Static quark-antiquark pairs at finite temperature

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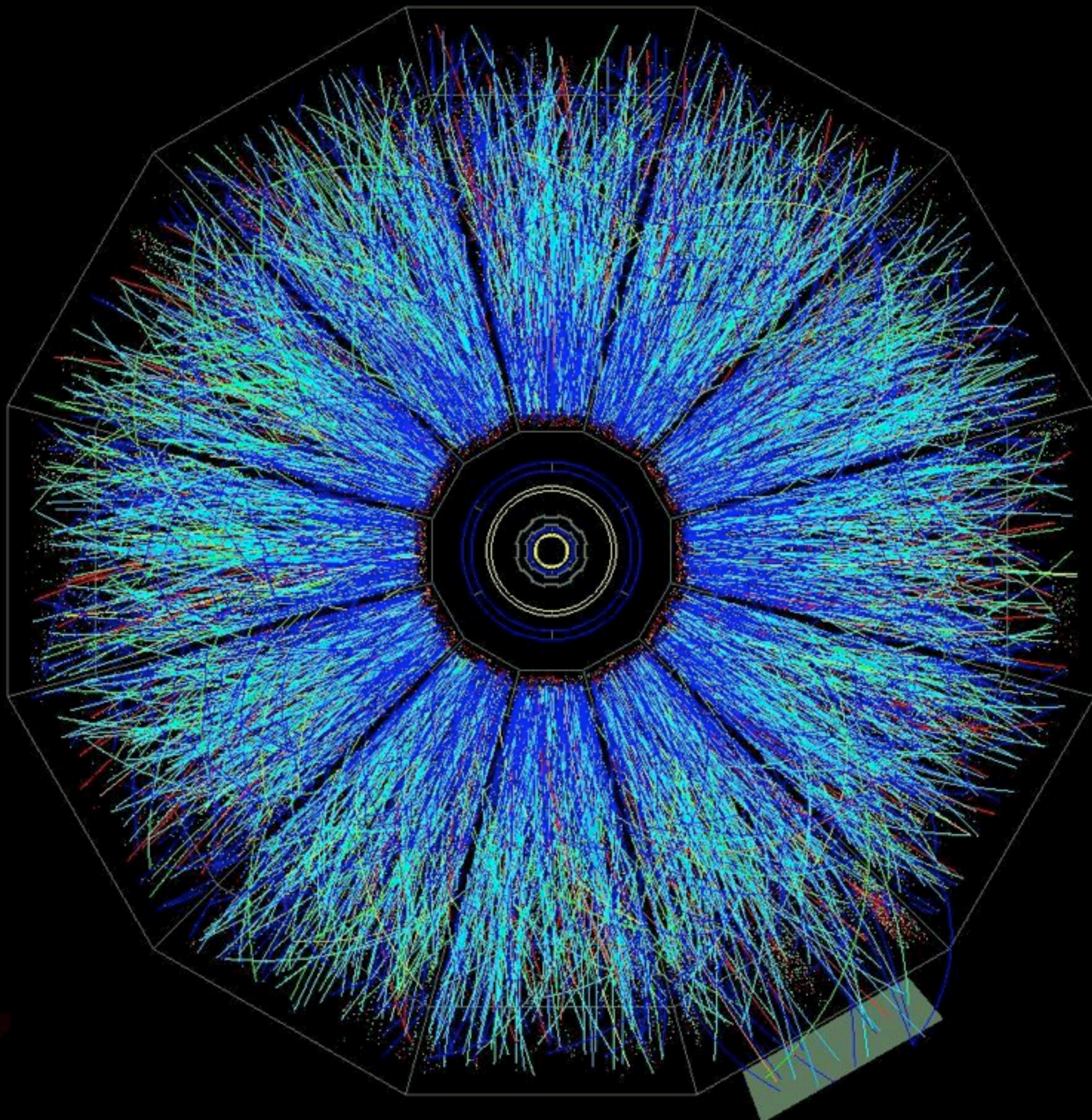
Outline

- Brief introduction toQGP, heavy quark bound states and Thermal Field Theory
- Potentials in two different temperature regions
- Conclusions
- Sources:

N. Brambilla, J. Ghiglieri, P. Petreczky and A. Vairo, "Static quark-antiquark pairs at finite temperature," arXiv:0804.0993 [hep-ph].

The Quark-Gluon Plasma

- A new state of matter
- It forms at high temperatures/densities $T_C \approx 175\mathrm{MeV}$
- Screening of the non-abelian charge, deconfined phase
- Heavy ion collisions (SPS, BNL, ALICE at LHC)



The J/Psi as a QGP probe

- Proposed in 1986 by Matsui and Satz
- Clean leptonic decay
- Hypothesis of thermal dissociation above the critical temperature
- The study of the potential in different temperature regions can provide useful information, without resorting to models

Potentials

- **Potential models**
  - Phenomenological nature
  - Introduced early (70’s)
  - Example: Cornell $V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + \sigma r$
- **Effective field theories**: modern and rigorous definition of the potential (last 15 years): NRQCD, pNRQCD

Heavy quarks bound states

- Non-relativistic treatment: possible due to the large mass of the heavy quarks
- Hierarchy: $m \gg mv \gg mv^2$

  Hard scale (m), Soft scale (mv), Ultrasoft scale (mv^2)

- Another scale in QCD: Λ_{QCD}
- Many scales, EFT more suitable
- We consider the static limit $m \to \infty$

Temperature: more scales

$$m \gg mv \gg mv^2$$

$$?$$

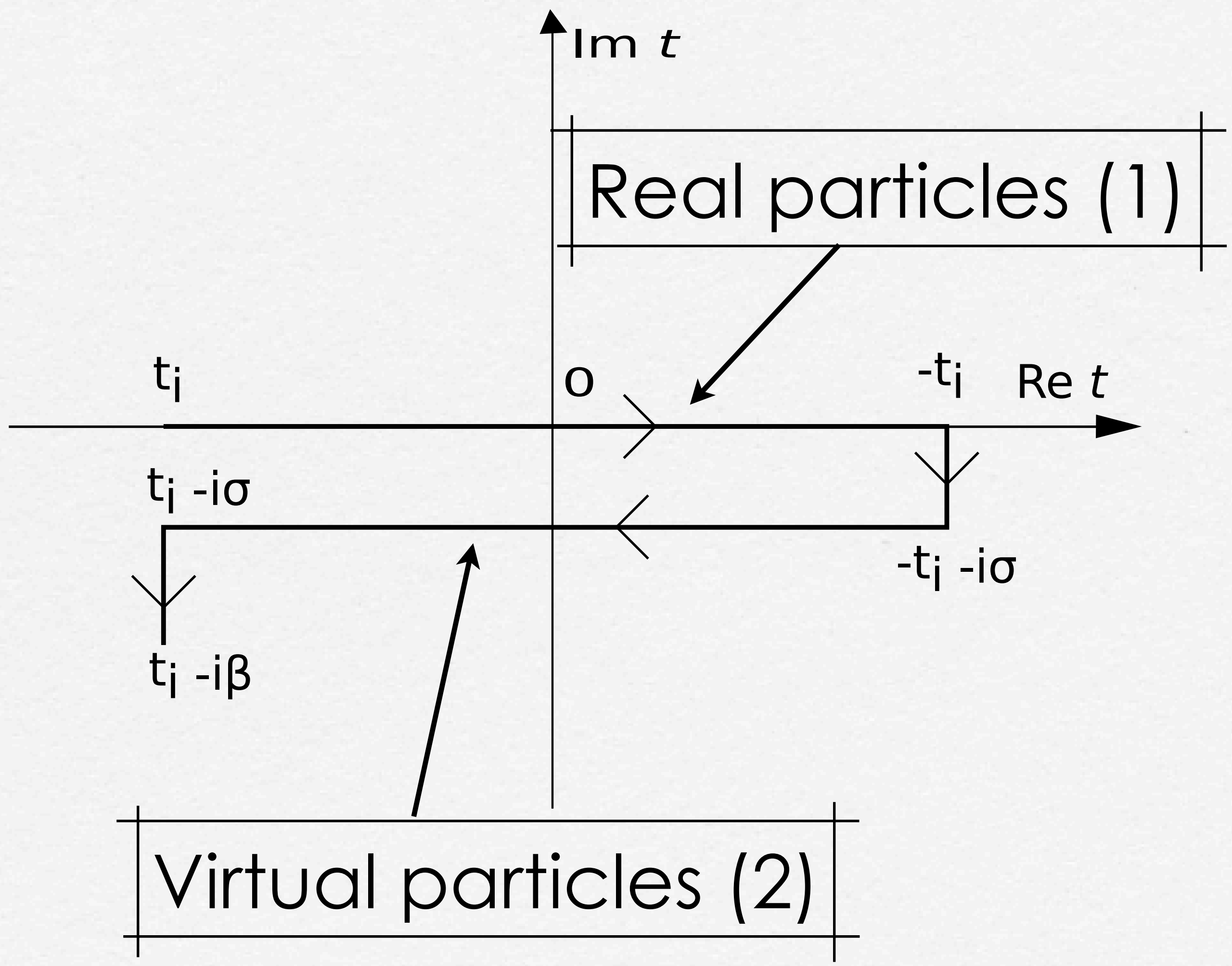
$$T \gg gT \gg g^2T \ldots$$

$m_D \sim gT$ Debye scale Screening scale

$$mv \sim \frac{1}{r}$$

- We study $T \gg m_D \gtrsim \frac{1}{r}$ and $\frac{1}{r} \gg T \gg m_D \gg \Delta V$
- Perturbative study

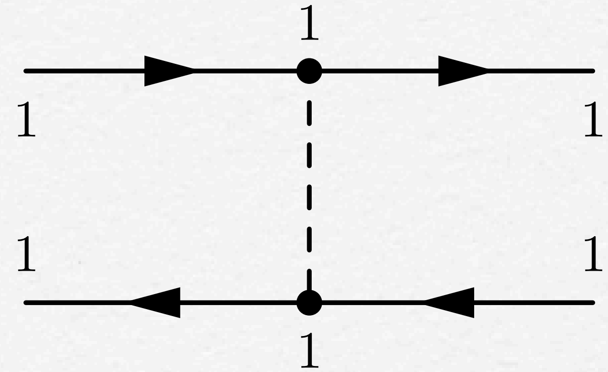
Real-time formalism



- Evolution along this path
- Limit $t_i \to -\infty$
- Doubling of the degrees of freedom

Potential for $T \gg \frac{1}{r} \sim m_D$

$-iV(r) =$



- Integration of the scale T: the longitudinal gluon propagator (Coulomb gauge) acquires a mass (the Debye mass):

$$\frac{i}{\mathbf{q}^2} \to \frac{i}{\mathbf{q}^2 + m_D^2} \qquad m_D^2 = g^2 T^2 \left(\frac{N_C}{3} + \frac{N_f}{6} \right)$$

- Integration of the scale $\frac{1}{r}$: we obtain the potential

Potential for $T \gg \frac{1}{r} \sim m_D$

$$V(r) = -\frac{g^2 C_F}{4\pi}\left(\frac{e^{-m_D r}}{r} - \frac{2iT}{m_D r}\int_0^\infty dz \frac{\sin(m_D r\, z)}{(z^2+1)^2}\right)$$

Real part:
Debye potential
screening

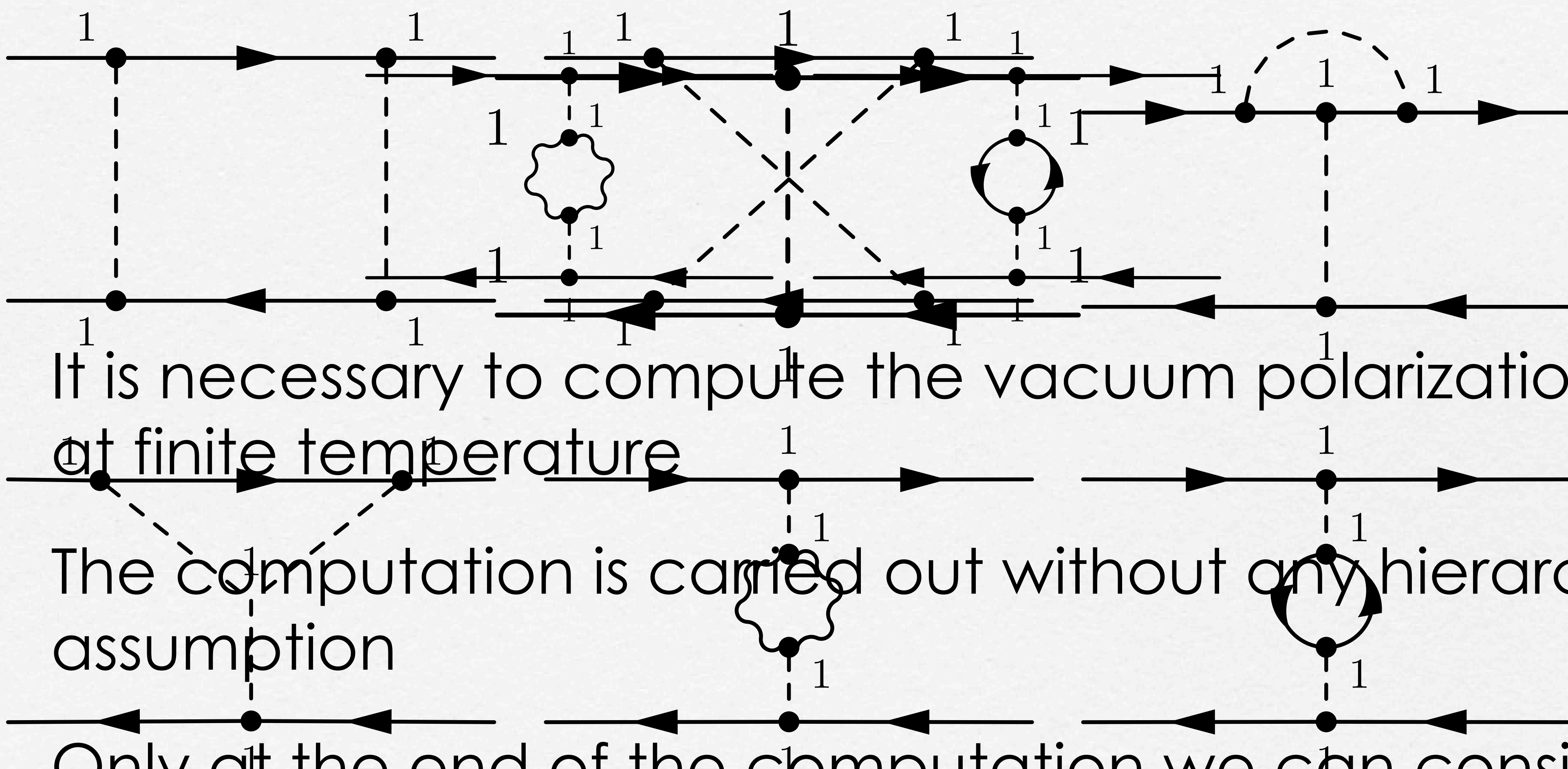
Imaginary part:
decay
Landau damping

- We have obtained the result of

M. Laine, O. Philipsen, P. Romatschke and M. Tassler, JHEP **0703**, 054 (2007) [arXiv:hep-ph/0611300].

Potential for $\frac{1}{r} \gg T \gg m_D \gg \Delta V$

$$m_D \sim gT \Rightarrow \frac{1}{r} \gg T \gg m_D$$



- It is necessary to compute the vacuum polarizations at finite temperature
- The computation is carried out without any hierarchy assumption
- Only at the end of the computation we can consider the contribution from the various momentum regions

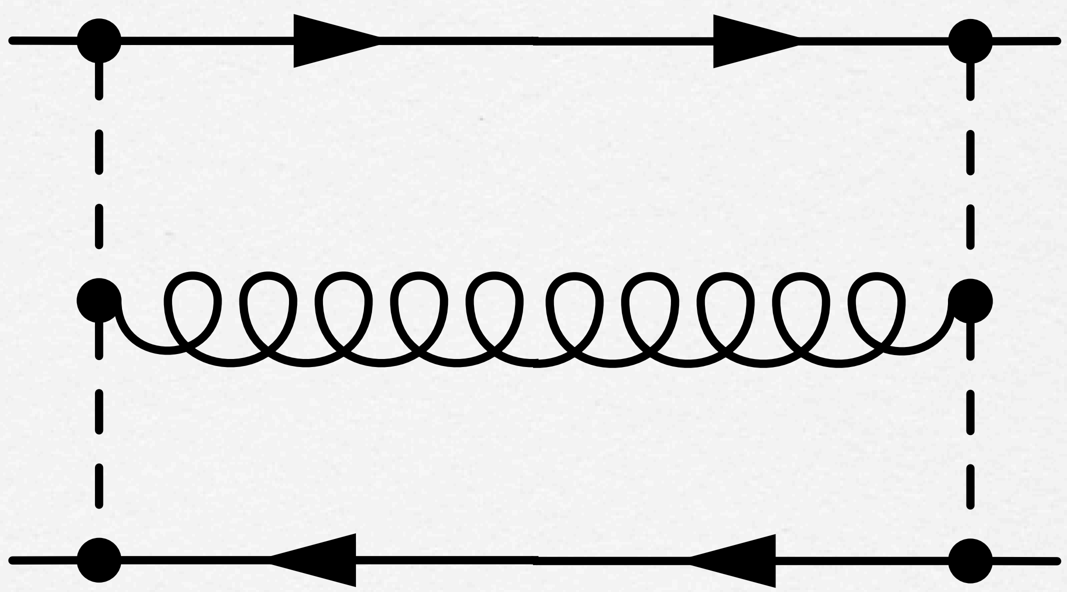
Potential for $\frac{1}{r} \gg T \gg m_D \gg \Delta V$

$$
\begin{aligned}
V(r) &= -C_F\frac{\alpha_{V_s}(1/r)}{r} \\
&+ \frac{\pi C_F C_A \alpha_s^2 T^2 r}{9} - \frac{3}{2}\zeta(3) C_F \frac{\alpha_s}{\pi} r^2 T m_D^2 + \frac{2}{3}\zeta(3) C_A C_F \alpha_s^2 r^2 T^3 + \frac{C_F}{6}\alpha_s r^2 m_D^3 + \dots \\
&+ i\left[-\frac{C_A^2 C_F}{6}\alpha_s^3 T + \frac{C_F}{6}\alpha_s r^2 T m_D^2 \left(2\gamma_E - \log\frac{T^2}{m_D^2} - 1 - 4\log 2 - 2\frac{\zeta'(2)}{\zeta(2)}\right)\right. \\
&\left. + \frac{4\pi}{9}\log 2 C_A C_F \alpha_s^2 r^2 T^3\right] + \dots
\end{aligned}
$$

- Contributions from the scale $k \sim \frac{1}{r}$
- Contributions from the scale $k \sim T$
- Contributions from the scale $k \sim m_D$
- Imaginary part
  - Singlet->octet thermal dissociation

Singlet to octet thermal dissociation

- Energetically forbidden at T=0



Conclusions

- Rigorous QCD study of the potential
- New results in the regime $\frac{1}{r} \gg T$
- New thermal dissociation process
- Possible predictions on J/Psi and Υ phenomenology in the QGP