Extended linear sigma model in medium

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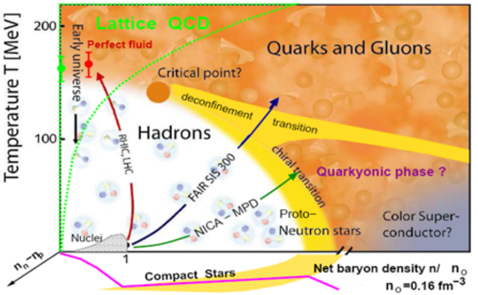
Overview

QCD phase diagram

Phase diagram in the $T - \mu_\mathrm{B} - \mu_\mathrm{I}$ space



- At $\mu_\mathrm{B} = 0$
  $T_c = 151(3)$ MeV
  Y. Aoki, *et al.*, PLB **643**, 46 (2006)
- Is there a CEP?
- At $T = 0$ in μ_B where is the phase boundary?
- Behavior as a function of $\mu_\mathrm{I}/\mu_\mathrm{S}$?

Details of the phase diagram are heavily studied theoretically (Lattice, EFT), and experimentally (RHIC, LHC, FAIR, NICA)

Structure of scalar mesons

	Mass (MeV)	width (MeV)	decays
$a_0(980)$	980 ± 20	$50 - 100$	$\pi\pi$ dominant
$a_0(1450)$	1474 ± 19	265 ± 13	$\pi\eta$, $\pi\eta'$, $K\bar{K}$
$K_s(800) = \kappa$	682 ± 29	547 ± 24	$K\pi$
$K_s(1430)$	1425 ± 50	270 ± 80	$K\pi$ dominant
$f_0(500) = \sigma$	400–550	$400 - 700$	$\pi\pi$ dominant
$f_0(980)$	980 ± 20	$40 - 100$	$\pi\pi$ dominant
$f_0(1370)$	1200–1500	$200 - 500$	$\pi\pi \approx 250$, $K\bar{K} \approx 150$
$f_0(1500)$	1505 ± 6	109 ± 7	$\pi\pi \approx 38$, $K\bar{K} \approx 9.4$
$f_0(1710)$	1722 ± 6	135 ± 7	$\pi\pi \approx 30$, $K\bar{K} \approx 71$

Possible scalar states: $\bar{q}q$, $\bar{q}q\bar{q}q$, meson-meson molecules, glueballs

pseudoscalar nonet: π, K, η, η', scalar nonet: A_0, K_0, 2 f_0

multiquark states: $f_0(980)$,$A_0(980)$ $f_0(600)$, $K_0(800)$???

meson-meson bound state $(K\bar{K})$: $f_0(980)$???

glueballs: $f_0(1500)$, $f_0(1710)$???

Addressed problems

- What are the effects of Polyakov loops and (axial)vector mesons on the chiral transition?
- How the order parameters behave at finite temperature/chemical potential?
- Which scalars are the chiral partners of the pseudoscalar nonet?
- What is the effect of the medium on the various masses?

Chiral symmetry

If the quark masses are zero (chiral limit) $\Longrightarrow$ QCD invariant under the following global transformation (chiral symmetry):

$$U(3)_L \times U(3)_R \simeq U(3)_V \times U(3)_A = SU(3)_V \times SU(3)_A \times U(1)_V \times U(1)_A$$

$U(1)_V$ term $\longrightarrow$ baryon number conservation

$U(1)_A$ term $\longrightarrow$ broken through axial anomaly

$SU(3)_A$ term $\longrightarrow$ broken down by any quark mass

$SU(3)_V$ term $\longrightarrow$ broken down to $SU(2)_V$ if $m_u = m_d \neq m_s$

$\longrightarrow$ totally broken if $m_u \neq m_d \neq m_s$ (realized in nature)

Since QCD is very hard to solve $\longrightarrow$ low energy effective models can be set up $\longrightarrow$ reflecting the global symmetries of QCD $\longrightarrow$ degrees of freedom: observable particles instead of quarks and gluons

Linear realization of the symmetry $\longrightarrow$ linear sigma model

(nonlinear representation $\longrightarrow$ chiral perturbation theory (ChPT))

Lagrangian (2/1)

$$
\begin{aligned}
\mathcal{L}_{\text{Tot}} &= \text{Tr}[(D_\mu\Phi)^\dagger(D_\mu\Phi)] - m_0^2\text{Tr}(\Phi^\dagger\Phi) - \lambda_1[\text{Tr}(\Phi^\dagger\Phi)]^2 - \lambda_2\text{Tr}(\Phi^\dagger\Phi)^2 \\
&- \frac{1}{4}\text{Tr}(L_{\mu\nu}^2 + R_{\mu\nu}^2) + \text{Tr}\left[\left(\frac{m_1^2}{2} + \Delta\right)(L_\mu^2 + R_\mu^2)\right] + \text{Tr}[H(\Phi + \Phi^\dagger)] \\
&+ c_1(\det\Phi + \det\Phi^\dagger) + i\frac{g_2}{2}(\text{Tr}\{L_{\mu\nu}[L^\mu, L^\nu]\} + \text{Tr}\{R_{\mu\nu}[R^\mu, R^\nu]\}) \\
&+ \frac{h_1}{2}\text{Tr}(\Phi^\dagger\Phi)\text{Tr}(L_\mu^2 + R_\mu^2) + h_2\text{Tr}[(L_\mu\Phi)^2 + (\Phi R_\mu)^2] + 2h_3\text{Tr}(L_\mu\Phi R^\mu\Phi^\dagger). \\
&+ g_3[\text{Tr}(L_\mu L_\nu L^\mu L^\nu) + \text{Tr}(R_\mu R_\nu R^\mu R^\nu)] + g_4[\text{Tr}\,(L_\mu L^\mu L_\nu L^\nu) \\
&+ \text{Tr}\,(R_\mu R^\mu R_\nu R^\nu)] + g_5\text{Tr}\,(L_\mu L^\mu)\ \text{Tr}\,(R_\nu R^\nu) + g_6[\text{Tr}(L_\mu L^\mu)\,\text{Tr}(L_\nu L^\nu) \\
&+ \text{Tr}(R_\mu R^\mu)\,\text{Tr}(R_\nu R^\nu)] + \bar{\Psi} i \partial\!\!\!/ \Psi - g_F\bar{\Psi}\,(\Phi_S + i\gamma_5\Phi_{PS})\,\Psi \\
&+ g_V\bar{\Psi}\gamma^\mu\left(V_\mu + \frac{g_A}{g_V}\gamma_5 A_\mu\right)\Psi
\end{aligned}
$$

$+$ Polyakov loops $\longrightarrow$ through grand canonical potential

Lagrangian (2/2)

where

$$D^\mu\Phi = \partial^\mu\Phi - ig_1(L^\mu\Phi - \Phi R^\mu) - ieA_e^\mu[T_3, \Phi]$$

$$\Phi = \sum_{i=0}^{8}(\sigma_i + i\pi_i)T_i, \quad H = \sum_{i=0}^{8} h_i T_i \qquad T_i : U(3) \text{ generators}$$

$$R^\mu = \sum_{i=0}^{8}(\rho_i^\mu - b_i^\mu)T_i, \quad L^\mu = \sum_{i=0}^{8}(\rho_i^\mu + b_i^\mu)T_i$$

$$L^{\mu\nu} = \partial^\mu L^\nu - ieA_e^\mu[T_3, L^\nu] - \{\partial^\nu L^\mu - ieA_e^\nu[T_3, L^\mu]\}$$

$$R^{\mu\nu} = \partial^\mu R^\nu - ieA_e^\mu[T_3, R^\nu] - \{\partial^\nu R^\mu - ieA_e^\nu[T_3, R^\mu]\}$$

$$\Psi = (u, d, s)^T$$

non strange – strange base:

$$\varphi_N = \sqrt{2/3}\varphi_0 + \sqrt{1/3}\varphi_8,$$

$$\varphi_S = \sqrt{1/3}\varphi_0 - \sqrt{2/3}\varphi_8, \qquad \varphi \in (\sigma_i, \pi_i, \rho_i^\mu, b_i^\mu, h_i)$$

broken symmetry: non-zero condensates $\langle\sigma_N\rangle, \langle\sigma_S\rangle \longleftrightarrow \phi_N, \phi_S$

Included fields - pseudoscalar and scalar meson nonets

$$\Phi_{PS} = \sum_{i=0}^{8} \pi_i T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\eta_N+\pi^0}{\sqrt{2}} & \pi^+ & K^+ \\ \pi^- & \frac{\eta_N-\pi^0}{\sqrt{2}} & K^0 \\ K^- & \bar{K}^0 & \eta_S \end{pmatrix} (\sim \bar{q}_i \gamma_5 q_j)$$

$$\Phi_S = \sum_{i=0}^{8} \sigma_i T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\sigma_N+a_0^0}{\sqrt{2}} & a_0^+ & K_S^+ \\ a_0^- & \frac{\sigma_N-a_0^0}{\sqrt{2}} & K_S^0 \\ K_S^- & \bar{K}_S^0 & \sigma_S \end{pmatrix} (\sim \bar{q}_i q_j)$$

Particle content:

Pseudoscalars: $\pi(138), K(495), \eta(548), \eta'(958)$

Scalars: $a_0(980 \text{ or } 1450), K_0^\star(800 \text{ or } 1430)$,

(σ_N, σ_S) : 2 of $f_0(500, 980, 1370, 1500, 1710)$

Included fields - vector meson nonets

$$V^\mu = \sum_{i=0}^{8} \rho_i^\mu T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\omega_N+\rho^0}{\sqrt{2}} & \rho^+ & K^{\star+} \\ \rho^- & \frac{\omega_N-\rho^0}{\sqrt{2}} & K^{\star 0} \\ K^{\star-} & \bar{K}^{\star 0} & \omega_S \end{pmatrix}^\mu$$

$$A^\mu = \sum_{i=0}^{8} b_i^\mu T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{f_{1N}+a_1^0}{\sqrt{2}} & a_1^+ & K_1^+ \\ a_1^- & \frac{f_{1N}-a_1^0}{\sqrt{2}} & K_1^0 \\ K_1^- & \bar{K}_1^0 & f_{1S} \end{pmatrix}^\mu$$

Particle content:
Vector mesons: $\rho(770), K^\star(894), \omega_N = \omega(782), \omega_S = \phi(1020)$
Axial vectors: $a_1(1230), K_1(1270), f_{1N}(1280), f_{1S}(1426)$

Spontaneous symmetry breaking

Interaction is approximately chiral symmetric, spectra is not $\longrightarrow$ SSB:

$$\sigma_{N/S} \to \sigma_{N/S} + \phi_{N/S} \qquad \phi_{N/S} \equiv < \sigma_{N/S} >$$

For tree level masses we have to select all terms quadratic in the new fields. Some of the terms include mixings arising from terms like $\mathrm{Tr}[(D_\mu\Phi)^\dagger(D_\mu\Phi)]$:

$$\begin{aligned}
\pi_N - a_{1N}^\mu &: -g_1\phi_N a_{1N}^\mu\partial_\mu\pi_N, \\
\pi - a_1^\mu &: -g_1\phi_N(a_1^{\mu+}\partial_\mu\pi^- + a_1^{\mu 0}\partial_\mu\pi^0) + \mathrm{h.c.}, \\
\pi_S - a_{1S}^\mu &: -\sqrt{2}g_1\phi_S a_{1S}^\mu\partial_\mu\pi_S, \\
K_S - K_\mu^\star &: \frac{ig_1}{2}(\sqrt{2}\phi_S - \phi_N)(\bar{K}_\mu^{\star 0}\partial^\mu K_S^0 + K_\mu^{\star -}\partial^\mu K_S^+) + \mathrm{h.c.}, \\
K - K_1^\mu &: -\frac{g_1}{2}(\phi_N + \sqrt{2}\phi_S)(K_1^{\mu 0}\partial_\mu\bar{K}^0 + K_1^{\mu +}\partial_\mu K^-) + \mathrm{h.c.}.
\end{aligned} \tag{1}$$

Polyakov loops in Polyakov gauge

Polyakov loop variables: $\Phi(\vec{x}) = \frac{\mathrm{Tr}_c L(\vec{x})}{N_c}$ and $\bar{\Phi}(\vec{x}) = \frac{\mathrm{Tr}_c \bar{L}(\vec{x})}{N_c}$ with

$$L(x) = \mathcal{P}\exp\left[i\int_0^\beta d\tau A_4(\vec{x},\tau)\right]$$

$\longrightarrow$ signals center symmetry ($\mathbb{Z}_3$) breaking at the deconfinement transition

low T: confined phase, $\langle\Phi(\vec{x})\rangle, \langle\bar{\Phi}(\vec{x})\rangle = 0$

high T: deconfined phase, $\langle\Phi(\vec{x})\rangle, \langle\bar{\Phi}(\vec{x})\rangle \neq 0$

Polyakov gauge: the temporal component of the gauge field is time independent and can be gauge rotated to a diagonal form in the color space

$$A_{4,d}(\vec{x}) = \phi_3(\vec{x})\lambda_3 + \phi_8(\vec{x})\lambda_8; \quad \lambda_3, \lambda_8 \text{ : Gell-Mann matrices.}$$

In this gauge the Polyakov loop operator is

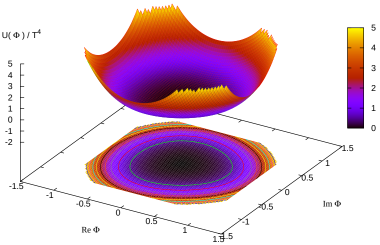
$$L(\vec{x}) = \mathrm{diag}(e^{i\beta\phi_+(\vec{x})}, e^{i\beta\phi_-(\vec{x})}, e^{-i\beta(\phi_+(\vec{x})+\phi_-(\vec{x}))})$$

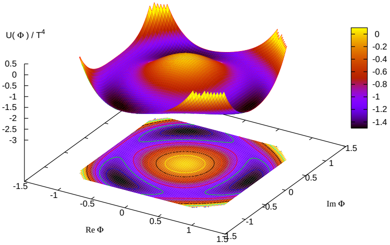
where $\phi_\pm(\vec{x}) = \pm\phi_3(\vec{x}) + \phi_8(\vec{x})/\sqrt{3}$

Polyakov loop potential

"Color confinement"
$\langle\Phi\rangle = 0 \longrightarrow$ no breaking of $\mathbb{Z}_3$
one minimum

"Color deconfinement"
$\langle\Phi\rangle \neq 0 \longrightarrow$ spontaneous breaking of $\mathbb{Z}_3$
minima at $0, 2\pi/3, -2\pi/3$
one of them spontaneously selected





from H. Hansen et al., PRD75, 065004 (2007)

Form of the potential

I.) Simple polynomial potential invariant under $\mathbb{Z}_3$ and charge conjugation: R.D.Pisarski, PRD 62, 111501

$$\frac{\mathcal{U}_{\rm poly}(\Phi,\bar{\Phi})}{T^4} = -\frac{b_2(T)}{2}\bar{\Phi}\Phi - \frac{b_3}{6}\left(\Phi^3+\bar{\Phi}^3\right) + \frac{b_4}{4}\left(\bar{\Phi}\Phi\right)^2$$

with $\quad b_2(T) = a_0 + a_1\frac{T_0}{T} + a_2\frac{T_0^2}{T^2} + a_3\frac{T_0^3}{T^3}$

II.) Logarithmic potential coming from the $SU(3)$ Haar measure of group integration K. Fukushima, Phys. Lett. **B591**, 277 (2004)

$$\frac{\mathcal{U}_{\rm log}(\Phi,\bar{\Phi})}{T^4} = -\frac{1}{2}a(T)\Phi\bar{\Phi} + b(T)\ln\left[1-6\Phi\bar{\Phi}+4\left(\Phi^3+\bar{\Phi}^3\right)-3\left(\Phi\bar{\Phi}\right)^2\right]$$

with $\quad a(T) = a_0 + a_1\frac{T_0}{T} + a_2\frac{T_0^2}{T^2}, \qquad b(T) = b_3\frac{T_0^3}{T^3}$

$\mathcal{U}(\Phi,\bar{\Phi})$ models the free energy of a pure gauge theory
$\longrightarrow$ the parameters are fitted to the pure gauge lattice data

Effects of Polyakov loops on FD statistics

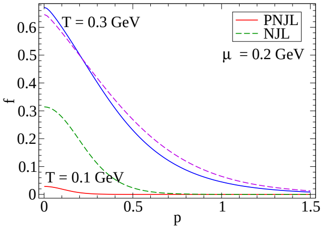
Inclusion of the Polyakov loop modifies the Fermi-Dirac distribution function

$$f(E_p-\mu_q)\longrightarrow f_\Phi^+(E_p) = \frac{\left(\bar\Phi+2\Phi e^{-\beta\left(E_p-\mu_q\right)}\right)e^{-\beta\left(E_p-\mu_q\right)}+e^{-3\beta\left(E_p-\mu_q\right)}}{1+3\left(\bar\Phi+\Phi e^{-\beta\left(E_p-\mu_q\right)}\right)e^{-\beta\left(E_p-\mu_q\right)}+e^{-3\beta\left(E_p-\mu_q\right)}}$$

$$f(E_p+\mu_q)\longrightarrow f_\Phi^-(E_p) = \frac{\left(\Phi+2\bar\Phi e^{-\beta\left(E_p+\mu_q\right)}\right)e^{-\beta\left(E_p+\mu_q\right)}+e^{-3\beta\left(E_p+\mu_q\right)}}{1+3\left(\Phi+\bar\Phi e^{-\beta\left(E_p+\mu_q\right)}\right)e^{-\beta\left(E_p+\mu_q\right)}+e^{-3\beta\left(E_p+\mu_q\right)}}$$

$\Phi,\bar\Phi\to 0 \Longrightarrow f_\Phi^\pm(E_p)\to f(3(E_p\pm\mu_q))$ $\quad\Phi,\bar\Phi\to 1 \Longrightarrow f_\Phi^\pm(E_p)\to f(E_p\pm\mu_q)$

three-particle state appears: mimics confinement of quarks within baryons



the effect of the Polyakov loop is more relevant for $T < T_c$

at $T=0$ there is no difference between models with and without Polyakov loop: $\Theta(3(\mu_q-E_p))\equiv\Theta((\mu_q-E_p))$

H. Hansen et al., PRD75, 065004

T/μ_B dependence of the Polyakov-loops

By derivating the grand canonical potential for Polyakov loops (Ω) according to Φ and $\bar{\Phi}$ and equate to zero (extremum eqn.)

$$-\frac{d}{d\Phi}\left(\frac{U(\Phi,\bar{\Phi})}{T^4}\right)+\frac{2N_c}{T^3}\sum_{q=u,d,s}\int\frac{d^3\mathbf{p}}{(2\pi)^3}\left(\frac{e^{-\beta E_q^-(p)}}{g_q^-(p)}+\frac{e^{-2\beta E_q^+(p)}}{g_q^+(p)}\right)=0$$

$$-\frac{d}{d\bar{\Phi}}\left(\frac{U(\Phi,\bar{\Phi})}{T^4}\right)+\frac{2N_c}{T^3}\sum_{q=u,d,s}\int\frac{d^3\mathbf{p}}{(2\pi)^3}\left(\frac{e^{-\beta E_q^+(p)}}{g_q^+(p)}+\frac{e^{-2\beta E_q^-(p)}}{g_q^-(p)}\right)=0$$

$$g_q^+(p) = 1+3\left(\bar{\Phi}+\Phi e^{-\beta E_q^+(p)}\right)e^{-\beta E_q^+(p)}+e^{-3\beta E_q^+(p)}$$

$$g_q^-(p) = 1+3\left(\Phi+\bar{\Phi} e^{-\beta E_q^-(p)}\right)e^{-\beta E_q^-(p)}+e^{-3\beta E_q^-(p)}$$

$$E_q^\pm(p)=E_q(p)\mp\mu_B/3,\;\; E_{u/d}(p)=\sqrt{p^2+m_{u/d}^2}, E_s(p)=\sqrt{p^2+m_s^2}$$

T/μ_B dependence of the condensates ($\phi_{N/S}$)

Extremum equation: $\left\langle \frac{\partial \mathcal{L}_{\text{Tot}}}{\partial \sigma_{N/S}} \right\rangle_T = 0$ (after the SSB)

Hybrid approach: fermions at one-loop, mesons at tree-level (their effects are much smaller)

$$m_0^2 \phi_N \quad + \quad \left(\lambda_1 + \frac{1}{2}\lambda_2\right)\phi_N^3 + \lambda_1 \phi_N \phi_S^2 - h_N + \frac{g_F}{2} N_c \left(\langle u\bar{u}\rangle_T + \langle d\bar{d}\rangle_T\right) = 0$$

$$m_0^2 \phi_S \quad + \quad (\lambda_1 + \lambda_2)\phi_S^3 + \lambda_1 \phi_N^2 \phi_S - h_S + \frac{g_F}{\sqrt{2}} N_c \langle s\bar{s}\rangle_T = 0$$

$$\langle q\bar{q}\rangle_T = -4 m_q \int \frac{d^3\mathbf{p}}{(2\pi)^3} \frac{1}{2E_q(p)} \left(1 - f_\Phi^-(E_q(p)) - f_\Phi^+(E_q(p))\right)$$

Determination of the parameters of the Lagrangian

16 unknown parameters $(m_0, \lambda_1, \lambda_2, c_1, m_1, g_1, g_2, h_1, h_2, h_3, \delta_S, \Phi_N, \Phi_S, g_F, g_V, g_A)$ $\longrightarrow$ Determined by the min. of χ^2:

$$\chi^2(x_1,\ldots,x_N) = \sum_{i=1}^{M}\left[\frac{Q_i(x_1,\ldots,x_N) - Q_i^{\mathrm{exp}}}{\delta Q_i}\right]^2 ,$$

where $(x_1,\ldots,x_N) = (m_0, \lambda_1, \lambda_2, \ldots)$, $Q_i(x_1,\ldots,x_N)$ calculated from the model, while Q_i^{exp} taken from the PDG

multiparametric minimalization $\longrightarrow$ MINUIT

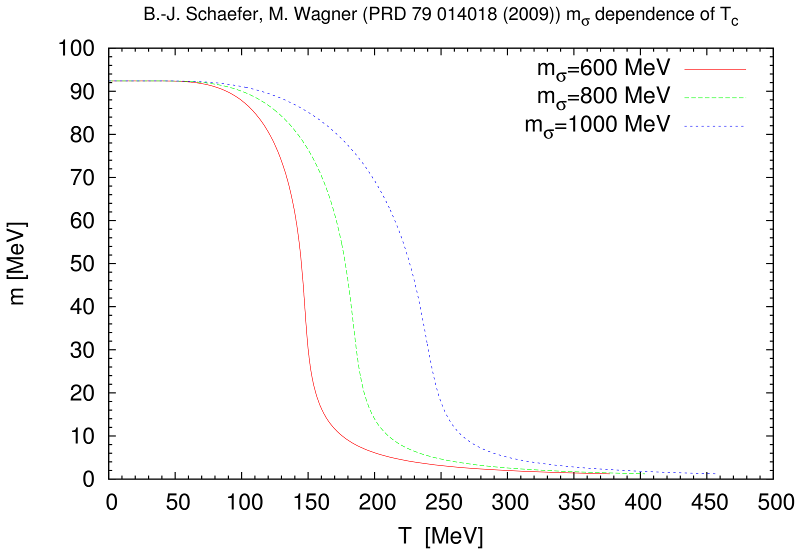
- PCAC $\rightarrow$ 2 physical quantities: f_π, f_K
- Tree-level masses $\rightarrow$ 16 physical quantities: $m_{u/d}, m_s, m_\pi, m_\eta, m_{\eta'}, m_K, m_\rho, m_\Phi, m_{K^\star}, m_{a_1}, m_{f_1^H}, m_{K_1}, m_{a_0}, m_{K_s}, m_{f_0^L}, m_{f_0^H}$
- Decay widths $\rightarrow$ 12 physical quantities: $\Gamma_{\rho\to\pi\pi}, \Gamma_{\Phi\to KK}, \Gamma_{K^\star\to K\pi}, \Gamma_{a_1\to\pi\gamma}, \Gamma_{a_1\to\rho\pi}, \Gamma_{f_1\to KK^\star}, \Gamma_{a_0}, \Gamma_{K_S\to K\pi}, \Gamma_{f_0^L\to\pi\pi}, \Gamma_{f_0^L\to KK}, \Gamma_{f_0^H\to\pi\pi}, \Gamma_{f_0^H\to KK}$

Parameters

Parameter	Value
ϕ_N [GeV]	0.1622
ϕ_S [GeV]	0.1262
C_1 [GeV^2]	-0.7537
C_2 [GeV^2]	0.3953
λ_1	undetermined
λ_2	65.3221
h_1	undetermined
h_2	11.6586
h_3	4.7028
δ_S [GeV^2]	0.1534
c_1 [GeV]	1.12
g_1	-5.8943
g_2	-2.9960
g_F	4.9429

- inclusion of vector particles changes the parameter values (directly they are not present in the equations solved at finite T)
- with this set $f_0^L = 1303$ GeV
- by setting $\lambda_1 \to f_0^L$ mass can be lowered

$\phi_N(T)$ *without* Polyakov loop and vector mesons



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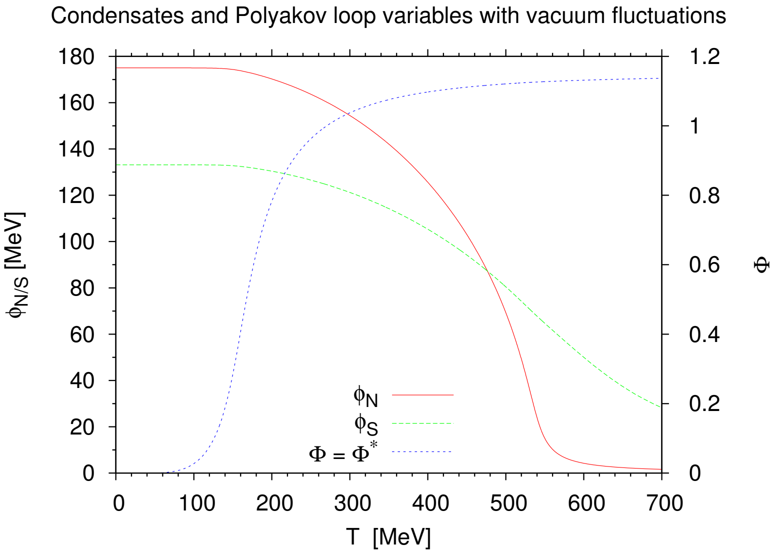
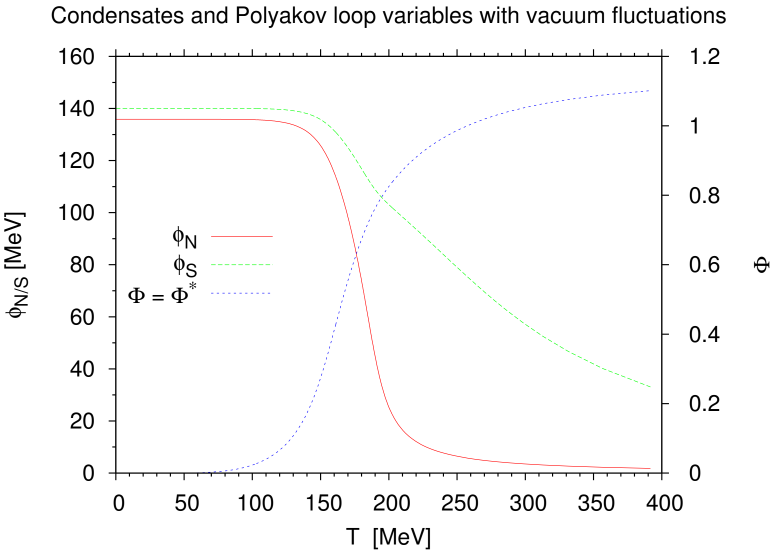
- Fermion vacuum fluctuations
- Fermion thermal fluctuations
- Fermion contributions to the tree-level meson masses

$\phi_{N/S}(T), \Phi/\bar{\Phi}(T)$ *with* Polyakov loop $m_{f_0^L} = 1326$ MeV



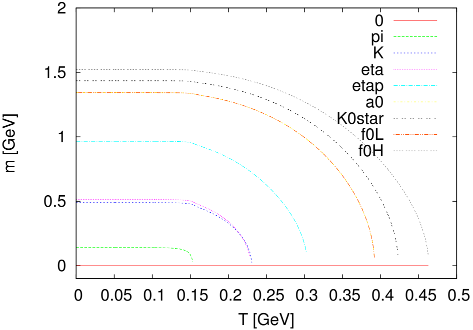
With low mass scalars, $m_{f_0^L} = 402$ MeV



Curvature masses

Tree-level masses (e.g. pion mass):

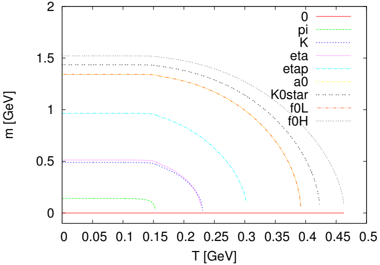
$$m_\pi^2 = Z_\pi^2 \left[m_0^2 + \Lambda_N \Phi_N^2 + \lambda_1 \Phi_S^2 \right]$$
$$Z_\pi = \frac{m_{a_1}}{\sqrt{m_{a_1}^2 - g_1^2 \phi_N^2}}$$



Curvature masses

“Dressed” masses (e.g. pion mass):

$$m_\pi^2 = Z_\pi^2 \left[m_0^2 + \Lambda_N \Phi_N^2 + \lambda_1 \Phi_S^2\right] + \text{something}$$
$$Z_\pi = \frac{m_{a_1}}{\sqrt{m_{a_1}^2 - g_1^2 \phi_N^2}}$$

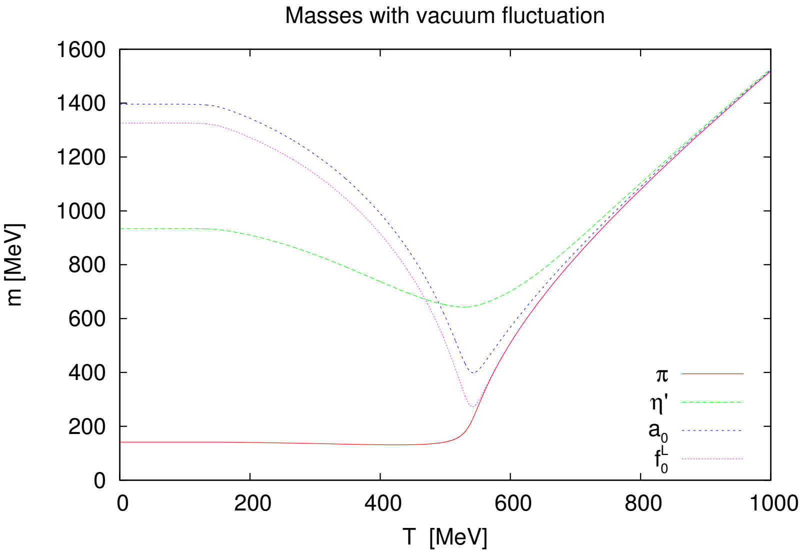


$\longrightarrow$ to cure this behavior:

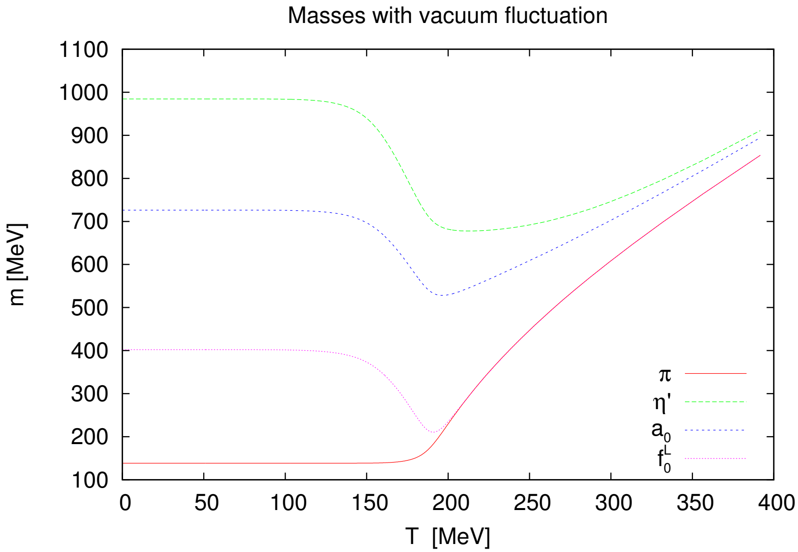
curvature mass contribution from the fermion grand canonical potential:

$$+\frac{\partial^2 \Omega_q}{\partial \pi_a \partial \pi_b} \qquad (2)$$

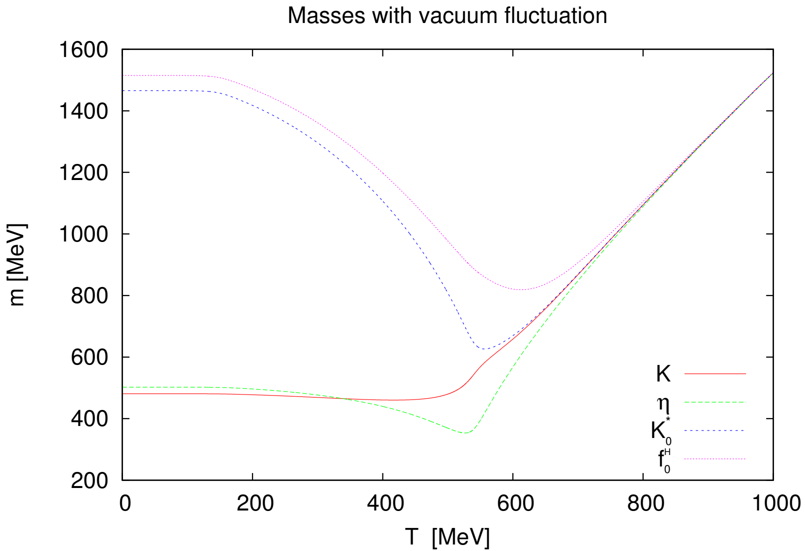
π, η', a_0, f_0^L masses with $m_{f_0^L} = 1326$ MeV



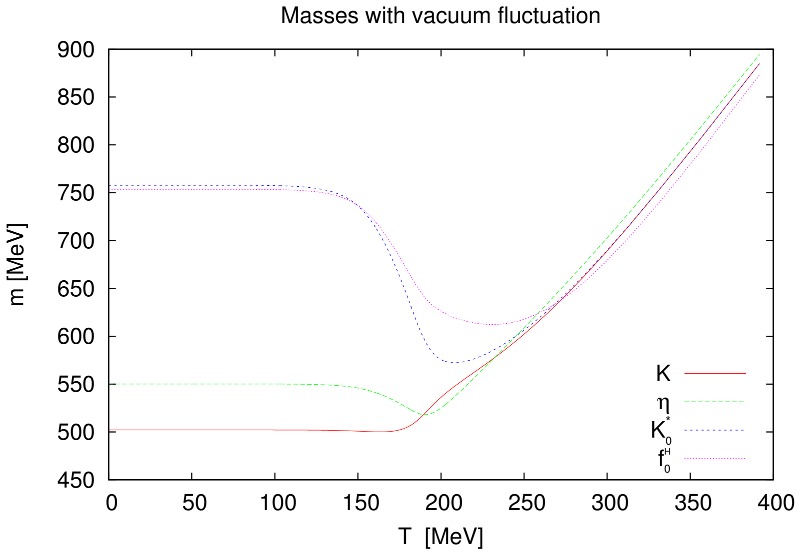
π, η', a_0, f_0^L masses with $m_{f_0^L} = 402$ MeV



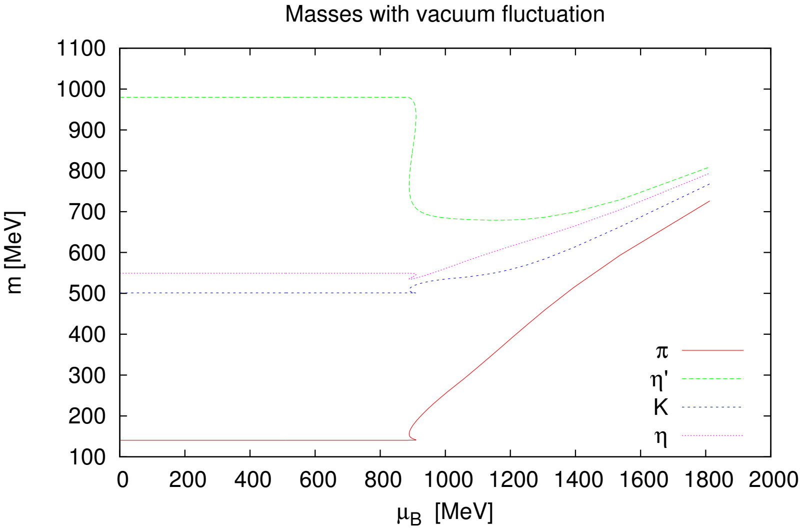
$K, \eta, K^\star, f_0^H$ masses with $m_{f_0^L} = 1326$ MeV



$K, \eta, K^\star, f_0^H$ masses with $m_{f_0^L} = 402$ MeV



μ_B dependence of the π, η, η', K masses



Summary

- An extended linear σ - model with constituent quarks and Polyakov - loops was shown
- The meson phenomenology was very well described by scalars above 1 GeV
- We used hybrid approach at $T = 0$: only fermion loops, since it has the largest contribution
- At finite T/μ_B there was 4 coupled equations for the 4 order parameters
- The correct pseudocritical temperature requires low f_0 mass

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→ To do . . .

→ Explore the phase diagram for finite chemical potential as well, CEP

→ Improve the vacuum phenomenology by tetraquarks (and glueballs)

Thank you for your attention!