ISOSPIN EFFECTS on PARTICLE PRODUCTION, FLOWS and PHASE TRANSITIONS at HIGH BARYON DENSITY

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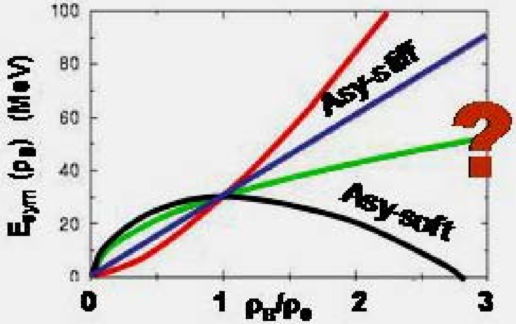
Tentative Plan of the Talk

1. Symmetry Energy
   The problem at High Baryon Density
   Heavy Ion Collisions at $E_{lab} \geq$ 400AMeV

2. n/p, 3H/3He ratio & flows (impact of $m^*_{n,p}$)
   Isospin effects on fragment production
   Relativistic structure of E_{sym}
   Fully Covariant Transport → Lorentz Term
   Symmetry Potential Effects on the Inelastic Channels

3. Isospin effects on the Transition to a Mixed Hadron-Quark Phase at High Baryon Density: Homework
   Strong Isospin Distillation: large asymmetry in the Quark Phase
   Implementation in the Transport Codes → Signatures?

EUROPEAN
SCIENCE
FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE



HiDeSymE

Symmetry Energy

Mass Formula

$$E(A,Z) = a_v A - a_s A^{2/3} - a_C Z(Z-1)A^{-1/3} - a_I (N-Z)^2 / A + \delta_{pair}$$

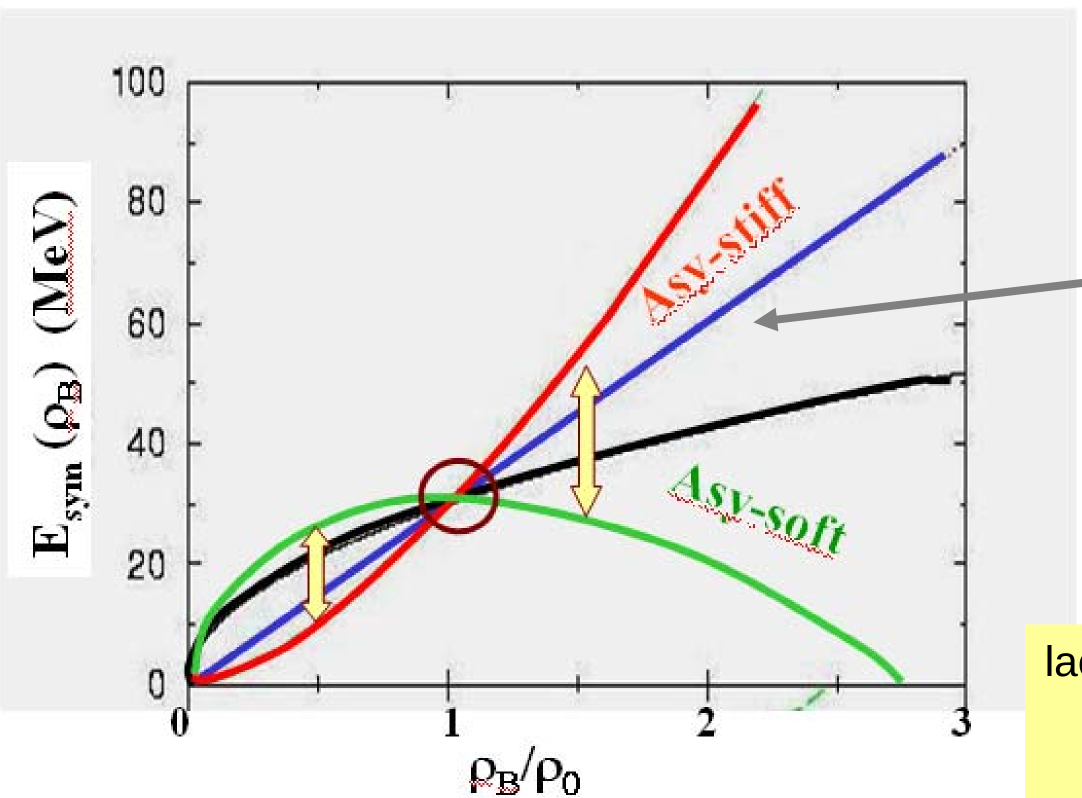
Density dependence of E_{sym}, .i.e. -> EOS for any n,p content

$$E(\rho_B,\alpha) = E(\rho_B) + E_{sym}(\rho_B)\alpha^2 + O(\alpha^4) + \ldots$$

$$E_{sym} = \frac{1}{2}\frac{\partial^2 E}{\partial \alpha^2}\bigg|_{\alpha=0}$$

$$\alpha = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

Effective interactions



High density/energy Probes

- n/p and LCP ratios
- isospin flows
- fragment isospin content
- pion flow and ratios
- kaon ratios
- neutron stars
- ….

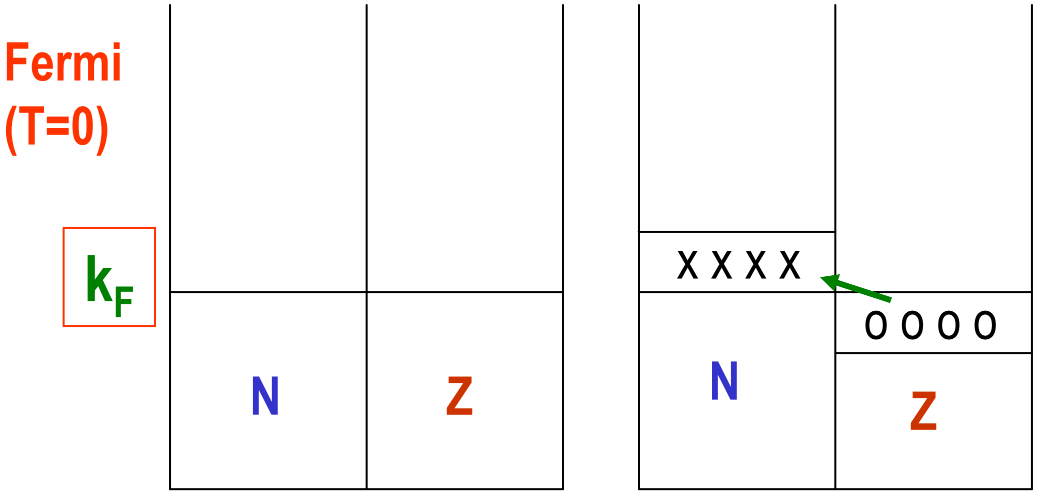
lack of data, but…CHIMERA+LAND at GSI
SAMURAI at RIKEN
Cooling Storage Ring at Lanzhou

Symmetry Energy

$$E/A(\rho) = E(\rho) + E_{sym}(\rho) I^2$$

$I=(N-Z)/A$

Symmetric → Asymmetric



$\approx \varepsilon_F/3 \sim \rho^{2/3}$

Interaction (nucleon sector)

Two-body $\sim \rho$, many-body correlations?

→ search for $\sim \rho^{\gamma}$

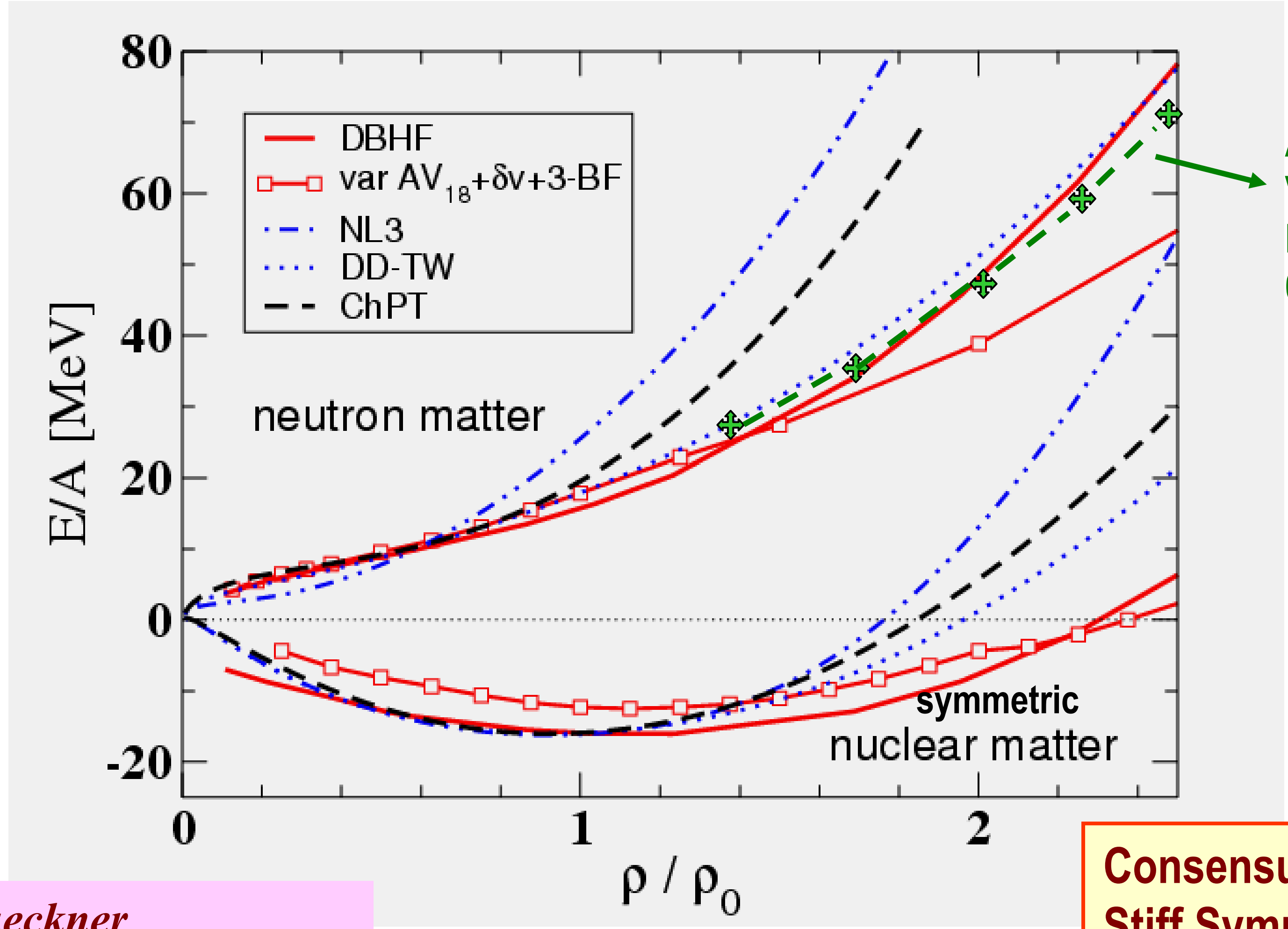
but γ can be density dependent…

→ momentum dependence?

neutron/proton mass splitting

a_4 term (~30MeV) of the Weiszäcker Mass Formula:
at saturation E_{sym}(Fermi) $\approx$ E_{sym}(Interaction)

EOS of Symmetric and Neutron Matter



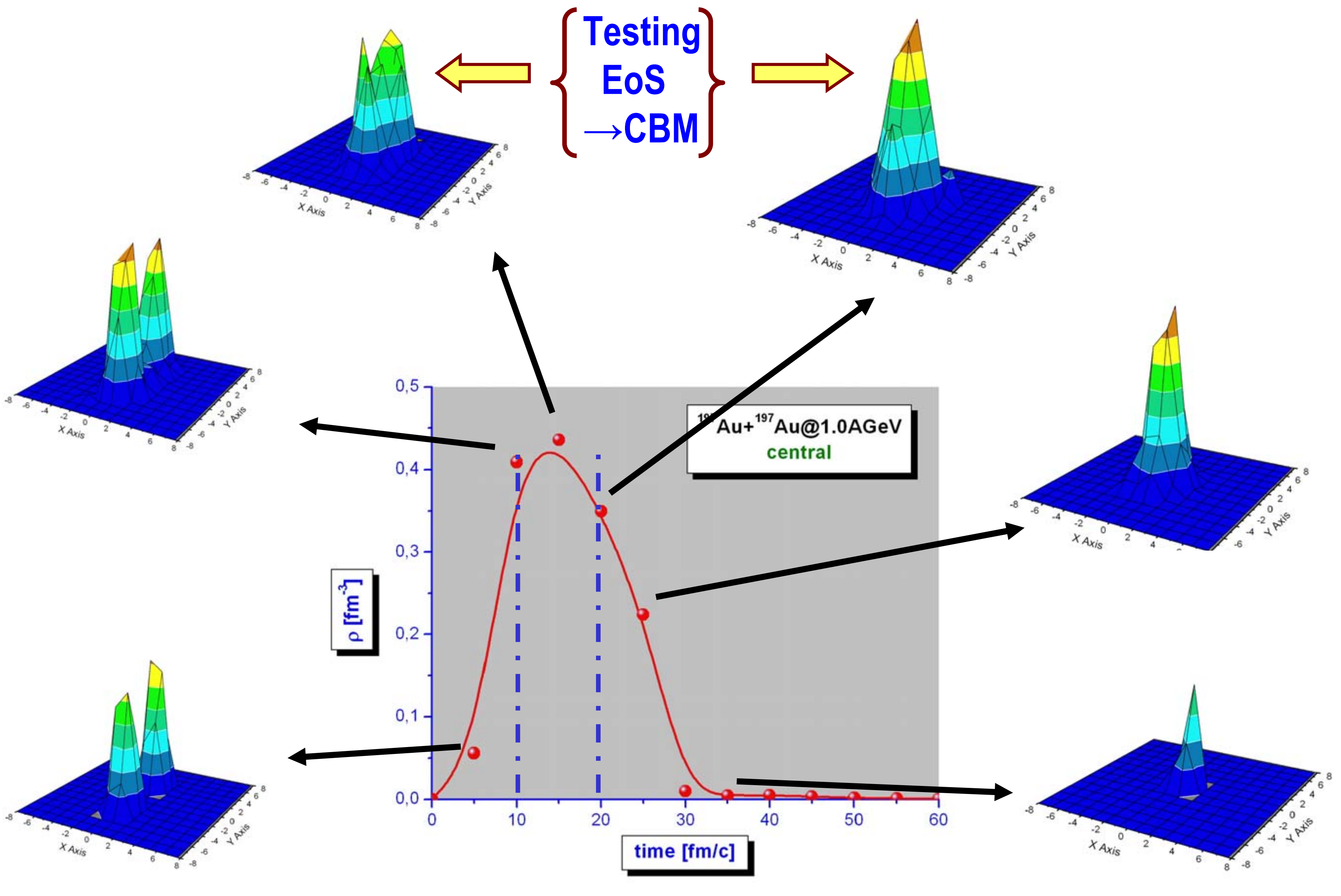
AFDMC
V8'+3body
Fantoni et al
0807.5043

Dirac-Brueckner
Variational+3-body(non-rel.)
RMF(NL3)
Density-Dependent couplings
Chiral Perturbative

Consensus on a Stiff Symmetry Term at high density?

Ch.Fuchs, H.H.Wolter, WCI Final Report
EPJA 30 (2006) 5-21

Au+Au 1AGeV central: Phase Space Evolution in a CM cell



ISOSPIN EMISSION & COLLECTIVE FLOWS:

- Checking the symmetry repulsion and

the n,p splitting of effective masses

High p_T selections: - source at higher density
- squeeze-out

The Boltzmann-Nordheim-Vlasov equation with a non local potential

$$\langle \vec{p} | V | \vec{p}\,' \rangle = \int \frac{d\vec{r}}{(2\pi\hbar)^3} \exp\left[\frac{-i}{\hbar} (\vec{p} - \vec{p}\,') \cdot \vec{r} \right] V_{12}(\vec{r})$$

$V_{12}(r)$ form factor: Yukawa……

The BNV equation becomes:

$$\frac{\partial f}{\partial t} + \left(\frac{\vec{p}}{m} + \vec{\nabla}_{\vec{p}} U(f) \right) \cdot \vec{\nabla}_{\vec{r}} f - \vec{\nabla}_{\vec{r}} U(f) \cdot \vec{\nabla}_{\vec{p}} f = I_{coll}(f)$$

$$m^* = \frac{p_F}{\frac{p_F}{m} + \left.\frac{\partial U}{\partial p}\right|_{p=p_F}}$$

← local

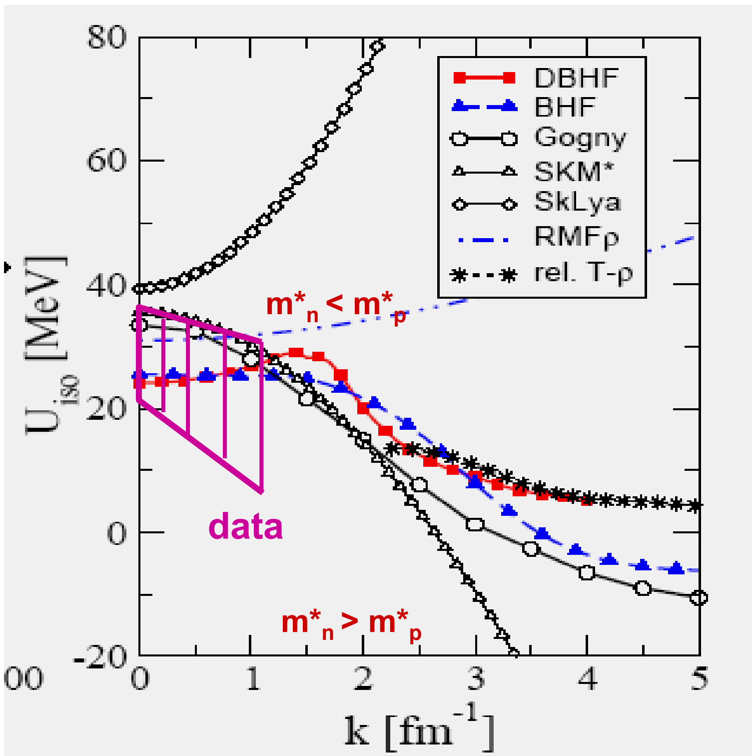
Momentum dependence : non-relativistic code → mass-splitting effects

Mean Field

$$
\begin{aligned}
U(\rho,\delta,\mathbf{p},\tau) \;=\; & A_u(x)\frac{\rho_{\tau'}}{\rho_0} + A_l(x)\frac{\rho_\tau}{\rho_0} \\
& + B\left(\frac{\rho}{\rho_0}\right)^{\sigma}(1 - x\delta^2) - 8x\tau\frac{B}{\sigma+1}\frac{\rho^{\sigma-1}}{\rho_0^{\sigma}}\delta\rho_{\tau'} \\
& + \frac{2C_{\tau,\tau}}{\rho_0}\int d^3\mathbf{p}'\frac{f_\tau(\mathbf{r},\mathbf{p}')}{1+(\mathbf{p}-\mathbf{p}')^2/\Lambda^2} \\
& + \frac{2C_{\tau,\tau'}}{\rho_0}\int d^3\mathbf{p}'\frac{f_{\tau'}(\mathbf{r},\mathbf{p}')}{1+(\mathbf{p}-\mathbf{p}')^2/\Lambda^2}. \qquad (1)
\end{aligned}
$$

Symmetry energy

$$
\begin{aligned}
E_{sym}(\rho) = & \frac{1}{2}\left(\frac{\partial^2 E}{\partial\delta^2}\right)_{\delta=0} \\
= & \frac{8\pi}{9mh^3\rho}p_f^5 + \frac{\rho}{4\rho_0}(A_l(x) - A_u(x)) - \frac{Bx}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} \\
& + \frac{C_l}{9\rho_0\rho}\left(\frac{4\pi}{h^3}\right)^2\Lambda^2\left[4p_f^4 - \Lambda^2 p_f^2\ln\frac{4p_f^2+\Lambda^2}{\Lambda^2}\right] \\
& + \frac{C_u}{9\rho_0\rho}\left(\frac{4\pi}{h^3}\right)^2\Lambda^2\left[4p_f^4 - p_f^2(4p_f^2+\Lambda^2)\ln\frac{4p_f^2+\Lambda^2}{\Lambda^2}\right]
\end{aligned}
$$



Gives a different contribution at equilibrium but in HIC $\mathbf{E_{sym}^{pot}(\rho,k)}$

-> $m^*_p \neq m^*_n$

$$
\frac{m_q^*}{m} = \left[1 + \frac{m}{\hbar^2 k}\frac{\partial U_q}{\partial k}\right]^{-1}
$$

RMFT-SkLya opposite behavior, but there are several sources of MD…

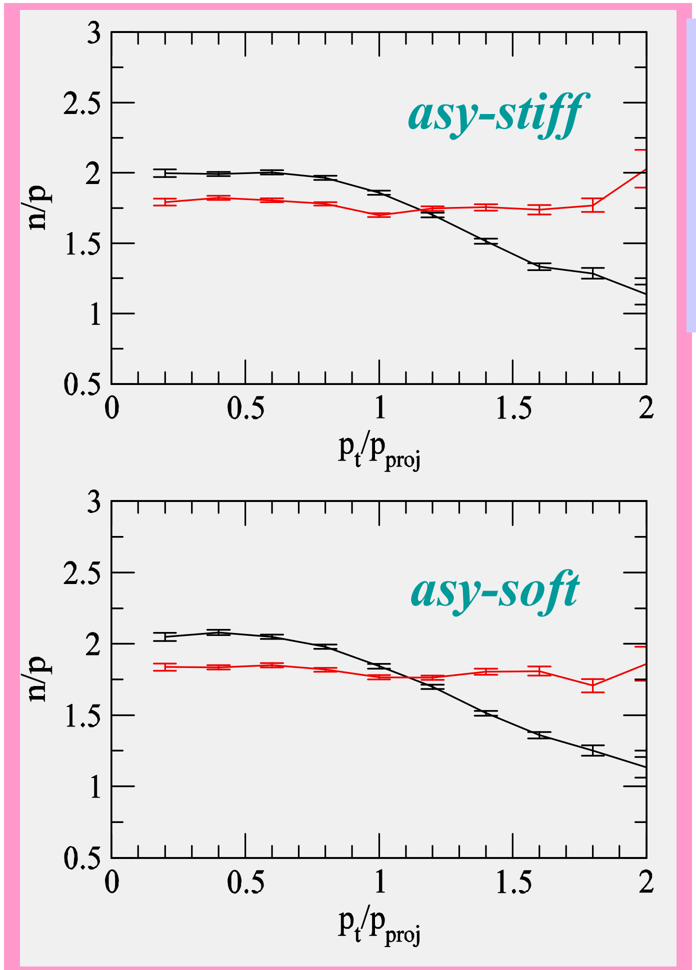
Lane potential

$$
U_{Lane}(k) = \frac{1}{2I}(U_{neutr} - U_{prot})
$$

MSU-RIA05/nucl-th/0505013, NPA 806 (2008) 79-104 (Isospin Equilibration)

Mass splitting: N/Z of Fast Nucleon Emission

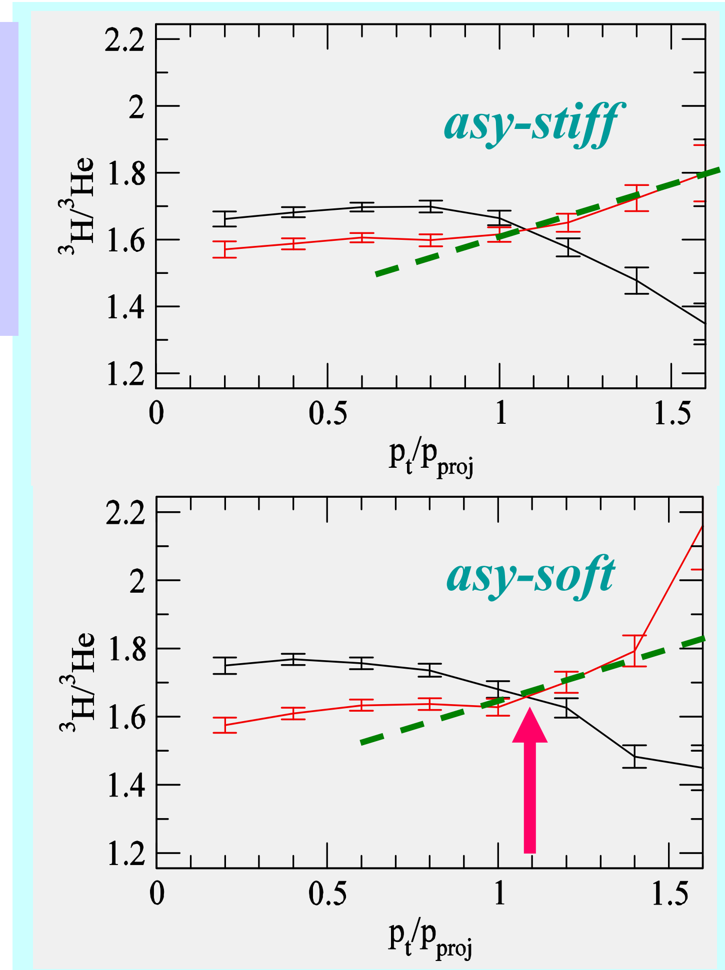
n/p ratio yields



^{197}Au+^{197}Au
600 AMeV
b=5 fm,
y(0)≤0.3
(squeeze-out)

- $m^*_n > m^*_p$
- $m^*_n < m^*_p$

Light isobar $^3H/^3He$ yields



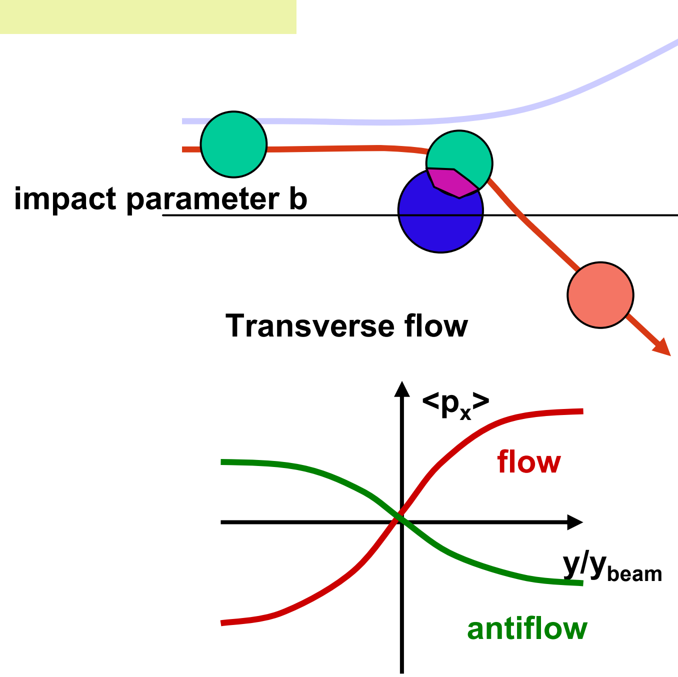
Observable very sensitive at high p_T
to the mass splitting and not to the asy-stiffness

Crossing of
the symmetry potentials for
a matter at $\rho \approx 1.7\,\rho_0$

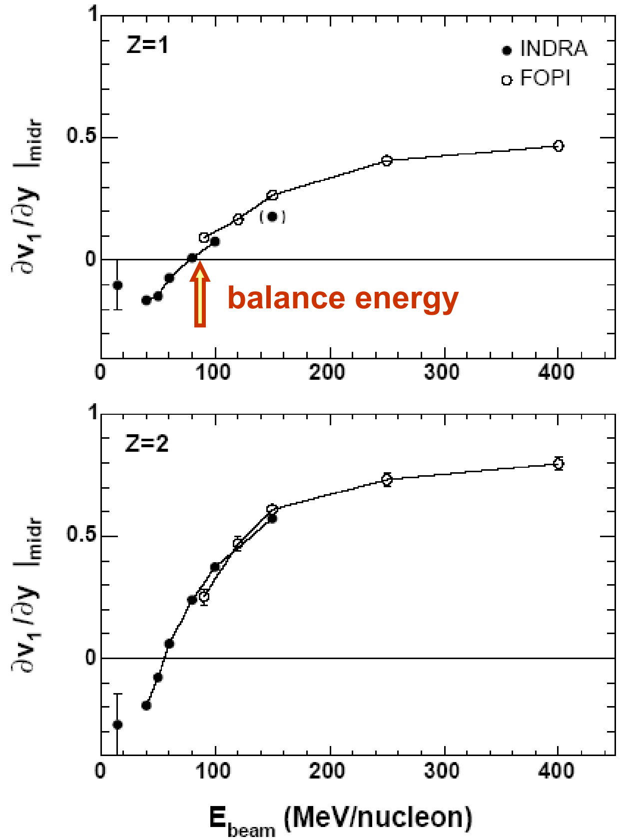
Transverse flow:

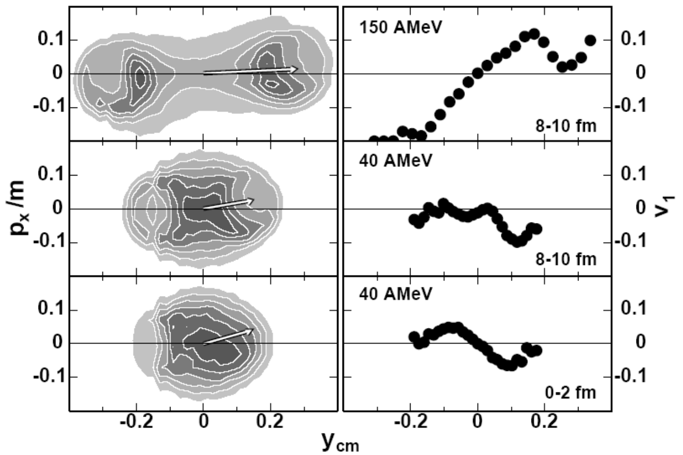
A probe for mean field behaviour, i.e. for EOS

$$V_1(y, p_t) = \langle p_x \rangle / \langle p_t \rangle_y$$



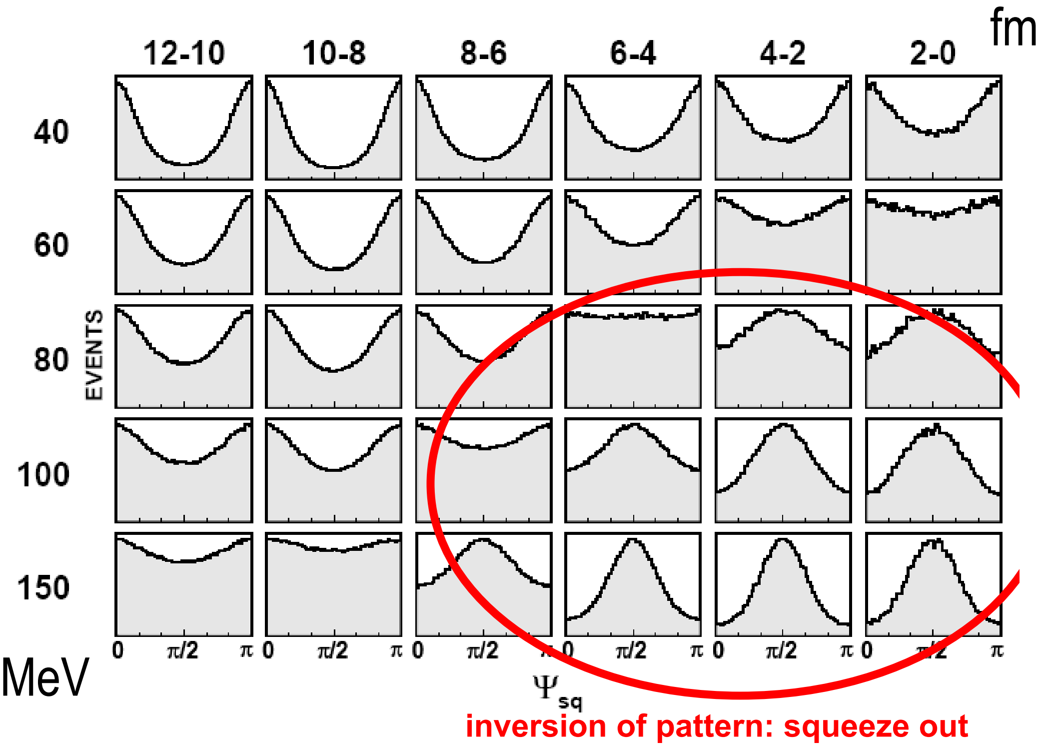
Beam energy dependence:





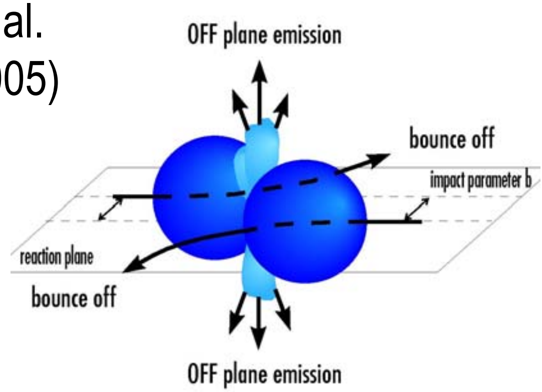
Elliptic flow

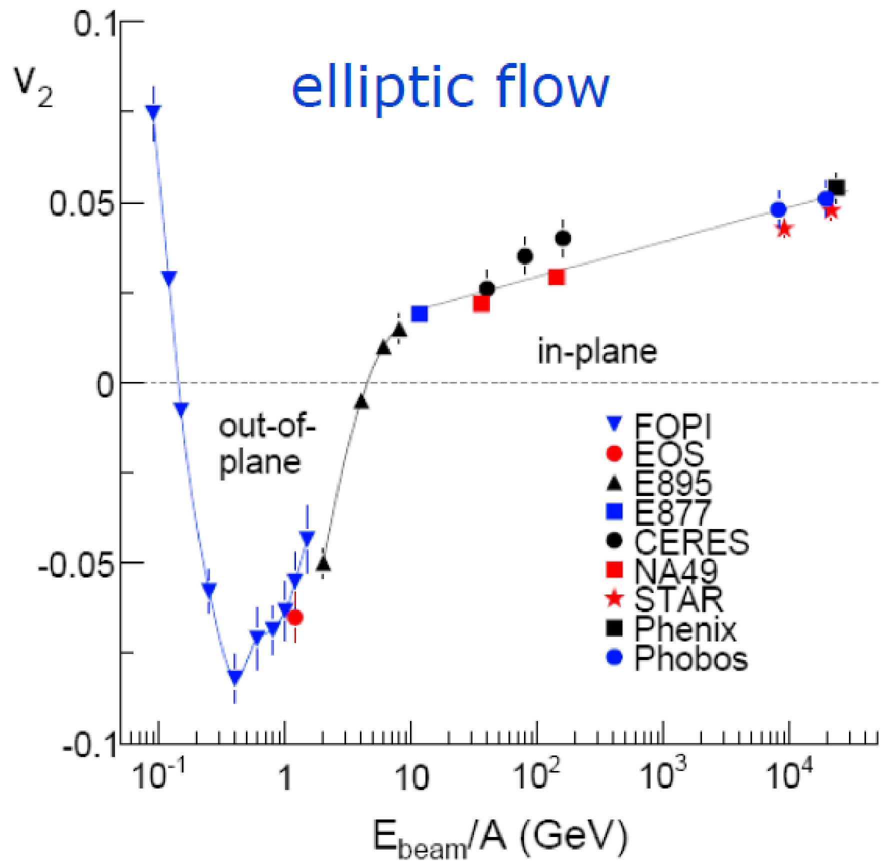
Evolution with impact parameter and energy



$$V_2(y, p_t) = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle_y$$

J.Lukasic et al.
PLB 606 (2005)





Mass splitting impact on Elliptic Flow

$^{197}Au+^{197}Au$, 400 AMeV, b=5 fm

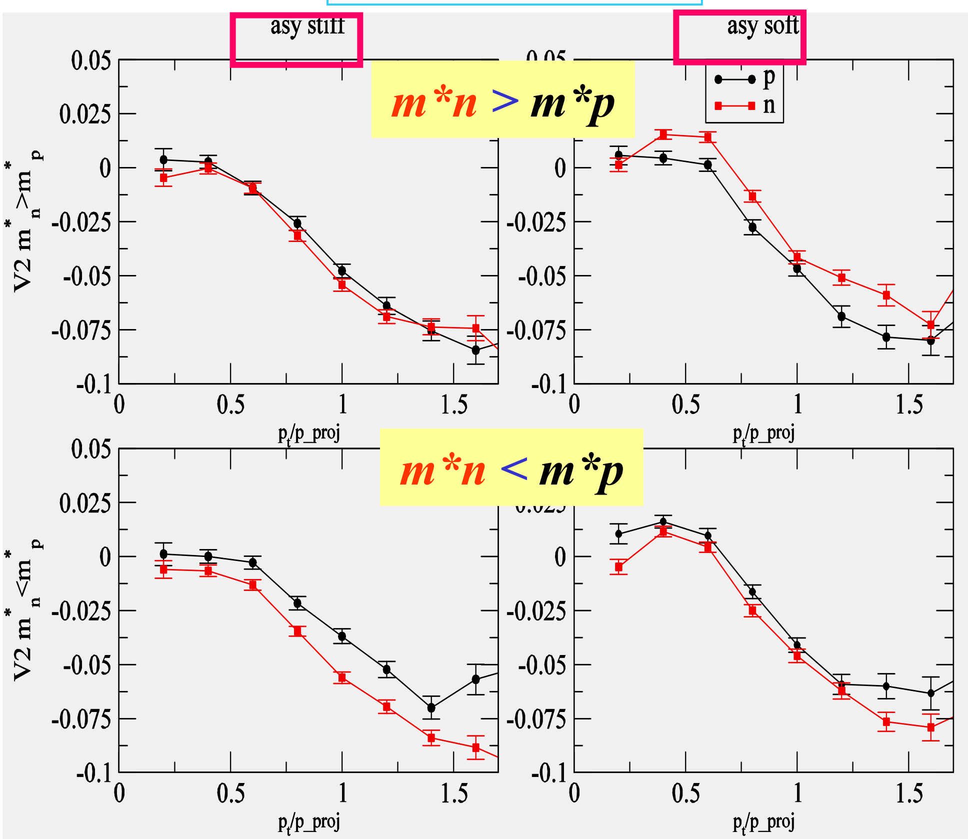
V.Giordano, ECT* May 09

$m^*_n<m^*_p$: larger neutron squeeze out at mid-rapidity

- Larger neutron repulsion for asy-stiff

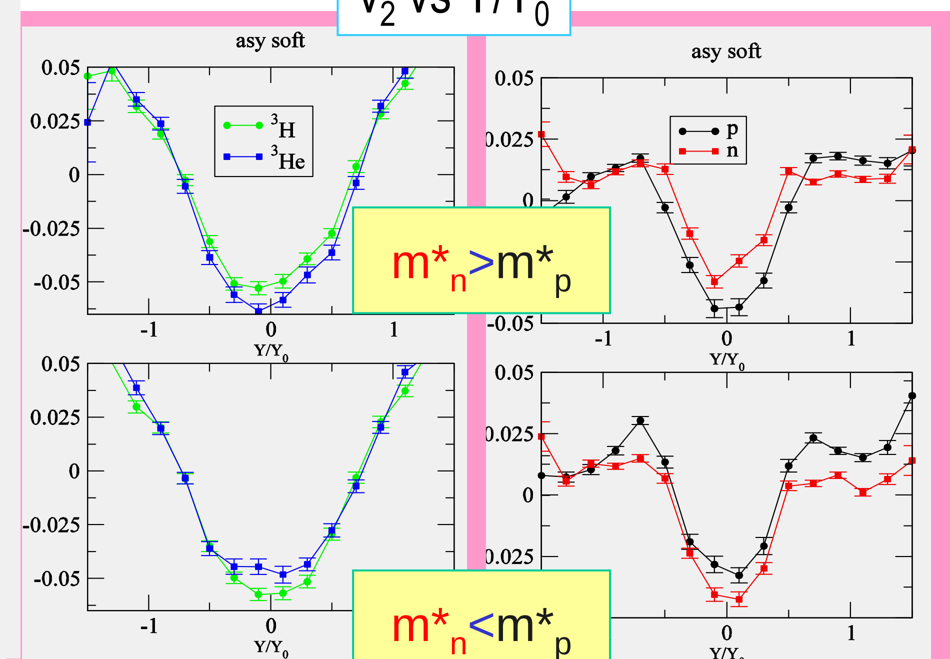
Increasing relevance of isospin effects for $m^*_n<m^*_p$

v_2 vs p_T , $y^{(0)}\leq 0.5$



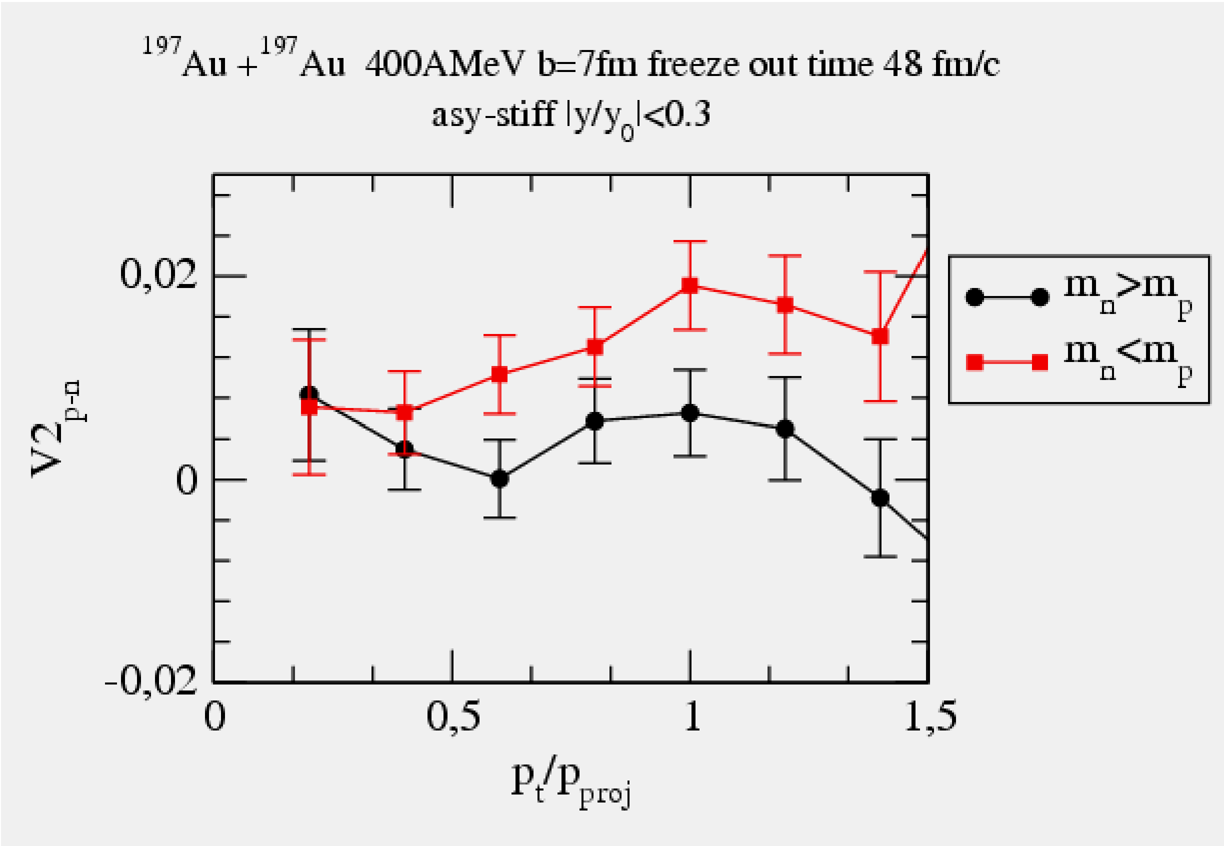
v_2 vs rapidity for ^3H and ^3He: Larger flow but less isospin effects

v_2 vs Y/Y_0



Au+Au 400AMeV Semicentral

Elliptic proton-neutron flow difference vs p_t at mid-rapidity



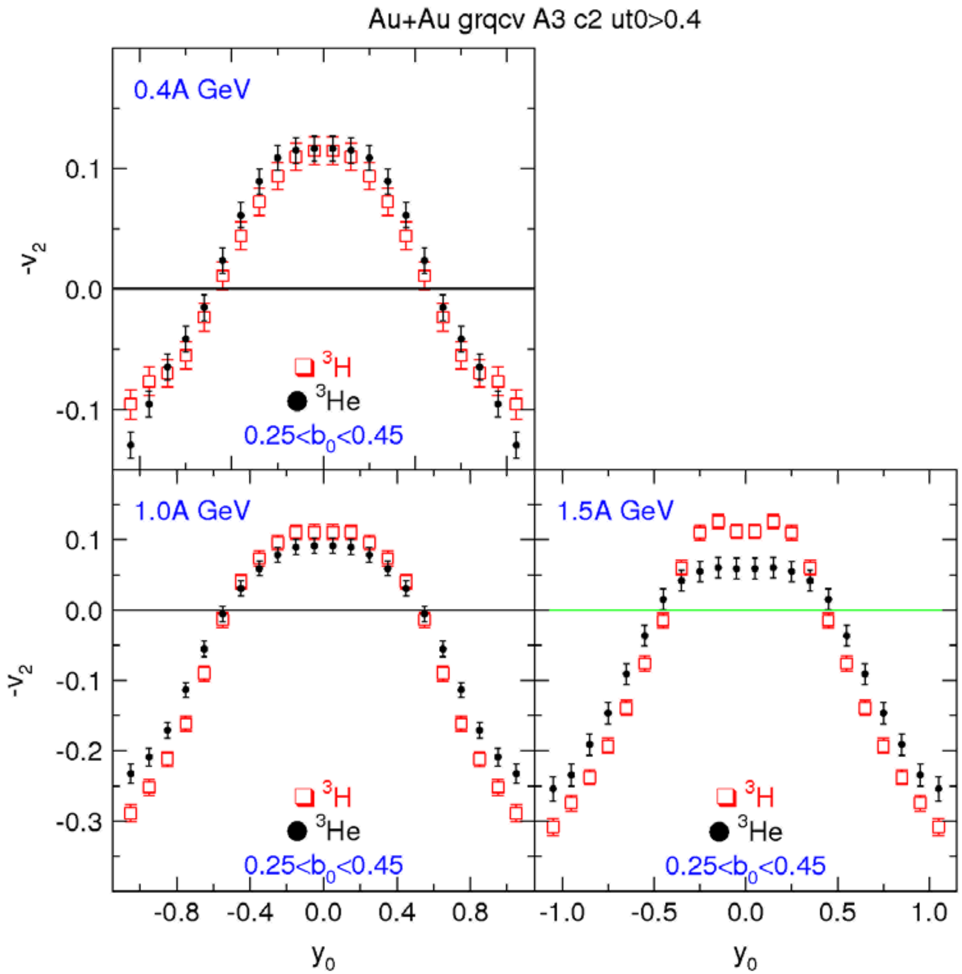
+ relativistic Lorentz force…..(vector charged meson)

Pure Mean Field Effect: no influence of the mass splitting on the elastic NN cross sections

Q.Li, C.Shen, M.Di Toro, arXiv:0908.2825

W.Reisdorf, ECT* May 09: FOPI 3H-3He V2 Results
Au+Au with increasing beam energy

Hunting isospin with v_2 : the mass 3 pair

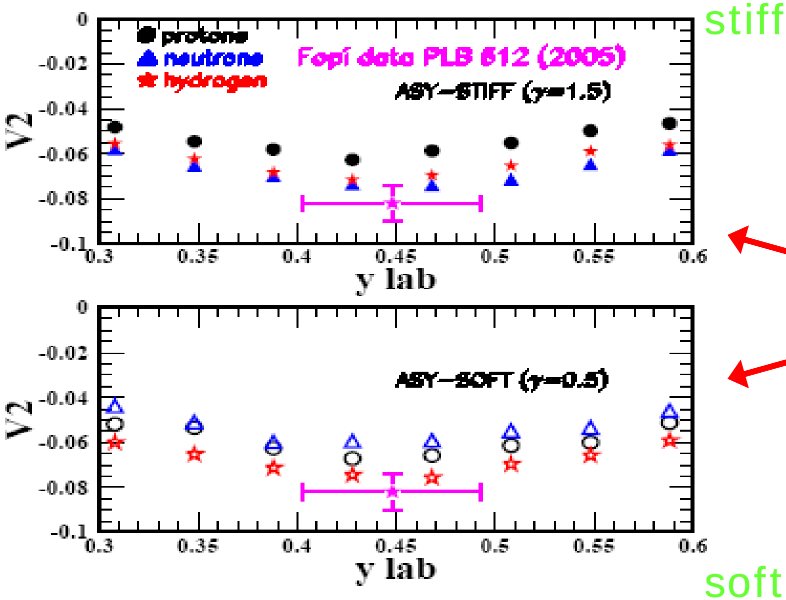


A small gradual change in
The difference ^{3}H-^{3}He when
Raising the beam energy for
Au+Au (N/Z = 1.5)

Relativistic Lorentz effect?

Early FOPI data (Y. Leifels) and ASY_EOS Collaboration:

H.Wolter
ECT* May 09

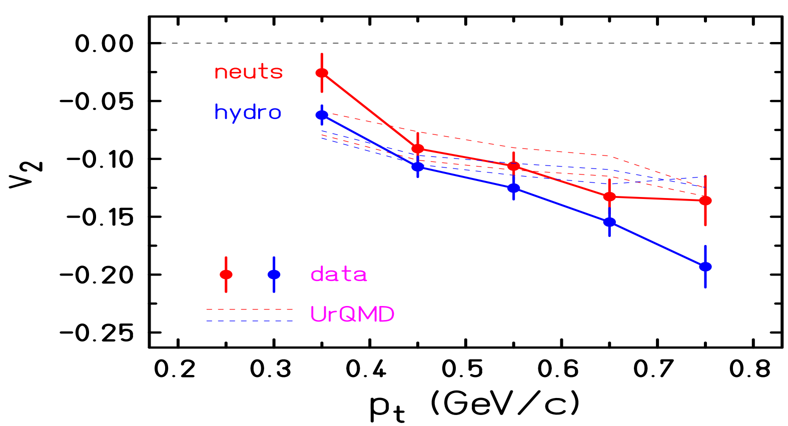


UrQMD vs. FOPI data:
Au+Au @ 400 A MeV

inversion of neutron and hydrogen flows

squeeze-out more sensitive than the directed flow

b = 5.5 – 7.5 fm



Constraining the Symmetry Energy at Supra-Saturation Densities
With Measurements of Neutron and Proton Elliptic Flows

Co-Spokespersons: R.C. Lemmon[1] and P. Russotto[2]

Collaboration

F. Amorini[2], A. Anzalone[17], T. Aumann[3], V. Avdeichikov[12], V. Baran[23], Z. Basrak[4], J. Benlliure[13], I. Berceanu[11], A. Bickley[14], E. Bonnet[6], K. Boretzky[3], R. Bougault[30], J. Brzychczyk[8], B. Bubak[22], G. Cardella[7], S. Cavallaro[2], J. Cederkall[12], M. Chartier[5], M.B. Chatterjee[16], A. Chbihi[6], M. Colonna[17], D. Cozma[11], B. Czech[10], E. De Filippo[7], K. Fissum[12], D. Di Julio[12], M. Di Toro[2], M. Famiano[27], J.D. Frankland[6], E. Galichet[18], I. Gasparic[4], E. Geraci[15], V. Giordano[2], P. Golubev[12], L. Grassi[15], A. Grzeszczuk[22], P. Guazzoni[21], M. Heil[3], J. Helgesson[31], L. Isaksson[12], B. Jacobsson[12], A. Kelic[3], M. Kis[4], S. Kowalski[22], E. La Guidara[20], G. Lanzalone[29], N. Le Neindre[30], Y. Leifels[3], Q. Li[9], I. Lombardo[2], O. Lopez[30], J. Lukasik[10], W. Lynch[14], P. Napolitani[30], N.G. Nicolis[24], A. Pagano[7], M. Papa[7], M. Parlog[30], P. Pawlowski[10], M. Petrovici[11], S. Pirrone[7], G. Politi[15], A. Pop[11], F. Porto[2], R. Reifarth[3], W. Reisdorf[3], E. Rosato[19], M.V. Ricciardi[3], F. Rizzo[2], W.U. Schroder[28], H. Simon[3], K. Siwek-Wilczynska[26], I. Skwira-Chalot[26], I. Skwirczynska[10], W. Trautmann[3], M.B. Tsang[14], G. Verde[7], E. Vient[30], M. Vigilante[19], J.P. Wieleczko[6], J. Wilczynski[25], P.Z. Wu[5], L.Zetta[21], W. Zipper[22]

Multifragmentation at High Energies

$E_{sym}(\rho)$ Sensitivity: compression phase

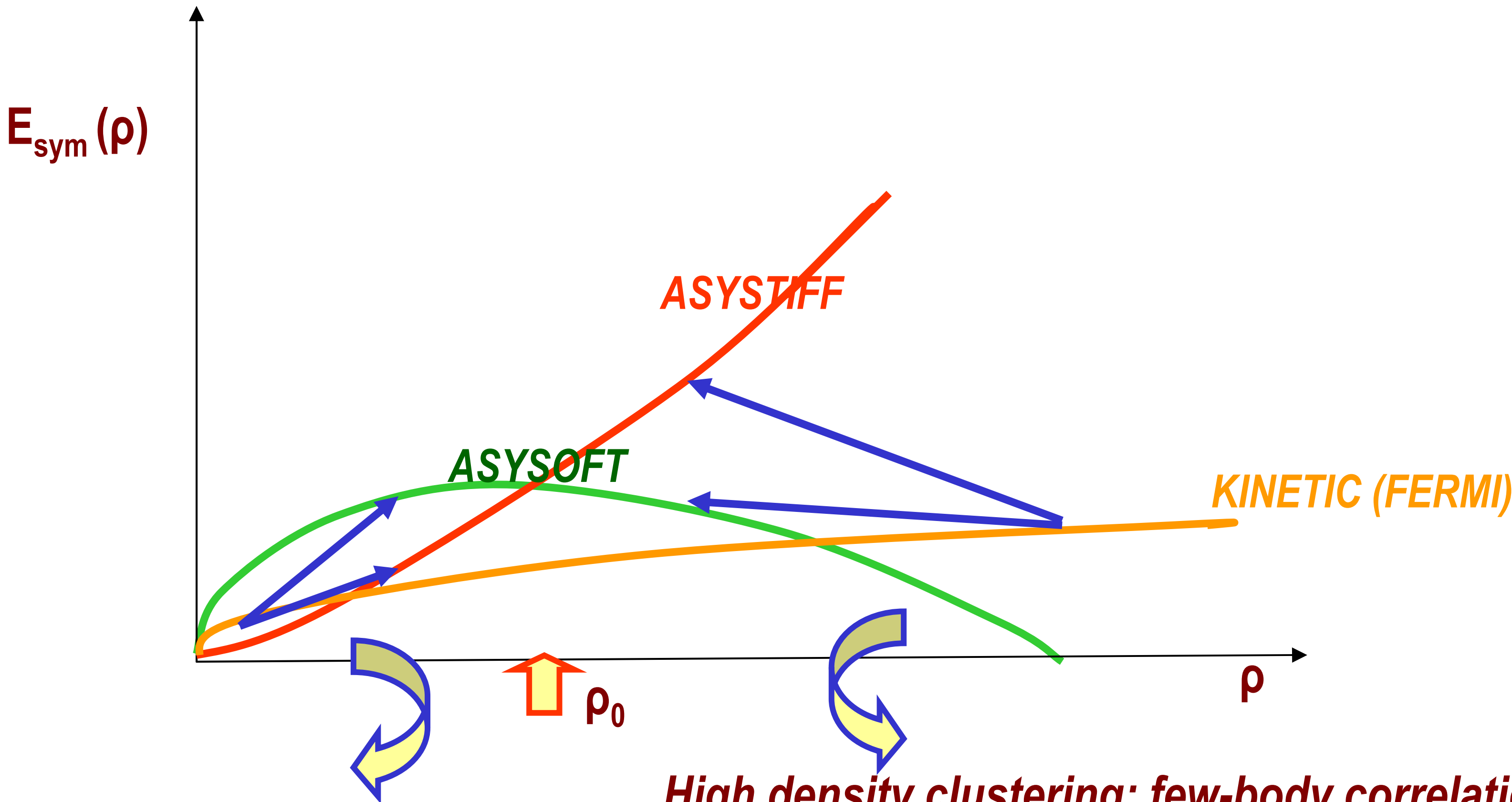
Isospin Distillation + Radial Flow

High Density Slope

Asy-stiff more effective

Problem: large radial flow → few heavier clusters survive, with memory of the high density phase

The Isospin "Ballet" in Multifragmentation



High density clustering: few-body correlations and phase-space coalescence

Low density clustering: spinodal mechanism

Asysoft: more symmetric clusters, larger neutron distillation combined to a larger pre-eq neutron emission

Asystiff: more symmetric clusters, combined to a larger fast neutron emission

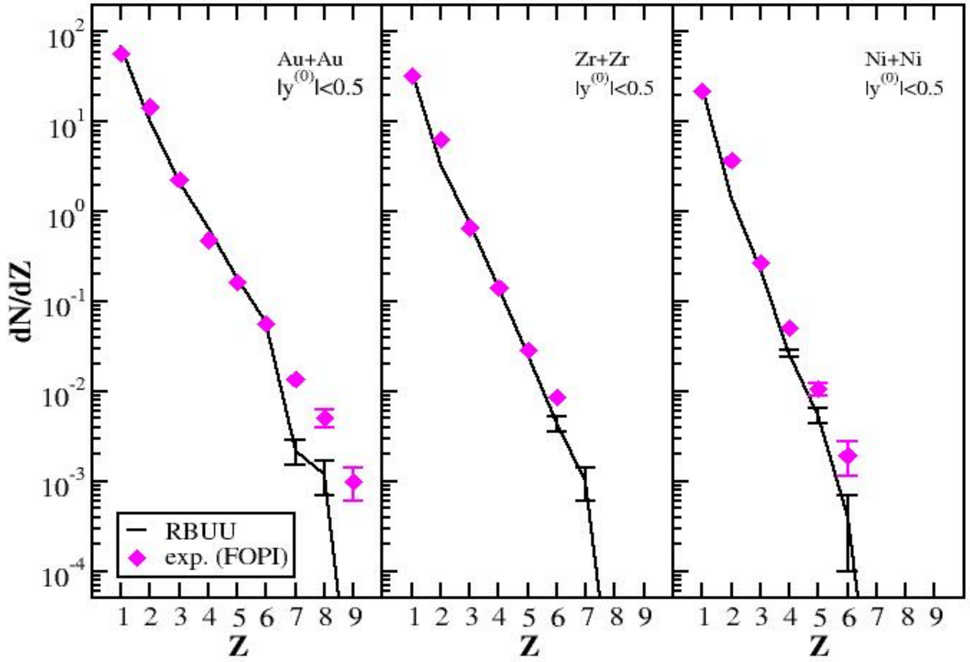
Fragment Formation in Central Collisions at Relativistic Energies

Au+Au, Zr+Zr, Ni+Ni at 400 AMeV → Central

Stochastic RBUU + Phase Space Coalescence

- Global fit to experimental charge distributions

Fast clusterization in the high density phase



E.Santini et al., NPA756(2005)468

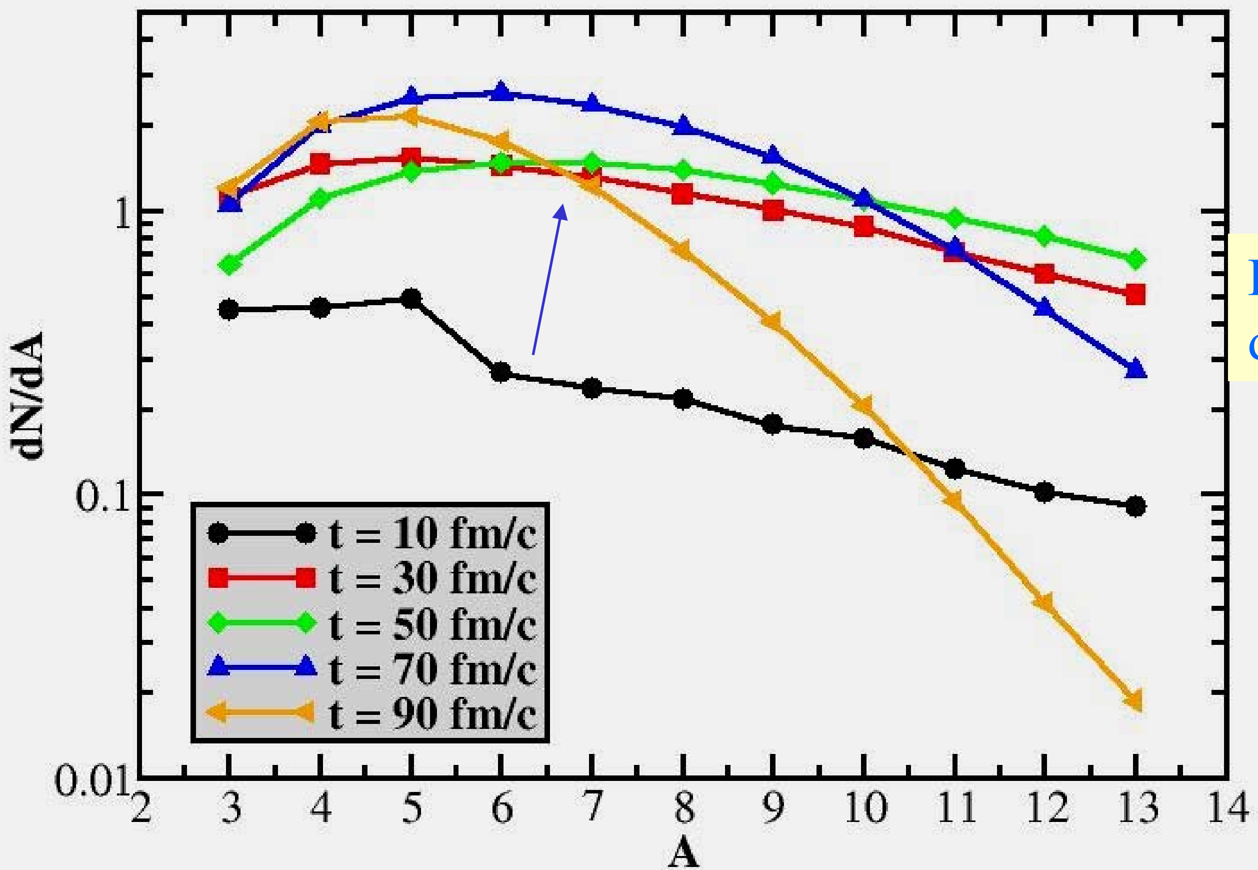
Stochastic RBUU +
Phase Space Coalescence

Time-evolution of fragment formation

(E. Santini et al., NPA756(2005)468)

Au+Au 0.4 AGeV Central

Z=3,4



Fast clusterization in the high density phase

Heavier fragments: "relics" of the high density phase

⇓

Isospin Content vs. Symmetry Term ?

Isospin degrees of freedom in QHD

QHD-I meson-like fields exchange model

$$L = \overline{\Psi}\left[\gamma_\mu\left(i\partial^\mu - g_V\hat{V}^\mu\right) - \left(M - g_S\hat{\Phi}\right)\right] + \frac{1}{2}\left(\partial^\mu\hat{\Phi}\partial_\mu\hat{\Phi} - m_S^2\hat{\Phi}^2\right) - \frac{1}{4}\hat{W}_{\mu\nu}\hat{W}^{\mu\nu} + \frac{1}{2}m_V^2\hat{V}_\mu\hat{V}^\mu$$

- σ – ω model → Only kinetic contribution to E_{sym}

QHD-II

- **Charged mesons :** $\delta, \vec{\rho}$ →

$$E_{sym} = \frac{1}{6}\frac{k_F^2}{E_F^{*2}} + \frac{1}{2}\left[f_\rho - f_\delta\left(\frac{M^*}{E^*}\right)^2\right]\rho_B$$

(scalar isovector) (vector-isovector)

$$\vec{\rho}: \quad b_0 = \frac{g_\rho}{m_\rho^2}\left(\rho_p - \rho_n\right) \propto \rho_3$$

$$\vec{\delta}: \quad \delta_3 = \frac{g_\delta}{m_\delta^2}\left(\rho_{sp} - \rho_{sn}\right) \propto \rho_{s3}$$

Relativistic structure also
in isospin space !

E_{sym} = cin. + (ρ–vector) – (δ–scalar)

The Dirac equation becomes:

$$N: \left[\gamma_\mu i\partial^\mu - g_V\gamma_0 V^0 - g_\rho\gamma_0\tau_3 b^0 - \left(M - g_S\Phi - g_\delta\tau_3\delta_3\right)\right]\Psi = 0$$

→ Splitting n & p M^*

RMF Symmetry Energy: the δ - mechanism

Liu Bo et al., PRC65(2002)045201

$$E_{sym} = \frac{1}{6}\frac{k_F^2}{E_F^{*2}} + \frac{1}{2}\left[f_\rho - f_\delta \left(\frac{M^*}{E^*} \right)^2 \right] \rho_B$$

→ No δ → $f_\rho \cong 1.5\, f_\rho^{FREE}$

→ $f_\delta = 2.5\, fm^2$ → $f_\rho \cong 5 f_\rho^{FREE}$

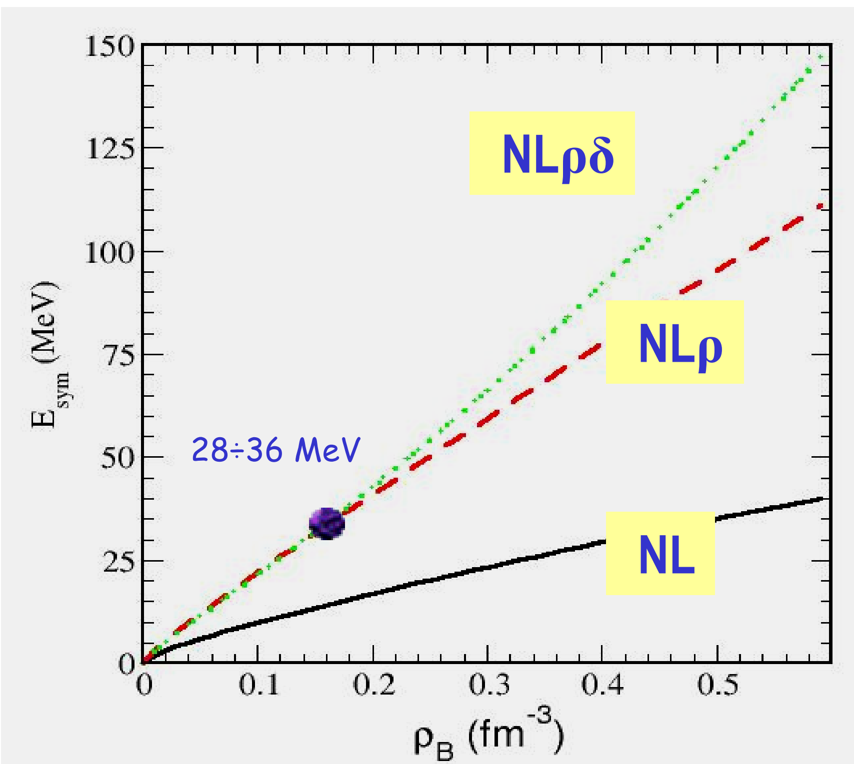
$$f_{\rho,\delta} \equiv \left(\frac{g_{\rho,\delta}}{m_{\rho,\delta}} \right)^2$$

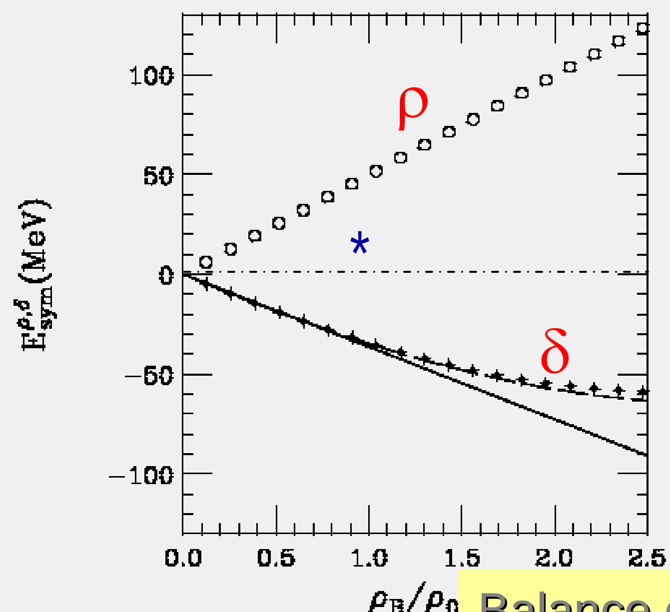
$a_4 = E_{sym}(\rho_0)$ → fixes (f_ρ, f_δ)

DBHF, DHF } $f_\delta \approx 2.0 \div 2.5\, fm^2$

F. Hoffmann et al., PRC64 (2001) 034314

V. Greco et al., PRC63(2001)035202





Balance of isospin fields of ~ 100 MeV

Self-Energies: kinetic momenta and (Dirac) effective masses

$$k_i^{*\mu} \equiv k_i^{\mu} - \Sigma_i^{\mu}$$

$$m_i^{*} \equiv M - \Sigma_{s,i}$$

$$\Sigma_s(n,p) = f_\sigma \sigma(\rho_s) \mp f_\delta \rho_{s3}$$

$$\Sigma^\mu(n,p) = f_\omega j^\mu \mp f_\rho j_3^\mu$$

Upper sign: n

$$(\rho, j)_3 \equiv (\rho, j)_p - (\rho, j)_n$$

$$\rho_{B3} \equiv \rho_{Bp} - \rho_{Bn} < 0, n - rich$$

Dirac dispersion relation: single particle energies

$$\varepsilon_i + M = +\Sigma_i^0 + \sqrt{k^2 + m_i^{*2}} \longrightarrow$$

n-rich:

- Neutrons see a more repulsive vector field, increasing with fρ and isospin density
- m*(n)<m*(p)

QHD → Relativistic Mean Field Transport Equation

Covariance is essential → Inelastic Processes
→ Lorentz Force

Phys.Rep.410(2005)335-466

RMF (RBUU) transport equation

Wigner transform ∩ Dirac + Fields Equation ➡ ***Relativistic Vlasov Equation + Collision Term…***

$$\left[\frac{p_i^{*\mu}}{M_i^*}\partial_\mu + \left(\frac{p_{\nu i}^*}{M_i^*}\mathcal{F}_i^{\mu\nu} + \partial^\mu M_i^*\right)\partial_\mu^{(p^*)}\right] f_i(x,p^*) = \mathcal{I}_c$$

$$k_i^{*\mu} \equiv k_i^\mu - \Sigma_i^\mu$$

$$m_i^* \equiv M - \Sigma_{s,i}$$

$$F^{\mu\nu} = \partial^\mu \Sigma^\nu - \partial^\nu \Sigma^\mu$$

drift

mean field

$$\frac{\partial f}{\partial t} + \frac{\vec{p}}{m}\cdot\vec{\nabla}_r f + \vec{\nabla}_r U \cdot \vec{\nabla}_p f = I_{coll}$$

Non-relativistic Boltzmann-Nordheim-Vlasov

"Lorentz Force"→ Vector Fields
pure relativistic term

Symmetry Energy Effects

Inelastic Channels

Elastic Collision term:

$$\mathcal{I}_c = \frac{g}{(2\pi)^3}\int \frac{dp_2^*}{p_2^{*0}}\frac{dp_3^*}{p_3^{*0}}\frac{dp_4^*}{p_4^{*0}}\int d\Omega\,(p^* + p_2^*)^2 \frac{d\sigma}{d\Omega}\delta^4(p^* + p_2^* - p_3^* - p_4^*)$$
$$\times\{f_3 f_4[1-f][1-f_2] - f f_2[1-f_3][1-f_4]\}$$

Relativistic Landau Vlasov Propagation

C. Fuchs, H.H. Wolter, Nucl. Phys. A589 (1995) 732

Discretization of f(x,p*)→ Test particles represented by covariant Gaussians in xp-space

$$f(x,p^*) = \sum_{i=1}^{AN_{test}} \int_{-\infty}^{+\infty} d\tau \;\; g(x - x_i(\tau))g(p^* - p_i^*(\tau))$$

→ Relativistic Equations of motion for x^μ and $p^{*\mu}$ for centroids of Gaussians

$$\frac{d}{d\tau}x_i^\mu = \frac{p_i^*(\tau)}{M_i^*(x_i)} \; ,$$

$$\frac{d}{d\tau}p_i^{*\mu} = \frac{p_{i\nu}^*(\tau)}{M_i^*(x_i)}\mathcal{F}_i^{\mu\nu}(x_i(\tau)) + \partial^\mu M_i^*(x_i)$$

u_ν Test-particle 4-velocity → Relativity: - momentum dependence always included due to the Lorentz term $\left(u_\nu F^{\mu\nu}\right)$

- E*/M* boosting of the vector contributions

Collision Term: local Montecarlo Algorithm imposing an average Mean Free Path plus Pauli Blocking

→ in medium reduced Cross Sections

Isospin Flows at Relativistic Energies

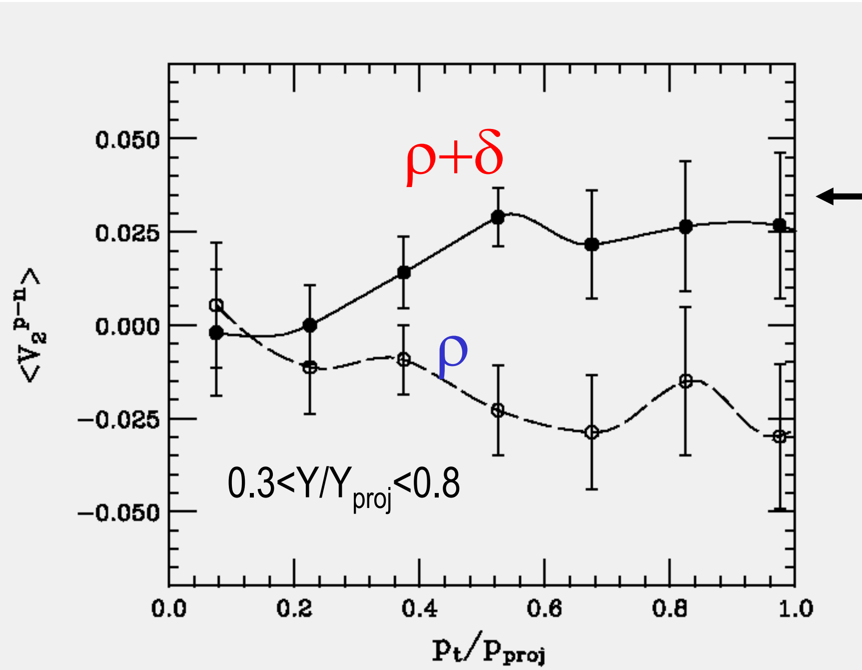
$E_{sym}(\rho)$: Sensitivity to the Covariant Structure

Enhancement of the Isovector-vector contribution via the Lorentz Force

High p_t selections: source at higher density
→ Symmetry Energy at 3-4ρ_0

Elliptic flow Difference

132Sn+132Sn, 1.5AGeV, b=6fm: NL-ρ & NL-($\rho+\delta$)



- Difference at high p_t ⇔ first stage

High p_t neutrons are emitted "earlier"

Equilibrium (ρ,δ) dynamically broken: Importance of the covariant structure

approximations

$$\frac{d\vec{p}_p^{\,*}}{d\tau} - \frac{d\vec{p}_n^{\,*}}{d\tau} \simeq 2\left[\gamma f_\rho - \frac{f_\delta}{\gamma}\right]\vec{\nabla}\rho_3 = \frac{4}{\rho_B}E^*_{sym}\vec{\nabla}\rho_3$$

$$2\left[f_\rho - f_\delta\frac{M^*}{E_F^*}\right] = \frac{4}{\rho_B}E_{sym}^{pot}$$

Dynamical boosting of the vector contribution

V.Greco et al., PLB562(2003)215

Meson Production at Relativistic Energies: π^-/π^+, K^0/K^+

$E_{sym}(\rho)$: Sensitivity to the Covariant Structure

Self-energy rearrangement in the inelastic vertices with different isospin structure → large effects around the thresholds

High p_t selections: source at higher density → rate problems

PION PRODUCTION

G.Ferini et al., NPA 762 (2005) 147, NM Box
PRL 97 (2006) 202301, HIC

Main mechanism $NN \Rightarrow N\Delta \searrow \pi N$

nn → $p\Delta^-$ → $n\pi^-$; nn → $n\Delta^0$ → $p\pi^-$

pp → $p\Delta^+$ → $n\pi^+$; pp → $n\Delta^{++}$ → $p\pi^+$

n⟶p "transformation"

$$\Rightarrow \frac{\pi^-}{\pi^+}$$

Vector self energy more repulsive for neutrons and more attractive for protons

1. C.M. energy available: "threshold effect"

$$\varepsilon_{n,p} = E^*_{n,p} + f_\omega \rho_B \mp f_\rho \rho_{B3} \longrightarrow \begin{array}{l} s_{nn}(NL) < s_{nn}(NL\rho) < s_{nn}(NL\rho\delta) \\ s_{pp}(NL) > s_{pp}(NL\rho) > s_{pp}(NL\rho\delta) \end{array}$$

π(-) enhanced
π(+) reduced

2. Fast neutron emission: "mean field effect"

$$\frac{n}{p}\downarrow \Rightarrow \frac{Y(\Delta^{0,-})}{Y(\Delta^{+,++})}\downarrow \Rightarrow \frac{\pi^-}{\pi^+}\downarrow \Rightarrow decrease: NL \rightarrow NL\rho \rightarrow NL\rho\delta$$

Some compensation in "open" systems, HIC, but "threshold effect" more effective, in particular at low energies

No evidence of Chemical Equilibrium!!

The Threshold Effect: nn→pΔ^- vs pp→nΔ^{++}

1.
If you have one inelastic collision how do you conserve the energy?
At threshold this is really fundamental!
For elastic collision the issue is not there!

What is conserved is not the effective E*,p* momentum-energy but the canonical one.

2.
Compensation of Isospin Effects in s_{th} due to simple constituent quark assumption for Σ(Δ)

$$\Sigma_i(\Delta^-) = \Sigma_i(n)$$
$$\Sigma_i(\Delta^0) = \frac{2}{3}\Sigma_i(n) + \frac{1}{3}\Sigma_i(p)$$
$$\Sigma_i(\Delta^+) = \frac{1}{3}\Sigma_i(n) + \frac{2}{3}\Sigma_i(p)$$
$$\Sigma_i(\Delta^{++}) = \Sigma_i(p) \quad ,$$

The Threshold Effect: $nn \to p\Delta^-$ vs $pp \to n\Delta^{++}$

$nn \to p\Delta^-$

$$s_{in} = 4\left(E_n^* + \Sigma_n^0\right)^2$$

$$s_{th} = \left[m_p - \Sigma_s(p) + \Sigma^0(p) + m_{\Delta-} - \Sigma_s(\Delta^-) + \Sigma^0(\Delta^-)\right]^2$$

$pp \to n\Delta^{++}$

$$s_{in} = 4\left(E_p^* + \Sigma_p^0\right)^2$$

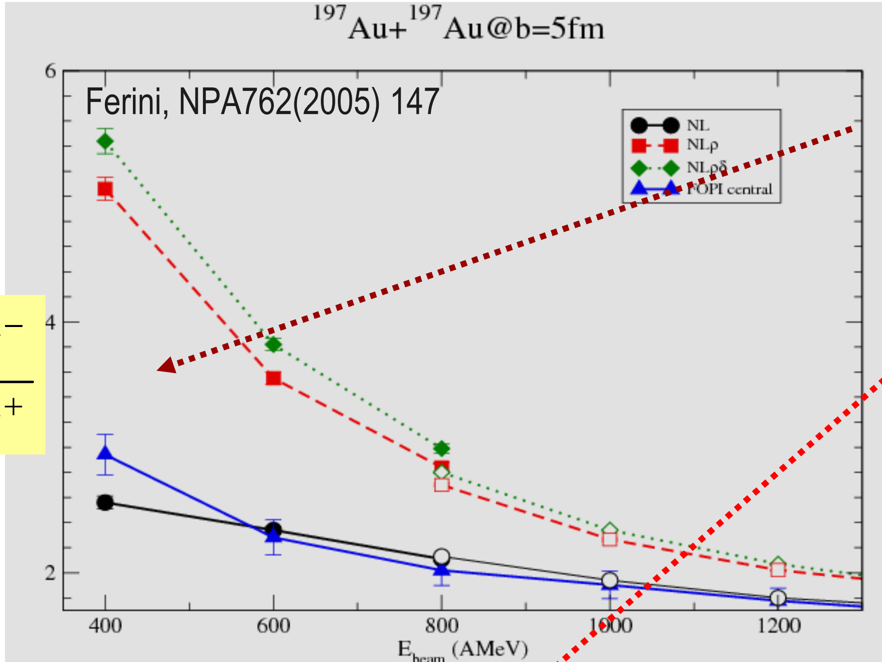
$$s_{th} = \left[m_n - \Sigma_s(n) + \Sigma^0(n) + m_{\Delta++} - \Sigma_s(\Delta^{++}) + \Sigma^0(\Delta^{++})\right]^2$$

Compensation of Isospin Effects

Almost same thresholds → the s_{in}(NN) rules the relative yields
→ very important at low energies ⇒ $\dfrac{\pi^-}{\pi^+}$ increase near threshold

Comparing calculations & experiments

$$\frac{\pi^-}{\pi^+}$$



disagreement in magnitude, particularly at low energies,

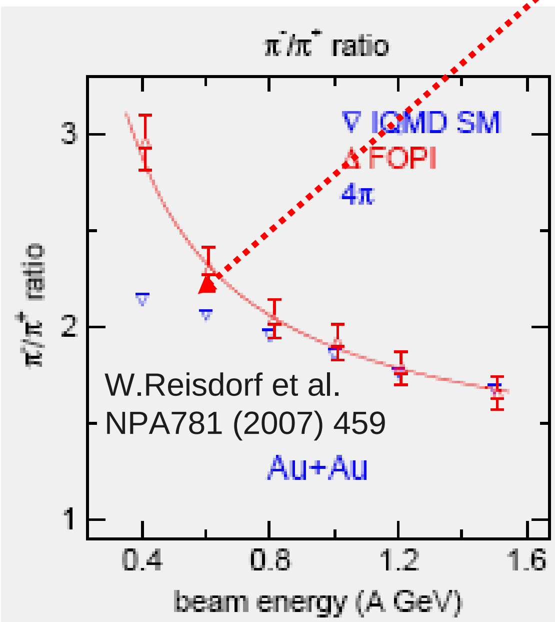
Threshold effect too strong

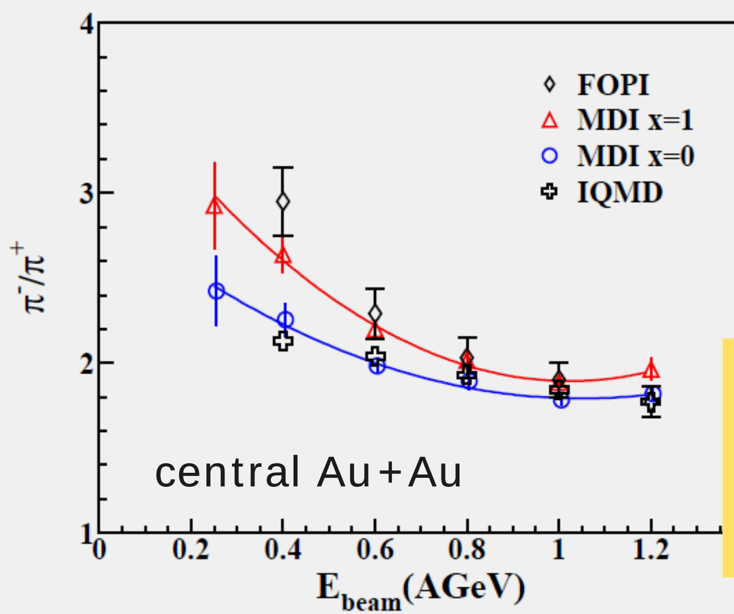
(reduced by the effective mass splitting in the production cross sections ?)

Others have the opposite problem

Rapidity and p_T selection important

Note when there is no E_{sym}
Transport predictions are much closer !

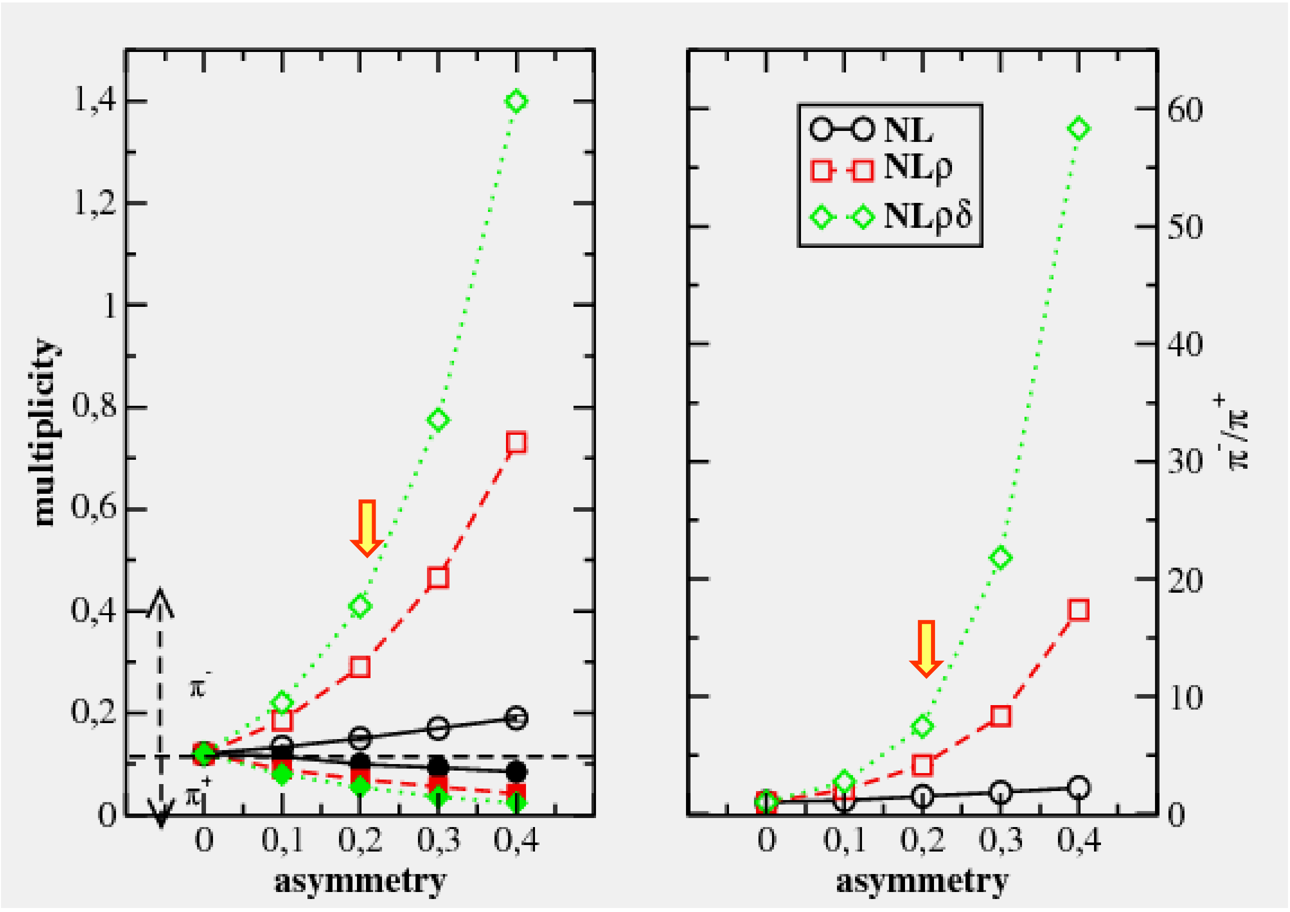




Zhigang Xiao et al.
PRL 102, 062502 (2009)
Evidence for a very soft E_{sym} at high ρ ?

Equilibrium Pion Production : Nuclear Matter Box Results → Chemical Equilibrium

Density and temperature like in Au+Au 1AGeV at max.compression (ρ~2ρ0, T~50MeV)



vs. asymmetry

NPA762(2005) 147

Larger isospin effects: - no neutron escape
- Δ's in chemical equilibrium, less n-p "transformation"

$$\frac{\pi^-}{\pi^+} = \exp\left[(\mu_n - \mu_p)/T\right] \cong \exp\left[2\rho_B f_\rho \alpha / T\right]$$

~ 5 (NLρ) to 10 (NLρδ)

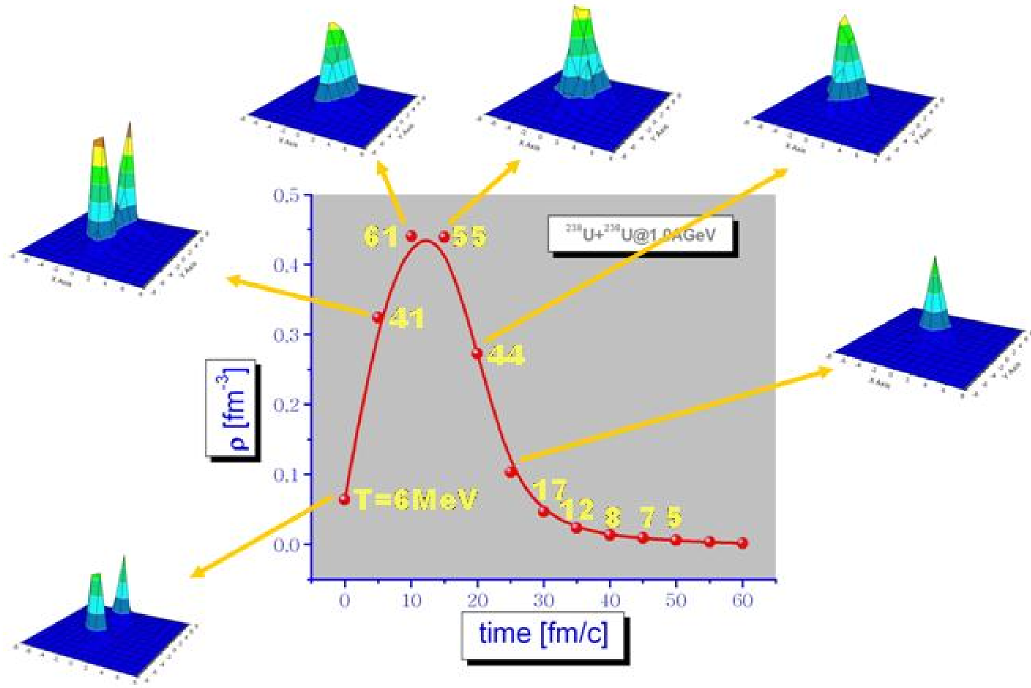
ISOSPIN IN RELATIVISTIC HEAVY ION COLLISIONS:

- Earlier Deconfinement at High Baryon Density

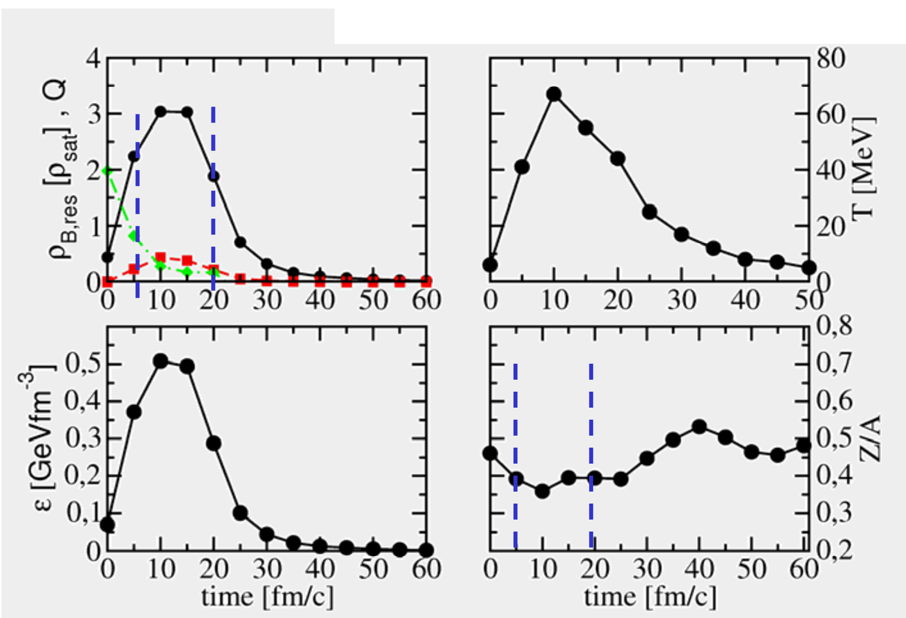
- Is the Critical End-Point affected?

M.Di Toro, V.Greco, B.Liu, S.Plumari, NICA White Paper Contribution (2009)
M.Di Toro et al., arXiv:0909.3247[nucl-th]

System Size Dependence & Equilibration (U+U)



In a C.M. cell



$$^{238}U + ^{238}U, 1AGeV, \quad b = 7\ fm$$

Exotic matter over 10 fm/c ?

NPA775(2006)102-126

HOMEWORK
Hadron-Quark EoS at High Baryon Density

Hadron : "STANDARD" EoS (with Symmetry Term)

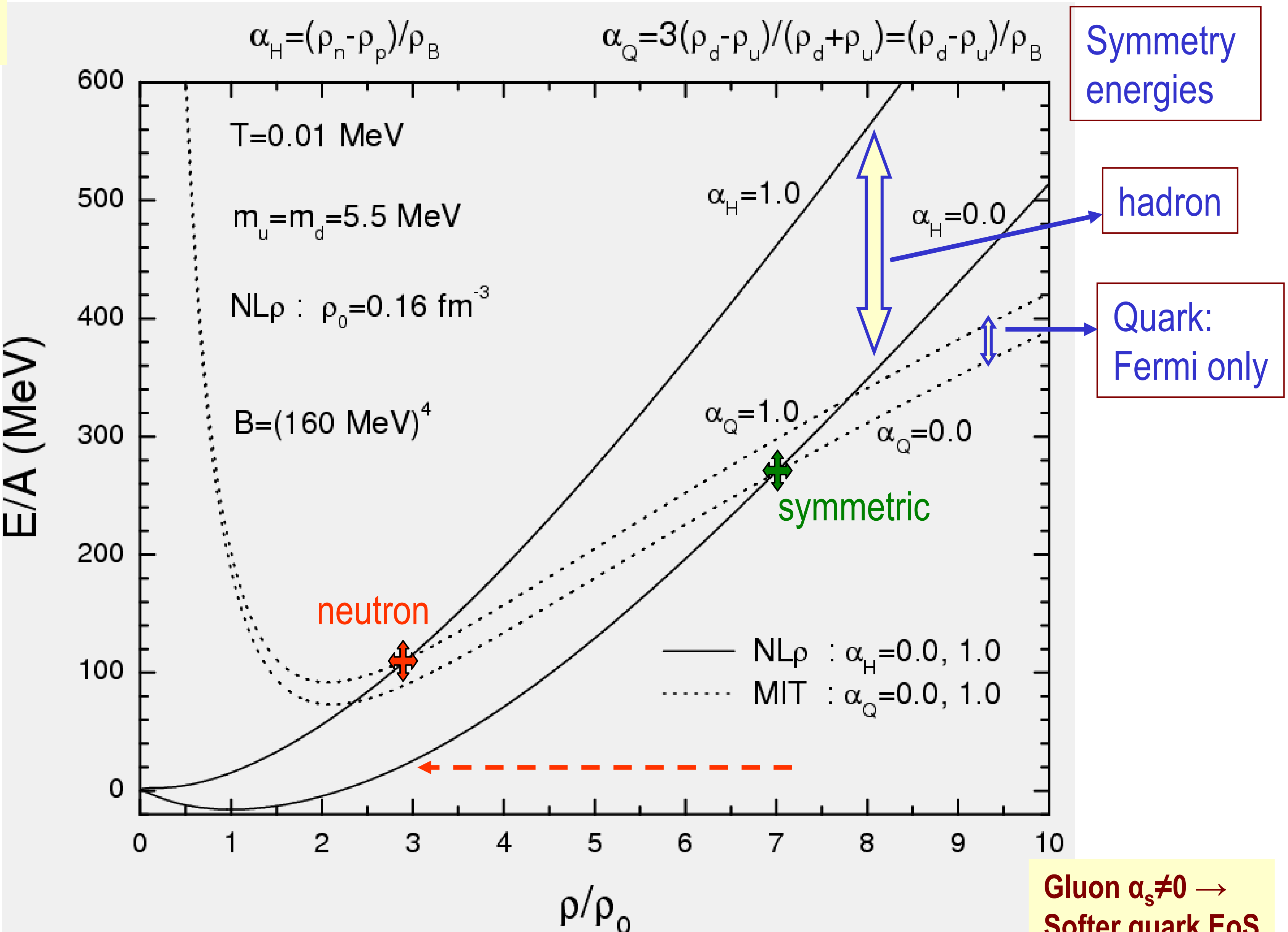
Quark: "STANDARD" MIT-Bag Model

ISOSPIN EFFECTS on the MIXED PHASE

Zero Temperature: two pages with a pencil….

EoS of Symmetric/Neutron Matter: Hadron (NLρ) vs MIT-Bag → Crossings

T=0,
Gluon α_s=0



Gluon α_s≠0 →
Softer quark EoS

Gibbs conditions for two conserved charges

$$\mu_B^H(\rho_B^H,\rho_3^H,T)=\mu_B^Q(\rho_B^Q,\rho_3^Q,T)$$
$$\mu_3^H(....)=\mu_3^Q(....)$$
$$P^H(\rho_B^H,\rho_3^H,T)=P^Q(\rho_B^Q,\rho_3^Q,T)$$

Mixed Phase →

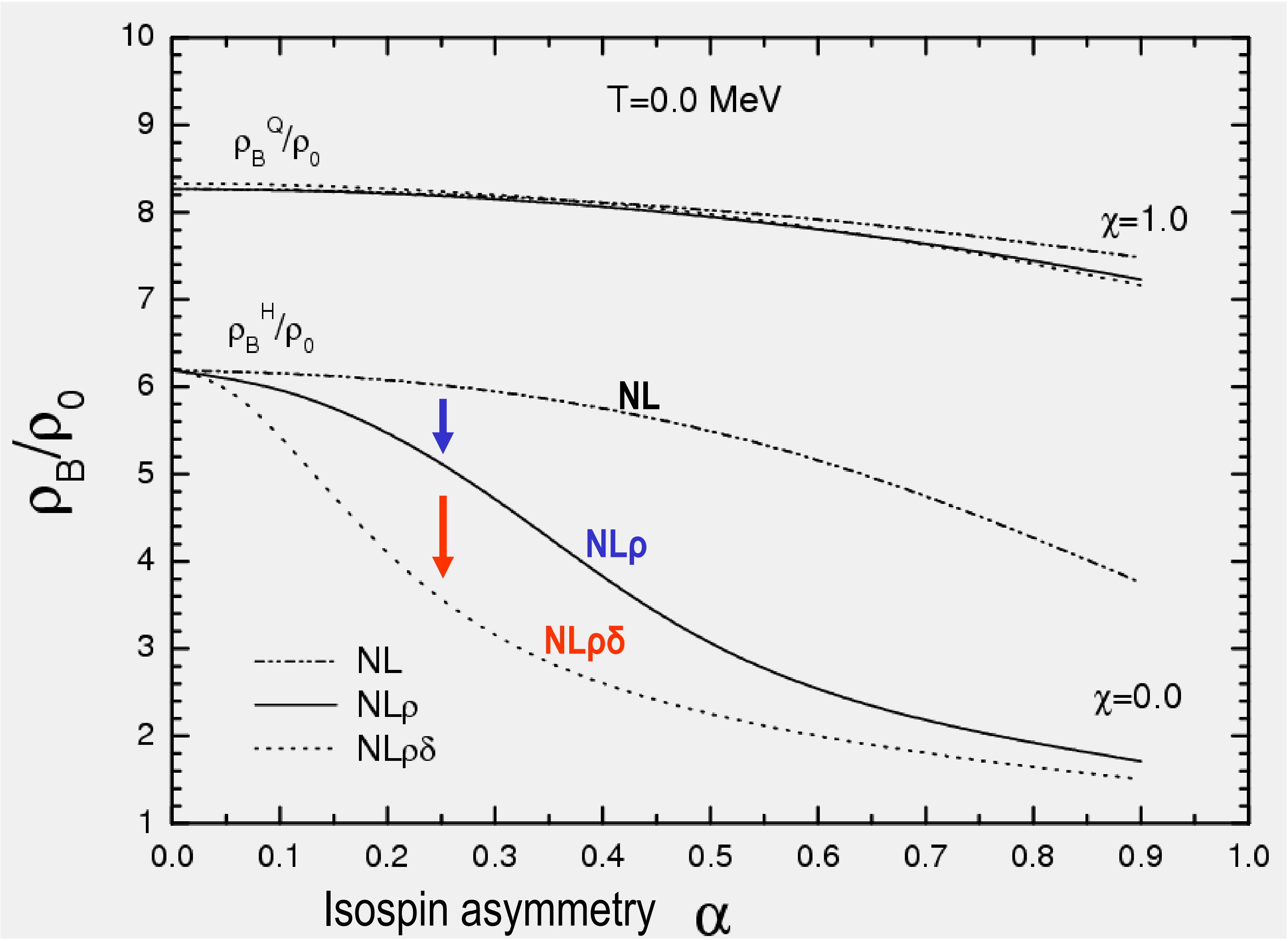
$$\rho_B=(1-\chi)\rho_B^H+\chi\rho_B^Q$$
$$\rho_3=(1-\chi)\rho_3^H+\chi\rho_3^Q$$

Hadron-RMF

Quark-Bag model (two flavors)

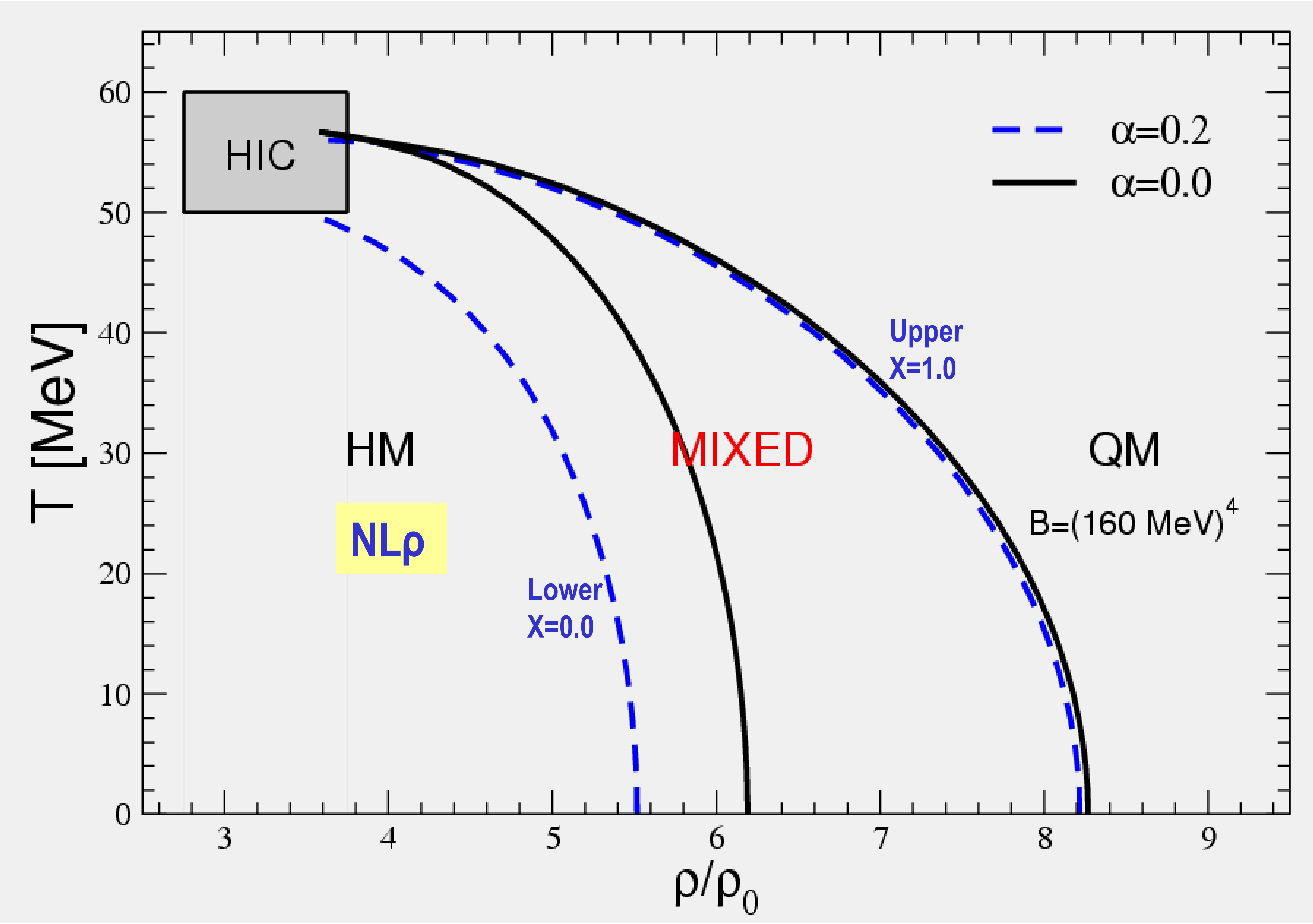
→ ***(T, ρ_B, ρ_3, χ) : binodal surface, mixed phase***

Mixed Phase: Boundary Shifts at Low Temperature

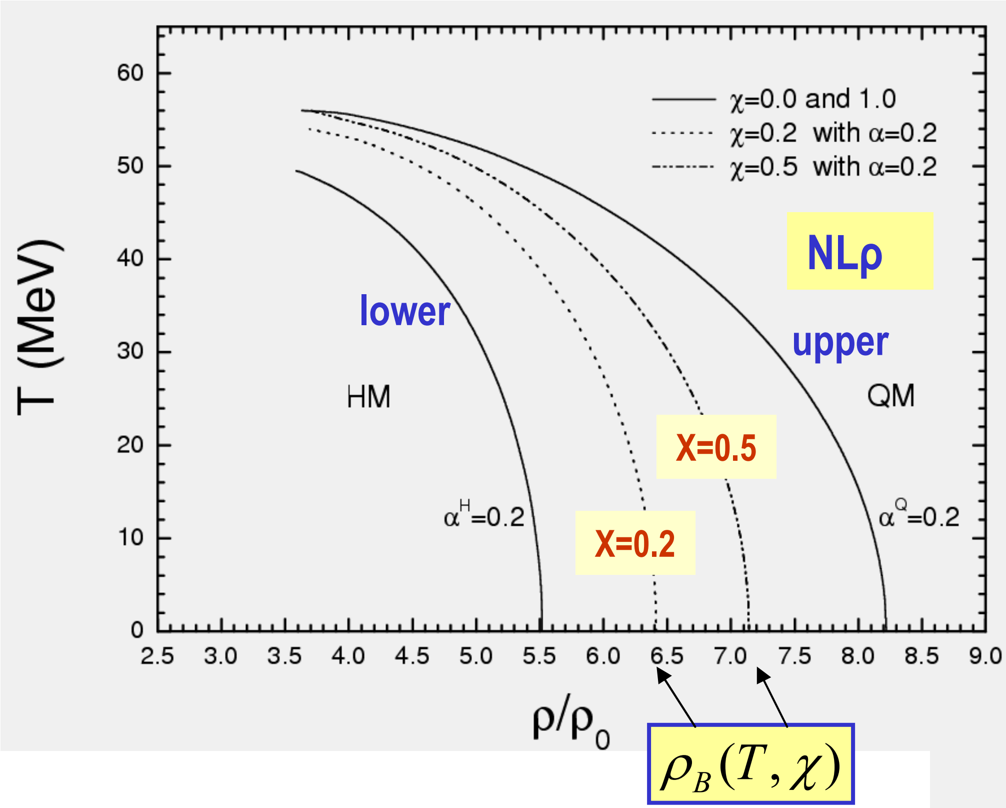


Lower Boundary much affected by the Symmetry Energy

Symmetric to Asymmetric (not Exotic) Matter

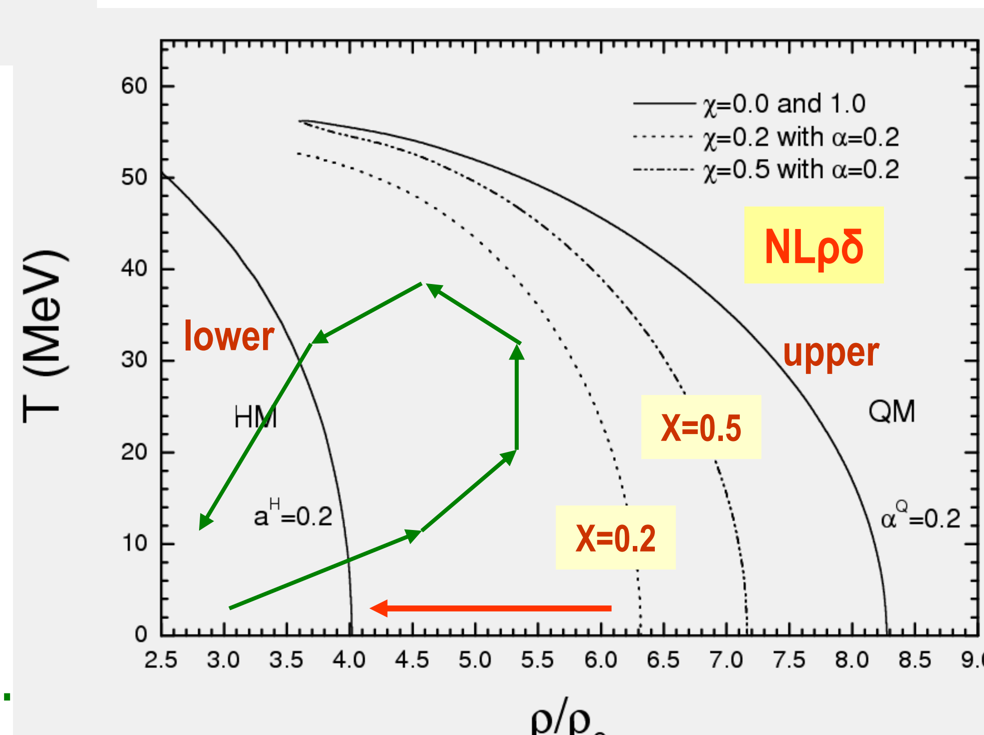


Inside the Mixed Phase
(asymmetry α=0.2)



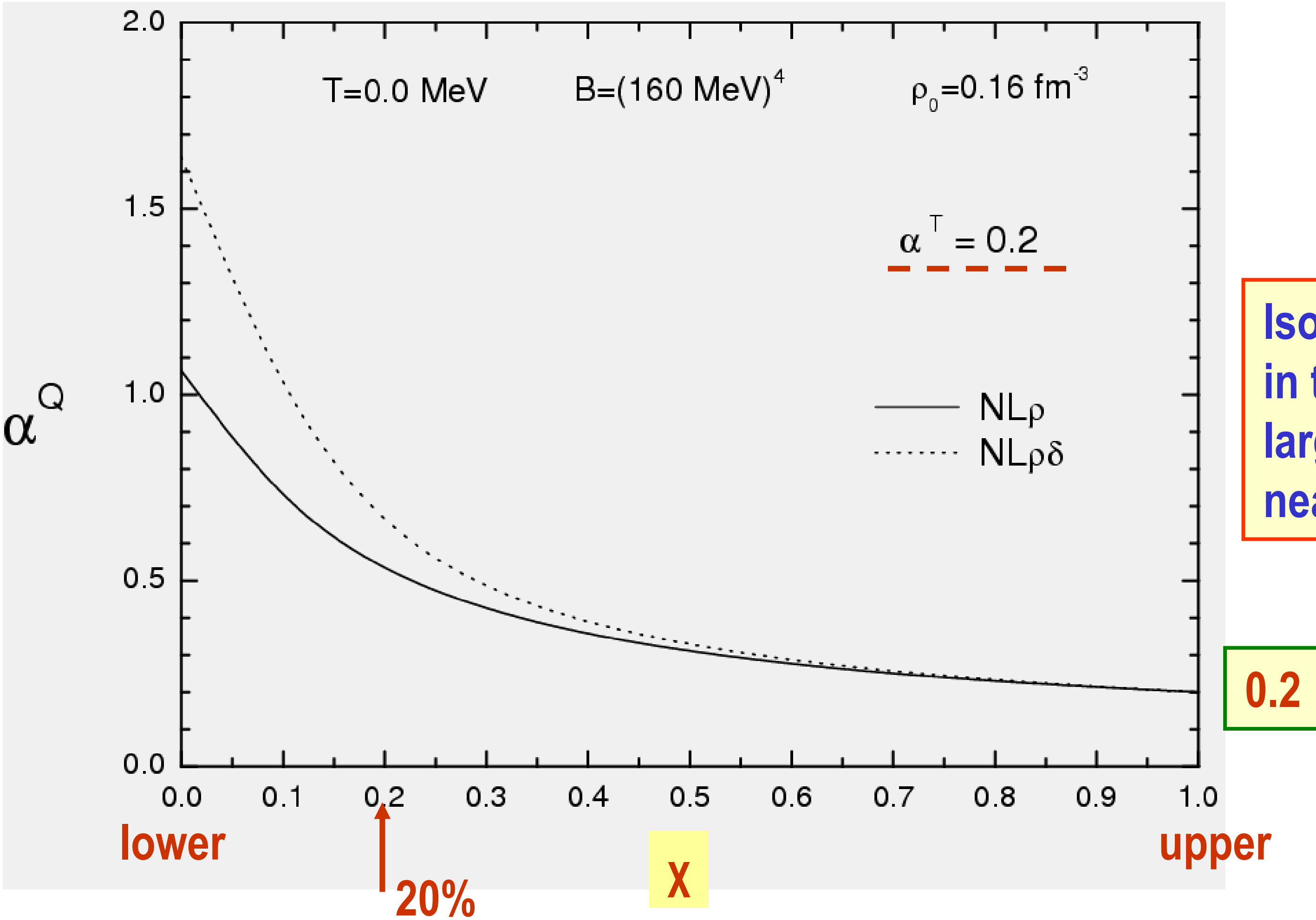
Dependence on the High Density Hadron EoS

NLρδ :
more repulsive
high density
Symmetry Energy
in the hadron phase



Long way to reach 20% quark matter, but…

1. Isospin Densities in the Two Phases

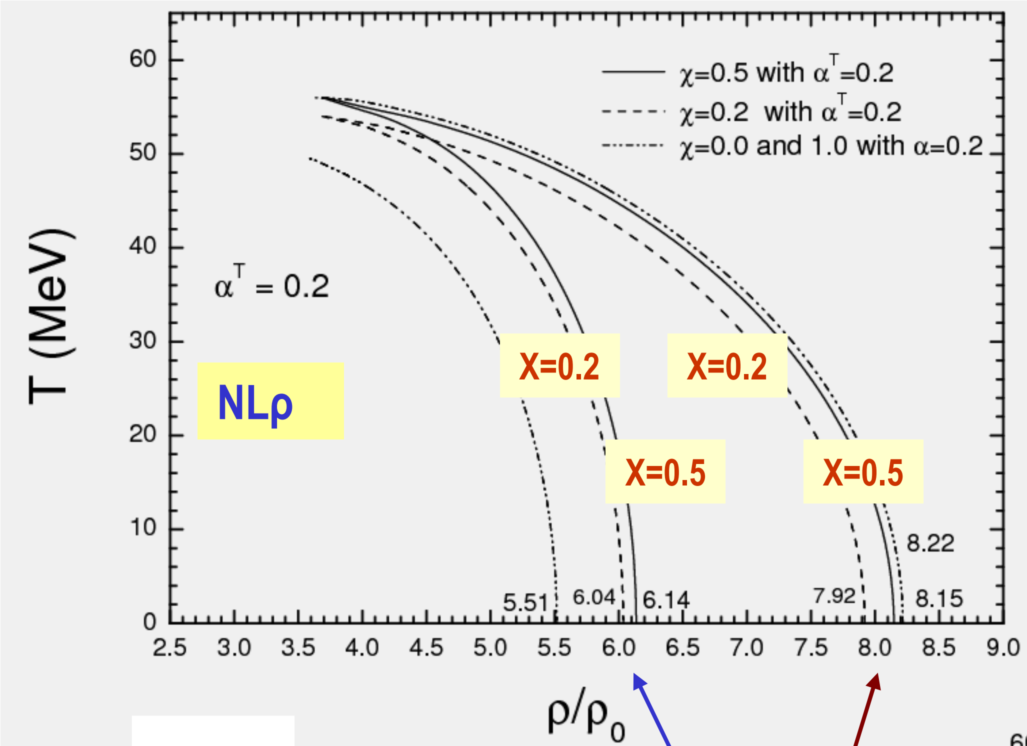


Isospin Asymmetry in the Quark Phase: large Isospin Distillation near the Lower Border?

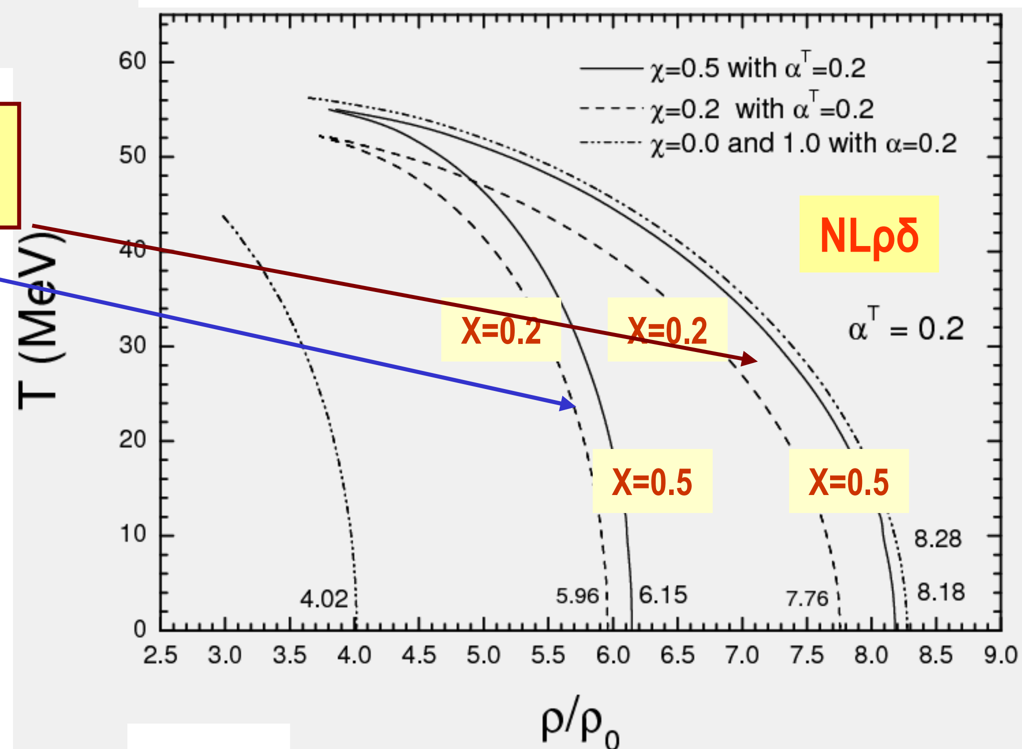
Signatures? Neutron migration to the quark clusters (instead of a fast emission)

→ Symmetry Energy in the Quark Phase?

2. Baryon Densities in the Two Phases



ρ_B^H ρ_B^Q



Larger Baryon Density in the Quark Phase

→ Signatures?

Conclusions for the Mixed Phase Physics

Experiments

Isospin dependence of the Mixed Phase Signatures
(reduced v_2 at high p_T, n_q-scaling break down….)

Isospin Trapping:
- Reduction of n-rich cluster emission
- Anomalous production of Isospin-rich hadrons at high p_T
- u-d mass splitting ($m_u > m_d$)

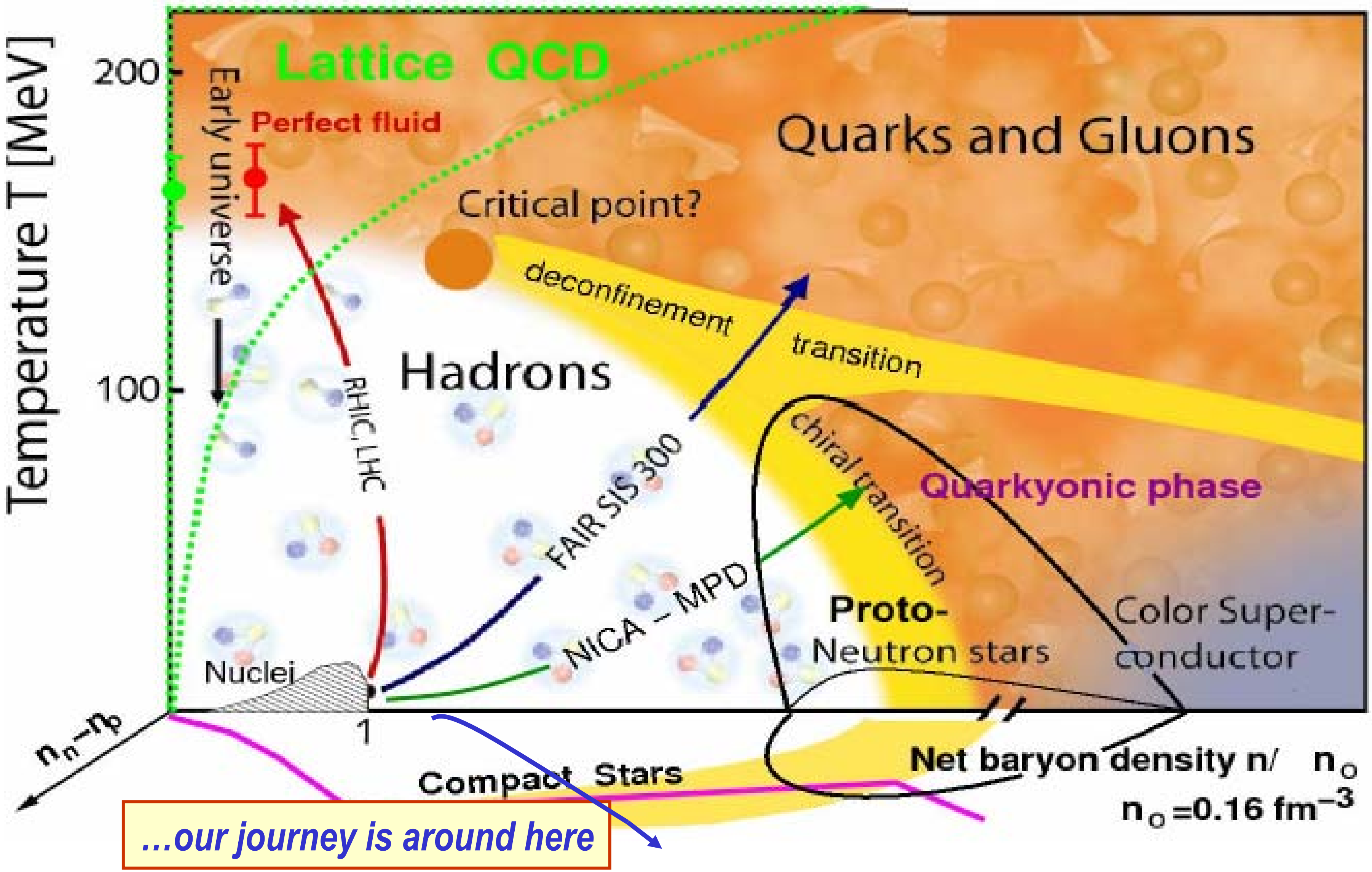
Larger Baryon Density in the Quark Phase:
- Large Yield of Isospin-rich Baryons at high p_T

Theory

Isospin effects on the spinodal decomposition

Isovector Interaction in Effective QCD Lagrangians

Nuclear Matter Phase Diagram….NICA updated



Conclusion: Every Complex Problem has a Simple Solution

….most of the time Wrong (Umberto Eco)

NUCLEAR MATTER at HIGH BARYON AND ISOSPIN DENSITY

V.Baran, M.Colonna, M. Di Toro, G. Ferini, V. Giordano, V. Greco, Liu Bo, S. Plumari, V.Prassa, T.Gaitanos, H.H.Wolter

LNS-INFN and Phys.Astron.Dept. Catania, IHEP Beijing, Univ.of Bucharest, Giessen, Munich, Thessaloniki, …..and the Etna

Back-up Slides

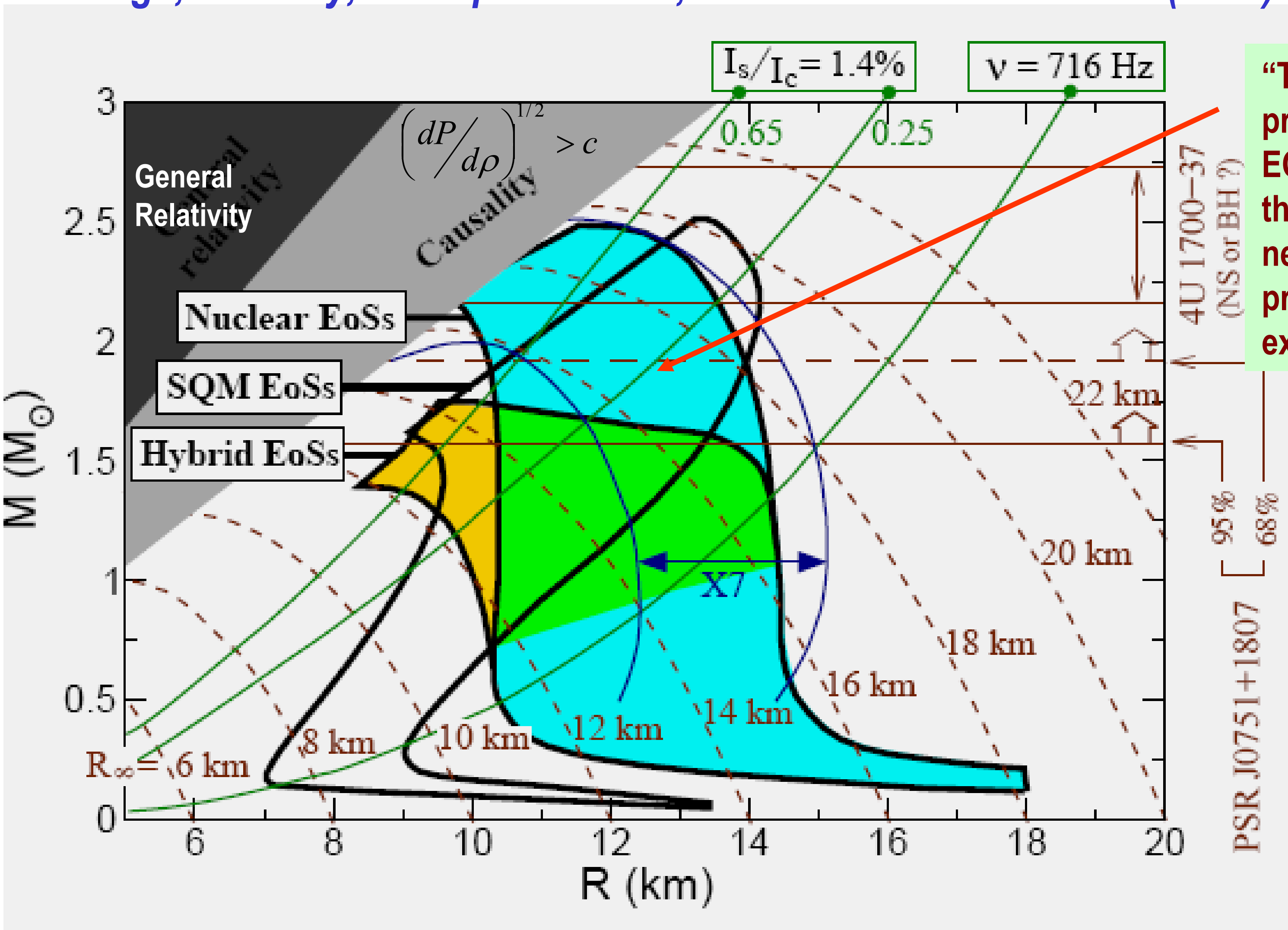
REVIEWS

"Reaction Dynamics with Exotic Nuclei"
V. Baran, M. Colonna, V. Greco, M. Di Toro
Phys. Rep. 410 (2005) 335 (Relat. Extension)

"Recent Progress and New Challenges in Isospin Physics with HIC"
Bao-An Li, Lie-Wen Chen, Che Ming Ko
Phys. Rep. 464 (2008) 113

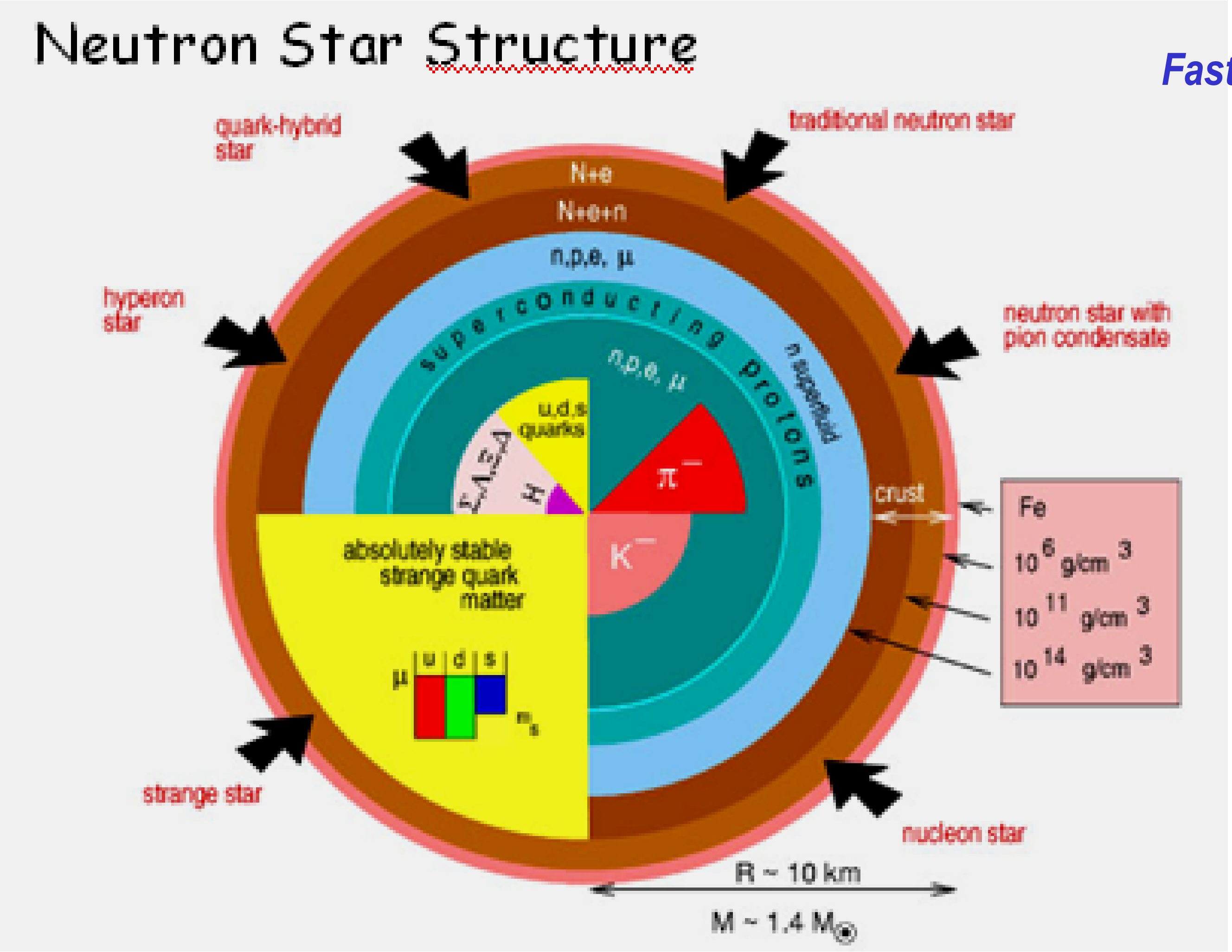
N-STARS: Present status with observation constraints

D.Page, S.Reddy, astro-ph/0608360, Ann.Rev.Nucl.Part.Sci. 56 (2006) 327



"The broad range of predicted radii for nucleon EOS will be narrowed in the near future owing to neutron-skin thickness and probably also to heavy-ion experiments"

Softer EOS→smaller R (larger ρ-central), smaller maximum Mass



Fast cooling: Direct URCA process

$$p + e \rightarrow n + \nu_e$$

Fermi momenta matching

$$P_{F,e} = P_{F,p} = (3\pi^2 y\rho)^{1/3}$$

$$P_{\nu_e} \approx kT/c << P_{F,n}$$

$$P_{F,n} = [3\pi^2(1-y)\rho]^{1/3}$$

$$2^3 y^{DU} \geq (1 - y^{DU}) \Rightarrow y^{DU} \geq \frac{1}{9}$$

Proton fraction, y=Z/A, fixed by Esym(ρ) at high baryon density:

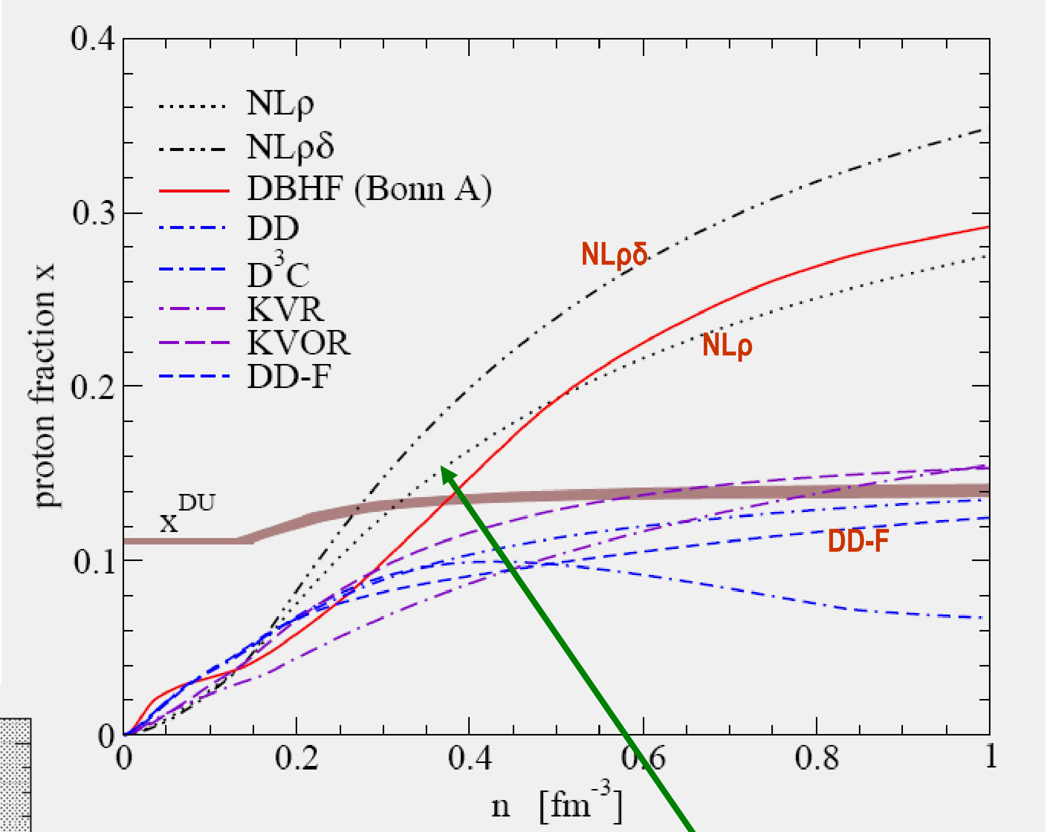
$$\mu_e = \mu_n - \mu_p = 4E_{sym}(\rho)(1-2y) \approx P_{F,e} = (3\pi^2 y\rho)^{1/3}$$

β-equilibrium

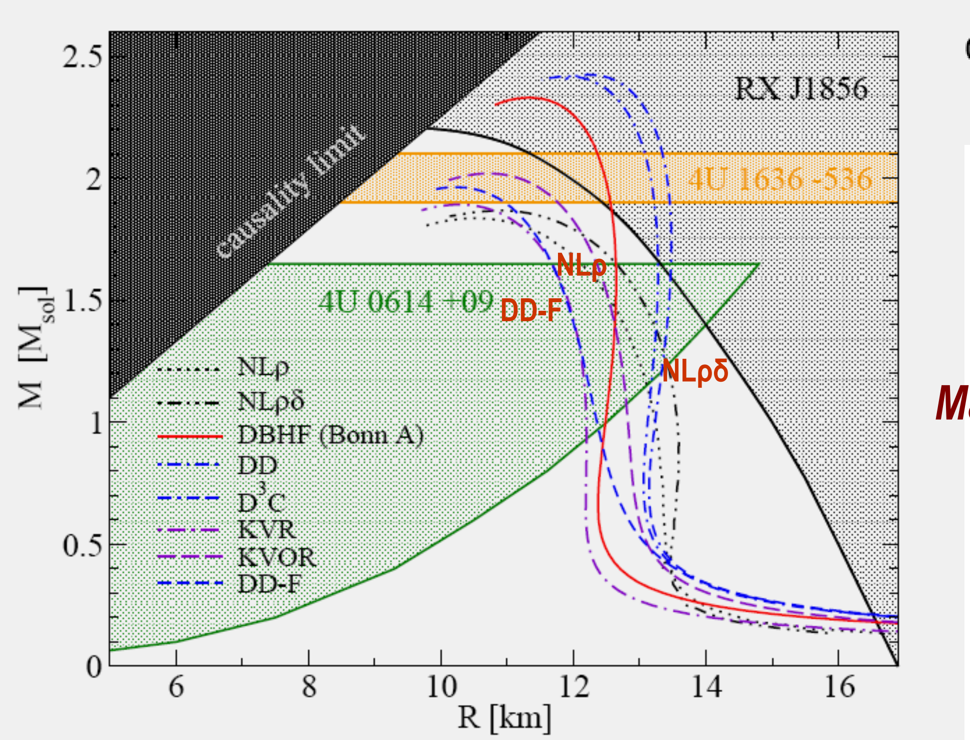
Charge neutrality, $\rho_e = \rho_p = y\rho$

Neutron Star (npeμ) properties

Direct URCA threshold



- Transition to quark matter?
- Faster Cooling for Heavier NS?



Mass/Radius relation

compact stars & heavy ion data
T.Klaehn et al. PRC 74 (2006) 035802

Effective masses: different definitions

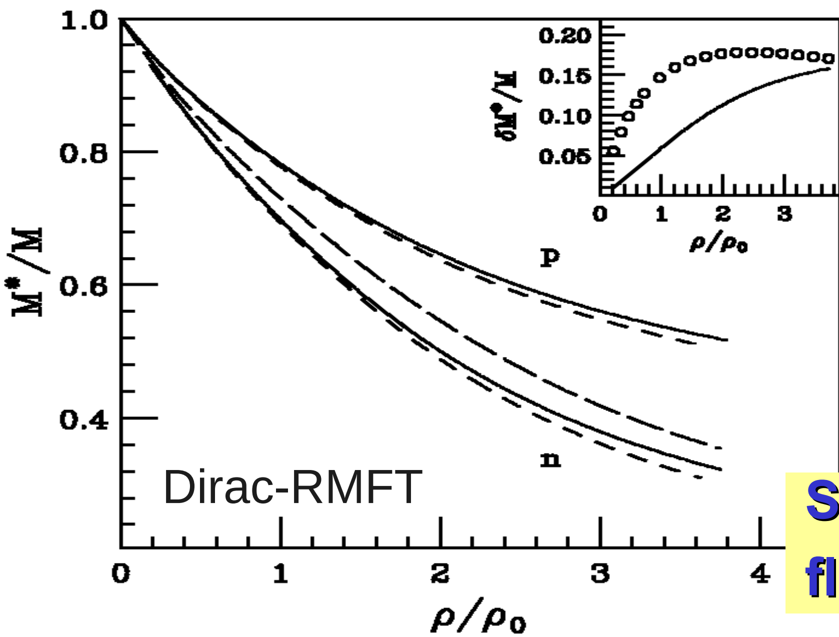
Non-relativistic mass

Parametrize non-locality in space & time

$$m^*_{nr} = \left[m + \frac{1}{k} \frac{d}{dk} U_{s.p.} \right]^{-1}$$

Dirac mass (for Rel.Mod.)

$$m^*_D = m + \Sigma_s$$



Diffence in proton/neutron

- BHF: $m^*_{NR,n} > m^*_{NR,p}$
- RMF: $m^*_{D,n} < m^*_{D,p}$; $m^*_{NR,n} < m^*_{NR,p}$ $(\rho + \delta)$

  Baran, Di Toro et al., Phys. Rep. 410 ('05) 335
- DBHF with Σ extracted by fi t method: $m^*_{D,n} > m^*_{D,p}$

  Alonso & Sammarunca, PRC 67 ('03) 054301
- non-rel. mass in DBHF: $m^*_{NR,n} > m^*_{NR,p}$

  van Dalen, C.F, Faessler, PRL 95 (2005) 022302

C. Fuchs, H.H. Wolter, EPJA 30(2006)5

The real issue with RMFT is not the Dirac or the non-relativistic, but the zero range approximation that means an explicit MD contribution is missed
in the self-energies

Sensitive observables: nucleon emission, flow, particle production (π^-/π^+, ...)

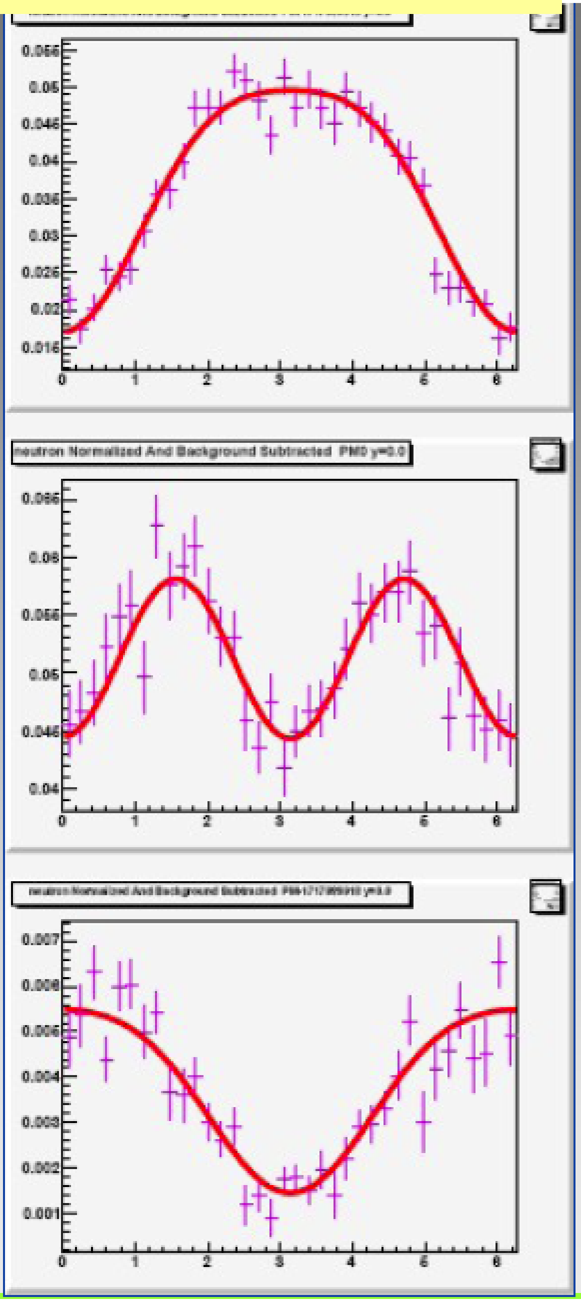
Neutron and Z=1 Elliptic Flows from FOPI-LAND Data at SIS-GSI: Au+Au 400 AMeV
W.Trautmann ECT*, May 11 2009

azimuthal angular distributions
for neutrons,
background subtracted

$y/y_p = 0.2$:
- near target rapidity
- mostly directed flow

y/yp = 0.5:
- mid-rapidity
- strong squeeze-out

y/yp = 0.8:
- near projectile rapidity
- mostly directed flow



fitted with:

$f(\Delta\varphi)=a_0*(1.0+2v_1*\cos(\Delta\varphi)+2v_2*\cos(2\Delta\varphi))$

$\Delta\varphi = \varphi_{particle} - \varphi_{reaction\ plane}$

p_t dependence, various centralities and rapidities

p_t dependence of v_2

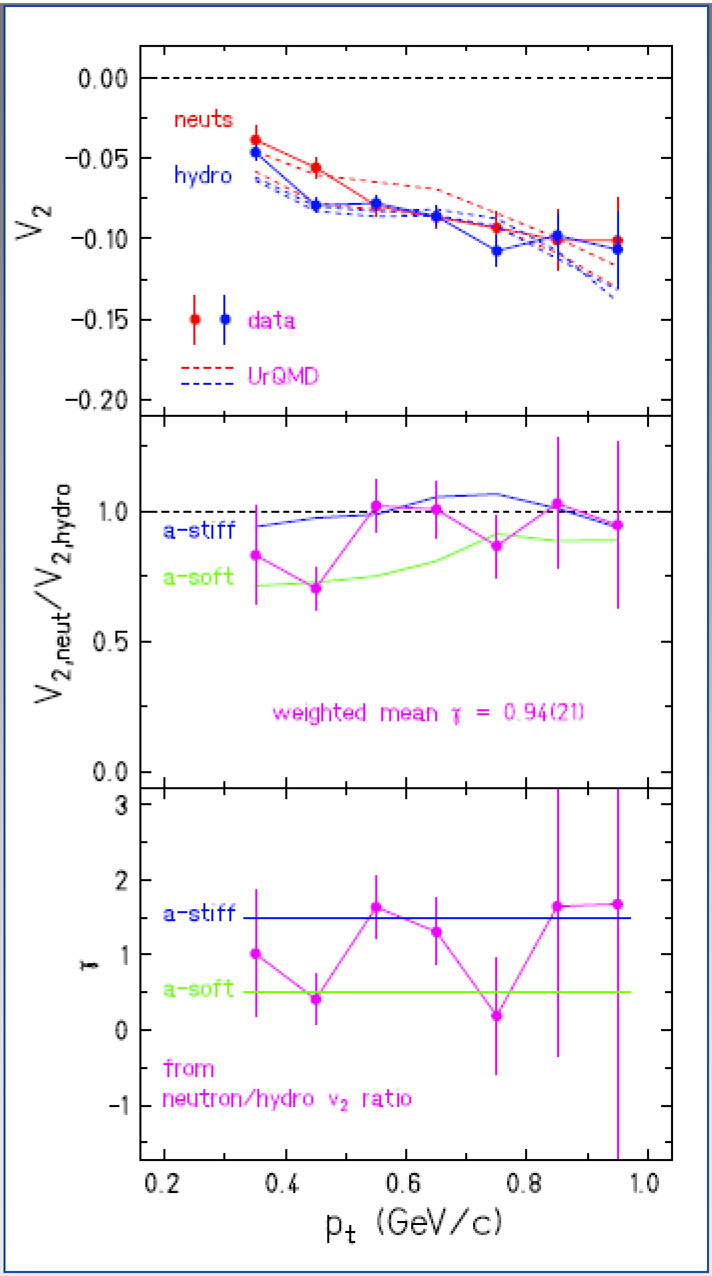
Data:
(PM3-PM5, $0.25<y/y_p<0.75$)
- $|v_2|$ increases as expected
- well reproduced by UrQMD
- but: 15% correction missing

Q. Li

let's look at ratios only:
- large errors at large p_t
- UrQMD: decreasing sensitivity at $p_t>0.8$

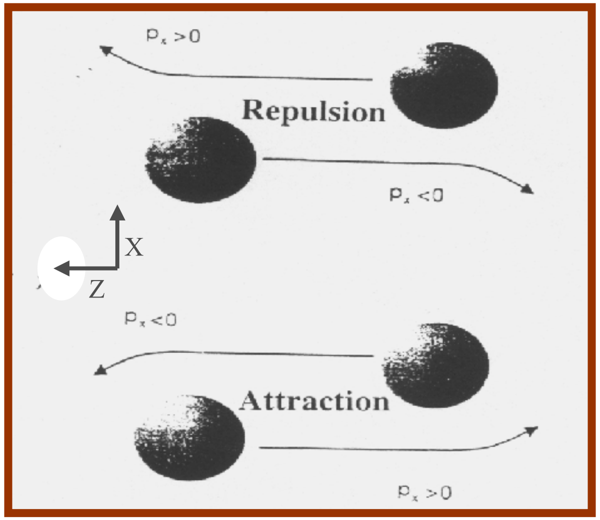
result from neut/hydro ratios:
- $<\gamma> = 0.94 \pm 0.21$
- potential part just below linear

$E_{sym} \sim E_{sym}(\text{fermi}) + \rho^{\gamma}$, no mass splitting

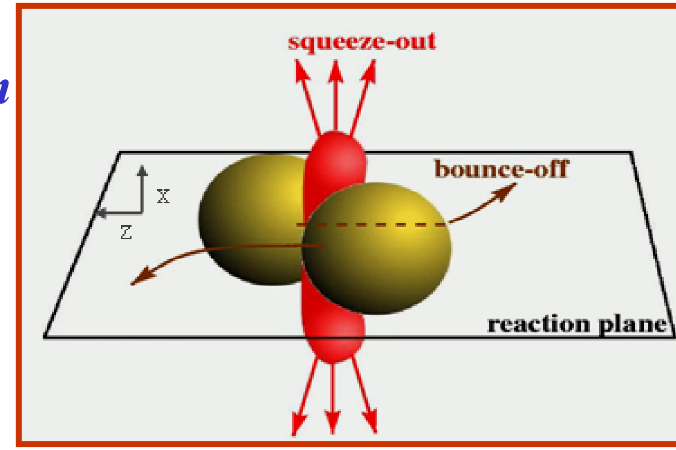


Collective flows

In-plane



Out-of-plane

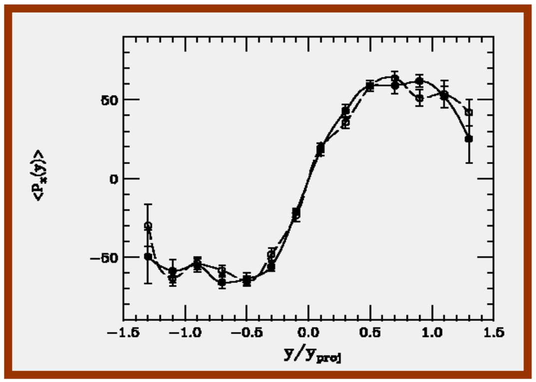


y = rapidity

p_t = transverse momentum

$$V_1(y, p_t) = \langle p_x \rangle / \langle p_t \rangle_y$$

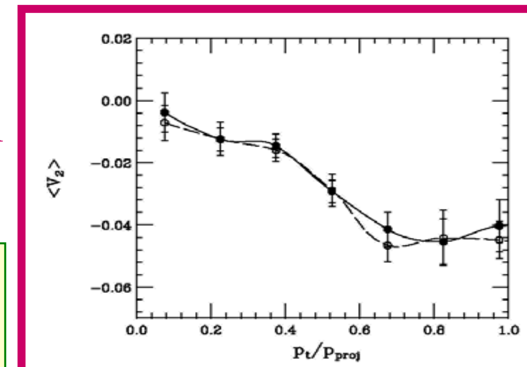
$$V_2(y, p_t) = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle_y$$



V_1 vs. y

$$V_2 \begin{cases} = -1 & \text{full out} \\ = 0 & \text{spherical} \\ = +1 & \text{full in} \end{cases}$$

V_2 vs p_t



Isospin

$$V_1^{p-n}(p_t) = V_1^p(p_t) - V_1^n(p_t)$$

$$V_2^{p-n}(p_t) = V_2^p(p_t) - V_2^n(p_t)$$

$$< v_{Differential}(y, p_t) > \equiv \frac{1}{N+Z} \sum \tau_i v_i(y, p_t)$$

$$\tau_i = +1(n), -1(p)$$

+ : isospin fractionation

-- : missed neutrons, smaller

Flow Difference vs.Differential flows

Bag-Model EoS: Relativistic Fermi Gas (two flavors)

Energy density

$$\epsilon = 3 \times 2 \sum_{q=u,d} \int \frac{\mathrm{d}^3 k}{(2\pi)^3} \sqrt{k^2 + m_q^2}\,(n_q + \bar{n}_q) + B,$$

Pressure

$$P = \frac{3 \times 2}{3} \sum_{q=u,d} \int \frac{\mathrm{d}^3 k}{(2\pi)^3} \frac{k^2}{\sqrt{k^2 + m_q^2}} (n_q + \bar{n}_q) - B,$$

Number density

$$\rho_i = 3 \times 2 \int \frac{\mathrm{d}^3 k}{(2\pi)^3} (n_i - \bar{n}_i), \quad i = u, d;$$

q, qbar
Fermi
Distributions

$$n_q = \frac{1}{1 + \exp\{(E_q - \mu_q)/T\}}$$

$$\bar{n}_q = \frac{1}{1 + \exp\{(E_q + \mu_q)/T\}}$$

...only kinetic symmetry energy

Baryon/Isospin Densities
and Chemical Potentials

$$\rho_B = \frac{\rho_u + \rho_d}{3}, \qquad \rho_3 = \rho_u - \rho_d$$

$$\mu_B = \frac{3}{2}(\mu_u + \mu_d), \mu_3 = \frac{\mu_u - \mu_d}{2}$$

DIRAC OPTICAL POTENTIAL

Dispersion relation $(E-\Sigma_0)^2 = p^2 + (m-\Sigma_s)^2$

$$\downarrow$$

$$\varepsilon + m \Rightarrow \sqrt{k_\infty^2 + m^2}$$

$\longrightarrow$

$$V_{opt} = \Sigma_0 - \Sigma_s + \frac{1}{2m}\left(\Sigma_s^2 - \Sigma_0^2\right) + \frac{\Sigma_0}{m}\varepsilon$$

$\longrightarrow$ RMF

Schrödinger mass

$$\frac{m_q^*}{m} = \left[1 + \frac{m}{\hbar^2 k}\frac{\partial U_q}{\partial k}\right]^{-1}$$

$$m_S^* = \frac{m}{1+\frac{\Sigma_0}{m}} \approx m - \Sigma_0 = m_D^* + (\Sigma_s - \Sigma_0)$$

~50 MeV

Dirac mass

$$m_D^* = m - \Sigma_s$$

Asymmetric Matter

$(\sigma, \omega, \rho, \delta)$

$$\Sigma_0 \Rightarrow \Sigma_0 \mp f_\rho \rho_{B3}$$

$$\Sigma_s \Rightarrow \Sigma_s \mp f_\delta \rho_{S3}$$

upper signs: neutron

$$\rho_{B3} \equiv \rho_{Bp} - \rho_{Bn} < 0, n-rich$$

$$m_S^*(n,p) = m_{Dsym}^* + (\Sigma_s - \Sigma_0)_{sym} \pm \rho_{B3}\left(f_\rho - \frac{m_D^*}{E_F^*} f_\delta\right) \rightarrow$$

$$m_D^*(n) < m_D^*(p)$$

$$m_S^*(n) < m_S^*(p)$$

Phys.Rep.410(2005)335-466, MSU-RIA05 nucl-th/0505013 AIP Conf. 791(2005)70-82

BEYOND RMF: k-dependence of the Self-Energies

$$f(\sigma,\omega,\rho,\delta) \equiv f_i(\rho_B,k) \quad \Leftrightarrow \quad \text{DBHF}$$

Schroedinger mass

$$m_S^* = m_D^* + (\Sigma_s - \Sigma_0) + (m - \Sigma_s)\Sigma_s' - (m + \varepsilon - \Sigma_0)\Sigma_0'$$

$$\Sigma_0' \equiv \frac{d\Sigma_0}{d\varepsilon} < 0$$ High momentum saturation of the optical potential

$$\Sigma_s' \equiv \frac{d\Sigma_s}{d\varepsilon} < 0$$ High momentum increase of the Dirac Mass

Asymmetric Matter

$$m_D^*(n) < m_D^*(p)$$
but
$$m_S^*(n) >,< m_S^*(p)$$

Problem still open……
..sensitive observables

Phys.Rep.410(2005)335-466, MSU-RIA05 nucl-th/0505013 AIP Conf. 791(2005)70-82

Relativistic Landau Vlasov Propagation

C. Fuchs, H.H. Wolter, Nucl. Phys. A589 (1995) 732

Discretization of f(x,p*)→ Test particles represented by covariant Gaussians in xp-space

$$f(x,p^*) = \sum_{i=1}^{AN_{test}} \int_{-\infty}^{+\infty} d\tau \;\; g(x - x_i(\tau))\, g(p^* - p_i^*(\tau))$$

→ Relativistic Equations of motion for x^μ and $p^{*\mu}$ for centroids of Gaussians

$$\frac{d}{d\tau} x_i^\mu = \frac{p_i^*(\tau)}{M_i^*(x_i)} \; ,$$

$$\frac{d}{d\tau} p_i^{*\mu} = \frac{p_{i\nu}^*(\tau)}{M_i^*(x_i)} \mathcal{F}_i^{\mu\nu}(x_i(\tau)) + \partial^\mu M_i^*(x_i)$$

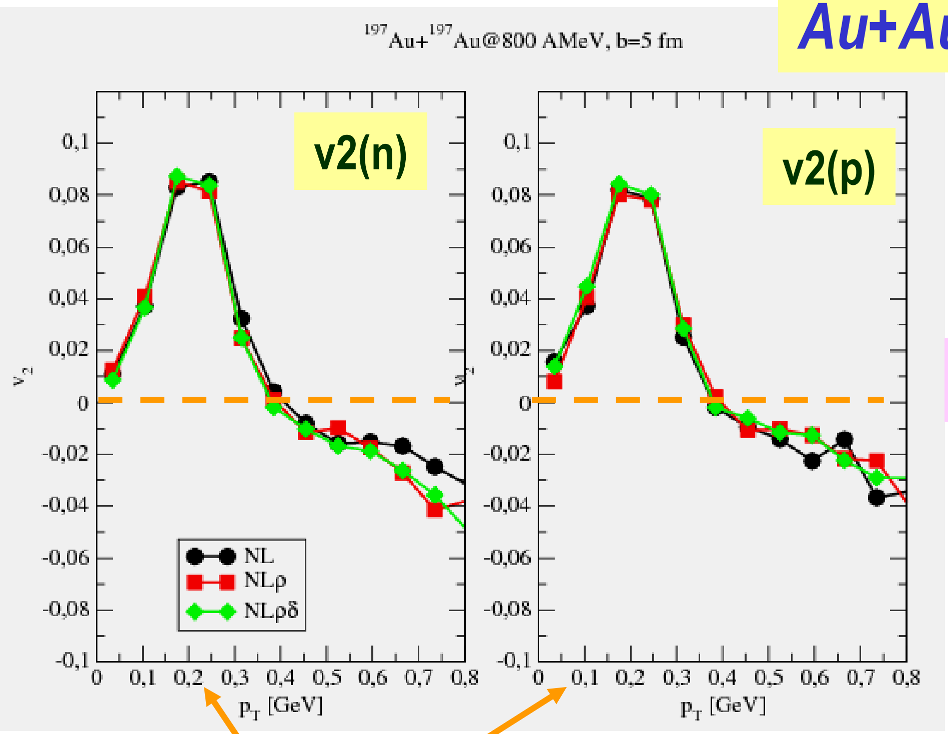
u_ν Test-particle 4-velocity → Relativity: - momentum dependence always included due to the Lorentz term $\left(u_\nu F^{\mu\nu}\right)$
- E*/M* boosting of the vector contributions

Collision Term: local Montecarlo Algorithm imposing an average Mean Free Path plus Pauli Blocking
→ in medium reduced Cross Sections

Au+Au 800 A MeV elliptic flows, semicentral

v2(n), v2(p) vs. p_t

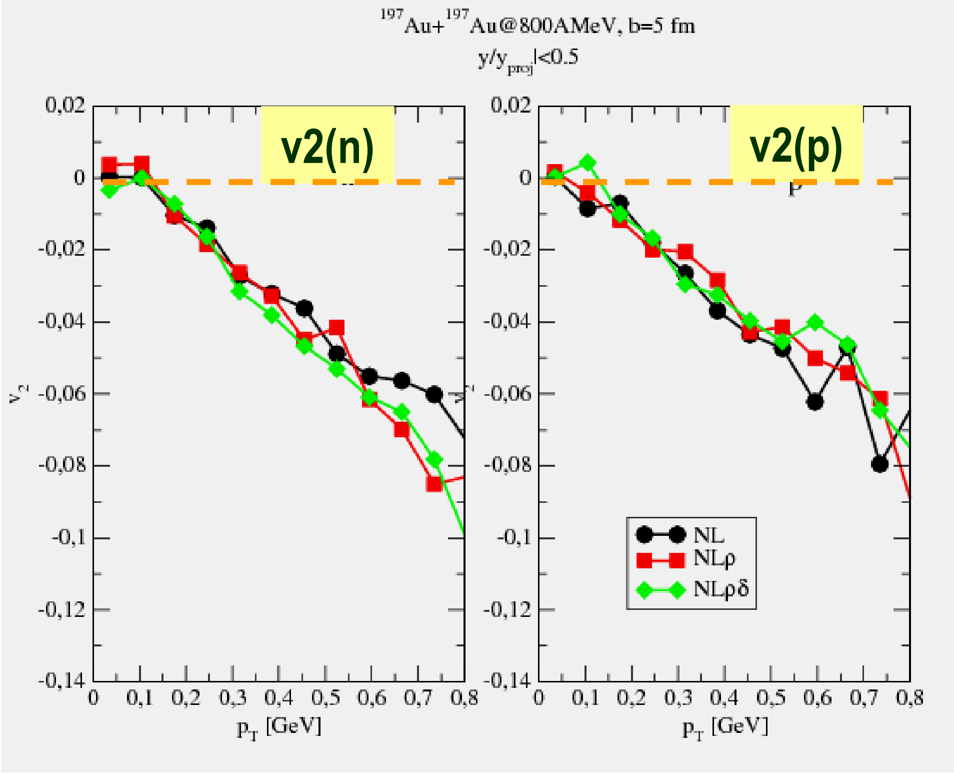
Rapidity selections



All rapidities

Low p_t spectator contributions

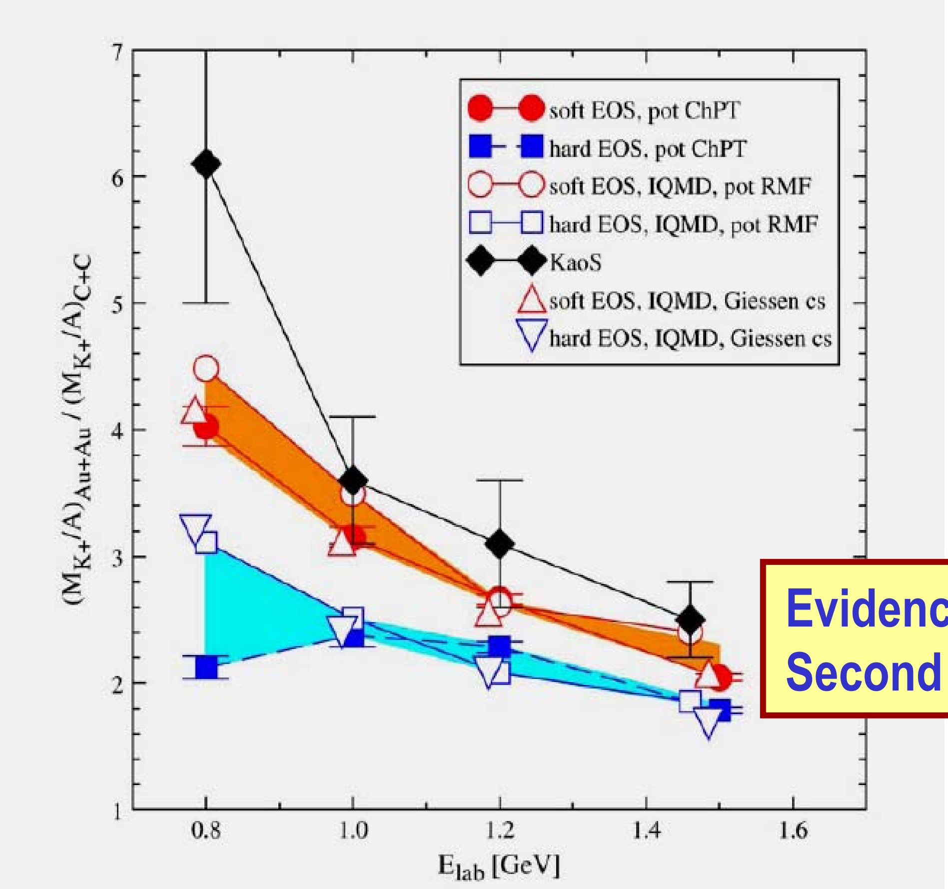
|y°| < 0.5



Pion vs Kaon as a measure of EOS

In the 80's there was the idea of using pions to infer the EOS
C.M. Ko & J. Aichelin, PRL55(85)2661 pointed out that kaons provide a <u>more sensitive and more clean</u> probe of high density EOS.
No conclusion on EOS from pion production

C. Fuchs, Prog.Part. Nucl. Phys. 56 (06)



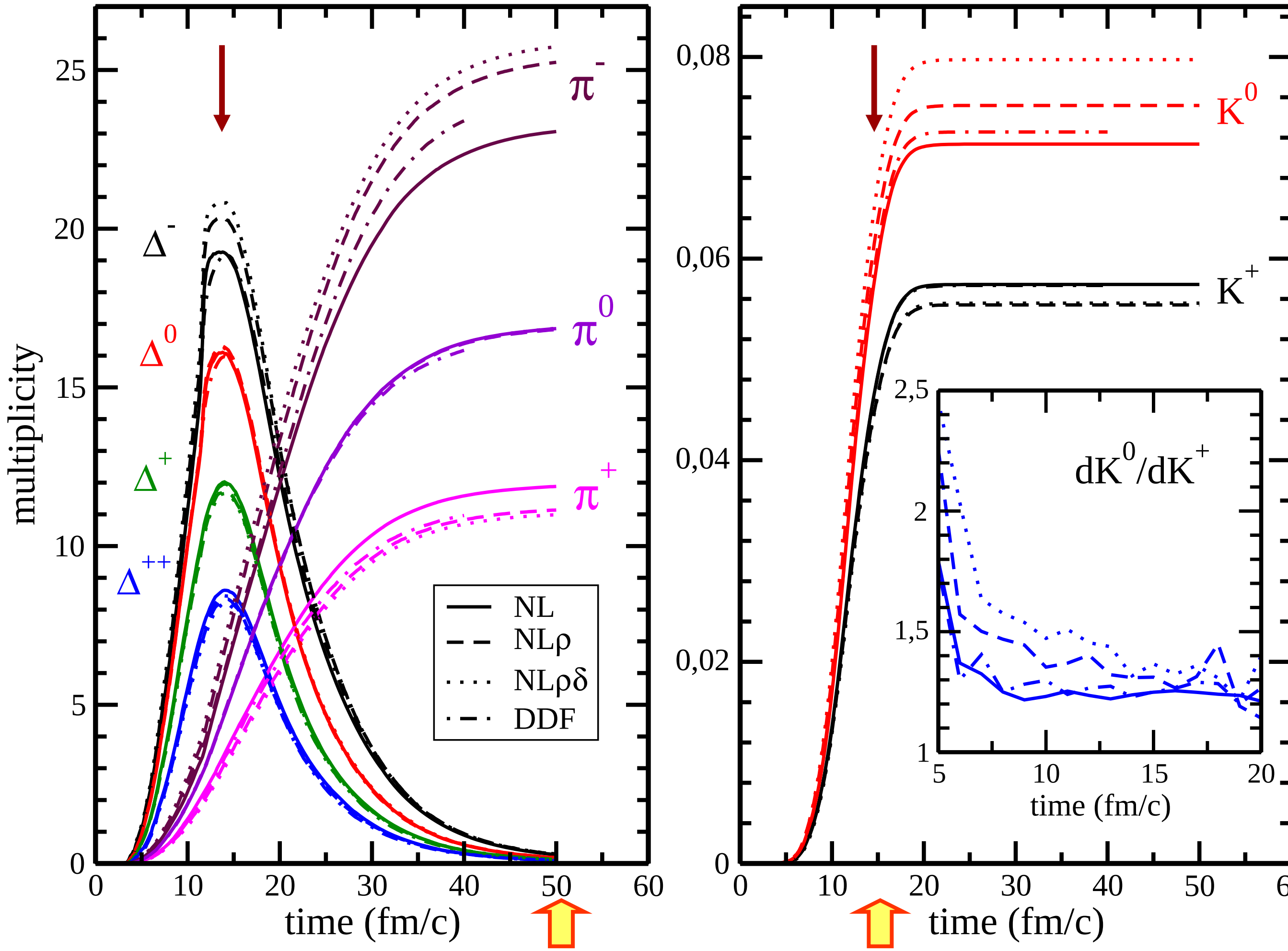
- Pions produced and absorbed during the entire evolution of HIC

- Kaons are closer to threshold -> come only from high density
- Kaons have large mean free path -> no rescattering & absorption
- Kaons small width -> on-shell

Evidence of a Soft EoS at high densities:
Second step processes needed around the threshold

Large Threshold Effects?

Pion/Kaon production in "open" system: Au+Au 1AGeV, central



Pions: large freeze-out, compensation

Kaons:

- **early production: high density phase**
  → **maximum of the Δ-production**
- **isovector channel effects**

.....but second step processes (less asymmetry)

G.Ferini et al.,PRL 97 (2006) 202301

Kaon production in “open” system: Au+Au 1AGeV, central
Main Channels

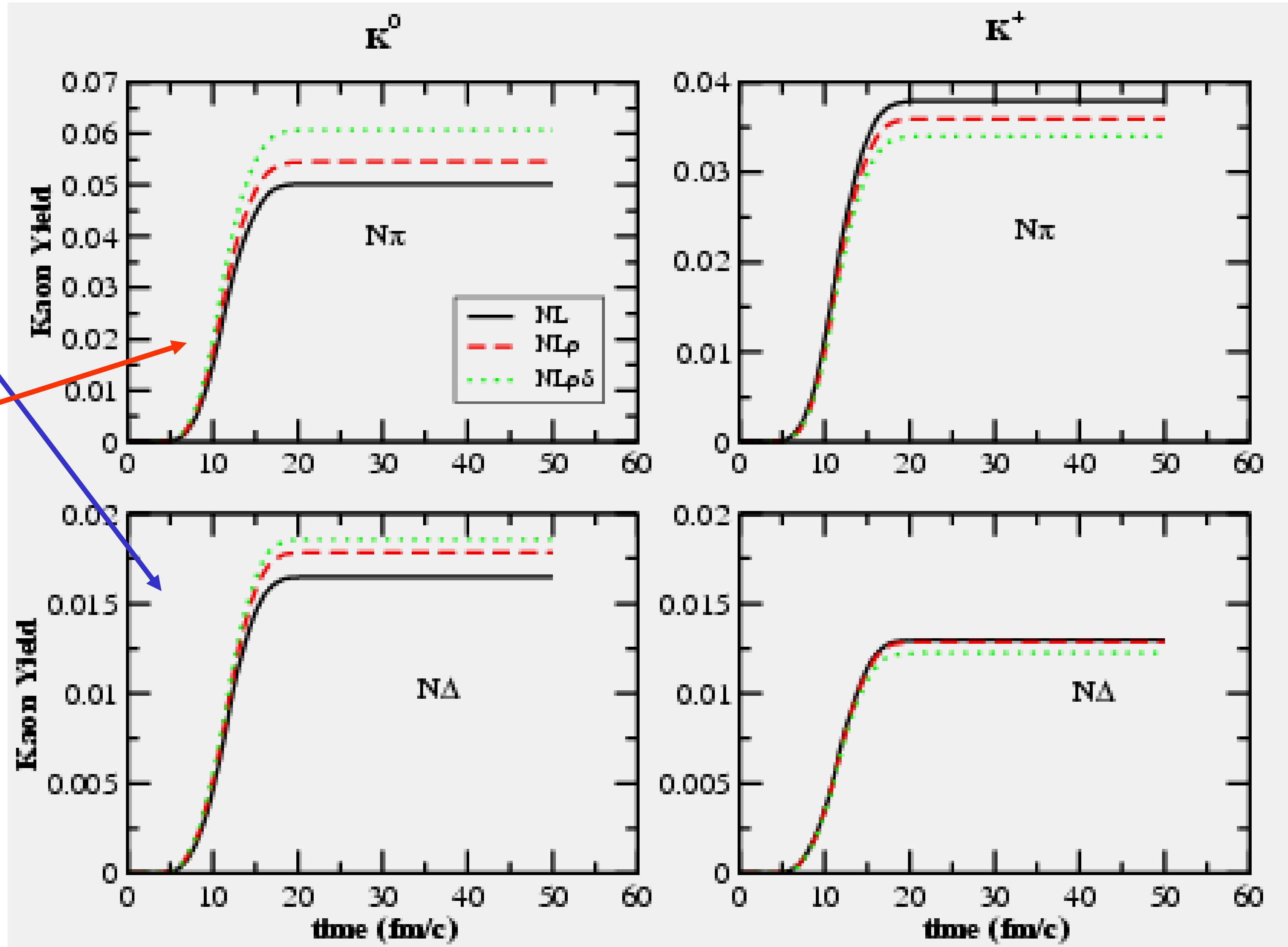
$NN \rightarrow BYK$

$N\Delta \rightarrow BYK$

$\Delta\Delta \rightarrow BYK$

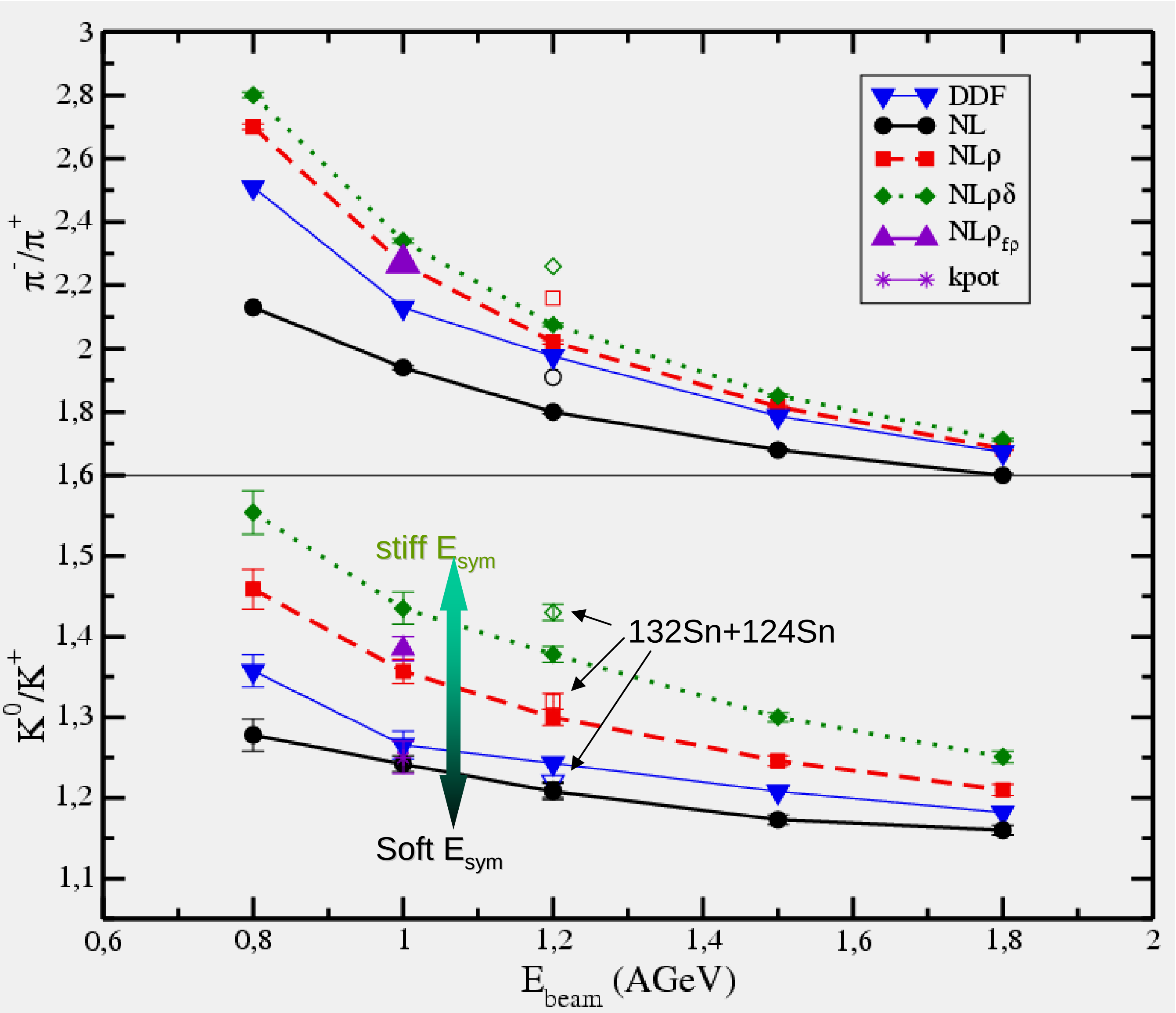
$\pi N \rightarrow YK$

$\pi\Delta \rightarrow YK$



K^0 vs K^+:opposite contribution of the δ-coupling….but second steps

Au+Au central: Pi and K yield ratios vs. beam energy



Kaons:
~15% difference between DDF and NLρδ

K-potentials: similar effects on K^0, K^+

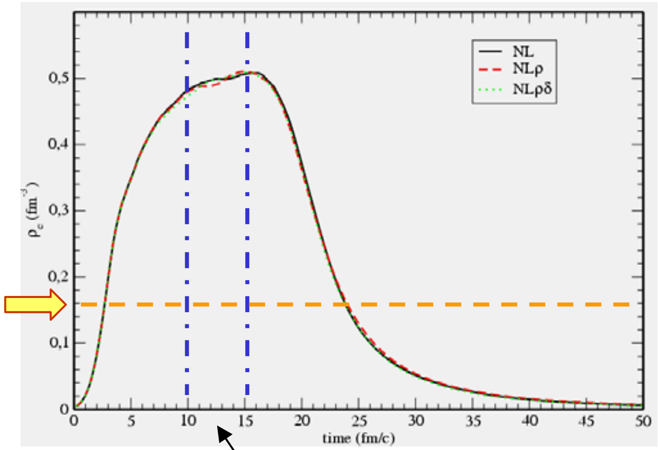
Inclusive multiplicities

Pions: less sensitivity ~10%, but larger yields

G.Ferini et al.,PRL 97 (2006) 202301

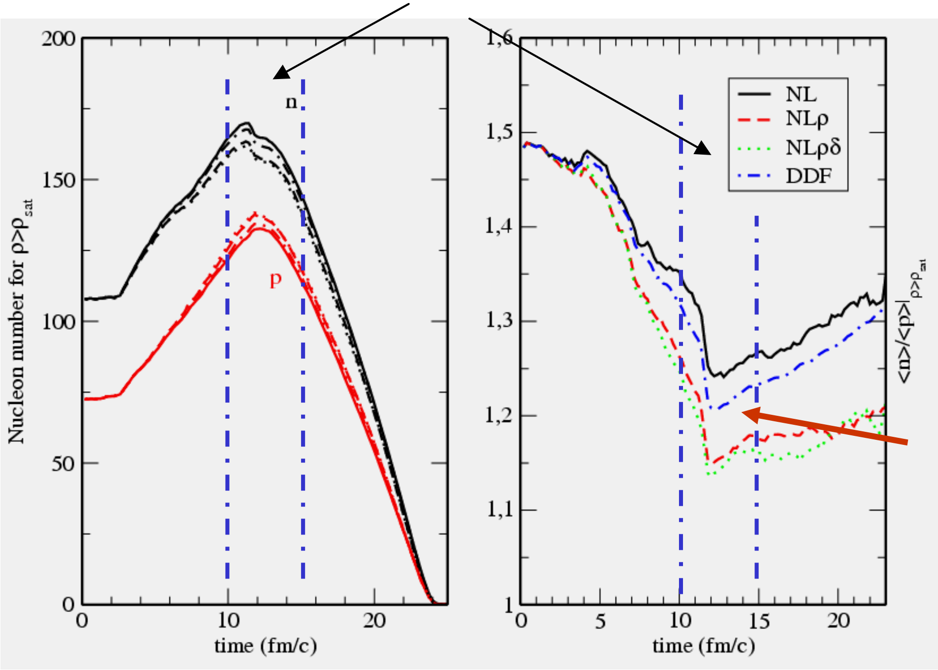
Au+Au 1AGeV: density and isospin of the Kaon source

"central" density



Time interval of Kaon production

n,p at High density



n/p at High density

Drop:

Contribution of fast neutron emission

and

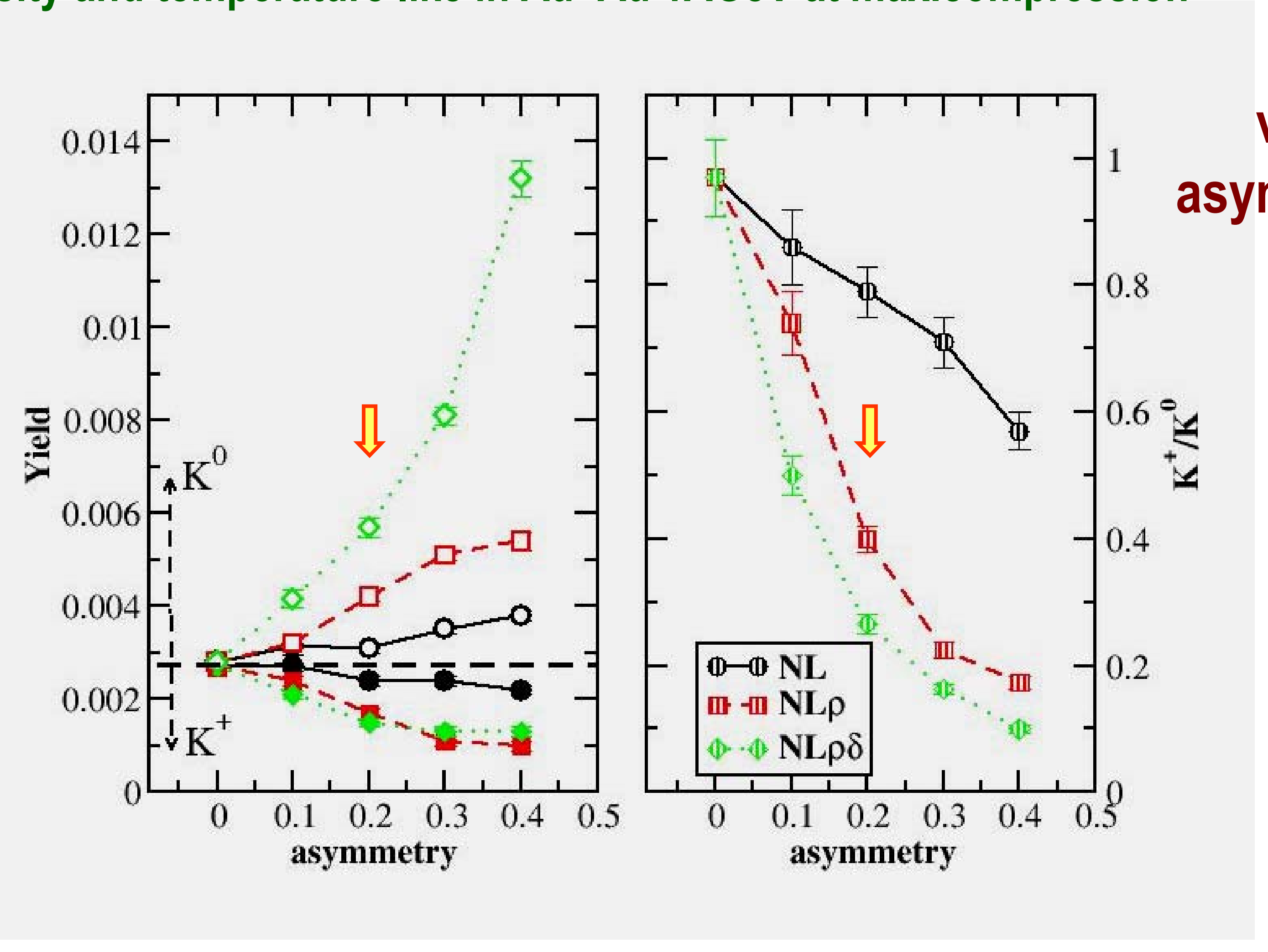
Inelastic channels:

n→p *transformation*

Nuclear Matter Box Results

NPA762(2005) 147

Density and temperature like in Au+Au 1AGeV at max.compression



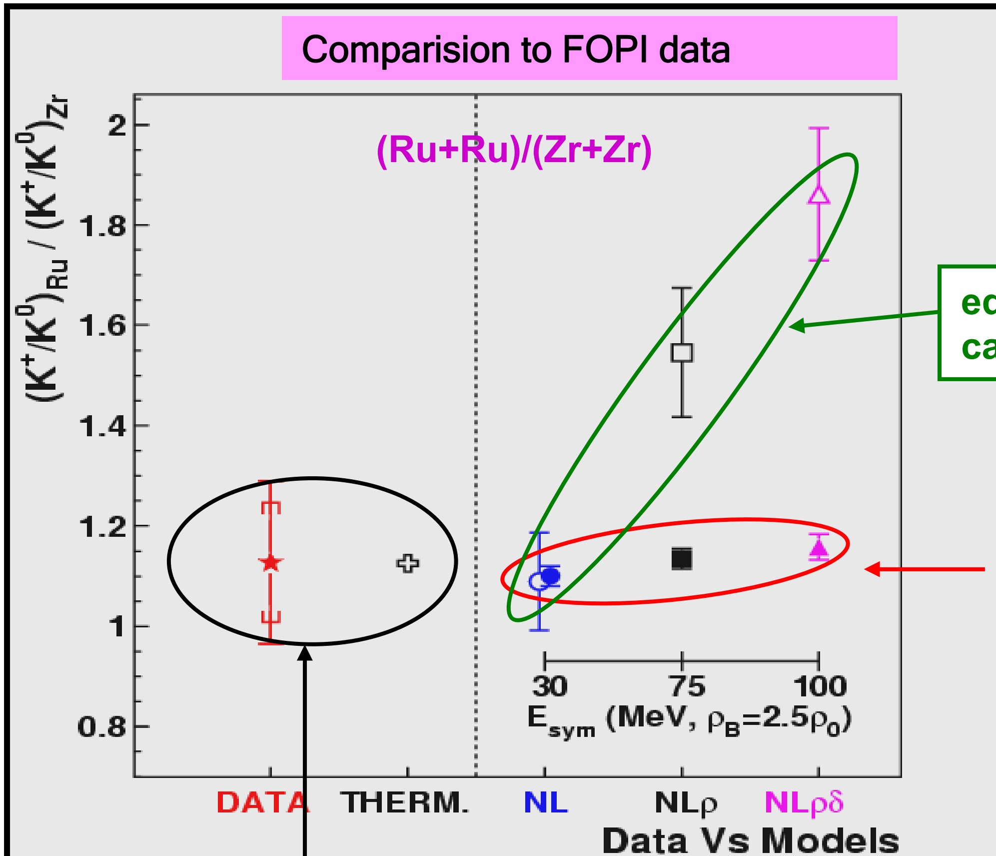
vs. asymmetry

Larger isospin effects: - no neutron escape

- Δ's in chemical equilibrium→less n-p "transformation"

Kaon ratios: comparison with experiment

G. Ferini, et al., NPA 762 (2005) and PRL 97 (2006)



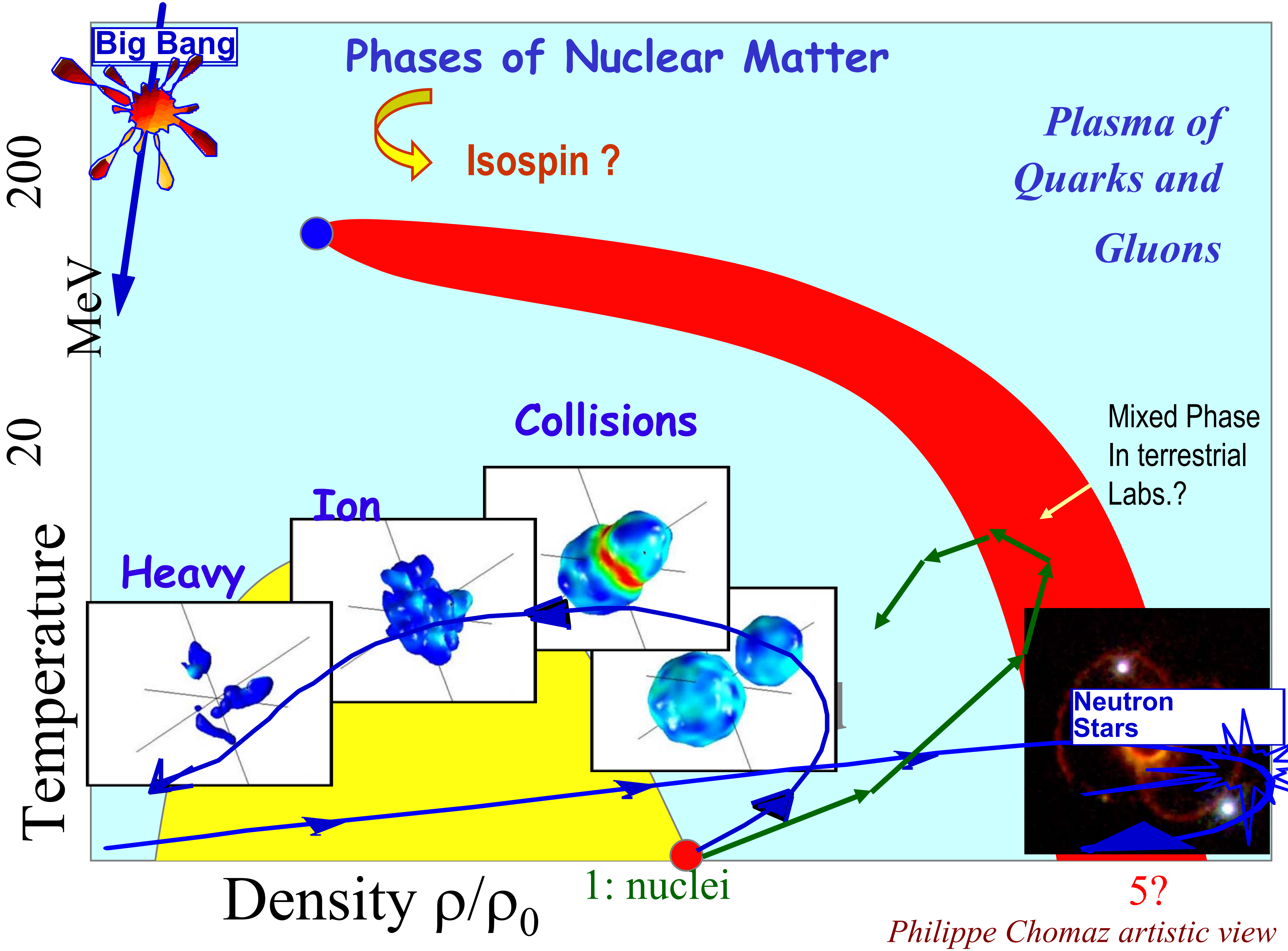
equilibrium (box) calculations

Open system (reaction) calculations

Data (Fopi)

X. Lopez, et al. (FOPI), PRC 75 (2007)

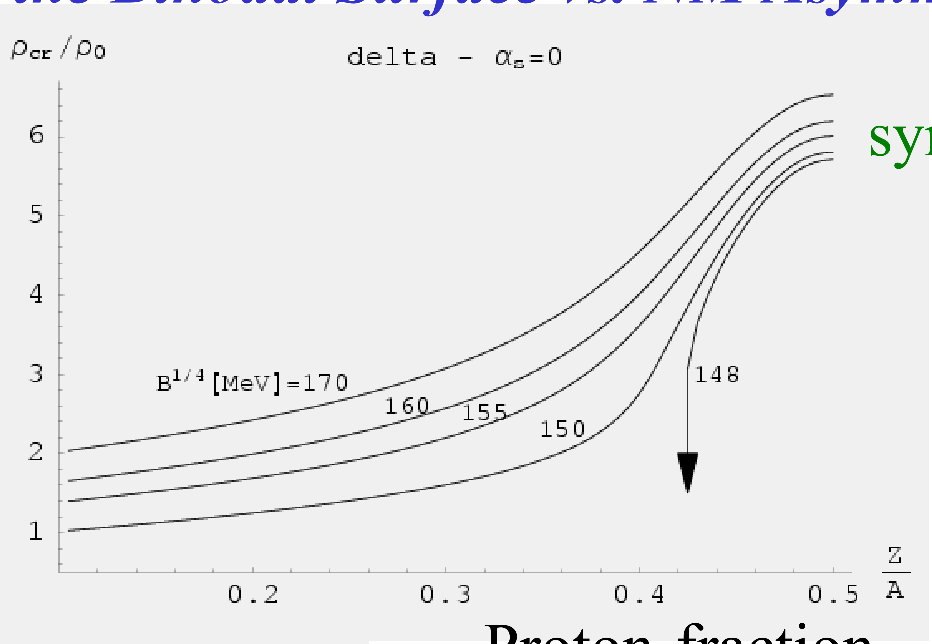
- sensitivity reduced in collisions of finite nuclei
- single ratios more sensitive
- enhanced in larger systems
- larger asymmetries
- more exclusive data


Big Bang
Phases of Nuclear Matter
Isospin ?
Plasma of Quarks and Gluons
200
20
MeV
Temperature
Collisions
Ion
Heavy
Mixed Phase
In terrestrial
Labs.?
Neutron
Stars
Density ρ/ρ0
1: nuclei
5?
Philippe Chomaz artistic view

Lower Boundary of the Binodal Surface vs. NM Asymmetry

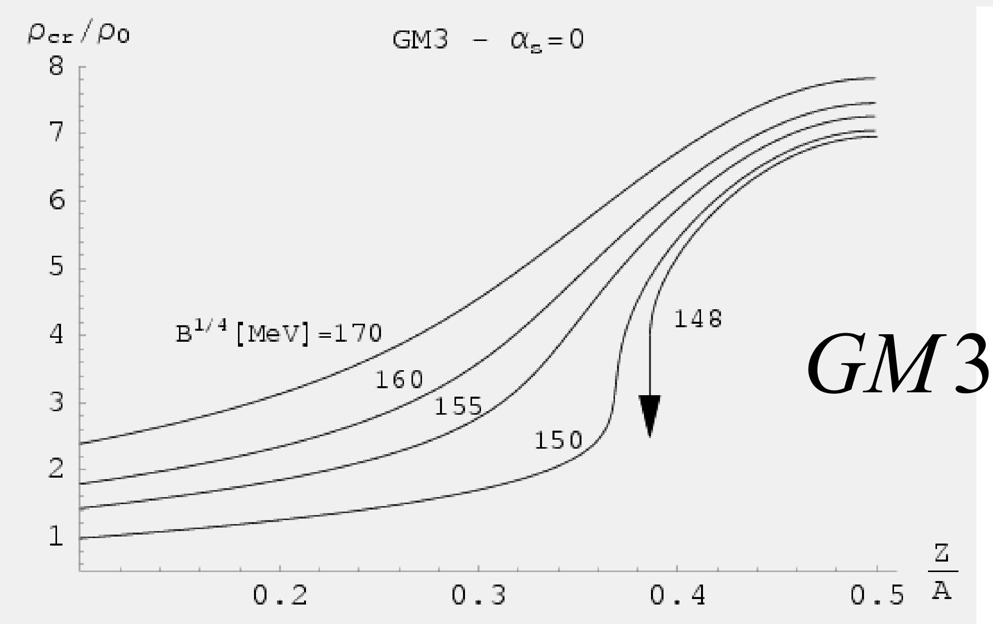
$$Hadron : NL\rho\delta$$

vs. Bag-constant choice



symmetric

Proton-fraction

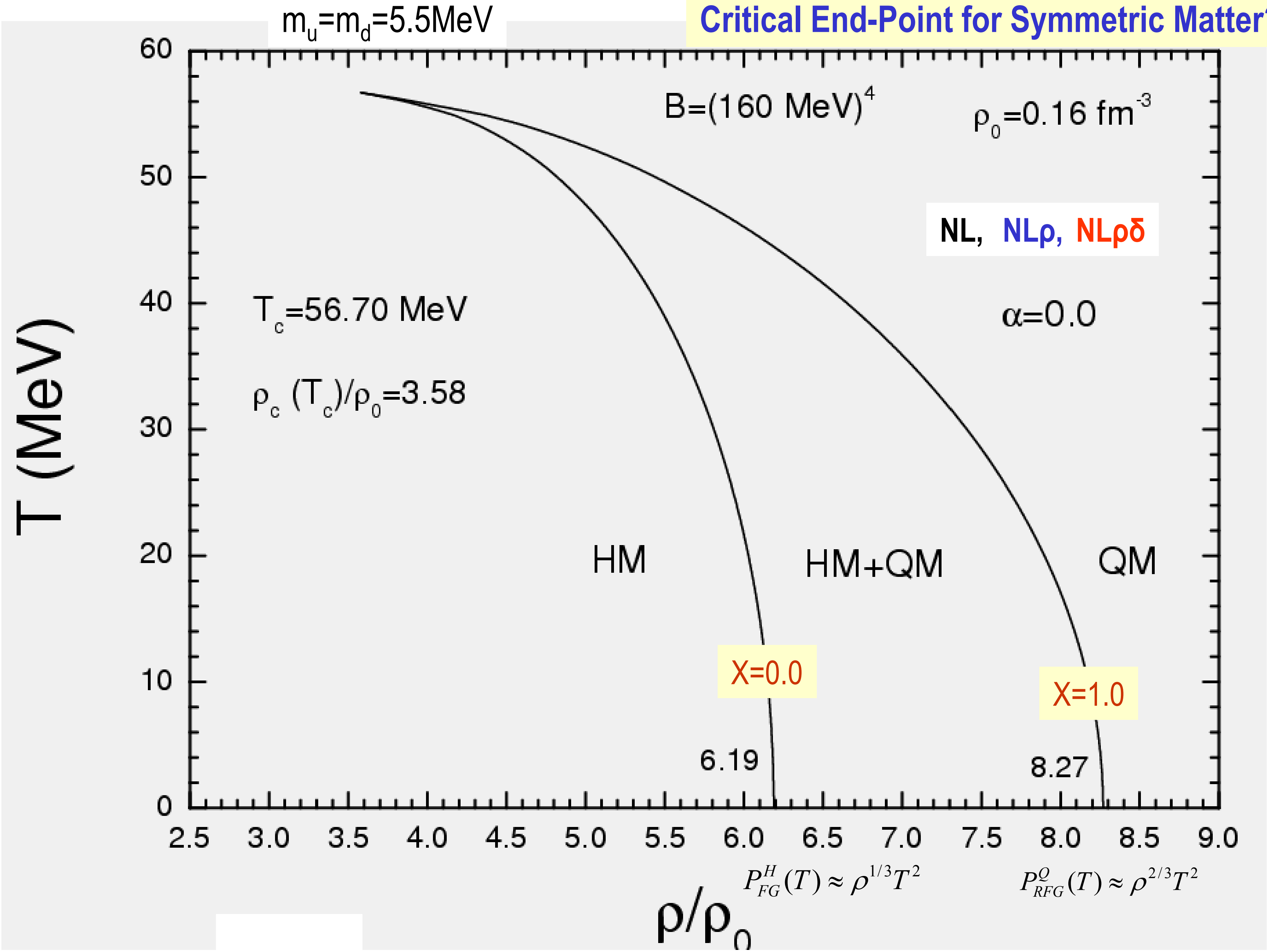


$$GM3 \Leftrightarrow NL\rho$$

α = 1-2 Z/A

NPA775(2006)102-126

Critical End-Point for Symmetric Matter?



NJL Effective Lagrangian (two flavors): non perturbative ground state with q-qbar condensation

$$L_{NJL} \approx \bar{q}[i\gamma^{\mu}\partial_{\mu} - (m - 2G\Phi)]q - G\Phi^2; \Phi = <\bar{q}q>$$

$$Euler - Lagrange \rightarrow$$

$$[i\gamma^{\mu}\partial_{\mu} - (m - 2G\Phi)]q = 0$$

Gap Equation

$$M = m + 4N_f N_c \int_0^{\Lambda_p} \frac{d^3p}{(2\pi)^3} \frac{M}{E_p} [1 - n_p(T,\mu) - \bar{n}_p(T,\mu)]$$

$$n_p(T,\mu) = [\exp(E_p - \mu)/T + 1]^{-1} \quad \rightarrow 1 \qquad \rightarrow 1/2$$

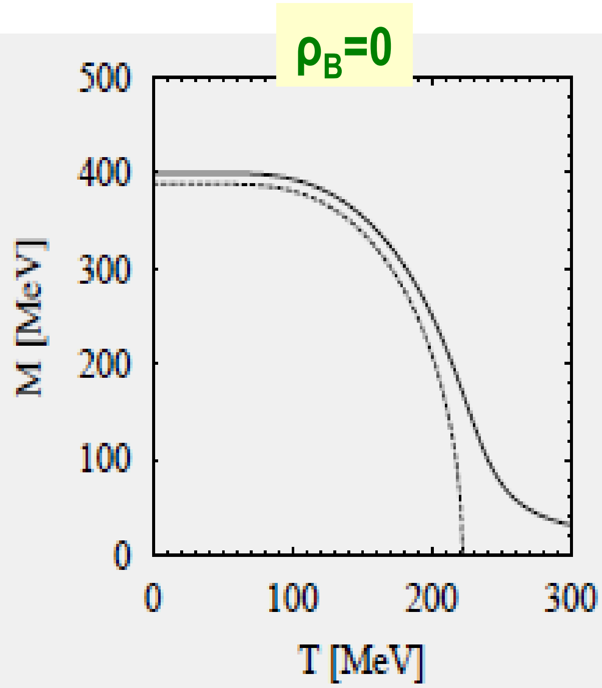
$$\bar{n}_p(T,\mu) = [\exp(E_p + \mu)/T + 1]^{-1} \quad \rightarrow 0 \qquad \rightarrow 1/2$$

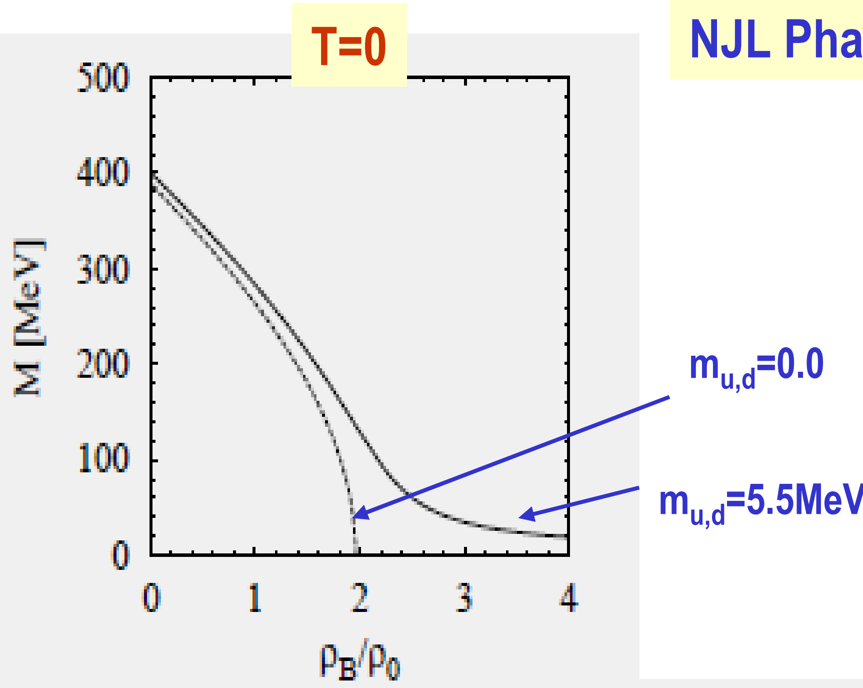
Large μ **or** Large T ⇒ **0**

M.Buballa, Phys.Rep. 407 (2005)

Chiral restoration

NJL Phase Diagram

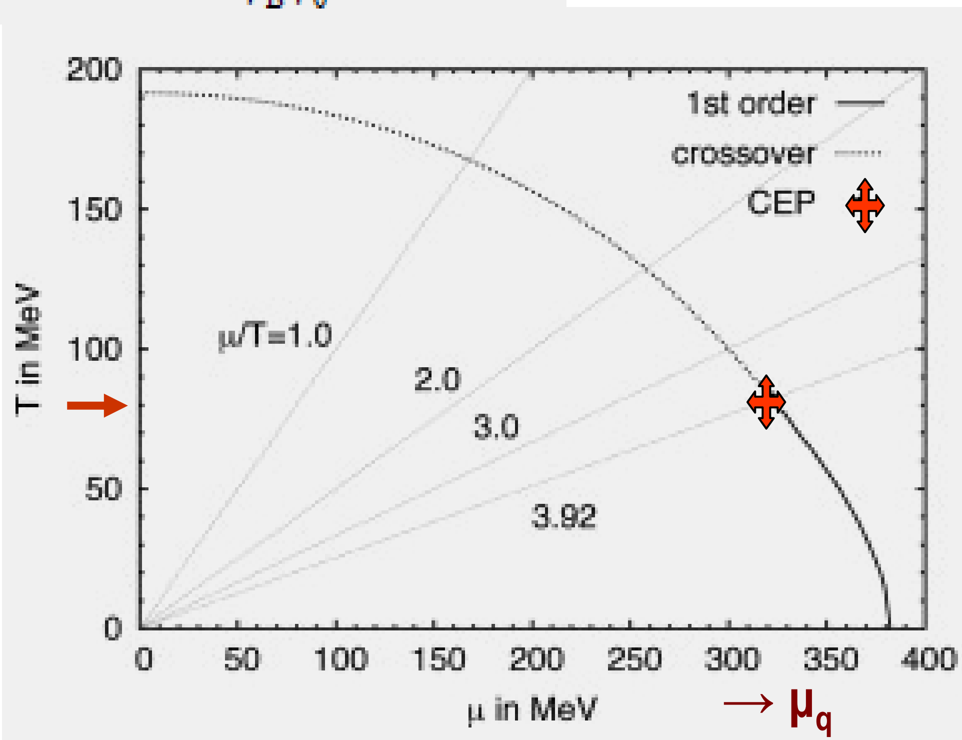




Parameters: Λ_p, G, m

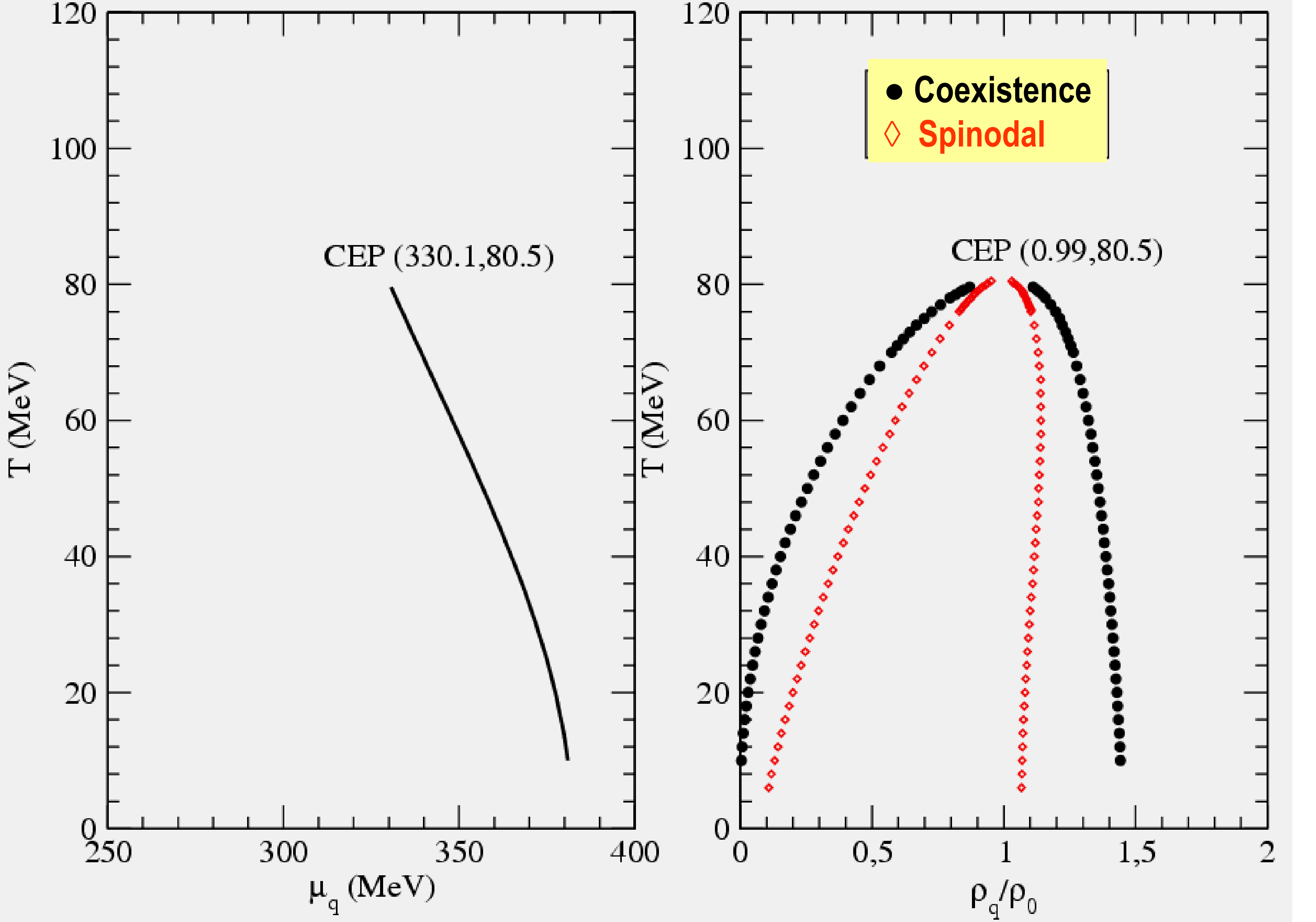
vs.

M_π, f_π, <qqbar> (estimation)



M.Buballa, Phys.Rep. 407 (2005)

Standard Parameters Λ=588 MeV, $g\Lambda^2$=2.44, m_0=5.6 MeV



S.Plumari, Thesis 2009

Isospin Extension of the NJL Effective Lagrangian (two flavors)

Mass (Gap) – Equation with two condensates

$$M_i = m_i - 4G_1\Phi_i - 4G_2\Phi_j, i \neq j(u,d)$$

$$\Phi_u = <\bar{u}u>, \Phi_d = <\bar{d}d>$$

$$G_1 = (1-\alpha)G_0$$

$$G_2 = \alpha G_0$$

α : flavor mixing parameter → α = ½ , NJL, Mu=Md

α → 0 , small mixing, favored → physical η mass

α → 1 , large mixing

M.Buballa, Phys.Rep. 407 (2005)

$$M_u = m - 4G_0\Phi_u + 4\alpha G_0(\Phi_u - \Phi_d)$$
$$M_d = m - 4G_0\Phi_u + 4(1-\alpha)G_0(\Phi_u - \Phi_d)$$

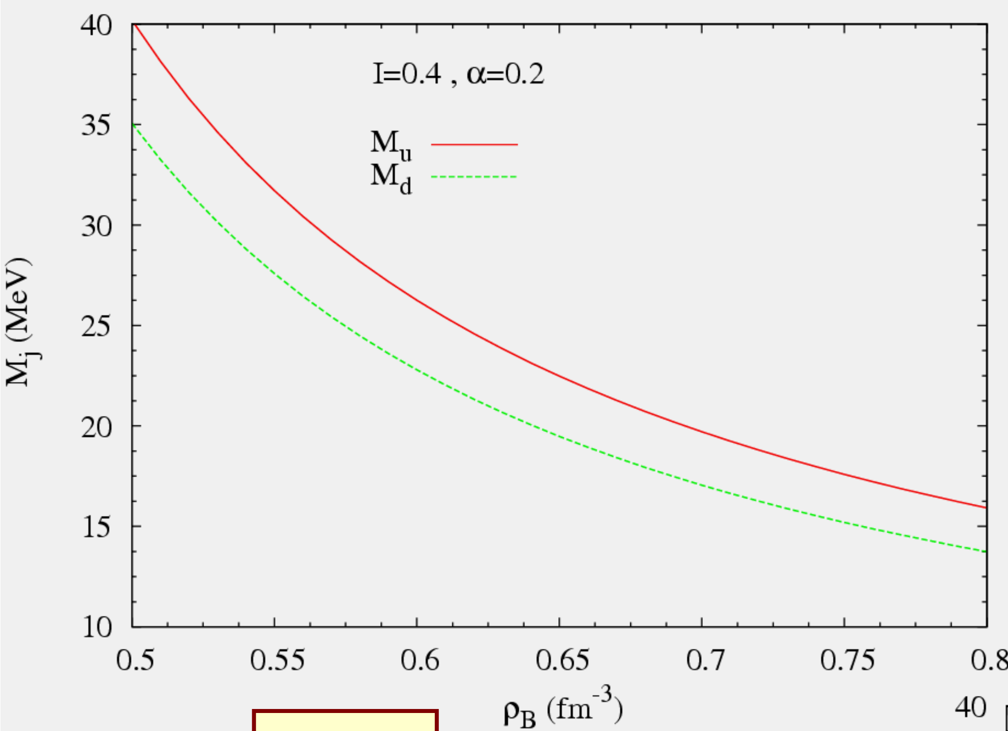
Neutron-rich matter at high baryon density:
$|\Phi d|$ decreases more rapidly due to the larger ρ_d

$\rightarrow (\Phi_u - \Phi_d) < 0$

$$\alpha \rightarrow 0 \Rightarrow M_u > M_d \Rightarrow M_p^* > M_n^*$$
$$\alpha \rightarrow 1 \Rightarrow M_u < M_d \Rightarrow M_p^* < M_n^*$$

α in the range 0.15 to 0.25……

Iso-NJL

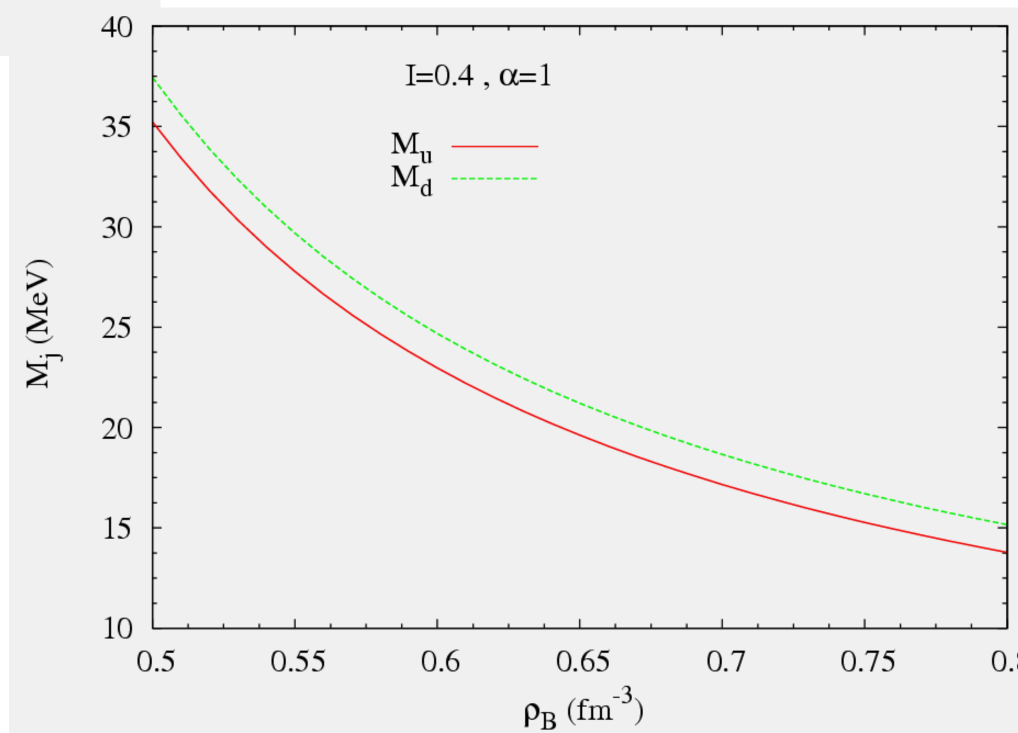


α =0.2

Very n-rich matter: I=(N-Z)/A=0.4

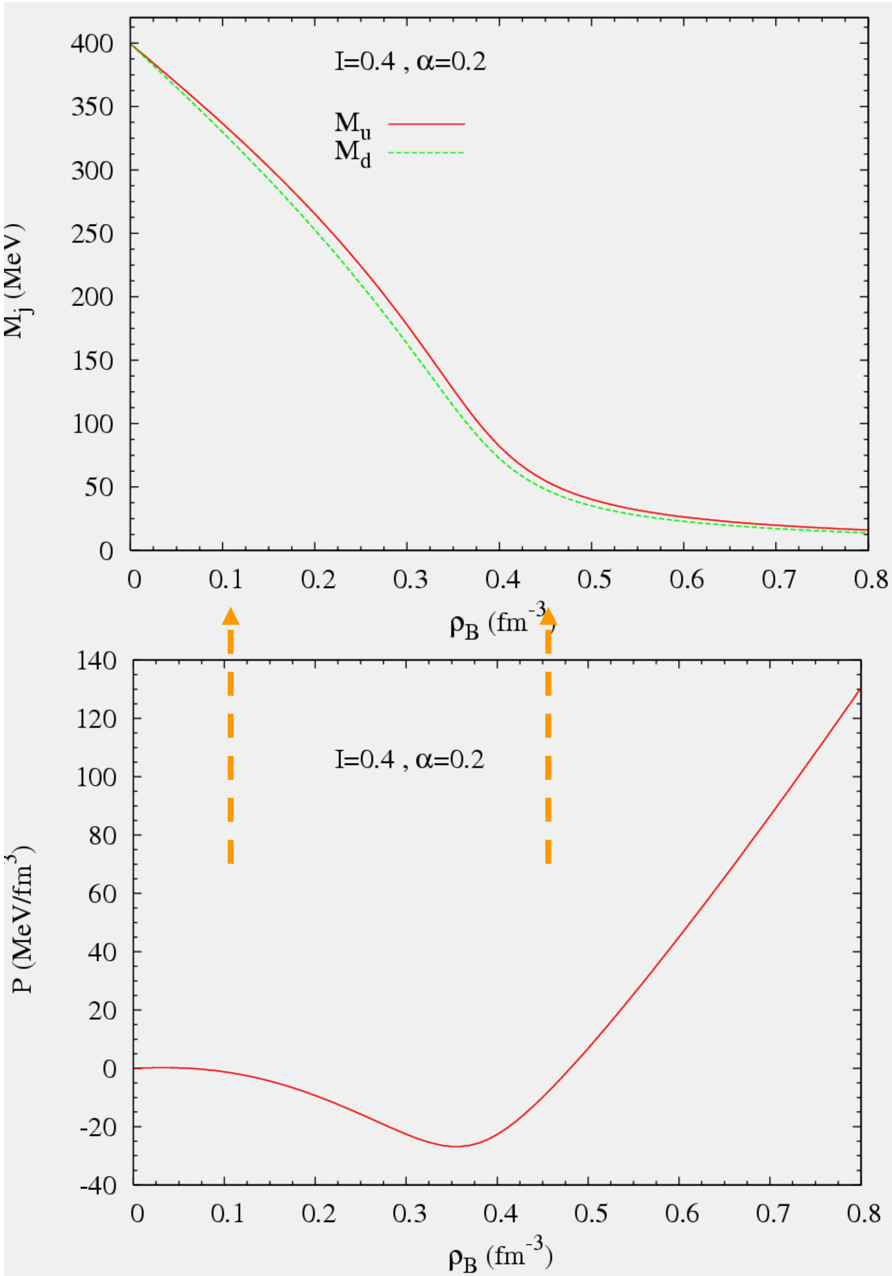
Masses in the Chiral Phase

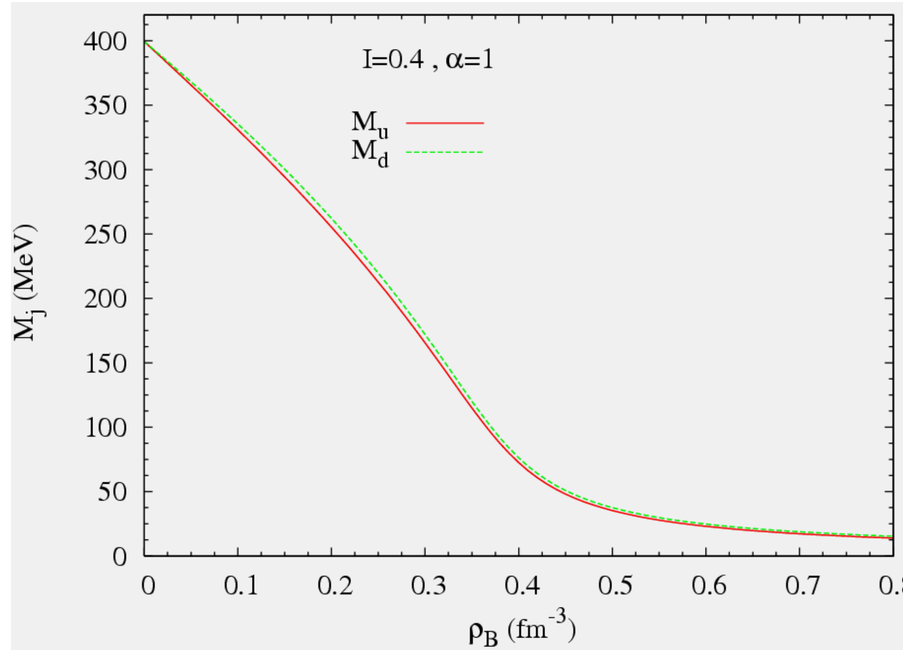
Solutions of the Iso-Gap Equation
S.Plumari, Thesis 2009



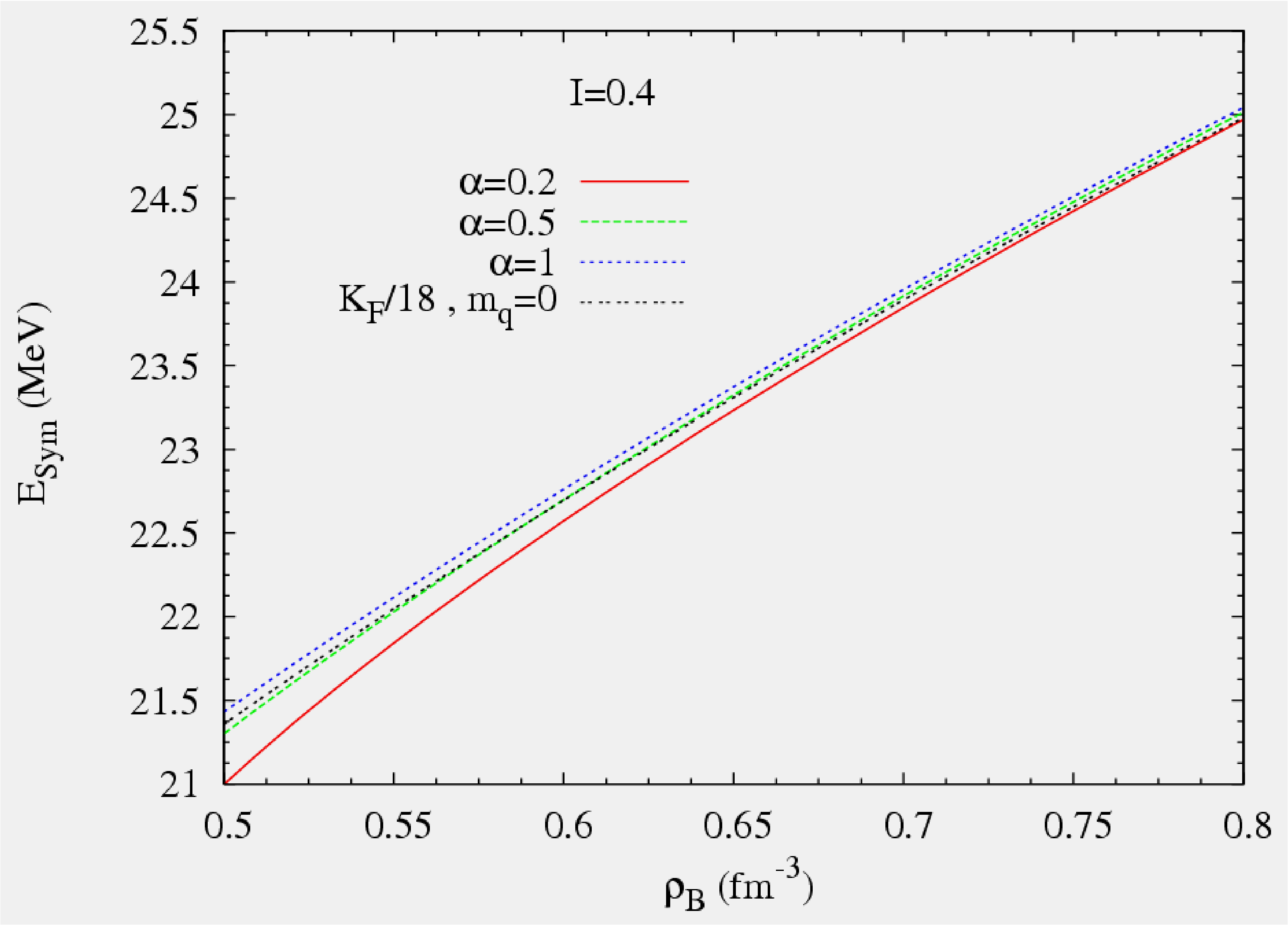
α =1

m = 6MeV
Λ = 590MeV
$G_0\Lambda^2$=2.435
→
M_{vac}=400MeV
<qbarq>=(-241.5MeV)^3
m_π=140.2MeV
f_π=92.6MeV


I=0.4 , α=0.2
M_u
M_d
M_j (MeV)
ρ_B (fm^{-3})
I=0.4 , α=0.2
P (MeV/fm^3)
ρ_B (fm^{-3})


I=0.4 , α=1
M_u
M_d
M_j (MeV)
ρ_B (fm^{-3})

Symmetry Energy in the Chiral Phase: something is missing



….only kinetic contribution