Initial conditions at RHIC

for hydrodynamics

Yasushi Nara (Akita International Univ.))
Tetsufumi Hirano (Univ. of Tokyo)

- CGC initial conditions, KLN, fKLN, MC-KLN.
- Eccentricity fluctuations within MC-KLN
- Initial fluctuations + hydrodynamics + hadronic cascade results for elliptic flow in Cu+Cu and Au+Au collisions.

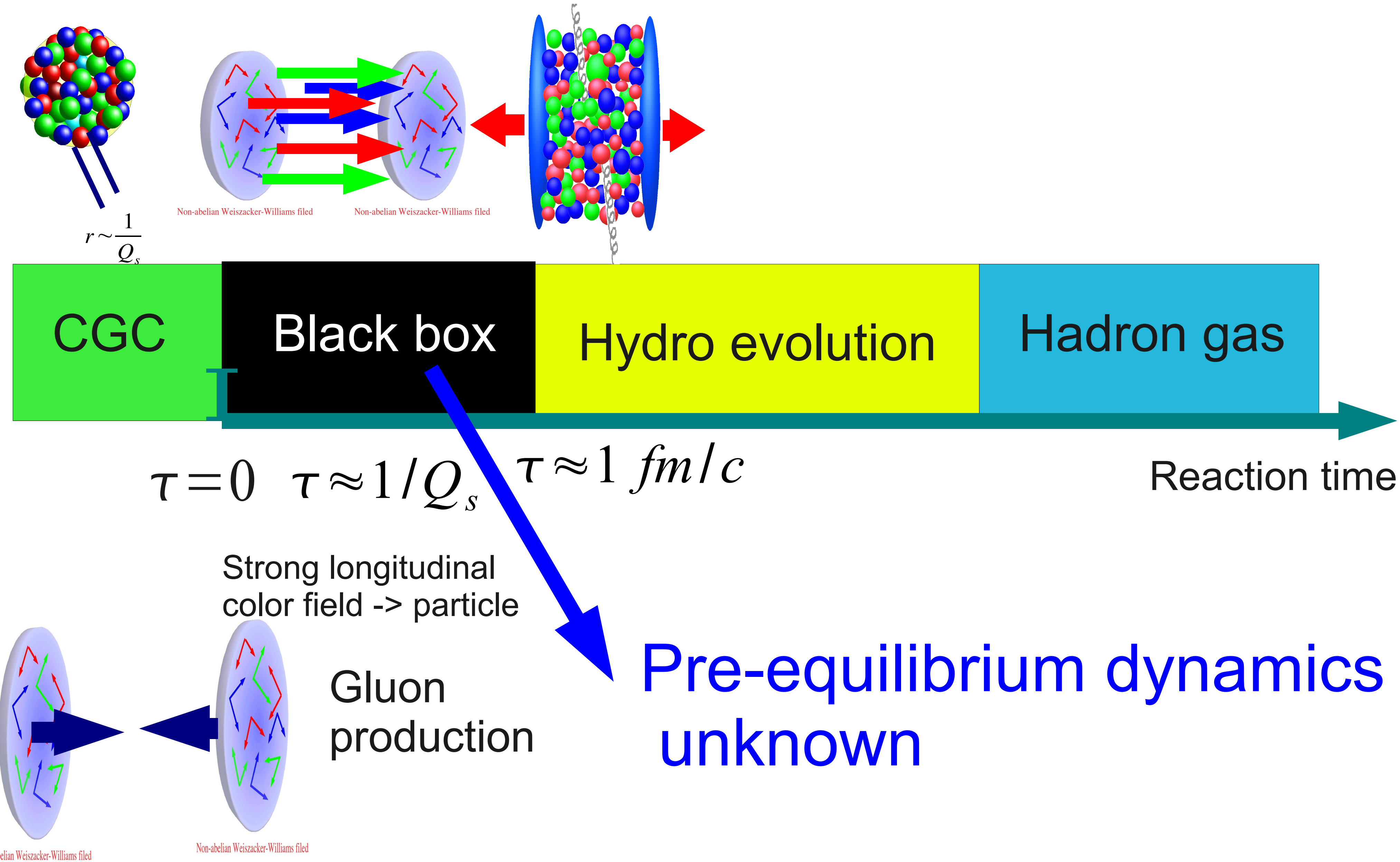
The 2nd Asian Triangle Heavy Ion Conference ATHIC 2008, Tsukuba Oct. 13-15, 2008

Hydrodynamics and inputs

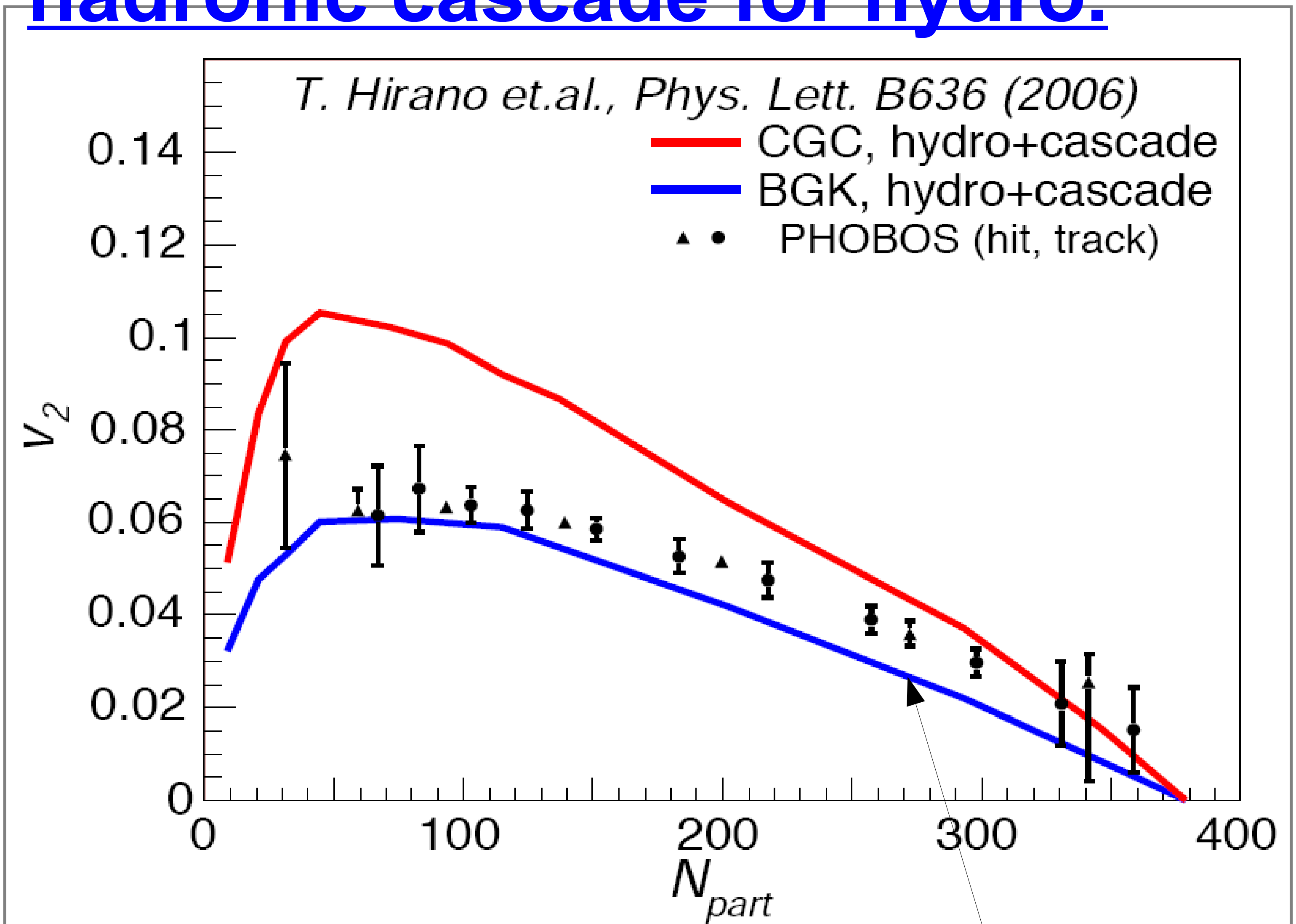
- Initial condition: how to start
  - thermalization time
  - energy density
  - (flow profile)
- Equation of state and dissipative effects: how to evolve
  - ideal gas EoS, lattice QCD
- Freezeout: how to stop
  - Hadron cascade after burner
  - (hadronic dissipative effects)

Purpose: test uncertainties of the initial conditions.

High energy heavy ion collisions



Effects of Initial condition and hadronic cascade for hydro.



Glauber + Ideal hydro + hadronic cascade underestimates

Initial transverse geometry

Glauber model

$$\frac{dN}{d^2 \boldsymbol{x}_\perp dy} \sim N_{part,1}(\boldsymbol{x}_\perp) + N_{part,2}(\boldsymbol{x}_\perp)$$

Initial energy density or entropy is taken from Wounded nucleon model:

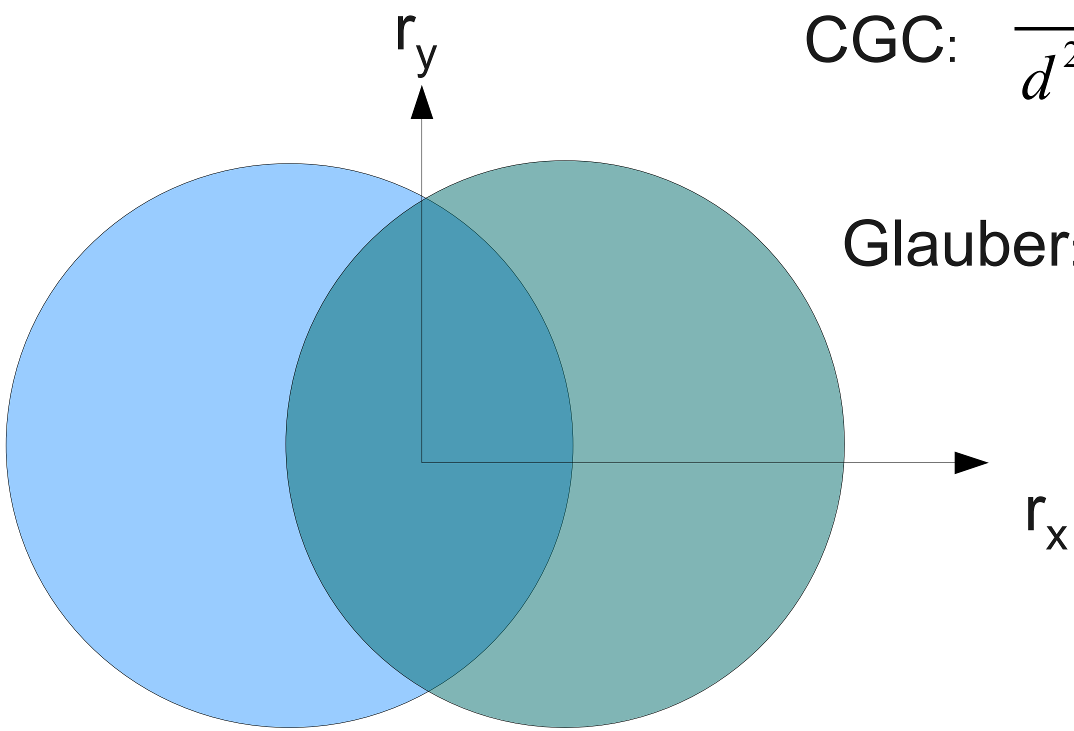
number of participants or collision scaling.

Color Glass Condensate (KLN)

$$\frac{dN_g}{d^2 x_t dy} = \frac{4\pi N_c}{N_c^2 - 1} \int \frac{d^2 p_t}{p_t^2} \int d^2 k_t \alpha_s \phi(x_{1,} k_t^2) \phi(x_{2,} (p_t - k_t)^2)$$

$$\frac{dN}{d^2 \boldsymbol{x}_\perp dy} \sim \min\{Q_{s,1}^2(\boldsymbol{x}_\perp), Q_{s,2}^2(\boldsymbol{x}_\perp)\} \sim \min\{N_{part,1}(\boldsymbol{x}_\perp), N_{part,2}(\boldsymbol{x}_\perp)\}$$

Why large eccentricity in KLN?

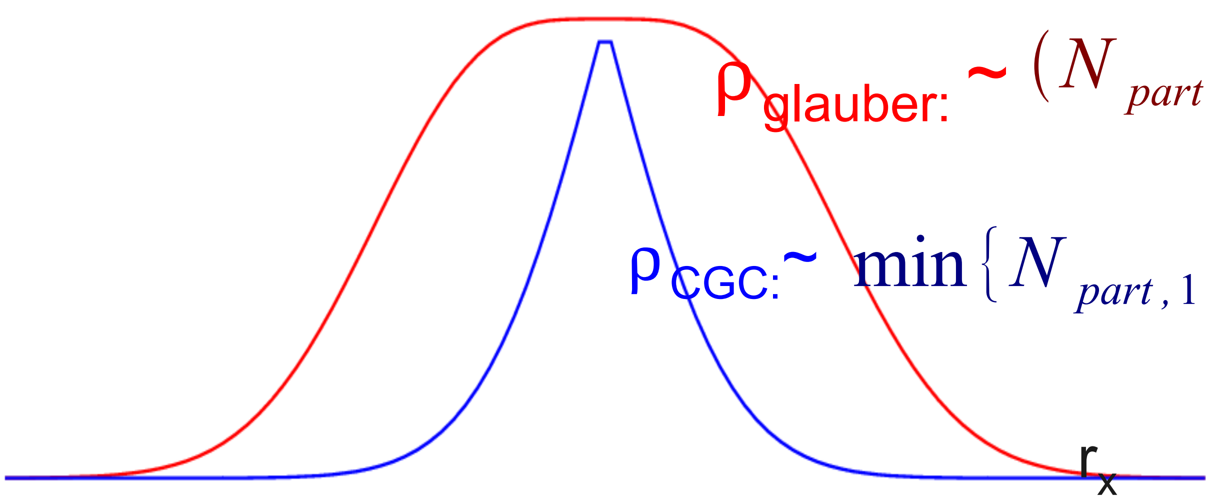


CGC: $$\frac{dN}{d^2 \boldsymbol{x}_\perp dy} \sim \min\{N_{part,1}(\boldsymbol{x}_\perp), N_{part,2}(\boldsymbol{x}_\perp)\}$$

Glauber: $$\frac{dN}{d^2 \boldsymbol{x}_\perp dy} \sim N_{part,1}(\boldsymbol{x}_\perp) + N_{part,2}(\boldsymbol{x}_\perp)$$

$$\rho_{\mathrm{Glauber}}(0, r_y) \sim \rho_{\mathrm{CGC}}(0, r_y)$$

$$\rho_{\mathrm{Glauber}}(r_x, 0) > \rho_{\mathrm{CGC}}(r_x, 0)$$



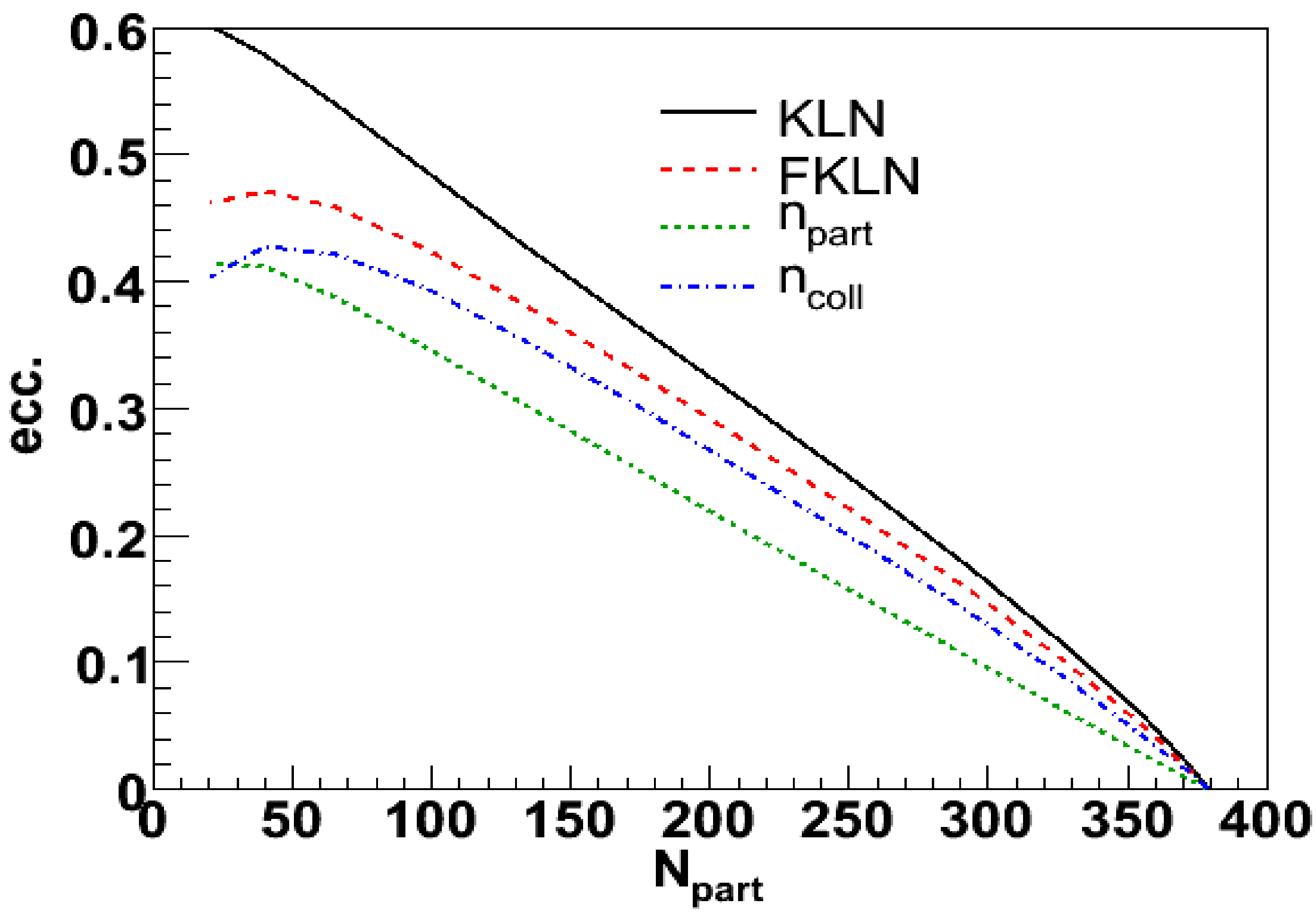
$\rho_{\text{glauber:}} \sim (N_{part,1}(r_x, 0) + N_{part,2}(r_x, 0))$

$\rho_{\text{CGC:}} \sim \min\{N_{part,1}(r_x, 0), N_{part,2}(r_x, 0)\}$

$\rightarrow$ $\epsilon_{CGC} > \epsilon_{Glauber}$

Eccentricity from KLN and fKLN

$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle x^2 + y^2 \rangle}$$

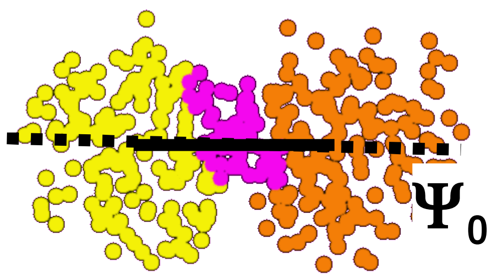


fKLN: Correct treatment of surface of nucleus: minimum saturation scale is set to the saturation scale of nucleon.

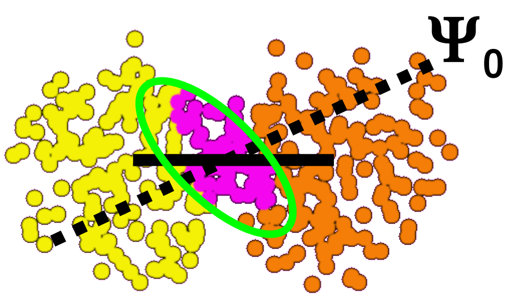
Eccentricity fluctuations

Event-by-event fluctuations in the shape of the initial collision zone for small systems or small transverse overlap regions may be important.

Specifically fluctuations in the nucleon positions.



$$\epsilon_{\mathrm{std}} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

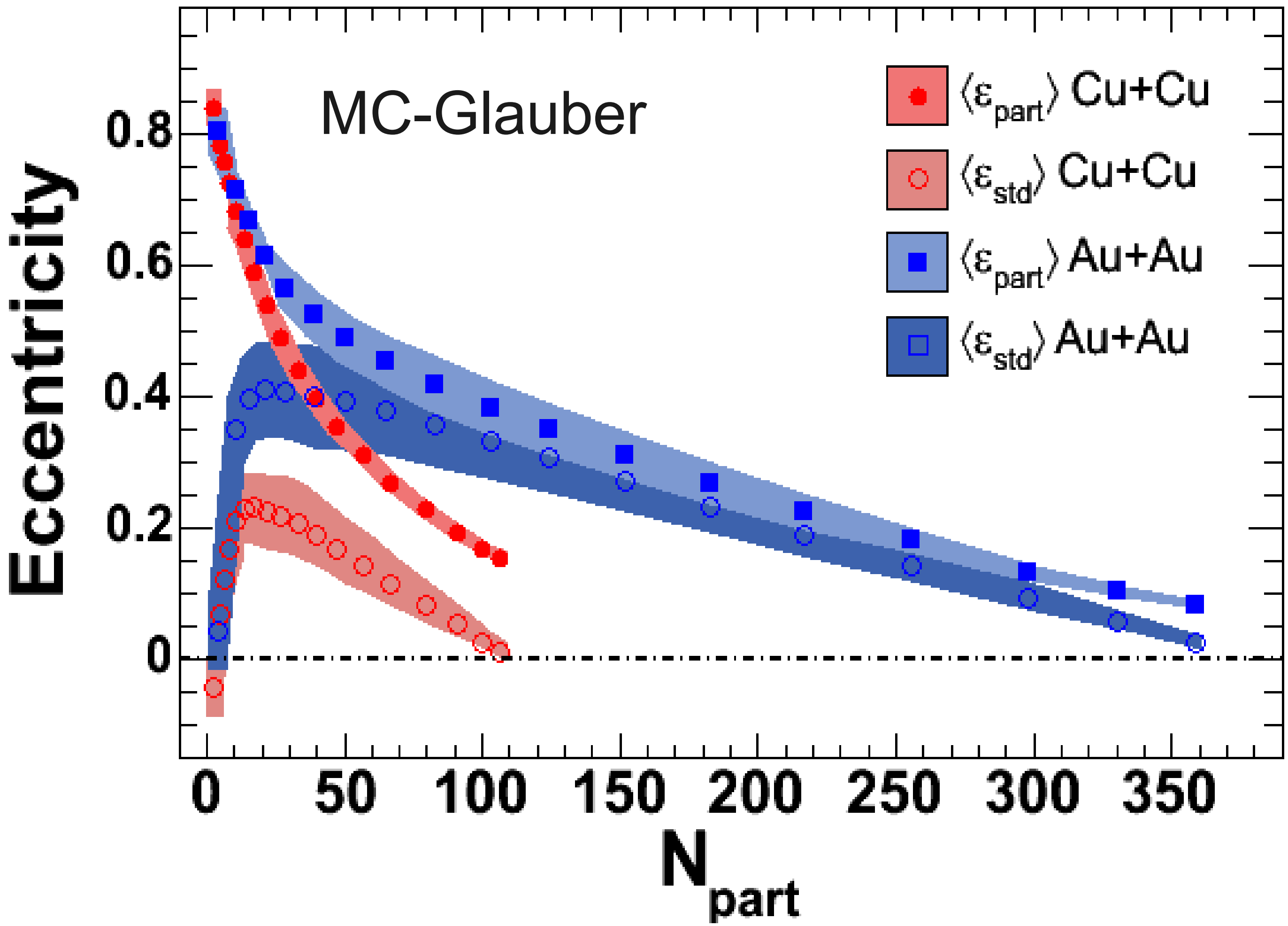


$$\langle \epsilon_{\mathrm{part}} \rangle = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\,\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$

$$\sigma_x^2 = \langle x^2 \rangle - \langle x \rangle^2,\ \ \sigma_y^2 = \langle y^2 \rangle - \langle y \rangle^2,\ \ \sigma_{xy}^2 = \langle xy \rangle - \langle y \rangle \langle x \rangle$$

R.S.Hollis (PHOBOS) nucl-ex0707.0125

Eccentricity is large



ε was underestimated in early hydro calculations: it is increased by fluctuations in the positions of nucleons within the nucleus.

Monte-Carlo version of KLN (MC-KLN)

- Sample A and B nucleons according to the Woods-Saxon distribution.
- Local density of nucleons is obtained by

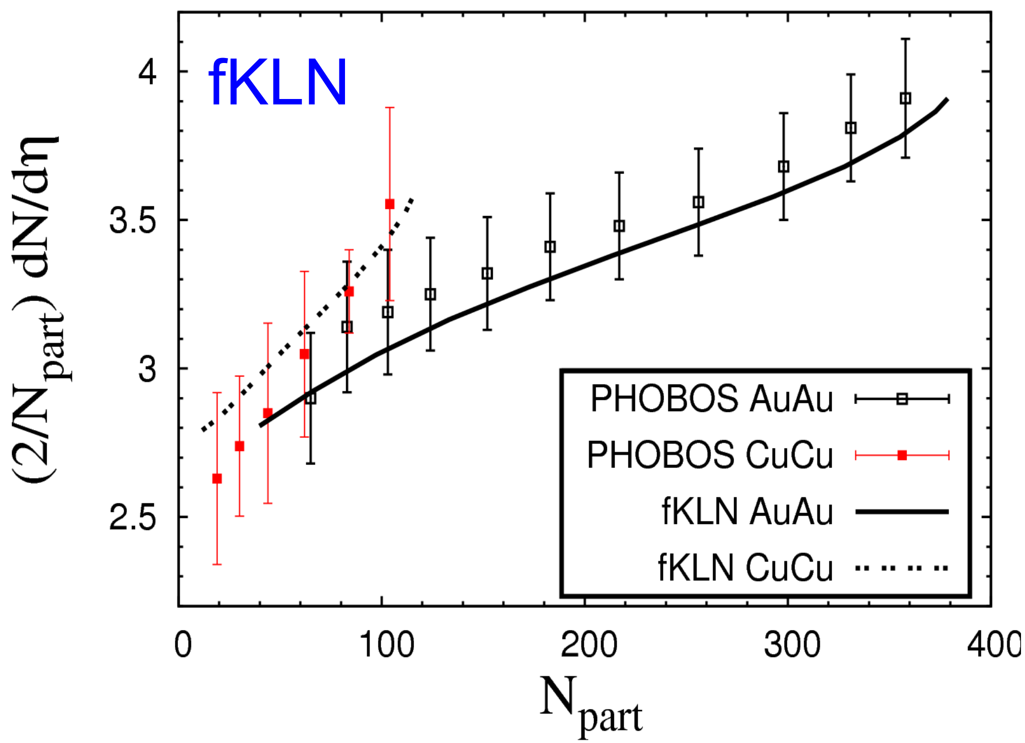
$$t_A(r_\perp) = \frac{number\, of\, nucleons}{S}$$

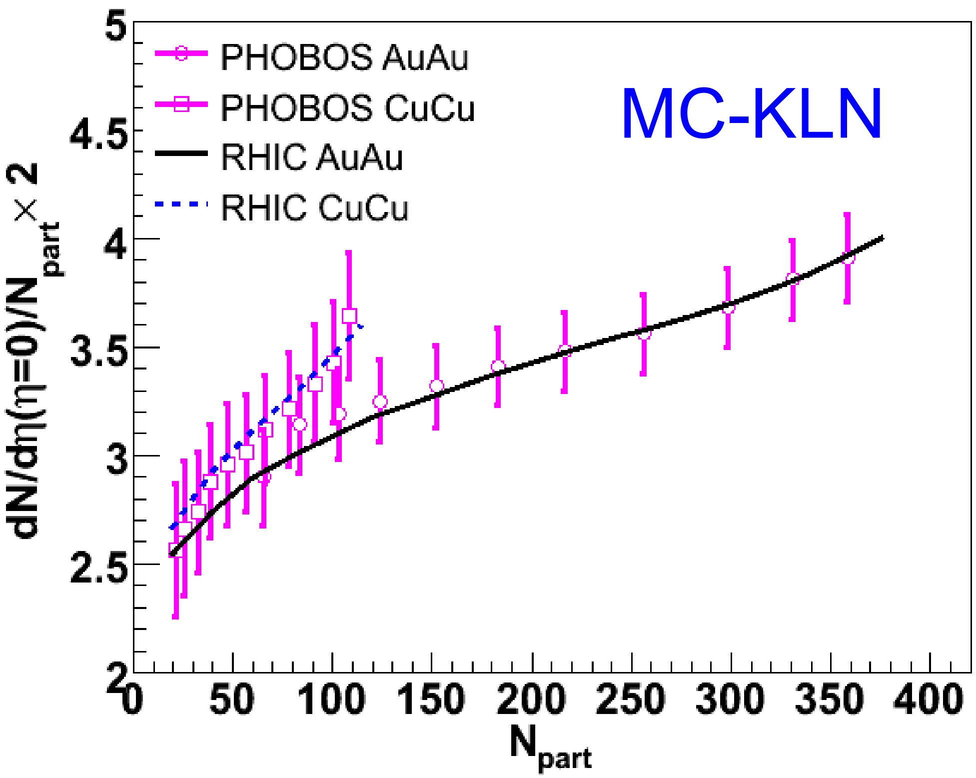
- Saturation scale at a given transverse coordinate is given by

$$Q^2_{s,A}(r_\perp) = 2\mathrm{GeV}^2 \left(\frac{t_A(r_\perp)}{1.53} \right) \left(\frac{0.01}{x} \right)^\lambda$$

- For each generated configuration, we apply the k_t-factorization formula at each transverse coordinate.
- Average over many events.

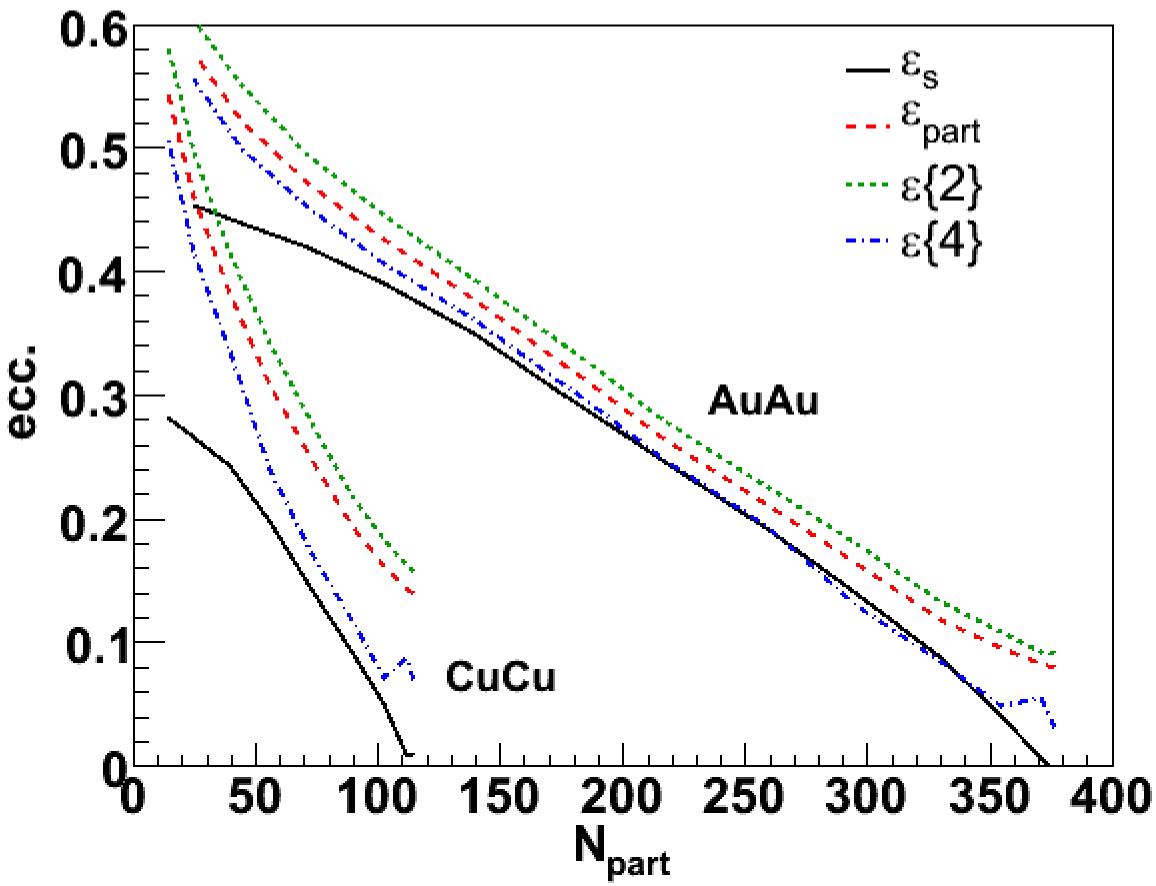
Comparison of Multiplicities in Au+Au and Cu+Cu collisions





Better fit when fluctuations are included.

Eccentricity Fluctuations from MC-KLN



$$\varepsilon_{part} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$

$$\sigma_{xy} = \langle xy \rangle - \langle x \rangle \langle y \rangle$$

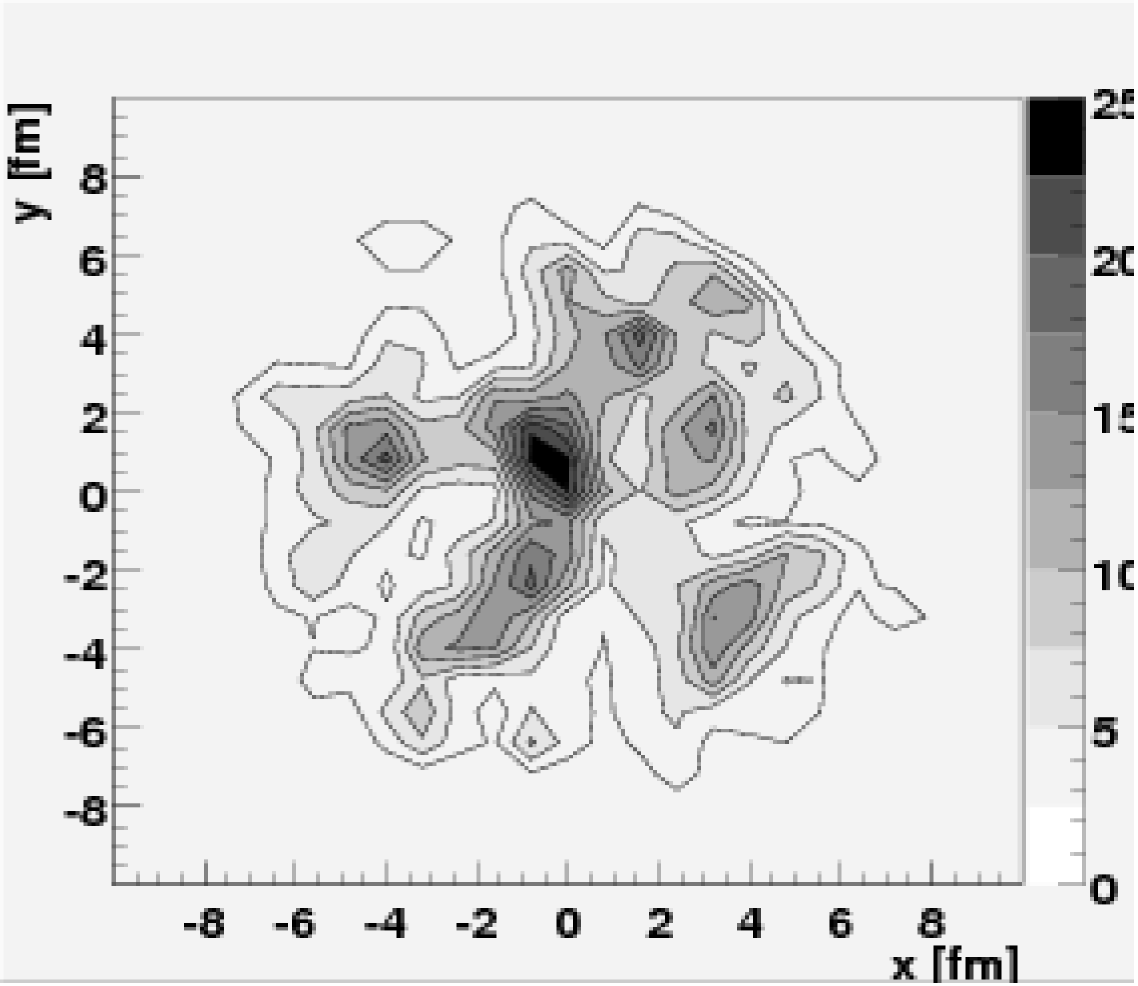
$$\sigma_x^2 = \langle x^2 \rangle - \langle x \rangle^2$$

$$\varepsilon\{2\} = \sqrt{\langle \varepsilon_{part}^2 \rangle}$$

$$\varepsilon\{4\} = (2\langle \varepsilon_{part}^2 \rangle^2 - \langle \varepsilon_{part}^4 \rangle)^{1/4}$$

event-by-event fluctuations in hydro?

Y. Hama, R. Peterson, G. Andrade, F. Grassi, W.Qian, T. Osada, C. Aguiar, T. Kodama

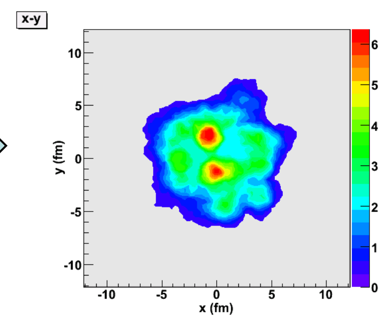


Initial condition for Au+Au
from NeXus

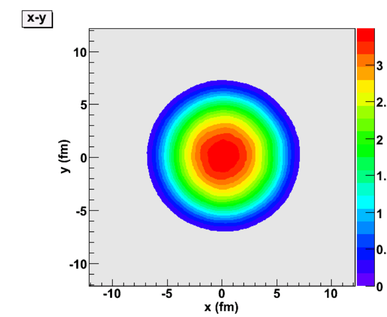
H. J. Drescher, F. M. Liu, S. Ostapchenko1, T. Pierog, and K. Werner, Phys. Rev. C 65, 054902 (2002)

Initial Condition with an Effect of Eccentricity Fluctuation

Throw a dice to choose b:
$b_{min} < b < b_{max}$

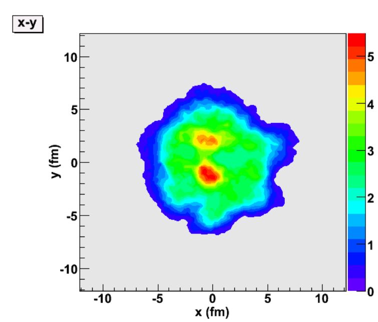


average over events

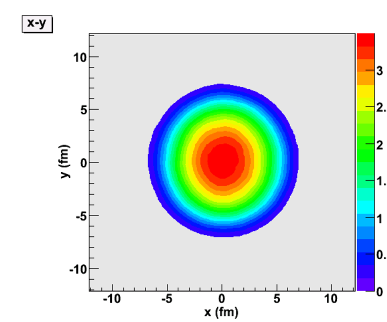


Rotate to real reaction plane

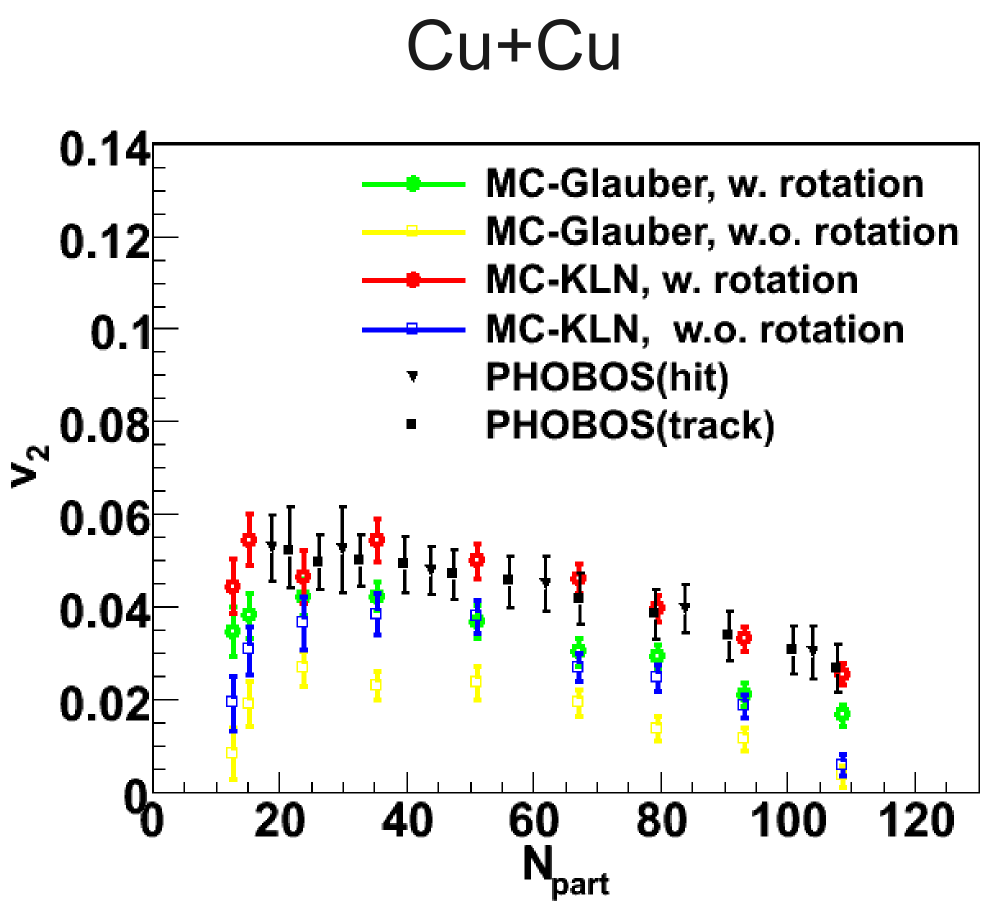
E.g.)
b_{min}= 0.0fm
b_{max}= 3.3fm
in Au+Au collisions at 0-5% centrality

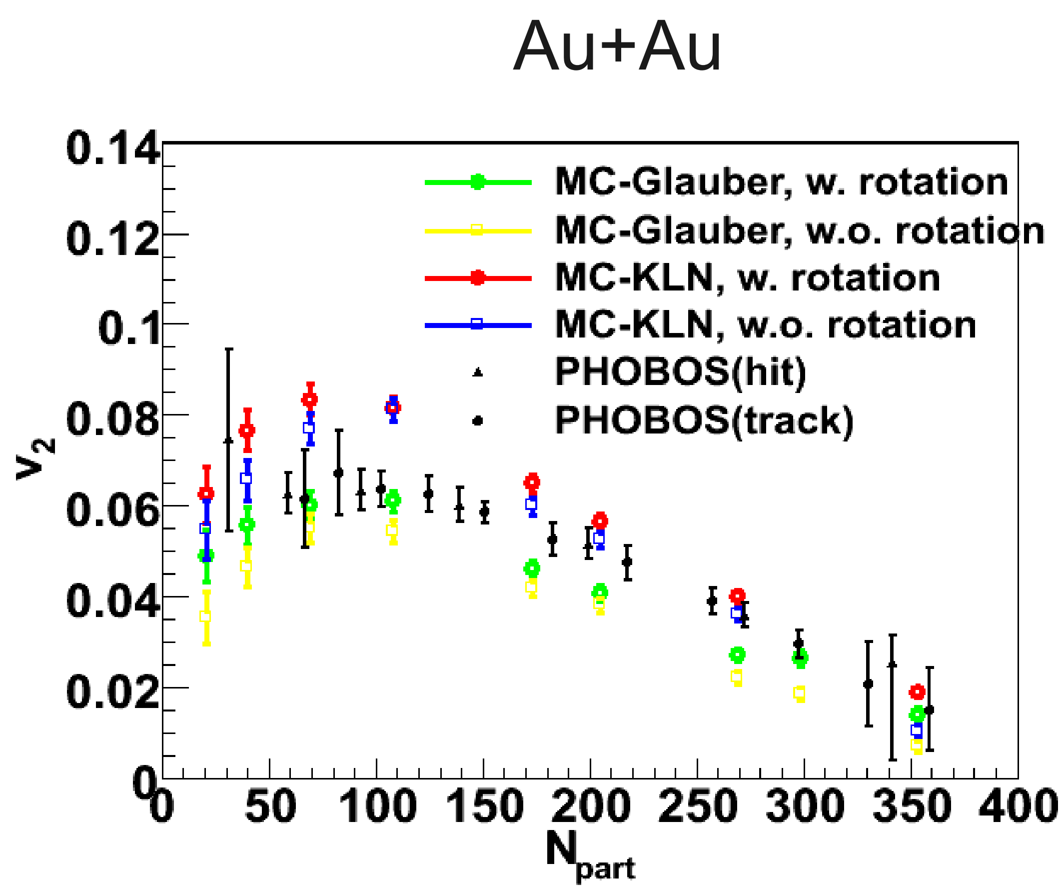


average over events



Initial fluctuations+Hydro+Hadron cascade



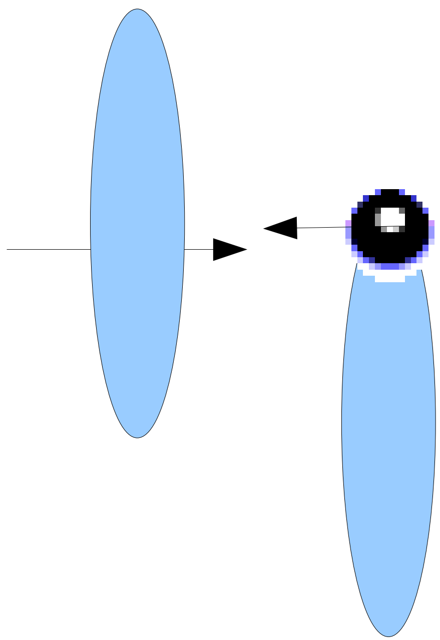


summary

- We presented the results of hydro+hadron cascade with initial eccentricity fluctuations within MC-Glauber and CGC (MC-KLN model).
  - Eccentricity larger and elliptic flow also larger.
  - Explain elliptic flow at central collisions.
  - Glauber initial condition underestimates the elliptic flow data.
  - CGC initial condition slightly overestimates the data.

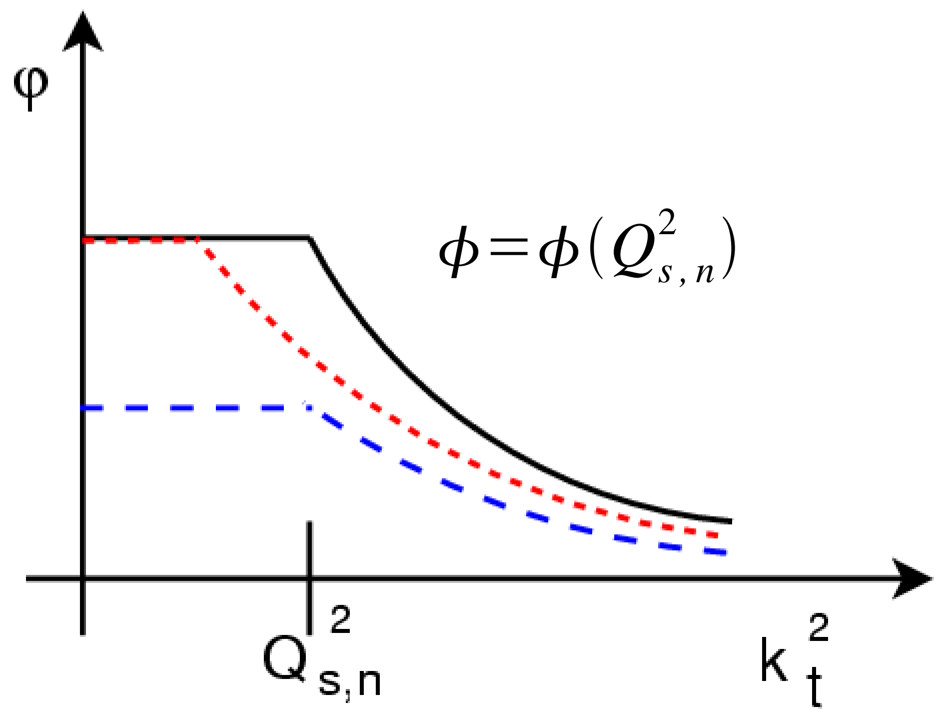
Main uncertainty in this work is the effect of EoS

How to implement universal saturation scale in KLN framework?



$$\phi_A = \phi(p_A Q^2_{s,n})$$

$$\phi_A = p_A \phi(Q^2_{s,n})$$



P_A Probability to find at least one nucleon at a given transverse coordinate.

Saturation scale for nucleon

$$\phi_A = p_A \phi\left(\frac{T_A}{p_A}\right) \qquad T_{1,A} = \frac{\sum_{i\geq 0} p(i) t_A(i)}{\sum_{i\geq 1} p(i)} = \frac{T_A}{p_A}$$

fKLN Ansatz

$$\frac{dN_g}{d^2x_\perp dy} = \frac{4\pi N_c}{N_c^2-1}\int\frac{d^2p_t}{p_t^2}\int d^2k_t \alpha_s p_A p_B \phi(T_A/p_A)\phi(T_B/p_B)$$

$$\frac{dN}{dy}\sim \min\{Q_{s,A}^2, Q_{s,B}^2\}$$

$$\approx\int\frac{d^2p_t}{p_t^2}\int d^2k_t \phi(p_A p_B T_A/p_A)\phi(p_A p_B T_B/p_B)$$

$$=\int\frac{d^2p_t}{p_t^2}\int d^2k_t \phi(n_{part,A})\phi(n_{part,B})$$

Recover original KLN!

If we take $p_A = 1-(1-\sigma_{NN}T_A/A)^A$