CONFINEMENT AND DUALITY IN QCD

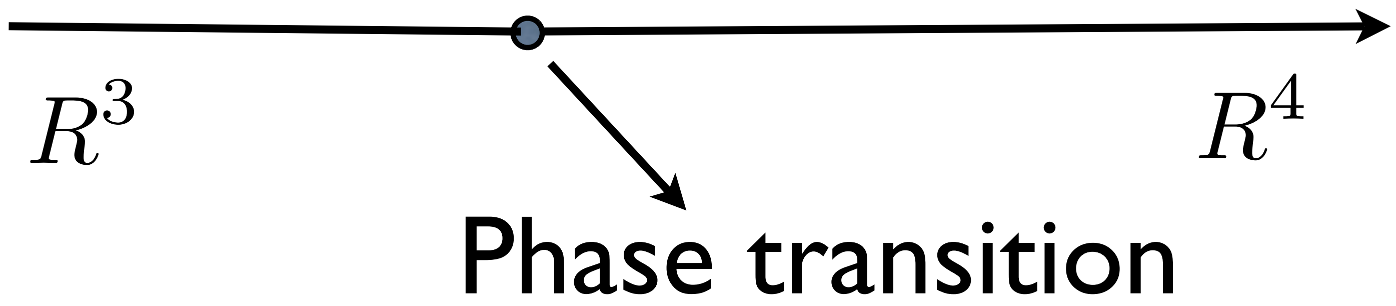
Mithat Unsal
(SLAC)

Large N parts in collaboration with L.G. Yaffe,

Finite N, with M.Shifman

- Are there any QCD-like gauge theories which are analytically tractable in 4d?
- Meaning of the question? (like Polyakov model on R^3 or Seiberg-Witten)
- pure YM, Vector-like, chiral ? Obvious answer: No!
- Strong coupling gauge dynamics may also be relevant to (multi)-TeV scale physics.

Thermal vs nonthermal QCD on $\mathcal{R}^3 \times S^1$



- Thermal versus quantum fluctuations.
- Non-thermal compactifications: not all QCD-like theories alike.
- QCD(adj) with periodic spin connection. Center symmetry never breaks! (complex reps, not so.)

- QCD(adj) is solvable on small circle (in the same sense as SW or Polyakov model.)

- Exhibits (linear) confinement without continuous chiral symmetry breaking on small circle. Discrete chiral symmetry is always broken.

- There must exist a non-thermal chiral transition in the absence of any change in center symmetry realization!

- Massless fermions at small circle, massless Goldstone bosons at large!

QCD(adj)

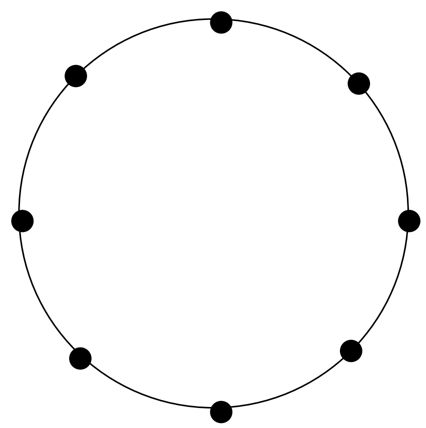
$$S = \int_{R^3 \times S^1} \frac{1}{g^2} \mathrm{tr} \left[\frac{1}{4} F_{MN}^2 + i \bar{\lambda}^I \bar{\sigma}^M D_M \lambda_I \right]$$ short distance

Center Z_{N_c}

Chiral $(SU(n_f) \times Z_{2N_c n_f})/Z_{n_f}$

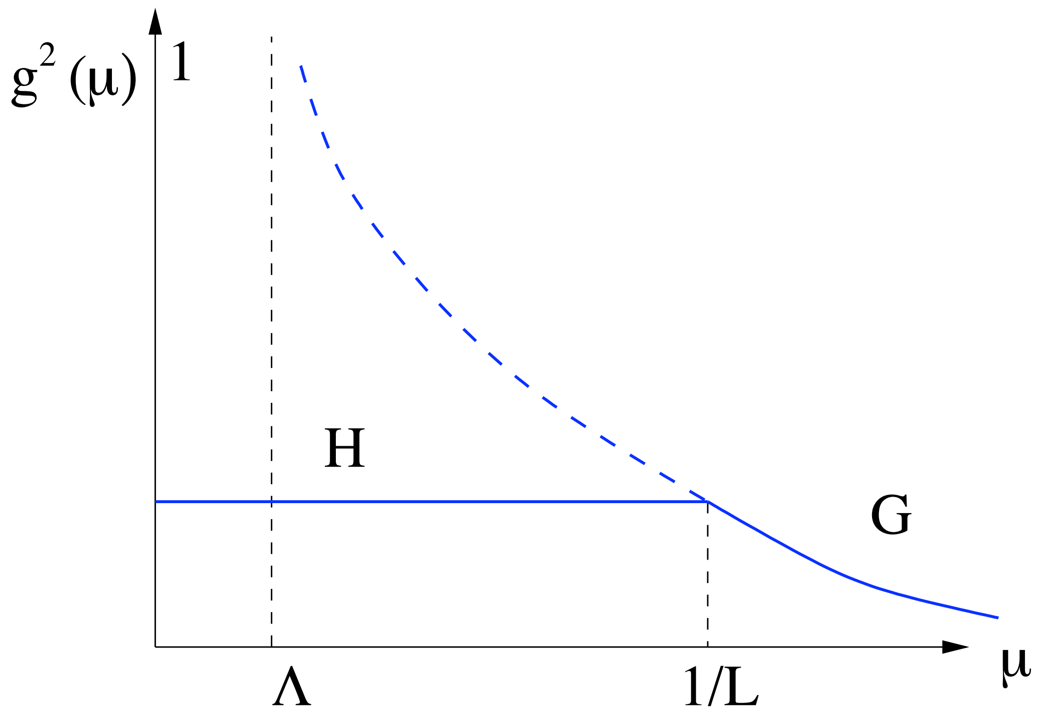
Evaluate the one loop effective potential for the Wilson line.

Eigenvalues repel. Minimum at



At weak coupling, the fluctuations are frozen "Higgs regime"

Perturbation theory

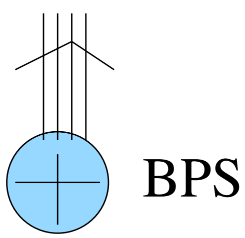


$$G = SU(2), \quad H = U(1)$$

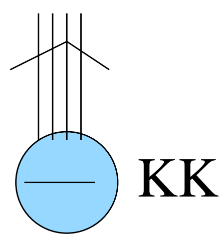
IR in perturbation theory is a free theory of fermions and "photons". Is this perturbative fixed point destabilized non-perturbatively?

$$\left(\int_{S^2} F,\ \int_{R^3\times S^1} F\tilde{F}\right)$$

Magnetic Monopoles

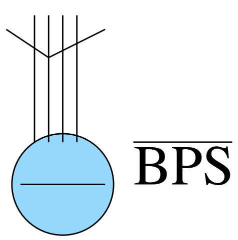


(1, 1/2)

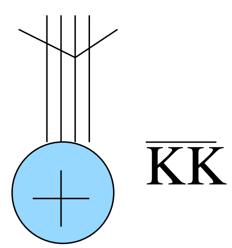


(–1, 1/2)

$$e^{-S_0} e^{i\sigma} \det_{I,J} \psi^I \psi^J,$$



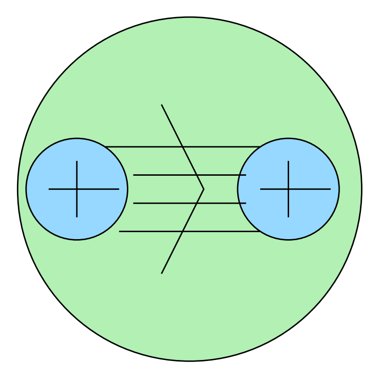
(–1, –1/2)



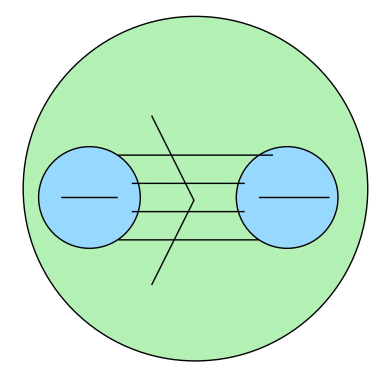
(1, –1/2)

$$e^{-S_0} e^{i\sigma} \det_{I,J} \bar{\psi}^I \bar{\psi}^J$$

Magnetic Bions



(2,0)



(–2, 0)

$$e^{-2S_0}\left(e^{2i\sigma} + e^{-2i\sigma}\right)$$

Discrete shift symmetry : $\sigma \longrightarrow \sigma + \pi$

$$L^{\rm dQCD} = \frac{1}{2}(\partial\sigma)^2 - b\, e^{-2S_0} \cos 2\sigma + i\bar{\psi}^I \gamma_\mu \partial_\mu \psi_I + c\, e^{-S_0} \cos\sigma (\det_{I,J} \psi^I \psi^J + {\rm c.c.})$$

↘ magnetic bions ↘ magnetic monopoles

Same mechanism in N=1 SYM, unrecognized previously. Beware of many erroneous statements in literature.

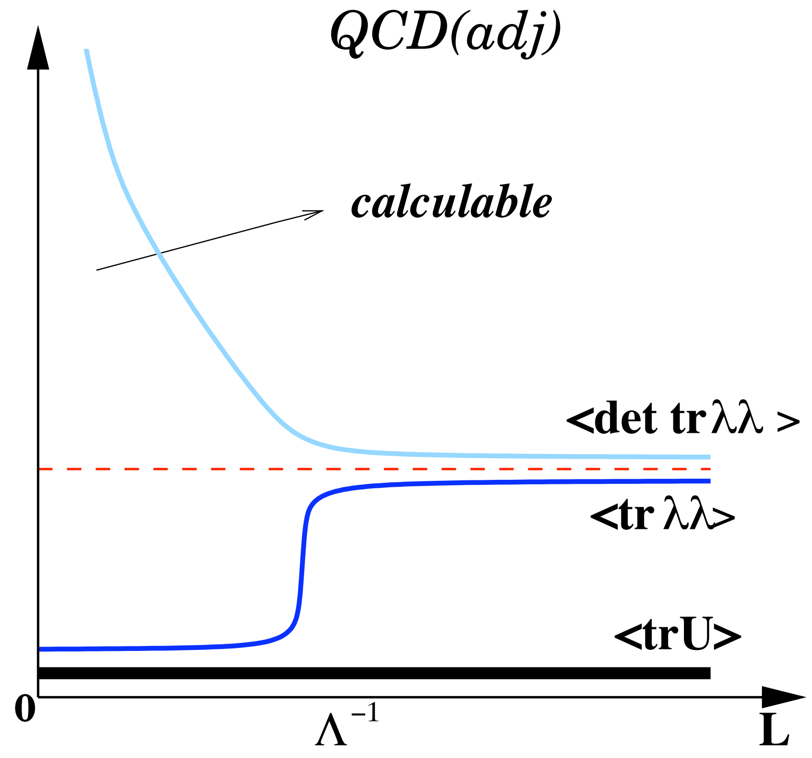
Important point in the solution of N=1 SYM is unbroken center symmetry, not supersymmetry

[See Giedt's and Catterall's talks for progress in susy lattice formulations.]

A) Mass gap in gauge sector due to magnetic bion mechanism, so is linear confinement, and stable flux tubes.

B) Discrete chiral symmetry is always broken.

C) Continuous chiral symmetry is unbroken at small radius.



Red line N=1SYM.

Remark

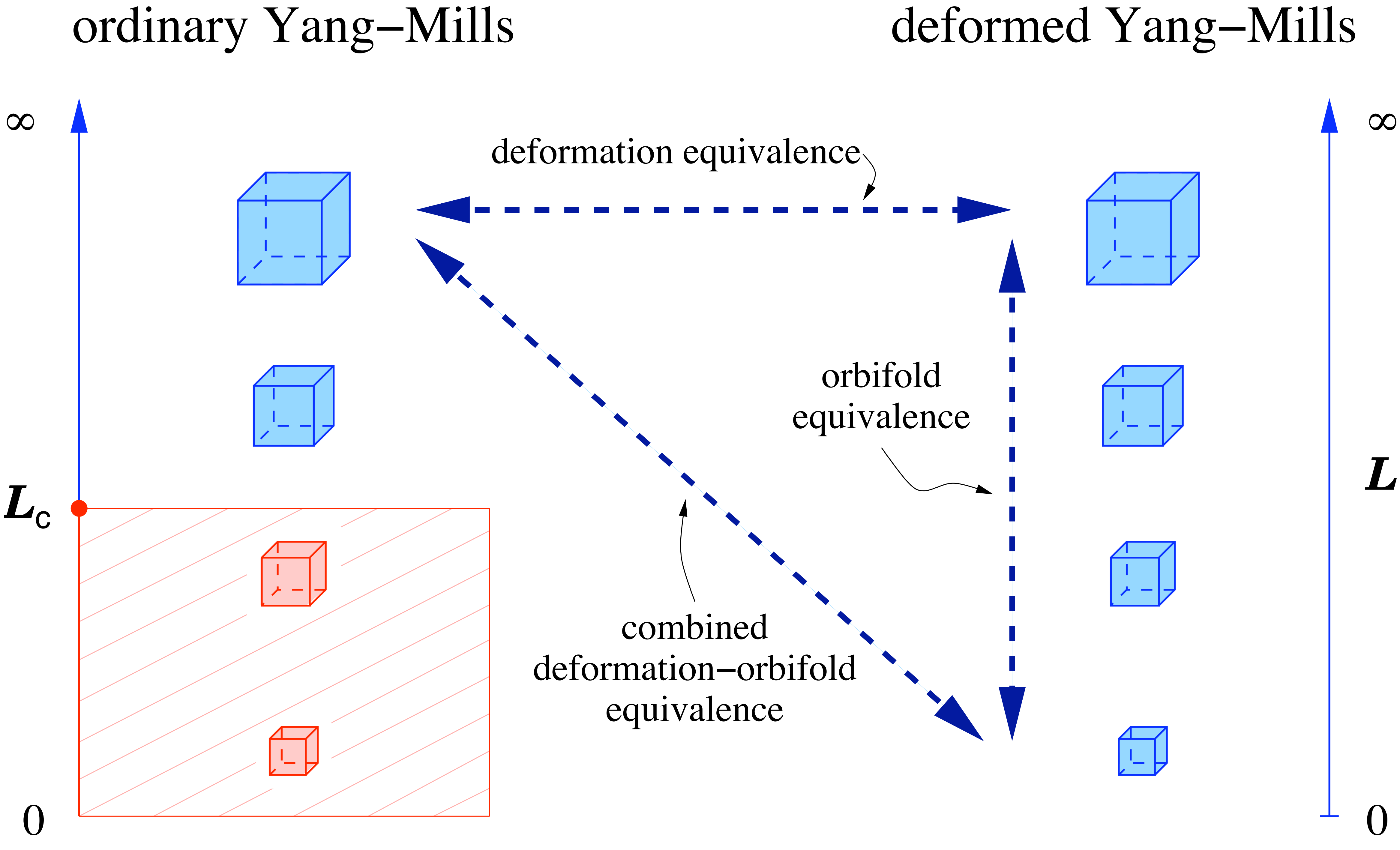
- Not same as Polyakov model with massless adjoint fermions which neither confines, nor has a mass gap. The masslessness of the photon is protected by U(1) shift symmetry. U(1) breaks spontaneously, and photon is the Goldstone boson. (Affleck, Harvey, Witten 1982)

- Distinguishing notion between QCD(adj) and Polyakov model with massless fermions: discrete versus continuous topological symmetry. (Not explained in this talk.)

Region of validity of dual formulation

- $LN_c\Lambda \ll 1$, why not $L\Lambda \ll 1$?
- Separation of scales between W-bosons and dual photons.
- Deeper reason: Large N volume independence EK reduction
- The large N volume independence holds provided unbroken center symmetry. Thus, the chiral transition scale must move to arbitrarily small radius at large N.
- New dynamical scale in QCD: Λ^{-1}/N

- Complex representation fermions, chiral theories, pure YM? Center is always broken at small radius.
- New idea: Add center stabilizing double trace deformations. Different theory? Not so fast.



ordinary Yang–Mills
deformed Yang–Mills
∞
∞
deformation equivalence
orbifold
equivalence
combined
deformation–orbifold
equivalence
L_c
L
0
0

At large N, the deformation is a new cure to the old EK problem, and is a useful tool for QCD-like theories (with Yaffe).

[See Barak Bringoltz's talk for progress in this direction.]

At finite N, (with Shifman): Conjecture: For the deformed theories with only discrete global symmetries, the physics of the theory at large and small radius are smoothly connected.

- Deformed theories, 1-flavor QCD* (F/BF/AS/S) and YM* are analytically tractable at small radius. Confinement, mass gap, discrete chiral symmetry breaking can be shown analytically.

- There are difficulties for complex rep fermions, since one has both electrically and magnetically charged relevant excitations in the IR. However, this is surmountable.

- Double trace deformations are also useful for a large class of chiral gauge theories. It is fair to say that our current knowledge of such theories is next to nothing. (in progress, with Shifman.)

- The dynamics of chiral theories are really bizarre (or unique), and we have some promising analytical results. (to appear.)