Probing new physics with flavour: the status in 2012

Ulrich Nierste

Karlsruhe Institute of Technology

Universität Münster
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Contents

Basics

Flavour physics

studies transitions between fermions of different generations.

flavour = fermion species

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

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

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

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

Elektroweak interaction

Gauge group: $SU(2) \times U(1)_Y$

doublets: $Q_L^j = \begin{pmatrix} u_L^j \\ d_L^j \end{pmatrix}$ und $L^j = \begin{pmatrix} \nu_L^j \\ \ell_L^j \end{pmatrix}$
$j = 1, 2, 3$ labels the generation.

Examples: $Q_L^3 = \begin{pmatrix} t_L \\ b_L \end{pmatrix}$, $L^1 = \begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}$

singlets: u_R^j, d_R^j and e_R^j.

Important: Only left-handed fields couple to the W boson.

Yukawa interaction

Higgs doublet $H = \begin{pmatrix} G^+ \\ v + \frac{h^0 + iG^0}{\sqrt{2}} \end{pmatrix}$ with $v = 174\,\mathrm{GeV}$.

Charge-conjugate doublet: $\widetilde{H} = \begin{pmatrix} v + \frac{h^0 - iG^0}{\sqrt{2}} \\ -G^- \end{pmatrix}$

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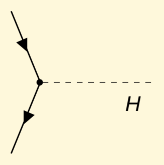

Quark Yukawa lagrangian:

$$-L_Y^q = Y_{jk}^d \, \overline{Q}_L^j \, H \, d_R^k \; + \; Y_{jk}^u \, \overline{Q}_L^j \, \widetilde{H} \, u_R^k \; + \; \text{h.c.}$$

The Yukawa matrices Y^f are arbitrary complex 3×3 matrices.

With three unphysical rotations in flavour space achieve

$$Y^u = \widehat{Y}^u = \begin{pmatrix} y_u & 0 & 0 \\ 0 & y_c & 0 \\ 0 & 0 & y_t \end{pmatrix} \qquad \text{and} \qquad Y^d = V^\dagger \widehat{Y}^d$$

$$\text{with} \qquad \widehat{Y}^d = \begin{pmatrix} y_d & 0 & 0 \\ 0 & y_s & 0 \\ 0 & 0 & y_b \end{pmatrix}$$

and $y_i \geq 0$.

V is the Cabbibbo-Kobayashi-Maskawa (CKM) matrix.

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$$d_L^j = V_{jk} d_L^{k\prime}$$

diagonalises Y^d and puts the Cabbibbo-Kobayashi-Maskawa (CKM) matrix V into the W boson vertices.

Flavour physics is governed by extremely small numbers:

$$Y^d = V^\dagger \widehat{Y}^d = \begin{pmatrix} 10^{-5} & -7\cdot 10^{-5} & (12+6i)\cdot 10^{-5} \\ 4\cdot 10^{-6} & 3\cdot 10^{-4} & -6\cdot 10^{-4} \\ (2+6i)\cdot 10^{-8} & 10^{-5} & 2\cdot 10^{-2} \end{pmatrix}$$

evaluated at the energy scale m_t. Off-diagonal element with largest magnitude: $V_{ts}^* y_b = -6\cdot 10^{-4}$.

Flavour puzzle of the Standard Model

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Flavour puzzle of the Standard Model

Flavour-changing neutral current (FCNC) processes are further loop-suppressed. $\Rightarrow$ El Dorado for new-physics searches.

Expand the CKM matrix V in $V_{us} \simeq \lambda = 0.2254$:

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

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

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

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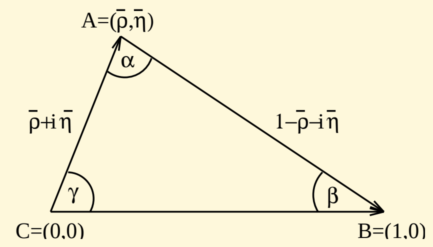
Unitarity triangle:

Exact definition:

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



Win-win situation

If ATLAS and CMS find particles not included in the SM:

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If ATLAS and CMS find no new particles (apart from the SM Higgs boson):

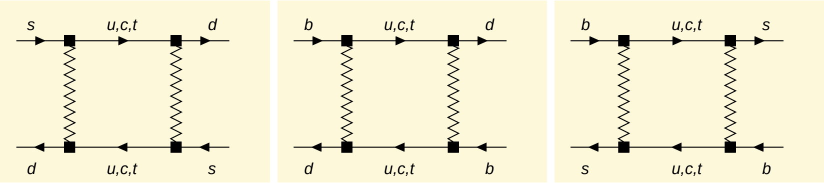
Flavour physics probes new interactions associated with particle masses exceeding 100 TeV.

Flavour experiments

		advantages	disadvantages
LHCb	b, c	best statistics	no decays w. missing energy
Belle-II, SuperB	b, c, τ	good for photons, missing energy, coherent $(B, \overline{B})$	less statistics than LHCb, latecomers
BES-III	c, τ	coherent $(D, \overline{D})$	smaller τ production rate
NA62	$K^+ \to \pi^+ \nu\overline{\nu}$ and other K	best for K^+	
KOTO	$K_L \to \pi^0 \nu\overline{\nu}$	best for K_L	
MEG	$\mu \to e\gamma$, eee	best for charged LFV	
Project X	μ, K, ν		

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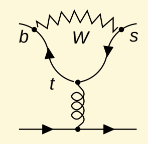
- Penguin decays: $B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$, $B \to K\pi$, $B_d \to \phi K_S$, $B_s \to \mu^+\mu^-$, $K \to \pi\nu\bar{\nu}$.



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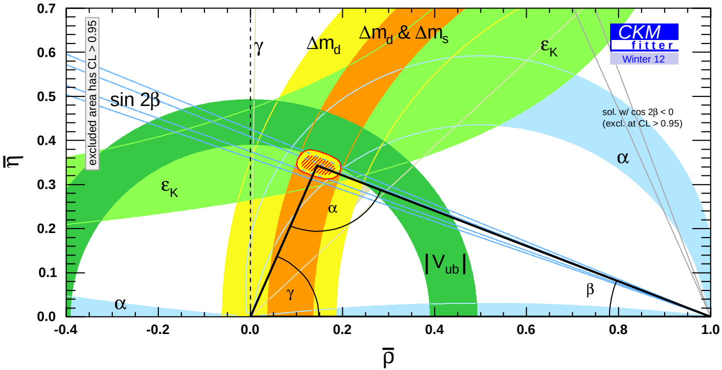
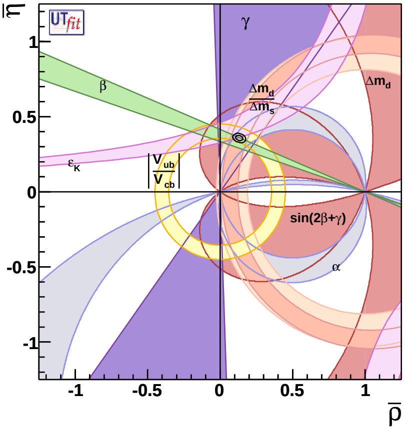
- CKM-suppressed or helicity-suppressed tree-level decays: $B^+ \to \tau^+\nu$, $B \to \pi\ell\nu$, $B \to D\tau\nu$, probe charged Higgses and right-handed W-couplings.

Global fit in the SM from CKMfitter:



Statistical method: Rfit, a Frequentist approach.

Global fit in the SM from UTfit:



Statistical method: Bayesian.

$B-\bar{B}$ mixing in the Standard Model

$B_q-\bar{B}_q$ mixing with $q=d$ or $q=s$ involves the 2×2 matrices M and Γ.

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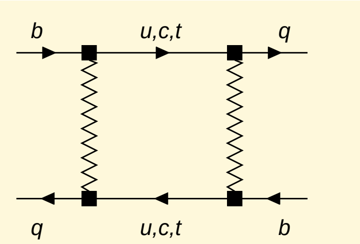

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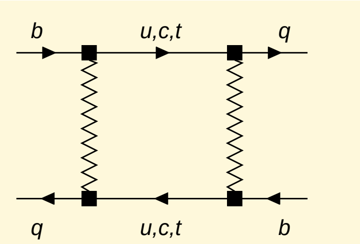

3 physical quantities in $B_q-\bar{B}_q$ mixing:

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

The two eigenstates found by diagonalising $M - i\,\Gamma/2$ differ in their masses and widths:

$$\begin{aligned} \text{mass difference} \qquad \Delta m_q &\simeq 2|M_{12}^q|, \\ \text{width difference} \qquad \Delta\Gamma_q &\simeq 2|\Gamma_{12}^q|\cos\phi_q \end{aligned}$$

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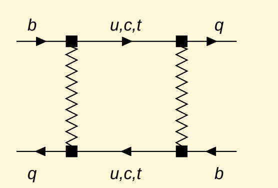
CP asymmetry in flavor-specific decays (semileptonic CP asymmetry):

$$a_{\rm fs}^q = \frac{|\Gamma_{12}^q|}{|M_{12}^q|}\sin\phi_q$$

$B-\bar{B}$ mixing basics

Consider $B_q-\bar{B}_q$ mixing with $q = d$ or $q = s$:
A meson identified ("tagged") as a B_q at time $t = 0$ is described by $|B_q(t)\rangle$.



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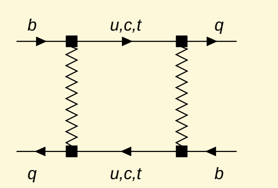

For $t > 0$:

$$|B_q(t)\rangle = \langle B_q|B_q(t)\rangle|B_q\rangle + \langle \bar{B}_q|B_q(t)\rangle|\bar{B}_q\rangle + \ldots,$$

with "$\ldots$" denoting the states into which $B_q(t)$ can decay.

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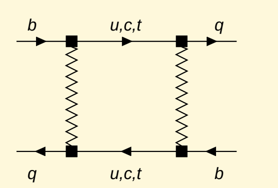

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with "$\ldots$" denoting the states into which $B_q(t)$ can decay.

Analogously: $|\bar{B}_q(t)\rangle$ is the ket of a meson tagged as a $\bar{B}_q$ at time $t=0$.

Probabilities for B_q survival and $B_q - \bar{B}_q$ mixing:

$$|\langle B_q|B_q(t)\rangle|^2 = |\langle \bar{B}_q|\bar{B}_q(t)\rangle|^2 = \frac{e^{-\Gamma_q t}}{2}\left[\cosh\frac{\Delta\Gamma_q\, t}{2} + \cos(\Delta m_q\, t)\right]$$

$$|\langle \bar{B}_q|B_q(t)\rangle|^2 \simeq |\langle B_q|\bar{B}_q(t)\rangle|^2 \simeq \frac{e^{-\Gamma_q t}}{2}\left[\cosh\frac{\Delta\Gamma_q\, t}{2} - \cos(\Delta m_q\, t)\right]$$

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The CP asymmetry in flavor-specific decays is measured by counting leptons. E.g.:

$$\frac{a_{\rm fs}^s}{2} \simeq \frac{N(\overset{(-)}{B_s} \to X\ell^+) - N(\overset{(-)}{B_s} \to X\ell^-)}{N(\overset{(-)}{B_s} \to X\ell^+) + N(\overset{(-)}{B_s} \to X\ell^-)}$$

Generic new physics

Phases $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$ in the Standard Model:

$$\phi_d^{\rm SM} = -4.3^\circ \pm 1.4^\circ, \qquad \phi_s^{\rm SM} = 0.2^\circ.$$

Define the complex parameters Δ_d and Δ_s through

$$M_{12}^q \equiv M_{12}^{\rm SM,q} \cdot \Delta_q\,, \qquad \Delta_q \equiv |\Delta_q| e^{i\phi_q^\Delta}.$$

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

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In the Standard Model $\Delta_q = 1$. Use $\phi_s = \phi_s^{\mathrm{SM}} + \phi_s^\Delta \simeq \phi_s^\Delta$.
The measurements of LHCb, CDF and DØ average to

$$\Delta m_s = (17.69 \pm 0.08)\ \mathrm{ps}^{-1},$$

implying with lattice WA $f_{B_s}\sqrt{B^{\overline{\mathrm{MS}}}} = (212 \pm 14)$ MeV:

$$|\Delta_s| = 1.03 \pm 0.14_{\mathrm{(th)}} \pm 0.01_{\mathrm{(exp)}}$$

New CP phases ϕ_d^Δ and ϕ_s^Δ

The mixing-induced CP asymmetry $A_{\rm CP}^{\rm mix}(B_d \to J/\psi K_S)$ determines

$$2\beta + \phi_d^\Delta \qquad \text{with} \quad \beta = \arg\left(-\frac{V_{td}^* V_{tb}}{V_{cd}^* V_{cb}}\right).$$

Experimentally: $2\beta + \phi_d^\Delta = 21.1^\circ \pm 0.9^\circ$.

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$A_{\rm CP}^{\rm mix}(B_s \to J/\psi \phi)$ and $A_{\rm CP}^{\rm mix}(B_s \to J/\psi f_0)$ determine

$$2\beta_s - \phi_s^\Delta \qquad \text{with} \quad \beta_s = \arg\left(-\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*}\right) = 2.2^\circ.$$

D0 measures the dimuon asymmetry for a mixture of B_d and B_s mesons with

$$a_{\rm fs} = (0.594 \pm 0.022) a_{\rm fs}^d + (0.406 \pm 0.022) a_{\rm fs}^s$$

Recall: $a_{\rm fs}^q = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin \phi_q$.

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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."*

Summer 2010

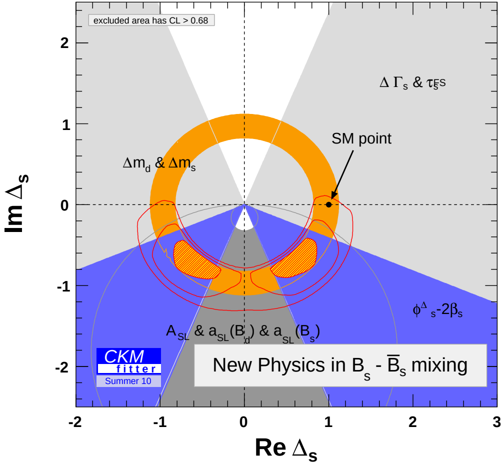
Global analysis of $B_s-\bar{B}_s$ mixing and $B_d-\bar{B}_d$ mixing with A. Lenz and the CKMfitter Group (J. Charles, S. Descotes-Genon, A. Jantsch, C. Kaufhold, H. Lacker, S. Monteil, V. Niess) arXiv:1008.1593

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:

$$\Delta_q \equiv \frac{M_{12}^q}{M_{12}^{q,\mathrm{SM}}}, \qquad \Delta_q \equiv |\Delta_q| e^{i\phi_q^\Delta}.$$

2010 result for $B_s-\bar{B}_s$ mixing:



SM point $\Delta_s = 1$ disfavoured by 2.7σ.

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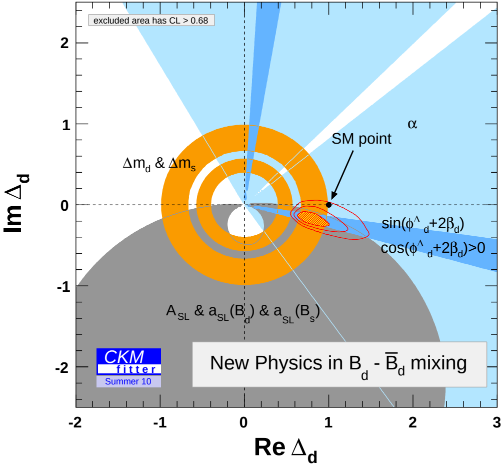

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Main driver:
$B^+ \to \tau^+ \nu_\tau$

CKM matrix V

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fixed by measurements of

$|V_{us}| = 0.2254 \pm 0.0013$,

$|V_{cb}| = (40.9 \pm 0.7) \cdot 10^{-3}$

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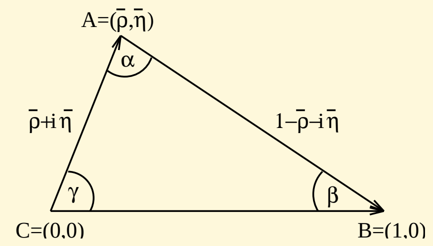


The $|V_{ub}|$ puzzle

Three ways to measure $|V_{ub}|$:

- exclusive decay $B \to \pi \ell \nu$,
- inclusive decay $B \to X \ell \nu$ and
- leptonic decay $B^+ \to \tau^+ \nu_\tau$.

The $|V_{ub}|$ puzzle

Three ways to measure $|V_{ub}|$:

- exclusive decay $B \to \pi \ell \nu$,
- inclusive decay $B \to X \ell \nu$ and
- leptonic decay $B^+ \to \tau^+ \nu_\tau$.

Average of several BaBar and Belle measurements:

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

Standard Model:

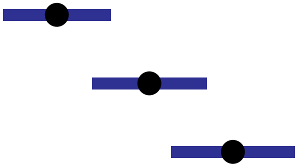
$$B(B^+ \to \tau^+ \nu_\tau) \quad = \quad 1.13 \cdot 10^{-4} \cdot \left(\frac{|V_{ub}|}{4 \cdot 10^{-3}} \right)^2 \left(\frac{f_B}{200 \text{ MeV}} \right)^2$$

The $|V_{ub}|$ puzzle

$$|V_{ub,\mathrm{excl}}| = (3.51 \pm 0.47) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{incl}}| = (4.32 \pm 0.50) \cdot 10^{-3}$$

$$|V_{ub,B\to\tau\nu}| = (5.10 \pm 0.59) \cdot 10^{-3}$$



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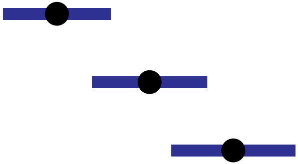

Here $f_B = (191 \pm 13)$ MeV is used:

$$\begin{aligned} |V_{ub,B\to\tau\nu}| &= \left[5.10 \pm 0.47|_{\mathrm{exp}} \pm 0.35|_{\mathrm{f_B}}\right] \cdot 10^{-3} \\ &= [5.10 \pm 0.59] \cdot 10^{-3} \end{aligned}$$

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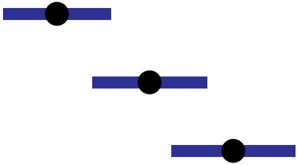

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\end{aligned}
$$

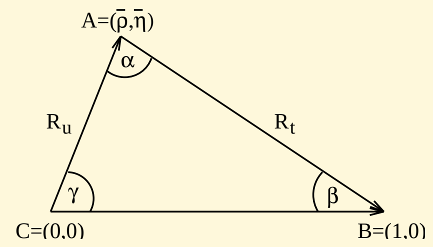
$\Rightarrow$ no puzzle with individual $|V_{ub}|$ determinations

The $|V_{ub}|$ puzzle

Indirect determination:

find $|V_{ub}| \propto |V_{cb}| R_u$

from $R_u = \frac{\sin\beta}{\sin\alpha}$



With $\alpha = 89^\circ{}^{+4.4^\circ}_{-4.2^\circ}$ and $\beta = 21.15^\circ \pm 0.89^\circ$ find

$$|V_{ub}|_{\rm ind} = (3.41 \pm 0.15) \cdot 10^{-3}$$

Essential: β from $A_{\rm CP}^{\rm mix}(B_d \to J/\psi K_S)$

The $|V_{ub}|$ puzzle

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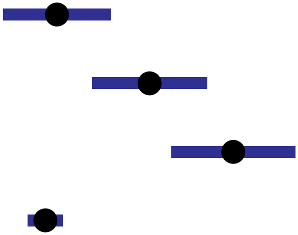

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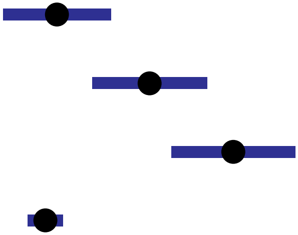

Alleviate the 2.9σ tension between $|V_{ub,\text{ind}}|$ and $|V_{ub,B\to\tau\nu}|$ with new physics in

- $B^+ \to \tau^+\nu_\tau$ or
- $A_{\text{CP}}^{\text{mix}}(B_d \to J/\psi K_S)$. $\leftarrow$ easier!

In Summer 2010 the combination of all flavour data was in excellent agreement with the hypothesis of new physics in M_{12}^d and M_{12}^s, while all other (essentially tree-level) quantities entering the global UT fit are SM-like.

Hypothesis	Summer 2010 p-value
$\Delta_d = 1$ (2D)	$2.7\,\sigma$
$\Delta_s = 1$ (2D)	$2.7\,\sigma$
$\Delta_d = \Delta_s$ (2D)	$2.1\,\sigma$
$\Delta_d = \Delta_s = 1$ (4D)	$3.6\,\sigma$

Summer 2011

The mixing-induced CP asymmetries in $B_s \to J/\psi\phi$ and $B_s \to J/\psi f_0$ determine $\phi_s^\Delta - 2\beta_s$ with $2\beta_s = 2.2^\circ$.

CDF 2010, $J/\psi\phi$: $\phi_s^\Delta = -23^{\circ}{}^{+23^\circ}_{-34^\circ}$

DØ EPS 2011, $J/\psi\phi$: $\phi_s^\Delta = -30^{\circ}{}^{+22^\circ}_{-21^\circ}$

LHCb 12/2011, $J/\psi f_0$: $\phi_s^\Delta = -23^\circ \pm 25^\circ \pm 1^\circ$

LHCb 12/2011, $J/\psi\phi$: $\phi_s^\Delta = 10.8^\circ \pm 10.3^\circ \pm 3.4^\circ$

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LHCb LP 2011 average: $\phi_s^\Delta = 3.9^\circ \pm 9.2^\circ \pm 4.0^\circ$

My average: $\phi_s^\Delta = -1.8^\circ \pm 8.6^\circ$

with CDF/DØ errors inflated by a factor of 1.25 as a guesstimate for correlations.

All measurements are in mutual agreement and consistent with the SM prediction $\phi_s^\Delta = 0$.

Spring 2012

ArXiv:1112.1726:
CDF 2010, $J/\psi\phi$: $-57.4^\circ \leq \phi_s^\Delta \leq -0.1^\circ$

LHCb has analysed 1 fb^{-1} of data (was 0.37 fb^{-1} in 2011 paper), extended $B_s \to J/\psi\pi^+\pi^-$ analysis to much wider window around $M_{\pi\pi} = M_{f_0}$.

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LHCb Moriond 2012, average: $\phi_s^\Delta = 2.1^\circ \pm 4.8^\circ \pm 1.6^\circ$

My average of CDF, DØ and LHCb data:

$$\phi_s^\Delta = -0.3^\circ \pm 4.7^\circ \pm 1.6^\circ$$

But:

30 Jun 2011: DØ result presents the semileptonic CP asymmetry measured in the dimuon channel:

$$a_{\rm fs} = (-7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3}$$

for a mixture of B_d and B_s mesons with

$$a_{\rm fs} \quad = \quad (0.594 \pm 0.022) a_{\rm fs}^d + (0.406 \pm 0.022) a_{\rm fs}^s$$

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$a_{\rm fs}$ favours $\phi_s^\Delta < 0$ in agreement with the $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$ measurements of CDF and DØ and $A_{\rm CP}^{\rm mix}(B_s \to J/\psi f_0)$ from LHCb.... but poor agreement with $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$ from LHCb.

Theory prediction with new physics:

$$a_{\rm fs} = (3.2 \pm 0.6) \cdot 10^{-3} \frac{\sin \phi_d^\Delta}{|\Delta_d|} + (2.1 \pm 0.4) \cdot 10^{-3} \frac{\sin \phi_s^\Delta}{|\Delta_s|}$$

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$\Rightarrow$ The central value of

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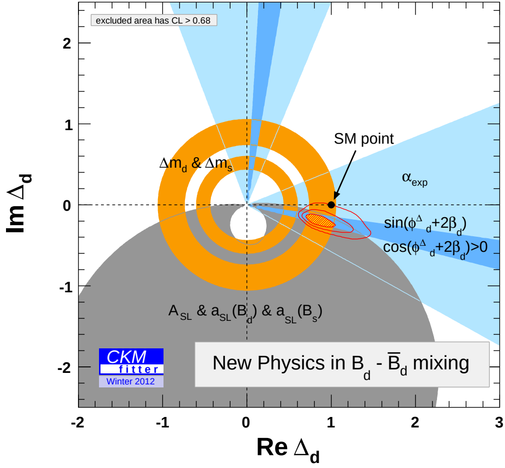
How much of $a_{\rm fs}$ could come from $a_{\rm fs}^d$?

Post-Moriond-2012 status for $B_d - \bar{B}_d$ mixing:



SM point $\Delta_d = 1$ disfavoured by 3.0σ.

1σ range:

$$\phi_d^\Delta = -13.4^{\circ}{}^{+3.3^\circ}_{-2.2^\circ}$$

Drivers:

$B^+ \to \tau^+ \nu_\tau$, $a_{\rm fs}$

Lenz et al., 1203.0238

The fit prefers $\phi_d^\Delta < 0$, so that $a_{\rm fs}^d$ returned by the fit is well below $a_{\rm fs}^{d\,\rm SM} = (-0.41 \pm 0.06) \cdot 10^{-3}$:

$$a_{\rm fs}^d = \left(-3.32^{+0.66}_{-0.41}\right) \cdot 10^{-3}$$

This is better than the direct measurements by Belle, BaBar and CLEO, averaging to

$$a_{\rm fs}^d = (-4.7 \pm 4.6) \cdot 10^{-3},$$

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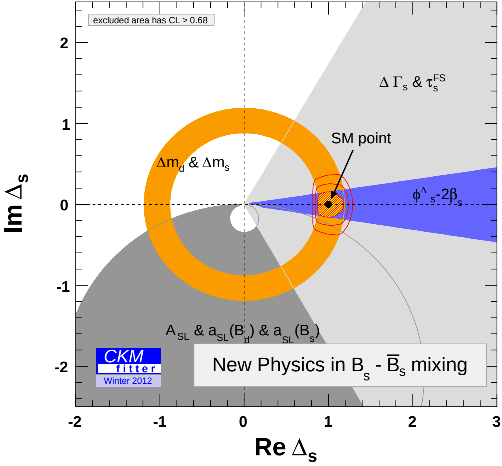
but assumes that there is no new physics in Γ_{12}^d.
The contribution from new physics in $B_d - \bar{B}_d$ mixing to $a_{\rm fs}$ is therefore

$$0.594 \left(-3.32^{+0.66}_{-0.41}\right) \cdot 10^{-3} = \left(-2.0^{+0.4}_{-0.2}\right) \cdot 10^{-3}$$

The contribution from ϕ_d^Δ reduces the discrepancy in $a_{\rm fs}$ from 3.9σ to $\sim 3.0\sigma$.

Post-Moriond-2012 result for $B_s - \bar{B}_s$ mixing:



Perfect agreement with SM point $\Delta_s = 1$ (0.0σ).

Lenz et al., 1203.0238

Pulls

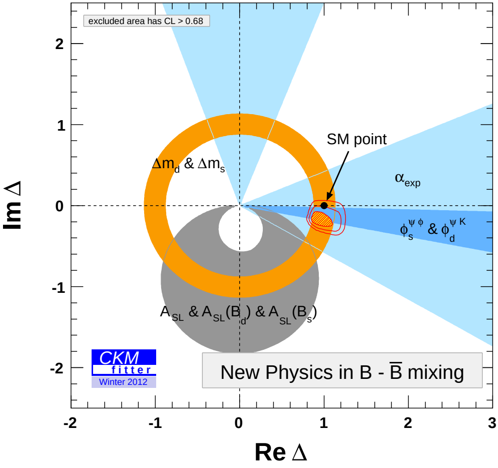
Quantity	SM
$A_{\rm CP}^{\rm mix}(B_d \to J/\psi\, K_S)$	2.7σ
$A_{\rm CP}^{\rm mix}(B_s \to J/\psi\, \phi)$	0.3σ
Δm_d	1.0σ
Δm_s	0.0σ
$a_{\rm fs}$	3.7σ
$B(B \to \tau\nu)$	2.8σ
$B(B \to \tau\nu), a_{\rm fs}$	4.3σ

Pulls

Quantity	SM	NP
$A_{\rm CP}^{\rm mix}(B_d \to J/\psi\, K_S)$	2.7σ	2.1σ
$A_{\rm CP}^{\rm mix}(B_s \to J/\psi\, \phi)$	0.3σ	2.7σ
Δm_d	1.0σ	
Δm_s	0.0σ	
$a_{\rm fs}$	3.7σ	3.0σ
$B(B \to \tau\nu)$	2.8σ	1.1σ
$B(B \to \tau\nu), a_{\rm fs}$	4.3σ	2.8σ

The pulls show the deviation between the measurements and the prediction of the fit without the quantity.

Minimal flavour violation, set $\Delta_d = \Delta_s \equiv \Delta$.
Post-Moriond-2012 situation:



SM point $\Delta = 1$ disfavoured by 2.1σ.

Lenz et al., 1203.0238

Summary of p-values

Hypothesis	NP in Δ_d and Δ_s	MFV-NP, $\Delta_d = \Delta_s$
$\mathrm{Im}\Delta_d = 0$	3.2σ	2.6σ
$\mathrm{Im}\Delta_s = 0$	0.0σ	
$\Delta_d = 1$	3.0σ	2.1σ
$\Delta_s = 1$	0.0σ	
$\mathrm{Im}\Delta_d = \mathrm{Im}\Delta_s = 0$	2.8σ	
$\Delta_d = \Delta_s = 1$	2.4σ	

No preference of generic scenario over MFV scenario. The SM is disfavoured with 2.4σ, but scenarios which put NP only into M_{12}^q do not describe the data as well as they did in 2010, when the hypothesis $\Delta_s = \Delta_d = 1$ in the generic scenario was disfavoured with 3.6σ.

New physics in Γ_{12}^q?

Recall the LHCb measurement

$$\frac{\Gamma_d}{\Gamma_s} = \frac{\tau_{B_s}}{\tau_{B_d}} = 0.997 \pm 0.013$$

in excellent agreement with the SM prediction
$\tau_{B_s}/\tau_{B_d} = 0.998 \pm 0.003$.
Changing the Cabibbo-favoured tree-level quantity $|\Gamma_{12}^s|$ by opening new enhanced decay channels such as $B_s \to \tau^+\tau^-$ will spoil this ratio.

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Changing the Cabibbo-favoured tree-level quantity $|\Gamma_{12}^s|$ by opening new enhanced decay channels such as $B_s \to \tau^+\tau^-$ will spoil this ratio.

Phenomenologically, new physics in the doubly Cabibbo-suppressed quantity Γ_{12}^d is still allowed, but requires somewhat contrived models of new physics.

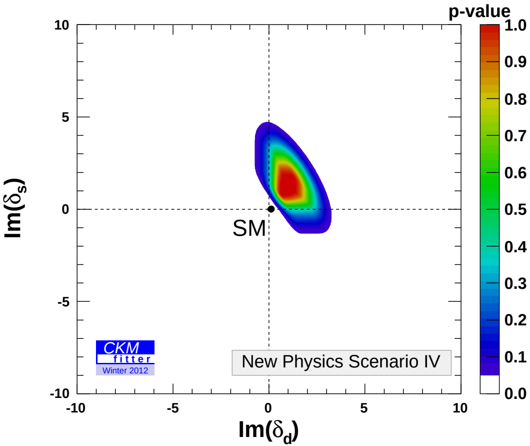
Fit with new physics in Γ_{12}^q

Define

$$\delta_q = \frac{\Gamma_{12}^q / M_{12}^q}{\mathrm{Re}\,(\Gamma_{12}^{\mathrm{SM},q} / M_{12}^{\mathrm{SM},q})}, \qquad \text{for} \quad q = d, s.$$

and fit for real and imaginary parts of Δ_d, Δ_s, δ_d, and δ_s.

Fit with new physics in Γ_{12}^q



Excellent fit, SM point disfavoured by 3.2σ.

If $\delta_s = \delta_s^{\rm SM}$, need new $\mathcal{O}(1)$ effects in Γ_{12}^d.

Lenz et al., 1203.0238

Conclusions

- Flavour physics complements the high-p_T programme at ATLAS and CMS. FCNC processes indirectly probe mass scales exceeding 100 TeV.

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- Still: In scenarios with new physics in M_{12}^q only, the SM is disfavoured by $2.4\,\sigma$, driven by the DØ dimuon asymmetry and $B(B \to \tau\nu)$.
- A good fit is found if also new physics in Γ_{12}^d is allowed, but the needed $\mathcal{O}(1)$ effects are hard to motivate in realistic models.

The quantum numbers of the SM point towards a grand unified theory (GUT), the gauge couplings converge to a common GUT value at high energies, similarly y_τ and y_b converge, and neutrinos have small masses as predicted by GUT pioneers.

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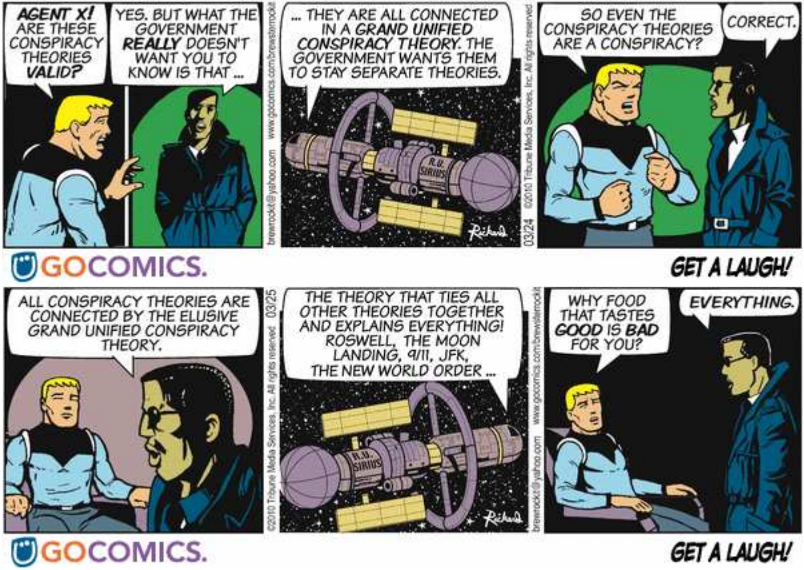
So is this just a conspiracy of Nature? Or even...


AGENT X! ARE THESE CONSPIRACY THEORIES VALID?
YES. BUT WHAT THE GOVERNMENT REALLY DOESN'T WANT YOU TO KNOW IS THAT ...
... THEY ARE ALL CONNECTED IN A GRAND UNIFIED CONSPIRACY THEORY. THE GOVERNMENT WANTS THEM TO STAY SEPARATE THEORIES.
SO EVEN THE CONSPIRACY THEORIES ARE A CONSPIRACY?
CORRECT.
GOCOMICS.
GET A LAUGH!
ALL CONSPIRACY THEORIES ARE CONNECTED BY THE ELUSIVE GRAND UNIFIED CONSPIRACY THEORY.
THE THEORY THAT TIES ALL OTHER THEORIES TOGETHER AND EXPLAINS EVERYTHING! ROSWELL, THE MOON LANDING, 9/11, JFK, THE NEW WORLD ORDER ...
WHY FOOD THAT TASTES GOOD IS BAD FOR YOU?
EVERYTHING.
GOCOMICS.
GET A LAUGH!