Hadronic modes in the Quark-Gluon Plasma

hep-ph/0505080

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3) INFN Bruno Rossi Fellowship

Outline of the talk

- Introduction
  - QCD Phase Diagram
  - Mesonic states above T_c
- Our model
  - Dirac-Brueckner approach
  - Medium effects
  - Numerical results
- Conclusions and outlook

Introduction

- Lattice QCD (lQCD): $T_c \sim 170$ MeV and $\epsilon_c \sim 1$GeV/fm^3
- pQCD: For $T \gg T_c$ relevant degrees of freedom quarks and gluons with a screened (rather than antiscreened) color interaction
- Experiment: At RHIC reached $\epsilon > \epsilon_c$ and rapid thermalization of the fireball and collective behaviors observed
- Phenomenology: Hydrodynamics describes with good accuracy the properties of the matter obtained at RHIC (not for very high p_t)

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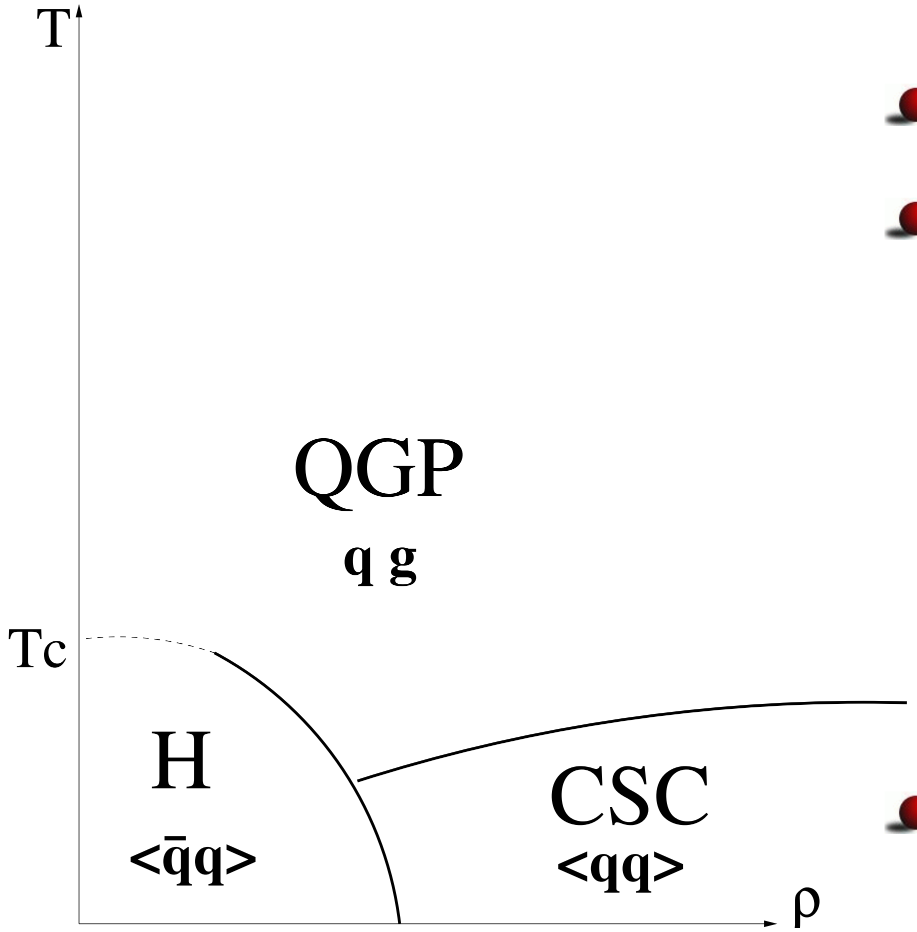
Hydro requires thermalization times below 1 fm/c.

- One mechanism of thermalization: scattering of quarks in resonant states (for heavy quarks see Rapp after this talk in room 0.83)

QCD phase diagram



- No isospin axis
- Three possible phases
  - H Hadronic
  - QGP Quark-gluon plasma
  - CSC Color Superconductor
- $T_c \sim 170$ MeV from lattice simulations

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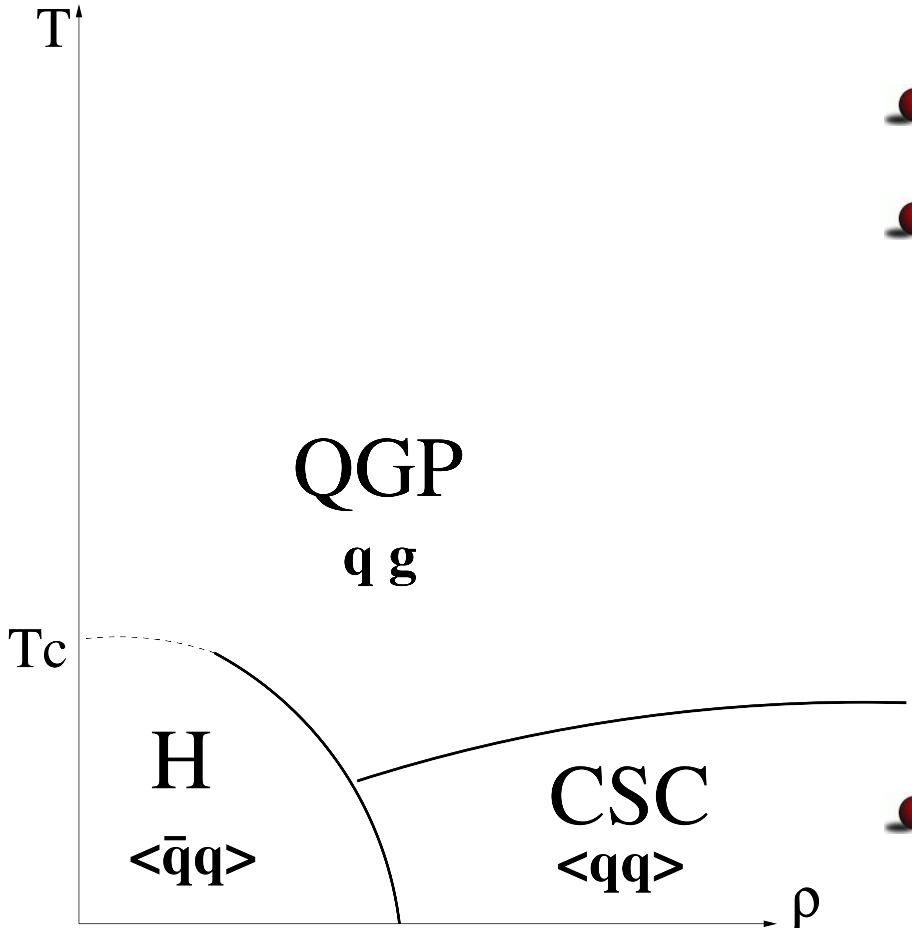

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Plasma: System of charged and neutral particles which exhibit collective behavior.

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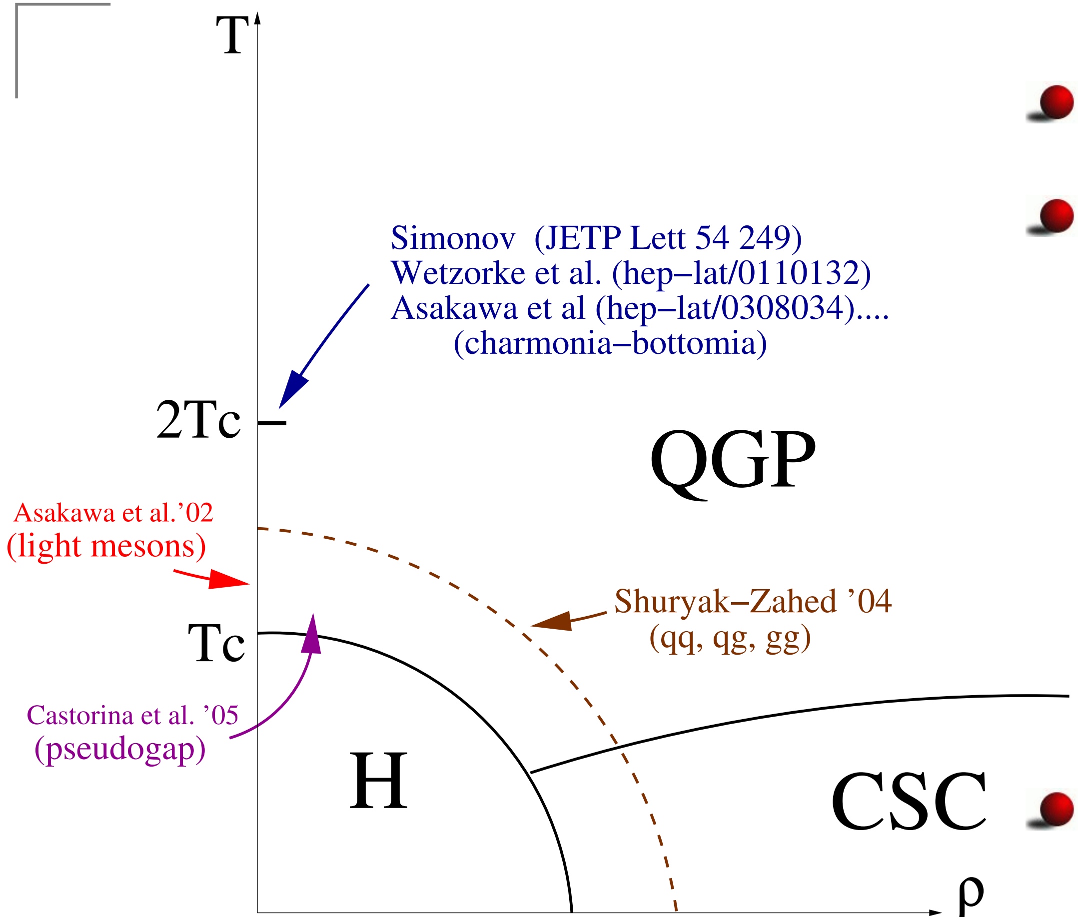

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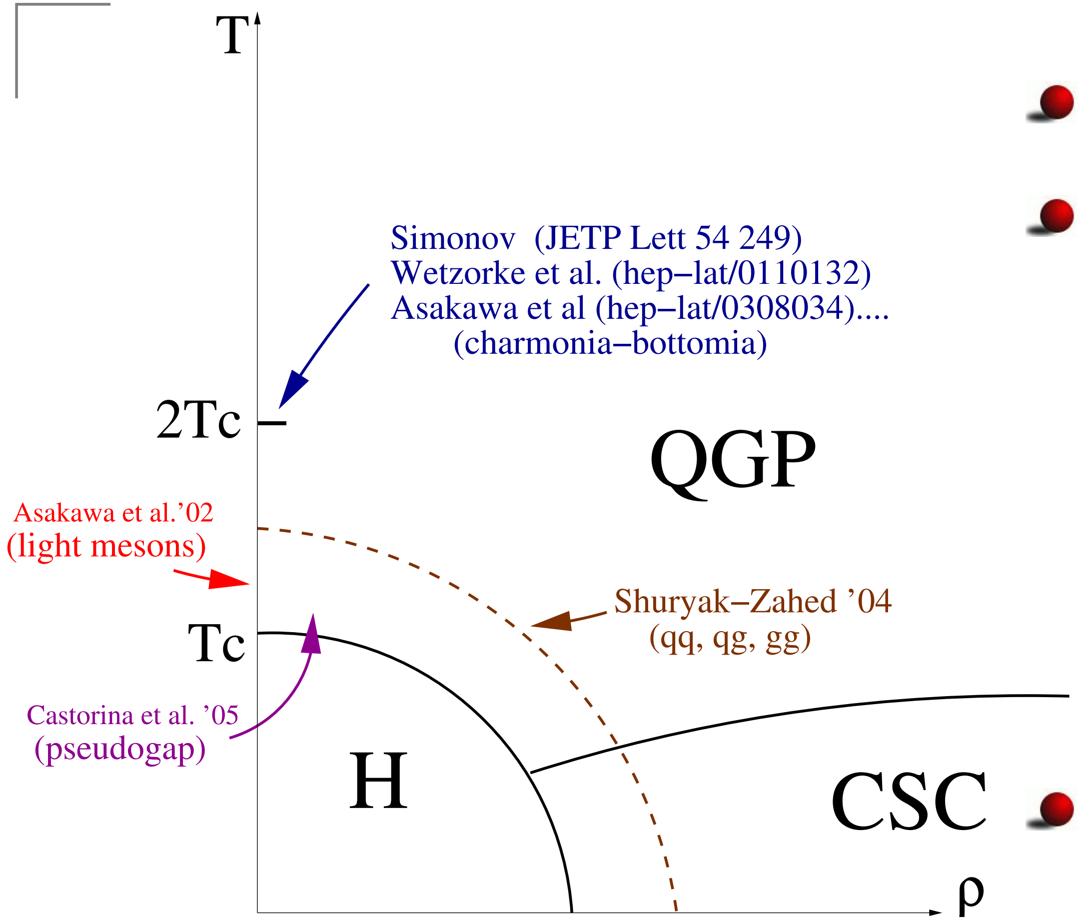

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Plasma: System of charged and neutral particles which exhibit collective behavior. A definition a bit too generic

Our model

We assume that

- The QGP consists of quarks, gluons. Quarks can form bound (resonant) mesonic states.
- Potential model with the quark interactions in the singlet and octet channels can be extracted from lattice QCD simulations.
- The Dirac-Brueckner approach is used to take into account medium effects on quarks (quasiparticle description)

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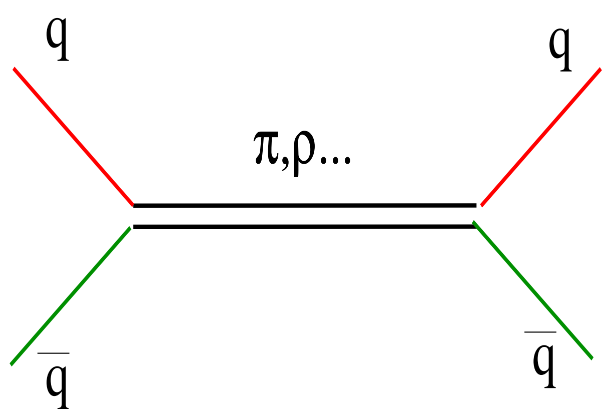

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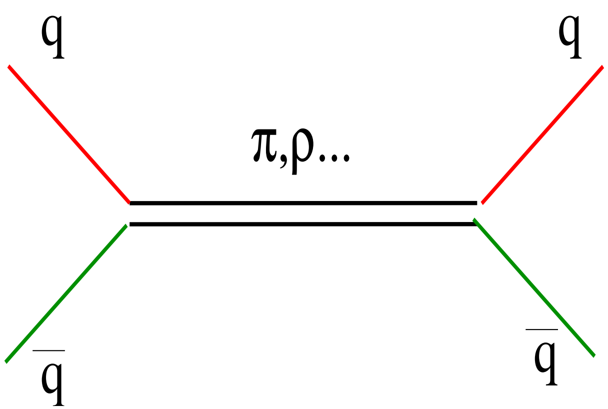

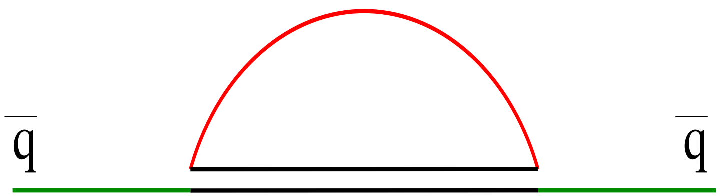

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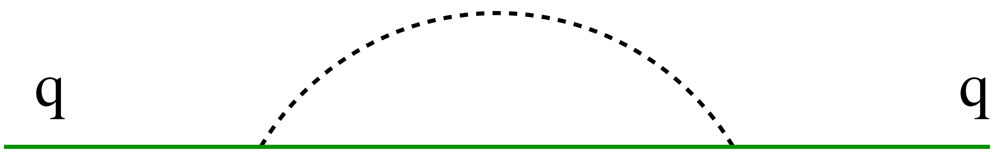
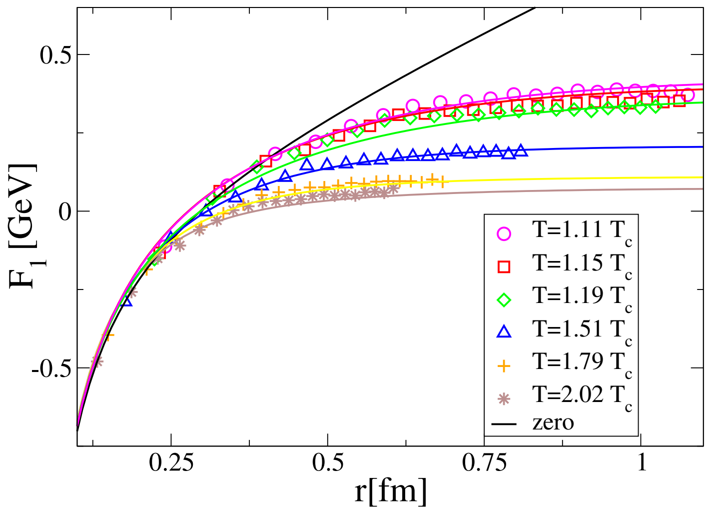
Note that the typical HTL quark self-energy diagram is not directly included in our procedure



Parametrization of the Free energy

We extract the potential from the variation of the free-energy due to a $q\bar{q}$ pair (*Petreczky et al. '04*):



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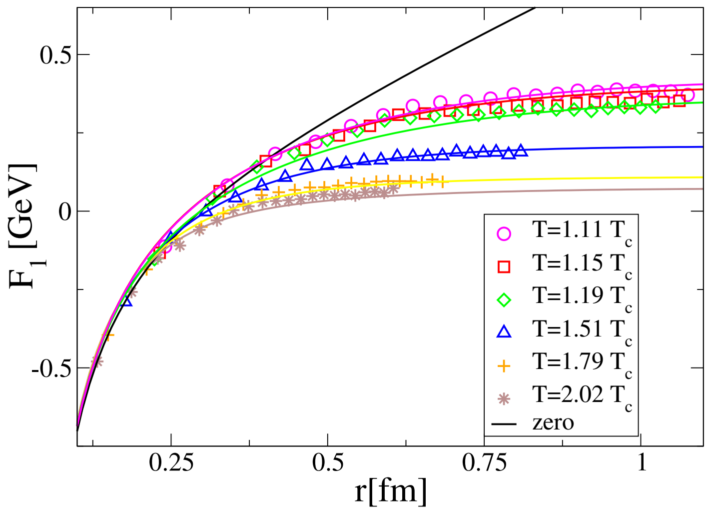

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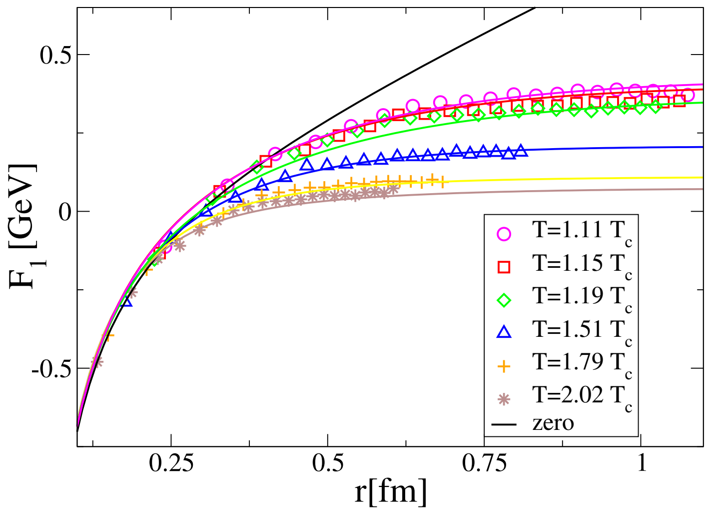

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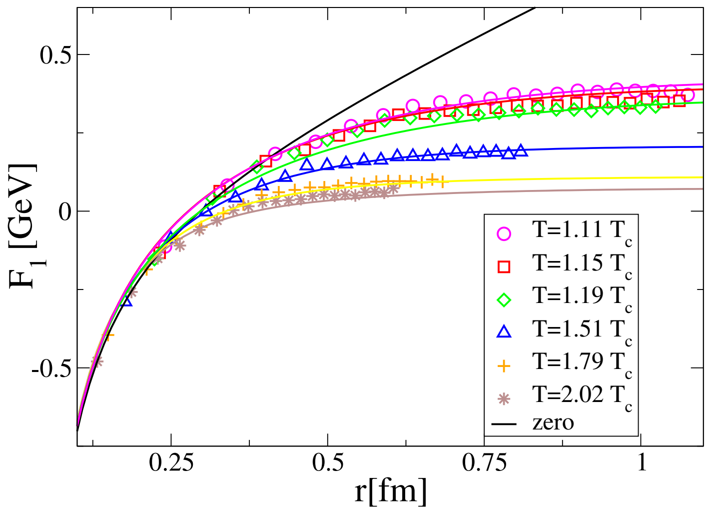

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Fitting function (similar to *Karsch et al. '88)* :

$$F_1(r,T) = -\frac{\alpha}{r}e^{-A\mu r} + \frac{\sigma}{\mu}(1 - e^{-\mu r})$$

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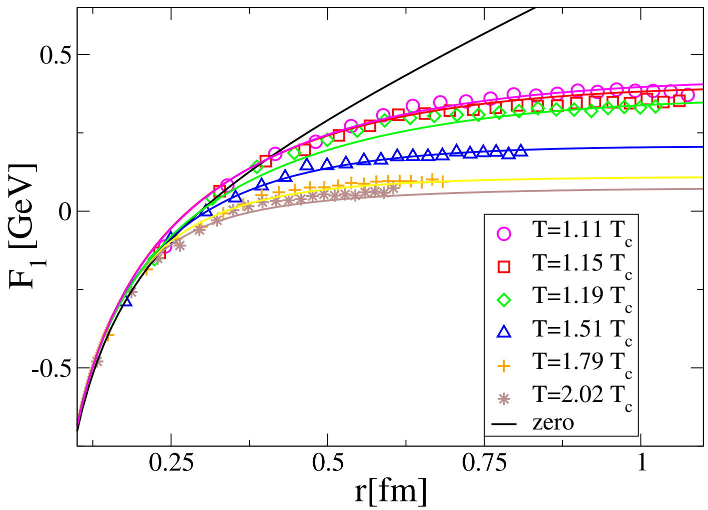

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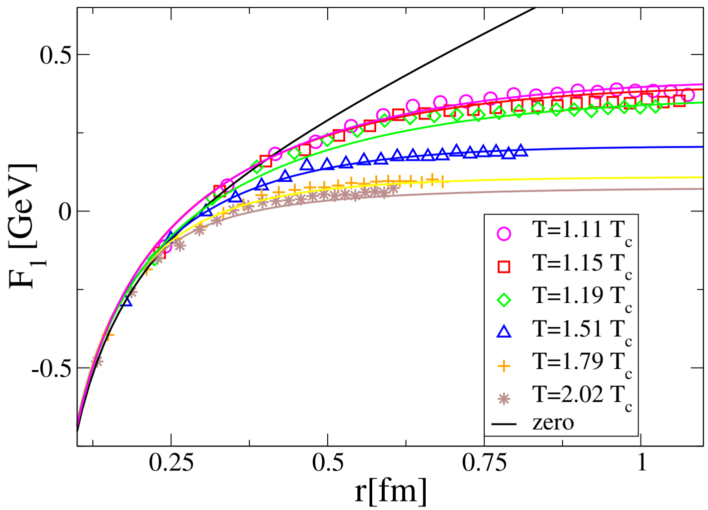

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A fitting function; μ “screening mass"

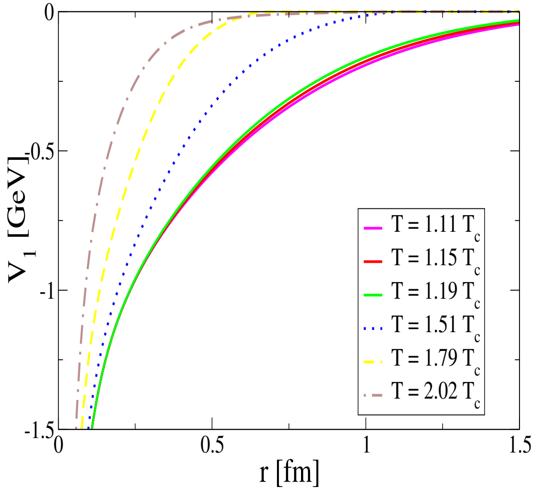
Potential

Internal energy

$$E_1 = F_1 - T\frac{dF_1}{dT}.$$

We assume that the asymptotic value of the internal is the in-medium quark mass. Therefore the potential in the color-singlet channel is

$$V_1(r,T) = E_1(r,T) - E_1(\infty,T) \qquad V_8 = -\frac{1}{8}V_1$$



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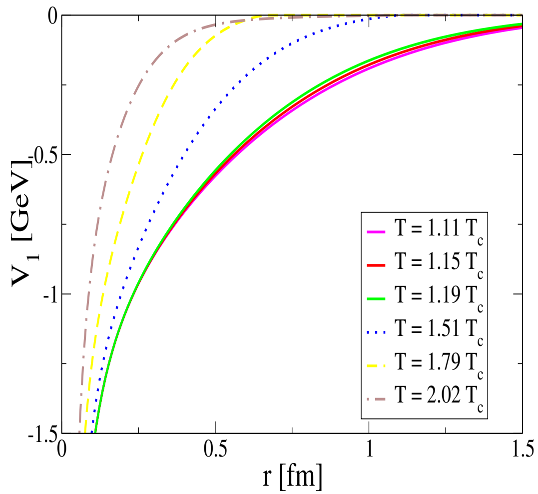
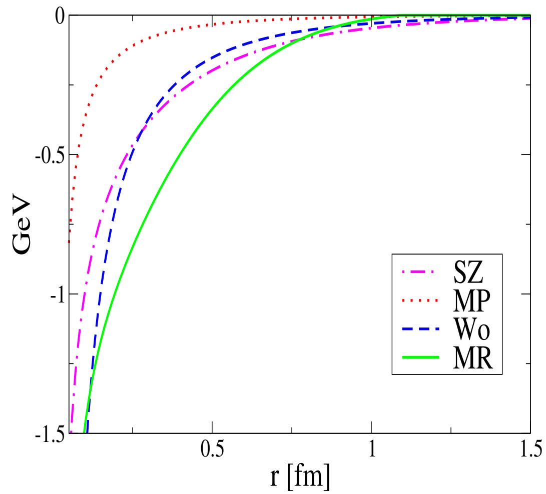
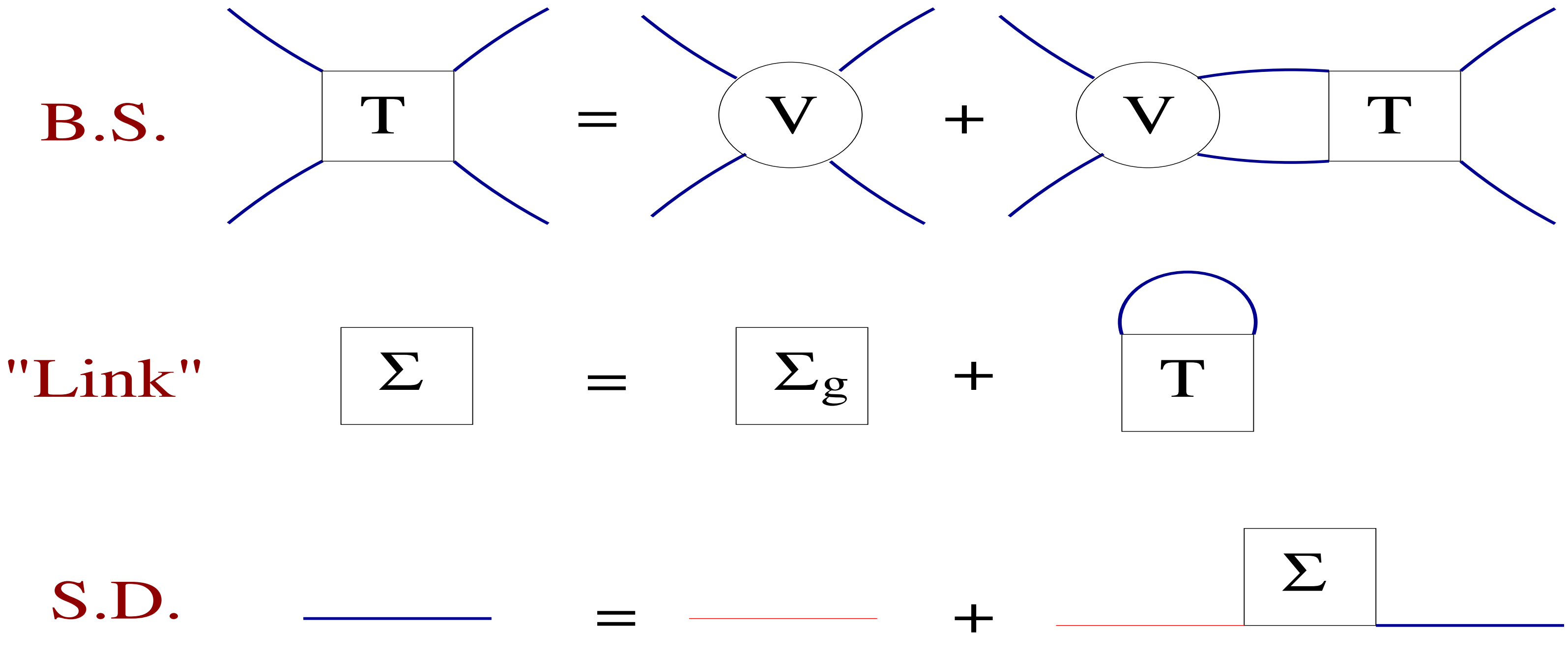




Self-consistency

The full set of Dirac-Brueckner equations



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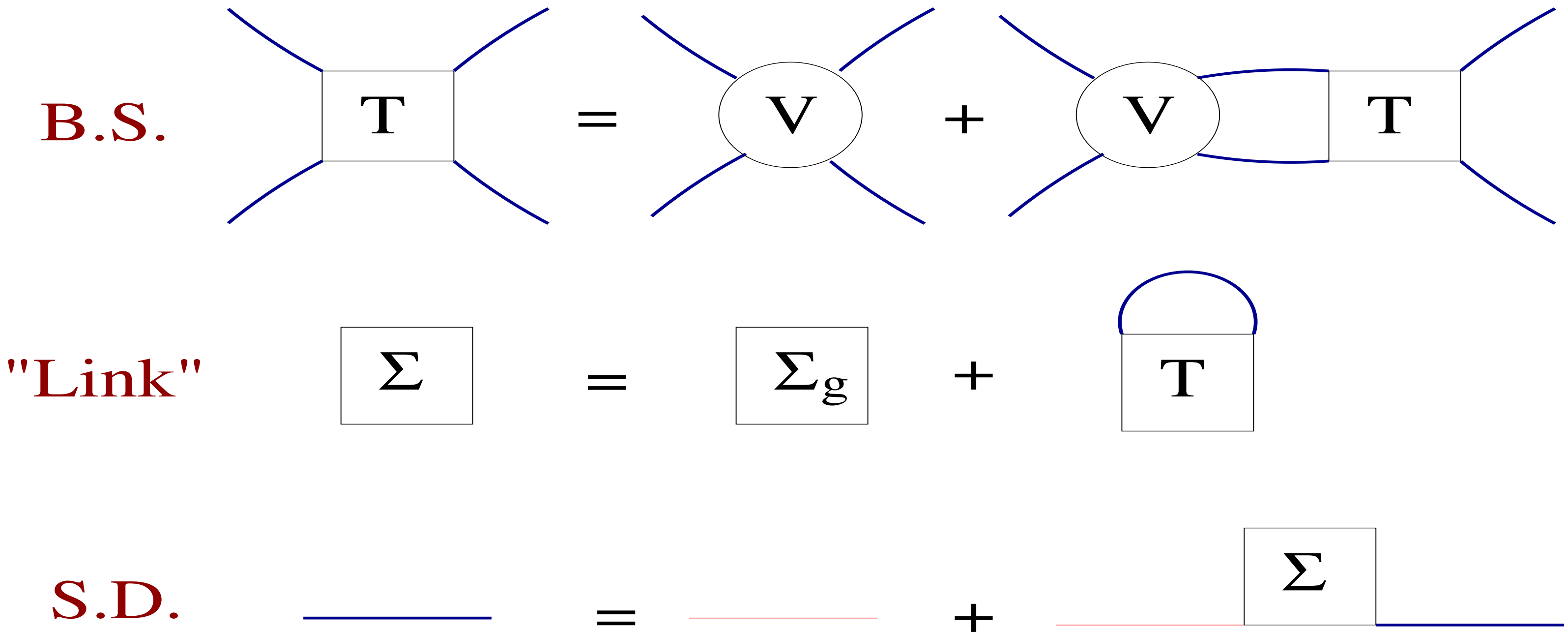

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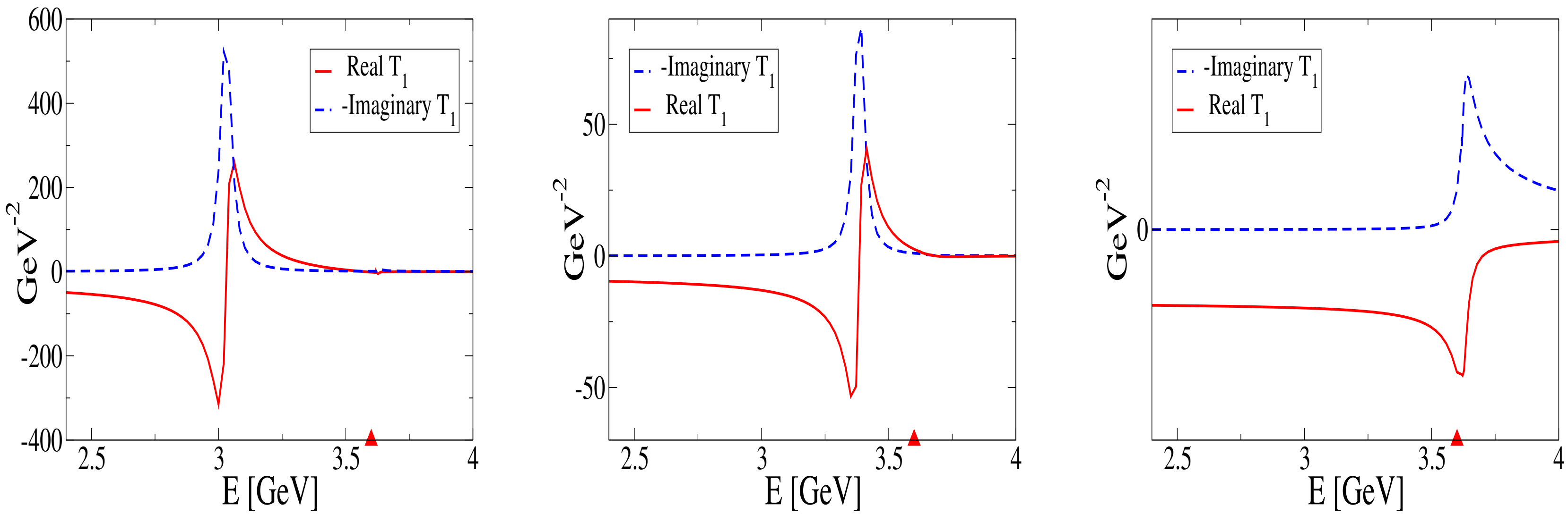
Σ_g is a "gluon-induced" self-energy, parameterized as a mass m in the dispersion law:

$$\omega_k = \sqrt{k^2 + m^2} + \Sigma_R(\omega_k, k)$$

A check: "J/Ψ"



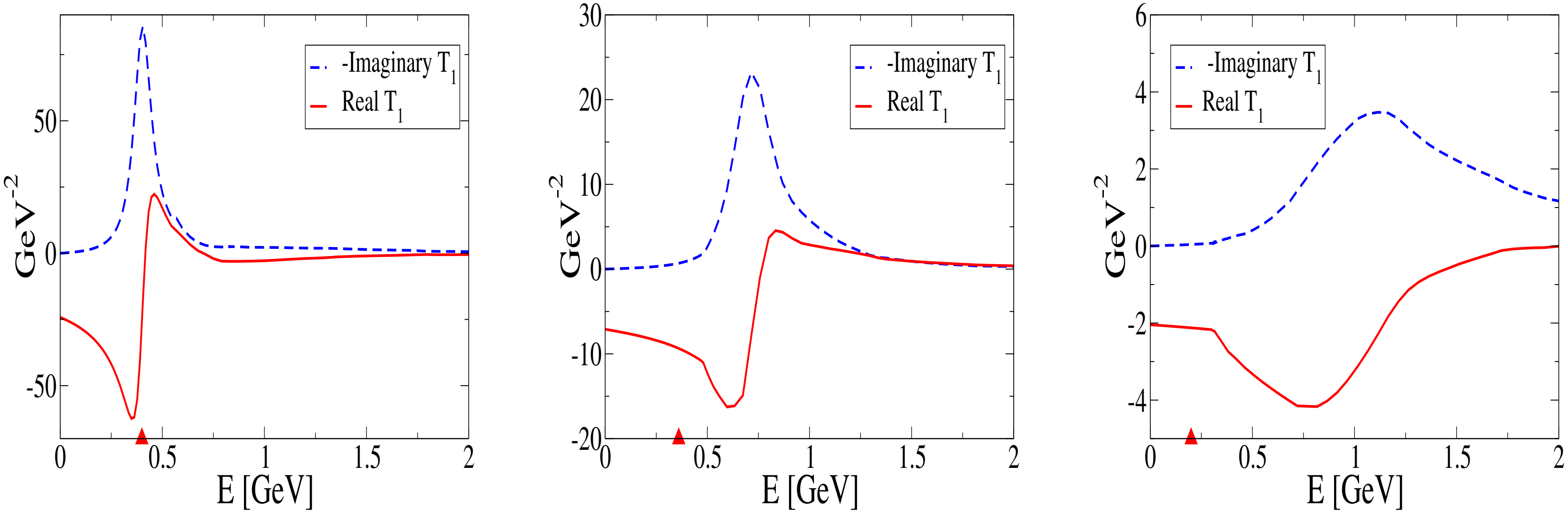
$T = 1.2\,T_c$ $T = 1.5\,T_c$ $T = 2.0\,T_c$

Real and imaginary part of T-matrix in the singlet channel for the in medium "J/Ψ" meson as a function of CM energy E charm effective mass $m = 1.8$ GeV

No self-consistency: $\Sigma_R = 0$ and $\Sigma_I = -10$ MeV.

Dissociation at $T_D \sim 2T_c$.

Light quarks T-matrix (singlet)



$T = 1.2\,T_c$ $T = 1.5\,T_c$ $T = 1.75\,T_c$

Real and imaginary part of the light-quark (on-shell) T-matrix in the singlet color channel with a "gluon-induced" mass $m = 0.1$ GeV.

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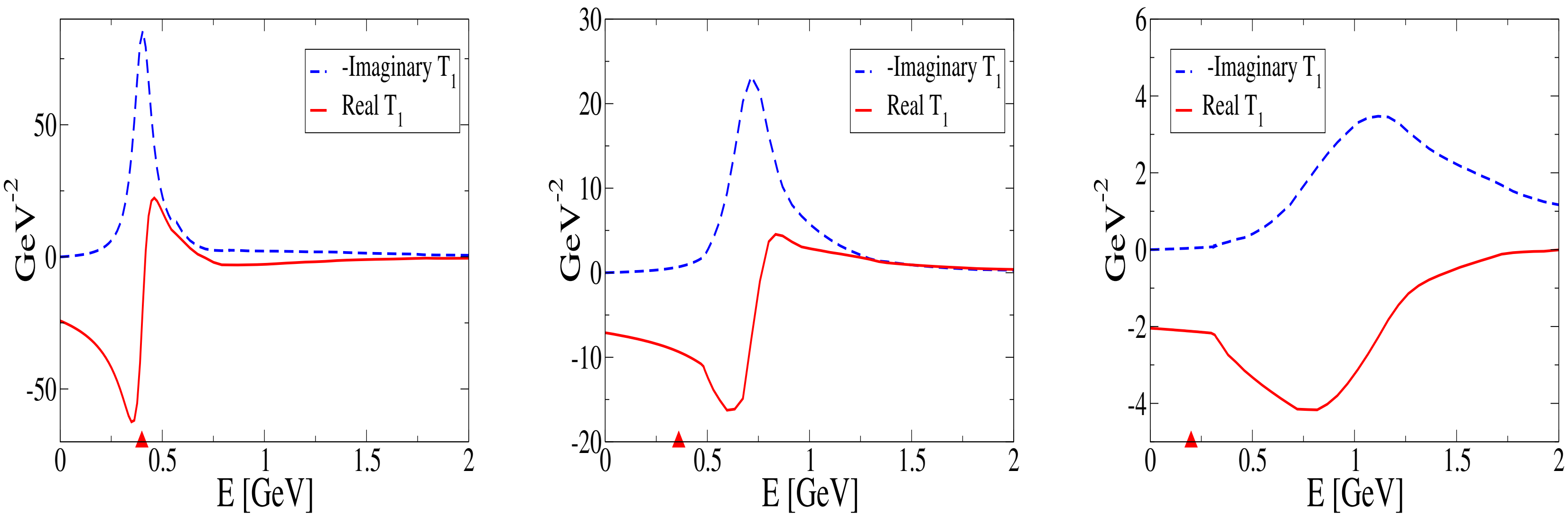

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- Dissociation temperature $T \sim 1.2 T_c$.

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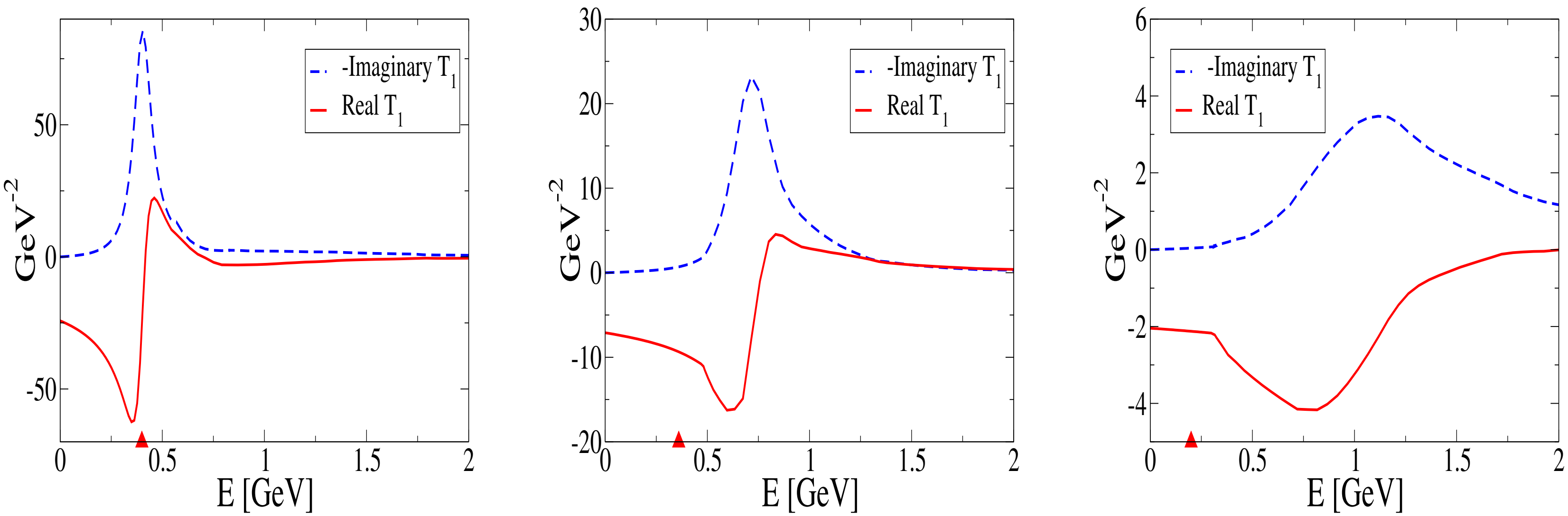

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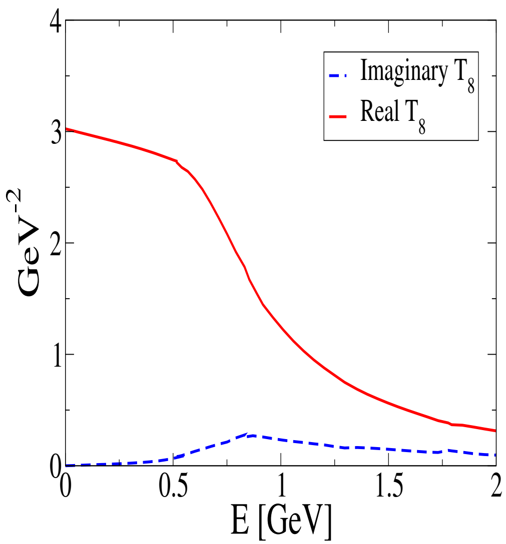
- Dissociation temperature $T \sim 1.2T_c$.
- For $T > 1.2T_c$ mesonic states survive as resonant states.

Light quarks T-matrix (octet)



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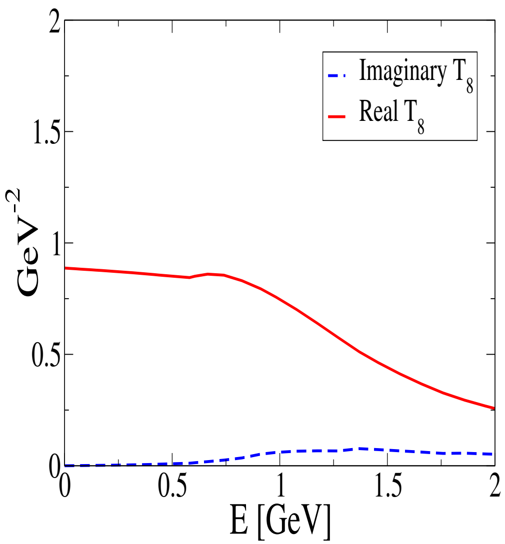

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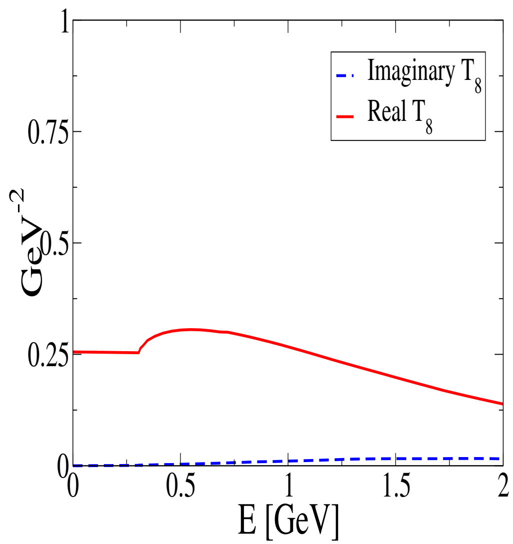
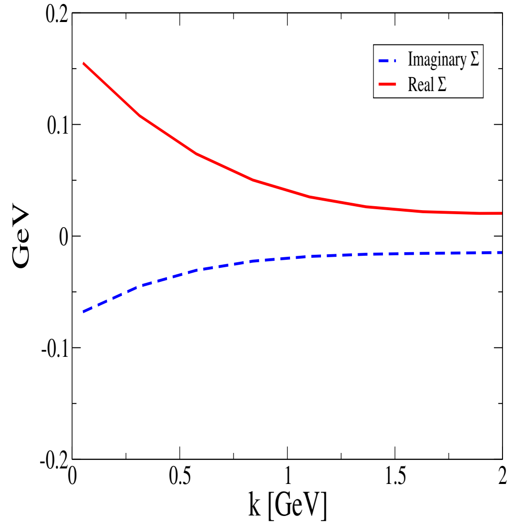


$T = 1.75\,T_c$

Real and imaginary part of the light-quark (on-shell) T-matrix in the color octet channel; $m = 0.1$ GeV.

Light quarks Self-energy



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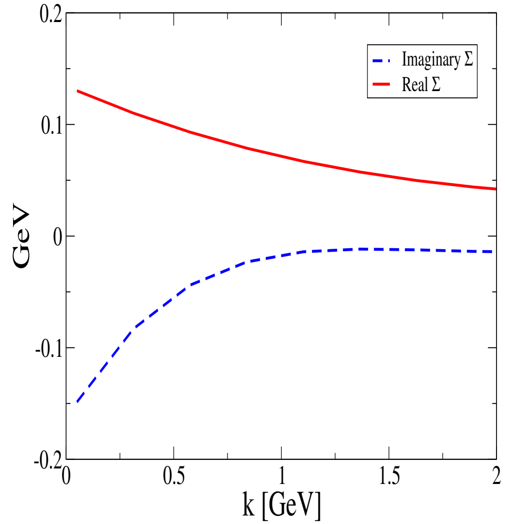

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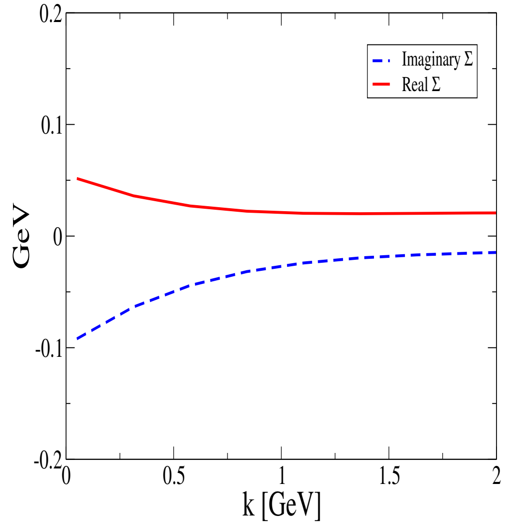

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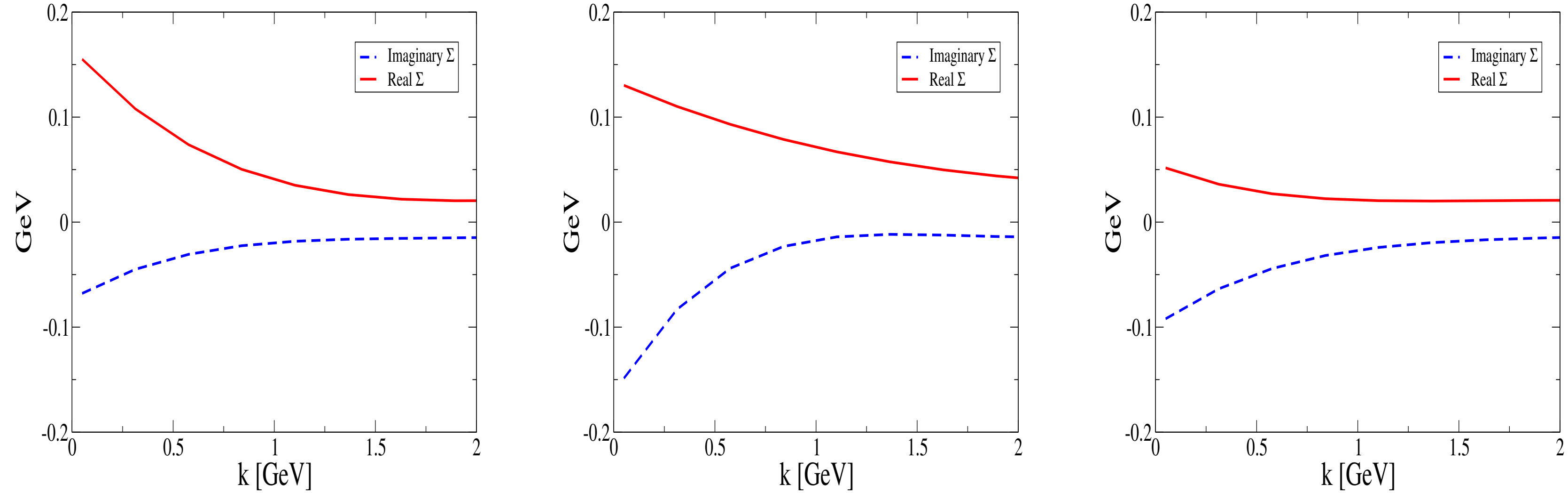
Real and imaginary part of the light-quark (on-shell) self-energy (singlet+octet); $m = 0.1$ GeV.

- Real part dominated by the octet contribution.

Light quarks Self-energy



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Real and imaginary part of the light-quark (on-shell) self-energy (singlet+octet); $m = 0.1$ GeV.

- Real part dominated by the octet contribution.
- Imaginary part dominated by the singlet contribution.

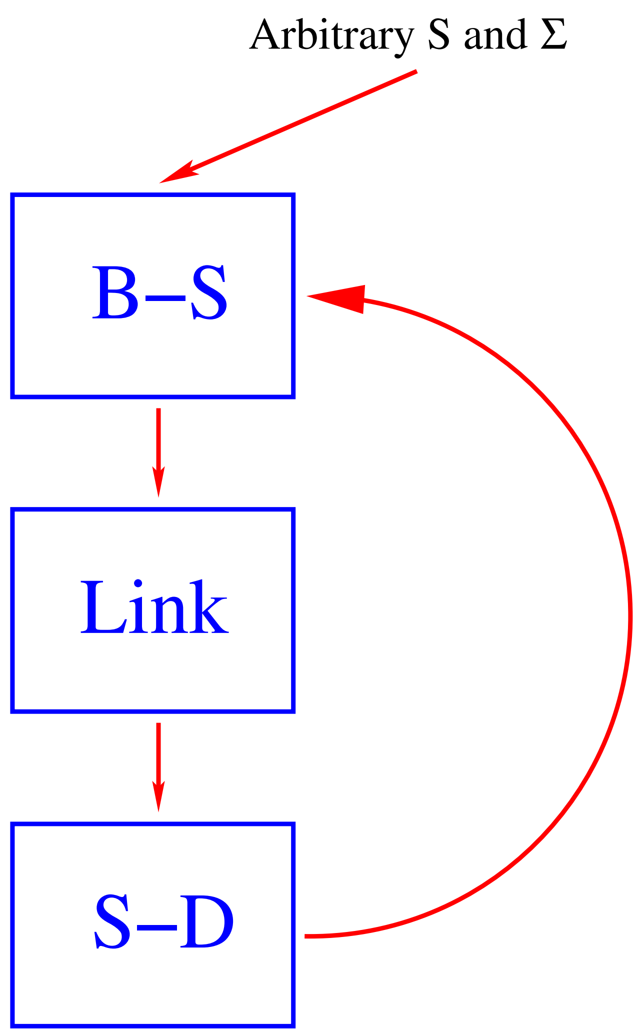
Conclusions and outlook

- We have analyzed the mechanism of scattering of quarks in bound or resonant states in the QGP $T \sim 1 - 2T_c$
- ”Quasiparticles” acquire a large mass ~ 150 MeV from the octet channel and a large width ~ 200 MeV from the singlet
- The mechanism which produces the large width is the scattering into resonant states

- This could be a mechanism to quickly thermalize the QGP and to explain the collective behavior observed.
- Next step is to study heavy quarks and to find a way to consider in a self-consistent way the gluons.

Numerical Solution

We "solve" the Dirac-Brueckner equations by iteration



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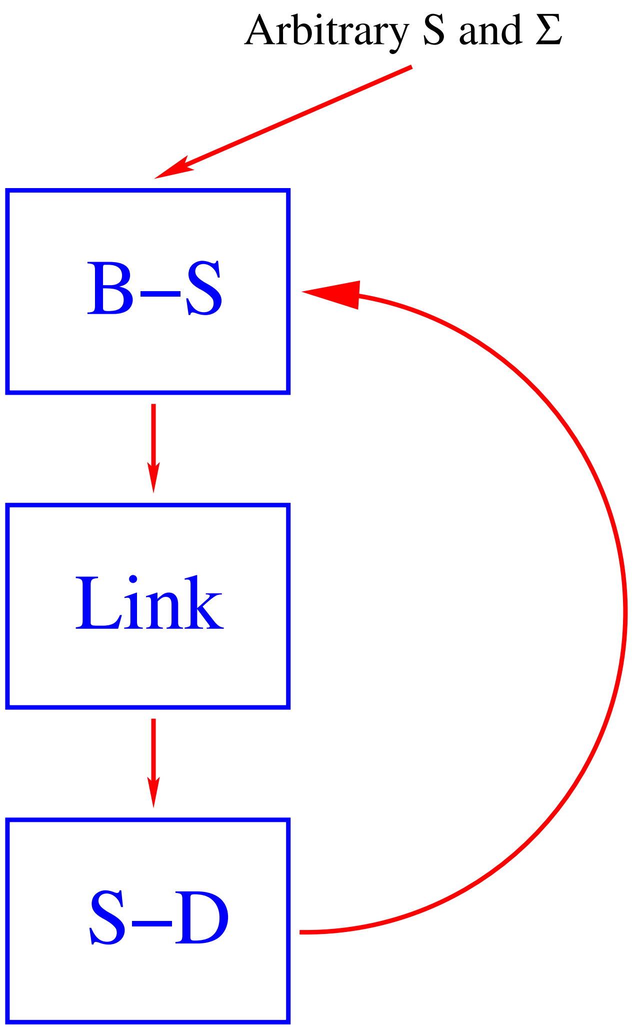

- Begin with an arbitrary self-energy
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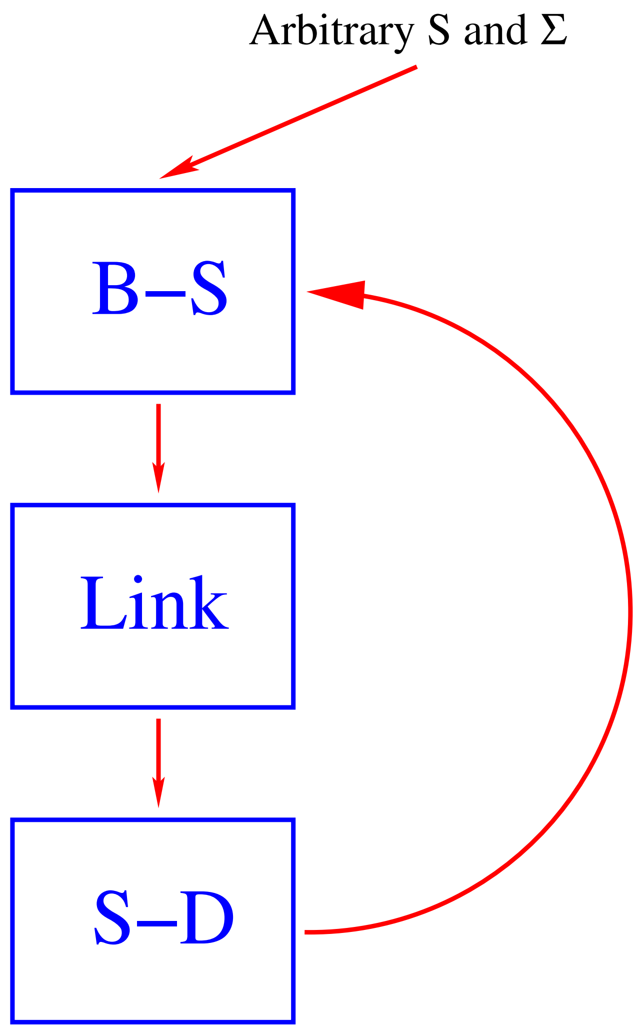

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Check of stability and independence on step 1

Potential models ($\mu = 0$)

Charm and bottom quarks are heavy. In bound states and for $m \ll E_k$ one can use non-relativistic potential model

$$\left(2m_a + \frac{\nabla^2}{m_a} + V_1(r,T)\right)\psi_a = M(T)\psi_a\,,$$

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with $a = b, c$. Without a medium ($T \simeq 0$) the Cornell potential

$$V_1(r,T) = -\frac{\alpha}{r} + \sigma r$$

works for $c\bar{c}$ and $b\bar{b}$: *Eichten et al.* Phys. Rev. D 17, 3090 (1978).

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- Phenomenology
- Lattice *Wong '04* and *Mocsy et al. '04* $T^D_{J/\Psi} \sim 2T_c$
- pQCD

Dirac-Brueckner approach

Quark-antiquark scattering can be described covariantly by the Bethe-Salpeter (B.S.) equation for the T-matrix

$$T = K + \int KSST\,,$$

where K is the interaction kernel and

$$S = S_0 + S_0 \Sigma S$$

is the single-particle propagator.

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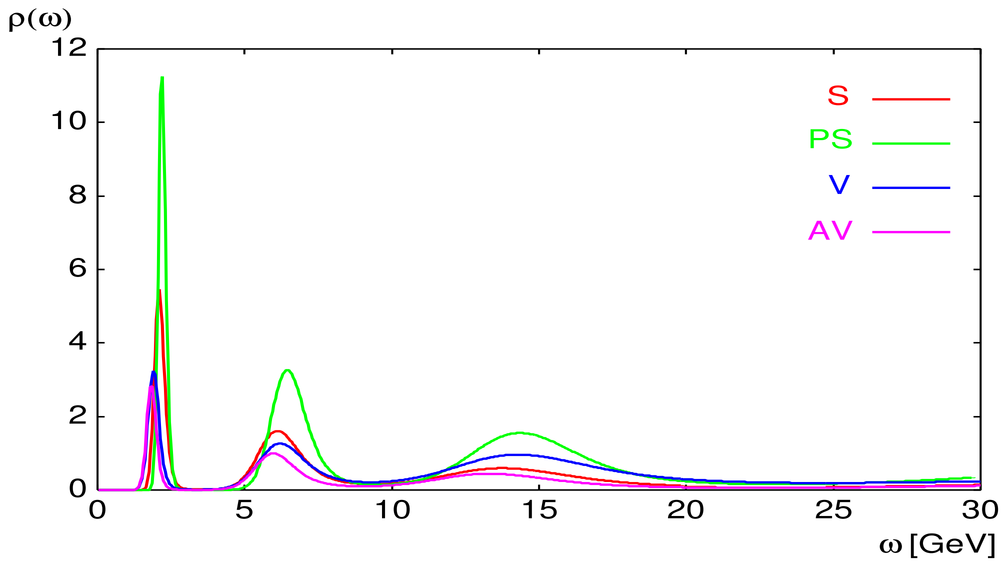
- Interaction in the octet channel with $V_8 = -\frac{1}{8} V_1$

Mesonic states above T_c

Maximum Entropy Method (MEM) analysis of correlators allows the evaluation of mesonic spectral functions:



Quenched $32^3 \times 54$ ($T = 1.4\,T_c$) with $m_\pi/m_\rho \simeq 0.7$

Asakawa et al. Nucl. Phys. A 715 (2003) 701

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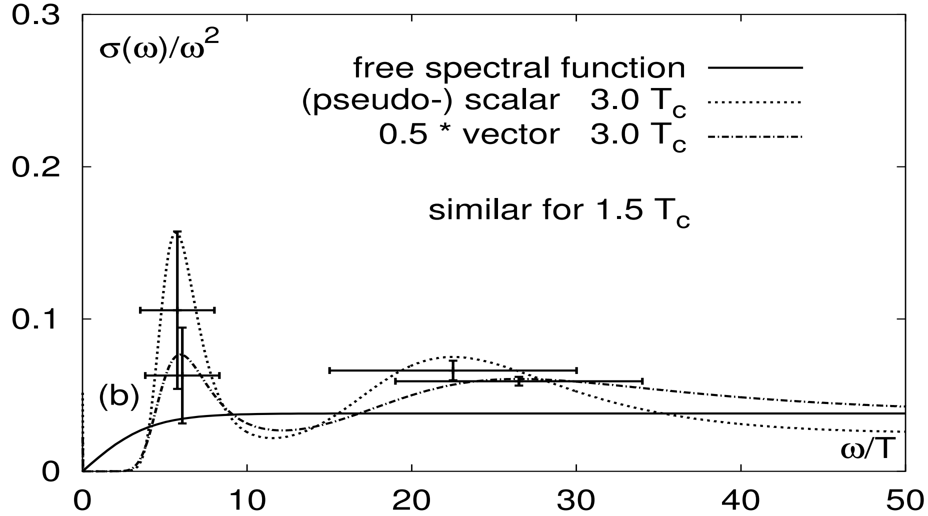

Quenched $24^3 \times 32$; vanishing quark mass

Wetzorke et al. hep-lat/0110132

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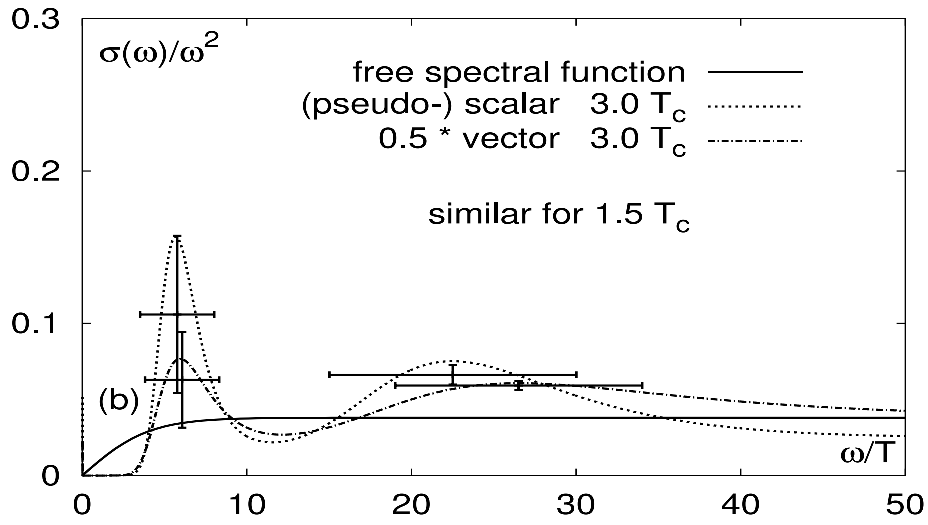

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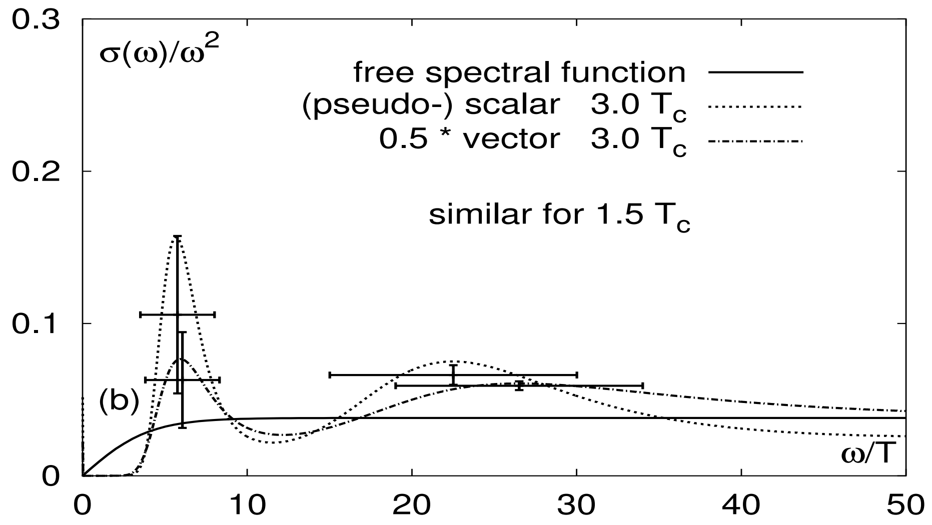

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If no structure is present the spectral function is flat. Powerful method but one needs a big calculation power.