Flavor Physics:
A Theory Overview

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Windows on the Universe
Rencontres du Vietnam
ICISE Quy Nhon
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SISSA
International School for Advanced Studies

INFN
Istituto Nazionale
di Fisica Nucleare

1) Precision Flavor Physics in the quark sector (neutrinos covered by Andre de Gouvêa)

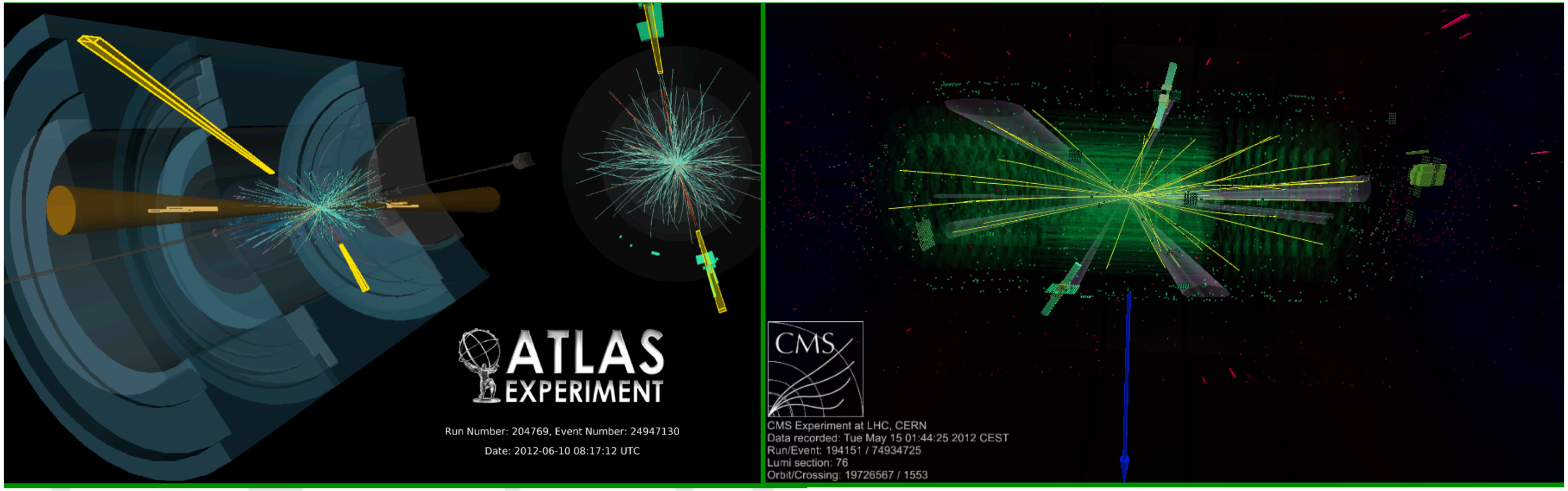
2) CKM analysis and CP violation in the SM

3) $B \longrightarrow \tau\, \nu$ & $B_s \longrightarrow \mu\, \mu$

4) Flavor BSM

5) Conclusions

- many thanks to M. Bona, M. Ciuchini, L. Silvestrini & Vagnoni for discussions and for a few slides



The Higgs Particle has been discovered

$M_H \approx 125$ GeV

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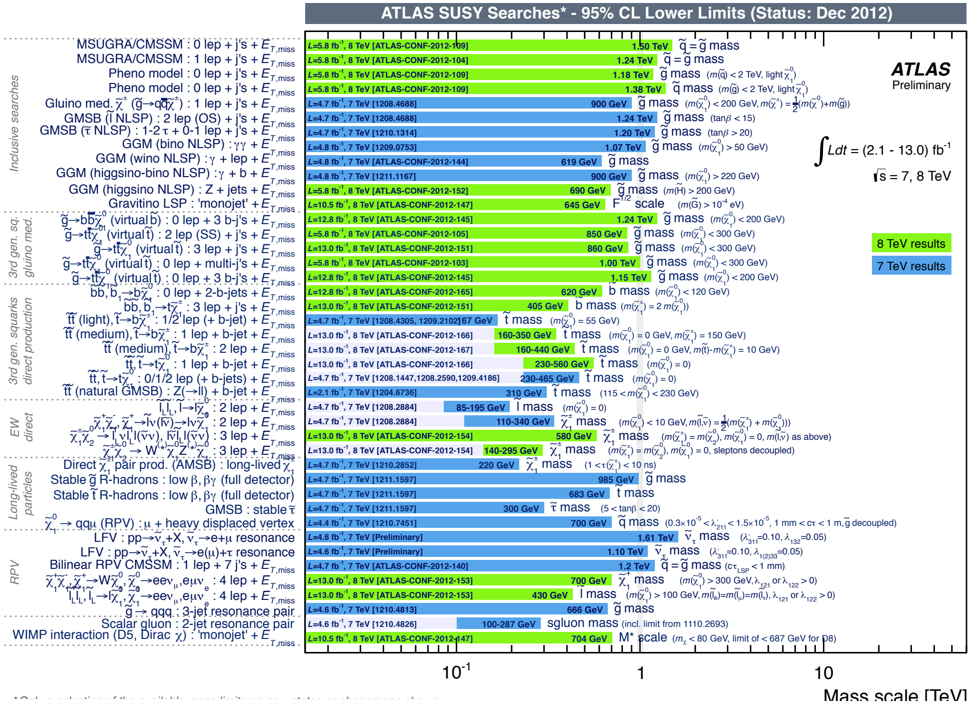
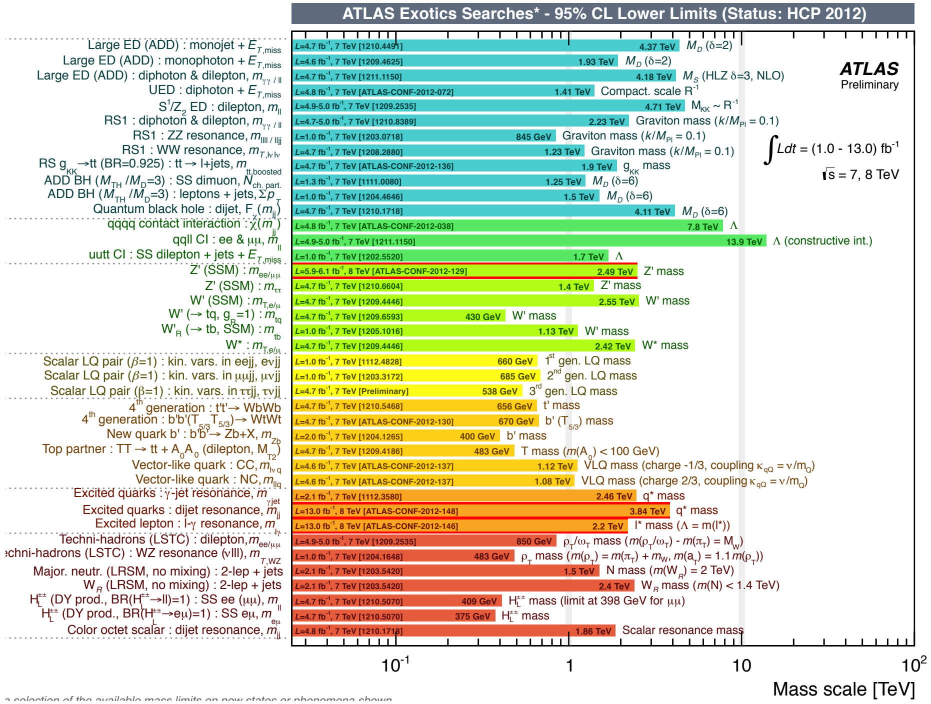
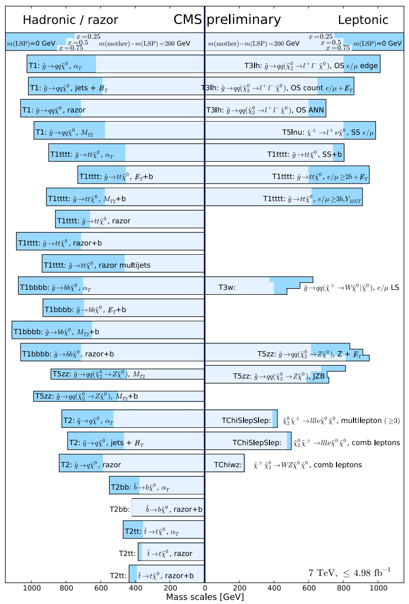
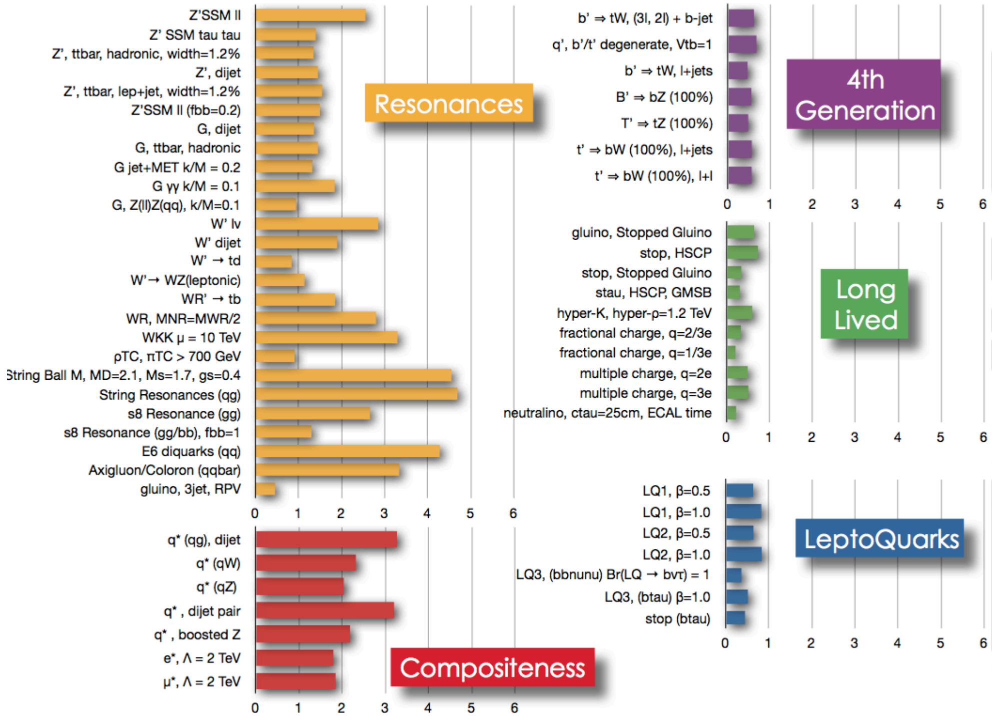








But that's all:

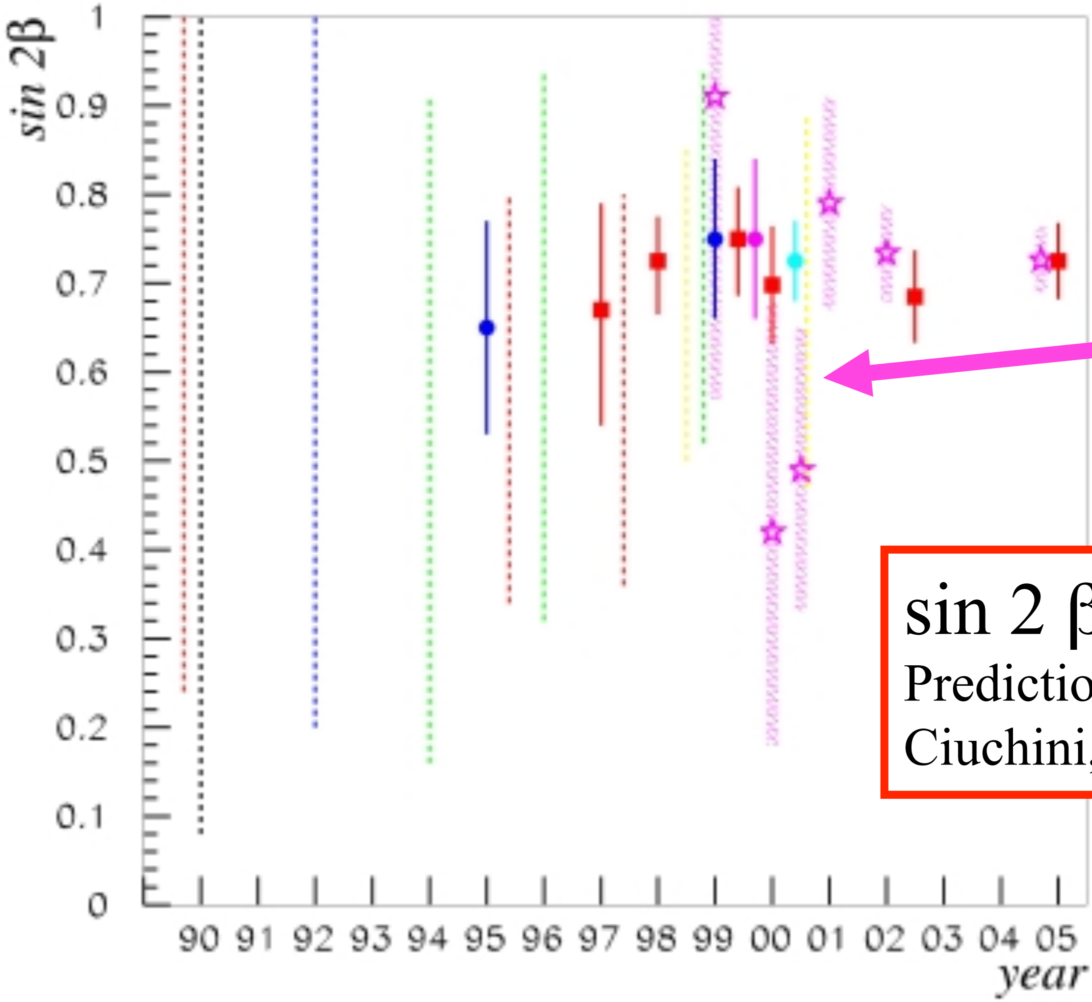
Higgs only Higgs!!

STANDARD MODEL UNITARITY TRIANGLE ANALYSIS

- *Provide the best determination of the CKM parameters;*
- *Test the consistency of the SM (``direct" vs ``indirect" determinations) @ the quantum level;*
- *Provide predictions for SM observables (in the past for example sin 2β and Δm_s*

Theoretical predictions of Sin 2 β in the years

predictions exist since '95



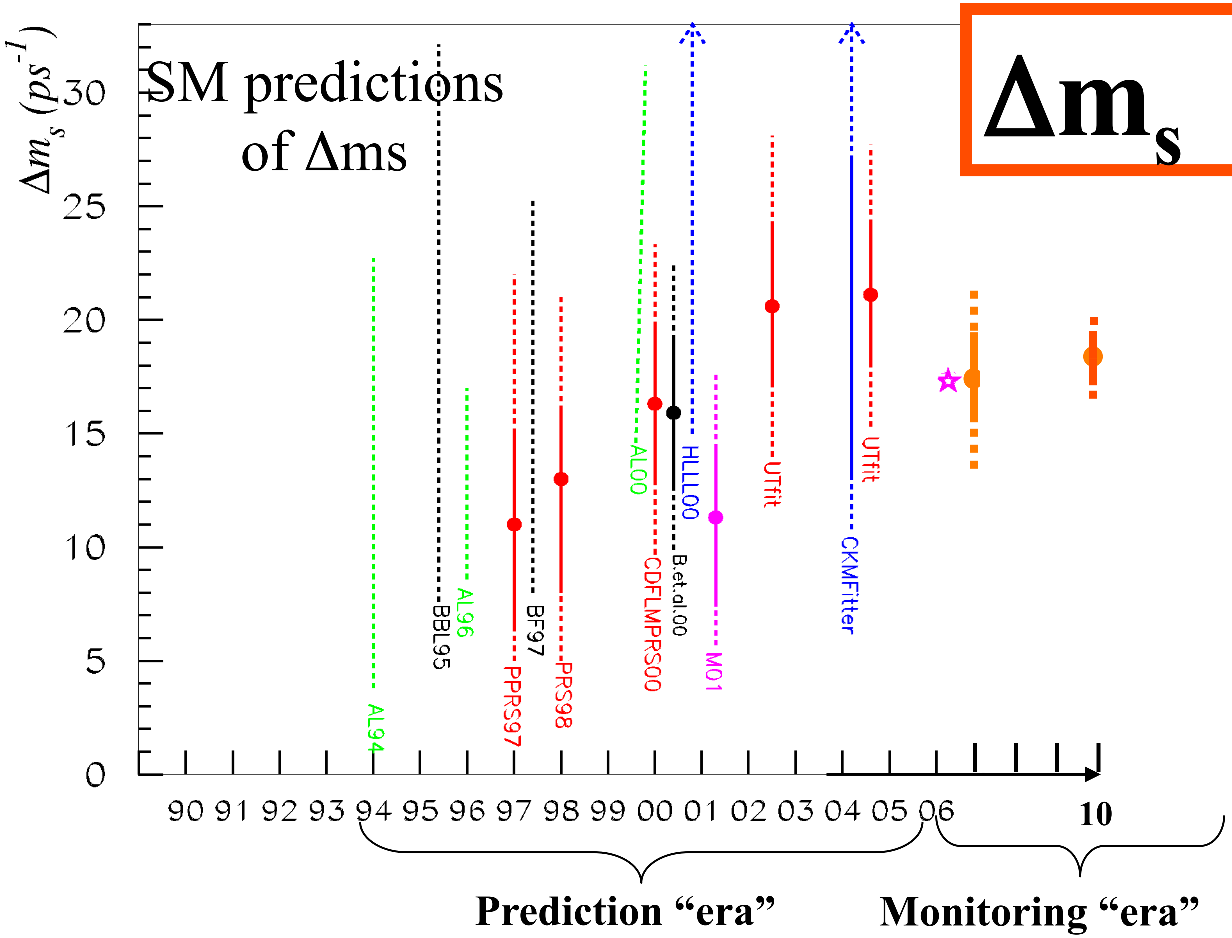
experiments

$\sin 2\,\beta_{UTA} = 0.65 \pm 0.12$

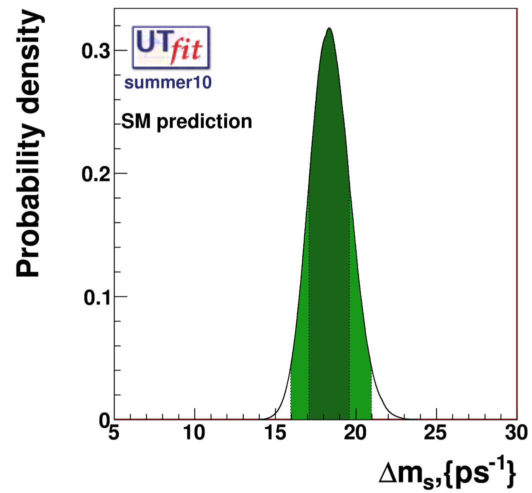
Prediction 1995 from

Ciuchini,Franco,G.M.,Reina,Silvestrini

Δm_s

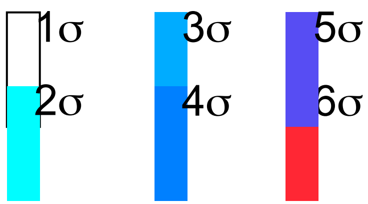


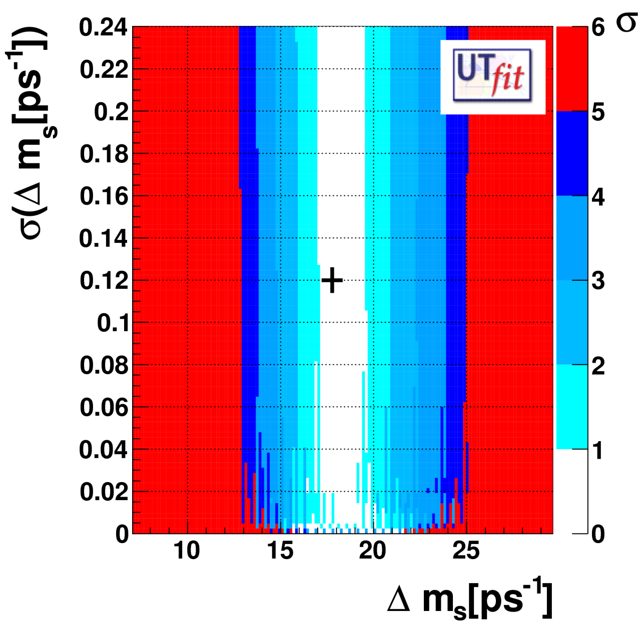
SM expectation
$\Delta m_s = (16.92 \pm 0.99\ )\ ps^{-1}$



Exp
$\Delta m_s = (17.72 \pm 0.04\ \ )\ ps^{-1}$

Legenda





Flavor physics in the Standard Model

In the SM, the quark mass matrix, from which the CKM matrix and ~~CP~~ violation originate, is determined by the coupling of the Higgs boson to fermions.

$$\mathcal{L}^{\text{quarks}} = \mathcal{L}^{\text{kinetic}} + \mathcal{L}^{\text{gauge}} + \mathcal{L}^{Yukawa}$$

CP invariant

~~CP~~ and symmetry breaking are striclty correlated

$$\mathcal{L}(\Lambda_{Fermi}) = \mathcal{L}(\Lambda, H, H^{\dagger}) + \mathcal{L}^{kin} + \mathcal{L}^{gauge}_{SM} + \mathcal{L}^{Yukawa}_{SM} + \frac{\mathcal{L}_5}{\Lambda} + \frac{\mathcal{L}_6}{\Lambda^2} + \ldots$$

EWSB

has many accidental simmetries

may violate accidental simmetries

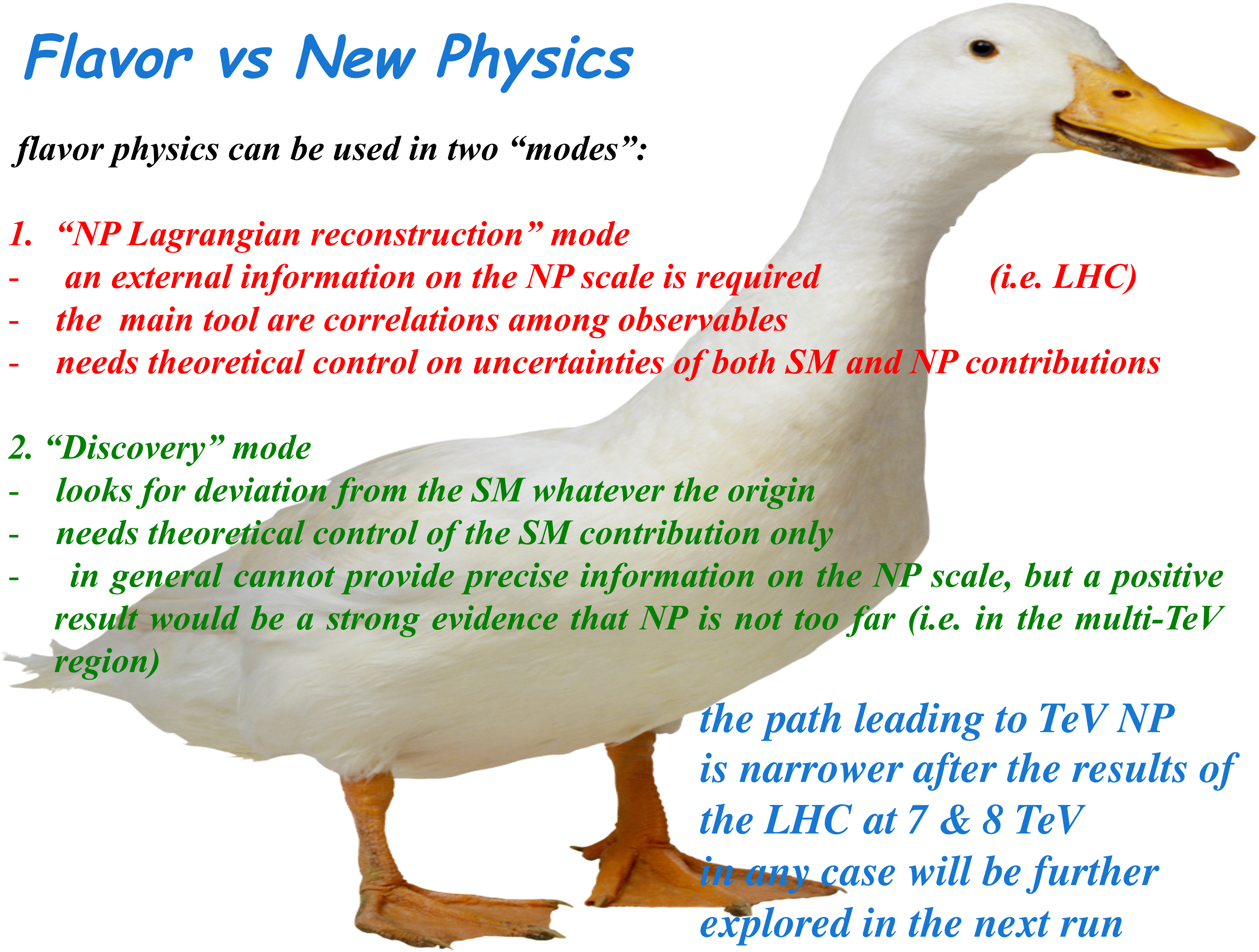
Two accidental symmetries:

Absence of FCNC at tree level (& GIM suppression of FCNC @loop level)

No CP violation @ tree level

Flavour Physics is extremely sensitive To New Physics (NP)

Flavor vs New Physics



flavor physics can be used in two "modes":

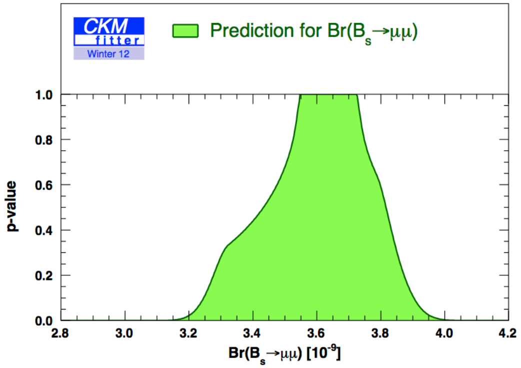
1. "NP Lagrangian reconstruction" mode

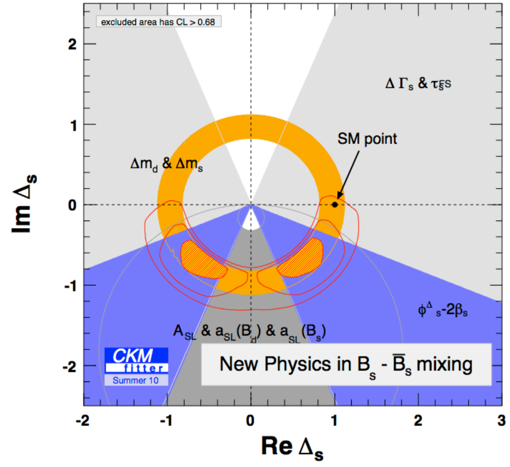
- ***an external information on the NP scale is required (i.e. LHC)***
- ***the main tool are correlations among observables***
- ***needs theoretical control on uncertainties of both SM and NP contributions***

2. "Discovery" mode

- ***looks for deviation from the SM whatever the origin***
- ***needs theoretical control of the SM contribution only***
- ***in general cannot provide precise information on the NP scale, but a positive result would be a strong evidence that NP is not too far (i.e. in the multi-TeV region)***

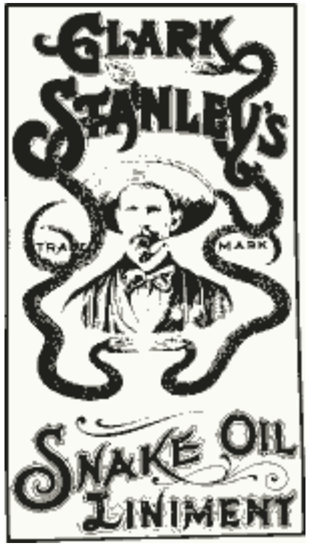
the path leading to TeV NP is narrower after the results of the LHC at 7 & 8 TeV in any case will be further explored in the next run

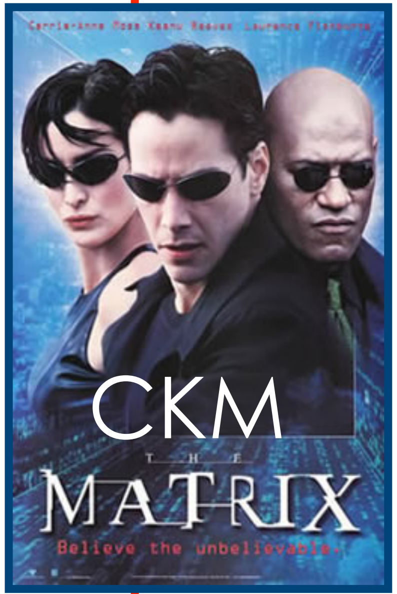




Jérôme Charles, Olivier Deschamps,
Sébastien Descotes-Genon, Ryosuke Itoh,
Andreas Jantsch, Heiko Lacker,
Andreas Menzel, Stéphane Monteil,
Valentin Niess, Jose Ocariz,
Jean Orloff, Stéphane T'Jampens,
Vincent Tisserand, Karim Trabelsi

See also
Laiho & Lunghi & Van de Water (http://krone.physik.unizh.ch/~lunghi/webpage/LatAves/page3/page3.html);
Lunghi & Soni (1010.67069).





M.Bona *et al.*, UTfit
JHEP0507:028, 2005

www.utfit.org

A. Bevan, M. Bona, M. Ciuchini,
D. Derkach, E. Franco, V. Lubicz,
G. Martinelli, F. Parodi, M. Pierini,
C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni

See also
Laiho & Lunghi & Van de Water (http://krone.physik.unizh.ch/~lunghi/webpage/LatAves/page3/page3.html);
Lunghi & Soni (1010.67069).

N(N-1)/2 angles and (N-1)(N-2) /2 phases

N=3 3 angles + 1 phase KM

the phase generates complex couplings i.e. <u>CP violation;</u>

6 masses +3 angles +1 phase = 10 parameters

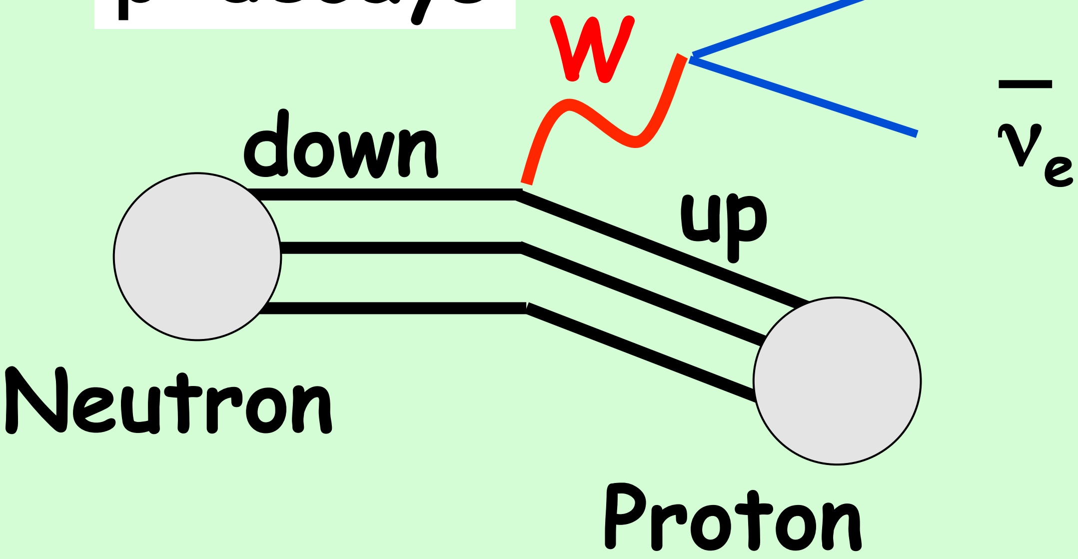
V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{tb}	V_{ts}	V_{tb}

$$= \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{bmatrix}$$

Quark masses & Generation Mixing

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

β-decays



$|V_{ud}|$

$|V_{ud}| = 0.9735(8)$

$|V_{us}| = 0.2196(23)$

$|V_{cd}| = 0.224(16)$

$|V_{cs}| = 0.970(9)(70)$

$|V_{cb}| = 0.0406(8)$

$|V_{ub}| = 0.00409(25)$

$|V_{tb}| = 0.99(29)$

(0.999)

The Wolfenstein Parametrization

$1 - 1/2\,\lambda^2$	λ	$A\,\lambda^3(\rho - i\,\eta)$
$-\lambda$	$1 - 1/2\,\lambda^2$	$A\,\lambda^2$
$A\,\lambda^3 \times (1 - \rho - i\,\eta)$	$-A\,\lambda^2$	1

V_{ub}

$+\ O(\lambda^4)$

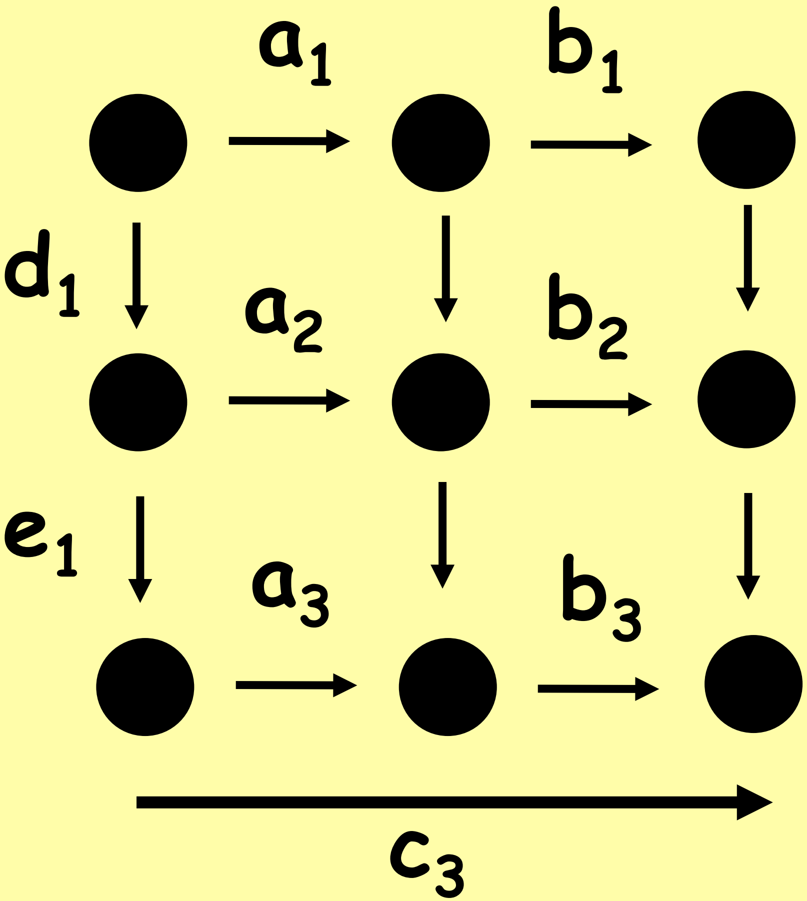
V_{td}

$\sin\theta_{12} = \lambda$
$\sin\theta_{23} = A\,\lambda^2$
$\sin\theta_{13} = A\,\lambda^3(\rho - i\,\eta)$

$\lambda \sim 0.2 \quad A \sim 0.8$

$\eta \sim 0.2 \quad \rho \sim 0.3$

The Bjorken-Jarlskog Unitarity Triangle



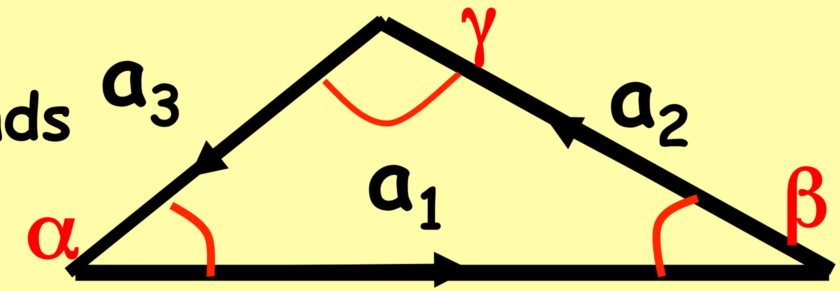
$|V_{ij}|$ is invariant under phase rotations

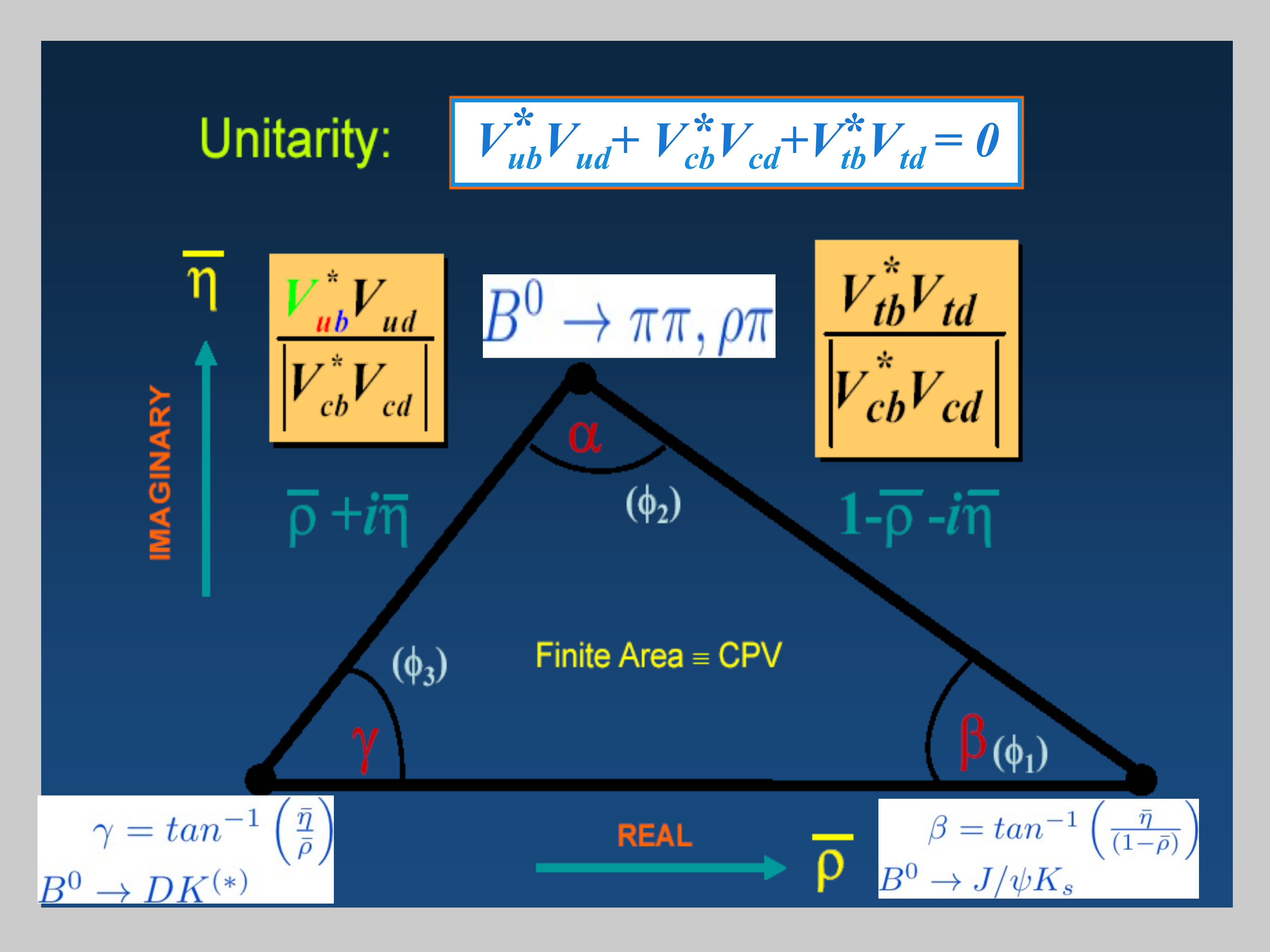
$$a_1 = V_{11} V_{12}^* = V_{ud} V_{us}^*$$

$$a_2 = V_{21} V_{22}^* \quad a_3 = V_{31} V_{32}^*$$

$$\boxed{\begin{array}{l} a_1 + a_2 + a_3 = 0 \\ (b_1 + b_2 + b_3 = 0 \text{ etc.}) \end{array}}$$

Only the orientation depends on the phase convention





Unitarity:
$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$
$\bar{\eta}$
IMAGINARY
$\frac{V_{ub}^* V_{ud}}{|V_{cb}^* V_{cd}|}$
$B^0 \to \pi\pi, \rho\pi$
$\frac{V_{tb}^* V_{td}}{|V_{cb}^* V_{cd}|}$
α
(ϕ_2)
$\bar{\rho} + i\bar{\eta}$
$1-\bar{\rho} - i\bar{\eta}$
(ϕ_3)
Finite Area ≡ CPV
γ
$\beta\,(\phi_1)$
$\gamma = tan^{-1}\left(\frac{\bar{\eta}}{\bar{\rho}}\right)$
$B^0 \to DK^{(*)}$
REAL
$\bar{\rho}$
$\beta = tan^{-1}\left(\frac{\bar{\eta}}{(1-\bar{\rho})}\right)$
$B^0 \to J/\psi K_s$

Measure	V_{CKM}	Other NP parameters
$\Gamma(b \to u)/\Gamma(b \to c)$	$\bar{\rho}^2 + \bar{\eta}^2$	$\bar{\Lambda}, \lambda_1, F(1), \ldots$
ε_K	$\eta[(1-\bar{\rho}) + \ldots]$	B_K
Δm_d	$(1-\bar{\rho})^2 + \bar{\eta}^2$	$f_{B_d}^2 B_{B_d}$
$\Delta m_d/\Delta m_1$	$(1-\bar{\rho})^2 + \bar{\eta}^2$	ξ
$A_{CP}(B_d \to J/\psi K_s)$	$\sin 2\beta$	$-$

$$Q^{EXP} = V_{CKM} \times \langle H_F | \hat{O} | H_I \rangle$$

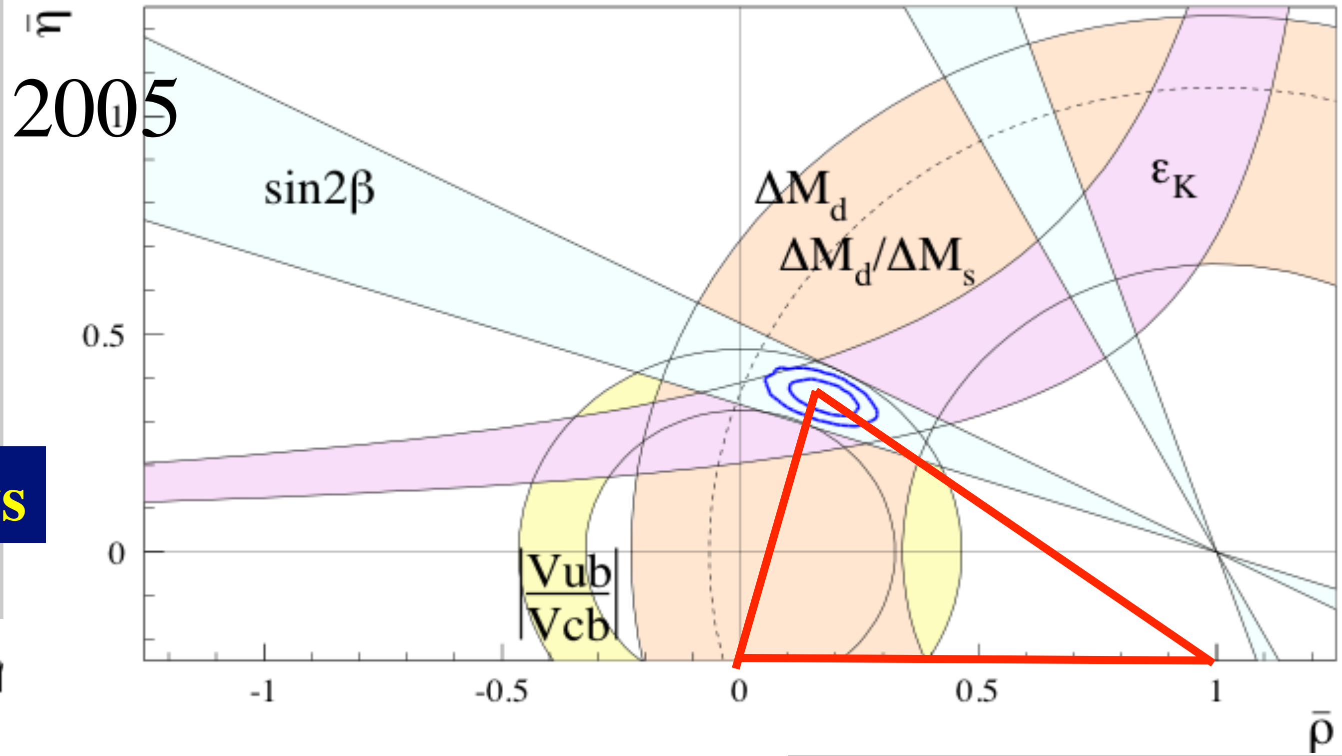
For details see:
UTfit Collaboration

http://www.utfit.org

classical UT analysis

Unitary Triangle SM

semileptonic decays



Experimental co

Meas.	$V_{CKM}\times$other	$(\bar\rho,\bar\eta)$
$\frac{b\to u}{b\to c}$	$\lvert V_{ub}/V_{cb}\rvert^2$	$\bar\rho^2+\bar\eta^2$
Δm_d	$\lvert V_{td}\rvert^2 f_{B_d}^2 B_{B_d}$	$(1-\bar\rho)^2+\bar\eta^2$
$\frac{\Delta m_d}{\Delta m_s}$	$\left\lvert\frac{V_{td}}{V_{ts}}\right\rvert^2 \xi^2$	$(1-\bar\rho)^2+\bar\eta^2$
ϵ_K	$f(A,\bar\eta,\bar\rho,B_K)$	$\propto \bar\eta(1-\bar\rho)$
$A(J/\psi K^0)$	$sin2\beta$	$\frac{2\bar\eta(1-\bar\rho)}{\sqrt{\bar\eta^2+(1-\bar\rho)^2}}$

K^0 - $\overline{K}^0$ mixing

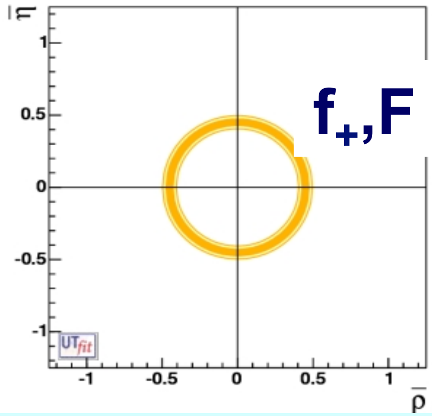
$B^0_{d,s}$ - $\overline{B}^0_{d,s}$ mixing

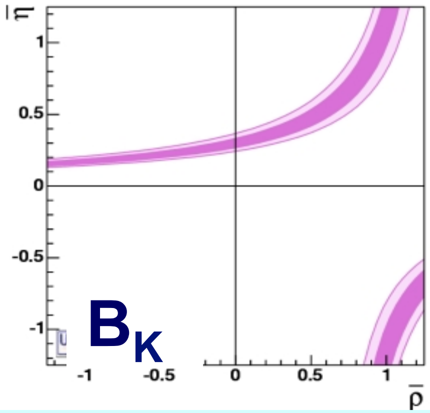
B_d Asymmetry

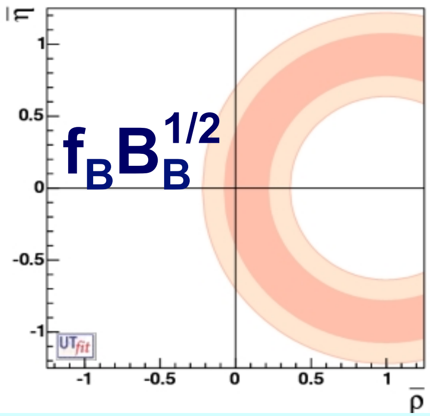
Classical Quantities used in the Standard UT Analysis

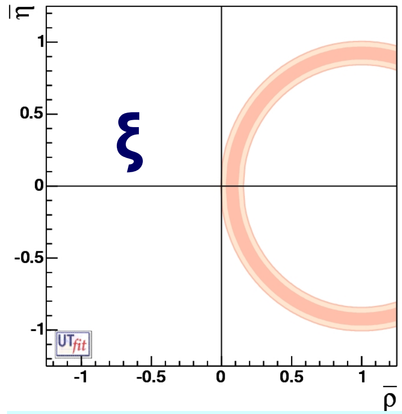
levels @
68% (95%) CL

V_{ub}/V_{cb} | ε_K | Δm_d | $\Delta m_d/\Delta m_s$



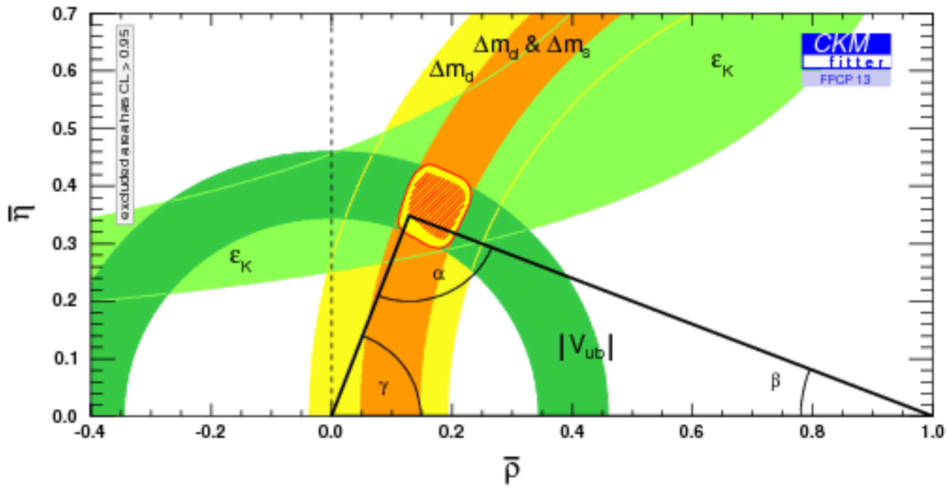




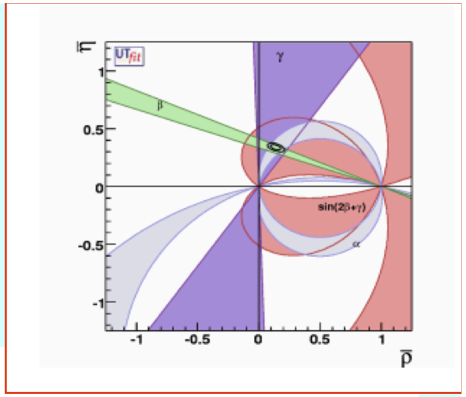


UT-LATTICE

Inclusive vs Exclusive
Opportunity for lattice QCD



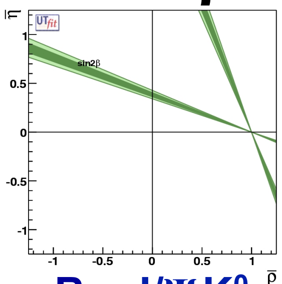
New Quantities used in the UT Analysis



UT-ANGLES

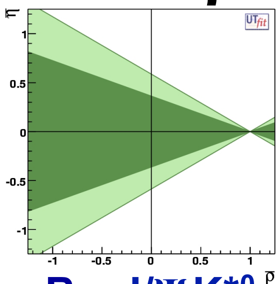
Several new determinations of UT angles are now available, thanks to the results coming from the B-Factory experiments

$\sin 2\beta$



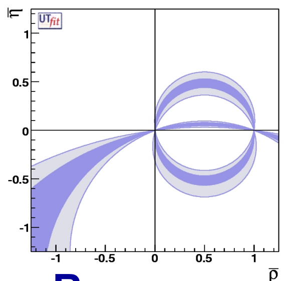
$B \to J/\Psi K^0$

$\cos 2\beta$



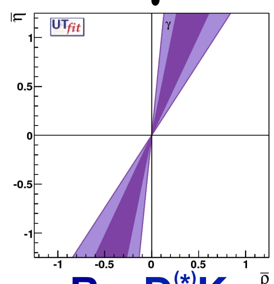
$B \to J/\Psi K^{*0}$

α



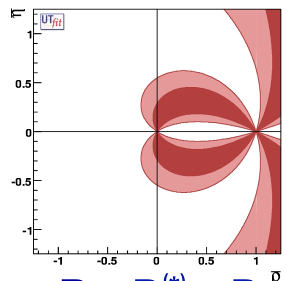
$B \to \pi\pi, \rho\rho$

γ



$B \to D^{(*)}K$

$\sin(2\beta+\gamma)$

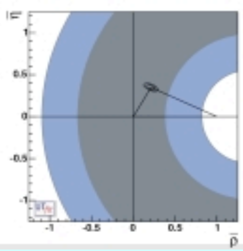


$B \to D^{(*)}\pi, D\rho$

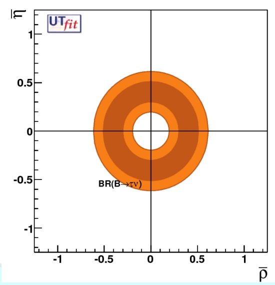
New Constraints from B and K rare decays (not used yet)

New bounds are available from rare B and K decays. They do not still have a strong impact on the global fit and they are not used at present.

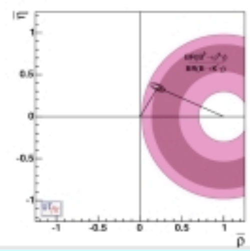
$K \to \pi \nu \bar{\nu}$



$B \to \tau \nu$

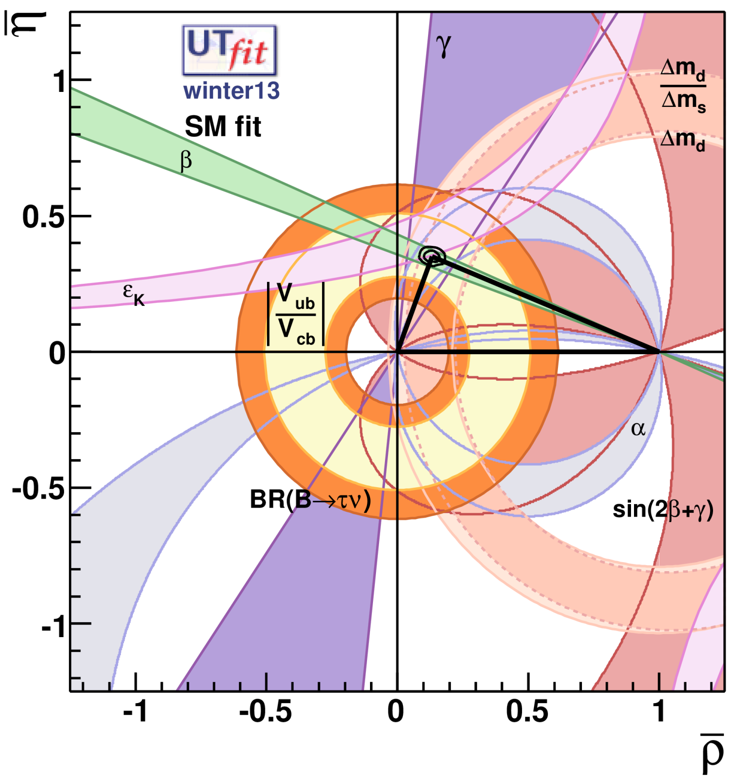


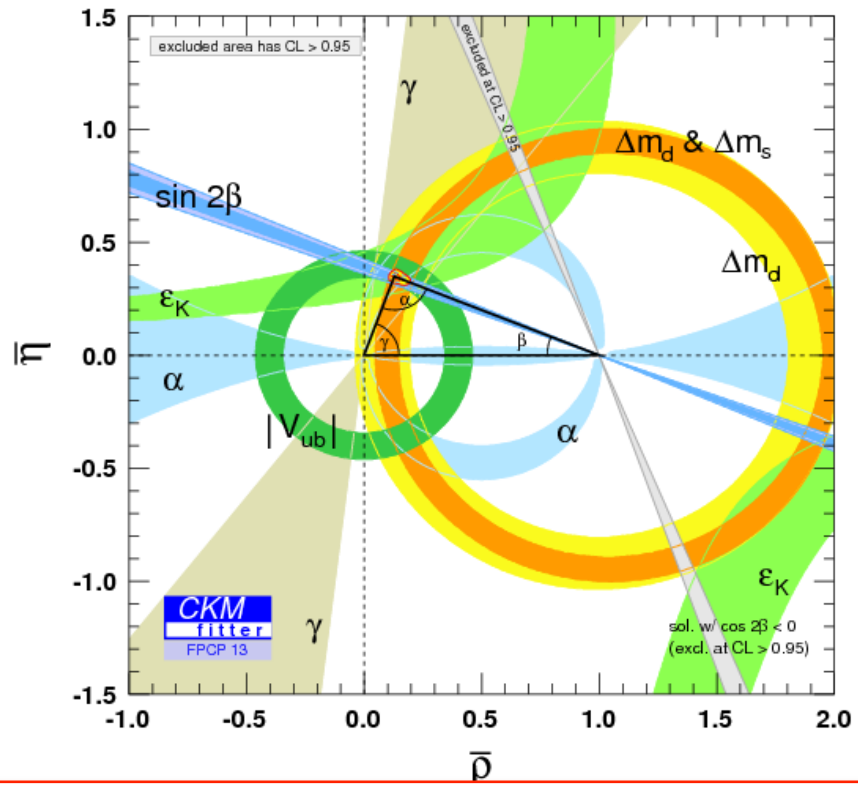
$(B \to \rho/\omega\, \gamma)/(B \to K^* \gamma)$



Unitarity Triangle analysis in the SM:

Observables	Accuracy
$\|V_{ub}/V_{cb}\|$	~ 15%
ε_K	~ 0.5%
Δm_d	~ 1%
$\|\Delta m_d/\Delta m_s\|$	~ 1%
$\sin 2\beta$	~ 3%
$\cos 2\beta$	~ 15%
α	~ 7%
γ	~ 10%
$BR(B \to \tau\nu)$	~ 25%





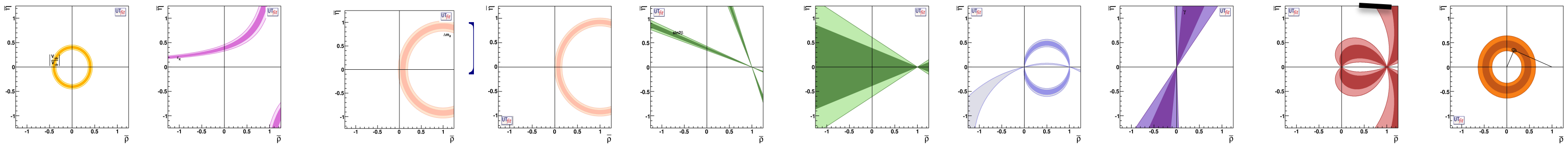
$\bar{\rho} = 0.132 \pm 0.021$ $\bar{\eta} = 0.350 \pm 0.014$

$\bar{\rho} = 0.129\,^{+0.018}_{-0.009}$ $\bar{\eta} = 0.348 \pm 0.012$

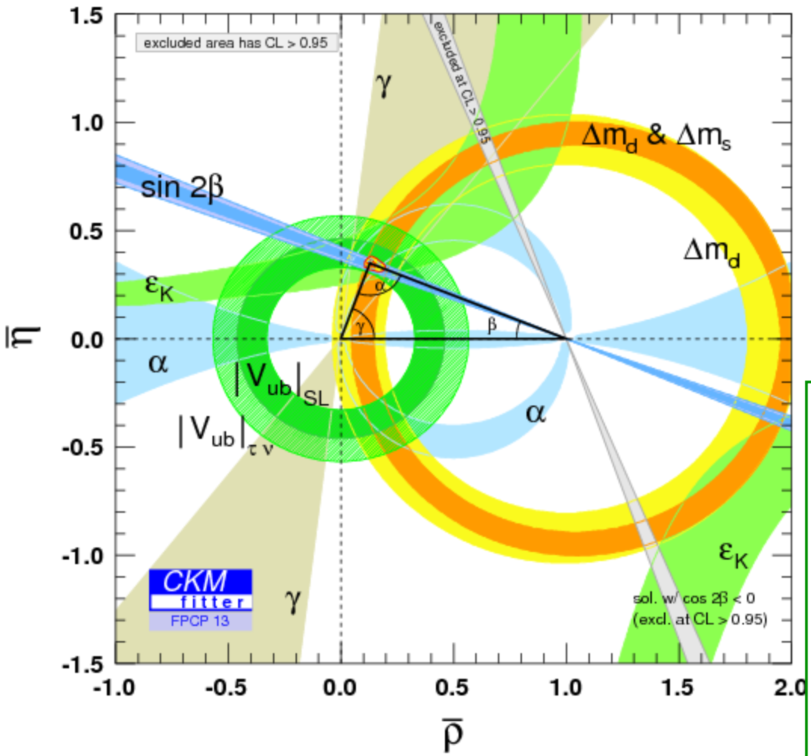
$\alpha = (88.7 \pm 3.1)^0$	$\alpha = (88.5\,^{+2.8}_{-1.5})^0$
$\sin 2\beta = 0.693 \pm 0.021$	$\sin 2\beta = 0.689 \pm 0.019$
$\beta = (21.95 \pm 0.87)^0$	$\beta = (21.79\,^{+0.78}_{-.73})^0$
$\gamma = (69.2 \pm 3.2)^0$	$\gamma = (69.7\,^{+1.3}_{-2.8})^0$
$A = 0.827 \pm 0.013$	$A = 0.823\,^{+0.012}_{-0.033}$
$\lambda = 0.2254 \pm 0.0007$	$\lambda = 0.2246\,^{+0.0019}_{-0.0001}$

Global Fit within the

SM Fit



In the hadronic sector, the SM CKM pattern represents the principal part of the flavor structure and of CP violation



Consistence on an over constrained fit of the CKM parameters

$\bar{\rho} = 0.129^{+0.018}_{-0.009}$

$\bar{\eta} = 0.348 \pm 0.012$

$\alpha = (88.5^{+2.8}_{-1.5})^0$

$\sin 2\beta = 0.689 \pm 0.019$

$\beta = (21.79^{+0.78}_{-73})^0$

$\gamma = (69.7^{+1.3}_{-2.8})^0$

$A = 0.823^{+0.012}_{-0.033}$

$\lambda = 0.2246^{+0.0019}_{-0.0001}$

CKM matrix is the dominant source of flavour mixing and CP violation

The CKM matrix in the SM

Spring 2013

$$\begin{pmatrix} 0.9742(1) & 0.2255(6) & 3.6(1)\cdot 10^{-3} e^{-i69(3)^\circ} \\ -0.2253(6)e^{i0.035(1)^\circ} & 0.9734(1)e^{-i0.0018(1)^\circ} & 4.21(6)\cdot 10^{-2} \\ 8.9(2)\cdot 10^{-3} e^{-i21.9(1)^\circ} & -4.13(6)\cdot 10^{-2} e^{i1.08(4)^\circ} & 0.99911(2) \end{pmatrix}$$

Standard parametrization (PDG)

$\sin\Theta_{12} = 0.2254 \pm 0.0007$ $\sin\Theta_{23} = (4.207 \pm 0.064)\cdot 10^{-2}$

$\sin\Theta_{13} = (3.64 \pm 0.13)\cdot 10^{-3}$ $\delta = (69.2 \pm 3.1)^\circ$

Wolfenstein parametrization

$\lambda = 0.22535 \pm 0.00065$ $A = 0.827 \pm 0.013$

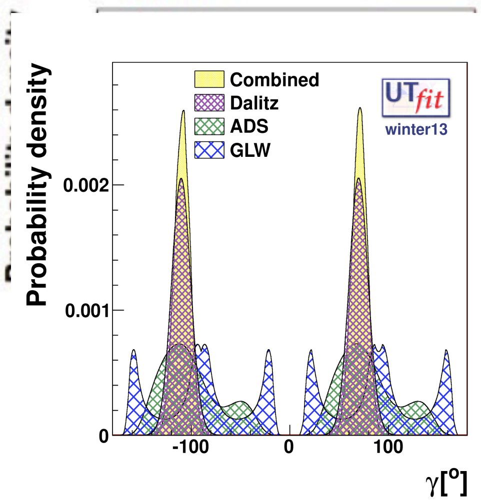
$\rho = 0.136 \pm 0.021$ $\eta = 0.359 \pm 0.014$

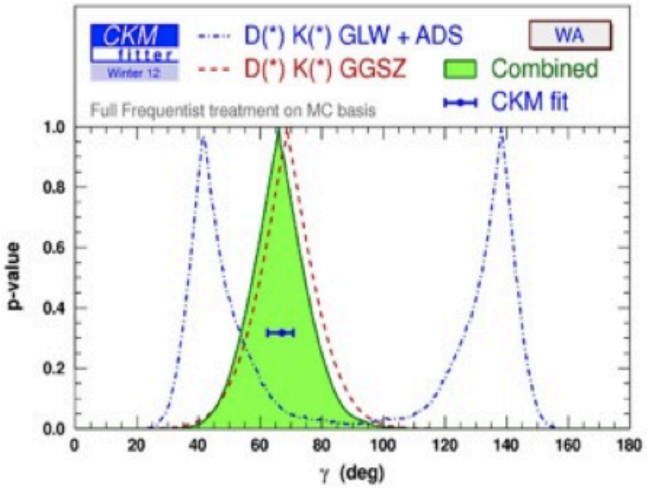
SM predictions: Bd & K

	Measurement	%	Prediction	Pull(σ)
$\sin 2\beta$	0.680 ± 0.023	3.5	0.755 ± 0.044	+1.5
γ	$(70.8 \pm 7.8)^\circ$	11	$(68.6 \pm 3.6)^\circ$	< 1
α	$(90.9 \pm 8.0)^\circ$	9	$(87.7 \pm 3.6)^\circ$	< 1
$\|V_{cb}\|\ 10^3$	41.0 ± 1.0	2.5	42.7 ± 0.8	+1.3
$V_{ub}\|\ 10^3$	3.82 ± 0.56	15	3.64 ± 0.13	< 1
$\varepsilon_K\ 10^3$	2.228 ± 0.011	0.5	1.88 ± 0.20	-1.7
$B(B \to \tau\nu)$	$(99 \pm 25)\ 10^{-6}$	25	$(83 \pm 8) \cdot 10^{-6}$	< 1

$B(B \longrightarrow \tau\, \nu)_{\mathrm{Old}} = (167 \pm 30)\ 10^{-6}$

The SM prediction can be obtained removing γ from the full fit.





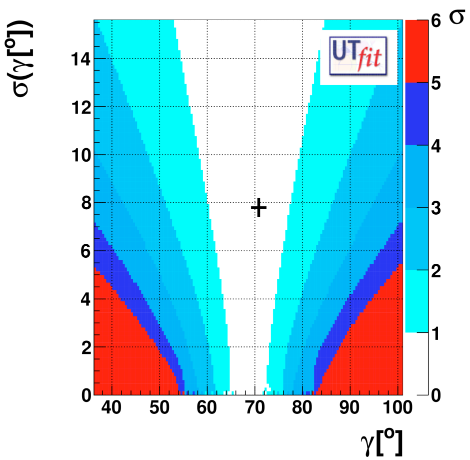
$$\gamma_{meas} = (69.2 \pm 3.2)^0$$

$$\gamma_{SM} = (68.6 \pm 3.6)^0$$

$$\gamma_{meas} = (68.0\,^{+8.0}_{-8.5})^0$$

$$\gamma_{SM} = (69.7\,^{+1.3}_{-2.8})^0$$

With new LHCb results we are now able to have good γ reconstruction in the GLW analysis.



The issue of central values is now under discussion, however, both results show that there's no tension in this sector.

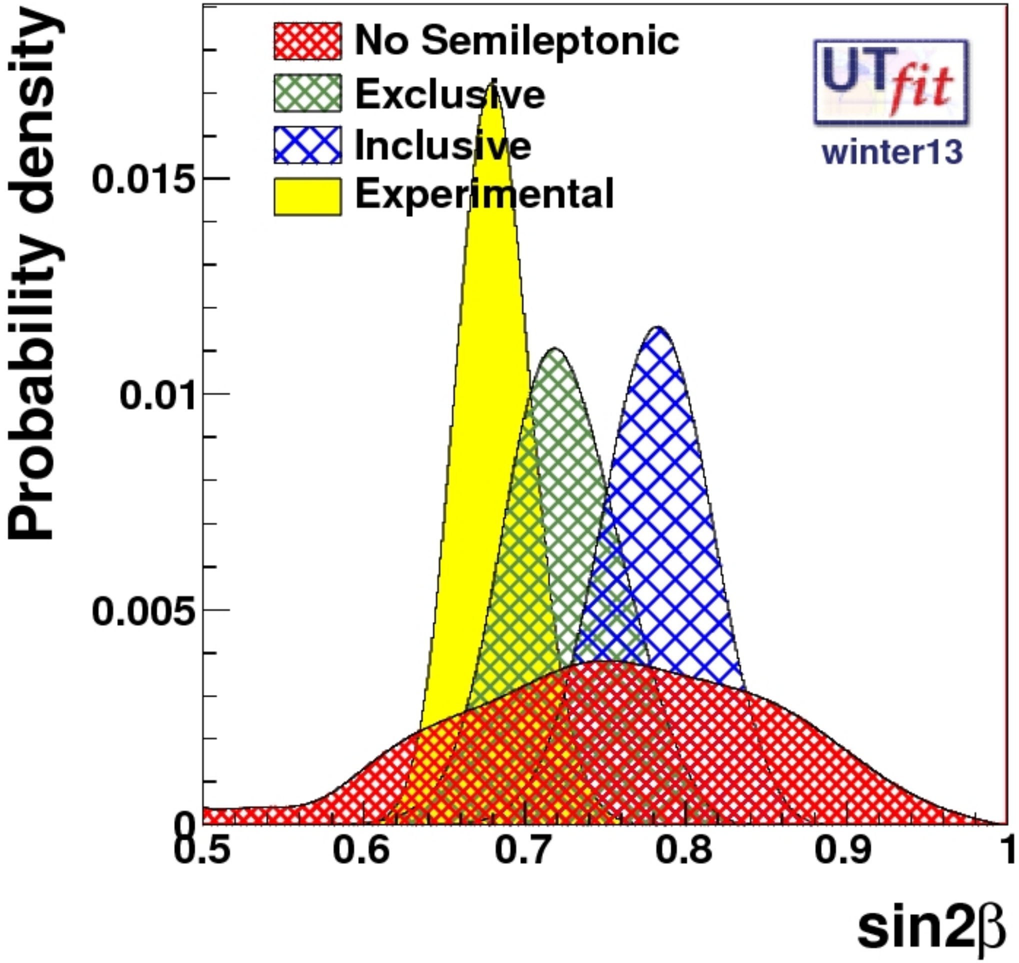
inclusives vs exclusives

Spring 2013

only exclusive values

$\mathbf{Sin2\beta_{UTfit} = 0.723 \pm 0.036}$

~1.3σ



only inclusive values

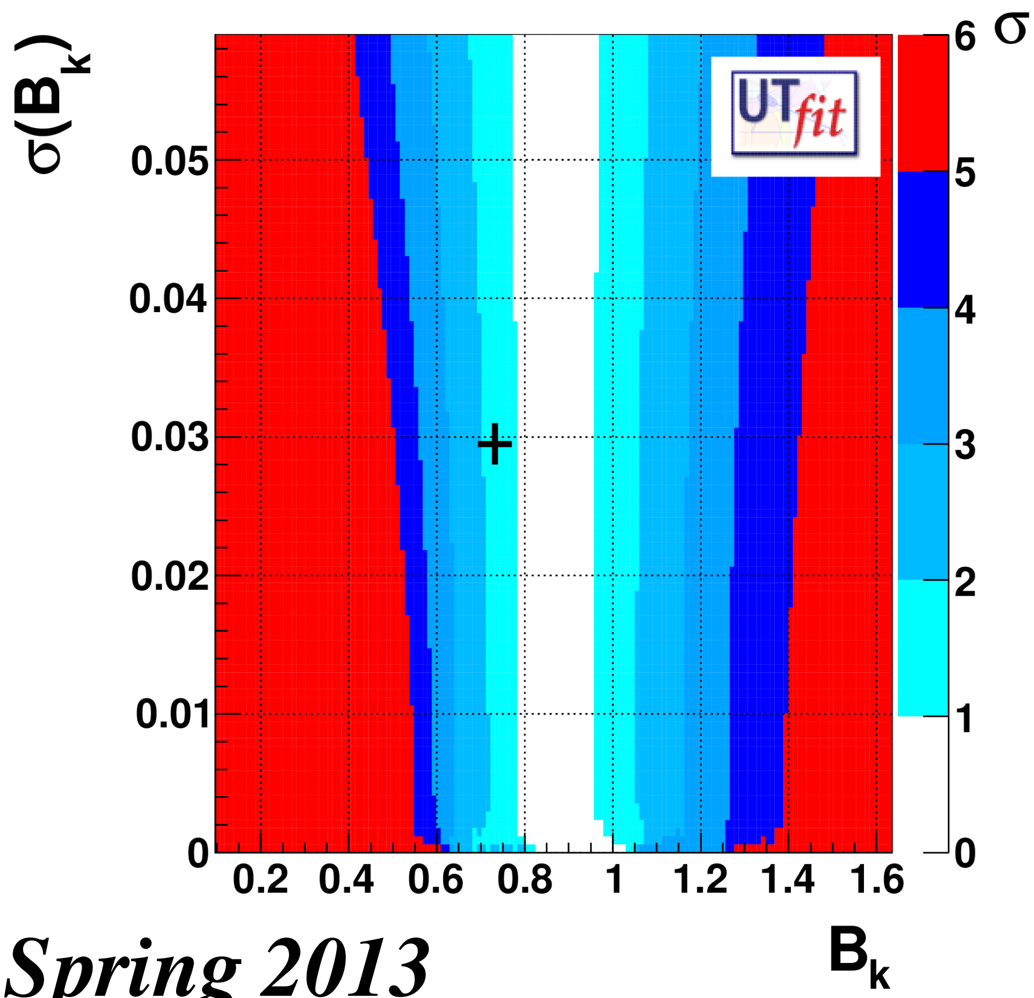
$\mathbf{sin2\beta_{UTfit} = 0.781 \pm 0.034}$

~2.6σ

$\mathbf{sin2\beta_{UTfit} = 0.76 \pm 0.10}$ ← ***no semileptonic***

~0.9σ

courtesy of M. Bona



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$B_{K\ lattice} = 0.733 \pm 0.029$

update FLAG value

$B_{K\ lattice} = 0.766 \pm 0.011$

$B_{K\ fit} = 0.866 \pm 0.086$

A. Buras, D. Guadagnoli, G. Isidori Phys.Lett. B688 (2010) 309-313, e-Print: arXiv:1002.3612 [hep-ph]

NEED A BETTER CONTROL OF Λ/mc CORRECTIONS

A larger value of $|V_{cb}|$ would reduce the deviation:

$|V_{cb}|_{excl}$: $1.5\ \sigma \rightarrow 1.1\ \sigma$

more standard model predictions:

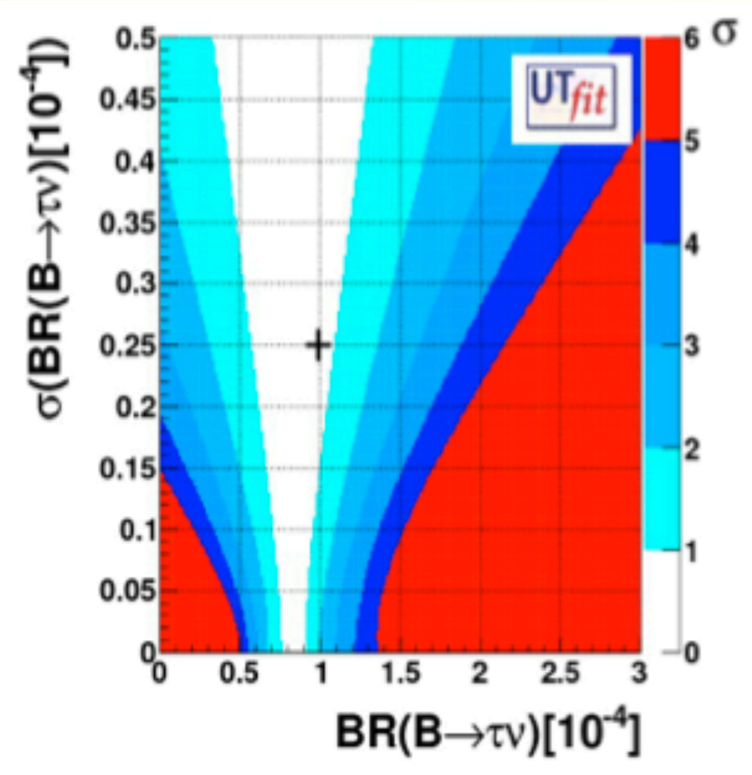
Spring 2013

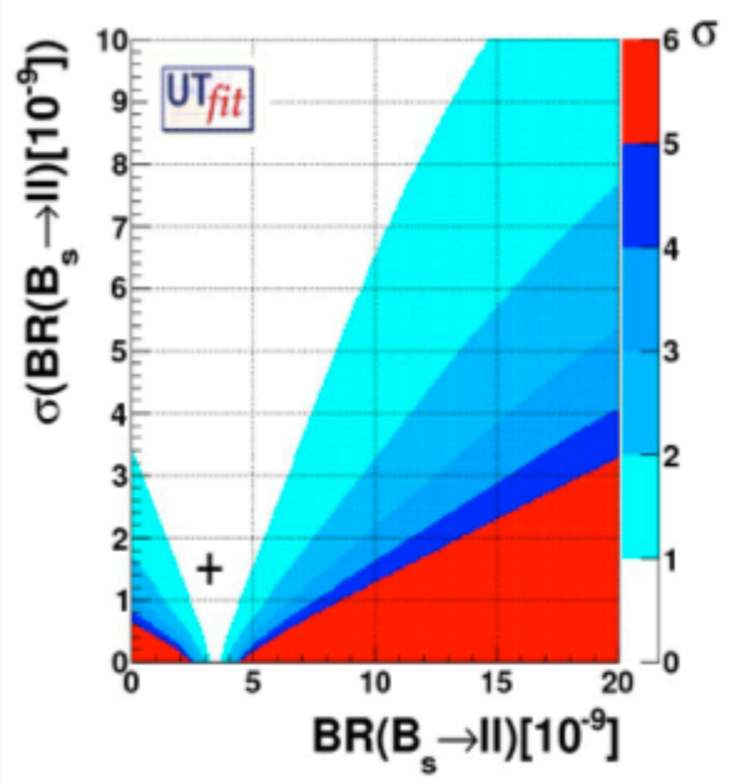
our home-made average:

BR(B→τν) = *1.14 ± 0.22* 10^{-4}

from LHCb evidence *2.90 ± 0.07*

BR(B_s→μμ) = 3.2 ± 1.5 10^{-9}





indirect determinations from UT

3.34 ± 0.12

BR(B→τν) = *0.814 ± 0.072* 10^{-4}

BR(B_s→ll) = (3.47 ± 0.26) 10^{-9}

M.Bona et al, 0908.3470 [hep-ph]

more standard model predictions:

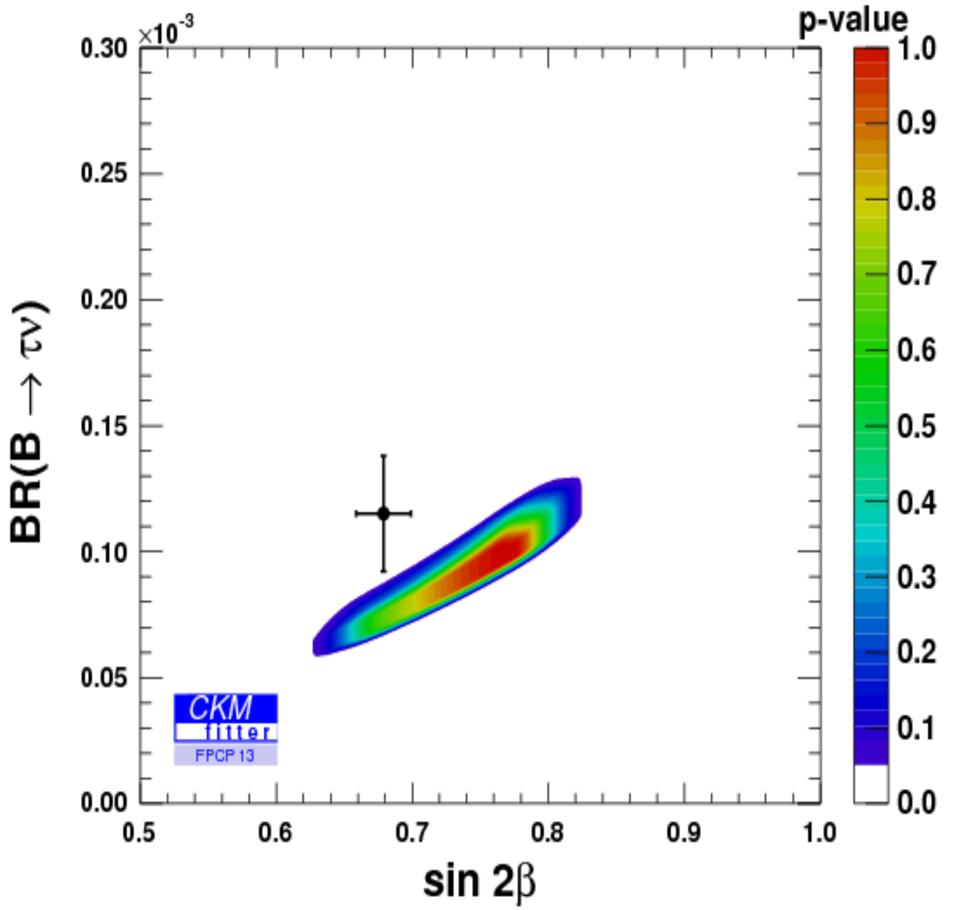
Spring 2013

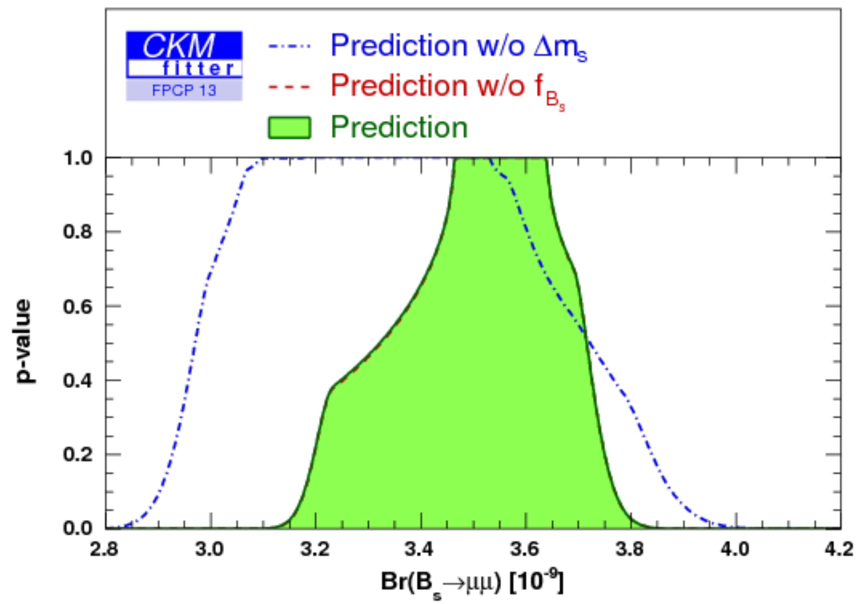
our home-made average:

BR(B→τν) = *1.14 ± 0.22* **10^{-4}**

from LHCb evidence *2.90 ± 0.07*

BR(B_s→μμ) = 3.2 ± 1.5 10^{-9}





BR(B_s→ll)[10^{-9}]

Br(B_s→$\mu^+\mu^-$)=($3.63^{+0.21}_{-0.34}$)x10^{-9}. Th

red) curve represents the prediction re

M.Bona et al, 09

* *the theory error in sin2β from $B \to J/\Psi K$ is small and under control. A conservative bound obtained from data is included in the analysis*

* *$BR(B \to \tau\nu)$ demands a large value of $|V_{ub}|$. The 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 still not theoretically sound as necessary (incl. vs excl., models, f.f.,…). Yet a simple shift of the central value alone cannot reconcile sin2β and $BR(B \to \tau\nu)$ (and ε_K)*

Is the present picture showing a **Model Standardissimo** ?

An evidence, an evidence, my kingdom for an evidence

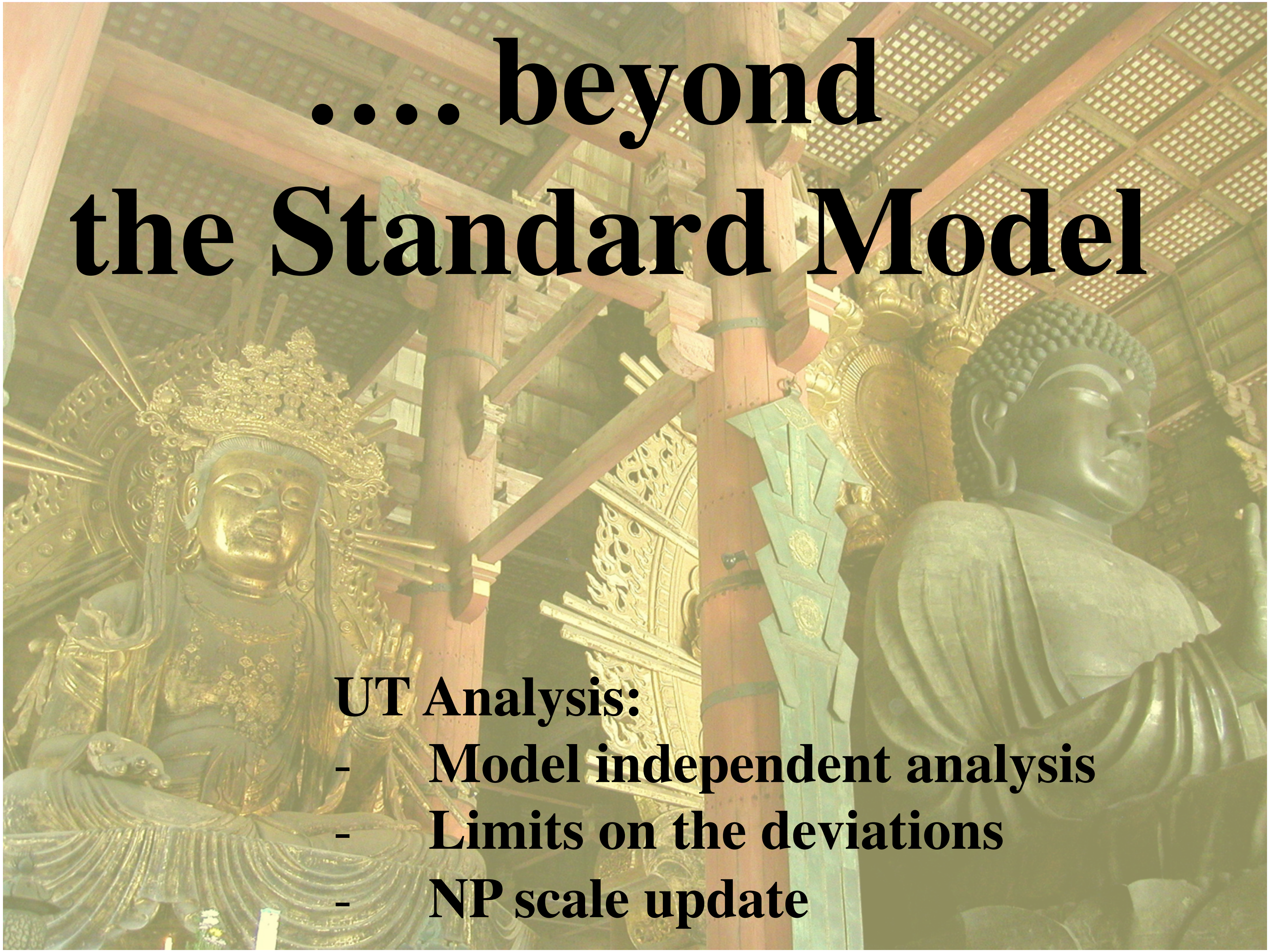
From Shakespeare's *Richard III*

1) **Possible tensions in the present SM Fit ?**
2) **Fit of NP-$\Delta F=2$ parameters in a Model "independent" way**
3) **"Scale" analysis in $\Delta F=2$**

What for a ``standardissimo" CKM which agrees so well with the experimental observations?

New Physics at the EW scale is "flavor blind"
-> MINIMAL FLAVOR VIOLATION, namely flavour originates only from the Yukawa couplings of the SM

New Physics introduces new sources of flavor, the contribution of which, at most < 20 % , should be found in the present data, e.g. in the asymmetries of Bs decays

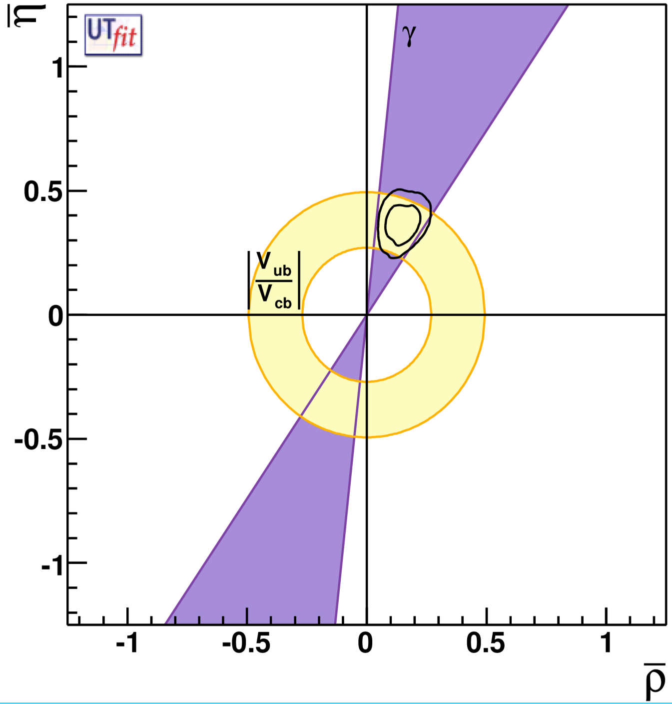


…. beyond the Standard Model

UT Analysis:

- **Model independent analysis**
- **Limits on the deviations**
- **NP scale update**

Only tree level processes Vub/Vcb and B-> DK$^{(*)}$



CP VIOLATION PROVEN IN THE SM !!

degeneracy of γ broken by A_{SL}

$$\Delta m_s = |A_s| = C_{B_s} \Delta m_s^{SM}$$

$$2\phi_s = -\arg A_s = 2\,(\beta_s - \phi_{B_s})$$

$$A_{SL}^s = \frac{\Gamma(\bar{B}_s \to l^+ X) - \Gamma(B_s \to l^- X)}{\Gamma(\bar{B}_s \to l^+ X) + \Gamma(B_s \to l^- X)} = Im\left(\frac{\Gamma_{12}^s}{A_s}\right)$$

Main Ingredients and General Parametrizations

Fit simultaneously CKM and NP parameters (generalized Utfit)

$$H^{\Delta F=2} = \hat{m} - \frac{i}{2}\hat{\Gamma} \quad A = \hat{m}_{12} = \langle \bar{M}|\hat{m}|M\rangle \quad \Gamma_{12} = \langle \bar{M}|\hat{\Gamma}|M\rangle$$

Neutral Kaon Mixing

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

B_d and B_s mixing

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

$$C_{B_s} e^{2i\phi_{B_s}} = \frac{A_s^{SM} e^{-2i\beta_s} + A_s^{NP} e^{2i(\phi_s^{NP} - \beta_s)}}{A_s^{SM} e^{-2i\beta_s}} = \frac{\langle \bar{B}_s | H_{eff}^{full} | B_s \rangle}{\langle \bar{B}_s | H_{eff}^{SM} | B_s \rangle}$$

$$\frac{\Gamma_{12}^q}{A_q} = -2\frac{\kappa}{C_{B_q}} \Bigg\{ e^{i2\phi_{B_q}} \left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{e^{i(\phi_q^{SM} + 2\phi_{B_q})}}{R_t^q} \left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right)$$
$$+ \frac{e^{i2(\phi_q^{SM} + \phi_{B_q})}}{R_t^{q^2}} \left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + e^{i(\phi_q^{\mathrm{Pen}} + 2\phi_{B_q})} C_q^{\mathrm{Pen}} \left(n_4 + n_9 \frac{B_2}{B_1}\right)$$
$$- e^{i(\phi_q^{SM} + \phi_q^{\mathrm{Pen}} + 2\phi_{B_q})} \frac{C_q^{\mathrm{Pen}}}{R_t^q} \left(n_5 + n_{10} \frac{B_2}{B_1}\right) \Bigg\}$$

C_q^{Pen} and ϕ_q^{Pen} parametrize possible NP contributions to Γ^q_{12} from b -> s penguins

Physical observables

$$\Delta m_s = |A_s| = C_{B_s} \Delta m_s^{SM}$$

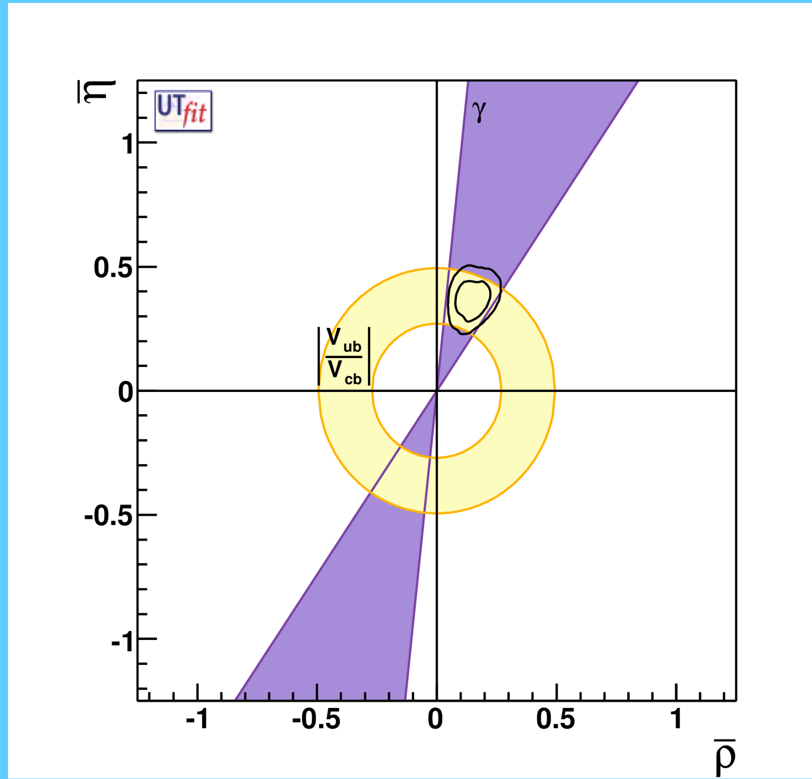
$$2\phi_s = -\arg A_s = 2\,(\beta_s - \phi_{B_s})$$

$$A_{SL}^s = \frac{\Gamma(\bar{B}_s \to l^+ X) - \Gamma(B_s \to l^- X)}{\Gamma(\bar{B}_s \to l^+ X) + \Gamma(B_s \to l^- X)} = Im\left(\frac{\Gamma_{12}^s}{A_s}\right)$$

$$A_{SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{SL}^d + f_s \chi_{s0} A_{SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$$

$$\frac{\Delta\Gamma_s}{\Delta m_s} = Re\left(\frac{\Gamma_{12}^s}{A_s}\right)$$

$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_S} \frac{1 + (\Delta\Gamma_s/2\Gamma_s)^2}{1 - (\Delta\Gamma_s/2\Gamma_s)^2}$$



assumptions:
three generations
no NP in tree level decays
no large NP EWP in $B \to \pi\pi$

$$\rho = 0.147 \pm 0.048 \qquad (\varrho_{SM} = 0.133 \pm 0.021)$$

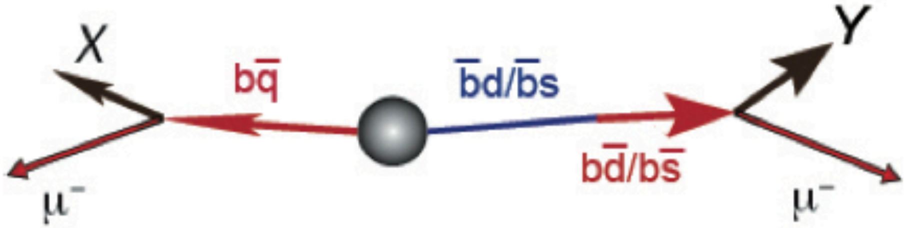
$$\eta = 0.370 \pm 0.057 \qquad (\eta_{SM} = 0.350 \pm 0.014)$$

A_{SL}

$A_{SL}{}^{d} = -0.0003 \pm 0.0021$

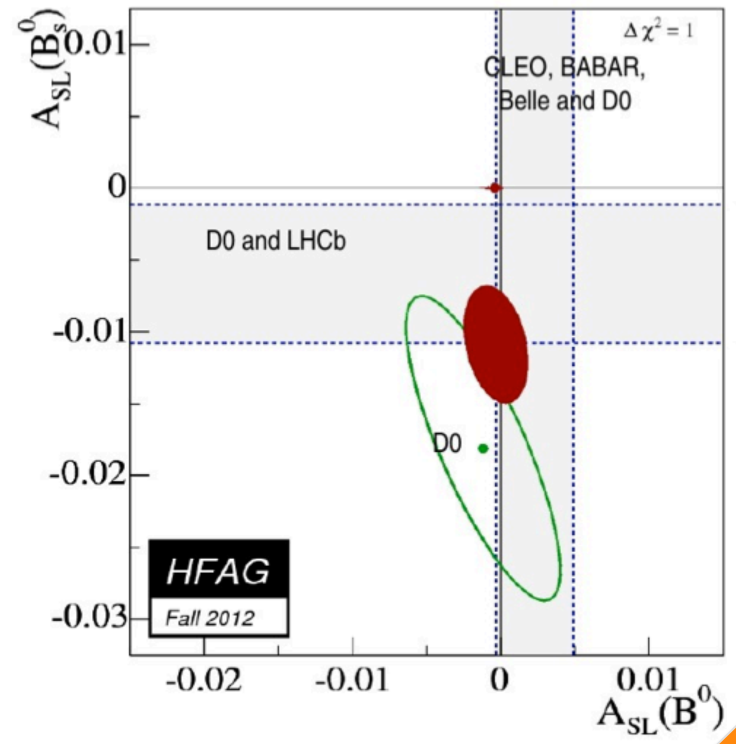
$A_{SL}{}^{s} = -0.0109 \pm 0.0040$

$r = -0.309$



Discrepancy driven by the D0 like-sign dimuon asymmetry

$A_{SL}{}^{b} = (-0.787 \pm 0.172 \pm 0.093)\%$



- Same-sign dimuon charge asymmetry yields A_{SL} DØ, CDF

$$(-8.5 \pm 2.8)\cdot 10^{-3}\ [2010] \to (-7.4 \pm 1.9)\cdot 10^{-3}\ [2011]$$

- Linear comb. of semileptonic (flavour specific) asym. for $B_{d,s}$

$$a^q_{SL} = \frac{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)-\Gamma(B_q(t)\to\ell^-\nu X)}{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)+\Gamma(B_q(t)\to\ell^-\nu X)} \neq 0 \Longrightarrow \text{CPV in mixing}$$

- Discrepancy from SM expectation $A_{SL} = -(0.20 \pm 0.03)\cdot 10^{-3}$

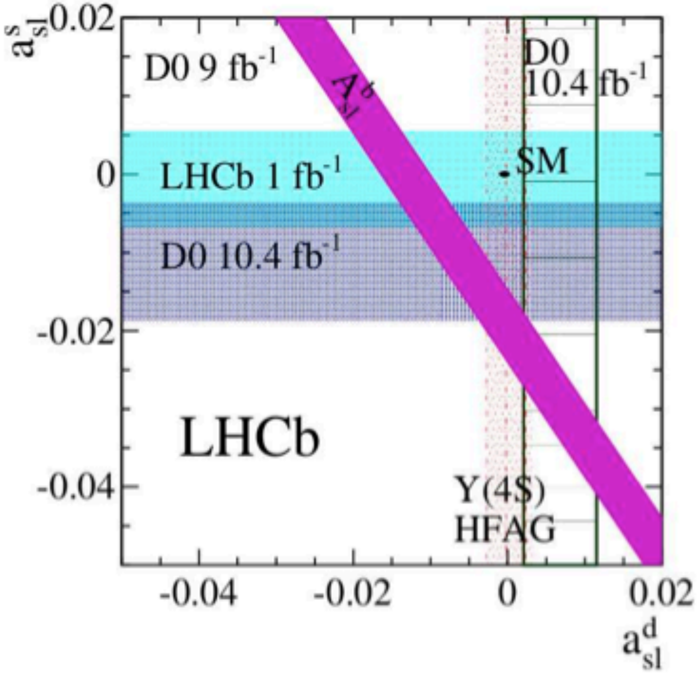
[Lenz, Nierste 11]

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

LHCb: pp collider $\to$ production asymmetry

$$A_{meas} = \frac{N(D_q^- \mu^+) - N(D_q^+ \mu^-)}{N(D_q^- \mu^+) + N(D_q^+ \mu^-)} = \frac{a_{sl}^q}{2} + [a_{prod} - \frac{a_{sl}^q}{2}]\kappa_q$$

due to fast B_s oscillation time integrated a_{sl}^s measurement possible ($\kappa_s = 0.2\%$)
however for a_{sl}^d time dependent analysis required ($\kappa_d \sim 30\%$)



a_{sl}^s = (-0.06 $\pm$ 0.50 $\pm$ 0.36)%

LHCb-PAPER-2013-033-001

single most precise result on a_{sl}^d

using partial reconstructed

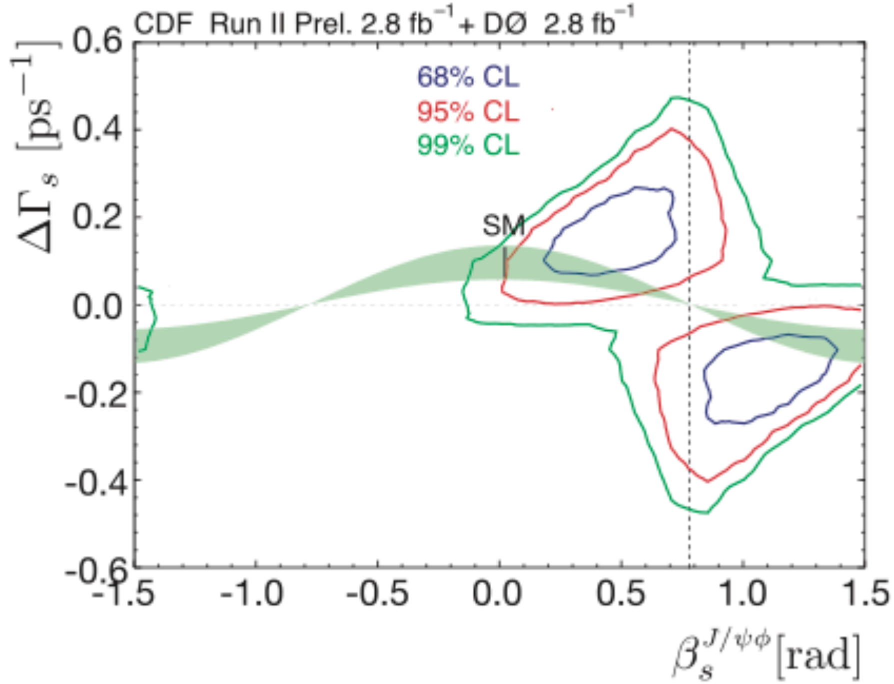
$B \to D^* \ell \nu$ + kaon tags:

a_{sl}^d = (0.06 $\pm$ 0.16$^{+0.36}_{-0.32}$)%

Babar: arXiv:1305.1575

ϕ_{Bs}

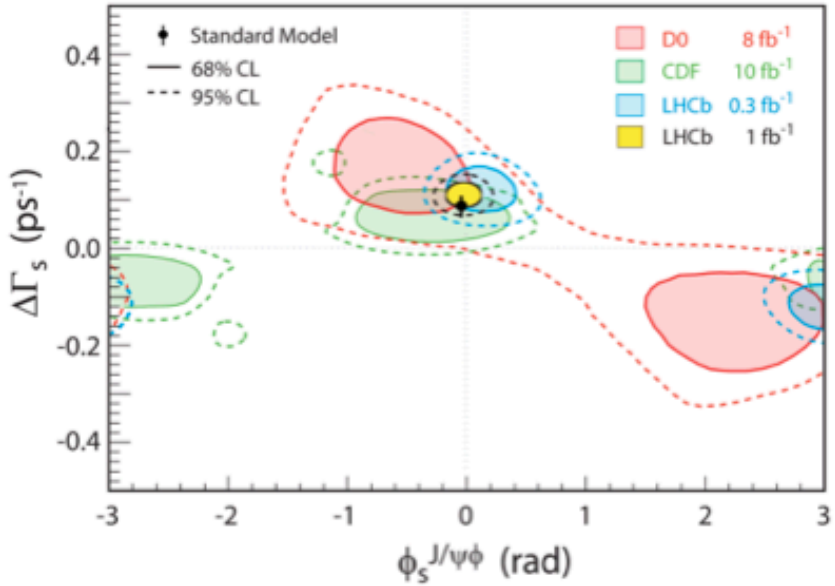
Angular analysis of $B_s \to J/\psi\phi$ to measure $(\phi_{Bs}, \Delta\Gamma_{Bs})$
In SM, $\phi_{Bs} \to -2\beta_s = 2 \cdot \arg(V_{cs}V_{cb}^*/V_{ts}V_{tb}^*) = -2.1° \pm 0.1°$



- 2010 CDF/DØ $\phi_{Bs} \in [-67.6°, -30.9°]U[-148.9°, -111.1°]$

ϕ_{Bs}

Angular analysis of $B_s \to J/\psi\phi$ to measure $(\phi_{Bs}, \Delta\Gamma_{Bs})$
In SM, $\phi_{Bs} \to -2\beta_s = 2 \cdot \arg(V_{cs}V_{cb}^*/V_{ts}V_{tb}^*) = -2.1^\circ \pm 0.1^\circ$

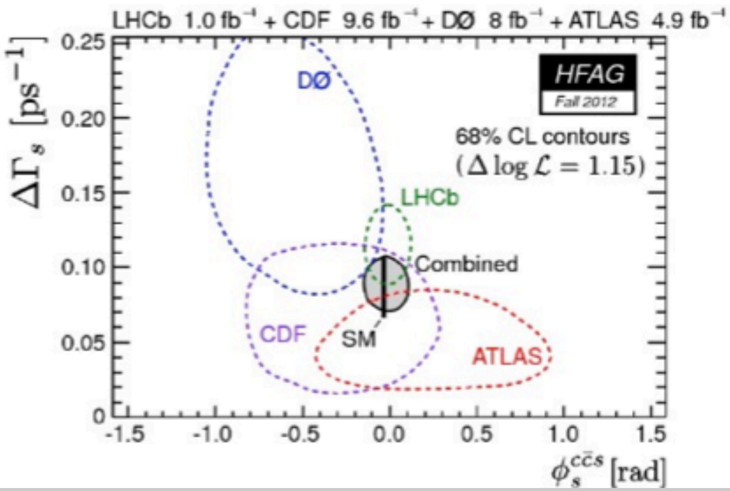


- 2012 updates
  - DØ (8.0 fb^{-1}): $\phi_{Bs} = -32^\circ{}^{+22^\circ}_{-21^\circ}$
  - CDF (9.6 fb^{-1}): $\phi_{Bs} \in [-34^\circ, -7^\circ]$
  - LHCb $J/\psi\phi$ (1 fb^{-1}): $\phi_{Bs} = -0.1^\circ \pm 5.8^\circ \pm 1.5^\circ$
  - LHCb $J/\psi K^+K^-$ (1 fb^{-1}): $\Delta\Gamma_s > 0$
- here: combine available LHCb and CDF $(\phi_{Bs}, \Delta\Gamma_s)$ likelihoods
[LHCb: 0.4 fb^{-1} (2011) and 1 fb^{-1} (2012), CDF: 5.2 fb^{-1}]

CPV IN B_s

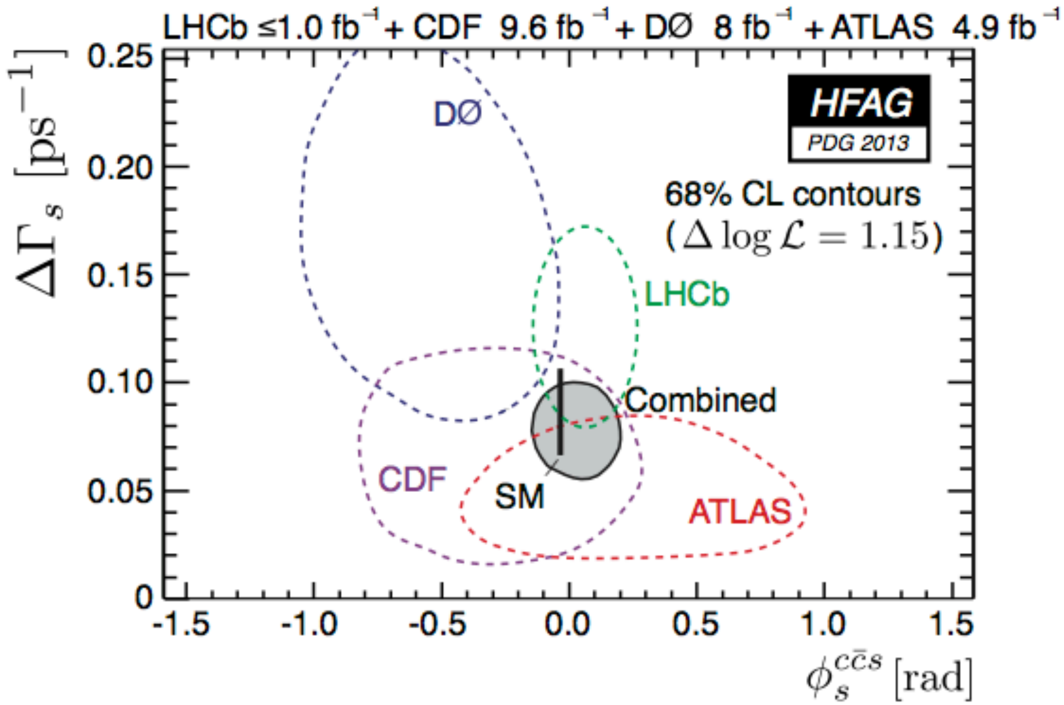
Spring 2013

	Measurement	%	Prediction	Pull (σ)
$\Delta m_s\,[ps^{-1}]$	17.72 ± 0.04	0.2	17.5 ± 1.3	< 1
$2\beta_s$	$(0.3 \pm 2.5)°$	120	$(2.13 \pm 0.09)°$	< 1
$\Delta\Gamma_s/\Gamma_s$	0.137 ± 0.016	12	0.147 ± 0.014	< 1
$A_{SL}{}^s \cdot 10^4$	-109 ± 40	37	-3.3 ± 6.8	+2.6



See also: Lenz & Nierste '07; Lenz et al. '11, '12; UTfit '07;...

Results



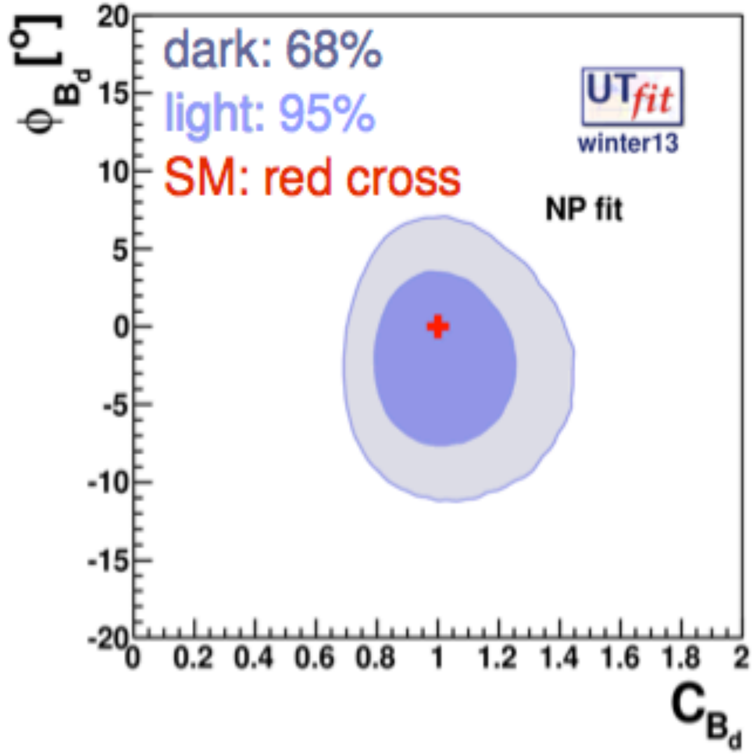
LHCb result (Phys. Rev. D 87 112010 (2013) - 1fb^{-1}):

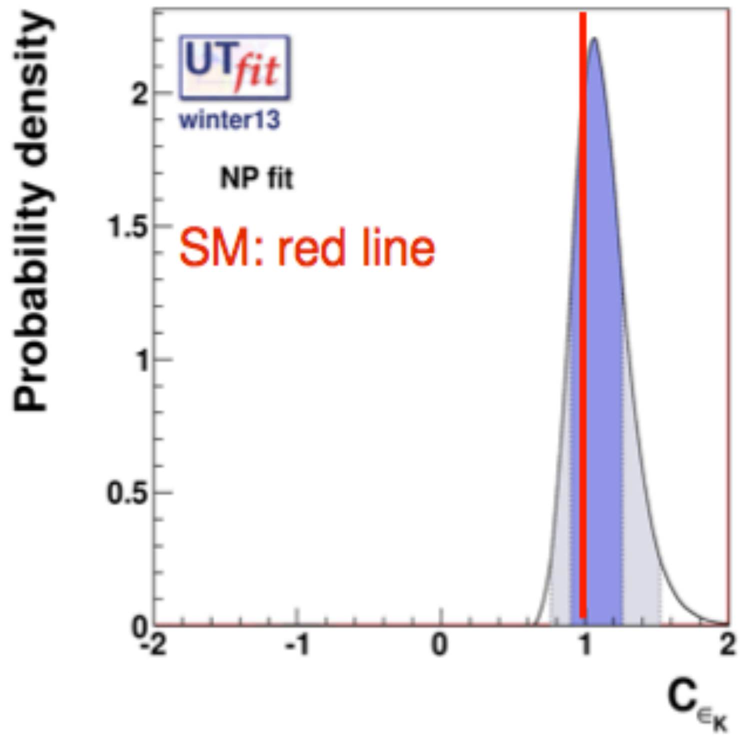
$$\phi_s = 0.01 \pm 0.07 \pm 0.01 \text{ rad}$$

$$\Delta\Gamma_s = 0.106 \pm 0.011 \pm 0.007 \text{ ps}^{-1}$$

$$\Gamma_s = 0.661 \pm 0.004 \pm 0.006 \text{ ps}^{-1}$$

NP parameters (i)





$$C_{B_d} = 1.01 \pm 0.15$$

$$\phi_{B_d} = (-2.2 \pm 3.7)°$$

$$C_{\varepsilon_K} = 1.08 \pm 0.18$$

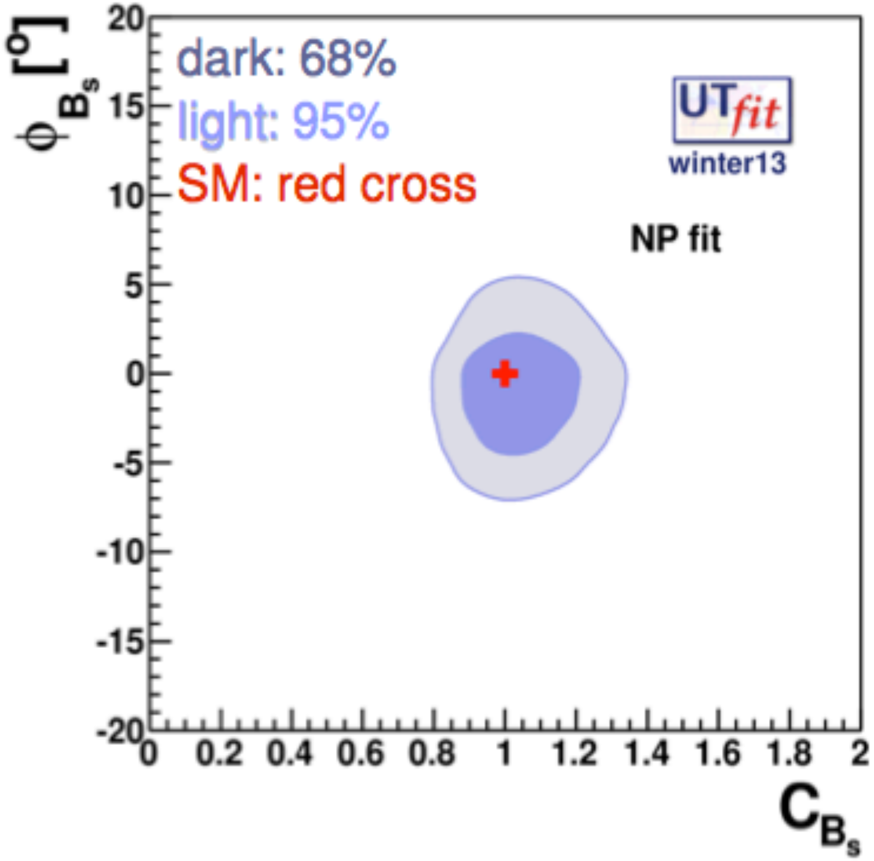
$$\Delta m_d = C_{B_d} (\Delta m_d)^{SM} \qquad a_{CP}^{B_d \to J/\psi K_S} \to \sin 2(\beta + \varphi_{B_d})$$

$$a_{SL}^d = \mathrm{Im}\left(\Gamma_{12}^d / A_d\right) \qquad \Delta\Gamma^d / \Delta m_d = \mathrm{Re}\left(\Gamma_{12}^d / A_d\right)$$

$$\mathrm{Im}\, A_K = C_\varepsilon \,\mathrm{Im}\, A_K^{SM}$$

$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

NP parameters (ii)



C_{B_s}= 1.03±0.10

Φ_{Bs}= (-0.84±2.5)°

$$\Delta m_s = C_{B_s} (\Delta m_s)^{SM} \qquad a_{CP}^{B_s \to J/\psi\varphi} \to -\beta_s + \varphi_{B_s}$$

$$a_{SL}^s = \mathrm{Im}\left(\Gamma_{12}^s / A_s\right) \qquad \Delta\Gamma^s / \Delta m_s = \mathrm{Re}\left(\Gamma_{12}^s / A_s\right)$$

TESTING THE NEW PHYSICS SCALE

Effective Theory Analysis ΔF=2

$$C_j(\Lambda) = \frac{L F_j}{\Lambda^2} \Rightarrow \Lambda = \sqrt{\frac{L F_j}{C_j(\Lambda)}}$$

Effective Hamiltonian in the mixing amplitudes

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

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

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

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

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

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

C(Λ) coefficients are extracted from data

L is loop factor and should be :
L=1 tree/strong int. NP
$L=\alpha_s^2$ or α_W^2 for strong/weak perturb. NP

$F_1=F_{SM}=(V_{tq}V_{tb}^*)^2$ $F_{j=1}=0$	**MFV**
$\lvert F_j \rvert = F_{SM}$ arbitrary phases	**NMFV**
$\lvert F_j \rvert = 1$ arbitrary phases	**Flavour generic**

results from the Wilson coefficients

the results obtained for the flavour scenarios:
In deriving the lower bounds on the NP scale, we assume $L_i = 1$, corresponding to strongly-interacting and/or tree-level NP.

L. Silvestrini

present lower bound on the NP scale for $L=1$ and $F_i = 1$:

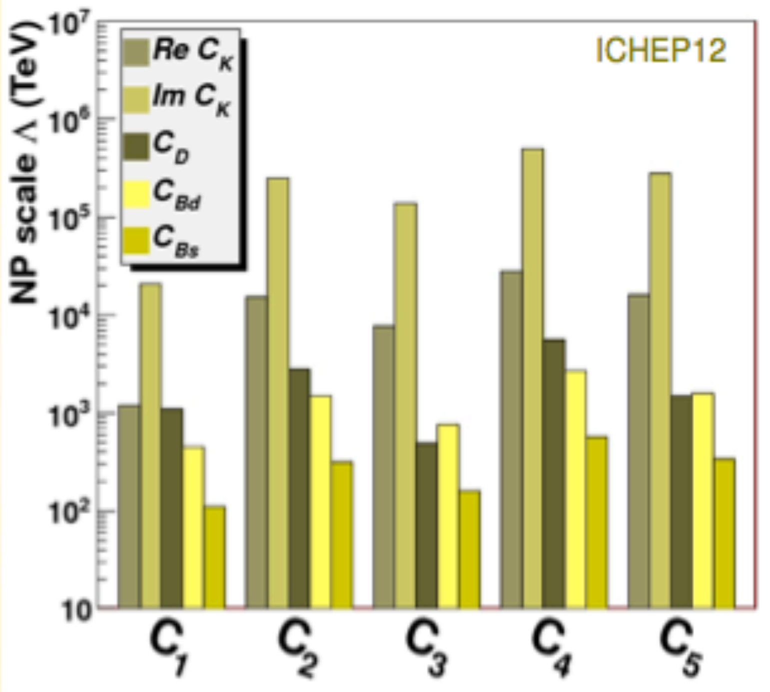
from ε_K: 4.9 10^5 TeV

from D mixing: 1.3 10^4 TeV

from B_d mixing: 3 10^3 TeV

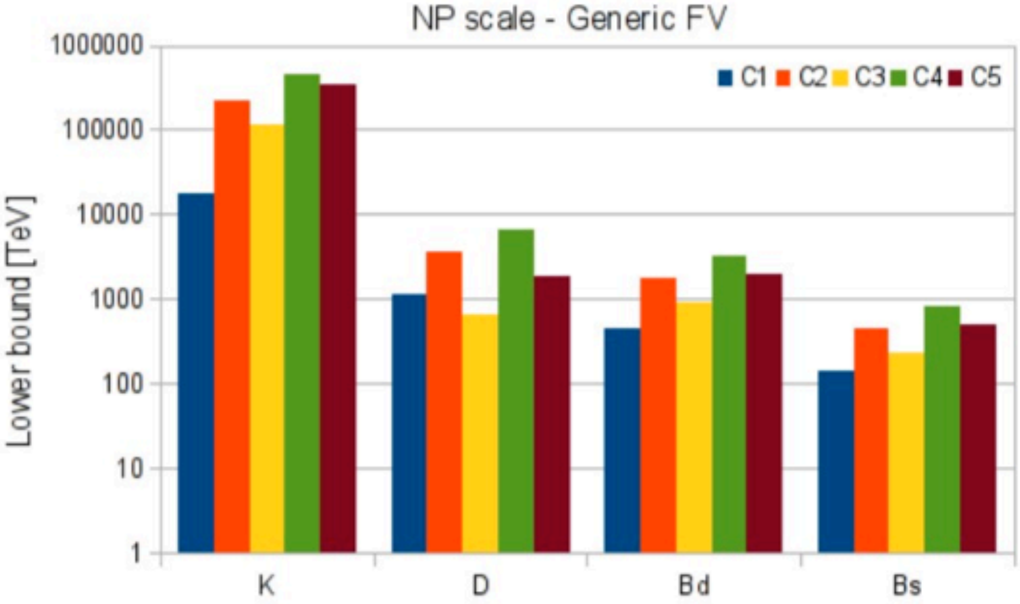
from B_s mixing: 8 10^2 TeV

V. Bertone et al.
arXiv:1207.1287 [hep-lat], 2012



Scenario	strong/tree	α_s loop	α_W loop
NMFV	19	1.9	0.6
General	$2.7 \cdot 10^5$	$2.7 \cdot 10^4$	$9 \cdot 10^3$

Lower bounds on NP scale
(in TeV at 95% prob.)



Generic Flavor Violation

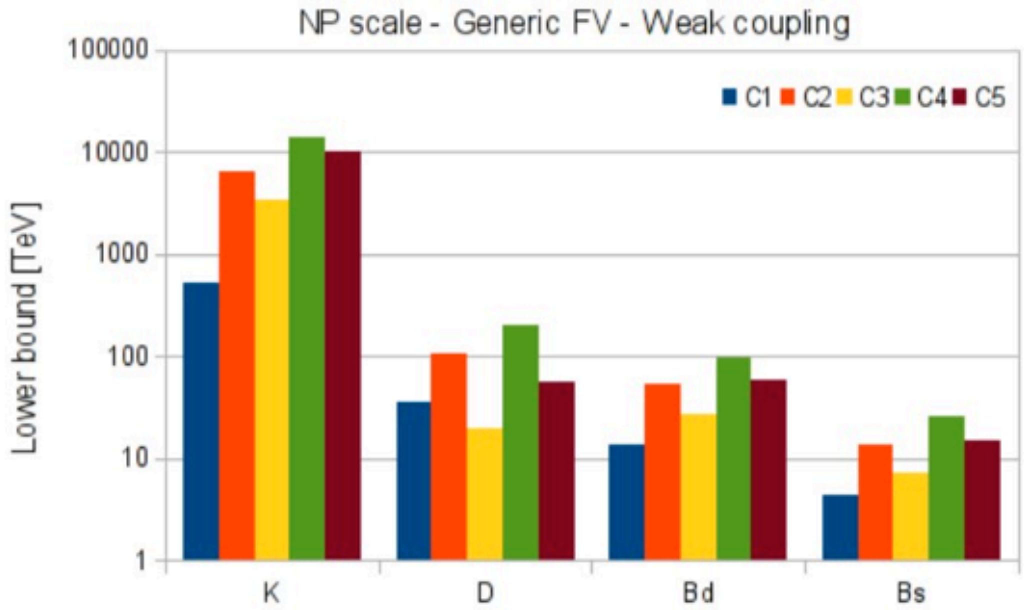
Non-perturbative NP

$\Lambda > 4.6\ 10^5$ TeV

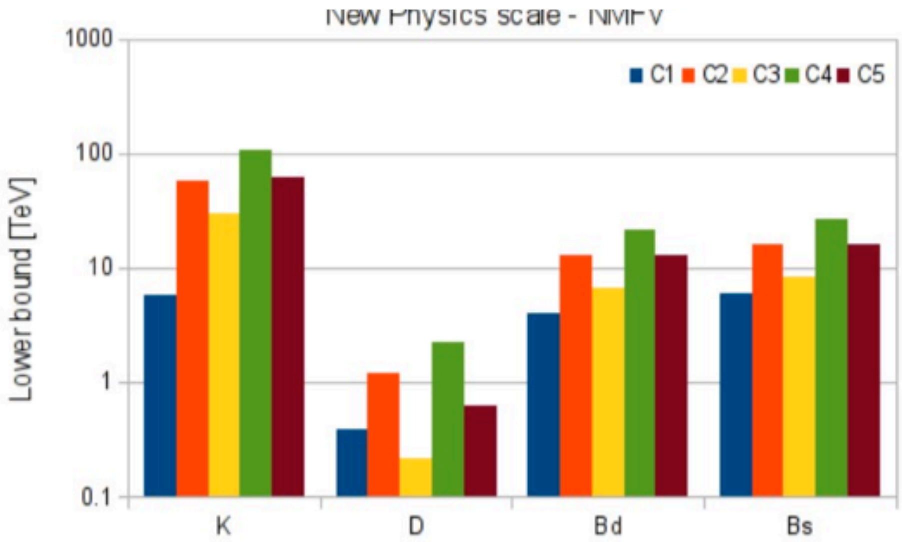
NP in α_W loops

$\Lambda > 1.4\ 10^4$ TeV

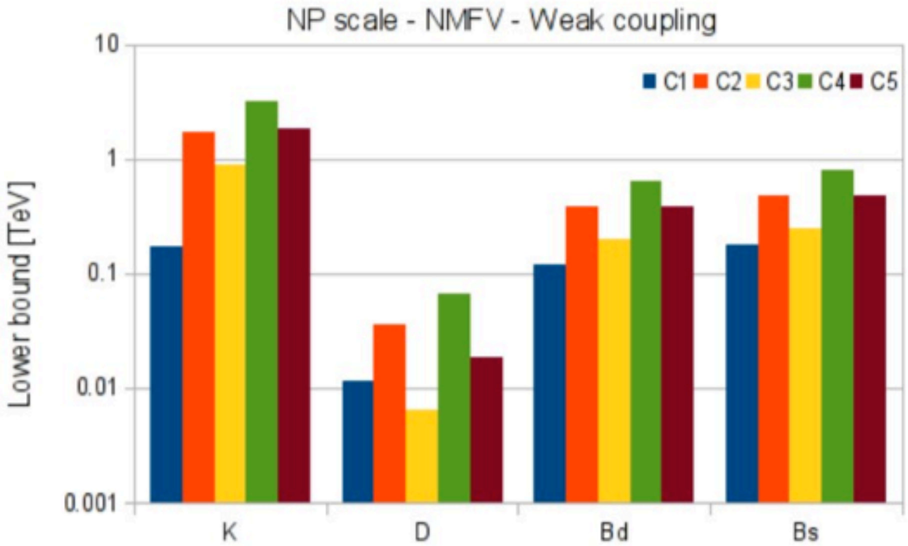
preliminary results



NMFV: SM-like Flavor Couplings



Non-perturbative NP
$\Lambda > 105$ TeV



NP in α_W loops
$\Lambda > 3.2$ TeV

preliminary results

CONCLUSIONS

1) The high precision of the SM UT Analysis allows to test the SM and to search for NP at a level which is competitive with direct searches
2) CKM matrix is the dominant source of flavour mixing and CP violation $\sigma(\rho)$~15% & $\sigma(\eta)$ ~4%. SM analysis shows a good overall consistency
3) There are a few tensions that should be understood : $\sin 2\beta$, $Br(B \rightarrow \tau \nu)$ and to a lesser extent ε_K. A single value of V_{ub} cannot resolve the tensions.
4) In B_s some tension in $a_{\mu\mu}$ and leptonic asymmetries (assuming SM Γ_{12})
5) The suggestion of a large Bs mixing phase has not survived to LHCb measurements.

Thus for the time being we have to remain with a STANDARDISSIMO STANDARD MODEL but …

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UTfit

THANKS FOR YOUR ATTENTION

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