Lattice Field Theory

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Overview

Participation and leadership in two large European collaborations with general QCD research programme

Currently particular interest in

ALPHA	**ETMC**
Non-perturbative matching of heavy-light currents HQET	structure functions
$B \to \pi$ form factor (Belle2)	neutron EDM
α_s (LHC)	$(g-2)_\mu$
	hadronic contributions to electroweak observables

Effects of the charm quark

NLO SU(2) ChPT constants

...

Different discretizations and analysis methods

$\to$ understanding of systematics

Chiral condensate

Order parameter of spontaneous chiral symmetry breaking

$$\Sigma = -\lim_{m\to 0}\lim_{V\to\infty}\langle \bar{u}\, u\rangle$$

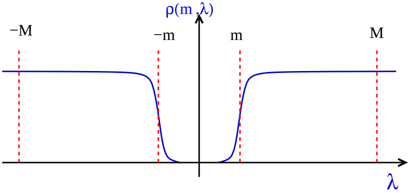
Fundamental property of QCD

Direct computation virtually impossible.

Banks–Casher relation

$$\Sigma = \pi \lim_{\lambda\to 0}\lim_{m\to 0}\lim_{V\to\infty}\rho(\lambda, m)$$

Density $\rho(\lambda, m)$ of eigenvalues of $\gamma_5 D_m$.



Count number ν of modes in $[\, m \,,\, M \,] \to \Sigma^R = \frac{\partial}{\partial M_R}\nu_R$

Results

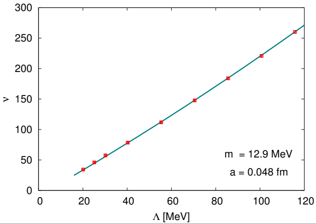
ALPHA (arXiv:1406.4987)

$N_f = 2$

$$\Sigma^{1/3} = 261(6)(8)\,\mathrm{MeV}$$

Using $r_0 = 0.503(10)$ fm

$$r_0\Sigma^{1/3} = 0.665(22)$$



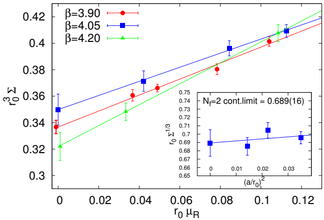
ETMC JHEP 1310 (2013) 175

N_f =2

$$r_0\Sigma^{1/3} = 0.689(16)(29)$$

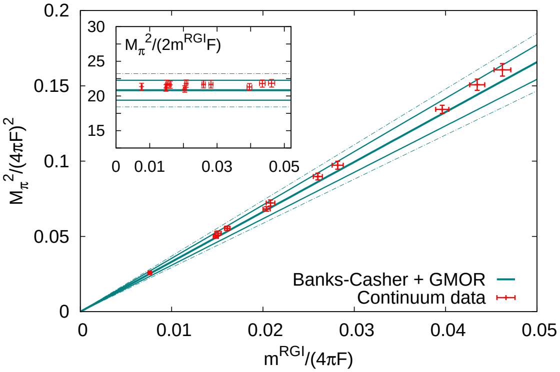
N_f =2+1+1

$$r_0\Sigma^{1/3} = 0.680(20)(21)$$



Good agreement within statistical uncertainties.
Numbers in $\overline{\mathrm{MS}}$ at $\mu = 2\mathrm{GeV}$

ALPHA: Comparison to GMOR



Consistent result with Gell-Mann–Oakes–Renner relation

$$m_\pi^2 = 4\,\frac{\Sigma}{F^2}\,m + \mathrm{O}(m^2)$$

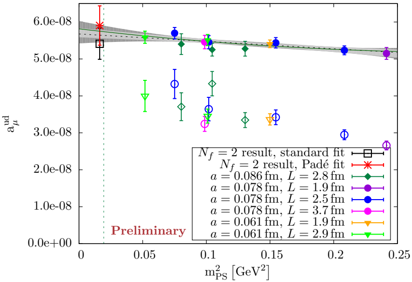
Chiral symmetry breaking qualitatively and quantitatively understood.

ETMC: Lattice QCD results at the physical point

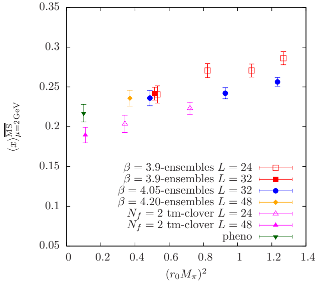
Simulations at physical quark masses
→ exclude one source of syst. error

One (coarse) lattice spacing so far

	M_{Ds}/M_K	M_{Ds}/M_D	f_K/f_π	f_{Ds}/f_D
lat.	3.96(2)	1.049(4)	1.197(6)	1.19(2)
PDG	3.988	1.0556(02)	1.197(06)	1.26(6)

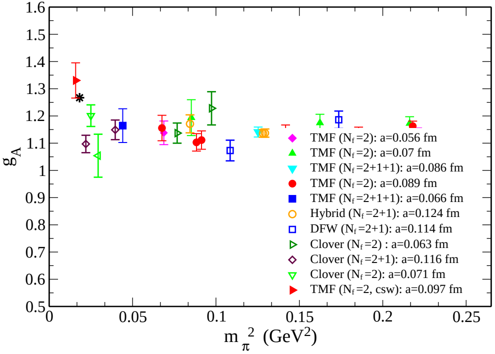


muon anomalous moment



average quark momentum in pion

ETMC: Nucleon axial charge g_A



Long-standing problem

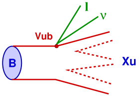
Need to carefully controll

- Quark mass effects → physical point
- Finite volume effects
- Discretization effects
- Unwanted contributions from excited states

V_{ub}

Determination of $|V_{\mathrm{ub}}|$

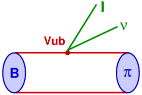
Values in PDG from three different channels:



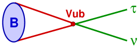
Inclusive $\mathrm{B} \to X_{\mathrm{u}}\ell\nu$ $\quad V_{\mathrm{ub}} = (4.41 \pm 0.15^{+0.15}_{-0.17}) \times 10^{-3}$

Exclusive $\mathrm{B} \to \pi\ell\nu$ $\quad V_{\mathrm{ub}} = (3.23 \pm 0.31) \times 10^{-3}$

Exclusive $\mathrm{B} \to \tau\nu$ $\quad V_{\mathrm{ub}} = (4.2 \pm 0.42) \times 10^{-3}$



Discrepancy reduced by recent $B \to \tau\nu$, but still some tension.



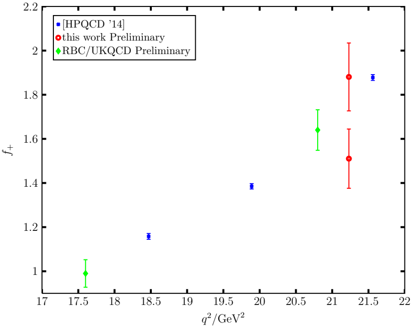
Theoretical and experimental input needed

Non-perturbative determination of form factors for $\mathrm{B_s} \to \mathrm{K}\ell\nu$ decay

Benchmark for (and similar to) $\mathrm{B} \to \pi\ell\nu$

ALPHA: Semi-leptonic decays $\mathrm{B_s} \to \mathrm{K}\ell\nu$

$$\langle \mathrm{K}(p_\mathrm{K}^\mu)|V^\mu|\mathrm{B_s}(p_{\mathrm{B_s}}^\mu)\rangle = f_+(q^2)\left[p_{\mathrm{B_s}}^\mu + p_\mathrm{K}^\mu - \frac{m_{\mathrm{B_s}}^2 - m_\mathrm{K}^2}{q^2} q^\mu\right] + f_0(q^2)\frac{m_{\mathrm{B_s}}^2 - m_\mathrm{K}^2}{q^2} q^\mu$$



blue: HPQCD '14
$a = 0.09\mathrm{fm}, m_\pi = 320\mathrm{MeV}$
Pert. renormalisation

red: ALPHA
continuum, static,
$m_\pi = 340\,\mathrm{MeV}$,
NP renormalisation

green: RBC/UKQCD, PRELIM.
Chiral, continuum.
Pert. Renormalisation

Consistent results $\to V_{\mathrm{ub}}$ **puzzle remains**

Improvements in progress: NLO$(1/m_\mathrm{h}), N_\mathrm{f} = 2+1, \mathrm{B} \to \pi$, several q^2

Simulations

Selection of interesting physics observables

Further results on

- Topological susceptibility
- Nucleon structure
- Decoupling of charm quarks
- . . .

Fine lattices + light quark masses essential

Need to move beyond $N_{\mathrm{f}} = 2 \rightarrow$ higher complexity

Balance different sources of syst. + stat. uncertainties.

quark mass effects

discretization effects

finite volume

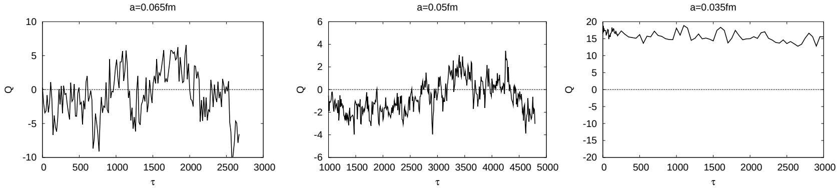
flavor content

Continuum limit

Problem

Standard simulation setup → **topological freezing in continuum**

ALPHA'09



Continuum QCD property → all actions, all known algorithms

Remaining tunneling a cutoff effect.

Solution

Open boundary conditions in time Lüscher, S.S'12

Field space connected in the continuum.

Effect proven in pure gauge theory.

CLS 2+1

Berlin, Humboldt U
CERN
DESY
Dublin, Trinity College
Mainz
Madrid, U Autonoma
Milano, U Bicocca
Münster
Odense
Regensburg
Rome, La Sapienza
Rome, Tor Vergata
Valencia
Wuppertal

Based on blanc map ©Fobos92

Non-perturbatively improved Wilson fermions

$N_f = 2 + 1$ **dynamical flavors**

CLS 2+1

Unique features of the CLS simulations

Open boundary conditions

Solution of topological freezing problem

Twisted mass reweighting

Safe simulations with Wilson fermions at small quark masses

Deflated solver for Dirac equation

Eliminates most of rising cost as $m_q \to 0$.

Monitoring of slow observables

Tuning strategy and statistics based on flow observables

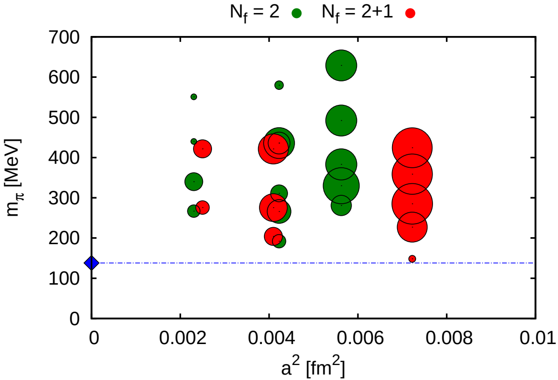
Computer resources: PRACE (+ national projects)

LATTQCDNf3: PI: A. Vladikas, INFN (70M core-hours @ FERMI)

ContQCD: PI: S. S., NIC, DESY (40M core-hours @ SuperMUC)

Plan to publicly release the configurations → **ILDG**

CLS 2+1 configurations



Comparable statistics in $N_\mathrm{f} = 2$ and $N_\mathrm{f} = 2 + 1$ project.

$N_\mathrm{f} = 2$ production 2007-2012

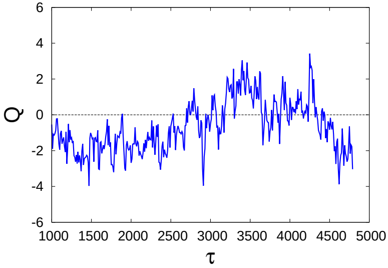
$N_\mathrm{f} = 2 + 1$ one year production $\rightarrow$ 100TB, 25′000 configs

Topological charge in CLS 2+1

Simulations down to $a \approx 0.05$ fm

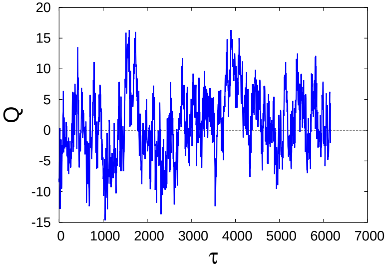
Topological charge well decorrelating

$N_\mathrm{f} = 2$, $a \approx 0.05$ fm, periodic bc



DD-HMC algorithm

$N_\mathrm{f} = 2+1$, $a \approx 0.05$ fm, open bc



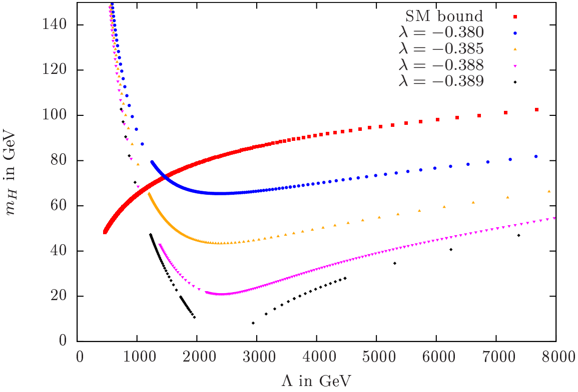
Mass precond. HMC algorithm

Lower Higgs boson mass bound in in presence $\lambda_6\Phi^6$ term

$$V_{\mathrm{H}}[\phi] = \frac{1}{2}m_0^2\,|\phi|^2 + \lambda\,|\phi|^4 + \lambda_6\,|\phi|^6$$

$|\phi|^6$ term proxy for BSM physics

Evaluation of constraint effective potential in lattice pert. theory



ARXIV:1310.6260

Constraints on λ_6 coupling strength

Summary

$N_f = 2$ results in many areas

- Chiral condensate + topological susceptibility
- B physics → agreement between different approaches
- Pion and nucleon structure

ETMC + CLS working on more realistic flavor content

→ **goal to bring $\mathrm{O}(1\%)$ accuracy to more observables**

Need to understand many physical effects → find balance.

Physical point simulations from CLS and ETMC

Activities beyond QCD

Hamiltonian approach to field theory
→ chemical potential, real time evolution

Higgs physics