Fluctuations of the initial condition from the Glauber models*

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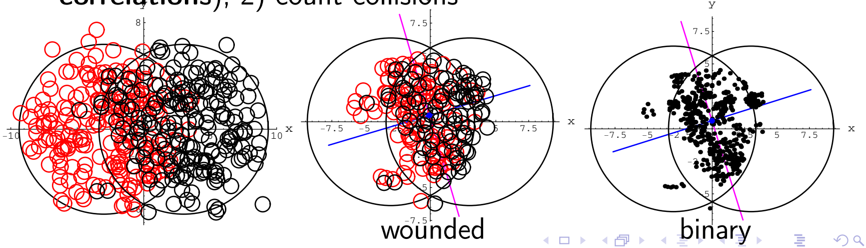
*research with Maciej Rybczyński, Łukasz Obara, and Mikołaj Chojnacki

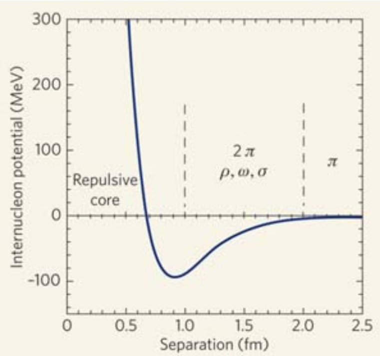
Wounded nucleons

- Wounded nucleons [Białas, Błeszyński, Czyż, 1976] are a basic concept in heavy-ion analyses
- RHIC: 86% wounded + 14% binary describes the multiplicities
- Determination of centrality, impact parameter, analyses of fluctuations, ...
- Basic steps in simulations: 1) generate nucleon positions in nuclei from a WS distribution in an independent way (**no correlations**), 2) count collisions



The NN force

Correlations in nuclei are important for fluctuations
[Baym, Blattel, Frankfurt, Heiselberg, Strikman, 1995]

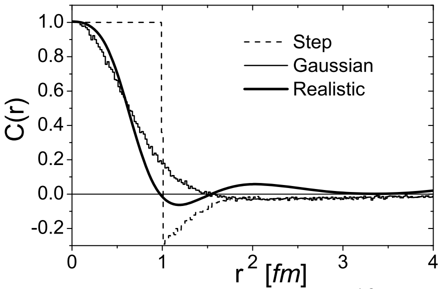


⟵ central NN force

$$\rho^{(2)}(r_1,r_2)=\frac{A(A-1)}{A^2}\rho^{(1)}(r_1)\rho^{(1)}(r_2)\left(1-C(r_1,r_2)\right)$$

NN correlations

Recent progress: *A Monte Carlo generator of nucleon configurations in complex nuclei including Nucleon-Nucleon correlations* [Alvioli, Drescher, Strikman, arXiv:0905.2670]



(two-particle correlation for $^{16}0$)

generate configurations with the inclusion of two-body correlations according to the wave function

$$\Psi(r_1, \ldots, r_N) = \Pi_{i<j} f(r_{ij}) \Phi_{\text{indep.}}(r_1, \ldots, r_N)$$

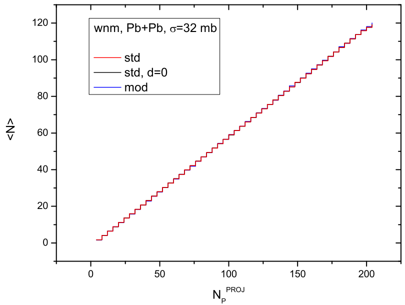
Metropolis algorithm

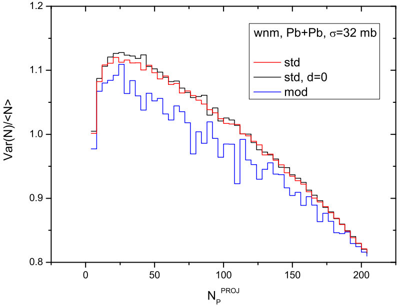
GLISSANDO

GLauber Initial State Simulations AND mOre
[WB, Rybczyński, Bożek, Oct. 2007, Comput. Phys. Commun. 180(2009)69]
read the provided distributions with correlations

Multiplicity, NA49 setup

N_p^{PROJ} - number of wounded nucleons in the projectile
$\langle N \rangle = kqN_w/2$, where $k = 3$ - number of charged particles produced per wounded pair, $q = 0.2$ - detector acceptance (SPS setup)





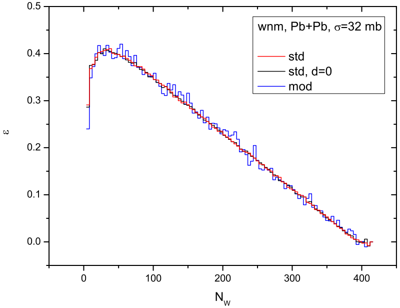
std - independent with expulsion distance $d = 0.4$ fm
std, $d = 0$ - independent with no expulsion

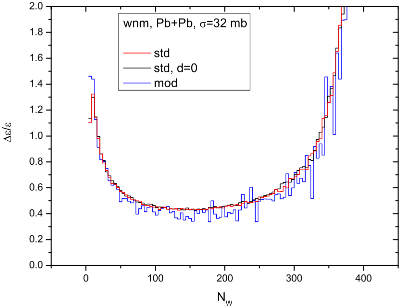
mod - with correlations, configurations from Alvioli et al.

fluctuations reduced

Eccentricity, fixed axes

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

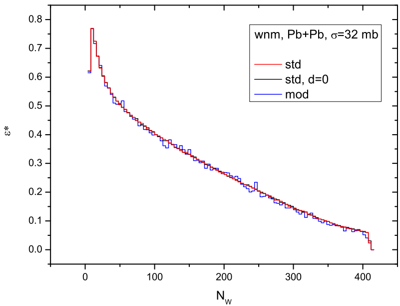


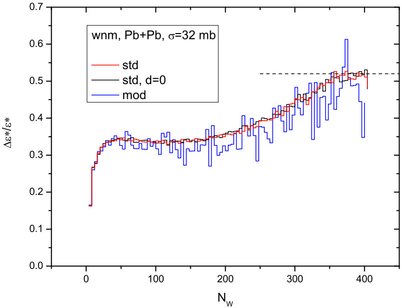


fluctuations slightly decreased

Eccentricity, variable axes

ϵ^* computed in an event-by-event rotated frame (principal-axes frame), where it is maximal ("participant" eccentricity)





fluctuations slightly decreased

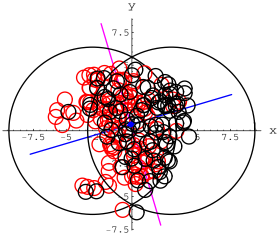
for central collisions the limit $\Delta\epsilon^*/\epsilon^* = \sqrt{4/\pi - 1} \simeq 0.52$ follows (for uncorrelated systems) from the central limit theorem
[WB, Bożek, Rybczyński, Phys. Rev. C76(2007)054905]

Summary of correlation effects

- One-body observables are left intact by two-body correlations
- Event-by-event fluctuations are reduced, as the distribution with fluctuations is more regular
- Effects for the multiplicity fluctuations are substantial
- Effects for the eccentricity studies are very small

Size fluctuations

(so far the study without correlations discussed above)



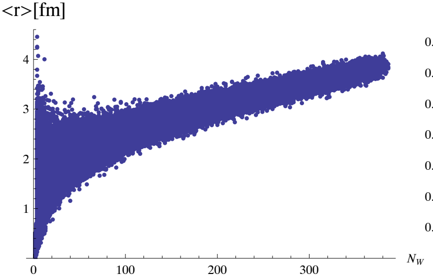
compute event-by-event the average size, here defined as

$$\langle r \rangle = \frac{1}{N_w} \sum_{i=1}^{N_w} \sqrt{x_i^2 + y_i^2}$$

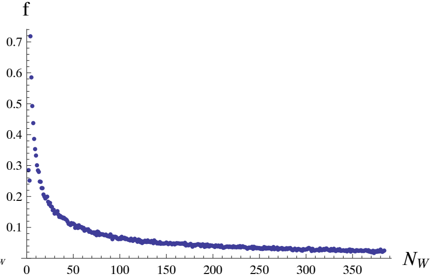
$\langle\langle . \rangle\rangle$ - averaging also over events

Size fluctuation

$\sigma_{NN} = 32$ mb (SPS)



scaled standard deviation $f = \frac{\Delta\langle r\rangle}{\langle\langle r\rangle\rangle}$



a few percent effect for intermediate centralities

independent of energy from SPS ($\sigma_{NN} = 32$ mb) to LHC ($\sigma_{NN} = 63$ mb)

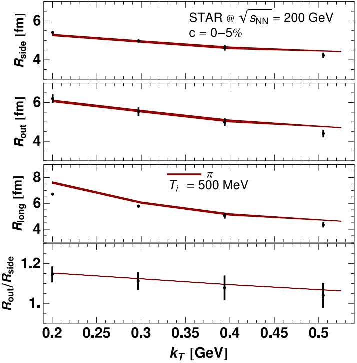
Hydrodynamics

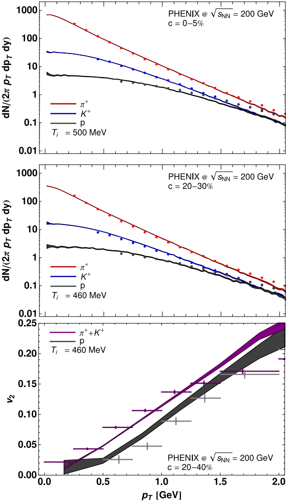
Hydro carries over the initial size fluctuation to $\langle p_T \rangle$ fluctuations

- initial state $\rightarrow$ hydrodynamics $\rightarrow$ freezeout $\rightarrow$ hadrons
- more compressed initial condition leads to a faster build-up of flow, and then higher transverse velocity at freezeout, which in turn leads to higher $\langle p_T \rangle$
- $\Delta p_T / \langle p_T \rangle \simeq A \Delta \langle r \rangle / \langle \langle r \rangle \rangle$
- we estimate the proportionality constant via simulations with hydro (Lhyquid - M. Chojnacki, W. Florkowski) and THERMINATOR

Best cases - solution of the HBT puzzle

Consider the solutions of hydro with Gaussian initial conditions

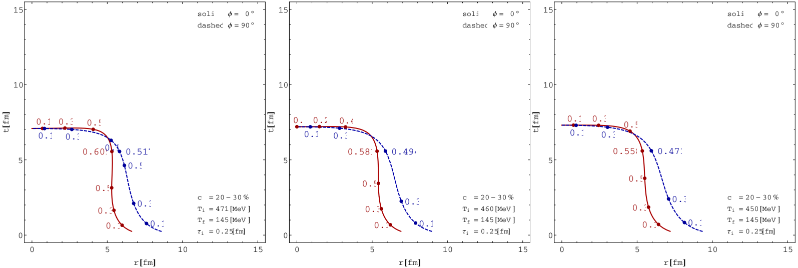




WB, Chojnacki, Florkowski, Kisiel, PRL 101 (2008) 022301

Fluctuations of the FO surface

Fluctuations of the size of the initial condition → hydro → fluctuations of the freezeout surface and velocity



initial source: 5% shrunk optimum 5% expanded

p_T fluctuations

fluctuations of the freezeout surface and velocity $\to$ THERMINATOR $\to$ fluctuations e-by-e of $\langle p_T \rangle$

$$c = 0 - 5 \to N_w \simeq 350 \qquad \sigma_{\rm dyn}(p_T)/\langle p_T \rangle \simeq 1.4\%$$
$$c = 20 - 30 \to N_w \simeq 160 \qquad \sigma_{\rm dyn}(p_T)/\langle p_T \rangle \simeq 2.3\%$$
$$c = 60 - 70 \to N_w \simeq 30 \qquad \sigma_{\rm dyn}(p_T)/\langle p_T \rangle \simeq 4.5\%$$

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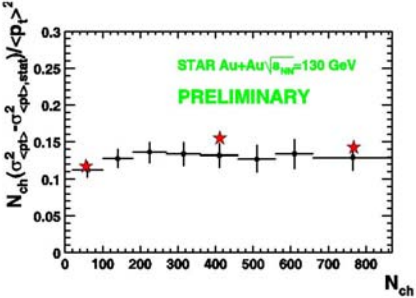
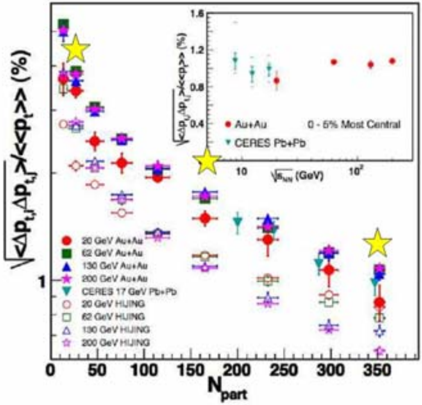


Agreement with the data!

[data from S. Voloshin 2001]

p_T fluctuations, various data



[data from PRC 72 (2005) 044902]

Summary of size fluctuations

- a few percent effect, explains the experimental p_T fluctuations
- proper scaling with N_w: $\sigma^2_{\rm dyn}(p_T) \sim 1/N_w$ – proper dependence on centrality
- many attempts made previously: (mini) jets, clusters, temperature fluctuations
- "geometric/statistical" origin
- weak dependence on energy