Chiral transition of fundamental and adjoint quarks

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1. Introduction (some lattice QCD results)
2. Problems with an effective (massive) gluon propagator
3. A model for chiral symmetry breaking
4. Chiral transition: fundamental X adjoint
5. Conclusions

1. Introduction (some lattice QCD results)

Chiral symmetry breaking:

Values of

$$\langle \bar{\psi}\psi \rangle \neq 0 \quad (= 0)$$

N_c , N_f , T, group, representation, chem.pot.,..

At finite T → T_c - chiral symmetry is recovered
T_d - deconfinement

[A. Bazavov et al., Phys.Rev.D80, 014504 (2009)]
[Y. Aoki et al., JHEP 0906, 088 (2009)]

$T_c \approx T_d$ **→ quarks in the fundamental representation**

quarks in the adjoint representation →

$$\frac{T_c}{T_d} \approx 7.7 \pm 2.1$$

[F.Karsch and M.Lutgemeier, Nucl.Phys.B 550, 449 (1999)]
[J.Engels et al., Nucl.Phys. B 724, 357 (2005)]
[E.Bigilci et al., JHEP 0911, 035 (2009)]

At T=0 → large N_f -- QCD chiral symmetry is recovered

($N_f \approx$ 11-13)

[Ph. De Forcrand, S.Kim and W.Unger, JHEP 1302, 051 (2013)]
[E. T. Tombouilis, Phys.Rev. D 87, 034513 (2013)]

Lattice → χsb x confinement (center vortices)

Quarks in the fundamental representation: Relation between χsb and confinement

In SU(2) → removal of center vortices → deconfinement and recovery of χ symmetry

[H.Reinhardt et al., Phys.Rev.D 66, 085004 (2002)]
[J.Gattnar, et al., Nucl. Phys. B 716, 105 (2005)]
[Ph. de Forcrand and M.D'Elia, PRL 82, 4582 (1999), P.O.Bowman et al., PRD 78, 054509 (2008)]

In SU(3) → removal of center vortices → picture not so clear

[P.O.Bowman et al., Phys.Rev.D 84, 034501 (2011)]

Remarks: a) Cornwall [Phys.Rev.D26, 1453 (1982)]
Mechanism of dynamical gluon mass generation
leads to an effective theory which has vortex solutions
(vortices – confinement ↔ M_g)
b) Confinement – string tension [V(r)≈ Kr], ...

Confinement (vortices?) → necessary for χsb – quarks in fund. rep.

It seems that confinement and χsb are related, but...

Note: many papers
some yes, some not
Removal of vortices

Confinement disappears as N_f is increased !!!

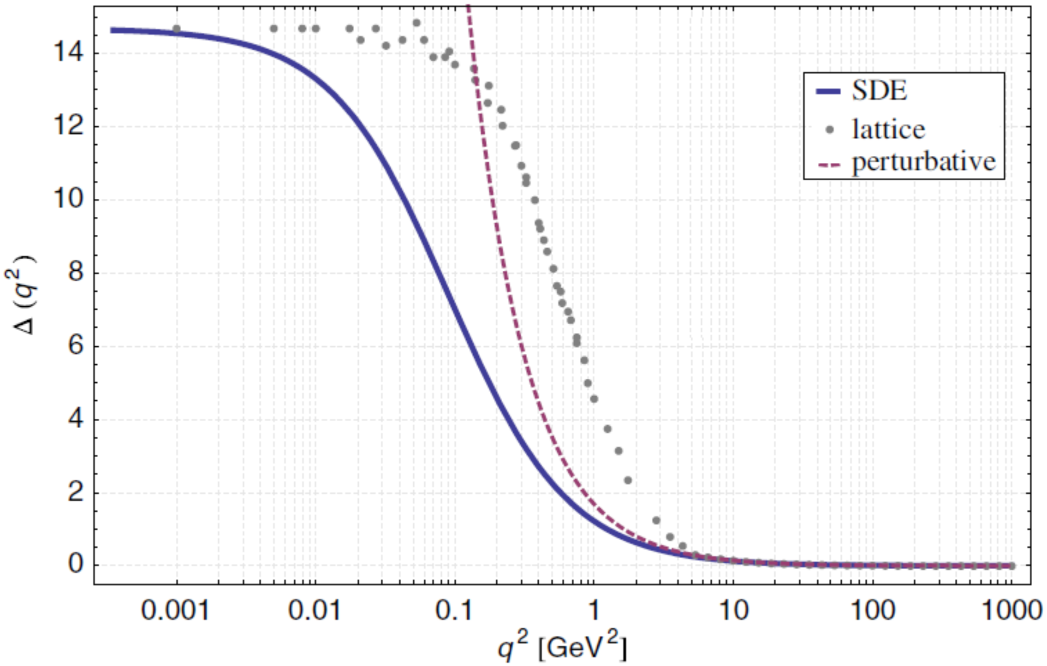
SU(3) $N_f = 7$, SU(2) $N_f = 3$

[Y.Iwasaki et al. Phys.Rev.Lett. 69 , 21 (1992); PRD 69, 014507(2009)]

Different behaviors → N_f, R, N ... deconfinement X vortices X χsb !!!

Gluon and ghost propagators → lattice and SDE

Gluon acquires a "dynamically generated mass" (pure gauge QCD – Cornwall 1982)



Agreement: lattice x SDE
SU(2) and SU(3)

Lattice:

[A.Cucchieri and T.Mendes, PoS QCD-TNT 09, 031 (2009);
PRLett. 100, 241601 (2008), PRD81, 016005 (2010)]
[I.Bogolubsky et al., Phys.Lett. B 676, 69 (2009)

SDE:

[A.C.Aguilar, D.Binosi and J.Papavassiliou, PRD ....]

M_g → phenomenological value ≈ 500 ± 200 MeV [A.Natale,, PoS QCD-TNT 09, 031 (2009)]

Lattice simulations with quarks → Larger M_g [A.Ayala et al., Phys.Rev.D 86, 074512 (2012)]

2. Problems with an effective (massive) gluon propagator

Schwinger-Dyson Equation ($m \equiv M_g$)

$$\Sigma(p^2) \propto \int dk\, K(p,k)\, \Sigma(k^2)$$

$$K(p,k) \propto \frac{\alpha(p^2)}{p^2 + m^2}$$

gluon propagator IR finite

$\alpha(p^2)$ IR finite →

$$g^2(k^2) \approx \frac{1}{b\ln[(k^2 + 4m^2)/\Lambda^2]}$$

change with the representation

Problem – not enough chiral symmetry breaking

[J.M.Cornwall, arXiv:0812.0359]
[Haeri and Haeri, Phys. Rev. D 43, 3732 (1991)]
[A.Natale and Rodrigues da Silva, Phys. Lett. B392, 444 (1997)]

Not for adjoint quarks -- C_{2R}

Also ---- where is the (linear) confining potential?

3. A model for chiral symmetry breaking

Possible solutions:

1) **Vortices – have to be included into the SDE**

2) **Vertex – improved vertex (vertex q-g is enhanced due to quark-ghost scat. kernel) + lattice propagator**
   [Aguilar and Papavassiliou, PRD 83, 014013 (2011)]

How to introduce vortices into the SDE?

Vortices introduced "by hand" - Cornwall, PRD 83, 076001 (2011)

Vortices appear in the effective theory, after quantum corrections (that generate "gluon masses")

Model for χsb

Quantum corrections → gauge boson masses
Vortices appear in the effective theory of massive bosons
Vortices generate a confining potential ("propagator")

What is necessary? Area law, linear potential, ... →

$1/k^4$ propagator?
(Mandelstam 1979)

↓

this one is not OK! Why?

1) Severe IR divergences (ok, but this is known ....)
2) Does not lead to massless states (Goldstone bosons)!

Cornwall's proposal (2011):
effective confining propagator

$$D(k^2) \sim \frac{8\pi K_F}{(k^2+m^2)^2}$$

Entropic properties of the confining propagator:

Cornwall, PRD 83, 076001 (2011) , Mod.Phys.Lett. A27 (2012) 1230011

Dynamically massive quarks contribute to the area law entropy $\sim -\frac{K_F}{M}$

Contribution of the confining effective propagator to the potential:

$$V(r) \approx -\frac{K_F}{m} + K_F r + O(m)$$

effective Hamiltonian that variationally minimized implies →

$$\langle H_e \rangle = 2\sqrt{K_F} - \frac{3K_F}{\pi M}$$

m∼M and massless bound states are formed when $\mathbf{M} = \frac{3\sqrt{K_F}}{2\pi}$

Phenomenology of an effective confining propagator + one-gluon exchange

Doff, Machado, Luna, A.N. [Ann.Phys.327(2012)1030; New J.Phys.14(2012)103043; Phys.Rev.D88(2013) 055008]

$$\Sigma(p^2) \propto K_F \int d^4k\, K_c\,(p,k)\Sigma(k^2) + \; g^2 \; \int d^4 \; K_g(p,k)\Sigma(k^2\,)$$

No double counting - $K_c \quad confining\, kernel \; - \; vortices \; - topology$

$K_g \quad dressed\, one - gluon\, exchange$

Results for fundamental and adjoint representations:

Doff et al. , Ann.Phys. and Capdevilla, Doff and AN, Phys.Lett.B 728, 626 (2014)

$$\Sigma(0) = M \qquad fundamental\, quarks \; - 95\% \;\; K_c$$

$$adjoint\, quarks - basically \;\; K_g$$

4. Chiral transition: fundamental X adjoint

Results (T=0): Mass and condensate

$$M = \Sigma(0) \quad ; \quad \langle q\bar{q} \rangle = -\frac{N_R}{4\pi^2}\int_0^{\kappa^2} dp^2 \frac{p^2 M(p^2)}{[p^2+M(p^2)]}$$

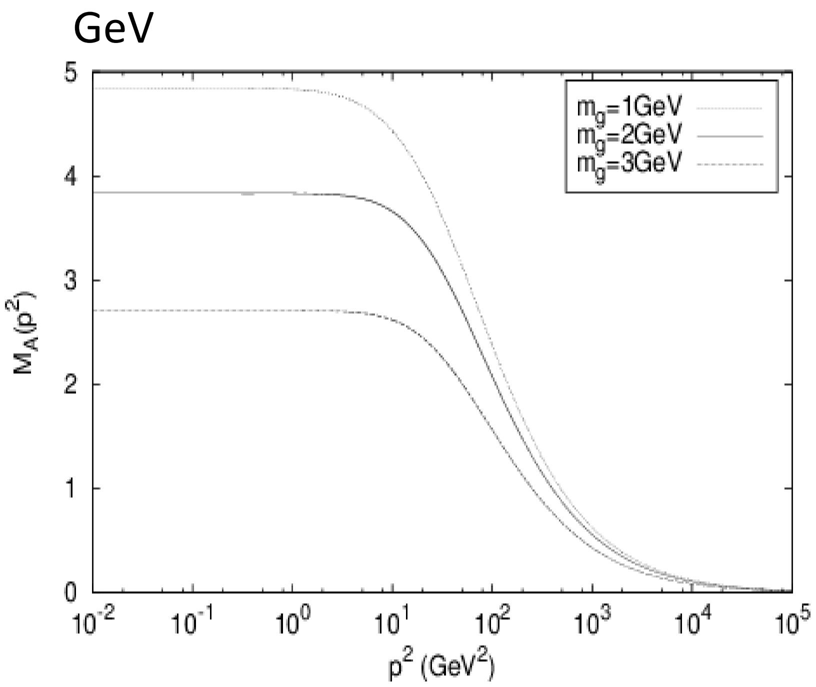
$$\kappa = 3M$$

Fundamental quarks

	Confining prop.		Confining + 1-gluon ex.
M (MeV)	**212**	→	**221**

$\langle q\,\bar{q}\rangle^{1/3}$ 180 MeV (leading order)

(exp. ~ 229 MeV)



Adjoint quarks (2)

K_A , C_{2A} , m_{gA}

M = 4.8, 3.8, 2.7 GeV

for different gluon masses

Problem: How gluon masses change with n_f, rep.,...?

$\langle q\,\bar{q}\rangle^{1/3}$ = 5.3 ; 4.2 ; 3.0 GeV

Values at $T \neq 0$ →

$\mathbf{T \neq 0}$

$$\langle \bar{q}q\,(T)\rangle = \langle \bar{q}q\,(0)\rangle(\kappa^2) + N_R \int \frac{d^4k}{(2\pi)^4} \times A(T, M(T), k)$$

$A(T, M(T), k) \rightarrow$ fermion propagator $T \neq 0$/ Dolan & Jackiw formalism

Chiral transition temperature $\rightarrow$

$$\langle \bar{q}q\,(T_c)\rangle = M(T_c) \equiv 0$$

$$Final\ result \rightarrow T_c{}^2 \sim -\frac{6\langle \bar{q}q\,(0)\rangle}{N_R M}$$

$$T_d^2 = \frac{3}{\pi(d-2)} K_R$$

Deconfinement temperature

[R.Pisarski and O.Alvarez, Phys.Rev.D 26, 3735 (1982)]

T_c/T_d ratio

$$\left(\frac{T_c}{T_d}\right)^2 \approx \frac{6.7}{\pi}\frac{M^2}{K_R}$$

Representation	M_g(GeV)	M(0) (GeV)	T_c/T_d
fundamental	0.6	0.22	0.76
adjoint	1.0	4.8	10.9
adjoint	2.0	3.8	8.56
adjoint	3.0	2.7	6.08

Lattice → 7.7±2.1

5. Conclusions

1. χsb Cornwall's model – consitent with lattice data
   (χsb fundamental quarks – small contribution from 1-g exchange – not pure "confinement mass")

2. Differences between χsb for fundamental and adjoint quarks seems to imply 2 scales

3. Ratio T_c / T_d compatible with lattice data

4. We need more lattice data: M_g and K as function of N_f and fermionic representation (still much to learn about χsb)

Vertex – improved vertex (vertex q-g is enhanced due to quark-ghost scat. kernel) + lattice propagator

Aguilar and Papavassiliou, PRD 83, 014013 (2011)

1) **q-g vertex – consistency with lattice?**
   A.Kizilersu et al., EPJC 50, 871 (2007)

2) **Gluon propagator from the lattice (pure gauge)**
   gluon mass increases with dynamical quarks
   A. Ayala, et al. , Phys. Rev. D 86, 074512 (2012).

3) **Adjoint quarks → if q-g vertex is improved (also for adjoint),**
   T_c adjoint will be even bigger!!! ???