SU(2) gauge theory with $N_f = 24$ massive fermions

Ahmed Salami*, Jarno Rantaharju, Tobias Rindlisbacher, Kari Rummukainen, Kimmo Tuominen
Department of Physics, University of Helsinki, P.O. Box 64, 00014 University of Helsinki, Finland
ahmed.salami@helsinki.fi

UNIVERSITY OF HELSINKI

Introduction

SU(2) gauge theory with $N_f = 24$ massless fermions is expected to have an UV Landau pole and is free at IR. With massive fermions the IR behaviour changes: at energy scales $\ll m_f$ the fermions decouple and the system behaves as confining SU(2) gauge theory. We demonstrate this cross-over on the lattice using gradient flow coupling constant measurements. We also measure the mass spectrum of the model and verify that it matches free theory expectations at moderate quark masses.

Finite mass RG evolution

Running of coupling g^2 and quark mass m under a change of length-scale λ is governed by (BF-MOM scheme [2]):

$$\frac{dg^2}{d\log(\lambda)} = -\beta(g^2, \lambda\, m)\ ,\ \frac{d\log(m)}{d\log(\lambda)} = \gamma(g^2, \lambda\, m)$$

with beta function β and mass-anomalous dim. γ.

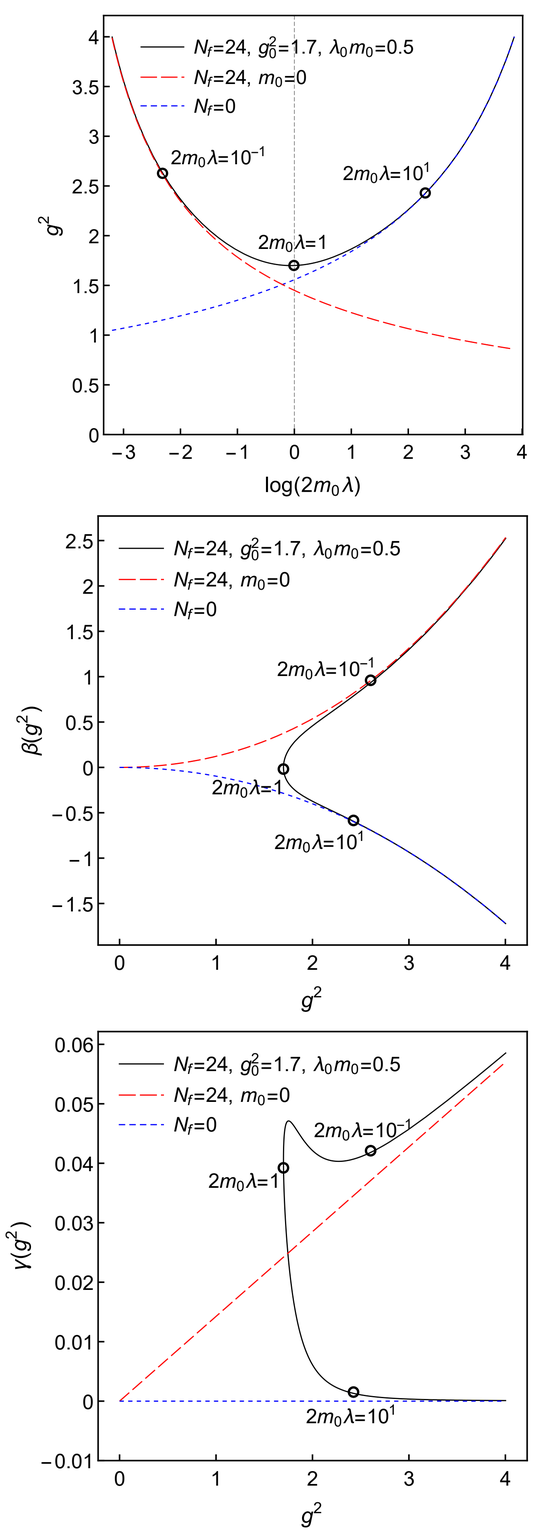

Figure 1: 2-loop running coupling (top), 2-loop beta function (middle) and 1-loop mass anomalous dimension (bottom) in the BF-MOM scheme [2, 4].

References

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Simulation setup

Lattice action: $S = S_G(U) + S_F(V) + c_{\rm SW}\, S_{\rm SW}(V)$ on toroidal L^4 lattices. S_G is the Wilson gauge and S_F the Wilson fermion action with SU(2) gauge link matrix U in fundamental rep. and V a corresponding HEX smeared [3] link. $S_{\rm SW}$ is the clover term with SW coefficient $c_{\rm SW} = 1$ [6].
Hybrid Monte Carlo (HMC) algorithm using leapfrog integrator with unit-length trajectories and the number of leapfrog steps adjusted to yield acceptance rates above 80%.
Simulations were carried out for L=32,40,48 with inverse bare couplings β=$4/g_0^2 \in \{-0.25, 0.001, 0.25\}$ and the fermion hopping parameter κ chosen to obtain PCAC quark masses $m_q \in [0.01, 0.8]$.

Results I: gradient flow running coupling

We determine the gradient flow running coupling $g^2_{\rm GF}(\lambda_L, L)$ as function of flow scale $\lambda_L = \sqrt{8\,t}$ on an $L = 48$ hypercubic, toroidal lattice following the method described in [5]. The flow is governed by the Lüscher-Weisz Symanzik action [1]. In Fig. 2 we show some results obtained by fitting the perturbative running coupling discussed in Fig. 1 to our data for the gradient flow running coupling $g^2_{\rm GF}$. The quark mass dependent change of slope of $g^2_{\rm GF}$ as function of λ_L matches the expectations from perturbation theory: for large m_q the gradient flow coupling is on the rapidly increasing, confining pure gauge branch, while for small m_q it is on the decreasing, quasi-IR-free massless $N_f = 24$ branch.

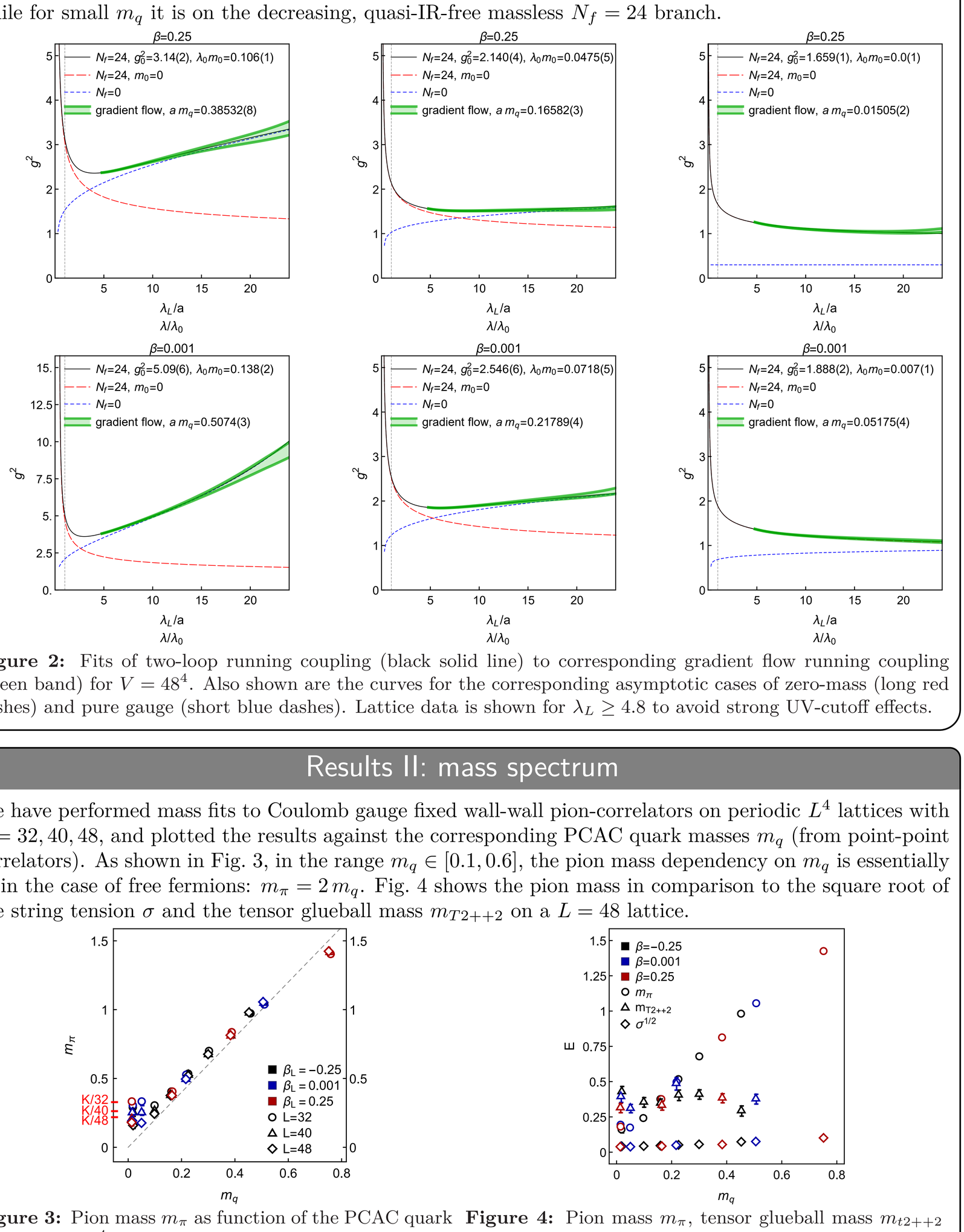

Figure 2: Fits of two-loop running coupling (black solid line) to corresponding gradient flow running coupling (green band) for $V = 48^4$. Also shown are the curves for the corresponding asymptotic cases of zero-mass (long red dashes) and pure gauge (short blue dashes). Lattice data is shown for $\lambda_L \geq 4.8$ to avoid strong UV-cutoff effects.

Results II: mass spectrum

We have performed mass fits to Coulomb gauge fixed wall-wall pion-correlators on periodic L^4 lattices with $L = 32, 40, 48$, and plotted the results against the corresponding PCAC quark masses m_q (from point-point correlators). As shown in Fig. 3, in the range $m_q \in [0.1, 0.6]$, the pion mass dependency on m_q is essentially as in the case of free fermions: $m_\pi = 2\, m_q$. Fig. 4 shows the pion mass in comparison to the square root of the string tension σ and the tensor glueball mass m_{T2++2} on a $L = 48$ lattice.

Figure 3: Pion mass m_π as function of the PCAC quark mass m_q on L^4 lattice. The plateaus at small m_q drop faster than $1/L$. Dashed line corresponds to $m_\pi = 2\, m_q$.

Figure 4: Pion mass m_π, tensor glueball mass m_{t2++2} and square root of string tension $\sqrt{\sigma}$ as functions of the PCAC quark mass m_q for linear system size $L = 48$.

Conclusions

We have reviewed the running coupling of a SU(2) gauge theory with $N_f = 24$ massive fermions in BF-MOM perturbation theory [2] and demonstrated that the predicted transition from behaving as the massless theory in the UV (UV-Landau pole and IR-triviality) to behaving like pure gauge in the IR (confining) can be well observed on the lattice in the evolution of the gradient flow running coupling. We have also shown that, although the effective coupling is non-zero, the mass spectrum of the theory behaves as in the case of quasi-free quarks for sufficiently small fermion masses (before decoupling).