New Physics in Mixing

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CKM 2010

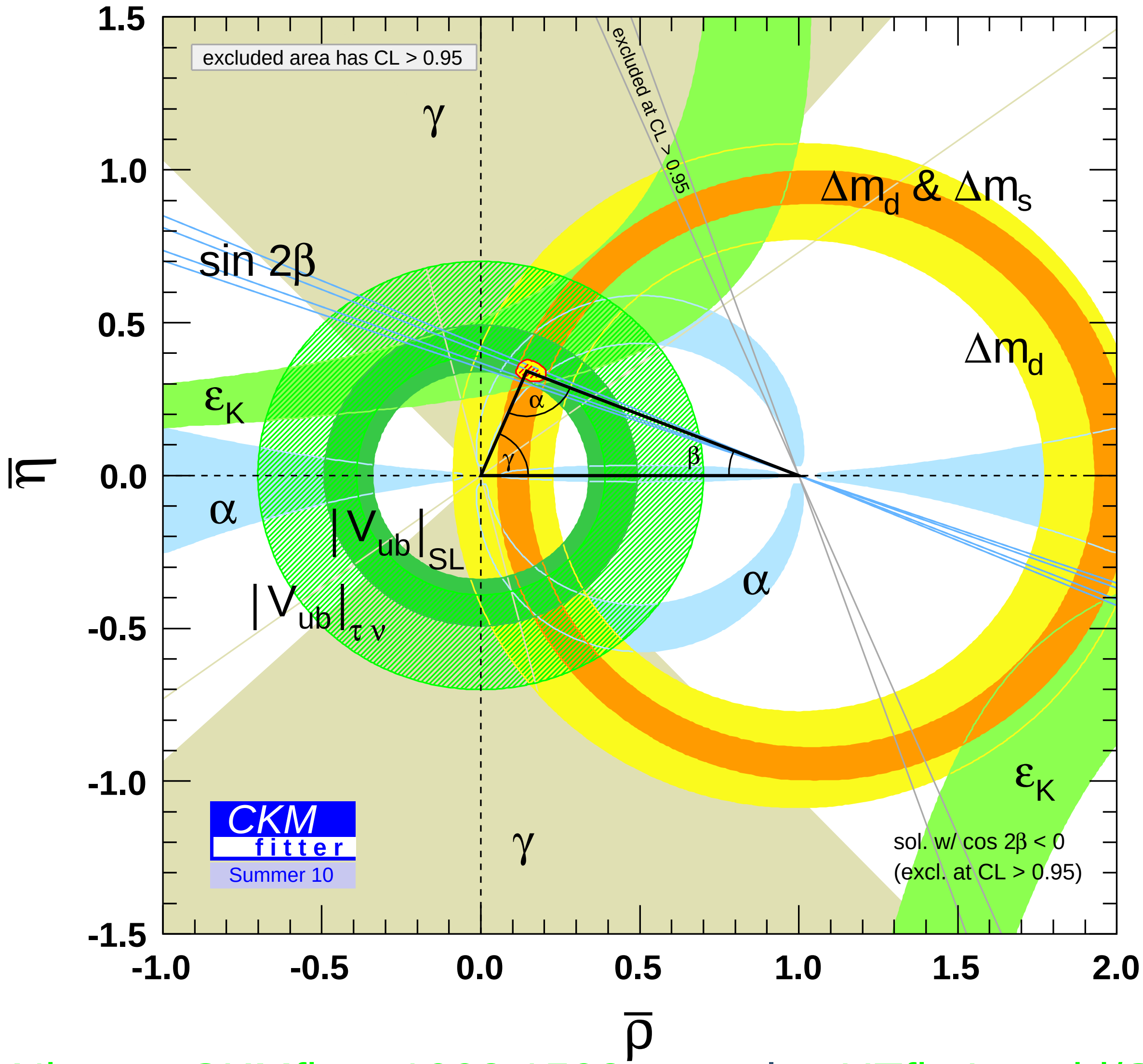
Good overall consistency

$$V_{CKM} = \begin{pmatrix} 0.97426 \pm 0.00030 & 0.22545 \pm 0.00095 & 0.00356 \pm 0.00020 \\ 0.22529 \pm 0.00077 & 0.97341 \pm 0.00021 & 0.04508^{+0.00075}_{-0.00528} \\ 0.00861^{+0.00021}_{-0.00037} & 0.04068 \pm 0.00138 & 0.999135^{+0.000057}_{-0.000018} \end{pmatrix}$$

Fit from A.L, Nierste, CKMfitter 1008.1593
see also UTfit 1010.5089, Lunghi/Soni 1010.6069, Laiho/Lunghi/Van de Water 1102.3917, PDG, HFAG ...

2008

CKM 2010



$$A = 0.815^{+0.011}_{-0.029}$$
$$\lambda = 0.22543(77)$$
$$\bar{\rho} = 0.1444^{+0.029}_{-0.018}$$
$$\bar{\eta} = 0.342(16)$$

Picture from A.L, Nierste, CKMfitter 1008.1593, see also UTfit, Lunghi/Soni, Laiho et al...

The first row: V_{ud}

- Nuclear β-decay
- Neutron β-decay
- Pion β-decay

$$|V_{ud}| = 0.97425 \pm 0.00022$$

PDG 2010, Hardy, Towner 2009

The first row: V_{us}

- K_{l3}-decays
- Hadronic τ decays
- Semi leptonic Hyperon decays

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

Antonelli et al. 1005.2323; Boyle et al. 1004.0886

The first row: V_{ub}

Exclusive	$\lvert V_{ub}\rvert = 0.00351 \pm 0.00047$
Inclusive	$\lvert V_{ub}\rvert = 0.00432 \pm 0.00027$
$B \to \tau\nu$	$\lvert V_{ub}\rvert = 0.00504 \pm 0.00064$
Fit	$\lvert V_{ub}\rvert = 0.00356 \pm 0.00020$

HFAG; HPQCD 2007; MILC Fermilab 2008;Ball/Zwicky 2005; Lange/Neubert/Paz 2005; Andersen/Gardi 2006,2008; Gambino/Giordano/Ossola/Uraltsev 2007; Aglietti/Di Lodovico/Ferrera/Ricciardi 2009; Aglietti/Ferrera/Ricciardi 2007; Bauer/Ligeti/Luke 2001,...

- V_{ub} is actually of order λ^4 and not λ^3: $0.00356 = (0.2254)^{3.79}$
- Hadronic uncertainties (lattice, LCSR) underestimated?
- Soni and Lunghi: do not to use V_{ub} in the global fit
- Crivellin0907.2461; Buras/Gemmler/Isidori 1007.1993: RH currents $\Rightarrow$ *incl.* $\neq$ *excl.*
- New Physics in $B \to \tau\nu$ vs. B_d-mixing

The first row: $V_{ub'}$

Test the accuracy of the CKM elements of the first row:

$$
\begin{aligned}
\delta(V_{ud}) &= 0.00022 \\
\delta(V_{us}) &= 0.00130 \\
\delta(V_{ub}) &= 0.00020 \\
\sqrt{1 - V_{ud}^2 - V_{us}^2} &= 0.00564^{+0.02669}_{-0.00564}
\end{aligned}
$$

Investigate hypothetical 4th generation of fermions
Assume V_{CKM4} is unitary

$\Rightarrow V_{ub'}$ **can still be larger than** V_{ub}: $V_{ub'} < 0.04$

Bobrowski, A.L., Rohrwild, Riedl, 0902.4883; Buras et al. 2010; Eberhardt, A.L., Rohrwild 1005.3505; Das, London, Sinha, Soffer 1008.4925; Alok, Dighe, London 1011.2634; Soni and Nandi 1011.6091;...

The second row: V_{cd}

- Semi leptonic Charm decays $D \to \pi l \nu$
- Charm Production in Neutrino Interactions

$$|V_{cd}| = 0.230 \pm 0.011$$

PDG 2010

The second row: V_{cs}

- Neutrino Scattering
- On-shell W decays
- Semi leptonic Charm decays

$$|V_{cs}| = 1.023 \pm 0.036$$

PDG 2010

The second row: V_{cb}

- $B \to X_c l \nu$
- $B \to D^{(*)}$ transitions

$$\text{Inclusive} \qquad |V_{cb}| = (41.85 \pm 0.43 \pm 0.59) \cdot 10^{-3}$$
$$\text{Exclusive} \qquad |V_{cb}| = (38.85 \pm 0.77 \pm 0.84) \cdot 10^{-3}$$

HFAG 2010; Gambino/Uraltsev (2004); Benson/Bigi/Uraltsev (2005); Benson/Bigi/Mannel/Uraltsev (2003);...

- Inclusive is again larger
- Try to make some combinations

$$|V_{cb}| = \begin{cases} (40.6 \pm 1.3) \cdot 10^{-3} & \text{PDG 2010} \\ (40.89 \pm 38 \pm 0.59) \cdot 10^{-3} & 1008.1593 \end{cases}$$

The second row: $V_{cb'}$

Test the accuracy of the CKM elements of the second row:

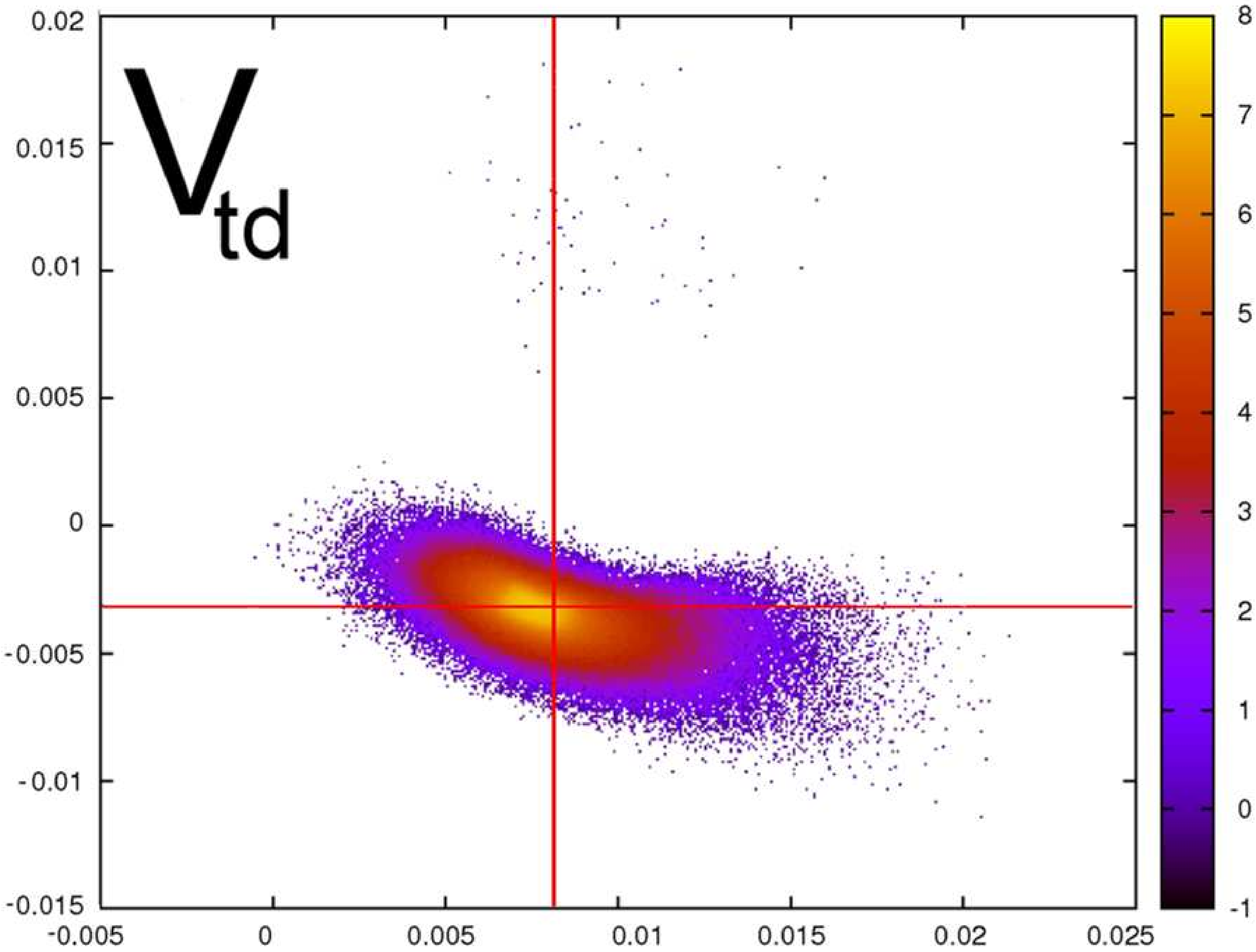
$$\begin{aligned} \delta(V_{cd}) &= 0.011 \\ \delta(V_{cs}) &= 0.036 \\ \delta(V_{cb}) &= 0.013 \end{aligned}$$

Investigate hypothetical 4th generation of fermions
Assume V_{CKM4} is unitary

$\Rightarrow V_{cb'}$ **can still be larger than** V_{cb}: $V_{cb'} < 0.15$

Bobrowski, A.L., Rohrwild, Riedl, 0902.4883; Buras et al. 2010; Eberhardt, A.L., Rohrwild 1005.3505; Das, London, Sinha, Soffer 1008.4925; Alok, Dighe, London 1011.2634; Soni and Nandi 1011.6091;

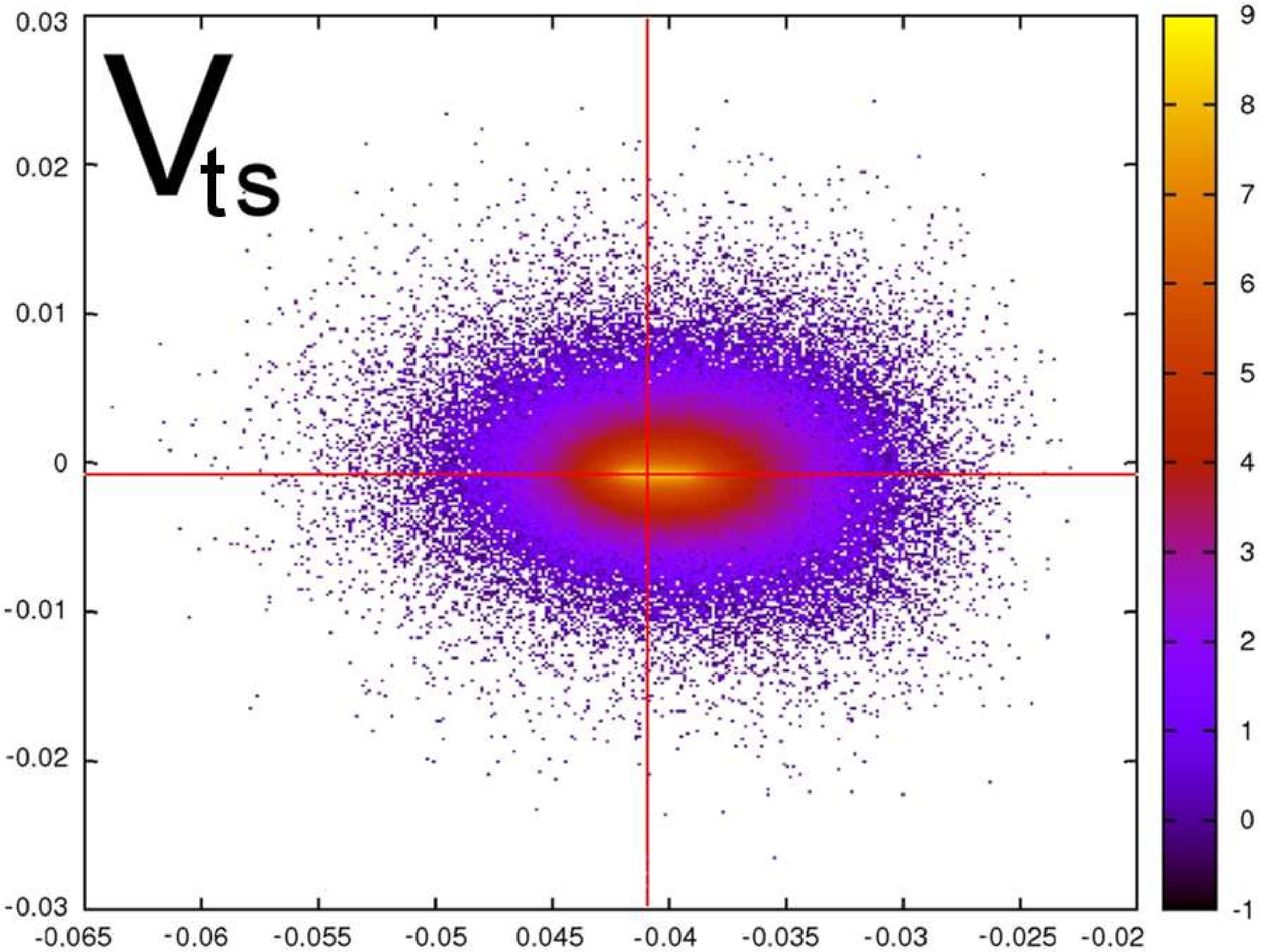
Im V_{td} vs. Re V_{td}



Eberhardt, A.L., Rohrwild 1005.3505

The third row: V_{ts}

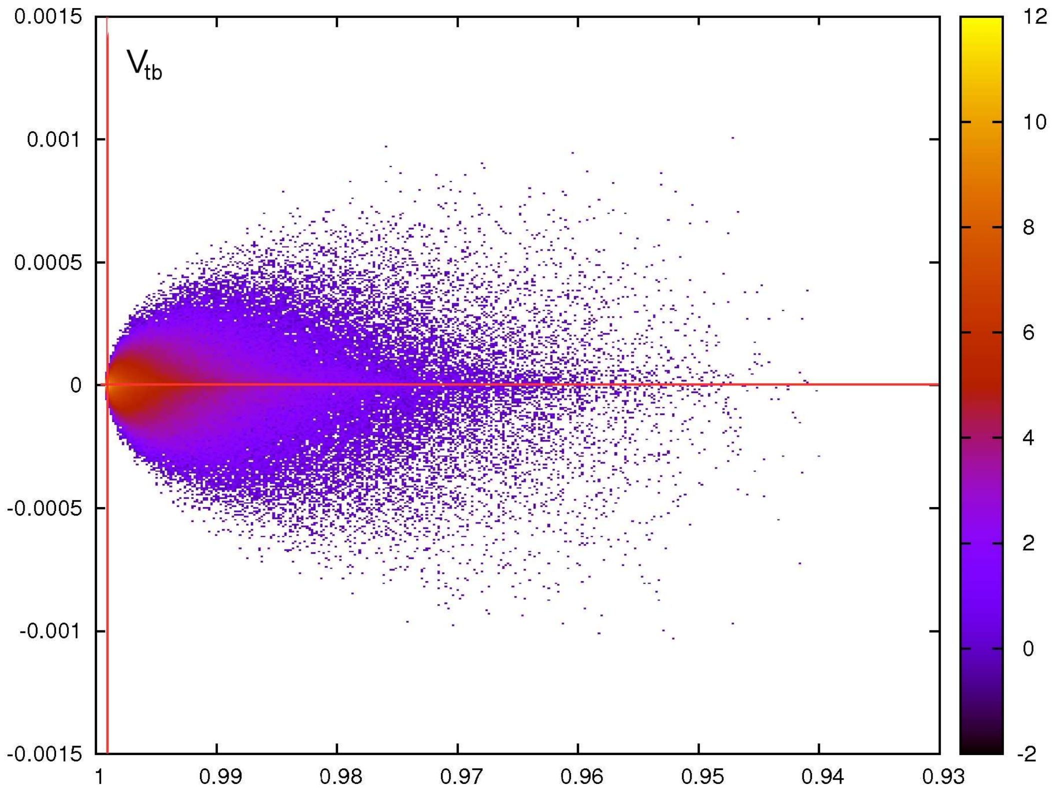
V_{ts} vs. Re V_{ts}



Eberhardt,
A.L.,
Rohrwild
1005.3505

The third row: V_{tb}

Im V_{tb} vs. Re V_{tb}



Eberhardt, A.L., Rohrwild 1005.3505

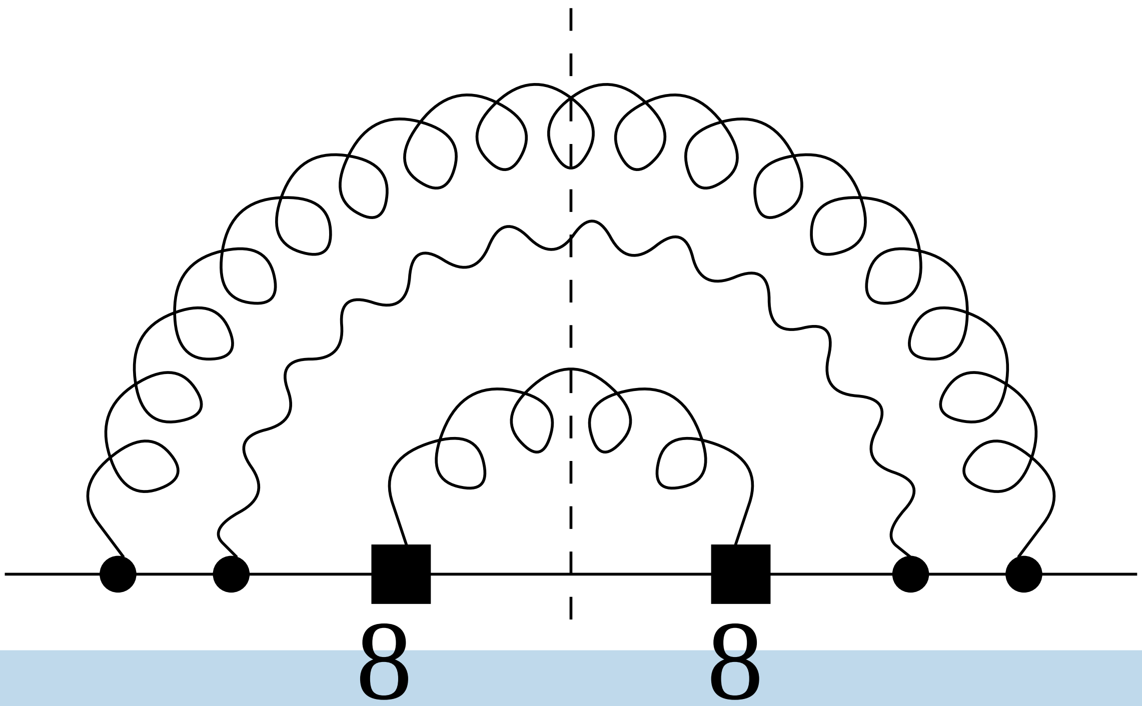
Single Top production Wagner 1101.4235; CDF 0903.0885,1004.1181; D0 0903.0850

$$V_{tb} = 0.88 \pm 0.07$$

$b \to s\gamma$: Another success of the CKM paradigm

$$Br(b \to s\gamma)^{\rm Exp} = (3.55 \pm 0.26) \cdot 10^{-4}$$
$$Br(b \to s\gamma)^{\rm Theo} = (3.15 \pm 0.23) \cdot 10^{-4}$$

Exp: HFAG, BaBar, BELLE, CLEO
Theory in NNLO Misiak et al. 2007,...
List of References in Misiak, PoS(FPCP 2010)025



Flavor Physics in the news

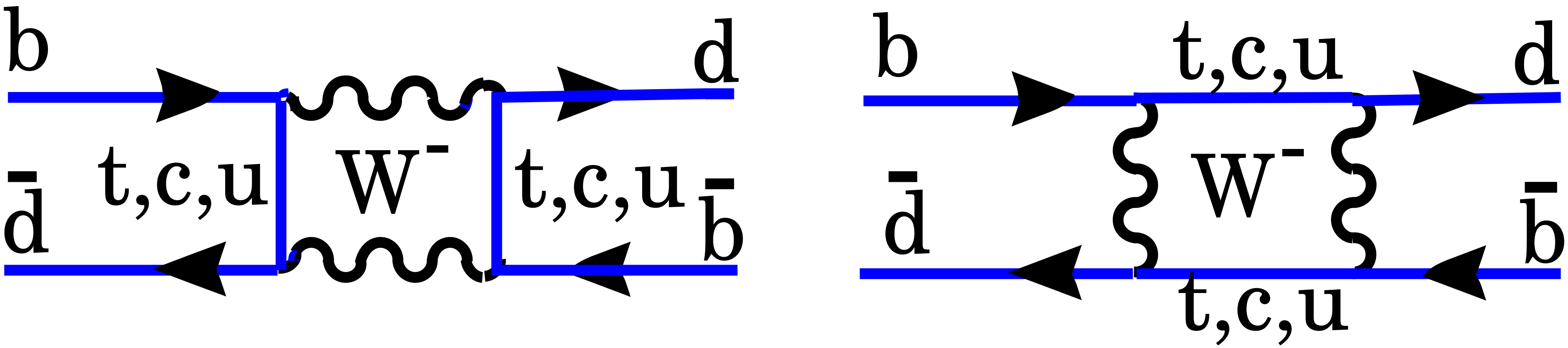
- 17.5.2010 **New York Times**
  A new Clue to explain existence
- 19.5.2010 **BBC News**
  New Clue to anti-matter mystery
- 20.5.2010 **Scientific American**
  Fermilab finds new mechanism for matter’s dominance over antimatter
- 20.5.2010 **The Times**
  Atom-smasher takes man closer to heart of matter
- 25.5.2010 **Spiegel**
  Neue Asymmetrie zwischen Materie und Antimaterie entdeckt
- 28.5.2010 **Science**
  Hints of greater matter-antimatter asymmetry challenge theorists
- 28.5.2010 **Die Zeit**
  Rätselhafte Asymmetrie
- 29.5.2010 **Chicago Tribune**
  Fermilab test throws off more matter than antimatter - and this matters
- ...

Mixing I

Time evolution of a decaying particle: $B(t) = \exp\left[-i m_B t - \Gamma_B/2 t\right]$
can be written as

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

BUT: In the neutral B-system transitions like $B_{d,s} \to \bar{B}_{d,s}$ are possible due to weak interaction: **Box diagrams**

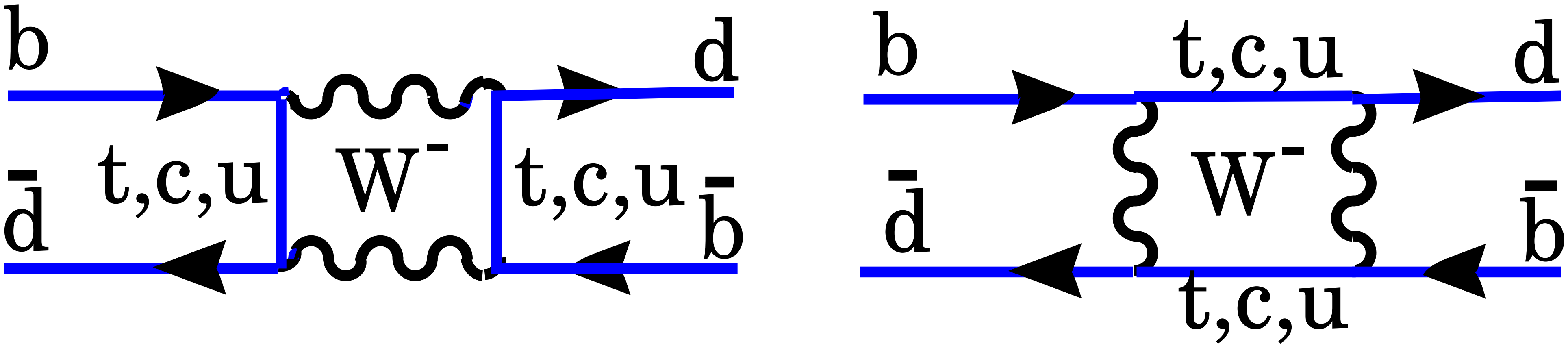


Mixing III

Time evolution of a decaying particle: $B(t) = \exp\left[-i m_B t - \Gamma_B/2 t\right]$
can be written as

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

BUT: In the neutral B-system transitions like $B_{d,s} \to \bar{B}_{d,s}$ are possible due to weak interaction: **Box diagrams**



$\Rightarrow$ **off-diagonal elements** in $\hat{M}$, $\hat{\Gamma}$: M_{12}, Γ_{12} (complex)

Diagonalization of $\hat{M}$, $\hat{\Gamma}$ gives the physical eigenstates B_H and B_L with the masses M_H, M_L and the decay rates Γ_H, Γ_L

CP-odd: $B_H := p\, B + q\, \bar{B}$, CP-even: $B_L := p\, B - q\, \bar{B}$ with $|p|^2 + |q|^2 = 1$

Mixing IV

$|M_{12}|$, $|\Gamma_{12}|$ and $\phi = \text{arg}(-M_{12}/\Gamma_{12})$ can be related to three observables:

- **Mass difference:** $\Delta M := M_H - M_L = 2|M_{12}| \left(1 - \frac{1}{8}\frac{|\Gamma_{12}|^2}{|M_{12}|^2}\sin^2\phi + ...\right)$
  $|M_{12}|$: heavy internal particles: t, SUSY, ...

- **Decay rate difference:** $\Delta\Gamma := \Gamma_L - \Gamma_H = 2|\Gamma_{12}|\cos\phi \left(1 + \frac{1}{8}\frac{|\Gamma_{12}|^2}{|M_{12}|^2}\sin^2\phi + ...\right)$
  $|\Gamma_{12}|$: light internal particles: u, c, ... (almost) no NP!!!

- **Flavor specific/semileptonic CP asymmetries:**
  $\bar{B}_q \to f$ and $B_q \to \bar{f}$ forbidden
  No direct CP violation: $|\langle f|B_q\rangle| = |\langle \bar{f}|\bar{B}_q\rangle|$
  e.g. $B_s \to D_s^- \pi^+$ or $B_q \to X l \nu$ (*semileptonic*)

$$a_{sl} \equiv a_{fs} = \frac{\Gamma(\overline{B}_q(t) \to f) - \Gamma(B_q(t) \to \overline{f})}{\Gamma(\overline{B}_q(t) \to f) + \Gamma(B_q(t) \to \overline{f})} = -2\left(\left|\frac{q}{p}\right| - 1\right) = \text{Im}\frac{\Gamma_{12}}{M_{12}} = \frac{\Delta\Gamma}{\Delta M}\tan\phi$$

New Physics in B-Mixing

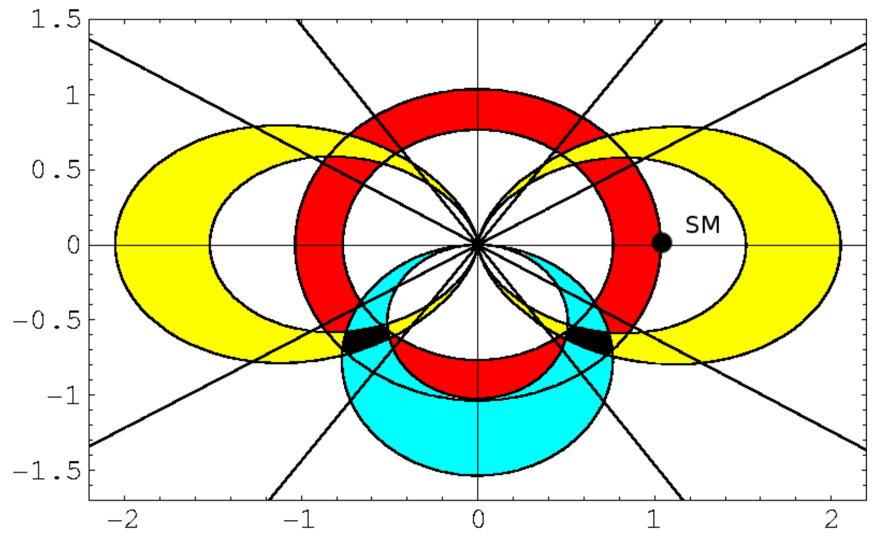
$$\Gamma_{12,s} = \Gamma_{12,s}^{\rm SM}\,, \qquad M_{12,s} = M_{12,s}^{\rm SM} \cdot \Delta_s\,; \qquad \Delta_s = |\Delta_s| e^{i\phi_s^\Delta}$$

$$\Delta_s = r_s^2 e^{2i\theta_s} = C_{B_s} e^{2i\phi_{B_s}} = 1 + h_s e^{2i\sigma_s}$$

$$\begin{aligned} \Delta M_s &= 2|M_{12,s}^{\rm SM}| \cdot |\Delta_s| \\ \Delta\Gamma_s &= 2|\Gamma_{12,s}| \cdot \cos\left(\phi_s^{\rm SM} + \phi_s^\Delta\right) \\ \frac{\Delta\Gamma_s}{\Delta M_s} &= \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\rm SM}|} \cdot \frac{\cos\left(\phi_s^{\rm SM} + \phi_s^\Delta\right)}{|\Delta_s|} \\ a_{fs}^s &= \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\rm SM}|} \cdot \frac{\sin\left(\phi_s^{\rm SM} + \phi_s^\Delta\right)}{|\Delta_s|} \end{aligned}$$

$$\sin(\phi_s^{\rm SM}) \approx 1/240$$

For $|\Delta_s| = 0.9$ and $\phi_s^\Delta = -\pi/4$ one gets the following bounds in the **complex Δ-plane**:



The Mass Difference ΔM

Calculating the box diagram with an internal top-quark yields

$$M_{12,q} = \frac{G_F^2}{12\pi^2}(V_{tq}^* V_{tb})^2 M_W^2 S_o(x_t) B_{B_q} f_{B_q}^2 M_{B_q} \hat{\eta}_B$$

(Inami, Lim '81)

- Hadronic matrix element: $\frac{8}{3} B_{B_q} f_{B_q}^2 M_{B_q} = \langle \bar{B}_q | (\bar{b}q)_{V-A} (\bar{b}q)_{V-A} | B_q \rangle$
- Perturbative QCD corrections $\hat{\eta}_B$ (Buras, Jamin, Weisz, '90)

Theory 1102.4274 vs. Experiment : HFAG 11

$\Delta M_d = 0.543 \pm 0.091\, ps^{-1}$	$\Delta M_d = 0.507 \pm 0.004\, ps^{-1}$ ALEPH, CDF, D0, DELPHI, L3, OPAL, BABAR, BELLE, ARGUS, CLEO
$\Delta M_s = 17.30 \pm 2.6\, ps^{-1}$	$\Delta M_s = 17.70 \pm 0.12\, ps^{-1}$ CDF, D0, LHCb

Important bounds on the unitarity triangle and new physics

Determination of Γ_{12}

Sensitive to real intermediate states $\Rightarrow$ much more complicated than M_{12}

1. OPE I: Integrate out W: like $M_{12} \propto f_B^2 B$
2. OPE II: Heavy quark expansion $\Rightarrow \Gamma_i^{(j)} \propto f_B^2 \sum C_k B_K$

$$\Gamma_{12} = \left(\frac{\Lambda}{m_b}\right)^3 \left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + ...\right) + \left(\frac{\Lambda}{m_b}\right)^4 \left(\Gamma_4^{(0)} + ...\right) + \left(\frac{\Lambda}{m_b}\right)^5 \left(\Gamma_5^{(0)} + ...\right) + ...$$

1996: Beneke, Buchalla, Dunietz

1998: Beneke, Buchalla, Greub, A.L., Nierste

2003: Ciuchini, Franco, Lubicz, Mescia, Tarantino; Beneke, Buchalla, A.L., Nierste

2006: A.L., Nierste

2007: Badin, Gabbiani, Petrov

OPE II might be questionable - quark hadron duality

$\Rightarrow$ **test reliability of OPE II via lifetimes (no NP effects expected)**

$\Rightarrow$ **calculate corrections in all possible “directions”, to get a feeling for the convergence**

Strategy

1. **Test reliability of the theoretical framework via lifetimes**

   — no NP effects expected —

2. **Currently no precise prediction of Γ_{12} and M_{12} possible**

   — compared to $\Delta M^{\text{Exp.}}$ —

3. **Clean SM prediction of Γ_{12}/M_{12} possible**

   — many non-pert. uncertainties cancel —

4. **Search for NP in Γ_{12}/M_{12}**

Lifetimes of heavy hadrons

- $\tau(B^+)/\tau(B_d)$: HQE seems to fit, but we need urgently more precise hadronic matrix elements
- $\tau(B_s)/\tau(B_d)$: More data as well as non-perturbative matrix elements needed— $0.996...1.000$ vs. 0.973 ± 0.015
- $\tau(\Lambda_b)$, $\tau(\Xi_b)$ and $\tau(B_c)$: more data and further theory work (perturbative and non-perturbative) neccessary
- $\tau(D)$, D-mixing: work in progress
  Bobrowski, A.L., Riedl, Rohrwild 1002.4794; Bobrowski, A.L. 1011.5608;
  Bobrowski, A.L. Nierste, Prill, to appear
  It is not unplausible that HQE might give reasonable estimates

Prediction for $\Delta\Gamma_s$ and $\Delta\Gamma_s/\Delta M_s$

$$\Delta\Gamma_s = \left(\frac{f_{B_s}}{240\,\text{MeV}}\right)^2 \left[0.105B + 0.024\tilde{B}'_S - \left(0.030B_{\tilde{R}_2} - 0.006B_{R_0} + 0.003B_R\right)\right]$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = 10^{-4}\cdot\left[46.2 + 10.6\frac{\tilde{B}'_S}{B} - \left(13.2\frac{B_{\tilde{R}_2}}{B} - 2.5\frac{B_{R_0}}{B} + 1.2\frac{B_R}{B}\right)\right]$$

Now a precise determination of $\Delta\Gamma/\Delta M$ is possible!

$$\Delta\Gamma_s = 2|\Gamma_{12}^s|\cos\left(\phi_s^{\text{SM}} + \phi_s^{\Delta}\right)$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = \frac{|\Gamma_{12}^s|}{|M_{12}^s|}\cdot\Delta M_s^{\text{Exp.}}\cdot\cos\left(\phi_s^{\text{SM}} + \phi_s^{\Delta}\right)$$

Numerical update 1102.4274 (A.L., U. Nierste)

if $\phi_s^\Delta \approx 0$: $\Delta\Gamma_s = (0.087 \pm 0.021)\,\text{ps}^{-1}$

if $\Delta_s \approx 1$: $\frac{\Delta\Gamma_s}{\Gamma_s} = 0.137 \pm 0.027$

$\Delta\Gamma_s$ in NLO-QCD I

Theory vs. Experiment

A.L., Nierste 0612167/1102.4274 vs. Belle 10: 1005.5177 und HFAG 11

$$\frac{\Delta\Gamma_s}{\Gamma_s} = (14.7 \pm 6.0)\ \% \quad \leftrightarrow \quad \left(14.7^{+3.6}_{-3.0}{}^{+4.4}_{-4.2}\right)\ \%$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = (13.7 \pm 2.7)\ \% \quad \leftrightarrow \quad \left(15.4^{+6.7}_{-6.5}\right)\ \%$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = (49.7 \pm 9.4) \cdot 10^{-4} \quad \leftrightarrow \quad (57 \pm 24) \cdot 10^{-4}$$

- New Belle result with 121 fb^{-1}
- $m_c \to \infty$, $m_b - 2m_c \to 0$, $N_c \to \infty$ might be violated sizeably

$\Delta\Gamma_s$ in NLO-QCD II

Improvement in theoretical accuracy

$\Delta\Gamma_s^{\rm SM}$	2011	2006
Central Value	$0.087\,\text{ps}^{-1}$	$0.096\,\text{ps}^{-1}$
$\delta(\mathcal{B}_{\widetilde{R}_2})$	17.2%	15.7%
$\delta(f_{B_s})$	13.2%	33.4%
$\delta(\mu)$	7.8%	13.7%
$\delta(\widetilde{\mathcal{B}}_{S,B_s})$	4.8%	3.1%
$\delta(\mathcal{B}_{R_0})$	3.4%	3.0%
$\delta(V_{cb})$	3.4%	4.9%
$\delta(\mathcal{B}_{B_s})$	2.7%	6.6%
...	....	...
$\sum \delta$	24.5%	40.5%

Semi leptonic CP-asymmetries a_{fs} and $\Delta\Gamma_d$

SM predictions: A.L., U. Nierste, 1102.4274; A.L. 1108.1218

$$a_{fs}^s = (1.9 \pm 0.3) \cdot 10^{-5} \qquad \phi_s = 0.22^\circ \pm 0.06^\circ$$

$$a_{fs}^d = -(4.1 \pm 0.6) \cdot 10^{-4} \qquad \phi_d = -4.3^\circ \pm 1.4^\circ$$

$$A_{sl}^b = 0.406 a_{sl}^s + 0.594 a_{sl}^d = (-2.3 \pm 0.4) \cdot 10^{-4}$$

Experimentelle Schranken

$$a_{fs}^s = (-1150 \pm 610) \cdot 10^{-5}$$ (HFAG 11)

$$\phi_s = -51.6^\circ \pm 12^\circ$$ (A.L., Nierste, CKMfitter, 1008.1593)

$$a_{fs}^d = -(49 \pm 38) \cdot 10^{-4}$$ (HFAG 11)

$$\frac{\Delta\Gamma_d}{\Gamma_d} = (-17 \pm 21) \cdot 10^{-3}$$ (Belle EPS 2011)

$$A_{sl}^b = -(7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3}$$ (D0,1106.6308)

$$A_{sl}^b(Exp.)/A_{sl}^b(Theory) = \mathbf{34} \qquad 3.9 - \sigma\text{-effect}$$

New Physics in B-Mixing

There is still plenty of room for a “pinch “ of new physics in B-mixing

The dimuon asymmetry

But the central value of the diμasymmetry is larger than theoretically possible

$$A_{sl}^{Max.} \approx (0.594 \pm 0.022)(5.4 \pm 1.0) \cdot 10^{-3} \frac{\sin(\phi_d^{SM} + \phi_d^{\Delta})}{|\Delta_d|}$$

$$+(0.406 \pm 0.022)(5.0 \pm 1.1) \cdot 10^{-3} \frac{\sin(\phi_s^{SM} + \phi_s^{\Delta})}{|\Delta_s|}$$

$$\approx (-3.1; -4.8[1\sigma]; -9.0[3\sigma]) \cdot 10^{-3}$$

$$A_{sl}^{D0} = (-7.8 \pm 2.0) \cdot 10^{-3}$$

A.L. 1108.1218

- Stat. fluctuation (1.5 σ) of the D0 result? (Actual value is below -4.8 per mille?)
- Is something wrong with $\Gamma_{12}^{\rm SM}$?

$$\Gamma_{12} = \left(\frac{\Lambda}{m_b}\right)^3 \left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + ...\right) + \left(\frac{\Lambda}{m_b}\right)^4 \left(\Gamma_4^{(0)} + ...\right) + \left(\frac{\Lambda}{m_b}\right)^5 \left(\Gamma_5^{(0)} + ...\right) + ...$$

1998:Beneke/Buchalla/Greub/A.L./Nierste;2003:Beneke/Buchalla/A.L./Nierste;Ciuchini/Franco/ Lubicz/Mescia/Tarantino;2006/11:A.L./Nierste;2007:Badin/Gabbiani/Petrov

?Problems with theory for Γ_{12} I?

Is the theoretical description of Γ_{12} correct?

- Does the HQE converge? A.L. 1106.3200
  - Naive: $1/m_b$ and for $c\bar{c}$ -loop: $1/\sqrt{m_b - 4m_c^2}$
    Can this be a problem?

$$\frac{\Lambda}{m_b}\frac{1}{\sqrt{1-4z}} = (1.11 \pm 0.01...1.3)\frac{\Lambda}{m_b}$$

$\Rightarrow$ **no problem!**

  - Simply calculate the corrections (A.L., Nierste 1102.4274; A.L. 1106.3200)

$$\begin{aligned} \Delta\Gamma_s &= \Delta\Gamma_s^0 \left(1 + \delta^{\text{Lattice}} + \delta^{\text{QCD}} + \delta^{\text{HQE}}\right) \\ &= 0.142 \text{ ps}^{-1} \left(1 - 0.14 - 0.06 - 0.19\right) \end{aligned}$$

Explicit calculation shows that expansion factor = 1/5 $\Rightarrow$ **really no problem!**

?Problems with theory for Γ_{12} II?

- Large Duality violations in HQE for Γ_{12}?
  How large?
  - Assume: New physics is acting in M_{12}
    $\Rightarrow \mathcal{O}(200\%)$ Duality violation neccessary
  - Assume: No new physics in M_{12}, all effect due to failure of HQE
    $\Rightarrow \mathcal{O}(3300\%)$ Duality violation neccessary

  How to test?
  - Test validity of HQE with lifetimes $\Rightarrow$ **no hint for a problem!**
  - Compare with exclusive approach:
    - Aleksan et al. 1993

$$\frac{\Delta\Gamma_s}{\Gamma_s} = \mathcal{O}(15\%)$$

    - C. K. Chua, W. S. Hou and C. H. Shen, arXiv:1107.4325

    Good agreement of exclusive and inclusive (HQE) pproach
  - **Direct measurement of $\Delta\Gamma_s$ coming soon**

?Problems with theory for Γ_{12} III?

- Large ($\mathcal{O}(200 - 4100\%)$ NP effects in Γ_{12}?
  Why not seen somewhere else?
  - Lifetimes

$$\frac{\tau(B_s)}{\tau(B_d)} \qquad \frac{\tau(B^+)}{\tau(B_d)}$$

  - Inclusive charmless branching ratio, e.g. $b \to sX$
    Missing charm puzzle, e.g. A. Lenz ,hep-ph/0011258

$$\begin{aligned} n_c &= 0 + [r(1c) + 2r(2c)]\, B_{sl}^{Exp.} \\ &= 1 + [r(2c) - r(0c)]\, B_{sl}^{Exp.} \\ &= 2 - [r(1c) + 2r(0c)]\, B_{sl}^{Exp.} \end{aligned}$$

!!!Need precise experimental values for $r(0c, 1c, 2c) = \Gamma_{0c,1c,2c}/\Gamma_{sl}$ and B_{sl}!!!

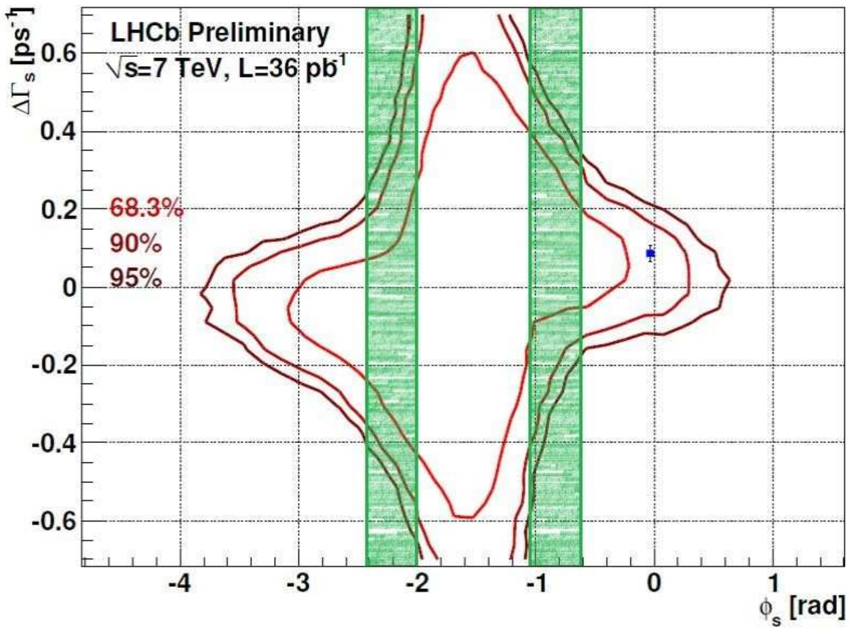
No hint for incorrectness of $\Gamma_{12}^{\mathrm{Theo}}$ except: A_{sl}^b is 1.5σ above bound

Further Hints for New Physics in FP I

Angular analysis of $B_s \to J/\psi\phi$ at CDF, D0 and LHCb: some small hints for deviations from SM: **hopefully soon a measurement**

$$S_{\psi\phi}^{\rm SM} = 0.0036 \pm 0.002 \to \sin\left(2\beta_s - \phi_s^\Delta - \delta_s^{\rm Peng,SM} - \delta_s^{\rm Peng,NP}\right) = 0.78^{+0.12}_{-0.19}$$

Fit 1008.1593



A simple relation for B mixing I

Many observables in the B_s mixing system:

Elimination of $\Gamma_{12}^{\mathrm{Theo}}$ via

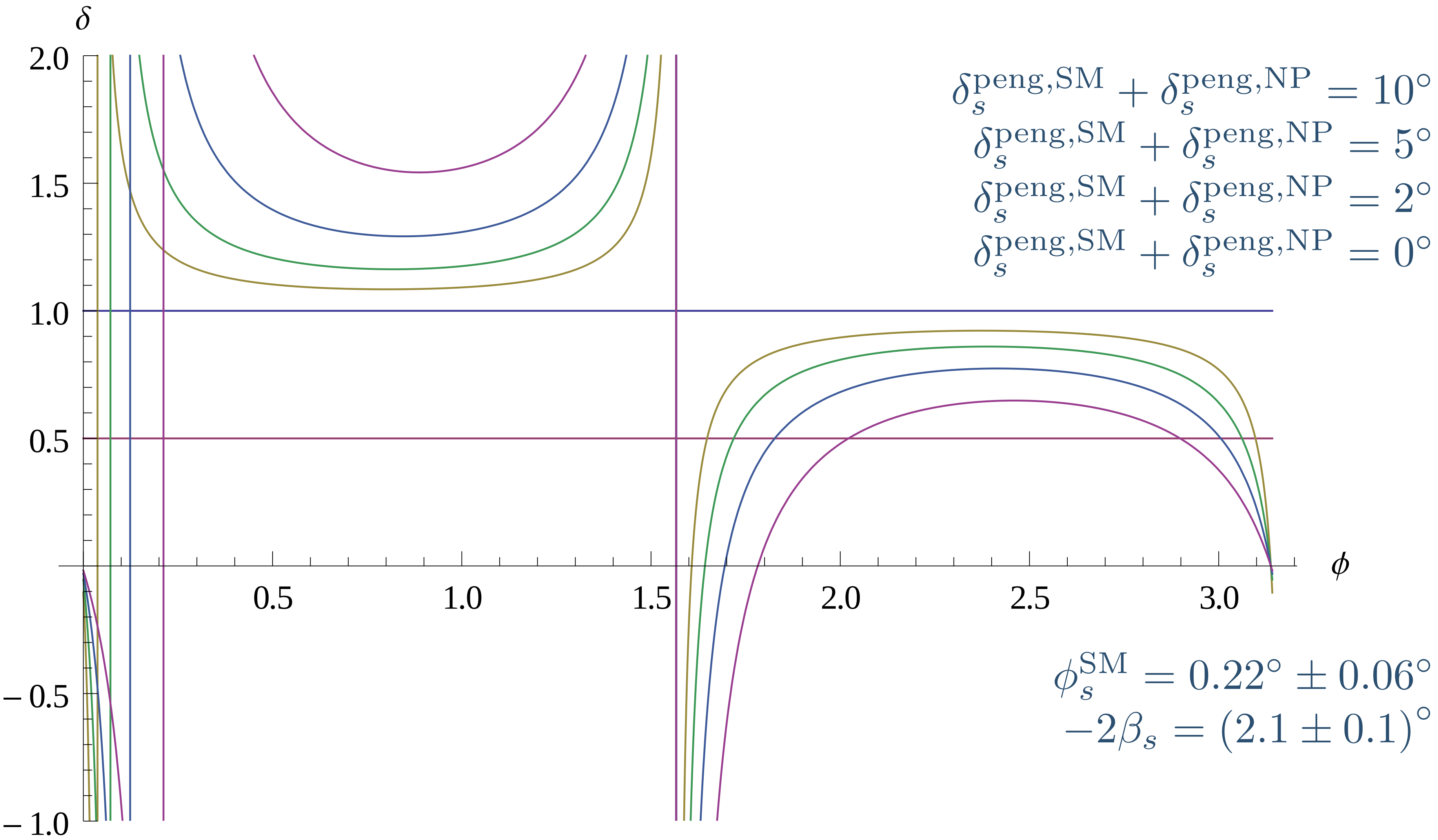
$$a_{sl}^s = -\frac{\Delta\Gamma}{\Delta M}\frac{S_{\psi\phi}}{\sqrt{1-S_{\psi\phi^2}}}\cdot\delta$$

not possible at that simple level, because $\delta \neq 1$

$$\delta = \frac{\tan\left(\phi_s^{\mathrm{SM}}+\phi_s^{\Delta}\right)}{\tan\left(-2\beta_s^{\mathrm{SM}}+\phi_s^{\Delta}+\delta_s^{\mathrm{peng,SM}}+\delta_s^{\mathrm{peng,NP}}\right)}$$

A.L. 1106.3200

A simple relation for B mixing II



- Above relation can be used to determine $\delta_s^{\text{peng,SM}} + \delta_s^{\text{peng,NP}}$
- To extract ϕ_s^Δ one needs $\Gamma_{12}^{s,\text{SM}}$

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Further Hints for New Physics in FP II

B_d**-mixing:** The golden plated mode Bigi/Sanda 1981

$$\begin{array}{rcl} \sin\left[2\beta(2\phi_1)\right]^{\text{Exp.}} & < & \sin\left[2\beta(2\phi_1)\right]^{\text{Fit}} \\ 0.678 \pm 0.020 & & 0.831^{+0.013}_{-0.030} \\ \beta(\phi_1) = (21.4 \pm 0.8)^\circ & & \left(28.09^{+0.7}_{-1.49}\right)^\circ \end{array}$$

Pointed out by Lunghi, Soni 0803.4340 and then by Buras, Guadagnoli 0805.3887

Statistical significane

- 1102.3917: Laiho, Lunghi, Van de Water: $2.5 - 3.3\sigma$
- 1010.6069: Lunghi, Soni : 3.3σ
- 1010.5089: UTfit : 2.6σ
- 1008.1593: A.L., Nierste, CKMfitter : 2.8σ
- ...

Further Hints for New Physics in FP III

- $B \to \tau\nu$
  NP in B_d-mixing vs. Lattice vs. 2HDM — New result from Belle?

- $B \to \mu\mu$ Very rare in the SM A.L. 1108.1218

$$Br(B_s \to \mu\mu) = (3.1 \pm 0.1) \cdot 10^{-9}$$

  Recent Experiments:

$$\text{CDF:} \quad Br(B_s \to \mu\mu) = \left(18^{+11}_{-9}\right) \cdot 10^{-9}$$

$$\text{CMS:} \quad Br(B_s \to \mu\mu) < 19 \cdot 10^{-9} \quad 95\% C.L.$$

$$\text{LHCb:} \quad Br(B_s \to \mu\mu) < 15 \cdot 10^{-9} \quad 95\% C.L.$$

  Still a lot of room for New Physics!

- $B \to K^{(*)}ll$
  Some hints for deviations, but recent measurements (LHCb, CDF) are consistent with the SM — New result from Belle?
  Still a lot of room for New Physics!

Further Hints for New Physics in FP IV

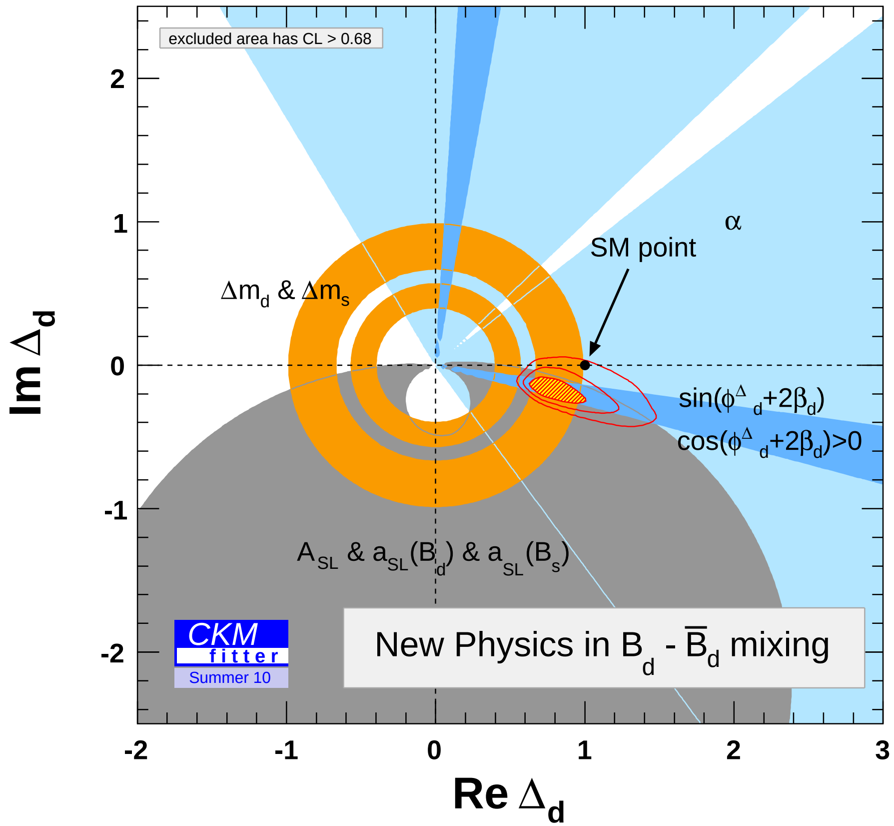
- ϵ_K - lattice values for B_K

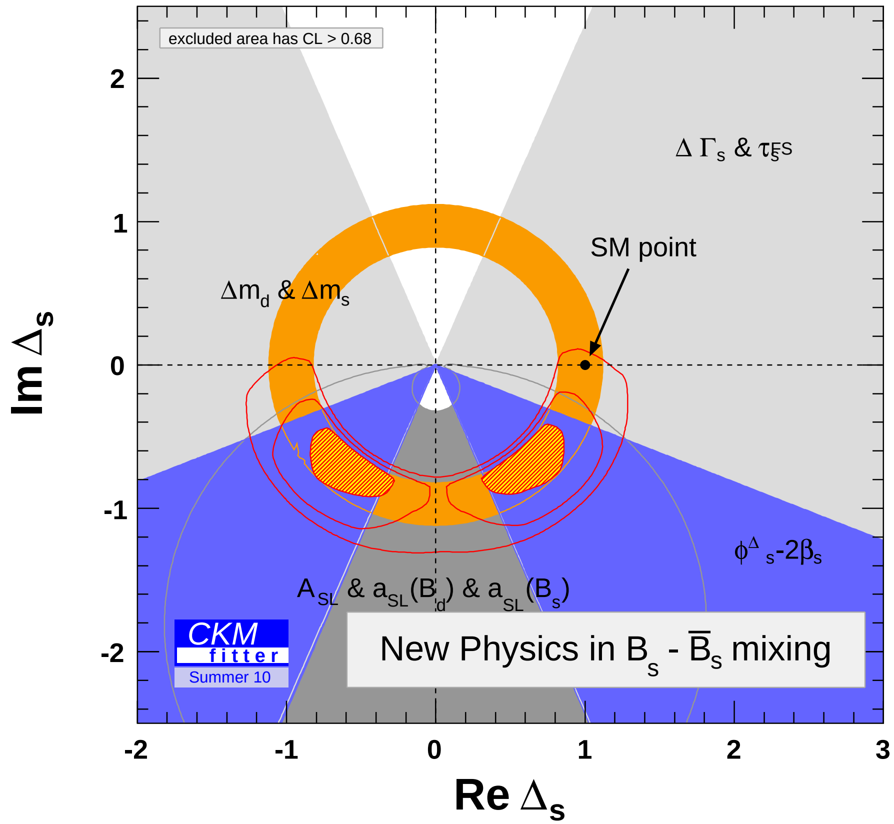
CKMfitter	0.724 ± 0.067	0.5σ
Laiho/Lunghi/VandeWater	0.737 ± 0.020	1.9σ

  Also $\epsilon_K \propto V_{cb}^4$!

- Hadronic decays Talks by Ben-Haim, Lipkin, Ruffini

Combined fit of Δ_d and Δ_s 1008.1593





Im Δ_d = 0 = Im Δ_s is excluded with 3.8 σ - Soon updated!

How to continue?

- **Soon many new data**
- How to interpret this data?
  - Since CKM works very well, MFV seems to be very promising
    But this is not the only possibility
    E.g. SM4: Effects of $\mathcal{O}(100\%)$ in B-mixing are still not excluded
    Cancellations within $\delta V_{td,s,b}$ and t'-loop
  - Investigate individual models hundreds of papers in arxive
    Investigate correlations e.g. Master of correlations: Buras et al.
- Still a lot of basic theoretical work (i.e. no model buildung) has to be done (final two transparancies)

What will we learn soon?

- **LHCb: Is $S_{\psi\phi}$ large?** Also more info from TeVatron
- **LHCb, Belle: How large is $\Delta\Gamma_s$?** Also TeVatron
- **More info on the semileptonic CP asymmetries**
  - Dimuonasymmetry A_{sl}: CDF and D0
  - $a_{sl}^{s,d}$: B-factories, CDF, D0, LHCb?
  - $a_{sl}^{s} - a_{sl}^{d}$: LHCb
- **New data on** $B \to K^{(*)}ll$: B-factories, TeVatron, LHCb
- **New bounds on** $B_s \to \mu\mu$: CDF, LHCb
- **New data on** $B \to \tau\nu$: B-factories
- **More data for Charm mixing**: TeVatron, LHCb, B-factories
- ? $\mu \to e\gamma$?

Much more to come: $K \to \pi\nu\nu$,...

What to do list - Bread and Butter

Improve our understanding of the CKM matrix

First row:

- Understand V_{ub}
- Improve accuracy in V_{us}

Second row:

- Improve accuracy in V_{cs}
- Improve accuracy in V_{cb}

Third row:

- Improve accuracy in V_{tb}
- Find a way to measure V_{td}, V_{ts}

Measurement of inclusive rates $B \to 0, 1, 2\ c$ **and** B_{sl}

Check $2Br(B_s \to D_s^{(*)\pm} D_s^{(*)\pm} = \Delta\Gamma^{CP} / \Gamma$

What to do list - Mixing

Improve our understanding of the mixing system

Test of HQE with lifetimes

- τ_{B+}/τ_{B_d} and τ_{B_s}/τ_{B_d} fits well $\Rightarrow$ currently no hints for deviations from HQE
- Precise non-perturbative matrix elements for 4-quark operators urgently needed
- Perturbative improvements of lifetime predictions

Theoretical predictions for mixing observables

- Precise decay constants and Bag parameter for ΔM
- Additional Bag parameters at dimension 6 and 7 for Γ_{12}
- α_s/m_b corrections for Γ_{12}
- α_s^2 corrections for Γ_{12}

Theoretical predictions for charm mixing observables

- Push HQE to its limits
- Try to imrove the exclusive approach

Exciting times are ahead of us!

THANK YOU