Updates from UTfit within and beyond the Standard Model

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unitarity Triangle analysis in the SM

SM UT analysis:
- provide the best determination of CKM parameters
- test the consistency of the SM ("direct" vs "indirect" determinations)
- provide predictions for SM observables (ex. $\sin2\beta$, $\Delta m_s$, ...)

.. and beyond

NP UT analysis:
- model-independent analysis
- provides limit on the allowed deviations from the SM
- updated NP scale analysis
CKM matrix and Unitarity Triangle

\[ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \]

\[ \alpha = \pi - \beta - \gamma \]

\[ \bar{\rho} + i\bar{\eta} \]

\[ \bar{\rho} + i\bar{\eta} \]

\[ \gamma = \text{atan} \left( \frac{\eta}{\bar{\rho}} \right) \]

\[ \beta = \text{atan} \left( \frac{\bar{\eta}}{(1 - \bar{\rho})} \right) \]

\[ \frac{\bar{\rho} + i\bar{\eta}}{1 - \bar{\rho} - i\bar{\eta}} \]

many observables 
functions of \( \bar{\rho} \) and \( \bar{\eta} \):
overconstraining

\[ B^0 \rightarrow \pi\pi, \rho\pi \]

\[ B^0 \rightarrow J/\psi K_S \]

\[ V_{ud}V_{ub}^* \]

\[ V_{cd}V_{cb}^* \]

\[ V_{td}V_{tb}^* \]

\[ \alpha(\phi_2) \]

\[ \gamma(\phi_3) \]

\[ \beta(\phi_1) \]
Other UT analyses exist, by:
CKMfitter (http://ckmfitter.in2p3.fr/),
Laiho&Lunghi&Van de Water (http://krone.physik.unizh.ch/~lunghi/webpage/LatAves/page3/page3.htm),
Lunghi&Soni (1010.6069)
the method and the inputs:

\[ f(\bar{\rho}, \bar{\eta}, X|c_1, \ldots, c_m) \sim \prod_{j=1,m} f_j(C|\bar{\rho}, \bar{\eta}, X) \]

\[ \prod_{i=1,N} f_i(x_i) f_0(\bar{\rho}, \bar{\eta}) \]

Bayes Theorem

\[ X \equiv x_1, \ldots, x_n = m_t, B_K, F_B, \ldots \]

\[ C \equiv c_1, \ldots, c_m = \epsilon, \Delta m_d/\Delta m_s, A_{CP}(J/\psi K_S), \ldots \]

Standard Model + OPE/HQET/Lattice QCD to go from quarks to hadrons, \( mt \)

\begin{tabular}{|c|c|c|}
\hline
(b \rightarrow u)/(b \rightarrow c) & \bar{\rho}^2 + \bar{\eta}^2 & \bar{\Lambda}, \lambda_1, F(1), \ldots \tabularnewline
\hline
\epsilon_K & \bar{\eta}[(1 - \bar{\rho}) + P] & B_K \tabularnewline
\hline
\Delta m_d & (1 - \bar{\rho})^2 + \bar{\eta}^2 & f_B^2 B_B \tabularnewline
\hline
\Delta m_d/\Delta m_s & (1 - \bar{\rho})^2 + \bar{\eta}^2 & \xi \tabularnewline
\hline
A_{CP}(J/\psi K_S) & \sin 2\beta & \tabularnewline
\hline
\end{tabular}

M. Bona et al. (UTfit Collaboration) JHEP 0507:028,2005 hep-ph/0501199

M. Bona et al. (UTfit Collaboration) JHEP 0603:080,2006 hep-ph/0509219
**B<sub>d</sub> and B<sub>s</sub> mixing**

\[ \Delta m_d = (0.507 \pm 0.004) \text{ ps}^{-1} \]
\[ \Delta m_s = (17.72 \pm 0.04) \text{ ps}^{-1} \]

\[ \Delta m_d \approx [(1 - \rho)^2 + \eta^2] \frac{f_{B_s}^2 B_{B_s}}{\xi^2} \]
\[ \Delta m_s \approx f_{B_s}^2 B_{B_s} \]

**B<sub>Bq</sub> and f<sub>Bq</sub> from lattice QCD**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( B_K )</td>
<td>0.766 ± 0.010</td>
</tr>
<tr>
<td>( f_{B_s} )</td>
<td>0.2277 ± 0.0045</td>
</tr>
<tr>
<td>( f_{B_s}/f_{B_d} )</td>
<td>1.202 ± 0.022</td>
</tr>
<tr>
<td>( \hat{B}_{B_s} )</td>
<td>1.33 ± 0.06</td>
</tr>
<tr>
<td>( \hat{B}<em>{B_s}/\hat{B}</em>{B_d} )</td>
<td>1.006 ± 0.011</td>
</tr>
</tbody>
</table>

FLAG updated after Lattice'13
**V_{cb} and V_{ub}**

\[ V_{cb} (excl) = (39.55 \pm 0.88) \times 10^{-3} \]

\[ V_{cb} (incl) = (41.7 \pm 0.7) \times 10^{-3} \]

\[ V_{cb} = (40.9 \pm 1.0) \times 10^{-3} \]

\[ V_{ub} (excl) = (3.42 \pm 0.22) \times 10^{-3} \]

\[ V_{ub} (incl) = (4.40 \pm 0.31) \times 10^{-3} \]

\[ V_{ub} = (3.75 \pm 0.46) \times 10^{-3} \]
CP-violating inputs

$\varepsilon_K$ from K-K mixing

$\rightarrow B_K = 0.766 \pm 0.010$  

Lattice '13

$\sin 2\beta$ from $B \rightarrow J/\psi K^0$ + theory

$\sin 2\beta(J/\psi K^0) = 0.680 \pm 0.023$  

HFAG + CPS

$\alpha$ from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays:

combined: $$(90.7 \pm 7.4)^\circ$$

$\gamma$ from $B \rightarrow D K$ decays (tree level)
\( \gamma \) and DK trees

\[ \gamma = (70.1 \pm 7.1)^\circ \]

\[ r_B(DK) = 0.0999 \pm 0.0059 \]

\[ r_B(D*K) = 0.118 \pm 0.018 \]

\[ r_B(DK^*) = 0.130 \pm 0.057 \]
Unitarity Triangle analysis in the SM:

\[ |\frac{v_{cb}}{v_{ub}}| = \bar{\rho}^2 + \bar{\eta}^2 \]

\[ \bar{\eta}[(1 - \bar{\rho}) + P] \]

\[ \Delta m_d = (1 - \bar{\rho})^2 + \bar{\eta}^2 \]

\[ \Delta m_s / \Delta m_d \]

\[ 2\beta + \gamma \]

\[ B \rightarrow \tau \nu \]
Unitarity Triangle analysis in the SM:

<table>
<thead>
<tr>
<th>Observables</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>V_{ub}/V_{cb}</td>
</tr>
<tr>
<td>$\epsilon_K$</td>
<td>~ 0.5%</td>
</tr>
<tr>
<td>$\Delta m_d$</td>
<td>~ 1%</td>
</tr>
<tr>
<td>$</td>
<td>\Delta m_d/\Delta m_s</td>
</tr>
<tr>
<td>$\sin 2\beta$</td>
<td>~ 3%</td>
</tr>
<tr>
<td>$\cos 2\beta$</td>
<td>~ 15%</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>~ 8%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>~ 10%</td>
</tr>
<tr>
<td>$\text{BR}(B \to \tau \nu)$</td>
<td>~ 19%</td>
</tr>
</tbody>
</table>
Unitarity Triangle analysis in the SM:

\[ \bar{\rho} = 0.159 \pm 0.015 \]
\[ \bar{\eta} = 0.346 \pm 0.013 \]
angles vs the others

\[ \bar{\rho} = 0.134 \pm 0.029 \]
\[ \eta = 0.339 \pm 0.017 \]

\[ \bar{\rho} = 0.182 \pm 0.023 \]
\[ \eta = 0.382 \pm 0.030 \]
compatibility plots

A way to “measure” the agreement of a single measurement with the indirect determination from the fit using all the other inputs: test for the SM description of the flavor physics

Color code: agreement between the predicted values and the measurements at better than 1, 2, ...nσ

The cross has the coordinates (x,y)=(central value, error) of the direct measurement

$$\gamma_{\text{exp}} = (70.1 \pm 7.1)° \quad \gamma_{\text{UTfit}} = (64.8 \pm 1.8)°$$

$$\alpha_{\text{exp}} = (90.7 \pm 7.4)° \quad \alpha_{\text{UTfit}} = (92.2 \pm 2.3)°$$
**tensions**

\[
\sin^2 \beta_{\text{exp}} = 0.680 \pm 0.023 \\
\sin^2 \beta_{\text{UTfit}} = 0.771 \pm 0.038
\]

\[
V_{ub_{\text{exp}}} = (3.76 \pm 0.46) \cdot 10^{-3} \\
V_{ub_{\text{UTfit}}} = (3.70 \pm 0.12) \cdot 10^{-3}
\]

\[
B_{K_{\text{exp}}} = 0.766 \pm 0.010 \\
B_{K_{\text{UTfit}}} = 0.873 \pm 0.073
\]

\(~2.0\sigma\)

\(~1.8\sigma\)
**tensions**

\[ \sin^2 \beta_{\text{exp}} = 0.680 \pm 0.023 \]
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\[ \sim 2.0 \sigma \]

\[ \sim 1.8 \sigma \]
# Unitarity Triangle analysis in the SM:

<table>
<thead>
<tr>
<th>Observables</th>
<th>Measurement</th>
<th>Prediction</th>
<th>Pull (#σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sin2β</td>
<td>0.680 ± 0.023</td>
<td>0.771 ± 0.038</td>
<td>~ 2.0</td>
</tr>
<tr>
<td>γ</td>
<td>70.1 ± 7.1</td>
<td>64.8 ± 1.8</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>α</td>
<td>90.7 ± 7.4</td>
<td>92.2 ± 2.3</td>
<td>&lt; 1</td>
</tr>
<tr>
<td></td>
<td>V_{ub}</td>
<td>· 10^3</td>
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</tr>
<tr>
<td></td>
<td>V_{ub}</td>
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</tr>
<tr>
<td>B_K</td>
<td>0.766 ± 0.10</td>
<td>0.873 ± 0.073</td>
<td>~ 1.8</td>
</tr>
<tr>
<td>BR(B → τν)[10^{-4}]</td>
<td>1.14 ± 0.22</td>
<td>0.811 ± 0.071</td>
<td>~ 1.4</td>
</tr>
<tr>
<td>BR(B_s → ll)[10^{-9}]</td>
<td>2.9 ± 0.7</td>
<td>3.98 ± 0.16</td>
<td>~ 1.4</td>
</tr>
<tr>
<td>BR(B_d → ll)[10^{-9}]</td>
<td>0.37 ± 0.15</td>
<td>0.106 ± 0.004</td>
<td>~ 1.7</td>
</tr>
</tbody>
</table>

The pull is obtained excluding the given constraint from the fit.
**inclusives vs exclusives**

\[
\sin 2\beta_{\text{UTfit}} = 0.745 \pm 0.031
\]

\sim 1.5\sigma

\[
\sin 2\beta_{\text{UTfit}} = 0.788 \pm 0.031
\]

\sim 2.7\sigma
inclusives vs exclusives

\[
\sin^2 \beta_{\text{UTfit}} = 0.745 \pm 0.031 \quad \sim 1.5\sigma
\]

\[
\sin^2 \beta_{\text{UTfit}} = 0.788 \pm 0.031 \quad \sim 2.7\sigma
\]
more standard model predictions:

$$\text{BR}(B \rightarrow \tau \nu) = (1.14 \pm 0.22) \times 10^{-4}$$

indirect determinations from UT

$$\text{BR}(B \rightarrow \tau \nu) = (0.811 \pm 0.071) \times 10^{-4}$$

M.Bona et al, 0908.3470 [hep-ph]
more standard model predictions:

from CMS+LHCb

\[ \text{BR}(B_s \rightarrow \mu \mu) = (2.9 \pm 0.7) \times 10^{-9} \]

\[ \text{BR}(B_s \rightarrow \mu \mu) = (3.98 \pm 0.16) \times 10^{-9} \]

from CMS+LHCb

\[ \text{BR}(B_d \rightarrow \mu \mu) = (3.7 \pm 1.5) \times 10^{-10} \]

\[ \text{BR}(B_d \rightarrow \mu \mu) = (1.06 \pm 0.04) \times 10^{-10} \]

indirect determinations from UT

\[ \text{BR}(B_s \rightarrow ll) = (3.98 \pm 0.16) \times 10^{-9} \]

\[ \text{BR}(B_d \rightarrow ll) = (1.06 \pm 0.04) \times 10^{-10} \]

~1.4\(\sigma\)

~1.7\(\sigma\)

time-integration included
UT analysis including new physics

fit simultaneously for the CKM and the NP parameters (generalized UT fit)

- add most general loop NP to all sectors
- use all available experimental info
- find out NP contributions to $\Delta F=2$ transitions

$B_d$ and $B_s$ mixing amplitudes

$(2+2$ real parameters$):$

$$A_q = C_{B_q} e^{2i \phi_{B_q}} A_q^{SM} e^{2i \phi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP} - \phi_q^{SM})} \right) A_q^{SM} e^{2i \phi_q^{SM}}$$

\[
\begin{align*}
\Delta m_{q/K} &= C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \\
A_{B_d \rightarrow J/\psi K_S} &= \sin 2(\beta + \phi_{B_d}) \\
A_{CP}^{CP} &= \sin 2(-\beta_s + \phi_{B_s}) \\
A_{SL} &= \text{Im} \left( \frac{\Gamma_{12}^q}{A_q} \right) \\
\Delta \Gamma^q / \Delta m_q &= \text{Re} \left( \frac{\Gamma_{12}^q}{A_q} \right)
\end{align*}
\]
new-physics-specific constraints

semileptonic asymmetries:
sensitive to NP effects in both size and phase
\[ A_{SL}(B_d)[10^{-3}] = -0.5 \pm 5.6, \quad A_{SL}(B_s)[10^{-3}] = -4.1 \pm 4.5 \]

same-side dilepton charge asymmetry:
admixture of \( B_s \) and \( B_d \) so sensitive to NP effects in both systems
\[ A_{\mu\mu}^{SL} \times 10^3 = -7.9 \pm 2.0 \]

lifetime \( \tau_{FS} \) in flavour-specific final states:
average lifetime is a function to the width and the width difference (independent data sample)
\[ \tau_{B_s}^{FS} [\text{ps}] = 1.417 \pm 0.042 \]

\( \phi_s = 2\beta_s \) vs \( \Delta \Gamma_s \) from \( B_s \to J/\psi \phi \)
angular analysis as a function of proper time and b-tagging. Additional sensitivity from the \( \Delta \Gamma_s \) terms

B factories,
CDF + D0 + LHCb

D0 arXiv:1106.6308

HFAG

LHCb: Gaussian
NP analysis results

\[ \bar{\rho} = 0.147 \pm 0.045 \]
\[ \bar{\eta} = 0.368 \pm 0.048 \]

SM is

\[ \bar{\rho} = 0.159 \pm 0.015 \]
\[ \bar{\eta} = 0.346 \pm 0.013 \]
NP parameter results

dark: 68%
ligh: 95%
SM: red cross

$C_{\varepsilon K} = 1.05 \pm 0.16$

$C_{B_d} = 1.00 \pm 0.13$
$\phi_{B_d} = (-2.0 \pm 3.2)^\circ$

$A_q = C_{B_d} e^{2i\phi_{B_d}}$

$C_{B_s} = 1.07 \pm 0.08$
$\phi_{B_s} = (0.6 \pm 2.0)^\circ$
NP parameter results

The ratio of NP/SM amplitudes is:

- $< 20\% @68\%$ prob. (34\% @95\%) in $B_d$ mixing
- $< 18\% @68\%$ prob. (26\% @95\%) in $B_s$ mixing

see also Lunghi & Soni, Buras et al., Ligeti et al.
testing the new-physics scale

At the high scale
new physics enters according to its specific features

At the low scale
use OPE to write the most general effective Hamiltonian.
the operators have different chiralities than the SM
NP effects are in the Wilson Coefficients C

NP effects are enhanced
◉ up to a factor 10 by the values of the matrix elements especially for transitions among quarks of different chiralities
◉ up to a factor 8 by RGE

$$\mathcal{H}_{\Delta B=2} = \sum_{i=1}^{5} C_i Q_{i}^{bq} + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i^{bq}$$

$$Q_1^{q_i q_j} = \bar{q}_{jL}^{\alpha} \gamma_{\mu} q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} \gamma_{\mu} q_{iL}^{\beta} \ ,$$

$$Q_2^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jR}^{\beta} q_{iL}^{\beta} \ ,$$

$$Q_3^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jR}^{\beta} q_{iL}^{\beta} \ ,$$

$$Q_4^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} q_{iR}^{\beta} \ ,$$

$$Q_5^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} q_{iR}^{\beta} \ .$$

M. Bona et al. (UTfit)  
JHEP 0803:049,2008  
arXiv:0707.0636

Marcella Bona, QMUL
The Wilson coefficients $C_i$ have in general the form

$$C_i(\Lambda) = \frac{F_i L_i}{\Lambda^2}$$

- $F_i$: function of the NP flavour couplings
- $L_i$: loop factor (in NP models with no tree-level FCNC)
- $\Lambda$: NP scale (typical mass of new particles mediating $\Delta F=2$ transitions)

Putting bounds on the Wilson coefficients give insights into the NP scale in different NP scenarios that enter through $F_i$ and $L_i$. 
The dependence of $C$ on $\Lambda$ changes on flavor structure. We can consider different flavour scenarios:

- **Generic**: $C(\Lambda) = \alpha/\Lambda^2 F_i \sim 1$, arbitrary phase
- **NMFV**: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2 F_i \sim |F_{SM}|$, arbitrary phase
- **MFV**: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2 F_1 \sim |F_{SM}|$, $F_{i\neq 1} \sim 0$, SM phase

$\alpha (L_i)$ is the coupling among NP and SM

- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_W (\alpha_S)$ in case of loop coupling through weak (strong) interactions

If no NP effect is seen
- lower bound on NP scale $\Lambda$

If NP is seen
- upper bound on NP scale $\Lambda$

$F$ is the flavour coupling and so
$F_{SM}$ is the combination of CKM factors for the considered process
results from the Wilson coefficients

Generic: $C(\Lambda) = \alpha/\Lambda^2$, $F_i \sim 1$, arbitrary phase

$\alpha \sim 1$ for strongly coupled NP

To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by $\alpha_s (\sim 0.1)$ or by $\alpha_W (\sim 0.03)$.

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

NP in $\alpha_W$ loops

$\Lambda > 1.5 \times 10^4$ TeV

Non-perturbative NP

$\Lambda > 5.0 \times 10^5$ TeV
results from the Wilson coefficients

NMFV: \[ C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2, \quad F_i \sim |F_{SM}|, \text{ arbitrary phase} \]

\[ \alpha \sim 1 \] for strongly coupled NP

To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by \( \alpha_s (\sim 0.1) \) or by \( \alpha_W (\sim 0.03) \).

\[ \alpha \sim \alpha_W \] in case of loop coupling through weak interactions

NP in \( \alpha_W \) loops

\[ \Lambda > 3.4 \text{ TeV} \]

Non-perturbative NP

\[ \Lambda > 113 \text{ TeV} \]
conclusions

- SM analysis displays good overall consistency
- Still open discussion on semileptonic inclusive vs exclusive, new discussion on the new lattice averages?
- UTA provides determination also of NP contributions to $\Delta F=2$ amplitudes. It currently leaves space for NP at the level of 15-20%
- So the scale analysis points to high scales for the generic scenario and even above LHC reach for weak coupling. Indirect searches become essential.
- Even if we don't see relevant deviations in the down sector, we might still find them in the up sector.
Back up slides
The CP symmetry is violated in any field theory having in the Lagrangian at least one phase that cannot be re-absorbed.

The mass eigenstates are not eigenstates of the weak interaction. This feature of the Standard Model Hamiltonian produces the (unitary) mixing matrix $V_{\text{CKM}}$.

$$
\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\approx
\begin{pmatrix}
1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho} - i\bar{\eta}) \\
-\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\
A\lambda^3(1 - \bar{\rho} - i\bar{\eta}) & -A\lambda^2 & 1
\end{pmatrix}
$$
Latest \(\sin 2\beta\) results:

\[
\sin(2\beta) = \sin(2\phi_1) \quad \text{HFAG Monardi 2012 PRELIMINARY}
\]

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.679 ± 0.020</td>
</tr>
<tr>
<td>BaBar</td>
<td>0.657 ± 0.036 ± 0.012</td>
</tr>
<tr>
<td>Belle</td>
<td>0.670 ± 0.029 ± 0.013</td>
</tr>
<tr>
<td>Average</td>
<td>0.665 ± 0.024</td>
</tr>
<tr>
<td>BaBar</td>
<td>0.694 ± 0.061 ± 0.031</td>
</tr>
<tr>
<td>Belle</td>
<td>0.642 ± 0.047 ± 0.021</td>
</tr>
<tr>
<td>Average</td>
<td>0.663 ± 0.041</td>
</tr>
</tbody>
</table>

\(\Delta S = 0.000 ± 0.012\)

M. Ciuchini, M. Pierini, L. Silvestrini

raw asymmetry as function of \(\Delta t\)

\(\sin 2\beta(J/\psi K^0) = 0.665 ± 0.024\)
1) Fit the amplitudes in the SU(3)-related decay $J/\psi\pi^0$ and keep solution compatible with $J/\psi K$

2) Obtain the upper limit on the penguin amplitude and add 100% error for SU(3) breaking

3) Fit the amplitudes in $J/\psi K^0$ imposing the upper bound on the CKM suppressed amplitude and extract the error on $\sin 2\beta$

$\Delta S = 0.000 \pm 0.012$

Marcella Bona, QMUL
α: CP violation in $B^0 \rightarrow \pi\pi/\rho\rho$

$$\lambda_{\pi\pi} = e^{2i\alpha} \frac{1 + |P/T| e^{i\delta} e^{i\gamma}}{1 + |P/T| e^{i\delta} e^{-i\gamma}}$$

$$C_{\pi\pi} \propto \sin(\delta)$$

$$S_{\pi\pi} = \sqrt{1 - C_{\pi\pi}^2 \sin(2\alpha_{\text{eff}})}$$

Contours give $-2\Delta \ln(L) = \Delta \chi^2 = 1$, corresponding to 60.7% CL for 2 dof
α: CP violation in $B^0 \rightarrow \pi\pi/\rho\rho$

α from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays:
combined: $(91.1 \pm 6.7)^\circ$
**γ and DK trees**

\( B \to D^{(*)0} \left( D^{(*)0} \right) K^{(*)} \) decays can proceed both through \( V_{cb} \) and \( V_{ub} \) amplitudes.

\[
\begin{align*}
B^- & \to D^0 K^- \\
A(B^- \to D^0 K^-) &= A_B \\
A(B^+ \to \bar{D}^0 K^+) &= A_B \\
B^- & \to \bar{D}^0 K^- \\
A(B^- \to \bar{D}^0 K^-) &= A_B r_B \epsilon^{i(\delta_B - \gamma)} \\
A(B^+ \to D^0 K^+) &= A_B r_B \epsilon^{i(\delta_B + \gamma)}
\end{align*}
\]

**sensitivity to \( \gamma \): the amplitude ratio \( r_B \)**

\[
r_B = \left| \frac{B^- \to \bar{D}^0 K^-}{B^- \to D^0 K^-} \right| = \sqrt{\eta^2 + \rho^2} \times F_{CS} \quad \text{hadronic contribution channel-dependent}
\]

\( V_{ub} = |V_{ub}| e^{-i\psi} (\sim \lambda^3) \)

\( \delta_B = \text{strong phase diff.} \)
new-physics-specific constraints

B meson mixing matrix element NLO calculation

\[
\frac{\Gamma_{12}^q}{A_q^{\text{full}}} = -2 \kappa \left\{ C_{B_q} \left( n_1 + \frac{n_6 B_2 + n_{11}}{B_1} \right) - \frac{e^{(\phi_q^{\text{SM}} + 2\phi_{B_q})}}{R_t^q} \left( n_2 + \frac{n_7 B_2 + n_{12}}{B_1} \right) \right. \\
+ \frac{e^{2(\phi_q^{\text{SM}} + \phi_{B_q})}}{R_t^q} \left( n_3 + \frac{n_8 B_2 + n_{13}}{B_1} \right) + e^{(\phi_{\text{pen}} + 2\phi_{B_q})} C_q^{\text{pen}} \left( n_4 + n_9 \frac{B_2}{B_1} \right) \\
- \frac{e^{(\phi_q^{\text{SM}} + \phi_{\text{pen}} + 2\phi_{B_q})}}{R_t^q} \left( n_5 + n_{10} \frac{B_2}{B_1} \right) \left\} 
\]

\( \phi_s = 2\beta_s \) vs \( \Delta \Gamma_s \) from \( B_s \rightarrow J/\psi \phi \)
angular analysis as a function of proper time
and b-tagging
additional sensitivity from the \( \Delta \Gamma_s \) terms

\( \phi_s \) and \( \Delta \Gamma_s \):
2D experimental likelihood from CDF and D0

\( \phi_s \) and \( \Delta \Gamma_s \):
central values with gaussian errors from LHCb
# UT analysis including NP

M. Bona *et al.* (UTfit)


<table>
<thead>
<tr>
<th>UTfit updates</th>
<th>( \rho, \eta )</th>
<th>( C_{Bd}, \phi_{Bd} )</th>
<th>( C_{eK} )</th>
<th>( C_{bs}, \phi_{Bs} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{ub}/V_{cb} )</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \gamma ) (DK)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \varepsilon_K )</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sin 2\beta )</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta m_d )</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \alpha )</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_{SL} B_d )</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>( \Delta \Gamma_d/\Gamma_d )</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>( \Delta \Gamma_s/\Gamma_s )</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>( \Delta m_s )</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_{CH} )</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Model independent assumptions**

- SM \xrightarrow{\text{SM+NP}}
- (\( V_{ub}/V_{cb} \))\(^{\text{SM}}\) \xrightarrow{\text{SM+NP}} (\( V_{ub}/V_{cb} \))\(^{\text{SM+NP}}\)
- \( \gamma \)\(^{\text{SM}}\) \xrightarrow{\text{SM+NP}} \( \gamma \)\(^{\text{SM+NP}}\)

**Tree level**

- **Bd Mixing**
  - \( \beta \)\(^{\text{SM}}\) \xrightarrow{\phi_{Bd}} \( \beta \)\(^{\text{SM+NP}}\)
  - \( \alpha \)\(^{\text{SM}}\) \xrightarrow{\phi_{Bd}} \( \alpha \)\(^{\text{SM+NP}}\)
  - \( \Delta m_d \) \xrightarrow{C_{Bd}\Delta m_d}\(^{\text{SM+NP}}\)

- **Bs Mixing**
  - \( \Delta m_s \)\(^{\text{SM}}\) \xrightarrow{C_{Bs}\Delta m_s}\(^{\text{SM+NP}}\)
  - \( \beta_s \)\(^{\text{SM}}\) \xrightarrow{\phi_{Bs}} \( \beta_s \)\(^{\text{SM+NP}}\)

- **K Mixing**
  - \( \varepsilon_K \)\(^{\text{SM}}\) \xrightarrow{C_{\varepsilon_K}\varepsilon_K}\(^{\text{SM+NP}}\)

Marcella Bona, QMUL
contribution to the mixing amplitudes

analytic expression for the contribution to the mixing amplitudes

$$\langle \bar{B}_q | \mathcal{H}_{\text{eff}}^{\Delta B=2} | B_q \rangle_i = \sum_{j=1}^{5} \sum_{r=1}^{5} \left( b_j^{(r,i)} + \eta_c^{(r,i)} \right) \eta^{a_j} C_i(\Lambda) \langle \bar{B}_q | Q_{r}^{b_q} | B_q \rangle$$

arXiv:0707.0636: for ”magic numbers” a,b and c, $\eta = \alpha_s(\Lambda)/\alpha_s(m_t)$

[numerical values updated last in summer’12]

analogously for the K system

$$\langle \bar{K}^0 | \mathcal{H}_{\text{eff}}^{\Delta S=2} | K^0 \rangle_i = \sum_{j=1}^{5} \sum_{r=1}^{5} \left( b_j^{(r,i)} + \eta_c^{(r,i)} \right) \eta^{a_j} C_i(\Lambda) R_r \langle \bar{K}^0 | Q_{r}^{sd} | K^0 \rangle$$

To obtain the p.d.f. for the Wilson coefficients $C_i(\Lambda)$ at the new-physics scale, we switch on one coefficient at a time in each sector and calculate its value from the result of the NP analysis.
Results from the Wilson coefficients

the results obtained for the flavour scenarios:
In deriving the lower bounds on the NP scale, we assume \( L_i = 1 \), corresponding to strongly-interacting and/or tree-level NP.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>95% allowed range (GeV(^{-2}))</th>
<th>Lower limit on ( \Lambda ) (TeV) for arbitrary NP</th>
<th>Lower limit on ( \Lambda ) (TeV) for NMFV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re( C^1_K )</td>
<td>([-9.6, 9.6] \cdot 10^{-13})</td>
<td>1.0 \cdot 10^3</td>
<td>0.35</td>
</tr>
<tr>
<td>Re( C^2_K )</td>
<td>([-1.8, 1.9] \cdot 10^{-14})</td>
<td>7.3 \cdot 10^3</td>
<td>2.0</td>
</tr>
<tr>
<td>Re( C^3_K )</td>
<td>([-6.0, 5.6] \cdot 10^{-14})</td>
<td>4.1 \cdot 10^3</td>
<td>1.1</td>
</tr>
<tr>
<td>Re( C^4_K )</td>
<td>([-3.6, 3.6] \cdot 10^{-15})</td>
<td>\textcircled{17} \cdot 10^3</td>
<td>4.0</td>
</tr>
<tr>
<td>Re( C^5_K )</td>
<td>([-1.0, 1.0] \cdot 10^{-14})</td>
<td>10 \cdot 10^3</td>
<td>2.4</td>
</tr>
<tr>
<td>Im( C^1_K )</td>
<td>([-4.4, 2.8] \cdot 10^{-15})</td>
<td>1.5 \cdot 10^4</td>
<td>5.6</td>
</tr>
<tr>
<td>Im( C^2_K )</td>
<td>([-5.1, 9.3] \cdot 10^{-17})</td>
<td>10 \cdot 10^4</td>
<td>28</td>
</tr>
<tr>
<td>Im( C^3_K )</td>
<td>([-3.1, 1.7] \cdot 10^{-16})</td>
<td>5.7 \cdot 10^4</td>
<td>19</td>
</tr>
<tr>
<td>Im( C^4_K )</td>
<td>([-1.8, 0.9] \cdot 10^{-17})</td>
<td>\textcircled{24} \cdot 10^4</td>
<td>62</td>
</tr>
<tr>
<td>Im( C^5_K )</td>
<td>([-5.2, 2.8] \cdot 10^{-17})</td>
<td>14 \cdot 10^4</td>
<td>37</td>
</tr>
</tbody>
</table>

To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by \( \alpha_s \sim 0.1 \) or by \( \alpha_W \sim 0.03 \).
Upper and lower bound on the scale

Lower bounds on NP scale from K and $B_d$ physics (TeV at 95% prob.)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>strong/tree</th>
<th>$\alpha_s$ loop</th>
<th>$\alpha_W$ loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFV</td>
<td>5.5</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>NMFV</td>
<td>62</td>
<td>6.2</td>
<td>2</td>
</tr>
<tr>
<td>General</td>
<td>24000</td>
<td>2400</td>
<td>800</td>
</tr>
</tbody>
</table>

Upper bounds on NP scale from $B_s$:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>strong/tree</th>
<th>$\alpha_s$ loop</th>
<th>$\alpha_W$ loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMFV</td>
<td>35</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>General</td>
<td>800</td>
<td>80</td>
<td>30</td>
</tr>
</tbody>
</table>

- the **general** case was already problematic (well known flavour puzzle)
- **NMFV** has problems with the size of the $B_s$ effect vs the (insufficient) suppression in $B_d$ and (in particular) K mixing
- **MFV** is OK for the size of the effects, but the $B_s$ phase cannot be generated

Data suggest some hierarchy in NP mixing which is stronger than the SM one
The future of CKM fits

LHCb reach from:
O. Schneider, 1st LHCb Collaboration Upgrade Workshop

SuperB reach from:

\[ \Delta m_s \]
10/fb (5 years)
0.07\%(+0.5\%)

\[ A^s_{SL} \]
75/ab (5 years)

\[ \phi_s (J/\psi \phi) \]
0.01+syst

\[ \sin 2\beta (J/\psi K_s) \]
0.010
0.005

\[ \gamma \text{ (all methods)} \]
2.4\(^\circ\)
1-2\(^\circ\)

\[ \alpha \text{ (all methods)} \]
4.5\(^\circ\)
1-2\(^\circ\)

\[ |V_{cb}| \text{ (all methods)} \]
o
< 1%

\[ |V_{ub}| \text{ (all methods)} \]
o
1-2\%

\[ \text{Current lattice error} \]

<table>
<thead>
<tr>
<th>Hadronic matrix element</th>
<th>[2011 LHCb]</th>
<th>60 TFlop Year</th>
<th>1-10 PFlop Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ f^K_{K^0}(0) ]</td>
<td>0.9% (22% on 1-f_\pi)</td>
<td>0.4% (10% on 1-f_\pi)</td>
<td>&lt; 0.1% (2.4% on 1-f_\pi)</td>
</tr>
<tr>
<td>[ \hat B_K ]</td>
<td>11%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>[ f_B ]</td>
<td>14%</td>
<td>2.5 - 4.0%</td>
<td>1 - 1.5%</td>
</tr>
<tr>
<td>[ f_{B^<em>B^</em>_s} ]</td>
<td>13%</td>
<td>3 - 4%</td>
<td>1 - 1.5%</td>
</tr>
<tr>
<td>[ \xi ]</td>
<td>5% (26% on \xi)</td>
<td>1.5 - 2% (9-12% on \xi)</td>
<td>0.5 - 0.8 % (3-4% on \xi)</td>
</tr>
<tr>
<td>[ F_B \rightarrow D/\bar D \pi \nu ]</td>
<td>4% (40% on 1-F)</td>
<td>1.2% (13% on 1-F)</td>
<td>0.5% (5% on 1-F)</td>
</tr>
<tr>
<td>[ f^B_{K^0} } ]</td>
<td>11%</td>
<td>4 - 5%</td>
<td>2 - 3%</td>
</tr>
<tr>
<td>[ T_B \rightarrow K^* \bar \nu ]</td>
<td>13%</td>
<td>----</td>
<td>3 - 4%</td>
</tr>
</tbody>
</table>

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Today

With a SuperB in 2015