Staggering towards improved chiral symmetry

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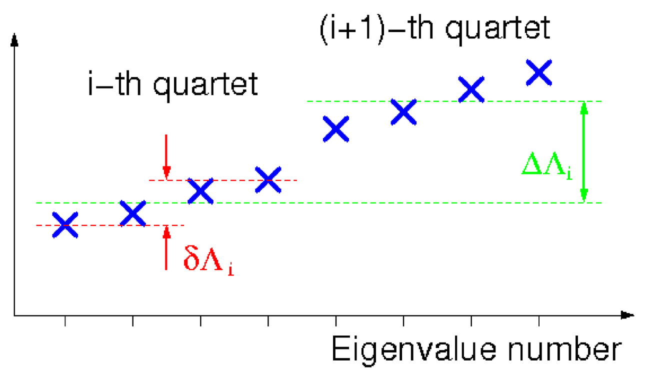
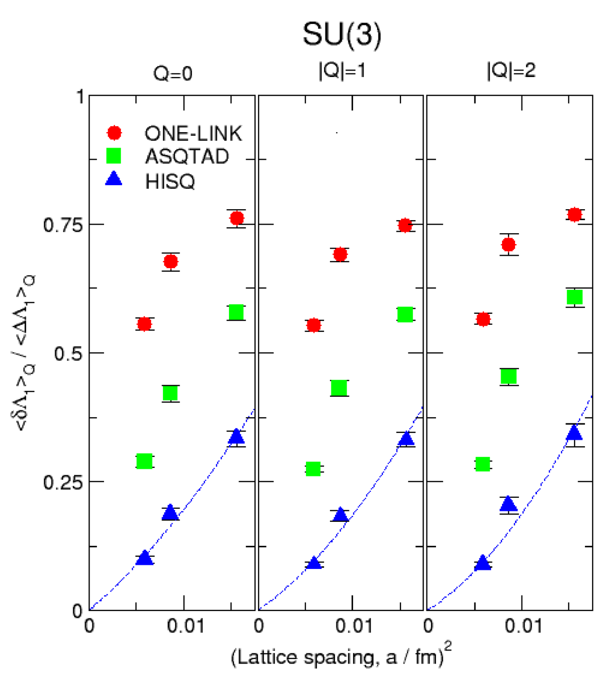
Abstract

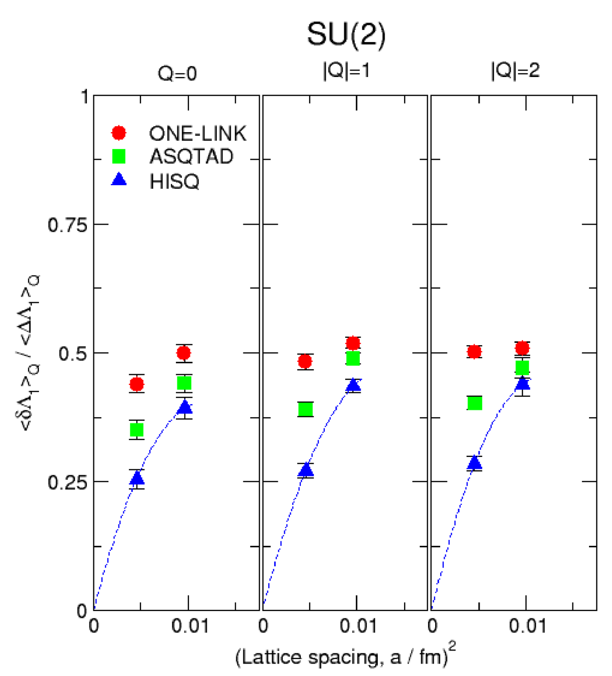
- Staggered fermions offer an efficient method for simulating lattice QCD, but at the price of reduced chiral symmetry and extra tastes.
- To quantify any systematic errors, we need to understand taste-breaking, chiral symmetry restoration and the rooting trick.
- We begin this by studying the smallest Dirac eigenvalues in the ε-regime in quenched SU(3) and SU(2) simulations.
- We show that highly improved staggered operators, such as Asqtad and Hisq, speed up the restoration of chiral symmetry and drastically reduce taste-breaking at lattice spacings $a \simeq 0.07 - 0.10$ fm, as used in current dynamical simulations.

Taste symmetry and eigenvalue quartets

- Staggered fermions only appear in groups of 4 **tastes**, so every Dirac eigenvalue is part of a degenerate quartet.
- Gauge field interaction break the taste symmetry and degeneracy by $\mathcal{O}(a^2)$ at finite lattice spacing.
- The splitting shows how well improvement controls taste breaking
- Look at the ratio of:
  - $\delta\Lambda_i$: difference between largest and smallest
  - $\Delta\Lambda_i$: diff. between means of neighbouring quartets







Hisq reduces taste splitting to $\mathcal{O}(10\%)$ on superfine lattices.

Taste degeneracy and chiral symmetry

- QCD has an SU(4)⊗SU(4) chiral symmetry group.
- Taste interactions break this to U(1)⊗U(1) at finite a.
- Improved taste degeneracy should help restore the full continuum chiral symmetry group.
- We can test this by plotting histograms of low-lying eigenvalues

The ε-regime

The lattice size is chosen to be: $\frac{1}{\Lambda_{\rm QCD}} \ll L \ll \frac{1}{m_\pi}$

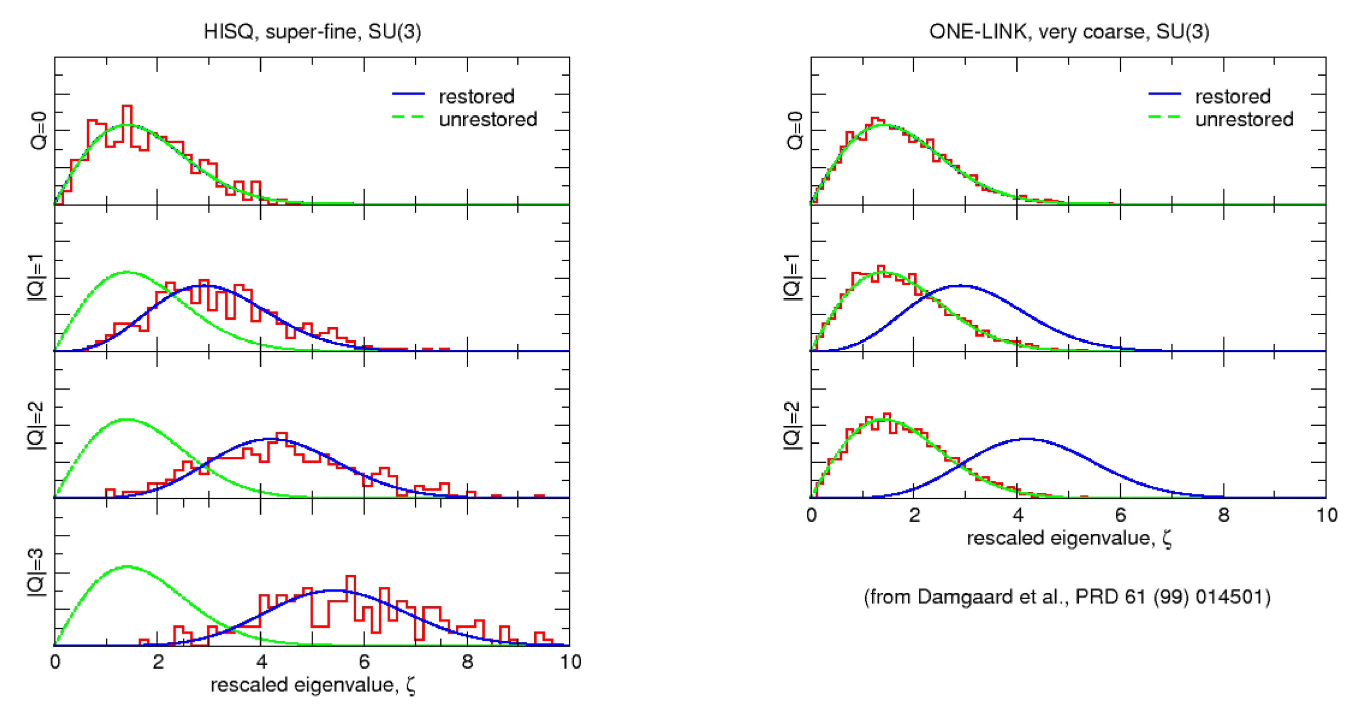
- Large enough that we can integrate out the effects of all hadrons except the pions
- Small enough that we need only consider the static pion modes
- QCD reduces to a non-linear sigma model with same chiral symmetries
- We can predict the distribution of low-lying Dirac eigenvalues analytically:
  - One physical parameter: chiral condensate $\Sigma \simeq (250 \text{ MeV})^3$
  - Unfolded, dimensionless eigenvalues: $\zeta = \lambda\Sigma V$
- Different predictions for different chiral symmetry groups (and different Q).
- Compare with measurements to quantify restoration of continuum chiral symmetry group.
- Can classify predictions in terms of Random Matrix Ensembles.

Gauge group:	SU(3)	SU(2)
Restored	chiral Unitary ensemble	chiral Orthogonal ensemble
Unrestored	chiral Unitary ensemble for $Q = 0$	chiral Symplectic ensemble

Details of the simulations

- Quenched gauge fields: Symanzik and tadpole improved gauge action.
  - Very similar to UKQCD/MILC dynamical simulations.
  - $a = 0.07,\ 0.10,\ 0.12$ fm: "super-fine", "fine", "coarse" (in dynamical MILC parlance)
  - Set scale using string tension $a\sqrt{\sigma} = 440$ MeV
  - Measure topological charge Q using 5-Loop improved gluonic method
- Staggered valence operators:
  - One-link: no improvement, antiquated
  - Asqtad: improved, as used for sea quarks in dynamical runs
  - Hisq: very improved, used for some valence quarks

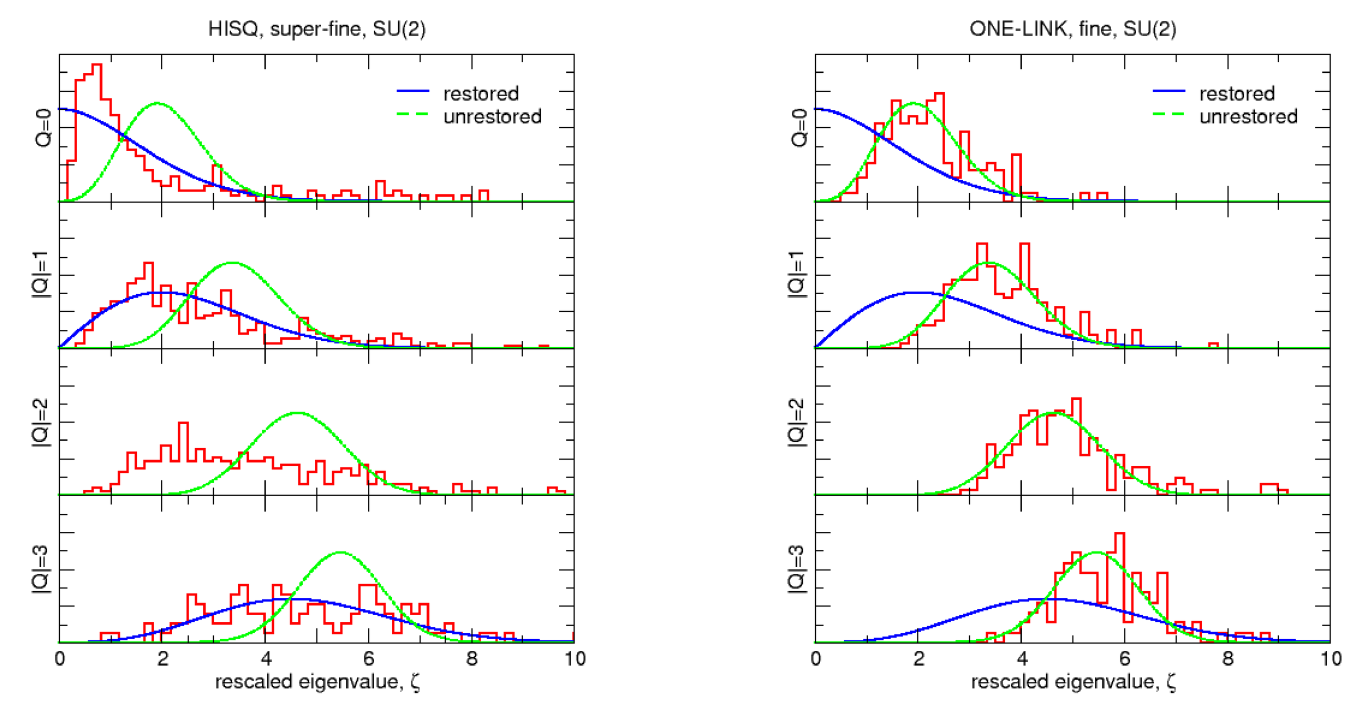
SU(3) results: Hisq superfine vs. One-link *very* coarse ($\beta_{\rm Wil} = 5.2$)



(from Damgaard et al., PRD 61 (99) 014501)

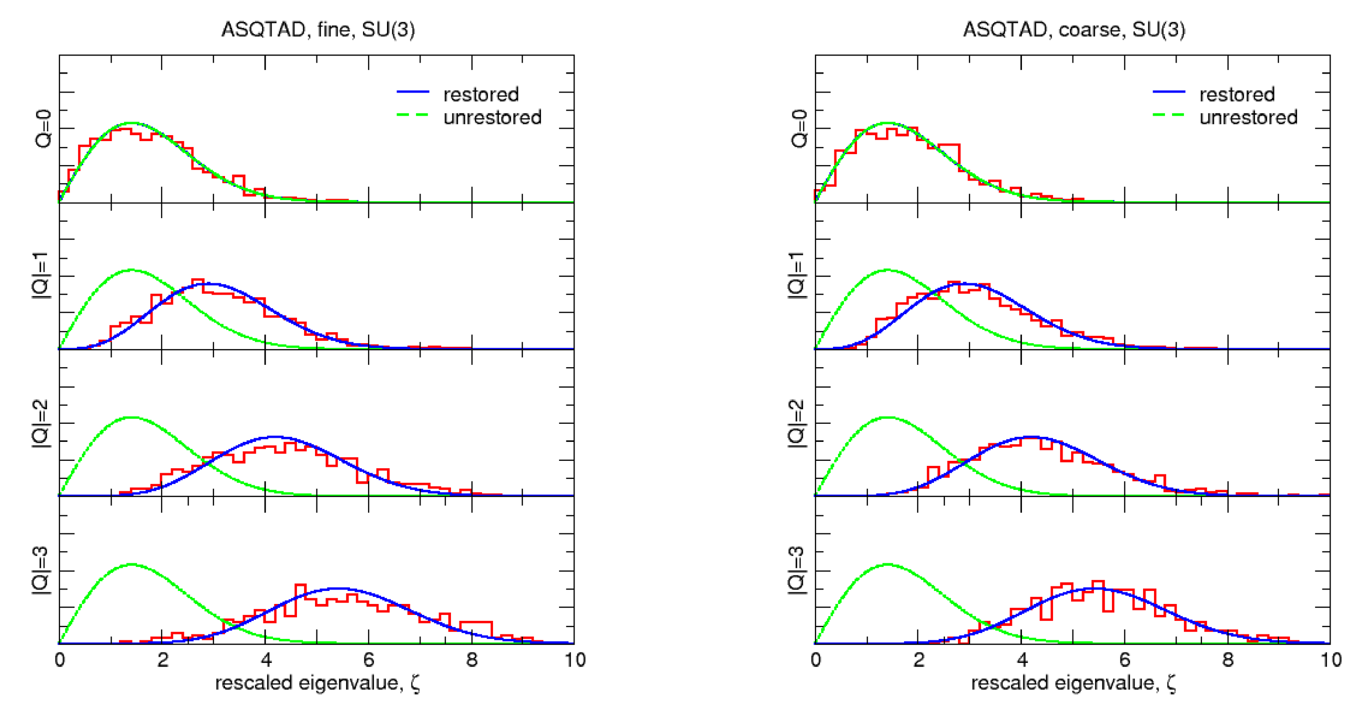
Clear restoration of continuum chiral symmetry group at smaller a.

SU(2) results: Hisq superfine vs. One-link fine



Crossover much more striking, and at smaller lattice spacing for SU(2).

SU(3) results: Asqtad fine and coarse



Asqtad gives continuum–like behaviour over full range of lattice spacings.

Conclusions

- Improved staggered fermions have good taste degeneracy
- The continuum chiral symmetry group is restored at small a
- Improvement ensures quenched restoration has already occurred at lattice spacings used for dynamical lattice spacings.
- Effects of dynamical quarks now being investigated

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