Partial Chiral Symmetry restoration and QCD Scalar Susceptibilities in Nuclear Matter

(M. Ericson, P. Guichon, M. Martini, D. Davesne, G.C)

- Chiral restoration in hadronic matter
- Scalar and pseudoscalar susceptibilities
- Susceptibility in a chiral effective theory
- Some consequences

A- CHIRAL RESTORATION IN HADRONIC MATTER

A1 -IN-MEDIUM SPECTRAL FUNCTIONS

Restructuring of the QCD vacuum (Dropping of the condensates)

Observable consequences in the excitation spectrum

In-medium hadronic spectral functions

$$\rho_h(\omega\,,\,\vec{q}) = -\frac{1}{\pi}\,Im D_h(\omega\,,\,\vec{q})$$

- Evolution of the "centroids" (masses) : no universal links between masses and condensates *i.e.* masses vs f_π
- Shape of the hadronic spectral functions and related quantities (χ)
- Softening, sharpening (σ) or broadening (K, ρ), dissolving of the resonances

A2- CHIRAL RESTORATION AND HADRON STRUCTURE

- **Dropping of the quark condensate at finite ρ_B, T**

$$\frac{\langle\langle\bar{q}q\rangle\rangle(\mu_B,T)}{\langle\bar{q}q\rangle_{vac}} = 1 - \sum_h \frac{\rho_s(\mu_B,T)\sigma_h}{f_\pi^2\, m_\pi^2}$$

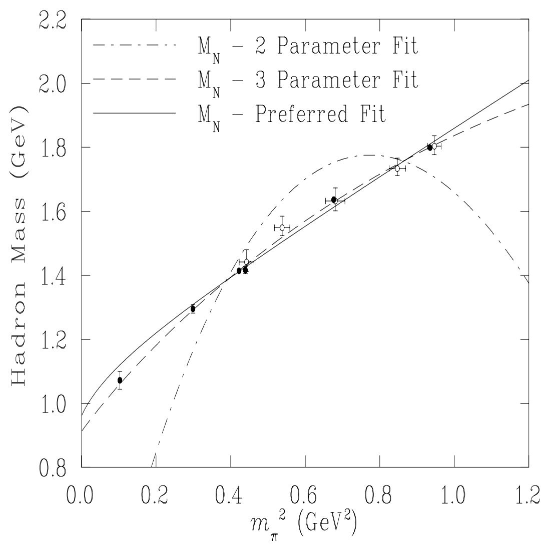
$$\sigma_h = m_q \frac{\partial M_h}{m_q} = m_\pi^2 \frac{\partial M_h}{m_\pi^2}$$

$$\rho_s(\mu_B, T) = \frac{\partial\Omega(\mu_B,T)}{\partial M_h}$$

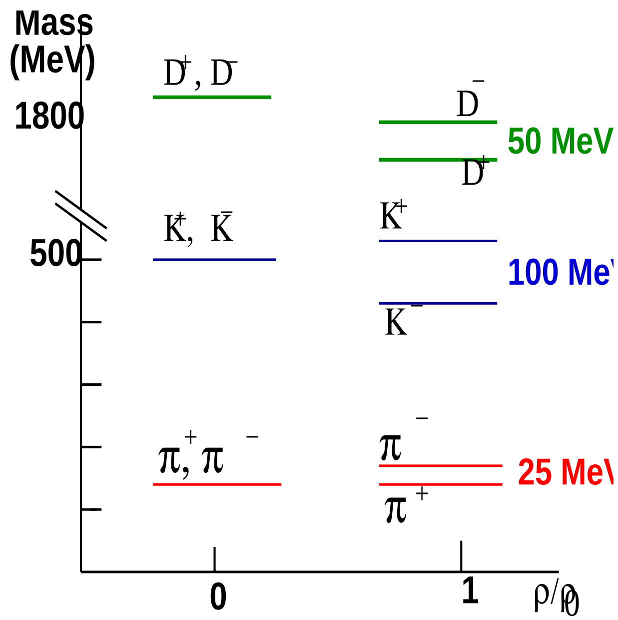
Dominated by lightest hadrons , heavy hadrons decouple from the condensate

- **Nuclear matter**, leading order $\frac{\langle\langle\bar{q}q\rangle\rangle(\rho)}{\langle\bar{q}q\rangle_{vac}} \simeq 1 - 0.35\,\frac{\rho}{\rho_0} - \frac{T^2}{8\,f_\pi^2}$

- **Extrapolation of lattice data** (Leinweber,Thomas)
  - $M_{N,\Delta} = \alpha + \beta\, m_\pi^2 + \quad Pion\, loop(\Lambda)$
  - The specific contribution of the pion cloud is very important and depends on a scale : the nucleon size (hidden in χPT)
  - $\sigma_N \simeq 50 MeV$, half of it from the pion cloud



A3- IN-MEDIUM MASS SPLITTING



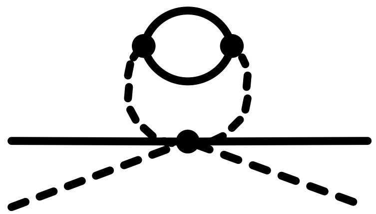
• Pattern of symmetry breaking generated by chiral dynamics

Deeply bound pionic states : In medium increase of the isovector scattering length b_1

$\Delta M_{\pi^-}^{exp} = 23 \sim 27 MeV$ in the center of Pb

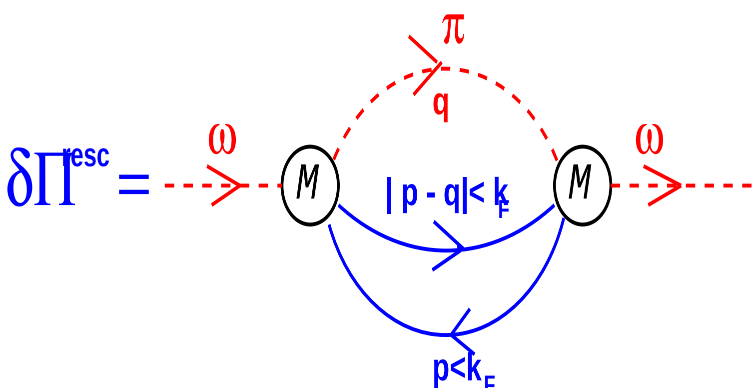
• Chiral effective theory

Vertex correction : pion cloud effect



$$\frac{b_1^*}{b_1} = 1 + \frac{\sigma_N \rho}{f_\pi^2 m_\pi^2} - \frac{7}{6}\frac{\Sigma_N^{(\pi)} \rho}{f_\pi^2 m_\pi^2} \simeq 1 + 0.18 \frac{\rho}{\rho_0}$$

Energy dependance of rescattering in presence of Pauli correlations



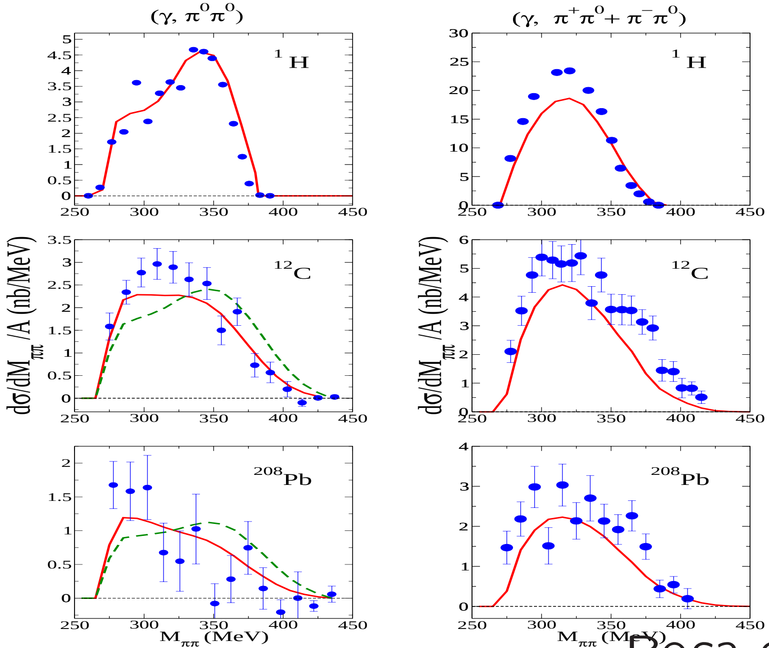
Everything together

$$\frac{b_1^*}{b_1} = 1.19 \quad at \quad \rho = 0.5\rho_0$$

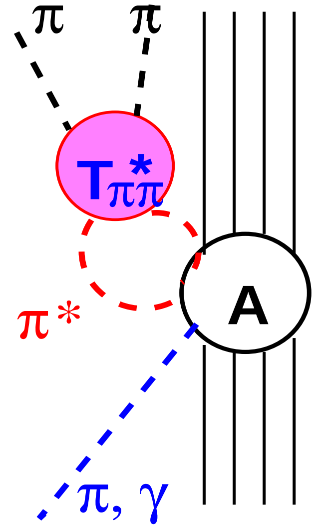
A4- 2π PROCESSES AND CHIRAL SYMMETRY

- $A(\pi,\pi\pi)$ (CHAOS, CB), $A(\gamma,\pi\pi)$(TAPS)

Downwards shift of the $\pi\pi$ invariant mass distribution in the scalar-isoscalar channel $I = J = 0$



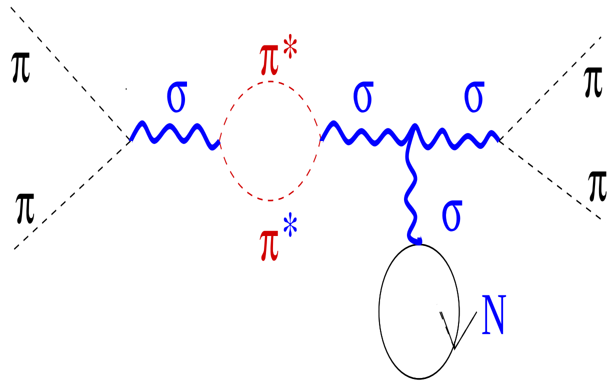
Roca et al



- What is the role of

- Chiral Dynamics

- Chiral restoration ?



- In-medium $I = J = 0$ $\pi\pi$ interaction

– In-medium pions (Schuck-Chanfray)

– Dropping of m_σ, f_π (Hatsuda-Kunihiro)

- **Dropping of the sigma mass**

– Associated with partial chiral restoration
  Linear sigma model (Hatsuda) : 30% dropping at $\rho = \rho_0$

$$\frac{m_\sigma^{*2}}{m_\sigma^2} = 1 + 3\,\frac{\langle s\rangle}{f_\pi} \qquad \frac{\langle\bar{q}q\rangle^*}{\langle\bar{q}q\rangle_{vac}} = 1 + \frac{\langle s\rangle}{f_\pi} - \frac{\langle\phi_\pi^2\rangle}{2\,f_\pi^2}$$

– But constraints from nuclear matter stability

– Closely related to the $p-h$ contribution to the nuclear scalar susceptibility

- **In-medium modified two-pion interaction**

– Closely related to to the pion cloud contribution to the nuclear scalar susceptibility

– Also linked to chiral restoration

In-medium Scalar and Pseudoscalar susceptibilities

Partial Chiral symmetry restoration ?

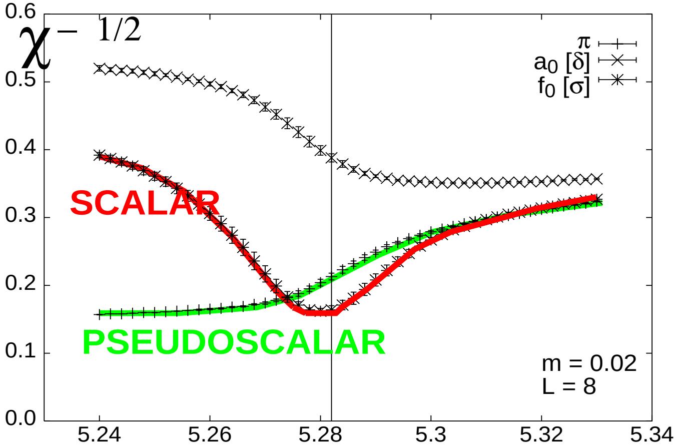
B- SCALAR AND PSEUDOSCALAR SUSCEPTIBILITIES

B1- FLUCTUATIONS OF THE CONDENSATE

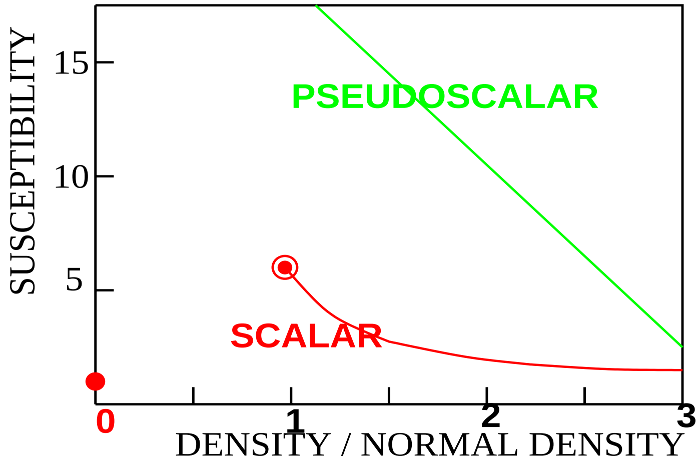
Scalar susceptibility : from the scalar correlator *i.e.* the correlator of the scalar quark density fluctuations

$$\chi_s = \frac{\partial\langle\langle\bar{q}\,q\rangle\rangle}{\partial m} = 2\int dt\, d\vec{r}\,\langle\langle\delta\,\bar{q}\,q(0,0),\,\delta\,\bar{q}\,q(\vec{r},t)\rangle\rangle$$

Thermal susceptibilty on Lattice (Karsch)



Finite density : effective chiral theory (M. Ericson, G. C)



Chiral Restoration : $\chi_S \rightarrow \chi_{PS}$

B2- SCALAR SUSCEPTIBILITY

$$\chi_S = \frac{\partial \langle \bar{q}q \rangle}{\partial m_q} = 2 \int dt'\, d\mathbf{r}'\, \Theta(t - t')\langle -i \left[\bar{q}\, q(0)\, ,\, \bar{q}\, q(\mathbf{r}'\ t')\right] \rangle$$

$$\chi_S = \left(\frac{\partial^2 \omega}{\partial m_q^2}\right)_\mu = Re G_S(\omega = 0, \vec{q} \to 0) = \int_0^\infty d\omega \left(-\frac{2}{\pi\omega}\right) Im G_S(\omega, \vec{q} = 0)$$

$\longrightarrow$ A strong contribution of low energy nuclear excitations is expected

$\longrightarrow$ Linear sigma model $\bar{q}q \longrightarrow \frac{\langle \bar{q}q \rangle_{vac}}{f_\pi} \sigma$: The nuclear susceptibility is related to the in-medium σ propagator

B3- PSEUDOSCALAR SUSCEPTIBILITY

$$\chi_{PS} = 2 \int dt'\, d\mathbf{r}'\, \Theta(t - t')\langle -i \left[\bar{q}\, i\gamma_5 \frac{\tau_\alpha}{2} q(0)\, ,\, \bar{q}\, i\gamma_5 \frac{\tau_\alpha}{2} q(\mathbf{r}'\ t')\right] \rangle = \frac{\langle \bar{q}q \rangle(\rho)}{m_q}$$

(using $\partial^\mu \mathcal{A}^\alpha_\mu(x) = 2\, m_q\, \bar{q}\, i\gamma_5 \frac{\tau_\alpha}{2}\, q(x)$ and soft pion theorem))

$\longrightarrow$ χ_{PS} behaves like the chiral condensate

B4- LEADING ORDER ESTIMATE

- Grand Potential : $\omega = \int \frac{4\, d^3p}{(2\pi)^3}\,(E_p - \mu)\,\theta\,(\mu - E_p)$

- Chiral condensate :

$$\langle \bar{q}q\rangle(\rho) - \langle \bar{q}q\rangle_{vac} = \frac{1}{2}\left(\frac{\partial\omega}{\partial m_q}\right)_\mu = \frac{1}{2}\frac{\partial M}{\partial m_q}\,\left(\frac{\partial\omega}{\partial M}\right)_\mu \equiv \frac{\sigma_N}{2\,m_q}\,\rho_S$$

σ_N : nucleon sigma term, ρ_S : scalar density

- Nuclear susceptibility :

$$\chi_S(\rho) = (\chi_S)_{vac} + \rho_S\,\frac{\partial}{\partial m_q}\left(\frac{\sigma_N}{2\,m_q}\right) + \frac{\sigma_N}{2\,m_q}\,\left(\frac{\partial\rho_S}{\partial m_q}\right)_\mu \equiv \rho_S\,\chi_S^N + \chi_S^{nuclear}$$

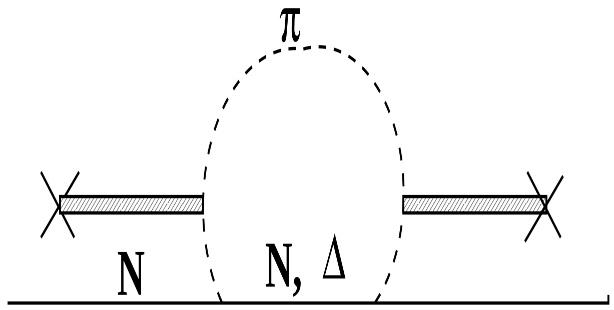
χ_S^N : nucleonic scalar susceptibility

- **Nucleonic contribution** : dominated by the pion cloud through the Leading non analytical contribution

$$\chi_S^N = -\frac{2\langle\bar{q}q\rangle^2_{vac}}{f_\pi^4\, m_\pi}\,\frac{9}{64\pi}\left(\frac{g_A}{f_\pi}\right)^2\left(\frac{\Lambda}{\Lambda+m_\pi}\right)^4$$

LNAC : $\rho_S\,\chi_S^N = 0.08\ (\chi_{PS})_{vac}$

With Δ +FF+Pauli : $\rho_S\,\chi_S^N \simeq 0.04 - 0.05\ (\chi_{PS})_{vac}$



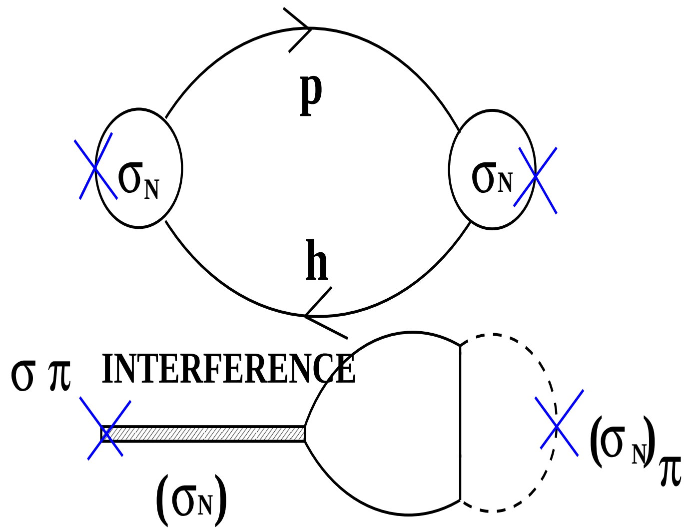
- **Nuclear (p-h) excitation contribution** : Compressibility K

$$\chi_S^{nuclear} = \frac{\sigma_N^2}{2\,m_q^2}\left(\frac{\partial\rho_S}{\partial M}\right)_\mu \equiv \frac{\sigma_N^2}{2\,m_q^2}\left(-\frac{2\,p_F\,M_N^2}{\pi^2}\right)$$

$$\left(-\frac{2\,p_F\,M_N^2}{\pi^2}\right) = \Pi^0_{ph}(\omega=0,\vec{q}\to 0) = -\left(\frac{9\,\rho}{K}\right)_{\rho=\rho_0}$$

Sigma model : $\sigma_N = M_N\,\frac{m^2\pi}{m_\sigma^2} + \sigma_N^{(\pi)}$

$\chi_S^{nuclear} = 0.35\ (\chi_{PS})_{vac}$



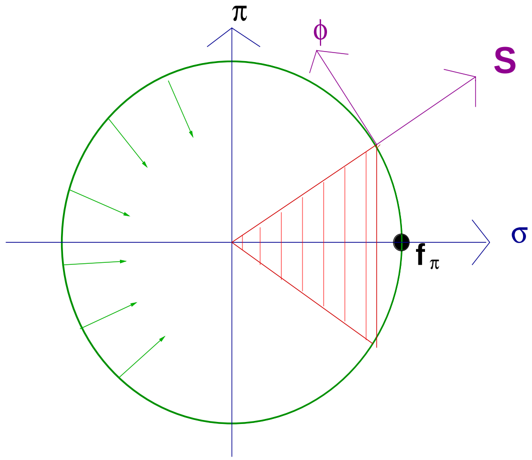
C- SUSCEPTIBILITY IN A CHIRAL EFFECTIVE THEORY

C1- BASICS

- Order parameter : $\mathcal{M} = \left(\frac{\bar{q}\,q}{2}\right) + i\vec{\tau}\cdot\left(i\,\bar{q}\,\gamma_5\,\frac{\vec{\tau}}{2}\,q\right) = \sigma + i\vec{\tau}\cdot\vec{\pi}$

- From Cartesian to Polar coordinates

$$\sigma + i\vec{\tau}\cdot\vec{\pi} = (f_\pi + s\,)\,\exp\left[i\frac{\vec{\tau}\cdot\vec{\phi}}{f_\pi}\,G\left(\frac{\phi^2}{f_\pi^2}\right)\right]$$



– Pion ϕ : phase fluctuation

– Scalar field $s = S - f_\pi$: amplitude fluctuation

– $\frac{\langle\bar{q}q\rangle_{medium}}{\langle\bar{q}q\rangle_{vacuum}} = 1 - \frac{\langle\phi_\pi^2(\rho)\rangle}{2\,f_\pi^2} - \frac{|\langle s(\rho)\rangle|}{f_\pi}$

- Effective Lagrangian

$$\mathcal{L} = i\bar{N}\gamma^\mu\partial_\mu N - M_N^*(s)\bar{N}N + \frac{1}{2}\partial^\mu s\partial_\mu s - \frac{m_\sigma^2 - m_\pi^2}{8f_\pi^2}\left(s^2 + 2f_\pi s + \frac{2f_\pi^2 m_\pi^2}{m_\sigma^2 - m_\pi^2}\right)^2 + \mathcal{L}_\omega + \mathcal{L}_{\pi NN}^{pwave} + \mathcal{L}_\pi + \mathcal{L}_{WT}$$

$$M_N^*(s) = M_N\left(1 + \frac{s}{f_\pi}\right)$$

BUT NO MATTER STABILITY

C2- MATTER STABILITY IN CHIRAL THEORIES

"Shifted" vacuum with chiral order parameter $\bar{S} < f_\pi$

Energy density : $\epsilon(\rho, \bar{S}) = \sum_{p<p_F} \sqrt{p^2 + M_N^*(\bar{S})} + V(\bar{S}) + C_V\, \rho^2$

- NJL (Bentz, Thomas, Birse) : Nucleon $\equiv qq - q$ state. $M_q^* = g_q\, \bar{S}$
- Chiral QHD : $S = f_\pi + s \equiv$ chiral invariant scalar field : $M_N^* = g_{sNN}\, \bar{S}$

$g_{sNN}^*(\bar{S}) = \frac{\partial M_N^*}{\partial \bar{S}}$ drops Needed to stabilize nuclear matter

– NJL : Infrared cutoff : simulate confinement

– QMC : Polarization of the quark WF : nucleon structure

Nuclear saturation vs Nucleon structure and QCD (lattice)

C3- MEAN FIELD : IN-MEDIUM SIGMA MASS AND NUCLEAR SCALAR SUSCEPTIBILITY

- Include the scalar response κ_{NS} of the nucleon to a scalar field

$$M_N^* = M_N \left(1 + \frac{\bar{s}}{f_\pi}\right) + \frac{1}{2}\kappa_{NS}\,\bar{s}^2$$

- Minimization : $\frac{\partial\varepsilon}{\partial\bar{s}} = g_S^*\,\rho_S + V'(\bar{s}) = 0,\quad g_S^*(\bar{s}) = \frac{\partial M_N^*}{\partial\bar{s}}$ drops with ρ
- In-medium sigma mass : $m_\sigma^{*2} = \frac{\partial^2\varepsilon}{\partial\bar{s}^2} = V''(\bar{s}) + \kappa_{NS}\,\rho_S$

- χ_S related to in-medium sigma propagator dressed by ph excitations

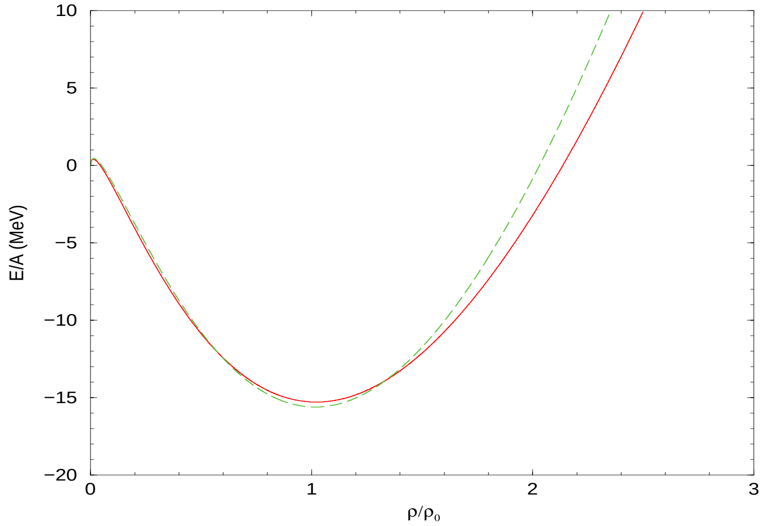
$$\chi_S = -2\,\frac{\langle\bar{q}q\rangle^2_{vac}}{f_\pi^2}\left(-\frac{1}{m_\sigma^{*2}} + \frac{1}{m_\sigma^{*2}}\,\Pi_{SS}(0)\,\frac{1}{m_\sigma^{*2}}\right)$$

$\Pi_{SS}(0)$ is the full scalar polarization propagator (related to K)

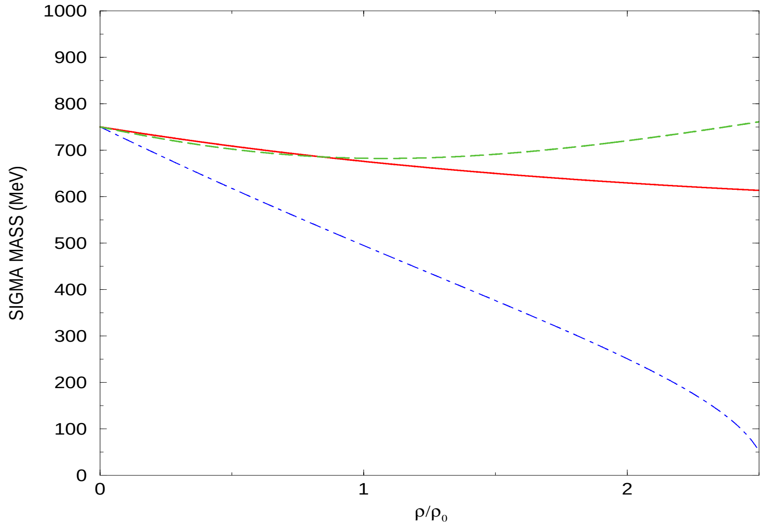
$$\Pi_{SS}(0) = g_S^{*2}\,\frac{M_N^*}{E_F^*}\,\Pi_0(0)\left[1 - \left(\frac{g_\omega^2}{m_\omega^2}\,\frac{E_F^*}{M_N^*} - \frac{g_S^{*2}}{m_\sigma^{*2}}\,\frac{M_N^*}{E_F^*}\right)\Pi_0(0)\right]^{-1}$$

- Parameters : m_σ ($\pi\pi$ phase shifts), g_ω and κ_{NS}

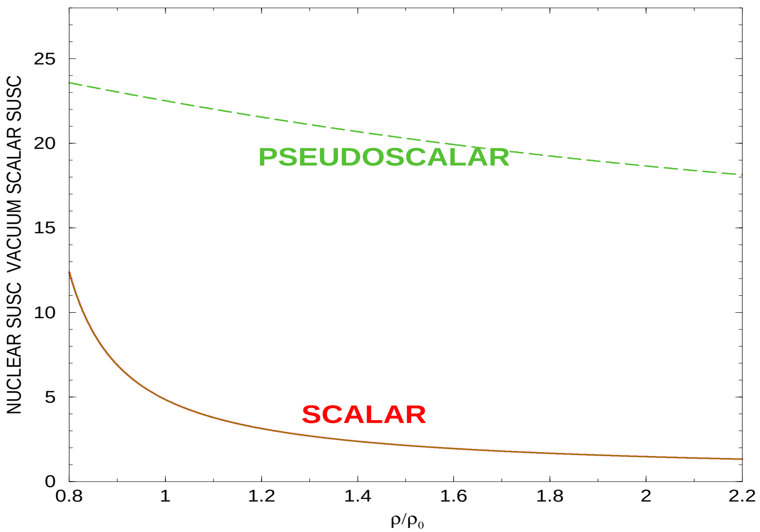
- **2 sets of parameters**



- **In-medium sigma mass**



- **Nuclear susceptibility**



- Nucleon structure effect compensates the chiral dropping !

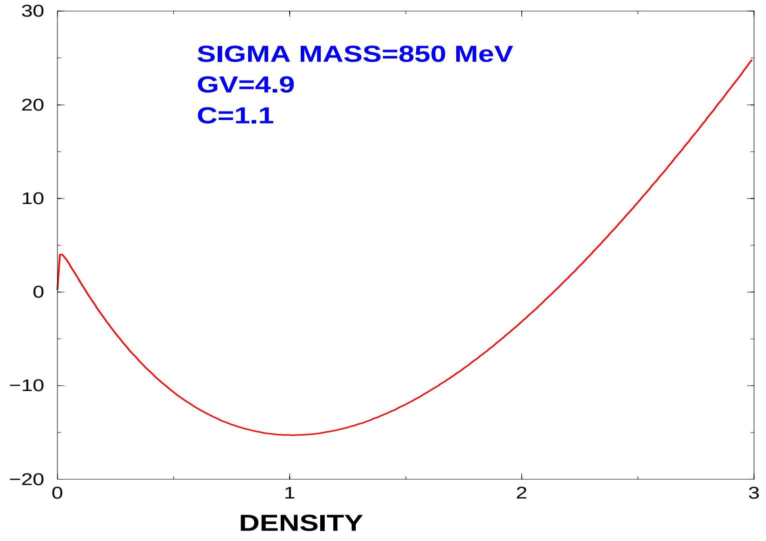
- κ_{NS} Probably too large

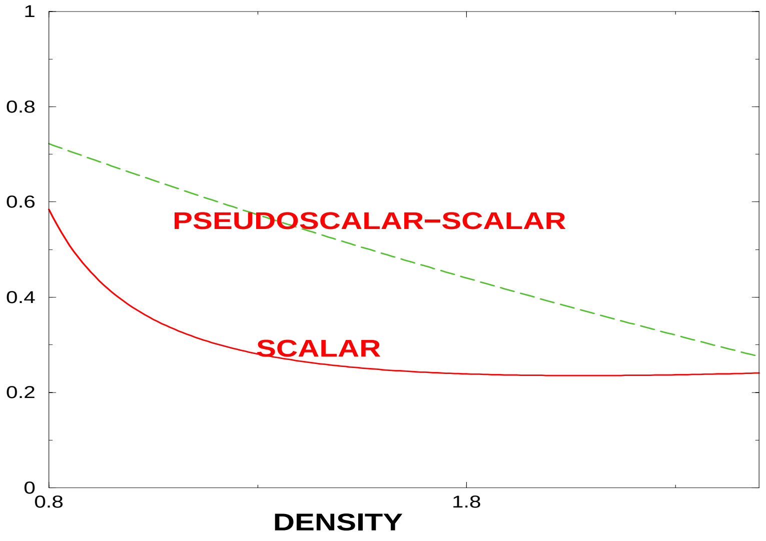
- $\rightarrow$ Introduce pion loops (CHIPT or pionic correlation energy)

• With pionic contribution to the nucleon sigma term and pion Fock term

$$\chi_S = -2\,\frac{\langle\bar{q}q\rangle^2_{vac}}{f_\pi^2}\left(-\frac{1}{m_\sigma^{*2}} + \frac{1}{m_\sigma^{*2}}\left(\frac{\sigma_N^{(\pi)} + \sigma_N^{(\sigma)}}{\sigma_N^{(\sigma)}}\right)^2_{eff}\Pi_{SS}(0)\,\frac{1}{m_\sigma^{*2}}\right)$$

BINDING ENERGY $CHI/CHIPS_{vac}$





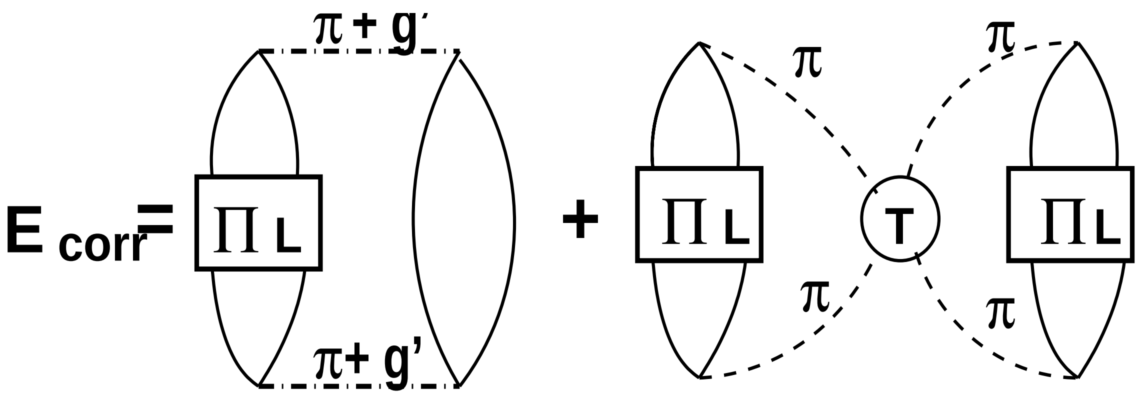
C4- PION CLOUD CONTRIBUTION TO THE IN-MEDIUM SUSCEPTIBILITY : i.e., pion loop or in-medium modified pion cloud contribution to the nucleonic susceptibility

- **Correlation energy** (to be incorporated numerically in the EOS)

$$E_{corr+Fock} = \int_0^1 \frac{d\lambda}{\lambda} \left(\int \frac{id^4q}{(2\pi)^4} \lambda^2 \, D_{0\pi}(q) \, \Pi_L(q;\lambda) \, + \, \lambda^2 \frac{m_\pi^2}{12\, \bar{S}^2} \langle \phi^2 \rangle^2 \right)$$

$\Pi_L(q;\lambda) = \Pi_0(q) / \left(1 \, - \, \lambda^2 \, (g' + V_{\pi exch}) \Pi_0(q)\right)$ is the full longitudinal spin-isospin polarization propagator and $\Pi_0(q)$ is the Lindhardt function including (a slightly in-medium modified) $g_{\pi NN}$

$\langle \phi^2 \rangle = 3 \int \frac{id^4q}{(2\pi)^4} \, \vec{q}^2 \, D^2_{0\pi}(q) \, \Pi_L(q)$ is the in-medium modified pion scalar density.



- **In-medium quark condensate** (Feynman-Hellman theorem)

$$\langle \bar{q}q\rangle^{\pi\, cloud}_{Medium} = \frac{m_\pi^2}{2\, m_q}\frac{\partial E_{corr+Fock}}{\partial m_\pi^2} = -\langle \bar{q}q\rangle_{Vac}\,\frac{\bar{S}}{f_\pi}\,\frac{\langle \phi^2\rangle}{2\,\bar{S}^2}\left(1 + \frac{\langle \phi^2\rangle}{12\,\bar{S}^2}\right) \equiv \frac{1}{2m_q}\,\langle H_{\chi SB}\rangle^{\pi\, cloud}_{Medium}$$

Compatible with χPT at finite T (Gasser-Leutwyler, GC-Ericson-Wambach)

- **Susceptibility from the pion cloud**

$$\chi_S^{\pi\, cloud} = \frac{\partial \langle \bar{q}q\rangle^{\pi\, cloud}_{Medium}}{\partial m_\pi^2} = -2\,\frac{\langle \bar{q}q\rangle^2_{Vac}}{f_\pi^2}\,\frac{\bar{S}}{f_\pi}\,\frac{3}{2\,\bar{S}^2}\left(\frac{G(0) - G_{vac}(0)}{1 - \frac{V_{\pi\pi}}{2}\,G(0)}\right)$$

$G(E) = \int \frac{d\mathbf{q}}{(2\pi)^3}\int \frac{i\, dq_0}{2\pi}\, D_\pi(\mathbf{q}, q_0)\, D_\pi(-\mathbf{q}, E - q_0)$ is the in-medium two-pion propagator (pion dressed by $p - h$ and $\Delta - h$)

RESULTS

- Vacuum : $(\chi_S)_{vac} = 0.04\ (\chi_{PS})_{vac}$

- First order (one p-h insertion) : $\delta\chi_S^{nuclear} = \rho_S\, \chi_S^N = 0.064\ (\chi_{PS})_{vac}$

- Full calculation : (full pion dressing $+\pi\pi$ rescatt.) $\delta\chi_S^{nuclear} = 0.10\ (\chi_{PS})_{vac}$

D- SOME CONSEQUENCES

D1- THE SCALAR SUSCEPTIBILITY AND $\pi\pi$ PRODUCTION

- **The $\pi\pi$ T matrix**

$$T_{\pi\pi}(E) = V_{\pi\pi}(E) + V_{\pi\pi}(E)\, G(E)\, T_{\pi\pi}(E)$$

$$G(E) = \int \frac{d\mathbf{q}}{(2\pi)^3} \int \frac{i\, dq_0}{2\pi}\, D_\pi(\mathbf{q}, q_0)\, D_\pi(-\mathbf{q},\, E - q_0)$$

– $T_{\pi\pi}(E)$ calculable in unitarized χPT (Valencia) or in sigma model (Lyon-Darmstadt) but the medium effects near the 2π threshold are actually independant of the sigma mass if the sigma mass remains stable.

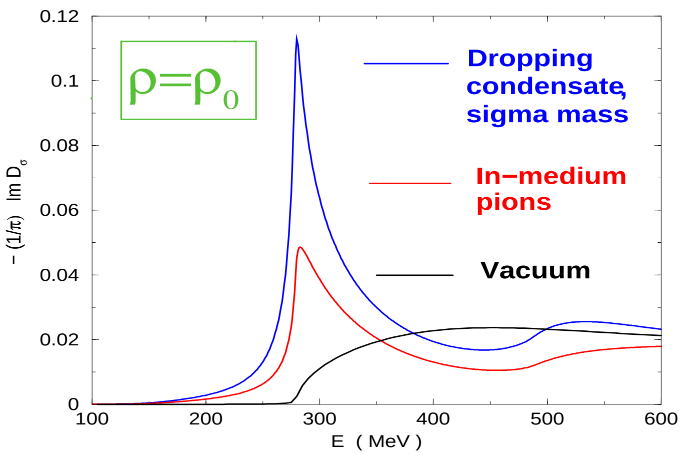
– The medium effects seen in $\pi\pi$ production experiment are embedded in $G(E \simeq 2\, m_\pi)$, the in-medium two-pion propagator (pion dressed by $p - h$ and $\Delta - h$)

– The in-medium modification of the pionic susceptibility is embedded in $G(E = 0)$

Sigma model (phase shifts)

$$T_{\pi\pi}(E) = \frac{6\,\lambda(E^2 - m_\pi^2)}{1 - 3\lambda G(E)}\, D_\sigma(E)$$

$$D_\sigma(E) = (E^2 - m_\sigma^2 - \frac{6\lambda^2 f_\pi^2 G(E)}{1 - 3\lambda G(E)})^{-1}$$



• The full nuclear scalar susceptibility

- The σ (Chiral partner of the π) vs the s (Chiral invariant)
- Strong $\sigma\pi\pi$ coupling weak derivative $s\pi\pi$ coupling
- Express the pion-pion T matrix in terms of either the σ propagator or the s propagator

$$\chi_S = -2\,\frac{\langle\bar{q}q\rangle^2_{vac}}{f_\pi^2}\,D_\sigma(0)$$

$$D_\sigma(E) = D_s(E) + \frac{3}{2\bar{S}_\pi^2}\left(1 - 2\,\frac{E^2-m_\pi^2}{E^2-m_\sigma^2}\right)\tilde{G}$$

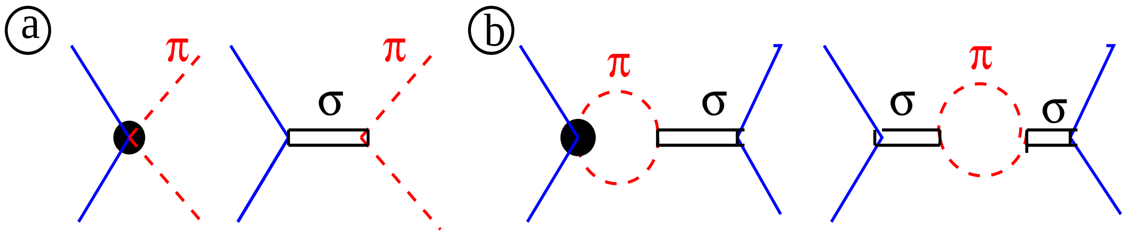
$\tilde{G}$ is the full two-pion propagator : $G = G + \frac{1}{2}\,G\,V_{\pi\pi}\,\tilde{G}$

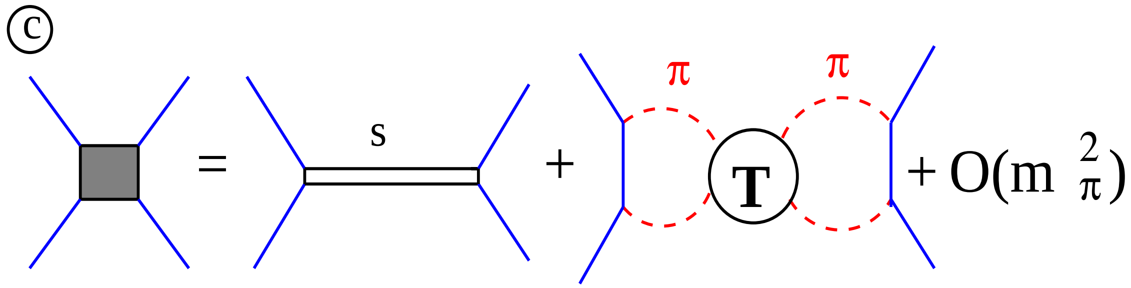
• The chiral invariant s mode is the exchanged meson in the scalar NN potential and is free of pionic many-body effect : weak coupling to in-medium modified 2π states. It couples to (p-h) low energy nuclear excitations and gives the nuclear piece of the susceptibility. This is the sigma meson of nuclear physics.

• The medium effects in the σ propagator and in two-pion processes come from the second 2π modes. It gives the pion cloud piece of the scalar susceptibility.

D2- NUCLEAR PHYSICS IMPLICATIONS : THE NN SCALAR POTENTIAL

Nucleons exchange not only σ but also 2π states with delicate compensations (M. Birse)



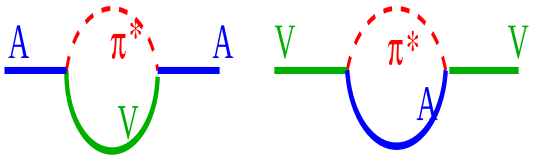


• THE NONLINEAR σ FORMULATION IS MUCH MORE ECONOMICAL

• THE MEDIUM EFFECT IN THE 2π PROCESSES ARE MOSTLY ABSENT IN THE NN SCALAR EXCHANGE

D3- CORRELATOR MIXING

- **Axial-vector mixing**



At finite temperature

$$\Pi_V^{\mu\nu}(q;T) = (1-\epsilon)\,\Pi_V^{\mu\nu}(q;T=0) + \epsilon\,\Pi_A^{\mu\nu}(q;T=0)$$

$$\Pi_A^{\mu\nu}(q;T) = (1-\epsilon)\,\Pi_A^{\mu\nu}(q;T=0) + \epsilon\,\Pi_V^{\mu\nu}(q;T=0)$$

$$\epsilon = \frac{T^2}{6\,f_\pi^2} = \frac{2}{f_\pi^2}\int \frac{d\mathbf{k}}{(2\pi)^3}\,\frac{n(\omega_k)}{\omega_k} = \frac{2}{3}\,\frac{<<\Phi^2>>}{f_\pi^2}$$

Also at finite density (G.C , M. Ericson), (Rapp-Wambach), (Wolf) : Dilepton production

- **Scalar-pseudoscalar mixing**

$$D_\sigma(E) = D_s(E) + \frac{3}{2\bar{S}_\pi^2}\left(1 - 2\,\frac{E^2-m_\pi^2}{E^2-m_\sigma^2}\right) G \qquad D_\sigma(E,T=0) \simeq D_s(E) \simeq 1/E^2 - m_\sigma^2$$

For soft thermal pions, $q << E$:

$$3\,G(E,T) = 3\int \frac{d\mathbf{q}}{(2\pi)^3}\int \frac{i\,dq_0}{2\pi}\,D_\pi(\mathbf{q},q_0)\,D_\pi(-\mathbf{q},\,E-q_0) \simeq \frac{<<\Phi^2>>}{E^2-m_\pi^2}$$

$$D_\sigma(E,T) = \left(1 - \frac{<<\Phi^2>>}{\bar{S}_\pi^2}\right) D_\sigma(E,T=0) + \frac{<<\Phi^2>>}{2\,\bar{S}_\pi^2}\,D_\pi(E,T=0)$$

CONCLUSION

- Sizeable effects in the nuclear scalar susceptibility

- Scalar and pseudoscalar susceptibilities becomes closer $\longrightarrow$ partial chiral restoration

- Nucleon structure effect compensates the chiral dropping of the sigma mass ; related to the p-h piece of the scalar susceptibility

- $\sigma - 2\pi$ medium effects in two-pion processes related to the pionic nuclear scalar susceptibility. Linked to a scalar-pseudoscalar mixing effect associated with partial chiral restoration.

- The chiral invariant s mode couples to (p-h) low energy nuclear excitations and gives the nuclear piece of the susceptibility.

- Extension at higher density and/or temperature. How to constrain the effective theories ? Renormalization group ?