

New perspectives for heavy flavour physics from the lattice



Rainer Sommer

DESY, A Research Centre of the Helmholtz Association



Les rencontres de Moriond, March 2009

The principle

First principle “solution” of QCD

experiments, hadrons

$$m_p = 938.272 \text{ MeV}$$

$$M_\pi = 139.570 \text{ MeV}$$

$$m_K = 493.7 \text{ MeV}$$

$$m_D = 1896 \text{ MeV}$$

$$m_B = 5279 \text{ MeV}$$

fundamental parameters
& hadronic matrix elements

$$\alpha(\mu)$$

$$m_u(\mu), m_s(\mu)$$

$$m_c(\mu), m_b(\mu)$$

$$F_B, F_{B_s}, \xi \dots$$

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continuum limit $a \rightarrow 0$

Some sample results from the literature

Review of E. Gamiz lattice 2008

examples of results

$m_c^{\overline{\text{MS}}}(3 \text{ GeV})$	=	0.986(10) GeV	HPQCD
$m_b^{\overline{\text{MS}}}(m_b)$	=	4.20(4) GeV	HPQCD
$\xi = \frac{F_{B_s} \sqrt{m_{B_s}}}{F_B \sqrt{m_B}}$	=	1.211(38)(24)	FNAL/MILC
F_{B_s}	=	243(11) MeV	FNAL/MILC
F_{D_s}	=	241(3) MeV	HPQCD

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Precision up to 1 % is claimed

The machinery



The present numbers quoted for phenomenology with small errors are dominated by "rooted staggered" sea quark computations [MILC-collaboration]

rooting: (sea quarks)

- ▶ → non-local
 - ▶ locality (= renormalizability = correctness) argued to be recovered as $a \rightarrow 0$
[Bernard,Golterman,Sharpe]
- series of ingredients: Symanzik effective theory – chiral PT, replica trick

NRQCD (or Fermilab action) for b-quarks

- ▶ power law divergences

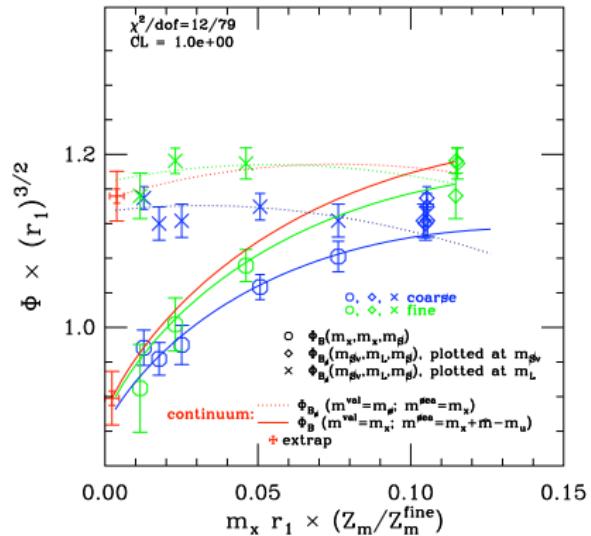
$$\frac{g_0^{2k}}{a m_b} \sim \frac{1}{a [\log(a)]^k m_b} \xrightarrow[a \rightarrow 0]{\sim} \infty$$

delicate analysis of continuum limit

The machinery

staggered chiral perturbation theory

$m \rightarrow (m_u + m_d)/2$ & $a \rightarrow 0$ in one (necessary due to rooting)

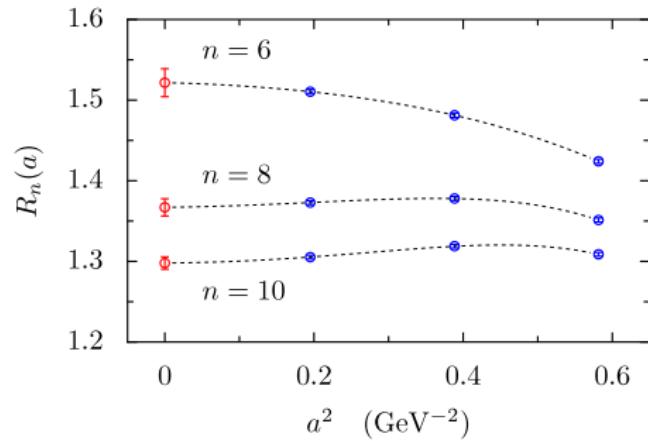


many parameter fits

The machinery

Bayesian fits

$a \rightarrow 0$ from high order polynomial in a with few points



The machinery



It appears good to perform independent computations with an independent technology

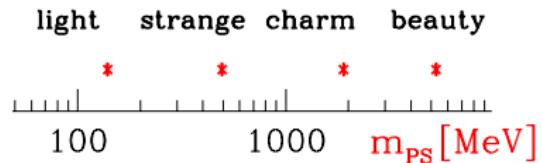
- ▶ manifestly local
- ▶ non-perturbative subtraction of power law divergences

Such computations are in progress

... but first let us understand that LQCD is a challenge

The challenge

multiple scale problem
always difficult
for a numerical treatment



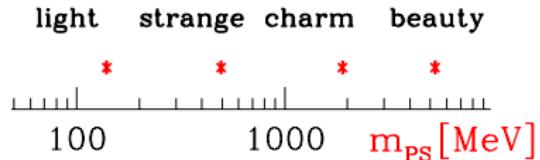
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lattice cutoffs:

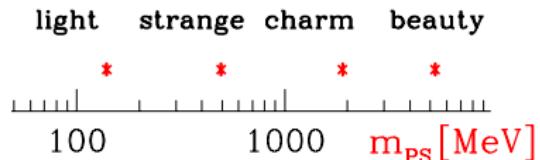
$$\Lambda_{\text{UV}} = a^{-1}$$

$$\Lambda_{\text{IR}} = L^{-1}$$



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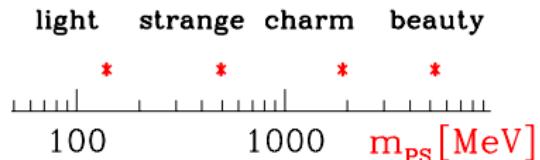
$$\Lambda_{\text{IR}} = L^{-1}$$

$$\begin{array}{c} L^{-1} \ll m_\pi, \dots, m_D, m_B \ll a^{-1} \\ O(e^{-L M_\pi}) \\ \downarrow \\ L \gtrsim 4/M_\pi \sim 6 \text{ fm} \end{array} \qquad \qquad \begin{array}{c} m_D a \lesssim 1/2 \\ \downarrow \\ a \approx 0.05 \text{ fm} \end{array}$$

$$L/a \gtrsim 120$$

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beauty not yet accommodated: effective theory, Λ_{QCD}/m_b expansion

Perspectives

- ▶ new algorithms
- ▶ new machines
- ▶ development / demonstration of
effective field theory strategies

Perspectives: algorithms

- ▶ mass preconditioning [M. Hasenbusch]
- ▶ multiple time scale integrators [C. Urbach et al.]
- ▶ odd number of flavours, $m_s \neq m_c$:
RHMC [M. Clark, A. Kennedy]
- ▶ Domain decomposition + deflation [M. Lüscher]

performance improved enormously:

from $\text{time} \propto m_{\text{quark}}^{-n}$, $n \gtrsim 3$ to

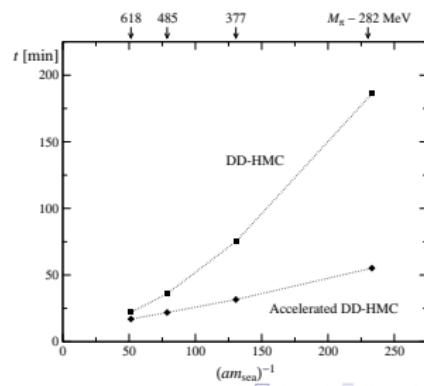
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[M. Lüscher, 2008]



Perspectives: machines

For illustration: the German situation (roughly)

year	machine	speed/Tflops	share for a typical collaboration
1984	Cyber205	0.0001	/100
1994	APE100	0.0500	/4

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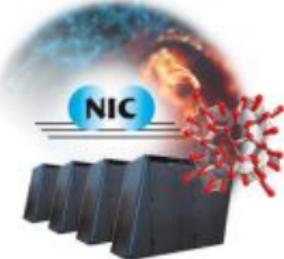
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2009.5	BG/P	1000.0000	/20(?)



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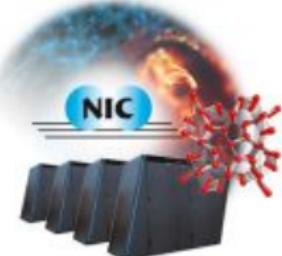


Growth (recently) stronger than Moore's law

Perspectives: machines

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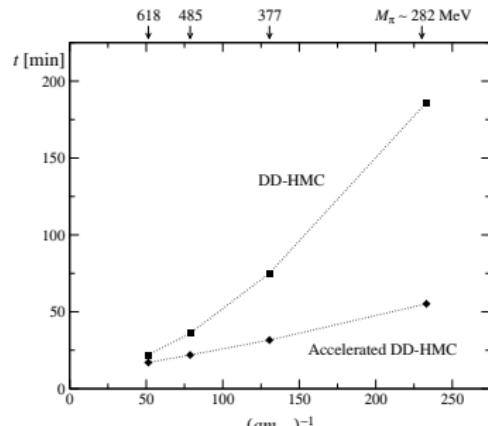


Growth (recently) stronger than Moore's law
unrelated to "Konjunkturpaket I/II"

Perspectives: algorithms & machines

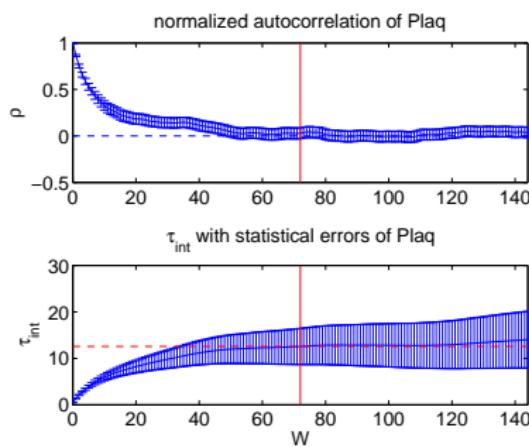
Example: 128×64^3 , $a = 0.04 \text{ fm}$, $L = 2.6 \text{ fm}$

at $m_q = m_s/2$: (2 trajectories)/hour=(1 MD unit)/hour
on 1024 node BG/P (1/64 Pflops)



execution time of
accelerated DD-HMC

256×128^3 at the physical point ($M_\pi = M_\pi^{\text{physical}}$) seems in reach



$2\tau_{\text{int}} = \# \text{ MD unit per effective independent measurement}$

Perspectives: strategies for b quark

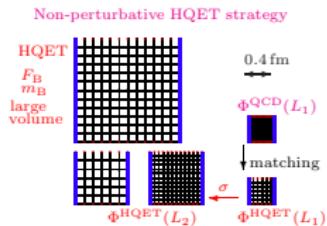
- ▶ Non-perturbative HQET (expansion in Λ_{QCD}/m_b)

[Heitger & S., 2001]

- ▶ Step scaling strategy

[G.M. de Divitiis, M. Guagnelli, F. Palombi, R. Petronzio & N. Tantalo]

Very much related and may be combined!

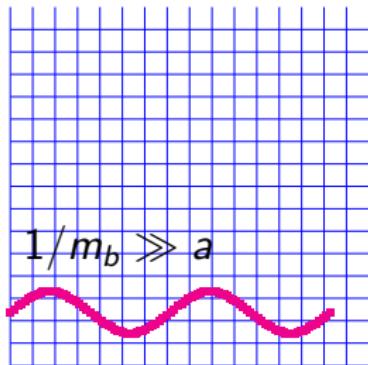


Non-perturbative matching of HQET and QCD

- The trick: start in small volume,
 $L = L_1 \approx 0.4 \text{ fm}$, $a = 0.01 \text{ fm}$

Φ_k finite volume masses,
decay constants ...

QCD

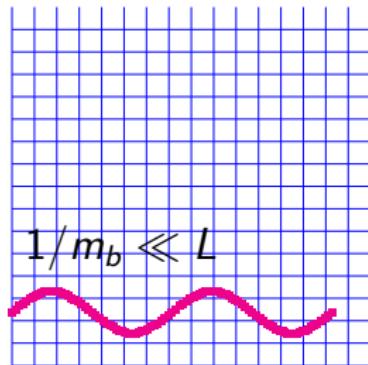


HQET

$$\Phi_k^{\text{QCD}} = \Phi_k^{\text{HQET}}$$

$$k = 1, 2, \dots, N_{\text{HQET}}$$

$$N_{\text{HQET}} = \# \text{ of parameters}$$

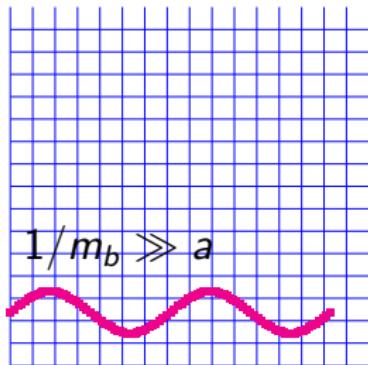


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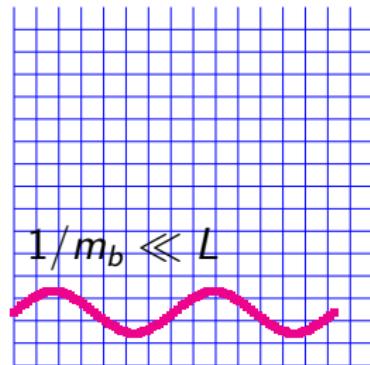
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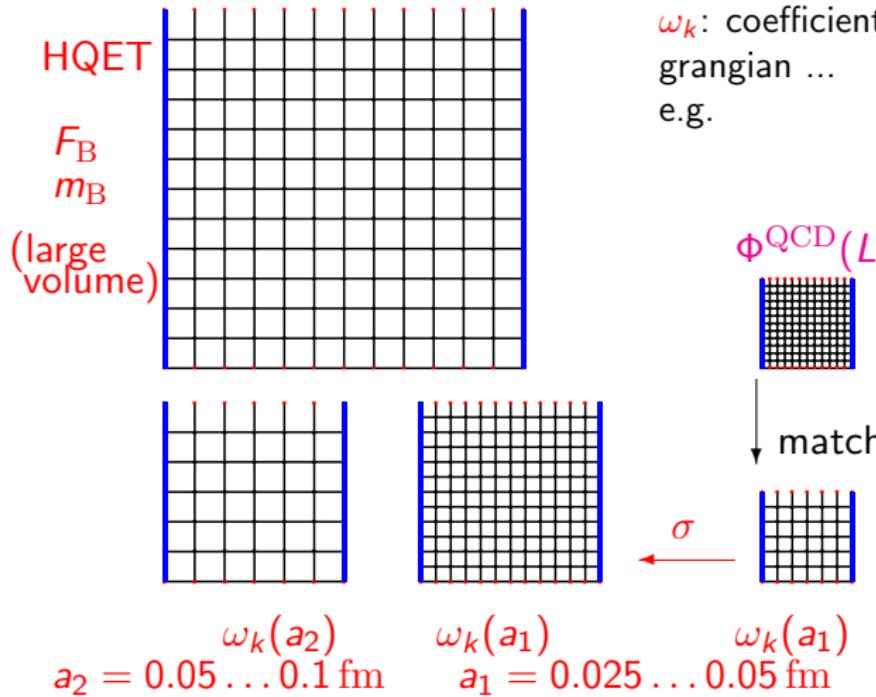
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- HQET-parameters from QCD-observables in small volume
 - at small lattice spacing $L^{-1} \ll m_b \ll a^{-1}$
 - power divergences subtracted non-perturbatively

The HQET strategy: first view

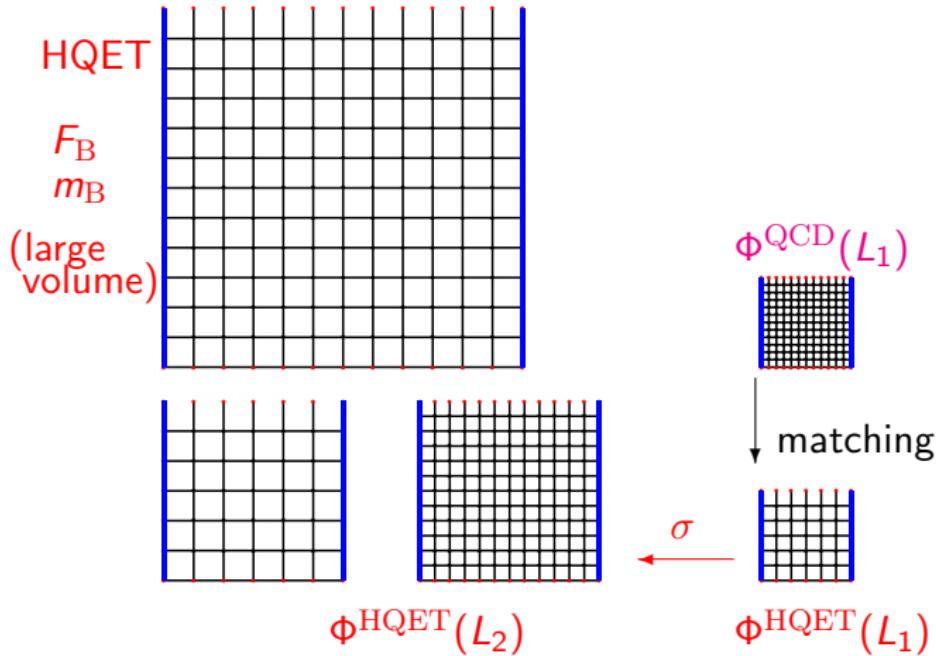


ω_k : coefficients in effective Lagrangian ...

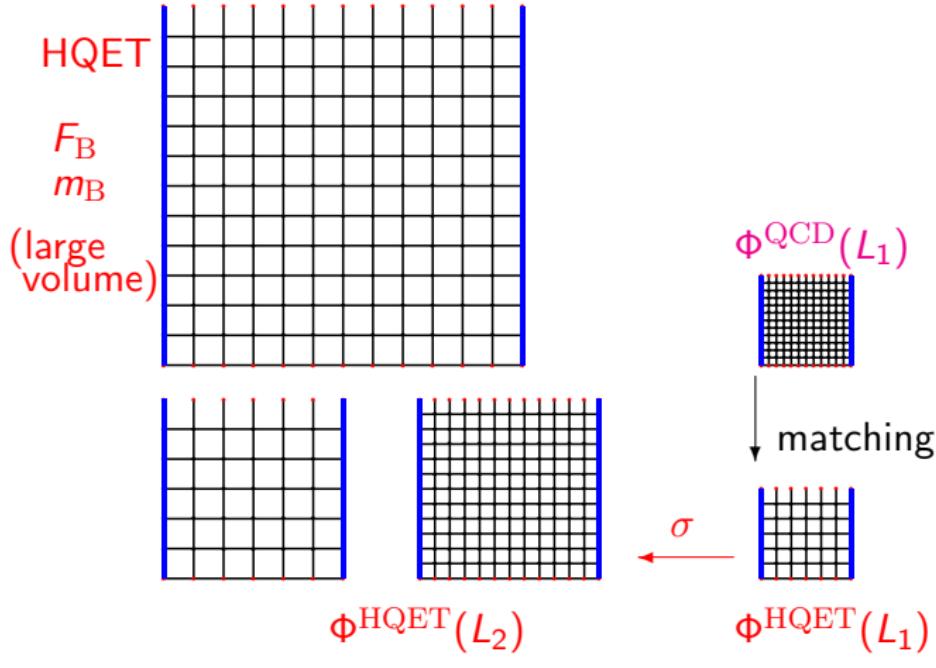
e.g.

$$\omega_2 \bar{b} \sigma \cdot \mathbf{B} b$$
$$\omega_2 \sim 1/(2m_b)$$

The HQET strategy: second view



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- continuum limit can be taken in all steps

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Main strategy				
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1	16.78(28)	17.17(32)	17.14(30)	17.15(30)
$3\% = O(\Lambda^2/m_b^2)$		$0.6\% \ll \text{total error} = O(\Lambda^3/m_b^3)$		

$\ln F_B:$
 $O(\Lambda^2/m_b^2) = 2(1)\%$
[Blossier, Della
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- ▶ $\bar{m}_b^{\overline{\text{MS}}}(r_0) = 4.347(48) \text{ GeV}$ quenched, $r_0 = 0.5 \text{ fm}$ (4-loop RGE)
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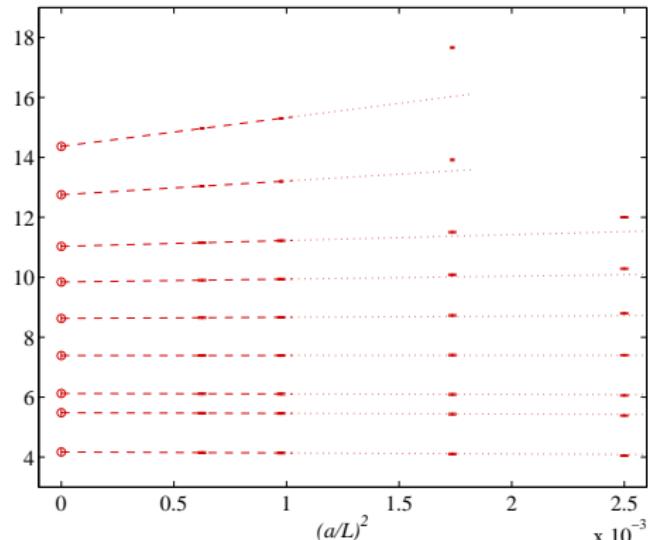
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[Della Morte, Garron, Papinutto & S]
- ▶ And with previous strategy (static with $x \propto 1/m_b$ interpolations)
 $\bar{m}_b^{\overline{\text{MS}}}(\bar{m}_b) = 4.421(67) \text{GeV}$ [Guazzini, S., Tantalo]
- ▶ 1–1.5% precision; uncertainty dominated by ΔZ_M , $M = Z_M m_0$

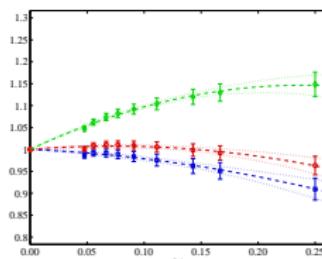
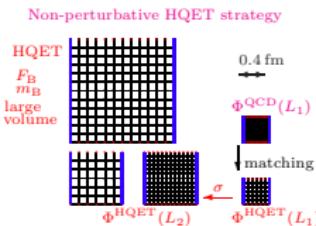
Perspectives

At present this strategy is being applied to $N_f = 2$ QCD
(just up and down sea)



in progress within **CLS**

B. Blossier, G. De Divitiis, M. Della Morte, P. Fritzsch, N. Garron, J. Heitger, G. von Hippel, T. Mendes, R. Petronzio, S. Schäfer, H. Simma, R.S., N. Tantalo



$N_f = 2$ QCD: Coordinated Lattice Simulations

Teams

- * Berlin (team leader Ulli Wolff)
- * CERN (L. Giusti, M. Lüscher)
- * DESY-Zeuthen (Rainer Sommer)
- * Madrid (Carlos Pena)
- * Mainz(Hartmut Wittig)
- * Rome (Roberto Petronzio)
- * Valencia (Pilar Hernández)

Physics planned at present

- * Fundamental parameters up to M_b
 - * Pion interactions
 - * Baryon physics
 - * Kaon physics
- also with mixed actions

β	$a[\text{fm}]$	lattice	$L[\text{fm}]$	masses	
5.30	0.08	48×24^3	1.9	6 masses	CERN, Rome
5.30	0.08	64×32^3	2.6	6 masses	CERN, Rome
5.50	0.06	64×32^3	1.9	5 masses	DESY,Berlin,Madrid
5.70	0.04	96×48^3	1.9	2 masses	DESY,Berlin
5.70	0.04	128×64^3	2.6	2 masses	DESY,Berlin, started

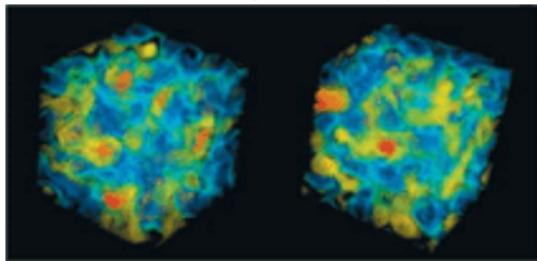
Promising for charm (and beauty)

Conclusions: the present mood

BREAKTHROUGHS OF THE YEAR

9) Proton's Mass 'Predicted' [Dürr et al.]

Thanks to the uncertainties of quantum mechanics, however, myriad gluons and quark-antiquark pairs flit into and out of existence within a proton in a frenzy that's nearly impossible to analyze but that produces 95% of the particle's mass.

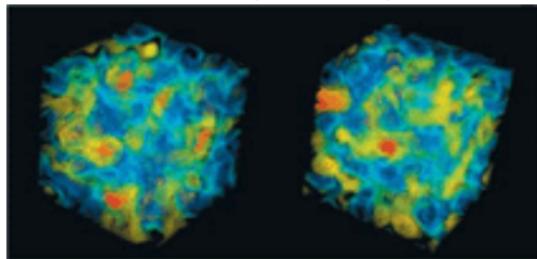


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$E = mc^2$ "belegen die Forscher Einsteins Spezielle Relativitätstheorie von 1905 auf subatomarer Ebene: "Auch dort sind Energie und Masse äquivalent. Aber das war bisher nur eine Hypothese", sagte Lellouch."

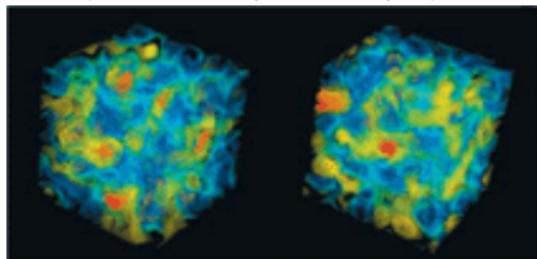
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Conclusions: the present mood

BREAKTHROUGHS OF THE YEAR

9) Proton's Mass 'Predicted' [Dürr et al.]

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this is going a bit overboard but there are **good perspectives** for matching experimental **precisions** on

(semi-) leptonic B decays, B-mixing; not on purely hadronic decays!

...
by the time superB comes

Tight Schedule Toward Upgrade

