FLAVOUR CONSTRAINTS ON NP

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- Introduction
- Generalized UTA with NP
- D-$\overline{D}$ mixing and CP violation
- Bounds on the NP scale from $\Delta F=2$ processes
- Conclusions and outlook

Many thanks to D. Derkach and to M. Bona!

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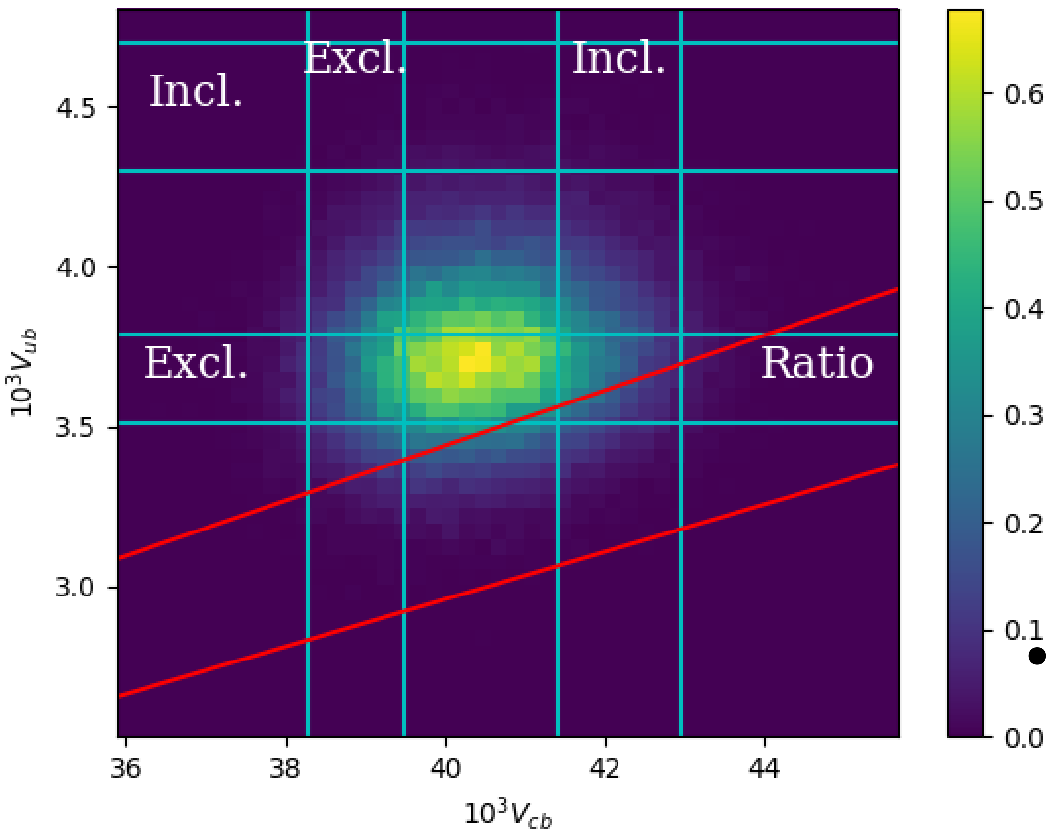
INTRODUCTION

- All flavour mixing & weak CPV in the SM described by CKM parameters, e.g. λ, A, $\bar{\rho}$, $\bar{\eta}$
- FCNC couplings CKM- and GIM-suppressed
  - highly sensitive to NP
  - more SM suppression ⇔ more NP sensitivity
  - $\Delta F=2$ best case: double suppression!
- CPV in charm mixing null test of the SM

NEW PHYSICS IN $\Delta F=2$

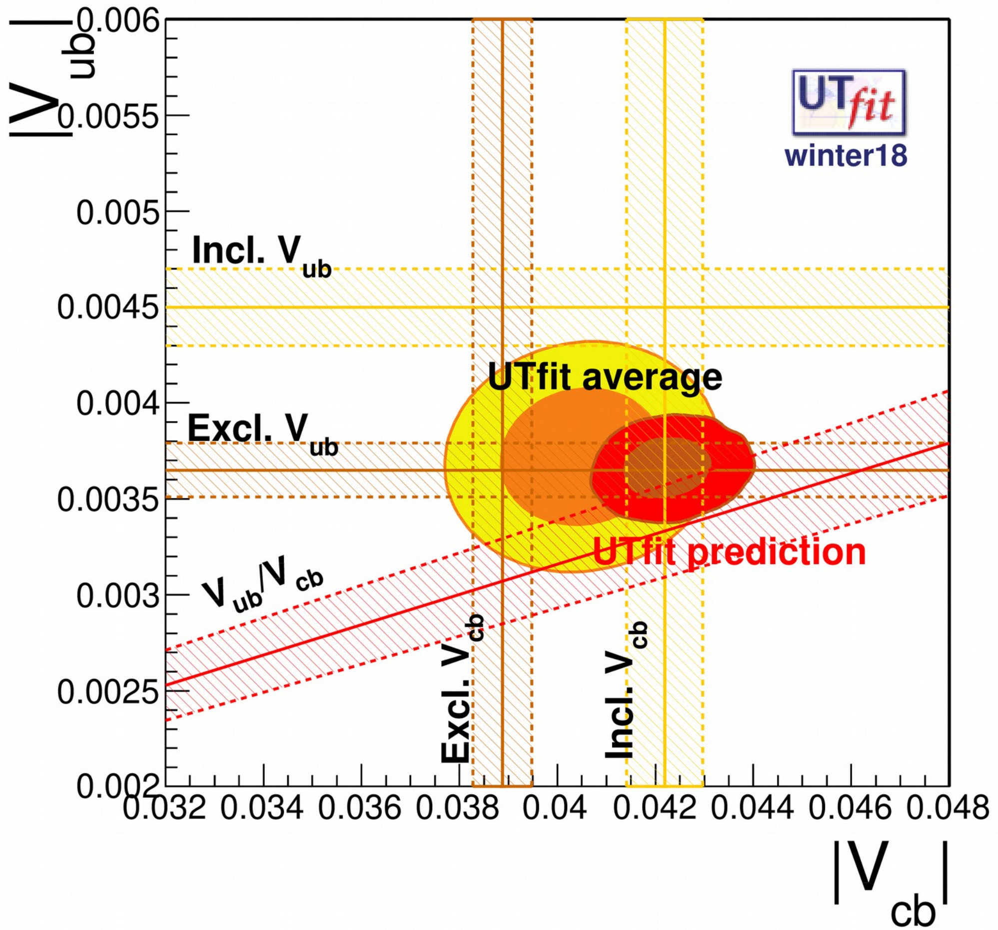
- Generalize the UTA allowing for NP in loop-mediated processes:
  - V_{us}, V_{cb}, V_{ub}, γ from trees and α unaffected (provided no huge NP effect in EWP)
  - NP allowed in $\Delta F=2$ processes
- Extract both CKM parameters and NP contributions

$|V_{ub}|$ AND $|V_{cb}|$ INCL. & EXCL.



- Skeptic 2D combination of HFLAV & LHCb:
  - $|V_{cb}|_{excl}$ = (38.88 ± 0.60) 10^{-3}
  - $|V_{cb}|_{incl}$ = (42.19 ± 0.78) 10^{-3}
  - $|V_{ub}|_{excl}$ = (3.65 ± 0.14) 10^{-3}
  - $|V_{ub}|_{incl}$ = (4.50 ± 0.20) 10^{-3}
  - $|V_{ub}/V_{cb}|$ = (7.90 ± 0.57) 10^{-2}
- we get:
  - $|V_{ub}|$ = (3.74 ± 0.23) 10^{-3}
  - $|V_{cb}|$ = (40.5 ± 1.1) 10^{-3}, ρ=0.09

$|V_{ub}|$ AND $|V_{cb}|$ INCL. & EXCL.



- HQ relations used in CLN parameterization of B→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

NP ANALYSIS: RESULTS

$\bar{\rho} = 0.125 \pm 0.025$

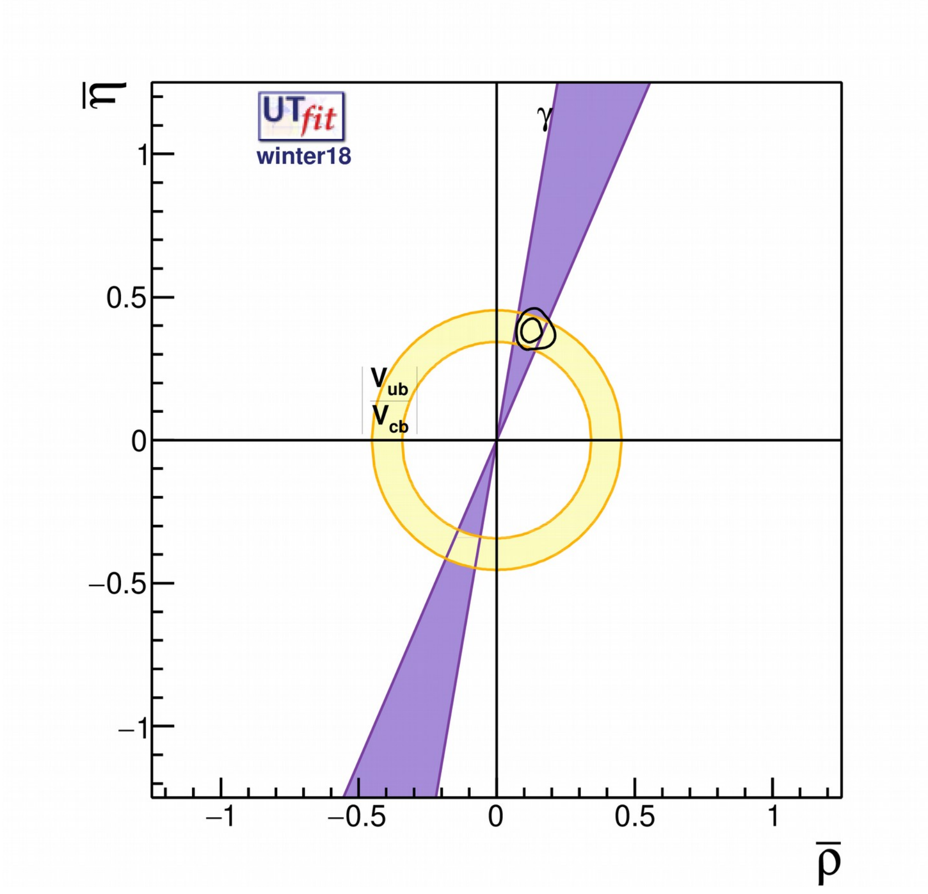
$\bar{\eta} = 0.381 \pm 0.028$

to be compared w.

$\bar{\rho} = 0.145 \pm 0.014$

$\bar{\eta} = 0.349 \pm 0.010$

in the SM



NP CONTRIBUTIONS TO ΔF=2

- Phenomenological parameterization:

$$C_{B_q} e^{2i\phi_{B_q}} = \frac{\langle B_q | H_{\rm eff}^{\rm full} | \bar{B}_q \rangle}{\langle B_q | H_{\rm eff}^{\rm SM} | \bar{B}_q \rangle} = 1 + \frac{A_q^{\rm NP}}{A_q^{\rm SM}} e^{2i\phi_q^{\rm NP}}$$

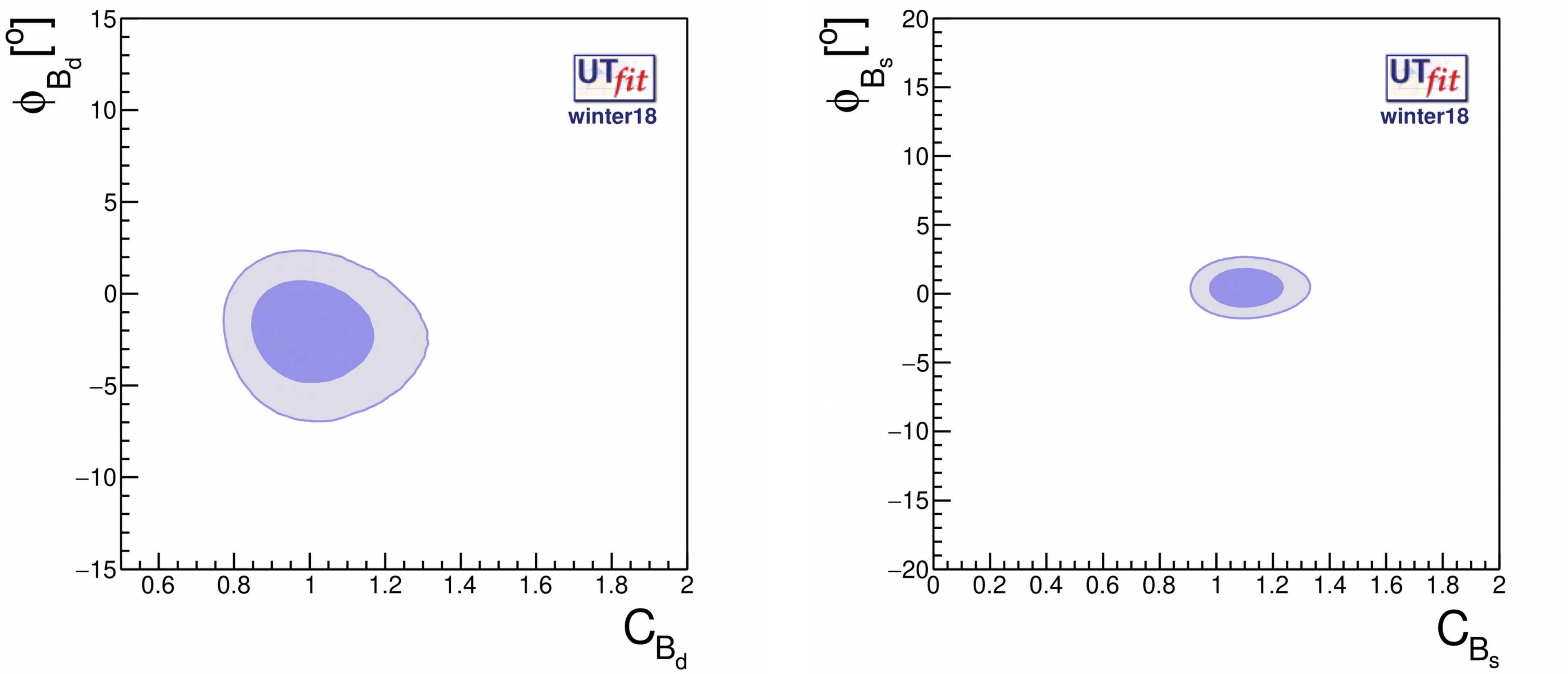
$$\Delta m_{d,s}^{\rm exp} = C_{B_{d,s}} \Delta m_{d,s}^{\rm SM}$$

$$\sin 2\beta^{\rm exp} = \sin(2\beta + 2\phi_{B_d}) \qquad \phi_s^{\rm exp} = \beta_s - \phi_{B_s}$$

$$A_{\rm SL}^{d,s;\rm exp} = {\rm Im}\left(\frac{\Gamma_{12}^{\rm SM}}{M_{12}^{\rm SM}}\right) \frac{\cos 2\phi_{B_{d,s}}}{C_{B_{d,s}}} - {\rm Re}\left(\frac{\Gamma_{12}^{\rm SM}}{M_{12}^{\rm SM}}\right) \frac{\sin 2\phi_{B_{d,s}}}{C_{B_{d,s}}}$$

$$C_{\varepsilon_K} = \frac{\varepsilon_K^{exp}}{\varepsilon_K^{\rm SM}} = \frac{{\rm Im}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm full} | \bar{K}^0 \rangle}{{\rm Im}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm SM} | \bar{K}^0 \rangle} \qquad C_{\Delta m_K} = \frac{\Delta m_K^{exp}}{\Delta m_K^{\rm SM}} = \frac{{\rm Re}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm full} | \bar{K}^0 \rangle}{{\rm Re}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm SM} | \bar{K}^0 \rangle}$$

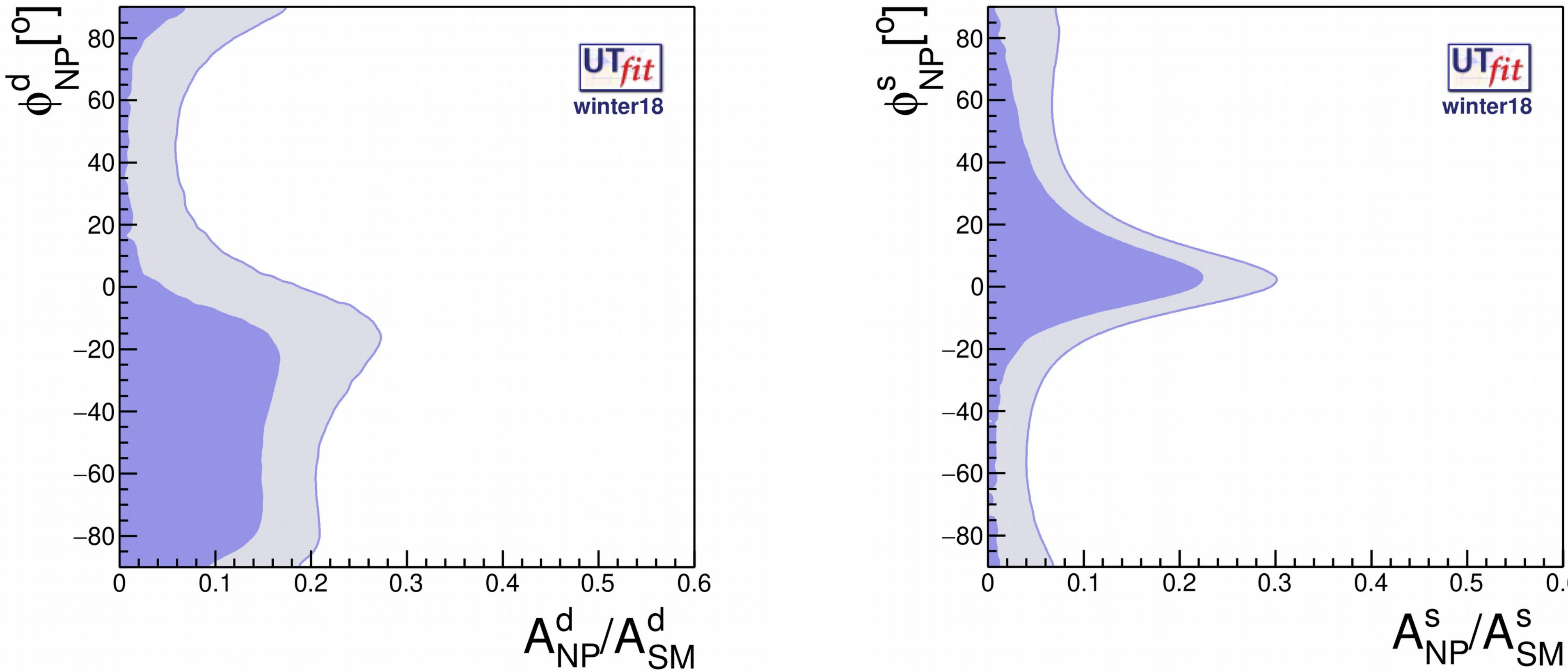
RESULTS ON NP PARAMETERS



$C_{\varepsilon K} = 1.08 \pm 0.12$, $C_{Bd} = 1.00 \pm 0.11$, $\phi_{Bd} = (-2.0 \pm 1.8)°$,

$C_{Bs} = 1.10 \pm 0.09$, $\phi_{Bs} = (0.4 \pm 0.9)°$

RESULTS ON NP PARAMETERS



Marginalizing on the phase: $A_{NP}{}^d/A_{SM}{}^d < 21\%$ and $A_{NP}{}^s/A_{SM}{}^s < 21\%$ at 95% probability

D-$\bar{D}$ MIXING

- D mixing is described by:
  - Dispersive D-$\bar{D}$ amplitude M_{12}
    - SM: long-distance dominated, not calculable
    - NP: short-distance, calculable on the lattice
  - Absorptive D-$\bar{D}$ amplitude Γ_{12}
    - SM: long-distance, not calculable
    - NP: negligible
  - Observables: M_{12}, Γ_{12}, $\Phi_{12}=\arg(\Gamma_{12}/M_{12})$

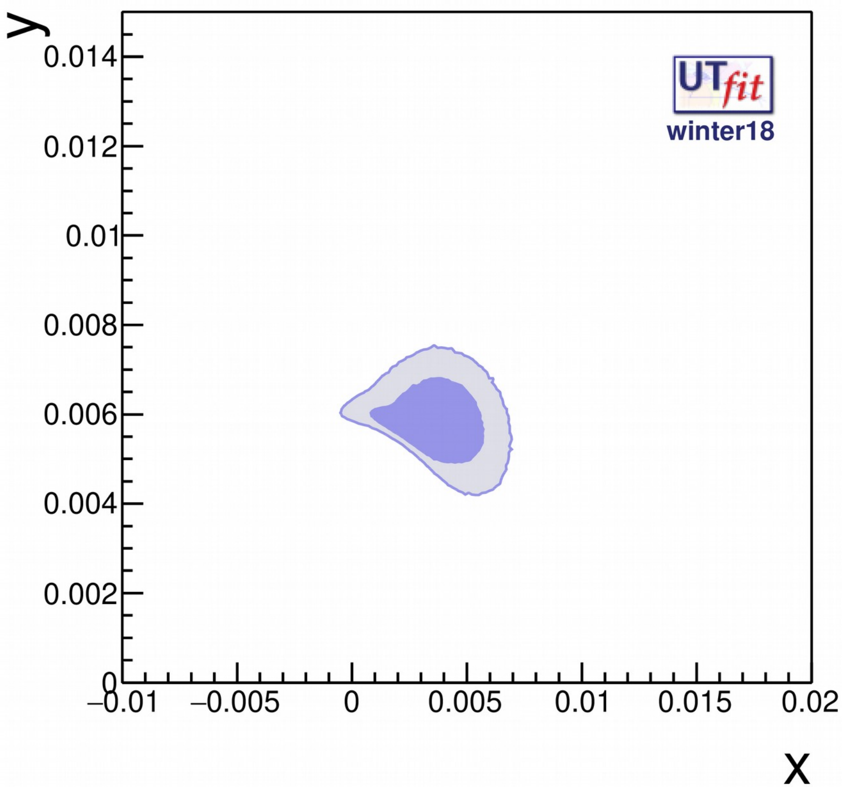
"REAL SM" APPROXIMATION

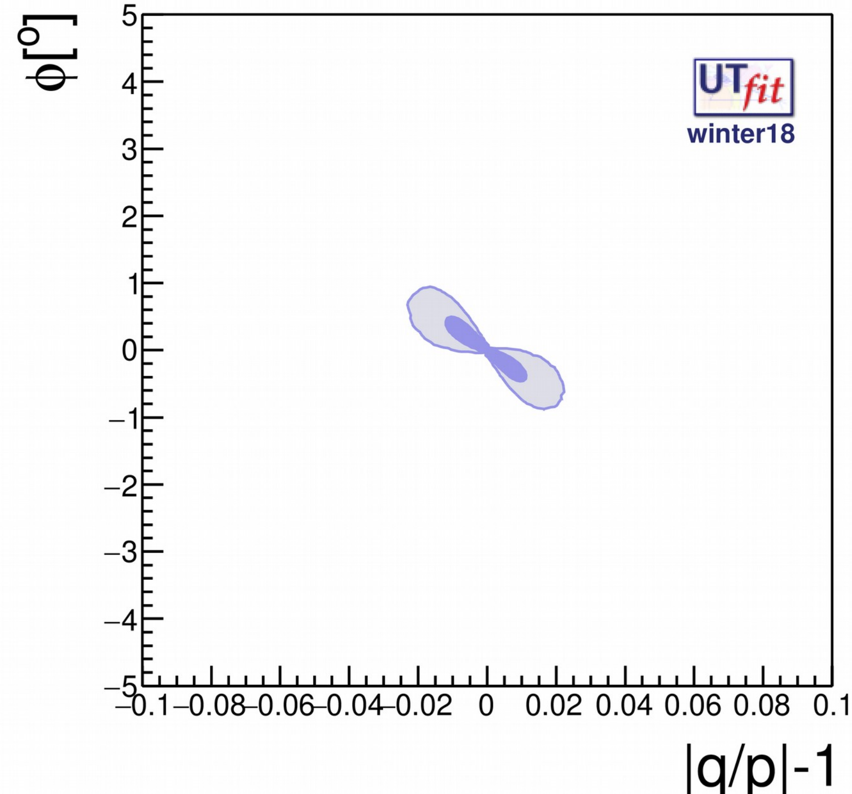
- In the SM, imaginary parts suppressed by tiny CKM factor $r=6.5\ 10^{-4}$
- Given present experimental errors, it is perfectly adequate to assume that SM contributions to M_{12} and Γ_{12} are real
- All decay amplitudes relevant for D mixing can also be taken real
- NP could generate a nonvanishing phase for M_{12}

"REAL SM" APPROXIMATION

- Define $|D_{S,L}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$ and $\delta = (1-|q/p|^2)/(1+|q/p|^2)$. All observables can be written in terms of $x = \Delta m/\Gamma$, $y = \Delta\Gamma/2\Gamma$ and δ
- Introduce $\phi = \arg(q/p) = \arg(y + i\delta x)$
- $|q/p| \neq 1 \Leftrightarrow \phi \neq 0$ clear signals of NP
- Combine all available data with the assumption of real decay amplitudes and real Γ_{12}
- Preliminary winter18 combination

D mixing fit results

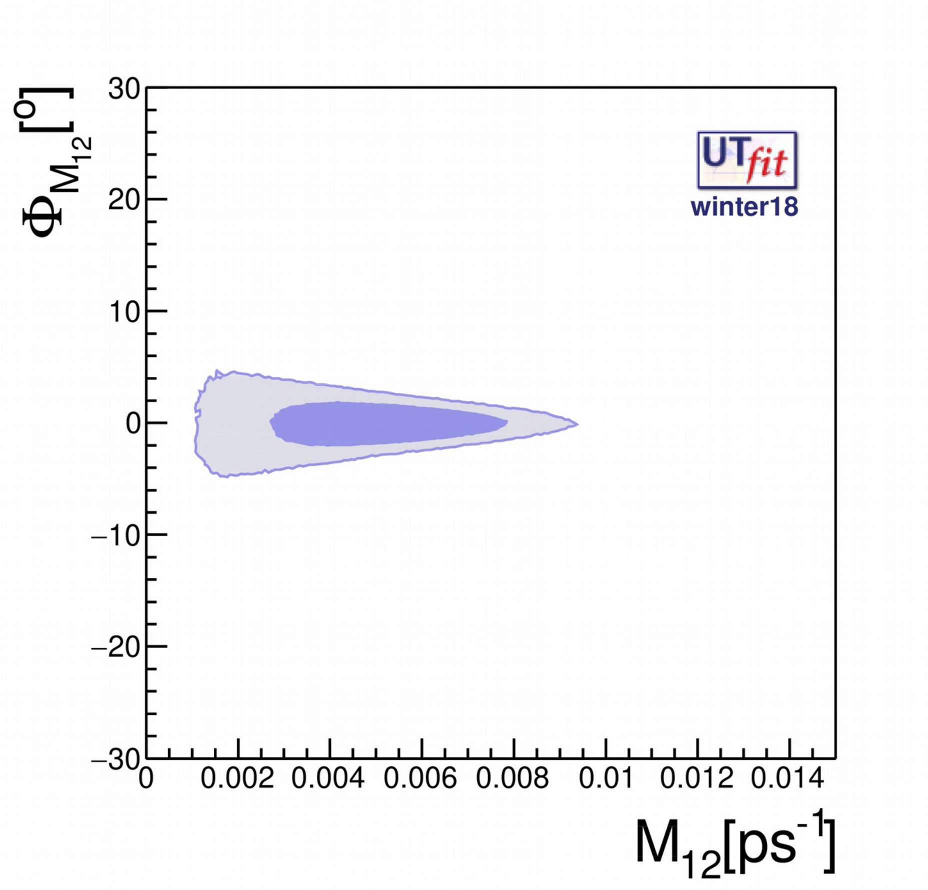




$x = (3.9 \pm 1.4)\ 10^{-3}$, $y = (5.9 \pm 0.6)\ 10^{-3}$,

$\phi = (0.02 \pm 0.32)^\circ$, $|q/p|-1 = (0 \pm 9)\ 10^{-3}$

D mixing fit results



$M_{12} = (4.8 \pm 1.7)\ 10^{-3}$ ps^{-1}

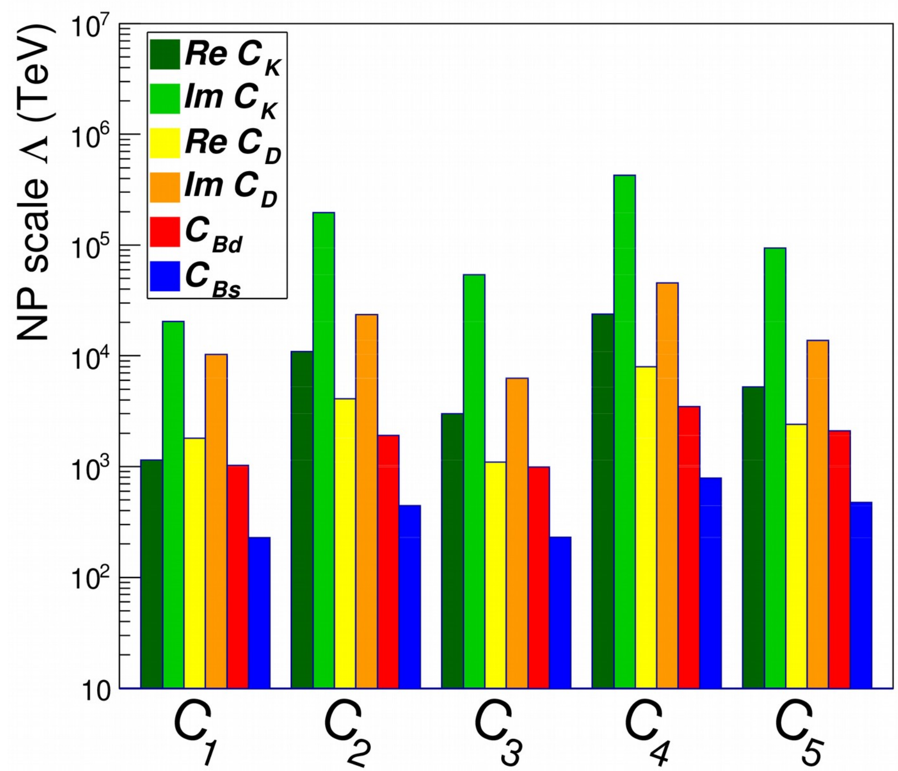
$\phi_{12} = (-0.1 \pm 1.3)^\circ$

FROM ΔF=2 TO THE NP SCALE

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

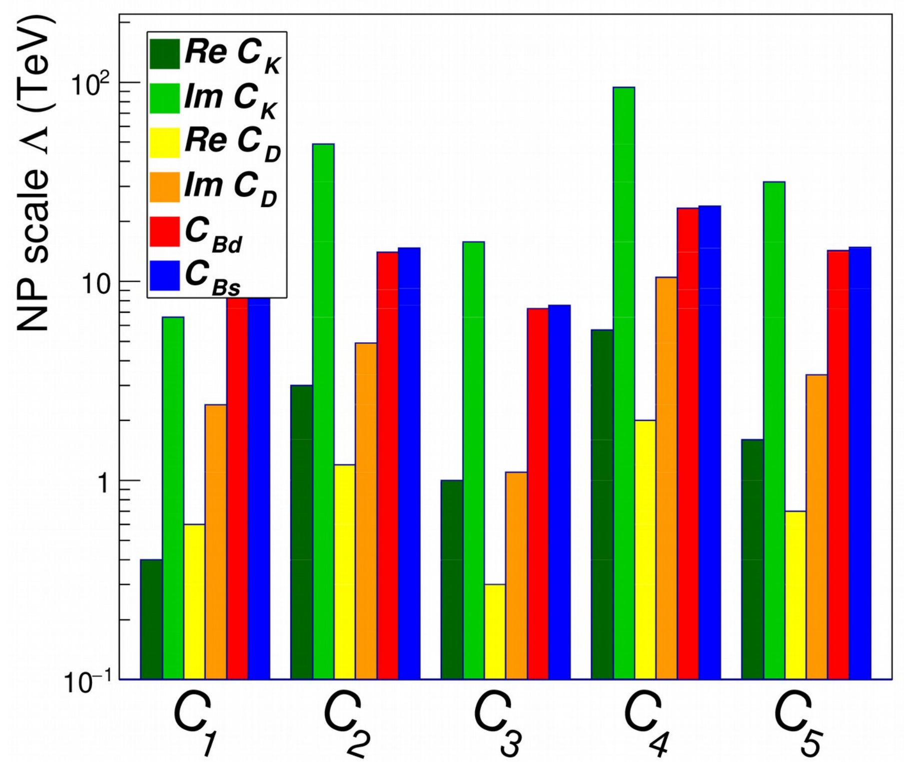
GENERIC STRONGLY-INTERACTING NP

- Best bound from ε_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:
  - $\Lambda > 4\ 10^5$ TeV
- Weakly interacting:
  - $\Lambda > 10^4$ TeV



NMFV STRONGLY-INTERACTING NP

- If new chiral structures present, ε_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)
  - $\Lambda > 94$ TeV
- Weakly interacting:
  - $\Lambda > 3$ TeV



SUMMARY OF THE BOUNDS

Parameter	95% allowed range (GeV^{-2})	Lower limit on Λ (TeV) for arbitrary NP	Lower limit on Λ (TeV) for NMFV
ReC_K^1	$[-6.8, 7.7] \cdot 10^{-13}$	$1.1 \cdot 10^3$	0.4
ReC_K^2	$[-8.3, 7.7] \cdot 10^{-15}$	$11.0 \cdot 10^3$	3.0
ReC_K^3	$[-1.0, 1.1] \cdot 10^{-13}$	$3.0 \cdot 10^3$	1.0
ReC_K^4	$[-1.7, 1.8] \cdot 10^{-15}$	$23.8 \cdot 10^3$	5.7
ReC_K^5	$[-3.4, 3.6] \cdot 10^{-14}$	$5.3 \cdot 10^3$	1.6
ImC_K^1	$[-1.2, 2.4] \cdot 10^{-15}$	$20.4 \cdot 10^3$	6.6
ImC_K^2	$[-2.6, 1.4] \cdot 10^{-17}$	$196.9 \cdot 10^3$	48.8
ImC_K^3	$[-1.8, 3.4] \cdot 10^{-16}$	$54.1 \cdot 10^3$	15.8
ImC_K^4	$[-2.9, 5.5] \cdot 10^{-18}$	$426.3 \cdot 10^3$	94.2
ImC_K^5	$[-6.0, 11.2] \cdot 10^{-17}$	$94.4 \cdot 10^3$	31.6
ReC_D^1	$[-2.5, 3.1] \cdot 10^{-13}$	$1.8 \cdot 10^3$	0.6
ReC_D^2	$[-6.0, 4.7] \cdot 10^{-14}$	$4.1 \cdot 10^3$	1.2
ReC_D^3	$[-6.6, 8.2] \cdot 10^{-13}$	$1.1 \cdot 10^3$	0.3
ReC_D^4	$[-1.2, 1.6] \cdot 10^{-14}$	$8.0 \cdot 10^3$	2.0
ReC_D^5	$[-1.4, 1.7] \cdot 10^{-13}$	$2.4 \cdot 10^3$	0.7
ImC_D^1	$[-9.4, 8.9] \cdot 10^{-15}$	$10.3 \cdot 10^3$	2.4
ImC_D^2	$[-1.7, 1.8] \cdot 10^{-15}$	$23.6 \cdot 10^3$	4.9
ImC_D^3	$[-2.5, 2.4] \cdot 10^{-14}$	$6.3 \cdot 10^3$	1.1
ImC_D^4	$[-4.8, 4.4] \cdot 10^{-16}$	$45.5 \cdot 10^3$	10.5
ImC_D^5	$[-5.3, 4.9] \cdot 10^{-15}$	$13.8 \cdot 10^3$	3.4
$\lvert C_{B_d}^1 \rvert$	$< 9.5 \cdot 10^{-13}$	$1.0 \cdot 10^3$	9.1
$\lvert C_{B_d}^2 \rvert$	$< 2.7 \cdot 10^{-13}$	$1.9 \cdot 10^3$	14.0
$\lvert C_{B_d}^3 \rvert$	$< 1.0 \cdot 10^{-12}$	994.1	7.3
$\lvert C_{B_d}^4 \rvert$	$< 8.2 \cdot 10^{-14}$	$3.5 \cdot 10^3$	23.3
$\lvert C_{B_d}^5 \rvert$	$< 2.3 \cdot 10^{-13}$	$2.1 \cdot 10^3$	14.3
$\lvert C_{B_s}^1 \rvert$	$< 1.9 \cdot 10^{-11}$	228.8	9.2
$\lvert C_{B_s}^2 \rvert$	$< 5.1 \cdot 10^{-12}$	443.7	14.7
$\lvert C_{B_s}^3 \rvert$	$< 1.9 \cdot 10^{-11}$	230.0	7.6
$\lvert C_{B_s}^4 \rvert$	$< 1.6 \cdot 10^{-12}$	785.7	23.8
$\lvert C_{B_s}^5 \rvert$	$< 4.5 \cdot 10^{-12}$	474.0	14.8

Preliminary – bounds on Re C_K and Re C_D strongly depend on prior on SM LD

CONCLUSIONS

- Current bounds on $\Delta F=2$ amplitudes probe scales up to $\sim 10^5$ TeV
- They represent a serious challenge to models attempting to explain current tensions in B physics ($R(D)$, $R(D^*)$, $R(K)$, $R(K^*)$)
- Excellent prospects with future data from LHCb and BelleII

BACKUP SLIDES

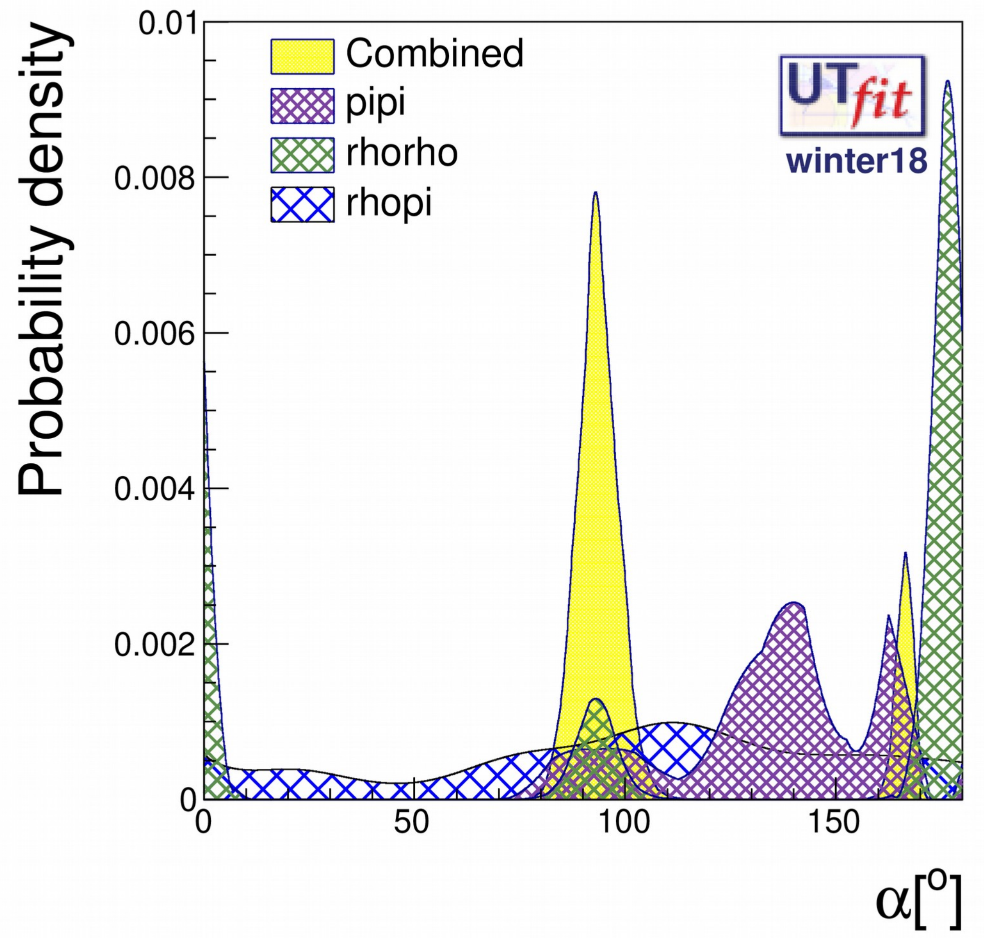
INPUTS

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

INPUTS II

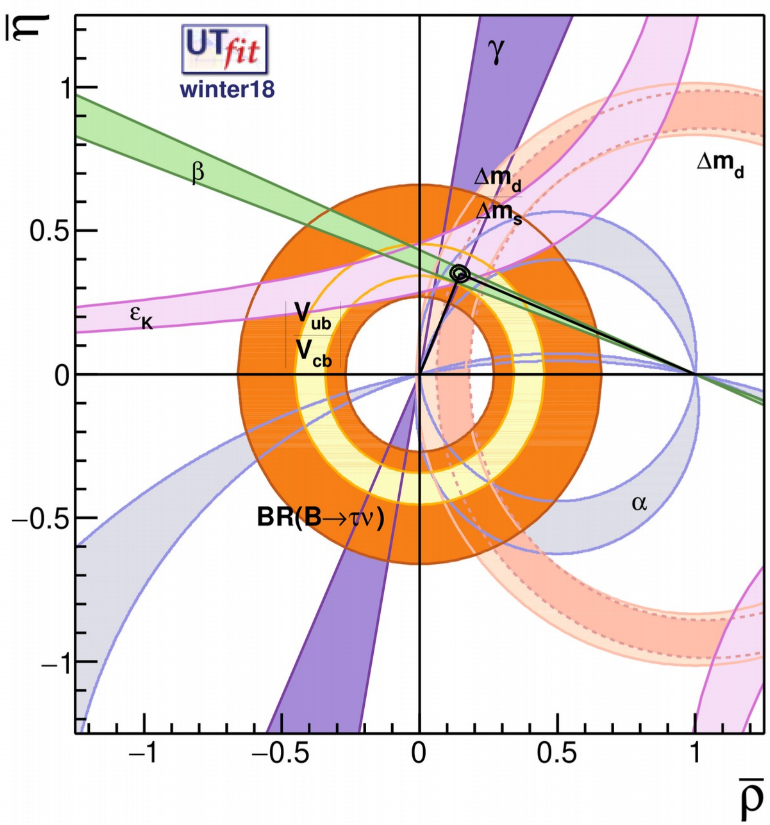
- F_{Bs} = 226 ± 5 MeV, B_{Bs} = 1.35 ± 0.06, F_{Bs}/F_{Bd} = 1.203 ± 0.013, B_{Bs}/B_{Bd} = 1.032 ± 0.038 (our average of FLAG 2+1+1 and 2+1) + B_i for NP
- Δm_s = 17.757 ± 0.021 /ps, Δm_d = 0.5065 ± 0.0019 /ps (HFLAV summer 17)
- sin2β = 0.689 ± 0.020 ($J/\Psi K_s$ average with -0.01 ± 0.01 from u-penguins)
- ϕ_s = -0.021 ± 0.031 (HFLAV)
- A_{SL}^d = -0.0021 ± 0.0017, A_{SL}^s = -0.0006 ± 0.0028 (HFLAV)

INPUT FOR α



Probability density
0.01
0.008
0.006
0.004
0.002
0
Combined
pipi
rhorho
rhopi
UTfit
winter18
0
50
100
150
α[°]

THE SM UTA



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