Non Perturbative QCD Calculations for B-physics (and related topics)

Guido Martinelli CERN 30//5/2008

Ateneo Federato della Scienza e della Tecnologia

DIPARTIMENTO DI FISICA

SAPIENZA
UNIVERSITÀ DI ROMA

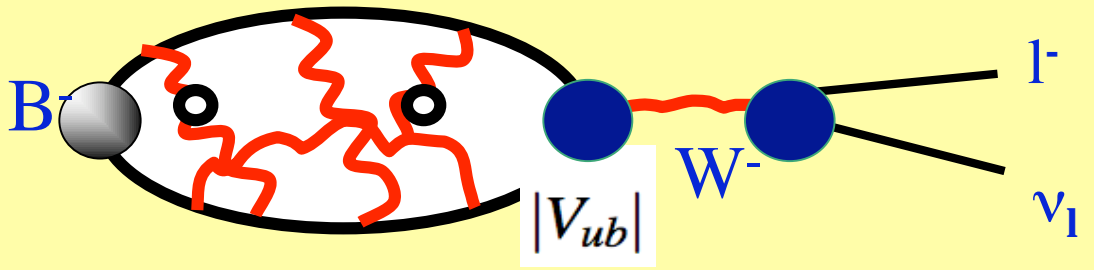
Plan of the Talk

1) *Generalities*
2) *Past: Predictions vs Postdictions*
3) *Present: Lattice vs angles*
4) *V_{ub} inclusive, V_{ub} exclusive vs sin 2β*
5) *Experimental determination of lattice parameters*
6) *Flavor Physics Beyond the SM*
7) *Future*

$$Q^{EXP} = V_{CKM}\langle F|\hat{O}|I\rangle$$

$$Q^{EXP} = \sum_i C^i_{SM}(M_W, m_t, \alpha_s)\langle F|\hat{O}_i|I\rangle + \sum_{i'} C^{i'}_{Beyond}(\tilde{m}_\beta, \alpha_s)\langle F|\hat{O}_{i'}|I\rangle$$

See yesterday talk by Buras
(but my formula is much simpler !!}



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

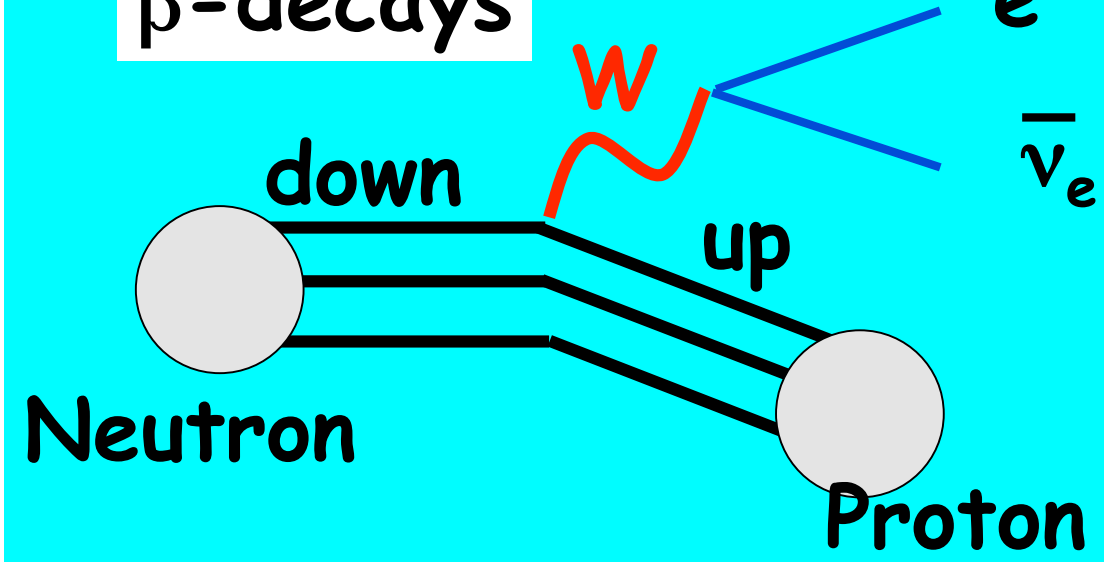
$$f_B^2 \, |V_{ub}|^2$$

$$\langle 0 | \bar{b} \gamma_\mu \gamma_5 d | B^0(p) \rangle = i f_B p_\mu$$

Quark masses & Generation Mixing

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

β-decays



$$\frac{d\Gamma}{dq^2} \propto |V_{ij}|^2 f(q^2)^2$$

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

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

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

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

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

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

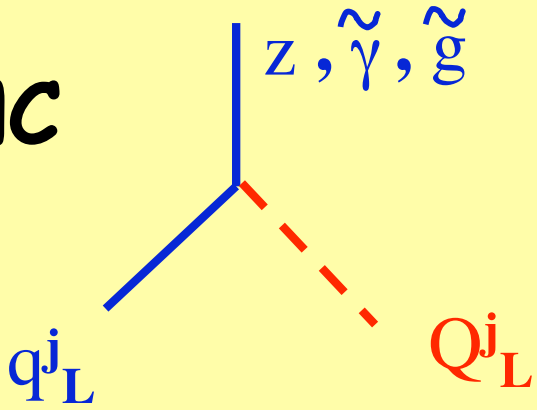
$|V_{tb}| = 0.99(29)$

(0.999)

In general the mixing mass matrix of the SQuarks (SMM) is not diagonal in flavour space analogously to the quark case We may either

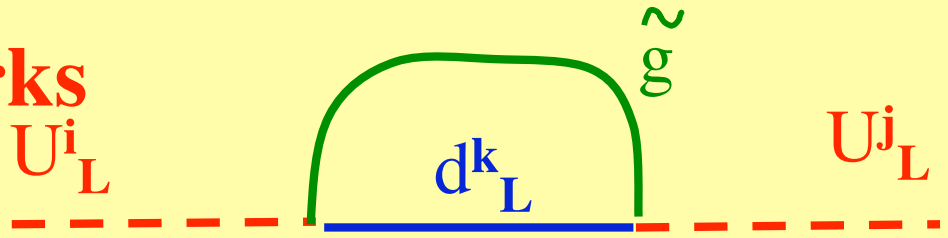
Diagonalize the SMM

FCNC

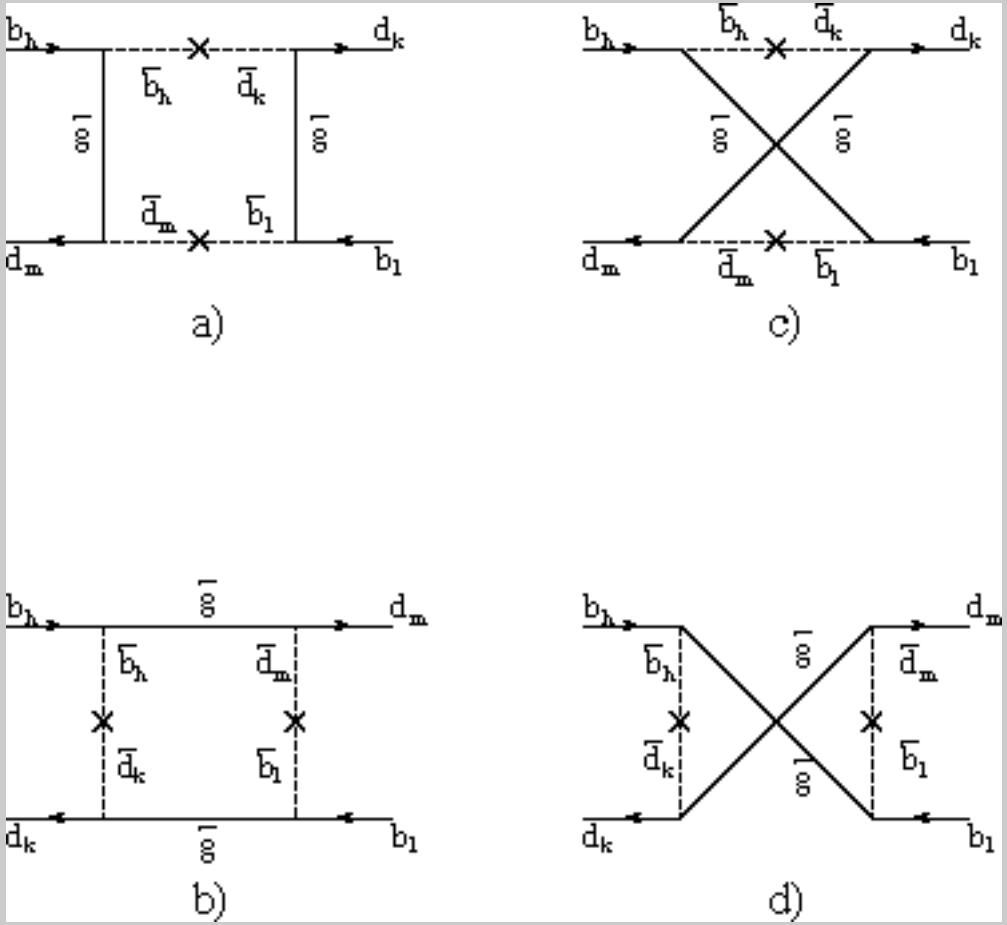


or Rotate by the same matrices the SUSY partners of the u- and d- like quarks

$(Q^j_L)' = U^{ij}_L \, Q^j_L$



In the latter case the Squark Mass Matrix is not diagonal



$$(m^2_Q)_{ij} = m^2_{average}\,\mathbf{1}_{ij} + \Delta m^2_{ij} \qquad \delta_{ij} = \Delta m^2_{ij} / m^2_{average}$$

New local four-fermion operators are generated

$Q_1 = (\bar{s}_L{}^A \gamma_\mu d_L{}^A)\,(\bar{s}_L{}^B \gamma_\mu d_L{}^B)$ SM

$Q_2 = (\bar{s}_R{}^A\, d_L{}^A)\,(\bar{s}_R{}^B\, d_L{}^B)$

$Q_3 = (\bar{s}_R{}^A\, d_L{}^B)\,(\bar{s}_R{}^B\, d_L{}^A)$

$Q_4 = (\bar{s}_R{}^A\, d_L{}^A)\,(\bar{s}_L{}^B\, d_R{}^B)$

$Q_5 = (\bar{s}_R{}^A\, d_L{}^B)\,(\bar{s}_L{}^B\, d_R{}^A)$

+ those obtained by $L \leftrightarrow R$

Similarly for the b quark e.g.

$(\bar{b}_R{}^A\, d_L{}^A)\,(\bar{b}_R{}^B\, d_L{}^B)$

$$\mathcal{L}_{SM}^{\Delta F=2} = \Sigma_{ij=d,s,b} (V_{td_i} V^*_{td_j})^2 \, C_{ij} \, [\bar{d}_i \gamma_\mu (1- \gamma_5) d_j]^2$$

$$\mathcal{L}^{\Delta F=2}_{general} = \Sigma_\alpha \Sigma_{ij=d,s,b} C^{ij}_{\ \alpha} Q^{ij}_{\ \alpha}$$

1) α = different Lorentz structures L×L, L ×R etc.

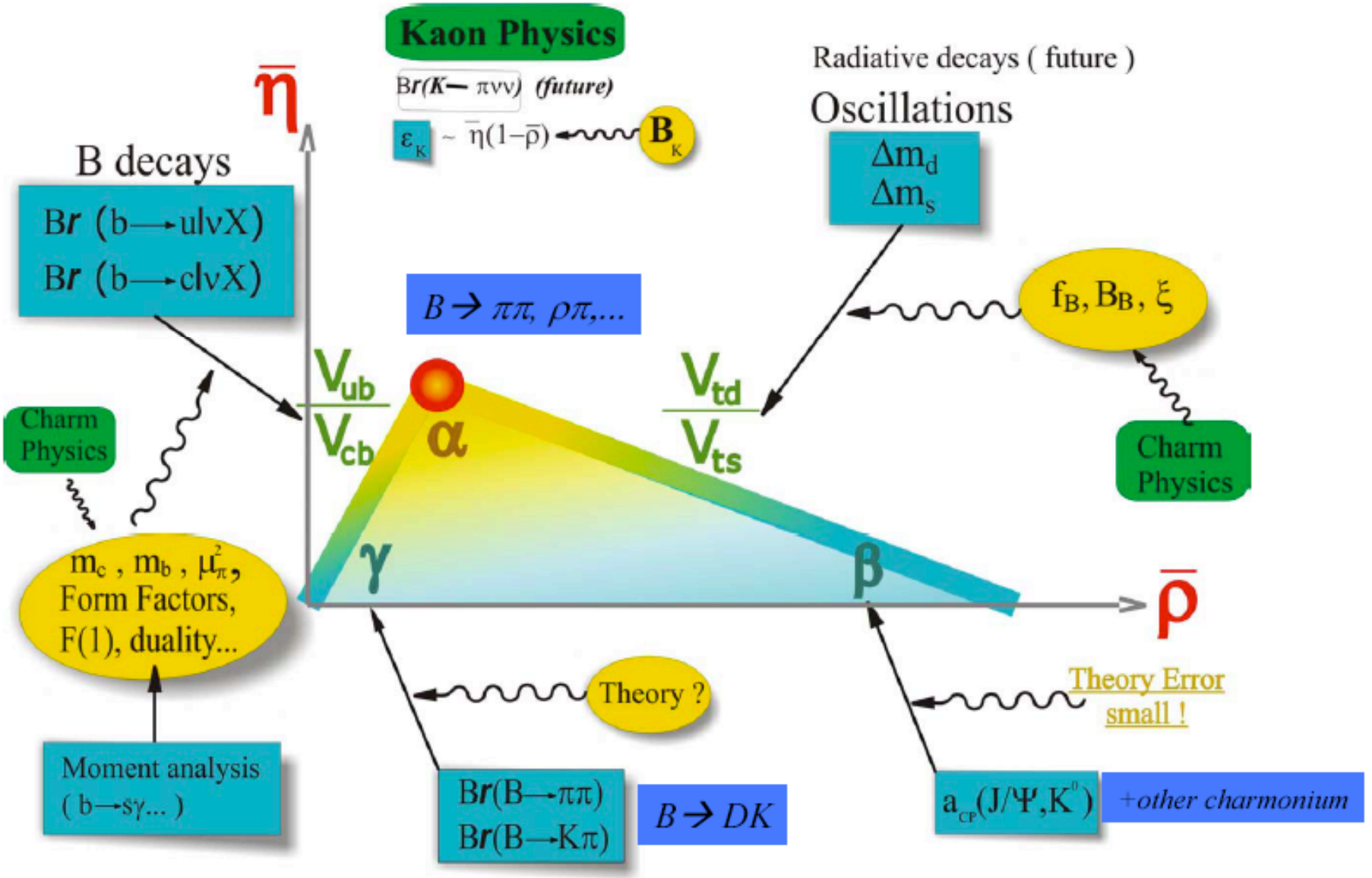
2) $C^{ij}_{\ \alpha}$ =complex coefficients from perturbation theory computed at the NLO

3) $\langle \bar{K} | Q^{ij}_{\ \alpha} | K \rangle$ from lattice QCD (APE-SPQR Collaboration Allton et al., Donini et al., Becirevic et al.)

Visualization of the unitarity of the CKM matrix

Unitarity Triangle in the $(\rho-\eta)$ plane

From
A. Stocchi
ICHEP 2002



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
$A_{CP}(B_d\to J/\psi\, K_s)$	$\sin 2\beta$	–

For details see:
UTfit Collaboration
hep-ph/0501199
hep-ph/0509219
hep-ph/0605213
hep-ph/0606167
http://www.utfit.org

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

classical UT analysis

sin 2β is measured directly from $B \rightarrow J/\psi\, K_s$ decays at Babar & Belle

$$\mathcal{A}_{J/\psi\, K_s} = \frac{\Gamma(B_d^0 \rightarrow J/\psi\, K_s, t) - \Gamma(\bar{B}_d^0 \rightarrow J/\psi\, K_s, t)}{\Gamma(B_d^0 \rightarrow J/\psi\, K_s, t) + \Gamma(\bar{B}_d^0 \rightarrow J/\psi\, K_s, t)}$$

$$\mathcal{A}_{J/\psi\, K_s} = \sin 2\beta \quad \sin(\Delta m_d\, t)$$

DIFFERENT LEVELS OF THEORETICAL UNCERTAINTIES (STRONG INTERACTIONS)

1) First class quantities, with reduced or negligible theor. uncertainties

$$A_{CP}(B \to J/\psi K_s) \quad \gamma \quad from\ B \to DK$$
$$K^0 \to \pi^0 \nu\bar{\nu}$$

2) Second class quantities, with theoretical errors of O(10%) or less that can be reliably estimated

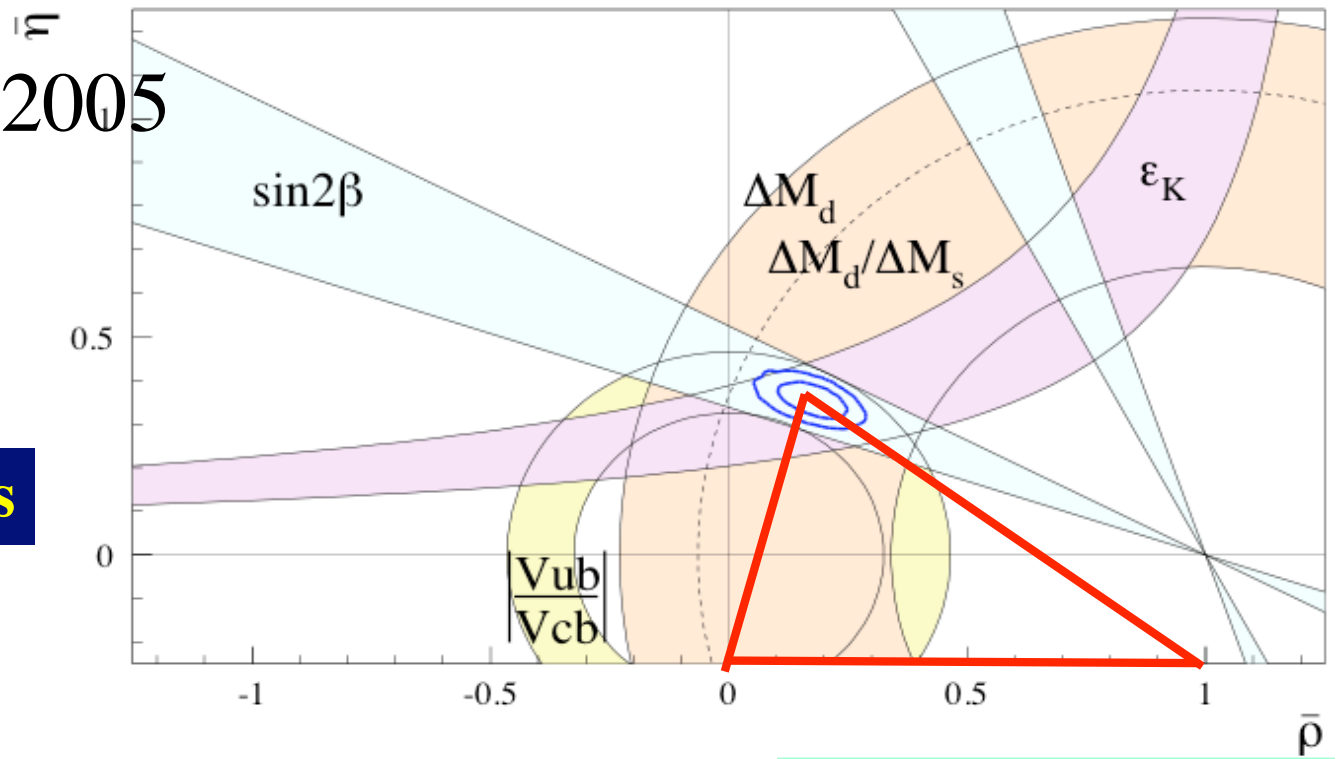
$$\varepsilon_K \quad \Delta M_{d,s}$$
$$\Gamma(B \to c,u), \quad K^+ \to \pi^+ \nu\bar{\nu}$$

3) Third class quantities, for which theoretical predictions are model dependent (BBNS, charming, etc.)

In case of discrepacies we cannot tell whether is *new physics or we must blame the model*

$$B \to K\pi \quad B \to \pi^0\pi^0$$
$$B \to \phi K_s$$

Unitary Triangle SM



semileptonic decays

Experimental co

Meas.	V_{CKM} × 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

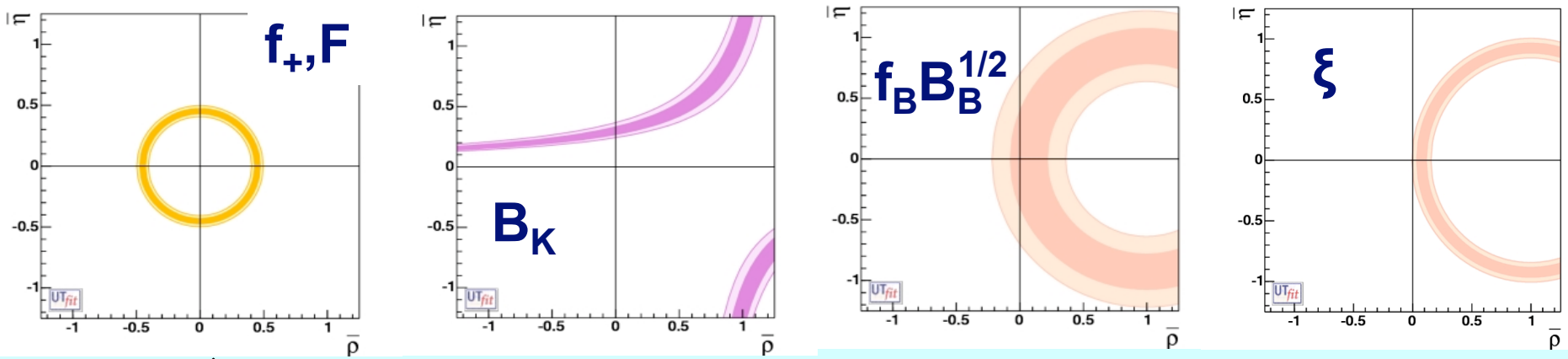
$B^0_{d,s}$ - $\overline{B}^0_{d,s}$ mixing

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
see later

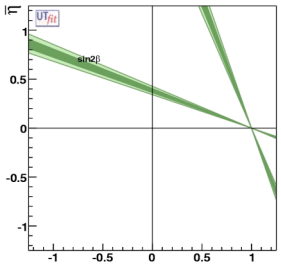
before
only a lower bound

New Quantities used in the UT Analysis

UT-ANGLES

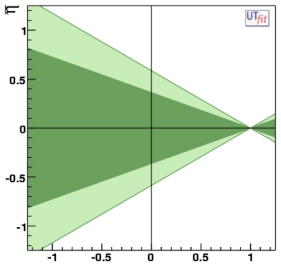
Several new determinations of UT angles are now available, thanks to the results coming from the B-Factory experiments

$\sin 2\beta$



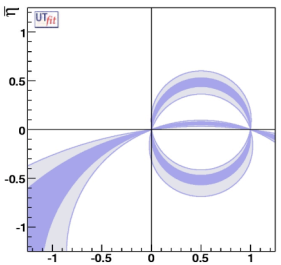
$B \to J/\Psi K^0$

$\cos 2\beta$



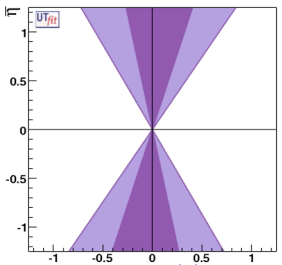
$B \to J/\Psi K^{*0}$

α



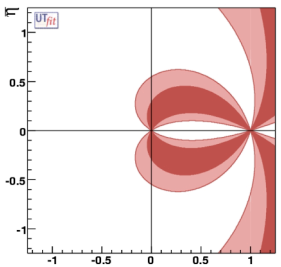
$B \to \pi\pi, \rho\rho$

γ



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

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

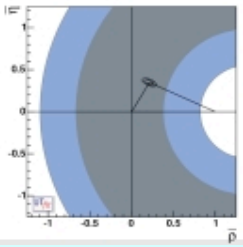


$B \to D^{(*)}\pi, D\rho$

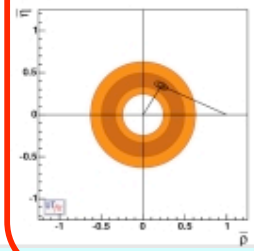
New Constraints from B and K rare decays (not used yet)

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.

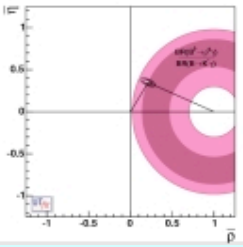
$K \to \pi \nu \bar{\nu}$



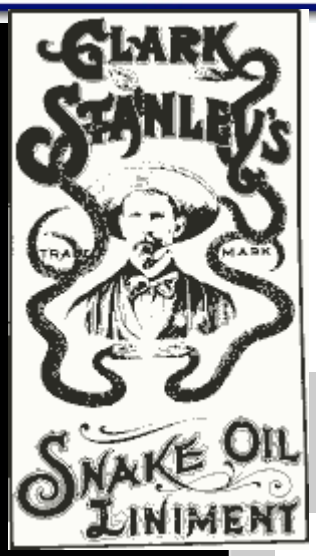
$B \to \tau \nu$



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

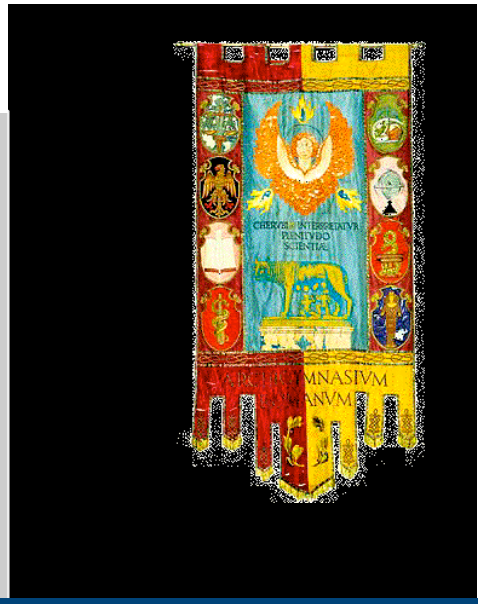


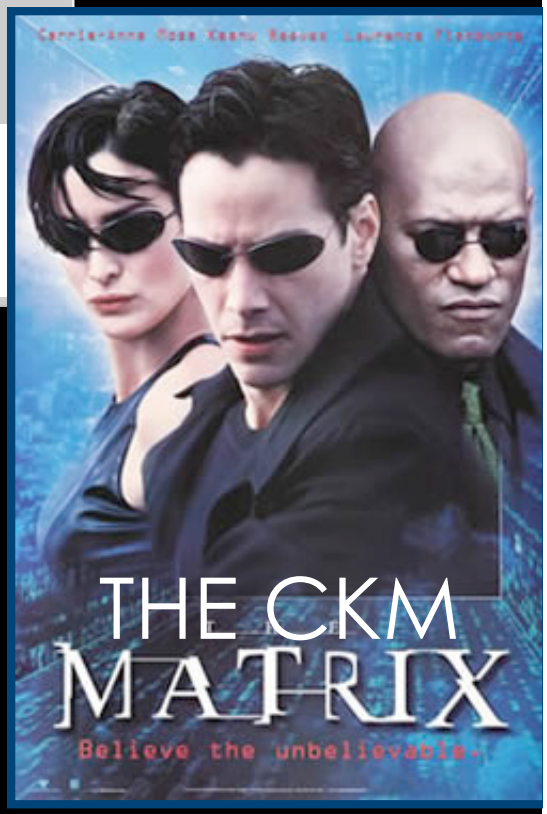
THE COLLABORATION



M.Bona, M.Ciuchini, E.Franco, V.Lubicz,
G.Martinelli, F.Parodi,M.Pierini,
P.Roudeau, C.Schiavi,L.Silvestrini,
V. Sordini, A.Stocchi, V.Vagnoni

Roma, Genova, Annecy, Orsay,
Bologna





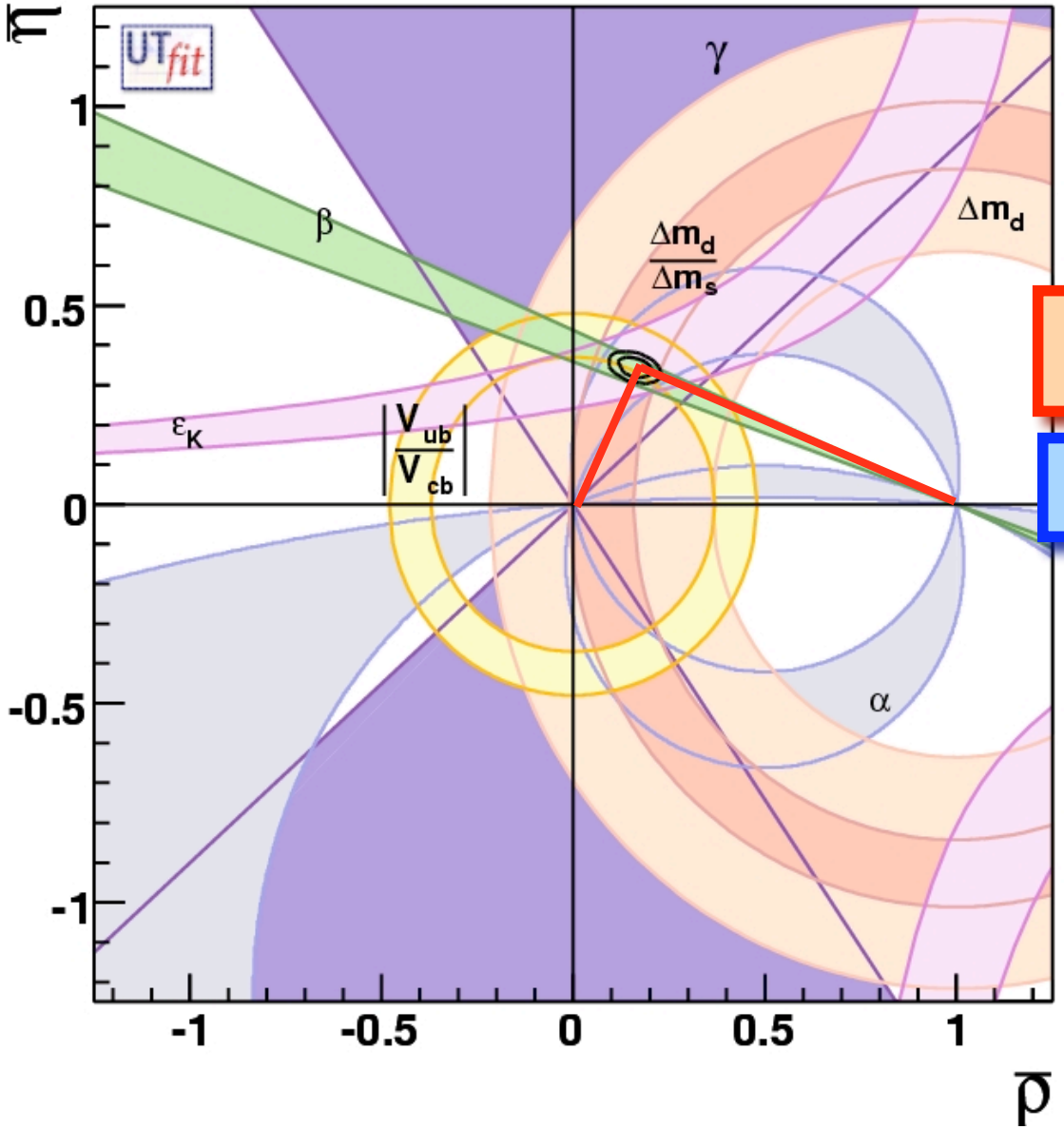
2006 ANALYSIS

- New quantities e.g. B -> DK included
- Upgraded exp. numbers (after ICHEP)
- CDF & Belle new measurements

www.utfit.org

Results for ρ and η & related quantities

With the constraint from Δm_s



contours @ 68% and 95% C.L.

ρ = 0.147 ± 0.029

η = 0.342 ± 0.016

$\alpha = (91 \pm 8)^0$

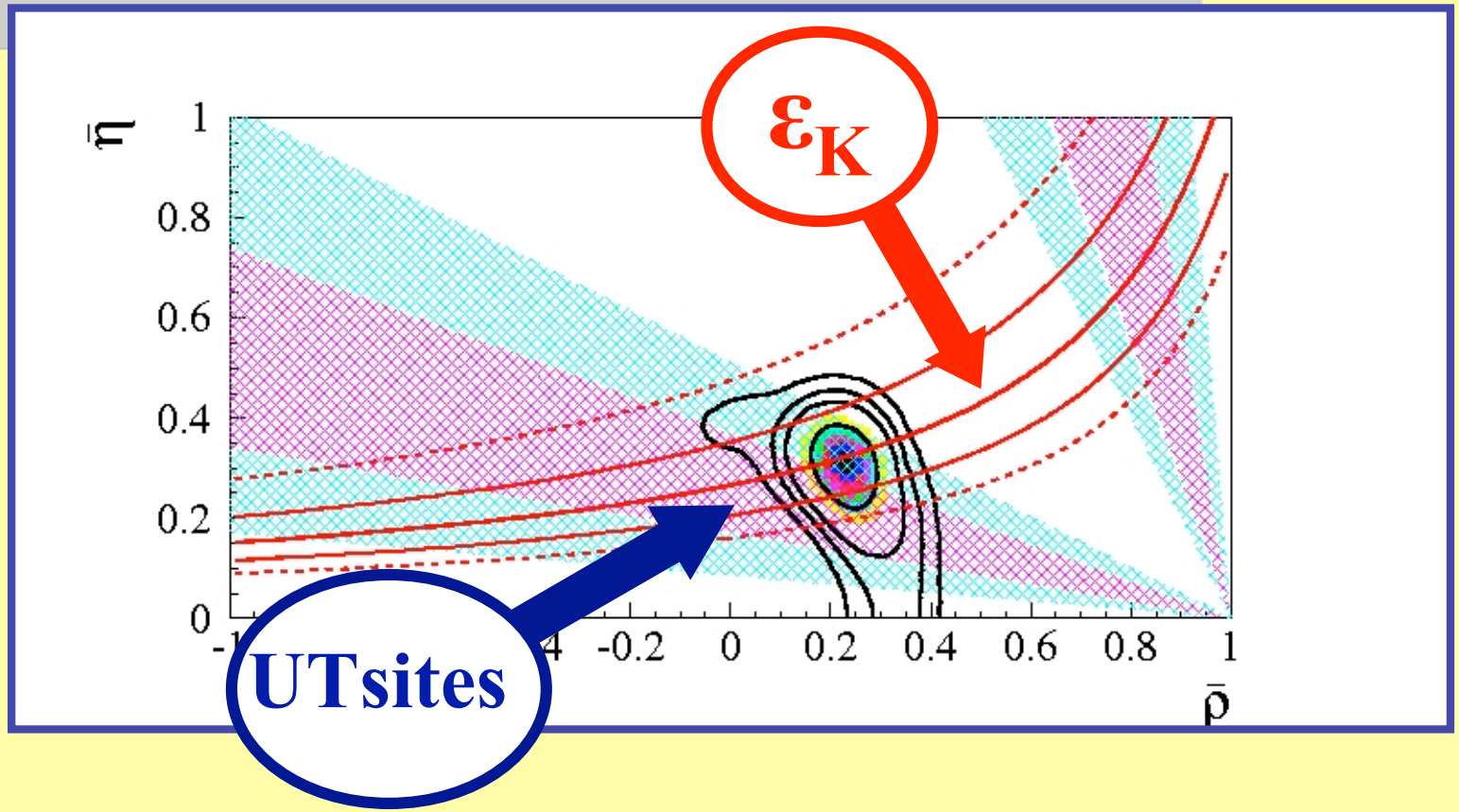
$\sin 2\beta = 0.690 \pm 0.023$

$\gamma = (66.7 \pm 6.4)^0$

A closer look to the analysis:

1) **Predictions vs Postdictions (past)**
2) **Lattice vs angles**
3) **V_{ub} inclusive, V_{ub} exclusive vs sin 2β**
4) **Experimental determination of lattice parameters**

CKM origin of CP Violation in $K^0 - \bar{K}^0$ Mixing



Ciuchini et al. ("pre-UTFit"),2000

Comparison of $\sin 2\beta$ from direct measurements (Aleph, Opal, Babar, Belle and CDF) and UT analysis

$\sin 2\beta_{measured} = \mathbf{0.668 \pm 0.028}$

$\sin 2\beta_{UTA} = 0.736 \pm 0.042$

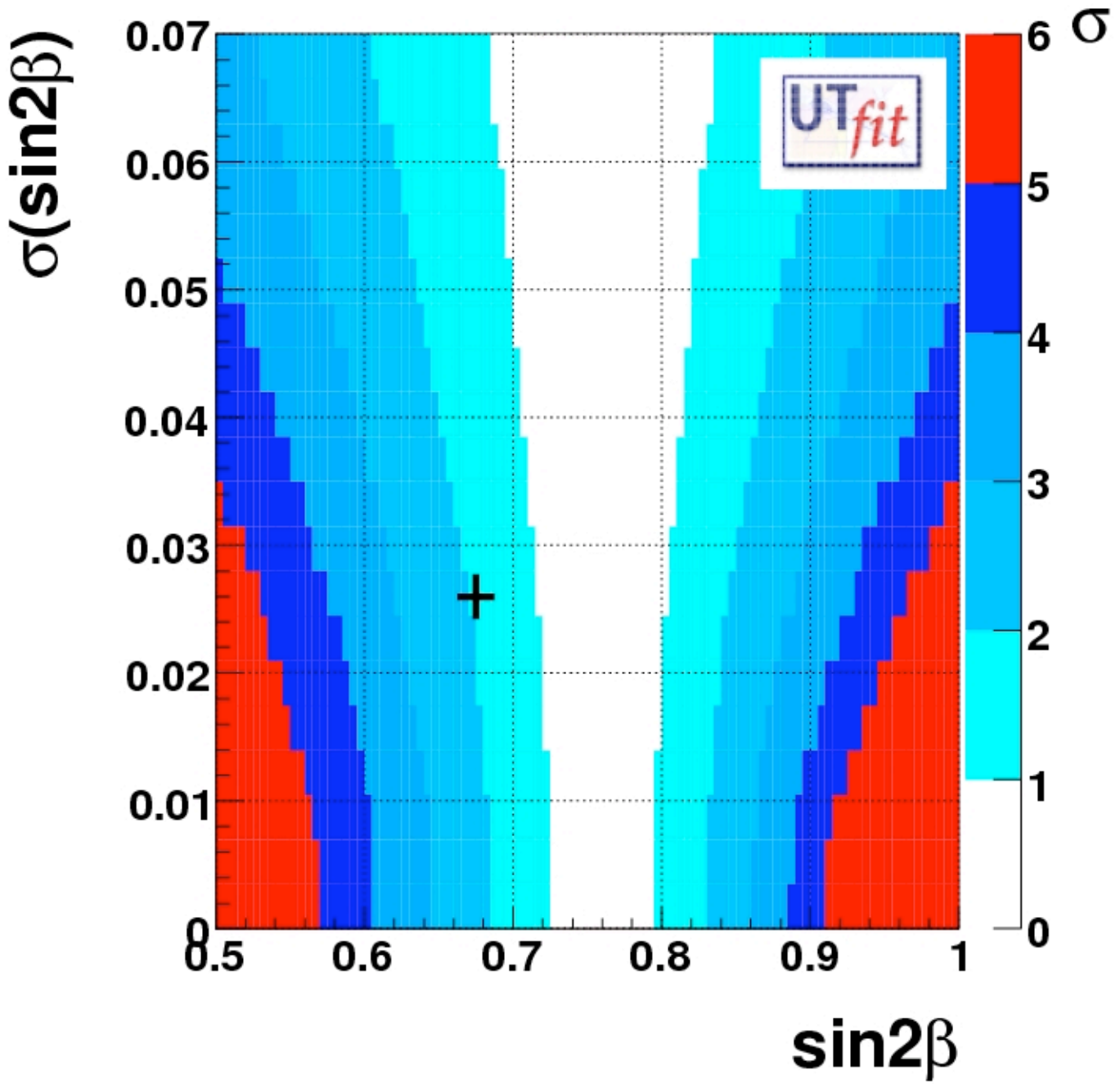
correlation (tension) with V_{ub}, see later

$\sin 2\beta_{UTA} = 0.698 \pm 0.066$
prediction from Ciuchini et al. (2000)

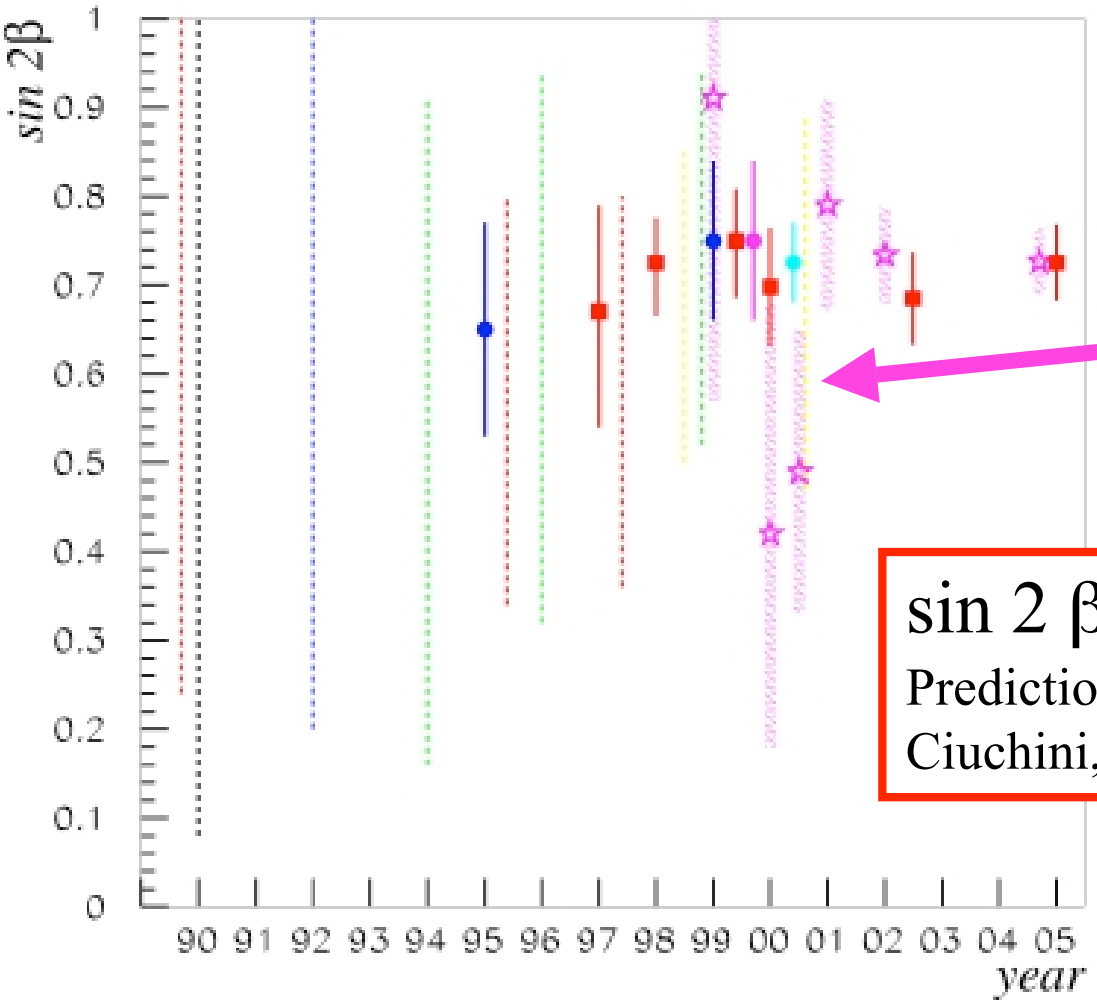
$\sin 2\beta_{UTA} = 0.65 \pm 0.12$
Prediction 1995 from
Ciuchini,Franco,G.M.,Reina,Silvestrini

$\sin 2\beta_{tot} = 0.690 \pm 0.023$

Very good agreement
no much room for physics beyond the SM !!


σ(sin2β)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
0.6
0.7
0.8
0.9
1
sin2β
UTfit
σ
6
5
4
3
2
1
0

Theoretical predictions of Sin 2 β in the years



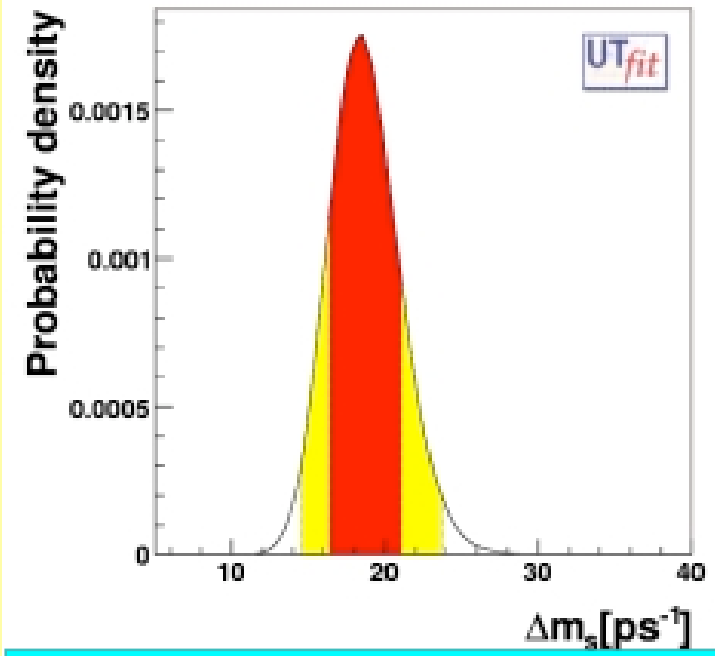
predictions exist since '95

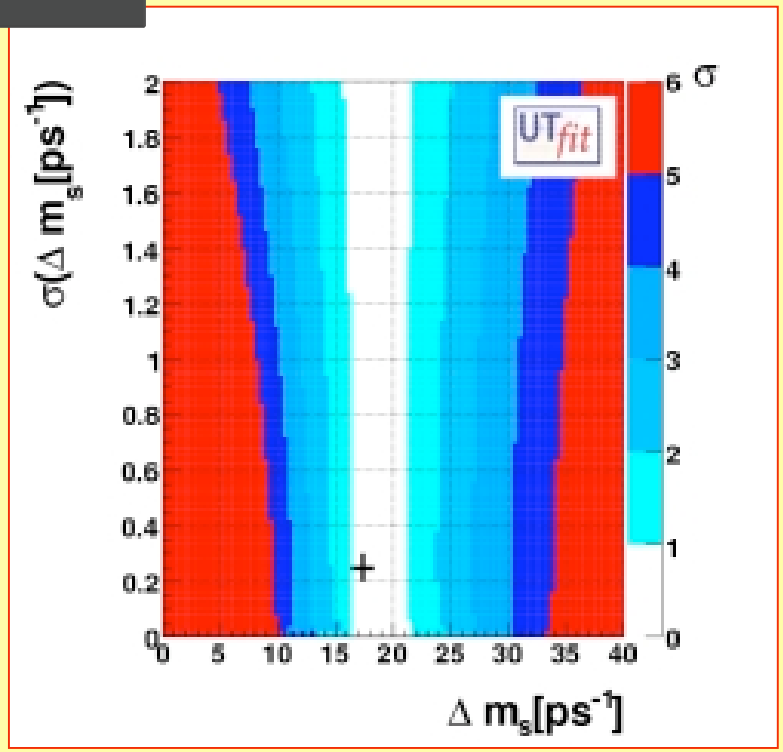
experiments

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

Prediction 1995 from
Ciuchini,Franco,G.M.,Reina,Silvestrini

NEWS from NEWS (Standard Model)





Δm_s Probability Density

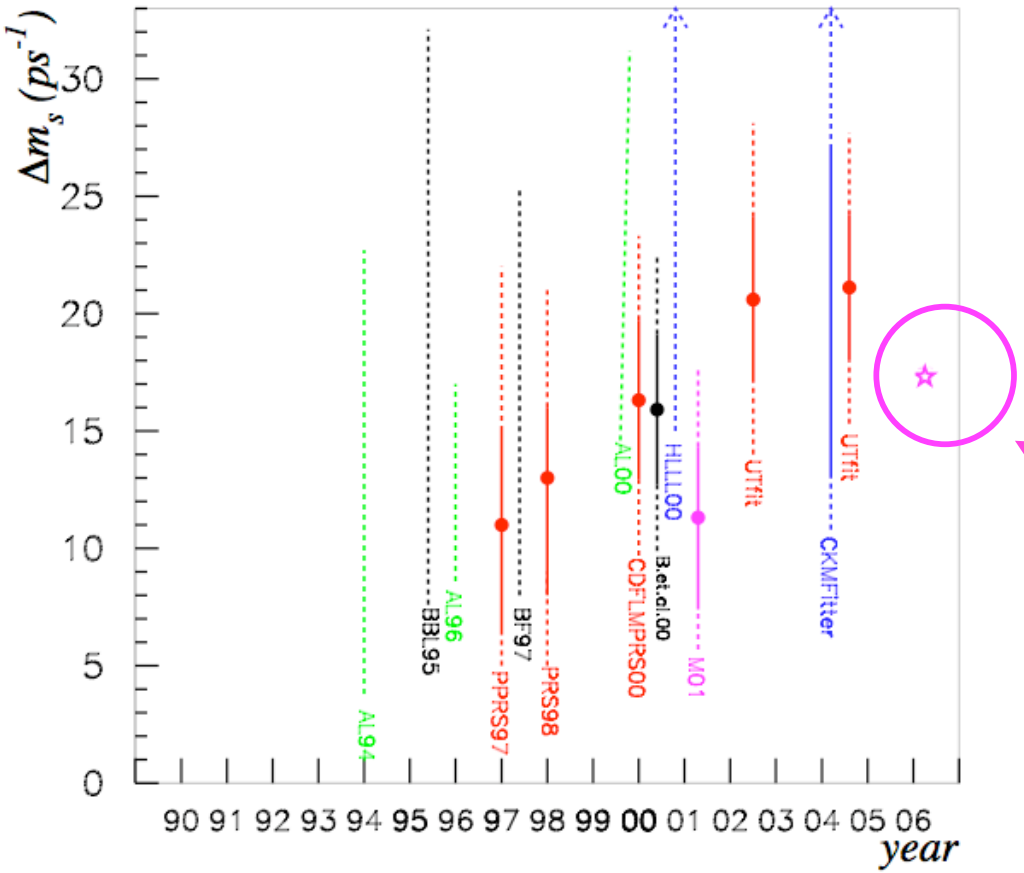
$\Delta m_s = 18.4 \pm 2.4\, ps^{-1}$ *INDIRECT*

$\Delta m_s = 17.77 \pm 0.12\, ps^{-1}$ *DIRECT*

$\Delta m_s = (16.3 \pm 3.4)\, ps^{-1}$

Ciuchini et. al. 2000

Theoretical predictions of Δm_s in the years



predictions exist since '97

CDF

A GREAT SUCCESS OF (QUENCHED) LATTICE QCD CALCULATIONS

A closer look to the analysis:

1) **Predictions vs Postdictions**
2) **Lattice vs angles**
3) **V_{ub} inclusive, V_{ub} exclusive vs sin 2β**
4) **Experimental determination of lattice parameters**

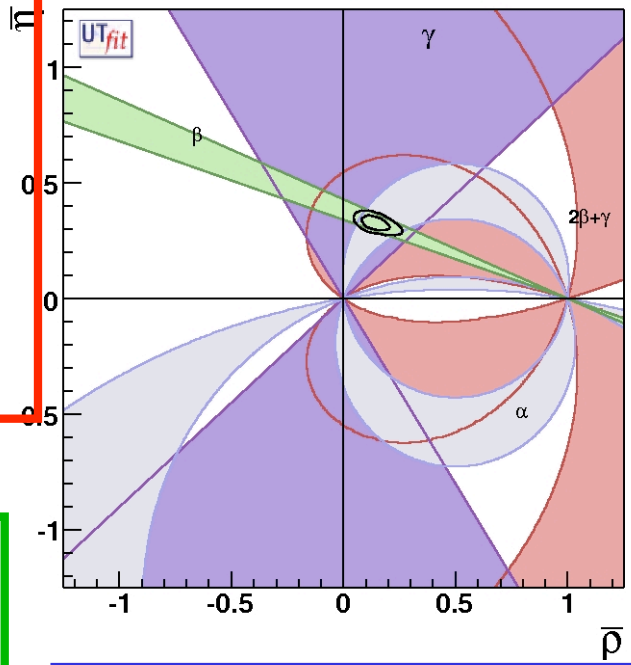
The UT-angles fit does not depend on theoretical calculations (treatement of errors is not an issue)

Comparable accuracy due to the precise sin2β value and substantial improvement due to the new Δm_s measurement

Crucial to improve measurements of the angles, in particular γ (tree level NP-free determination)

Still imperfect agreement in $\bar{\eta}$ due to sin2β and V_{ub} tension

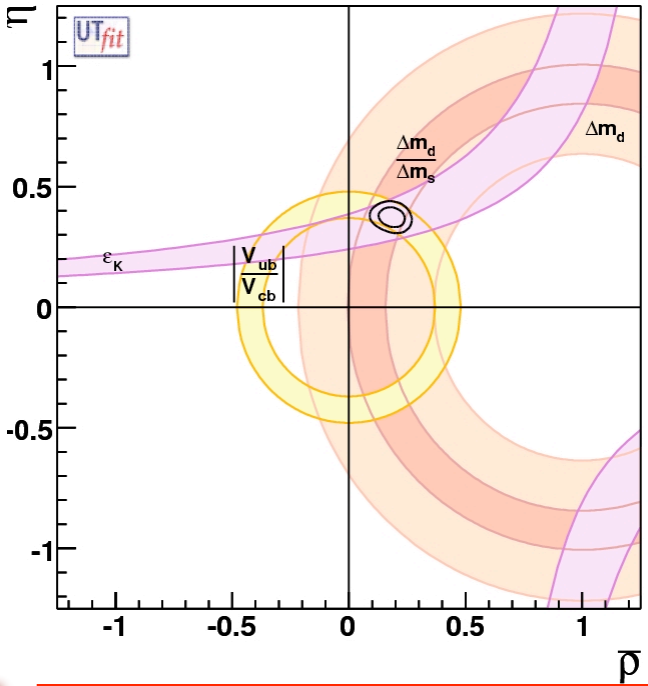
UT-angles



$\rho = 0.139 \pm 0.042$

$\eta = 0.325 \pm 0.021$

UT-lattice



$\rho = 0.188 \pm 0.036$

$\eta = 0.373 \pm 0.027$

ANGLES VS LATTICE 2007

A closer look to the analysis:

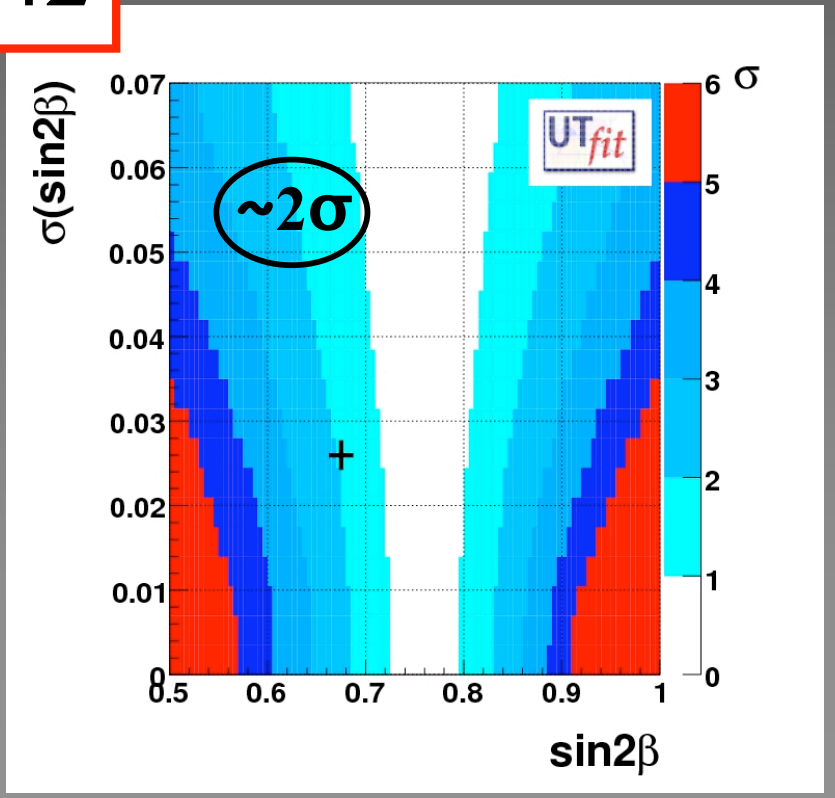
1) **Predictions vs Postdictions**
2) **Lattice vs angles**
3) **V_{ub} inclusive, V_{ub} exclusive vs sin 2β**
4) **Experimental determination of lattice parameters**

Correlation of $\sin 2\beta$ with V_{ub}

$\sin 2\beta_{measured} = 0.668 \pm 0.028$

$\sin 2\beta_{UTA} = 0.736 \pm 0.042$

Although compatible, these results show that there is a ``tension'' . This is due to the correlation of Vub with $\sin 2\beta$



V_{UB} PUZZLE

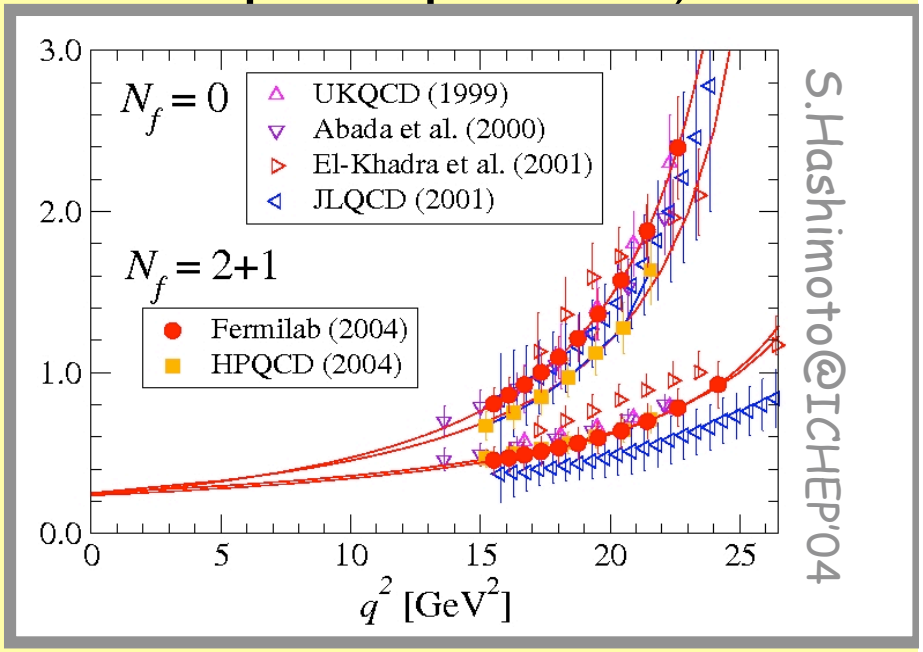
$\|V_{ub}\| \times 10^4$	excl.	35.0	4.0	Lattice QCDSR
$\|V_{ub}\| \times 10^4$	incl.	44.9	3.3	HQET+Model
$\|V_{ub}\| \times 10^4$	average	40.9	2.5	

Inclusive: uses non perturbative parameters most **not** from lattice QCD (fitted from the lepton spectrum)

$$\bar{\Lambda} \quad \lambda_1 \sim \frac{\bar{b}\vec{D}^2 b}{2m_b} \quad \lambda_2 \sim \frac{\bar{b}\sigma_{\mu\nu}G^{\mu\nu}b}{2m_b}$$

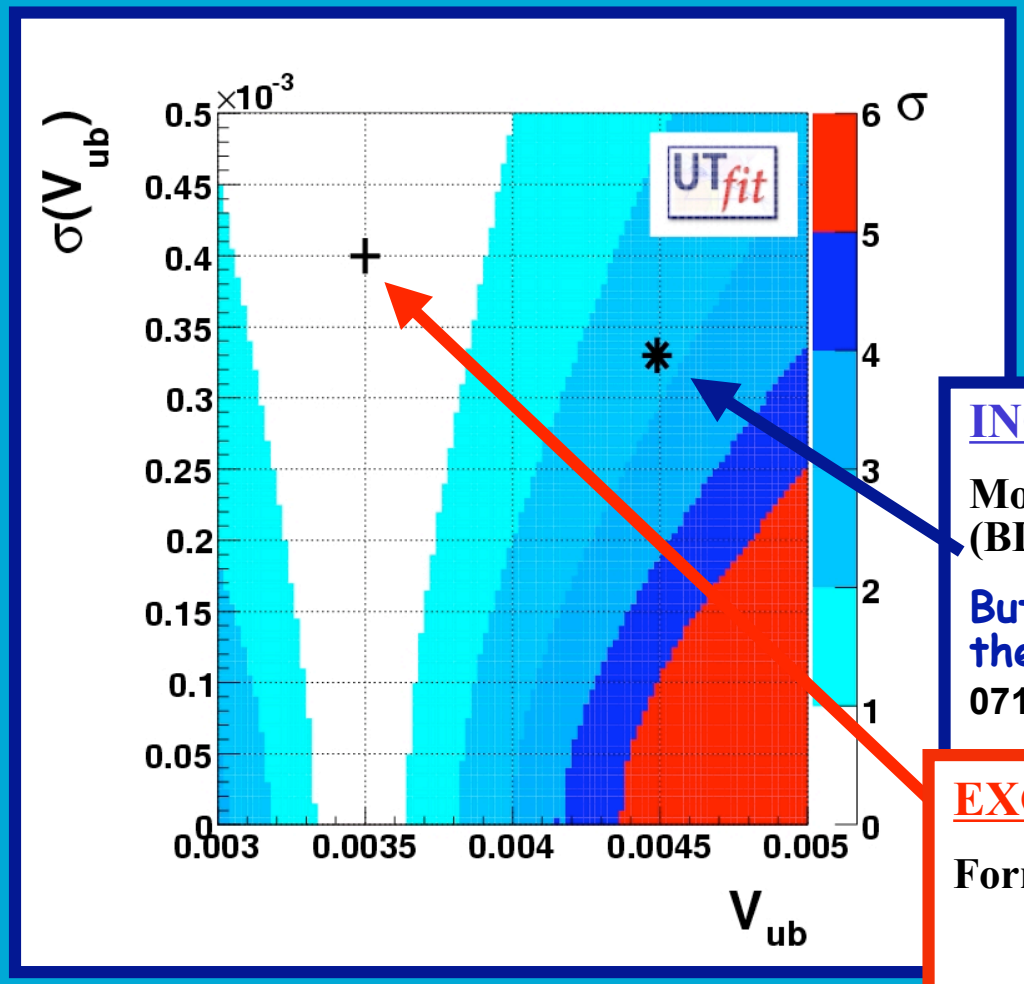
Exclusive: uses non perturbative form factors from LQCD and QCDSR

$$f^+(q^2) \quad V(q^2) \quad A_{1,2}(q^2)$$



Tension between inclusive Vub and the rest of the fit

Tension between inclusive Vub and the rest of the fit



INCLUSIVE $V_{ub} = (43.1 \pm 3.9)\ 10^{-4}$

Model dependent in the threshold region (BLNP, DGE, BLL)

But with a different modelling of the threshold region [U.Aglietti et al., 0711.0860] $V_{ub} = (36.9 \pm 1.3 \pm 3.9)\ 10^{-4}$

EXCLUSIVE $V_{ub} = (34.0 \pm 4.0)\ 10^{-4}$

Form factors from LQCD and QCDSR

V_{UB} PUZZLE

Khodjamirian

Recent $|V_{ub}|$ determinations from $B \to \pi l \nu_l$

[ref.]	$f^+_{B\pi}(q^2)$ calculation	$f^+_{B\pi}(q^2)$ input	$\|V_{ub}\| \times 10^3$
Okamoto et al.	lattice ($n_f = 3$)	-	$3.78 \pm 0.25 \pm 0.52$
HPQCD	lattice ($n_f = 3$)	-	$3.55 \pm 0.25 \pm 0.50$
Arnesen et al.	-	lattice$\oplus$SCET	$3.54 \pm 0.17 \pm 0.44$
BecherHill	-	lattice	$3.7 \pm 0.2 \pm 0.1$
Flynn et al	-	lattice $\oplus$ LCSR	$3.47 \pm 0.29 \pm 0.03$
Ball, Zwicky	LCSR	-	$3.5 \pm 0.4 \pm 0.1$
this work	LCSR	-	$3.5 \pm 0.4 \pm 0.2 \pm 0.1$

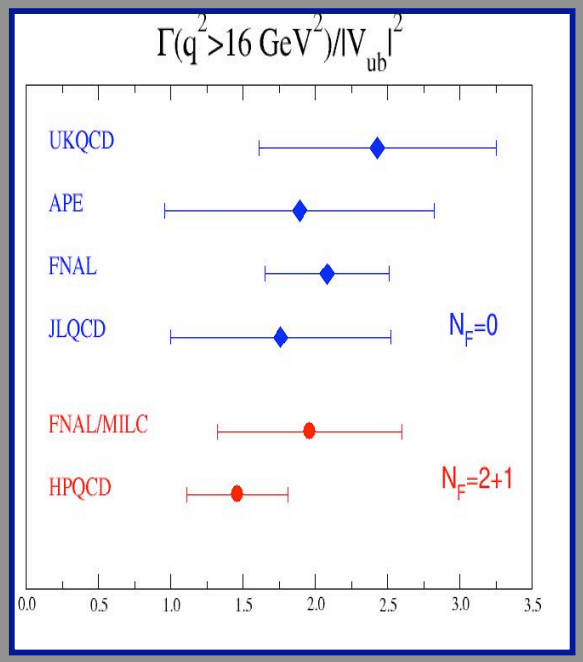
V_{UB} PUZZLE

LATTICE QCD:
improve V_{ub} excl. to solve the tension

Also:

$$B \to K^* \gamma$$
$$B \to \phi \gamma$$

Beneke CERN '08

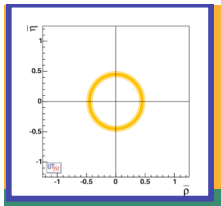


$|V_{ub}|$ crisis (about to be resolved?)

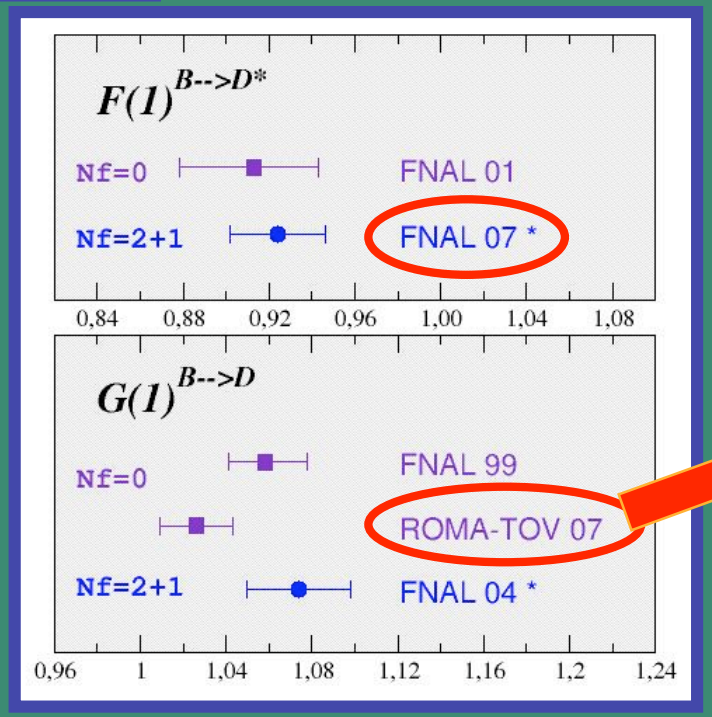
- $|V_{ub}| f_+^{B\pi}(0) = (9.1 \pm 0.6 \pm 0.3) \times 10^{-4}$ from semileptonic $B \to \pi l \nu$ spectrum + form factor extrapolation (Ball, 2006)
  Also lattice results (HPQCD) tend to small values.
- $|V_{ub}| f_+^{B\pi}(0) = (8.1 \pm 0.4\,(?)) \times 10^{-4}$ from $B \to \pi^+\pi^-, \pi^+\pi^0, \pi\rho, \ldots$ + factorization
  (MB, Neubert, 2003; Arnesen et al, 2005; MB, Jäger, 2005)

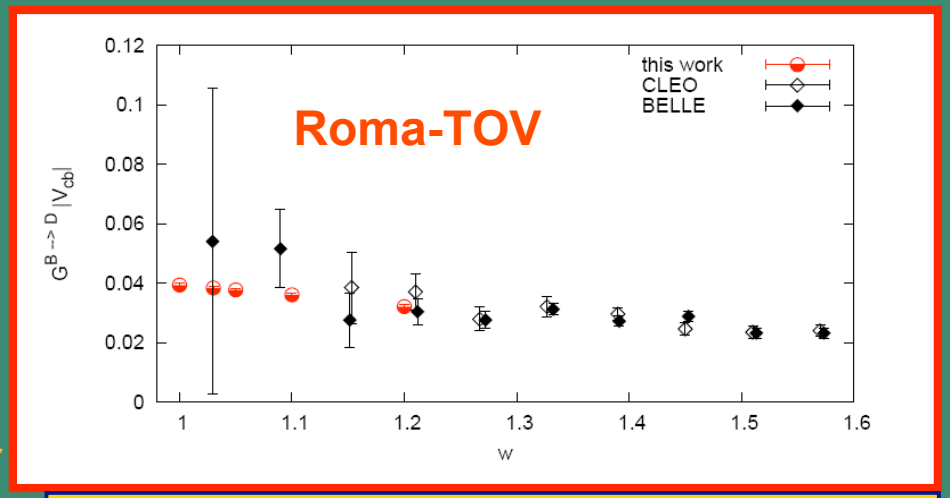
$\Longrightarrow$ $|V_{ub}| \simeq 3.5 \times 10^{-4}$, in contrast to determination from moments of inclusive $b \to u\ell\nu$ decay, which was $|V_{ub}| \simeq (4.5 \pm 0.3) \times 10^{-4}$.

But: according to (Neubert, LP07) $|V_{ub}| \simeq (3.7 \pm 0.3) \times 10^{-4}$ after reevaluation of m_b input and omitting $B \to X_s\gamma$ moments!



Vcb from B → D/D* lv decays



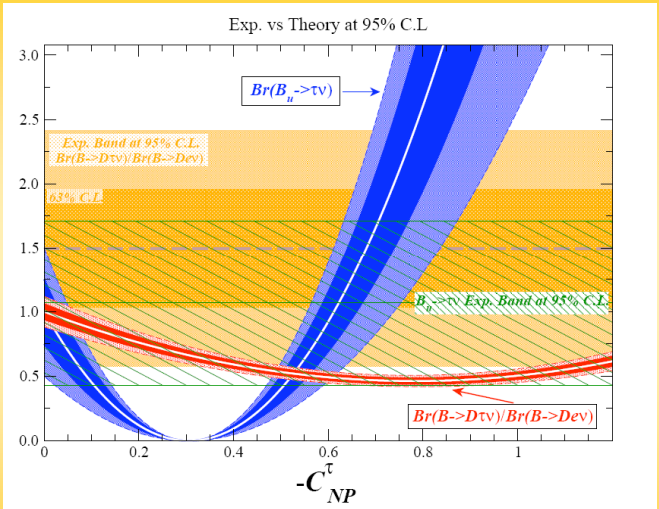


Two new results

-FNAL: B→D*, Nf=2+1

-Roma TOV: B→D, Nf=0:
New method (SSM+Tbc), w≥1 (slope ρ^2), both vector and scalar form factors

Kamenik and Mescia, 0802.3790[hep-ph]



Charged Higgs contribution to the scalar amplitude in B→Dτν

Unitarity test of the first V_{CKM} row

Nuclear β-deccays *Kl3,Kl2* *b→u semileptonic*

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

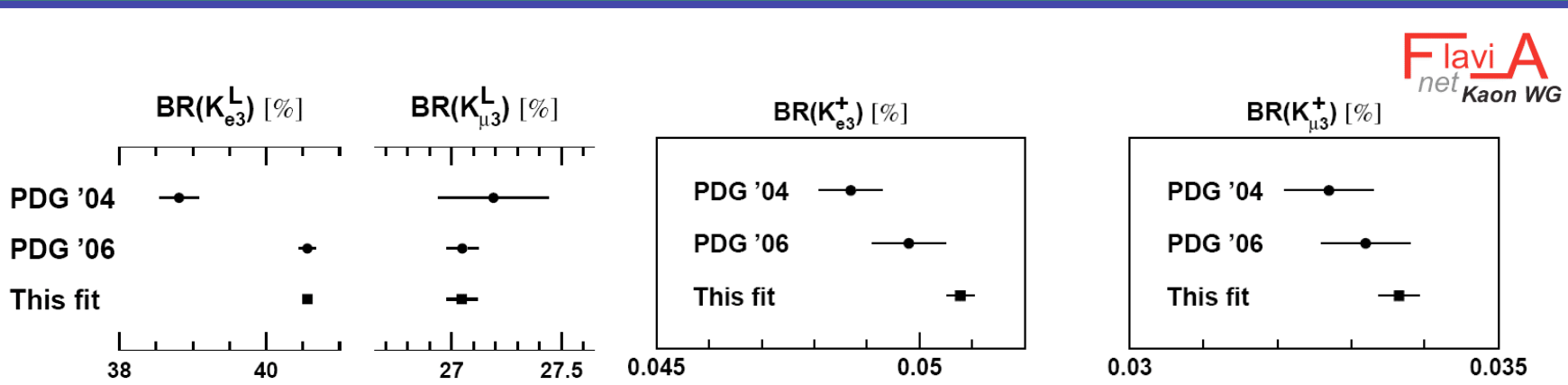
ERROR: $5 \cdot 10^{-4}$ $5 \cdot 10^{-4}$ $\sim 10^{-6}$

The PDG 2004 quoted a 2σ deviation from unitarity:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = -0.0029 \pm 0.0015$$

Extraordinary experimental progress: the old PDG average for Vus has been superseded by the new results:

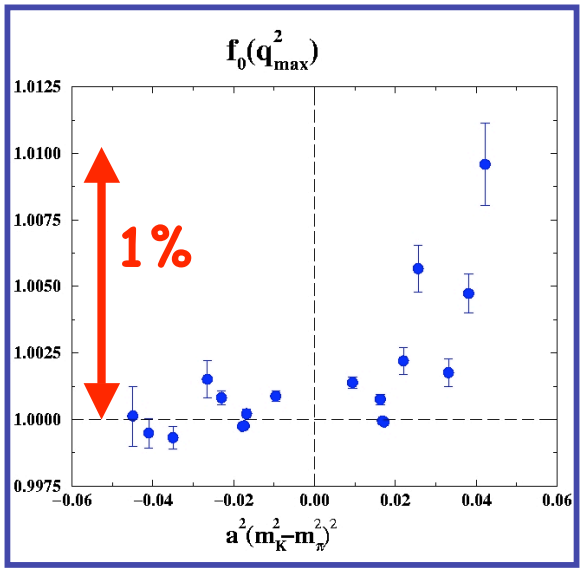
KLOE ISTRA+ NA48 KTeV



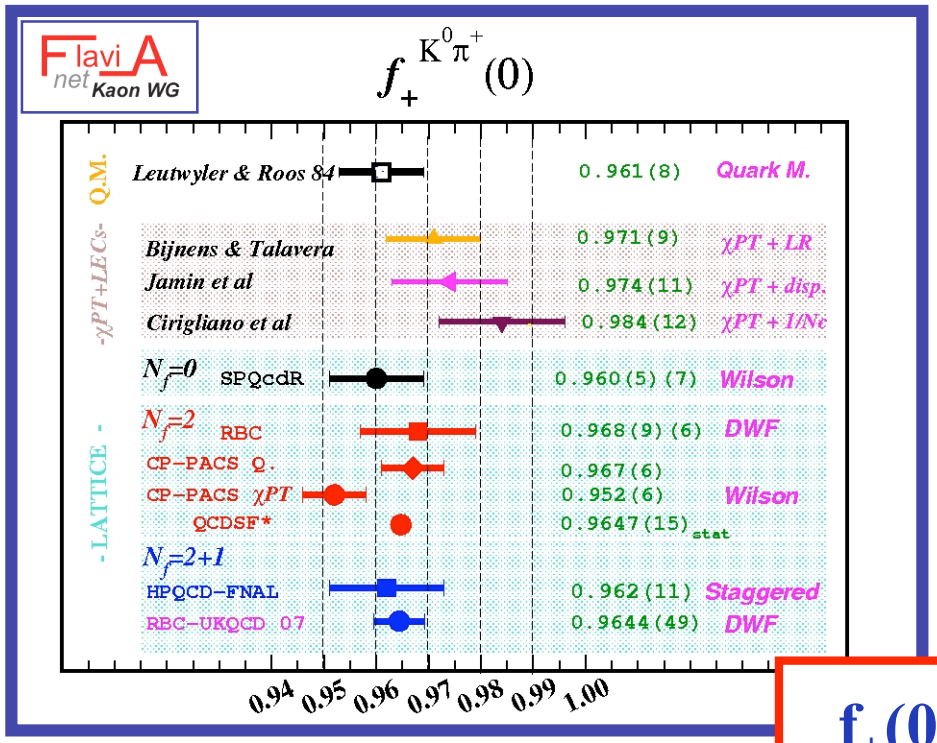
Lattice QCD

THE O(1%) PRECISION CAN BE REACHED

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



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



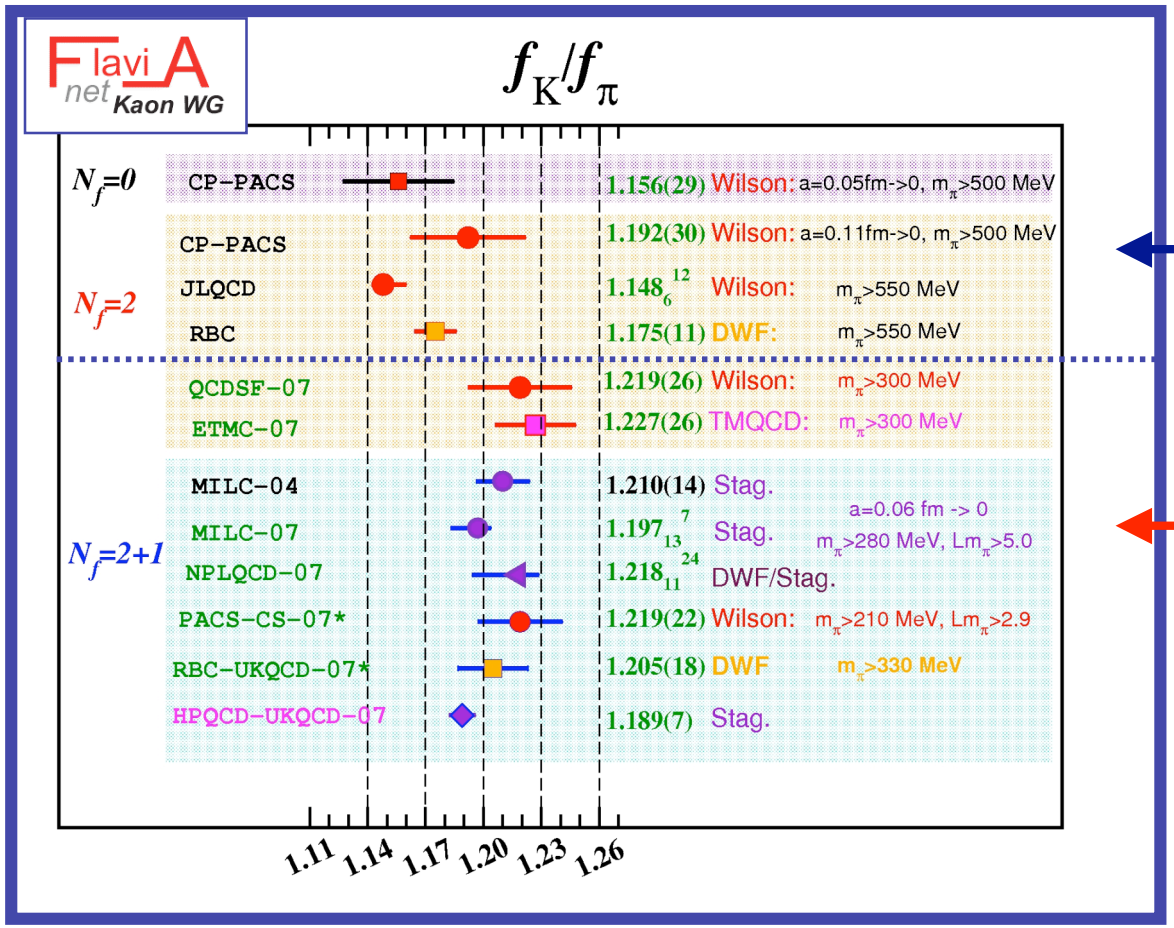
- Good agreement between Nf=0, 2 and 2+1 calculations

-A new precise Nf=2+1 calculation by RBC/UKQCD

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

$f_+(0)=0.964(5) \Rightarrow |Vus|=0.2246(12)$

fk/fπ: LATTICE SUMMARY



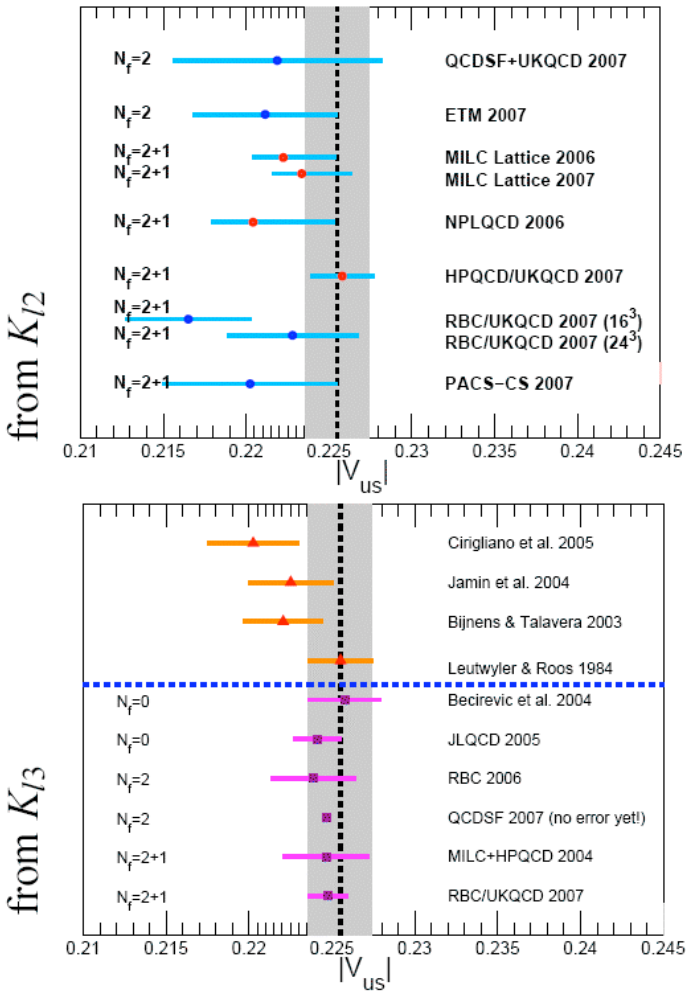
"Heavy" quark masses

"Light" quark masses: many new results in the last year

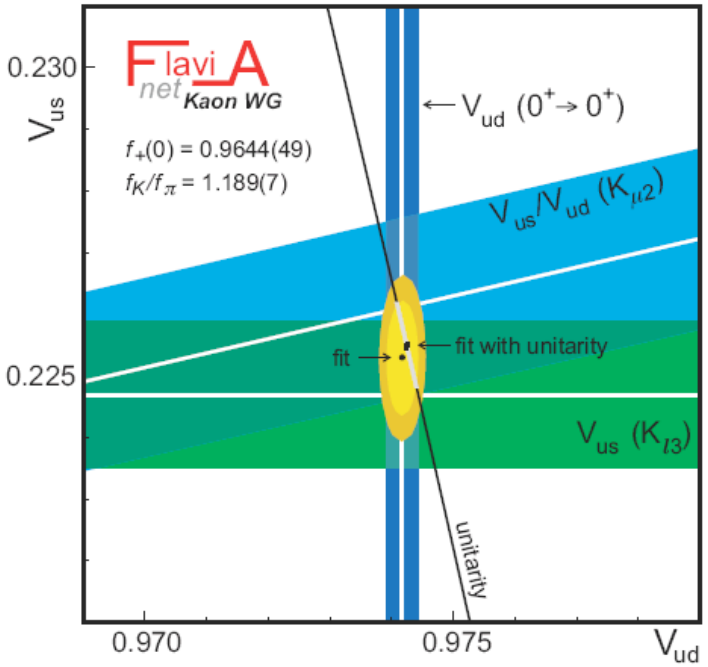
fk/fπ=1.198(10)	|Vus|=0.2241(24)	A.Jüttner@Latt'07
fk/fπ=1.189(7)	|Vus|=0.2261(15)	Flavianet Kaon WG

Vus SUMMARY

A.Jüttner, Latt'07



First row unitarity test



ma I 11/06/2001

Hadronic Parameters From UTfit

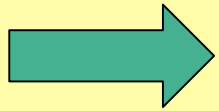
1) Predictions vs Postdictions
2) Lattice vs angles
3) V_{ub} inclusive, V_{ub} exclusive vs sin 2β
4) Experimental determination of lattice parameters

IMPACT of the NEW MEASUREMENTS on LATTICE HADRONIC PARAMETERS

$$f_{B_s}\hat{B}_{B_s}^{1/2} \quad \xi \quad \hat{B}_K$$

Comparison between experiments and theory

Comparison between experiments and theory



exps vs predictions

$f_{Bs}\sqrt{B_{Bs}} = 262 \pm 35$ MeV

lattice

$f_{Bs}\sqrt{B_{Bs}} = 261 \pm 6$ MeV

UTA 2% ERROR !!

$\xi = 1.24 \pm 0.08$ **UTA**

$\xi = 1.23 \pm 0.06$

lattice

$B_K = 0.75 \pm 0.09$

$B_K = 0.79 \pm 0.04 \pm 0.08$

Dawson

SPECTACULAR AGREEMENT (EVEN WITH QUENCHED LATTICE QCD)

exps vs predictions

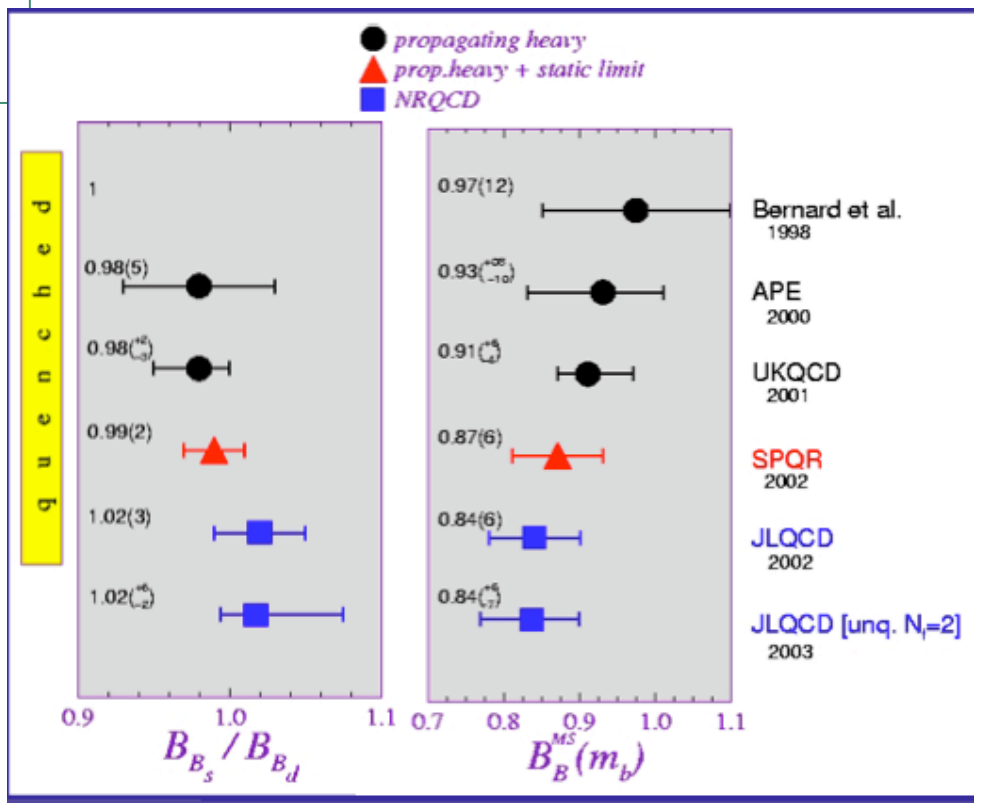
Using the lattice determination of the B-parameters $B_{Bd} = B_{Bs} = 1.28 \pm 0.05 \pm 0.09$

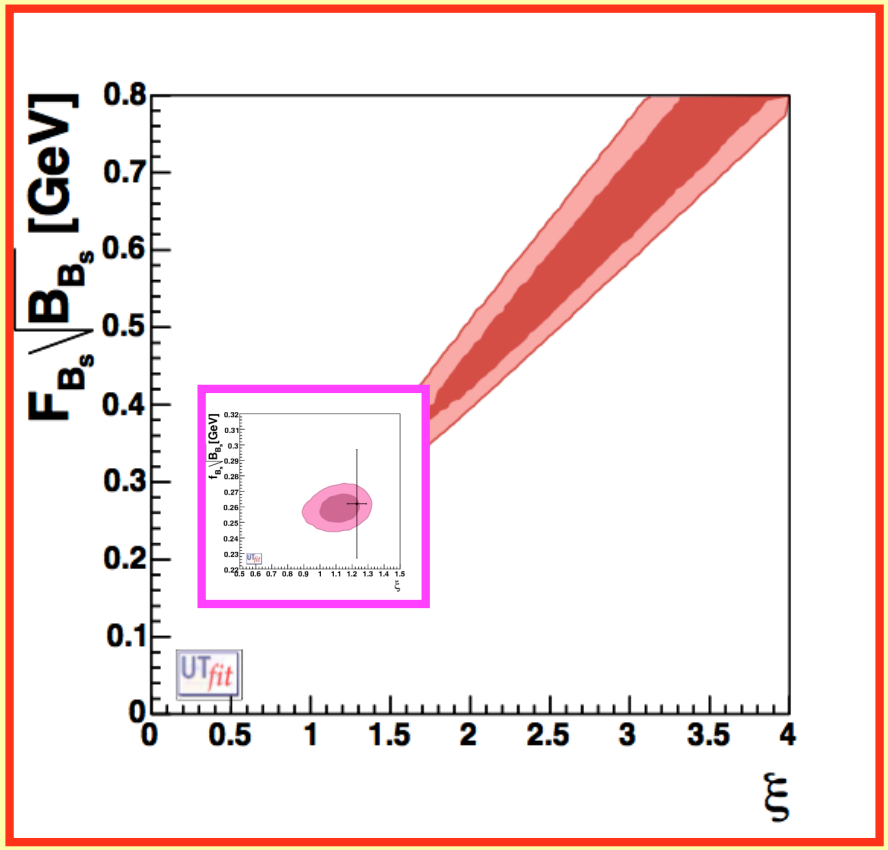
$f_B = 190 \pm 14$ MeV

$f_B = 189 \pm 27$ MeV

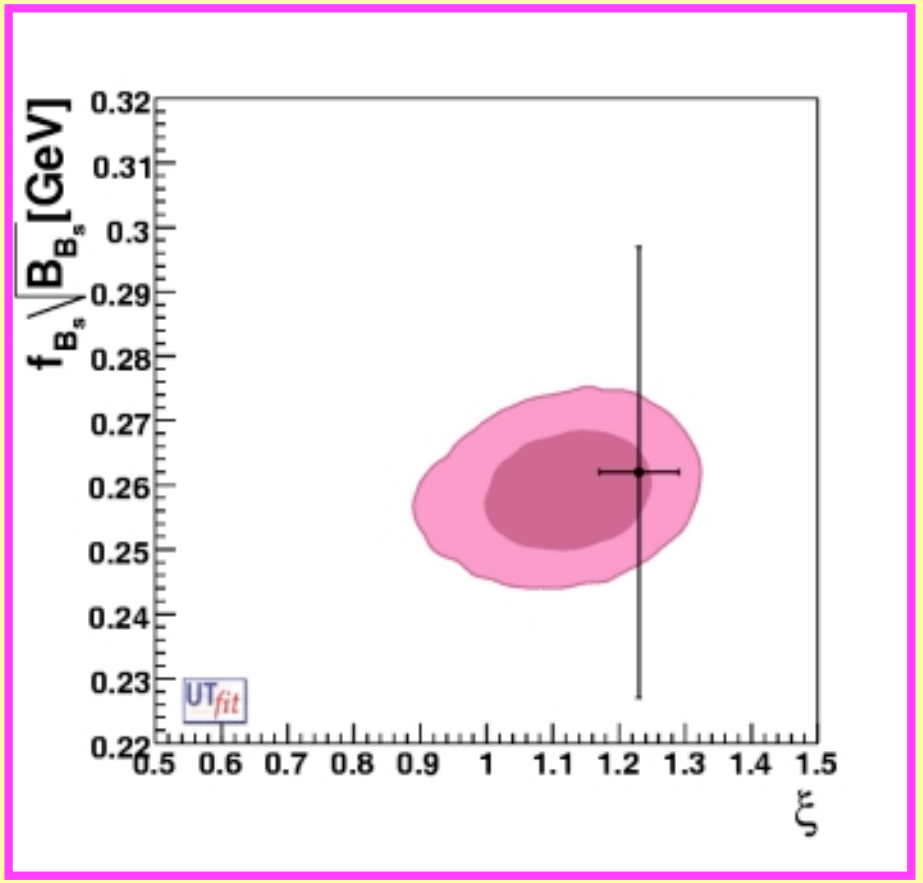
$f_{Bs} = 229 \pm 9$ MeV

$f_{Bs} = 230 \pm 30$ MeV




$F_{B_s}\sqrt{B_{B_s}}$ [GeV]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
ξ
UTfit

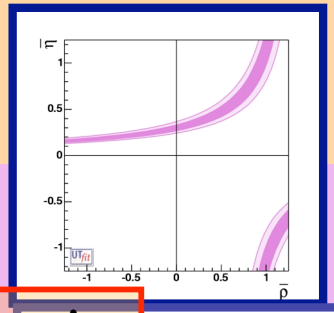
NEW

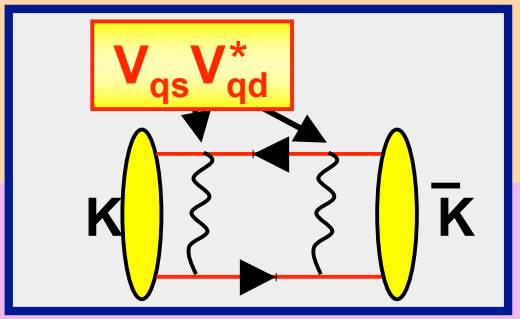

$f_{B_s}\sqrt{B_{B_s}}$ [GeV]
0.32
0.31
0.3
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.22
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
ξ
UTfit

OLD

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

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





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

L.Lellouch@Latt'00

Quench. error

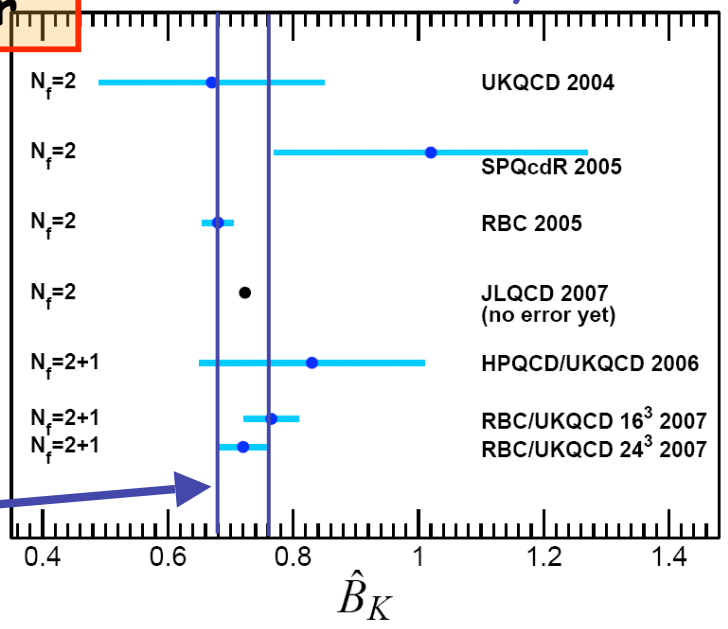
$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08$

C.Dawson@Latt'05

$\hat{B}_K = 0.720 \pm 0.039$

A.Jüttner@Latt'07

A.Jüttner, Latt'07



Precise results from chiral fermions

CP-PACS, 0803.2569 [hep-lat]

A very precise quenched calculation

$\hat{B}_K = 0.782 \pm 0.005 \pm 0.007$

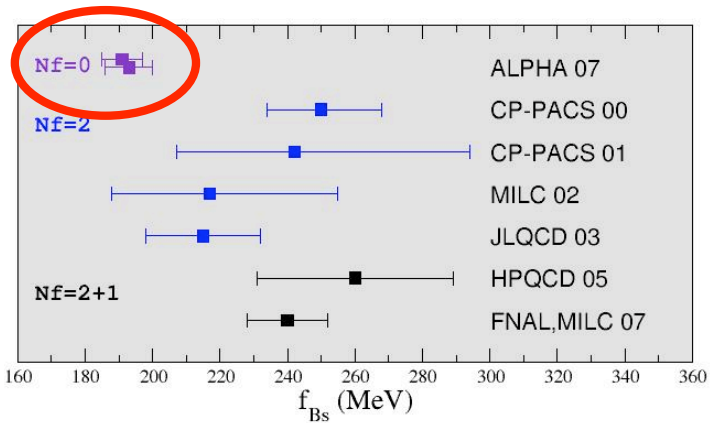
LQCD, Gavela et al., 1987:

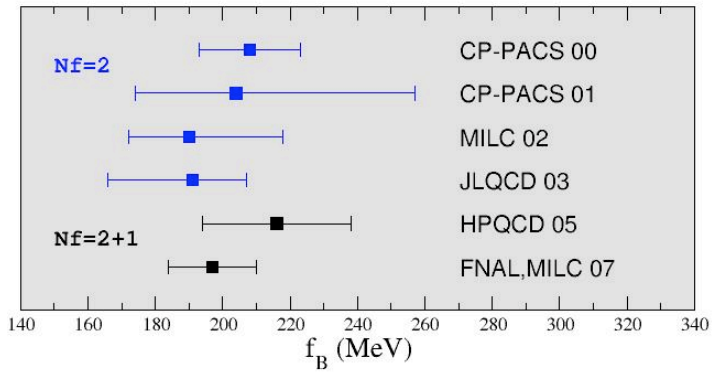
$\hat{B}_K = 0.90 \pm 0.20$

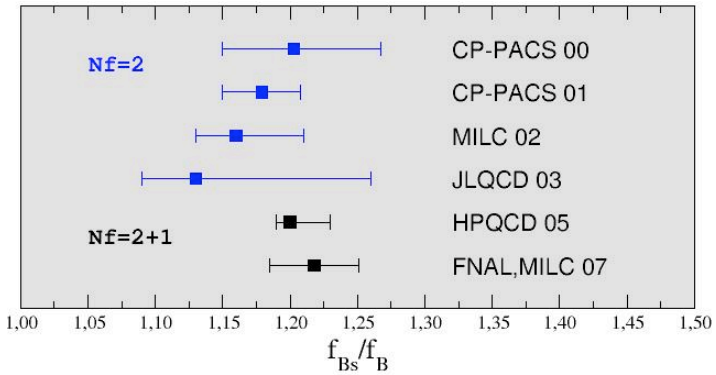
QCD SR, Pich, De Rafael, 1985:

$\hat{B}_K = 0.33 \pm 0.09$

B-mesons decay constants: f_B and f_{Bs}







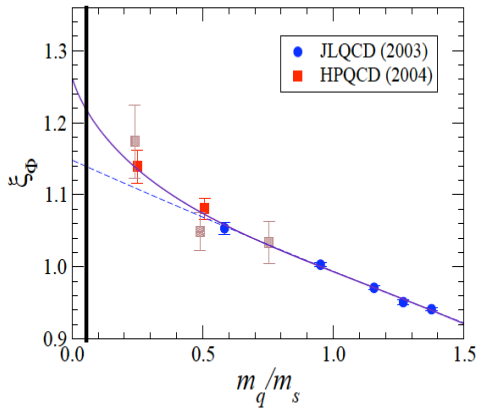
Inputs for $\Delta m_{d/s}$ and $B \to \tau\nu$

$f_{Bs} = 230 \pm 30$ MeV

$f_B = 189 \pm 27$ MeV

$f_{Bs}/f_B = 1.23 \pm 0.06$

Averages used in the UT fit



Chiral logs effects

Light m_q ($<m_s/2$) crucial for f_{Bs}/f_B

Kronfeld and Ryan, 2002:

$f_{Bs}/f_B = 1.32 \pm 0.10$

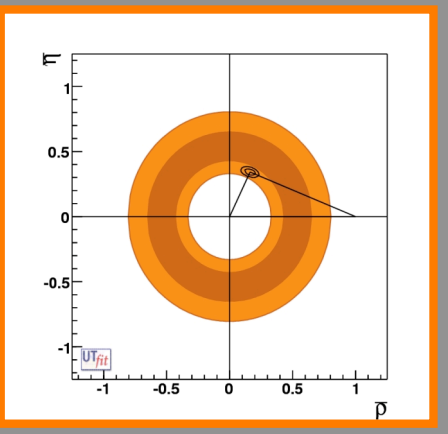
N Ro

$B \to \tau \nu_\tau$

BaBar: $(1.20 \pm 0.40 \pm 0.36) \times 10^{-4}$

Belle: $(1.79\ ^{+0.56}_{-0.49}\ ^{+0.46}_{-0.51}) \times 10^{-4}$

Average: $(1.41 \pm 0.43) \times 10^{-4}$



Potentially large NP contributions (i.e. MSSM at large tanβ, Isidori & Paradisi)

$f_B = (190 \pm 14)$ MeV [UTA]
$V_{ub} = (36.7 \pm 1.5)\ 10^{-4}$ [UTA]

$$BR(B \to \tau \nu_\tau) = (0.89 \pm 0.16) \times 10^{-4}$$

(Best SM prediction)

$f_B = (189 \pm 27)$ MeV [LQCD]
$V_{ub} = (35.0 \pm 4.0)\ 10^{-4}$ [Exclusive]

$$BR(B \to \tau \nu_\tau) = (0.84 \pm 0.30) \times 10^{-4}$$

(Independent from other NP effects)

$f_B = (189 \pm 27)$ MeV [LQCD]
$V_{ub} = (44.9 \pm 3.3)\ 10^{-4}$ [Inclusive]

$$BR(B \to \tau \nu_\tau) = (1.39 \pm 0.44) \times 10^{-4}$$

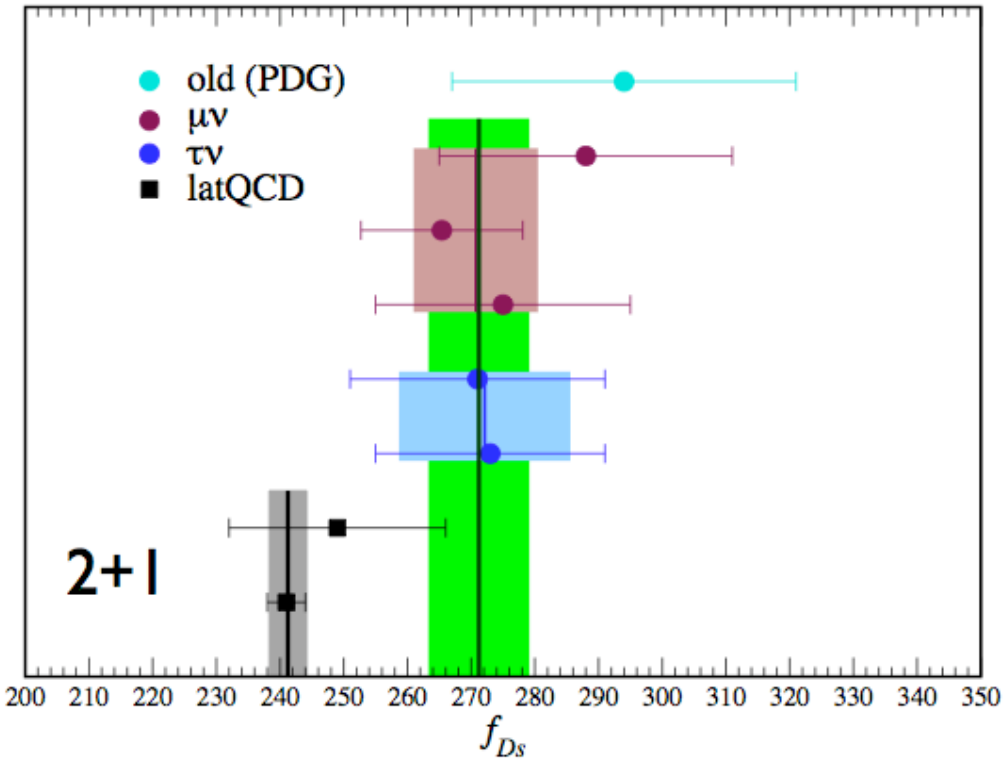
From BR($B \to \tau \nu_\tau$) and V_{ub}(UTA):

$$f_B = (240 \pm 40)\ MeV$$

Kronfeld CERN 2008

f_{Ds}

With CLEO's update from FPCP last week ...



$\chi^2/dof = 0.13$

BaBar

CLEO

Belle

CLEO $\pi\nu$

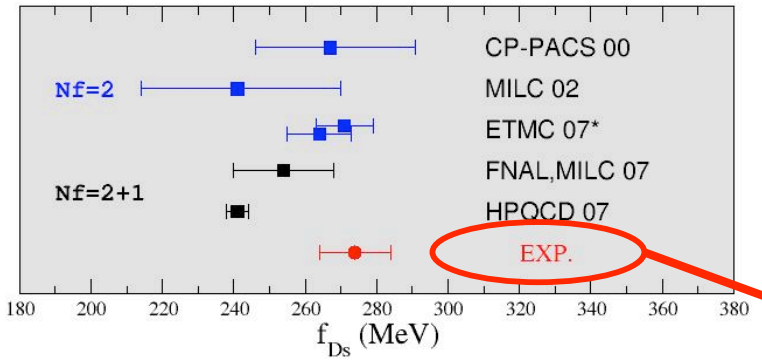
CLEO $e\nu\nu$

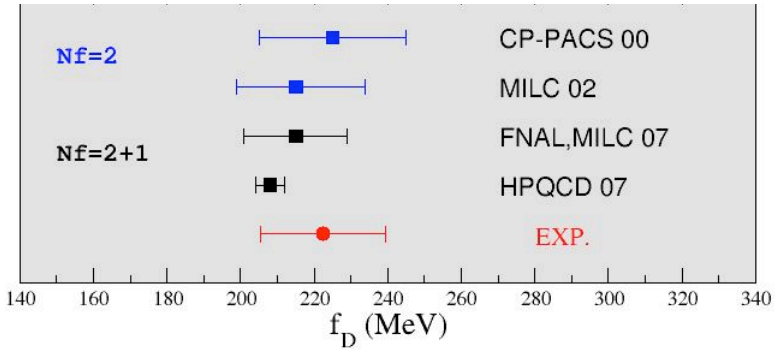
Fermilab/MILC

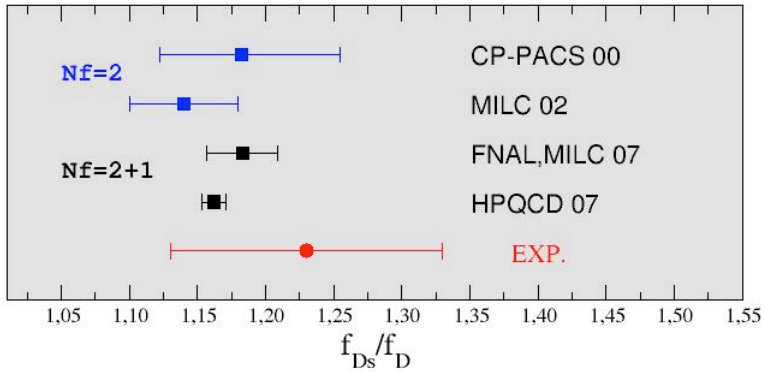
HPQCD

a 3.6σ discrepancy, or $2.9\sigma \oplus 2.2\sigma$.

D-mesons decay constants: f_D, f_{Ds}





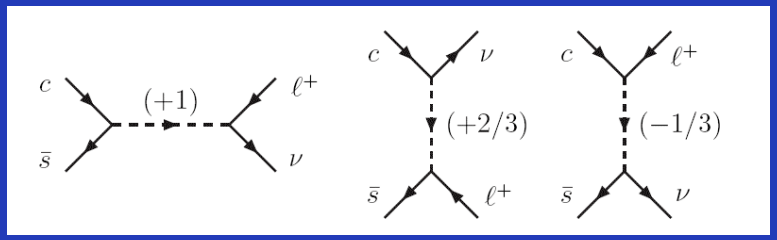


"CLEO-c has the potential to provide a unique and crucial validation of LQCD"

Ian Shipsey @ FPCP 2002
Co-Spokesperson of the CLEO Collaboration

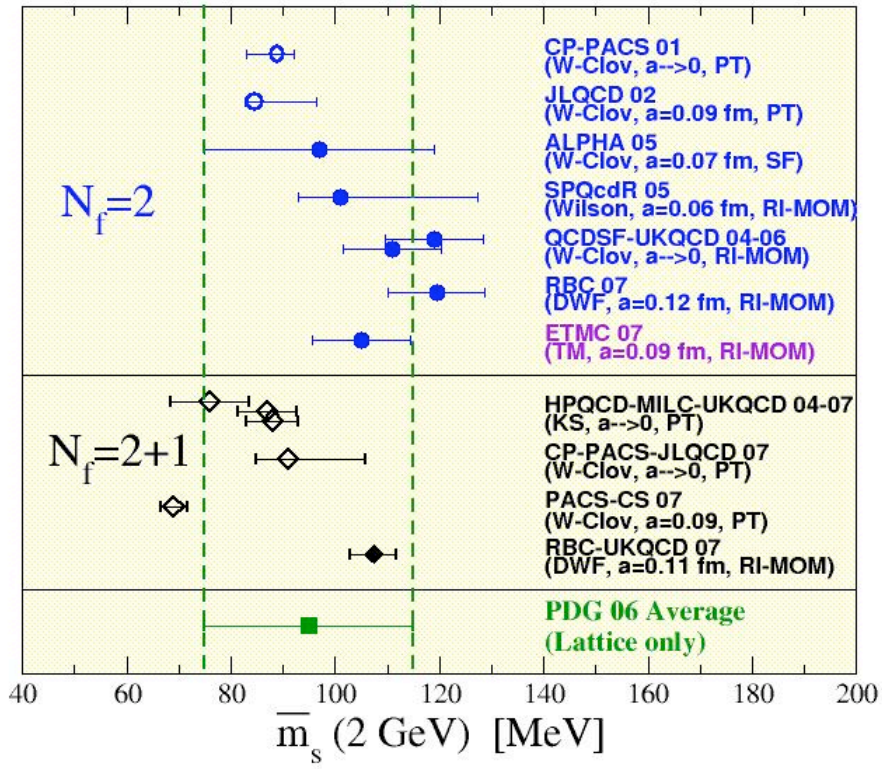
A new result by HPQCD, which claims a 1.2% precision on fDs, shows a discrepancy of about 3.5-4.0 σ with the experimental average.

B.Dobrescu, A.Kronfeld, 0803.0512: "Evidence for nonstandard leptonic decays of Ds mesons"



ms: LATTICE SUMMARY

from ETM Collaboration, 0710.0329 [hep-lat]



(*) Empty symbols: perturbative renormalization

CP-PACS, 0803.2569 [hep-lat]

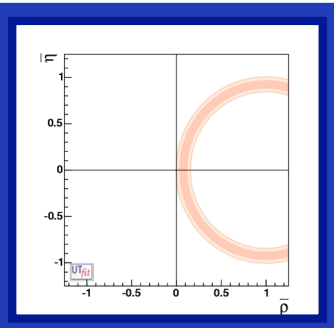
A very "precise" quenched calculation

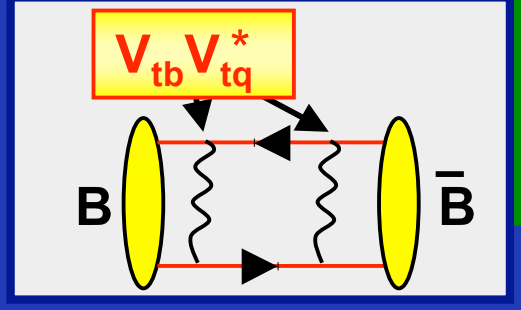
$m_s^{MS}(2\ \text{GeV}) = 105.6\ (1.2)\ \text{MeV}$

The same accuracy can be reached in unquenched determinations

The error introduced by the use of perturbative renormalization is typically larger than other systematic effects, including quenching

$\bar{B}$-B mixing: B_{Bd} and B_{Bs}

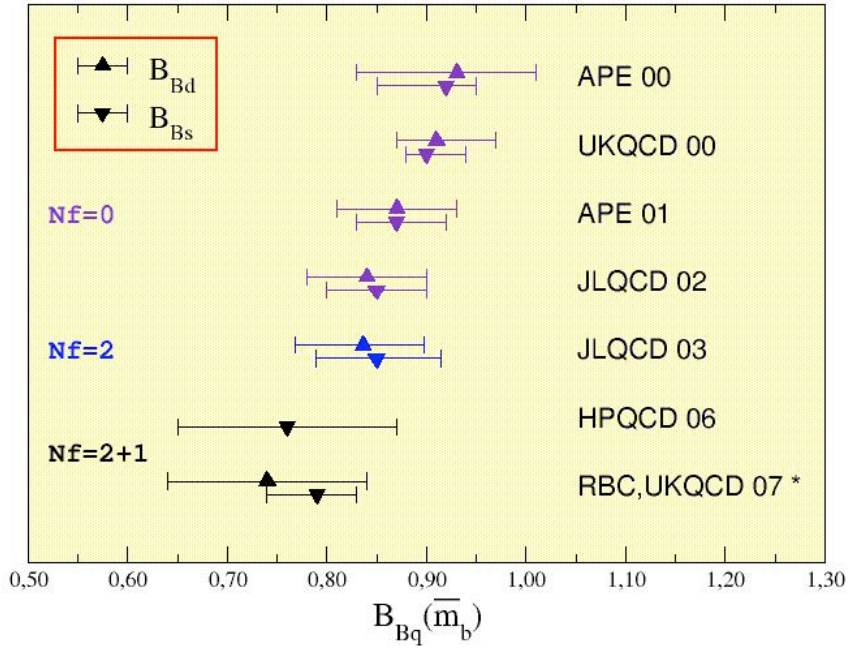




$$\langle K^0 | (s_L{}^A \gamma_\mu d_L{}^A)(s_L{}^B \gamma_\mu d_L{}^B) | K^0 \rangle = 8/3\, f^2_K M^2_K B_K(\mu)$$

-Small chiral logs effects:
$B_{Bd} \approx B_{Bs}$

-Small quenching effects:
consistent Nf=0, Nf=2
and Nf=2+1 results



Averages used in the UT fit

$$f_{Bs}\sqrt{\hat{B}_{Bs}} = 262 \pm 35 \text{ MeV}$$

$$\xi = 1.23 \pm 0.06$$

$$B_{Bd}(\bar{m}_b) = B_{Bs}(\bar{m}_b) = 0.84 \pm 0.03 \pm 0.06$$

.... beyond the Standard Model

New local four-fermion operators are generated

$Q_1 = (\bar{s}_L{}^A \gamma_\mu d_L{}^A)\,(\bar{s}_L{}^B \gamma_\mu d_L{}^B)$ SM

$Q_2 = (\bar{s}_R{}^A\, d_L{}^A)\,(\bar{s}_R{}^B\, d_L{}^B)$

$Q_3 = (\bar{s}_R{}^A\, d_L{}^B)\,(\bar{s}_R{}^B\, d_L{}^A)$

$Q_4 = (\bar{s}_R{}^A\, d_L{}^A)\,(\bar{s}_L{}^B\, d_R{}^B)$

$Q_5 = (\bar{s}_R{}^A\, d_L{}^B)\,(\bar{s}_L{}^B\, d_R{}^A)$

+ those obtained by L $\leftrightarrow$ R

Similarly for the b quark e.g.

$(\bar{b}_R{}^A\, d_L{}^A)\,(b_R{}^B\, d_L{}^B)$

$$\langle \bar{K}^0|O_1(\mu)|K^0\rangle = \frac{8}{3} M_K^2 f_K^2\, B_1(\mu)\ ,$$

$$\langle \bar{K}^0|O_2(\mu)|K^0\rangle = -\frac{5}{3}\left(\frac{M_K}{m_s(\mu)+m_d(\mu)}\right)^2 M_K^2 f_K^2\, B_2(\mu)\ ,$$

$$\langle \bar{K}^0|O_3(\mu)|K^0\rangle = \frac{1}{3}\left(\frac{M_K}{m_s(\mu)+m_d(\mu)}\right)^2 M_K^2 f_K^2\, B_3(\mu)\ ,$$

$$\langle \bar{K}^0|O_4(\mu)|K^0\rangle = 2\left(\frac{M_K}{m_s(\mu)+m_d(\mu)}\right)^2 M_K^2 f_K^2\, B_4(\mu)\ ,$$

$$\langle \bar{K}^0|O_5(\mu)|K^0\rangle = \frac{2}{3}\left(\frac{M_K}{m_s(\mu)+m_d(\mu)}\right)^2 M_K^2 f_K^2\, B_5(\mu)\ ,$$

	Donini et al.	Babich et al.	Nakamura et al.
B_1	0.68(21)	0.56(6)	0.52(4)
B_2	0.67(7)	0.87(8)	0.54(2)
B_3	0.95(15)	1.41(16)	0.71(2)
B_4	1.00(9)	0.94(6)	0.70(1)
B_5	0.66(11)	0.62(8)	0.62(1)

	Donini et al.	Babich et al.	Nakamura et al.
R_1	1	1	1
R_2	-6.7(20)	-16(3)	-19(1)
R_3	1.9(6)	5.2(9)	5.0(3)
R_4	12(3)	21(3)	30(3)
R_5	2.6(9)	4.6(9)	8.8(7)

Table 1: *B_i-parameters (left) and ratios R_i (right) for the full basis of four-fermions operators in $K - \bar{K}$ mixing. All results are in the RI-MOM scheme at the scale $\mu = 2$ GeV.*

1) Quenched
2) Non improved / no continuum extrapolation
3) light quark masses to heavy

B Mixing in General SUSY models

D. Becirevic et al. 2001

$$\langle \bar{B}_d | \mathcal{H}_{\rm eff}^{\Delta B=2} | B_d \rangle = \mathrm{Re}\,\mathcal{A}_{SM} + i\,\mathrm{Im}\,\mathcal{A}_{SM} + \mathcal{A}_{SUSY}\,\mathrm{Re}(\delta^d_{13})^2_{AB} + i\,\mathcal{A}_{SUSY}\,\mathrm{Im}(\delta^d_{13})^2_{AB}\,,$$

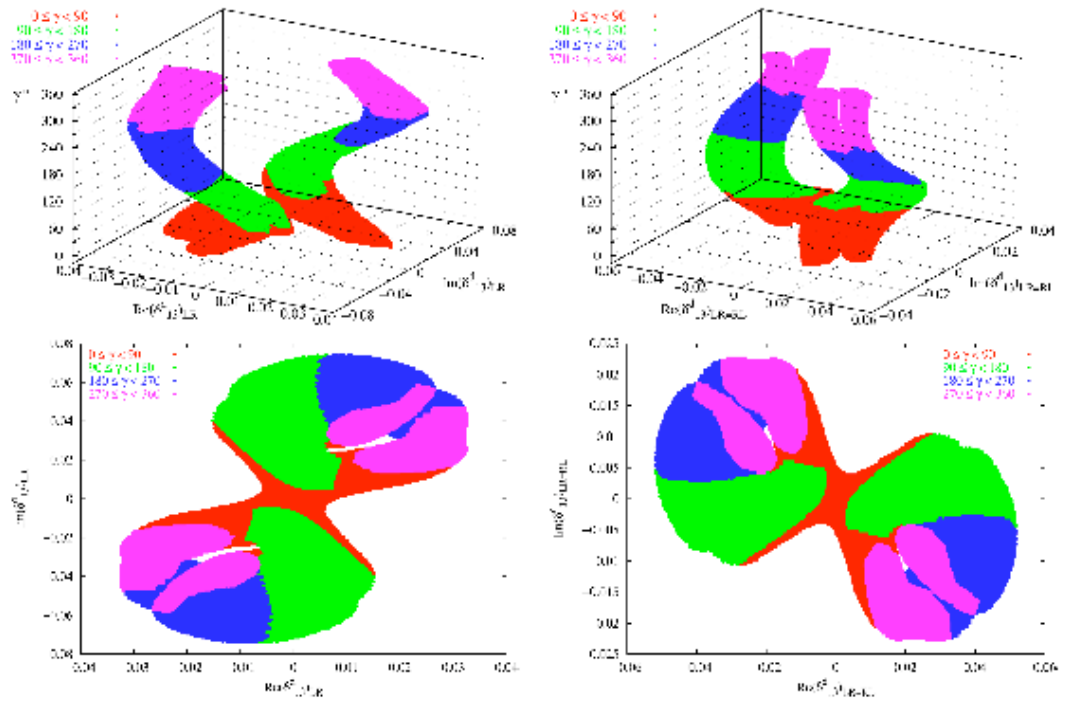
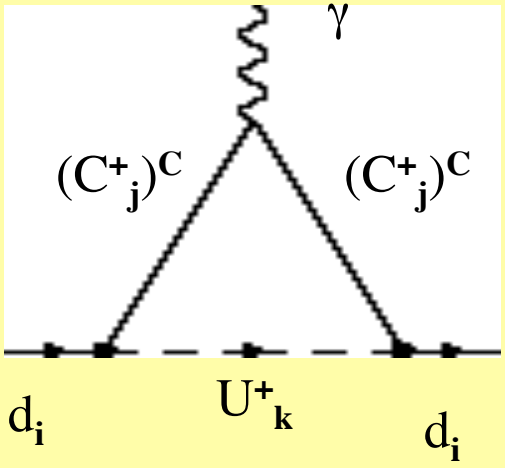
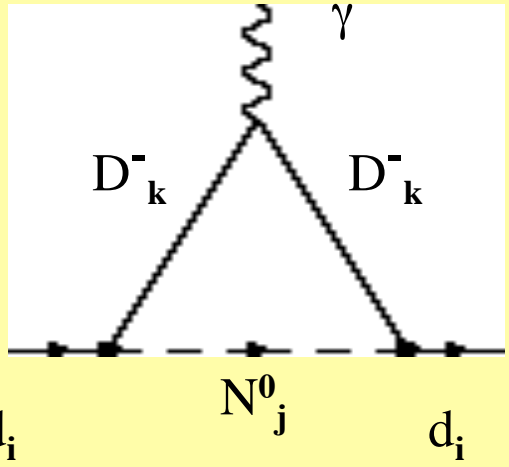
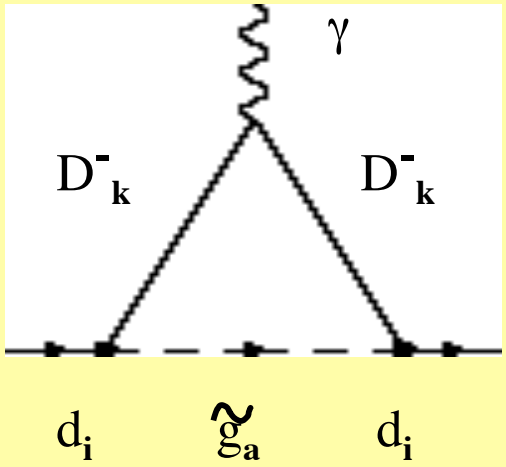


Figure 3: *Allowed regions in the* (γ, $Re(\delta^d_{13})_{LR}$, $Im(\delta^d_{13})_{LR}$) *space with* $(\delta^d_{13})_{LR}$ *only (left) and* $(\delta^d_{13})_{LR} = (\delta^d_{13})_{RL}$ *(right). The two lower plots are the corresponding projections in the* $Re(\delta^d_{13})_{LR}$–$Im(\delta^d_{13})_{LR}$ *plane. Different colours denote values of* γ *belonging to different quadrants.*

Neutron electric dipole moment in SuperSymmetry ($\Delta F=0$)







$$\mathcal{L}^{\Delta F=0} = -i/2\, C_e\, \bar{\psi}\sigma_{\mu\nu}\gamma_5\psi\, F^{\mu\nu}$$
$$-i/2\, C_C\, \bar{\psi}\sigma_{\mu\nu}\gamma_5\, t^a\psi\, G^{\mu\nu a}$$
$$-1/6\, C_g\, f_{abc}\, G^a_{\mu\rho}\, G^{b\rho}_{\nu}\, G^c_{\lambda\sigma}\, \varepsilon^{\mu\nu\lambda\sigma}$$

$C_{e,C,g}$ can be computed perturbatively

Chromomagnetic operators vs ε'/ε and ε

$$\mathcal{H}_g = C^+_g O^+_g + C^-_g O^-_g$$

$$O^{\pm}_g = \frac{g}{16\pi^2} \left(s_L \, \sigma^{\mu\nu} \, t^a \, d_R \, G_{\mu\nu}{}^a \pm s_R \, \sigma^{\mu\nu} \, t^a \, d_L \, G_{\mu\nu}{}^a \right)$$

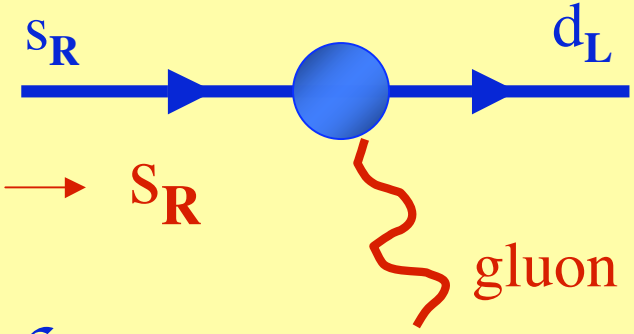
- It contributes also in the Standard Model (but it is chirally supressed $\propto m_K^4$)
- Beyond the SM can give important contributions to ε' (Masiero and Murayama)
- It is potentially dangerous for ε (Murayama et. al., D'Ambrosio, Isidori and G.M.)
- It enhances CP violation in $K \rightarrow \pi\pi\pi$ decays (D'Ambrosio, Isidori and G.M.)
- Its cousin $O^{\pm}_{\gamma}$ gives important effects in $K_L \rightarrow \pi^0 e^+ e^-$

($\langle \pi^0 | Q_\gamma^+ | K^0 \rangle$ computed by D. Becirevic et al. , The SPQ$_{cd}$R Collaboration, Phys.Lett. B501 (2001) 98)

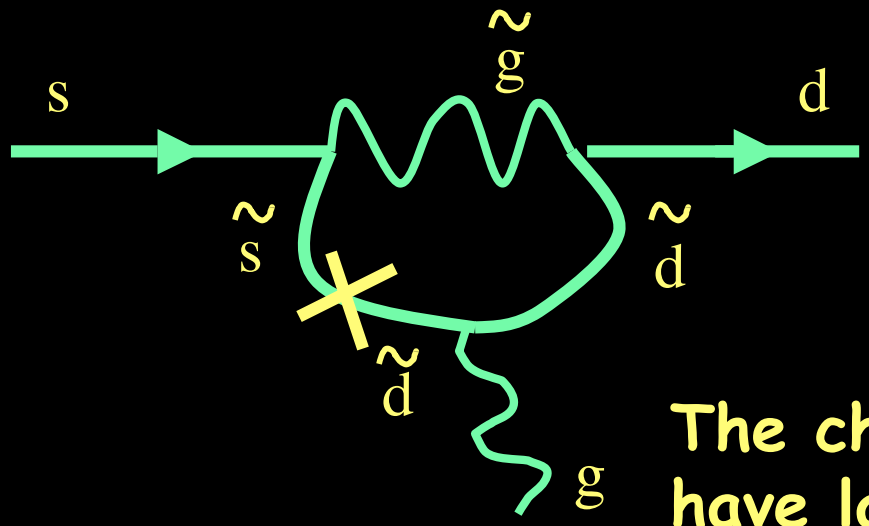
The Chromomagnetic operator

$$O_\sigma = m_s \, \bar{d}_L \, \sigma_{\mu\nu} \, t^a \, s_R \, G^{\mu\nu a}$$

mass term necessary to the helicity flip $s_L \rightarrow s_R$



$$\langle \pi\pi / O_\sigma / K \rangle \sim O(M_K^4) \qquad [\langle \pi\pi / \mathcal{H}_W / K \rangle \sim O(M_K^2)\ ]$$



Masiero-Murayama

$$m_s \rightarrow \alpha_s \; \delta^{12}_{LR} \; (M^2_W / m^2_{\tilde{q}}) \; m_{\tilde{g}}$$

The chromomagnetic operator may have large effects in ε'/ε

~~CP~~ from SUSY flavour mixing

define $\delta_{\pm} = \delta^{21}_{LR} \pm (\delta^{12}_{LR})^*$ then

$\delta_+ \longrightarrow$

$K \longrightarrow \pi$

$K \longrightarrow 3\ \pi$

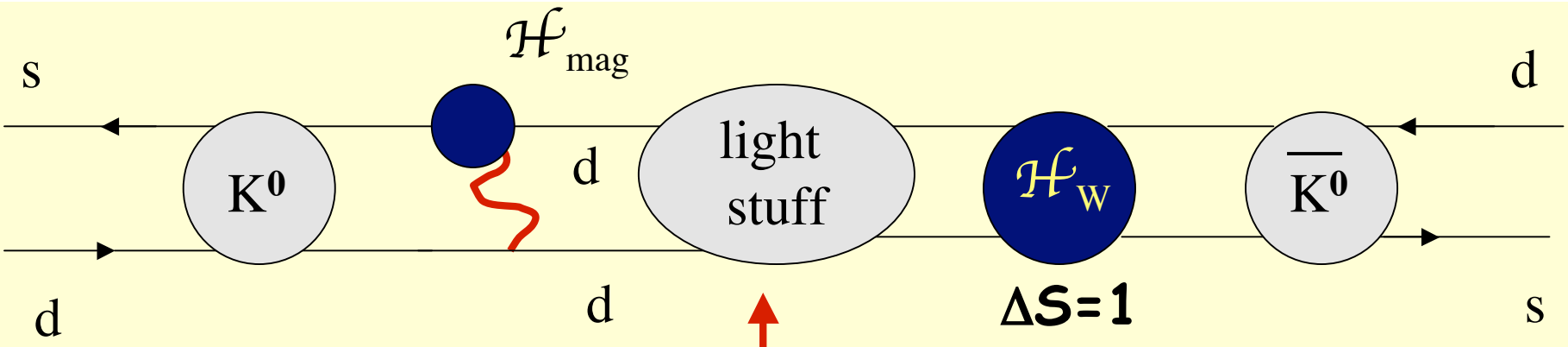
$K_L \longrightarrow \pi^0 e^+ e^-$

parity even

$\delta_- \longrightarrow$ $K \longrightarrow 2\ \pi$

parity odd

$K \longrightarrow \pi$ in $K^0 - \overline{K^0}$ mixing (see next page)



$$\mathcal{A}^{SUSY}(K^0 \rightarrow \overline{K^0}) = \mathcal{A}_{boxes} + \mathcal{A}_{1mag} + \mathcal{A}_{2mag}$$

π^0, η, η', etc.

$$\mathcal{A}_{1mag} = \frac{2 \langle \overline{K^0} | \mathcal{H}_W | \pi^0 \rangle \langle \pi^0 | \mathcal{H}_{mag} | K^0 \rangle}{M^2_K - M^2_\pi}$$

$$\propto \mathrm{Im}(\delta_+) \times 4.8\ 10^{-13}\ \mathrm{GeV}^2\ K_1$$

The K-factor K_1 accounts for other contributions besides the π^0, as the etas, more particle states, etc.

Boxes		$\mathrm{Im}(\delta^2_+)$ or $\mathrm{Im}(\delta^2_-)$
1-mag		$\mathrm{Im}(\delta_+)$
2-mag		$\mathrm{Im}(\delta^2_+)$
K_L	$\pi^o e^+ e^-$	$\mathrm{Im}(\delta^2_+)^2$
$\varepsilon'/\varepsilon \rightarrow$		$\mathrm{Im}(\delta_-)$

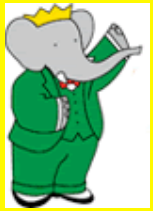
If the K-factor K_1 is not too small,
the strongest limits on $\mathrm{Im}(\delta_+)$ come
from $\mathcal{A}_{1\mathrm{mag}}$ in $K^0 - \overline{K^0}$ mixing $(10^{-4} - 10^{-5})$!!

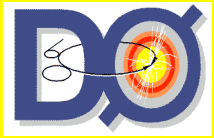
D'Ambrosio, Isidori and G.M.; X-G He, Murayama, Pakvasa and Valencia

FUTURE OF LATTICE CALCULATIONS (lubicz Padova SUPERB)

In the era of precision experimental flavour physics

ε_K	$(2.280 \pm 0.013)\ 10^{-3}$	0.6%
Δm_d	$(0.507 \pm 0.005)\ ps^{-1}$	1%
Δm_s	$(17.77 \pm 0.12)\ ps^{-1}$	0.7%
$Sin2\beta$	0.668 ± 0.028	4%
$\lvert V_{us}\rvert f_+(0)$	0.21664 ± 0.00048	0.2%
…	…	…

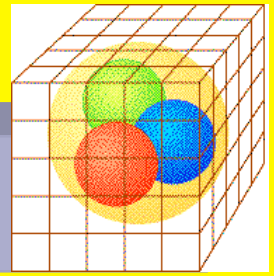




… …

we are also entering 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.

Present theoretical accuracy (lubicz '08)

Measurement	CKM matrix element	Hadronic matrix element	Current lattice error	Estimated error in 2015
$K \to \pi\, l\, \nu$	$\lvert V_{us}\rvert$	$f_+^{K\partial}(0)$	0.9% (22% on 1-f_+)	??
ε_K	$\mathrm{Im}V_{td}^2$	$\hat{B}_K$	11%	??
$B \to l\, \nu$	$\lvert V_{ub}\rvert$	f_B	14%	??
Δm_d	$\lvert V_{td}\rvert$	$f_{Bd}B_{Bd}^{1/2}$	14%	??
$\Delta m_d / \Delta m_s$	$\lvert V_{td}/V_{ts}\rvert$	ξ	5% (26% on ξ-1)	??
$B \to D/D^*\, l\, \nu$	$\lvert V_{cb}\rvert$	$\Phi_{B \to D/D^* l\nu}$	4% (40% on 1-Φ)	??
$B \to \pi/\rho\, l\, \nu$	$\lvert V_{ub}\rvert$	$f_+^{B\partial}$,...	11%	??
$B \to K^*/\rho\ (\gamma, l^+l^-)$	$\lvert V_{td}/V_{ts}\rvert$	$T_1^{B\to K^*/\tilde{n}}$	13%	??

In almost all the cases, uncertainties in Lattice QCD calculations are dominated by systematic errors.

- **Statistical**

  - O(100) independent configurations are typically required tom keep these errors at the percent level

- **Discretization errors and continuum extrapolation:**
  $a \to 0$ [Now $a \lesssim 0.1$ fm]

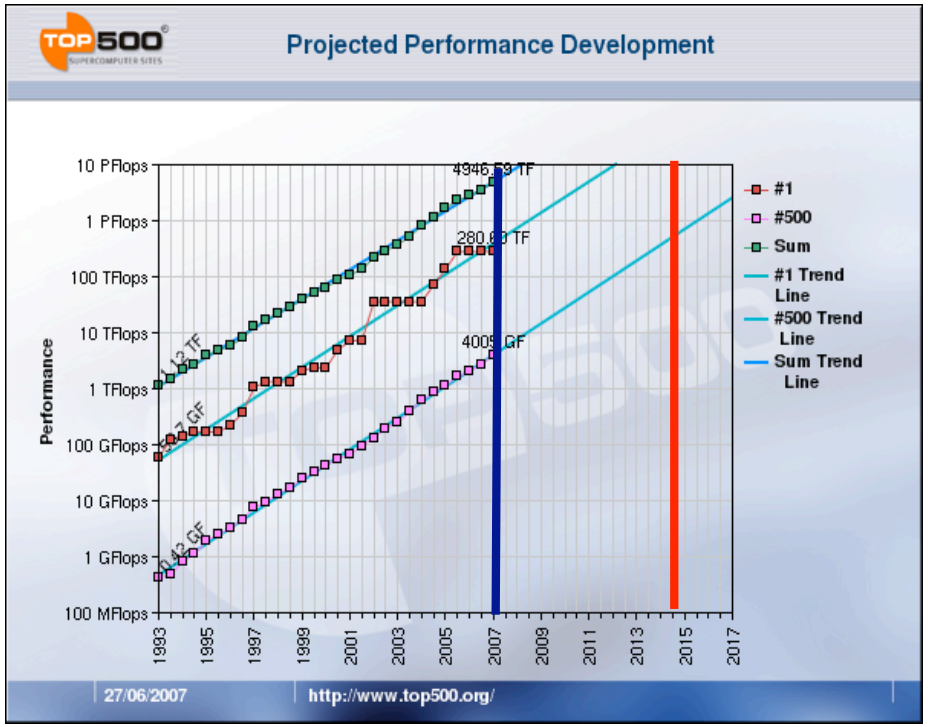
- **Chiral extrapolation:** $\hat{m}_q \to m_{u,d}^{phys.}$ [Now $m_{u,d} \gtrsim m_s/6$]

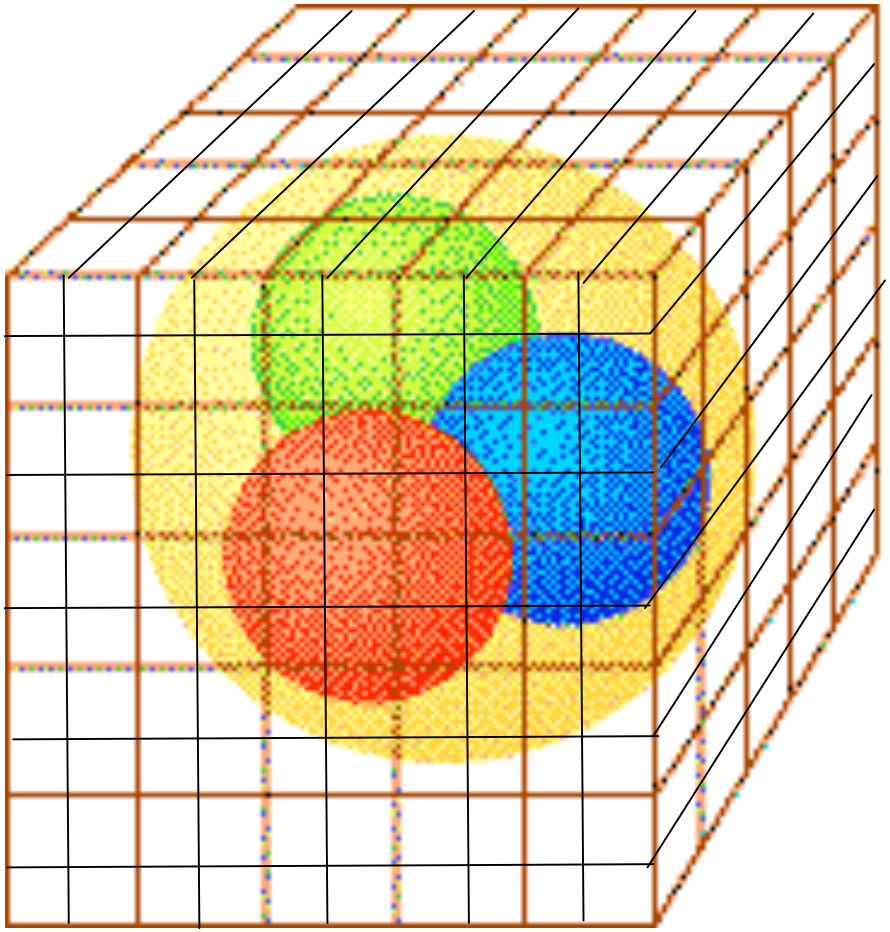
- **Heavy quarks extrapolation:** $m_H \to m_b, \ldots$ [Now $m_H \simeq m_c$]

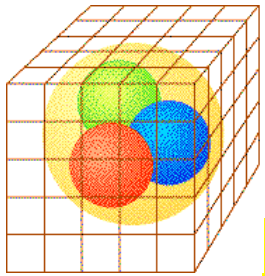
- **Finite volume** [Now $L \simeq 2\text{-}2.5$ fm]

- **Renormalization constants:** $O_{cont}(\mu) = Z(a\mu, g)\, O_{latt}(a)$

  - In most of the cases Z can be calculated non-perturbatively: accuracy can be better than 1%







Predictions on the 10 years scale are educated guesses

Today ~ 1 – 10 Tflops → 2015 ~ 1 – 10 PFlops

Cost of the target simulations:

Light quarks phys.

Nconf = 120

a = 0.05 fm
[$1/a$ = 3.9 GeV]

$\hat{m}/m_s$ = 1/12
[m_π = 200 MeV]

L_s = 4.5 fm
[$V = 90^3 \times 180$]

0.07 PFlop-years Wilson
1-2 PFlop-years GW

Heavy quarks phys

Nconf = 120

a = 0.033 fm
[$1/a$ = 6.0 GeV]

$\hat{m}/m_s$ = 1/12
[m_π = 200 MeV]

L_s = 4.5 fm
[$V = 136^3 \times 270$]

0.9 PFlop-years Wilson

Overhead for Nf=2+1 and lattices at larger a and m is about 3

Affordable with 1-10 PFlops !!

A previous estimate

S.Sharpe @ Lattice QCD: Present and Future, Orsay, 2004
and report of the U.S. Lattice QCD Executive Committee

Hadronic matrix element	Current lattice error	6 TFlop Year	60 TFlop Year	1-10 PFlop Year
$f_+^{K\partial}(0)$	0.9% (22% on 1-f_+)	0.7% (17% on 1-f_+)	0.4% (10% on 1-f_+)	??
$\hat{B}_K$	11%	5%	3%	??
f_B	14%	3.5 - 4.5%	2.5 - 4.0%	??
$f_{Bs}B_{Bs}^{1/2}$	13%	4 - 5%	3 - 4%	??
ξ	5% (26% on ξ-1)	3% (18% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	??
$\Phi_{B \to D/D^* l\nu}$	4% (40% on 1-Φ)	2% (21% on 1-Φ)	1.2% (13% on 1-Φ)	??
$f_+^{B\partial}$,...	11%	5.5 - 6.5%	4 - 5%	??
$T_1^{B\to K^*/\tilde{n}}$	13%	----	----	??

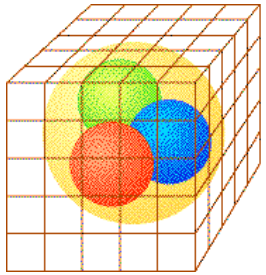
Estimates of error for 2015

Hadronic matrix element	Current lattice error	6 TFlop Year	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\partial}(0)$	0.9% (22% on 1-f_+)	0.7% (17% on 1-f_+)	0.4% (10% on 1-f_+)	**< 0.1% (2.4% on 1-f_+)**
$\hat{B}_K$	11%	5%	3%	**1%**
f_B	14%	3.5 - 4.5%	2.5 - 4.0%	**1 – 1.5%**
$f_{Bs}B_{Bs}^{1/2}$	13%	4 - 5%	3 - 4%	**1 – 1.5%**
ξ	5% (26% on ξ-1)	3% (18% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	**0.5 – 0.8 % (3-4% on ξ-1)**
$\Phi_{B \to D/D^*lv}$	4% (40% on 1-Φ)	2% (21% on 1-Φ)	1.2% (13% on 1-Φ)	**0.5% (5% on 1-Φ)**
$f_+^{B\partial}$,…	11%	5.5 - 6.5%	4 - 5%	**2 – 3%**
$T_1^{B\to K^*/\tilde{n}}$	13%	----	----	**3 – 4%**

Precision flavour physics at the SuperB

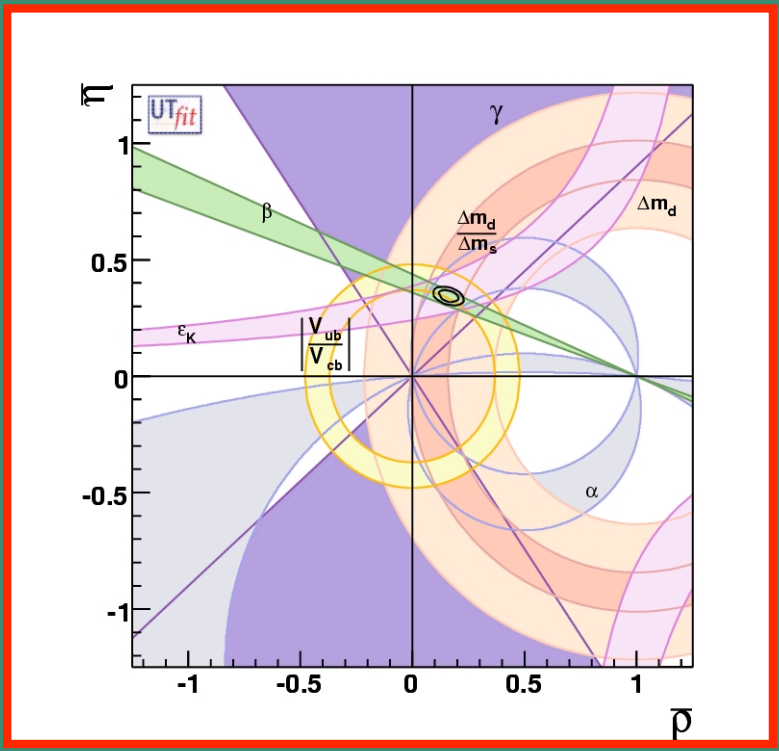
UTA in 2015

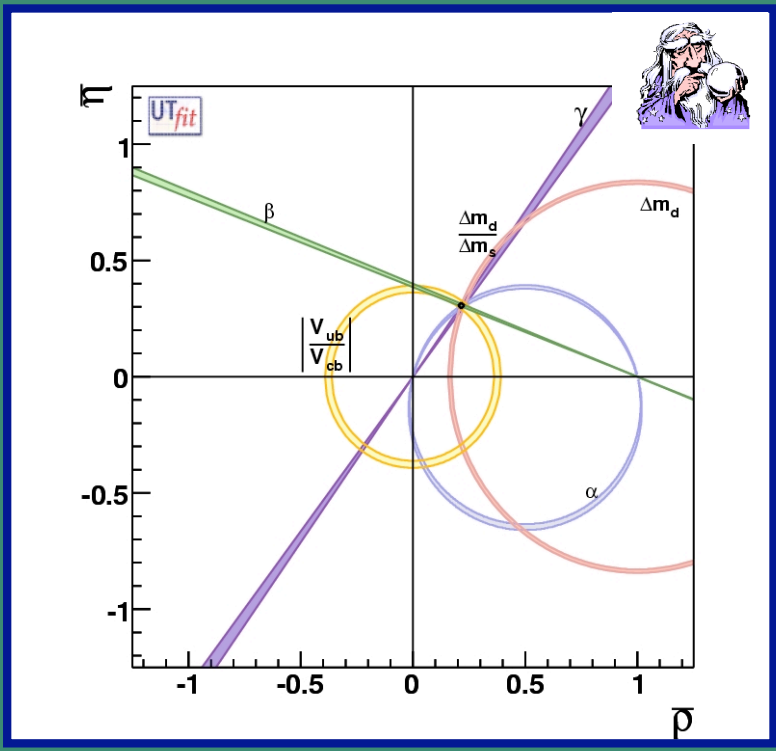
Table of inputs



	Central Value	Current error	Error in 2015
sin2β	0.680	0.026 (4%)	0.005 (0.7%)
α	105°	7° (7%)	1° (1%)
γ	54°	20° (37%)	1° (2%)
λ	0.2258	0.0014 (0.6%)	0.0008 (0.4%)
$\|V_{cb}\|$ (10^{-3})	41.7	2.2 (5%)	0.2 (0.5%)
$\|V_{ub}\|$ (10^{-4})	36.4	2.0 (5%)	0.7 (2%)
Δm_d (ps^{-1})	0.507	0.005 (1%)	0.002 (0.4%)
Δm_s (ps^{-1})	18.06	0.12 (0.7%)	0.05 (0.2%)
mt (GeV)	163.8	3.2 (2%)	1.5 (1%)
$f_{Bs}\sqrt{B_s}$ (MeV)	262	35 (13%)	2.5 (1%)
ξ	1.13	0.06 (5%)	0.006 (0.5%)
fB (MeV)	189	27 (14%)	1.9 (1%)
BR($B\to\tau\nu$) (10^{-4})	0.83	0.48 (64%)	0.03 (4%)
B_K	0.90	0.09 (11%)	0.009 (1%)
ε_K	2.280	0.013 (0.6%)	0.013 (0.6%)
ASL(Bd) [10^{-3}]	- 0.7	5	0.1

UTA in the SM: 2007 vs 2015





σ(ρ̄) / ρ̄ = 20%

σ(η̄)/ η̄ = 4.7%

σ(ρ̄) / ρ̄ = 1.3%

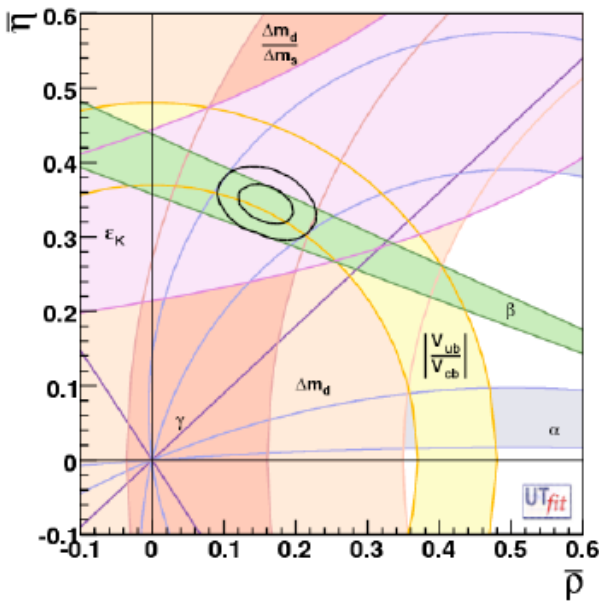
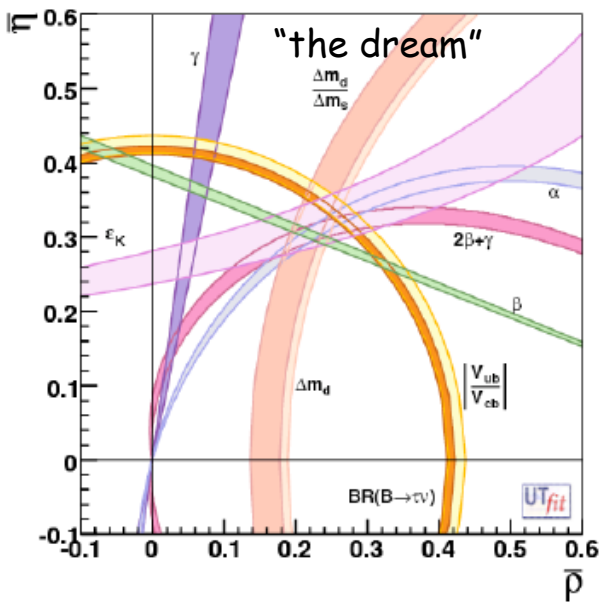
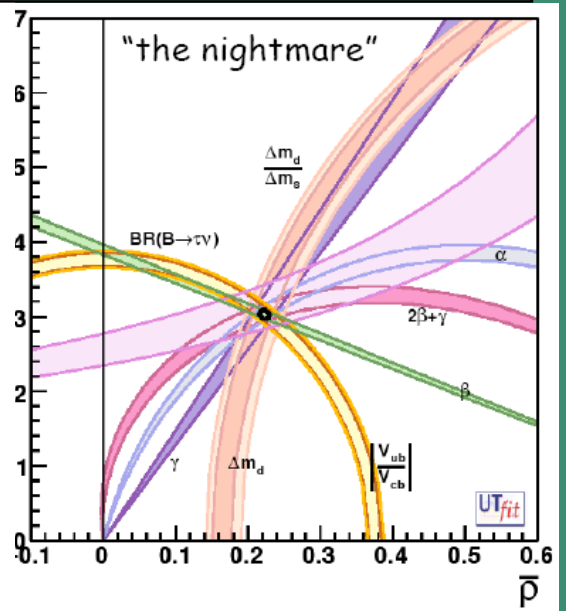
σ(η̄)/ η̄ = 0.8%

The goal of a SuperB factory: Precision flavour physics for indirect New Physics searches

An important example:

- Test the CKM paradigm at the 1% level

Today



With a SuperB in 2015