

Hydrodynamics for Relativistic Heavy Ion Collisions

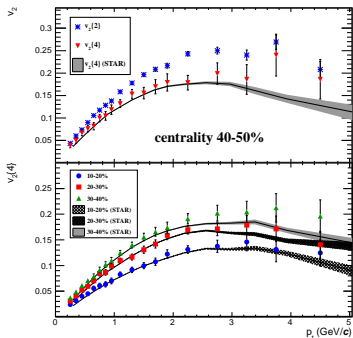
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Wojtek Broniowski and Iwona Wyskiel

Peniche, 08.05.2012

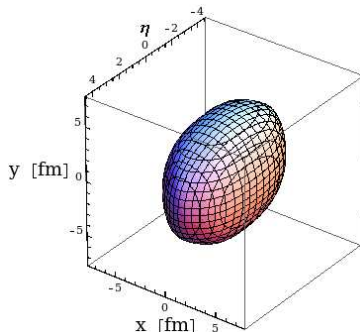
ALICE Pb-Pb@2.76TeV



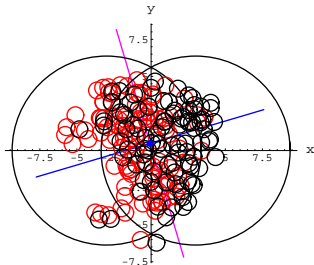
Strong collective flow

Hydrodynamic expansion of dense matter

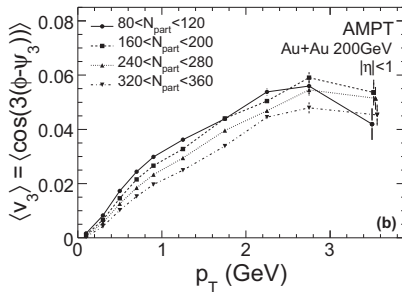
- ▶ Relativistic hydro : $\partial_\mu T^{\mu\nu} = 0$
- ▶ nearly perfect fluid
- ▶ local temp. ; local velocity
- ▶ 3+1D
- ▶ **initial conditions**
- ▶ **equation of state**
- ▶ **viscosity**
- ▶ **event by event**



Initial profile

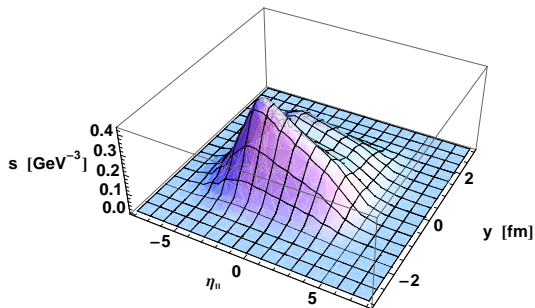
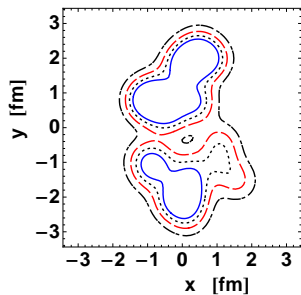


- Glauber \leftrightarrow fKLN
fluctuating initial density
 \rightarrow larger eccentricity
 \rightarrow fluctuating eccentricity
 \rightarrow triangular deformation ϵ_3

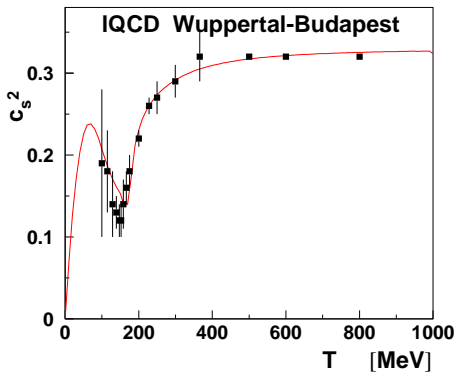


B. Alver, G. Roland

Fluctuating initial conditions

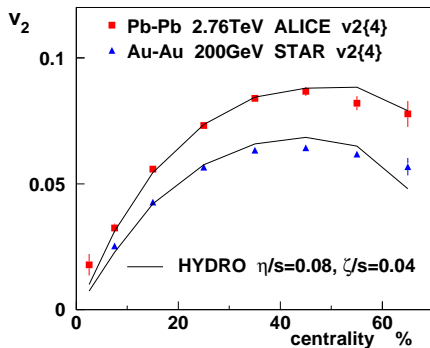


event by event hydrodynamics



IQCD + Hadron Gas

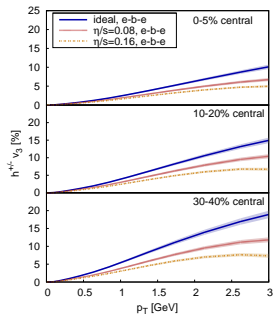
HBT requires hard EOS



$$\begin{aligned}
 \frac{dN}{dyd^2p_{\perp}} = \frac{dN}{2\pi dy p_{\perp} dp_{\perp}} & (1 + 2v_1 \cos(\phi - \Psi_1) + 2v_2 \cos(2\phi - 2\Psi_2) \\
 & + 2v_3 \cos(3\phi - 3\Psi_3) + \dots)
 \end{aligned}$$

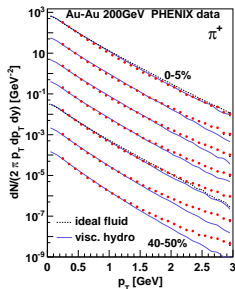
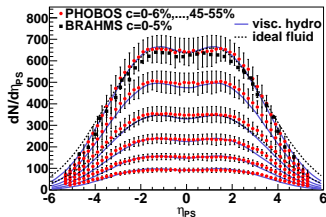
3 + 1-D viscous hydrodynamics

Au-Au 200GeV

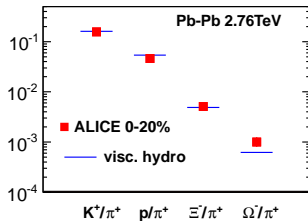
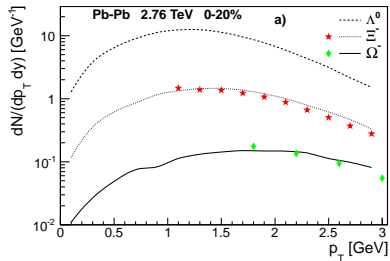
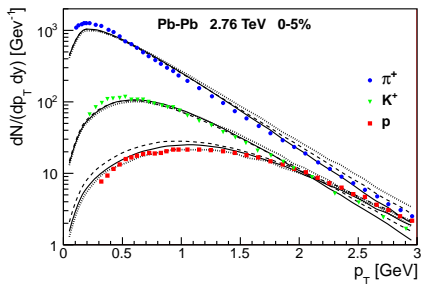


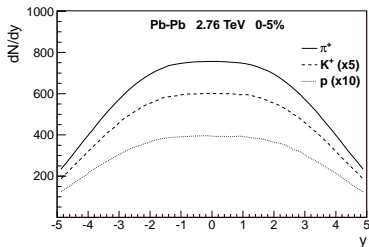
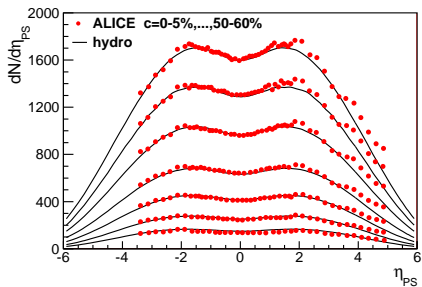
first 3+1D visc. : B.Schenke et al.

independent code : PB

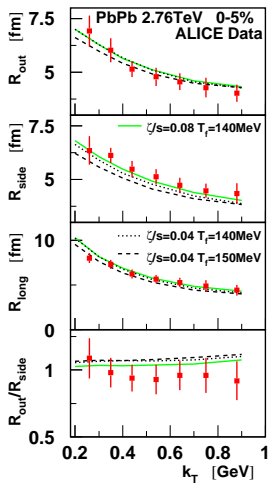


Pb-Pb 2.76TeV

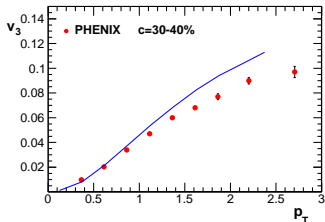
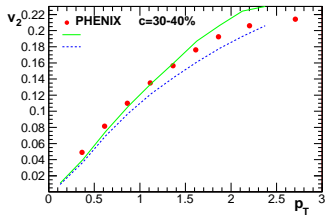
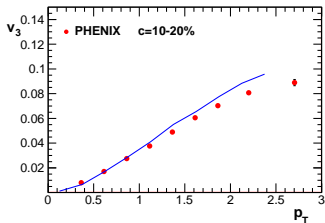
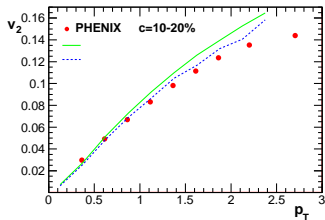




HBT

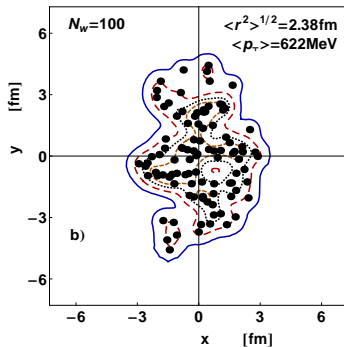
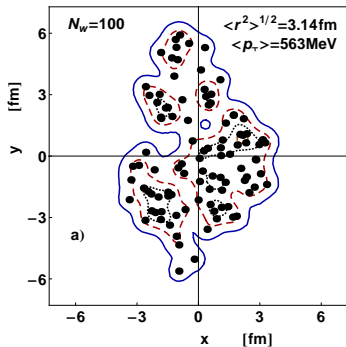


v_2 and v_3 Au-Au@200 GeV

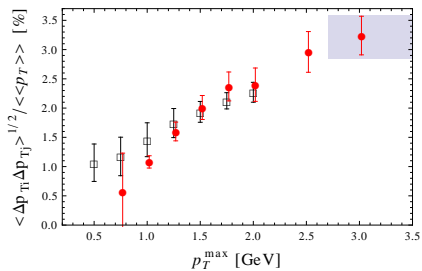
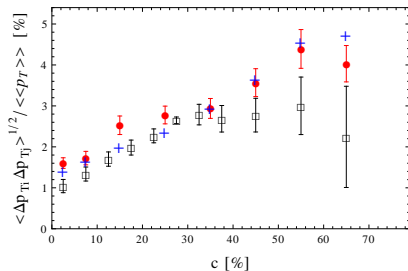


event-by-event

Size fluctuations \leftrightarrow p_{\perp} fluctuations - “ v_0 ”



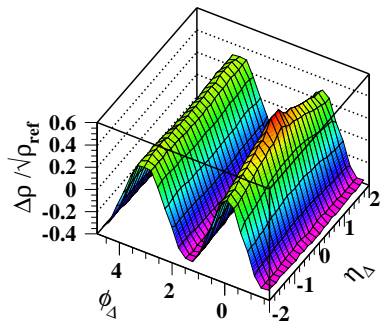
PHENIX data vs. hydro.



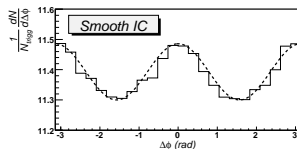
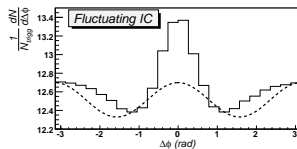
$$\frac{\Delta p}{p} \simeq 0.3 \frac{\Delta r}{r}$$

Two-particle correlations

STAR



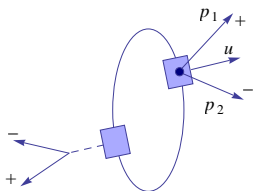
flow correlations



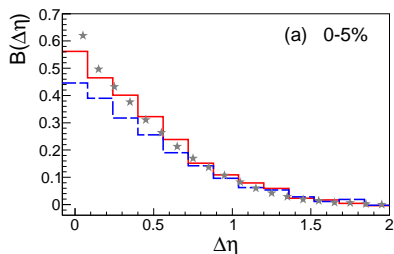
J. Takahashi et al.

Charge balancing

local charge conservation



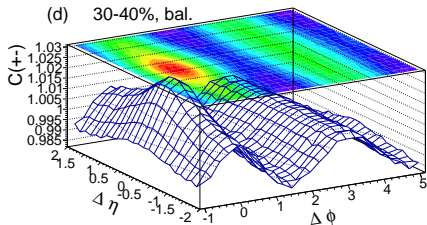
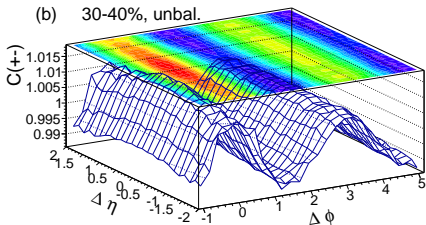
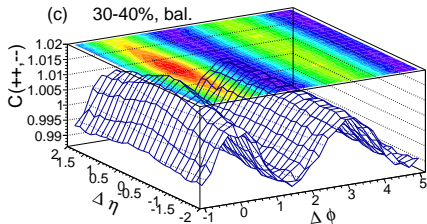
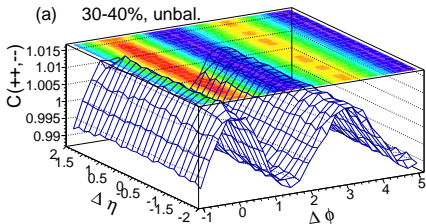
charge balance function



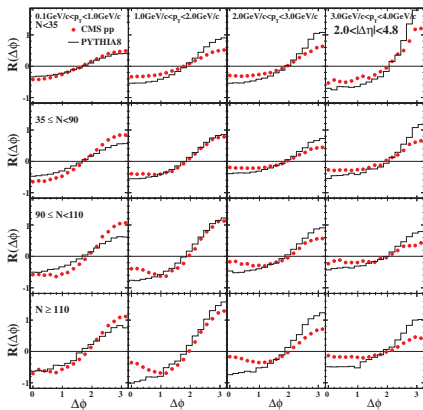
Charge balancing

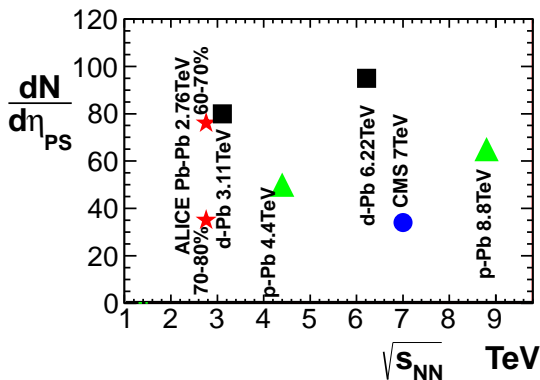
no charge balancing

charge balancing



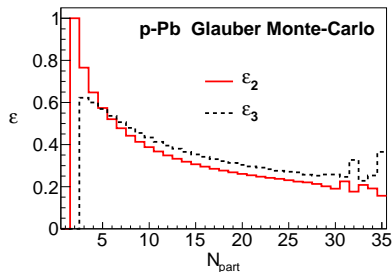
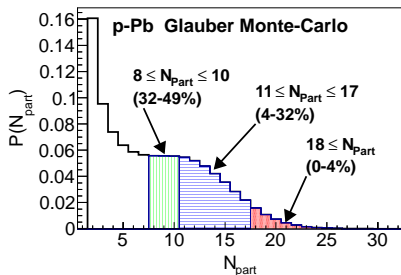
Flow in p-p ??

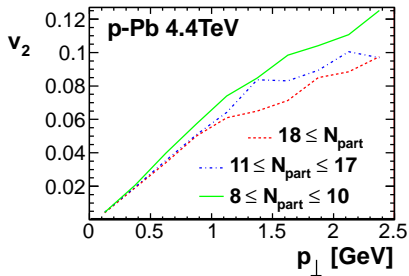




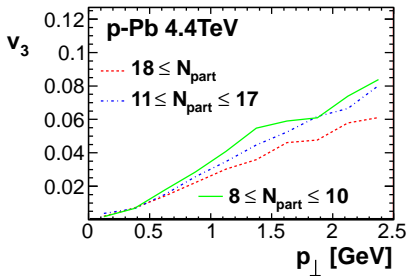
large multiplicity - large fireball - collective expansion?

Fireball in p-Pb

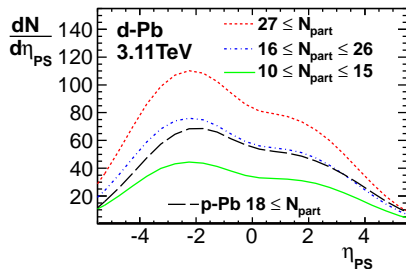




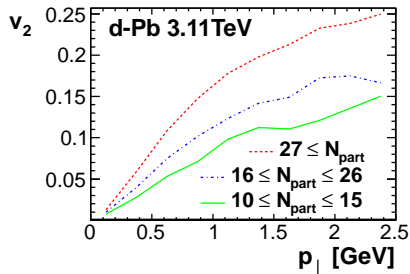
elliptic flow in p-Pb



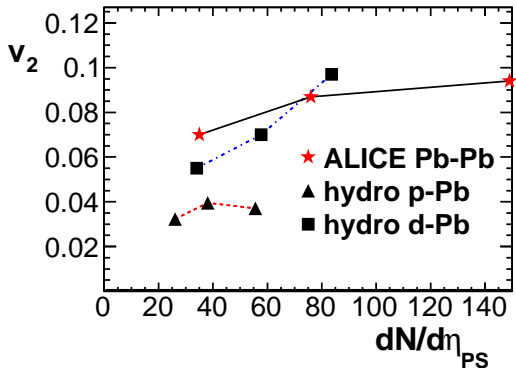
triangular flow



hydrodynamic expansion



large elliptic flow



- ▶ collective flow effects \simeq peripheral Pb-Pb
- ▶ can be observed
- ▶ p-Pb (d-Pb) is not p-p superposition
- ▶ only p-p as baseline

- ▶ viscous hydrodynamics works (?) at RHIC and LHC
- ▶ sophistications: 3 + 1D - event by event
- ▶ p_{\perp} fluctuations, v_1 , v_2 , v_3 reflect initial size and shape
- ▶ dihadron correlations - soft ridge explained
- ▶ p-Pb at 4.4TeV - fireball \neq NN + cold nucl. matter effects