Flavour Physics: Status and Perspectives

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SuperB: Flavour Physics

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CENTRO DE CIENCIAS DE BENASQUE PEDRO PASCUAL

SuperB

Flavour in the SM

$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm gauge} + \mathcal{L}_{\rm Higgs} + \mathcal{L}_{\rm Yukawa}$$

$$\mathcal{L}_{\rm Yukawa} = \bar{Q}_L Y_U U_R \tilde{\varphi} + \bar{Q}_L Y_D D_R \varphi + \bar{L}_L Y_E E_R \varphi + H.c.$$

If Y's = 0, $\mathcal{L}_{\rm SM}$ is invariant under the flavour group

$$G_F = U(3)^5 = U(3)_{Q_L} \otimes U(3)_{U_R} \otimes U(3)_{D_R} \otimes U(3)_{L_L} \otimes U(3)_{E_R}$$

Non-vanishing Y's break the global symmetry

$$G_F \to U(1)_B \otimes U(1)_e \otimes U(1)_\mu \otimes U(1)_\tau$$

13 physical parameters survive (without ν_R):

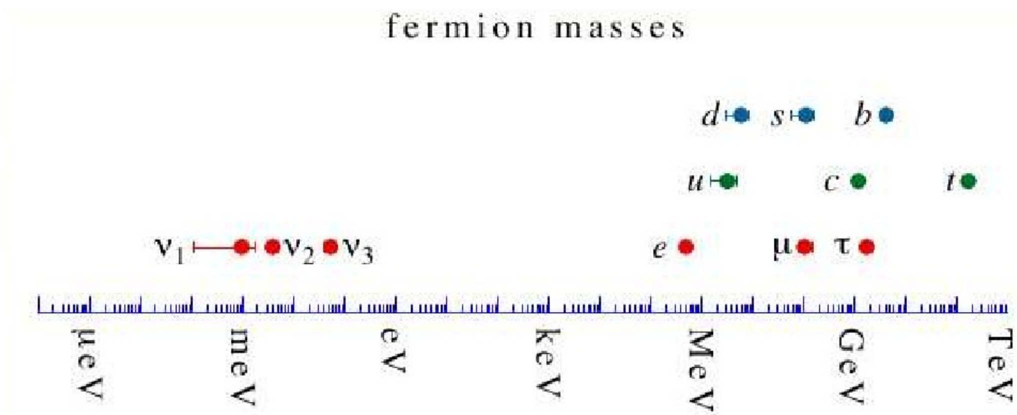
9 fermion masses, 4 CKM parameters

SM: flavour properties

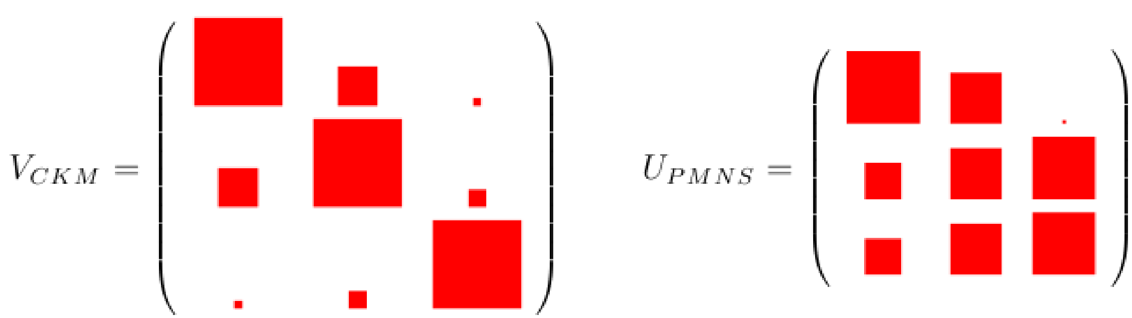
* SM FCNCs and CP-violating processes occur at the loop level
* SM quark FV and CPV are governed by the weak interactions and suppressed by mixing angles
* SM quark CPV comes from a single source (neglecting θ_{QCD})

SM: "flavour problems"

* fermion masses span several orders of magnitude



* The pattern of the CKM (and PMNS?) matrix is non-trivial

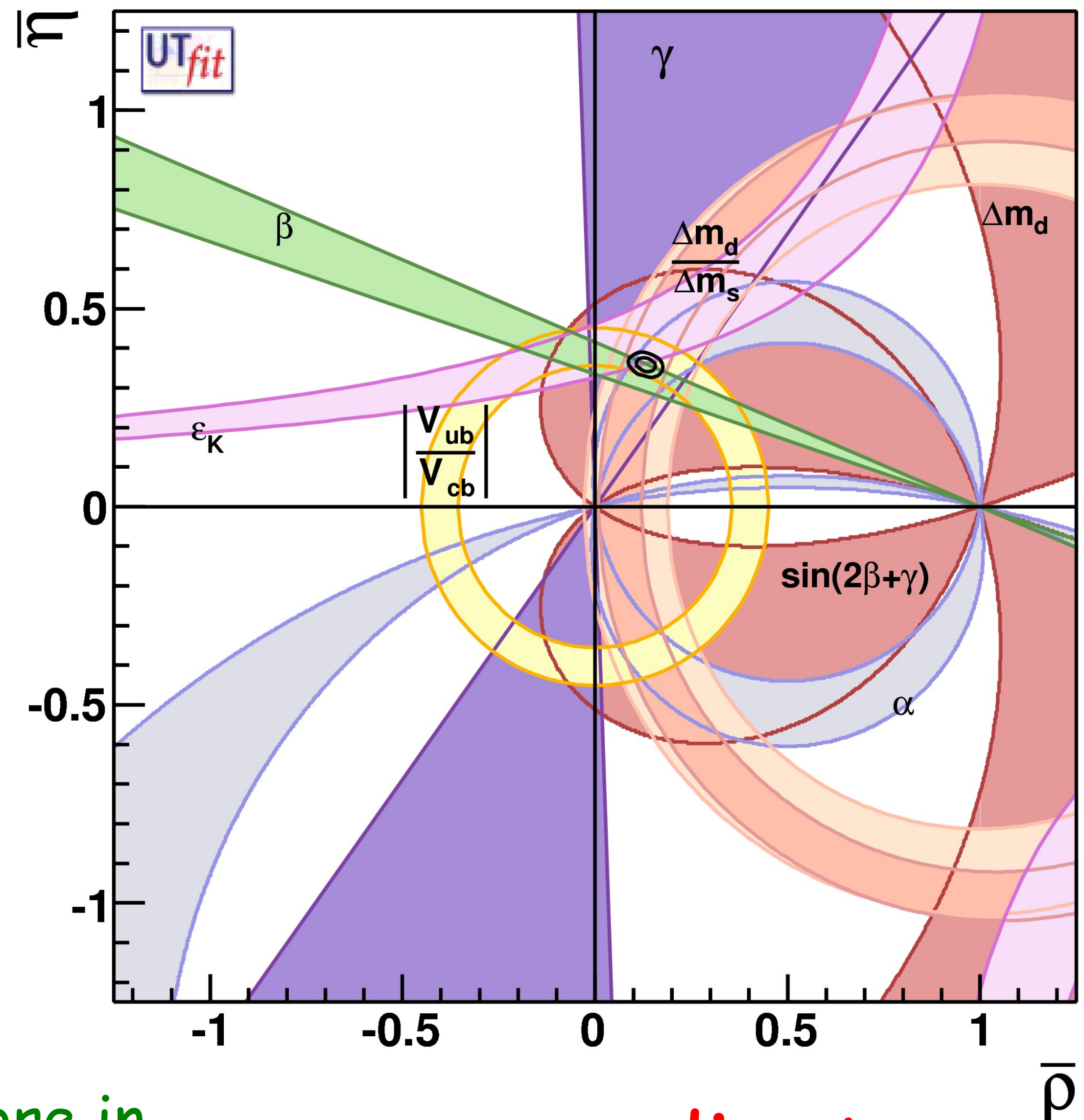


UT: status of the SM analysis

UTfit coll., Summer '10

SM determination of the Unitarity Triangle

$$R_u\, e^{i\gamma} + R_t\, e^{-i\beta} = 1$$



$R_u = 0.379 \pm 0.013$

$R_t = 0.939 \pm 0.021$

$\gamma = (69.8 \pm 3.0)^\circ$

$\beta = (22.42 \pm 0.74)^\circ$

$\alpha = (87.8 \pm 3.0)^\circ$

more in Achille's talk

apex coordinates

$\bar{\rho} = 0.132 \pm 0.021$ (15%)

$\bar{\eta} = 0.358 \pm 0.012$ (4%)

The CKM matrix

UTfit coll., Summer '10

$$\begin{pmatrix} 0.9742(2) & 0.2255(7) & 3.6(1)\cdot 10^{-3} e^{-i70(3)^\circ} \\ -0.2253(6) e^{i0.035(1)^\circ} & 0.9734(2) e^{-i0.0018(1)^\circ} & 4.12(4)\cdot 10^{-2} \\ 8.7(2)\cdot 10^{-3} e^{-i22.5(7)^\circ} & -4.04(4)\cdot 10^{-2} e^{-i1.09(4)^\circ} & 0.99915(2) \end{pmatrix}$$

Standard parametrization (PDG)

$\sin\Theta_{12} = 0.2255 \pm 0.0007$ $\sin\Theta_{23} = (4.117 \pm 0.043)\cdot 10^{-2}$

$\sin\Theta_{13} = (3.64 \pm 0.11)\cdot 10^{-3}$ $\delta = (69.7 \pm 2.9)^\circ$

Wolfenstein parametrization

$\lambda = 0.2255 \pm 0.0007$ $A = 0.81 \pm 0.01$

$\rho = 0.135 \pm 0.021$ $\eta = 0.367 \pm 0.013$

SM predictions: B_d & K

	Prediction	Measurement	Pull(σ)
$\sin 2\beta$	0.771±0.036	0.654±0.026	+2.5
γ	$(74\pm11)^\circ$	$(69.6\pm3.1)^\circ$	< 1
α	$(88\pm3)^\circ$	$(91\pm6)^\circ$	< 1
$\|V_{cb}\|\cdot10^3$	42.7±1.0	40.8±0.5	+1.7
$\|V_{ub}\|\cdot10^3$	3.55±0.14	3.76±0.20	< 1
$\varepsilon_K\cdot10^3$	1.92±0.18	2.229±0.010	-1.7
$B(B\to\tau\nu)$	$(81\pm7)\cdot10^{-6}$	$(172\pm28)\cdot10^{-6}$	-3.2

SM predictions: B_s

	Prediction	Measurement	Pull(σ)
Δm_s [ps^{-1}]	18.3±1.3	17.77±0.12	< 1
β_s	(1.08±0.04)°	Tevatron	+2.1
$\Delta\Gamma_s$ [ps^{-1}]	0.11±0.02	average	0.0*
$a^s_{SL} \cdot 10^5$	1.7±0.4	-170±910	< 1
$a_{\mu\mu} \cdot 10^4$	-1.7±0.5	-95.7±29.0	+3.2

2010 CDF measurement of β_s–$\Delta\Gamma_s$ not included yet

What about FCNC?

i) B → $X_s \gamma$ $E_\gamma > 1.6$ GeV

SM prediction: M. Misiak et al., hep-ph/0609232

$$\mathcal{B}(\bar{B} \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

World average:

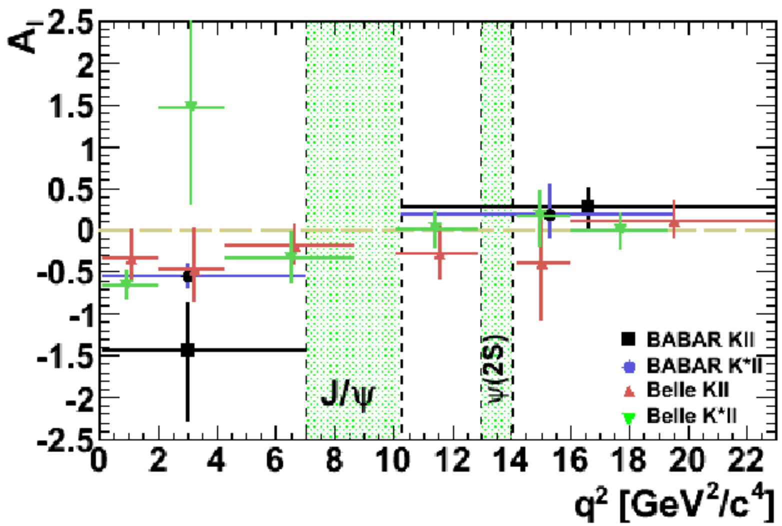
$$B(\bar{B} \to X_s\gamma) = (3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$$

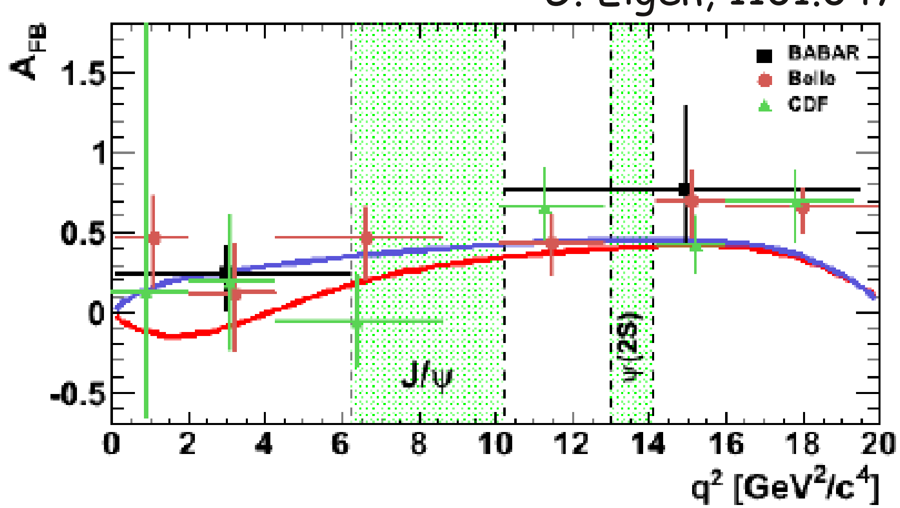
(-1.1σ)

ii) B → $X_s \ell\ell$

BaBar measurement of $A_I(0)$ in B → K*ℓℓ is 3.9σ away from zero

G. Eigen, 1101.0470v1





In the lepton sector…

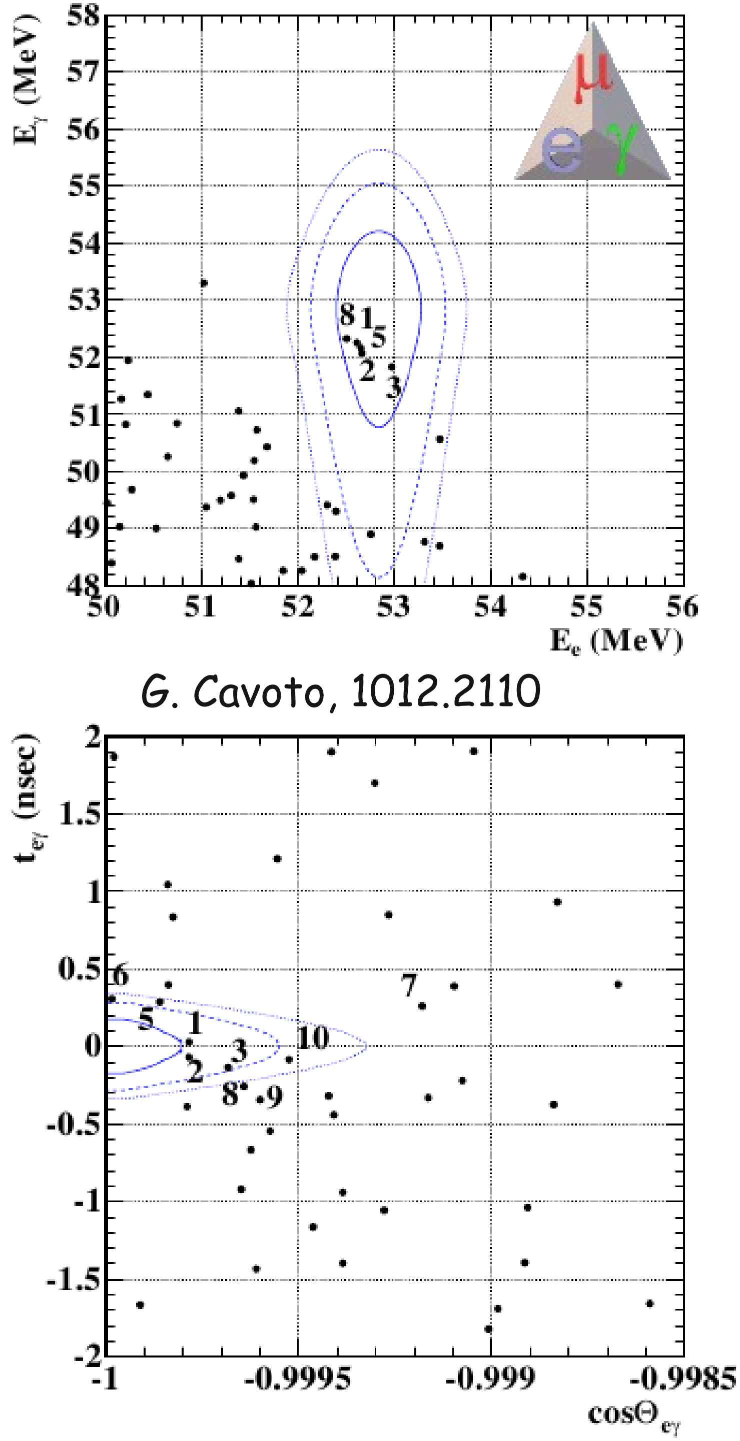
No evidence of lepton flavour violation so far… SM is fine

MEGA:

$$\mathrm{BR}(\mu^+ \to e^+\gamma) < 1.5 \times 10^{-11}$$
$$(90\%\ \mathrm{C.L.})$$

MEG:

$$\mathrm{BR}(\mu \to e\gamma) \leq 1.2 \times 10^{-11}$$
$$(90\%\ \mathrm{C.L.})$$



G. Cavoto, 1012.2110

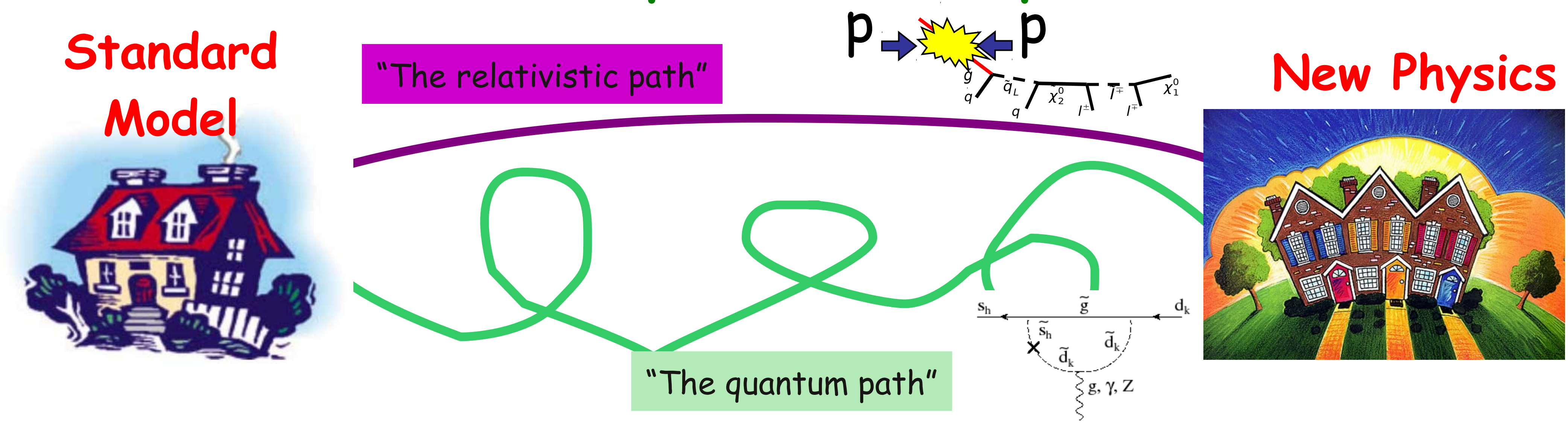
Waiting for further (hopefully good) news from MEG soon!

Flavour in the SM: summary

* SM UT analysis (still) displays a good overall consistency and no significant failure
* Tensions are present in $BR(B \to \tau\nu)$ and $\sin 2\beta$ (and to a lesser extent in ε_K). The two tensions pull $|V_{ub}|$ in opposite directions: no "V_{ub} explanation" possible
* Predictions for B_s physics also show tensions in $a_{\mu\mu}$ and $B_s \to J/\psi\phi$. They point to large but different value of ϕ_s (assuming standard Γ_{12}). $a_{\mu\mu}$ also suggests a non-standard Γ_{12} (tree-level new physics or failure of the OPE?)
* ~4σ deviation from the SM in $A_I(B \to K^*\ell\ell)$?
* No surprises in charm data (as far as one can tell!)

Beyond the SM with flavour physics: why?

Indirect searches look for new physics through virtual effects of new particles in loop corrections



New Physics does not necessarily share the peculiar SM pattern of FV and CPV: very large NP effects are possible

Past (SM) successes:

1970: charm from $K^0 \to \mu^+\mu^-$ (GIM)

1973: 3rd generation from ϵ_K (Kobayashi & Maskawa)

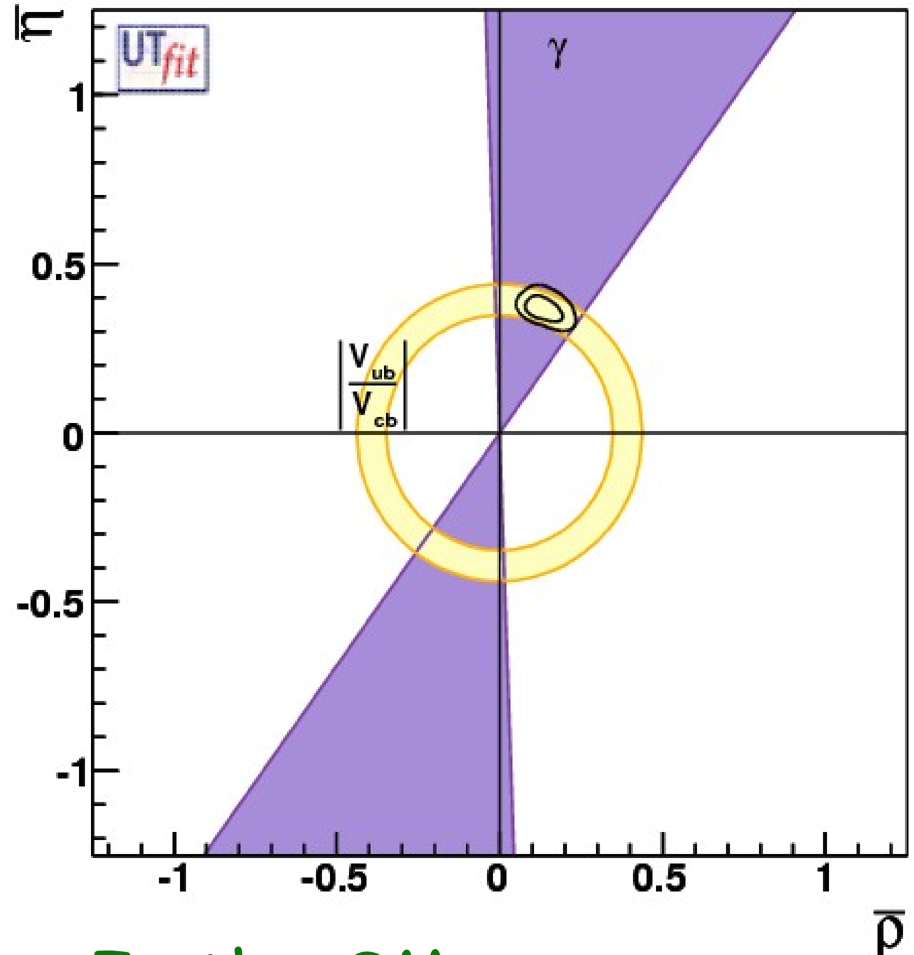
mid 80's: heavy top from Δm_B

UT parameters in the presence of NP

(almost) model-independent determination of the CKM parameters

Assumptions:
* CKM + NP flavour structures
* three SM generations
* no NP in tree-level decays

(* no large NP EWP in $B \to \pi\pi$)



$$\bar{\rho} = 0.135 \pm 0.040$$

$$\bar{\eta} = 0.374 \pm 0.026$$

In the SM was:

$$\bar{\rho} = 0.132 \pm 0.021$$

$$\bar{\eta} = 0.358 \pm 0.012$$

Parameterization of generic NP contributions to the mixing amplitudes

B_d and B_s mixing amplitudes (2+2 real parameters):

C_{Bq} & ϕ_{Bq} or A_q^{NP}/A_q^{SM} & ϕ_q^{NP}

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

$$\phi_d^{SM} = \beta, \quad \phi_s^{SM} = -\beta_s$$

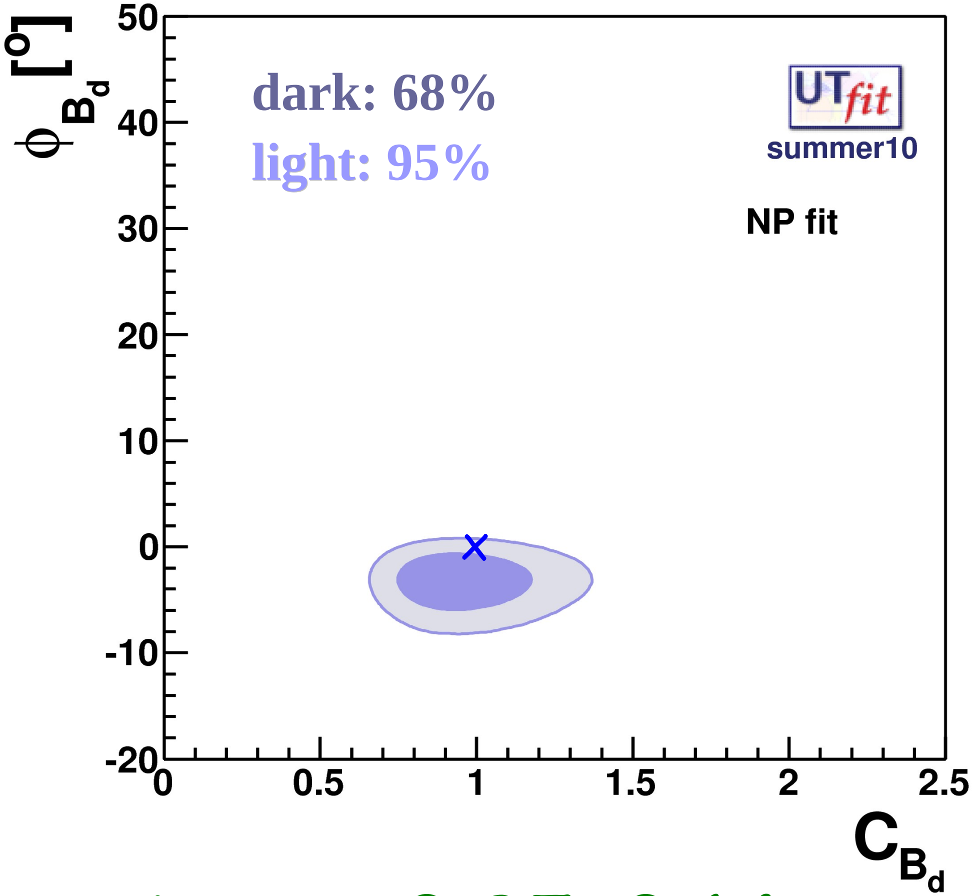
Observables:

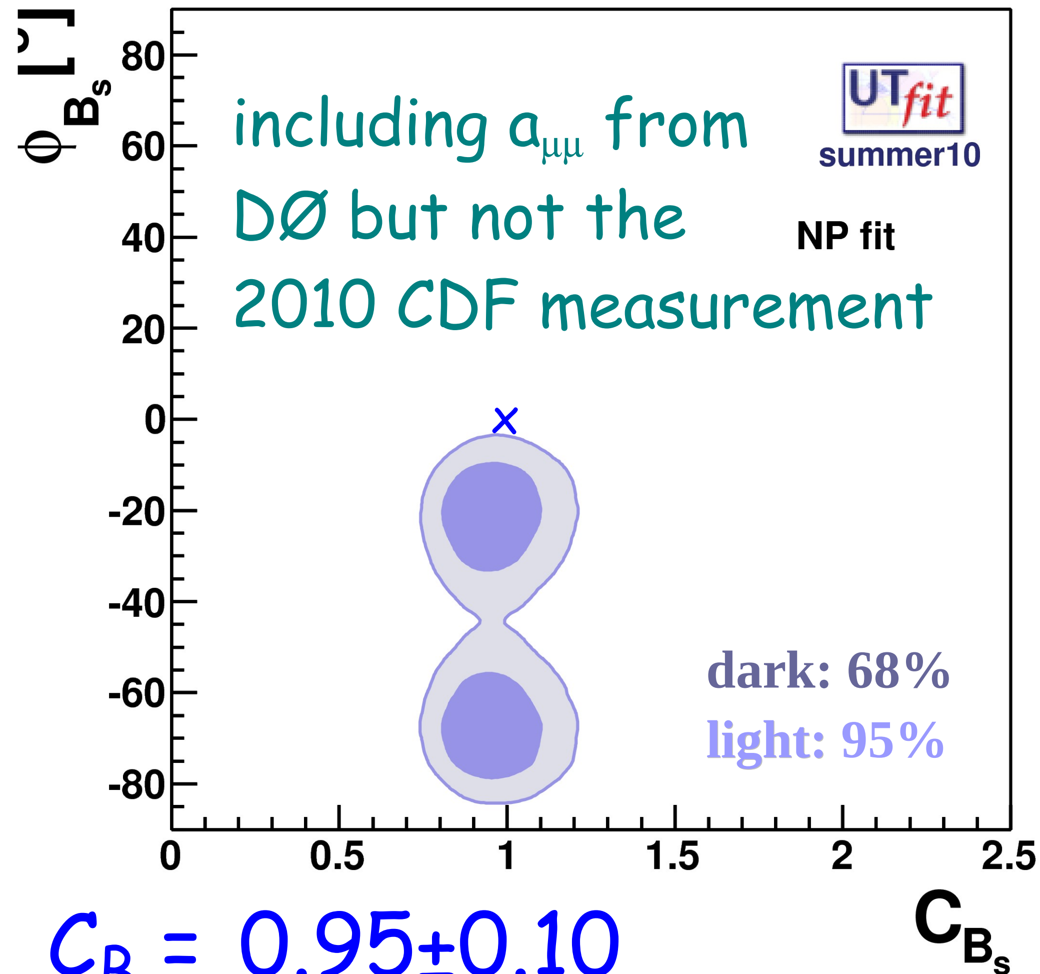
$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$a_{CP}^{B_d \to J/\psi K_S} \to \sin 2(\beta + \phi_{B_d}) \qquad a_{CP}^{B_s \to J/\psi \phi} \to -\beta_s + \phi_{B_s}$$

$$a_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right) \qquad \Delta\Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

Results for the NP parameters





C_{B_d} = 0.95±0.14

[0.70, 1.27]

ϕ_{B_d} = (-3.1±1.7)°

[-7.0, 0.1]°

C_{B_s} = 0.95±0.10

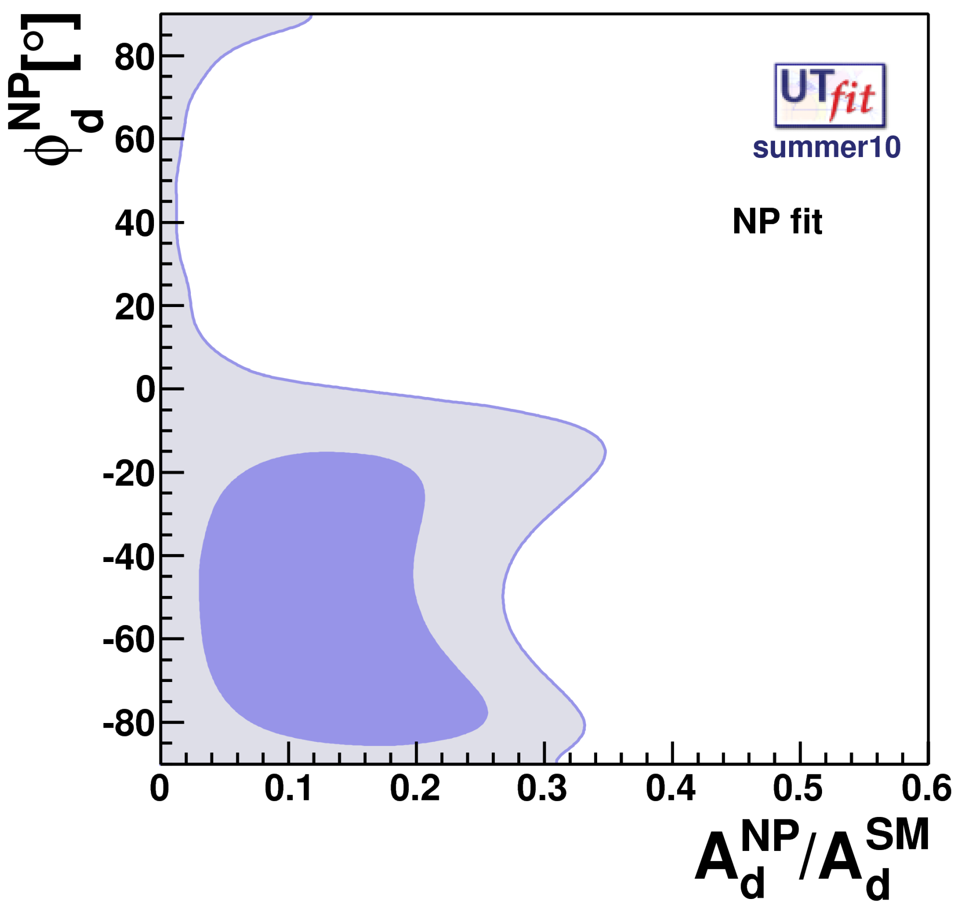
[0.78, 1.16]

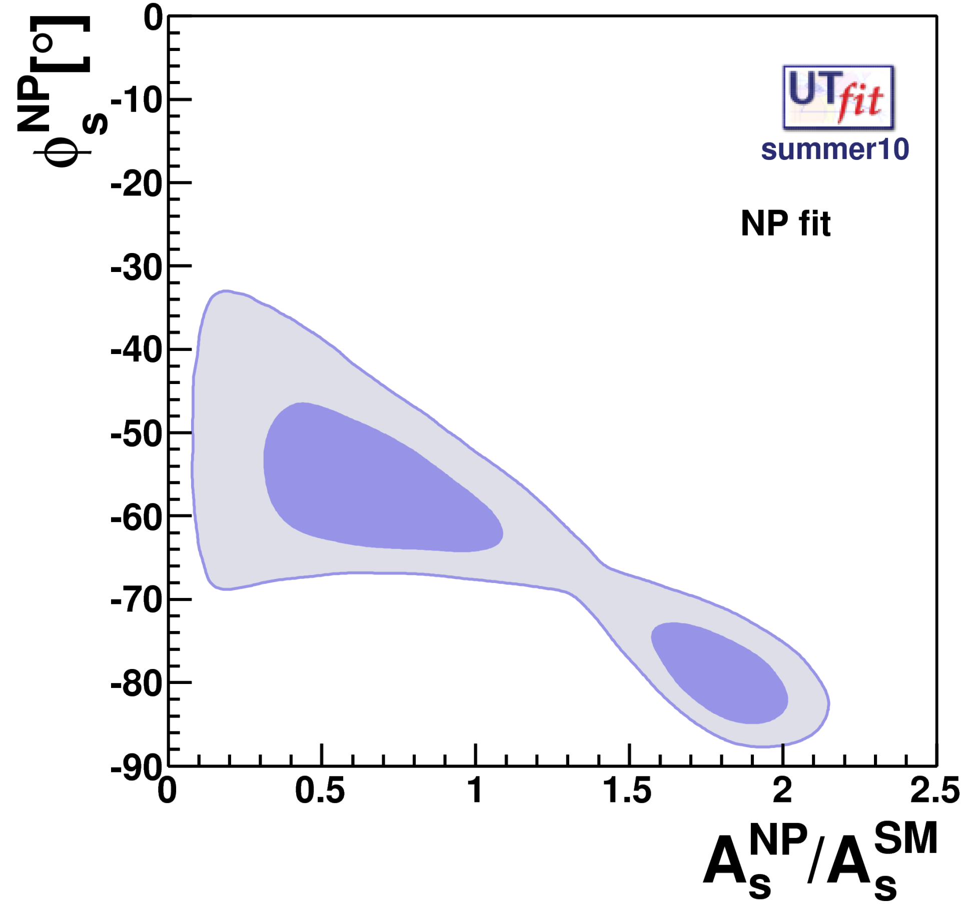
3.1σ

ϕ_{B_s} = (-20±8)°U(-62±8)°

[-38, -6]°U[-81, -51]°

Implications for the NP amplitudes





The ratio of NP/SM contributions is:

< 35% @95% p. (preferred ~10%) in B_d mixing

< 220% @95% p. (preferred ~60% & ~180%) in B_s

see also Lunghi & Soni, 0903.5059, Ligeti et al., 1006.0432

EFT approach to New Flavour Physics

$$\mathscr{L}_{eff}=\mathscr{L}_{SM}+\sum_{k=1}\left(\sum_i C_i^k\, Q_i^{(k+4)}\right)/\Lambda^k$$

NP flavour effects are governed by two players:

i) **the value of the new physics scale Λ**

ii) **the effective flavour-violating couplings C's**

In explict models:

Λ ~ mass of virtual particles (Fermi th.: M_W)

C ~ loop coupling × flavour coupling

(SM/MFV: α_w × CKM)

EFT analysis of ΔF=2 transitions

The mixing amplitudes $A_q e^{2i\phi_q} = \langle \bar{M}_q | H_{eff}^{\Delta F=2} | M_q \rangle$

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \bar{q}_L^\alpha \gamma_\mu b_L^\alpha \, \bar{q}_L^\beta \gamma^\mu b_L^\beta \qquad \text{(SM/MFV)}$$

$$Q_2 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_R^\beta b_L^\beta \qquad Q_3 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_R^\beta b_L^\alpha$$

$$Q_4 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad Q_5 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_L^\beta b_R^\alpha$$

$$\tilde{Q}_1 = \bar{q}_R^\alpha \gamma_\mu b_R^\alpha \, \bar{q}_R^\beta \gamma^\mu b_R^\beta$$

$$\tilde{Q}_2 = \bar{q}_L^\alpha b_R^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad \tilde{Q}_3 = \bar{q}_L^\alpha b_R^\beta \, \bar{q}_L^\beta b_R^\alpha$$

7 new operators beyond MFV involving quarks with different chiralities

H_{eff} can be recast in terms of the $C_i(\Lambda)$ computed at the NP scale Λ

- $C_i(\Lambda)$ can be extracted from the data (one by one)
- the associated NP scale Λ can be defined from

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

tree/strong interact. NP: $L \sim 1$

perturbative NP: $L \sim \alpha_s^2, \alpha_W^2$

Flavour structures:

MFV	Next-to-MFV	generic
- $F_1 = F_{SM} \sim (V_{tq}V_{tb}^*)^2$	- $\lvert F_i \rvert \sim F_{SM}$	- $\lvert F_i \rvert \sim 1$
- $F_{i\neq 1} = 0$	- arbitrary phases	- arbitrary phases

PRELIMINARY update of hep-ph/0509219, see also Lunghi, Soni and Isidori, Nir, Perez, 1002.0900

present lower bound on the NP scale (TeV):

sector	$C_4(GeV^{-2})$	$\Lambda_{GEN}(TeV)$	$\Lambda_{NMFV}(TeV)$
K	4.6×10^{-18}	$(47/5/1.5)\times10^4$	107/11/3.5
B_d	9.3×10^{-14}	$(33/3.3/1.1)\times10^2$	7/0.7/0.2
B_s	1.5×10^{-11}	260/26/9	8/0.8/0.3

* $\Delta F=2$ chirality-flipping operators are RG enhanced and thus probe larger NP scales

* suppression of the $1 \leftrightarrow 2$ transitions weakens the lower bounds easing the flavour problem

Bounds on Λ_{MFV} from $\Delta F=2$ processes: for low tanβ

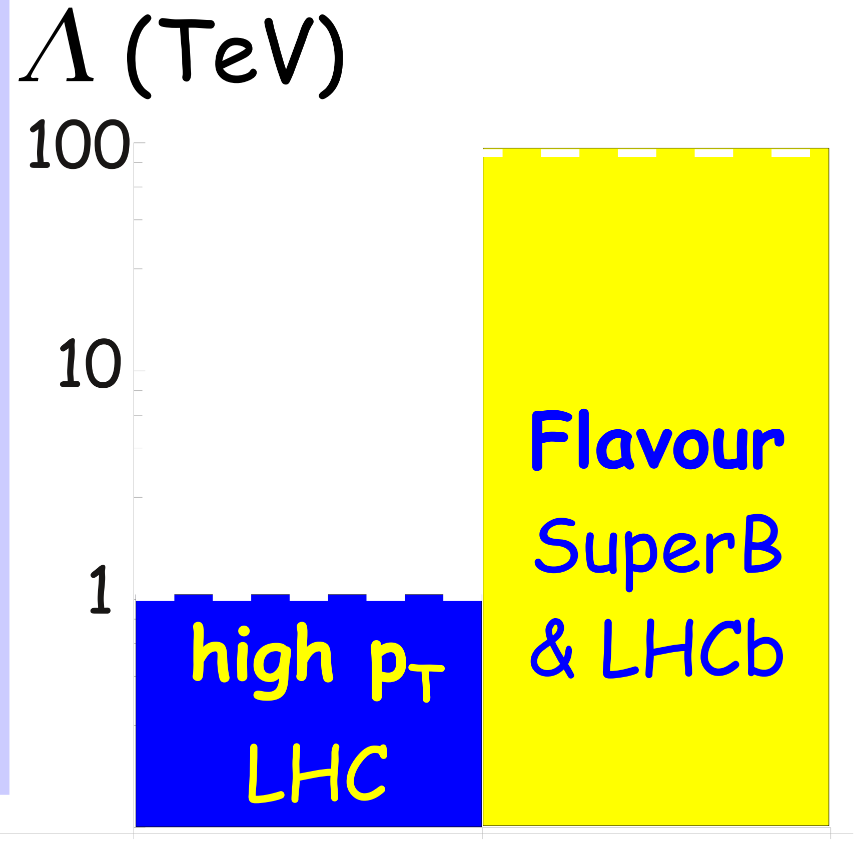
$F_{tt} \in [-0.326,0.487] \rightarrow \Lambda_{MFV} > 8.4\ (6.9)$ TeV

Λ_0= 2.4 TeV, cfr D'Ambrosio et al.

Implications for the SuperB case

1. NP at the TeV scale
- new particles found at LHC
- flavour problem effective, but suppressed FC couplings could be measured (MFV?)

2. NP beyond the TeV scale
- flavour problem in K only
- flavour physics can probe the multi-TeV scales



MSSM: reconstructing the Lagrangian

Parameters	MSSM	SM
gauge+Higgs	14	6
masses	30 (+ν_R 36)	9 (+ν_R 12)
mixing angles	39 (+ν_R 54)	3 (+ν_R 6)
phases	41 (+ν_R 56)	1 (+ν_R 2)
Total	124 (+ν_R 160)	19 (+ν_R 26)

SM parameter match: FC vs FV&CPV 16-8

MSSM parameter match: FC vs FV&CPV 50-110

* fast increase of the # of FV&CPV parameters

* FV&CPV are related to basic properties of the NP Lagrangian (e.g. SUSY breaking in the MSSM)

Flavour violation in the squark sector

In the superCKM basis, all NP FV effects come from squark mass matrices

LHC, ILC - HE frontier

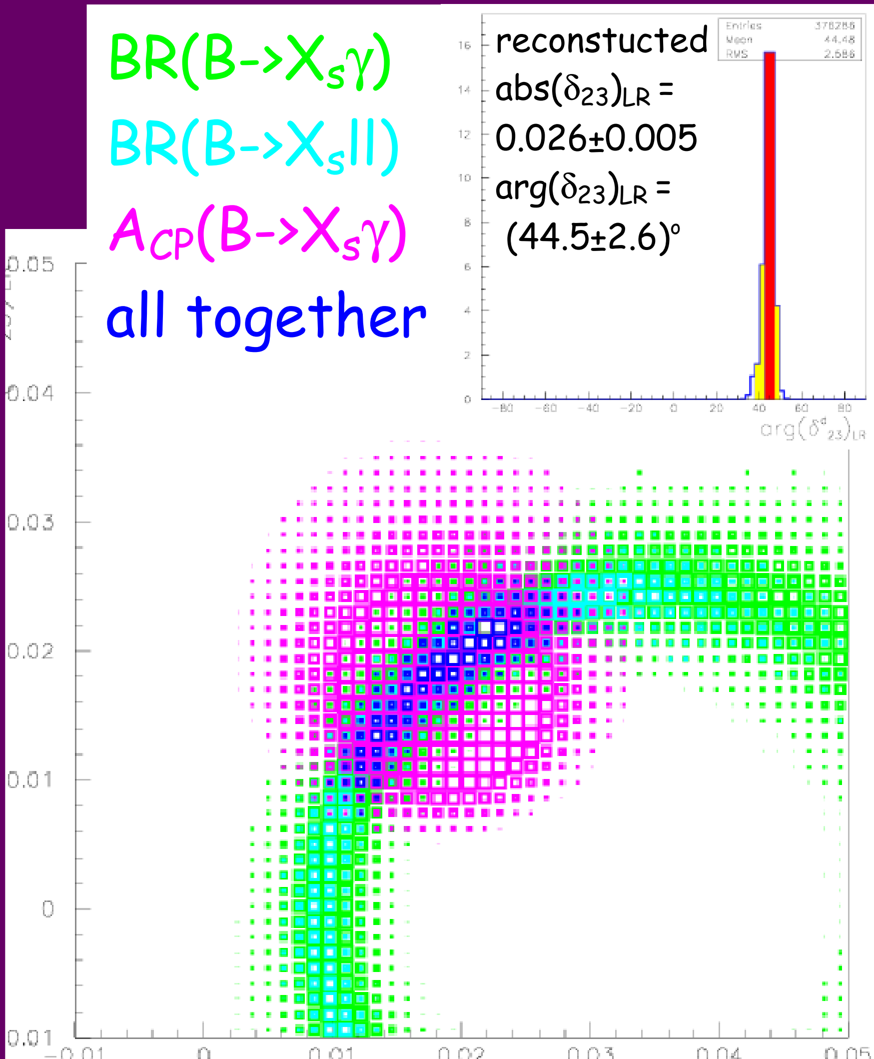
$$M^2_{\tilde{d}} = \begin{pmatrix} \left(M^{\tilde{d}}_{1L}\right)^2 & \Delta^{\tilde{d}\,LL}_{12} & \Delta^{\tilde{d}\,LL}_{13} & \Delta^{\tilde{d}\,LR}_{11} & \Delta^{\tilde{d}\,LR}_{12} & \Delta^{\tilde{d}\,LR}_{13} \\ \Delta^{\tilde{d}\,LL^*}_{12} & \left(M^{\tilde{d}}_{2L}\right)^2 & \Delta^{\tilde{d}\,LL}_{23} & \Delta^{\tilde{d}\,RL^*}_{12} & \Delta^{\tilde{d}\,LR}_{22} & \Delta^{\tilde{d}\,LR}_{23} \\ \Delta^{\tilde{d}\,LL^*}_{13} & \Delta^{\tilde{d}\,LL^*}_{23} & \left(M^{\tilde{d}}_{3L}\right)^2 & \Delta^{\tilde{d}\,RL^*}_{13} & \Delta^{RL*}_{23} & \Delta^{\tilde{d}\,LR}_{33} \\ \Delta^{\tilde{d}\,LR^*}_{11} & \Delta^{\tilde{d}\,RL}_{12} & \Delta^{\tilde{d}\,RL}_{13} & \left(M^{\tilde{d}}_{1R}\right)^2 & \Delta^{\tilde{d}\,RR}_{12} & \Delta^{\tilde{d}\,RR}_{13} \\ \Delta^{\tilde{d}\,LR^*}_{12} & \Delta^{\tilde{d}\,LR*}_{22} & \Delta^{\tilde{d}\,RL}_{23} & \Delta^{\tilde{d}\,RR^*}_{12} & \left(M^{\tilde{d}}_{2R}\right)^2 & \Delta^{\tilde{d}\,RR}_{23} \\ \Delta^{\tilde{d}\,LR^*}_{13} & \Delta^{\tilde{d}\,LR^*}_{23} & \Delta^{\tilde{d}\,LR^*}_{33} & \Delta^{\tilde{d}\,RR^*}_{13} & \Delta^{\tilde{d}\,RR^*}_{23} & \left(M^{\tilde{d}}_{3R}\right)^2 \end{pmatrix}$$

and similarly for $M^2_{\tilde{u}}$

NP scale: $(M^d_{iA} M^d_{jB})^{1/2}$

FV & CPV couplings: $(\delta^d_{ij})_{AB} = (\Delta^d_{ij})^{AB} / (M^d_{iA} M^d_{jB})$

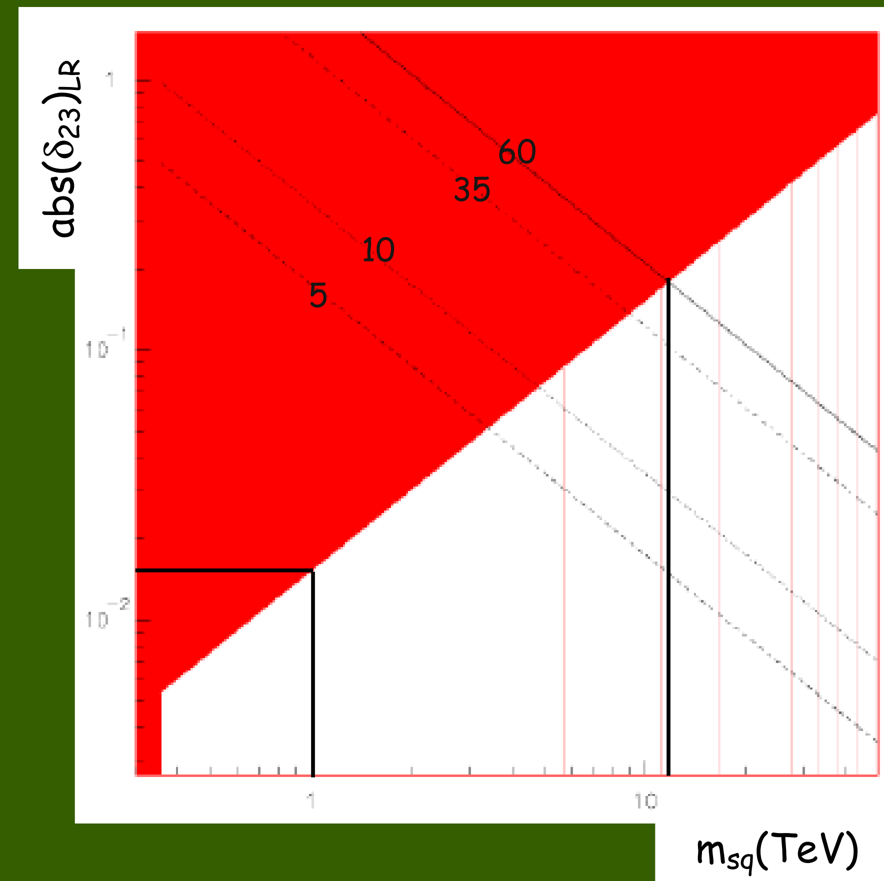
Determination of $(\delta^d_{23})_{LR}$ using SuperB data



$Im(\delta^d_{23})_{LR}$ vs $Re(\delta^d_{23})_{LR}$

reconstruction of $(\delta^d_{23})_{LR}=0.028\ e^{i\pi/4}$ for $\Lambda = m_{\tilde{g}} = m_{\tilde{q}} = 1$ TeV

"3σ" sensitivity plot



i) sensitive to $m_{\tilde{q}} < 20$ TeV

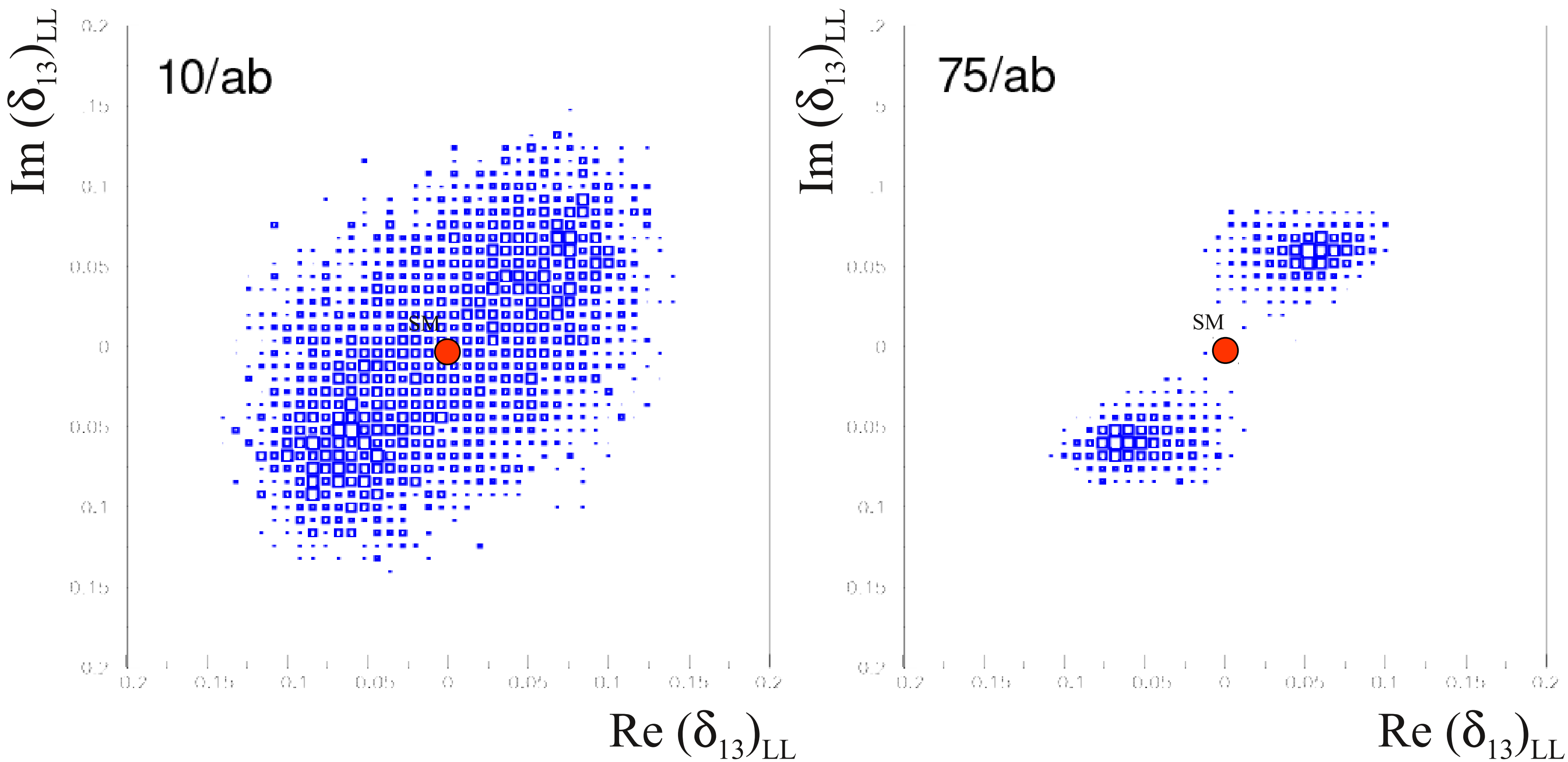
ii) sensitive to $|(\delta^d_{23})_{LR}| > 10^{-2}$ for $m_{\tilde{q}} < 1$ TeV

Determination of $(\delta^d_{13})_{LL}$ using SuperB data

reconstruction of $(\delta^d_{13})_{LL}=0.085\ e^{i\pi/4}$

for $m_{\tilde{g}}=m_{\tilde{q}}=1$ TeV

constraints: β, A_{SL}, Δm_d



An example: hierarchical soft terms

Nardecchia, Giudice, Romanino, arXiv:0812.3610
Cohen, Kaplan, Nelson, hep-ph/9607394
Dine, Kagan, Samuel, PLB243 (1990)

Sparticles at the EW scale

but for 1st and 2nd generation squarks and sleptons

- no "unnatural" correction to the Higgs mass
- alleviate the flavour problem
- indicate "natural" values for the δ's:

$$\hat{\delta}^{LL}_{db} \approx V^*_{td} \sim \mathbf{0.01} \qquad \hat{\delta}^{LL}_{sb} \approx V^*_{ts} \sim \mathbf{0.05}$$

$$\hat{\delta}^{LR}_{i3} \equiv \frac{\mathcal{M}^2_{L3,R3}}{\tilde{m}^2}\hat{\delta}^{LL}_{i3} \qquad i,j=1,2$$

$$\hat{\delta}^{LL}_{ij} \equiv \hat{\delta}^{LL}_{i3}\hat{\delta}^{LL*}_{j3} \qquad \hat{\delta}^{LR}_{ij} \equiv \frac{\mathcal{M}^2_{L3,R3}}{\tilde{m}^2}\hat{\delta}^{LL}_{i3}\hat{\delta}^{RR*}_{j3}$$

these figures are in the ballpark of SuperB sensitivities

Flavour BSM: summary

* general UT analysis provides a NP-friendly determination of the CKM parameters
* NP contribution to the B_d mixing amplitude are at 10% level (<30%@95% p.), to B_s mixing at 60% or 180% (<220%@95% p.)
* present tensions suggest non-MFV new physics contributions
* SuperB can study the flavour structure of TeV NP with CKM-like FV couplings
* SuperB can probe the 10+ TeV region

Perspectives

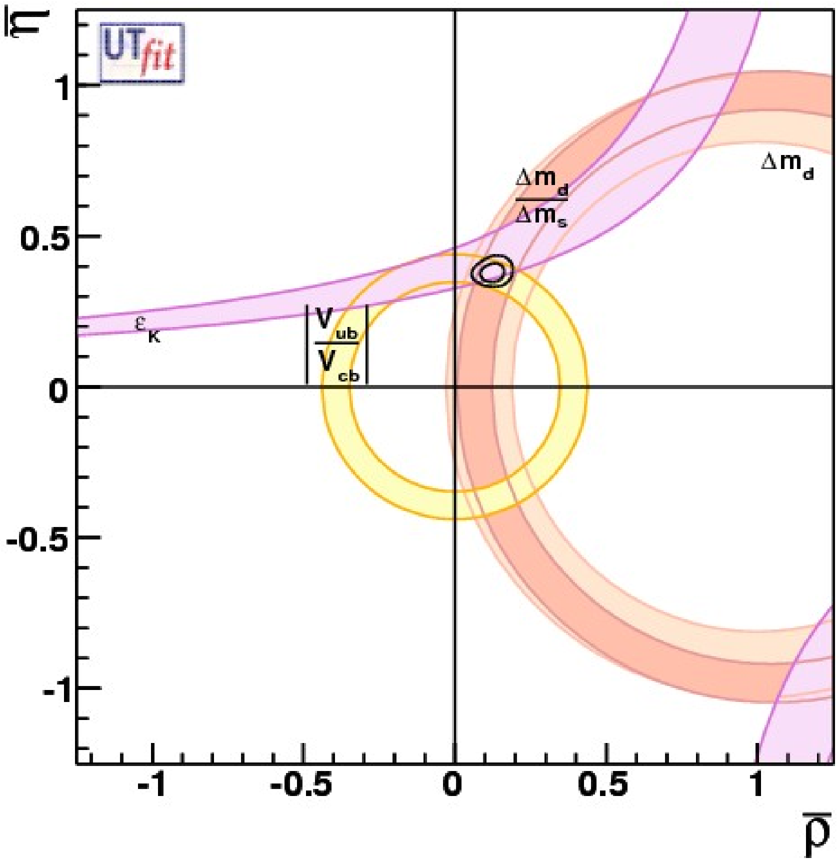
Backup

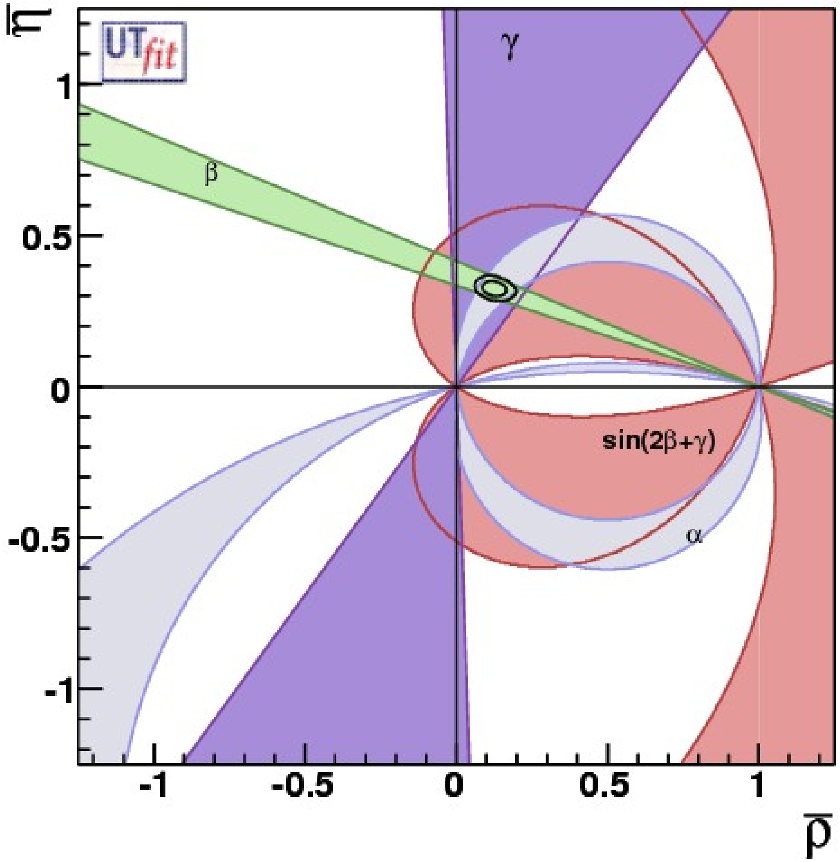
predictions of the hadronic parameters

independent of lattice

LQCD inputs used:

F.F., B_K, B_{Bs}, B_{Bs}/B_{Bd} f_{Bs}, f_{Bs}/f_{Bd}

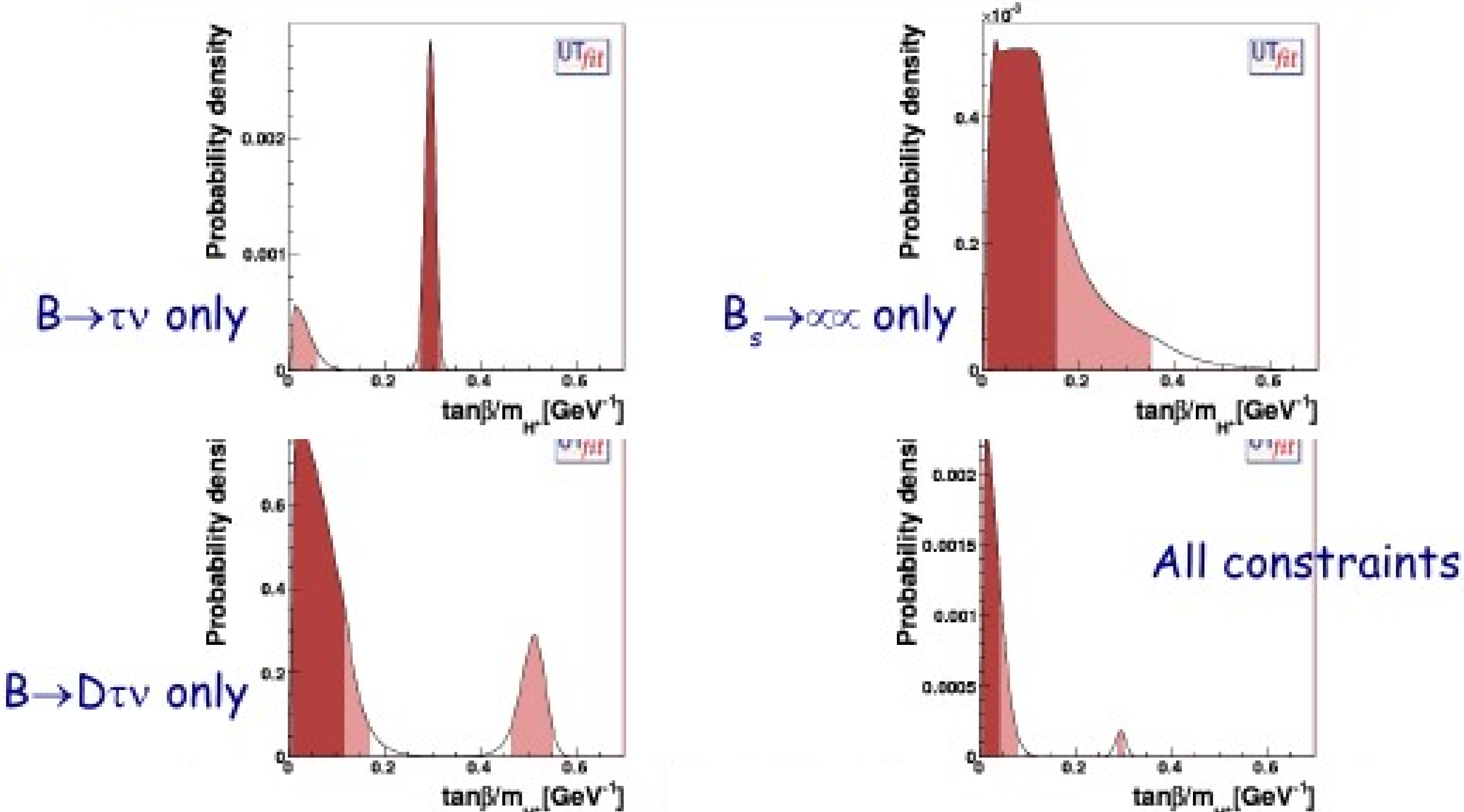




UT lattice+UT angles:

<u>SM</u> determination of hadronic parameters

Two Higgs Doublet Model II



Additional constraints:

* $BR(B_s \to \mu\mu) < 5.8\times10^{-8}$ @95% C.L.

* $\Delta m_s = (17.77 \pm 0.12)\ ps^{-1}$

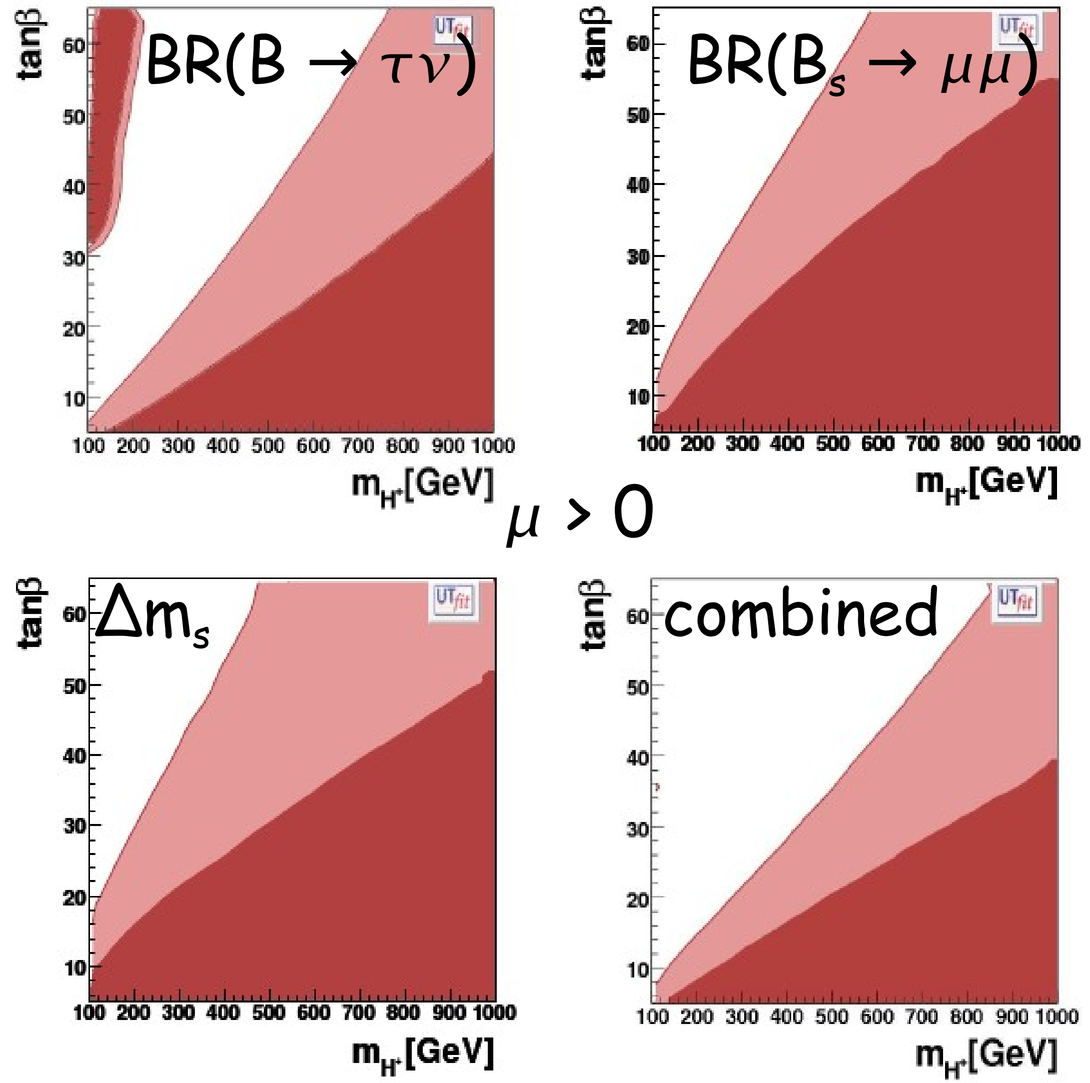
* additional constraints exclude the "fine-tuned" region at very large $\tan\beta$

* bound similar to 2HDM

$$\tan\beta < 7.3 m_{H^+}/(100\ \mathrm{GeV})$$

In addition:

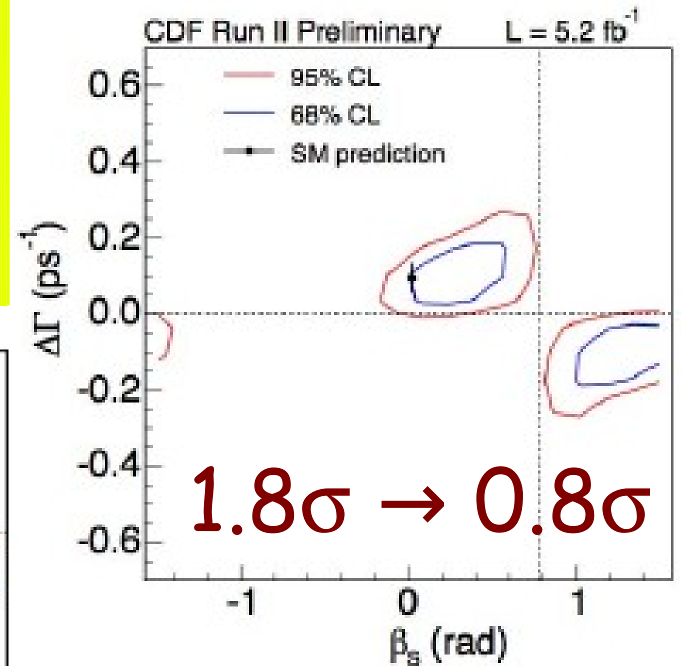
$BR(B_s \to \mu\mu) < 19\times10^{-9}$ (5xSM) @95% prob.



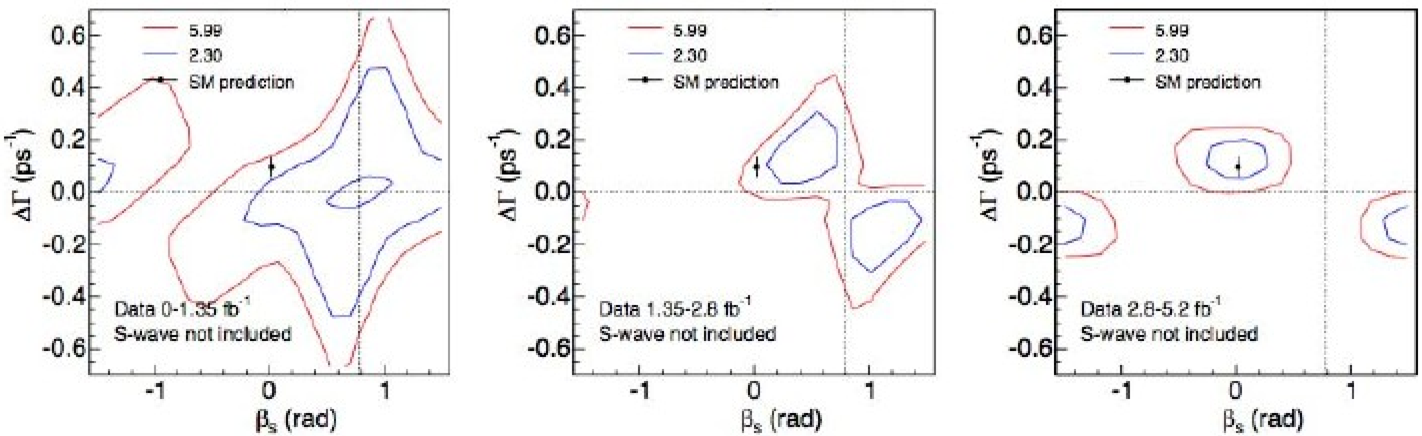
* the theory error in $\sin 2\beta$ from $B \to J/\Psi K$ is small and fully under control. A conservative bound obtained from data is included in the analysis
* $BR(B \to \tau\nu)$ wants a large $|V_{ub}|$. Its theoretical uncertainty, due to f_B, is controlled by the fit
* the ε_K deviation is triggered by improvements in B_K from the lattice and the inclusion of the ξ term à la Buras-Guadagnoli(+Isidori). Yet the ε_K formula is not under control at the few percent level
* $|V_{ub}|$ from semileptonic decays is debatable (incl. vs excl., models, f.f.,…). Yet a simple shift of the central value cannot reconcile $\sin 2\beta$ and $BR(B \to \tau\nu)$ (and ε_K)

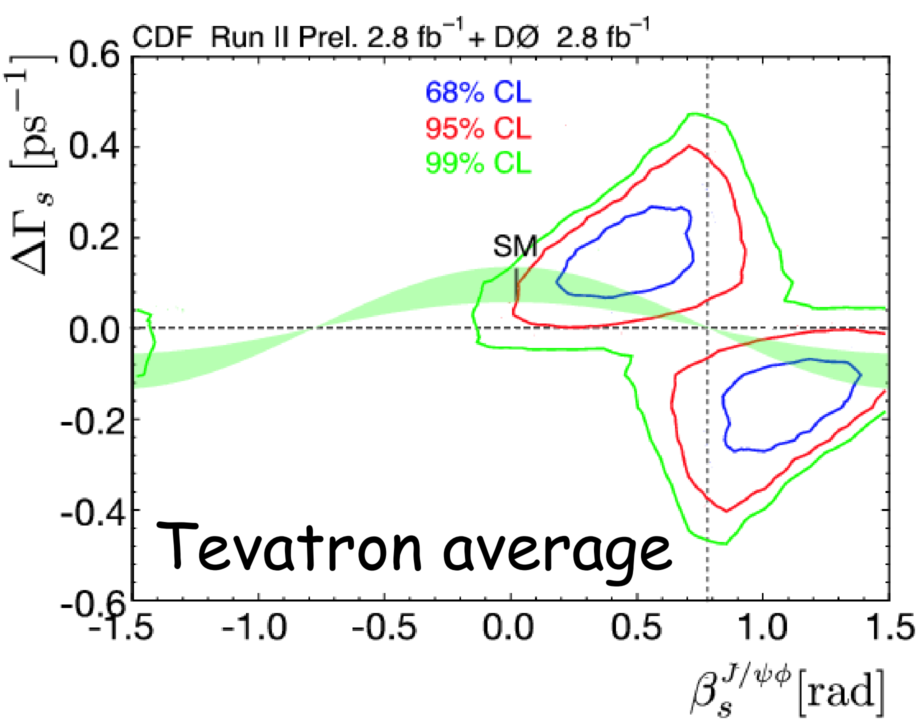
* the new CDF measurement of $B_s \to J/\Psi\phi$ reduces the significance of the deviation, but large values are still possible. The likelihood is not available yet, a CDF Bayesian study is also underway
* the new DØ measurement of $a_{\mu\mu}$ points to large β_s, but also to a large $\Delta\Gamma_s$ requiring a non-standard Γ_{12}. If confirmed, two options (both unlikely IMO):
  i. huge (tree-level-like) NP contributions to Γ_{12}: needed a factor ~2.5 (question: why in Γ_{12} only?)
  ii. bad failure of the OPE for Γ_{12}. Yet no evidence of it in lifetimes. If true, can we trust semileptonic decays to ~5% level or less?

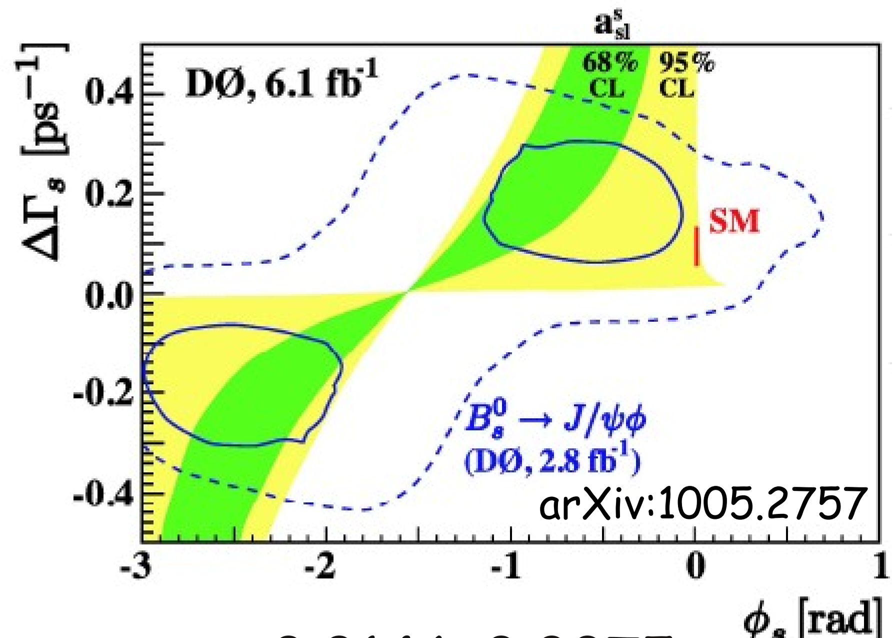
2010: "Great confusion under the sky"



CDF@FPCP '10

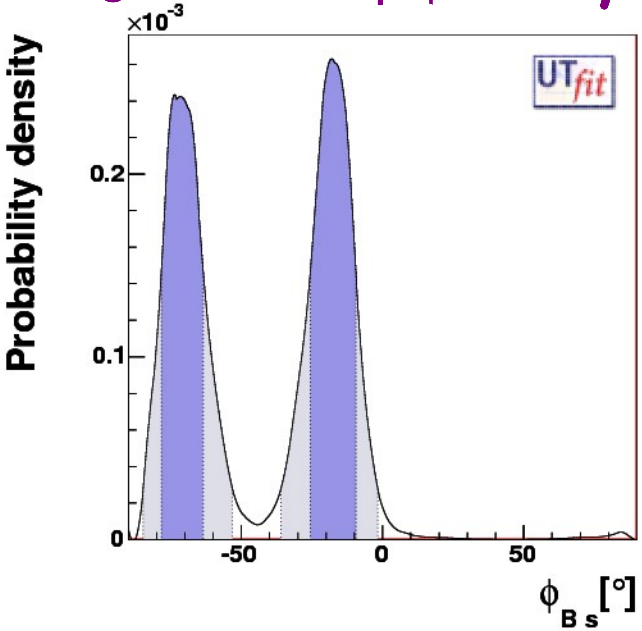




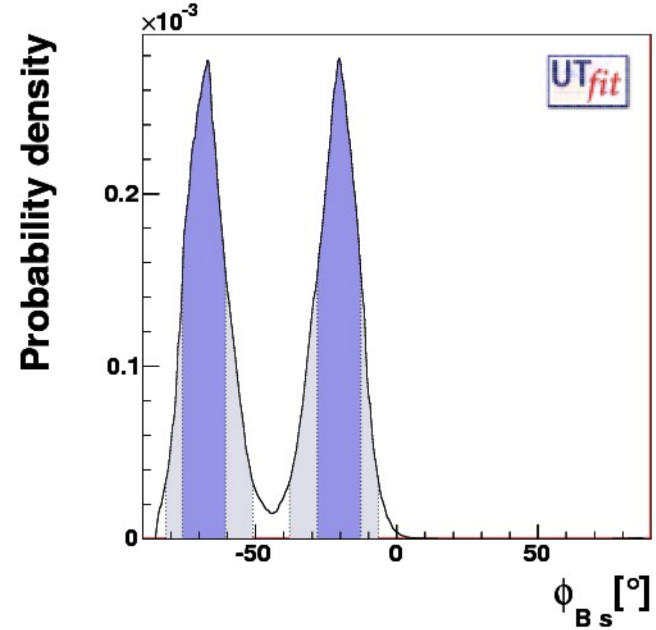


$a_{\mu\mu} \rightarrow a^s_{SL} = -0.0146 \pm 0.0075$

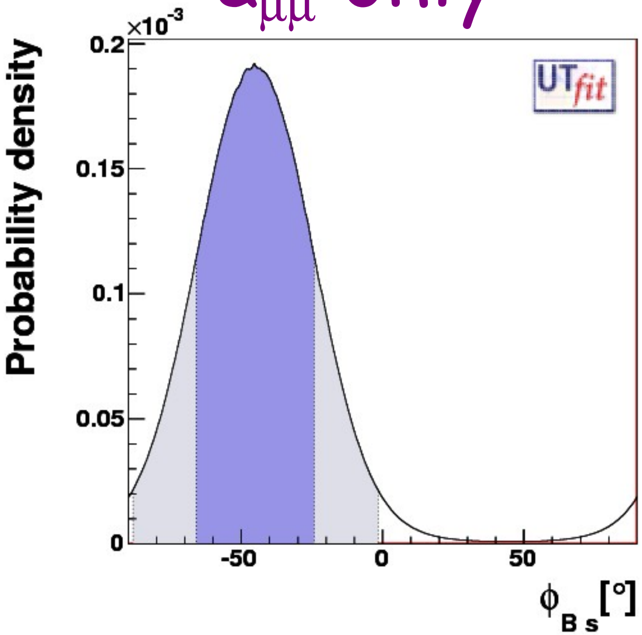
$B_s \rightarrow J/\psi\phi$ only



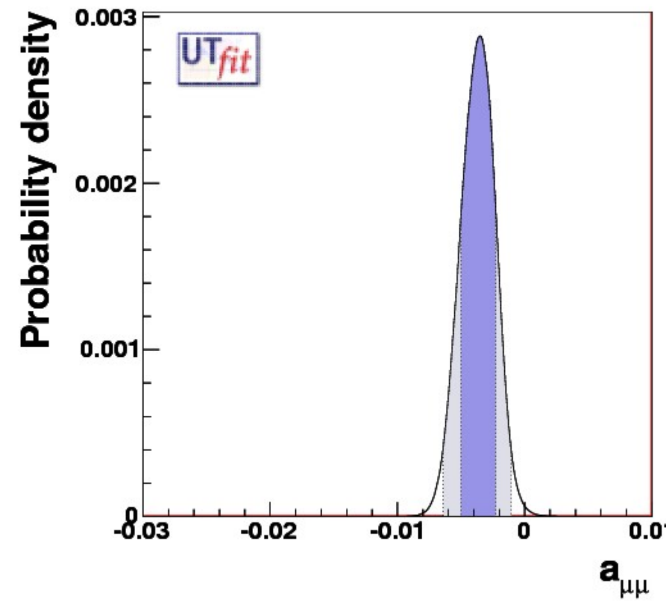
all constraints



$a_{\mu\mu}$ only



$a_{\mu\mu} = (-3.7 \pm 1.4) \cdot 10^{-3}$



2. the ΔF=2 effective Hamiltonian

The mixing amplitudes $A_q e^{2i\phi_q} = \langle M_q | H_{eff}^{\Delta F=2} | \bar{M}_q \rangle$

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \bar{q}_L^\alpha \gamma_\mu b_L^\alpha \, \bar{q}_L^\beta \gamma^\mu b_L^\beta \qquad \text{(SM/MFV)}$$

$$Q_2 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_R^\beta b_L^\beta \qquad Q_3 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_R^\beta b_L^\alpha$$

$$Q_4 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad Q_5 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_L^\beta b_R^\alpha$$

$$\tilde{Q}_1 = \bar{q}_R^\alpha \gamma_\mu b_R^\alpha \, \bar{q}_R^\beta \gamma^\mu b_R^\beta$$

$$\tilde{Q}_2 = \bar{q}_L^\alpha b_R^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad \tilde{Q}_3 = \bar{q}_L^\alpha b_R^\beta \, \bar{q}_L^\beta b_R^\alpha$$

7 new operators beyond SM/CMFV involving quarks with different chiralities

H_{eff} can be recast in terms of the high-scale $C_i(\Lambda)$

- $C_i(\Lambda)$ can be extracted from the data (one by one)
- the associated NP scale Λ can be defined as

$$\Lambda = \sqrt{\frac{L F_i}{C_i(\Lambda)}}$$

tree/strong interact. NP: $L \sim 1$

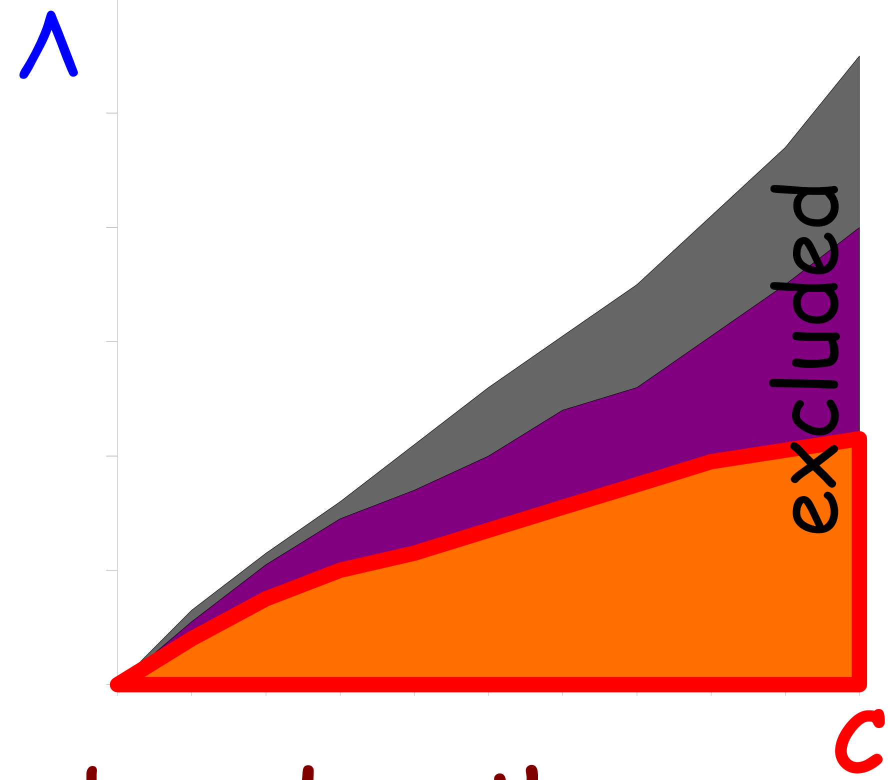
perturbative NP: $L \sim \alpha_s^2, \alpha_W^2$

Flavour structures:

MFV	next-to-MFV	generic
- $F_1 = F_{SM} \sim (V_{tq}V_{tb}^*)^2$	- $\lvert F_i \rvert \sim F_{SM}$	- $\lvert F_i \rvert \sim 1$
- $F_{i\neq1} = 0$	- arbitrary phases	- arbitrary phases

Pictorially :

- exp. constraints give a bound on Λ for any given *c* and vice-versa
- curves correspond to different model classes



For example: present lower bound on the NP scale from ΔF=2 transitions (TeV @95% p.)

B + K | UTfit, arXiv:0707.0636

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800

B only (w/o new Φ_s)

strong/tree	α_s loop	α_W loop
–	–	–
14	1.4	0.4
2200	220	66

Theory keeps up...

lattice QCD can reach the O(1%) precision goal in time

V. Lubicz, SuperB CDR, updated for the physics white paper

Measurement	Hadronic Parameter	Status End 2006	6 TFlops (Year 2009)	**Status End 2009**	60 TFlops (Year 2011)	1-10 PFlops (Year 2015)
$K \to \pi l \nu$	$f_+^{K\pi}(0)$	0.9 %	0.7 %	0.5 %	0.4 %	$<$ 0.1 %
ε_K	$\hat{B}_K$	11 %	5 %	5 %	3 %	1 %
$B \to l \nu$	f_B	14 %	3.5-4.5 %	5 %	2.5-4.0 %	1.0-1.5 %
Δm_d	$f_{Bs}\sqrt{B_{B_s}}$	13 %	4-5 %	5 %	3-4 %	1-1.5 %
$\Delta m_d/\Delta m_s$	ξ	5 %	3 %	2 %	1.5-2 %	0.5-0.8 %
$B \to D/D^* l \nu$	$\mathscr{F}_{B\to D/D^*}$	4 %	2 %	2 %	1.2 %	0.5 %
$B \to \pi/\rho\, l \nu$	$f_+^{B\pi}, \ldots$	11 %	5.5-6.5 %	11 %	4-5 %	2-3 %
$B \to K^*/\rho\, (\gamma, l^+l^-)$	$T_1^{B\to K^*/\rho}$	13 %	——	13 %	——	3-4 %