Lattice e flavour nell'era di SuperB

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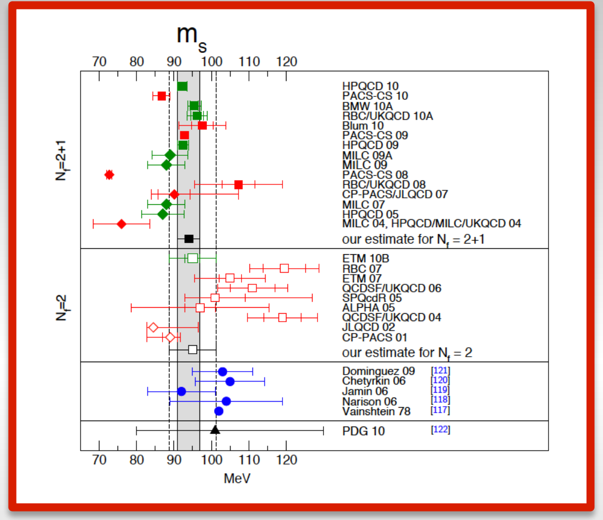
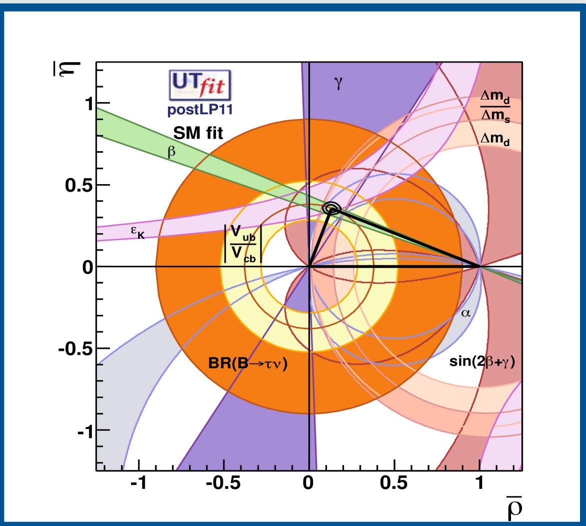




CORTONA 2012

Convegno Informale di Fisica Teorica

30 Maggio - 1 Giugno 2012

GRAZIE

AL COMITATO ORGANIZZATORE:

Marisa Bonini, Raffaella Burioni, Giovanni Cicuta, Francesco DiRenzo, Luca Griguolo, Enrico Onofri, Ettore Vicari

CORTONA 1990

1

FATTORI DI FORMA E COSTANTI DI DECADIMENTO DEI MESONI D E B NELLA QCD SUL RETICOLO

Collaborazione ELC
(C.R. Allton, M. Crisafulli, V.L., L. Maiani, G. Martinelli, C.T. Sachrajda)

1) DECADIMENTI SEMILEPTONICI DEI MESONI D

- $\boxed{D \to K \ell \nu_e}$
- $\boxed{D \to K^* \ell \nu_e}$

2) MISURA DI f_B

[IMPORTANTE PER IL $B^0 - \bar{B}^0$ MIXING

$\langle B^0 | O^{(\Delta B=2)} | \bar{B}^0 \rangle = \frac{8}{3} f_B^2 m_B^2 B$, $B \sim 1$]

Lattice e flavour nell'era di SuperB

CORTONA 2012

SOMMARIO

- Motivazioni per la fisica del flavour e ruolo della QCD sul reticolo
- Le masse dei quark u, d, s
- La matrice CKM e il test di unitarieta' della prima riga: Vus, f_K/f_π, $f_+(0)$
- Gli effetti di isospin breaking
- L' analisi del triangolo unitario: il passato, il presente e il futuro (SuperB)

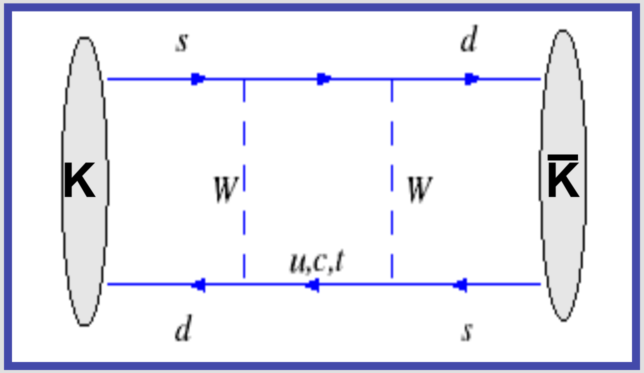
The Standard Model does not:

- include gravity ($M_{Planck} = (\hbar c/G_N)^{1/2} \approx 10^{19}$ GeV)
- explain the origin of flavour, i.e. masses, mixing and CPV (M_{Flav}= ??)
- give a natural explanation of the hiearchy problem ($M_{Weak} << M_{Planck}$)
- provide (exact) gauge coupling unification ($M_{GUT} \approx 10^{15}$-10^{16} GeV)
- explain the smallness of neutrino masses ($m_\nu \approx (\lambda v)^2/M$, $M \approx 10^{15}$ GeV)
- produce the observed matter-antimatter asymmetry
- provide a viable dark matter candidate
- explain “dark“ (vacuum) energy

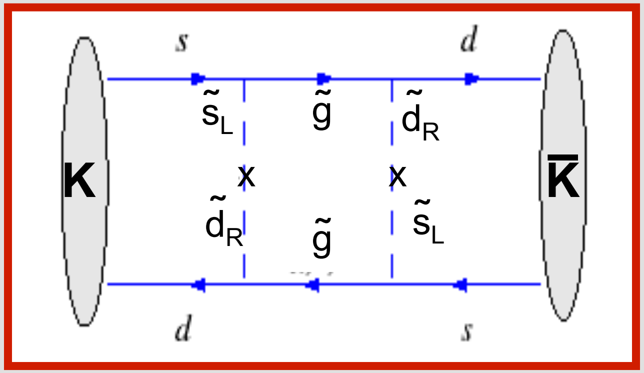
Cosmology

Motivations for flavour physics

Standard Model



New Physics



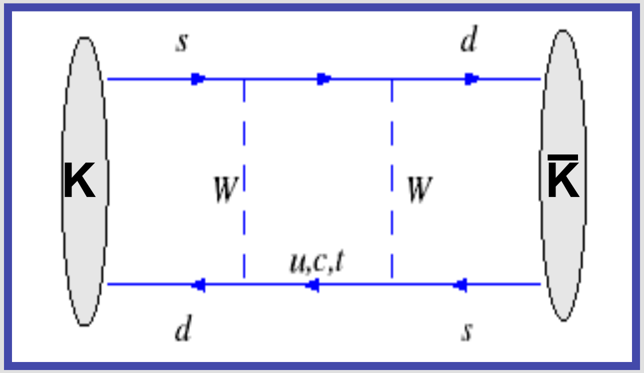
Indirect searches look for new physics (NP) through virtual effects of new particles in loop corrections

- In the SM, FCNC and CP-violating processes occur at the loop level
- In the SM, FV and CPV are governed by the weak interactions and suppressed by mixing angles
- In the SM, quark CPV comes from a single source (neglecting θ_{QCD})

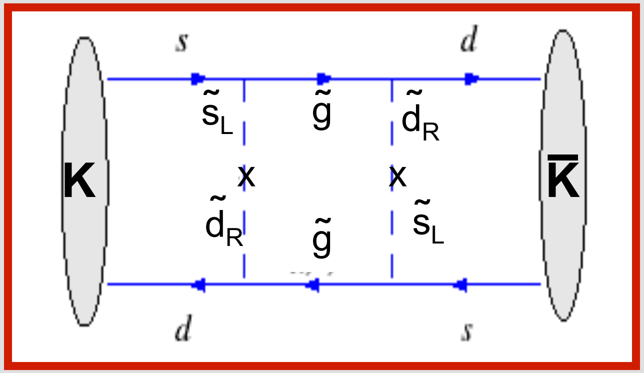
NP does not necessarily share the SM pattern of FV and CPV: very large NP effects are possible

Motivations for flavour physics

Standard Model



New Physics



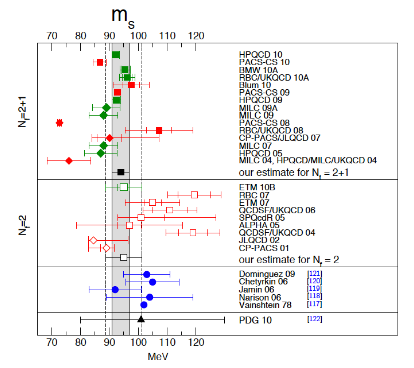
Past (SM) successes in anticipating heavy flavours:

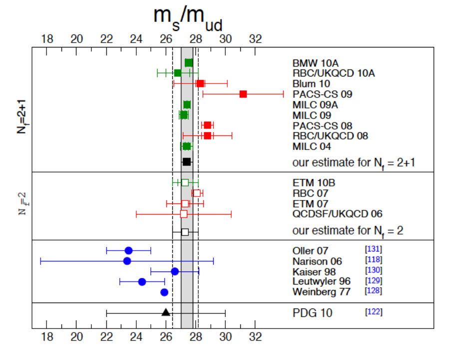
- 1970: charm from $K^0 \rightarrow \mu\mu$ (GIM)
- 1973: 3rd generation from ϵ_K (Kobayashi and Maskawa)
- mid 80s: heavy top from semileptonic decays and Δm_B

Current and next-generation flavour experiments will improve the experimental precision/sensitivity by one order of magnitude

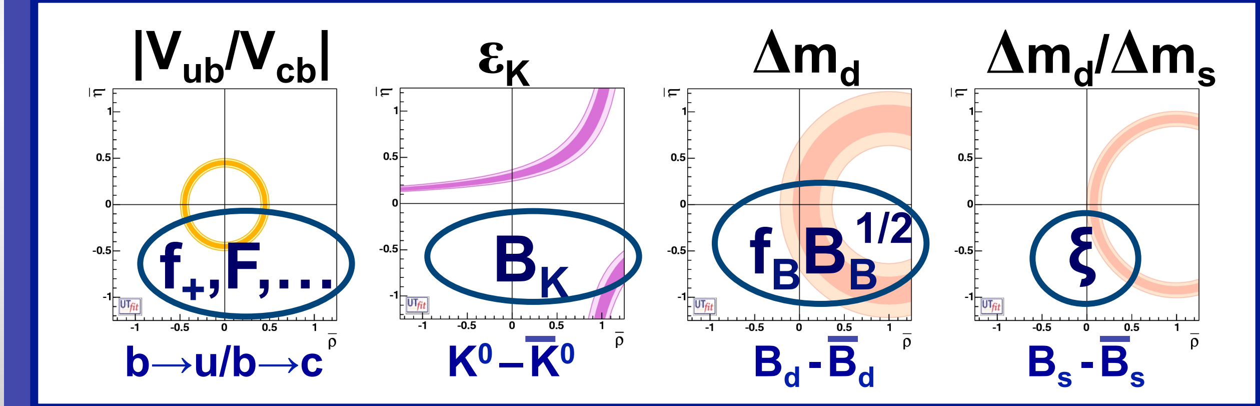
- Enough NP-insensitive observables to pin down the SM contribution with the required accuracy
- Several NP-sensitive observables not limited by systematics or theoretical uncertainties

Lattice QCD and flavour physics





Quark masses



$|V_{ub}/V_{cb}|$ — $f_{+}, F, \ldots$ — $b \to u / b \to c$

ε_K — B_K — $K^0 - \bar{K}^0$

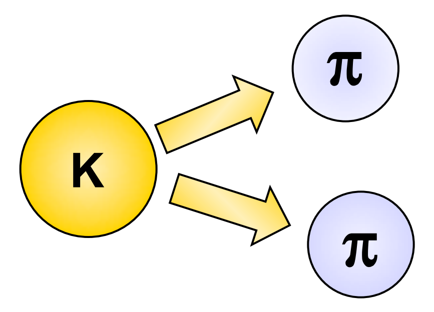
Δm_d — $f_B B_B^{1/2}$ — $B_d - \bar{B}_d$

$\Delta m_d / \Delta m_s$ — ξ — $B_s - \bar{B}_s$

CKM matrix elements

UTA

Beyond SM physics



More difficult problems

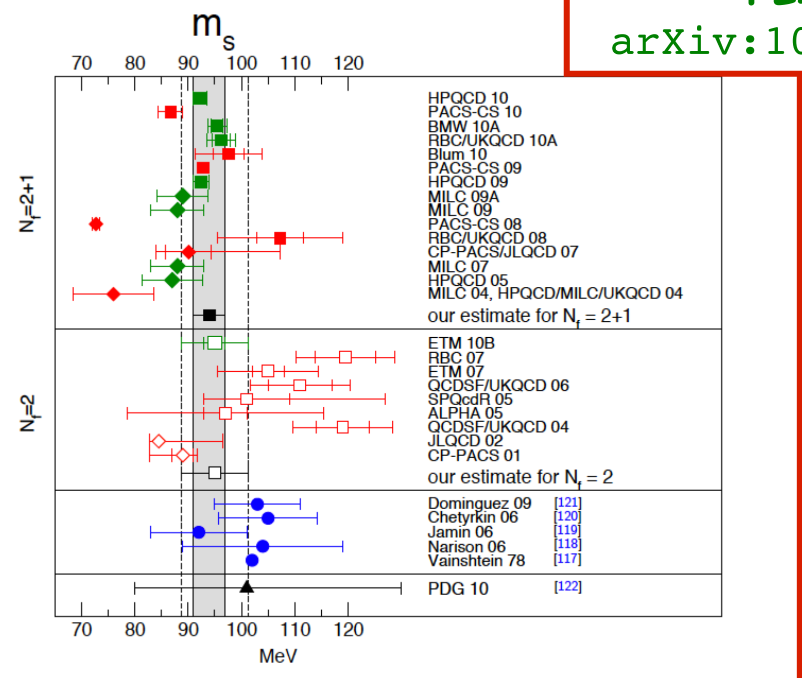
Not covered in this talk

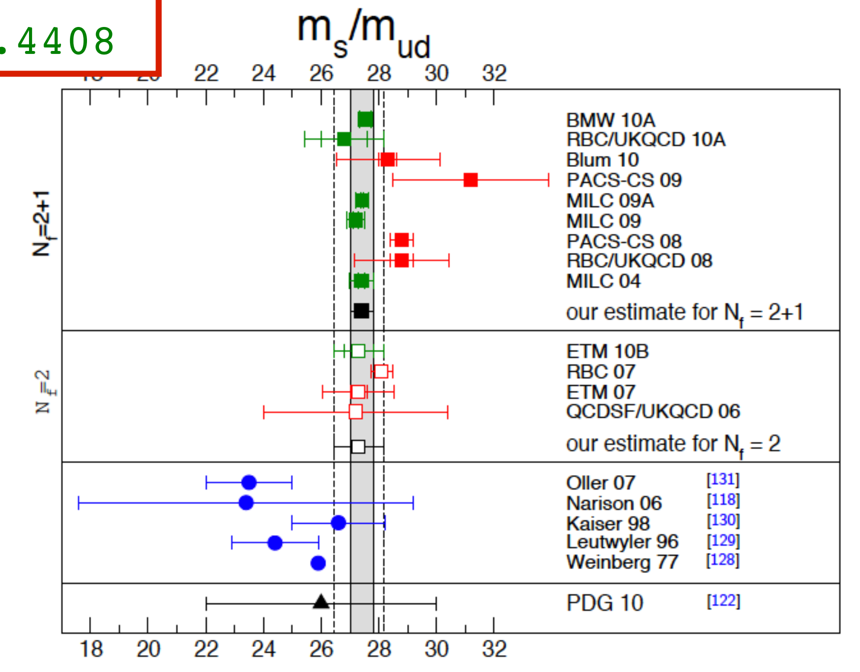
QUARK MASSES

A benchmark calculation for Lattice QCD

FLAG

arXiv:1011.4408





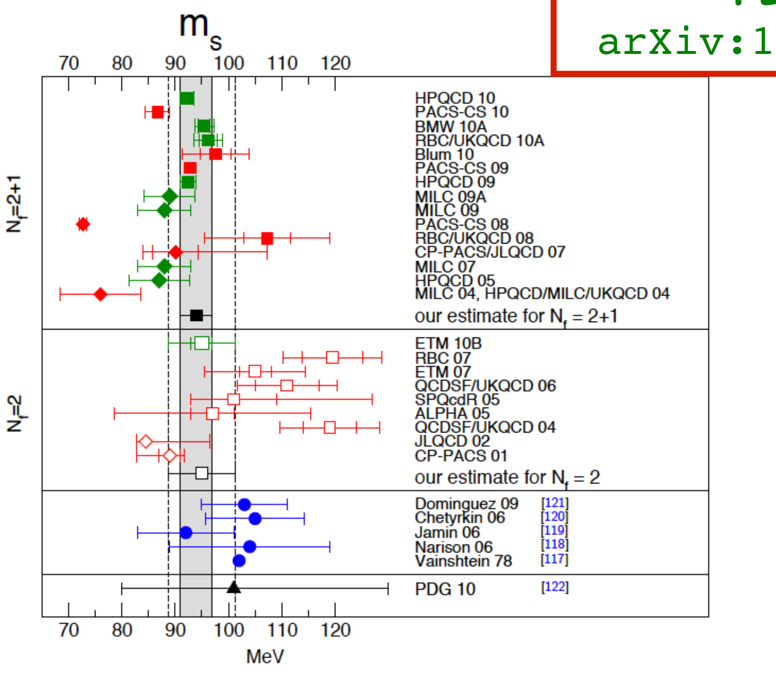
- Many different methods to regularize QCD on the lattice
- Green (Red) : Included (Not included) in the average
- Full (Empty) : Nf=2+1 (Nf=2) dynamical quarks [Nf=2+1+1 in progress]
- Squares (Diamonds) : Non-perturbative (Perturbative) renormalization

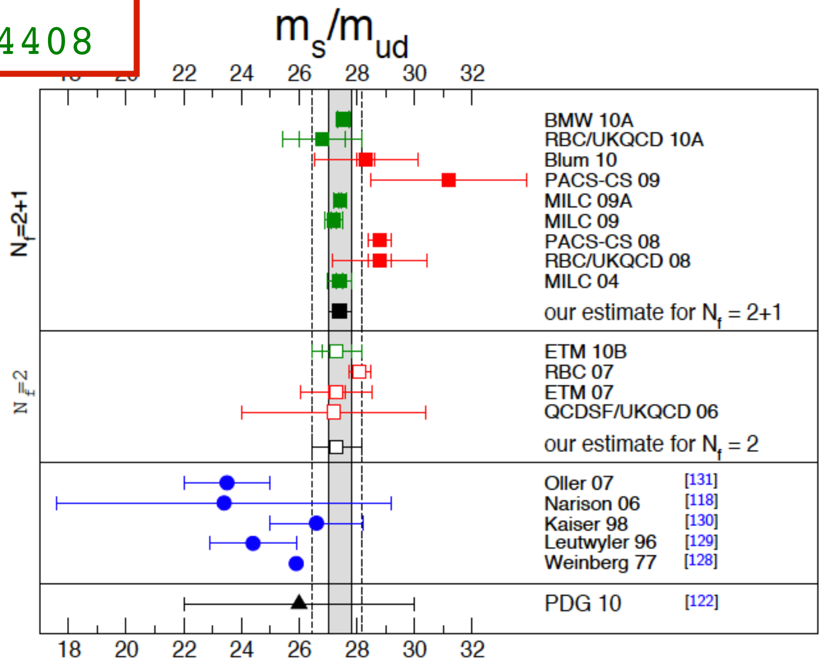
QUARK MASSES

A benchmark calculation for Lattice QCD

FLAG

`arXiv:1011.4408`





$\bar{m}_s = 94 \pm 3$ MeV (Nf=2+1)

$\bar{m}_s = 95 \pm 6$ MeV (Nf=2)

$m_s/m_{ud} = 27.4 \pm 0.4$ (Nf=2+1)

$m_s/m_{ud} = 27.3 \pm 0.9$ (Nf=2)

The accuracy is at the few per cent level

The FLAG colour coding

- Chiral extrapolation:
  - ★ $M_{\pi,\mathrm{min}} < 250$ MeV
  - ● $250\ \mathrm{MeV} \leq M_{\pi,\mathrm{min}} \leq 400$ MeV
  - ■ $M_{\pi,\mathrm{min}} > 400$ MeV

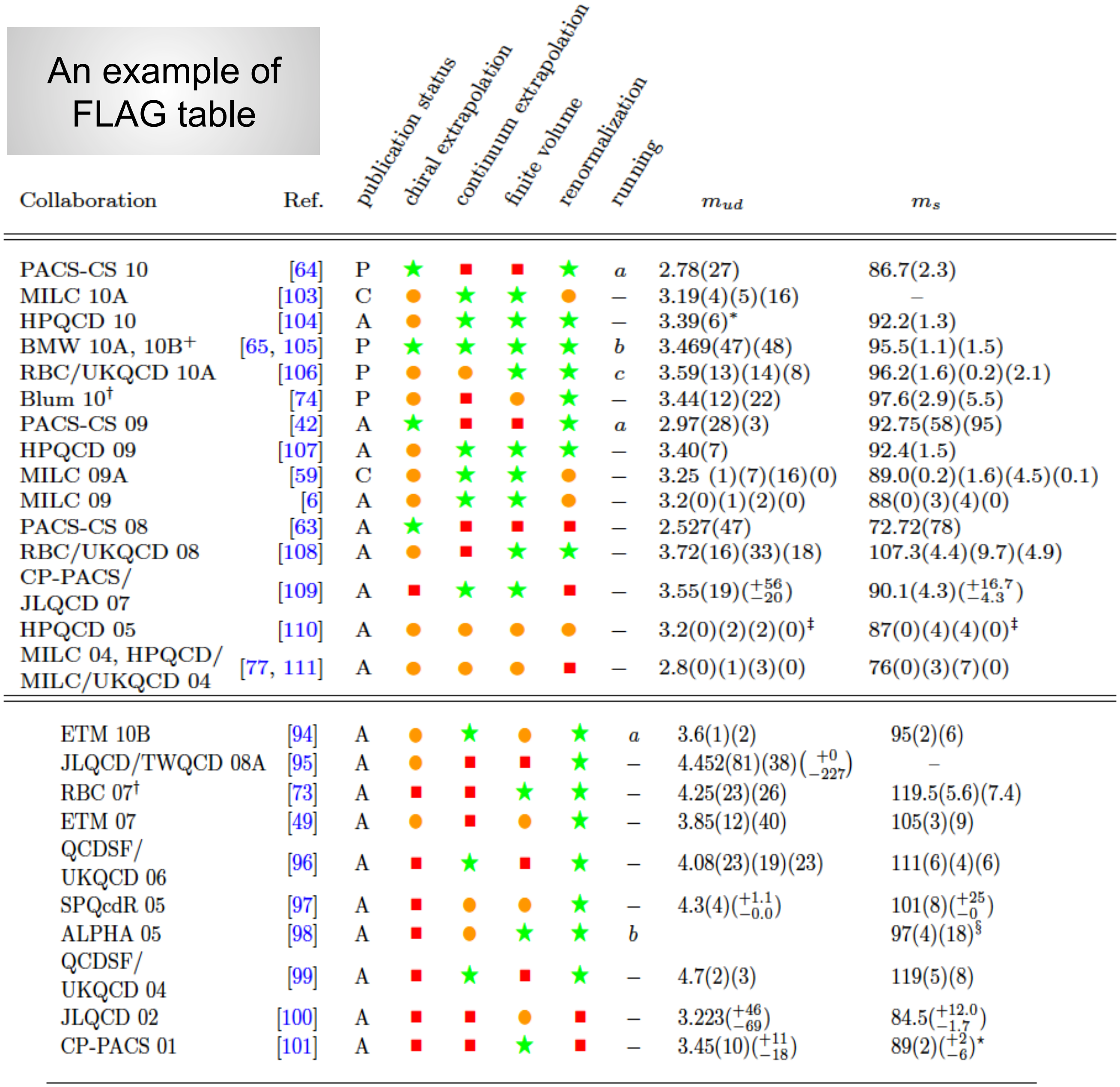
- Continuum extrapolation:
  - ★ 3 or more lattice spacings, at least 2 points below 0.1 fm
  - ● 2 or more lattice spacings, at least 1 point below 0.1 fm
  - ■ otherwise

- Finite-volume effects:
  - ★ $(M_\pi L)_{\mathrm{min}} > 4$ or at least 3 volumes
  - ● $(M_\pi L)_{\mathrm{min}} > 3$ and at least 2 volumes
  - ■ otherwise

- Renormalization (where applicable):
  - ★ non-perturbative
  - ● 2-loop perturbation theory (with a converging series)
  - ■ otherwise

FLAG - Flavour Lattice Averaging Group

An example of FLAG table



Collaboration	Ref.	publication status	chiral extrapolation	continuum extrapolation	finite volume	renormalization	running	m_{ud}	m_s
PACS-CS 10	[64]	P	★	■	■	★	*a*	2.78(27)	86.7(2.3)
MILC 10A	[103]	C	●	★	★	●	–	3.19(4)(5)(16)	–
HPQCD 10	[104]	A	●	★	★	★	–	$3.39(6)^*$	92.2(1.3)
BMW 10A, 10B$^+$	[65, 105]	P	★	★	★	★	*b*	3.469(47)(48)	95.5(1.1)(1.5)
RBC/UKQCD 10A	[106]	P	●	●	★	★	*c*	3.59(13)(14)(8)	96.2(1.6)(0.2)(2.1)
Blum 10†	[74]	P	●	■	●	★	–	3.44(12)(22)	97.6(2.9)(5.5)
PACS-CS 09	[42]	A	★	■	■	★	*a*	2.97(28)(3)	92.75(58)(95)
HPQCD 09	[107]	A	●	★	★	★	–	3.40(7)	92.4(1.5)
MILC 09A	[59]	C	●	★	★	●	–	3.25 (1)(7)(16)(0)	89.0(0.2)(1.6)(4.5)(0.1)
MILC 09	[6]	A	●	★	★	●	–	3.2(0)(1)(2)(0)	88(0)(3)(4)(0)
PACS-CS 08	[63]	A	★	■	■	■	–	2.527(47)	72.72(78)
RBC/UKQCD 08	[108]	A	●	■	★	★	–	3.72(16)(33)(18)	107.3(4.4)(9.7)(4.9)
CP-PACS/ JLQCD 07	[109]	A	■	★	★	■	–	$3.55(19)(^{+56}_{-20})$	$90.1(4.3)(^{+16.7}_{-4.3})$
HPQCD 05	[110]	A	●	●	●	●	–	$3.2(0)(2)(2)(0)^\ddagger$	$87(0)(4)(4)(0)^\ddagger$
MILC 04, HPQCD/ MILC/UKQCD 04	[77, 111]	A	●	●	●	■	–	2.8(0)(1)(3)(0)	76(0)(3)(7)(0)
ETM 10B	[94]	A	●	★	●	★	*a*	3.6(1)(2)	95(2)(6)
JLQCD/TWQCD 08A	[95]	A	●	■	■	★	–	$4.452(81)(38)(^{+0}_{-227})$	–
RBC 07†	[73]	A	■	■	★	★	–	4.25(23)(26)	119.5(5.6)(7.4)
ETM 07	[49]	A	●	■	●	★	–	3.85(12)(40)	105(3)(9)
QCDSF/ UKQCD 06	[96]	A	■	★	■	★	–	4.08(23)(19)(23)	111(6)(4)(6)
SPQcdR 05	[97]	A	■	●	●	★	–	$4.3(4)(^{+1.1}_{-0.0})$	$101(8)(^{+25}_{-0})$
ALPHA 05	[98]	A	■	●	★	★	*b*		$97(4)(18)^\S$
QCDSF/ UKQCD 04	[99]	A	■	★	■	★	–	4.7(2)(3)	119(5)(8)
JLQCD 02	[100]	A	■	■	●	■	–	$3.223(^{+46}_{-69})$	$84.5(^{+12.0}_{-1.7})$
CP-PACS 01	[101]	A	■	■	★	■	–	$3.45(10)(^{+11}_{-18})$	$89(2)(^{+2}_{-6})^\star$

FLAG-1

G.Colangelo,
S.Dür, A.Jüttner,
L.Lellouch,
H.Leutwyler,
V.Lubicz,
S.Necco,
C.Sachrajda,
S.Simula,
T.Vladikas,
U.Wenger,
H.Wittig

`arXiv: 1011.4408`

Uncertainties are being carefully investigated

The CKM matrix

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{td} \end{pmatrix}$$

A 3x3 unitary matrix which originates from the misalignement in flavour space of the up and down component of the SU(2)$_L$ quark doublet of the Standard Model

In the quark mass eigenstate basis, V$_{CKM}$ appears in the quark charged-current interaction Lagrangian. It is the only source of flavour-changing transitions and CP violation in the SM

$$L^{cc} = \frac{g}{2\sqrt{2}} \sum_{i,j} \bar{u}_i \gamma_\mu (1-\gamma_5)(V_{CKM})_{ij} d_j W^\mu + h.c.$$

$$\sum_k (V^+_{CKM})_{ik} (V_{CKM})_{kj} = \delta_{ij}$$

3 diagonal + 6 triangular relations

⇒ 9 real parameters: 3 angles, 1 phase

+ 5 unphysical phases rotated away by a redefinition of the quark fields

$$\Rightarrow \boxed{\theta_{12}, \theta_{13}, \theta_{23}, \delta}$$

The CKM matrix

$$V_{CKM}=\begin{pmatrix}1&0&0\\0&c_{23}&s_{23}\\0&-s_{23}&c_{23}\end{pmatrix}\times\begin{pmatrix}c_{13}&0&s_{13}e^{-i\delta}\\0&1&0\\-s_{13}e^{i\delta}&0&c_{13}\end{pmatrix}\times\begin{pmatrix}c_{12}&s_{12}&0\\-s_{12}&c_{12}&0\\0&0&1\end{pmatrix}\Rightarrow$$

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

The PDG
"standard"
parametrization

$\lambda\equiv s_{12}$ $A\lambda^2\equiv s_{23}$ $A\lambda^3(\rho-i\eta)\equiv s_{13}e^{-i\delta}$

Wolfenstein '83
Buras et al., '94

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

$(\bar\rho,\bar\eta)$ is the apex of the UT

$\bar\rho\simeq\rho(1-\lambda^2/2)$ $\bar\eta\simeq\eta(1-\lambda^2/2)$

THE CKM 1st ROW UNITARITY TEST

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

The most stringent unitarity test

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

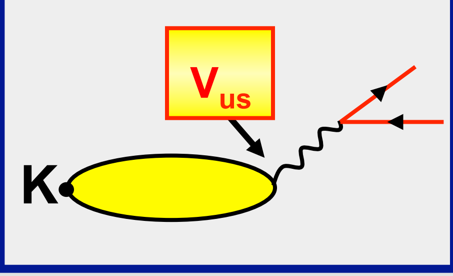
Processes: $K \to l\nu$, $K \to \pi l\nu$

Theory input: f_K/f_π , $f_+(0)$

Vus/Vud from Kμ2/πμ2 decays

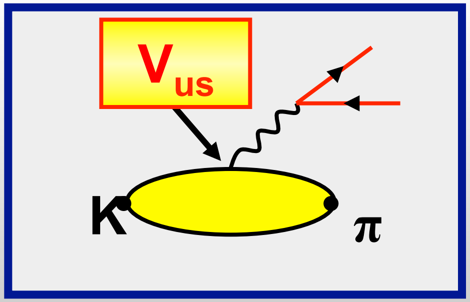
$$\frac{\Gamma(K\to\mu\bar{\nu}_\mu(\gamma))}{\Gamma(\pi\to\mu\bar{\nu}_\mu(\gamma))} = \frac{|V_{us}|^2}{|V_{ud}|^2}\left(\frac{f_K}{f_\pi}\right)^2 \frac{m_K\left(1-\frac{m_\mu^2}{m_K^2}\right)}{m_\pi\left(1-\frac{m_\mu^2}{m_\pi^2}\right)} \times 0.9930(35)$$

[Marciano 04]



Vus from Kl3 decays

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



$$\frac{|V_{us}|}{|V_{ud}|}\frac{f_k}{f_\pi} = 0.2758(5)$$

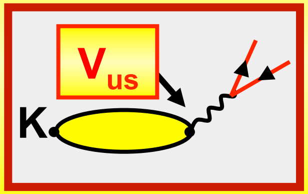
FlaviA net Kaon WG

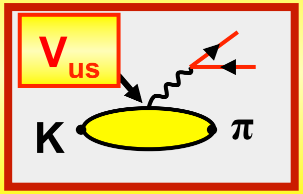
$$|V_{us}|\, f_+(0) = 0.2163(5)$$

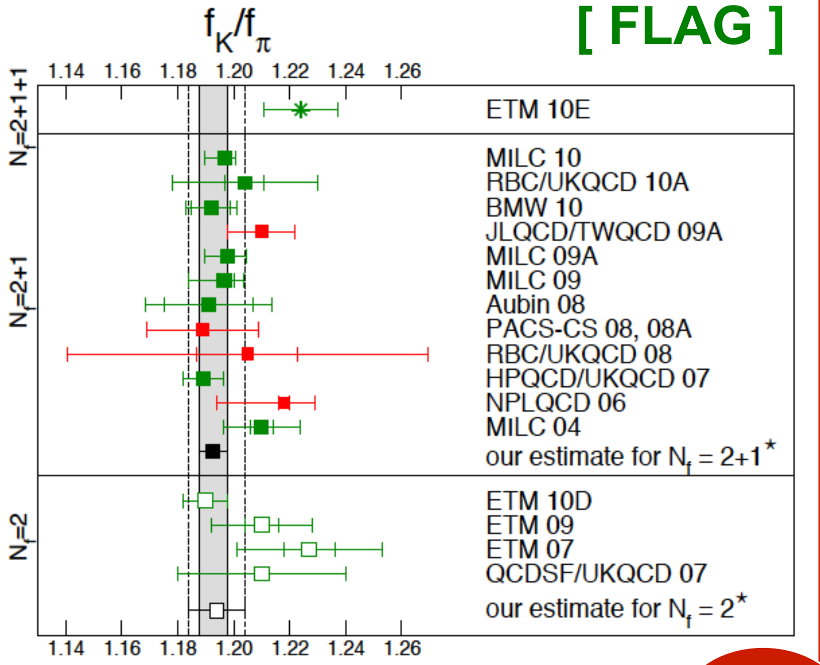
arXiv:1005.2323 [hep-ph]

Lattice results:

f_K/f_π and $f_+(0)$





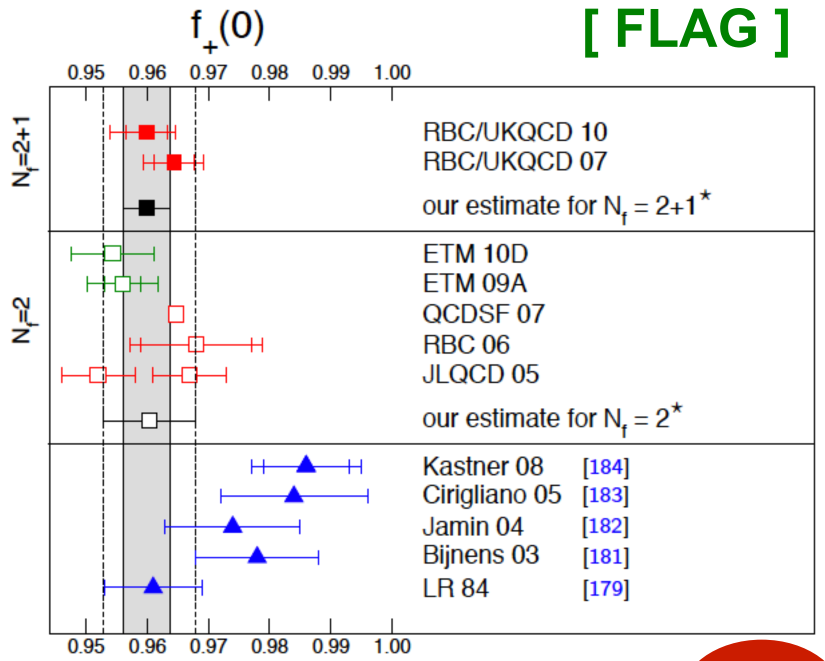


0.4%

$f_K/f_\pi = 1.193(5)$ (Nf=2+1)

$f_K/f_\pi = 1.210(18)$ (Nf=2)

First result with Nf=2+1+1 available

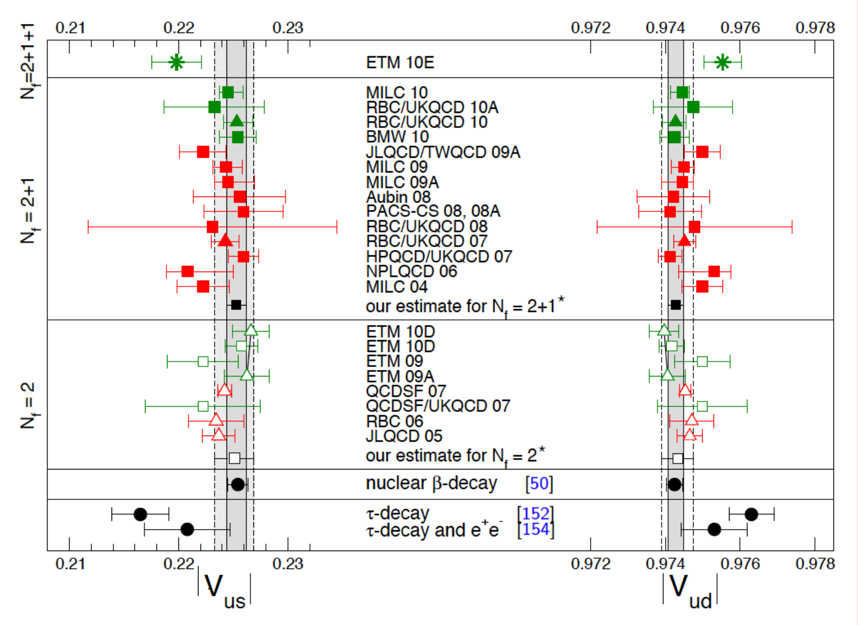


0.8%

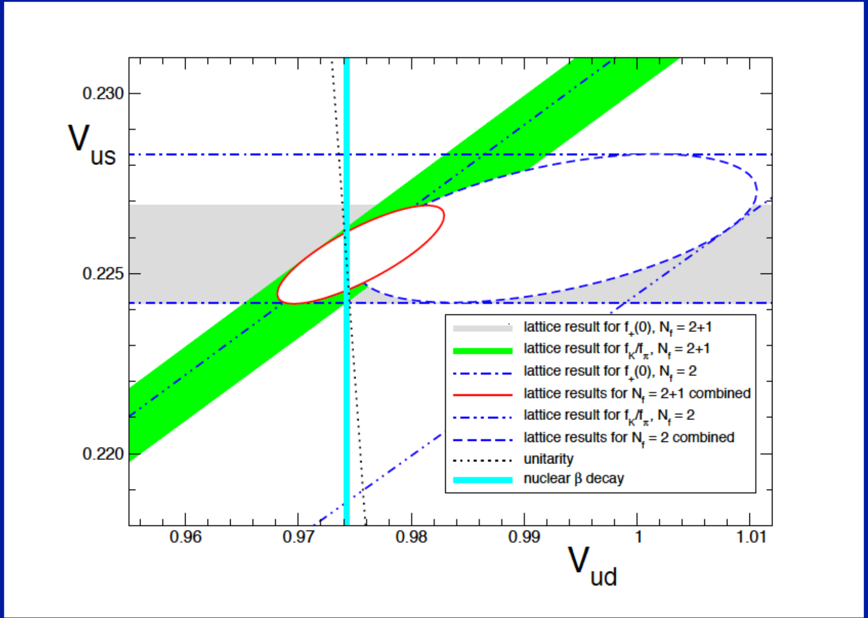
$f_+(0) = 0.956(8)$ (Nf=2 & 2+1)

Predictions of analytical model tends to be larger than lattice results

The 1st row unitarity test



Results from f_K/f_π [squares] and $f_+(0)$ [triangles]



The 1st row unitarity plot [FLAG]

From Kl2 and Kl3 decays

- $|V_{ud}| = 0.9743(2)$
- $|V_{us}| = 0.2254(9)$

Combining with $|V_{ud}|$ from nuclear β decays:

$$\Delta_{CKM} = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = (0 \pm 7)\cdot 10^{-4}$$

ISOSPIN BREAKING EFFECTS

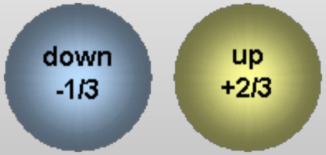
The lattice determinations are usually obtained in the limit of exact ISOSPIN SYMMETRY, i.e. $m_u = m_d$ and $Q_u = Q_d = 0$

E.g. $f_+(0) = 0.956(8)$ 0.8% $f_K/f_\pi = 1.193(5)$ 0.4%

Though small, isospin breaking effects are important at the current level of precision in flavour physics. Their typical size is:

$Q_u \neq Q_d$: $O(\alpha_{e.m.}) \approx 1/100$ "Electromagnetic"

$m_u \neq m_d$: $O[(m_d - m_u)/\Lambda_{QCD}] \approx 1/100$ "Strong"



Isospin breaking effects are also responsible for the stability of matter through the proton-neutron mass difference

The calculation of IB effects be on the lattice is challenging

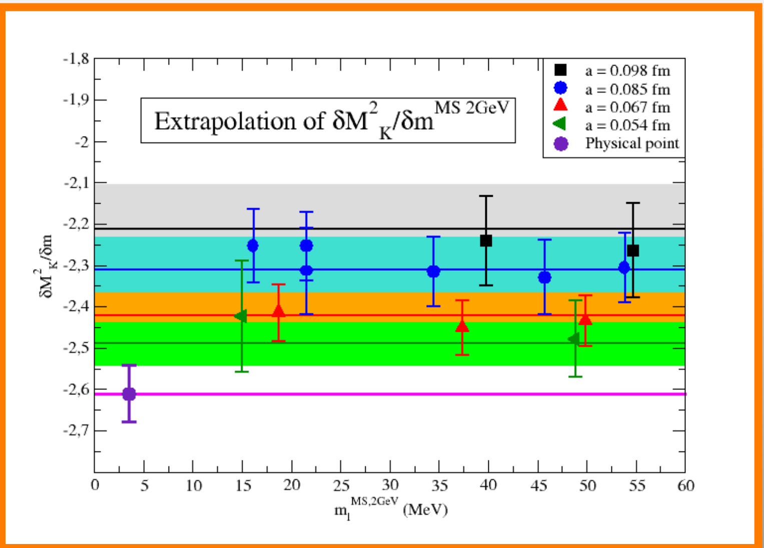
A strategy for Lattice QCD: the (md-mu) expansion

RM123 collaboration, G.M. de Divitiis et al., arXiv:1110.6294

Expand the functional integral in powers of $\delta m = (mu-md)/2$

$$\langle O \rangle \propto \int D\phi\, O\, e^{-S_0+\delta m\,\hat{S}} \overset{1st}{\simeq} \int D\phi\, O\, e^{-S_0}\left(1+\delta m\,\hat{S}\right) \simeq \langle O \rangle_0 + \delta m \langle O\,\hat{S} \rangle_0$$

The mass difference md-mu is a free parameter of the Lagrangian and one experimental input is needed to fix it. A simple choice is the mass splitting between the neutral and charged kaon



- We find: $\delta M_K^{QCD} / \delta m^{\overline{MS},2GeV} = 2.64(7)$
- Using as input (from FLAG):

$$\left(M_{K^0} - M_{K^+}\right)_{QCD} = 2\,\delta M_K^{QCD} = 6.0(6)_{QED}\ \text{MeV}$$

one obtains:

$$\bar{m}_d - \bar{m}_u = 2.28\,(6)_{LQCD}(23)_{QED}\ MeV$$

$$\bar{m}_d / \bar{m}_u = 0.51(4)$$

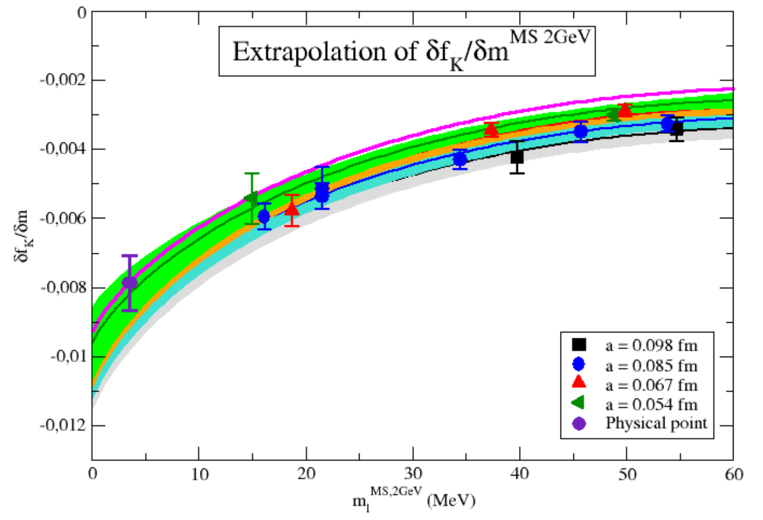
Isospin breaking effects in the ratio fK/fπ

- We find: $\delta f_K^{QCD} / \delta m^{\overline{MS},2GeV} = -0.47(5)$
- Using the previous result for md-mu, we obtain

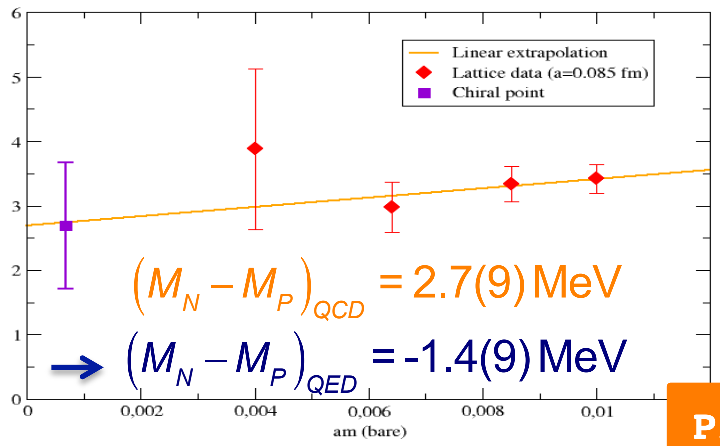
$$\delta\left(f_K / f_\pi\right) / \left(f_K / f_\pi\right)_{QCD} = -0.0034\,(3)_{LQCD}\,(3)_{QED}$$

- It can be compared with the ChPT estimate

$$\delta\left(f_K / f_\pi\right) / \left(f_K / f_\pi\right)_{QCD} = -0.0022(6)$$



The neutron-proton mass splitting

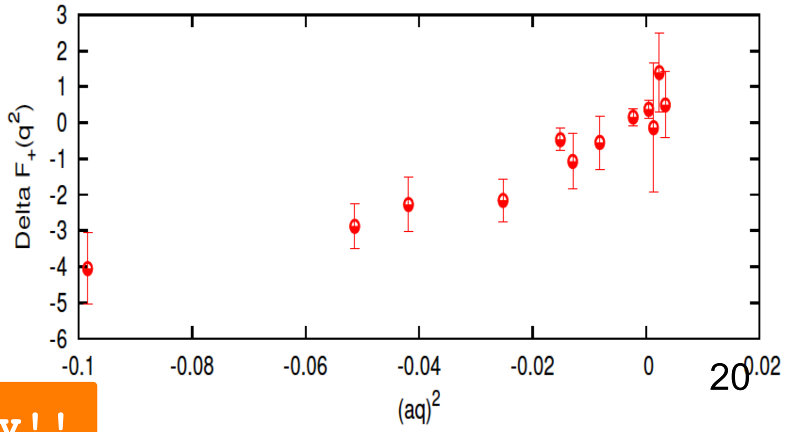


$$\left(M_N - M_P\right)_{QCD} = 2.7(9)\,\text{MeV}$$

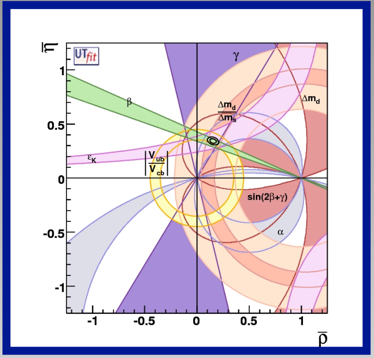
→ $\left(M_N - M_P\right)_{QED} = -1.4(9)\,\text{MeV}$

Preliminary!!

The K→πlν semileptonic form factors



THE UNITARITY TRIANGLE ANALYSIS



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

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

Processes: $B \to l\,\nu$, $B \to D/\pi\, l\,\nu$,

$K - K$, $B_{(s)} - B_{(s)}$

Theory input: f_B, f_{Bs}, $f_+(0)$,

B_K, B_B, …

The unitarity triangle

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

The relation can be rewritten as:

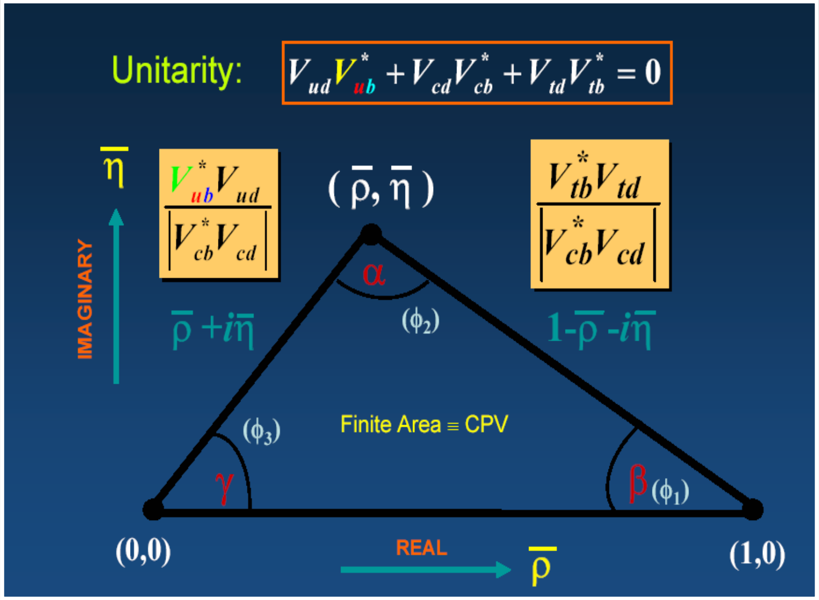
$$R_u e^{i\gamma} + R_t e^{-i\beta} = 1$$

with:

$$R_u = \left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| \qquad \gamma = arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

$$R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| \qquad \beta = arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

CPV ~ J = Im $V_{ij}V_{il}^*V_{kl}V_{kj}^*$



The apex of the UT defines $(\bar{\rho}\ ,\ \bar{\eta})$

$$R_u e^{i\gamma} \equiv \bar{\rho} + i\bar{\eta}$$

$$R_t e^{-i\beta} = 1 - \bar{\rho} - i\bar{\eta}$$

$$\rho + i\eta = \sqrt{\frac{1-A^2\lambda^4}{1-\lambda^2}}\,\frac{\bar{\rho}+i\bar{\eta}}{1-A^2\lambda^4(\bar{\rho}+i\bar{\eta})}$$

$$\simeq \left(1+\frac{\lambda^2}{2}\right)(\bar{\rho}+i\bar{\eta}) + O(\lambda^4)$$

The UTfit Collaboration


Marco


Enrico


Maurizio


Luca


Cecilia


Vincenzo


Carlo


Vittorio


Guido


Marcella


Fabrizio


Denis


Achille


Viola


Adrian

cnrs
dépasser les frontières

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DI GENOVA

THE UNITARITY TRIANGLE ANALYSIS

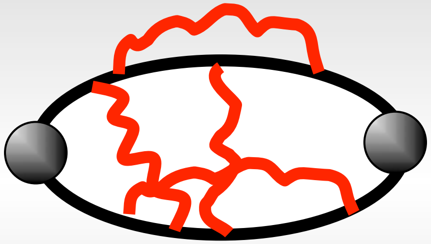
① The past

The "quenched" era

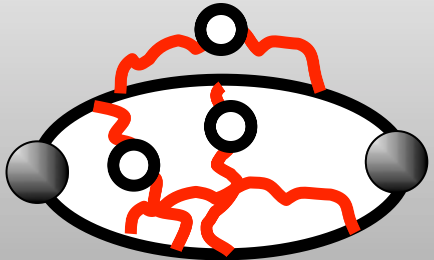
Uncertainties in LQCD before 2006

For many years, uncertainties in lattice calculations have been dominated by the quenched approximation (or, more precisely, by the uncertainty on the quenching error)

	f_B [MeV]	$f_{Bs}\sqrt{B_s}$ [MeV]	ξ
J.Flynn **Latt'96**	175(25) 14%	----	----
C.Bernard **Latt'00**	200(30) 15%	267(46) 17%	1.16(5) 4%
L.Lellouch **Ichep'02**	193(27)(10) 15%	276(38) 14%	1.24(4)(6) 6%
Hashimoto **Ichep'04**	189(27) 14%	262(35) 13%	1.23(6) 5%
N.Tantalo **CKM'06**	223(15)(19) 11%	246(16)(20) 10%	1.21(2)(5) 4%



QUENCHED



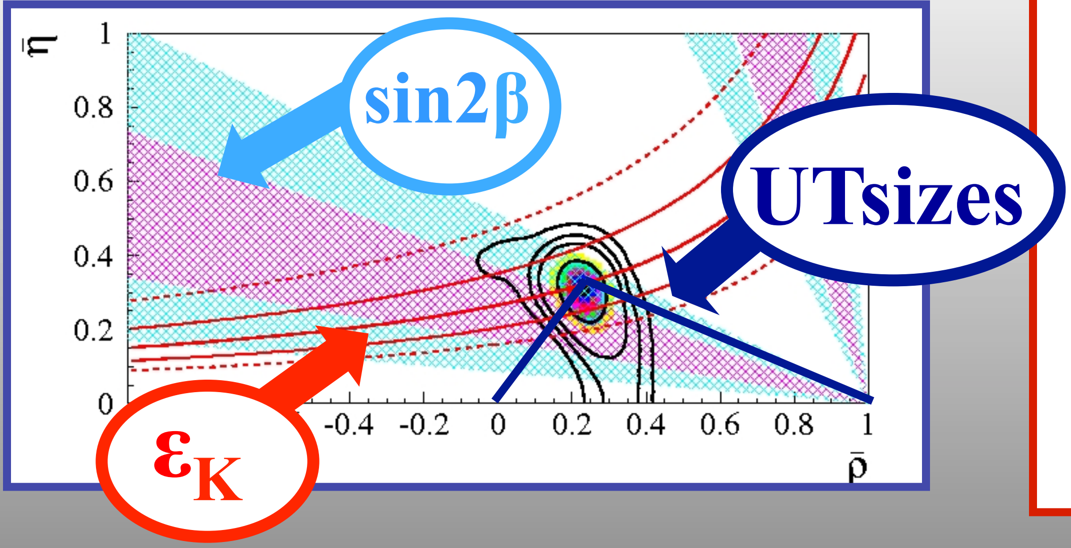
UNQUENCHED

In spite of the relatively large lattice uncertainties, important results for flavour physics have been achieved

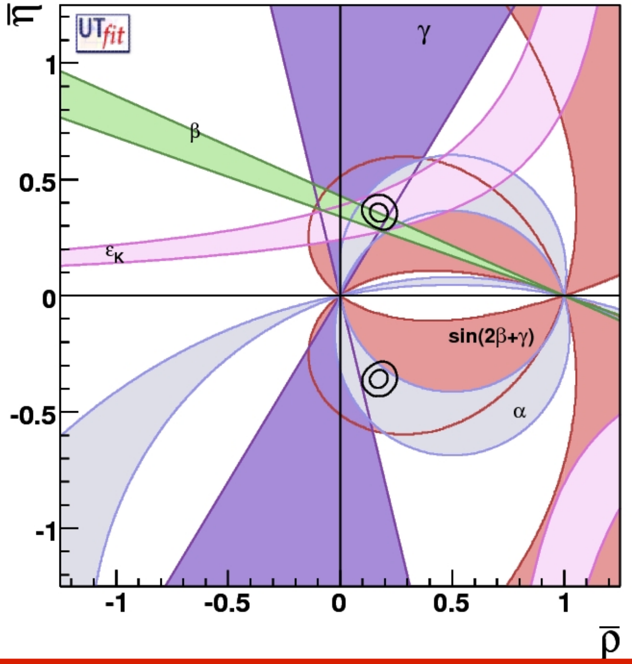
CKM PARADIGM OF ~~CP~~

CP-conserving and CP-violating processes determine the same CKM phase

Ciuchini et al.,2000



UTfit, today



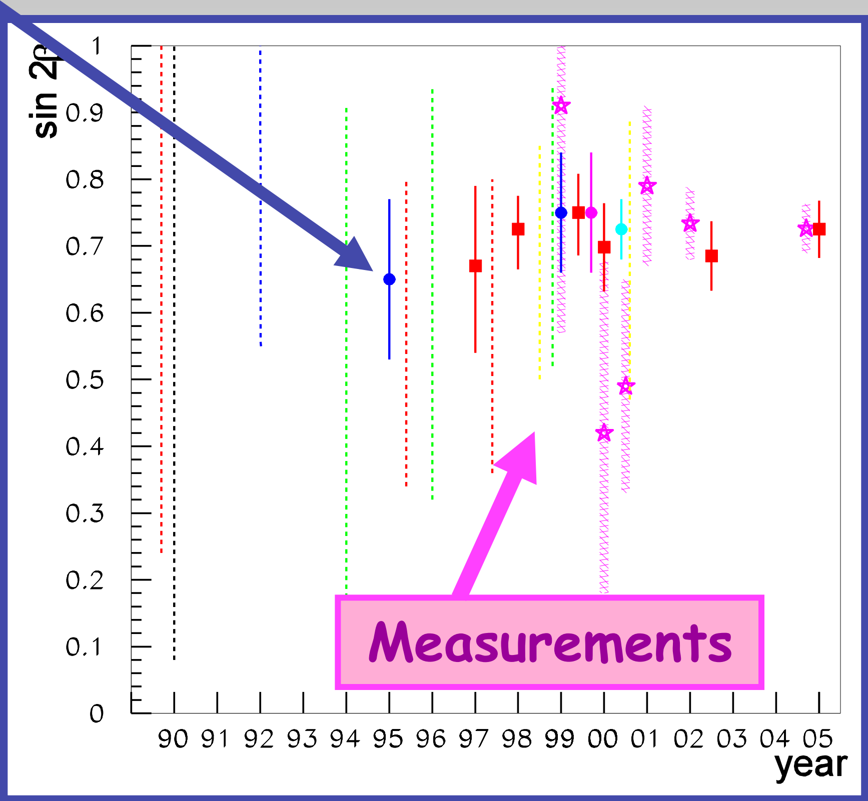
PREDICTION OF Sin2β

Ciuchini et al.,1995:
$\sin 2\beta_{UTA} = 0.65 \pm 0.12$

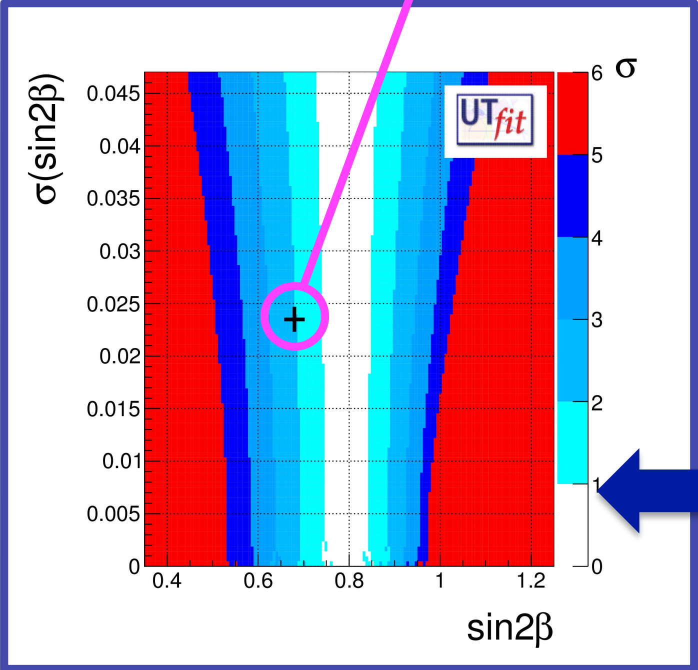
Ciuchini et al.,2000:
$\sin 2\beta_{UTA} = 0.698 \pm 0.066$

Direct measurement today:
$\sin 2\beta_{J/\psi\, K0} = 0.679 \pm 0.024$

Predictions exist since 1995



Measurements



Some tension in the SM fit today:
$\sin 2\beta_{UTA} = 0.800 \pm 0.050$

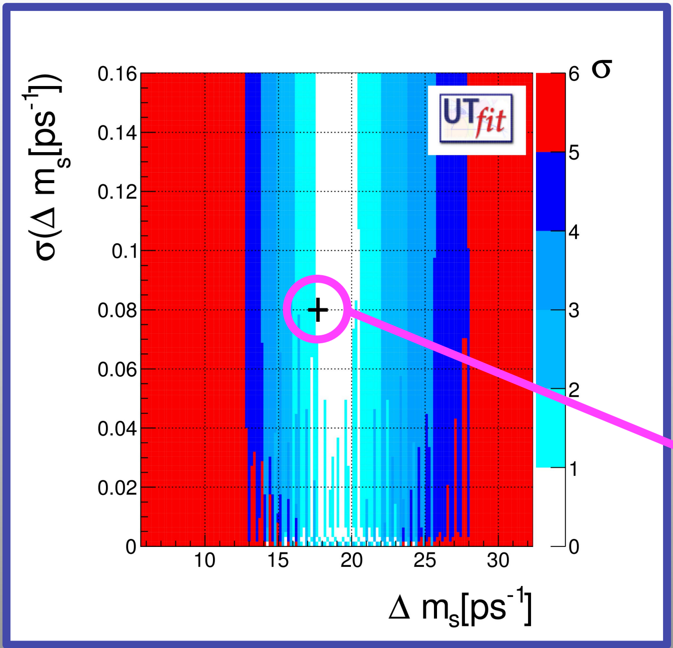
SM PREDICTION OF Δm_s
LOOKING FOR NEW PHYSICS EFFECTS

Ciuchini et al.,2000:

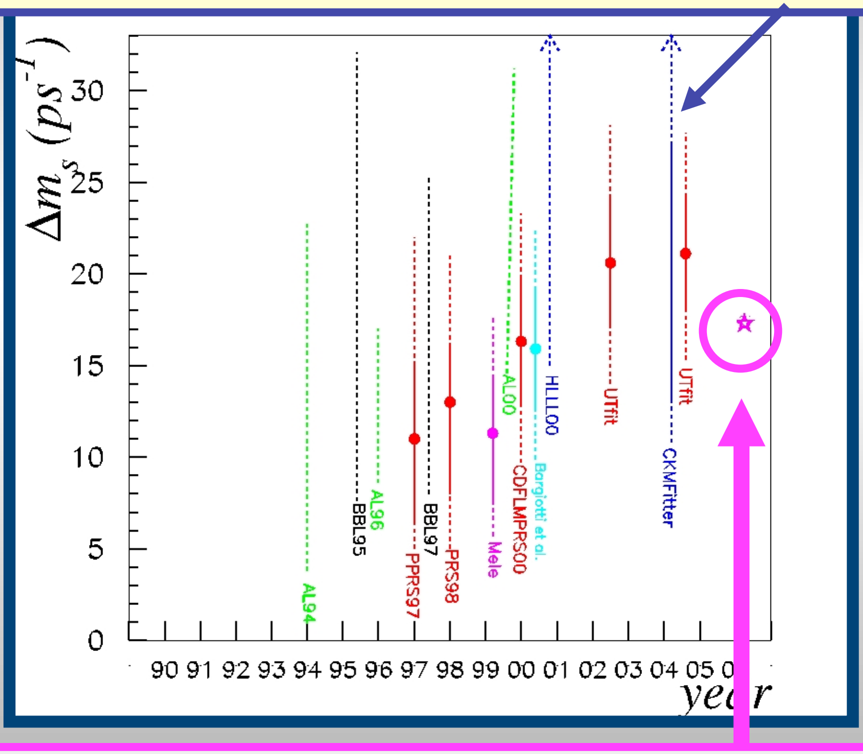
$\Delta m_s = (16.3 \pm 3.4)\ \mathrm{ps}^{-1}$

UTfit today:

$\Delta m_s = (19.0 \pm 1.5)\ \mathrm{ps}^{-1}$



The predicted range was very large in the frequentistic CKMFitter approach



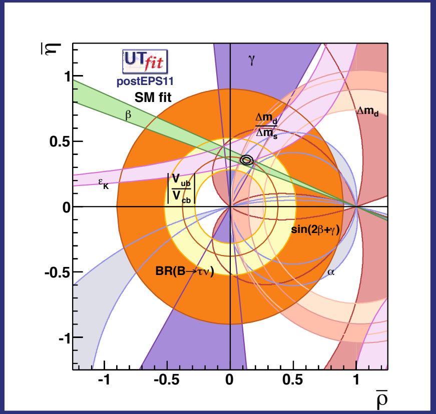
Direct measurement today

$\Delta m_s = (17.7 \pm 0.08)\ \mathrm{ps}^{-1}$

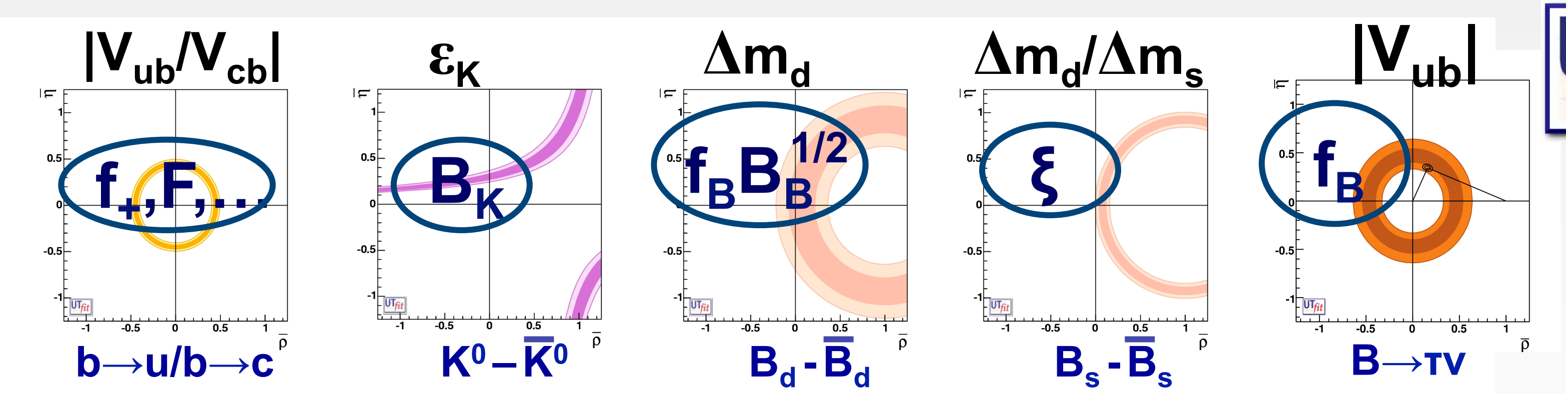
THE UNITARITY TRIANGLE ANALYSIS

② The present

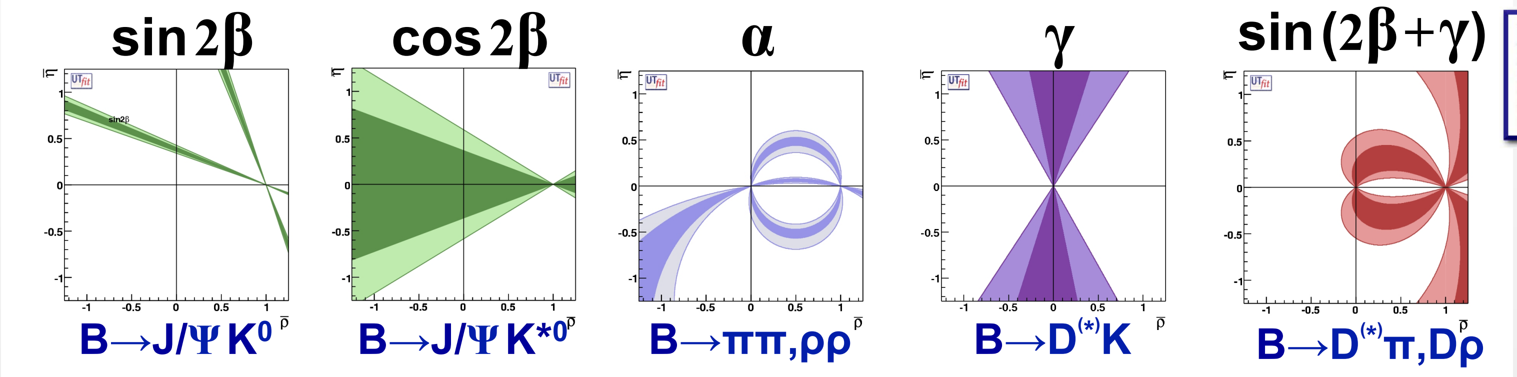
LATTICE QCD AND THE UNITARITY TRIANGLE ANALYSIS

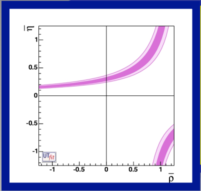


UT-LATTICE

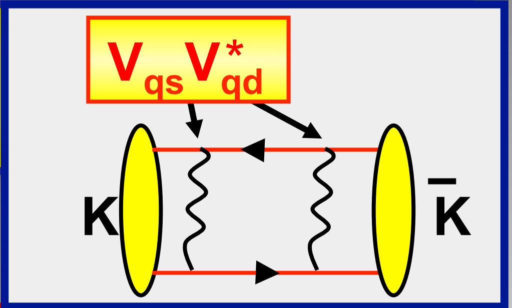


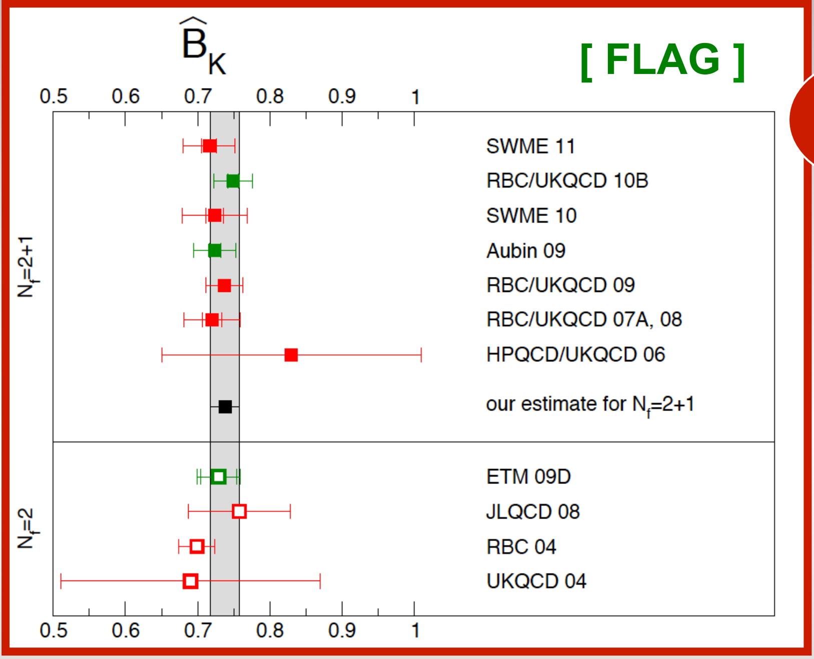
UT-ANGLES





K^0–$\bar{K}^0$ mixing: B_K





3%

$$\hat{B}_K = 0.738(20) \quad (\text{Nf=2+1})$$

$$\hat{B}_K = 0.729(30) \quad (\text{Nf=2})$$ **[FLAG]**

After the FLAG report, a new result has been presented, which claims a remarkable accuracy:

$$\hat{B}_K = 0.773(12)$$ `BMW'11`

The average quoted at the latest Lattice conference is:

1.6% !!

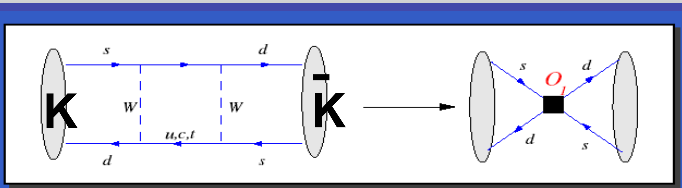
$$\hat{B}_K = 0.755(12)$$

R. Mawhinney @ Lattice 2011

3%

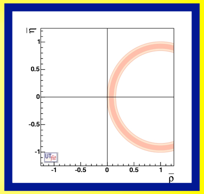
The input currently used in the UTfit is:

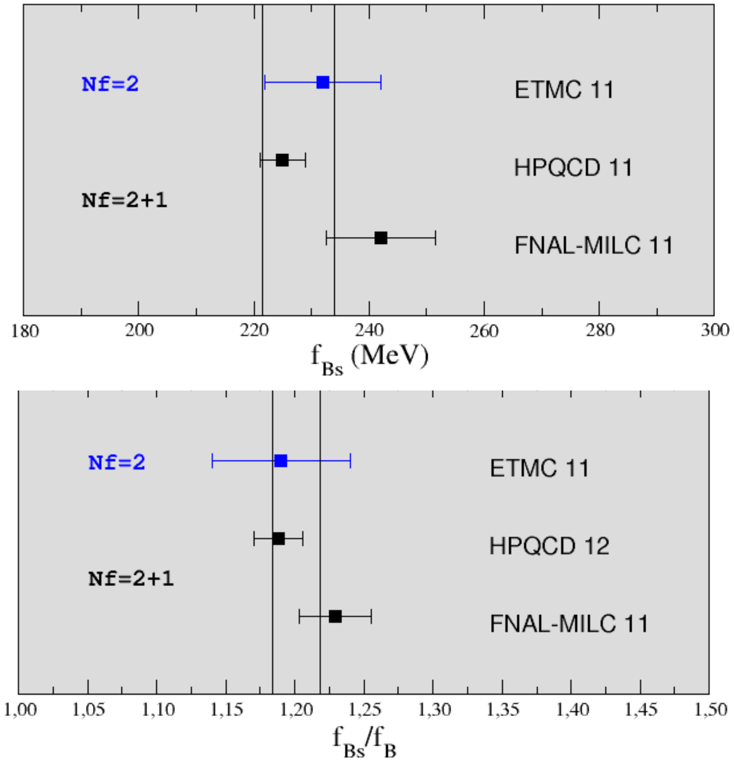
$$\hat{B}_K = 0.750(20)$$



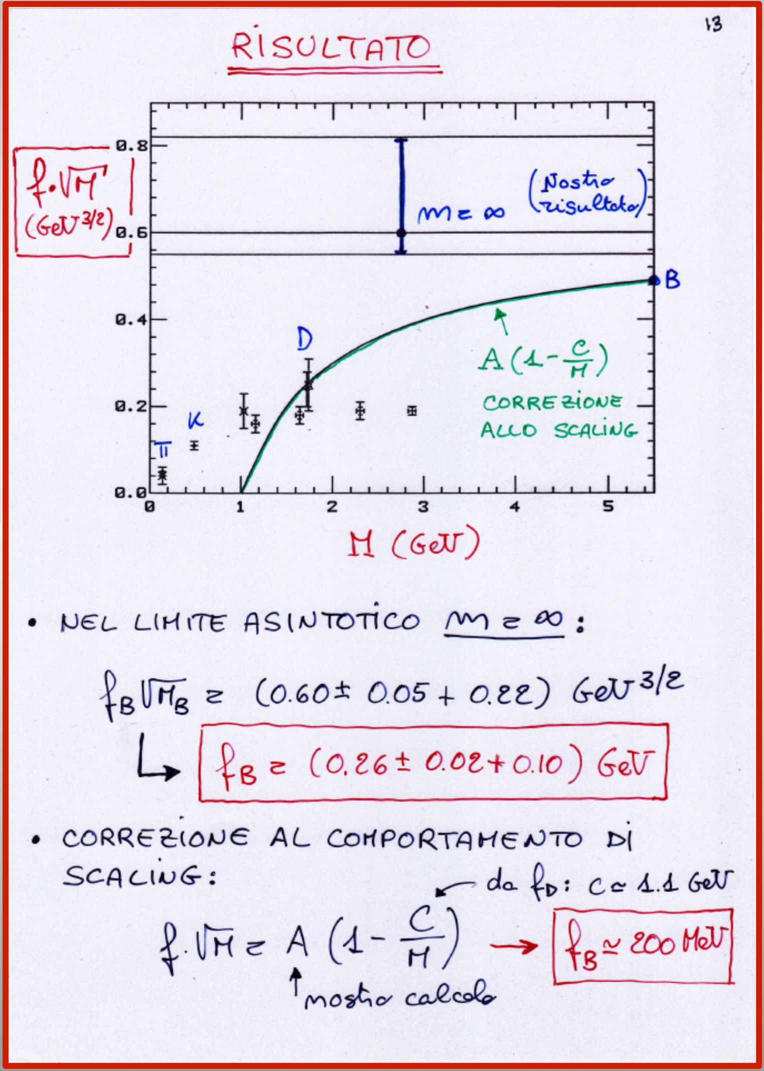
$$\langle \bar{K}^0 | Q(\mu) | K^0 \rangle = \frac{8}{3} f_K^2 m_K^2 B_K(\mu)$$

B-meson decay constants: f_B, f_{B_s}





CORTONA 1990



RISULTATO

- NEL LIMITE ASINTOTICO $m = \infty$:

$$f_B \sqrt{M_B} = (0.60 \pm 0.05 + 0.22)\ GeV^{3/2}$$

$$\hookrightarrow \boxed{f_B = (0.26 \pm 0.02 + 0.10)\ GeV}$$

- CORREZIONE AL COMPORTAMENTO DI SCALING:

da f_D: $C \simeq 1.1$ GeV

$$f \cdot \sqrt{M} = A \left(1 - \frac{C}{M}\right) \rightarrow \boxed{f_B \simeq 200\ MeV}$$

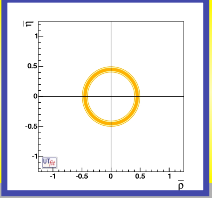
nostro calcolo

2% $f_{Bs} = 227(4)$ MeV $f_{Bs}/f_B = 1.192(16)$

C.Davies @ Lattice 2011

4% $f_{Bs} = 233(10)$ MeV $f_{Bs}/f_B = 1.200(20)$

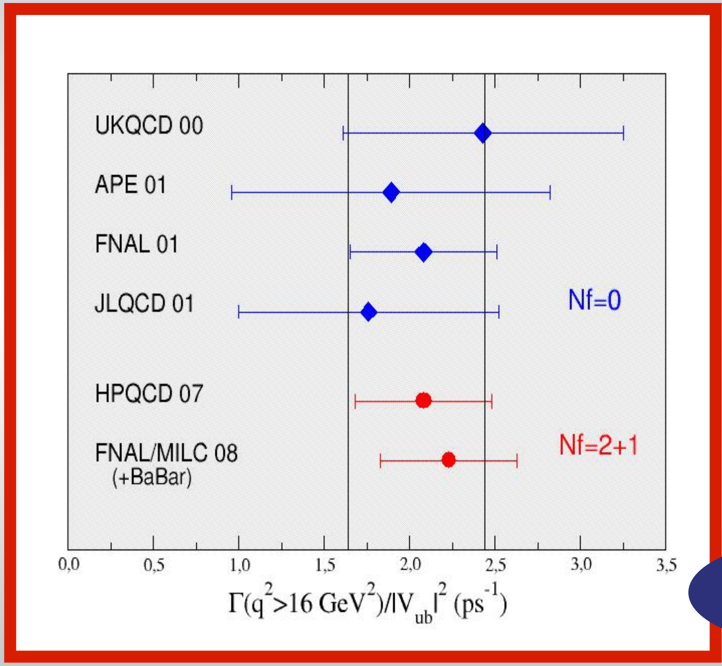
$\longrightarrow$ $f_B = 194(9)$ MeV **used by** UTfit

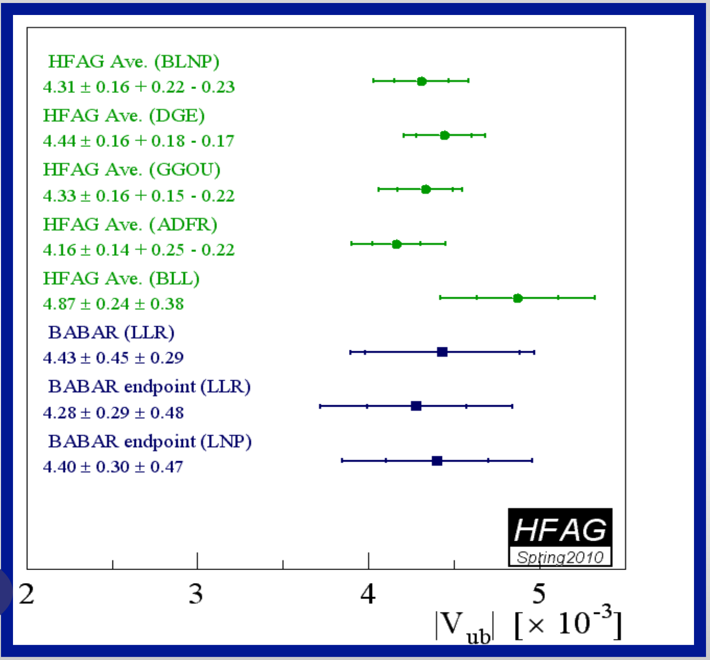


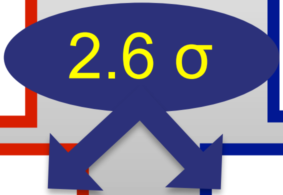
Exclusive and Inclusive Vub

THEORETICALLY CLEAN BUT ONLY TWO MODERN LATTICE CALCULATIONS

IMPORTANT LONG DISTANCE CONTRIBUTIONS. THE RESULTS ARE MODEL DEPENDENT



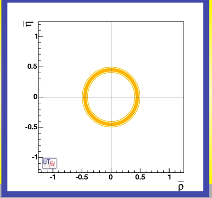




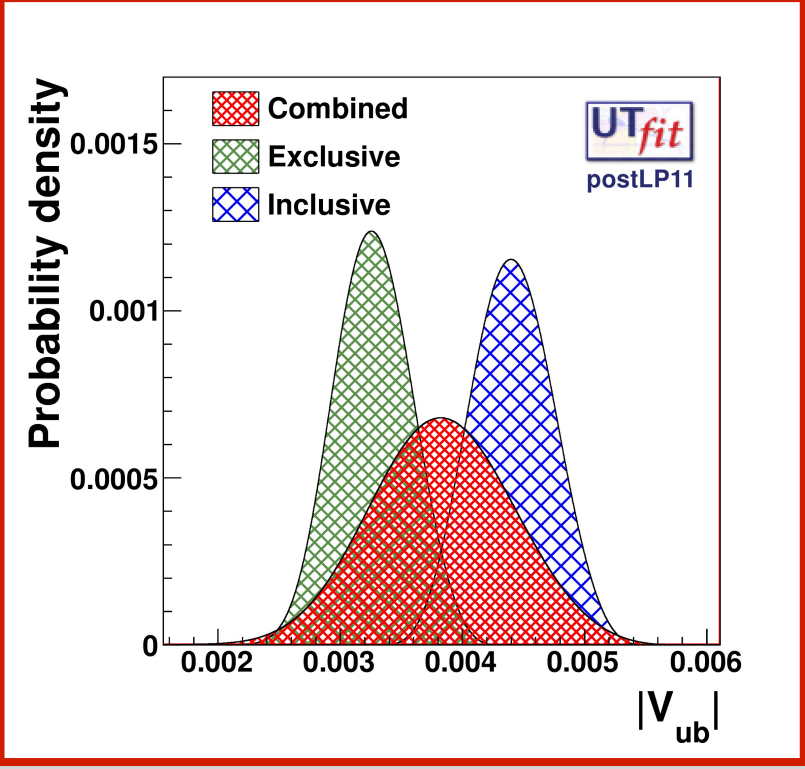
$|V_{ub}|_{excl.} = (32.8 \pm 3.0)\ 10^{-4}$

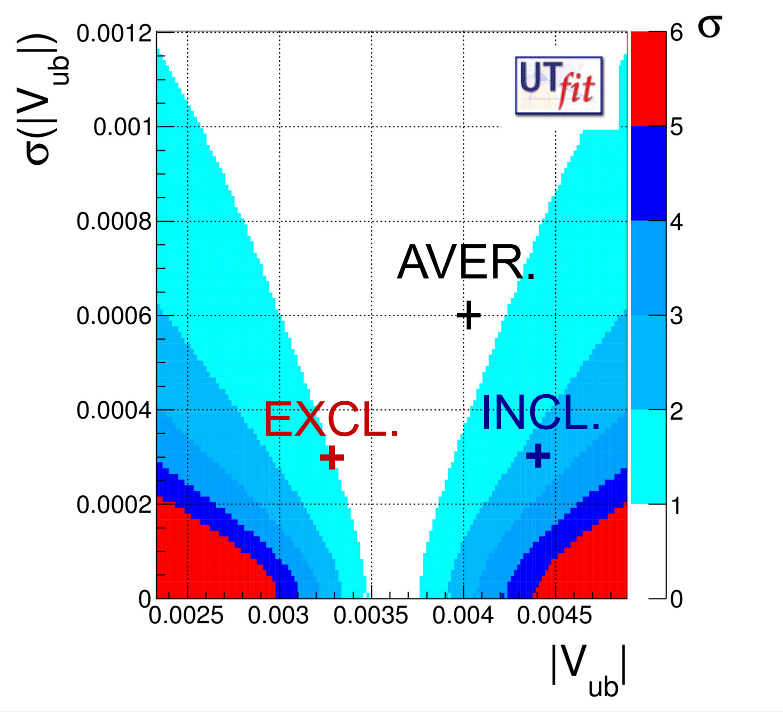
$|V_{ub}|_{incl.} = (44.0 \pm 3.1)\ 10^{-4}$

The uncertainty of inclusive Vub estimated from the spread among different models. This is questionable



Exclusive vs Inclusive Vub



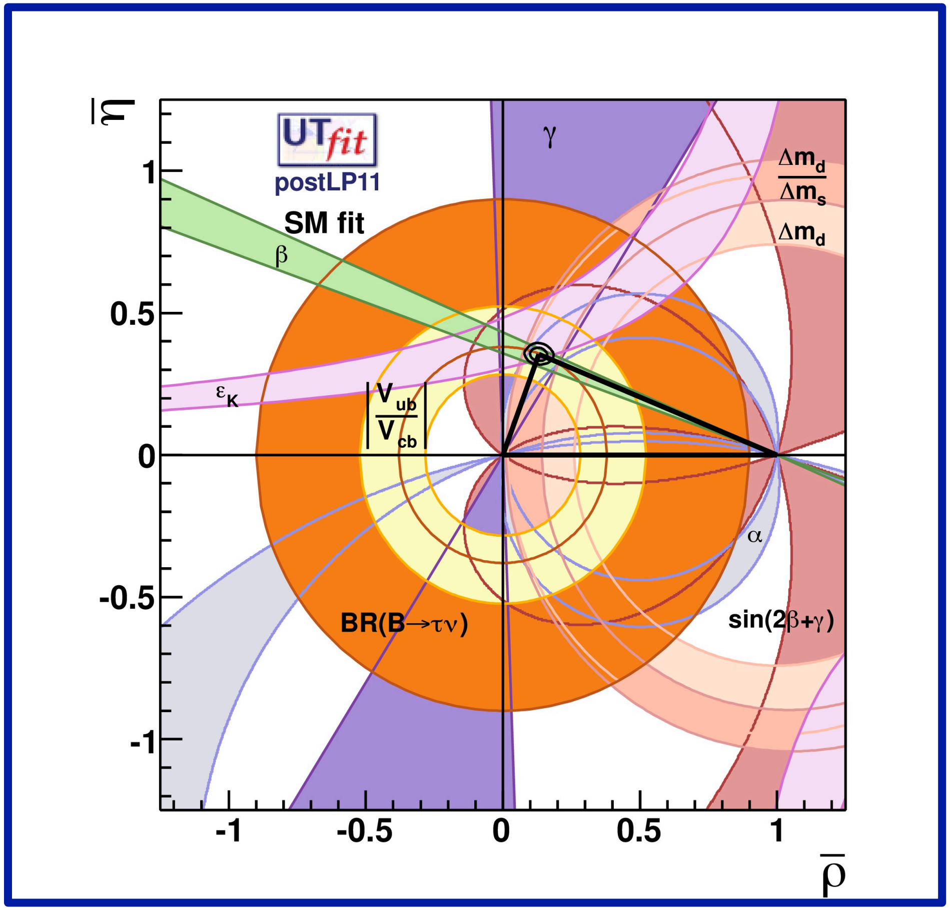


$|V_{ub}|_{input} = (38.2 \pm 5.6)\ 10^{-4}$

$|V_{ub}|_{SM\text{-}Fit} = (36.1 \pm 1.4)\ 10^{-4}$

Improve the accuracy of exclusive Vub in order to clarify the issue

STANDARD MODEL PREDICTIONS



The CKM Wolfenstein parameters:

$$\bar{\rho} = 0.131 \pm 0.022$$ 17%

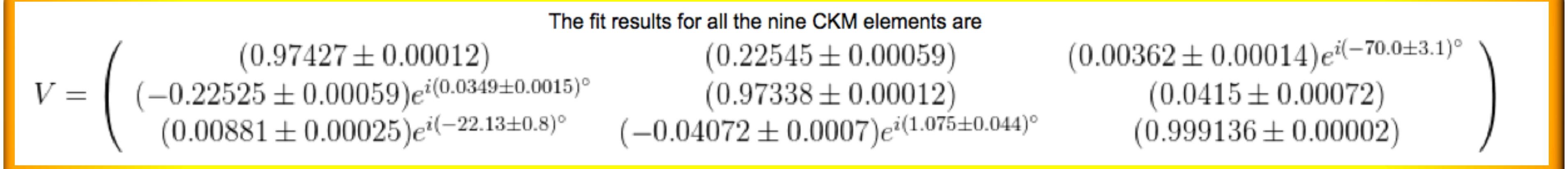
$$\bar{\eta} = 0.354 \pm 0.015$$ 4%

$$A = 0.817 \pm 0.015$$

$$\lambda = 0.2252 \pm 0.0010$$

Input value:

$$\lambda = 0.2250 \pm 0.0023$$

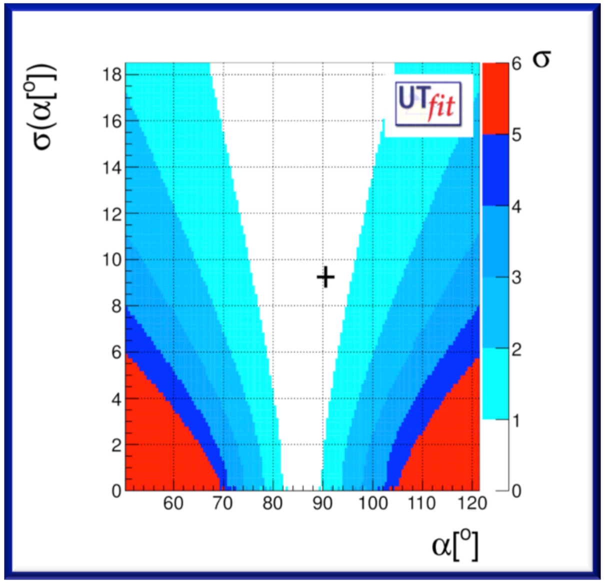


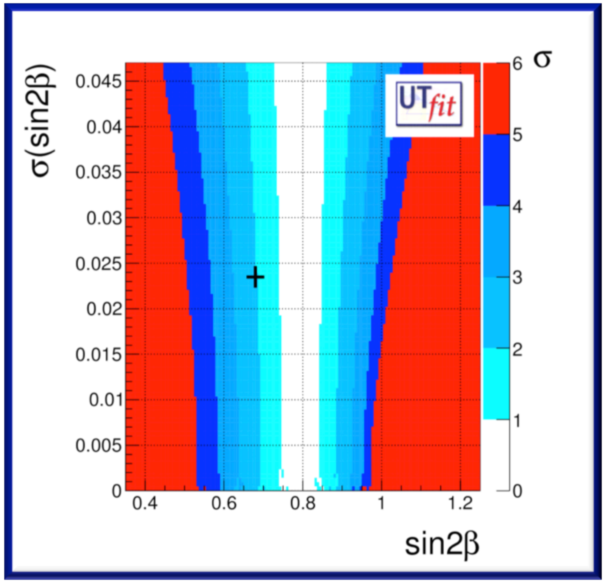
The fit results for all the nine CKM elements are

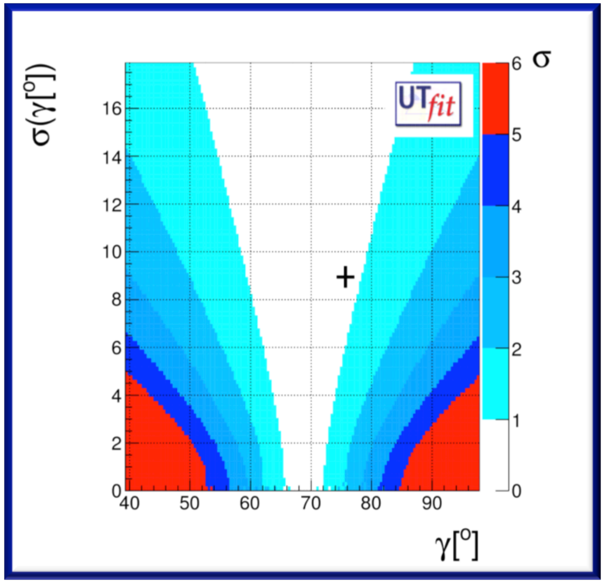
$$V = \begin{pmatrix} (0.97427 \pm 0.00012) & (0.22545 \pm 0.00059) & (0.00362 \pm 0.00014)e^{i(-70.0\pm3.1)^\circ} \\ (-0.22525 \pm 0.00059)e^{i(0.0349\pm0.0015)^\circ} & (0.97338 \pm 0.00012) & (0.0415 \pm 0.00072) \\ (0.00881 \pm 0.00025)e^{i(-22.13\pm0.8)^\circ} & (-0.04072 \pm 0.0007)e^{i(1.075\pm0.044)^\circ} & (0.999136 \pm 0.00002) \end{pmatrix}$$

STANDARD MODEL PREDICTIONS

The angles:







$(91.4 \pm 6.1)^\circ$

$(85.8 \pm 3.9)^\circ$

0.679 ± 0.024

0.80 ± 0.05

2.2σ tension

$(75.7 \pm 9.2)^\circ$ &

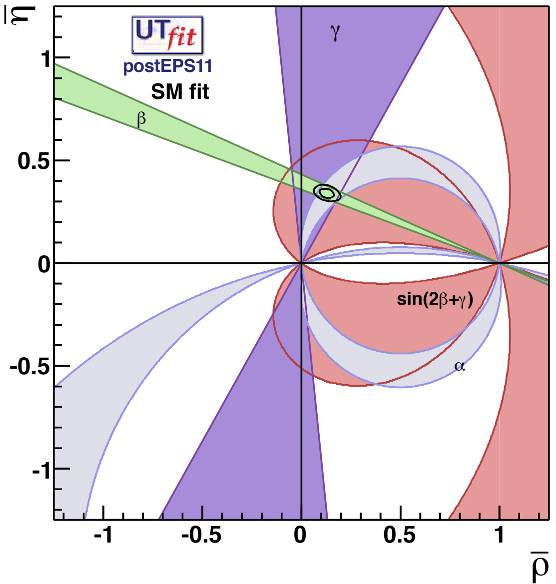
$(-103.9 \pm 9.2)^\circ$

$(68.5 \pm 3.2)^\circ$

- Fit input
- SM fit prediction

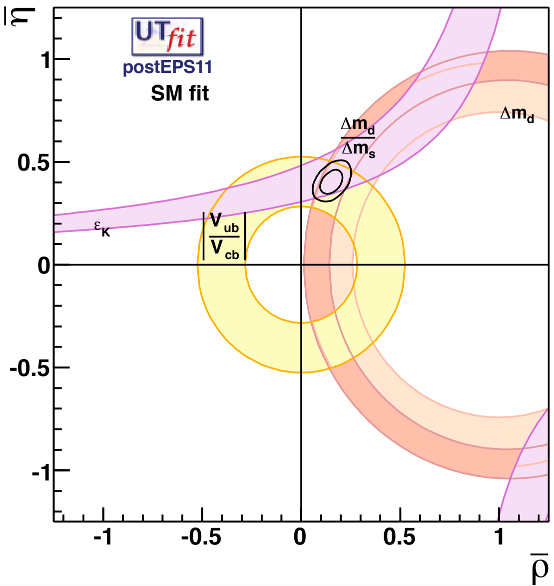
STANDARD MODEL PREDICTIONS

UT-angles



$$\bar{\rho} = 0.129 \pm 0.027$$
$$\bar{\eta} = 0.340 \pm 0.016$$

UT-lattice

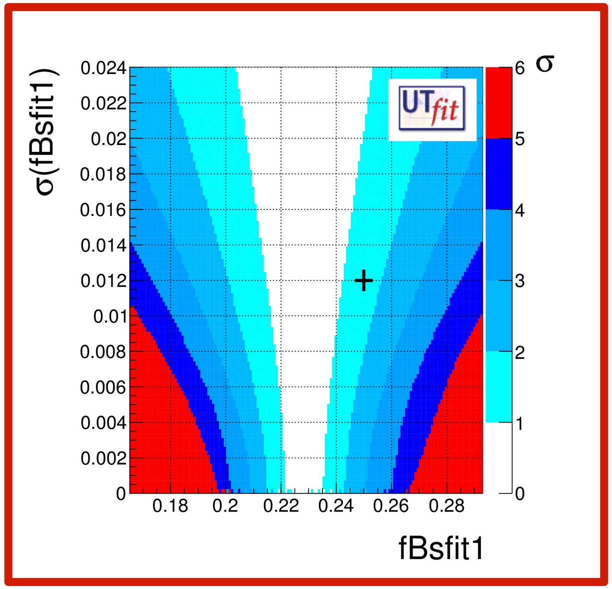


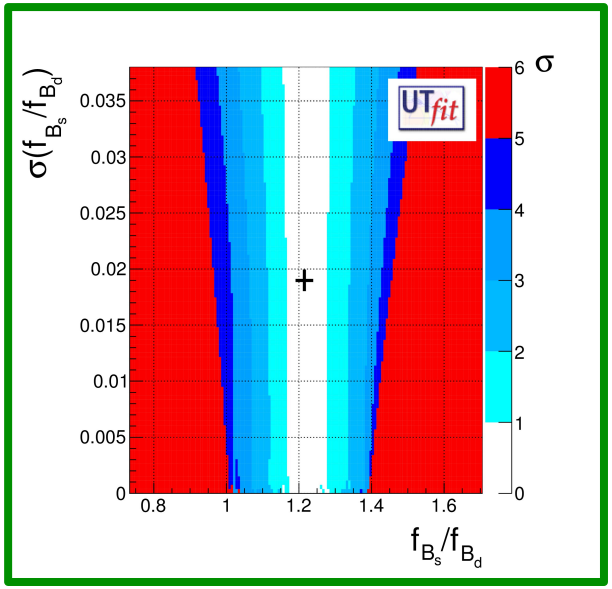
$$\bar{\rho} = 0.155 \pm 0.038$$
$$\bar{\eta} = 0.404 \pm 0.039$$

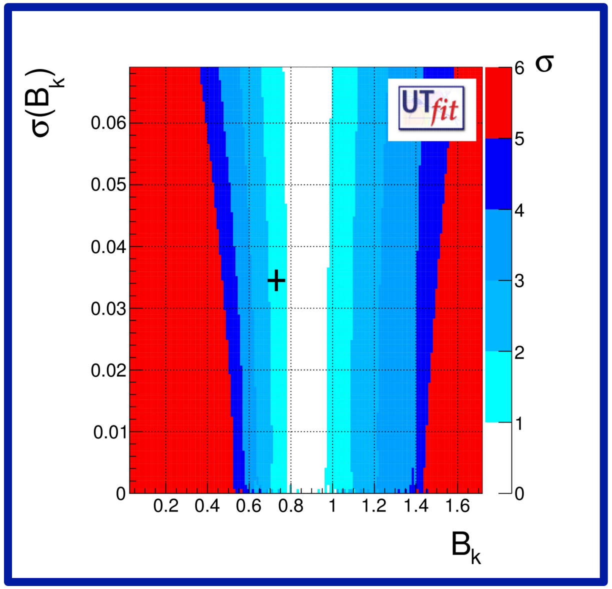
Lattice inputs are not so relevant today for the Standard Model analysis.
But they are crucial when looking for new physics signals

STANDARD MODEL PREDICTIONS

Assuming the validity of the Standard Model one can perform a fit of the hadronic parameters:







$$f_{Bs} = 250 \pm 12 \text{ MeV} \quad [2011]$$
$$f_{Bs} = 233 \pm 10 \text{ MeV} \quad [2012]$$
$$f_{Bs} = 229 \pm 7 \text{ MeV}$$

$$f_{Bs} / f_{Bd} = 1.215 \pm 0.019 \; [2011]$$
$$f_{Bs} / f_{Bd} = 1.200 \pm 0.020 \; [2012]$$
$$f_{Bs} / f_{Bd} = 1.219 \pm 0.054$$

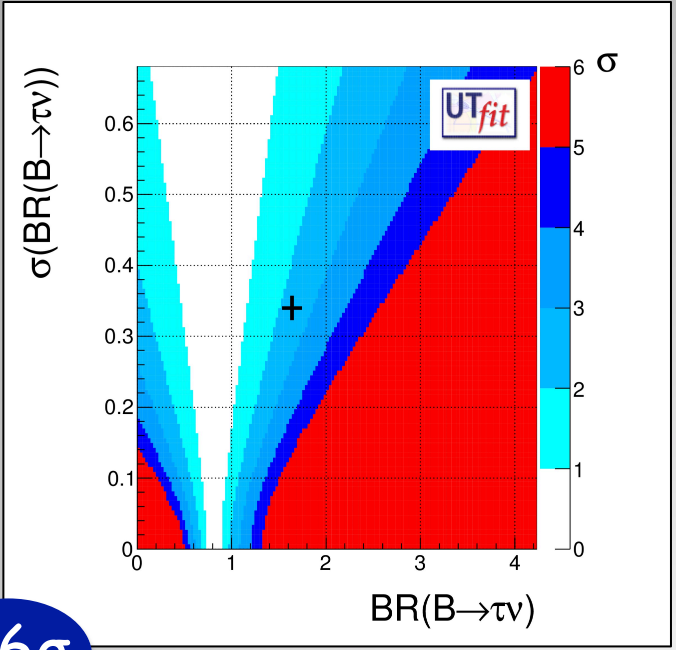
$$\hat{B}_K = 0.731 \pm 0.035 \; [2011]$$
$$\hat{B}_K = 0.750 \pm 0.020 \; [2012]$$
$$\hat{B}_K = 0.872 \pm 0.094$$

- Fit input
- SM fit prediction

STANDARD MODEL PREDICTIONS

Current average:

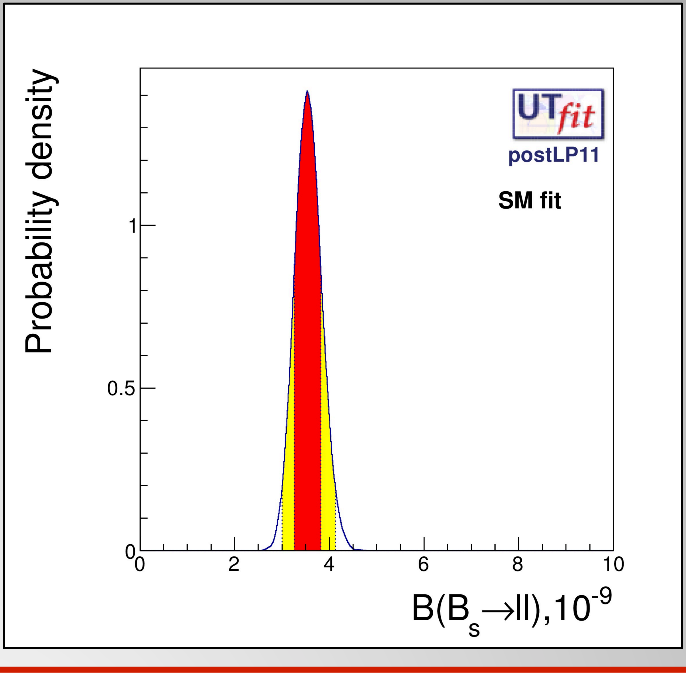
$\mathrm{BR}(B\to\tau\nu) = (1.64 \pm 0.34)\times 10^{-4}$



2.6σ

Best upper bound:

$\mathrm{BR}(B_s\to\mu\mu) < 4.5\times 10^{-9}$ @ 95%CL



Standard Model determinations from UTfit:

$\mathrm{BR}(B\to\tau\nu) = (0.83 \pm 0.09)\times 10^{-4}$

$\mathrm{BR}(B_s\to\mu\mu) = (3.54 \pm 0.28)\times 10^{-9}$

Last minute news from BaBar !!

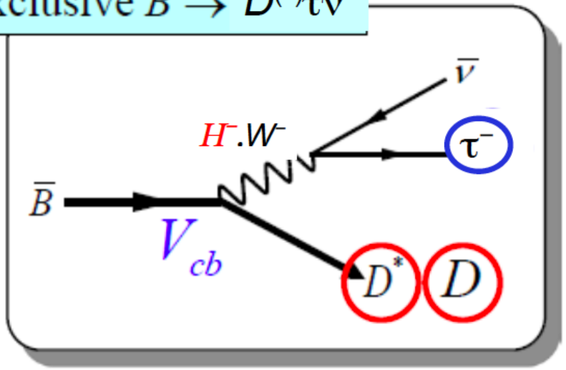
Vera Lüth
SLAC - Stanford University

Presentation at FPCP 2012 @ Hefei (China)
May 21 – 25, 2012

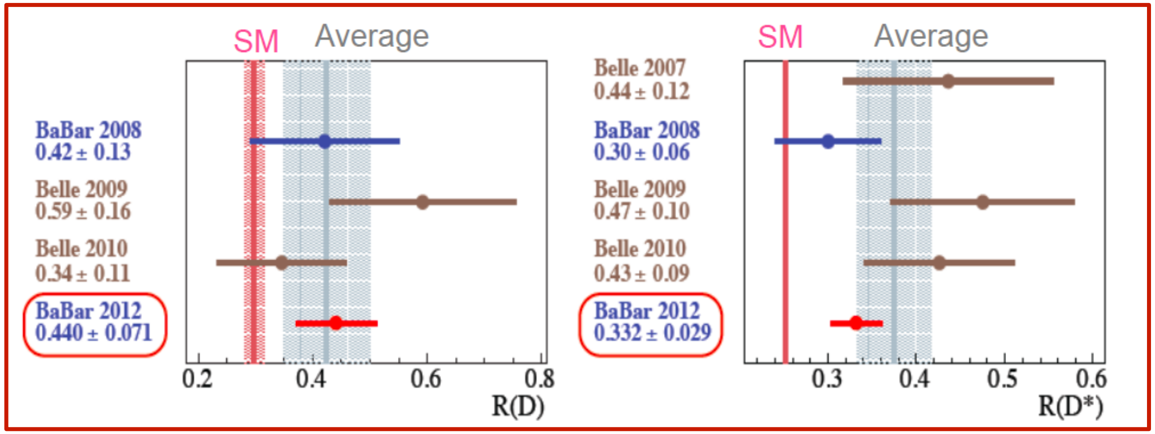
arXiv:1205.5442 [hep-ex] 24 May 2012

$$R(D)=\frac{\Gamma(\overline{B}\rightarrow D\tau\nu)}{\Gamma(\overline{B}\rightarrow D\ell\nu)} \qquad R(D^*)=\frac{\Gamma(\overline{B}\rightarrow D^*\tau\nu)}{\Gamma(\overline{B}\rightarrow D^*\ell\nu)}$$

Exclusive $B \rightarrow D^{(*)}\tau\nu$



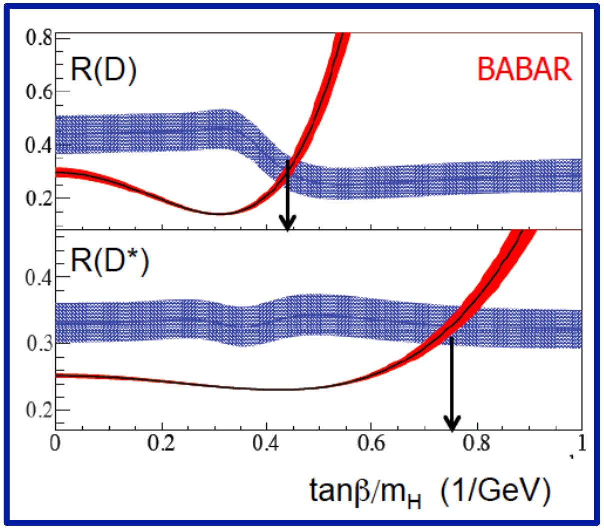
N.B. Average does not include this measurement



The SM prediction is excluded at 3.4σ

$$H_t^{2\mathrm{HDM}} = H_t^{\mathrm{SM}} \times \left(1 - \frac{\tan^2\beta}{m_{H\pm}^2}\frac{q^2}{1 \mp m_c/m_b}\right)$$

- for $D\tau\nu$
+ for $D^*\tau\nu$



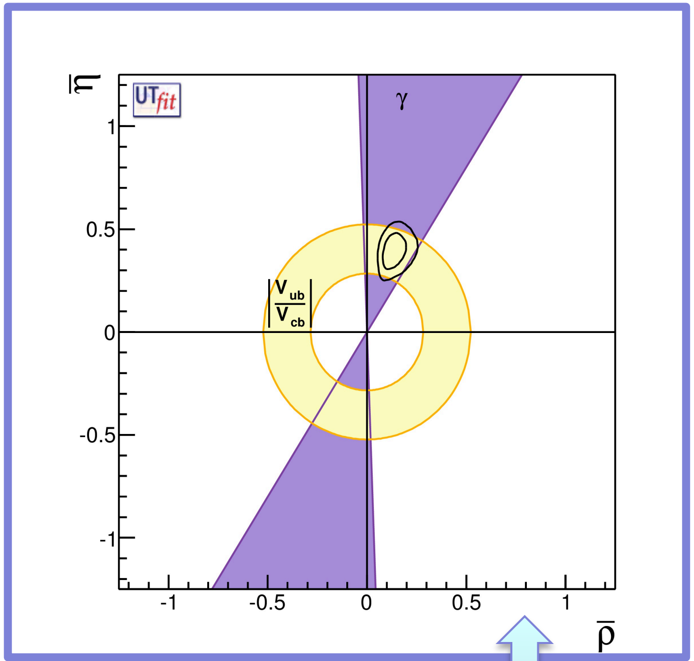
THE UTA BEYOND THE STANDARD MODEL

Model-independent determination of the CKM parameters

Assumptions:

- three generations
- no NP in tree-level decays

(* no large NP contributions to EW penguin in B→ ππ and Γ_q)



$$\bar{\rho} = 0.134 \pm 0.044$$
$$\bar{\eta} = 0.403 \pm 0.058$$

In the SM was

$$\bar{\rho} = 0.131 \pm 0.022$$
$$\bar{\eta} = 0.354 \pm 0.015$$

The degeneracy on γ broken by A_{SL}

A number of additional constraints are included: semileptonic asymmetries (A^d_{SL}, A^s_{SL}), lifetime differences and mixing phases ($\Delta\Gamma_d/\Gamma_d$, $\Delta\Gamma_s/\Gamma_s$, φ_s).

THE UTA BEYOND THE STANDARD MODEL

NP in mixing amplitudes parameterized in a general form:

- K mixing amplitude

  (2 real parameters)

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

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

- B_d and B_s mixing amplitudes

  (2+2 real parameters)

$$A_q e^{2i\phi_q} = C_{Bq}\, e^{2i\phi_{Bq}}\, A_q^{SM} e^{2i\phi_q^{SM}}$$

In the Standard Model: $C_{xx} = 1$, $\varphi_{xx} = 0$

Observables:

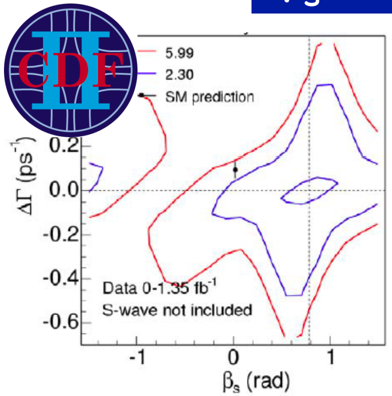
$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon\, \varepsilon_K^{SM}$$

$$a_{CP}^{B_d \to J/\psi K_S} \to \sin 2(\beta + \phi_{B_d}) \qquad a_{CP}^{B_s \to J/\psi \phi} \to -\beta_s + \phi_{B_s}$$

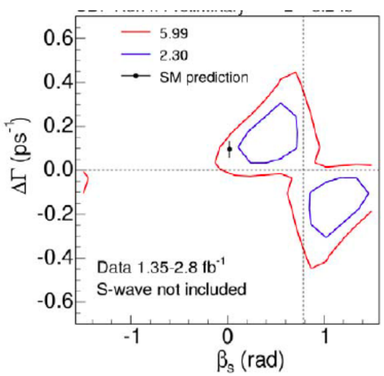
$$a_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right) \qquad \Delta\Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

THE UTA BEYOND THE STANDARD MODEL

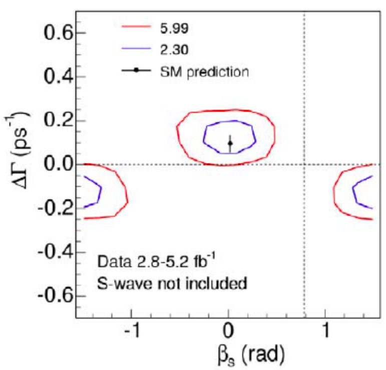
φ_s vs $\Delta\Gamma_s$ from $B_s \to J/\psi\,\varphi$



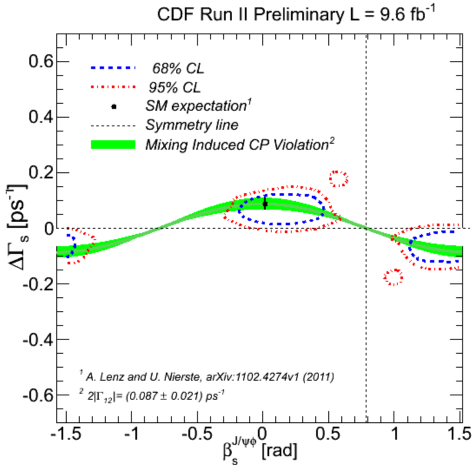
CDF: end of 2007



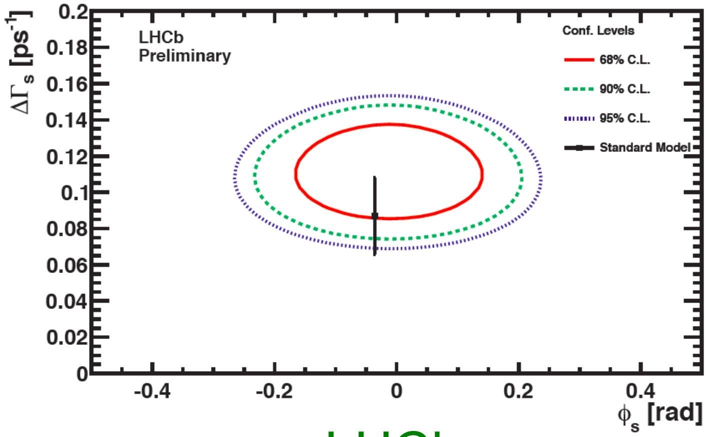
Added in 2008



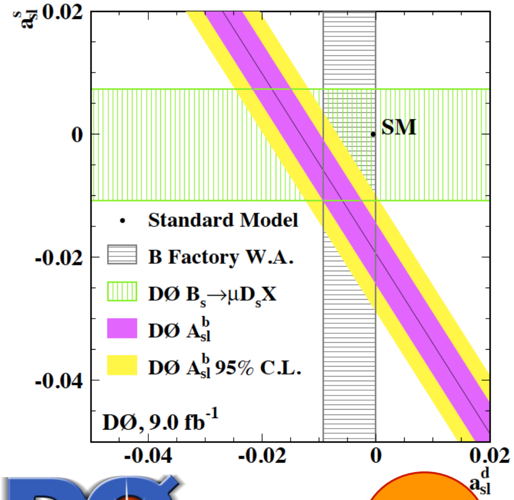
Added in 2010



Full data sample

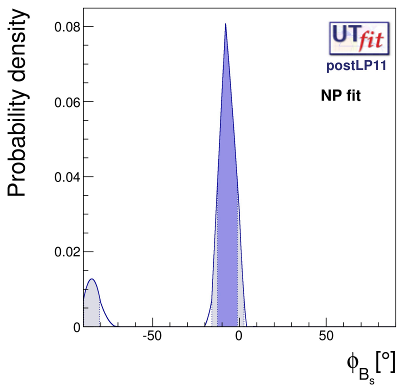


LHCb



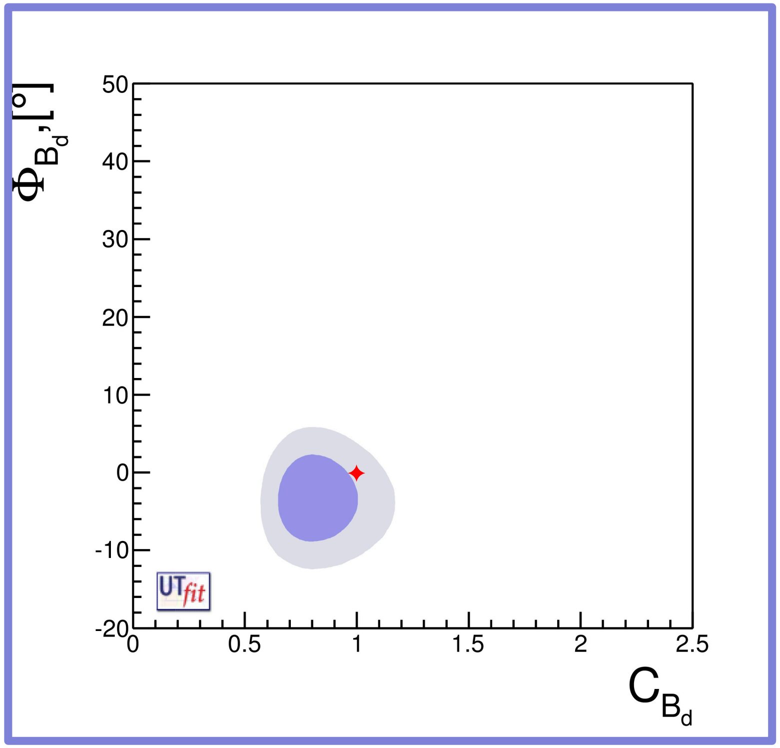
4σ!

$$A_{SL}^{\mu\mu} = \left(-7.9 \pm 2.0\right) \times 10^{-3}$$



THE UTA BEYOND THE STANDARD MODEL

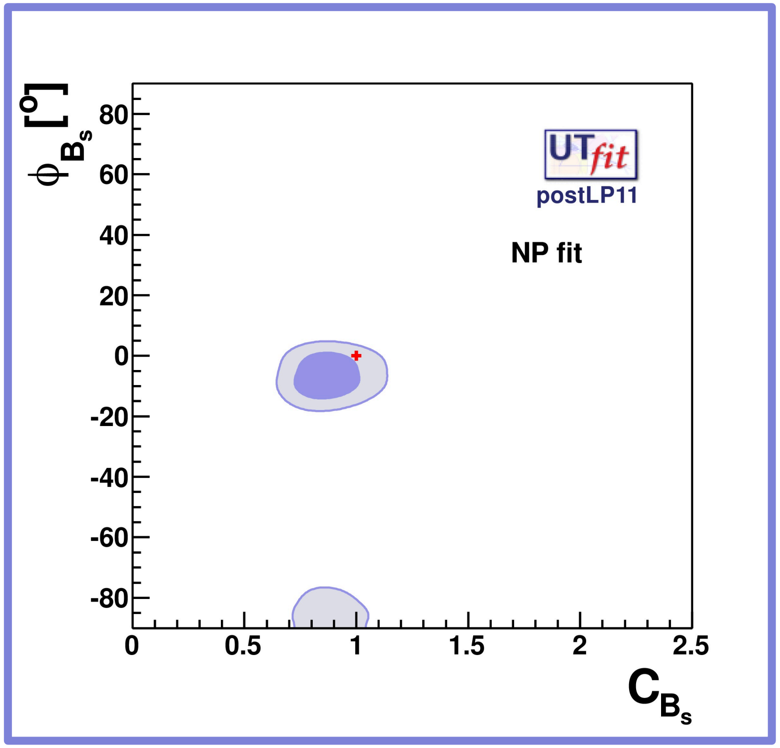
B_d-B_d mixing



C_{Bd} = 0.81 ± 0.12

φ_{Bd} = (-3.4 ± 3.7)°

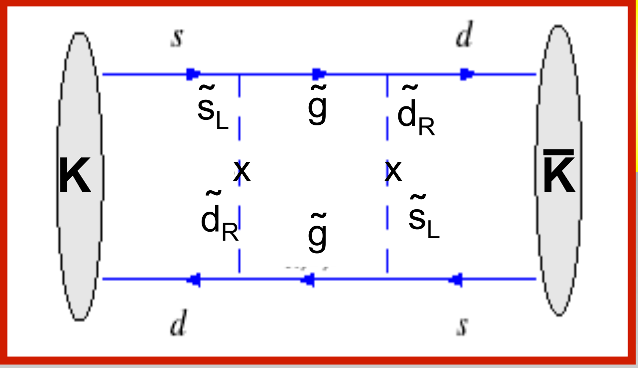
B_s-B_s mixing



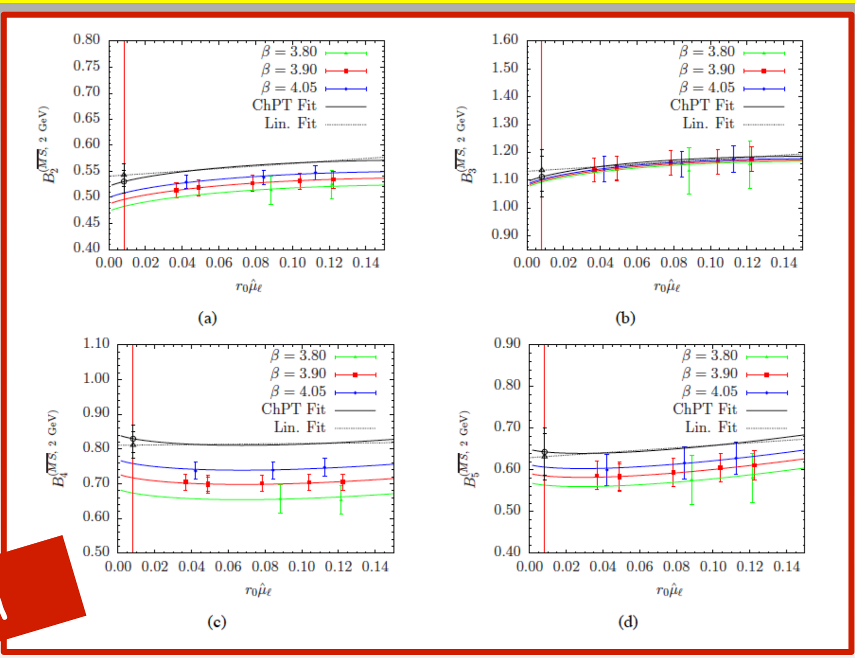
C_{Bs} = 0.87 ± 0.10

φ_{Bs} = (-6.9 ± 5.6)°

K-$\bar{K}$ MIXING BSM



$$
\begin{aligned}
\mathcal{O}_1 &= [\bar{s}^\alpha \gamma_\mu (1-\gamma_5) d^\alpha][\bar{s}^\beta \gamma_\mu (1-\gamma_5) d^\beta] \\
\mathcal{O}_2 &= [\bar{s}^\alpha (1-\gamma_5) d^\alpha][\bar{s}^\beta (1-\gamma_5) d^\beta] \\
\mathcal{O}_3 &= [\bar{s}^\alpha (1-\gamma_5) d^\beta][\bar{s}^\beta (1-\gamma_5) d^\alpha] \\
\mathcal{O}_4 &= [\bar{s}^\alpha (1-\gamma_5) d^\alpha][\bar{s}^\beta (1+\gamma_5) d^\beta] \\
\mathcal{O}_5 &= [\bar{s}^\alpha (1-\gamma_5) d^\beta][\bar{s}^\beta (1+\gamma_5) d^\alpha]
\end{aligned}
$$



in preparation

European Twisted Mass Collaboration

B_i (RI-MOM at 2 GeV)

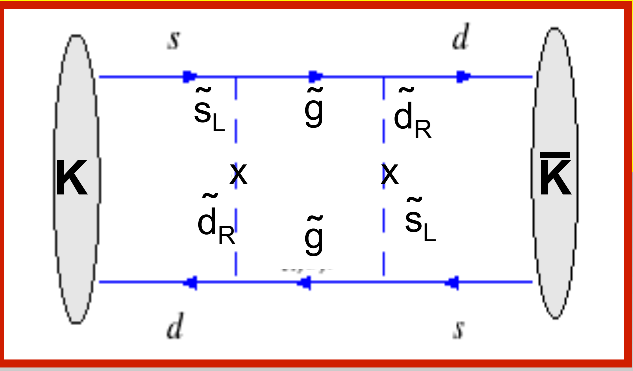
	This work	Ref. [6]		Ref. [5]	
	CL	$a = 0.09$ fm	$a = 0.13$ fm	$a = 0.07$ fm	$a = 0.09$ fm
1	0.51(02)	0.56(05)	0.53(04)	0.68(21)	0.70(15)
2	0.73(04)	0.87(07)	0.90(10)	0.67(07)	0.72(09)
3	1.29(11)	1.41(12)	1.53(40)	0.95(15)	1.21(10)
4	1.04(07)	0.94(05)	0.90(13)	1.00(09)	1.15(05)
5	0.76(09)	0.62(05)	0.56(14)	0.66(11)	0.88(06)

ETMC 2012

Babich et al. 2006

Donini et al. 1999

Previous results in the quenched approximation only (and quite in disagreement)



K-$\bar{\text{K}}$ MIXING BSM

LOWER BOUNDS ON THE NP SCALE:

UTfit 0707.0636

$$C_i(\Lambda)=F_iL_i/\Lambda^2$$

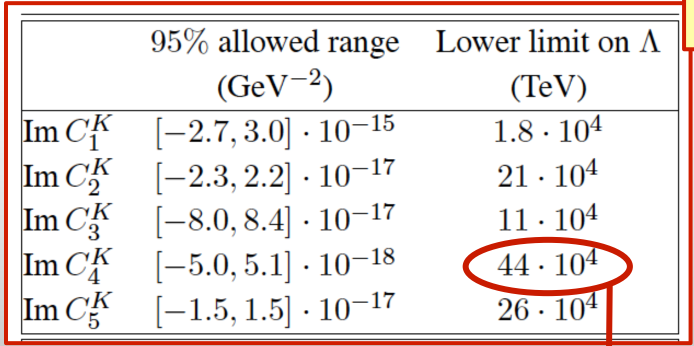
$$\left\langle K \middle| H_{\text{eff}}^{\text{NP}} \middle| \bar{K} \right\rangle = \sum_{i,j} C_j(\Lambda)\, W_{ji}(\Lambda,\mu)\, \underbrace{\left\langle K \middle| Q_i(\mu) \middle| \bar{K} \right\rangle}_{\text{LATTICE QCD}}$$

NP SCALE

L_i = loop factor
F_i = flavour coupling

(e.g. $L_i \simeq (\alpha_S)^2$ for gluino exchange in the MSSM)

$L_i = F_i = 1$



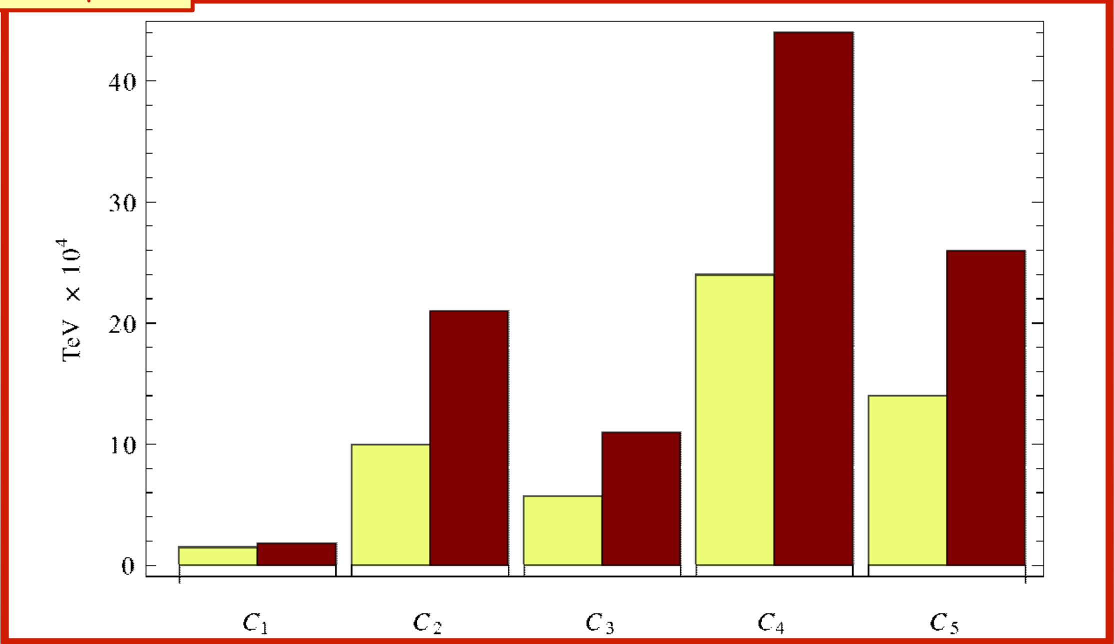
	95% allowed range (GeV^{-2})	Lower limit on Λ (TeV)
Im C_1^K	$[-2.7, 3.0] \cdot 10^{-15}$	$1.8 \cdot 10^4$
Im C_2^K	$[-2.3, 2.2] \cdot 10^{-17}$	$21 \cdot 10^4$
Im C_3^K	$[-8.0, 8.4] \cdot 10^{-17}$	$11 \cdot 10^4$
Im C_4^K	$[-5.0, 5.1] \cdot 10^{-18}$	$44 \cdot 10^4$
Im C_5^K	$[-1.5, 1.5] \cdot 10^{-17}$	$26 \cdot 10^4$

$\alpha_s(\Lambda)\,\Lambda \sim 4 \cdot 10^4$ TeV

$\alpha_W\,\Lambda \sim 10^4$ TeV

$\sqrt{F_{SM}}\,\Lambda \sim 10^2$ TeV

$\sqrt{F_{SM}}\,\alpha_W\,\Lambda \sim 3$ TeV



THE UNITARITY TRIANGLE ANALYSIS

③ The future

The SuperB era

La SuperB e il Cabibbo-Lab

News

- Il CabibboLab apre le porte a nuovi fisici, ingegneri e tecnici
- Un super laser per SuperB
- SuperB: Scelto il team che costruirà l'acceleratore

MEETINGS

31/5/2012 - 5/6/2012
4th SuperB Collaboration Meeting - Isola d'Elba Italy

19/3/2012 - 23/3/2012
3rd SuperB Collaboration Meeting - LNF

13/12/2011 - 16/12/2011
2nd SuperB Collaboration Meeting - LNF

Il Cabibbo-Lab

Il Cabibbo-Lab è il centro di ricerca internazionale per la **fisica fondamentale** e **applicata** che occuperà un'area di circa 30 ettari nel campus dell'Università di Roma Tor Vergata. Proposto dall'Istituto Nazionale di Fisica Nucleare (INFN), il progetto condurrà entro cinque anni alla costruzione dell'acceleratore SuperB, uno dei più significativi tra i 14 **progetti bandiera**del Piano di Ricerca Nazionale del MIUR, approvato dal CIPE.

Prima macchina acceleratrice ideata per soddisfare allo stesso tempo le esigenze della fisica fondamentale e di quella applicata, **SuperB** è il cuore del Cabibbo-Lab: un tunnel sotterraneo di 1,3 km di circonferenza dove si scontreranno elettroni e positroni, con l'obiettivo di fare luce su alcuni dei più affascinanti **interrogativi di fisica contemporanea** e rendere disponibili allo stesso tempo sorgenti di luce con caratteristiche tali da permettere di studiare la materia organica e le nanostrutture.

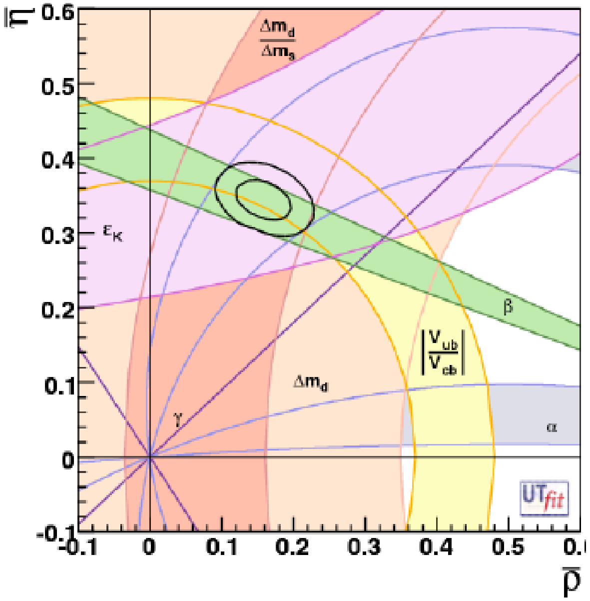
In perfetta sinergia con l'acceleratore LHC del Cern di Ginevra, il progetto SuperB si appresta ad affrontare una nuova frontiera della fisica sperimentale delle alte energie, aumentando a livelli senza precedenti l'intensità delle collisioni tra le particelle accelerate e garantendo in questo modo la produzione di **fenomeni fisici rarissimi** e ancora inesplorati. SuperB permetterà così lo studio dei meccanismi che hanno prodotto la scomparsa dell'**antimateria** poco dopo il Big Bang e le forze che tengono uniti i componenti fondamentali della materia.

A lato degli obiettivi di fisica fondamentale, da subito un'ampia comunità scientifica interdisciplinare, italiana e internazionale beneficerà della possibilità di utilizzare la **luce di sincrotrone** emessa dagli elettroni nell'acceleratore. Si tratta di fasci di luce con caratteristiche uniche per coerenza e collimazione, tali da consentire di visualizzare strutture biologiche o inorganiche a una risoluzione mai raggiunta, e di scattare delle "**microistantanee**" dei processi biochimici in atto. Offrendo una storica

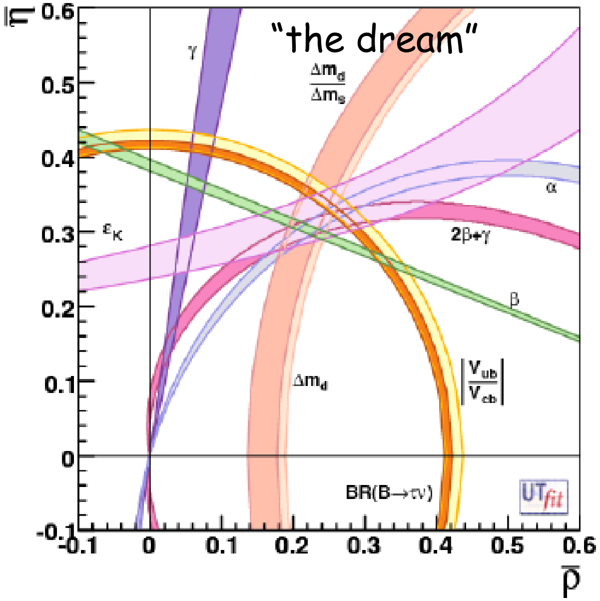
LQCD at a SuperB factory (2016-)

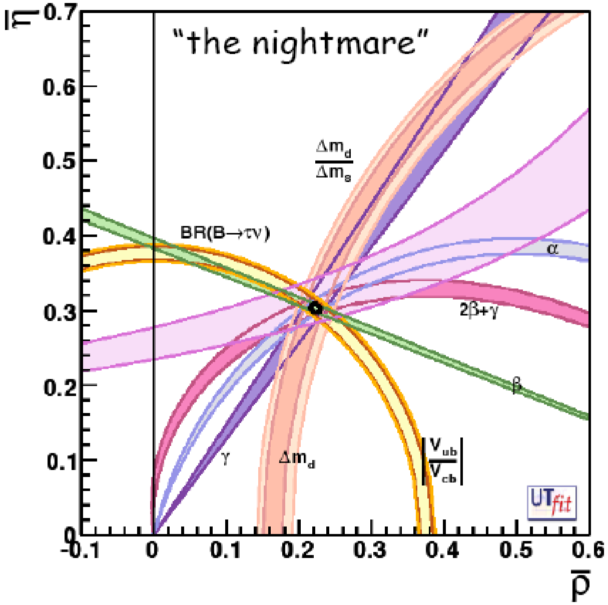
For example: testing the CKM paradigm at the 1% level

Today



With a SuperB in 2016





The theoretical accuracy must compete with the experimental one.

Can we reach the 1% accuracy in Lattice QCD ??

Cost of the "SuperB" lattice simulation

Simulation parameters

Nconf = 120

a = 0.033 fm

[$1/a$ = 6.0 GeV]

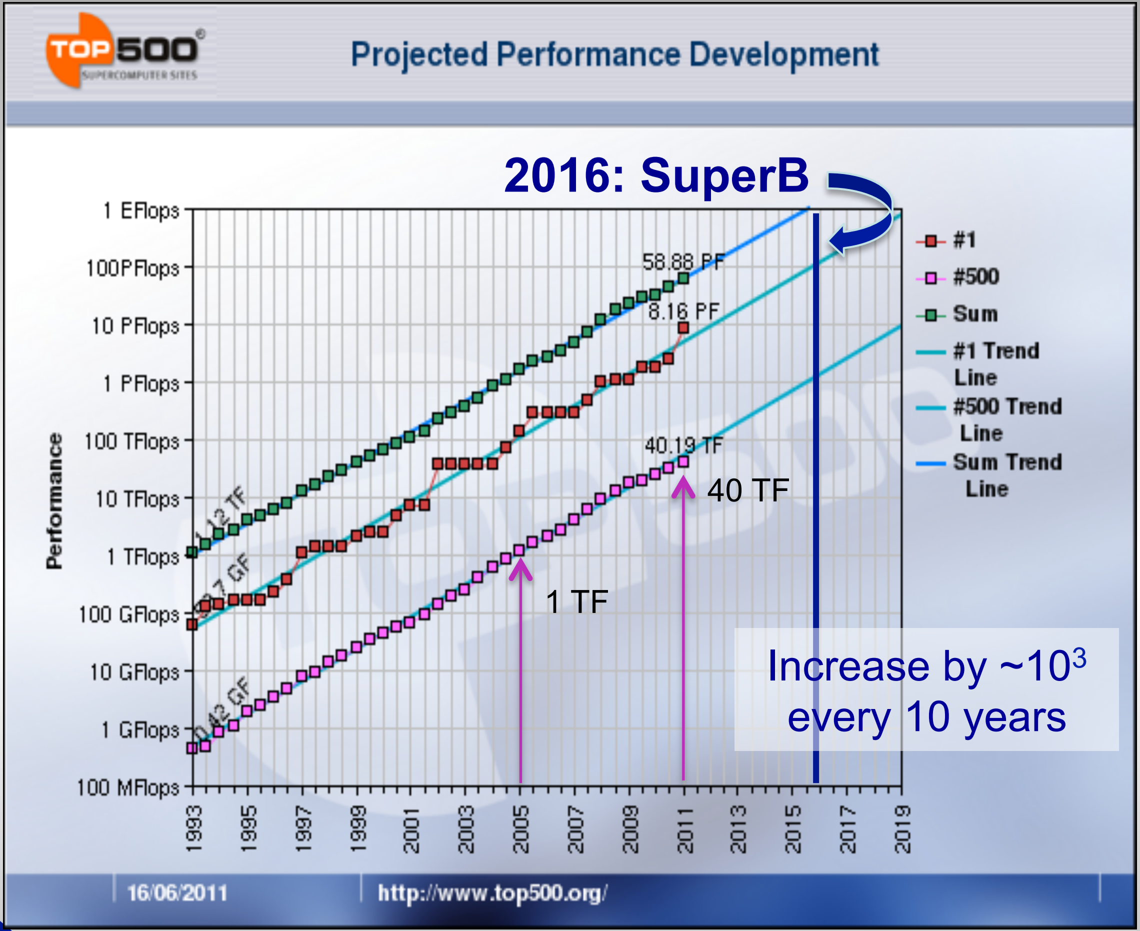
$\hat{m}/m_s = 1/12$

[M_π = 200 MeV]

L_s = 4.5 fm

[$V = 136^3 \times 270$]

~ 3 PFlop-years



2016: SuperB

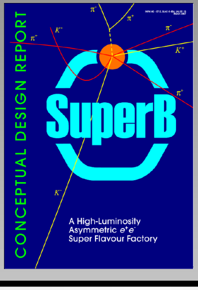
1 TF

40 TF

Increase by ~10^3 every 10 years

Affordable with 1-10 PFlops available for Lattice QCD in 2016 !

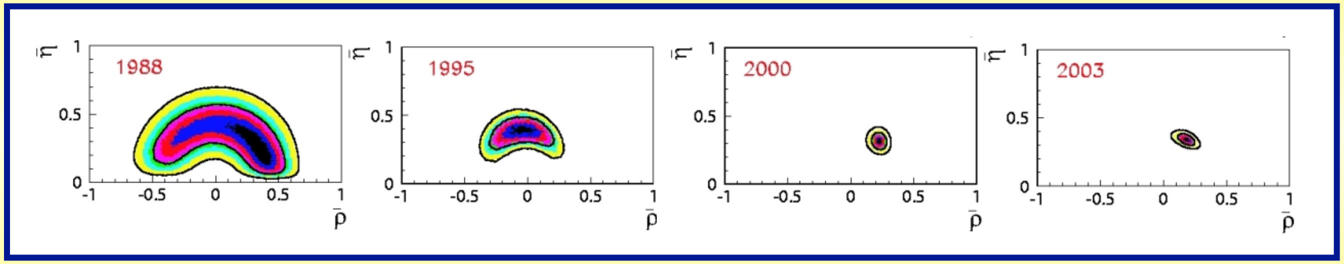
VL @



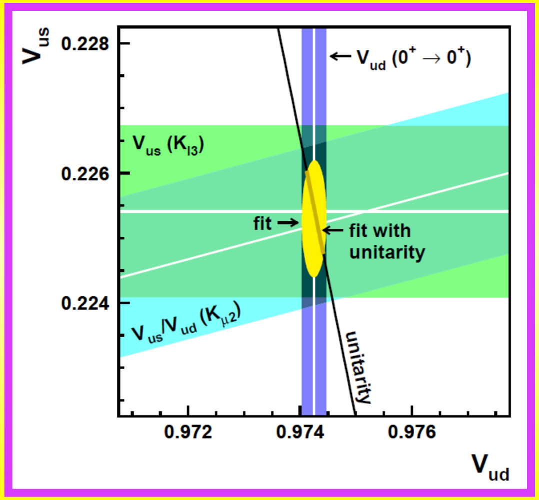
VL, SuperB CDR,
arXiv:0709.0451
updated in arXiv:1008.1541

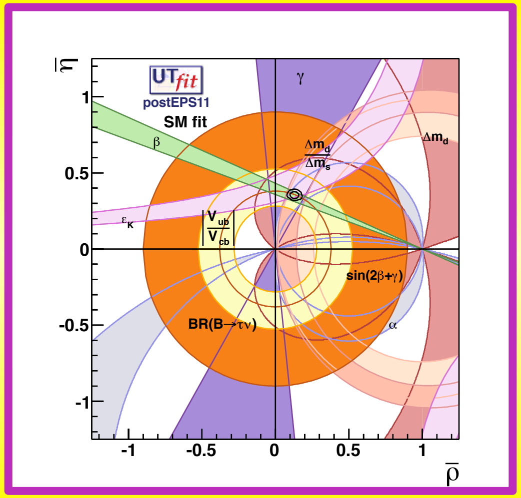
Hadronic matrix element	Lattice error in 2006	Lattice error in 2009	6 TFlop Year [2009]	60 TFlop Year [2012 LHCb]	1-10 PFlop Year [2016 SuperB]
$f_+^{K\pi}(0)$	0.9%	**0.5%**	0.7%	0.4%	**< 0.1%**
$\hat{B}_K$	11%	**5%**	5%	3%	**1%**
f_B	14%	**5%**	3.5 - 4.5%	2.5 - 4.0%	**1 – 1.5%**
$f_{Bs}B_{Bs}^{1/2}$	13%	**5%**	4 - 5%	3 - 4%	**1 – 1.5%**
ξ	5%	**2%**	3%	1.5 - 2 %	**0.5 – 0.8 %**
$\mathcal{F}_{B \to D/D^*l\nu}$	4%	**2%**	2%	1.2%	**0.5%**
$f_+^{B\pi}, \ldots$	11%	**11%**	5.5 - 6.5%	4 - 5%	**2 – 3%**
$T_1^{B \to K^*/\rho}$	13%	**13%**	----	----	**3 – 4%**

The past

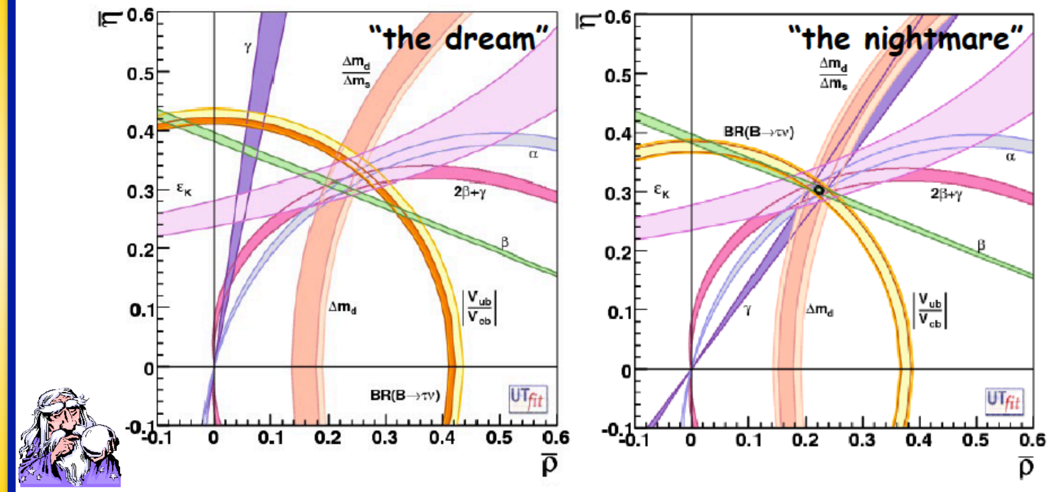


the present





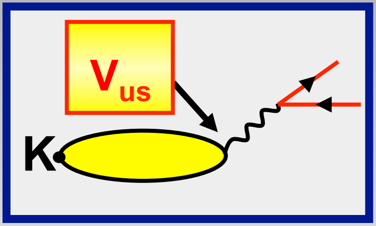
and the future

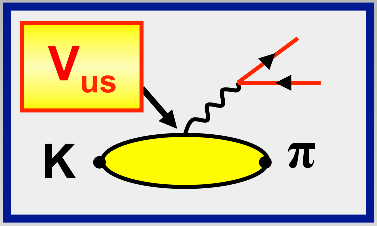


2016 @ SuperB

Supplementary slides

LQCD independent estimates of f_K/f_π, $f_+(0)$





$$\frac{|V_{us}|}{|V_{ud}|}\frac{f_k}{f_\pi} = 0.2758(5)$$ ①

$$|V_{us}|\, f_+(0) = 0.2163(5)$$ ②

FlaviA net Kaon WG

Assuming the Standard Model and combining with nuclear β decays

$$|V_{ud}|^2 + |V_{us}|^2 + \cancel{|V_{ub}|^2} = 1$$ ③

$$|V_{ud}| = 0.97425(22)$$ ④

From 20 superallowed transitions

[Hardy and Towner 08]

one obtains:

$$f_k/f_\pi = 1.192(6)$$

$$f_+(0) = 0.960(5)$$

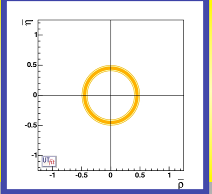
and:

$$|V_{us}| = 0.2254(10)$$

The error is at the per mille level: a challenge for Lattice QCD

FLAG [**F**lavianet **L**attice **A**veraging **G**roup] (1st report)

G.Colangelo, S.Dürr, A.Jüttner, L.Lellouch, H.Leutwyler, V.Lubicz, S.Necco,
C.Sachrajda, S.Simula, T.Vladikas, U.Wenger, H.Wittig



Exclusive vs Inclusive Vcb

EXCLUSIVE: 2 APPROACHES

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

Good agreement

1.8 σ

$|V_{cb}|_{excl.} = (39.5 \pm 1.0)\ 10^{-3}$

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