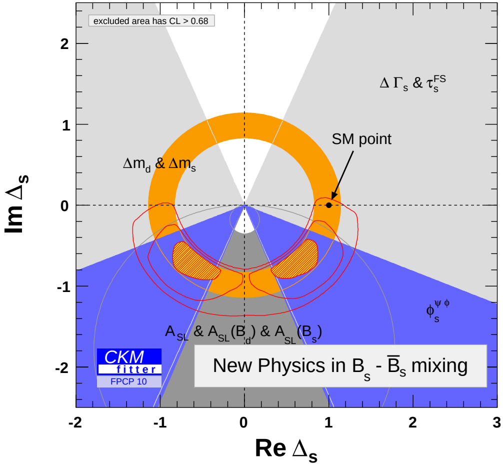
$$B^{\mathrm{SM}}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_{B^+} m_\tau^2}{8\pi} \left(1 - \frac{m_\tau^2}{m_{B^+}^2}\right)^2 |V_{ub}|^2 f_B^2 \tau_{B^+}.$$

But with e.g. $f_B = 210\,\mathrm{MeV}$ and $|V_{ub}| = 4.4 \cdot 10^{-3}$ find $B^{\mathrm{SM}}(B^+ \to \tau^+ \nu_\tau) = 1.51 \cdot 10^{-4}$. These parameters comply with the global fit to the UT only, if new physics changes the constraints from $A_{CP}^{\mathrm{mix}}(B_d \to J/\psi K_S)$, Δm_d or $\Delta m_d / \Delta m_s$.

Global fit in the SM:





SM point $\Delta_s = 1$ dis-favoured by $\geq 2.7\sigma$.

without 2010 CDF/DØ data on $B_s \to J/\psi\phi$

Global fit to UT hinting at $\phi_d^\Delta < 0$:
Other authors have seen a tension with the SM in the same direction stemming from ϵ_K.

Lunghi,Soni; Buras,Guadagnoli

In our fit the tension with ϵ_K is mild, because we use a more conservative error on the hadronic parameter $\widehat{B}_K = 0.724 \pm 0.004 \pm 0.067$ and because the Rfit method is more conservative.

p-values:

Calculate χ^2/N_{dof} with and without a hypothesis to find:

Hypothesis	p-value
$\Delta_d = 1$	$2.5\,\sigma$
$\Delta_s = 1$	$2.7\,\sigma$
$\Delta_d = \Delta_s = 1$	$3.4\,\sigma$
$\Delta_d = \Delta_s$	$2.1\,\sigma$

Is the result driven by the DØ dimuon asymmetry?
One can remove $a_{\rm fs}$ as an input and instead predict it from the global fit:

$$a_{\rm fs} = \left(-4.2^{+2.7}_{-2.6}\right) \cdot 10^{-3} \qquad \text{at } 2\sigma.$$

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This is just 1.5σ away from the DØ/CDF average

$$a_{\rm fs} = (-8.5 \pm 2.8) \cdot 10^{-3}.$$

The fit in scenario II (real $\Delta_s = \Delta_d$) is not better than the SM fit and gives $\Delta = 0.907^{+0.091}_{-0.067}$.

Scenario III (complex $\Delta_s = \Delta_d$) fits the data quite well irrespective of whether $B(B^+ \to \tau^+ \nu_\tau)$ is included or not.

Hypothesis	p-value
$\Delta = 1$	$3.1\,\sigma$

Supersymmetry

The MSSM has many new sources of flavour violation, all in the supersymmetry-breaking sector.

No problem to get big effects in $B_s - \overline{B}_s$ mixing, but rather to suppress the big effects elsewhere.

Squark mass matrix

Diagonalise the Yukawa matrices Y^u_{jk} and Y^d_{jk}

$\Rightarrow$ quark mass matrices are diagonal, super-CKM basis

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E.g. Down-squark mass matrix:

$$M^2_{\tilde{d}} = \begin{pmatrix} \left(M^{\tilde{d}}_{1L}\right)^2 & \Delta^{\tilde{d}\,LL}_{12} & \Delta^{\tilde{d}\,LL}_{13} & \Delta^{\tilde{d}\,LR}_{11} & \Delta^{\tilde{d}\,LR}_{12} & \Delta^{\tilde{d}\,LR}_{13} \\ \Delta^{\tilde{d}\,LL}_{12}{}^{*} & \left(M^{\tilde{d}}_{2L}\right)^2 & \Delta^{\tilde{d}\,LL}_{23} & \Delta^{\tilde{d}\,RL}_{12}{}^{*} & \Delta^{\tilde{d}\,LR}_{22} & \Delta^{\tilde{d}\,LR}_{23} \\ \Delta^{\tilde{d}\,LL}_{13}{}^{*} & \Delta^{\tilde{d}\,LL}_{23}{}^{*} & \left(M^{\tilde{d}}_{3L}\right)^2 & \Delta^{\tilde{d}RL}_{13}{}^{*} & \Delta^{\tilde{d}\,RL*}_{23} & \Delta^{\tilde{d}\,LR}_{33} \\ \Delta^{\tilde{d}\,LR}_{11}{}^{*} & \Delta^{\tilde{d}RL}_{12} & \Delta^{\tilde{d}RL}_{13} & \left(M^{\tilde{d}}_{1R}\right)^2 & \Delta^{\tilde{d}\,RR}_{12} & \Delta^{\tilde{d}\,RR}_{13} \\ \Delta^{\tilde{d}\,LR}_{12}{}^{*} & \Delta^{\tilde{d}\,LR*}_{22} & \Delta^{\tilde{d}RL}_{23} & \Delta^{\tilde{d}\,RR}_{12}{}^{*} & \left(M^{\tilde{d}}_{2R}\right)^2 & \Delta^{\tilde{d}\,RR}_{23} \\ \Delta^{\tilde{d}\,LR}_{13}{}^{*} & \Delta^{\tilde{d}\,LR}_{23}{}^{*} & \Delta^{\tilde{d}\,LR}_{33}{}^{*} & \Delta^{\tilde{d}\,RR}_{13}{}^{*} & \Delta^{\tilde{d}\,RR}_{23}{}^{*} & \left(M^{\tilde{d}}_{3R}\right)^2 \end{pmatrix}$$

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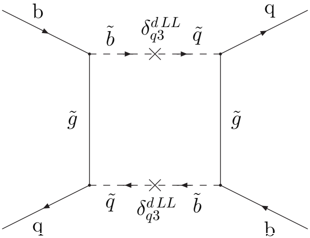
$\Rightarrow$ quark mass matrices are diagonal, super-CKM basis

E.g. Down-squark mass matrix:

$$M^2_{\tilde{d}} = \begin{pmatrix} \left(M^{\tilde{d}}_{1L}\right)^2 & \Delta^{\tilde{d}\,LL}_{12} & \Delta^{\tilde{d}\,LL}_{13} & \Delta^{\tilde{d}\,LR}_{11} & \Delta^{\tilde{d}\,LR}_{12} & \Delta^{\tilde{d}\,LR}_{13} \\ \Delta^{\tilde{d}\,LL}_{12}{}^{*} & \left(M^{\tilde{d}}_{2L}\right)^2 & \Delta^{\tilde{d}\,LL}_{23} & \Delta^{\tilde{d}\,RL}_{12}{}^{*} & \Delta^{\tilde{d}\,LR}_{22} & \Delta^{\tilde{d}\,LR}_{23} \\ \Delta^{\tilde{d}\,LL}_{13}{}^{*} & \Delta^{\tilde{d}\,LL}_{23}{}^{*} & \left(M^{\tilde{d}}_{3L}\right)^2 & \Delta^{\tilde{d}RL}_{13}{}^{*} & \Delta^{\tilde{d}\,RL*}_{23} & \Delta^{\tilde{d}\,LR}_{33} \\ \Delta^{\tilde{d}\,LR}_{11}{}^{*} & \Delta^{\tilde{d}RL}_{12} & \Delta^{\tilde{d}RL}_{13} & \left(M^{\tilde{d}}_{1R}\right)^2 & \Delta^{\tilde{d}\,RR}_{12} & \Delta^{\tilde{d}\,RR}_{13} \\ \Delta^{\tilde{d}\,LR}_{12}{}^{*} & \Delta^{\tilde{d}\,LR*}_{22} & \Delta^{\tilde{d}RL}_{23} & \Delta^{\tilde{d}\,RR}_{12}{}^{*} & \left(M^{\tilde{d}}_{2R}\right)^2 & \Delta^{\tilde{d}\,RR}_{23} \\ \Delta^{\tilde{d}\,LR}_{13}{}^{*} & \Delta^{\tilde{d}\,LR}_{23}{}^{*} & \Delta^{\tilde{d}\,LR}_{33}{}^{*} & \Delta^{\tilde{d}\,RR}_{13}{}^{*} & \Delta^{\tilde{d}\,RR}_{23}{}^{*} & \left(M^{\tilde{d}}_{3R}\right)^2 \end{pmatrix}$$

Not diagonal! $\Rightarrow$ new FCNC transitions.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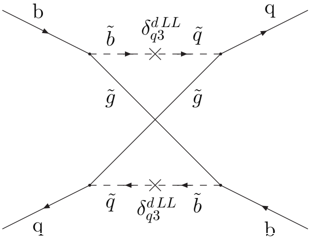
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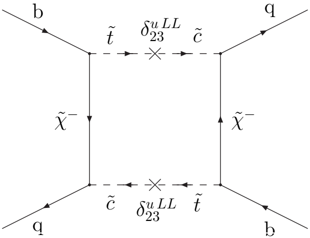
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Model-independent analyses constrain

$$\delta_{ij}^{q\,XY} = \frac{\Delta_{ij}^{\tilde{q}\,XY}}{\frac{1}{6}\sum_s \left[M_{\tilde{q}}^2\right]_{ss}}$$

with $XY = LL, LR, RR$ and $q = u, d$

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  parallel talk by M. Davidkov, 27-1, FR 14:17

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  parallel talk by M. Davidkov, 27-1, FR 14:17
- To derive meaningful bounds on $\delta_{ij}^{q\,LR}$ chirally enhanced higher-order contributions must be taken into account.
  A. Crivellin, UN, 2009

Are there natural ways to motivate sizable new flavour violation in $B_s - \overline{B}_s$ mixing and $B_d - \overline{B}_d$ mixing while simultaneous suppressing flavour violation elsewhere?

Flavour violation from trilinear terms

Origin of the SUSY flavour problem: Misalignment of squark mass matrices with Yukawa matrices.

Unorthodox solution: Set Y^u_{ij} and Y^d_{ij} to zero, except for $(i,j) = (3,3)$.

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Radiative flavour violation: S. Weinberg 1972

flavour from soft SUSY terms:

W. Buchmüller, D. Wyler 1983,
T. Banks 1988,
F. Borzumati, G.R. Farrar,
N. Polonsky, S.D. Thomas 1998, 1999
J. Ferrandis, N. Haba 2004

Today: Strong constraints from FCNCs probed at B factories.

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But: Radiative flavour violation in the MSSM is still viable, albeit only with A^d_{ij} and A^u_{ij} entering

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Andreas Crivellin, UN, PRD 79 (2009) 035018

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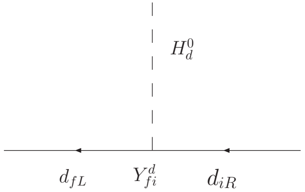

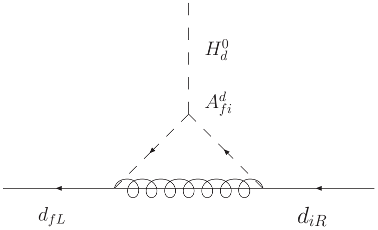

Electric dipole moments

Darkest corner of the MSSM: The phases of A^q_{ii} and μ generate too large EDMs. If light quark masses are generated radiatively through soft SUSY-breaking terms, this “supersymmetric CP problem” is substantially alleviated:

- The phases of A^q_{ii} and m_q are aligned, i.e. zero.
- The phase of μ (essentially) does not enter the EDMs at the one-loop level, because the Yukawa couplings of the first two generations are zero.

Borzumati, Farrar, Polonsky, Thomas 1998,1999

Flavour and SUSY GUTs

Linking quarks to neutrinos: Flavour mixing:
quarks: Cabibbo-Kobayashi-Maskawa (CKM) matrix
leptons: Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix

Consider SU(5) multiplets:

$$\mathbf{\overline{5}_1} = \begin{pmatrix} d_R^c \\ d_R^c \\ d_R^c \\ e_L \\ -\nu_e \end{pmatrix}, \qquad \mathbf{\overline{5}_2} = \begin{pmatrix} s_R^c \\ s_R^c \\ s_R^c \\ \mu_L \\ -\nu_\mu \end{pmatrix}, \qquad \mathbf{\overline{5}_3} = \begin{pmatrix} b_R^c \\ b_R^c \\ b_R^c \\ \tau_L \\ -\nu_\tau \end{pmatrix}.$$

If the observed large atmospheric neutrino mixing angle stems from a rotation of $\mathbf{\overline{5}_2}$ and $\mathbf{\overline{5}_3}$, it will induce a large $\tilde{b}_R - \tilde{s}_R$-mixing (Moroi; Chang,Masiero,Murayama).

$\Rightarrow$ new b_R–s_R transitions from gluino–squark loops possible.

Key ingredients: Some weak basis with

$$\mathrm{Y}_d = V^*_{\mathrm{CKM}} \begin{pmatrix} y_d & 0 & 0 \\ 0 & y_s & 0 \\ 0 & 0 & y_b \end{pmatrix} U_{\mathrm{PMNS}}$$

and right-handed down squark mass matrix:

$$\mathrm{m}^2_{\tilde{d}}\,(M_Z) = \mathrm{diag}\left(m^2_{\tilde{d}}, m^2_{\tilde{d}}, m^2_{\tilde{d}} - \Delta_{\tilde{d}}\right).$$

with a calculable real parameter $\Delta_{\tilde{d}}$, typically generated by top-Yukawa RG effects.

Rotating Y_d to diagonal form puts the large atmospheric neutrino mixing angle into $m^2_{\tilde{d}}$:

$$U^\dagger_{\mathrm{PMNS}}\, m^2_{\tilde{d}}\, U_{\mathrm{PMNS}} = \begin{pmatrix} m^2_{\tilde{d}} & 0 & 0 \\ 0 & m^2_{\tilde{d}} - \frac{1}{2}\,\Delta_{\tilde{d}} & -\frac{1}{2}\,\Delta_{\tilde{d}}\, e^{i\xi} \\ 0 & -\frac{1}{2}\,\Delta_{\tilde{d}}\, e^{-i\xi} & m^2_{\tilde{d}} - \frac{1}{2}\,\Delta_{\tilde{d}} \end{pmatrix}$$

The CP phase ξ affects $\mathrm{B_s}-\overline{\mathrm{B}}_\mathrm{s}$ mixing!

Realistic GUTs involve further dimension-5 Yukawa terms to fix the Yukawa unification in the first two generations. One can use these terms to shuffle a part of the effect from $b_R \to s_R$ into $b_R \to d_R$ transitions. This "leakage" is strongly constrained by $\mathrm{K}-\overline{\mathrm{K}}$ mixing. Trine,Wiesenfeldt,Westhoff 2009

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Similar constraints can be found from $\mu \to e\gamma$.

Borzumati,Yamashita 2009; Girrbach,Mertens,UN,Wiesenfeldt 2009

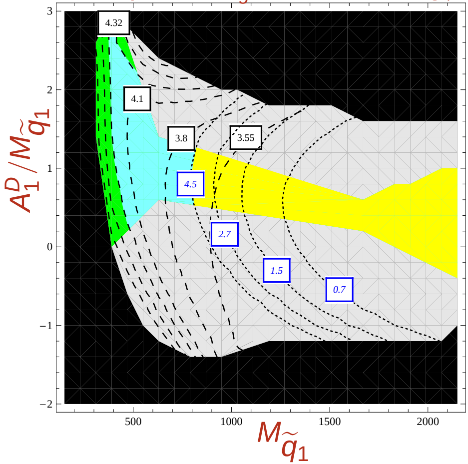
Chang-Masireo-Murayama model

We have considered $B_s - \overline{B}_s$ mixing, $b \to s\gamma$, $\tau \to \mu\gamma$, vacuum stability bounds, lower bounds on sparticle masses and the mass of the lightest Higgs boson.
The analysis involves 7 parameters in addition to those of the Standard Model.

Generic results: Largest effect in $B_s - \overline{B}_s$ mixing
tension with $M_h \geq 114\,\mathrm{GeV}$

J. Girrbach, S. Jäger, M. Knopf, W. Martens, UN, C. Scherrer, S. Wiesenfeldt

Contour plot for $M_{\tilde{g}} = 350\,\text{GeV}$, $\arg\mu = 0$:



Black: negative soft masses^2
Green: excluded by $\tau \to \mu\gamma$ and $b \to s\gamma$
Blue: excluded by $\tau \to \mu\gamma$
Gray: excluded by $B_s - \overline{B}_s$ mixing
Yellow: allowed

dashed lines: $10^4 \cdot Br(b \to s\gamma)$; dotted lines: $10^8 \cdot Br(\tau \to \mu\gamma)$.

Parallel talks addressing topics touched in this talk:

MO Pheno 23-2	17:37	David Straub
TU Pheno 24-1	14:17	Jennifer Girrbach
TU Pheno 24-1	15:25	Stefania Gori
TH Model Building 26-1	14:17	Andreas Crivellin
FR Model Building 27-1	14:17	Momchil Davidkov
FR Model Building 27-1	14:34	Jisuke Kubo
FR Pheno 27-2	17:37	Wolfgang Altmannshofer

Conclusions

- The DØ result for the dimuon asymmetry in B_s decays supports the hints for $\phi_s < 0$ seen in $B_s \to J/\psi\phi$ data. The central value is easier to accomodate if both a_{fs}^s and a_{fs}^d receive negative contributions from new physics.

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- The DØ result for the dimuon asymmetry in B_s decays supports the hints for $\phi_s < 0$ seen in $B_s \to J/\psi\phi$ data. The central value is easier to accomodate if both $a_{\rm fs}^s$ and $a_{\rm fs}^d$ receive negative contributions from new physics.
- A global fit to the UT indeed shows a slight preference for a new CP phase $\phi_d^\Delta < 0$, driven by $B(B^+ \to \tau^+\nu_\tau)$ (and possibly ϵ_K). In a simultaneously global fit to the UT and the $\mathrm{B_s}-\overline{\mathrm{B}}_\mathrm{s}$ mixing complex a plausible picture of new CP-violating physics emerges.

Conclusions

- Large CP-violating contributions to $B_s - \overline{B}_s$ mixing are possible in supersymmetry without violating constraints from other FCNC processes. If confirmed the DØ/CDF results imply physics beyond the MFV-MSSM.

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- Large CP-violating contributions to $\mathrm{B_s} - \overline{\mathrm{B}}_\mathrm{s}$ mixing are possible in supersymmetry without violating constraints from other FCNC processes. If confirmed the DØ/CDF results imply physics beyond the MFV-MSSM.
- An attractive variant is the MSSM with vanishing Yukawa couplings for the first two generations and radiative flavour violation.
- Models of GUT flavour physics with $\tilde{b}_R - \tilde{s}_R$ mixing driven by the atmospheric neutrino mixing angle can explain the Tevatron data on $\mathrm{B_s} - \overline{\mathrm{B}}_\mathrm{s}$ mixing without conflicting with $b \to s\gamma$ and $\tau \to \mu\gamma$.