Initial conditions and fluctuations

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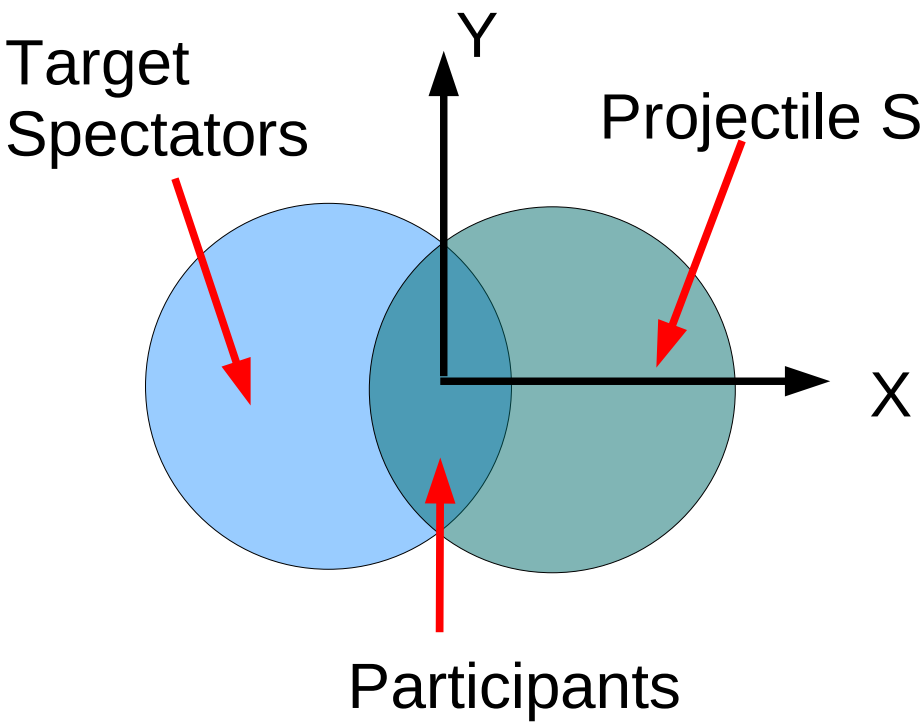
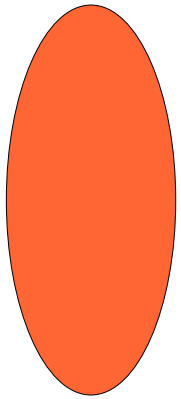
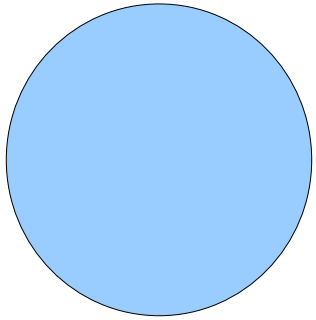
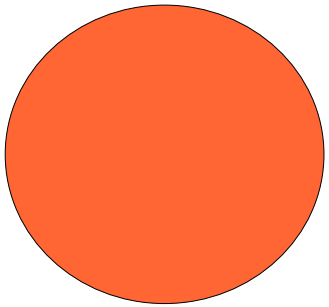
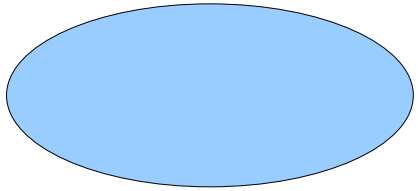
- Initial eccentricity from k_t-factorization / CGC
- Need to get the surface “right”
- Need to account for nucleon fluctuations (sources on light cone)

Pressure gradients and elliptic flow



	Coordinate space	Momentum space
	$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle x^2 + y^2 \rangle}$	$v_2 = \frac{\langle p_x^2 - p_y^2 \rangle}{\langle p_x^2 + p_y^2 \rangle}$
Initial		
Later		

Idea : Pressure gradients convert spatial anisotropy to momentum anisotropy

Glauber model for the initial transverse density profile

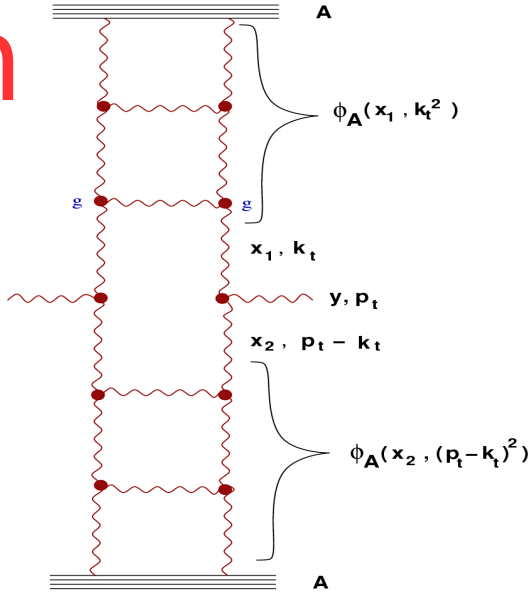
Wounded nucleon model: number of participants scaling

$$\frac{dN}{d^2 r_t dy} \sim \rho_{\rm part} \ ,$$

$$\rho_{part}(\vec{r}_\perp, \vec{b}) = \rho^A_{part}(\vec{r}_\perp, \vec{b}) + \rho^B_{part}(\vec{r}_\perp, \vec{b})$$
$$= \quad T_A(\vec{r}_\perp + \vec{b}/2)\left(1-(1-\sigma^{inel}_{NN} T_B(\vec{r}_\perp - \vec{b}/2)/B)^B\right)$$
$$+ T_B(\vec{r}_\perp - \vec{b}/2)\left(1-(1-\sigma^{inel}_{NN} T_A(\vec{r}_\perp + \vec{b}/2)/A)^A\right)$$

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

Inclusive gluon production



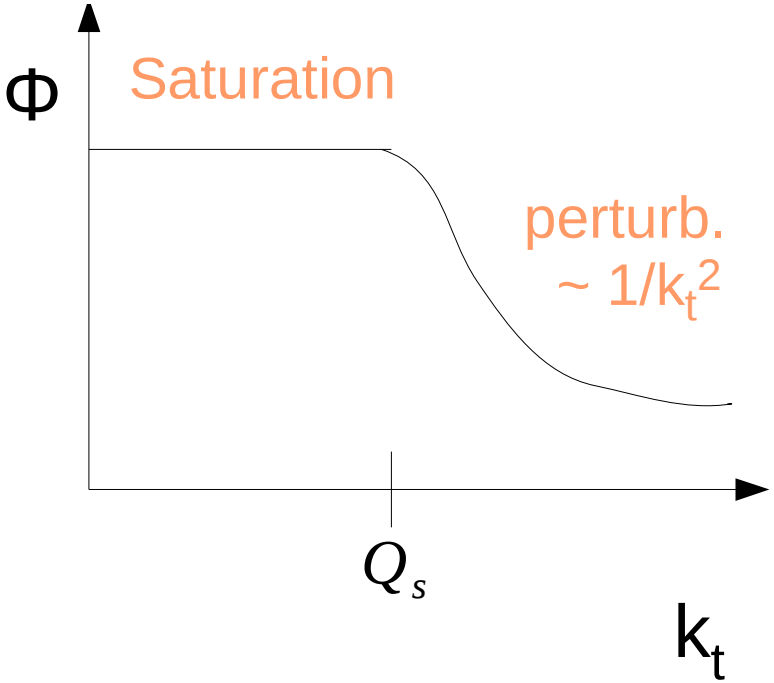
K_t-factorization:

$$\frac{dN}{d^2 r_t dy} \sim \int \frac{d^2 p_t}{p_t^2} \int d^2 k_t \; \alpha_s \, \phi_A(x_1, k_t^2) \; \phi_B(x_2, (p_t - k_t)^2)$$

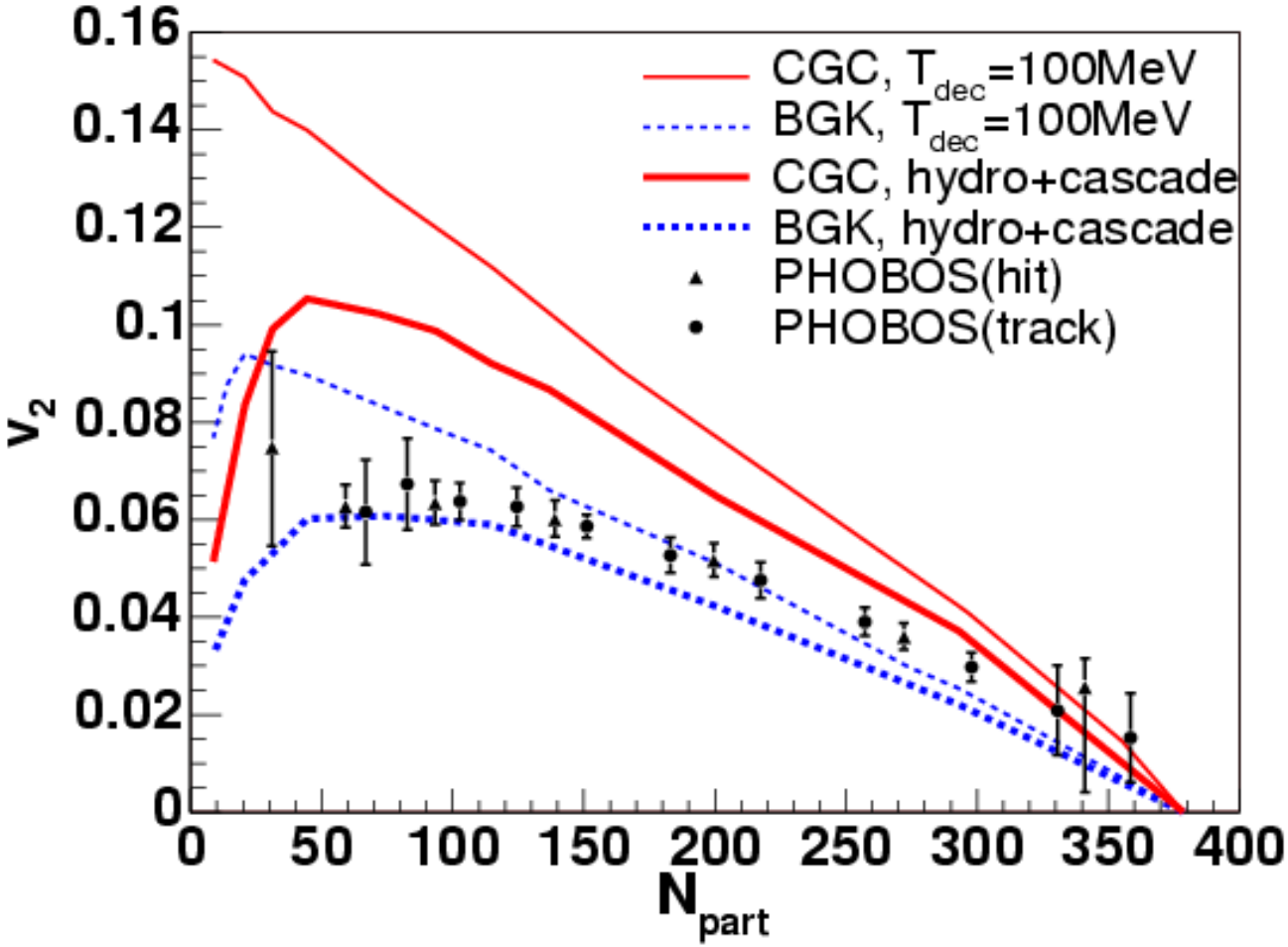
Kharzeev, Levin, Nardi model:

$$\phi(x, k_t^2; \vec{r}_t) \sim \frac{1}{\alpha_s(Q_s^2)} \frac{Q_s^2(x, \vec{r}_t)}{max(Q_s^2, k_T^2)}$$

$$Q_s^2 \sim \rho_{\text{part}} \, x^{-\lambda} \quad (\lambda \approx 0.28)$$



Hydro with CGC vs. Glauber initial conditions

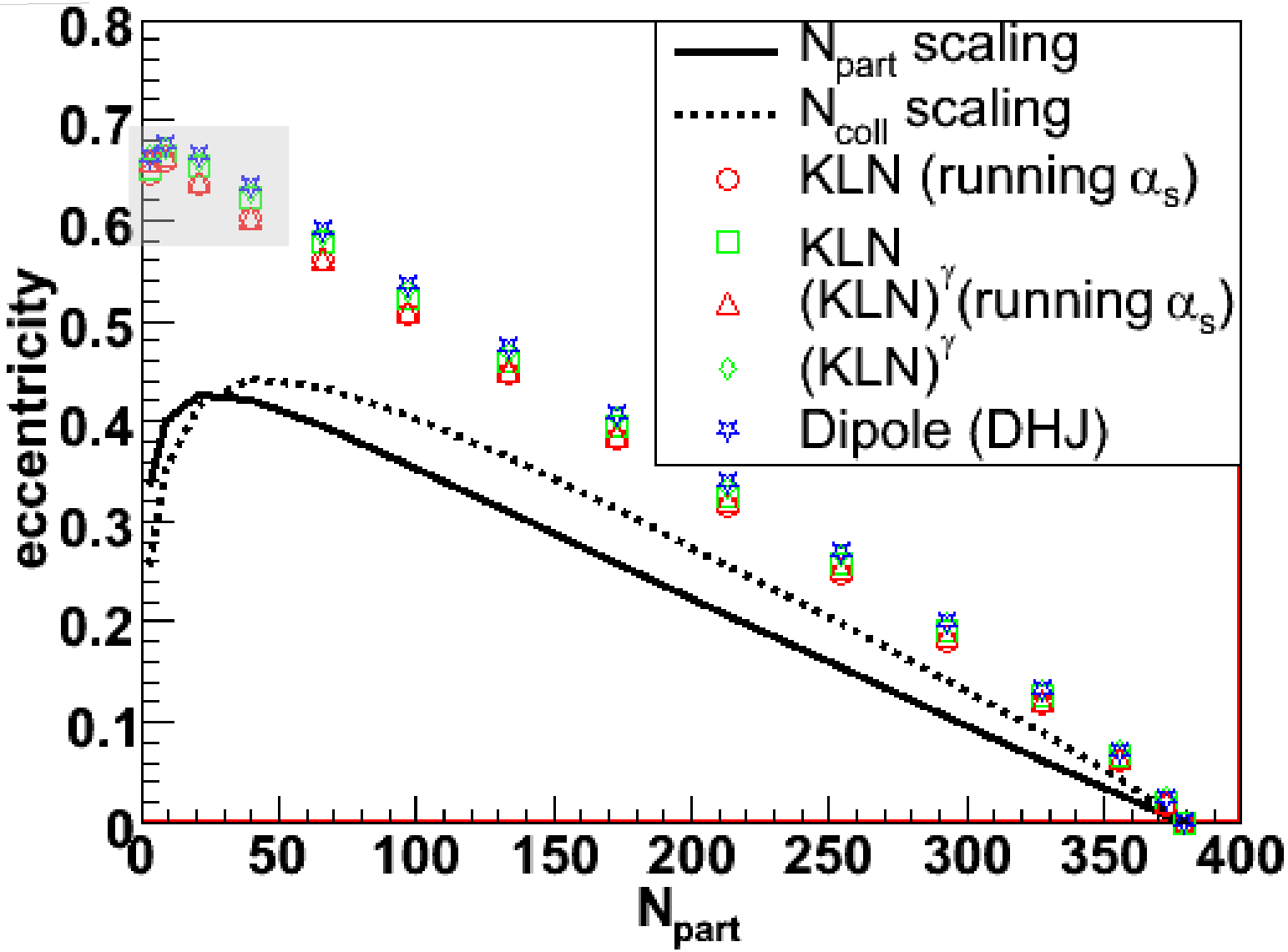


T. Hirano at al., Phys. Lett. B636 (2006) 299

Ideal hydro with CGC initial condition (KLN) and τ_0 ~ 1 fm/c overpredicts elliptic flow!

Eccentricity from kt-factorization

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

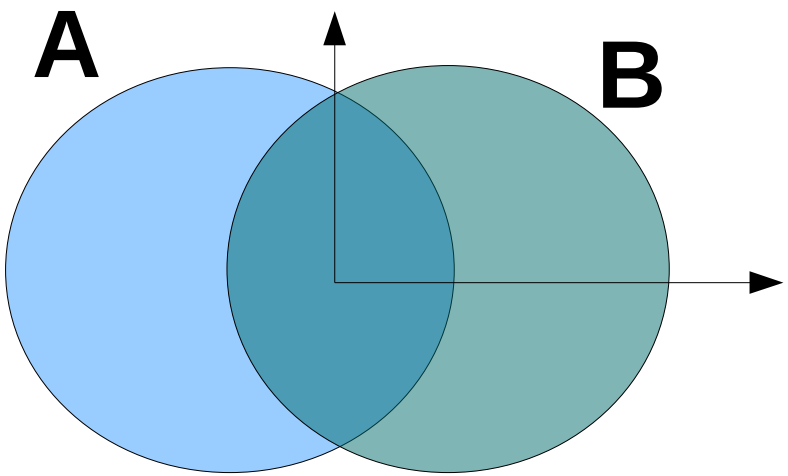


nucl-th/0605012

Scaling properties:

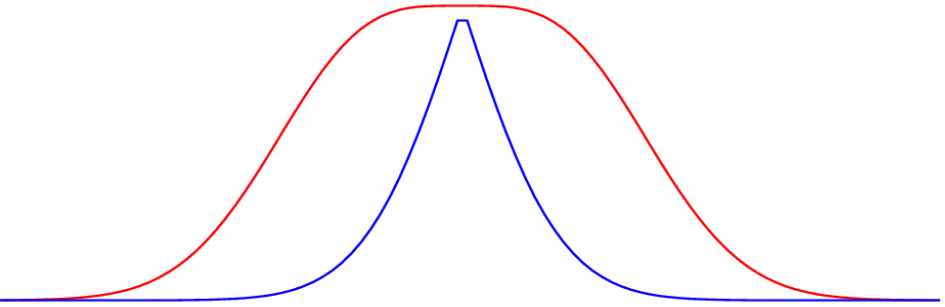
$$\frac{dN_g}{d^2 r_\perp dy} = \frac{4\pi N_c}{N_c^2 - 1} \int \frac{d^2 p_t}{p_t^2} \int d^2 k_t \alpha_s \phi(x_1, k_t^2) \phi(x_2, (p_t - k_t)^2)$$

$$\sim \underline{\underline{Q_{s\,min}^2}} \log \frac{Q_{s\,max}^2}{Q_{s\,min}^2}$$



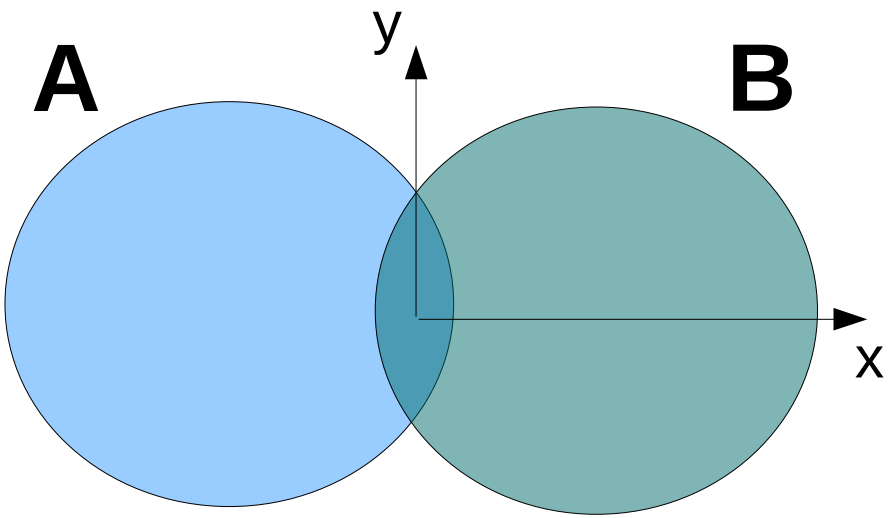
CGC: $\frac{dN}{dy} \sim \min(\rho_{\text{part}}^A, \rho_{\text{part}}^B)$

Glauber: $\frac{dN}{dy} \sim \frac{\rho_{\text{part}}^A + \rho_{\text{part}}^B}{2}$



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

Peripheral Collisions:



little A ↔ B asymmetry in x-direction: $Q_s(A) \sim Q_s(B)$

→ $\epsilon_{CGC} \simeq \epsilon_{Glauber}$

- Semi-central coll.: $\epsilon_{CGC} > \epsilon_{Glauber}$
- Periph. coll.: $\epsilon_{CGC} \to \epsilon_{Glauber}$

Problems

- uGDF Φ does not factorize, Q_s not 'universal'

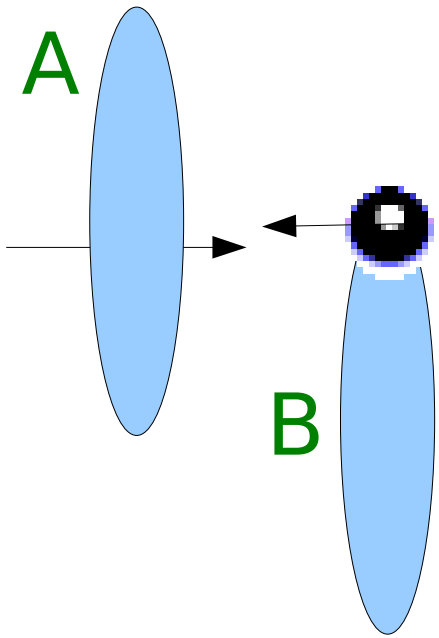
  (Lappi, Venugopalan, nucl-th/0609021)

- $Q_s \rightarrow 0$ at the surface

  (IR sensitivity, unreliable for calculating ecc.)

fKLN

nucl-th/0605012
nucl-th/0611017



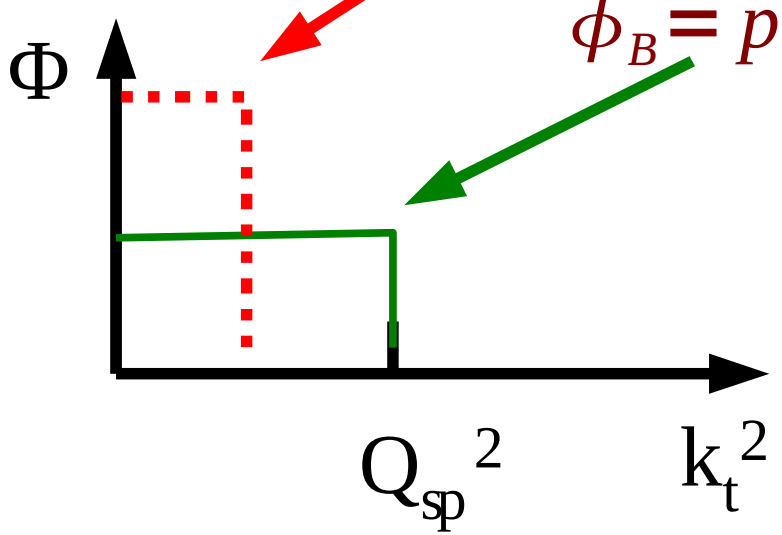
$$Q_{sB}^2 = Q_{sp}^2 T_B$$

$$T_B = \frac{\sum_{i\geq 0} p_i t_i}{\sum_{i\geq 1} p_i} = \frac{\langle T_B \rangle}{p_B}$$

$$\langle T_B \rangle (\vec{r}_\perp) = \int dz\, \rho_{WS}(z, \vec{r}_\perp)$$

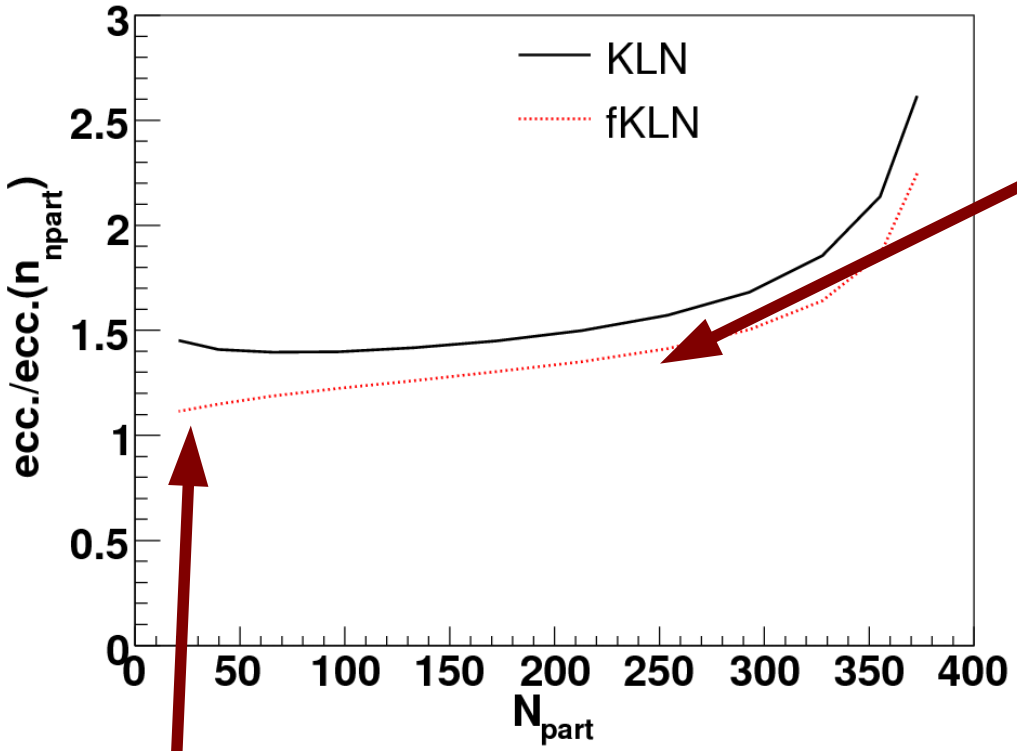
$$\phi_B = \phi\left(Q_{sp}^2 \langle T_B(r_t) \rangle\right) \quad ,$$

$$\phi_B = p_B\, \phi(Q_{sp}^2)$$

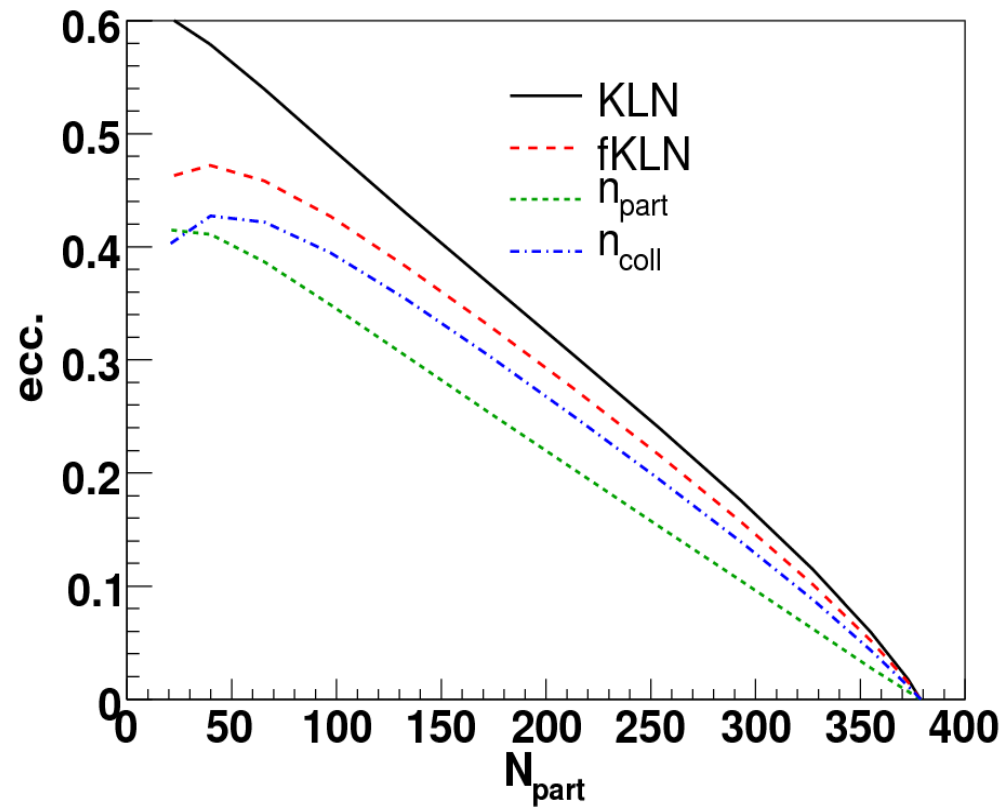


$$\phi_B(\langle T_B \rangle) \rightarrow p_B\, \phi_B(\langle T_B \rangle / p_B)$$

$$\frac{dN}{d^2 r_t} \sim p_A\, \phi_A \otimes p_B\, \phi_B$$



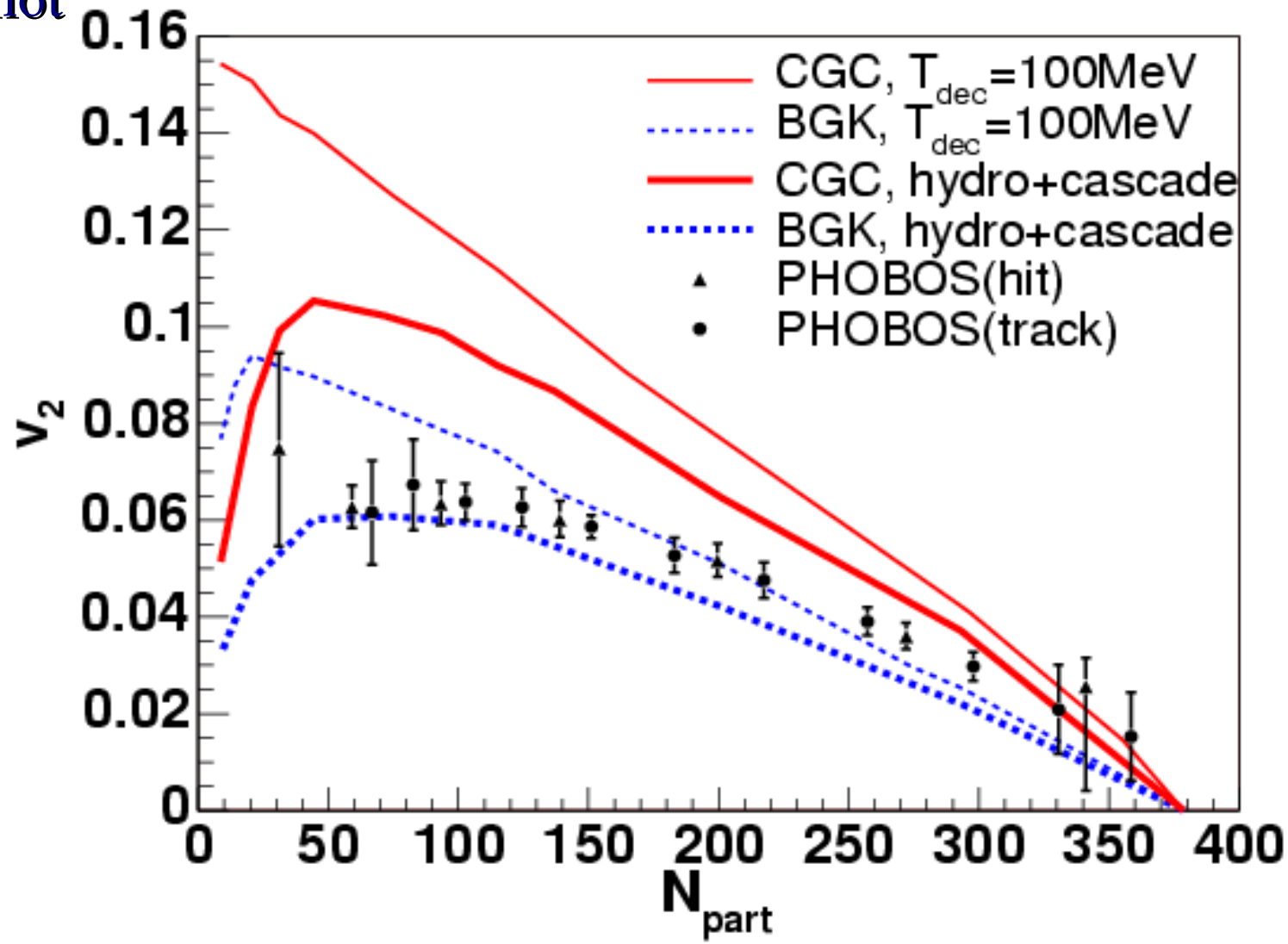
~ 30% effect, comparable to dissip. correction



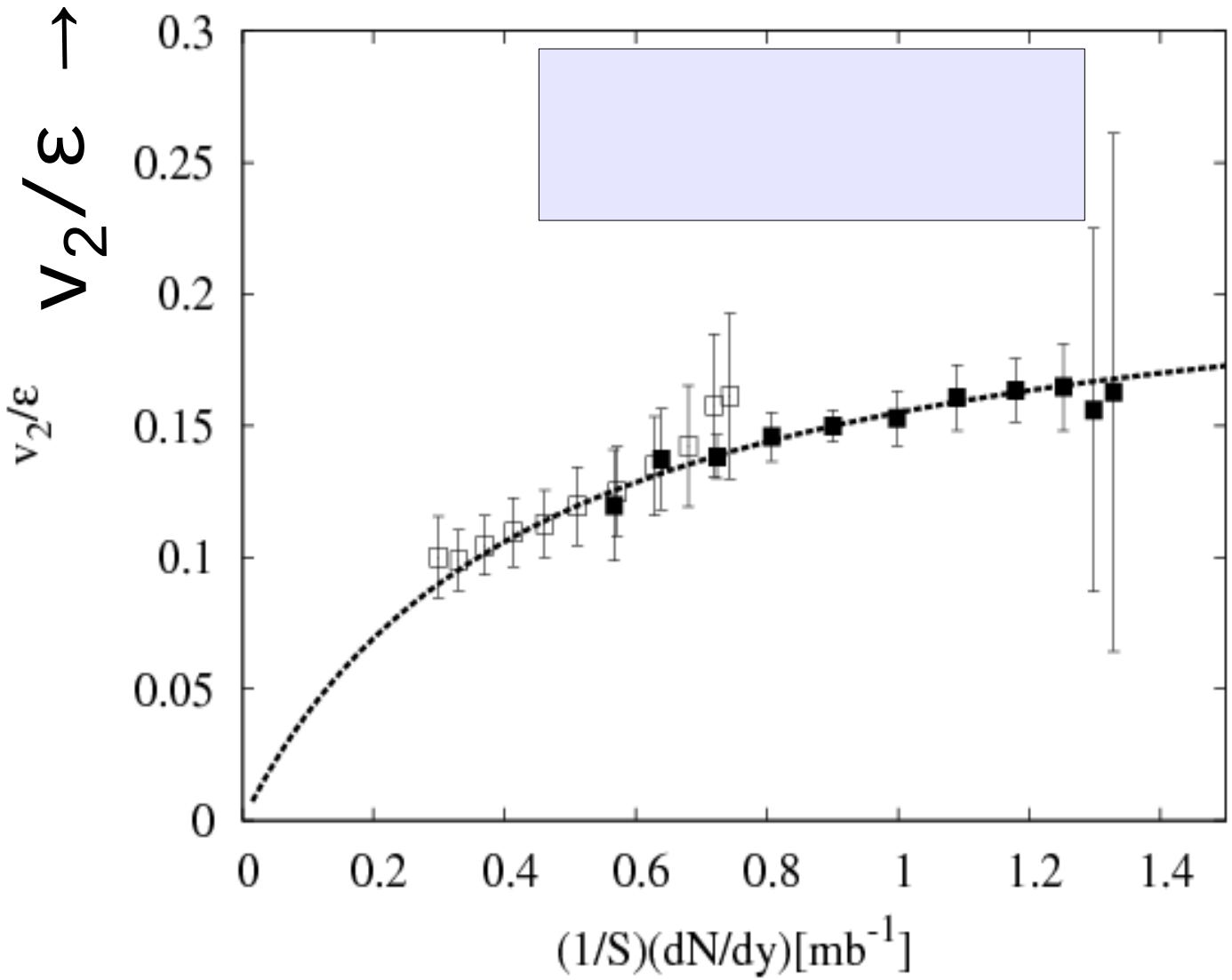
fKLN approaches Glauber in peripheral collisions !

hydro best for central collisions
(if ini. cond. appropriate)

so, this is probably not best way to plot :

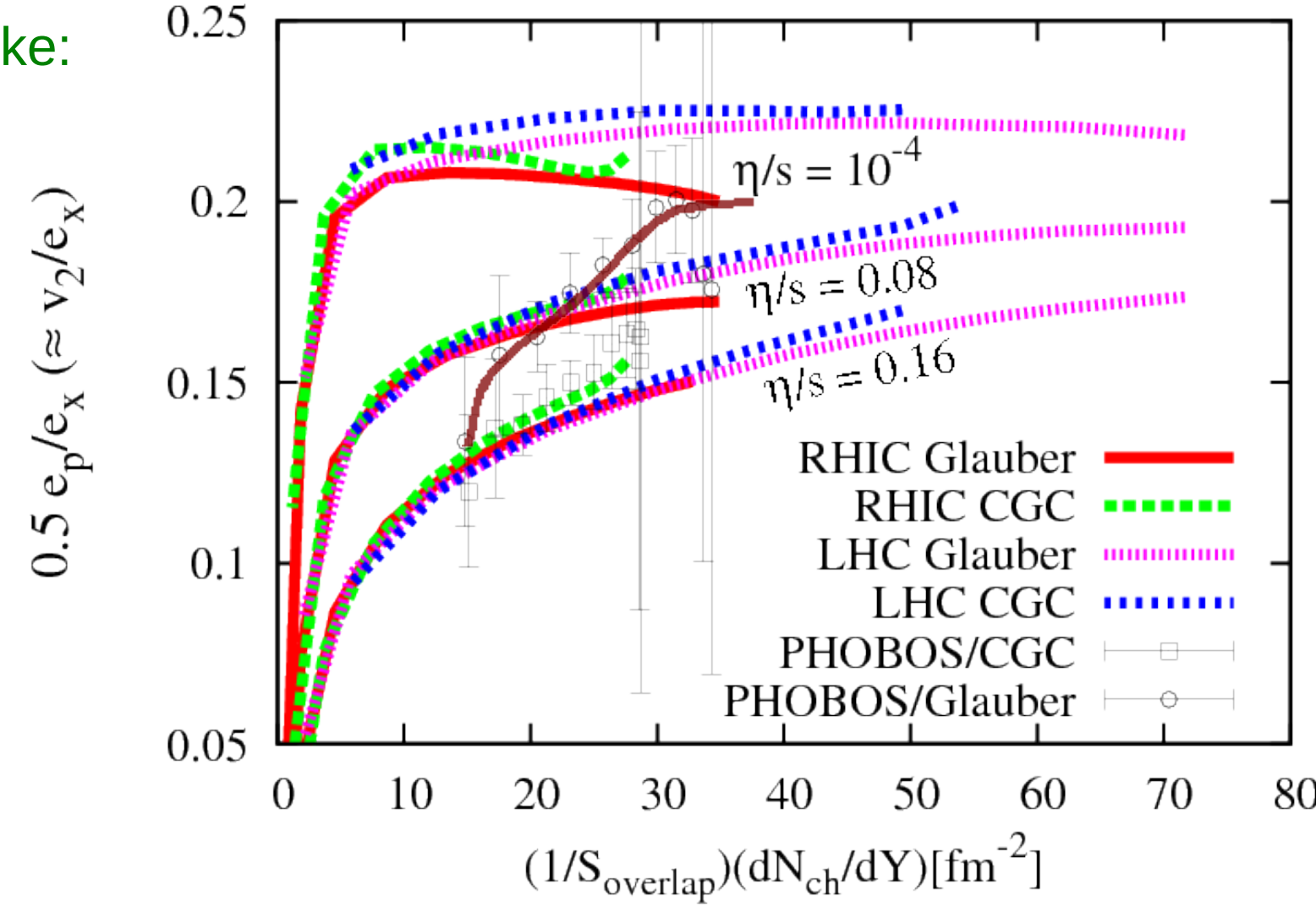


Voloshin/Poskanzer plot: scaled flow vs density



centrality →

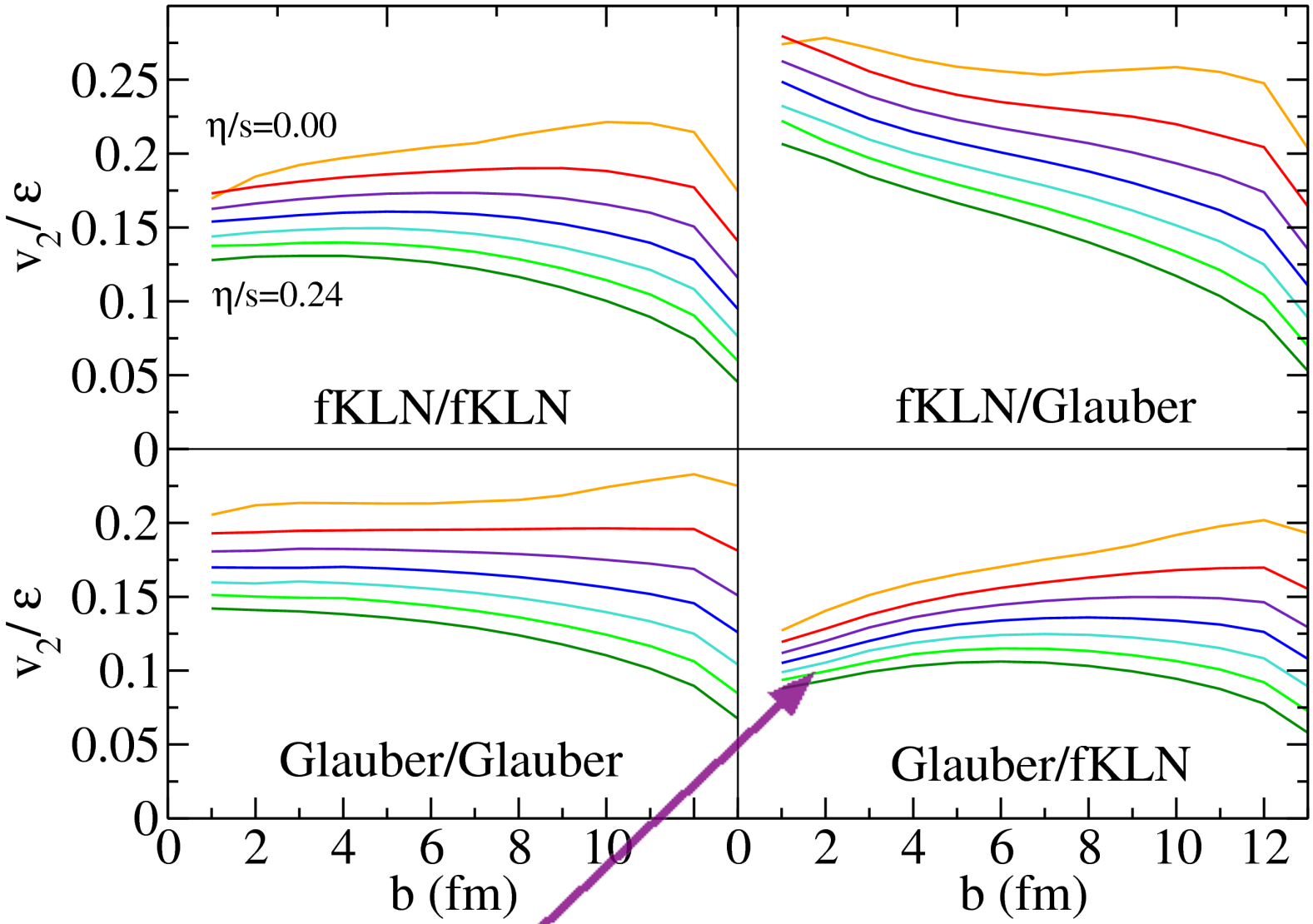
Luzum, Romatschke:
arXiv:0901.4588



hydro + Glauber ain't good friends !?

→ **hydro can help to nail initial conditions !**

Heinz, Moreland, Song: arXiv:0908.2617



$v_2^{data}/\varepsilon^{MC\text{-}KLN}$ increases with centrality!

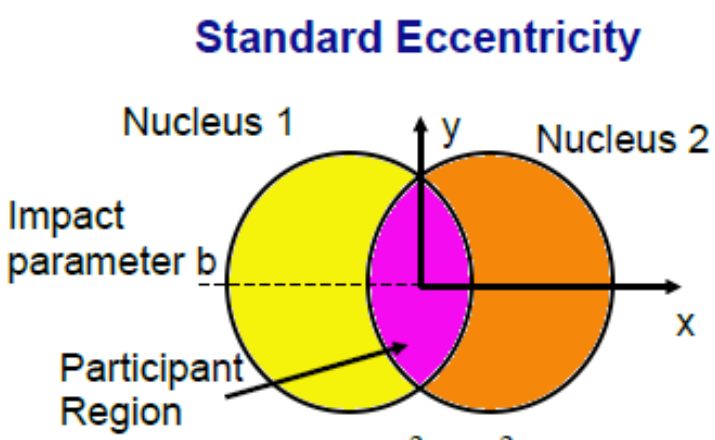
(unlike Glauber-hydro)

at small b, one should account for fluctuations though.

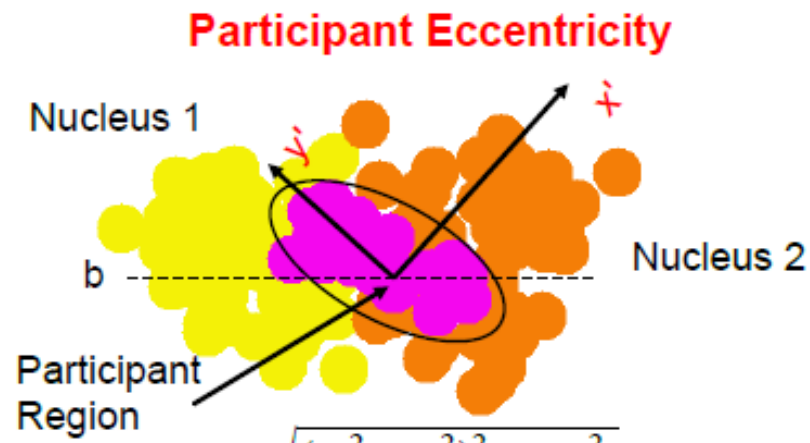
Fluctuations of nucleons ("light-cone sources")

important for

- central / peripheral Au+Au
- smaller systems (Cu+Cu)
- fluctuations of v_2



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

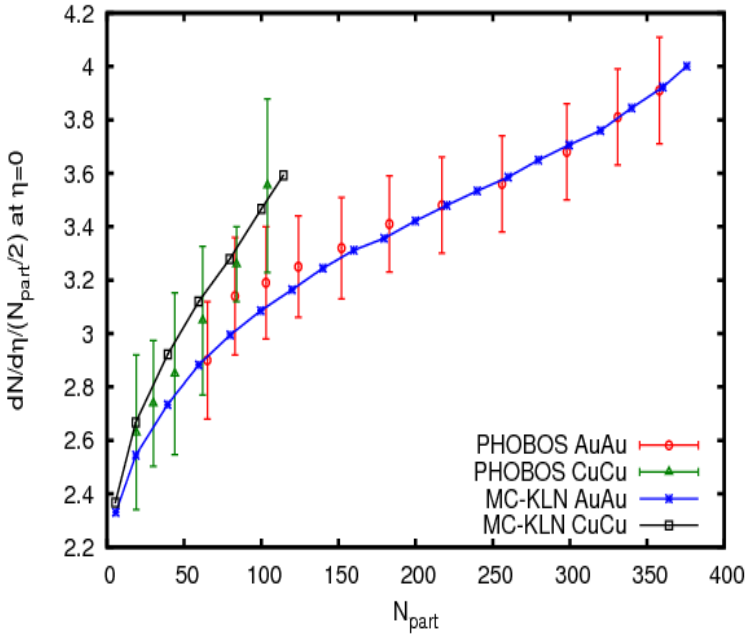


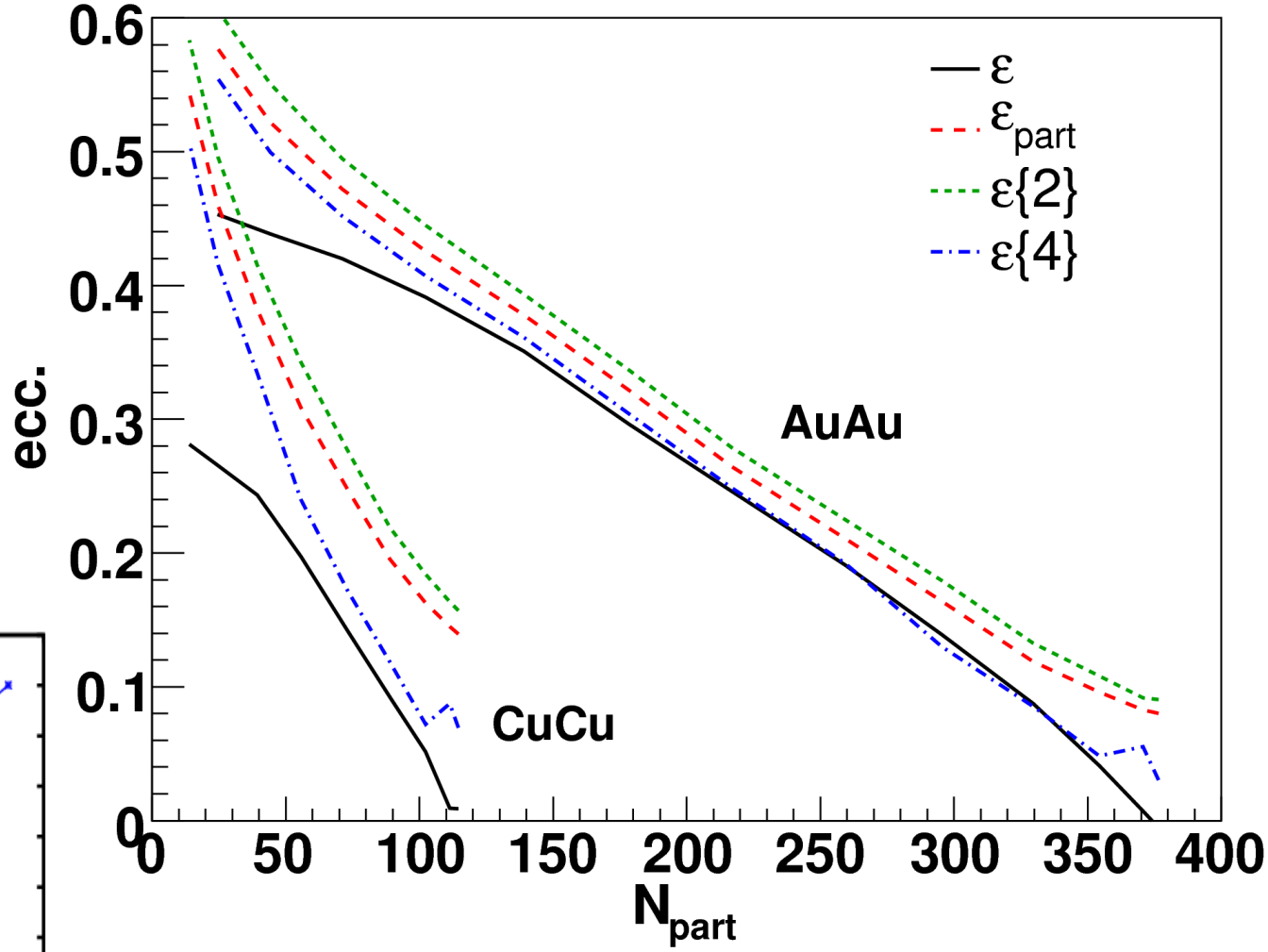
$$\epsilon_{part} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 - 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$

PHOBOS

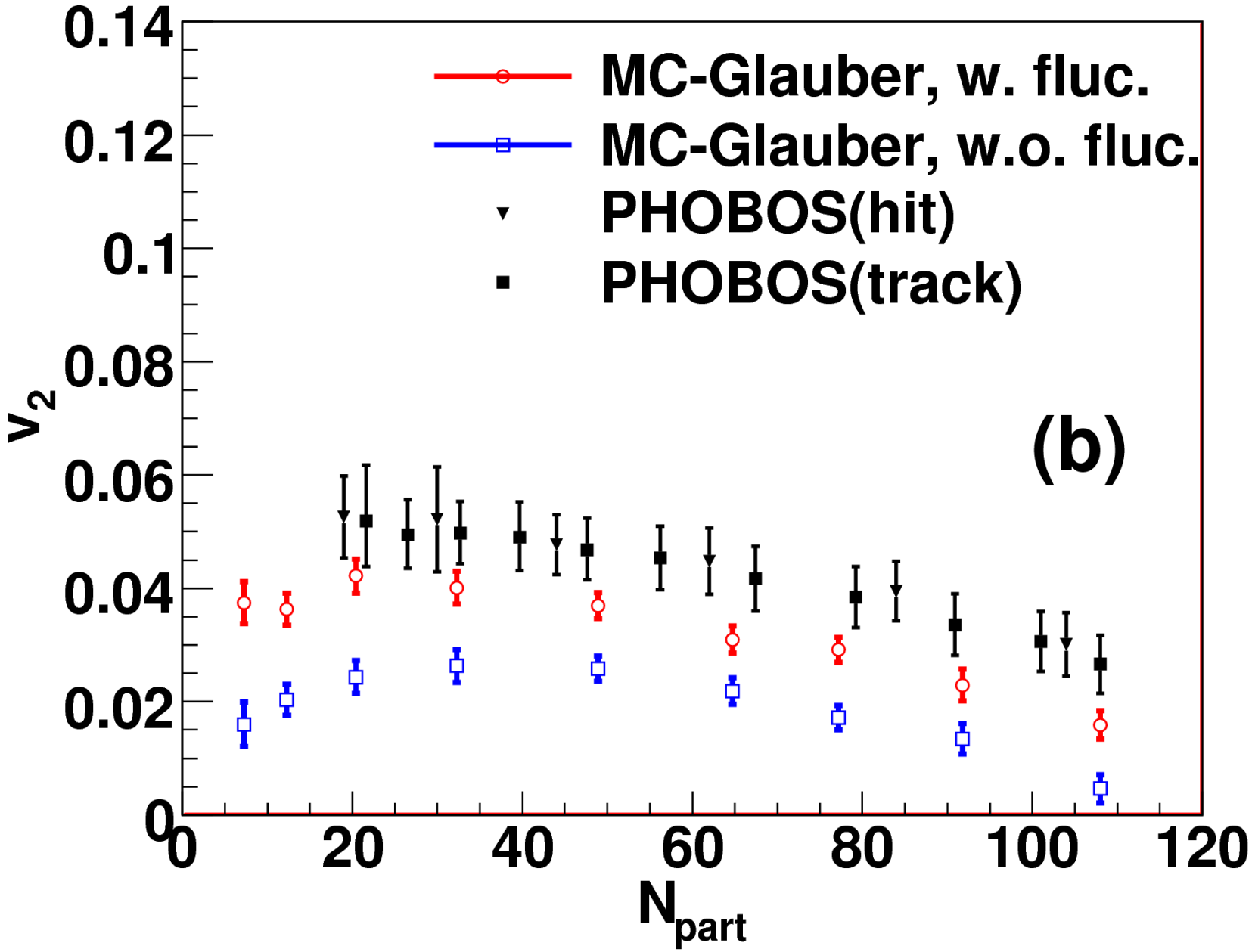
MC-KLN model

Drescher, Nara: nucl-th/0611017





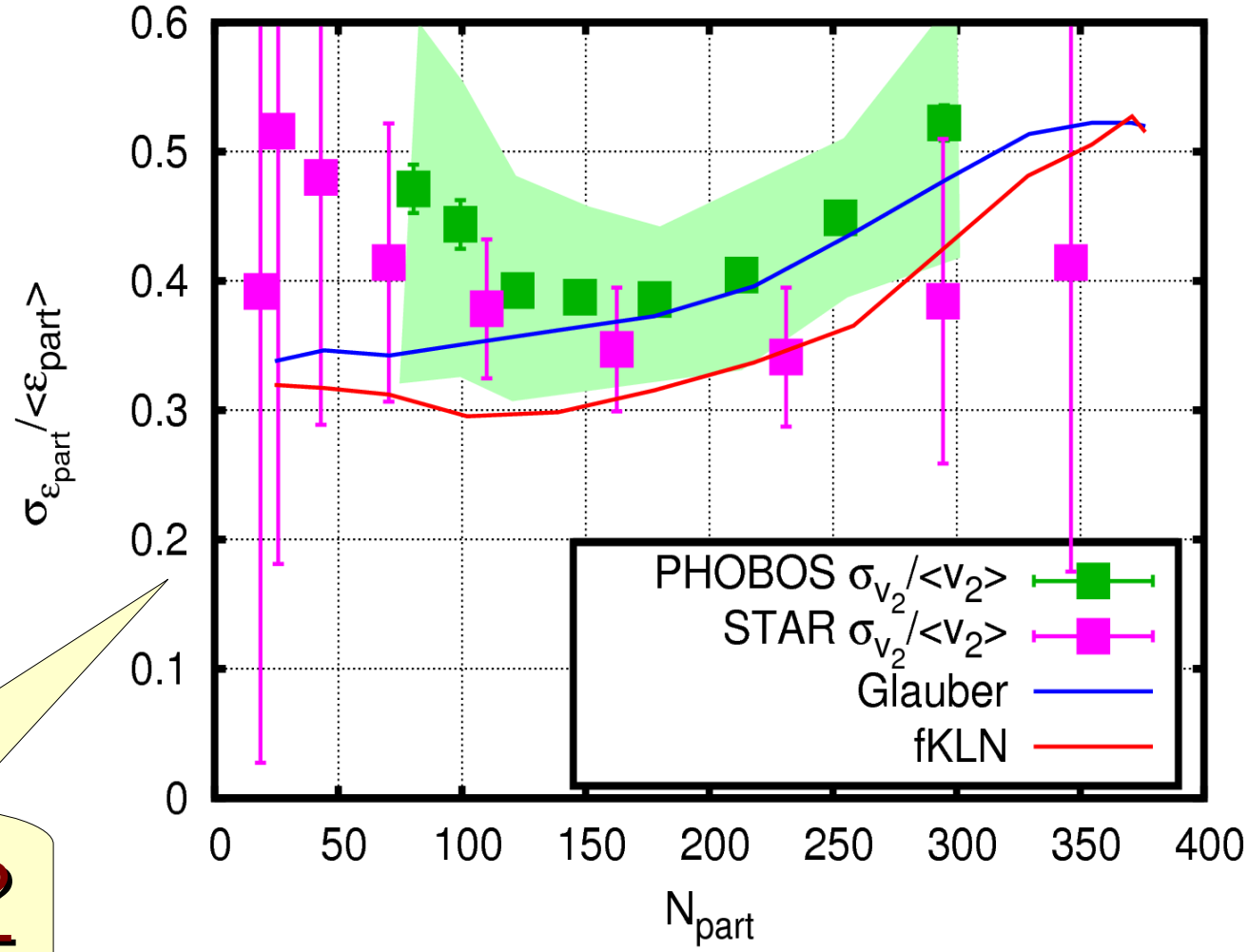
Hirano, Nara: arXiv:0904.4080



Eccentricity fluctuations:

$v_2 = C(c_s, \eta/s)\, \varepsilon$

$$\frac{\delta v_2}{v_2} = \frac{\delta \varepsilon}{\varepsilon}$$ true or not ?



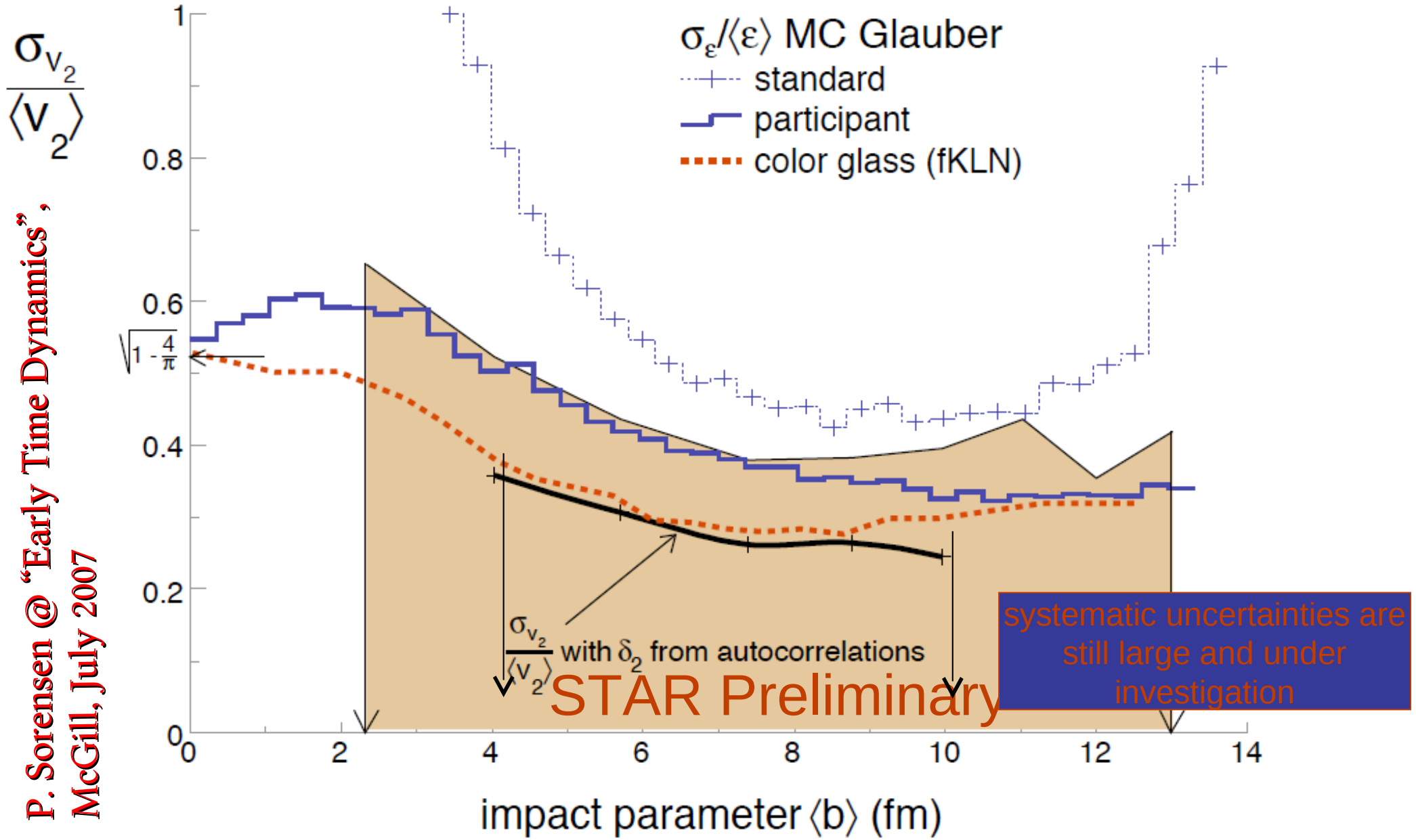
P. Sorensen (STAR)

non-flow ???

comparison to geometric σ_ε

fluctuations from finite bin widths have not been removed yet

likely to reduce ratio below the model!



P. Sorensen @ "Early Time Dynamics", McGill, July 2007

Summary :

Thanks !

- non-trivial QCD dynamics determines initial conditions ?!
- v_2/ε (Voloshin plot)
- fluctuations of nucleons important for Cu+Cu and central Au+Au
- $\delta v_2/v_2 = \delta\varepsilon/\varepsilon$ (?) constrains I.C.