Determination of the EQUATION OF STATE (EOS) in HEAVY ION COLLISIONS

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EOS and HIC

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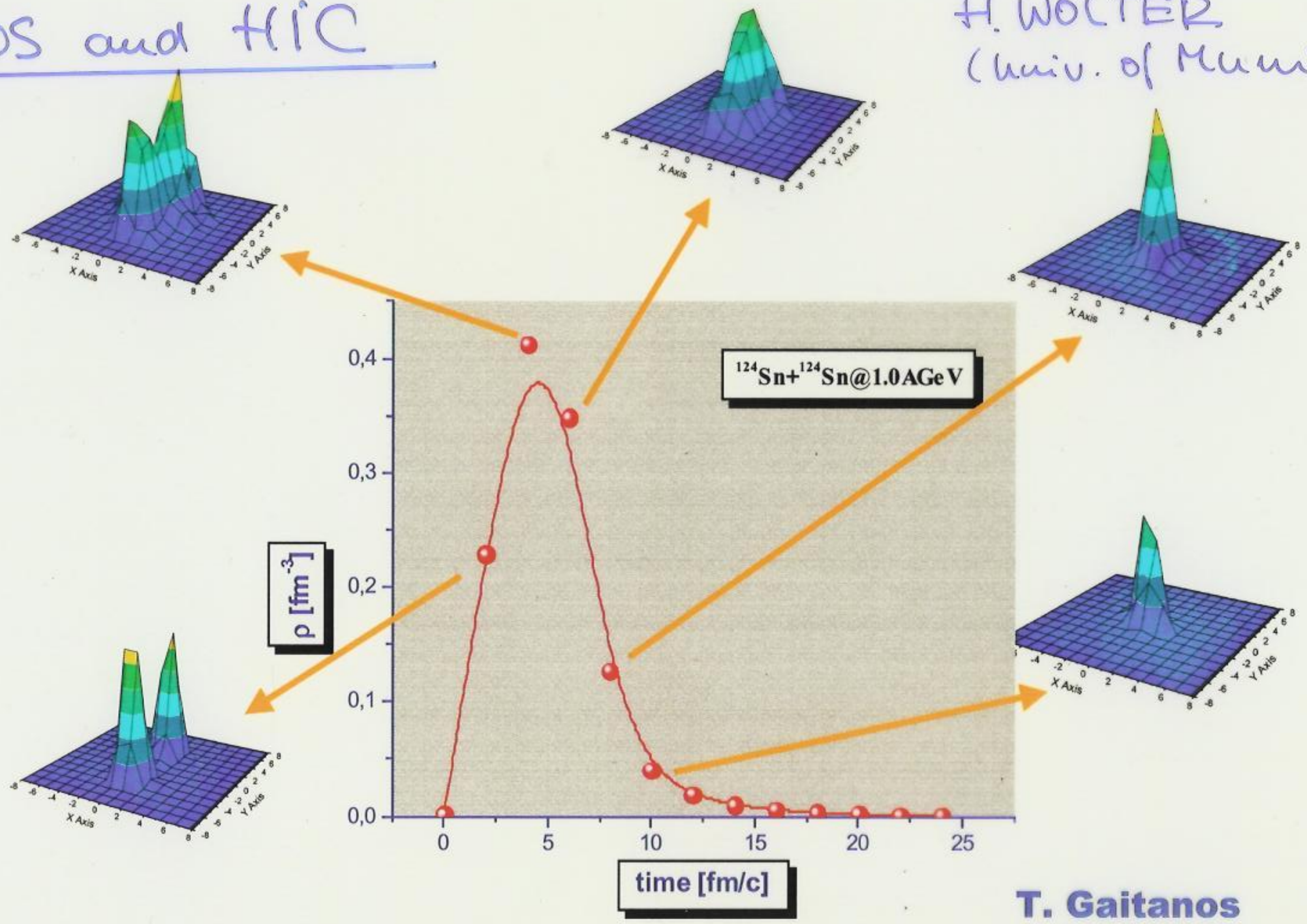


T. Gaitanos

How to extract the EOS from HIC ?

static concept $\qquad$ dynamical process

Transport description for 1-body phasespace distr. $\boxed{f(x,p)}$

e.g. (relativistic) RBUU

$$\left[p^*_\mu \partial^\mu + \left(p^*_\nu F^{\nu\mu} + m^* \partial^\mu m^* \right) \partial^{(p)}_\mu \right] f(x,p) = I_{coll}[f, \sigma_{med}]$$

$$\left.\begin{aligned} m^* &= m - \Sigma_s && \text{scalar} \\ p^*_\mu &= p_\mu - \Sigma_\mu && \text{vector} \\ F^{\nu\mu} &= \partial^\nu \Sigma^\mu - \partial^\mu \Sigma^\nu && \end{aligned}\right\} \text{mean fields (self energies) (EOS)}$$

relation?

$$\Sigma = i\,\mathrm{Tr}\left[G(f)\, f \right] \quad \longleftrightarrow \quad \sigma_{med} \approx |G(f)|^2$$

Dirac-Brueckner G-Matrix

Strategies:

(A) microscopic

$$G^{DB} \longrightarrow \left\{ \begin{matrix} \Sigma^{DB}(k,\rho) \\ \sigma^{DB}_{med} \end{matrix} \right|_{equil} \longrightarrow \left\{ \begin{matrix} \Sigma^{eff} \\ \sigma^{eff}_{med} \end{matrix} \right|_{non-eq} \longrightarrow \text{observables}$$

parameter free, consistent Σ, ρ ; test of DB out of equil.!

(B) phenomenological

$\Sigma(k,\rho)$ $\qquad$ e.g. Skyrme hard/soft + MD

mom. dep. $\qquad$ dens. dep

fit to data → determine EOS! $\quad \sigma_{med}$?

TRANSPORT CALCULATION with

MICROSCOPIC, NON-EQUILIBRIUM SELF ENERGIES

(C. Fuchs, T. Gaitanos, H.H.W.)

$\frac{df}{dt}[\Sigma] = I_{coll}[f, \sigma_{med}]$ transport

Coupled

$\Sigma = -i\,\mathrm{Tr}\,[T[f]f]$ microscopic int.

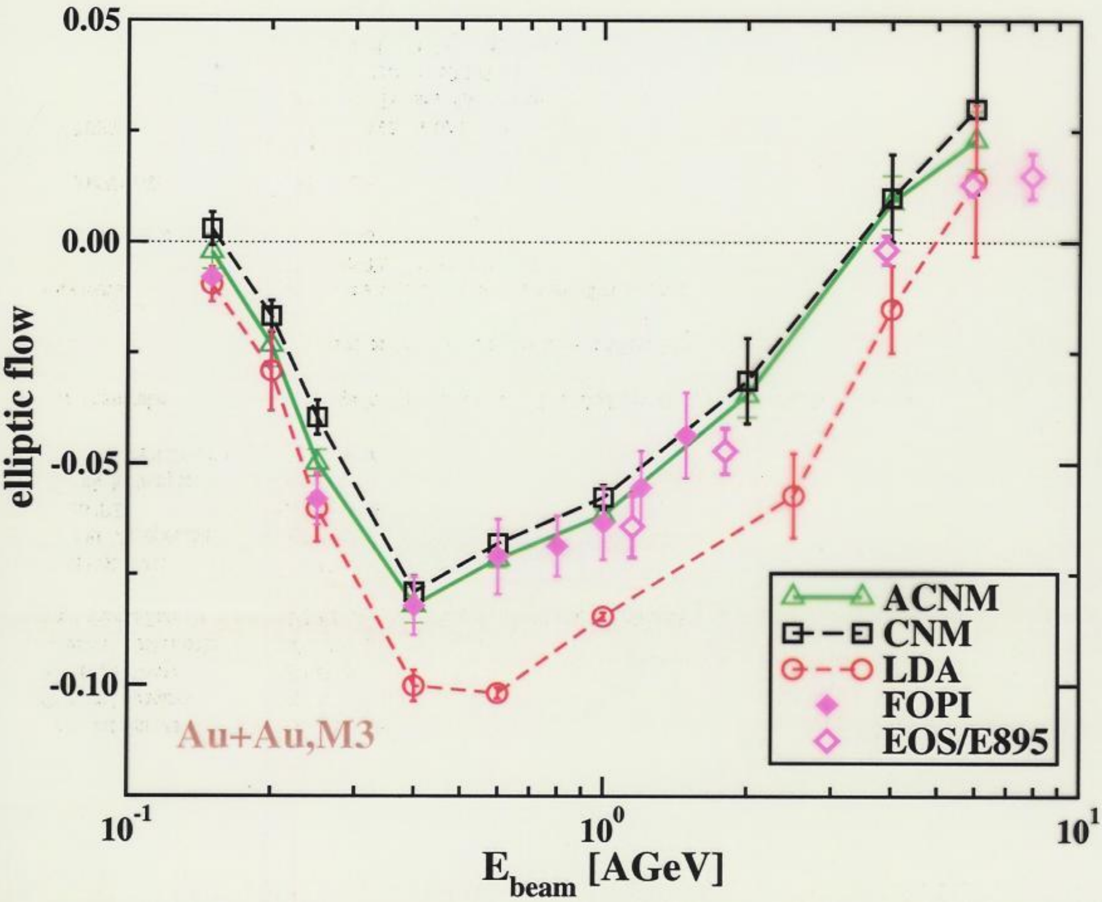
$T = V + V\,\frac{Q[f]}{e}\,T$ $\quad \sigma_{med} \sim |T|^2$ (e.g. Dirac-Brück)

local dens. LDA  equilibr. approx.

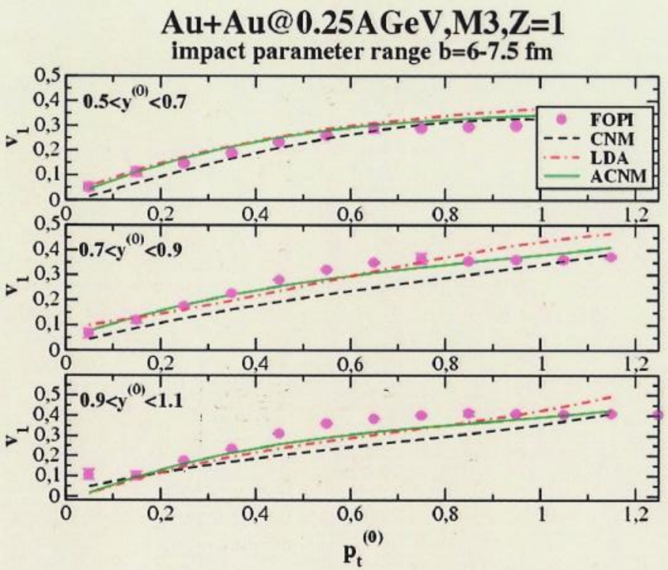
coll. nucl. matter CNM  local non-equilibrium

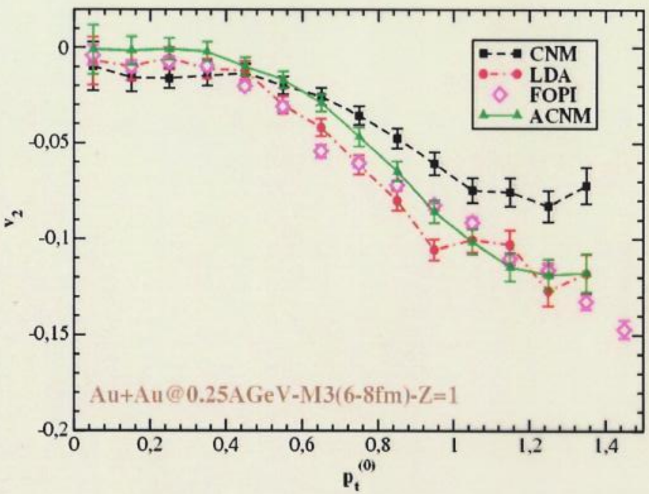
asymm. ACNM  " (with asymm. density)

Constructed covar. from DB



Non-equilibrium Effects in Collective Flow Observables

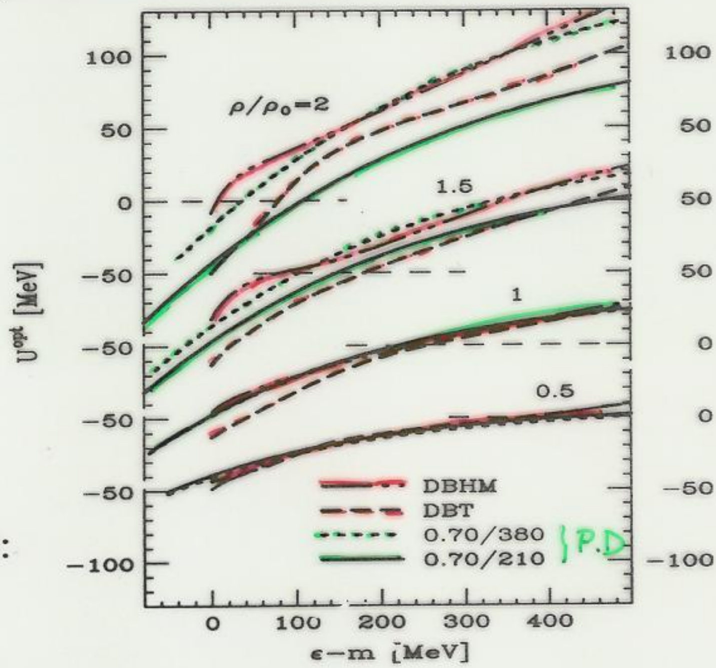




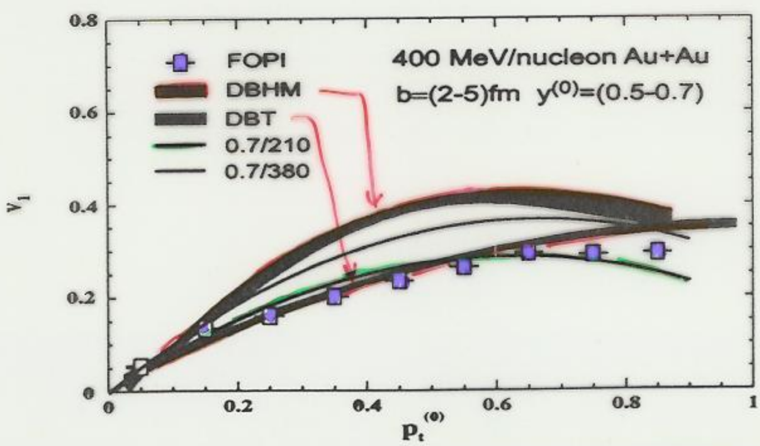
Dependence on a Realization

DBHF model (Gaitanos, Wolter & Fuchs) vs Landau

Optical Potential:

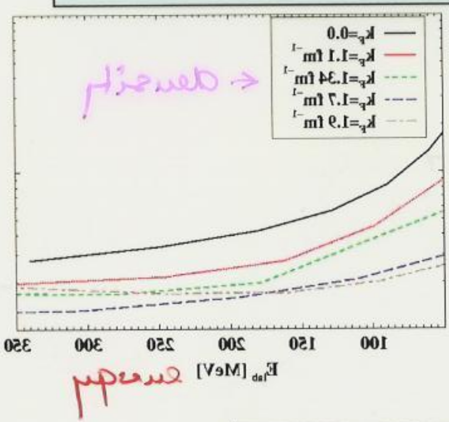


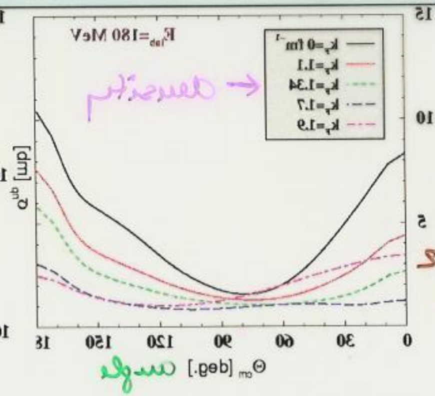
First-order flow $v_1 = <\cos\phi>$ testing potential in the kin-en region of $\epsilon - m = (0 - 100)$ MeV:



Effect of in-medium cross sections on stopping and flow: Au+Au

DB in-medium cross sections

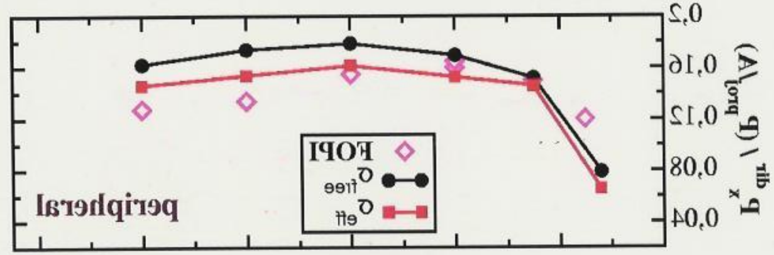




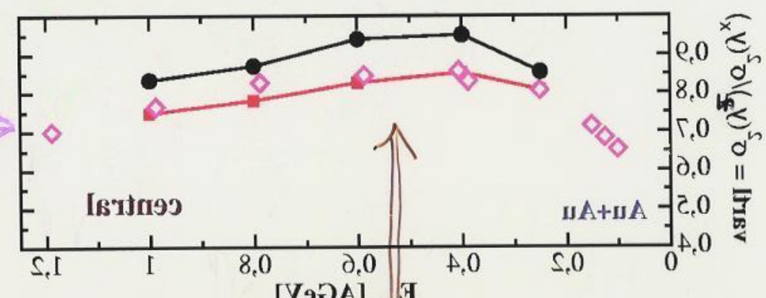
$$\frac{d\sigma}{d\Omega}(E,\Omega,k_F) = \frac{M_{K^*}}{\dots}\left|T_{DB}\right|^2$$

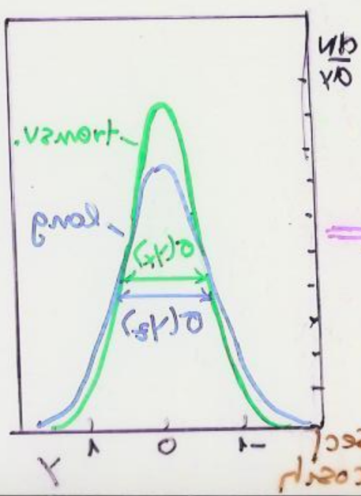
CNM $\{k_F, k_{F_2}, v_{rel}\}$

Directed flow



Ratio of rapidity Distribution in beam and transverse directions





correlation: {max. of eff. cross sec / max of shear viscosity}

Isospin Dependence
(relativistic language)

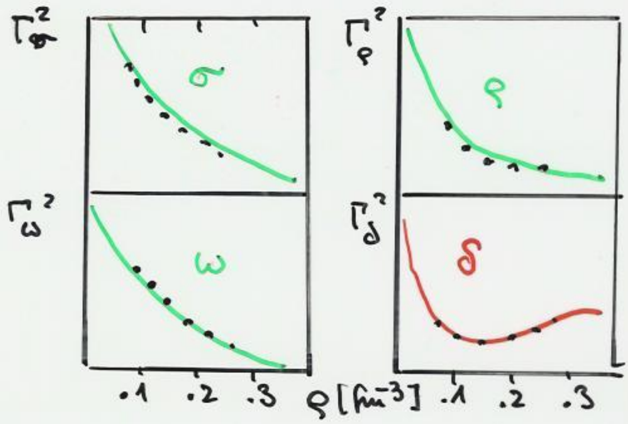
	isoscalar	isovector
scalar	σ	δ
vector	ω	ρ

} meson-exch (-like fields)

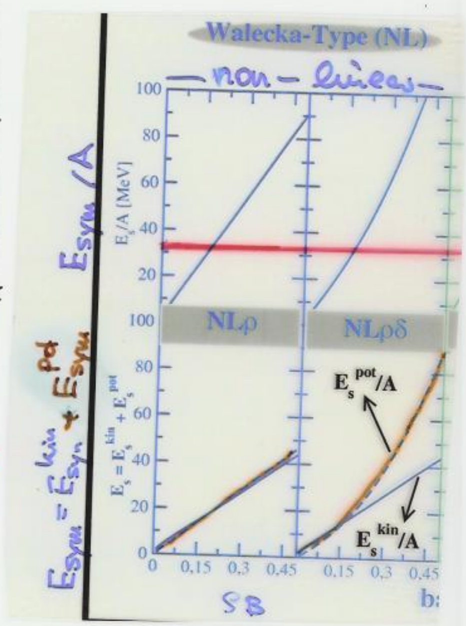
2 Strategies again:

(A) microscopic (DB) $\quad \Sigma_i = \Gamma_i(k,\rho)\,\rho_i \; ; \; i=\sigma,\omega,\rho,\delta$

vertex fct.



(B) phenomenological $\quad$ NLρ, NL$\rho\delta$



Consequences

$$E_{sym} = \frac{1}{6}\frac{k_F^2}{E_F} + \frac{1}{2}\left(\Gamma_\rho - \Gamma_\delta\left(\frac{m^*}{E_F}\right)^2\right)\rho_B$$

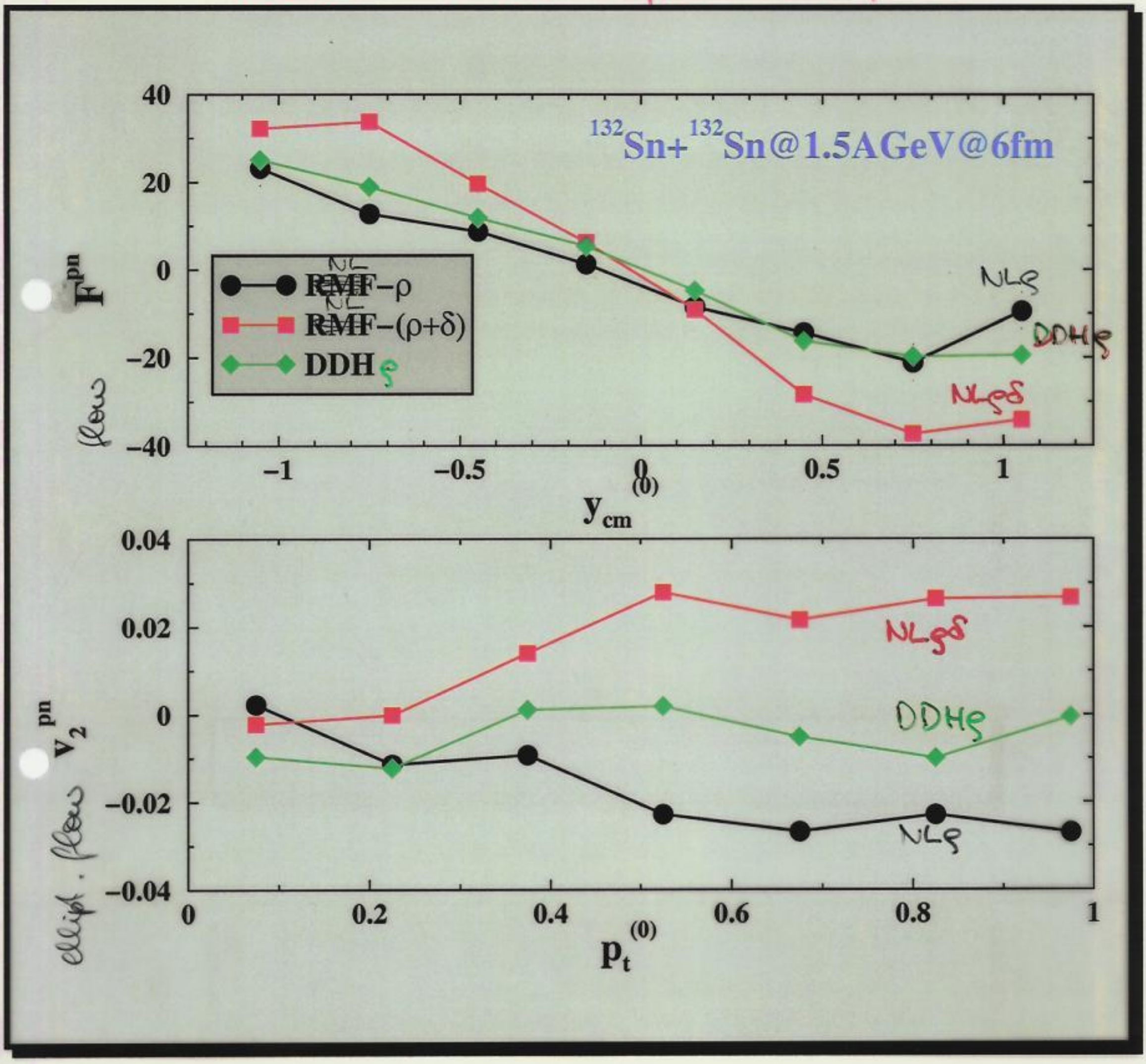
dens. dep. cancellation

$$m^*_{p/n} = m - (\Gamma_\sigma \mp \Gamma_\delta)\,\sigma$$

effective mass splitt.

Collective Flow at SIS Energies

Neutron – Proton differential flow



- V. Greco et al., PLB(2003) in press (nucl-th/0212102) PLB 562 (03) 215
- V. Greco et al., NPA(2003) ~~in press~~ (nucl-th/0301033)
- T. G., V. Greco et al., ~~in preparation~~ NPA submitted (nucl/th 0309021)

Isospin Tracing Method (FOPI)

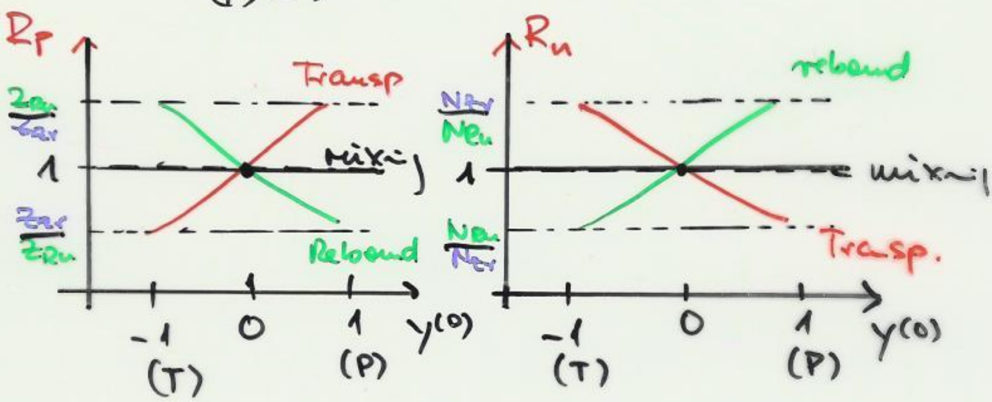
Ru + Zr System

$$\left.\begin{array}{ll} {}^{96}_{40}\mathrm{Zr}_{56} & N/Z = 1.4 \\ {}^{96}_{44}\mathrm{Ru}_{52} & N/Z = 1.18 \end{array}\right\} \quad \frac{Z_{Zr}}{Z_{Ru}} = 0.91 ; \quad \frac{N_{Zr}}{N_{Ru}} = 1.08$$

Isospin tracing Ratio

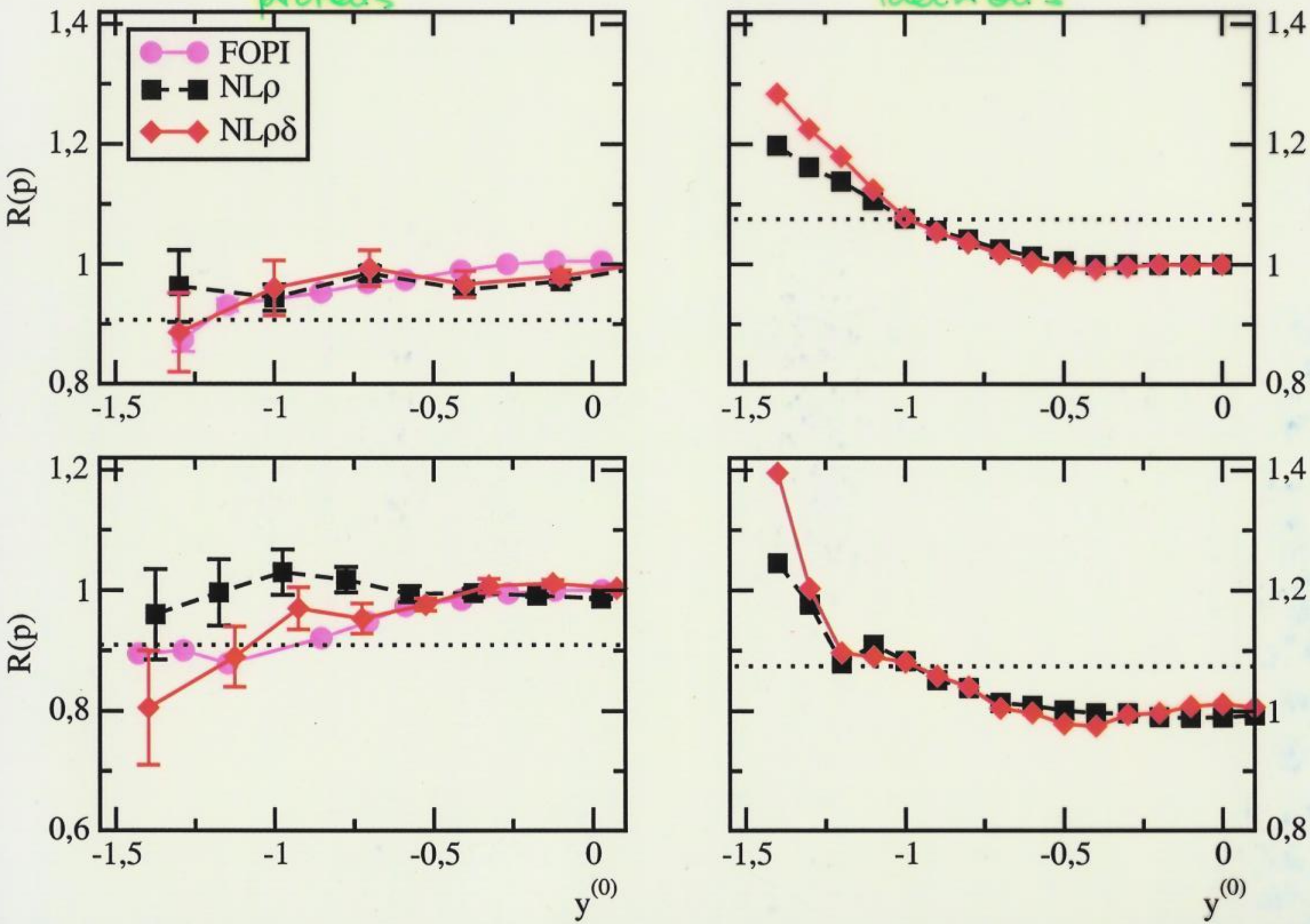
$$R_i = \frac{Y_i^{RuZr}}{Y_i^{ZrRu}} \quad , \; i = p, n, d, t, {}^3He, \pi^\pm, ..$$

$$\begin{array}{cc} \uparrow & \uparrow \\ (P) & (T) \end{array}$$



Isospin Tracing Ratio's $\frac{Y_i^{RuZr}}{Y_i^{ZrRu}}$; central

protons neutrons

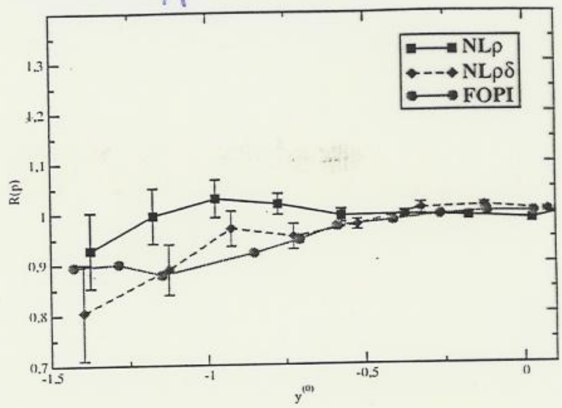


E = 0.4 AGeV

E = 1.5 AGeV

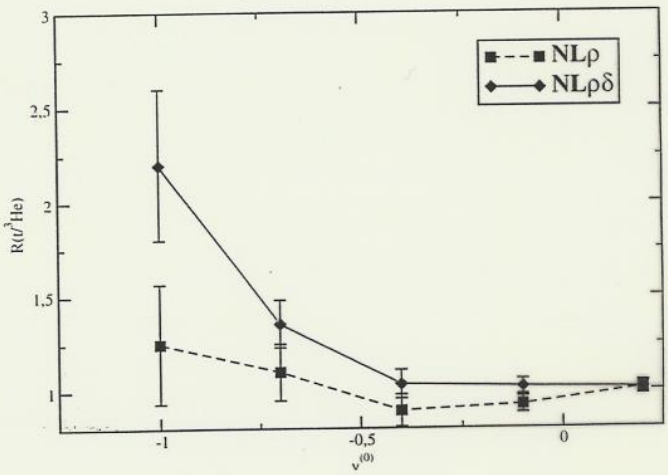
Isospin Tracing $\frac{Y_i^{RuZr}}{Y_i^{ZrRu}}$

Protons



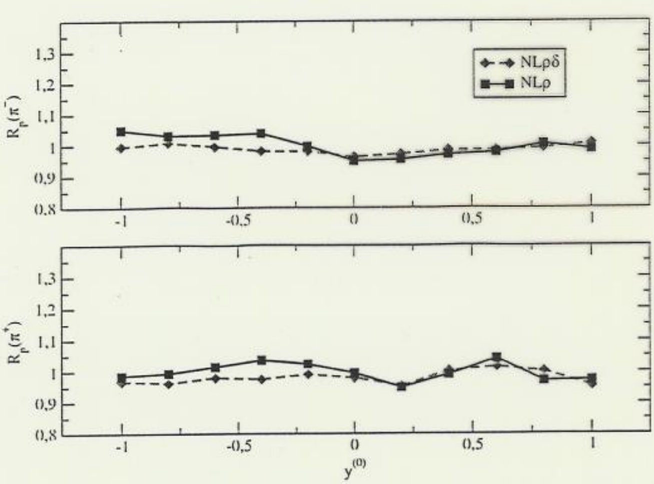
1.5GeV

t/³He



0.4GeV

π±



0.4GeV

Conclusions

Microscopic EOS (DB) provides
density-, momentum-, isospin-dependence

Description ok, when non-equil. effects
taken into account. Comparable in quality
to phenomenological EOS

Medium dependence of σ_{med} is seen

δ-like fields should be included
and lead to observable effects.