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Thermalization of gluons at RHIC including gg<->ggg interactions in a parton cascade

Zhe Xu and Carsten Greiner

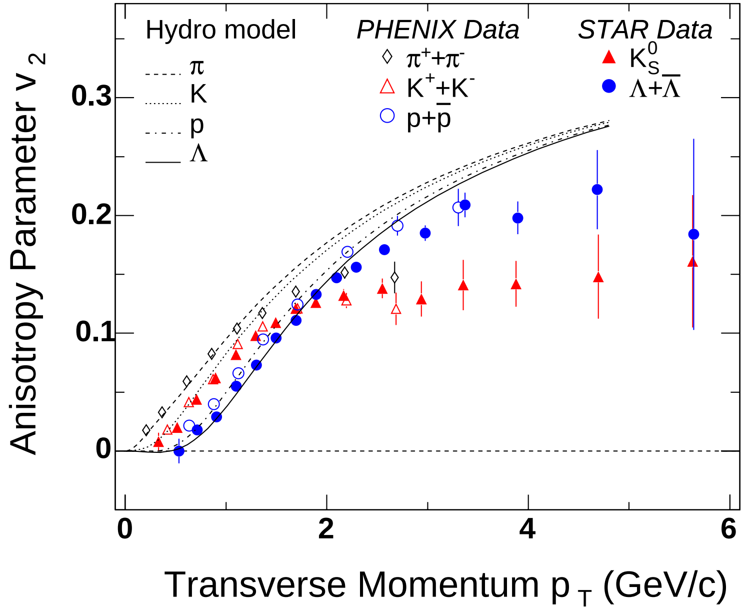
- Motivation
- Parton cascade with the **stochastic algorithm**
- Initial conditions
- Results
- Summary and outlook

Quark Matter 2005, Budapest

Motivation

elliptic flow --- `early signature´ of QGP

$$\frac{dN_h}{dp_T^2 dy d\phi} = \frac{dN_h}{dp_T^2 dy} \frac{1}{\pi} (1 + 2v_1 \cos\phi + 2v_2 \cos 2\phi + ...)$$



evidence for an early buildup of pressure and
a fast thermalization of the quark-gluon system

- How can one describe the fast thermalization by the partonic collisions?
- How can one understand the hydrodynamical behavior by the partonic collisions?

transport simulation: on-shell parton cascade

Z. Xu and C. Greiner, PRC 71, 064901 (2005)

solving the Boltzmann-equations for quarks and gluons

$$p^\mu \partial_\mu f(x,p) = C_{gg\leftrightarrow gg}(x,p) + C_{gg\leftrightarrow ggg}(x,p)$$

(Z)MPC, VNI/BMS

new development

parton scatterings in leading order pQCD

$$\left|M_{gg\to gg}\right|^2 = \frac{9g^4}{2}\frac{s^2}{(q_\perp^2+m_D^2)^2},$$

$$\left|M_{gg\to ggg}\right|^2 = \left(\frac{9g^4}{2}\frac{s^2}{(q_\perp^2+m_D^2)^2}\right)\left(\frac{12g^2q_\perp^2}{k_\perp^2\left((\vec{k}_\perp-\vec{q}_\perp)^2+m_D^2\right)}\right)\Theta_{LPM}$$

J.F.Gunion, G.F.Bertsch, Phys. Rev. D 25, 746(1982)

$$\alpha_s \approx \frac{12\pi}{(33-2n_f)\ln(s/\Lambda_{QCD})}$$

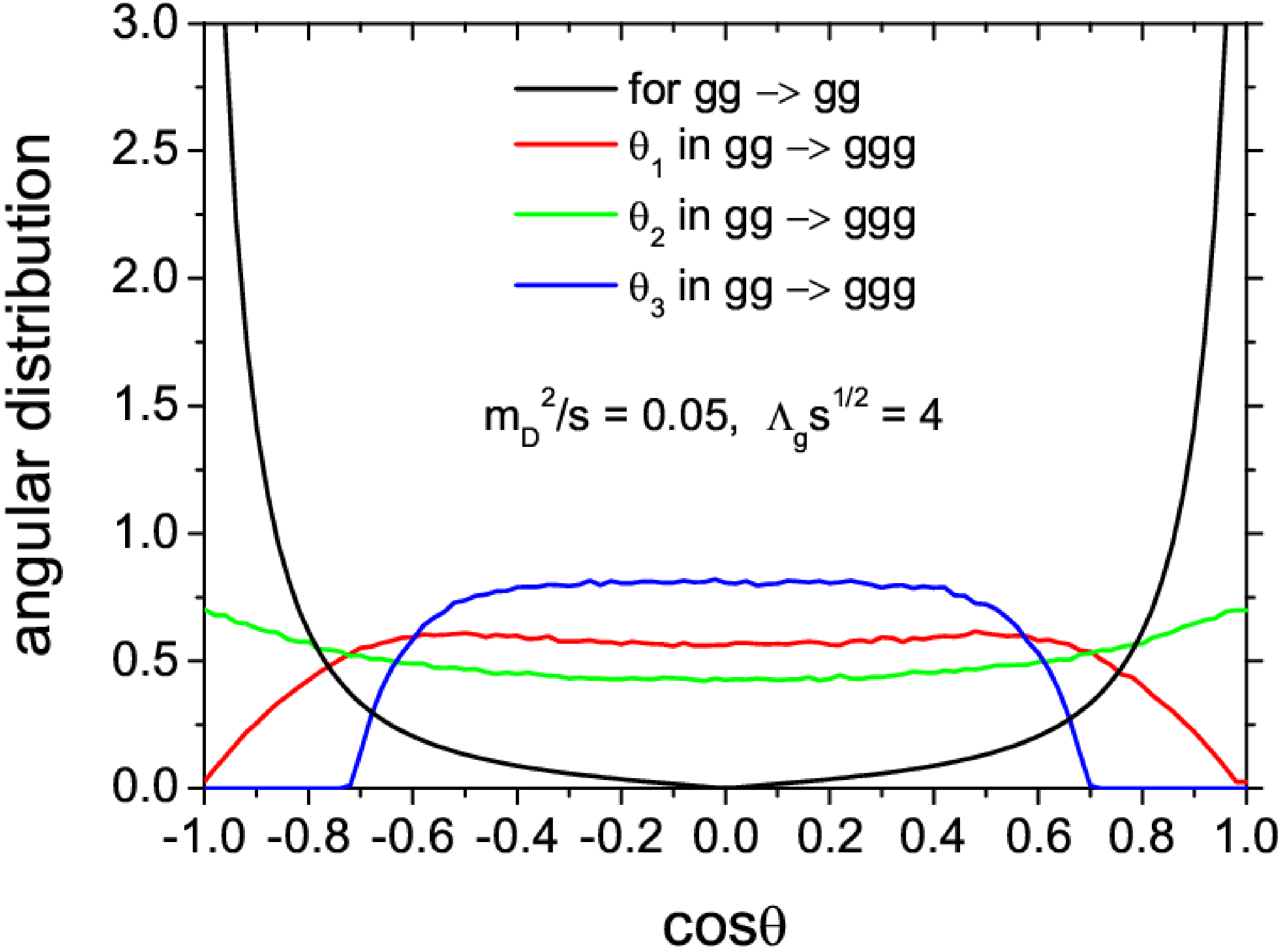
screening mass: $m_D^2 = 16\pi\alpha_s \int \frac{d^3p}{(2\pi)^3}\frac{1}{p}(3f_g + n_f f_q),$

LPM suppression: the formation time $\Delta\tau \approx \frac{1}{k_\perp}\cosh y < \Lambda_g$

$\longrightarrow$ $\Theta(k_\perp\Lambda_g - \cosh y)$

Example

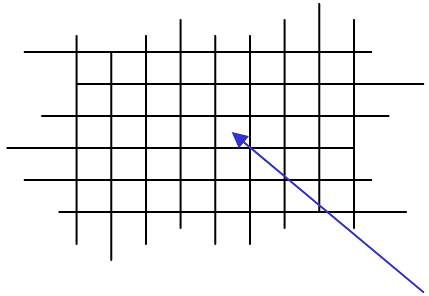
$$\alpha_s \sim 0.3 \quad \Lambda_g \sim 0.5\ fm \quad T \sim 400 MeV \quad \text{fugacity} \sim 0.5$$



Stochastic algorithm

P.Danielewicz, G.F.Bertsch, Nucl. Phys. A 533, 712(1991)
A.Lang et al., J. Comp. Phys. 106, 391(1993)

cell configuration in space →



for particles in Δ^3x with momentum $\mathbf{p}_1,\mathbf{p}_2,\mathbf{p}_3$ ...

collision probability:

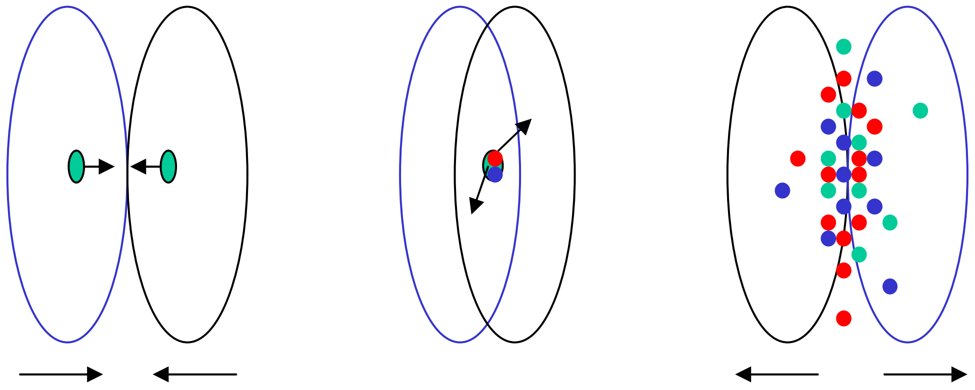
$$for\ 2 \leftrightarrow 2 \quad P_{22} = v_{rel}\sigma_{22}\frac{\Delta t}{\Delta^3 x}$$

$$for\ 2 \rightarrow 3 \quad P_{23} = v_{rel}\sigma_{23}\frac{\Delta t}{\Delta^3 x}$$

$$for\ 3 \rightarrow 2 \quad P_{32} = \frac{I_{32}}{8E_1E_2E_3}\frac{\Delta t}{(\Delta^3 x)^2}$$

$$I_{32} = \frac{1}{2}\int \frac{d^3 p_{1'}}{(2\pi)^3 2E_{1'}} \frac{d^3 p_{2'}}{(2\pi)^3 2E_{2'}} \left| M_{123\rightarrow 1'2'} \right|^2 (2\pi)^4 \delta^{(4)}(p_1 + p_2 + p_3 - p_{1'} - p_{2'})$$

Initial conditions: minijets production with $p_t > p_0$



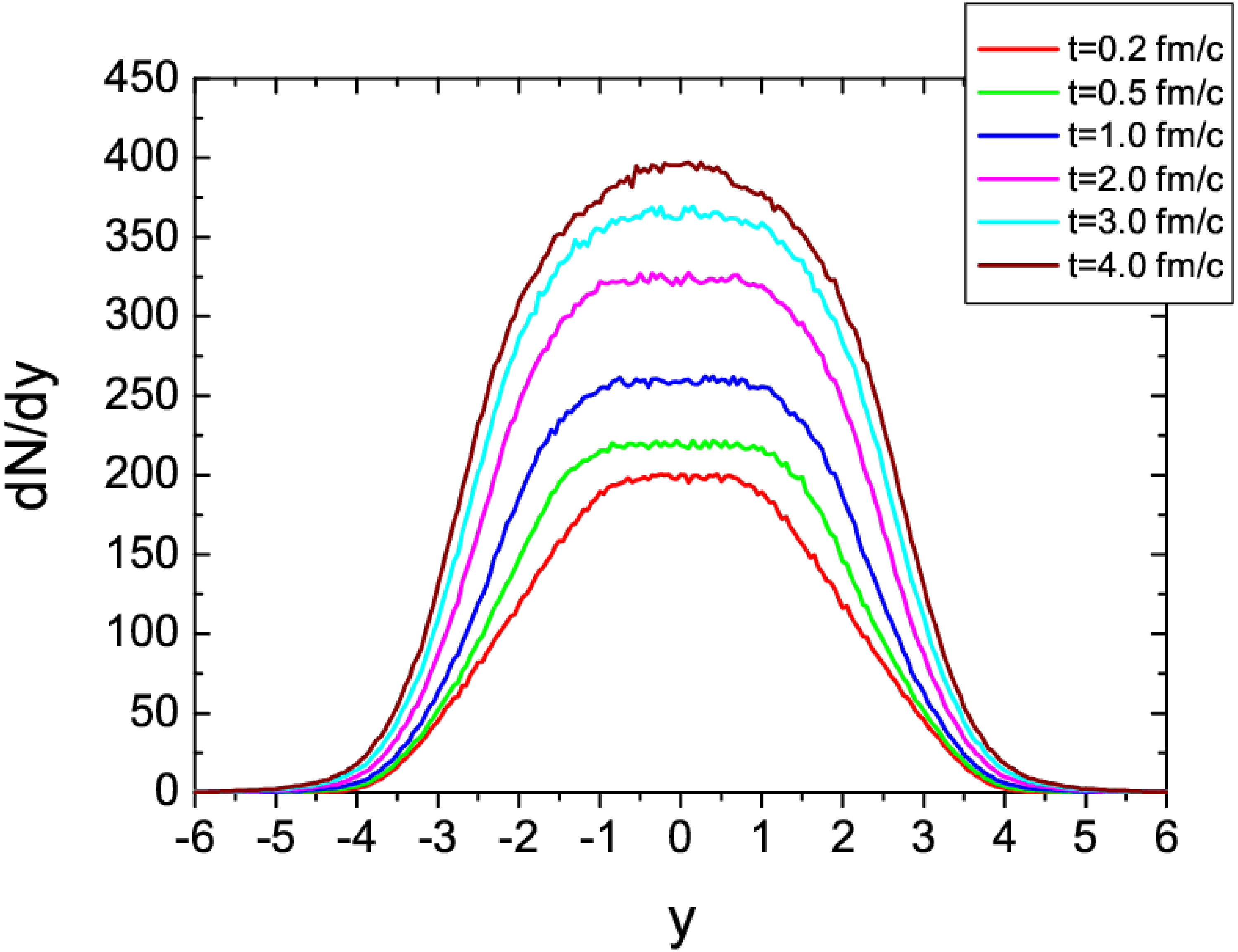
$$\frac{d\sigma_{jet}}{dp_T^2 dy_1 dy_2} = K \sum_{a,b;c,d} x_1 f_a(x_1, p_T^2)\, x_2 f_b(x_2, p_T^2) \frac{d\sigma^{ab\to cd}}{d\hat{t}}$$

binary approximation ⇨ $N_{jet}^{AA} \approx 2\, T_{AA}(b=0)\, \sigma_{jet}^{pp}$

$N_g \approx 830$ for a central Au+Au collision at **RHIC** at 200 AGeV using **p_0=2 GeV**

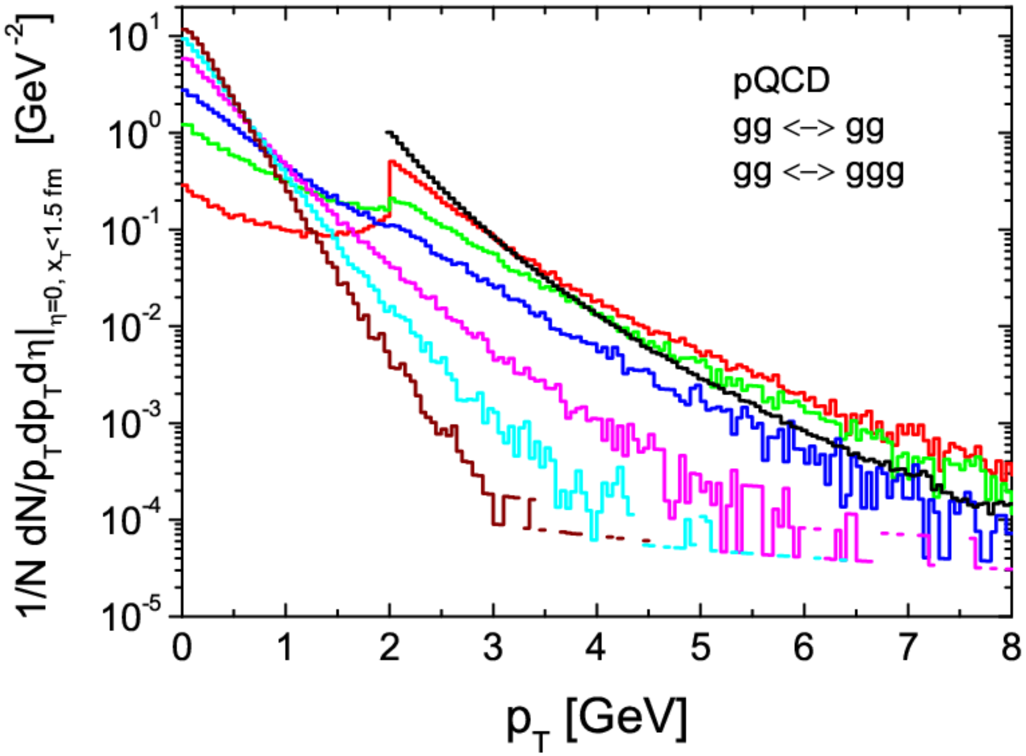
Results

rapidity distribution



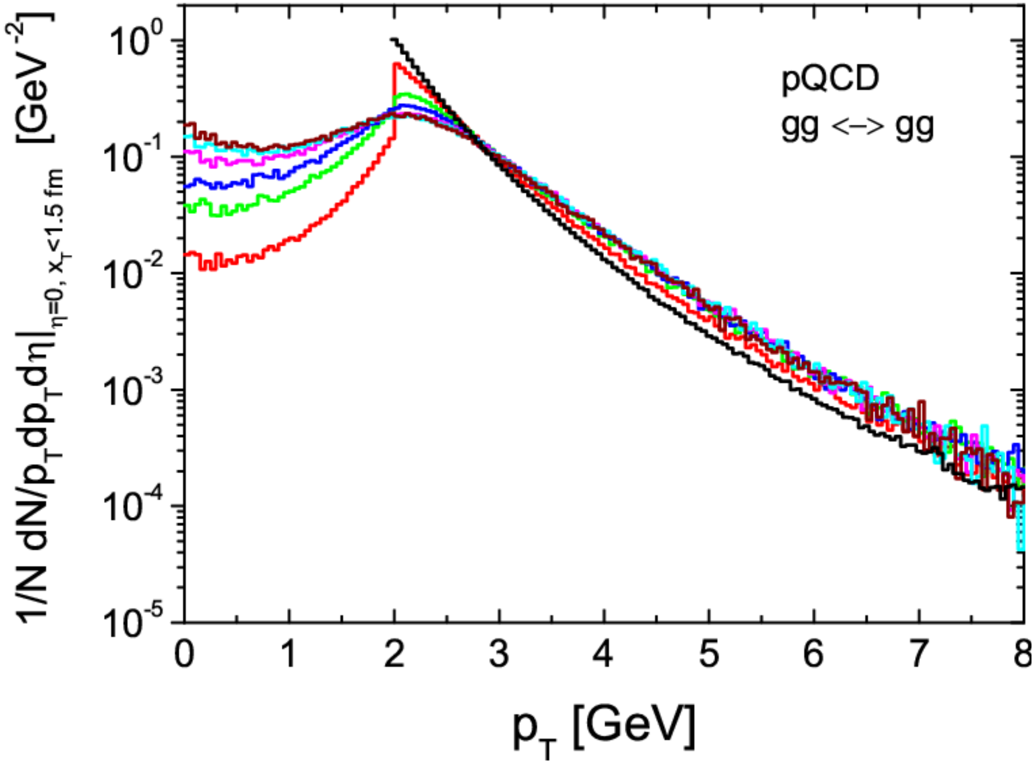
the central region:
η: [-0.5:0.5] and $x_t < 1.5$ fm

including gg<–>ggg



thermalization and
hydrodynamical behavior

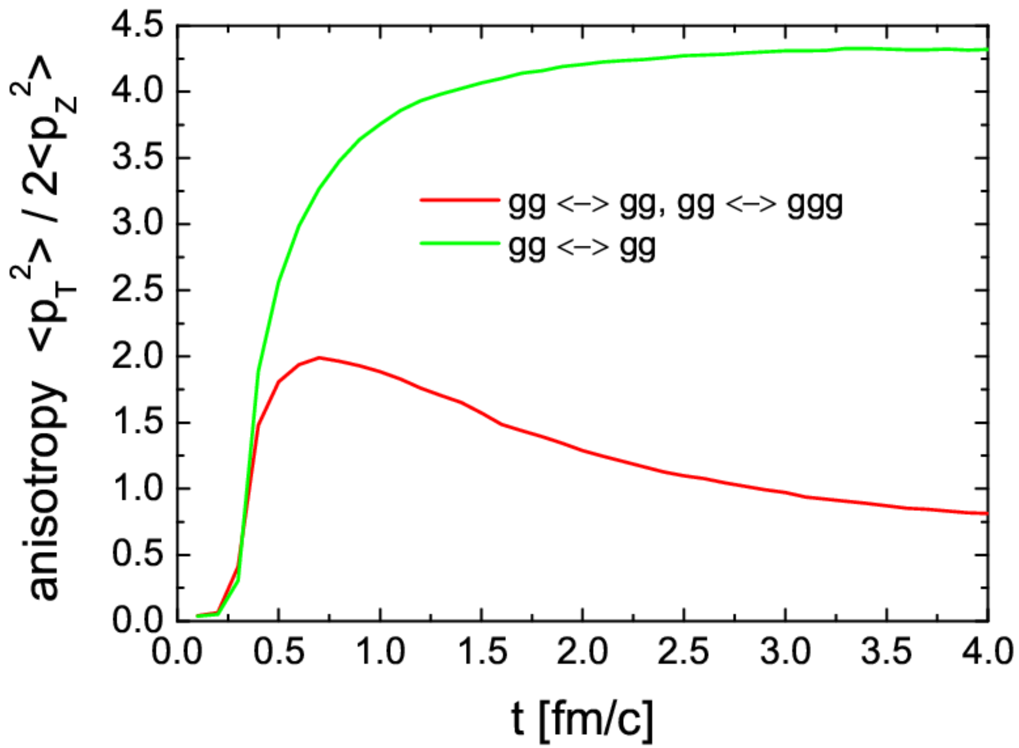
without gg<–>ggg

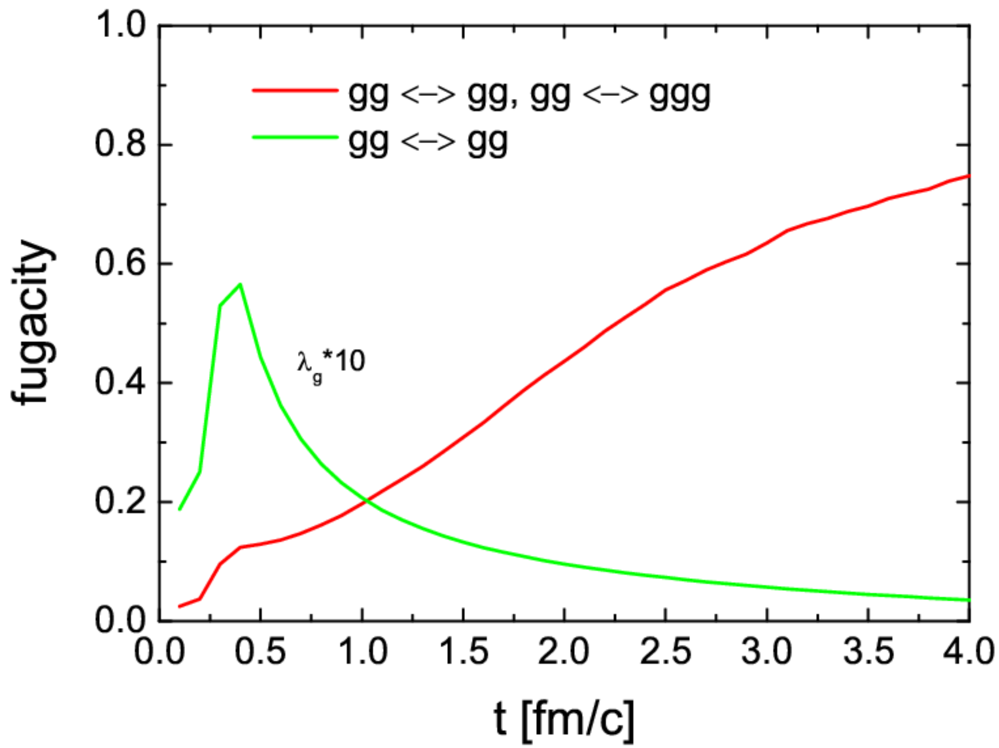


NO thermalization and
free streaming

Kinetic and chemical equilibration

in the central region: η: [-0.5:0.5] and x_t < 1.5 fm



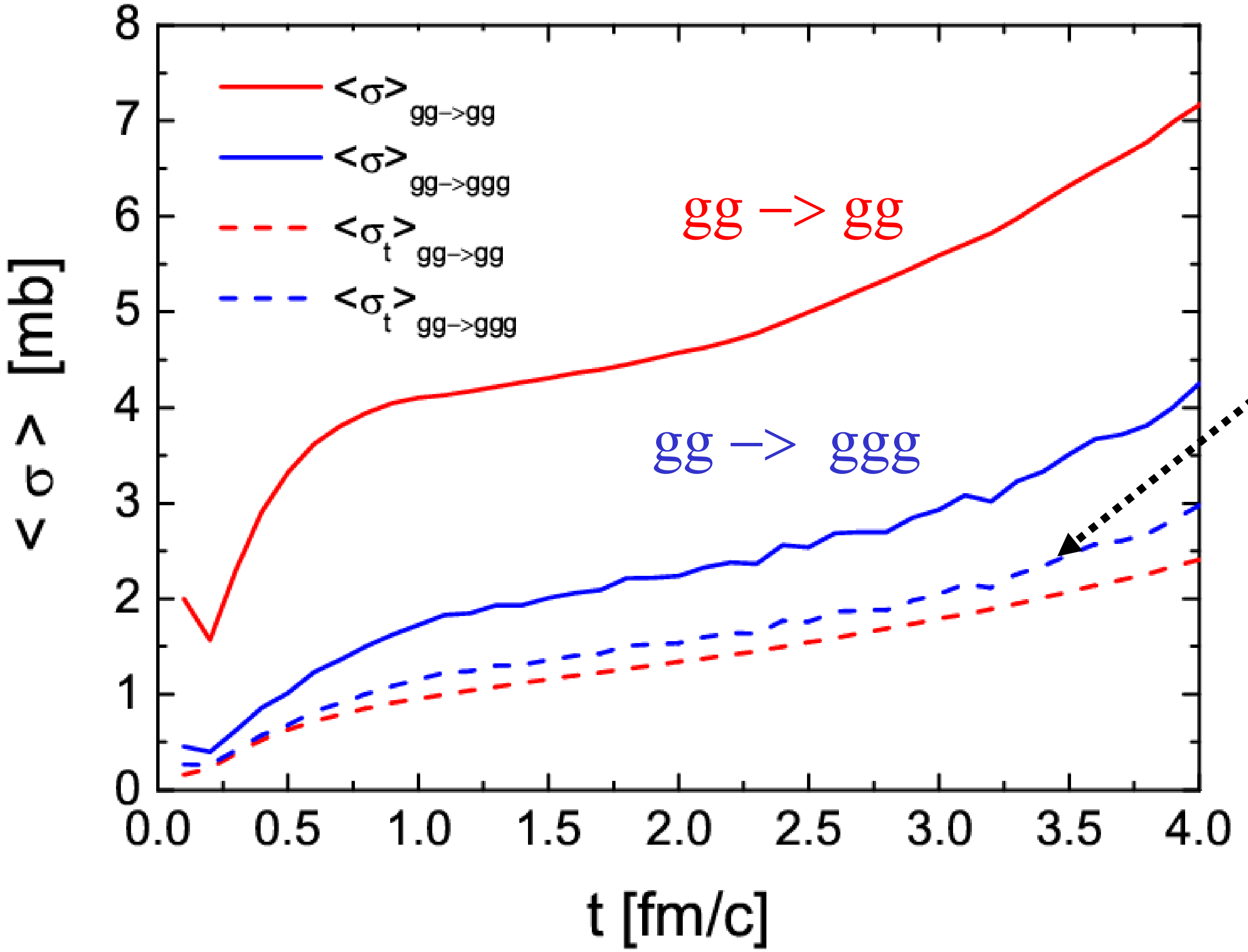


1~2 fm/c for the kinetic equilibration

~ 4 fm/c for the chemical equilibration

cross sections

in the central region: η: [-0.5:0.5] and $x_t < 1.5$ fm

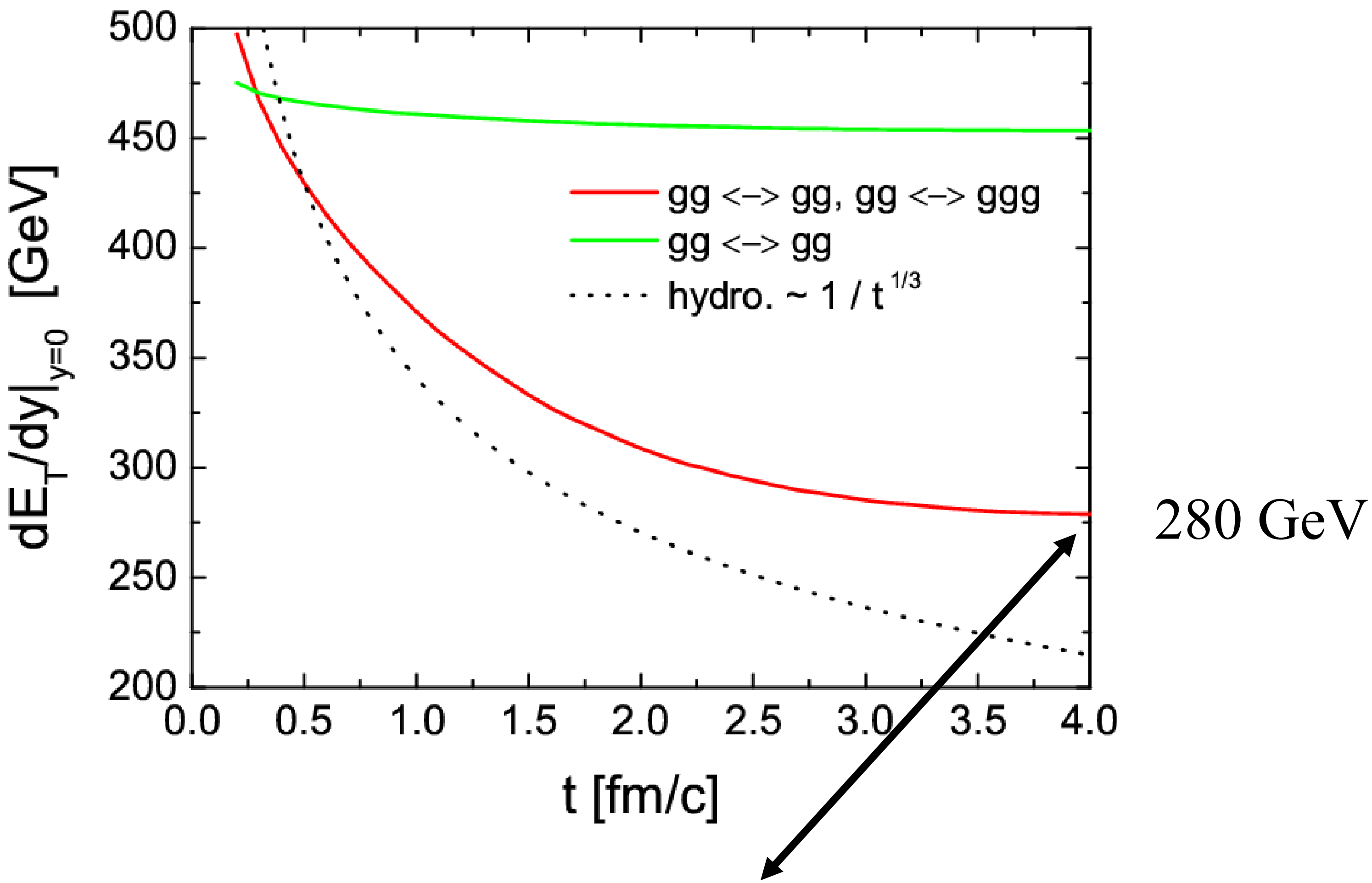


transport cross section:

$$\sigma_t = \int d\sigma \sin^2\theta_{cm}$$

The inelastic collisions are the dominant processes to drive the system to kinetic equilibrium.

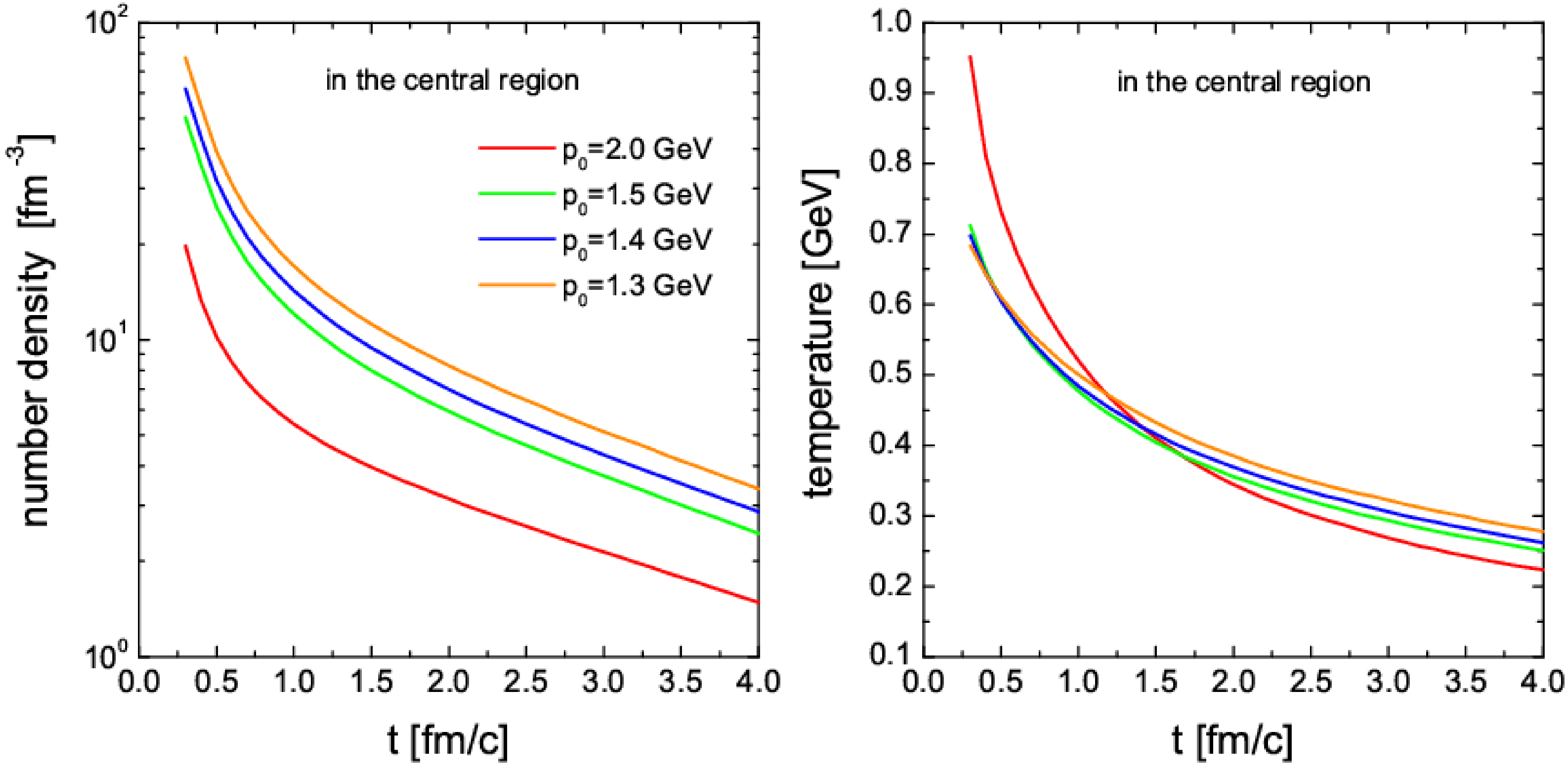
transverse energy at y=0



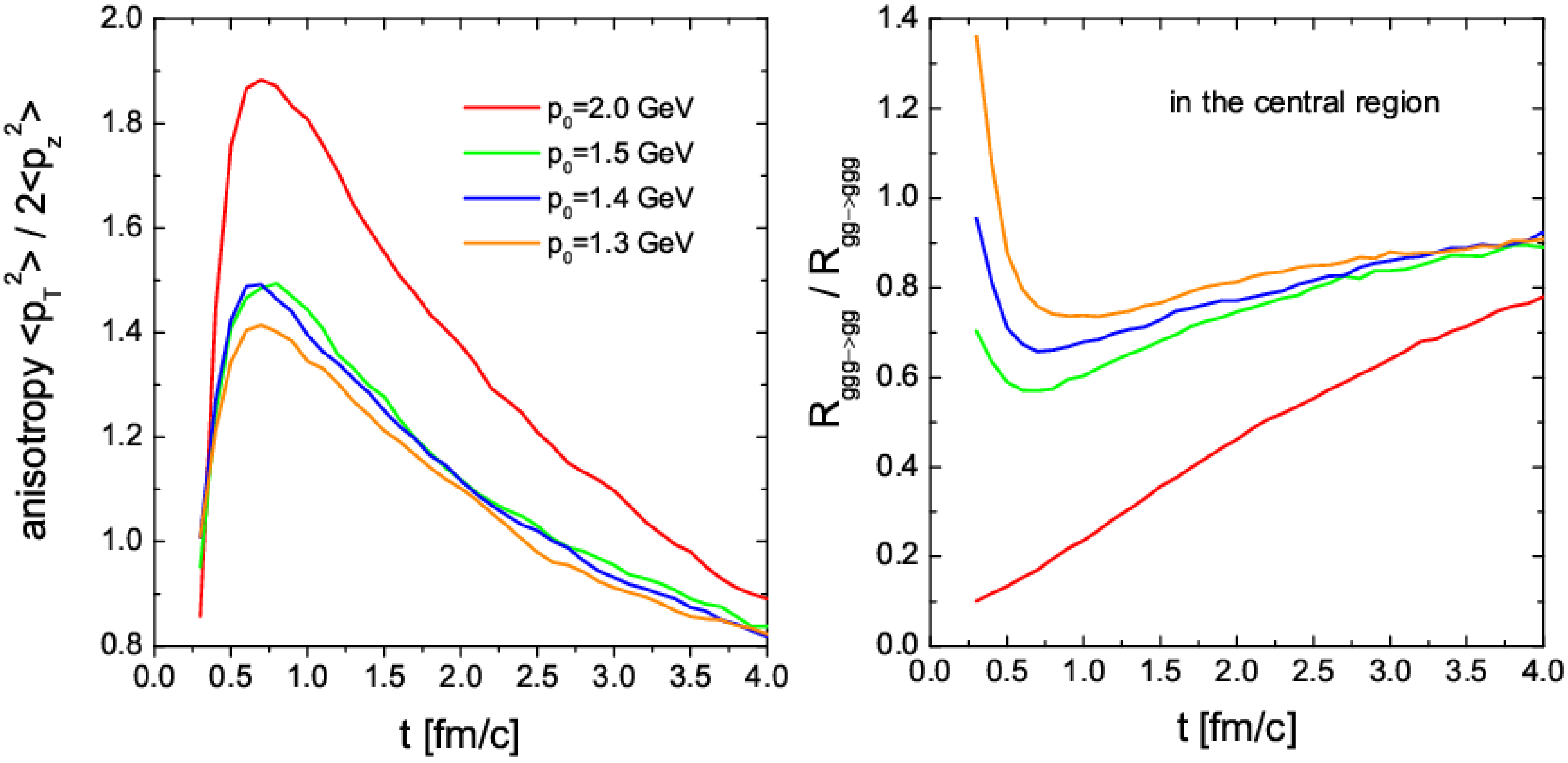
experimental data: $\frac{dE_T}{dy}|_{y=0} = 620 \pm 33\ GeV$ STAR

Initial conditions with smaller p_0

in the central region: η: [-0.5:0.5] and x_t < 1.5 fm



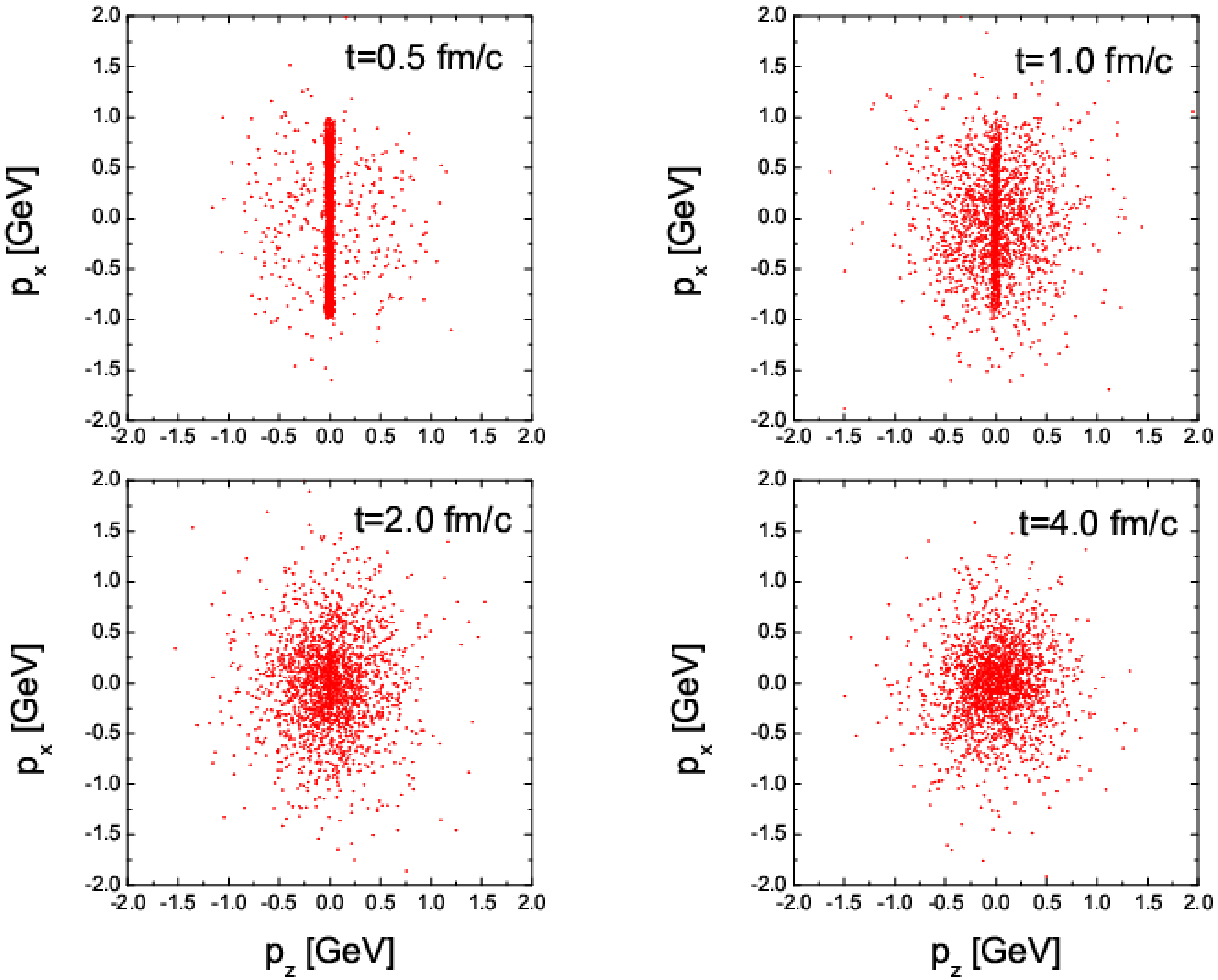
Kinetic and chemical equilibration



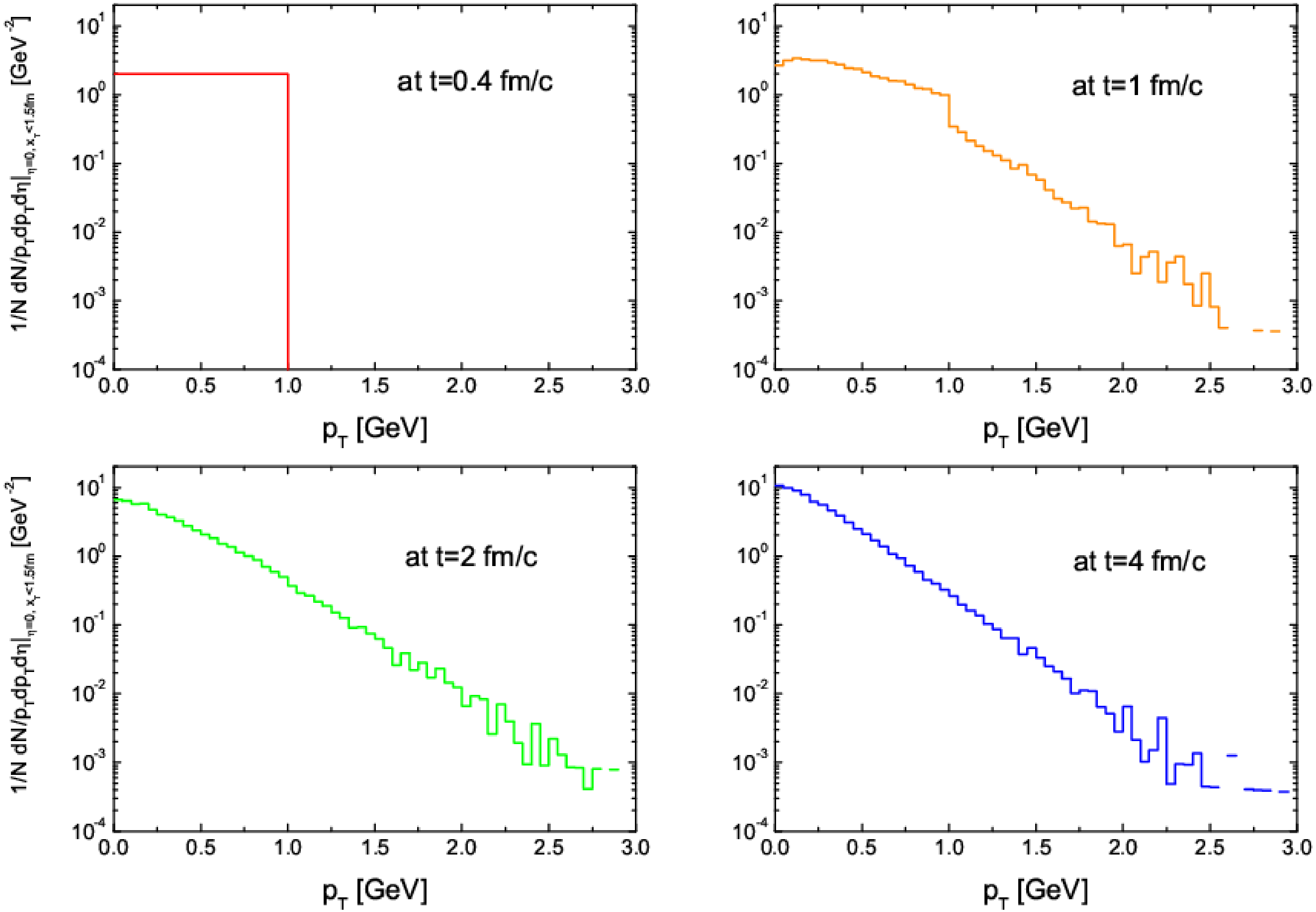
Initial condition with Color Glass Condensate

$$f(x,p) \sim \delta(p_z)\Theta(Q_s^2 - p_T^2)$$

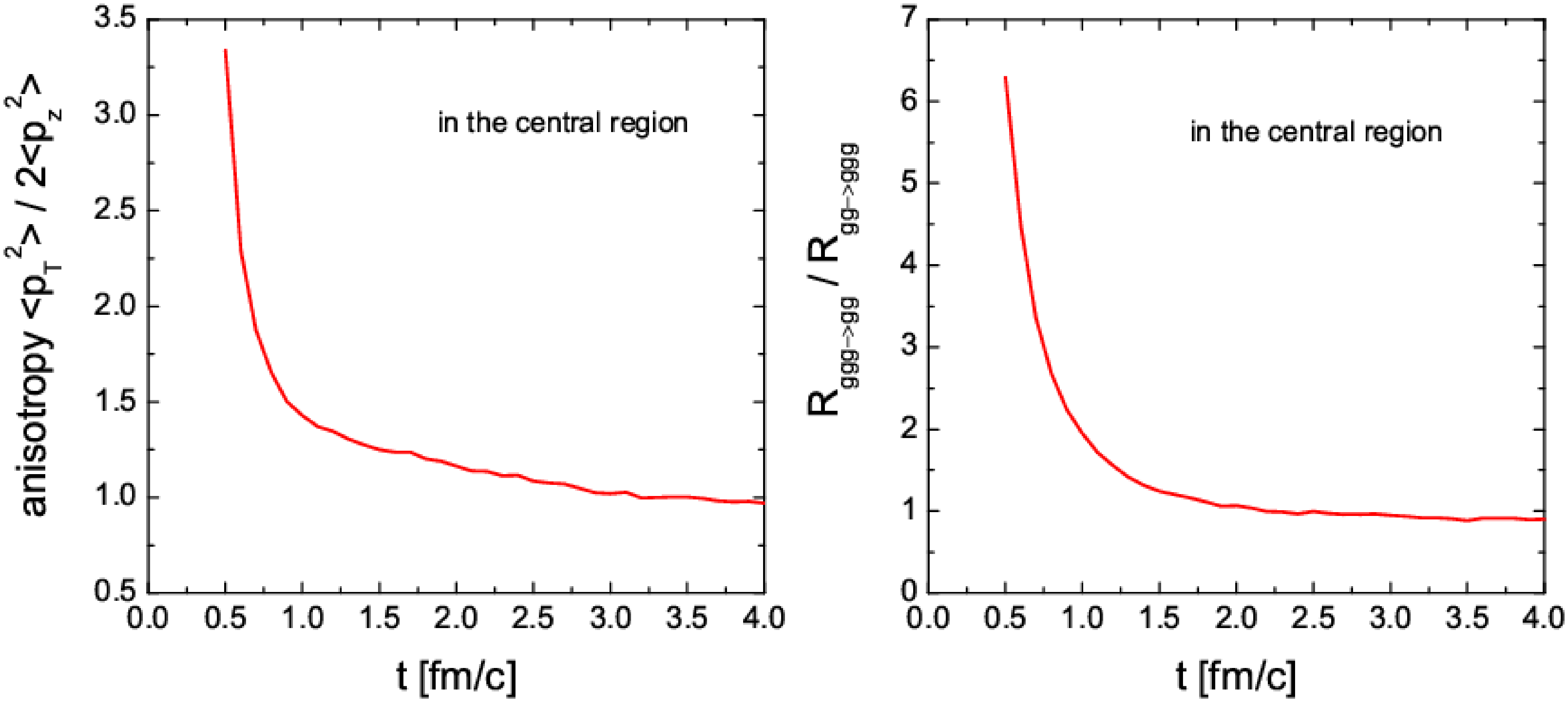
η: [-0.05:0.05] and x_t < 1.5 fm



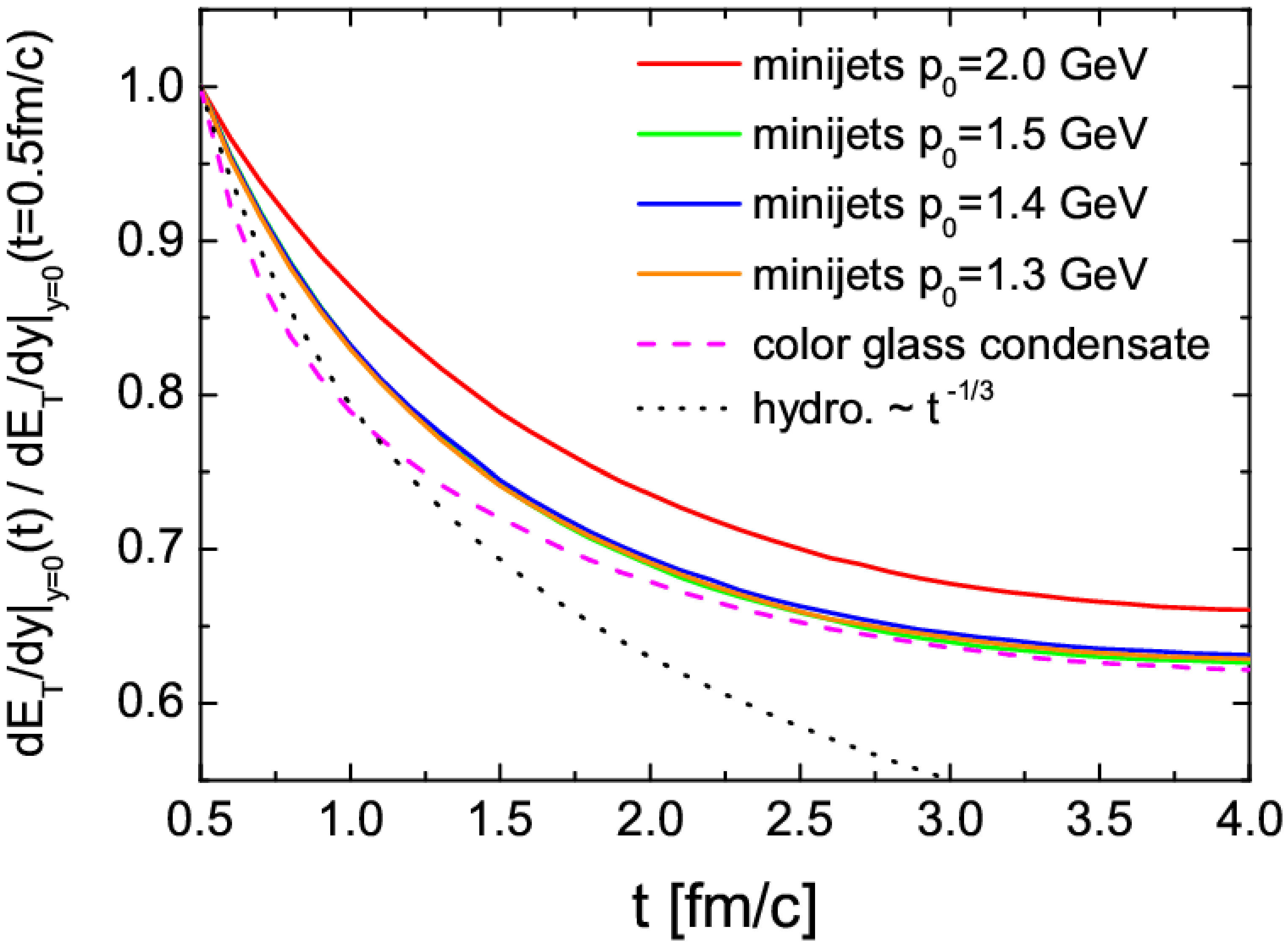
in the central region: η: [-0.5:0.5] and $x_t < 1.5$ fm



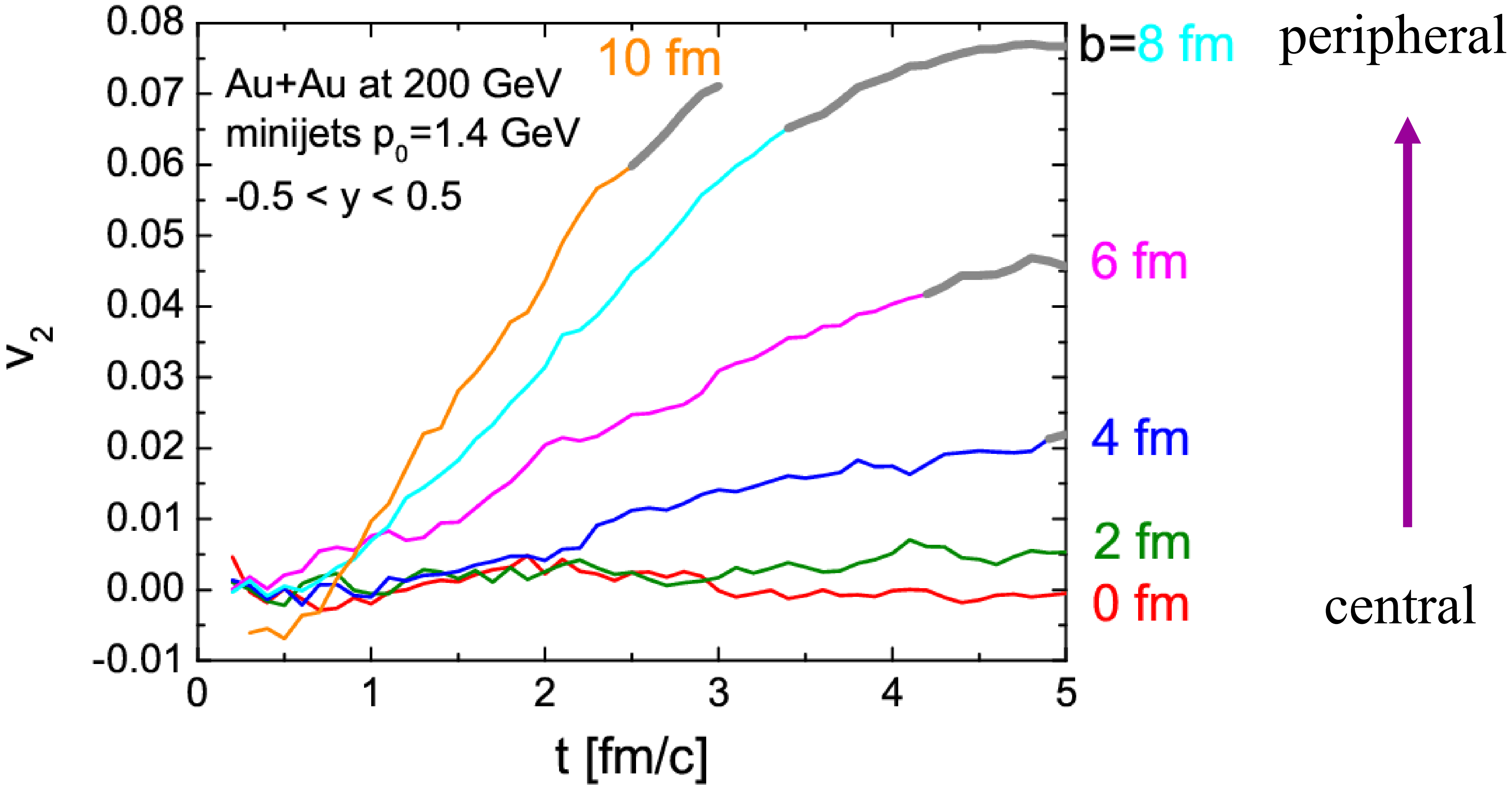
Kinetic and chemical equilibration

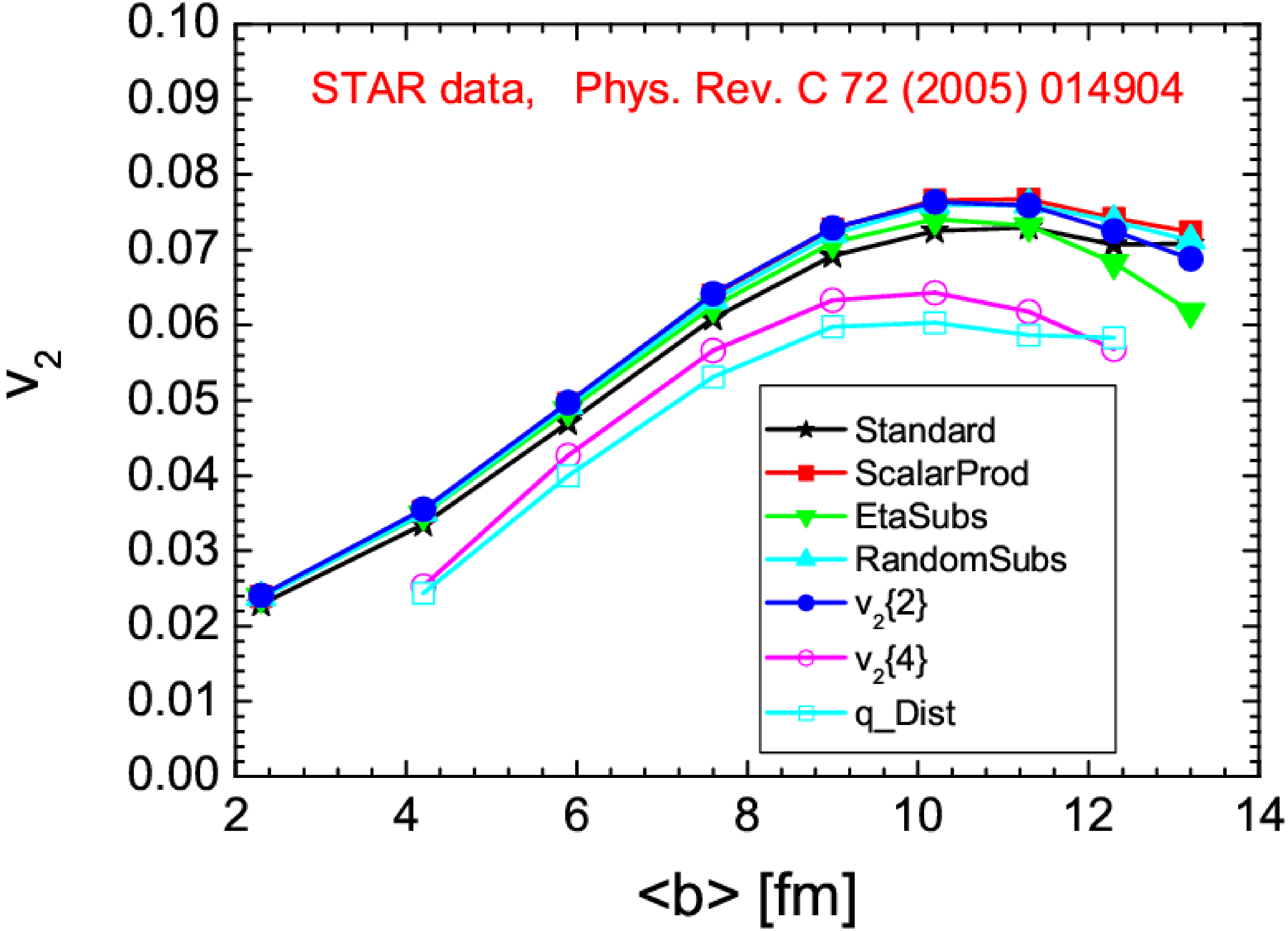


transverse energy at y=0 in Au+Au central collision

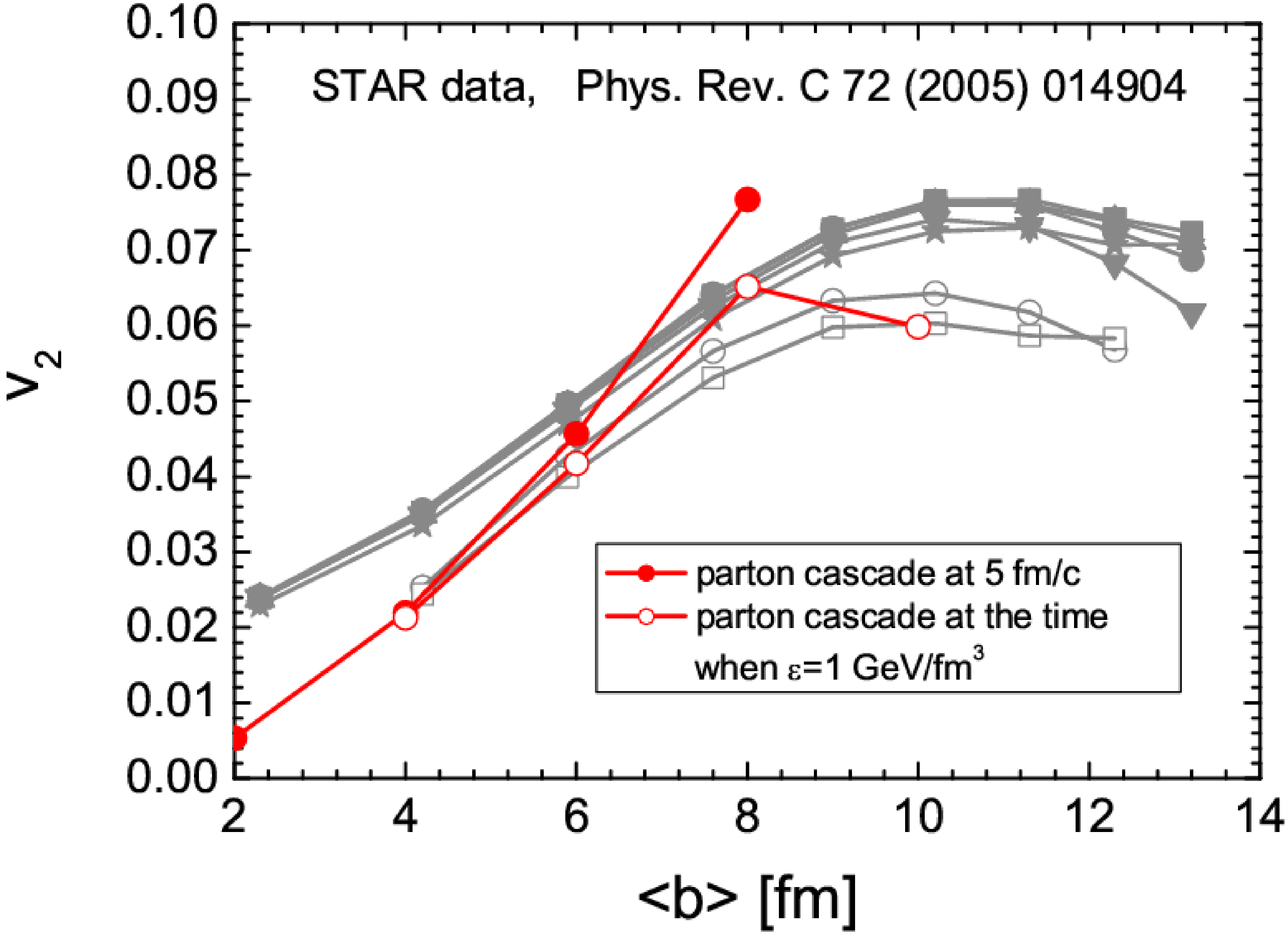


elliptic flow in noncentral Au+Au collisions at RHIC: preliminary results




STAR data, Phys. Rev. C 72 (2005) 014904
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
v_2
2
4
6
8
10
12
14
<b> [fm]
Standard
ScalarProd
EtaSubs
RandomSubs
$v_2\{2\}$
$v_2\{4\}$
q_Dist

Comparison with RHIC data



Summary

- A new parton cascade including inelastic multiparton scatterings gg↔ggg
- Hints of thermalization and hydrodynamical expansion at RHIC
- PQCD gg↔ggg are important for the thermalization.
- PQCD gg↔ggg generate the elliptic flow in noncentral collisions.

Outlook

- viscous hydro.
- bottom-up thermalization with CGC
- including quarks, heavy quark production
- Jet quenching