FLAVOUR OVERVIEW

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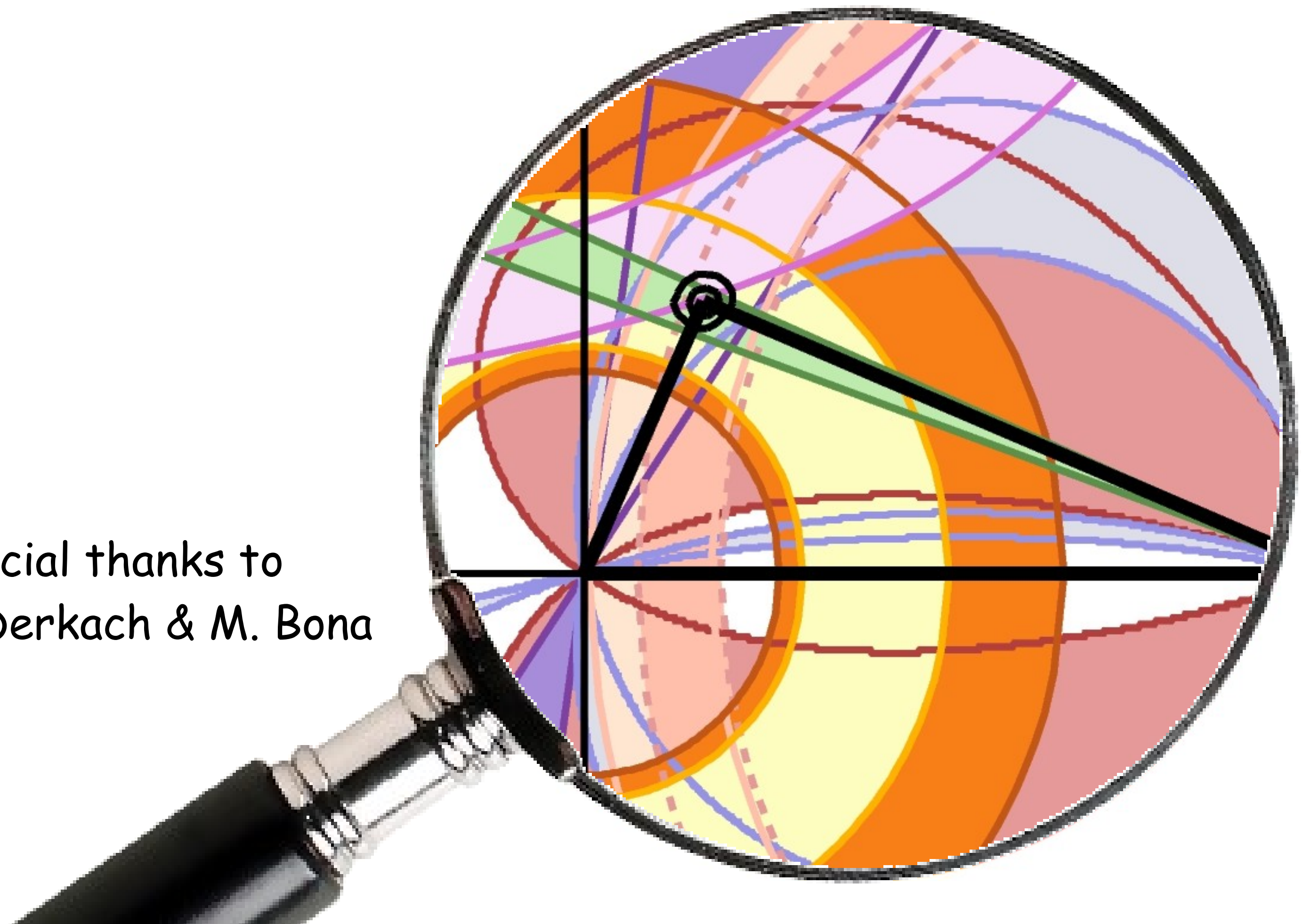

Special thanks to
D. Derkach & M. Bona

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INTRODUCTION

- In the past 45 years, we (almost) always found what we expected, where we expected
- Distinguish between arguments and indirect evidence:
  - GIM: charm @ GeV
  - Unitarization of Fermi theory: NP at 10^2 GeV
  - KM: 3^{rd} generation

INTRODUCTION II

- Flavour, EW fit: m_t~170 GeV
- EW fit: m_H=100±30 GeV

- Now we are left with arguments only:
  - Hierarchy problem / scale separation / naturalness
  - WIMP miracle
  - gauge coupling unification
- Although suprises are possible and would be very welcome, need more indirect evidence!

INTRODUCTION III

- No tree-level flavour changing neutral currents in the SM
- GIM suppression of FCNC @ the loop level
- Tiny CP violation in K and D mesons due to small coupling between third and first two generations

$\Rightarrow$ Flavour & CP violation ideal places to get indirect evidence of NP! (c & t already done!)

INTRODUCTION IV

- Compute FCNC & CPV as accurately as possible in the SM, assess compatibility with experiment
- Add loop-mediated NP in the game, determine SM couplings and NP contributions
- Constrain coefficients of higher dimensional operators
- Get bounds/indications on the scale of NP

OUTLINE

- Status of the SM UTA
- UTA beyond the SM & constraints on NP
- NP scale analysis in different classes of models
- bounds on SUSY
- possible NP signals?
- conclusions & outlook

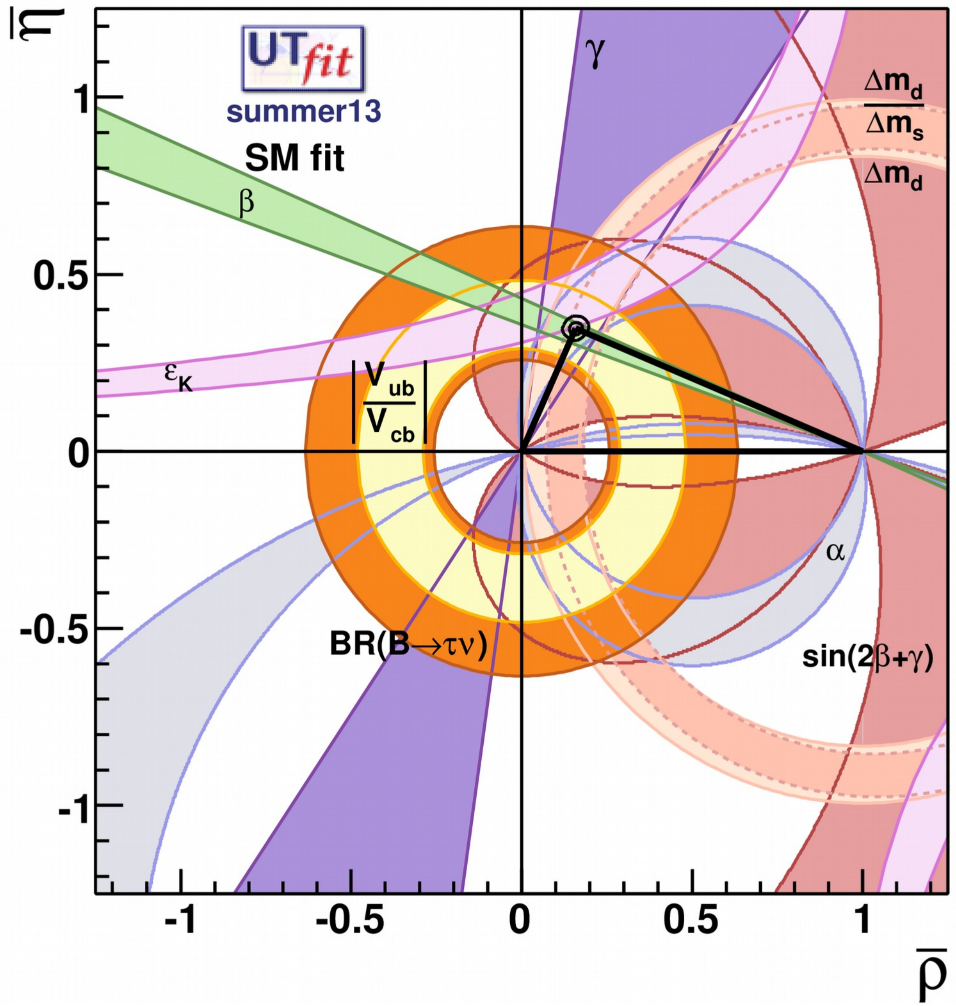
THE UNITARITY TRIANGLE

- All flavour violation in the SM from charged current coupling: CKM matrix V

$$V_{\rm CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\bar\rho - i\bar\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

- Top quark exchange dominates FCNC loops: third row (V_{tq}) determines FCNC's $\leftrightarrow \bar\rho, \bar\eta$, apex of the Unitarity Triangle from $V_{ub}^*V_{ud} + V_{cb}^*V_{cd} + V_{tb}^*V_{td}=0$

PRESENT STATUS



$\bar{\rho} = 0.159 \pm 0.015$

$\bar{\eta} = 0.346 \pm 0.013$

$A = 0.829 \pm 0.012$

$\lambda = 0.2253 \pm 0.0006$

More in http://www.utfit.org

See also CKMfitter

$$V_{CKM} = \begin{pmatrix} (0.97428 \pm 0.00014) & (0.22532 \pm 0.00063) & (0.00371 \pm 0.00012)e^{i(-65.3\pm2.0)^\circ} \\ (-0.22517 \pm 0.00063)e^{i(0.0352\pm0.001)^\circ} & (0.9734 \pm 0.00014)e^{i(-0.00188611\pm0.00005)^\circ} & (0.04209 \pm 0.00052) \\ (0.00864 \pm 0.00014)e^{i(-22.26\pm0.8)^\circ} & (-0.04137 \pm 0.00052)e^{i(1.052\pm0.039)^\circ} & (0.999106 \pm 0.000021) \end{pmatrix}$$

SUMMER 2013 NOVELTIES

- Updated lattice inputs according to FLAG summer13 averages, several errors halved:
  - $B_K = 0.766 \pm 0.010$ (was 0.75 ± 0.02)
  - $F_{Bs} = 227.7 \pm 4.5$ MeV (was 233 ± 10)
  - $10^3\, V_{ub}^{excl} = 3.42 \pm 0.22$ (was 3.28 ± 0.30)
- New experimental results, among which:
  - $BR(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7)10^{-9}$ (LHCb+CMS)
  - $BR(B_d \to \mu^+\mu^-) = (3.7 \pm 1.5)10^{-10}$ (LHCb+CMS)

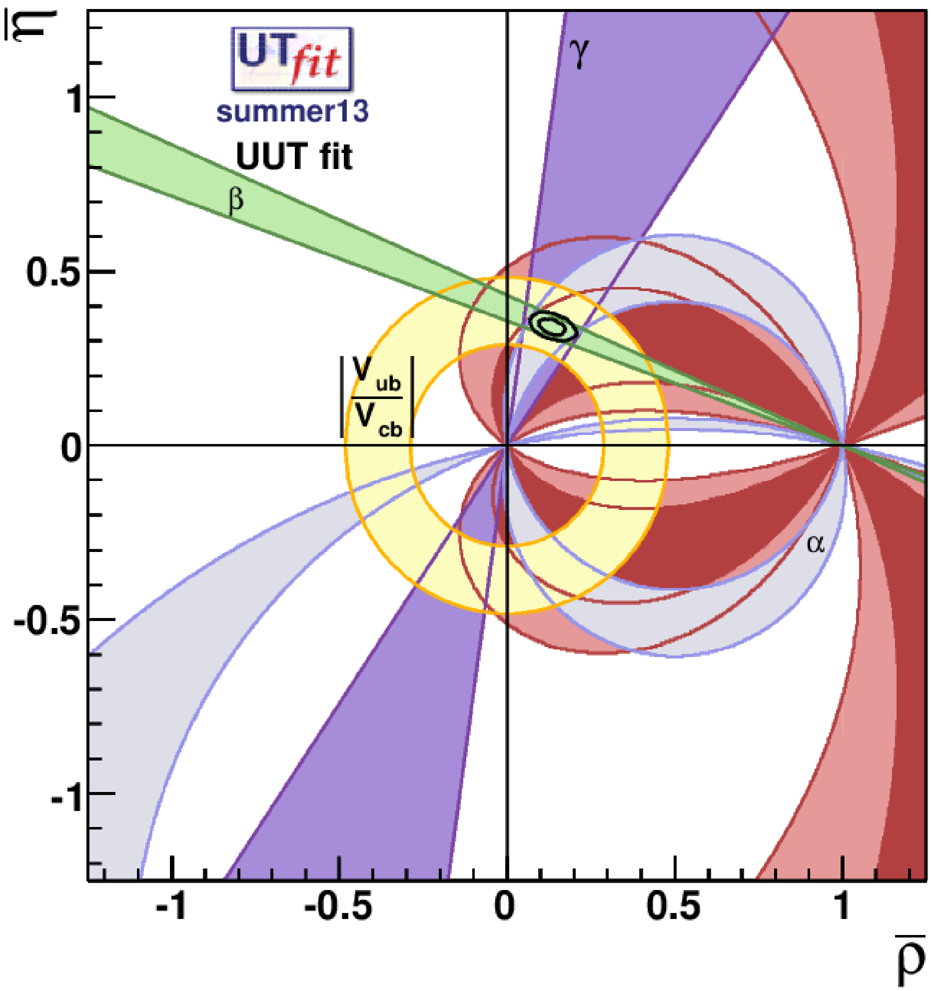
PREDICTIONS AND PULLS

Observables	Measurement	Prediction	Pull (#σ)
$\sin 2\beta$	0.680 ± 0.023	0.771 ± 0.038	**~ 2**
$\lvert V_{ub}\rvert \cdot 10^3$	3.75 ± 0.46	3.70 ± 0.12	< 1
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	4.40 ± 0.31	–	**~ 2**
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	3.42 ± 0.22	–	~ 1.1
$\lvert V_{cb}\rvert \cdot 10^3$	40.9 ± 1.0	42.52 ± 0.57	~ 1.3
B_K	0.766 ± 0.10	0.873 ± 0.073	~ 1.8
$BR(B \to \tau\nu)[10^{-4}]$	1.14 ± 0.22	0.811 ± 0.071	~ 1.4
$BR(B_s \to \mu\mu)[10^{-9}]$	2.9 ± 0.7	3.98 ± 0.16	~ 1.4
$BR(B_d \to \mu\mu)[10^{-9}]$	0.37 ± 0.15	0.106 ± 0.004	~ 1.7
$10^3\ A_{SL}^s$	-4.8±5.2	0.013±0.002	<1
$10^3\ A_{\mu\mu}$	- 7.9±2.0	-0.14±0.02	**~3.9**

THE UUT & MFV MODELS

- Consider MFV models ($Y_{u,d}$ only source of flavour & CPV) D'Ambrosio et al.,...
- Can define a Universal Unitarity Triangle using only observables unaffected by MFV-NP: V_{ub}, V_{cb} & angles Buras et al.
- UUT results starting point for model-dependent studies

UUT RESULTS



$\bar{\rho} = 0.134 \pm 0.029$

$\bar{\eta} = 0.340 \pm 0.017$

$A = 0.809 \pm 0.020$

$\lambda = 0.2253 \pm 0.0006$

In the SM was:

$\bar{\rho} = 0.159 \pm 0.015$

$\bar{\eta} = 0.346 \pm 0.013$

BOUNDS ON MFV MODELS

- In MFV models @ low/moderate tanβ, NP effects amount to a modification of the top loop: in $\Delta F=2$, $S_0(x_t) \to S_0(x_t) + \delta S$, with $\delta S = 4c(\Lambda_{SM}/\Lambda)^2$ and $\Lambda_{SM} \sim 2.4$ TeV

Gabrielli & Giudice; D'Ambrosio et al; Buras et al; UTfit

- We find $\delta S \in [-0.28, 0.48]$ @ 95% probability
- This corresponds to $\Lambda > 6.9$ TeV for $c=1$ and to $\Lambda > 9.1$ TeV for $c=-1$

MFV @ LARGE tanβ

- For large tanβ Y_b becomes important, and Higgs exchange can dominate over SM in helicity suppressed amplitudes: $B\to\tau\nu$, $B_s\to\mu\mu$

Grzadkowski&Hou

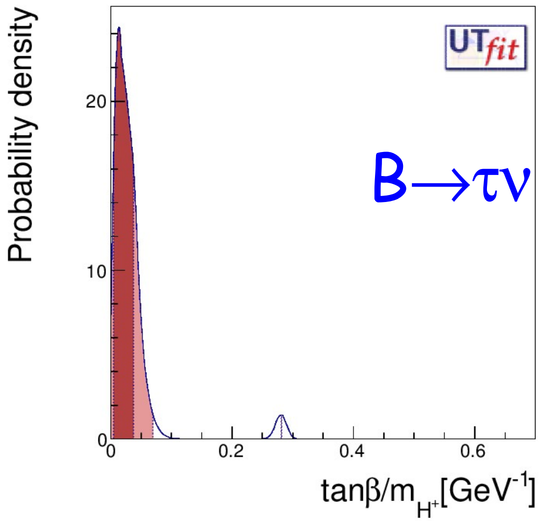
- In 2HDMII, $(\tan\beta/m_{H+})^4$-enhanced contributions: $BR/BR_{SM}\sim(1 - m_B^2 \tan^2\beta/m_{H+}^2)^2$

Hou

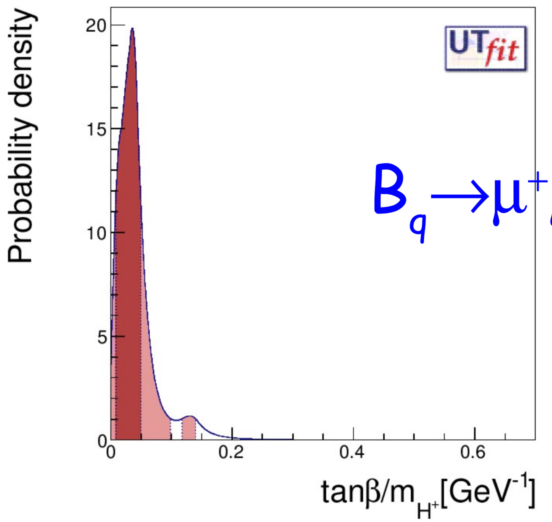
- In the MSSM, loop effects induce $(\tan\beta/m_{H+})^6$-enhanced contributions to $B_s\to\mu\mu$: $(\mu A_t/m_{stop}^2 \tan^3\beta/m_{H+}^2)^2$

Babu&Kolda;Isidori&Retico; Buras et al;Isidori&Paradisi; Altmannshofer et al;Behring et al; Mahmoudi et al;...

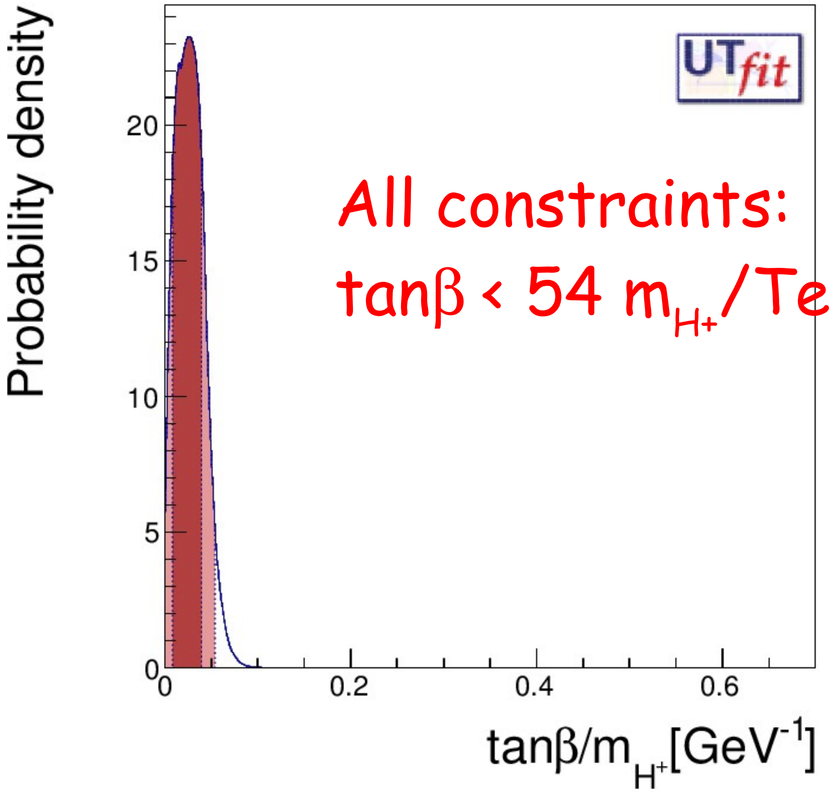
2HDMII and leptonic B decays



$B \to \tau\nu$ only



$B_q \to \mu^+\mu^-$ only

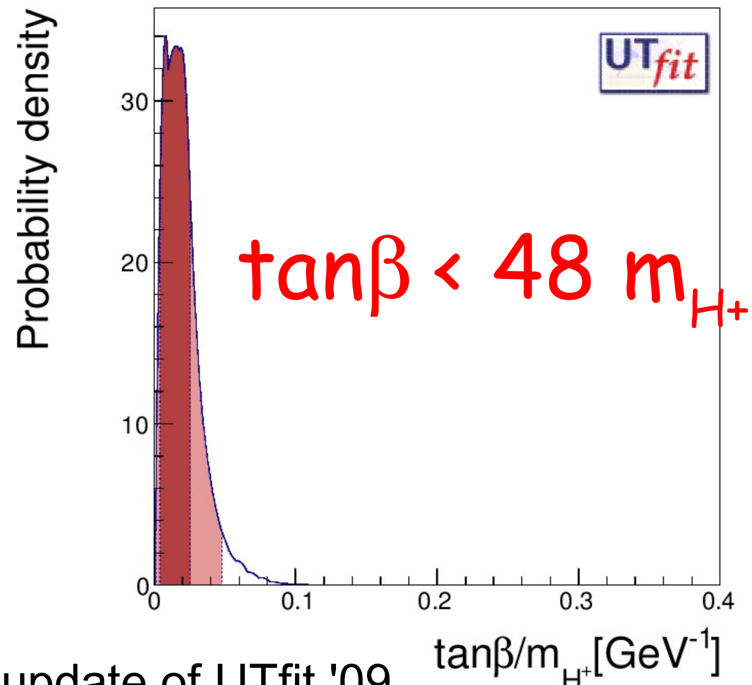


All constraints:

$\tan\beta < 54\ m_{H+}/\mathrm{TeV}$

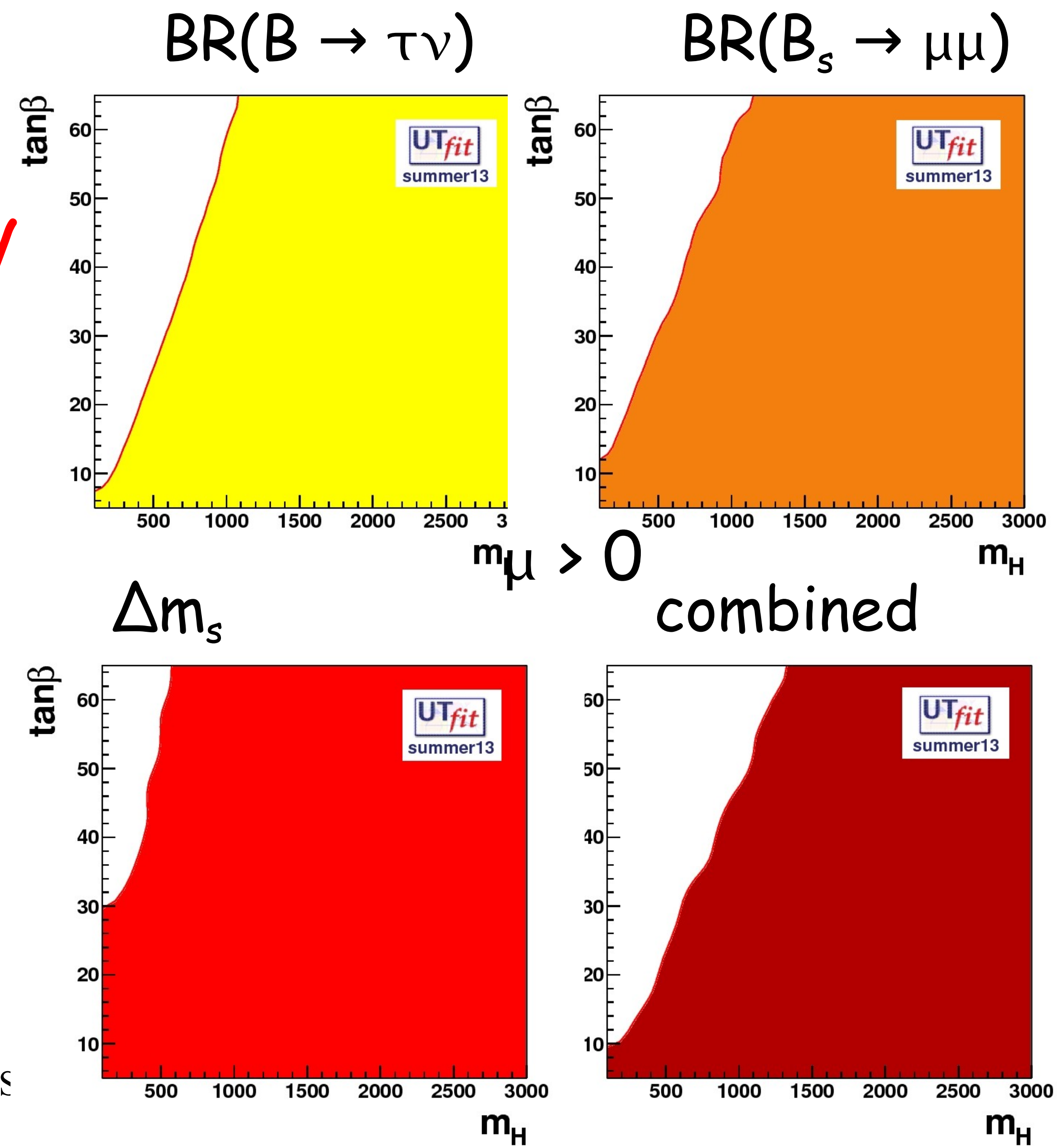
update of UTfit '09

MFV-MSSM at large tanβ



$\tan\beta < 48\ m_{H+}/\mathrm{TeV}$

update of UTfit '09



$\mu,\ m_{sq}, m_{gl} \in [1,3]\ \mathrm{TeV}$

$A_u \in [-3,3]\ \mathrm{TeV}$

UTfit beyond MFV

1. fit simultaneously for CKM and NP
   - add most general NP to all sectors
   - use all available experimental info
   - find out how much room is left for NP in $\Delta F=2$ transitions

Soares, Wolfenstein; Deshpande, Dutta, Oh; Silva, Wolfenstein; Cohen et al.; Grossman, Nir, Worah; Laplace et al; Ciuchini et al; Ligeti; CKMFitter; UTfit; Botella et al.; Agashe et al.; ...

2. perform an $\Delta F=2$ EFT analysis to put bounds on the NP scale
   - consider different choices of the FV and CPV couplings

UTfit; Davidson, Isidori, Uhlig; Isidori, Nir, Perez;...

1. Parameterization of generic NP contributions to the mixing amplitudes

K mixing amplitude (2 real parameters):

$$\mathrm{Re}\,A_K = C_{\Delta m_K}\,\mathrm{Re}\,A_K^{SM} \qquad \mathrm{Im}\,A_K = C_\varepsilon\,\mathrm{Im}\,A_K^{SM}$$

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

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

Observables:

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

$$A_{CP}^{B_d \to J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \qquad A_{CP}^{B_s \to J/\psi \phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$

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

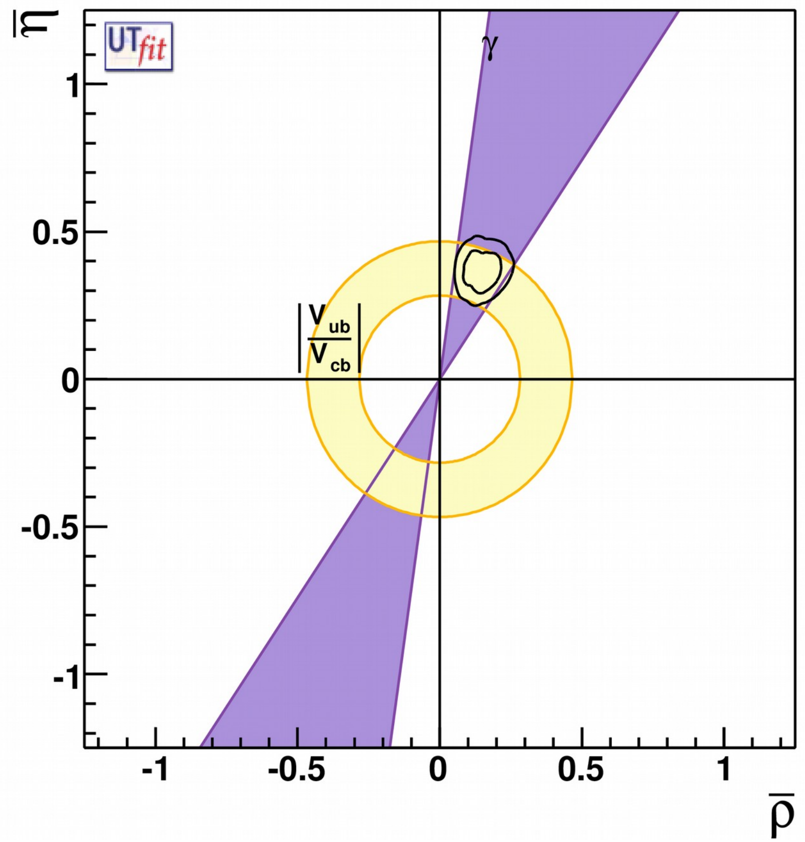
UT parameters in the presence of NP

Model-independent determination of the CKM parameters

(no NP in tree-level decays)

$\bar{\rho} = 0.147 \pm 0.045$

$\bar{\eta} = 0.368 \pm 0.048$

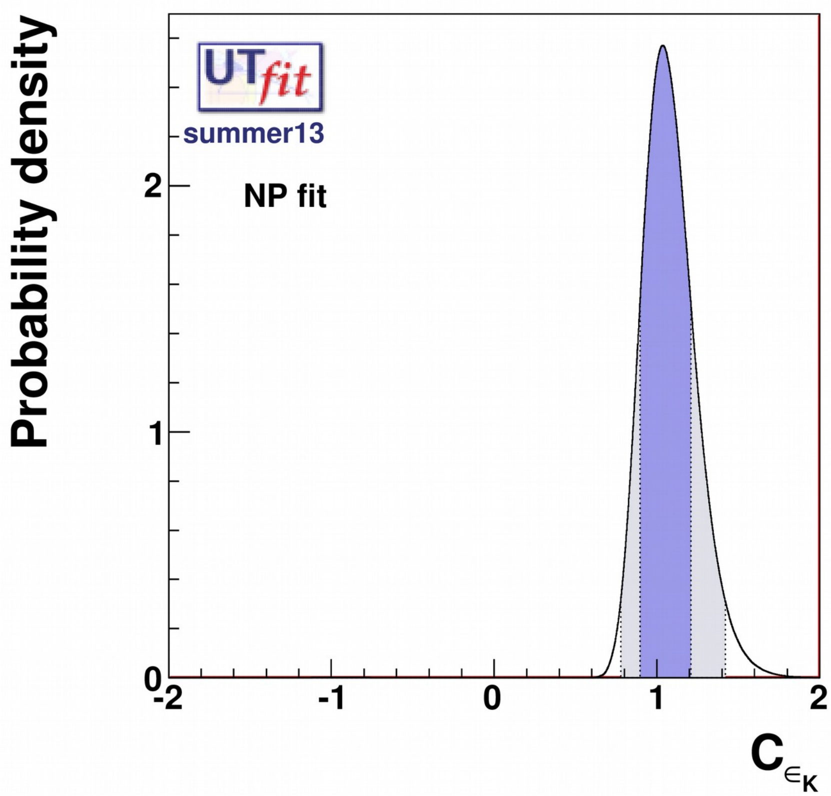


In the SM was:

$\bar{\rho} = 0.159 \pm 0.015$

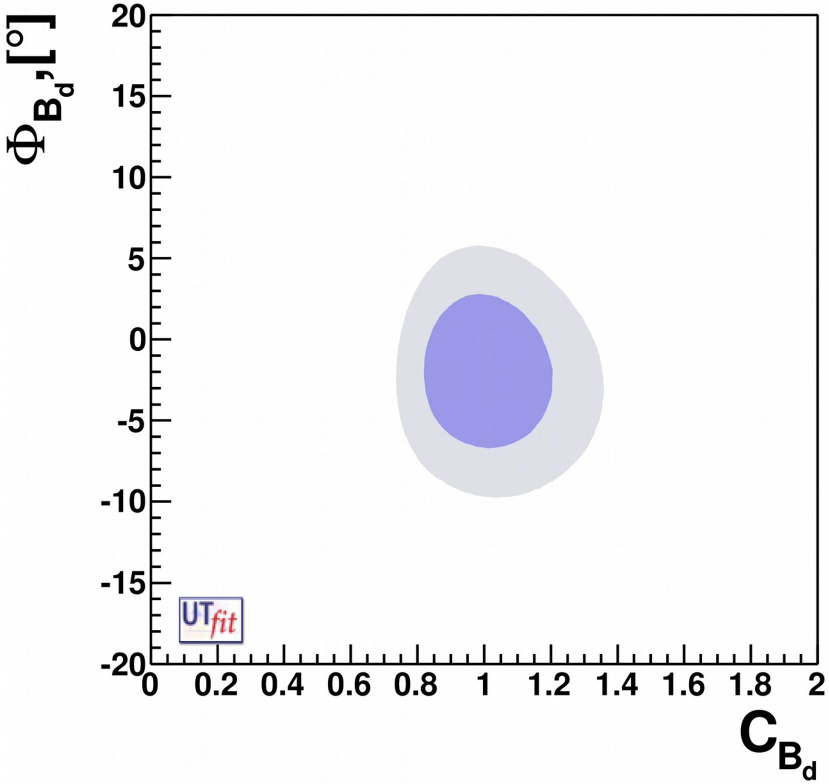
$\bar{\eta} = 0.346 \pm 0.013$

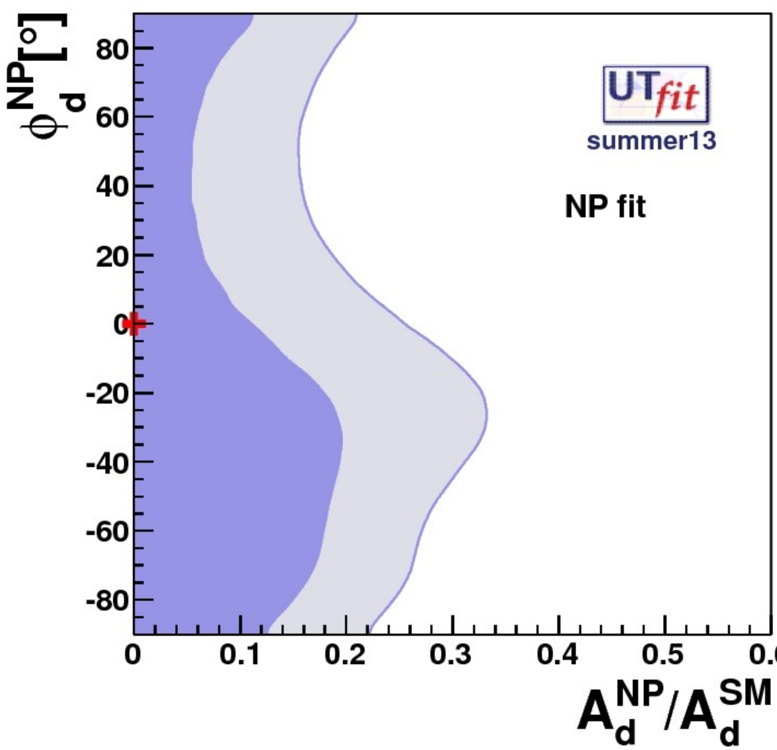
NP FIT RESULTS



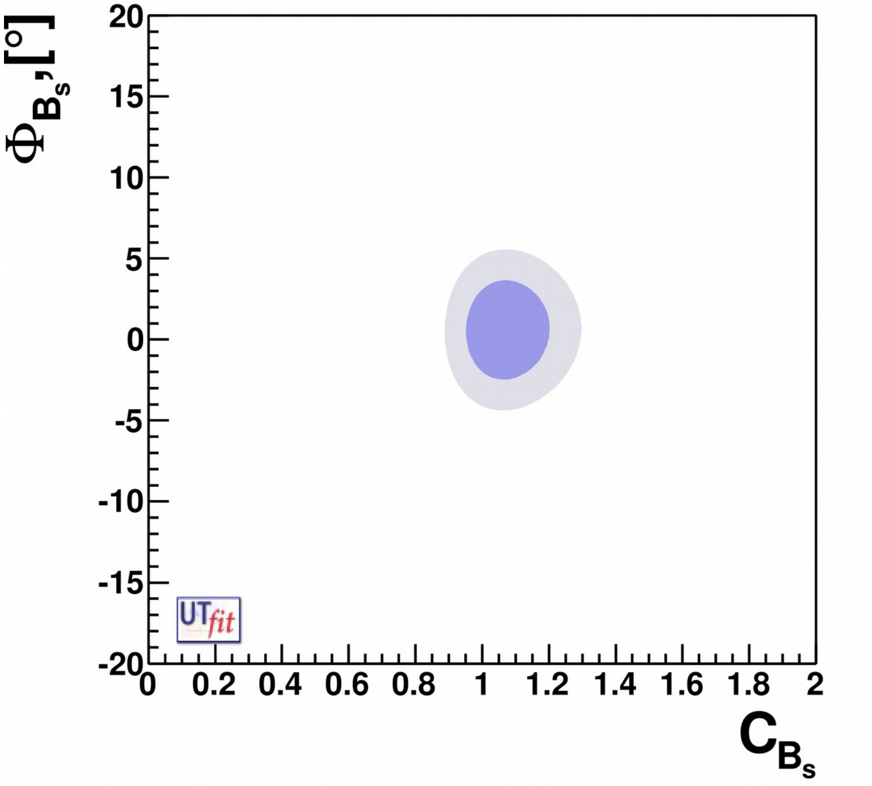
- $C_{\varepsilon K}$ = 1.05 ± 0.16

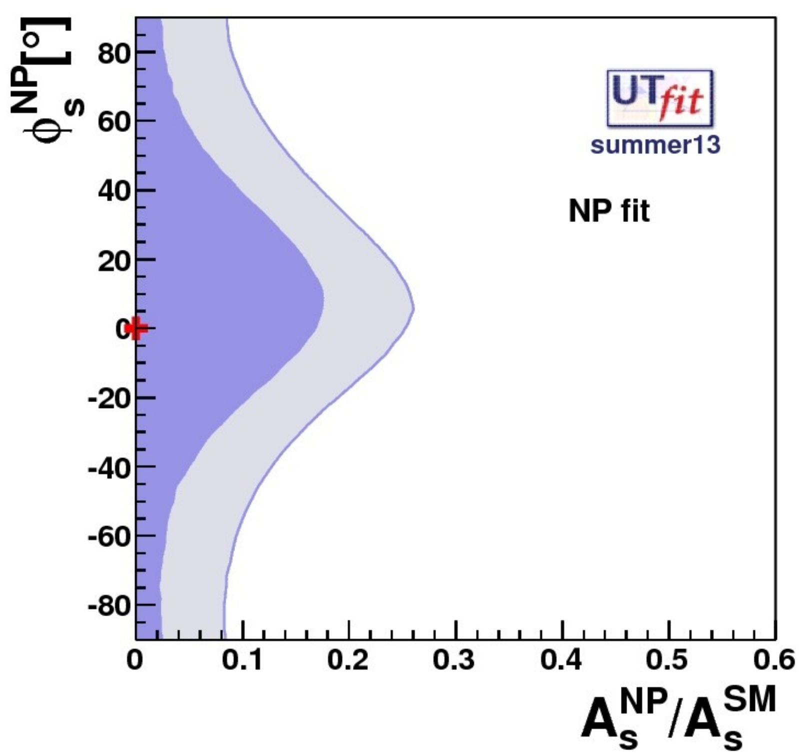
([0.77,1.42] @ 95% probability)





- C_{Bd} = 1.00 ± 0.13 ([0.77,1.28] @ 95% probability)
- ϕ_{Bd} = (-2.0 ± 3.2)° ([-8,4.2]° @ 95% probability)





- C_{Bs} = 1.07 ± 0.08 ([0.92,1.25] @ 95% probability)
- ϕ_{Bs} = (-0.6 ± 2.0)° ([-3.0,4.6]° @ 95% probability)
- The D0 dimuon asymmetry remains @ 3.7σ

D-$\bar{D}$ MIXING

- Established experimentally only in 2007
- Great experimental progress recently
- SM long distance contributions difficult to estimate, but solid prediction: no CPV in mixing
- Direct CPV possible in SCS decays; experimental situation unclear

BASIC FORMULAE

- All mixing-related observables can be expressed in terms of $x=\Delta m/\Gamma$, $y=\Delta\Gamma/2\Gamma$ and $|q/p|$, or better in terms of M_{12}, Γ_{12} and $\Phi_{12}=\arg(\Gamma_{12}/M_{12})$:

$$|M_{12}| = \frac{1}{\tau_D}\sqrt{\frac{x^2+\delta^2 y^2}{4(1-\delta^2)}}\,, \quad |\Gamma_{12}| = \frac{1}{\tau_D}\sqrt{\frac{y^2+\delta^2 x^2}{1-\delta^2}}\,, \quad \sin\Phi_{12} = \frac{|\Gamma_{12}|^2+4|M_{12}|^2-(x^2+y^2)|q/p|^2/\tau_D^2}{4|M_{12}\Gamma_{12}|}$$

$$\delta = \frac{1-|q/p|^2}{1+|q/p|^2}\,, \quad \phi = \arg(q/p) = \arg(y+i\delta x)\,, \quad A_M = \frac{|q/p|^4-1}{|q/p|^4+1}\,, \quad R_M = \frac{x^2+y^2}{2}\,, \qquad (1)$$

$$\begin{pmatrix} x'_f \\ y'_f \end{pmatrix} = \begin{pmatrix} \cos\delta_f & \sin\delta_f \\ -\sin\delta_f & \cos\delta_f \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}\,, \quad (x'_\pm)_f = \left|\frac{q}{p}\right|^{\pm 1} (x'_f\cos\phi \pm y'_f \sin\phi)\,, \quad (y'_\pm)_f = \left|\frac{q}{p}\right|^{\pm 1} (y'_f\cos\phi \mp x'_f \sin\phi)\,,$$

$$y_{\rm CP} = \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\frac{y}{2}\cos\phi - \left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\frac{x}{2}\sin\phi\,, \quad A_\Gamma = \left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\frac{y}{2}\cos\phi - \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\frac{x}{2}\sin\phi\,,$$

$$R_D = \frac{\Gamma(D^0\to K^+\pi^-)+\Gamma(\bar{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^-\pi^+)+\Gamma(\bar{D}^0\to K^+\pi^-)}\,, \quad A_D = \frac{\Gamma(D^0\to K^+\pi^-)-\Gamma(\bar{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^+\pi^-)+\Gamma(\bar{D}^0\to K^-\pi^+)}\,,$$

CPV IN D MIXING

- updating the UTfit average we obtain:
  - $x = (4.2 \pm 1.8)\ 10^{-3}$, $y = (6.4 \pm 0.8)\ 10^{-3}$, $|q/p|-1 = (2 \pm 8)\ 10^{-2}$, $\phi = (0.3 \pm 2.6)^\circ$
  - $\Phi_{12} = (2 \pm 11)^\circ$
- impressive improvement, CPV now very well measured
- more stringent constraints on CP-violating NP

2. 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

LATTICE QCD INPUT

- During the past year, ETMC recomputed the full set of matrix elements for K, D, B_d and B_s mixing beyond the SM:

K mixing, 1207.1287v4 (see also Boyle et al. 1206.5737)

$\overline{\text{MS}}$ (2 GeV)				
B_1	B_2	B_3	B_4	B_5
0.53(2)	0.52(2)	0.89(5)	0.78(3)	0.57(4)

$B_{d,s}$ mixing, 1308.1851

($\overline{\text{MS}}$–BMU, m_b)				
$B_1^{(d)}$	$B_2^{(d)}$	$B_3^{(d)}$	$B_4^{(d)}$	$B_5^{(d)}$
0.85(4)	0.72(3)	0.88(13)	0.95(5)	1.47(12)
$B_1^{(s)}$	$B_2^{(s)}$	$B_3^{(s)}$	$B_4^{(s)}$	$B_5^{(s)}$
0.86(3)	0.73(3)	0.89(12)	0.93(4)	1.57(11)

D mixing, to appear (preliminary)

$\overline{MS}$ (3GeV)				
B_1	B_2	B_3	B_4	B_5
0.75(02)	0.66(02)	0.96(05)	0.91(04)	1.10(05)

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

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

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

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

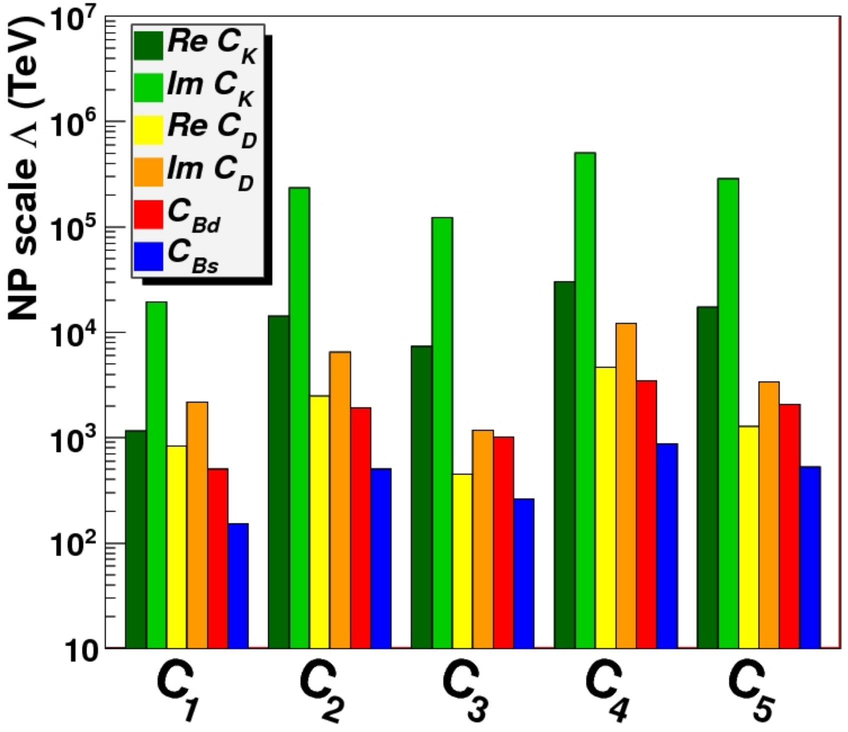
perturbative NP: $L \sim \alpha_s^2, \alpha_W^2$

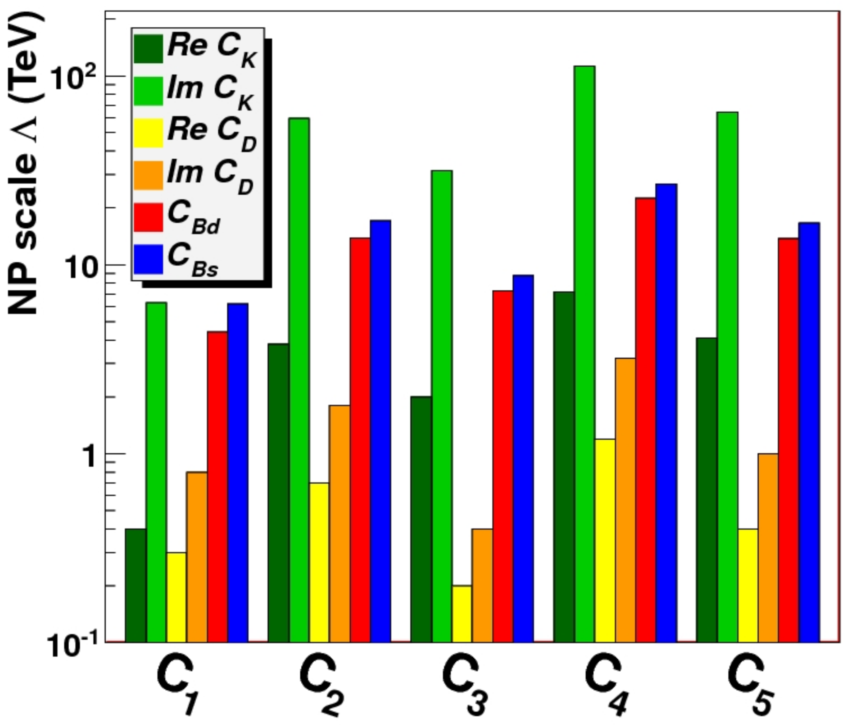
Flavour structures:

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

Parameter	95% allowed range (GeV^{-2})	Lower limit on Λ (TeV) for arbitrary NP	Lower limit on Λ (TeV) for NMFV
$\mathrm{Re}C_K^1$	$[-6.9, 7.4] \cdot 10^{-13}$	$1.2 \cdot 10^3$	0.4
$\mathrm{Re}C_K^2$	$[-5.0, 4.7] \cdot 10^{-15}$	$14.2 \cdot 10^3$	3.8
$\mathrm{Re}C_K^3$	$[-1.7, 1.8] \cdot 10^{-14}$	$7.4 \cdot 10^3$	2.0
$\mathrm{Re}C_K^4$	$[-1.0, 1.1] \cdot 10^{-15}$	$30.2 \cdot 10^3$	7.2
$\mathrm{Re}C_K^5$	$[-3.1, 3.3] \cdot 10^{-15}$	$17.4 \cdot 10^3$	4.1
$\mathrm{Im}C_K^1$	$[-1.9, 2.7] \cdot 10^{-15}$	$19.3 \cdot 10^3$	6.3
$\mathrm{Im}C_K^2$	$[-1.8, 1.3] \cdot 10^{-17}$	$235.7 \cdot 10^3$	59.8
$\mathrm{Im}C_K^3$	$[-4.7, 6.6] \cdot 10^{-17}$	$123.1 \cdot 10^3$	31.4
$\mathrm{Im}C_K^4$	$[-2.8, 4.0] \cdot 10^{-18}$	$502.3 \cdot 10^3$	112.6
$\mathrm{Im}C_K^5$	$[-8.5, 12.0] \cdot 10^{-18}$	$288.9 \cdot 10^3$	64.0
$\mathrm{Re}C_D^1$	$[-5.5, 14.3] \cdot 10^{-13}$	835.4	0.3
$\mathrm{Re}C_D^2$	$[16.4, 6.2] \cdot 10^{-14}$	$2.5 \cdot 10^3$	0.7
$\mathrm{Re}C_D^3$	$[-1.9, 5.0] \cdot 10^{-12}$	447.2	0.2
$\mathrm{Re}C_D^4$	$[-1.8, 4.6] \cdot 10^{-14}$	$4.7 \cdot 10^3$	1.2
$\mathrm{Re}C_D^5$	$[-2.4, 6.1] \cdot 10^{-13}$	$1.3 \cdot 10^3$	0.4
$\mathrm{Im}C_D^1$	$[-2.1, 1.7] \cdot 10^{-13}$	$2.2 \cdot 10^3$	0.8
$\mathrm{Im}C_D^2$	$[-1.9, 2.4] \cdot 10^{-14}$	$6.5 \cdot 10^3$	1.8
$\mathrm{Im}C_D^3$	$[-7.2, 5.9] \cdot 10^{-13}$	$1.2 \cdot 10^3$	0.4
$\mathrm{Im}C_D^4$	$[-6.7, 5.4] \cdot 10^{-15}$	$12.2 \cdot 10^3$	3.2
$\mathrm{Im}C_D^5$	$[-8.9, 7.2] \cdot 10^{-14}$	$3.4 \cdot 10^3$	1.0
$\lvert C_{B_d}^1 \rvert$	$< 3.9 \cdot 10^{-12}$	504.4	4.4
$\lvert C_{B_d}^2 \rvert$	$< 2.7 \cdot 10^{-13}$	$1.9 \cdot 10^3$	13.9
$\lvert C_{B_d}^3 \rvert$	$< 9.9 \cdot 10^{-13}$	$1.0 \cdot 10^3$	7.3
$\lvert C_{B_d}^4 \rvert$	$< 8.4 \cdot 10^{-14}$	$3.4 \cdot 10^3$	22.5
$\lvert C_{B_d}^5 \rvert$	$< 2.4 \cdot 10^{-13}$	$2.1 \cdot 10^3$	13.8
$\lvert C_{B_s}^1 \rvert$	$< 4.3 \cdot 10^{-11}$	152.6	6.2
$\lvert C_{B_s}^2 \rvert$	$< 3.9 \cdot 10^{-12}$	506.4	17.1
$\lvert C_{B_s}^3 \rvert$	$< 1.5 \cdot 10^{-11}$	260.8	8.8
$\lvert C_{B_s}^4 \rvert$	$< 1.3 \cdot 10^{-12}$	870.4	26.8
$\lvert C_{B_s}^5 \rvert$	$< 3.6 \cdot 10^{-12}$	525.6	16.6

BOUNDS ON THE NP SCALE





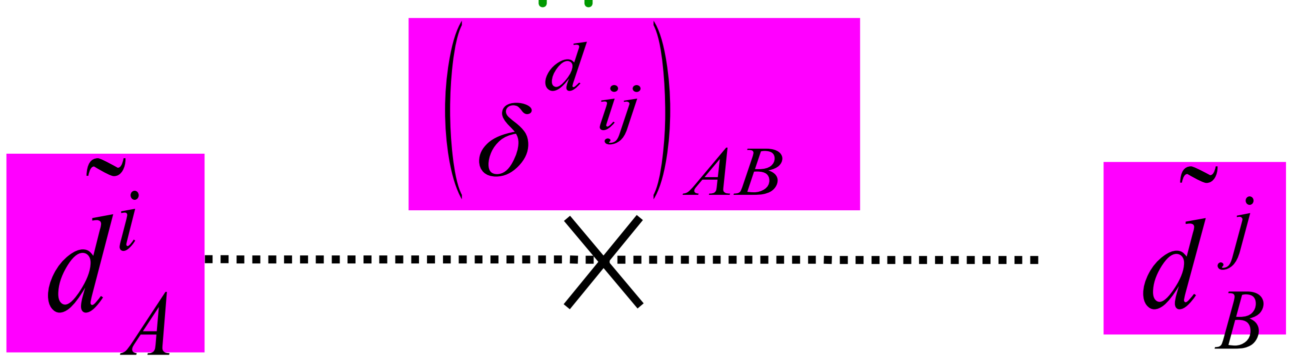
General FV: $\Lambda > 5\ 10^5$ TeV

NMFV: $\Lambda > 10^2$ TeV

CONSTRAINTS ON THE MSSM

Consider a MSSM with generic soft SUSY-breaking terms, but

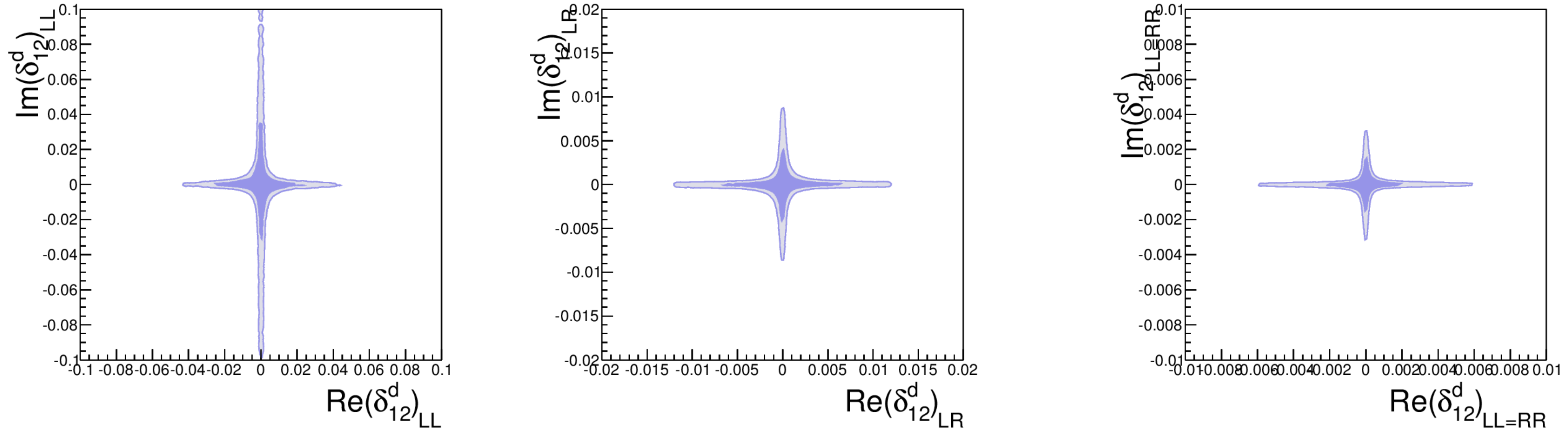
- dominant gluino contributions only
- mass insertion approximation



- four insertions AB=LL, LR, RL, RR

Translate bounds on NP in $\Delta F=2$ into bounds on off-diagonal mass insertions

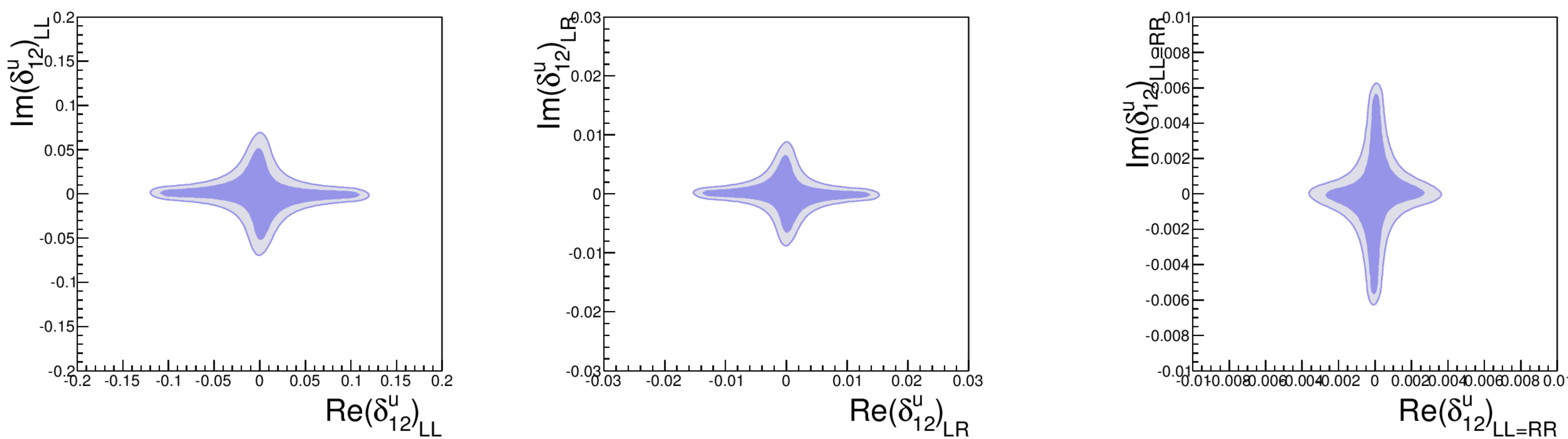
KAON MIXING



	$\sqrt{\lvert \mathrm{Re}\left[(\delta^d_{12})_{LL}\right]^2 \rvert}$	$\sqrt{\lvert \mathrm{Re}\left[(\delta^d_{12})_{LR}\right]^2 \rvert}$	$\sqrt{\lvert \mathrm{Re}\left[(\delta^d_{12})_{LL=RR}\right]^2 \rvert}$
bound on δ ($\tilde{m} = 1$ TeV)	$1 \cdot 10^{-1}$	$1 \cdot 10^{-2}$	$6 \cdot 10^{-3}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	10	$--$	170
	$\sqrt{\lvert \mathrm{Im}\left[(\delta^d_{12})_{LL}\right]^2 \rvert}$	$\sqrt{\lvert \mathrm{Im}\left[(\delta^d_{12})_{LR}\right]^2 \rvert}$	$\sqrt{\lvert \mathrm{Im}\left[(\delta^d_{12})_{LL=RR}\right]^2 \rvert}$
bound on δ ($\tilde{m} = 1$ TeV)	$8 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$6 \cdot 10^{-4}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	100	$--$	1700

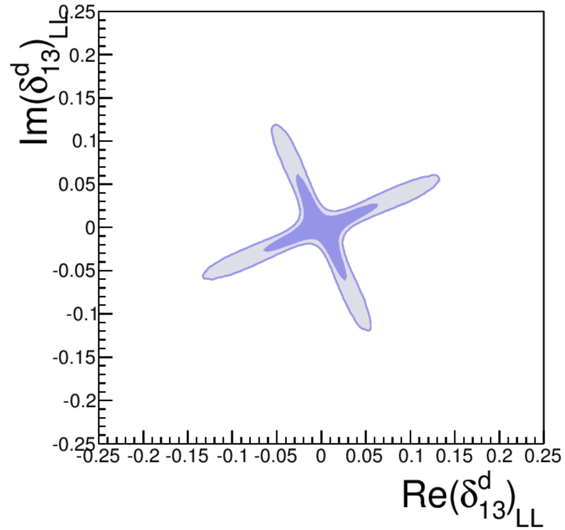
See also Mescia&Virto; Kersten&Velasco-Sevilla

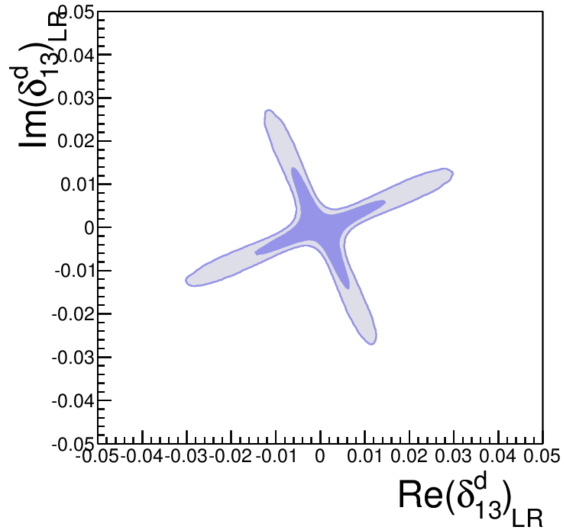
D MIXING

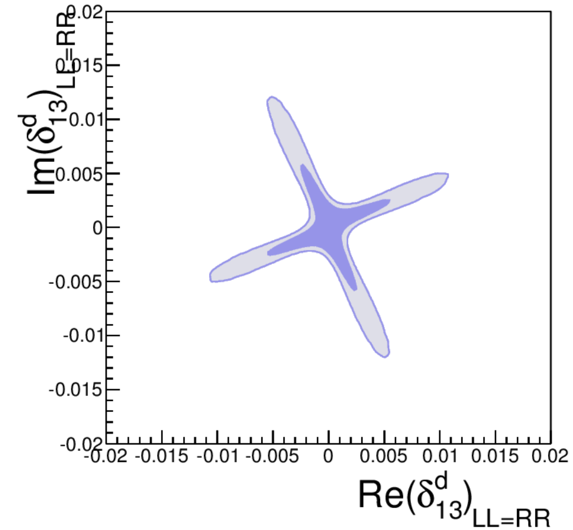


	$\sqrt{\left\|\mathrm{Re}\left[(\delta^u_{12})_{LL}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Re}\left[(\delta^u_{12})_{LR}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Re}\left[(\delta^u_{12})_{LL=RR}\right]^2\right\|}$
bound on δ ($\tilde{m} = 1$ TeV)	$1 \cdot 10^{-1}$	$1 \cdot 10^{-2}$	$6 \cdot 10^{-3}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	10	$--$	170
	$\sqrt{\left\|\mathrm{Im}\left[(\delta^u_{12})_{LL}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Im}\left[(\delta^u_{12})_{LR}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Im}\left[(\delta^u_{12})_{LL=RR}\right]^2\right\|}$
bound on δ ($\tilde{m} = 1$ TeV)	$3 \cdot 10^{-2}$	$4 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	30	$--$	500

B_d MIXING

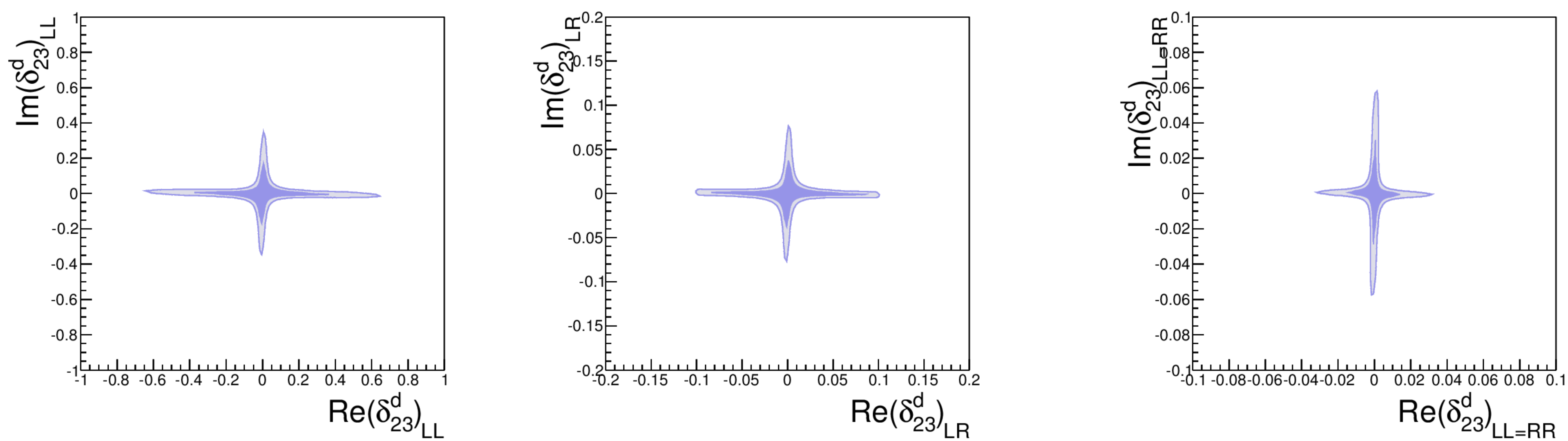






	$\sqrt{\left\|\mathrm{Re}\left[(\delta^d_{13})_{LL}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Re}\left[(\delta^d_{13})_{LR}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Re}\left[(\delta^d_{13})_{LL=RR}\right]^2\right\|}$
bound on δ ($\tilde{m} = 1$ TeV)	$9 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$8 \cdot 10^{-3}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	10	$--$	125
	$\sqrt{\left\|\mathrm{Im}\left[(\delta^d_{13})_{LL}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Im}\left[(\delta^d_{13})_{LR}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Im}\left[(\delta^d_{13})_{LL=RR}\right]^2\right\|}$
bound on δ ($\tilde{m} = 1$ TeV)	$1 \cdot 10^{-1}$	$2 \cdot 10^{-2}$	$9 \cdot 10^{-3}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	10	$--$	110

B_s MIXING



	$\sqrt{\left\|\mathrm{Re}\left[(\delta^d_{23})_{LL}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Re}\left[(\delta^d_{23})_{LR}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Re}\left[(\delta^d_{23})_{LL=RR}\right]^2\right\|}$
bound on δ ($\tilde{m} = 1$ TeV)	$6 \cdot 10^{-1}$	$1 \cdot 10^{-1}$	$5 \cdot 10^{-2}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	1.7	$--$	20
	$\sqrt{\left\|\mathrm{Im}\left[(\delta^d_{23})_{LL}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Im}\left[(\delta^d_{23})_{LR}\right]^2\right\|}$	$\sqrt{\left\|\mathrm{Im}\left[(\delta^d_{23})_{LL=RR}\right]^2\right\|}$
bound on δ ($\tilde{m} = 1$ TeV)	$1 \cdot 10^{-1}$	$2 \cdot 10^{-2}$	$1 \cdot 10^{-2}$
bound on $\tilde{m}$ (TeV) for $\delta_{\mathrm{LL,RR}} = 1$	10	$--$	100

ANY SIGNS OF NP?

- CPV in SCS D decays: progress made in th understanding, but exp situation unclear
- $A_{\mu\mu}$ seems difficult to reconcile with $A_{SL}^{s,d}$
- $B \rightarrow D^{(*)}\tau\nu$ decays seem to systematically deviate from SM predictions
  - Deviation inconsistent with 2HDMII and simple MFV models @ large $\tan\beta$
  - $B \rightarrow \tau\nu$ does not display such large deviation

ANY SIGNS OF NP? II

- LHCb has recently made big progress in the study of $B \to K^* \mu\mu$ decays
- Factorization needed to compute observables
- Power corrections (charming penguins, etc) can spoil the accuracy of th predictions
- Go with the inclusive and/or carefully assess th uncertainties before claiming deviations from the SM

CONCLUSIONS

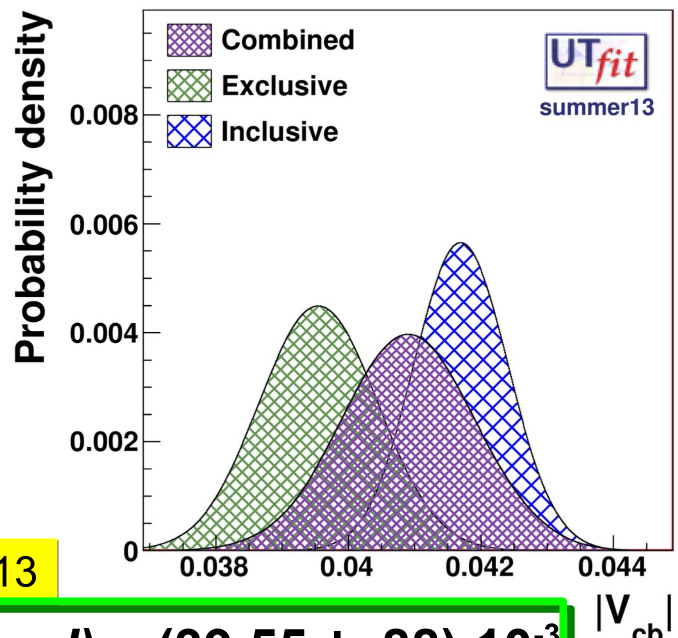
- The SM UTA has reached high precision and redundancy, allowing to test the SM and search for NP
- Overall picture consistent with the SM, with nonstandard CPV in $\Delta F=2$ possible at the few degrees level in all sectors
- Stringent bounds on the NP scale from $\Delta F=2$ processes

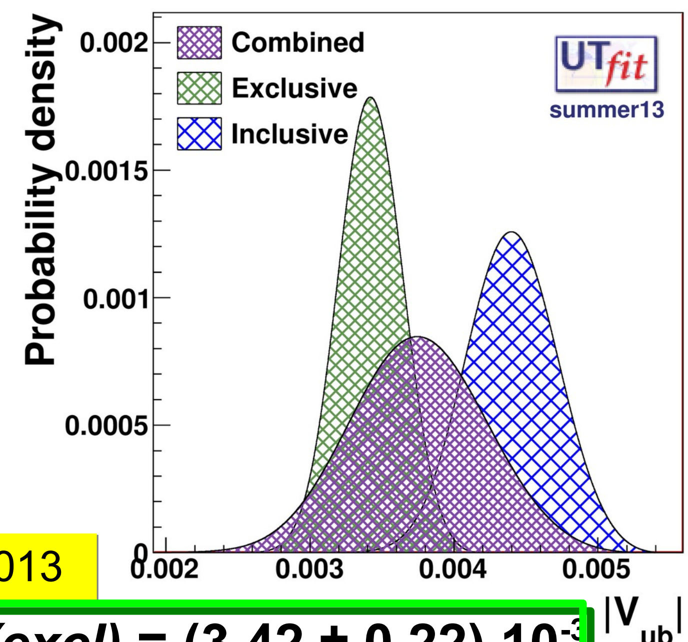
OUTLOOK

- Continue indirect searches for NP, particularly in the flavour sector:
  - flavour factories (b, τ-c, rare K decays)
  - LFV searches
- If I had the money, I would go for TLEP:
  - redo LEP in one minute, run as Z, H and t factory
- Indirectly probe scales > 100 TeV

BACKUP SLIDES

SEMILEPTONIC DECAYS





FLAG 2013

V_{cb} *(excl)* = (39.55 ± .88) 10^{-3}

HFAG

V_{cb} *(incl)* = (41.7 ± 0.7) 10^{-3}

~1.8σ discrepancy

UTfit input value: average à la PDG

V_{cb} = (40.9 ± 1.0) 10^{-3}

uncertainty ~ 2.4%

FLAG 2013

V_{ub} *(excl)* = (3.42 ± 0.22) 10^{-3}

UTfit from HFAG

V_{ub} *(incl)* = (4.40 ± 0.31) 10^{-3}

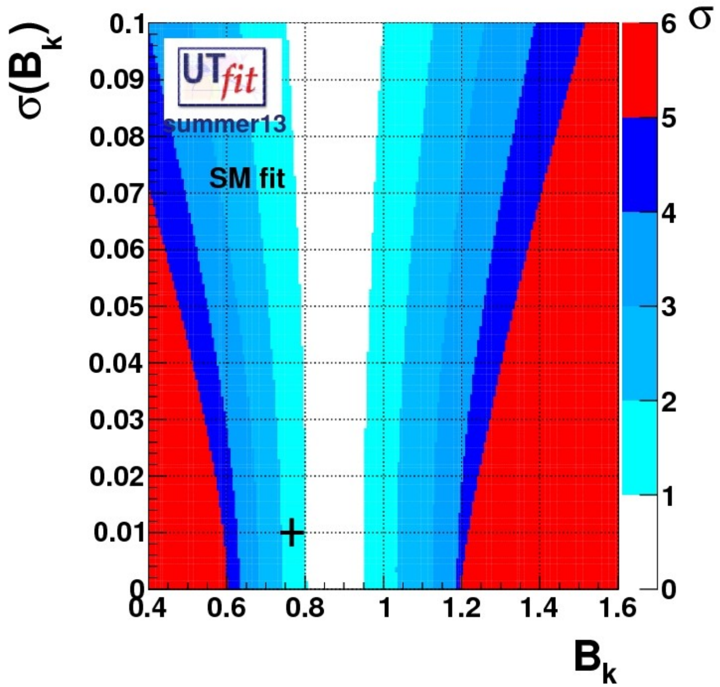
~2.6σ discrepancy

UTfit input value: average à la PDG

V_{ub} = (3.75 ± 0.46) 10^{-3}

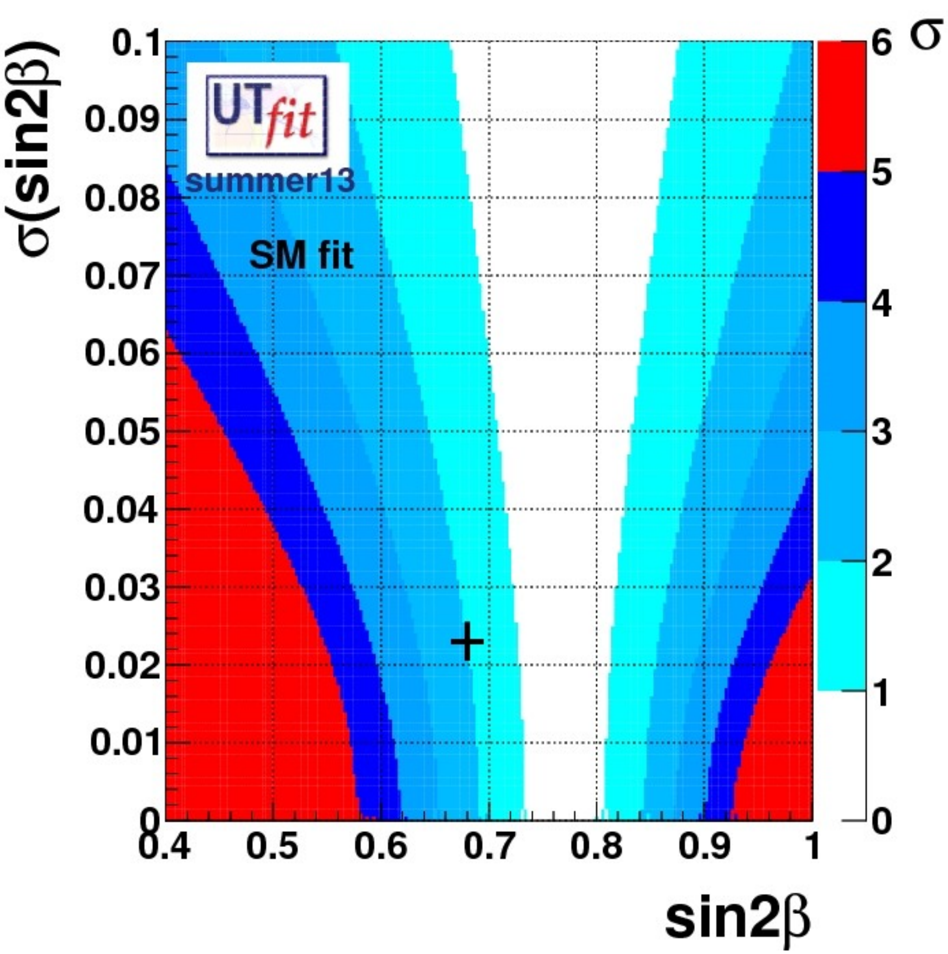
uncertainty ~ 12%

CPV IN KAONS: ε_K



- Including ImA_0 contribution & LD à la Buras-Guadagnoli-Isidori
- Contribution of D=8 operators in the OPE under evaluation
- Implementation of NNLO in progress
- $B_k^{input} = 0.766 \pm 0.010$, $B_k^{prediction} = 0.873 \pm 0.073$, compatibility: 1.8σ
- Using NNLO by Brod&Gorbahn, $B_k^{prediction} = 0.91 \pm 0.10$, compat.: 1.4σ

CPV IN B_d: sin2β



- Including theory error on the extraction of sin2β from $B_d \rightarrow J/\psi K_S$
- $\sin 2\beta^{exp} = 0.680 \pm 0.023$
  $\sin 2\beta^{prediction} = 0.771 \pm 0.038$
  compatibility: 2.0 σ
- Compatibility strongly depends on input for V_{ub}:
  $\sin 2\beta^{excl} = 0.745 \pm 0.031$
  compatibility: 1.5 σ
  $\sin 2\beta^{incl} = 0.788 \pm 0.031$
  compatibility: 2.7 σ

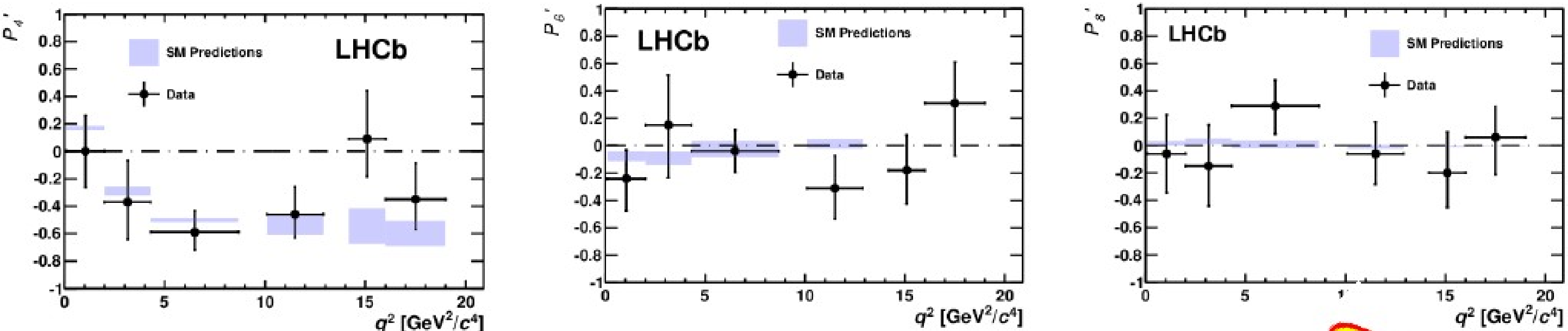
B_s MIXING & CPV

	Exp. Result	Prediction	Pull (σ)
$\Delta m_s[ps^{-1}]$	17.768±0.024	16.7±1.0	~1
$2\beta_s[°]$	0.6±4.0	1.05±0.04	<1
$\Delta\Gamma_s/\Gamma_s$	0.134±0.025	0.162±0.012	~1
$10^3 A_{SL}^s$	- 4.8±5.2	0.013±0.002	<1
$10^3 A_{\mu\mu}$	- 7.9±2.0	-0.14±0.02	3.9

New Observables in $B^0 \to K^*\mu^+\mu^-$

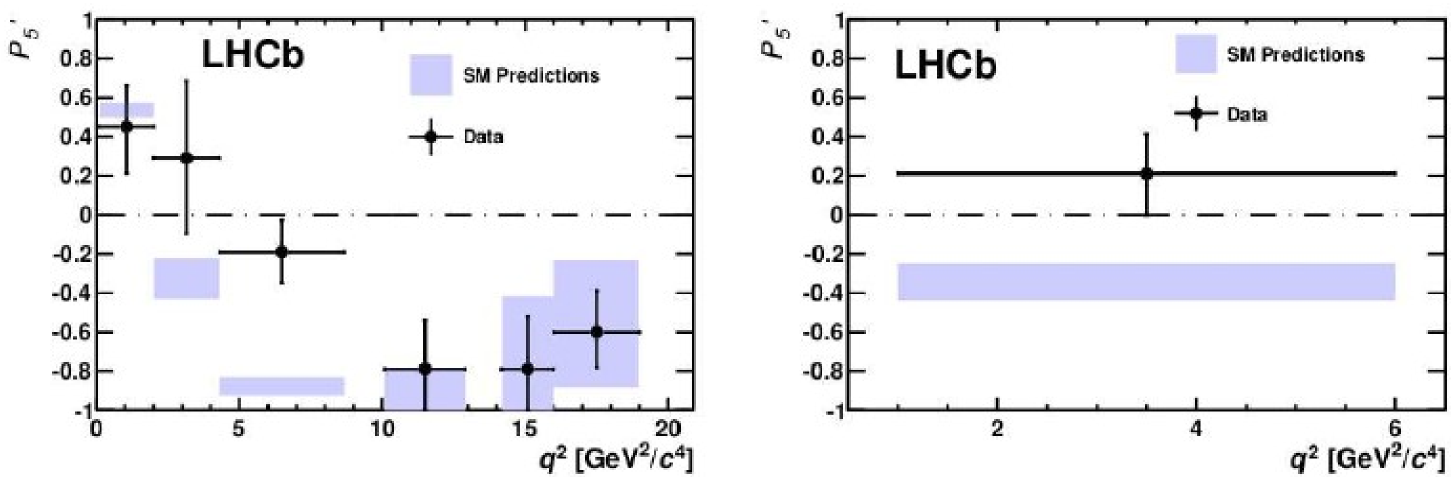
LHCb-PAPER-2013-037

Very good agreement in P_4', P_6', P_8'



new @ EPS2013

some tension in P_5' (3.7 σ):

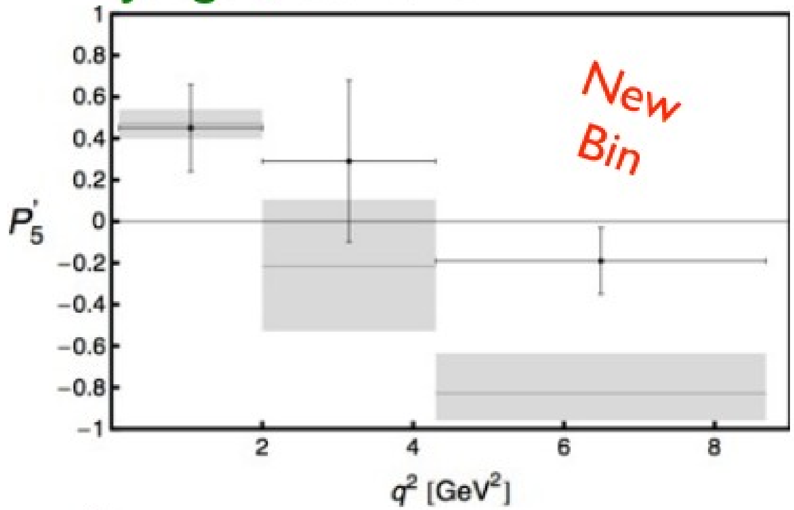


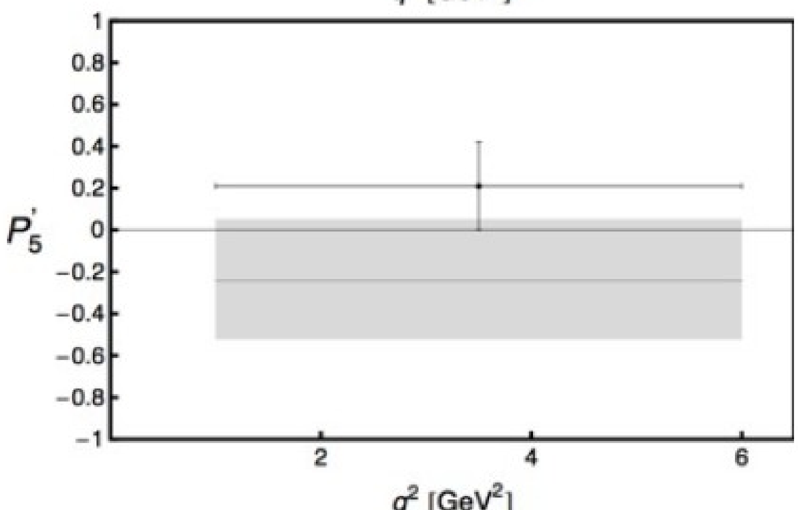
Discussion at EPS resulted in an article: Descotes, Matias, Virto arXiv:1307.5683

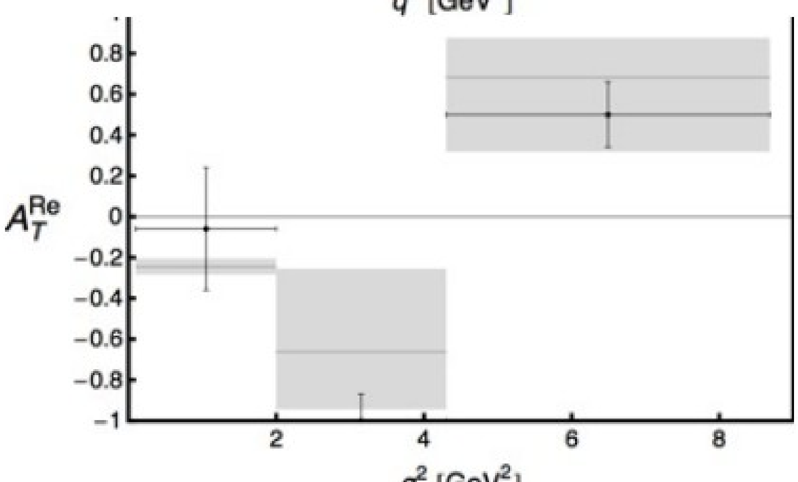
0.5% probability to see such a deviation with 24 independent measurements.

S. Hansmann-Menzemer @ EPS2013

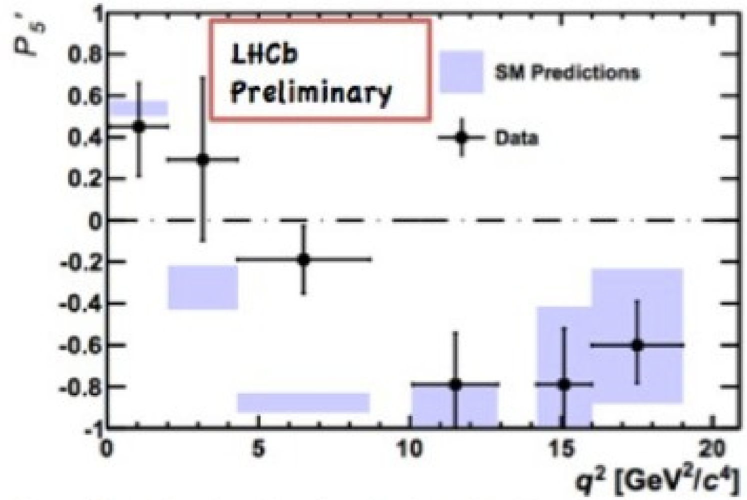
Jaeger, Camalich

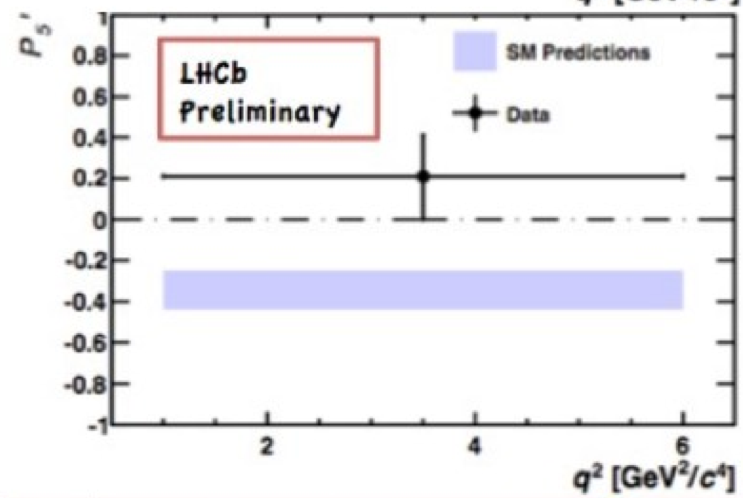


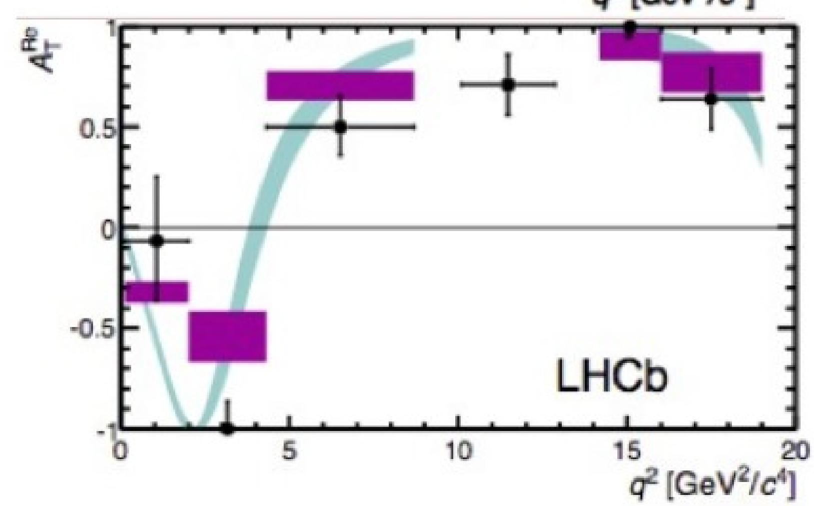




Descotes-Genon et al







A. Kagan
@ DPF13

Inclusive $B \to X_s \ell\ell$ Decays

Less theoretical uncertainties for inclusive $B \to X_s \ell\ell$ analysis,

statistical uncertainties comparable

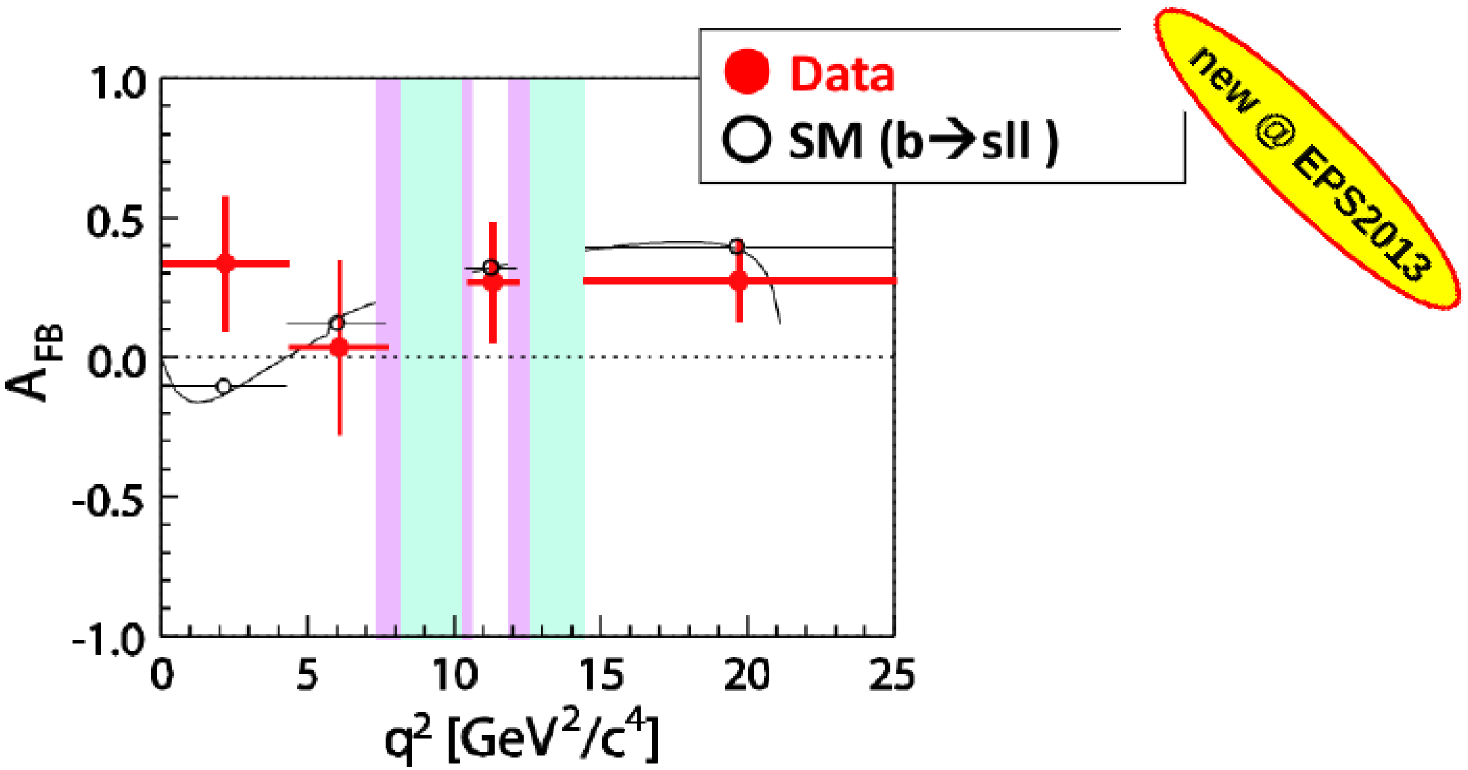
36 (18 $\times$ 2) modes studied

20 (10 $\times$ 2) modes used for final result

$\equiv$ 50% of all X_s

$\sim$ 140 $B \to X_s e^+ e^-$ +

$\sim$ 160 $B \to X_s \mu^+ \mu^-$ candidates



$P(B_q \rightarrow \overline{B_q}) \neq P(\overline{B_q} \rightarrow B_q)$

di-muon asymmetry ($B^0 + B_s$)

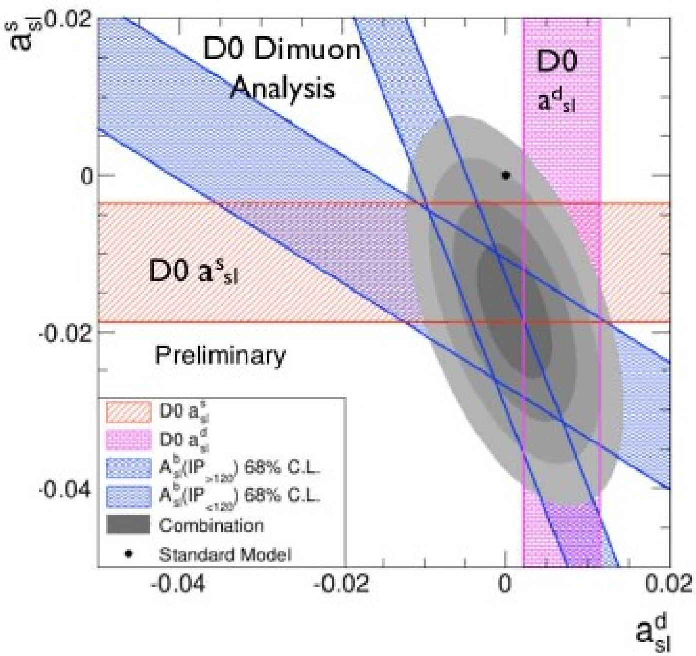
$B \longrightarrow \bar{B} \longrightarrow \mu^-$

$\bar{B} \longrightarrow \mu^-$

$\bar{B} \longrightarrow B \longrightarrow \mu^+$

$B \longrightarrow \mu^+$

$$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)}$$



semileptonic (untagged) asymmetry:

$$a^s_{sl} \propto \frac{N(\mu^+ D_s^{(*)-}) - N(\mu^- D_s^{(*)+})}{N(\mu^+ D_s^{(*)-}) + N(\mu^- D_s^{(*)+})}$$

$$a^d_{sl} \propto \frac{N(\mu^+ D^{(*)-}) - N(\mu^- D^{(*)+})}{N(\mu^+ D^{(*)-}) + N(\mu^- D^{(*)+})}$$

assuming no production asymmetry and

no CP in semileptonic decays

PRD 86, 072009 (2012), PRL, 10, 011801 (2013),
PRD 84, 052007 (2011)

D0 only results:

A_{CP} = (-0.276 $\pm$ 0.067 $\pm$ 0.063)% (9.0 fb^{-1})

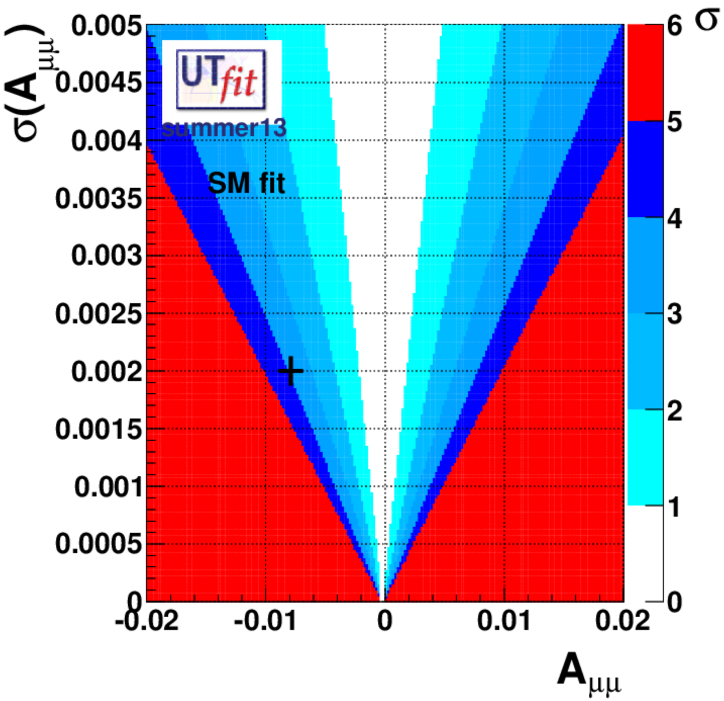
3.9 $\sigma \equiv$ 0.33% compatible with SM

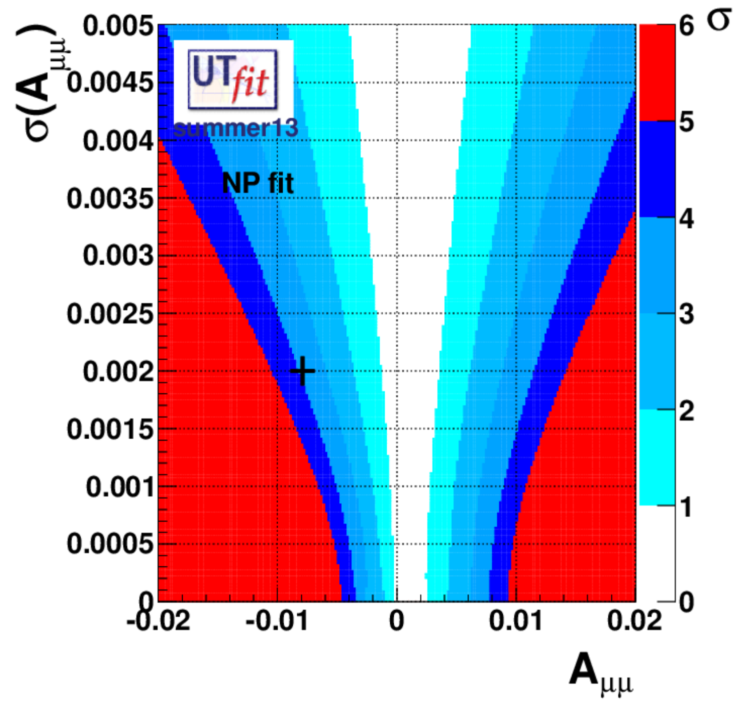
ϕ_s, a_{sl} as well not compatible in NP models ...

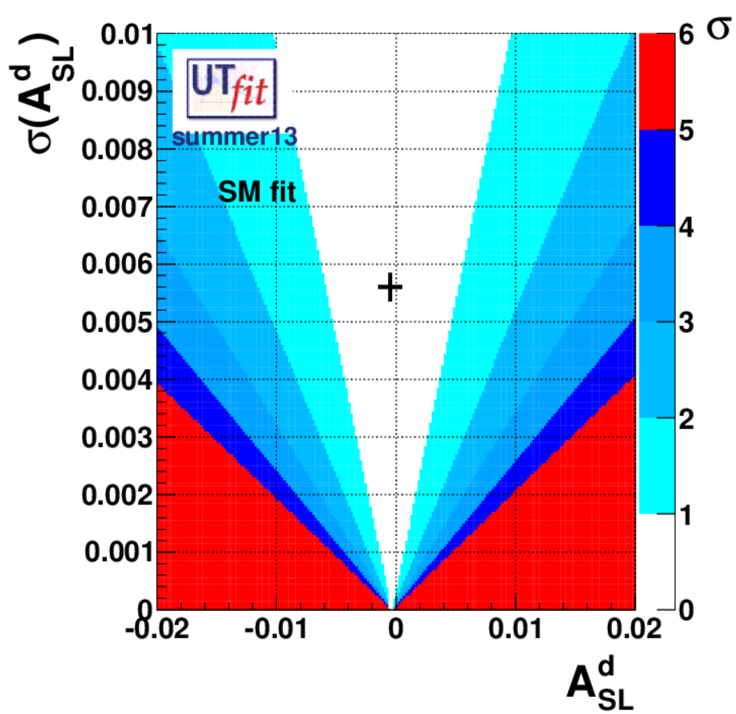
expected sensitivity of 10.4 fb^{-1} analysis:

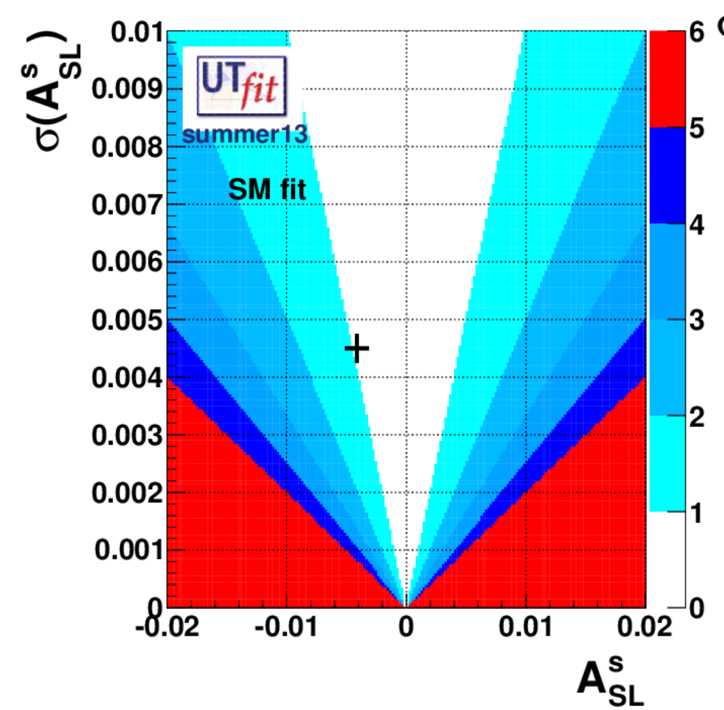
A_{CP} = (xxx $\pm$ 0.064 $\pm$ 0.055)%

new @ EPS2013


UTfit
summer13
SM fit
$\sigma(A_{\mu\mu})$
$A_{\mu\mu}$
σ


UTfit
summer13
NP fit
$\sigma(A_{\mu\mu})$
$A_{\mu\mu}$
σ


UTfit
summer13
SM fit
$\sigma(A^d_{SL})$
A^d_{SL}
σ


UTfit
summer13
SM fit
$\sigma(A^s_{SL})$
A^s_{SL}
σ