Lattice QCD and flavour physics

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ROMA TRE UNIVERSITÀ DEGLI STUDI

Workshop on

"Indirect Searches for New Physics at the time of LHC"

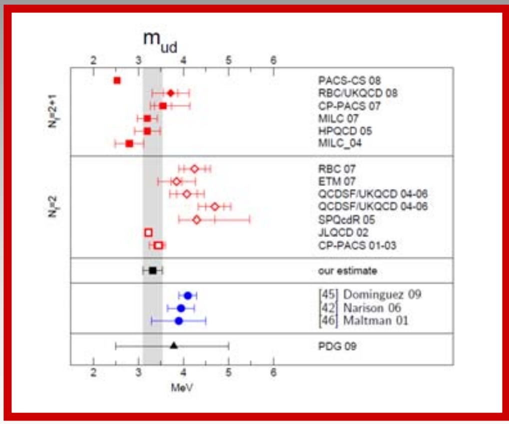
15/02/2010 - 26/03/2010

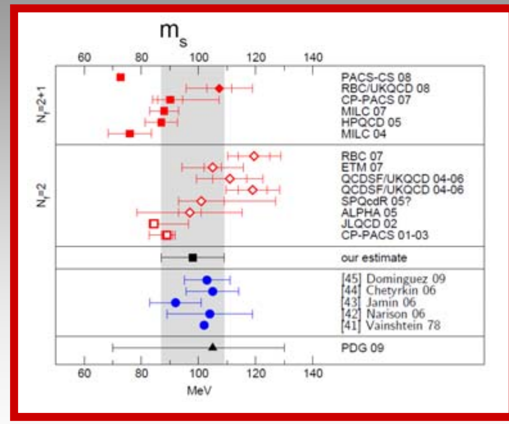
OUTLINE:

The accuracy of LQCD in the flavour sector

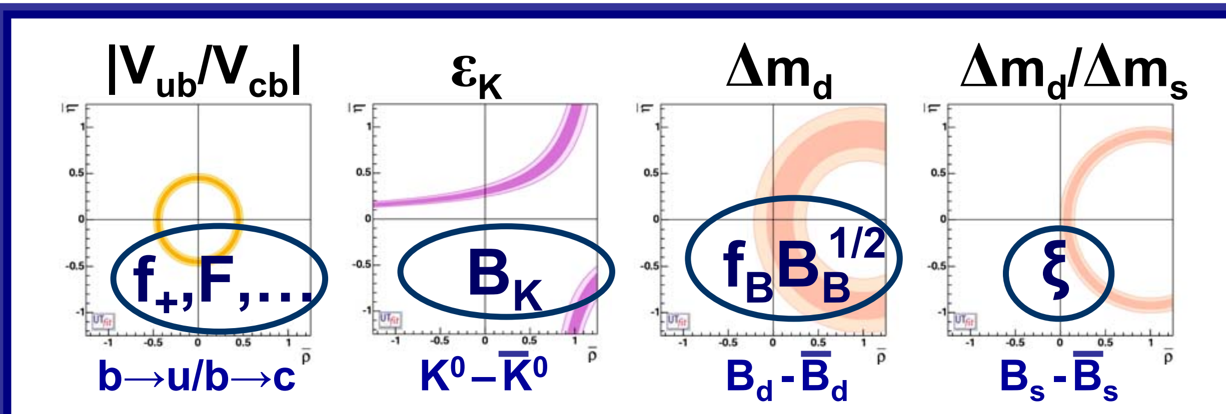
- **the past** (the quenched era)
- **the present**
- **the future** (LHCb, superB)

Lattice QCD and flavour physics





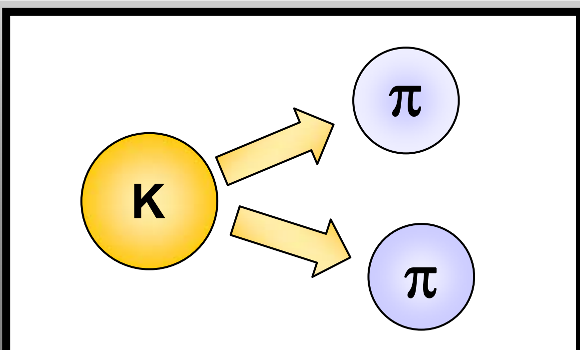
Quark masses



CKM matrix elements

UTA

Beyond SM physics



More difficult problems

Covered in this talk

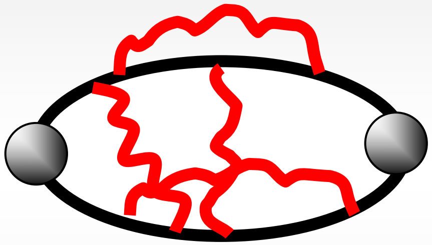
Accuracy of Lattice QCD

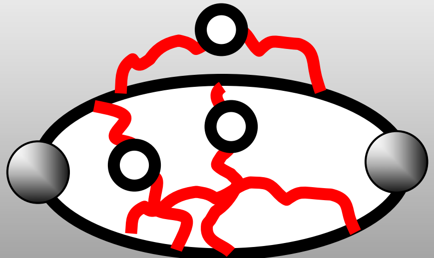
The past

For many years, uncertainties in lattice calculations have been dominated by the quenched approximation

History of lattice errors (before 2006)

	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%



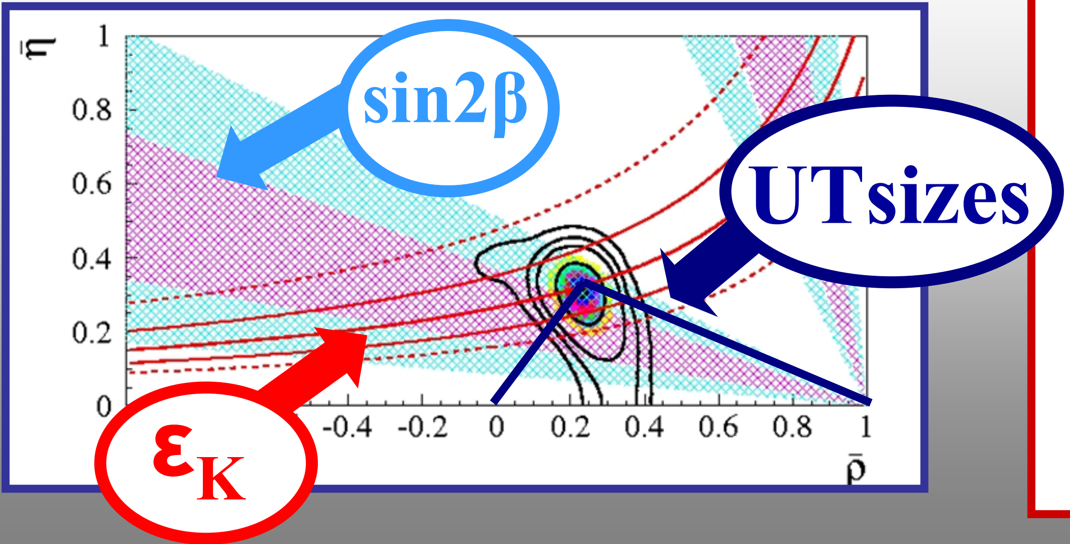


In spite of the relatively large lattice uncertainties, important results for flavour physics have been achieved

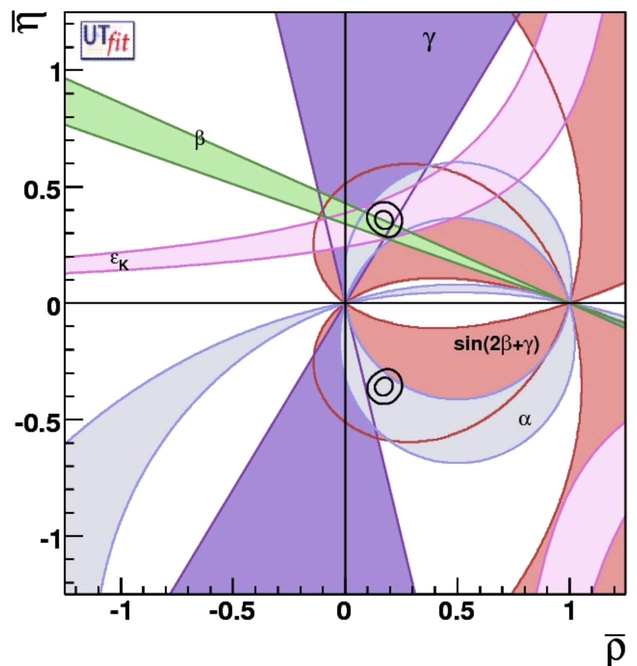
CKM PARADIGM OF ~~CP~~

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

Ciuchini et al.,2000



UTfit, today



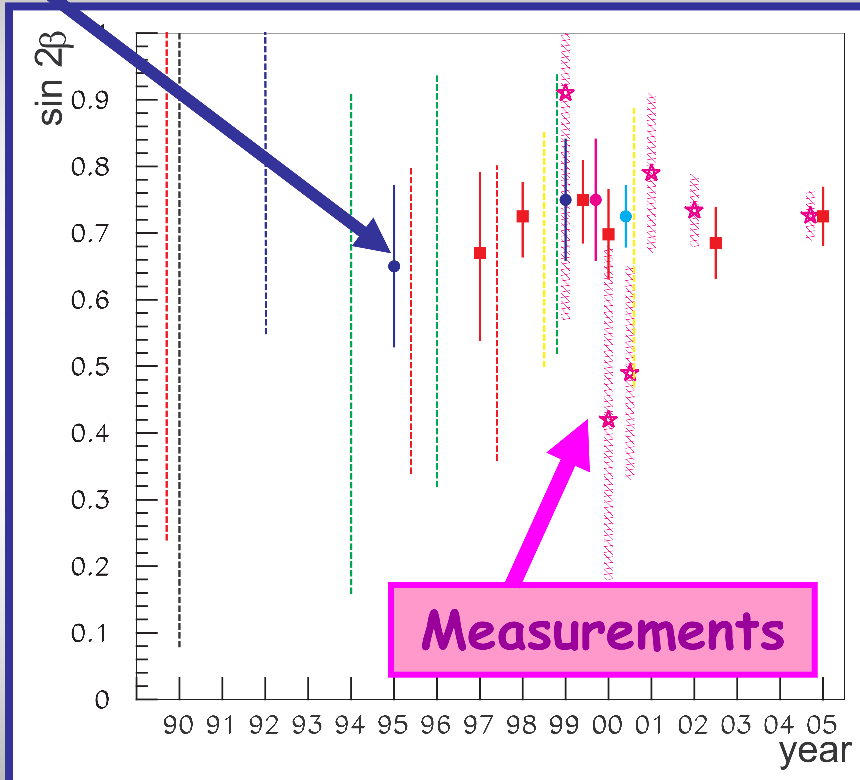
PREDICTION OF Sin2β

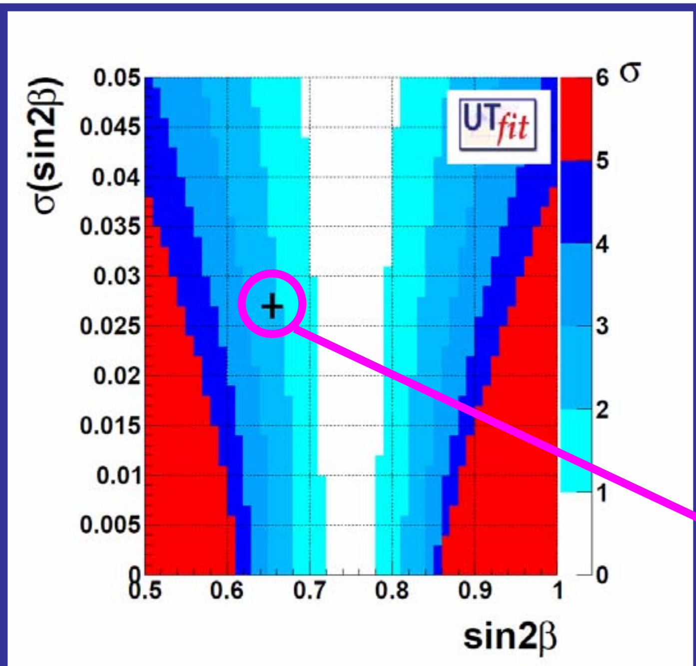
Ciuchini et al.,1995:
$Sin2\beta_{UTA} = 0.65 \pm 0.12$

Ciuchini et al.,2000:
$Sin2\beta_{UTA} = 0.698 \pm 0.066$

UTfit today:
$Sin2\beta_{UTA} = 0.751 \pm 0.035$

Predictions exist since 1995





Direct measurement today:
$Sin2\beta_{J/\psi K0} = 0.655 \pm 0.027$

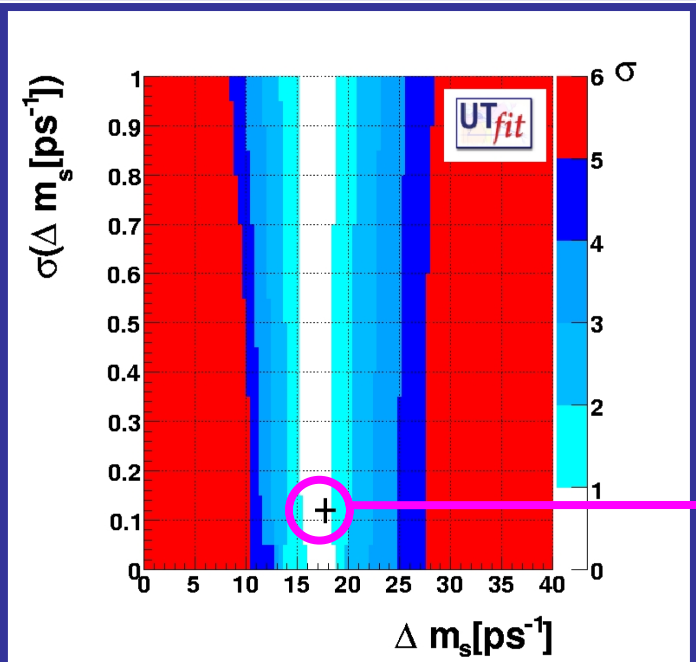
SM PREDICTION OF Δm_s
LOOKING FOR NEW PHYSICS EFFECTS

Ciuchini et al.,2000:

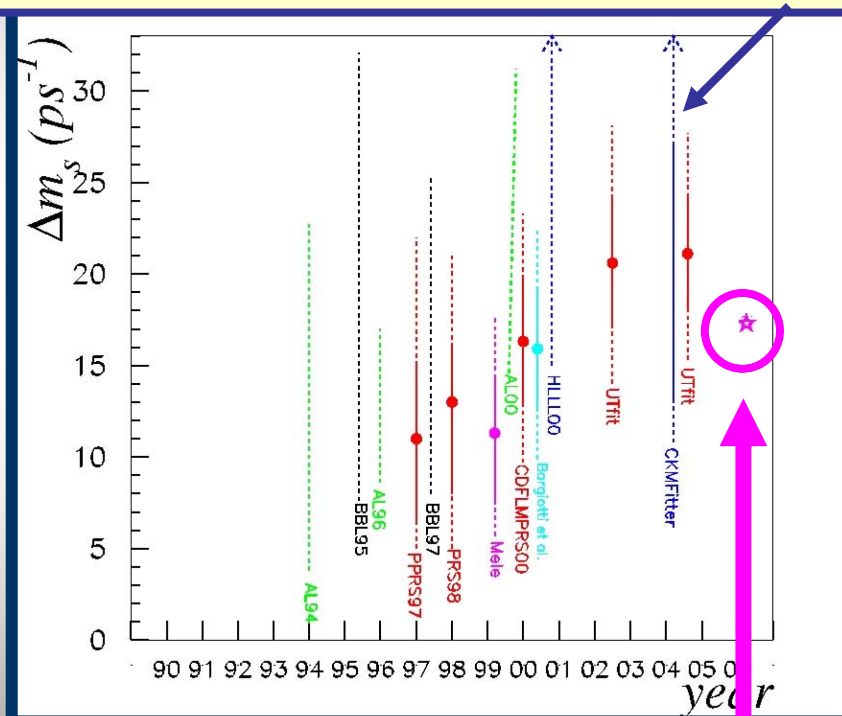
$\Delta m_s = (16.3 \pm 3.4)\ ps^{-1}$

UTfit today:

$\Delta m_s = (16.8 \pm 1.6)\ ps^{-1}$



The predicted range was very large in the frequentistic CKMFitter approach



Direct measurement today

$\Delta m_s = (17.77 \pm 0.12)\ ps^{-1}$

The present

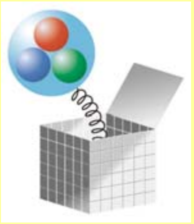
PRECISION FLAVOUR PHYSICS

Experiments 2010

$\|V_{us}\| f_+(0)$	0.21661 ± 0.00047	0.2%
$\frac{\|V_{us}\| F_K}{\|V_{ud}\| F_\pi}$	0.27599 ± 0.00059	0.2%
ε_K	$(2.228 \pm 0.011) \times 10^{-3}$	0.5%
Δm_d	$(0.507 \pm 0.005)\ ps^{-1}$	1%
Δm_s	$(17.77 \pm 0.12)\ ps^{-1}$	0.7%
$\sin 2\beta$	0.655 ± 0.027	4%

Lattice 2010

	Lattice 2010	2006
$f_+(0)$	0.5%	0.9%
F_K / F_π	0.9%	1.1%
B_K	5%	11%
$f_B \sqrt{B_B}$	5%	13%
$f_{Bs} \sqrt{B_{Bs}}$	5%	13%
—	—	—

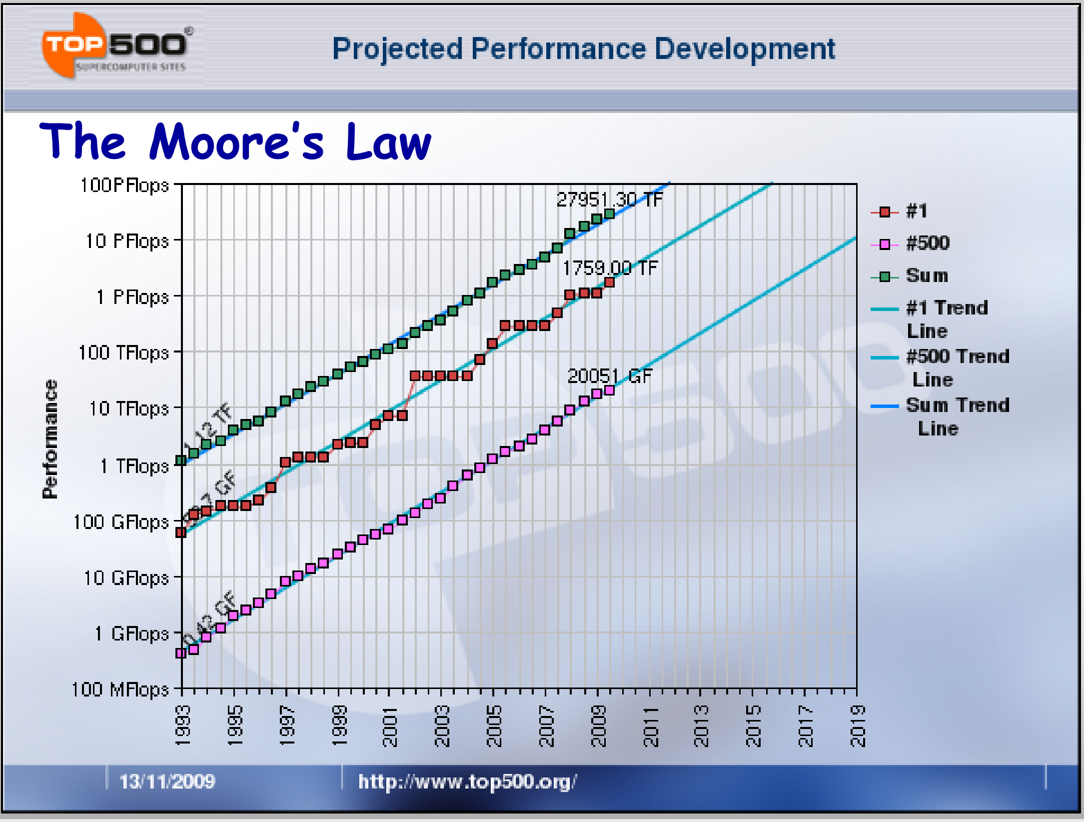


KAON AND B PHYSICS ON THE LATTICE

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

THE "PRECISION ERA" OF LATTICE QCD: WHY NOW

1) Increasing of computational power
→ Unquenched simulations



For Lattice QCD today: ~ 5-30TFlops
(like the # 500 in the TOP500 list)

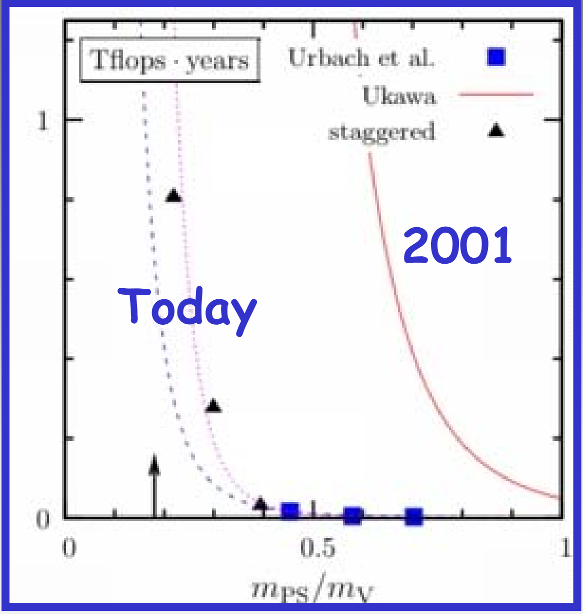
TeraFlops machines are required to perform unquenched simulations. Available only since few years.

CPU cost for Nf=2 Wilson fermions:

[Del Debbio et al. 2006]

$$\text{TFlops-years} \simeq 0.15 \left(\frac{N_{conf}}{100}\right)\left(\frac{L_s}{3\ \text{fm}}\right)^5\left(\frac{L_t}{2L_s}\right)\left(\frac{0.15}{\hat{m}/m_s}\right)\left(\frac{0.08\ \text{fm}}{a}\right)^6$$

2) Algorithmic improvements:
⟹ Light quark masses in the ChPT regime



CPU cost (for Nf=2 Wilson fermions):

Ukawa 2001 (The Berlin wall):

$$\text{TFlops-years} \simeq 3.1 \left(\frac{N_{conf}}{100}\right) \left(\frac{L_s}{3\text{ fm}}\right)^5 \left(\frac{L_t}{2L_s}\right) \left(\frac{0.2}{\hat{m}/m_s}\right)^3 \left(\frac{0.1\text{ fm}}{a}\right)^7$$

Del Debbio et al. 2006:

$$\text{TFlops-years} \simeq 0.03 \left(\frac{N_{conf}}{100}\right) \left(\frac{L_s}{3\text{ fm}}\right)^5 \left(\frac{L_t}{2L_s}\right) \left(\frac{0.2}{\hat{m}/m_s}\right) \left(\frac{0.1\text{ fm}}{a}\right)^6$$

Today: $M_\pi^{latt} \approx 200-300\text{ MeV} \quad \left(\hat{m}_{ud}^{latt}/m_s \approx 1/6 - 1/12\right)$ **ChPT**

Few years ago: $M_\pi^{latt} \approx 500\text{ MeV} \quad \left(\hat{m}_{ud}^{latt}/m_s \approx 1/2\right)$

The FLAG working group

FLAG (constituted in November 2007)

Flavianet **L**attice **A**veraging **G**roup

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

A working group of: FlaviA net

Aims: for each quantity, provide to the network's working groups and to the wider community

- a collection of current lattice results and references
- a summary of the essential aspects of each calculation, using an easy-to-read "color code" classification (★ ● ■)
- averages of lattice results (when it makes sense)

The FLAG colour coding

A number of sources of systematic errors are identified and to each calculation a colour with respect to each of these is assigned:

★ (green star)	when the systematic error has been estimated in a satisfactory manner and convincingly shown to be under control
● (orange circle)	when a reasonable attempt at estimating the systematic error has been made, although this could be improved
■ (red square)	when no or a clearly unsatisfactory attempt at estimating the systematic error has been made

- Chiral extrapolation:

  ★ $M_{\pi,\mathrm{min}} < 250$ MeV

  ● $250\ \mathrm{MeV} \le M_{\pi,\mathrm{min}} \le 400$ MeV

  ■ $M_{\pi,\mathrm{min}} > 400$ MeV

  It is assumed that the chiral extrapolation is done with at least a three-point analysis. In case of nondegeneracies among the different pion states M_π stands for an average pion mass.

The FLAG colour coding

- 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

  It is assumed that the action is $O(a)$-improved. The colour coding criteria for non-improved actions change as follows: one lattice spacing more needed.

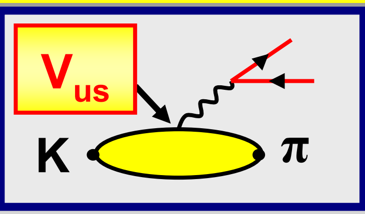
- Finite-volume effects:
  - ★ $(M_\pi L)_{\rm min} > 4$ or at least 3 volumes
  - ● $(M_\pi L)_{\rm min} > 3$ and at least 2 volumes
  - ■ otherwise

  It is assumed that $L_{\rm min} \geq 2$ fm, otherwise a red dot will be assigned. In case of nondegeneracies among the different pion states M_π stands for an average pion mass.

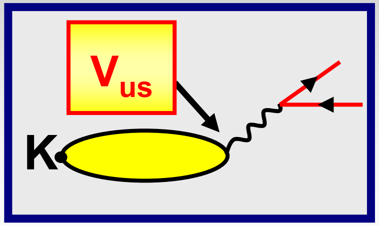
- Renormalization (where applicable):
  - ★ non-perturbative
  - ● 2-loop perturbation theory (with a converging series)
  - ■ otherwise

- Running (where applicable):
  - ★ non-perturbative
  - ● otherwise
  - ■ —

V_{us} from kaon decays: $f_+^{K\pi}(0)$ and f_K/f_π



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



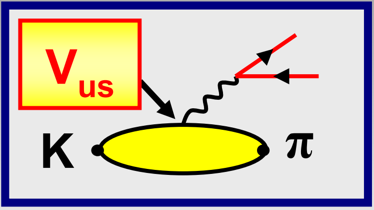
$$\frac{\Gamma(K\to\mu\bar{\nu}_\mu(\gamma))}{\Gamma(\pi\to\mu\bar{\nu}_\mu(\gamma))} = \frac{|V_{us}|^2}{|V_{ud}|^2}\left(\frac{f_K}{f_\pi}\right)^2 \frac{m_K(1-\frac{m_\mu^2}{m_K^2})}{m_\pi(1-\frac{m_\mu^2}{m_\pi^2})} \times 0.9930(35)$$

[Marciano 04]

Collaboration	N_f	publication status	chiral extrapolation	finite volume errors	continuum extrapolation	$f_+(0)$
RBC/UKQCD 07	2+1	A	●	★	■	0.9644(33)(34)(14)
ETMC 09	2	P	●	●	●	0.9560(57)(62)
QCDSF 07	2	C	■	★	■	$0.9647(15)_{stat}$
RBC 06	2	A	■	★	■	0.968(9)(6)
JLQCD 05	2	C	■	★	■	0.967(6)
SPQ$_{CD}$R 04	0	A	■	★	■	0.960(5)(7)

Collaboration	N_f	publication status	chiral extrapolation	finite volume errors	continuum extrapolation	F_K/F_π
ALVdW 09	2+1	C	●	●	●	1.192(12)(16)
BMW 09	2+1	C	★	★	★	1.195(8)(11)
RBC/UKQCD 09	2+1	C	●	★	●	1.225(12)(14)
MILC 09b	2+1	A	★	★	★	$1.198(2)(^{+6}_{-8})$
MILC 09a	2+1	A	★	★	★	$1.197(3)(^{+6}_{-13})$
PACS-CS 08	2+1	P	★	■	■	1.189(20)
HPQCD/UKQCD 08	2+1	A	★	●	★	1.189(2)(7)
RBC/UKQCD 07	2+1	A	●	★	■	1.205(18)(62)
NPLQCD 07	2+1	A	●	■	■	$1.218(2)(^{+11}_{-24})$
MILC 04	2+1	A	★	●	●	1.210(4)(13)
ETMC 09	2	A	●	●	★	1.210(6)(15)(9)
ETMC 07	2	A	●	●	■	1.227(9)(24)
QCDSF/UKQCD 07	2	C	●	★	●	1.21(3)

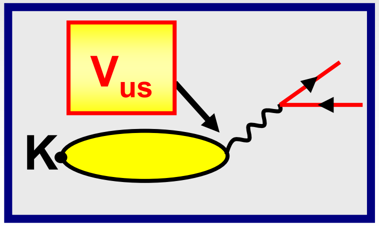
V_{us} from kaon decays: $f_+^{K\pi}(0)$ and f_K/f_π



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

$$|V_{us}| f_+(0) = 0.21661(47)$$ (1)

FlaviA net Kaon WG



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

[Marciano 04]

$$\left|\frac{V_{us}F_K}{V_{ud}F_\pi}\right| = 0.27599(59)$$ (2)

Assuming the Standard Model and combining with nuclear β decays:

(3) $$|V_{ud}|^2 + |V_{us}|^2 + \not{|V_{ub}|^2} = 1$$

$$|V_{ud}| = 0.97425(22)$$ (4)

From nuclear β decays
20 superallowed transitions
[Hardy and Towner 08]

one obtains: [FLAG]

$$f_+(0) = 0.9608(46)$$

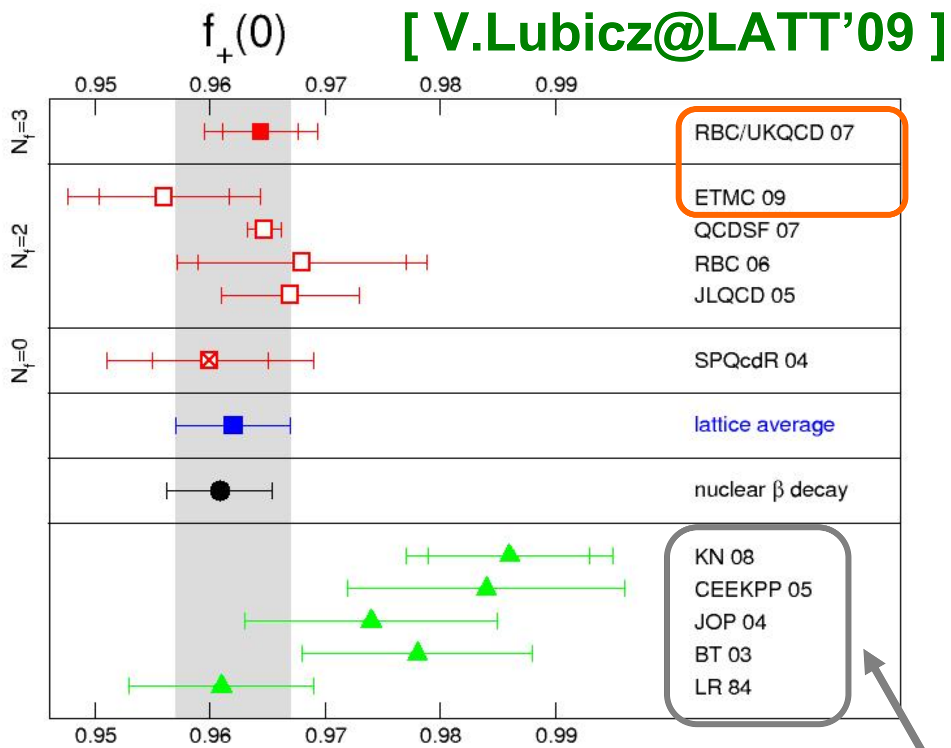
$$F_K/F_\pi = 1.1927(59)$$

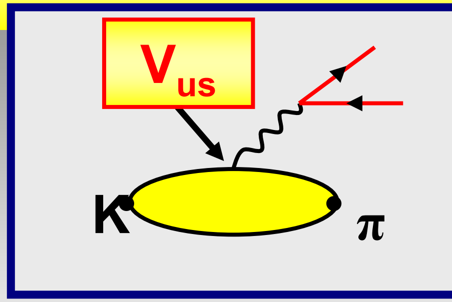
Lattice independent estimates of the hadronic parameters

and

$$|V_{us}| = 0.22544(95)$$

V_{us} from kaon decays: $f_+^{K\pi}(0)$ and f_K/f_π





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

- $|V_{us}|_{Kl3} = 0.2252(13)$
- $|V_{us}| = 0.2255(10)$

  Using unitarity and $|V_{ud}|$ from nuclear β decays

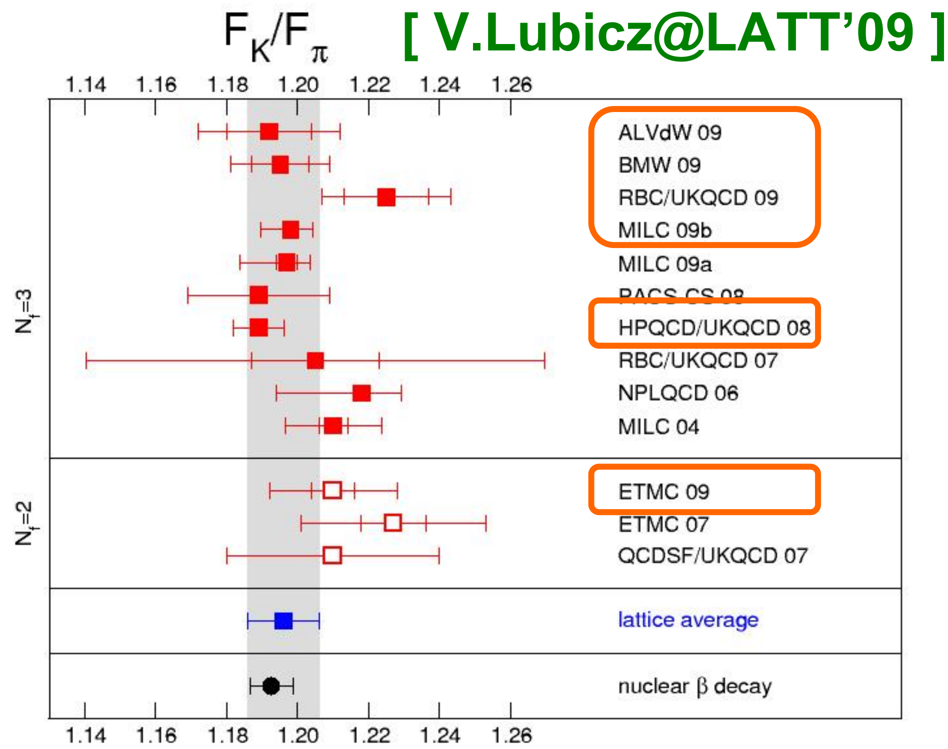
$f_+(0) = 0.962\,(3)\,(4)$ **0.5%**

Error in 2006: 0.9%

Analytical model calculations tends to give larger predictions than lattice results

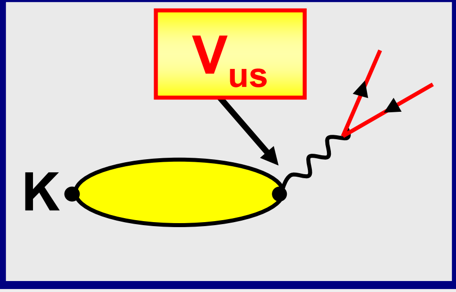
V_{us} from kaon decays: $f_+^{K\pi}(0)$ and f_K/f_π

[V.Lubicz@LATT'09]



f_K/f_π = 1.196 (1) (10) **0.8%**

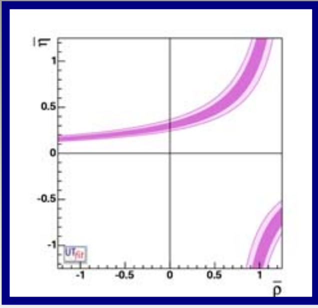
The accuracy is comparable to the one reached on $f_+(0)$ [0.5%]

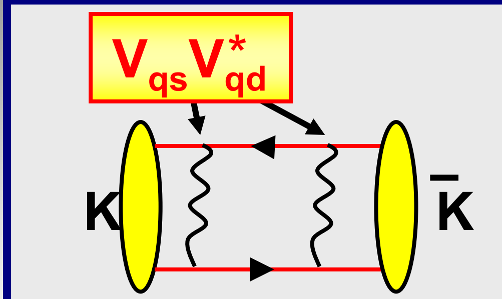


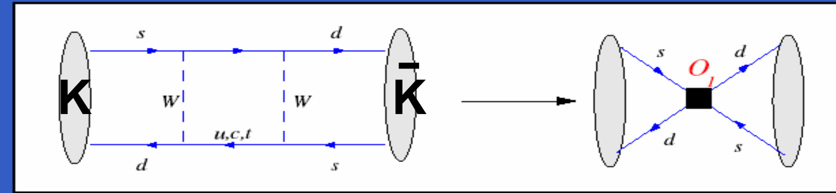
$$\frac{\Gamma(K\to\mu\bar\nu_\mu(\gamma))}{\Gamma(\pi\to\mu\bar\nu_\mu(\gamma))}=\frac{|V_{us}|^2}{|V_{ud}|^2}\left(\frac{f_K}{f_\pi}\right)^2\frac{m_K(1-\frac{m_\mu^2}{m_K^2})}{m_\pi(1-\frac{m_\mu^2}{m_\pi^2})}\times 0.9930(35)$$ [Marciano 04]

- $|V_{us}|_{Kl2}$ = 0.2248(19)
- $|V_{us}|_{Kl3}$ = 0.2252(13)
- $|V_{us}|$ = 0.2255(10)
  Using unitarity and $|V_{ud}|$ from nuclear β decays

K^0–$\bar{K}^0$ mixing: B_K







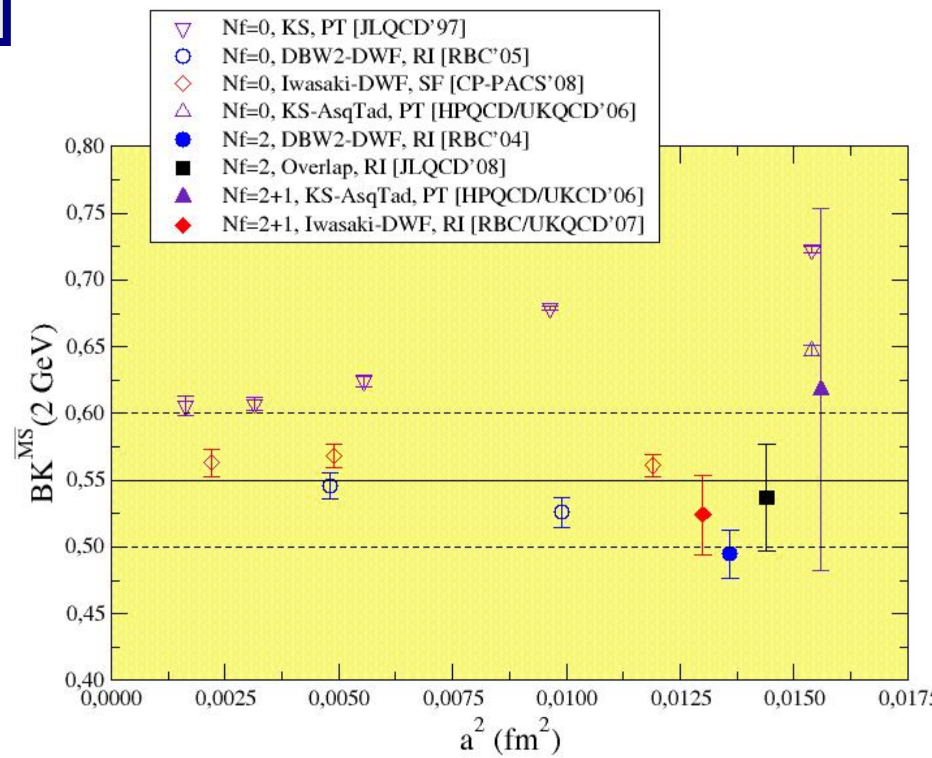
$$\langle \bar{K}^0 | Q(\mu) | K^0 \rangle = \frac{8}{3} f_K^2 m_K^2 B_K(\mu)$$

$\hat{B}_K = 0.90 \pm 0.03 \pm 0.15$ — S.Sharpe@Latt'96 — **17%**

$\hat{B}_K = 0.86 \pm 0.05 \pm 0.14$ — L.Lellouch@Latt'00 — **17%**

$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08$ — C.Dawson@Latt'05 — **11%**

$\hat{B}_K = 0.731 \pm 0.036$ — V.Lubicz@Latt'09 — **5%**



[VL, C.Tarantino 0807.4605]

Until 2008 few unquenched calculations at fixed (and rather large) lattice spacing

K^0–$\overline{K}^0$ mixing: B_K

$\hat{B}_K = 0.724\,(8)\,(28)$ [Nf=2+1, ALVdW 09]

$\hat{B}_K = 0.738\,(8)\,(25)$ [Nf=2+1, RBC/UKQCD 09]

$\hat{B}_K = 0.730\,(30)\,(30)$ [Nf=2, ETM 09]

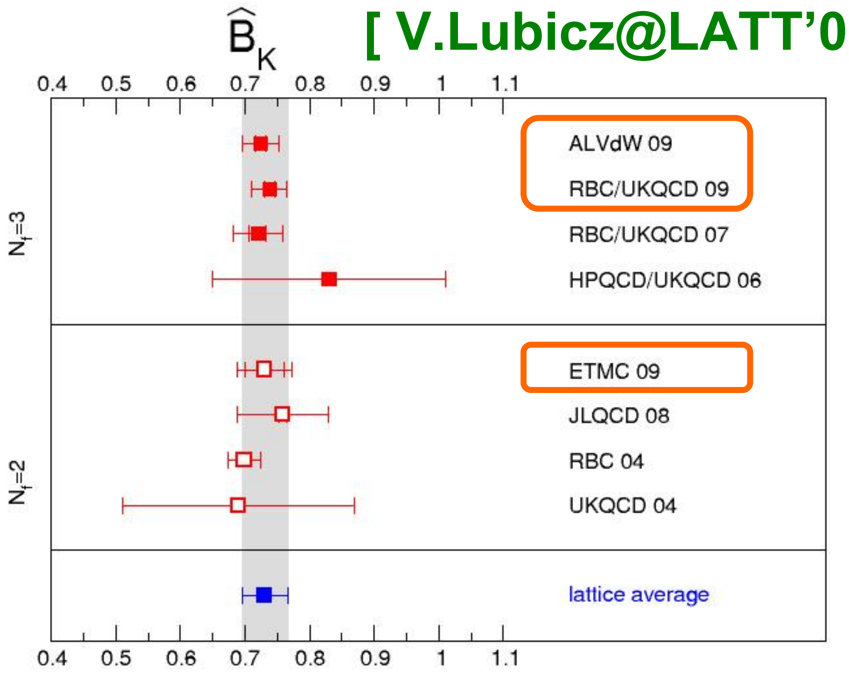
3 results with no red tags, all new

No visible effect of the partial quenching (Nf=2).

Collaboration	N_f	publication st	lattice artefac	smallest pion	finite volume	renormalizati	running	$B_K^{\overline{MS}}(2\,\text{GeV})$	$\hat{B}_K$
ALVdW 09	2+1	P	●	★	●	★	●	0.527(6)(20)	0.724(8)(28)
RBC/UKQCD 09	2+1	C	●	●	★	★	●	0.537(6)(18)	0.738(8)(25)
RBC/UKQCD 07	2+1	A	■	●	★	★	●	0.524(10)(28)	0.720(13)(37)
HPQCD/UKQCD 06	2+1	A	■	●	★	■	●	0.618(18)(135)	0.83(18)
ETMC 09	2	C	★	●	●	★	●	0.518(21)(21)	0.730(30)(30)
JLQCD 08	2	A	■	●	■	★	●	0.537(4)(40)	0.758(6)(71)
RBC 04	2	A	■	■	■†	★	●	0.495(18)	0.699(25)
UKQCD 04	2	A	■	■	■†	■	●	0.49(13)	0.69(18)

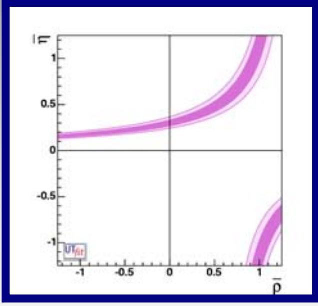
$K^0-\bar{K}^0$ mixing: B_K

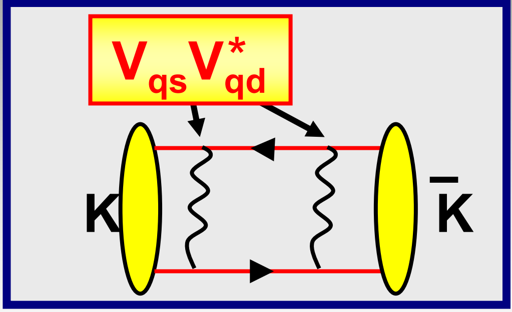
[V.Lubicz@LATT'09]



$\hat{B}_K = 0.731\,(7)\,(35)$ **5%**

Error in 2006: 11%





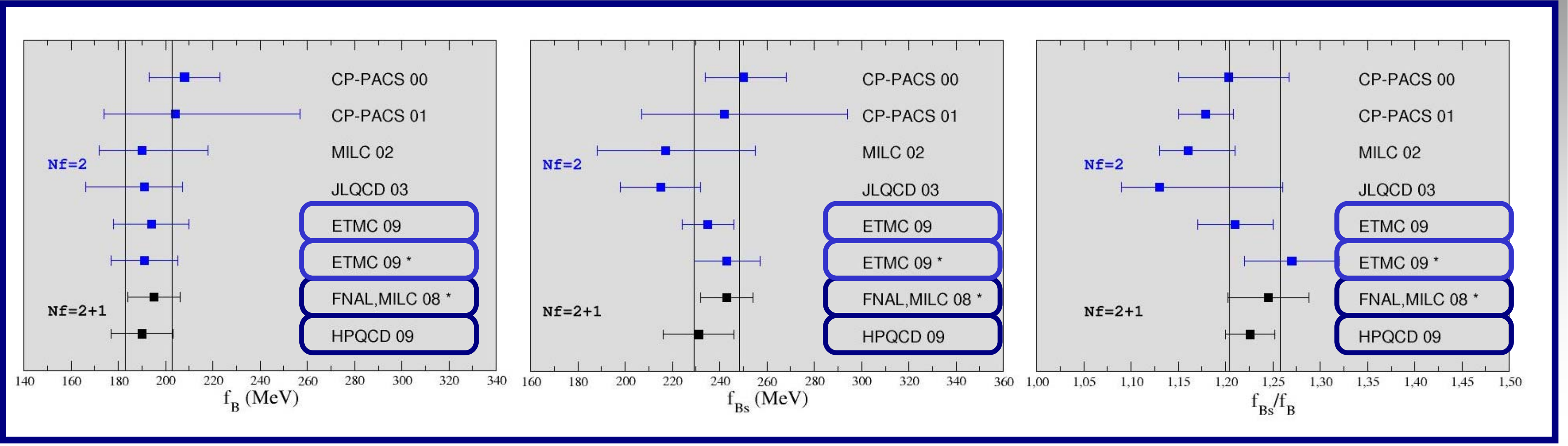
From the UT fit, assuming the Standard Model

$\hat{B}_K = 0.87\,(8)$

with $K\varepsilon$ = 0.94(2),

A.Buras, D.Guadagnoli, G.Isidori, arXiv:1002.3612

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



Averages from J.Laiho, E.Lunghi, R.Van de Water, 0910.2928

f_{Bs}= 238.8 ± 9.5 MeV

f_B = 192.8 ± 9.9 MeV

4-5%

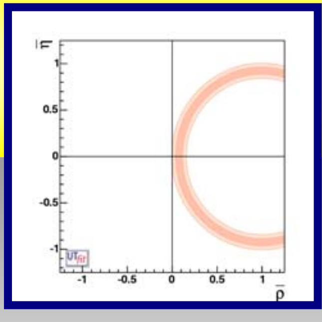
Error in 2006: 14%

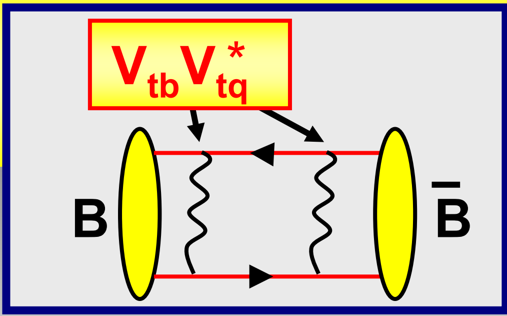
f_{Bs}/f_B = 1.231 ± 0.027

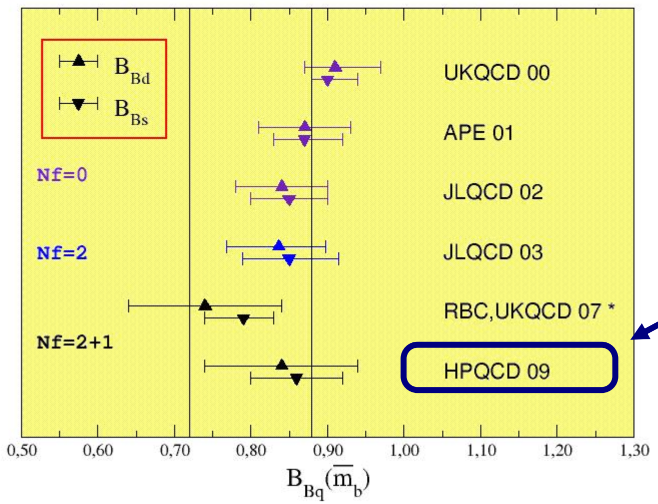
2%

Error in 2006: 5%

B-$\bar{B}$ mixing: $B_{Bd/s}$







Only one modern calculation HPQCD [0902.1815]

$\hat{B}_{Bd} = 1.26 \pm 0.11$

$\hat{B}_{Bs} = 1.33 \pm 0.06$

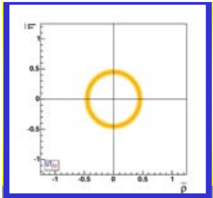
Combining with fB and fBs:

$f_{Bs}\sqrt{\hat{B}_{Bs}} = 275 \pm 13$ MeV — 5%

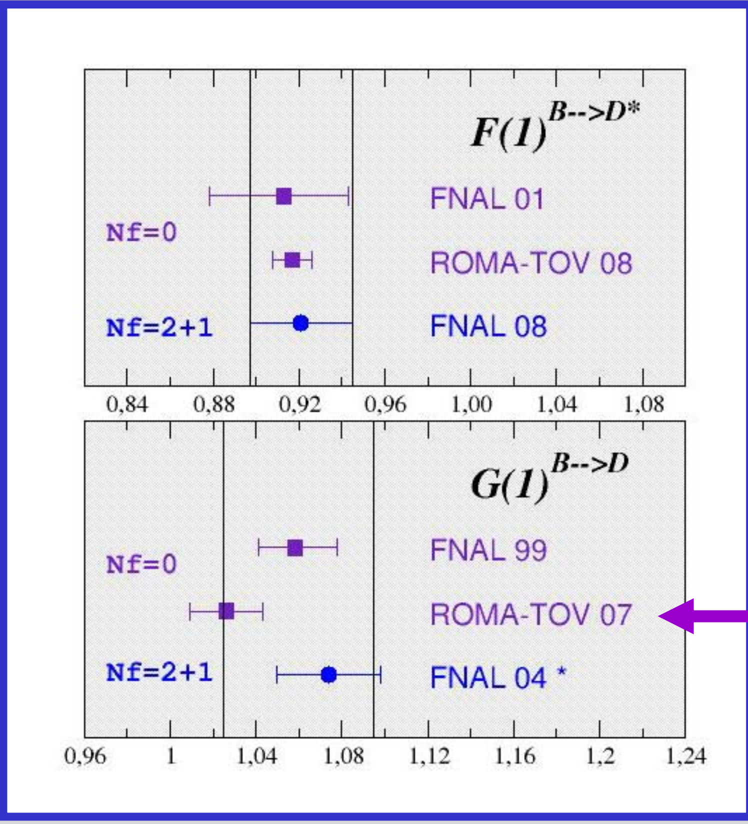
$\xi = 1.243 \pm 0.028$ — 2%

Error in 2006: 13%

Error in 2006: 5%



Exclusive Vcb



Averages from VL, C.Tarantino 0807.4605

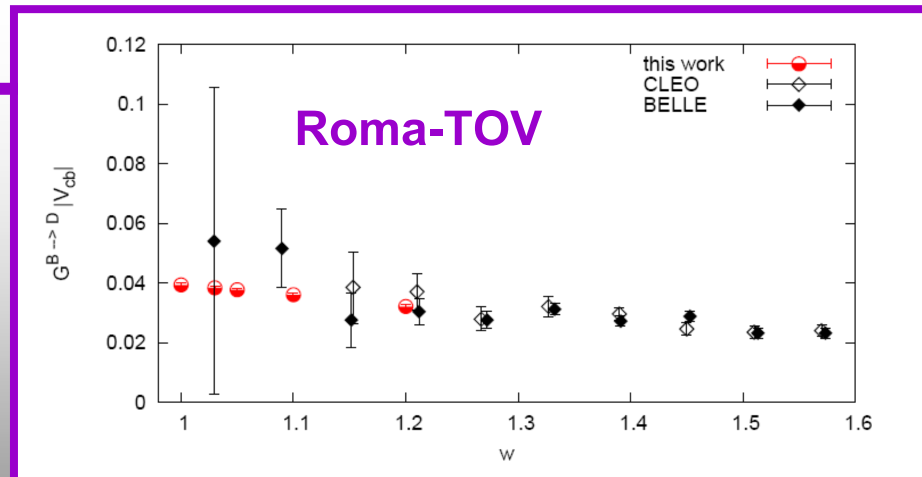
F(1) = 0.924 ± 0.022 — **2%**

G(1) = 1.060 ± 0.035 — **3%**

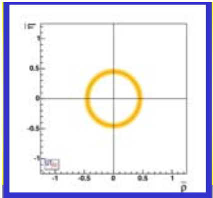
<u>TWO DIFFERENT APPROACHES</u>:

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

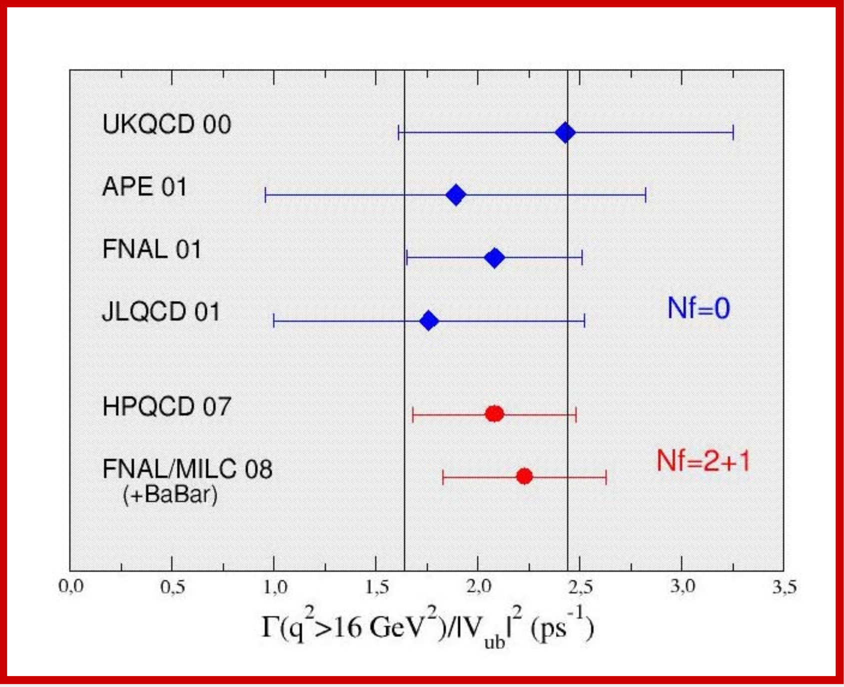
Remarkable agreement

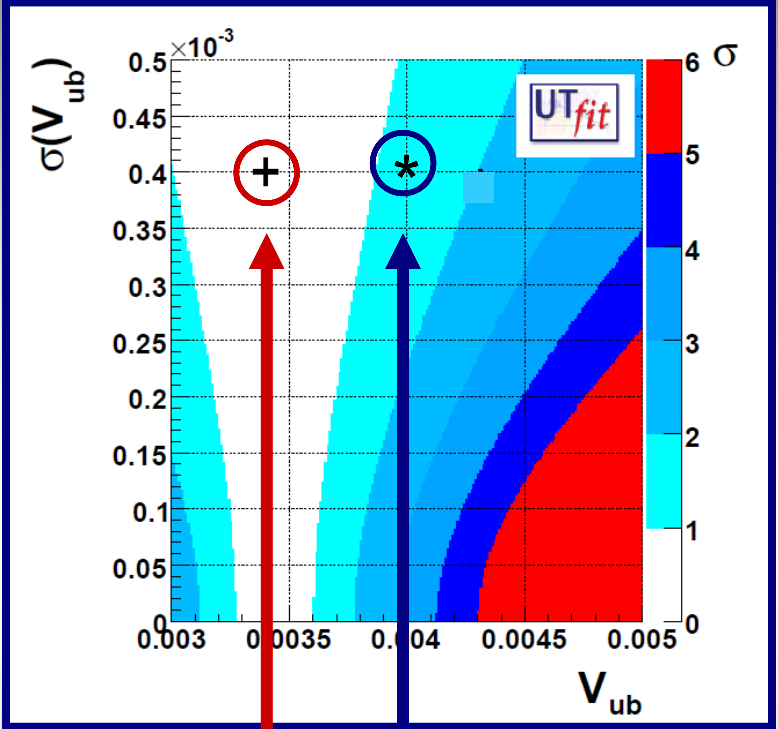


Error in 2006: 4%



Exclusive Vub





$|V_{ub}|_{excl.} = (35.0 \pm 4.0)\ 10^{-4}$ **11%**

Error in 2006: 11%

MORE LATTICE CALCULATIONS REQUIRED

$V_{ub}^{excl.} = (3.5 \pm 0.4)\ 10^{-3}$

From LQCD and QCDSR

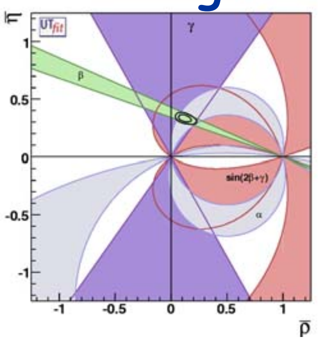
$V_{ub}^{incl.} = (4.0 \pm 0.4)\ 10^{-3}$

Model dependent

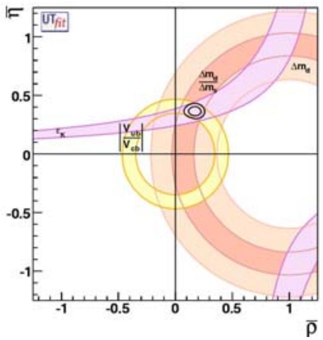
BLNP, DGE, GGOU, ADFR, BLL

OF LATTICE PARAMETERS

UT-angles



UT-lattice



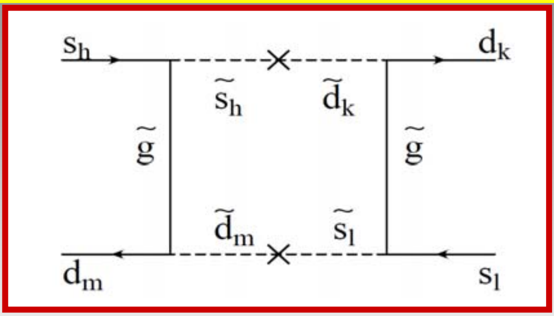
Assuming the validity of the **Standard Model** one can perform a fit of the hadronic parameters:

2%! from Δms

	B_K	$f_{Bs}\sqrt{B_{Bs}}$ (MeV)	ξ
UTA	0.87 ± 0.08	265 ± 4	1.25 ± 0.06
Lattice	0.73 ± 0.04	275 ± 13	1.24 ± 0.03

Lattice inputs are less relevant today for the SM analysis.
But they are crucial when looking for new physics effects

K-$\bar{K}$ AND B-$\bar{B}$ MIXING BEYOND THE SM



$$Q_1 = \bar{d}_L^\alpha \gamma_\mu s_L^\alpha \bar{d}_L^\beta \gamma^\mu s_L^\beta \, , \qquad Q_4 = \bar{d}_R^\alpha s_L^\alpha \bar{d}_L^\beta s_R^\beta \, ,$$

$$Q_2 = \bar{d}_R^\alpha s_L^\alpha \bar{d}_R^\beta s_L^\beta \, , \qquad Q_5 = \bar{d}_R^\alpha s_L^\beta \bar{d}_L^\beta s_R^\alpha \, ,$$

$$Q_3 = \bar{d}_R^\alpha s_L^\beta \bar{d}_R^\beta s_L^\alpha \, ,$$

[M.Ciuchini et al., hep-lat/9808328]

K-$\bar{K}$	B_1^{sd}	B_2^{sd}	B_3^{sd}	B_4^{sd}	B_5^{sd}
APE 99	0.68(21)	0.67(7)	0.95(15)	1.00([illegible])	0.66(11)
Babich et al 06	0.56(6)	0.87(8)	1.41(16)	0.94(6)	0.62(8)
CP-PACS 06 *	0.52(4)	0.54(2)	0.71(2)	0.70(1)	0.62(1)

B-$\bar{B}$	B_1^{bs}	B_2^{bs}	B_3^{bs}	B_4^{bs}	B_5^{bs}
APE 01	0.88(5)	0.84(4)	0.91(9)	1.15(6)	1.74(7)
JLQCD 02	0.86(5)	0.86(5)	—	—	—
HPQCD 06	0.76(11)	0.84(13)	0.90(14)	—	—

NEW CALCULATIONS ARE NEEDED !!

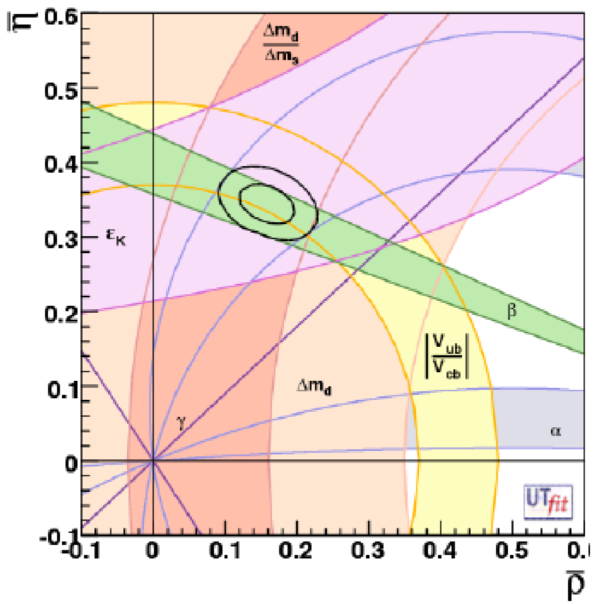
The full operator basis only in the quenched approximation
For K-$\bar{K}$ mixing results quite in disagreement

The future

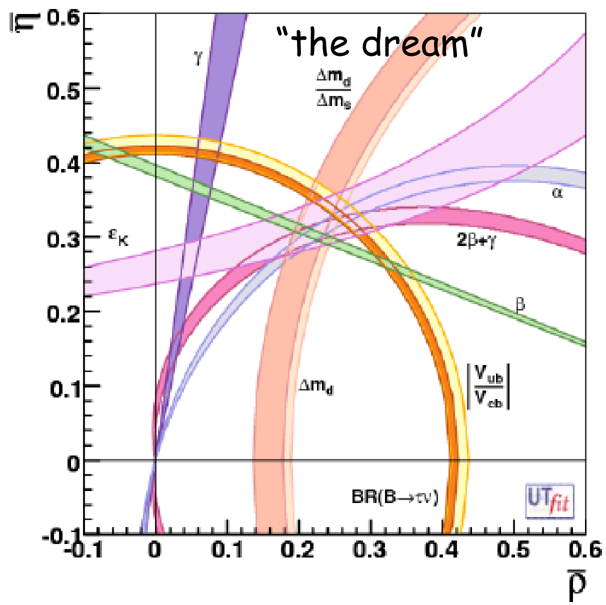
The goal of the SuperB factory is precision flavour physics for indirect New Physics searches

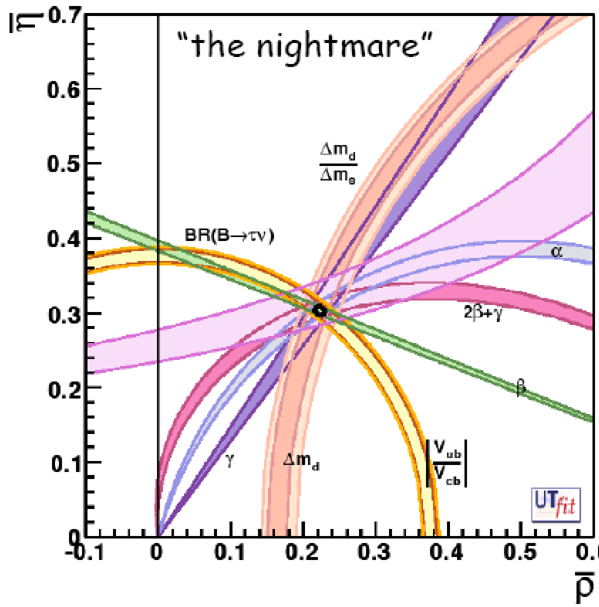
For example: testing the CKM paradigm at the 1% level

Today



With a SuperB in 2015





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

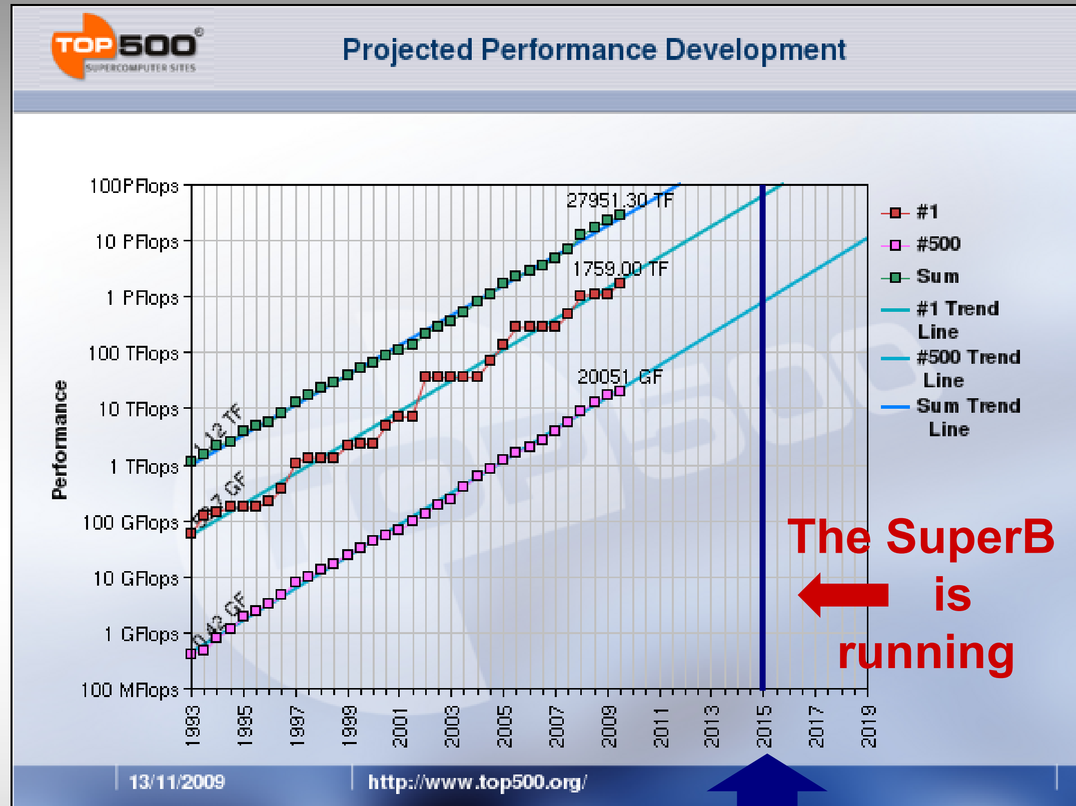
Nconf = 120

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



The SuperB is running

Affordable with 1-10 PFlops available for Lattice QCD in 2015 !

VL @

V.Lubicz @

Villa Mondragone
Monte Porzio Catone - Italy
13 - 15 November 2006

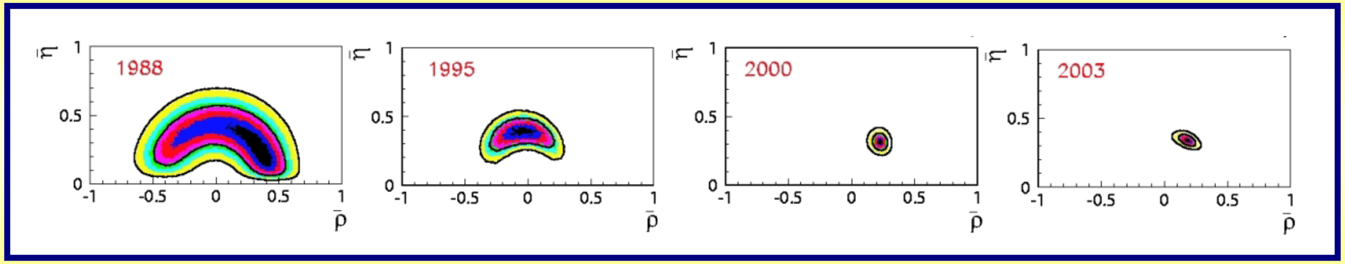
Hadronic matrix element	Current latt. error (2006)	6 TFlop Year [2009]	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on $1-f_+$)	0.7% (17% on $1-f_+$)	0.4% (10% on $1-f_+$)	**< 0.1% (2.4% on $1-f_+$)**
$\hat{B}_K$	11%	5%	3%	**1%**
f_B	14%	3.5 - 4.5%	2.5 - 4.0%	**1 – 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)**
$\mathcal{F}_{B\to D/D^*l\nu}$	4% (40% on $1-\mathcal{F}$)	2% (21% on $1-\mathcal{F}$)	1.2% (13% on $1-\mathcal{F}$)	**0.5% (5% on $1-\mathcal{F}$)**
$f_+^{B\pi}, \ldots$	11%	5.5 - 6.5%	4 - 5%	**2 – 3%**
$T_1^{B\to K^*/\rho}$	13%	----	----	**3 – 4%**

THE 2009 STATUS REPORT

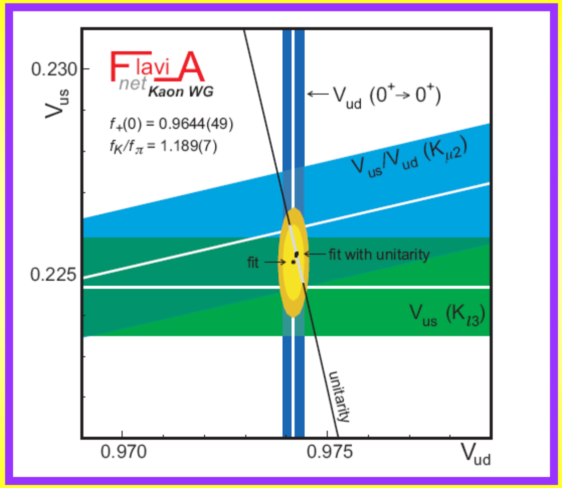
Hadronic matrix element	Lattice error in 2006	Lattice error in 2009	6 TFlop Year [2009]	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9%	**0.5%**	0.7%	0.4%	**< 0.1%**
$\hat{B}_K$	11%	**5%**	5%	3%	**1%**
f_B	14%	**5%**	3.5 - 4.5%	2.5 - 4.0%	**1 – 1.5%**
$f_{Bs}B_{Bs}^{1/2}$	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%**

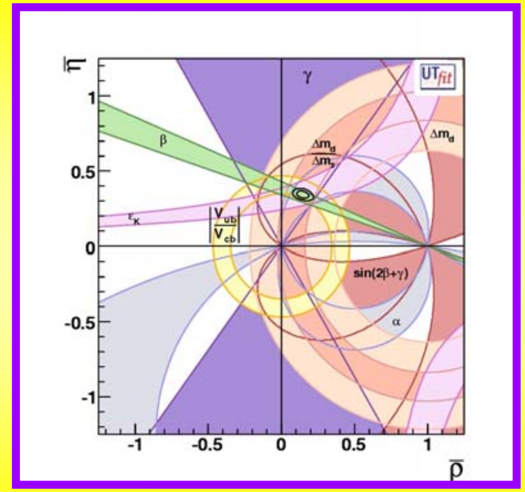
The expected accuracy has been reached! (except for Vub)

The past



the present





and the future