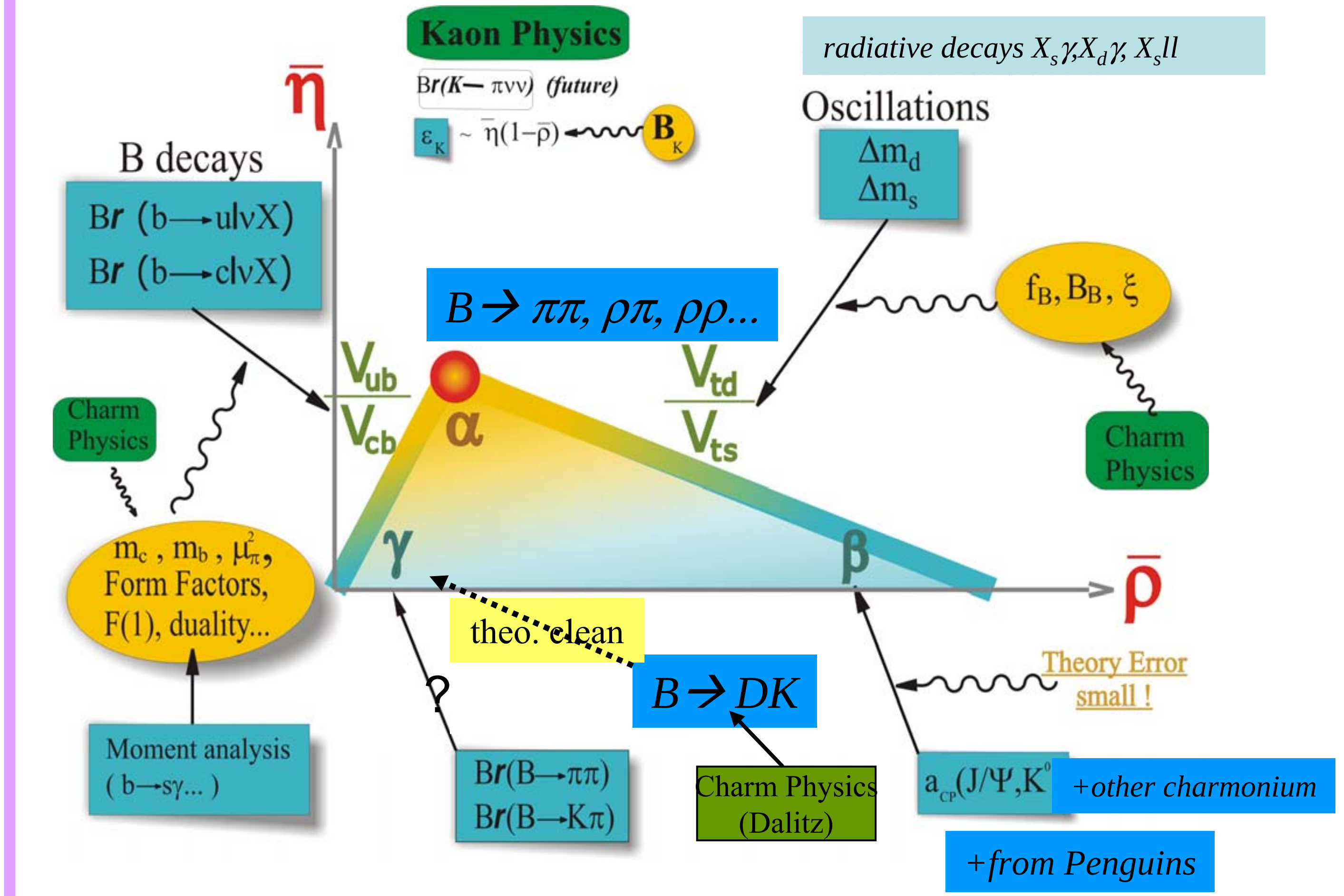
CKM Physics



Kaon Physics
Br(K→ πνν) (future)
ε_K ~ η̄(1−ρ̄)
B_K
radiative decays X_sγ,X_dγ, X_sll
Oscillations
Δm_d
Δm_s
B decays
Br (b→ulνX)
Br (b→clνX)
B→ ππ, ρπ, ρρ...
f_B, B_B, ξ
Charm Physics
V_ub / V_cb
α
V_td / V_ts
Charm Physics
η̄
γ
β
ρ̄
m_c , m_b , μ²_π,
Form Factors,
F(1), duality...
theo. clean
B→ DK
Theory Error
small !
?
Moment analysis
(b→sγ...)
Br(B→ππ)
Br(B→Kπ)
Charm Physics
(Dalitz)
a_CP(J/Ψ,K⁰
+other charmonium
+from Penguins

Flavour Physics in the *Standard Model* (SM) in the quark sector:

~ half of the *Standard Model*

10 free parameters

6 quarks masses

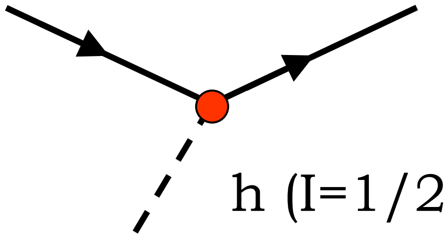
4 CKM parameters

In the Standard Model, charged weak interactions among quarks are codified in a 3 X 3 unitarity matrix : the **CKM Matrix**.

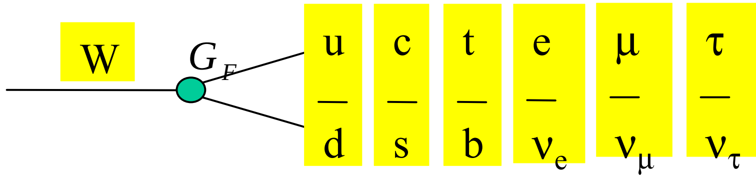
The existence of this matrix conveys the fact that the quarks which participate to weak processes are a linear combination of mass eigenstates

The fermion sector is poorly constrained by SM + Higgs Mechanism
mass hierarchy and CKM parameters

The mass is a LEFT-RIGHT coupling and has to respect the gauge invariance $SU(2)_L \times U(1)_Y$



$$\overline{\psi}_L \phi \psi_R \qquad \phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \qquad I = \frac{1}{2} \quad Y = 1$$



$$M^D = \begin{pmatrix} D11 & D12 & D13 \\ D21 & D22 & D23 \\ D31 & D32 & D33 \end{pmatrix} \qquad M^U = \begin{pmatrix} U11 & U12 & U13 \\ U21 & U22 & U23 \\ U31 & U32 & U33 \end{pmatrix}$$

9+9 Complex parameters

$$M^{D,U}_{DIAG} = V^{D,U}_L M^{D,U} (V^{D,U}_R)^+$$

$$M^D_{DIAG} = \begin{pmatrix} m_d & & \\ & m_s & \\ & & m_b \end{pmatrix} \qquad M^U_{DIAG} = \begin{pmatrix} m_u & & \\ & m_c & \\ & & m_t \end{pmatrix}$$

$$V(CKM) = V^U_L (V^D_L)^+ = \begin{pmatrix} \text{4 parameters} \\ \lambda, A, \rho, \eta \end{pmatrix}$$

$$L_M = M^d_{ij} \overline{d}^{Int.}_{L\,j} d^{Int.}_{R\,j} + M^u_{ij} \overline{u}^{Int.}_{L\,j} u^{Int.}_{R\,j} + M^l_{ij} \overline{l}^{Int.}_{L\,j} l^{Int.}_{R\,j}$$

To have mass matrices diagonal and real, we have defined: $M^f(diag) = V^f_L M^f V^{f\dagger}_R$

The mass eigenstates are:

$$d_{L_i} = (V^d_L)_{ij} d^{Int.}_{L_j} \quad ; \quad d_{R_i} = (V^d_R)_{ij} d^{Int.}_{R_j}$$

The Lagrangian for the gauge interaction is:

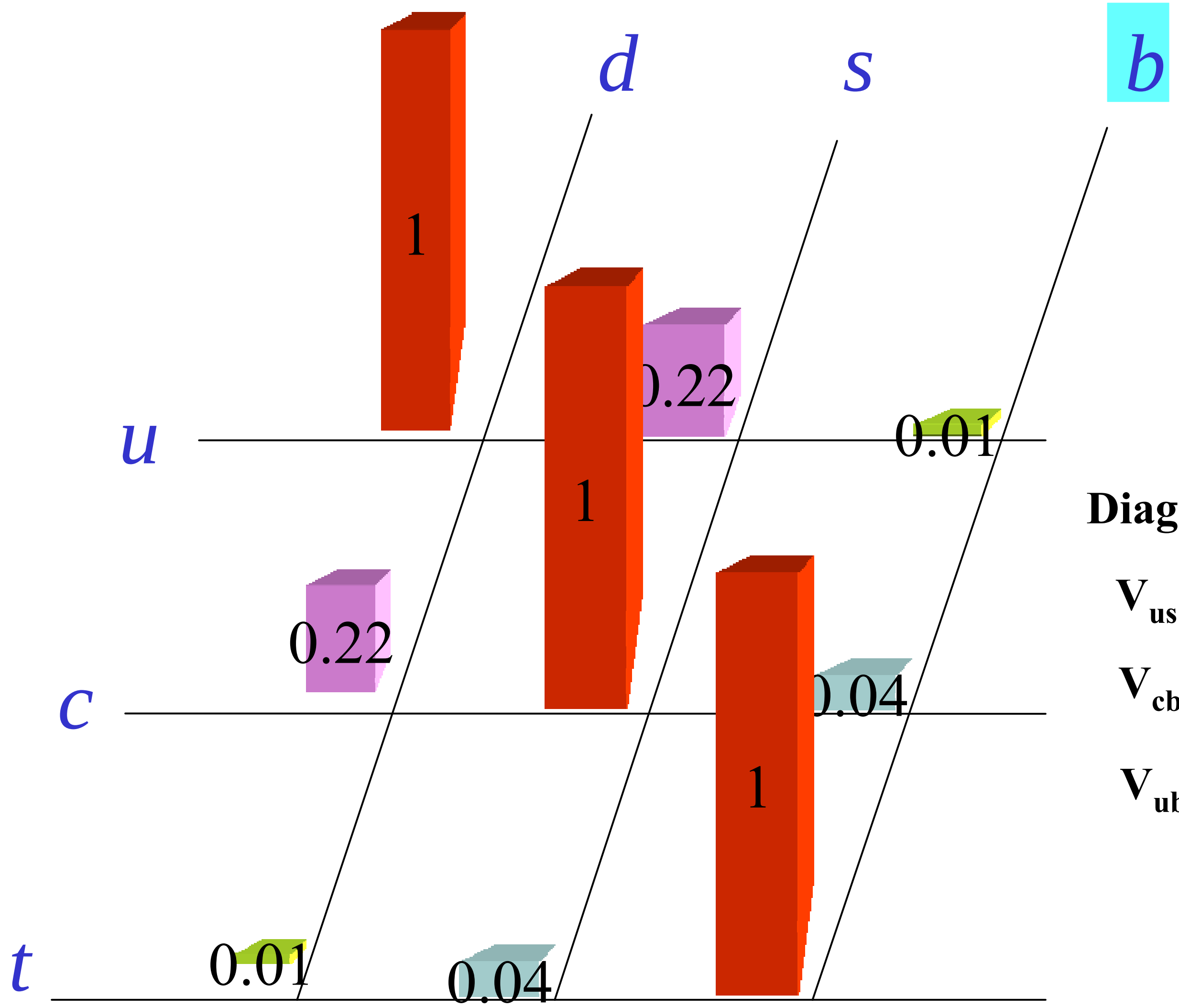
$$L_W = \frac{g}{2} \overline{u}_{L_i} \gamma^\mu (V^u_L V^{d\dagger}_L) d_{L_j} W^a_\mu + h.c.$$

$$\begin{pmatrix}\bar{u} & \bar{c} & \bar{t}\end{pmatrix}\begin{pmatrix}V_{ud} & V_{us} & V_{ub}\\ V_{cd} & V_{cs} & V_{cb}\\ V_{td} & V_{ts} & V_{tb}\end{pmatrix}\begin{pmatrix}d\\ s\\ b\end{pmatrix}$$

Generally for a rotation 3x3 matrix in complex plane

3angles + 1 « irreducible » phase

The only responsible of CP violation in SM



Diagonal elements ~ 1

V_{us} , V_{cd} ~ 0.2

V_{cb} , V_{ts} ~ 4×10^{-2}

V_{ub} , V_{td} ~ 4×10^{-3}

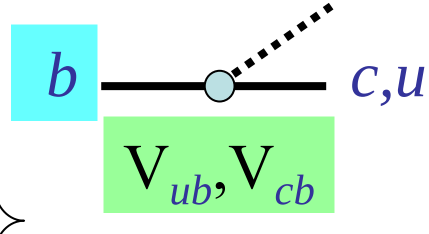
The **CKM** Matrix

Wolfenstein parametrization

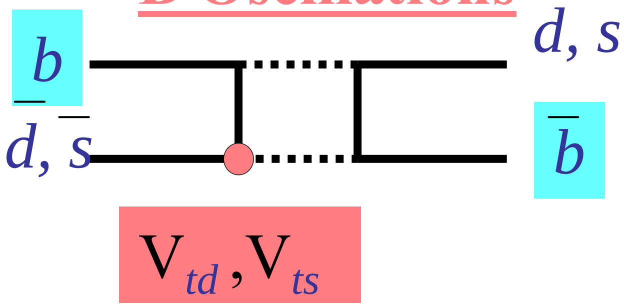
4 parameters : **λ ,A, ρ, η**

$$
\begin{array}{c|ccc}
 & d & s & b \\
\hline
u & 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\
c & -\lambda & 1-\lambda^2/2 & A\lambda^2 \\
t & A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1
\end{array}
$$

V_{tb}



B decays



B Oscillations

The *b-Physics* plays a very important role in the determination of those parameters

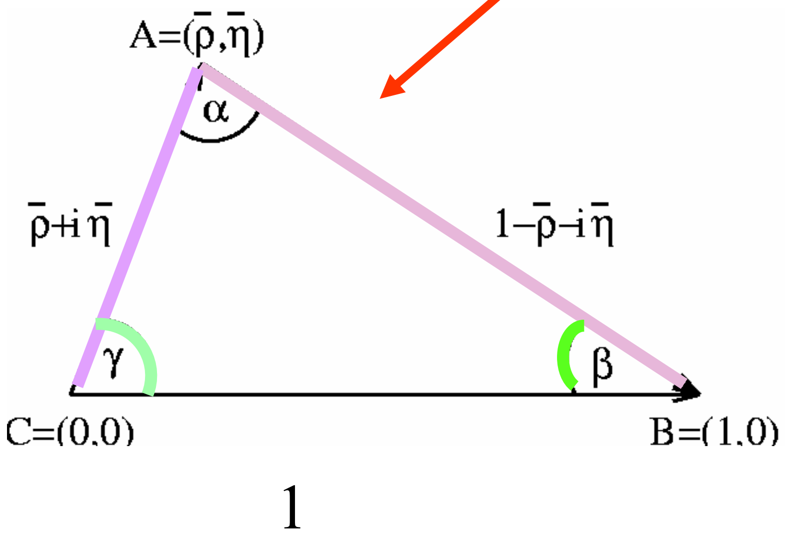
The Unitarity Triangle

The CKM is unitary

$$V V^\dagger = V^\dagger V = 1$$

The non-diagonal elements of the matrix products correspond to 6 triangle equations

$V_{ud}^* V_{us} + V_{cd}^* V_{cs} + V_{td}^* V_{ts} = 0$	$\lambda\ \lambda\ \lambda^5$
$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$	$\lambda^3\ \lambda^3\ \lambda^3$
$V_{us}^* V_{ub} + V_{cs}^* V_{cb} + V_{ts}^* V_{tb} = 0$	$\lambda^4\ \lambda^2\ \lambda^2$
$V_{ud}^* V_{td} + V_{us}^* V_{ts} + V_{ub}^* V_{tb} = 0$	$\lambda^3\ \lambda^3\ \lambda^3$
$V_{td}^* V_{cd} + V_{ts}^* V_{cs} + V_{tb}^* V_{cb} = 0$	$\lambda^4\ \lambda^2\ \lambda^2$
$V_{ud}^* V_{cd} + V_{us}^* V_{cs} + V_{ub}^* V_{cb} = 0$	$\lambda\ \lambda\ \lambda^5$



$$\overline{AB} = \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = \sqrt{(1-\bar\rho)^2 + \bar\eta^2} = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right| \sim \frac{1}{\lambda}\left|\frac{V_{td}}{V_{ts}}\right|$$

$$\overline{AC} = \frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} = \sqrt{\bar\rho^2 + \bar\eta^2} = \left(1 - \frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right|$$

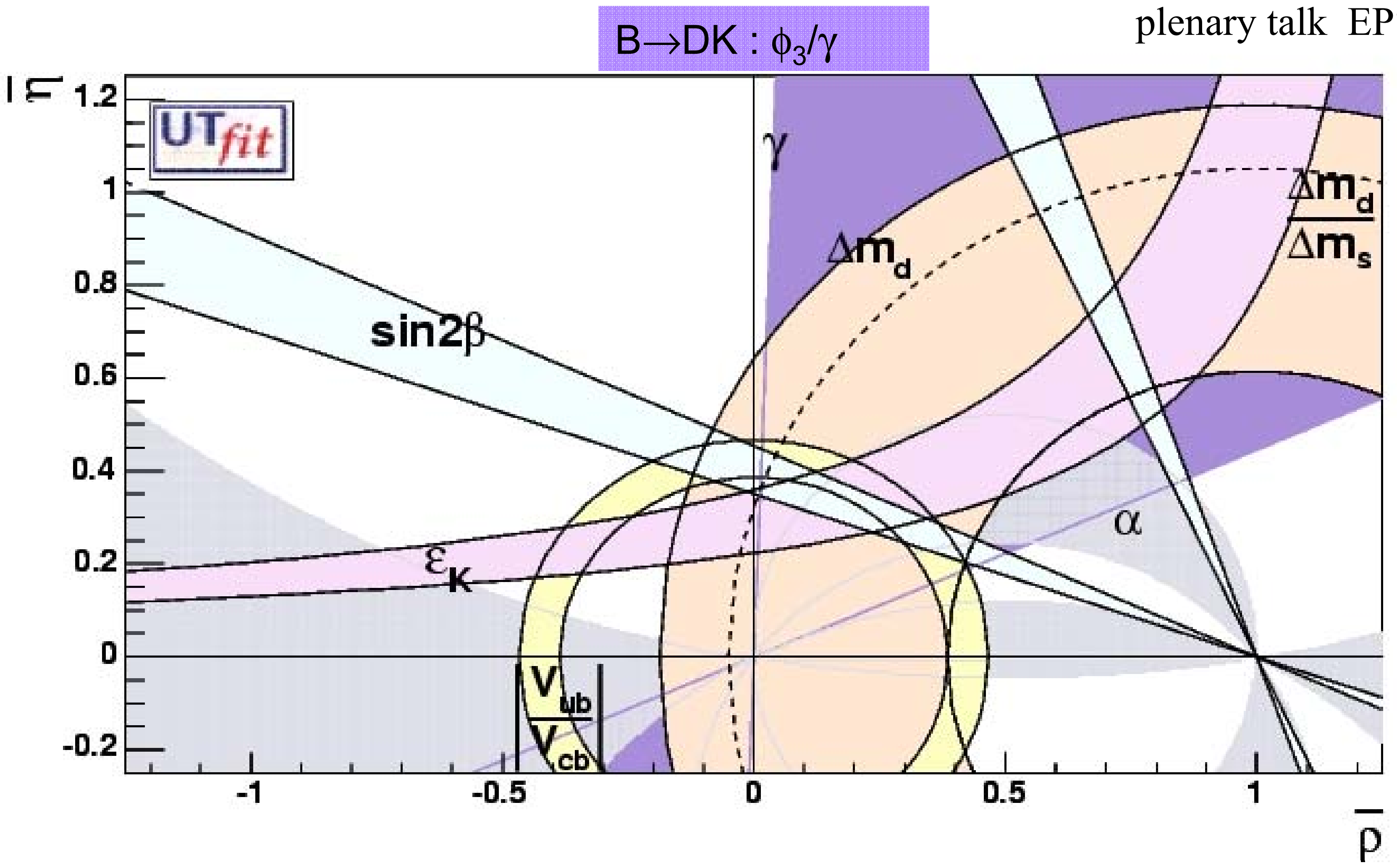
$$\beta = \arg\left(\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right) = \operatorname{atan}\left(\frac{\bar\eta}{(1-\bar\rho)}\right)$$

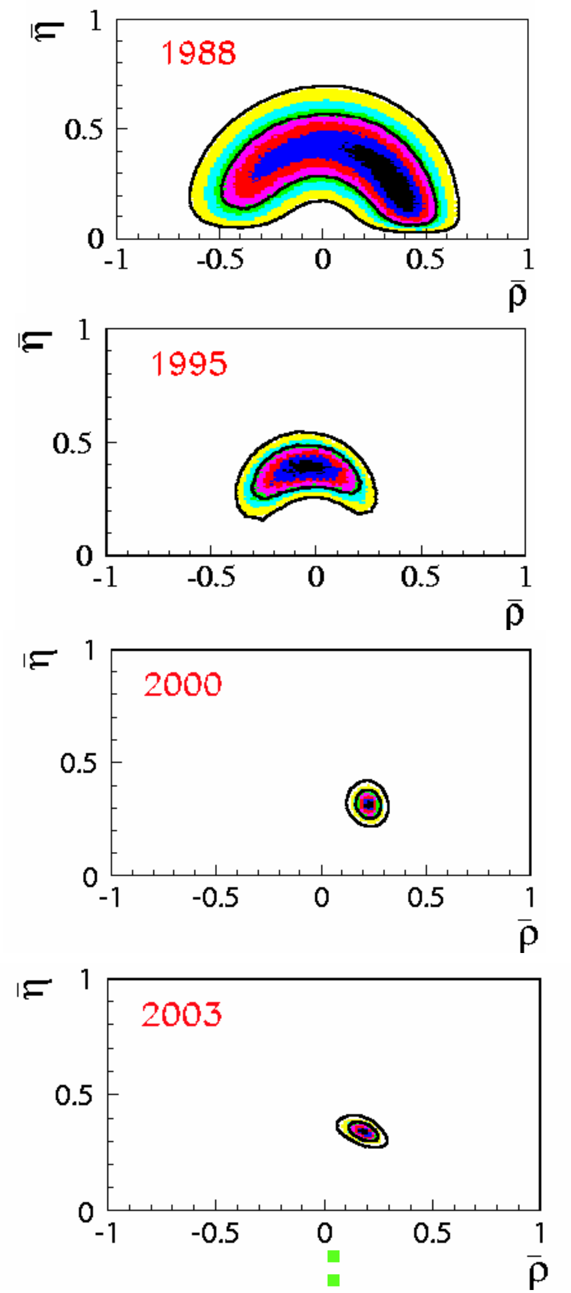
$$\gamma = \arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right) = \operatorname{atan}\left(\frac{\bar\eta}{\bar\rho}\right)$$

$$\alpha + \beta + \gamma = \pi$$

How to fit the UT parameters and fit new physics

From M.H. Schune
plenary talk EPS2005





From childhood

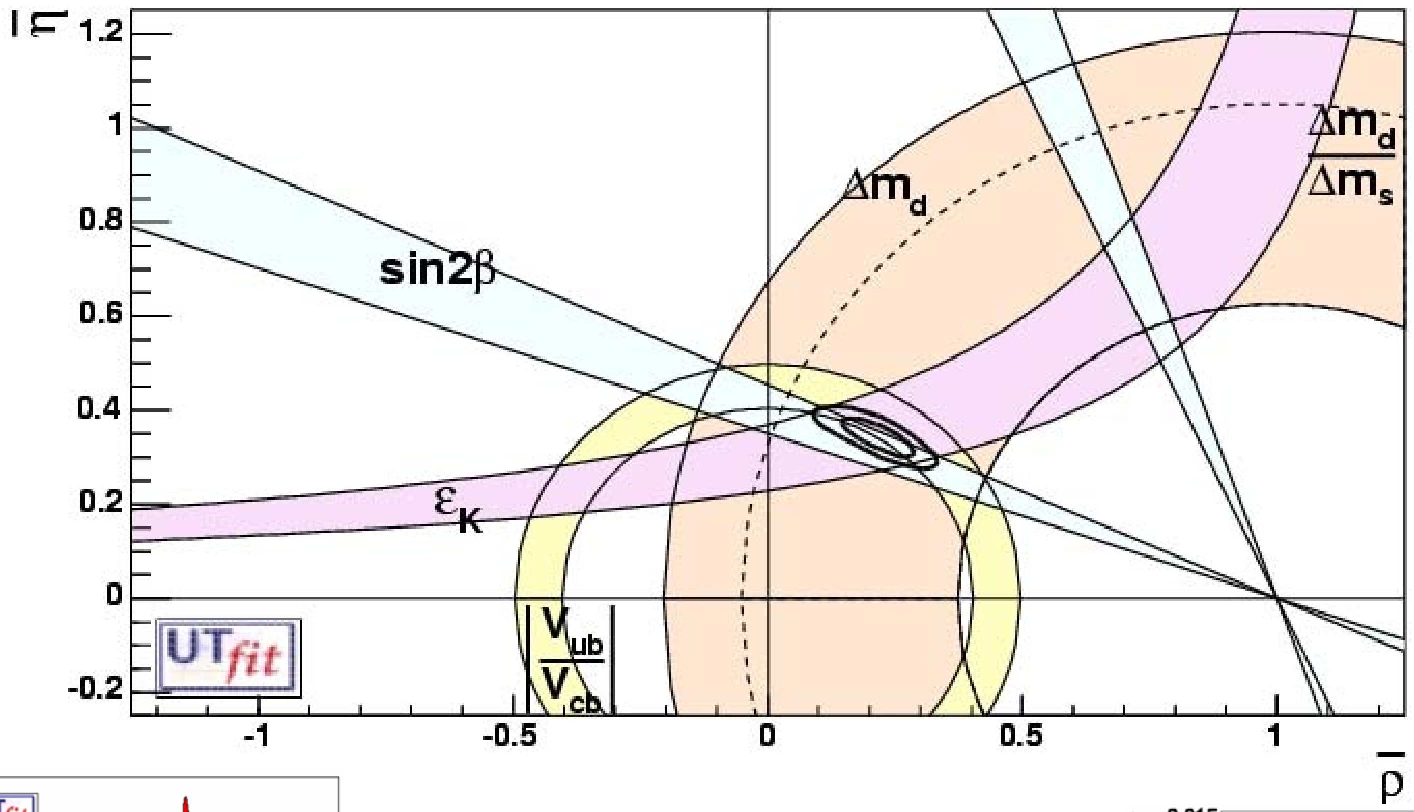
To precision era

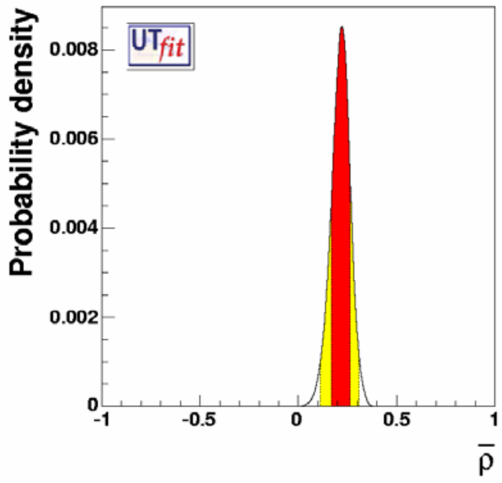
STD FIT

The Standard UTfit

Parameter	*Value*	*Error(Gaussian)*	*Error(Flat)*
λ	0.2258	0.014	
V_{cb} ($\times 10^{-3}$) (excl.)	41.4	2.1	
V_{cb} ($\times 10^{-3}$) (incl.)	41.6	0.7	0.6
V_{ub} ($\times 10^{-4}$) (excl.)	38.0	2.7	4.7
V_{ub} ($\times 10^{-4}$) (incl.)	43.9	4.4	-
Δm_d (ps^{-1})	0.502	0.006	
Δm_s (ps^{-1})	> 14.5 ps^{-1} 95%CL	sens.18.3 ps^{-1} 95% CL	
m_t (GeV)	165.0	3.9	
m_c (GeV)	1.3		0.1
m_b (GeV)	4.21	0.08	-
$f_{B_s}\sqrt{\hat{B}_{B_s}}$ (MeV)	276	38	-
ξ	1.24	0.04	0.06
B_K	0.79	0.06	0.09
ε_K (10^{-3})	2.280	0.013	-
$\sin 2\beta$	0.687	0.032	

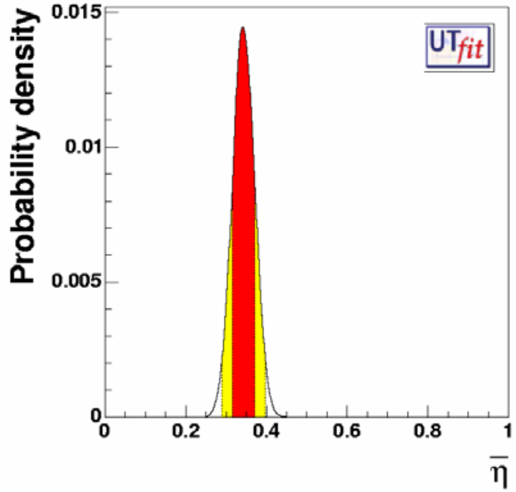
UT*Fit* within the SM





$\bar{\rho} = 0.214 \pm 0.047$

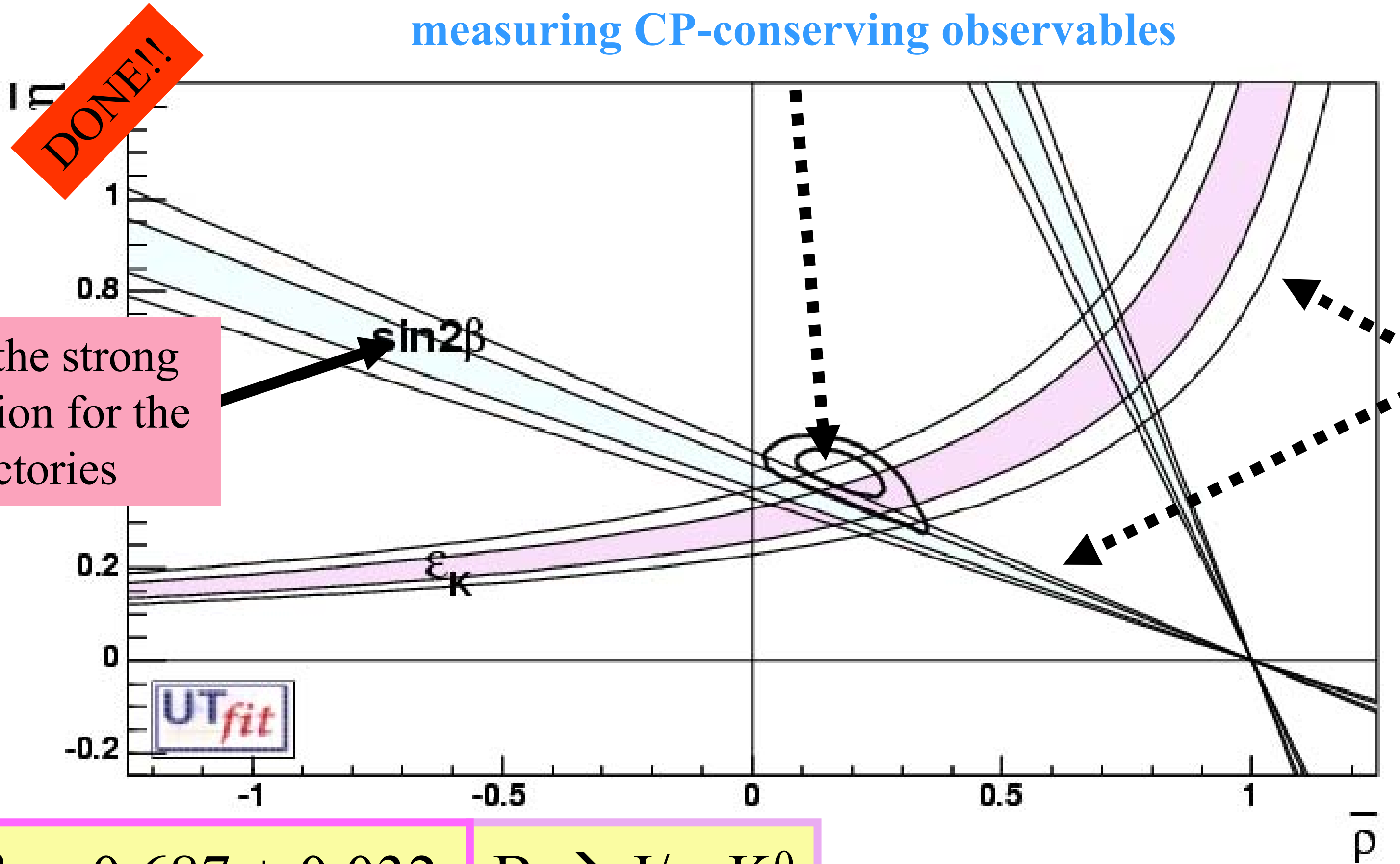
$\bar{\eta} = 0.343 \pm 0.028$



UT*Fit* within the SM

Crucial Test of the SM in the quarks sector

determination of CP violating parameters measuring CP-conserving observables



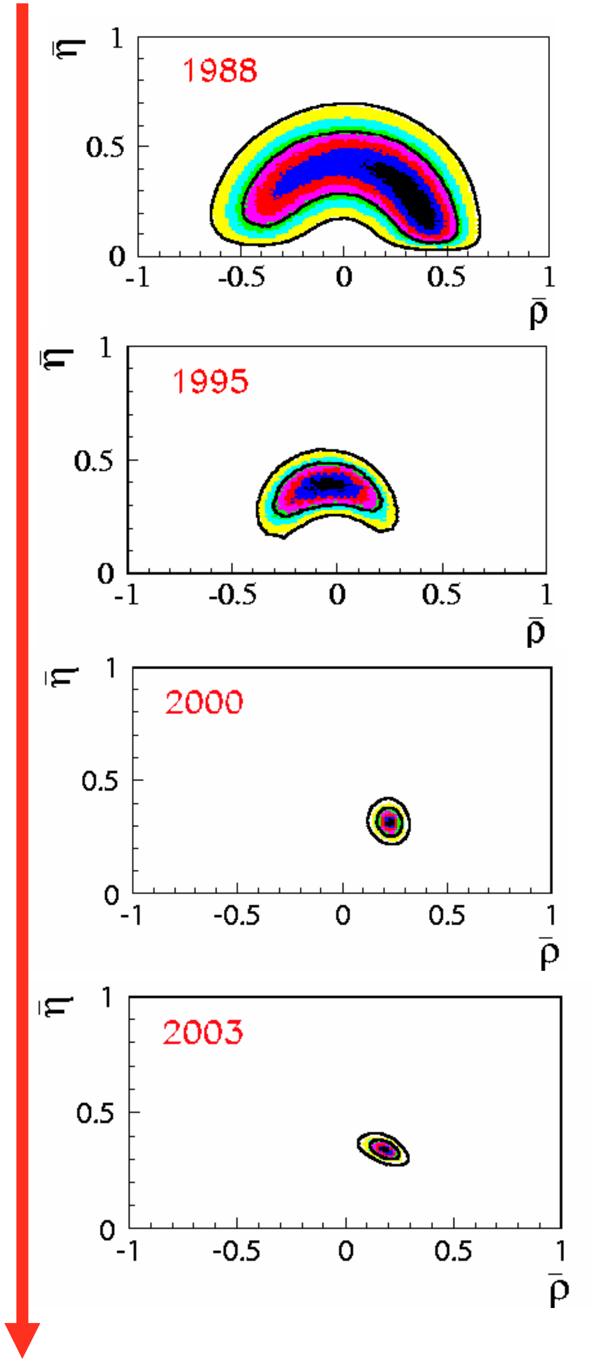
was/is the strong motivation for the B-Factories

CP-violating observables

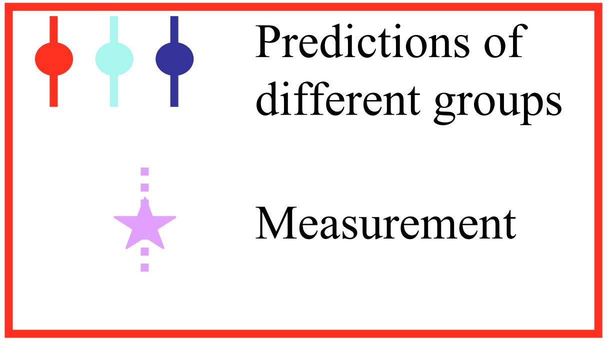
$\sin 2\beta = 0.687 \pm 0.032$	$B \rightarrow J/\psi K^0$
$\sin 2\beta = 0.793 \pm 0.033$	*from sides-only*

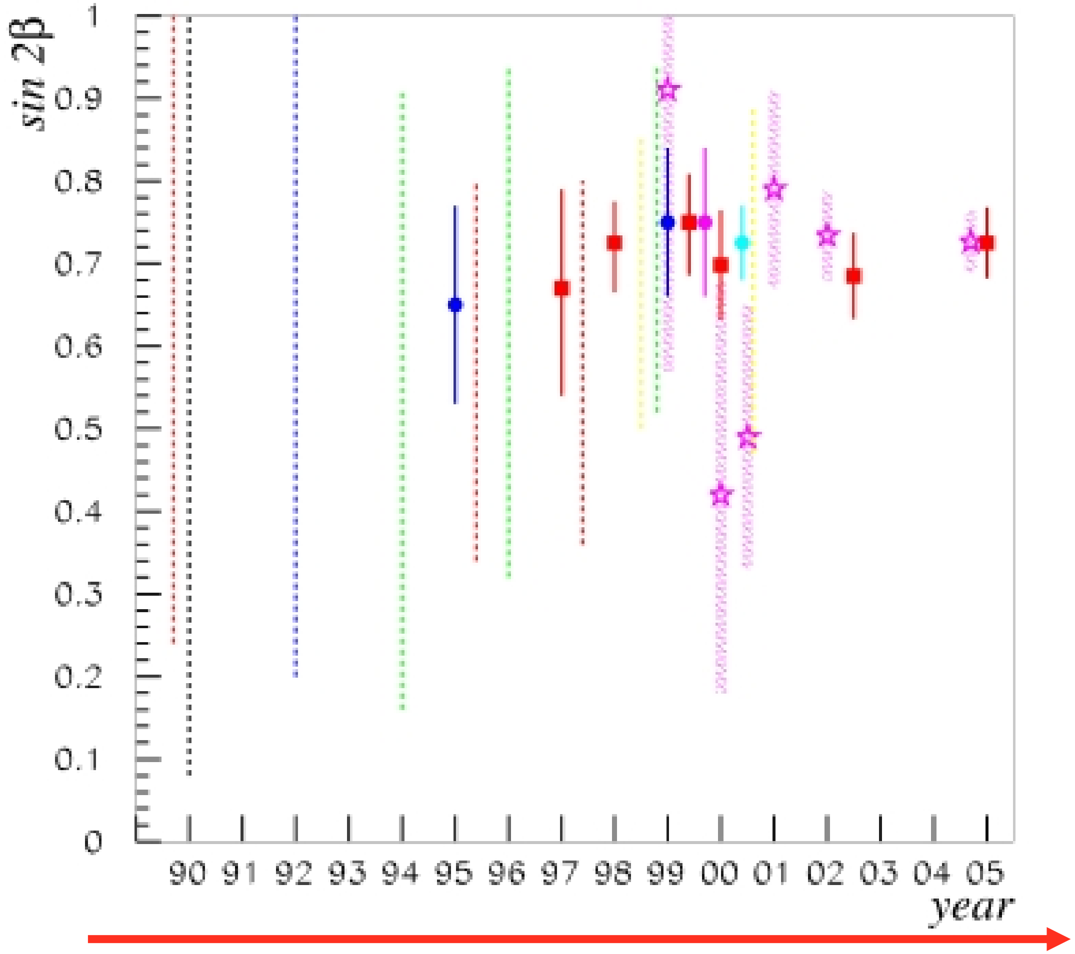
Coherent picture of CP Violation in SM

Some discrepancy wrt past


η̄
1
1988
0.5
0
-1
-0.5
0
0.5
1
ρ̄
1995
2000
2003

sin2β Saga

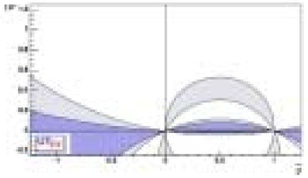

Predictions of different groups
Measurement


sin 2β
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05
year

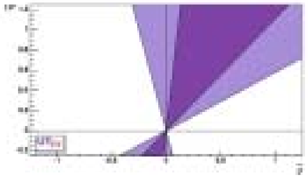
UT*Fit* within the SM

B-Factories has also shown that the other angles can be measured.

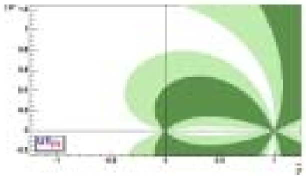
α



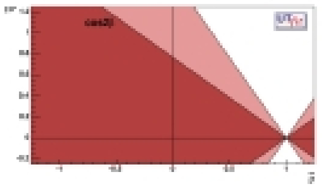
γ

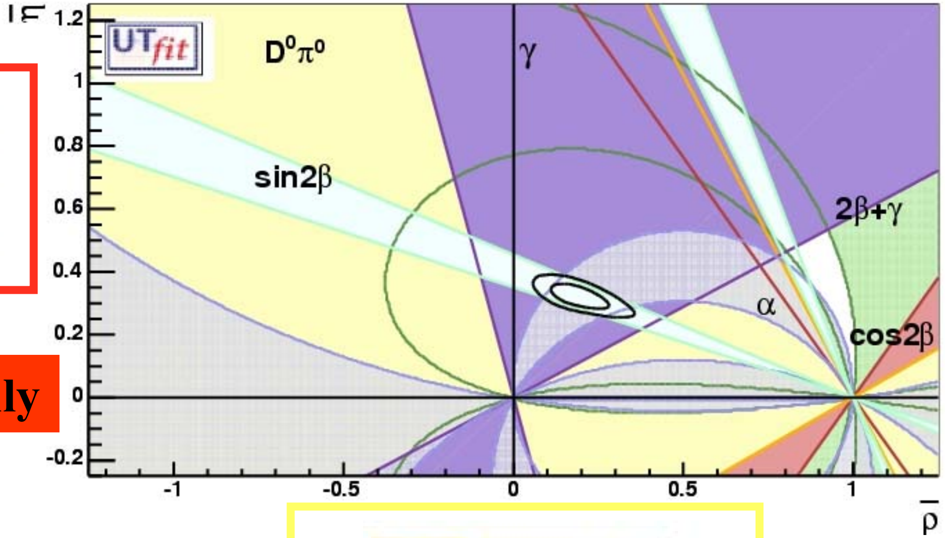


sin(2β+γ)

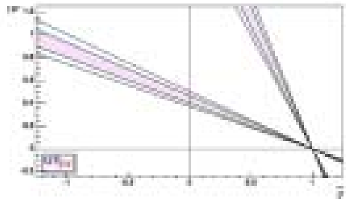


cos2β



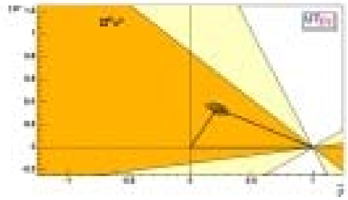


sin(2β)



UT with angles only

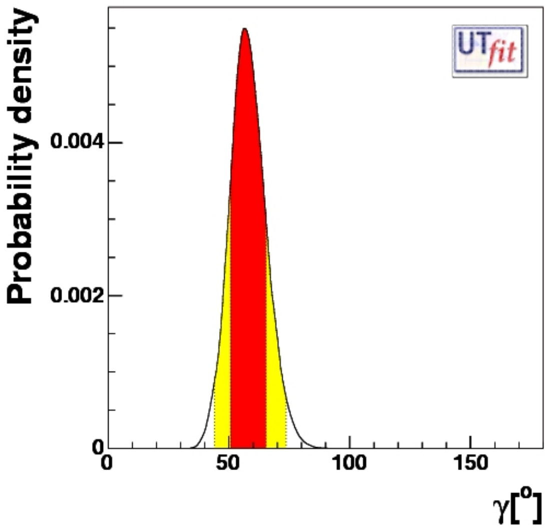
β



See Nando Ferroni Seminar

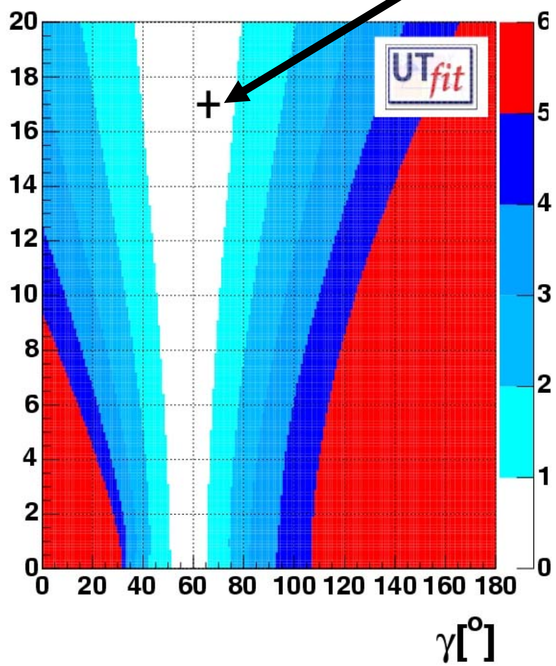
We are already well beyond the first phase.

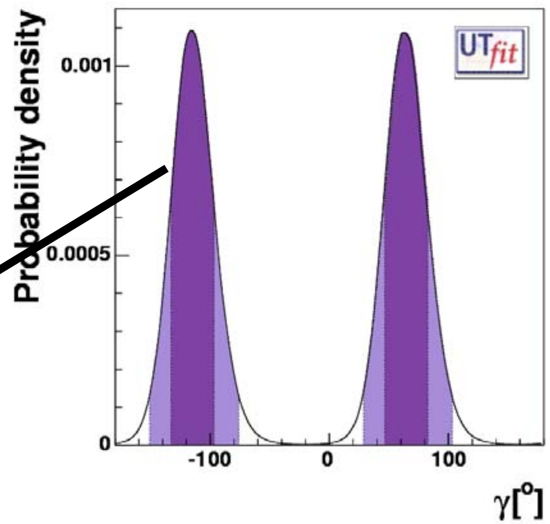
Tree Processes could be used to « discover » NP : comparing «direct» (which are NP free) and «indirect» (where there is NP contributions) measurements of the same quantity.



$\gamma = (57.9 \pm 7.4)°$

NEW crucial TEST
« Partially » DONE

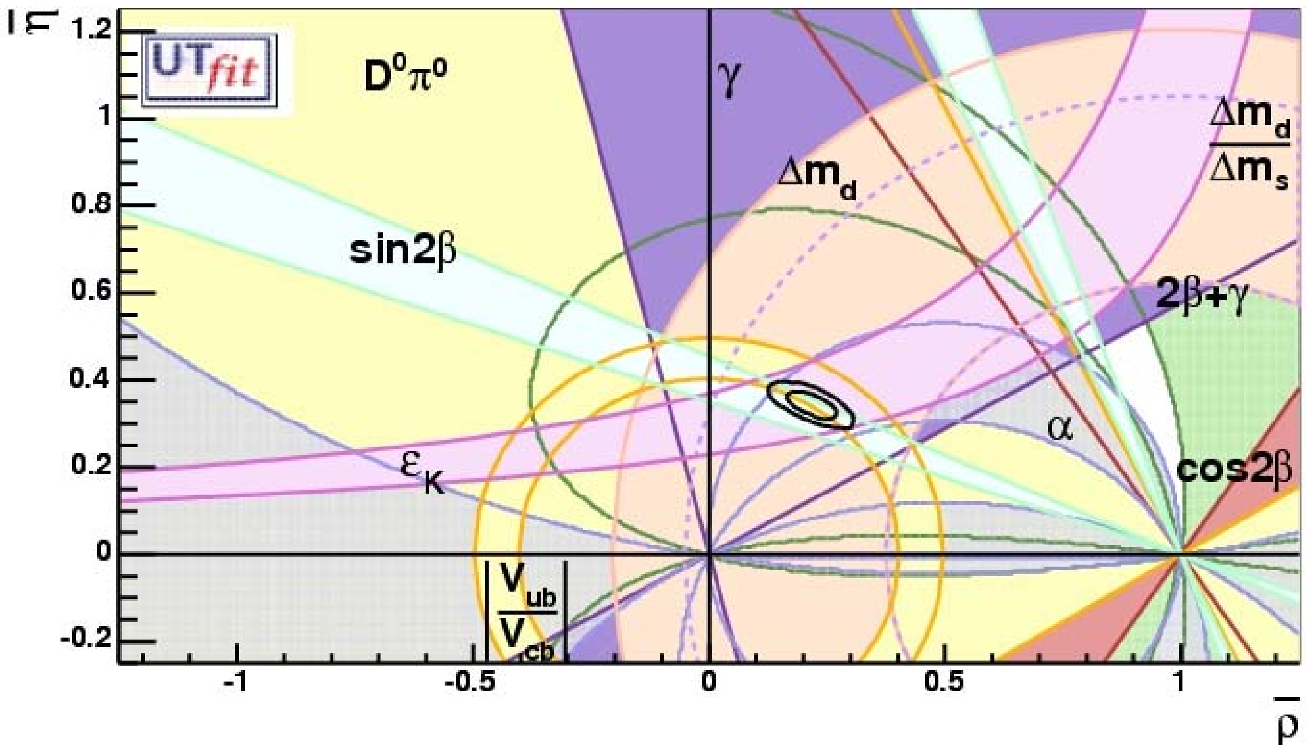




$\gamma = \quad 65.0 \pm 18.0$
$\gamma = -115.0 \pm 18.0$

Other piece showing that :we are probably beyond the era of « alternatives» to the CKM picture. NP should appear as «corrections» to the CKM picture

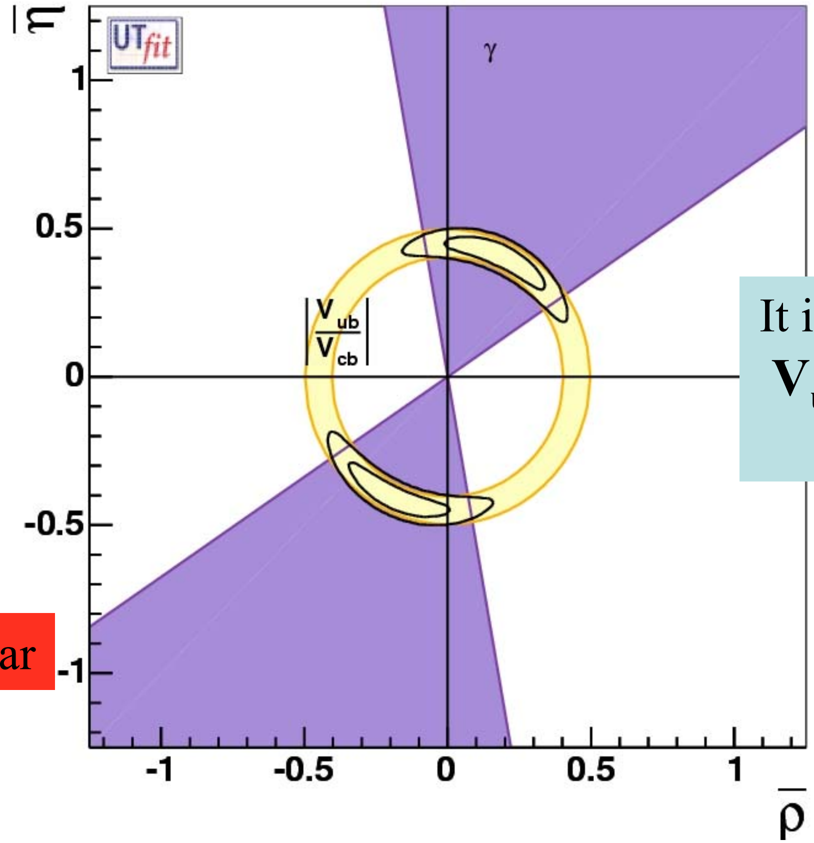
All available information together



$\sin(2\beta)$ β	0.735 ± 0.024 $(23.8 \pm 1.5)°$
α	$(98.5 \pm 5.7)°$
$\gamma°$	$(57.6 \pm 5.5)°$
$\bar{\rho}$	0.216 ± 0.036
$\bar{\eta}$	0.342 ± 0.022

Fit with NP independent variables

If we use only Tree level processes *-which can be assumed to be NP free-*



It is very important to improve
V_{ub}/V_{cb} from s.l decays
γ from tree level proceses

See Gino Isidori seminar

$\bar{\rho}$	± (0.18± 0.11)
$\bar{\eta}$	± (0.41 ± 0.05)

(similar plot in Botella et al. hep-ph/0502133)

Fit in a NP model independent approach

ΔF=2

Parametrizing NP physics in ΔF=2 processes →

$$C_q e^{2i\varphi_d} = \frac{Q^{NP}_{\Delta B=2}}{Q^{SM}_{\Delta B=2}}$$

$$\Delta m_d^{EXP} = C_q \Delta m_d^{SM}$$

$$A_{CP}(J/\Psi K^0) = \sin(2\beta + 2\phi_d)$$

$$\alpha^{EXP} = \alpha^{SM} - \phi_d$$

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

Soares, Wolfenstein PRD47;
Deshpande,Dutta, Oh PRL77;
Silva, Wolfenstein PRD55;
Cohen et al. PRL78;
Grossman, Nir, Worah PLB407;
Ciuchini et al. @ CKM Durham

Constraints

	ρ , η	C_d,φ_d	$C_{\varepsilon K}$	C_s,φ_s
V_{ub}/V_{cb}	X			
Δm_d	X	X		
ε_K	X		X	
ACP (J/Ψ K)	X	X		
α ($\rho\rho,\rho\pi,\pi\pi$)	X	X		
γ (DK)	X			
Not yet available:				
Δm_s				X
ACP (J/Ψ ϕ)	~X			X
γ (D_sK)	X			X

5 new free parameters
- C_s,φ_s — B_s mixing
- C_d,φ_d — B_d mixing
- $C_{\varepsilon K}$ — K mixing

Today : fit possible with 6 contraints and
5 free parameters (ρ, η, C_d,φ_d ,$C_{\varepsilon K}$)

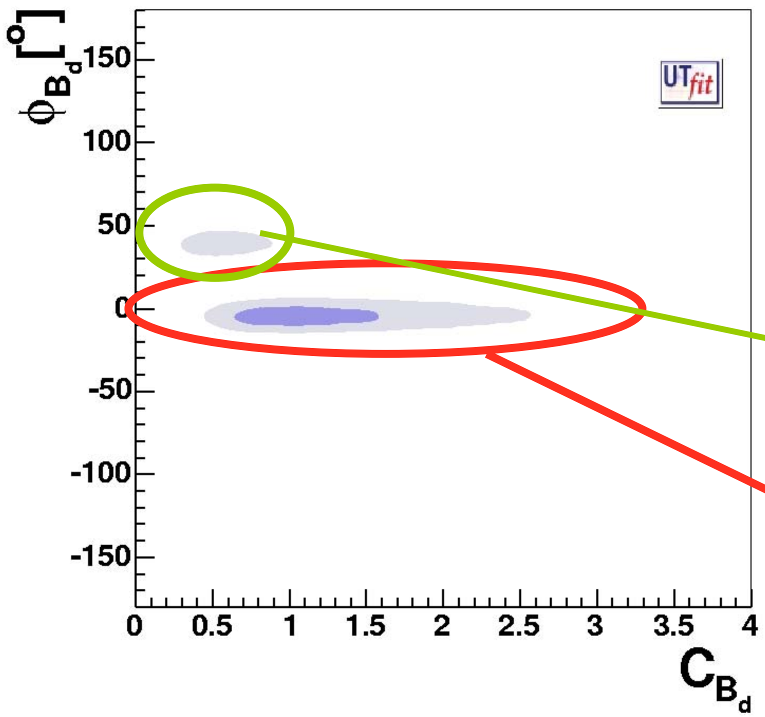
Fit in a NP model independent approach

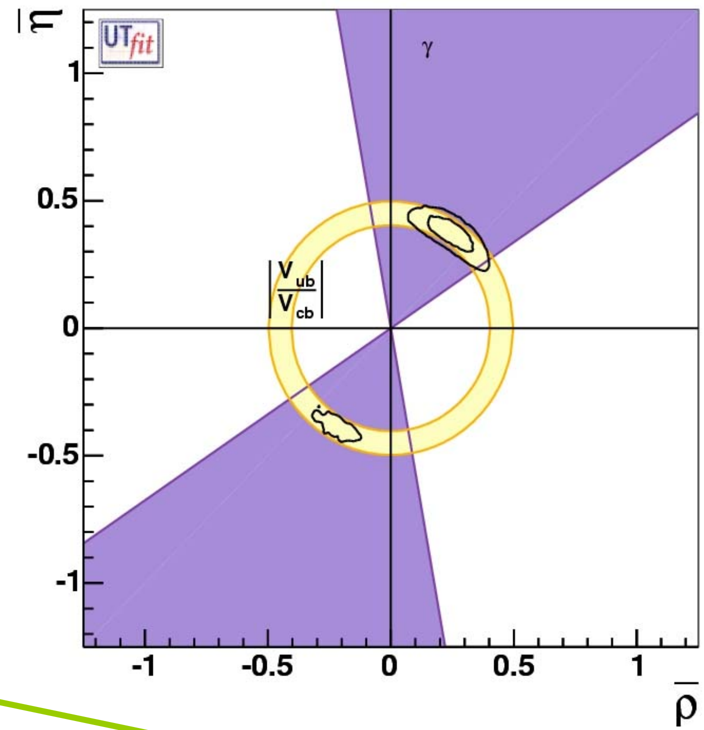
Using

V_{ub}/V_{cb} Δm_d ACP (J/Ψ K)

γ (DK) ε_K

α $\cos 2\beta$ A_{SL}





NP solution 7%

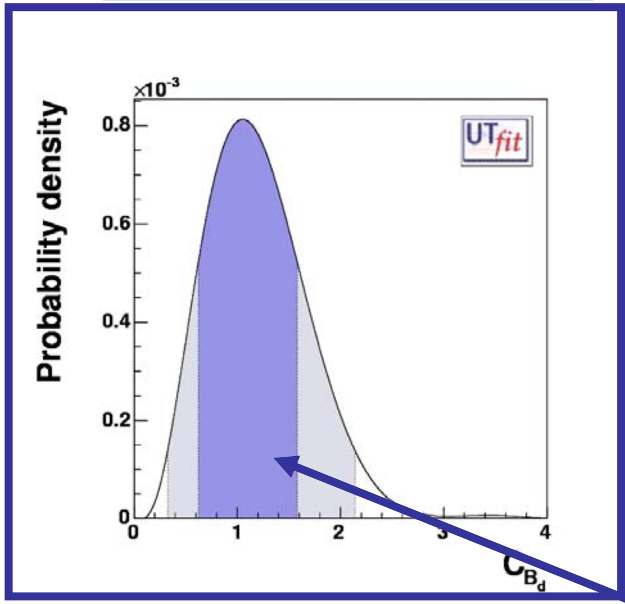
SM-like solution 93%

$$A_{SL} \equiv \frac{\Gamma(\bar{B}^0 \to \ell^+ X) - \Gamma(B^0 \to \ell^- X)}{\Gamma(\bar{B}^0 \to \ell^+ X) + \Gamma(B^0 \to \ell^- X)}$$

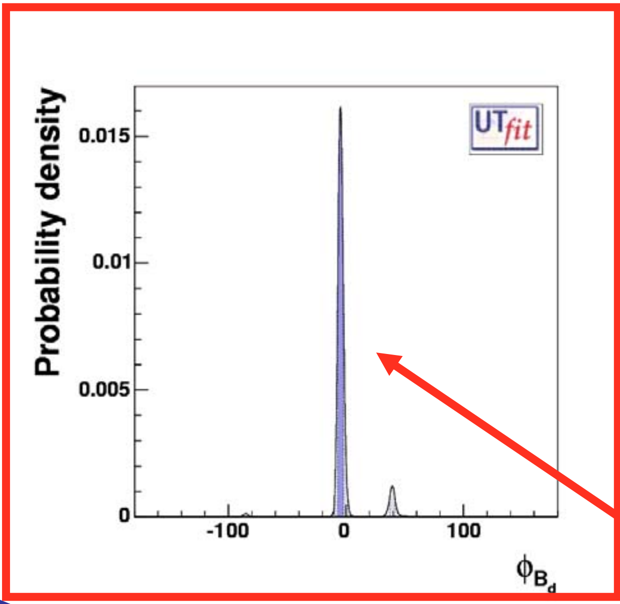
$$A_{SL} = -\mathrm{Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{SM} \frac{\sin 2\phi_d}{C_d} + \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{SM} \frac{\cos 2\phi_d}{C_d}$$

Laplace et al., PRD65

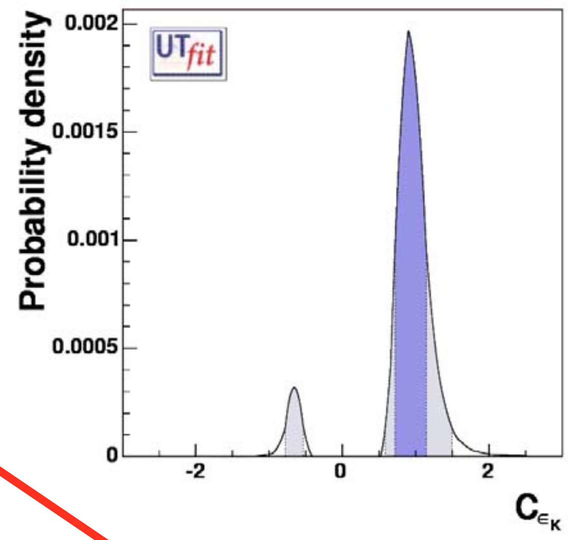
$C_{Bd} = 1.10 \pm 0.48$



$\phi_{Bd} = (4.6 \pm 2.6)^o$



$C_{\varepsilon} = 0.93 \pm 0.22$



NP in ΔB=2 and ΔS=2 could be up to 50% wrt SM only if has the same phase of the SM

WHY
IT IS IMPORTANT
TO GO ON….

TWO POSSIBLE SCENARIOS

MFV	New CP in $b \rightarrow s$

What to do ?

- Improvements existing measurements	***- $\Delta F=1$ Penguins transitions***
- Rare decays (not discussed in this talk)	***- The B_s physics (LHCb/Tevatron)***

I'll give just two examples

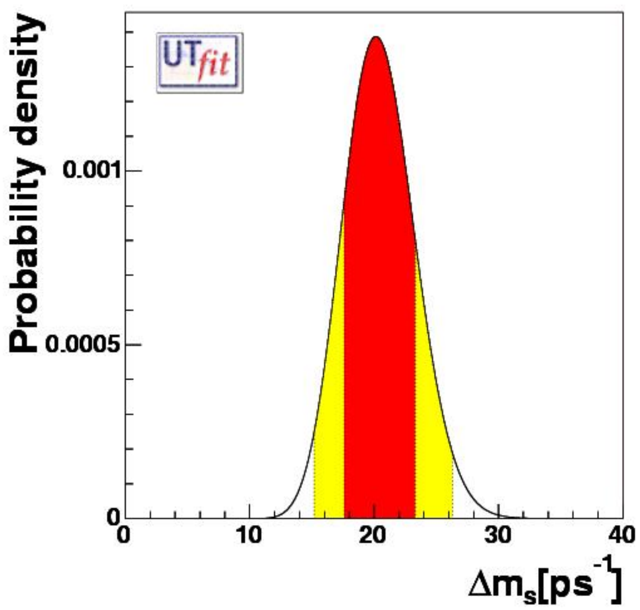
Subjet of the Gino Isidori seminar

LHCb/(TeVatron ?)

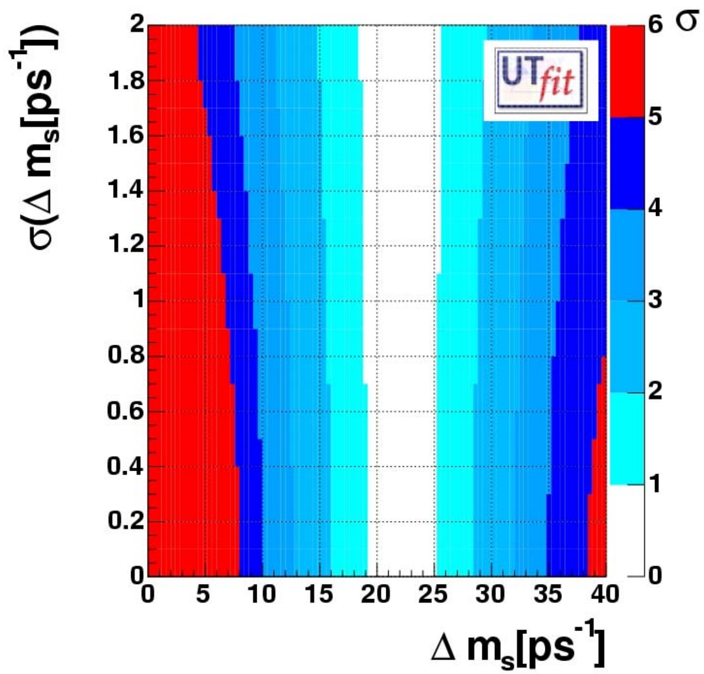
A crucial test the measurement of Δm_s

Δm_s will be precisely measured as soon as it will be measured ~ $\sigma(\Delta m_s) < 1 ps^{-1}$

without using the limit on $\mathbf{\Delta m_s}$



$\Delta ms = 22.2 \pm 3.1\ ps^{-1}$
[15.0, 26.1] @ 95% CL



Δm > $31\ ps^{-1}$ @ 3 σ
> $38\ ps^{-1}$ @ 5 σ

It is crucial to improve the precision on the Lattice quantities (f_{Bs},ξ) to have a better prediction for Δm_s to be compared with the future measurement

CKM Matrix in ≤2010-where we will be

We have supposed that

- **B Factories** will collect $2ab^{-1}$
- two years data taking at **LHCb** ($4fb^{-1}$)

Inputs

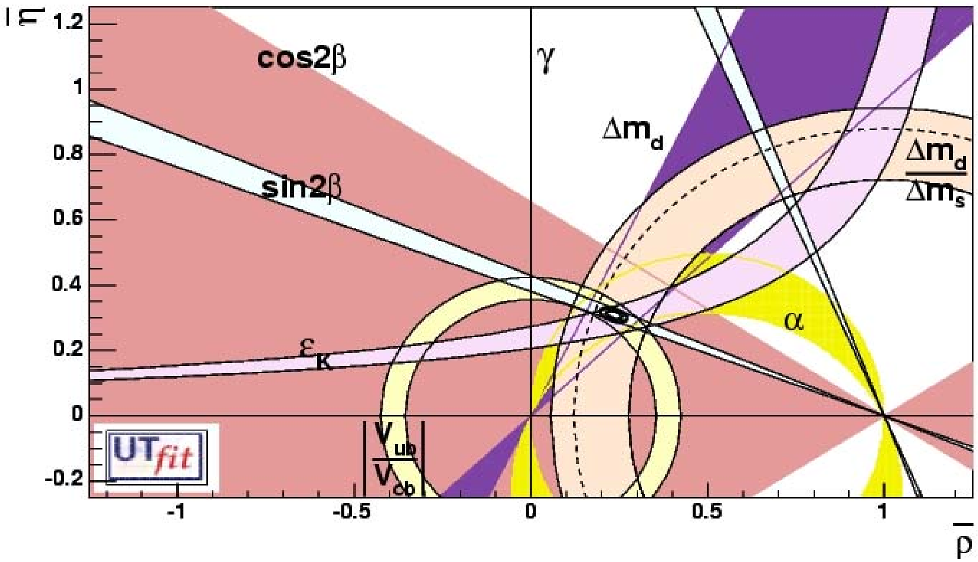
$\beta < 1°$ from charmonium
$\alpha \sim 7°$
$\gamma \sim 5°$
(half B-factories/half LHCb)

$\sin 2\chi \pm 0.045$

$V_{ub} \sim 5\%$
$V_{cb} \sim 1\%$

Δm_s at $0.3ps^{-1}$
(Tevatron or/and LHCb)

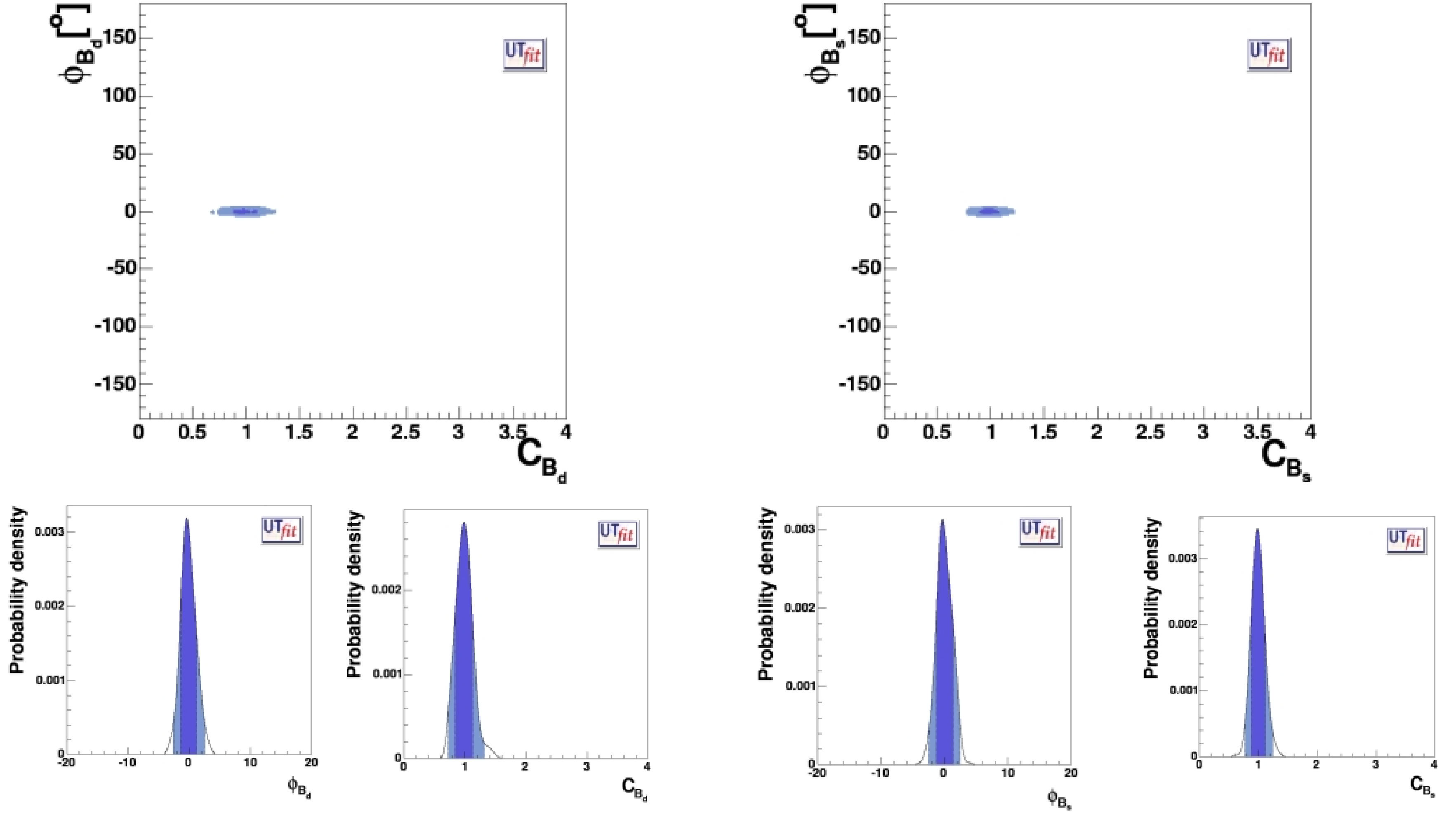
$f_B\sqrt{B_B} \sim 5\%$
$\xi \sim 3\%$
$B_K \sim 5\%$



Outputs

$\sin(2\beta)$	0.694 ± 0.012
$\sin(2\alpha)$	-0.543 ± 0.093
$\gamma[°]$	51.7 ± 3.0
$\bar{\rho}$	0.240 ± 0.017
$\bar{\eta}$	0.307 ± 0.010

In the « sad » hypotesis the SM still work in 2010….



φ_{Bd} = (-0.1 ± 1.3)^o

C_{Bd} = 0.98 ± 0.14

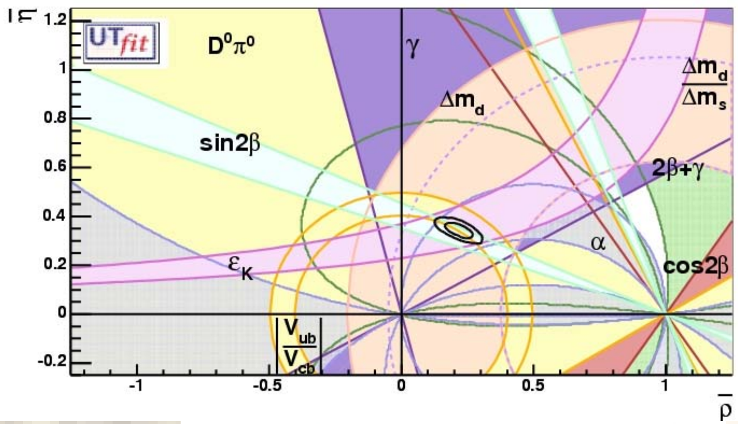
φ_{Bs} = (0.0 ± 1.3)^o

C_{Bs} = 0.99 ± 0.12

VERY IMPORTANT in 2010 : same and impressive precision on b →d and b →s transitions

We cannot stop before having doing that !!

Conclusions

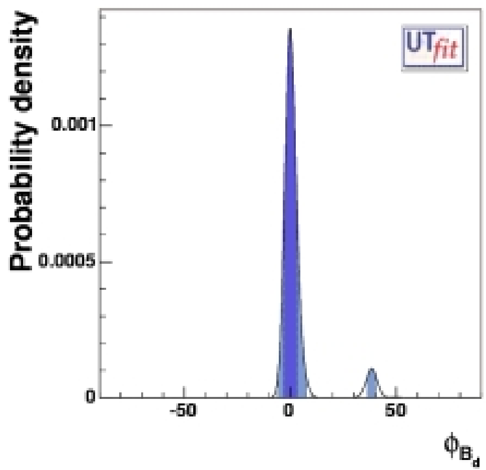


UT*fits* are in a mature age with recent precise measurement of UT sides and angles

The SM CKM picture of CP violation and FCNC is strongly supported by data

Generic NP in the $b \to d$ start to be quite constrained

$\phi_{Bd} \sim 0$



At least in this sector, we are beyond the alternative to CKM picture, and we should look at « corrections ».

We need precision measurements to test NP and to push the NP scale in interesting ranges and to play the complementarity at LHC

What about the $b \to s$ sector ? Still large room for NP. LHCb plays the central role on it.

$A_{FB}(X_s l^+ l^-)$, $A_{FB}(K^*\gamma)$
Δm_s, $B_s \to J/\psi\phi$ $B_s \to \mu\mu$