Spectroscopy of two dimensional N=2 Super Yang Mills theory

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Research Training Group
Quantum and Gravitational Fields

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Motivation

Many interesting non-perturbative aspects of SUSY

confinement, massless composite fermions,
spontaneous chiral symmetry breaking,...

Our focus: N=2 SYM in d=2

dimensional reduction of N=1 d=4 SYM
gauge group SU(2) [DESY-Münster Collaboration]

Restoration of SUSY via parameter fine-tuning

SUSY on the lattice

Problem

$\left\{Q^I, (Q^I)^\dagger\right\} \sim P^\mu \rightarrow$ SUSY must be broken on the lattice
or: Leibniz rule is violated $\rightarrow$ Action not invariant under SUSY

two possible solutions

- Accidental Symmetry
- Preserve subset of SUSY

Model
N=2 SYM in d=2

Reducible Model

$$\mathcal{L} = \frac{1}{g^2}\mathrm{tr}\left\{-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{i}{2}\overline{\lambda}\Gamma_\mu D^\mu\lambda - \frac{1}{2}D_\mu\phi_m D^\mu\phi^m + \frac{1}{2}\overline{\lambda}\Gamma_{1+m}\left[\phi^m,\lambda\right] + \frac{1}{4}\left[\phi_m,\phi_n\right]\left[\phi^m,\phi^n\right]\right\}$$

Field Content

- λ Majorana fermion with four spin indices
- Γ_μ four dimensional Gamma matrices
- A_μ two dimensional gauge fields
- ϕ^m two scalars

Model
N=2 SYM in d=2

Reducible Model

$$\mathcal{L} = \frac{1}{g^2}\mathrm{tr}\left\{-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{i}{2}\overline{\lambda}\Gamma_\mu D^\mu\lambda - \frac{1}{2}D_\mu\phi_m D^\mu\phi^m + \frac{1}{2}\overline{\lambda}\Gamma_{1+m}\left[\phi^m,\lambda\right] + \frac{1}{4}\left[\phi_m,\phi_n\right]\left[\phi^m,\phi^n\right]\right\}$$

Wilson Fermions

- introduce Wilson term for λ
- preserves the R symmetry
- flat directions in the scalar potential

Fine-tuning
General Considerations

Loop Expansion

- super renormalizable
- only relevant operator $m_s^2 \phi^m \phi_m$
  continuum limit: $m_s^2 = 0.3297413(1)$ [Suzuki and Taniguchi,2005]

Chiral Limit

- in the continuum limit: chiral symmetry restored
- improve lattice results with additional fine tuning
- introduce the operator $m_F \bar{\lambda} \lambda$

Fine-tuning
Ward Identities

- the originating operator is

$$\mathrm{Tr}_c \left\{ \overline{\lambda}_b (x) \left(\gamma_{\mu\nu}\right)_a^b F^{\mu\nu} (x) \right\}$$

Bosonic Ward Identity

$$\beta \langle S_B \rangle = -\frac{3}{8} \left\langle \frac{i}{2} \overline{\lambda}(x) \not{D} \lambda(x) \right\rangle = 4.5V$$

- problematic for fine-tuning
- we use the Ward Identity

$$\beta \left\langle \frac{1}{2} [\phi_1, \phi_2]^2 \right\rangle = \frac{1}{4} \left\langle \frac{i}{2} \overline{\lambda} \Gamma_2 [\phi_1, \lambda] + \frac{i}{2} \overline{\lambda} \Gamma_3 [\phi_2, \lambda] \right\rangle$$

Lattice setup and Continuum Limit

Continuum Limit

coupling constant in two dimensions:

$$\beta = \frac{N_c}{a^2 g^2} \xrightarrow[\text{limit}]{\text{Continuum}} \infty$$

Lattice setup

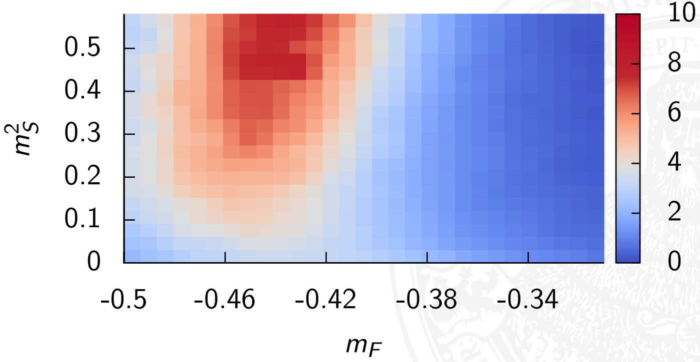
- RHMC algorithm
- Symanzik improved action
- Wilson fermions
- 16x16 and 32x32 lattices, larger lattices: work in progress
- $\beta = 1.5, 2.0, 2.5, 3.0$

Chiral Limit

Parameter space

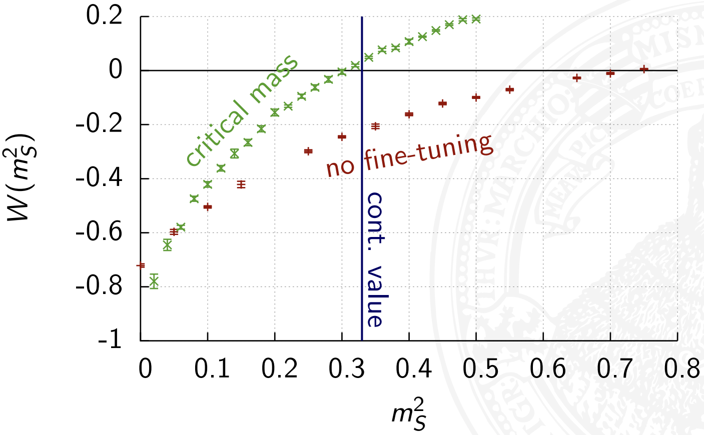
Chiral Susceptibility

16×16 lattice



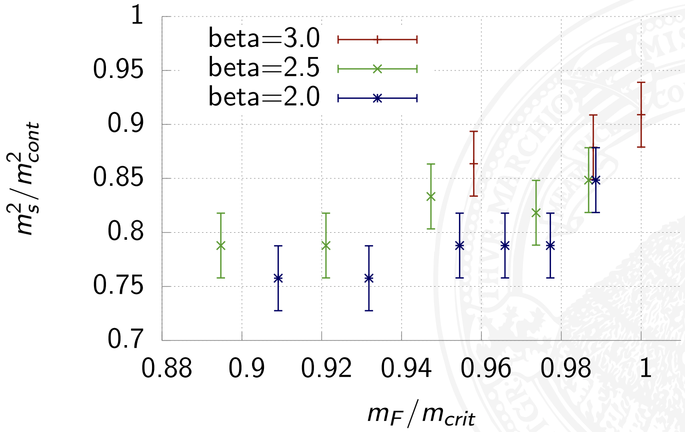
Chiral Limit
Ward Identity

16×16 lattice



Chiral Limit
Ward Identity

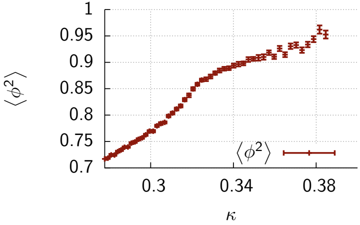
32 × 32 lattice



Flat directions

$\langle\phi^2\rangle$ Measurement

Data for $m_s^2 = 0$



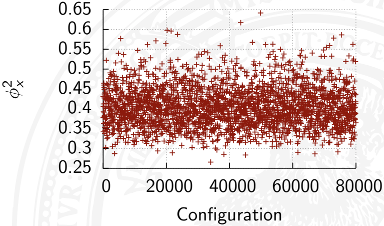


Figure: On the left: value and variance of $\langle\phi^2\rangle$ depending on κ. On the right: example data for $\kappa = 0.3125$,chiral limit: $\kappa_{crit} \approx 0.31$

Mass spectrum
Expectations from four dimensions

Veneziano and Yankielowicz

particle	spin	name
$\bar{\lambda}\gamma_5\lambda$	0	a-η'
$\bar{\lambda}\lambda$	0	a-f_0
$F_{\mu\nu}\Sigma^{\mu\nu}\lambda$	$\frac{1}{2}$	gluino-glueball

[Veneziano and Yankielowicz, 1982]

Farra,Gabadadze and Schwetz

particle	spin	name
$F_{\mu\nu}\epsilon^{\sigma\rho}_{\mu\nu}F^{\sigma\rho}$	0	0^--glueball
$F_{\mu\nu}F^{\mu\nu}$	0	0^+-glueball
$F_{\mu\nu}\Sigma^{\mu\nu}\lambda$	$\frac{1}{2}$	gluino-glueball

[Farra,Gabadadze and Schwetz, 1998]

Mass spectrum
Pion

- gaugino mass related to pion mass $m_g \sim m_\pi^2$ [Donini et al. 1998]
- connected part of $\eta' \sim \pi$ [Veneziano and Yankielowicz, 1982]

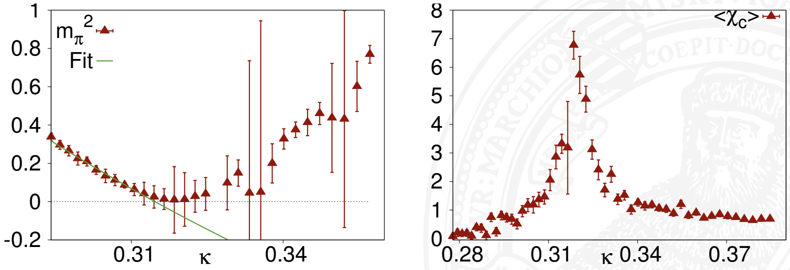


Figure: Pion mass squared with $\kappa_{crit} \approx 0.315$(left) and chiral Susceptibility with $\kappa_{crit} \approx 0.320$(right)

Meson Masses

16×16

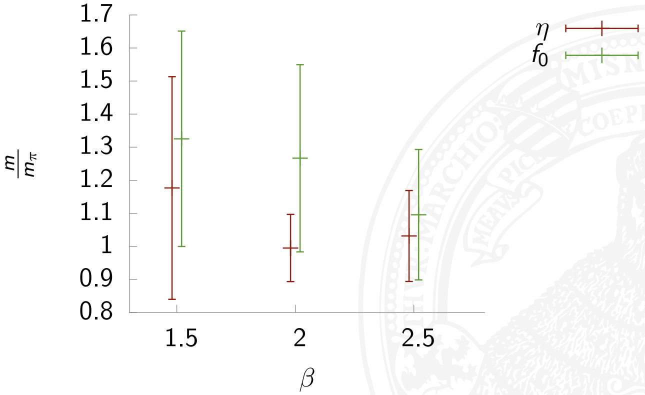


Figure: Ground states for three different β

Glue Ball
Correlator

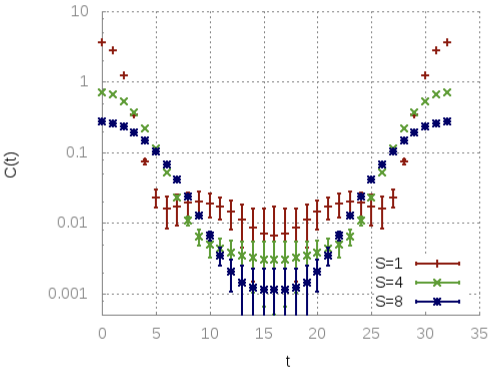
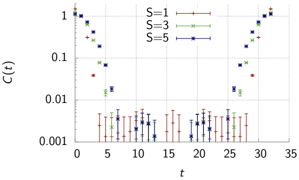


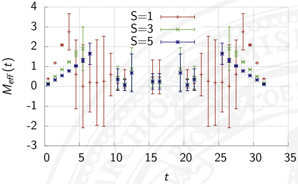
Figure: Glue Ball Correlator for different Smearing parameters

- Smearing Steps N_S
- Smearing Parameter p_S
- in Graph: $S = N_S \cdot p_S$

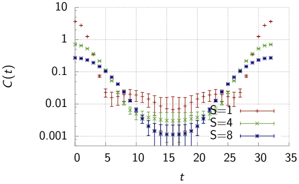
Comparison Glue Balls

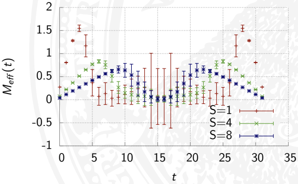
pure Gauge Theory





N=2 SYM





Summary

Conclusion

- We simulated N=1 SYM dimensional reduced to two dimensions on the lattice in the chiral limit
- probably mass degenerate Meson ground states
- probably massless Glue Balls
- other parts of the super multiplet: work in progress

Outlook

- perform the continuum limit
- increase lattice size
- check further Ward identities