Orientifold Planar Equivalence: the Quenched Meson Spectrum

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(with G. Moraitis, A. Patella, A. Rago)

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Orientifold planar equivalence

- The antisymmetric and the antifundamental representations coincide for $SU(3)$ (but not in general for $SU(N)$) $\Rightarrow$ different SU(N) generalizations of QCD.
- In the planar limit, the (anti)symmetric representation is equivalent to another gauge theory with the same number of Majorana fermions in the adjoint representation (in a common sector). In particular, QCD with one massless fermion in the antisymmetric representation is equivalent to $\mathcal{N} = 1$ SYM in the planar limit $\Rightarrow$ copy analytical predictions from SUSY to QCD.
- The orientifold planar equivalence holds if and only if the C-symmetry is not spontaneously broken in both theories $\Rightarrow$ a calculation from first principles is mandatory.
- Assuming that planar equivalence works, how large are the $1/N$ corrections?

A. Armoni, M. Shifman and G. Veneziano. *SUSY relics in one-flavor QCD from a new 1/N expansion.* Phys. Rev. Lett. 91, 191601, 2003.

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- The orientifold planar equivalence holds if and only if the $\mathcal{C}$-symmetry is not spontaneously broken in both theories $\Rightarrow$ a calculation from first principles is mandatory.
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M. Unsal and L. G. Yaffe. *(In)validity of large N orientifold equivalence.* Phys. Rev. D74:105019, 2006.

A. Armoni, M. Shifman and G. Veneziano. *A note on C-parity conservation and the validity of orientifold planar equivalence.* Phys.Lett.B647:515-518,2007.

Orientifold planar equivalence

Meson Spectrum
Biagio Lucini
Motivations
Correlation Functions
Proof of the quenched equivalence
The numerical calculation
Large-N extrapolation
Conclusions and perspectives

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Dynamical fermions difficult to simulate $\Rightarrow$ start with the quenched theory

A. Armoni, B. Lucini, A. Patella and C. Pica. *Lattice Study of Planar Equivalence: The Quark Condensate.* Phys.Rev.D78:045019,2008.

The Quenched Chiral Condensate

$$\frac{\langle\lambda\lambda\rangle_{\rm Adj}(m=0.012)}{N^2} = 0.23050(22) - \frac{0.3134(72)}{N^2}$$

$$\frac{\langle\bar{\psi}\psi\rangle_{\rm AS}(m=0.012)}{N^2} = 0.23050(22) - \frac{0.4242(11)}{N} - \frac{0.612(43)}{N^2} - \frac{0.811(25)}{N^3}$$

$$\frac{\langle\bar{\psi}\psi\rangle_{\rm S}(m=0.012)}{N^2} = 0.23050(22) + \frac{0.4242(11)}{N} - \frac{0.612(43)}{N^2} + \frac{0.811(25)}{N^3}$$

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Outline

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Mesonic two-point functions on the lattice

Aim

To measure the mesonic two-point functions with Wilson fermions in the two-index representations of the gauge group, in the quenched lattice theory.

- Wilson action.
- Wilson Dirac operator.
- The two-index representations.
- The mesonic two-point correlation functions.

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$$S_{YM} = -\frac{2N}{\lambda} \sum_{p} \Re\mathrm{e}\, \mathrm{tr}\, U(p)$$

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$$D_{xy;\alpha\beta} = (m + 4r)\delta_{xy}\delta_{\alpha\beta} - K_{xy;\alpha\beta}$$

$$K_{xy;\alpha\beta} = -\frac{1}{2}\left[(r-\gamma_\mu)_{\alpha\beta}\, R\left[U_\mu(x)\right]\delta_{y,x+\hat{\mu}} + (r+\gamma_\mu)_{\alpha\beta}\, R\left[U^\dagger_\mu(y)\right]\delta_{y,x-\hat{\mu}}\right]$$

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$$\mathrm{tr}\,\mathrm{Adj}[U] = |\,\mathrm{tr}\,U|^2 - 1$$

$$\mathrm{tr}\,\mathrm{S/AS}[U] = \frac{(\mathrm{tr}\,U)^2 \pm \mathrm{tr}(U^2)}{2}$$

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$$
\begin{aligned}
C^R_{\Gamma_1\Gamma_2}(x,y) &= r_R \left\langle \bar{\psi}^R_a(x)\Gamma_1^\dagger \psi^R_b(x)\bar{\psi}^R_b(y)\Gamma_2\psi^R_a(y) \right\rangle_{YM} \\
&= r_R \left\langle \mathrm{tr}_R \left(D^{-1}_{yx;\alpha\beta}\Gamma_1^{\gamma\beta\star} D^{-1}_{xy;\gamma\delta}\Gamma_2^{\delta\alpha} \right) \right\rangle_{YM}
\end{aligned}
$$

$$
\begin{cases} r_R = 1 & R = \mathrm{S/AS} \\ r_R = 1/2 & R = \mathrm{Adj} \end{cases}
$$

Outline

Heuristic proof of the quenched equivalence

Equivalence

$$\lim_{N\to\infty} \frac{1}{N^2} C^{S/AS}_{\Gamma_1\Gamma_2}(x,y) = \lim_{N\to\infty} \frac{1}{N^2} C^{\mathrm{Adj}}_{\Gamma_1\Gamma_2}(x,y)$$

- Expand in Wilson loops.
- Replace the two-index representations.
- Take the large-N limit.
- Use invariance under charge conjugation.

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$$\frac{1}{N^2} C^{S/AS}_{\Gamma_1\Gamma_2}(x,y) = \frac{1}{2} \sum_{\mathcal{C}\supset(x,y)} \alpha_{\mathcal{C}} \frac{\langle [\mathrm{tr}\, W_{\mathcal{C}}]^2\rangle \pm \langle \mathrm{tr}[W^2_{\mathcal{C}}]\rangle}{N^2}$$

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$$\langle \mathrm{tr}\, W^\dagger_{\mathcal{C}} \rangle = \langle \mathrm{tr}\, W_{\mathcal{C}} \rangle \qquad \Rightarrow \qquad \lim_{N\to\infty} \frac{1}{N^2} C^{S/AS}_{\Gamma_1\Gamma_2}(x,y) = \lim_{N\to\infty} \frac{1}{N^2} C^{\mathrm{Adj}}_{\Gamma_1\Gamma_2}(x,y)$$

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A more formal proof of the equivalence exists which does not use the expansion in Wilson loops, but is much more involved

Outline

Simulation strategy

- Simulations performed for $N = 2, 3, 4, 6$
- $\beta(N)$ chosen in such a way that $(aT_c)^{-1} = 5$ $(a \simeq 0.145 \text{ fm})$
- Calculations on a 32×16^3 lattice, which corresponds to $L \simeq 2.3$ fm
- $C^R_{\Gamma_1\Gamma_2}$ determined for $\Gamma_1 = \Gamma_2 = \gamma_5$ (π channel) and $\Gamma_1 = \Gamma_2 = \gamma_i$ (ρ channel)
- Mass extracted from the ansatz $C^R_{\Gamma_1\Gamma_2}(t) = A \cosh\left(m(t - T/2)\right)$
- Chiral extrapolation of m_ρ using $m_\rho(m_\pi) = cm_\pi^2 + m_\rho(m_\pi = 0)$
- Extrapolation to large N

The calculation has been performed using the HiRep code

(L. Del Debbio, A. Patella, C. Pica, arXiv:0805.2058)

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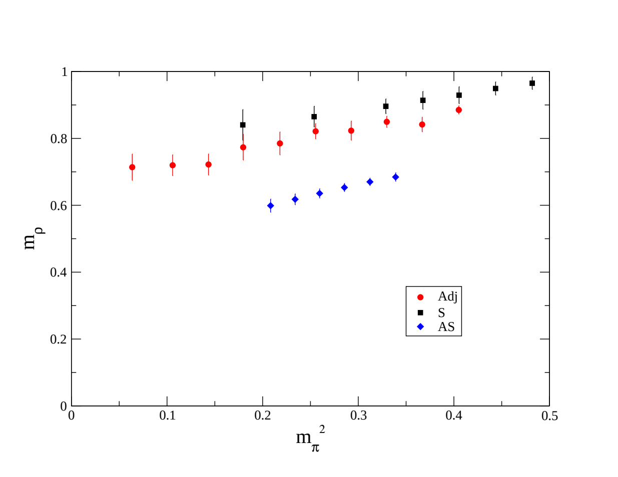
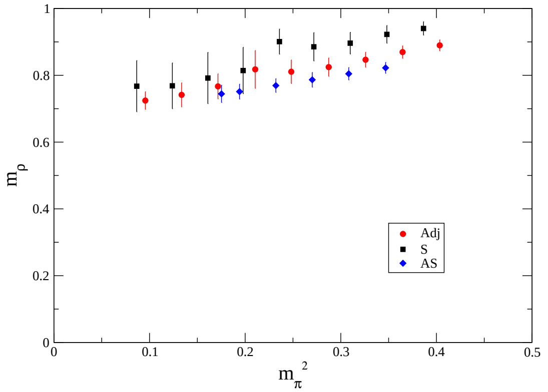
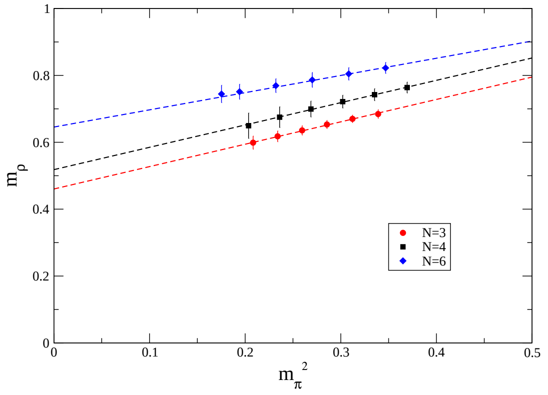
m_ρ vs. m_π in SU(3)



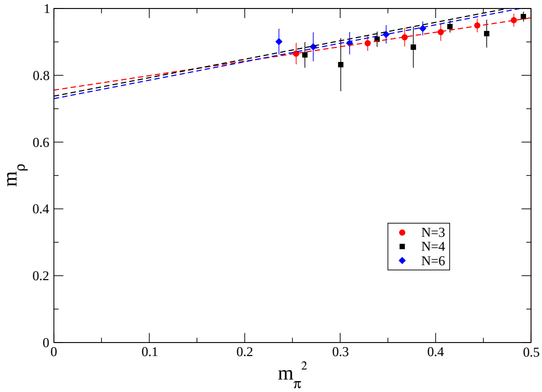
m_ρ vs. m_π in SU(6)



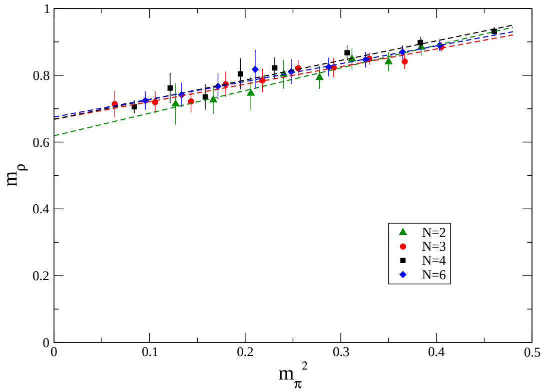
m_ρ vs. m_π (Antisymmetric)



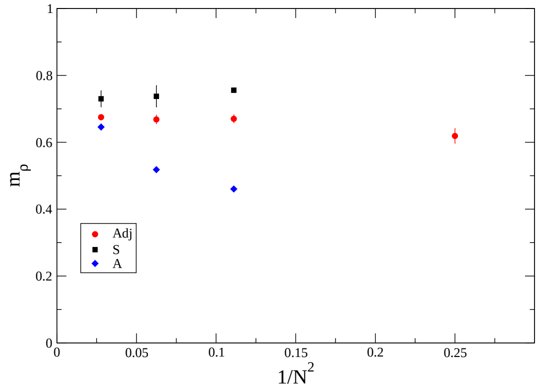
m_ρ vs. m_π (Symmetric)



m_ρ vs. m_π (Adjoint)



Chiral extrapolation of m_ρ



Outline

Order of corrections

The correlator in the adjoint representation decays with a mass m_ρ^{Adj} that can be expressed as a power series in $1/N^2$, while m_ρ^{AS} and m_ρ^{S} have $1/N$ corrections that are related:

$$m_\rho^{\mathrm{Adj}}(N) = F\left(\frac{1}{N^2}\right) \ ;$$

$$m_\rho^{\mathrm{S}}(N) = M\left(\frac{1}{N^2}\right) + \frac{1}{N}\mu\left(\frac{1}{N^2}\right) \ ;$$

$$m_\rho^{\mathrm{AS}}(N) = M\left(\frac{1}{N^2}\right) - \frac{1}{N}\mu\left(\frac{1}{N^2}\right) \ .$$

$M = \left(m_\rho^{\mathrm{S}} + m_\rho^{\mathrm{AS}}\right)/2$ and $\mu = N\left(m_\rho^{\mathrm{S}} - m_\rho^{\mathrm{AS}}\right)/2$ can be expressed as a power series in $1/N^2$

Orientifold planar equivalence is the statement $F(N=\infty) = M(N=\infty)$

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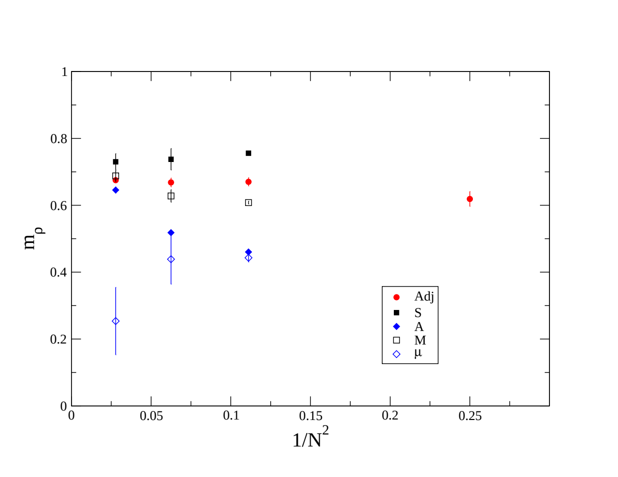

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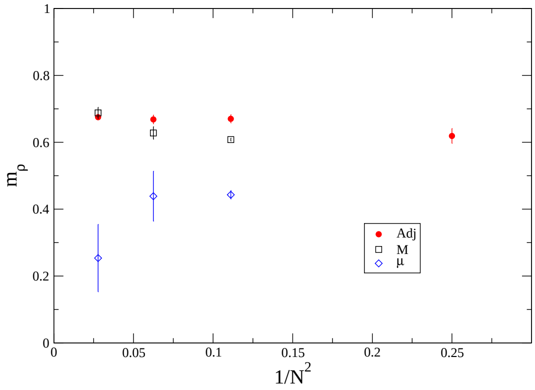
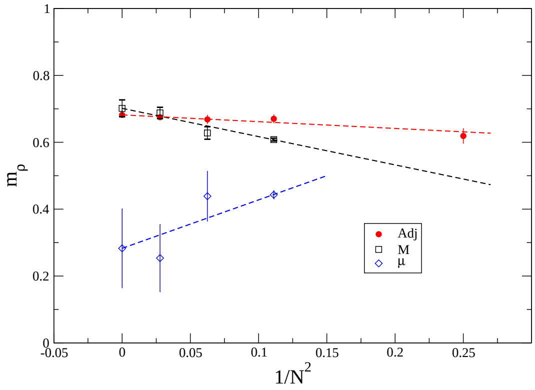


Large-N fits



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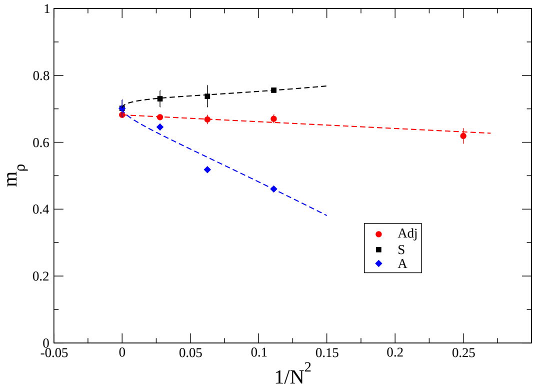

Fit results

$$m_\rho^{\mathrm{Adj}} = 0.6819(51) - \frac{0.202(67)}{N^2} ;$$

$$m_\rho^{\mathrm{S}} = 0.701(25) + \frac{0.28(12)}{N} - \frac{0.85(24)}{N^2} + \frac{1.4(1.0)}{N^3} ;$$

$$m_\rho^{\mathrm{AS}} = 0.701(25) - \frac{0.28(12)}{N} - \frac{0.85(24)}{N^2} - \frac{1.4(1.0)}{N^3} .$$

Orientifold planar equivalence verified within 3.5%

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Conclusions and perspectives

- Check of the orientifold planar equivalence in a simple case
- Computation of the ρ and π masses for two-index irredicible representations and evaluation of the corrections in $1/N$
- SU(3) AS is numerically far from the large N limit of the adjoint representation, but it is obtainable from it with a controlled power expansion
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