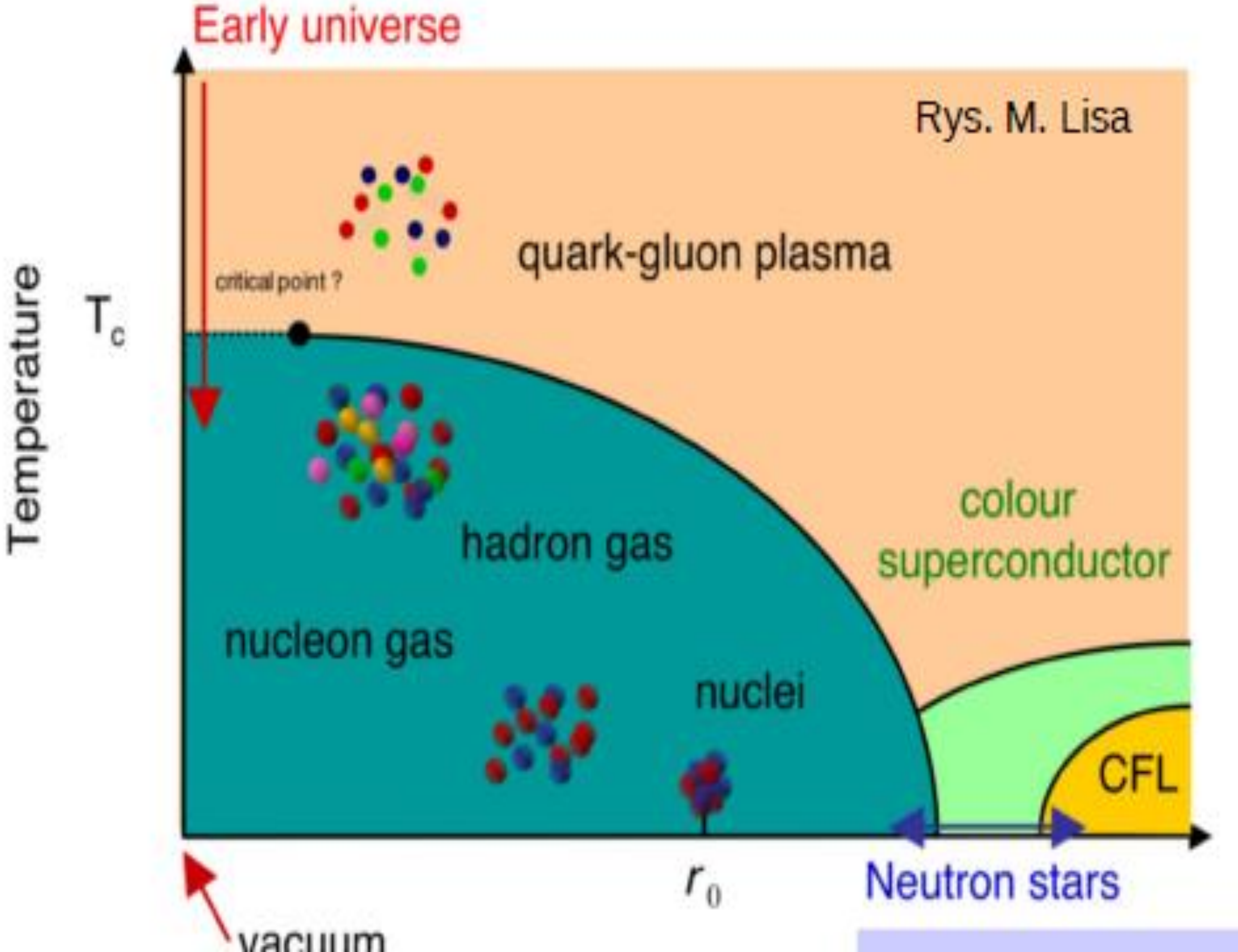
Non-extensive critical effects in the nuclear mean field

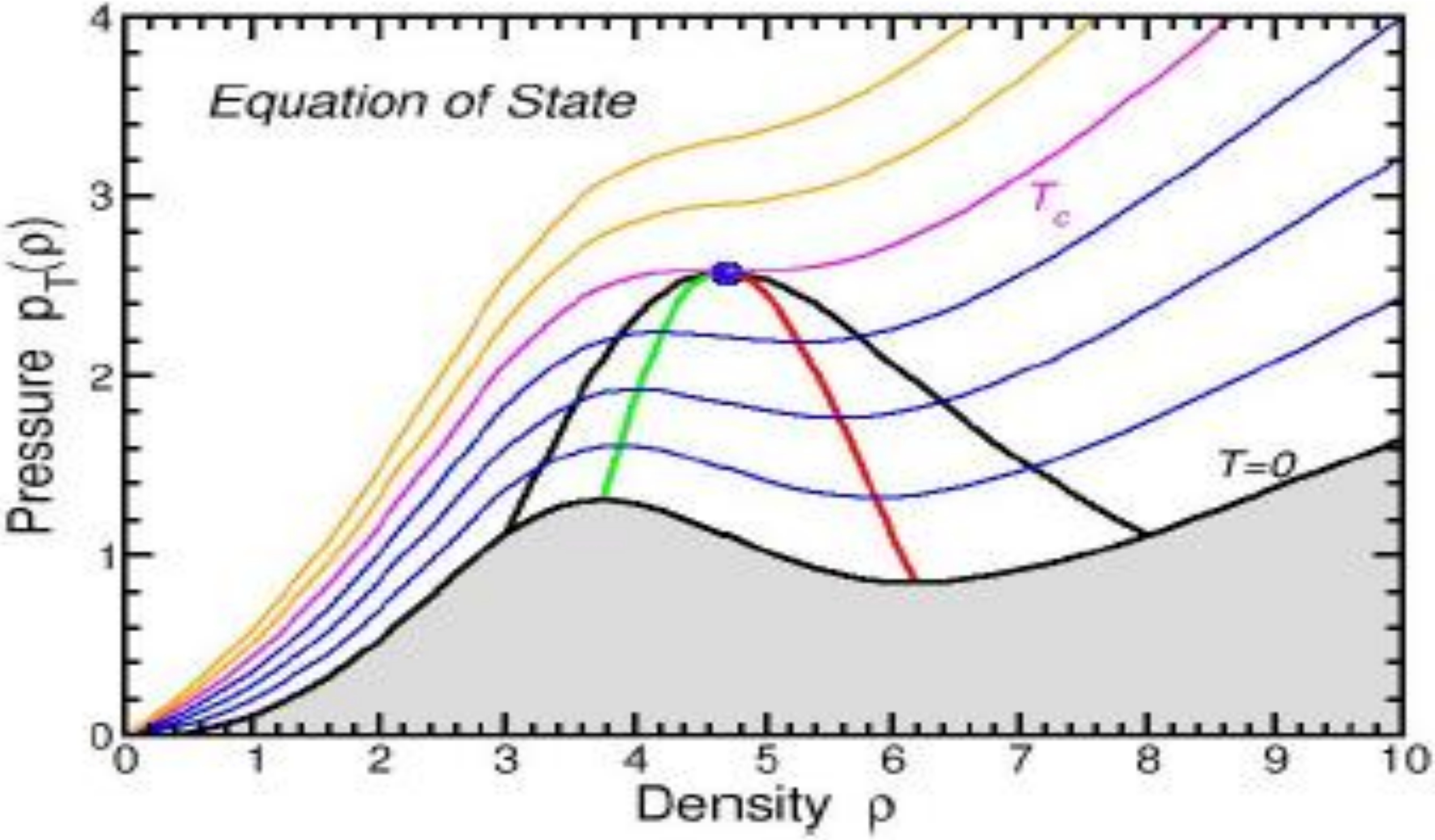
J. Rozynek, Warsaw

Nonextensive NJ-L model of QCD matter revisited
Eur.Phys. J. A. (2016) with **G. Wilk**

Nonextensive distributions for a relativistic Fermi gas
Eur. Phys. J. A. (2015)



Early universe
Rys. M. Lisa
quark-gluon plasma
critical point ?
Temperature
T_c
hadron gas
colour
superconductor
nucleon gas
nuclei
CFL
r_0
Neutron stars
vacuum



Equation of State
Pressure $p_T(\rho)$
Density ρ
T_c
$T=0$
0
1
2
3
4
5
6
7
8
9
10

Content:

- **Motivation**
- **Example: NJL model of QCD**

  → **Nonextensive NJL model: q_NJL**

- **Results**
- **Summary**

Motivation

- The critical phenomena in strongly interaction matter are generally investigated using the mean-field model and are characterized by well defined critical exponents.

- However, such models provide only average properties of the corresponding order parameters and neglect altogether their possible fluctuations. Also the possible long range effect and correlations are neglected in the mean field approach.

- One of the possible phenomenological ways to account for such effects is to use the nonextensive approach.

- Here we investigate the critical behavior in the nonextensive version of the Nambu Jona-Lasinio model (NJL). It allows to account for such effects in a phenomenological way by means of a single parameter q, the nonextensivity parameter.

- In particular, we show how the nonextensive statistics influences the region of the critical temperature and chemical potential in the NJL mean field approach.

Motivation

- **The critical phenomena in strongly interaction matter are generally investigated using the mean-field model and are characterized by well defined critical exponents.**

- **However, such models provide only average properties of the corresponding order parameters and neglect altogether their possible fluctuations. Also the possible long range effect and correlations are neglected in the mean field approach.**

- **One of the possible phenomenological ways to account for such effects is to use the nonextensive approach.**

(… digression on nonextensivity and the like …)

Digression: …. nonextensive approach…. what does it mean?

The nonextensive statistical mechanics proposed by Tsallis [2] generalizes the usual BG statistical mechanics in that the entropy function (we use the convention that the Boltzmann constant is set equal to unity),

$$S_{\mathrm{BG}} = -\sum_{i=1}^{W} p_i \ln p_i \Longrightarrow S_q = -\sum_{i=1}^{W} p_i^q \ln_q p_i , \quad (17)$$

$S_q \to S_{q=1} = S_{\mathrm{BG}}$ for $q \to 1$. Here, q is the nonextensive parameter and $\ln_q p = [p^{1-q} - 1]/(1-q)$. The additivity for two independent subsystems A and B (i.e., such that $p^{A\oplus B} = p^A \cdot p^B$) is now lost and takes the form:

$$S_q^{A\oplus B} = S_q^A + S_q^B + (1-q) S_q^A S_q^B , \quad (18)$$

they are called nonextensive[4].

[2] Tsallis C J 1988 *Stat. Phys.* **52** 479
Salinas S R A and Tsallis C (ed) 1999 Special issue on nonextensive statistical mechanics and thermodynamic *Braz. J. Phys.* **29**
Gell-Mann M and Tsallis C (ed) 2004 *Nonextensive Entropy: Interdisciplinary Applications* (New York: Oxford University Press)
Tsallis C 2009 *Eur. Phys. J.* A **40** 257

Digression: …. nonextensive approach…. what does it mean?

This phenomenon is ubiquitous in all branches of science and very well documented. It occurs always whenether:

(*) there are long range correlations in the system (or „system is small" – like our Universe with respect to the gravitational interactions)

(*) there are memory effects of any kind

(*) the phase-space in which system operates is limited or has fractal structure

(*) there are intrinsic fluctuations in the system under consideration

(*) ……………………….

Digression: …. nonextensive approach…. what does it mean?

This phenomenon is ubiquitous in all branches of science and very well documented. It occurs always whenether:

[4] Wilk G and Włodarczyk Z 2009 *Eur. Phys. J.* A **40** 299

[5] Alberico W M and Lavagno A 2009 *Eur. Phys. J.* A **40** 313

[6] Osada T and Wilk G 2008 *Phys. Rev.* C **77** 044903

Osada T and Wilk G 2009 *Centr. Eur. J. Phys.* **7** 432

[7] Biyajima M, Mizoguchi T, Nakajima N, Suzuki N and Wilk G 2006 *Eur. Phys. J.* C **48** 597

[8] Biró T S and Purcsel G 2009 *Centr. Eur. J. Phys.* **7** 395

Biró T S, Purcsel G and Ürmošy K 2009 *Eur. Phys. J.* A **40** 325

[9] Drago A, Lavagno A and Quarati P 2004 *Physica* A **344** 472

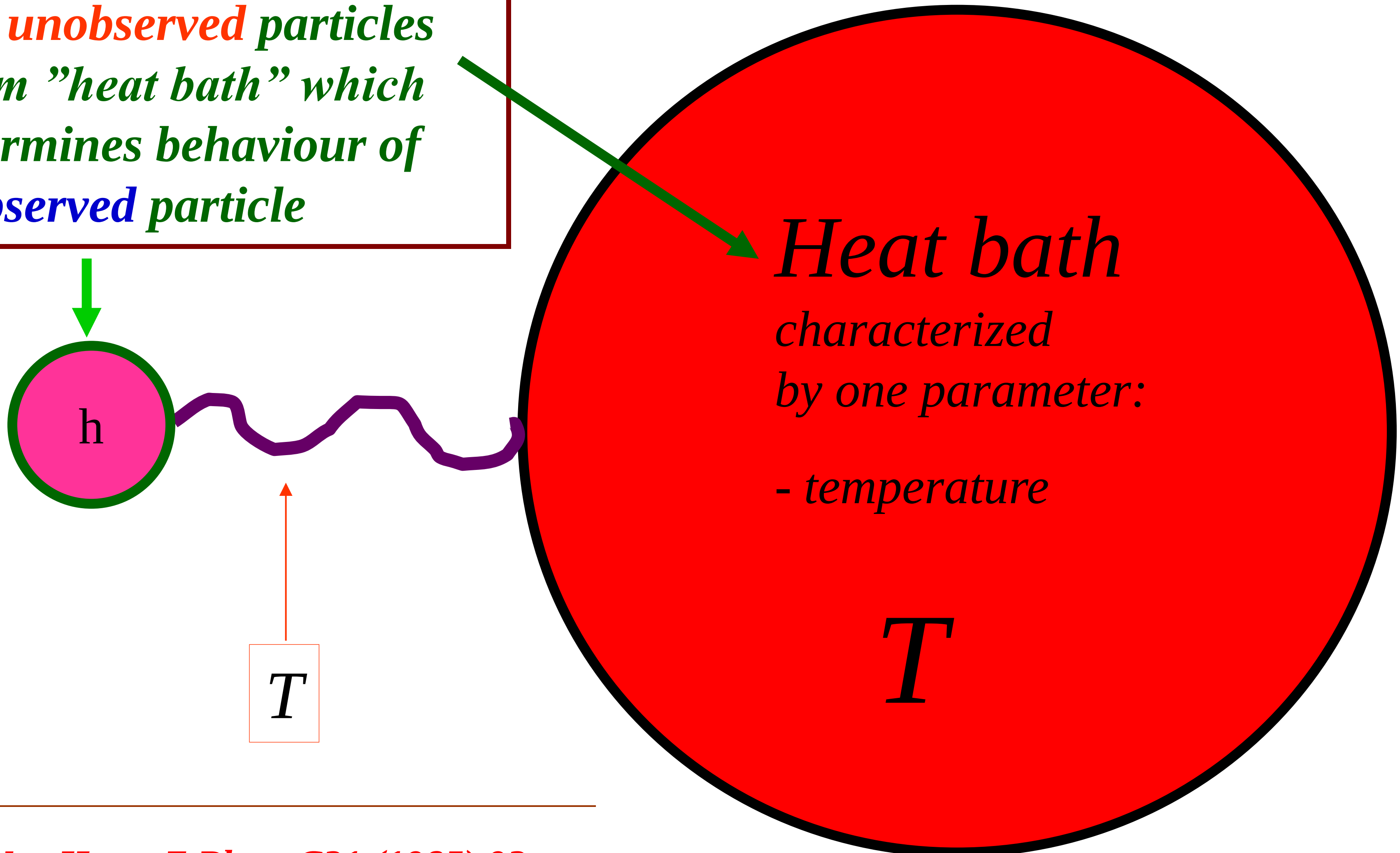
[10] Biró T S and Purcsel G 2005 *Phys. Rev. Lett.* **95** 162302

Biró T S and Purcsel G 2008 *Phys. Lett.* A **372** 1174

Biró T S 2008 *Europhys. Lett.* **84** 56003

Digression: …. nonextensive approach…. what does it mean?
……………………………………………………….illustration

N-particle system ⇒
N-1 unobserved particles
form "heat bath" which
determines behaviour of
1 observed particle



L.Van Hove, Z.Phys. C21 (1985) 93,
Z.Phys. C27 (1985) 135.

Digression: …. nonextensive approach…. what does it mean?

……………………………………………………………….illustration

But: In such "thermodynamical" approach one has to remember assumptions of infinity and homogenity made when proposing this approach - only then behaviour of the observed particle will be characterised by single parameter - the "temperature" T

In reality: This is true only approximately and in most cases we deal with system which are neither infinite and nor homogeneous

In both cases: Fluctuations occur and new parameter(s) in addition to T is(are) necessary

Can one introduce it keeping simple structure of statistical model approach?

Yes, one can, by applying nonextensive statistical model.

Wilk G and Włodarczyk Z 2000 *Phys. Rev. Lett.* **84** 1770

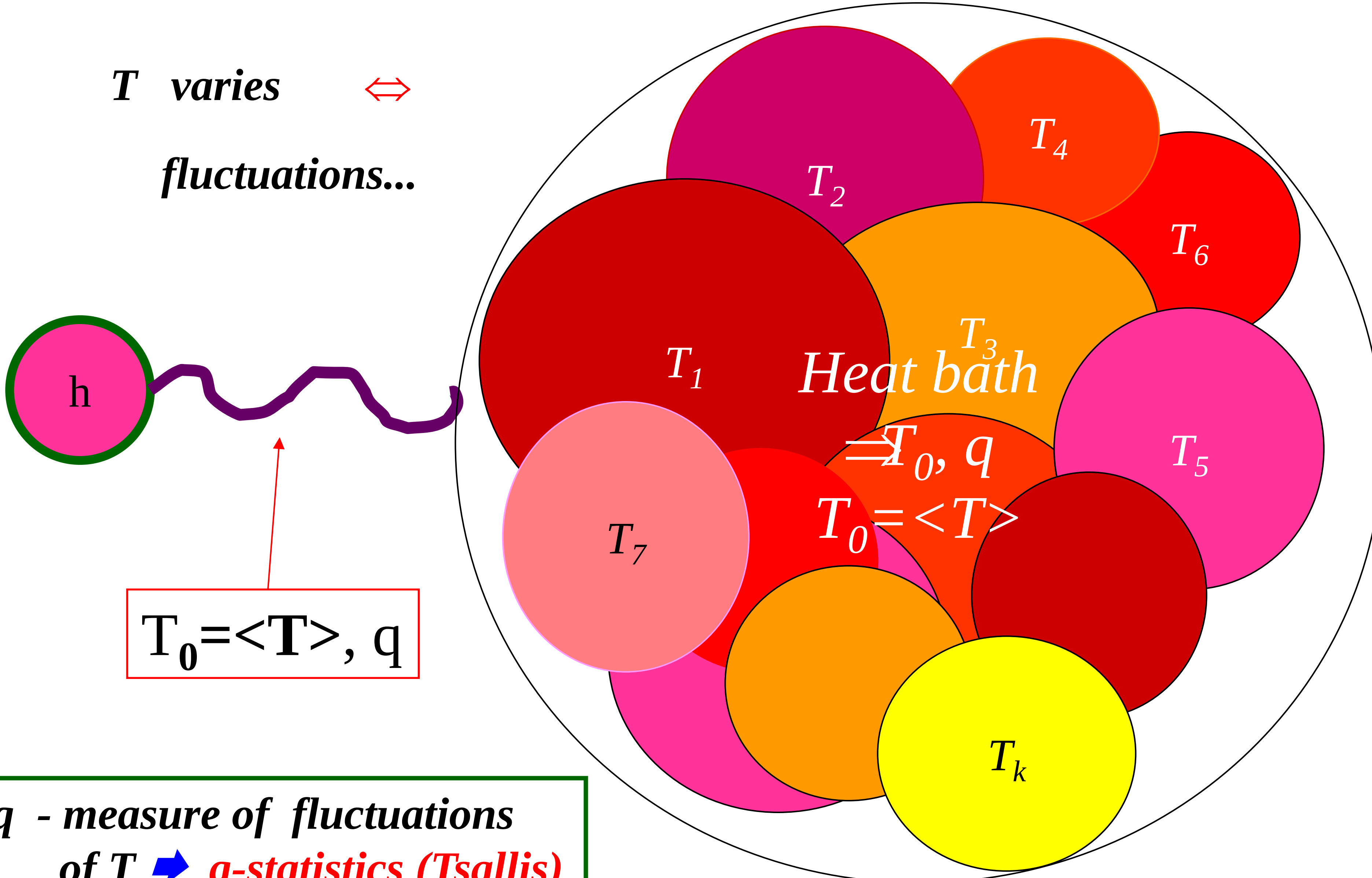
Wilk G and Włodarczyk Z 2001 *Chaos Solitons Fractals* **13** 581

Biró T S and Jakovác A 2005 *Phys. Rev. Lett.* **94** 132302

Digression: …. nonextensive approach…. what does it mean?
……………………………………………………………….illustration

T varies ⇔

fluctuations...



q - measure of fluctuations of T ➡ ***q-statistics (Tsallis)***

Motivation

- Recently, q-statistics has been applied to the Walecka many-body field theory

Pereira F I M, Silva B and Alcaniz J S 2007 *Phys. Rev.* C 76 015201

resulting (among others) in the enhancement of the scalar and vector meson fields in nuclear matter, in diminishing of the nucleon effective mass and in the hardening of the nuclear equation of state (only $q>1$ case was considered there).

- Here we investigate the critical behavior in the nonextensive version of the Nambu Jona-Lasinio model (NJL). It allows to account for such effects in a phenomenological way by means of a single parameter q, the nonextensivity parameter. The NJL model we modify is that presented in

Costa P, Ruivo M C and de Sousa A 2008 *Phys. Rev.* D 77 096001

In particular, we show how the nonextensive statistics influences the region of the critical temperature and chemical potential in the NJL mean field approach.

Non extensive thermodynamics and neutron star properties

MENEZES, DEPPMAN, CASTRO J.Phys.A(2016)

Abstract. In the present work we apply non extensive statistics to obtain equations of state suitable to describe stellar matter and verify its effects on microscopic and macroscopic quantities. Two snapshots of the star evolution are considered and the direct Urca process is investigated with two different parameter sets. q-values are chosen as 1.05 and 1.14. The equations of state are only slightly modified, but the effects are enough to produce stars with slightly higher maximum masses. The onsets of the constituents are more strongly affected and the internal stellar temperature decreases with the increase of the q-value, with consequences on the strangeness and cooling rates of the stars.

In the extensive approach to dense, hot matter the particle and antiparticle occupation numbers, n_i and $\bar{n}_i$, can be obtained from the Jayne's extremalization of the entropic measure

$$S = \sum_i \left[n_i \ln n_i + (1 - n_i) \ln(1 - n_i) \right] + \left[n_i \rightarrow \bar{n}_i \right], \tag{1}$$

under the constraints imposed by the total number of particles, N, and the total energy of the system, E (ϵ_i is the energy of the i-th energy level) [16],

$$\sum_i (n_i - \bar{n}_i) = N \qquad \text{and} \qquad \sum_i (n_i + \bar{n}_i)\, \epsilon_i = E. \tag{2}$$

As a result we get the Fermi-Dirac distributions,

$$n_i = \frac{1}{\exp(x_i) + 1}, \qquad \bar{n}_i = \frac{1}{\exp(\bar{x}_i) + 1}, \tag{3}$$

which depend on the dimensionless quantities

$$x = \beta(\epsilon - \mu) \qquad \text{and} \qquad \bar{x} = \beta(\epsilon + \mu). \tag{4}$$

where $\beta = 1/T$, $\epsilon = \sqrt{p^2 + m^2}$, m is fermion mass and μ its chemical potential. For $\epsilon = 0$, the distributions $n(x)$ and $\bar{n}(\bar{x}) = n(\bar{x})$ satisfy following relation:

$$n(x) + n(\bar{x}) = 1. \tag{5}$$

$$\tilde{S}_q^{(a)} = \sum_i \left[n_{qi}^q \ln_q n_{qi} + (1 - n_{qi})^q \ln_q (1 - n_{qi}) \right] +$$

$$\text{where} \quad \ln_q x = \frac{x^{1-q} - 1}{1 - q}.$$

q=1 → $\ln(n_i)$

Entropy Extremalization gives:

$$n_{qi} = \frac{1}{e_q(x_{qi}) + 1}, \qquad \bar{n}_{qi} = \frac{1}{e_q(\bar{x}_{qi}) + 1},$$

$$\text{where} \quad x_{qi} = \beta(E_{qi} - \mu), \quad \bar{x}_{qi} = \beta(E_{qi} + \mu),$$

$$\text{and} \quad e_q(x) = [1 + (q-1)x]^{\frac{1}{q-1}}.$$

with conditions

$$\sum_i \left(n_{qi}^q - \bar{n}_{qi}^q \right) = \hat{N}, \quad \sum_i \left(n_{qi}^q + \bar{n}_{qi}^q \right) E_{qi} = \hat{E}.$$

(follow Lagrange multipliers)

Our ***NJL*** Lagrangian has the usual form:

$$\mathcal{L} = \bar{q}\,(i\partial\cdot\gamma - \hat{m})\,q + \frac{g_S}{2}\sum_{a=0}^{8}\Big[(\bar{q}\lambda^a q)^2 + (\bar{q}(i\gamma_5)\lambda^a q)^2\Big]$$

$$+\ g_D\Big[\det\big[\bar{q}(1+\gamma_5)q\big] + \det\big[\bar{q}(1-\gamma_5)q\big]\Big]\,.$$

We have 2 coupled **equations** for quark **mass** and **condensate**:

$$M_i = m_i - 2g_S\,\langle\bar{q}_i q_i\rangle - 2g_D\,\langle\bar{q}_j q_j\rangle\,\langle\bar{q}_k q_k\rangle\,,$$

$$\langle\bar{q}_i q_i\rangle = -\frac{N_c}{\pi^2}\sum_{i=u,d,s}\left[\int\frac{p^2 M_i}{E_i}(1 - n_i - \bar{n}_i)\right]dp.$$

NJL - Finite Densities in the Grand Canonical Ensemble {V,T,μ_i}

$$\Omega(T,V,\mu_i) = E - TS - \sum_{i=u,d,s} \mu_i N_i.$$

$$E = -\frac{N_c}{\pi^2} V \sum_{i=u,d,s} \left[\int p^2 dp \frac{p^2 + m_i M_i}{E_i} (1 - n_i - \bar{n}_i) \right] -$$

$$- g_S V \sum_{i=u,d,s} \left(\langle \bar{q}_i q_i \rangle\right)^2 - 2 g_D V \langle \bar{u}u \rangle \langle \bar{d}d \rangle \langle \bar{s}s \rangle,$$

$$S = -\frac{N_c}{\pi^2} V \sum_{i=u,d,s} \int p^2 dp \cdot \tilde{S},$$

$$\text{where} \quad \tilde{S} = [n_i \ln n_i + (1 - n_i) \ln(1 - n_i)] + [n_i \to 1 - \bar{n}_i],$$

$$N_i = \frac{N_c}{\pi^2} V \int p^2 dp \, (n_i - \bar{n}_i).$$

$$\Omega_q(T,V,\mu_i) = E_q - TS_q - \sum_{i=u,d,s} \mu_i N_{qi}. \qquad (42)$$

The pressure and the energy density are defined as, respectively,

$$P_q(\mu,T) = -\frac{1}{V}[\Omega_q(\mu,T) - \Omega_q(0,0)], \qquad (43)$$

$$\varepsilon_q(\mu,T) = \frac{1}{V}[E_q(\mu,T) - E_q(0,0)], \qquad (44)$$

where $\Omega_q(0,0) = E_q(0,0)$ denotes the vacuum energy.

The first derivatives give, respectively, q-entropy and q-density,

$$S_q = \sum_{i=u,d,s} \frac{\partial \Omega_q}{\partial T}\bigg|_\mu \quad \text{and} \quad \varrho_q = \sum_{i=u,d,s} \frac{\partial \Omega_q}{\partial \mu}\bigg|_T. \qquad (45)$$

The second derivatives result in nonextensive versions of the heat capacity, C_μ, and the barionic susceptibility χ_B,

$$C_\mu = \frac{\partial S_q}{\partial T}\bigg|_\mu \quad \text{and} \quad \chi_B = \frac{\partial \varrho_q}{\partial \mu}\bigg|_T. \qquad (46)$$

Because

$$dE_q = \frac{\partial E_q}{\partial S_q} dS_q + \frac{\partial E_q}{\partial N_q} dN_q = \frac{\partial E_q}{\partial T} dT + \frac{\partial E_q}{\partial \mu} d\mu, \qquad (47)$$

one can define temperature the T and the heat capacity C_μ as, respectively,

$$\frac{1}{T} = \frac{\partial S_q}{\partial E_q} \quad \text{and} \quad \frac{1}{T^2 C_\mu} = -\frac{\partial^2 S_q}{\partial E_q^2}. \qquad (48)$$

The corresponding nonextensive energy, E_q, entropy, S_q, and number density, N_q, are now given by

$$E_q = -\frac{N_c}{\pi^2} V \sum_{i=u,d,s} \left[\int p^2 dp \frac{p^2 + m_i M_{qi}}{E_{qi}} (1 - n_{qi}^q - \bar{n}_{qi}^q) \right] - \\ - g_S V \sum_{i=u,d,s} \left(\langle \bar{q}_i q_i \rangle_q \right)^2 - 2 g_D V \langle \bar{u}u \rangle_q \langle \bar{d}d \rangle_q \langle \bar{s}s \rangle_q; \quad (49)$$

$$S_q = -\frac{N_c}{\pi^2} V \sum_{i=u,d,s} \int p^2 dp \cdot \tilde{S}_{qi}^{(R)} \qquad (50)$$

$$N_{qi} = \frac{N_c}{\pi^2} V \int p^2 dp \left(n_{qi}^q - \bar{n}_{qi}^q \right). \qquad (51)$$

$$d\varepsilon_q = T ds_q + \mu d\rho_q, \quad dP_q = s_q dT + \rho_q d\mu, \tag{57}$$

where the energy density $\varepsilon_q = E_q/V$, the entropy density $s_q = S_q/V$ and the density $\rho_q = N_q/V$. The relations to be checked are

$$T = \left.\frac{\partial \varepsilon_q}{\partial s_q}\right|_{\rho_q}, \quad \mu = \left.\frac{\partial \varepsilon_q}{\partial \rho_q}\right|_{s_q}, \quad \rho_q = \left.\frac{\partial P_q}{\partial \mu}\right|_{T}, \quad s_q = \left.\frac{\partial P_q}{\partial T}\right|_{\mu}. \tag{58}$$

The last two are easy to check numerically. In the first two one has first to convert derivatives in s and ρ to derivatives in T and μ and to calculate

$$T = \left.\frac{\partial \varepsilon_q}{\partial s_q}\right|_{\rho_q} = \frac{\frac{\partial \varepsilon_q}{\partial T} + \frac{\partial \varepsilon_q}{\partial \mu}\frac{d\mu}{dT}}{\frac{\partial s_q}{\partial T} + \frac{\partial s_q}{\partial \mu}\frac{d\mu}{dT}} \quad \text{where} \quad \frac{d\mu}{dT} = -\frac{\frac{\partial \rho_q}{\partial T}}{\frac{\partial \rho_q}{\partial \mu}}, \tag{59}$$

$$\mu = \left.\frac{\partial \varepsilon_q}{\partial \rho_q}\right|_{s_q} = \frac{\frac{\partial \varepsilon_q}{\partial T} + \frac{\partial \varepsilon_q}{\partial \mu}\frac{d\mu}{dT}}{\frac{\partial \rho_q}{\partial T} + \frac{\partial \rho_q}{\partial \mu}\frac{d\mu}{dT}} \quad \text{where} \quad \frac{d\mu}{dT} = -\frac{\frac{\partial s_q}{\partial T}}{\frac{\partial s_q}{\partial \mu}}. \tag{60}$$

Results

We concentrate on such features of the q-NJL model:

(1) Chiral symmetry restoration in the q-NJL („Results-chiral”)

(2) Spinodial decomposition in the q-NJL („Results-spinodial”)

(3) Critical effects in the q-NJL („Results-critical effects”)

As our goal was to demonstrate the sensitivity to the nonextensive effects represented by |q-1| ≠0, we do not reproduce here the whole wealth of results provided in

Costa P, Ruivo M C and de Sousa A 2008 *Phys. Rev.* D 77 096001

but concentrate on the most representative results.

Results-chiral

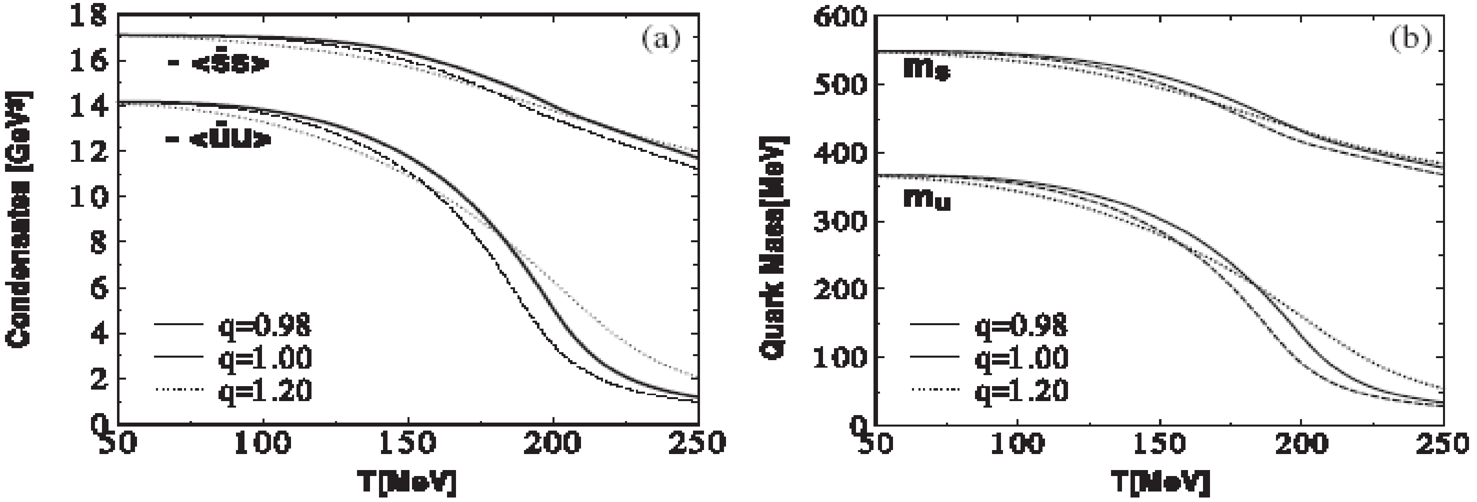


Figure 1. (a) Quark condensates and (b) effective quark masses as functions of the temperature for different values of the nonextensive parameter q ($q = 1$ corresponds to Boltzmann–Gibbs statistics).

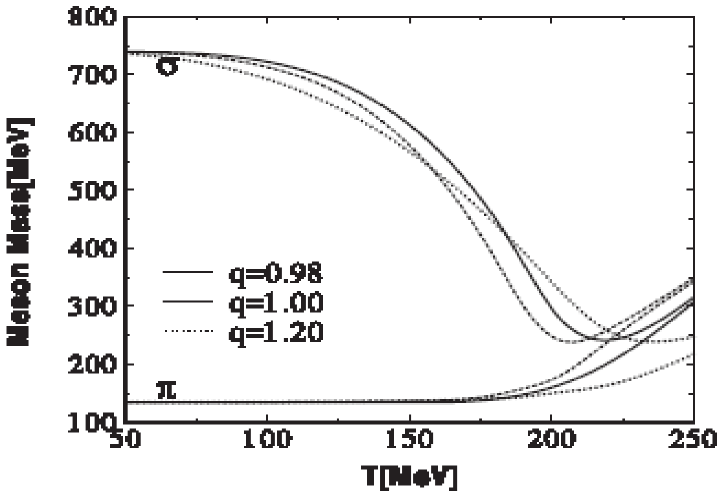


Figure 2. Masses of π and σ mesons as functions of the temperature for different values of the nonextensive parameter q ($q = 1$ corresponds to BG statistics).

Results-chiral

They were calculated assuming zero chemical potentials and solving numerically the q-version of gap equation

$$M_i = m_i - 2g_S \langle \bar{q}_i q_i \rangle - 2g_D \langle \bar{q}_j q_j \rangle \langle \bar{q}_k q_k \rangle,$$

with $\langle \bar{q}_i q_i \rangle \rightarrow \langle \bar{q}_i q_i \rangle_q$ given by:

$$\langle \bar{q}_i q_i \rangle_q = -\frac{N_c}{\pi^2} \sum_{i=u,d,s} \left[\int \frac{p^2 M_i}{E_i} \left(1 - n^q_{qi} - \bar{n}^q_{qi}\right) \right] \mathrm{d}p.$$

In what concerns temperature dependence:

There is still an ongoing discussion on the meaning of the temperature in nonextensive systems. However, in our case the small values of the parameter q deduced from data allow us to argue that, to first approximation, $T_q = T$ used here . In high energy physics it is just the hadronizing temperature (and instead of the state of equilibrium one deals there with some kind of stationary state). For a thorough discussion of the temperature of nonextensive systems, see Abe S 2006 *Physica* A 368 430

Results-chiral

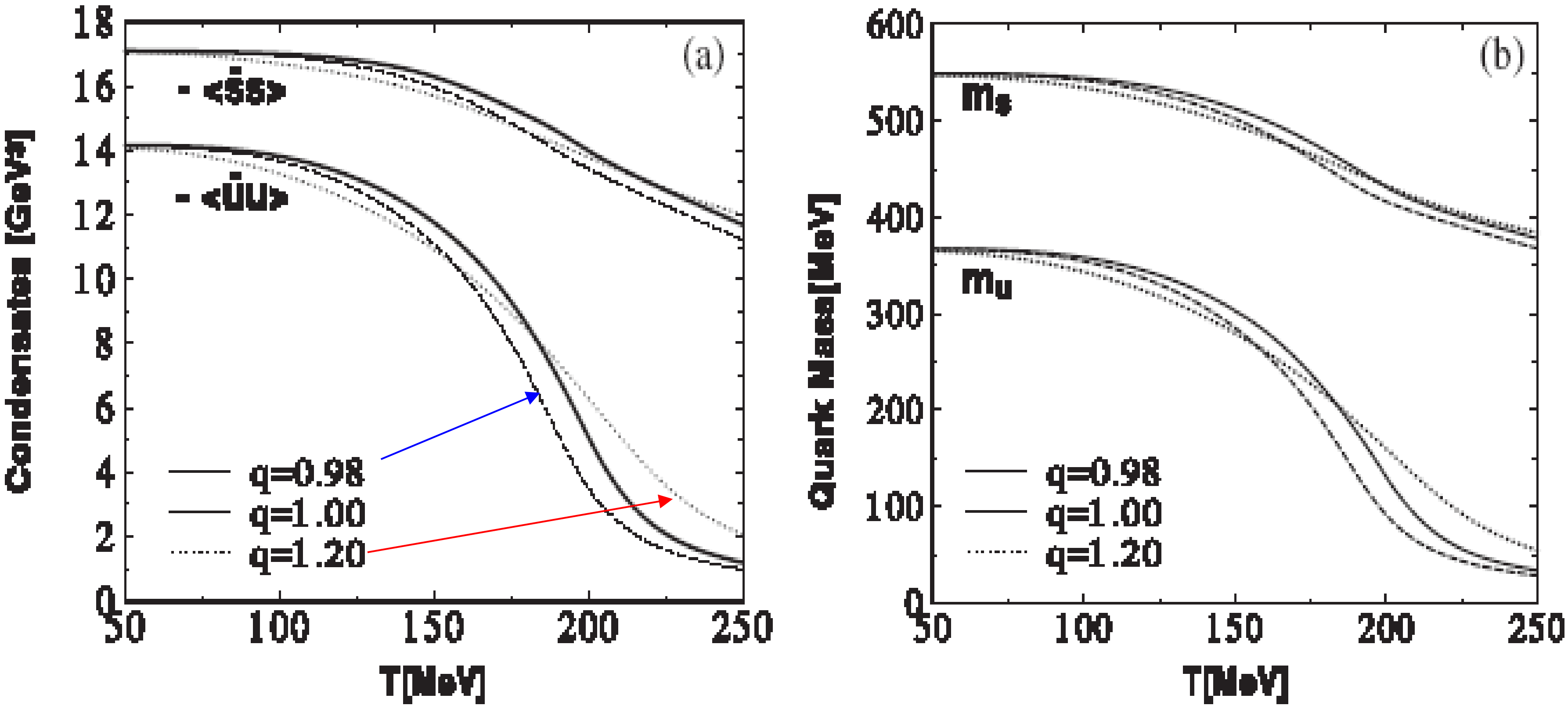


Figure 1. (a) Quark condensates and (b) effective quark masses as functions of the temperature for different values of the nonextensive parameter q ($q = 1$ corresponds to Boltzmann–Gibbs statistics).

(*) Notice the difference between q<1 and q>1 cases.
(*) The effects caused by nonextensivity are practically invisible for heavier quarks.

Results-chiral

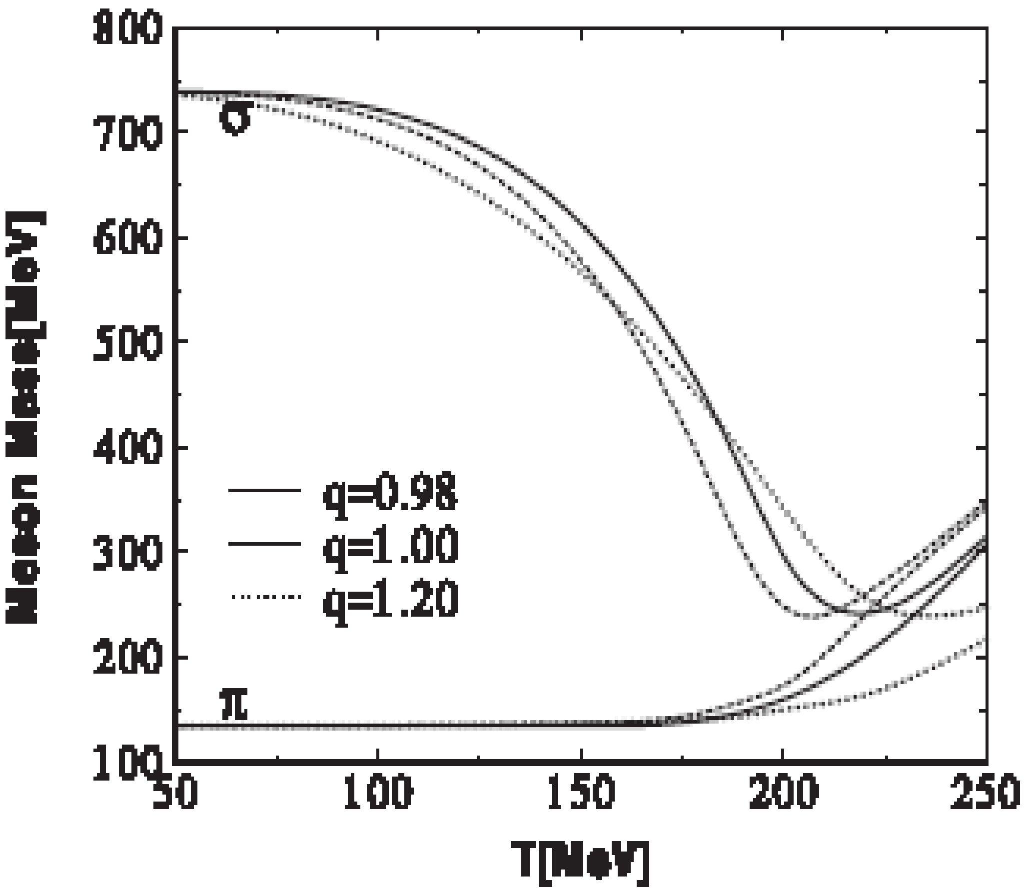


Figure 2. Masses of π and σ mesons as functions of the temperature for different values of the nonextensive parameter q ($q = 1$ corresponds to BG statistics).

Results-chiral

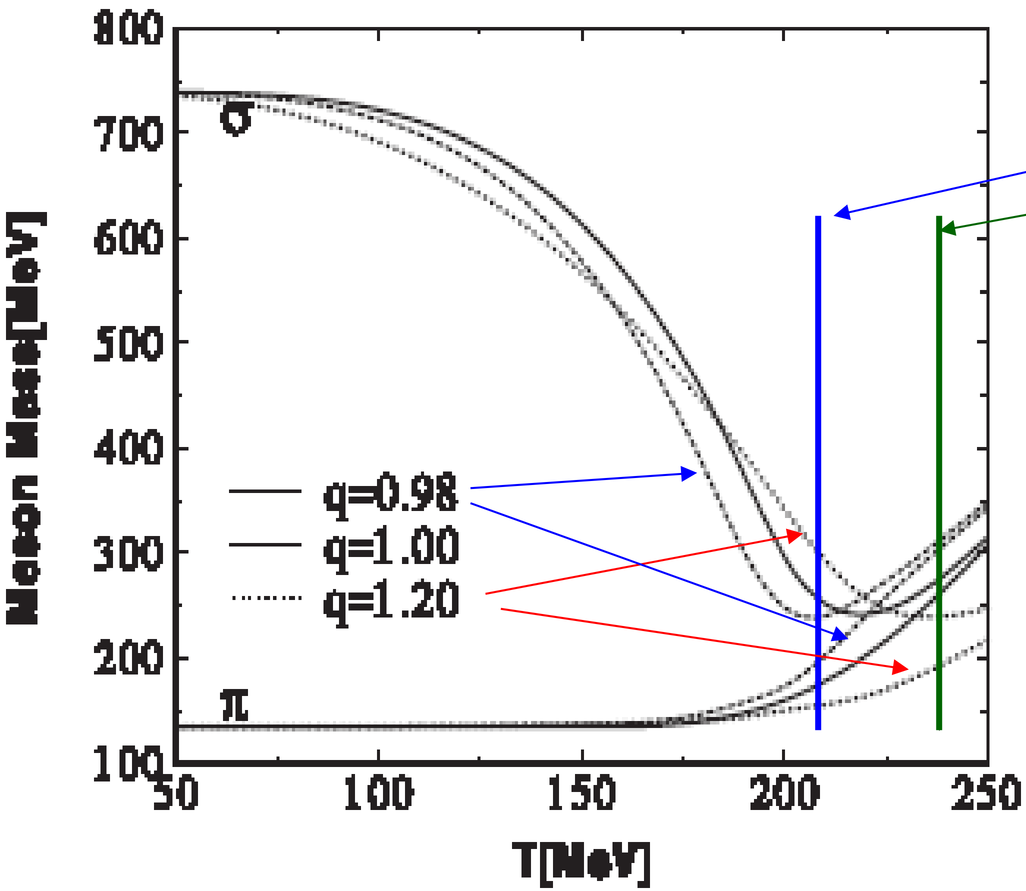


Figure 2. Masses of π and σ mesons as functions of the nonextensive parameter q ($q = 1$ corresponds to BG statis

(*) Temperature for which σ mass reaches minimum is smaller for q<1 and larger for q>1

(by amount ~|q-1|).

(*) Final values of masses is larger for q<1 and smaller for q>1 (by amount ~|q-1|).

(*) Fluctuations (q>1) dilute the region where the chiral phase transition takes place.

(*) Correlations (q<1) only shift the condensates, quark masses and and meson masses towards smaller temperatures.

(*) They refer to quarks, not hadrons as in q-Walecka model (where only q>1, i.e., fluctuations were considered with similar effect).

Results-spinodial

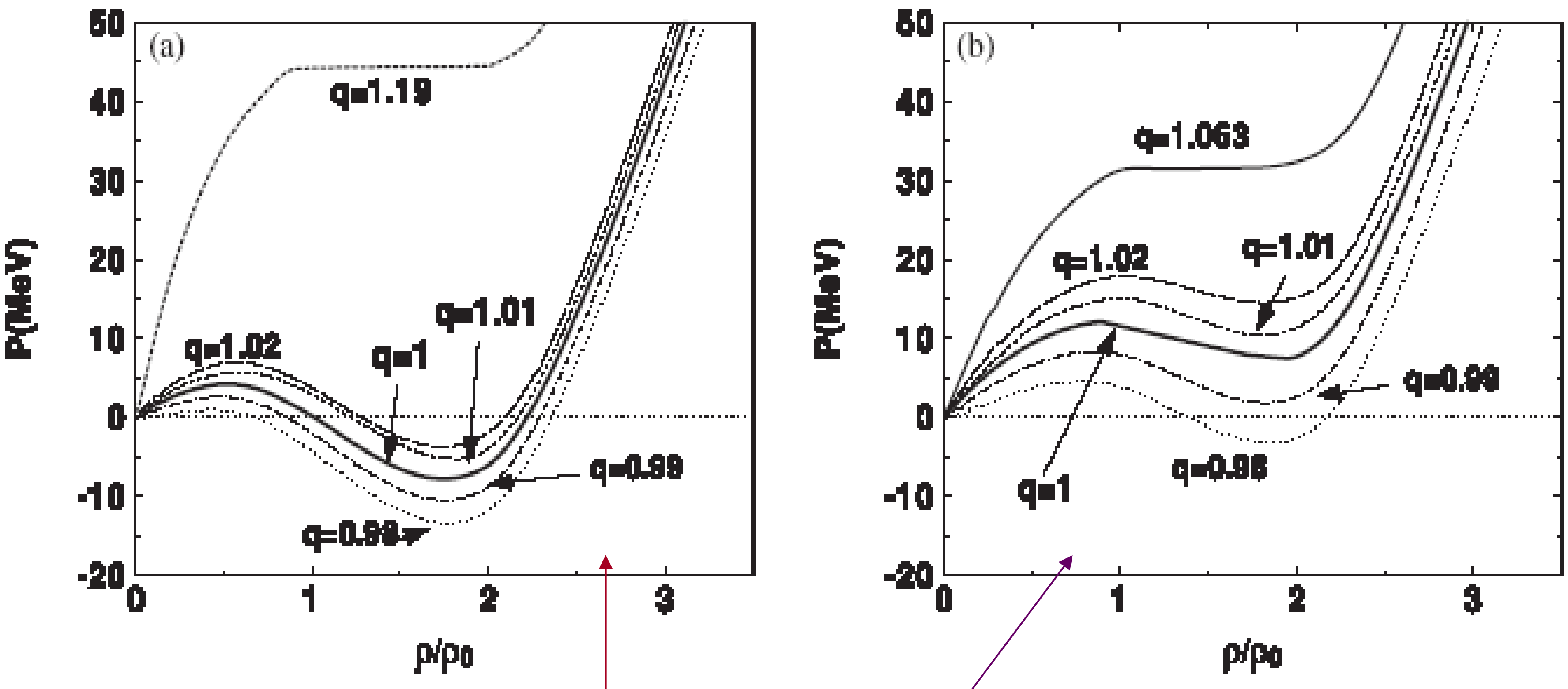


Figure 5. The pressure calculated for different values of the nonextensivity parameter q for temperatures $T = 30$ MeV (a) and $T = 50$ MeV (b) as a function of the compression ρ/ρ_0. The curves for q for which the temperature considered is the critical temperature are also shown, they correspond to $q = 1.19$ for $T = 30$ MeV and $q = 1.063$ for $T = 50$ MeV.

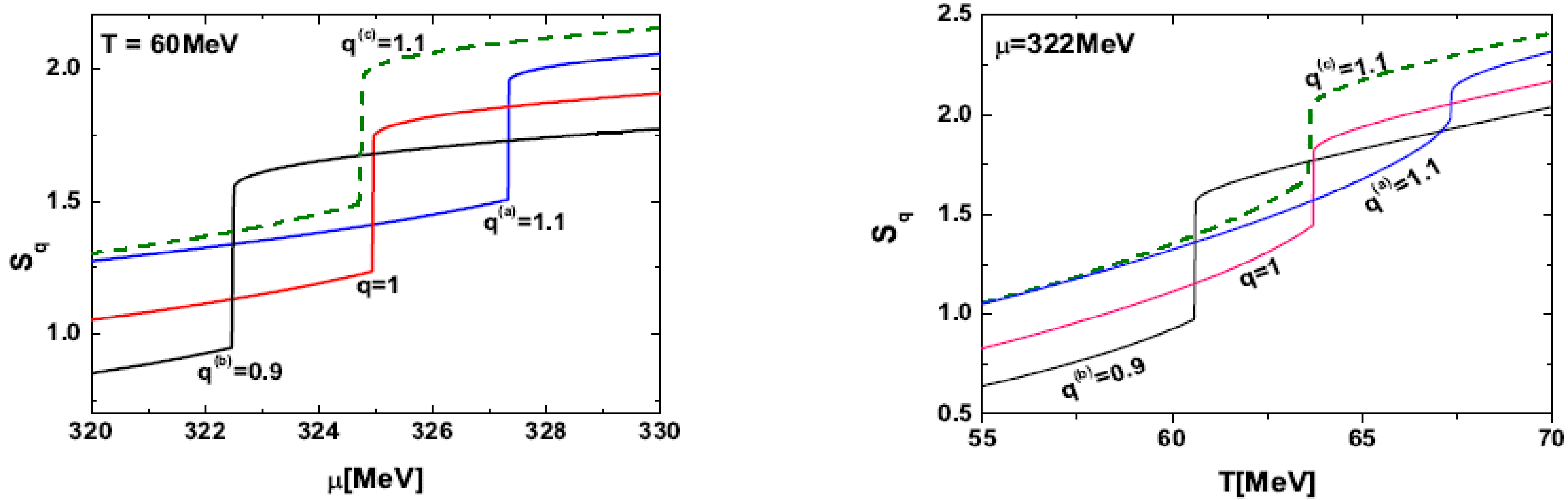


Fig. 3. (Color online) Entropy as a function of the chemical potential (left panel) and temperature (right panel) calculated for different values of q corresponding to different realizations of the q-NJL model and compared with the BG case of $q = 1$.

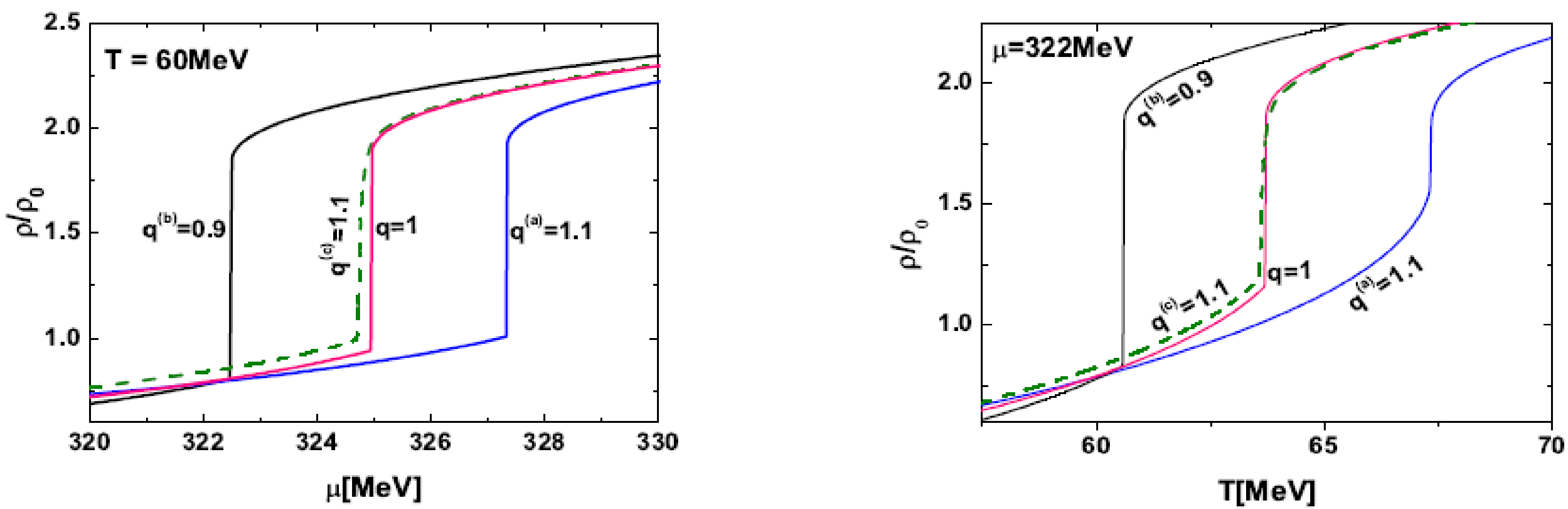


Fig. 4. (Color online) Compression ρ/ρ_0 as a function of the chemical potential (left panel) and the pressure (right panel) for different values of q corresponding to different realizations of the q-NJL model and compared with the BG case of $q = 1$.

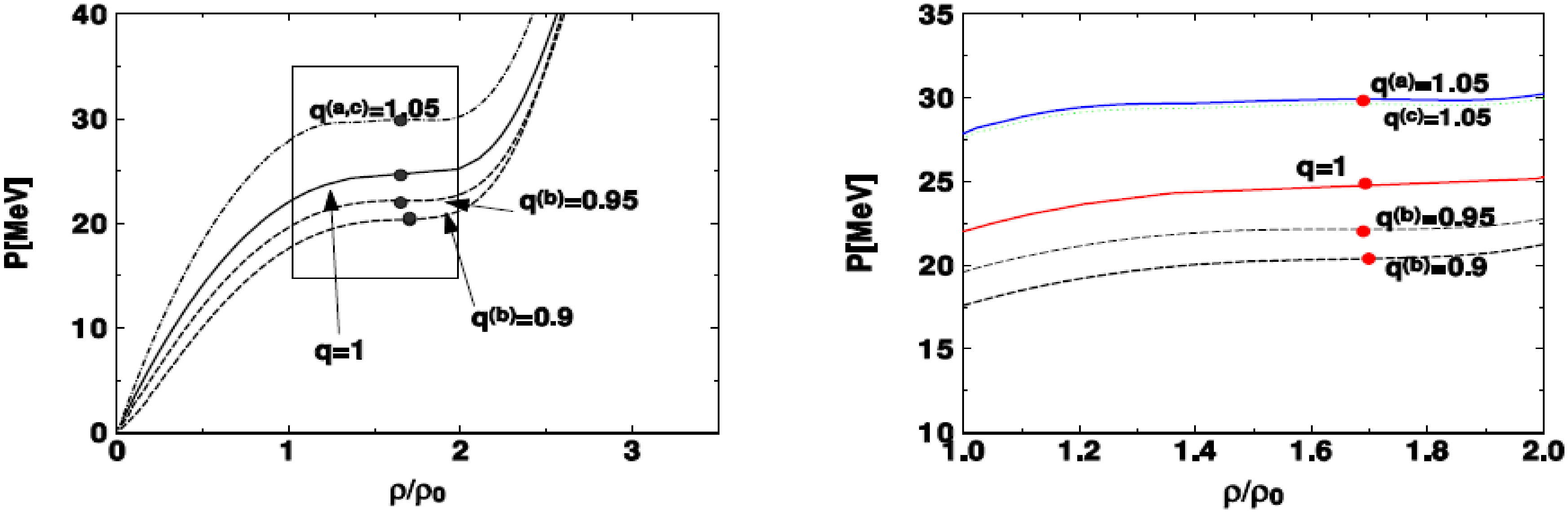


Fig. 6. (Color online) The pressure at critical temperature T_{cr} as a function of compression ρ/ρ_0 calculated for different values of q corresponding to different realizations of the q-NJL model and compared with the BG case of $q = 1$ (the area marked on the upper panel is shown in detail in the lower panel). The dots indicate the positions of the inflection points for which the first derivative of pressure by compression vanishes.

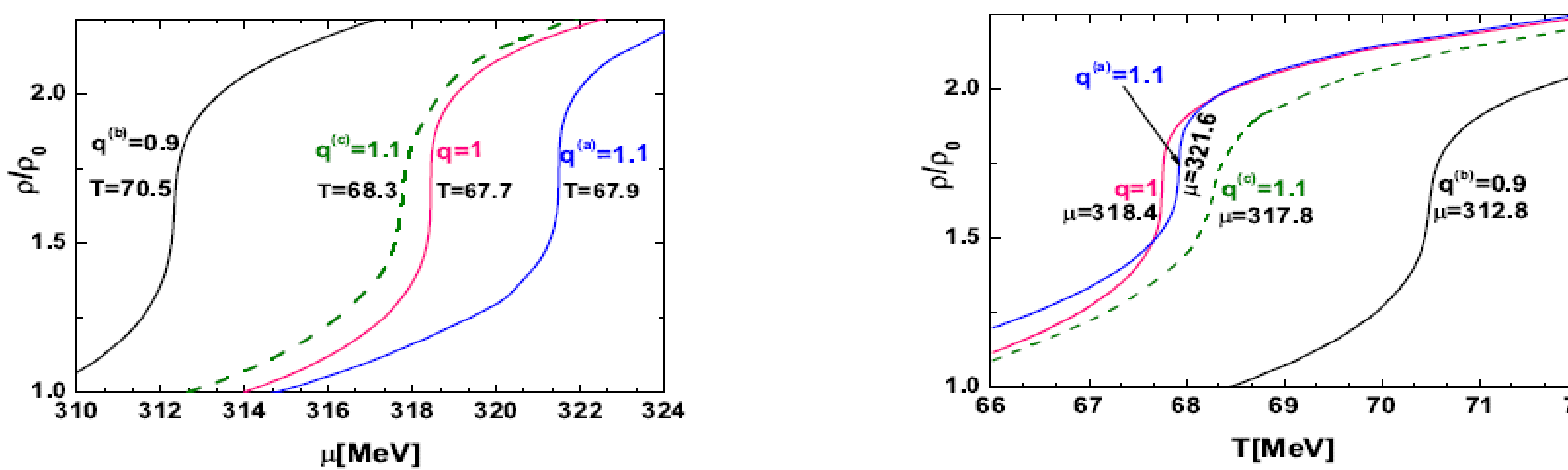


Fig. 7. (Color online) Compression ρ/ρ_0 as a function of chemical potential (left panel) and temperature (right panel) calculated in the vicinity of the phase transition for different values of q corresponding to different realizations of the q-NJL model and compared with the BG case of $q = 1$.

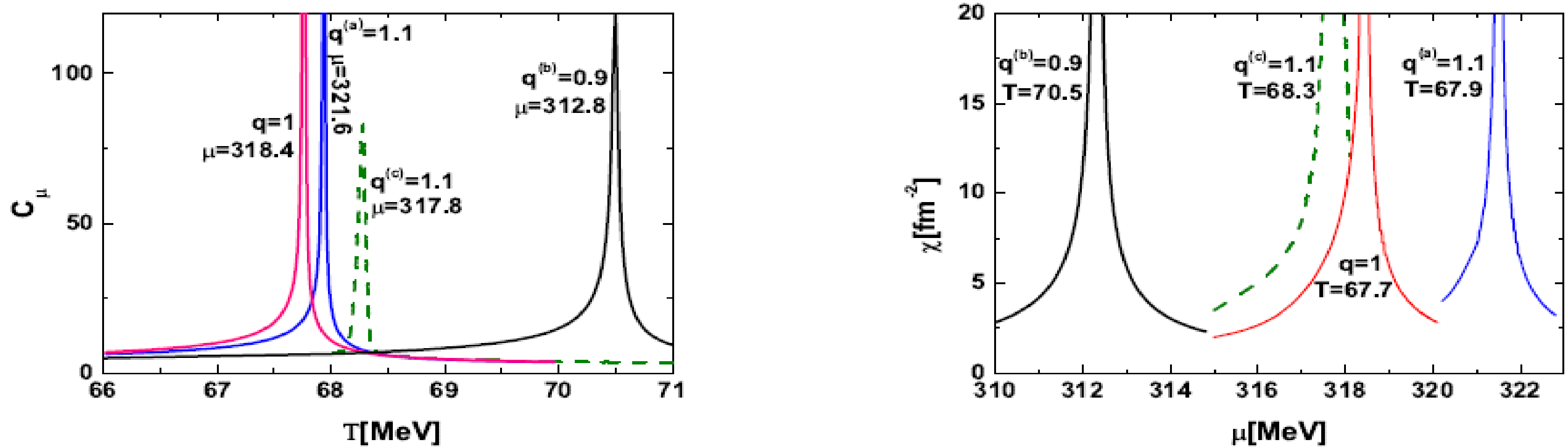


Fig. 8. (Color online) Left panel: Heat capacity as a function of temperature calculated in the vicinity of the phase transition point for different values of q corresponding to different realizations of the q-NJL model and compared with the BG case of $q = 1$. The respective values of chemical potential used are indicated. Right panel: Susceptibility as a function of chemical potential calculated in the vicinity of the phase transition point, and for different values of q corresponding to different realizations of the q-NJL model and compared with the BG case of $q = 1$. The respective values of the temperatures are indicated.

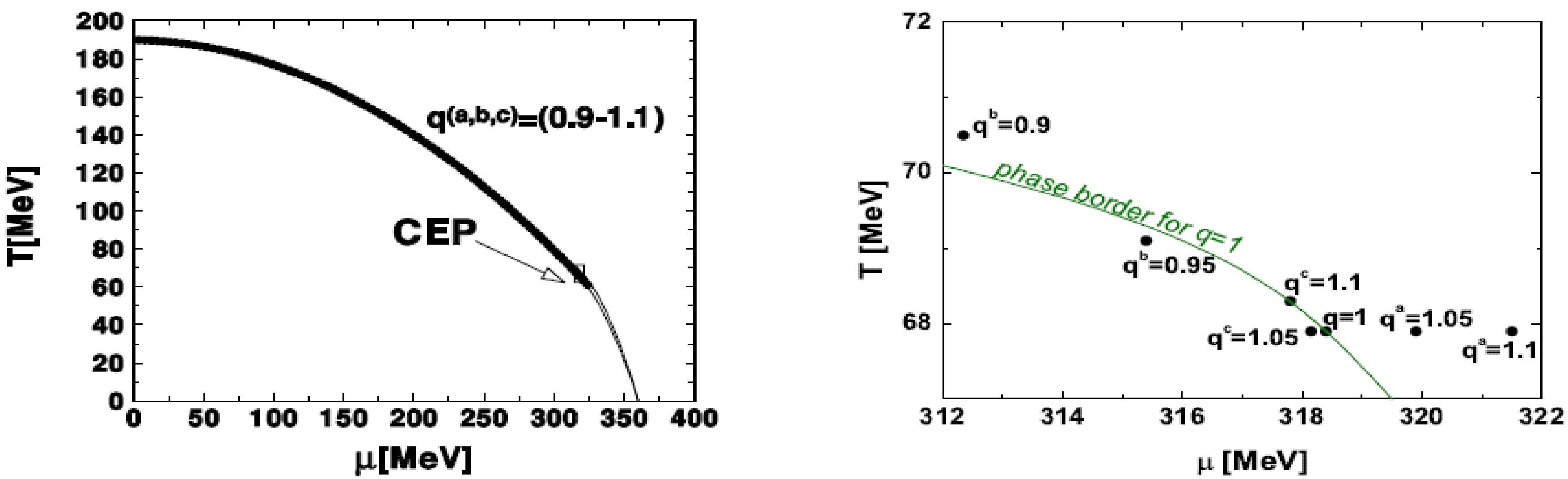
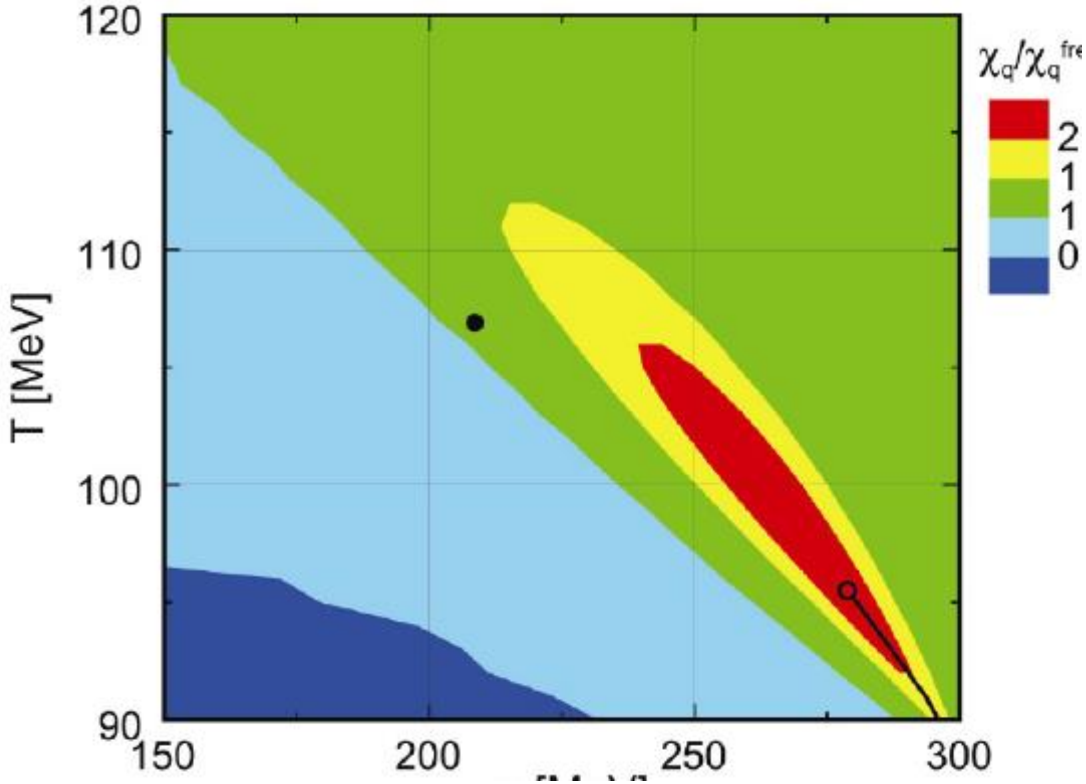


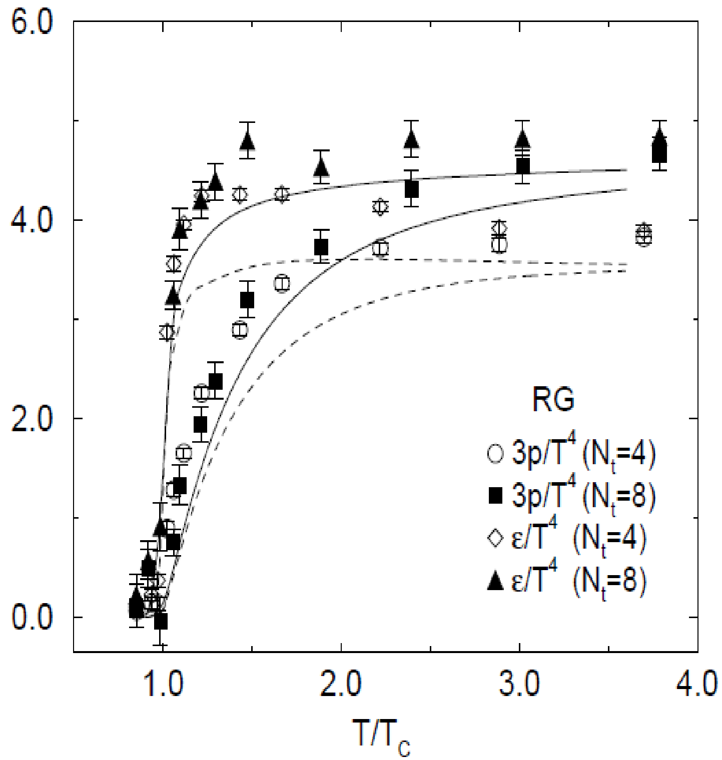
Fig. 9. (Color online) Phase diagram in the q-NJL model in the $T - \mu$ plane for different values of q corresponding to different realizations of the q-NJL model and compared with the BG case of $q = 1$. The left panel shows a general view where, for the scale used, all curves essentially coincide. The right panel shows an enlarged region near the critical point (CEP).

Hatta Ikeda PRD 67 (2003)



EOS in Critical Region

Lattice Calculation – QCD calculations



CP-Pacs Coll. 1999

The pressure of hot QCD up to $g^6 \ln(1/g)$

K. Kajantie,[1] M. Laine,[2] K. Rummukainen,[1] and Y. Schröder[3]

[1] *Department of Physics, P.O.Box 64, FIN-00014 University of Helsinki, Finland*

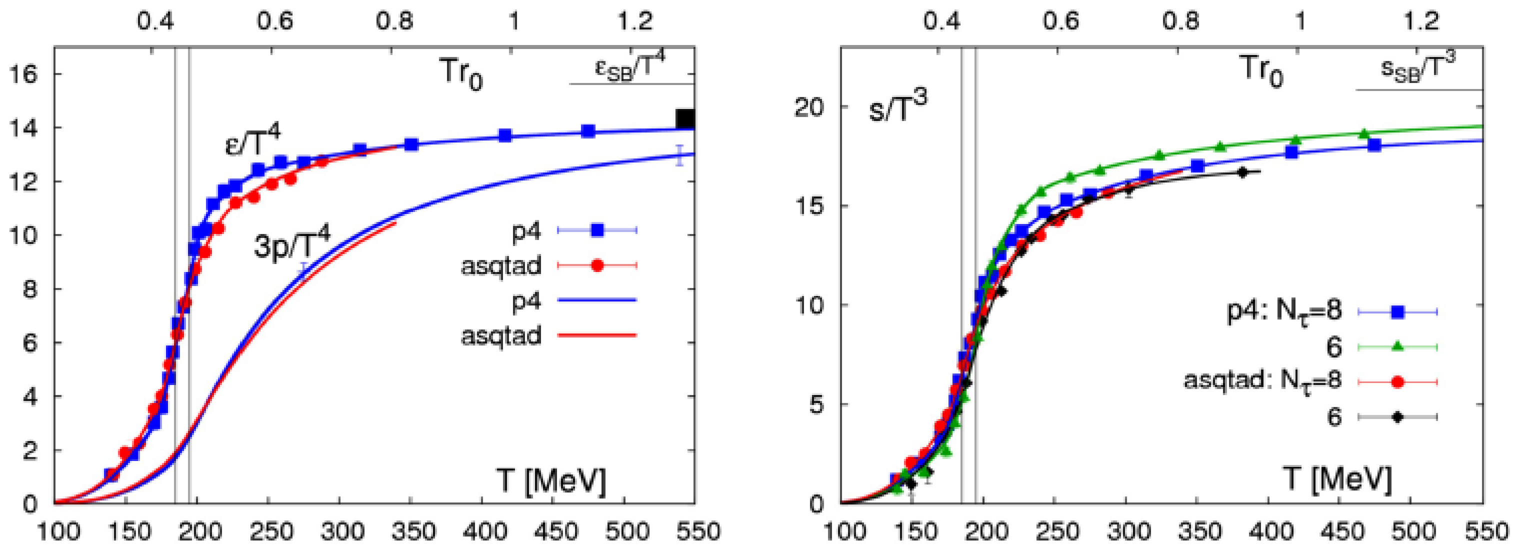
[2] *Theory Division, CERN, CH-1211 Geneva 23, Switzerland*

[3] *Center for Theoretical Physics, MIT, Cambridge, MA 02139, USA*

Abstract

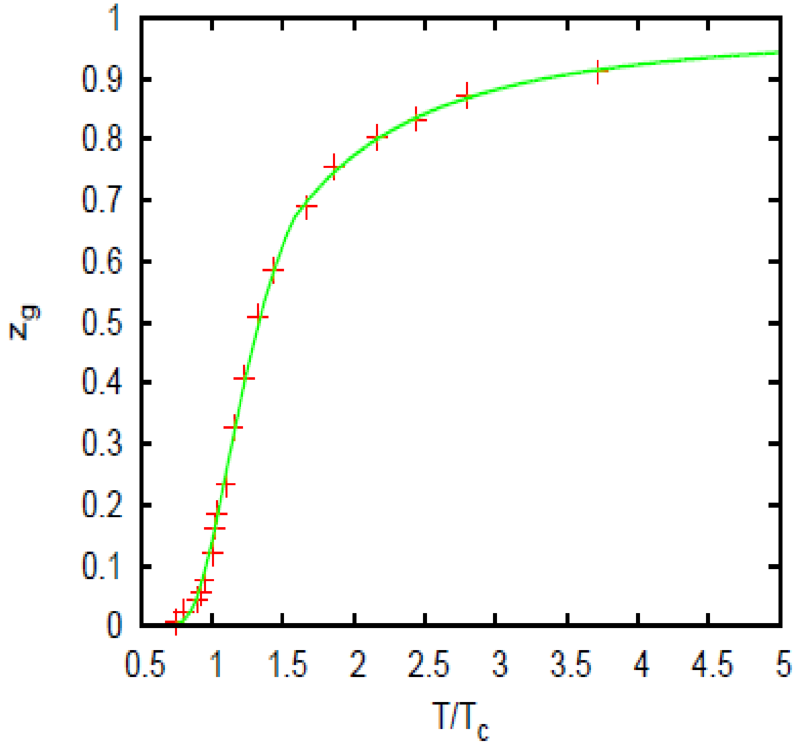
The free energy density, or pressure, of QCD has at high temperatures an expansion in the coupling constant g, known so far up to order g^5. We compute here the last contribution which can be determined perturbatively, $g^6 \ln(1/g)$, by summing together results for the 4-loop vacuum energy densities of two different three-dimensional effective field theories. We also demonstrate that the inclusion of the new perturbative $g^6 \ln(1/g)$ terms, once they are summed together with the so far unknown perturbative and non-perturbative g^6 terms, could potentially extend the applicability of the coupling constant series down to surprisingly low temperatures.

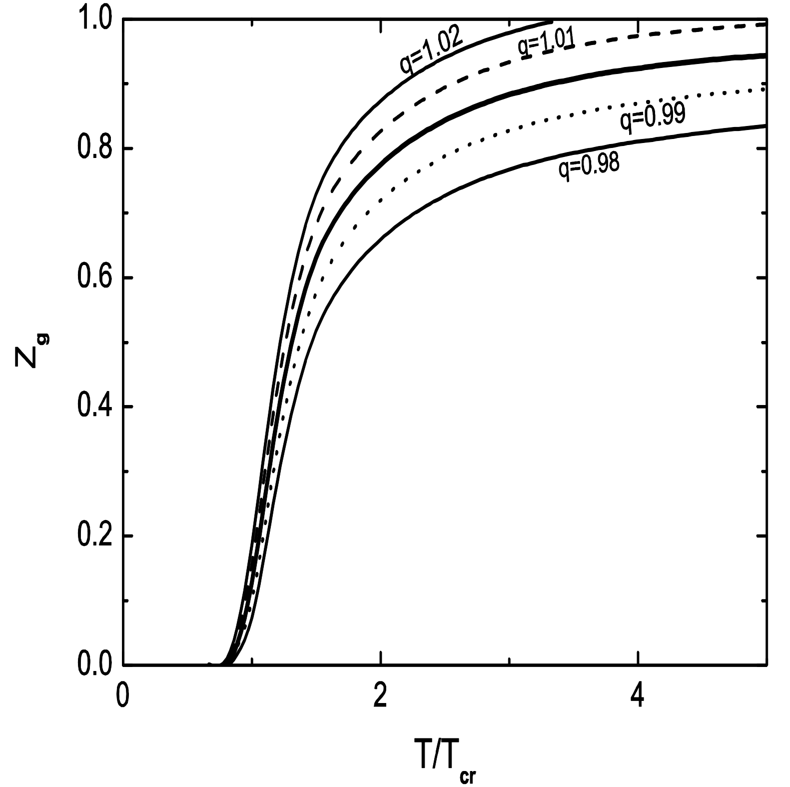
Lattice Calculations
Bazavov et al. PRD 90 (2009)



Thermodynamics with effective fugacities z(t) which capture all interaction

$$f_{eq}^{g/q} = \frac{1}{\left[z_{g/q}^{-1} \exp(\beta p) \mp 1\right]}$$





Summary

We have investigated two possible scenarios corresponding to $q<1$ and $g>1$ which corespond to differenntialt physical interpretation (correlation or fluctuations – 2 different envirovments).

For $q<1$ we observe decreasing of pressure which reaches negative value for a broad range of temperatures.

Lower Entropy - correlated particles in equilibrium.

The $q>1$ we observe the increasing of critical barion chemical potential and therefore above the critical line we have quark gas and not mixed phase.

For a given density we obtain bigger pressure,

Higher Entropy out of equilibrium - decay into hadrons

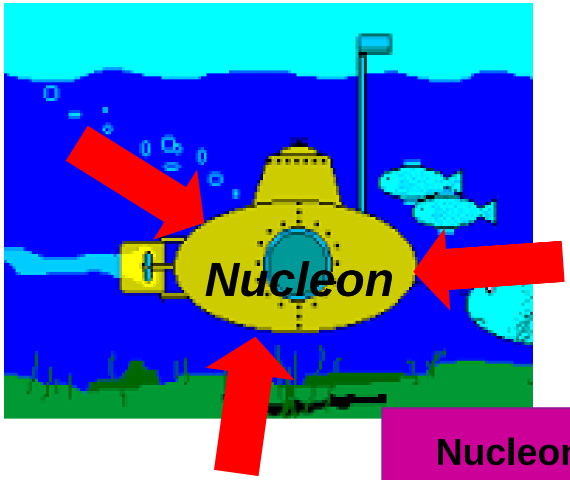
- stiffer EOS like in Walecka model

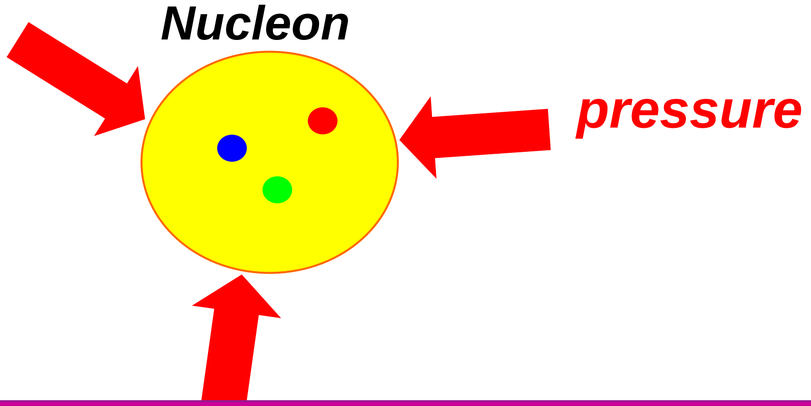
Nonextensive example – Dynamical Bag Model

Finite volume effect in compressed medium

Nucleon inside saturated NM

Compressed inside Neutron Star or in H I collision

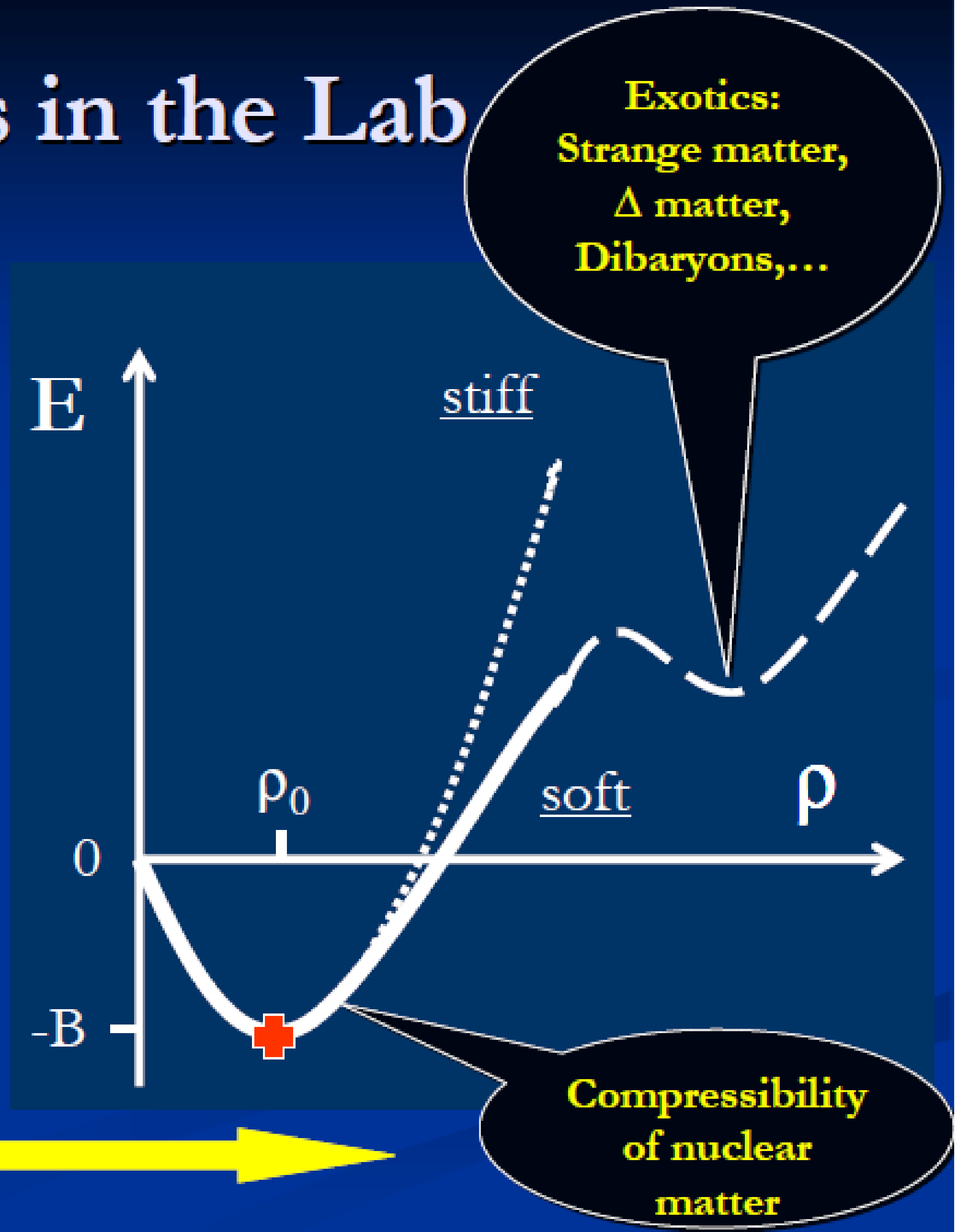




Nucleon properties inside compressed nuclear matter J. Phys. G: Nucl. Part. Phys. 42 (2015) 045109. ***arXiv:1406.3832***

Hadrons in the Lab

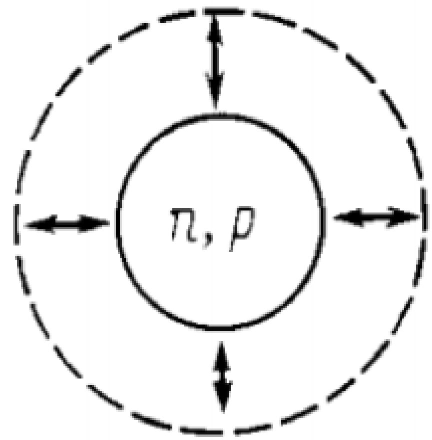
- Equation of State for Nuclear Matter:
  - Monopole excitation of nuclei: **„Breathing Mode“**



Vibrations of giant monopole resonances

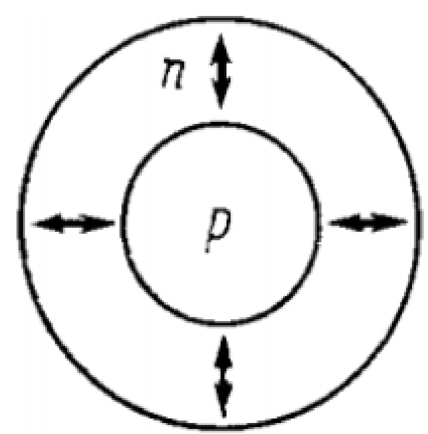
Electric L=0

E0, T=0



Electric L=0

Ξ0,T=1



(In) Compressibility from GMR

$$K_A = K_{vol} + K_{surf} A^{-1/3} + K_{curv} A^{-2/3} + (K_{sym} + K_{ss} A^{-1/3}) \left(\frac{N-Z}{A} \right)^2 + K_{Coul} \frac{Z^2}{A^{4/3}} + \cdots \ ,$$

where K_A is defined by

$$K_A = \frac{m}{\hbar^2} E_{GMR}^2 \langle r^2 \rangle \ .$$

K~200MeV !!

Monopole giant resonances and nuclear compressibility in relativistic mean field theory

Vretener at al.

Table 2: Constrained GCM energies of isoscalar monopole states. The values of K_{nm} and the excitation energies are in MeV.

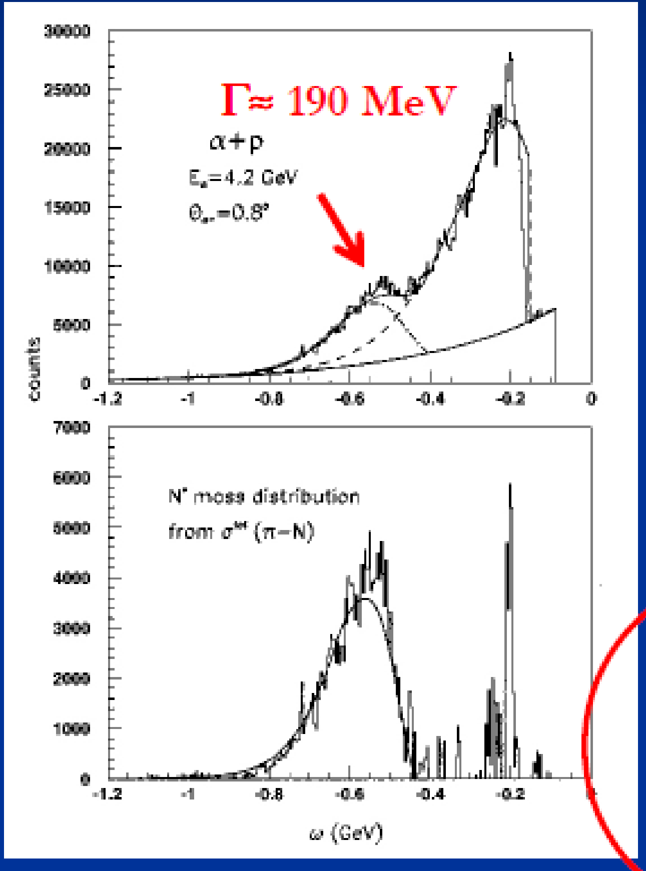
		K_{nm}	^{16}O	^{40}Ca	^{48}Ca	^{90}Zr	^{208}Pb
1	NL-1	211.7	20.2	16.6	15.9	14.1	11.0
2	NL-1 [5]	211.7	20.6	17.1		14.7	11.7
3	NL-3	271.8	22.6	19.6	18.9	16.9	13.0
4	NL-SH	355.0	25.0	22.0	21.5	19.5	15.0
5	NL-2	399.2	27.1	24.4	23.0	21.9	16.6

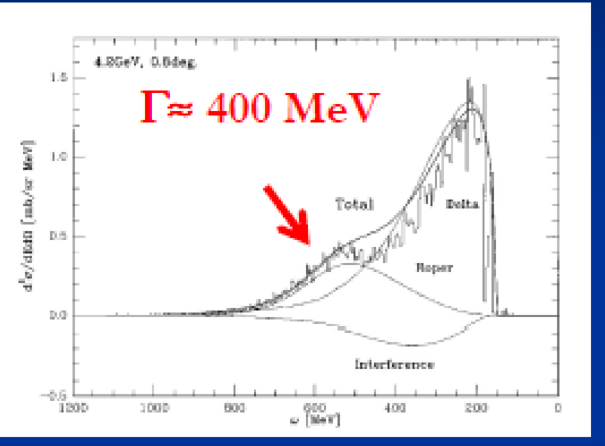
Table 3: Constrained GCM energies of isovector monopole states. The values of a_{sym} and the excitation energies are in MeV.

	a_{sym}	^{40}Ca	^{90}Zr	^{208}Pb
NL-1	43.5	29.0	26..3	16.5
NL-3	37.4	28.6	27.4	18.0
NL-SH	36.1	28.5	27.9	18.4
NL-2	43.9	30.3	28.8	16.9
exp. [21]		31.1±2.2	28.5±2.6	26.0±3.0

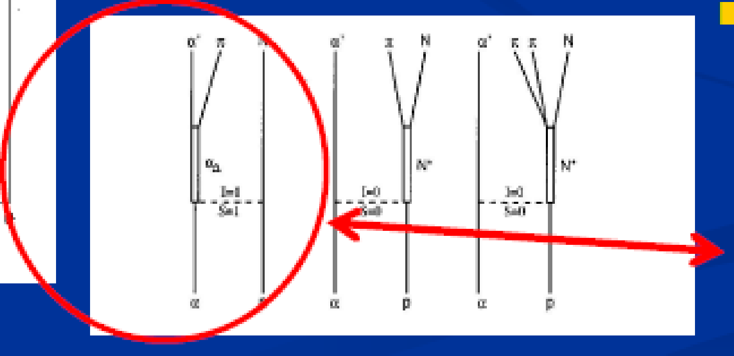
New Generation of Experiments:

1. $\alpha\, p \rightarrow \alpha\, X$ (Saclay)





Hirenzaki et al., PRC 53, 277 (1996)



- scalar-isoscalar probe α

  however:

- interfering background from projectile excitation

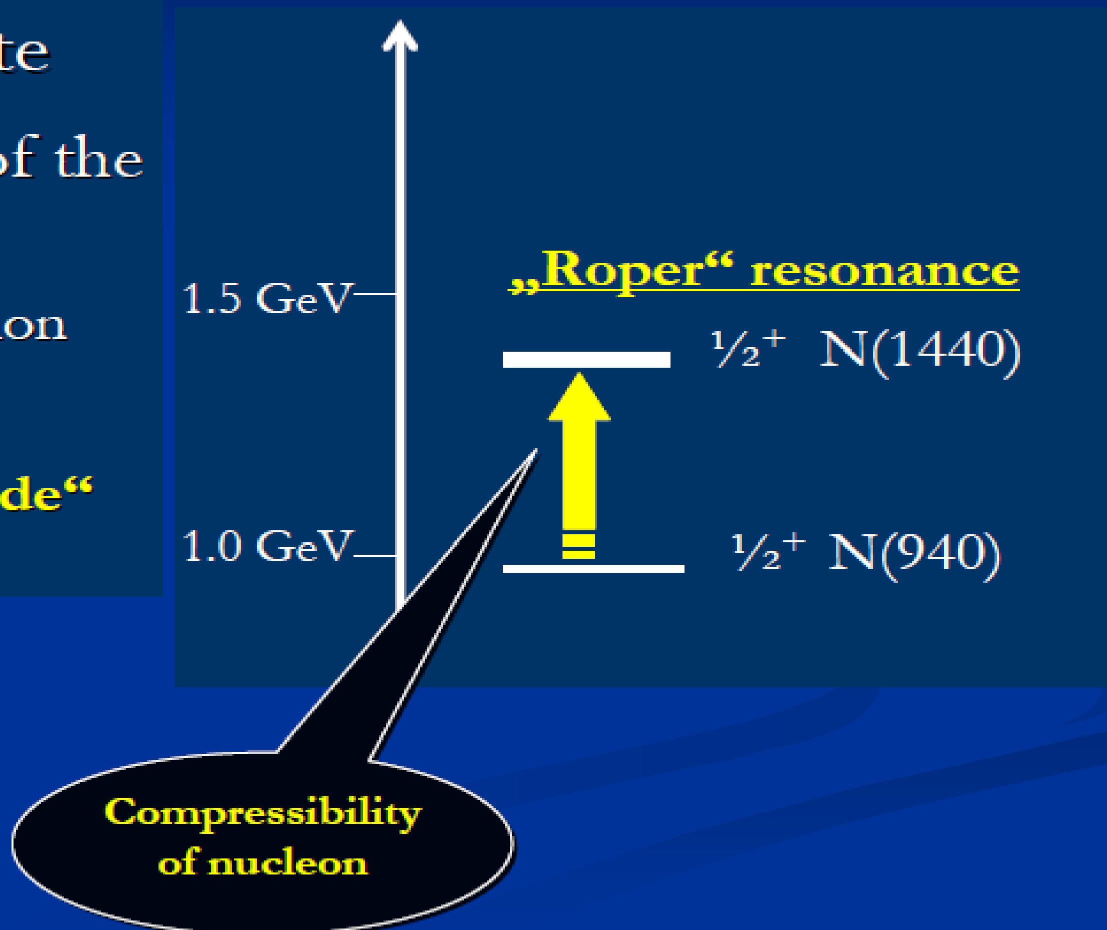
Morsch et al., PRL 69, 1336 (1992) and PRC 61, 024002 (1999)

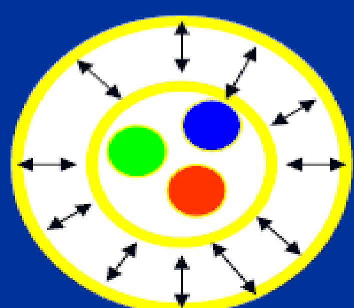
Hadrons in the Lab

- Equation of State

  Compressibility of the nucleon:

  - Monopole excitation of the nucleon: **„Breathing Mode“**





Quark sum rules $K_N^{-1} \Rightarrow M\, E_x^2 \langle r_N^2 \rangle$ (Morsch PRL (1992) and later works)

So far excluded volume effects were calculated for a constant nucleon mass and in constant radius.

To improve it let us introduce enthalpy in a Bag Model of nucleon.

- **Enthalpy** is a measure of the total energy of a thermodynamic system. It includes the system's internal energy and thermodynamic potential (a state function), as well as its volume Ω and pressure p_H (the energy required to "make room for it" by displacing its environment, which is an extensive quantity).

$H_A = E_A + p_H \Omega_A$ Nuclear Enthalpy (1)

$H_N = M_{pr} + p_H \Omega_N$ Nucleon Enthalpy (2)

Our version of Hugenholz-Van Hove relation for finite nucleons in NM

$$H_A^T/A = \varepsilon_A - (\partial M_A/\partial \Omega_{A-})_A/\varrho = \varepsilon_A + p_H/\varrho = E_F$$

Enthalpy vs Hugenholz - van Hove relation with chemical potential

$$\mu \doteq (\partial M_A/\partial A)_{\Omega_A} \equiv (\partial H_A/\partial A)_{p_H} = \varepsilon_A + \frac{p_H}{\varrho} = H_A/A$$

$$E_F \doteq P_N^0(P_F) = (\partial M_A/\partial A)_{\Omega_A} = \varepsilon_A + p_H/\varrho = \mu$$

In the NM in equilibrium $p_H = 0$ therefore $H_A = E_A$. Dividing H_A by A we obtain the following relation between single particle enthalpy h_A and $\varepsilon_A = E_A/A$,

$$h_A = \varepsilon_A + p_H/\varrho. \qquad (1a)$$

Please note that the same equation fulfills a Fermi energy $E_F \equiv P_N^0(p_F) = \varepsilon_A + p_H/\varrho$ of nucleon with a Fermi momentum p_F; well-known as the HvH [9] relation, also proven in the self-consistent RMF approach [10]. It turns out that definitions of the Fermi energy or a single particle enthalpy have the same energy balance.

We will argue that the enthalpy rather than the rest energy should be used in the momentum distribution sum rules (MSR) in NM and in a nucleon.

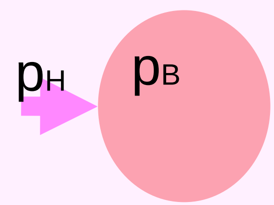
Bag Model in Compress Medium

$p_H=0$

$$E^0_{Bag}(R) = \frac{3\omega_0 - Z_0}{R} + \frac{4\pi}{3} B(\varrho_0) R^3 \sim 1/R,$$

$$p_H = p_B = \frac{3\omega_0 - Z_0}{4\pi R^4} - B(\varrho) \rightarrow (B(\varrho)+p_H)R^4 = const$$

$$R = \left[\frac{3\omega_0 - Z_0}{4\pi(B(\varrho)+p_H)}\right]^{1/4},$$



A

$$M_{pr} = E_{Bag} = 4\pi R^3\left[\frac{4}{3}(B+p_H) - \frac{p_H}{3}\right] = E^0_{Bag}\frac{R_0}{R} - p_H\Omega_N.$$

B

$$H_N = E^0_{Bag}\frac{R_0}{R} \sim 1/R.$$

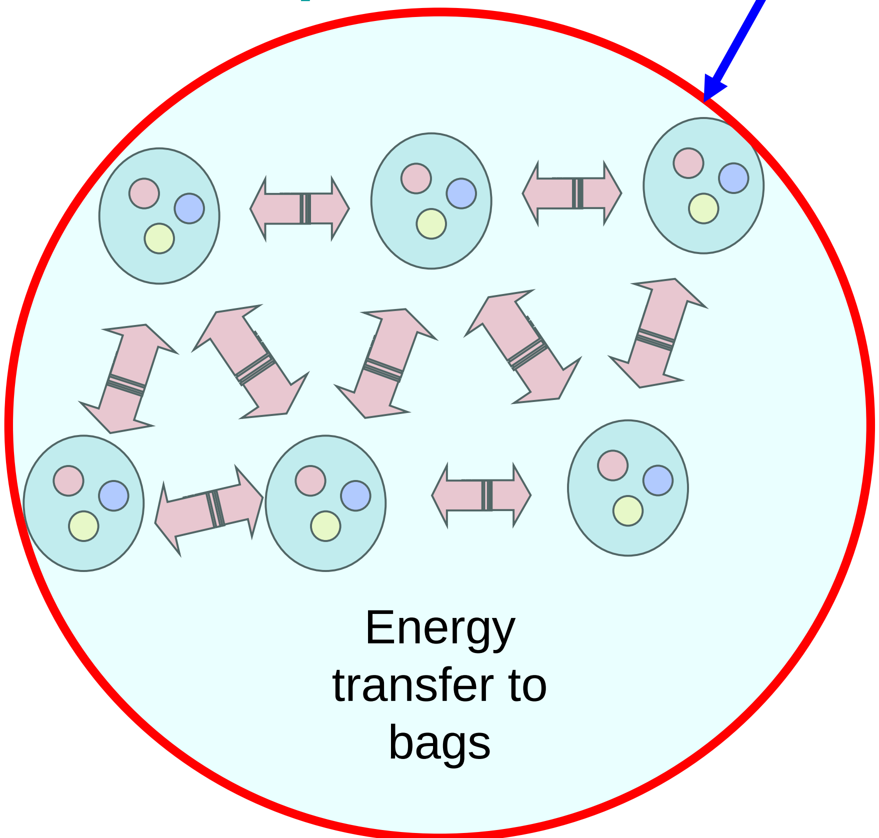
Two Scenarios

affecting nuclear compressibility K^{-1}

- **Constant Mass**

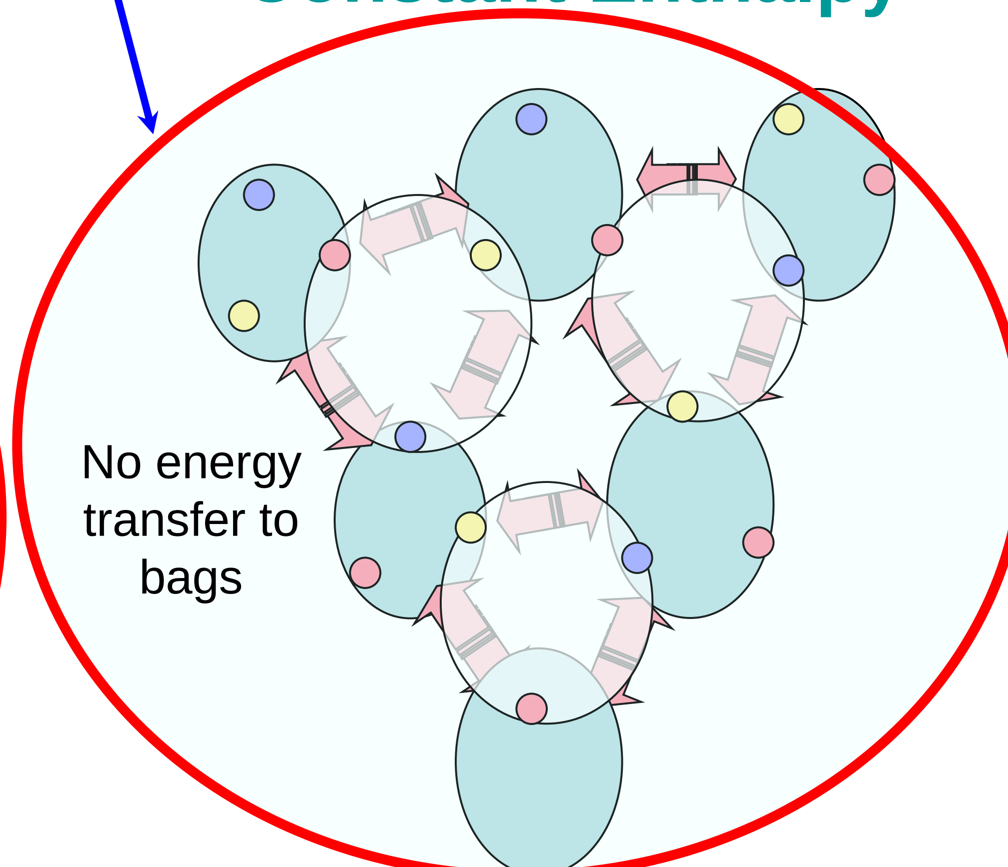
= Increasing Enthalpy

1/R



- **Constant Volume**

= Constant Enthalpy



Thermodynamical Consistency

$$H_A^T/A = \varepsilon_A - (\partial M_A/\partial \Omega_{A-})_A/\varrho = \varepsilon_A + p_H/\varrho = E_F$$

$$M_{pr}(\varrho) = M_N - p_H(\varrho)\Omega_N$$

$$p_H(\varrho) = \varrho^2 \varepsilon'_A(\varrho)/(1-\varrho\Omega_N). \quad = \rho(E_F - \varepsilon_A)$$

$$\delta \mathbf{p_H} / \delta\rho = \mathbf{E_F} = \mu$$

Nuclear compressibilty and two scenarios

A - Constant Nucleon Mass

$$K_N^{-1}|_{M_N,R\to R_0} = -3\Omega_N^2 \frac{\partial[M_N(R_0/R-1)/\Omega_N]}{\partial\Omega_N} = M_N \simeq 940\,\mathtt{MeV}$$

B - Constant Nuclear Radius

$$K_N^{-1}|_{\Omega_N} \to \infty.$$

Semi-experimental Value

Quark sum rules $K_N^{-1} \Rightarrow M\, E_x^2 \langle r_N^2 \rangle$ (Morsch PRL (1992) and later works)

$$K_N^{-1} = (1.4 \pm 0.3)\ \mathrm{GeV}$$

7GeV alfa-p

Same For scenario A (with energy transfer to bag) **and B** (no transfer):

$$K_A^{-1} - K_{A\Omega}^{-1} = 9\varrho^2 \frac{\partial^2(p_H\Omega_N)}{\partial\varrho^2} = 9\varrho^2 \frac{\partial^2}{\partial\varrho^2}\left[\frac{r\varrho}{1-r}\frac{\partial\varepsilon}{\partial\varrho}\right] = \frac{9r\varrho^2}{1-r}\left[f(\varrho)\frac{d\varepsilon}{d\varrho} + \left(\frac{6-5r}{1-r}\right)\frac{d^2\varepsilon}{d\varrho^2} + \dots\right]$$

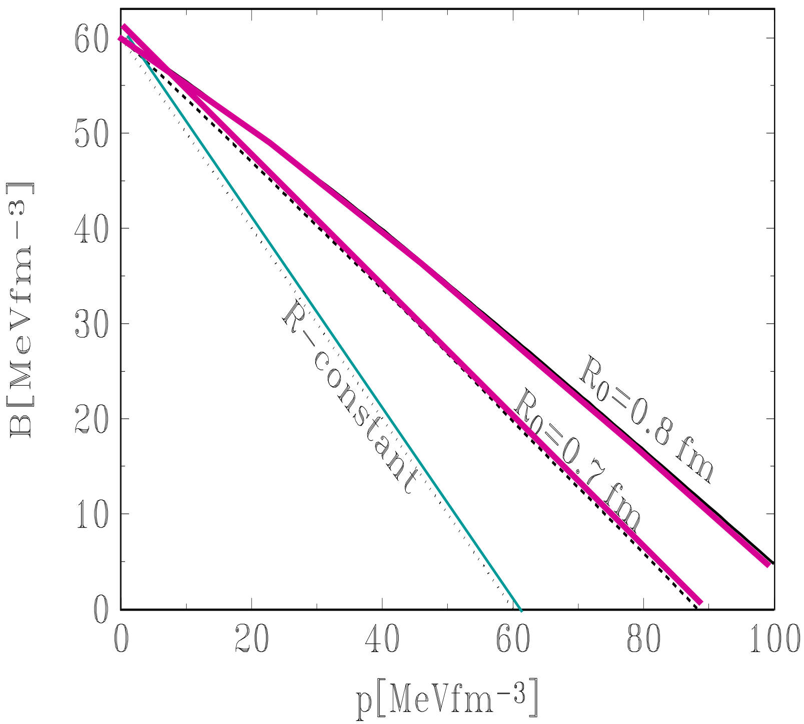
$$K_{A\Omega}^{-1}\,|_{p_H=0} \cong \left[\frac{(1-\varrho\Omega_N)^2}{1+4\varrho\Omega_N(1-\varrho\Omega_N)}\right] K_A^{-1} \simeq \frac{1}{2} K_A^{-1}\,|_{p_H=0}$$

$+ K_N$?

Dynamical Bag

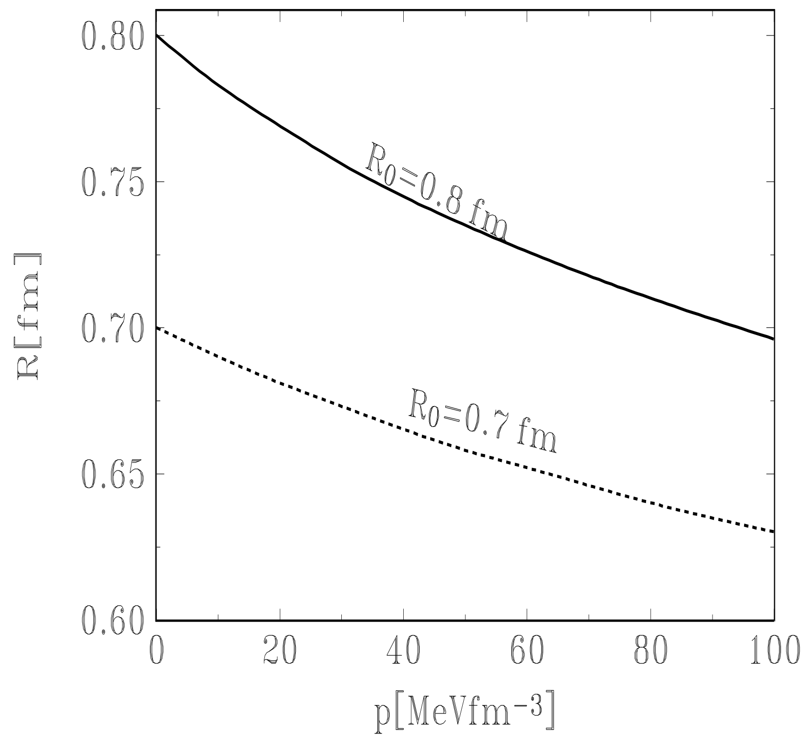
Bag constant in function of nuclear pressure

$$B = B(\varrho_0)(R_0/R)^4 - p.$$



Nucleon radius in compressed NM for a constant nucleon mass

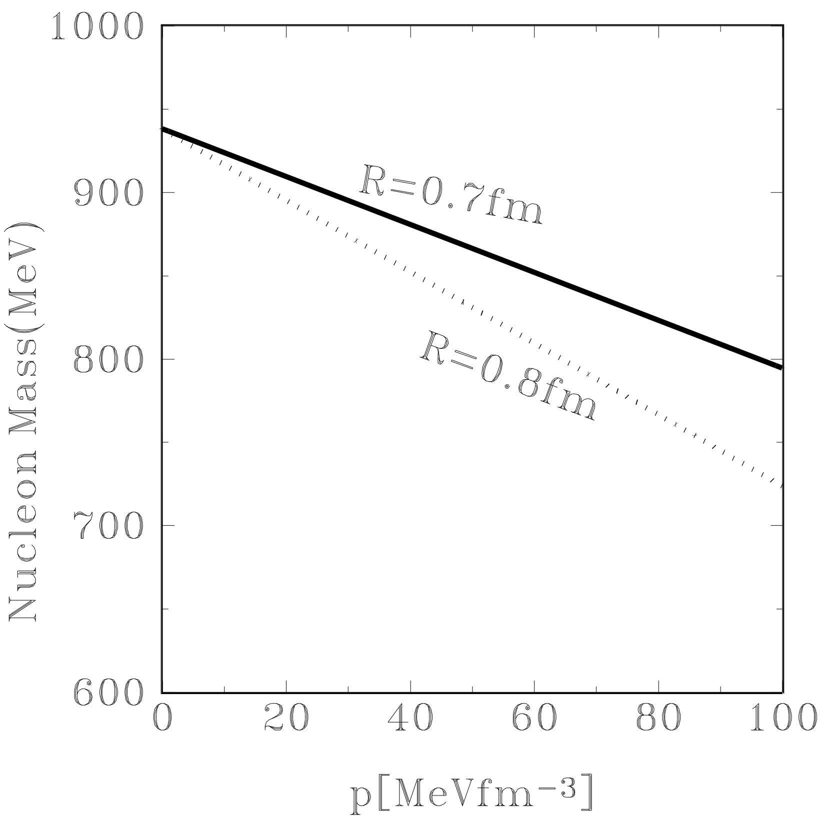
$$M_N R_0/R = M_N + 4/3\pi R^3 p$$



Dynamical Bag - continue

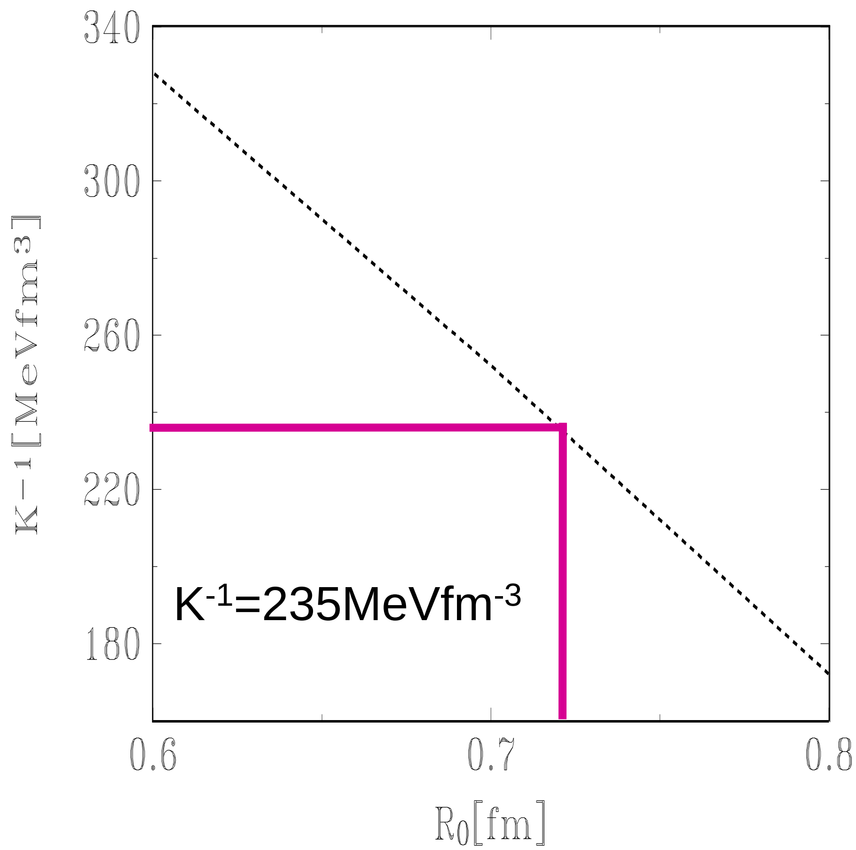
Nucleon Mass for different nucleon radii in compressed NM

$$M_{pr}(\varrho) = M_N - p_H(\varrho)\Omega_N,$$
$$p_H(\varrho) = \varrho^2 \varepsilon_A'(\varrho)/(1-\varrho\Omega_N).$$

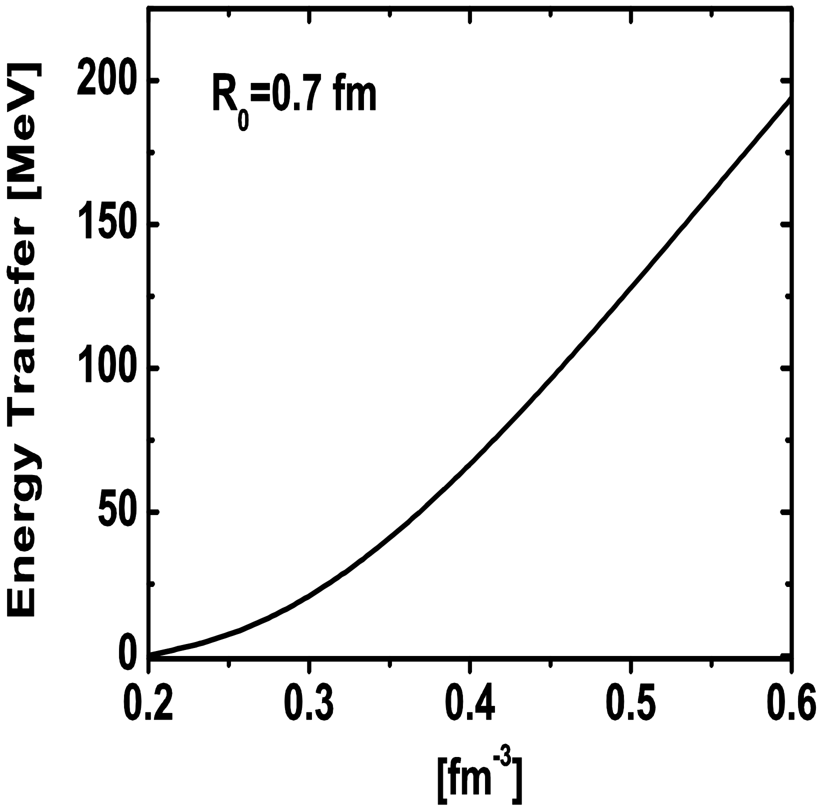


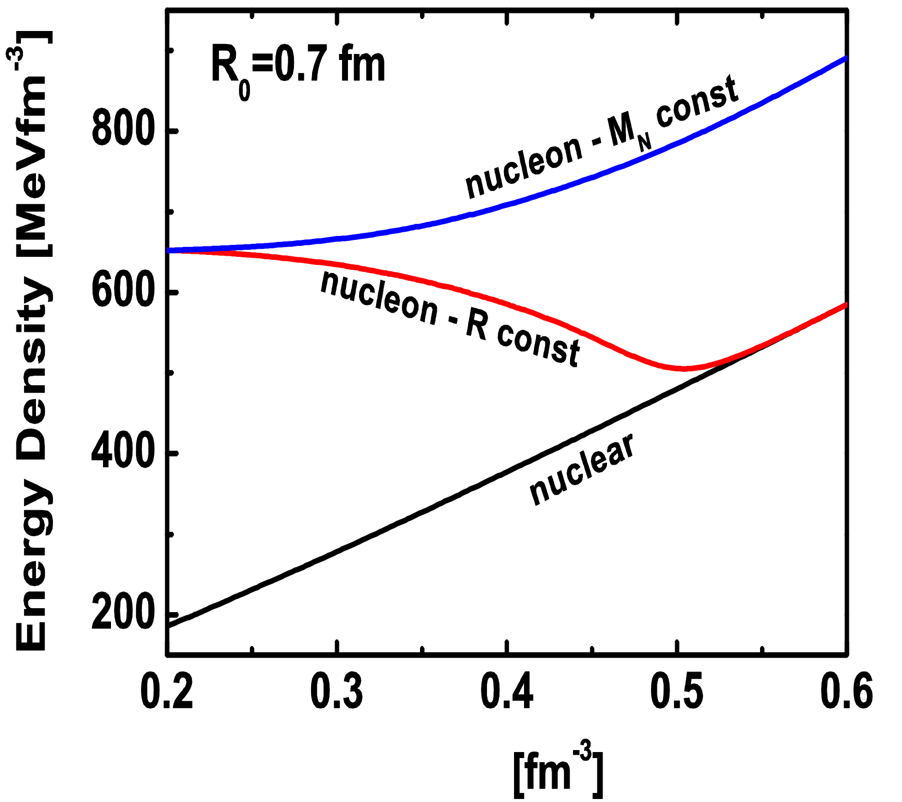
Nuclear compressibility for different constant nucleon radii in compressed NM

$$K^{-1} = 9\partial p_H/\partial \rho$$

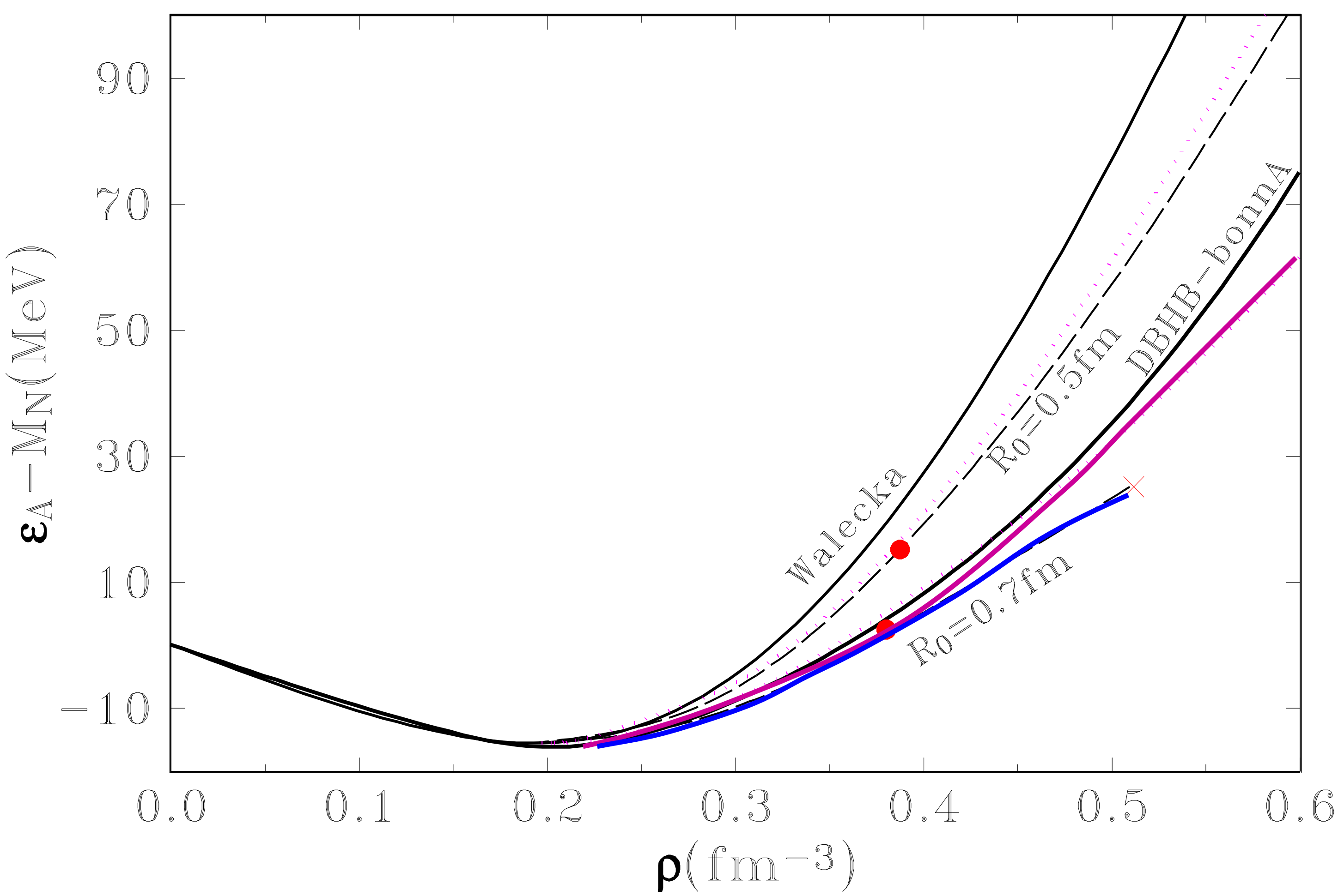


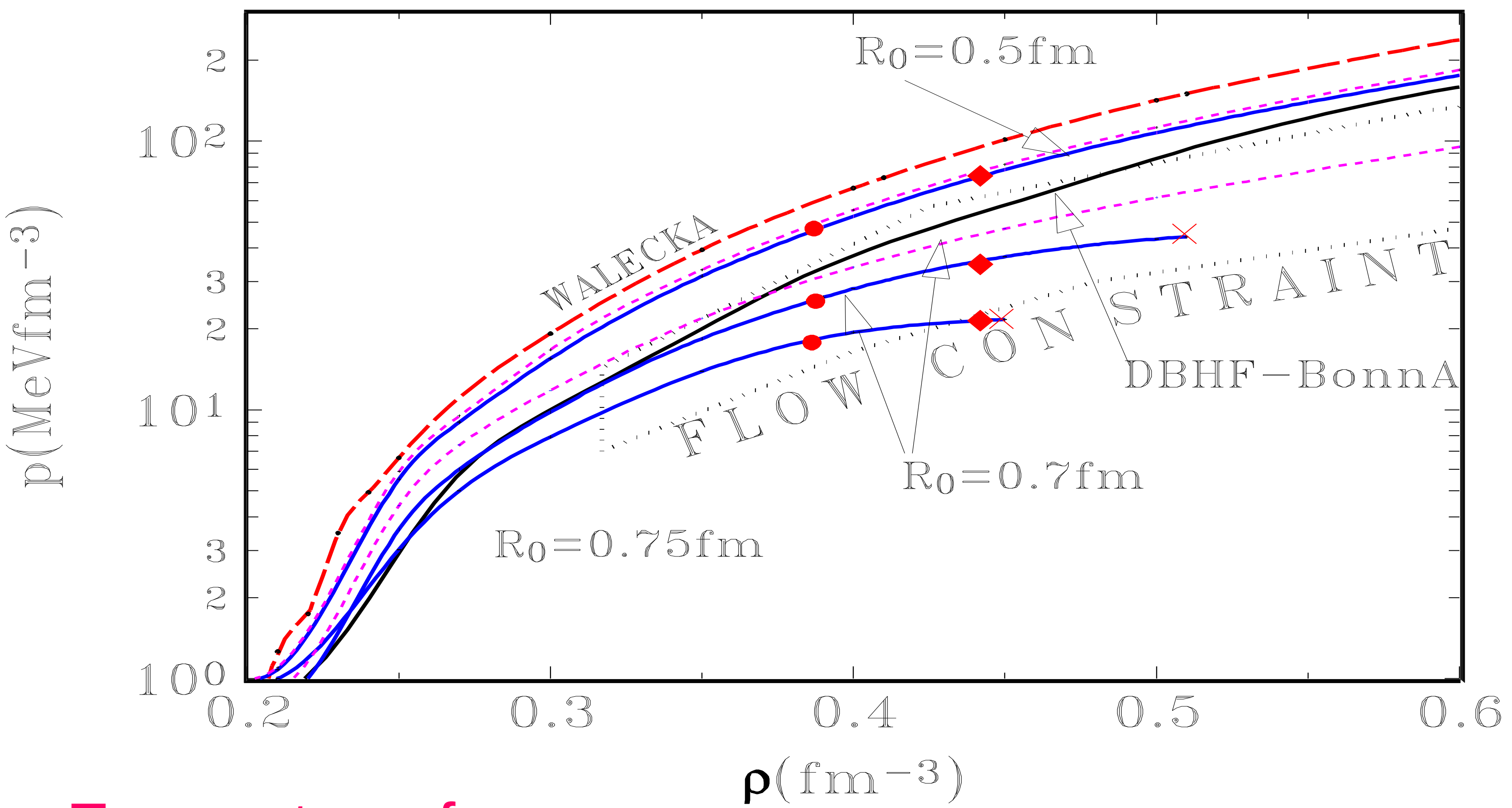
Energy transfer to nucleon





Equation of State





Energy transfer

$$\varrho_{cr}^{B} = \frac{M_N}{\varepsilon_A}\varrho_{cp} = \frac{3M_N}{4\pi\ \varepsilon_B(\varrho_{cr})\ R^3(\varrho_{cr})}.$$

Order of phase transition?

No energy transfer

$$\varrho_{cr}^{A} = \frac{(M_N - p\Omega_N)}{\varepsilon_A}\varrho_{cp} = \frac{M_N}{\varepsilon_A(\varrho_{cr})}\varrho_{cp} - p/\varepsilon_A.$$

Finite Nucleon Volumes - Conclusions

A. Lower compressibility

B. Constant nucleon mass requires increasing enthalpy energy transfer to bag →

STIFFER EOS

C. Constant nucleon volume give the constant enthalpy with decreasing nucleon mass

SOFTER EOS

Similar to Relativistic Mean Field nonlinear corrections

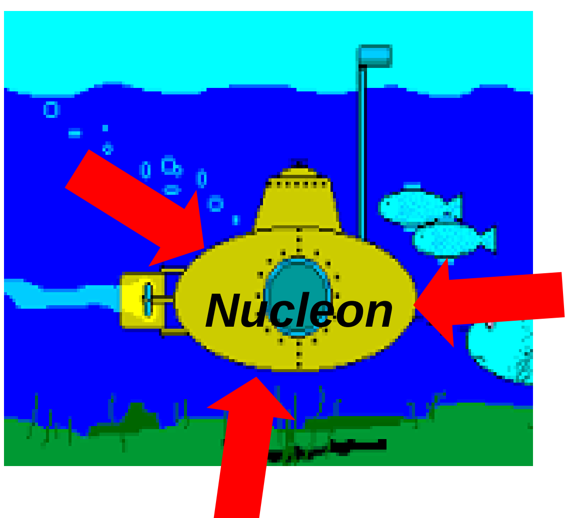
$$U(\sigma) = \frac{1}{2} m_\sigma^2 \sigma^2 + \frac{1}{3} b_2 \sigma^3 + \frac{1}{4} b_3 \sigma^4$$

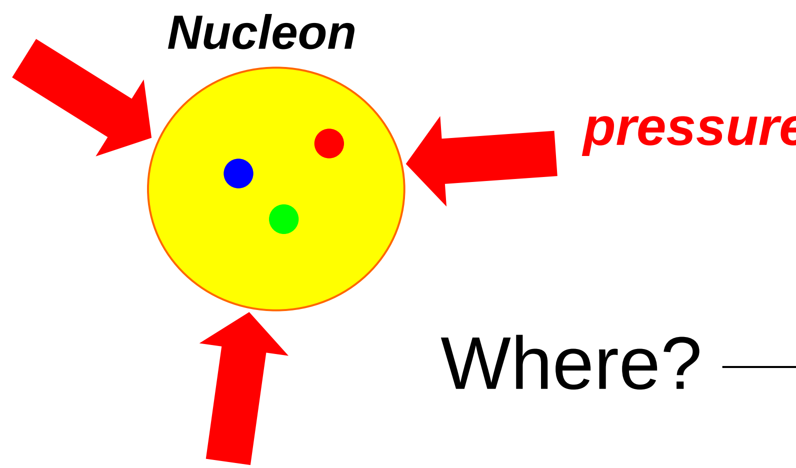
which provide proper compressibility of Nuclear Matter and were introduced by Boguta & Bodmer – **(new fit?)**

Finite volume effect in compressed medium

Nucleon inside saturated NM

Compressed inside Neutron Star or in H I collision

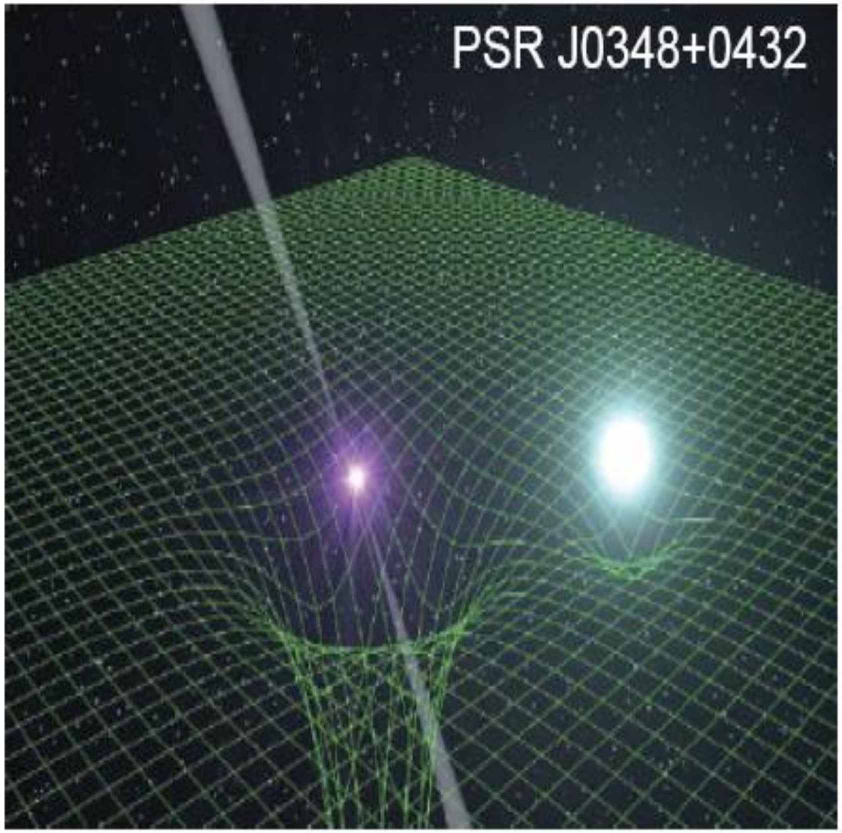




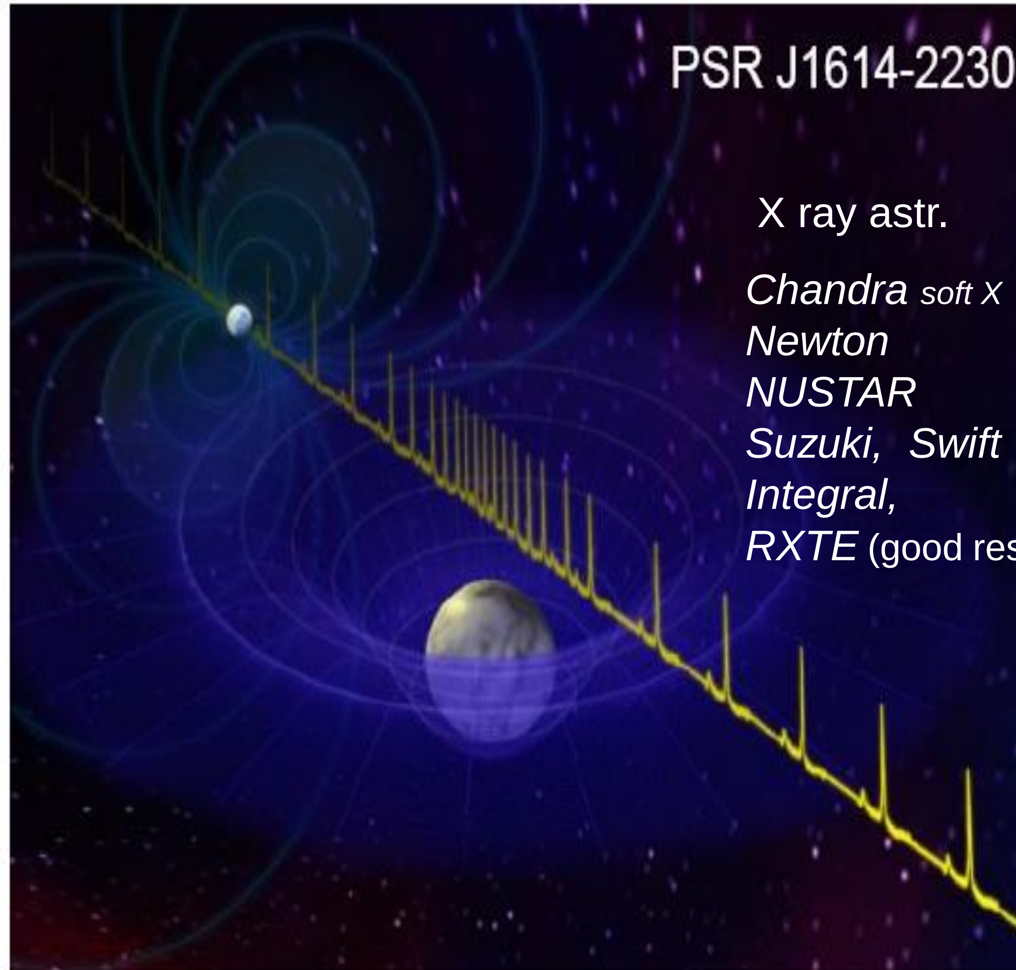
Where? ⟶

Neutron Stars

Average density $5*10^{14} g/cm^3$~2 nuclear density

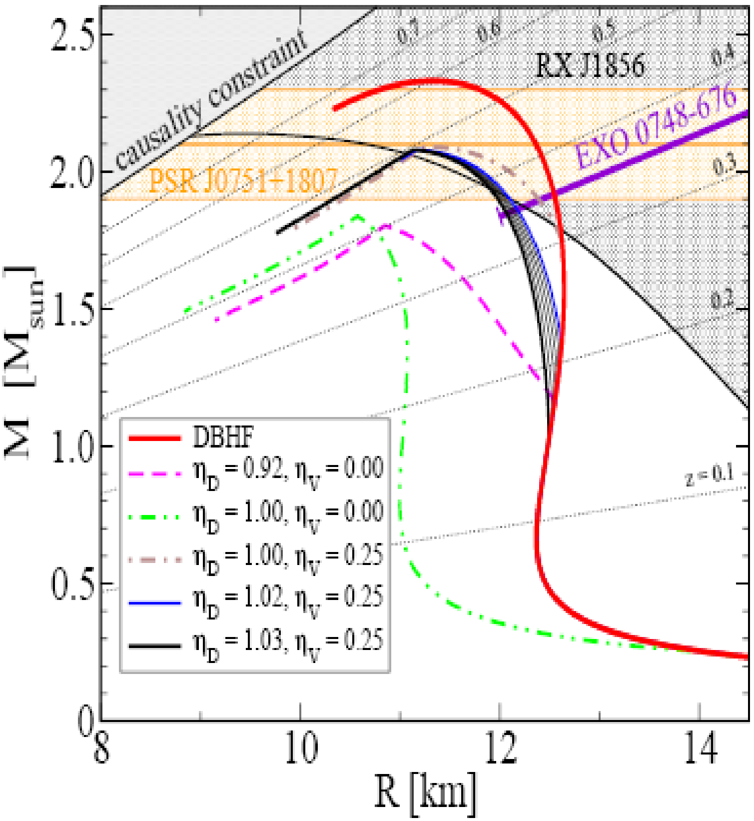


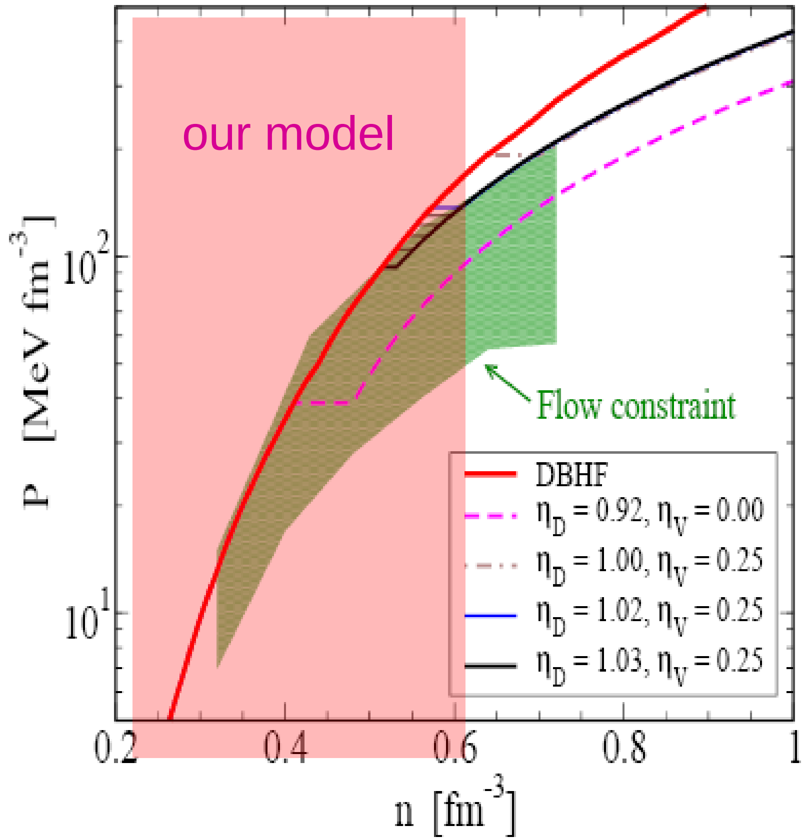
Antoniadis et al., Science 340 (2013) 448
Demorest et al., Nature 467 (2010) 1081



Masa~$2M_{\odot}$ -New Limit of Tolman-Oppenheim-Volkoff equation

Mass-Radius constraint and Flow constraint

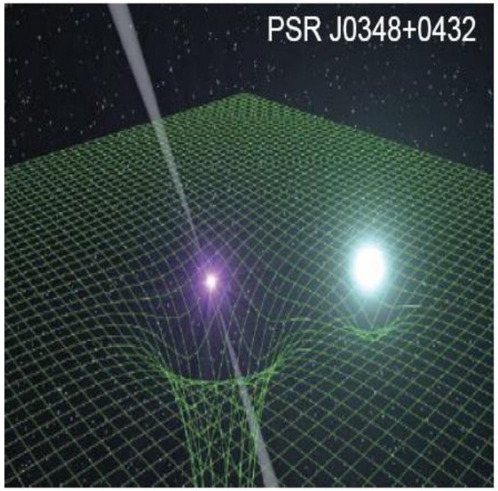


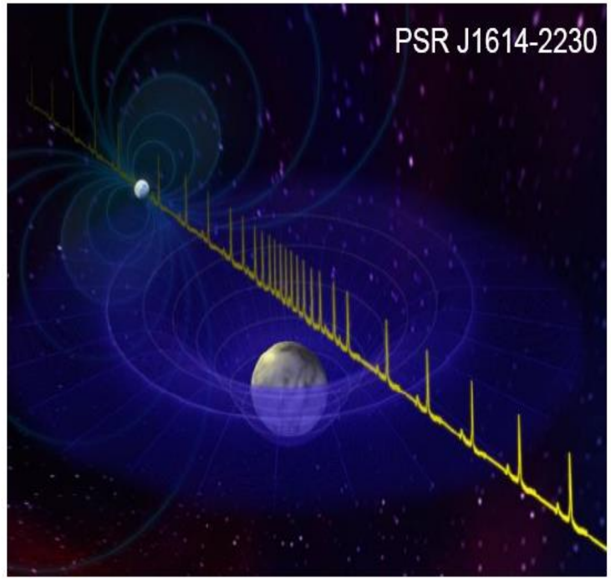


- Large Mass ($\sim 2\, M_\odot$) and radius ($R \geq 12$ km) $\Rightarrow$ stiff quark matter EoS;
  Note: DU problem of DBHF removed by deconfinement! and: CFL core Hybrids unstable!
- Flow in Heavy-Ion Collisions $\Rightarrow$ not too stiff EoS !
  Note: Quark matter removes violation by DBHF at high densities

Klähn, D.B., Sandin, Fuchs, Faessler, Grigorian, Roepke, Truemper, [arxiv:nucl-th/0609067] (2006) *PRC 74*

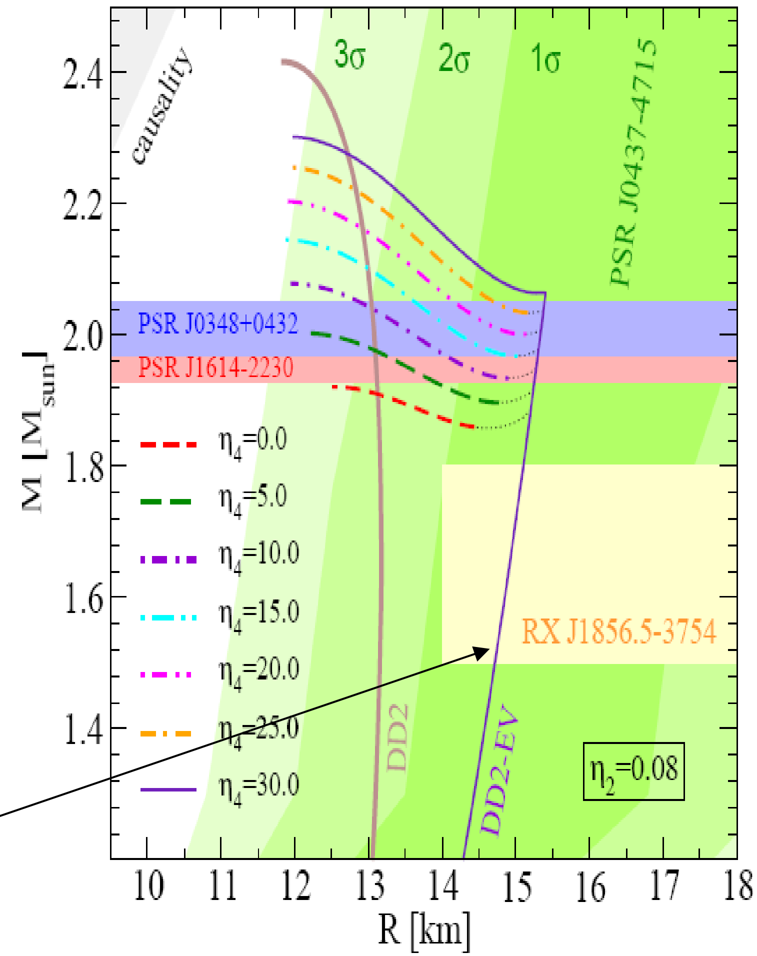
Astrophysical observations and "Data"





Antoniadis et al., Science 340 (2013) 448
Demorest et al., Nature 467 (2010) 1081

From: Chandra, Newton, NuStar, Suzuki, Swift, RXTE (very good resolution)



Average density $5*10^{14}$g/cm^3~2 nuclear density

A new quark-hadron hybrid equation of state for astrophysics

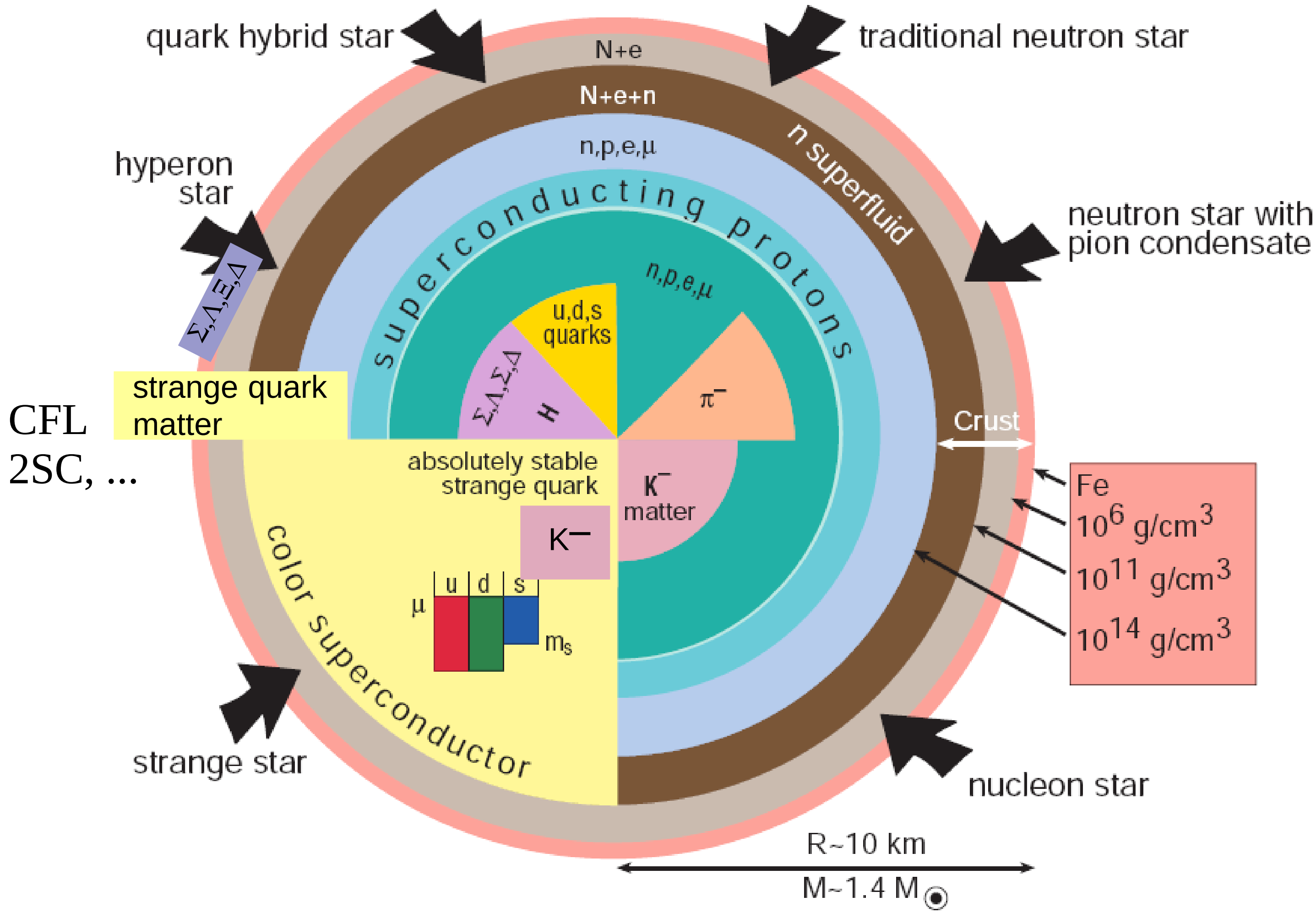
I. High-mass twin compact stars

Sanjin Benić[1,2] ⋆, David Blaschke[3,4] ⋆⋆, David E. Alvarez-Castillo[4,5] ⋆⋆⋆, Tobias Fischer[3] †, and Stefan Typel[6]

Volume effects with constant mass and radius !!!

“Neutron” Star Composition in 2005

(F. Weber, Prog. Part. Nucl. Phys. 54 (2005) 193-288)

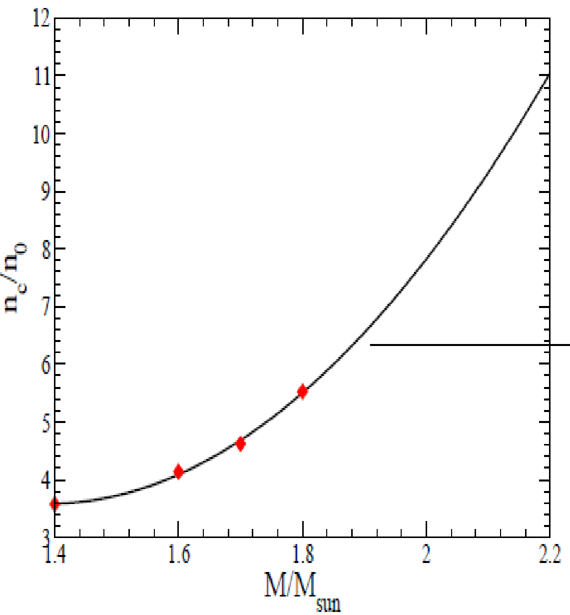


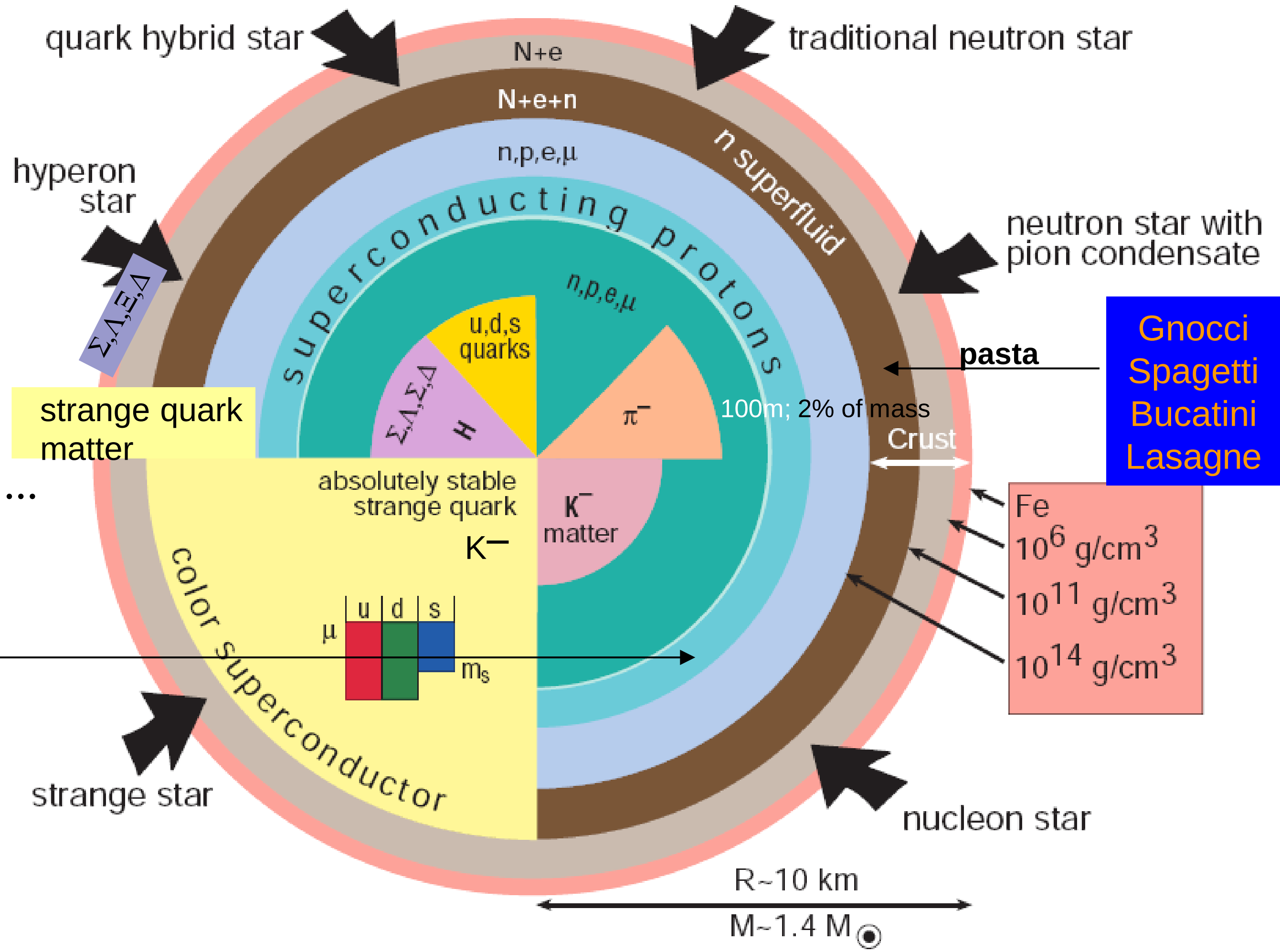
“Neutron” Star Composition in 2005

(F. Weber, Prog. Part. Nucl. Phys. 54 (2005) 193-288)

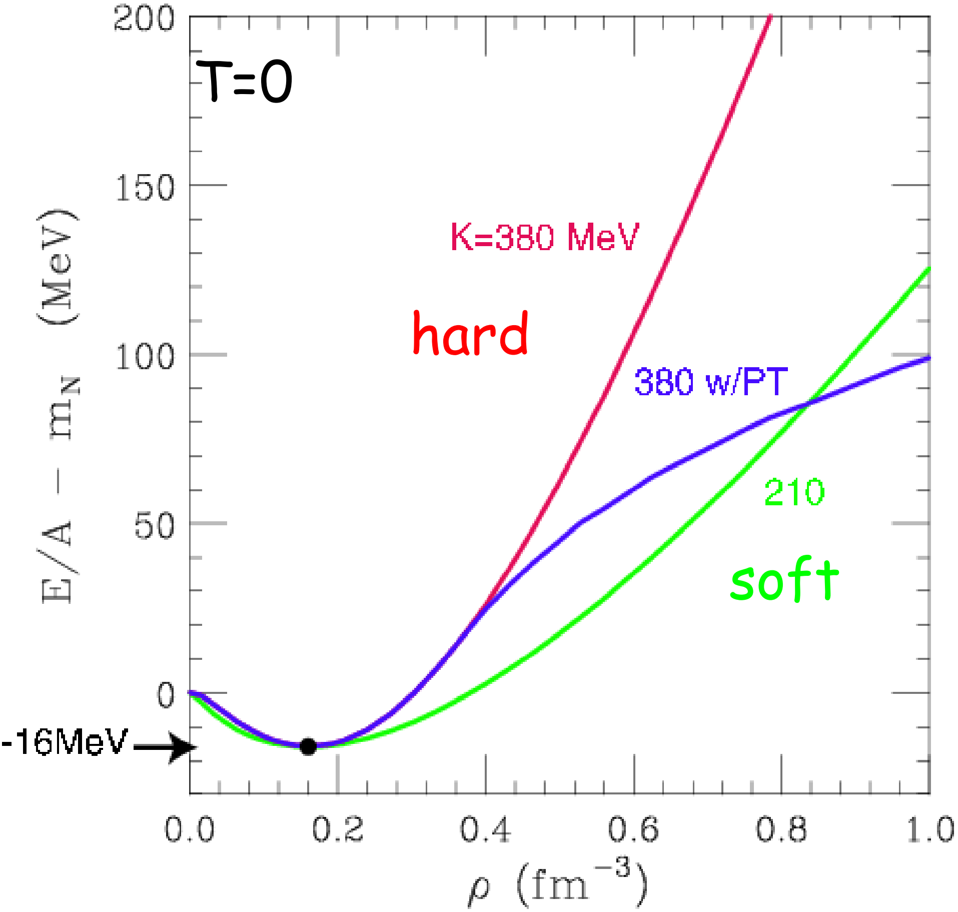
Proton superconductivity and the masses of neutron stars

Negreiros, Schramm, Weber

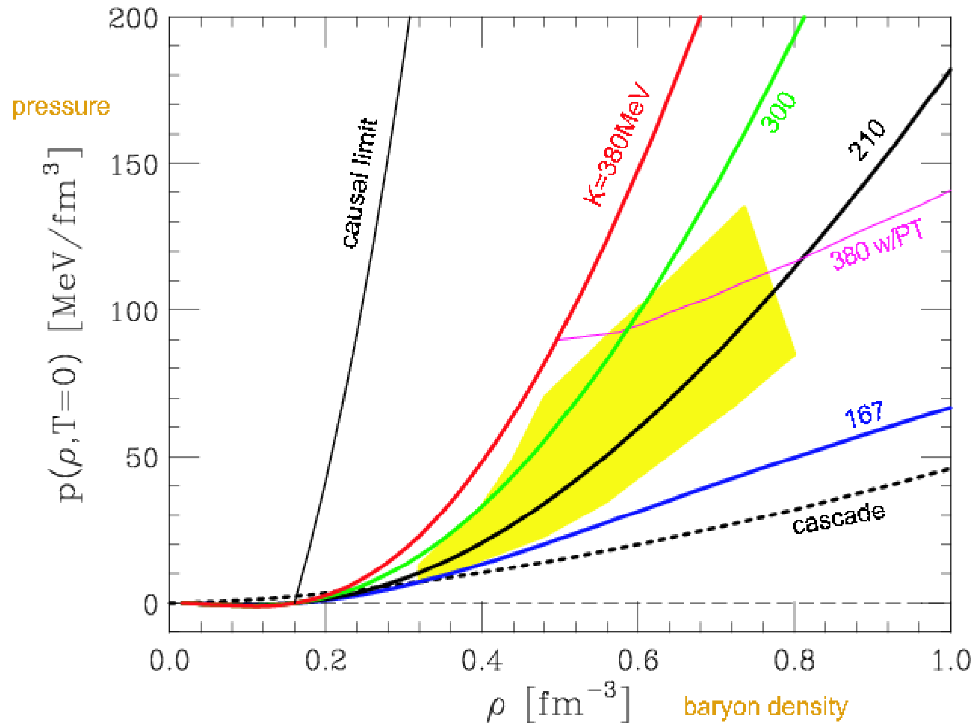




The nuclear equation of state



E/A as a fct of the density
(nuclear physics)



Pressure as a fct of density
(astrophysics)

Przyblizenie nukleonow przez obiekty punktowe w obliczeniach struktury jądrowej jest chyba najpowazniejszym niekontrolowanym przybliżeniem - (P. Ring)

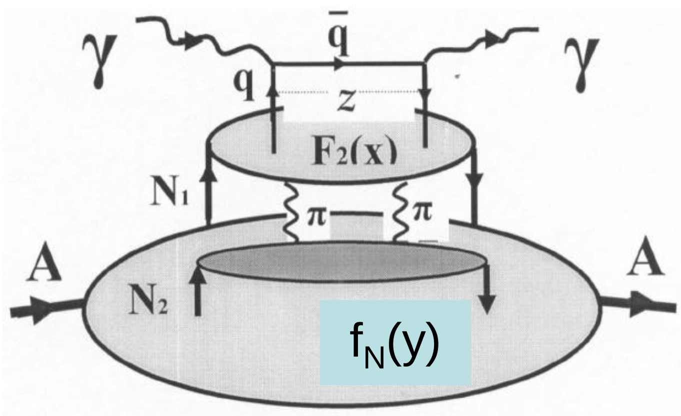
Dotyczy ono np. takiej wielkości jak ściśliwość materii jądrowej. Wiemy że same nukleony mają swoją „twardość” więc wydaje się oczywiste że obliczenia ściśliwości jądrowej zależeć będą od ściśliwości zawartych w nich nukleonów. Taki rachunek został przeprowadzony i prowadzi do istotnej modyfikacji jądrowego równanie stanu.

Dotychczasowe rachunki albo wogóle nie uwzgledniają rozmiarów nukleonu albo ustalają jego rozmiary i masę dla calego przebiegu gęstości i ciśnienia.

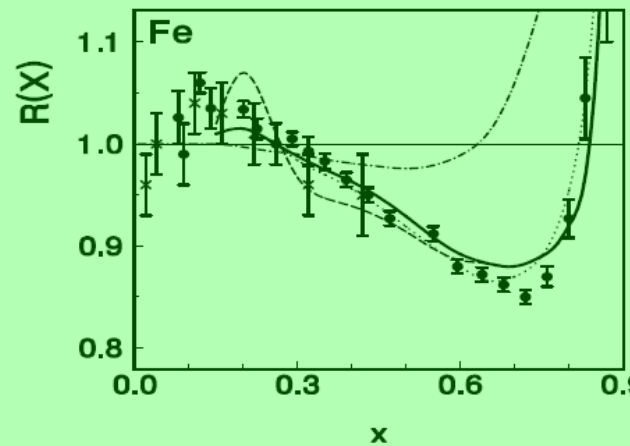
Dlatego głównym motywem wyboru takiego tematu pracy jest uwzglednienie rozmiarów nukleonu, zarówno dla gęstości równowagi klasycznej materii jądrowej której skladnikami są hadrony o zmieniających się rozmiarach, jak i w obszarze krytycznym gdzie nastepuje przejście fazowe z materii hadronowej do (silnie skorelowanej?) materii kwarkowej.

Jaka jest masa nukleonu w ośrodku materii jadrowej ?
Czy moze zależeć od modelu?
Wiemy z opisu reakcji jądrowych że masa nukleonu się nie zmienia w materii jadrowej dla gęstości równowagi.
Nie jest to juz tak oczywiste w relatywistycznej teorii średniego pola RMF gdzie są nukleony poruszają się w silnych polach skalarnym i wektorowym.
Dlatego opis efektu EMC na tarczy związanego nukleonu odpowiedział no to pytanie.

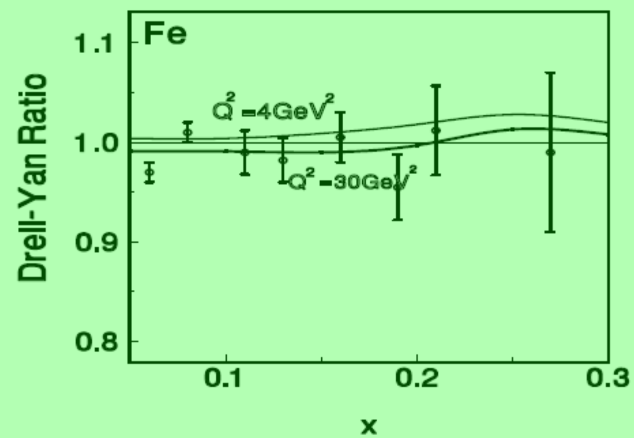
Efekt EMC +DY -przedstawione dopasowania głęboko nieelast. procesów uzyskano dla niezmienionej masy nukleonu w ośrodku



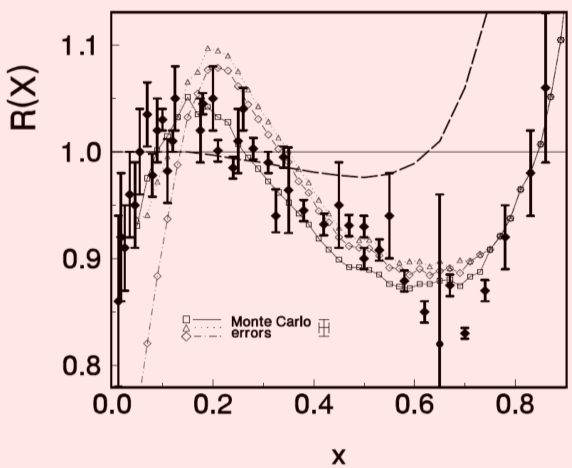
$$M_x = M_N + \frac{(1 - f(x))}{2} < V_N >$$



Only 1% of nuclear pions



Shifting pion mass



JR G.Wilk PLB 473 (2000)

Phys. Rev. C71 (2005)

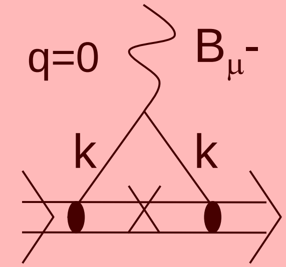
RMF and Momentum Sum Rule

The relativistic nuclear dynamics of nucleons in the nucleus is described by the Light Cone (LC), momentum distribution function $f_N(y)$ (Jaffe) where $y = AP_N^+/P_A^+$, a fraction of longitudinal momentum of A nucleons in the nucleus is Lorentz invariant. Let us now focus our attention on the sum rule for longitudinal momenta $P_N^+ = P_N^0 + P_N^Z$. Do they sum in the rest frame to the nuclear energy E_A, or rather to nuclear enthalpy H_A? To answer this question we can examine the distribution

$$f_N(y) = \int \frac{d^4 P_N}{(2\pi)^4} \delta \left(y - \frac{AP_N^+}{P_A^+} \right) Tr\left[\gamma^+ S(P_N, P_A)\right]. \qquad (4)$$

Frankfurt, Strikman Phys. Reports 160 (1988)

Finally with a good normalization of S_N we have:



Flux Factor

$$f_N(y) = \frac{4}{\varrho}\int_0^{P_F} \frac{S_N(P_N)d^3\boldsymbol{P}_N}{(2\pi)^3}\left(1+\frac{P_N^3}{E_N^*}\right)\delta(y - AP_N^+/P_A^0) =$$

$$= (3/4)[P_A^0/(AP_F)]^3[(AP_F/P_A^0)^2 - (y - AE_F/P_A^0)^2]. \quad (5)$$

$P^0_A = E_A = A\varepsilon_A$

and Momentum Sum Rule

$$\frac{1}{A}\int dy\, y f_N(y) = \frac{E_F}{P_A^0} \equiv \frac{\frac{\partial}{\partial A}(E_A)_{\Omega_A}}{P_A^0} = \frac{\varepsilon_A + p_H/\varrho}{P_A^0}. \quad (6)$$

$$\int dy\, y f_N(y) = \frac{E_F}{h_A} = 1. \; .$$

Fermi Energy

Enthalpy/A

So far excluded volume effects were calculated for a constant nucleon mass and in constant radius.

To improve it let us introduce enthalpy in a Bag Model of nucleon.

- **Enthalpy** is a measure of the total energy of a thermodynamic system. It includes the system's internal energy and thermodynamic potential (a state function), as well as its volume Ω and pressure p_H (the energy required to "make room for it" by displacing its environment, which is an extensive quantity).

$$H_A = E_A + p_H \Omega_A \qquad \text{Nuclear Enthalpy} \qquad (1)$$

$$H_N = M_{pr} + p_H \Omega_N \qquad \text{Nucleon Enthalpy} \qquad (2)$$

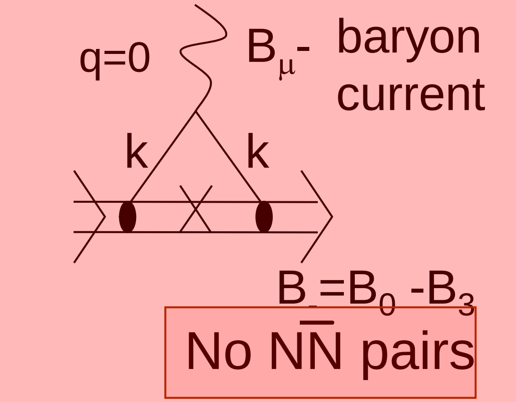
Our version of Hugenholz-Van Hove relation for finite nucleons in NM

$$H_A^T/A = \varepsilon_A - (\partial M_A/\partial \Omega_{A-})_A/\varrho = \varepsilon_A + p_H/\varrho = E_F$$

Wnioski i co dalej.

1. Efekty związane ze zmianą objętości i masy nukleonów w materii jądrowej odkrywają niezmiernie ważną rolę w równaniu stanu i w związku z tym są istotne w ka-żdym obszarze zastosowań: od ścisliwosci dla gęstości równo wagi do obliczeń modelowych mas gwiazd neutronowych i eksperymentów ciężkojonowych.
2. Rachunki są kontynuowane dla gorącej materii jądrowej z uwzglednieniem hiperonów i rezonansów barionowych.
3. Planowane jest (hybrydowe?) uwględnienie przejścia fazowego do materii kwarkowej opisywnej modelem Nambu- Jona-Lasinio oraz efektów nieekstensywnych.
4. Kwarki konstytuentne?

Finally with a good normalization of S_N we have:



Flux Factor

$$f_N(y) = \frac{4}{\varrho}\int_0^{P_F} \frac{S_N(P_N)d^3\boldsymbol{P}_N}{(2\pi)^3}\left(1+\frac{P_N^3}{E_N^*}\right)\delta(y - AP_N^+/P_A^0) =$$

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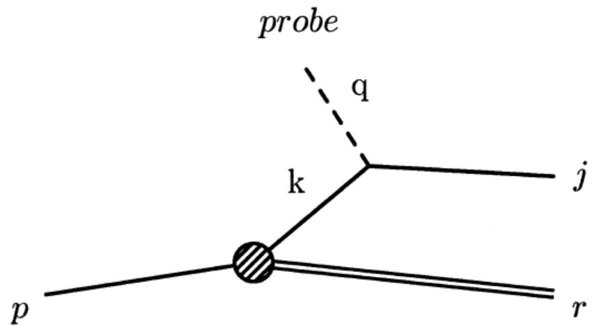
$$\int dy y f_N(y) = \frac{E_F}{h_A} = 1. \; .$$

Fermi Energy

Enthalpy/A

A model for parton distribution



$$f_i(k)dk = N(\sigma_i, m_i)e^{-\frac{(k_0-m_i)^2+k_1^2+k_2^2+k_3^2}{2\sigma_i^2}}dk$$

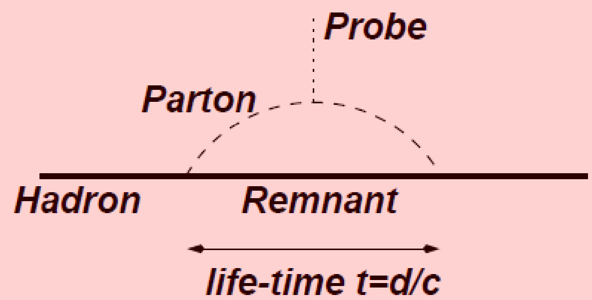
Primodial quark transverse momentum distribution p^+_{rest}= H(R)

$$k^+ = xp^+$$

Kinematical conditions for Monte Carlo technique

$$m_i^2 \leq j^2 < W^2 \quad \text{and} \quad r^2 > \sum_i m_i^2$$

Line cone variables in the nucleon rest frame

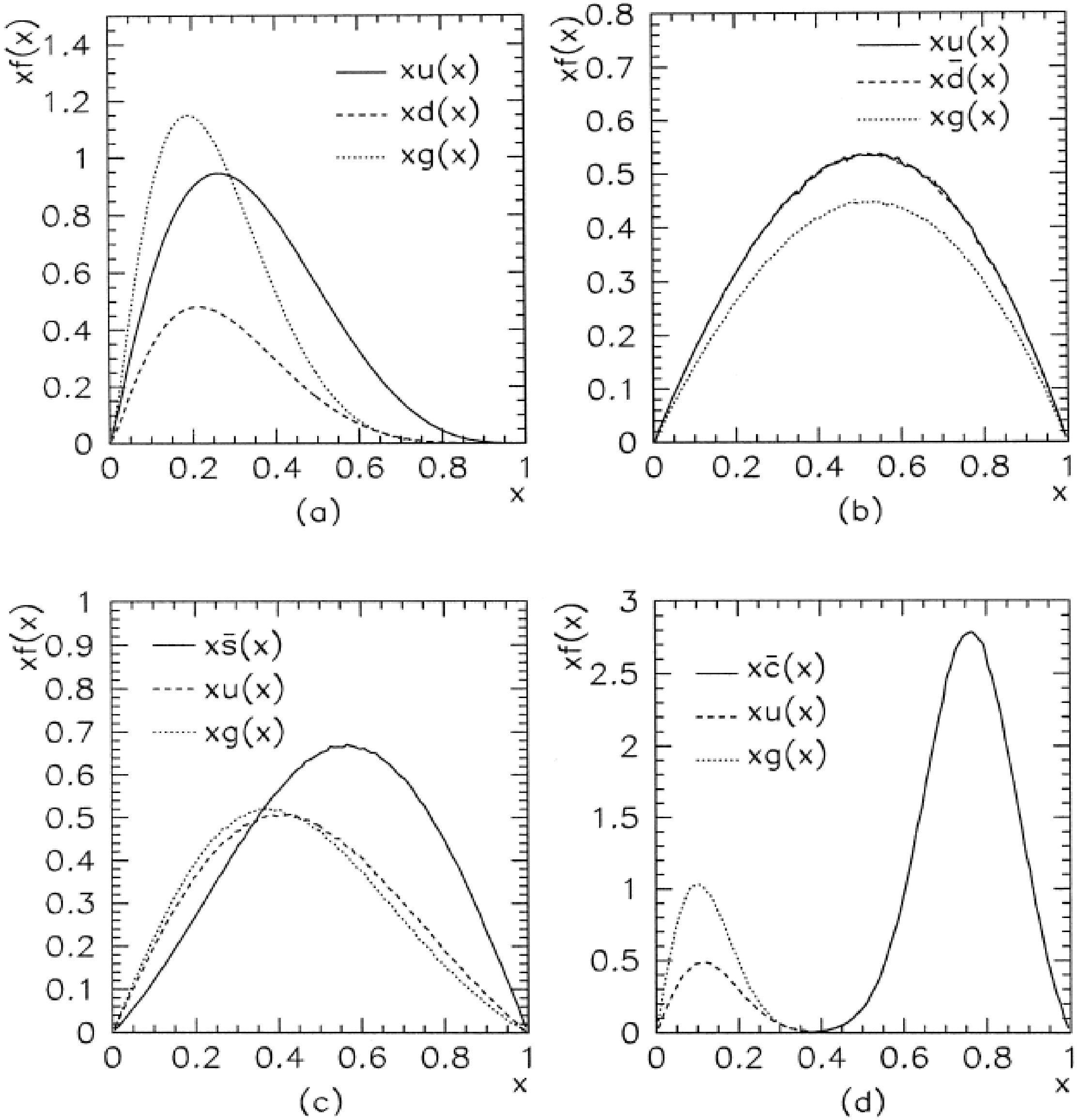


Fluctuation of a hadron into a parton

Neglecting transver quark momenta

$$f_i(x) = N'(\tilde{\sigma}_i)\exp\left(-\frac{x^2}{4\tilde{\sigma}_i^2}\right)\text{erf}\left(\frac{1-x}{2\tilde{\sigma}_i}\right)$$

$$\tilde{\sigma} = \frac{1}{d_h m_h}$$



. 2. The valence quark and gluon distributions obtained from the model applied to (a) the proton, (b) the pion, (c) the strange meson K^+, the charm meson $\overline{D}^0$. The Gaussian widths used are 135 MeV for gluons and 150 MeV for q and $\overline{q}$, except $\sigma_u = 180$ MeV in (a)

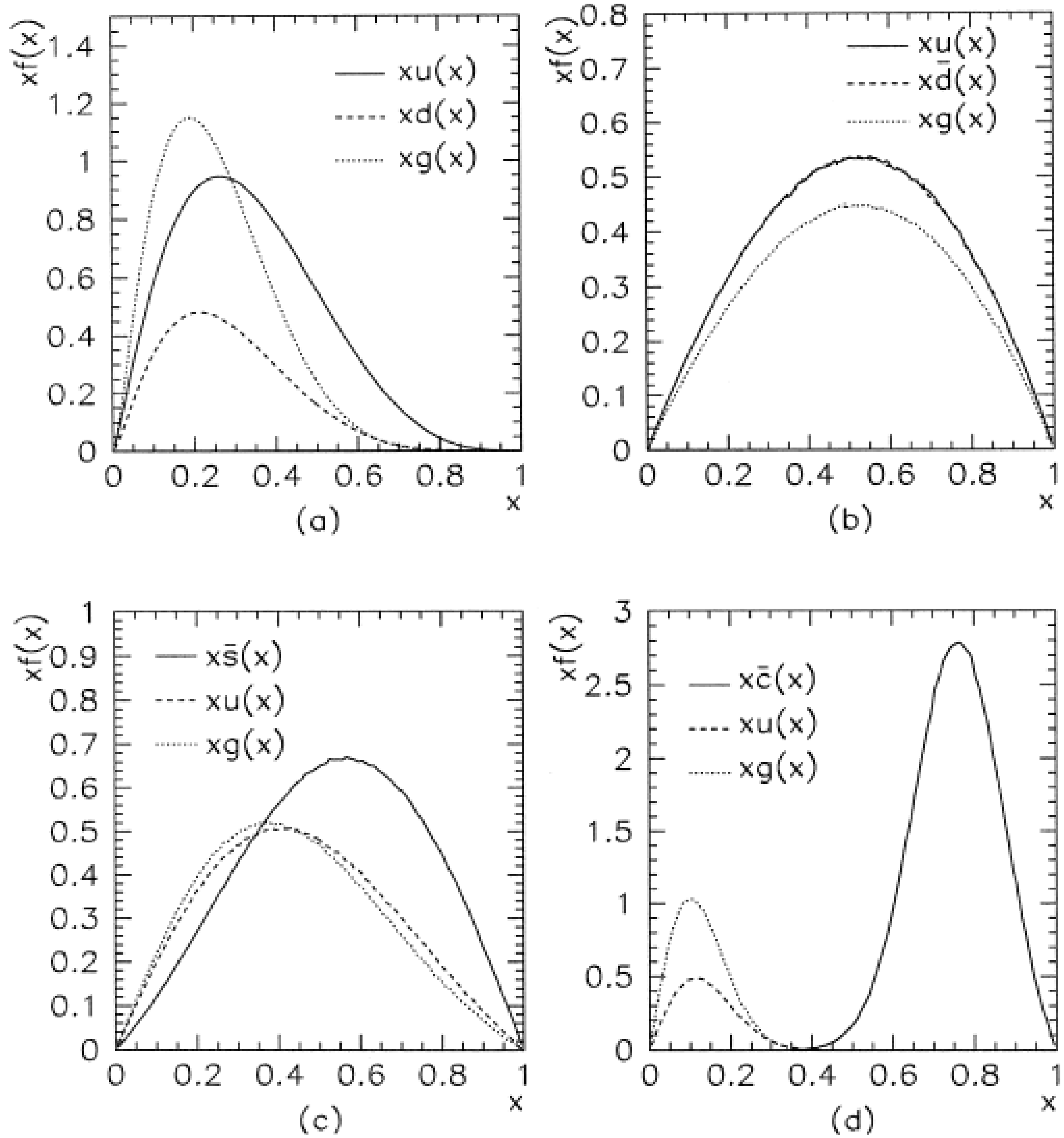


Fig. 2. The valence quark and gluon distributions obtained from the model applied to (a) the proton, (b) the pion, (c) the strange meson K^+, (d) the charm meson $\overline{D}^0$. The Gaussian widths used are 135 MeV for gluons and 150 MeV for q and $\overline{q}$, except $\sigma_u = 180$ MeV in (a)

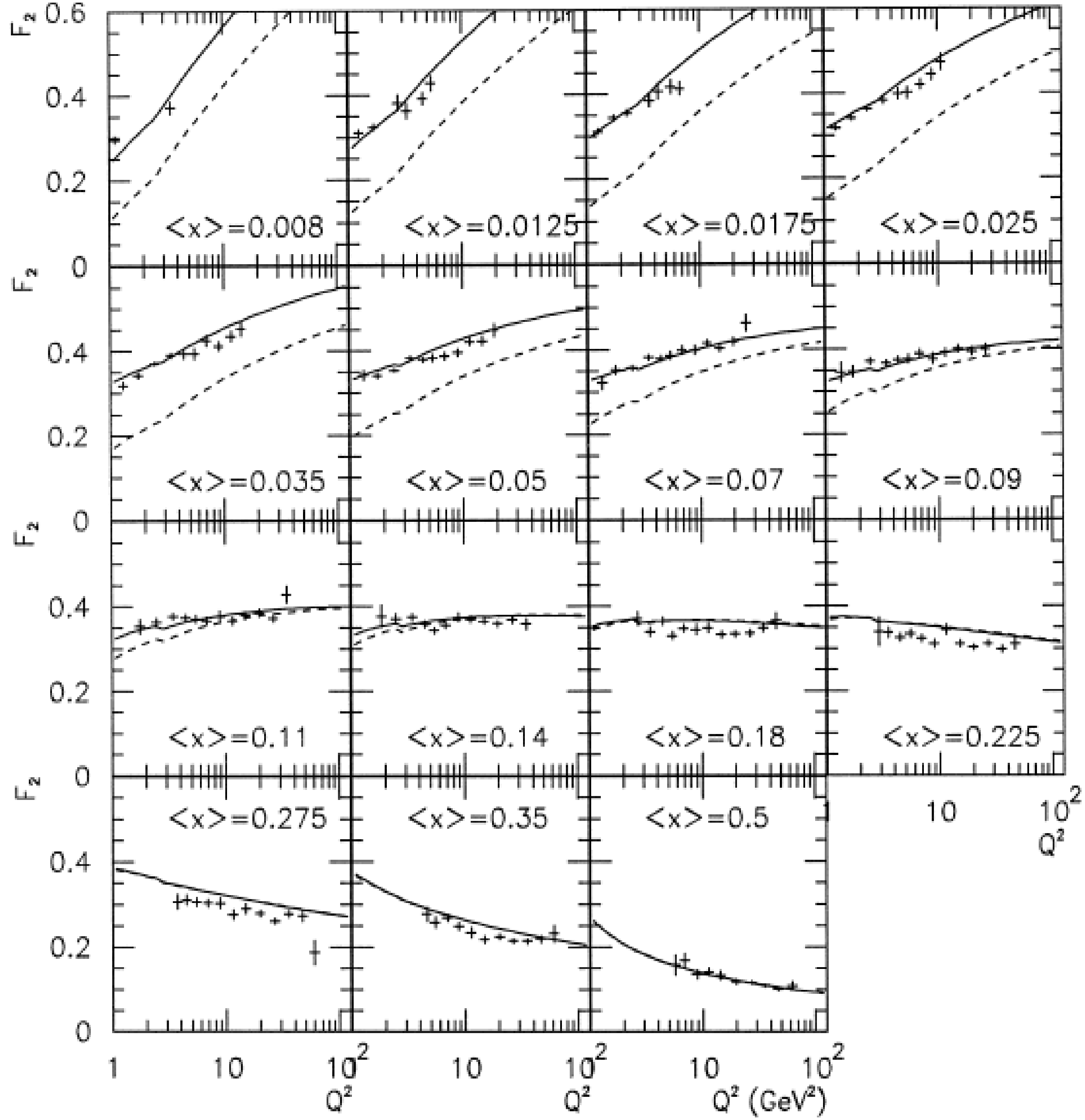
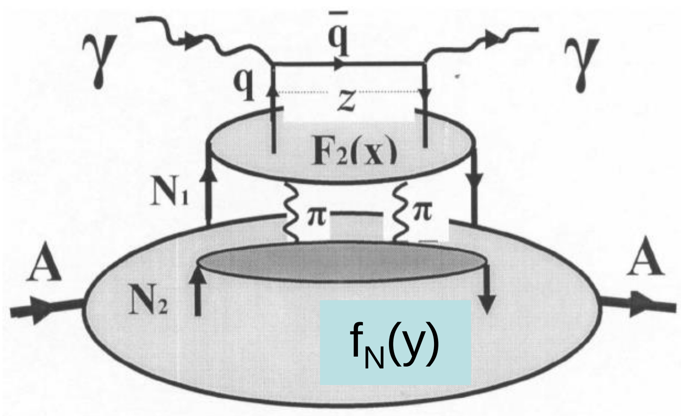
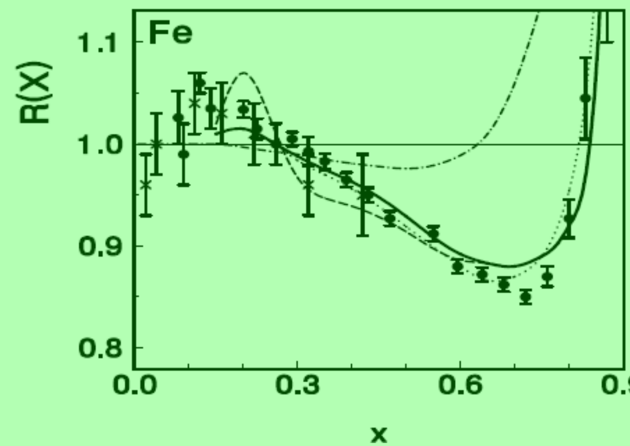


Fig. 3. The DIS structure function F_2 versus Q^2 in bins of x. Fixed target NMC data [7] compared to the model starting from only valence quarks and gluons (dashed) and including also a sea quark component (full). (The small break in the curves at $Q^2 \sim m_c^2$ is due to the charm threshold.)

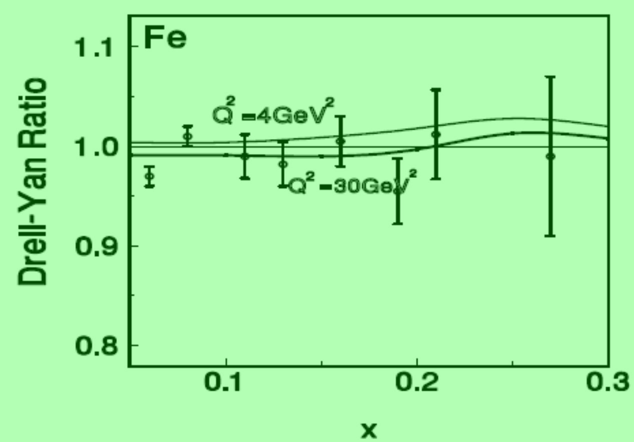
Nuclear Models - equilibrium



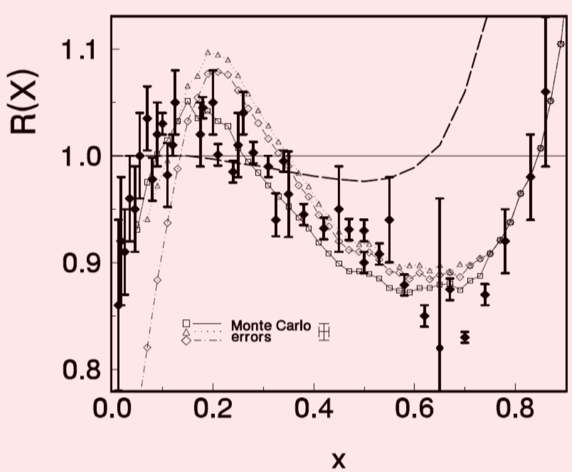
$$M_x = M_N + \frac{(1 - f(x))}{2} < V_N >$$



Only 1% of nuclear pions



Shifting pion mass



JR G.Wilk PLB 473 (2000)

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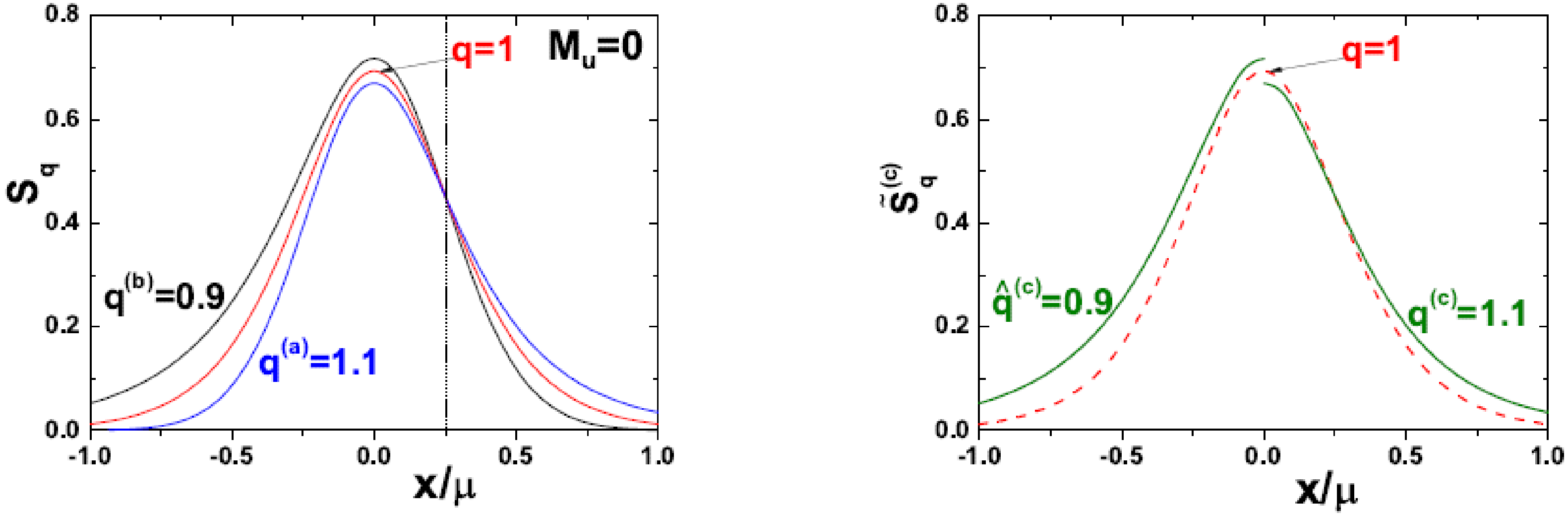


Fig. 1. (Color online) Schematic view of $S_q = \tilde{S}_q^{(R=a,b)}$ defined by Eqs. (54) and (55) (left panel) and $S_q^{(c)} = \tilde{S}^{(R=c)}$ defined by Eq. (56) (right panel), all presented as a function of the scaled variable x/μ. The respective values of q used are shown. All these results are compared with the extensive case of $q = 1$ (blue curves). Calculations were performed assuming $M_{qi} = 0$, $T = 60$ MeV and $\mu = 322$ MeV. The meaning of q and $\hat{q}$ on the right panel corresponds to definition of $\tilde{q}$ presented in Eq. (36).

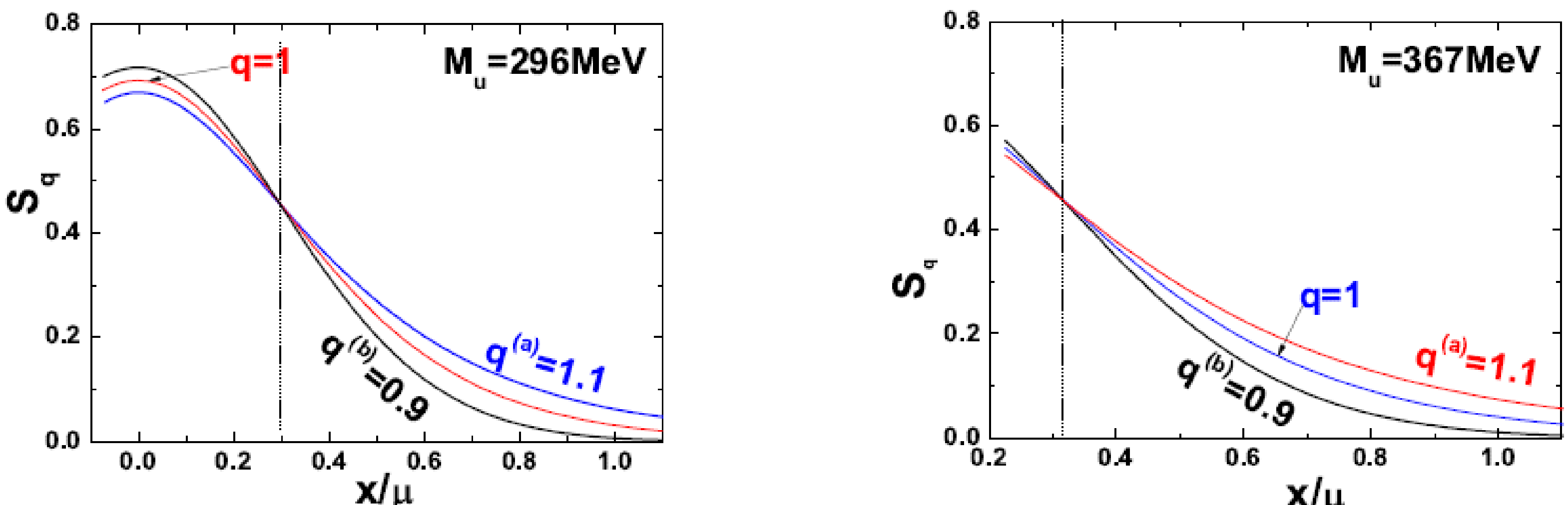


Fig. 2. (Color online) The same as in the left panel of Fig. 1 but for different masses M_u.

Toy Model

(Neglecting transverse quark momenta)

$$f_i(x) = N'(\tilde{\sigma}_i) \exp\left(-\frac{x^2}{4\tilde{\sigma}_i^2}\right) \operatorname{erf}\left(\frac{1-x}{2\tilde{\sigma}_i}\right)$$

$$\tilde{\sigma} = \frac{1}{d_h m_h} \quad m_h$$

In our case $d_h m_h$ => R*H(R) is const.

But the $x=k^+/H(R)$ depends on nucleon radius

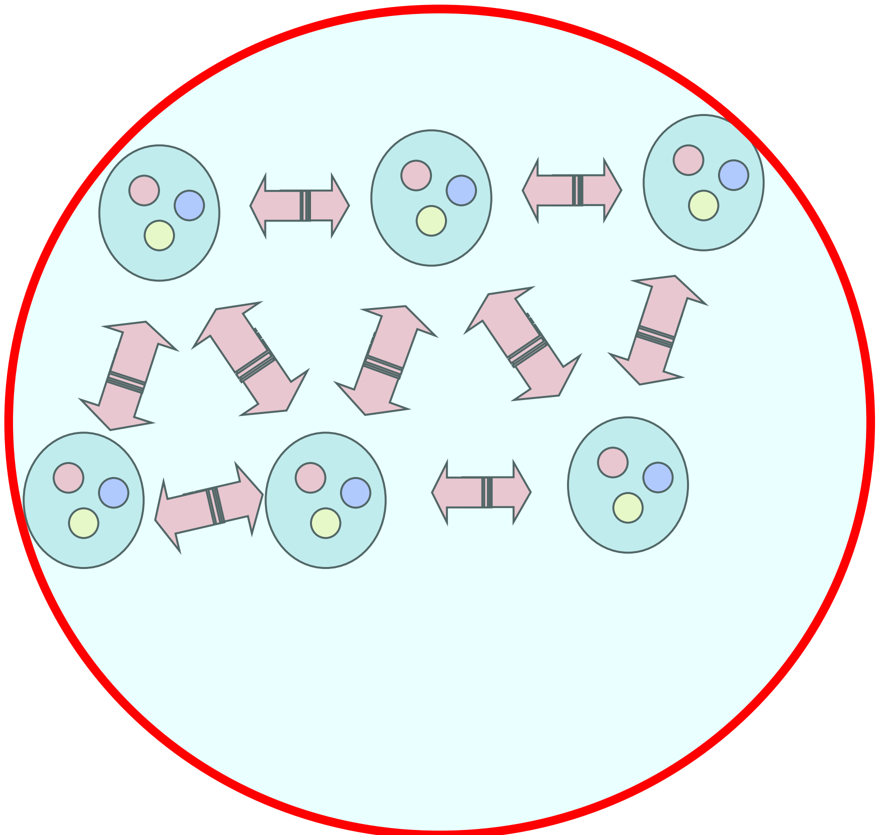
Two Scenarios

for NN repulsion with qq attraction

- **Constant Mass**

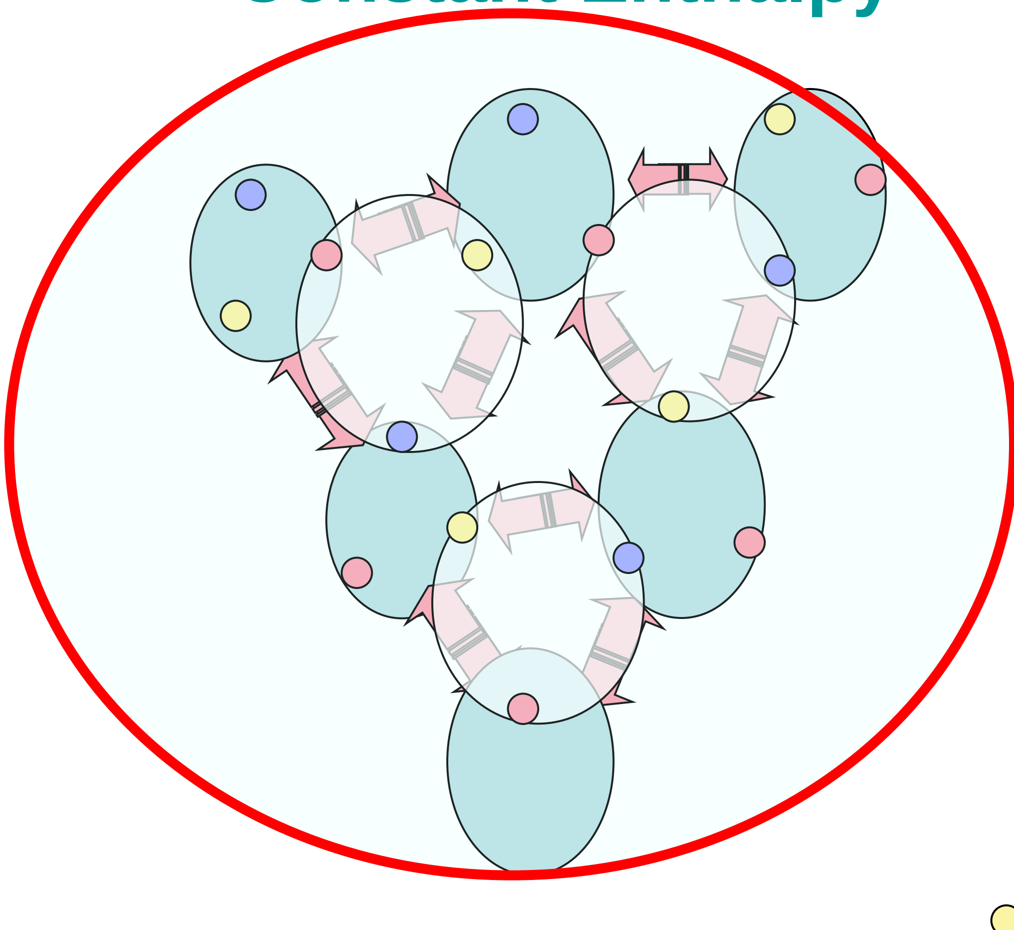
= Increasing Enthalpy

1/R

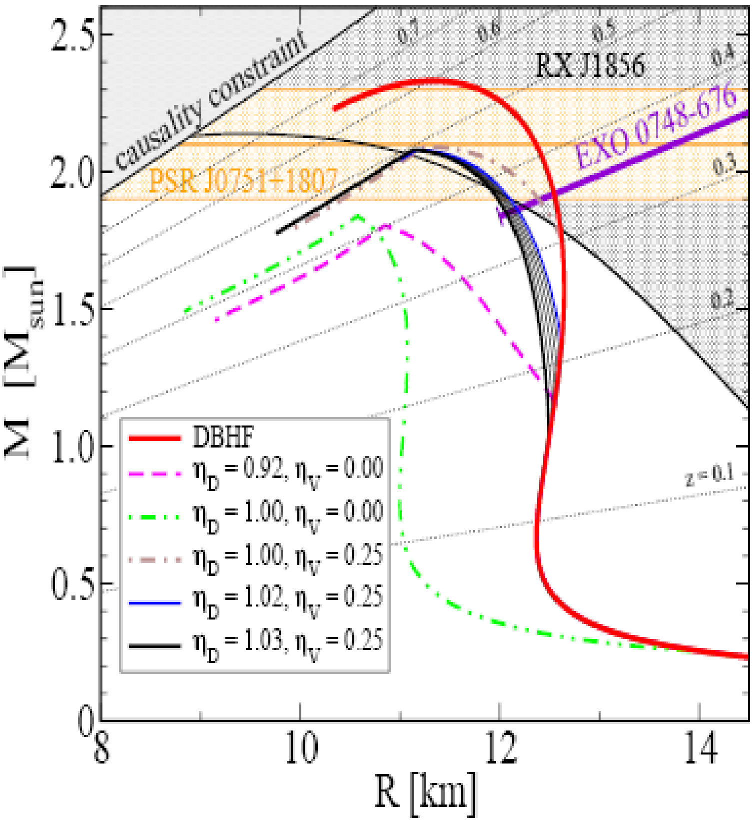


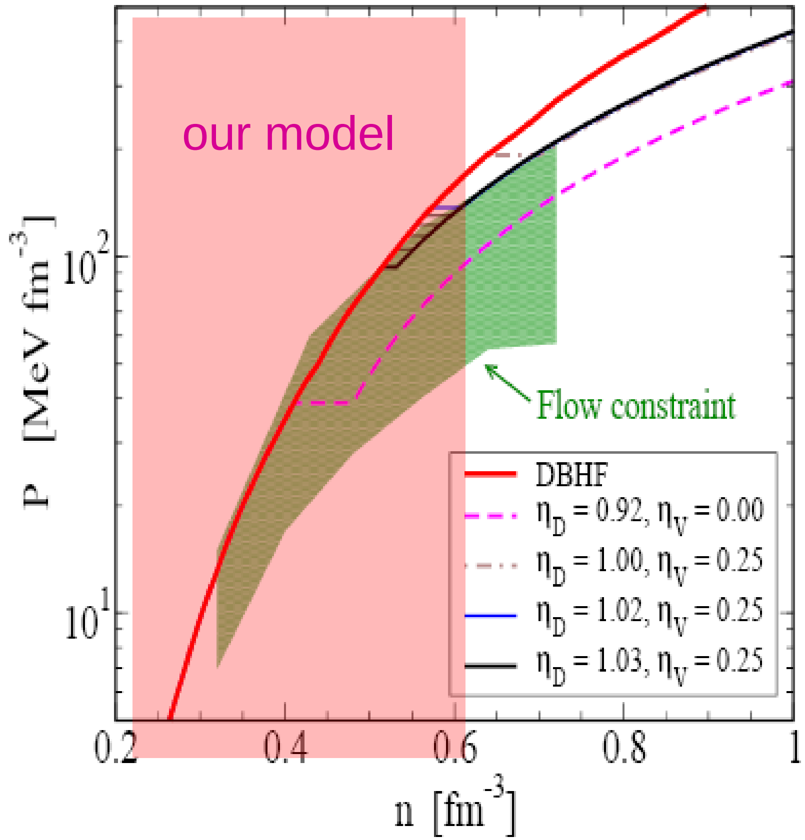
- **Constant Volume**

= Constant Enthalpy



Mass-Radius constraint and Flow constraint (II)

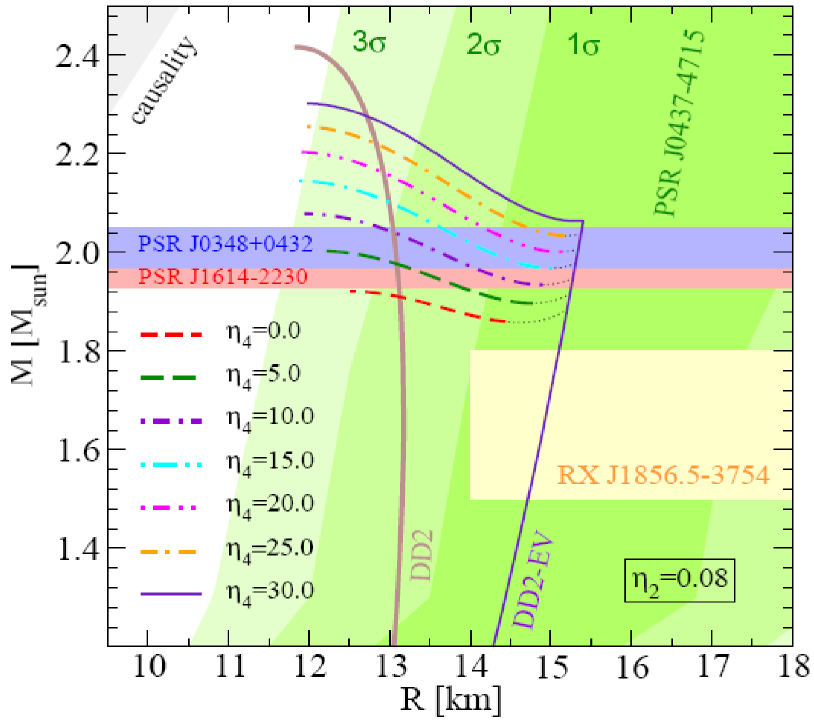




- Large Mass ($\sim 2\ M_{\odot}$) and radius ($R \geq 12$ km) $\Rightarrow$ stiff quark matter EoS;
  Note: DU problem of DBHF removed by deconfinement! and: CFL core Hybrids unstable!
- Flow in Heavy-Ion Collisions $\Rightarrow$ not too stiff EoS !
  Note: Quark matter removes violation by DBHF at high densities

Klähn, D.B., Sandin, Fuchs, Faessler, Grigorian, Roepke, Truemper, [arxiv:nucl-th/0609067] (2006) *PRC 74*

Astrophysical "data"



A new quark-hadron hybrid equation of state for astrophysics

I. High-mass twin compact stars

Sanjin Benić[1,2] ⋆, David Blaschke[3,4] ⋆⋆, David E. Alvarez-Castillo[4,5] ⋆⋆⋆, Tobias Fischer[3] †, and Stefan Typel[6]

The E0 strength distribution in ^{90}Zr, ^{116}Sn, ^{144}Sm and ^{208}Pb have been measured with inelastic scattering of 240 MeV α particles at small angles. The E0 strengths in ^{116}Sn,^{144}Sm and ^{208}Pb were found to be concentrated in symmetric peaks and centroid of the strength distributions were located at E_x= 16.00±07, 15.31±11, and 14.24±11 MeV respectively. In ^{90}Zr the E0 distribution was found to have a high energy tail extending up to Ex = 25 MeV. The resulting centroid of the E0 strength for ^{90}Zr is Ex=17.89±20 MeV. These results and the previously reported result for ^{40}Ca lead to K_{nm}=231±5 MeV by comparing to mecroscopic

Nuclear convolution Model