Pion and kaon production at 2-40 AGeV

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Plan:

1. Motivation
2. GiBUU model
3. Numerical results
4. Summary and outlook

Workshop "The Physics of High Baryon Density", ECT* Trento, 29.05-02.06.2006

Motivation

To test pure hadronic scenario from K^+/π^+ ratio and kaon slopes M. Wagner, A.L., U. Mosel, PRC **71**, 034910 (2005); A.L., K. Gallmeister, U. Mosel, work in progress.

- **CBM experiment planned at GSI**.
- Compare with earlier HSD and UrQMD calculations H. Weber et al., PRC **67**, 014904 (2003).
- Meson + meson$\leftrightarrow K + \bar{K}$ reactions.
- Problems: excessive pions and too steep kaon slopes in transport models.
- Counting many-body collisions: is the binary collision scenario valid ?
- In-medium modified FRITIOF model.

GiBUU model

Transport equation:

$$\left(\frac{\partial}{\partial t}+\frac{\partial H_{mf}}{\partial \mathbf{p}_1}\frac{\partial}{\partial \mathbf{r}}-\frac{\partial(H_{mf}+U_{Coul})}{\partial \mathbf{r}}\frac{\partial}{\partial \mathbf{p}_1}\right)f(\mathbf{r},\mathbf{p}_1,t)$$
$$= \int \frac{g d\mathbf{p}_2}{(2\pi\hbar)^3}\int d\Omega\, v_{12}\frac{d\sigma_{NN}(\sqrt{s})}{d\Omega}(f_3 f_4(1-f_1)(1-f_2)$$
$$-f_1 f_2(1-f_3)(1-f_4)) + \text{coupling terms}\ ,$$

where $f_i \equiv f(\mathbf{r},\mathbf{p}_i,t)$ $(i=1,2,3,4)$, $g=4$.

coupling terms: $NN \leftrightarrow NR$, $NN \leftrightarrow \Delta\Delta$, $NN \rightarrow \text{string}+\text{string}$, ...

Above 2 AGeV neglect mean fields: cascade mode.

Included particles:

nucleons, N^* resonances[1]: $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $S_{11}(1650)$, $D_{15}(1675)$, $F_{15}(1680)$, $P_{13}(1879)$, $F_{17}(1990)$, $G_{17}(2190)$;

Δ resonances[1]: $P_{33}(1232)$, $P_{33}(1600)$, $S_{31}(1620)$, $S_{31}(1900)$, $F_{35}(1905)$, $P_{31}(1910)$, $D_{35}(1930)$, $F_{37}(1950)$, $D_{35}(2350)$;

Λ baryons $(S=-1, I=0)$: $\Lambda(1116)$, $S_{01}(1405)$, $D_{03}(1520)$, $P_{01}(1600)$, $S_{01}(1670)$, $D_{03}(1690)$, $S_{01}(1800)$, $P_{01}(1810)$, $F_{05}(1820)$, $D_{05}(1830)$, $P_{03}(1890)$, $G_{07}(2100)$, $F_{05}(2110)$;

Σ baryons $(S=-1, I=1)$: $\Sigma(1189)$, $P_{13}(1385)$, $P_{11}(1660)$, $D_{13}(1670)$, $S_{11}(1750)$, $D_{15}(1775)$, $F_{15}(1915)$, $F_{17}(2030)$;

$+$ cascades $+$ charmed baryons;

Mesons: $\pi, \eta, \rho, \sigma, \omega, \eta', \phi, \eta_c, J/\psi, K, \bar{K}, K^*, \bar{K}^*$, $+$ charmed mesons.

[1] Resonances with at least ** in D.M. Manley and E.M. Saleski, PRD **45**, 4002 (1992).

Baryon-baryon collisions:

For $\sqrt{s} < 2.6$ GeV: $BB \to BB$ (elastic & inelastic), $NN \leftrightarrow NN\pi$ (direct), $BB \to BYK$, $BB \to NNK\bar{K}$, where $B = N$ or R.

$\sigma_{BB \to NNK\bar{K}}$ (W. Cassing et al., 1997);
$\sigma_{BB \to BYK}$ (K. Tsushima et al., 1999);
$\sigma^{in-medium}_{NN \leftrightarrow NR}$ (A.L. and U. Mosel, 2003).

For $\sqrt{s} > 2.6$ GeV: $BB \to \mathrm{string} + \mathrm{string}$ (FRITIOF).

Meson-baryon collisions:

For $\sqrt{s} < 2$ GeV: $MB \to R \to MB$, $MB \to MB$, $MB \to MMB$.

$\sigma_{\pi B \to KY}$ (K. Tsushima et al., 1997);
$\sigma_{\pi B \to NK\bar{K}}$ (A. Sibirtsev et al., 1997).

For $\sqrt{s} > 2$ GeV: $MB \to \mathrm{string} + \mathrm{string}$ (FRITIOF) or $MB \to \mathrm{string}$ (M. Wagner et al., 2005)

Meson-meson collisions: $MM \leftrightarrow K\bar{K}$.

$\sigma_{\pi\pi \to K\bar{K}}$ (W. Cassing et al., 1997);
$\sigma_{\pi\rho \to K^*\bar{K}, K\bar{K}^*} = \sigma_{\rho\rho \to K\bar{K}} = \sigma_{\pi\pi \to K\bar{K}}$;
$\sigma_{MM \to K\bar{K}} = 2$ mb — for all other channels;
back reactions — by detailed balance (M. Wagner et al., 2005).

Basic version:

M. Effenberger, E.L. Bratkovskaya, and U. Mosel, Phys. Rev. C **60**, 44614 (1999)

M. Effenberger, PhD thesis, Uni. Giessen, 1999, http://theorie.physik.uni-giessen.de/html/dissertations.html

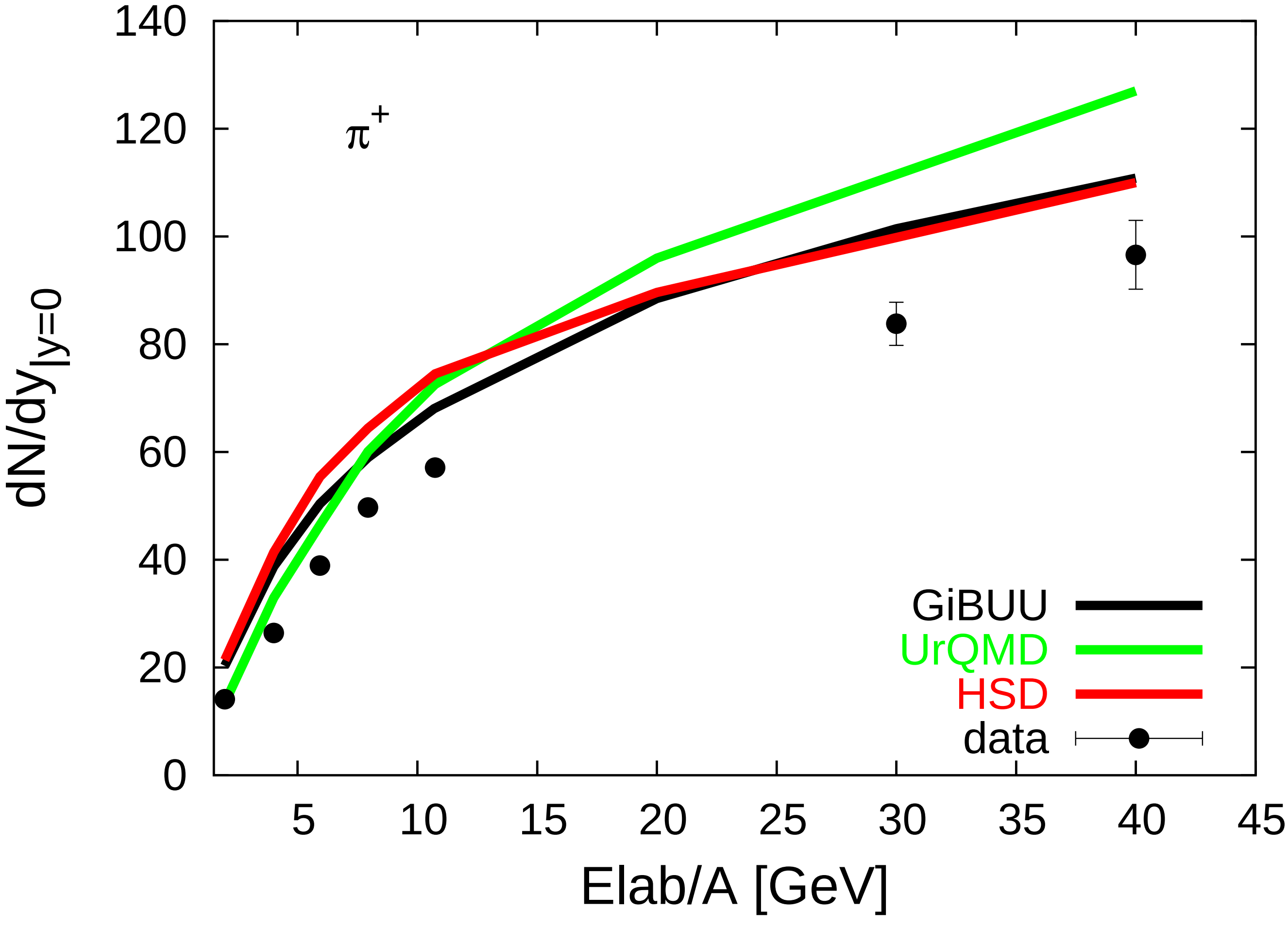
High-energy collisions:

T. Falter, W. Cassing, K. Gallmeister and U. Mosel, PRC **70**, 054609 (2004),

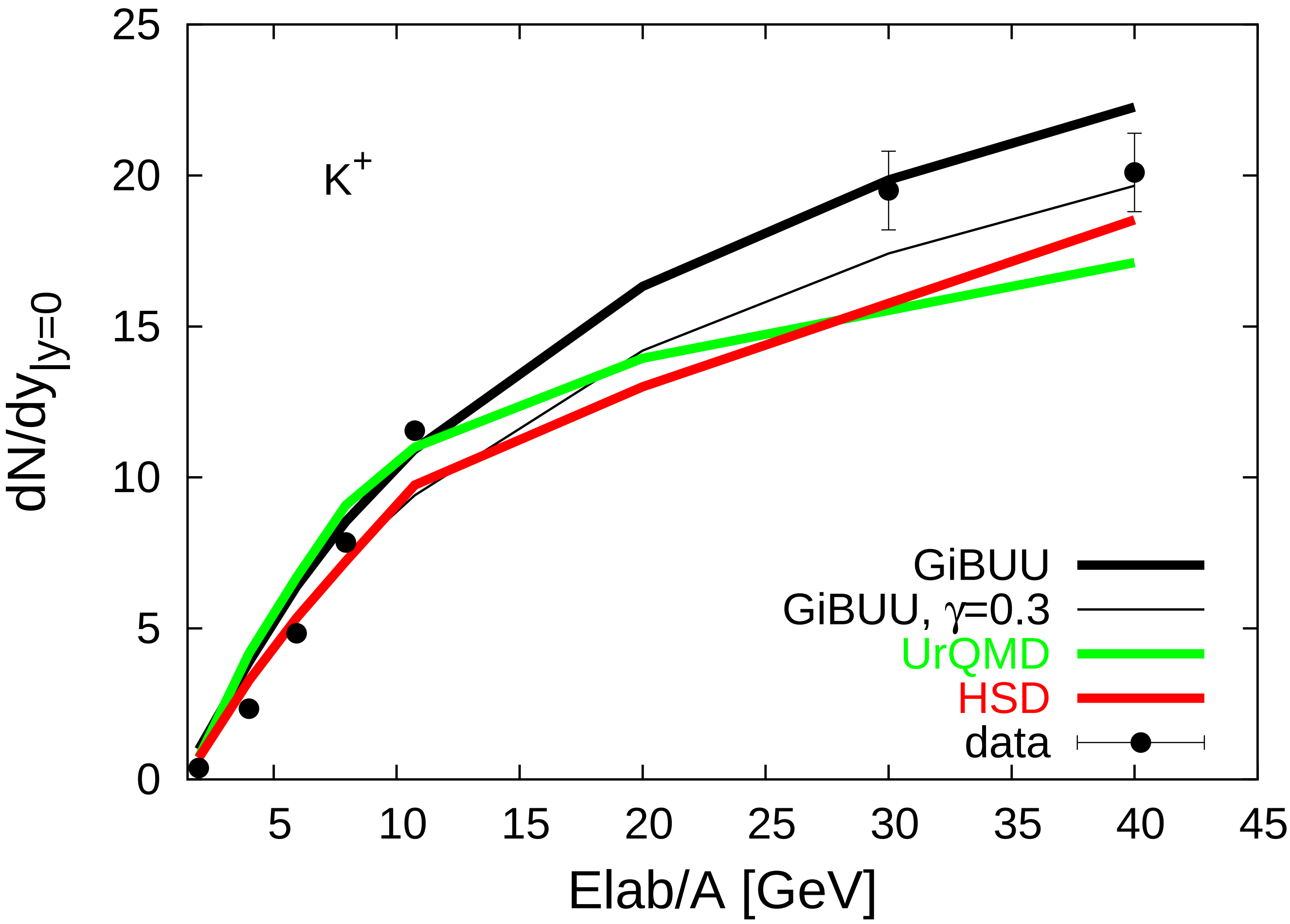
M. Wagner, A.L., and U. Mosel, PRC **71**, 034910 (2005).

Numerical results

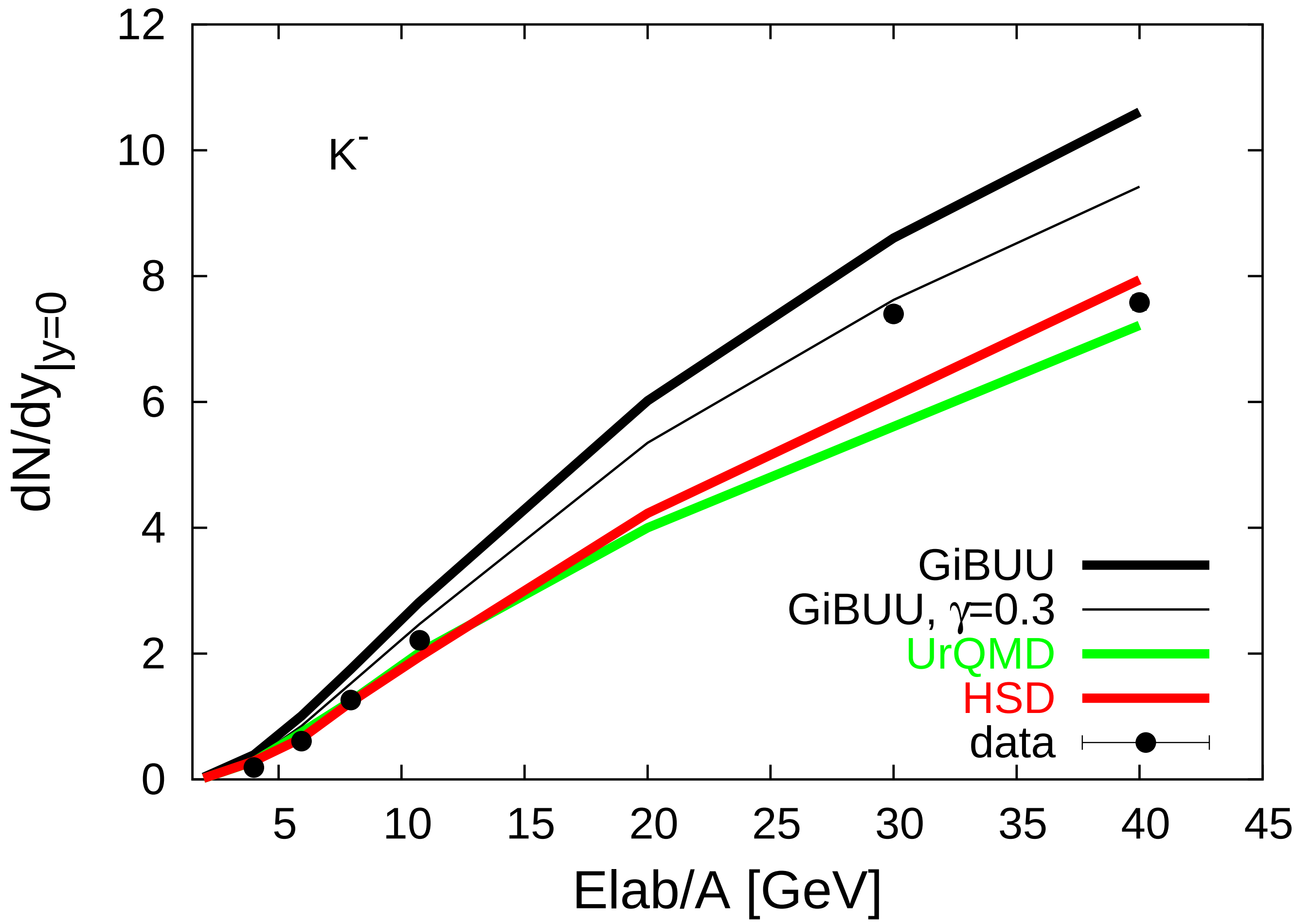
π^+ midrapidity yield vs the beam energy for central collisions Au+Au (AGS) and Pb+Pb (SPS). Data:
L. Ahle et al., PLB **476**, 1 (2000); S. Afanasiev et al., PRC **66**, 054902 (2002); V. Friese, J. Phys. G **30**, S119 (2004).



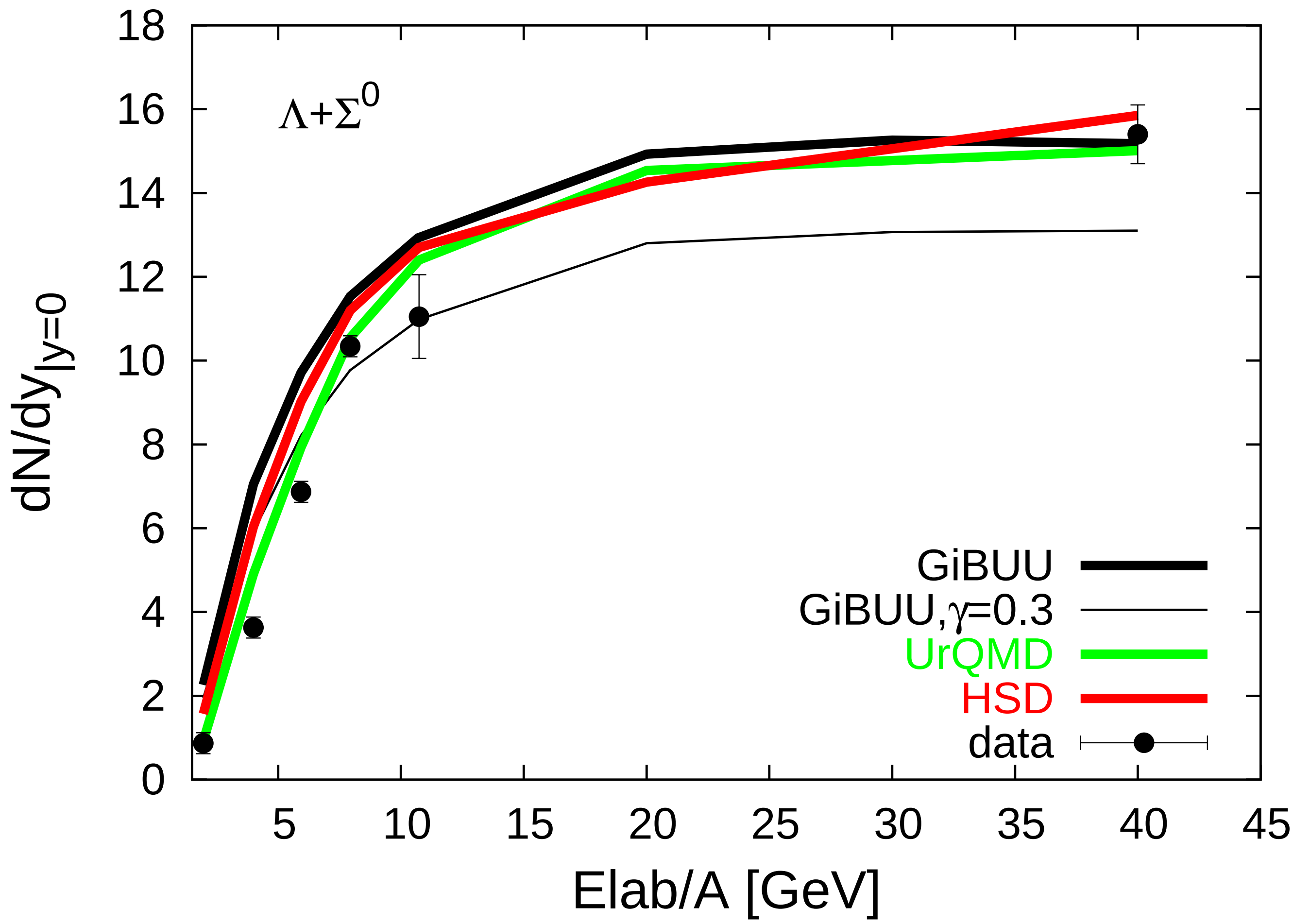
K^+ midrapidity yield vs the beam energy for central collisions Au+Au (AGS) and Pb+Pb (SPS). Data: L. Ahle et al., PLB **476**, 1 (2000); S. Afanasiev et al., PRC **66**, 054902 (2002); V. Friese, J. Phys. G **30**, S119 (2004).



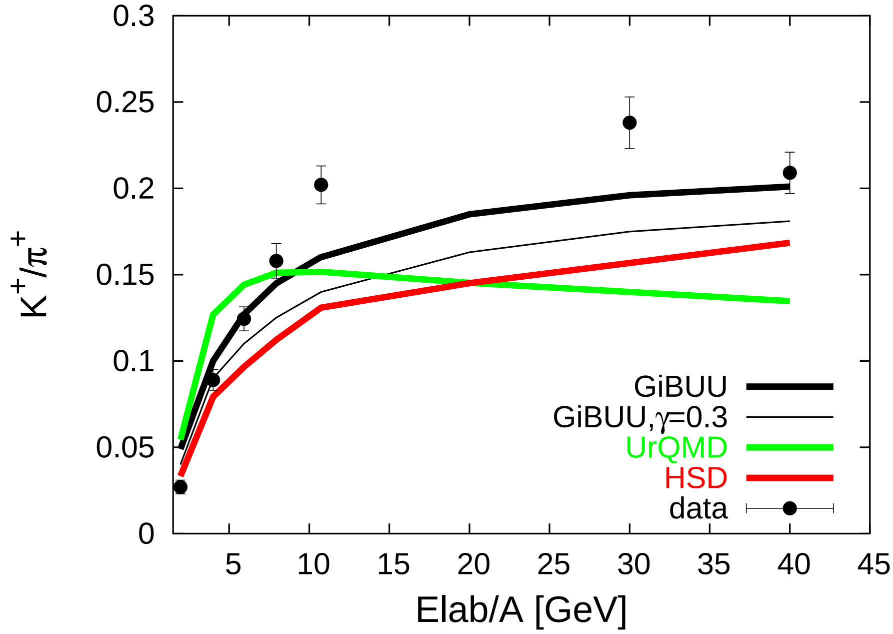
K^- midrapidity yield vs the beam energy for central collisions Au+Au (AGS) and Pb+Pb (SPS). Data: L. Ahle et al., PLB **490**, 53 (2000); S. Afanasiev et al., PRC **66**, 054902 (2002); V. Friese, J. Phys. G **30**, S119 (2004).

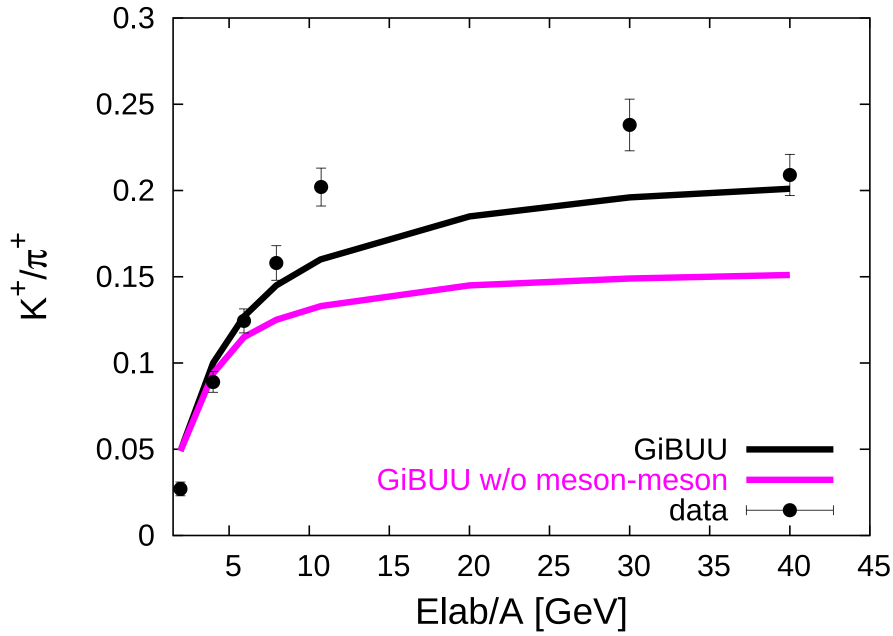


$\Lambda + \Sigma^0$ midrapidity yield vs the beam energy for central collisions Au+Au (AGS) and Pb+Pb (SPS). Data: A. Mischke et al., J. Phys. G **28**, 1761 (2002); A. Mischke et al., NPA **715**, 453 (2003); S. Ahmad et al., PLB **382**, 35 (1996); C. Pinkenburg, NPA **698**, 495 (2002); F. Antinori, NPA **661**, 130 (1999).

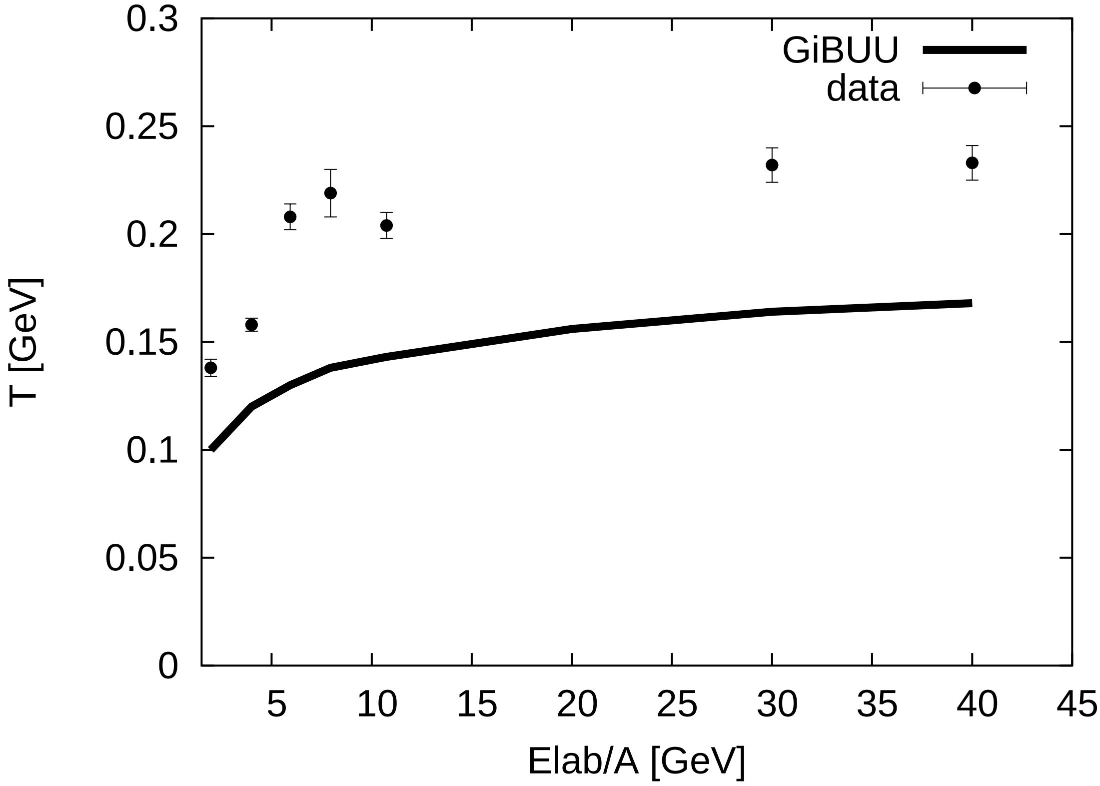


K^+/π^+ ratio at midrapidity vs the beam energy. Data: L. Ahle et al., PLB **476**, 1 (2000); S. Afanasiev et al., PRC **66**, 054902 (2002); V. Friese, J. Phys. G **30**, 119 (2004).

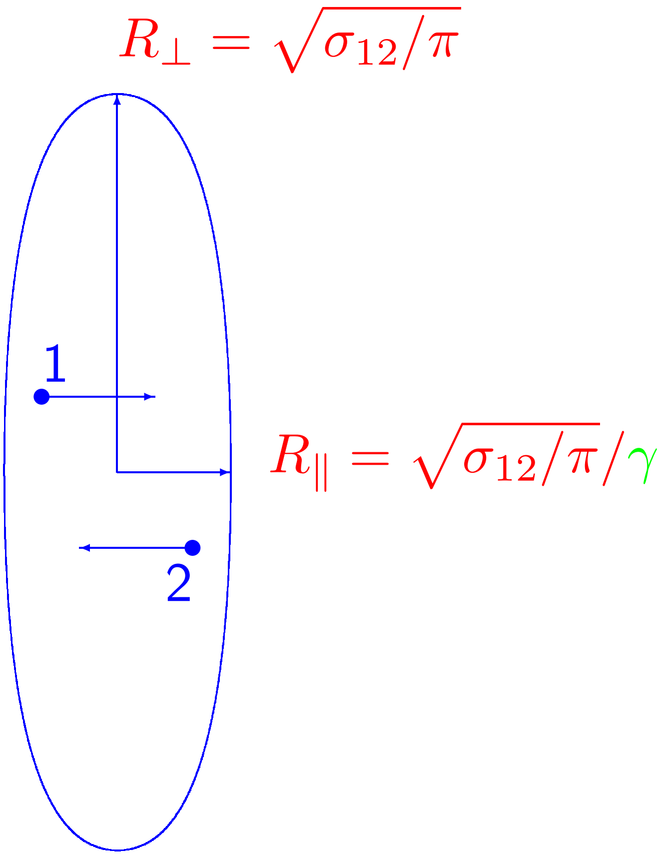




Inverse slope parameter T of the K^+ transverse mass spectra at midrapidity obtained by a fit: $d^2\sigma/(2\pi m_\perp dm_\perp dy) = a\exp\{-m_\perp/T\}$. Data:
L. Ahle et al., PLB **490**, 53 (2000); S. Afanasiev et al., PRC **66**, 054902 (2002); V. Friese, J. Phys. G **30**, 119 (2004).

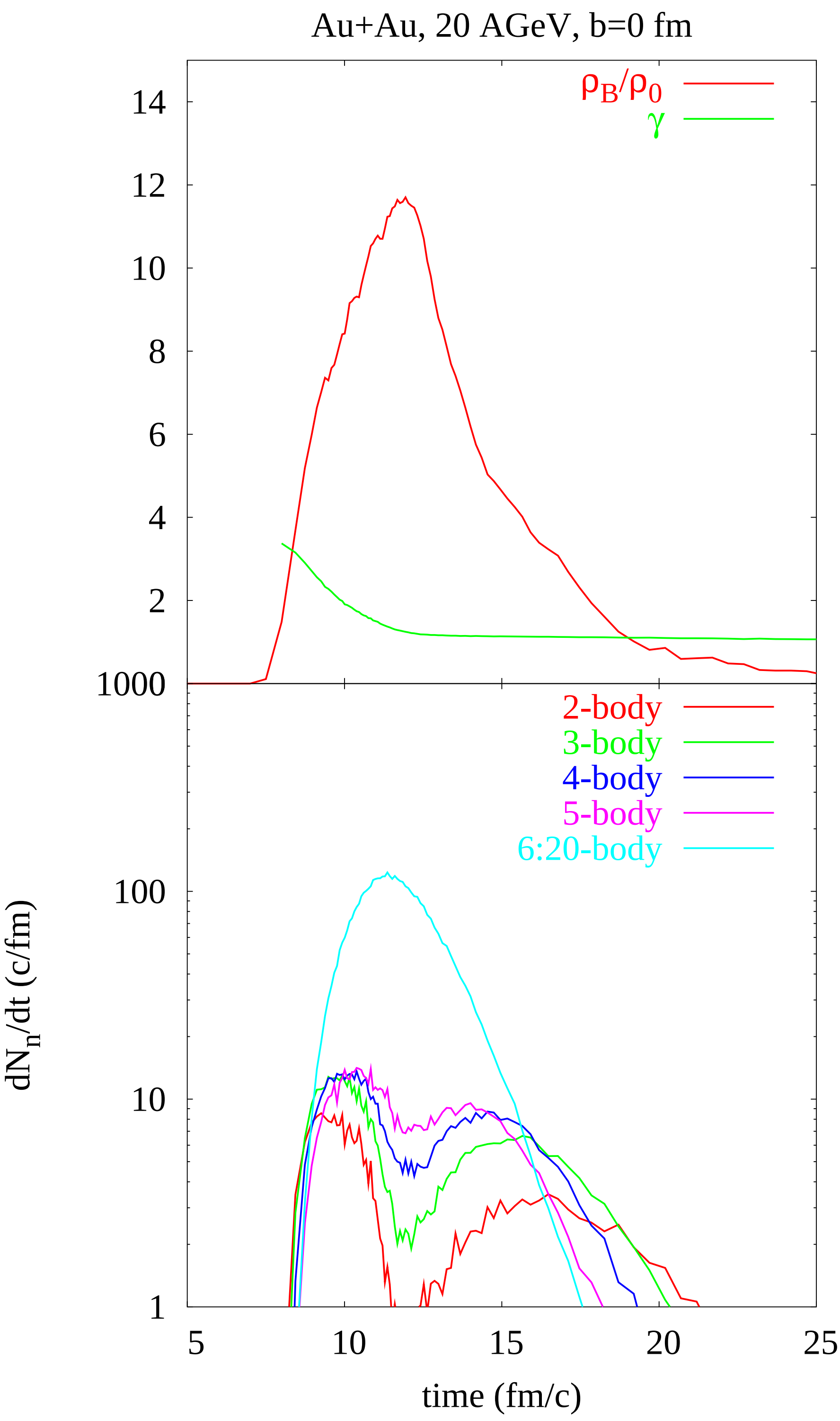


Counting many-body collisions



1 and 2 — colliding baryons, $\sigma_{12} \simeq 40$ mb.
def: n-body collision happens if $(n-2)$ baryons are found in the ellipsoid with half-axes $R_\perp = \sqrt{\sigma_{12}/\pi}$ and $R_\parallel = \sqrt{\sigma_{12}/\pi}/\gamma$ centered at the c.m. of colliding particles.

Baryon density in $(1\ \mathrm{fm})^3$ central cubic cell, n-body collision frequencies in $(7\ \mathrm{fm})^3$ central cubic cell.



$\rho_B \simeq 10\rho_0 = 1.6$ fm^{-3}, $\sigma_{12} = 40$ mb,

Gas parameter:

$$\left(\frac{\text{interaction radius}}{\text{interparticle distance}}\right)^3 = (\sigma_{12}/\pi)^{3/2}\rho_B \simeq 2 > 1$$

$\Rightarrow$ Binary collision approximation is not valid.

$\Rightarrow$ **Cross sections must be in-medium reduced.**

In-medium modification of the FRITIOF model

Multiple meson production in a baryon-baryon collision :

$$B_1 B_2 \to B_3 B_4 M_5 M_6 ... M_N$$

- In-medium dispersion relations for incoming and outgoing particles :

$$\begin{aligned}(p_i^*)^0 &= \sqrt{(\mathbf{p}_i^*)^2 + (m_i^*)^2}\ , \quad i = 1, 2, 3, 4 \\ (k_i^*)^0 &= \sqrt{(\mathbf{k}_i^*)^2 + (m_i^*)^2}\ , \quad i = 5, 6, ..., N\end{aligned}$$

- Matrix element is not changed in nuclear medium

$\Rightarrow$

$$\sigma^{med}(\sqrt{s^*}) = F \sigma^{vac}(\sqrt{s})\ ,$$

$$F = \frac{m_1^* m_2^* m_3^* m_4^*}{m_1 m_2 m_3 m_4} \frac{I}{I^*} \frac{\Phi_{N-2}(\sqrt{s^*}; m_3^*, m_4^*, ..., m_N^*)}{\Phi_{N-2}(\sqrt{s}; m_3, m_4, ..., m_N)}\ .$$

$$
\begin{aligned}
& d\Phi_{N-2}(p_1^* + p_2^*; p_3^*, p_4^*, k_5^*, k_6^*, ..., k_N^*) \\
& \quad = \quad \delta^{(4)}(p_1^* + p_2^* - p_3^* - p_4^* - k_5^* - k_6^* - ... - k_N^*) \\
& \quad \times \quad \frac{d^3 p_3^*}{(2\pi)^3 2 (p_3^*)^0} \frac{d^3 p_4^*}{(2\pi)^3 2 (p_4^*)^0} \frac{d^3 k_5^*}{(2\pi)^3 2 (k_5^*)^0} \cdots \\
& \quad \times \quad \frac{d^3 k_N^*}{(2\pi)^3 2 (k_N^*)^0}
\end{aligned}
$$

— $(N-2)$-body phase space element,

$$
\begin{aligned}
I^* &= q(\sqrt{s^*}, m_1^*, m_2^*)\sqrt{s^*} \ , \\
I &= q(\sqrt{s}, m_1, m_2)\sqrt{s}
\end{aligned}
$$

— flux factors,

$$
q(\sqrt{s}, m_1, m_2) = [(s + m_1^2 - m_2^2)^2/(4s) - m_1^2]^{1/2}
$$

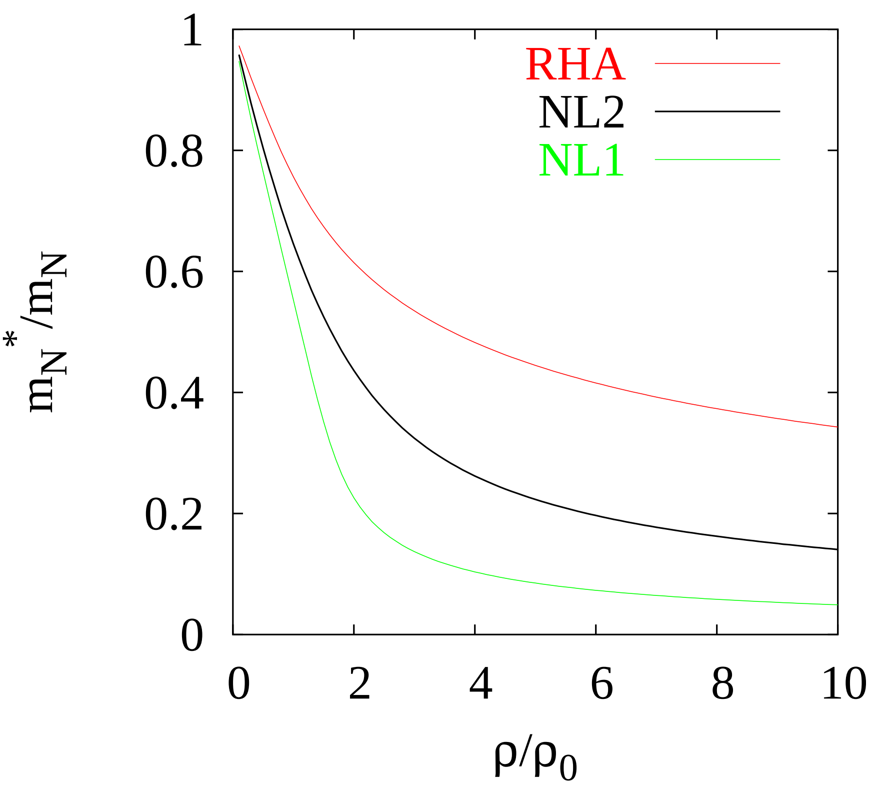
— c.m. momentum of incoming baryons,

$$
s = (p_1 + p_2)^2, \quad s^* = (p_1^* + p_2^*)^2 \ .
$$

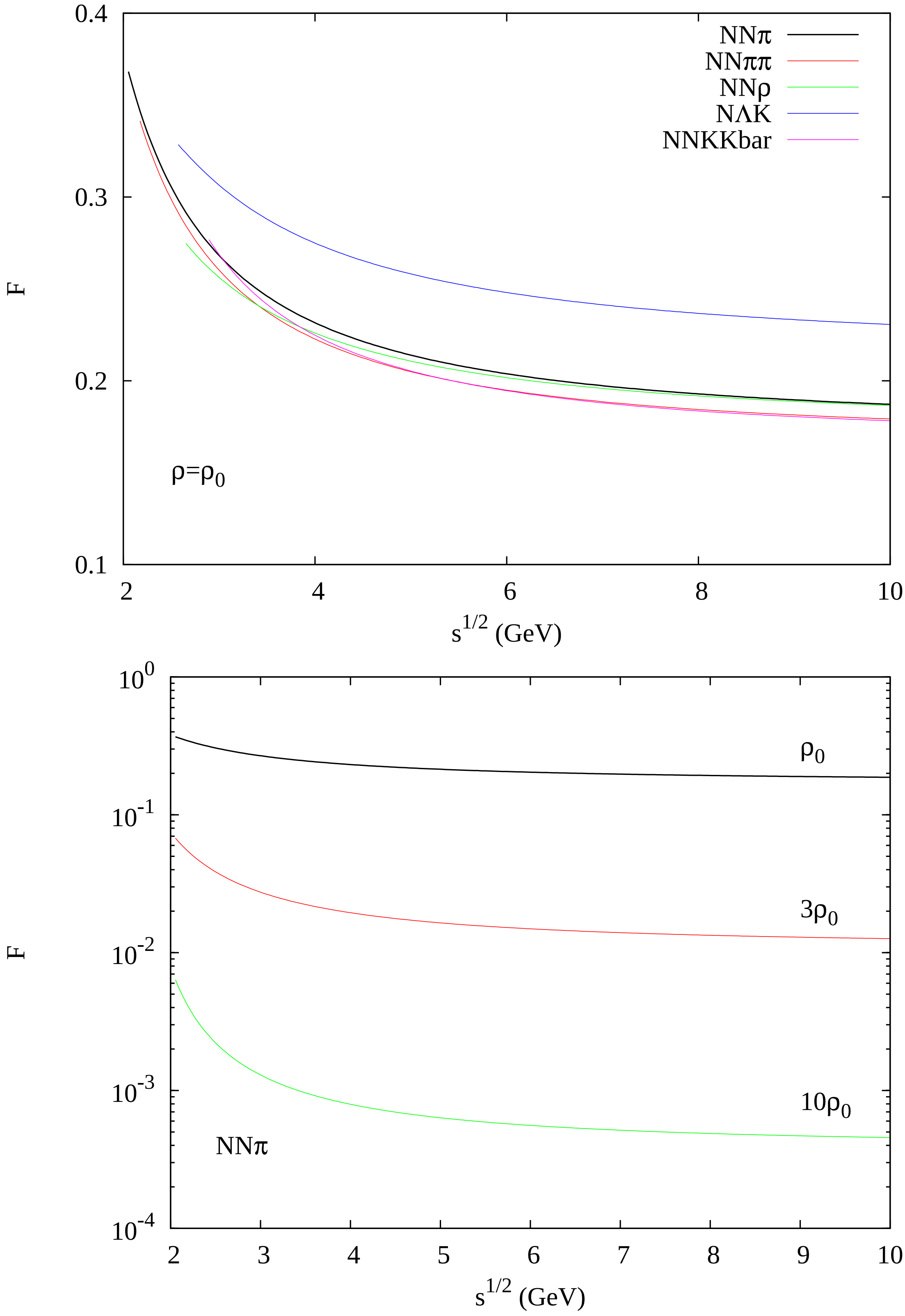
- Excess energy above threshold is the same as in vacuum :

$$\sqrt{s^*} = \sqrt{s} - m_3 - m_4 - \cdots - m_N + m_3^* + m_4^* + \cdots + m_N^*$$

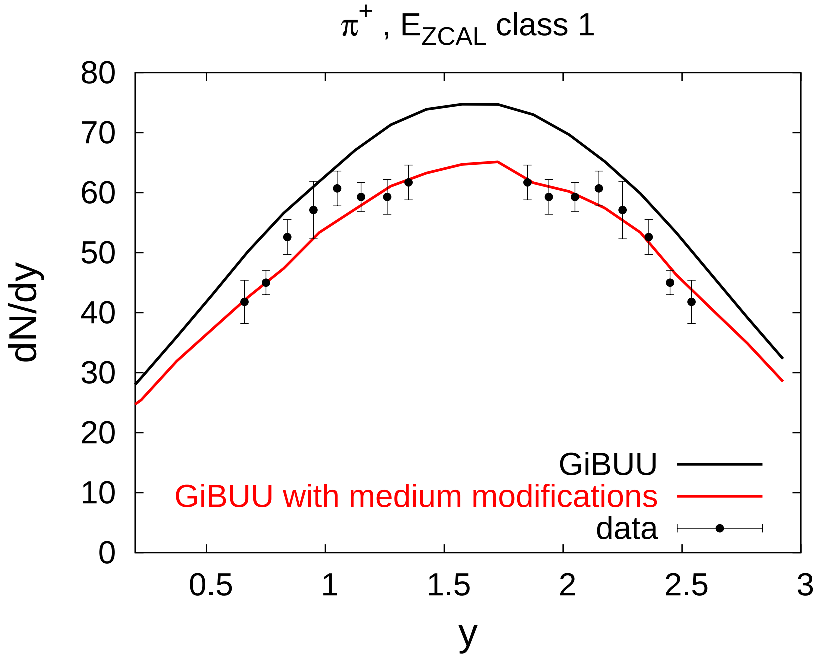
- Use RMF model for the baryons (NL2 version from S. Lee et al., PRL **57**, 2916 (1986)) and the Brown-Rho potentials for K, $\bar{K}$ ($U_K(\rho_0) = 32$ MeV, $U_{\bar{K}}(\rho_0) = -144$ MeV, c.f. G.E. Brown and M. Rho, NPA **596**, 503 (1996))

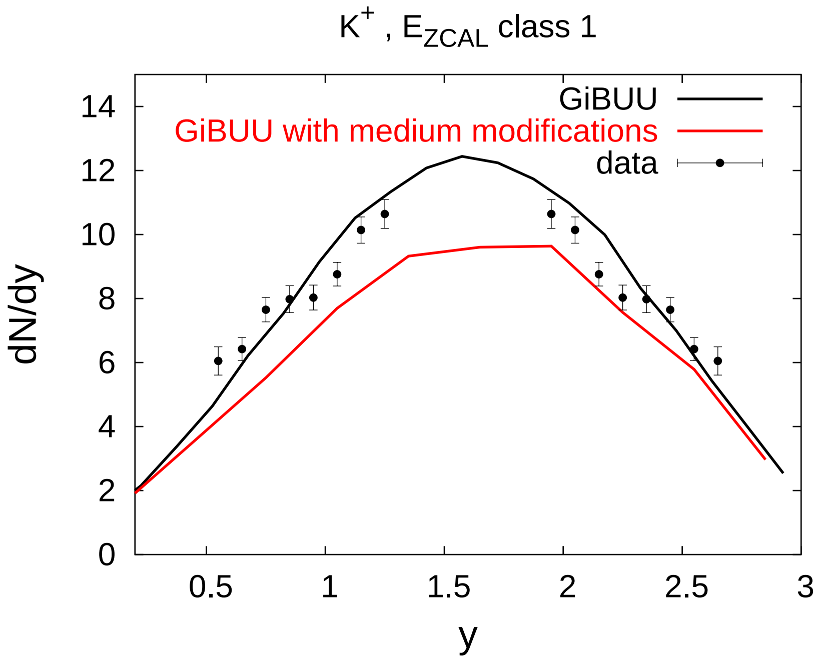


In-medium modification factor F of the NN cross section vs c.m. energy.

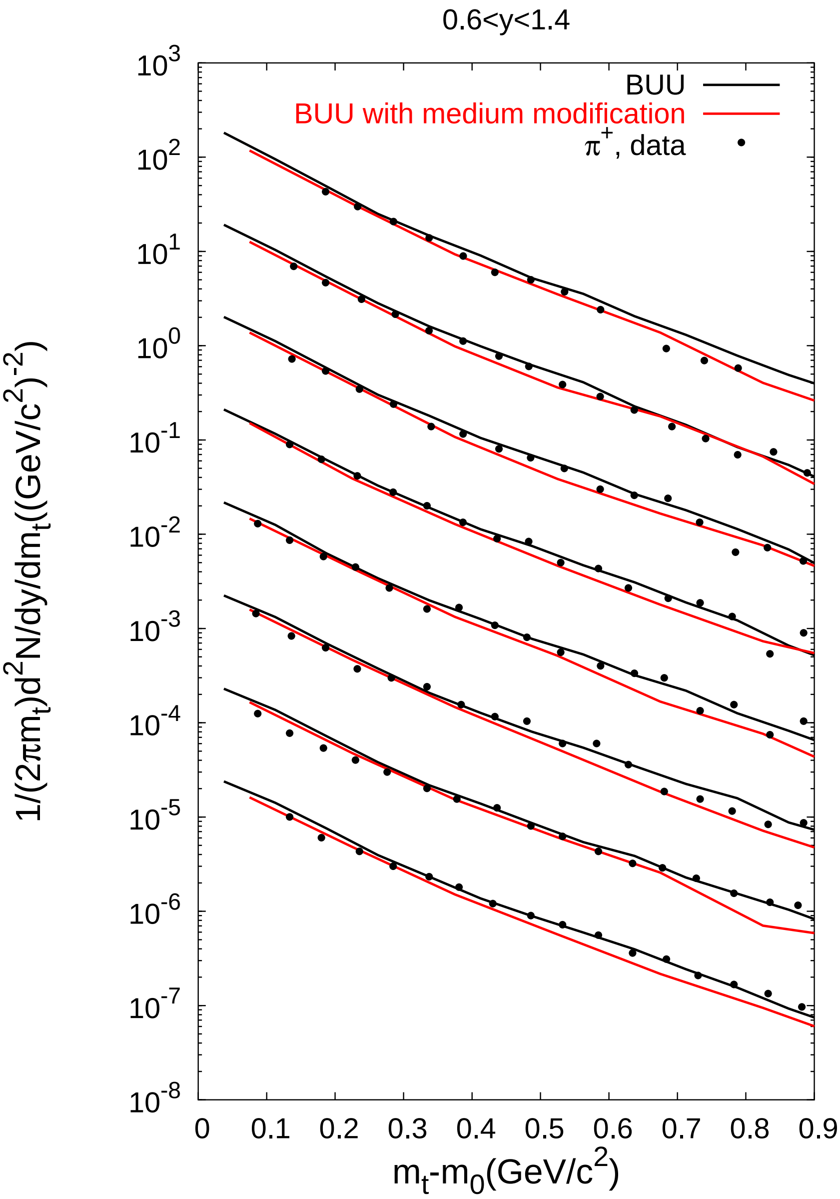


Rapidity distributions of π^+ and K^+ for central collisions Au+Au at 10.7 A GeV.
Data: L. Ahle et al., PRC **59**, 2173 (1999).

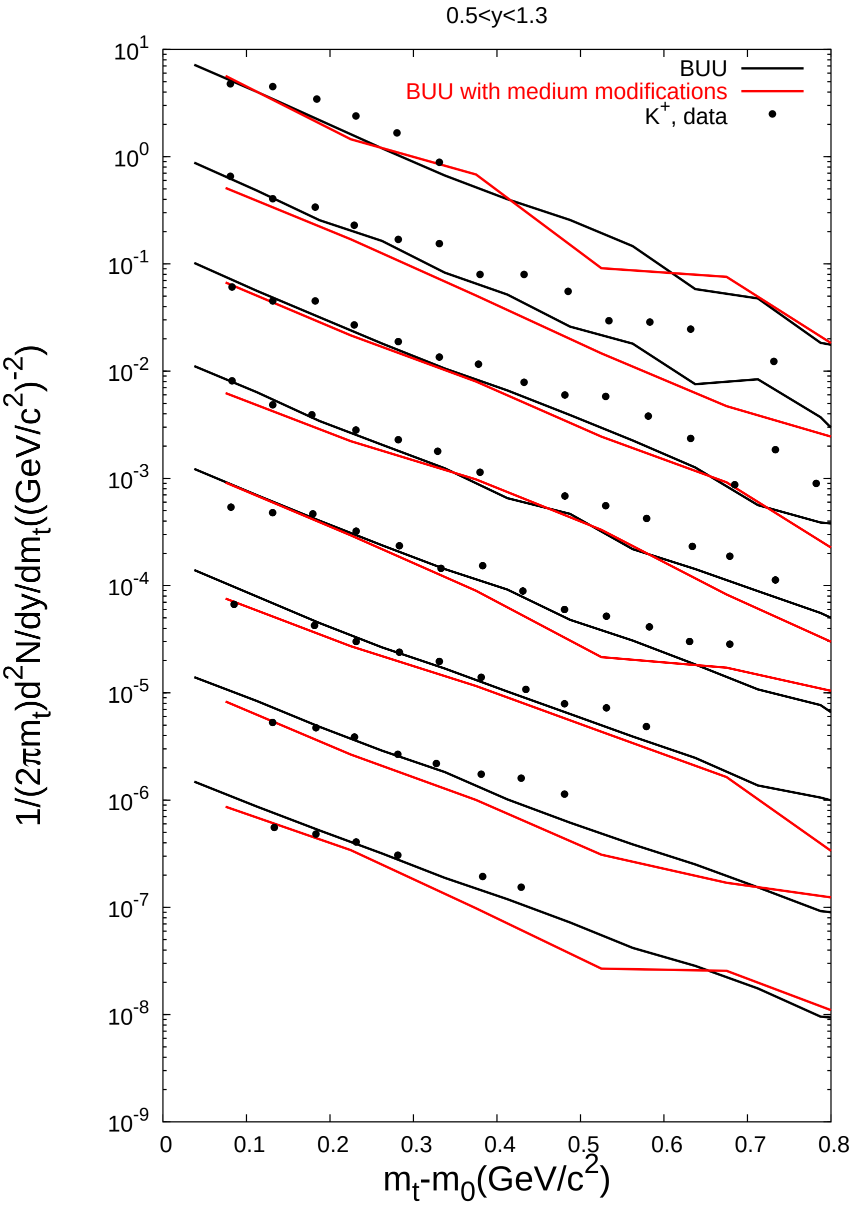




Transverse mass spectra of π^+ for central collisions Au+Au at 10.7 A GeV (E_{ZCAL} class 1). Rapidity slices range from 0.6-0.7 for the uppermost line to 1.3-1.4 for the lowermost line with a step of 0.1. The spectra are multiplied by $10^0, 10^{-1}, ..., 10^{-7}$ from the uppermost to the lowermost line.
Data: L. Ahle et al., PRC **59**, 2173 (1999).



Transverse mass spectra of K^+ for central collisions Au+Au at 10.7 A GeV (E_{ZCAL} class 1). Rapidity slices range from 0.5-0.6 for the uppermost line to 1.2-1.3 for the lowermost line with a step of 0.1. The spectra are multiplied by $10^0, 10^{-1}, ..., 10^{-7}$ from the uppermost to the lowermost line.
Data: L. Ahle et al., PRC **59**, 2173 (1999).



Summary and outlook

- Standard GiBUU gives overall agreement with HSD and UrQMD on π^+ and K^+ multiplicities. Data on π^+ multiplicity are overestimated, K^+ multiplicity is well described. Too soft kaon m_t-spectra in GiBUU calculations.

- Problem with standard calculations:
  binary collision scenario is not valid at high density, provided the vacuum cross sections are used.

- The FRITIOF model with in-medium reduced cross sections gives the correct pion multiplicity, however, the kaon multiplicity becomes too low.

Further steps: use new GiBUU code Oliver Buss et al., nucl-th/0603003, better description of the prehadron collisions and simulation of the many-body collisions (with Kai Gallmeister, work in progress).