Effects of chiral symmetry restoration on meson and dilepton production

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Plan:

- **Motivation.**

- **Parity-doublet model (PDM).**

- **Giessen Boltzmann-Uehling-Uhlenbeck (GiBUU) model: relativistic mean field, collision term.**

- **Dynamics of particle production in central Au+Au collision at 1A GeV: N*(1535), η, ρ. Non-linear Walecka model vs PDM.**

- **Comparison with TAPS data on η and π^0 transverse mass spectra and HADES data on e^+e^- production.**

- **Summary.**

Motivation

Lattice QCD calculations predict the appearance of close in mass hadrons of the same spin but opposite parity, i.e. parity doubling, if chiral symmetry is restored

L. Y. Glozman, C. B. Lang, and M. Schrock, PRD 86, 014507 (2012) [arXiv:1205.4887];
G. Aarts, C. Allton, D. De Boni, S. Hands, B. Jäger, C. Praki, and J.-I. Skullerud,
JHEP 06, 034 (2017) [arXiv:1703.09246]

How can one model this effect for baryons within the effective field theories?

- Possible applications are hadron reaction models, HIC simulations, nuclear structure and astrophysics.

- Walecka-type Lagrangians are not chiral because of mass term

$$-m_N \bar{N} N = -m_N (\bar{N}_R N_L + \bar{N}_L N_R)$$

Here $N_R \equiv P_R N, \quad N_L \equiv P_L N$ are right- and left-handed components of the of the the nucleon Dirac field,

$$P_R = \frac{1}{2}(1+\gamma_5) = P_R^\dagger, \quad P_L = \frac{1}{2}(1-\gamma_5) = P_L^\dagger, \quad P_R^2 = P_R, \quad P_L^2 = P_L, \quad P_L P_R = P_R P_L = 0$$

- projectors.

The right- and left-handed components are transformed independently under the chiral group $SU(2)_R$x $SU(2)_L$

$$N \to (e^{-i\Theta_{R,a}\frac{\tau_a}{2}} P_R + e^{-i\Theta_{L,a}\frac{\tau_a}{2}} P_L) N \ , \quad \tau_a \text{ - isospin Pauli matrices.}$$

- Linear sigma model is a good starting point since the term

$$g\bar{N}(\sigma + i\gamma_5 \boldsymbol{\tau\pi})N$$

is chirally invariant.

- We need, however, cross-product terms for the two parity partners N_1 (P=+) and N_2 (P=-)

$$g[\bar{N}_1(\gamma_5\sigma + i\boldsymbol{\tau\pi})N_2 - \bar{N}_2(\gamma_5\sigma + i\boldsymbol{\tau\pi})N_1]$$

This term is chirally invariant if both partners are transformed in the same way under chiral rotations, so-called “naive” assignment:

$$\begin{aligned} N_1 &\rightarrow (e^{-i\Theta_{R,a}\frac{\tau_a}{2}}P_R + e^{-i\Theta_{L,a}\frac{\tau_a}{2}}P_L)N_1 \ , \\ N_2 &\rightarrow (e^{-i\Theta_{R,a}\frac{\tau_a}{2}}P_R + e^{-i\Theta_{L,a}\frac{\tau_a}{2}}P_L)N_2 \ . \end{aligned}$$

After diagonalisation of the mass matrix, this model leads to complete decoupling of the two partners and disappearing masses with growing baryon density.
D. Jido, M. Oka, A. Hosaka, Prog. Theor. Phys. 106, 873 (2001)
In contrast, QCD predicts that the masses should be finite when the chiral symmetry is restored.

In other words, spontaneous chiral symmetry breaking due to $<\bar{q}q>$ condensate should generate mass splitting between positive and negative parity hadrons.

Parity-doublet model (PDM)

C.E. DeTar, T. Kunihiro, PRD 39, 2805 (1989); D. Jido et al., NPA 671, 471 (2000); Prog. Theor. Phys. 106, 873 (2001)

- mirror assignment for the chiral symmetry basis states N_1 (P=+), N_2 (P=-):

$$
\begin{aligned}
N_1 &\rightarrow (e^{-i\Theta_{R,a}\frac{\tau_a}{2}} P_R + e^{-i\Theta_{L,a}\frac{\tau_a}{2}} P_L) N_1 \ , \\
N_2 &\rightarrow (e^{-i\Theta_{R,a}\frac{\tau_a}{2}} P_L + e^{-i\Theta_{L,a}\frac{\tau_a}{2}} P_R) N_2 \ ,
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{L} = \ & \bar{N}_1[i\partial + g_1(\sigma + i\gamma_5 \boldsymbol{\tau}\boldsymbol{\pi})]N_1 + \bar{N}_2[i\partial + g_2(\sigma - i\gamma_5 \boldsymbol{\tau}\boldsymbol{\pi})]N_2 \\
& -m_0(\bar{N}_1\gamma_5 N_2 - \bar{N}_2\gamma_5 N_1) + \underbrace{\mathcal{L}_0 + \mathcal{L}_1} + \mathcal{L}_{\text{mes}}(\sigma, \boldsymbol{\pi}) \ .
\end{aligned}
$$

Contact fermionic interactions
(short-range repulsion, needed for nuclear EOS)

Note: cross-product terms are chirally-invariant::

$$
\bar{N}_1\gamma_5 N_2 \rightarrow \bar{N}_1(e^{+i\Theta_{R,a}\frac{\tau_a}{2}} P_L + e^{+i\Theta_{L,a}\frac{\tau_a}{2}} P_R)\gamma_5(e^{-i\Theta_{R,a}\frac{\tau_a}{2}} P_L + e^{-i\Theta_{L,a}\frac{\tau_a}{2}} P_R)N_2 = \bar{N}_1\gamma_5 N_2 \ .
$$

- mass eigenstates are obtained by the SO(4) transformation in the isospin-flavor space (SO(16) in full Dirac-spin-isospin-flavor space):

nucleon → N_+

N*(1535) → N_-

$$
\begin{pmatrix} N_+ \\ N_- \end{pmatrix} = \begin{pmatrix} \cos\Theta & \gamma_5 \sin\Theta \\ -\gamma_5 \sin\Theta & \cos\Theta \end{pmatrix} \begin{pmatrix} N_1 \\ N_2 \end{pmatrix} .
$$

Isoscalar and isovector four-fermion NJL-type interaction terms:

$$\begin{aligned}\mathcal{L}_0 &= -G_0(\bar{N}_1\gamma^\mu N_1 + \bar{N}_2\gamma^\mu N_2)^2 \ , \\ \mathcal{L}_1 &= -G_1[(\bar{N}_1\gamma^\mu \boldsymbol{\tau} N_1 + \bar{N}_2\gamma^\mu \boldsymbol{\tau} N_2)^2 + (\bar{N}_1\gamma^\mu\gamma_5 \boldsymbol{\tau} N_1 - \bar{N}_2\gamma^\mu\gamma_5 \boldsymbol{\tau} N_2)^2] \ .\end{aligned}$$

Bosonisation provides statistically equivalent description (Hubbard-Stratonovich transformation):

$$\begin{aligned}\mathcal{L}_0 &= \frac{m_\omega^2}{2}\omega^\mu\omega_\mu - g_\omega\omega_\mu(\bar{N}_1\gamma^\mu N_1 + \bar{N}_2\gamma^\mu N_2) \ , \\ \mathcal{L}_1 &= \frac{m_\rho^2}{2}(\boldsymbol{\rho}^\mu\boldsymbol{\rho}_\mu + \boldsymbol{a}_1^\mu\boldsymbol{a}_{1\mu}) - g_\rho\bar{N}_1(\boldsymbol{\rho}^\mu - \gamma_5\boldsymbol{a}_1^\mu)\gamma_\mu\boldsymbol{\tau}N_1 - g_\rho\bar{N}_2(\boldsymbol{\rho}^\mu + \gamma_5\boldsymbol{a}_1^\mu)\gamma_\mu\boldsymbol{\tau}N_2 \ ,\end{aligned}$$

with $m_\omega^2/g_\omega^2 = 1/(2G_0)$ and $m_\rho^2/g_\rho^2 = 1/(2G_1)$.

Formally equivalent to Walecka Lagrangian w/o space-time derivatives.

The meson Lagrangian Y. Motohiro et al., PRC 92, 025201 (2015); I.J. Shin et al., arXiv:1805.03402; M. Kim et al., PRC 101, 064614 (2020):

$$\begin{aligned}\mathcal{L}_{\rm mes} &= \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma + \frac{1}{2}\partial_\mu\vec{\pi}\partial^\mu\vec{\pi} \\ &+\frac{\bar{\mu}^2}{2}(\sigma^2+\boldsymbol{\pi}^2) - \frac{\lambda}{4}(\sigma^2+\boldsymbol{\pi}^2)^2 + \frac{\lambda_6}{6}(\sigma^2+\boldsymbol{\pi}^2)^3 + \varepsilon\sigma \ .\end{aligned}$$

6-point interaction (needed for realistic values of incompressibility)

Explicit chir. symmetry breaking term (due to finite quark masses)

Full model Lagrangian in the basis of mass eigenstates (physical basis) :

$$\begin{aligned}\mathcal{L} \;=\;& \bar{N}_+[i\partial - m_+ - ig_{\pi N_+N_+}\gamma_5\tau\pi - (g_\omega\omega^\mu + g_\rho\tau\rho^\mu - g_{a_1}\gamma_5\tau a_1^\mu)\gamma_\mu]N_+ \\ &+\bar{N}_-[i\partial - m_- - ig_{\pi N_-N_-}\gamma_5\tau\pi - (g_\omega\omega^\mu + g_\rho\tau\rho^\mu + g_{a_1}\gamma_5\tau a_1^\mu)\gamma_\mu]N_- \\ &+\frac{m_\omega^2}{2}\omega^\mu\omega_\mu + \frac{m_\rho^2}{2}(\rho^\mu\rho_\mu + a_1^\mu a_{1\mu}) \\ &-ig_{\pi N_+N_-}\bar{N}_+\tau\pi N_- + ig_{\pi N_+N_-}\bar{N}_-\tau\pi N_+ \\ &+g_{a_1N_+N_-}\bar{N}_+\gamma_\mu\tau a_1^\mu N_- + g_{a_1N_+N_-}\bar{N}_-\gamma_\mu\tau a_1^\mu N_+ + \mathcal{L}_{\rm mes} \;,\end{aligned}$$

$$m_\pm = \frac{1}{2}\left[\sqrt{\sigma^2(g_1+g_2)^2 + 4m_0^2} \pm \sigma(g_2 - g_1)\right] .$$

Decreasing scalar field σ leads to the mass degeneracy of the parity partners, $m_\pm \to m_0$

Vacuum conditions:

$$\sigma \equiv \sigma_0 = f_\pi = 93 \text{ MeV}$$ (consistent with Goldberger-Treiman relation),

$$m_+(\sigma_0) = m_N, \quad m_-(\sigma_0) = m_{N^*(1535)}.$$

Coupling constants:

$$\begin{aligned} g_{\pi N_+N_+} &= -g_1\cos^2\Theta - g_2\sin^2\Theta \;, \\ g_{\pi N_-N_-} &= g_2\cos^2\Theta + g_1\sin^2\Theta \;, \\ g_{\pi N_+N_-} &= \frac{g_1-g_2}{2}\sin 2\Theta \;, \\ g_{a_1} &= g_\rho\cos 2\Theta \;, \\ g_{a_1N_+N_-} &= g_\rho\sin 2\Theta \;. \end{aligned}$$

$$\tan 2\Theta = -\frac{2m_0}{\sigma(g_1+g_2)},$$

Non-diagonal transitions at finite mixing angle θ

Mean field approximation:

- pion mean field (P=-) disappears in nuclear matter ground state;

- isovector-axial vector $\mathbf{a}_1^{\mu}$ mean field vanishes in spin-saturated nuclear matter.

Lagrange's EoMs:

$$\partial_\mu \partial^\mu \sigma(x) - \bar{\mu}^2 \sigma + \lambda \sigma^3 - \lambda_6 \sigma^5 - \varepsilon = -\sum_{i=\pm} \frac{\partial m_i}{\partial \sigma} \langle \bar{N}_i(x) N_i(x) \rangle \ ,$$

$$\omega^\nu(x) = \frac{g_\omega}{m_\omega^2} \sum_{i=\pm} \langle \bar{N}_i(x) \gamma^\nu N_i(x) \rangle \ ,$$

$$\boldsymbol{\rho}^\nu(x) = \frac{g_\rho}{m_\rho^2} \sum_{i=\pm} \langle \bar{N}_i(x) \gamma^\nu \boldsymbol{\tau} N_i(x) \rangle \ ,$$

In-medium Dirac equation:

$$[\gamma^\mu (i\partial_\mu - V_\mu) - m_\pm] N_\pm(x) = 0 \ , \qquad V_\mu = g_\omega \omega_\mu + g_\rho \boldsymbol{\tau} \boldsymbol{\rho}_\mu \ .$$

Plane-wave solutions:

$$N_\pm \propto \exp(-ipx),$$

$$[\gamma^\mu p^*_\mu - m_\pm] N_\pm = 0 \ , \quad p^*_\mu \equiv p_\mu - (V_\mu)_{I_z I_z}, \quad I_z = \pm 1/2.$$

kinetic four-momentum

Dispersion relation (in-medium mass-shell condition): $(p^*)^2 - m_\pm^2 = 0$.

Table 1: The sets of parameters of the PDM.

	Set P3 [a]	Set 2 [b]
m_0 (MeV)	790	700
m_σ (MeV)	370.63	384.428
m_ω (MeV)	783	783
m_ρ (MeV)	—	776
g_ω	6.79	7.05508
g_ρ	0	4.07986
g_1	13.00	14.1708
g_2	6.97	7.76222
$\lambda_6 f_\pi^2$	0	15.7393
m_+ (MeV)	939	939
m_- (MeV)	1500	1535
K (MeV)	510.57	215

[a] D. Zschiesche et al., PRC 75, 055202 (2007);

[b] I.J. Shin et al., arXiv:1805.03402.

Harmonic oscillator decomposition near vacuum value $\sigma = f_\pi$:

$$\begin{aligned}\mathcal{H}_{\rm mes} &= -\frac{\bar{\mu}^2}{2}(\sigma^2+\boldsymbol{\pi}^2) + \frac{\lambda}{4}(\sigma^2+\boldsymbol{\pi}^2)^2 - \frac{\lambda_6}{6}(\sigma^2+\boldsymbol{\pi}^2)^3 - \varepsilon\sigma \\ &= {\rm const} + \frac{m_\pi^2}{2}\boldsymbol{\pi}^2 + \frac{m_\sigma^2}{2}\Delta\sigma^2 + O(\boldsymbol{\pi}^2\Delta\sigma) + O(\Delta\sigma^3),\end{aligned}$$

$$\Delta\sigma = \sigma - f_\pi, \qquad \frac{\partial \mathcal{H}_{\rm mes}}{\partial\sigma}_{|\sigma=f_\pi} = 0 \ .$$

$$\Rightarrow \left\{\begin{aligned}\bar{\mu}^2 &= \frac{m_\sigma^2 - 3m_\pi^2}{2} + \lambda_6 f_\pi^4 \ , \\ \lambda &= \frac{m_\sigma^2 - m_\pi^2}{2f_\pi^2} + 2\lambda_6 f_\pi^2 \ , \\ \varepsilon &= m_\pi^2 f_\pi \ .\end{aligned}\right.$$

Infinite nuclear matter

Saturation conditions:

$$\frac{\partial \mathcal{E}(\rho_B)/\rho_B}{\partial \rho_B}_{|\rho_B=\rho_0} = 0 \ ,$$

$$\frac{\mathcal{E}(\rho_0)}{\rho_0} \simeq -16 \ \mathrm{MeV} \ , \ \rho_0 = 0.16 \ \mathrm{fm}^{-3},$$

$$\mathcal{E}(\rho_B) \equiv T^{00}(\rho_B) - T^{00}(0) - m_N \rho_B$$

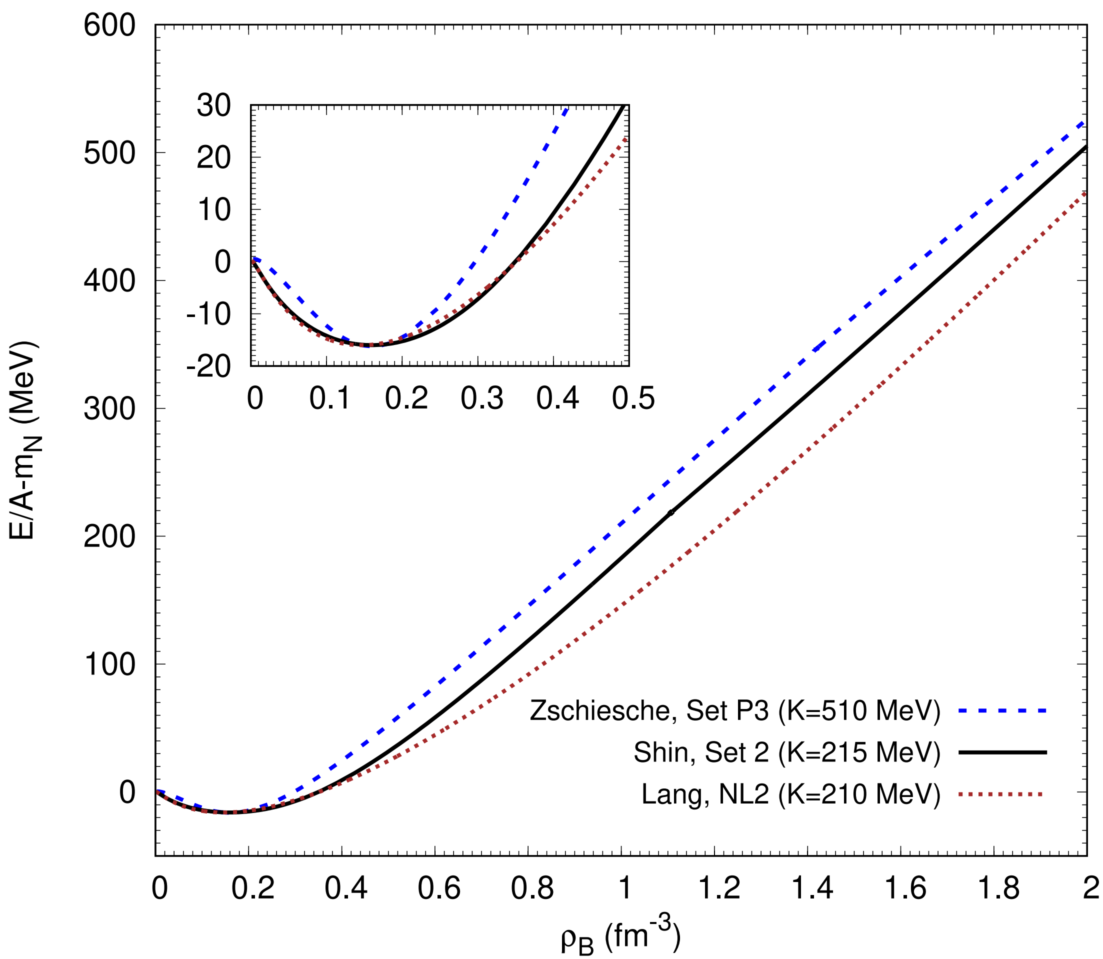
- non-relativistic energy density;

$$K = 9\rho_0^2 \frac{\partial^2 \mathcal{E}(\rho_B)/\rho_B}{\partial \rho_B^2}_{|\rho_B=\rho_0} \simeq 200 - 380 \ \mathrm{MeV}$$

- incompressibility.

from GMR frequencies

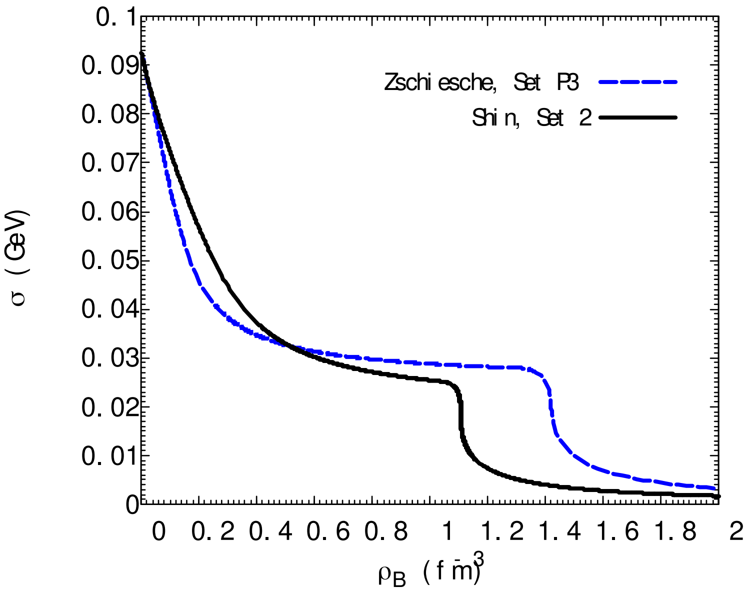
phen. upper limit

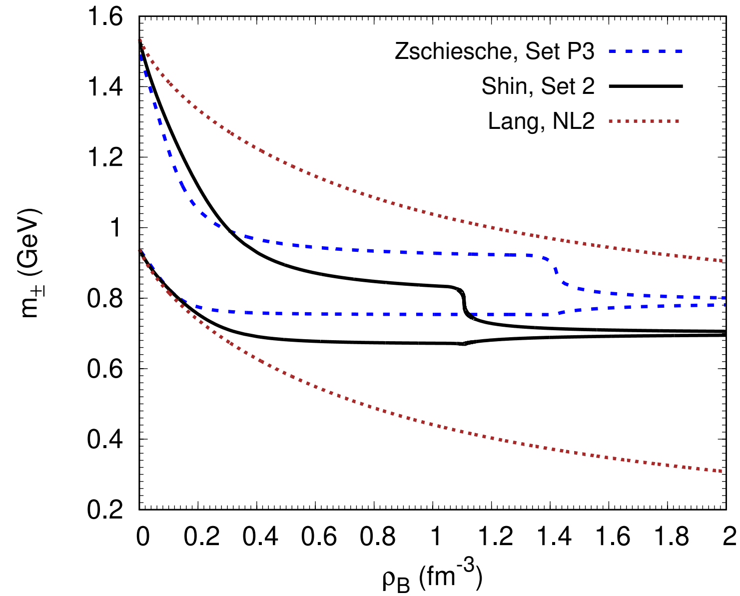


Set 2 and NL2 produce similar EoS at $\rho_B \leq 3\rho_0$ accessible in HIC at E_{lab}=1-2A GeV.

D. Zschiesche et al., PRC 75, 055202 (2007);
I.J. Shin et al., arXiv:1805.03402; } PDM

A. Lang et al., NPA 541, 507 (1992). } non-linear Walecka model





- The chiral 1-st order phase transition at baryon densities of 1-1.4 fm^{-3} unlikely to be reached before the transition to QGP will happen. However, a faster decrease of m_- at low densities may have observable consequences.

- Since $m_{N^*(1535)} - m_N - m_\eta \approx 50$ MeV the decay channel N*(1535) → N η closes already at $\rho_B \approx 0.4\rho_0$ D. Jido, E.E. Kolomeitsev, H. Nagahiro, S. Hirenzaki, NPA 811, 158 (2008). Impact on the photoproduction of η-mesic nuclei. Also in qualitative agreement with observed $A^{2/3}$ dependence of η photoproduction M. Roebig-Landau et al., PLB 373, 45 (1996); H. Kim, D. Jido, M. Oka, NPA 640, 77 (1998).

- In HIC, however, the low-mass N*(1535)-resonances may increase their masses since the system expands.

Main idea: decreasing threshold of N N → N N*(1535) should enhance the production of N*(1535) in HIC. This should lead to larger η production via N*(1535) → N η.

GiBUU model

- **solves the coupled system of kinetic equations for the baryons (N,N*,Δ,Λ,Σ,…), corresponding antibaryons ($\bar{N}$,$\bar{N}^*$,$\bar{\Delta}$,$\bar{\Lambda}$,$\bar{\Sigma}$,…), and mesons (π,K,...)**

- **initializations for the lepton-, photon-, hadron-, and heavy-ion-induced reactions on nuclei**

Open source code in Fortran 2003 downloadable from:

https://gibuu.hepforge.org/trac/wiki

Details of GiBUU: ***O. Buss et al., Phys. Rep. 512, 1 (2012).***

Kinetic equation with relativistic mean fields

Distribution function in phase space (r,p*)

Number of sort "j" particles = $\int \frac{g_s^j d^3r d^3p^*}{(2\pi)^3} f_j^*(x,\mathbf{p}^*)$

$$(p_0^*)^{-1}\left[p_\mu^*\partial^\mu + (p_\mu^*\mathcal{F}_j^{\alpha\mu} + m_j^*\partial^\alpha m_j^*)\frac{\partial}{\partial p^{*\alpha}}\right] f_j^*(x,\mathbf{p}^*) = I_j[\{f^*\}]\ , \qquad (*)$$

$\mu = 0,1,2,3,\quad \alpha = 1,2,3,\quad j = N,\bar{N},\Delta,\bar{\Delta},\Lambda,\bar{\Lambda},\pi,K,\ldots \qquad x \equiv (t,\mathbf{r})$

Collision term (includes Pauli blocking for outgoing nucleons)

m_j^* **- effective (Dirac) mass,**

$p^{*\mu} = p^\mu - V_j^\mu$ **- kinetic four-momentum with effective mass shell constraint** $p^{*\mu}p_\mu^* = m_j^{*2}$,

$V_j^\mu = g_{\omega j}\omega^\mu + g_{\rho j}\tau_j^3\rho^{3\mu} + q_jA^\mu$ **- vector field,** $\qquad \tau_j^3 = +(-)1 \text{ for } j = p,\bar{n}\ (\bar{p},n)$,

$\mathcal{F}_j^{\mu\nu} = \partial^\mu V_j^\nu - \partial^\nu V_j^\mu$ **- field tensor.**

- For momentum-independent fields Eq.(*) is equivalent to the BUU equation

$$(\partial_t + \nabla_\mathbf{p}\varepsilon_j\nabla_\mathbf{r} - \nabla_\mathbf{r}\varepsilon_j\nabla_\mathbf{p})f_j(x,\mathbf{p}) = I_j[\{f\}]$$

$$\varepsilon_j(x,\mathbf{p}) = V_j^0 + \sqrt{m_j^{*2} + \mathbf{p}_j^{*2}}\ , \quad f_j(x,\mathbf{p}) = f_j^*(x,\mathbf{p}^*)\ .$$

Direct derivations of relativistic kinetic equation:

Yu.B. Ivanov, NPA 474, 669 (1987);
B. Blättel, V. Koch, U. Mosel, Rept. Prog. Phys. 56, 1 (1993).

Collision term of the GiBUU model*):

Baryon-baryon collisions:
$NN \to NN, \ \ NN \leftrightarrow NR, NN \leftrightarrow \Delta\Delta, \ \ NR \to NR', \ \ NN \to NNM \ (M = \pi, \ \omega, \ \phi),$
$np \to d\eta$ (via $np\eta$ final state)

Meson-baryon collisions:
$\pi N \to R, \ MN \ (M = \pi, \omega, \phi, \rho, \sigma, \eta), \pi\Delta, \eta\Delta, \rho\Delta, \pi N^*(1440), \ \omega\pi N, \ \phi\pi N, \ \pi\pi N, \ \pi\pi\pi N;$
$\omega N \to R, \ \pi N, \ \omega N, \ \pi\pi N; \ \rho N \to R, \ \pi N; \ \sigma N \to R, \ \pi N, \ \sigma N;$
$\eta N \to R, \ \pi N; \ \phi N \to \phi N, \ \pi N, \ \pi\pi N;$
$\pi\Delta \to R; \ \rho\Delta \to R; \eta\Delta \to \pi N; \pi N^*(1440) \to R$

Meson-meson collisions:
$MM \to R, \ (M = \pi, \eta, \eta', \sigma, \rho, \omega)$

$3 \to 2$ collisions: $NN\pi \to NN$

$3 \to 3$ collisions: $NN\Delta \to NNN$

*) Baryon-baryon (meson-baryon) collisions at $\sqrt{s} > 4$ GeV (2.2 GeV) are simulated via PYTHIA6.
Channels with strangeness and charm and baryon-antibaryon annihilation channels
are not listed.

Time evolution of Au+Au central collision at 1A GeV

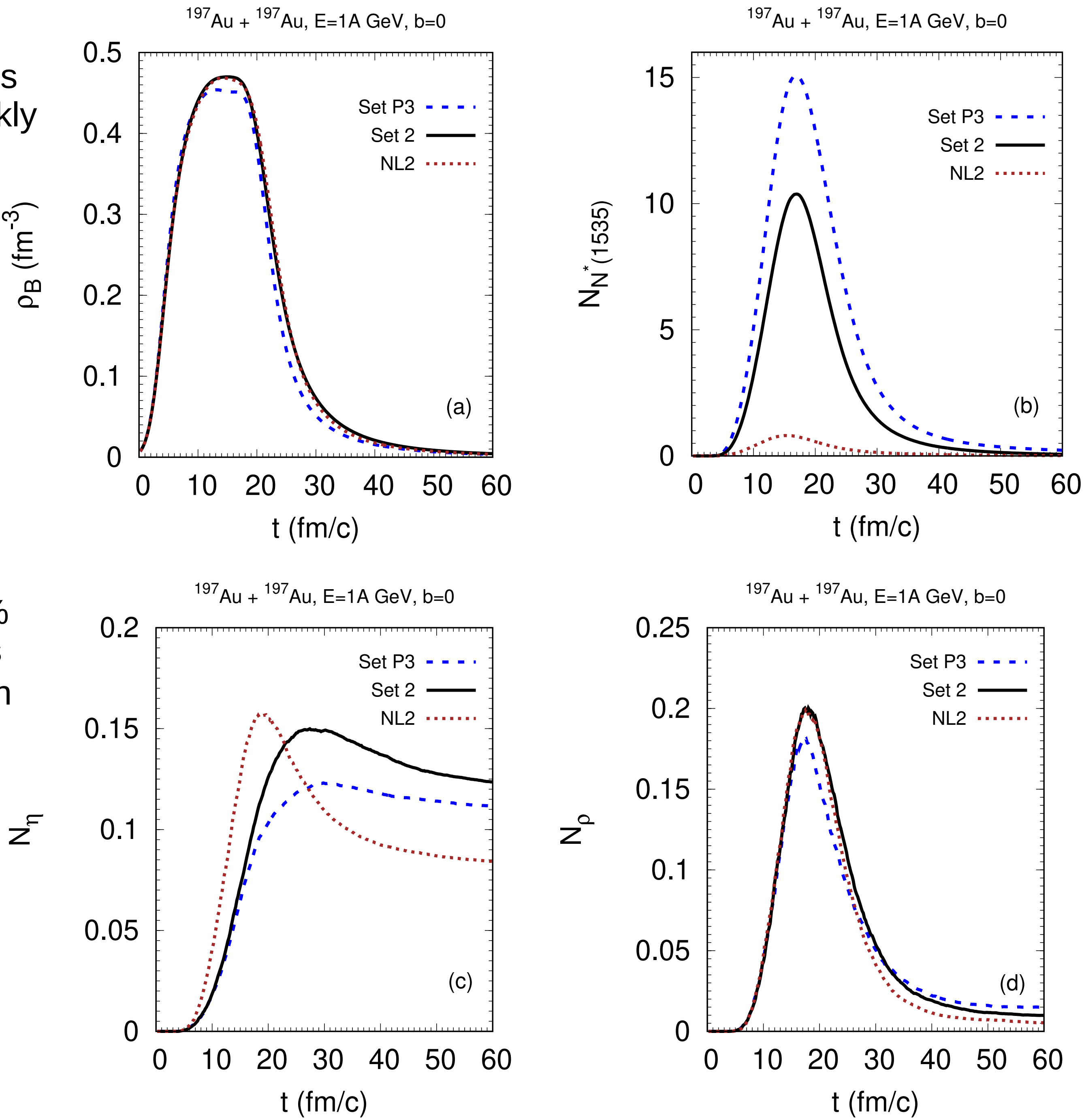
- Central baryon density depends on the used RMF set only weakly

- N*(1535) multiplicity with PDM is an order of magnitude larger than in NL2

- η multiplicity with PDM is ≈50% larger than wit NL2. Decreases at large times due to absorption

$$\eta N \to N^*(1535) \to \pi N.$$

- ρ multiplicity at large times is enhanced in PDM



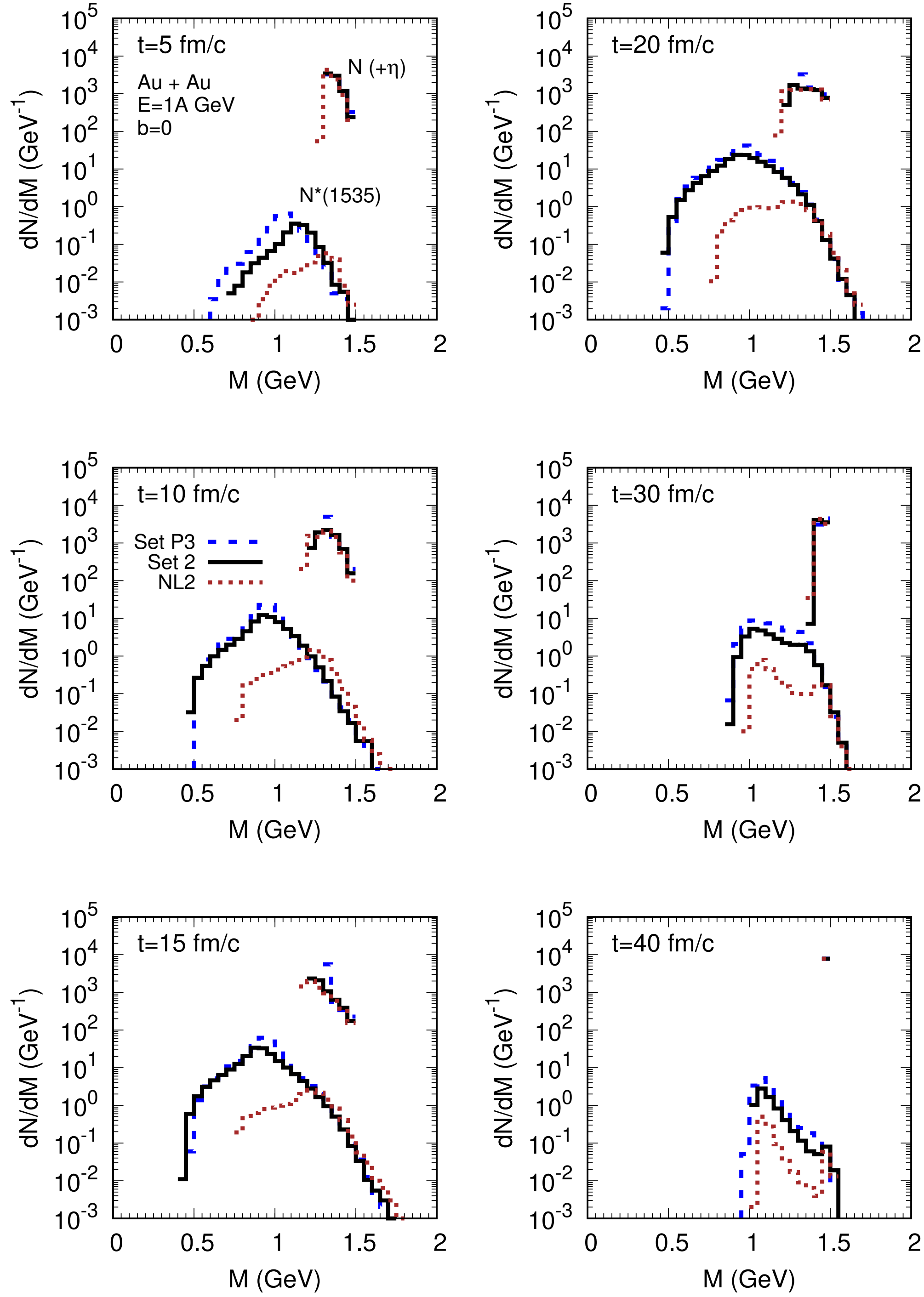
Invariant mass distributions of N(1535) and N*

(N distribution is right-shifted by the η mass)

- Excess of N*(1535) production at low inv. masses at t ≤ 20 fm/c with PDM

- At later times the system expands, N*(1535)'s migrate towards larger inv. masses and disappear via absorption N* N → NN and decays: N* → πN (51%), ηN (43%), ρN (3%), σN (1%), πN*(1440) (2%).

- Thus, most of the low-mass excess of N*(1535)'s goes into other channels than ηN.



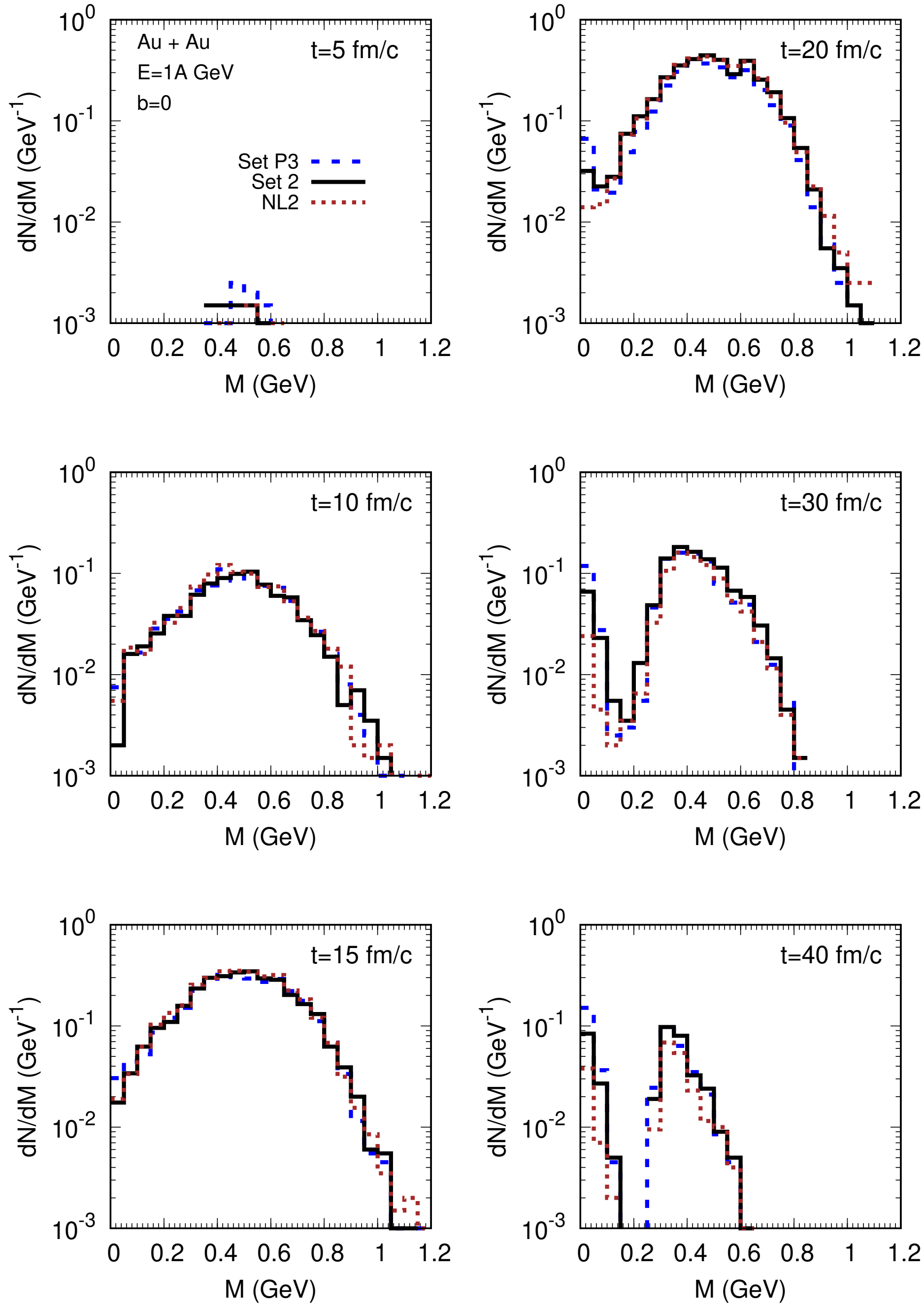
Invariant mass distribution of ρ meson

- N*(1520) → ρN contributes mostly.

- No difference between RMF sets for early times t ≤ 15 fm/c.

- At later times the excess of long-lived ρ's below ππ threshold is visible in PDM due to the contribution from N*(1535) → ρN.

Calculation is done with in-medium spectral function of ρ-meson, see **AL, U. Mosel, L. von Smekal, PRC 102, 064913 (2020) [arXiv:2009.11702]**



Comparison with experiment

Transverse mass spectra at midrapidity

In thermal equilibrium:

$$\frac{d^2\sigma}{dy m_t^2 dm_t} \propto e^{-m_t/T}$$

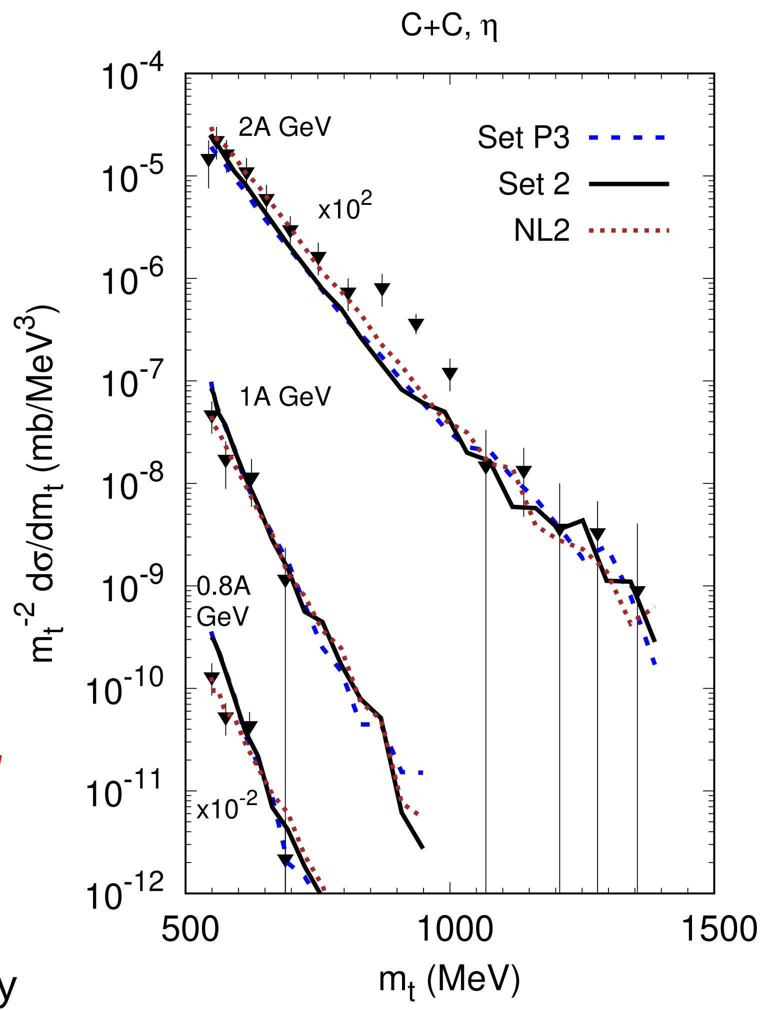
- m_t -scaling.

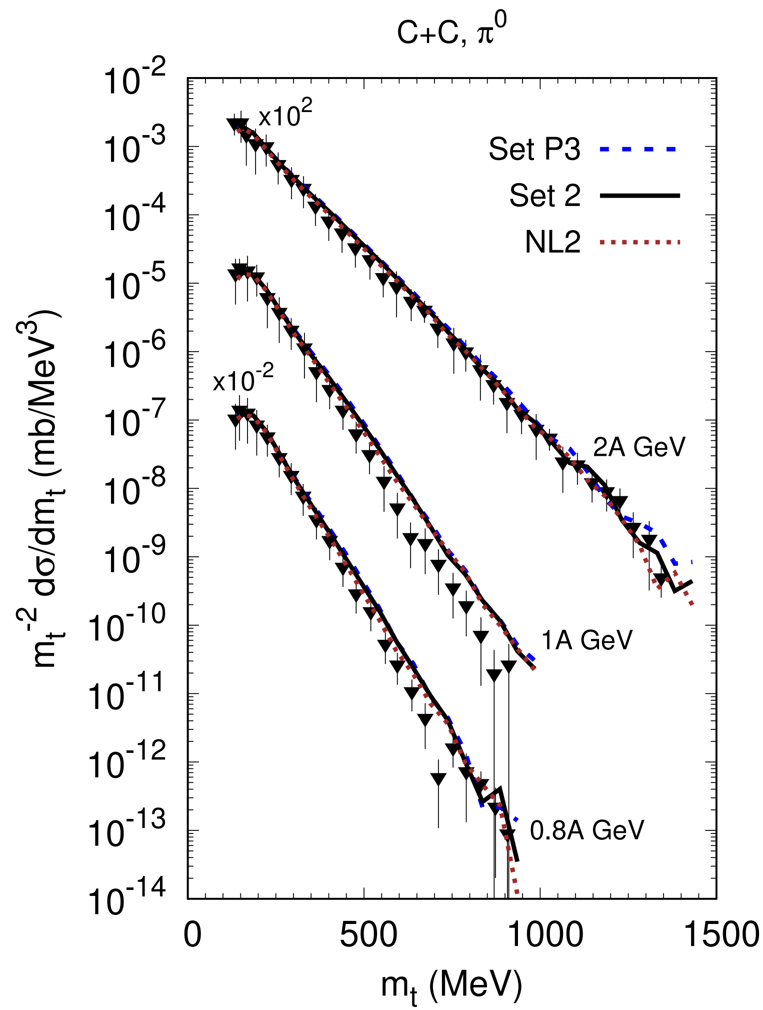
Small systems (like C+C) are likely to deviate from thermal equilibrium:

- cross sections become Important;

- lowering the threshold of NN → NN*(1535) in PDM enhances the yield of low-m_t η's at E_{lab}=0.8 and 1A GeV

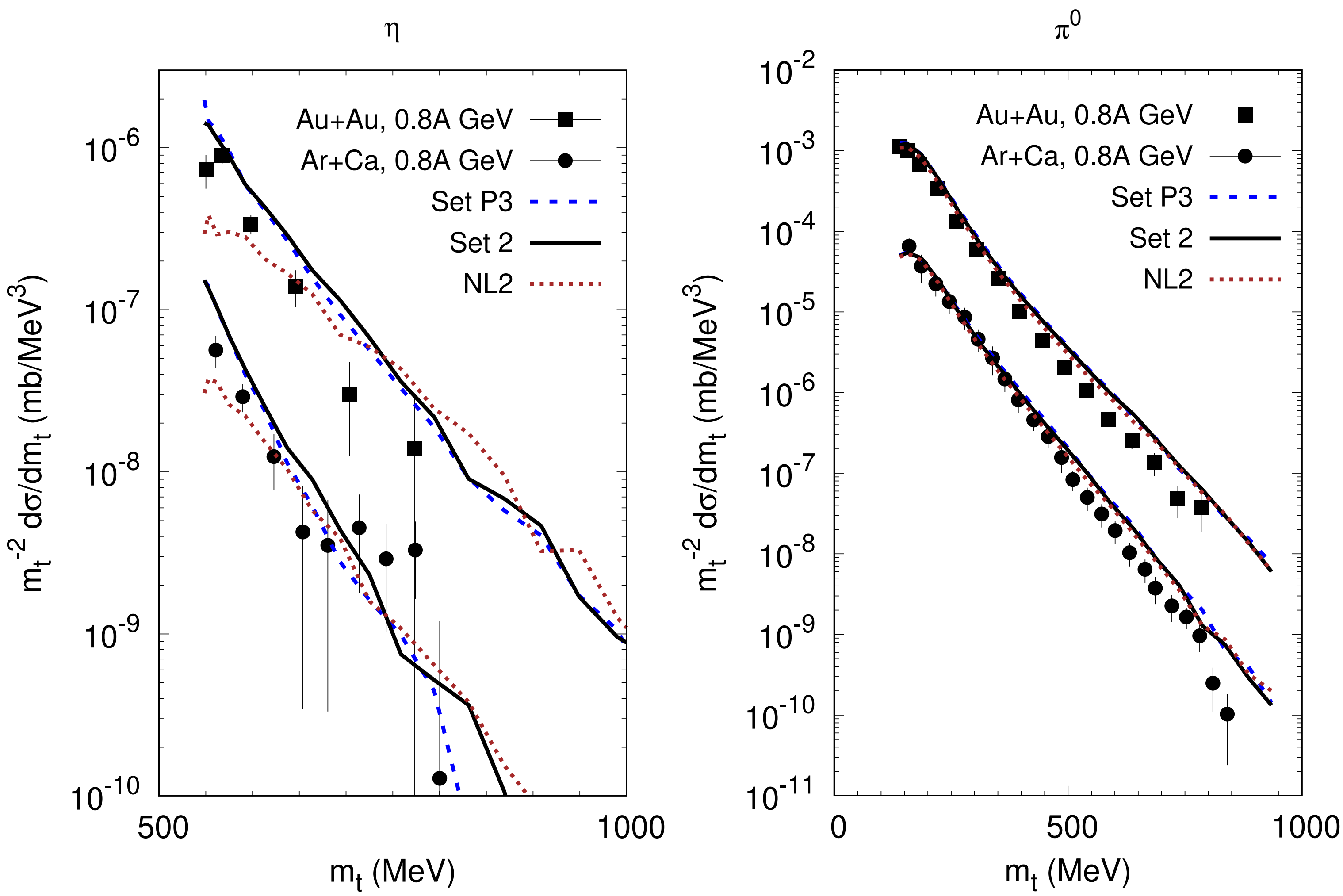
Note: threshold beam energy for pp → ppη is 1.255 GeV





- no effect of RMF on π^0

Data: R. Averbeck et al. (TAPS), Z. Phys. A 359, 65 (1997)

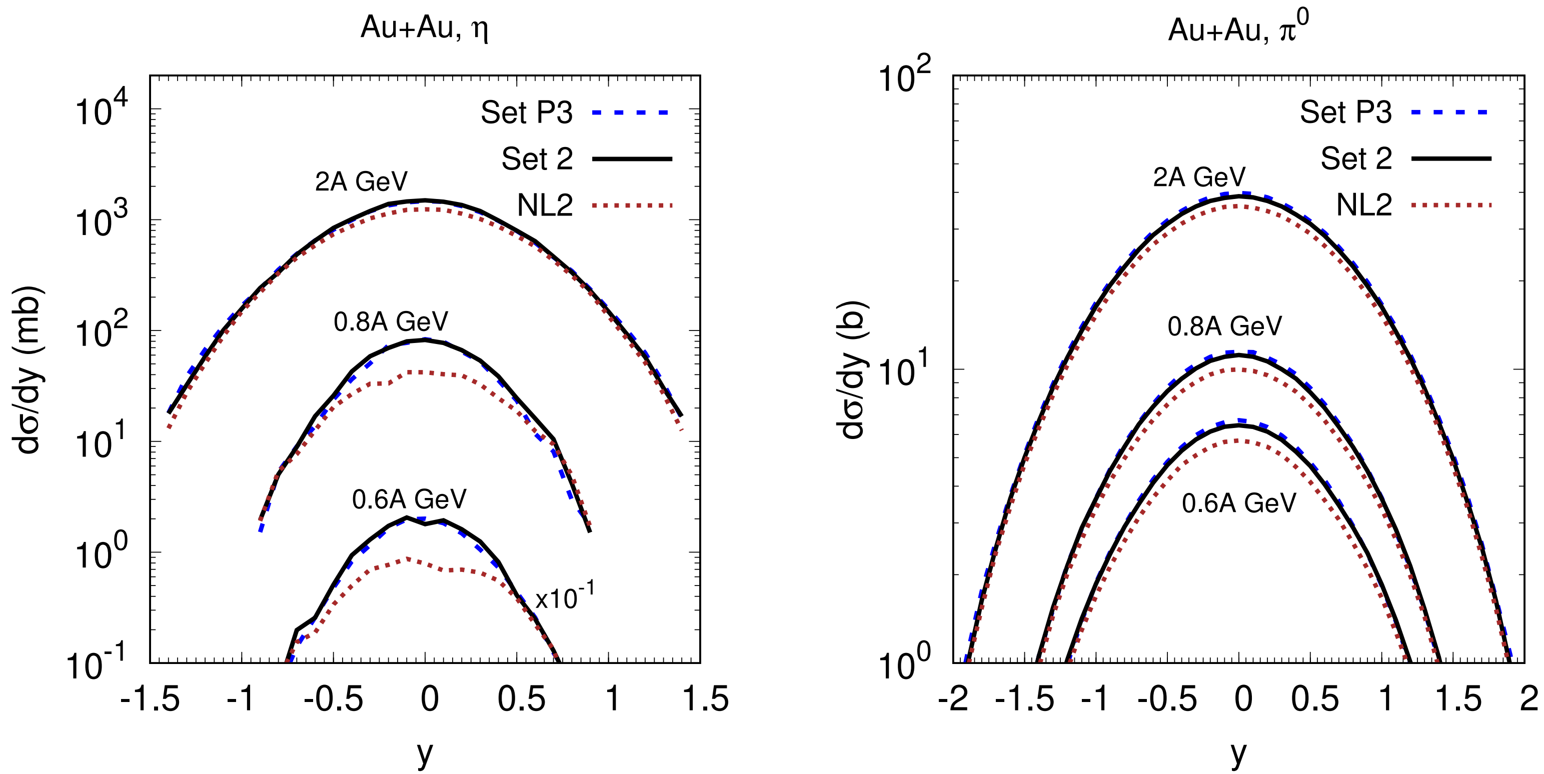


- For heavier systems the enhancement of η production at low m_t in PDM is more pronounced.

The effect of incompressibility is invisible: no difference between Set P3 (K=510 MeV) and Set 2(K=215 MeV). TAPS data seem to favor PDM (slopes better). No effect of RMF on pions.

Data Ar+Ca: A. Marin et al. (TAPS), PLB 409, 77 (1997);
Data Au+Au: A.R. Wolf et al. (TAPS), PRL 80, 5281 (1998)

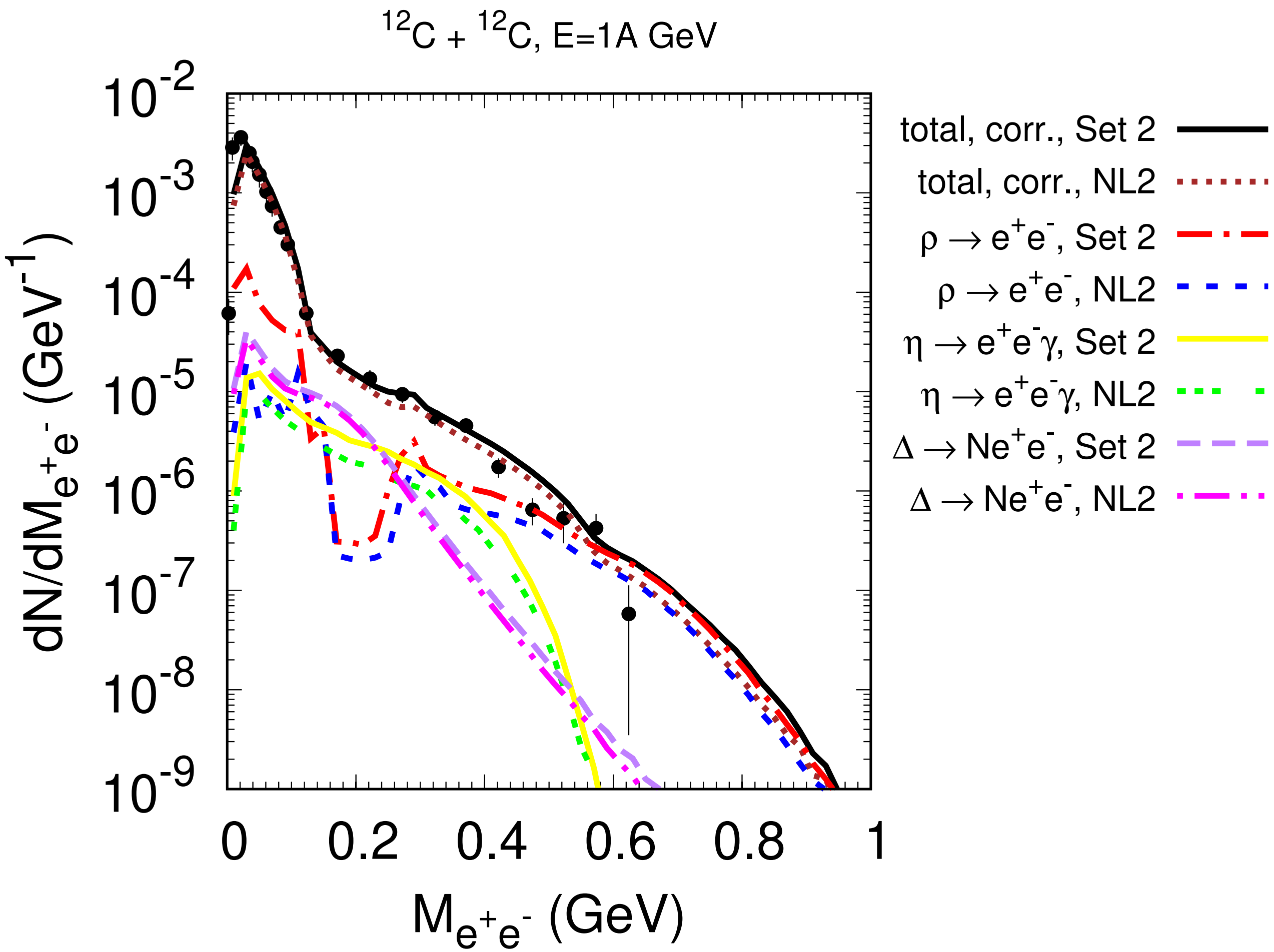
Rapidity spectra



- strongest effect at midrapidity, overall a factor of 2 enhancement of η production cross section at 0.6A GeV: 15.4±0.3 mb (PDM Set 2), 7.8±0.2 mb (Walecka NL2)

- pion production is also somewhat larger with PDM due N*(1535) → πN

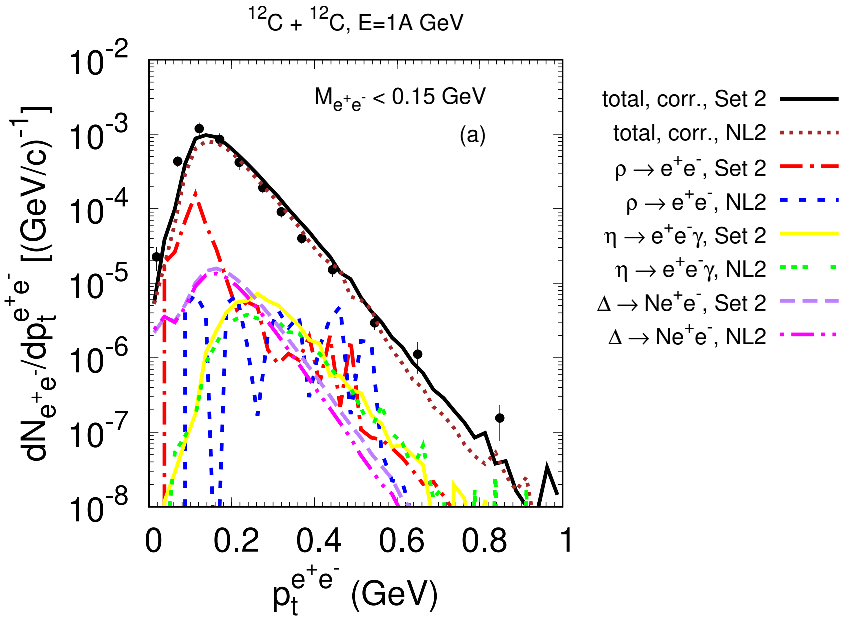
Dilepton (e^+e^-) production

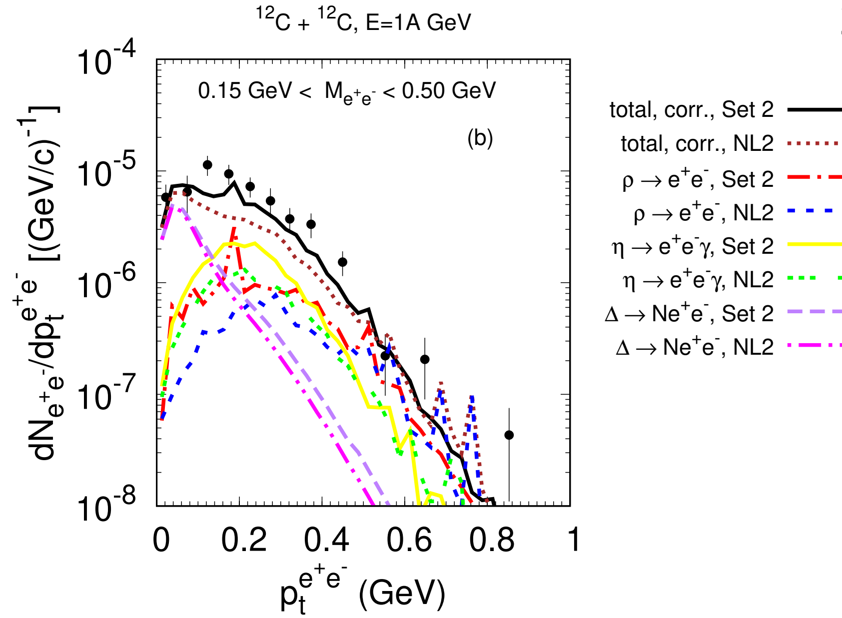


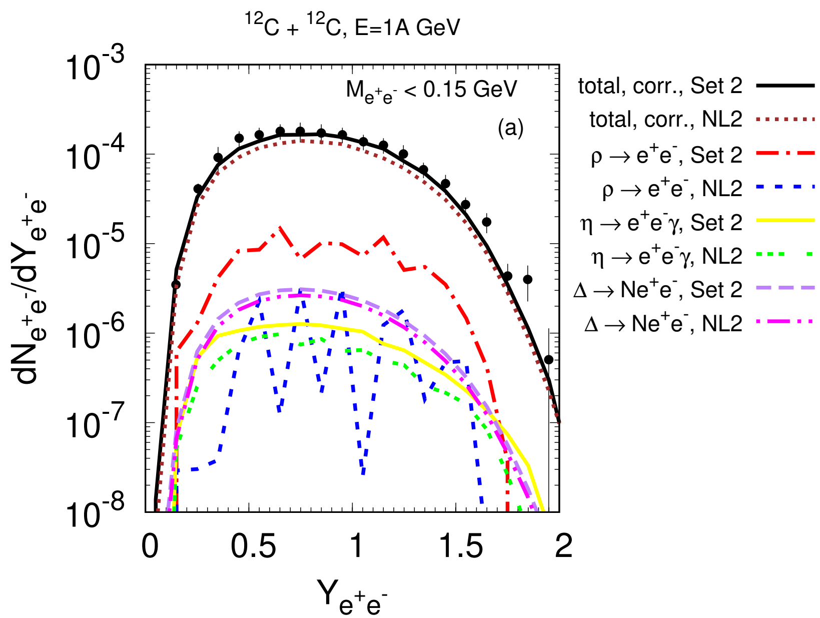
- Enhanced ρ direct, η Dalitz, and Δ Dalitz components with PDM (Set 2)

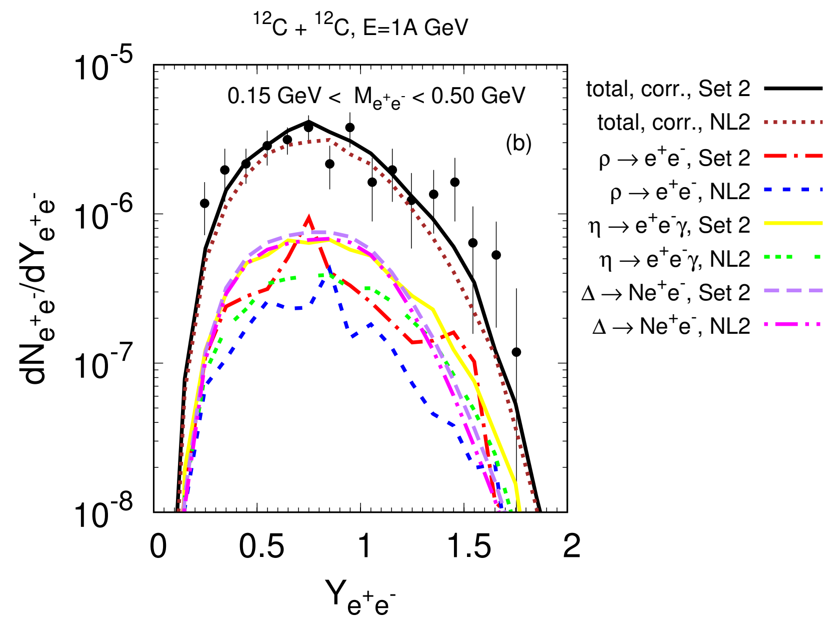
- Slightly larger yield at M_{e+e-}=0.15-0.5 GeV with PDM (Set 2)

Data: ***G. Agakishiev et al. (HADES), PLB 663 (2008) 43***









ρ excess with PDM (Set 2) is stronger at low p_t and at midrapidity. However, hidden by π^0 Dalitz.

η excess in PDM (Set 2) is stronger at $p_t \approx 0.2$ GeV (due to photon recoil momentum) and at midrapidity

Data: ***Y. Pachmayer (HADES), PhD thesis, Frankfurt U. (2008).***

Summary

- PDM is implemented in the microscopic transport model GiBUU.

- Decreasing Dirac mass gap between N*(1535) and nucleon with increasing baryon density leads to the strong (10 times) enhancement of N*(1535) production at low inv. masses in Au+Au at 1A GeV central collisions.

- In the expanding nuclear system the low-mass N*(1535) gradually increase their Dirac masses and get above N*(1535) → η N decay threshold. This leads to the enhanced η production (by about 50%) in PDM vs non-linear Walecka model (NL2).

- Enhanced low-m_t yield of η's with PDM. The effect is stronger at subthreshold beam energies (below 1.25 A GeV). TAPS data for Au+Au and Ar+KCl at 0.8A GeV are described with PDM better than with NL2.

- Dilepton inv. mass spectra slightly enhanced at intermediate inv. mass range 0.15-0.5 GeV. Better agreement with HADES data for C+C at 1A GeV with PDM.