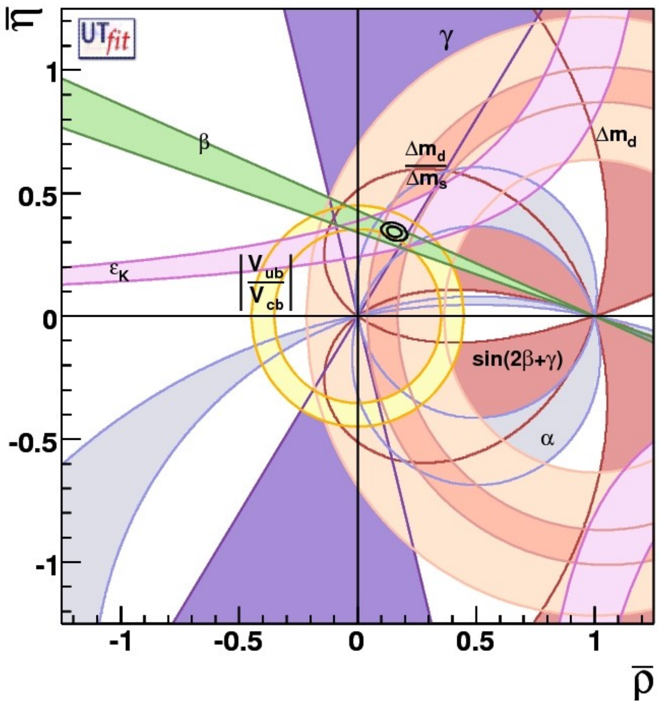
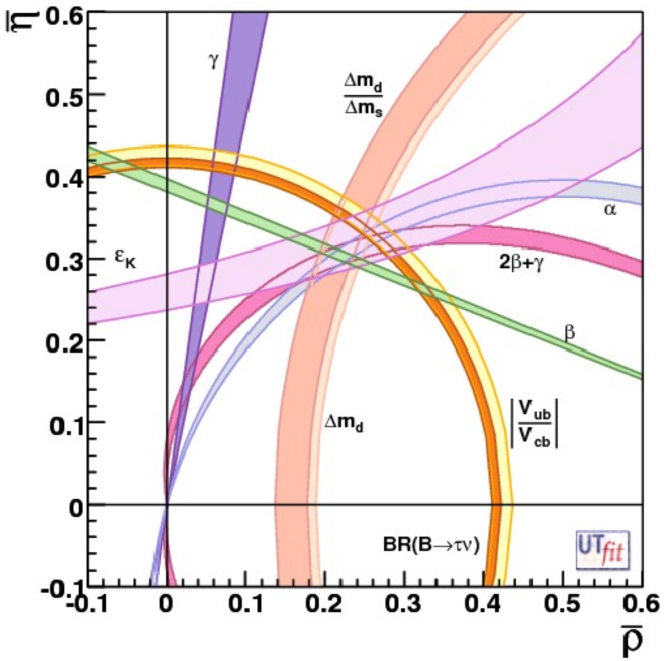
UT ANALYSIS: THEORETICAL STATUS AND FUTURE PERSPECTIVES

Luca Silvestrini

INFN, Rome

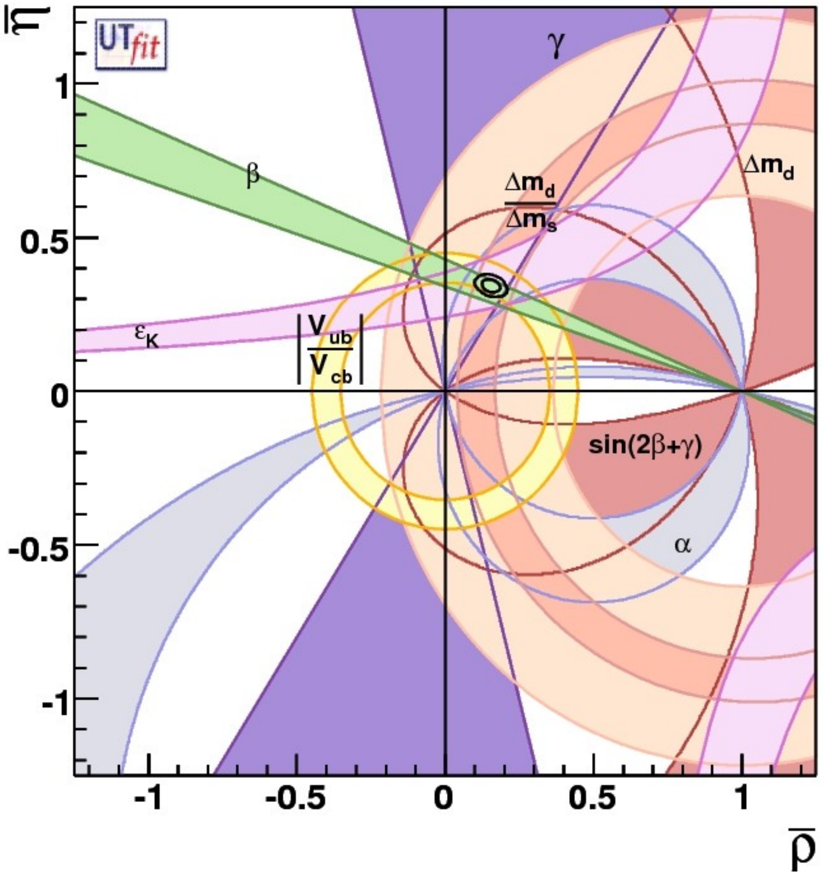




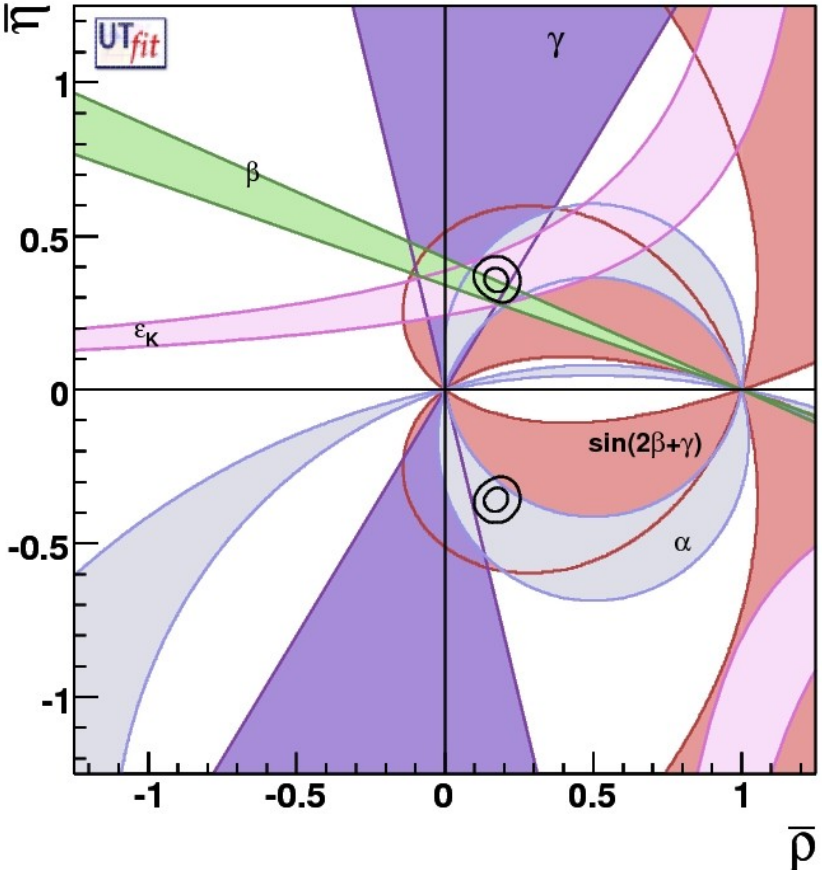
INTRODUCTION

- SM UTA: determination of CKM, prediction for CPV & FCNC, SM consistency check
- UUT & NP MI UTA: determination of CKM, prediction of SM contribution to CPV & FCNC, extraction of NP contrib.
- NP UTA: determination of CKM parameters, NP flavour couplings and masses, predictions, consistency check

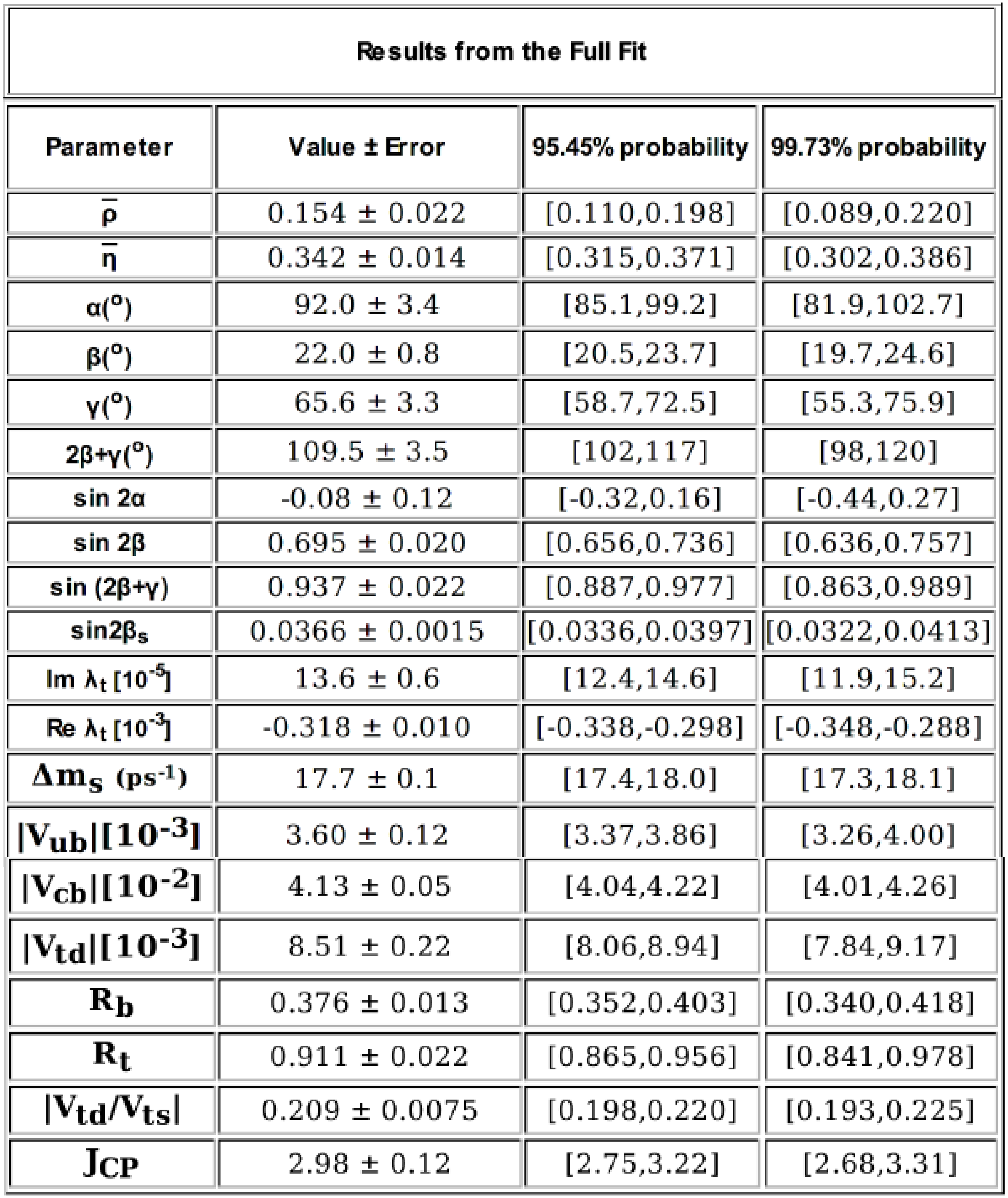
SM UTA: PRESENT



Full fit



CP-conserving vs CP-violating



Results from the Full Fit

Parameter	Value ± Error	95.45% probability	99.73% probability
$\bar{\rho}$	0.154 ± 0.022	[0.110,0.198]	[0.089,0.220]
$\bar{\eta}$	0.342 ± 0.014	[0.315,0.371]	[0.302,0.386]
$\alpha(^\circ)$	92.0 ± 3.4	[85.1,99.2]	[81.9,102.7]
$\beta(^\circ)$	22.0 ± 0.8	[20.5,23.7]	[19.7,24.6]
$\gamma(^\circ)$	65.6 ± 3.3	[58.7,72.5]	[55.3,75.9]
$2\beta+\gamma(^\circ)$	109.5 ± 3.5	[102,117]	[98,120]
sin 2α	-0.08 ± 0.12	[-0.32,0.16]	[-0.44,0.27]
sin 2β	0.695 ± 0.020	[0.656,0.736]	[0.636,0.757]
sin $(2\beta+\gamma)$	0.937 ± 0.022	[0.887,0.977]	[0.863,0.989]
sin$2\beta_s$	0.0366 ± 0.0015	[0.0336,0.0397]	[0.0322,0.0413]
Im λ_t $[10^{-5}]$	13.6 ± 0.6	[12.4,14.6]	[11.9,15.2]
Re λ_t $[10^{-3}]$	-0.318 ± 0.010	[-0.338,-0.298]	[-0.348,-0.288]
Δm_s (ps^{-1})	17.7 ± 0.1	[17.4,18.0]	[17.3,18.1]
$\lvert V_{ub}\rvert[10^{-3}]$	3.60 ± 0.12	[3.37,3.86]	[3.26,4.00]
$\lvert V_{cb}\rvert[10^{-2}]$	4.13 ± 0.05	[4.04,4.22]	[4.01,4.26]
$\lvert V_{td}\rvert[10^{-3}]$	8.51 ± 0.22	[8.06,8.94]	[7.84,9.17]
R_b	0.376 ± 0.013	[0.352,0.403]	[0.340,0.418]
R_t	0.911 ± 0.022	[0.865,0.956]	[0.841,0.978]
$\lvert V_{td}/V_{ts}\rvert$	0.209 ± 0.0075	[0.198,0.220]	[0.193,0.225]
J_{CP}	2.98 ± 0.12	[2.75,3.22]	[2.68,3.31]

SM CONSISTENCY CHECK

- Compare direct and indirect (from all other observables) determinations

	direct	indirect	pull
sin 2β	0.668 ± 0.028	0.736 ± 0.034	1.5
$\lvert V_{ub}\rvert \; 10^3$	3.5 ± 0.4 (excl) 3.99 ± 0.15 ± 0.4 (incl)	3.48 ± 0.16	1.6
Δm_s [ps^{-1}]	17.77 ± 0.12	16.8 ± 1.6	
β_s [°]	-18 ± 8	1.05 ± 0.04	2.9
$BR(B \to \tau\nu)\; 10^4$	1.73 ± 0.34	0.85 ± 0.11	2.4

UTA & NP in ΔF=2

Consider ratios of (SM+NP)/SM ΔF=2 amplitudes

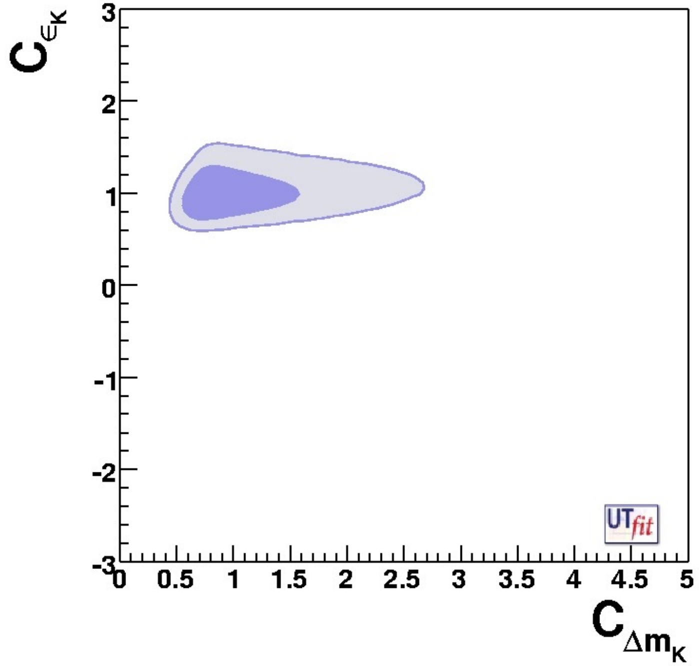
$$C_{B_q}\, e^{2i\phi_{B_q}} = \frac{\langle B_q|H_{\rm eff}^{\rm full}|\bar{B}_q\rangle}{\langle B_q|H_{\rm eff}^{\rm SM}|\bar{B}_q\rangle} = \frac{A_q^{\rm SM} e^{2i\phi_q^{\rm SM}} + A_q^{\rm NP} e^{2i(\phi_q^{\rm SM}+\phi_q^{\rm NP})}}{A_q^{\rm SM} e^{2i\phi_q^{\rm SM}}}$$

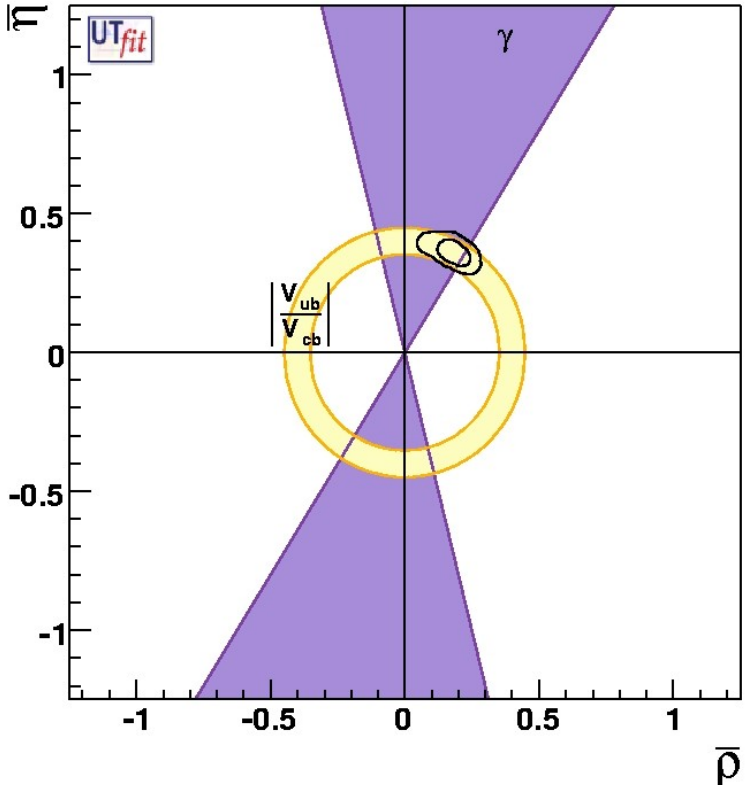
$$C_{\epsilon_K} = \frac{{\rm Im}[\langle K^0|H_{\rm eff}^{\rm full}|\bar{K}^0\rangle]}{{\rm Im}[\langle K^0|H_{\rm eff}^{\rm SM}|\bar{K}^0\rangle]}\,, \qquad C_{\Delta m_K} = \frac{{\rm Re}[\langle K^0|H_{\rm eff}^{\rm full}|\bar{K}^0\rangle]}{{\rm Re}[\langle K^0|H_{\rm eff}^{\rm SM}|\bar{K}^0\rangle]}$$

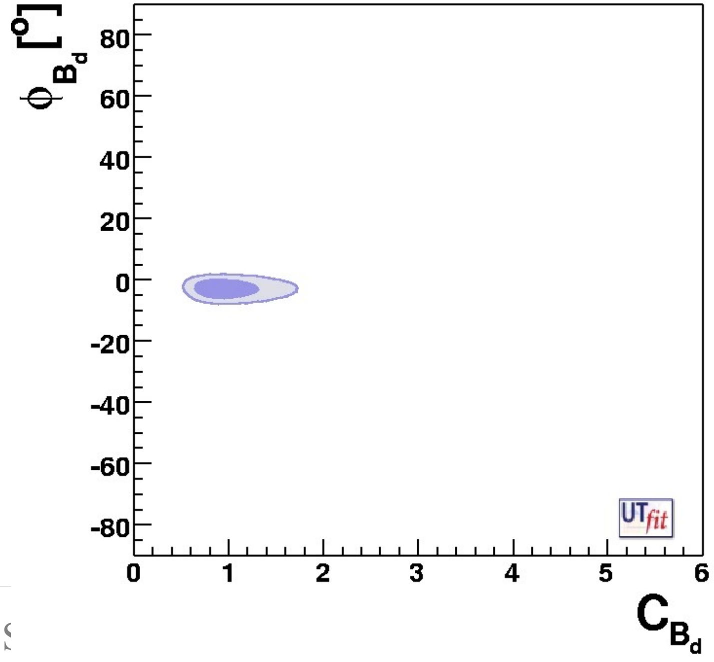
Determine ρ, η, C's and φ's using generalized UT analysis

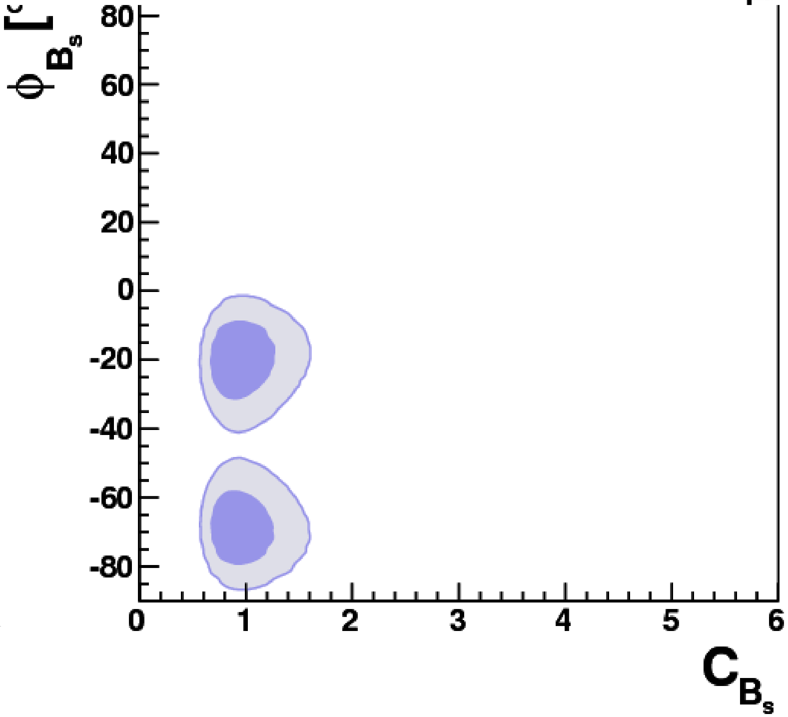
Derive bounds on NP scale and/or couplings

Our present knowledge:









SUMMARY OF CONSTRAINTS

Parameter	Output	Parameter	Output
$C_{\Delta m_K}$	0.96 ± 0.34	C_{ε_K}	0.99 ± 0.16
C_{B_d}	0.96 ± 0.23	ϕ_{B_d}	$\boxed{(-2.9 \pm 1.9)^\circ}$
C_{B_s}	0.94 ± 0.19	ϕ_{B_s}	$\boxed{(-19 \pm 8)^\circ \cup (-69 \pm 7)^\circ}$
$\bar{\eta}$	0.360 ± 0.031	$\bar{\rho}$	0.177 ± 0.044
$\bar{\eta}_{SM}$	0.342 ± 0.014	$\bar{\rho}_{SM}$	0.155 ± 0.022

No deviation seen in K physics, slight offset in phase of B_d mixing, ample room for NP in phase of B_s mixing (might become solid evidence w. Tevatron & LHCb)

THE SCALE OF NP

- The constraints we obtained can be used to put lower bounds on the scale of NP models with a given flavour structure:

$A_{NP}/A_{SM} \sim C/C_{SM}$

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

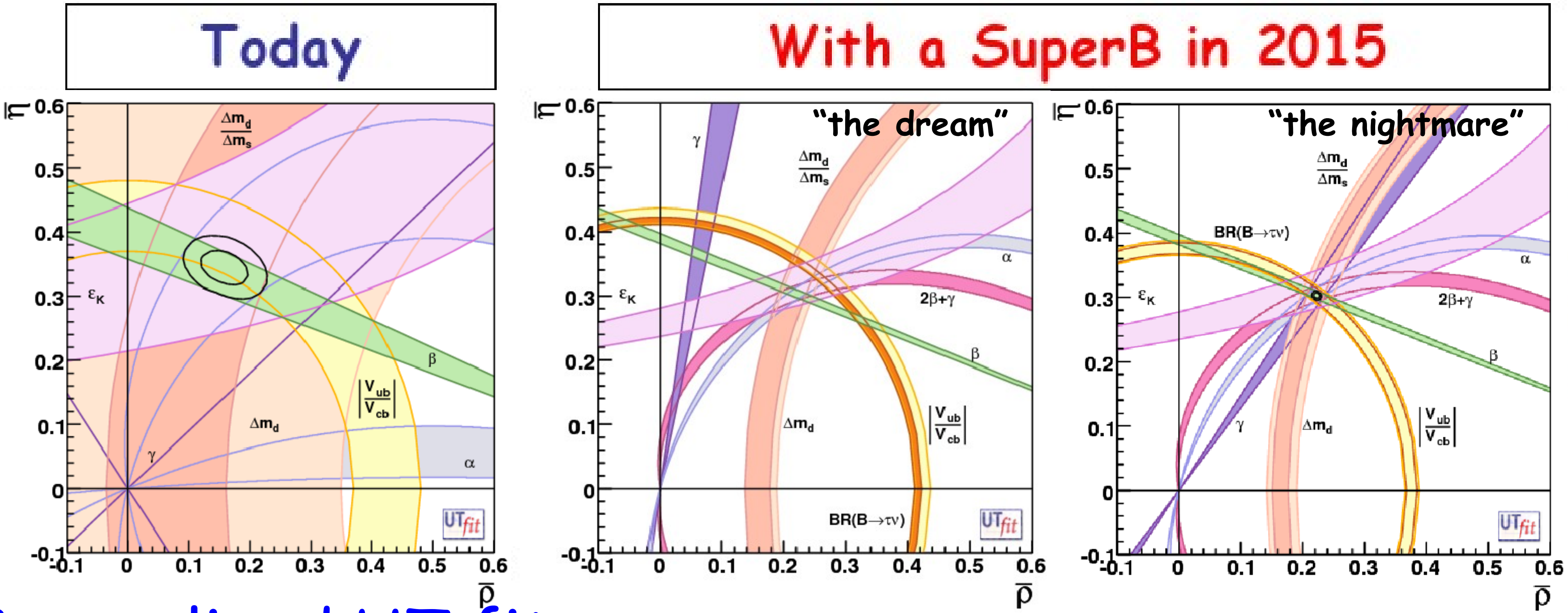
- K_i numeric coefficient of O(1), F_i flavour structure, L loop coefficient, Λ NP scale

LOWER BOUNDS ON THE NP SCALE (TeV)

Scenario	strong/tree	α_s loop	α_W loop
MFV (small $\tan\beta$)	5.5	0.5	0.2
MFV (large $\tan\beta$)	5.1	0.5	0.2
M_H in MFV at large $\tan\beta$	$5\sqrt{(a_0+a_1)(a_0+a_2)}\left(\frac{\tan\beta}{50}\right)$		
NMFV	62	6.2	2
General	24000	2400	800

To be relevant for the hierarchy problem, NP must have a highly nontrivial flavour structure!!

The final goal: CKM matrix at the %


Today

With a SuperB in 2015

“the dream”

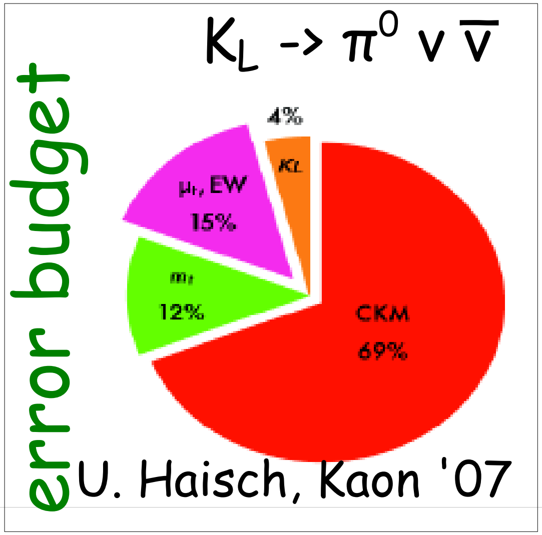
“the nightmare”

Generalized UT fits:

CKM at % in the presence of NP!

	today	SuperB
$\bar{\rho}$	0.177±0.044	±0.005
$\bar{\eta}$	0.360±0.031	±0.005

Will detect deviations from the SM at the level of 3% in C_{B_d} and of 0.5° in ϕ_{B_d}


error budget

$K_L \to \pi^0 \nu \bar{\nu}$

U. Haisch, Kaon '07

CAN THEORY REACH THE % GOAL?

α

- Extracted via isospin analysis in $B\to\pi\pi$ and $B\to\rho\rho$ and via Dalitz analysis of $B\to\rho\pi$
- Isospin analysis affected by discrete ambiguities
- Theoretical uncertainties due to EWP and isospin breaking, model-dependent estimates are at the level of 1-2°
- Th matches present & future exp accuracy: today 7°, LHCb 4.5°, SuperB 1-2°

β

- Extracted from $A_{CP}(t)$ in b → ccs decays (discrete ambiguity solved with vectors)
- Th. error due to subleading decay amplitudes of $O(\lambda^2\ P/C)$
- Model estimates give $O(10^{-3})$, data-driven gives $O(10^{-2})$ but can be improved measuring b → ccd decays
- Th matches and follows exp accuracy

$\beta_{(s)}$ FROM PENGUINS

- Comparing $\beta_{(s)}^{peng}$ with $\beta_{(s)}^{b \to ccs}$ gives an estimate of A_{peng}
- Th. error due to subleading SM amplitudes
  - $O(\lambda^2 P^{GIM}/P < \lambda^2)$ in $b \to sss$ & $b \to dds$
  - $O(\lambda^2 T/P > \lambda^2)$ in $b \to uus$
  - Concentrate on pure penguins!
- Use Dalitz analyses to maximize sensitivity
- Use modes with SU(3)-related control channels (ex. $B_s \to K^{*0} K^{*0}$)

γ

- Extracted from b→cud(s) tree decays, not affected by loop-mediated NP, theory error negligible now and in the future
- $B_s \to K^* \pi$ possible as α from $B \to \rho\pi$
- Extraction from penguin decays $B \to K\pi$, $B \to KK$ and $B \to \pi\pi$ relies on input from factorization or flavour symmetries: error difficult to estimate. More suitable to look for NP in penguins taking γ as input!

β_s

- Extracted from $B_s \to J/\psi\phi$ with angular analysis (strong phase ambiguity) or from other channels
- Theory error due to subleading decay amplitudes of $O(\lambda^2\ P/C)$, comparable to SM
- Difficult to improve using flavour symmetries, requires further investigation to meet LHCb accuracy.

$|V_{cb}|$

- Extracted from b→c semileptonic decays, not affected by loop-mediated NP
- Exclusive decays: need B→D(D*) FF from LQCD. Can decrease from 4% (now, comparable to exp) to 0.5% (2015, subdominant).
- Inclusive decays: th error dominant, can decrease from 1.5% now to 1% in 2015 with higher order perturbative calculations

$|V_{ub}|$

- Extracted from b→u semileptonic decays
- Exclusive decays: need B→ρ(π) FF from LQCD. Can decrease from 11% (now) to 2-3% (2015), always comparable to exp.
- Inclusive decays: th error dominant (5-10%), due to m_b, WA, shape function and higher orders. Studying q^2 spectrum and lowering the M_X cut leaves m_b as dominant. Ultimate reach for 2015 could be 1%.

ε_K

- Two sources of theoretical uncertainty:
  - Hadronic ΔF=2 matrix element(s) (SM:1, NP:5): $B_K^{UT}=0.75\pm0.07$, $B_K^{LAT}=0.75\pm0.07$. Can reach 1% in 2015.
  - Contribution of Im A_0: presently subleading, but above the 1% level. In the SM, can be extracted from ε'/ε using Im A_2 from LQCD. Beyond the SM, requires knowledge of Im A_2^{NP}.

ΔM_d, ΔM_s

- Within the SM only source of theoretical uncertainty is the ME:
  - $f_{Bs}\sqrt{B_{Bs}}^{UT}=265\pm4$ MeV, $f_{Bs}\sqrt{B_{Bs}}^{LAT}=270\pm30$ MeV. Can reach 1% in 2015.
  - $\xi^{UT}=1.26\pm0.05$, $\xi^{LAT}=1.21\pm0.04$. Can reach 0.5% in 2015.
- Beyond the SM need 4 additional matrix elements. In principle same accuracy attainable.

$\Delta\Gamma_d$, $\Delta\Gamma_s$, A_{SL}^d, A_{SL}^s

- Difficult situation in the SM: cancellations & higher orders (α^2 & α/m_b). Must be careful with "guessed" improvements. Re-evaluation of SM under way.
- Beyond the SM penguin effects in A_{SL} are enhanced. Might be relevant in 2015.

SuperB CDR

Estimates of error for 2015

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Hadronic matrix element	Current lattice error	6 TFlop Year	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.7% (17% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	5%	3%	1%
f_B	14%	3.5 - 4.5%	2.5 - 4.0%	1 – 1.5%
$f_{B_s} B_{B_s}^{1/2}$	13%	4 - 5%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	3% (18% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	0.5 – 0.8 % (3-4% on ξ-1)
$\mathcal{F}_{B \to D/D^* l\nu}$	4% (40% on 1-$\mathcal{F}$)	2% (21% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	0.5% (5% on 1-$\mathcal{F}$)
$f_+^{B\pi}, \ldots$	11%	5.5 - 6.5%	4 - 5%	2 – 3%
$T_1^{B \to K^*/\rho}$	13%	----	----	3 – 4%

S.Sharpe @ Lattice QCD: Present and Future, Orsay, 2004 and report of the U.S. Lattice QCD Executive Committee

CONCLUSIONS

- Theory already good enough: α, β, γ
- Reasonable LQCD improvements needed to match % accuracy: exclusive semileptonic, Δm_d, Δm_s
- Improvements needed, must work really hard to reach exp accuracy:
  - OPE: inclusive semileptonic
  - Flavour symmetries and/or data-driven and/or th. breakthrough: $b \to s$ penguins, β_s, ε_K, A_{SL}, $\Delta\Gamma$