UNITARITY TRIANGLE OVERVIEW

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• Introduction
• Inputs to the UTA
• SM analysis
• Generalized UTA with NP
• Bounds on the NP scale
• Conclusions and outlook

Many thanks to D. Derkach and to M. Bona!
Due to heavy rain in Bologna, CNAF had to shut down a few servers, including the one where our high-statistics fresh run is stored...

Nevertheless I will show last-minute, low-statistics new results, to be taken as extremely preliminary...

...also because HFLAV just updated $\gamma$ so we'll rerun anyway, full results to appear on our web page soon...
Unitarity Triangle Analysis

- All flavour mixing in the SM described by four CKM parameters, e.g. \( \lambda, A, \rho, \eta \)

- CKM unitarity implies triangular relations:
  \[ (V^†V)_{db} = 0 \iff \text{triangle with apex } (\rho, \eta) \]
  - Test the consistency of the SM both “visually” and quantitatively
  - Compare CP-conserving and CP-violating obs.
  - Get constraints on deviations from the SM
INPUTS

- $\alpha_s(M_Z) = 0.1180 \pm 0.0009$ (PDG no EW + de Blas et al '17 EWPO)
- $m_t(m_t) = 165.72 \pm 0.73$ GeV (from WA of $m_t^{\text{pole}}$)
- $m_b(m_b) = 4.177 \pm 0.026$ GeV, $m_c(m_c) = 1.288 \pm 0.025$ GeV, $m_s(2$ GeV) $= 0.0930 \pm 0.0019$ GeV (our average of FLAG 2+1+1 and 2+1)
- $|V_{us}| = 0.2248 \pm 0.0007$ (our average of FLAG 2+1+1 and 2+1 from K physics assuming unitarity)
- $|V_{ud}| = 0.97417 \pm 0.00021$ Hardy & Towner '14
- $B_K = 0.740 \pm 0.029$ (our average of FLAG 2+1+1 and 2+1) + NP $B_i$
- $\kappa_c = 0.97 \pm 0.02$ (LD contribution to Im$\Gamma_{12}$ & Im$M_{12}$ from BGI '10 - SM fit only)
INPUTS II

- \( F_{Bs} = 226 \pm 5 \text{ MeV}, B_{Bs} = 1.35 \pm 0.06, F_{Bs}/F_{Bd} = 1.203 \pm 0.013, B_{Bs}/B_{Bd} = 1.032 \pm 0.038 \) (our average of FLAG 2+1+1 and 2+1) + \( B_i \) for NP
- \( \Delta m_s = 17.757 \pm 0.021 /\text{ps}, \Delta m_d = 0.5065 \pm 0.0019 /\text{ps} \) (HFLAV summer 17)
- \( \sin 2\beta = 0.689 \pm 0.020 \) (\( J/\Psi K_s \) average with \(-0.01 \pm 0.01\) from u-penguins)
- \( \phi_s = -0.021 \pm 0.031 \) (HFLAV)
- \( A_{SL}^d = -0.0021 \pm 0.0017, A_{SL}^s = -0.0006 \pm 0.0028 \) (HFLAV)
\( |V_{ub}| \) AND \( |V_{cb}| \) INCL. & EXCL.

- Skeptic 2D combination of HFLAV & LHCb:
  - \( |V_{ub}|_{\text{excl}} = (3.65 \pm 0.14) \times 10^{-3} \)
  - \( |V_{ub}|_{\text{incl}} = (4.50 \pm 0.20) \times 10^{-3} \)
  - \( |V_{ub}/V_{cb}| = (7.90 \pm 0.57) \times 10^{-2} \)

we get:
  - \( |V_{ub}| = (3.74 \pm 0.23) \times 10^{-3} \)
  - \( |V_{cb}| = (40.5 \pm 1.1) \times 10^{-3}, \rho=0.09 \)
$|V_{ub}|$ AND $|V_{cb}|$ INCL. & EXCL.

- HQ relations used in CLN parameterization of $B \to D^* \, FF$ may be driving the discrepancy; BGL + Belle unfolded data gives larger $|V_{cb}|$
  - Grinstein & Kobach '17; Bigi, Gambino & Schacht '17

- However, relaxing HQ relations might be in tension with first preliminary results of FNAL-MILC at non-zero recoil
  - Bernlochner, Ligeti, Papucci, Robinson '17

- New ideas to compute FF on the lattice at small $q^2$
  - Martinelli et al., in progress
INPUT FOR $\gamma$

Combined input used in this run:
$\gamma = (75.5 \pm 4.8)^\circ$

HFLAV update:
$\gamma = (73.2 \pm 4.5)^\circ$

Indirect determination:
$\gamma = (65.8 \pm 2.2)^\circ$
INPUT FOR $\alpha$
THE SM UTA

$\bar{\rho} = 0.145 \pm 0.015$

$\bar{\eta} = 0.350 \pm 0.013$
THE SM UTA

\[ \bar{\rho} = 0.145 \pm 0.015 \]
\[ \bar{\eta} = 0.350 \pm 0.013 \]

Implications of LHCb measurements and future prospects

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\[ \bar{\rho} = 0.142 \pm 0.014 \]
\[ \bar{\eta} = 0.342 \pm 0.011 \]
THE SM UTA
COMPATIBILITY PLOTS

\[ \sigma(\sin 2\beta) \]

\[ \sigma(\gamma) \]

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NEW PHYSICS ANALYSIS

• Generalize the UTA allowing for NP in loop-mediated processes:
  − $V_{us}, V_{cb}, V_{ub}, \gamma$ from trees and $\alpha$ unaffected
  − NP allowed in $\Delta F=2$ processes:
    • $\varepsilon_K = C_{eK} \varepsilon_{K}^{SM}$
    • $A_q = C_{Bq} \exp(2i\phi_{Bq}) A_{q}^{SM} \exp(2i\phi_{Bq}^{SM})$
  • Extract both CKM parameters and NP contributions
NP ANALYSIS: RESULTS

\[ \overline{\rho} = 0.118 \pm 0.024 \]
\[ \overline{\eta} = 0.384 \pm 0.028 \]

to be compared w.

\[ \overline{\rho} = 0.145 \pm 0.015 \]
\[ \overline{\eta} = 0.350 \pm 0.013 \]
in the SM
\[ C_{\varepsilon K} = 1.06 \pm 0.12, \quad C_{B_d} = 1.00 \pm 0.10, \quad \phi_{B_d} = (-2.0 \pm 1.8)^\circ, \]

\[ C_{B_{s}} = 1.11 \pm 0.09, \quad \phi_{B_{s}} = (0.5 \pm 0.9)^\circ \]

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FROM $\Delta F=2$ TO THE NP SCALE

- $H_{\text{eff}}^{\Delta F=2} = \sum_{i=1}^{5} C_i \, O_i + \sum_{i=1}^{3} C_i' \, O_i'$

- In the SM only $O_1$ (V-A)

- Operators with $i>1$ are RG- and chirally-enhanced

- In general, $C_i \sim F_i L_i / \Lambda^2$

- Take $L_i=1$ and $F_i=1$ (generic) or $F_i \sim F_1^{SM}$ (next-to-minimal flavour violation)
Best bound from $\varepsilon_K$, dominated by CKM error

CPV in charm mixing follows, exp error dominant

$B_d$ and $B_s$ behind, error from both CKM and B-params

Non-perturbative NP:
- $\Lambda > 4 \times 10^5$ TeV

Weakly interacting:
- $\Lambda > 10^4$ TeV
**NMFV STRONGLY-INTERACTING NP**

If new chiral structures present, $\varepsilon_K$ still gives best constraint

$B_d$ and $B_s$ most powerful if no new operators arise

Non-perturbative NMFV NP (e.g. composite Higgs)
- $\Lambda > 97$ TeV

Weakly interacting:
- $\Lambda > 3$ TeV

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CONCLUSIONS

- UTA fundamental tool to
  - obtain best determinations of SM parameters and best predictions for FCNC and CP
  - obtain best determination of SM parameters in the presence of loop-mediated NP
  - constrain NP contributions to $\Delta F=2$ amplitudes
  - get very stringent constraints on the NP scale
Assuming:
- $\delta |V_{ub}|/|V_{ub}| \sim 1\%$
- $\delta |V_{cb}|/|V_{cb}| \sim 1\%$
- $\delta \gamma \sim 0.4^\circ$
- $\delta \alpha \sim 1^\circ$

we get:
- $\delta \bar{\rho} = \pm 0.003$ (now $\pm 0.024$)
- $\delta \bar{\eta} = \pm 0.005$ (now $\pm 0.028$)
Assuming:
- $\delta \beta \sim 0.07^\circ$
- $\delta \beta_s \sim 0.1^\circ$

we get:
- $\delta C_{\varepsilon K} \sim 0.06$ (now 0.12)
- $\delta C_{Bd} \sim \delta C_{Bs} \sim 0.02$ (now 0.1)
- $\delta \phi_{Bd} \sim 0.4^\circ$ (now 1.8°)
- $\delta \phi_{Bs} \sim 0.1^\circ$ (now 0.9°)