Towards a discretization of supersymmetric QCD

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Continuum limit of Lattice Super QCD

Due to the Leibniz rule not holding for discretized derivative operators, supersymmetry gets broken when put on the lattice.
To achieve a supersymmetric continuum limit nonetheless, one has to finetune the parameters.

After sucesses with super Yang-Mills, our current goal is a supersymmetric continuum limit of *N*=1 super QCD in 4 dimensions, a theory for which finetunig is immensly hard due to the amount of parameters.

As firsts steps towards this, we implement an improved scalar derivative operator which should reduce the amount of supersymmetry breaking and map out the phase space of the scalar sector

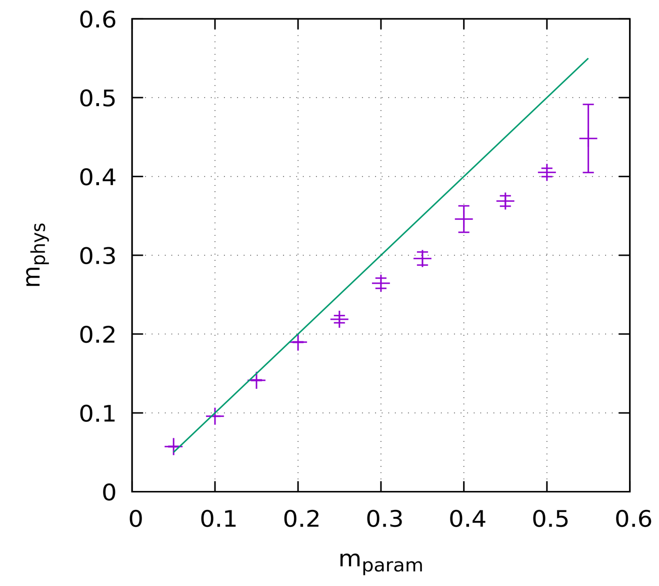
Improved scalar discretization

In supersymmetry, superpartners are the exact same particle with different spin. When put on the lattice discretizing them in as close of a manner as possible is benificial, as it reduces the amount of susy breaking. While impractical for gauge-fermion superpairs, it is a feasible option for fermion-scalar pairs.

When using Wilson fermions, one can construct a symmetric scalar derivative out of Wilson-Dirac operators. This not only provides identical discretizations for fermion-sfermion superpartners, but also deals with the potential doublers of the scalars.

$$\begin{aligned}\mathcal{L}_{\text{kin}} &= \phi^\dagger \not{\partial}_W^\dagger \not{\partial}_W \phi \\ &= \phi^\dagger \left(-\gamma^\mu \nabla_\mu + m + m_W\right)\left(\gamma^\nu \nabla_\nu + m + m_W\right) \\ &= \phi^\dagger \left(-\nabla_\mu \nabla_\nu + (m + m_W)^2\right)\phi\end{aligned}$$

"Wilson Scalar" derivative for complex doublet fields



Scalar sector of *N*=1 Super QCD

To ease the finetuning of *N*=1 SQCD, it would be benificial to know a rough sketch of the phase structure as the tuning is best done in the broken phase.

To facilitate this, we reduced the theory down to its gauged scalar part and probed its phase space.

There is a gauge dependent first order phase transition, which approaches a second order transition with lower gauge coupling.

$$\mathcal{L} = \mathcal{L}_{\text{SYM}} + \mathcal{L}_{\text{GWZ}} + \mathcal{L}_{\text{Yukawa}} + \mathcal{L}_{\text{ScalPot}}$$

$$\mathcal{L} = \frac{1}{4} F^c_{\mu\nu} F^{\mu\nu\, c} + \frac{1}{2}\bar{\lambda}^c \gamma_\mu \left(D^\mu \lambda^c\right)$$

Super Yang-Mills, gluons F, gluinos λ

$$\mathcal{L} = \bar{\psi} \not{D} \psi + m\bar{\psi}\psi + D^\mu \phi_1^\dagger D_\mu \phi_1 + D^\mu \phi_2 D_\mu \phi_2^\dagger + m^2(\phi_1^\dagger \phi_1 + \phi_2 \phi_2^\dagger)$$

Wess-Zumino, quarks ψ, squarks φ₁, φ₂

$$\mathcal{L} = i\sqrt{2} g \left(\phi_1^\dagger \bar{\lambda}^c T^c P_+ \psi - \overline{\psi} P_- \lambda^c T^c \phi_1 + \phi_2 \bar{\lambda}^c T^c P_- \psi - \overline{\psi} P_+ \lambda^c T^c \phi_2^\dagger\right)$$

Yukawa interactions

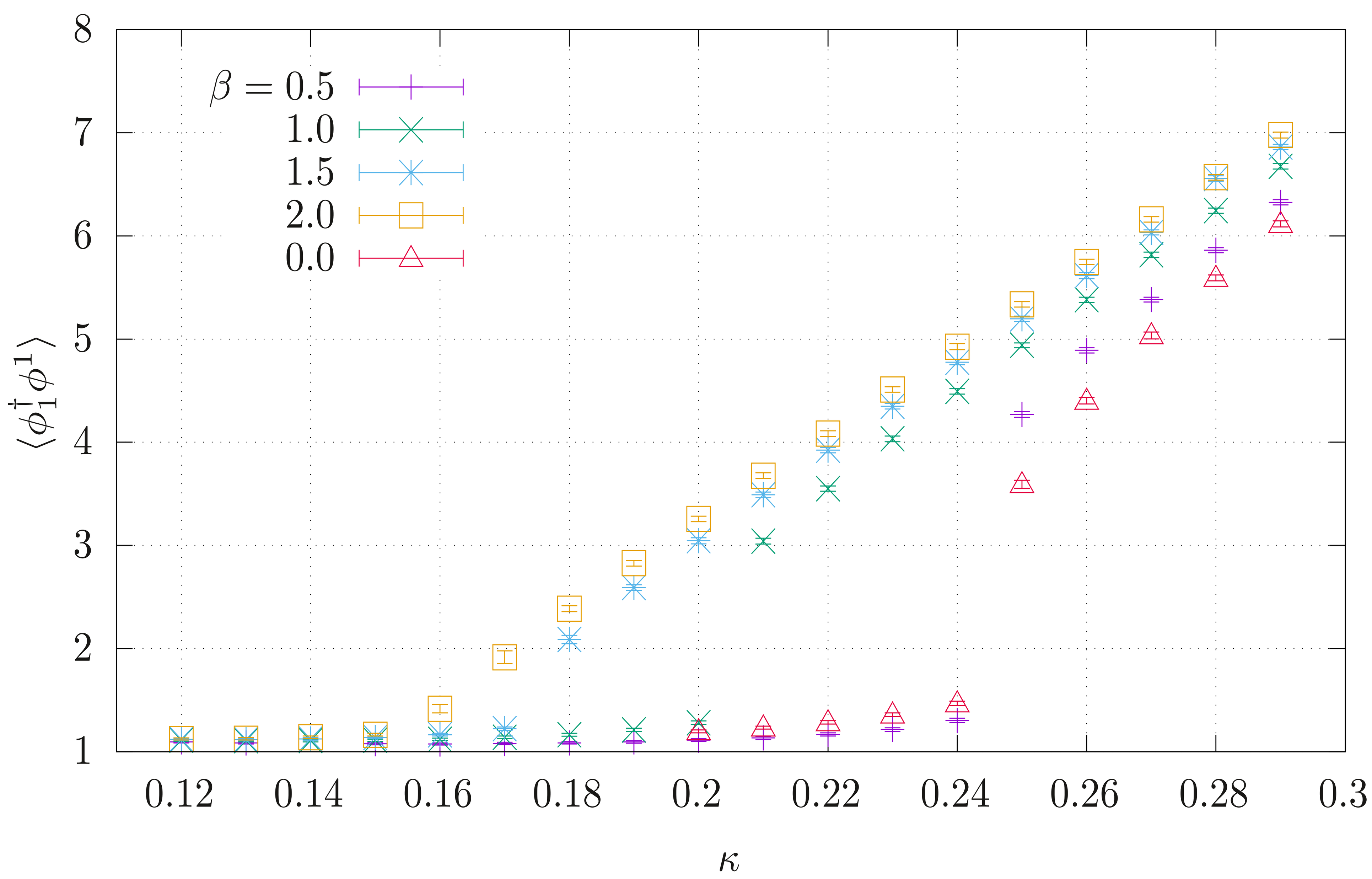
$$\mathcal{L} = \frac{g^2}{2}\left(\phi_1^\dagger T^c \phi_1 - \phi_2 T^c \phi_2^\dagger\right)^2$$

Scalar potential

reduced to:

$$\begin{aligned}\mathcal{L} &= \frac{1}{4} F^{\mu\nu} F_{\mu\nu} \\ &\quad + D^\mu \phi^\dagger D_\mu \phi + m^2\left(\phi_1^\dagger \phi_1 + \phi_2 \phi_2^\dagger\right) \\ &\quad + \frac{g^2}{2}\left(\phi_1^\dagger T^c \phi_1 - \phi_2 T^c \phi_2^\dagger\right)^2\end{aligned}$$

Phase transition of the scalar sector



Outlook

The next step in the fintuning process would be introducing fermions one at a time, either quarks or gluinos to the theory and observe any changes to the phase diagram.

The scalar discretization could also be useful for a perturbative lattice approach.

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FWF Austrian Science Fund