B_s mixing: gate to new physics?

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FlaviA net

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Standard Model

Symmetry group: $SU(3) \times SU(2)_L \times U(1)_Y$

Particle content:

$$\begin{pmatrix} u_L, u_L, u_L \\ d_L, d_L, d_L \end{pmatrix} \quad \begin{pmatrix} c_L, c_L, c_L \\ s_L, s_L, s_L \end{pmatrix} \quad \begin{pmatrix} t_L, t_L, t_L \\ b_L, b_L, b_L \end{pmatrix}$$

$$\begin{matrix} u_R, u_R, u_R \\ d_R, d_R, d_R \end{matrix} \quad \begin{matrix} c_R, c_R, c_R \\ s_R, s_R, s_R \end{matrix} \quad \begin{matrix} t_R, t_R, t_R \\ b_R, b_R, b_R \end{matrix}$$

$$\begin{pmatrix} \nu_{e,L} \\ e_L \end{pmatrix} \quad \begin{pmatrix} \nu_{\mu,L} \\ \mu_L \end{pmatrix} \quad \begin{pmatrix} \nu_{\tau,L} \\ \tau_L \end{pmatrix}$$

$$e_R \quad \mu_R \quad \tau_R$$

$$g \quad \gamma \quad W^+ \quad W^- \quad Z$$

$$H$$

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. . . to be stress-tested by the LHC.

Contents

B physics

Strategies to explore the TeV scale:

High energy:
direct production of new particles
Tevatron, LHC

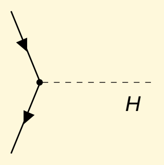
High precision:
quantum effects from new particles
high statistics

With precision measurements one studies the couplings and mixing patterns of the new particles which the LHC will discover.

Yukawa sector

Yukawa coupling of the Higgs field:

$$y_{ij}\overline{f}_i f_j(v+H)$$



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diagonalisation $\Rightarrow$ fermion masses and CKM matrix V_{CKM}.

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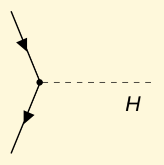

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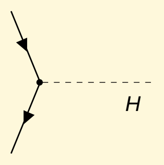

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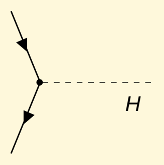

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10 parameters in the quark sektor,
10 or 12 parameters in the lepton sector.

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, $\overline{\rho}$, $\overline{\eta}$

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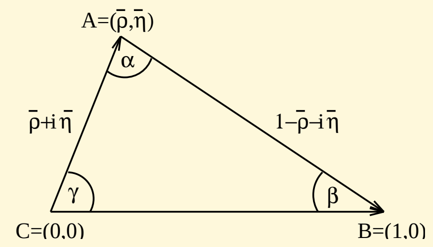
Unitarity triangle:

Exact definition:

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



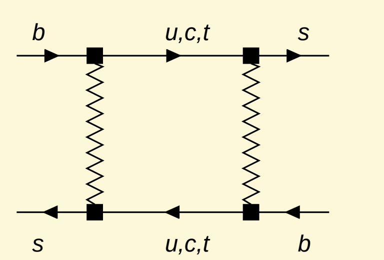
If new physics is associated with the scale Λ, effects on weak processes (such as weak B decays) are generically suppressed by a factor of order M_W^2/Λ^2 compared to the Standard Model.

$\Rightarrow$ study processes which are suppressed in the Standard Model.

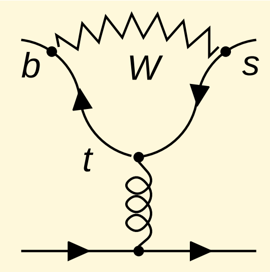
Especially sensitive to new physics are processes, in which (only) the Standard Model contribution is suppressed.

$\Rightarrow$ flavour-changing neutral current (FCNCs) processes

Examples for FCNC processes:

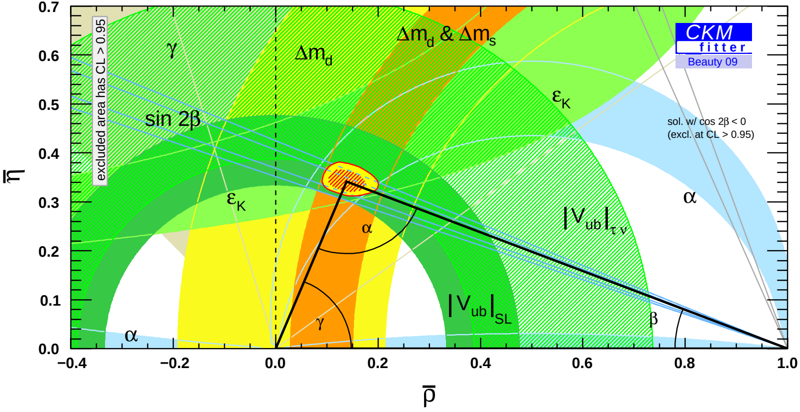


$B_s - \overline{B}_s$ mixing



penguin diagrams

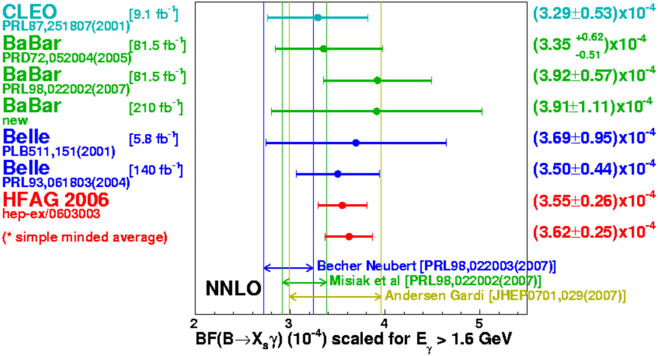
Experimental status of the unitarity triangle



consistent with the Standard Model

CKM mechanism confirmed at $\sim 2\sigma$.

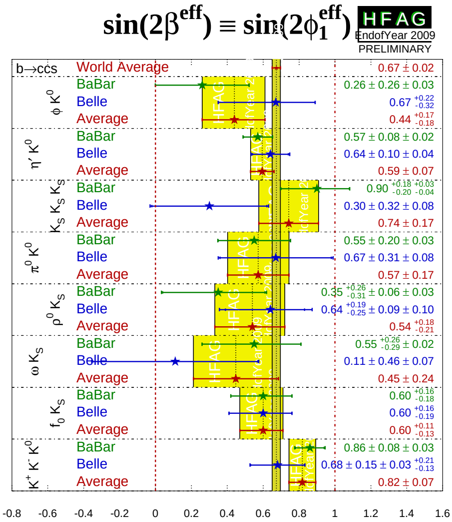
Experimental status of $b \to s\gamma$

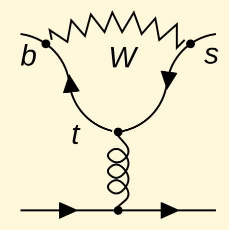


consistent with the Standard Model prediction within $\sim 1.5\sigma$:

$$\mathcal{B}(B \to X_s\gamma)_{E_\gamma > 1.6\,\text{GeV}} = (3.15 \pm 0.23)\cdot 10^{-4}$$ Misiak et al. 2006

Experimental status of CP asymmetries in $b \to s$ transitions





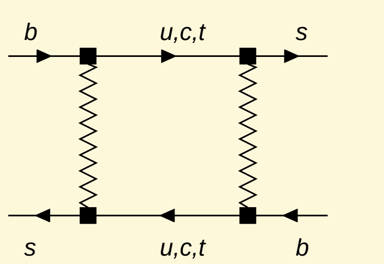
Naive average: $\sin(2\beta_{\rm eff}) = 0.62 \pm 0.04$. agrees with SM expectation 0.673 ± 0.023 at 1.3σ.

Better criterion: absolute deviation from the Standard Model.

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

Standard Model:

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



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

$\Rightarrow$ $\Delta m_s \simeq 2|M_{12}^s|$ and the phase $\arg M_{12}^s$ can change.

Generic new physics:

Define the complex parameter Δ_s through

$$M_{12}^{s} \equiv M_{12}^{\mathrm{SM,s}} \cdot \Delta_s \, .$$

In the Standard Model $\Delta_s = 1$.

Alex Lenz, U.N. 2006

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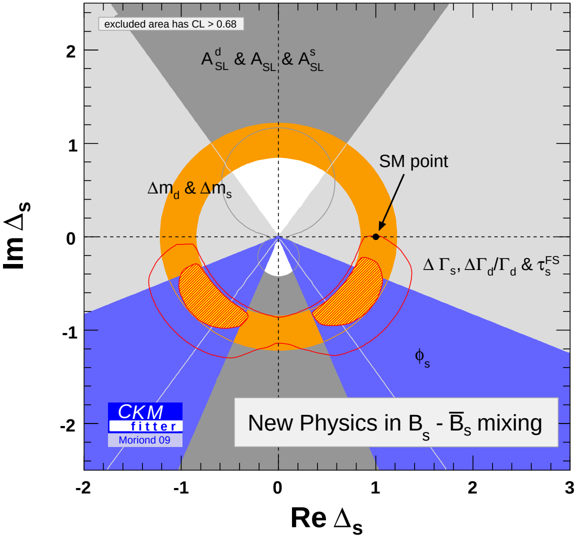
Measurements constraining Δ_s:

- mass difference Δm_s,
- width difference $\Delta\Gamma_s$,
- CP asymmetry in flavour-specific (e.g semi-leptonic) decays a_{fs},
- CP asymmetry in $B_s \to J/\psi\phi$.



Before May 14, 2010:

consistent with SM at CL$\lesssim$ 95%.

	Physics probed:
Unitarity Triangle:	$b \to d$, $s \to d$, $b \to u$
$B \to X_s \gamma$:	$b_R \to s_L$
$\not{CP}$ in $b \to s$ transitions:	$b \to s$

$\Rightarrow$ Yukawa sector seems to be the dominant source of flavour violation.

The CKM picture works too well:

Flavour problem of TeV scale physics

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TeV–scale new physics is dominantly minimally flavour–violating (MFV).

Do we need new physics at the TeV scale?

Do we need new physics at the TeV scale?
Maybe flavour physics just tells us that there is none?

Physics beyond the Standard Model: phenomena

- Gravity. It is associated with the Planck scale $M_P = G_N^{-1/2} \approx 10^{19}\,\text{GeV}$.

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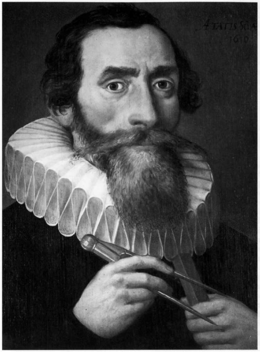
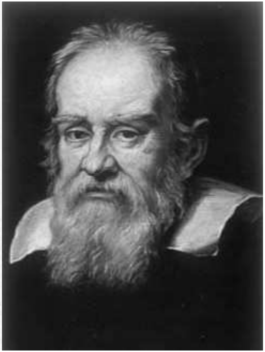
Pioneers of physics beyond the Standard Model:

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  We don't understand 95% of the universe's energy budget.

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  $\Rightarrow$ We don't understand the remaining 5% either!

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- Flavour oscillations of neutrinos unless one adds a dimension-5 term, which brings in (the inverse of) a new mass scale $M \sim 10^{15}\,\text{GeV}$.
- Charge quantisation: $Q(\nu) = 0$ and $Q(e) = 3Q(d)$ to all digits behind the decimal point.

The fermions magically fit into $SU(5)$ multiplets:

$$\underline{5} \equiv \begin{pmatrix} d^c \\ d^c \\ d^c \\ e_L \\ -\nu_{e,L} \end{pmatrix} \qquad \underline{10} \equiv \begin{pmatrix} 0 & u^c & -u^c & u_L & d_L \\ -u^c & 0 & u^c & u_L & d_L \\ u^c & -u^c & 0 & u_L & d_L \\ -u_L & -u_L & -u_L & 0 & e^c \\ -d_L & -d_L & -d_L & -e^c & 0 \end{pmatrix}$$

Here the superscript c denotes antiparticle fields of right–handed fermions.

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Here the superscript c denotes antiparticle fields of right–handed fermions.
Even better: The 15 fermion fields of each generation and an extra right-handed neutrino field fit into a $\underline{16}$ of

$$SO(10) \supset SU(5)$$

In an $SO(10)$ GUT $U(1)_{B-L}$ is gauged and broken at the $SO(10)$-breaking scale M_{10}, a see-saw mechanism for small neutrino masses is easily implemented.

Supersymmetry

- tames the quantum corrections to the Higgs mass,
- provides a dark-matter candidate, the lightest supersymmetric particle (LSP),
- improves the unification of gauge couplings required by GUTs,
- can link gravity to the other gauge interactions.

$B_s - \overline{B}_s$ mixing basics

Schrödinger equation:

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

where $B_s \sim \overline{b}s$ and $\overline{B}_s \sim b\overline{s}$.

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

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

Two mass eigenstates:

$$\begin{aligned} \text{Lighter eigenstate:} \quad |B_L\rangle &= p|B_s\rangle + q|\overline{B}_s\rangle. \\ \text{Heavier eigenstate:} \quad |B_H\rangle &= p|B_s\rangle - q|\overline{B}_s\rangle \end{aligned}$$

with masses $M_{L,H}$ and widths $\Gamma_{L,H}$.
Further $|p|^2 + |q|^2 = 1$.

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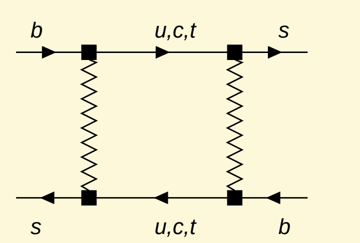
Relation of Δm and $\Delta\Gamma$ to $|M_{12}|$, $|\Gamma_{12}|$ and ϕ:

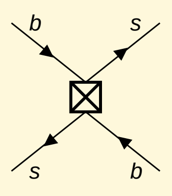
$$\Delta m = M_H - M_L \simeq 2|M_{12}|, \qquad \Delta\Gamma = \Gamma_L - \Gamma_H \simeq 2|\Gamma_{12}| \cos\phi$$

M_{12} stems from the dispersive (real) part of the box diagram, internal $(\bar{t}, t)$.
Γ_{12} stems from the absorpive (imaginary) part of the box diagram, internal $(\bar{c}, c)$.
(u's are negligible).



Theoretical uncertainty of M_{12} dominated by matrix element:

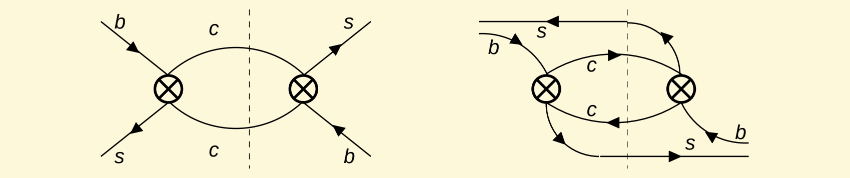
$$\langle B_s | \bar{s}_L \gamma_\nu b_L \, \bar{s}_L \gamma^\nu b_L | \overline{B}_s \rangle \quad = \quad \frac{2}{3} m_{B_s}^2 \, f_{B_s}^2 \, B$$



Optical theorem:

$$\Gamma_{12} = -\frac{1}{2M_{B_s}} \text{Abs} \langle B_s | \, i \int d^4x \; T \, \mathcal{H}_{eff}(x) \mathcal{H}_{eff}(0) | \bar{B}_s \rangle$$

from final states common to B_s and $\overline{B}_s$.



Crosses: Effective $|\Delta B| = 1$ operators from W-mediated b-decay.

Γ_{12} is a CKM-favored tree-level effect associated with final states containing a $(\overline{c}, c)$ pair.

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

$$a_{\rm fs}^s = \frac{\Gamma(\overline{B}_s(t) \to f) - \Gamma(B_s(t) \to \overline{f})}{\Gamma(\overline{B}_s(t) \to f) + \Gamma(B_s(t) \to \overline{f})}$$

with e.g. $f = X \ell^+ \nu_\ell$. Untagged rate:

$$A_{\rm fs,unt}^s \equiv \frac{\int_0^\infty dt \left[\Gamma(\overset{(-)}{B_s} \to \mu^+ X) - \Gamma(\overset{(-)}{B_s} \to \mu^- X)\right]}{\int_0^\infty dt \left[\Gamma(\overset{(-)}{B_s} \to \mu^+ X) + \Gamma(\overset{(-)}{B_s} \to \mu^- X)\right]} \simeq \frac{a_{\rm fs}^s}{2}$$

Dilepton events:

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

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

May 15, 2010: DØ presents measurements of

$$A^b_{\rm sl} = \frac{N_+ - N_-}{N_+ + N_-} = \frac{\int_0^\infty dt \left[\Gamma(\overset{(-)}{B} \to \mu^+ X) - \Gamma(\overset{(-)}{B} \to \mu^- X)\right]}{\int_0^\infty dt \left[\Gamma(\overset{(-)}{B} \to \mu^+ X) + \Gamma(\overset{(-)}{B} \to \mu^- X)\right]}$$

and

$$A^b_{\rm sl} = \frac{N_{++} - N_{--}}{N_{++} + N_{--}}$$

for a mixture of B_d and B_s mesons with

$$A^b_{\rm sl} = (0.506 \pm 0.043) a^d_{\rm sl} + (0.494 \pm 0.043) a^s_{\rm sl}$$

Choosing a linear combination which minimises the error DØ finds:

$$A^b_{\rm sl} = (-9.57 \pm 2.51 \pm 1.46) \cdot 10^{-3}$$

which is 3.2σ away from $A^{b,\rm SM}_{\rm sl} = \left(-0.23^{+0.05}_{-0.06}\right) \cdot 10^{-3}$.

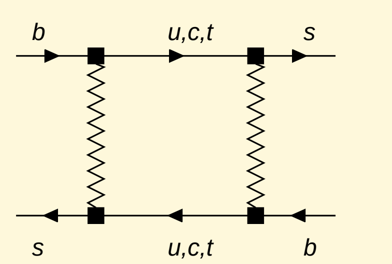
A. Lenz, UN, 2006

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

Standard Model:

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

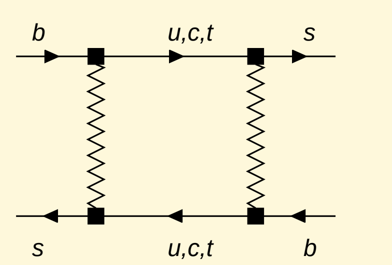
Γ_{12}^s from absorptive part of box, only internal u, c contribute.



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.

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



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$\Rightarrow$ $\Delta m_s \simeq 2|M_{12}^s|$ can change.

and in $\phi_s \simeq \arg(-M_{12}^s/\Gamma_{12}^s)$ the GIM suppression of ϕ_s can be lifted.

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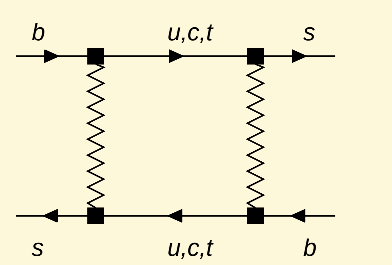

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$\Rightarrow$ $|\Delta\Gamma_s| = \Delta\Gamma_{s,\mathrm{SM}}\,|\cos\phi_s|$ is depleted and $|a_{\mathrm{fs}}^s|$ is enhanced, by up to a factor of 200.

To identify or constrain new physics one wants to measure both the magnitude and phase of M_{12}^s.

$$\rightarrow \qquad \Delta m_s = 2|M_{12}^s|$$

Three untagged measurements are sensitive to $\arg M_{12}^s$:

1. $|\Delta\Gamma_s| = 2|\Gamma_{12}^s|\,|\cos\phi_s|$
2. $a_{\text{fs}}^s = \left|\frac{\Gamma_{12}^s}{M_{12}^s}\right| \sin\phi_s$
3. the angular distribution of $\overset{(-)}{B_s} \rightarrow VV'$, where V, V' are vector bosons.

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Gold-plated tagged measurement of $\arg M_{12}^s$:

Mixing-induced CP asymmetry in $a_{\rm mix}^{\rm CP}(B_s \rightarrow J/\psi\phi)$ (with angular analysis)

Generic new physics

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

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

Define the complex parameter Δ_s through

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

In the Standard Model $\Delta_s = 1$.

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The CDF measurement

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

and $$f_{B_s}\sqrt{B} = 214 \pm 15\ \text{MeV}$$ HPQCD 2009

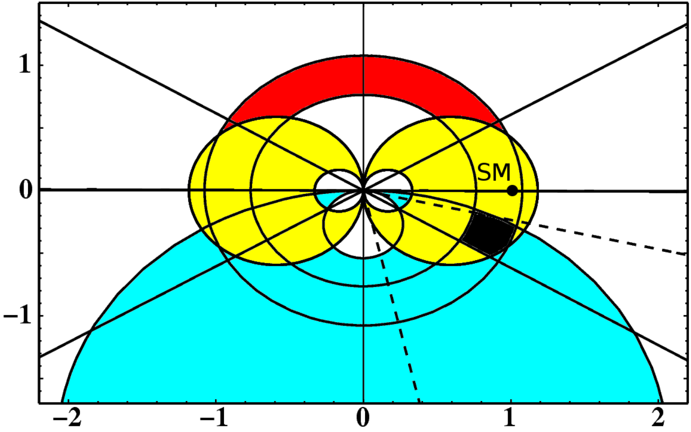
imply $$|\Delta_s| = 0.96 \pm 0.14_{\rm (th)} \pm 0.01_{\rm (exp)}$$

Status of December 2006: CDF or DØ data available for

- mass difference Δm_s,
- the semileptonic CP asymmetry a^s_{fs},
- the angular distribution in $\overset{(-)}{B}_s \to J/\psi\phi$ and
- $\Delta\Gamma_s$

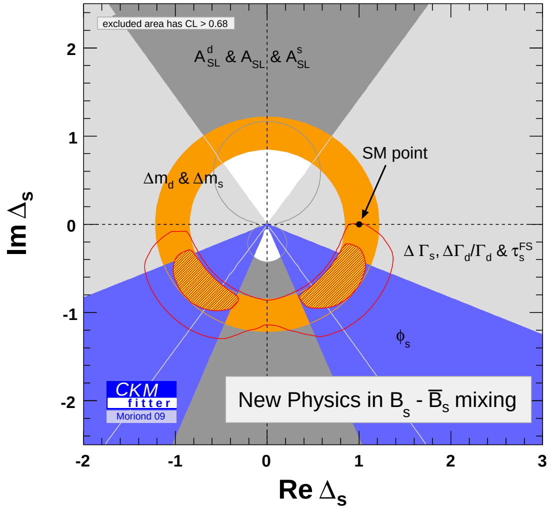
to constrain Δ_s.

The complex Δ_s plane in 2006:



We black area shown corresponds to a deviation from the Standard Model by 2σ. The area delimited by the dashed lines has mirror solutions in the other three quadrants. Alex Lenz, UN

The complex Δ_s plane before May 14, 2010:



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

Since there is not much room for new physics in $a_{\rm fs}^d$, the DØ measurement of $A_{\rm sl}^b = (-9.57 \pm 2.51 \pm 1.46) \cdot 10^{-3}$ implies $a_{\rm fs}^s = (-19 \pm 6) \cdot 10^{-3}$.

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To maximise $|a_{fs}^s|$ choose the minimal value $|\Delta_s|_{\min} = 0.82$ to find

$$a_{fs}^s \geq -7.2 \cdot 10^{-3} \sin\phi_s.$$

The DØ result therefore corresponds to

$$\sin\phi_s \leq -2.6 \pm 0.8$$

The DØ result is therefore at least 1.9σ away from any model of new physics.

Supersymmetry

The MSSM has many new 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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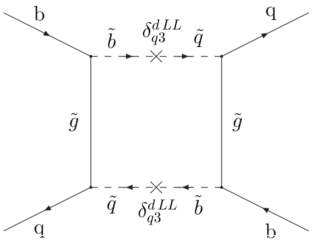
Not diagonal! $\Rightarrow$ new FCNC transitions.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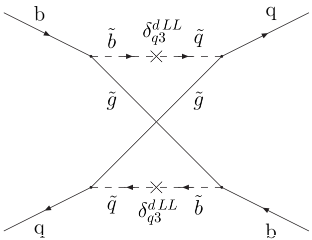
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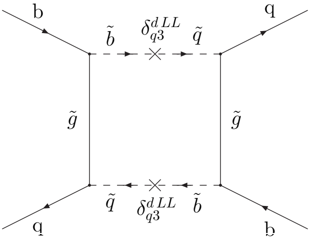
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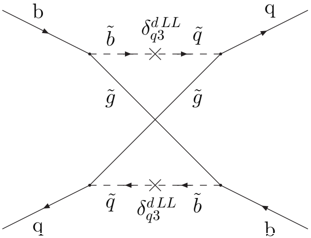
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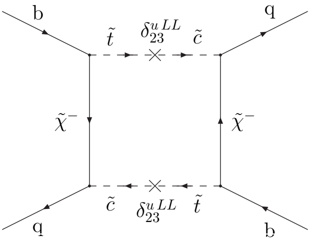
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Flavour and SUSY GUTs

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).

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

Chang-Masiero-Murayama model

Symmetry breaking chain:
$SO(10) \rightarrow SU(5) \rightarrow SU(3) \times SU(2)_L \times U(1)_Y$.

1. The SUSY-breaking terms are universal at the Planck scale.

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1. The SUSY-breaking terms are universal at the Planck scale.
2. Renormalization effects from the top-Yukawa coupling destroy the universality at $M_{\rm GUT}$.
3. Rotating $\overline{\mathbf{5}}_2$ and $\overline{\mathbf{5}}_3$ into mass eigenstates generates a $\tilde{b}_R - \tilde{s}_R$ element in the mass matrix of right-handed squarks.

Phenomenological effect: leads to MSSM with

1. new loop-induced $b_R \to s_R$ and $b_L \to s_R$ transitions, while all other FCNC transitions are CKM-like,

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2. all MSSM masses and couplings fixed in terms of a few GUT parameters.

$\Rightarrow$ well-motivated falsifiable version of the MSSM without minimal flavour violation (MFV),
puts largest effects into $b_R \to s_R$, where Standard Model leaves the most room for new physics.

SO(10) superpotential:

$$W_Y = \frac{1}{2} 16_i \, Y_u^{ij} \, 16_j \, 10_H + \frac{1}{2} 16_i \, Y_d^{ij} \, 16_j \, \frac{45_H \, 10'_H}{M_{\text{Pl}}} + \frac{1}{2} 16_i \, Y_N^{ij} \, 16_j \, \frac{\overline{16}_H \overline{16}_H}{M_{\text{Pl}}}$$

with the Planck mass M_{Pl} and

16_i:	one matter superfield per generation, $i = 1, 2, 3$,
10_H:	Higgs superfield containing MSSM Higgs superfield H_u,
$10'_H$:	Higgs superfield containing MSSM superfield H_u,
45_H:	Higgs superfield in adjoint representation,
$\overline{16}_H$:	Higgs superfield in spinor representation.

“Most minimal flavor violation”

The Yukawa matrices Y_u and Y_N are always symmetric. In the CMM model they are assumed to be simultaneously diagonalisable at the scale $Q = M_{\rm Pl}$, where the soft SUSY-breaking terms are universal.
All flavour violation stems from Y_d:

$$\mathsf{Y}_d = V_{\rm CKM}^* \begin{pmatrix} y_d & 0 & 0 \\ 0 & y_s & 0 \\ 0 & 0 & y_b \end{pmatrix} U_{\rm PMNS}$$

For flavour physics relevant: large top-Yukawa coupling in Y_u.
In a basis with diagonal Y_u the low-energy mass matrix for the right-handed down squarks reads:

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

with a calculable real parameter $\Delta_{\tilde{d}}$.
Rotating Y_d to diagonal form puts the large atmospheric neutrino mixing angle into $\mathsf{m}^2_{\tilde{d}}$:

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

The CP phase ξ affects $B_s-\overline{B}_s$ mixing!

Phenomenology

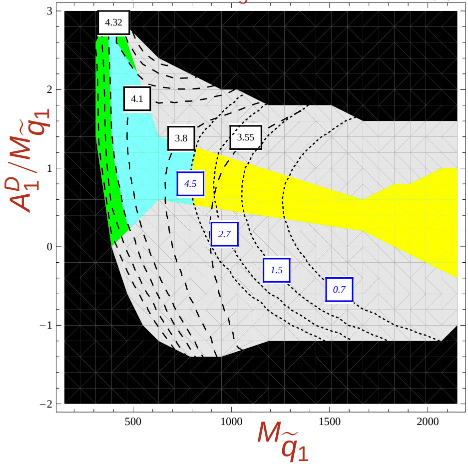
We have considered $B_s - \overline{B}_s$ mixing, $b \to s\gamma$, $\tau \to \mu\gamma$, vacuum stability bounds, lower bounds on sparticle masses and the mass of the lightest Higgs boson.
The analysis involves 7 parameters in addition to those of the Standard Model.

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

Collaborators:

Sebastian Jäger, Markus Knopf, Waldemar Martens, Christian Scherrer and Sören 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: $10^8 \cdot Br(\tau \to \mu\gamma)$.

Conclusions

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- $B_s - \overline{B}_s$ mixing is very sensitive to new physics. Large effects are possible in supersymmetry without violating constraints from other FCNC processes.
- 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. However, the central value is unphysical.
- A study in the CMM model of GUT flavour physics has revealed a possible large impact of the atmospheric mixing angle on $B_s - \overline{B}_s$ mixing without conflicting with $b \to s\gamma$ and $\tau \to \mu\gamma$.