HADRONS & HADRONIC MATTER IN CHIRAL QUARK MODELS (V)

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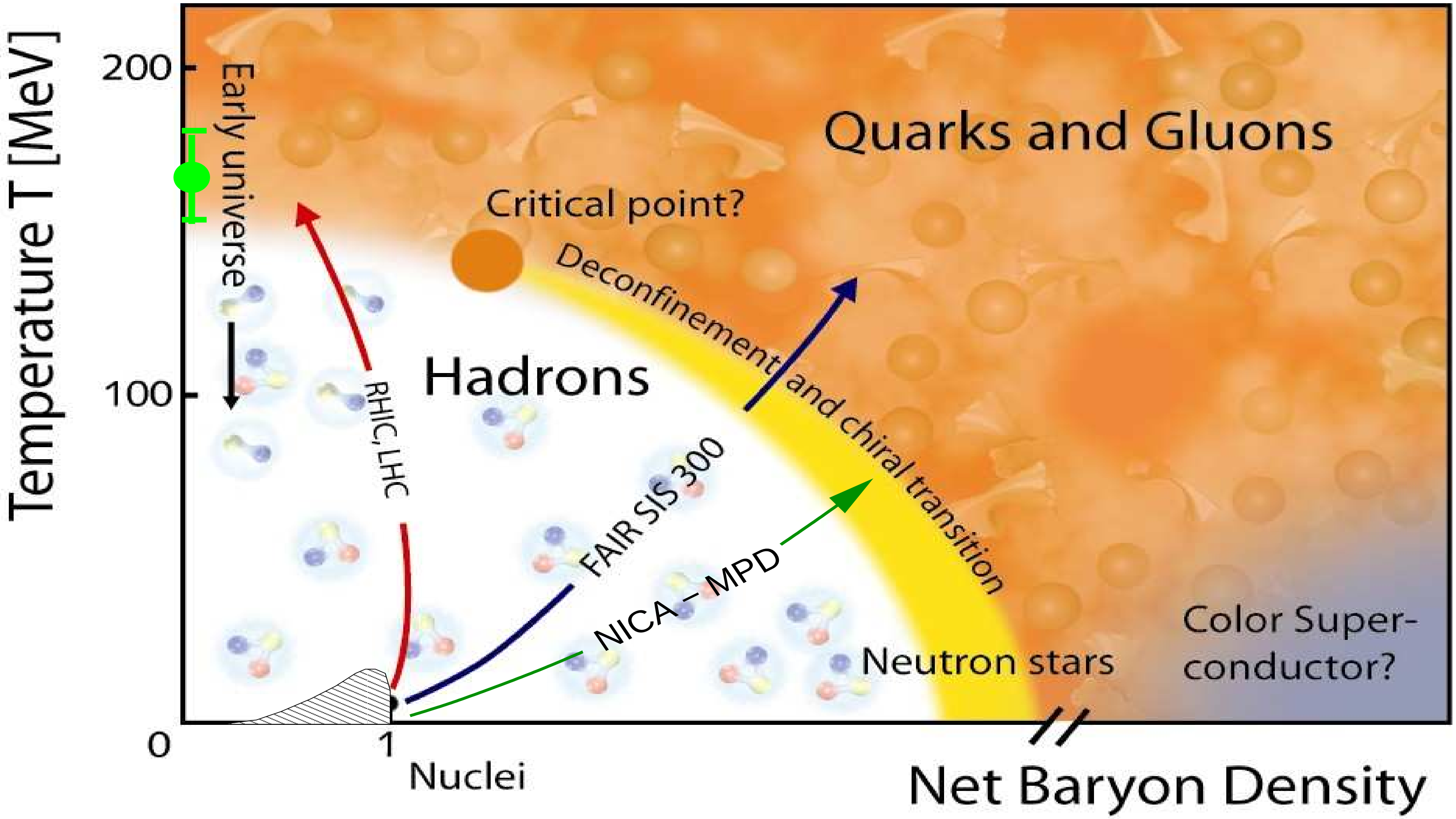
Main ideas for this lecture (punchline):

- Phase diagram and EoS at nonzero μ: baryon number density in the confined phase carried by baryons!
- Baryons as bound states, can be treated as a new species $\Longrightarrow$ “chemical picture”
  First step: reproduce relativistic mean-field model of nuclear matter (Walecka)
- Physical picture: quark-diquark scattering states!
- Generalized Beth-Uhlenbeck EoS with Mott transition for baryons:
  bound states $\Longrightarrow$ resonances in the scattering continuum

Lattice QCD, hadron structure and hadronic matter; Dubna, 05.-16.09.2011

PHASEDIAGRAM OF QCD: LATTICE SIMULATIONS



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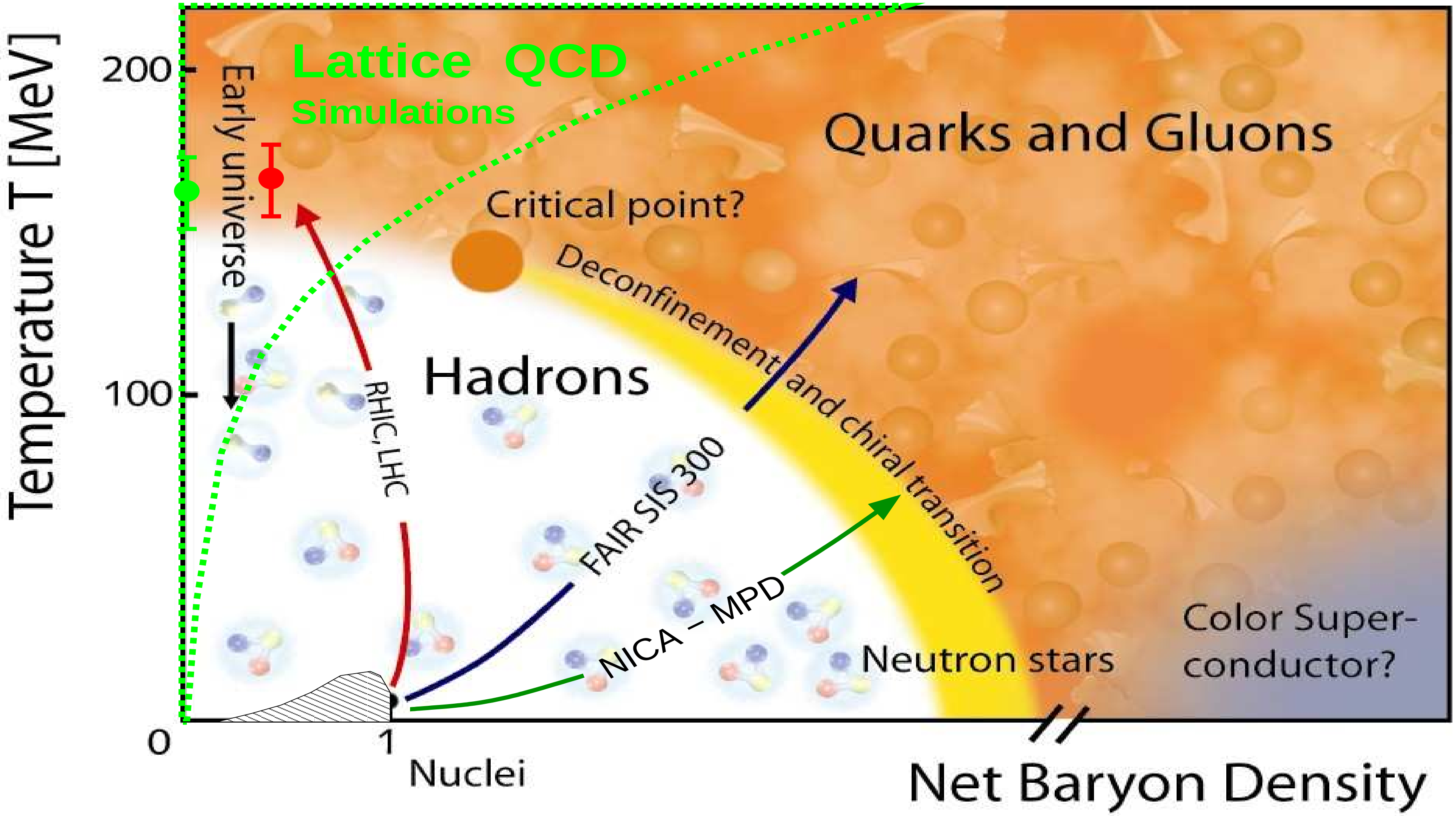


Relativistic Nozieres–Schmitt-Rink theory (I)

Lagrangian for $N_f = 2$, $N_c = 3$ quark matter, OGE inspired

$$\mathcal{L} = \bar{q}(i\partial\!\!\!/ + \mu\!\!\!/ - m)q - \frac{g^2}{2}\sum_{a=1}^{8} \bar{q}T^a\gamma_\mu q\, \bar{q}T^a\gamma^\mu q$$

Fierz transformation, select scalar diquark channel $(P_\eta)^{ij}_{ab} = iC\gamma_5\epsilon^{ij}\epsilon_{abc}$

$$\mathcal{L} = \bar{q}(i\partial\!\!\!/ + \mu\!\!\!/ - m)q + \frac{G}{4}\sum_{\eta=1}^{3}[iq^t P_\eta q][i\bar{q}\bar{P}_\eta\bar{q}^t] + \frac{G}{4}\sum_{\eta=1}^{3}[iq^t P_\eta\gamma_5 q][i\bar{q}\bar{P}_\eta\gamma_5\bar{q}^t]\cdots$$

Spinor doublet (bispinor) $Q = (q, \bar{q}^t)$ representation, $\bar{P}_\eta = \gamma_0(P_\eta)^\dagger\gamma_0$

$$\mathcal{L} = \frac{1}{2}\bar{Q}\begin{pmatrix} i\partial\!\!\!/ + \mu\!\!\!/ - m & 0 \\ 0 & i\partial\!\!\!/^t - \mu\!\!\!/^t + m \end{pmatrix} Q + \frac{G}{4}\bar{Q}\begin{pmatrix} 0 & 0 \\ P_\eta & 0 \end{pmatrix} Q\bar{Q}\begin{pmatrix} 0 & \bar{P}_\eta \\ 0 & 0 \end{pmatrix} Q$$

Partition function with $\mathcal{L}_E = -\mathcal{L}|_{t\to -i\tau}$

$$Z = \int \mathcal{D}Q \exp\left[-\int_0^\beta d\tau \int d\boldsymbol{x}\mathcal{L}_E(Q)\right]$$

Relativistic Nozieres–Schmitt-Rink theory (II)

Hubbard–Stratonovich transformation to fermion pair fields

$$\Delta_\eta(\tau,x) = \tfrac{G}{2}\langle \bar{Q} \begin{pmatrix} 0 & 0 \\ P_\eta & 0 \end{pmatrix} Q\rangle, \quad \Delta^*_\eta(\tau,x) = \tfrac{G}{2}\langle \bar{Q} \begin{pmatrix} 0 & \bar{P}_\eta \\ 0 & 0 \end{pmatrix} Q\rangle,$$

Integrating out the fermion fields

$$Z = \int \mathcal{D}\Delta\mathcal{D}\Delta^* \exp\left[-\int d\tau d\boldsymbol{x} \left(\frac{|\Delta(-i\tau,\boldsymbol{x})|^2}{G}\right)\right] \times \exp\left[\frac{1}{2}\log \mathrm{Det}_{(x,y)} \begin{pmatrix} S^{-1}_{Fx,y} & \bar{P}_\eta\Delta(x)\delta_{x,y} \\ P_\eta\Delta^*(x)\delta_{x,y} & \bar{S}^{-1}_{Fx,y} \end{pmatrix}\right]$$

Bare fermion propagator

$$S^{-1}_{Fx,y} = (i\partial\!\!\!/ + \mu\!\!\!/ - m)\delta_{x,y}, \quad \bar{S}^{-1}_{Fx,y} = \gamma_5 C S^{-1}_{Fy,x} C\gamma_5; \quad \delta_{x,y} = T\sum_n \int \frac{d\boldsymbol{p}}{(2\pi)^3} e^{-i\omega_n(\tau_x-\tau_y)+i\boldsymbol{p}\cdot(\boldsymbol{x}-\boldsymbol{y})}$$

Nambu-Gorkov propagator and self energy

$$\boldsymbol{S}^{-1}_{Fx,y} = \begin{pmatrix} S^{-1}_{Fx,y} & 0 \\ 0 & \bar{S}^{-1}_{Fx,y} \end{pmatrix}, \quad -\boldsymbol{\Sigma}_{x,y} = \begin{pmatrix} 0 & \bar{P}_\eta\Delta_\eta(x)\delta_{x,y} \\ P_\eta\Delta^*_\eta(x)\delta_{x,y} & 0 \end{pmatrix},$$

Factorize the fluctuation contribution to the partition function

$$Z(\mu,T) \equiv e^{-\beta\Omega(\mu,T)} = Z_0(\mu,T) Z_{\mathrm{fluc}}(\mu,T),$$

Relativistic Nozieres–Schmitt-Rink theory (III)

The thermodynamic potential for the free quark system is ($\epsilon_{p\pm} = \sqrt{m^2 + p^2} \mp \mu$)

$$\frac{\Omega_0}{V} = -\frac{1}{\beta V} \ln Z_0 = -2N_f N_c T \sum_{\alpha=\pm} \int \frac{d\boldsymbol{p}}{(2\pi)^3} \ln\left(1 + e^{-\epsilon_{p\alpha}/T}\right),$$

and the fluctuation contribution is determined from $\Omega_{\text{fluc}} = -\ln Z_{\text{fluc}}/\beta$ with

$$Z_{\text{fluc}} = \int \mathcal{D}\Delta\mathcal{D}\Delta^* \exp\left[-\int d\tau d\boldsymbol{x} \left(\frac{|\Delta_\eta(-i\tau, \boldsymbol{x})|^2}{G}\right) + \frac{1}{2} \ln \mathrm{Det}_{(x,y)} \left(\delta_{x,y} - \sum_z \boldsymbol{S}_{Fx,z} \boldsymbol{\Sigma}_{z,y}\right)\right].$$

Expanding up to quadratic order in (Δ, Δ^*) (Gaussian approximation), we have

$$Z_{\text{fluc}} \equiv e^{-\beta\Omega_{\text{fluc}}} = \prod_{\eta, N, \boldsymbol{P}} \int d\Delta_\eta(i\Omega_N, \boldsymbol{P}) d\Delta^*_\eta(i\Omega_N, \boldsymbol{P}) \exp\left[-\frac{T}{V}\left(\frac{1}{G} - \chi_{\mu,T}(i\Omega_N, \boldsymbol{P})\right) |\Delta_\eta(i\Omega_N, \boldsymbol{P})|^2\right],$$

where Ω_N and $\boldsymbol{P}$ denote the *bosonic* Matsubara-frequency and momentum.
Integrating out the Gaussian fluctuation leads to (vacuum contr. $\chi_0 \equiv \chi_{\mu=0,T=0}$ subtracted)

$$\Omega_{\text{fluc}} = d_B T \sum_{N:\text{even}} \int \frac{d\boldsymbol{P}}{(2\pi)^3} \log\left[\frac{1}{G} - \chi_{\mu,T}(i\Omega_N, \boldsymbol{P})\right] - d_B \int_{-\infty}^{\infty} d\Omega \int \frac{d\boldsymbol{P}}{(2\pi)^3} \log\left[\frac{1}{G} - \chi_0(i\Omega, \boldsymbol{P})\right],$$

RELATIVISTIC NOZIERES–SCHMITT-RINK THEORY (IV)

The *pair correlation function* $\chi_{\mu,T}(i\Omega_N, \boldsymbol{P})$ at one-loop level is defined by $\Longrightarrow$ Seminar

$$\begin{aligned}
\chi_{\mu,T}(i\Omega_N,\boldsymbol{P}) &= 2T\sum_n \int \frac{d\boldsymbol{q}}{(2\pi)^3}\mathrm{tr}[S_F(i\omega_n+i\Omega_N,\boldsymbol{q}+\boldsymbol{P})S_F(-i\omega_n,-\boldsymbol{q})] \\
&= -2\int\frac{d\boldsymbol{q}}{(2\pi)^3}\Big(1+\frac{m^2+\boldsymbol{q}\cdot(\boldsymbol{q}+\boldsymbol{P})}{E_{\boldsymbol{q}}E_{\boldsymbol{q}+\boldsymbol{P}}}\Big)\frac{1-f_F(E_{\boldsymbol{q}+\boldsymbol{P}}-\mu)-f_F(E_{\boldsymbol{q}}-\mu)}{i\Omega_N+2\mu-E_{\boldsymbol{q}+\boldsymbol{P}}-E_{\boldsymbol{q}}} \\
&\quad -4\int\frac{d\boldsymbol{q}}{(2\pi)^3}\Big(1-\frac{m^2+\boldsymbol{q}\cdot(\boldsymbol{q}+\boldsymbol{P})}{E_{\boldsymbol{q}}E_{\boldsymbol{q}+\boldsymbol{P}}}\Big)\frac{-f_F(E_{\boldsymbol{q}+\boldsymbol{P}}-\mu)+f_F(E_{\boldsymbol{q}}+\mu)}{i\Omega_N+2\mu-E_{\boldsymbol{q}+\boldsymbol{P}}+E_{\boldsymbol{q}}} \\
&\quad +2\int\frac{d\boldsymbol{q}}{(2\pi)^3}\Big(1+\frac{m^2+\boldsymbol{q}\cdot(\boldsymbol{q}+\boldsymbol{P})}{E_{\boldsymbol{q}}E_{\boldsymbol{q}+\boldsymbol{P}}}\Big)\frac{1-f_F(E_{\boldsymbol{q}+\boldsymbol{P}}+\mu)-f_F(E_{\boldsymbol{q}}+\mu)}{i\Omega_N+2\mu+E_{\boldsymbol{q}+\boldsymbol{P}}+E_{\boldsymbol{q}}},
\end{aligned}$$

The (retarded) dynamic pair susceptibility $\Gamma(\omega, \boldsymbol{P})$ can be obtained by the analytic continuation of the pair correlation to the real ω-axis:

$$\Gamma^{-1}_{\mu,T}(\omega,\boldsymbol{P}) = \frac{1}{G} - \chi_{\mu,T}(\omega+i\delta,\boldsymbol{P}).$$

It corresponds to the quark pair propagator and its spectral density for $G = \mathcal{G}$

$$\rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P}) = \Im\Gamma^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P})\ ; \quad \Gamma^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P}) = \frac{1}{1/\mathcal{G}-\chi_{\mu,T}(i\Omega_N,\boldsymbol{P})} = -\int_{-\infty}^{\infty}\frac{d\omega}{\pi}\frac{\rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P})}{i\Omega_N-\omega}.$$

THERMODYNAMIC POTENTIAL IN TERMS OF SPECTRAL DENSITY

Differentiation and integration of $\Omega_{\rm fluc}$ with respect to G gives

$$\Omega_{\rm fluc} = d_B \int_0^G \frac{d\mathcal{G}}{\mathcal{G}^2} \int_{-\infty}^{\infty} \frac{d\omega}{\pi} \frac{d\boldsymbol{P}}{(2\pi)^3} T \sum_N \frac{\omega \rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P})}{\Omega_N^2+\omega^2} - (T=\mu=0 \text{ part})$$

Identity $\rho^{\mathcal{G}}_{-\mu,T}(\omega,\boldsymbol{P}) = -\rho^{\mathcal{G}}_{\mu,T}(-\omega,\boldsymbol{P})$ entails charge conjugation symmetry $\mu \leftrightarrow -\mu$.
Matsubara summation yields [$\tilde{f}_B(\omega) = f_B(\omega) + \theta(-\omega)$ with $f_B(\omega) = 1/(e^{\beta\omega}-1)$]

$$\Omega_{\rm fluc} = -d_B \int_0^G \frac{d\mathcal{G}}{\mathcal{G}^2} \int_{-\infty}^{\infty} \frac{d\omega}{\pi} \frac{d\boldsymbol{P}}{(2\pi)^3} \tilde{f}_B(\omega) \rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P}) - d_B \int_0^G \frac{d\mathcal{G}}{\mathcal{G}^2} \int_{-\infty}^{\infty} \frac{d\omega}{\pi} \frac{d\boldsymbol{P}}{(2\pi)^3} \frac{\epsilon(\omega)}{2} \delta\rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P})$$

In-medium spectral shift: $\delta\rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P}) = \rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P}) - \rho^{\mathcal{G}}_{0,0}(\omega,\boldsymbol{P})$. The result

$$\Omega_{\rm fluc} = \Omega_{\rm NSR} + \Omega_{\rm qfl}$$

shows quantum fluctuation $\Omega_{\rm qfl}$ besides the Nozieres–Schmitt-Rink contribution $\Omega_{\rm NSR}$.

$\Omega_{\rm qfl}$ can be ignored for:

(i) high temperature $T > T_c$ and (ii) weak coupling $T_c/E_F \ll 1$

THERMODYNAMIC POTENTIAL IN TERMS OF PHASE SHIFT

Integrating the spectral density over the coupling constant leads to

$$\int_0^G \frac{d\mathcal{G}}{\mathcal{G}^2}\rho^{\mathcal{G}}_{\mu,T}(\omega,\boldsymbol{P}) = \frac{i}{2}\log\left(\frac{\frac{1}{G}-\chi_{\mu,T}(\omega+i\delta,\boldsymbol{P})}{\frac{1}{G}-\chi_{\mu,T}(\omega-i\delta,\boldsymbol{P})}\right) \equiv \delta_{\mu,T}(\omega,\boldsymbol{P}).$$

The in-medium phase shift $\delta_{\mu,T}(\omega,\boldsymbol{P})$ is the argument of the dynamic pair susceptibility

$$\frac{\frac{1}{G}-\chi_{\mu,T}(\omega\pm i\delta,\boldsymbol{P})}{|\frac{1}{G}-\chi_{\mu,T}(\omega,\boldsymbol{P})|} = e^{\mp i\delta_{\mu,T}(\omega,\boldsymbol{P})}.$$

The contributions to the thermodynamical potential can be expressed as

$$\Omega_{\rm NSR} = -d_B\int_{-\infty}^{\infty}\frac{d\omega}{\pi}\frac{d\boldsymbol{P}}{(2\pi)^3}\tilde{f}_B(\omega)\delta_{\mu,T}(\omega,\boldsymbol{P}),$$

$$\Omega_{\rm qfl} = -d_B\int_{-\infty}^{\infty}\frac{d\omega}{\pi}\frac{d\boldsymbol{P}}{(2\pi)^3}\frac{\epsilon(\omega)}{2}\left[\delta_{\mu,T}(\omega,\boldsymbol{P})-\delta_{0,0}(\omega,\boldsymbol{P})\right],$$

where $\Omega_{\rm NSR}$ is exactly the Nozieres–Schmitt-Rink result in J. Low Temp. Phys. **59** (1985) 195

THOULESS CRITERION AND RENORMALIZATION OF COUPLING (I)

In the weak attractive coupling regime, the Thouless condition defines the critical temperature T_c by the divergence of the static and long wavelength limit of the dynamic pair susceptibility

$$\Gamma^{-1}_{\mu,T_c}(0,\mathbf{0}) = \frac{1}{G} - \chi_{\mu,T_c}(0,\mathbf{0}) = 0\ , \quad \chi_{\mu,T_c}(0,\mathbf{0}) = 2\int^{\Lambda} \frac{d\boldsymbol{q}}{(2\pi)^3} \frac{\tanh\frac{E_q-\mu}{2T_c}}{E_q-\mu} + (\mu \to -\mu).$$

Cutoff-dependence of $T_c = \Lambda f(m/\Lambda, \mu/\Lambda, G\Lambda^2)$ reduced by partial renormalization using low-energy scattering T-matrix ("1" $= (\boldsymbol{p}, a, i, h_1)$ labels quark momentum, color, flavor, spin)

$$T(12 \to 34) = T(\boldsymbol{p},\boldsymbol{k})(\Gamma_{12}\Gamma_{34} - (3 \leftrightarrow 4)), \quad \Gamma_{12} = \frac{\varepsilon_{ab}}{\sqrt{2}}\frac{\varepsilon_{ij}}{\sqrt{2}}\frac{\sigma^3_{h_1h_2}}{\sqrt{2}},$$

where $T(\boldsymbol{p},\boldsymbol{k})$ can be evaluated with the Lippman-Schwinger resummation

$$T(\boldsymbol{p},\boldsymbol{k}) = \frac{-G}{1 - G\chi_{0,0}(2E_p + i\delta, \mathbf{0})} \equiv -\Gamma_{0,0}(2E_p, \mathbf{0}).$$

At sufficiently low energy, $2E_p = 2m + \frac{p^2}{m}$, the scattering amplitude $f(\boldsymbol{p},\boldsymbol{k}) = -\frac{m}{4\pi}T(\boldsymbol{p},\boldsymbol{k})$ is

$$f(\boldsymbol{p},\boldsymbol{k}) = \frac{e^{i\delta}\sin\delta}{p} = \frac{1}{p\cot\delta - ip} \sim \frac{1}{-\frac{1}{a_s} + \frac{1}{2}r_e p^2 - ip},$$

with the s-wave scattering length a_s and the effective range r_e to be extracted from $\Gamma_{0,0}(2E_p, \mathbf{0})$.

Thouless criterion and renormalization of coupling (II)

The effective range is UV finite, while the inverse scattering length is quadratically divergent

$$-\frac{m}{4\pi a_s} = \frac{1}{G} - 2\int \frac{d\boldsymbol{q}}{(2\pi)^3}\left(\frac{1}{E_q - m} + \frac{1}{E_q + m}\right) = \frac{1}{G} - \chi_{0,0}(2m, \mathbf{0}) \equiv -\frac{1}{G_R},$$

Thouless criterion with renormalization of coupling and pair correlation reads

$$-\frac{1}{G_R} - \chi^{\mathrm{Ren}}_{\mu,T_c}(0,\mathbf{0}) = 0, \quad \chi^{\mathrm{Ren}}_{\mu,T}(\omega,\boldsymbol{P}) \equiv \chi_{\mu,T}(\omega,\boldsymbol{P}) - \chi_{0,0}(2m,\mathbf{0}).$$

Bound state or resonance ? In vacuum ($\mu = T = 0$) from condition: $-1/G_R - \chi^{\mathrm{Ren}}_{0,0}(\omega,\mathbf{0}) = 0$.
Since $\chi^{\mathrm{Ren}}_0(2m,0) = 0$ follows: if $-1/G_R > 0$ then a resonance pole is located at $|\omega| > 2m$; otherwise a *stable bound state* is located at $|\omega| < 2m$, because $\Im\chi(|\omega| < 2m,\mathbf{0}) = 0$.
Then the critical coupling $G_R = G_{c1}$ for the zero binding is given by the condition

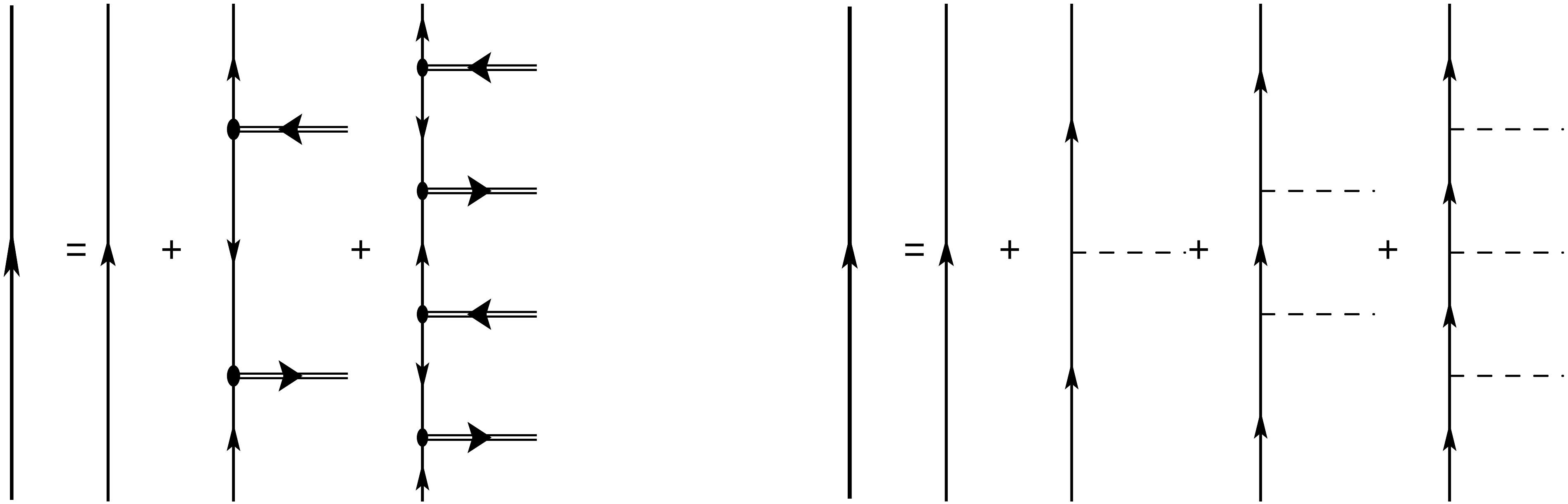
$$-\frac{1}{G_{c1}} - \chi^{\mathrm{Ren}}_0(2m,\mathbf{0}) = -\frac{1}{G_{c1}} = 0,$$

so that $1/a_s = 0$, so-called unitary limit.
For the relativistic case, a second critical coupling exists at $G_R = G_{c2}$, when the bound state becomes massless: $-1/G_{c2} = \chi^{\mathrm{Ren}}_0(0,\mathbf{0}) < 0$.

EXPANSION IN MESONIC AND DIQUARK FLUCTUATIONS

$$Z_{\text{fluct}} = \int D\Delta^\dagger D\Delta D\phi \exp\{-\frac{|\Delta|^2}{4G_D} - \frac{\phi^2}{4G} - Tr\; lnS^{-1}[\Delta, \Delta^\dagger, \phi]\}$$

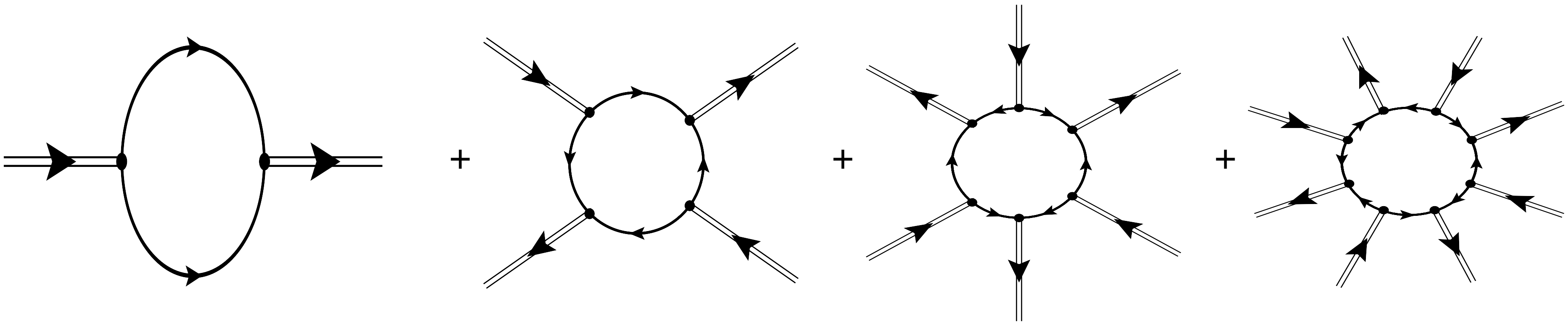
Cahill, Roberts, Prashifka: Aust. J. Phys. 42 (1989) 129, 161
Cahill, ibid, 171; Reinhardt: PLB 244 (1990) 316; Buck, Alkofer, Reinhardt: PLB 286 (1992) 29

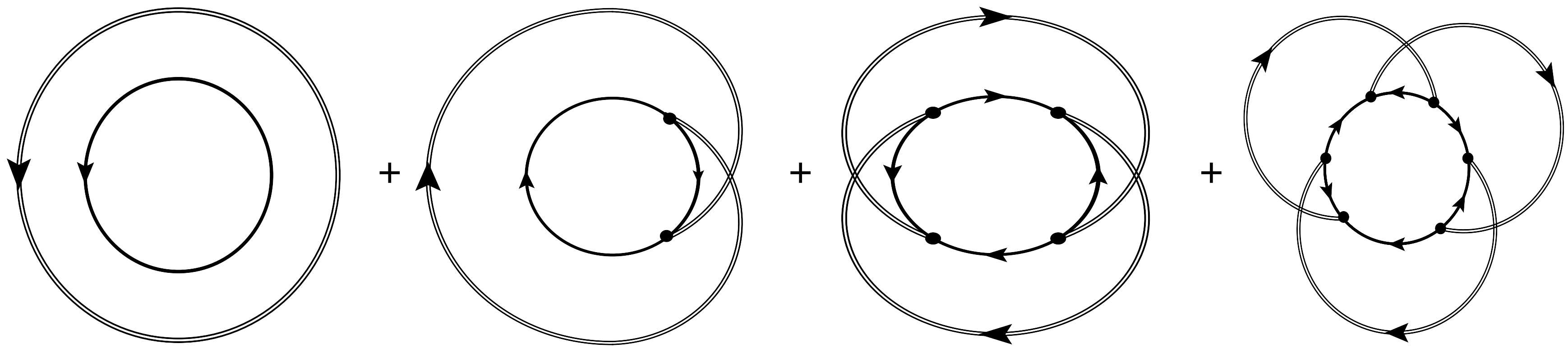


How to perform the path integral over diquark and meson fields?

TRACE OVER QUARK, INTEGRATION OVER DIQUARK FIELDS

Cahill, Roberts, Prashifka: Aust. J. Phys. 42 (1989) 129, 161
Cahill, ibid, 171; Reinhardt: PLB 244 (1990) 316; Buck, Alkofer, Reinhardt: PLB 286 (1992) 29



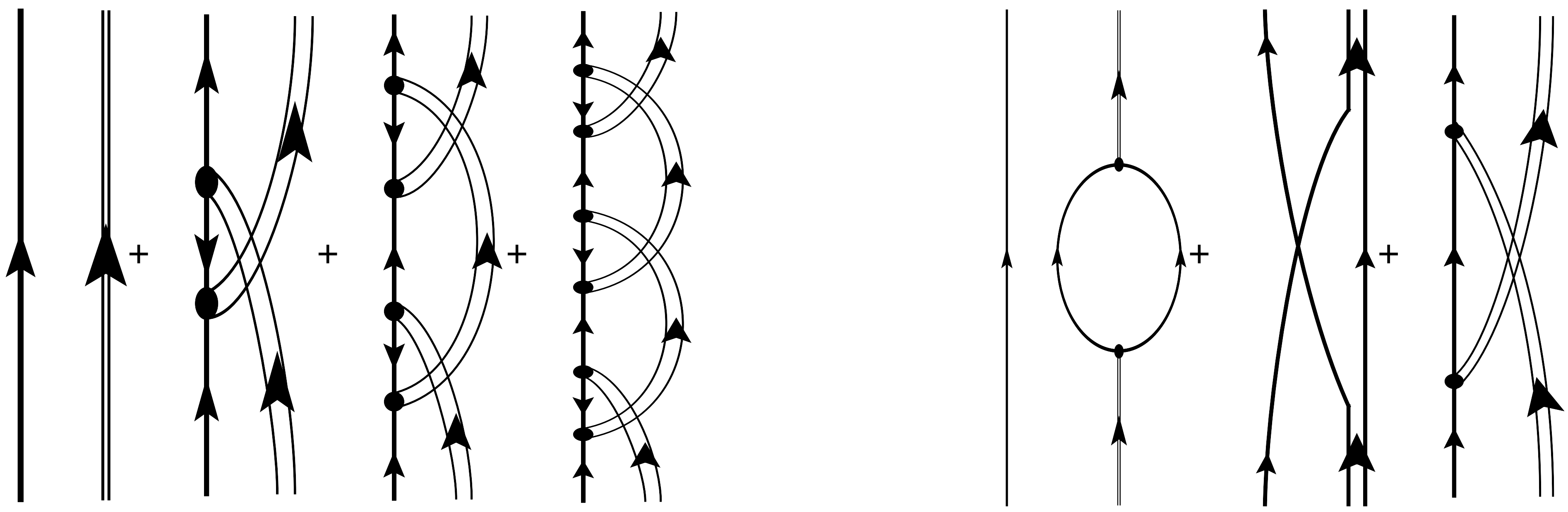


Very nice! But where is the nucleon?

BARYON AS A PARTIAL DIAGRAM RESUMMATION

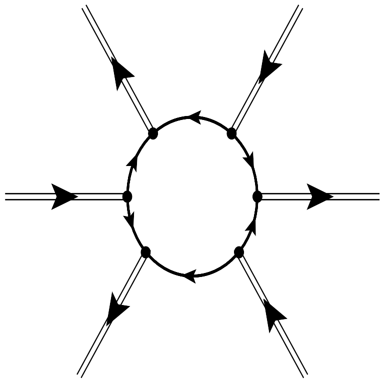
$$Z_{\text{fluct}} = \int D\Delta^\dagger D\Delta D\phi \exp\{-\frac{|\Delta|^2}{4G_D} - \frac{\phi^2}{4G} - Tr\, lnS^{-1}[\Delta, \Delta^\dagger, \phi]\}$$

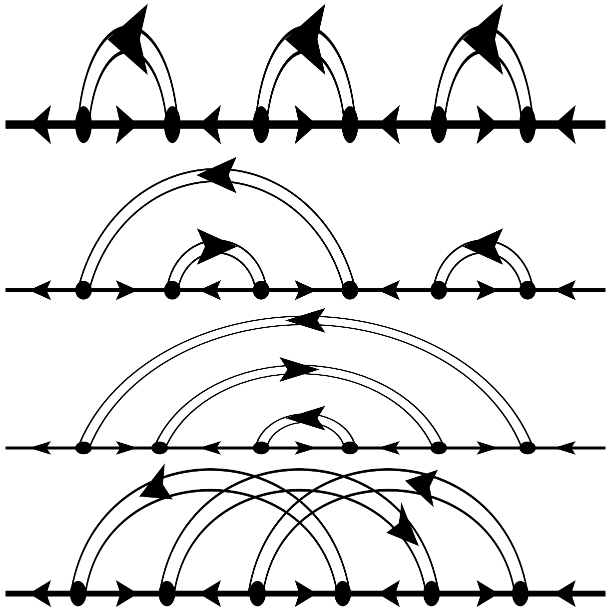
Cahill, Roberts, Prashifka: Aust. J. Phys. 42 (1989) 129, 161
Cahill, ibid, 171; Reinhardt: PLB 244 (1990) 316; Buck, Alkofer, Reinhardt: PLB 286 (1992) 29

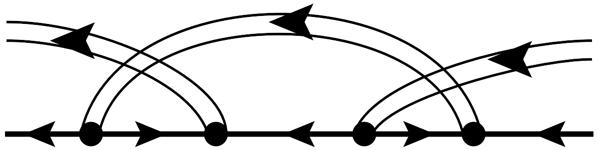


Faddeev equation for quark-diquark states, bound by quark exchange

WHICH DIAGRAMS HAVE BEEN FORGOTTEN ?

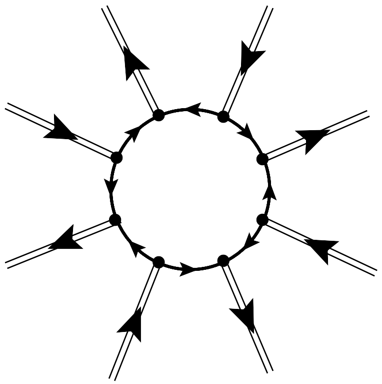


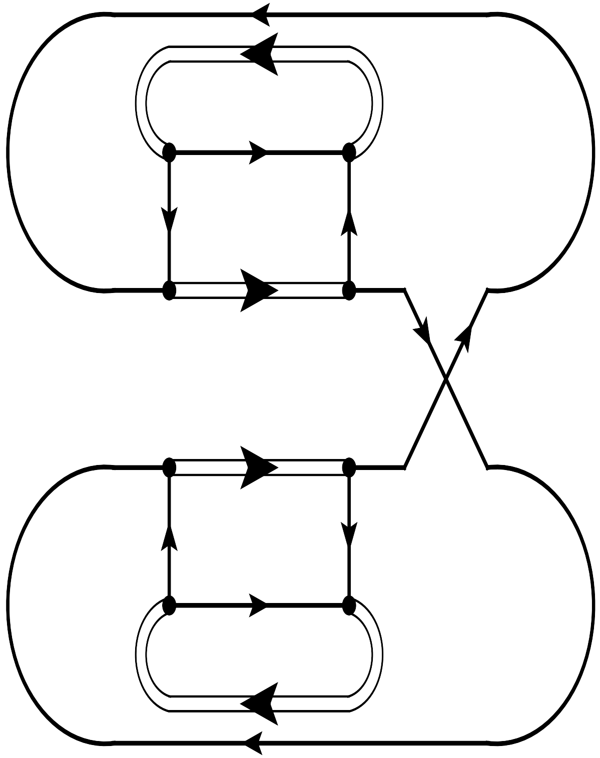


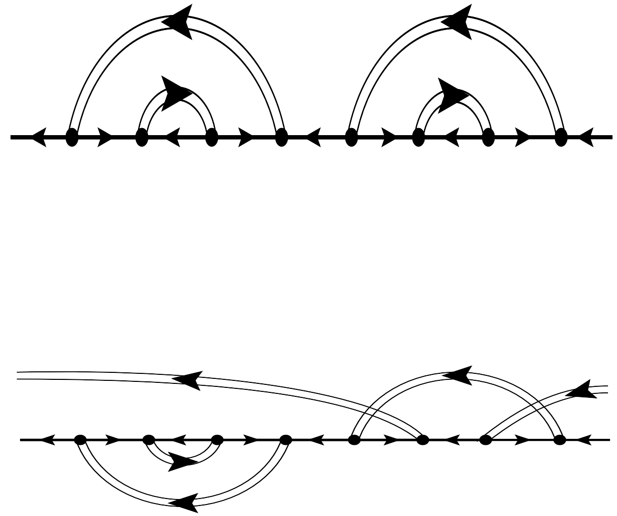


Self-energy type diagrams for the quark propagator

WHICH DIAGRAMS HAVE BEEN FORGOTTEN ?



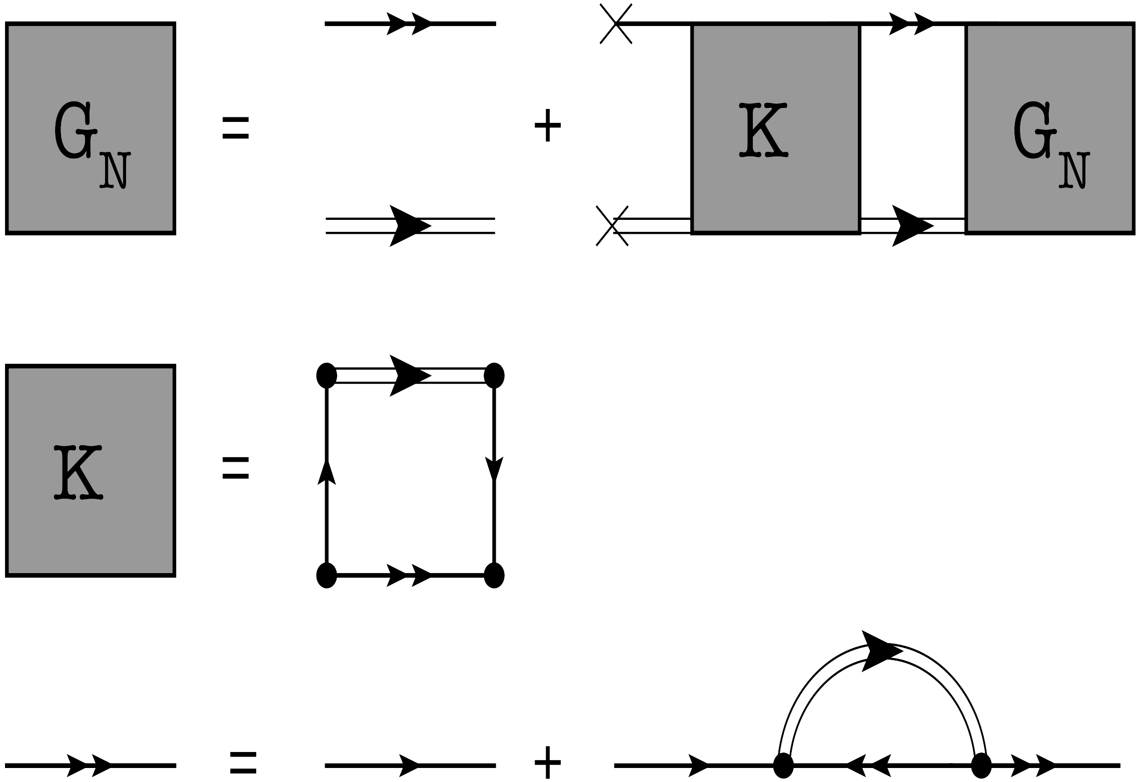




Self-energy diagrams for the quark propagator $\rightarrow$ quark exchange between nucleons

General. Bethe-Salpeter eq. for quark-diquark states

Cluster decomposition for quark matter from loop expansion



From Diquarks to Baryons (I)

The inverse diquark propagator is then obtained from

$$(S_D^A)^{-1}(k_0,k) = \frac{1}{4G_D} - \Pi_D^A(k_0,k) \quad , \quad \Pi_D^A(k_0,k) = \int \frac{d^4q}{(2\pi)^4} S_Q(q)\Sigma^A(k)S_Q(q-k)\Sigma^A(k)$$

Propagator can be expressed via the spectral density after analytic continuation

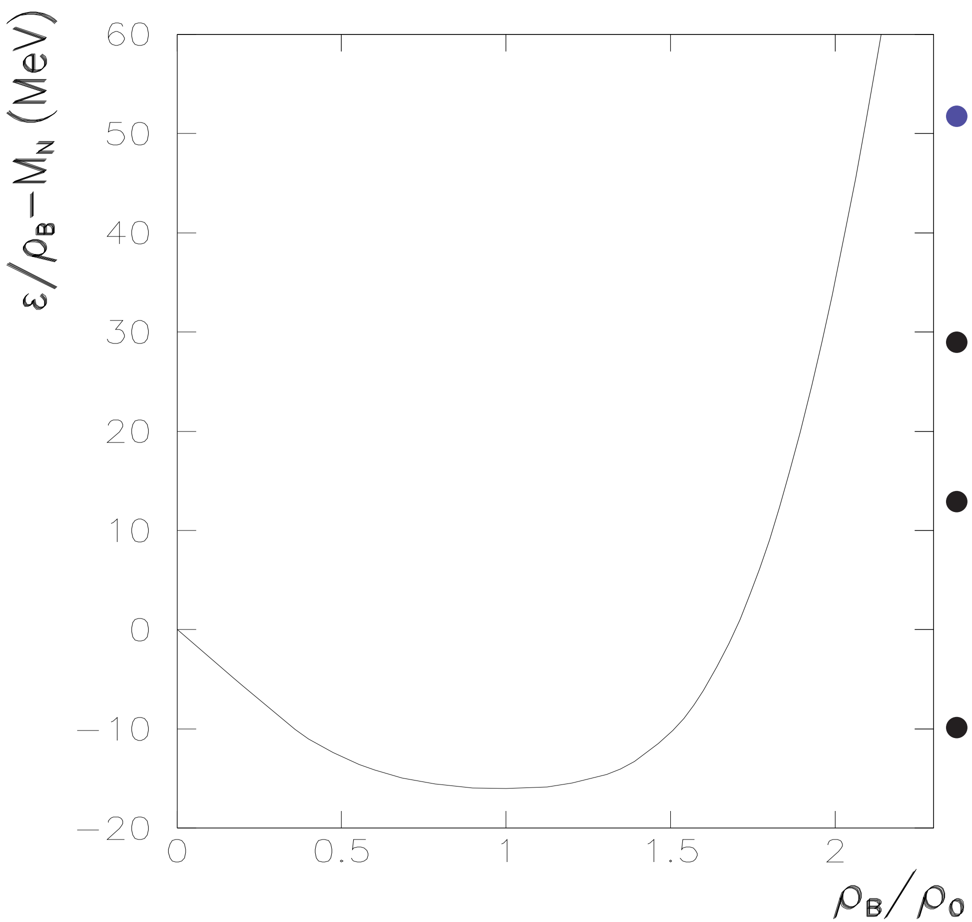
$$S_D^A(z,k) = \int_{-\infty}^{\infty} \frac{\mathrm{d}\omega}{2\pi} \frac{\varrho_D^A(\omega,k)}{z-\omega} \quad , \quad \varrho_D^A(\omega,k) = \lim_{\varepsilon\to 0} \frac{8G_D^2 \mathrm{Im}\Pi_D^A(\omega+i\varepsilon,k)}{[1-2G_D\mathrm{Re}\Pi_D^A(\omega+i\varepsilon,k)]^2 + [2G_D\mathrm{Im}\Pi_D^A(\omega+i\varepsilon,k)]^2}$$

Similar, baryon propagator and spectral density

$$S_B^{-1}(P_0,P) = \frac{1}{G_B} - \Pi_B(P_0,P) \quad , \quad \Pi_B(P_0,P) = \sum_{A=2,5,7} \int \frac{\mathrm{d}k^4}{(2\pi)^4} S_Q^{11,A}(P-k)S_D^A(k)$$

Further details:
Wang, Wang, Rischke, arXiv:1008.4029 [nucl-th]
Zablocki, Blaschke, Buballa, in preparation (2011)

Towards Nuclear Matter from Chiral Quark Models



- RMF with density-dependent meson masses and couplings from NJL* model
- Next steps: solve nucleon EoM at finite μ including chiral transition
- Is Polyakov-loop NJL sufficient for a description of the Quarkyonic Phase?
- Thermodynamics from the QCD-DSE approach ? (Roberts, Klähn, ...)

Figure from: Huguet, Caillon, Labarsouque, NPA 781 (2007) 448

COLLABORATIONS

Thanks to:

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ESF Research Networking Programme
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Reference manual
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Research Networking Program
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November 22, 2010

General Requirements:

- Densities: $10^{-8} \leq n/n_0 \leq 10$
- Temperatures: $0 \leq T \leq 200$ MeV
- Proton fractions: $0 \leq Y_p \leq 0.6$; $\beta = 1 - 2Y_p$

New Developments:

- Dissolution of clusters due to Pauli blocking
- Realistic high-density modeling: DD-RMF/3FSC PNJL
- Thermodynamics of 1^{st} order PT; pasta phases

I. For Contributors:

- How to prepare EoS tables
- How to submit EoS tables
- Extending CompOSE

II. For Users:

- Hadronic EoS: Statistical, Skyrme, DBHF, ...
- Quark Matter EoS: Bag, PNJL, ...
- Phase transition: Maxwell, Gibbs, Pasta, ...

INVITATION: CONTRIBUTE TO THE NICA WHITE PAPER

Draft v 3.03

June 20, 2010

SEARCHING for a QCD MIXED PHASE at the NUCLOTRON-BASED ION COLLIDER FACILITY (NICA White Paper)

http://theor.jinr.ru/twiki-cgi/view/NICA/WebHome

http://theor.jinr.ru

Contents

Summary

- Hadron production in HIC $\rightarrow$ Triple point in QCD phase diagram!
- Compressed nuclear matter: **quarkyonic phase** (QP)! Coexisting chiral symm. + conf.
- Here: PNJL model as microscopic formulation of the QP
- Prospects for HIC (CBM & NICA) and Supernovae: color superconducting (quarkyonic) phases accessible!

Outlook: next steps ...

- Walecka model as limit of PNJL model: chiral transition effects in nuclear EoS
- Beyond meanfield: mesons and baryons in the PNJL, higher clusters: sextetting
- Astrophysics: Maximum mass & cooling of quarkyonic stars; quarkyonic supernovae
- HIC: signals of CSC phase transition (dilepton enhancement?)