CERN, Geneva, september 17, 2010

G. Chanfray, IPN Lyon, IN2P3/CNRS, Université Lyon 1

Celebration in Honour of
Magda and Torleif 80th Birthday

Pion cloud alar field
and chiral nmetry
in nucle hysics

Local clustering (of theorists)
induced by
by Ericson-Ericson correlations

ANNALS OF PHYSICS: 36, 323–362 (1966)

Optical Properties of Low-Energy Pions in Nuclei

M. Ericson

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AND

T. E. O. Ericson

CERN, Geneva, Switzerland

Intermediate energy physics

- Pion in nuclei, pionic modes in nuclei
- Nuclear (spin-isospin) responses

Pion goldstone boson of broken **Chiral Symmetry**

Order parameter: quark condensate

Neutrino physics

Evolution of the order parameters: quark condensate
Fluctuations of the quark condensate: chiral susceptibility

Scalar field, pion loop and confinement in nuclear physics

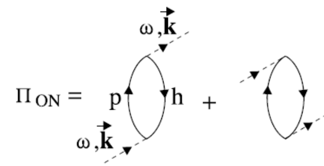
Pion propagation in nuclear matter

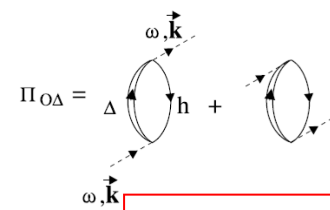
- Ericson-Ericson: analogy with light propagation in matter

  Dipole excitation vs spin-isospin (Delta) excitation

- In-medium pion propagator

$$D(\omega, \mathbf{k}) = \left(\omega^2 - \omega_k^2 - S(\omega, \mathbf{k})\right)^{-1}$$

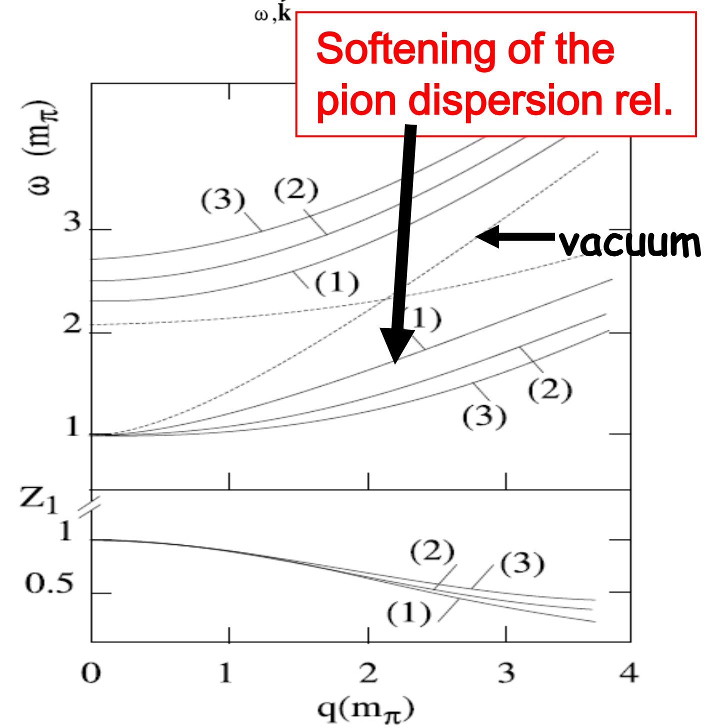




$$S(\omega, \mathbf{k}) = \mathbf{k}^2\, \tilde{\Pi}_0(\omega, \mathbf{k}) \qquad \tilde{\Pi}_0(\omega, \mathbf{k}) = \frac{\Pi_0(\omega, \mathbf{k})}{1 - g'\, \Pi_0(\omega, \mathbf{k})}$$

(EELL)

Not badly approximated by a two-level model



At high energy the strength function is dominated by two (collective) excitations
- The pionic branch Ω_1
- The Delta branch Ω_2

Related quantity: the (longitudinal) spin-isospin response

$$R_L(\omega,\mathbf{k}) = \left(\frac{g_{\pi NN}}{2M_N}\right)^2 v^2(\mathbf{k},\omega)\sum_n |<n|\sum_{i=1}^{i=A}\boldsymbol{\sigma}(i).\mathbf{k}\,\tau_j(i)\,e^{i\mathbf{k}.\mathbf{R}_i}|0>|^2\,\delta(E_n-\omega)$$

HIGH ENERGY SPIN—ISOSPIN MODES IN NUCLEI

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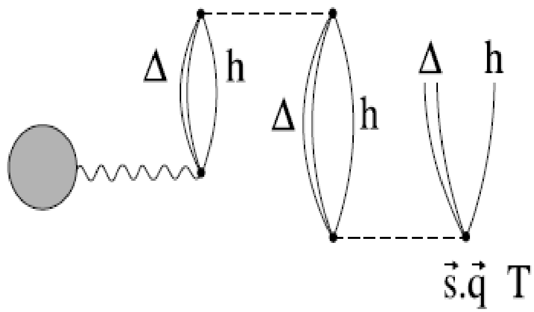
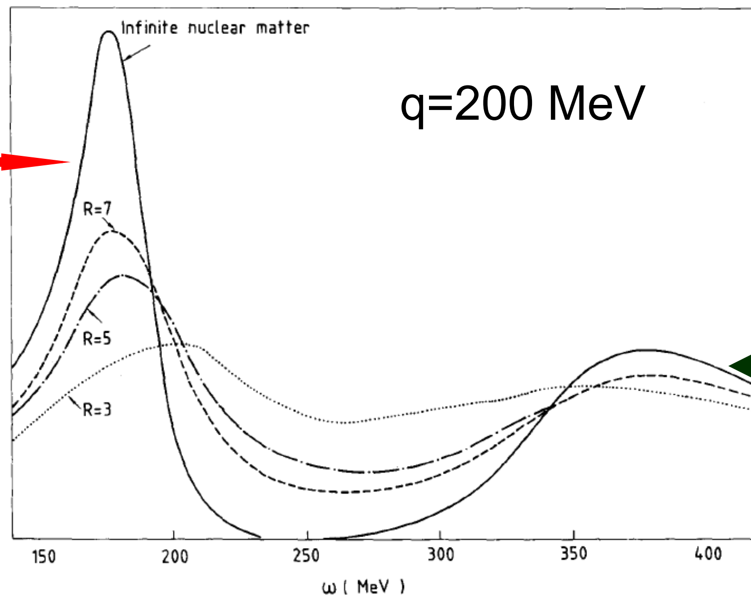
Received 31 January 1984
Revised manuscript received 23 March 1984

The high energy response of nuclei to a spin—isospin excitation is investigated. We predict the existence of a strong con trast between the spin transverse and spin longitudinal responses. The second one undergoes a shadow effect in the Δ re- gion and displays the occurence of the pionic branch.



Finite nuclei calculation

Pionic branch

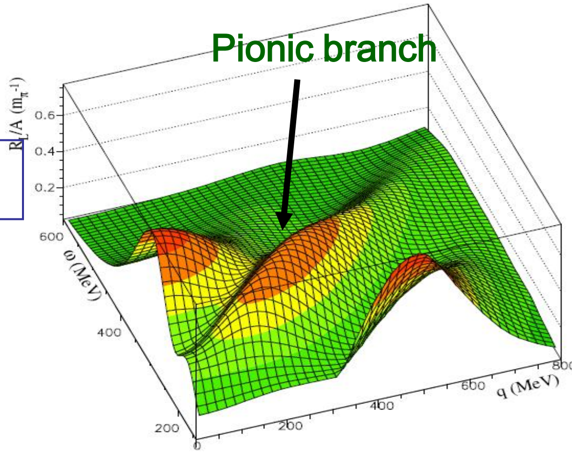


Δ branch

Experimental evidence: (^{3}He,T), SATURNE

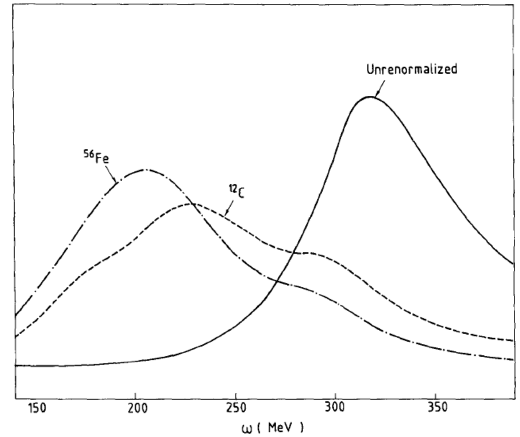
$\omega = 0.812\, q$

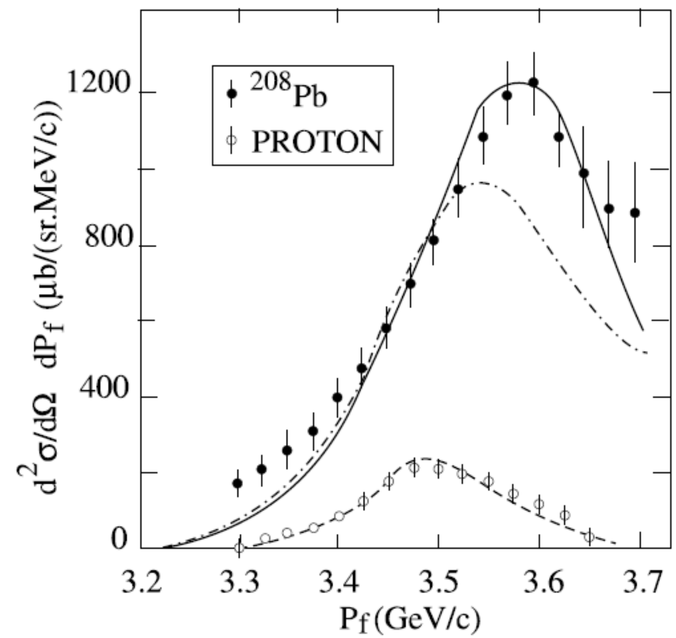
^{16}O



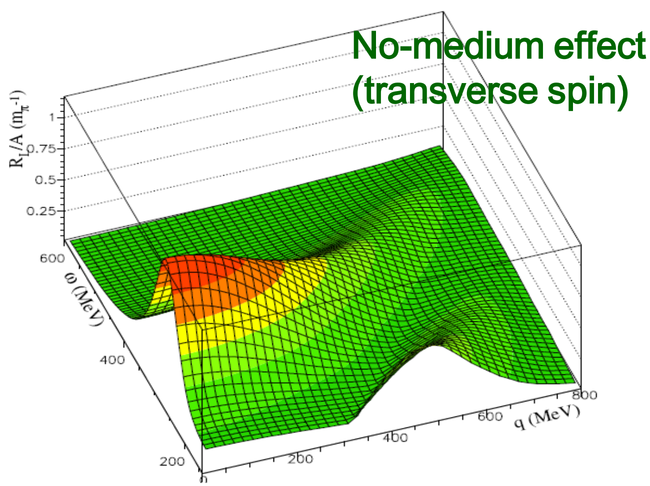
RPA response

J. Delorme
P. Guichon





To be compared with



(^{3}He,T): Shift of the strength attributed to the pionic branch

Response functions

The Role of Two Particle–Two Hole Excitations in the Spin–Isospin Nuclear Response

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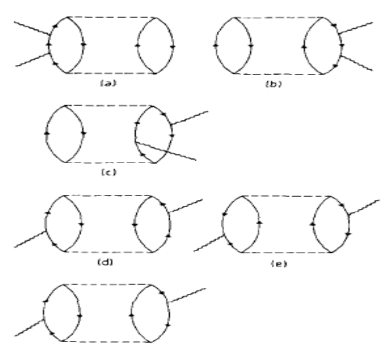
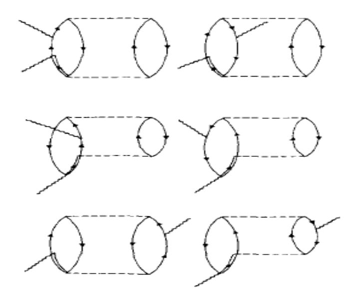
AND

A. MOLINARI

Istituto di Fisica Teorica dell'Università di Torino, Torino, Italy; and INFN, Sezione di Torino, Torino, Italy

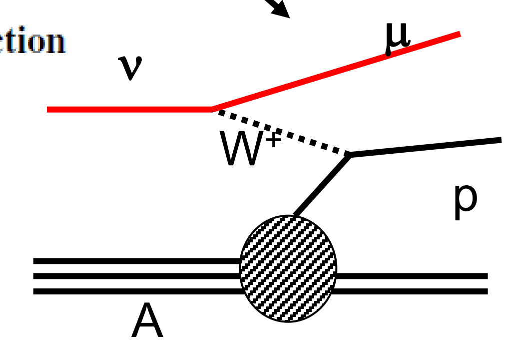
Just a few diagrams !





Neutrino-nucleus interaction

Nucleus as detector for neutrino physics



PHYSICAL REVIEW C **80**, 065501 (2009)

Unified approach for nucleon knock-out and coherent and incoherent pion production in neutrino interactions with nuclei

M. Martini,[1,2,3] M. Ericson,[1,3] G. Chanfray,[1] and J. Marteau[1]

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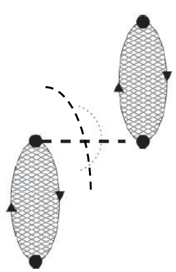
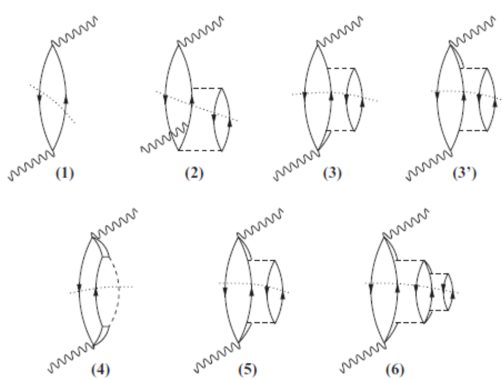
(Received 17 October 2009; published 23 December 2009)

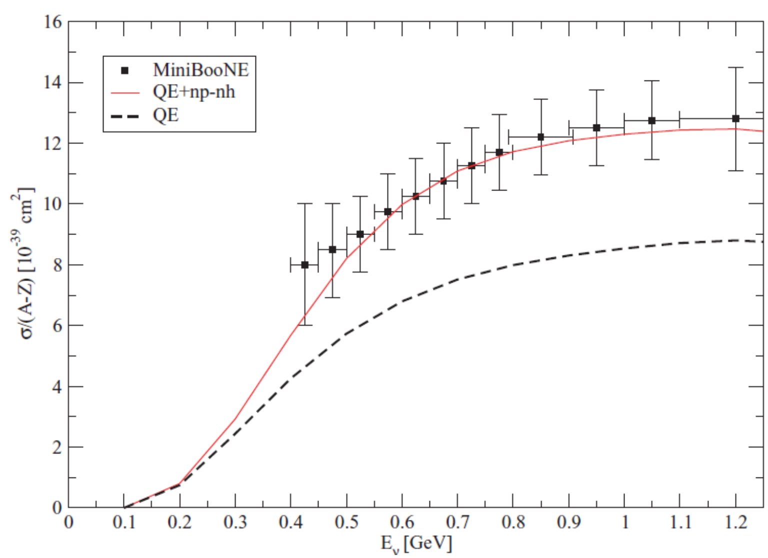
We present a theory of neutrino interactions with nuclei aimed at the description of the partial cross sections, namely quasielastic and multinucleon emission, coherent and incoherent single-pion production. For this purpose,

$$R(\omega, q) = -\frac{\mathcal{V}}{\pi}\mathrm{Im}[\Pi(\omega, q, q)]$$

$$\mathrm{Im}\Pi = |\Pi|^2\,\mathrm{Im}V + |1 + \Pi V|^2\,\mathrm{Im}\Pi^0$$







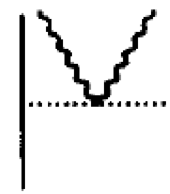
"Quasielastic" ν_μ-^{12}C cross section

Pion cloud and chiral restoration

Eighties : pion content (excess) in nuclei: Collective pionic modes, **EMC effect**

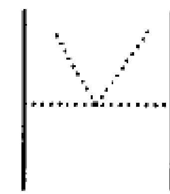
Enhancement factor of the forward compton amplitude on nuclei: from pion cloud (M.E, Rosa-Clot)

$$F_{\text{pion exch}}(0) = \frac{e^2}{4M} K = \frac{4}{3} e^2 n_\pi \left\langle \frac{1}{\omega_\pi} \right\rangle = 2 \frac{e^2}{m_\pi} m_\pi \left\langle \frac{1}{\omega_\pi} \right\rangle \frac{2}{3} n_\pi$$



Soft pion-nucleus amplitude (M.E, G.C)

$$\Sigma_{\text{pion exch}} = 2 \Sigma_\pi m_\pi \left\langle \frac{1}{\omega_\pi} \right\rangle n_\pi = \boxed{\frac{m_\pi^2}{2\rho} < \Phi^2 >}$$



Dropping of the quark condensate

$$\boxed{R = \frac{< A|\bar{q}q|A > (\rho_N)}{< \bar{q}q >} = 1 - \frac{\rho_N \tilde{\Sigma}_A}{f_\pi^2 m_\pi^2}}$$

Full pion nucleon sigma term $\quad \tilde{\Sigma}_A = \frac{1}{A} \langle A | \, Q_i^5, [Q_i^5, H] \, | A \rangle$

Pion cloud contribution $\quad \boxed{\tilde{\Sigma}_A^{(\pi)}} = \frac{1}{A} < A | \int d\mathbf{r} \, \frac{1}{2} m_\pi^2 \, \Phi^2(\mathbf{r}, t=0) | A > = \boxed{\frac{m_\pi^2}{2\rho} < \Phi^2 >}$

Dispersive analysis, pion photoproduction data: $\quad \Sigma_N^{(\pi)} \simeq 30 MeV \quad$ Lattice data (A.W. Thomas)

Eur. Phys. J. A 8, 283–289 (2000)

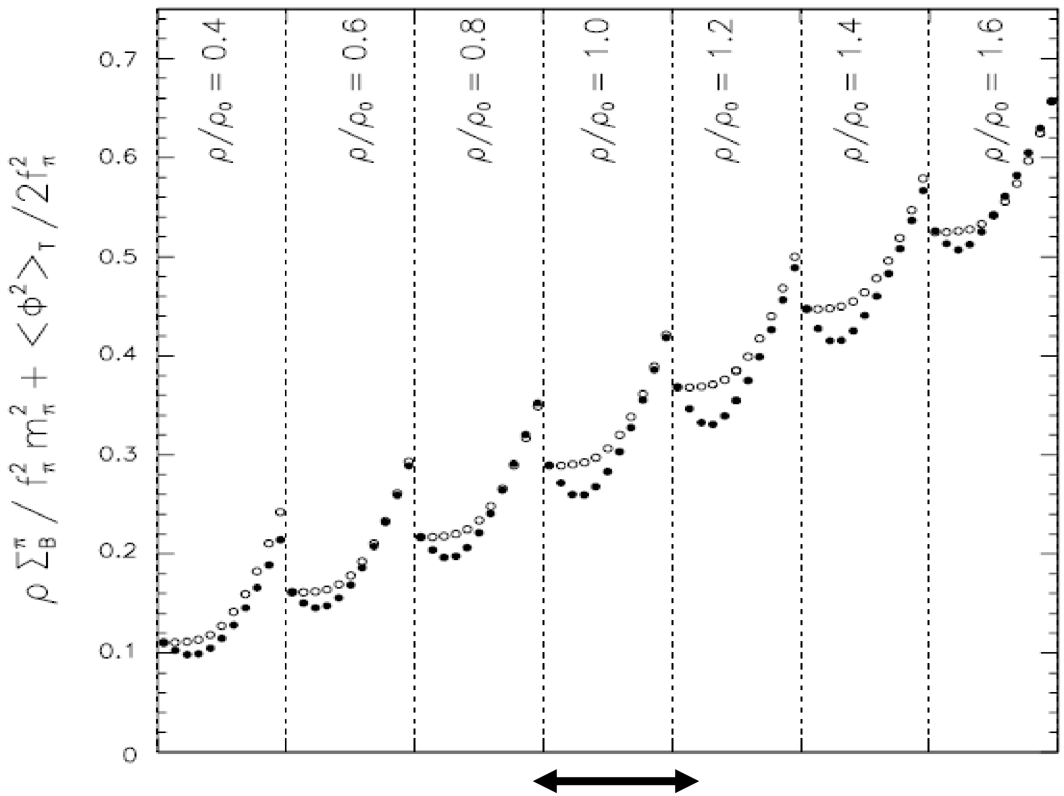
Pion scalar density and chiral symmetry restoration at finite temperature and density

G. Chanfray[1,a], D. Davesne[1], J. Delorme[1], M. Ericson[1,2], and J. Marteau[1]

[1] Institute de Physique Nucléaire de Lyon, IN2P3-CNRS et Université Cl. Bernard, 43, Bvd. du 11 novembre 1918, F-69622 Villeurbanne Cedex, France
[2] CERN, Theory Division, CH-1211 Geneva 23, Switzerland

Relative decrease of the quark condensate

- Virtual pion cloud +Thermal pions



T= 10 to 150 MeV

Scalar susceptibility at finite density

ÉTUDE DES FLUCTUATIONS D'AIMANTATION DANS LE FER AU VOISINAGE DE LA TEMPÉRATURE DE CURIE PAR DIFFUSION DES NEUTRONS

par

Magda ERICSON-GALULA

Soutenues le 17 Décembre 1958 devant la Commission d'examen

MM. PERRIN — Président
GUINIER, FRIEDEL — Examinateurs
NEEL, HERPIN — Invités

$$\chi_m = \frac{\partial M\,(magnetisation)}{\partial B\,(magnetic\,field)}$$

Eur. Phys. J. A **16**, 291–297 (2003)

Fluctuations of the quark densities in nuclei

G. Chanfray[1,a] and M. Ericson[1,2]

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[2] Theory Division, CERN, CH12111 Geneva, Switzerland

$$\chi_S = \frac{\partial \langle \bar{q}q \rangle\;(quark\,condensate)}{\partial m\,(quark\,mass)}$$

- Contribution of low energy nuclear excitations
- Increase the range of scalar density fluctuations

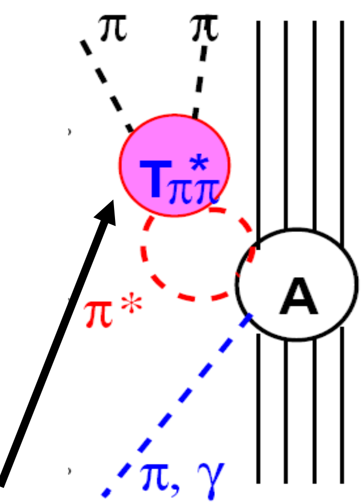
$$\chi_S \approx D_\sigma(0) \approx \frac{1}{m_\sigma^{*2}}$$

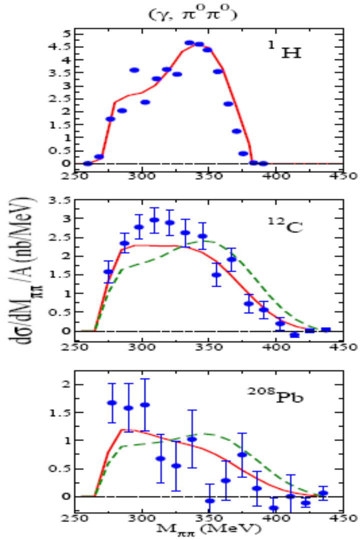
Decrease m^*_σ
Increase χ_S

Two-pion states in nuclear and hadronic matter: Original idea: Softening of the pion dispersion relation: Modification (softening) of the two-pion states

•Scalar-isoscalar modes (σ channel)

Downwards shift ot the strength
(TAPS data, Valencia group calculation)



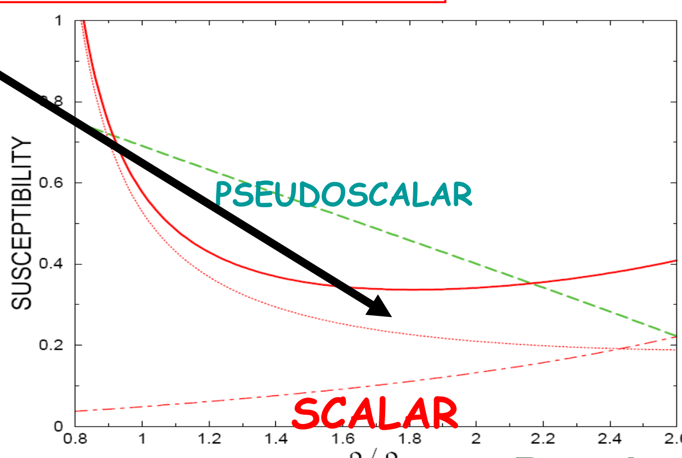


Scalar π–π modes (chiral partner of the pion) softened at finite ρ

Indicator: QCD scalar susceptibility

$$\chi_S = \left(\frac{\partial \langle \bar{q}q \rangle}{\partial m}\right)_\mu \equiv \chi_S^{nuclear} + \chi_S^{pionloop}.$$

Pion loop enhancement

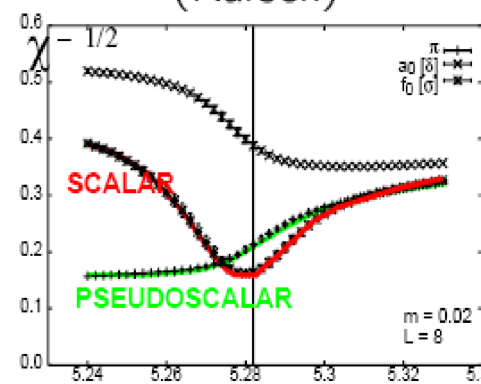


Density

?

Chiral restoration

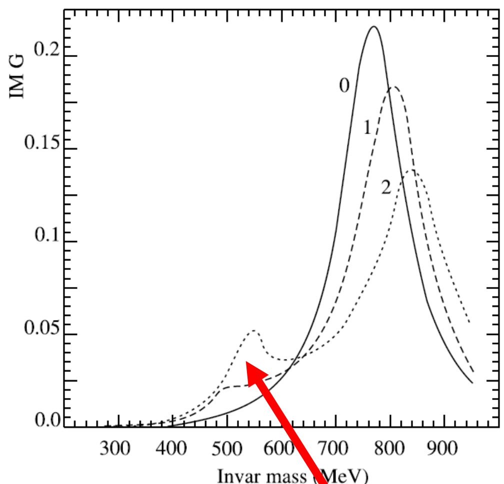
Thermal susceptibilty on Lattice (Karsch)



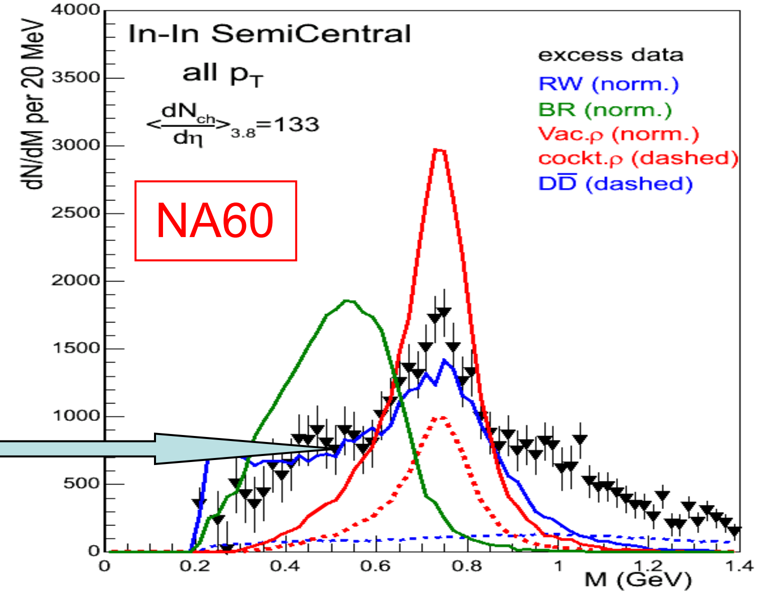
Temperature

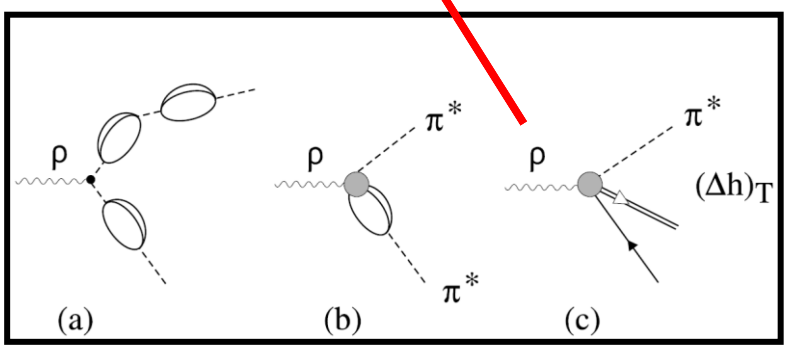
•Vector mesons and axial-vector mixing

Rho meson propagator from the Vector dominance phenomenology

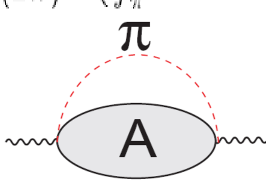


+ direct coupling of the rho to resonances





$$K_{ij}(q) = \int \frac{id^4k_1}{(2\pi)^4}\left(\frac{1}{f_\pi^2}(A_{ij}(k_1)\,D(k_2) + A_{ij}(k_2)\,D(k_1)\right)$$



Mechanism for partial chiral restoration !

Pion number and correlator mixing

G. Chanfray [a], J. Delorme [a], M. Ericson [a,1], M. Rosa-Clot [b]

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[b] *Dipartimento di Fisica, Università di Firenze e INFN, Firenze, Italy*

Received 21 July 1998; received in revised form 8 February 1999
Editor: J.-P. Blaizot

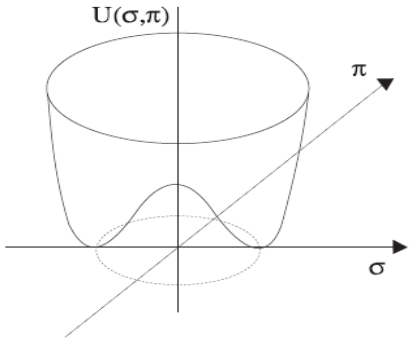
Mixing of Vector correlator with axial vector correlator driven by π cloud

Generalization at finite ρ of Dey-Eletski_-Ioffe

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

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

Scalar field in nuclear physics

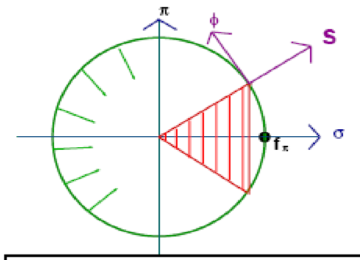


Chiral symmetry and quantum hadrodynamics

G. Chanfray,[1] M. Ericson,[1,2] and P. A. M. Guichon[3]
[1]*IPN Lyon, IN2P3-CNRS et UCB Lyon I, F-69622 Villeurbanne Cedex, France*
[2]*Theory Division, CERN, CH-12111 Geneva, Switzerland*
[3]*SPhN/DAPNIA, CEA-Saclay, F-91191 Gif sur Yvette Cedex, France*
(Received 5 December 2000; published 4 April 2001)

Basic modes: fields associated with fluctuations of the condensate

$$W = S\, exp\left(i\vec{\tau}\cdot\vec{\Phi}/f_\pi\right)$$



THE CHIRAL CIRCLE

Pion Φ (Ξ orthoradial mode): phase fluctuation

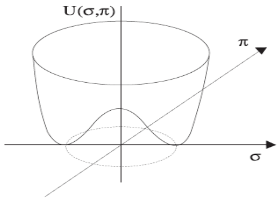
Chiral invariant scalar S field: amplitude (radial) fluctuation

We identify S with the « σ meson » of nuclear physics and relativistic (Walecka) theories, i.e., the background attractive scalar field at the origin of the binding

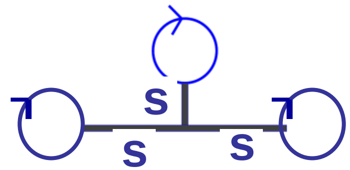
Nuclear medium: « shifted » vacuum characterized by the scalar field S

Coupling of the nucleon $M_N(S)$ to the scalar field : $g_S = \partial M_N / \partial S$

•Problems



Chiral effective potential generates attractive tadpole



Matter instability

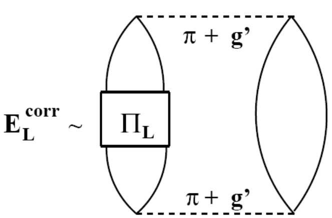
•Cure: The **nucleon reacts** against the nuclear scalar field: **quark confinement mechanism**

$$M_N(s) = M_N + g_S\, s + \frac{1}{2}\kappa_{NS}\, s^2$$

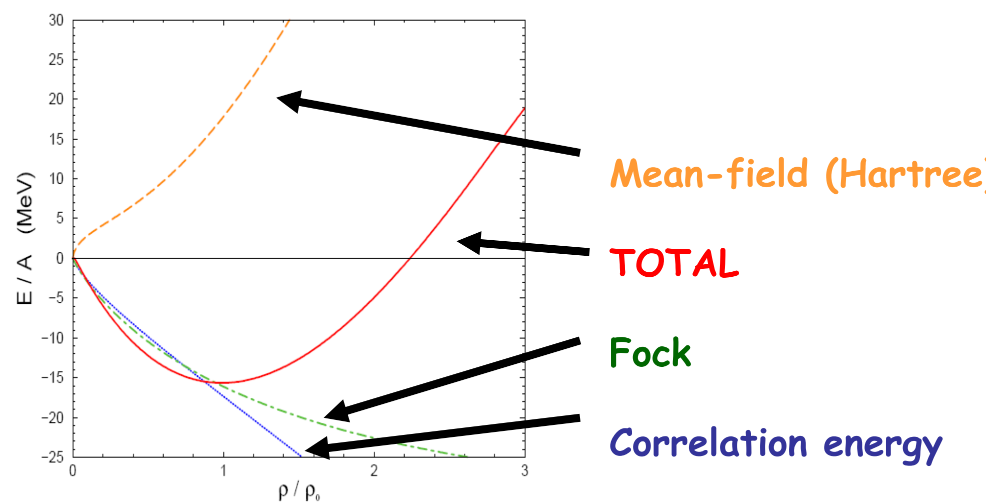
The scalar response of the nucleon generates three-body repulsive forces which stabilize nuclear matter (from lattice, or nucleon modelling)

$$\kappa_{NS} > 0 \quad \Leftrightarrow \quad g_S = \partial M_N / \partial S \quad \text{decreasing function of the nuclear scalar field}$$

Mean-field + Pion loop
+ short range correlation



No true free parameter!



The relevant questions

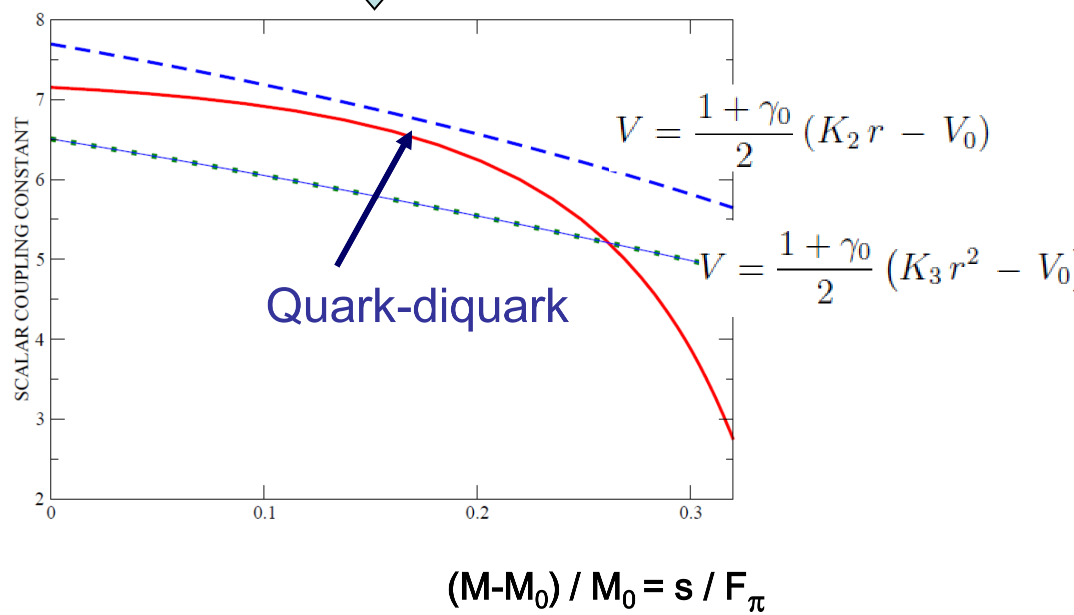
•Status of the background scalar field: difficult to avoid starting from chiral symmetry breaking in vacuum (NJL)

•The real question is its relevance for nuclear matter studies: nucleon structure problem balance between chiral symmetry breaking and confinement in nucleon mass origin

•Pure confinement (bag): the chiral invariant scalar field just decouples from nucleon
•Pure χSB (additive NJL, chiral soliton): no scalar response, no matter stability
•Mixed origin: positive scalar response, **g_S decreases with density**

In short an (important ?) part of the saturation mechanism is associated with the progressive decoupling of the nucleon to the scalar field associated with the dropping of the chiral condensate.

Delicate balance between ChiSB (sufficient binding) and confinement (scalar response)



It was (and still is) a great pleasure
To have been « captured »
by the Ericson-Ericson correlated cluster

Happy birthday,
Magda and Torleif