Lattice QCD and New Physics

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- *Outline*

❶ Flavour Physics and New Physics:

- ➲ High Precision calculations: Lattice QCD

❷ Opportunity of new physics and Lattice QCD

- ➲ Charged Current modes: $K\to\pi l\nu$, $K\to\mu\nu$, $B\to\tau\nu$, $B\to D\tau\nu$: ***H^+, right-handed current ...***

- ➲ Flavour Changing Neutral Current observables: ΔM_s, ε_K, $B\to K^*\mu\mu$: ***H^0, gluino ...***

Recontres de Moriond, March 6[rd]-13[th] 2010

Flavour Physics and New Physics

Next Discovery in Flavour Physics mostly driven by the modes

① CP asym. in $B_s \to \psi\phi$. $\beta_s^{SM} \approx 0$

② $B_s \to \mu\mu$

③ $K \to \pi \nu\nu$

④ $K_{\mu 2}/K_{e2}$

LHCb

yesterday-talk by P. Jenny

NA62-JPARC

tomorrow-talk by C. Smith

➲ *to large extent, hadronic uncertainties is not a big issue for these modes!!*:

➲ However, *discriminating potentially New Physics effects will involve a much larger set of flavour-changing processes =>*

$B \to \tau\nu$, $B \to D\tau\nu$, $B \to \pi(\rho) l \nu$, ΔM_s, ε_K, $B \to K^* \mu\mu$

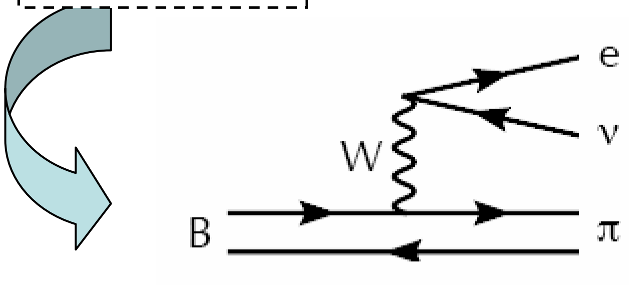
➲ BIG ISSUE: *keeping under good control hadronic uncertainties*

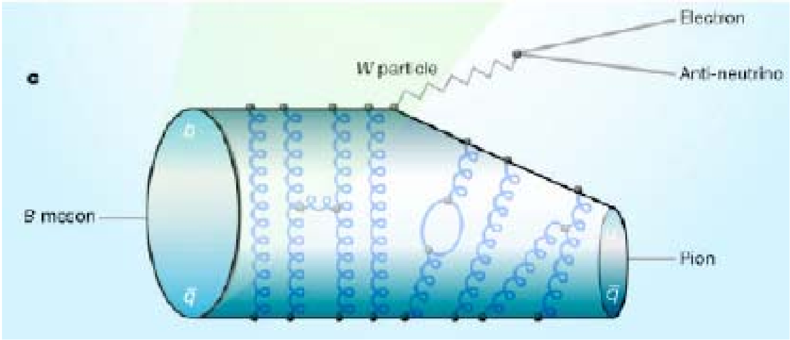
LATTICE QCD

Flavour Physics and New Physics: Lattice QCD

In order to interpret the experimental results in quark sector, *must include effects of confining quarks into hadrons* ⇔ *Non-Perturbative regime*

$B \to \pi \bar{l} \gamma^{\mu} \nu$





$$\textbf{Amplitude} = C_W \times \langle B | \bar{b} \gamma^{\mu} u | \pi \rangle \bar{l} \gamma^{\mu} \nu$$

Hard modes: $\alpha(m_b)$~weak:

- effective theories: OPE, HQET

Soft modes: $\alpha(m_\rho)$~strong!

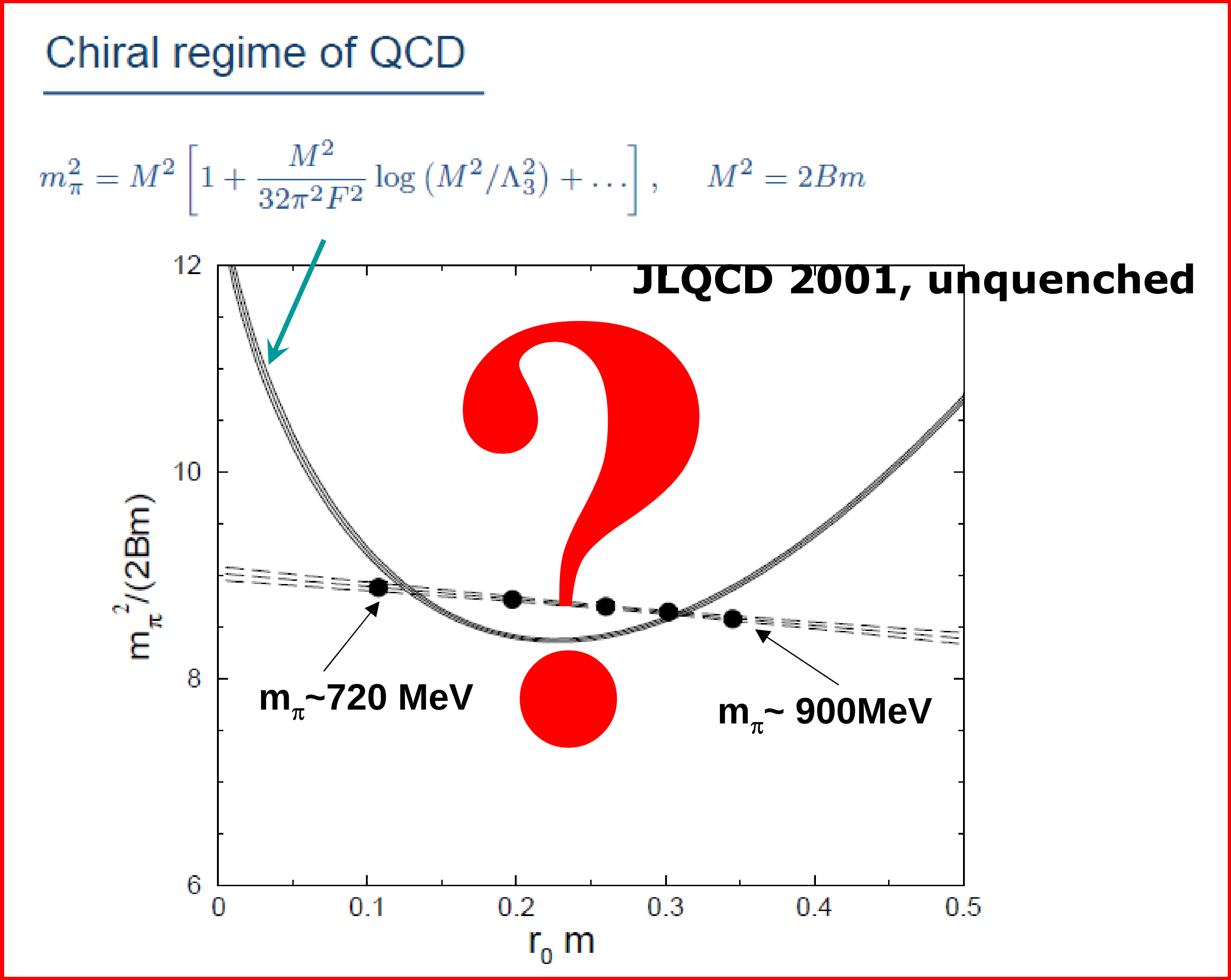
- Matrix elements: ***Lattice QCD*** ☹

- ***Matrix elements can be computed on Lattice QCD*** in an accurate and controllable manner, thanks the systematic character of Lattice simulations

- ***NOW true thanks to tremendous progress in the present years!***

Chiral Regime of QCD

A problem with (old) lattice simulations:
Heavy pion mass!

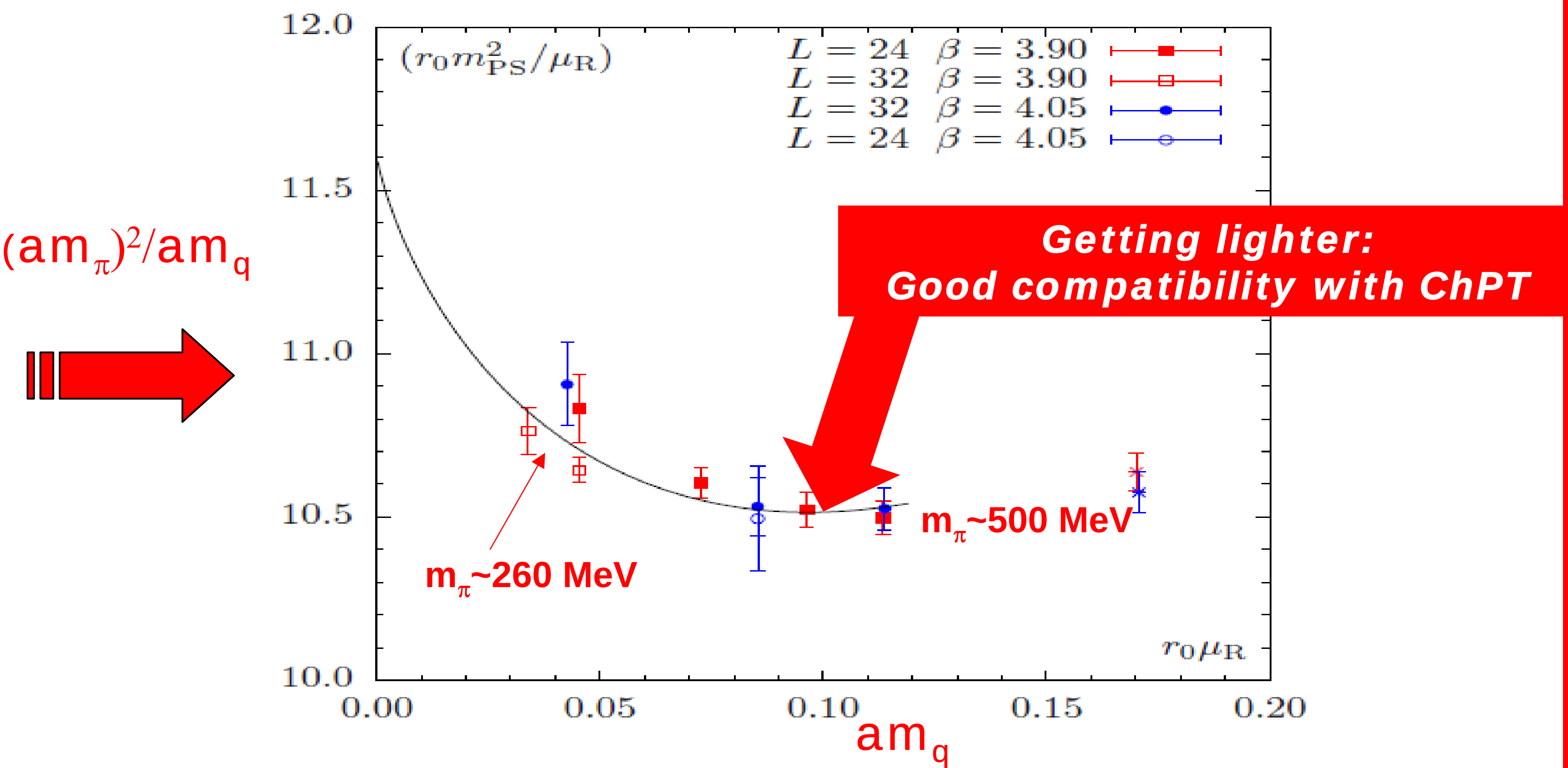


Incompatibility with ChPT?

Chiral Regime of QCD

No more problems with (new) lattice simulations:
Good compatibility with ChPT

$$m_\pi^2 = M^2 \left[1 + \frac{M^2}{32\pi^2 F^2} \log\left(M^2/\Lambda_3^2\right) + \ldots \right], \qquad M^2 = 2Bm$$



ETMC arXiV:0803.0224

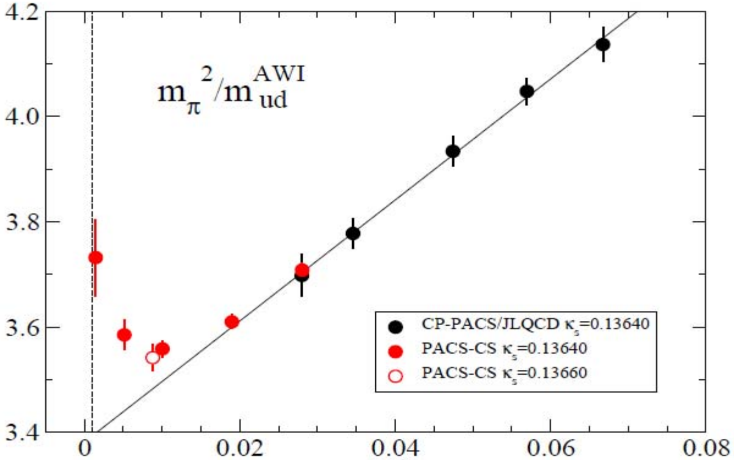
2008, unquenched, Wilson-like fermions

Similar plots by other collaborations (using QCD actions from first principle)

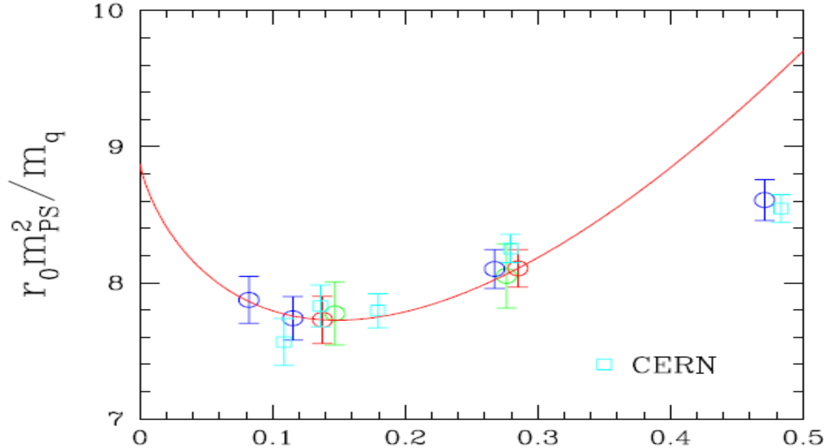
Chiral regime of QCD

$(am_\pi)^2/am_q$

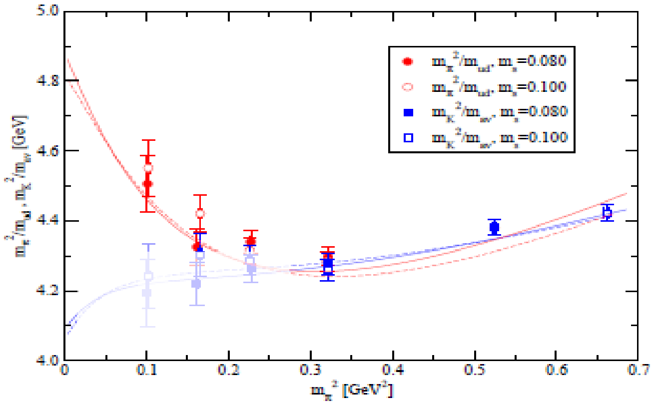
Hints of chiral Logs



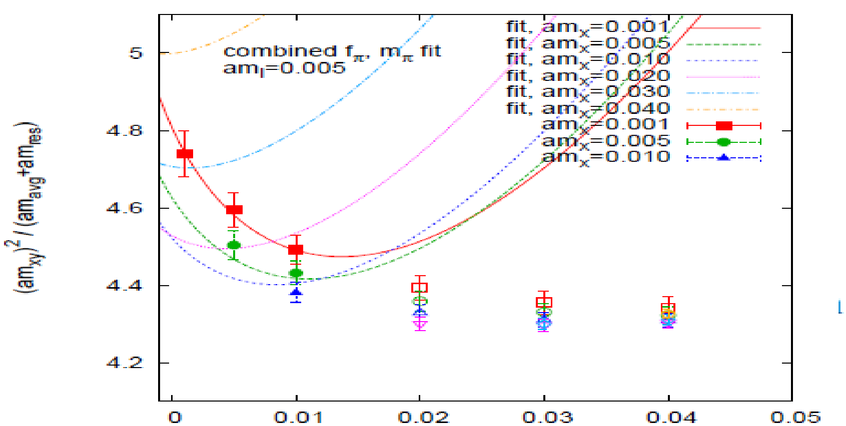
PACS-CS'08, N_F=2+1, Clover:
a=0.09 fm, M_π=156 MeV, $L\,M_\pi$ ~2.3!!



QCDSF'08, N_F=2, Clover:
a=0.07 fm, M_π=313 MeV, LM_π ~4



JLQCD/TWQCD'08, N_F=2+1, Overlap:
a=0.11 fm, M_π=300 MeV, $L\,M_\pi$ ~2.6!!



RBC/UKQCD'06, N_F=2+1, DWF
a=0.114 fm, M_π=310, LM_π ~3-4

What about phenomenology?

★ *Up to now, only a few observables available from first principle QCD action* **(2006 - on)**

➲ ***Wilson-like & Domain-Wall fermions***

■ some observables are still in the "quenched approximation" (1974-2002);

● most unquenched estimates are from staggered fermions **(MILC: 2002 – on)**

☺ ***First realistic QCD study => MILC opened up unquenched era!!***

😐 *but unsatisfactory in high-precision era!:*

➲ *staggered ansatz:* $\det[D_{NF=1}] \cong \det[D_{stag}]^{1/4}$ to eliminate spurious "tastes":

➲ *non-local theory!* Shamir, Bernard, Golterman, Sharpe, Creutz '04-'08

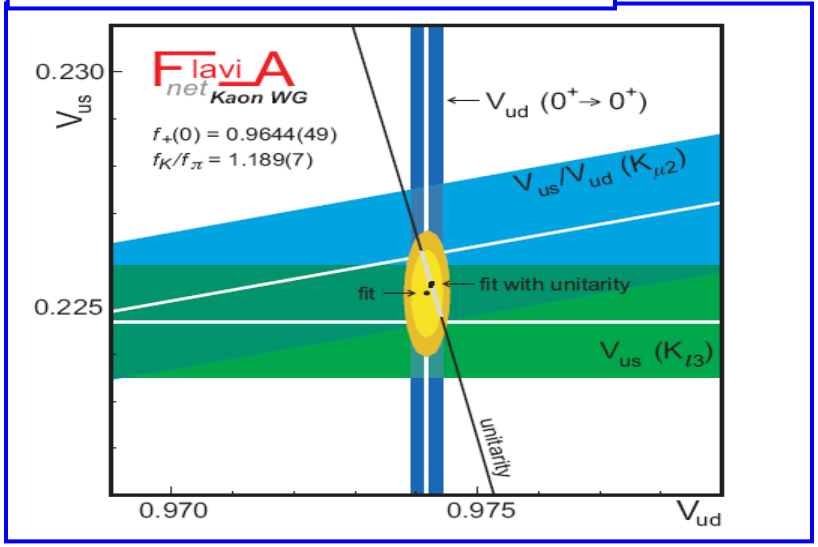
➲ ***QCD when lattice spacing goes 0?***

➲ ***at finite a, significant lattice artefacts: to subtract by complicated fit***

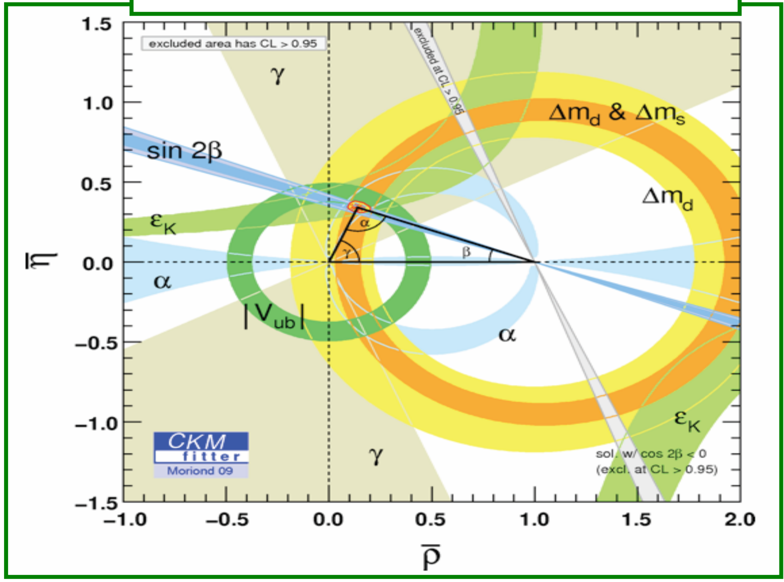
😐 *Phenomenogical safe lattice data still need some time but progress already visible!*

2010: Lattice QCD in Flavour Physics

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



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



K→lν: exp. err 0.2% ★★

lattice err. on f_K/f_π :

2-3% (2006)→**0.7%** (2010)

K→πlν: exp. err 0.2% ★

lattice err. on $f_+(0)$:

0.9% (2006)→**0.5%** (2010)

B→D(D*)lν: exp. err 1.5% ● ■

lattice err. on *F(1) & G(1)* :

5% (2006)→**2.5%** (2010)

ε_K: K^0-$\bar{K}^0$ mixing
exp. err 0.5% ★

lattice err. on B_K:

11% (2006)→**5%** (2010)

ΔM_d: B^0_d-B^0_d mixing
exp. err 1% ●

lattice err. on $f_{Bd}\sqrt{B_{Bd}}$:

13% (2006)→**6%?** (2010)

ΔM_s: B^0_s-B^0_s mixing
exp. err 0.7% ●

lattice err. on $f_{Bs}\sqrt{B_{Bs}}$:

13% (2006)→**6%?** (2010)

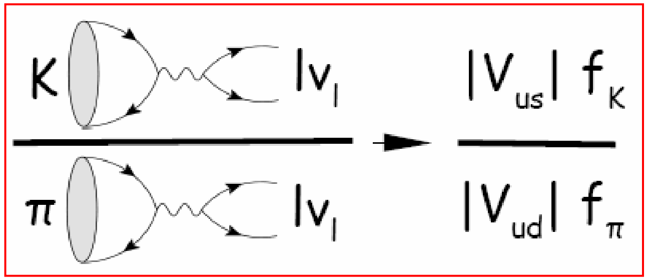
B→π(ρ)lν:
exp. err 10% ● ■

lattice err. on $f_+(q^2)$:

11% (2007)!

★ Simulation from first-principle action. ■ Quenched simulation. ● Staggered fermions

f_K/f_π: an example of Modern lattice measure



Hadronic uncertainties from

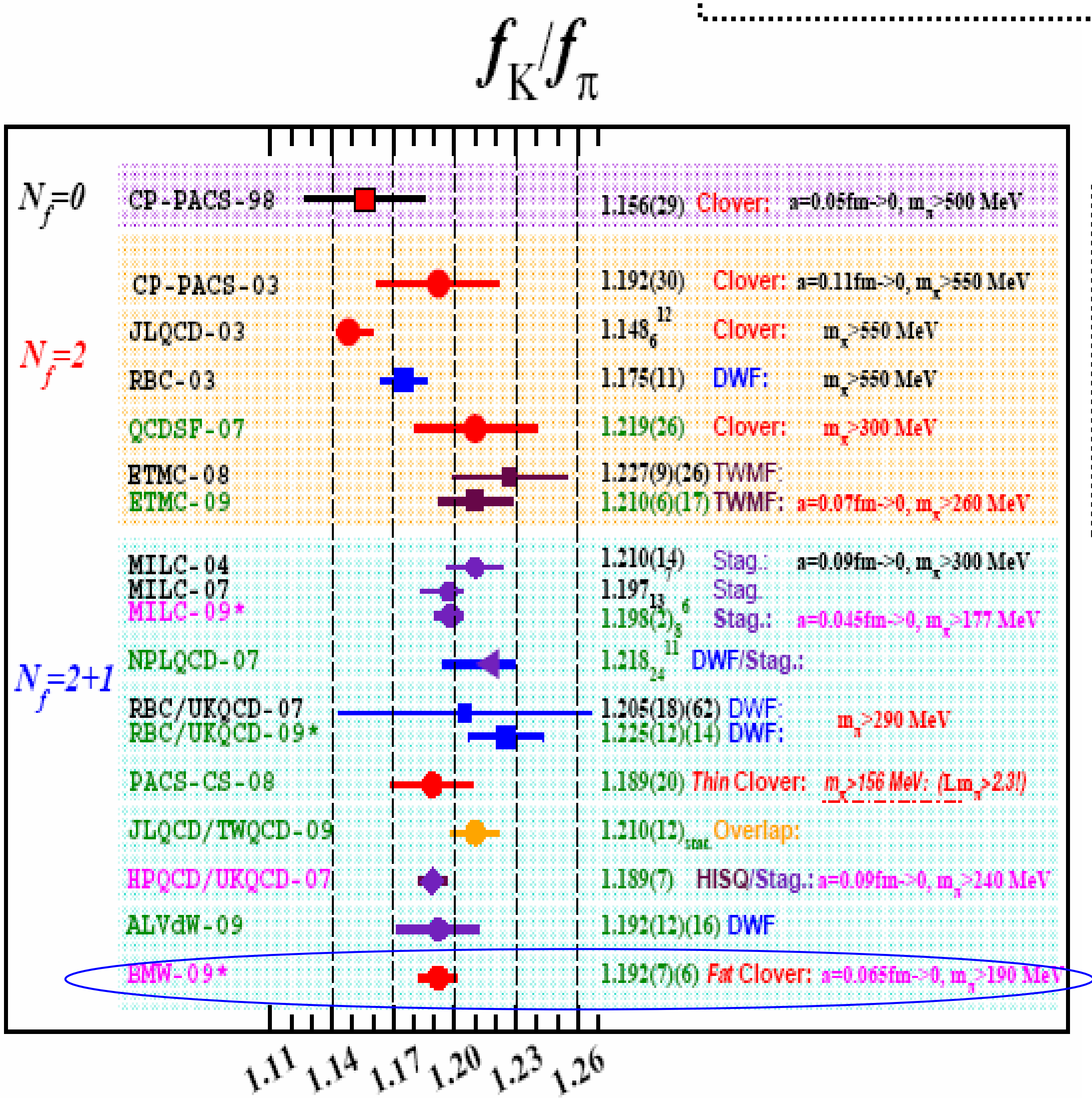
$$\langle 0|\bar{s}\gamma^\mu\gamma_5 u|K\rangle = p^\mu f_K$$

$$\langle 0|\bar{d}\gamma^\mu\gamma_5 u|\pi\rangle = p^\mu f_\pi$$

f_K/f_π: lattice enters high precision era

❖ ***No Competition from non-Lattice approaches:***

$$f_K/f_\pi = 1 + (m_K^2 - m_\pi^2) \times \text{unknown-coef.}$$



Lattice systematic under control!

- ❑ **Independent determinations** (Wilson-like, Domain Wall, Stag.);
- ❑ **Many lattice spacings** (Continuum Limit reached);
- ❑ **Light m_π~190 MeV**;
- ❑ **Finite size effects under control**.

$$f_K/f_\pi = 1.192 \pm 0.009 \quad [0.75\%];$$

postdiction?

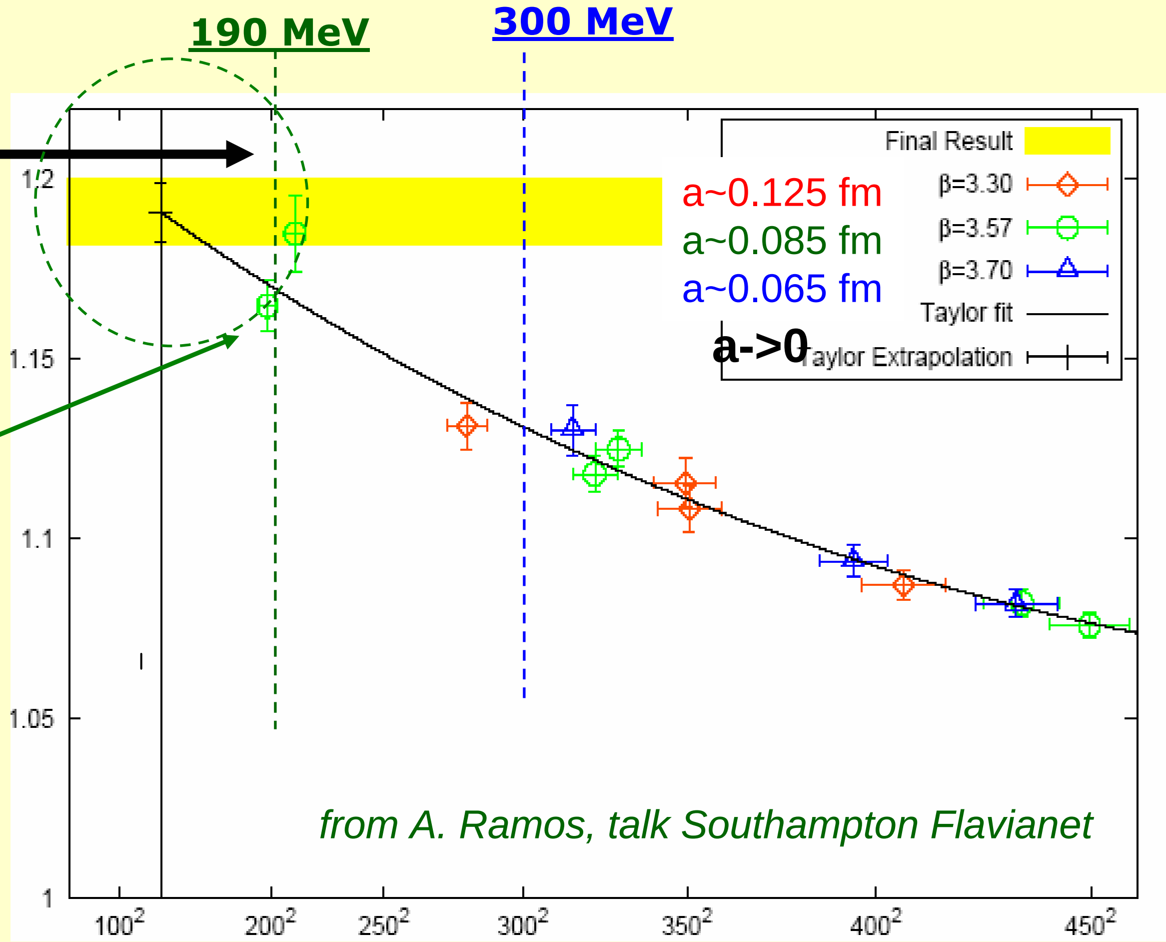
$$f_K/f_\pi - 1 = 0.192 \pm 0.009 \quad [5\%]$$

good prospects to improve f_K/f_π-1 to 1% accuracy?

f_K/f_π - Evaluations

• *getting very close to the physical point;* **190 MeV**

The final result extrapolated at the physical pion is only 2% above the lightest point simulated! ☺



• **BMW result: N_F=2+1, *Clover*, a=0.06->0, $m_\pi \geq 190$ MeV, L $m_\pi \sim 4$**

f_K/f_π=1.192(7) (6) => σ_{rel} ~0.75% **($\delta_{SU(3)}$~5%)**

Durr, Fodor, Hoebling, Katz, Krieg, Kurth, Lellouch, Lippert, Ramos, Szabo, hep-lat 1001.4692

Beyond SM from K_{l2} and K_{l3}

Not-trivial SM test

$$\left(|V_{ud}|^2 + |V_{us}|^2 + \cancel{|V_{ub}|^2}\right) \neq 1$$

$$G_{CKM}^2 \equiv G_F^2 \times \left(|V_{ud}|^2 + |V_{us}|^2\right) \neq 1 \times G_F^2$$

CKM Unitarity breaking ⟷ **Gauge Universality Breaking**

covered by Martin Gonzalez-Alonso on Wed

➢ ***appealing BSM possibilities***

$$B(K \to \mu\nu) / \; B(K \to \pi l \nu)$$

- ***MSSM***
  Hou - Isidori & Paradisi, → ***constrain on scalar densities***
- ***a Higgsless model***
  Bernard, Oertel, Passemar & Stern → ***constraint on right-handed currents***

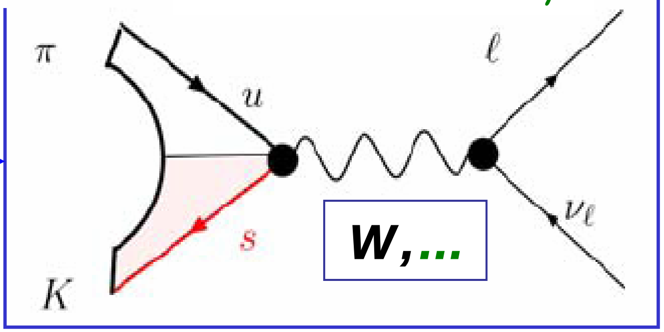
Higgsless Model: resonances => **SM** + $\left(\bar{s}\gamma_R^\mu u\right)\left(\bar{\ell}\gamma_L^\mu \nu\right)$

Bernard, Hirn, Oertel, Passemar & Stern

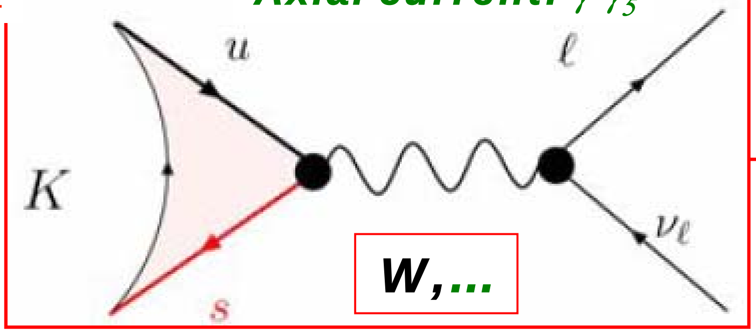
- *"Higgs-Goldstone field" to give mass to W and Z;*
- *no elementary Higgs particle => higher order operators (composite, partial, no Higgs)*

=> Effects from right-handed currents compatible to EWPT

$K_{\ell 3}$ ***vector current:*** γ^μ



$K_{\ell 2}$ ***Axial current:*** $\gamma^\mu\gamma_5$



K_{l3} : RHC => $|V_{us}|^{Kl3} \to |V_{us}|^{Kl3}(1 + \varepsilon^{RH})$

K_{l2} : RHC => $|V_{us}|^{Kl2} \to |V_{us}|^{Kl2}(1 - \varepsilon^{RH})$

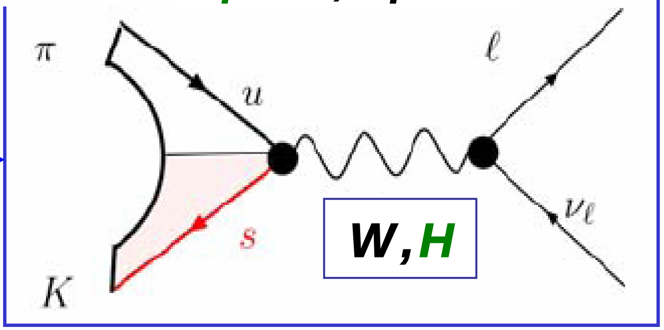
FlaviA net Kaon WG

$$1-2\varepsilon^{RH} = 1.004(6)$$

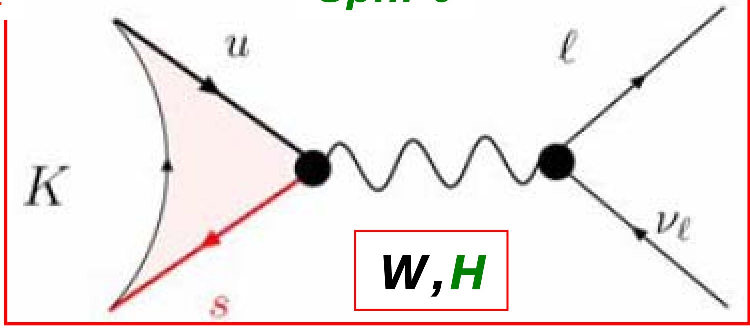
Collider Signature: W', Strong dynamics@TeV

2HDM, Susy: Charged Higgs => SM + $(\bar{s}_R u_L)(\bar{\ell}\nu_L)$

$K_{\ell 3}$ — Spin 0, Spin 1



$K_{\ell 2}$ — Spin 0



K_{l3} : Higgs effects => $f_0(q^2)$ -> $f_0(q^2)(1 + g^H q^2/m^2_H)$

- to test g^H **=>** *calculate slope and curvature* of $f_0(q^2)$!

$|V_{us}|^{Kl3}$ *is* NP free as soon as we use $f_0(q^2)$ from data

K_{l2} : Higgs effects=> $|V_{us}|^{Kl2}$-> $|V_{us}|^{Kl2}(1 + g^H m^2_K/m^2_H)$

- to test g^H **=>** *f_K from theory: f_K/f_π better determined* constrain on scalar densities

Hadronic uncertainties => estimate this ratio from the same simulation!

$$\frac{B(K\to\mu\nu)}{B(\pi\to\mu\nu)}\times\frac{B(n\to pl\nu)}{B(K\to\pi l\nu)}=\left(\frac{f_K}{f_\pi}\frac{1}{f_+(0)}\right)^2\times\left(1+g^H\frac{m_K^2}{m_{H^+}^2}\right)^2 (\text{known f.s})$$

similarly search on H^+ from

$B^\pm \to \tau^\pm \nu$

$$Br(B\to\tau\nu)\propto|V_{ub}|^2 f_B^2 m_B m_\tau^2\times\left(1+g^H\frac{m_B^2}{m_{H^+}^2}\right)^2$$

- *hadronic uncertainty in f_B: ~15% accuracy from Lattice*

Best for indirect H^+ searches but only feasible at •SuperB

$B^\pm \to D\,\tau^\pm \nu$

$$\frac{d\Gamma(B\to D\tau\nu)}{dq^2}\propto|V_{cb}|^2\rho_V(q^2)\times\left(1-\frac{m_\tau^2}{m_B^2}\left|1+g^H\frac{q^2}{m_{H^+}^2}\right|^2\rho_S(q^2)\right)$$

2. *hadronic uncertainty in ρ_V, ρ_S*

Only scalar component sensitivity to H^+ but opportunity for Lhcb

but different theoretical and experimental prospects

■ Quenched simulation. ● Staggered fermions

constrain on scalar densities

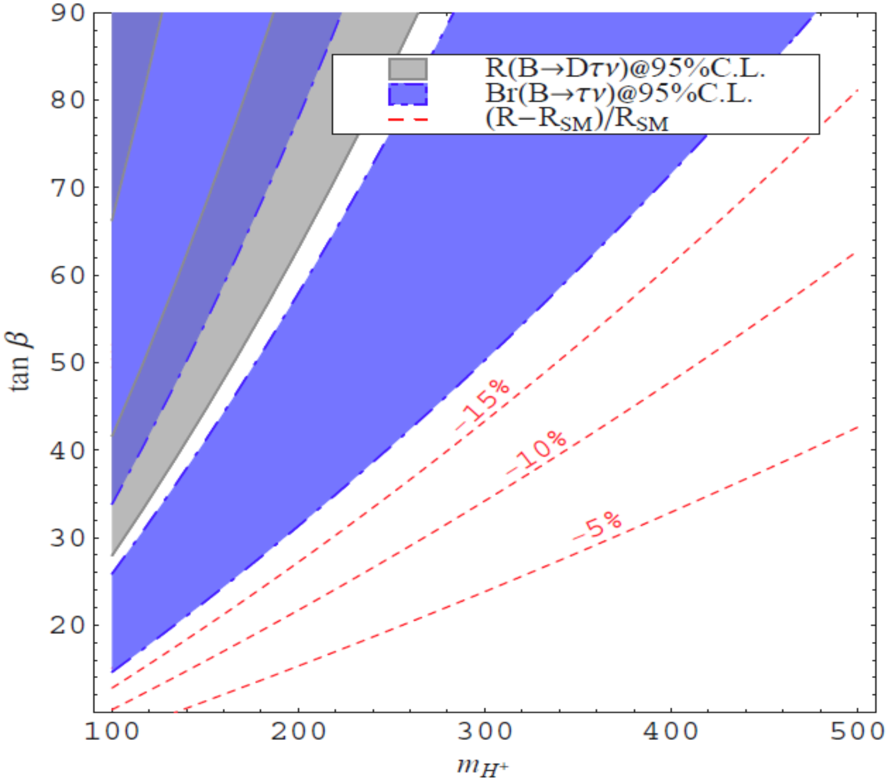
$B^{\pm} \to D\ \tau^{\pm}\ \nu$

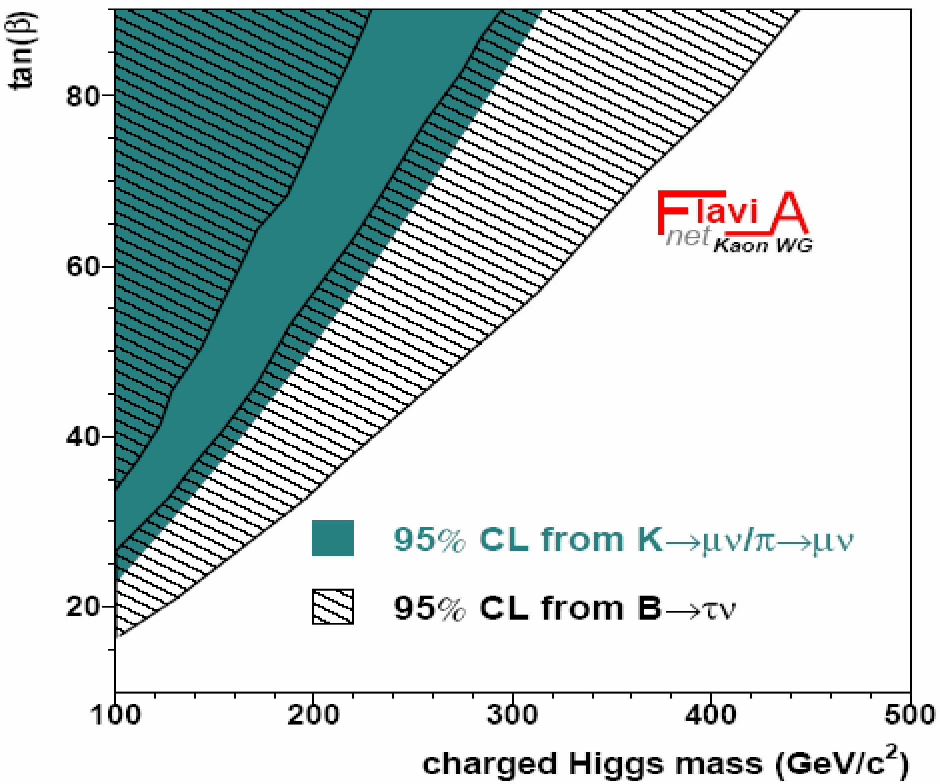
$B^{\pm} \to \tau^{\pm}\ \nu$

$$\frac{B(K \to \mu\nu)}{B(\pi \to \mu\nu)} \times \frac{B(n \to pl\nu)}{B(K \to \pi l\nu)}$$

Example MFV@large tanβ

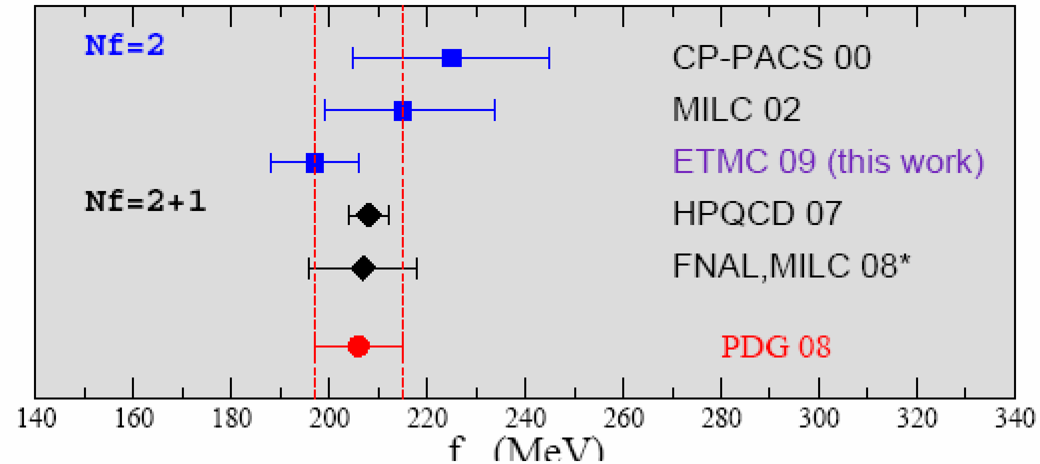
$$g^H = -\tan\beta^2/(1+\varepsilon_0 \tan\beta)$$



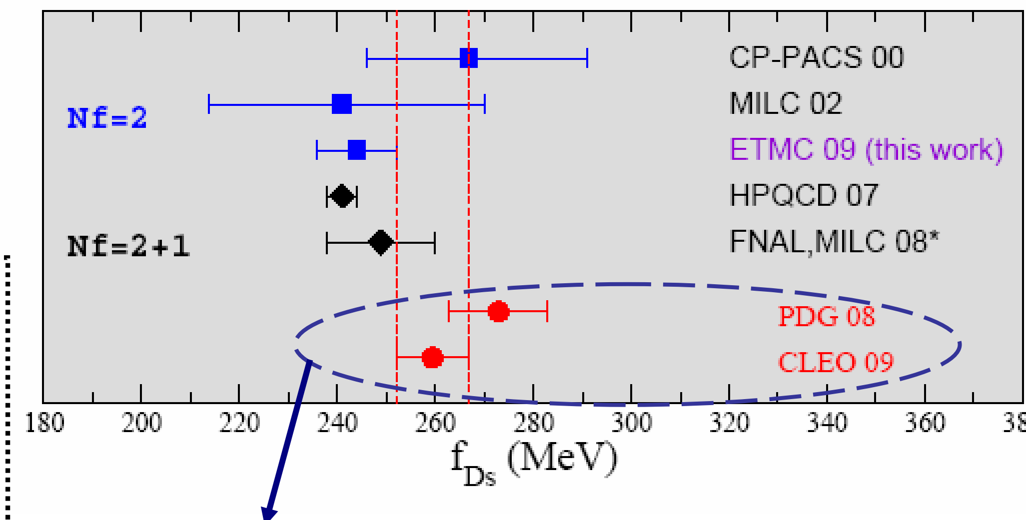


Kamenik & F.M '08:
Nierste, Trine, Westhoff '08

2008 f_{Ds} puzzle: 3-4σ deviation with experiments



- ***f_D and f_{Ds} recently measured at CLEO, BaBar and Belle with good accuracy!*** *(assuming CKM unitarity)*



- ***Valuable cross check of Lattice QCD.***

- ***Overall consistency of lattice results;***
- **But still *only a few uncorrelated lattice simulations.***
- *Mind discretization error from charm mass*

f_{Ds} "puzzle" weakened by CLEO-c 2009 accurate measurement

$\Delta F=2$ *observables:*
ε_K, ΔM_d *and* ΔM_s

- Important role for the SM Unitarity Triangle analysis:
- **strong constraints for non-minimal flavour models:**
  - **MSSM** -> generic down squarks insertion [Gabbiani et al. 1994]
  - **Little Higgs** [A. Buras et al. 2004]

Lattice role and New Physics Opportunities!

ΔF=2 constraints in Minimal Flavour Violation (MFV)

EFT: D'Ambrosio, Giudice, Isidori & Strumia '02

$$\mathcal{L}_{\rm eff}^{\rm MFV} = \sum_i \frac{\delta C_i}{\Lambda^2} \mathcal{O}_i^{(6)}$$

flavour violation mediated by Yukawa beyond SM too!!

$\mathcal{O}$ *basis invariant under* $SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$

- ***Due to the large top Y***, $Y_U Y_U^+ \propto y_t^2 \sim O(1)$

1) $\mathcal{O}_{SM}^{(6)} = \bar{Q}_L Y_U Y_U^+ \gamma^\mu Q_L \cdot \bar{Q}_L Y_U Y_U^+ \gamma^\mu Q_L$

- $(V_{ts}^* V_{td})^2 \times \bar{s}_L \gamma^\mu d_L \bar{s}_L \gamma^\mu d_L \longrightarrow \varepsilon_K$
- $(V_{tb}^* V_{td})^2 \times \bar{b}_L \gamma^\mu d_L \bar{b}_L \gamma^\mu d_L \longrightarrow \Delta M_d$
- $(V_{ts}^* V_{tb})^2 \times \bar{b}_L \gamma^\mu s_L \bar{b}_L \gamma^\mu s_L \longrightarrow \Delta M_s$

1 Higgs doublet, SM basis complete -> CMFV

Buras, Gambino, Gorbahn, Jager, L. Silvestrini '00

- ***Adding Higgs doublets***, $Y_D \propto m_b / m_t \frac{\langle H_U \rangle}{\langle H_D \rangle} \sim O(1)$ ***(tanβ enhancement of down-type YDs)***

2) $\left(\bar{Q}_L Y_D Y_D^+ Y_U Y_U^+ \gamma^\mu Q_L\right)^2$

- $(V_{td}^* V_{tb})^2 \, y_b^2 \times \bar{b}_L \gamma^\mu d_L \bar{b}_L \gamma^\mu d_L \longrightarrow \Delta M_d$
- $(V_{ts}^* V_{tb})^2 \, y_b^2 \times \bar{b}_L \gamma^\mu s_L \bar{b}_L \gamma^\mu s_L \longrightarrow \Delta M_s$

3) $\bar{D}_R Y_D^+ Y_U Y_U^+ Q_L \cdot \bar{Q}_L Y_U Y_U^+ Y_D D_R$

- $(V_{ts}^* V_{tb})^2 \, y_b y_s \times \bar{b}_R s_L \bar{b}_L s_R \longrightarrow \Delta M_s$

A few extra $\mathcal{O}^{(6)}$*s in a clear pattern between s->d & b->d, b->s transitions*

Improved Lattice calculation needed to discriminate this MFV pattern!

ΔF=2 constraints in MFV and Lattice QCD

- Up to now, unquenched results only for SM operators:

$$\bar{s}_L \gamma^\mu d_L \bar{s}_L \gamma^\mu d_L \propto B_K \rightarrow \sigma_{rel} \sim 5\%,$$

★ Simulation from first-principle action:
RBC-UKQCD N_F=2+1 Domain Wall f.:
No contiuum limit?? **$M_\pi \geq$ 330 MeV**

➢ *Need further calculation on the Lattice!*

$$\bar{b}_L \gamma^\mu s_L \bar{b}_L \gamma^\mu s_L \propto B_s f_{Bs}^2 \rightarrow \sigma_{rel} \sim 16\%.$$

$$\bar{b}_L \gamma^\mu d_L \bar{b}_L \gamma^\mu d_L \propto B_d f_{Bd}^2 \rightarrow \sigma_{rel} \sim 16\%$$

● Simulation from staggered fermions?

➢ *Need further calculation on the Lattice!*

➢ *At current lattice spacing, m_b*a~1,*
b quark cannot be directly simulated

- *Up to now, only fix a lower bound from the scale of New Physics*

UTfit 0707.0636

$\Lambda \geq$ 5.5 TeV

$\Lambda \geq$ 0.5 TeV
loop-suppr.

ε_K	ΔM_d	ΔM_s
	$\sin(2\beta)$	$\sin(2\beta_s)$

- *a* 2.2σ tension in βs=φs from CDF/D0? => lower bound from Bs system!
=> awaiting LHCb!

$\Delta F=1$ $b \rightarrow s$ transitions:
$B \rightarrow K^{*} \mu^{+} \mu^{-}$ ...

Lattice role, LHCb and New Physics Opportunities!

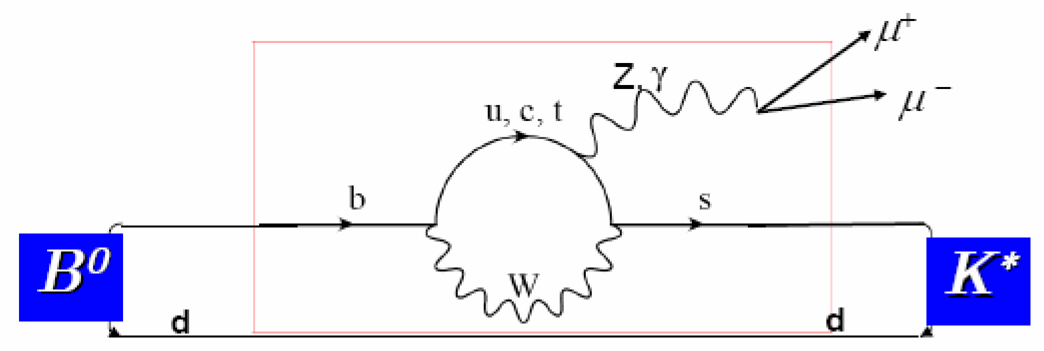
Experiment	BaBar [8]	Belle [7]	CDF [9]
$\mathrm{BR}(B \rightarrow K^{*} \mu^{+} \mu^{-}) \times 10^{7}$	$11.1 \pm 1.9 \pm 0.7$	$10.8^{+1.0}_{-1.0} \pm 0.9$	$8.1 \pm 3.0 \pm 1.0$
Number of $B\bar{B}$ events	384×10^{6}	657×10^{6}	–

still small statistics ->~230 events -> the rarest decay!

-> ~7500 events at LHCb for $B \rightarrow K^{*} \mu^{+} \mu^{-}$

$B \to K^* \mu^+ \mu^-$ modes

1. Flavour Changing Neutral Current $b \to s$ processes-> rare process



⇒*Exploiting the decay $K^* \to K\pi$, LHCb will access to a plethora of new observables:*

$$\bar{B}^0 \to \bar{K}^{*0}(\to K^-\pi^+)\mu^+\mu^-$$

$$\frac{d^4\Gamma_{\bar{B}_d}}{ds\, d\theta_l\, d\theta_K\, d\phi} \propto I_1 + I_2 \cos 2\theta_l + I_3 \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_l \cos\phi + I_5 \sin\theta_l \cos\phi + + I_6 \cos\theta_l + I_7 \sin\theta_l \sin\phi + I_8 \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_l \sin 2\phi.$$

⇒ correlations among angular coefficients is dependent on New Physics modes and allows to discriminate among different New Physics Models.

Egede, Hurth, Matias, Ramon, Reece '08;

Altmannshofer, Ball, Bharucha, Buras, Straub Wick '08;

$$A(B \to K^* \mu\mu) = \langle K^* | Heff | B \rangle = \begin{cases} C_7 \times \bar{b}\sigma^{\mu\nu} s F_{\mu\nu} \\ C_9 \times \bar{b}\gamma_L^{\mu} s \bar{l}\gamma^{\mu} l + C_{10} \times \bar{b}\gamma_L^{\mu} s \bar{l}\gamma^{\mu}\gamma_5 l \\ C_S \times \bar{b}_L s_R \bar{l} l \end{cases}$$

➢ **Matrix elements ⇔ 7 form factors** **Lattice QCD**

$$\langle K^*(p_{K^*})|\bar{s}\gamma_\mu P_{L,R} b|B(p)\rangle = i\epsilon_{\mu\nu\alpha\beta}\epsilon^{\nu *} p^\alpha q^\beta \frac{V(q^2)}{m_B + m_{K^*}} \mp$$
$$\mp \frac{1}{2}\left\{ \epsilon^*_\mu (m_B + m_{K^*}) A_1(q^2) - (\epsilon^* \cdot q)(2p - q)_\mu \frac{A_2(q^2)}{m_B + m_{K^*}} - \right.$$
$$\left. - \frac{2 m_{K^*}}{q^2} (\epsilon^* \cdot q)[A_3(q^2) - A_0(q^2)] q_\mu \right\},$$

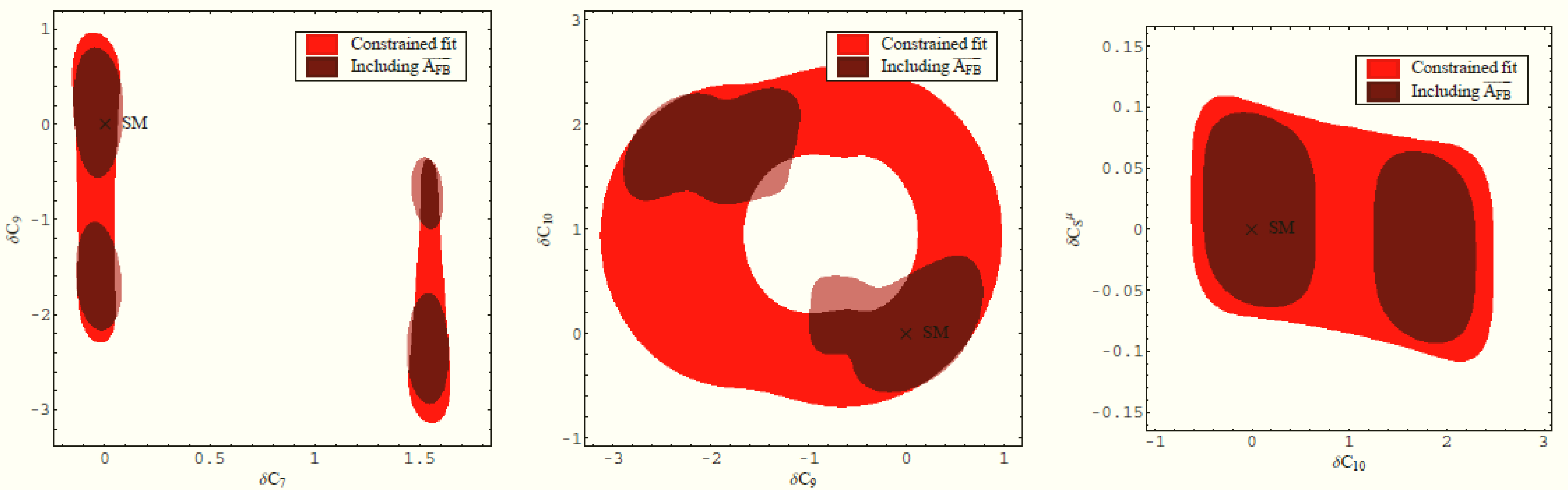
$$\langle K^*(p_{K^*})|\bar{s} i \sigma_{\mu\nu} q^\nu P_{R,L} b|B(p)\rangle = -i\epsilon_{\mu\nu\alpha\beta}\epsilon^{\nu *} p^\alpha q^\beta T_1(q^2) \pm$$
$$\pm \frac{1}{2}\left\{ [\epsilon^*_\mu (m_B^2 - m_{K^*}^2) - (\epsilon^* \cdot q)(2p - q)_\mu] T_2(q^2) + \right.$$
$$\left. + (\epsilon^* \cdot q)\left[q_\mu - \frac{q^2}{m_B^2 - m_{K^*}^2}(2p - q)_\mu \right] T_3(q^2) \right\}.$$

❖ Up to now, only T_1 on the Lattice but quenched (Becirevic, Lubicz, Mescia '06)

$A_{FB}(B_d \to K^* l^+ l^-)$, already plays a special role:

- ❖ very large experimental error;
- ❖ Golden modes for LHCb
  - ➲ **Necessary to improve lattice form factors!**

$A_{FB}(B_d \to K^* l^+ l^-)$: **2 bins**	***exp*** **(large):** *Babar+Belle '09*	
$[q^2 < 6.25\ \text{GeV}^2]$	$0.24^{+0.19}_{-0.24}$	-0.01 ± 0.02
$[q^2 > 10.24\ \text{GeV}^2]$	$0.76^{+0.53}_{-0.34}$	0.20 ± 0.08 [



Model-independent Analysis **in MFV!**

FCNC constraints from $Br(B_d \to X_s \gamma)$, $Br(B_d \to X_s l^+ l^-)$, $Br(B_d \to \mu^+ \mu^-)$, ΔM_s

Hurth, Isidori, Kamenik, F.M '08

Summarising:

➲ *Evidence of New Physics in the Flavour physics mainly*

1. CPV in $B_s \to \psi\phi$, $\beta_s^{SM} \approx 0$
2. $B_s \to \mu\mu$
3. $K \to \pi \nu\nu$
4. $K_{\mu 2}/K_{e2}$

LHCb (1, 2)

yesterday-talk by P. Jenny

NA62-JPARC (3, 4)

tomorrow-talk by C. Smith

➲ then, *discriminating among New Physics Models will involve deeper investigations:*

$B \to \tau\nu$, $B \to D\tau\nu$, $B \to \pi(\rho) l \nu$, ΔM_s, ε_K, $B \to K^*\mu\mu$

➲ Challenge is *keeping under good control hadronic uncertainties*

LATTICE QCD

Conclusions:

LATTICE QCD -> tremendous progress in recent years:

- reliable *unquenched simulations with pions close to the physical point => m_π=156 MeV (PACS-CS), **m_π**=190 MeV (BMW)*

- *f_K/f_π paradigma of present lattice progress!*
- *many other calculations should be come soon at the same precision!*

In particular, for B-physics observables => LHCb

Still a long work for 1%-precision in B-physics, according New Physics expectation (MFV).

❶ ***discretization errors:*** $a * m_B << 1$

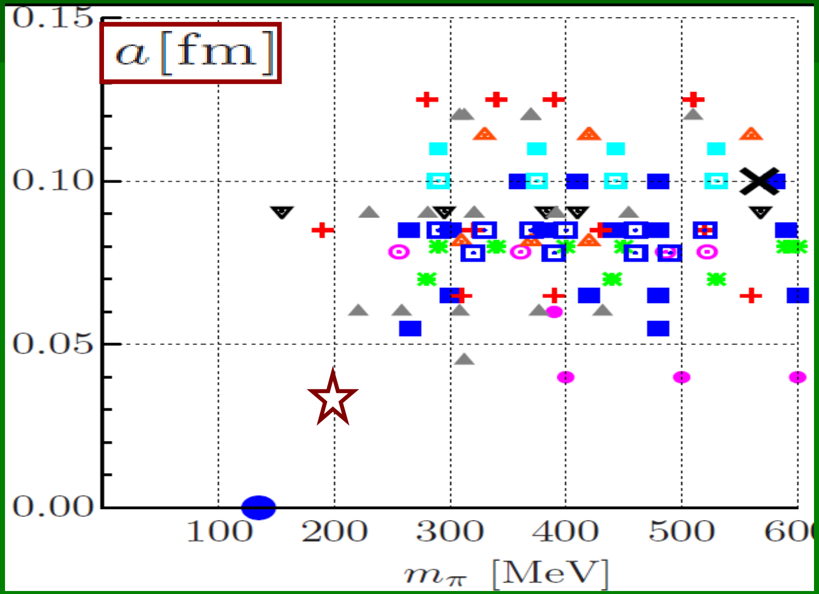
=> ***a ∼ 0.033 fm*** (6 *GeV*): (*a* ≥ 0.07 *fm*)

❷ ***finite volume effects:*** $L * m_\pi >> 1$

=> ***L ≥ 4.5 fm*** (*L* ≤ 3 *fm*)

❸ ***chiral regime*: 200 ≤ m_π ≤ 300 MeV**

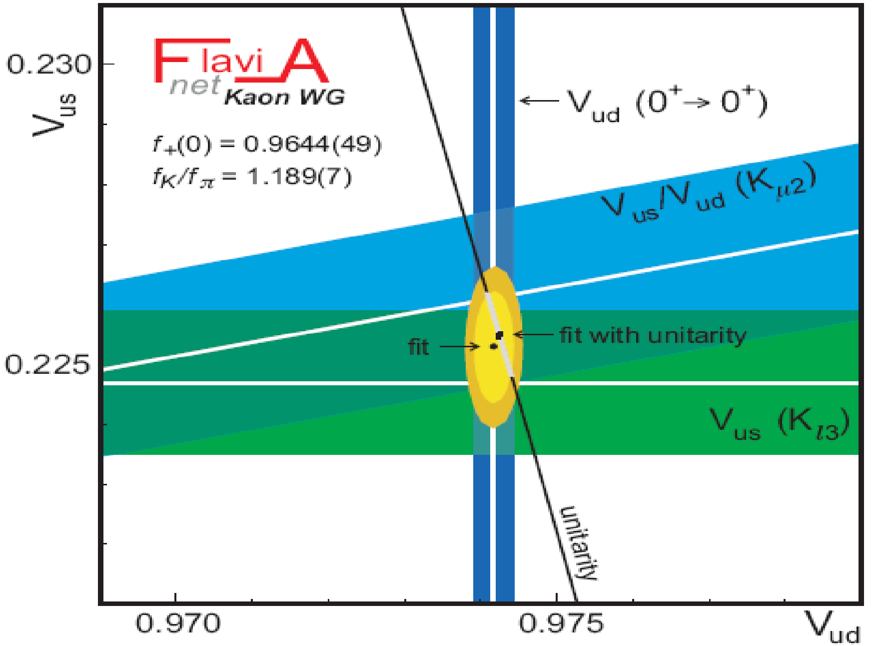
V. Lubicz Super-B report.



courtesy of G. Herdoiza

Flavour Physics Tests

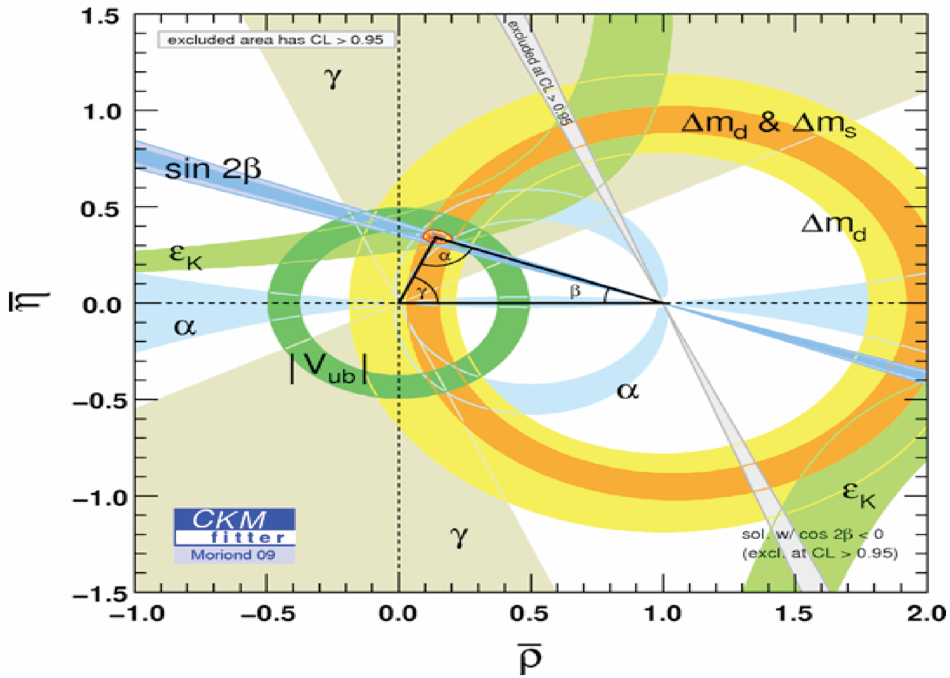
$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9995(7)$$



- *Universality test of Quark-Lepton weak gauge coupling:* ***rel. error~0.7%***

On Wednesday: talk by M. Gonzalez-Alonso "New Physics bounds on CKM unitarity"

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



- Unitarity triangle: CP violation on the Standard Model:

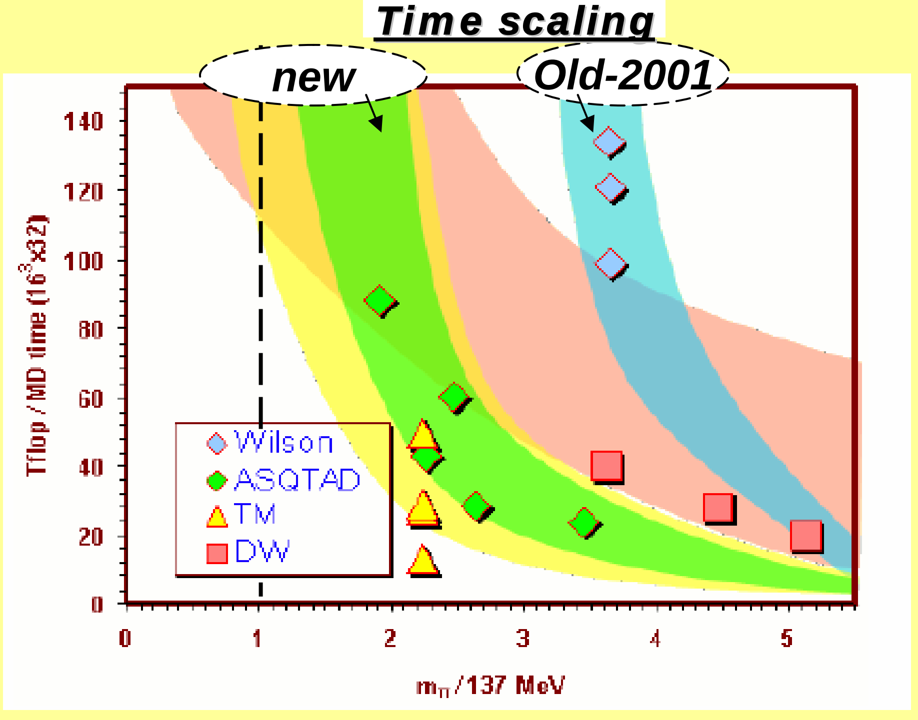
rel. error on ρ~17% η~5%

see talks by P. Urquijo and O. Long

➤ ***Constraining V_{us}, ρ, η as precisely as possible from as many independent modes as possible in order to search for New Physics!***

GOOD NEWS!
Precision Lattice Era

$$Z_{QCD} = \int \mathcal{D}A_\mu e^{-S_g} \prod_q \det(\not{D} + m_q^{sea})$$

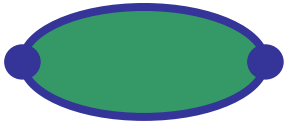


Recent outstanding achievements:

• **Wilson:** *CERN-TOV.'05,*	m_π~280 MeV	(N_F=2)
• **Twisted-mass:** *ETMC'07,*	m_π~280->250 MeV	(N_F=2 → N_F=2+1+1)
•**"Clover":** *BMW'08,*	m_π~190 MEV	(N_F=2+1)
• **Clover:** *PACS-CS'08,*	m_π~156 MEV	(N_F=2+1)
• **Overlap:** *JLQCD/TW'08,*	m_π~290 MEV	(N_F=2 & 2+1)
• **Domain Wall:** *RBC-'06,*	m_π~330 MEV	(N_F=2+1)
• **Staggered:** *MILC-2002*,	m_π~280 MeV	(N_F=2+1) ??

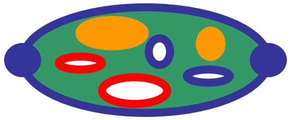
QUENCHED QCD
N_F=0

$m_q^{sea} \to \infty$



N_F=2+*1*
(m_u+m_d) + m_s

$m_c^{sea} \to \infty$



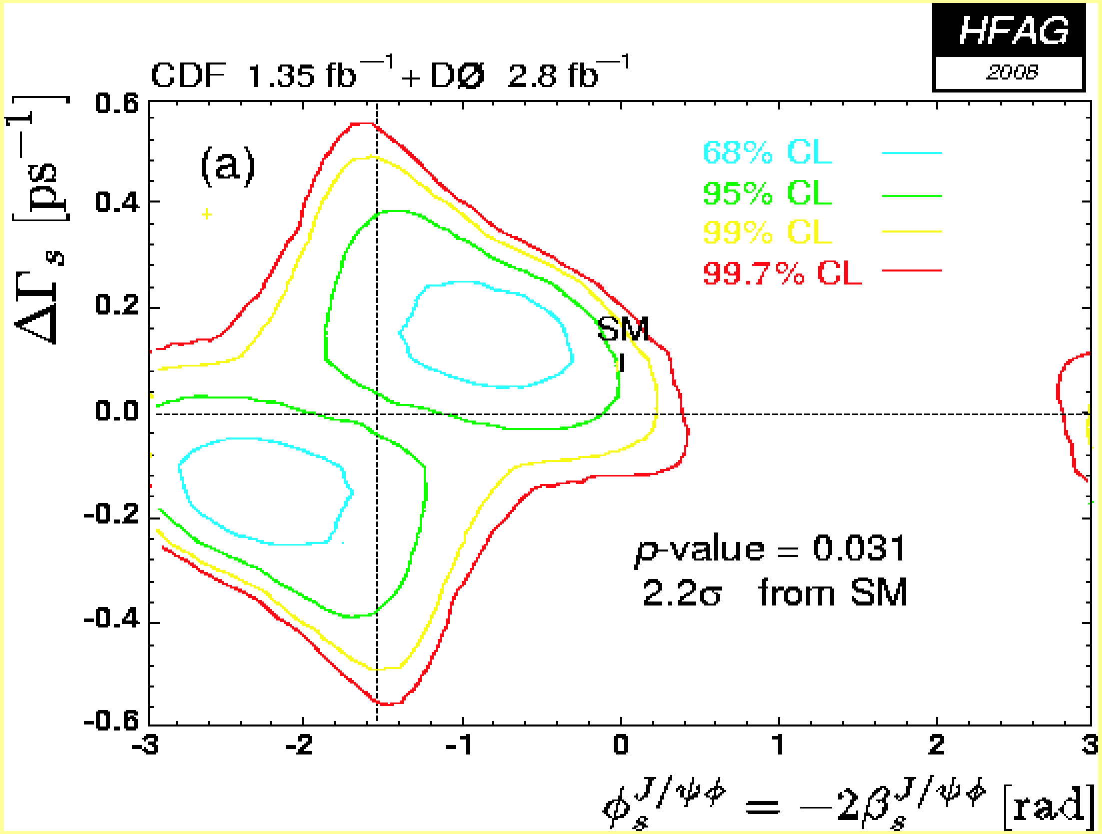
- CPV signals in the B_s sector:

$\beta_s^{MFV} \approx \beta_s^{SM}$

$B_s \to \psi \phi$

t-dependent CP asymmetries

LHCb **Tevatron**



Key observable to kill MFV
2.2σ deviation!

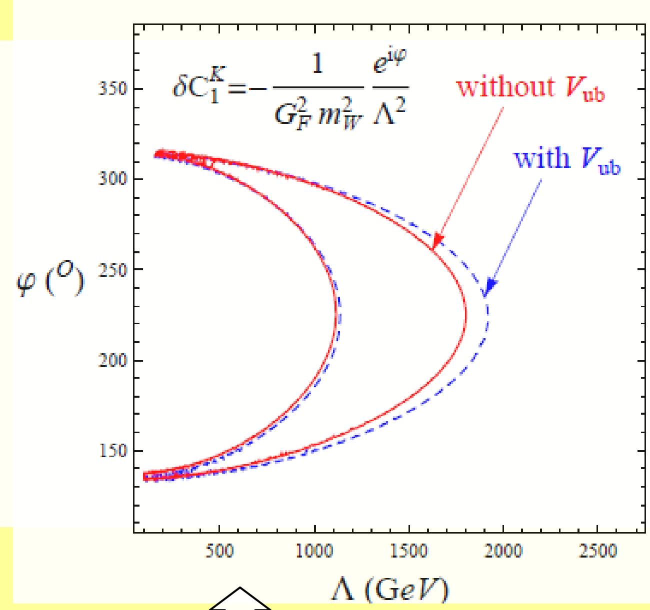
$\phi_s = -2\beta_s$

tensions on ΔF=2 observables $\Rightarrow$ upper limit for Λ_{new} ?!

❖ ε_K

$$\varepsilon_K \propto B_K * C_{SM} + \frac{\mathrm{Im} A_0}{\mathrm{Re} A_0} = 0.92(2) * B_K * C_{SM}$$

1. **RBC '07-'08; Aubin et al '09 → 5%**
2. **Buras & Guadagnoli 08, 09**



68% C.L.

	Operator	Λ (TeV)
K mixing	$O_1^{(K)}$	< 1.9
	$O_4^{(K)}$	< 24
B_s mixing	$O_1^{(d)}$ & $O_1^{(s)}$	$1.0 \div 1.4$ no V_{ub}
		$1.1 \div 2.0$ with V_{ub}

Lunghi & Soni 09
(Gaussian analysis!!)

$$\delta\mathcal{H}_{\text{eff}} = -\frac{(V_{tq}V_{tq'}^*)^2}{16\pi^2} \frac{e^{i\varphi}}{\Lambda^2} O_i$$

❖ ϕ_s

$B_s \to \psi\,\phi$

t-dependent CP asymmetries

D0 and CDF data: $\phi_s = -0.76^{+0.37}_{-0.33}$

or $\phi_s = -2.37^{+0.33}_{-0.37}$