Heavy and strong: decoupling of heavy quarks in the strong coupling

Gradient Flow coupling in a massive scheme

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In Short

- strong coupling of quarks and gluons
- decoupling of heavy quarks at low energy
- finite-volume massive coupling based on the Gradient Flow
- simulations of Lattice Quantum Chromodynamics on fine lattices

Quantum Chromodynamics (QCD) is the theory which describes the strong interactions among the elementary particles called quarks and gluons, which are the building blocks of hadrons such as the proton and the neutron. Through the formulation of QCD on a Euclidean lattice the theory becomes amenable to computer simulations and it is possible to compute hadron properties from first principles. The running coupling of the strong force can also be computed from lattice QCD. A precise knowledge of this fundamental parameter of the standard model of elementary particles is crucial for the search of new physics as discrepancies between the model's predictions and experiments at colliders like the LHC are potentially tiny. At the moment determinations of the strong coupling from lattice QCD based on finite volume renormalization schemes yield the most precise results [1]. The effects of the charm and bottom quarks are included using the perturbative decoupling relations for heavy quarks. In previous works [2,3] decoupling was studied in a non-perturbative setting through simulations in large volume of a model, $N_\mathrm{f} = 2$ QCD with two mass-degenerate heavy quarks. In this project we aim to extend the study of decoupling to the computation of a finite volume coupling in a setting with three mass-degenerate heavy quarks. The massive coupling implicitely defines a scale which is given by the inverse box size L^{-1}. We will study the dependence of the coupling (and the scale) on the heavy quark mass and compare it to perturbation theory based on the decoupling relations for heavy quarks.

We want to compute a Gradient Flow (GF) coupling $\bar{g}_\mathrm{GF}$ [4] in a massive scheme with $N_\mathrm{f} = 3$ quarks of mass M. If M is sufficiently large decoupling of the heavy quarks applies. The massive coupling can be then compared to the decoupling prediction based on the factorization formula for the mass-dependence and perturbation theory [2], and the knowledge of the GF beta-functions in pure gauge theory and for $N_\mathrm{f} = 3$ QCD. We plan to simulate at two quark masses $M = 2M_\mathrm{charm}, M_\mathrm{bottom}$ equal to twice the charm quark mass and the bottom quark mass. In order to compute $\bar{g}_\mathrm{GF}$ in the continuum limit we need simulations with several lattice resolutions keeping $z = LM$ fixed. Decoupling of heavy quarks holds up to corrections proportional to $1/z^2$ [3]. In finite volume with Schrödinger Functional boundary conditions which we use, one needs to control $1/z$ effects from the boundaries. In order to tune the quark mass parameter we will have to determine renormalization and improvement coefficients for the quark mass in $N_\mathrm{f} = 3$ QCD which are presently not known. This requires another set of simulations of QCD with Schrödinger Functional boundary conditions in constant physical volume at different resolutions at and around zero quark mass.

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More Information

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[2] M. Bruno, J. Finkenrath, F. Knechtli, B. Leder, R. Sommer, *Phys. Rev. Lett.* **114**, no. 10, 102001 (2015). doi:10.1103/PhysRevLett.114.102001

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[4] P. Fritzsch, A. Ramos, *JHEP* **1310**, 008 (2013). doi:10.1007/JHEP10(2013)008

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