Two-body nucleon-nucleon correlations in Glauber models - GLISSANDO 2*

M. Rybczyński[1], W. Broniowski[1,2]

[1]Institute of Physics, Jan Kochanowski University, Kielce, Poland
[2]The Henryk Niewodniczański Institue for Nuclear Physics Polish Academy of Sciences, Cracow, Poland

**based on W. Broniowski and M. Rybczyński, Phys. Rev. C81 (2010) 064909*

OUTLINE

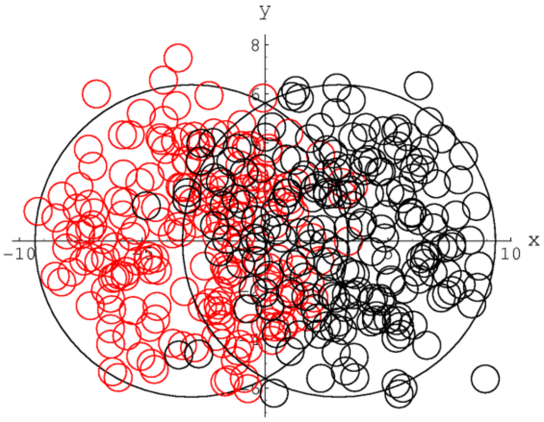
1. NN correlations
   - The important role of two-body nucleon correlations in nuclear distributions
   - Can be simulated with hard-core repulsion with d = 0.9 fm

2. Perfect tool: GLISSANDO – GLauber Initial State Simulation AND mOre
   - Superposition of produced particle distribution on the distribution of sources
   - Core-corona
   - Higher-order Fourier components in collective flow (triangular flow)
   - 3D distributions, initial conditions for hydro
   - Gaussian wounding profile

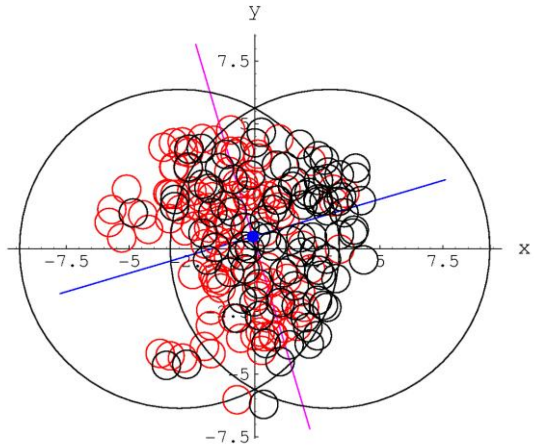
3. Sample results of simulation:
   - Eccentricity
   - Multiplicity fluctuations
   - Size fluctuations

4. Wounding profile dependence
   - important effects
   - quenching of eccentricity!

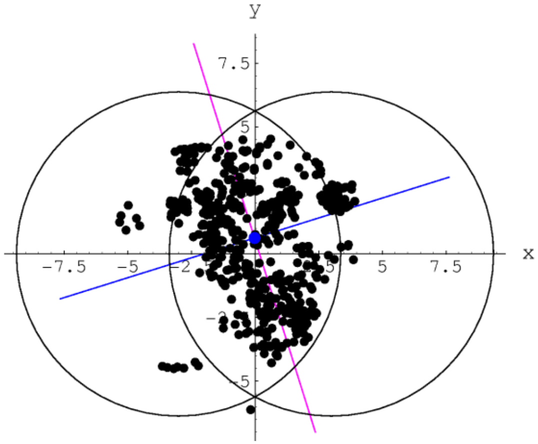
MONTE-CARLO SIMULATIONS IN GLAUBER MODELS: A TYPICAL GOLD-GOLD EVENT



all nucleons



wounded nucleons



binary collisions

Most popular picture of the early phase of collision

New:

- NN correlations (from external distributions)
- weight of sources fluctuates (superposition model)
- Gaussian wounding profile more realistic (and matters)

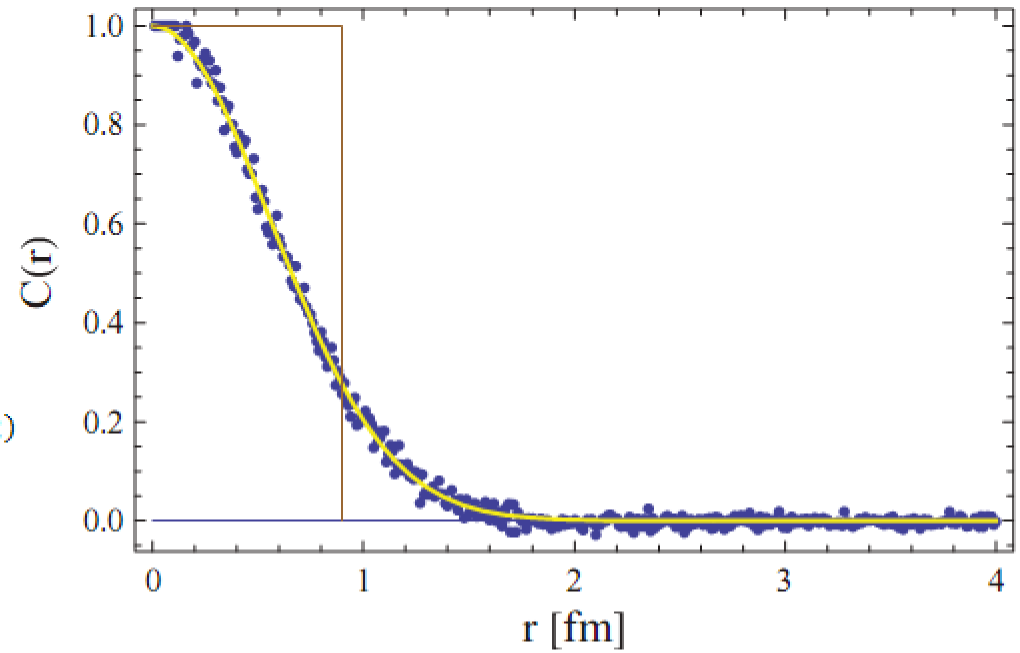
NUCLEAR CORRELATIONS

M. Alvioli, H.J Drescher and M. Strikman, Phys. Lett. B680 (2009) 225
M. Alvioli, H.J Drescher and M. Strikman (2009), http://www.phys.psu.edu/~malvioli/eventgenerator/

$$C(r) = 1 - \frac{\rho_C^{(2)}(r)}{\rho_U^{(2)}(r)}$$

$$\rho_C^{(2)}(r) = \int d^2\Omega \int d^3R\,\rho^{(2)}(\mathbf{R}+\mathbf{r}/2, \mathbf{R}-\mathbf{r}/2)$$

$$\rho_U^{(2)}(r) = \int d^2\Omega \int d^3R\,\rho^{(1)}(\mathbf{R}+\mathbf{r}/2, \mathbf{R}-\mathbf{r}/2)\cdot\rho^{(1)}(\mathbf{R}+\mathbf{r}/2, \mathbf{R}-\mathbf{r}/2)$$



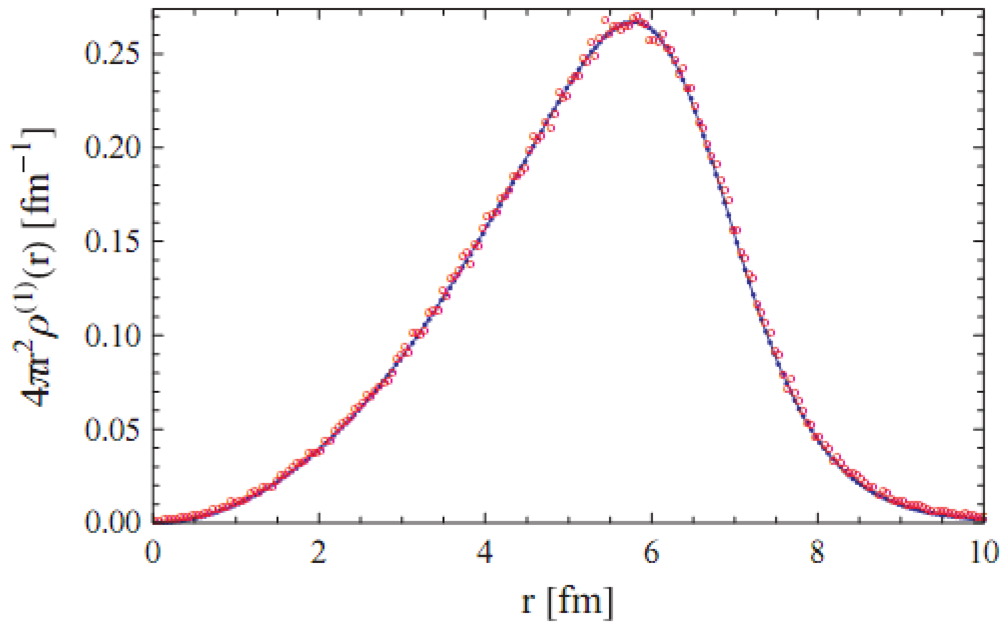
The effects of these correlations on heavy-ion observables turn out to be indistinguishable from the hard-core repulsion with **d=0.9 fm** - see the following part of this talk.

CONFIGURATION OF NUCLEONS IN NUCLEUS

$$\rho^{(1)}(r) = \frac{A}{1 + \exp\left(\frac{r-R}{a}\right)}$$

For ^{208}Pb: $R = 6.59(1)\ fm$

$a = 0.549(2)\ fm$

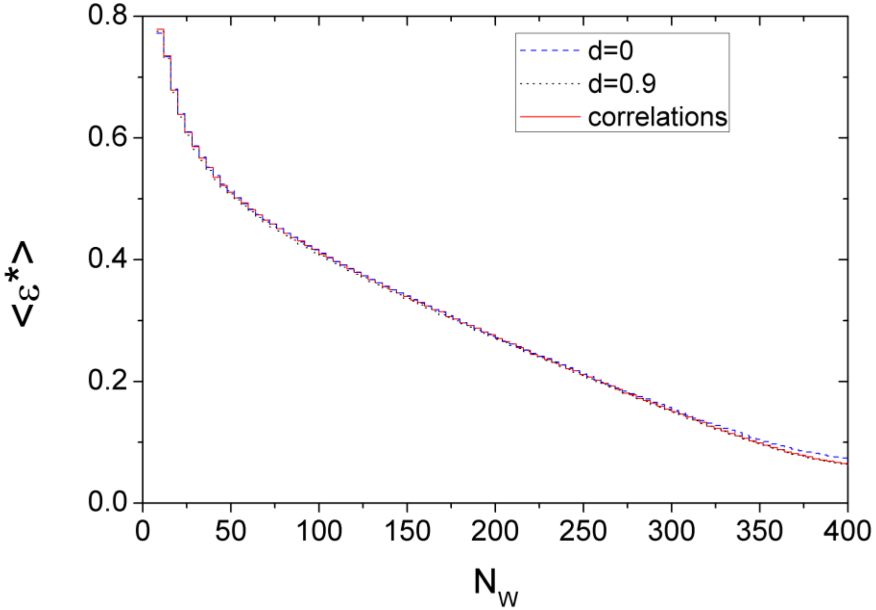


Dots:
Phys. Lett. B680, 225 (2009)
http://www.phys.psu.edu/~malvioli/eventgenerator/

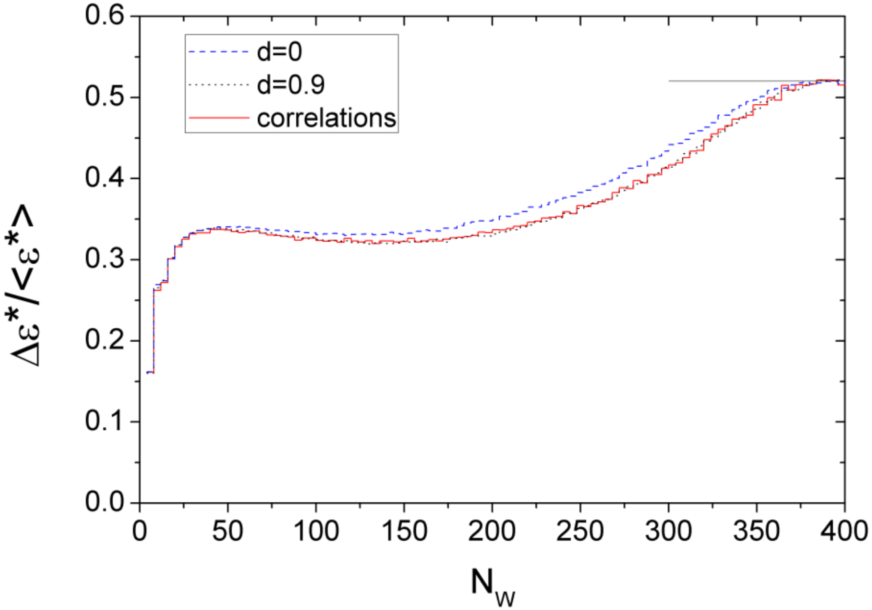
Line: our simulation with **d=0.9 fm**

One-body density reproduced
Need to shrink the initial distribution
(W.Broniowski, M.Rybczyński and P.Bożek, Comput. Phys. Commun. 180 (2009) 69)

RESULTS OF SIMULATION: eccentricity



$$\varepsilon^* = \frac{\sqrt{\left(\sigma_x^2 - \sigma_y^2\right)^2 + 4\sigma_{xy}^2}}{\sigma_x^2 + \sigma_y^2}$$

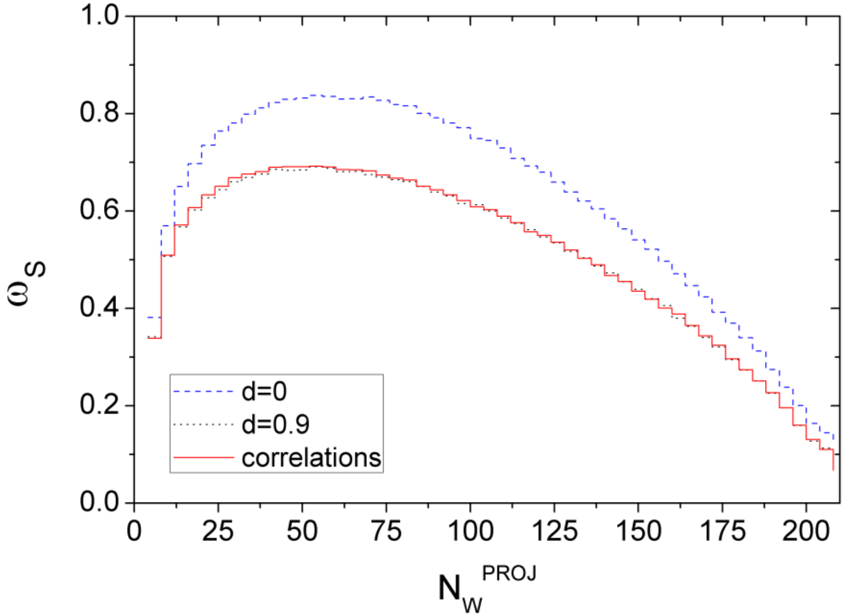


Details in:

B. Alver et al. (PHOBOS), Phys. Rev. Lett. 98 (2007) 242303

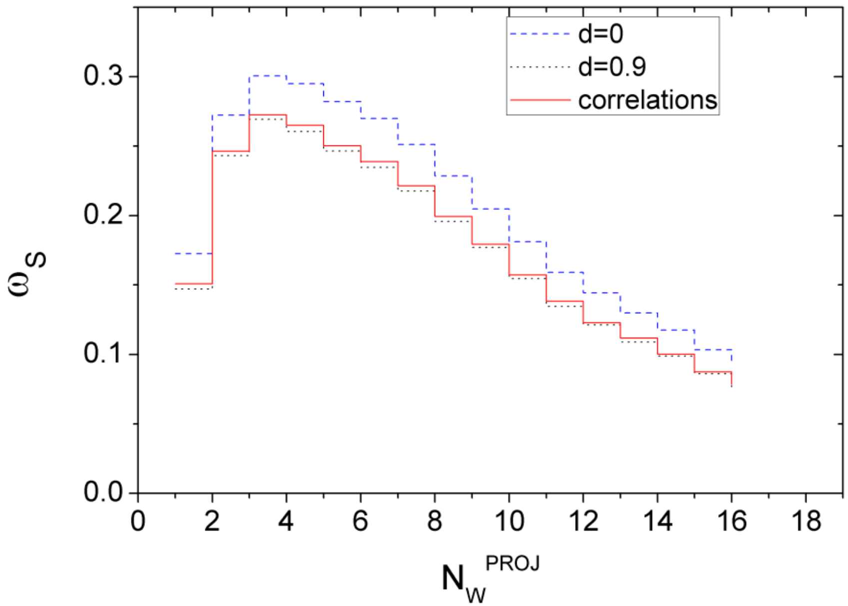
W. Broniowski, M. Rybczyński, Phys. Rev. C81 (2010) 064909

RESULTS OF SIMULATION: multiplicity fluct.



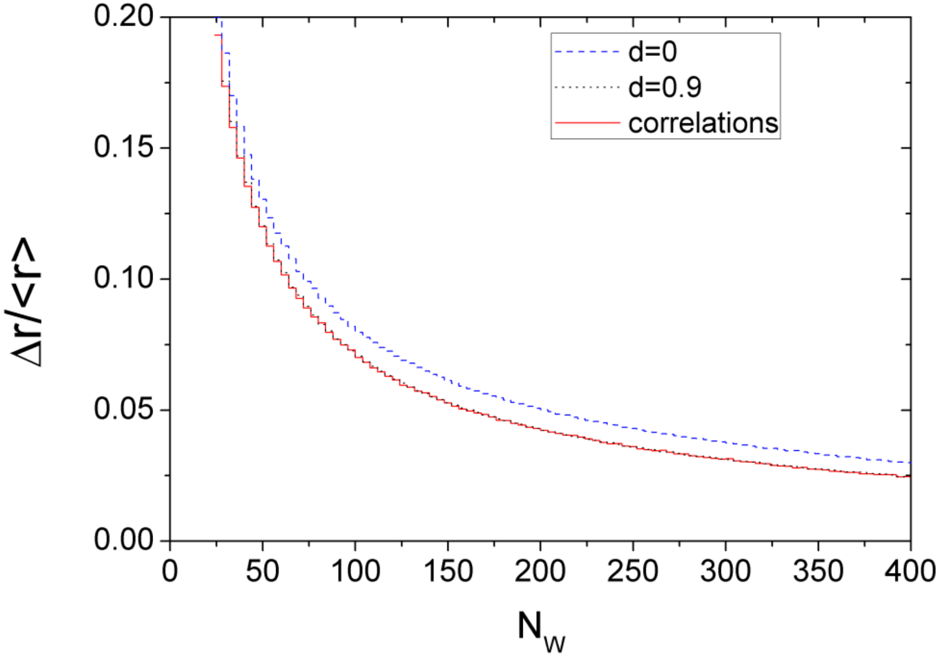
$$N_S = (1-\alpha)\frac{N_W}{2} + \alpha N_{bin}$$

$$\omega_S = \frac{Var(N_S)}{\langle N_S \rangle}$$

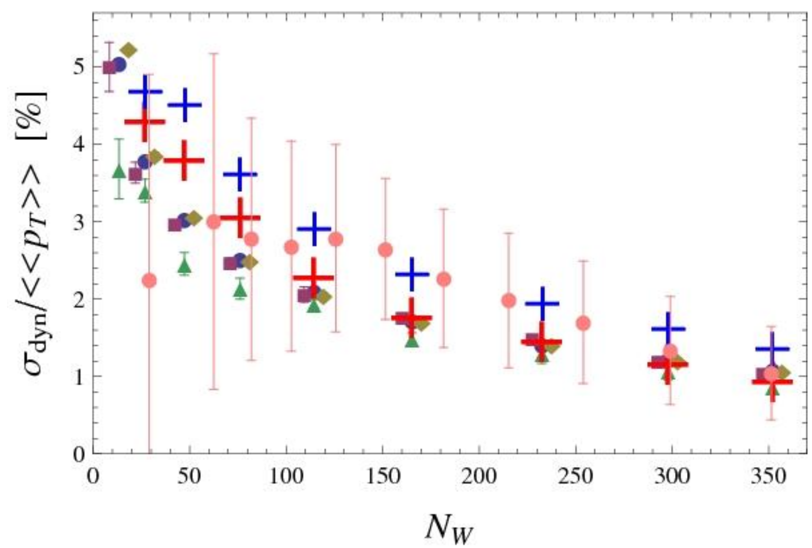


The fluctuations of multiplicity as measured by NA49 (C. Alt et al. (NA49), Phys. Rev. C75 (2007) 064904) remain unexplained

RESULTS OF SIMULATION: size fluct.



$$r = \sum_i w_i \sqrt{(x_i - \langle x \rangle)^2 + (y_i - \langle y \rangle)^2}$$



small points - STAR, Au+Au, various enegries,
pink points - Phenix@200 GeV,
red crosses - wounded nucleon model,
blue crosses – mixed model with alpha=0.145

Details in:
Phys. Rev. C80 (2009) 051902

Size fluctuations explain in a natural way (with hydro as the intermediate stage) the transverse-momentum fluctuations at RHIC
(smaller size -> larger momentum gradient -> larger hydro push -> larger flow velocity at freezout -> larger p_T and vice versa)

GLISSANDO

GLauber Initial State Simulation AND mOre

www.ujk.edu.pl/homepages/mryb/GLISSANDO/

GLISSANDO is a Glauber Monte-Carlo generator for early-stages of relativistic heavy-ion collisions, written in c++ and interfaced to ROOT.

The program can be used for simulation of large variety of colliding systems: p+A, d+A and A+A at wide spectrum of energies.

Several models are implemented: the wounded-nucleon model, the binary collisions model, the mixed model, and the model with hot-spots.

NEW VERSION HAS MORE FEATURES

- The possibility of feeding into the simulations the nuclear distributions accounting for the two-body NN correlations (read from external files, see Alvioli, Drescher and Strikman, Phys. Lett. B680 (2009) 225, the distributions can be found at http://www.phys.psu.edu/~malvioli/eventgenerator/)

- The use of the Gaussian NN wounding profile (which is more realistic than the commonly-used spherical wounding profile, see the analysis by Białas and Bzdak Acta Phys. Polon. B38 (2007) 159)

- The generation of the core-mantle (core-corona) distributions (see Bożek Acta Phys.Polon. B36 (2005) 3071 and Werner Phys. Rev. Lett. 98 (2007) 152301, see also Becattini and Manninen Phys. Lett. B673 (2009) 19 and Bożek Phys. Rev. C79 (2009) 054901)

- The analysis of the triangular shape deformation parameter and profile, relevant for the triangular flow, see Alver and Roland, Phys. Rev. C81 (2010) 054905 and Alver, Gombeaud, Luzum, and Ollitrault, arXiv:1007.5469

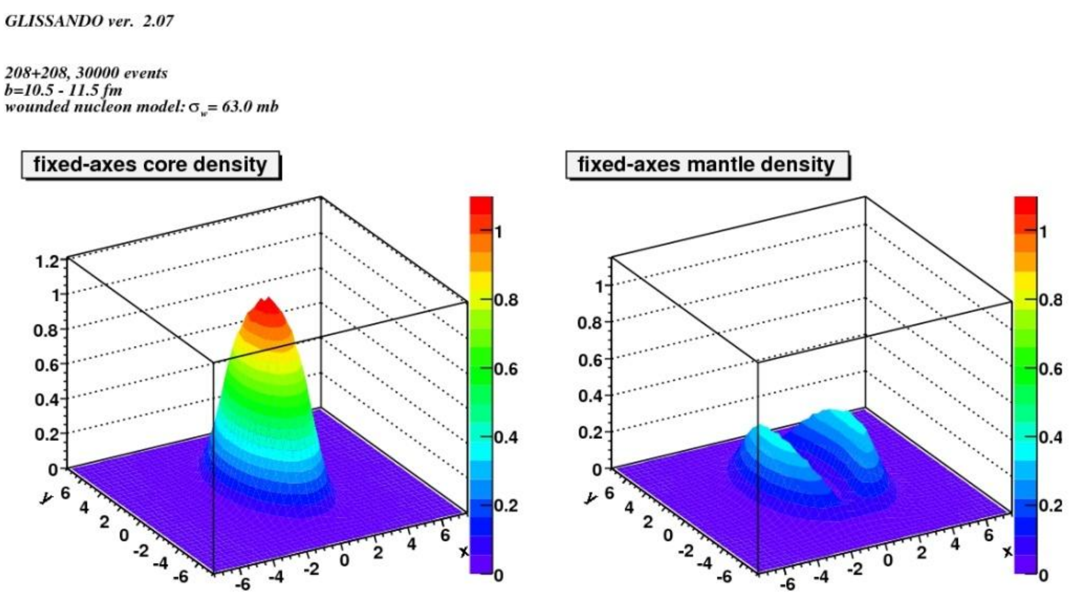
- Generation of rapidity distributions in the wounded-nucleon picture according to the model of Białas and Czyż Acta Phys. Polon. B36 (2005) 905, as implemented by Bożek arXiv:1002.4999. This allows to obtain the fully 3-dimensional distribution of matter in the early Glauber phase of the collision.

GENERAL FEATURES OF GLISSANDO 2

The program generates inter alia the fixed axes (standard) and variable-axes (participant) two- and three-dimensional profiles of the density of sources in the transverse plane and their Fourier components.

Pb+Pb@5.5 TeV/n, Core-corona distributions

core - collided more than once
corona- collided once



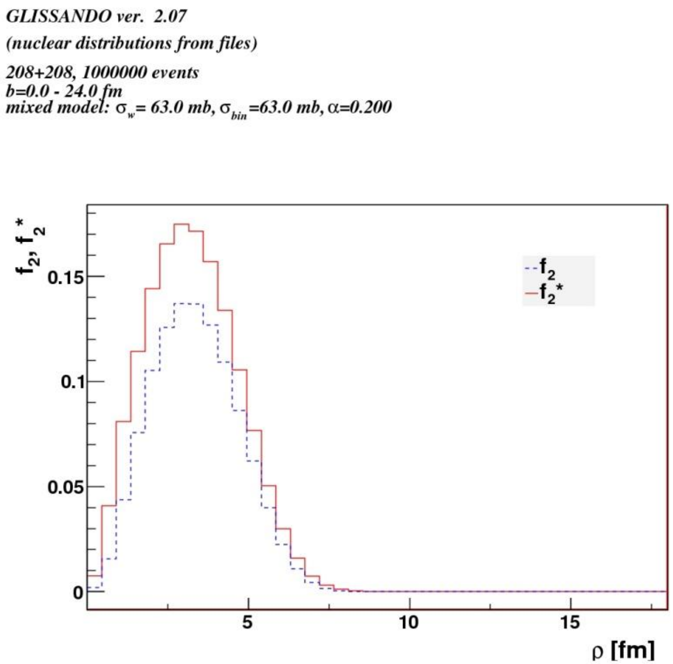
Details in:
P. Bożek, Acta Phys.Polon. B36 (2005) 3071
K. Werner, Phys. Rev. Lett. 98 (2007) 152301

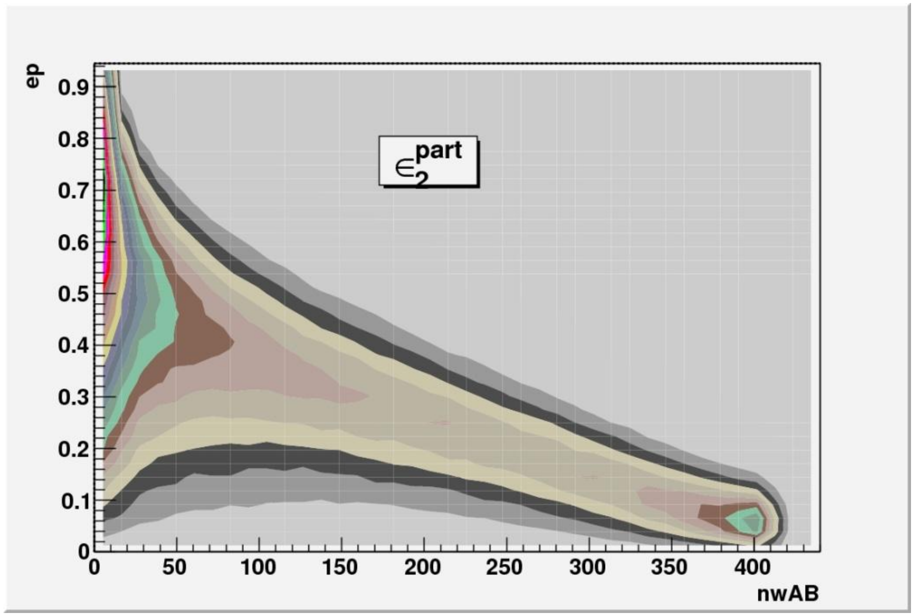
These profiles can be used in further analyses of physical phenomena, such as the jet quenching, event-by-event hydrodynamics, or analysis of the elliptic flow and its fluctuations.

GENERAL FEATURES OF GLISSANDO 2

Characteristics of the event (multiplicities, eccentricities, Fourier coefficients, etc.) are evaluated and stored in a file for further off-line studies.
A number of scripts is provided for that purpose.

Pb+Pb@5.5 TeV/n



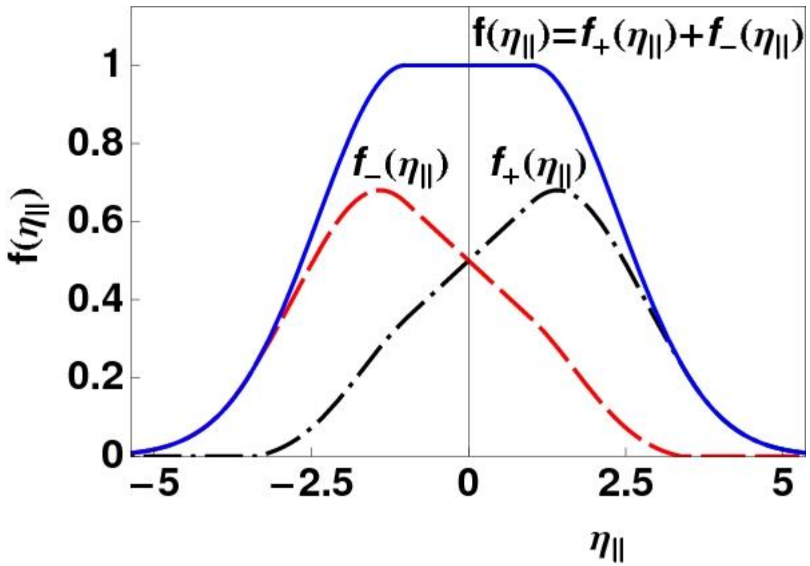


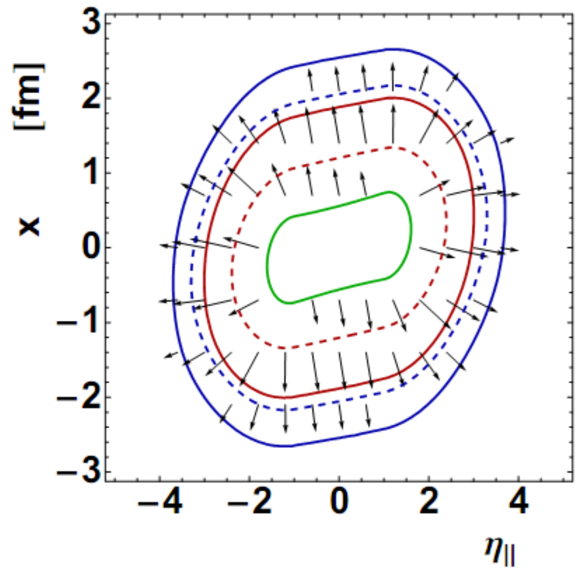
f_2 - radial profile of the second Fourier harmonic - fixed axes
f_2^* - radial profile of the second Fourier harmonic - variable axes (participant geometry)
(can be used to emulate initial conditions for event-by-event hydro)

OTHER POSSIBILITIES

- Possibility of overlaying rapidity distribution over the distribution of sources

- Tilted boundary condition

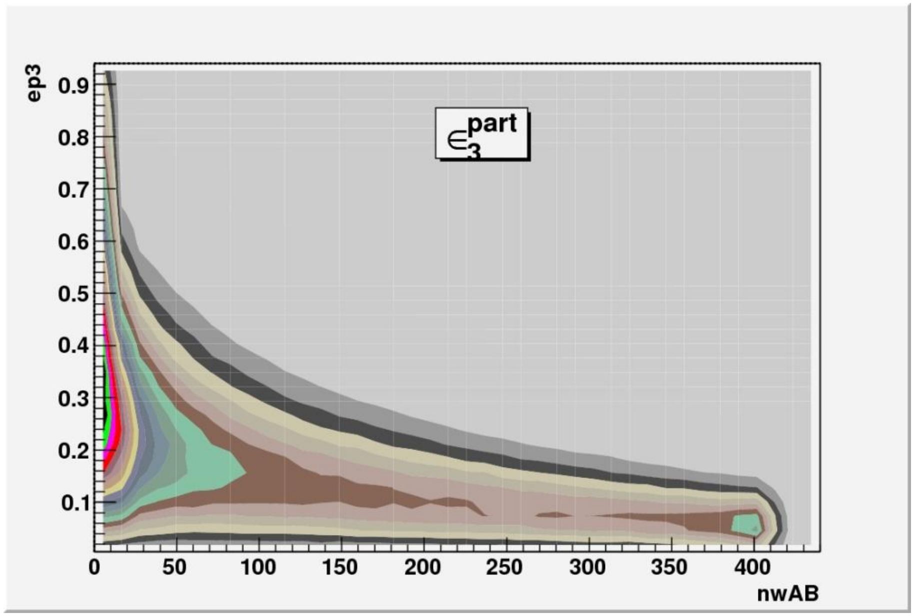


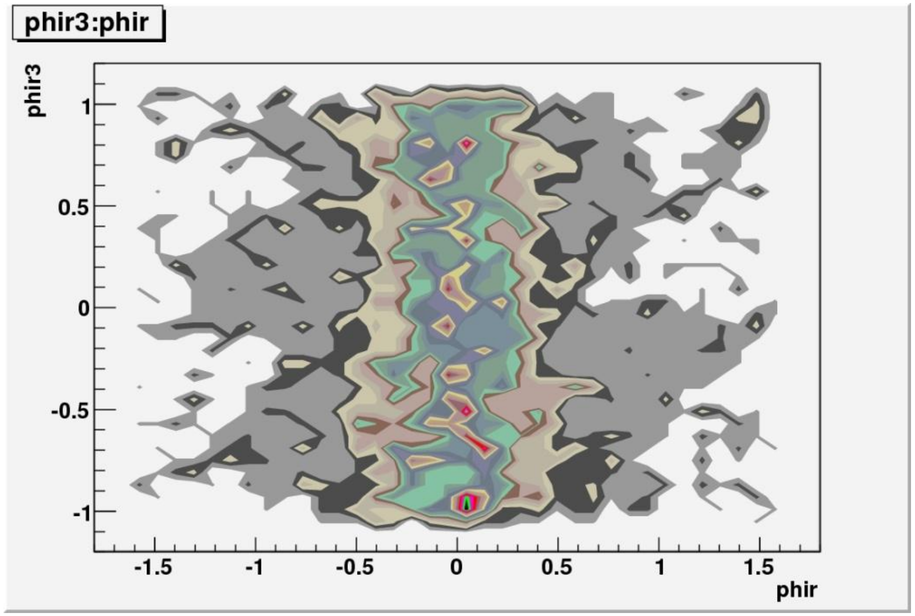


P. Bożek, and I. Wyskiel, Phys. Rev. C81 (2010) 054902 explains for the first time the directed flow v_1 in the hydro approach!

OTHER POSSIBILITIES

- **Triangular flow**





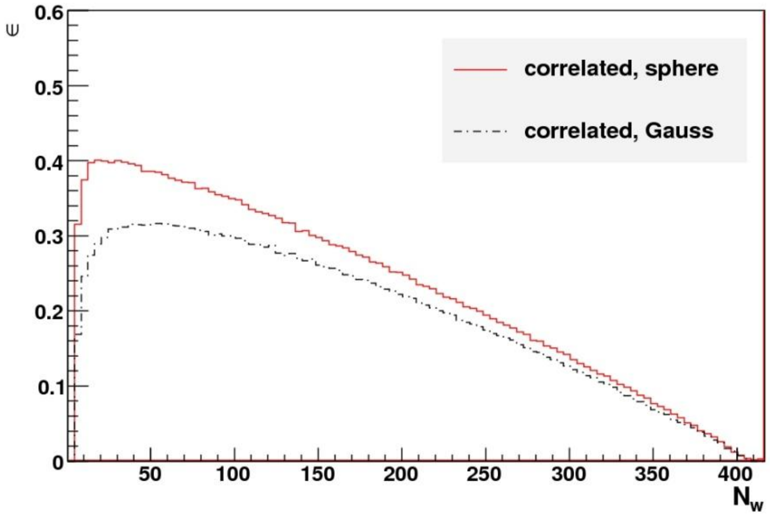
- ε_3^{part} - the triangular deformation coefficient
- lack of correlation between the axes which maximize the second and third Fourier moment

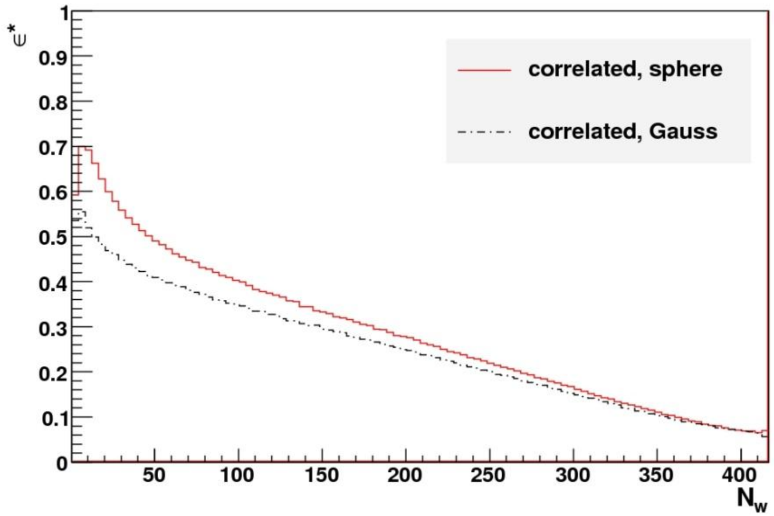
See: Alver and Roland, Phys. Rev. C81 (2010) 054905
Alver et al., arXiv:1007.5469

THE WOUNDING PROFILE

SPHERE: $|r_1 - r_2| < R_0 \quad (\pi R_0^2 = \sigma_{inel})$

GAUSS (more realistic) explains the NN elastic differential cross section
(Białas and Bzdak, Acta Phys. Polon. B38 (2007) 159)





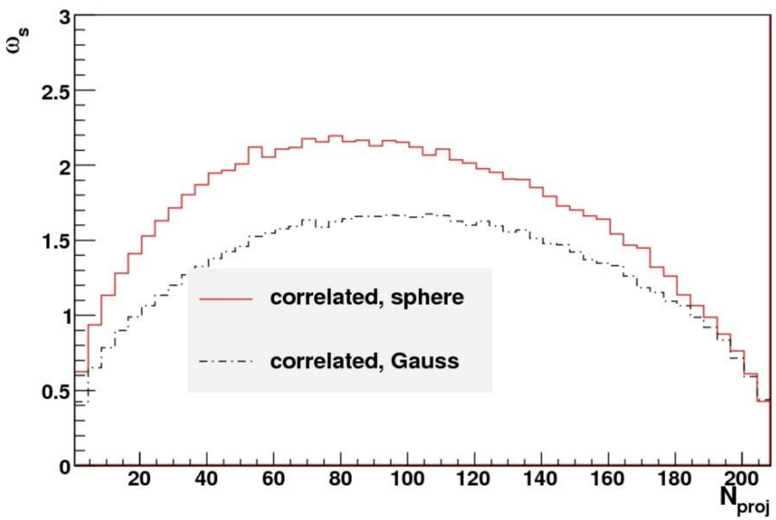
10-15% quenching! - more relevant for peripheral collisions.

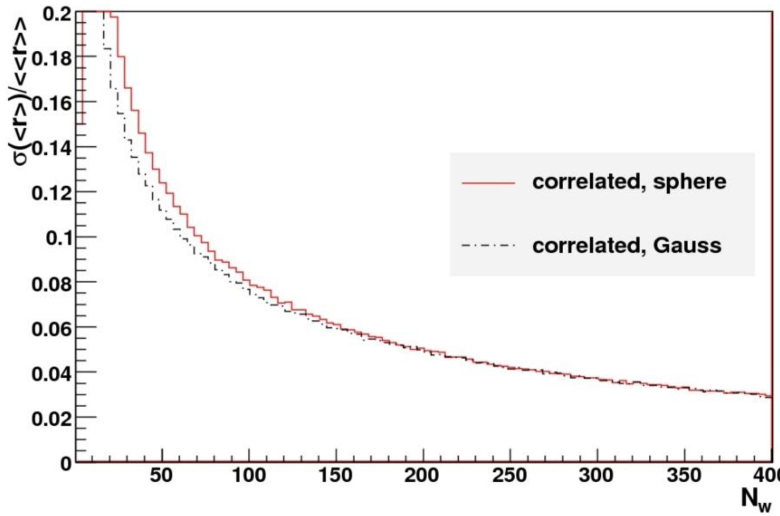
Explanation: with more diluted wounding profile the in-plane nucleons have a larger chance to get wounded, which decreases epsilon.

THE WOUNDING PROFILE

SPHERE: $|r_1 - r_2| < R_0 \quad (\pi R_0^2 = \sigma_{inel})$

GAUSS (more realistic) explains the NN elastic differential cross section
(Białas and Bzdak, Acta Phys. Polon. B38 (2007) 159)





CONCLUSIONS (I)

1. The influence of the nuclear correlations is important for the variety of heavy-ion observables

2. Those correlations can be easily simulated assuming hard-sphere distance between nucleons, d=0.9 fm

3. The shape of wounding profile affects the magnitude of fluctuations of some observables. Quenching of epsilon.

CONCLUSIONS (II)

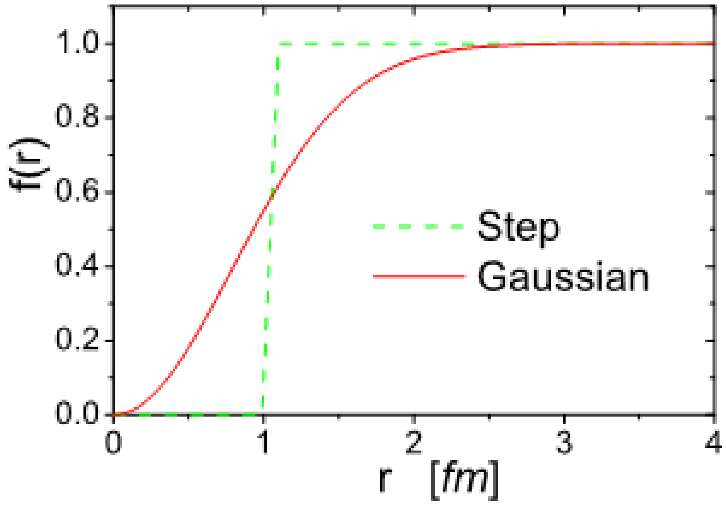
- We hope that with its flexibility and simplicity GLISSANDO will become a useful tool for the heavy-ion community.
- The open-source nature of the code allows for check-ups additions and improvements.
- We have provided examples of numerous applications: determination of A+B cross-section and centrality classes, analysis of eccentricities both in the fixed- and variable-axes frame, event-by-event fluctuations, correlation of various quantities.
- Program is obtainable from: http://www.ujk.edu.pl/homepages/mryb/GLISSANDO/
- We can assist anyone interested in running the code or tayloring it to his/her needs (for the price of one citation!)

Back-up

NUCLEAR CORRELATIONS

$|\Psi|^2$ is used as a Metropolis weight function

$$\Psi(\boldsymbol{r}_1, \ldots, \boldsymbol{r}_A) = \prod_{i<j}^{A} \hat{f}(r_{ij}) \Phi(\boldsymbol{r}_1, \ldots, \boldsymbol{r}_A)$$



where Φ is given by the independent particle model

Variational **realistic correlation function** used

THE WOUNDING PROFILE (GAUSS)

the wounding profile in b - a parameterization

$$\sigma(b) = A\, exp\left(-\frac{Ab^2}{R_0^2}\right)$$

specific parameters:
R_0 controls the inelastic cross section,
A controls the slope of the differential elastic cross section at t=0

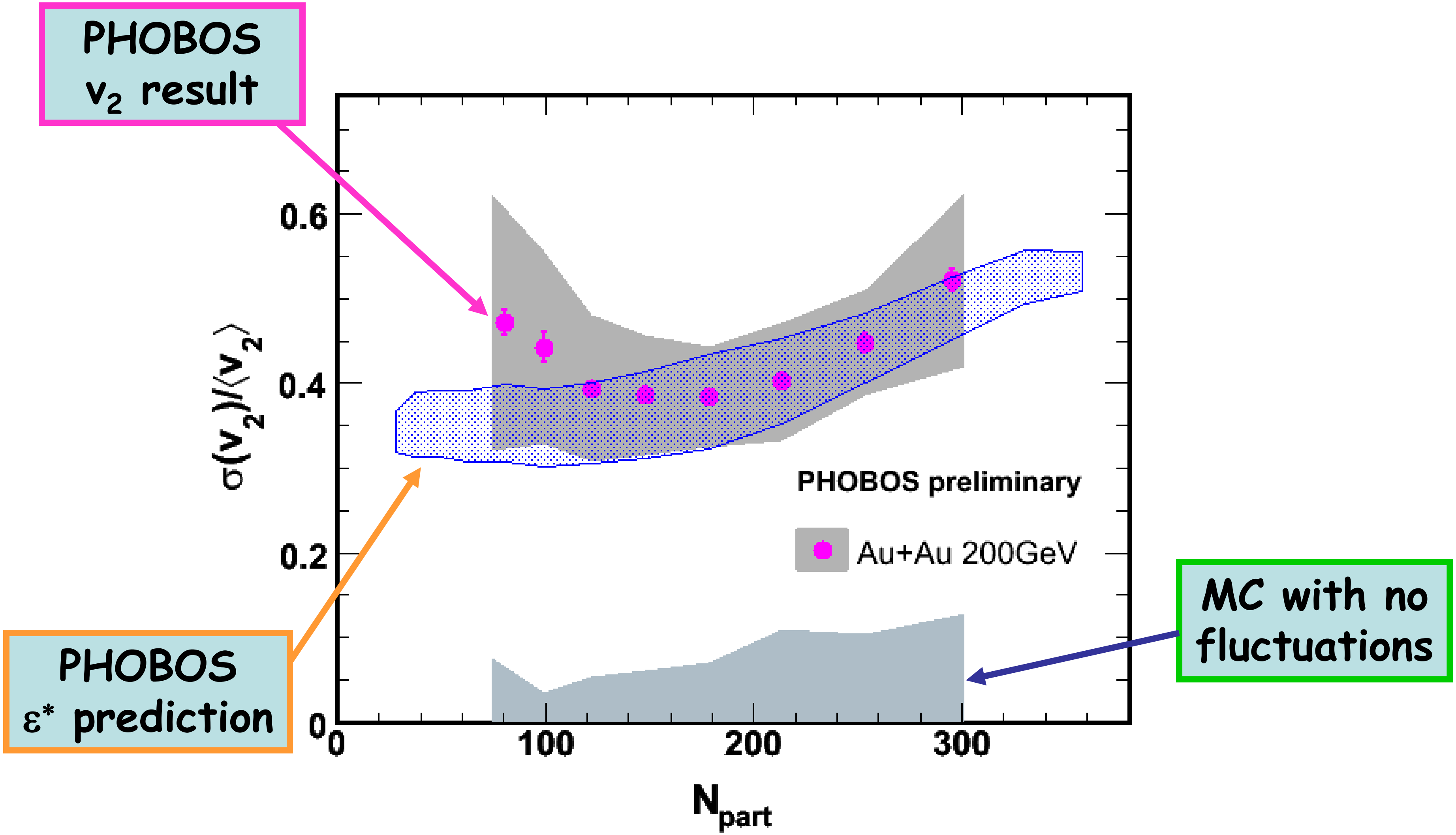
inelastic NN cross section

$$\sigma_{inel} = \pi R_0^2$$

elastic NN amplitude

$$t_{el}(b) = 1 - \sqrt{1 - \sigma(b)}$$

v_2 AND ε^* FLUCTUATIONS: RHIC DATA



Magnitude of v_2 fluctuations is in agreement with ε^* fluctuations

MULTIPLICITY FLUCTUATIONS

$$\frac{Var(N)}{\langle N \rangle} \equiv \omega$$

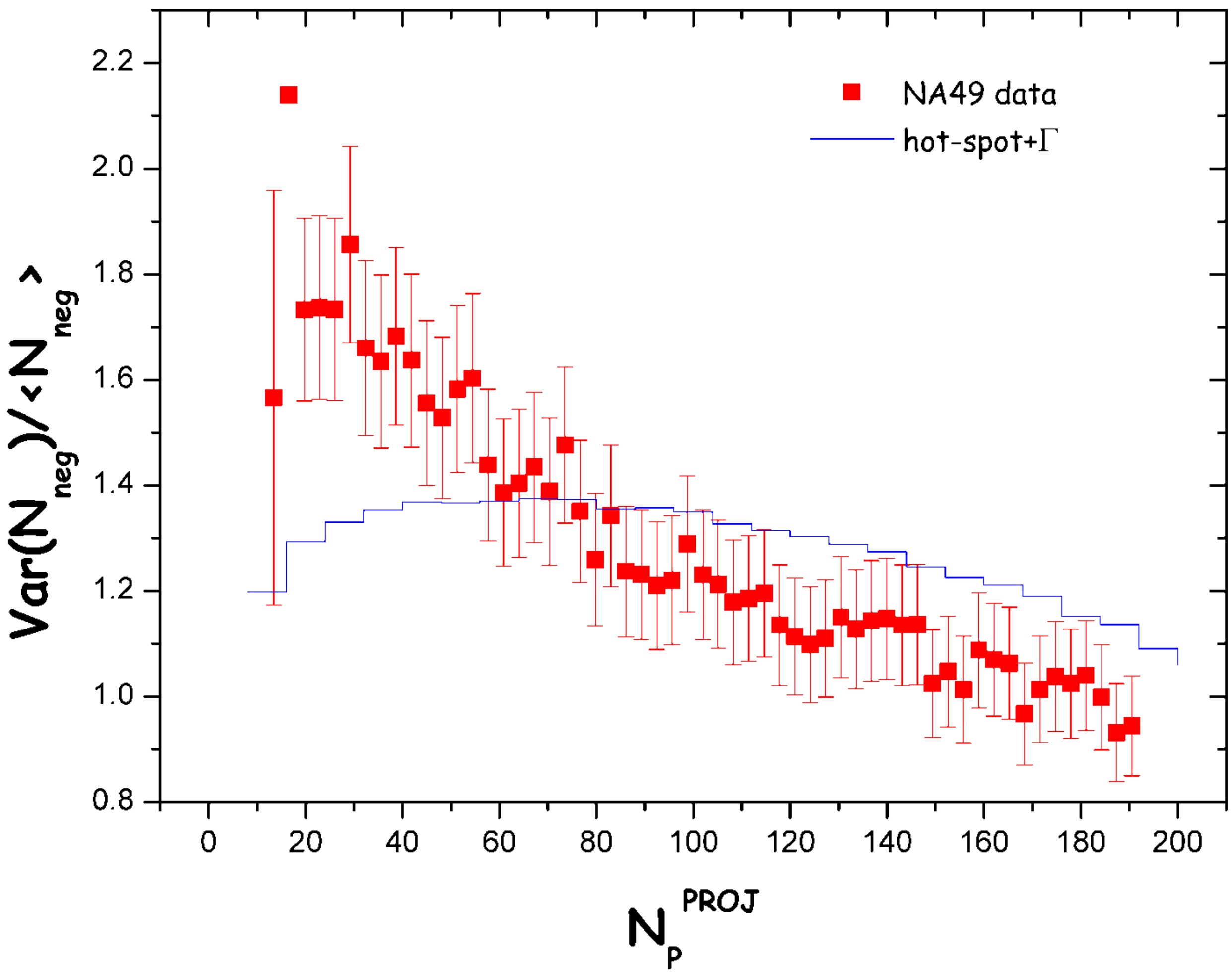
$$\frac{Var(N_S)}{\langle N_S \rangle} \equiv \omega_S$$

N – measured multiplicity
N$_S$ – number of sources, $N_S = (1-\alpha)\frac{N_W}{2} + \alpha N_{bin}$

$$\omega = (1-q) + q \cdot \langle m \rangle \cdot \omega_S$$

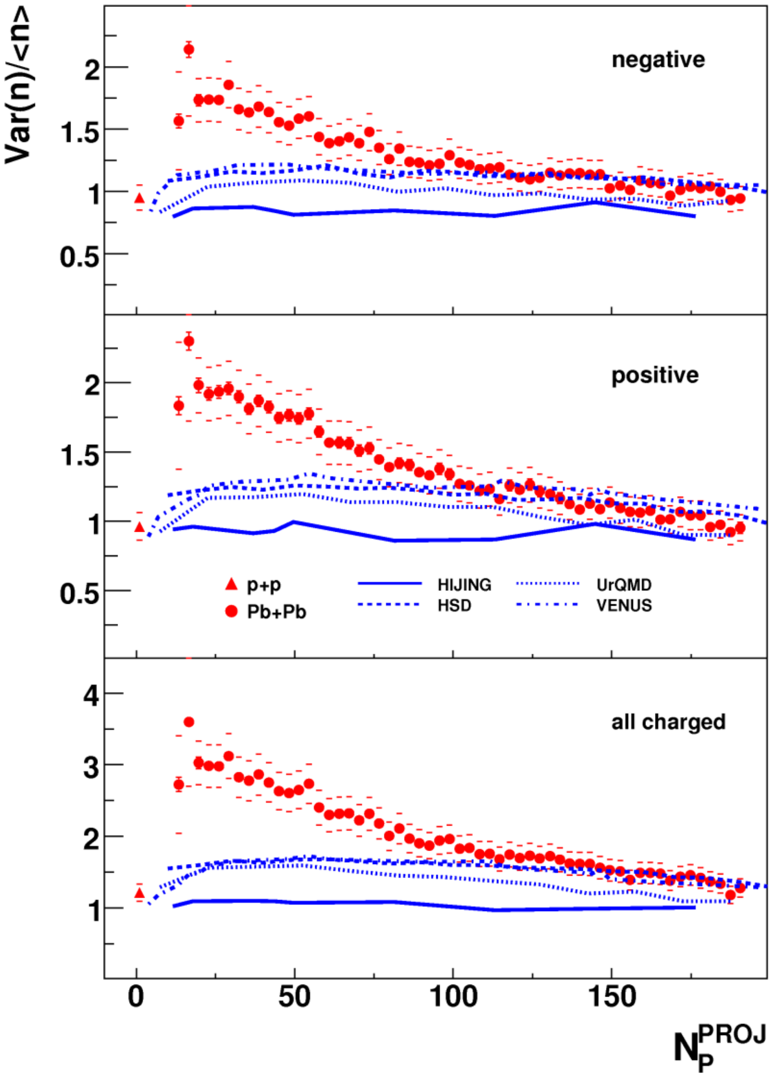
q – acceptance
m – multiplicity of particles produced in a single source

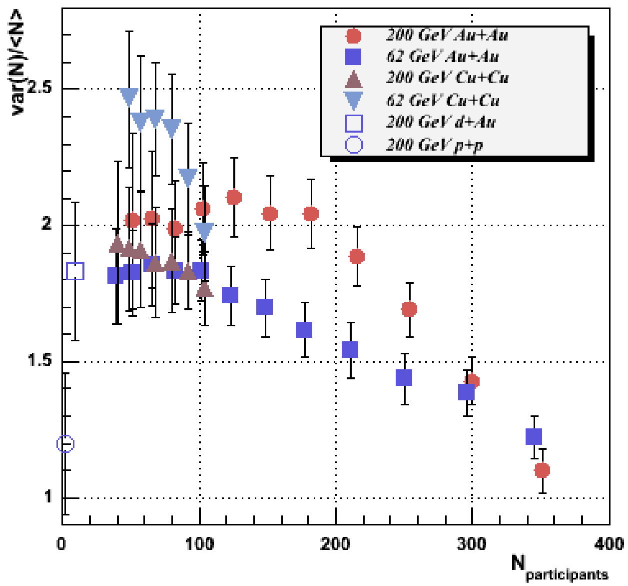
MULTIPLICITY FLUCTUATIONS @ SPS



Glauber Monte-Carlo in NA49 acceptance

EXPERIMENTAL RESULTS ON MULTIPLICITY FLUCTUATIONS





PHENIX data

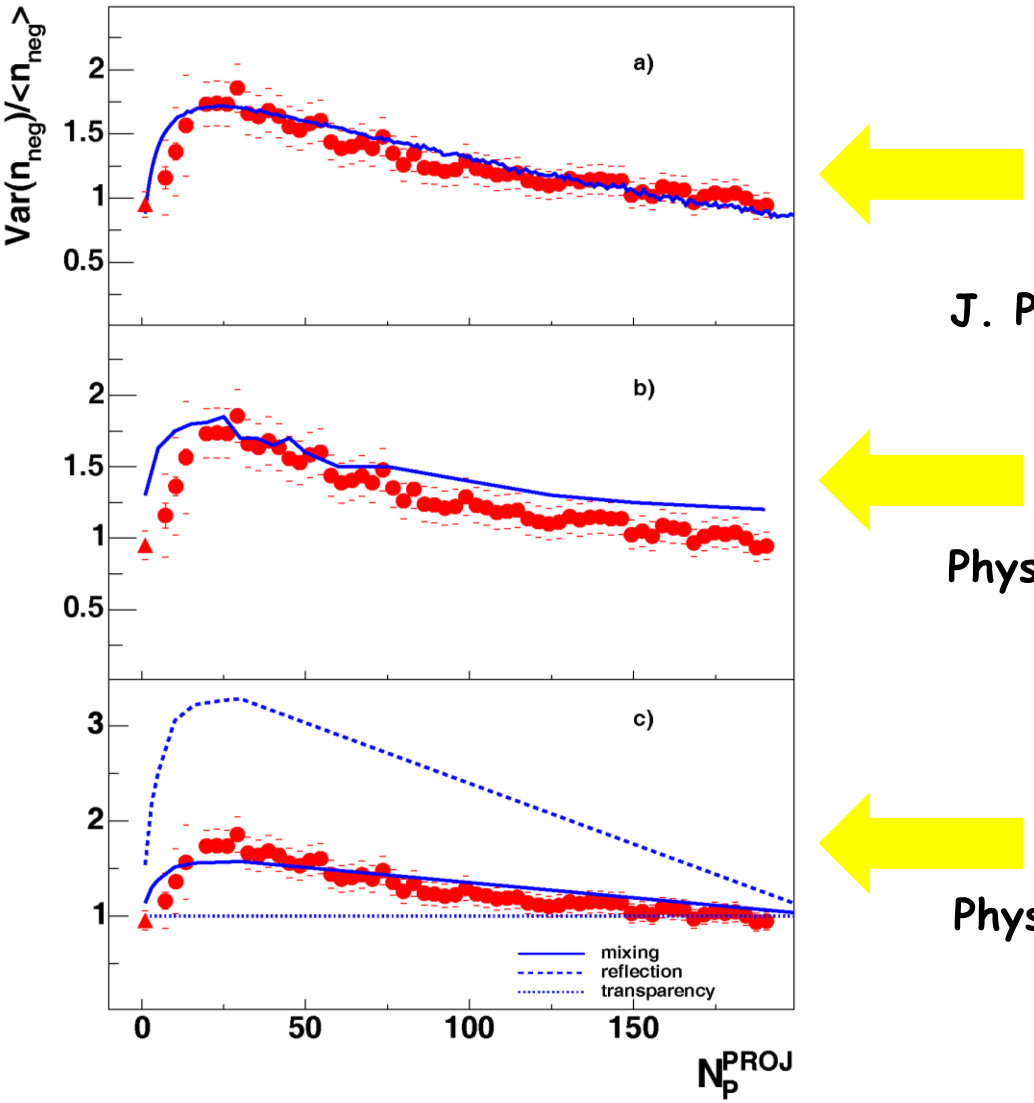
LARGE

fluctuations for semi-peripheral collisions

NA49 data @17.3 GeV

(C. Alt et al. (NA49), Phys. Rev. C75 (2007) 064904)

COMPARISON WITH MODELS



TWO-PARTICLE CORRELATIONS

J. Phys.:Conf. Series 5 (2005) 238

PERCOLATIONS

Phys. Rev. C 72 (2005) 044903

MIXING

Phys. Lett. B 640 (2006) 155