The Abdus Salam
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Flavor Physics - III

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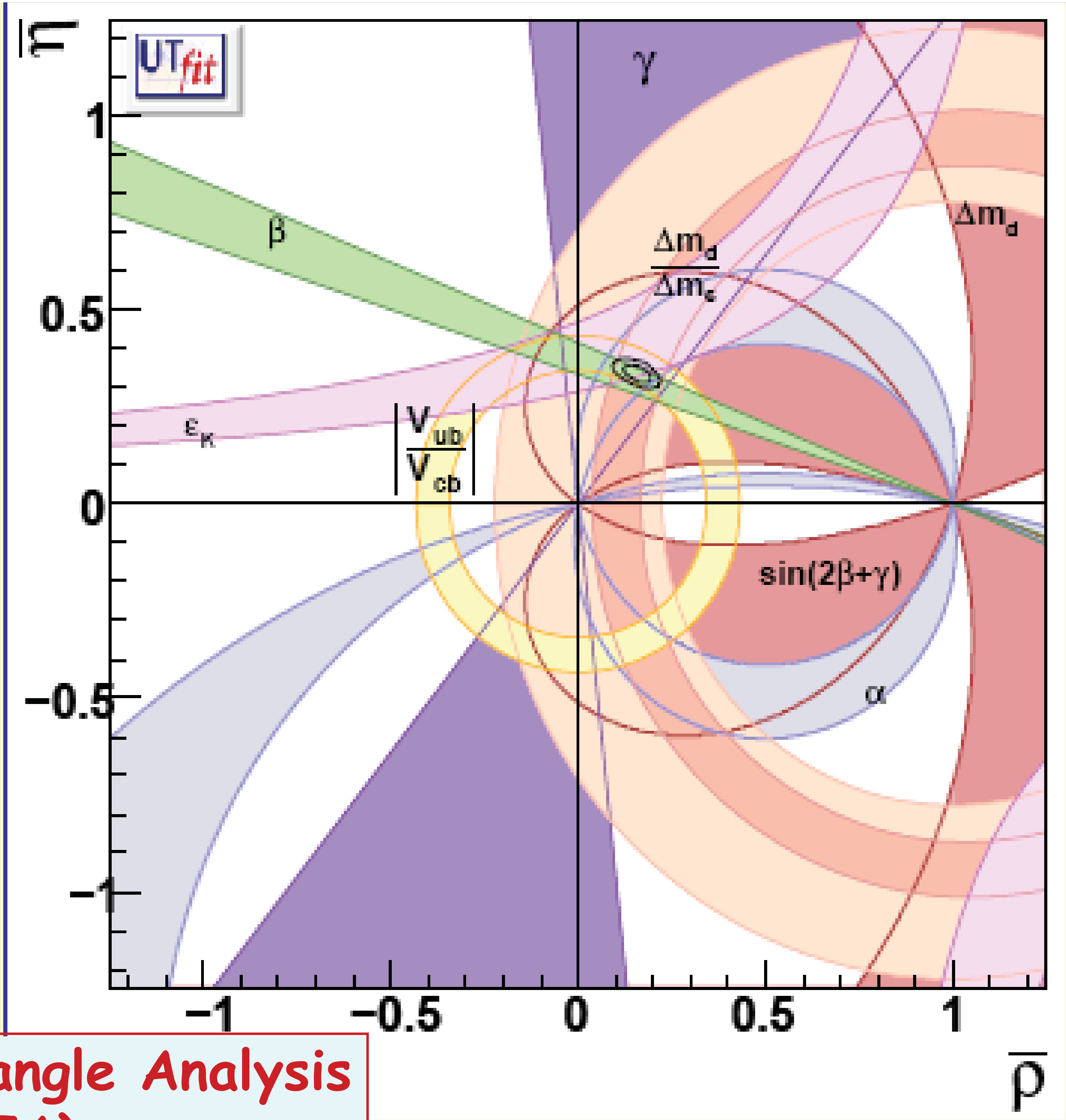


Unitarity Triangle Analysis (UTA)

Weak eigenstates   Mass eigenstates

The CKM Matrix

$$\bar{U}_L \, \gamma^\mu \, \underbrace{V_u^\dagger V_d}_{V_{CKM}} \, D_L \, W_\mu^+$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- 3x3 unitary matrix
- 4 parameters: 3 angles and 1 phase
- The phase is responsible of CP-violation

(With exact CPT, CP is equivalent to T, T is a antiunitary operator ⇒ T $V_{CKM} \rightarrow V^*_{CKM}$ which differs from V_{CKM} due to the phase)

First important aim of Flavour Physics:
Accurate determination of the CKM parameters

At present an accuracy of few % has been achieved!

Standard parameterization for a 3x3 unitary matrix

$$\hat{V}_{CKM} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -s_{23}c_{12} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

$V_{us} \approx 0.2 \equiv \lambda$ is small,
V_{CKM} can be expanded in λ

$$c_{23} \approx c_{13} \approx 1$$

$$s_{23} = O(\lambda^2)$$

$$s_{13} = O(\lambda^3)$$

Expanding up to $O(\lambda^3)$ and introducing new convenient paramenters (A, λ, ρ, η)

$$s_{23} \equiv A\lambda^2, \quad s_{13}e^{-i\delta} \equiv A\lambda^3(\rho - i\eta)$$

one gets:

The Unitarity Triangle Analysis (UTA)

Wolfenstein parameterization (up to $O(\lambda^3)$)

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cong \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Accurately measured: - λ=0.225(1) (several kaon exp., among which KLOE@Frascati)
- A=0.81(2) (B-factories)

($\eta \neq 0 \leftrightarrow$ CP-violation)

Some $O(\lambda^5)$ corrections are required by the present accuracy and are included by keeping higher order terms in the original parameterization rexpressed in terms of A, λ, ρ, η (so that the CKM matrix satisfies unitarity at all orders)

$$V_{ud} = 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 + \mathcal{O}(\lambda^6)$$

$$V_{us} = \lambda + \mathcal{O}(\lambda^7)$$

$$V_{ub} = A\lambda^3(\varrho - i\eta)$$

$$V_{cd} = -\lambda + \frac{1}{2}A^2\lambda^5[1 - 2(\varrho + i\eta)] + \mathcal{O}(\lambda^7)$$

$$V_{cs} = 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1 + 4A^2) + \mathcal{O}(\lambda^6)$$

$$V_{cb} = A\lambda^2 + \mathcal{O}(\lambda^8)$$

$$V_{td} = A\lambda^3\left[1 - (\varrho + i\eta)(1 - \frac{1}{2}\lambda^2)\right] + \mathcal{O}(\lambda^7)$$

$$V_{ts} = -A\lambda^2 + \frac{1}{2}A(1 - 2\varrho)\lambda^4 - i\eta A\lambda^4 + \mathcal{O}(\lambda^6)$$

$$V_{tb} = 1 - \frac{1}{2}A^2\lambda^4 + \mathcal{O}(\lambda^6)$$

To an excellent accuracy:

$$V_{us} = \lambda, \qquad V_{cb} = A\lambda^2,$$

$$V_{ub} = A\lambda^3(\varrho - i\eta), \qquad V_{td} = A\lambda^3(1 - \bar{\varrho} - i\bar{\eta})$$

$$\bar{\rho} = \rho\left(1 - \frac{\lambda^2}{2}\right), \qquad \bar{\eta} = \eta\left(1 - \frac{\lambda^2}{2}\right)$$

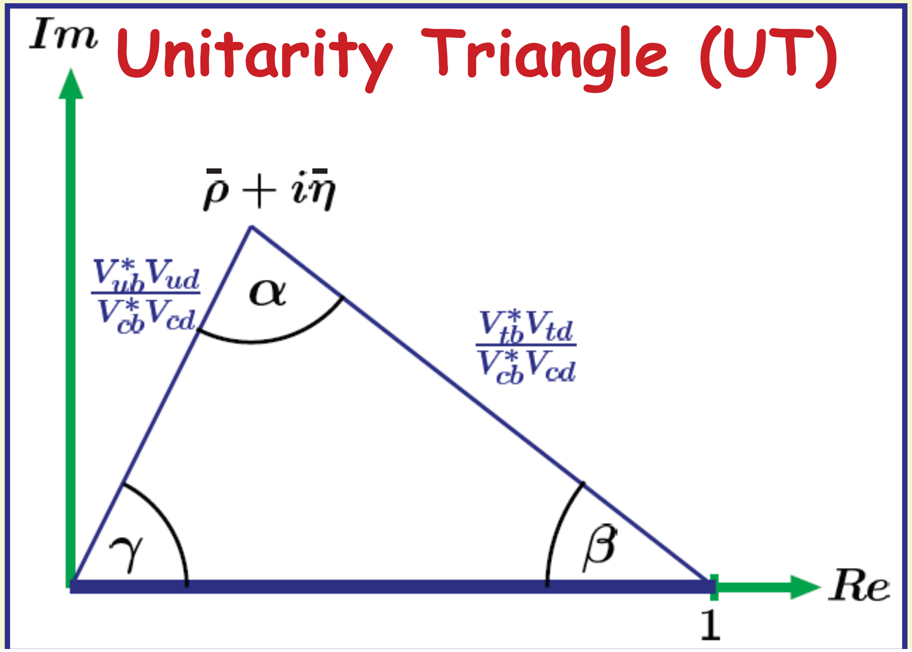
The Unitarity Triangle Analysis (UTA)

- Unitarity ($V^{\dagger}_{CKM} V_{CKM} = 1$) provides 9 conditions on the CKM parameters

- Among these it is of great phenomenological interest

$$V^*_{ub} V_{ud} + V^*_{cb} V_{cd} + V^*_{tb} V_{td} = 0$$

It defines a triangle in the $(\bar{\rho},\bar{\eta})$-plane
(with sides of similar size, so that CP-violation is visible)



There are two collaborations working at the UTA

CKM fitter

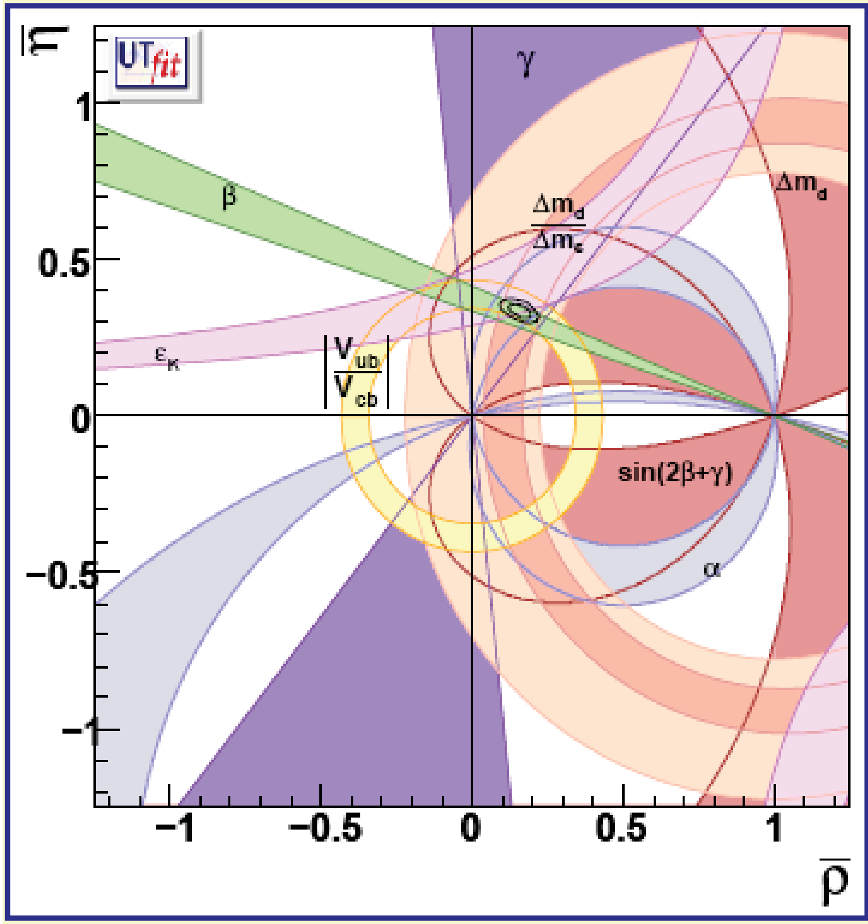
13 members from
France, Switzerland, Germany and Japan

UTfit

Collaboration of Theorists and Experimentalists

Adrian Bevan	Queen Mary, University of London
Marcella Bona	Queen Mary, University of London
Marco Ciuchini	INFN Sezione di Roma Tre
Denis Derkach	LAL-IN2P3 Orsay
Enrico Franco	University of Roma "La Sapienza"
Vittorio Lubicz	University of Roma Tre
Guido Martinelli	University of Roma "La Sapienza"
Fabrizio Parodi	University of Genova
Maurizio Pierini	CERN
Carlo Schiavi	University of Genova
Luca Silvestrini	INFN Sezione of Roma
Viola Sordini	IPNL-IN2P3 Lyon
Achille Stocchi	LAL-IN2P3 Orsay
Cecilia Tarantino	University of Roma Tre
Vincenzo Vagnoni	INFN Sezione of Bologna

Great Accuracy achieved in the UTA



Experimental Constraints

Obs.	Accuracy	
ε_K	$\approx 0.4\%$	Requiring the calculation of hadronic matrix elements
Δm_d	$\approx 1\%$	
$\left|\frac{\Delta m_s}{\Delta m_d}\right|$	$\approx 1\%$	
$\left|\frac{V_{ub}}{V_{cb}}\right|$	$\approx 5\%$	
$\sin 2\beta$	$\approx 4\%$	Not requiring it
$\cos 2\beta$	$\approx 15\%$	
α	$\approx 7\%$	
γ	$\approx 15\%$	
$(2\beta+\gamma)$	$\approx 50\%$	

For a significant comparison between exp. measurements and theor. predictions, hadronic uncertainties must be well under control

The fundamental role of Lattice QCD

Lattice QCD:

- √ non-perturbative approach
  (path-integral method)
- √ only the QCD parameters
- √ theory regularization
- ✗ discrete space and finite volume

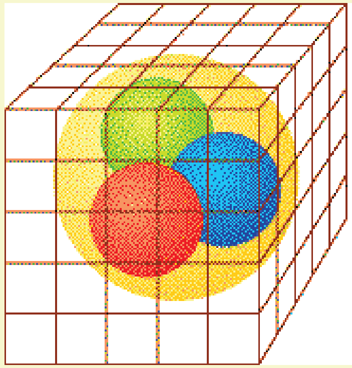
Path Integral:

Green functions ≡ derivatives of the generating functional

$$Z(J_\mu,\eta,\bar{\eta}) = \int \delta A\, \delta\bar{q}\, \delta q\ e^{-S(A,q,\bar{q}) + \int J_\mu A_\mu + \int \bar{\eta} q + \int \bar{q}\eta}$$

In order to formally define the integrals, one considers a discrete LATTICE in a finite volume:

infinite-dimension integrals → ordinary multiple integrals



$$\langle O(A,q,\bar{q})\rangle = \int \delta A\, \delta\bar{q}\, \delta q\ O(A,q,\bar{q})\ e^{-S(A,q,\bar{q})}$$

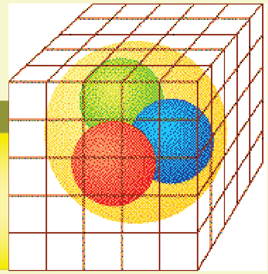
Few configurations only are relevant ☺

$$\cong \overline{O} = \frac{1}{N}\sum_{i=1}^{N} O(C_i)$$

Generated by a Monte Carlo

In the era of precision Flavour Physics
We have also entered the era of

Precision LATTICE QCD



Unquenched calculations with relatively **low quark masses** are now being performed by **several groups** using **different approaches** (lattice action, renormalization,…).

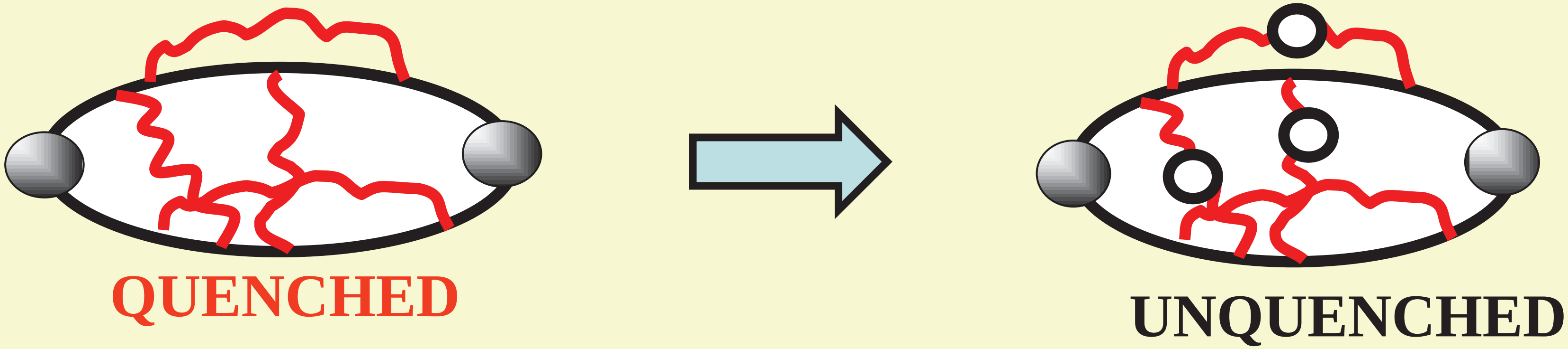
Crucial when aiming at a percent precision.

"PRECISION" LATTICE QCD: WHY NOW

1)Increasing of computational power

(Several machines of O(10-100 TeraFlops))

→ Unquenched simulations



2) Algorithmic improvements:

→ Light quark masses in the ChPT regime

FLAVOUR PHYSICS ON THE LATTICE

Collaboration	Quark action	Nf	a [fm]	$(M_\pi)^{min}$ [MeV]	Observables
MILC + FNAL, HPQCD,…	Improved staggered	2+1	≥ 0.045	230	f_K, B_K, $f_{D(s)}$, $D\to\pi/K\,l\nu$, $f_{B(s)}$, $B_{B(s)}$, $B\to D/\pi\,l\nu$
PACS-CS	Clover (NP)	2+1	0.09	156	f_K
RBC/UKQCD	DWF	2+1	≥ 0.08	290	$f_+(0)$, f_K, B_K
BMW	Clover smeared	2+1	≥ 0.07	190	f_K
JLQCD	Overlap	2 2+1	0.12	290	B_K
ETMC	Twisted mass	2 2+1+1	≥ 0.07	260	$f_+(0)$, f_K, B_K,$f_{D(s)}$, $D\to\pi/K\,l\nu$, $f_{B(s)}$
QCDSF	Clover (NP)	2	≥ 0.06	300	$f_+(0)$, f_K

Importance and Success of Lattice QCD in Flavour Physics

$|V_{us}| \equiv \lambda$
(CKM parameter: $\sin\theta_{Cabibbo}$)

- V_{us} and the "1st row" unitarity test
- The Unitarity Triangle Analysis (UTA)

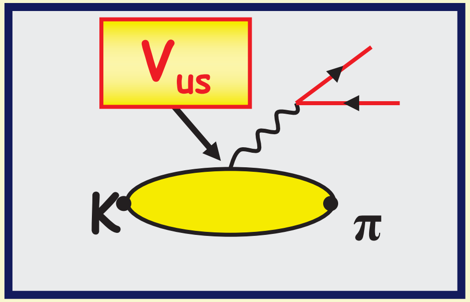
1st row: the most stringent unitarity test

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

Source:	Nuclear β-dec.	Kl3,Kl2	b→u semil.
Abs. error:	$4 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$\sim 10^{-6}$

$\lambda = V_{us}$ from Kl3 decays

$$\Gamma_{K\to\pi l\nu} = C_K^2 \frac{G_F^2 m_K^5}{192\pi^2} \, I \, S_{EW} [1 + \Delta_{SU(2)} + 2\Delta_{EM}] \times |V_{us}|^2 |f_+^{K\pi}(0)|^2$$



Ademollo-Gatto: $f_+(0) = 1 - O(m_s - m_u)^2$ ⇐ O(1%). But represents the largest theoret. uncertainty

ChPT

$$f_+(0) = 1 + f_2 + f_4 + O(p^8)$$

Vector Current Conservation	$f_2 = -0.023$ Independent of L_i (Ademollo-Gatto)	THE LARGEST UNCERTAINTY

Old standard estimate:

Leutwyler, Roos (1984)

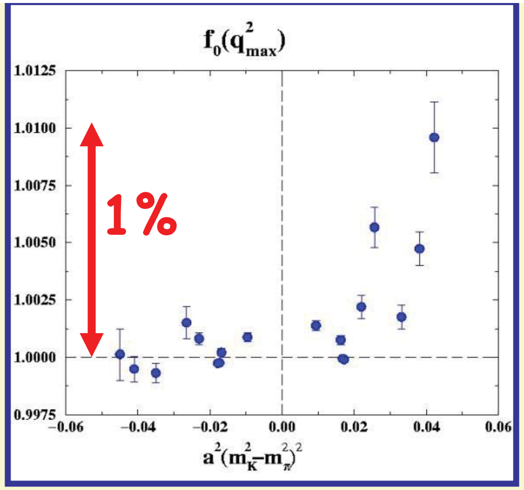
(QUARK MODEL)

$f_4 = -0.016 \quad 0.008$

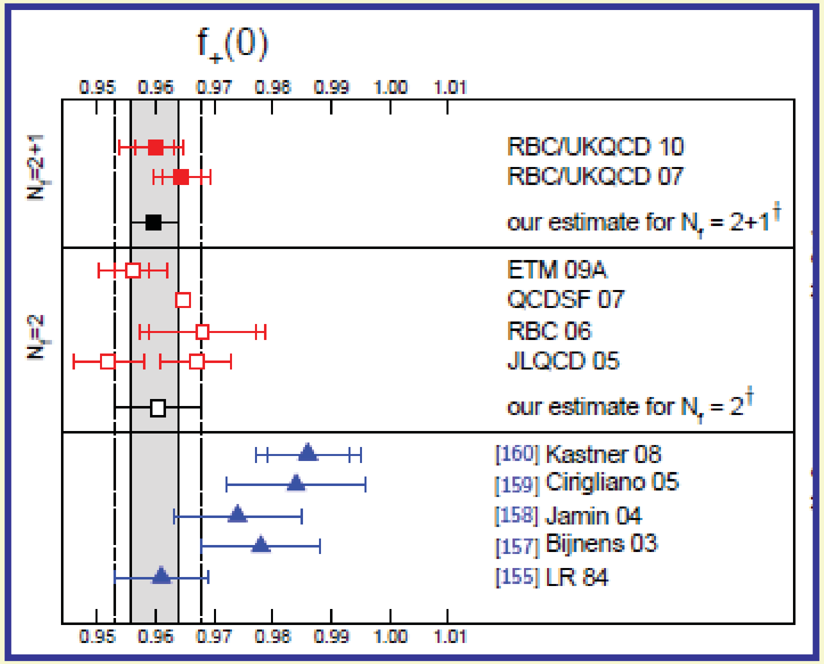
Lattice QCD

THE O(1%) PRECISION CAN BE REACHED

D.Becirevic, G.Isidori, V.Lubicz, G.Martinelli, F.Mescia, S.Simula, C.T., G.Villadoro. [NPB 705,339,2005]



The basic ingredient is a double ratio of correlation functions [FNAL for B→D,D*]



- Good agreement between Nf=2 and 2+1 calculations and the first quenched result

- Analytical (model dependent) results slightly higher than Lattice QCD

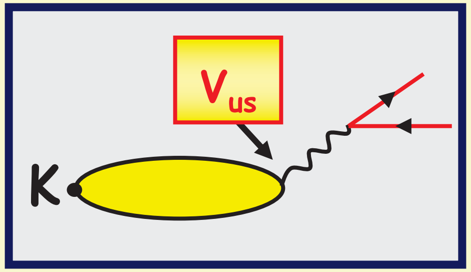
Flavour Lattice Averaging Group (FLAG) [1011.4408]

$f_+(0)=0.956(8) \rightarrow |V_{us}|=0.225(1)$

V_{us}/V_{ud} from $K\mu2/\pi\mu2$ decays

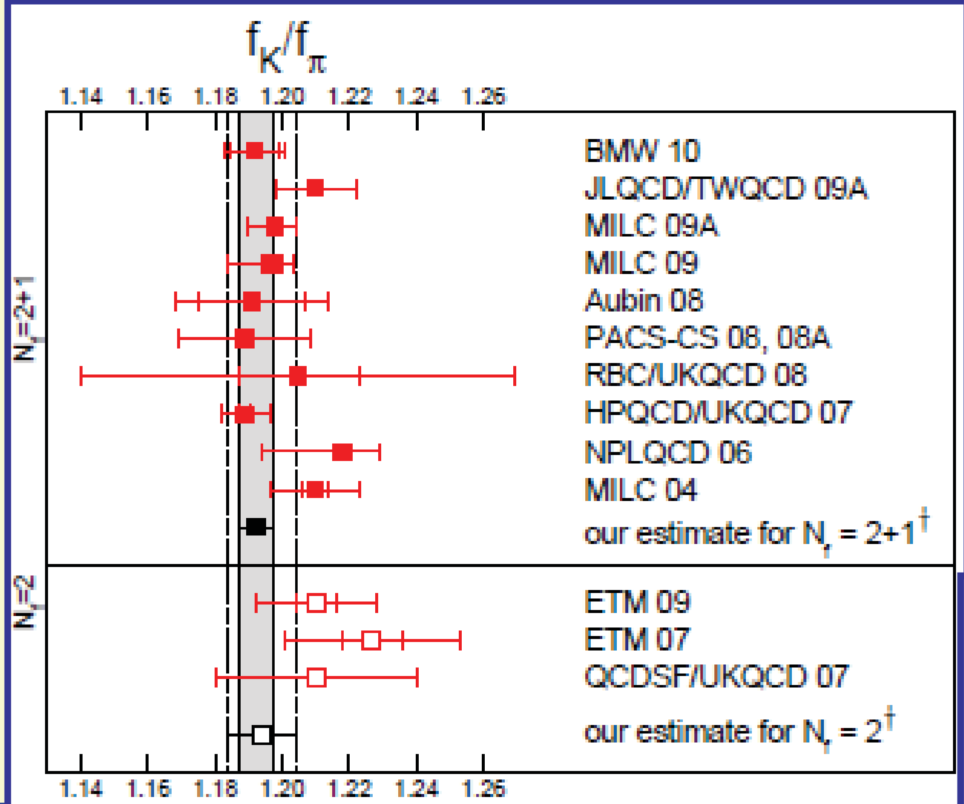
$$\frac{\Gamma(K \to \mu\bar{\nu}_\mu(\gamma))}{\Gamma(\pi \to \mu\bar{\nu}_\mu(\gamma))} = \frac{|V_{us}|^2}{|V_{ud}|^2}\left(\frac{f_K}{f_\pi}\right)^2 \frac{m_K(1-\frac{m_\mu^2}{m_K^2})}{m_\pi(1-\frac{m_\mu^2}{m_\pi^2})} \times 0.9930(35)$$

[Marciano 04]



The lattice determination of f_K/f_π, together with the experimental measurement of the leptonic decay Br's, and with $|V_{ud}|$ from nucleon beta decays, allows to extract $|V_{us}|$

f_K/f_π: LATTICE SUMMARY

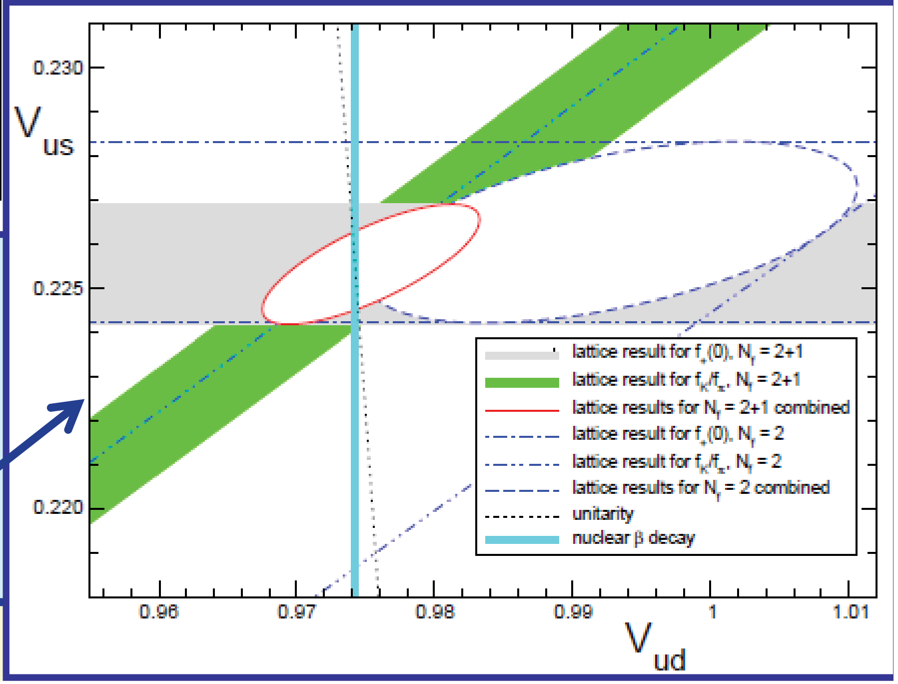


FLAG

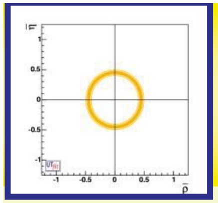
f_K/f_π=1.193(6)

$|V_{us}|$=0.225(1)

FLAG

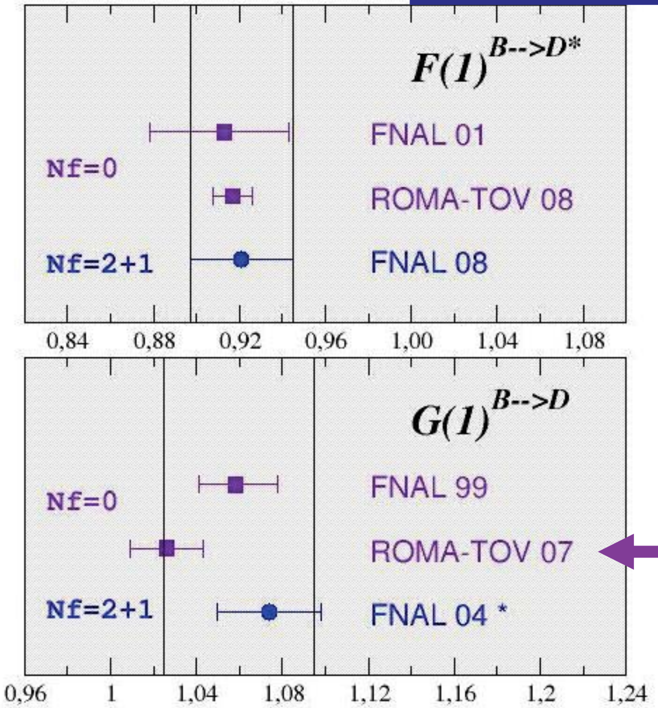


- There is no visible difference between N_f=2 and 2+1 with present uncertainties
- Kl3 and Kl2 determinations of V_{us} are in perfect agreement
- First row unitarity test works well



Exclusive $V_{cb} = A\,\lambda^2$

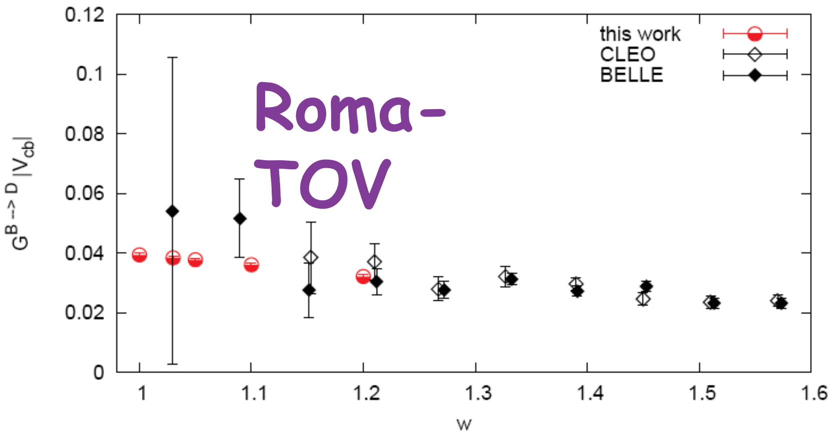
$$\frac{d\Gamma^{B\to D\ell\nu_\ell}}{dw} = |V_{cb}|^2 \frac{G_F^2}{48\pi^3}(M_B+M_D)^2 M_D^3 (w^2-1)^{3/2}\left[G^{B\to D}(w)\right]^2$$



TWO DIFFERENT APPROACHES:

- "double ratios" (FNAL)
- "step scaling" (TOV)

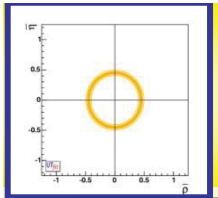
Remarkable agreement



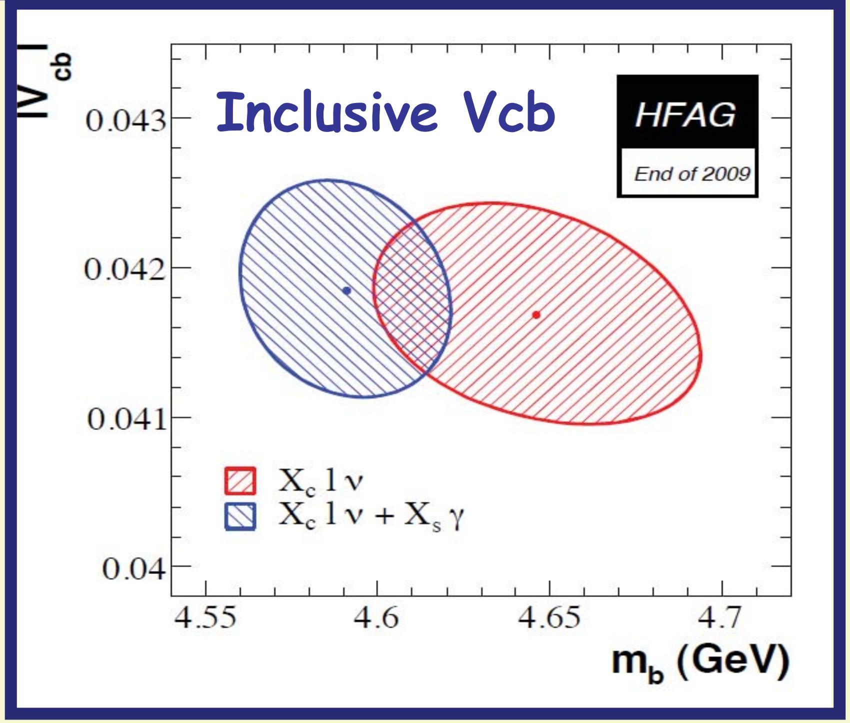
Averages from
V. Lubicz, CT 0807.4605

F(1) = 0.924	0.022	2%
G(1) = 1.060	0.035	3%

$|V_{cb}|_{excl.} = (39.0 \pm 0.9)\ 10^{-3}$



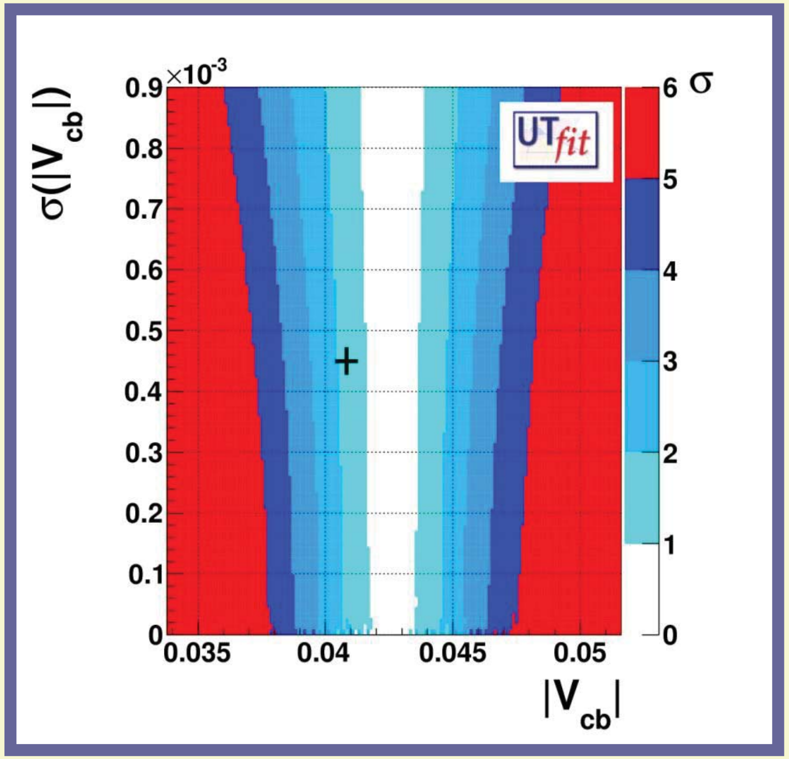
Exclusive vs Inclusive V_{cb}



$|V_{cb}|_{incl.} = (41.7 \pm 0.7)\ 10^{-3}$

2.5 σ

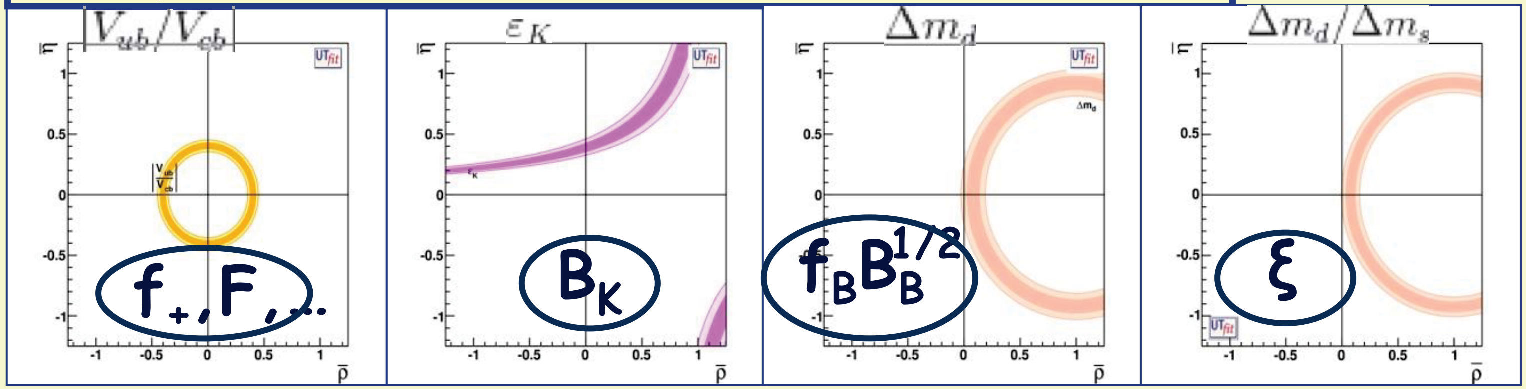
$|V_{cb}|_{excl.} = (39.0 \pm 0.9)\ 10^{-3}$



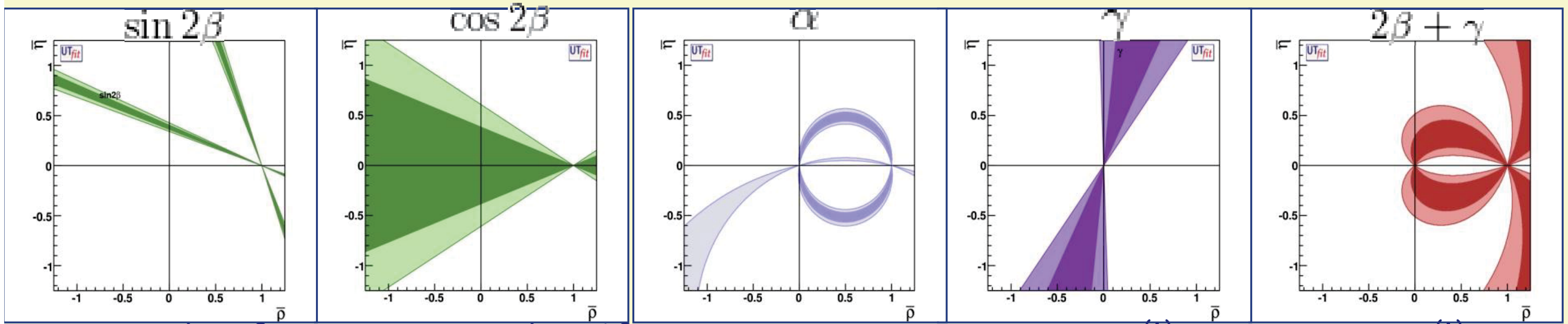
$|V_{cb}|_{SM\text{-}Fit} = (42.7 \pm 1.0)\ 10^{-3}$

THE UTA CONSTRAINTS

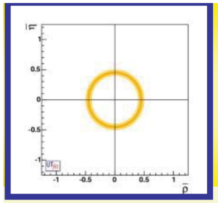
Relying on LATTICE calculations



UT-ANGLES



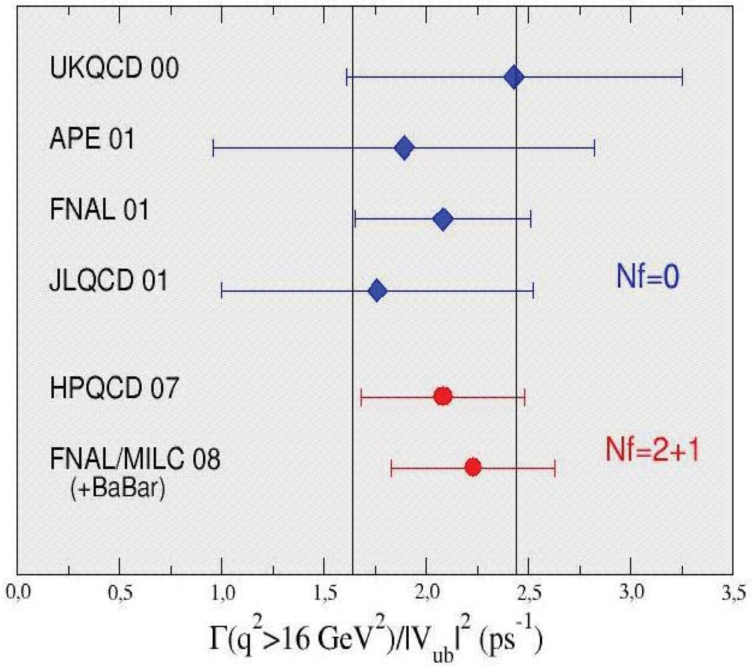
$B \to J/\Psi K^0$ $B \to J/\Psi K^{*0}$ $B \to \pi\pi, \rho\rho$ $B \to D^{(*)}K$ $B \to D^{(*)}\pi, D\rho$



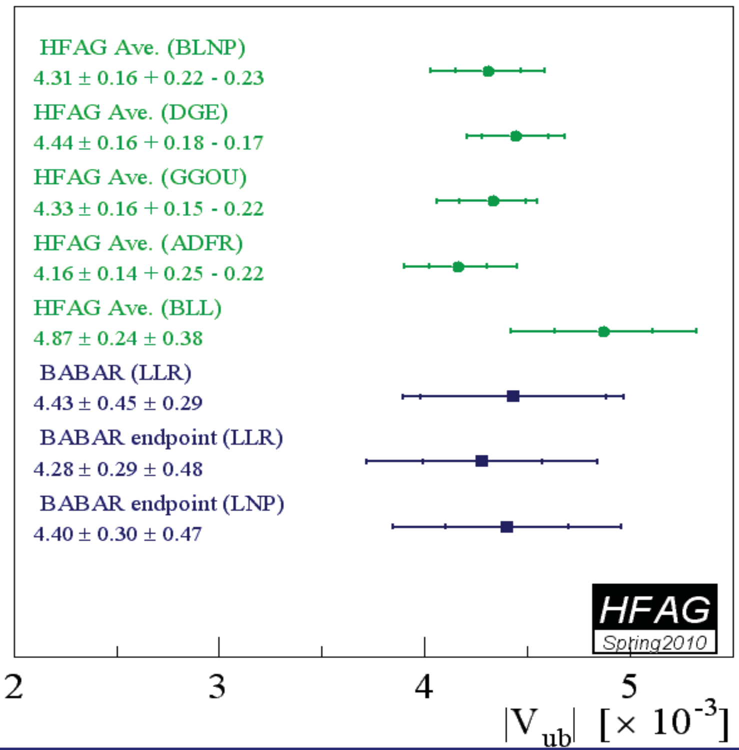
Exclusive vs Inclusive V_{ub}

THEORETICALLY CLEAN BUT MORE LATTICE CALCULATIONS ARE WELCOME

$$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{192\pi^3 m_B^3} \left[(m_B^2 + m_\pi^2 - q^2)^2 - 4 m_B^2 m_\pi^2 \right]^{3/2} |f_+(q^2)|^2$$



IMPORTANT LONG DISTANCE CONTRIBUTIONS (in the threshold region). THE RESULTS ARE MODEL DEPENDENT



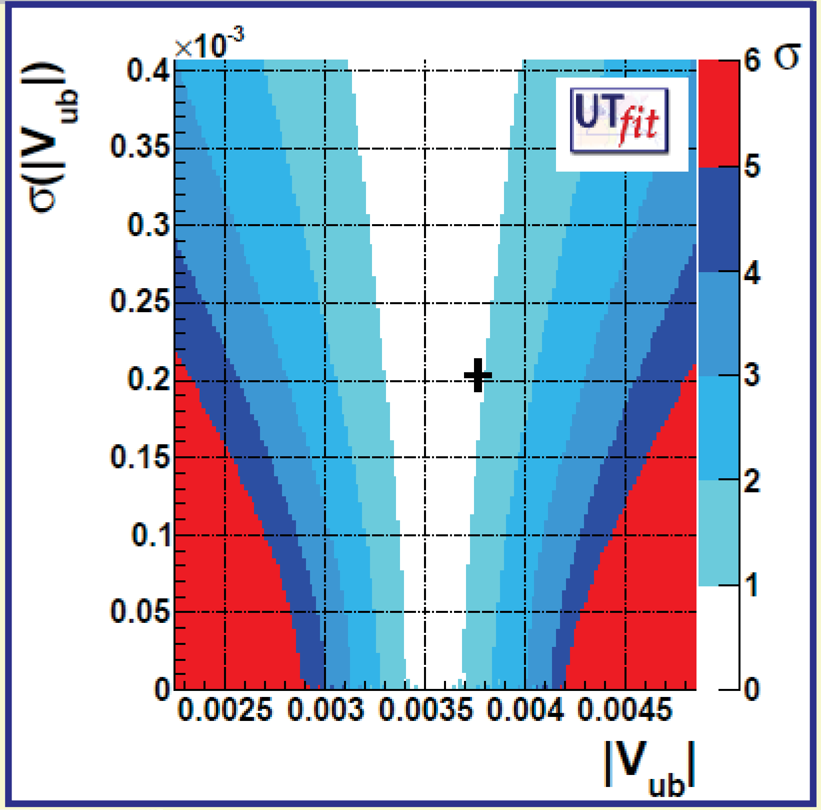
$|V_{ub}|_{excl.} = (35.0 \pm 4.0)\ 10^{-4}$

$|V_{ub}|_{incl.} = (42.0 \pm 1.5 \pm 5.0)\ 10^{-4}$

Exclusive vs Inclusive V_{ub}

- The uncertainty of inclusive V_{ub} estimated from the spread among different models. This is questionable

- The fit in the SM favors a low value of V_{ub}, as indicated by exclusive decays



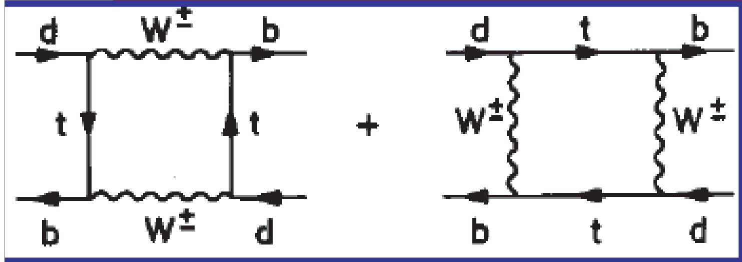
$|V_{ub}|_{incl.} = (42.0 \pm 1.5 \pm 5.0)\ 10^{-4}$

$|V_{ub}|_{excl.} = (35.0 \pm 4.0)\ 10^{-4}$

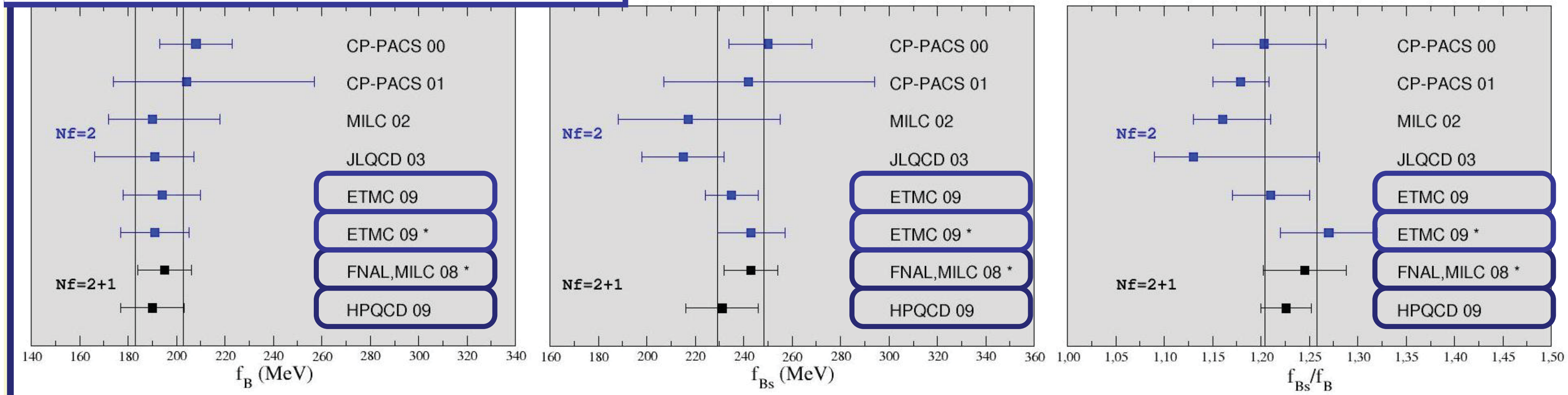
- Improve the accuracy of exclusive V_{ub} in order to clarify the issue

$|V_{ub}|_{SM\text{-}Fit} = (35.5 \pm 1.4)\ 10^{-4}$

B-mesons decay constants f_B, f_{Bs} and B-$\bar{B}$ mixing, $B_{Bd/s}$



$$\Delta M_q = \frac{G_F^2}{6\pi^2}\eta_B m_{B_q}(\hat{B}_{B_q} F_{B_q}^2) M_W^2 S_0(x_t)|V_{tq}|^2$$



f_{Bs} = 238.8   9.5 MeV

f_B = 192.8   9.9 MeV

4-5%

f_{Bs}/f_B = 1.231   0.027

2%

Combining with the only modern calculation **HPQCD [0902.1815]:**

$\hat{B}_{Bd} = 1.26 \pm 0.11$, $\hat{B}_{Bs} = 1.33 \pm 0.06$

$f_{Bs}\sqrt{\hat{B}_{Bs}}$ = 275   13 MeV

5%

$\xi = 1.243 \pm 0.028$

2%

ε_K: indirect CP-violation due to K^0-$\bar{K}^0$ mixing

Mixing formalism as in the B system

$$CP|K^0\rangle = -|\bar{K}^0\rangle, \qquad CP|\bar{K}^0\rangle = -|K^0\rangle$$

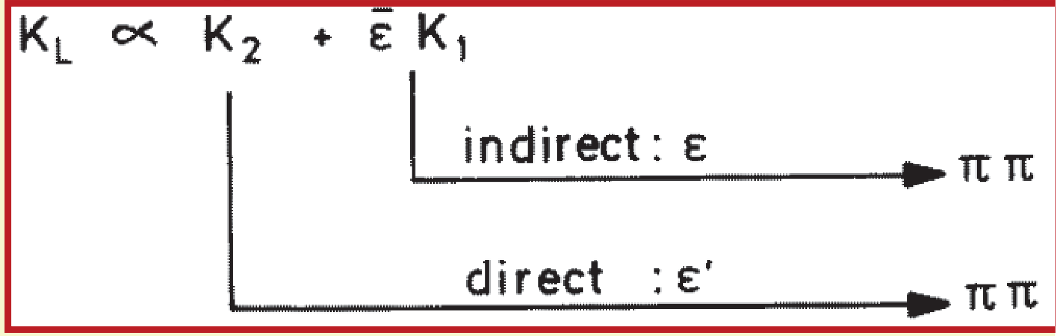
$$i\frac{d\psi(t)}{dt} = \hat{H}\psi(t) \qquad \psi(t) = \begin{pmatrix} |K^0(t)\rangle \\ |\bar{K}^0(t)\rangle \end{pmatrix}$$

$$\hat{H} = \begin{pmatrix} M - i\frac{\Gamma}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{12}^* - i\frac{\Gamma_{12}^*}{2} & M - i\frac{\Gamma}{2} \end{pmatrix}$$

H eigenstates (in the flavor and CP bases)

$$K_{L,S} = \frac{(1+\bar{\varepsilon})K^0 \pm (1-\bar{\varepsilon})\bar{K}^0}{\sqrt{2(1+|\bar{\varepsilon}|^2)}}$$

$$K_S = \frac{K_1 + \bar{\varepsilon}K_2}{\sqrt{1+|\bar{\varepsilon}|^2}}, \qquad K_L = \frac{K_2 + \bar{\varepsilon}K_1}{\sqrt{1+|\bar{\varepsilon}|^2}}$$



Within the K system:

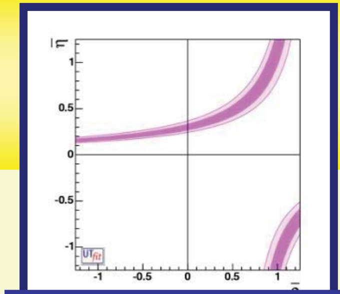
$$\mathrm{Im}M_{12} \ll \mathrm{Re}M_{12}, \qquad \mathrm{Im}\Gamma_{12} \ll \mathrm{Re}\Gamma_{12}$$

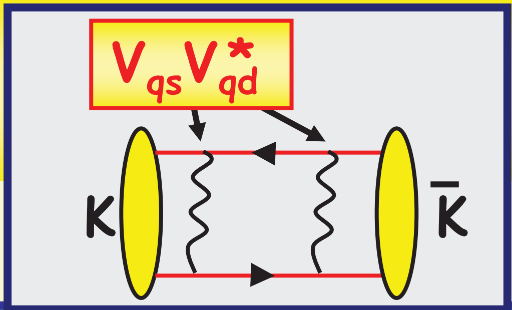
$$\Delta M_K = 2\mathrm{Re}M_{12}, \qquad \Delta\Gamma_K = 2\mathrm{Re}\Gamma_{12}$$

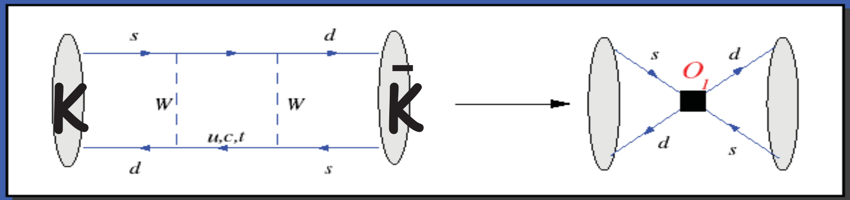
$$\epsilon_K = \sin\phi_\epsilon e^{i\phi_\epsilon}\left[\frac{\mathrm{Im}M_{12}^{(6)}}{\Delta m_K} + \rho\xi\right]$$

- Phase convention independent
- different CKM w.r.t B case
- The 3 GIM combinations are all relevent

K^0-$\bar{K}^0$ mixing: B_K







$$\langle \bar{K}^0 | Q(\mu) | K^0 \rangle = \frac{8}{3} f_K^2 m_K^2 B_K(\mu)$$

Pre-history

QCD SR, Pich, De Rafael, 1985:

$\hat{B}_K$= 0.33 0.09

1/Nc exp., Buras, Gerard, 1985:

$\hat{B}_K$= 0.75

LQCD, Gavela et al., 1987:

$\hat{B}_K$= 0.90 0.20

History

Quench. error

$\hat{B}_K$= 0.90 0.03 0.15

S.Sharpe@Latt'96 17%

$\hat{B}_K$= 0.86 0.05 0.14

L.Lellouch@Latt'00 17%

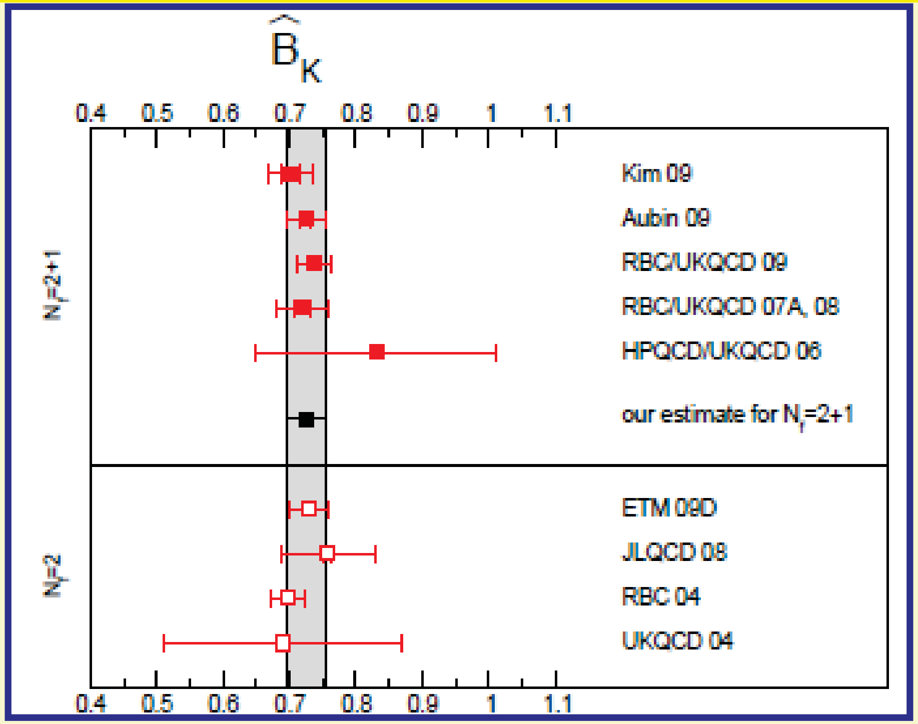
$\hat{B}_K$= 0.79 0.04 0.08

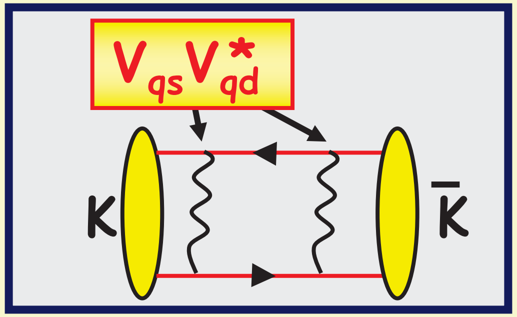
C.Dawson@Latt'05 11%

$\hat{B}_K$= 0.731 0.036

V.Lubicz@Latt'09 5%

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





$\hat{B}_K = 0.724(8)(29)$

[FLAG]

5%

Buras&Guadagnoli (0805.3887)+Buras&Guadagnoli&Isidori (1002.3612):

decrease of the SM prediction of ε_K by ~6%

$$\epsilon_K = \sin\phi_\epsilon e^{i\phi_\epsilon}\left[\frac{\mathrm{Im}M_{12}^{(6)}}{\Delta m_K} + \rho\xi\right]$$

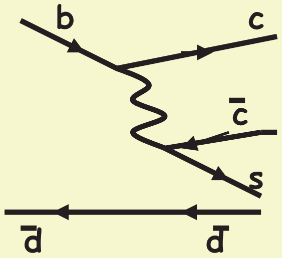
Long-distance

β (ϕ_1)

$V_{td}=|V_{td}|e^{-i\beta}$

Golden mode: $B \to J_\psi K_S$

Dominated by one tree-level amplitude $b \to c\bar{c}s$ ⇒ Simple expr. for the t-dep. CP-asymmetry $A_{CP}(t) = -\sin 2\beta \sin(\Delta M_d t)$



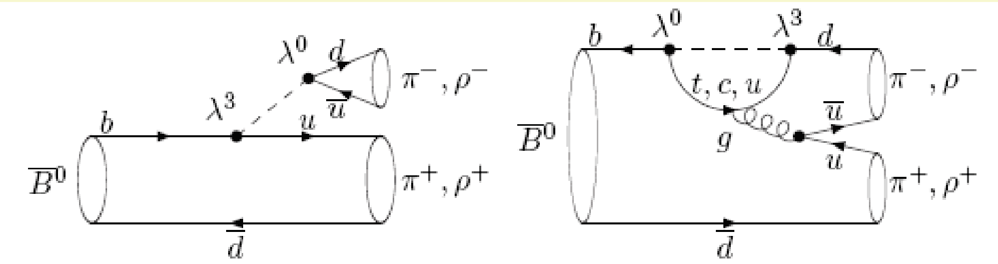
Main theoretical uncertainty from the hadronic matrix elements of the CKM-suppressed $b \to \bar{u}us$ contribution (irreducile theory error ~1%)

- Similar semplification in other $b \to c\bar{c}s$ channels: $\Psi(2S)K_S$, $\chi_{c1} K_S$, $\eta_c K_S$, $J_\psi K_L$, $J_\psi K^*$, $B_s \to \Psi\phi$
- Alternative determinations (sensitive to NP) from the charmless $b \to s$ one-loop (penguin) amplitude: $B \to \eta' K_{S,L}$, $B \to \phi K_S$
- $\cos 2\beta$ from a time-dep. analysis of $B \to J_\psi K^*$, $B \to D\pi^0$ ($\cos 2\beta > 0$ solving the $\beta \leftrightarrow (\pi/2 - \beta)$ ambiguity)

α (ϕ_2)

$$\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]$$

from charmless decays: $B\to\pi\pi$, $B\to\rho\rho$, $B\to\rho\pi$
($\leftrightarrow$tree-level transition $b\to u\bar{u}d$ carrying V_{ub})



The penguin contribution, introducing different CKM factors, complicate the extraction of α: tree-penguin disentanglement is required

$\Downarrow$

Analysis of a large set of observables:
Br's, $A_{CP}(t)$ both in neutral and charged B decays

B$\to\pi\pi$: isospin analysis [M.Gronau, D.London, 1990] + info from $Br(B_s\to K^+K^-)$ [M.Bona et al (UTfit), hep-ph/0701204]
B$\to\rho\rho$: advantage of the suppression of $Br(B\to\rho^0\rho^0)$ and of the related uncertainty
B$\to\rho\pi$: advantage of $\rho^+\pi^-$ and $\rho^-\pi^+$ reachable by both B^0 and $\overline{B^0}$, no model-dependance for the strong phase
[A.E.Snyder, H.R.Quinn, 1993]

Main theoretical uncertainty
from isospin violations
mainly in ew penguins and FSI
(irreducile theory error few%)

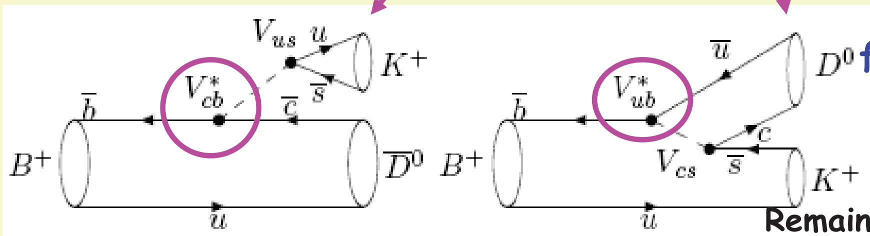
γ (ϕ_3)

$V_{ub} = |V_{ub}| e^{-i\gamma}$

Determination of γ from B→DK decays:

[I.I.Y.Bigi, A.I.Sanda, 1988, A.B.Carter, A.I. Sanda, 1988]

- $B^+ \to DK^+$ can produce both D^0 and $\bar{D}^0$, via $\bar{b} \to \bar{c}u\bar{s}$ and $\bar{b} \to \bar{u}c\bar{s}$
- D^0 and $\bar{D}^0$ can decay to a common final state
- The two amplitudes interfere with a relative phase δ_B γ, for $B^+(B^-)$



Main contributions from (theoretically clean) tree-level diagrams

Remaining theoretical uncertainty from simplifying D-$\bar{D}$ mixing neglection (irreducile theory error 0.1%)

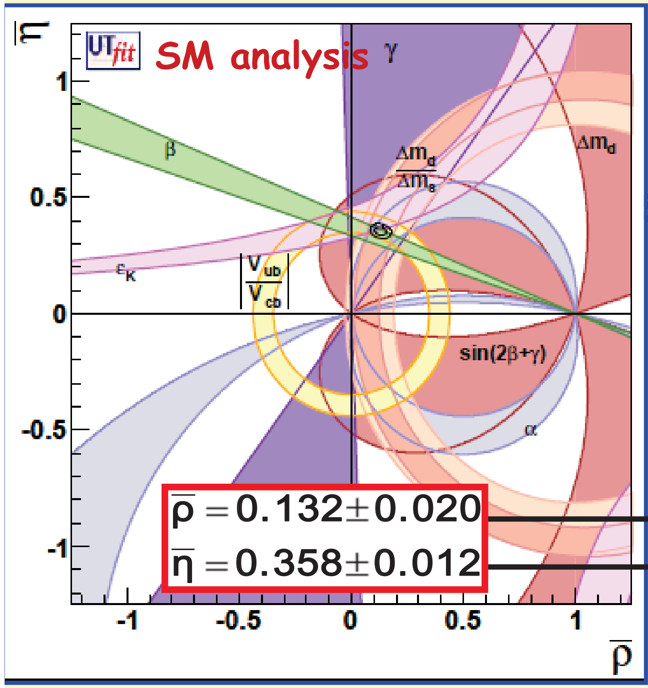
Various methods consider different final states:

- CP-eigenstates (Gronau,London,Wyler [GLW]) ($\pi^+\pi^-$, K^+K^-, $K_S\pi^0$, $K_S\phi$, $K_S\omega$,...)
- doubly Cabibbo suppressed D modes (Atwood,Dunietz,Soni [ADS]) ($K^+\pi^-$, $K^+\rho^-$, $K^*\pi^-$, ...)
- three-body D decaying modes (Dalitz plot analysis) ($K_S\pi^+\pi^-$ provides the best estimate at present)

[A.Giri, hep-ph/0303187]

The best strategy is a combined analysis taking into account many D and D* modes

The UTA within the Standard Model



~16%

~ 3%

The experimental constraints:

$\varepsilon_K, \Delta m_d, \left|\frac{\Delta m_s}{\Delta m_d}\right|, \left|\frac{V_{ub}}{V_{cb}}\right|$ ⇒ relying on theoretical calculations of hadronic matrix elements

$\sin 2\beta, \cos 2\beta, \alpha, \gamma(\;2\beta+\gamma)$ ⇒ independent from theoretical calculations of hadronic parameters

overconstrain the CKM parameters consistently

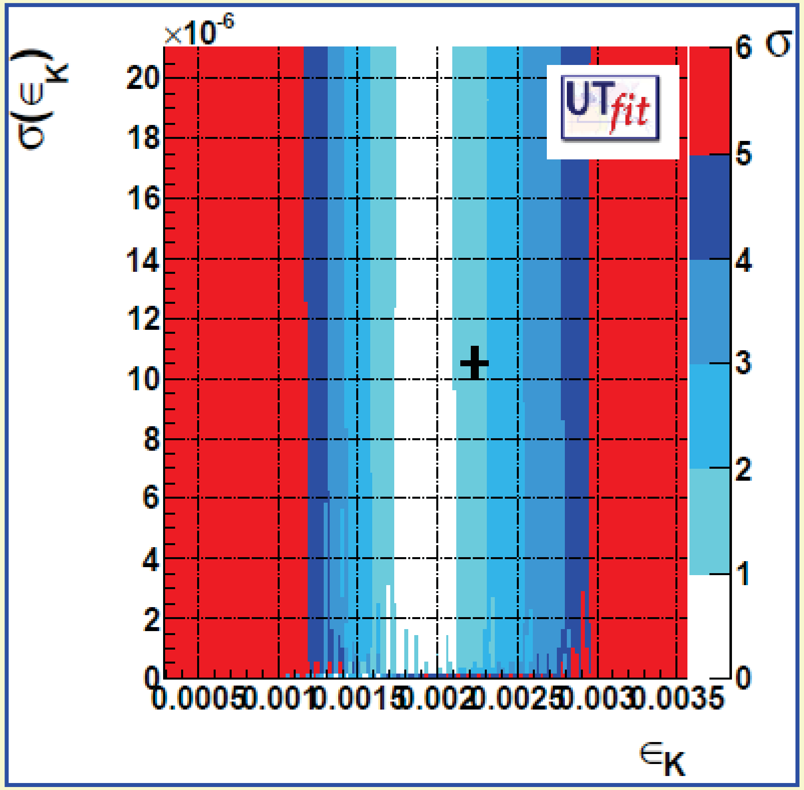
The UTA has established that the CKM matrix is the dominant source of flavour mixing and CP violation

From a closer look

From the UTA (excluding its exp. constraint) → Prediction

	Prediction	Measurement	Pull
$\sin 2\beta$	0.771 ± 0.036	0.654 ± 0.026	2.6 ←
γ	$69.6° \pm 3.1°$	$74° \pm 11°$	<1
α	$85.4° \pm 3.7°$	$91.4° \pm 6.1°$	<1
$\lvert V_{cb} \rvert \cdot 10^3$	42.69 ± 0.99	40.83 ± 0.45	+1.6
$\lvert V_{ub} \rvert \cdot 10^3$	3.55 ± 0.14	3.76 ± 0.20	<1
$\varepsilon_K \cdot 10^3$	1.92 ± 0.18	2.230 ± 0.010	-1.7 ←
$BR(B \to \tau \nu) \cdot 10^4$	0.805 ± 0.071	1.72 ± 0.28	-3.2 ←

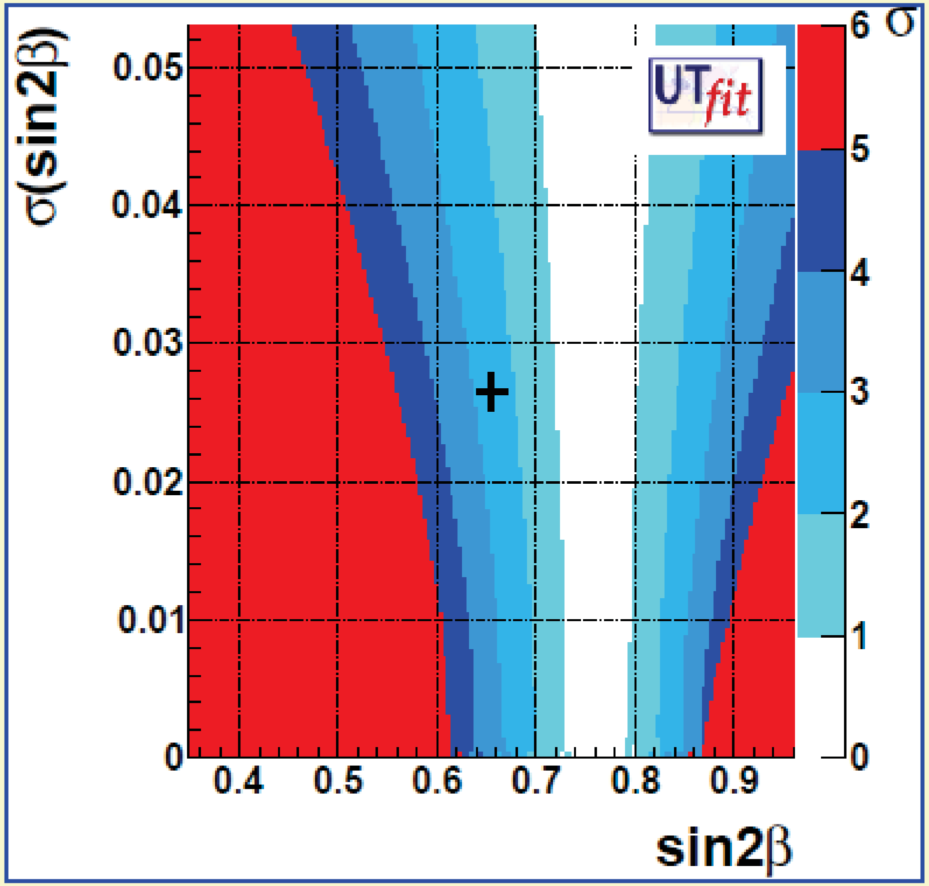
ε_K



NEWS:
Brod&Gorbahn (1007.0684): NNLO QCD analysis of the charm-top contribution in box diagrams
(3% enhancement of ε_K),
charm-charm contribution in progress

NEXT FUTURE:
Further few percents could come from dimension-8 operators: $\sim m_K^2/m_c^2$ corrections (calculation in progress)

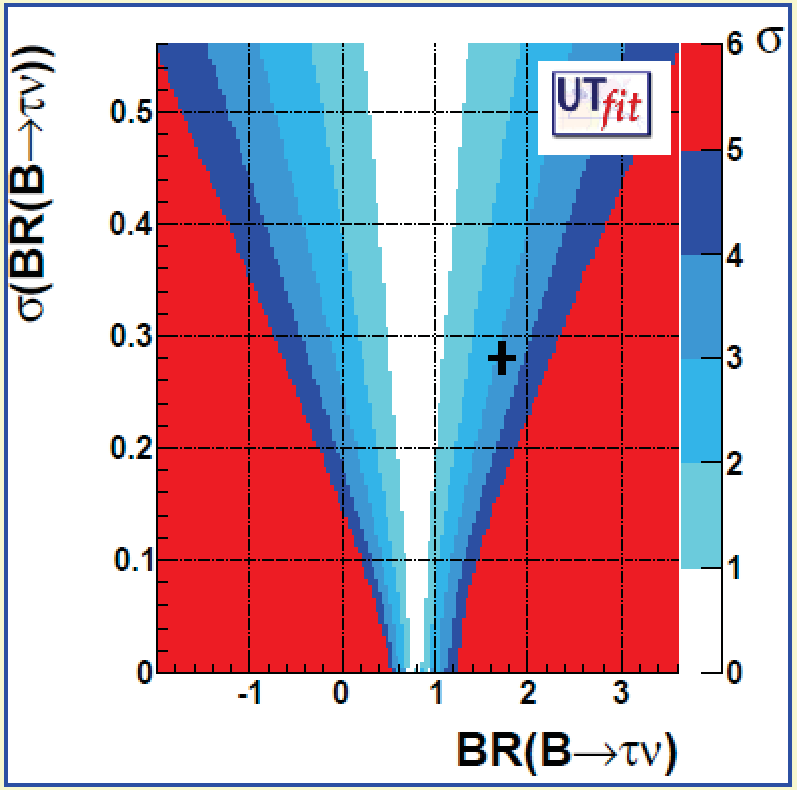
sin2β



The indirect determination of sin(2β) turns out to be at ~2.6 σ from the experimental measurement (the theory error in the extraction from $B \rightarrow J_{\psi} K_S$ is well under control)

$B \to \tau \nu$

$BR(B \to \tau \nu)_{SM} = (0.805\ \ 0.071) \cdot 10^{-4}$
[UTfit, update of 0908.3470]
turns out to be smaller by ~3.2 σ
than the experimental value
$BR(B \to \tau \nu)_{exp} = (1.72 \pm 0.28) \cdot 10^{-4}$



The experimental state of the art

BaBar Semileptonic tag (0912.2453)
BaBar Hadronic tag (0708.226, 1008.0104)

Belle Semileptonic tag (1006.4201)
Belle Hadronic tag (hep-ex/0604018)
[full data set analysis is on the way]

$$BR(B \to \tau\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

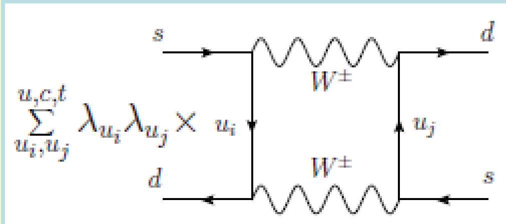
- $BR(B \to \tau \nu)_{exp}$ prefers a large value for $|V_{ub}|$ (f_B under control and improved by the UTA)
- But a shift in the central value of $|V_{ub}|$ would not solve the β tension
  the debate on V_{ub} (excl. vs incl, various models…) is not enough to explain all

The UTA beyond the Standard Model

Update of UTfit 0909.5065

Model-independent UTA: bounds on deviations from the SM (+CKM)

- Parametrize generic **NP** in $\Delta F=2$ processes, in all sectors
- Use all available experimental info
- Fit simultaneously the **CKM** and **NP** parameters



NP contributions in the mixing amplitudes:

$$H^{\Delta F=2} = m + \frac{i}{2}\Gamma \qquad A = m_{12} = \langle M|m|\bar{M}\rangle \qquad \Gamma_{12} = \langle M|\Gamma|\bar{M}\rangle$$

K mixing amplitude (2 real parameters):

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

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

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

SM	→	SM+NP
$(V_{ub}/V_{cb})^{SM}$ γ^{SM}	tree level	$(V_{ub}/V_{cb})^{SM}$ γ^{SM}
β^{SM} α^{SM} Δm_d	***Bd Mixing***	$\beta^{SM}+\phi_{Bd}$ $\alpha^{SM}-\phi_{Bd}$ $C_{Bd}\Delta m_d$
Δm_s^{SM} $-\beta_s^{SM}$	***Bs Mixing***	$C_{Bs}\Delta m_s^{SM}$ $-\beta_s^{SM}+\phi_{Bs}$
ε_K^{SM} Δm_K^{SM}	***K Mixing***	$C_{\varepsilon_K}\,\varepsilon_K^{SM}$ $C_{\Delta mK}\,\Delta m_K^{SM}$

From this (NP) analysis:

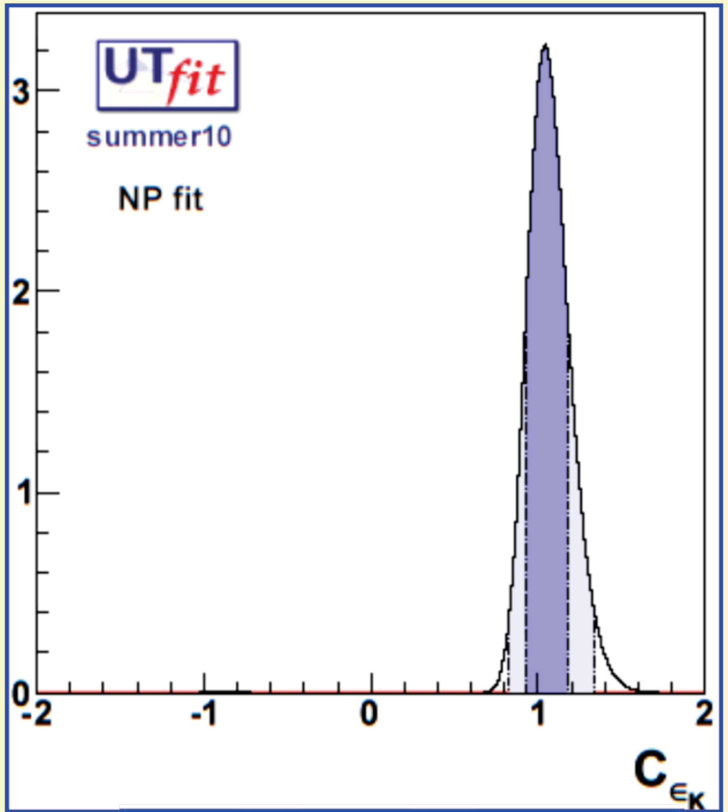
$$\bar{\rho} = 0.135 \pm 0.040$$
$$\bar{\eta} = 0.374 \pm 0.026$$

In good agreement with the results from the SM analysis

$$\bar{\rho} = 0.132 \pm 0.020$$
$$\bar{\eta} = 0.358 \pm 0.012$$

Results for the K and B_d mixing amplitudes

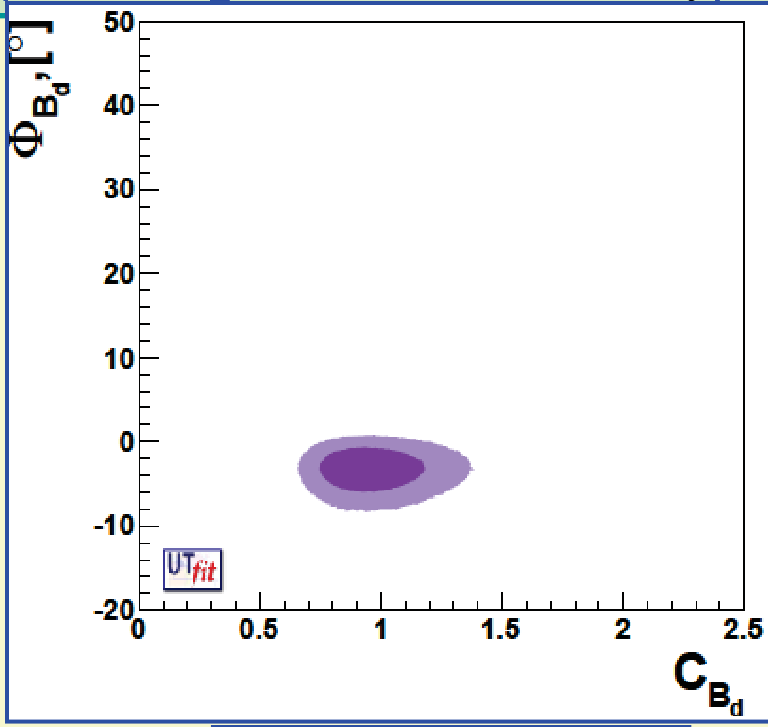
For $K-\bar{K}$ mixing, the NP parameter are found in agreement with the SM expectations



$C_{\varepsilon_K} = 1.05 \pm 0.12$

$[0.82, 1.34] \leftrightarrow 95\%$

For $B_d-\bar{B}_d$ mixing, the mixing phase ϕ_{Bd} is found 1.8 σ away from the SM expectation (reflecting the tension in $\sin 2\beta$)



$C_{B_d} = 0.95 \pm 0.14$

$[0.70, 1.27] \leftrightarrow 95\%$

$\Phi_{B_d} = (-3.1 \pm 1.7)^\circ$

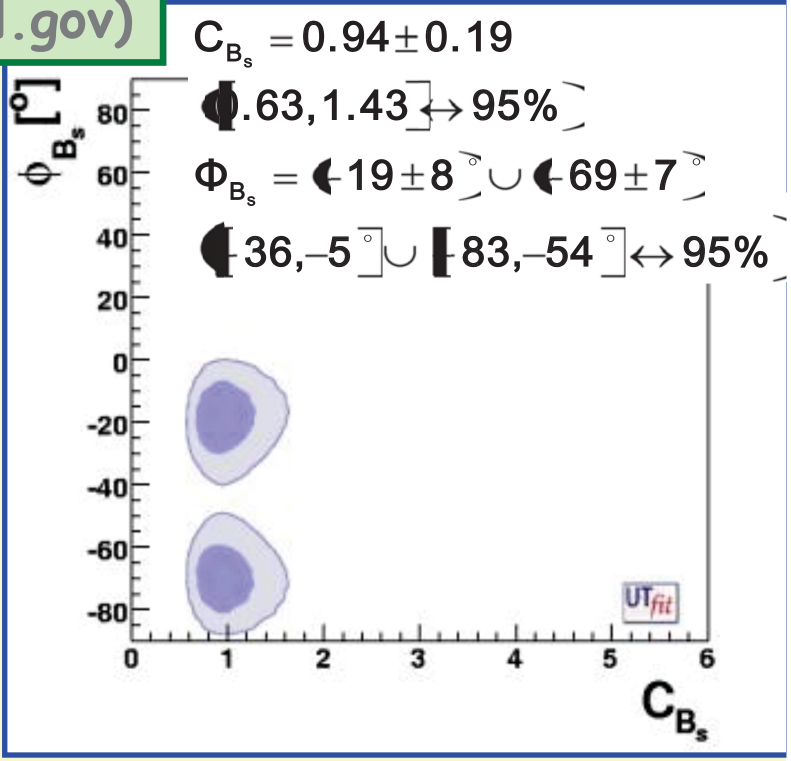
$[-7.0, 0.1]^\circ \leftrightarrow 95\%$

Results for the B_s mixing amplitude: INTERESTING NEWS ⟹ NEW QUESTION MARKS

In 2009, by combining CDF and DØ results for ϕ_{Bs}:

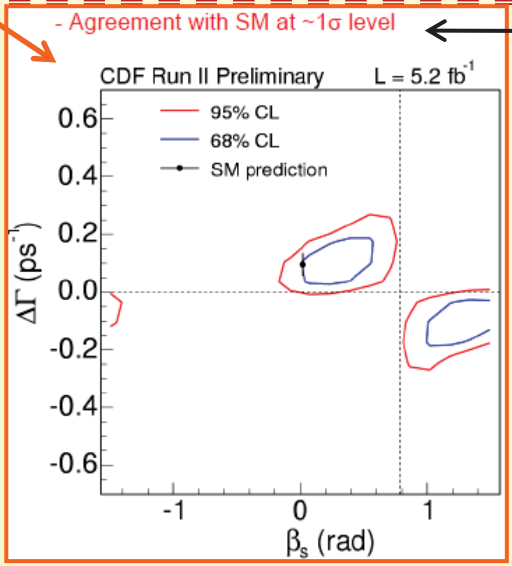
UTfit: 2.9σ (update of 0803.0659)
HFAG: 2.2σ (0808.1297)
CKMfitter: 2.5σ (0810.3139)
Tevatron B w.g.: 2.1σ (http://tevbwg.fnal.gov)

More than 2σ deviation for every statistical approach!



In 2010, two surprising news:

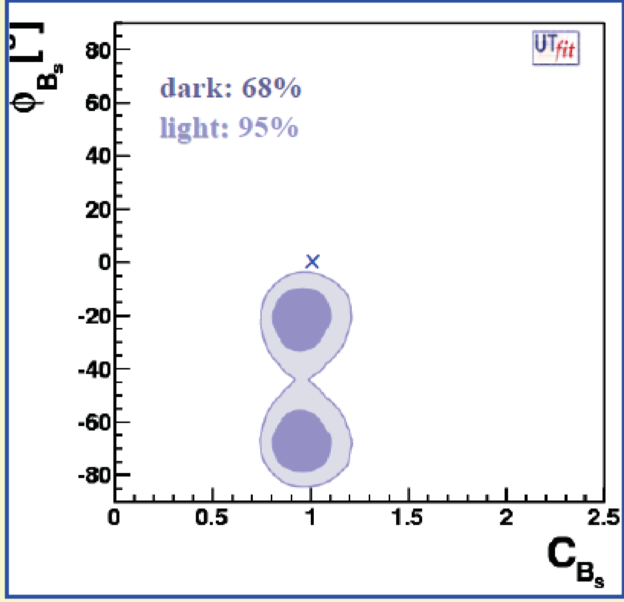
The new CDF measurement reduces the significance of the deviation.
The likelihood is not yet available, a CDF Bayesian study is underway



Before it was 1.8 σ

The new DØ measurement of $a_{\mu\mu}$ points to large β_s but also to large $\Delta\Gamma_s$ requiring a non-standard Γ_{12} ?!?!?
If confirmed, two (UNLIKELY) explantions:
•Huge (tree-level-like) NP contributions in Γ_{12}
(a factor 2.5: why only in Γ_{12}??)
•Bad failure of the OPE in Γ_{12}
(while in Γ_{11} (b-hadron lifetimes) works well)

Updated Results including NEW DØ results
(new CDF results are not yet available)



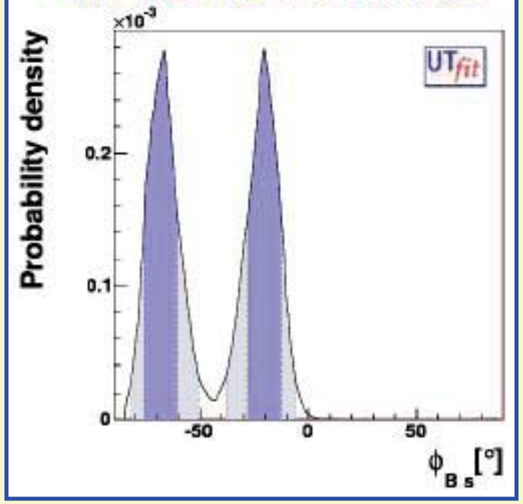
$$C_{B_s} = 0.95 \pm 0.10$$

$$[0.78, 1.16] \leftrightarrow 95\%$$

$$\Phi_{B_s} = (-20 \pm 8)^\circ \cup (-68 \pm 8)^\circ$$

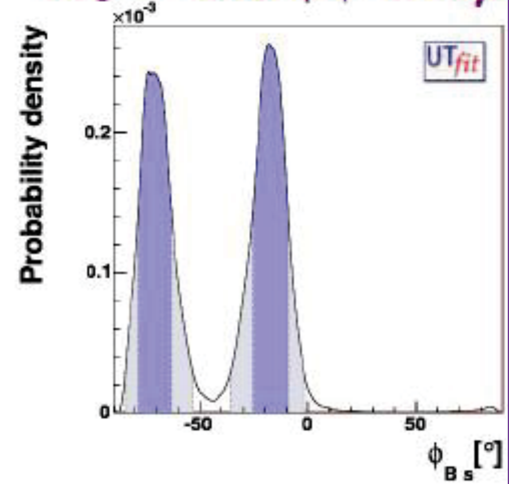
$$[-38, -6]^\circ \cup [-81, -51]^\circ \leftrightarrow 95\%$$

all constraints

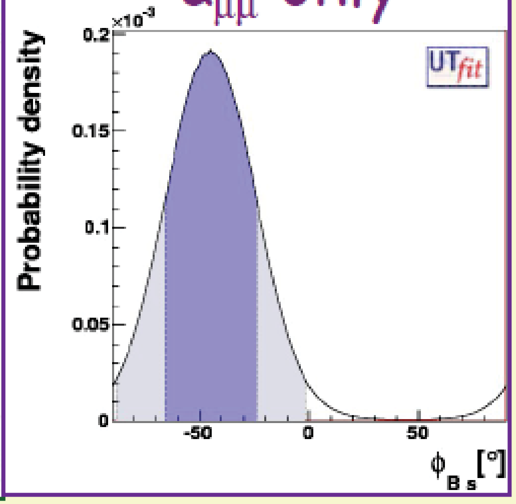


Deviation from the SM
at 3.1σ

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



$a_{\mu\mu}$ only



$a_{\mu\mu}$ and $B_s \rightarrow J/\Psi\ \phi$ point to large
but different values of ϕ_{Bs}
(N.B. the UTA beyond the SM
allows for NP in loops only,
i.e. tree-level NP in Γ_{12} is not allowed)

Further confirmations
from experiments
are looked forward!

- Are there NP models solving these tensions?
- What are the effects in Flavour Physics within various NP models?
- How to search and discriminate them?
- …