4th International Workshop „Critical point and onset of deconfinement“

Dynamical study of fluctuations in relativistic nuclear collisions

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- Introduction
- Fluctuations in the number of participants
- Multiplicity fluctuations
- Baryon number and electric charge fluctuations
- Energy dependense of multiplicity fluctuations
- Fluctuations at RHIC

In collaboration with Elena Bratkovskaya (Frankfurt) and Mark Gorenstein (Kiev)

Study of fluctuations within transport models

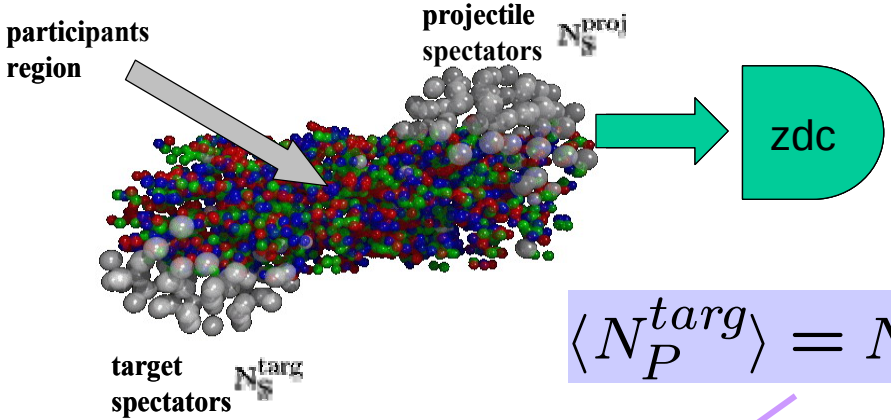
HSD – Hadron-String-Dynamics transport approach

UrQMD – Ultra-relativistic-Quantum-Molecular-Dynamics

Transport models allow to study:

- **statistical and dynamical fluctuations**
- **event-by-event analysis similar to the experiment**
- **the influence of the experimental acceptance on the final results on fluctuations**
- **the centrality dependence**
- **the energy dependence of fluctuations**

Fluctuations in the number of participants in HSD & UrQMD

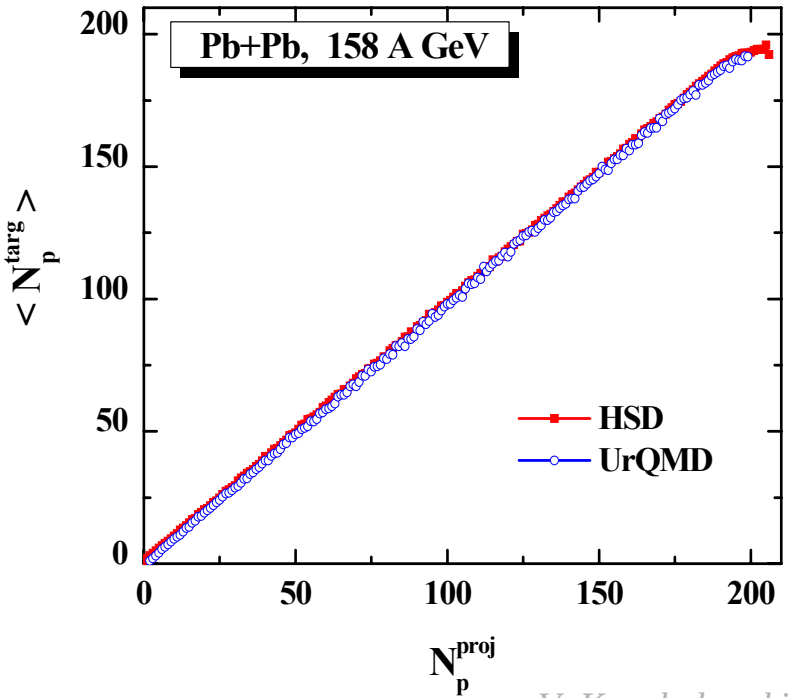


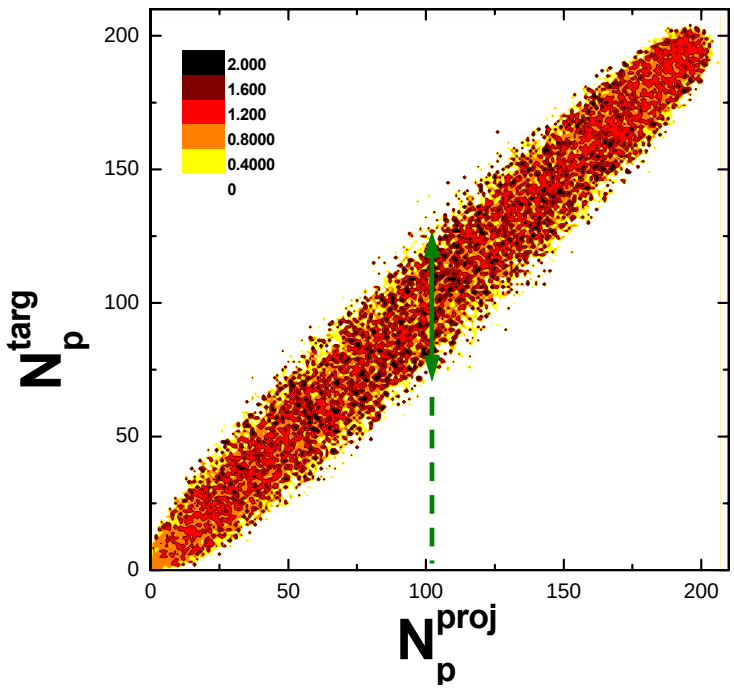
$N_P^{proj}=A-N_S^{proj}$ – projectile participants

$N_P^{targ}=A-N_S^{targ}$ – target participants

$$\langle N_P^{targ} \rangle = N_P^{proj}$$

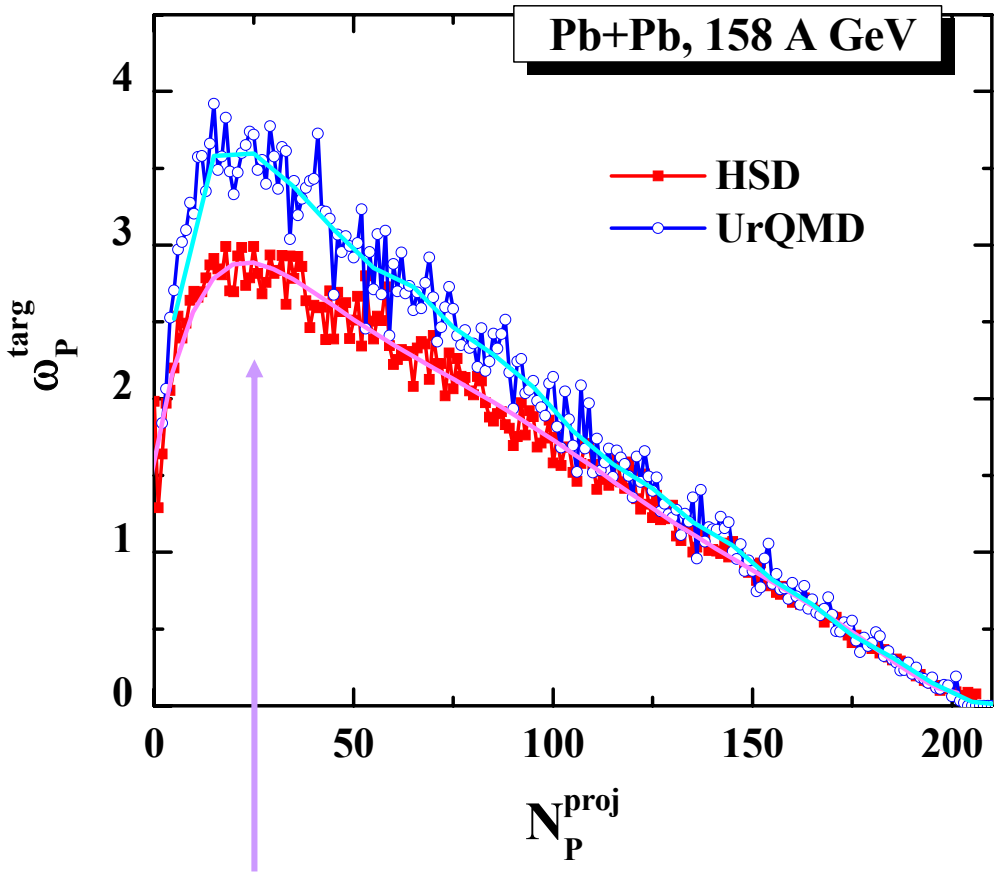
$$N_P^{targ} \neq N_P^{proj}$$





Fluctuations in the number of participants in HSD & UrQMD

PRC 73 (2006) 034902



The scaled variance of "X":

$$\omega_X = \frac{\langle X^2 \rangle - \langle X \rangle^2}{\langle X \rangle}$$

ω_P^{targ} is the scaled variance of the number of target participants N_p^{targ}

in each sample with N_p^{proj} = const the number of target participants N_p^{targ} fluctuates considerably: $\omega_p^{targ} \sim 3$ at $N_p^{proj} \sim 25$

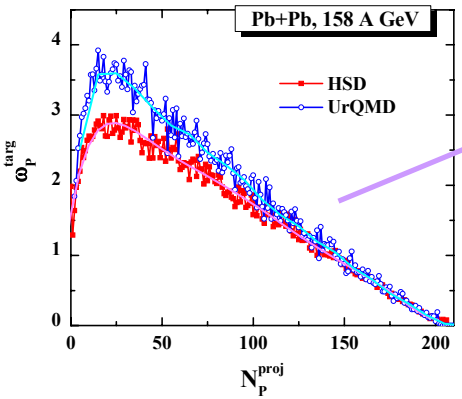
Baryon number fluctuations (HSD)

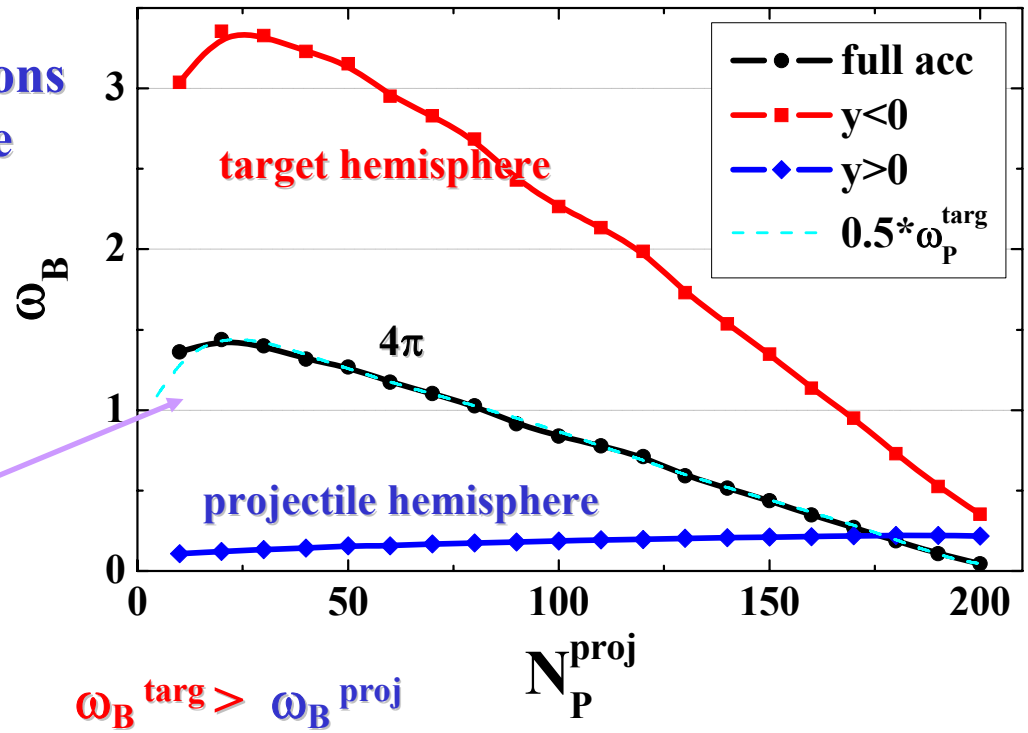
Baryon number is a conserved quantity:

the net baryon number in the full phase space $B \equiv N_B - N_{\bar{B}}$
is equal to the total number of participants $N_p = N_p^{proj} + N_p^{targ}$

at fixed N_p^{proj} **the** N_p **number fluctuates due to the fluctuations of** N_p^{targ} **in the full phase space**

$$\omega_B \cong \frac{1}{2}\omega_P^{targ}$$

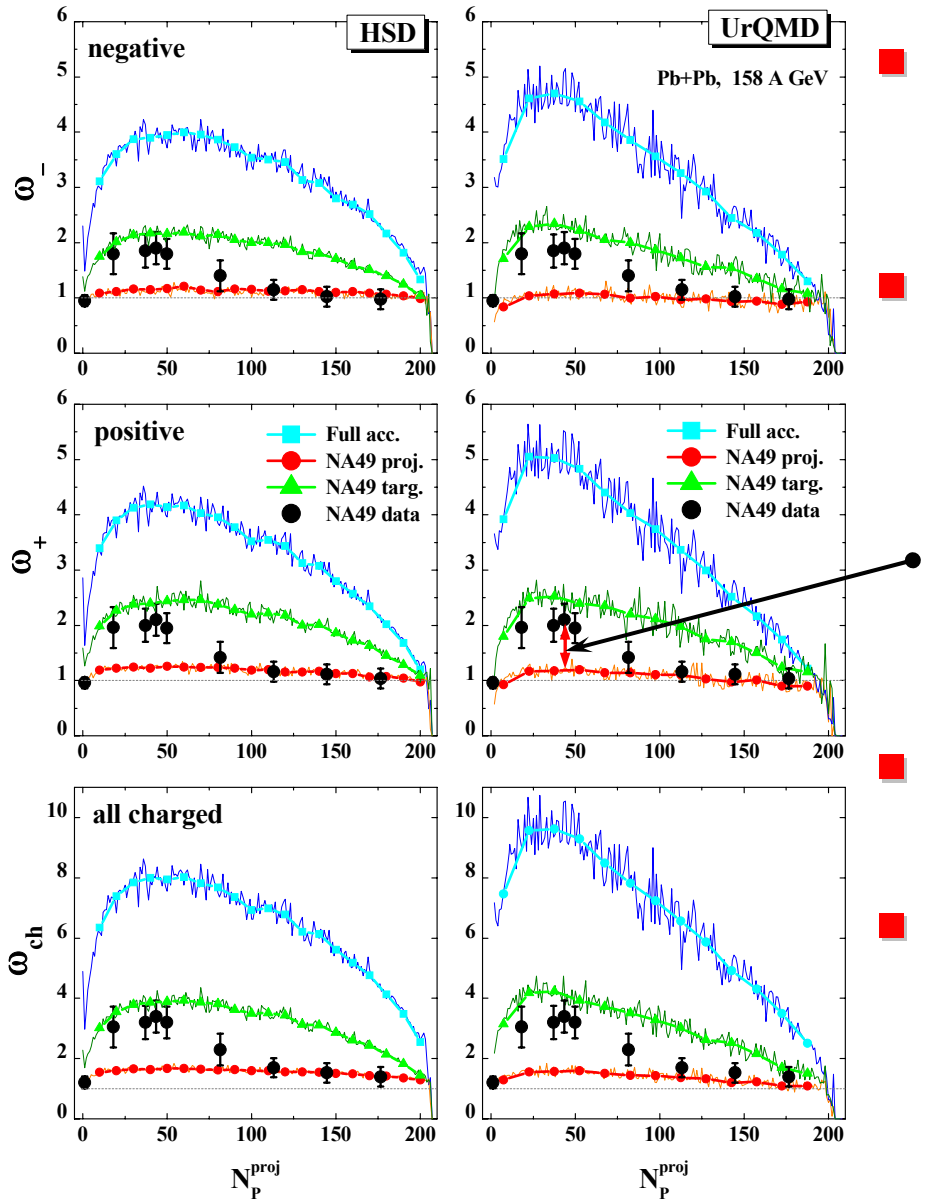




$\omega_B^{targ} > \omega_B^{proj}$

PRC 74 (2006) 064911

Multiplicity fluctuations in projectile and target hemispheres

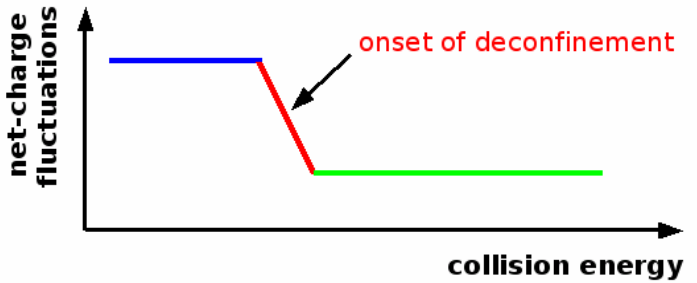


- HSD and UrQMD show strong multiplicity fluctuations of dynamical origin;
- HSD and UrQMD show strong multiplicity fluctuations in 4π ‚full' acceptance, however, the observed (by NA49) non-trivial system size dependence of multiplicity fluctuations is not reproduced by HSD and UrQMD
- ϕ-p_T acceptance cuts strongly decrease fluctuations !
- Fluctuations in target hemisphere are larger than in projectile hemisphere

PRC 73 (2006) 034902

Net-electric charge fluctuations

sensitive to the EoS at the early stage of the collision and to its changes in the deconfinement phase transition region



Jeon, Koch, PRL85 (2000) 2076
Asakawa, Heinz, Muller PRL85 (2000) 2072

net-charge fluctuations are smaller in QGP than in a hadron gas

Definition of Φ-measure of fluctuations:

Gazdzicki, Mrowczynski, Z. Phys. C 54 (1992) 127:

$$\Phi_x = \sqrt{\frac{\langle Z^2 \rangle}{\langle N \rangle}} - \sqrt{\overline{z^2}}, \quad z_i = x_i - \bar{x}, \quad Z = \sum_{i=1}^{N} (x_i - \bar{x}_i)$$

X – single-particles variable
N – number of particles in 1 event
<...> - averaging single-particle distribution over events

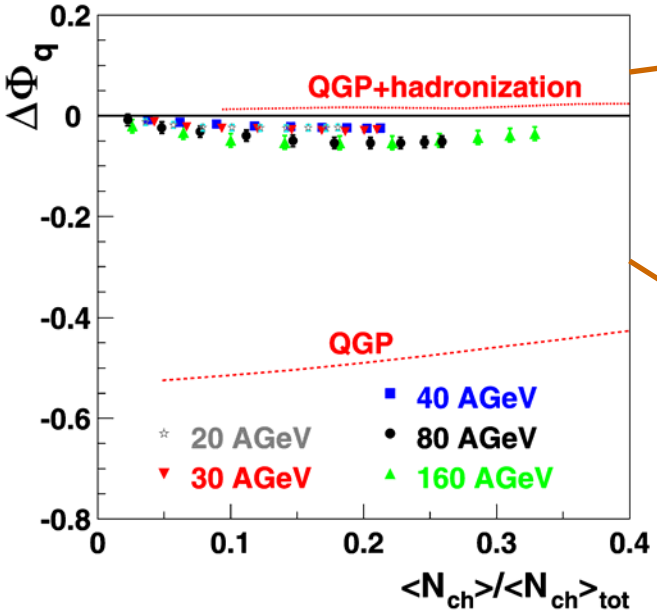
$$\Delta\Phi_q = \Phi_q - \Phi_{q,GCC}$$

$$\Phi_{q,GCC} = \sqrt{1-P} - 1, \quad P = \frac{\langle N_{ch} \rangle}{\langle N_{ch} \rangle_{tot}}$$

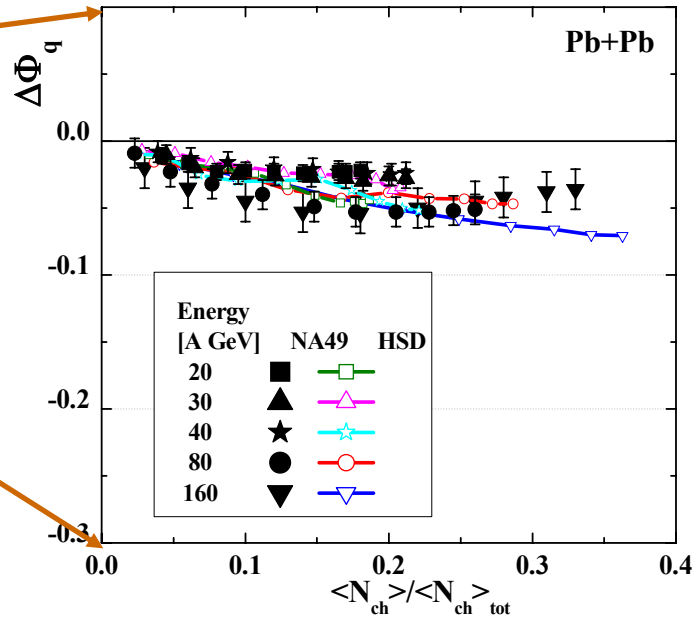
GCC – global charge conservation

$\Delta\Phi_q = 0,$ if particles are correlated by global charge conservation only!

NA49: Net-electric charge fluctuations



NA49, PRC 70 (2004) 064903

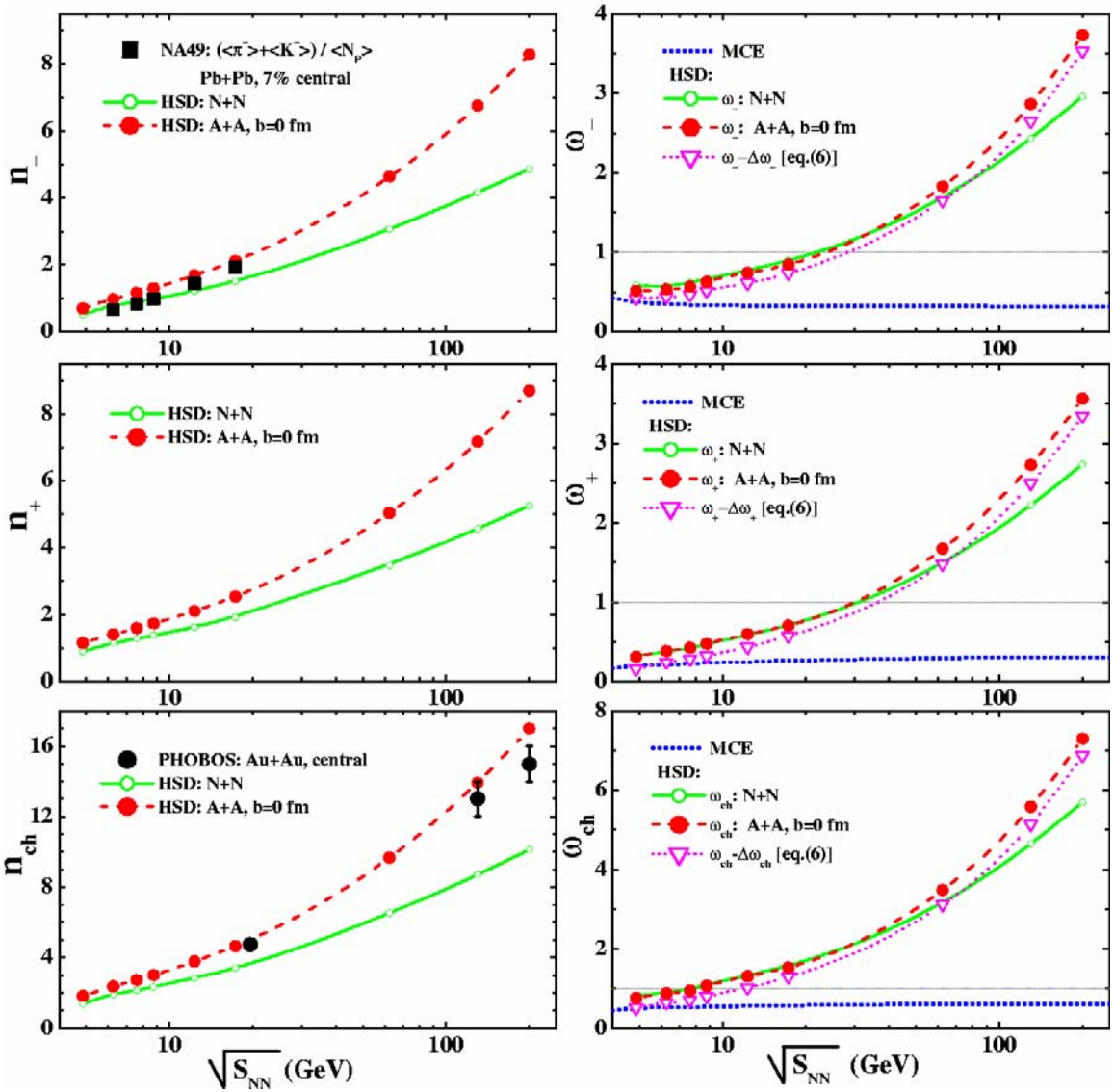


PRC 74 (2006) 064911

The decay of resonances strongly modifies the initial QGP fluctuations!

Energy Dependence of Multiplicity Fluctuations in N+N and central A+A

PLB, in press [nucl-th/0703052]



- HSD gives good description of experimental data for charged hadron multiplicities in A+A.
- Fluctuations in p+p and A+A are very close within HSD.
- Fluctuations of the number of participants do not explain excess over p+p fluctuations

$$\omega_i = \omega_i^{\blacktriangledown} + n_i\ \omega_P \quad (6)$$

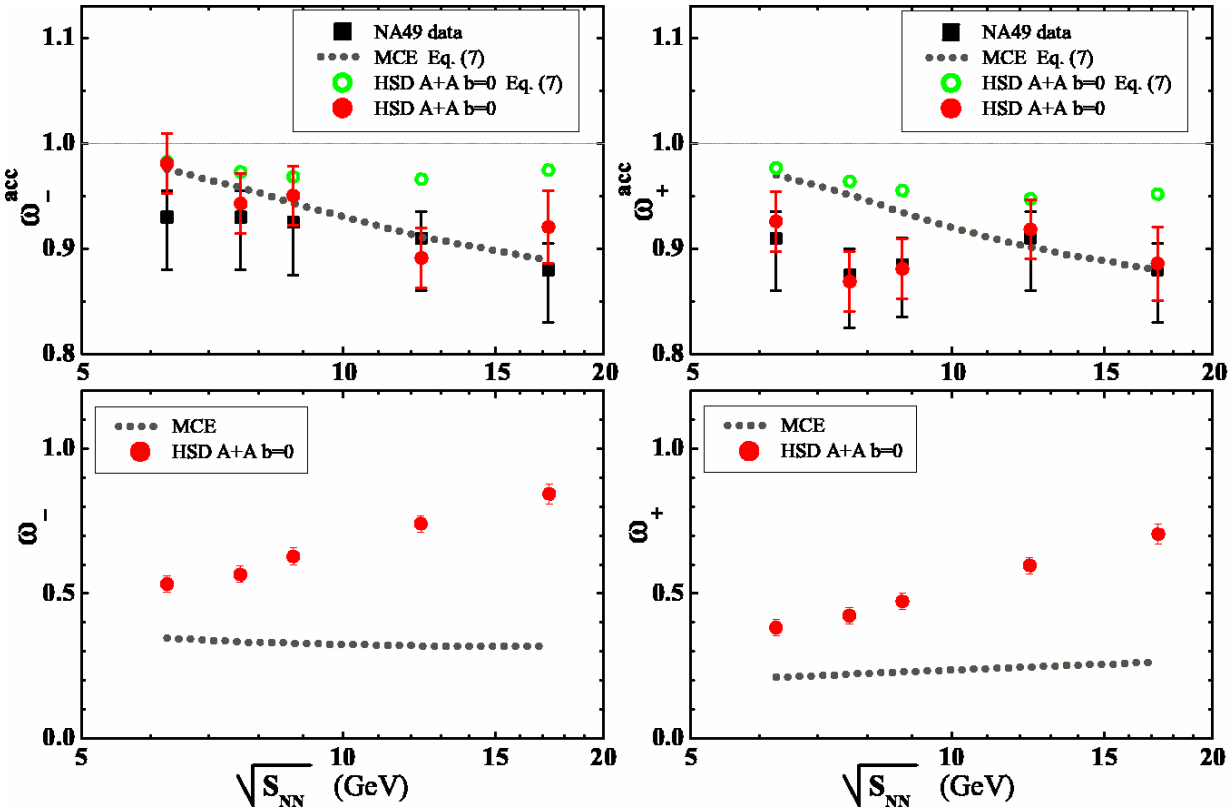
- Statistical model shows very small and energy independent fluctuations and contradicts to the transport calculations where ω reaches significant values for the large energies.

Begun at al, PRC (2006) 044903

Similar results for $\omega^{\pm}$ from UrQMD (see talk of M.Bleicher)

Energy Dependence of Multiplicity Fluctuations: NA49 data

Acceptance scaling formulae: $\omega_i^{acc} = 1 - q_i + q_i\ \omega_i^{4\pi}$ (7)



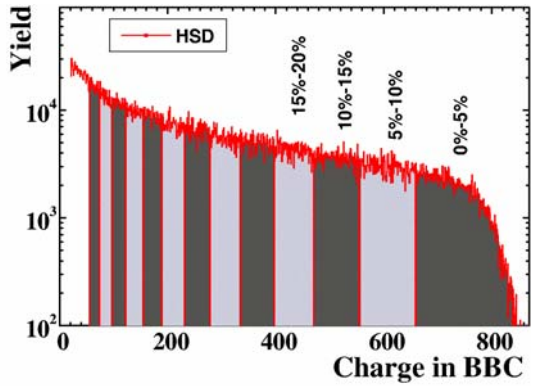
NA49 cannot clearly distinguish between statistical and transport models because of small acceptance q=0.04...0.16 and small differences between the model predictions in this range of energy !

PLB, in press [nucl-th/0703052]

Fluctuations at RHIC

0704.1831[nucl-th]

- Fluctuations of the participant number within different centrality classes in PHENIX for Au+Au @ √s = 200 GeV are significant!



- Using the model of independent sources:

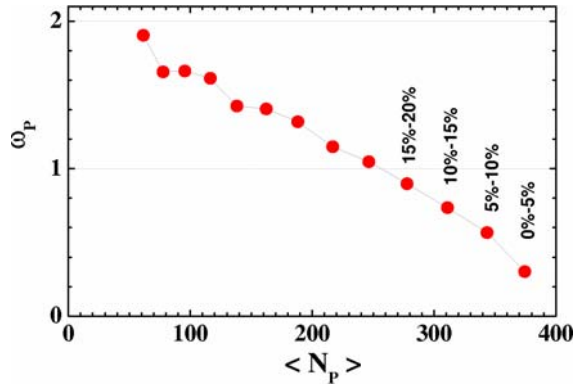
$$\omega_i = \omega_i^* + n_i \ \omega_P$$

and acceptance scaling formula:

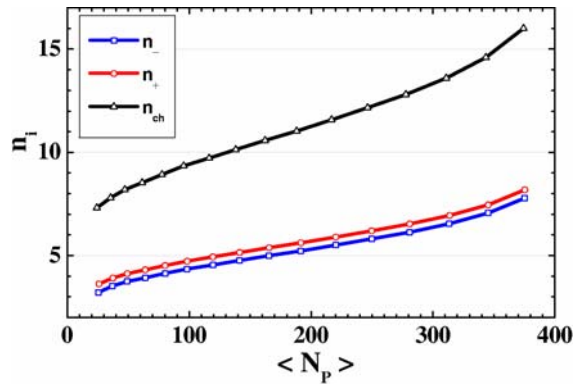
$$\omega_i^{acc} = 1 - q_i + q_i \omega_i$$

we obtain equation:

$$\omega_i^{acc} = 1 - q_i + q_i \omega_i^* + q_i n_i \ \omega_P$$



- From HSD we took only: ω_p, q_i, n_i



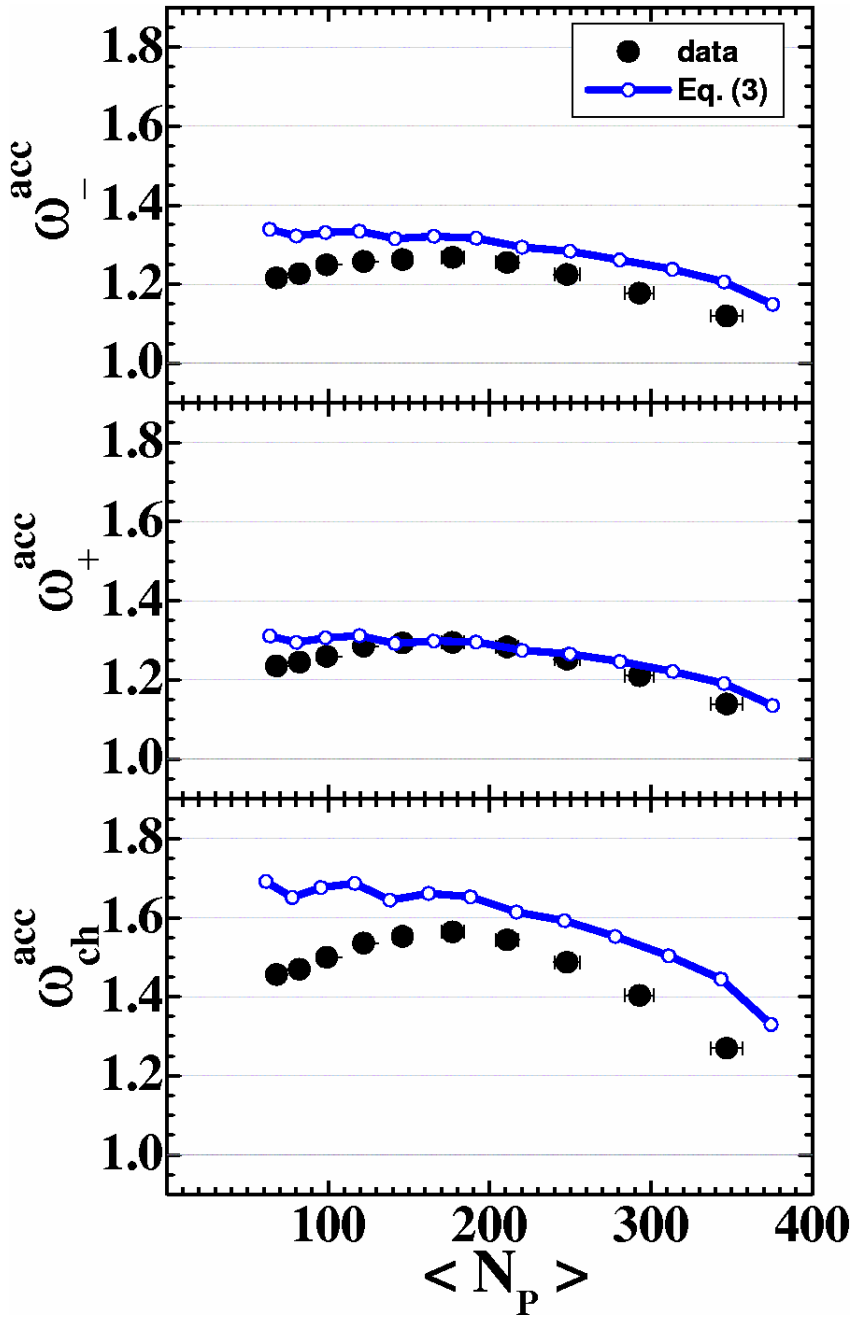
Fluctuations at RHIC

0704.1831[nucl-th]

$$\omega_i^{acc} = 1 - q_i + q_i\omega_i^* + q_i n_i \ \omega_P \quad (3)$$

eq.(3) describes exp. data from PHENIX for Au+Au @ √s = 200 GeV

Multiplicity fluctuations represent fluctuations of participants!



Conclusions

- The fluctuations in the number of target participants – for fixed projectile participants - strongly influence all observable fluctuations
- The measured fluctuations of the electric charge in different acceptance windows are consistent with HSD results.
- Statistical and transport models show different results in central A+A collisions for multiplicity fluctuations versus energy. New measurements at higher energies and with larger acceptance are needed!
- In collider-type experiments the fluctuations of the number of participants are significant. To avoid them one has to consider the most central collisions with more rigid events selection.

Thanks to:

Mark Gorenstein

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Olena Linnyk

Horst Stöcker

Marcus Bleicher

Stephane Haussler

Model of independent sources

Gazdzicki, Gorenstein, hep-ph/0511058

Number of independent sources is proportional to number of participants:

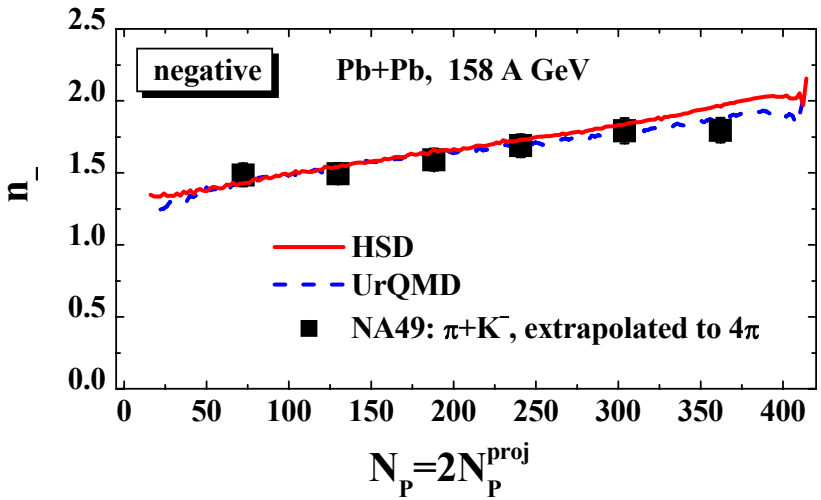
$$\omega_i = \omega_i^* + \frac{1}{2}\omega_P^{targ} n_i$$

ω_i^* is the fluctuation from a single NN source

fluctuation in the number of nucleon participants in A+A

$\omega_-^* = 1.5$
$\omega_+^* = 1.1$
$\omega_{ch}^* = 2.5$

HSD: N+N (averaged over pp+nn+pn)



n_i is the particle number of ι-th type (i=+,-,ch) per participant $N_p = N_p^{proj} + N_p^{targ}$

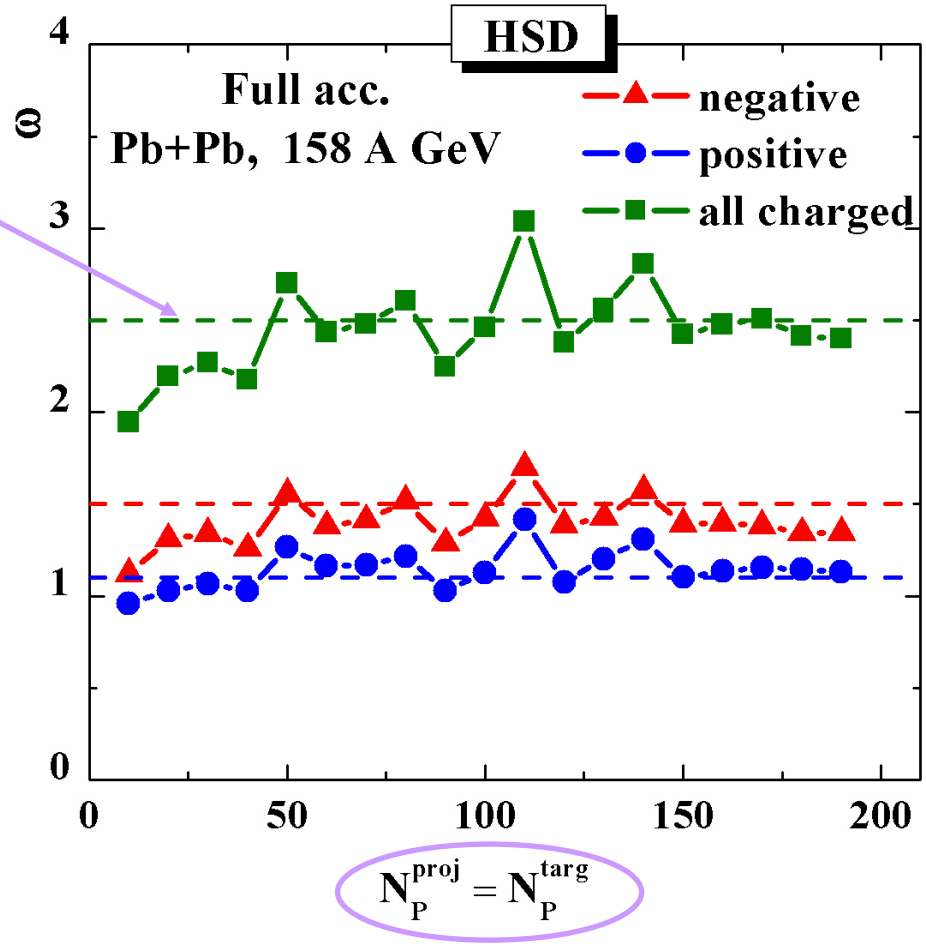
$$n_i = \frac{\langle N_i \rangle}{\langle N_P \rangle}$$

ω_P^{targ} is the scaled variance for the fluctuations of the number of target participants N_p^{targ}

Model of independent sources

$$\omega_i = \omega_i^* + \frac{1}{2}\omega_P^{targ} n_i$$

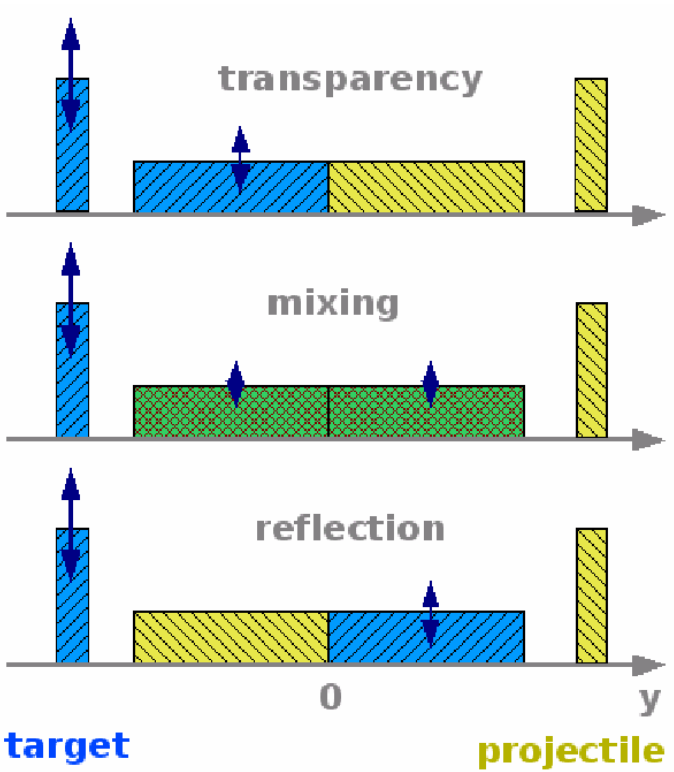
for $N_p^{proj} = N_p^{targ}$: $\omega_P^{targ} = 0$

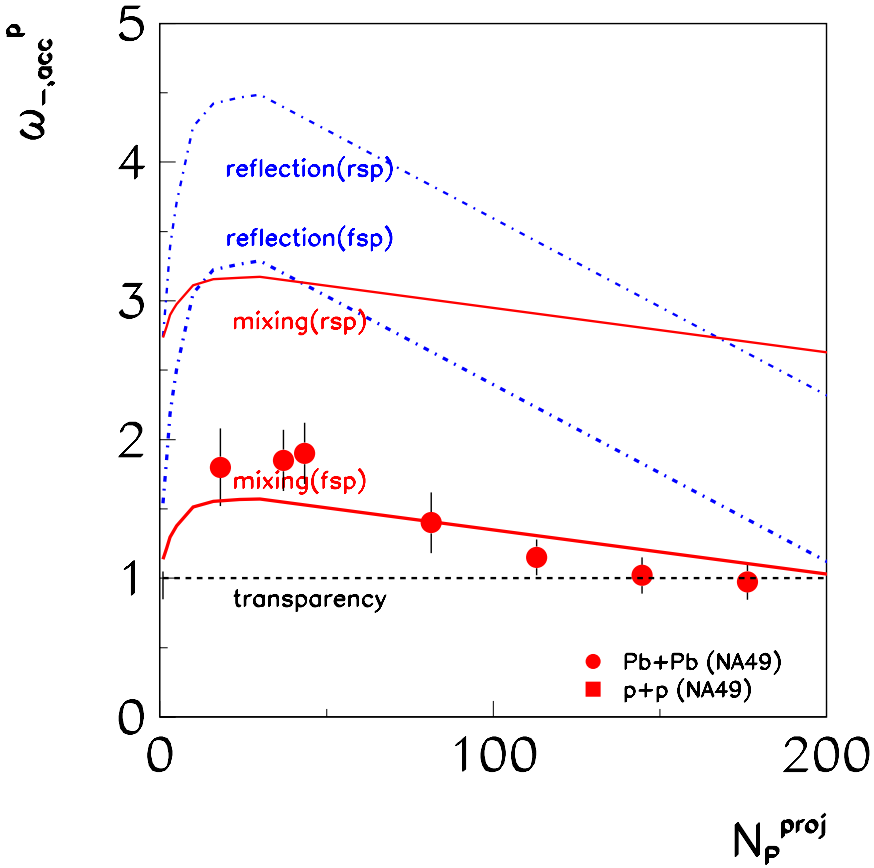


Fluctuations in A+A collisions are dominated by the fluctuations of the particle number in single N+N collisions

Multiplicity fluctuations as a probe of transparency, mixing and reflection of initial flows in HIC

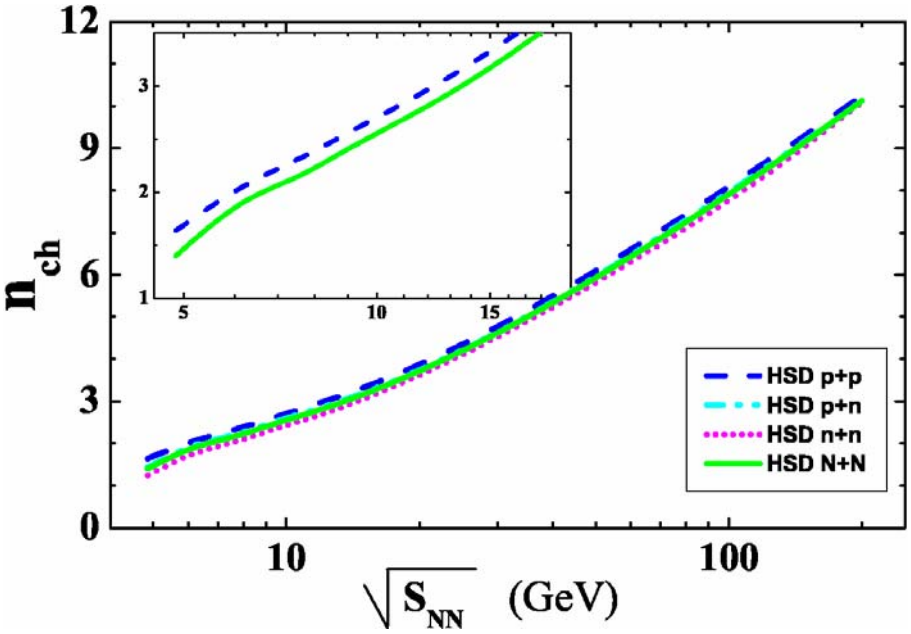
Gazdzicki, Gorenstein, hep-ph/0511058:

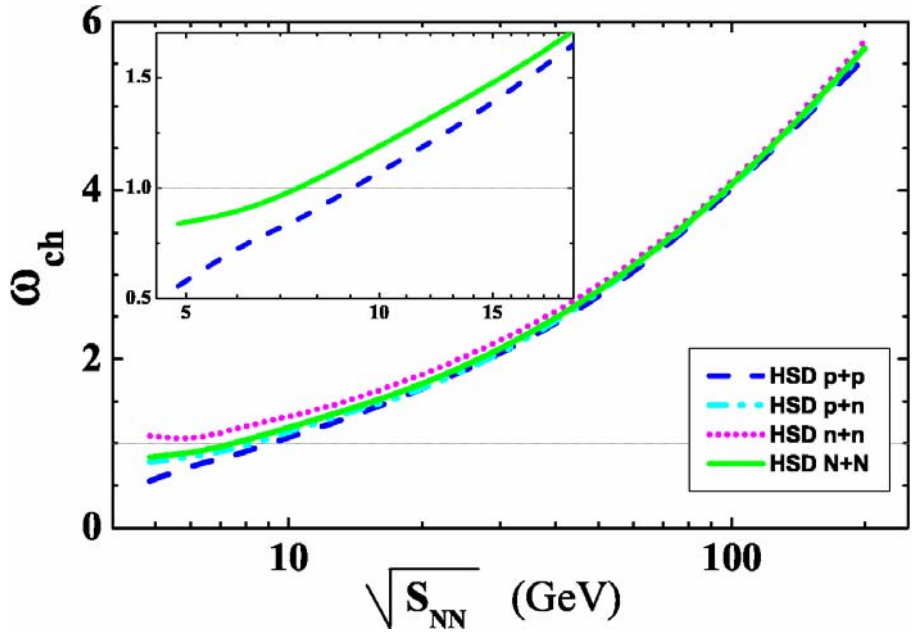




- Model of independent sources favors mixing (but not extreme!) scenario
- HSD & UrQMD show smaller mixing as follows from NA49 data, i.e. too transparent

“Nucleon-nucleon” collisions

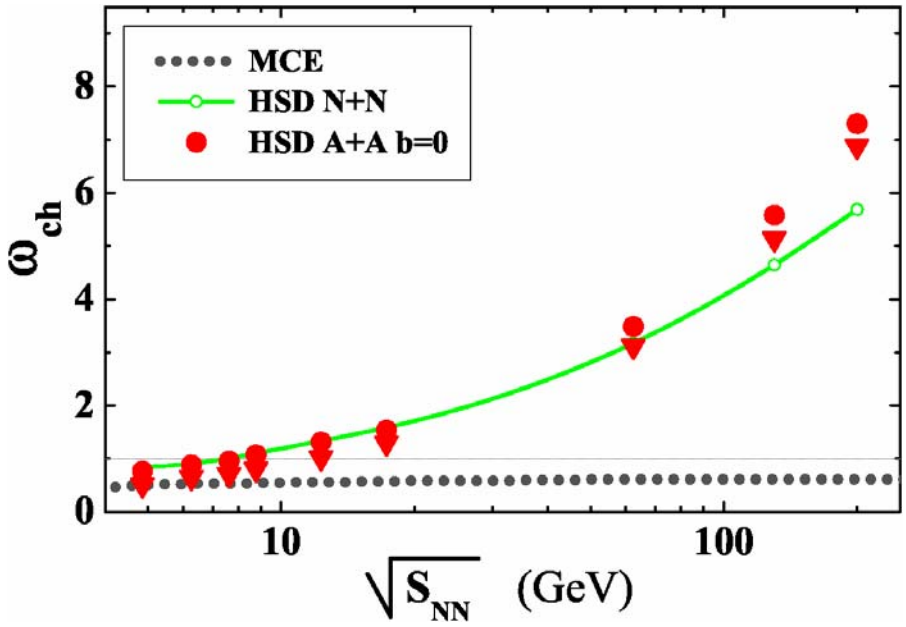




$$\langle N_i^{NN} \rangle = \alpha_{pp} \langle N_i^{pp} \rangle + \alpha_{pn} \langle N_i^{pn} \rangle + \alpha_{nn} \langle N_i^{nn} \rangle ,$$

$$\omega_i^{NN} = \frac{1}{\langle N_i^{NN} \rangle} \left[\alpha_{pp}\, \omega_i^{pp}\, \langle N_i^{pp} \rangle + \alpha_{pn}\, \omega_i^{pn}\, \langle N_i^{pn} \rangle + \alpha_{nn}\, \omega_i^{nn}\, \langle N_i^{nn} \rangle \right]$$

N+N & A+A central collisions



$$\omega_i = \omega_i^{\blacktriangledown} + n_i \; \omega_P$$

Pb+Pb @ 158 AGeV, $b = 0$:

$\langle N_P \rangle \simeq 392$

$\omega_P \simeq 0.055$

Fluctuations at RHIC