Simulations of $\mathcal{N} = 1$ supersymmetric Yang-Mills theory with three colours

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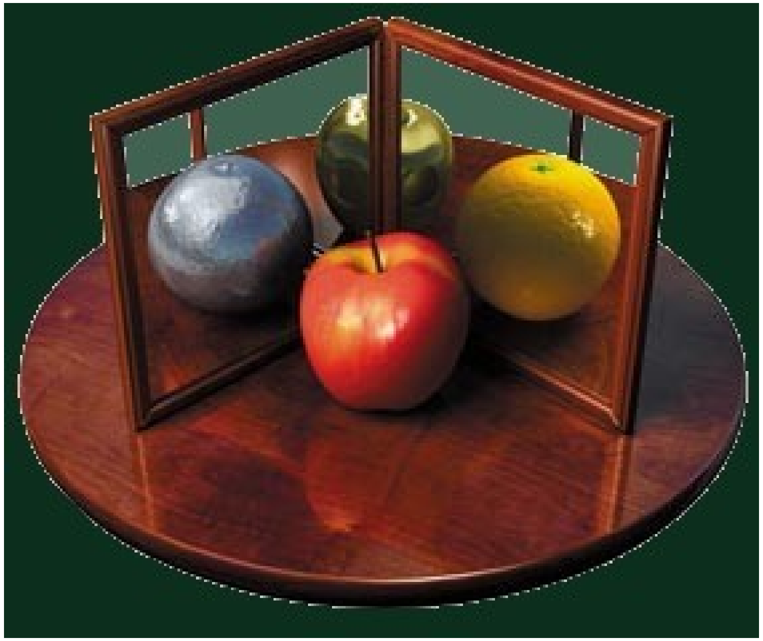
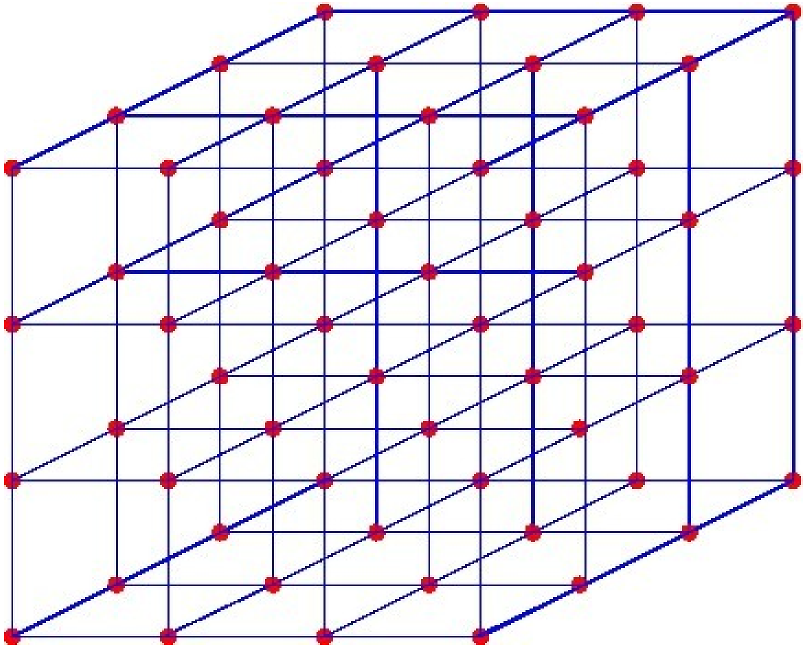
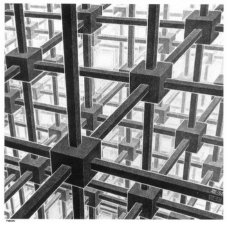
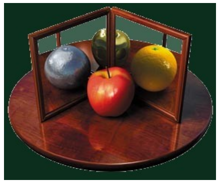




Lattice 2016, Southampton, 26/July/2016

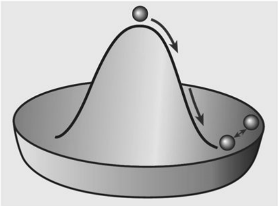
Introduction

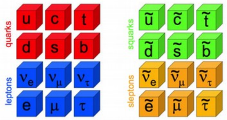




Tuning SUSY

Vacua





Mass spectrum

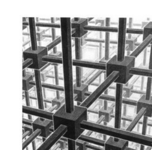
Scale
setting

Conclusions

SUSY on the lattice is important to test non-perturbative aspects of supersymmetric theories

- We look for non-perturbative mechanisms of spontaneous breaking of SUSY
- We study many non-perturbative aspects: confinement/deconfinement, chiral symmetry, topology
- We test effective theories for the low energy spectrum
- We can test the orientifold equivalence:

$$N_f = 1 \;\; QCD \Leftrightarrow \mathcal{N} = 1 \;\; SYM$$



We study $\mathcal{N} = 1$ supersymmetric Yang-Mills theory with gauge group SU(3)

- The Euclidean action in the continuum:

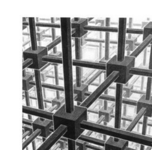
$$S(g, m_g) = \int d^4x \left\{ \frac{1}{4}(F^a_{\mu\nu} F^a_{\mu\nu}) + \frac{1}{2}\bar{\lambda}_a(\gamma^\mu D^{ab}_\mu + m)\lambda_b - \frac{\Theta}{16\pi}\epsilon_{\mu\nu\rho\sigma}F^{\mu\nu}F^{\rho\sigma} \right\}$$

- Gauge fields A_μ (gluons)
- Majorana fermions λ_a (gluinos) in the adjoint representation

- SUSY relates boson gauge fields and fermions:

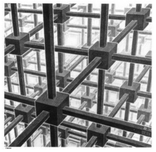
$$A_\mu(x) \to A_\mu(x) - 2i\bar{\lambda}(x)\gamma_\mu\epsilon$$

$$\lambda^a(x) \to \lambda^a(x) - \sigma_{\mu\nu}F^a_{\mu\nu}(x)\epsilon$$



SUSY is broken on the lattice

- SUSY is related to infinitesimal translations $\{Q_\alpha, Q_\beta\} = (\gamma^\mu C)_{\alpha,\beta} P_\mu$
- Gluino mass $m_g \neq 0$
- Finite volume

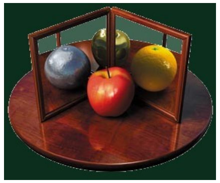


We tune the $\mathrm{m}_g = 0$ limit by $\mathrm{a}\text{–}m_\pi$

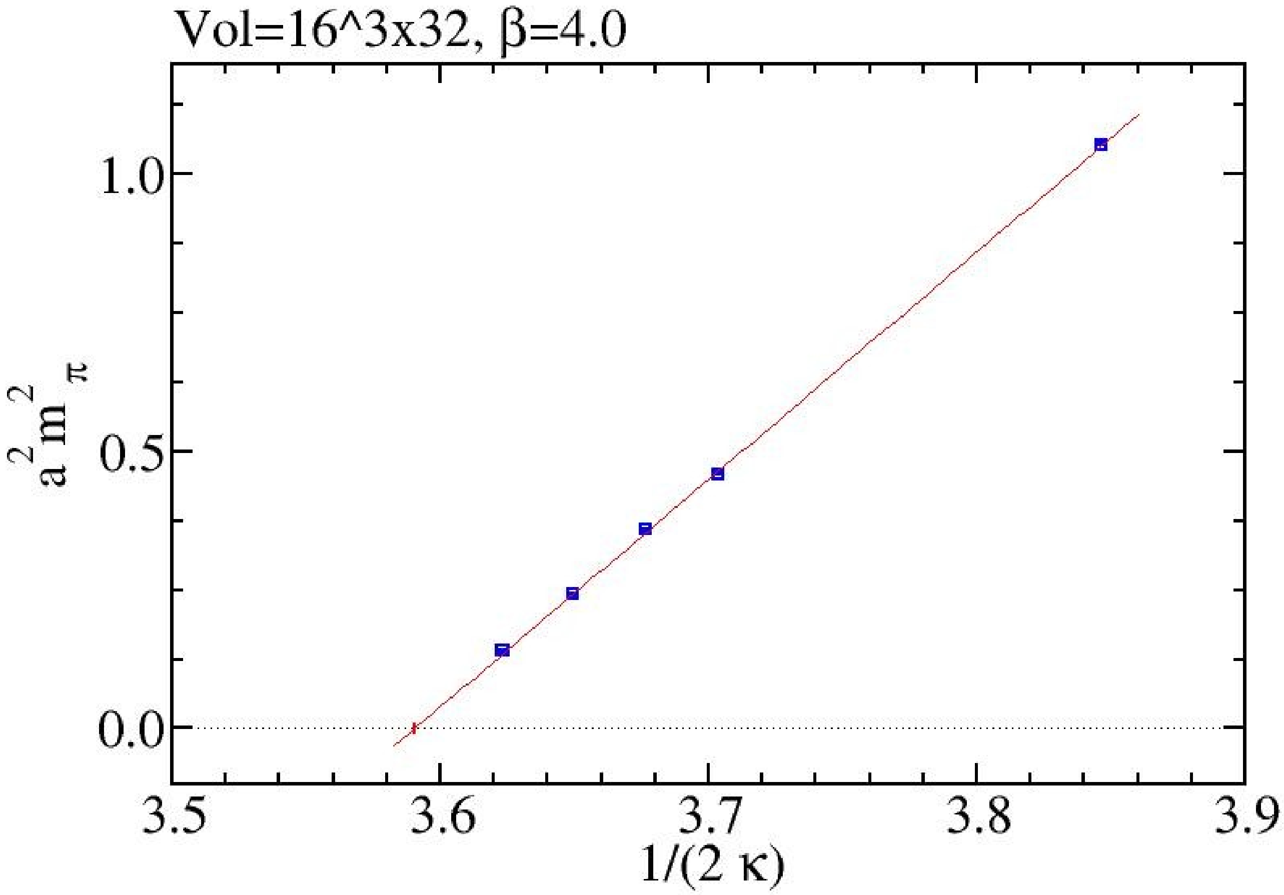
- The adjoint pion is not a physical particle!
- It is the connected part of the $\mathrm{a}\text{–}\eta'$ ($\bar{\lambda}\gamma_5\lambda$) correlator
- Assumption: $m^2_{\mathrm{a}-\pi} \propto m_{\tilde{g}}$

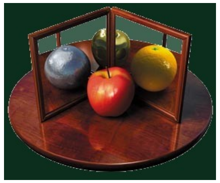
- OZI (Okubo-Zweig-Iizuka) approximation
- Well defined in ”Partially Quenched Chiral Perturbation Theory”

  G.Münster, H.Stüwe, JHEP1405 (2014) 034

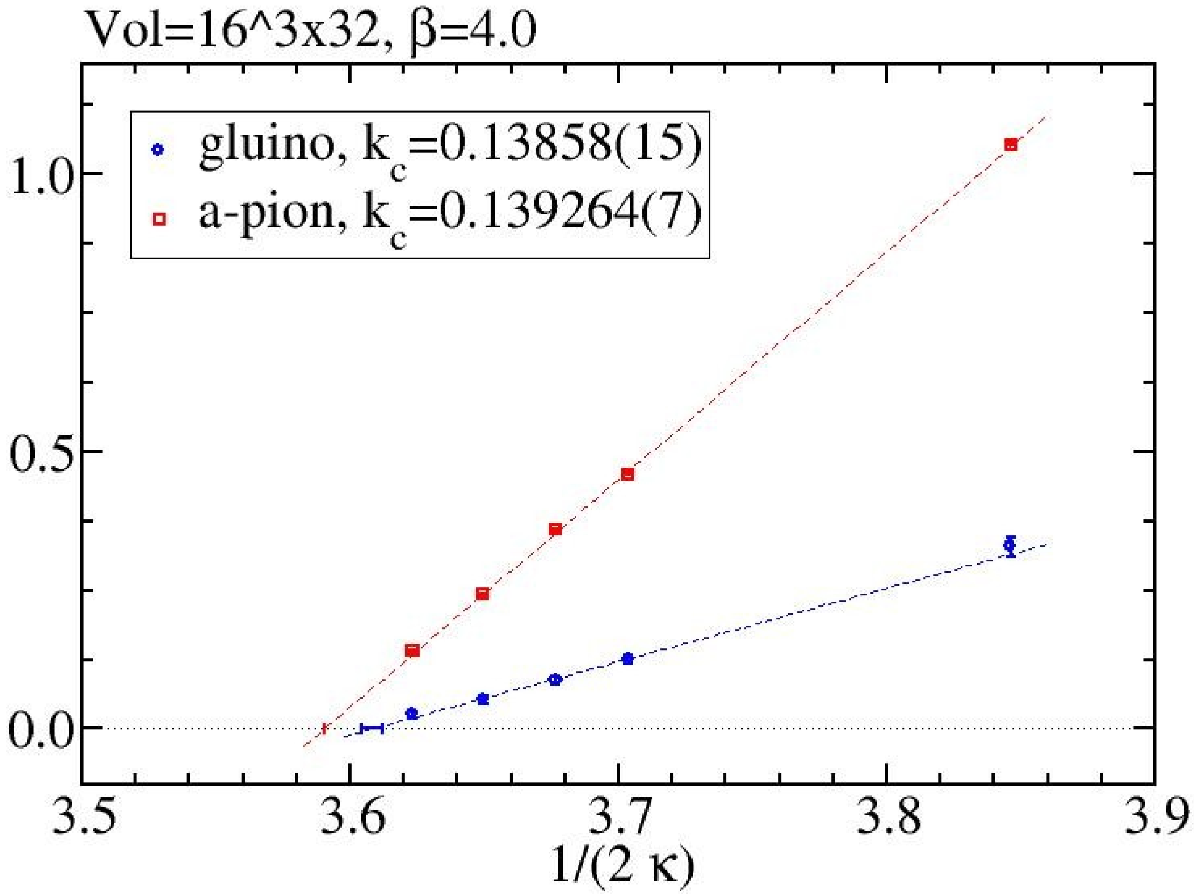


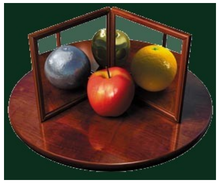
m_π^2 is linear in $1/\kappa$ ($\chi^2/dof = 20.8$)

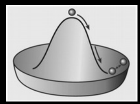




κ_c obtained from $\mathrm{a}\!-\!m_\pi$ is compatible (in 4.5σ) with that obtained from SUSY Ward Identities







$\mathcal{N}=1$ SUSY is characterised by chiral symmetry

$$\lambda \to \lambda' = \exp(-i\omega\gamma_5)\lambda$$

Classical $U(1)_A$ axial symmetry

gluino mass zero!

$$\partial_\mu J_5^\mu = \partial_\mu(\bar{\lambda}\gamma^\mu\gamma_5\lambda) = N_c \frac{g^2}{32\pi^2}\epsilon_{\mu\nu\rho\sigma}F^{\mu\nu}F^{\rho\sigma}$$

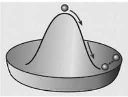
This anomalous contribution
can be absorbed by the theta-term!

$$\Theta \to \Theta - 2N_c\,\omega,$$

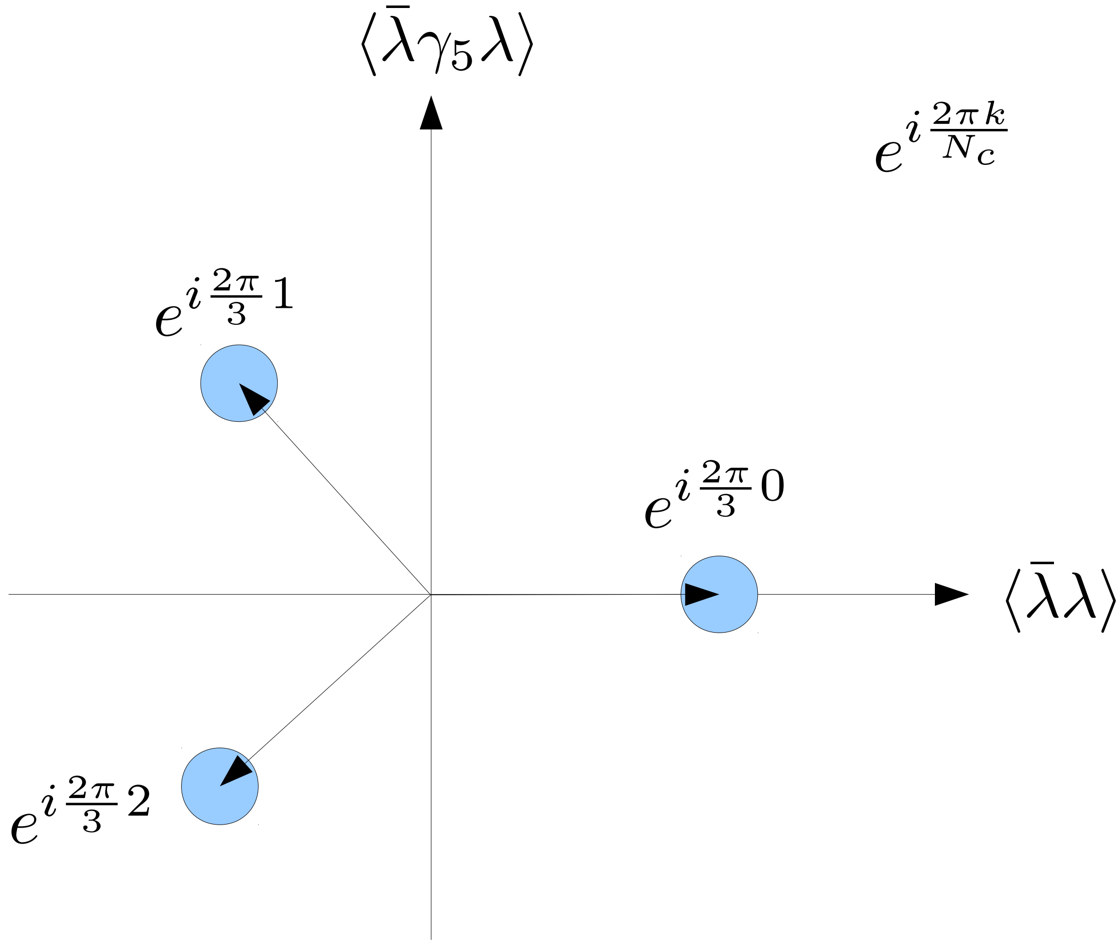
$$\omega = \frac{n\pi}{N_c},\; n = 0,\ldots,2N_c-1$$

$$U(1)_A \to Z_{2N_c} \to Z_2$$

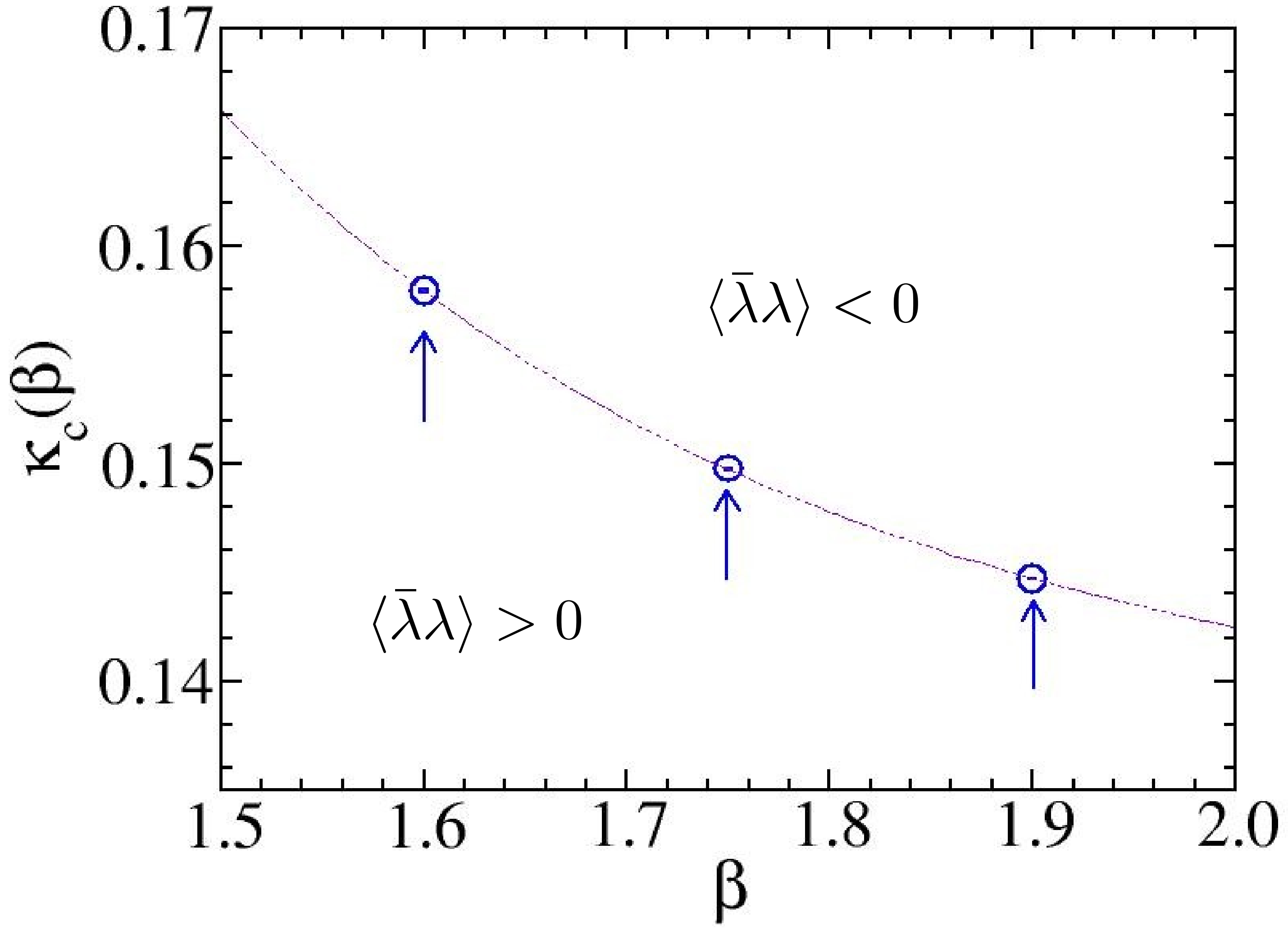
$$\langle\lambda^\alpha\lambda^\alpha\rangle = c\Lambda^3 e^{i\frac{2\pi k}{N_c}}$$



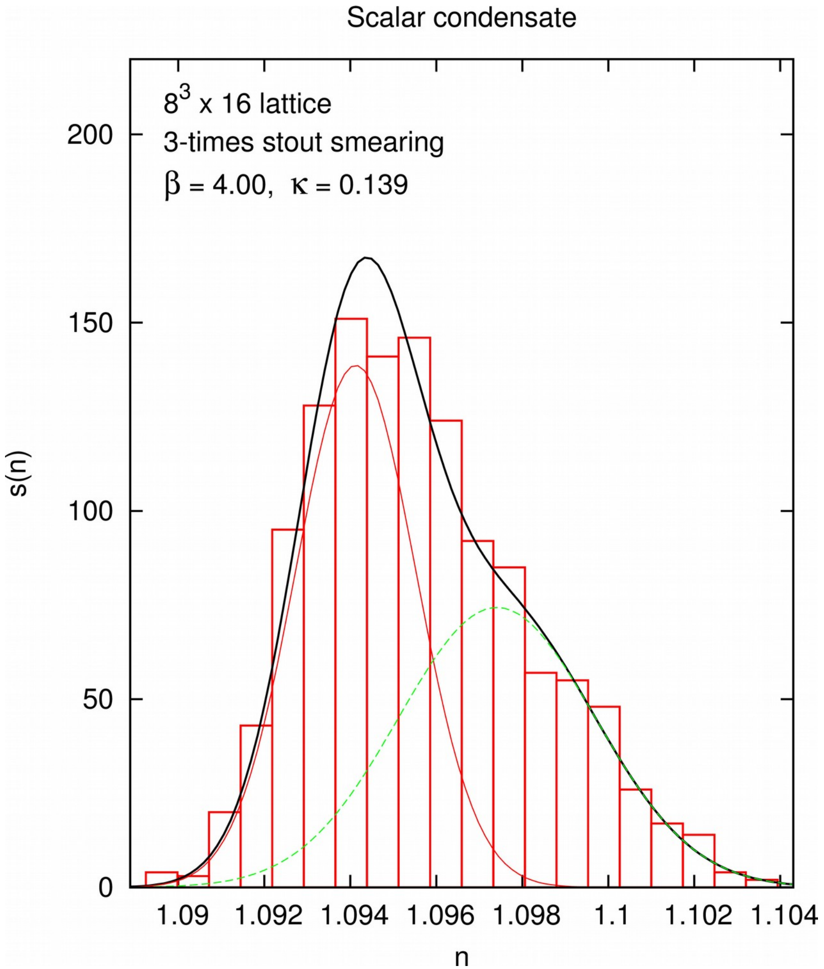
For SU(3) we expect 3 vacua (with a first order transition between them)

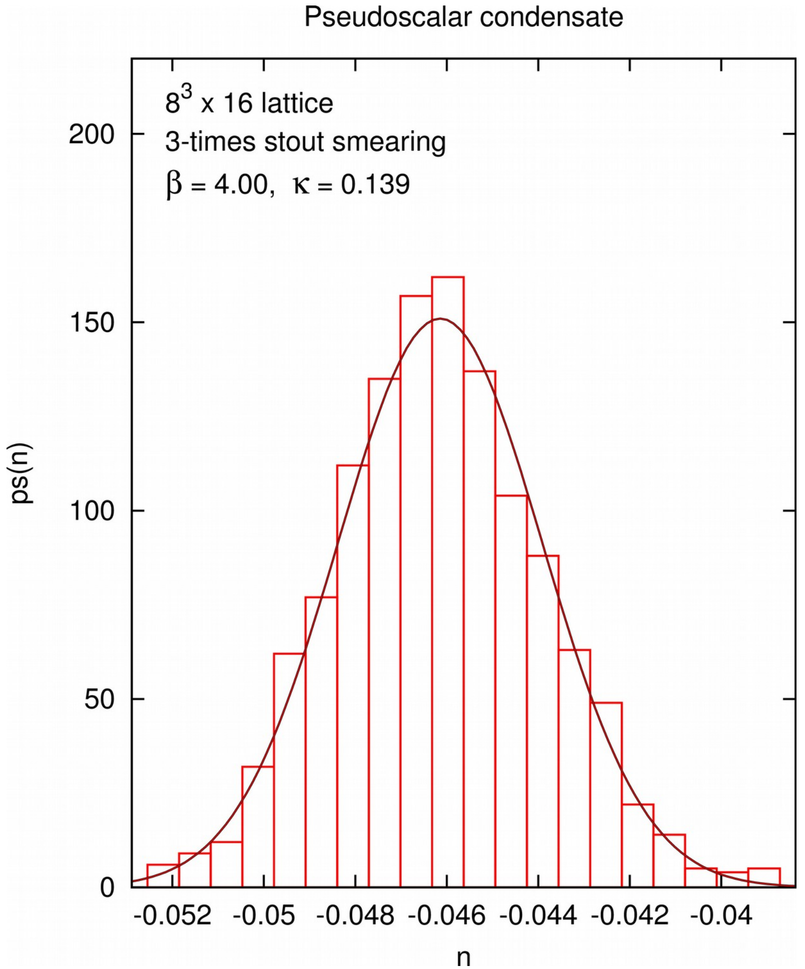


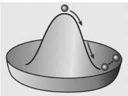
We know the expected phase structure [this was for SU(2)]:



We see a double peak structure in the scalar condensate but not in the pseudoscalar

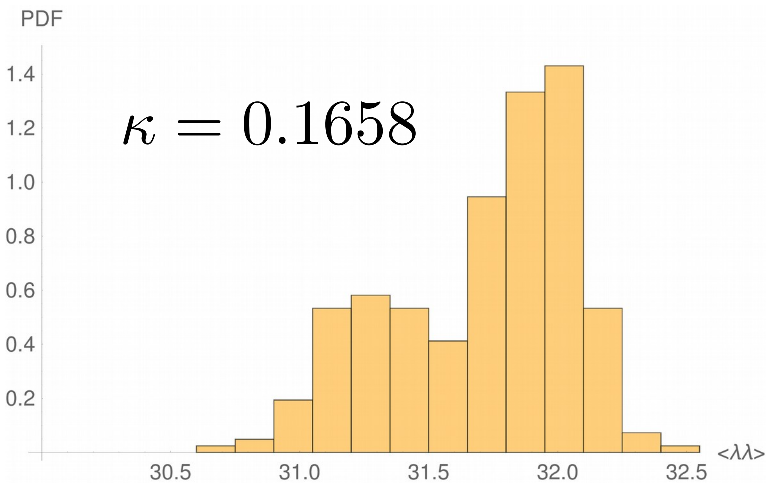


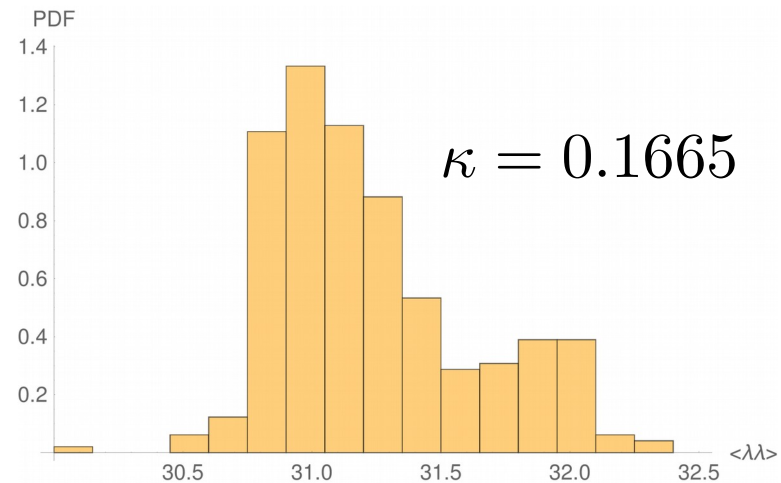


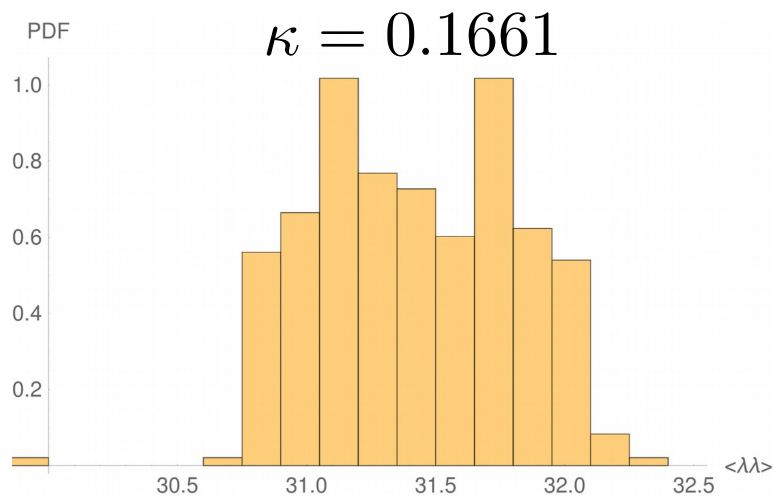


Here the double peak is clearer

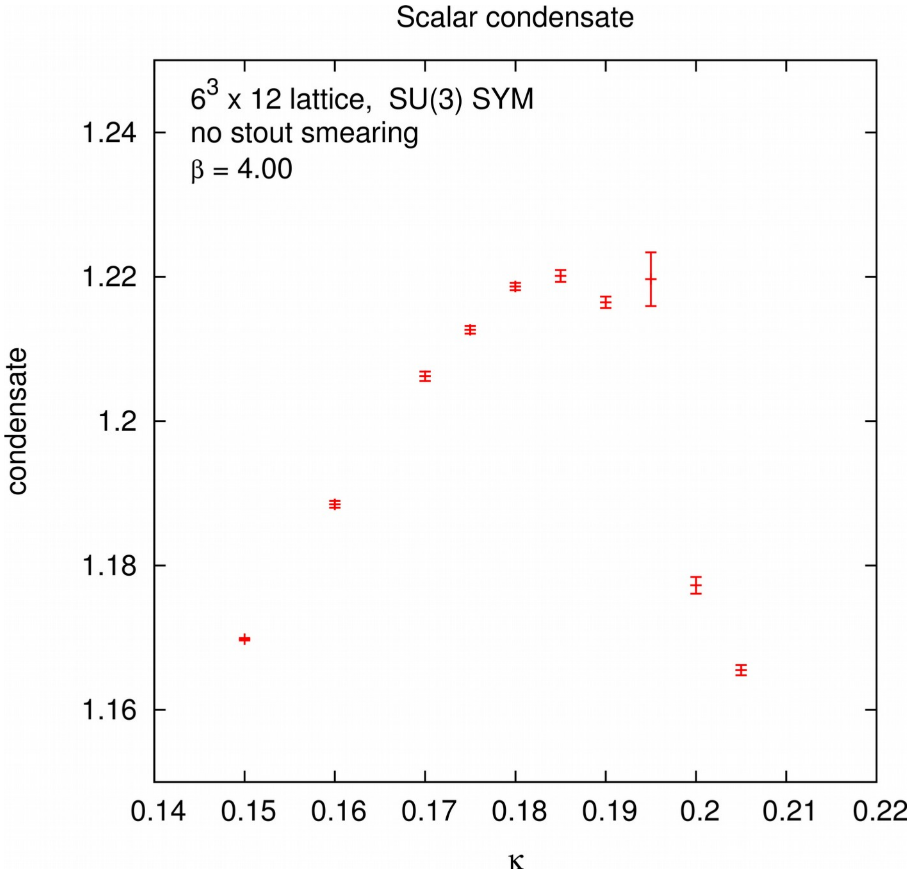
$$6^4, \beta = 5.6, c_w = 1.587, \kappa_c = 0.166(1)$$

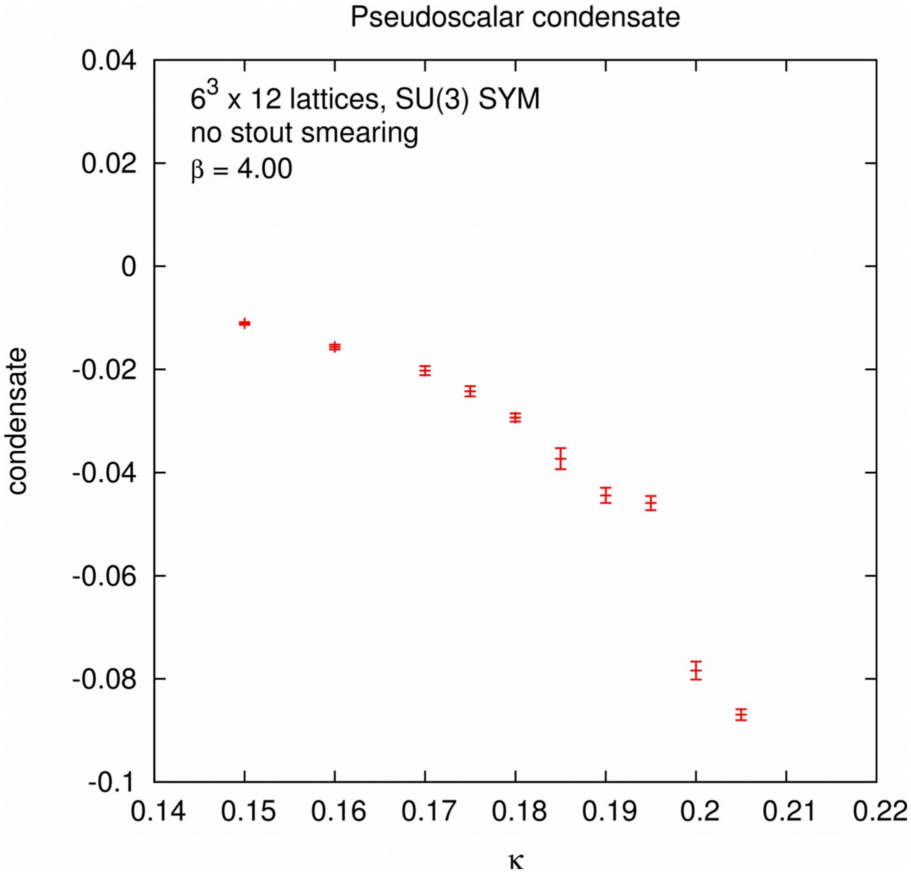


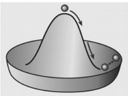




In our last, preliminary, results we see a jump also in the pseudoscar channel

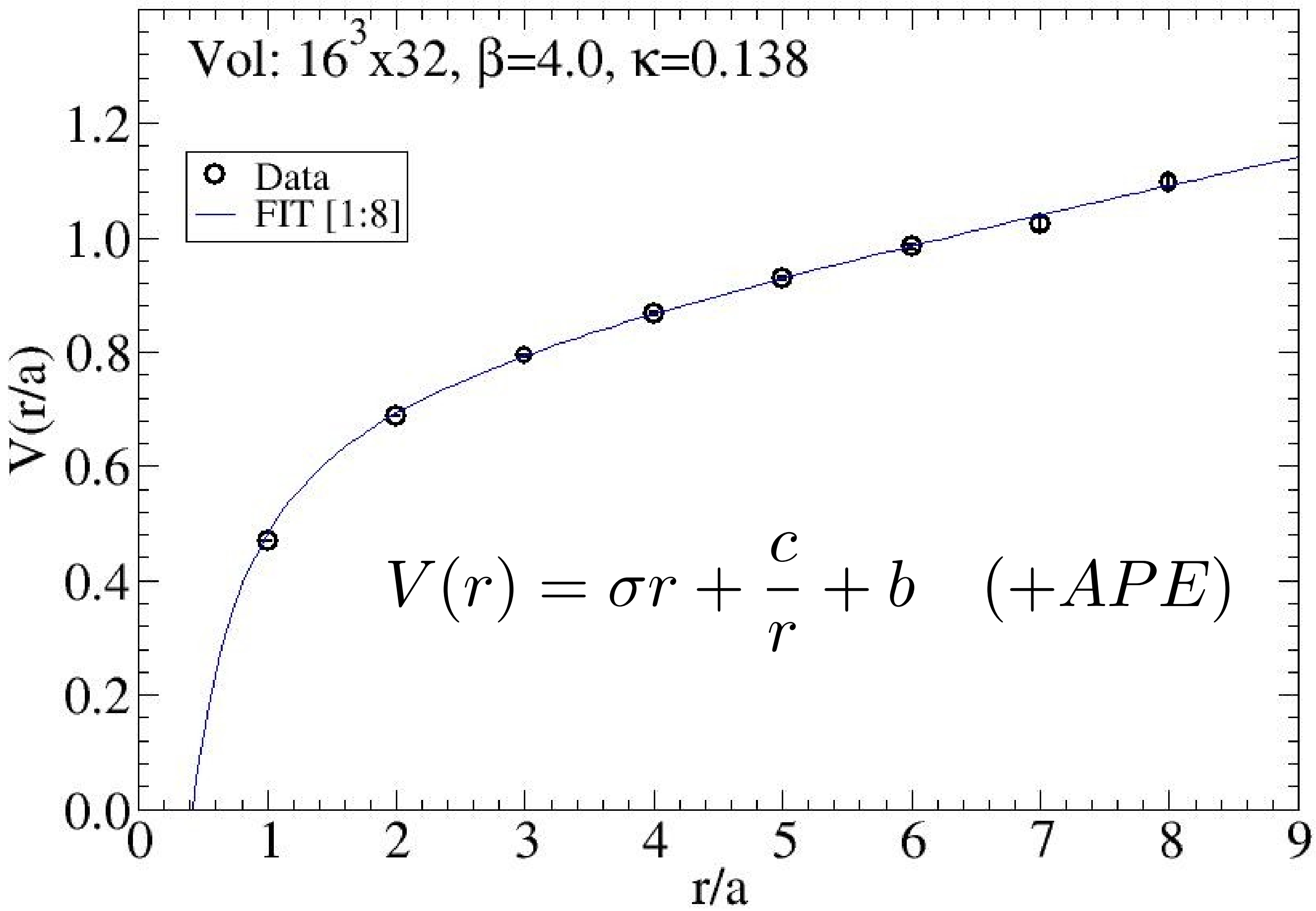







IRROMPIBLE
INQUEBRAVEL
INCASSABLE
NON-SHATTER
19
20

We fix the scale using the Sommer Parameter r_0



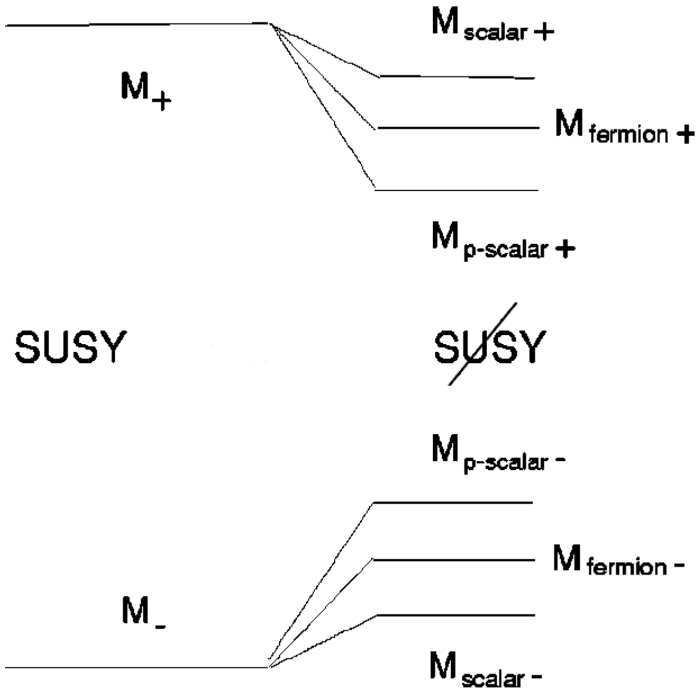
$$V(r) = \sigma r + \frac{c}{r} + b \quad (+APE)$$

$$\hat{r}_0 = \sqrt{\frac{1.65 + c}{\sigma}}$$

$$r_0^2 \left(\frac{\partial V}{\partial r} \right)_{r_0} = 1.65, \quad r_0 = 0.5 fm$$

There are many works which describe the two lower supermultiplets

- The gluino mass breaks SUSY softly. One expects:

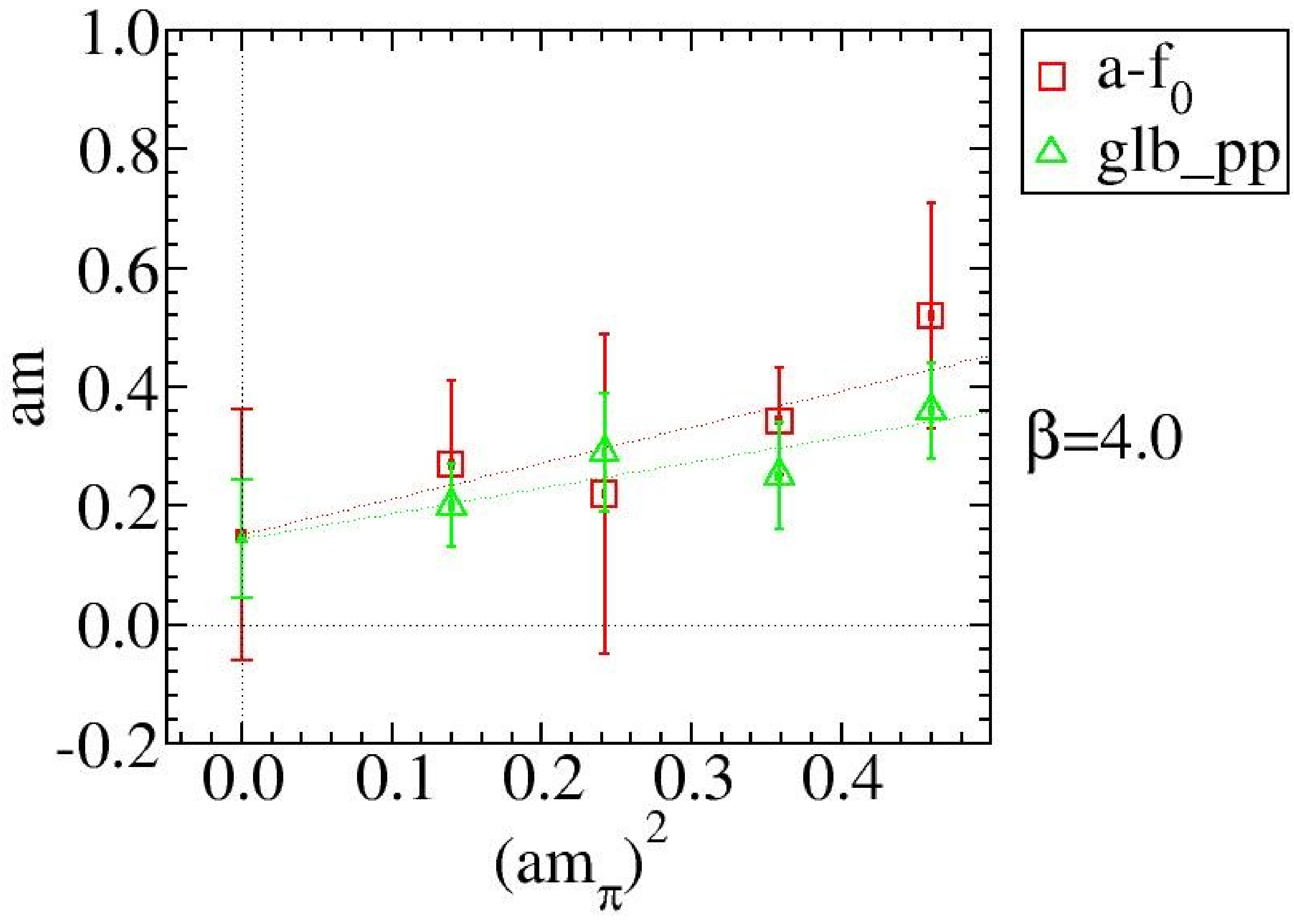


- scalar meson: $\mathrm{a}\!-\!f_0$
- gluino-glue: $\tilde{g}g$
- pseudoscalar meson: $\mathrm{a}\!-\!\eta'$

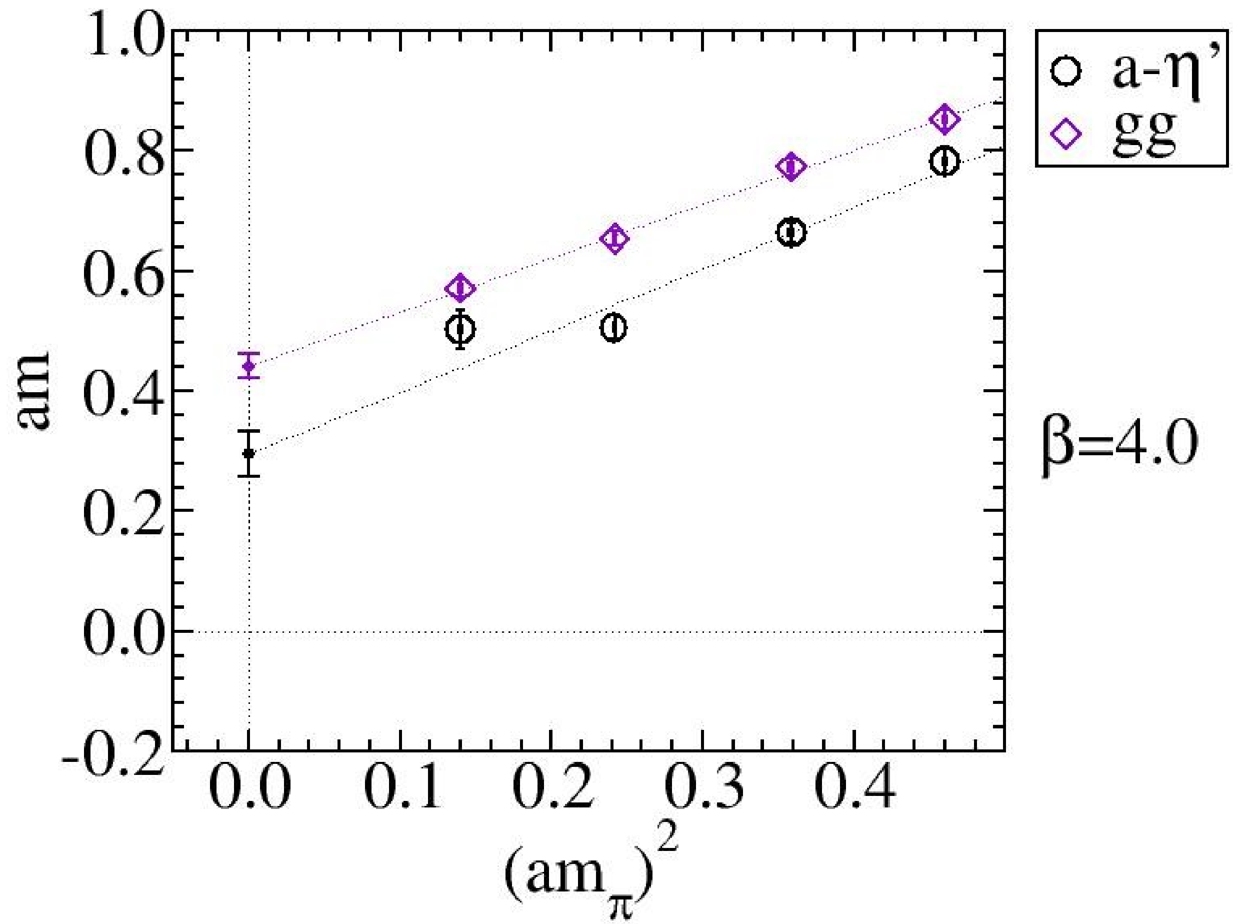
- pseudoscalar glueball: gg
- gluino-glue: $\tilde{g}g$
- scalar glueball: gg

- G. Veneziano, S. Yankielowicz, Phys. Lett. B113 (1982) 231
- R.Farrar, G.Gabadadze, M.Schwetz, Phys.Rev.D60 (1999) 035002
- A.Feo, P.Merlatti, F.Sannino, Phys.Rev.D70 (2004) 096004

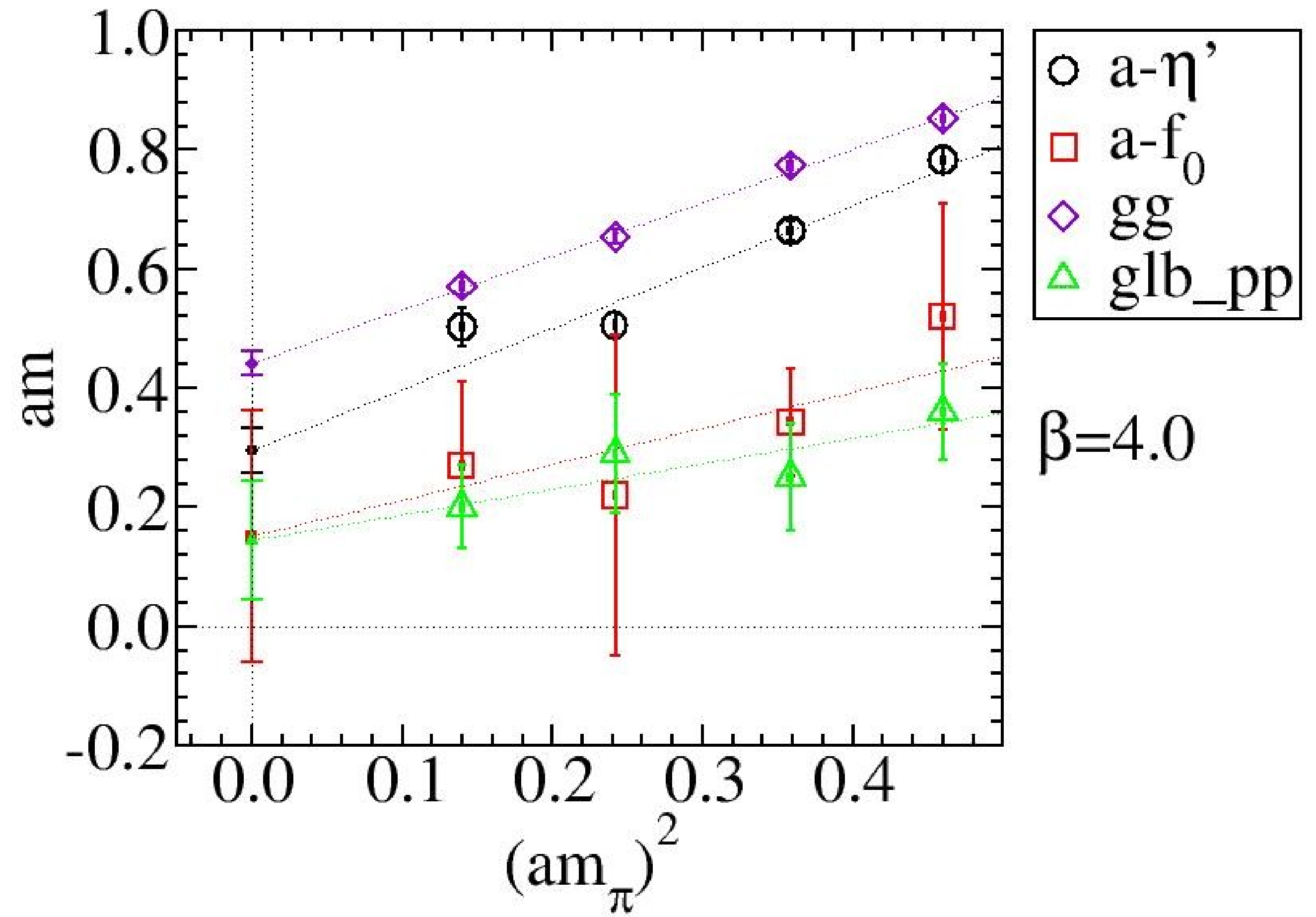
The chiral limit for the scalar channels gives compatible results but still large errors



The pseudoscalar channel has smaller errors. Extrapolations to the chiral limit not compatible: discretisation effects



The global summary for the chiral limit tells us we are on the right track to see SUSY restoration




THE END

Conclusions

- We started to study SYM with SU(3)
- We can tune the theory using the adjoint-pion (problem WI ?)
- We have started to explore the phase diagram of the theory: clear sign of a first order transition only in the scalar condensate
- We have started to explore the spectrum of the theory: so far mainly one lattice spacing $\beta = 4.0$

Outlook

- Complete measurements at $\beta = 4.30$
- Spectrum in the continuum limit
- A better signal of a first order transition in the pseudoscalar gluino condensate