Unitarity triangle fits: Standard model & Search for New Physics

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Wien July 25 2015
• Provide the best determination of the CKM parameters;
• Test the consistency of the SM (``direct” vs ``indirect” determinations) @ the quantum level;
• Provide predictions for SM observables (in the past for example sin 2β and Δm_S)
Flavor physics in the Standard Model

In the SM, the quark mass matrix, from which the CKM matrix and CP violation originate, is determined by the coupling of the Higgs boson to fermions.

\[ \mathcal{L}_{\text{quarks}} = \mathcal{L}_{\text{kinetic}} + \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{Yukawa}} \]

\[ \mathcal{L}(\Lambda_{\text{Fermi}}) = \mathcal{L}(\Lambda, H, H^\dagger) + \mathcal{L}_{\text{kin}} + \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{Yukawa}} + \frac{\mathcal{L}_5}{\Lambda} + \frac{\mathcal{L}_6}{\Lambda^2} + \ldots \]

\(\text{CP invariant}\)

\(\text{CP and symmetry breaking are strictly correlated}\)

\(\text{EWSB has many accidental symmetries}\)

\(\text{may violate accidental symmetries}\)
Absence of FCNC at tree level (& GIM suppression of FCNC @loop level)

Almost no CP violation at tree level

Flavour Physics is extremely sensitive to New Physics (NP)
Flavor and New Physics

flavor physics can be used in two “modes”:

1. “NP Lagrangian reconstruction”
   - an external information on the NP scale is required (i.e. LHC)
   - the main tool are correlations among observables
   - needs good theoretical control on uncertainties of both SM and NP contributions

2. “Discovery”
   - looks for deviation from the SM whatever the origin
   - needs good theoretical control of the SM contribution only
   - in general cannot provide precise information on the NP scale, but a positive result would be a strong evidence that NP is not too far (i.e. in the multi-TeV region)

the path leading to TeV NP is narrower after the results of the LHC at 7 & 8 TeV
this will be further explored in the next run
M. Bona et al., UTfit
JHEP0507:028, 2005

www.utfit.org

A. Bevan, M. Bona, M. Ciuchini,
D. Derkach, E. Franco, V. Lubicz,
G. Martinelli, F. Parodi, M. Pierini,
C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni
### The Wolfenstein Parametrization

<table>
<thead>
<tr>
<th>$1 - 1/2 \lambda^2$</th>
<th>$\lambda$</th>
<th>$A \lambda^3(\rho - i \eta)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-\lambda$</td>
<td>$1 - 1/2 \lambda^2$</td>
<td>$A \lambda^2$</td>
</tr>
<tr>
<td>$A \lambda^3 \times (1 - \rho - i \eta)$</td>
<td>$-A \lambda^2$</td>
<td>$1$</td>
</tr>
</tbody>
</table>

$$V_{td}$$

$$V_{ub}$$

$+ O(\lambda^4)$

- $\lambda \sim 0.2$
- $A \sim 0.8$
- $\eta \sim 0.2$
- $\rho \sim 0.3$

- $\sin \theta_{12} = \lambda$
- $\sin \theta_{23} = A \lambda^2$
- $\sin \theta_{13} = A \lambda^3(\rho - i \eta)$
Unitarity:

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

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

\[ \rho + i\eta \]

\[ 1 - \rho - i\eta \]

\[ \gamma = \tan^{-1}\left(\frac{\eta}{\rho}\right) \]

\[ B^0 \rightarrow DK^{(*)} \]

\[ \beta = \tan^{-1}\left(\frac{\eta}{1-\rho}\right) \]

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

Finite Area = CPV
<table>
<thead>
<tr>
<th>Measure</th>
<th>$V_{CKM}$</th>
<th>Other NP parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma(b \to u)/\Gamma(b \to c)$</td>
<td>$\bar{\rho}^2 + \bar{\eta}^2$</td>
<td>$\Lambda, \lambda_1, F(1), \ldots$</td>
</tr>
<tr>
<td>$\varepsilon_K$</td>
<td>$\eta[(1 - \bar{\rho}) + \ldots]$</td>
<td>$B_K$</td>
</tr>
<tr>
<td>$\Delta m_d$</td>
<td>$(1 - \bar{\rho})^2 + \bar{\eta}^2$</td>
<td>$f_{B_d}^2 B_{B_d}$</td>
</tr>
<tr>
<td>$\Delta m_d/\Delta m_1$</td>
<td>$(1 - \bar{\rho})^2 + \bar{\eta}^2$</td>
<td>$\xi$</td>
</tr>
<tr>
<td>$A_{CP}(B_d \to J/\psi K_s)$</td>
<td>$\sin 2\beta$</td>
<td>$-$</td>
</tr>
</tbody>
</table>

$$Q^{EXP} = V_{CKM} \times \langle H_F | \hat{O} | H_I \rangle$$

For details see: UTfit Collaboration

http://www.utfit.org
Quantities used in the Standard UT Analysis

$V_{ub}/V_{cb}$  $\varepsilon_K$  $\Delta m_d$  $\Delta m_d/\Delta m_s$

Inclusive vs Exclusive Opportunity for lattice QCD

UT-LATTICE

levels @ 68% (95%) CL
Other Quantities used in the UT Analysis

UT-ANGLES

Several new determinations of UT angles are now available, thanks to the results coming from the B-Factory experiments.

\[
\begin{align*}
sin 2\beta &\quad \cos 2\beta &\quad \alpha &\quad \gamma &\quad sin (2\beta + \gamma) \\
B \to J/\Psi K^0 &\quad B \to J/\Psi K^* &\quad B \to \pi\pi, \rho\rho &\quad B \to D^* K &\quad B \to D^{*}\pi, D\rho
\end{align*}
\]

New Constraints from B and K rare decays (not used yet)

New bounds are available from rare B and K decays. They do not still have a strong impact on the global fit and they are not used at present.

\[
\begin{align*}
K &\to \pi \nu \bar{\nu} &\quad B &\to \tau \nu &\quad (B \to \rho/\omega \gamma)/(B \to K^*\gamma)
\end{align*}
\]
2015 results

\[ \rho = 0.142 \pm 0.019 \quad \eta = 0.348 \pm 0.013 \]

\[ \alpha = (90.5 \pm 2.6)^0 \]
\[ \sin 2\beta = 0.691 \pm 0.018 \]
\[ \beta = (21.82 \pm 0.72)^0 \]
\[ \gamma = (67.4 \pm 2.7)^0 \]
\[ A = 0.828 \pm 0.012 \]
\[ \lambda = 0.22549 \pm 0.00066 \]

Consistence on an over constrained fit of the CKM parameters

In the hadronic sector, the SM CKM pattern represents the principal part of the flavor structure and of CP violation.

CKM matrix is the dominant source of flavour mixing and CP violation.
CKM-TRIANGLE ANALYSIS
State of The Art 2015

<table>
<thead>
<tr>
<th></th>
<th>Measurement</th>
<th>Fit</th>
<th>Prediction</th>
<th>Pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>$(92.7 \pm 6.2)^\circ$</td>
<td>$(90.1 \pm 2.7)^\circ$</td>
<td>$(88.3 \pm 3.4)^\circ$</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>6.7 %</td>
<td>2.9 %</td>
<td>3.8 %</td>
<td></td>
</tr>
<tr>
<td>$\sin 2\beta$</td>
<td>$0.680 \pm 0.024$</td>
<td>$0.696 \pm 0.022$</td>
<td>$0.747 \pm 0.039$</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>3.5 %</td>
<td>2.6 %</td>
<td>5.2 %</td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$(71.4 \pm 6.5)^\circ$</td>
<td>$(67.4 \pm 2.8)^\circ$</td>
<td>$(66.7 \pm 3.0)^\circ$</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>9.1 %</td>
<td>4.2 %</td>
<td>4.5 %</td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>\times 10^3$</td>
<td>$3.81 \pm 0.40$</td>
<td>$3.66 \pm 0.12$</td>
</tr>
<tr>
<td></td>
<td>10 %</td>
<td>3.3 %</td>
<td>3.3 %</td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>\times 10^2$</td>
<td>$4.09 \pm 0.11$</td>
<td>$4.206 \pm 0.053$</td>
</tr>
<tr>
<td></td>
<td>2.6 %</td>
<td>1.2 %</td>
<td>1.4 %</td>
<td></td>
</tr>
<tr>
<td>$\epsilon_K \times 10^3$</td>
<td>$2.228 \pm 0.011$</td>
<td>$2.227 \pm 0.011$</td>
<td>$2.08 \pm 0.18$</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>0.5 %</td>
<td>0.5 %</td>
<td>8.7 %</td>
<td></td>
</tr>
<tr>
<td>$\Delta m_s \ (\text{ps}^{-1})$</td>
<td>$17.761 \pm 0.022$</td>
<td>$17.755 \pm 0.022$</td>
<td>$17.3 \pm 1.0$</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>0.1 %</td>
<td>0.1 %</td>
<td>5.7 %</td>
<td></td>
</tr>
<tr>
<td>$BR(B \to \tau \nu) \times 10^4$</td>
<td>$1.06 \pm 0.20$</td>
<td>$0.83 \pm 0.07$</td>
<td>$0.81 \pm 0.7$</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>18.9 %</td>
<td>7.9 %</td>
<td>8.2 %</td>
<td></td>
</tr>
<tr>
<td>$BR(B_s \to \mu \mu) \times 10^9$</td>
<td>$2.9 \pm 0.7$</td>
<td>$3.90 \pm 0.15$</td>
<td>$3.94 \pm 0.16$</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>24.1 %</td>
<td>3.8 %</td>
<td>4.0 %</td>
<td></td>
</tr>
<tr>
<td>$BR(B_d \to \mu \mu) \times 10^9$</td>
<td>$0.39 \pm 0.15$</td>
<td>$0.1098 \pm 0.0057$</td>
<td>$0.1103 \pm 0.0058$</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>38.5 %</td>
<td>5.2 %</td>
<td>5.2 %</td>
<td></td>
</tr>
<tr>
<td>$\beta_s$</td>
<td>$(0.97 \pm 0.95)^\circ$</td>
<td>$(1.056 \pm 0.039)^\circ$</td>
<td>$(1.056 \pm 0.039)^\circ$</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>98 %</td>
<td>4.4 %</td>
<td>4.1 %</td>
<td></td>
</tr>
</tbody>
</table>

$B(B \to \tau \nu)_{\text{Old}} = (1.67 \pm 0.30) \times 10^{-4}$
**LATTICE PARAMETERS**

<table>
<thead>
<tr>
<th></th>
<th>Lattice</th>
<th>Prediction</th>
<th>Pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{B}_K$</td>
<td>0.766 ± 0.010</td>
<td>0.84 ± 0.07</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>1.3 %</td>
<td>8.3 %</td>
<td></td>
</tr>
<tr>
<td>$f_{B_s}$</td>
<td>0.226 ± 0.005</td>
<td>0.2256 ± 0.0039</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2.2 %</td>
<td>2.7 %</td>
<td></td>
</tr>
<tr>
<td>$f_{B_s}/f_{B_d}$</td>
<td>1.204 ± 0.016</td>
<td>1.197 ± 0.056</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>1.3 %</td>
<td>0.4 %</td>
<td></td>
</tr>
<tr>
<td>$B_s$</td>
<td>0.875 ± 0.040</td>
<td>0.875 ± 0.030</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>1.3 %</td>
<td>0.4 %</td>
<td></td>
</tr>
<tr>
<td>$B_s/B_d$</td>
<td>1.03 ± 0.08</td>
<td>1.096 ± 0.062</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>7.8 %</td>
<td>5.7 %</td>
<td></td>
</tr>
</tbody>
</table>
CKM Matrix in the SM

\[
V_{CKM} = \begin{pmatrix}
(0.9743 \pm 0.00014) & (0.22509 \pm 0.00061) & (0.00366 \pm 0.00012) e^{i(-67.8 \pm 2.8)^\circ} \\
(-0.22498 \pm 0.00066) e^{i(0.0353 \pm 0.00009)^\circ} & (0.97343 \pm 0.00015) e^{i(-0.0018333 \pm 5 \times 10^{-5})^\circ} & (0.04206 \pm 0.00053) \\
(0.00876 \pm 0.00015) e^{i(-22.03 \pm 0.83)^\circ} & (-0.04129 \pm 0.00054) e^{i(1.054 \pm 0.039)^\circ} & (0.999107 \pm 2.235 \times 10^{-5})
\end{pmatrix}
\]

The fit results for all the nine CKM elements are

**Standard Parametrization (PDG)**

\[\sin \theta_{12} = 0.22504 \pm 0.00065\]
\[\sin \theta_{23} = 0.04206 \pm 0.00054\]
\[\sin \theta_{13} = 0.00366 \pm 0.00012\]
\[\delta = 67.8 \pm 2.8\]

**Wolfenstein Parametrization (PDG)**

\[\lambda = 0.22514 \pm 0.00066\]
\[A = 0.828 \pm 0.012\]
<table>
<thead>
<tr>
<th>inclusive $V_{ub}$</th>
<th>(4.41 ± 0.22) $\times 10^{-3}$</th>
<th>(3.69 ± 0.15) $\times 10^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>inclusive $V_{cb}$</td>
<td>(4.22 ± 0.07) $\times 10^{-2}$</td>
<td>(3.92 ± 0.07) $\times 10^{-2}$</td>
</tr>
</tbody>
</table>

$$V_{ub} = (3.81 ± 0.40) \times 10^{-3}$$
$$V_{cb} = (4.09 ± 0.11) \times 10^{-2}$$

$$\sin^2\beta_{\text{exp}} = 0.680 ± 0.024$$
$$\sin^2\beta_{\text{UTfit}} = 0.747 ± 0.039$$
$$B_K = 0.84 ± 0.07$$

$$\sin^2\beta_{\text{incl}} = 0.782 ± 0.028$$
$$B_K = 0.74 ± 0.05$$

$$\sin^2\beta_{\text{excl}} = 0.725 ± 0.019$$
$$B_K = 0.93 ± 0.07$$
The relative ratio of CKM elements is easily calculable:

\[ \frac{|V_{ub}|}{V_{cb}} = \frac{\lambda}{1 - \frac{\lambda^2}{2}} \sqrt{\rho^2 + \eta^2} \]

QCD corrections to be considered
- inclusive measurements: OPE
- exclusive measurements: form-factors from lattice QCD

\[ V_{ub}(\text{excl}) = (3.42 \pm 0.22) \times 10^{-3} \]
\[ V_{ub}(\text{incl}) = (4.40 \pm 0.31) \times 10^{-3} \]
\[ V_{ub} = (3.75 \pm 0.46) \times 10^{-3} \]

\[ \sim 1.9 \sigma \text{ discrepancy} \]

\[ V_{cb}(\text{excl}) = (39.55 \pm 0.88) \times 10^{-3} \]
\[ V_{cb}(\text{incl}) = (41.7 \pm 0.7) \times 10^{-3} \]
\[ V_{cb} = (40.9 \pm 1.0) \times 10^{-3} \]

\[ \sim 2.5 \sigma \text{ discrepancy} \]

There is still an inconsistency between inclusive and exclusive measurements. We take this into account inflating the combined uncertainty (a-la PDG).
Beta results

\[ a_{f_{CP}}(t) = \frac{\text{Prob}(B^0(t) \to f_{CP}) - \text{Prob}(\bar{B}^0(t) \to f_{CP})}{\text{Prob}(B^0(t) \to f_{CP}) + \text{Prob}(\bar{B}^0(t) \to f_{CP})} = C_f \cos \Delta m_d t + S_f \sin \Delta m_d t \]

The decay is dominated by a single (tree level) amplitude, thus a can be simplified:

\[ a_{f_{CP}}(t) = -\eta_{CP} \sin(\Delta m_d t) \sin 2\beta \]

We also analyse $\bar{B}^0 \to J/\psi \pi^0$ to obtain the theoretical uncertainty related to the penguin pollution in a data-driven way. This gives us an additional correction:

\[ \Delta S \in [-0.02, 0.00] \text{ at 68\% prob.} \]

\[ \sin(2\beta) = (0.680 \pm 0.023) \]
inclusives vs exclusives

$$\sin^2 \beta_{\text{exp}} = 0.680 \pm 0.024$$

$\sin^2 \beta_{\text{UTfit}} = 0.726 \pm 0.020$

$\sim 1.3\sigma$

$\sin^2 \beta_{\text{UTfit}} = 0.709 \pm 0.029$

$\sim 0.9\sigma$

$\sin^2 \beta_{\text{UTfit}} = 0.781 \pm 0.027$

$\sim 2.6\sigma$
Many of the tensions of the past unfortunately disappeared.

There still remain important differences between inclusive and exclusive determinations of $V_{ub}$ and $V_{cb}$.

But this seems rather to be a theory problem!!
1) Fit of NP-ΔF=2 parameters in a Model “independent” way

2) “Scale” analysis in ΔF=2

Is the present picture showing a Model Standardissimo?

An evidence, an evidence, my kingdom for an evidence

From Shakespeare's Richard III
What for a "`standardissimo" CKM which agrees so well with the experimental observations?

New Physics at the EW scale is "flavor blind" -> MINIMAL FLAVOR VIOLATION, namely flavour originates only from the Yukawa couplings of the SM

New Physics introduces new sources of flavor, the contribution of which, at most < 20 %, should be found in the present data, e.g. in the asymmetries of Bs decays
.... beyond the Standard Model

UT Analysis:
- Model independent analysis
- Limits on the deviations
- NP scale update
**CP VIOLATION PROVEN IN THE SM !!**

Only tree level processes Vub/Vcb and B→DK(*)

Three generations, no NP in tree level decays, no large NP EWP in B→ππ

Degeneracy of $\gamma$ broken by $A_{SL}$

$$\Delta m_s = |A_s| = C_{B_s} \Delta m_s^{SM}$$

$$2\phi_s = -\arg A_s = 2(\beta_s - \phi_{B_s})$$

$$A_{SL}^s = \frac{\Gamma(\bar{B}_s \to l^+X) - \Gamma(B_s \to l^-X)}{\Gamma(\bar{B}_s \to l^+X) + \Gamma(B_s \to l^-X)} = \text{Im} \left( \frac{\Gamma_{s12}^s}{A_s} \right)$$
Main Ingredients and General Parametrizations

Fit simultaneously CKM and NP parameters (generalized Utfit)

\[ H^\Delta_F = \hat{m} - \frac{i}{2} \hat{\Gamma} \]
\[ A = \hat{m}_{12} = \langle \tilde{M} | \hat{m} | M \rangle \]
\[ \Gamma_{12} = \langle \tilde{M} | \hat{\Gamma} | M \rangle \]

Neutral Kaon Mixing

\[ ReA_K = C_{\Delta m_K} ReA_K^{SM} \]
\[ ImA_K = C_\varepsilon ImA_K^{SM} \]
$B_d$ and $B_s$ mixing

\[ A_q e^{2i\phi_q} \equiv C_{Bq} e^{2i\phi_{Bq}} \times A_q^{SM} e^{2i\phi_{q}^{SM}} = \left( 1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_{q}^{NP} - \phi_{q}^{SM})} \right) \times A_q^{SM} e^{2i\phi_{q}^{SM}} \]

\[ C_{B_s} e^{2i\phi_{B_s}} = \frac{A_s^{SM} e^{-2i\beta_s} + A_s^{NP} e^{2i(\phi_{s}^{NP} - \beta_s)}}{A_s^{SM} e^{-2i\beta_s}} = \frac{\langle \bar{B}_s | H_{eff}^{full} | B_s \rangle}{\langle \bar{B}_s | H_{eff}^{SM} | B_s \rangle} \]

\[ \Gamma_{12}^q = -2\frac{\kappa}{C_{Bq}} \left\{ e^{i2\phi_{Bq}} \left( n_1 + \frac{n_6 B_2 + n_{11}}{B_1} \right) - \frac{e^{i(\phi_{q}^{SM} + 2\phi_{Bq})}}{R_t^q} \left( n_2 + \frac{n_7 B_2 + n_{12}}{B_1} \right) \right. \\
\left. + \frac{e^{i2(\phi_{q}^{SM} + \phi_{Bq})}}{R_t^q} \left( n_3 + \frac{n_8 B_2 + n_{13}}{B_1} \right) + e^{i(\phi_{q}^{Pen} + 2\phi_{Bq})} C_q^{Pen} \left( n_4 + \frac{n_9 B_2}{B_1} \right) \right\} \]

$C_q^{Pen}$ and $\phi_{q}^{Pen}$ parametrize possible NP contributions to $\Gamma_{12}^q$ from $b \to s$ penguins.
Physical observables

\[ \Delta m_s = |A_s| = C_{B_s} \Delta m_s^{SM} \]

\[ 2\phi_s = -\arg A_s = 2 (\beta_s - \phi_{B_s}) \]

\[ A_{SL}^s = \frac{\Gamma(\bar{B}_s \to l^+X) - \Gamma(B_s \to l^-X)}{\Gamma(\bar{B}_s \to l^+X) + \Gamma(B_s \to l^-X)} = \text{Im} \left( \frac{\Gamma_{12}^s}{A_s} \right) \]

\[ A_{SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{SL}^d + f_s \chi_{s0} A_{SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}} \]

\[ \frac{\Delta \Gamma_s}{\Delta m_s} = \text{Re} \left( \frac{\Gamma_{12}^s}{A_s} \right) \]

\[ \tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 + (\Delta \Gamma_s/2 \Gamma_s)^2}{1 - (\Delta \Gamma_s/2 \Gamma_s)^2} \]
NP model independent Fit $\Delta F=2$

Parametrizing NP physics in $\Delta F=2$ processes

$$C_{Bq} e^{2i\phi_{Bq}} = \frac{A_{NP}^{\Delta B=2}}{A_{SM}^{\Delta B=2}} A_{SM}^{\Delta B=2}$$

<table>
<thead>
<tr>
<th>Tree processes</th>
<th>$\rho , \eta$</th>
<th>$C_d$</th>
<th>$\varphi_d$</th>
<th>$C_s$</th>
<th>$\varphi_s$</th>
<th>$C_{\Psi K}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$ (DK)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{ub}/V_{cb}$</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta m_d$</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACP (J/$\Psi K$)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACP (D$\pi(p)$,DK$\pi$)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta \chi$</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha$ (\rho,\rho,\rho,\pi)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta A_{CP}$</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tau(B_s)$, $\Delta \Gamma_s/\Gamma_s$</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta m_s$</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASL(Bs)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACP (J/$\Psi \phi$)</td>
<td>~X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\epsilon_K$</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
**SM analysis** \[\rightarrow\] **NP-\(\Delta F=2\) analysis**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>SM Values</th>
<th>NP-(\Delta F=2) Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\rho)</td>
<td>0.142 ± 0.019</td>
<td>0.147 ± 0.043</td>
</tr>
<tr>
<td>(\eta)</td>
<td>0.348 ± 0.013</td>
<td>0.384 ± 0.044</td>
</tr>
</tbody>
</table>

\(\rho, \eta\) fit quite precisely in NP-\(\Delta F=2\) analysis and consistent with the one obtained on the SM analysis

[error double]

(main contributors tree-level \(\gamma\) and \(V_{ub}\))

Please consider these numbers when you want to get CKM parameters in presence of NP in \(\Delta F=2\) amplitudes (all sectors 1-2,1-3,2-3)

5 new free parameters
- \(C_s, \varphi_s\), \(B_s\) mixing
- \(C_d, \varphi_d\), \(B_d\) mixing
- \(C_eK\), \(K\) mixing

Today:
- fit is overconstrained
- Possible to fit 7 free parameters
  - \((\rho, \eta, C_d, \varphi_d, C_s, \varphi_s, C_eK)\)
NP parameters (i)

\[ C_{B_d} = 1.09 \pm 0.15 \]
\[ \phi_{B_d} = (-2.9 \pm 2.8)^0 \]

\[ C_{\varepsilon_K} = 1.07 \pm 0.14 \]

\[ \Delta m_d = C_{B_d} (\Delta m_d)^{SM} \]
\[ a_{CP}^{B_d \rightarrow J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \]
\[ a_{SL}^d = \text{Im} \left( \frac{\Gamma_1^d}{A_d} \right) \]
\[ \Delta \Gamma^d/\Delta m_d = \text{Re} \left( \frac{\Gamma_1^d}{A_d} \right) \]

\[ \text{Im} A_K = C_{\varepsilon} \text{Im} A_K^{SM} \]
\[ \varepsilon_K = C_{\varepsilon} \varepsilon_K^{SM} \]
\[ C_{B_s} = 1.14 \pm 0.09 \]
\[ \Phi_{B_s} = (-0.1 \pm 1.0)^0 \]

\[ \Delta m_s = C_{B_s} (\Delta m_s)^{SM} \]
\[ a_{CP}^{B_s \to J/\psi \phi} \rightarrow -\beta_s + \varphi_{B_s} \]
\[ a_{SL}^s = \text{Im}\left(\frac{\Gamma_{12}^s}{A_s}\right) \]
\[ \Delta \Gamma^s / \Delta m_s = \text{Re}\left(\frac{\Gamma_{12}^s}{A_s}\right) \]
TESTING THE NEW PHYSICS SCALE

Effective Theory Analysis $\Delta F = 2$

Effective Hamiltonian in the mixing amplitudes

$$H_{\text{eff}}^{\Delta B = 2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{5} \overline{C}_i(\mu) \overline{Q}_i(\mu)$$

$$Q_1 = \overline{q}_L \gamma \mu b_L \overline{q}_L \gamma \mu b_L$$  (SM/MFV)

$$Q_2 = \overline{q}_R \gamma \mu b_L \overline{q}_R b_L$$

$$Q_3 = \overline{q}_R \gamma \mu b_L \overline{q}_R b_L$$

$$Q_4 = \overline{q}_R b_L \overline{q}_L \gamma \mu b_R$$

$$Q_5 = \overline{q}_R b_L \overline{q}_L \gamma \mu b_R$$

$$\overline{Q}_1 = \overline{q}_R \gamma \mu b_R \overline{q}_R \gamma \mu b_R$$

$$\overline{Q}_2 = \overline{q}_R \gamma \mu b_R \overline{q}_L \gamma \mu b_R$$

$$\overline{Q}_3 = \overline{q}_R b_R \overline{q}_R b_R$$

$$C_j(\Lambda) = \frac{LF_j}{\Lambda^2} \Rightarrow \Lambda = \sqrt{\frac{LF_j}{C_j(\Lambda)}}$$

C(\Lambda) coefficients are extracted from data

$\Lambda$ is loop factor and should be:

$\Lambda = 1$ tree/strong int. NP

$\Lambda = \alpha_s^2$ or $\alpha_w^2$ for strong/weak perturb. NP

$F_1 = F_{\text{SM}} = (V_{tq} V_{tb}^*)^2$  MFV

$F_{j=1} = 0$

$|F_j| = F_{\text{SM}}$

arbitrary phases  NMFV

$|F_j| = 1$

arbitrary phases  Flavour generic
Results from a fit to the Wilson Coefficients

Results obtained with $L=1$ corresponding to tree level NP effects and an arbitrary flavor structure

$\varepsilon_K$ \hspace{1cm} $\Lambda = 5 \times 10^5 \text{TeV}$

$D$ \hspace{1cm} $\Lambda = 1 \times 10^4 \text{TeV}$

$B_d$ \hspace{1cm} $\Lambda = 3 \times 10^3 \text{TeV}$

$B_s$ \hspace{1cm} $\Lambda = 8 \times 10^2 \text{TeV}$
NP scale $\Lambda$ (TeV)

- $\Re C_K$
- $\Im C_K$
- $\Im C_D$
- $C_{Bd}$
- $C_{Bs}$

NMFV
CONCLUSIONS

1) The high precision of the SM UT Analysis allows to test the SM and to search for NP at a level which is competitive with direct searches.
2) CKM matrix is the dominant source of flavour mixing and CP violation $\sigma(\rho) \sim 15\%$ & $\sigma(\eta) \sim 4\%$. SM analysis shows a very good overall consistency.
3) The main tensions disappeared.
4) Inclusive vs exclusive semileptonic decays still need theoretical improvement and BK !!

Thus for the time being we have to remain with a STANDARDISSIMO STANDARD MODEL but …
THANKS FOR YOUR ATTENTION