The initial conditions for hydro at RHIC / LHC

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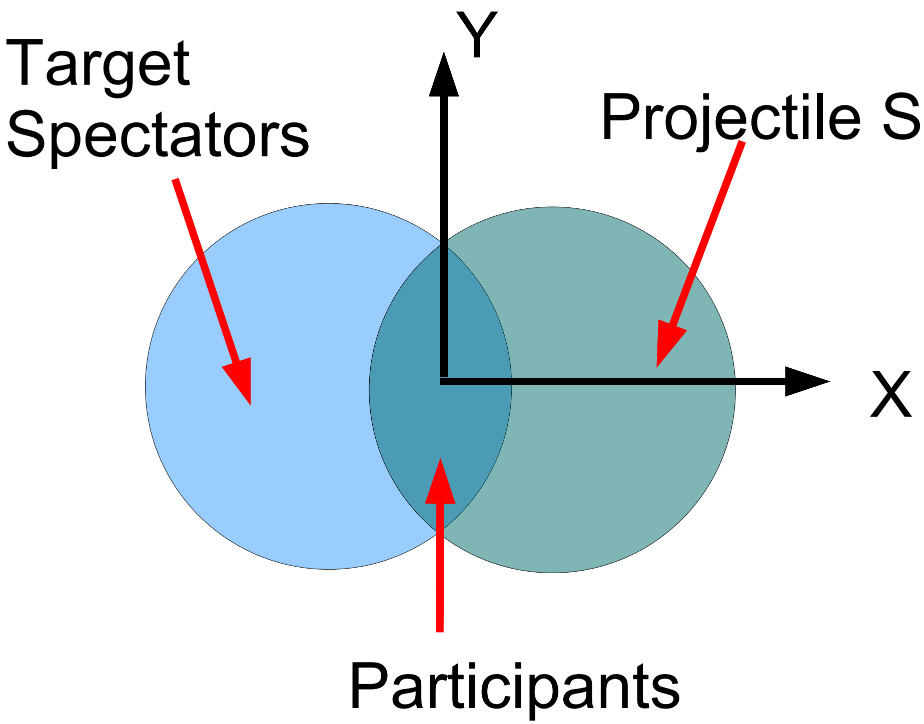
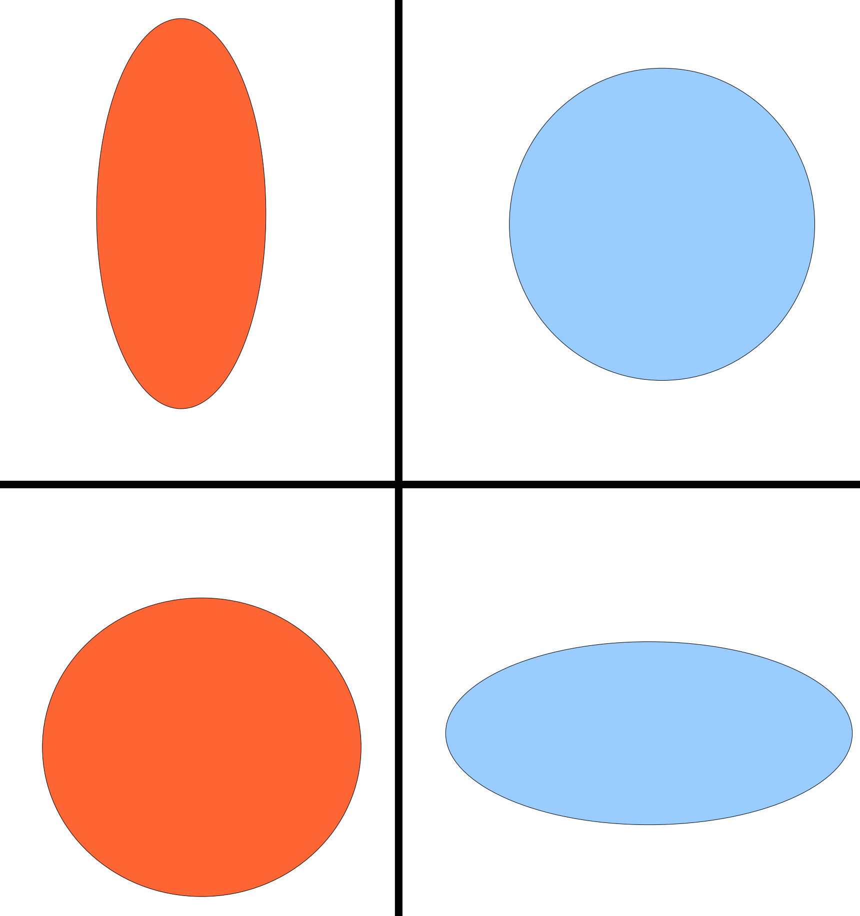
- Eccentricity → elliptic flow: extracting η/s and hydro limit (EoS)

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

Standard model for the initial transverse density profile

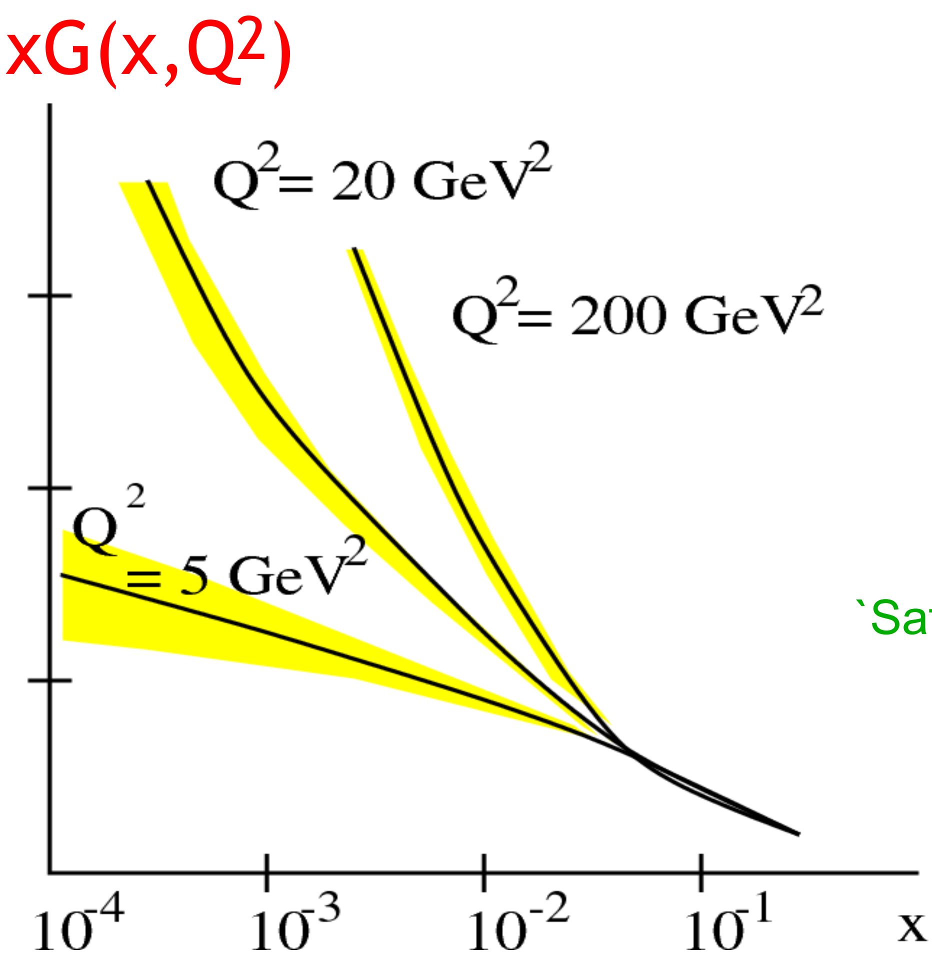
Wounded nucleon model: number of participants scaling

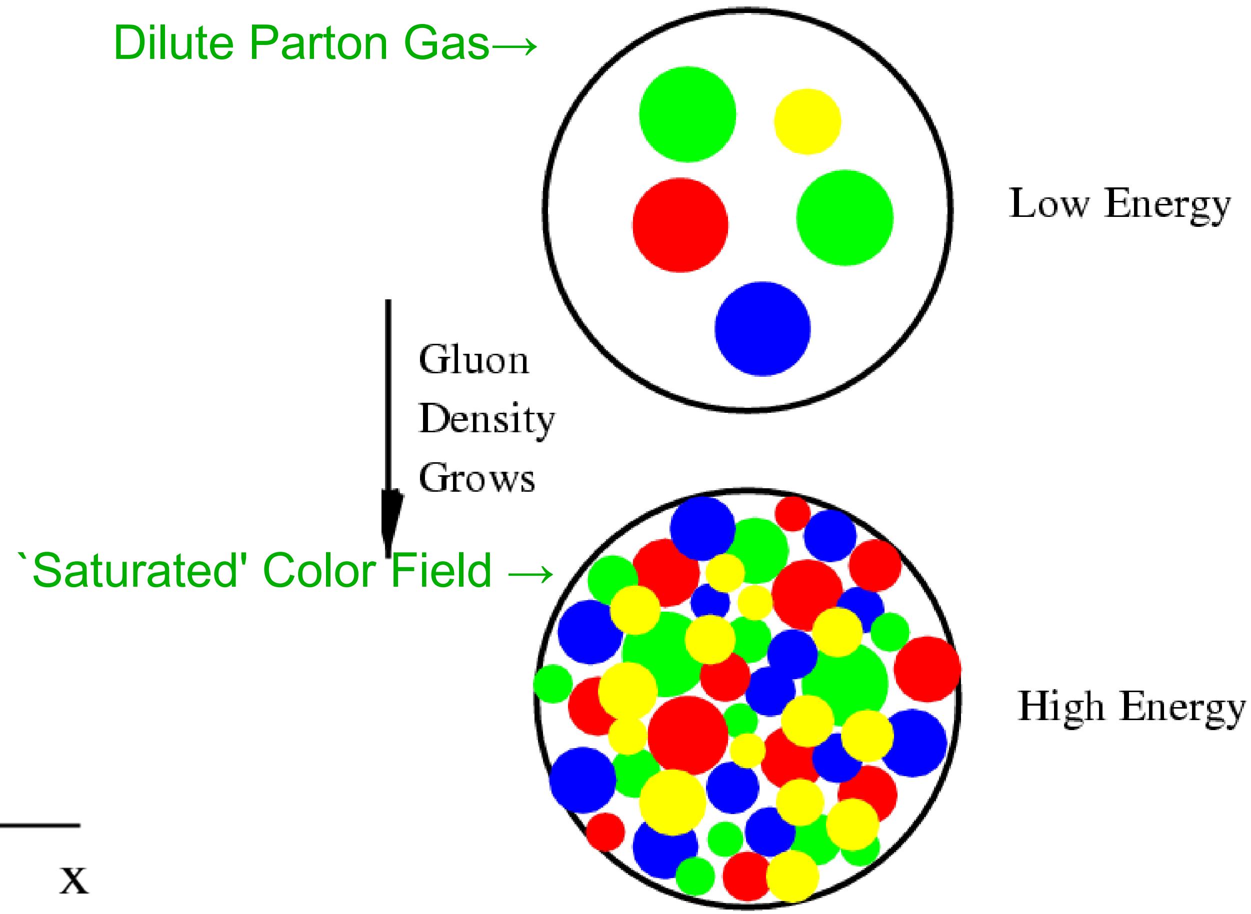
$$\frac{dN}{d^2r_t dy} \sim \rho_{\rm part} \ ,$$

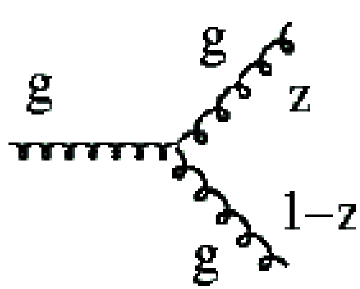
$$\begin{aligned}\rho_{part}(\vec{r}_\perp,\vec{b}) &= \rho^A_{part}(\vec{r}_\perp,\vec{b}) + \rho^B_{part}(\vec{r}_\perp,\vec{b}) \\ &= T_A(\vec{r}_\perp+\vec{b}/2)\left(1-(1-\sigma^{inel}_{NN}T_B(\vec{r}_\perp-\vec{b}/2)/B)^B\right) \\ &\quad + T_B(\vec{r}_\perp-\vec{b}/2)\left(1-(1-\sigma^{inel}_{NN}T_A(\vec{r}_\perp+\vec{b}/2)/A)^A\right)\end{aligned}$$

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

Gluon Saturation at High Energy



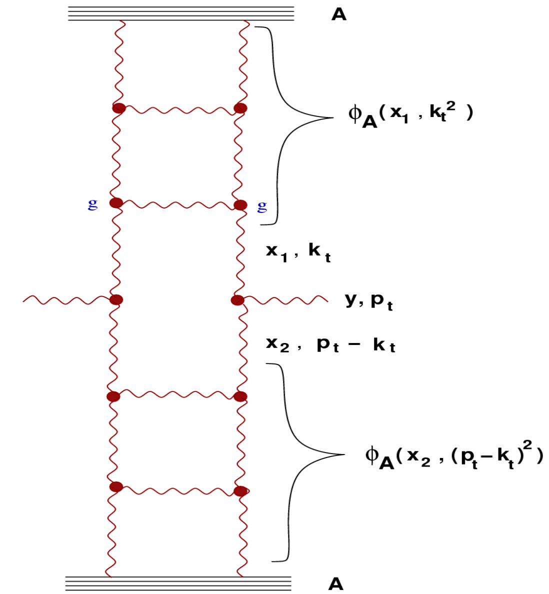




$$P_{gg}(z) = 2N_c\left(\frac{1-z}{z} + \frac{z}{1-z} + z(1-z)\right)$$

Inclusive gluon production

K_t-factorization:

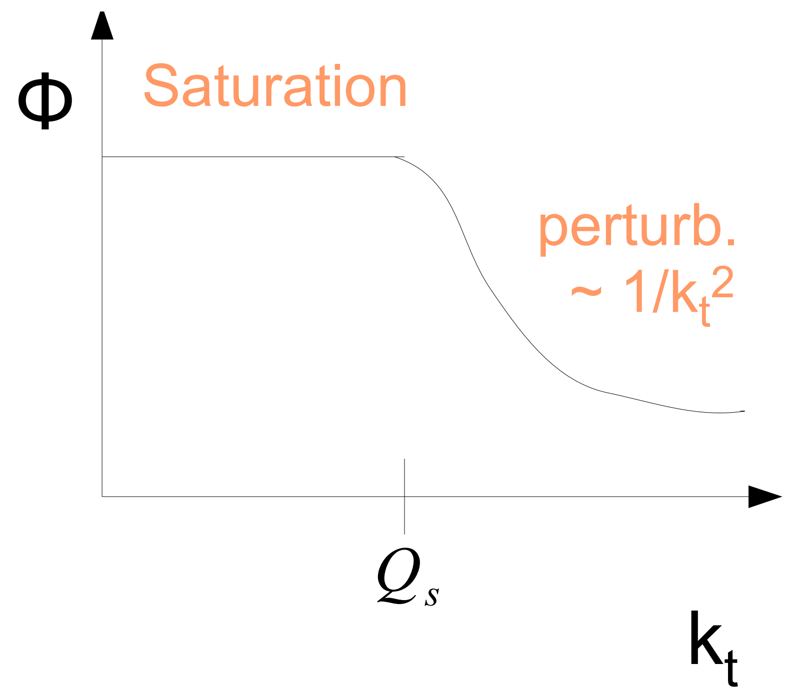


$$\frac{dN}{d^2r_t dy} \sim \int \frac{d^2p_t}{p_t^2} \int d^2k_t \, \alpha_s \, \phi_A(x_1, k_t^2) \, \phi_B(x_2, (p_t - k_t)^2)$$

Kharzeev, Levin, Nardi model:

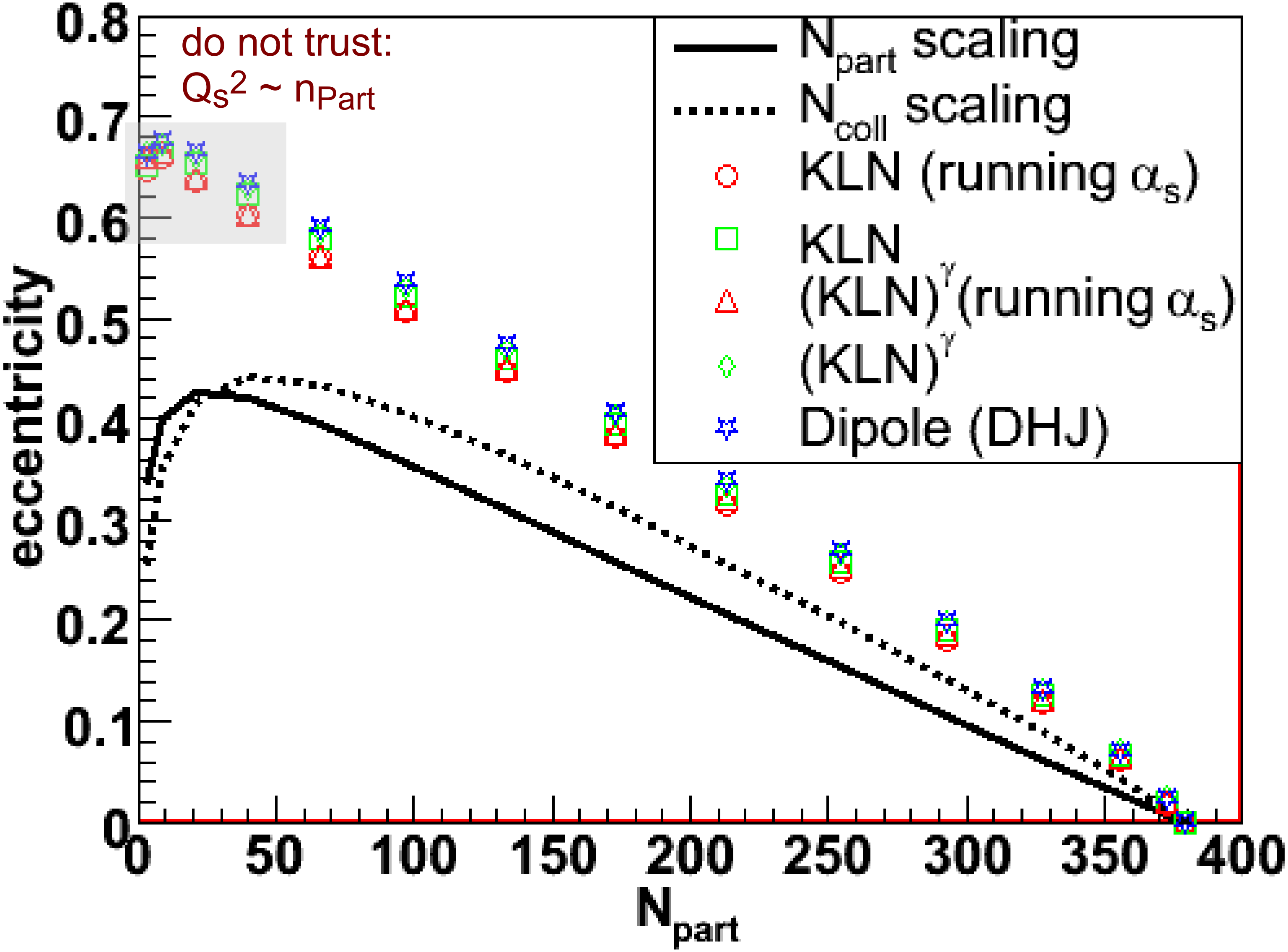
$$\phi(x, k_t^2; \vec{r}_t) \sim \frac{1}{\alpha_s(Q_s^2)} \frac{Q_s^2(x, \vec{r}_t)}{max(Q_s^2, k_T^2)}$$

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



Eccentricity from kt-factorization

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



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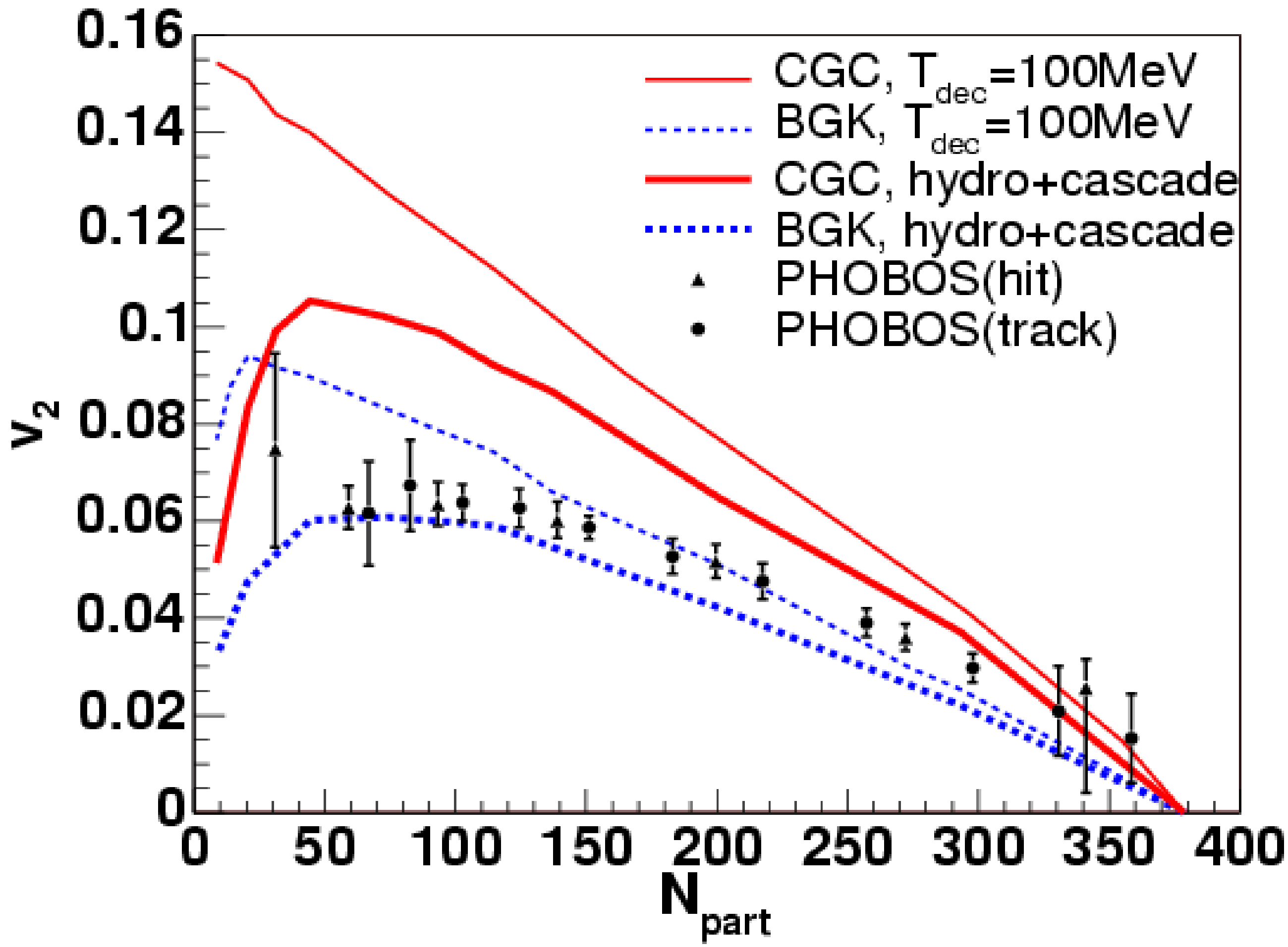
Hydro with CGC vs. Glauber initial conditions



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!

Scaling properties:

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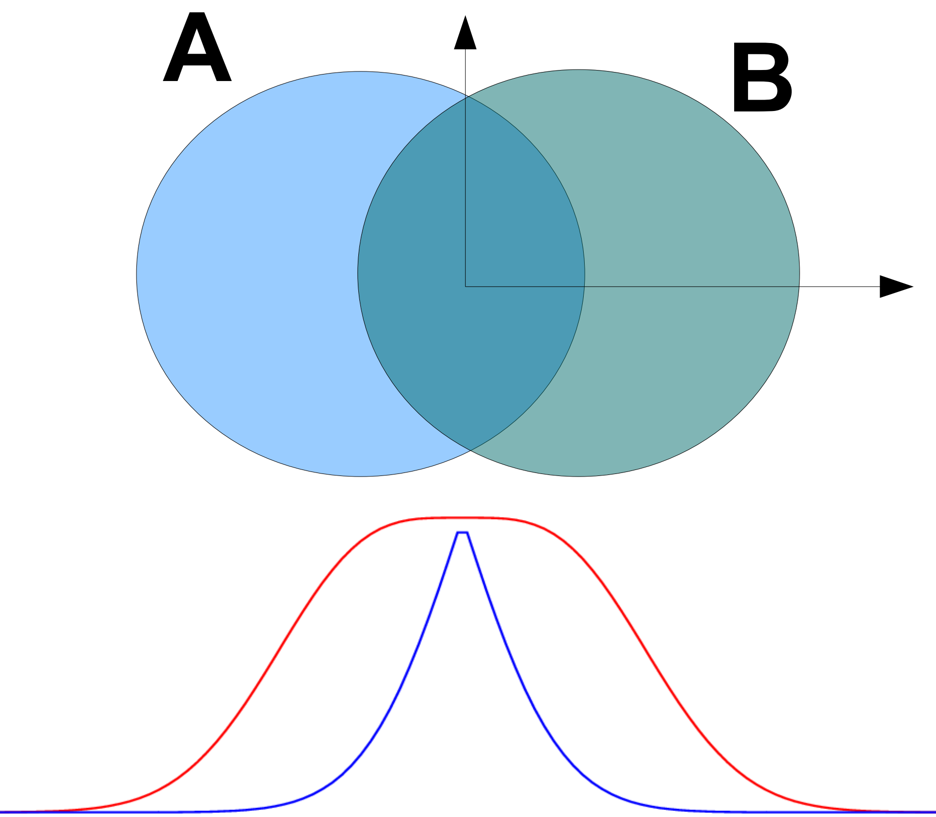
$$\frac{dN_g}{d^2 r_\perp dy} = \frac{4\pi N_c}{N_c^2-1}\int \frac{d^2 p_t}{p_t^2}\int d^2 k_t \alpha_s \phi(x_1, k_t^2)\phi(x_2, (p_t-k_t)^2)$$

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

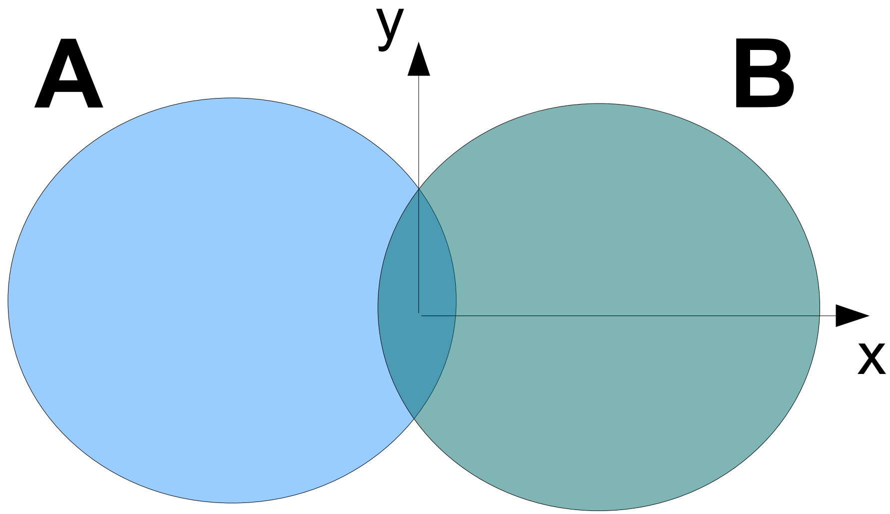


CGC: $\frac{dN}{dy} \sim \min(\rho_{\mathrm{part}}^A, \rho_{\mathrm{part}}^B)$

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

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

Peripheral Collisions:



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

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

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

Problems

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

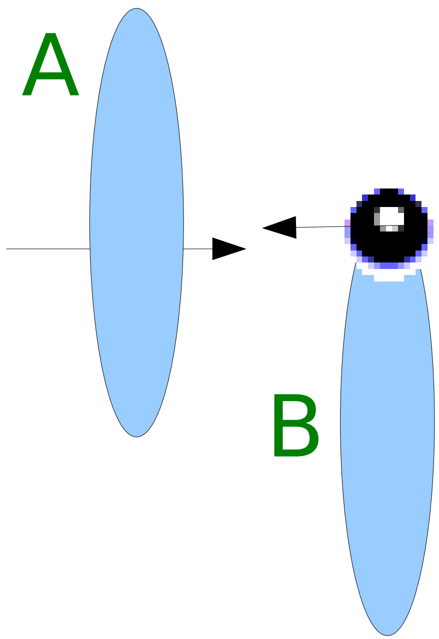
  (Lappi, Venugopalan, nucl-th/0609021)

- $Q_s \to 0$ at the surface

  (IR sensitivity, unreliable for periph.
  collisions and/or lighter ions)

fKLN

nucl-th/0605012
nucl-th/0611017



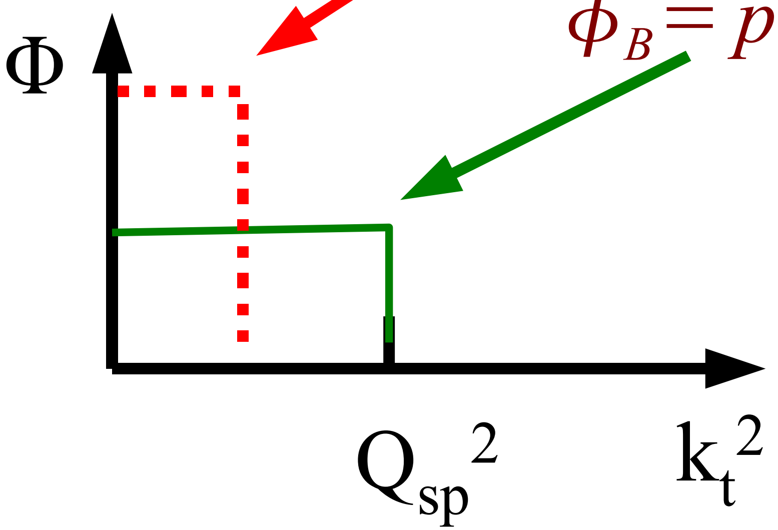
$$Q^2_{sB} = Q^2_{sp} T_B$$

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

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

$$\phi_B = \phi(Q^2_{sp}\ \langle T_B(r_t)\rangle)\ ,$$

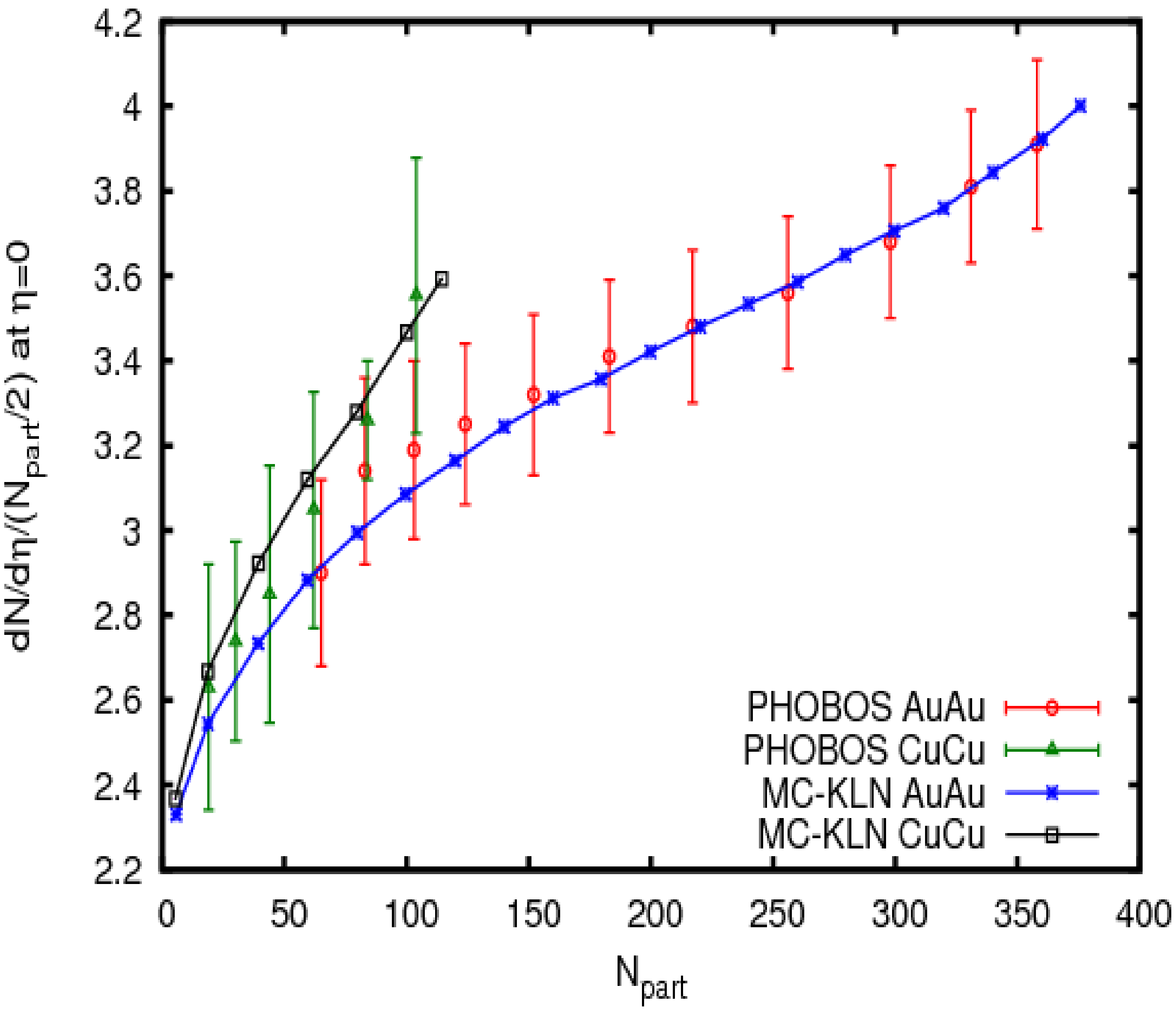
$$\phi_B = p_B\ \phi(Q^2_{sp})$$

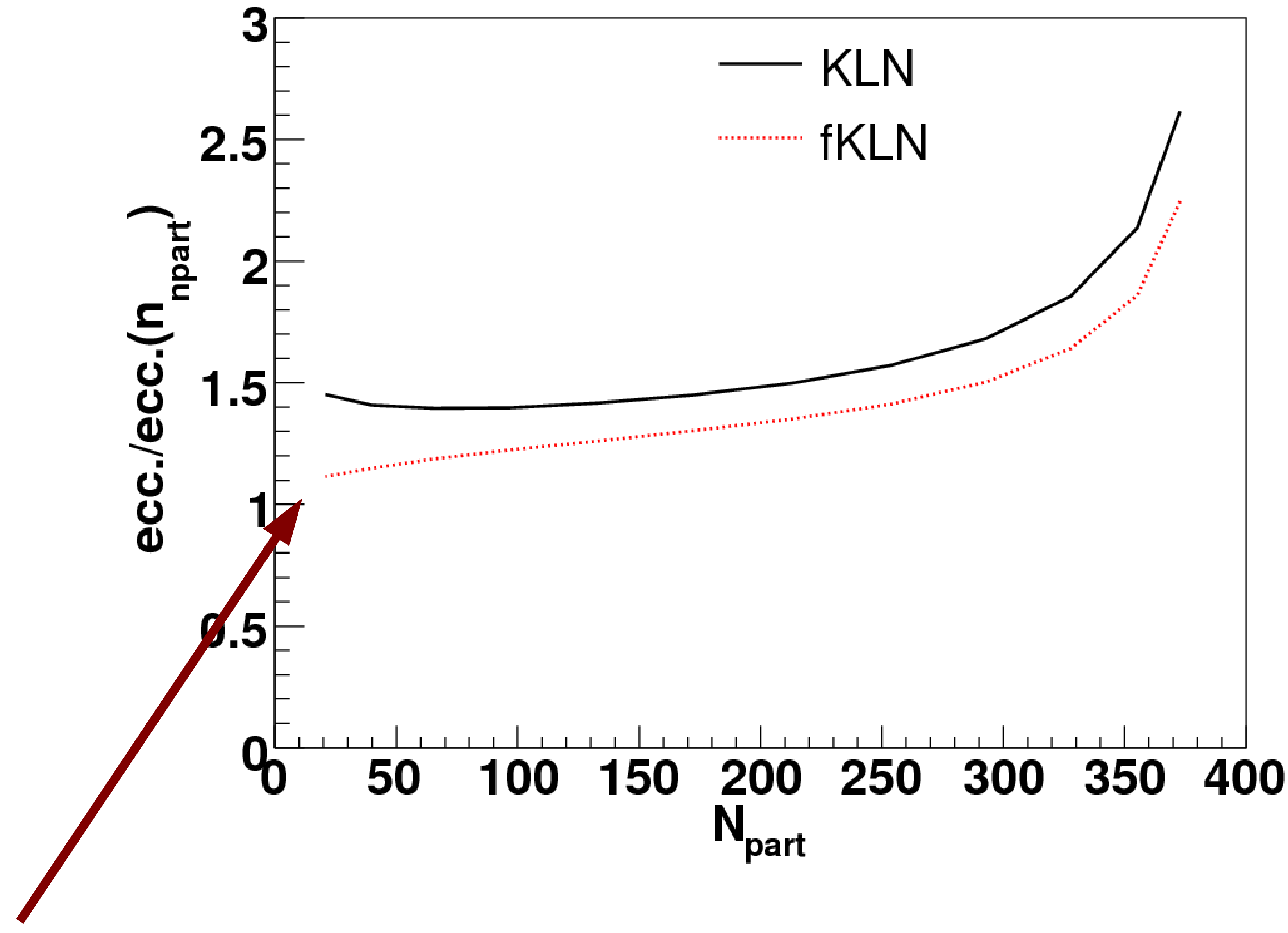


$$\phi_B(\langle T_B\rangle) \to p_B\, \phi_B(\langle T_B\rangle/p_B)$$

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

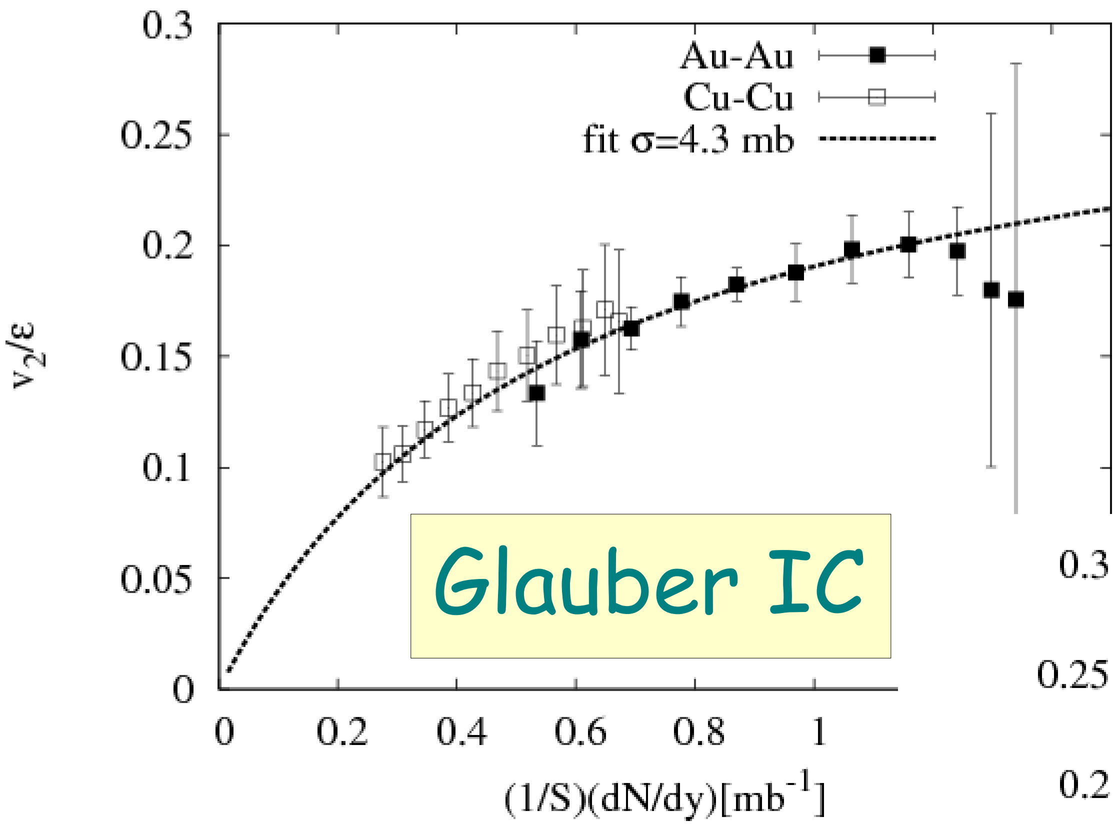
Results: Multiplicity



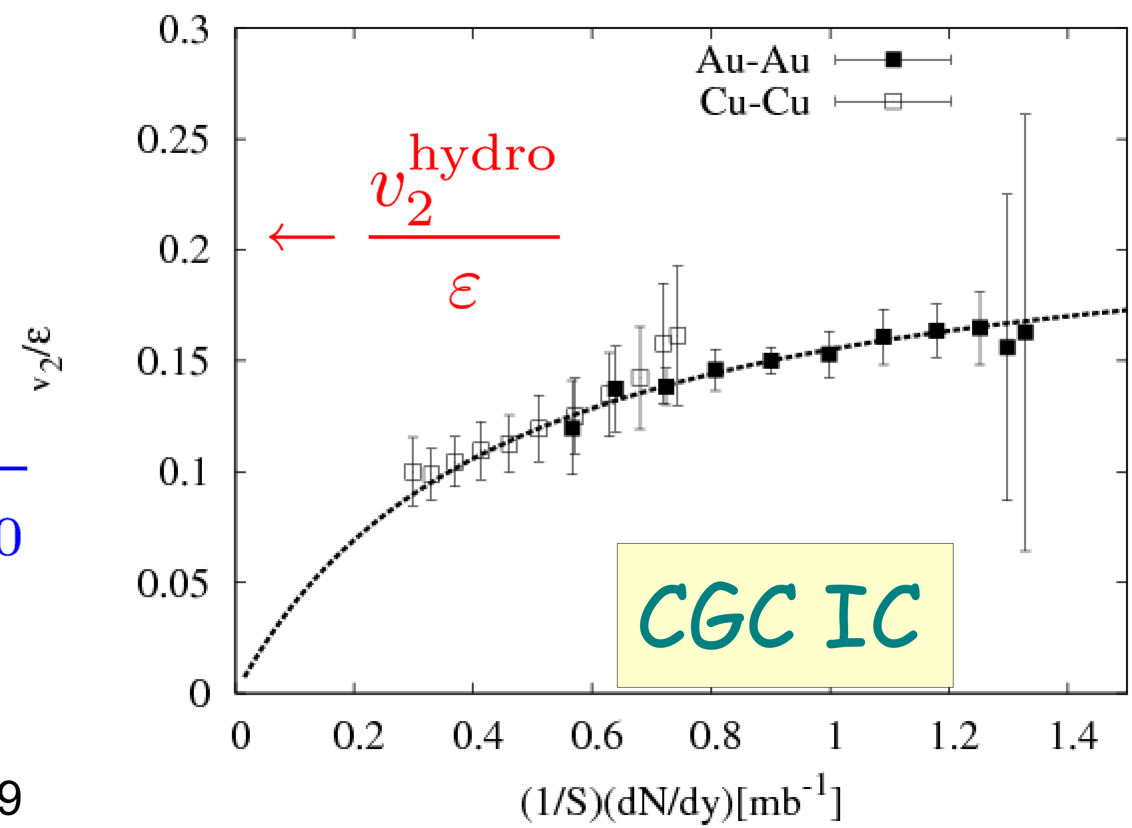


fKLN reproduces Glauber in peripheral collisions !

Voloshin/Poskanzer plot: scaled flow vs density



$\leftarrow \frac{v_2^{\rm hydro}}{\varepsilon}$



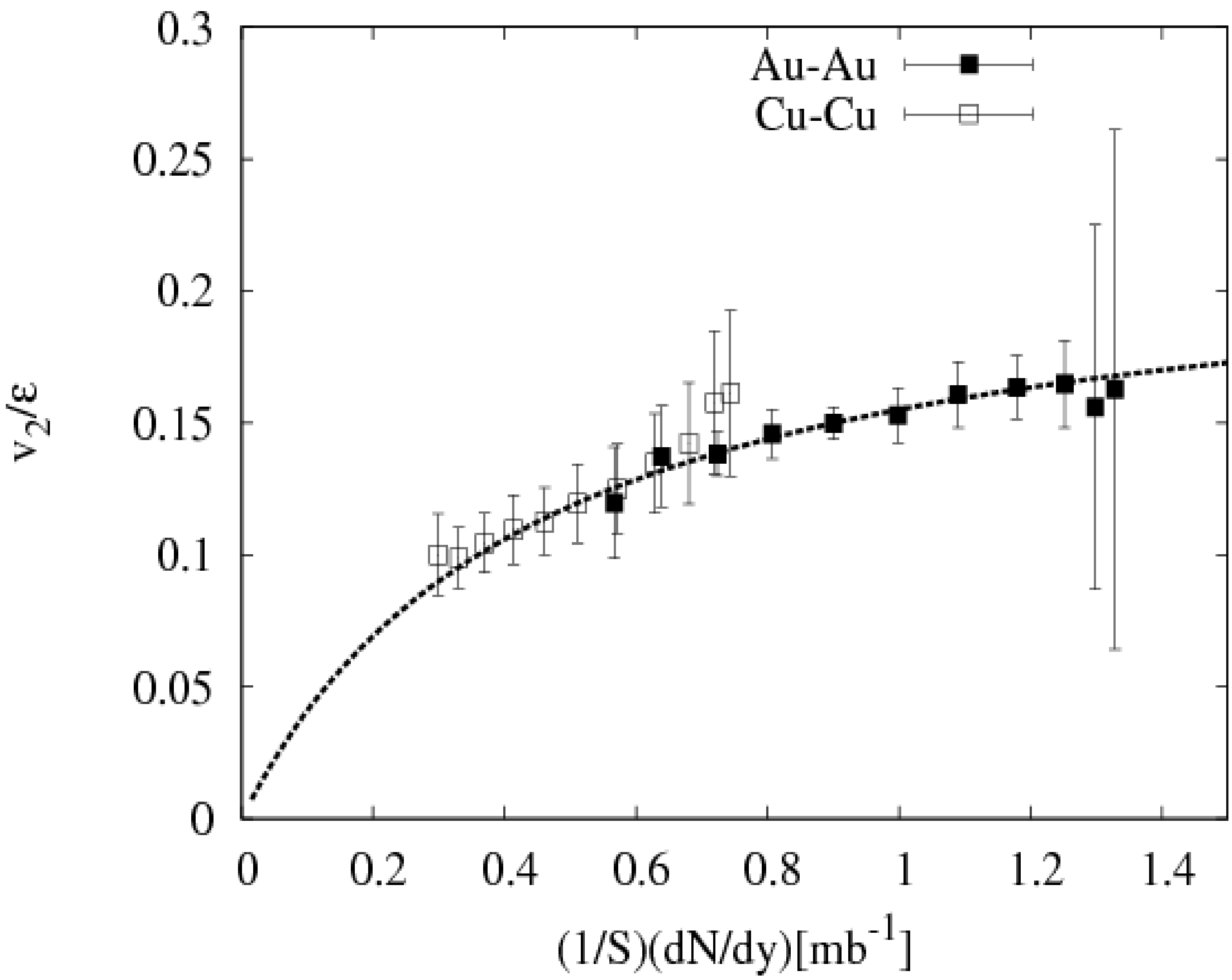
$\leftarrow \frac{v_2^{\rm hydro}}{\varepsilon}$

$$\frac{v_2}{\varepsilon} = \frac{v_2^{\rm hydro}}{\varepsilon}\frac{1}{1+K/K_0}$$

$$\frac{1}{K} = \frac{\sigma}{S}\frac{dN}{dy}c_s$$

nucl-th/0508009

extracted EoS, viscosity depend on IC !



- Consistent with hydro limit: $K/K_0 \sim 0.4$
- Saturation seen
- Finite X-section
  σ ~ 7.6 mb (CGC)
  σ ~ 4.3 mb (Glauber)
- Viscosity estimate
  η/s ~ 0.1 (CGC)
  η/s ~ 0.2 (Glauber)
- Speed of sound
  c_s(CGC) / c_s(Gl.) ~ .7

Drescher, Dumitru, Gombeaud, Ollitrault, arXiv:0704.3553

- Ideal hydro <u>should</u> overshoot flow data:

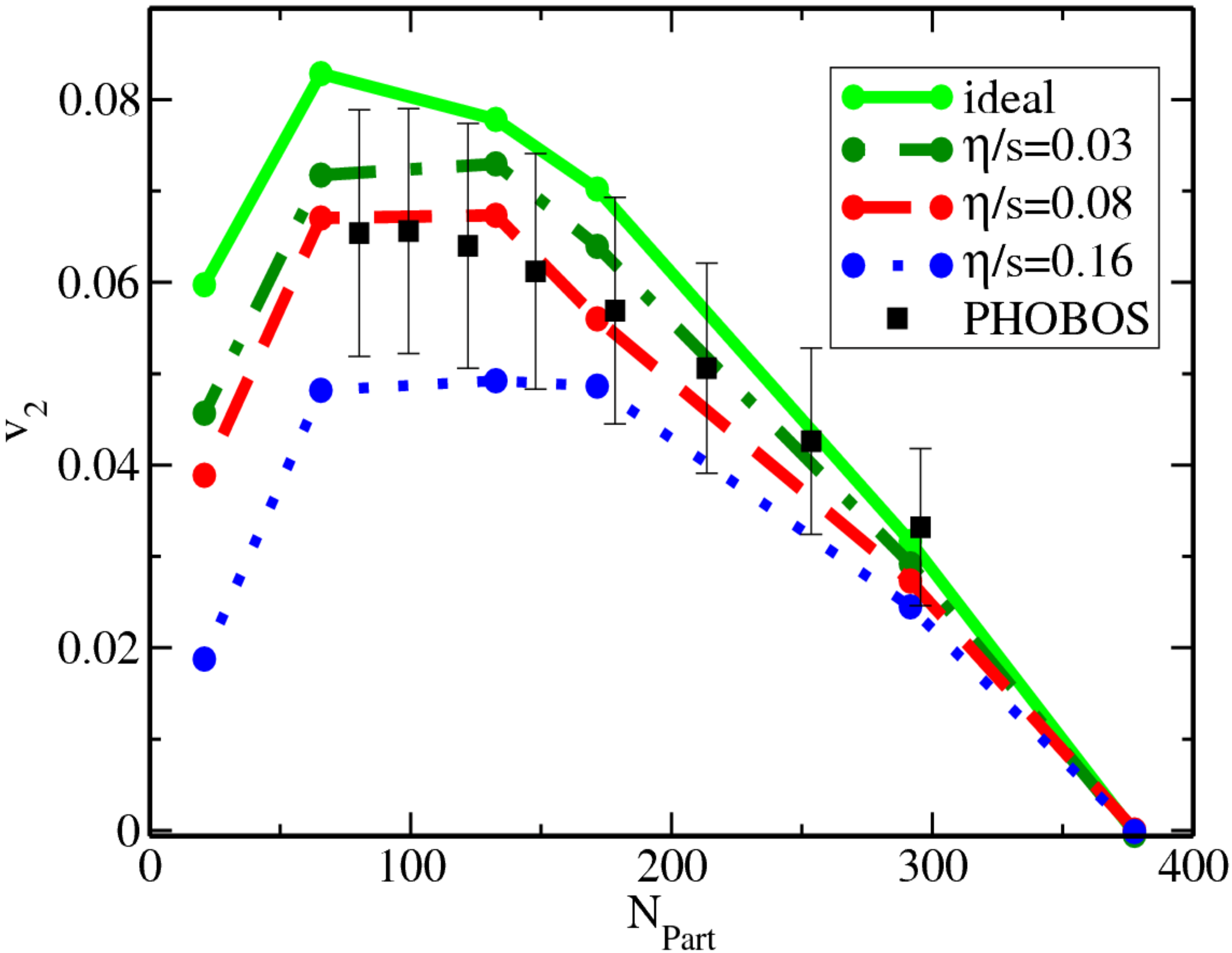
  EoS should give $v_2^{\rm hydro}/\varepsilon \simeq 0.3$ (Glauber)

  $v_2^{\rm hydro}/\varepsilon \simeq 0.2$ (CGC)

- Higher eccentricity of CGC-IC:
  → lower c_s ("softer" EoS), not larger η/s

- Hydro ok for semi-central Au+Au:
  dissip. correction ~ 30%

-30% agrees with 2+1d viscous hydro:



but EoS should be harder !

Romatschke & Romatschke, arXiv:0706.1522

Summary

- Initial conditions key element of hydro fits to RHIC data
- CGC initial condition:
  higher eccentricity for semi-central Au+Au $\rightarrow$
  requires softer EoS, lower η/s