CGC initial conditions at RHIC and LHC

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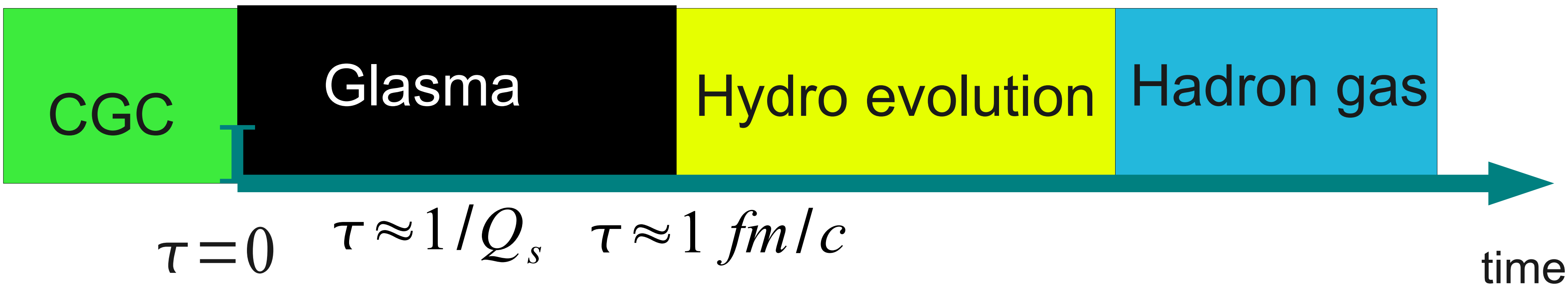
with the collaboration with A. Dumitru

- Monte-Carlo version of KLN (MCKLN)
- Eccentricity from CGC (KLN).
- Monte-Carlo version of kt-factorization with rcBK (MCrcBK)
- impact parameter dependent MCrcBK (bMCrcBK)

27th Winter workshop on nuclear dynamics 6-13 February 2011

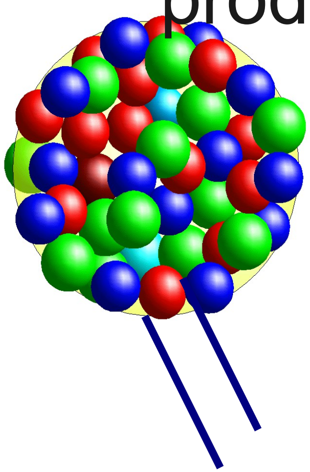
High energy heavy ion collisions



Gluon production

Pre-equilibrium dynamics unknown

How to reach local equilibrium?



$$r \sim \frac{1}{Q_s}$$

Hydrodynamics and inputs

- Initial condition:
  - thermalization time
  - initial energy density
  - (flow profile)
- Equation of state:
  - ideal gas EoS, lattice QCD
- freezeout:
  - Hadron cascade after burner
  - (hadronic dissipative effects)
- Dissipative effects

Purpose: test uncertainties of the initial conditions.

Standard model for the initial transverse density profile

Initial energy density or entropy is taken from Wounded nucleon model:
number of participants or collision scaling.

$$n_{part}(\boldsymbol{x}_\perp, \boldsymbol{b}) = T_A(\boldsymbol{x}_\perp + \boldsymbol{b}/2)\left(1 - \left(1 - \sigma_{NN}^{inel} T_B(\boldsymbol{x}_\perp - \boldsymbol{b}/2)/B\right)^B\right) + T_B(\boldsymbol{x}_\perp - \boldsymbol{b}/2)\left(1 - \left(1 - \sigma_{NN}^{inel} T_A(\boldsymbol{x}_\perp + \boldsymbol{b}/2)/A\right)^A\right)$$

$$n_{coll}(\boldsymbol{x}_\perp, \boldsymbol{b}) = \sigma_{NN}^{inel} T_A(\boldsymbol{x}_\perp + \boldsymbol{b}/2) T_B(\boldsymbol{x}_\perp - \boldsymbol{b}/2)$$

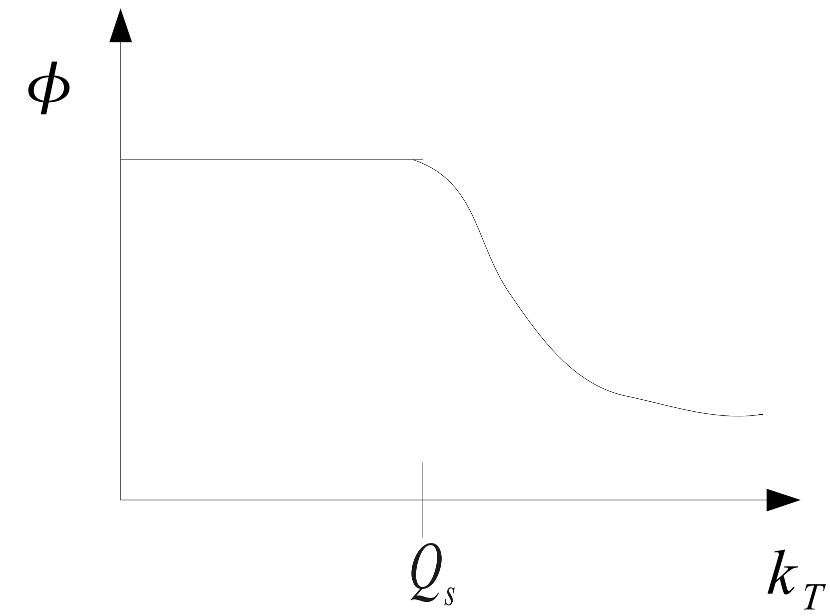
$$T_A(\boldsymbol{x}_\perp) = \int dz\, \rho_A(\boldsymbol{x}_\perp, z) \qquad \rho_A(\boldsymbol{r}) = \frac{\rho_0}{1 + \exp[(r - R_0)/a]}$$

Kt-factorization in the KLN model

Kharzeev, Levin, Nardi

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

$$\phi(x_{1,}k_t^2)\sim\frac{1}{\alpha_s(Q_s^2)}\frac{Q_s^2}{max(Q_s^{2,}k_T^2)}$$



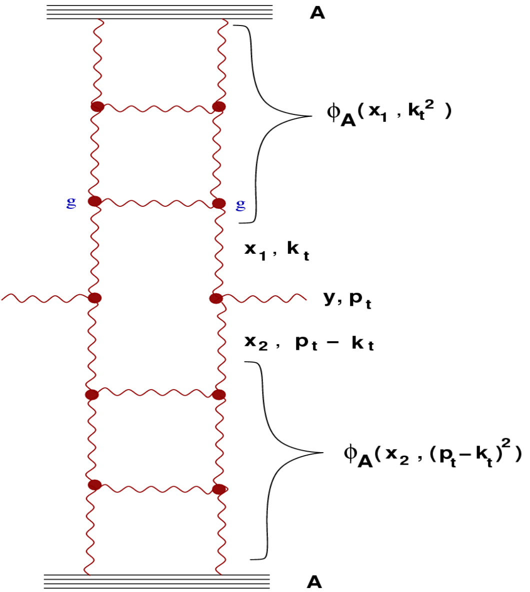
$$Q_s^2\sim 2.0\,\frac{\rho_{part}}{1.53}\left(\frac{0.01}{x}\right)^{\lambda}$$

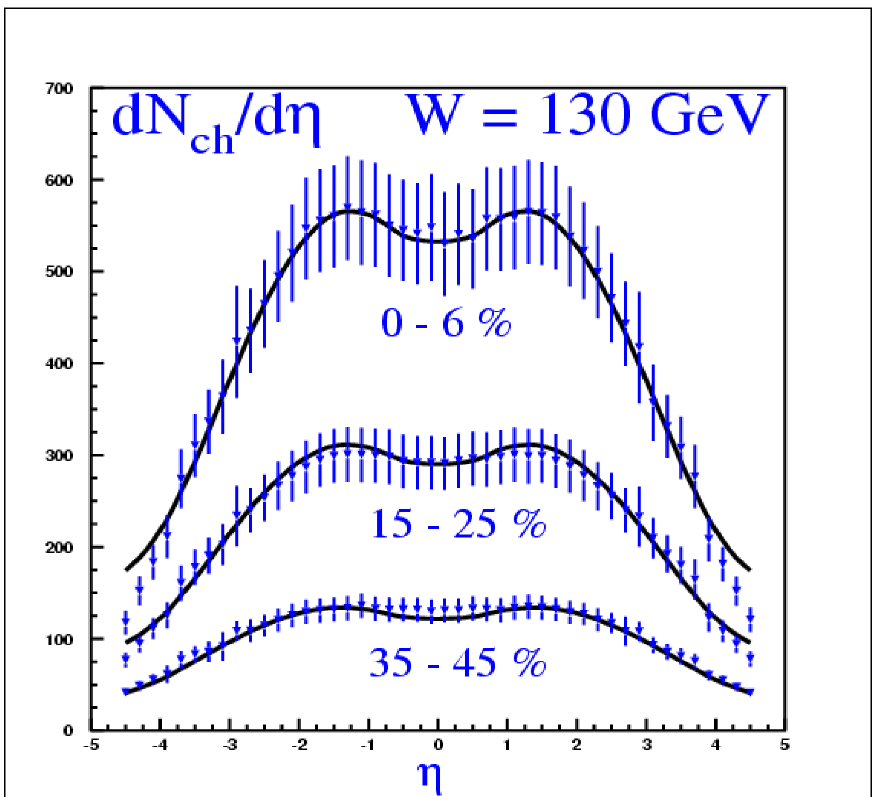
$$\rho_{part}(\boldsymbol{x}_\perp)=T_A(\boldsymbol{x}_\perp+\boldsymbol{b}/2)\left(1-(1-\sigma_{NN}^{inel}T_B(\boldsymbol{x}_\perp-\boldsymbol{b}/2)/B)^B\right)$$

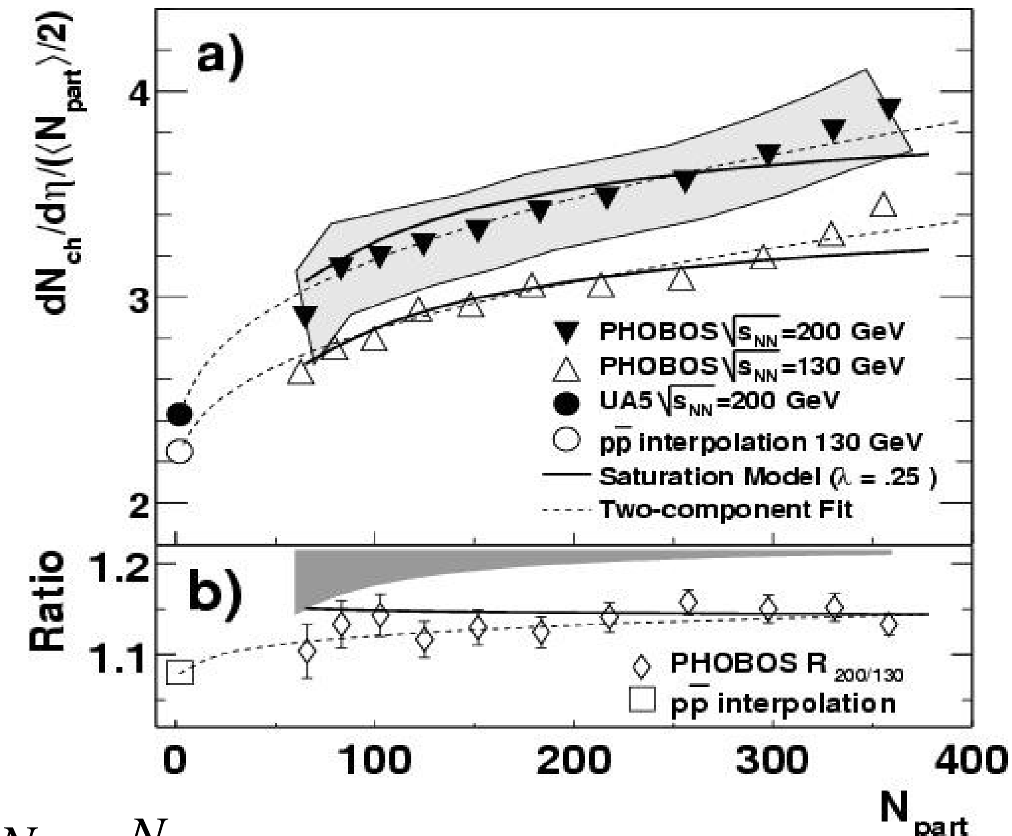
D. Kharzeev, E. Levin, M. Nardi

KLN predictions

Rapidity, centrality and energy dependence







$$\frac{dN}{d\eta} \approx \frac{N_{part}}{\alpha_s(Q_s^2)}$$

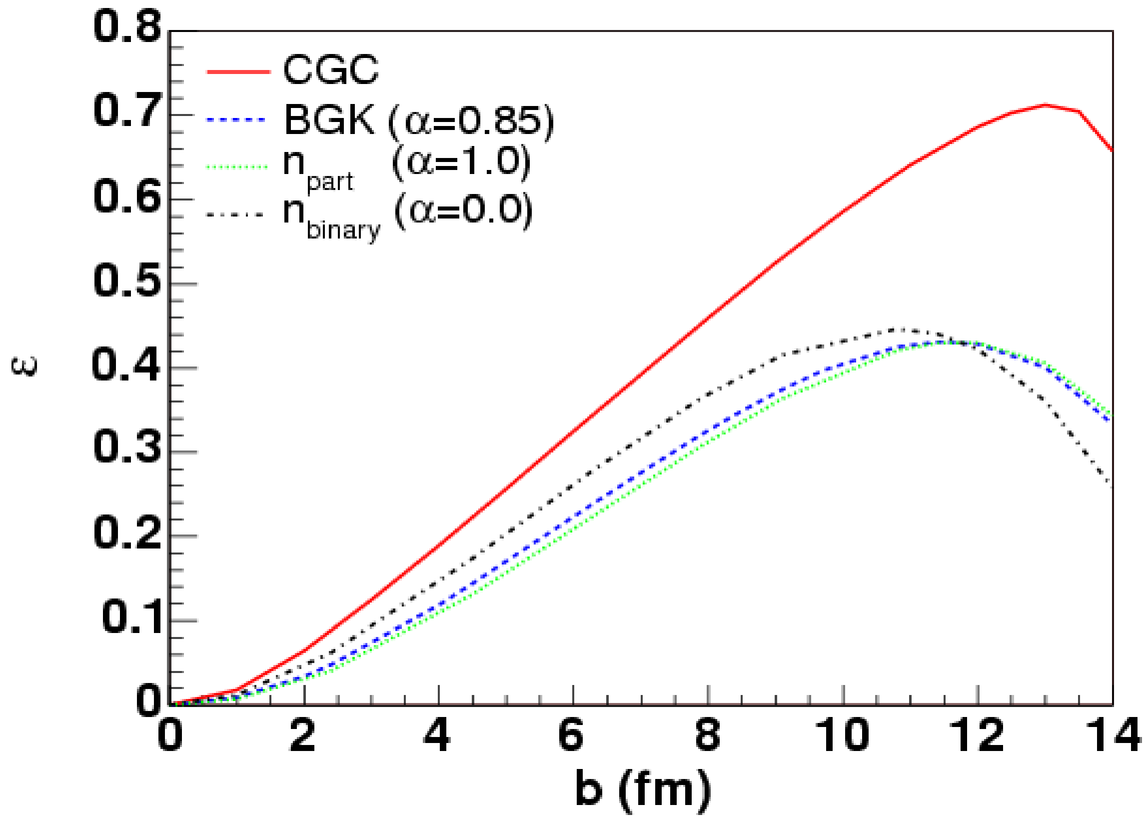
$$x = \frac{Q_s}{\sqrt{s}} \text{ at midrapidity}$$

$$Q_s^2(x) \sim \left(\frac{x_0}{x}\right)^{\lambda}$$

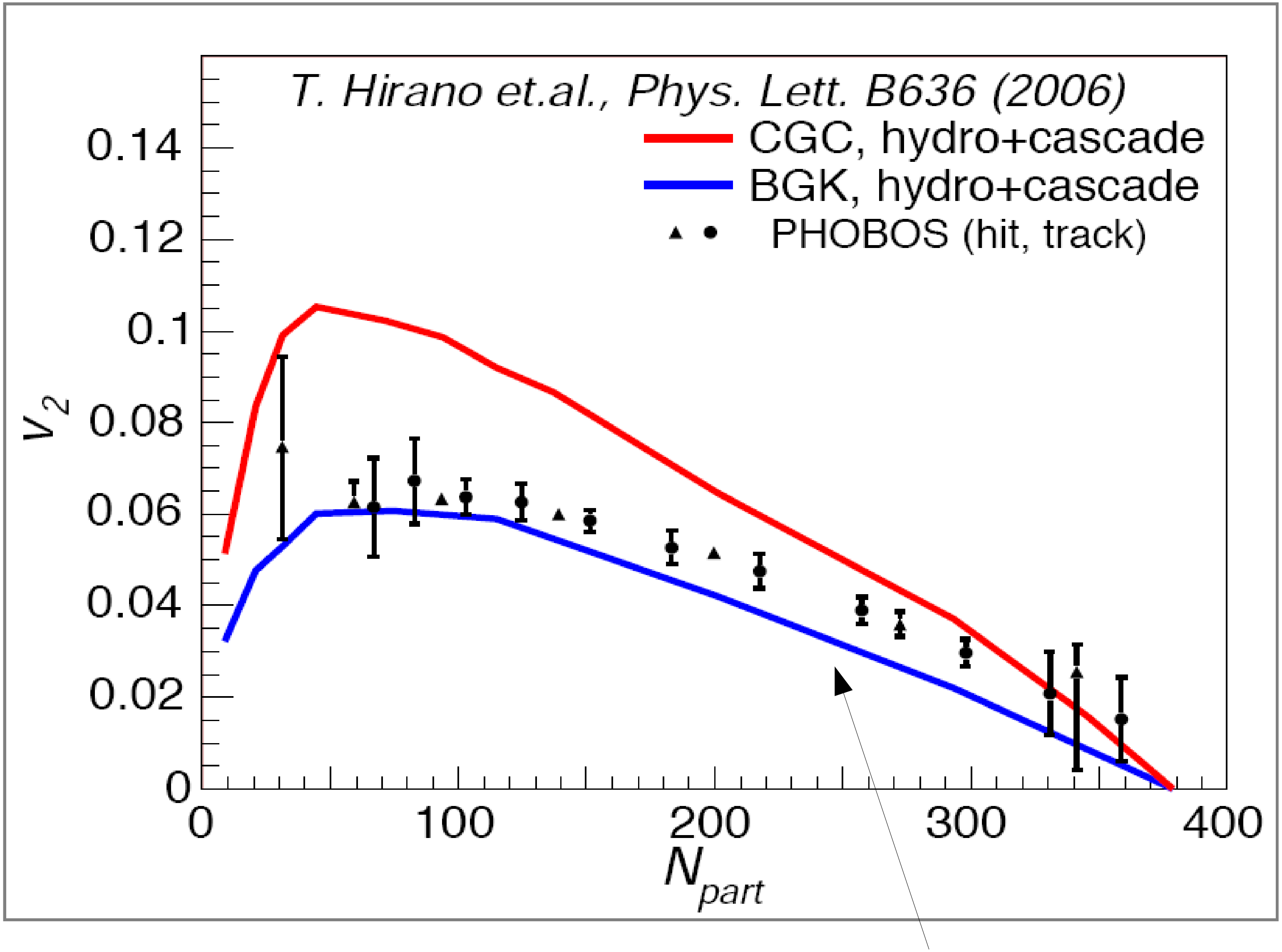
$$Q_s^2 \propto s^{\lambda/2}, \ \lambda \approx 0.25$$

Large v2 in CGC because of $\varepsilon_{CGC} > \varepsilon_{Glauber}$

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



Initial condition for hydro matters.



Glauber + Ideal hydro + hadronic cascade underestimates

Initial transverse geometry

Glauber model

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

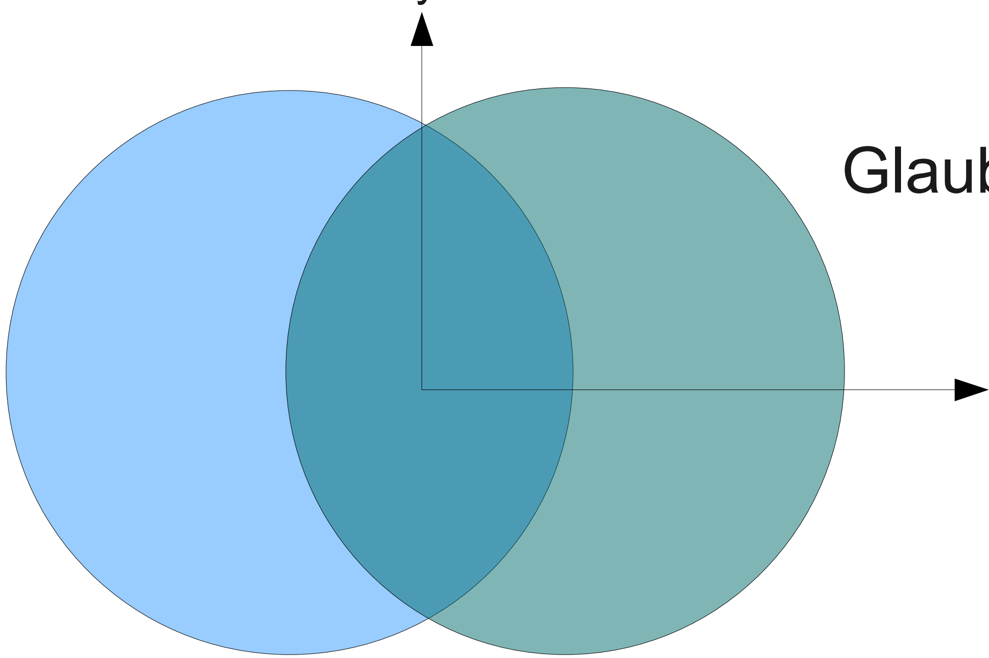
Initial energy density or entropy is taken from Wounded nucleon model:
number of participants or collision scaling.

Color Glass Condensate (KLN)

$$\frac{dN_g}{d^2x_t dy} = \frac{4\pi N_c}{N_c^2-1}\int\frac{d^2p_t}{p_t^2}\int d^2k_t \alpha_s \phi(x_1, k_t^2)\phi(x_2, (p_t-k_t)^2)$$

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

Why large eccentricity in KLN?

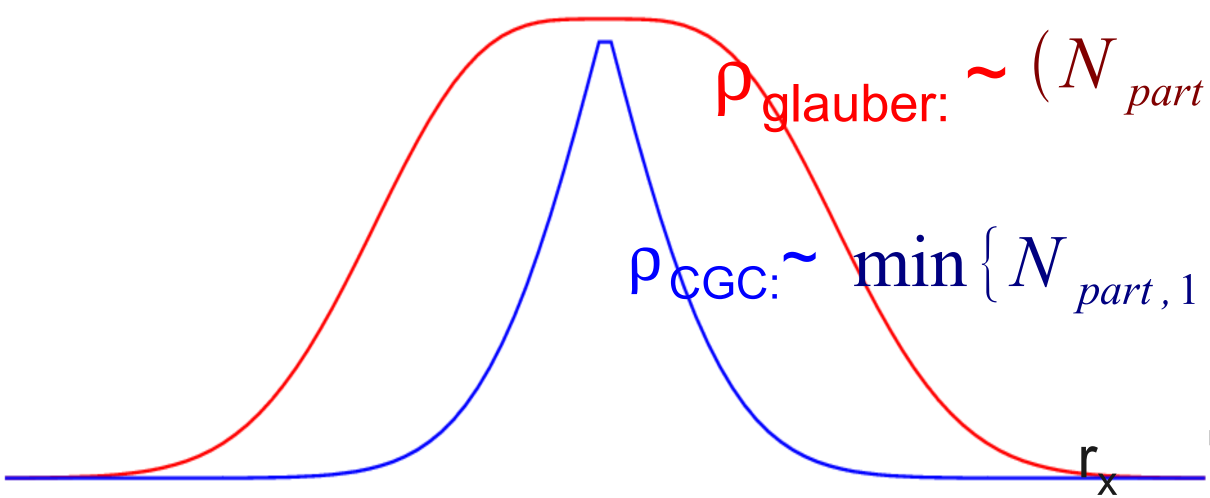


CGC: $$\frac{dN}{d^2 \boldsymbol{x}_\perp dy} \sim \min\{N_{part,1}(\boldsymbol{x}_\perp), N_{part,2}(\boldsymbol{x}_\perp)\}$$

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

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

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

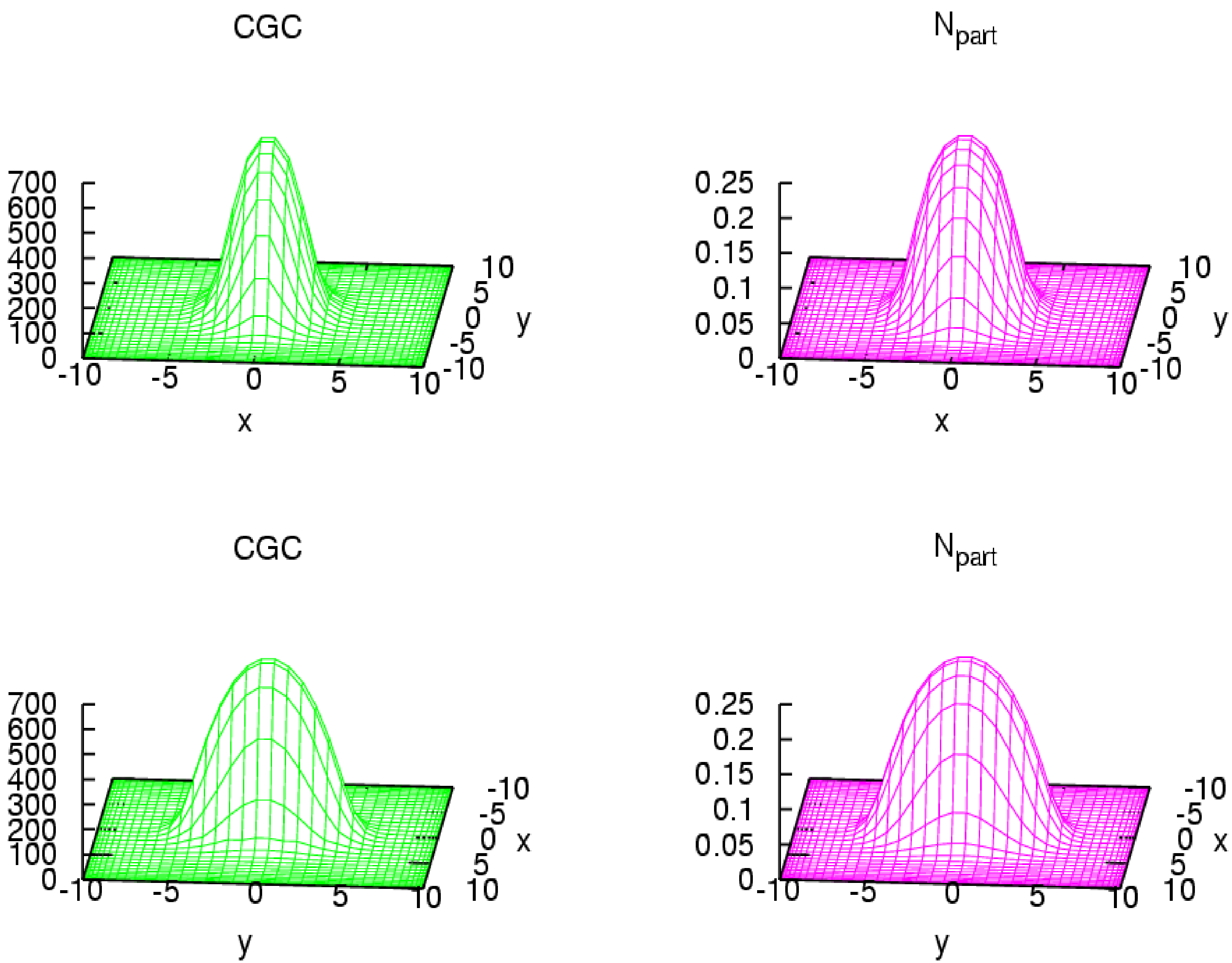


$\rho_{\text{glauber:}} \sim (N_{part,1}(r_x, 0) + N_{part,2}(r_x, 0))$

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

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

Densities for Au+Au b=8fm



Monte-Carlo version of KLN (MC-KLN)

- Sample A and B nucleons according to the Woods-Saxon distribution.
- Nucleon-nucleon collision will occur if $(x_i - x_j)^2 + (y_i - y_j)^2 \leq \frac{\sigma_{NN}}{\pi}$
- Local density of nucleons at each grid is obtained by

$$t_A(\boldsymbol{r}_\perp) = \frac{\text{number of nucleons}}{S}$$

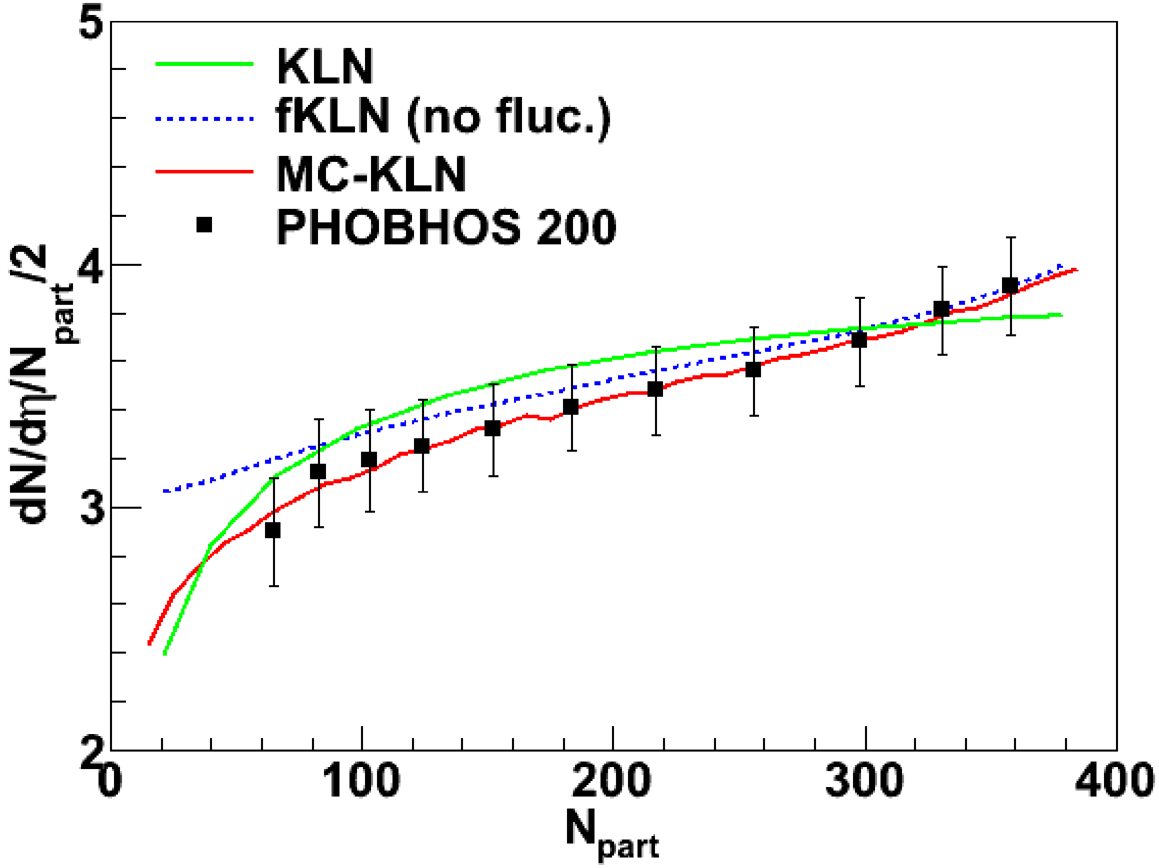
which is used to simulate coherent scattering

- Saturation scale at a given transverse coordinate is given by

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

- For each generated configuration, we apply the k_t-factorization formula at each transverse grid.

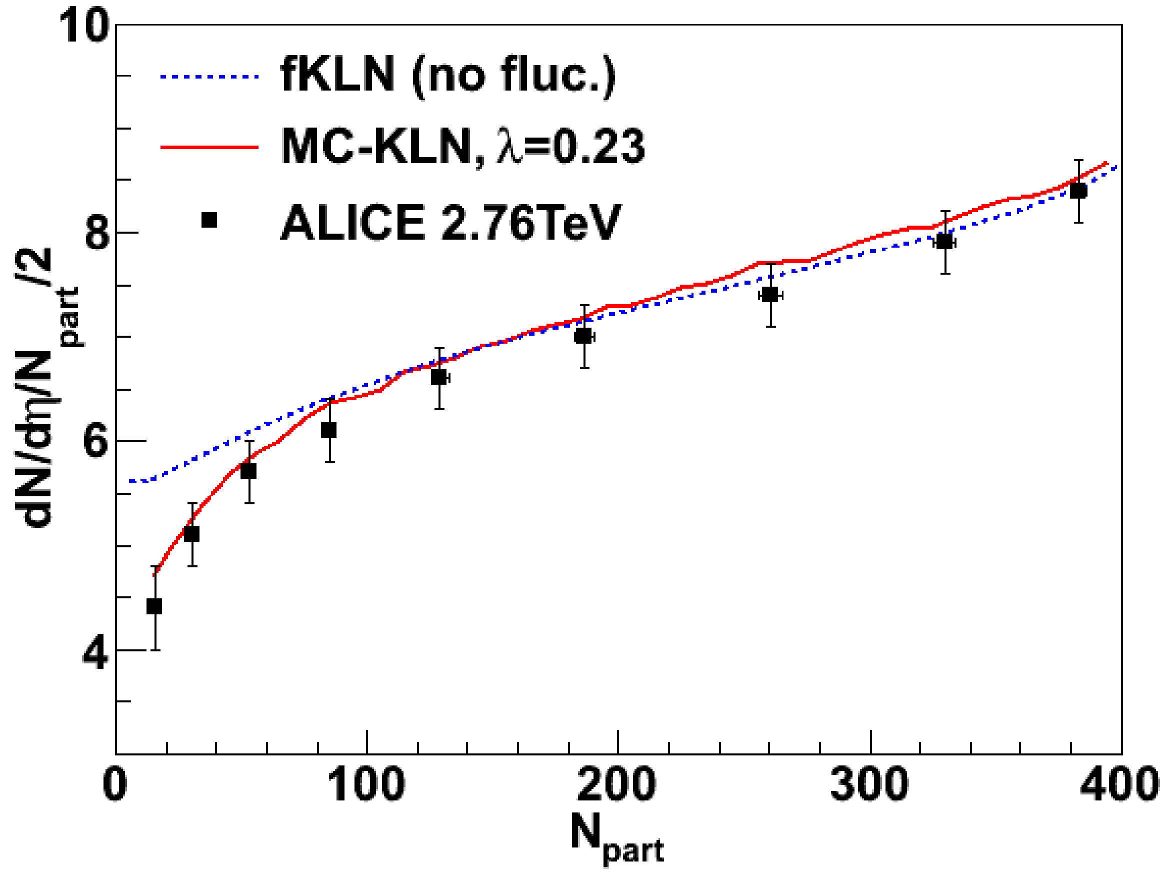
Centrality dependence at y=0



$$\frac{1}{N_{\text{part}}}\frac{dN}{dy} = c\ln\left(\frac{Q_s^2}{\Lambda_{\text{QCD}}^2}\right)$$

The effect of fluctuation is seen in the peripheral collisions (Npart < 200).

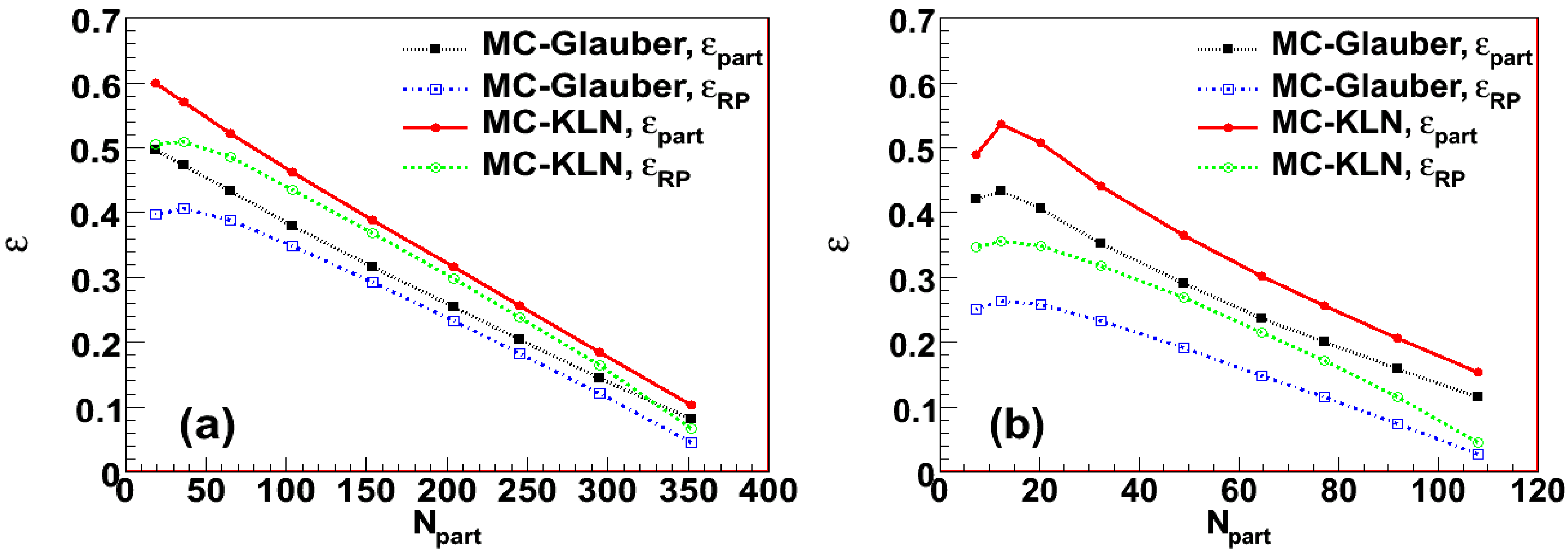
centrality dependence at LHC energy



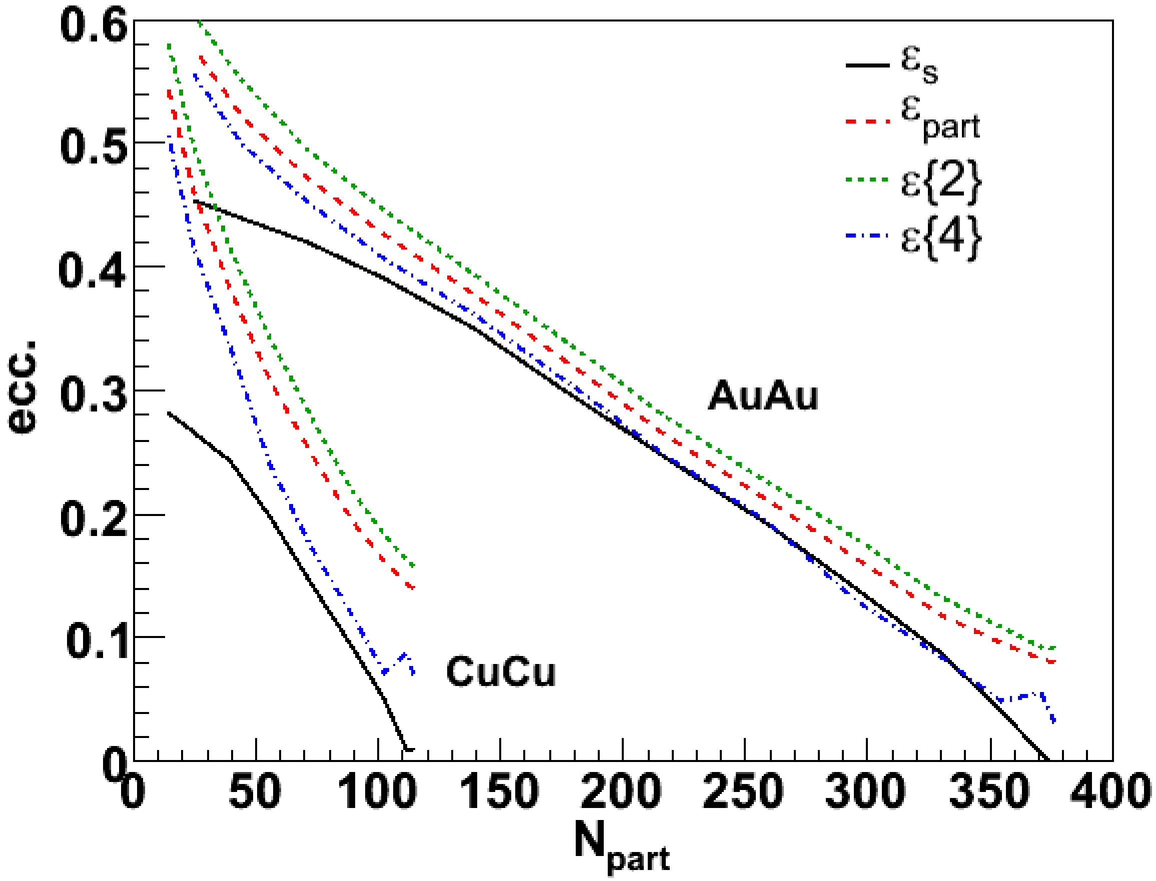
Initial Eccentricities

Au+Au

Cu+Cu



Eccentricity Fluctuations from MC-KLN



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

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

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

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

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

MC version of kt-factorization with running coupling BK (rcBK) wave function

implemented by A.Dumitru by using the solution of rcBK from J. L. Albacete.

It is available from

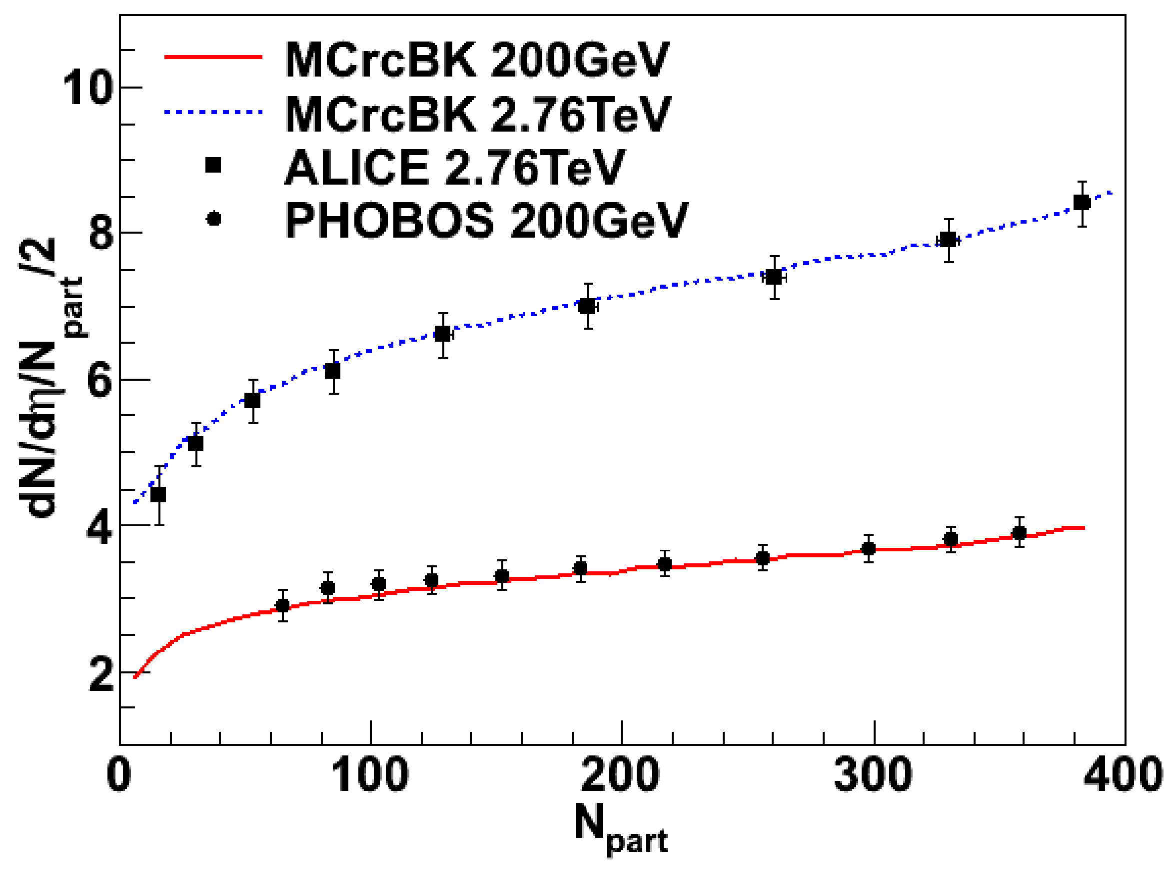
http://physics.baruch.cuny.edu/node/people/adumitru/res_cgc

$$\varphi(k,x,b) = \frac{C_F}{\alpha_s(k)\,(2\pi)^3}\int d^2\mathbf{r}\; e^{-i\mathbf{k}\cdot\mathbf{r}}\,\nabla^2_{\mathbf{r}}\mathcal{N}_G(r,Y=\ln(x_0/x),b)$$

$\mathcal{N}_G$ is related to the quark dipole scattering amplitude from rcBK eq.

$$\mathcal{N}_G(r,x) = 2\,\mathcal{N}(r,x) - \mathcal{N}^2(r,x)\,.$$

MC version of kt-factorization with rcBK wave function



MCrcBK with Gaussian nucleon

So far, nucleon-nucleon collision will occur if

$$(x_i - x_j)^2 + (y_i - y_j)^2 \leq \frac{\sigma_{NN}}{\pi}$$

In the case of nucleon with Gaussian shape:

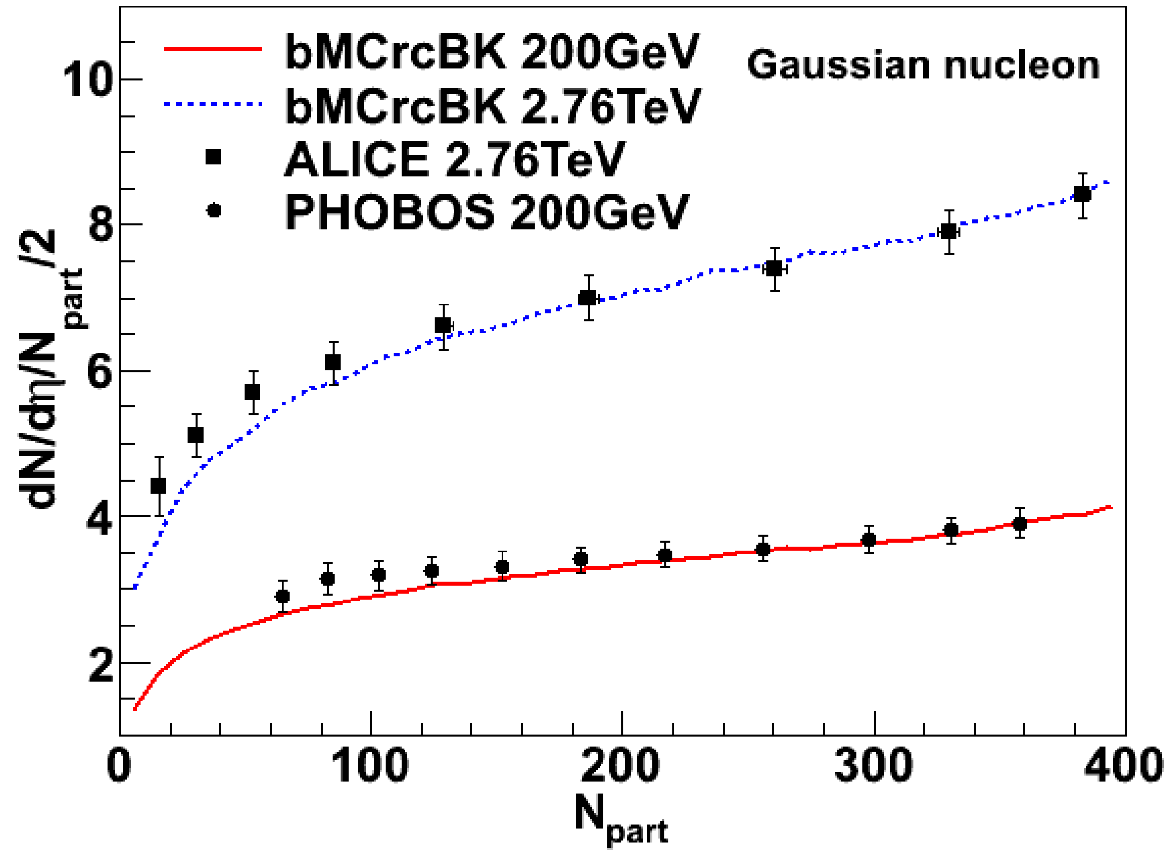
$$T_p(r) = \frac{1}{2\pi B} \exp[-r^2/(2B)]$$

NN collision probability $P(b) = 1 - \exp[-kT_{pp}(b)]$

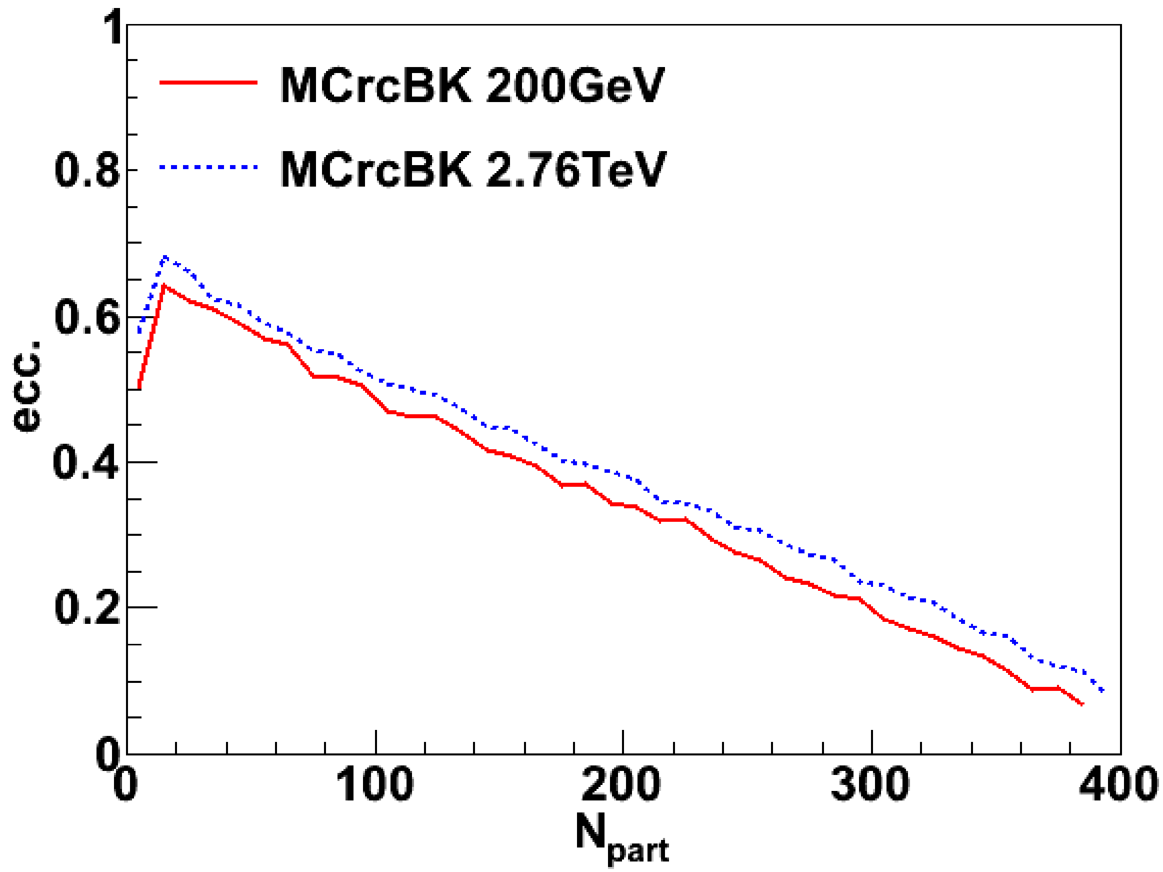
$$T_{pp}(b) = \int d^2 s T_p(s) T_p(s-b)$$

k is fixed by the relation $\sigma_{in} = \int d^2 b \, (1 - \exp[-kT_{pp}(b)])$

MCrcBK with Gaussian nucleon



eccentricity from MCrcBK



No incident energy dependence for eccentricity

summary

- We presented the results of Monte Carlo version of kt-factrization fromula MCKLN and MCrcBK.
  - Initial color fluctuation is important for multiplicities
  - Eccentricity larger and elliptic flow also larger.
  - Eccentricity at LHC is very similar to the one at RHIC.
  - McrcBK prediction on centrality dependence on dN/deta at LHC is consistent with ALICE data.