Searching for the continuum limit of SU(2) with one adjoint Dirac flavour

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Context

SU(2) with one adjoint Dirac flavour is a theory with a number of interesting aspects:

- It can be used as the basis for beyond the standard model theories of electroweak symmetry breaking
- It can help to pin down the lower end of the conformal window in SU(2)
- It may be dual to the critical theory of a topological phase transition

Lattice theory

We simulate using the unimproved Wilson gauge action

$$S_{\mathrm{G}} = \beta \sum_p \mathrm{Tr}\left[1 - \frac{1}{2}U(p)\right]$$

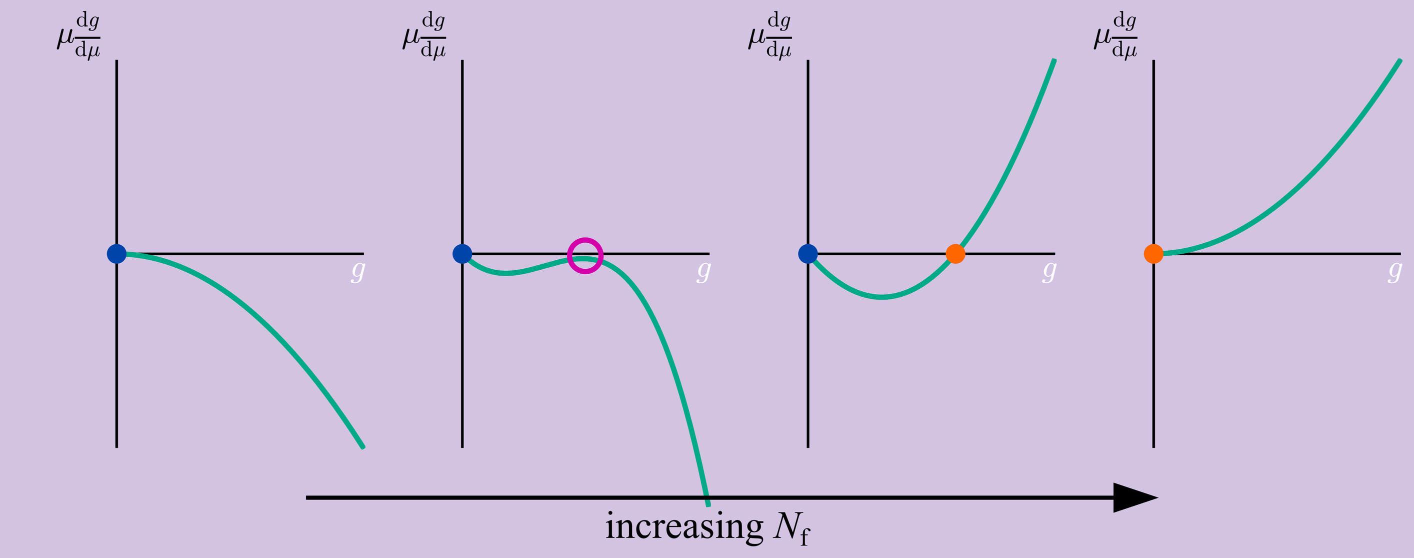
and the Wilson fermion action

$$S_{\mathrm{F}} = \sum_{x,y} \bar{\psi}(x) D(x,y) \psi(y)$$

$$D(x,y) = \delta_{x,y} - \kappa \left[(1-\gamma_\mu) U_\mu(x) \delta_{y,x+\mu} + (1+\gamma_\mu) U^\dagger_\mu(x-\mu) \delta_{y,x-\mu}\right]$$

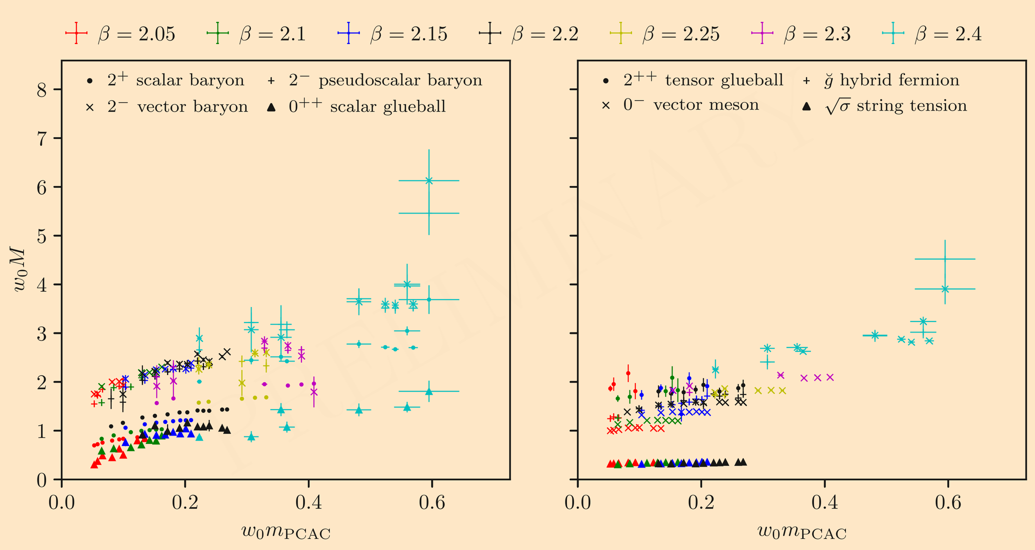
We use the HiRep code on CPU in Swansea, and the Grid code on GPU on the DiRAC Extreme Scaling Service, for simulations. Measurements are performed using HiRep on CPU.

The conformal window



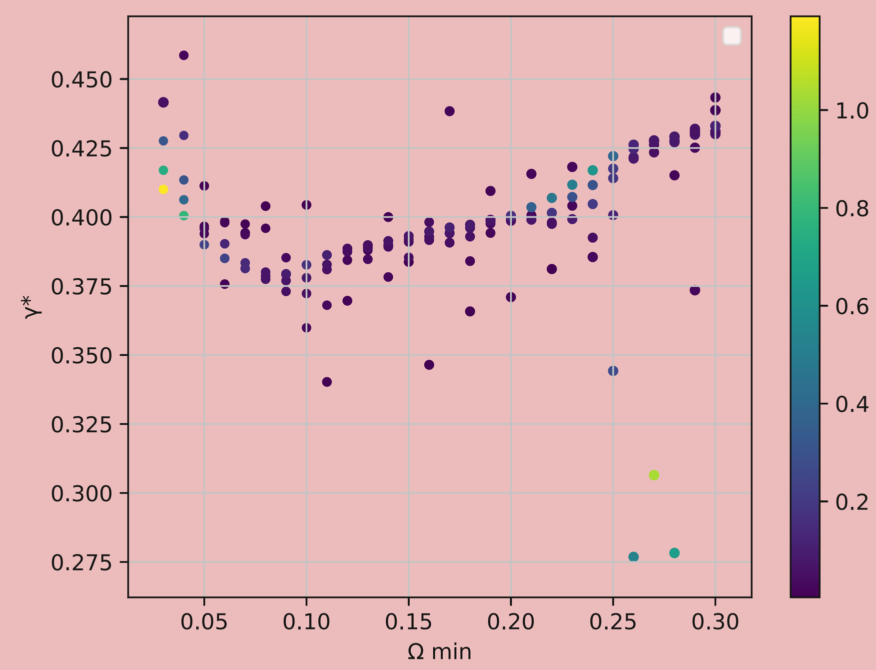
While in QCD the beta function is always non-positive, higher values of Nf show a region where there is a conformal fixed point. Immediately below this conformal window there may be a region where there is near-conformal behaviour, a large mass anomalous dimension, and slow-running ("walking") coupling.

Mass spectrum



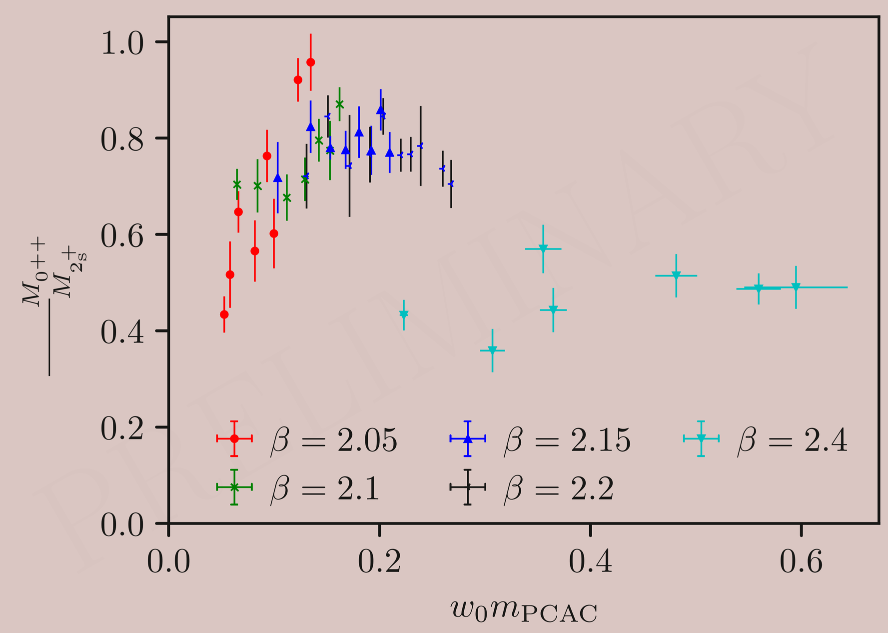
The masses of states in units of the gradient flow scale are relatively constant for each value of the coupling studied, with some variation from one to the next. This is expected from a conformal or near-conformal theory, and can be studied more closely with a hyperscaling analysis (below). Our ability to access low fermion masses (nearer the chiral limit) decreases as we increase the coupling, as the required computation time blows up.

Dirac mode number



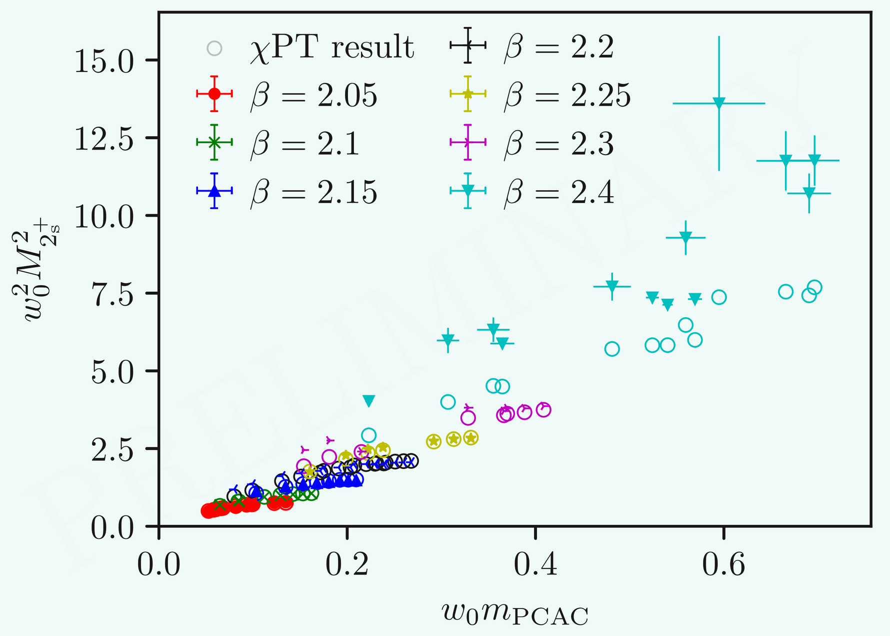
In addition to fitting the hyperscaling of the spectrum (below), we may also extract an estimate for the mass anomalous dimension by fitting the scaling of the Dirac eigenmode spectrum. The analysis of this requires finding a region of stability as the fit window is changed. Computing this for the lightest value of the fermion mass for each value of beta gives compatible values with those obtained from hyperscaling fits.

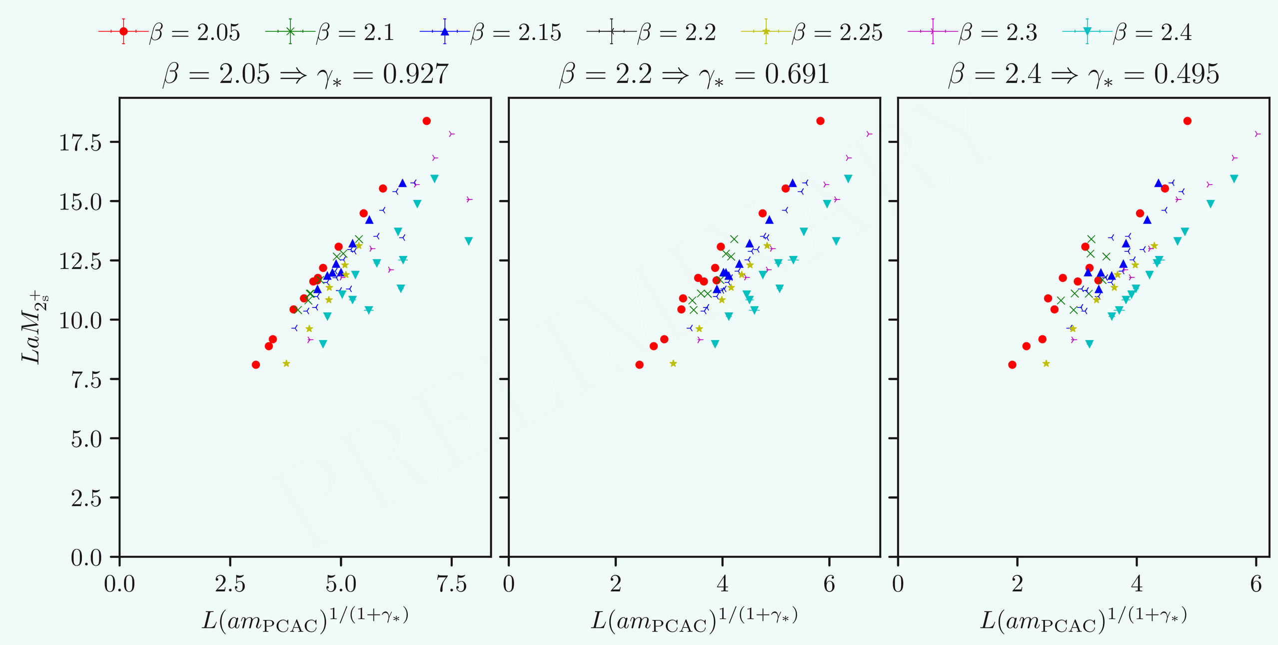
Light scalar state



Conformal and near-conformal theories are frequently seen to have scalars as the lightest state, lighter than the would-be Nambu–Goldstone bosons. This is seen in this theory, and persists as the value of beta is increased.

Hyperscaling vs chiral perturbation theory





In a QCD-like theory with chiral symmetry breaking we expect the spectrum to obey chiral perturbation theory. Meanwhile for a conformal theory we would expect to see finite-size hyperscaling, as the deforming fermion mass is the only scale in the theory. Chiral perturbation theory (left) does not fit these data well (with the discrepancy growing with beta). FSHS (right) gives a good fit at each value of beta, but the anomalous dimension shrinks as we approach the continuum.

Conclusions

As we have previously observed, the theory displays many hints of near-conformal behaviour. However, we see significant deviations from scaling as we approach the continuum limit, which may be interesting physics but may be lattice artefacts. We are at the limit of what we can do with the current setup and reasonable computing resources. As such we are in the process of preparing new simulations with a new lattice setup that should reduce the influence of lattice artefacts and give a clearer picture. We have requested time in the 15th DiRAC call to enable this work.

References

HiRep: https://github.com/claudiopica/HiRep
Grid: https://github.com/paboyle/Grid
Data: doi:10.5281/zenodo.5139618

Swansea University Prifysgol Abertawe
SUPERCOMPUTING WALES UWCHGYFRIFIADURA CYMRU
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