The Polarization Tensor of the Massless Mode in Yang-Mills Thermodynamics

Markus Schwarz

Karlsruhe Institute of Technology (KIT)

1st Symposium on Analysis of Quantum Field Theory
9th International Conference of Numerical Analysis and Applied Mathematics
Haldiki, Greece, 19-25 September 2011

21 September 2011
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

Selfconsistent Calculation
   Transverse Dispersion Relation
   Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

Selfconsistent Calculation
  Transverse Dispersion Relation
  Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
Review of Ralf’s talk

- After coarse-graining, nonperturbative YMT ground state described by scalar field $\phi(T)$ [Herbst,Hofmann ’04, Hofmann ’05, Giacoa,Hofmann ’05]

- Effective action for top. trivial sector

$$S_E[a_\mu] = \int_0^{\frac{1}{T}} dx_4 \int dx^3 \text{Tr} \left( \frac{1}{2} G_{\mu\nu} G_{\mu\nu} + D_\mu \phi D_\mu \phi + \Lambda^6 \phi^{-2} \right)$$

- In deconfining phase ($T > \Lambda$): $SU(2) \rightarrow U(1)$

- Two tree-level massive modes (TLH) with mass $m^2(T) = 4e^2(T)|\phi(T)|^2 = 4e^2 \Lambda^3 / 2\pi T$,
  one tree-level massless mode (TLM)

- Eff. coupling $e(T)$ has plateau value $e_{\text{plateau}} \sim \sqrt{8\pi} \approx 8.8$,
  no PT but loop expansion

- $|\phi|$ yields max. resolution
<table>
<thead>
<tr>
<th>Table of Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review of YMT</td>
</tr>
<tr>
<td>Polarization Tensor and Momentum Constraints</td>
</tr>
<tr>
<td>Approximate Calculation</td>
</tr>
<tr>
<td>Selfconsistent Calculation</td>
</tr>
<tr>
<td>Transverse Dispersion Relation</td>
</tr>
<tr>
<td>Longitudinal Dispersion Relation</td>
</tr>
<tr>
<td>Monopole Properties from a 2-Loop Correction to the Pressure</td>
</tr>
<tr>
<td>Summary and Outlook</td>
</tr>
</tbody>
</table>
Polarization Tensor, Motivation

- Effect TLH modes on propagation of TLM modes described by polarization tensor $\Sigma^{\mu\nu}$.

- On one-loop level: $\Sigma^{\mu\nu}$

  (one-loop sufficient, cmp. talk by Dariush)

- simplest radiative correction

- generic radiative correction

- interesting consequences for physics
Polarization Tensor, Decomposition

\(U(1)\) gauge symmetry unbroken, \(\Rightarrow \Sigma^{\mu\nu} 4D\) transverse: \(p_\mu \Sigma_{\mu\nu} = 0\)

Decomposition into spatially transversely and longitudinally part:

\[\Sigma^{\mu\nu} = G(p_4, p) P_T^{\mu\nu} + F(p_4, p) P_L^{\mu\nu}\]

with

\[P_L^{\mu\nu} \equiv \delta^{\mu\nu} - \frac{p_\mu p_\nu}{p^2} - P_T^{\mu\nu},\]

projecting also onto \(p\).
Free Propagators

Free propagator for TLH and TLM modes in

- unitary gauge (particle content manifest)
- Coulomb gauge ($\nabla A = 0$)

$$D_{\mu\nu, ab}^{TLH, 0}(k) = -\delta_{ab} \tilde{D}_{\mu\nu} \frac{1}{k^2 + m^2}, \quad \{a, b\} \in \{1, 2\}$$

$$D_{\mu\nu, ab}^{TLM, 0}(p) = -\delta_{a3}\delta_{b3} \left( P_{\mu\nu}^T \frac{1}{p^2} + \frac{u_\mu u_\nu}{p^2} \right)$$

$u_\mu = \delta_{4\mu}$ four-velocity of head bath.

$\tilde{D}_{\mu\nu}$ projects out the component transverse to $k$

$P_{\mu\nu}^T$ projects out the component transverse to $p$.

Gauge fixed completely $\implies$ no ghost fields needed.
Dressed Propagator

Propagator for interacting TLM mode (imaginary time)

\[ D_{\mu\nu,ab}^{TLM}(p) = -\delta_{a3}\delta_{b3} \left( P_{\mu\nu}^{T} \frac{1}{p^2 + G} + \frac{p^2}{p^2} \frac{u_{\mu} u_{\nu}}{p^2 + F} \right) \]

\[ F(p_4, p) = \left( 1 - \frac{p_4^2}{p^2} \right)^{-1} \Sigma^{44} \] describes propagation of longitudinal mode \( A_4 \)

For \( p \parallel e_3 \), \( G(p_4, p) = \Sigma^{11} = \Sigma^{22} \) describes propagation of transverse mode \( A_i \)
Vertices and Momentum constraints

\[ \Gamma_{[3]}^{\mu\nu\rho} \]

- Momentum conservation at each vertex.
- Effective vertex contains modes with \( |p^2| > |\phi|^2 \):

\[ \Gamma_{[4]}^{\mu\nu\rho\sigma} \]

- Exclude these modes in effective theory to avoid "double counting" (already included in \( a_{\mu}^{\text{g.s.}} \); cmp. talk by Ralf)
Momentum constraints

\[ |\phi| \text{ yields maximum resolution in effective theory } \Rightarrow \text{ constraints on momentum transfer in vertex} \]

\[ p = p_1 + p_2 - p_3 \]

s-channel: \[ |(p_1 + p_2)^2| \leq |\phi|^2 \]
t-channel: \[ |(p_1 - p_3)^2| \leq |\phi|^2 \]
u-channel: \[ |(p_2 - p_3)^2| \leq |\phi|^2 \]

Recall

Finite temperature QFT defined in imaginary time \( x_4 \) with fields being periodic in \( x_4 \). Only discrete \( p_4 \) momenta allowed (Matsubara sums).

Problem

Momentum constraints formulated in terms of physical, continuous four momenta.
Real time propagators

Solution
Express Matsubara sums as integrals over continuous real time $t$. [Kapusta, LeBellac]
Free propagator for TLH and TLM modes in unitary Coulomb gauge and real-time formalism

\[
D_{\mu\nu,ab}^{TLM,0}(p) = \delta_a^3 \delta_b^3 \left\{ P_{\mu\nu}^T \left[ \frac{-i}{p^2 + i\epsilon} - 2\pi \delta(p^2) n_B(|p_0|/T) \right] + i \frac{u_{\mu} u_{\nu}}{p^2} \right\}
\]

\[
D_{\mu\nu,ab}^{TLH,0}(k) = -2\pi \delta_{ab} \tilde{D}_{\mu\nu} \delta(k^2 - m^2) n_B(|k_0|/T), \quad a, b \in \{1, 2\}
\]
No vacuum propagator for TLH modes (cmp. talk by Ralf):

- (a)
- (b)
Modified dispersion relation of TLM

Dressed propagator of transverse and longitudinal TLM mode (real time)

\[
D_{\mu\nu,ab}^{TLM}(p_t) = -\delta_{a3}\delta_{b3} P_{\mu\nu}^T \left[ \frac{i}{p_t^2 - G} + 2\pi \delta(p_t^2 - G) n_B(|p_0,t|/T) \right]
\]

\[
D_{\mu\nu,ab}^{TLM}(p_l) = \delta_{a3}\delta_{b3} u_{\mu}u_{\nu} \left[ \frac{p_l^2}{p_l^2} \cdot \frac{i}{p_l^2 - F} - 2\pi \delta(p_l^2 - F) n_B(|p_0,l|/T) \right]
\]

Poles yield dispersion relations \((p_0 = \omega + i\gamma, \text{ assume } \gamma \ll \omega)\):

\[
\omega_t^2(p_t) = p_t^2 + \text{Re} G(\omega(p_t), p_t)
\]

\[
\gamma(p_t) = \frac{-\text{Im} G(\omega(p_t), p_t)}{2\omega}
\]

\[
\omega_l^2(p_l) = p_l^2 + \text{Re} F(\omega_L(p_l), p_l)
\]

\[
\gamma_l(p_l) = \frac{-\text{Im} F(\omega_L(p_l), p_l)}{2\omega_l}
\]
Diagrams for $G$ and $F$

Choosing $p \parallel e_3$:

$$G(p_0, p) = \Sigma^{11} = \Sigma^{22}$$

$$F(p_0, p) = \left(1 - \frac{p_0^2}{p^2}\right)^{-1} \Sigma^{00}$$

$\Sigma^{\mu \nu}$ sum of two diagrams:

Purely imaginary: $\Rightarrow$ yields $\gamma$

One-loop level sufficient (see talk by Dariush)!

Purely real: $\Rightarrow$ yields dispersion relation
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

Selfconsistent Calculation
  Transverse Dispersion Relation
  Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
Approximation $p^2 = 0$

Applying Feynman rules to $\text{Re} G = \text{Re} \Sigma^{11}$ yields gap equation:

$$\text{Re} G(p_0, p) = \Sigma^{11}_B(p) = 8\pi e^2 \int_{|(p+k)^2| \leq |\phi|^2} \left[ - \left( 3 - \frac{k^2}{m^2} \right) + \frac{k_1^1 k_1^1}{m^2} \right]$$

$$\times n_B(|k_0|/T) \delta (k^2 - m^2) \frac{d^4 k}{(2\pi)^4} \bigg|_{p^2 = G}$$

4 vertex imposes constraint $|(p+k)^2| \leq |\phi|^2$

**Difficulty**

Equation (1) is a transcendental equation for $G$.

**Approximation**

Use $p^2 = 0$ in constraint [Schwarz, Giacosa, Hofmann '06].

Valid if $G \ll p^2$. Check later!
Consequences of $p^2 = 0$

1. For finite $\Sigma^{00}$, $F(p_0, p) = \left(1 - \frac{p_0^2}{p^2}\right)^{-1} \Sigma^{00}$ vanishes. Hence, no propagation of longitudinal modes.

2. Diagram A vanishes:

   ![Diagram A](image)

   Momentum conservation at vertex vorbids TLM mode with $p^2 = 0$ to split into two on-shell particles with mass $m$.

3. Diagram $A = 0$, hence no imaginary part of $G$, hence $\gamma = 0$ and assumption $\gamma \ll \omega$ satisfied trivially.
Calculation of diagram B, \( p^2 = 0 \)

With \( p^2 = 0 \):

\[
G(|p|, p) = 8\pi e^2 \int_{|2pk+k^2| \leq |\phi|^2} \left[ g^{11} \left( 3 - \frac{k^2}{m^2} \right) + \frac{k^1 k^1}{m^2} \right] \\
\times n_B (|k_0| / T) \delta (k^2 - m^2) \frac{d^4 k}{(2\pi)^4}
\]

Via \( \delta \)-function, integration over \( k_0 \) yields \( k_0 \to \pm \sqrt{k^2 + m^2} \).

Using \( p_0 \geq 0, p^2 = 0, k^2 = m^2 = 4e^2|\phi|^2 \), \( \theta \equiv \angle(p, k) \), and \( k_0 = \pm \sqrt{k^2 + m^2} \) constraint reads:

\[
\left| 2|p| \left( \pm \sqrt{k^2 + 4e^2|\phi|^2} - |k| \cos \theta \right) + 4e^2|\phi|^2 \right| \leq |\phi|^2
\]

Integrand symmetric under \( k_0 \to -k_0 \), but constraint is not!
Dealing with constraints, + sign

Consider + sign and observe:

\[
\left| 2|p| \left( + \sqrt{k^2 + 4e^2|\phi|^2} - |k| \cos \theta \right) + 4e^2|\phi|^2 \right| \leq |\phi|^2
\]

1. Term in parentheses always positive.

2. \( e \gtrsim \sqrt{8\pi} \sim 8.8 \)

Hence, constraint never satisfied.
Dealing with constraints, -- sign

Using $X \equiv |p|/T$, $y \equiv k/|\phi|$, $|\phi|/T = 2\pi \lambda^{-3/2}$, and $\lambda \equiv 2\pi T/\Lambda$

constraint reads

$$-1 \leq -\lambda^{3/2} \frac{X}{\pi} \left( \sqrt{y^2 + 4e^2 + y_3} \right) + 4e^2 \leq 1$$

Convenient to use polar coordinates $y_1 = \rho \cos \varphi$, $y_2 = \rho \sin \varphi$.

Constraint then reads

$$\frac{4e^2 - 1}{\lambda^{3/2}} \frac{\pi}{X} \leq \sqrt{\rho^2 + y_3^2 + 4e^2 + y_3} \leq \frac{4e^2 + 1}{\lambda^{3/2}} \frac{\pi}{X}$$

Integration over $\varphi$ not constraint!
Dealing with constraints, – sign

\[
\frac{4e^2 - 1}{\lambda^{3/2}} \frac{\pi}{X} \leq \sqrt{\rho^2 + y_3^2 + 4e^2 + y_3} \leq \frac{4e^2 + 1}{\lambda^{3/2}} \frac{\pi}{X}
\]

1. \(y_3, \rho\) plane
Dealing with constraints, – sign

\[ \frac{4e^2 - 1}{\lambda^{3/2}} \frac{\pi}{X} \leq \sqrt{\rho^2 + y_3^2 + 4e^2 + y_3} \leq \frac{4e^2 + 1}{\lambda^{3/2}} \frac{\pi}{X} \]

1. \( y_3, \rho \) plane
2. \( y_3 < y_{\text{max}} \equiv \frac{4e^2 + 1}{\lambda^{3/2}} \frac{\pi}{X} \)
Dealing with constraints, – sign

\[
\frac{4e^2 - 1}{\lambda^{3/2}} \frac{\pi}{X} \leq \sqrt{\rho^2 + y_3^2 + 4e^2} + y_3 \leq \frac{4e^2 + 1}{\lambda^{3/2}} \frac{\pi}{X}
\]

1. \(y_3, \rho\) plane

2. \(y_3 < y_{\text{max}} \equiv \frac{4e^2+1}{\lambda^{3/2}} \frac{\pi}{X}\)

3. \(\rho \leq \rho_{\text{max}}(y_3) \equiv \sqrt{\left(\frac{\pi}{X}\right)^2 \frac{4e^2+1}{\lambda^3} - \frac{2\pi}{X} \frac{4e^2+1}{\lambda^{3/2}y_3 - 4e^2}}\)

for

\(y_3 \leq y_3^M \equiv \frac{\pi}{2X} \frac{4e^2+1}{\lambda^{3/2}} - \frac{2\lambda^{3/2}X}{\pi} \frac{e^2}{4e^2+1}\)
Dealing with constraints, – sign

\[ \frac{4e^2 - 1}{\lambda^{3/2}} \frac{\pi}{X} \leq \sqrt{\rho^2 + y_3^2 + 4e^2} + y_3 \leq \frac{4e^2 + 1}{\lambda^{3/2}} \frac{\pi}{X} \]

1. \( y_3, \rho \) plane

2. \( y_3 < y_{\text{max}} \equiv \frac{4e^2+1}{\lambda^{3/2}} \frac{\pi}{X} \)

3. \( \rho \leq \rho_{\text{max}}(y_3) \equiv \sqrt{\left(\frac{\pi}{X}\right)^2 \frac{(4e^2+1)^2}{\lambda^3} - \frac{2\pi}{X} \frac{4e^2+1}{\lambda^{3/2}y_3-4e^2}} \)
   for
   \[ y_3 \leq y_3^M \equiv \frac{\pi}{2X} \frac{4e^2+1}{\lambda^{3/2}} - \frac{2\lambda^{3/2}X}{\pi} \frac{e^2}{4e^2+1} \]

4. \( \rho \geq \rho_{\text{min}}(y_3) \equiv \sqrt{\left(\frac{\pi}{X}\right)^2 \frac{(4e^2-1)^2}{\lambda^3} - \frac{2\pi}{X} \frac{4e^2-1}{\lambda^{3/2}y_3-4e^2}} \)
   for
   \[ y_3 \leq y_3^m \equiv \frac{\pi}{2X} \frac{4e^2-1}{\lambda^{3/2}} - \frac{2\lambda^{3/2}X}{\pi} \frac{e^2}{4e^2-1} \]
Expression for $G, \quad p^2 = 0$

Constraint in terms of boundaries for $(y_3, \rho)$ integration:

\[
\frac{G(X, T)}{T^2} = \left[ \int_{-\infty}^{y_3^m} dy_3 \int_{\rho_{\min}}^{\rho_{\max}} d\rho + \int_{y_3^m}^{y_3^M} dy_3 \int_0^{\rho_{\max}} d\rho \right]
\]

\[
e^{2\rho/\lambda^3} \left( \frac{\rho^2}{4e^2} - 4 \right) \frac{n_B \left( 2\pi \lambda^{-3/2} \sqrt{\rho^2 + y_3^2 + 4e^2} \right)}{\sqrt{\rho^2 + y_3^2 + 4e^2}}
\]

$X = |p|/T$ momentum of external TLM mode in units of temperature,

$\lambda \equiv 2\pi T/\Lambda$ temperature in units of YM scale $\Lambda$.

Integration performed numerically via Gaussian quadrature (unlike Monte-Carlo for 3-loop, comp. talk by Dariush).
Result for $G$, $\rho^2 = 0$
Result for $G, p^2 = 0$

All results based on $|G/T^2| \ll X^2!$

- $X \gtrsim 0.2$: $G < 0$ (anti-screening)
- Dip: $G = 0$
- $X \lesssim 0.2$: $G > 0$ (screening)

- $G \ll p^2$ for $X \gtrsim 0.2$
- $G = 0$ at $X \sim 0.2$, dispersion relation solved selfconsistently
- $G \geq p^2$ for $X \lesssim 0.1$, approximation breaks down
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

Selfconsistent Calculation
  Transverse Dispersion Relation
  Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

**Selfconsistent Calculation**

Transverse Dispersion Relation

Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
Full calculation of $G$

Gap equation:

$$\text{Re}G(p_0, p) = 8\pi e^2 \int_{|(p+k)^2| \leq |\phi|^2} \left[-\left(3 - \frac{k^2}{m^2}\right) + \frac{k^1 k^1}{m^2}\right]$$

$$\times n_B (|k_0|/T) \delta (k^2 - m^2) \frac{d^4 k}{(2\pi)^4} \bigg|_{p^2 = G}$$

$$\equiv H(T, p, G)$$

Via $\delta$-function, integration over $k_0$ yields $k_0 \to \pm \sqrt{k^2 + m^2}$.

With $p_0 = \pm \sqrt{p^2 + G(p_0, p)}$ and $p \parallel e_3$ constraint reads

$$\left| G + 2 \left(\pm \sqrt{p^2 + G\sqrt{k^2 + m^2 - pk_3}}\right) + m^2 \right| \leq |\phi|^2$$
Full calculation of $G$

Strategy to solve $\Re G(p_0, p) = H[T, p, G(p_0, p)]$

[Ludescher, Hofmann '08]:

1. fix $T$ and $p$ (integrand in $H$ independent of $p_0 \Rightarrow G = G(p)$)
2. prescribe any value of $G_1$
3. calculate $H(T, p, G_1)$ using Monte-Carlo integration
4. repeat steps 2 and 3 to obtain $H(T, p, G)$
5. solve $G = H(T, p, G)$ numerically using Newton’s method
Selfconsistent result for $G$, real part
Selfconsistent result for $G$, real part

- $X \gtrsim 0.2$: $G < 0$ (anti-screening)
- Dip: $G = 0$
- $X \lesssim 0.2$: $G > 0$ (screening)

Comparison with approximate result:
- Zeros of $G$ agree (must be)
- For $X \gtrsim 0.2$, approximate agrees with selfconsistent result (expected)
- Results different when $G \gtrsim X^2$ (not surprising)
Selfconsistent result for $G$, imaginary part

Imaginary part: $\text{Im} G \propto \frac{p \cdot p}{k \cdot p - k}$
At left vertex: particle with mass $\sqrt{G}$ decaying into two on-shell particles with mass $m$ only possible if

$$\frac{G}{T^2} \geq 4 \frac{m^2}{T^2} = 64 \pi^2 \frac{e^2}{\lambda^3}$$

(2)

- $G \leq 0$: condition (2) never satisfied
- $G > 0$:

$$\frac{G(X = 0, T)}{T^2} \propto \frac{1}{\lambda^3} \ll 64 \pi^2 \frac{e^2}{\lambda^3} \sim 5 \times 10^4 / \lambda^3$$

condition (2) never satisfied

Diagram $A = 0$, hence no imaginary part of $G$, hence $\gamma = 0$ and assumption $\gamma \ll \omega$ satisfied trivially.
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

**Selfconsistent Calculation**

- Transverse Dispersion Relation
- Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
Full Calculation of $F$

Assume $F \in \mathbb{R}$ (turns out to be selfconsistent)

Apply Feynman rules to $p^2 = \text{Re}\Sigma^{00} = \ldots$

yields gap equation:

$$p^2 = \Sigma^{00}_B(p) = 8\pi e^2 \int_{|(p+k)^2|\leq|\phi|^2} \left[ \left( 3 - \frac{k^2}{m^2} \right) + \frac{k^0 k^0}{m^2} \right]$$

$$\times \ n_B \left( |k_0| / T \right) \delta (k^2 - m^2) \left. \frac{d^4 k}{(2\pi)^4} \right|_{p^2 = F}$$

(3)

Strategy to find $F$ similar to that of finding $G$ [Falquez,Hofmann,Baumbach ’11].
Selfconsistent Result for $F$

$$Y_I \equiv \frac{\omega_I(p_I, T)}{T} = \sqrt{\frac{F(p_I^2, T)}{T^2}} + \frac{p_I^2}{T^2}, \quad X \equiv \frac{|p_I|}{T}$$
Selfconsistent Result for $F$

\[ Y_l \equiv \frac{\omega_l(p_l, T)}{T} = \sqrt{\frac{F(p_l^2, T)}{T^2}} + \frac{p_l^2}{T^2}, \quad X \equiv \frac{|p_l|}{T} \]

- 3 branches
- $Y_L$ defined only for $X \lesssim 0.34$
- superluminal group velocity
Selfconsistent Result for $F$, Interpretation

Interpretation in terms of magnetic monopoles
[Falquez,Hofmann,Baumbach ’11]

- longitudinal modes due to charge density waves
- light like propagation:
  - stable (yet unresolved) monopoles released by large holonomy caloron dissociation [Diakonov et al. ’04]
  - density disturbance can only be propagated by radiation field, which propagates at the speed of light

- superluminal propagation:
  - unstable monopoles contained in small holonomy caloron
  - extended calorons provide instantaneous correlation between monopoles, leading to superluminal propagation
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

Selfconsistent Calculation
  Transverse Dispersion Relation
  Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
2-Loop Corrections

- “Bubble diagrams” yield pressure (cmp. talk by Dariush)

- For $T \gg T_c$ only relevant diagram:

\[ \Delta P \propto -4 \times 10^{-4} T^4 \]

- Temperature of TLM gas reduced!
Monopole Properties

Explanation

Energy used to break up calorons, creating monopole anti-monopole pairs [Schwarz, Giacosa, Hofmann ’06].

Detailed analysis shows [Ludescher, Keller, Giacosa, Hofmann ’08]:

- average monopole-antimonopole distance $\bar{d} < |\phi|^{-1}$
  $\Rightarrow$ monopoles unresolved in effective theory

- screening length $l_s$ due to small-holonomy calorons: $l_s = 3.3\bar{d}$
  $\Rightarrow$ magnetic flux of monopole and antimonopole cancel (no area law for spatial Wilson loop)
Table of Contents

Review of YMT

Polarization Tensor and Momentum Constraints

Approximate Calculation

Selfconsistent Calculation
  Transverse Dispersion Relation
  Longitudinal Dispersion Relation

Monopole Properties from a 2-Loop Correction to the Pressure

Summary and Outlook
Summary and Outlook

- Coarsegrained YMT ground state described by scalar field $\phi(T)$, $SU(2) \xrightarrow{\phi} U(1)$
- $|\phi|$ constrains loop momenta
- Calculated polarization tensor $\Sigma^{\mu\nu}$ for TLM mode on 1-loop level
- Approximation $p^2 = 0$ in constraint
  - Constraint solvable analytically
  - Dispersion relation for transverse mode; no propagating longitudinal mode
- Selfconsistent calculation
  - Constraint implemented numerically
  - Dispersion relation for transverse- and longitudinal mode
- In YMT monopoles are unresolvable and screened

Question
Is 1-loop calculation sufficient?

Answer
See talk by Dariush!

Thank you.
U. Herbst, R. Hofmann,
Asymptotic freedom and compositeness
[hep-th/0411214].

R. Hofmann
“Nonperturbative approach to Yang-Mills thermodynamics”

F. Giacosa, R. Hofmann,
“Thermal ground state in deconfining Yang-Mills thermodynamics”

J. Kapusta, G. Charles
“Finite-temperature field theory : principles and applications”
References II

M. Le Bellac
“Thermal field theory”
Cambridge Univ. Press, 1996.

M. Schwarz, R. Hofmann, F. Giacosa,
“Radiative corrections to the pressure and the one-loop polarization tensor of massless modes in SU(2) Yang-Mills thermodynamics”

J. Ludescher, R. Hofmann,
“Thermal photon dispersion law and modified black-body spectra”
